# EddyPro® 5

## Eddy Covariance Software

LI-COR®

# Instruction Manual

With Support for SMARTFlux™

**NOTICE**

The information contained in this document is subject to change without prior notice.



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# Table of Contents

## Section 1. What is EddyPro®?



## Section 2. The Interface



## Section 3. SMARTFlux™ Configuration

## Section 4. Using EddyPro® 5

## Section 5. Output Files Overview



## Section 6. Interface Feature Reference

## Section 7. Calculation Reference

## Appendix A. References

## Glossary

## Index

# 1 What is EddyPro®?

EddyPro is software for processing raw eddy covariance (EC) data to compute biosphere/atmosphere fluxes of $CO_2$, $H_2O$, $CH_4$, other trace gases, and energy. It is based on the ECO$_2$S[1] package, which was released as free software by the consortium participating in the IMECC-EU European project[2]. EddyPro is customized to efficiently process eddy covariance data logged to LI-COR® gas analyzers (.ghg files). It also supports other raw file types, including data stored as ASCII tables, binary files (including the TOB1 format), and SLT (EddySoft and EdiSol) formats.

ECO$_2$S is the result of a software development and validation effort that started in 2006 in the framework of the CarboEurope IP project[3], was partially supported by the ICOS European Infrastructure[4]. This project came to a conclusion in 2011 with the release of ECO$_2$S 1.6.5. During the IMECC-EU project, the first complete versions of the software were thoroughly validated against six other eddy covariance packages, including EdiRe and EddySoft software.

In 2010, LI-COR® selected this software platform as the foundation for the EddyPro data processing and analysis package. EddyPro 4 is the latest result of this effort. It is designed to provide easy, accurate EC flux computations.

EddyPro is released as open source software, with one official version that is fully documented, maintained, and supported by LI-COR®, Inc.

**Suggested Documentation Reference:** LI-COR, Inc. 2013. EddyPro® 5 Help and User's Guide. LI-COR, Inc. Lincoln, NE.

**Suggested Software Reference:** EddyPro® (Version 5) [Computer software]. 2013. Lincoln, NE. LI-COR, Inc; Infrastructure for Measurements of the European Carbon Cycle consortium.

[1] http://gaia.agraria.unitus.it/eco2s
[2] http://imecc.ipsl.jussieu.fr
[3] http://www.carboeurope.org
[4] http://www.icos-infrastructure.eu

## What to Expect from EddyPro®

EddyPro will calculate fluxes accurately, given the available data. The interface is simple, and even users with little-to-no knowledge of the underlying eddy covariance (EC) theory should be able to use it with ease.

How does EddyPro make this possible? Inspired by the $ECO_2S$ philosophy, LI-COR® designed an innovative raw file format (called the GHG format, denoted by a .ghg file extension) that embeds all relevant meta-information inside the data file. Because each raw file includes all the information needed to be properly interpreted and processed, each raw file can be handled independently from the others. GHG files are automatically created by properly configured LI-COR® data logging software. EddyPro also allows you to calculate corrected fluxes starting from raw files in other formats, such as generic ASCII, Binary, TOB1, and SLT files. In these cases, meta-information must be provided before processing through the EddyPro graphical interface.

Processing EC data requires a long sequence of operations including raw data filtering, calibration, and other algorithms for calculating and correcting fluxes. For many processing steps, several options are available. Despite many efforts, the scientific community has yet to reach definitive agreements on which of these are best. Making all these options available can only be done at the cost of increasing the complexity of the software. The solution in EddyPro is to provide two paths for data processing: Express Mode and Advanced Mode.

In Express Mode, EddyPro uses pre-determined processing settings that are well established and accepted in the community. This approach dramatically reduces the need for user interaction, allowing you to get fluxes with just a few clicks! Express Mode is suitable for most eddy covariance setups, including:

- systems operated over relatively flat and homogeneous terrain,
- systems with open path gas analyzers (e.g. LI-7500A, LI-7700),
- systems with closed (LI-7000) or enclosed (LI-7200) path analyzers with short or properly heated intake tubes,
- systems that include up to 3 analyzers.

In Advanced Mode, you can choose how corrections are applied, and configure these settings to suit your research needs, making it the correct choice for data collected in situations that deviate from those listed above. Effective use of Advanced Mode requires both a certain level of understanding of the EC theory and a deeper interaction with the software.

# Using EddyPro®

## Installing EddyPro

EddyPro is compatible with computers running the Windows® operating systems (XP, Vista, and 7), both 32 and 64 bit versions. The latest official version of EddyPro can be acquired from www.licor.com/eddypro. Installing the software is a simple matter of downloading it, and then launching the .exe file which is stored on your computer. Accept the terms of the license agreement and click "Next" or "OK" until the installation is complete.

Launch EddyPro by clicking the icon on your desktop, or navigate to the EddyPro icon in your computer's "Start" menu.

## Learning EddyPro

The simplest way to learn EddyPro is to use the software. Three levels of instruction are available directly through the software interface.

The first level- EddyPro Tips - provides several-sentence descriptions of each feature in the software when you hover your mouse over a feature. This is active by default, and it can be turned on or off through the **Tools** menu (click **EddyPro Tips**) feature.

The second level - guided mode - indicates when required fields have not been completed. For example, if you are processing data in the ASCII format and you wish to advance through the interface, EddyPro will prohibit you from advancing from the **Project Creation** page to the **Basic Settings** page until the metadata has been entered completely. Further, EddyPro will list the incomplete fields in the "Messages" panel. Messages in red font are essential. Messages in blue or green font appear when the information provided to EddyPro is adequate to complete the project. Messages are visible by default and it can be turned on or off through the **View** menu (click **EddyPro Messages**).

The third level provides detailed descriptions of certain features when you click ? (help question marks) in the interface. This takes you directly to the appropriate topic in the software documentation.

# What's New in this Version

## Version 5.1.1 (2014-03-14)

Version 5.1.1 is a minor update with bug fixes and refinements.

**Engine bugs fixed**

- Bug causing EddyPro to ignore the next raw file when current file is shorter than expected.
- Bug causing 'full co-spectra' files not to be read in 'eddypro_fcc'.

## Version 5.1.0 (2014-01-29)

Version 5.1.0 is a minor update with bug fixes and refinements.

**Engine bugs fixed**

- Import of TOB1 files, now avoids copying the same TOB1 file multiple times and speeds up processing of long TOB1 files (typical use case).
- Bug that was causing storage fluxes to be identically zero in most use cases.
- File in src_common was importing module rp-related (did not cause computation issues).

**Engine refinements**

- Modified Absolute Limits Statistical test defaults as follows:
  - Minimum sonic temperature set to -40 °C (was -20 °C).
  - Maximum $CO_2$ set to 900 ppm (was 600 ppm)
- Fixed ranges of accepted biomet values:
  - Changed minimum ambient pressure to 40 kPa (was 80 kPa).
  - Made all interval min/max closed instead of open, most importantly for RH, to include values of 0 and 100.
- Optimized the output time stamp in case of shorter-than-expected raw files.

**GUI (Graphical User Interface) bugs fixed**

- Improved computation progress bar to represent progress more accurately.
- Decimal digits of the 4th gas molecular values were lost in the Basic Settings page when saved.

**GUI Refinements**

- Improved information available in Run page.
- Added default button selection to SMARTFlux system package dialog.
- Modified absolute limits statistical tests as described above.

## Version 5.0.0 (2013-12-09)

EddyPro® Version 5.0 introduces the SMARTFlux system configuration file creator.

### GUI

- Implemented SMARTFlux bar and file package creation buttons.
- Removed "Number of files to merge" control.
- Removed "Gas analyzer height" from Metadata editor.
- Introduced "Open Sans" font.

### Engine bugs fixed

- Bug causing crash on short raw files.
- Software not reading strings longer than 200 characters in `.eddypro` file.
- Potential problems with timestamps in non-ISO format.
- Crash if last raw file of the dataset is not a valid one (too short, invalid header, etc.).
- Bug causing the software not to process correctly averaging intervals shorter than file length in certain circumstances.
- Use dynamic metadata files. Same variables as usual, but now full independence of processed time period from definition of dynamic metadata dates.
- Bug causing the spectral correction of Fratini et al. (2012) to virtually always use the fallback solution (model) rather than the direct method (thanks Olli Peltola and Ivan Mammarella!).
- Bug causing the spectral assessment to fail if a large number of spectra files were to be used.

### Engine Refinements

- Changed units of ET fluxes in the full output file. New units are mm+1hour-1.
- Changed Express settings. Cross-wind correction is no longer applied by default.
- Exception handling with SLT-EdiSol files if header reports implausible record length.
- Merged and simplified spectral correction code.
- Period to be processed extended to include the very last averaging interval, which was excluded from the automatic selection of start&end date performed in the GUI.
- Initialization of stats and their values when variables are missing.

### Engine New Features

- Creation of unique temp folder for allowing parallel runs.
- Possibility to process indefinitely long raw files. Possibility to process datasets for multiple years in one session.
- Smart understanding of initial timestamp in the dataset.

## Version 4.2.1 (2013-10-03)

### GUI Improvement

EddyPro update 4.2.1 is a minor update that fixes a GUI bug related to the retrieval of declination correction for magnetic north from the U.S. National Oceanic and Atmospheric Administration (NOAA) website. The update corrects an error that occurs when the website is unavailable.

## Version 4.2 (2013-08-22)

EddyPro update 4.2 is a minor update that includes several bug fixes and improvements to the processing engine and graphical user interface (GUI), including:

### Engine Improvements

- Fixed use of "Flags" (set in the "Basic Settings" page) for filtering out individual raw data records.
- Fixed import of SLT-EddySoft raw files featuring low-resolution data.
- Fixed formulation of tube transfer function for laminar regimes and - only in FCC - for turbulent regimes.
- Fixed problem with Fratini et al. 2012 spectral correction giving NaN in cases of high fluxes.
- Fixed bug in the running mean and exponential running mean detrending algorithms.
- Fixed bug in planar fit with no velocity bias that caused rotations not to be performed.
- Fixed bug in time lag optimizer causing a crash.
- Fixed initialization of footprint results for Kormann and Meixner (2001) and Hsieh (2000) models.
- Fixed labels of custom variables in full output, when created by FCC program (added "_mean" padding to each variable name).
- Fixed management of missing variables when passing from raw processing engine to FCC.
- Fixed the use of flow rate from raw data files when available, with both GHG and non-GHG files, if time lags are not explicitly set by user.

- Fixed bug that caused mismatch in full output headers when advanced processing settings were used.
- Fixed missing LI-7700 $CH_4$ flux output in full output file when data is screened using LI-7700 Diagnostic Value.
- Fixed wind coordinates rotation when AXIS configuration (Gill anemometers) or R2 anemometer is selected, for angle of attack correction.
- Added ET (evapotranspiration flux, in mm) to full output results.
- Added optional crosswind correction of sonic temperature for Gill WindMaster™ and WindMaster™ Pro anemometers (needed for type 1352, not for types 1561 or 1590).
- Refinement: extended range of accepted ambient pressures, now the minimum value accepted by EddyPro is 40 kPa, which replaces the former value of 80 kPa.
- Refinement: when running in Express mode, the default version of the angle of attack correction depends on the anemometer model (Nakai et al. 2006 for R3 and R2).
- Refinement: increased resolution of footprint results, from 5 to 1 meter, Kormann and Meixner (2001) and Hsieh (2000) models.
- Refinement: support for TOB1 files with no header lines (explicit user specification of variable types 'IEEE4' or 'FP2' is needed).
- Refinement: inverted time lag compensation and tilt correction procedures.
- Refinement: stationarity test evaluated after time lag compensation and tilt correction.
- Refinement: minor modifications to QC flags to better match flag definitions according to TK3 approach (M. Mauder, personal communications).
- Refinement: resolving to the Integral Turbulence Time Scale simple definition from Billesbach (2011) if direct calculation fails.

**GUI Improvements**

- Fixed behavior of North alignment for Generic Anemometer in the Metadata Editor
- Fixed bug that caused the default angle-of-attack to override user selection when re-opening a saved project.
- Fixed flags threshold and policy persistence when re-opening a saved project.
- Fix bug that prevented overriding "Lowest noise frequency" settings.
- Fixed overwriting of the anemometer user selection on the Basic Settings page in case of multiple anemometers.

- Fixed bug that prevented undue field persistence when changing units of the input in the Metadata Editor.
- Fixed Magnetic Declination fetching not working properly due to NOAA website changes.
- Refinement:Added dialog when clearing the raw data directory.
- Refinement: Modified raw file name format displayed in the corresponding dialog.
- Refinement: Permitted negative altitudes in Metadata Editor
- Refinement: Improved Metadata Editor stability.
- Refinement: Added Gain-Offset automatic selection in the Metadata Editor.
- Refinement: Added colors to variables ignored or not numeric in the Metadata Editor.
- Refinement: Disabled unnecessary fields and set Ignore to "yes" in case of non-numeric variables in the Metadata Editor.
- Refinement: Prevented column selection bug in metadata tables that triggered first row editing.
- Refinement: Ctrl+mouse-wheel resizes the GUI main window.
- Refinement: Disabled Ctrl+F12 shortcut to launch the program.
- Refinement: Cross-wind correction checkbox is always enabled, though checked as suggestion when needed.
- Refinement: Changed angle-of-attack correction policy with Gill anemometers.
- Refinement: Increased absolute limits ranges for statistical test on gases.
- Refinement: Changed policies to update software, project and metadata files versions at saving time.
- Refinement: Custom variables created in the file description table of the Metadata Editor will be permanently available in the local computer for future uses.

## Version 4.1 (2013-01-01)

EddyPro version 4.1 introduced 2 new major data processing options, completed a few features already drafted in version 4.0, and fixed a number of bugs found in version 4.0. The improvements in this version include:

**New features**

- Spectral correction scheme, implemented after Fratini et al. (2012), specifically designed for closed-path systems, but applicable to any eddy covariance setup.

- New angle-of-attack correction algorithm from Nakai and Shimoyama (2012).

**Improvements**

- Use of previous results to dramatically reduce program execution time.
- Express processing uses the new angle-of-attack correction algorithm from Nakai and Shimoyama (2012) rather than the correction from Nakai et al. (2006) used in previous versions.
- Support for binary SLT files containing more than 6 variables.
- External biomet data files are no longer limited to 18,000 records.
- Renamed **Dataset Selection** page to **Basic Settings** page.

**Major bug fixes**

**Automatic time lag optimization**

- **Bug description:** The bug was under the **Automatic time lag optimization** procedure (Advanced Settings > Processing Options > Time lag compensation). The bug is such that time lags assessed for $H_2O$ (if this gas is treated in flux computation) are erroneously used also for $CO_2$ or $CH_4$. Selection of an erroneous time lag results in flux underestimations: the more the used time lag deviates from the real one, the more fluxes are underestimated.
- **Who is affected:** Anyone who used the **Automatic time lag optimization** option for flux computations in a previous version of EddyPro is likely to be affected. However, the severity of the effects depends upon the gas analyzer in use. For open-path analyzers (e.g., LI-7500A), the bias if most likely negligible, if present at all. For enclosed-path analyzers (e.g., LI-7200), the bias is probably detectable but still negligible, because time lags of $H_2O$ do not deviate dramatically from those of $CO_2$, especially if conditions of low relative humidity (<50-60%, typically during daytime). In such analyzers, effects are further minimized if a short (< 1 m) and/or heated or insulated sampling line was used. For closed-path analyzers with sampling lines longer than 2 m, (e.g., LI-7000 or LI-6262), the effects are likely to be relevant and we thus recommend that you recalculate fluxes using EddyProversion 4.1.
- **Who is not affected:** All users who ran EddyPro in Express Mode or those who did not use the **Automatic time lag optimization**.

> **Note:** We recommend using the **Automatic time lag optimization** procedure especially for closed-path setups featuring medium and long (>3-4 m) sampling lines. The bug that affected this option is corrected in EddyPro 4.1.

**Calculation of average $CH_4$ mole fractions and mixing ratios from the LI-7700**

- **Bug description:** The bug prevented the band-broadening correction from being applied in the calculation of average $CH_4$ concentrations. Note that this did not affect flux calculations, as the band-broadening correction is applied to fluxes separately in EddyPro 4.0. The effects of this bug were visible especially in conditions of very low ambient pressure with respect to normal values.

**Other bug fixes**

- Fixed bug that caused the program to crash when the number of files selected for planar fit calculations were more than the maximum allowed (3,000). The bug was fixed and this maximum value was increased to 18,000.
- Fixed bug that caused the calculation of maximum wind speed to fail in cases in which raw data records have at least one wind components set to -9999 (EddyPro's internal error code). Most often this bug resulted in a maximum wind speed of 17318.7 m/s, that was the result of wind speed calculated from 3 wind components set to -9999. This bug had no effects on fluxes.
- Fixed bug that caused the crosswind correction of sonic temperature to be calculated erroneously for individual data records that have any wind component set to -9999. This bug resulted in implausible values for sonic temperature and thus either in fluxes set to -9999, or to extremely spiky fluxes. Note that for most anemometers the crosswind correction is applied in the firmware, so there is no need to apply it at processing time with EddyPro.
- Fixed bug that caused the header of "full output" file to be erroneous when using the option **Use standard output format**.
- Fixed bug that caused the night-time/daytime indication in the "full output" file to fail in some circumstances.
- Fixed a bug in the **Random uncertainty estimate**, that caused the software to crash with an "Out of memory" error message.

**GUI changes**

- Added a general **Restore Default Values** button to restore all the Advanced Settings to the Express (default) Settings.
- Added constraints between fields to help fill the **Metadata File Editor** tables.
- Improved management of previous versions of Project and Metadata files for backward compatibility.
- Added a Software Version field in the **Metadata File Editor** IRGA table.
- Added an automatic **Detect Dataset Dates** button for the raw data files.
- Prevented wheel mouse scrolling on setting controls.
- Improved management on low resolution displays.
- Added automatic saving when exiting sub-dialog.
- Fixed opening of associated .eddypro project files when double clicking the file.
- Added button to clear the output console.
- Improved guided mode information messages.
- Fixed many minor GUI bugs.

## Version 4.0 (2012-04-25)

EddyPro version 4.0 introduced additional computation options that were limited in the earlier releases of the software known as EddyPro 3.0 and EddyPro Express. This version provides a wide variety of options that make it possible to compute eddy covariance fluxes using one of many established techniques.

**New Features**

- Support for biomet data (biological and meteorological data) collected from ancillary sensors.
- Ensemble spectra, cospectra, modeled spectra, and ensemble spectra based on time period.
- New Metadata Retriever tool to compile all site metadata from GHG files into a single metadata file that can be edited or viewed.
- Planar Fit tool customization with graphical controls.
- Time Lag Optimization tool now supports automatic time lag optimization to account for time lags.
- Random Uncertainty estimation tool.

## Version 3.0.1 (not public)

**Bug fixes**

- Fixed initialization of latitude, longitude, and altitude when using dynamic metadata.

- Fixed Kljun et al. (2004) Footprint Estimation: Now uses measurement height minus displacement height to compute footprint. Previously used measurement height.
- Fixed sampling line flow-rate calculation when average flow rate from high-frequency data is used to initialize nominal, minimum and maximum time lags.
- Dialog boxes: Fixed bug that caused dialog boxes to display default settings when a project is re-opened, even if the settings had been altered previously. This presented risk that a setting could be reset to the default if a user opened a dialog box and clicked OK while the incorrect settings were displayed, and subsequently saved the project.
- Other minor bug fixes. See EddyPro® > Help > About > Changes for more information.

## Version 3.0.0 Final Release (2012-02-06)

**New features**

- Support for additional raw data file types, including ASCII Table, TOB1, SLT (EddySoft), SLT (EdiRe), Generic binary.
- Support for the "dynamic metadata," or site parameters that change over time.
- Support for other trace gases measured by an additional gas analyzer.
- Advanced processing options:
  - Wind speed measurement off-sets for U, V, and W.
  - Axis rotation for tilt correction options: planar fit, double rotation, triple rotation, planar fit with no velocity bias.
  - Detrending options: block averaging, linear detrending, running mean, exponentially weighted average.
  - Time lag compensation: constant, maximum covariance with default, maximum covariance without default.
  - Window for data tapering before FFT-ing: Square, Bartlett, Welch, Hamming, Hann.
- Fully configurable statistical tests, including:
  - Spike count/removal.
  - Amplitude resolution.
  - Drop-outs.
  - Absolute limits.
  - Skewness and kurtosis.
  - Discontinuities.
  - Time lags.

  - Angle of attack.
  - Steadiness of horizontal wind.
- Comprehensive output files, including
  - Full output (fluxes, quality flags, turbulence data, statistics).
  - Ameriflux results format.
  - GHG-Europe results format.
  - Statistical files (level 1 through 7).
  - Reduced spectral outputs (all binned spectra and cospectra; all binned ogives).
  - Full spectral and cospectral output for all wind and gas species variables.

## 3.0.0 Beta (2011-12-14)

First public release of 3.0.0 Beta. This version introduced the Advanced Options for testing.

## 2.3.0 (2011-07-20)

**Major bug fixes**

- An error occurred in the calculation of corrected fluxes if the $N_2O$ analyzer was a closed-path one, while the $CH_4$ analyzer was open-path or $CH_4$ was not present at all. The bug resulted in corrected fluxes of $N_2O$ equal to -9999 (that is, if your $N_2O$ fluxes are not -9999, they are not affected by this bug).
- Definition of "relative separations". No impact on calculations, only on the output metadata.
- Control on use of cell temperature (fixed re-initialization of column information).
- In statistical tests (Spike count/removal and Amplitude Resolution/Drop Out) length of implied windows modified so as to scale with the length of the averaging period.

**Improvements**

- Handling of situations where $H_2O$ readings are not available (air density, momentum flux).
- Control over peculiar situations in Fluxes23 (WPL section).
- Introduced support for TOB1 format "FP2."
- Introduced detection of very implausible values in the raw files, and their substitution with error codes.
- Error codes in raw files (-9999) are no longer modified during conversions of raw units into EddyPro units.

- Better handling of situation when all GHG files have invalid metadata or are corrupted.
- Better handling of the computations exit codes.

### 2.2.0 (2011-06-20)

**Bug fixes**

- Fixed bug concerning fluxes calculated from $CH_4$ and $N_2O$ mole fraction measurements from closed path systems. The bug affected also fluxes calculated with $CO_2$ mole fractions, if the paired $H_2O$ was measured as either molar density or mixing ratio. In all cases, the bug resulted in flux values =-9999 (that is, if your fluxes are not -9999, they are not affected by this bug).
- Fixed Altitude field zeroing in the Metadata editor.
- Changed the docking policies of the Tips dock: now it's movable and floatable top and bottom and it could also be tabbed with the Console.
- Changed the dimension policy of the Tips dock: now it's expandable.
- Fixed misspellings.
- Used native dialog for the 'Save metadata as' button.
- GUI code cleaned up.

### 2.1.4 (2011-06-02)

- Fixed incorrect filtering of $CH_4$ vars in the Processing page, in case of Generic gas analyzer.
- Added the Change Log file viewer in the About dialog.

### 2.1.3 (2011-05-31)

- Fixed the SoS to temperature conversion.
- More detailed diagnostic on the metadata file validation at console.
- Quality flags recalculated according to Mauder and Foken (2004), which should eliminate most (possibly not all) of the -9999 in the quality flags.
- Added CHANGELOG.txt to source and installer packages.

### 2.1.2 (2011-05-18, not public)

- Fixed problem of Access denied authorization during the processing of the data.

### 2.1.1 (2011-04-26)

- Fixed typo about the unit of measure of the Raw Data Description table (umol/mol^3, instead of umol/m^3).

### 2.1.0 (2011-04-21)

- Optimized GUI for support low resolution screens (up to 800x600 px).
- Rearranged widgets beetwen Project page and Processing page (ID moved to Processing).
- Added input dialog for the ID field.
- Improved look&feel of Combo box and Spin box.
- Changed policies for scrollbar and scrolling behaviour into the tables.
- Changed default value in some table fields.
- Changed from QByteArrays to QString where is the possibilities of weak conversions.
- Fixed selection of "None" variables into **Processing Page** combo's when there are already some variables selected.
- Updated the manual.

### 2.0.0 (2011-04-05)

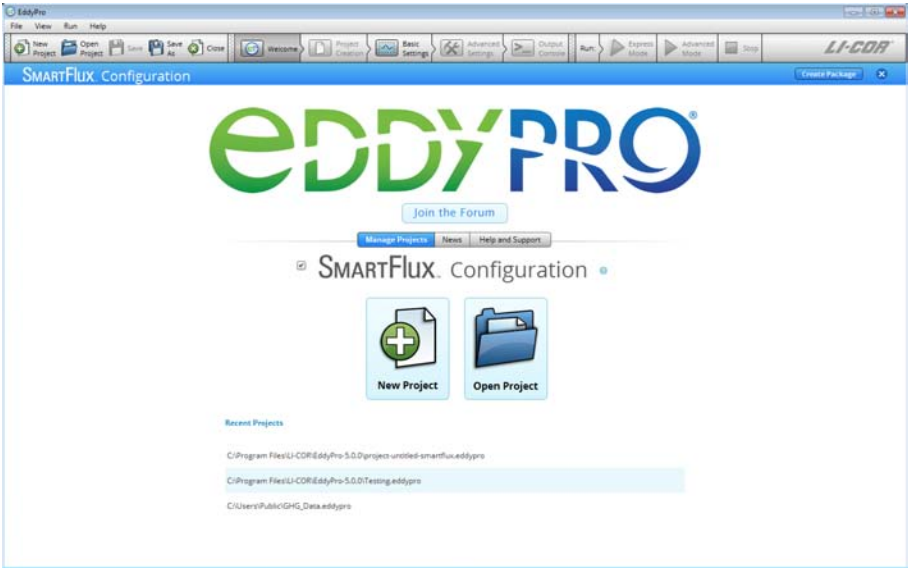
- First public release of EddyPro® (Express version only).

# 2 The Interface

This section provides a high-level overview of the EddyPro interface. It should help you become familiar with the menus, toolbars, and the settings that are available on each page of EddyPro.

## Welcome Page

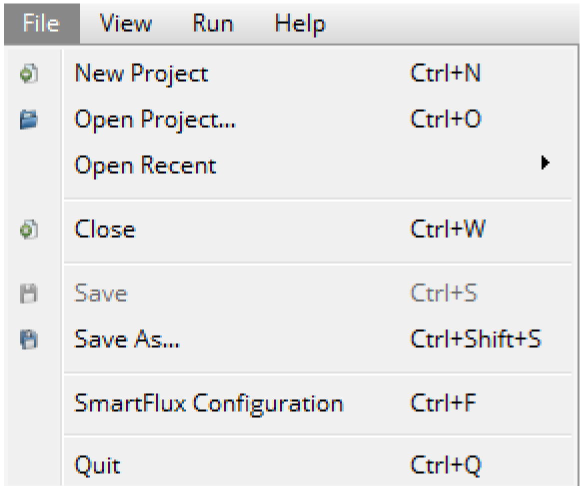
Upon entering the application, you will see the Welcome Page, which includes options to start a new project or open an existing project, and the customary menus and toolbars. These include:




### Menus

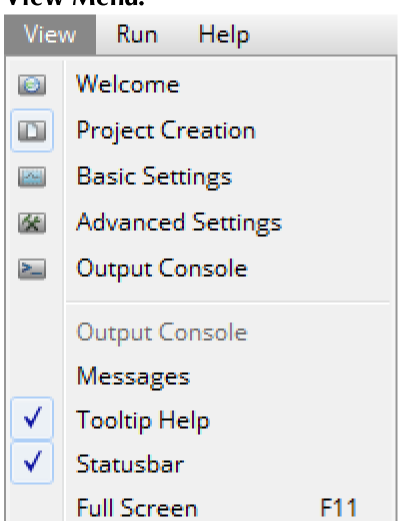
In the top left of the EddyPro® window, you will see four menus:

- **File Menu:**




Provides options to create a **New Project**, **Open Project...**, **Open Recent** projects, **Close** the current project, **Save** the current project, or **Save As...** to save a copy with a new file name.

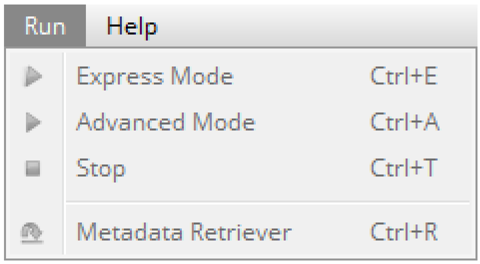
- **View Menu:**




Provides navigation between the **Project Creation** page, **Basic Settings** page, **Advanced Settings** page, and **Output Console**. You can also toggle EddyPro

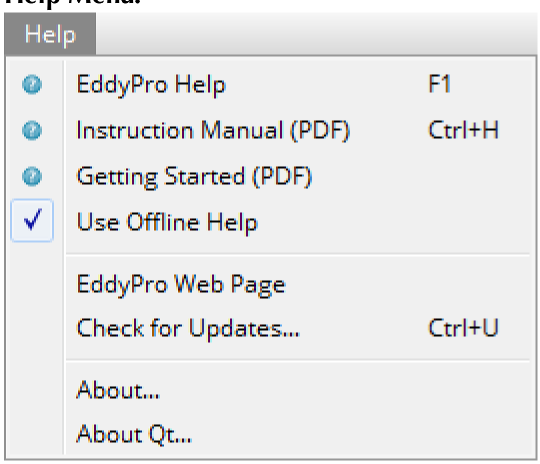
Tips and EddyPro messages. Some of these options are only available after you have entered the software suite.

- **Run Menu:**




Here you can choose to run a project as **Advanced** or **Express**, or to **Pause/Stop** a run. It also includes the **Metadata Retriever** run option. These options are available after the project has been started.

- **Help Menu:**




Here you can access the online or offline **Help System**, view **Video Tutorials**, check for software updates, view information about the application, and view information about the Qt development environment. If you are not online, select "Use Offline Help" to access a version of the help resources that are installed with the EddyPro application.

### Toolbars

- The **File Toolbar** includes many of the same options available under the **File Menu** (New Project, Open Project, Save, Save As.., and Close).


- The **Navigation Toolbar** has five buttons.These are used to navigate between pages in the software.

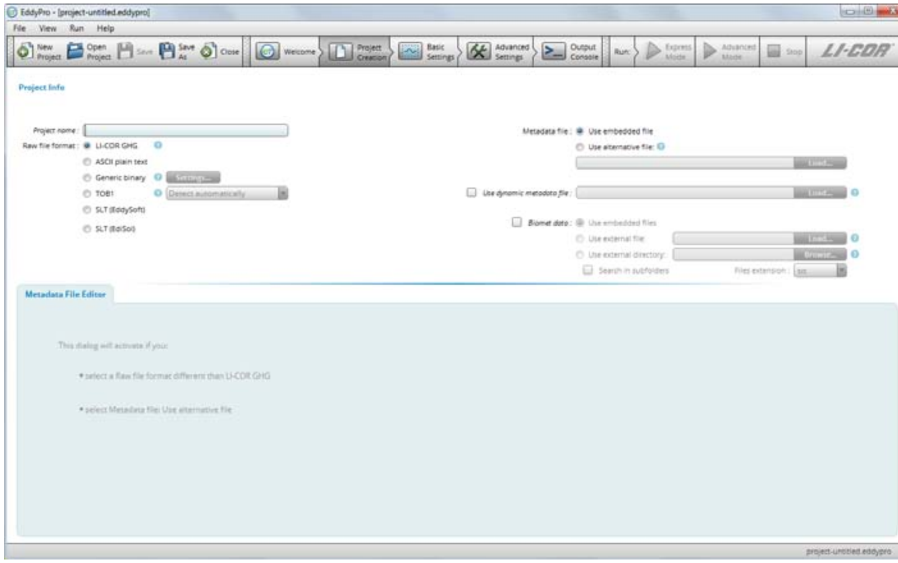

- The **Run Toolbar** provides the buttons that initiate data processing. The run buttons activate after EddyPro has enough information to complete the project. **Express Mode** uses predefined default settings to process the project. **Advanced Mode** uses which ever settings you apply in the software interface. **Stop** will end a data processing session.


The tool bars can be moved to the desired position on your computer display.

## Project Creation Page

The Project Creation page is where you specify details about your project, including the project name and raw file name format. The visible fields on the projects page depend on the file type you are processing. For LI-COR® GHG file types, under a typical scenario, you will only need to enter the **Project Name** before advancing to the **Basic Settings** page. Under other circumstances, or any time you are processing a file other than the LI-COR® GHG file type, you will need to use the Metadata File Editor to create or modify an existing metadata file.

You can also specify a dynamic metadata file, or instruct EddyPro® to use meteorological data from another file or files contained in a folder.




Fields in the Project Page are described below:

## Project Name

Enter a name for the flux computation project. This will be the default file name for this project, but you can edit it while saving the project. This field is optional. The graphical interface does not allow the use of characters that result in file names unacceptable to the underlying operating system (for Windows these include: \ / : @ ? * ” < >).

## Raw file format

Select the format of your raw files. These are described below:

**LI-COR GHG:** A LI-COR customized raw file format. Each GHG file is an archive containing the raw high-speed data (.data) and information on the study site (.metadata), both in readable text format. It can also include biological and meteorological data. See "LI-COR® GHG File Type" on page 6-2.

**ASCII Plain Text:** Any text file organized in data columns, with or without header. All typical field separators (tab, space, comma and semicolon) are supported. The Campbell® Scientific TOA5 format is an example of a supported ASCII data file.

**Generic Binary:** Generic binary (unformatted) raw data files. Limited to fixed-length binary words that contain data stored as single precision (real) numbers. Click the ***Settings...*** button and provide specifications of the binary format so EddyPro can read the files correctly.

- **Number of ASCII header lines:** Enter the number of ASCII (readable text) header lines present at the beginning of your binary files. Enter 0 if there is no ASCII header.
- **ASCII header end of line:** If an ASCII header is present in the files, specify the line terminator. Typically, Windows operating systems use Carriage Return + Line Feed (0x0D+0x0A), Linux operating systems and Mac OS X use Line Feed (0x0A), while Mac operating systems up to version 9 and OS-9 use Carriage Return (0x0D).
- **Number of bytes per variable:** Specify the number of bytes reserved for each variable stored as a single precision number. Typically, 2 bytes are reserved for each number.
- **Endianess:** In a multi-bytes binary word, *little endian* means that the most significant byte is the last byte (highest address); *big endian* means that the most significant byte is the first byte (lowest address).

**TOB1:**Raw files in the Campbell® Scientific binary format. Support of TOB1 format is limited to files containing only ULONG and IEEE4 fields, or ULONG and FP2 fields. In the second case, FP2 fields must follow any ULONG field, while for ULONG and IEEE4 there is no such limitation.

> **Note:** ULONG fields are not interpreted by EddyPro, thus they can only be defined as “ignore” variables.

- **Detect Automatically:** Let EddyPro figure out whether TOB1 files contain (ULONG and) IEEE4 fields or (ULONG and) FP2 fields.
- **Only ULONG and IEEE4 fields:** Choose this option to specify that your TOB1 files contain only IEEE4 fields and possibly ULONG fields. EddyPro does not interpret ULONG fields. This means that any variable stored in ULONG format must be marked with “ignore” in the Raw File Description table. Typically ULONG format is used for time stamp information.
- **Only ULONG and FP2 fields:** Choose this option to specify that your TOB1 files contain only FP2 fields and possibly ULONG fields. ULONG fields, if present, must come first in the sequence of fields. EddyPro does not interpret ULONG fields. This means that any variable stored in ULONG format must

be declared marked with the “ignore” option in the Raw File Description table. Typically ULONG format is used for time stamp information.

**SLT (EddySoft):** Format of binary files created by EddyMeas, the data acquisition tool of the EddySoft suite, by O. Kolle and C. Rebmann (Max Planck Institute, Jena, Germany). This is a fixed-length binary format. It includes a binary header in each file that needs to be interpreted to correctly retrieve data. EddyPro does everything automatically.

**SLT (EdiSol):** Format of binary files created by EdiSol, the data acquisition tool developed by Univ. of Edinburg, UK. This is a fixed-length binary format. It includes a binary header in each file that needs to be interpreted to correctly retrieve data. EddyPro does everything automatically.

## Metadata

Metadata is information that describes the raw eddy covariance data. More specifically, it describes where and how the data were collected, what instruments were used, and how the data are arranged in the data files. Choose whether to use metadata files embedded into GHG files (LI-COR® GHG only) or to bypass them by using an alternative metadata file. See "Metadata File Editor" on the next page and "LI-COR® GHG File Type" on page 6-2.

**Use embedded file:** Select this option to use file-specific meta-information, retrieved from the metadata file residing inside the GHG archive.

**Use alternative file:** Select this option to use an alternative metadata file. In this case all files are processed using the same meta-information, retrieved from the alternative metadata file. This file is created and/or edited in the ***Metadata File Editor***. If you are about to process GHG files, you can speed up the completion of the alternative METADATA by unzipping any raw file and loading the extracted METADATA from the “Use alternative metadata file” ***Load*** button. Make changes if needed and save the file.

**Load:** Load an existing metadata file to edit it in the Metadata File Editor. If you use the Metadata File Editor to create and save a new metadata file from scratch, its path will appear here.

**Use dynamic metadata file:** Check this option and provide the corresponding path to instruct EddyPro to use an externally-created file that contains time changing metadata, such as canopy height, instrument separations and more. See "Time-varying (Dynamic) Metadata" on page 6-5.

## Biomet Data

**Biomet data:** Select this option and choose the source of biomet data. Biomet data are slow (< 1Hz) measurements of biological and meteorological variables that complement eddy covariance measurements. Some biomet measurements can be used to improve flux results (ambient temperature, relative humidity and pressure, global radiation, PAR and long-wave incoming radiation). All biomet data available are screened for physical plausibility, averaged on the same time scale of the fluxes, and provided in a separate output file.

- **Use embedded files:** Choose this option to use data from biomet files embedded in the LI-COR GHG files. This option is only available for GHG files collected with the LI-7550 embedded software v6.0.0 or newer, provided a biomet system was used during data collection. EddyPro will automatically read biomet files from the GHG bundles, interpret them and extract relevant variables.
- **Use external file:** Choose this option if you have all biomet data collected in a single external file. Provide the path to this file by using the ***Load...*** button.
- **Use external directory:** Choose this option if you have biomet data collected in more than one external file, and provide the path to the directory that contains those files by using the ***Browse...*** button.

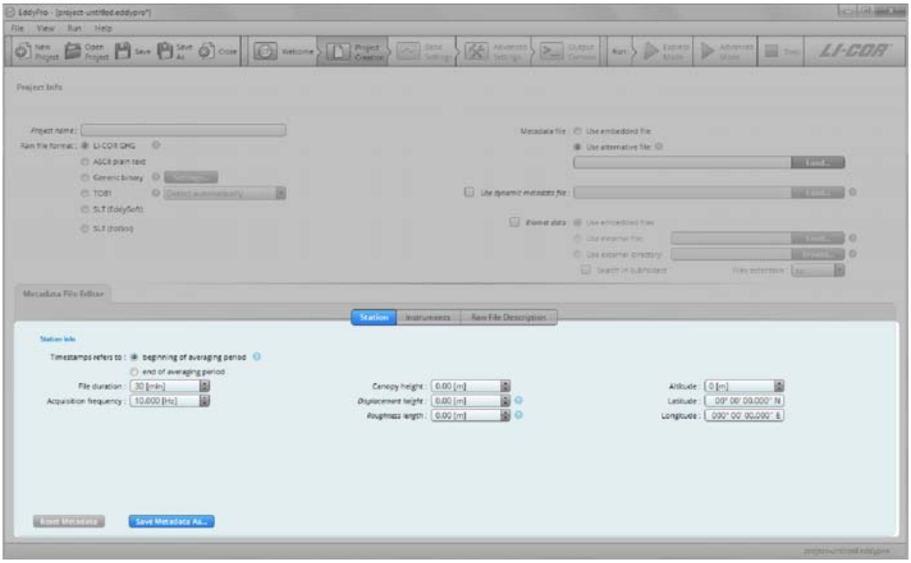
**Important:** All biomet files must be formatted according the guidelines that you can find in "External Biomet File(s)" on page 4-15.

## Metadata File Editor

The **Metadata File Editor** is part of the Project Creation page. It is used to create and edit metadata for the processing project. Metadata may include site information, station information, and information that describes how data are arranged in data files. If you are processing LI-COR® GHG files, you may use the Metadata File Editor to modify the embedded metadata files. If you are processing other file types, use the Metadata File Editor to enter and save metadata. There are three tabs: Station, Instruments, and Raw File Description.

### Station

Under this tab, provide information that describes the research station. This information will be used for every data file processed with this metadata file.



**Timestamp refers to:** Select whether the timestamp provided in raw file names refers to the beginning or to the end of the data interval. See "Beginning of Dataset" on page 6-13.

- **beginning of averaging period:** Select this option if timestamps in raw file names refer to the beginning of the data interval.
- **end of averaging period:** Select this option if timestamps in raw file names refer to the end of the data interval.

**Note:** Timestamps on EddyPro® output files always refer to the end of the averaging interval.

**File duration:** Enter the time span covered by each raw file.

**Acquisition frequency:** Referred to as **update rate** or **output rate** in the LI-7500A, LI-7200, or LI-7700 software. Enter the acquisition frequency (number of samples per second) used to collect raw data.

**Altitude:** Elevation above sea level to the base of the flux tower.

**Canopy height:** Effective average distance between the ground and the top of the plant canopy. Also referred to as *aerodynamic canopy height*.

**Displacement height:** Zero plane displacement height is the average level at which elements of the plant community absorb momentum. If left blank, this parameter is automatically estimated based on canopy height. See "Displacement Height" on page 6-14.

**Roughness length:** Canopy roughness length is a quantification of the surface roughness. If left blank, this parameter is automatically estimated, based on canopy height. See "Roughness Length" on page 6-14.

**Latitude:** Latitude at the site. Use N and S for north and south latitudes, respectively.

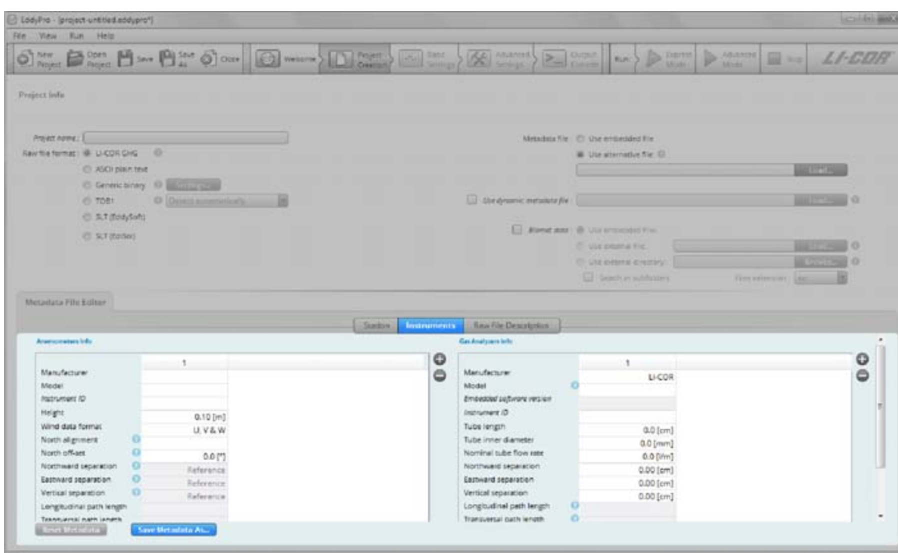
**Longitude:** Longitude at the site. Use E and W for east and west longitudes, respectively.

**Reset Metadata:** Reset the default settings in the Metadata File Editor. Does not affect other settings of the project.

**Save metadata as...:** Save the metadata file with a new file name. To save the processing project, use the file menu or toolbar.

### Instruments

Enter information that describes all anemometer(s) and gas analyzer(s) used at the EC station to collect the data you want to process.



## Anemometer Information

Describe the anemometers used at the EC station to collect wind and sonic temperature data you want to process.

**Manufacturer:** Specify the manufacturer of the anemometer among those supported. Choose *Other* for any manufacturer not explicitly listed. This field is mandatory.

**Model:** Identify the model of the anemometer. Choose *Generic Anemometer* for any model not explicitly listed. This field is mandatory.

**Instrument ID:** Enter an ID for the anemometer, to distinguish it from the other instruments. This is only for your records and providing it is optional.

**Height:** Enter the distance between the ground and the center of the device sampling volume. This field is mandatory.

**Wind data format:** Specify in which format the wind components are provided. This can be *U, V, W*; *Polar* and *W*; or *axis velocities*.

**North alignment:** For Gill anemometers, specify whether the spar or axis of the anemometer is oriented toward north. This field only applies to Gill anemometers.

**North offset:** Enter the anemometer's yaw offset with respect to local magnetic north, positive eastward (magnetic north as assessed with a compass, not corrected for declination). See "North Offset" on page 6-15.

**Northward separation:** Specify the distance between the current anemometer and the reference anemometer, as measured horizontally along the north-south axis (the one you assess with a compass). The distance is positive if the current anemometer is placed to the north of the reference anemometer. The reference anemometer is the first one you describe. For this anemometer you cannot enter the separation and you find the string *Reference*. See "Northward, Eastward, and Vertical Separation" on page 6-16.

**Eastward separation:**. Specify the distance between the current anemometer and reference anemometer, as measured horizontally along the east-west axis (the one you assess with a compass). The distance is positive if the current anemometer is placed to the east of the reference anemometer. The reference anemometer is the first one you describe. For this anemometer you cannot enter the separation and you find the string *Reference*. See "Northward, Eastward, and Vertical Separation" on page 6-16.

**Vertical separation:** Specify the distance between the current anemometer and reference anemometer, as measured horizontally along the vertical axis. The distance is positive if the current anemometer is placed above the reference anemometer. The reference anemometer is the first one you describe. For this anemometer you cannot enter the separation and you find the string *Reference*. See "Northward, Eastward, and Vertical Separation" on page 6-16.

**Longitudinal path length (anemometer):** Path length in the direction defined by any transducer pair. Consult the anemometer's specifications or user manual. See "Longitudinal/Transversal Path Lengths and Time Response" on page 6-13.

**Transversal path length (anemometer):** Path length in the direction orthogonal to the longitudinal path length (e.g., as defined by the diameter of transducers). See "Longitudinal/Transversal Path Lengths and Time Response" on page 6-13.

**Time response (anemometer):** Time response of the anemometer. Its inverse defines the maximum frequency of the atmospheric turbulence that the instrument is able to resolve. Consult the anemometer's specifications or user manual. See "Longitudinal/Transversal Path Lengths and Time Response" on page 6-13.

**+** Add a new anemometer.

**-** Remove the currently selected anemometer.

### Gas Analyzers Information

Describe gas analyzers used at the EC station to collect data you want to process.

**Manufacturer:** Specify the manufacturer of the gas analyzer. For gas analyzers other than LI-COR, select *Other*. This field is mandatory.

**Model:** Identify the model of the gas analyzer. For gas analyzers other than LI-COR, select the appropriate typology. OP and CP stand for open path and closed path, respectively. See "Model (Gas Analyzer)" on page 6-12.

**Software version:** Identify the embedded software version that was running on the LI-7550 Analyzer Interface Unit at the time data were collected. Mandatory only for the LI-7200 and LI-7500A $CO_2$/$H_2O$ analyzers.

**Instrument ID:** Enter an ID for the gas analyzer. This is only for your records and providing it is optional.

**Height:** Enter the distance between the ground and the center of the device sampling volume or inlet of the intake tube. This field is mandatory.

**Tube length:** Specify the length of the intake tube in centimeters. This field is mandatory for closed path instruments. Ignore it for open path instruments.

**Tube inner diameter:** Specify the inside diameter of the intake tube in centimeters. This field is mandatory for closed path instruments. Ignore it for open path instruments.

**Nominal tube flow rate:** Specify the flow rate in the intake tube expected during normal operation. This field is mandatory for closed path instruments. Ignore it for open path instruments.

**Northward separation:** Specify the distance between the center of the sample volume (or the inlet of the intake tube) of the current gas analyzer and the reference anemometer, as measured horizontally along the north-south axis (the one you assess with a compass). The distance is positive if the gas analyzer is placed to the north of the anemometer. See "Northward, Eastward, and Vertical Separation" on page 6-16.

**Eastward separation:** Specify the distance between the center of the sample volume (or the inlet of the intake tube) of the current gas analyzer and the reference anemometer, as measured horizontally along the east-west axis (the one you assess with a compass). The distance is positive if the gas analyzer is placed to the east of the anemometer. See "Northward, Eastward, and Vertical Separation" on page 6-16.

**Vertical separation:** Specify the distance between the center of the sample volume (or the inlet of the intake tube) of the current gas analyzer and the reference anemometer, as measured vertically. The distance is positive if the gas analyzer is above the anemometer. See "Northward, Eastward, and Vertical Separation" on page 6-16.

**Longitudinal path length (gas analyzer):** Path length in the direction of the optical source. Consult analyzer's specifications or user manual. See "Longitudinal/Transversal Path Lengths and Time Response" on page 6-13.

**Transverse path length (gas analyzer):** Path length in the direction orthogonal to the optical source. Consult the analyzer's specifications or user manual. See "Longitudinal/Transversal Path Lengths and Time Response" on page 6-13.

**Time response (gas analyzer):** Time response of the gas analyzer. Its inverse defines the maximum frequency of the atmospheric turbulent concentration fluctuations that the instrument is able to resolve. Consult analyzer's specifications or user manual. See "Longitudinal/Transversal Path Lengths and Time Response" on page 6-13.

**Extinction coefficient of water, $K_w$:** In Krypton or Lyman-α hygrometers, the extinction coefficients for water vapor, associated with the third-order Taylor expansion of the Lambert–Beer law around reference conditions (van Dijk et al. 2003).

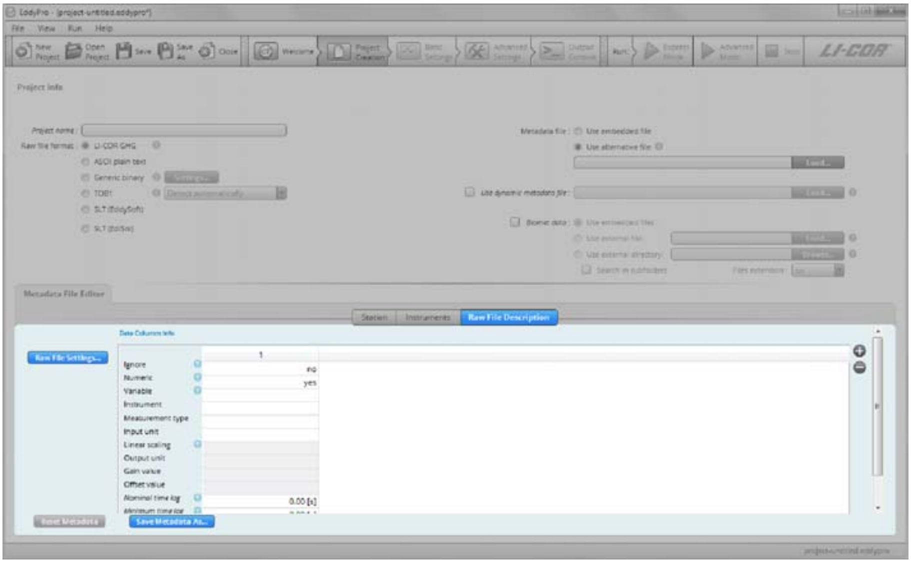
**Extinction coefficient of oxygen $K_o$:** In Krypton or Lyman-α hygrometers, the extinction coefficients for oxygen, associated with the third-order Taylor expansion of the Lambert–Beer law around reference conditions (van Dijk et al. 2003).

**+** Add another gas analyzer.

**-** Remove the currently selected gas analyzer.

## Raw File Description

In this tab you describe the raw files, including their format and content. If needed, you can also provide scaling information to turn raw variables into physical units and estimation time lags for non-anemometric variables.



**Ignore:** Select *yes* to instruct EddyPro to ignore a column (variable). Columns to be ignored include time stamps, line counters, etc.

> **Note:** If a variable is not numeric, this must be specified even if you set *yes* in the *ignore* field.

**Numeric:** Select *no* to tell EddyPro that a column (variable) is not purely numeric. Purely numeric variables are strings included within two consecutive field separators and containing only digits from 0 to 9 and, at most, the decimal dot. Any other character makes a variable not numeric. For example, time stamps in the form of 2011-09-26 or times as 23:20:562 are not numeric variables.

**Variable:** Specify the variable that is contained in the current column of the raw files (or position, for binary files). Choose from the available list or type in a custom variable label.

> **Note:** Custom variables created in the file description table of the Metadata Editor will be permanently available in the local computer for future use.

**Instrument:** Select the instrument that measured the current variable. Instruments listed here are those entered under the instruments tab.

**Measurement type:** Only applicable to gas concentrations. Enter the description of the concentration measurement (either *Molar/Mass density*, *Mole fraction*, or *Mixing ratio*). For all other variables, either leave the field blank or select *Other*. *Molar/Mass density* is a measure of moles/mass per unit volume of air. *Mole fraction* is a measure of mass per mass of wet air. *Mixing ratio* is a measure of mass per mass of dry air. Measures of mass can be expressed as number of moles, grams, etc.

**Input unit:** Specify the units of the variable as it is stored in the raw file.

**Linear scaling:** Specify whether to perform a linear conversion to rescale data. Variables that are already in any of the supported physical units do not need to be rescaled. See "Linear Scaling" on page 6-20.

**Output unit:** Only if you are doing a conversion, enter the output units (physical units after conversion). The following *Gain* and *Offset* values must be such that the input variable is converted into the selected output unit.

**Gain value:** Enter the gain (slope) of the linear relation between input and output units.

**Offset value:** Enter the offset (y-axis intercept) of the linear relation between input and output units.

**Nominal time-lag:** Enter the expected (nominal) time lag of the variable, with respect to the measurements of the anemometer that you plan to use for flux computation, as applicable. Time lags should be specified at least for gas concentrations and can be estimated based on instrument separation (open path) or on the sampling line characteristics and the flow rate (closed path). See "Nominal, Minimal, and Maximum Time Lag" on page 6-21.

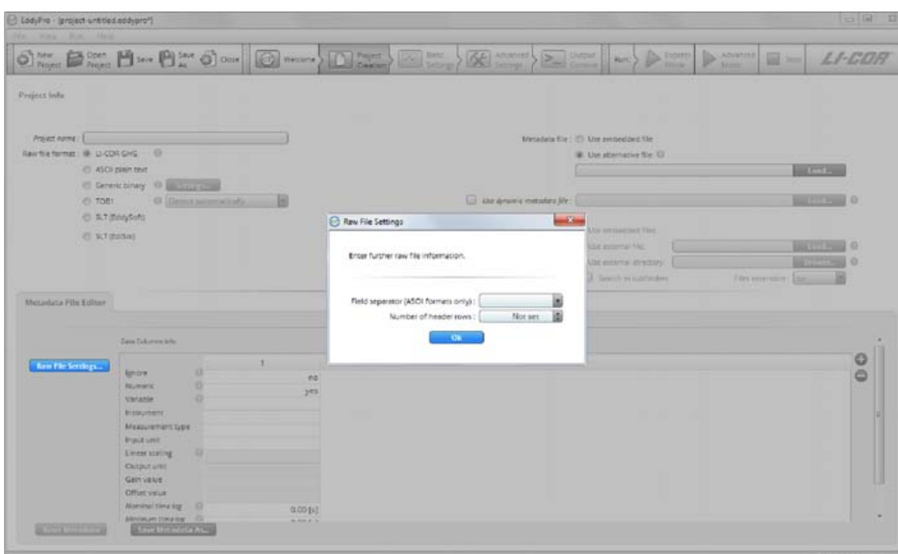
**Minimum time-lag:** Enter the minimum expected time lag for the current variable, with respect to anemometric measurements.

**Maximum time-lag:** Enter the maximum expected time lag for the current variable, with respect to anemometric measurements.

**+** Add a variable.

**-** Remove a variable

## Raw File Settings...

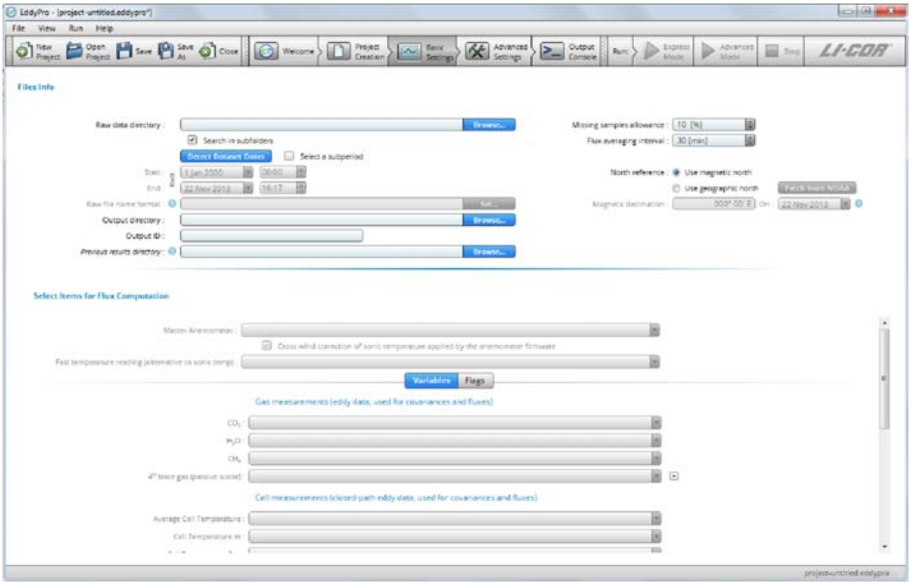


**Field separator character:** Specify the character that separates individual values within the same sample in the raw files.

**Number of header rows:** Enter the number of rows in the header of the file, if present. In most cases, the software will be able to filter away individual text lines that do not comply with the description provided here. Therefore, most files with a variable number of header lines are supported.

## Basic Settings Page

This page calls for information about the raw data used in this project. These options are used to specify directories, file length, a subset of data, and the items to include in flux computations.



### Files Info

**Raw data directory:** Use the *Browse…* button to specify the folder that contains the raw data. If data are also contained in subfolders, select the *Search in subfolders* box.

**Search in subfolders:** Check this box if data are in subfolders in the selected directory. EddyPro® will process files that are in the *Raw data directory* and its *subfolders* if this box is checked.

**Detect Dataset Dates:** Click this button to ask EddyPro to retrieve the starting and ending date of the raw dataset contained in the *Raw data directory*. You can override this automatic setting by using the *Select a subperiod* option.

**Select a subperiod:** If you wish to process a subset of data in the *Raw data directory*, check this box and enter the time constraints for the subset in the fields below. Leave this field unchecked to process all the data in the folder.

**Starting date and time:** This is the starting date of the dataset under consideration. It may or may not coincide with the date of the first raw file. This is used to select a subset of available raw data for processing.

**Ending date and time:** This refers to the ending date of the dataset under consideration. It may or may not coincide with the date of the last raw file. This is used to select a subset of available raw data for processing.

**Raw file name format:** For raw files other than GHG, your entry in this field should indicate which parts of the file name are the year, month (mm if using dd for day, omit if using ddd), day (dd for day of month or ddd for day of year), hour (HH), minute (MM), and the extension of the file. See "Raw File Name Format" on page 6-1.

**Output directory:** Specify where the output files will be stored. Click the **Browse…** button and navigate to the desired directory. You can also type/edit it directly from this text box. The software will create subfolders inside the selected output directory.

**Output ID:** Enter the ID. This string will be appended to each output file so a short ID is recommended. Again, the graphical interface does not allow the use of characters that result in file names unacceptable to the underlying operating system (for Windows® these include: \ / : @ ? * ″ < >).

**Previous output directory:** This is the path of a directory containing results from previous run(s). EddyPro will attempt to speed up the flux computation procedure by checking for any partial results obtained from previous run(s). If they are contained in this folder EddyPro will check the settings against the current settings to determine if these data are suitable as an intermediate starting point in the current data processing session. See "Using Results from Previous Runs" on page 6-24.

**Missing sample allowance:** Select the maximum percent of missing samples that are allowed in each output file. If the number of missing values exceeds this setting the file will be ignored in the dataset.

**Flux averaging interval:** This is the time span over which fluxes will be averaged. The flux averaging interval can be shorter than, equal to, or longer than the raw file duration. Set to *0* to use the input file duration as the flux averaging interval, in which case *File as is* appears in the field.

**North reference:** Indicate whether you want the output data to be referenced to magnetic or geographic north. If you choose geographic north, EddyPro can retrieve the Magnetic Declination at your site from NOAA (U.S. National Oceanic and Atmospheric Administration) online resources. You can also enter the magnetic declination manually. EddyPro assumes that north is assessed at the site using the compass, so that everything you provide to the software is with respect to local geographic north. If your measurements are taken with respect to due (magnetic) north, then just select the option *Use magnetic north* or enter a declination of zero degrees.

**Magnetic Declination:** Based upon the latitude and longitudinal coordinates entered, EddyPro determines the magnetic declination from the NOAA (National Oceanic and Atmospheric Organization) internet resources (U.S. National Geophysical Data Center).

## Select items for flux computation

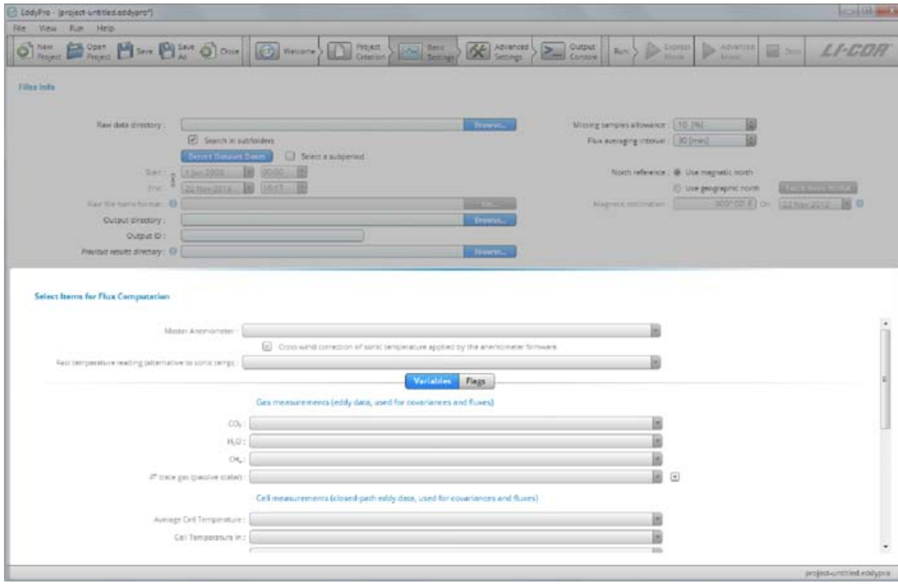
Specify variables to be used for flux computation.

**Master sonic:** Select the sonic anemometer from which wind and sonic temperature data should be used for calculating fluxes.

**Fast temperature reading:** If raw files contain valid readings of air temperature collected at high frequency (e.g., by a thermocouple), you can use any of them in place of sonic temperature. In this case, corrections specific to sonic temperature (crosswind correction, humidity correction), will not be applied.

**Crosswind correction for sonic temperature:** Check this box if the crosswind correction is applied internally by the anemometer firmware before outputting sonic temperature. Be aware that some anemometers do apply the correction internally, others not, and others provide it as an option.

> **Note:** Users of Gill WindMaster™ and WindMaster™ Pro: The crosswind correction is not applied internally in anemometer units of type 1352, while it is available in the firmware of later types 1561 and 1590.




**Flags:** Each column of the raw data file that was not tagged as “to be ignored” can be used as a mask to filter out individual high frequency records. Up to ten flags can be specified.

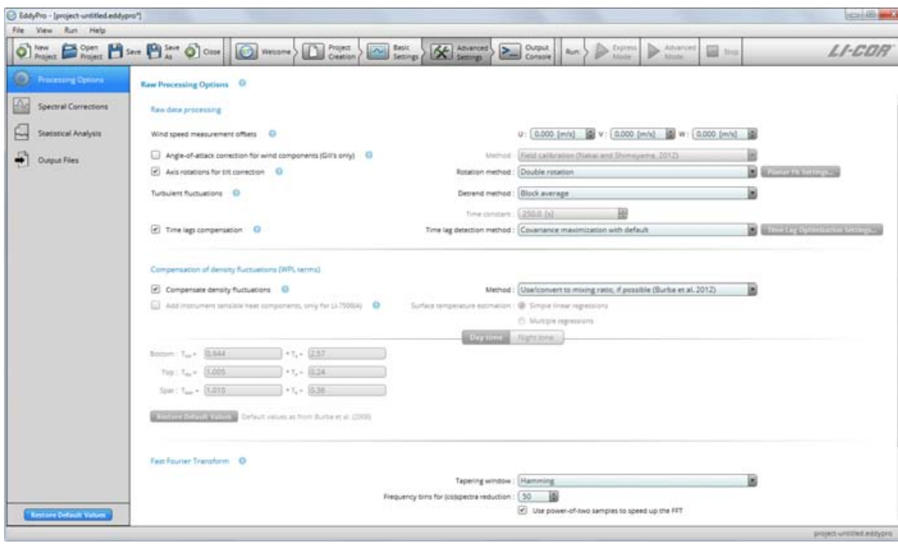
> **Note:** An entire record (that is, all variables measured at a certain time instant, one line of raw data) is eliminated any time a flag variable does not comply its quality criterion. See "Flags" on page 6-26.

# Advanced Settings

Advanced Settings are used to configure EddyPro for complex data processing. The options available here are generally useful for research applications, custom configuration for sites with complex topography, atypical instrument setups, and for advanced users with high-level knowledge eddy covariance techniques.

The Advanced Settings page includes four tabs: Processing Options, Statistical Tests, Spectral Corrections, and Output Files.

## Processing Options




## Raw Data Processing

**Wind speed measurement offsets:** Wind measurements by a sonic anemometer may be biased by systematic deviation, which needs to be eliminated (e.g., for a proper assessment of tilt angles). You may get these offsets from the calibration certificate of your units, but you could also assess it easily, by recording the 3 wind components from the anemometer enclosed in a box with still air (zero-wind test). Any systematic deviation from zero of a wind component is a good estimation of this bias.

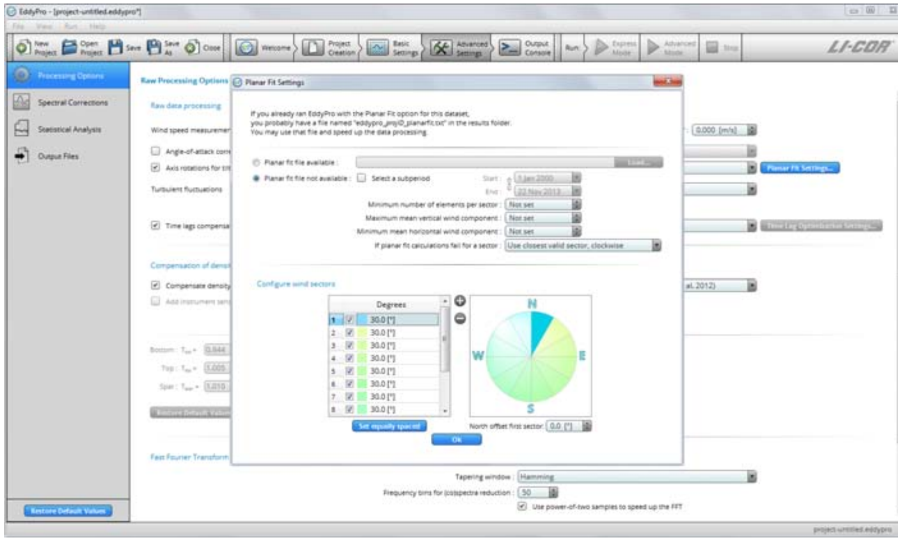
**Angle-of-attack correction for wind components:** Applies only to vertical mount Gill sonic anemometers with the same geometry of the R3 (e.g., R2, WindMaster). This correction is to compensate the effects of flow distortion induced by the anemometer frame on the turbulent flow field. See "Angle-of-Attack Correction" on page 7-20.

- **Field calibration (Nakai and Shimoyama, 2012):** Select this option to apply the angle-of-attack correction according to the method described in the referenced paper, which makes use of a field calibration instead of the wind tunnel calibration.
- **Wind tunnel calibration (Nakai et al., 2006):** Select this option to apply the angle-of-attack correction according to the method described in the referenced paper, which makes use of a wind tunnel calibration instead of the field calibration.

**Axis rotation for tilt correction:** Select the appropriate method for compensating anemometer tilt with respect to local streamlines. Uncheck the box to *not perform* any rotation (not recommended). If your site has a complex or sloping topography, a planar-fit method is advisable. Click on the “**Planar Fit Settings...**” to configure the procedure. See "Axis Rotation for Tilt Correction" on page 7-22.

- **Double rotation:** Aligns the *x*-axis of the anemometer to the current mean streamlines, nullifying the vertical and crosswind components.
- **Triple rotation:** Double rotations plus a third rotation that nullifies the cross-stream stress. Not suitable in situations where the cross-stream stress is not expected to vanish, e.g., over water surfaces.
- **Planar fit:** Aligns the anemometer coordinate system to local streamlines assessed on a long time period (e.g., 2 weeks or more). Can be performed sector-wise, meaning that different rotation angles are calculated for different wind sectors. Click on the “Planar Fit Settings...” to configure the procedure.
- **Planar fit with no velocity bias:** Similar to classic planar fit, but assumes that the any bias in the measurement of vertical wind is compensated, and forces the fitting plane to pass through the origin (that is, such that if average $u$ and $v$ are zero, also average $w$ is zero). Can be performed sector-wise, meaning that different rotation angles are calculated for different wind sectors. Click on the “Planar Fit Settings...” to configure the procedure.

## Planar Fit Settings




- **Planar fit file available:** If you got a satisfying planar fit assessment in a previous run with EddyPro, which applies to the current dataset, you can use the same assessment by providing the path to the file "eddypro_planar_fit_ID.txt". This file, which contains the results of the assessment, was generated by EddyPro® in the previous run. This will shorten program execution time and assure full comparability between current and previous results.
- **Planar fit file not available:** Choose this option and provide the following information if you need to calculate (sector-wise) planar fit rotation matrices for your dataset. The planar fit assessment will be completed first, and then the raw data processing and flux computation procedures will automatically be performed.
- **Start:** Starting date of the time period to be used for planar fit assessment. This time period cannot be longer than about 1 month. As a general recommendation, select a time period during which the instrument setup and the canopy height and structure did not undergo major modifications. Results obtained using a given time period (e.g., 2 weeks) can be used for processing a longer time period, in which major modifications did not occur at the site. The higher the *Number of wind sectors* and the *Minimum number of elements per sector*, the longer the period should be.

- **End:** End date of the time period to be used for planar fit assessment. This time period cannot be longer than about 1 month. As a general recommendation, select a time period during which the instrument setup and the canopy height and structure did not undergo major modifications. Results obtained using a given time period (e.g., 2 weeks) can be used for processing a longer time period, in which major modifications did not occur at the site. The higher the *Number of wind sectors* and the *Minimum number of elements per sector*, the longer the period should be.
- **Minimum number of elements per sector:** Enter the minimum number of mean wind vectors (calculated over each flux averaging interval), required to calculate planar fit rotation matrices. A too small number may lead to inaccurate regressions and rotation matrices. A too large number may lead to sectors without planar fit rotation matrices. If for a certain averaging interval, wind is blowing from a sector for which the rotation matrix could not be calculated, the policy selected in *If planar fit calculations fail for a sector* apply.
- **Maximum mean vertical wind component:** Set a maximum vertical wind component to instruct EddyPro to ignore flux averaging periods with larger mean vertical wind components, when calculating the rotation matrices. Using elements with too large (unrealistic) vertical wind components would corrupt the assessment of the fitting plane, and of the related rotation matrices.
- **Minimum mean horizontal wind component:** Set a minimum horizontal wind component to instruct EddyPro to ignore flux averaging periods with smaller mean horizontal wind components, when calculating the rotation matrices. When the horizontal wind is very small, the attack angle may be affected by large errors, and so would be the vertical wind component, resulting in poor quality data that would degrade the planar fit assessment.
- **If planar fit calculations fail for a sector:** Select how EddyPro should behave when encountering data from a wind sector, for which the planar fit rotation matrix could not be calculated for any reason. Either use the rotation matrix for the closest sector (clockwise or counterclockwise), or switch to double-rotations for that sector.

**Set equally spaced:** Clicking this button will cause the EddyPro to divide the whole 360° circle in *n* equally-wide sectors, where *n* is the number of sectors currently entered.

> **Note:** The operation will not modify the north offset.

**North offset first sector:** This parameter is meant to allow you to design a sector that spans through the north. Entering an offset of $\alpha$ degrees will cause all sectors to rotate $\alpha$ degrees clockwise.

> **Note:** North is intended here as local, magnetic north (the one you assess with the compass at the site).

### Turbulent fluctuations:

Choose from the following detrending methods:

- **Block average:** Simply removes the mean value from the time series. Obeys Reynolds decomposition rule (the mean value of the fluctuations is zero).
- **Linear detrending:** Calculates fluctuations as the deviations from a linear trend. The linear trend can be evaluated on a time basis different from the flux averaging interval. Specify this time basis using the *time constant* entry. For classic linear detrending, with the trend evaluated on the whole flux averaging interval, set time constant = 0, which will be automatically converted into the text “Same as Flux averaging interval”.
- **Running mean:** High-pass, finite impulse response filter. The current mean is determined by the previous *N* data points, where *N* depends on the *time constant*. The smaller the time constant, the more low-frequency content is eliminated from the time series.
- **Exponential running mean:** High-pass, infinite impulse response filter. Similar to the simple running mean, but weighted in such a way that distant samples have an exponentially decreasing weight in the current mean, never reaching zero. The smaller the time constant, the more low-frequency content is eliminated from the time series.
- **Time constant:** Applies to the linear detrending, running mean, and exponential running mean methods. In general, the higher the time constant, the more low-frequency content is retained in the turbulent fluctuations.

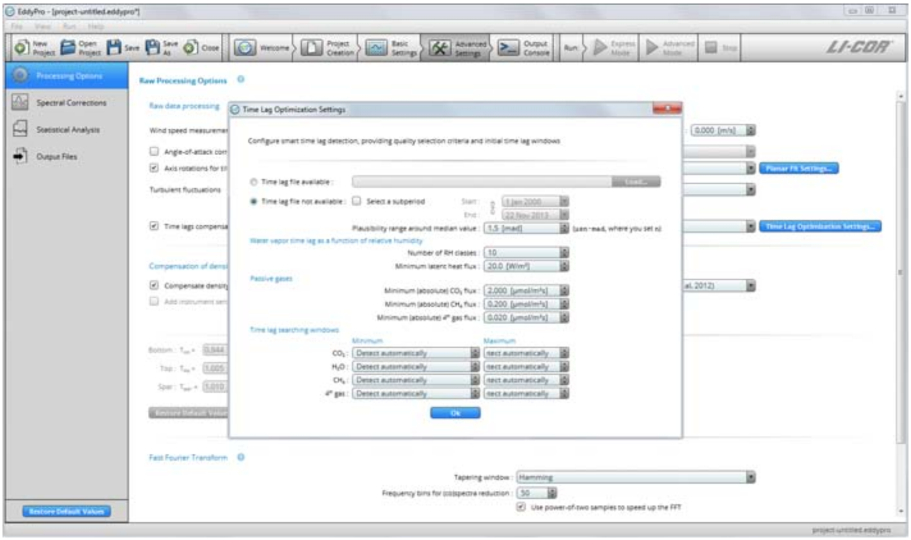
> **Note:** For the linear detrending the unit is minutes, while for the running means it is seconds.

**Time lags compensation:** Select the method to compensate for time lags between anemometric measurements and any other high frequency measurements included in the raw files. Time lags arise mainly due to physical distances between sensors and the passage of air into/through sampling lines.

Uncheck this box to instruct EddyPro not to compensate time lags (not recommended).

- **Constant:** EddyPro will apply constant time lags for all flux averaging intervals, using the **Nominal time lag** stored inside the GHG files or in the **Alternative metadata file** (for files other than GHG). While it can speed up the computation somewhat, this method is not suggested for physically displaced sensors or closed/enclosed path gas analyzers.
- **Covariance maximization:** Calculates the most likely time lag within a plausible window, based on the covariance maximization procedure. The window is defined by the **Minimum time lags** and **Maximum time lags** stored inside the GHG files or in the **Alternative metadata file** (for files other than GHG), for each variable. See "Detecting and Compensating for Time Lags" on page 7-27.
- **Covariance maximization with default:** Similar to the **Covariance maximization**, calculates the most likely time lag based on the covariance maximization procedure. However, if a maximum of the covariance is not found inside the window (but at one of its extremes), the time lag is set to the **Nominal time lag** value stored inside the GHG files or in the alternative metadata file.
- **Automatic time lag optimization:** Select this option and configure it clicking on the *Time lag optimization Settings...* to instruct EddyPro to perform a statistical optimization of time lags. It will calculate nominal time lags and plausibility windows and apply them in the raw data processing step. For water vapor, the assessment is performed as a function of relative humidity.

### Time Lag Optimization Settings:



- **Time lag file available:** If you have a satisfactory time lag assessment from a previous run and these results apply to the current dataset, you can use the time lag assessment by providing the path to the file named `eddypro_timelag_opt_ID.txt`, which was generated by EddyPro in the previous run. It contains the results of the assessment. This will shorten program execution time and assure full comparability between current and previous results.
- **Time lag file not available:** Choose this option and provide the following information if you need to optimize time lags for your dataset. Time lag optimization will be completed first, and then the raw data processing and flux computation procedures will automatically be performed.
- **Start:** Starting date of the time period to be used for time lag optimization. This time should not be shorter than about 1-2 months. As a general recommendation, select a time period during which the instrumental setup did not undergo major modifications. Results obtained using a given time period (e.g., 2 months) can be used for processing a longer time period, in which major modifications did not occur in the setup. The stricter the threshold setup in this dialogue, the longer the period should be in order to get robust results.

- **End:** End date of the time period to be used for time lag optimization. This time should not be shorter than about 1-2 months. As a general recommendation, select a time period during which the instrumental setup did not undergo major modifications. Results obtained using a given time period (e.g. 2 months) can be used for processing a longer time period, in which major modifications did not occur in the setup. The stricter the threshold setup in this dialogue, the longer the period should be in order to get robust results.
- **Plausibility range around median value:** The plausibility range is defined as the median time lag, ±*n* times the MAD (median of the absolute deviations from the median time lag). Specify *n*here. The value of 1.5 was heuristically found to be optimal.

**Water vapor time lag as a function of relative humidity:**

- **Number of RH classes:** Select the number or relative humidity classes, to assess water vapor time lag as a function of RH. The whole range or RH variation (0-100%) will be evenly divided according to the selected number of classes. For example, selecting 10 classes causes EddyPro to assess water vapor time lags for the classes 0-10%, 10-20%,..., 90-100%. Selecting 1 class, the label *Do not sort in RH classes* appears and will cause EddyPro to treat water vapor exactly like other passive gases. This option is only suitable for open path systems or closed path systems with short, heated sampling lines.
- **Minimum latent heat flux:** $H_2O$ time lags corresponding to latent heat fluxes smaller than this value will not be considered in the time lag optimization. Selecting high-enough fluxes assures that well developed turbulent conditions are met and the correlation function is well characterized.

**Passive gasses:**

- **Minimum (absolute) $CO_2$ flux:** $CO_2$ time lags corresponding to fluxes smaller than this value will not be considered in the time lag optimization. Selecting high-enough fluxes assures that well developed turbulent conditions are met and the correlation function is well characterized.
- **Minimum (absolute) $CH_4$ flux:** $CH_4$ time lags corresponding to fluxes smaller than this value will not be considered in the time lag optimization. Selecting high-enough fluxes assures that well developed turbulent conditions are met and the correlation function is well characterized.

- **Minimum (absolute) 4th gas flux:** 4th gas time lags corresponding to fluxes smaller than this value will not be considered in the time lag optimization. Selecting high-enough fluxes assures that well developed turbulent conditions are met and the correlation function is well characterized.

**Time lag searching windows:**

- **Minimum:** Minimum time lag for each gas, for initializing the time lag optimization procedure. The searching window defined by ***Minimum*** and ***Maximum*** should be large enough to accommodate all possible time lags. Leave as *Detect automatically* if in doubt, EddyPro will initialize it automatically.
- **Maximum:** Maximum time lag for each gas, for initializing the time lag optimization procedure. The searching window defined by Minimum and Maximum should be large enough to accommodate all possible time lags. In particular, maximum time lags of water vapor in closed path systems can up to ten times higher than its nominal value, or even higher. Leave as *Detect automatically* if in doubt, EddyPro will initialize it automatically.

## Compensation for density fluctuations (WPL terms)

**Compensate density fluctuations:** Choose whether to apply the compensation of density fluctuations to raw concentrations available as mole densities or molar fractions (moles gas per mole of wet air). The correction does not apply if raw concentrations are available as mixing ratios (mole gas per mole dry air). See "Calculating Fluxes Level 1, 2, and 3 (Corrected Fluxes)" on page 7-60.

- **Use mixing ratio or convert to mixing ratio (Burba et al., 2011):** If raw mixing ratios are available, the compensation is not needed. If raw gas data are either mole densities or molar fractions, selecting this option EddyPro will attempt to convert them into mixing ratios sample-by-sample, given that the necessary data are available.
- **Webb et al., 1980 / Ibrom et al., 2007:** The traditional "WPL terms," implemented as an *a posteriori* correction. For open path systems, it corrects density fluctuations using measured sensible heat and evapotranspiration fluxes, corrected for spectral losses and water vapor effects, as applicable. For closed/enclosed path instruments EddyPro uses the formulation proposed by Ibrom et al. (2007). However, in EddyPro all terms are used, including the temperature-induced and pressure-induced expansion/contraction terms, neglected in the original publications.

**Add instrument sensible heat component (LI-7500 only):** Only applies to the LI-7500. It takes into account air density fluctuations due to temperature fluctuations induced by heat exchange processes at the instrument surfaces, as from Burba et al. (2008). This may be needed for data collected in very cold environments. See "Accounting for Density Fluctuations Induced by Instrument-related Heat Exchange (LI-7500 only)" on page 7-47.

- **Simple linear regressions:** Instrument surface temperatures are estimated based on air temperature, using linear regressions as from Burba et al., 2008, eqs. 3-8. Default regression parameters are from Table 3 in the same paper. If you have experimental data for your LI-7500 unit, you may customize those values. Otherwise we suggest using the default values.
- **Multiple regressions:** Instrument surface temperatures are estimated based on air temperature, global radiation, long-wave radiation and wind speed, as from Burba et al., 2008, Table 2. Default regression parameters are from the same table. If you have experimental data for your LI-7500 unit, you may customize those values. Otherwise we suggest using the default value.

### Fast Fourier Transform

Fast Fourier Transform (FFT) is used for the frequency domain analysis (spectra and co-spectra) of the time series data. Configure the following:

**Tapering window:** Select the shape of the window used to taper the time series before the Fast Fourier Transform. The tapering procedure is a sample-wise multiplication in the time domain between the time series and the window, performed to reduce the discontinuities of the time series at the boundaries and avoid spectral energy overestimation. Kaimal & Kristensen (1991) suggested the Hamming window. See "Calculating Spectra, Cospectra, and Ogives" on page 7-32.

**Frequency bins for spectra and cospectra reduction:** Select the number of exponentially-spaced frequency bins to reduce spectra and cospectra. All spectral samples falling in a given bin are averaged, so that smoother curves result, greatly reduced in length. In EddyPro binned spectra are used for in-situ spectral assessments. See "Calculating Spectra, Cospectra, and Ogives" on page 7-32.

**Use power-of-two samples to speed up FFT:** Check this box to instruct EddyPro to use a number of samples equal to the power-of-two closest to the currently available samples, for calculating spectra. This option greatly speeds up the

FFT procedure and is therefore recommended. See "Calculating Spectra, Cospectra, and Ogives" on page 7-32.

## Other Options

**Quality check:** Select the quality flagging policy. Flux quality flags are obtained from the combination of two partial flags that result from the application of the steady-state and the developed turbulence tests. Select the flag combination policy.

- **Mauder and Foken 2004:** Policy described in the documentation of the TK2 Eddy Covariance software that also constituted the standard of the CarboEurope IP project and is widely adopted. “0” means high quality fluxes, “1” means fluxes are ok for budget analysis, “2” fluxes should be discarded from the result dataset.
- **Foken 2003:** A system based on 9 quality grades. “0” is best, “9” is worst. The system of Mauder and Foken (2004) and of Goeckede et al. (2006) are based on a rearrangement of these system.
- **Goeckede et al., 2006:** A system based on 5 quality grades. “0” is best, “5” is worst.

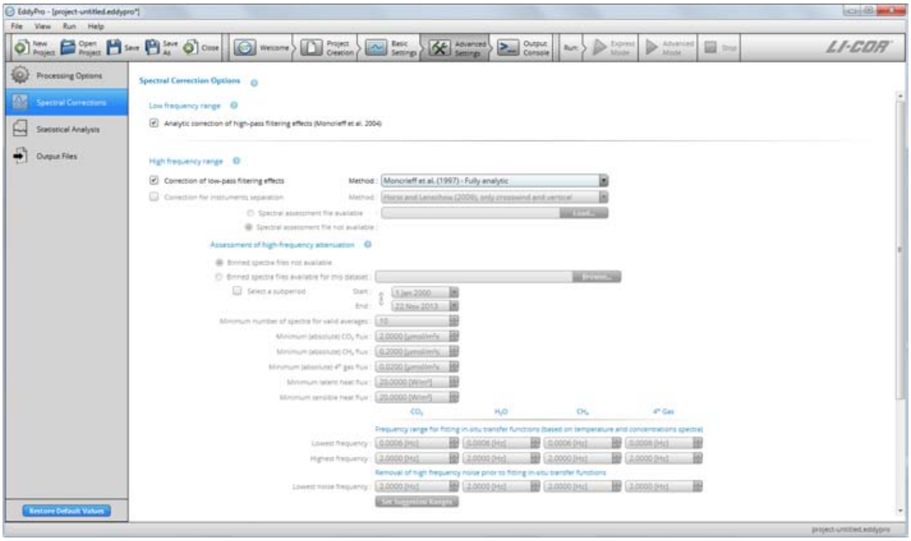
**Flagging Policy:** Select the quality flagging policy. Flux quality flags are obtained from the combination of two partial flags that result from the application of the steady-state and the developed turbulence tests. Select the flag combination policy.

- **Mauder and Foken, 2004:** Policy described in the documentation of the TK2 eddy covariance software that also constituted the standard of the CarboEurope IP project and is widely adopted. “0” means high quality fluxes, “1” means fluxes are acceptable for budget analysis, “2” fluxes should be discarded from the result dataset.
- **Foken, 2003:** A system based on 9 quality grades. “0” is best, “9” is worst. The system of Mauder and Foken (2004) and of Göckede et al. (2006) are based on a rearrangement of these system.
- **Göckede et al., 2006:** A system based on 5 quality grades. “0” is best, “5” is worst.

**Footprint Estimation:** Select whether to calculate flux footprint estimations and which method should be used. Flux crosswind-integrated footprints are provided as distances from the tower contributing 10%, 30%, 50%, 70% and 90% to measured fluxes. Also, the location of the peak contribution is given. See "Estimating the Flux Footprint" on page 7-65.

- **Kljun et al. (2004):** A crosswind integrated parameterization of footprint estimations obtained with a 3D Lagrangian model by means of a scaling procedure.
- **Kormann and Meixner (2001):** A crosswind integrated model based on the solution of the two dimensional advection-diffusion equation given by van Ulden (1978) and others for power-law profiles in wind velocity and eddy diffusivity.
- **Hsieh et al. (2000):** A crosswind integrated model based on the former model of Gash (1986) and on simulations with a Lagrangian stochastic model.

## Spectral Corrections




### Low frequency range

**Analytic correction of high-pass filtering effects:** Check this option to apply a correction for flux spectral losses in the low frequency range, due to the finite averaging time and dependent on the detrending method selected. The correction is implemented after Moncrieff et al. (2004). See "Importing Data" on page 7-3

### High frequency range

#### Correction of low-pass filtering effects:

**Method:** Check this option to apply a correction for flux spectral losses in the high frequency range, and select a method. For open path systems, any method is valid. For closed path systems, we suggest the method of Horst (1997) or Ibrom et al. (2007) for short and heated sampling lines. The method by Ibrom et al. (2007) is the most appropriate for non-heated and/or long sampling lines. See "Low-pass Filtering Correction" on page 7-52.

- **Moncrieff et al. (1997):** This method models all major sources of flux attenuation by means of a mathematical formulation. The use of this method is suggested for open path EC systems or for closed path systems if the sampling line is short and heated. This method may seriously underestimate the attenuation (and hence the correction) - notably for water vapor - when the sampling line is long and/or not heated, because of the dependency of attenuation of $H_2O$ on relative humidity.
- **Massman (2000, 2001):** This method provides a simple analytical expression for the spectral correction factors. The use of this method is suggested for open path EC systems or for closed path systems if the sampling line is short and heated. This method may seriously underestimate the attenuation (and hence the correction) for water vapor, when the sampling line is long and/or not heated, because of the dependency of attenuation of $H_2O$ on relative humidity. For closed path systems, this method is only applicable for $CO_2$, $H_2O$, $CH_4$, $N_2O$ and $O_3$ fluxes.
- **Horst (1997):** Correction method based on an analytical formulation of the spectral correction factor that requires an in-situ assessment of the system's cut-off frequency. Provide the information below to specify how to perform such assessment.
- **Ibrom et al., 2007:** Correction method based on an analytical formulation of the spectra correction factors, that requires an in-situ assessment of the system's cut-off frequencies, separately for each instrument and gas, and as a function of relative humidity for water vapor. Provide the settings in the *Assessment of high-frequency attenuation* to specify how to perform the assessment. This method is recommended in most cases, notably for closed-path systems placed high over rough canopies.
- **Fratini et al., 2012:** Correction method based on the combination of a direct approach (similar to Hollinger et al., 2009) and the analytical formulation of

Ibrom et al., 2007. It requires an in-situ assessment of the system's cut-off frequencies, separately for each instrument and gas, and as a function of relative humidity for water vapor. It also requires full length cospectra of measured sensible heat. This method is recommendable in most cases, notably for closed-path systems placed low over smooth surfaces.

**Correction for instrument separation:** The methods by Horst (1997) and Ibrom et al. (2007) do not account for the separation between anemometer and gas analyzer. Select one of the available options to add an extra correction accounting for this source of flux underestimation. See "Northward, Eastward, and Vertical Separation" on page 6-16.

- **Horst and Lenschow (2009), along-wind, crosswind and vertical:** Select this option to account for sensor separations in any direction. Note that correcting for along-wind separations may result in overcorrection, if any time lag compensation method was also selected.
- **Horst and Lenschow (2009), only crosswind and vertical:** Select this option to account for sensor separations only in the crosswind and vertical directions. Recommended when a time lag compensation method is selected.

**Spectral assessment file available:** Toggle this option and provide the path of the corresponding file, if you have already run EddyPro® and have a spectral assessment file that applies to the current dataset. This way, you can save execution time and process a dataset of any length. See "Using Results from Previous Runs" on page 6-24.

### Assessment of high-frequency attenuation

**Binned spectra files not available:** Select this option if you have not computed "Binned spectra and cospectra files" for the current dataset in a previous run of EddyPro. Note that the binned (co)spectra files do not need to correspond exactly to the current dataset, rather they need to be representative of it. Binned spectra are used to quantify spectral attenuations, thus they must have been collected in conditions comparable to those of the current dataset (e.g., same EC system and similar canopy heights, measurement height, instruments spatial separations, etc.). At least one month of spectra files is needed for a robust spectral attenuation assessment. If you select this option, the option "All binned spectra and cospectra" in the Output Files page will be automatically selected and the check-box will be deactivated.

**Binned spectra files available:** Select this option if you already obtained "Binned spectra and cospectra files" for the current dataset (in a previous run of

EddyPro). Note that such binned (co)spectra files do not need to correspond exactly to the current dataset, rather they need to be representative of it. Binned spectra are used here for quantification of spectral attenuations, thus they must have been collected in conditions comparable to those of the current dataset (e.g., same EC system and similar canopy heights, measurement height, instruments spatial separations, etc.). At least one month worth of spectra files is needed for a robust spectral attenuation assessment. If you select this option, the option "All binned spectra and cospectra" in the Output Files page will be automatically deselected.

- **Starting date:** Starting date of the time period to be used for assessment of the cut-off frequencies. The longer the time span, the more accurate the assessment will be.
- **Ending time:** Ending date of the time period to be used for assessment of the cut-off frequencies. The longer the time span, the more accurate the assessment will be.
- **Minimum number of spectra for valid ensemble averages:** Spectra are ensemble-averaged before calculating cut-off frequencies, to avoid erroneous results due to noise in individual spectra. Set here the minimum number of spectra for the ensemble average to be valid. If for a given variable this number is not reached, cut-off frequencies are not calculated for that variable. The higher this number, the more accurate the results, but the longer the time span needs to be to get to a result.
- **Minimum (absolute) $CO_2$ gas flux:** $CO_2$ spectra corresponding to $CO_2$ fluxes less than this threshold will not be used to for ensemble averages.
- **Minimum (absolute) $CH_4$ gas flux:** $CH_4$ spectra corresponding to $CH_4$ fluxes less than this threshold will not be used to for ensemble averages.
- **Minimum (absolute) 4th gas flux:** 4th gas spectra corresponding to 4th gas fluxes less than this threshold will not be used to for ensemble averages.
- **Minimum latent heat flux:** $H_2O$ spectra corresponding to latent heat fluxes less than this threshold will not be used to for ensemble averages.
- **Minimum sensible heat flux:** Temperature spectra corresponding to sensible heat fluxes less than this threshold will not be used to for ensemble averages.
- **Lower frequency:** An Infinite Impulse Response filter transfer function is fitted to the ratio of gas to temperature spectra, assuming spectral similarity and un-attenuated temperature spectra. However, at low frequencies, similarity may be compromised. Set here the lower frequency for the fitting operation. You can specify one for each gas.

- **Higher frequency:** An Infinite Impulse Response filter transfer function is fitted to the ratio of gas to temperature spectra, assuming spectral similarity and un-attenuated temperature spectra. However, at high frequency spectra may be compromised by noise and/or aliasing. Here, set the higher frequency for the fitting operation. You can specify one for each gas.
- **Lower noise frequency:** EddyPro can eliminate high-frequency noise from spectra, by linearly interpolating and subtracting the high frequency part of the spectrum. Here, select the frequency that defines the beginning of the noisy region.

### Fratini et al. (2012) method settings

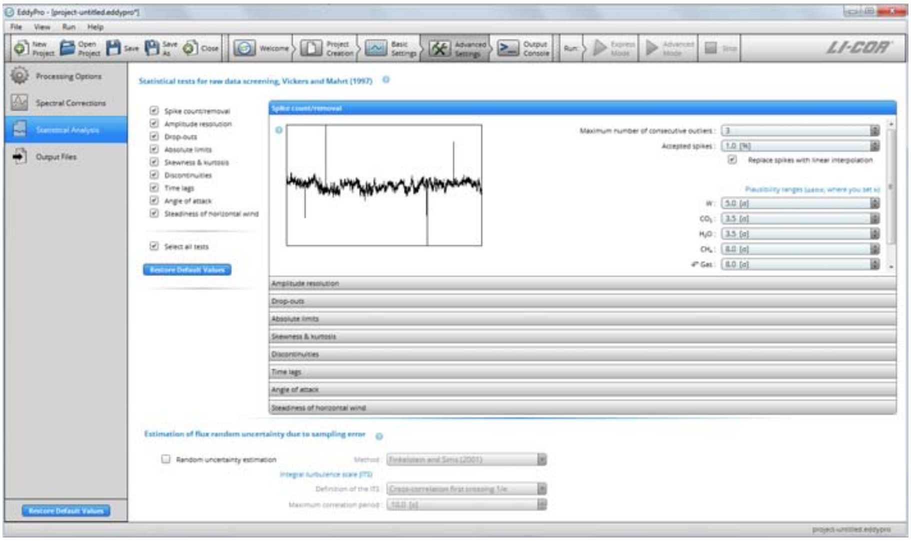
**Full w/T cospectra files not available:** Select this option if you do not have *Full cospectra of w/T* for the current dataset (from a previous run of EddyPro). Note that existing cospectra files need to correspond exactly to the current dataset. Full cospectra of w/T (sensible heat) are used for definition of the spectral correction factor for each flux with the method by Fratini et al. (2012). If you select this option, the option *Full length cospectra w/*$T_s$ in the Output Files page will be automatically selected and deactivated.

**Full w/T cospectra files available:** Select this option if you already obtained *Full cospectra of w/T* for the current dataset (from a previous run of EddyPro). Note that the cospectra files need to correspond exactly to the current dataset. Full cospectra of w/T (sensible heat) are used for definition of the spectral correction factor for each flux with the method by Fratini et al. (2012). If you select this option, the option *Full length cospectra w/*$T_s$ in the Output Files page will be automatically deselected and activated.

- **Include anemometer losses for path averaging and time response:** Select this option to instruct EddyPro to correct sensible heat cospectra for those losses, before using them as a model to calculate correction factors according to Fratini et al. (2012).
- **Threshold fluxes for using model and direct method:** Select threshold flux values: for fluxes smaller than the thresholds, EddyPro will use the correction factor model of Ibrom et al. (2007). For fluxes larger than the threshold, EddyPro will use the direct method as from Fratini et al. (2012).

## Statistical Analysis

Select (on the left side) and configure (on the right side) up to 9 tests for assessing statistical quality of raw time series. Use the results of these tests to filter out results, for which flags are turned on. All tests are implemented after Vickers and Mahrt (1997). See the original publication for more details and how to interpret results. See "Despiking and Raw Data Statistical Screening" on page 7-9.




## Spike count/removal

Detects the number of spikes in each time series. Use the checkbox “Replace spikes with linear interpolation” to replace detected spikes with linear interpolation of neighboring values. Configure the definition of spikes and the flagging policy in the corresponding section of the right-side panel. See "Spike Removal and Spike Test" on page 7-9.

## Amplitude resolution

Detects situations in which the signal variance is too low with respect to instrumental resolution. Configure the assessment procedure and the flagging policy in the corresponding section of the right-side panel. See "Amplitude Resolution Test" on page 7-11.

## Drop-outs

Detects relatively short periods in which time series stick to some value which is statistically different from the average value calculated over the whole period. Configure the assessment procedure and the flagging policy in the corresponding section of the right-side panel. See "Drop-outs Test" on page 7-12.

### Absolute limits

Assesses whether each variable attains, at least once in the current time series, a value that is outside a user-defined plausible range. In this case, the variable is flagged. The test is performed after the despiking procedure. Thus, each out-ranged value found here is not a spike. It will remain in the time series and affect calculated statistics, including fluxes. Check the “Filter outranged values” to eliminate such outliers. See "Absolute Limits" on page 7-13.

### Skewness & Kurtosis

Third and forth order moments are calculated on the whole time series and variables are flagged if their values exceed certain thresholds that you can customize in the corresponding section of the right-side panel. See "Skewness and Kurtosis" on page 7-13.

### Discontinuities

Detect discontinuities that lead to semi-permanent changes, as opposed to sharp changes associated with smaller-scale fluctuations. Configure the assessment of discontinuities in the corresponding section of the right-side panel. See "Discontinuities" on page 7-14.

### Time lags

This test flags scalar time series if the maximal *w*-covariances, determined via the covariance maximization procedure and evaluated over a predefined time-lag window, are too different from those calculated for the user-suggested time lags. Configure the expected time lags and the accepted discrepancies in the corresponding section of the right-side panel. See "Time Lags" on page 7-15.

### Angle of attack

Calculates sample-wise angle of attacks throughout the current flux averaging period, and flags it if the percentage of angles of attack exceeding a user-defined range is beyond a threshold that you can set on the right-side panel. See "Angle of Attack" on page 7-15.

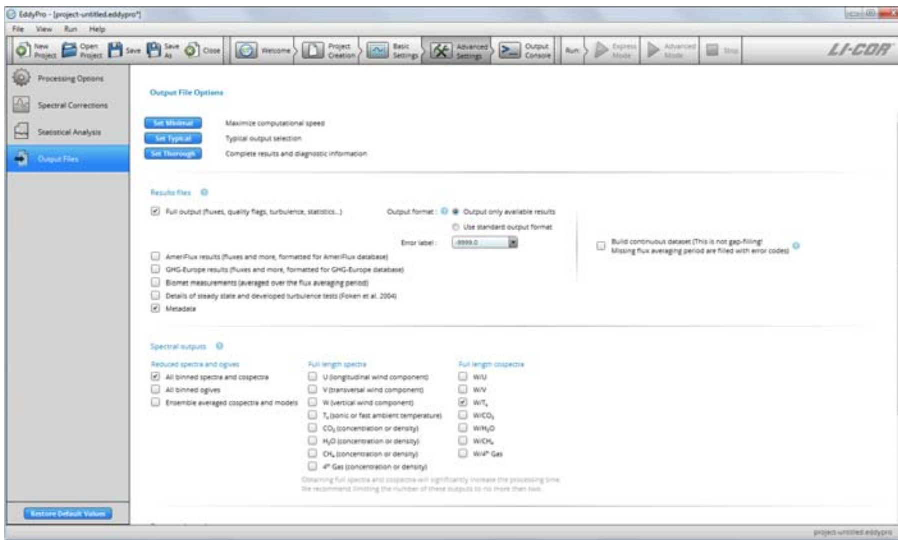
### Steadiness of horizontal wind

Assesses whether the along-wind and crosswind components of the wind vector undergo a systematic reduction/increase throughout the file. If the quadratic combination of such systematic variations is beyond the user-selected limit, the flux-averaging period is hard-flagged for instationary horizontal wind. See "Steadiness of Horizontal Wind" on page 7-16.

### Estimation of flux random uncertainty due to sampling errors

EddyPro® 4 can calculate flux random uncertainty due to sampling errors according to two different methods: Mann and Lenschow (1994) and Finkelstein and Sims (2001). See "Random Uncertainty Estimation" on page 7-16.

## Output Files




**Set Minimal:** Click this button to select a minimal set of output files, providing you with the essential results while speeding up the computation process. Suggested for processing long datasets without a need for an in-depth analysis and validation of the computations.

**Set Typical:** Click this button to select a balanced set of output files, providing you with the essential results as well as diagnostic information. The computation time increases with respect to the minimal output configuration.

**Set Thorough:** Click this button to select a complete set of output files, providing you with all the results as well as complete diagnostic information. The computation time increases considerably with this option.

### Results files and options

**Full Output:** This is the primary EddyPro® results file. It contains fluxes, quality flags, micrometeorological variables, gas concentrations and densities, footprint estimations and diagnostic information along with ancillary variables such as uncorrected fluxes, main statistics, etc.

### Output format

- **Output only available results** to write on the **Full output** file only the results which are actually available, eliminating "error code" columns that are created when results are unavailable.
- **Use standard output format** to write the **Full output** file in its predefined standard format, regardless of the results currently available. This may come in handy if you wish to import the file in a post-processing analysis tool.
- **Error label:** Customize the error code into any string that you prefer (such as NaN). You can choose from the drop-down list or enter any string you want. The default is "-9999."

**AmeriFlux results:** A selection of main results formatted so as to be easily completed with missing variables and submitted to the AmeriFlux database. See "AmeriFlux Output Format" on page 5-18.

**GHG-Europe results:** A selection of main results formatted so as to be easily completed with missing variables and submitted to the GHG-Europe database. See "GHG Europe Output Format" on page 5-18.

**Biomet measurements:** Average values of all available biomet measurements, calculated over the same time period selected for fluxes. Biomet measurements that are recognized by EddyPro (i.e., marked by recognized labels) are screened for physical plausibility before calculating the average value and they are converted to units that coincide with other EddyPro results. All other variables are solely averaged and provided on output.

**Details of steady state and developed turbulence tests (Foken et al., 2004):** Partial results obtained from the steady state and the developed turbulence tests. It reports the percentage of deviation from expectation and individual test flags.

**Metadata:** Summarizes metadata used for the processed data sets. If an alternative metadata file is used without a dynamic metadata file, the contents of this file will be identical to the alternative metadata. If you are processing GHG files and/or using a dynamic metadata file, this results file will tell you which metadata were used in processing.

### Spectral outputs

**Reduced spectra and ogives:** If selected, a subfolder will be created that contains one file for each flux averaging period. These files contain all relevant binned spectra and cospectra and are necessary for in-situ spectral correction methods (Horst, 1997; Ibrom et al. (2007)).

**Full length spectra:** If selected, a subfolder will be created that contains one file for each flux averaging period. These files contain full spectra and/or cospectra of selected variables.

**Full length cospectra:** Cospectra with the vertical wind component, calculated for each variable, for each flux averaging interval. Results files are stored in a separate subfolder inside the output folder.

### Processed raw data

- **Statistics:** Files containing main statistics on the time series (mean values, variances, covariances, Skewness, Kurtosis) for all sensitive variables, after the selected processing step. These files are stored in a dedicated folder.
- **Time series:** Files containing time series for the selected variables, after the selected processing step. One file for each selection is created for each flux averaging interval (up to 7 files for each flux averaging interval). Files are stored in a dedicated folder.
- **Variables:** When you select **Time series**, EddyPro enables options to select variables from the time series.

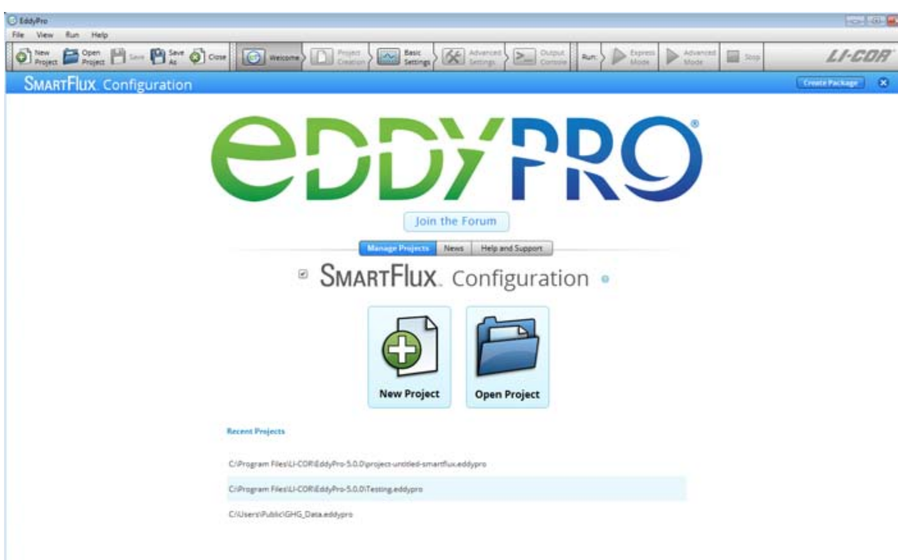
# 3 SMARTFlux™ Configuration

The SMARTFlux system is an add-on component for LI-COR eddy covariance systems that are based upon the LI-7500A and LI-7200 gas analyzers running embedded software known as GHG v7. It includes an all-weather processor and GPS antenna. It installs in the LI-7550 Analyzer Interface Unit.

SMARTFlux system uses EddyPro® software to process LI-COR® GHG files. SMARTFlux system provides:

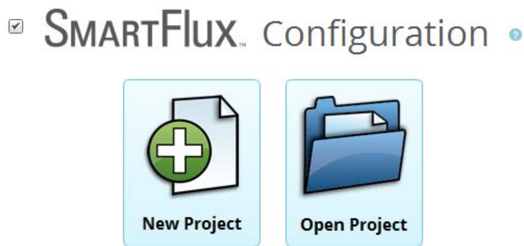
- Fully corrected eddy covariance results processed by EddyPro in Express or Advanced mode in real-time with a 30-minute averaging interval.
- GPS location and time keeping for populating metadata location information and synchronizing system clocks with GPS satellite clocks.
- Input voltage readout for diagnostic purposes.

SMARTFlux Configuration mode is used to create a custom configuration file for the SMARTFlux system.



To use this mode, check the box, and proceed through EddyPro as you normally would. The steps are summarized below:

1. Click the **SMARTFlux Configuration** box.
2. Select **New Project** or **Open Project**.




If you are creating a **New Project** and you do not intend to use planar-fit, automatic time-lag optimizations, or in situ spectral corrections:

Set the Raw Data Directory (one .ghg file is necessary, see "Creating an Advanced SMARTFlux Configuration File" on page 3-33).

Select Variables, if applicable.

Set Flags.

Configure Advanced Settings (see "Overview of Advanced Mode" on page 3-29).

If you are creating the SMARTFlux configuration file from an existing project:

Click **Open Project** and select the project.

Alter any settings that need to be changed.

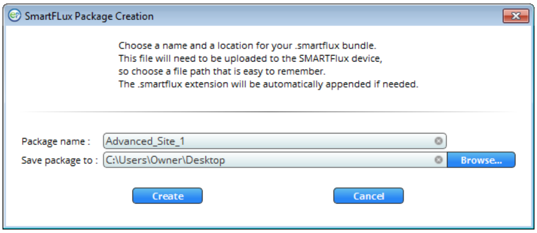
Configure Advanced Settings (see "Overview of Advanced Mode" on page 3-29).

If you are using **planar-fit**, automatic **time-lag optimization**, or **in situ spectral corrections** (see "Using Planar Fit, In-situ Spectral Corrections and Timelag Optimization in SMARTFlux " on page 3-33 for details):

- Begin with a new project or existing project, as described above.
- Select a planar-fit file that was generated by EddyPro using data from your site.
- Select the automatic time-lag optimization file that was generated by EddyPro using data from your site.
- Select the in-situ spectral corretions file that was generated by EddyPro using data from your site.

3. Click **Create Package** in the upper right of EddyPro.

When prompted, name the package, select a directory and click **Create**.




The configuration file has a `.smartflux` extension.

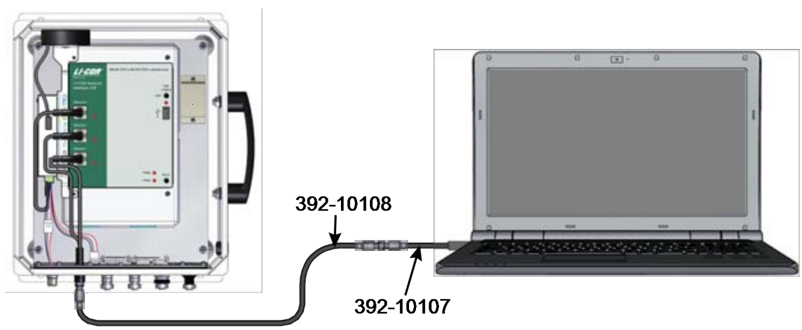
Upload the file to the SMARTFlux system. See "Loading a SMARTFlux Configuration File" on page 3-27 to load the file into the SMARTFlux system.

# Initial Configuration

Follow these steps for LI-7550s that have SMARTFlux™ pre-installed, or retrofit units. If you want to process fluxes with EddyPro Advanced settings, you must **create a SMARTFlux configuration file in EddyPro version 5** (see "Overview of Advanced Mode" on page 3-29).

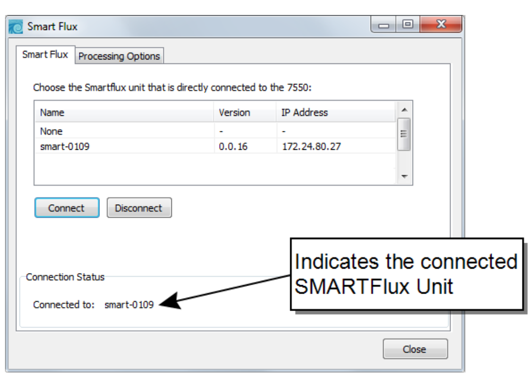
## 1 Connect a Computer to the GHG System

Power up the gas analyzer and connect the Ethernet cables to your computer. See "Configuring Systems with Additional Networked Sensors" on page 3-6 if you have an LI-7700, a 7900 Biomet system, or a wireless communication system at your site.




## 2 Connect with SMARTFlux system

Launch the GHG v7 (LI-7500A/LI-7200) PC software and connect to the gas analyzer. Click the **SMARTFlux** button. Select the SMARTFlux Module and click **Connect**.

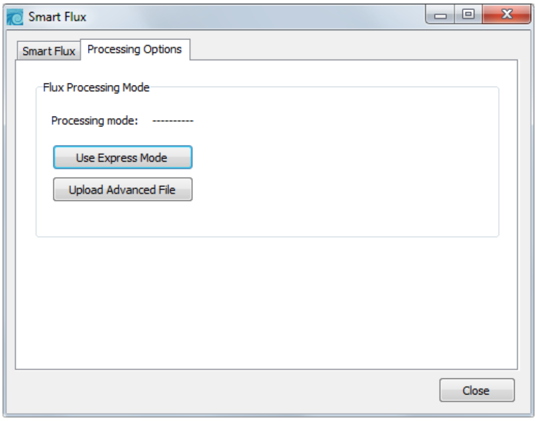
## 3 Configure the GHG Eddy Covariance System

Be sure that the eddy covariance system is configured properly by entering the required information in the GHG v7 (LI-7500A/ LI-7200) software. See "Site Setup" on page 3-10 and the subsequent sections for more information.

> **IMPORTANT:** Some entries in GHG software are mandatory in order for EddyPro to proceed with the calculations. If you do not enter this information or enter it incorrectly, EddyPro will not calculate correct fluxes. Take special care to complete the fields marked as ***mandatory***.

## 4 Select the Processing Mode

SMARTFlux system uses EddyPro Express settings by default. Under the **Processing Options** tab, click either **Use Express Mode** or **Upload Advanced File** and then select the file created by EddyPro 5. See "Loading a SMARTFlux Configuration File" on page 3-27.



## Configuring Systems with Additional Networked Sensors

If your eddy covariance system has additional networked devices, such as an LI-7700 Open Path $CH_4$ Analyzer, 7900 Biomet system, and/or a cellular communication system, it is likely that all the Ethernet ports will be occupied by the additional components. How do you connect over Ethernet when all the Ethernet ports are taken? Keep reading to find out.

> **Note:** This simplest solution is to connect to the LI-7550 with the RS-232 cable and configure the networked connections.

Another solution is to acquire a 5-port Ethernet switch (LI-COR part # 616-12721) and install it in the 7900 Biomet enclosure or a small weather-proof enclosure.

If you cannot connect with RS-232 and you do not have an Ethernet switch, you can still connect two networked devices and the SMARTFlux system. Here is how:

1. Unplug the Ethernet cable for one of your devices (e.g., the Biomet system) and install an Ethernet cable between your computer and the vacated Ethernet port.
2. In the GHG software, **Connect** with the device that is still attached to the other Ethernet port (e.g., the LI-7700).
3. Then, you can unplug the Ethernet cable for that device (e.g., the LI-7700) and install the Ethernet cable between your computer to the newly-vacated port.
4. Reconnect the Ethernet cable for the device that was disconnected in step 1. Now, **Connect** with that device (e.g., the Biomet system) in the GHG software.
5. Unplug the computer's Ethernet cable from the LI-7550 and reinstall the Ethernet cables for the networked sensors.

When you've configured the connection for a device in the software, you can unplug and plug in the Ethernet cable without risk. The devices will automatically resume communication shortly after the cable is reinstalled.

## Eddy Covariance Checklist

Table 3-1 below is a checklist of settings that either must be set or that we recommend setting before you can record valid eddy covariance data that can be processed by the SMARTFlux™ system or EddyPro® software. Go through this checklist to be sure that everything is set properly.

**Table 3-1**. Checklist of mandatory and recommended EC system settings. ***Note:*** *Some of the settings below are required in order to log valid EC datasets.*

| Field | Setting |
|---|---|
| **Settings > Time** | |
| Clock Sync (PTP): | Automatic |
| Time Zone: | Your time zone |
| **Site Setup > USB Log File** | |
| Update Rate (Hz): | 10 Hz (recommended; 5 Hz min) |
| File Duration: | 30 Minutes |
| Compress files (.ghg) | ✓ (check this box) |
| When out of space: | Delete oldest files from Archive and then from Data |
| **Site Setup > Site Description** | |
| Station name: | Name of the station |
| Canopy height (m): | Measured at site |
| Use SMARTFlux Coordinates | ✓ (check this box) |
| **Site Setup > Anemometer** | |
| Manufacturer: | Make of anemometer |
| Model: | Model of anemometer |
| Head correction applied internally: | For the CSAT3, ✓ if true |
| North Alignment: | For Gill models, select the setting set in the anemometer |
| Wind data format: | Select the setting set in the anemometer |
| North Offset (°): | Measured at site |
| Height (m): | Measured at site |

**Table 3-1**. Checklist of mandatory and recommended EC system settings. Note: Some of the settings below are required in order to log valid EC datasets. (...continued)

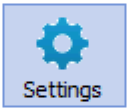
| Field | Setting |
|---|---|
| **Anemometer > Input Settings**[1] | |
| Aux1 | Type: U; Units: m/s; m: 6; b: 0 |
| Aux2 | Type: V; Units: m/s; m: 6; b: 0 |
| Aux3 | Type: W; Units: m/s; m: 1 b: 0 |
| Aux4 | Type: Ts; Units: °C; m: 11; b: 15 |
| **Site Setup > $CO_2$/$H_2O$ Analyzer** | |
| Northward separation (cm): | Measured at site |
| Eastward separation (cm): | Measured at site |
| Vertical separation (cm): | Measured at site |
| $CO_2$/$H_2O$ Log Values | Select All or Default |
| **Flow Module** | (if using the LI-7200) |
| Tube length (cm): | Length of intake tube |
| Tube diameter (mm): | Inside diameter of intake tube |
| Flow Rate (lpm): | Set to "On" |
| **Site Setup > $CH_4$ Analyzer** | (if using an LI-7700) |
| Connect to LI-7700 | Select if using LI-7700 |
| Northward separation (cm): | Measured at site |
| Eastward separation (cm): | Measured at site |
| Vertical separation (cm): | Measured at site |
| $CH_4$ Log Values | Select All or Default |
| **Site Setup > Biomet** | (if using a Biomet system) |
| Connect to Biomet | Select if using Biomet system |
| Sync clock to 7550 | ✓ (check this box) |
| **SMARTFlux** | |
| Connect to SMARTFlux system | Click the SMARTFlux button and select the unit |

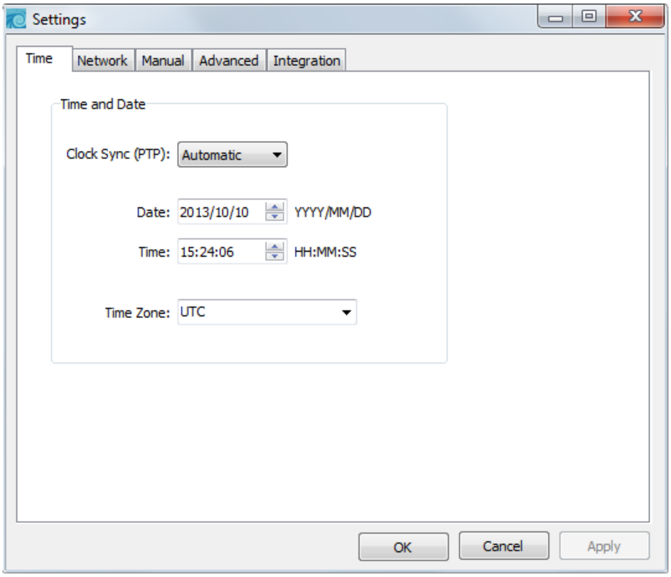
[1]The Auxiliary input settings given here correspond with anemometer analog output settings of U, V: ±5V, ±30 m/s; W: ±5V, ±5 m/s; Ts: ±5V, -40 to +70 °C.

## GHG System Clock

In order to synchronize instrument clocks with GPS satellites, PTP time keeping must be enabled in the LI-7550.

Click **Settings**, under the **Time** tab, set **Clock sync (PTP)** to **Preferred** and the time/location will be updated when the data is received from satellites. When using PTP time keeping, the other fields (Date, Time, and Time Zone) are populated automatically.




**NOTE:** SMARTFlux system PTP time keeping will override any settings you enter because GPS satellite clocks are considered the most precise clocks in the system.

If you do not want to use GPS time, simply unplug the GPS antenna cable from the SMARTFlux system. This will also disable the GPS location, however, and is not recommended.

## Site Setup


Site information is entered in the GHG v7 (LI-7500A/LI-7200) software and recorded in the GHG files that are logged by the gas analyzer. To enter site information, install the PC software on your computer and connect with the gas analyzer.

The **Site Setup** window allows you to enter the site information that is required to compute flux results. This information is logged in a metadata file. You are not required to consider the metadata file explicitly, as it is created and modified in the gas analyzer configuration software and used unobtrusively by EddyPro and the SMARTFlux system. Nevertheless, all information is stored as plain text and can be retrieved and edited at any time.

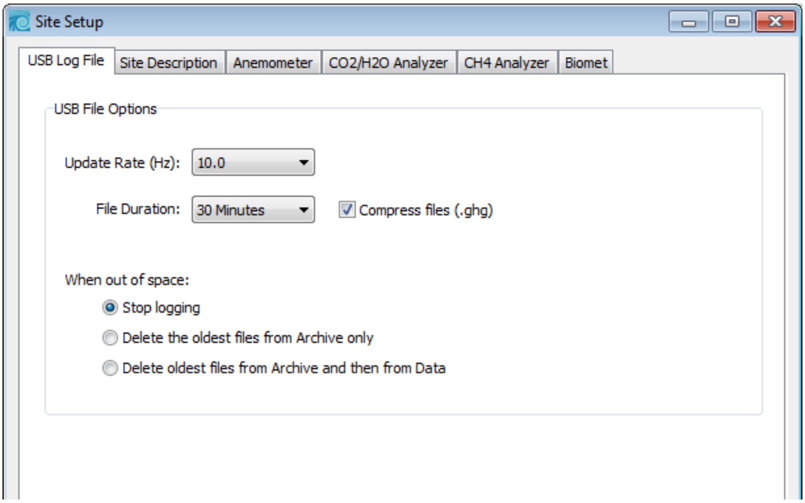
The Site Setup window provides the following tabs:

- USB Data Collection: See "USB Data Collection" on the facing page.
- Site Description: See "Enter the Site Description" on page 3-12.
- Sonic Anemometer: See "Enter Anemometer Information" on page 3-14.
- $CO_2$/$H_2O$ Analyzer: See "Enter CO2/H2O Analyzer Information" on page 3-20.
- $CH_4$ Analyzer: See "CH4 Analyzer Data" on page 3-23.
- Biomet: See "Enter Biomet System Information" on page 3-26.

## USB Data Collection

Data are logged to a USB flash drive inside the LI-7550 Analyzer Interface Unit. Datalogging will begin when the USB flash drive is inserted into the port.

The USB Log File tab allows you to configure the Update Rate, File Duration, and the action to take should the USB flash drive run out of space. The values to be logged to the USB flash drive from the $CO_2$/$H_2O$ analyzer, the optional LI-7700 $CH_4$ Analyzer, and the 7900 Biomet system, are chosen under the $CO_2$ Analyzer, $CH_4$ Analyzer, and Biomet tabs, respectively.




**IMPORTANT:** For eddy covariance applications, we recommend collecting data at a rate of 10 Hz or higher. 5 Hz is the minimum for tall canopies; 20 Hz may be necessary in some situations.

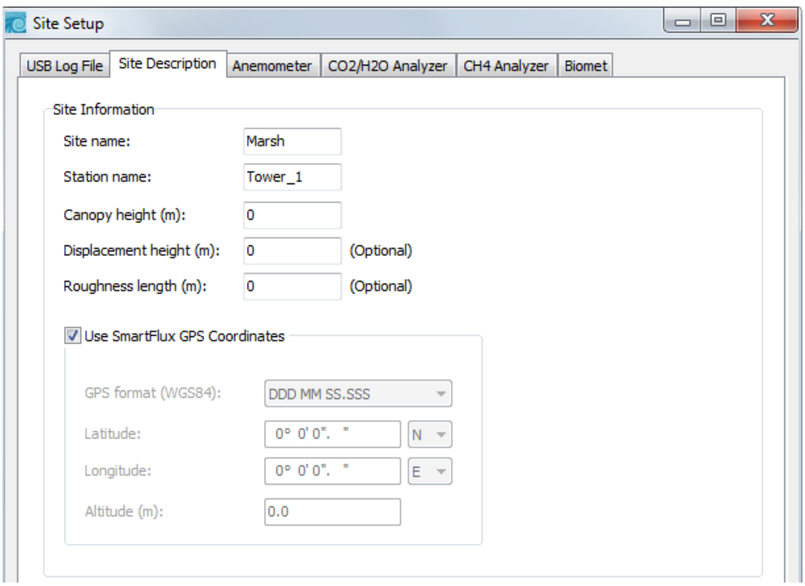
The files are split based on the instrument clock; thus, with the 30-minute interval, start logging at 10:22, the file will be split at 10:30, 11:00, 11:30, etc.

All raw files are assigned a timestamp with the format `YYYY-MM-DDTHHMMSS_InstrumentName.ext` where date and time are year, month, day, and HHMMSS is 24-hour time (e.g. hour 15 = 3:00 p.m.). The file extension appended is either .data, .metadata, or .status.

## Enter the Site Description

The Site Description tab is used to enter information about the site. This information configures the metadata file that is used for flux processing.

> **IMPORTANT:** Some entries in GHG software are mandatory in order for EddyPro to proceed with the calculations. If you do not enter this information or enter it incorrectly, EddyPro will not calculate correct fluxes. Take special care to complete the fields marked as ***mandatory***.




**Site name:** Name of the research site (e.g., LI-COR Experimental Site).

**Station Name:** Optional, name of the flux station within the site.

**Canopy Height *(mandatory)*:** Canopy height, in meters.

**Displacement Height:** Also referred to as zero plane displacement height, the displacement height of a vegetated surface (usually designated *d*) is the height at which the wind speed would go to zero if the logarithmic wind profile was maintained from the outer flow all the way down to the surface (that is, in the absence of vegetation). In other words, it is the distance over the ground at which a non-vegetated surface should be placed to provide a logarithmic wind field equal to the observed one. For forest canopies, the displacement height is estimated to vary between 0.6 and 0.8 times the height of the canopy. If not entered explicitly, EddyPro® computes displacement height as:

$$d = 0.67 \text{ x canopy height} \quad (3\text{-}1)$$

**Roughness Length:** In the logarithmic wind profile, the roughness length is the height at which wind speed is zero (indicated by $z_0$). It provides an estimate of the average roughness elements of the surface. With vegetated surfaces, because the vegetation itself provides a certain roughness, the logarithmic wind profile goes to zero at a height equal to the displacement height plus the roughness length. If not entered explicitly, EddyPro® computes roughness length as:

$$z_0 = 0.15 \text{ x canopy height} \quad (3\text{-}2)$$

**Use SMARTFlux system GPS Coordinates *(mandatory)*:** Uses GPS location from the SMARTFlux system for the station location.

**GPS format (WGS84):** Latitude and longitude coordinates are automatically detected by the SMARTFlux™ system unit or can be entered manually.

| Format | Description | Example |
|---|---|---|
| DDD MM SS.SSS | Degrees, minutes and seconds with North, South, East, or West suffix | 12°20′44″ N, 98°45′55″ W |
| DDD MM.MMM | Degrees and decimal minutes with North, South, East, or West suffix | 12°20.736′ N, 98°45.924′ W |
| Decimal Degrees | Decimal degrees with negative numbers for South and West | 12. 3456, -98.7654 |

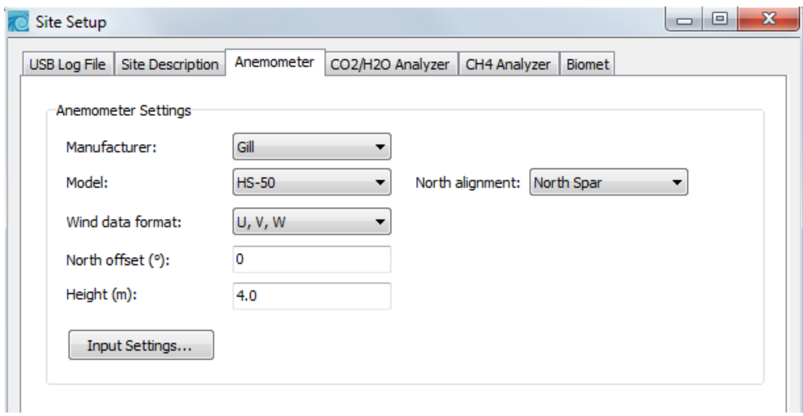
**Latitude *(mandatory, if "Use GPS Coordinates is not selected")*:** Site latitude coordinates, entered in format chosen above at GPS format.

**Longitude *(mandatory, if "Use GPS Coordinates is not selected")*:** Site longitude coordinates, entered in format chosen above at GPS format.

**Altitude *(mandatory, if "Use GPS Coordinates is not selected")*:** Altitude (in meters) of the research site of interest.

## Enter Anemometer Information

The Anemometer page allows you to enter information about the sonic anemometer, including the manufacturer and model, data output format, offset from true north, and height. Some of the available options (e.g. North Alignment) will change, depending on the chosen model.



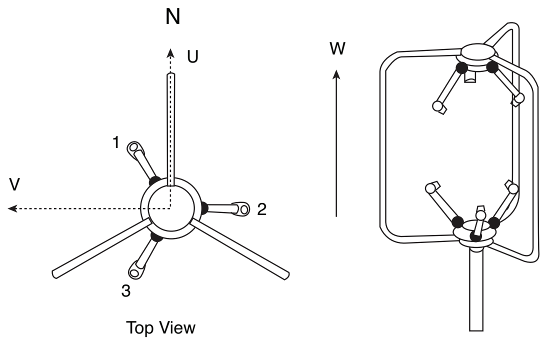

Choose the sonic anemometer manufacturer and model in the pull-down menus. LI-COR supports the following sonic anemometer models:

| Manufacturer | Model(s) | | | |
|---|---|---|---|---|
| Campbell Scientific® | CSAT3 | | | |
| Gill Instruments | HS-50™ | HS-100™ | R2 | R3-50™ |
| | R3-100™ | WindMaster™ | WindMaster™ Pro | |
| Metek | uSonic-3 Class A | | uSonic-3 Scientific | |
| R.M. Young | 81000 | | | |

**Wind Data Format:** From the three axis velocities, the wind speed is calculated, and output as either signed U, V, and W, as Polar and W, or as raw velocity values. The type of output is set during the anemometer configuration.

Choose the wind data format from the pull-down menu:

- U, V, W (some Gill anemometers): U is defined as toward the direction in line with the north spar, as shown in the diagram below. V is defined as toward the direction of 90° counter-clockwise from the N/Reference spar. W is defined as vertically up the mounting shaft.




- Polar, W - The wind speed in the UV plane, with direction in degrees from 0 to 359°, with respect to the Reference spar (normally aligned to North).
- Axis velocities - Raw velocity values for U, V, W.

**North Offset (°):** Offset, in degrees (0-359°) from which the Reference spar varies from true north.

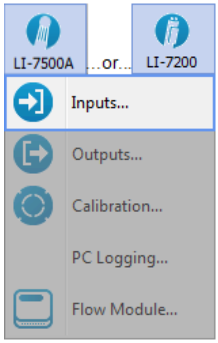
> Important note on North Offset:
> EddyPro requires the offset with respect to true north as two pieces of information: The offset with respect to true north, and the magnetic declination. Currently the GHG v7 software does not provide an entry for magnetic declination.
> For the best results, enter the North Offset to magnetic North. This will create small differences in the wind direction between EddyPro and the SMARTFlux results (a constant offset equal to the magnetic declination), but the flux results will be the same, if all other settings are the same.

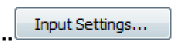
**Height (m)** ***(mandatory)*****:** Sonic anemometer height above the ground, in meters, measured to center of the anemometer sample volume.

**Input Settings** ***(mandatory)*****:** The [Input Settings...] button opens the Auxiliary Inputs window, where you configure the measurement type, units, label, and calibration coefficients.

## About Sonic Anemometer Inputs

The LI-7500A or LI-7200 menu presents options to configure the sonic anemometer inputs.

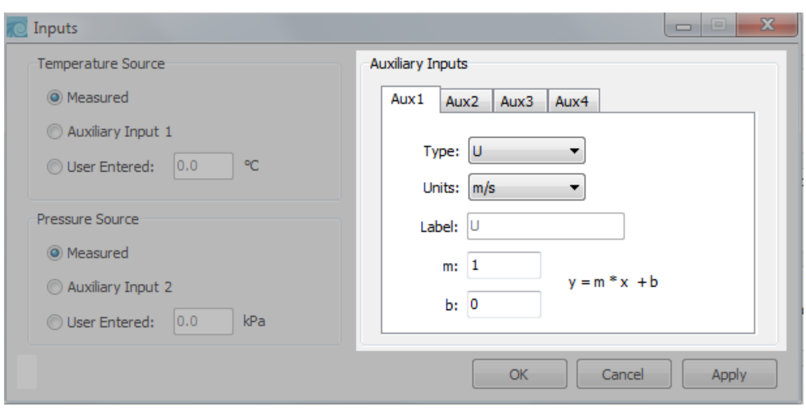



You can also open this dialog from the **Input Settings...** 

button under Site Setup > Anemometer tab.

> **IMPORTANT:** It is mandatory to specify the scaling of the anemometric measurements under the **Inputs** dialog, to allow EddyPro to correctly read this data and calculate fluxes.

- The four **Auxiliary Inputs** (Aux1...Aux4) correspond with U, V, W, and $T_s$ (or SOS) output from the anemometer.
- **Type** specifies the variable.
- **Units** are the units that will be logged with the variable.
- **Label** is logged in the data and metadata. It identifies the variable.
- **Slope** and **offset** values relate the measured variable with the voltage.

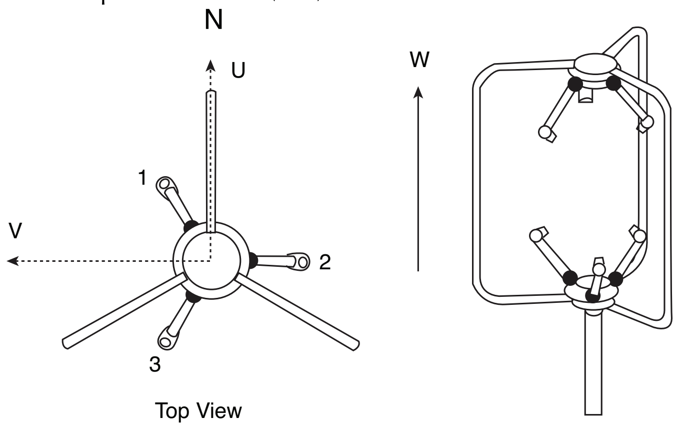


## Configuring the Anemometer Inputs

**1. Choose the Type of Input**

The 'Type' field allows you to choose from:

**U** – Horizontal wind speed (m/s) as measured toward the direction in line with the north spar (see diagram below)
**V** – Horizontal wind speed (m/s) as measured toward the direction of 90° counterclockwise from the north spar
**W** – Vertical wind speed (m/s) as measured up the mounting shaft
**$T_s$** – Sonic temperature (°C)
**SOS** – Speed of sound (m/s)




**2. Choose the appropriate Units**

The units available are typical anemometric units. The software provides some controls over the units that are available with each variable:

| Type | Units |
|---|---|
| Other | Other, m/s, cm/s, volts, K, and C |
| U | m/s, cm/s, volts |
| V | m/s, cm/s, volts |
| W | m/s, cm/s, volts |
| Ts | K, C, volts |
| SOS | m/s, cm/s, volts |

**3. Enter the Label (optional).**

The label is automatically set and cannot be changed for U, V, W, $T_s$, or SOS unless 'Other' is selected. The Label will appear in the file header in both the data and/or metadata files and is required for EddyPro and SMARTFlux system.

## Slope Offset Examples

The units selected for each auxiliary input determine the label in the data file header, as well as the file header in the metadata file used with the SMARTFlux system. Enter the slope and offset values that convert the sonic anemometer outputs into scaled units.

The following table gives the appropriate values for m (multiplier) and b (offset) to be used when converting raw voltages into units of m/s, using the default sonic anemometer output ranges of -30 to +30 m/s for U and V, and -5 to +5 m/s for W.

| | U, V (-30 to +30 m/s | | W (-5 to +5 m/s) | | Sonic Temp. (-40 to 70 °C) | | Speed of Sound (300 to 370 m/s) | |
|---|---|---|---|---|---|---|---|---|
| **Sonic output (V)** | **m** | **b** | **m** | **b** | **m** | **b** | **m** | **b** |
| 0-5V | 12 | -30 | 2 | -5 | 22 | -40 | 14 | 300 |
| ±5V | 6 | 0 | 1 | 0 | 11 | 15 | 7 | 335 |
| ±2.5V | 12 | 0 | 2 | 0 | 22 | 15 | 14 | 335 |

**Example:** You have configured the Gill WindMaster™ to output raw voltages for auxiliary input U over the range of 0-5V, and over a full scale wind speed of -30 to +30 m/s. You want to convert the raw voltages to wind speed and output the values in units of m/s. What is the wind speed when the sonic anemometer outputs a raw voltage value of 0.5V?

1. Set the 'Type' field to U.
2. Set the 'Units' field to m/s. The Label is set automatically.
3. Enter 12 for the Multiplier (m)
4. Enter -30 for the Offset (b)

Using the slope-intercept formula:

$$y = m*x + b \tag{3-3}$$

the wind speed is calculated as

$$y = 12(0.5) + (-30) = -24 \text{ m/s} \tag{3-4}$$

**Example 2:** You have configured the Gill WindMaster™ to output raw voltages for auxiliary input U over the range of ±5V, and over a full scale wind speed of

-30 to +30 m/s. You want to convert the raw voltages to wind speed and output the values in units of m/s. What is the wind speed when the sonic anemometer outputs a raw voltage value of 1.5V?

1. Set the 'Type' field to U.
2. Set the 'Units' field to m/s. The Label is set automatically.
3. Enter 6 for the Multiplier (m).
4. Enter 0 for the Offset (b).

Using the slope-intercept formula (3-3 on the previous page), the wind speed is calculated as:

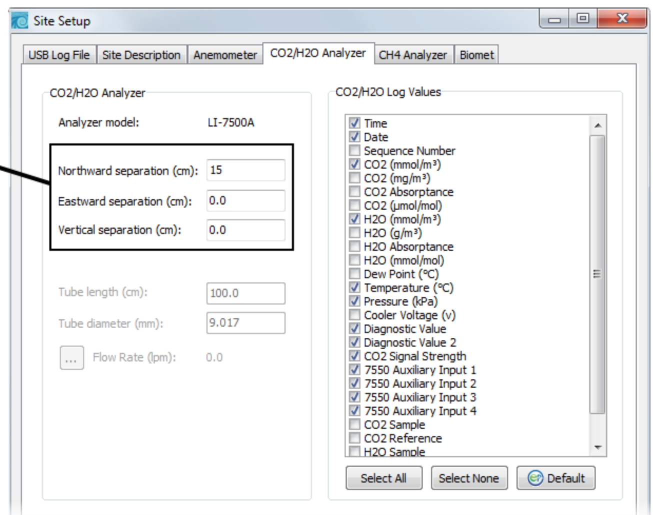
$$y = 6(1.5) + 0 = 9 \text{ m/s} \qquad 3\text{-}5$$

## Enter $CO_2/H_2O$ Analyzer Information

Measurement of the separation between the $CO_2/H_2O$ gas analyzer(s) and the sonic anemometer is necessary to estimate the high-frequency flux losses due to the distance between the instruments that measured the vertical wind component and the gas concentration(s). In order to allow EddyPro® to determine the distance from a gas analyzer and the anemometer, distances are provided in a Cartesian coordinate system.

The $CO_2/H_2O$ Analyzer tab displays the type of $CO_2/H_2O$ analyzer used (LI-7500A, LI-7200), the values to log to the USB drive, and the gas analyzer position relative to the sonic anemometer.

**Important:**
Entering the wrong values here will result in incorrect flux calculations.
At least one of these values must be different from 0.
Separations are relative to the sonic anemometer and are measured at the site.




**NOTES:**

- Units must be provided in centimeters (cm) or meters (m).
- The reference anemometer described in the metadata file serves as the center (0, 0) of the coordinate system.
- For all gas analyzers and other anemometers (if any), the distances from the reference anemometer are provided along the north-south axis and the east-west axis.
- Distances are positive if the second instrument is to the north, east, or above the reference anemometer.

**Northward Separation (cm):** North/south distance between the $CO_2$/$H_2O$ Analyzer and the reference anemometer. Positive values if north and negative values if south of the anemometer.

**Eastward Separation (cm):** East/west distance between the $CO_2$/$H_2O$ Analyzer and the reference anemometer. Positive values if east and negative values if west of the anemometer.

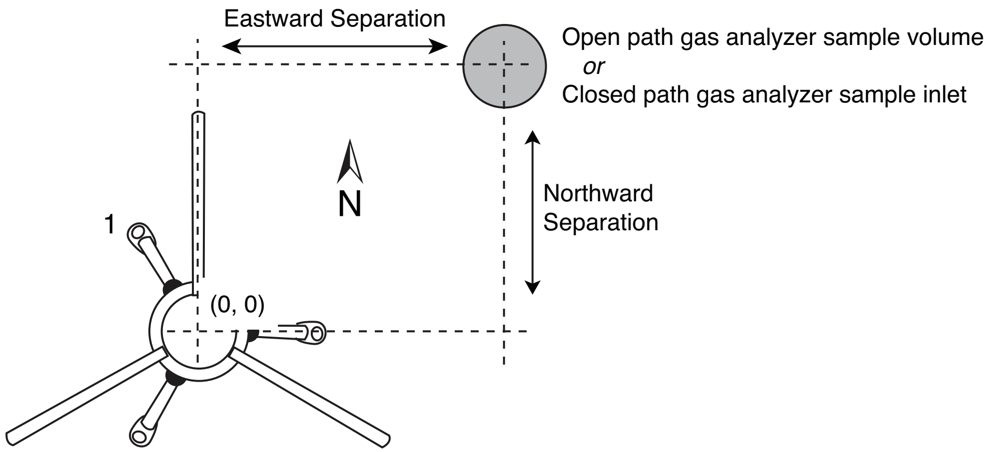



*Figure 3-1. Eastward and Northward separations.*

**Vertical Separation (cm):** Vertical distance between the $CO_2$/$H_2$ Analyzer and the reference anemometer. This value is negative if the center of the analyzer sample volume (LI-7500A, LI-7700) or intake tube inlet (LI-7200) is below the center of the reference anemometer sample volume and positive if the gas sample is above.

> **NOTE:** At least one separation must be different from 0.

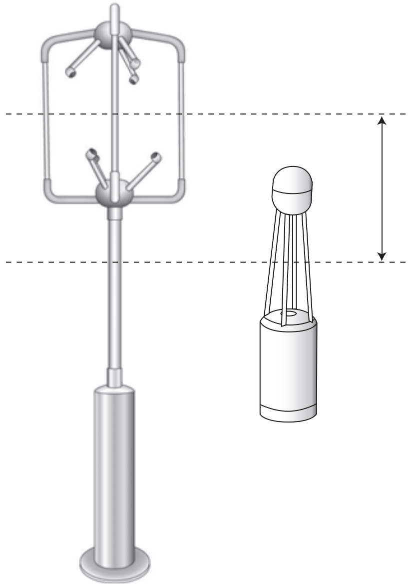
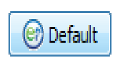


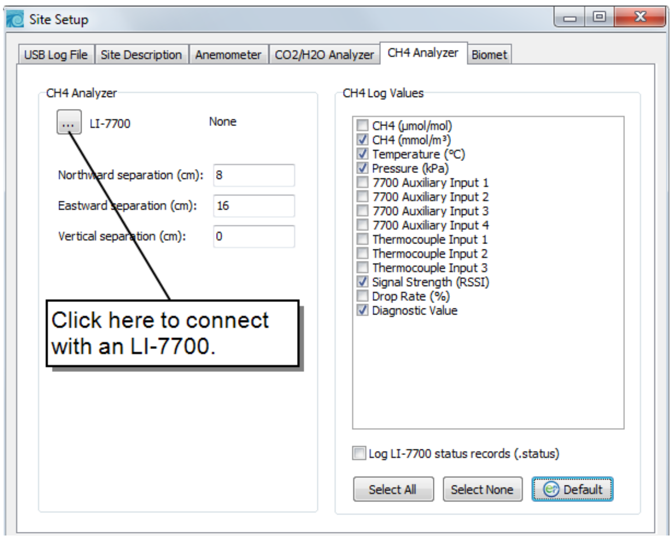
*Figure 3-2. Vertical separation.*

**$CO_2$/$H_2O$ Log Values:** Click 

to select data records recommended for use with the SMARTFlux system and EddyPro® software. Or select variables of your choice.

## $CH_4$ Analyzer Data

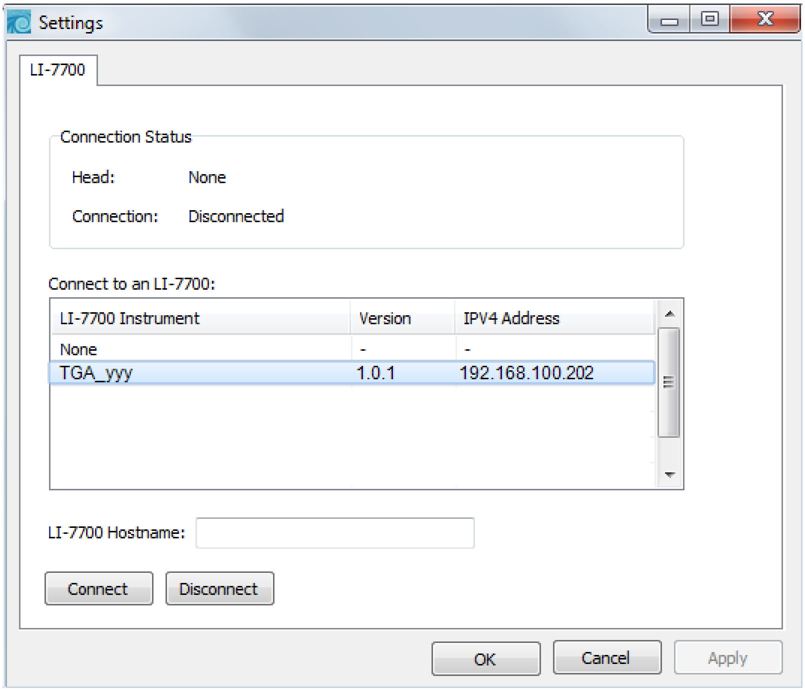
The LI-7550 Analyzer Interface Unit can be connected to any LI-7700 Open Path $CH_4$ Analyzer on the network to integrate LI-7700 data into the same data set collected by the LI-7500A/LI-7200 for greenhouse gas flux calculations.




### Connect to an LI-7700


Click the  button next to LI-7700 or the LI-7700 button from the main window to open the **Settings** dialog, where you can connect to an LI-7700 $CH_4$ analyzer.

The LI-7700 tab displays a list of LI-7700 instruments available on the network (same subnet as computer). Select an LI-7700 from the list, or enter an IP address in the 'LI-7700 Hostname' field (networked device on different subnet mask as computer) and click **Connect**. Click **Apply** or **OK**. When you start logging data with the LI-7550 via USB, the selected variables for the LI-7700 will be logged and used in flux calculations.




**Note:** In some scenarios you may connect to an LI-7700 by typing in a known IP address or instrument name into the LI-7700 Hostname field.

## Enter Analyzer Information

Here you specify the separation between the sonic anemometer and the LI-7700 sample volume.

**NOTE:** At least one separation must be different from 0.

**Northward Separation (cm):** North/south distance between the LI-7700 Analyzer and the reference anemometer. Positive values if north and negative values if south of the anemometer (see Figure 3-1 on page 3-21).

**Eastward Separation (cm):** East/west distance between the LI-7700 Analyzer and the reference anemometer. Positive values if east and negative values if west of the anemometer (see Figure 3-1 on page 3-21).

**Vertical Separation (cm):** Vertical distance between the LI-7700 Analyzer and the reference anemometer. This value is negative if the center of the LI-7700 sample volume is below the center of the reference anemometer sample volume and positive if the gas sample is above (see Figure 3-2 on page 3-22).

### Select Variables

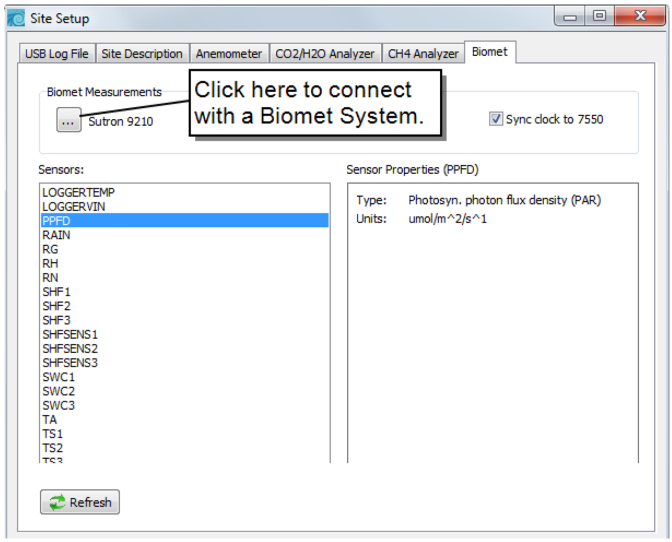
In the Site Setup dialog, click 

to select the recommended variables for processing in EddyPro and the SMARTFlux system or click Select All to log all variables.

You can enable the ‘Log LI-7700 status records (.status)’ check box to collect LI-7700 STATUS records. Refer to the LI-7700 Instruction Manual for more information.

## Enter Biomet System Information

The LI-7550 Analyzer Interface Unit can be connected to any 9210 Sutron data logger on the network, to log biomet data with data collected by the LI-7500A/LI-7200 for greenhouse gas flux calculations.




Click on the  button next to Sutron 9210 to open the **Settings** window, where you can connect to a Sutron data logger. After connection, the software will display a list of biomet sensors configured for use with the selected Sutron datalogger (under **Sensors**). Click on any sensor in the list to display the Sensor Properties (e.g. Type and Units) for the selected sensor. Note that the Sensors and Sensor Properties are configured through the 9210; these lists are for reference only.

**NOTE:** Enable the 'Sync clock to 7550' to synchronize the Sutron 9210 and LI-7550 clocks.

Refer to the 7900 Biomet Station Instruction Manual for more information.

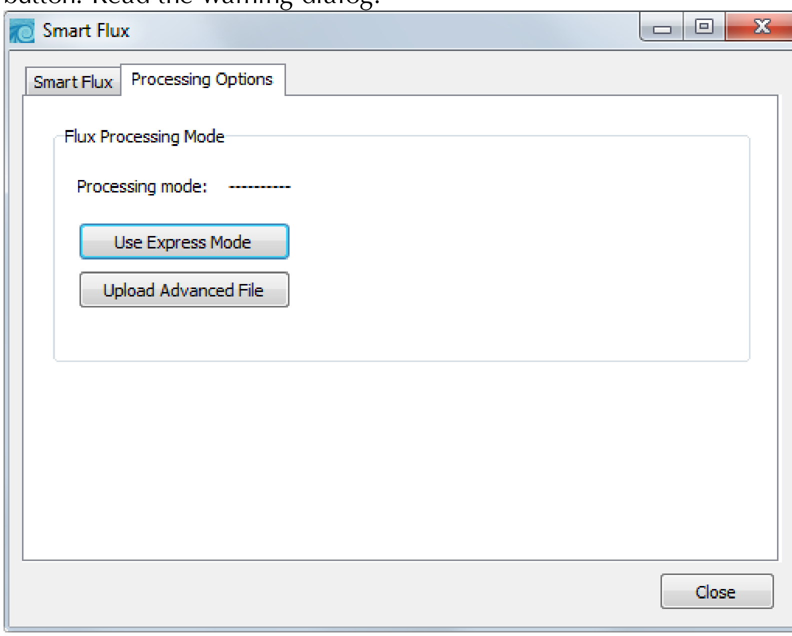
## Loading a SMARTFlux Configuration File

The SMARTFlux system is supported by GHG v7 (LI-7500A/ LI-7200 software) and above.

> **Note:** EddyPro Express settings are loaded by default so you only need to load a configuration file if you use EddyPro Advanced settings.


To load an EddyPro Advanced configuration file:

1. Open the SMARTFlux system dialog.
2. Select the **Processing Options** tab, and click the **Upload Advanced File** button. Read the warning dialog.

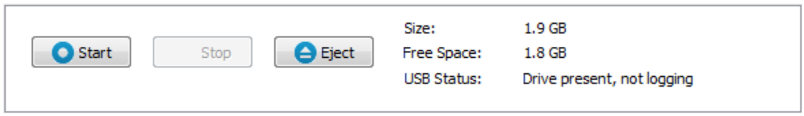



3. Browse to the file created in EddyPro v5 (extension *.smartflux) and select it.

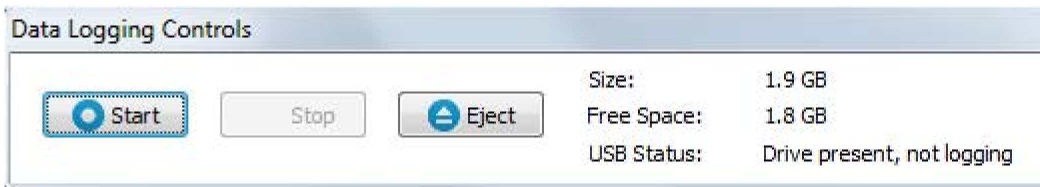
After loading the file, the SMARTFlux system will compute flux results based upon the defined Advanced settings (be sure to turn on datalogging first (see "Begin Logging Data" on the next page).

# Begin Logging Data

Under the **Site Setup** menu, each tab has **Start**, **Stop**, and **Eject** buttons.




You can open the logging controls by clicking the log button.




Click **Start** to begin logging data. Press **Stop** to quit logging, and **Eject** to unmount the USB drive.

> **Note:** If you unmount the drive you will have to physically remove and reinsert the USB drive in order for the LI-7550 to recognize it again.

## Verify Flux Computations

In this version of the SMARTFlux system, the best way to verify that fluxes are calculated is to review the data after 30 minutes of collection. To allow time for computation, let the system run for about 35 minutes and then select the **Results** tab. Computed flux results will be visible.

# Express Mode

EddyPro Express mode is the default configuration for the flux computation in the SMARTFlux system. Express settings are loaded automatically unless you specify an EddyPro Advanced configuration file. In most cases, EddyPro Express provides final, fully corrected and valid fluxes that can be directly used for further analysis. In a few special cases, however, Express fluxes may not be fully accurate and only serve a diagnostic purpose.

## Automatic Variable Selection

In standard EddyPro, even when running in Express mode, you still can select the variables to be used in flux computation, in the **Basic Settings > Select Items for flux computation** section. More precisely, EddyPro provides default choices based on the variables described in the metadata file (either embedded in GHG files, or created in **Project Creation > Metadata file editor**), and you can keep these choices or pick other variables. For example, $CO_2$ fluxes from the LI-7200 can be calculated from $CO_2$ measurements available as either mixing ratio, mole fraction or number density. If all of these measurements are available in the metadata file, then EddyPro defaults to the mixing ratio, and you are allowed to either keep this choice or pick one of the other two.

EddyPro defaults, and the order in which other viable variables are listed in the drop-down menus, reflect best practices suggested by LI-COR and depend on the deployed instrument(s). The exact same logic is used in SMARTFlux to select the variables to be used when multiple choices are available. In particular:

- **$CO_2$/$H_2O$ measured by an LI-7200:** The order of preference is (1) mixing ratio, (2) mole fraction and (3) number density
- **$CO_2$/$H_2O$ measured by an LI-7500A:** Only number density can be used for flux computation
- **$CH_4$ measured by an LI-7700:** Only number density can be used for flux computation
- **Air temperature and pressure:** Precedence is given to measurements from an LI-7700 if available.
- **Diagnostics flags:** If available for the deployed instruments, diagnostic flags are used to filter out individual raw data based on diagnostic information.

## Overview of Advanced Mode

Advanced Mode provides you with the high-level capabilities of the EddyPro Advanced, computing fully corrected flux results in real-time with the processing options of your choice.

The SMARTFlux configuration file, needed to run EddyPro in Advanced mode inside the SMARTFlux module, is created in EddyPro 5 or higher. This, and subsequent versions of EddyPro provide the capability to export a SMARTFlux configuration file, that can then be uploaded via the GHG v7 (LI-7200/LI-7500A) Windows application.

There are additional considerations if you use **EddyPro Advanced** in SMARTFlux. For many scenarios, you will simply need to configure the advanced settings as you see best, and load the SMARTFlux configuration file into SMARTFlux following the instruction provided hereafter.

However, if you wish to use a **Planar-fit method for Axis Rotation**, the **Automatic Time Lag Optimization** option, or one of the **in-situ spectral correction** methods (Horst, 1997; Ibrom et al., 2007), *you will need to process an existing data set from the site in order to configure the parameters for these settings*, as explained in "Using Planar Fit, In-situ Spectral Corrections and Timelag Optimization in SMARTFlux " on page 3-33.

> **Important:** In order for the parameters to be valid, the site must not have undergone any significant changes between the time when the existing data set was collected and when the SMARTFlux system is deployed. The instrument configuration should remain unchanged during the sampling period if the settings are to apply to the SMARTFlux system configuration file as well. For closed-path systems, the dataset used to optimize time lags and for the spectral assessment must refer to a period in which the sampling line did not undergo major modifications, such as replacement of tube or filters, change of the flow rate, etc.

When you create the configuration file, only the controls that can be configured for the SMARTFlux system are enabled, and the other controls are disabled. Similarly to EddyPro Advanced and Express, some controls must be configured, while others are optional.

## Advanced Mode Options

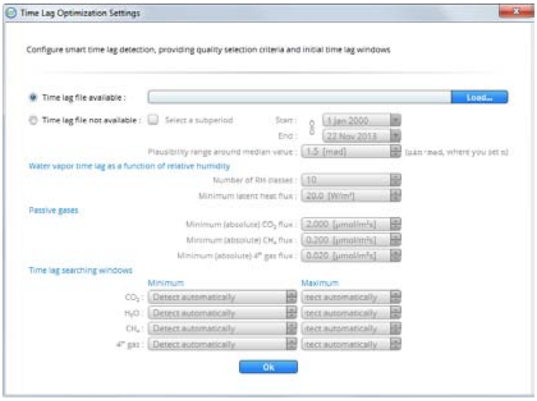
Similarly to EddyPro Advanced and Express, some controls must be configured, while others are optional. When you create the SMARTFlux system configuration file, only the controls that can be configured for SMARTFlux are enabled, and the other controls are disabled. In particular, you will find that:

1. The **Project Creation** page is not available. This is because inside SMARTFlux, EddyPro does not need any of the information that is entered in the Project Creation page. The file type (LI-COR GHG), the use of metadata (“embedded”) and the use of biomet data (“embedded”) are all predefined settings in SMARTFlux.

2. In **Basic Settings**:
   a. The selection of **Dataset dates** is deactivated because SMARTFlux processes GHG files one by one, as they are created by the GHG v7 LI-7550 embedded software.
   b. The **Previous results directory** is deactivated because this option is not applicable to SMARTFlux.
   c. The **Flux averaging interval** is deactivated because SMARTFlux operates on a predefined interval of 30 minutes. In SMARTFlux there is no option to calculate fluxes on any other time interval.
   d. The **Master Anemometer** is deactivated because LI-COR GHG systems are designed around one only anemometer, which is detected automatically in SMARTFlux as the “master”.
3. In **Advanced Settings > Processing Options**, all processing options are active, and you can select them as you would do in EddyPro. The only exception are:
   a. The **Planar Fit Settings...** dialogue, which activates when the **Planar fit** or the **Planar fit with no velocity bias** option is chosen as the **Axis rotation for tilt correction** method, presents only the **Planar fit file available** option. If you want to use the planar fit method in SMARTFlux, you will have to load a previously created planar fit file at this time. Refer to "Using Planar Fit, In-situ Spectral Corrections and Timelag Optimization in SMARTFlux " on page 3-33 for instruction how to create the planar fit file and more details on how to use it in SMARTFlux.


   b. The **Time lag Optimization Settings...**, which activates when the **Automatic time lag optimization** option is chosen as a **Time lag**

**compensation** method, only gives the **Time lag file available** option. If you want to use the automatic timelag optimization option in SMARTFlux, you will have to load a previously created timelag optimization file at this time. Refer to "Using Planar Fit, In-situ Spectral Corrections and Timelag Optimization in SMARTFlux " on the facing page for instruction how to create the timelag optimization file and more details on how to use it in SMARTFlux.




4. In **Advanced Settings > Spectral Corrections** both low frequency and high frequency corrections are available. However:
   a. In the **Correction for low-pass filtering effects**, the method by Fratini et al. (2012) is deactivated, because this method requires an auxiliary file that is currently not available in SMARTFlux.
   b. If an in-situ method is selected (Horst 1997 or Ibrom et al., 2007), only the option **Spectral assessment file available** is active, similar to the planar fit and timelag optimization options discussed above. If you want to use one of these in-situ methods in SMARTFlux, you will have to load a previously created spectral assessment file at this time. Refer to "Using Planar Fit, In-situ Spectral Corrections and Timelag Optimization in SMARTFlux " on the facing page for instruction how to create the spectral assessment file and more details on how to use it in SMARTFlux.
5. In **Advanced Settings > Statistical Analysis**, all processing options are active, and you can select them as you would do in EddyPro with no exceptions.
6. In **Advanced Settings > Output Files**, most options are active, with the following exceptions:

a. The **Set Minimal**, **Set Typical** and **Set Thorough** pre-selection buttons are deactivated, because those pre-selections do not apply completely to SMARTFlux.
b. The **Full output file** and related settings are deactivated because this file shall always be created, and in a predefined format, in SMARTFlux.
c. The **Ensemble averaged cospectra and models** is unchecked and deactivated, because this output cannot be created in SMARTFlux, were GHG files are processed one at a time. For creating those outputs, use standard EddyPro instead.
d. All full length (co)spectra outputs are deactivated. These files occupy large amounts of disk space and are thus not allowed in SMARTFlux. For obtaining full length (co)spectra files, use standard EddyPro instead.
e. Processed raw data outputs are deactivated. These files occupy large amounts of disk space and are thus not allowed in SMARTFlux. For obtaining those outputs, use standard EddyPro instead.

### Creating an Advanced SMARTFlux Configuration File

If you have at least one GHG file from the EC system for which you are going to use SMARTFlux, you can customize the Advanced processing options, and select the variables you prefer for computing fluxes on-the-fly. In this case, in **Basic Settings** simply select the **Raw data directory** where your raw data are stored, and EddyPro will automatically populate the section **Select Items for flux computation**, as it usually does when used in the standard mode.

At this point, select the variables, configure the flags, and set the processing options of your preference and simply click the **Create File** button visible on the right side of the blue SMARTFlux ribbon. This will create a bundle with extension **.smartflux** and save it in the selected output directory.

### Using Planar Fit, In-situ Spectral Corrections and Timelag Optimization in SMARTFlux

In order to use planar-fit, in-situ spectral corrections or timelag optimization in the SMARTFlux system, EddyPro needs to access the respective “planar_fit”, “spectral_assessment” and “timelag_optimization” files, referred to as “additional configuration files” hereafter. These files contain summaries of calculations performed on relatively large datasets (Table 3-2 on the next page) and that apply also to data to be collected in the future.

For example, you can use three-months of data to calculate a "spectral assessment", and then use this spectral assessment that is summarized in a short text file, to correct fluxes calculated from data collected after those three months, if the system configuration didn't change to such an extent, that the spectral assessment is no longer representative. Similar considerations apply to the planar fit and the timelag optimization procedures. Refer to EddyPro documentation for more details on when and how to use these three advanced procedures.

The additional configuration files are created by EddyPro (3.0 and above), when used in the standard desktop mode. If you have been running your EC system – for which you intend to user SMARTFlux - for some time, you may already have created one or more of these files, or you may have a GHG dataset suitable for creating them, if the corresponding implementation is deemed necessary to calculate accurate fluxes (again, refer to EddyPro documentation to learn more about when it is suggested to use these options). If you do not have previously collected GHG files, then you will need to run the system for a suitable amount of time (for example using SMARTFlux in Express mode), then use EddyPro in desktop mode to create the additional configuration files of your interest, and then provide them to SMARTFlux as explained below.

**Table 3-2**. Recommended dataset durations for Advanced settings.

| EddyPro Advanced Setting | Recommended Dataset |
|---|---|
| Planar Fit Settings | 2 weeks minimum; < 2 months |
| Time Lag Optimization | 1 to 2 months or more |
| Spectral Corrections, Assessment of high frequency attenuation | 1 month or more |

Thus, assuming that you have a sufficiently long GHG dataset (Table 3-2 above), the procedure to correctly configure SMARTFlux to use planar-fit, in-situ spectral corrections or timelag optimization is illustrated here, using the in-situ spectral corrections as an example. Analogous procedures shall be followed for the planar-fit or the timelag optimization.

1. Open EddyPro (5.0 or above recommended) in normal desktop mode and complete the **Project Creation** and **Basic Settings** pages as usual (refer to EddyPro documentation if needed). In the **Advanced Settings > Spectral Corrections**, configure **Corrections for low-pass filtering effects** to use one of the in-situ methods, i.e. Horst (1997), Ibrom et al. (2007) or Fratini et

al. (2012). In the same page, customize the settings to instruct EddyPro to use the dataset of your choice and to filter data appropriately, so as to obtain a sound assessment of spectral attenuations. Click **Run** and when this is completed, locate the spectral assessment file (it contains the string "spectral_assessment" in the file name) in the subdirectory \spectral_analysis that you will find inside the selected Output folder. This is the file that you will use for SMARTFlux.

2. Open EddyPro (5.0 or above) in SMARTFlux Setup Mode. Configure everything as explained in the previous sections. In the **Advanced Settings > Spectral Corrections**, configure **Corrections for low-pass filtering effects** to use one of the in-situ methods among Horst (1997) and Ibrom et al. (2007) (the method of Fratini et al. (2012) is currently not usable in SMARTFlux). In the **"Spectral assessment file available"** entry, select the spectral assessment file created earlier. Then proceed normally and when done, click on the **Create File** button to create the .smartflux bundle, as explained above.

An analogous procedure can be used to create and use the planar fit and the timelag optimization configuration files.

## Results Files

The SMARTFlux™ system writes EddyPro results files to the ***USB flash drive in the LI-7550***.

In addition to the raw LI-COR® GHG files (including any .data and .metadata files), you can retrieve flux results files, daily summary files, and archived files.

### Flux Results

These are the output files from EddyPro. They follow a format typical of EddyPro outputs, as described in detail in the EddyPro help (envsupport.licor.com/help/EddyPro5/index.htm#Output_Files_Overview.htm).

### Daily Summaries

These logged data summaries, typically named something like `YYYY-MM-DD_AIU-xxxx_Summary`, include the high-speed data logged in the LI-7550 analyzer interface unit. These are the variables selected in "Enter CO2/H2O Analyzer Information" on page 3-20.

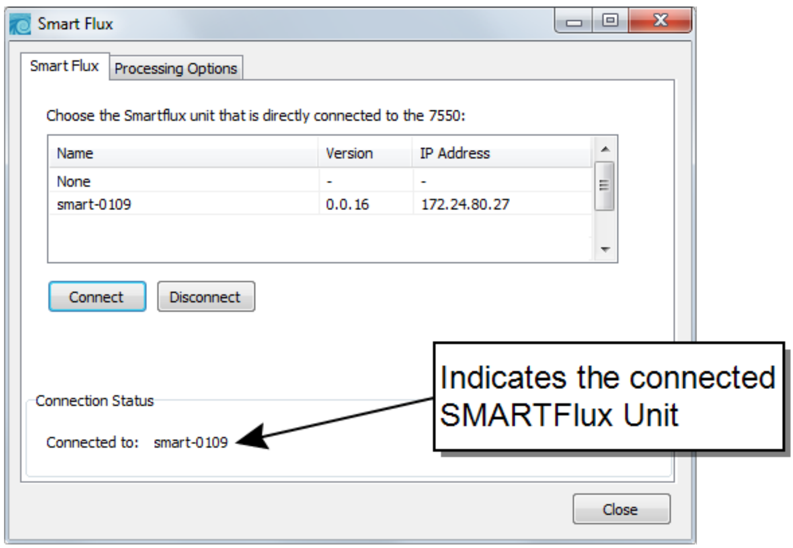
The EddyPro summaries, typically named somethings like `YYYY-MM-DD_EP-Summary`, include the Half-hour eddy covariance flux results. This file is created at the end of each day by collecting the results of each 30-minute file and placing them in a row. The variables included in this file are specified in EddyPro automatically if you select Basic processing or manually if you select Advanced processing (see "Advanced Mode Options" on page 3-30).

## SMARTFlux Software Update

Periodically LI-COR® will release updated software for SMARTFlux system. Software updates will include bug fixes, new features, or performance improvements. We recommend that you keep the software on your instruments up-to-date.

### Check the Software Version


The SMARTFlux system software version and IP Address are displayed in the **Connect** window in the gas analyzer software.



## Update the Software

You will be notified by email if and when we release a critical software update. Download updated software from the technical support website: http://www.licor.com/env/support/

On the support web site, select your instrument, then select "Software," and save the update package to your computer.

To update the software:

1. Unzip the compressed update package and double click the file called "flux updater.exe".
2. Each SMARTFlux system module that is on your network will be visible in the Flux Updater window. Select the module you want to update and click **Update Firmware**.
3. The updater will load the new system files. This process takes about 30 seconds to a minute to complete. Do not power off the device while it is updating.
4. After the update is complete, you can verify the software version in the updater or in the gas analyzer software (see "Check the Software Version" on the previous page).

# 4 Using EddyPro® 5

## Processing GHG Data with Correct Site Parameters

If you logged the eddy covariance data to an LI-7550 in the LI-COR® GHG format and entered the correct site information, the GHG file will contain an embedded METADATA file with information needed for processing the accompanying DATA file.

If, during the acquisition period, you changed settings in the gas analyzer data logging interface in order to account for changes in the site parameters, these changes will be stored in the metadata. EddyPro® allows you to account for the time dependency by processing each DATA file using meta-information retrieved from the paired METADATA file embedded in the GHG archive.

> **Note:** If there were no changes in the project metadata for the eddy covariance dataset under consideration, you can speed up processing by using a single metadata file for the entire project, as described in the following section.

To process the dataset, launch EddyPro:

1. Start a **New Project**.
2. Enter a **Project name** (optional).
3. Click the **Basic Settings** button to enter the Basic Settings page. See "Basic Settings" on page 4-11

## Processing GHG Data with Incorrect or No Site Parameters

If you collected eddy covariance data using LI-COR® data logging software, your dataset will be comprised of raw files in GHG format. Each GHG file contains a METADATA file with information needed for processing the paired DATA file. If, during the acquisition period, you changed settings in the data logging interface in order to account for modification of critical meta-information, the obtained dataset will contain dynamic, time-dependent metadata. EddyPro® allows you to account for this time dependency, processing each DATA file using meta-information retrieved from the paired METADATA file embedded in the GHG archive.

However, there are two situations, in which you might want or need to by-pass embedded METADATA files:

- When embedded METADATA files have incorrect information (e.g., because they contain errors in critical meta-information);
- When all embedded METADATA files, correct or incorrect, are identical because no changes were made during data acquisition.

In these cases EddyPro® provides a way to by-pass embedded METADATA files and use an alternative file.

> **Important:** Using an alternative METADATA file means that all GHG files are processed with the same meta-information (unless you provide a Time-varying metadata file). It also implies that all DATA files must have the exact same format, which must be correctly described in the alternative METADATA file.

To use an alternative metadata file for your dataset:

1. Start a **New Project** and select LI-COR GHG as the file type.
2. Enter a **Project name** (optional).
3. In the **Basic Settings** page, enter the **Raw data directory**, where your raw data are stored.
4. Return to the **Project Creation** page and select the option **Metadata file: Use alternative file**. The **Metadata File Editor** will activate with the metadata from the first GHG file in your project.
   Make changes to the metadata file as needed.

5. Click **Save metadata as...** and save the file with a new file name. This file is the **Alternative metadata file**. You can modify it here or use it as it is.
6. When all mandatory meta-information is entered with plausible values, the **Basic Settings** button activates.

   Click it to enter the Basic Settings Page. See "Basic Settings" on page 4-11.

## Processing ASCII, Binary, TOB1, or SLT Files

EddyPro® can process raw data in a variety of formats, including virtually all sorts of Generic ASCII, Binary, TOB1 (Campbell Scientific®, Inc.), and SLT (EddySoft and EdiSol) formats.

For interpreting and processing those files, EddyPro needs the same meta-information needed for GHG files, but for these file types, the meta-information is not available directly in the data files. Therefore, you must create and use an alternative METADATA file. Selecting any **Raw file format** other than LI-COR GHG will cause the **Metadata file** entry to automatically toggle to the **Use alternative file** option and the **Metadata File Editor** to activate.

**Note:** The **Use embedded files** option deactivates, because in this case there is no embedded METADATA file available.

1. Launch EddyPro and start a **New Project**.
2. Enter a **Project name** (optional).
3. Select either ASCII plain text, Generic binary, TOB1, SLT (EddySoft), or SLT (EdiSol) as the **Raw file format**.
4. Enter all the required information in the **Metadata File Editor**. The graphical interface will help you prepare a valid METADATA file by preventing you from entering unphysical or implausible values and by activating the **Basic Settings** button only when all mandatory fields hold valid entries. Fill out the mandatory entries in the **Station**, **Instruments** and **Raw file description** tabs, in this order. Also configure the **Raw File Settings** dialog. The Metadata file will be saved automatically when it is edited. The path of the saved file will appear in the text field adjacent to the *Use*

*alternative file* option of the **Metadata file** entry. See "Using the Metadata File Editor" on page 4-4

5. Click the Basic Settings button to advance to the Basic Settings page. See "Basic Settings" on page 4-11.


## Using the Metadata File Editor

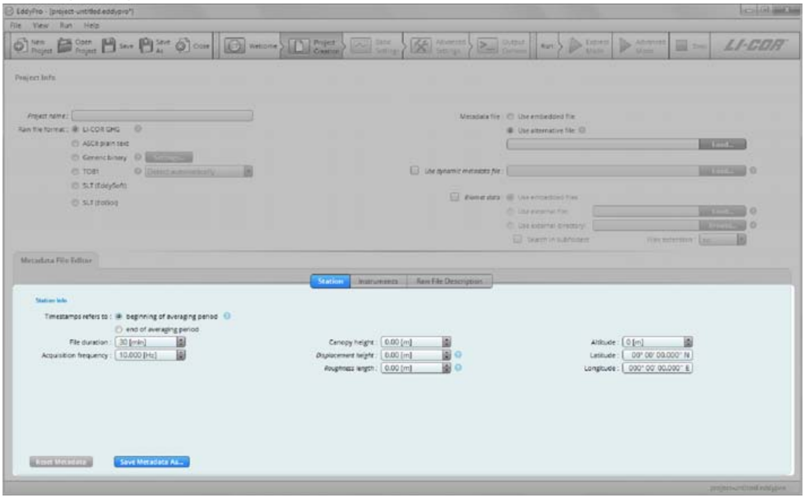
The Metadata File Editor is used to enter site information, instrument information, and a description of the data file structure. This information is required for any dataset processed in EddyPro®. You will use the Metadata File Editor under two circumstances:

- when incorrect site information is included in an existing metadata file, or
- when you are processing ASCII plain text, Generic binary, TOB1, SLT (EddySoft), or SLT (EdiSol) files.

The Metadata File Editor will activate when you select a raw file format other than LI-COR GHG or if you select **Use Alternative File**. It has three tabs: **Station**, **Instruments**, and **Raw File Description**, as well as a dialog box called **Raw File Settings**.

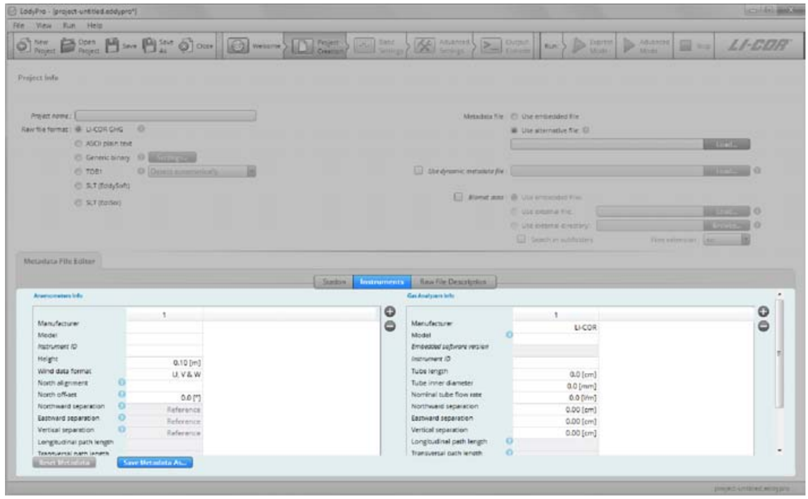
When you begin editing the Metadata File Editor, EddyPro will prompt you to save the metadata file. After you save it, all subsequent edits are saved automatically.

1. Configuring the Station Tab:



- **Time Stamp Refers to:** Specify whether the time stamp in the file name refers to the beginning or end of the time series contained within the file. See "Beginning of Dataset" on page 6-13.
- **File duration:** Set the duration of input files.
- **Acquisition frequency:** This refers to the number of samples per second in the data files.
- **Canopy height:** Distance between the soil surface and the top of the canopy.
- **Displacement height:** See "Displacement Height" on page 6-14.
- **Roughness length:** See "Roughness Length" on page 6-14.
- **Altitude:** Elevation above sea level of the flux site.
- **Latitude and Longitude:** WGS84 coordinates in decimal degrees.

2. Configure the Instruments Tab. It has fields for anemometers and gas analyzers:



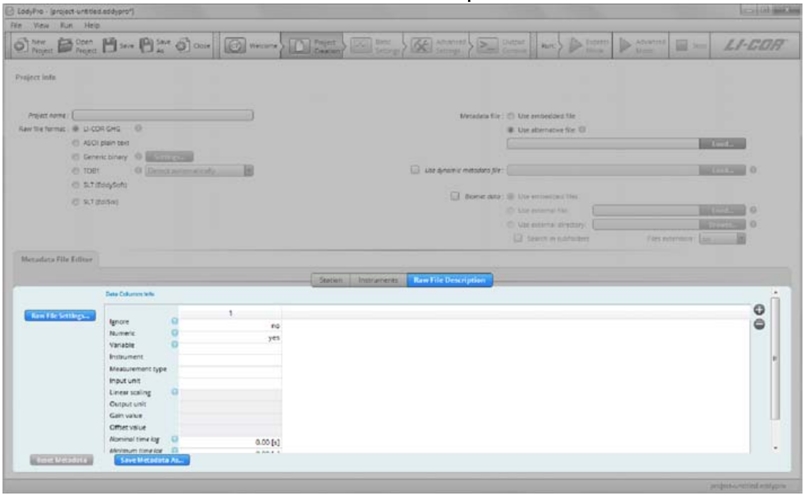
For Anemometer Info, enter:

- **Manufacturer:** The make of your anemometer.
- **Model:** The model of the anemometer.
- **Instrument ID:** This is for your records.
- **Height:** Distance between the ground and the anemometer.
- **Wind data format:** Output format for the anemometer. Choose from *U, V, W*: *Polar* and *W*; or *axis velocities*.
- **North alignment:** Set to Axis or Spar, if applicable.
- **North offset:** See "North Offset" on page 6-15.
- **Northward, Eastward, or Vertical separation:** Used to specify the distance between sensors. For the anemometer you only need to use this field if the data file includes records from two anemometers. See Sensor Separation.
- **Longitudinal path length:** Path length in the direction of a pair of transducers.
- **Transversal path length:** Path length in the direction orthogonal to the longitudinal path length.
- **Time response:** Time response of the anemometer. Its inverse defines the maximum frequency of the atmospheric turbulence that the instrument is able to resolve. Consult the anemometer's specifications or user manual.

For Gas Analyzers Info:

- **Manufacturer:** The make of your gas analyzer.
- **Model:** The model of your gas analyzer. See Gas Analyzer Model.
- **Instrument ID:** This is for your records, to distinguish instruments.
- **Height:** The distance between the ground and the anemometer.
- **Tube length:** For closed path analyzers only, enter the length of the intake tube. Ignore for open path analyzers.
- **Tube inner diameter:** For closed path analyzers only, the inside diameter of the intake tube.
- **Nominal tube flow rate:** For closed path analyzers only, the flow rate setting. Ignore for open path analyzers.
- **Northward, Eastward, or Vertical separation:** Used to specify the distance between anemometer and gas analyzer. See "Northward, Eastward, and Vertical Separation" on page 6-16.
- **Longitudinal path length:** Path length between the optical source and detector of the analyzer.
- **Transversal path length:** Path length in the direction orthogonal to the longitudinal path length.
- **Time response:** Time response of the gas analyzer. Its inverse defines the maximum frequency of the atmospheric turbulent concentration fluctuations that the instrument is able to resolve. Consult the analyzer's specifications or user manual.
- **Extinction coefficient in water, $K_w$:** In Krypton or Lyman-a hygrometers, the extinction coefficients for water vapor of the hygrometers, associated with the third-order Taylor expansion of the Lambert–Beer law around reference conditions (van Dijk et al. 2003).
- **Extinction coefficient in water, $K_o$:** In Krypton or Lyman-a hygrometers, the extinction coefficients for oxygen of the hygrometers, associated with the third-order Taylor expansion of the Lambert–Beer law around reference conditions (van Dijk et al. 2003).

**3.** Enter information in the Raw File Description tab:




The Raw File Description tab is where you tell EddyPro how data are arranged in the raw data files. Click the plus button (+) to add columns. In each column specify the following:

- **Ignore:** Select ‘yes’ to instruct EddyPro to ignore a column. Columns to be ignored include time stamps, line counters, etc.
- **Numeric:** Select ‘no’ to tell EddyPro that a column is not purely numeric. Purely numeric variables are strings included within two consecutive field separators and containing only digits from 0 to 9 and, at most, the decimal dot. Any other character makes a variable not numeric. For example, time stamps in the form of 2011-09-26 or times as 23:20:562 are not numeric variables. If a variable is not numeric, this must be specified even if you set ’yes’ in the ignore field.
- **Variable:** Specify the variable that is contained in the current column of the raw files or enter a custom variable of your choice. Custom variables are saved to the computer registry so they are available to you when you start a new project.
- **Instrument:** Select the instrument that measured the current variable. Instruments listed here are those you entered under the Instruments tab.
- **Measurement type:** Only applicable to gas concentrations, enter the units used to describe the gas concentration measurement. For other variables, leave the field blank or select *Other*.

- **Input unit:** Specify the units for the variable, as it is stored in the raw data file.
- **Linear scaling:** Specify a linear conversion type to rescale available data, if needed. Variables that are already in any of the supported physical units do not need to be rescaled.
- **Output unit:** Enter the output units (physical units after conversion). The following *A* and *B* values must be such that the input variable is converted into the selected output unit.
- **Gain value:** Enter the gain for the *Gain-Offset* conversion.
- **Offset value:** Enter the offset for the *Gain-Offset* conversion.
- **Nominal time lag:** Enter the expected (nominal) time lag of non-anemometric variables, with respect to the reference anemometer, where applicable. Time lags should be specified at least for gas concentrations and can be estimated based on instrument separation (open path) or the intake tube and flow rate (closed path).
- **Minimum time lag:** Enter the minimum plausible time lag for the current variable, with respect to the sonic anemometer.
- **Maximum time lag:** Enter the minimum plausible time lag for the current variable, with respect to the sonic anemometer.

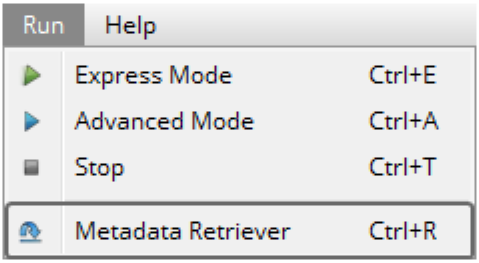
More information on the metadata may be required in the **Raw File Settings** dialog:


- **Field separator character:** Specify the character that separates individual values within the same sample in the raw files (for ASCII formats only).
- **Number of header rows:** Enter the number of rows in the header of the file, if present. In most cases, the software will be able to filter away individual text lines that do not comply with the description provided here. Therefore, most files with a variable number of header lines are supported.

The Metadata file will be saved automatically. After completing it, the Basic Settings tab will become active, and you can proceed with the project.

# Metadata Retriever Tool

Under the **Run** menu in the main menu bar, the **Metadata retriever** tool is accessible.




This tool is only available when the selected file type is LI-COR GHG. The tool is intended to extract information from all ".metadata" files included in the GHG dataset, and collect them into a unique file that can:

- Be provided to EddyPro® as a **Dynamic metadata file**, possibly after making changes to account for information that was not updated during data collection;
- Be used to analyze evolution of site (canopy height, roughness length, etc.) and setup (anemometer height, sensors separation, etc.) parameters.

The **Metadata retriever** is by all means a "run mode." If you click on the **Metadata retriever** button, EddyPro will start processing the selected dataset. However, all settings entered in the GUI will be ignored (except for those that are needed to identify the dataset, i.e., the raw data directory and the start/end dates) and EddyPro will simply unzip all GHG archives, retrieve the metadata contained in them and output them in a corresponding metadata file.

## When to Use This Tool?

The **Metadata retriever** tool is useful, for example, if you are aware that the metadata files in the GHG dataset contain errors or were not updated at the proper time. In this scenario, using GHG files with "embedded metadata" is not a viable option, because (some) embedded files are corrupted or include incorrect data. Thus, you need to bypass them using the "alternative metadata" file. However, if you still need to account for time-dependent site/setup parameters, you need to use a dynamic metadata file: the latter file can be created by first running the Metadata retriever and then manually (e.g., in a text editor or spreadsheet program) adjusting the wrong parameters, paying attention to only modify the numbers, and not the format of the timestamp or the spellings in the header lines.

### How to Use This Tool

Use a retrieved metadata file in the same way you would use an Dynamic metadata file. See "Time-varying (Dynamic) Metadata" on page 6-5.

## Basic Settings

During a data processing session, you will use the **Basic Settings** page to specify preferences for your project. For all projects, you enter the **Basic Settings** page after completing all required fields in the **Project Creation** page and clicking on the button.


> **Note:** Can't get to the **Basic Settings** page? EddyPro® will only let you advance from one page to the next if all required fields have been completed. View EddyPro Messages (**View > EddyPro Messages**) for more guidance.

To use the **Basic Settings** page:

1. Enter the **Raw data directory** that includes the raw data files. If files are in subfolders, select the **Search in subfolders** check box.
2. (optional) If you wish to process a subset of the data, check the "**Select a subperiod**" box, specify the **Starting date of dataset**, and **Ending date of dataset**. These fields are optional and only need to be manipulated if you do not want to process all the data in the raw data directory. If in doubt, ensure that the date range encompasses your entire dataset.
3. For ASCII, Binary, TOB1, or SLT files only, EddyPro requires you to enter the raw file name format. Follow the steps in the software to enter the raw file name correctly.
4. In the **Output directory** field, enter the directory where you want your output files to be placed.
5. Enter an **Output ID**. This will be appended to the file name of each output file.

6. Set the **Missing samples allowance**. If the number of missing samples in a file exceeds the threshold, the file will be ignored by EddyPro.
7. Select variables that you want to include in the flux computation project in the **Select Items for Flux Computation** section. If your raw files contain multiple columns for a variable (e.g., $CO_2$), specify which column to use.
8. Configure the **Flags** settings.
9. Save the project.
10. To process the data immediately, click 

. To process the data with advanced settings, click 

and configure the Advanced Settings. See "Using Advanced Settings: Processing Options" on page 4-29

The **Select Items for Flux Computation** section is used to choose which variables are used to calculate fluxes, from those available in the raw files. Raw files may contain redundant measurements, such as two or more readings for the same gas concentration, temperatures or pressure, as well as wind data from more than one anemometer. However, EddyPro only uses one reading of each sensitive variable for each processing project. For example, only one $CO_2$ concentration reading can be used to calculate $CO_2$ fluxes.

The **Flags** section is used to configure flags. Each column of the raw data file that was not tagged as “to be ignored” can be used as a mask to filter out individual high frequency records. Up to ten flags can be specified.

**Note:** An entire record (that is, all variables measured at a certain time instant, one line of raw data) is eliminated any time a flag variable does not comply its quality criterion.

## Using Biomet Data

EddyPro® 4 allows you to import and use biomet measurements for improved flux computation and other purposes. Biomet measurements include meteorological as well as ecological (e.g., soil and vegetation) measurements. These data are typically sampled at lower rates than the eddy covariance data (e.g., once per second) and averaged over longer time periods (e.g., 1 to 30 minutes). Traditionally, biomet data – collected by means of a datalogger - are stored in one or more files, distinct from “high-frequency” eddy data. However, the new LI-COR eddy covariance solution allows you to collect GHG files, the improved raw file format that bundles eddy data (and the corresponding metadata) together with biomet data (and, again, the corresponding metadata). The advantages are evident:

- Eddy covariance and biomet data (“high-frequency” and “low-frequency” data) corresponding to the same time span are stored together;
- Both eddy covariance and biomet data are documented in the paired metadata files, so the whole GHG bundle is a self-descriptive file that can be interpreted and processed also by someone who did not collect those data and does not have any information regarding the site where they were collected and the instruments deployed;
- Biomet data embedded in GHG files are automatically extracted, interpreted, filtered and used by EddyPro, along with the paired eddy data.

While processing eddy covariance data for each given time period (for example from 8:00 to 8:45, no matter the flux averaging interval), EddyPro retrieves all biomet data available, whose time stamp falls in that time slot. Biomet data are then used for two main purposes:

- Improve flux computation by using slow, accurate measurements of absolute meteorological quantities such as air temperature, pressure, relative humidity, etc.;
- Screen values and calculate averages of all available biomet measurements, on the same time scale as the flux averaging interval.

### Use of Biomet Data for Improved Flux Computation and Correction

EddyPro uses biomet data for the following purposes:

- Ambient temperature, pressure and relative humidity, if available, are used to replace the mean values of the same quantities as estimated from eddy covariance data or from site characteristics. For example, in the absence of a reliable ambient temperature reading in the eddy covariance data (as that provided, for example, by the LI-7700), mean ambient temperature is estimated using sonic temperature, corrected for crosswind and humidity effects. However, absolute sonic temperature may be inaccurate (while its fluctuations, used for calculating sensible heat fluxes, are typically accurately captured), thereby biasing all results that make use of mean ambient temperature (e.g., the WPL correction). If ambient temperature is available in the biomet data file, this can be averaged over the selected flux averaging interval and used directly for improved flux computations/corrections. Similar considerations can be done for the absolute water content of ambient air as derived from eddy covariance data, or for ambient pressure as assumed from site altitude;

- Data of global radiation and long-wave incoming radiation can be used in the "multiple regression" version of the off-season uptake correction (Burba et al., 2008);
- Data of photosynthetically active radiation (PAR, also called PPFD, photosynthetic photon flux density) can be used to assess day and night-time radiation loading on the surface of the instrument, to apply the appropriate coefficients and modelization of the instrument surface temperature in the off-season uptake correction.

> **Note:** Before using biomet data, EddyPro screens them for quality (checks that values are within physically plausible ranges) and calculates averages over the appropriate time scale. If the resulting average values are physically implausible, EddyPro automatically switches to classic eddy covariance data-based calculations.

### Averaging Biomet Data for Further Analysis

Besides using some biomet variables for flux computation and refinement, EddyPro processes all available biomet measurements by doing the following:

- Screening individual measurements and excluding outranged values;
- Automatically converting units to conform with EddyPro standard units;
- Averaging all good measurements over the time range defined by the current time averaging period;
- Outputting average biomet values in a separate file, using the same conventions and formats as all other EddyPro output files, so as to be readily processed and merged, for example, with the "full output" file for further analysis.

### Supported Biomet File Formats

EddyPro® 4 supports biomet data in two main formats: embedded in compressed GHG eddy covariance data files and as external text files. These are described in some detail:

### Biomet Data Files Embedded in GHG Files

The preferred, easiest, and most robust system to store and process biomet data is to collect them with LI-COR biomet station. When collected through the LI-7550 interface box, biomet data are stored in an ASCII, tab-separated file in a format that closely resembles that of the EddyPro data files, featuring a preamble and a header with variable names and units. This biomet file, identified by the suffix `-biomet.data`, comes with a paired `-biomet.metadata` file, which describes the format and, more importantly, the content of the file, with identification of the variables, their units, the sampling and averaging rates, etc. This structure closely replicates that of the eddy `.data` and `.metadata`. If the LI-7550 is collecting both eddy and biomet data, all four files are bundled together in a unique GHG file containing all data corresponding to every time period of the specified length, and the corresponding metadata.

You can download a sample GHG file including eddy and biomet files from the LI-COR web site. We suggest taking a few minutes to explore its content. Unzip the GHG file using, for example, 7-zip (after installation, right-click → 7zip → Extract here..) and open any of the files with a text editor. You will quickly figure out the format of both the ".data" and ".metadata" files and the organization of the content.

### External Biomet File(s)

If you don't have biomet data collected in the GHG format, or if you want to process data collected as text files, you can still do so by formatting your biomet file(s) as described below.

> **Note:** EddyPro 4 accepts biomet data stored in one or more (as many as you have) external files.

External biomet files must be formatted (outside EddyPro, for example using MS Excel) in such a way that EddyPro can interpret them without the need to specify anything in the EddyPro GUI. This means that extreme care must be given in correctly labeling variables, writing units, defining timestamps, etc.

Hereafter you can find detailed guidelines that should allow you to correctly format your biomet file(s):

- Files are formatted as ASCII, comma-separated files;
- Each line (terminated by an CR/LF control pair, the usual Windows line terminator) is a record of biomet measurements, identified by a timestamp;
- The file starts with a 2-line header:
  - In the first line, a label is associated to each data column (including the timestamp) to identify the variable. Please refer to this table for the naming convention;
  - In the second line, a label is associated to each data column (including the timestamp) to identify the unit of each measurement. Please refer to this table for the unit convention;
  - Capitalization in the header is irrelevant;
  - Each label in the first line of the header is composed of a variable identifier and a series of 3 numbers separated by underscores such as (for air temperature):

```
TA_1_1_1
```

Where, "`TA`" is the variable identifier. If you have multiple readings of the same variable, increase the first number first, until you get to 10:

```
TA_1_1_1, TA_2_1_1, ..., TA_10_1_1
```

If you have more than 10 readings of the same variable, increase the second number:

```
TA_10_1_1, TA_1_2_1, TA_2_2_1 ..., TA_10_2_1, ...
```

> **Note:** This naming convention is similar to that used by the GHG-Europe project. However, the policy specified in the GHG-Europe labeling system is not fully implemented here. In the GHG-Europe specification the three indices have specific meanings and are designed to unequivocally identify data coming from a specific sensor (a metadata file will be developed to assign meanings to the three numbers). We require you to stick to our labeling convention, which is designed to meet the GHG-Europe specification in the long term.

- Timestamps: Timestamps can occupy up to 7 (comma-separated) fields, that can appear anywhere in the file (i.e., not necessarily in the first columns). In the first header line, timestamp columns are identified by the labels:

```
TIMESTAMP_1, TIMESTAMP_2, ..., TIMESTAMP_7
```

In the second header line, the format of the timestamp is specified according to the following conventions:

**Table 4-1**. Timestamp formats for biomet data in EddyPro 4.

| Variable | EddyPro Label | Description of corresponding data |
|---|---|---|
| yyyy | year | 4-digit integer number |
| mm | month of year | 1- or 2-digit integer number, between 1 and 366 |
| ddd | day of year | 1-, 2- or 3-digit integer number, between 1 and 366 |
| dd | day of month | 1- or 2-digit integer number, between 1 and 12 |
| HH | hour of the day | 1- or 2-digit number between 0 and 23 |
| MM | minute of the hour | 1- or 2-digit integer number between 0 and 59 |

The following examples are of valid timestamp headers and data:

```
TIMESTAMP_1, ...
yyyy-mm-dd HHMM, ...
2012-04-05 0800, ...

TIMESTAMP_1, TiMeStAmP_2, ...
yyyy-mm-dd, HHMM, ...
2012-04-05, 0800, ...

TIMESTAMP_1, TIMESTAMP_2, Timestamp_3, ...
yyyy, ddd, HHMM, ...
2012, 96, 0800, ...

TIMESTAMP_1, Timestamp_2, TIMESTAMP_3, Timestamp_4, ...
 yyyy, ddd, HH, MM, ...
 2012, 096, 8, 00, ...
```

Labeling and units conventions for formatting external biomet files:

**Table 4-2**. Biomet variables supported by EddyPro 4

| Variable | EddyPro Label | EddyPro Units | How to Write Units | Other Supported Units |
|---|---|---|---|---|
| Air Temperature | Ta | K | K | C, cC, F, cF, cK |
| Atmospheric pressure | Pa | Pa | Pa | hPa, kPa, PSI, Torr, mmHg, Atm, Bar |
| Relative humidity | RH | % | % | # |
| Canopy temperature | Tc | K | K | C, cC, F, cF, cK |
| Air temperature below canopy | Tbc | K | K | C, cC, F, cF, cK |

**Table 4-2**. Biomet variables supported by EddyPro 4 (...continued)

| Variable | EddyPro Label | EddyPro Units | How to Write Units | Other Supported Units |
|---|---|---|---|---|
| Diffuse radiation | Rd | W $m^{-2}$ | W+1m-2 | J $s^{-1}$ $m^{-2}$ |
| Reflected radiation | Rr | W $m^{-2}$ | W+1m-2 | J $s^{-1}$ $m^{-2}$ |
| Global radiation | Rg | W $m^{-2}$ | W+1m-2 | J $s^{-1}$ $m^{-2}$ |
| Net radiation | Rn | W $m^{-2}$ | W+1m-2 | J $s^{-1}$ $m^{-2}$ |
| UVA radiation | R_uva | W $m^{-2}$ | W+1m-2 | J $s^{-1}$ $m^{-2}$ |
| UVB radiation | R_uvb | W $m^{-2}$ | W+1m-2 | J $s^{-1}$ $m^{-2}$ |
| Longwave incoming radiation | LWin | W $m^{-2}$ | W+1m-2 | J $s^{-1}$ $m^{-2}$ |
| Longwave outgoing radiation | LWout | W $m^{-2}$ | W+1m-2 | J $s^{-1}$ $m^{-2}$ |
| Shortwave incoming radiation | SWin | W $m^{-2}$ | W+1m-2 | J $s^{-1}$ $m^{-2}$ |
| Shortwave outgoing radiation | SWout | W $m^{-2}$ | W+1m-2 | J $s^{-1}$ $m^{-2}$ |
| Shortwave below canopy | SWbc | W $m^{-2}$ | W+1m-2 | J $s^{-1}$ $m^{-2}$ |
| Shortwave incoming diffuse | SWdif | W $m^{-2}$ | W+1m-2 | J $s^{-1}$ $m^{-2}$ |
| Photosynthetic photon flux density | PPFD | µmol $m^{-2}$ $s^{-1}$ | umol+1m-2s-1 | µE $m^{-2}$ $s^{-1}$ |
| Diffuse PPFD | PPFDd | µmol $m^{-2}$ $s^{-1}$ | umol+1m-2s-1 | µE $m^{-2}$ $s^{-1}$ |
| Reflected PPFD | PPFDr | µmol $m^{-2}$ $s^{-1}$ | umol+1m-2s-1 | µE $m^{-2}$ $s^{-1}$ |
| Below Canopy PPFD | PPFDbc | µmol $m^{-2}$ $s^{-1}$ | umol+1m-2s-1 | µE $m^{-2}$ $s^{-1}$ |
| Total precipitation | P | m | m | um, µm, mm, cm, km |
| Rain precipitation | P_rain | m | m | um, µm, mm, cm, km |
| Snow precipitation | P_snow | m | m | um, µm, mm, cm, km |
| Snow depth | SNOWd | m | m | um, µm, mm, cm, km |
| Maximum wind speed | MWS | m $s^{-1}$ | m+1m-1 | cm $s^{-1}$, km $h^{-1}$ |
| Wind direction | WD | deg. from N | degrees | - |

**Table 4-2**. Biomet variables supported by EddyPro 4 (...continued)

| **Variable** | **EddyPro Label** | **EddyPro Units** | **How to Write Units** | **Other Supported Units** |
|---|---|---|---|---|
| Bole temperature | Tbole | K | K | C, cC, F, cF, cK |
| SapFlow | SapFlow | $g\ h^{-1}$ | g+1h-1 | - |
| StemFlow | StemFlow | $g\ h^{-1}$ | g+1h-1 | - |
| Soil temperature | Ts | K | K | C, cC, F, cF, cK |
| Soil heat flux | SHF | $W\ m^{-2}$ | W+1m-2 | $J\ s^{-1}\ m^{-2}$ |
| Soil water content | SWC | $m^3\ m^{-3}$ | m+3m-3 | - |

# Using Advanced Settings

The **Advanced Settings** page provides a variety of options that make it possible to process the eddy covariance data with customized parameters.

> **Note:** The default settings in the Advanced Settings section correspond with the settings used by Express Mode, meaning that you can process a dataset in Advanced Mode without altering these settings and still compute reasonable results for most datasets.

Advanced settings are listed under four tabs, including:


- See "Using Advanced Settings: Processing Options" on page 4-29
- See "Advanced Settings: Statistical Analysis" on page 4-34
- See "Advanced Settings: Spectral Corrections" on page 4-31
- See "Advanced Settings: Output Files" on page 4-35


## Selecting Advanced Processing Options

In the Advanced Mode, EddyPro® provides several options for many processing steps. It also provides many optional output files. Here we provide suggestions about which processing options are suitable under certain circumstances. While we want to stress that there is no general consensus on the best choice for any given situation, and that often alternative options bring similar results, there are situations in which a better choice can be identified unambiguously. We warmly invite you to use the forum to comment on these recommendations and to discuss new ones.

### Wind speed measurement offsets

This information is specific to each anemometer. You may find it in your anemometer calibration certificate (note that this is unit-specific information), or you may assess the offsets on your own, e.g., by placing the anemometer in a closed box (zero wind conditions) and taking an average of the recorded wind speeds over an extended period of time. If you do have this information, just enter it and EddyPro will subtract these offsets from the wind components prior of any other operation.

### Angle of attack correction for wind components (Gill anemometers only)

The angle of attack correction, also known as head correction or flow distortion correction, is currently available in EddyPro only for post-mounted Gill

Instruments sonic anemometers with the same geometry as the R3 (including the R2, WindMaster™ and WindMaster™ Pro). The application of this correction is virtually independent (Taro Nakai, personal communication) from the firmware correction "applied to calibrate out the affects of the transducers and head framework" (cited from the R3/R3A User Manual, Gill Instruments Ltd.). Thus, the application of this correction is always recommended for R3-style Gill Instruments sonic anemometers. If you are aware of similar corrections available for other sonic models/manufacturers supported by EddyPro, please use the forum to point us to a bibliographic reference or even to source code for the correction!

### Axis rotation for tilt correction

Traditionally, anemometer tilt correction was compensated using either the double-rotation or triple-rotation schemes. Nowadays, *the triple-rotation scheme is no longer recommended* (e.g., Marc Aubinet, personal communication), but it is available in EddyPro for back-compatibility purposes.

The *double-rotation method* is recommended when the site is characterized by substantial homogeneity, flatness and isotropy. Under these conditions, often found on grassland sites, for example, it is safe to assume that local wind streamlines are parallel to the surface, and the double rotation scheme is a robust method to compensate the vertical misalignment of the anemometer.

Also, the *double-rotation method* is suggested when canopy height and roughness changes quickly, such as during the growing season in a crop field. In situations characterized by a complex or sloping topography or strong canopy dishomogeneity, the *planar fit method* is the preferred choice. EddyPro provides two implementations of the planar fit method. The one labeled *Planar fit* is the traditional one (e.g., Wiczak et al. 2001).

The second one, labeled *Planar Fit with no velocity bias* is a different implementation proposed by van Dijk et al. (2003). The latter method is based on the observation that the coefficient $b_0$ that is included in the first one is not a good estimator of the anemometer bias on the measurement of the vertical wind component. Thus, the authors propose a modified version, in which any bias of the anemometer is intended as preliminary compensated, from which it follows the constraint that coefficient $b_0$ must be zero (implying that if average $u$ and $v$ are zero, also average $w$ is zero). Choosing either implementation is up to you. We recommend reading the relevant literature to make an informed decision. Also, the number of wind sectors to use depends on the topography at the site and on the wind regimes.

In summary, here are our recommendations:

1. For flat, horizontal and uniform/isotropic and extended fetches, or for sites with fast changing canopy structure, use the "double rotation" method.
2. In all other conditions use either implementation of the planar fit method.
3. When the planar fit is used, adjust the number of wind sectors according to the topography of the site, the structure of the canopy, and the wind regimes.

### Turbulent fluctuations

No obvious recommendation can be made here. As a general observation, using a detrending method (either *linear detrending* or one of the *running mean* implementations) becomes more important with increasing length of the flux averaging interval, to prevent long-term trends not related to turbulence (e.g., at sunrise and sunset) from turning into artificial flux contributions. The block average method, while retaining the largest amount of low frequency content (thus including possible spurious effects of trends), is the only method that obeys the Reynolds decomposition rule, on which the eddy covariance formulation is based. If you select a long flux averaging interval (1 hour, 2 hours, etc), selecting a detrending method with the proper time constant is probably the best choice, to avoid strong overestimation of fluxes induced by relevant non-turbulent trends turning into flux contributions.

> **Note:** Selecting the option to perform low frequency range spectral corrections will partially compensate the differences induced by different detrending methods.

### Time lag compensation

Time lags should be always compensated, the only exception being the case of an open path analyzer located very close to an anemometer or overlapping with it (however, this configuration is not recommended due to the important flow distortion effects that result). *Constant* time lags means that the software always uses the same value, which is the nominal one entered for each variable and stored in the metadata file, or the one automatically calculated by EddyPro if the nominal is left to zero. A constant time lag could be used when measuring with a closed path gas analyzer, using a flow controller to impose a constant flow rate in the tube and when measuring only passive gases (e.g., no water vapor), or also water vapor if the humidity in the sampling line is constantly kept very low, e.g., by means of an active heating system. For open path systems with detectable (>10-20 cm) distance between the sampling volume of the gas analyzer and of the anemometer, a constant time lag is not recommended, because the actual time lag will depend on the wind direction. Using a constant time lag results in a faster program execution.

With the *Covariance Maximization* option, the circular correlation technique is used to detect the time lag within a plausible window defined by the minimum and maximum time lags selected for each variable. With the *Covariance maximization with default* option, the same procedure is applied, however, if a maximum is not attained within the window (i.e., the covariance maximum is found at either endpoint of the time lag window), then the nominal value is used. If the time lag window (min-max) is well defined, the method *Covariance maximization with default* is probably the best option. However, if the time lag window is not properly defined (i.e., it is too narrow), the consequence of using this method can be flux underestimation. The simple *Covariance Maximization* is safer in these conditions, but in turn it may lead to flux overestimations when the time lag window is too broad and fluxes are small.

Both options, however, are unsuitable for water vapor in typical closed path set ups. In this case, the *Automatic time lag optimization* option is by far the most appropriate, as default time lags as well as plausibility windows are optimized as a function of relative humidity. Selecting this option, time lags for all other gases will also be optimized (with no consideration of relative humidity) by EddyPro. The downside of using this option is a longer program execution time.

### Compensation of density fluctuations

Native measurement of most gas analyzers is gas density, i.e., absolute number of molecules in a known volume of air, that needs to be transformed into a mixing ratio measurement (i.e., mass of gas per mass of air). The air density is used in this transformation. However, air density fluctuates on account of temperature and pressure fluctuations and depending on fluctuations in content of trace gases, notably water vapor. Such fluctuations need to be compensated in order to get a proper mixing ratio measurement, no matter if you are using an open or a closed path instrument.

However, the compensation strategy differs for the two different kinds of instruments. For open path systems, Webb et al. (1980, henceforth WPL) defined an a posteriori formulation to correct preliminary flux estimates. This formulation has been proven through theoretical and experimental validations. Thus, whenever open path analyzers are used, we recommend selecting *Webb et al. 1980 (open-path) / Ibrom et al. 2007 (closed-path)*. For closed path systems, instead, the correction can be applied a posteriori, using a revision of the WPL formulation specified by Ibrom et al. (2007b) (select the same option suggested for open path in this case), or a priori, by converting raw, high-frequency measurements from molar densities to mixing ratios (select the option *Use/convert to mixing ratio if possible (Burba et al. 2012)*. For closed path systems the two methods attain identical results, as demonstrated by Ibrom et al. (2007b) and Burba et al. (2012).

The main difference between the two options for closed path systems is that the a priori solution can only be applied if (a) raw data are already expressed as mixing ratios (e.g., LI-7200) or (b) raw data are expressed as molar densities and all necessary high frequency measurements are available to perform the point-by-point conversion (i.e., temperature, pressure and water vapor concentration inside the instrument cell). If any of these measurements are missing, the a priori method cannot be applied. On the other hand, the a posteriori method can be applied even if some data are missing, although in this case the density fluctuations will not be fully compensated.

**Note:** The a posteriori formulation implemented in EddyPro differs from the one provided in Ibrom et al. (2007b) because it also includes the temperature and pressure terms neglected in that paper. This allows the method to be applied for closed path systems featuring a short sampling line, where it is not safe to assume effective attenuation of ambient temperature and pressure fluctuations.

**Note:** If the a priori method is selected but any necessary raw data are missing for any given flux averaging period, EddyPro automatically switches to the a posteriori method.

In summary, here are our recommendations:

1. For open path eddy covariance systems, always select the option *Webb et al. 1980 (open-path) / Ibrom et al. 2007 (closed-path)*.
2. For closed path eddy covariance systems where raw data are available as accurate fast mixing ratios (e.g. LI-7200), always select the option *Use/convert to mixing ratio, if possible (Burba et al. 2012)*.

3. For closed path eddy covariance systems where raw data are available as accurate fast mole fractions and water vapor mole fractions are also available in the raw files, always select the option *Use/convert to mixing ratio, if possible (Burba et al. 2012)*.
4. For closed path eddy covariance systems where raw data are available as molar densities and water vapor mole fractions, and fast cell temperature and pressure are also available in the raw files, select either *Use/convert to mixing ratio, if possible (Burba et al. 2012)* or *Webb et al. 1980 (open-path) / Ibrom et al. 2007 (closed-path)*.
5. For closed path eddy covariance systems where raw data are available as molar densities, but either water vapor mole fractions or fast cell temperature or fast cell pressure is missing in the raw files, select *Webb et al. 1980 (open-path) / Ibrom et al. 2007 (closed-path)*.

### Add instrument sensible heat components (LI-7500)

Select this option if your concentration measurements were performed with an open path LI-7500 instrument, or with an LI-7500A used in the *summer* configuration and your data were collected in a very cold environment. This correction becomes increasingly important as the typical temperature at a site gets lower. You can customize the regression parameters if specific experiments have been conducted to optimize the correction for your instrument unit and system configuration. Otherwise, we suggest using default parameters as retrievable with the *Restore values as from Burba et al. (2008)*.

### Tapering window

Tapering is a data conditioning procedure necessary before the Fourier transform of a finite, non-periodic time series can be taken. Several tampering windows are available. Kaimal and Kristensen (1991) suggested the selection of the *Hamming* window in the context of environmental turbulence.

> **Note:** The differences introduced by different windows are minor in the calculated spectra, while there is no effect on fluxes, which are calculated before applying the tapering procedure.

### Quality check

The different flagging systems available are based on the results of the same quality tests, namely the steady state test and the well-developed turbulence test (e.g., Foken et al., 2004). The two tests provide individual flags (that can be output separately by selecting the option *Details of steady state and* *developed turbulence tests* in the **Output Files** page), which can be combined in different ways. The option *Mauder and Foken (2004) (0-1-2 system)* provides the flag "0" for high quality fluxes, "1" for intermediate quality fluxes and "2" for poor quality fluxes. This system is suitable for selecting flux results complying with international practices (e.g., FLUXNET). The other 2 systems provide finer flux flagging for more in depth analysis. Thus, the choice depends on your intentions.

> **Note:** This option has no impact on calculated fluxes.

### Footprint estimation

Three one dimensional (crosswind-integrated) footprint estimation methods are available, which can provide rather different results. The methods of Kormann and Meixner (2001) and Hsieh et al. (2000) provide closer results to each other, compared to the method of Kljun et al. (2004). However, this is partially a consequence of the similarities in the formulation and starting assumptions of the two methods compared to the third one. We do not endorse either method. Read the corresponding literature to select the most appropriate method according to your site conditions.

> **Note:** The method of Kljun et al. (2004) is not defined for certain atmospheric (stability, turbulence) conditions. In such situations, EddyPro switches to the method of Kormann and Meixner (2001) and duly informs you about it in the results files.

### Low frequency spectral correction

We suggest applying this correction in all cases.

### High frequency spectral correction

We suggest applying one of the high frequency correction methods in any case. Here we summarize our recommendations on which method to select in different conditions:

1. Open path systems: any method is valid, however, the methods of *Moncrieff et al. (1997) – Fully analytic* and *Massman (2000, 2001) - Fully analytic* allow faster data processing and can be applied to datasets of any length (even just 1 raw file), because the corrections do not rely on the in situ assessment of the EC system filtering properties.

2. Closed path systems with very short (e.g., 50 cm) and/or heated and insulated sampling line (to keep relative humidity very low) and without fine-mesh inlet filters (e.g., 1 μm mesh): in these conditions any method is valid. Similar to case (1), the methods of *Moncrieff et al. (1997) – Fully analytic* and *Massman (2000, 2001) - Fully analytic* provide faster data processing and can be applied to datasets of any length. The other three methods potentially provide a better representation of attenuations induced by the EC system and are thus more suited, but they require a dataset large enough (e.g., 1 month) for the assessment of the system cut-off frequency.
3. Closed path systems with longer sampling lines (> 1m) or featuring fine mesh inlet filters, but still heated and insulated (to keep relative humidity very low). In these cases, the methods *Horst (1997) – Analytic with in situ parameterization*, *Ibrom et al. (2007) – in situ/analytic* and *Fratini et al. (2012) – in situ/analytic* are more suitable because the other two methods do not account for the effects of inlet filters and potentially underestimate attenuations induced by the passage in the sampling line.
4. Closed path systems with non-heated/insulated sampling lines of any length, with or without inlet filters: if water vapor is of interest, in these conditions we suggest applying a correction of *Fratini et al. (2012) – in situ/analytic* or *Ibrom et al. (2007) – in situ/analytic* because these are designed to account for effects of relative humidity on water vapor in the sampling line. If water vapor is not of interest, the method *Horst (1997) – Analytic with in situ parameterization* is also appropriate.

### Correction for instrument separations

This additional spectra correction component is only available when the method of Ibrom et al. (2007) is selected. The reason is that the other two high frequency correction methods available intrinsically account for the instrument separation. The method of Ibrom et al. (2007) is mostly aimed at correcting for the attenuation of power spectra in closed path systems. Normally, the inlet of the sampling line of a closed path instrument is placed so close to the sampling volume of the anemometer, that one may consider the "instrument separation" not influential. However, for the sake of generality and because in EddyPro the method can be used also for open path systems, the option is provided to correct also for the instrument separations, according to the method proposed by Horst and Lenschow (2009). This method is available in two configurations:

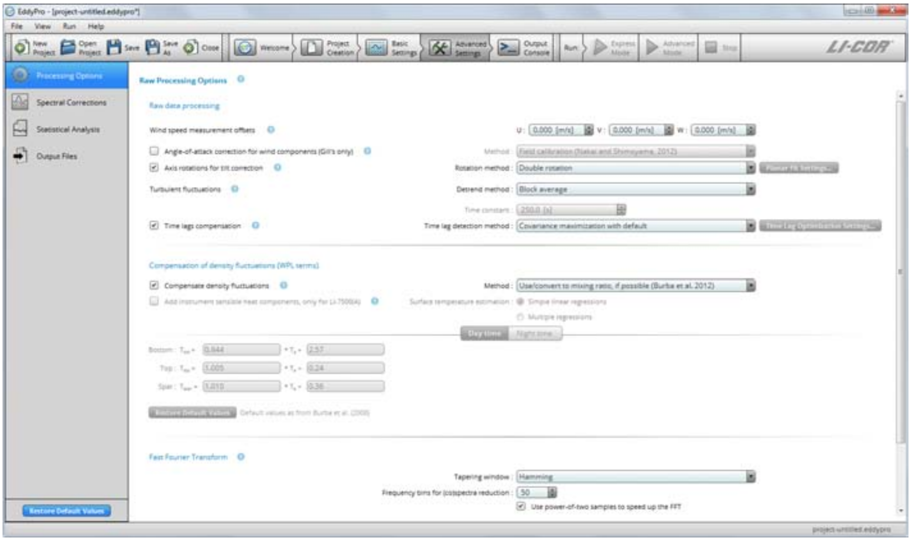
1. If you compensate time lags through a method that uses the covariance maximization procedure, this implicitly takes care of the along-wind

instruments separation, so you may select the option *Horst and Lenschow (2009), only crosswind and vertical*.

2. In all other cases or in any case if the instruments are separated by a relevant distance (depending on the height above the ground) select the option *Horst and Lenschow (2009), along-wind, crosswind and vertical*.

## Using Advanced Settings: Processing Options

> **Note:** The default settings in this section correspond with the settings used by Express Mode, meaning that you can process a dataset in Advanced Mode without altering these settings, and still compute reasonable results for most datasets.




The **Processing Options** tab includes the following settings.

Raw Data Processing

- Wind speed measurement offsets
- Angle of attack correction
- Axis rotation for tilt correction
- Detrending method
- Time lag compensation

Compensation for Density Fluctuations

- WPL
- Mixing ratio

Instrument related heat components

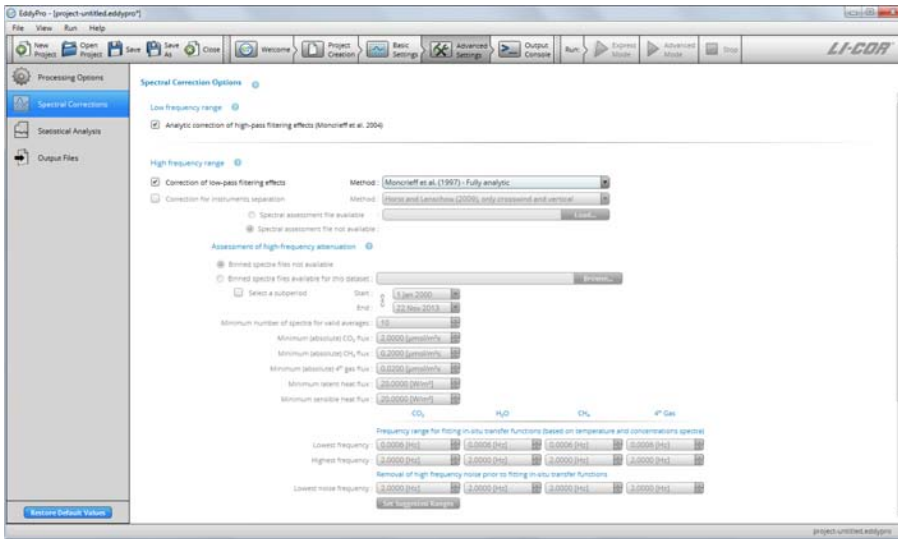
Fast Fourier Transform

Other Options

- Quality check
- Footprint estimation

## Advanced Settings: Spectral Corrections

> **Note:** The default settings in this section correspond with the settings used by Express Mode, meaning that you can process a dataset in Advanced Mode without altering these settings, and still compute reasonable results for most datasets.




Spectral corrections are needed to correct flux estimates for low and high frequency losses due to the instrumental setup, intrinsic sampling limits of the instruments, and some data processing choices. An overview and some details about the spectral correction methods available in EddyPro® are provided here. This tutorial focuses on the items available to you, to select and tune the correction procedure.

The first choice is whether to correct for the high-pass filtering losses implied by the fact that fluxes are calculated on a finite time period, and possibly by the detrending operation (e.g., linear detrending, running mean). Select *Analytic correction for high-pass filtering effects (Moncrieff et al., 2004)* to instruct EddyPro to apply this correction, which affects the low frequency range of the flux cospectra.

The second choice regards the application of a correction for the low-pass filtering losses, mainly related to intrinsic instrumental limits (finite path lengths and time responses) and to the actual instruments deployment, such as the separation between anemometer and gas analyzer, the height above the underlying canopy or surface, the deployment of a sampling line for closed path analyzer and the way this is conditioned (e.g., insulated or heated).

Five methods are available:

- The analytic method of Moncrieff et al. (1997),
- The analytic method of Massman (2000, 2001),
- The semi-analytic method of Horst (1997)
- The in situ method of Ibrom et al. (2007a), and
- The in situ method of Fratini et al. (2012).

The methods by Moncrieff et al. (1997) and by Massman (2000, 2001) model all major sources of flux attenuation by means of a mathematical formulation. When using this method, no further information is needed, so all of the fields in this page are deactivated. These methods are suggested for open path EC systems or for closed path systems if the sampling line is short and heated. The reason is that this method may seriously underestimate the attenuation (and hence the correction) - notably for water vapor - when the sampling line is long (and the attenuation is strong) and not heated because of the dependency of attenuation of $H_2O$ on relative humidity, which has been clearly recognized in recent research.

If the methods by Horst (1997), Ibrom et al. (2007), or Fratini et al. (2012) are selected, the “Assessment of high-frequency attenuation” section activates. In fact, all three methods require the preliminary, in situ assessment of the attenuation of scalar spectra. Such attenuation is quantified by determining the system low-pass transfer function. The procedure makes use of the temperature spectrum as a proxy for the unattenuated gas spectra (thereby assuming similarity of turbulent spectra among all gases and the air temperature) and fits a prescribed transfer function to the ratio of the gas to the temperature spectra. The assumed transfer function is that of the so-called Infinite Impulse Response (IIR) filter (Ibrom et al., 2007a). However, this procedure cannot be applied on individual spectra, which may be affected by noise or characteristics of the local turbulence. Instead, ensemble spectra are calculated for all variables involved (temperature and gas concentrations) using all available “high-quality” spectra and a least squared minimization is then used to fit the transfer function to the ratio of ensemble gas spectra to ensemble temperature spectra. This is what we call the “spectral assessment”. In this phase you need to instruct EddyPro on how to select the spectra to be used in this procedure.

To start with, select the starting and ending dates of the period to be used for the spectral assessment. The larger the time periods, the longer the procedure will take, but the more accurate the results will be. However, pay attention to select a period in which your instrumental setup did not undergo major modifications. You are going to average all spectra for this period to assess to what extent your instrumental configuration attenuated them compared to atmospheric conditions, thus you need to make sure that all spectra are representative of the same configuration.

The minimum number of spectra for valid ensemble averages is set to make sure that a sufficient amount of spectra are averaged, to level out noise and local turbulence characteristics, and highlight the main spectra features. Again, a large number here will ensure a more accurate assessment, but it will also require a longer period of time, because not all spectra are going to be valid and take part in the averaging procedure.

In fact, minimum flux values must also be set, to discriminate “good spectra.” A sufficient flux ensures that developed turbulent conditions are met and that spectra are well characterized in the inertial and dissipation ranges. Minimum water vapor minimum are indirectly set by specifying a lower limit for the latent heat flux. Similarly, good quality temperature spectra will be achieved when sensible heat flux will be above a certain threshold that you can specify.

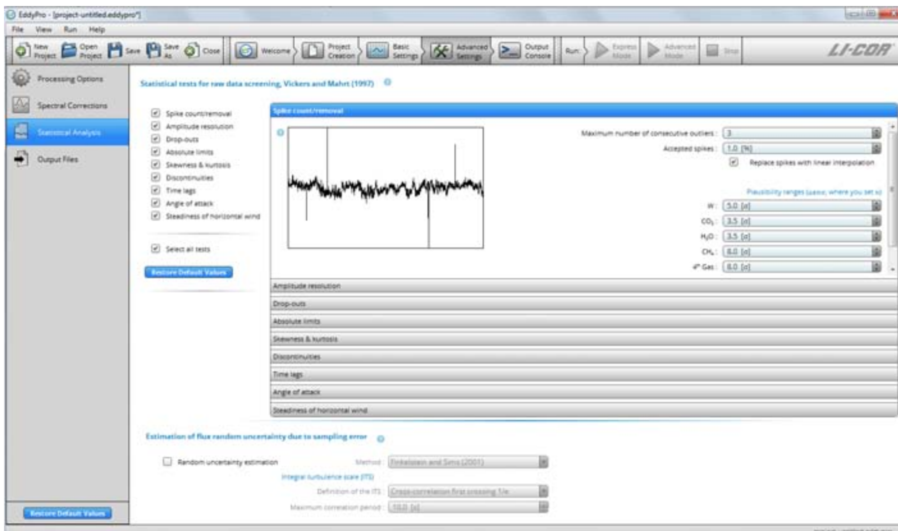
The **Spectral Corrections** tab includes the following options:

- See "Low frequency range" on page 2-32
- See "High frequency range" on page 2-33
- See "Assessment of high-frequency attenuation" on page 2-34

## Advanced Settings: Statistical Analysis

### Statistical Analysis

> **Note:** The default settings in this section correspond with the settings used by Express Mode, meaning that you can process a dataset in Advanced Mode without altering these settings, and still compute reasonable results for most datasets.

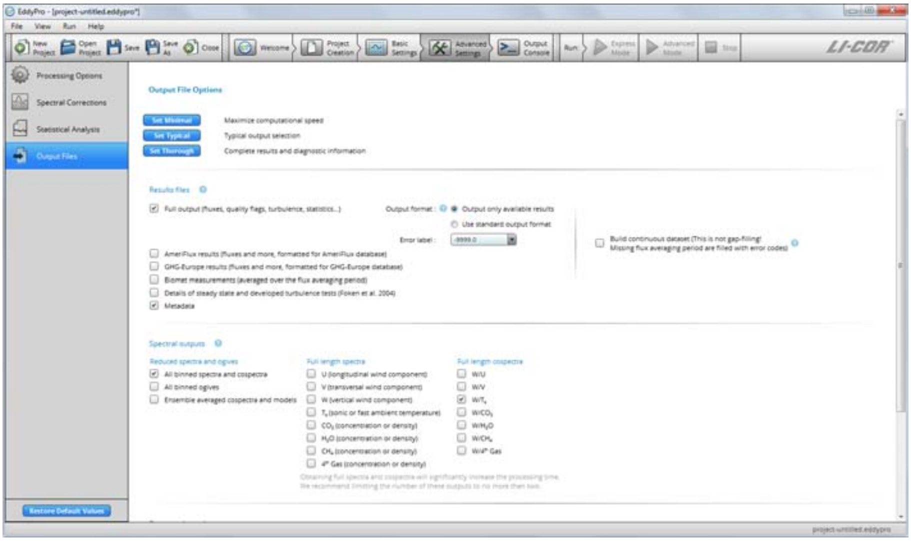



The **Statistical Tests** tab includes all tests recommended by Vickers and Mahrt (1997).

- See "Spike Removal and Spike Test" on page 7-9
- See "Amplitude Resolution Test" on page 7-11
- See "Drop-outs Test" on page 7-12
- See "Absolute Limits" on page 7-13
- See "Skewness and Kurtosis" on page 7-13
- See "Discontinuities" on page 7-14
- See "Time Lags" on page 7-15
- See "Angle of Attack" on page 7-15
- See "Steadiness of Horizontal Wind" on page 7-16

## Advanced Settings: Output Files

> **Note:** To keep processing time to a minimum, select only the output files that are needed. Selecting *full spectra* and *cospectra* will increase processing time significantly. Therefore, we recommend that you limit the number of these outputs to less than two.




The **Output Files** tab is used to tell EddyPro® which files to write upon completing the project. Here, there is a great deal of flexibility, depending on your research needs. Settings include:

- See "Results files and options" on page 2-40
- See "Spectral outputs" on page 2-41
- See "Processed raw data" on page 2-41

# Error Codes

In spite of our and your best efforts, sometimes things go awry. When things go awry in EddyPro®, there are a number of notifications that will indicate a problem has occurred. These are indicated in the output console and by error dialog boxes. There are a few scenarios in which an error message is likely.

- An improperly entered **Raw File Name Format** will result in one of the following error message in the output console:
  - fatal error(8): temporary file "flist.tmp" is empty.
  - no files with selected extension were found in the data folder.
  - *Program execution aborted*
  - fatal error(16): no file matches file name prototype.
  - *Program execution aborted*
  - fatal error(20): incorrect prototype for raw file names. please check "Raw file name format" entry
  - *Program execution aborted*

To correct this problem, go to the Project Page and correct the Raw File Name Format entry.

- The following error indicates that the alternative metadata file could not be found in the specified directory:
  - error(7): error while opening INI-format file.
  - fatal error(22): bypass metadata file not found.
  - *Program execution aborted*

Check the metadata file directory and file name. Correct them and try again.

- The following indicate that a problem occurred while opening file:
  - Fortran runtime error: Index '80001' of dimension 1 of array 'filebody' above upper bound of 80000
  - Total No. of samples in file(s): 11461
  - Number of samples for current period: 11461
  - warning(10008): left samples (if any) not enough for an averaging period. Skipping to next file(s).
  - Either of these errors may occur if the Metadata file information has errors.

Under the **Raw File Description**, check the **Number of header rows** and the **Label of data records** entries to be sure they are correct. Delete the Label of data records entry and try again.

# 5 Output Files Overview

After clicking "Run," EddyPro® will generate some temporary intermediate files and compute fluxes based on the information provided in the data and metadata. These files are stored in folders and subfolders in the "Output Directory" you assigned in the Project Page.

In these folders and files, you will find summary results. Each line in these files refers to a flux averaging period and starts with the corresponding raw file name and the timestamp of *the end* of the averaging period. File names are created with the **Output ID** that you entered in the Project Page.

> **Note:** Each run produces output files in the assigned directory. The output files are marked with the date and time of the run in the file name.

## Time Structure of Output Files

A fundamental concept behind the implementation of EddyPro is that you are attempting to obtain a dataset with a regular time step, which is the flux averaging period. To this aim, once EddyPro has read the names of all raw files to be processed, it will detect the first and the last one (in a chronological sense) and create a time structure (a timeline) where the beginning is given by the timestamp of the first file and the time step is given by the flux averaging period. Results of EddyPro calculations for each flux averaging period will be associated to the closest time step in the time structure, with the condition that the difference between the actual timestamp of the current averaging period and the closest timestamp in the time structure is less than half the averaging period.

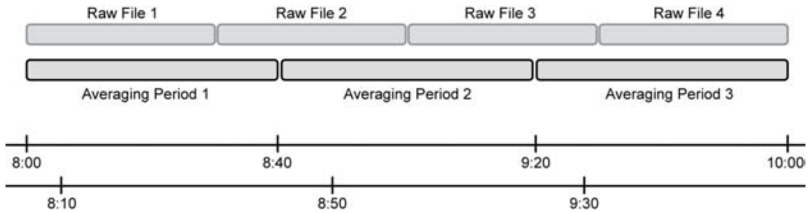



*Figure 5-1. Timelines representing the handling of averaging periods by EddyPro.*

Consider the figure above. Two timelines are represented in the bottom part of the figure. They represent two different time structures, both of which have the same time step (40 minutes) but with an offset of 10 minutes between the two. For example, they might have been established with EddyPro by setting a flux averaging period of 40 minutes (in both cases) but having found a first chronological raw file with a timestamp such as 04:00 (upper case) and 4:10 (bottom case). In EddyPro, both time series would be filled with results for the averaging periods sketched on the upper part of the figure: results would be the same for the 08:00/08:10, 08:40/08:50 and 09:20/09:30 pairs. Some trials with the software will help you gain a better understanding of this feature of EddyPro. Currently, there is no option to force EddyPro to consider files timestamp as the actual timeline.

## Common Features of EddyPro Output Files

EddyPro output results are provided in comma separated ASCII data files. Based on certain processing options, EddyPro may force you to output certain files. This is the case, for instance, with the high-frequency spectral corrections. If any of the available in-situ methods are selected, EddyPro will automatically select certain spectral outputs and deactivate the corresponding entry, so that you cannot unselect them. This is because those outputs are essential to the spectral assessment and correction procedure.

All text is written without spaces, except where not applicable; spaces are replaced by "_" (underscores). Files may have a header that briefly describes the content of the file. Then the data columns begin, with a first line providing the labels and, in some cases, a second line providing units.

The names of output files produced by EddyPro follow the convention:

`eddypro_projID_filecontent_`*`date_time`*`.csv` where EddyProis a constant string, projID is the Output ID entered in the Project Page, `filecontent` gives a short description of the content of the file, and `date` and `time` are refer to the date and time that the data were processed.

All EddyPro results begin with the same three fields: the name of the raw file for which results are provided (or the name of the first file in case results come from several adjacent raw files), and the date and time of the *end* of the averaging period for the current result record. For example:

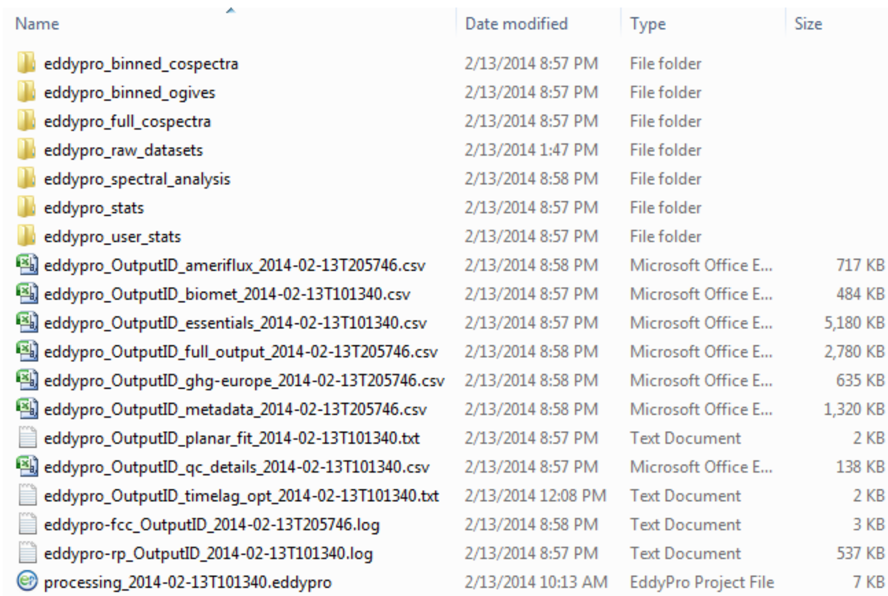
```
2011-01-29T130000_mysite.ghg,2011-01-29,13:30,
```

is the beginning of an output record referring to a dataset that ends at 13:30 of 29/01/2011, and is contained in the raw file `2011-01-29T130000_mysite.ghg` (or a set of files of which this is the first one).

An exception to this structure is necessary for output files in third-parties formats, such as FLUXNET and AmeriFlux, that require a different specification of results timestamps.

# List of Outputs

This section provides a summary of the output files generated by EddyPro. Some of the files described below may not be included in your output folder, depending upon the files specified in the Output Files tab (see "Output Files" on page 2-39). A full set of output files is shown in Figure 5-2 below.



| Name | Date modified | Type | Size |
|---|---|---|---|
| eddypro_binned_cospectra | 2/13/2014 8:57 PM | File folder | |
| eddypro_binned_ogives | 2/13/2014 8:57 PM | File folder | |
| eddypro_full_cospectra | 2/13/2014 8:57 PM | File folder | |
| eddypro_raw_datasets | 2/13/2014 1:47 PM | File folder | |
| eddypro_spectral_analysis | 2/13/2014 8:58 PM | File folder | |
| eddypro_stats | 2/13/2014 8:57 PM | File folder | |
| eddypro_user_stats | 2/13/2014 8:57 PM | File folder | |
| eddypro_OutputID_ameriflux_2014-02-13T205746.csv | 2/13/2014 8:58 PM | Microsoft Office E... | 717 KB |
| eddypro_OutputID_biomet_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 484 KB |
| eddypro_OutputID_essentials_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 5,180 KB |
| eddypro_OutputID_full_output_2014-02-13T205746.csv | 2/13/2014 8:58 PM | Microsoft Office E... | 2,780 KB |
| eddypro_OutputID_ghg-europe_2014-02-13T205746.csv | 2/13/2014 8:58 PM | Microsoft Office E... | 635 KB |
| eddypro_OutputID_metadata_2014-02-13T205746.csv | 2/13/2014 8:58 PM | Microsoft Office E... | 1,320 KB |
| eddypro_OutputID_planar_fit_2014-02-13T101340.txt | 2/13/2014 8:57 PM | Text Document | 2 KB |
| eddypro_OutputID_qc_details_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 138 KB |
| eddypro_OutputID_timelag_opt_2014-02-13T101340.txt | 2/13/2014 12:08 PM | Text Document | 2 KB |
| eddypro-fcc_OutputID_2014-02-13T205746.log | 2/13/2014 8:58 PM | Text Document | 3 KB |
| eddypro-rp_OutputID_2014-02-13T101340.log | 2/13/2014 8:57 PM | Text Document | 537 KB |
| processing_2014-02-13T101340.eddypro | 2/13/2014 10:13 AM | EddyPro Project File | 7 KB |

*Figure 5-2. Output folder created by EddyPro when all outputs are selected. In this example, the Output ID was EddyPro_Help.*

Table 5-1 below describes the files created by EddyPro.

**Table 5-1**. Typical outputs from an EddyPro run.

| File/Folder Name | Description |
|---|---|
| eddypro_binned_cospectra | Folder containing binned cospectra files (see "Binned Cospectra Outputs" on page 5-6). |
| eddypro_binned_ogives | Folder containing binned ogives files (see "Binned Ogives" on page 5-6). |
| eddypro_full_cospectra | Folder containing full cospectra files (see "Full Cospectra" on page 5-7). |

**Table 5-1**. Typical outputs from an EddyPro run. (...continued)

| File/Folder Name | Description |
|---|---|
| eddypro_raw_datasets | Folder containing raw datasets (see "Raw Datasets" on page 5-7). |
| eddypro_spectral_analysis | Folder containing spectral analysis files (see "Spectral Analysis" on page 5-8). |
| eddypro_stats | Folder containing statical output files (see "Stats" on page 5-8). |
| eddypro_user_stats | Folder containing user statistics files. |
| eddypro_OutputID_ameriflux_yyyy-mm-ddThhmmss.csv[1] | Output formatted for submission to the Ameriflux database. |
| eddypro_OutputID_essentials_yyyy-mm-ddThhmmss.csv | Intermediate flux results that have not been corrected. EddyPro uses this file when you want to quickly reprocess data. See "Using Results from Previous Runs" on page 6-24 for more information. |
| **eddypro_OutputID_full_output_yyyy-mm-ddThhmmss.csv** | **Final flux results.** |
| eddypro_OutputID_ghg-europe_yyyy-mm-ddThhmmss.csv | Output formatted for submission to the GHG Europe database. |
| eddypro_OutputID_metadata_yyyy-mm-ddThhmmss.csv | A summary of information stored in each of the metadata files for the project. |
| eddypro_OutputID_planar_fit_yyyy-mm-ddThhmmss.txt | Planar fit file computed for the dataset. |
| eddypro_OutputID_qc_details_yyyy-mm-ddThhmmss.csv | A summary of errors and tests for each 30 minute data set. |
| eddypro-fcc_OutputID_yyyy-mm-ddThhmmss.log | Flux Computation and Correction (FCC) summary file. Flux computation and correction errors are recorded in this file. |
| eddypro-rp_OutputID_yyyy-mm-ddThhmmss.log | Raw Processing (RP) summary file. Raw processing errors are recorded in this file. |
| processing_yyyy-mm-ddThhmmss.eddypro | EddyPro project file. |

[1] CSV stands for comma-separated values, which is a comma delimited text file that can be opened in most spreadsheet applications.

## Binned Cospectra Outputs

This folder includes one .csv file for each 30 minute dataset. See "Calculating Spectra, Cospectra, and Ogives" on page 7-32 for more information.

| Name | Date modified | Type | Size |
|---|---|---|---|
| 20120817-0030_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:47 PM | Microsoft Office E... | 17 KB |
| 20120817-0100_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:48 PM | Microsoft Office E... | 18 KB |
| 20120817-0130_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:48 PM | Microsoft Office E... | 18 KB |
| 20120817-0200_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:48 PM | Microsoft Office E... | 18 KB |
| 20120817-0230_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:49 PM | Microsoft Office E... | 18 KB |
| 20120817-0300_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:49 PM | Microsoft Office E... | 18 KB |
| 20120817-0330_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:49 PM | Microsoft Office E... | 18 KB |
| 20120817-0400_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:50 PM | Microsoft Office E... | 18 KB |
| 20120817-0430_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:50 PM | Microsoft Office E... | 18 KB |
| 20120817-0500_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:50 PM | Microsoft Office E... | 18 KB |
| 20120817-0530_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:51 PM | Microsoft Office E... | 18 KB |
| 20120817-0600_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:51 PM | Microsoft Office E... | 18 KB |
| 20120817-0630_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:51 PM | Microsoft Office E... | 18 KB |
| 20120817-0700_binned_cospectra_2014-02-13T101340.csv | 2/13/2014 1:51 PM | Microsoft Office E... | 18 KB |

## Binned Ogives

This folder includes one .csv file for each 30 minute dataset. See "Calculating Spectra, Cospectra, and Ogives" on page 7-32 for more information.

| Name | Date modified | Type | Size |
|---|---|---|---|
| 20120817-0030_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:47 PM | Microsoft Office E... | 16 KB |
| 20120817-0100_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:48 PM | Microsoft Office E... | 17 KB |
| 20120817-0130_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:48 PM | Microsoft Office E... | 17 KB |
| 20120817-0200_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:48 PM | Microsoft Office E... | 17 KB |
| 20120817-0230_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:49 PM | Microsoft Office E... | 18 KB |
| 20120817-0300_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:49 PM | Microsoft Office E... | 17 KB |
| 20120817-0330_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:49 PM | Microsoft Office E... | 17 KB |
| 20120817-0400_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:50 PM | Microsoft Office E... | 18 KB |
| 20120817-0430_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:50 PM | Microsoft Office E... | 17 KB |
| 20120817-0500_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:50 PM | Microsoft Office E... | 17 KB |
| 20120817-0530_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:51 PM | Microsoft Office E... | 17 KB |
| 20120817-0600_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:51 PM | Microsoft Office E... | 17 KB |
| 20120817-0630_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:51 PM | Microsoft Office E... | 17 KB |
| 20120817-0700_binned_ogives_2014-02-13T101340.csv | 2/13/2014 1:51 PM | Microsoft Office E... | 17 KB |

## Full Cospectra

This folder includes one .csv file for each 30 minute dataset. See "Calculating Spectra, Cospectra, and Ogives" on page 7-32 for more information.

| Name | Date modified | Type | Size |
|---|---|---|---|
| 20120817-0030_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:47 PM | Microsoft Office E... | 2,360 KB |
| 20120817-0100_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:48 PM | Microsoft Office E... | 2,739 KB |
| 20120817-0130_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:48 PM | Microsoft Office E... | 2,738 KB |
| 20120817-0200_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:48 PM | Microsoft Office E... | 2,768 KB |
| 20120817-0230_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:49 PM | Microsoft Office E... | 2,812 KB |
| 20120817-0300_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:49 PM | Microsoft Office E... | 2,768 KB |
| 20120817-0330_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:49 PM | Microsoft Office E... | 2,760 KB |
| 20120817-0400_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:50 PM | Microsoft Office E... | 2,818 KB |
| 20120817-0430_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:50 PM | Microsoft Office E... | 2,740 KB |
| 20120817-0500_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:50 PM | Microsoft Office E... | 2,718 KB |
| 20120817-0530_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:51 PM | Microsoft Office E... | 2,746 KB |
| 20120817-0600_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:51 PM | Microsoft Office E... | 2,732 KB |
| 20120817-0630_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:51 PM | Microsoft Office E... | 2,742 KB |
| 20120817-0700_full_cospectra_2014-02-13T101340.csv | 2/13/2014 1:51 PM | Microsoft Office E... | 2,757 KB |

## Raw Datasets

This folder includes one folder for each of iteration of processing (up to seven). Each folder includes a text file with the preliminary fluxes computed during that iteration. The calculations are described in "Calculating Turbulent Fluxes Level 0 (Uncorrected Fluxes)" on page 7-44, "Calculating Fluxes Level 1, 2, and 3 (Corrected Fluxes)" on page 7-60, "Calculating Turbulent Fluxes for a System Composed of an LI-7200 and LI-7700" on page 7-63, and "Calculating Turbulent Fluxes for a System Composed of an LI-7500 and LI-7700" on page 7-61.

| Name | Date modified | Type |
|---|---|---|
| level_1 | 2/13/2014 8:57 PM | File folder |
| level_2 | 2/13/2014 8:57 PM | File folder |
| level_3 | 2/13/2014 8:57 PM | File folder |
| level_4 | 2/13/2014 8:57 PM | File folder |
| level_5 | 2/13/2014 8:57 PM | File folder |
| level_6 | 2/13/2014 8:57 PM | File folder |
| level_7 | 2/13/2014 8:57 PM | File folder |

| Name | Date modified |
|---|---|
| 20120817-0030_raw_dataset_2014-02-13T101340.txt | 2/13/2014 1:47 PM |
| 20120817-0100_raw_dataset_2014-02-13T101340.txt | 2/13/2014 1:47 PM |
| 20120817-0130_raw_dataset_2014-02-13T101340.txt | 2/13/2014 1:48 PM |
| 20120817-0200_raw_dataset_2014-02-13T101340.txt | 2/13/2014 1:48 PM |
| 20120817-0230_raw_dataset_2014-02-13T101340.txt | 2/13/2014 1:48 PM |
| 20120817-0300_raw_dataset_2014-02-13T101340.txt | 2/13/2014 1:49 PM |
| 20120817-0330_raw_dataset_2014-02-13T101340.txt | 2/13/2014 1:49 PM |

## Spectral Analysis

This folder includes spectra and cospectra data files in .csv format. It also includes a spectral assessment file that can be used to reprocess a data set if the spectral assessment file applies. See "Calculating Spectral Correction Factors" on page 7-49 for more information.

| Name | Date modified |
|---|---|
| eddypro_OutputID_ensemble_and_model_cospectra_2014-02-13T205746.csv | 2/13/2014 8:58 PM |
| eddypro_OutputID_ensemble_cospectra_by_time_2014-02-13T205746.csv | 2/13/2014 8:58 PM |
| eddypro_OutputID_h2o_ensemble_spectra_2014-02-13T205746.csv | 2/13/2014 8:58 PM |
| eddypro_OutputID_passive_gases_ensemble_spectra_2014-02-13T205746.csv | 2/13/2014 8:58 PM |
| eddypro_OutputID_spectral_assessment_2014-02-13T205746.txt | 2/13/2014 8:58 PM |

## Stats

The stats folder includes a .csv file for each level of processing.

| Name | Date modified | Type | Size |
|---|---|---|---|
| eddypro_OutputID_st1_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 2,006 KB |
| eddypro_OutputID_st2_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 2,001 KB |
| eddypro_OutputID_st3_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 2,001 KB |
| eddypro_OutputID_st4_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 2,000 KB |
| eddypro_OutputID_st5_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 2,006 KB |
| eddypro_OutputID_st6_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 2,006 KB |
| eddypro_OutputID_st7_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 2,006 KB |

## User Stats

The user stats folder includes a .csv file for each level of processing.

| Name | Date modified | Type | Size |
|---|---|---|---|
| eddypro_OutputID_user_st1_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 932 KB |
| eddypro_OutputID_user_st2_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 932 KB |
| eddypro_OutputID_user_st3_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 932 KB |
| eddypro_OutputID_user_st4_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 932 KB |
| eddypro_OutputID_user_st5_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 932 KB |
| eddypro_OutputID_user_st6_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 932 KB |
| eddypro_OutputID_user_st7_2014-02-13T101340.csv | 2/13/2014 8:57 PM | Microsoft Office E... | 932 KB |

# The Full Output File

This is the most comprehensive output file produced by EddyPro®. It contains many of the intermediate and final variables calculated during data processing. Results values are grouped by the first line of the header to facilitate interpretation. Here we provide an overview of available outputs. For more specific description of each variable refer to the Variables Table.

## Headings

The first row in the file (when opened in a spreadsheet) gives the top-level headings below. The second row includes subheadings for variables and values included in the results.

### File info

- Raw file name
- Date and time of the end of the averaging period
- Number of valid records found in the raw file
- Number of valid records used for the current averaging period

### Corrected fluxes

- Net vertical turbulent fluxes of momentum, sensible heat, latent heat and all available gases, calculated from uncorrected fluxes, by correcting for spectral attenuations, air density fluctuations and instrument-specific effects, as applicable. Quality flags and random uncertainty estimates are provided for all fluxes.

### Storage fluxes

- Storage fluxes of sensible and latent heat and for all available gases, estimated from concentrations and based on a 1-point profile.

### Vertical advection fluxes

- Vertical advection gas fluxes obtained by multiplication of the mean vertical wind speed and mean gas concentration. These are zero if the mean vertical velocity is forced to zero, as is the case with the double rotations schemas for tilt correction.

### Gas densities, concentrations, and time lags

- Average molar density, mole fraction (moles of gas per mole of wet air) and mixing ratio (moles of gas per mole of dry air) for available gases. Quantities are either calculated or estimated from raw data, depending on the available measurements. In particular, calculation of densities to concentrations (and vice-versa) requires measured temperatures and pressures, while estimation is done using barometric pressure and/or corrected sonic temperature, if measured values are not available. Toggling between mole fractions and mixing ratios requires fast measurements of water vapor.
- Time lags used for flux calculation and a flag indicating whether the time lag used was calculated with the covariance maximization procedure (value "F") or was the nominal one ("T").

### Air properties

- Evapotranspiration flux, expressed as millimeters or water per hour
- Mean ambient pressure and temperature, either calculated or estimated, depending on the content of raw files
- Mean ambient air density and molar volume and heat capacity, calculated
- Mean ambient water vapor density, partial pressure, partial pressure at saturation
- Mean ambient specific and relative humidity, water vapor pressure deficit and dew point temperature

### Unrotated and rotated wind

- Mean wind components in the anemometer coordinate framework
- Wind components after rotations for tilt correction
- Mean wind speed, instantaneous maximum wind speed and mean wind direction

### Rotation angles

- Yaw, pitch, and roll angles used to correct anemometer tilting, according to the selected method.

### Turbulence

- Turbulence parameters: friction velocity, Monin-Obukhov length, stability parameter, turbulent kinetic energy, Bowen ratio, and scaling temperature.

### Footprint

- Estimation of crosswind integrated footprints: model used, along wind distances providing peak, 10%, 30%, 50%, 70%, and 90% contributions to total fluxes. Footprint offset is the distance from the tower providing less than 1% contribution to total fluxes. See "Estimating the Flux Footprint" on page 7-65

### Uncorrected fluxes

- Net vertical turbulent fluxes of momentum, sensible heat, latent heat and all available gases, calculated from corresponding covariances by conversion of physical units, prior to application of corrections.
- Spectral correction factors calculated according to the selected method.

### Statistical flags

- Results of selected statistical tests, applied to all time series.

### Diagnostics

- Number of spikes detected for each sensitive variable used for flux computation.
- Detailed summary of diagnostics for LI-7500A, LI-7200, and LI-7700. The values here are the sum of records in each flux averaging interval, for which flags are set to "on" (bad data). Thus values here go from zero (best case) to the number of available records (worst case).
- Average AGC or Signal Strength (LI-7500A or LI-7200) and RSSI (LI-7700).

### Variances

- Variances of all sensitive variables, calculated at the end of the whole raw data processing, including despiking, corrections, rotations and detrending.

### Covariances

- Covariances between *w* (vertical wind component) and all non-anemometric sensitive variables calculated at the end of the whole raw data processing, including despiking, corrections, rotations, detrending, and time lag compensation.

### Custom variables

- Mean values for all non-sensitive variables are reported at the end of the output record.

### Variables Table

The following table summarizes all output results available in the rich output file. In the table, *var* stands for any available sensitive variable, *gas* stands for any available sensitive gas measurement and *extravar* stands for any non-sensitive variable.

**Table 5-2**. Shorthand for variables in output files from EddyPro 4.

| Label | Units, Format, or Range | Description |
|---|---|---|
| filename | - | Name of the raw file (or the first of a set) from which the dataset for the current averaging interval was extracted |
| date | yyyy-mm-dd | Date of the end of the averaging period |
| time | HH:MM | Time of the end of the averaging period |
| file_records | # | Number of valid records found in the raw file (or set of raw files) |
| used_records | # | Number of valid records used for current the averaging period |
| Tau | kg $m^{-1}$ $s^{-2}$ | Corrected momentum flux |
| qc_Tau | # | Quality flag for momentum flux |
| rand_err_Tau | kg $m^{-1}$ $s^{-2}$ | Random error for momentum flux, if selected |
| H | W $m^{-2}$ | Corrected sensible heat flux |
| qc_H | # | Quality flag for sensible heat flux |
| rand_err_H | W $m^{-2}$ | Random error for momentum flux, if selected |
| LE | W $m^{-2}$ | Corrected latent heat flux |
| qc_LE | # | Quality flag latent heat flux |
| rand_err_LE | W $m^{-2}$ | Random error for latent heat flux, if selected |
| *gas*_flux | µmol $m^{-2}$ $s^{-1}$(†) | Corrected *gas* flux |
| qc_*gas*_flux | # | Quality flag for *gas* flux |
| rand_err_*gas*_flux | µmol $s^{-1}$ $m^{-2}$(†) | Random error for *gas* flux, if selected |
| H_strg | W $m^{-2}$ | Estimate of storage sensible heat flux |

**Table 5-2**. Shorthand for variables in output files from EddyPro 4. (...continued)

| Label | Units, Format, or Range | Description |
|---|---|---|
| LE_strg | W $m^{-2}$ | Estimate of storage latent heat flux |
| *gas*_strg | µmol $s^{-1}$ $m^{-2}$(†) | Estimate of storage *gas* flux |
| *gas*_v-adv | µmol $s^{-1}$ $m^{-2}$(†) | Estimate of vertical advection flux |
| *gas*_molar_density | mmol $m^{-3}$ | Measured or estimated molar density of *gas* |
| *gas*_mole_fraction | µmol $mol^{-1}$(†) | Measured or estimated mole fraction of *gas* |
| *gas*_mixing_ratio | µmol $mol^{-1}$(†) | Measured or estimated mixing ratio of *gas* |
| *gas*_time_lag | s | Time lag used to synchronize *gas* time series |
| *gas*_def_timelag | T/F | Flag: whether the reported time lag is the default (T) or calculated (F) |
| sonic_temperature | K | Mean temperature of ambient air as measured by the anemometer |
| air_temperature | K | Mean temperature of ambient air, either calculated from high frequency air temperature readings, or estimated from sonic temperature |
| air_pressure | Pa | Mean pressure of ambient air, either calculated from high frequency air pressure readings, or estimated based on site altitude (barometric pressure) |
| air_density | kg $m^{-3}$ | Density of ambient air |
| air_heat_capactiy | J $K^{-1}$ $kg^{-1}$ | Specific heat at constant pressure of ambient air |
| air_molar_volume | $m^3$ $mol^{-1}$ | Molar volume of ambient air |
| ET | mm $hour^{-1}$ | Evapotranspiration flux |
| water_vapor_dens-ity | kg $m^{-3}$ | Ambient mass density of water vapor |
| e | Pa | Ambient water vapor partial pressure |
| es | Pa | Ambient water vapor partial pressure at saturation |
| specific_humidity | kg $kg^{-1}$ | Ambient specific humidity on a mass basis |
| RH | % | Ambient relative humidity |
| VPD | Pa | Ambient water vapor pressure deficit |
| Tdew | K | Ambient dew point temperature |
| u_unrot | m $s^{-1}$ | Wind component along the *u* anemometer axis |
| v_unrot | m $s^{-1}$ | Wind component along the *v* anemometer axis |

**Table 5-2**. Shorthand for variables in output files from EddyPro 4. (...continued)

| **Label** | **Units, Format, or Range** | **Description** |
|---|---|---|
| w_unrot | m $s^{-1}$ | Wind component along the *w* anemometer axis |
| u_rot | m $s^{-1}$ | Rotated *u* wind component (mean wind speed) |
| v_rot | m $s^{-1}$ | Rotated *v* wind component (should be zero) |
| w_rot | m $s^{-1}$ | Rotated *w* wind component (should be zero) |
| wind_speed | m $s^{-1}$ | mean wind speed |
| max_wind_speed | m $s^{-1}$ | Maximum instantaneous wind speed |
| wind_dir | ° (degrees) | Direction from which the wind blows, with respect to Geographic or Magnetic north |
| yaw | ° (degrees) | First rotation angle |
| pitch | ° (degrees) | Second rotation angle |
| u* | m $s^{-1}$ | Friction velocity |
| TKE | $m^{-2}$ $s^{-1}$ | Turbulent kinetic energy |
| L | M | Monin-Obukov length |
| (z-d)/L | # | Monin-Obukhov stability parameter |
| bowen_ratio | # | Sensible heat flux to latent heat flux ratio |
| T* | K | Scaling temperature |
| (footprint) model | - | Model for footprint estimation |
| x_offset | m | Along-wind distance providing <1% contribution to turbulent fluxes |
| x_peak | m | Along-wind distance providing the highest (peak) contribution to turbulent fluxes |
| x_10% | m | Along-wind distance providing 10% (cumulative) contribution to turbulent fluxes |
| x_30% | m | Along-wind distance providing 30% (cumulative) contribution to turbulent fluxes |
| x_50% | m | Along-wind distance providing 50% (cumulative) contribution to turbulent fluxes |
| x_70% | m | Along-wind distance providing 70% (cumulative) contribution to turbulent fluxes |
| x_90% | m | Along-wind distance providing 90% (cumulative) contribution to turbulent fluxes |
| un_Tau | kg $m^{-1}$ $s^{-2}$ | Uncorrected momentum flux |

**Table 5-2**. Shorthand for variables in output files from EddyPro 4. (...continued)

| Label | Units, Format, or Range | Description |
|---|---|---|
| Tau_scf | # | Spectral correction factor for momentum flux |
| un_H | W $m^{-2}$ | Uncorrected sensible heat flux |
| H_scf | # | Spectral correction factor for sensible heat flux |
| un_LE | W $m^{-2}$ | Uncorrected latent heat flux |
| LE_scf | # | Spectral correction factor for latent heat flux |
| un_*gas*_flux | µmol $s^{-1}$ $m^{-2}$(†) | Uncorrected *gas* flux |
| gas_scf | # | Spectral correction factor for gas flux |
| spikes | HFu/v/w/ts/co2 /h2o/ch4/n2 | Hard flags for individual variables for spike test |
| amp_res | HFu/v/w/ts/co2 /h2o/ch4/n2 | Hard flags for individual variables for amplitude resolution |
| drop_out | HFu/v/w/ts/co2 /h2o/ch4/n2 | Hard flags for individual variables for drop-out test |
| abs_lim | HFu/v/w/ts/co2 /h2o/ch4/n2 | Hard flags for individual variables for absolute limits |
| skw_kur | HFu/v/w/ts/co2 /h2o/ch4/n2 | Hard flags for individual variables for skewness and kurtosis |
| skw_kur | HFu/v/w/ts/co2 /h2o/ch4/n2 | Soft flags for individual variables for skewness and kurtosis test |
| discontinuities | HFu/v/w/ts/co2 /h2o/ch4/n2 | Hard flags for individual variables for discontinuities test |
| discontinuities | HFu/v/w/ts/co2 /h2o/ch4/n2 | Soft flags for individual variables for discontinuities test |
| time_lag | HFu/v/w/ts/co2 /h2o/ch4/n2 | Hard flags for gas concentration for time lag test |
| time_lag | HFu/v/w/ts/co2 /h2o/ch4/n2 | Soft flags for gas concentration for time lag test |
| attack_angle | HFu/v/w/ts/co2 /h2o/ch4/n2 | Hard flag for attack angle test |
| non_steady_wind | HFu/v/w/ts/co2 /h2o/ch4/n2 | Hard flag for non-steady horizontal test |

**Table 5-2**. Shorthand for variables in output files from EddyPro 4. (...continued)

| Label | Units, Format, or Range | Description |
|---|---|---|
| *var*_spikes | # | Number of spikes detected and eliminated for variable *var* |
| AGC | # | Mean value of AGC for LI-7500A and/or LI-7200, if present |
| RSSI | # | Mean value of RSSI for LI-7700, if present |
| *var*_var | -(‡) | Variance of variable *var* |
| w/*var*_cov | -(‡) | Covariance between *w* and variable *var* |
| *extravar*_mean | (‡) | Mean value of *extravar* |

† Concentrations and fluxes for water vapor are provided as [mmol mol$^{-1}$] and [mmol m$^{-2}$ s$^{-1}$] respectively.

‡ Units depend on the nature of the variable.

### Output format

The **Output format** option allows you to decide to **Output only available results** or **Use standard output format**.

The first option, **Output only available results** instructs EddyPro to reduce the file only to results that are actually available. One advantage of this option is that it results in smaller files that are easier to read in a spreadsheet. Files do not contain columns filled with error codes for the variables that are not available.

The second option, **Use standard output format** instructs EddyPro to create a file in a predefined standardized output format that includes columns form all possible results. One advantage of this option is that the file format does not vary in time, making it easier to import into post-processing analysis tools.

### Build continuous dataset

Select this option to instruct EddyPro to create a continuous dataset. For periods that have no results available (gaps), the software will introduce dummy records of “error codes” in such a way that the result files will contain a continuous time line. This is convenient since data gaps need to be recognized (especially when time series are plotted) and addressed (e.g., by means of a gap-filling procedure). However, the procedure requires a non negligible amount of time – especially for long datasets - so it is provided as an option.

The definition of the time line is based on the time stamp of the first raw file and on the selected flux averaging period.

## GHG Europe Output Format

This file contains a selection of output variables and is designed to comply with the flux data format of the GHG Europe project. Refer to the project database for a complete description of the variables included in this file and for an explanation of the header file.

## AmeriFlux Output Format

This file, which contains a subset of variables, is in a format that can be submitted directly to the AmeriFlux database. It has a 17-line precompiled header, which includes some empty fields that must be completed prior to submission. These fields cannot be calculated by EddyPro® and are filled with the "missing data" code (-69999). Refer to the AmeriFlux data submission guidelines for a description of the content of this file.

## Statistics Output

Along with the final results files (full output, FLUXNET and AmeriFlux files), EddyPro® creates at least one subfolder in the user-specified output folder:

- **..\eddypro_stats\:** contains seven files of basic statistics calculated on all available sensitive variables, at 7 different levels of processing. These files have a static format that includes statistical data for all sensitive variables, except the analyzer's cell in/out temperature. Statistics for variables that are not available are replaced by the string "n/a" (not available).

The seven levels of statistics refer to those calculated on the following datasets:

1. Unprocessed (dataset as imported from the raw file)
2. After despiking
3. After crosswind correction
4. After angle-of attack correction
5. After double rotation for tilt correction
6. After time lag compensation
7. After detrending

- **..\eddypro_user_stats\:** contains seven files of basic statistics calculated on all available non-sensitive variables (including user-defined variables and sensitive variables not used for flux computation). These files have a dynamic format, including statistics only for available non-sensitive variables. This folder and the seven files contained in it are created only if EddyPro detects at least one non-sensitive variable.

Like the statistics calculated on sensitive variables, the seven levels of statistics refer to those calculated on the following datasets:

1. Unprocessed (dataset as imported from the raw file)
2. After despiking
3. After crosswind correction
4. After angle-of-attack correction
5. After double rotation for tilt correction
6. After time lag compensation
7. After detrending

> **Note:** Statistics on non-sensitive variables may result in seemingly wrong values (such as zero or not-a-number). This may happen when, for example, a variable has a constant value throughout the file, as with some instrument diagnostic variables. In these cases, however, high order statistics loose representativeness and usefulness.

## Statistics Files Content:

### File information

- Raw file name
- Date and time of the end of the averaging period
- Number of valid records used for the current averaging period

### Statistics

- Mean values
- Variances
- Covariances of all variables with the three wind components
- Standard deviations
- Skewness
- Kurtosis

**Table 5-3**. The following table summarizes all output results available in the statistics files. In the table, var stands for any available sensitive or non-sensitive variable.

| Label | Description |
|---|---|
| filename | Name of the raw file (or first file of a set) from which the data in the current averaging interval was extracted |
| date | Date of the end of the averaging period |
| time | Time of the end of the averaging period |
| n_samples | Number of valid records found in the raw file (or set of raw files) |
| mean (var) | Mean value of variable (var) |
| var (var) | Variance of variable (var) |
| cov (u/var) | Covariance between the u wind component and var |
| cov(v/var) | Covariance between the v wind component and var |
| cov (w/var) | Covariance between the w wind component and var |
| st_dev(var) | standard deviation of variable var |
| skw(var) | skewness of variable var |
| kur(var) | kurtosis of variable var |

# 6 Interface Feature Reference

The section describes topics in the interface that are marked with a help question mark.

## Raw File Name Format

For each file type discovered in the ***Raw data directory***, EddyPro® will provide you a sample file name. The easiest way to enter the ***Raw file name format*** is to substitute timestamp information in the sample file name with the following characters:

- yy for a 2-digit year;
- yyyy for a 4-digit year;
- dd for a 2-digit day-of-month;
- mm for a 2-digit month-of-the-year;
- ddd for a 3-digit day-of-year (DOY);
- HH for a 2-digit hour;
- MM for a 2-digit minute.

> **Note:** All timestamp information must be present in raw file names. While day/month (or DOY) and hour information are virtually always available, years and minutes are sometimes not documented on file names. However, they are necessary to EddyPro. A tool is available on demand to automatically rename raw files including missing timestamp information;

For example, if the sample raw file name is:

`mysite_2009_001_0130.dat`,

acceptable prototypes would be:

`mysite_yyyy_ddd_HHMM.dat`, or

`xxxxxx_yyyy_ddd_HHMM.dat`;

but if the filename is

`mysite_0021200.R08`,

then information about the year ('08' in the extension) cannot be retrieved because EddyPro does not interpret the extension. In this case the file should first be renamed to something like:

`mysite_080021200.R08`

Then, a valid prototype would be:

`mysite_yydddHHMM.R08.`

## LI-COR® GHG File Type

The GHG format is LI-COR® Biosciences' custom raw file type, consisting of an archive containing the DATA file (extension ".data") and a METADATA file (extension ".metadata"). If selected, the archive will also contain LI-7700 status records as a separate file. This file format is based on $ECO_2S$ ENE format.

The DATA file is an ASCII table with a header, which has an unspecified number of rows, and data columns, which are separated by the TAB character. The header of the DATA file is ignored by EddyPro®. To read the content of the file, EddyPro uses the paired METADATA file to interpret the data columns and to retrieve meta-information needed to calculate fluxes.

The introduction of the METADATA file inside the GHG archive, while adding a negligible amount of bytes (it contributes for about 0.1% to the file size), allows you to:

- Avoid retrieving information needed for processing the file from any external data source;
- Easily store raw data for future reprocessing;
- Properly account for dynamic site parameters that change over the course of the data collection period (e.g. the canopy height of a crop);
- To a large extent, simultaneously process files acquired with different setups.

Ideally, you are not required to consider the METADATA file explicitly, as it is created and modified in the LI-COR gas analyzer configuration software, and used silently by EddyPro. Nevertheless, all information is stored as plain text and can be retrieved and edited at any time.

EddyPro 4.0 also supports the inclusion of biomet data (with biomet metadata), which can be used in flux computations. It is also summarized in the output files. See "Supported Biomet File Formats" on page 4-14

Sensitive meta-information in the METADATA file includes (for a description of each field, refer to the Metadata File Editor):

### Site and setup information

- Canopy height;
- Canopy roughness length;
- Boundary layer displacement height;
- Site coordinates and altitude;
- Acquisition frequency;
- File duration.

### Instruments

- Anemometer(s) manufacturer and model;
- Anemometer(s) height;
- Anemometer settings:
  - Whether the built in head correction is applied;
  - Whether the wind components are given in AXIS or SPAR configuration (Gill anemometers);
  - Yaw offset with respect to due north;
  - Displacement from the reference anemometer in a Cartesian north/east/vertical system (only for anemometers other than the reference one);
  - If applicable, the instrument time response and the paths length;
- Gas analyzer(s) manufacturer and model;
- Gas analyzer settings:
  - Flow rate and intake tube length and inner diameter (for closed path gas analyzers only);
  - Displacement of the reference anemometer in a Cartesian north/east/vertical system;
  - If applicable, the instrument time response and path lengths;
  - If applicable, the relevant extinction coefficients (for Krypton and Lyman-α hygrometers)

### Raw file columns

- Name of the variable;
- The instrument that measured the variable;
- For gas concentrations, the type of measurement (molar density, mole fraction or mixing ratio);

- Physical units of the variable, as stored in the raw file;
- If applicable, linear conversion information:
  - Type of conversion (Gain/Offset);
  - Units of the variable as stored in the raw file;
  - Gain/Offset;
  - Physical units of the variable, as expected after the linear conversion;
- Nominal time-lag for the variable, based either on the displacement of the instrument from the reference anemometer (open path analyzers), or on the intake tube properties and flow rate (closed path analyzers).
- Minimum and maximum plausible time lags, for automatic time lag determination by means of circular correlation.

## TOB1 File Type

TOB1 is a binary format often used for storing raw data obtained from Campbell Scientific® dataloggers. These files are customizable, as one can select the format of each individual variable (e.g. integer, single precision, etc.). EddyPro® can process TOB1 files with the following characteristics:

- TOB1 files that contain only variables in the formats “ULONG” and “IEEE4”, no matter how these are intercalated;
- TOB1 files that contain only variables in the formats “ULONG” and “FP2”, provided that the variables in the “ULONG” format precede those in the “FP2” format.

Thus, files containing variables in the “IEEE4” and “FP2” formats are not supported. Similarly, files in which “FP2” variables precede “ULONG” variables are not supported.

**Note:** “ULONG” variables are not actually imported (they are skipped), which implies that variables in this format must be described with the property of **Ignore**. This is usually not a limitation, because the “ULONG” format is normally reserved to timestamp information that EddyPro does not use anyway.

When you select the TOB1 format, a further option activates to specify the “IEEE4” or “FP2” format. If you are unsure, select the option **Detect automatically**. EddyPro will rely on the header of TOB1 files to determine the actual format.

When you describe TOB1 files in the **Metadata File Editor**, just consider each variable as a column, (although the term “column” is not appropriate for unformatted binary data), and proceed as you would do with any ASCII file.

## Generic Binary File Type

If your raw data are stored in a custom binary format, chances are that EddyPro® can still import and process them. Click the “Setting…” button to access a dialog that allows you to describe the file format.

First, if your raw files have an ASCII header, specify the number of lines of such header and their terminator character. Supported terminators are Cr+LF (typical in Windows), LF (Linux and Mac OS X) and CR (Max OS up to version 9 and OS-9). Then, provide the number of bytes reserved for each variable (typically 2 or 4) and the binary words endianess (that is, the order of the bytes significance): in a multi-bytes binary word, *little endian* means that the most significant byte is the last byte (highest address) while *big endian* means that the most significant byte is the first byte (lowest address).

**Note:**EddyPro supports only binary files where all variables are stored as single precision numbers in words of fixed length (fixed number of bytes). If files have words of different lengths (e.g. 2 bytes and 4 bytes) most likely they cannot be interpreted correctly, unless the longest words can be split into dummy variables of the same length of shorter ones, which assumes you don’t need to use those variables and they can thus be labeled with "ignore" in the Raw File Description. In our example, each of 4 byte word could be thought of as a two byte word, and thus considered as 2 variables, to be ignored.

When you describe generic binary files in the **Metadata File Editor**, just consider each variable as a "column" (although the term "column" is not appropriate for unformatted binary data), and proceed as you would do with any ASCII file.

## Time-varying (Dynamic) Metadata

Data processing and flux calculation with EddyPro® is based not only on raw data, but also on the metadata describing the site characteristics, the eddy covariance station setup and the raw data file themselves.

Metadata may vary along the dataset. For example, think about the growing canopy of an agricultural field, which may also imply an adjustment of the measurement height of the instruments. Maintenance and movement of instruments may imply a different relative positioning and orientation of the instruments. Also, instruments can be added or changed during the data collection or parameters, such as the acquisition frequency and the duration of the raw file, can change. All these possible changes must be taken into account for a proper data processing and flux computation and correction. The ideal way to do that is to collect raw data in LI-COR's GHG format. GHG files embed the metadata inside each raw file so, if the data logging software is updated with the current meta-information during data acquisition (and that's by far the most suitable moment for doing that!), all raw files will embed the correct metadata, and EddyPro will be able to correctly process them without any further intervention from you.

However, if you collected raw files in a format other than GHG, or if you didn't update the data logging software with the proper meta-information during acquisition of your GHG dataset, EddyPro provides you with the possibility of taking time-varying metadata into account. This will require a little effort on your part, to create a dynamic metadata file prior to using EddyPro. The dynamic metadata file is a comma separated text file featuring a header with the names of the contained variables, and a sequence of records starting with a timestamp, followed by the actual values.

Using the dynamic metadata does not imply that the ".metadata" file must not be created. Indeed, the ".metadata" file is used to initialize all the necessary metadata. On the contrary, the dynamic metadata file needs to contain only the parameters that undergo at least one modification along the dataset. Table 1 lists all metadata that can be provided in a dynamic metadata file, including the standardized variables names - indispensable for correctly interpreting the file content – and a short description of the variable meaning.

The associations between the data in the metadata file and the corresponding flux averaging periods is based on matching time stamps. The timestamp can be provided as date and time, only date or only the time. EddyPro will attempt to match all available timestamp information. If, for the current flux averaging period, there is no matching dynamic metadata contained in the file, EddyPro will use the closest preceding one. This means that you don't need to create a file that contains metadata for all flux averaging periods. Basically, you need to create a new metadata line each time a modification occurs for any metadata parameter.

As an example, imagine a dataset that starts on the 1st of January, with the $CO_2$ analyzer placed 20 cm at the North of the anemometer. On the 15th of February, at 10:30AM, the analyzer is moved and placed 30 cm eastward of the anemometer. The acquisition ends at the end of February and this was the only notable modification occurred during the two months. A valid metadata in this situation would read:

```
date,time,co2_irga_northward_separation,co2_irga_eastward_separation

2011-01-01,01:00,20.0,0.0

2011-02-15,10:30,0.0,30.0
```

where the first line is the header containing standardized labels (see Table). The second line indicates that, starting January 1st, 2011 at 1:00AM, the $CO_2$ analyzer is placed 20 cm northward of the master anemometer, and 0 cm eastward. These settings will bypass any different information provided in the alternative, "master" (and static) metadata file.

The third line says that, staring February 15th, 2011 at 10:30AM, the $CO_2$ analyzer was moved, and is now aligned with the master anemometer in the South-North direction, but displaced 30 cm eastward.

| **Variable** | **Label** | **Units/Format/values** | **Description and notes** |
|---|---|---|---|
| Date | date | yyyy-mm-dd | Year, month, and day of the current data. |
| Time | time | HH:MM | Hour and minute of the current data. The minute must correspond to the end of the period the metadata refer to. |
| File length | file_length | minutes | The duration in minutes of the raw files. |
| Acquisition frequency | acquisition_ frequency | Hz | Frequency of acquisition of raw data from gas analyzer (s) and anemometer(s) |

| Variable | Label | Units/Format/values | Description and notes |
|---|---|---|---|
| Canopy height | canopy_ height | m | Height of the canopy |
| Displacement height | displacement_ height | m | Displacement height |
| Roughness length | roughness_ length | m | Roughness length |
| Manufacturer of the mas-ter anemometer | master_sonic_ manufacturer | variable† | See list of supported man-ufacturers. |
| Model of the master anemometer | master_sonic_ model | variable‡ | See list of supported models and how to compose the name. |
| Height of the master anemometer | master_sonic_ height | m | This height also defines the "measurement height" used in calculations. |
| Format of wind data | master_sonic_ wformat | 'uvw'<br>'polar_w'<br>'axis' | The 'axis' option (wind com-ponents alighed with paths of the transducers pairs) applies only to Gill anem-ometers. |
| North alignment for wind data | master_sonic_ wref | 'spar''axis' | Only applies to Gill anem-ometers (learn more...). |
| North misalignment for wind data | master_sonic_ north_offset | deg from North | Any misalignment between "anemometer North" and geographic North, in degrees from North (positive if measured eastward). |
| Manufacturer of gas ana-lyzer for XXX | xxx_irga_man-ufacturer | variable* | See list of supported man-ufacturers. |
| Model of gas analyzer for XXX | xxx_irga_ model | variable** | See list of supported man-ufacturers. |
| Northward separation of XXX analyzer from mas-ter anemometer | xxx_irga_ northward_sep-aration | m | Positive if gas analyzer is placed North of anem-ometer. |

| Variable | Label | Units/Format/values | Description and notes |
|---|---|---|---|
| Eastward separation of XXX analyzer from master anemometer | xxx_irga_eastward_separation | m | Positive if gas analyzer is placed East of the master anemometer. |
| Length of the tube of the sampling line for XXX analyzer | xxx_irga_tube_length | cm | Only applicable to closed/enclosed path gas analyzers. |
| Diameter of the tube of the sampling line for XXX analyzer | xxx_irga_tube_diameter | mm | Only applicable to closed/enclosed path gas analyzers. |
| Flow rate in the sampling line of XXX analyzer | xxx_irga_flowrate | lit $min^{-1}$ | Only applicable to closed/enclosed path gas analyzers. |
| Extinction coefficient in water | xxx_irga_kw | $m^3$ $g^{-1}$ $cm^{-1}$ | Only applicable to Krypton/L:yman-α hygrometers./ |
| Extinction coefficient in oxygen | xxx_irga_ko | $m^3$ $g^{-1}$ $cm^{-1}$ | Only applicable to Krypton/L:yman-α hygrometers. |
| XXX analyzer longitudinal path length | xxx_irga_vpath_length | m | Path length of the gas analyzer in the main direction (direction between source and sensor). |
| XXX analyzer transversal path length | xxx_irga_hpath_length | m | Path length of the gas analyzer in the cross direction. |
| XXX analyzer time response | xxx_irga_tau | m | Analyzer's time response as provided by the manufacturer. |

†Supported Anemometer Manufacturers:

| Manufacturer | Label |
|---|---|
| Gill Instruments, Ltd. | gill |
| Campbell Scientific®, Inc. | csi |
| Metek GmbH | metek |
| R. M. Young | young |
| Others | other_sonic |

‡Supported Anemometer Models:

| Manufacturer | Label |
|---|---|
| Gill R2 | t2 |
| Gill R3-50 | r3_50 |
| Gill R3-100 | r3_100 |
| Gill R3A-100 | r3a_100 |
| Gill HS-50 | hs_50 |
| Gill HS-100 | hs_100 |
| Gill WindMaster® | wm |
| Gill WindMaster Pro | wmpro |
| Metek USA-1 | usa1_standard |
| Metek USA-1 fast | usa1_fast |
| Campbell Scientific® CSAT3 | csat3 |
| R. M. Young | 81000 |
| Others | generic_sonic |

*Supported Gas Analyzer Manufacturers:

| Manufacturer | Label |
|---|---|
| LI-COR, Inc. | licor |
| others | other |

**Supported Gas Analyzer Models:

| Manufacturer | Label |
|---|---|
| LI-COR LI-6262 | li6262 |
| LI-COR LI-7000 | li7000 |
| LI-COR LI-7500 | li7500 |
| LI-COR LI-7500A | li7500a |
| LI-COR LI-7200 | li7200 |
| LI-COR LI-7700 | li7700 |
| Generic Open Path | generic_open_path |
| Generic Closed Path | generic_closed_path |
| Open Path Krypton Hygrometer | open_path_krypton |
| Close Path Krypton Hygrometer | closed_path_krypton |

The model label must be created by adding an "instrument order number" to the labels listed above. You must imagine creating two lists of instruments, one for anemometers and one for gas analyzers. The first instrument of the list that you describe, takes the number 1, and the label becomes "instrumentlabel_1". The second takes number 2, and so on. Note that in the dynamic metadata file (different from the alternative metadata file) you can only describe 1 anemometer. This feature is needed to provide maximum flexibility. As an example, think about the following suite of measurements and corresponding instruments:

- Wind and temperature from a Gill R3A-100
- $CO_2$ concentration from an LI-7500A
- $H_2O$ concentration from a different LI-7500A
- $CH_4$ concentration from an LI-7700

In this case, you can provide dynamic metadata for 4 different instruments, and the instrument model label will take the following values:

- master_sonic_model = r3a_100_1
- co2_irga _model = li7500_1
- h2o_irga_model = li7500_2
- ch4_irga_model = li7700_3

with the advantage the instruments for $CO_2$ and $H_2O$, although of the same model, are differentiated by EddyPro thanks to the attached number.

## Use Alternative Metadata File

Metadata is simply information about the dataset - or data on the data. It includes site information, instrument information, and a description of the raw file structure.

There are three scenarios in which you need to use an alternative METADATA file, rather than those embedded inside the GHG files:

- You need to process raw files others than GHG files;
- You want to process GHG files but information in the embedded METADATA files needs to be bypassed because it is incorrect, for example;
- You want to process GHG files but information in the embedded METADATA files can be bypassed, for example, because it is identical for all GHG files. In this case, using an alternative METADATA file will result in a faster processing.

In the first case, no METADATA file is available, so it must be created and saved using the Metadata File Editor. Learn more about the **Metadata File Editor**.

In the latter two cases, a METADATA file is available, so the process of creating the alternative METADATA file can be greatly simplified. Unzip any GHG file using an archive manager (such as 7zip or ZipGenius). Locate the extracted METADATA file and load it from the “Use alternative metadata file” **Load** button. Make changes if needed and save the file.

> **Important:** Using an alternative METADATA file means that all GHG files will be interpreted and processed using identical meta-information. This implies that DATA files must be all identical in structure and that dynamic variations of meta-information cannot be taken into account unless you provide a dynamic metadata file.

## Model (Gas Analyzer)

EddyPro® can correctly process data acquired with LI-COR gas analyzers, as well data from instruments from other manufacturers. Gas analyzers others than LI-COR are considered as “generic analyzers.” You can specify a “Generic Open Path” or “Generic Closed Path” analyzer. The main difference between processing data from a LI-COR instrument and a generic instrument is that for the latter ones, there are no model-specific corrections implemented. This means that you can get robust flux estimates from non-LI-COR instruments as long as your data do not need to undergo a processing step that is specific to your instrument. Data from such analyzers are processed in a “standard” way and according to the selected processing options, mainly depending on whether the instrument is open or closed path. Also, for such unknown instruments you need to specify the path lengths and time response, which are needed to estimated the associated high-frequency losses.

As a notable exception, EddyPro correctly processes data from open and closed path Krypton or Lyman-α hygrometers, by applying the required oxygen correction (Tanner et al., 1993; Van Dijk et al., 2003).

In the case of a LI-COR instrument, the most suitable corrections are applied automatically (and in the correct sequence) by EddyPro, ensuring the most accurate flux estimates.

## Longitudinal/Transversal Path Lengths and Time Response

If you selected a “Generic Anemometer” or a generic gas analyzer (which includes “Generic Open Path”, “Generic Closed Path”, “OP/CP Krypton hygrometer” and “OP/CP Lyman-α hygrometer”), you need to specify the longitudinal (parallel to the light path for gas analyzers, parallel to a transducer pair for anemometers) and transversal path lengths and time response. Refer to the documentation provided by the instrument manufacturer for this information.

> **Note:** The information needed here in terms of path length is used to estimate flux losses due to spatial averaging in the anemometer or gas analyzer's measuring volume. For laser-based gas analyzers, most likely the path length required here does not coincide with the optical path length, which can be meters or kilometers long. The quantity needed here has more to do with the size of the measuring cell. Refer to the instrument manufacturer for a quantification of the instrument's longitudinal and transversal path lengths.

## Beginning of Dataset

By convention, all output files of EddyPro® report results for each averaging interval, associating them with the timestamp of the ending minute of each interval, regardless of the convention used in the file names.

For example, imagine a 30 minute raw file with a name such as:

```
2011-02-15-1230_mysite.raw
```

with the timestamp referring to the beginning of the averaging period. It means the file contains data from 12:30 to 13:00 of 02/15/2010. Assume now that you select 15 minutes as a flux averaging period. From this file, you will get two result records with the following headings:

```
2011-02-15-1230_mysite.raw, 2011-02-15, 12:45

2011-02-15-1230_mysite.raw, 2011-02-15, 13:00
```

where the time refers to the end of each 15 minute block.

On the contrary, if the timestamp in the raw file name referred to the end of the averaging period, the file contained data from 12:00 to 12:30 and the corresponding result records would read:

```
2011-02-15-1230_mysite.raw, 2011-02-15, 12:15

2011-02-15-1230_mysite.raw, 2011-02-15, 12:30.
```

## Displacement Height

The displacement height (or zero plane displacement height) of a vegetated surface – usually indicated with *d* - is the height at which the wind speed would go to zero if the logarithmic wind profile was maintained from the outer flow all the way down to the surface (that is, in the absence of the vegetation). In other words, it is the distance above the ground at which a non-vegetated surface should be placed to provide a logarithmic wind field equal to observed one. By another point of view, it should be regarded as the level at which the mean drag on the surface appears to act (Jackson, 1981). For forest canopies, it is estimated to vary between 0.6 and 0.8 times the height of the canopy (Arya, 1998; Stull, 1988).

If not entered explicitly, EddyPro® computes the displacement height as:
$d = 0.67 \times \text{Canopy Height}$.

## Roughness Length

In the logarithmic wind profile, the roughness length is the height at which wind speed is zero (indicated by $z_0$). It provides an estimate of the average roughness elements of the surface. With vegetated surfaces, because the vegetation itself provides a certain roughness, the logarithmic wind profile goes to zero at a height equal to the displacement height plus the roughness length.

If not entered explicitly, EddyPro® computes the roughness length as $z_0 = 0.15 \times canopy\ \ height$.

## Axes Alignment

Some Gill Instruments sonic anemometers allow you to output wind components in two configurations: AXIS or SPAR. In the AXIS configuration, the *u* horizontal component is aligned with one transducer pair, while in the SPAR configuration it is aligned with the North spar, which is identified either by an N or a notch on the instrument body. The difference between the two configurations is a 30 degree yaw offset (refer to the anemometer manual for more details). If your sonic anemometer does not have an AXIS/SPAR configuration option, just select "N/A" (not applicable).

See also: Adjusting the Anemometer Coordinate System.

## North Offset

For post-mounted anemometers (e.g., Gill WindMaster® and Metek USA-1), a tag is normally provided to align the anemometer correctly with respect to the due north. The anemometer, however, can be placed in any position. If it is positioned with the north arrow aligned off of north, the yaw offset must be measured and provided here. The offset angle should be provided in degrees past north, positive if the angle that takes from geographic north to anemometer north spans clockwise (eastward). Yoke-mounted anemometers (Gill HS and Campbell® Scientific CSAT3) are normally oriented facing the prevailing wind direction and independently of due north. In these cases, provide the angle between the main axis of the anemometer (pointing away from the support arm) and due north, with the same sign convention as with vertical mounted anemometers.

## Head or Flow Distortion Correction

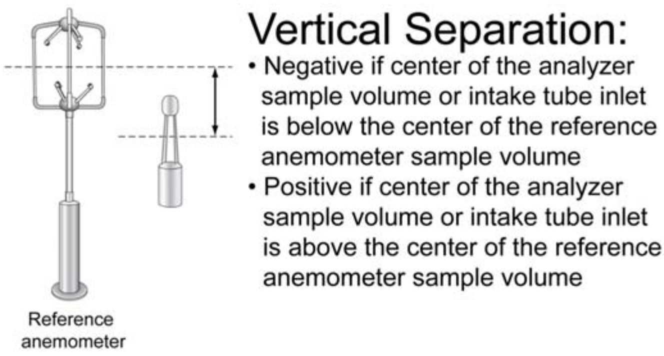
When the wind approaches with a considerable angle of attack (that is, from an angle other than horizontal), the frame of a post-mounted anemometers (such as Gill R2, R3, WindMaster, or Metek USA-1) distorts the flow, resulting in less accurate wind measurements. Furthermore, the transducer poles create a self-sheltering effect that also affects the measurement. This second effect also occurs with yoke-style anemometer (Gill HS and Campbell® Scientific CSAT3).

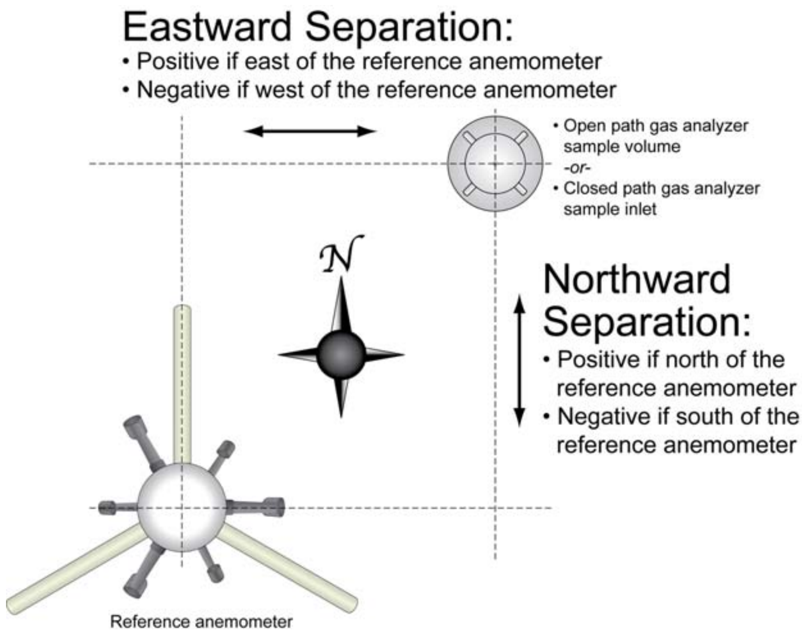
Several anemometer models use a firmware correction for these effects (referred to as “head correction,” “flow distortion correction,” or "angle of attack correction") and in some cases it can be turned on or off in the anemometer settings. Here you must specify whether the correction was applied in your anemometer(s) at the time data was collected.

## Northward, Eastward, and Vertical Separation

Measurement of the separation between the gas analyzer(s) and the sonic anemometer used is necessary to estimate the high-frequency flux losses due to the distance between the instruments that measured the vertical wind component and the gas concentration(s). Raw files might contain data from more than one anemometer. EddyPro®, however, will calculate fluxes using data from only one anemometer, which you select in the Processing Page.

In order to allow EddyPro to calculate the distance from a gas analyzer and the anemometer, distances are provided in a Cartesian coordinate system.






- Units must be provided in centimeters (cm).
- The first anemometer (reference anemometer) described in the METADATA file serves as the center of the coordinate system.
- Exact orientation of north-south and east-west axes are aligned with respect to true north, corrected for the local declination.
- For all gas analyzers and other anemometers (if any), the distances from the reference anemometer are provided along the north-south axis and the east-west axis.
- Distances are positive if the second instrument is to the north, east, or above the reference anemometer. This makes it possible for EddyPro to calculate distances between any pair of instruments.

## Sensitive and Non-sensitive Variables

In the Metadata File Editor, you can choose to **Ignore** a variable, specify if it is **Numeric** or not, and specify the **Variable** type. Ignore simply tells EddyPro® to ignore the field in processing. Select "yes" for variables that are not needed. This will speed up processing. For numeric variables, select yes to instruct EddyPro to treat it as a number. For Variable, choose the measurement type from the list.

***Sensitive variables** are recognized by the software and used for flux computation.* These variables can be selected from the drop-down list under **Variables** in **Raw File Description** tab of the Metadata File Editor.

**Table 6-1**. Sensitive variables recognized by EddyPro and used in flux computations.

| Name | Symbol | Description |
|---|---|---|
| *u* wind component | $u$ | Wind component along the anemometer x axis |
| *v* wind component | $v$ | Wind component along anemometer y axis |
| *w* wind component | $w$ | Wind component along anemometer z axis |
| horizontal wind intensity | $\rho$ | Intensity of wind vector with respect to anemometer horizontal plane |
| wind direction | $\theta$ | Wind direction with respect to anemometer North |
| sonic temperature | $T_s$ | Sonic temperature measured by the anemometer |
| speed of sound | *sos* | Speed of sound measured by the anemometer |
| $CO_2$ mole fraction | $\chi_{co2}$ | Mole $CO_2$ per mole of wet air |
| $CO_2$ mixing ratio | $r_{co2}$ | Mole $CO_2$ per mole of dry air |
| $CO_2$ molar density | $d_{co2}$ | Mole $CO_2$per cubic meter |
| $H_2O$ mole fraction | $\chi_{h2o}$ | Mole $H_2O$ per mole of wet air |
| $H_2O$ mixing ratio | $r_{h2o}$ | Mole $H_2O$ per mole of dry air |
| $H_2O$ molar density | $d_{h2o}$ | Mole $H_2O$ per cubic meter |
| $CH_4$ mole fraction | $\chi_{ch4}$ | Mole $CH_4$ per mole of wet air |
| $CH_4$ mixing ratio | $r_{ch4}$ | Mole $CH_4$ per mole of dry air |
| $CH_4$ molar density | $d_{ch4}$ | Mole $CH_4$ per cubic meter |
| $4^{th}$ gas mole fraction | $\chi_{pg}$ | Mole gas per mole wet air |
| $4^{th}$ gas mixing ratio | $r_{pg}$ | Mole gas per mole of dry air |
| $4^{th}$ gas molar density | $d_{pg}$ | Mole gas per cubic meter |
| cell temperature in | $T_{in}$ | Temperature at the inlet of the LI-7200 cell |

**Table 6-1**. Sensitive variables recognized by EddyPro and used in flux computations. (...-continued)

| Name | Symbol | Description |
|---|---|---|
| cell temperature out | $T_{out}$ | Temperature at the outlet of the LI-7200 cell |
| cell temperature | $T_{cell}$ | Average cell temperature of any closed/enclosed gas analyzer (LI-7200, LI-7000, LI-6262) |
| ambient temperature | $T_a$ | Temperature of ambient air as measured, for example, by an open-path analyzer (e.g., LI-7500, LI-7500A |
| ambient pressure | $P_a$ | Pressure of ambient air as measured, for example, by an open-path analyzer (e.g., LI-7500, LI-7500A) |
| LI-7500 diagnostic | - | Diagnostic flag output by the LI-7500 and LI-7500A. It is an integer value obtained as a combination of several binary flags. |
| LI-7200 diagnostic | - | Diagnostic flag output by the LI-7200. It is an integer value obtained as a combination of several binary flags. |
| LI-7700 diagnostic | - | Diagnostic flag output by the LI-7700. It is an integer value obtained as a combination of several binary flags. |

**Note:** Along with $CO_2$, $H_2O$, and $CH_4$, EddyPro can process a 4th gas that can be selected from among those listed in the drop-down list, or be completely customized (see the section on processing a generic passive scalar variable).

Diagnostic flags output at high frequency from LI-COR instruments are integer values that represent the combination of several binary flags, each providing information about the status of specific instrumental components (refer to the respective instruction manuals for more information on these flags). If raw files contain such a flag for one or more instruments, you can select them in the **Basic Settings** page. EddyPro will decipher them and provide you with the sum of the flagged samples in each raw file, which can help you to detect instrumental failures and filter results for quality. The only exception is the AGC value, for which EddyPro provides you the period-wise mean value, rather than the sum.

***Non-sensitive variables*** *are all those not used for flux computation.* EddyPro preserves these variables for a dedicated processing routine, which, includes despiking, tilt correction, detrending, time lag compensation and calculation of main statistics (mean values, variances, covariances, skewness and kurtosis). These variables include:

- Variables with a name explicitly entered in the **Variables** text box;
- All sensitive variables that are not selected for flux computation in the current processing project. For example, in a raw file there can be more than only $CO_2$ concentration measurements, from the same or from different instruments. However, only one $CO_2$ can be used at a time to calculate fluxes. The others are treated as non-sensitive variables.

Furthermore, as the data files can contain unused columns (to be ignored), EddyPro provides two options to declare useless variables. Selecting “ignore” or “not numeric” from the drop-down list will cause EddyPro to ignore the current column. The “not numeric” variable name is used to instruct EddyPro to skip the column as text. This is advisable because inherent limitations in file import capabilities of FORTRAN require files containing text columns to be read differently than purely numeric tables. This slows down the import process considerably. Selecting "not numeric" for columns containing text will enable the software to import data more quickly.

## Linear Scaling

EddyPro® allows a linear transformation to take each variable, either sensitive or non sensitive, from an input range to a defined output range. This operation is normally used to convert raw voltages into physical units, but it can be used for any other rescaling purpose. The linear transformation is performed by providing gain and offset scaling factors.

Conversions are performed according to:

$$X_{out} = \mathrm{Gain} \cdot X_{in} + \mathrm{Offset}$$

$X_{out}$ - output value
$X_{in}$ - input value
Gain - gain value
Offset - offset value

## Nominal, Minimal, and Maximum Time Lag

The name **time lag** refers to the delay with which the gas analyzer measures ambient quantities (concentrations, temperatures, pressures, etc.), with respect to the anemometer, taken as a reference. The anemometer provides measurements of an air parcel virtually instantaneously. The gas analyzer provides readings for the same parcel with a delay that can be due to: 1) the physical distance from the anemometer; 2) the need to take the air sample to the measuring cell through an intake tube (closed path analyzers).

The nominal time lag is the *expected* value of the delay time, which primarily depends on the distance between the measuring volumes and, for closed-path systems, the sampling line geometry and the flow rate. However, due to changing wind directions and possible instabilities of the flow rates, the actual time lag can deviate from the nominal one. In addition, transit time of water vapor along the intake tube of a closed path system can vary substantially with relative humidity, due to absorption/desorption processes at the tube walls.

For these reasons, a range of plausible time lags can be specified by providing its minimum and maximum values. Within this lag window EddyPro® attempts to determine the actual time lag for each averaging period, by means of the covariance maximization procedure. If not set explicitly, EddyPro will set nominal, minimum, and maximum time lag values according to meta-information available. Specifically, for closed path systems a nominal time lag ($\tau_{nom}$) is set by calculating the nominal transit time of the airflow along the intake tube, based on tube volume and the flow rate:

$$\tau_{\mathrm{nom}} = \frac{\text{tube length} \cdot \text{tube cross section}}{\text{flow rate}}$$

$$\tau_{\mathrm{min}} = \tau_{\mathrm{nom}} - 2$$

$$\tau_{\mathrm{max}} = \tau_{\mathrm{nom}} + 2 \cdot \tau_{\mathrm{nom}}$$

The range is set asymmetrically because it is more likely that the time lag will increase (due, for example, to lower flow rates caused by clogged filters), rather than decrease. The constant 2 in the last equation is replaced by 10 for water vapor, the reason being that the time lag of water vapor is observed to exhibit a strong dependence on relative humidity (e.g., Ibrom et al., 2007b)

For open path systems, by contrast, the nominal time lag is set to zero as the most likely value in sites that lack a prevailing wind direction. Minimum and maximum values are calculated based on the separation between the gas analyzer and the anemometer and a 0.5 m/s average wind speed:

$$\tau_{nom} = 0$$

$$\tau_{min} = \frac{-\text{sensor separation}}{0.5}$$

$$\tau_{max} = \frac{\text{sensor separation}}{0.5}$$

## Planar Fit Configuration Dialog

Under: Advanced Settings > Raw data processing > Rotation Method

Selecting either Planar Fit option (Standard Planar Fit and Planar Fit with no velocity bias) will cause the ***Planar Fit Settings*** button to activate. Click on it and access the planar fit configuration dialogue. Two options are available here: if you already have a planar fit rotation matrices file created by a previous EddyPro® run, which also applies to your current dataset, select the option ***Planar Fit file available*** and locate the corresponding file by using the ***Load*** button. Otherwise, select the option “Planar Fit file not available” and enter the following settings:

### Planar fit subset

- <u>Start date:</u> Starting date of the dataset to use for calculating planar fit rotation matrices
- <u>End date:</u> Ending date of the dataset to use for calculating planar fit rotation matrices

### Planar fit settings

- <u>Minimum number of elements per sector:</u> Set the minimum number of mean wind vectors (“elements”) to be used for each sector to assess the fitting plane and calculate the rotation matrix. The higher the number of elements, the more accurate the results, but also the longer the required planar fit subset.
- <u>Maximum mean vertical wind component:</u> Setting a maximum vertical wind component will cause EddyPro to ignore flux averaging periods with larger mean vertical wind components when calculating the rotation matrices. Using elements with too large (unrealistic) vertical wind

components would corrupt the assessment of the fitting plane and of the related rotation matrices.

- Minimum mean horizontal wind component: Setting a minimum horizontal wind component will cause EddyPro to ignore flux averaging periods with smaller mean horizontal wind components when calculating the rotation matrices. When the horizontal wind is very small, the attack angle may be affected by large errors, as would be the vertical wind component, resulting in poor quality data that would degrade the planar fit assessment.
- If planar fit calculations fail for a sector: Chose how EddyPro should behave if, for any given wind sector, planar fit sectors cannot be calculated (either because there are not enough wind data from that sector, because calculations fail, or because the sector was explicitly excluded, see below). Three options are available: use the planar fit rotation matrices calculated for the neighboring sector (counted either clockwise or counter-clockwise) or use double rotations.

Then use the visual tool to design the wind sectors. A few suggestions on the use of the designer:

- Use the + and – buttons to add or remove sectors;
- To remove a specific sector, click on it on the pie or on the table, and click on the – button;
- To create one only wind sector of 360°, click on the + button and click on "Set equally spaced" or, simply, double-click on the pie.
- To create N equally spaced wind sectors (of 360/N degrees), click N times on the + button and then click on "Set equally spaced";
- To create a sector that spans through the "North", use the "North offset first sector" field. Offset can go from -180 to + 180°;
- After creating 1 or more sectors, if you want to create a last sector to close the 360° angle, just double-click on the remaining empty portion of the pie;
- To instruct EddyPro to ignore any sector (i.e. not calculate the rotation matrix for that sector), uncheck it on the table.

The proper rotation matrix will then be used for each flux averaging period, according to the current mean wind direction.

> **Note:** The higher the number of sectors, the longer the planar fit subset must be, so as to assure that enough data are available for each sector to perform a robust bi-linear fit.

## Wind Speed Measurement Offsets

See also "Wind speed measurement offsets" on page 4-20.

Wind speed measurements by a sonic anemometer may be biased by systematic deviation, which needs to be eliminated (e.g., for a proper assessment of tilt angles). You can get such offsets from the calibration certificate of your units, or you can assess it easily by recording the 3 wind components from the anemometer enclosed in a box with still air (zero-wind test). Any systematic deviation from zero of a wind component is a good estimate of such bias.

## Magnetic Declination

The field identified as **North Reference** is used to tell EddyPro® what to use as North.

**Use magnetic North** simply instructs EddyPro to consider the reference North as magnetic North.

**Use geographic North** instructs EddyPro to compute the declination based upon the date and location (geographical coordinates). To accomplish this, EddyPro polls the United States National Oceanic and Atmospheric Administration (NOAA) web site for the correct declination. By default, EddyPro uses the current date, but you can specify the date in the drop-down menu.

**Note:** An Internet connection is required in order to retrieve the magnetic declination from the NOAA web site. EddyPro uses the International Geomagnetic Reference Field (IGRF11) model, which is described here: http://www.ngdc.noaa.gov/geomag-web/calculators/declinationHelp. To compute declination online, refer to the NOAA magnetic filed calculators at: http://www.ngdc.noaa.gov/geomag-web/#declination.

## Using Results from Previous Runs

Internally, processing raw data to get to corrected fluxes with EddyPro® happens in either 1 single step or 2 separate steps. This is carried out automatically by the software, so that you only need to click ***Run*** once and wait while EddyPro goes through the whole procedure and computes corrected fluxes. The two steps can be conveniently (though approximately) thought of as:

STEP1: raw data processing (RP hereafter)

STEP2: flux computation and correction (FCC)

However, in some cases (basically depending on the selected spectral correction method) the “flux computation and correction” calculations are performed within RP, so that the whole processing is performed using only STEP1. In all other cases, EddyPro goes through RP first and then uses partial results created by RP to feed the second step, FCC, and get to the final fluxes. In the first step (RP) raw data are imported, filtered, corrected and processed according to your selections, to extract all available information (mean values, covariances, uncorrected fluxes, turbulence parameters, etc.). If you selected a purely analytical spectral correction method - or no spectral correction at all - RP also corrects fluxes and provide final results. Otherwise, if you selected an in situ spectral correction method, RP outputs an intermediate results file (called “essentials”) containing all its results, that is passed on to FCC, which starts from there to calculate spectral corrections and finally, corrected fluxes. RP is by far the most time consuming processing step, reading in and processing thousands of raw files, each containing large datasets. FCC, in contrast, works on the calculated statistics, thus it is much faster (it takes roughly 10% of the overall processing time).

In general, for each new run, EddyPro should use both RP and FCC (with the exceptions described above) to get you to the final fluxes. However, if you already performed a run (let’s call it RUN1) with EddyPro and are now processing again (RUN2) the same data with different processing options, chances are that the RP step can be skipped, and the processing can start from results of RUN1, which would spare you a lot of execution time. The possibility of doing that depends on whether the new settings that you prepared for RUN2 are such that the processing steps performed in RP are identical between RUN1 and RUN2. In this case, EddyPro can start from the essentials results of RUN1, and just perform the remaining operations to compute a second set of results. All that you have to do here is to provide the ***Previous Output Directory***, where results from previous runs are stored. If a directory is provided, EddyPro will search inside that folder for all previous runs (so, make sure you store all your results in the same root directory, possibly organized in subdirectories for the sake of order) and, if one is found that matches the requirements (the control is performed on the older and the new “.eddypro” files), it will start from the partial results (the “essentials” file) of that run, and provide you with the final results of your new run.

In order for this mechanism to work, it is crucial that you do not alter or move some of the results files. At the end of each run, EddyPro creates a copy of the current ".eddypro" file in the output folder, where the essentials file is also stored. The two files are conceptually linked by the timestamp that appears in the file names. The ".eddypro" file is used to "evaluate" the previous run. As a good practice, you are invited not to eliminate the timestamp and the string "essentials" from the essentials file name. Furthermore, the paired ".eddypro" and essentials files need to be in the same folder. You are free to move and rename all other result files.

## Flags

Diagnostic flags reporting the status of instrumentation or instrument-defined quality assessment of the measurements can be streamed at high frequency along with actual measurements, so that they are found as a column (or a variable, in the case of binary files) in the raw files. Flags can be used to eliminate individual records (e.g., marked for poor quality) from further computations, thereby improving the quality of flux estimates. However, other variables can also be used in a similar fashion. For example, you may want to eliminate records, for which the vertical wind component is too large, or gas concentrations take on implausible values due to instrument failure. For this reason, in EddyPro® *any* variable (except those marked as ignore and/or not numeric) can be treated as a record flag, including variables used in flux computation.

In EddyPro, records elimination through flag marking is obtained by setting a threshold value for the selected flag variable and by defining whether records should be eliminated when the variable value goes above or below the threshold. For example, if you have a data column which is set to "0" for good quality and "1" for bad quality, you must: 1) select that variable as a flag; 2) set the threshold to 0.00; and 3) select "Discard if above threshold". This way, all records for which the variable takes the value "1" will be eliminated from the dataset. As a second example, suppose you want to use the gas concentration as such a flag, instructing EddyPro to eliminate all records for which a $CO_2$ concentration falls below 300 ppm. In this case, select the $CO_2$ variable as a flag, set the threshold to 300.00 and set the policy to "Discard if below threshold".

Make sure you enter the flag threshold in the units specified by EddyPro in the label following the threshold column. If units do not appear, use the same units used in the raw files.

> **Note:** If you describe more than one flag, EddyPro will eliminate all records flagged by at least one test. Note also that currently the same variable cannot be used in two different flag definitions. The result of such an operation is unpredictable; most likely, only the latest flag definition with the same variable will have an effect.

# 7 Calculation Reference

This section describes the steps executed by EddyPro® when it processes a data-set.

## Express Default Settings

The default settings in the **Advanced Settings** page correspond with the settings applied in Express Mode. These settings are given in the table below. In Express Mode, EddyPro® ignores any altered settings in the **Advanced Settings** page and it generates a predefined set of output files. Express Mode will not alter any user-specified settings in the **Advanced Settings** page.

| **Option** | **Settings** |
|---|---|
| Crosswind correction: | Not applied in EddyPro; assuming the correction was applied by the sonic anemometer. |
| **Processing Options** | |
| Axis rotation for tilt correction: | Double rotation |
| Turbulent fluctuations: | Block averaging |
| Time lag compensation: | Covariance maximization |
| **Statistical Tests** | |
| Spike count/removal: | Maximum number of consecutive outliers: 3<br>Accepted spikes: 1.0%<br>Replace spikes with linear interpolation: Yes<br>Plausibility ranges:<br>• W: 5.0 [σ]<br>• $CO_2$: 3.5 [σ]<br>• $H_2O$: 3.5 [σ]<br>• $CH_4$: 8.0 [σ]<br>• 4$^{th}$ Gas: 8.0 [σ]<br>• All other variables: 3.5 [σ] |

<table>
<tr><th>Option</th><th colspan="2">Settings</th></tr>
<tr><td>Amplitude resolution:</td><td colspan="2">Range of variation: 7.0 [σ]<br>Number of bins: 100<br>Accepted empty bins: 70%</td></tr>
<tr><td>Drop-outs:</td><td colspan="2">Percentile defining extreme bins: 10<br>Accepted central drop-outs: 10.0 [σ]<br>Accepted extreme drop-outs: 6.0%</td></tr>
<tr><td>Absolute limits:</td><td>Minimum<br>• U: -30.0 [m/s]<br>• W: -5.0 [m/s]<br>• $T_s$: -20.0 [°C]<br>• $CO_2$: 200 [μmol/mol]<br>• $H_2O$: 0.0 [mmol/mol]<br>• $CH_4$: 0.170 [μmol/mol]<br>• $4^{th}$ Gas: 0.03 [μmol/mol]</td><td>Maximum<br>• U: 30.0 [m/s]<br>• W: 5.0 [m/s]<br>• $T_s$: 50.0 [°C]<br>• $CO_2$: 600 [μmol/mol]<br>• $H_2O$: 40.0 [mmol/mol]<br>• $CH_4$: 1000 [μmol/mol]<br>• $4^{th}$ Gas: 1000 [μmol/mol]</td></tr>
<tr><td>Skewness and kurtosis:</td><td>Hard-flag threshold<br>• Skewness lower limit: -2.0<br>• Skewness upper limit: 2.0<br>• Kurtosis lower limit: 1.0<br>• Kurtosis upper limit: 8.0</td><td>Soft-flag threshold<br>• Skewness lower limit: -1.0<br>• Skewness upper limit: 1.0<br>• Kurtosis lower limit: 2.0<br>• Kurtosis upper limit: 5.0</td></tr>
<tr><td>Discontinuities:</td><td colspan="2">N/A</td></tr>
<tr><td>Time lags:</td><td colspan="2">N/A</td></tr>
<tr><td>Angle of attack:</td><td colspan="2">• Nakai et al. (2006) for Gill R2 and Gill R3 anemometers<br>• Nakai and Shimoyama (2012) for Gill WindMaster™ and Gill WindMaster™ Pro<br>• Not applied for all other anemometer models</td></tr>
<tr><td>Steadiness of horizontal wind:</td><td colspan="2">N/A</td></tr>
<tr><td>Spectral Corrections</td><td colspan="2"></td></tr>
<tr><td>Low frequency range:</td><td colspan="2">Analytic correction of high-pass filtering effects (Moncrieff et al., 2004)</td></tr>
<tr><td>High frequency range:</td><td colspan="2">Fully analytic method of Moncrieff et al. (1997)</td></tr>
</table>

> **Note:** Detrending in EddyPro Express Mode is performed by a block-averaging procedure, which calculates fluctuations around the average variable value, estimated on the whole averaging period. This implies that statistics at levels 6 and 7 are identical. However, for consistency with EddyPro Advanced and the original ECO2S, where detrending can be performed in other ways (such as linear detrending or running mean), the distinction is maintained. Similarly, the angle of attack correction may not be performed, depending on the processing choice and on the anemometer model. Accordingly, statistics at levels 2, 3 and 4 may or may not coincide.

## Preliminary Processing

In the course of a processing a project, EddyPro® carries out preliminary data processing before computing fluxes. Preliminary steps are described in this section.

### Importing Data

When you click the “Run” button in the EddyPro® interface, the program launches the processing module that, as a first step, reads the Processing Project file (“.eddypro”) compiled by the program, and then reports the settings specified in the graphical interface. Next, the processing module looks in the selected **Raw data folder** (and its subfolders if instructed to do so) and detects the names of all available raw files. By interpreting timestamps in the file names, the software prepares a chronological list of the files to be processed and creates a timeline, based on the timestamp of the first file and on the flux averaging interval specified in the interface. From this point forward, the timestamps in the filenames are no longer used as a timeline, but only to correctly time-reference the data in each file. Of course, if the flux averaging period is identical to the raw file duration, a perfect match of files timestamps and the timeline timestamps can be expected.

At this point the software is ready to start iterative processing of all available files. With each iteration, EddyPro reads files that are consecutive in time and loads the corresponding data. If a lag is found (e.g., because a file is missing) EddyPro stops the importation process and deals with the data that has been imported up to that point. At the next iteration, it will start from the next file available. After completing importation, EddyPro has loaded the *merged data-*

*set*, comprised of all data contained in the raw files read for the current iteration.

Once the merged dataset is prepared, EddyPro extracts the data needed for the first averaging period. In EddyPro this dataset is called the *averaging dataset*. If the merged dataset is longer than the one needed for the averaging dataset, EddyPro will make another iteration within the same merged dataset, trying to build up a second (and third, fourth and so on) averaging dataset.

## Defining the EddyPro® Dataset

The averaging dataset is comprised of all numeric data columns that were found in the raw file(s), including sensitive and non-sensitive variables. From this dataset, the *EddyPro dataset* (or *EP dataset*) is derived through the following operations:

If at least one column of the raw file is defined as a flag, EddyPro scans that column and filters individual data records according to the flag policy and value of the flag threshold. Recall that EddyPro supports up to two flag columns.

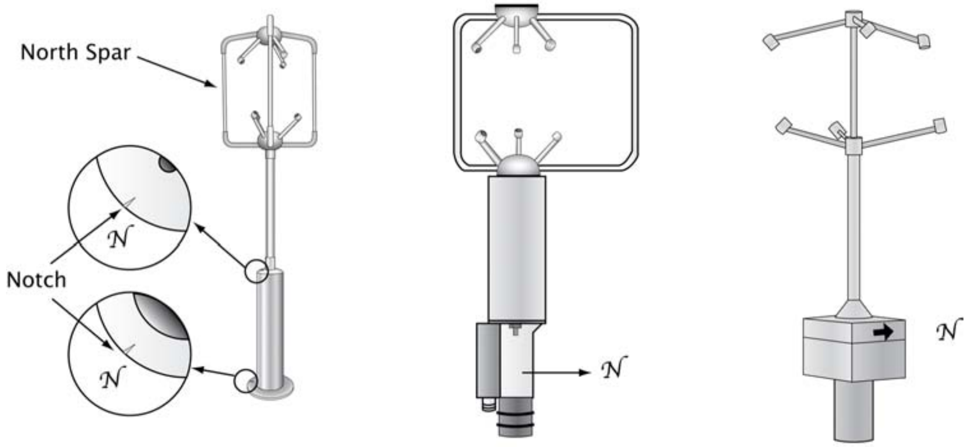
Variables of the averaging dataset are split into sensitive and non-sensitive variables. Sensitive variables are stored in the EP dataset, while non-sensitive variables are stored in what we call the *user dataset*. Starting from here, the two datasets undergo a different path of processing. In particular, the EPE dataset is used for the flux computation.

## Adjusting the Anemometer Coordinate System

Each anemometer model adopts a customized convention for providing wind components in an orthogonal coordinate system, so that the user is able to retrieve the actual wind direction with respect to geographic north. Anemometer north is shown by:

- On Gill post-mounted anemometers (e.g. R2, R3, WindMaster™, WindMaster™ Pro), by an “N” or a notch at the base;
- On Young 8100, by an “N”, and by the junction box (facing south);
- On Metek’s USA-1, by a black arrow on the electronic box or by a north bar on the sensor head;
- On Campbell Scientific® CSAT3 (yoke-styled), by the direction of the arm, opposite to the arm with respect to the transducers set;

- On Gill HS™ (yoke-styled), by the direction of the arm, opposite to the arm with respect to the transducers set;
- On Gill R3A™ by the direction of the symmetry axis, opposite to central spar.




R2, R3, WindMaster 81000 USA-1

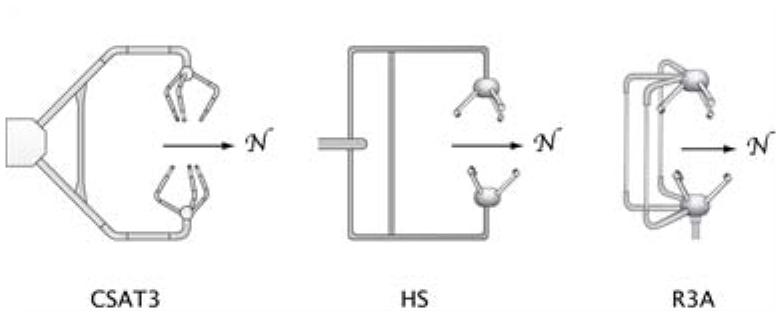



*Figure 7-1. North for asymmetric anemometer models.*

Any misalignment between anemometer north and geographic north is accounted in EddyPro® with the North offset, which is provided as part of the metadata (site information).

In addition to the definition of north, each anemometer model features a specific Cartesian coordinate system that can be right-hand (R3, HS, CSAT3, 8100) or left-hand (R2 and USA-1) and where a positive wind component can be defined as blowing *away from* or *toward* the positive axis orientation (see below).

EddyPro handles those differences by expressing wind components in a fixed right-hand coordinate system, where wind components in *x*, *y*, and *z* directions are indicated with *u*, *v*, and *w* respectively. Such a system coincides with the one used in the SPAR configuration Gill HS, R3, and WindMaster (see below).

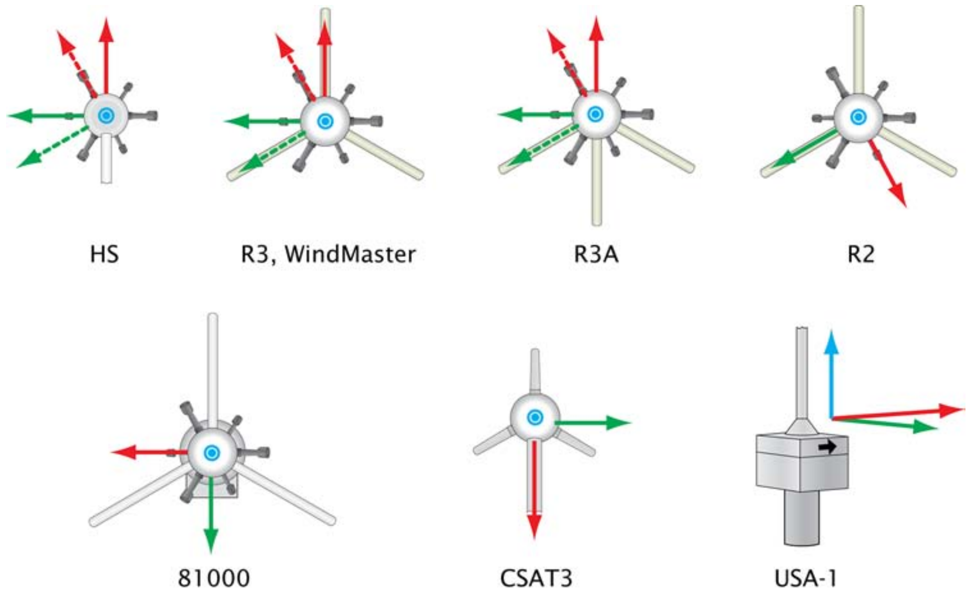



*Figure 7-2. Top view of various anemometer models (except USA-1, perspective view). Red arrows indicate the direction of positive u, green arrows indicate the direction of positive v, and blue arrows indicate the positive w, as provided by the anemometer. For Gill HS, R3, WindMaster, and R3A, solid arrows represent the coordinates in SPAR configuration, while dashed arrows are those AXIS configuration.*

To adjust coordinates, EddyPro changes the sign of one component of left-handed anemometers, and introduces a north offset (in addition to the one provided by the user) to rotate the original axis into the predefined system.

> **Note:** This offset is actually added only when calculating wind direction, and does not modify wind components. Thus, what one should expect is that EddyPro does not modify wind components of right-handed anemometers (at least until wind components are rotated for correcting anemometer tilting), while it inverts the sign of one horizontal component of left-handed anemometers, either *u* or *v*.

For example, the coordinate system of an R2 (left-handed) is adjusted by inverting the sign of the *u* components and by adding a North offset of -30°, while coordinate system of a CSAT3 (right-handed) is adjusted by solely adding a North offset of 180°.

## Calculating Relative Instrument Separations

EddyPro® can handle raw files containing data from multiple anemometers and multiple gas analyzers, with a maximum of 5 different instruments. The separation between any pair of instruments – notably between any anemometer and any gas analyzer – is calculated by EddyPro by evaluating distances in a Cartesian coordinate system. The first anemometer described in the METADATA file serves as the origin of such system and absolute separations for all other instruments (including other anemometers) are provided as a northward, eastward and vertical distances from the reference anemometer.

If, at processing time, you select a master anemometer other than the reference one, EddyPro will automatically calculate northward, eastward, and vertical relative separations of any gas analyzer from the selected anemometer, by means of simple differences of absolute separations. Then, the horizontal relative separation is evaluated from the northward and eastward separations. Horizontal and vertical separations are needed to estimate spectral losses according to Moncrieff at al. (1997). In addition, the three northward, eastward, and vertical relative separations are needed in a spectral correction method based on Horst and Lenschow, 2009.

## Calculating Cell Temperature (Closed path systems only)

The LI-7200 Enclosed $CO_2$/$H_2O$ Analyzer features two fast measurements of the cell temperature: one at the inlet ($T_{in}$) and one at the outlet ($T_{out}$) of the cell. It computes the average cell temperature ($T_{cell}$) with a weighted average of these two fast measurements as:

$$T_{cell} = 0.8 \cdot T_{out} + 0.2 \cdot T_{in}$$

You can select either or all of the three temperatures as outputs, which are stored in the raw files.

When the data are processed, however, $T_{in}$ and $T_{out}$ are used to compute $T_{cell}$ sample by sample, if the latter is not available. Thus, before any other processing step, EddyPro® does the following:

- If $T_{cell}$ is available, does nothing. In this case, EddyPro will ignore columns of $T_{in}$ and $T_{out}$ (if present in the raw files and selected for processing);

- If $T_{cell}$ is not available:
  - If $T_{in}$ and $T_{out}$ are both available, calculate $T_{cell}$ sample-by-sample using the weighted average equation above;
  - If $T_{in}$ is available and $T_{out}$ is not, sets $T_{cell}=T_{in}$;
  - If $T_{out}$ is available and $T_{in}$ is not, sets $T_{cell}=T_{out}$;
- If $T_{cell}$, $T_{in}$ and $T_{out}$ are not available, $T_{cell}$ is not defined. In this case, average cell temperature will be set equal to average sonic temperature (corrected for humidity effects).

## Despiking and Raw Data Statistical Screening

EddyPro® allows you to perform up to 9 tests to assess the statistical quality of the raw time series. Such tests, all derived from the paper of Vickers and Mahrt (1997), can be individually selected and configured to fit your dataset. EddyPro provides defaults for all configurable parameters, as derived from the original publication. For each test and for each concerned variable, EddyPro outputs a flag that indicates that the test was passed (0) or failed (1). If a test is not selected, the output value is 9. EddyPro does not filter results according to these flags. It is left up to the user to decide whether to investigate the flagged time series and assess them for physical plausibility.

### Spike Removal and Spike Test

The so-called *despiking* procedure consists in detecting and eliminating short-term outranged values in the time series.

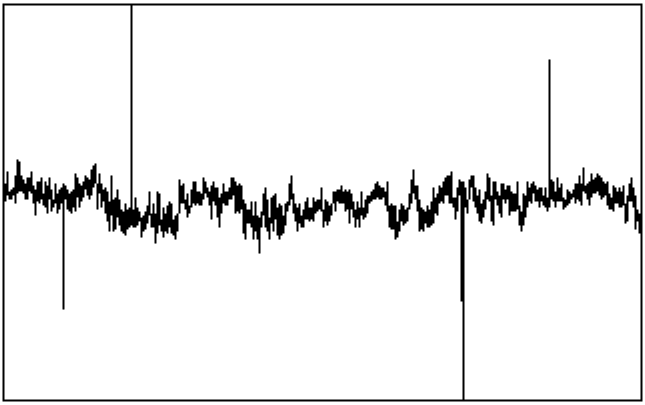


*Figure 7-3. Spikes in a typical data set.*

Following Vickers and Mahrt (1997), for each variable a spike is detected as up to 3 (settable) consecutive outliers with respect to a plausibility range defined within a certain time window, which moves throughout the time series. The rationale is that if more consecutive values are found to exceed the plausibility threshold, they might be a sign of an unusual yet physical trend. The width of the moving window is defined as one sixth of the current flux averaging period and the plausibility range is quantified differently for different variables. The table below provides EddyPro default values, that can be changed by the user. The window moves forward half its length at a time. The procedure is repeated up to twenty times, or until no more spikes are found for all variables. Detected spikes are counted and replaced by linear interpolation of neighboring values.

**Table 7-1**. Plausibility range for spike detection for each sensitive variable.

| Variable | Plausibility Range |
|---|---|
| *u*, *v* | window mean ±3.5 st. dev. |
| *w* | window mean ±5.0 st. dev. |
| $CO_2$, $H_2O$ | window mean ±3.5 st. dev. |
| $CH_4$, $N_2O$ | window mean ±8.0 st. dev. |
| Temperatures, Pressures | window mean ±3.5 st. dev. |

As an example, consider the time series in the figure below, where a time series is shown along with its mean value (gray line) and the plausibility range (blue lines). Here, the first 4 consecutive outliers on the left are considered as a local trend and not counted as a spike. On the contrary, the single red outlier on the right is considered as a spike.

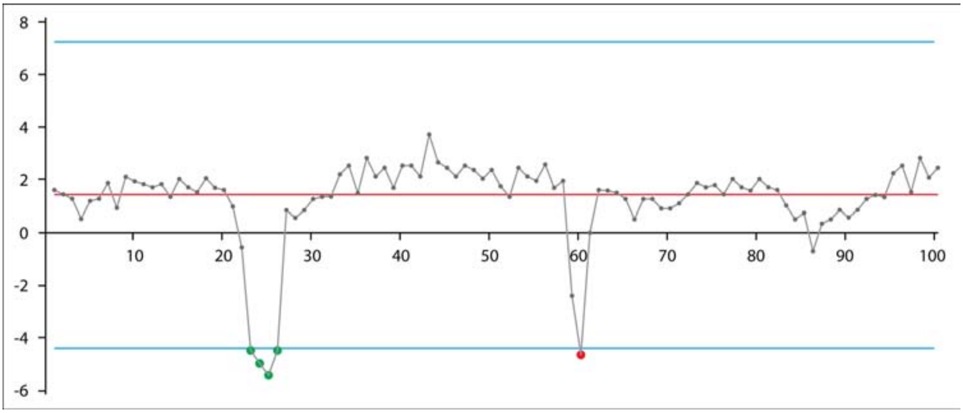



*Figure 7-4. Example of outliers not detected as a spike (green points) and as a spike (red data point) in EddyPro. The red line is the window mean, blue lines define the plausibility range.*

While despiking, EddyPro counts the number of spikes found. If, for each variable and for the flux averaging period, the number of spikes is larger than 1% (a user-settable value) of the number of data samples, the variable is hard-flagged for too many spikes.

> **Note:** 1, 2, or 3 consecutive outliers are counted as only one spike.

> **Note:** At each of the 20 iterations of the procedure, a spike that was detected (and replaced) at the previous repetition can appear again as a spike, due to the changed plausibility range; it is replaced thus again by linear interpolation, however it is not counted again for the purpose of flagging.

### Amplitude Resolution Test

For some records with weak variance (weak winds and stable conditions), the amplitude resolution of the recorded data may not be sufficient to capture the fluctuations, leading to a step ladder appearance in the data. A resolution problem also might result from a faulty instrument or data recording and processing systems (Vickers and Mahrt, 1997). This test attempts to detect these situations by assessing whether the number of different values each variable takes throughout the time series covers its range of variation with sufficient homogeneity. In a window moving throughout the time series, data for each variable are clustered into a user-specified number of bins and the frequency distribution is calculated. When the number of empty bins exceeds a critical threshold, the variable is flagged for a resolution problem. The range of variation for each variable is defined by the minimum among: 1) the difference between the maximum and the minimum value attained by the variable and 2) ±3.5 (a user-settable value) times the standard deviation of the variable in the current window.

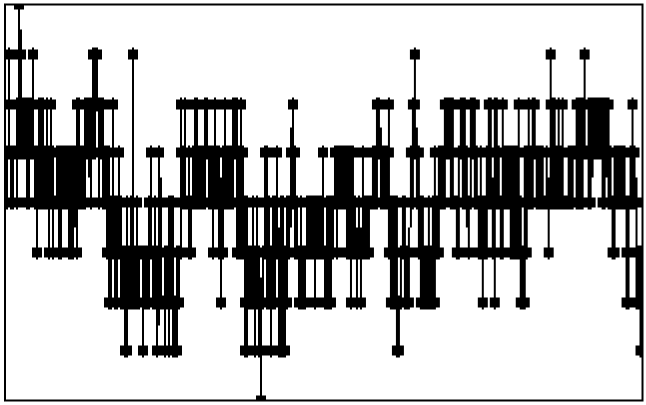


*Figure 7-5. Example of a time series affected by an instrument's poor resolution.*

### Drop-outs Test

The drop-outs test attempts to detect (relatively) short periods in which the time series sticks to some value that is statistically different from the average value calculated over the whole period. These values may well be within the measuring range of the instruments and within physically plausible values, but the time series stays for "too long" on a value that is far from the mean. This occurrence may be the sign of a short term instrument malfunction, for example due to rain or to the obstruction of the optical or sonic path or indicate an unresponsive instrument or electronic recording problems.

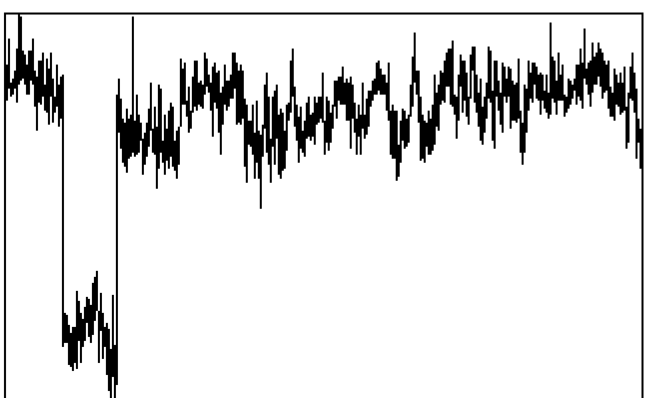


*Figure 7-6. Dropouts appear as short-lived periods in which the variable sticks to values statistically different from the overall trend.*

The test attempts at detecting drop-outs as too many consecutive values falling within bins too distant from the mean value of the time series. Extreme bins (as opposed to central bins) are expected to have smaller numbers of consecutive data points. Furthermore, fluxes are more sensitive to drop-outs in the extreme bins. Thus, thresholds are defined differently for extreme and central bins.

### Absolute Limits

This test simply assesses whether each variable attains, at least once in the current time series, a value that is outside a user-defined plausible range. In this case, the variable is flagged. The test is performed after the despiking procedure. Thus, each outranged value found here is not a spike, it will remain in the time series and affect calculated statistics, including fluxes. Therefore, it is mandatory to carefully set the expected plausible ranges for all variables and to consider each flux averaging period in which any variables are flagged for "absolute limits."

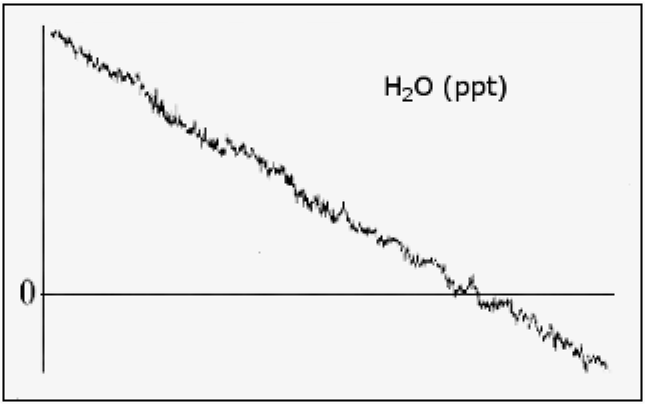



*Figure 7-7. Absolute limits set a bound on plausible data values.*

### Skewness and Kurtosis

Third and forth order moments are calculated on the whole time series and variables are flagged if their values exceed user-selected thresholds. Excessive skewness and kurtosis may help detect periods of instrument malfunction.

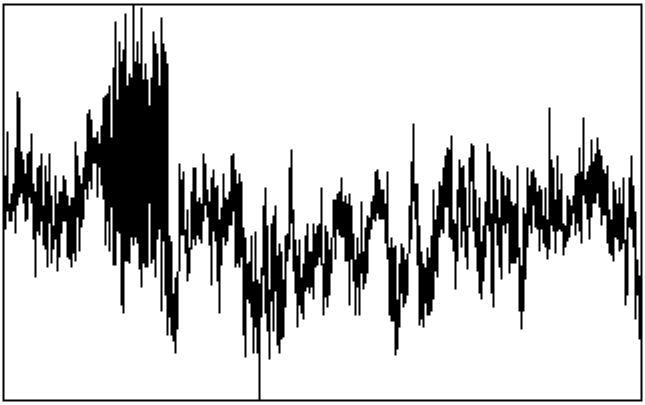


*Figure 7-8. Example of a time series flagged for excessive skewness and kurtosis.*

### Discontinuities

The goal of this test is to detect discontinuities that lead to semi-permanent changes, as opposed to sharp changes associated with smaller-scale fluctuations (Vickers and Mahrt, 1997). Discontinuities in the data are detected using the Haar transform, which calculates the difference in some quantity over two half-window means. Large values of the transform identify changes that are coherent on the scale of the window.

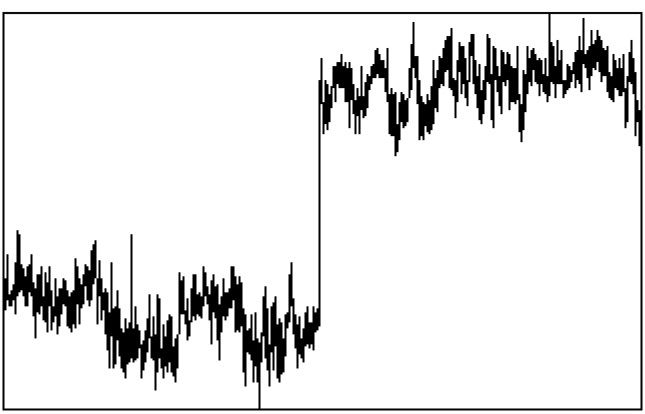


*Figure 7-9. Example of a time series featuring a "permanent" change in the mean value.*

### Time Lags

This test flags the scalar time series if the maximal *w*-covariances, determined via the covariance maximization procedure and evaluated over a predefined time-lag window, are too different from those calculated for the user-suggested time lags. That is, the mismatch between fluxes calculated with the expected time lags and with the "actual" time lags is too large.

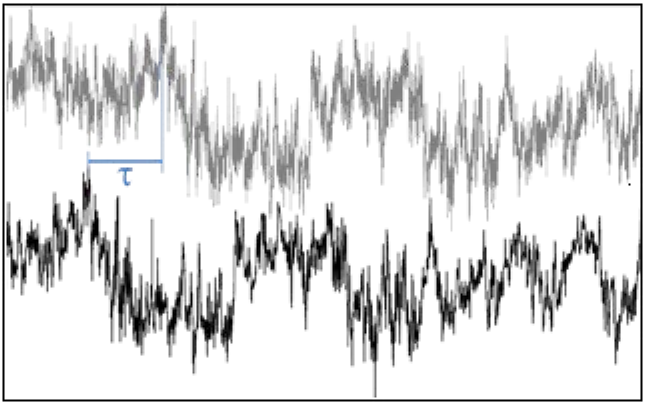



*Figure 7-10. Time lags are compensated by detecting the time difference in covariances or other methods.*

### Angle of Attack

This test calculates sample-wise angle of attacks throughout the current flux averaging period, and flags it if the percentage of angles of attack exceeding a user-defined range is beyond a (user-defined) threshold.

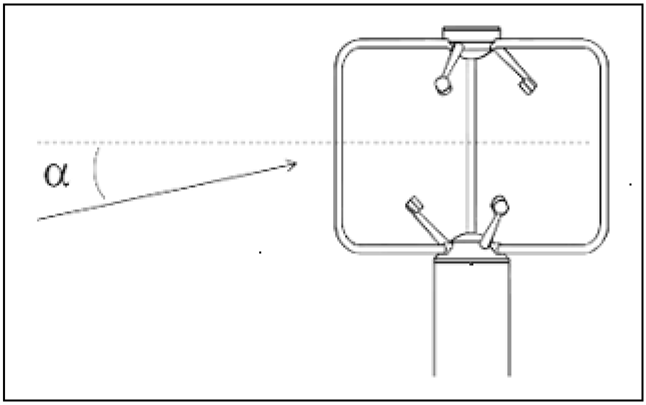



*Figure 7-11. The angle of attack test.*

### Steadiness of Horizontal Wind

This test assesses whether the along-wind and crosswind components of the wind vector undergo a systematic reduction (or increase) throughout the file. If the quadratic combination of such systematic variations is beyond the user-selected limit, the flux averaging period is hard-flagged for instationary horizontal wind (Vickers and Mahrt, 1997, Par. 6g).

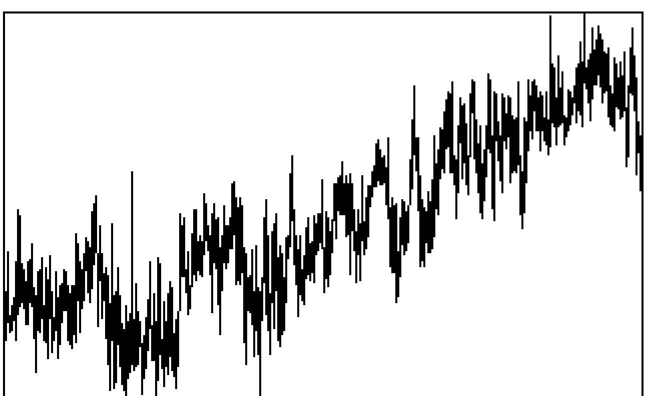


*Figure 7-12. Steadiness of horizontal wind assesses systematic changes in wind measurements in the time series.*

### Random Uncertainty Estimation

EddyPro® 4 can calculate flux random uncertainty due to sampling errors according to two different methods: Mann and Lenschow (1994) and Finkelstein and Sims (2001). Both methods require the preliminary estimation of the Integral Turbulence time-Scale (ITS), which – for our purposes – can be defined as the integral of the cross-correlation function. The cross-correlation function is given by:

$$R_{wc}(\tau) = \overline{w(\tau)c(t+\tau)}$$

where *w* is the vertical wind component, *c* is any scalar of interest (e.g., temperature, gas concentration, etc.), *t* is time and $\tau$ is the lag-time between the two time series. For $\tau$=0 the cross-correlation function provides the covariance of *w* and *c*; as $\tau$ attains values > 0 the cross-correlation function typically decreases towards values close to zero, representing an increasing un-correlation as $\tau$ increases (black line in Figure 7-13 below).

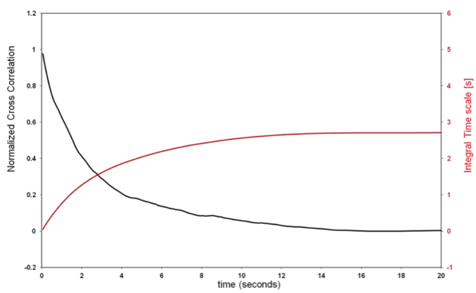



*Figure 7-13. Normalized cross correlation and integral time scale over time.*

The following integral represents the ITS:

$$ITS = \frac{1}{\overline{w'c'}} \int_0^{+\infty} R_{wc}(\tau)\, d\tau$$

The red line in the figure above represents the integral for any given value of the upper limit, which is theoretically set to infinite. In practical implementations, however, this integral must be stopped at a finite upper limit, which should be defined in such a way that the ITS represents the maximum correlation time of the two time series. EddyPro provides three possible ways of defining this upper limit:

**Cross-correlation first crossing 1/e:** The integral is stopped as soon as the cross-correlation function (which always starts at 1 for $\tau$=0) attains the value of 0.369. This gives the “shortest”, least conservative definition of the ITS. However, it provides the fastest execution and, more importantly, assures that a value of the ITS is virtually always found based on this definition. Furthermore, it provides the most consistent assessment of the ITS across different runs, because the shape of the cross-correlation function tends to be pretty consistent and similar to the one shown in the figure, for small values of $\tau$.

**Cross-correlation first crossing 0:** The integral is stopped as soon as the cross-correlation function (which always starts at 1 for $\tau$=0) crosses the x-axis. This definition provides a more conservative definition of ITS than the previous one, and is still "data-derived", i.e. it is not imposed by the user. The shortcoming with this definition is that the cross-correlation function may never cross the x-axis (in which case, EddyPro switches to the next definition); also when it does, the point in which it occurs may be somewhat random, as the cross-correlation function may vary erratically for large values of $\tau$.

**Integrate over the whole correlation period:** The integral is stopped when $\tau$ reaches the value defined in the field ***Maximum correlation period***, set by the user. This definition provides a conservative estimation but being imposed a priori, it does not assure that the cross-correlation function is actually close to zero at the upper integration limit. Also, the execution time may get longer with this choice, because the upper integration limit may be set arbitrarily high.

Once the ITS is calculated, the random uncertainty can be estimated. The random uncertainty of flux *F*, indicated with $\sigma_F$, is expressed in EddyPro as "absolute uncertainty", and takes the same units of the flux it refers to. The approach of Mann and Lenschow (1994) uses the following simple equation:

$$\frac{\sigma_F}{F} = \left(\frac{2 \cdot \text{ITS}}{T}\right)^{1/2} \left(\frac{1 + r_{wc}^2}{r_{wc}^2}\right)^{1/2}$$

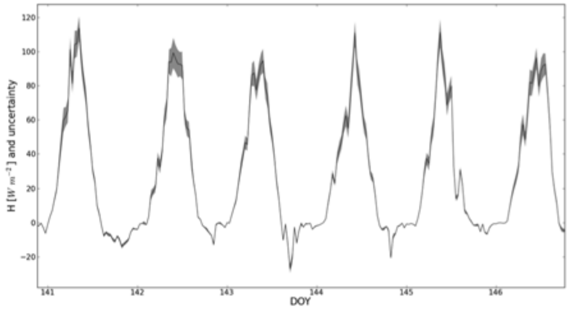
where $r_{wc}$ is correlation coefficient of $w$ and $c$ and $T$ is the flux averaging interval.

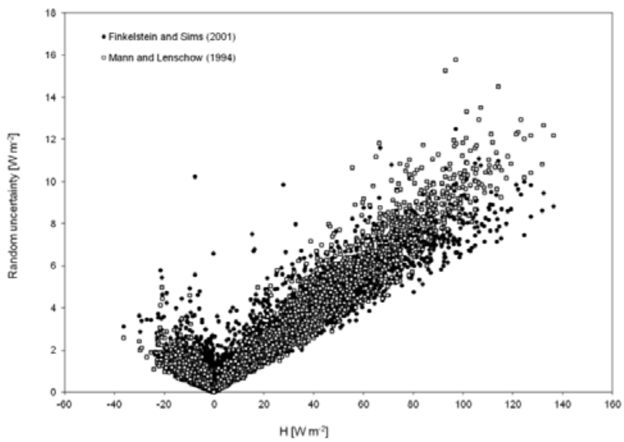
The approach of Finkelstein and Sims (2001), instead, is based on the calculation of the "variance of covariance" (their Eq. 8):

$$\sigma_F = \frac{1}{\sqrt{n}} \left( \Sigma_{p=-m}^{m} \gamma_{w,w}(p) \gamma_{c,c}(p) + \Sigma_{p=-m}^{m} (p) \gamma_{c,w}(p) \right)^{1/2}$$

with $\gamma_{w,w}(p)$, $\gamma_{c,c}(p)$, $\gamma_{w,c}$, and $\gamma_{c,w}(p)$ and given by Eq. 9 and 10 in the referenced paper, $n$ is the number of samples in the flux averaging interval and $m$ the discrete counterpart of the ITS (m = ITS * acquisition frequency).

The following figures exemplify the random uncertainty calculated for sensible heat fluxes:




## Crosswind Correction

In a 3-dimensional sonic anemometer, the sonic temperature (*$T_{si}$*) is estimated on each of the three measurement paths. The three estimates are then averaged into a single value of sonic temperature (*$T_s$*). The crosswind correction accounts for the effect of a wind component normal to the measurement path on each estimation of the sonic temperature:

$$\widetilde{T_s} = T_s + \frac{1}{3}\left(\frac{V_{n1}^2}{403} + \frac{V_{n2}^2}{403} + \frac{V_{n3}^2}{403}\right)$$

where $\widetilde{T}_s$ is the corrected sonic temperature and $V_{ni}$ is the wind component normal to the $i^{th}$ axis. Components $V_{ni}$ can be derived from actual (instantaneous) wind measurements in the anemometer's coordinate system with a simple geometrical transformation:

$$V_{n1} = A_1 u_m^2 + B_1 v_m^2 + C_1 u_m v_m$$

$$V_{n2} = A_2 u_m^2 + B_2 v_m^2 + C_2 u_m v_m$$

$$V_{n3} = A_3 u_m^2 + B_3 v_m^2 + C_3 u_m v_m$$

Where $u_m$ and $v_m$ are the measured wind components in the horizontal axes of the anemometer, and $A_i$, $B_i$, and $C_i$ are geometrical factors for th $i^{th}$ axis that depend on the geometry of the anemometer. Table 1 in Lui et al. (2001) gives geometrical factors for the following anemometers:

- CSAT3, Campbell Scientific®, Inc.
- R2, R3, R3A, HS by Gill Instruments
- USA-1 by Metek

**Note:** The correction is already applied in the firmware of some anemometers (e.g., the CSAT3). In these cases, applying the correction in EddyPro® will result in double accounting.

We recommend that you verify the settings in the instructions for your anemometer. Use the correction in EddyPro according to the following scenarios.

- *The correction is not implemented in the firmware.* In this case we suggest checking this option and let EddyPro perform the correction;
- *The correction is implemented in the firmware and it is not possible to turn it off.* In this case you should uncheck this option in EddyPro to avoid double accounting;
- *The correction is available in the firmware as an option.* In this case, you can decide to apply either the native correction or the EddyPro correction.

## Angle-of-Attack Correction

See "Angle of attack correction for wind components (Gill anemometers only)" on page 4-20 for more information.

The so-called angle-of-attack error arises due to the imperfect cosine response of an anemometer. When the wind approaches the anemometer with a considerable angle of attack (that is, at an angle that deviates significantly from horizontal), the frame of a post-mounted sonic (such as Gill R2, R3, WindMaster, or Metek USA-1) distorts the flow, resulting in inaccurate measurements. Furthermore, the transducer poles create a self-sheltering effect that also affects the measurement. This second effect also occurs with yoke-style anemometer (such as Gill HS and Campbell Scientific®, Inc. CSAT3).

Refining a method first described by van der Molen et al. (2004), Nakai et al. (2006) proposed a correction to compensate for the angle of attack error. A FORTRAN implementation, valid for R3-style Gill anemometers (also including R2, WindMaster™ and WindMaster™ Pro), is available at Taro Nakai's web page. The routine, developed by Taro Nakai and translated into FORTRAN by Michiel K. Van der Molen, was embedded into EddyPro® with minor modifications, after explicit authorization be the author.

The correction is implemented in EddyPro following Eq. 3-6 and bulleted procedure at p. 21 in Nakai et al. (2006). It is worthwhile to note that the application of this correction is virtually independent (Taro Nakai, personal communication) from the internal correction "applied to calibrate out the affects of the transducers and head framework" (cited from the R3/R3A User Manual, Gill Instruments Ltd.).

Nakai and Shimoyama (2012) further refine the correction, by carrying out a field experiment using Gill WindMaster™ anemometers, to overcome the critics to the correction of 2006 being derived from wind tunnel experiments. A C code for this new correction is available at Taro Nakai's web page. That code was translated into FORTRAN by G. Fratini and embedded in EddyPro® after authorization of the author. A stand-alone version of the same FORTRAN code is now also available at Nakai's software web page.

Considering which instrument models have been used to derive the corrections, we suggest applying the correction in its version of Nakai et al. (2006) when data from Gill R3 and Gill R2 are used, and using the version of Nakai and Shimoyama (2012) when using data from Gill WindMaster™ and WindMaster™ Pro.

At the present stage, it is unclear whether the correction shall be applied to the Gill HS, so we suggest you to refer to Gill for recommendations.

## Axis Rotation for Tilt Correction

See "Axis rotation for tilt correction" on page 4-21 for more information.

Tilt correction algorithms have been developed to correct wind statistics for any misalignment of the sonic anemometer with respect to the local wind streamlines. In particular, this implies that stresses and fluxes evaluated perpendicular to the local streamlines are affected by spurious contributions from the variance of along-streamlines components. Based mostly on Wilczak et al. (2001), EddyPro® supports three options for addressing anemometer tilting: the double rotation, triple rotation, and the planar fit method. Furthermore, the planar fit method is implemented in two different versions, as detailed in the following section.

### Double Rotation Method

With this method, the anemometer tilt is compensated by rotating raw wind components to nullify the average cross-stream and vertical wind components, evaluated on the time period defined by the flux averaging length. The rationale is that cross and perpendicular wind components average to zero during such time period. In the first rotation, the measured wind vector $u_m \equiv (u_m, v_m, w_m)$ is rotated about the $z$ axis into a temporary vector $u_{tmp}$, using a rotation angle $\theta$ such that the average crosswind wind component vanishes ($v_{tmp}=0$).

$$\theta = \tan^{-1}\left( v_m / u_m \right)$$

The first rotation equations are:

$$u_{tmp} = u_m \cos\theta + v_m \sin\theta$$

$$v_{tmp} = -u_m \sin\theta + v_m \cos\theta$$

$$w_{tmp} = w_m$$

The second rotation is performed about the new $y$-axis, using the angle $\phi$ that nullifies $w_{tmp}$:

$$\phi = \tan^{-1}\left( w_{tmp} / u_{tmp} \right)$$

The second rotation equations are:

$$u_{rot} = u_{tmp}\cos\phi + w_{tmp}\sin\phi$$

$$u_{rot} = v_{tmp}$$

$$w_{rot} = -u_{tmp}\sin\phi + w_{tmp}\cos\phi$$

The rotated vector $\boldsymbol{u_{rot}} \equiv (u_{rot},\ v_{rot},\ w_{rot})$ has zero *v* and *w* components, while its *u* component holds the value of the mean wind speed over the flux averaging interval.

> **Note:** In EddyPro rotation angles are evaluated using average wind components, but the rotation is applied sample-wise. That is, after the rotation the wind dataset is modified.

### Triple Rotation Method

The "triple rotation" method involves the first two rotations as described in 2.9.1 and a third rotation around the new x axis, where the roll rotation angle $\psi$ is defined to nullify the cross-stream stress component $(\overline{v'_{rot}\, w'_{rot}})$:

$$\psi = \tan^{-1}\left(\frac{2\overline{v_{rot}\, w_{rot}}}{\overline{v^2_{rot}} - w^2_{rot}}\right)$$

The third rotation equations are:

$$\tilde{u}_{rot} = u_{rot}$$

$$\tilde{v}_{rot} = v_{rot}\cos\varphi + w_{rot}\sin\varphi$$

$$\tilde{w}_{rot} = -v_{rot}\sin\varphi + w_{rot}\cos\varphi$$

Where $\tilde{u}_{rot} \equiv (\tilde{u}_{rot}, \tilde{v}_{rot}, \tilde{w}_{rot})$ is the triple rotated wind vector.

### The "Traditional" Planar Fit Method

The planar fit method (Wilczak et al., 2001) is based on the assessment of the anemometer tilt with respect to long-term local streamlines. This method is deemed more suitable in case of complex or sloping topography, when the mean vertical wind component or cross-stream stresses might actually differ from zero (Lee et al., 2004). In the planar fit method, the tilting is assessed by fitting a plane to the actual measurements of the average vertical wind component $\overline{w}_m$ , as a function of the horizontal components, $\overline{u}_m$ and $\overline{v}_m$ . The rationale is that if the anemometer is tilted with respect to the local streamlines, a certain amount of the horizontal wind speed will be found in the measured vertical component, and $\overline{w}$ will show a certain proportionality to (a linear combination of) $\overline{u}$ and $\overline{v}$ :

$$\overline{w}_m = b_0 + b_1\overline{u}_m + b_2\overline{v}_m$$

The fitting procedure involves a bilinear regression to determine the fitting parameters *$b_0$*, *$b_1$* and *$b_2$*. The two (partial) planar fit rotation angles are then defined so as to place the *z* axis perpendicular to the plane of the local streamlines and thus to nullify the long-term mean of the individual $\overline{w}$ values:

$$u_{pf} = M_{pf} \cdot u_m$$

where the rotation matrix *$M_{pf}$* is defined as:

$$M_{pf} = \begin{pmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{pmatrix} = \begin{pmatrix} \cos\alpha & 0 & -\sin\alpha \\ 0 & 1 & 0 \\ \sin\alpha & 0 & \cos\alpha \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\beta & \sin\beta \\ 0 & \sin\beta & \cos\beta \end{pmatrix}$$

and angles α and β are linked to the fitting plane coefficients by:

$$\sin\alpha = \frac{-b_1}{\sqrt{b_1^2 + b_2^2 + 1}} \quad \sin\beta = \frac{b_2}{\sqrt{b_2^2 + 1}}$$

$$\cos\alpha = \frac{\sqrt{b_2^2 + 1}}{\sqrt{b_1^2 + b_2^2 + 1}} \quad \cos\beta = \frac{1}{\sqrt{b_2^2 + 1}}$$

Equations 42-44 in Wilczak et al., (2001) provide a different formulation for the elements *$m_{ij}$*, valid also for large tilt angles. This is the formulation implemented in EddyPro.

A third rotation, similar to the first rotation in the Double Rotation Method, will align the wind vector with the main wind direction.

$$u_{rot} = u_{of}\cos\theta + v_{pf}\sin\theta$$

$$v_{rot} = -u_{pf}\sin\theta + v_{pf}\cos\theta$$

$$w_{rot} = w_{pf}$$

with $\theta = \tan^{-1}\left(\frac{v_{pf}}{u_{pf}}\right)$.

The planar fit method can be applied "sector-wise". In EddyPro you can define a number of (equally wide) wind sectors. The calculations will then be performed for each sector independently, and the appropriate rotation matrix will be applied, depending on the current wind direction.

### Planar Fit with no Velocity Bias

After verifying that the coefficient $b_0$ is not a proper estimator of the anemometer bias in the measurement of vertical wind component as suggested by Wiczak et al (2001), van Dijk et al. (2004) proposed a revision of the method, which assumes that any bias in the measurement of w is already accounted for in the anemometer calibration and thus that the fitting plane passes through the origin ($b_0$=0). Under these hypothesis the planar fit method reduces to

$$\overline{w}_m = b_1\overline{u}_m + b_2\overline{v}_m$$

with the same relations between $b_1$ and $b_2$ and the tilt angles as with the original planar fit. Both planar fit methods are available in EddyPro, with customizable planar fit settings, sectors, and more.

## Calculating Turbulent Fluctuations

See "Turbulent fluctuations" on page 4-22 for more information.

Different methods are described in literature for extracting turbulent fluctuations from time series data. The most commonly applied, in the context of eddy covariance, are the block-averaging, linear detrending (Gash and Culf, 1996) and two types of high-pass filters, namely the moving average (Moncrieff et al., 2004) and the exponentially weighted average (McMillen, 1988; Rannik and Vesala, 1999).

High-pass filters determine a local mean value in a time series by an averaging procedure that evaluates neighboring samples in order to extract a local trend and then removes this trend from the original data. The linear detrending method implies calculating deviations around any linear trend evaluated, for example, on the whole flux averaging period.

Block averaging, or Reynolds averaging, is the simple operation of calculating the mean value of the variable and calculating turbulence fluctuations as individual departures from the mean. There are benefits and drawbacks to all methods, related to the amount of genuine vs. artificial (e.g. instrumental drift) low frequency information that is eliminated when the trend is removed.

> **Note:** A block-averaging procedure is unavoidable at the moment when fluxes are evaluated by splitting the time series into flux averaging intervals. This procedure does partially dampen low frequency contributions as well.

For a thorough discussion refer to Moncrieff et al., 2004 and Rannik and Vesala, 1999.

## Converting Concentrations or Densities into Mixing Ratios

> See "Compensation of density fluctuations" on page 4-23 for more information.

For closed path gas analyzers, data may be converted to mixing ratios. At this point in the raw data processing, metadata concerning gas concentrations from closed path systems are analyzed by EddyPro® to autonomously decide whether to perform a sample-by-sample conversion into *mixing ratios* (*r*, moles of gas per mole of dry air). Expressing gas concentrations as mixing ratios is convenient because this makes it unnecessary to apply the WPL correction (Webb et al., 1980). It is an alternative way to account for air density fluctuations resulting from thermal expansion/contraction and concentration/dilution due to water vapor (see Ibrom et al., 2007b, for example). For a thorough discussion concerning the use of mixing ratios in closed path instruments, see Burba et al. (2011).

Conversion from mole fractions of any gas ($\chi_{gas}$, moles of gas per mole of wet air) into mixing ratios is performed according to:

$$r_{gas,i} = \chi_{gas,i} \frac{1}{1 - \chi_{h_2o,i}}$$

where $\chi_{h2o,i}$ is the mole fraction of water vapor and the subscript *i* is used to stress that these are "instantaneous" values (individual data samples).

Conversion of mole densities of any gas ($d_{gas}$, moles of gas per unit of volume) into mixing ratios is performed according to:

$$r_{gas,i} = d_{gas,i}\frac{v_{cell,i}}{1-\chi_{h_2o,i}}$$

where $v_{cell,i}$ (moles of wet air per unit of volume) is the molar volume inside the cell, evaluated for each data sample.

> **Note:** Actual units are handled automatically by EddyPro, as different gas concentrations might be measured with different units, due to their very different ambient concentrations, from the parts per thousand (*mmol/mol* or *ppt*) of water vapor to parts per billion of methane (*nmol/mol* or *ppb*).

However, these conversions are not always feasible. In particular, conversion of mole fractions into mixing ratios is performed if the following conditions hold:

1. The gas was measured by the same instrument that measured water vapor;
2. Water vapor is available as (or convertible into) mole fraction.

Conversion of molar densities into mixing ratios is performed if the following conditions hold:

1. The gas was measured by the same instrument that measured water vapor;
2. Water vapor is available as (or convertible into) mole fraction;
3. Fast cell temperature and pressure readings are available in the raw files.

If any of these conditions do not hold EddyPro applies the density correction following the classic WPL approach.

> **Note:** The conversion is performed before compensating eventual time lags, because water vapor, as an adsorbing/desorbing scalar, typically shows different time lags than passive scalars such as carbon dioxide (Ibrom et al., 2007b). The conversion must be performed using the water vapor concentration that was present in the cell at the moment the other scalar was measured. Compensating different time lags prior to the conversion would lead to the use of the wrong water vapor concentration sample for any given sample of the gas to be converted.

## Detecting and Compensating for Time Lags

> See "Selecting Advanced Processing Options" on page 4-20 for more information.

The last step of raw data processing in EddyPro®, prior to flux calculation and correction, regards the compensation of possible time lags between anemometric variables and variables measured by any other sensor, notably the gas analyzer(s). A time lag arises for different reasons in closed path and in open path systems.

The presence of the intake tube in closed path systems (with the inlet normally placed very close to the anemometer measuring volume) implies that gas concentrations are measured always with a certain delay with respect to the moment air is sampled. In addition, the residence time of sticky gases, such as $H_2O$, in the sampling line is a strong function of air relative humidity and temperature. Conversely, sonic anemometers measure wind speed and sonic temperature without detectable delays. In open path systems the delay is due to the physical distance between the two instruments (gas analyzer and anemometer), which are usually placed several decimeters or less apart to avoid mutual disturbances. The wind field takes some time to travel from one to the other, resulting in a certain delay between the moments the same air parcel is sampled by the two instruments.

It is a common practice to compensate for time lags before calculating covariances between anemometric variables and gas analyzer measurements. EddyPro provides four different methods for detecting and compensating time lags, besides the option of not compensating at all, which speeds up program execution but will almost certainly lead to systematic flux underestimations.

### Constant

In the Raw File Description table, you can enter ***Nominal time lags*** for variables not measured by the master anemometer. In closed path systems, a nominal time lag can be estimated from the volume of the intake tube and the average flow rate in the tube. In open path systems, a nominal lag can be computed by considering the transit time in the space between the instruments, with site-specific typical wind speeds and directions. Selecting *Constant* will instruct EddyPro to use such nominal values as fixed time lags. Using this option makes the program execution faster, because the automatic time lag detection procedure is avoided. However, this option is only suitable for closed path systems featuring an active control of the sampling line flow rate, such that the travel time of air in the tube does not change as a result of pump fluctuations, filter clogging, or any other reason. Also, this option is not recommended when measuring "sticky" gases such as $H_2O$, whose residence time varies according to climatic (RH, T) conditions, on account of sorption processes occurring at the tube walls (e.g., Runkle et al., 2012).

> **Note:** If you leave the Nominal time lag set to *zero*, EddyPro will automatically calculate the most plausible value for you.

### Covariance Maximization

A certain degree of uncertainty in the control over the flow rate (closed path) and the variability of wind regimes (open path) suggests an automatic time lag detection procedure, normally performed for each flux averaging period. Typically the detection is accomplished via the “covariance maximization” procedure, consisting in the determination the time lag that maximizes the covariance of two variables, within a window of plausible time lags (e.g., Fan et al., 1990):

$$Cov_{Max} = Cov(j_{\tau}) = \max_{j=m,..,M}\left(\sum_{i=1}^{N-j} w_i h_{i+j}\right)$$

In this equation, N is the total number of samples in the current flux averaging interval; m and M are the discrete counterparts of the minimum and maximum plausible time lags, respectively; $\tau$ is the best time lag estimate, and jz is its discrete counterpart. You can toggle between discrete indices and actual times in seconds by dividing the formers by the acquisition frequency ($f_a$, Hz), e.g., $\tau = j_\tau \bullet f_a^{-1}$.

The minimum and maximum plausible time lags are either taken from the ***Minimum time lag*** and ***Maximum time lag*** entered in the **Raw File Description** table or, if those are left at zero, automatically calculated by EddyPro.

### Covariance maximization with default

Selecting this option, if - during the covariance maximization procedure depicted above - a maximum is not attained within the plausibility window, a default is used, either taken as the ***Nominal time lag*** in the ***Raw File Description*** table or automatically calculated by EddyPro.

Using the covariance maximization procedure (either with or without default), a plausible time lag window has to be defined with the ***Minimum*** and ***Maximum time lags***, which constitute the end points of the plausibility window. A too narrowed plausible window might lead to frequent use of the default

(*Covariance maximization with default*) or either endpoint (*Covariance maximization*) time lag, because the actual time lag is often found outside defined plausibility range. This situation leads to systematic flux underestimations. Conversely, imposing a too broad plausibility window increases the possibility that unrealistic time lags are detected, especially when covariances are small and vary erratically with the lag time. These cases often result in flux overestimations. A trade-off must be reached between the two contrasting needs.

## Automatic time lag optimization

EddyPro also provides the possibility of analyzing the actual time lags found in the available dataset and determining the most suitable ***Nominal time lag*** and plausibility window (Minimum and Maximum time lags). This procedure implies a pre-processing step, before actually processing raw files, to statistically evaluate the most likely time lags and their ranges of variations. In this step, raw files are actually handled in a very similar manner as done later in the raw data processing step (e.g., despiking, angle-of-attack correction, detrending, etc.), but the processing stops at the calculation of the time lag. Here, the *Covariance Maximization* procedure is applied, adopting very broad (and user-customizable) time lag windows. Then, optimal time lags are calculated, in different ways for passive gases (e.g., $CO_2$, $CH_4$) and for $H_2O$.

### Time lag optimization for passive gases

For passive gases, whose time lag is not expected to depend on climatic conditions or other drivers, the nominal time lag is calculated as the median of all calculated time lags:

$$\tau_{nom} = \mathrm{median}\left(\tau_i\right)$$

where, for convenience, $\tau_i$ represents all time lags calculated from the available dataset.

The plausibility window is defined as:

$$\tau_{min} = \tau_{nom} - z * \mathrm{median}\left(\left|\tau_i - \tau_{nom}\right|\right) / 0.6745$$

$$\tau_{max} = \tau_{nom} + z * \mathrm{median}\left(\left|\tau_i - \tau_{nom}\right|\right) / 0.6745$$

where $z$ is a user-selectable parameter, that's optimal value was heuristically determined to be around 1.5.

**Note:** This assessment must be performed on a dataset long enough for calculating robust statistics. At least 1 month of data is recommended.

**Note:** The dataset used to optimize time lags must refer to a period, in which the sampling line did not undergo major modifications, such as replacement of tube or filters, change of the flow rate, etc. In the whole period, time lags are expected to be stationary.

### Time lag optimization for water vapor

The time lag of water vapor is a strong function of relative humidity (and secondarily, a function of temperature). Thus, for water vapor, nominal time lags and plausibility windows are assessed for relative humidity classes in the range 0 to 100%. In each class, the same definitions used for passive gases are also used:

$$\tau_{nom,\,class} = \text{median}\left(\tau_{i,class}\right)$$

$$\tau_{min,class} = \tau_{nom,class} - z * \text{median}\left(\left|\tau_{i,class} - \tau_{nom,class}\right|\right) / 0.6745$$

$$\tau_{max,class} = \tau_{nom,class} + z * \text{median}\left(\left|\tau_{i,class} - \tau_{nom,class}\right|\right) / 0.6745$$

where now the subscript class indicates that a different value is calculated for each class. Also here $z$ is a user-selectable parameter, with an optimal value is around 1.5.

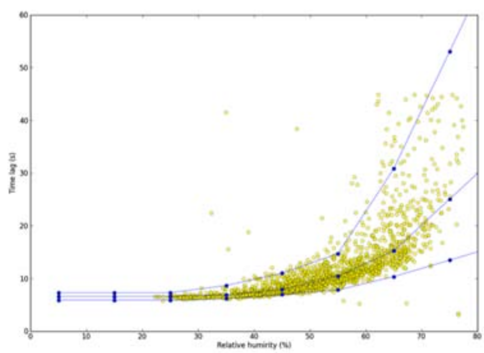
For each class, a minimum of 30 time lags need be present, for the statistics to be considered valid. Depending on the length of the dataset, such numerosity may not be reached for all class. In such cases, EddyPro behaves as follows:

- If the first $n$ classes do not have enough numerosity, their time lags (nominal, minimum, and maximum) are set equal to those of class ($n$ + 1);

- If the last $n$ classes do not have enough numerosity, their time lags are set to a linear extrapolation of classes ($n_t - n$) and ($n_t - n - 1$), where $n_t$ represent the total number of classes;
- If any intermediate class $i$ does not have enough numerosity, its time lags are set to the average of classes $i - 1$ and ($i + 1$).

> **Note:** Due to the class sorting, a much longer dataset is needed for water vapor. A minimum 2 months of raw data are deemed necessary, possibly spanning a broad range of climatic conditions. A longer dataset (> 6 month) will allow a more robust optimization.

The figure below shows the results of a time lag optimization procedure using 6 months of data. Yellow circles are actual time lags calculated using a very large time lag window while blue lines are nominal, minimum, and maximum time lags calculated by EddyPro as a function of RH, by means of the time lag optimization procedure.




> **Note:** During the following phase of raw data processing, the actual nominal, minimum, and maximum time lags are determined as a function of the current value of relative humidity.

## Calculating Spectra, Cospectra, and Ogives

EddyPro® allows calculation and output of most relevant spectra and cospectra. Namely spectra are available for the three wind components, the sonic temperature (or the alternative fast temperature reading used in place of sonic temperature, as applicable) and the gas concentrations/densities. Similarly, cospectra are available for covariances of w (vertical wind component) and all such variables. In the remainder of this paragraph we use the wording "(co)spectra" to refer to both spectra and cospectra.

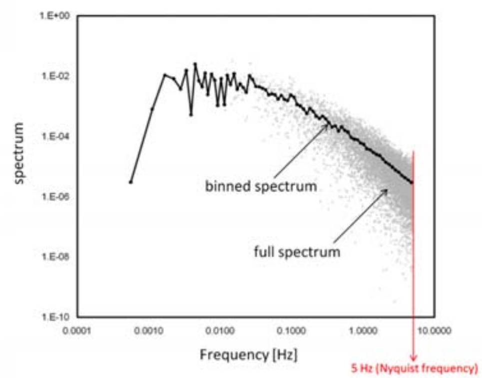
(Co)spectra are calculated after raw data have been fully processed, including the compensation of time lags, and are available in two different formats: either "full" or "binned". Full (co)spectra are calculated for each flux averaging period and contain a number of frequencies equal to half the number of raw records. As an example, a raw dataset of 18000 records (30 minutes at 10 Hz) will provide (co)spectra specified for 9000 frequencies, linearly distributed between the lower frequency of 1/(30 minutes) and the maximum frequency (the Nyquist frequency) of (10 Hz)/2. One property of full (co)spectra is that their integration over the entire frequency range provides the (co)variance of the concerned variables. For details on the derivation and interpretation of spectra and cospectra refer, for example, to Smith (1998).

However, the full (co)spectra dataset is difficult to handle because of the size of each individual (co)spectrum, and difficult to interpret because of the noise that typically affects the medium and high-frequency ranges. For these reasons, EddyPro also calculates and outputs reduced, or "binned" (co)spectra. The reduction procedure consists in dividing the frequency range in a user-specified number of exponentially spaced frequency bins (e.g. 100) and averaging individual (co)spectral values that fall within each bin. The exponential nature of the size increase of the bins assures that increasingly more spectral values are averaged as it moves toward higher frequencies, thereby increasingly reducing noise. The figure below shows an example of a full spectrum and the corresponding binned version.

Calculation of the full (co)spectra involves the following sequence of operations:

1. First, if one selects this option, raw time series are limited to a number of records equal to the power-of-two closest to the available number of records for the current flux averaging period. This step guarantees that the Fourier transforms are performed at the fastest speed possible. If you do not select this option, all available samples are used, but the computation slows down.
2. If applicable, statistics (variances and covariances) are now re-evaluated on the reduced time series and used later for (co)spectra normalization.
3. Fourier transform is performed by means of an FFT (Fast Fourier Transform) algorithm.
4. Full (co)spectra can now be calculated and output as selected by the user.

This procedure ensures that (co)spectra are such that their integration provides the corresponding (co)variances, as stated above.




The calculation of binned (co)spectra involves a slightly different sequence of steps:

1. First, if you select this option, raw time series are limited to a number of records equal to power of two closest to the available number of records for the current flux averaging period. This step guarantees that the Fourier transforms are performed at the fastest speed possible.
2. If applicable, statistics (variances and covariances) are now re-evaluated on the reduced time series and used later for (co)spectra normalization.
3. The reduced time series is now "tapered" using the selected tapering window. The tapering, (or windowing) procedure consists in multiplying (in a scalar sense) the time series with a suitable symmetric function. The aim, which you can learn in detail in Smith (1998), is to produce a time series that can be thought of as a part of an infinite periodic time series, to which the definition of discrete (co)spectra actually applies. Not applying the tapering procedure to short time series can result in spectral power overestimation. Kaimal and Kristensen (1991) suggested the use of the Hamming or the Hann windows. The figure below shows examples of tapering windows and the effect of their application to a time series. Also shown are the effects that different windows have on a sample spectrum.
4. The FFT is now applied to tapered time series are and full (co)spectra are calculated.
5. Full (co)spectra are normalized using relevant (co)variances.
6. Full (co)spectra are finally reduced into the exponentially spaced frequency base.

7. As a further option, EddyPro calculates and outputs ogives of all (co)spectra. At each given frequency, the ogive is simply the integration of the (co)spectrum from the current frequency to the Nyquist frequency. It can be thought of as a cumulative (co)spectrum, while its value at the lowest frequency provides the integration of the full (co)spectrum (i.e., the (co) variance). Ogives can be used to evaluate the suitability of the chosen flux averaging period.

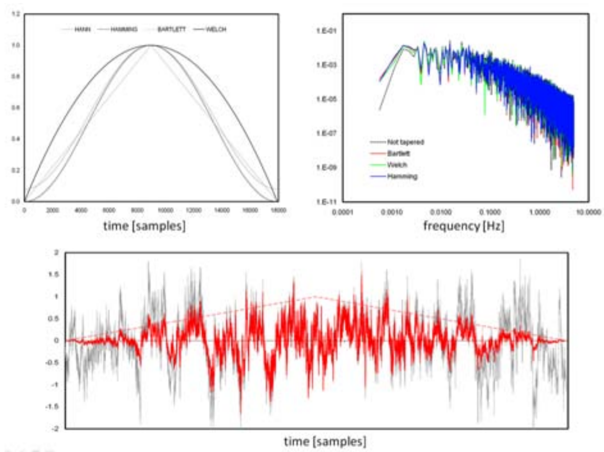



*Figure 7-14. Top left: Shape of tapering windows available in EddyPro. Top right: Effect of different tapering windows on a sample spectrum. Bottom: Effect (red) of the Bartlett window on a raw (gray) time series.*

## Ensemble Averaged Spectra and Cospectra

EddyPro® 4 can calculate averaged spectra and cospectra. However, because these quantities serve different purposes, the procedures for getting spectra and cospectra are different; also, these quantities are screened, sorted and averaged in different ways. So, let’s have a look at what EddyPro 4 does, why it does so, and what is available to you after the run.

### Ensemble Averaged Spectra of Passive Scalars

Ensemble averaged spectra of $CO_2$, $CH_4$ and a 4th passive gas are created when the corresponding raw data are available and if the spectral correction method of Horst (1997) or Ibrom et al. (2007a) was selected. Those correction methods are based on an in-situ determination of the EC system transfer function, which in EddyPro is performed as described in Ibrom et al. (2007), evaluating the underestimation of gas concentration variance via a comparison of the average spectrum of the gas under consideration, to that of (sonic) temperature, taken as a reference. The procedure involves the selection of “high-quality” spectra for both gases and temperature, performed on the basis of:

- the value of concerned fluxes
- the value of skewness and kurtosis of the concerned time series
- exclusion based on outranged spectral values

For this procedure, EddyPro uses binned spectra. This is the reason why, when one of these spectral correction methods is selected, the option “All binned spectra and cospectra” in the Output Files page is checked and deactivated: those methods requires those outputs. Once spectra have been selected as just described, they are averaged to get the results stored in the output file containing the identifier `passive_gases_ensemble_spectra` in its name. Refer to the output file descriptions for more details on the content of this output file.

### Ensemble Averaged Spectra of Water Vapor

Water vapor requires a different treatment respect to passive gases, because in closed-path systems its attenuation is strongly dependent on relative humidity (and secondary on temperature); for this reason, in addition to the screening procedure described above for passive gases, EddyPro sorts water vapor spectra into a user-defined number of relative humidity classes, to assess attenuation of $H_2O$ variance as a function of RH. Thus, you find ensemble averaged water vapor spectra in a separated output, identified by `h2o_ensemble_spectra` in the file name. Refer to the output file descriptions for more details on the content of this output file.

### Ensemble Averaged Cospectra Sorted by Time of the Day

Although not directly used for any calculation, EddyPro also calculates ensemble averaged cospectra of main fluxes (i.e., based on time series of w and gas concentrations/densities or temperature). In the output file identified by “ensemble_cospectra_by_time”, all available binned cospectra are sorted in 3-hour groups (from 00:00 to 03:00, from 03:00 to 06:00 and so on) so as to provide a “daily course” of average cospectral shapes. Before being considered for ensemble averaging, cospectra are screened for quality according to the following “soft” criteria:

- Sensible heat flux is greater than 5 W $m^{-2}$ (for all fluxes)
- Latent heat flux is greater than 3 W $m^{-2}$ (for $H_2O$);

- Absolute value of $CO_2$ flux is greater than 2 μmol $m^{-2}$ $s^{-1}$ (for $CO_2$);
- Absolute value of $CH_4$ flux is greater than $10^{-3}$ μmol $m^{-2}$ $s^{-1}$ (for $CH_4$);

**Note:** These cospectra are presented as function of the natural frequency, extending in the range defined by the inverse of the flux averaging interval to half the data acquisition sampling frequency.

## Ensemble Averaged Cospectra Sorted by Stability Regime

EddyPro sorts and averages cospectra according to the atmospheric stability regime, defined by the value of the Monin-Obukhov length L. Ensemble averaged cospectra are provided for unstable (-650 < L < 0) and stable (0 < L < 1000) stratifications. Before being considered for ensemble averaging, cospectra are screened for quality. Cospectra corresponding to stable stratifications are filtered using the same “soft” criteria described above, while cospectra corresponding to unstable stratifications are filtered using the flux thresholds entered by the user in the spectral correction configuration page (default values are used if the spectral correction page is not configured; default are visible in the GUI). In addition, EddyPro fits Massman’s model to the ensemble of individual cospectra.

$$\frac{nCo_{wc}(f)}{w'c'} = A_0 \frac{f/f_p}{\left(1 + \left(f/f_p\right)^{2\mu}\right)^{\frac{1.1667}{\mu}}}$$

where *n* (Hz) is the natural frequency, $f = (z-d)^* n/U$ is the normalized frequency and $A_0$, $f_p$ and $\mu$ are regression parameters. To perform this step, individual cospectra are expressed as a function of the normalized frequency. The overall normalized frequency range is defined a priori in EddyPro and extends from 1/4h up to 200 Hz. This is a wide range, which implies that often empty frequency bins are found in the output file, corresponding to normalized frequency ranges where no actual cospectral values were found. Finally, in the same output file, identified by the string `ensemble_cospectra_by_stability` in the name, “ideal” Kaimal cospectra are also found. For the stable regime, this is only a function of the normalized frequency. However, for the stable range, ideal cospectra are also a function of z/L. Thus EddyPro outputs Kaimal cospectra corresponding two extreme stable conditions, namely z/L = 0.01 (near neutral stratification) and z/L = 10 (strongly stable stratification).

## Calculating Ambient and Cell Statistics

At each relevant step of the raw data processing, statistics are calculated for all available variables, either sensitive or non-sensitive. Single-variable statistics include average, standard deviation, skewness, and kurtosis. Relevant covariances are also calculated, notably covariances among vertical wind component *w* and all other variables. In particular, covariances between *w* and ambient scalars such as gas concentrations or temperatures, used for flux estimates, are calculated after compensation of scalars time lags.

However, when a closed path instrument is used, other covariances might also be needed for correcting fluxes for the effect of air density fluctuations (Webb et al., 1980). Namely, for each given gas, the covariances $\overline{w'c'_{h2o}}$ and $\overline{w'T'_{cell}}$ (where $c_{h2o}$ is water vapor concentration expressed in any suitable units) are needed, calculated after compensating $c_{h2o}$ and $T_{cell}$ *using the time lag of the gas under consideration*. Here, of course EddyPro® checks that water vapor is measured by the same instrument that measures the concentration of the gas considered. Otherwise, the covariance $\overline{w'c'_{h2o}}$ is not calculated.

If you wish to learn more about accounting for air density fluctuations in closed path systems, refer to Ibrom et al. (2007b), for example.

## Calculating Ambient and Cell Parameters

The time lag compensation is the last step of raw data reduction. Covariances calculated after time lag compensation will be used to calculate uncorrected and corrected fluxes. Before actually calculating fluxes, EddyPro® evaluates some key average ambient variables such as temperature, pressure, and molar volume. The same quantities are calculated for the cell of each closed path gas analyzer in use (if any).

### Average ambient temperature

In order of priority, ambient temperature ($T_a$, *K*) is calculated as:

1. The average ambient temperature, if ambient temperature is available as a raw measurement; or
2. The average sonic temperature. In this case, it will be corrected later to account for effects of ambient humidity (Schotanus et al., 1983).

### Average ambient air pressure

In order of priority, ambient pressure ($P_a$, *Pa*) is computed as:

1. The average ambient pressure, if ambient pressure is available as a raw measurement; or
2. The site barometric pressure, calculated based on site altitude as (Campbell and Norman, 1998):

$$P_a = P_{a0} e^{-\text{Site Altitude}/8200}$$

where $P_{a0}$=101.3 *kPa*.

### Average ambient air molar volume

Ambient air molar volume ($v_a$, $m^3 mol^{-1}$) is calculated using ambient air temperature and pressure as:

$$v_a = \frac{\Re T_a}{P_a}$$

where $\Re = 8.314$ J $mol^{-1} K^{-1}$, the universal gas constant.

### Average cell temperature (closed path systems only)

In order of priority, cell temperature ($T_c$, *K*) is calculated as:

1. The average cell temperature, if cell temperature is available as a raw measurement or as calculated in calculating cell temperature, or
2. The average ambient temperature as calculated above.

### Average cell pressure (closed path systems only)

In order of priority, cell pressure ($P_c$, *Pa*) is calculated as:

1. The average cell pressure, if cell pressure is available as a raw measurement; or
2. The average ambient pressure as calculated above.

### Average cell molar volume (closed path systems only)

Cell air molar volume ($v_c$, $m^3$ $mol^{-1}$) is calculated using cell temperature and pressure as: $v_c = \frac{\Re T_c}{P_c}$ where $\Re = 8.314$ J $mol^{-1} K^{-1}$, the universal gas constant.

## Calculating Average Gas Concentrations and Densities

After having calculated ambient and cell molar volumes, for each available gas EddyPro® can calculate average concentrations expressed as mole fractions and mixing ratios, as well as average molar densities. The equations used are:

$$r_{gas} = \chi_{gas} \frac{1}{1 - \chi_{h2o}}$$

$$r_{gas} = d_{gas}\frac{v}{1-\chi_{h2o}}$$

where symbols have the usual meaning (see Converting raw gas density to mixing ratio) used here to indicate mean values, averaged over the flux averaging interval, and *v* is either ambient the air molar volume, $v_a$, or the cell molar volume $v_c$, depending on whether gases are measured from an open path or a closed path system, respectively.

These equations are combined appropriately, depending on the available measurements, to calculate unknowns.

> **Note:** For $CH_4$ measurements made with the LI-7700 Open Path $CH_4$ Analyzer, EddyPro reports mixing ratio and mole fraction values that are corrected for spectroscopic effects. It reports average number density values that are not corrected for spectroscopic effects. Refer to the LI-7700 Instruction Manual for more information.

## Calculating Micrometeorological Variables

Before calculating fluxes, EddyPro® calculates an additional set of micrometeorological parameters, which are used to calculate corrected fluxes or for future analysis of calculated fluxes. These are listed and briefly described here.

### Molecular weight of wet air ($M_a$, *kg mol*$^{-1}$)

Calculated as the sum of molecular weights of dry air and water vapor, weighted by the water vapor mole fraction:

$$M_a=M_{h2o}\bullet\chi_{h2o}+M_d\bullet(1-\chi_{h2o})$$

where the subscript *d* is used for quantities referring to dry air, and where $M_d$=0.02897 kg mol$^{-1}$ and $M_{h2o}$=0.01802 kg mol$^{-1}$.

### Ambient water vapor mass density ($\rho_{h2o}$, *kg m*$^{-3}$)

Calculated form water vapor mole fraction as:

$$\rho_{h2o} = \frac{\chi_{h2o}\cdot M_{h2o}}{v_a}$$

### Water vapor partial pressure (*e*, *Pa*)

Calculated from the ideal gas law:

$e=\rho_{h2o}R_{h2o}T_a$

where $R_{h2o} = \mathfrak{R} / M_{h2o}(J\,kg^{-1}K^{-1})$, is the water vapor gas constant.

### Water vapor partial pressure at saturation (*$e_s$*, *Pa*)

Calculated after Campbell and Norman (1998) as:

$$e_s = T_a^{-8.2} e^{77.345+0.0057 \cdot T_a - 7235 \cdot T_a^{-1}}$$

(*e*=2.7182, the base of the exponential function, not the water vapor partial pressure)

### Relative humidity (RH, %)

RH is computed according to its definition as:

$$RH = \frac{e}{e_s} \cdot 100$$

### Water vapor pressure deficit (*VPD*, *Pa*)

It is given by the difference between actual water vapor pressure and its saturation value:

$VPD = e - e_s$

### Dew point temperature (*$T_{dew}$*, *K*)

It is calculated after Campbell and Norman (1998) as:

$$T_{dew} = 240.97 \cdot \frac{\ln\left(\frac{e}{0.611}\right)}{17.502 - \ln\left(\frac{e}{0.611}\right)} + 273.16$$

where *e* is intended to be in *kPa*.

### Dry air partial pressure (*$P_d$*, *Pa*)

This is given simply by the difference between total (ambient) pressure and water vapor partial pressure.

$P_d = P_a - e$

### Dry air molar volume (*$v_d$*, *$m^3 mol^{-1}$*)

It is calculated after Ibrom et al. (2007b) as:

$$v_d = v_a \frac{P_a}{P_d},$$

this formula has the same result as the direct application of the ideal gas law.

### Dry air mass density ($\rho_d$, $kg\ m^{-3}$)

From the ideal gas law:

$$\rho_d = \frac{P_d}{R_d T_a},$$

where $R_d = \Re / M_d\ (J kg^{-1} K^{-1})$ is the dry air gas constant.

### Moist air mass density ($\rho_a$, $kg\ m^{-3}$)

It is given by the sum of dry air and water vapor mass densities:

$$\rho_a = \rho_d + \rho_{h2o}.$$

### Dry air heat capacity at constant pressure ($c_{p,d}$, $J\ kg^{-1}\ K^{-1}$)

It is calculated as a function of temperature as:

$$c_{p,d} = 1005 + \frac{(T_a + 23.12)^2}{3364},$$

where $T_a$ is expressed in degrees Celsius.

### Water vapor heat capacity at constant pressure ($c_{p,h2o}$, $J\ kg^{-1}\ K^{-1}$)

It is calculated as a function of temperature and relative humidity as:

$$c_{p,h2o} = 1859 + 0.13RH + \left(0.193 + 5.6 \cdot 10^{-3} RH\right) \cdot T_a + \left(10^{-3} + 5 \cdot 10^{-5} RH\right) \cdot T_a^2,$$

where $T_a$ is expressed in degrees Celsius.

### Specific humidity ($Q$, $kg\ kg^{-1}$)

It is calculated according to its definition as:

$$Q = \frac{\rho_{h2o}}{\rho_a}.$$

### Refining ambient temperature ($T_a$, $K$)

If ambient air temperature was calculated from sonic temperature, it is now corrected for the effect of ambient moisture content (van Dijk, 2004, eq. 3.49):

$$\widetilde{T}_a = \frac{T_a}{1 + 0.51Q}\cdot$$

Otherwise, if ambient air temperature was calculated by averaging raw data of ambient air temperature, $T_a$ does not need a correction. In this case, a temperature mapping factor ($T_{map}$) is calculated to rescale covariances that involve sonic temperature fluctuations arising from possible errors in the estimation of the acoustic path length of the anemometer (van Dijk, 2004):

$$T_{map} = \frac{T_a}{T_s} \Rightarrow \overline{T_s' x'} \rightarrow \overline{T_s' x'} \cdot T_{map}$$

where $x$ is any other variable, notably $w$.

### Refinement of cell temperature ($T_c$, $K$) (closed path systems only)

Cell temperature is now updated to account for the effect of ambient moisture content if, in the previous calculation, it was set equal to ambient air temperature. Recall that this happens only when no temperature reading from inside the cell is available.

### Moist air heat capacity at constant pressure ($C_p$, $J\ kg^{-1}\ K^{-1}$)

It is calculated as a function of ambient moisture content as:

$$c_p = c_{p,d}(1 - Q) + c_{p,h2o}Q$$

### Specific evaporation heat ($\lambda$, $J\ kg^{-1}$)

It is calculated as a function of ambient air temperature:

$$\lambda = 10^3(3147.5 - 2.37T_a)$$

### Water to dry air density ratio ($\sigma$, non-dimensional)

It is given by:

$$\sigma = \frac{\rho_{h2o}}{\rho_d}$$

## Iterative Calculations of Micrometeorological Variables

If, throughout the calculation of micrometeorological variables, sonic temperature was used as a proxy of air temperature, this is refined at the end to account for the effect of ambient humidity. Thus, an iteration is performed to recalculate all micrometeorological variables (including air temperature) with the refined temperature estimates. One iteration typically improves the estimates by about 1-2%, while further iterations normally do not bring detectable improvements. Obviously, if a "native" ambient air temperature measurement is available, the iteration is not performed.

# Calculating Fluxes

After completing preliminary calculations, EddyPro® can start evaluating fluxes, starting from uncorrected fluxes. With 'uncorrected fluxes' gas, energy, and momentum fluxes are obtained by merely adjusting units of relevant covariances, in order to match the desired output units.

This operation may imply the inclusion of some previously calculated physical parameters. These fluxes are 'uncorrected' because some effects are not accounted for in their calculation, notably the effects of air density fluctuations, of spectral losses, and effects of humidity on air temperature estimation through the sonic anemometer. Furthermore, sensors-specific effects such as the so-called off-season uptake effect for the LI-7500 and the spectroscopic effects for the LI-7700 are not taken into account in uncorrected fluxes.

All these effects, instead, are addressed later, with different paths of processing depending mainly on the type of analyzer used (closed or open path). In fact, EddyPro calculates a total of 4 levels of fluxes (from level '0', uncorrected fluxes, to level '3', fully corrected fluxes). However, only level '0' and level '3' are provided in the output. Intermediate levels '1' and '2' are not provided, mainly because they assume different meanings in different situations, thus their interpretation may be ambiguous and their utility is limited.

In the following sections, along with common fluxes, we also describe how cell fluxes are evaluated for the purpose of evaluating WPL terms in closed path systems. In general, the expression 'cell fluxes' refers to the sensible heat and evapotranspiration fluxes as evaluated by using cell covariances.

## Calculating Turbulent Fluxes Level 0 (Uncorrected Fluxes)

Level 0 fluxes are uncorrected. They are computed according to the following equations:

### Ambient sensible heat flux, uncorrected (*H, W m^-2*)

$$H_o = \rho_a c_p \overline{w' T_s'}$$

### $CO_2$ flux, uncorrected (*$F_{0,co2}$, μmol $m^{-2}$ $s^{-1}$*)

If $CO_2$ is measured as molar density with an open path analyzer:

$$F_{0,co_2} = 10^3 \cdot \overline{w'd'_{co_2}}$$

If $CO_2$ is measured as molar density with a closed path analyzer:

$$F_{0,co_2} = 10^3 \cdot \overline{w'd'_{co_2}}$$

If $CO_2$ is measured as mixing ratio:

$$F_{0,co_2} = \frac{1}{v_d} \cdot \overline{w'r'_{co_2}}$$

If $CO_2$ is measured as mole fraction:

$$F_{0,co_2} = \frac{1}{v_a} \cdot \overline{w'\chi'_{co_2}}$$

### $H_2O$ flux, uncorrected (*$F_{0,co2}$, mmol $m^{-2}$ $s^{-1}$*)

If $H_2O$ is measured as molar density with an open path analyzer:

$$F_{0,h_2o} = \overline{w'd'_{h2o}}$$

If $H_2O$ is measured as molar density with a closed path analyzer:

$$F_{0,h_2o} = \overline{w'd'_{h_2o}}$$

If $H_2O$ is measured as mixing ratio:

$$F_{0,h_2o} = \frac{1}{v_d} \cdot \overline{w'r'_{h_2o}}$$

If $H_2O$ is measured as mole fraction:

$$F_{0,h_2o} = \frac{1}{v_a} \cdot \overline{w'\chi'_{h_2o}}$$

### $CH_4$ flux, uncorrected: (*$F_{0,ch4}$, μmol $m^{-2}$ $s^{-1}$*)

If $CH_4$ is measured as molar density with an open path analyzer:

$$F_{0,ch_4} = \overline{w'd'_{ch_4}}$$

If $CH_4$ is measured as molar density with a closed path analyzer:

$$F_{0,ch_4} = \overline{w' d'_{ch_4}}$$

If $CH_4$ is measured as mixing ratio:

$$F_{0,ch_4} = \frac{1}{v_d} \cdot \overline{w' r'_{ch_4}}$$

If $CH_4$ is measured as mole fraction:

$$F_{0,ch_4} = \frac{1}{v_a} \cdot \overline{w' \chi'_{ch_4}}$$

**Latent heat flux, uncorrected (*$LE_0$, W $m^{-2}$*)**

$$LE_0 = 10^{-3} F_{0,h_2o} \cdot \lambda \cdot M_{h_2o}$$

**Evapotranspiration flux, uncorrected: (*$E_0$, kg $m^{-2}$ $s^{-1}$*)**

$$E_0 = 10^{-3} F_{0,h_2o} \cdot M_{h_2o}$$

**Momentum flux, uncorrected: (*$T_0$, kg $m^{-1}$ $s^{-2}$*)**

Calculated after van Dijk et al. (2004), eq. 2.85

$$T_0 = \rho_a \sqrt{\overline{u'w'}^2 + \overline{v'w'}^2}$$

**Friction velocity (*$u_*$, m$s^{-1}$*)**

Calculated according to its definition as: $u_* = \left(\overline{u'w'}^2 + \overline{v'w'}^2\right)^{1/4}$

**Potential temperature (*$T_p$, K*)**

Calculated according to:

$$T_p = T_a \cdot \left(\frac{P_{0,a}}{P_a}\right)^{0.286}$$

where $P_{0,a}=10^5 Pa$, and is the reference pressure.

**Monin-Obukhov length (*L,m*)**

Calculated according to its definition as:

$$L = -\frac{T_p u_*^3}{\kappa \cdot g \cdot \frac{H_0}{\rho_a c_p}}$$

where κ=~0.41, and is the von Kármán constant; g=~9.81 m $s^{-1}$, and is the gravity.

### Monin-Obukhov stability parameter (ζ, non-dimensional)

ζ is calculated as: $\zeta = \frac{h_m - d}{L}$

where $h_m$ is the measurement height above the ground, as measured in the center of the anemometer measurement volume, and *d* is the displacement height.

### Dynamic temperature (*T*., *K*)

Calculated according to its definition (e.g., Foken and Wichura, 1996):

$$T_* = -\frac{\overline{w'T_s'}}{u_*}$$

## Accounting for Density Fluctuations Induced by Instrument-related Heat Exchange (LI-7500 only)

See "Add instrument sensible heat components (LI-7500)" on page 4-25 for more information.

When $CO_2$ and $H_2O$ molar densities are measured with the an LI-7500 in cold environments (low temperatures below -10 °C), a correction should be applied to account for the additional instrument-related sensible heat flux, due to instrument surface heating/cooling. The correction is fully described and tested in literature (Burba et al., 2008; Grelle and Burba, 2007; Jarvi et al., 2009). EddyPro® implements the correction according to Table 1, Method 4 of Burba et al. (2008), which involves calculating a corrected sensible heat flux ($\widetilde{H}$) by adding estimated sensible heat fluxes from key instrument surface elements, including the bottom window ($H_{bot}$), top window ($H_{top}$), and spar ($H_{spar}$) - to the ambient sensible heat flux (*H*):

$$\widetilde{H} = H + H_{bot} + H_{top} + 0.15 \cdot H_{spar}$$

where the factor 0.15 accounts for the possibility that the heat flux may or may not enter the instrument path.

Additional sensible heat fluxes are calculated according to equations in the same Table 1 (Nobel's (1983) formulation) and the implied surface temperatures are estimated either with linear equations similar to those in Eqs. 3-8 in Burba et al. (2008), using slope and offset parameters from Table 3 in the same paper, or with multiple linear regression relationships between instrument temperatures and controlling factors (Table 2 in Burba et al., 2008). Corrected sensible heat flux is only used for calculating WPL terms when gas densities are measured by an LI-7500.

> **Note:** In results files and elsewhere, the used and reported sensible heat is the environmental one (*H*). We also stress again that this correction does not apply to data measured with an LI-7500A.

## Calculating Multipliers for Spectroscopic Corrections (LI-7700)

When an LI-7700 $CH_4$ analyzer is used, methane fluxes are calculated using Eq. 5.1 of the LI-7700 Instruction Manual. In this equation, which is formulated to highlight the correction terms for air density fluctuations (Webb et al., 1980), multipliers A, B, and C are specific of the LI-7700 analyzer, accounting for spectroscopic effects of temperature, pressure, and water vapor on methane molar density (***A***), spectroscopic effects of pressure and water vapor on the latent heat flux (***B***), and spectroscopic effects of temperature, pressure and water vapor on sensible heat flux (***C***). These multipliers are defined as:

$$A = \kappa$$

$$B = 1 + \left(1 - 1.46\overline{\chi_{h_2o}}\right)\alpha_v \overline{P_e}\frac{\kappa_{Pe}}{\overline{\kappa}} = 1 + \left(1 - 1.46\chi_{h_2o}\right) \cdot GROUP_1$$

$$C = 1 + \left(1 - \overline{\chi_{h_2o}}\right)T_a\frac{\kappa_T}{\overline{\kappa}} + \overline{\chi_{h_2o}}(B - 1)$$

$$= 1 + \left(1 - \overline{\chi_{h_2o}}\right) \cdot GROUP_2 + \overline{\chi_{h_2o}}(B - 1)$$

where groups of parameters have been conveniently created ($GROUP_1$ and $GROUP_2$). Refer to LI-7700 Instruction Manual for a detailed description of all parameters and variables that appear in these equations. For a description and testing of the correction please refer to (McDermitt et al., 2010).

The groups $\overline{\kappa}$, $GROUP_1$ and $GROUP_2$ are functions of air temperature ($T_a$), and equivalent pressure ($P_e$) and tabulated values are available with a resolution of 1° C and 1 kPa, for -50 to 55 °C and 50 to 115 kPa. Given actual values of $T_a$ and $P_e$ (the latter being a function of air pressure and water vapor mole fraction, $\chi_{h2o}$). EddyPro® employs a look-up table (LUT) and performs a bi-linear interpolation to calculate the best estimates of the three groups. Once the values of $\overline{\kappa}$, $GROUP_1$ and $GROUP_2$ have been obtained, multipliers ***A***, ***B***, and ***C*** can be calculated according to equations above, and kept available for the later calculation of methane fluxes.

> **Note:** The multipliers, as a function of air temperature, pressure and water vapor mole fraction, must be recalculated for each averaging period.

## Calculating Spectral Correction Factors

Spectral corrections compensate flux underestimations due to two distinct effects:

- Fluxes are calculated on a finite averaging time, implying that longer-term turbulent contributions are under-sampled at some extent, or completely. In EddyPro, the correction for these flux losses is referred to as *high-pass filtering* correction because the any detrending method acts similar to a high-pass filter, by attenuating flux contributions in the frequency range close to the (inverse of the) flux averaging interval.
- Instrument and setup limitations that do not allow sampling the full spatiotemporal turbulence fluctuations and necessarily imply some space or time averaging of smaller eddies, as well as actual dampening of the small-scale turbulent fluctuations. In EddyPro®, the correction for these flux losses is referred to as *low-pass filtering* correction.

In EddyPro, spectral corrections for high-pass filtering are implemented after Moncrieff et al. (1997). For any given flux, the spectral correction procedure requires a series of conceptual steps (for a thorough overview of spectral corrections in eddy covariance see, Ibrom et al. (2007a) and Massman (2004) for example):

1. Calculation or estimation of a reference flux cospectrum, representing the true spectral content of the investigated flux as it would be measured by a

perfect system;

2. Estimation of the high-pass and low-pass filtering properties implied by the actual measuring system and the chosen averaging period and detrending method;
3. Estimation of flux attenuation;
4. Calculation of the spectral correction factor and application of the correction.

In the implemented method, true cospectra estimation (step 1) is performed by using analytical cospectra formulations, according to Eqs. 12-18 in Moncrieff et al. (1997), a modification of the Kaimal formulation (Kaimal, 1972). Flux cospectra ($CO_F$) are expressed as a function of the natural frequency, $CO^F(f)$, and depend primarily of the considered flux (momentum, sensible heat or gas fluxes), on atmospheric stratification and wind speed and on the measuring height above the canopy. For this reason, cospectra must be recalculated at each flux averaging period.

Step 2 is usually performed by specifying a band pass transfer function ($TF(f)$), describing how individual flux contributions at each natural frequency are represented in the measured fluxes, due to the EC system properties and the processing choices (see the figure below). In the implemented method, the system transfer function is specified by the superimposition of a set of transfer functions describing individual sources of high-frequency or loss-frequency losses. Refer to Appendix A of the Moncrieff et al. (1997) for the full description of the transfer functions. Such transfer functions depend on the instrumental setup (through the instruments' path lengths, acquisition frequencies, separations etc.) but also on the atmospheric conditions (because some quantities are defined as a function of the average wind speed), thus they must be recalculated for each flux averaging period.

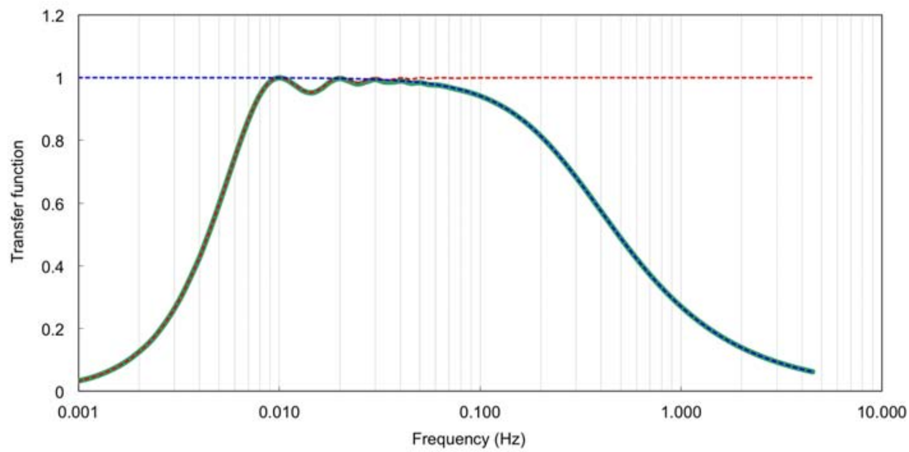



*Figure 7-15. Representation of the transfer function of a band-pass filter (green line), obtained as the superimposition of the transfer functions of a high-pass (red line) and a low-pass (blue line) filter.*

Spectral correction factors are calculated for each averaging period and for each mass and energy flux. The exact moment in which the correction is applied depends mainly on the instrument(s) used (open vs. closed path configurations), due to the interaction with other corrections. This is thoroughly explained in Calculating Level 1, 2, and 3 Fluxes, and Calculating Fluxes with Open Path Analyzers.

## High-pass Filtering Correction

See "Low frequency spectral correction" on page 4-26 for more information.

In EddyPro, high-pass filtering correction is applied (if requested) following Moncrieff et al. (2004). True flux cospectra estimation (Step 1) is performed by using analytical cospectra formulations, according to Eqs. 12-18 in Moncrieff et al. (1997), a modification of the Kaimal formulation (Kaimal, 1972). Cospectra are expressed as a function of the natural frequency $CO_f(f)$, and depending primarily of the considered flux (momentum, sensible heat or gas flux), on atmospheric stratification, wind speed and the measurement height over the canopy. For this reason, cospectra must be recalculated for each averaging period.

In Step 2, an analytical formulation is used of the transfer function that describes the effect of the high-pass filtering procedure (HPTF, high-pass transfer function). The shape of the HPTF is a function of the selected detrending method (block averaging, linear detrending, running mean or exponential running mean), and the corresponding time constant. HPTF formulations are summarized in Table 2.2 of Moncrieff et al. (2004).

In Step 3, flux attenuation in the low frequency end is estimated by “applying” the calculated HPTF to the modeled flux cospectrum. When it is done in the frequency domain, “applying” simply means a frequency-wise multiplication. Considering that a flux is proportional to the integral of the corresponding cospectrum over the whole frequency range, a high-pass spectral correction factor (HPSCF) can be calculated in Step 4 as:

$$\mathrm{HPSCF} = \frac{\int_0^{f_{max}} \mathrm{CO_F}\left(f\right) df}{\int_0^{f_{max}} \mathrm{CO_F}\left(f\right) \cdot \mathrm{HPTF}(f)\, df}$$

where $f_{max}$ is the highest frequency, corresponding to the smallest eddies contributing to the true flux.

## Low-pass Filtering Correction

See "High frequency spectral correction" on page 4-26 for more information.

Three low-pass filtering correction procedures are available in EddyPro, implementing the 4 steps in different ways. The methods are named after the corresponding reference publication. The method by Moncrieff et al. (1997) is referred to as purely analytic, for it makes use of mathematical formulations to model flux spectral properties and to describe flux attenuations due to the instrumental setup. The method by Horst (1997) is analytic in nature, but it is parameterized using in situ information. The method by Ibrom et al. (2007), instead, it mostly based on in situ determinations.

The three methods are briefly described below. Please refer to the original papers for more in depth information.

### Spectral corrections after Moncrieff et al. (1997)

In this method, true cospectra estimation (Step 1) is performed by using analytical cospectra formulations, again according to Eqs. 12-18 in Moncrieff et al.

(1997). Step 2 is performed by specifying a low-pass transfer function (LPTF), which depends on the EC system characteristics. In the implemented method, the LPTF is specified by the superimposition of a set of transfer functions describing individual sources of high-frequency losses. Refer to Appendix A of Moncrieff et al. (1997) for the full description of the individual transfer functions. Such transfer functions depend on the instrumental setup (through the instruments' path lengths, acquisition frequencies, separations etc.) but also on atmospheric conditions (because some quantities are defined as a function of the average wind speed), thus they must be recalculated for each flux averaging period.

In Step 3, flux attenuation in the high frequency end is estimated by applying the calculated LPTF to the estimated true flux cospectrum. Considering that the flux is given by the integration of the cospectrum over the whole frequency range, a low-pass spectral correction factor (LPSCF) can be calculated in Step 4 as:

$$\mathrm{LPSCF} = \frac{\int_0^{f_{max}} CO_F\left(f\right)df}{\int_0^{f_{max}} CO_F\left(f\right) \cdot \mathrm{LPTF}(f)df}$$

More accurately, when the method by Moncrieff et al. (1997) is selected for the low-pass filtering correction, a band-pass transfer function (BPTF) is calculated by multiplication of the HPTF and the LPTF. This BPTF is then applied to the analytic cospectra, to derive a Band Pass Spectral Correction (BPSCF) factor according to:

$$\mathrm{BPSCF} = \frac{\int_0^{f_{max}} CO_F\left(f\right)df}{\int_0^{f_{max}} CO_F\left(f\right) \cdot \mathrm{BPTF}(f)df}$$

The fractional flux loss $\Delta F/F$ is given by:

$$\frac{\Delta F}{F_{true}} = \frac{F_{true} - F_{meas}}{F_{true}} = \frac{\int_0^{f_{max}} CO_F(f)df - \int_0^{f_{max}} CO_F(f) \cdot \mathrm{BPTF}(f)df}{\int_0^{f_{max}} CO_F(f)df} = 1 - \frac{1}{\mathrm{SCF}}$$

where $F_{true}$ is the "true" flux (not affected by spectral attenuations) and $F_{meas}$ is the measured, or uncorrected flux.

### Spectral corrections after Massman (2000, 2001)

The method described by Massman (2000) and refined in Massman (2001) is based on the work of Moore (1986) and Horst (1997) and provides a simple correction formula based on the description of individual sources of flux losses as first-order filters and on the analytical formulation of cospectra by Horst (1997). The application of the method requires the calculation of the time constants associated to the first-order filters that describe the physical phenomenon, and whose analytical expression are detailed in Massman (2000, Table 1). The actual correction formulas are detailed in Massman (2001, Table 1), which refined Table 2 in the previous paper.

Note that the correction contains a modifier (last term in the second equation of Table 1 in Massman, 2001) for gas instruments with a time response of <0.3 seconds. The time response of the gas instruments is calculated on-the-fly by EddyPro as part of the method, so the modifier is applied only if appropriate.

All parameter needed in the correction are available to or are calculated by EddyPro, so there is no need of user's input to apply the method, with one only exception for closed-path gas analyzers: the "tube parameter" (Λ), that quantifies the attenuation of a gas in a tube flow and that is a function of the gas itself and of the tube Reynolds number. This parameter is calculated by EddyPro via a linear interpolation of the values provided in Massman (1991, Table 1), starting from the actual Reynolds number calculated for the current sampling line (i.e., starting from the provided tube geometry and flow rate). Table 1 in Massman (1991) details the value of Λ for $CO_2$, $H_2O$, $CH_4$, $N_2O$ and $O_3$, so the correction can only be applied for those gases.

In summary Massman's correction is applicable to all open-path systems and to closed-path systems limited to measurements and fluxes of $CO_2$, $H_2O$, $CH_4$, $N_2O$ and $O_3$.

### Spectral corrections after Horst (1997)

This method is also based on an analytic formulation for the high frequency spectral losses and of the flux cospectra. However, here the integrals are solved analytically to derive a simple equation for the flux attenuation (Eq. 11 in Horst, 1997):

$$LPSCF^{-1} = \frac{F_{meas}}{T_{true}} = \frac{1}{1 + (2\pi \cdot n_m \tau_c \overline{u} / z)^a}$$

where $\tau_c$ is the time constant of the filter implied by the EC system, $\alpha$ is a stability dependent constant, $z$ is the measuring height above the canopy, $\bar{u}$ is the averaging wind speed at that height and $n_m$ is the (normalized) frequency at which the cospectrum attains its maximum (peak frequency), $n = f \cdot z / \bar{u}$. The time constant $\tau_c$ is linked to the transfer function cut-off frequency $f_c$ (the frequency at which the function reduces the power by a factor of 2) by the relation: $2\pi\tau_c = 1 / f_c$. The original paper provides parameterizations for $\alpha$ and $n_m$, while the average wind speed is a standard result provided by EddyPro. The time constant, however, is assessed in EddyPro® using the procedure described in the following section. In particular, for water vapor fluxes measured with closed path systems, the time constant is assessed as a function of relative humidity, as described hereafter.

### Spectral corrections after Ibrom et al. (2007)

This method is specifically suited for correcting water vapor fluxes measured with closed path systems, where relative humidity (RH) was recognized to play a non negligible role in determining $H_2O$ signal attenuation and therefore flux underestimation, specifically in the high frequency range. However, with the proper adjustments made in EddyPro, the method can also be used for passive gases insensitive to RH, such as $CO_2$, $CH_4$ and others, as well as for open path analyzers.

In the first step, assuming spectral similarity (De Ligne et al., 2010; Massman, 2000), sonic temperature spectra ($S_{Ts}$), considered as unaffected by spectral attenuations at high frequencies and after application of an opportune normalization, are used as a proxy for the unattenuated gas concentration spectra.

The estimation of system filtering characteristics (Step 2) is based on the in situ determination of the system cut-off frequency, assuming that the Eddy Covariance system acts on the true gas spectra ($S$) as a low-pass filter, in such a way that measured spectra ($S_m$) are attenuated at the high frequency end. Mathematically, such effect is described with a first-order recursive, infinite impulse response (IIR) filter. The discrete Fourier transform ($H_{IIR}$) of the amplitude of such filter is well approximated by the Lorentzian:

$$H_{IIR}\left(f \mid f_c\right) = \frac{S_m(f)}{S(f)} = \frac{1}{1 + (f / f_c)^2}$$

where $f$ (Hz) is the natural frequency and $f_c$ (Hz) is the transfer function cut-off frequency. The latter is proportional to the inverse of the filter time constant

($\tau_c$, *s*), $f_c^{-1} = 2\pi\tau_c$ , and provides a quantification of amplitude attenuation of fluctuations. This filter shape was proven suitable for describing the filtering properties of EC systems featuring very long (50 m, Hollinger et al., 1999; Ibrom et al., 2007) and long (7m, Mammarella et al., 2009) sampling lines.

> **Note:** Following Ibrom et al. (2007), cut-off frequencies are assessed by fitting the *IIR* function (with $f_c$ being the fitting parameter) to the ratio of ensemble gas spectra to ensemble temperature. EddyPro uses all "high quality" spectra available in the dataset to calculate such ensemble spectra. The criteria for selecting high quality spectra are as follows:

- High enough fluxes: too low fluxes may be a sign of not well developed turbulent conditions, in which scalar spectra may not be well characterized,
- Low enough skewness and kurtosis: too large skewness or kurtosis are often associated to sharp variations occurring in the time series, which could be the consequence of faulty measurements and could compromise the resulting spectra,
- A low enough number of missing values: in EddyPro, spikes and missing values are replaced by linear interpolation before the spectral analysis. This operation has a minimal impact on the resulting spectra. However, if too many (> 10%) samples are replaced by linear interpolation, the resulting spectra are ignored in the spectral assessment.

For $H_2O$ measured by closed path systems, in order to uncover the increasing attenuation as RH increases, cut-off frequencies must be determined for different RH regimes. As suggested by Ibrom et al., EddyPro determines $f_c$ for nine classes in the range 5% < RH < 95% and fits an exponential function to the resulting RH/$f_c$ pairs:

$$f_c(RH) = \exp\left(E_1 \cdot RH^2 + E_2 \cdot RH + E_3\right)$$

where $E_1$, $E_2$, and $E_3$ are regression parameters.

For open path systems, where a dependency on RH is not expected, the procedure is applied in a slightly different way. By an algorithmic point of view, EddyPro still calculates an $f_c$ for each RH class, but then it averages these values and analytically parameterizes the above equation by setting $E_1$ and $E_2$ to zero and $E_3$ to the natural logarithm of the average $f_c$. This way, the above relation between the cut-off frequency and RH can safely be used also for open path systems, basically providing the same cut-off frequency for each RH.

For passive gases, instead, a unique cut-off frequency is assessed for the whole dataset, without consideration for RH, for neither open nor closed path systems.

Once cut-off frequencies have been assessed, the low-pass spectral correction factor (Step 4) is calculated using the parameterization:

$$LFSCF = \frac{d_1 U}{d_2 + f_c} + 1$$

where $U$ is the average wind speed and $d_1$ and $d_2$ are site-specific parameters to be determined using collected turbulence data. The actual procedure, which makes use of “degraded temperature time series,” is described in details in the original paper.

This spectral correction scheme only deals with flux attenuations induced by attenuation of the scalar spectra. Other sources of flux underestimation to be considered are intrinsic to the instrument deployment. Among them, relevant flux losses might come from the physical separation between the anemometer and the gas analyzer sampling volumes. While streamwise sensor displacement can be accounted for by compensating scalar time lags (assuming Taylor’s hypothesis of frozen turbulence), we suggest applying a further correction factor to account for any crosswind and/or vertical displacement, following the procedure proposed by Horst and Lenschow (2009, Eqs. 16–18 and 28–30): These are multiplicative factors, that are applied after fluxes have been partially corrected with the method proposed here. Find more details here.

The method of Ibrom et al. (2007) is deemed applicable for a vast range of EC setups, spanning open-path to closed-path setups deployed of rough forest canopies. However, due to the need for a relatively large dataset for the assessment of spectral attenuations (Steps 1-3), we suggest using this method when at least 1-2 months of raw data are available from an EC setup that did not undergo major modifications, such as replacement of sampling line components or significant displacement of the sensors relative to each other.

### Spectral corrections after Fratini et al. (2012)

In this method, Steps 1-3 are identical to those described here for the method of Ibrom et al. (2007). The calculation of spectral correction factors (Step 4) is performed in different ways for “small” and “large” fluxes, where the threshold between small and large fluxes can be specified by the user.

1. For small fluxes the method of Ibrom et al. (2007) is applied, i.e. the low-pass correction factor is calculated using the model:

$$LFSCF = \frac{d_1 U}{d_2 + f_c} + 1$$

However, refer to section 2.3 and Appendix A in Fratini et al. (2012) for subtle differences in the parameterization of the model and how they improve it.

2. For large fluxes, refining and simplifying the approach described by Hollinger et al. (1999), low-pass spectral correction factors (LPSCF), for each flux averaging interval are calculated using the following equation:

$$LPSCF = \frac{\int_{f_{min}}^{f_{max}} CO_H(f)\, df}{\int_{f_{min}}^{f_{max}} \left( f \right) \sqrt{H_{IIR}\left(f \mid f_c\right)}\, df}$$

where $CO_H$ is the current sensible heat (H, W m-2) cospectrum. The value of the cut-off frequency in the denominator is calculated from:

$$f_c(RH) = \exp\left(E_1 RH^2 + E_2 RH + E_3\right)$$

as in Ibrom et al. (2007), using the current value of *RH*.

Similar to the method of Ibrom et al. (2007), this method only corrects flux attenuations induced by attenuation of the scalar spectra. Potential further losses due to instrument separation can be corrected following the method of Horst and Lenschow (2009) as described elsewhere. See "Correction for spectral losses due to physical instrument separation" on page 7-59

In addition, cospectra of sensible heat used in this method as a reference for gas flux cospectra, can be preliminary corrected for the (normally small) attenuations induced by the anemometer's limited response time and finite averaging volume, as well as for the high-pass filtering effects due to the finite flux averaging interval and dependent on the detrending method, as described here. See "High-pass Filtering Correction" on page 7-51

The method of Fratini et al. (2012) is deemed applicable for a vast range of EC setups, from open-path systems over rough forests canopies to closed-path setups deployed close to smooth surfaces. However, due to the need of a relatively large dataset for the assessment of spectral attenuations (Steps 1-3), we suggest using this method when at least 1-2 months of raw data are available from an EC setup that did not undergo major modifications such as replacement of sampling line components, or significant displacement of the sensors relative to each other. In any case, we recommend using this method for correcting $H_2O$ and latent heat fluxes from closed path systems, specifically if deployed low over a relatively smooth surface, as if could be the case in agricultural or oceanic applications.

### Correction for spectral losses due to physical instrument separation

Being designed to correct spectral losses in closed-path systems (specifically for water vapor), the methods of Ibrom et al. (2007) and Fratini et al. (2012) do not natively account for losses due to spatial separation of the instruments (anemometer and gas analyzer), because this source of spectral losses is minor and can be safely neglected when compared to losses in the sampling lines. For open-path systems, however, spectral losses due to instrument separations are relatively more important (especially for systems placed low over smooth surfaces). EddyPro allows you to account for these losses by applying the correction method proposed by Horst and Lenschow (2009), when the methods of Ibrom et al. (2007) and Fratini et al. (2012) are selected. Horst and Lenschow (2009) describe 3 correction terms to account for along-wind, crosswind and vertical separations. Note that losses for any along-wind separation are largely compensated by the procedure of time lag compensation, if this is applied.

Thus, the method is available in two versions:

- Along-wind, crosswind and vertical: suggested when the time lag compensation procedure is not applied.
- Only crosswind and vertical: suggested when the time lag compensation procedure is applied.

The correction procedure is based on the following formulation for the dependency of the flux (*F(r)*) as a function of the distance between the instruments *(r)*, Eq. 13 in the original paper:

$$F(r) = F_0 \exp(-k_m r)$$

where $F_0$ is the unattenuated flux for r=0, and $k_m=2\pi n_m/z$ is the wavenumber at the peak of the wavenumber-weighted cospectrum, $kCo(k)$, $n_m = f_m z/U$, $f_m$ is the frequency at the peak of the cospectrum, and $U$ is the wind speed.

This formulation is then specified in the along-wind, crosswind, and vertical separations. Please refer to Horst and Lenschow (2009) for further details.

> **Note:** When the methods of Horst (1997) or Ibrom et al. (2007) are selected for the low-pass filtering correction, the "band-pass" spectral correction is applied by first correcting for the high-pass filtering effects (multiplication of uncorrected fluxes by HPSCF) and then multiplying by LPSCF. Rigorously speaking, this procedure is not correct because according to the definition of the band pass correction factor, the multiplication with the LPTF and the HPTF are not commutative with the integral operator. However, the error introduced by this procedure is deemed negligible in most occasions.

## Calculating Fluxes Level 1, 2, and 3 (Corrected Fluxes)

Calculating corrected fluxes in EddyPro® involves the application of the following corrections:

- Correction of any covariance (and related fluxes) that include sonic temperature, for the effects of humidity on air estimation via the sonic temperature. This correction was firstly described in Schotanus et al. (1983) and is applied in EddyPro according to the revision described in van Dijk et al. (2004, eq. 3.53):

$$\overline{w'T_a'} = \overline{w'T_s'} - 0.51Q \cdot \overline{w'T_s'} - 0.51T_s\overline{w'Q'}$$

where the covariance $\overline{w'Q'}$ (m s$^{-1}$) is calculated from the evapotranspiration flux (*E, kg m$^{-2}$ s$^{-1}$*):

$$\overline{w'Q'} = \frac{E}{\rho_a}.$$

- Correction of gas fluxes for air density fluctuation effects, henceforth referred to as the "WPL term" (Webb et al., 1980). The correction is applied in different ways for open path and closed path systems, as explained later in this section.
- Correction for high-frequency and low-frequency spectral attenuations, using correction factors from Calculating Spectral Correction Factors.
- Off-season uptake correction, using corrected sensible heat flux as calculated in the Calculating Off-season Uptake Correction section (applies only to the LI-7500).
- Spectroscopic correction using multipliers calculated in the Calculating LI-7700 Multipliers section.

The order of application of these corrections varies, depending on the gas analyzer type (open or closed path) and on how many gas analyzers were used. Hereafter we describe the corrections in the order in which they appear in a series of common cases.

## Calculating Turbulent Fluxes for a System Composed of an LI-7500 and LI-7700

The common example of an open path eddy covariance systems is a station equipped with an anemometer, LI-7500 or LI-7500A, and LI-7700.

In this case, corrected fluxes are calculated from uncorrected (fluxes as ) according to the following procedure:

### Level 1 Fluxes: Application of Spectral Corrections

Spectral corrections are applied first to open path fluxes. This is because sensible and latent heat fluxes used in the WPL (or air density fluctuation) correction are the "environmental ones," those actually present in the atmosphere and affecting measurements of molar densities in open path analyzers. These are best estimated by compensating uncorrected fluxes for spectral losses. However, sensible heat flux is not yet corrected here (explained later). Therefore, at level 1 we have:

$F_{1,gas} = F_{0,gas} \cdot SCF_{w,gas}$

where the subscript '*gas*' indicates that it is applied to all gases. Latent heat and evapotranspiration fluxes are spectrally corrected using the correction factor calculated for water vapor:

$LE_1 = LE_0 \cdot SCF_{w,h2o}$

$E_1 = E_0 \cdot SCF_{w,h2o}$

Furthermore, uncorrected momentum flux and friction velocity are corrected using the relevant spectral correction factor:

$T_1 = T_0 \cdot SCF_{u,w}$

$u_{*1} = u_{*0} \cdot SCF_{u,w}$

### Level 2 and 3 Fluxes

As a first step after spectral correction, evapotranspiration flux E is corrected with the WPL term, following the formulation proposed in Webb et al. (1980, eq. 42b):

$$E_2 = \left(1 + \mu\sigma\right)E_1 + \left(1 + \mu\sigma\right)\frac{H_1}{\rho_a c_p}\frac{\rho_w}{T_a}$$

where $\mu = M_d/M_{h2o}$, and $H_1 \equiv \widetilde{H}$ (that is, corrected for instrument-related sensible heat fluxes) if an LI-7500 was used for water vapor concentration.

Hence, Level 2 water vapor and latent heat fluxes are simply calculated as:

$$F_{2,h_2o} = E_2 \cdot 10^3 \cdot M_{h_2o}$$

$$LE_2 = \lambda \cdot E_2$$

Now sensible heat flux is corrected for humidity effects following van Dijk et al. (2004), revising Schotanus et al. (1983) as explained in Calculating Fluxes, Level 1, 2, and 3.

$$H_2 = H_1 - \rho_a c_p \cdot \alpha\left(T_s \cdot \frac{E_2}{\rho_a} + Q \cdot \overline{w' T_s'}\right)$$

where α=0.51, and then it is spectrally corrected to get the first fully corrected flux:

$$H_3 = H_2 \cdot SCF_{w,Ts}$$

Now that sensible heat is fully corrected, evapotranspiration flux is corrected again, adding the WPL terms with the revised *H*:

$$E_3 = \left(1 + \mu\sigma\right)E_1 + \left(1 + \mu\sigma\right)\frac{H_3}{\rho_a c_p}\frac{\rho_w}{T_a}$$

where, again, $H_3$ contains the additional sensible heat contributions in an LI-7500 is used. Water vapor and latent heat fluxes are easily refined:

$$F_{3,h_2o} = E_3 \cdot 10^3 \cdot M_{h_2o}$$

$$LE_3 = \lambda \cdot E_3$$

Now that evapotranspiration and sensible heat fluxes are fully corrected, fluxes of other gases such as carbon dioxide and methane can be corrected for air density fluctuations, according to Webb et al. (1980 eq. 44). For carbon dioxide, we get:

$$F_{2,ch_4} = A \cdot \left( F_{1,ch_4} + B \cdot \mu \cdot E_{NO\_WPL} \frac{d_{ch_4}}{\rho_d} + C \cdot \left( 1 + \mu\sigma \right) \frac{H_3}{\rho_a c_p} \frac{d_{ch_4}}{T_a} \right)$$

In the event that methane fluxes are computed with data from an open path instrument other than the LI-7700, EddyPro® automatically sets the multipliers ***A***, ***B***, and ***C*** to unity.

> **Note:** The evapotranspiration flux needed for this formulation is not corrected for the WPL term (but is corrected for spectral attenuations). In the present case, of water vapor measured with an open path analyzer:

$$E_{NO\_WPL} = E_1$$

Finally, corrected fluxes (Level 3) of $CO_2$ and $CH_4$, in systems with open path instruments, coincide with fluxes at Level 2, which thus provide the most accurate flux estimate available with EddyPro.

## Calculating Turbulent Fluxes for a System Composed of an LI-7200 and LI-7700

In this situation, corrected fluxes are calculated from uncorrected (fluxes as $F_0$) with the following procedure:

### Level 1 Fluxes: Application of Spectral Corrections

As a first step, uncorrected methane fluxes from the LI-7700 are corrected for spectral attenuation, as explained in Calculating Fluxes for Open Path Analyzers:

$F_{1,ch4} = F_{0,ch4} \cdot SCF_{w,ch4}$

Momentum flux and friction velocity are also spectrally corrected at Level 1, similarly:

$T_1 = T_0 \cdot SCF_{u,w}$

$u_{*1} = u_{*0} \cdot SCF_{u,w}$

Fluxes from the LI-7200 are not spectrally corrected at this stage, because the application of correction for air density fluctuation effects to concentrations calculated with closed path systems requires using uncorrected fluxes.

## Level 2 and 3 Fluxes

Whenever possible, air density fluctuation effects in closed path systems are addressed by converting raw gas concentration measurements into mixing ratios (see Converting to Mixing Ratios). However, when this is not possible due to unavailability of necessary raw information, the correction is implemented following the WPL approach, as refined by Ibrom et al. (2007b). As a first step, evapotranspiration flux is corrected for the WPL term using the formulation proposed in Webb et al. (1980, eq. 42b), properly modified to account for the fact that the relevant sensible heat flux is measured inside the cell of the LI-7200 (and not in ambient conditions):

$$E_2 = \left(1 + \mu\sigma\right)E_1 + \left(1 + \mu\sigma\right) \cdot \frac{\overline{w'T'_c}}{T_c}\rho_w - \left(1 + \mu\sigma\right) \cdot \frac{\overline{w'P'_c}}{P_c}\rho_w$$

where $\overline{w'T_c'}$ and $\overline{w'P_c'}$ are covariances of *w* and cell temperature pressure respectively, evaluated after dislodging the cell temperature time series using the time lag of $CO_2$. If covariance $\overline{w'T_c'}$ or $\overline{w'P_c'}$ are not available, they are assumed negligible and $E_1$ is corrected only for the dilution term due to water vapor:

$E_2 = (1 + \mu\sigma)E_1$

Fully corrected (level 3) evapotranspiration flux can now be calculated from $E_2$ by applying the proper spectral correction factor:

$E_3 = E_2 \cdot SCF_{w,h2o}$

Fully corrected latent heat and water vapor flux can now be calculated:

$F_{3,h2o} = E_3 \cdot 10^3 \cdot M_{h2o}$

$LE_3 = \lambda \cdot E_3$

Now, ambient sensible heat flux is corrected for humidity effects following van Dijk et al. (2004), revising Schotanus et al. (1983) as explained in Calculating Fluxes Level 1 2 and 3.

$$H_2 = H_1 - \rho_a c_p \cdot \alpha \cdot \left(T_s \cdot \frac{E_2}{\rho_a} + Q \cdot \overline{w'T_s'}\right)$$

Then it is spectrally corrected to get fully corrected sensible heat flux:

$H_3 = H_2 \cdot SCF_{w,Ts}$

Next, level 2 $CO_2$ flux is calculated by applying the correction for air density fluctuations. EddyPro® uses a formulation similar to Webb et al. (1980 eq. 24), where, however, sensible heat flux and latent heat flux are evaluated in the cell and using the time lag of $CO_2$:

$$F_{2,co_2} = \frac{v_c}{v_a}\left(F_{1,co_2} + \mu\sigma \cdot \frac{E_{cell}}{\rho_w} d_{co_2} + (1+\mu\sigma)\frac{H_{cell}}{\rho_a c_p T_c} d_{co_2} - (1+\mu\sigma)\frac{\overline{w'P'_c}}{P_c} d_{co_2}\right)$$

where $E_{cell}$ and $H_{cell}$ are calculated as:

$$E_{cell} = \overline{w'd'_{h_2o}}\Big|_{\tau\_co_2} \cdot M_{h_2o}$$

$$H_{cell} = \rho_a c_p \cdot \overline{w'T_c'}\Big|_{\tau\_co_2}$$

and the subscript $\tau\_co_2$ indicates that covariances are evaluated at time lags of $CO_2$. The factor $v_c/v_a$ is needed to compute ambient quantities from cell quantities.

Methane fluxes are evaluated similarly to in a manner similar to fluxes for the LI-7500 and LI-7700 analyzers:

$$F_{2,ch_4} = A \cdot \left(F_{1,ch_4} + B \cdot \mu \cdot E_{NO\_WPL}\frac{d_{ch_4}}{\rho_d} + C \cdot (1+\mu\sigma)\frac{H_3}{\rho_a c_p}\frac{d_{ch_4}}{T_a}\right)$$

where now, the spectrally corrected, not-WPL-corrected evapotranspiration flux is calculated as:

$$E_{NO\_WPL} = E_1 \cdot SCF_{w,h_2o} \ .$$

Finally, $CO_2$ fluxes are corrected for spectral attenuations:

$$F_{3,co_2} = F_{2,co_2} \cdot SCF_{w,co_2}$$

## Estimating the Flux Footprint

See "Footprint estimation" on page 4-26 for more information.

EddyPro® features three crosswind-integrated flux footprint models, useful to estimate the upwind area contributing to the measured fluxes. The flux footprint functions estimate the location and relative importance of passive scalar sources influencing flux measurements at a given receptor height, depending on receptor height, atmospheric stability, and surface roughness (Kljun et al., 2004). Regardless of the chosen model, the footprint estimation is provided as a set of distances from the anemometer location in the direction from which the wind blows. These distances express:

- Peak distance: the distance from the anemometer, from which the largest relative individual contribution to the flux
- Offset distance: the area between the anemometer and the offset provides up to 1% of the total flux
- 10%, 30%, 50%, 70%, 90%: the area between the anemometer and the NN% distance provides NN% of the total flux.

Hereafter, a short introduction to the implemented models is provided. Please refer to the respective papers for in-depth information and for an informed selection of the method to be used. The default option in EddyPro is the parameterization of Kljun et al. (2004), merely because it is the newest 'model' and it is a thoroughly validated one. However, at this stage we explicitly don't advocate the use of a particular model among those available.

## Footprint parameterization from Kljun et al (2004)

A footprint estimation is provided according to the "simple footprint parameterization" described in Kljun et al. (2004). The set of distances is calculated according to:

Peak contributing distance (*m*):

$$x_{peak} = X^*_{peak} h_m \left(\frac{\sigma_w}{u_*}\right)^{-0.8}, \quad X^* = c - d$$

NN% contribution (*m*):

$$x_{NN\%} = X^*_{NN\%} h_m \left(\frac{\sigma_w}{u_*}\right)^{-0.8}, \quad X^*_{NN\%} = L'_{NN\%} \cdot c - d$$

The second equation is used to provide the offset distance (NN = 1) and the 10% to 90% distances. In these equations, parameters c and d are calculated using Eqs. 13 to 16 in Kljun et al. (2004) (where the roughness length enters as a parameter). The distance $L'$[1] is tabulated for each percentage between 0 and 95% (see Figure A1 in the referenced paper). All other quantities are routinely calculated by EddyPro.

The footprint parameterization is valid only in certain ranges of micrometeorological conditions, well specified in the Kljun et al. (2004). In particular, the model is claimed to be valid if the following conditions hold:

- The measurement height is lower than the boundary layer height;
- The terrain is dynamically homogeneous;
- The stability parameter is in the range of: $-200<\zeta<1$ ;
- The friction velocity is larger than a specific threshold: $u_* \geq 0.2$ m s-*1*;
- The measurement height is larger than 1 m: $h_m \geq$ 1m.

EddyPro checks for the last three of these conditions and switches to the 'Kormann and Meixner' model (see later), if either condition is not met.

## Footprint model from Kormann and Meixner (2001)

This is a crosswind integrated model based on the solution of the two dimensional advection-diffusion equation given, e.g., by van Ulden (1978) for power-

[1]The FORTRAN source code for this calculation, along with the tabulated values of *L'*, were shared by the main author of the model, Natascha Kljun, for being embedded into ECO2S, and subsequently, EddyPro. We gratefully acknowledge Dr. Kljun for this contribution.

law profiles in wind velocity and eddy diffusivity. Contributing distances are calculated according to (Eq. 21 in the original paper):

$$f_x = \frac{1}{\Gamma(\mu)} \frac{\xi^{\mu}}{x^{1+\mu}} e^{-\xi/x}$$

where *x* is the distance from the location of the anemometer measured in the wind direction, $\xi = \xi(z)$ is a flux length scale that depends on the height above the ground *z*, $\mu$ is a dimensionless model constant and $\Gamma(\mu)$ is the gamma function.

The equation is actually used to calculate *x*, given the fraction of the flux contribution of interest (10%, 30%, etc.).

The equation for the peak distance is explicitly derived by the authors (Eq. 22), by merely finding the maximum from the former equation:

$$x_{peak} = \frac{\xi}{1+\mu}.$$

### Footprint model from Hsieh et al. (2000)

This is a crosswind integrated model based on the former model of Gash (1986) and on simulations with a Lagrangian stochastic model. Contributing distances are calculated according to (Eq. 17 in the original paper):

$$f_{x,z} = \frac{1}{k^2 x^2} D z_u^P |L|^{1-P} \exp\left(-\frac{1}{k^2 x} D z_u^P |L|^{1-P}\right)$$

where, again, *x* and *z* are the upwind distance from the measuring location and the measuring height, *L* is the Monin-Obukhov length and *k*, *D*, *P*, $z_u$ are model-specific parameters.

Similar to Kormann and Meixner (2001), the equation above is actually used to calculate *x*, given the fraction of the flux contribution of interest (10%, 30%, etc.).

The equation for the peak distance is explicitly derived by the authors (Eq. 19), by merely finding the maximum from the former equation:

$$x_{peak} = \frac{D z_u^P |L|^{1-P}}{2k^2}.$$

## Flux Quality Flags for Micrometeorological Tests

See "Quality check" on page 4-25 for more information.

Quality flags are calculated for all fluxes (sensible and latent heat, momentum and gas fluxes). The final flags provided on output files are based on a combination of partial flags calculated as a result of two tests, widely adopted and thoroughly described in literature (see Foken et al., 2004; Foken and Wichura, 1996; Göckede et al., 2008).

The two tests are known as the *steady state test* and the *developed turbulent conditions* test. For details on the two methods refer to the cited literature. In EddyPro®, each test provides a flag ranging from 1 (best) to 9 (poorest). The two flags are then combined into a unique flag, depending on the selected flagging policy:

- Mauder and Foken 2004: policy described in the documentation of the TK2 Eddy Covariance software that also constituted the standard of the CarboEurope IP project and is widely adopted. Here, the combined flag attains the value “0” for best quality fluxes, “1” for fluxes suitable for general analysis such as annual budgets and “2” for fluxes that should be discarded from the results dataset.
- Foken 2003: A system based on 9 quality grades. “0” is best, “9” is worst. The system of Mauder and Foken (2004) and of Göckede et al. (2006) are based on a rearrangement of this system.
- Göckede et al., 2006: A system based on 5 quality grades. “0” is best, “5” is worst.

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**Note:** References are linked to the original publication when possible.


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# Glossary

## A

**Absolute Limits Test**
Assesses whether each variable attains, at least once in the current time series, a value that is outside a user-defined plausible range.

**Acquisition Frequency**
The number of samples per second (Hz) recorded by the eddy covariance system. Sometimes called Update Rate (LI-7500A/LI-7200) or Output Rate (LI-7700).

**Advanced Mode**
An EddyPro run mode that enables many advanced processing options for atypical sites and comparison of methods.

**Altitude**
The elevation above sea level of the site (m).

**Amplitude Resolution Test**
A statistical test that detects records with weak variance (weak winds and stable conditions), in which the amplitude resolution of the recorded data may not be sufficient to capture the fluctuations, by assessing whether the number of different values each variable takes throughout the time series covers its range of variation with sufficient homogeneity.

**Angle of Attack**
The angle that the wind vector forms with respect to the horizontal plane of the sonic anemometer (the one defined by the U and V components). It is positive if the vertical wind component is negative, i.e. the wind goes in the downward direction. Angles-of-attack that are different from zero are thought to lead a distortion of the wind field due to interaction with the anemometer's transducers. Flow distortion corrections address this issue for some anemometer models.

**Angle of Attack Correction**

Correction for the flow distortion due to the interaction between the wind flow and the anemometer's structures (e.g., transducers). Corrections are available for post-mounted Gill Instruments sonic anemometer such as R3 and WindMaster. The relevance of this effect of c-clamp anemometer models is debated (Kochendorfer et al. 2012; Mauder, 2013).

**Angle of Attack Test**

Calculates sample-wise angle of attacks throughout the current flux averaging period, and flags it if the percentage of angles of attack exceeding a user-defined range is beyond a (user-defined) threshold.

**ASCII File**

A format for raw eddy covariance data. Data are most commonly stored in a column-wise fashion, and columns are usually separated by commas, tabs, semicolons or blank spaces. ASCII files are human-readable using any text editor and can feature a header stating the variable meanings and their units.

**Axis Rotation for Tilt Correction**

Method for compensating anemometer tilt with respect to local streamlines.

## B

**Biomet Data**

Shorthand for biological and meteorological data. May include slow, accurate measurements of air properties (temperature, pressure, water content, etc.), radiation components (direct, indirect, reflected, and sorted in spectral bands), soil and vegetation properties (biomass, water content, temperature, water and carbon flux, LAI, etc.). A few of these measurements can be used to improve flux computation, or to calculate other flux contributions such as storage fluxes, advection fluxes, soil fluxes.

## C

**Canopy Height**

The height (m) of the canopy above the ground at eddy covariance site.

**Covariance Maximization**

Procedure to estimate time lags between two time series. In eddy covariance, it is most commonly used to estimate time lags between vertical wind speed and other variables. It is based on the assumption that any setup limitation (physical separations, sampling lines, etc) reduces the correlation between time series, that would be observed in the environment. In a cross-correlation analysis between vertical wind speed and a variable, the time lag for which the resulting covariance is maximal is taken to be the timelag for that variable. The procedure is performed for all possible time lags in a in a 'time lag plausibility window'.

**Cut-off Frequency**

In eddy-covariance, the term is most often used to quantify the spectral features of an eddy flux system. The larger the cut-off frequency, the greater the ability of the system to measure flux contributions occurring at small spatial scales (small eddies). Typical realistic values range 0.1 to 5-8 Hz. Open-path systems tend to have higher cut-offs than closed-path systems, due to attenuations of high-frequency fluctuations of gas concentrations resulting from the sampling line. Shorter sampling lines mitigate the problem. EddyPro can calculate your system's cut-off if you don't know how to estimate it.

## D

**Detrending**

Refers to the operation of establishing and removing a trend in raw (high-frequency) time series before calculating turbulent fluctuations. Using the 'block average' procedure, no detrending is performed, and any instantaneous variation with respect to the global mean of a variable (evaluated over the flux averaging interval) is considered as a turbulent fluctuations. On the contrary, 'linear detrending' and '(exponential) running mean' methods remove a trend before evaluating fluctuations. With the latter methods, the trend can be modulated to follow the time series more or less closely, by respectively reducing or increasing the method's time constant.

**Discontinuities Test**

To detect discontinuities that lead to semi-permanent changes, as opposed to sharp changes associated with smaller-scale fluctuations.

**Displacement Height**

The height at which the wind speed would go to zero if the logarithmic wind profile was maintained from the outer flow all the way down to the surface (also known as zero plane displacement height).

**Double Rotation**

Aligns the x-axis of the anemometer to the current mean streamlines, nullifying the vertical and crosswind components.

**Drop-outs Test**

Attempts to detect (relatively) short periods in which the time series sticks to some value that is statistically different from the average value calculated over the whole period.

**Dynamic Metadata File**

For EC datasets not in the GHG format, the dynamic metadata file can be used to provide EddyPro with information concerning time-varying site, station, and instrumentation parameters, such as changing canopy height and roughness length, or instrument separations and height. A dynamic metadata file can also be used with GHG files, in case these do not contain accurate information (e.g. if a changing canopy height was not updated in the GHG software during data collection).

## E

**Eastward Separation**

East/west distance between the CO2/H2O Analyzer and the reference anemometer; positive values if east and negative values if west of the anemometer.

**Embedded Biomet File**

File containing Biomet data collected with LI-COR's biomet system and included (embedded) in the GHG files. Each GHG file contains all eddy-covariance and biomet measurement corresponding to a specific time period, and can be automatically processed in EddyPro, to refine computation of turbulent fluxes.

**Express Mode**

A setting in EddyPro that uses commonly-accepted settings that should apply to most well-designed eddy covariance setups.

**External Biomet File(s)**

For users of Biomet systems other than the LI-COR system, EddyPro allows the usage of Biomet data in flux computation. Data must be included in one or more external files with a prescribed CSV format, which can then be loaded in EddyPro.

**Extinction coefficient in oxygen Ko**

In Krypton or Lyman-a hygrometers, the extinction coefficients for oxygen of the hygrometers, associated with the third-order Taylor expansion of the Lambert–Beer law around reference conditions.

**Extinction coefficient in water Kw**

In Krypton or Lyman-a hygrometers, the extinction coefficients for water vapor of the hygrometers, associated with the third-order Taylor expansion of the Lambert–Beer law around reference conditions.

## F

**Fast Fourier Transform**

Fast Fourier Transform (FFT) is used for the frequency domain analysis (spectra and co-spectra) of the time series data.

**Flux Averaging Interval**

Time span over which fluxes and all other results are calculated. Most typical is 30 minutes, but longer or shorter averaging intervals may be needed in specific conditions (see Finnigan et al. 2003). You can look into the ogives output by EddyPro to determine the most appropriate averaging interval for a given site. The flux averaging interval does not need to match the duration of the collected raw files.

**Footprint Estimation**

Flux crosswind-integrated footprints are distances from the tower contributing 10%, 30%, 50%, 70% and 90% to measured fluxes.

## G

**Gain Value**

The gain (slope) of the linear relation between input and output units.

**Generic Binary File**

Raw eddy covariance data can be efficiently stored in a plain binary format. EddyPro can handle generic binary files (both little and big endian) as long as the length of binary words used to store each variable is constant throughout the file. Binary files are not human-readable and, although they are fast to import for processing, do not constitute a robust way of storing eddy covariance data, unless they are accompanied by appropriate metadata.

**GHG File**

A custom LI-COR file format that includes complete eddy covariance data sets and denoted by a .ghg file extension. At a minimum, GHG files contain a raw, high-frequency data file (extension .data) and the paired metadata file (extension .metadata). If a biomet system was part of the EC setup, GHG files can also contain a file with biomet data (ending in '-biomet.data') and the paired metadata file (ending in '-biomet_metadata'). All files are stored in ASCII text format.

**GHG Software**

The name of the desktop and embedded software on LI-COR LI-7500As and LI-7200s; used to log .ghg files.

## H

**Height**

Under instruments tab in the metadata file editor; the distance between the ground and the sample path of the sensor (m).

**High-pass Filtering Effects**

Applies a correction for flux spectral losses in the low frequency range, due to the finite averaging time and dependent on the detrending method selected.

## I

**Ignore**

In the metadata file editor, tells EddyPro to ignore a variable.

**Input Unit**

Related to re-scaling a variable in the metadata file editor, this specifies the input units.

## L

**Linear Scaling**

Used to rescale values (from voltage, for example) to meaningful units (such as m/s).

**Longitudinal Path Length (anemometer)**

Distance between a pair of anemometer transducers.

**Longitudinal Path Length (gas analyzer)**

The path length of the gas analyzer sample volume.

**Low-pass Filtering**

Applies a correction for flux spectral losses in the high frequency range.

## M

**Magnetic Declination**

The angle between magnetic (uncorrected compass) North and geographic (true). This angle changes slightly over time, according to variations of the earth's magnetic field. Based on Latitude, Longitude and date, EddyPro can retrieve the magnetic declination at your site from the dedicated NOAA web-service.

**Maximum Time Lag**

The maximum expected time lag for the current variable, with respect to anemometric measurements.

**Measurment Type**

The description of the concentration measurement (either Molar/Mass density, Mole fraction, or Mixing ratio).

**Metadata File**

The metadata file (extension .metadata) contains all meta information relevant to the collected raw data and necessary to process it appropriately. Metadata include site, station and instrumentation description, as well as meaning and units of all variables available in the corresponding data files. For maximal robustness, each EC raw data file should be accompanied by its own metadata, as is the case with GHG files.

**Minimum Time Lag**
The minimum expected time lag for the current variable, with respect to anemometric measurements.

## N

**Nominal Time Lag**
The expected (nominal) time lag of the variable, with respect to the measurements of the sonic anemometer.

**North Alignment**
For Gill sonic anemometers, this specifies whether the U wind component is aligned to the North spar of the anemometer (the spar marked with an N or a notch) or with the transducer closest to it. There is an offset of 30 degress between the two. For most models, wind components V and W will be perpendicular to U in a right handed coordinate system.

**North Offset**
The anemometer's yaw offset with respect to local magnetic North (positive eastward). Magnetic North is the direction in which the north end of a compass needle or other freely suspended magnet will point in response to the earth's magnetic field.

**North Reference**
The ‘North’ to which EddyPro should refer the wind direction. It can be magnetic (the direction that the north end of a compass needle points in response to the earth's magnetic field) or geographic (the direction along the earth's surface towards the geographic North Pole). The difference between the two is the magnetic declination.

**Northward Separation**
North/south distance between the CO2/H2O Analyzer and the reference anemometer; positive values if north and negative values if south of the anemometer.

**Numeric (yes/no)**
Specifies whether a variable is purely numeric or not.

## O

**Offset**
The offset (y-axis intercept) of the linear relation between input and output units.

**Output Directory**
The directory in the file system where your flux results will be written.

**Output ID**
An identifier in the name of the output file that specifies the results of a project.

**Output Unit**
The units of values that are rescaled using the linear scaling feature.

## P

**Planar Fit**
Aligns the anemometer coordinate system to local streamlines assessed on a long time period (e.g., 2 weeks or more). Can be performed sector-wise, meaning that different rotation angles are calculated for different wind sectors.

**Planar Fit with no Velocity Bias**
Similar to classic planar fit, but assumes that the any bias in the measurement of vertical wind is compensated, and forces the fitting plane to pass through the origin (that is, such that if average u and v are zero, also average w is zero).

## R

**Random Uncertainty**
Uncertainty is a quantification of the precision of a measurement. Sources of uncertainties can be traced to biogeochemical (source/sink), transport, and instrument factors. Random uncertainties due to sampling errors are a consequence of the limited number of independent samples that contribute substantially to a flux during any fixed sampling period (Finkelstein and Sims, 2001). Contrary to systematic uncertainties, which introduce a bias into the resulting fluxes and shall be minimized by accurate experimental design and instrument deployment, random uncertainties do not introduce

a bias, rather, they reduce our confidence that the reported number is the true value (Billesbach, 2011).

**Roughness Length**
The height at which wind speed is zero (indicated by z0).

## S

**Skewness and Kurtosis Test**
Excessive skewness and kurtosis may help detect periods of instrument malfunction. Third and forth order moments are calculated on the whole time series and variables are flagged if their values exceed user-selected thresholds.

**SLT File**
A format for raw eddy covariance data, often created by or used in conjunction with the EdiRe/EdiSol or EddySoft software packages. It is a fixed-length binary format, with or without a binary header describing the file content. EddyPro can handle both types of SLT files, but you must specify whether it is associated to EdiRe/EdiSol or to EddySoft.

**Spectral Correction Factor**
Multiplicative factors (typically > 1) used to correct tentative flux estimates for flux losses that can occur at both low and high frequencies. Spectral correction factors are calculated for each flux based on a spectral correction scheme. EddyPro supports different schemes, to suit different EC setups. Depending on the type of gas analyzer deployed, spectral corrections must be applied to fluxes before (open-path) or after (closed-path) consideration of WPL effects.

**Spectral Corrections**
Procedure to calculate spectral correction factors. In EddyPro, we distinguish between analytic and in-situ methods. Analytic methods do not require analysis of (co)spectral features derived from the data and are easy to implement, fast to perform and robust. However, they may underestimate spectral attenuations, especially for closed-path systems. In-situ methods are more appropriate to closed-path systems, but they require long (e.g., >1 month) datasets to analyze spectra features or raw time series, estimate cut-off frequencies and compute correction factors. In-situ methods, involving non-linear regressions, may also fail in certain conditions.

**Spike Count/Removal**

A statistical technique that detects the number of spikes in each time series and removes them based upon your settings.

**Steadiness of Horizontal Wind Test**

Assesses whether the along-wind and crosswind components of the wind vector undergo a systematic reduction (or increase) throughout the file.

## T

**Time Lag**

In eddy-covariance, the term ‘time lag’ refers to the time misalignment between different high-frequency time series. Time lags arise due to physical distances between instruments, to electronic delays and, in closed-path setups, to the passage of air through sampling lines.

**Time Lag Compensation**

Procedure to compensate for time lags between anemometric measurements and any other high frequency measurements included in the raw files, notably those used for fluxes. In EddyPro time lags can be ignored, set to a contestant value, calculated with the automatic procedure called covariance maximization, or optimized by means of the time lag optimization procedure.

**Time Lag Optimization**

Time lags of water vapor in closed-path systems often depend on relative humidity (and secondarily on air temperature), on account of enhanced sorption processes occurring at the walls of the sampling line when RH increases. The time lag optimization procedure consists of automatically defining the most appropriate time lag plausibility window and nominal time lag for water vapor for a specified number of relative humidity classes. The time lag optimization can also be used to derive plausibility windows for passive gases, as a special case.

**Time Lag Plausibility Window**

The range of physically plausible time lags, within which the actual time is expected to fall. Within this window, the ‘nominal time lag’ is the time lag of maximal likelihood, the one that is expected to occur most often. The minimum and maximum of the plausibility window, as well as the nominal time lags, are automatically calculated by EddyPro if not explicitly provided, with algorithms that depend on whether the EC system is open- or closed-path. The covariance maximization procedure (when requested) is applied only within the time lag plausibility window.

**Time Lags Test**

Flags the scalar time series if the maximal w-covariances, determined via the covariance maximization procedure and evaluated over a predefined time-lag window, are too different from those calculated for the user-suggested time lags. That is, the mismatch between fluxes calculated with the expected time lags and with the “actual” time lags is too large.

**Time Response (anemometer)**

Time response of the anemometer; its inverse defines the maximum frequency of the atmospheric turbulence that the instrument is able to resolve. Consult the anemometer’s specifications or user manual.

**Time Response (gas analyzer)**

Time response of the gas analyzer; its inverse defines the maximum frequency of the atmospheric turbulent concentration fluctuations that the instrument is able to resolve. Consult the analyzer’s specifications or user manual.

**TOB1 File**

A format for raw eddy covariance data, often used for storing data obtained from Campbell Scientific® dataloggers. It is a fixed-length binary format, featuring a ASCII (readable) header stating the collected variables, their units, and numerical format.

**Transversal Path Length (anemometer)**

Distance transverse to a pair of transducers on the anemometer.

**Transversal Path Length (gas analyzer)**

Path length in the distance orthagonal to the longitudinal path length.

**Triple Rotation**

Double rotations plus a third rotation that nullifies the cross-stream stress. Not suitable in situations where the cross-stream stress is not expected to vanish, e.g., over water surfaces.

**Tube Diameter**

For closed path gas analyzer, the diameter of the intake tube (cm).

**Tube Length**

For closed path gas analyzers, this specifies the length (cm) of the intake tube.

## V

**Vertical Separation**

Vertical distance between the CO2/H2O Analyzer and the reference anemometer; this value is negative if the center of the analyzer sample volume (LI-7500A, LI-7700) or intake tube inlet (LI-7200) is below the center of the reference anemometer sample volume and positive if the gas sample is above.

## W

**WPL Terms**

Refers to the flux contributions arising because of air compressibility. Gas analyzers measure gas density (i.e., mole or mass of gas per volume of air). However, volume of air can change due to fluctuations of (primarily) air temperature, pressure and water vapor concentration. Such fluctuations must be taken into account when computing fluxes, either by converting gas measurements into dry mole fraction (if possible), or by adding compensation terms developed by Webb et al. (1980) for open-path setups and by Ibrom et al. (2007) for closed-path setups. Select the most appropriate method in EddyPro's interface. If you select unsuitable WPL options, EddyPro will figure that out and automatically switch to the most appropriate WPL strategy, depending on the available measurements.

# Index

## W



## Z

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