Land-atmosphere interactions - 1

Actual and reference evapotranspiration on catchment scale

# Introduction

In this exercise you are going to estimate the *actual* evapotranspiration for the Hupsel catchment. You will make this estimate in two steps:

1. Determine the link between actual evapotranspiration of the Hupsel catchment and reference evapotranspiration. This analysis will be based mainly on the detailed (eddy-covariance) data observed at Hupsel in 2011 (since it is comparable in drought to 2020, see figures below).
2. Use the results from (1) to translate the reference evapotranspiration (of 2019) to an estimate of the catchment-wide actual ET in 2020 (May 14-27).

The analysis in step 1 will be mainly based on a the continuous energy balance observations made at the KNMI station in 2011 (eddy covariance measurements). However, since we lack continuous observations of the energy balance of the bare soil fields in the Hupsel catchment, we additionally use one week of data from a different experiment (TRANSREGIO). For this we have simultaneous data from a bare soil plot and a vegetated surface (in that case sugar beet).

Data will be made available in an excel worksheet. The computations will be done in excel as well.

|  |  |
| --- | --- |
|  |  |
|  |  |

**Figure**: Comparison of precipitation deficit for 2011 (left) and 2020 (right). Deficit for current year is the black line, red line for record year 1976, green for the 5% percentile driest year and blue for the median year.

# Objective

Objectives of this practical are:

* determine actual evapotranspiration for the Hupsel catchment (taking into account the different land-use types). That estimate will later be used to complete the water balance for the catchment (exercise with Claudia Brauer).
* determine reference evapotranspiration according to Makkink, Penman-Monteith (FAO-method) and Priestley-Taylor.

The results of these steps can be stored in the preformatted spreadsheet named **results\_meteo\_1\_YOURNAME.xlsx.** So if the exercise says ‘make a spreadsheet’ you simply have to fill/extend the corresponding sheet (numbered with the exercise number) in the results spreadsheet

When you have finalized the analysis, make sure that:

* you renamed the spreadsheet by replacing YOURNAME with your name(s).
* you have discussed your results with the lecturer.

If all of the above have been done, upload your results spreadsheet on Brightspace.

# Data and how it all fits together

All necessary data are available in the zip-file **Meteo\_StudentsPack.zip**: download, and unzip to your local drive.

Three datasets are contained in the zip-file:

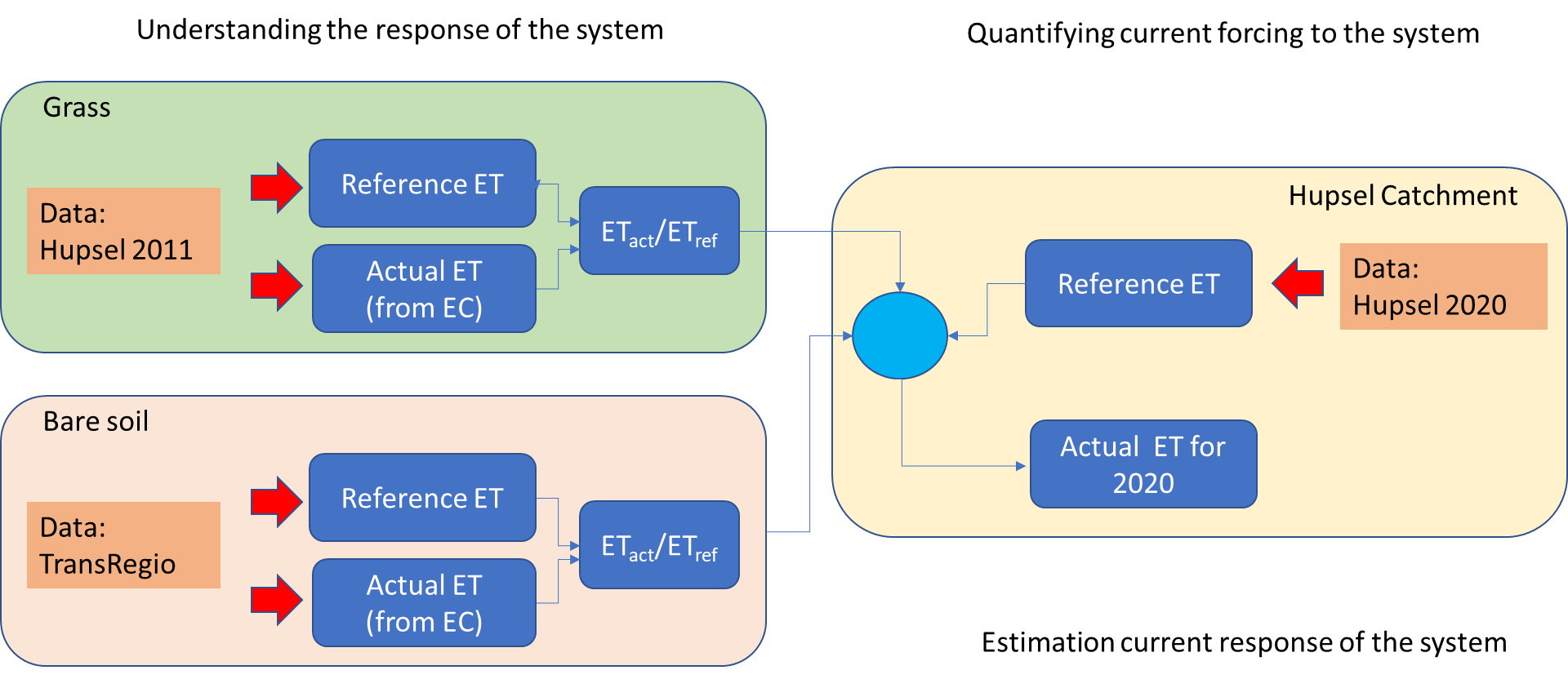
* **Hupsel2020\_KNMI\_Data.xlsx**: daily mean data from the Hupsel KNMI station of 2020 (May 14-27).
* **Hupsel2011\_KNMI+flux\_24hour.xlsx**: daily mean data from the Hupsel KNMI station of 2011 (April 26 – May 17) + daily means of all fluxes of the energy balance station (eddy-covariance + soil heat flux + net radiation). Note: the standard KNMI data set is indicated with a green header and data from the instruments temporarily installed by WUR-MAQ by a brown and yellow header.
* **TR32\_WetDry\_dataset.xlsx**: data set from a separate experiment including bare soil flux data.

To help you interpret the 2011 data better, some files with ready-made graphs are available in the folder Quicklooks:

* **Hupsel2011\_MetStationKNMI.pdf** and **Hupsel2011\_MetStationMAQ.pdf:** overview per day of basic meteorological parameters, radiation components and soil heat flux.
* **Hupsel2011\_ECmean.pdf**: mean quantities from the eddy-covariance system: one page per day.
* **Hupsel2011\_ECfluxes.pdf**: fluxes from the eddy-covariance system: one page per day.
* **Hupsel2011\_ECrawdata\_SAMPLE.pdf**: plots of the raw EC-data (here you can for instance see the magnitude of turbulent temperature and velocity fluctuations).

To give you an impression of what the eddy-covariance setup looked like, we’ve also included some photographs made in 2018 (**Photos\_Hupsel2018\_MeteoStation.pdf**).

How do all these data sets fit together? We will use historic data (Hupsel 2011 and Transregio) to quantify how grass and bare soil respond to external forcings (summarized in a reference ET). This response may be different for different conditions (e.g. related to periods of rain, high or low temperatures …). This quantified response is subsequently used to determine the actual ET for the Hupsel catchment for the current year (see sketch below).



# Intermezzo – background from previous courses

If you still master the contents of the course Atmosphere-Vegetation-Soil Interactions (AVSI), you can skip *most* of the text below (except the practical notes on the FAO-method) and continue to the section called ‘Procedure’. Part of the information below is needed for today’s exercise, other parts are only relevant for the second day of data analysis.

## Reference evapotranspiration

The theory on combination methods to estimate evapotranspiration has been dealt with in the course Atmosphere Vegetation Soil Interactions. You will need your book ‘Transport in the Atmosphere-Vegetaton-Soil Continuum’, or can consult the book chapters online (within the university only: <http://ebooks.cambridge.org/ebook.jsf?bid=CBO9781139043137>).

The main equations used to estimate evapotranspiration are repeated here:

Penman-Monteith: 

Priestley-Taylor: 

Makkink: 

## Terminology

To reduce the confusion we will list here the definitions as they are used here (where we mainly follow Moors (2002)).

* The total evapotranspiration E consists of:
  + Transpiration (*T*): the part of the total water vapour flux that enters the atmosphere from the soil through the vegetation (stomata and cuticula).
  + Evaporation of intercepted water (*Eint*): evaporation of water that has been intercepted by plants.
  + Soil evaporation (*Esoil*): evaporation of water from the soil (the soil may either be saturated or partly dry).
* Optimal evapotranspiration *Eopt* is the theoretical evapotranspiration that would occur if a given vegetation, completely covering the soil is exposed to prevailing meteorological conditions (without affecting the meteorological conditions). This quantity is often referred to as potential evapotranspiration (*Epot*). However, very often no reference is made to a specific vegetation and the use of a concept of ´the potential evapotranspiration´ then becomes useless.
* Reference evapotranspiration *Eref*: is the theoretical evapotranspiration that would occur if a well-defined, theoretical vegetation, completely covering the soil is exposed to prevailing meteorological conditions (without affecting the meteorological conditions).

## Methods for reference evapotranspiration

Internationally, the FAO method is widely used to estimate actual evapotranspiration based on a reference evapotranspiration determined using the Penman-Monteith equation. On the other hand, in the Netherlands the Makkink method is used, which has the advantage of simplicity and gives –for Dutch conditions– very similar results as the Penman-Monteith equation. The **reference vegetation** in the FAO method is short, well-watered grass with the following properties summarized in the table above.

Table 1 Overview of parameters to be used in the Penman-Monteith equation when applied in the FAO method for reference evapotranspiration.

|  |  |
| --- | --- |
| **Variable** | **Value or equation** |
| Albedo | 0.23 |
| net longwave radiation | , where *Ta* is the (absolute) air temperature and εatm is the atmospheric emissivity. |
| atmospheric emissivity | estimated as the sum of the clear sky emissivity and a cloud emissivity equal to 1:  , where *f*cloud is the cloud fraction and the clear sky emissivity is estimated as with *c1* and *c2* being empirical constants with standard values of 0.52 and 0.065 hPa-1/2 and *ea* is the water vapour pressure in hPa. |
| vegetation height | 0.12 m |
| displacement height | 0.08 m |
| roughness length momentum | 0.012 m |
| roughness length heat | 0.0012 m |
| aerodynamic resistance | , where *zu* and *zT* are the height of windspeed and temperature observations. Note that this expression for *ra* is valid for neutral conditions. |
| canopy resistance (daily mean data) | 70 sm-1 |
| canopy resistance (short time interval data) | 50 sm-1 at daytime, 200 sm-1 at nighttime |
| soil heat flux (daily mean data) | Neglected |
| soil heat flux (short time interval data) | 0.1 times net radiation at daytime, 0.5 times net radiation at nighttime |

Note that the cloud fraction can be estimated from the ‘sunshine duration’ in the KNMI data. Special attention needs to be paid to times when the sun is under the horizon as in that case no information on cloud amount is present. Hence, for the night time data probably the safest guess is to assume that cloud fraction is 0.5. For daily sums, the relative sunshine duration can be computed from the duration of sunshine and day length. In Hupsel sunrise is at 3:51 UTC on May 10 and at 3:31 UTC on May 24; sunset is at 19:18 UTC on May 10 and at 19:38 UTC on May 24.

# Determine response of grass and bare soil – step 1+2

To construct an estimate of the catchment-wide actual evapotranspiration, we mainly need continuous data on evapotranspiration from grass and bare soil. For grass we could use the data from the MAQ EC-system at the KNMI station. For the bare soil we use the TransRegio (TR32) dataset.

## Determine response of actual evapotranspiration for grass (Hupsel 2011 data) – step 1

We do have direct flux observations available for the grass surrounding the KNMI station. Can we assume that this local measurement is representative for the entire catchment (upscaling)?

Convert the latent heat flux to an evapotranspiration in mm/day and copy those values to the preformatted spreadsheet in tab ‘1 Grass response (do not use a ‘magic factor for the conversion to mm/day, but make a real computation; the expression for *Lv* can be found in the formularium). This is your estimate of the actual evapotranspiration for grass.

In order to determine the response (which can be interpreted as a kind of variable crop factor), we first need a reference evapotranspiration. For simplicity, use the Makkink method for this (check the earlier intermezzo for the equation; other required equations can be found in the formularium). Copy those values also to the answer spreadsheet (column ETref).

Now determine the response (crop factors) for each day. You will see that the factor varies from to day to day. Try to explain the largest deviations (both in positive and negative direction) based on the weather data (e.g. rain, wind, temperature, humidity, sunshine duration, …).

## Determine response of actual evapotranspiration for bare soil (TR32 data) – step 2

For the estimate of the bare soil evaporation we use an additional data set. The data from the TRANSREGIO experiment can be found in **TR32\_WetDry\_dataset.xlsx.** Note that rainfall occurred in the night from day-of-year (DOY) 219 to 220. This has a large impact on the bare soil evaporation (check also how long this impact lasts).

The method you follow here is identical to what you did for the grass data: determine actual bare soil evaporation, determine reference evaporation and determine the response factor.

Again, you copy those results to the answer spreadsheet (tab ‘2 BareSoil response’). Explain the variation in response factors you see on a day-to-day basis.

# Determine actual ET for Hupsel – step 3+4

## Estimate actual ET for grass and actual E for bare soil for 2020 (Hupsel KNMI data 2020) – step 3

Now it is time to combine your insights from the first two steps with the data from 2020. The estimation of actual ET fluxes for grass and bare soil requires two ingredients:

* Reference ET
* Proper response factors (crop factors) on a day-to-day basis.

The first step is straightforward (you computed reference ET according to Makkink in the previous steps). In the second step you have to construct a time series of response factors for both grass and bare soil:

* For each day in the 2020 data determine what the conditions were.
* Search for a day with similar conditions in the grass data set to determine the appropriate grass response factor (the date does not matter, but e.g. prior rainfall, temperatures, humidity, radiation) might be relevant).
* Do the same for the bare soil data set (main variation in that data set is soil moisture due to rainfall).

Using the reference ET and the daily response factor you can estimate the daily actual ET for grass and bare soil.

Copy your results to the answer document (tab ‘3 Grass and bare soil 2020’).

## Estimate actual ET for the Hupsel catchment for 2020 (Hupsel KNMI data 2020) – step 4

From the results of step 5, in combination with knowledge of the distribution of land use in the catchment (see **landuse\_hupsel.pdf** or the lecture notes) and additional assumptions (mention which!) construct an estimate of the daily sum of actual evapotranspiration (in mm/day) for the entire Hupsel catchment.

* Construct a timeseries of the daily actual evapotranspiration for the Hupsel catchment for the period (for May 14 to May 27 incl.)
* Discuss the uncertainties in your estimate (which part of your estimate is most uncertain; what is the impact of this uncertainty on the final estimate of the catchment mean evapotranspiration).

Collect your data and findings in the answer document in tab ‘4 catchment ETact + 6 ref ET’

# Various methods for reference ET – step 5-7

## Reference evapotranspiration – computation – step 5+6

At this stage we will compute the reference ET from daily average data. For Priestley-Taylor and Penman-Monteith we will use **observed** *Q\*-G.*

*Step 5: Compute derived quantities needed for reference ET methods for daily average data*Before you can compute the reference evapotranspiration with the various methods, first a number of derived quantities need to be determined, i.e. those variables that appear in the equations for *LvEref*, but are not measured directly or are not yet available as daily averages. For the present case those comprise:

* *es*(*T*) (saturated vapour pressure at air temperature)
* *s* (slope of the saturated vapour pressure as a function of temperature) (you already used this one for Makkink as well).
* *γ* (psychrometer constant)
* *ra* (aerodynamic resistance, using wind speed, see notes on the FAO method earlier in this document in the intermezzo on page 3).
* In your spreadsheet, make a column for each of these variables. Take care that you use the correct units!

*Step 6: Computations of daily mean* *reference evaporation*  
In order to keep the computation tractable, it is useful to split the equations in handy chunks (e.g. for Penman-Monteith into the radiation term and the aerodynamic term). Also, keep in mind that certain groups of variables occur in different evaporation formulas.

* The final outcome of this step are three columns in your spreadsheet, containing the following estimates of the reference evapotranspiration (in mm/day):
* Penman-Monteith (according to the FAO-method, but with measured *Q\** and *G*).
* Priestley-Taylor
* Makkink

## Reference evapotranspiration – analysis of methods and comparison to actual ET - step 7

*Step 7: Analysis*The first step will be to compare the different methods to determine reference evapotranspiration. There are a number of methods to do this:

* Plot timeseries of the various methods in one graph (actually, the answer spreadsheet contains a pre-cooked graph: ‘7 ET graph’)
* Make a scatter plot of one method against the other

Important features to look at are

* Is one method consistently lower or higher than another method?
* Do the methods show the same variability between days?
* What causes the day-to-day variation?
* Explain the differences between the different methods. Why do they differ on some days, and less so on other days.
* Investigate the relationship of the various reference methods to the catchment-wide ET obtained in step 5. Again, is there a consistent difference between, or does the difference from day to day?

# Closure

Make sure that you agree with your own results. I will directly copy your results to determine a group-estimate of the basin-wide ET, so it’s up to you to give me the most convincing value.

* Make sure that you renamed the spreadsheet by replacing YOURNAME with your name(s).
* Make sure that you have discussed you results with the teacher.
* If both of the above have been done, upload your results spreadsheet on Brightspace.

Thanks