Wind speed at light speed

ZX 300M V2 Data Analysis Guide

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1 Introduction

Welcome to the ZX 300 Data Analysis Guide. This manual will help you through the necessary steps to perform useful data analysis on your lidar wind data.

The steps covered in this guide are:

- Data extraction and conversion
- Data file contents overview
- Mast comparison guidelines
- Basic troubleshooting for data analysis

Data analysis is an open ended topic as the user's exact requirements will vary depending on the desired outcome of any campaign. The information in this guide is intended as a good basis for any processing. For further and more detailed analysis techniques, please get in touch with the ZX Lidars team by email at support@zxlidars.com or phone our offices on +44 (0)1531 651000.

2 Data Extraction and Conversion

To use the data produced by a ZX 300, you must first convert it to a readable format. The most common is CSV format for import into other software tools. There are a number of ways to convert the proprietary data format (.ZPH) into comma separated variable (.CSV) format:

1. Using Waltz
2. Using ZPH2CSV
3. Using the ZX 300 itself (see the accompanying Configuration guide)

2.1 Data Types

There are two types of data produced by the ZX 300:

- Averaged “10 minute” data and
- Unaveraged “1 second” data.

Each day will have an associated file of each type resulting in two data files per day. Both data types are contained on the ZX 300’s internal storage and can be accessed by the user.

The Averaged data is Quality Controlled (QC’d) and should be considered Finance Grade and “Bankable”.

The Unaveraged data is also QC’d and can be used in real time applications (Section 4).. The unit gathers the Unaveraged data during the day, then after each 10 minute period it will perform the averaging process and produce an Averaged data file which (by default) is sent via email to the user after the day is complete.

Data is always compressed by the ZX 300 to save storage space and bandwidth during transmission. The units store the data in “Zip” format which the use will have to decompress before use. Most operating systems should be able to perform the decompression with ease.

2.1.1 Averaged Data

The most popular and commonly used data produced by the ZX 300 is the Averaged data. This data is identified with the filename prefix “Wind10_”. For example:

Wind10_3002@Y2014_M03_D30.ZPH.zip
Wind10_3002@Y2014_M04_D01.ZPH.zip

Once uncompressed, the data will look like this:

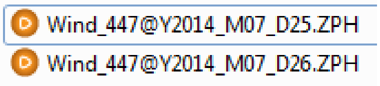
Wind10_3002@Y2014_M03_D30.ZPH
Wind10_3002@Y2014_M04_D01.ZPH

2.1.2 Unaveraged Data

The other wind data stored on the ZX 300 is the unaveraged “1 second” data – sometimes referred to as the high resolution data. This data is used to create the averaged data. The 1 second data is given the prefix “Wind_”, for example:

Wind_447@Y2014_M07_D25.ZPH.zip
Wind_447@Y2014_M07_D26.ZPH.zip

Once uncompressed, the data will look like this:



2.2 Using Waltz to convert your data

Waltz can convert the ZPH files to a more readable CSV format in a few simple steps. Waltz can convert multiple ZPH files in one action which will result in a single CSV. To import data into Waltz, either:

- Click the “Open” button:

Or:

- Drag and drop the file(s) into the Waltz window.

Once imported, click the “Export” button:

which will then open a dialogue box requesting the location and filename of the intended output file. See section 10 of the Waltz Manual for more information.

2.3 Using ZPH2CSV to convert your data

Following installation of ZPH2CSV, the user will need to run a command line to use ZPH2CSV. The tool is primarily intended for server automated data processing. It is used within Waltz so precisely the same libraries are used to perform the conversion so the results will be identical.

To use ZPH2CSV, type “ZPH2CSV ?” (without quotes) at the command line to receive instructions. The basic format of use is:

```
ZPH2CSV --input FILE1;FILE2;FILE3;… --output FILE.csv [options]
```

Note the use of the semicolon to separate filenames for input.

To produce more than one CSV file, a new instance of ZPH2CSV will need to be run.

2.4 Using the ZX 300 to produce CSV files

The ZX 300 contains ZPH2CSV within the firmware and it can be told to produce CSV files if required. The ZX 300 can also be told to email these CSV files in favour of the standard ZPH files. Please see the accompanying Configuration Guide on how to set up the ZephIR to do this.

The ZX 300 will store both CSV and ZPH files on its internal drive. It is strongly advised that you make sure the firmware on your ZephIR is up to date and that you use the most recent version of Waltz.

3 CSV Contents Overview

The contents of a CSV file will vary slightly according to the source ZPH – either 1 second or 10 minute data. The broad content format is the same and the following is constant for both data file types:

- Columns A-C contain timing and reference number information. The time in column B represents the ***start*** of the period contained in that row (e.g. start of 10 min period).
- Columns D and E contain Information and Status flags respectively.
- Columns F and G are the input voltage and (if applicable) external battery voltage respectively.
- Columns H-J are internal temperature and humidity readings
- Columns K-R contain information from the unit's met station (e.g. GPS, atmospheric conditions etc.)
- Column S contains information about any detected rain in the air – for slightly older versions of firmware and/or Waltz, this may read differently:
    4. "Raining" – If set to 1 then rain has been detected in this 10 minute period or:
    5. "Proportion of Packets with Rain (%)" – the percentage of packets in that 10 minute period (over all heights) that contain rain. This gives an indication of the severity of rainfall. If more than 1% of the packets has been determined to be affected by rainfall, the vertical wind speeds will be filtered out (9992).

After Column S begins the Wind Data which varies from 1 sec files to 10 min files. For a full list of CSV columns and information please see the CSV guide, which can be found in the Help menu in Waltz.

3.1 QC Filtering

The Averaged Data files have been Quality Controlled (QC) to meet IEC compliance and provide financial grade data. In order to do this, the ZX 300 removes data it does not consider adequate for IEC compliance. If data has been filtered, the ZX 300 indicates why the data point has been removed by using a filter code. ***These filter codes alone do not mean there is an issue with the ZephIR.*** They are deliberate and are used to inform the user of the conditions the ZephIR has been measuring. The codes have the following meaning:

9999 – High quality wind speed measurement is not possible. This is often caused by very low wind speed, or due to partial obscuration of the ZX 300 window, or significant interference with the laser beam at the specified height.

9998 – The ZX 300 automatically detects atmospheric conditions which adversely affect lidar wind-speed measurements. For example, in thick fog the beam from a lidar device may not be able to reach the measurement height. Also in certain cases when affected by significant precipitation, the ZX 300 will also reject the vertical component of the wind speed ***and only vertical wind speeds – horizontal speeds are unaffected by rain***. See above for further details.

On occasion, the ZX 300 may suffer an issue which may impact its ability to gather or record bankable data. If this happens, the ZX 300 will filter the data accordingly and also report what issue it has been affected by – check the information and status fields in conjunction with the filter codes to understand why the ZX 300 has filtered the data.

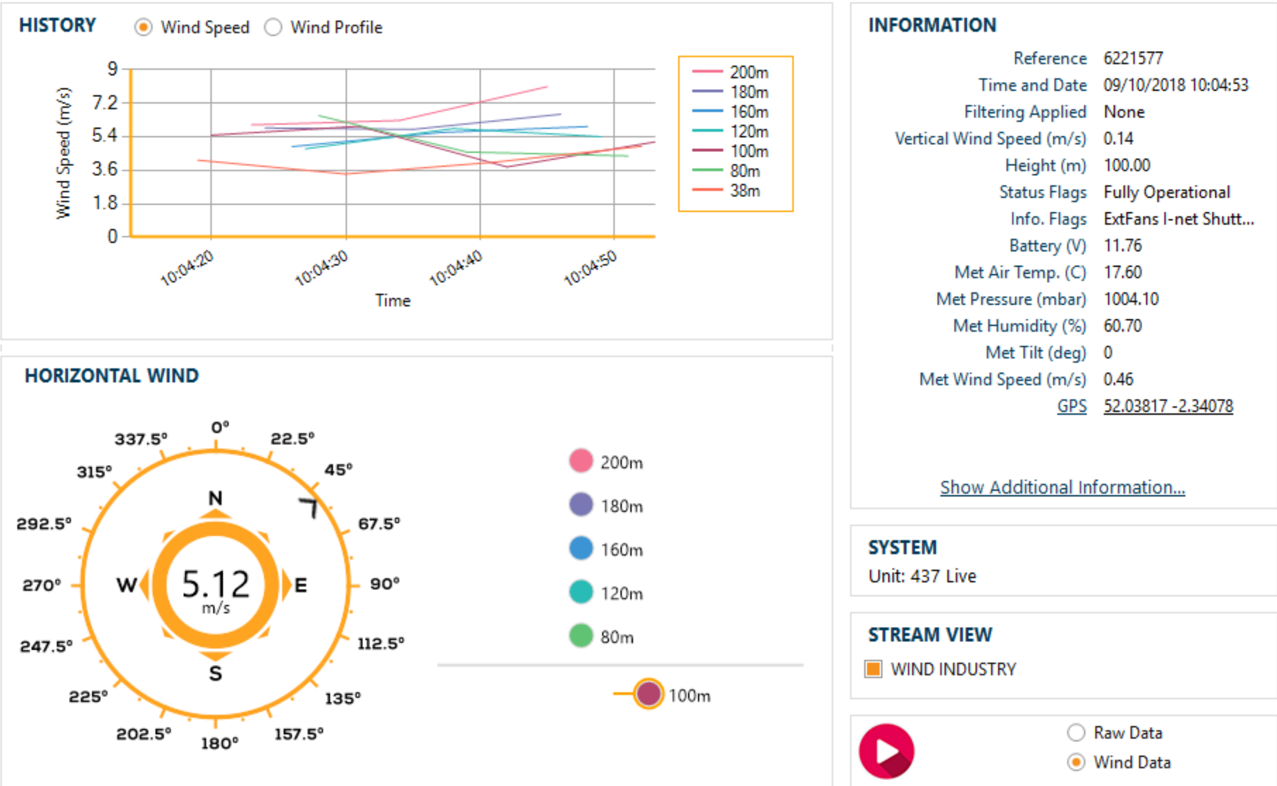
If the ZX 300 filters data and reports "Fully Operational", the data will have been filtered as it did not meet the required quality (e.g. fog, obscuration).

If the ZX 300 filters data and is not reporting “Fully Operational”, the status field will report the ZX 300’s operational status at the time which may explain why the unit has filtered the data (e.g. low power, safety interlock).

4 Real-Time Wind Data Output

ZX 300 was originally developed to provide accurate 10-minute data for the wind industry. However, as lidar becomes increasingly used for real-time operations, such as provision of wind data to inform wind farm construction activities, it has become important to deliver quality-controlled output at the 1-second level. ZX 300 addresses this requirement.

Waltz can be used to display the unaveraged (1-second) ZX 300 wind data in real time. An example is shown in the screenshot below.



Real-time data are quality controlled to ensure valid output; data may be rejected in unfavourable conditions, leading to apparent gaps in the output. For example, in thick fog where accurate measurement at greater heights is impossible, no data will be provided at those invalid heights.

The filters applied to the real-time data are designed to deliver high availability. A more stringent set of filters is applied for the 10-minute averaged output, to provide the standard finance-grade data. Users can select via Waltz whether to store unaveraged data that has been generated with the high-availability filters.

Screenshots to illustrate the above point, and an example of data output.

5 Comparison of ZX 300 and Met Mast Data

At present it is common for the performance of remote sensing equipment to be verified against a traditional met mast. This practice is likely to reduce in the future as more confidence in lidar is gained by the wind industry. Data comparisons usually consist of velocity and direction analysis, with possible extension to include parameters such as shear, inflow angle and turbulence intensity.

Care must be taken to filter mast data affected by shadowing or icing. Ensure analysis periods are concurrent, and that there is no relative time offset (e.g. 10-minute data can be time-stamped as period beginning or ending). For good comparisons, high-quality cups must be used in conjunction with an IEC-compliant mast arrangement. The following steps are used to perform a comparison between the lidar unit under test and the mast (used as reference):

- Apply a calm filter of 3m/s to both test and reference data sets
  - This eliminates data that is of little consequence for the wind industry, and where either sensor may be prone to larger error or offset
- Perform a least-squares fit, forced through the origin (0,0)
  - Ideal agreement will yield a gradient of exactly 1.00 and a coefficient of determination (R^2) that also approaches unity
- It is often sensible (particularly with Excel) to reduce the point size to the smallest on any comparison plots; otherwise the points can form a solid mass, and the impact of outliers can be greatly over-emphasised. The “transparency” option can also be useful with very large data sets.

Our preference for the forced regression is based on two arguments:

- When the wind speed does not occupy a large range, the fit parameters can be subject to larger error when the intercept is allowed to float.
- For wind resource assessment, the forced fit gives the best indication of any bias between the test and reference systems.
  - The gradient of the forced fit indicates whether the test unit will over- or under-estimate the wind resource with respect to the reference unit.
  - Note that the forced fit can lead to a slight reduction in the value of R^2

The value of R^2 is a useful indicator, but it must be used with caution. During a period of relatively constant wind speed, the value of R^2 is inevitably reduced but this should not be taken to imply a reduction in the accuracy of the lidar. Analysis of synthesised data is useful as a means to investigate possible shortcomings with R^2 as a metric for scatter. In general, the larger the range and spread of speeds, the higher is the value for R^2.

Measurements of turbulence intensity (TI) from a remote sensor differ from those measured by cup anemometers. This difference is a result of the measurement geometries employed by the two technologies, i.e. remote sensors measure the wind and its statistics over a volume whereas a cup anemometer is a point measurement. As a result, a correction is needed to convert the scan-averaged lidar measurement into an equivalent point measurement comparable with that recorded by a cup anemometer.

A height-dependent adjustment factor is applied automatically to the TI values in the 10-minute ZX 300 data. The factors were derived empirically by analysing the relative differences between ZephIR and cup anemometer TI from multiple collocated deployments across a wide range of environmental conditions.

6 Diagnosis of Problems in ZX 300/Mast Comparison Data Sets

6.1 Introduction

This section provides simple guidelines of what to look for when faced with correlation data that exhibit a poor gradient or R^2. When diagnosing such a problem, there are several types of cause to consider. The summary below is intended to be used as a quick check list to ensure all the most likely causes have been considered.

6.2 Mast Problems

Met mast anemometry is prone to a number of well-known problems that can lead to apparently poor agreement with lidar.

- Cup/vane icing can cause serious under-reading. Filtering of data below 2 degrees C is a common precaution.
- Shadowing effects: perform basic directional analysis to check whether directional filtering has been correctly applied. Check paired cups where possible to verify any assessment. This can be valuable even when the cups are not at the same height. Note that flow distortion by the mast can be significant at the 1-2% level even for an IEC-compliant set-up.
- Malfunctioning cup: check mean shear profile to identify any obvious anomalies via a clear discontinuity. Have the wrong cup calibrations been applied?

6.3 Analysis Problems

There are a number of simple causes of poor agreement that can be easily checked:

- Check time synchronisation in the case of poor R^2.
  - Even an offset of just a few minutes can lead to significantly degraded correlation, although the gradient is not affected. If poor synchronisation is suspected, plot the lidar and mast time series and look for a time offset.
  - In particular, look out for 10-minute offset (data sets can be labelled by period beginning or period ending), or integer number of hours in different time zones.
- Correlation analysis:
  - Check for housekeeping errors - have correct heights been compared?
  - Is there a large enough range of speeds during the analysis period for meaningful comparison?
  - Has the intercept been allowed to float (see previous section)? This can give large uncertainty in gradient when the wind speed range is low.

6.4 Terrain & Deployment Problems

For practical reasons, it is not always possible to follow precisely the best-practice guidelines as outlined in the previous sections. The impact of this can be more severe in complex terrain.

- Has the ZX 300 been aligned and levelled correctly on the ground? Has the ground subsided some time after deployment?
- What is the likelihood of complex flow? Has the impact of trees, turbine wakes been assessed?
- What is the ZX 300 – mast separation? In complex terrain, larger separation will have more impact and lead to reduced agreement.

- Height difference between ZX 300 and mast: it's not always clear how this should be taken into account. At low heights the flow follows the contours; at great heights it ignores them! This issue is minimised when the ZX 300 can be located very close to the mast.

Unlike point measurements from conventional anemometry such as cups, ground-based vertically-scanning lidars calculate the mean wind speed based on measurements recorded around the circumference of a scanned volume. This measurement philosophy relies on the assumption that the velocities around the scan are representative of the wind speed at the scan centre. When deployed in simple terrain, this assumption holds true and has led to the acceptance of lidars by international standards organisations such as the IEC. However, in strongly non-uniform flow, like that experienced in complex terrain, this assumption can break down and lead to possible differences between the lidar and measurements from conventional anemometry.

Conversion of wind speed data from lidars in non-homogeneous flow situations is possible through the application of high-resolution Computational Fluid Dynamics (CFD) modelling, which is used to derive the flow geometry throughout the measurement volume.

Should you wish to explore CFD conversion of your lidar data in complex terrain, please contact our customer service team: support@zxlidars.com.

6.5 Other Sources of Data Anomaly: Spatial Effects and Filtering

Lidar and cups evaluate the wind speed by interrogating very different spatial distributions. The cup can be considered a close approximation to a point sensor, whereas the lidar evaluates a disk that expands with increasing measurement height. In addition, the probe length of the laser beam leads to signal returning from a finite depth/height range. In ideal conditions, the speed is uniform around the disk, shear is linear across the probed depth, and the distribution of scatterers in the atmosphere is uniform. Much of the time, this is a close approximation to reality; however, even when these conditions are not satisfied the signal processing in ZX 300 is designed to return accurate values for the majority of scenarios.

ZX 300's 50 points around the disk allow it to carry out a number of diagnostic tests to determine when the accuracy has been compromised – an example of this is when turbine wakes encroach into the scan. The results of these tests are fed into the filtering (QC) module of the signal processing chain. Note that under the vast majority of conditions, ZX 300 is able to make a measurement of wind 100% of the time; any loss of availability is a consequence of data failing the QC tests leading to elimination by the filters.

While the lidar and cup clearly measure different things, there are many reasons why the lidar should not necessarily be considered to be "wrong" in the case of disagreement. Typically, for correctly mounted cups and correctly sited lidar in benign terrain, any differences between cup and lidar are unbiased; that is, they can lead to an overall increase in the scatter of the correlation plot but crucially do not significantly affect the gradient and hence the assessment of wind resource.

In flat terrain the lateral extent of the disk has minimal impact; however, the height distribution probed by the lidar can give rise to some differences with a cup. If the conditions are not compatible with finance-grade wind measurement then the data will be filtered. The precise setting of filter thresholds has been determined through the analysis of many years of ZX 300 data from multiple sites. In setting such thresholds, there is always a balance to be struck between availability and accuracy; there is inevitably an inverse trade-off for these parameters. The filter threshold settings have been optimised to ensure that the overall assessment of wind resource is not compromised, as demonstrated in numerous campaigns around the world.

Inevitably there will be certain atmospheric conditions that lead to data lying on the edge of a filter threshold: such data is liable to increased discrepancy with the cup/mast. The impact of these events will be a reduction in correlation and the value of R^2, but there will be no overall bias due to the statistical insignificance of the events, which can lead to short-lived under- or over-reads compared to the cup. This can also lead to small or fleeting disagreements between adjacent ZX 300 units, but these events are usually insignificant: ZX 300 to ZX 300 comparisons will typically demonstrate very high correlations and the gradients will lie very close to unity. This latter feature is a consequence of the rigorous calibration process applied to each lidar, which is very robust over an extended operating period.

ZX Lidars

About Us

In 2003 we released the first commercial wind lidar, pooling decades of fibre laser research from the science, security and energy industries. Designed specifically for the wind industry our Lidar has paved the way for many of the remote sensing devices seen in the market today. Our original lidar technology continues to innovate with world firsts such as taking measurements from a wind turbine spinner and being the first to deploy an offshore wind lidar, both fixed and floating. Our Lidars have also now amassed more than 10 million hours of operation across 1000+ deployments globally spanning a decade of commercial experience. Some of our proudest achievements are listed below; these are the earliest reported examples that we are aware of from open publications.

2003 - The first wind lidar to make upwind measurements from a turbine nacelle
2004 - The first and original commercially available lidar for the wind industry
2004 - The first wind lidar to investigate the behaviour of turbine wakes
2005 - The first wind lidar to be deployed offshore on a fixed platform
2007 - The first wind lidar to take measurements from a turbine spinner
2008 - The first wind lidar to be signed off against an industry-accepted validation process
2009 - The first wind lidar to be deployed offshore on a floating platform
2010 - The first wind lidar to re-finance and re-power a wind farm
2011 - The first wind lidar to be proven in a wind tunnel
2012 - The first wind lidar to be used with very short masts and secure project financing
2012 - The first wind lidar to be accredited for use with no or limited on-site anemometry for project financing by DNV GL
2014 - The largest batch of single-type lidar verifications against an IEC met mast
2015 - The first lidar designed specifically for offshore use, with the longest warranty available - 3 years as standard
2016 - The first wind lidar to support safe lifting on a jack-up vessel
2016 - The first wind lidar SCADA integrated on operational wind farms in replacement of site met masts
2017 - The first wind Lidar to be installed across a wind farm on a Lidar-per-turbine basis, uniquely mapping wakes across a wind farm
2018 - The first wind Lidar to satisfy all criteria for IEC Classification
2019 - The first wind Lidar to take wind measurements from a drone

ZX Lidars delivers wind lidar solutions and supporting services globally for our clients, with offices and agencies across Europe, the Americas and Asia Pacific.

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Our Products & Services

ZX300

Onshore vertical profiling wind Lidar

ZX300M

Floating & platform-mounted vertical profiling wind Lidar

ZXTM

Turbine-mounted horizontal profiling wind Lidar

ZX Measurement Services

Wind Data as a Service