Investigation of connections between water budget components and soil water content distribution on a forested site

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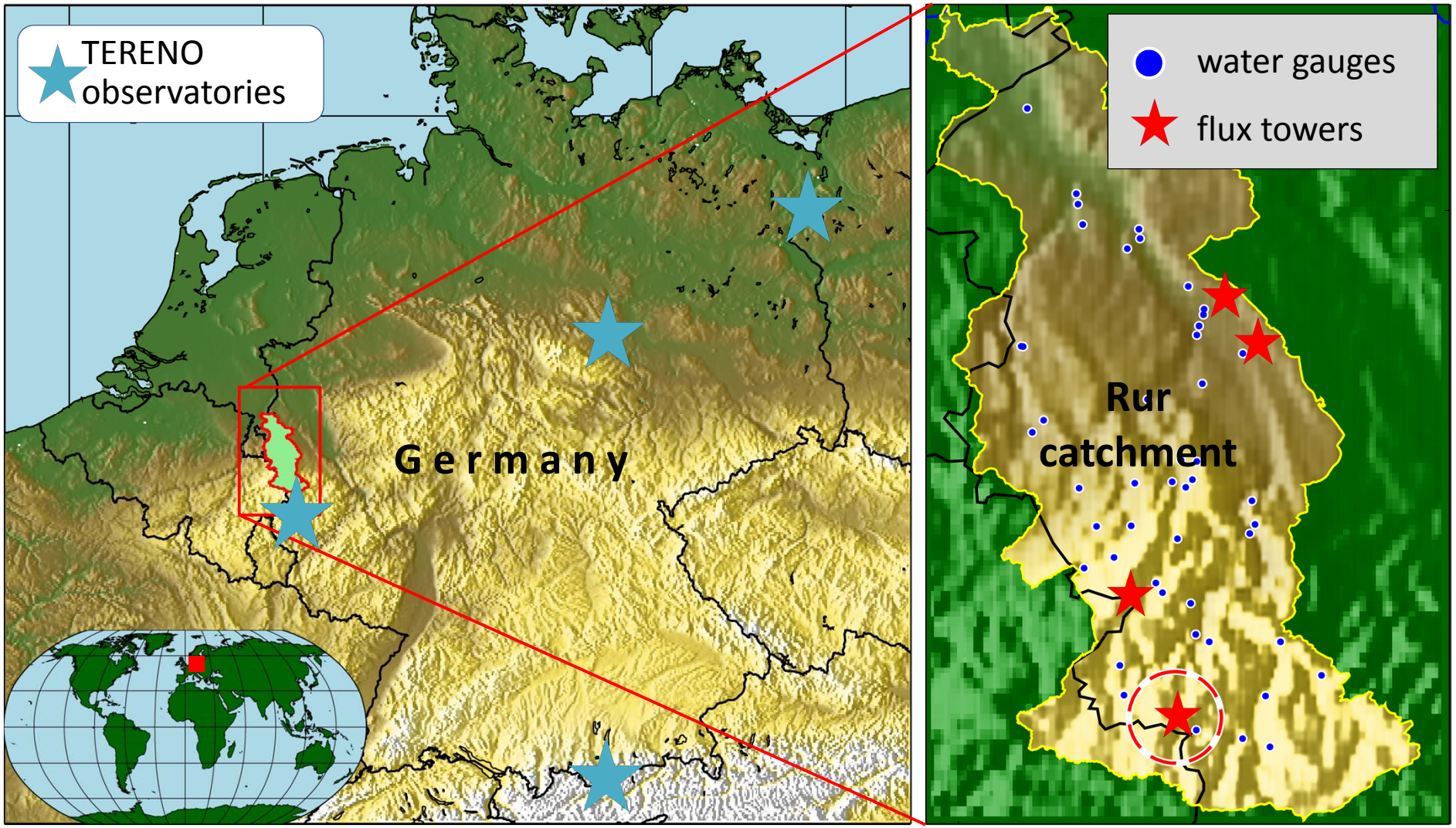
TERENO / DFG TR32

TERENO
TERRESTRIAL ENVIRONMENTAL OBSERVATORIES



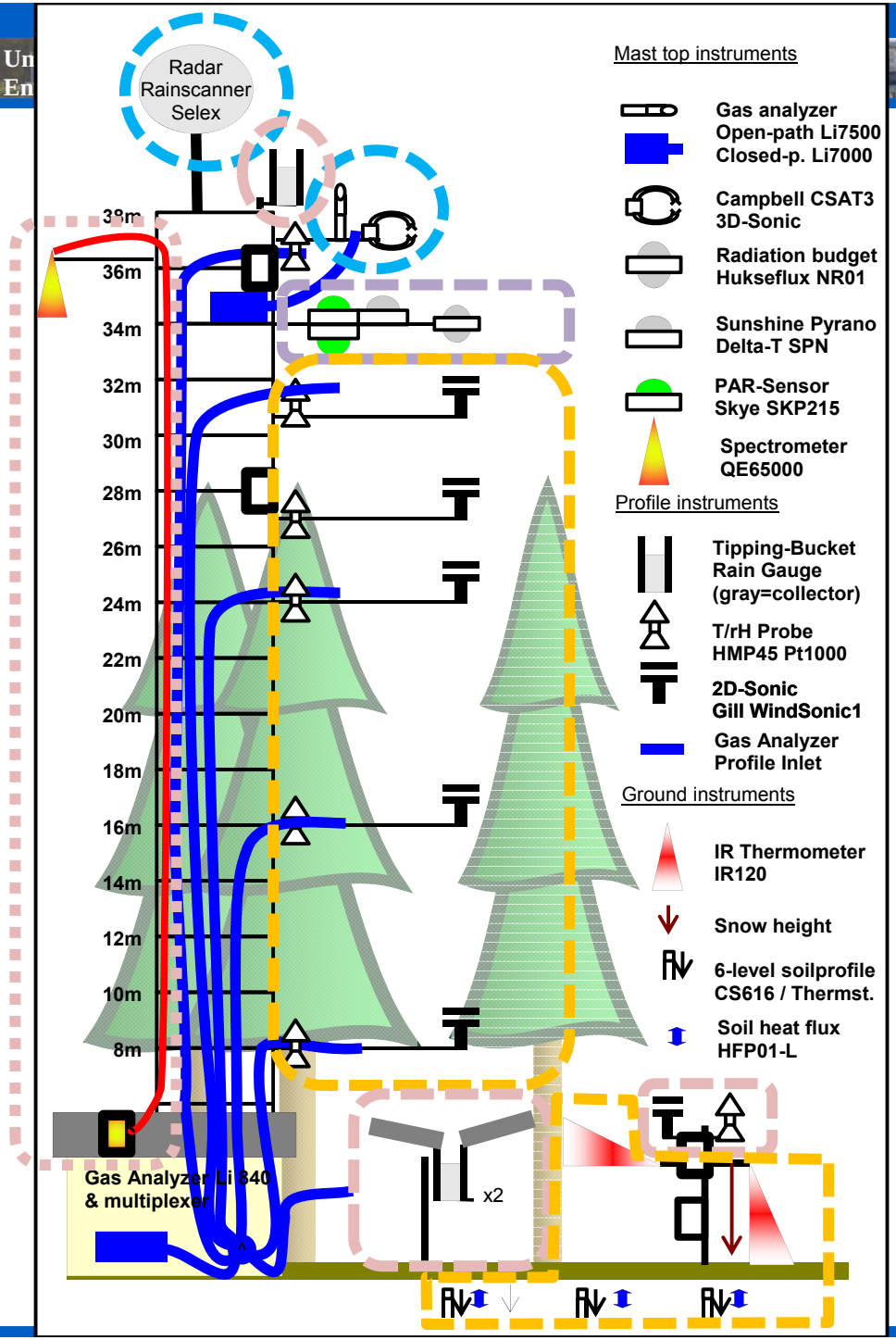
2010

2011

2012

2013

2014 ?



SoilNet at Wüstebach

- Area: ~38 ha
- Mean slope: ~9 %
- Annual Temp.: ~7°C
- Veg.: ~60 yr old spruce

SoilNet:

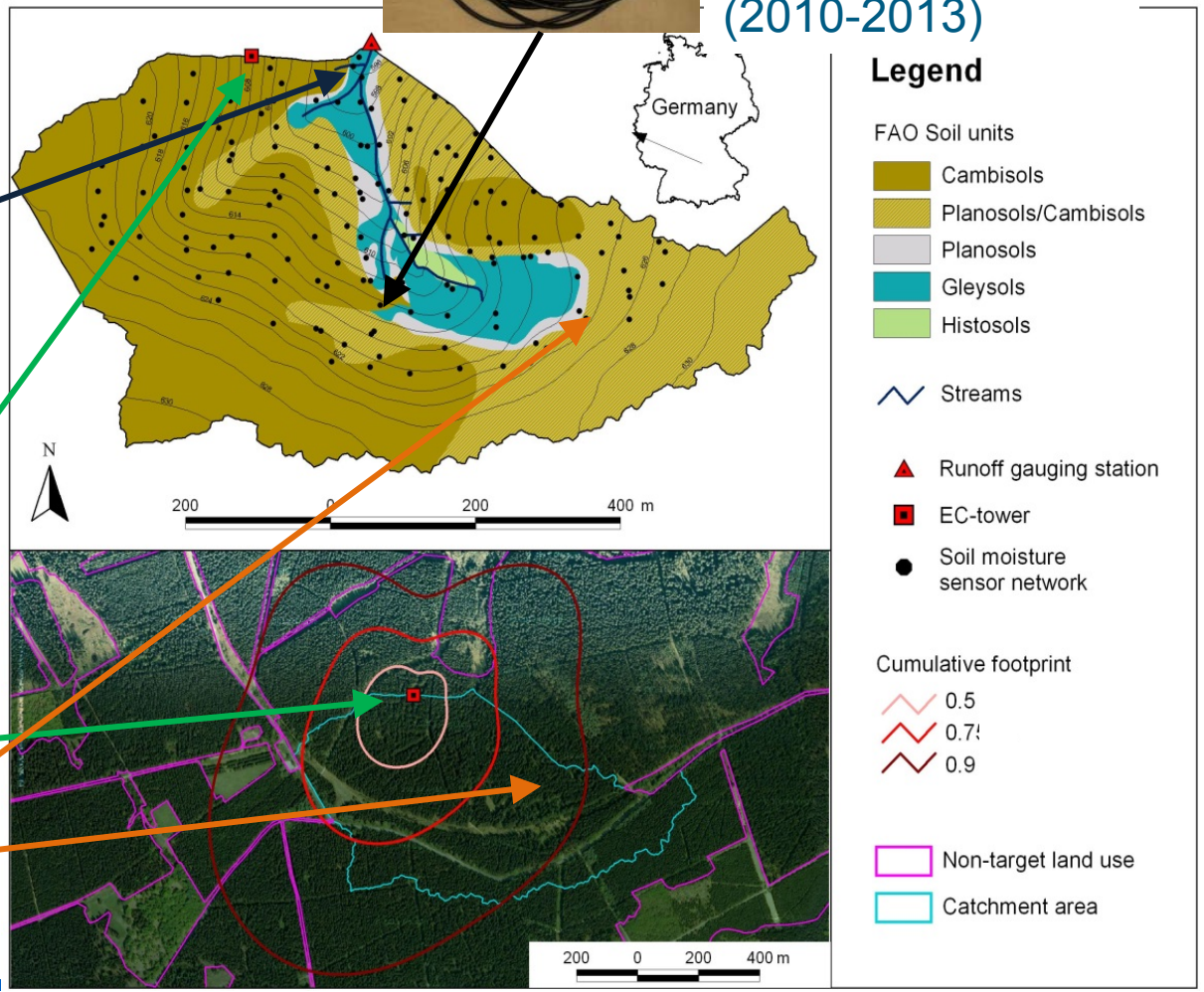
3 depths per point

109 points in (2010-2013)

Runoff level

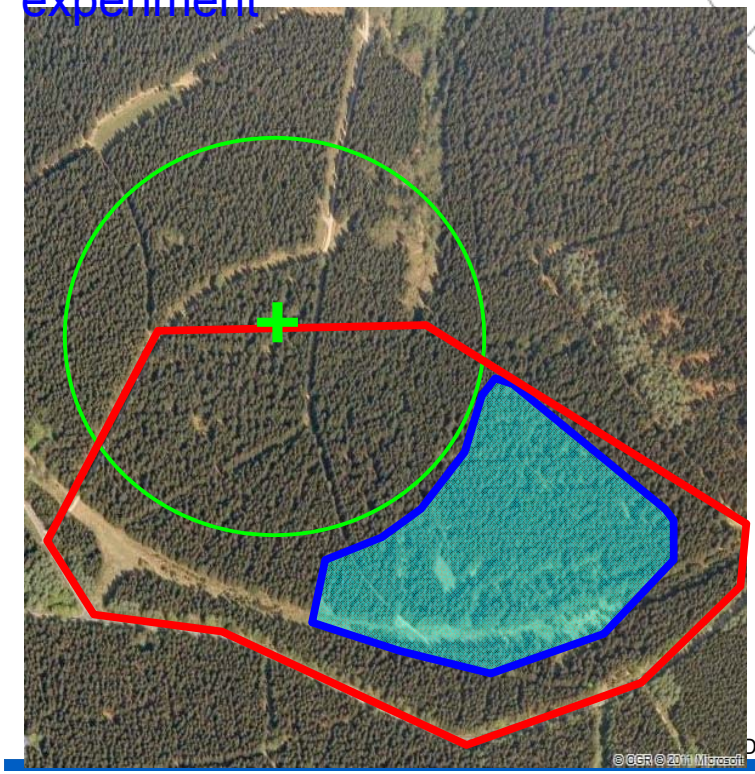
EC tower 38m

EC tower clear cut

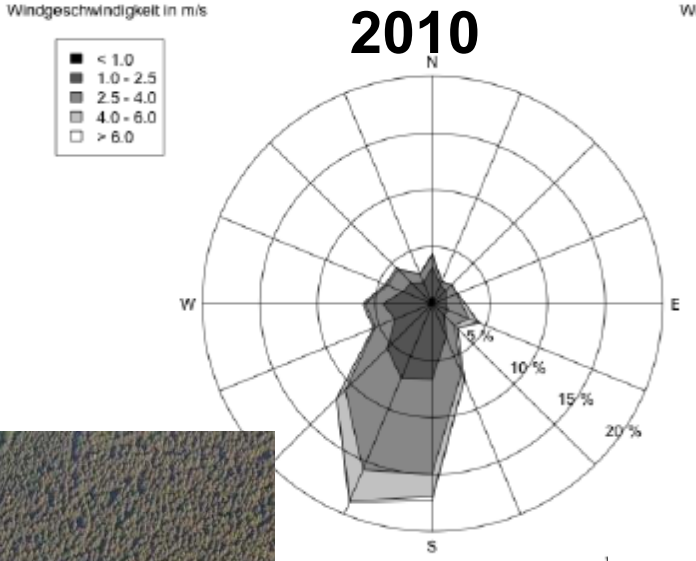


Wind distribution

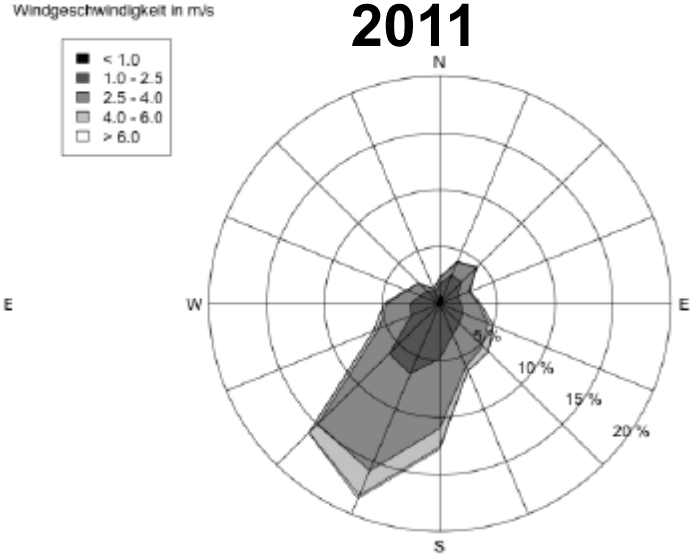
- EC-tower
- Hydrological Monitoring
- Deforestation / succession experiment



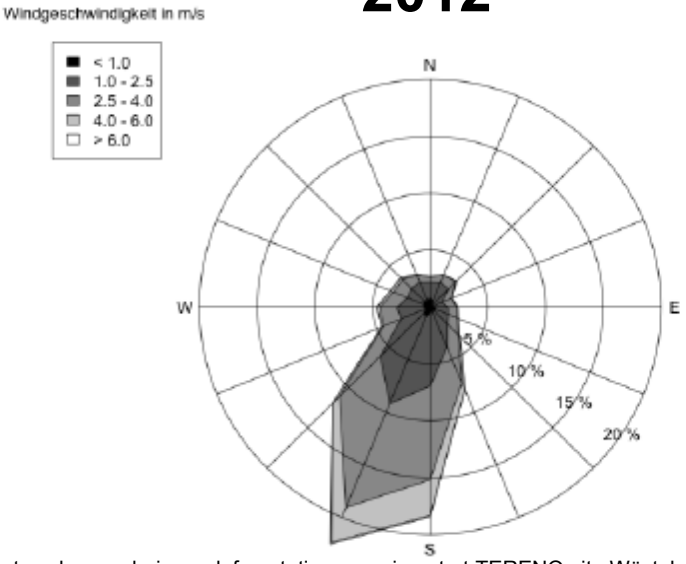
2010



2011



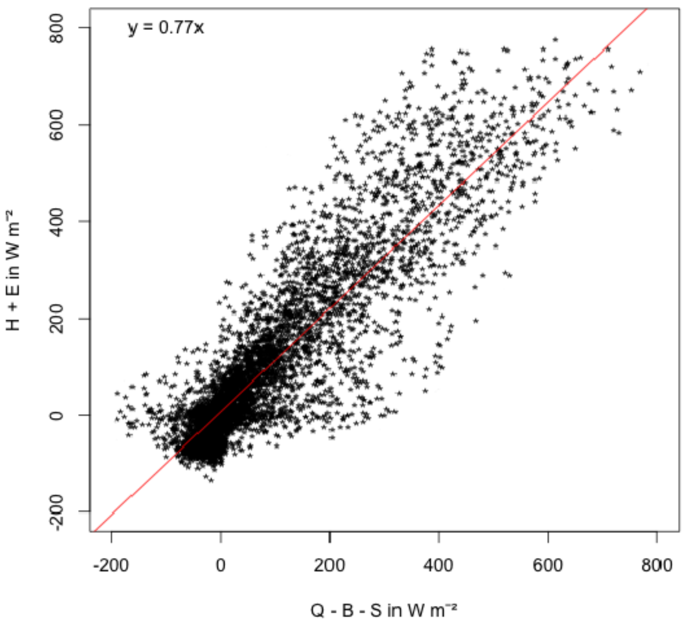
2012

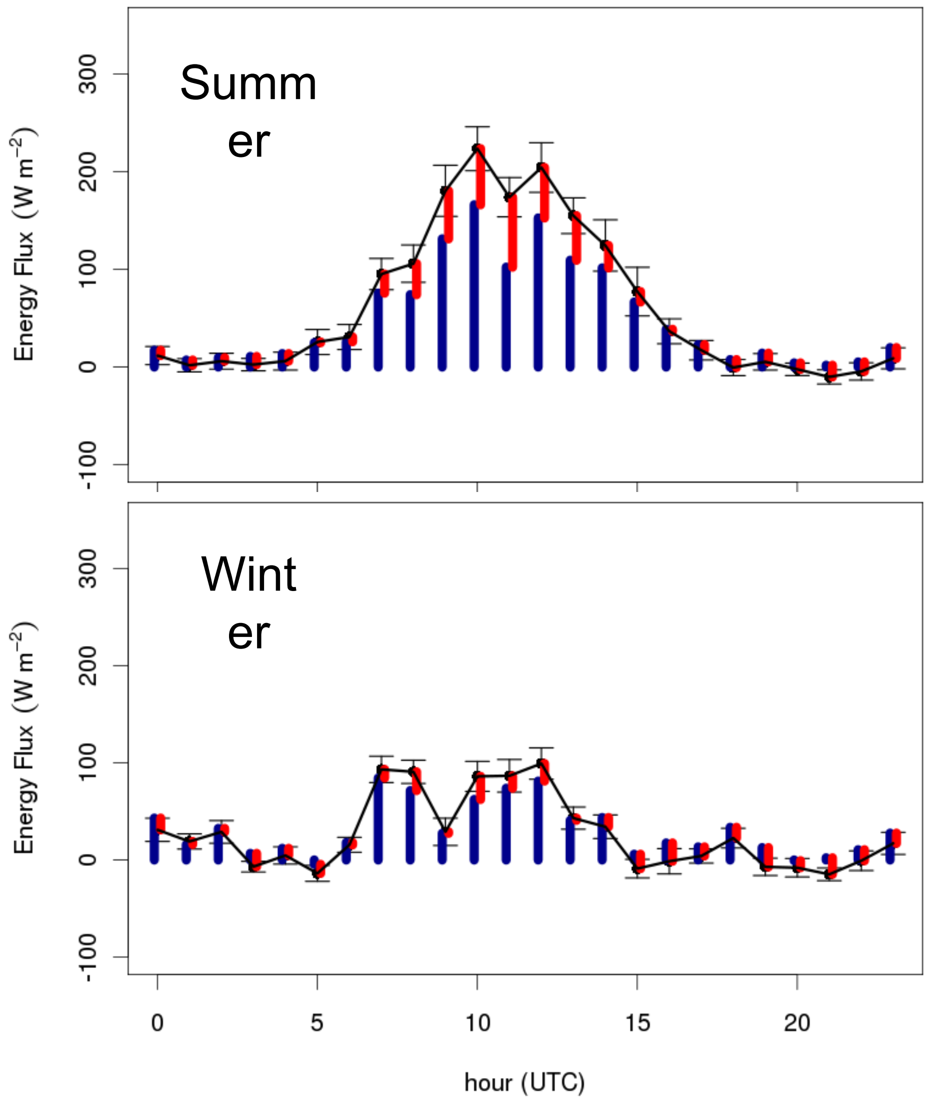


Drüe Forest exchange during a deforestation experiment at TERENO site Wüstebach

Energy balance

- **Fluxes show typical behavior**
- **Closure only fair due to poor knowledge of the storage terms**

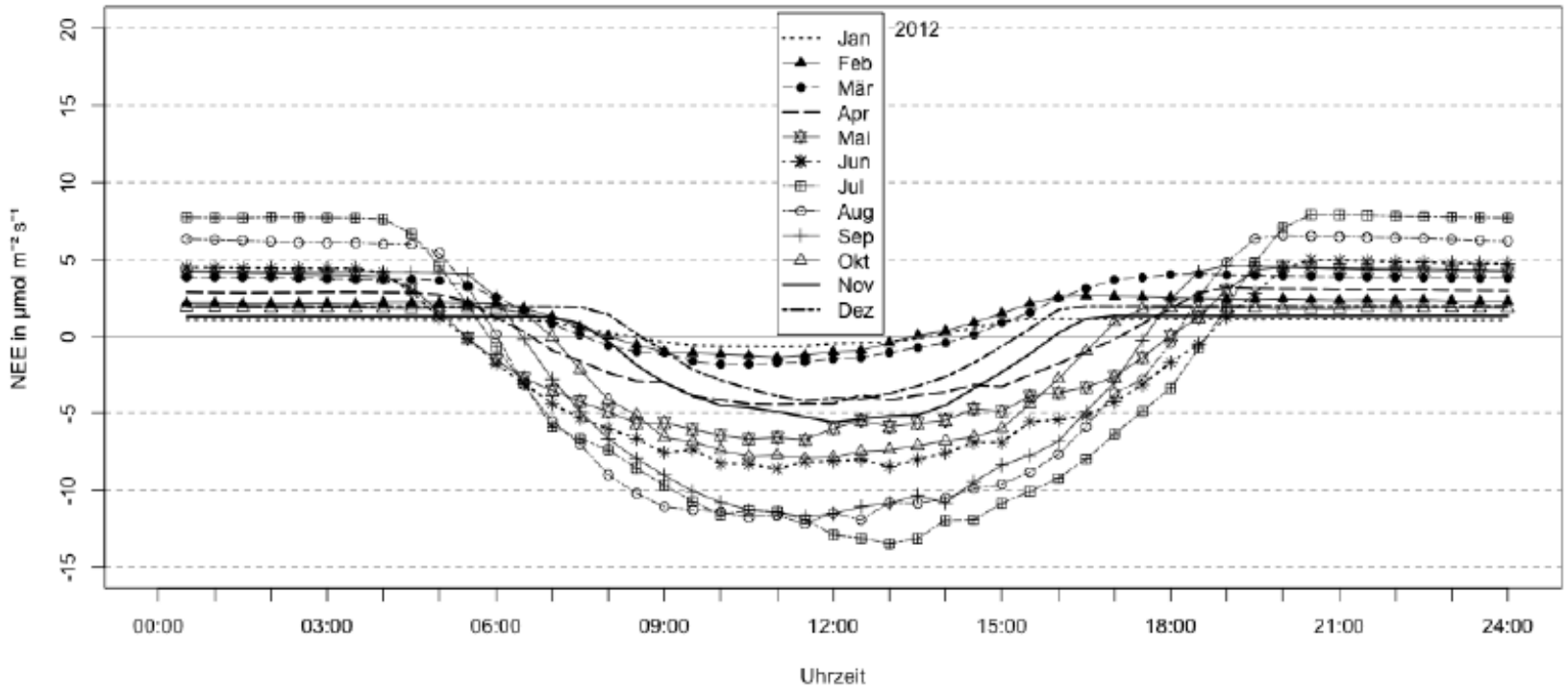




black line corresponds to the turbulent heat flux sum, error bars show standard deviation of daily values

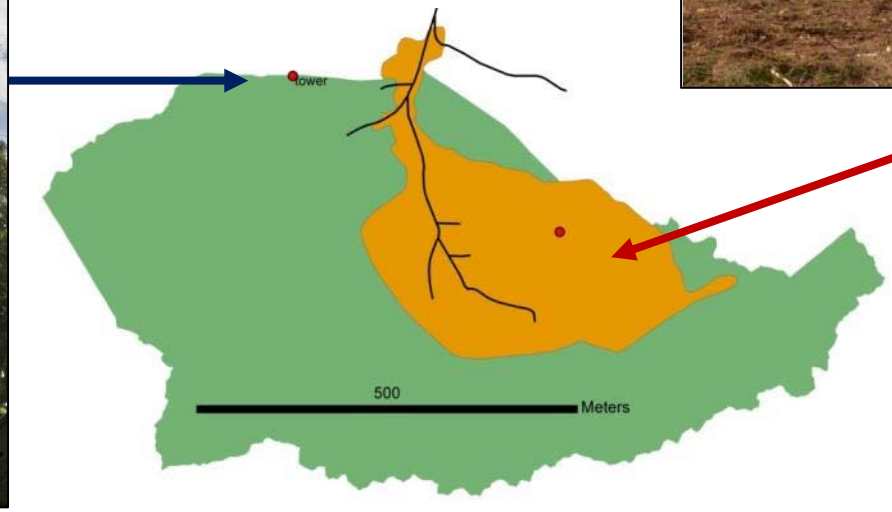
CO2 flux

- Typical daily cycles and light response
- 40% averaging intervals fail QC Often foggy, light rain, hoar)
- Gap filling an issue to be solved

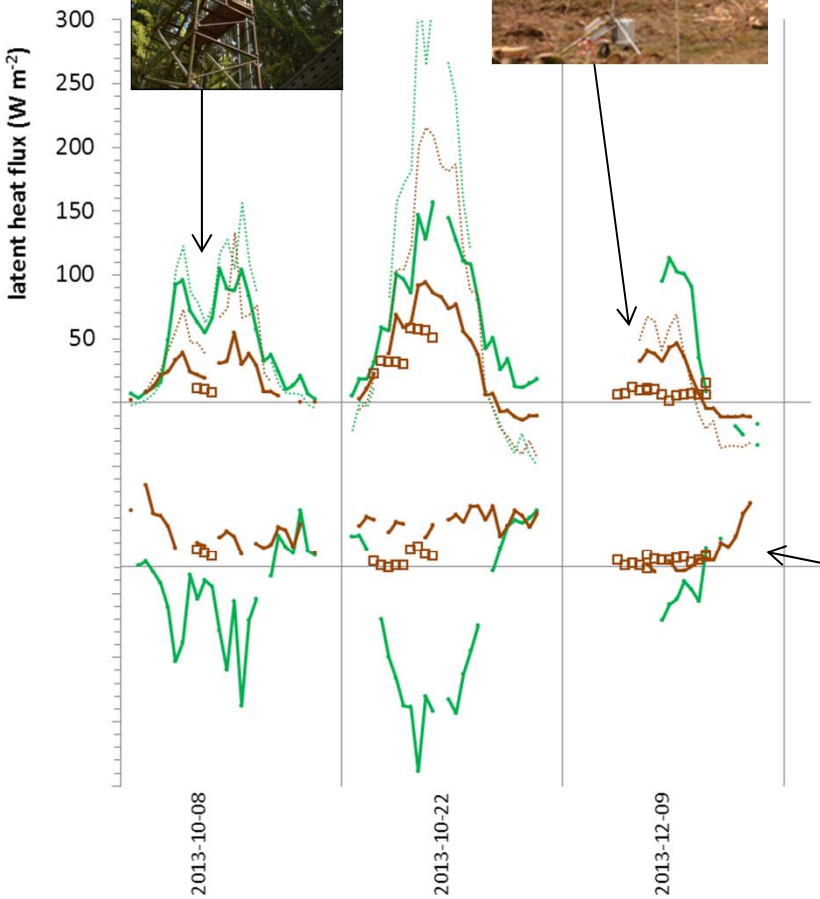


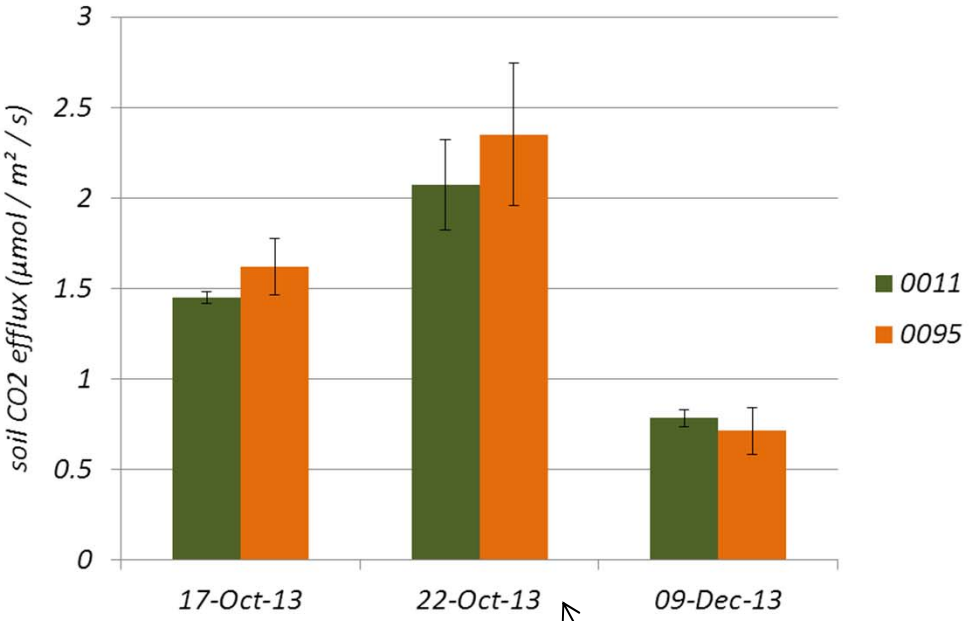
Deforestation in September 2013

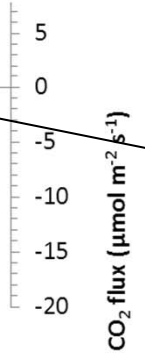
- Comparison measurements (forest vs.deforested)
  - Eddy Covariance
  - Soil CO2 efflux chamber
- Transparent chamber (deforested)



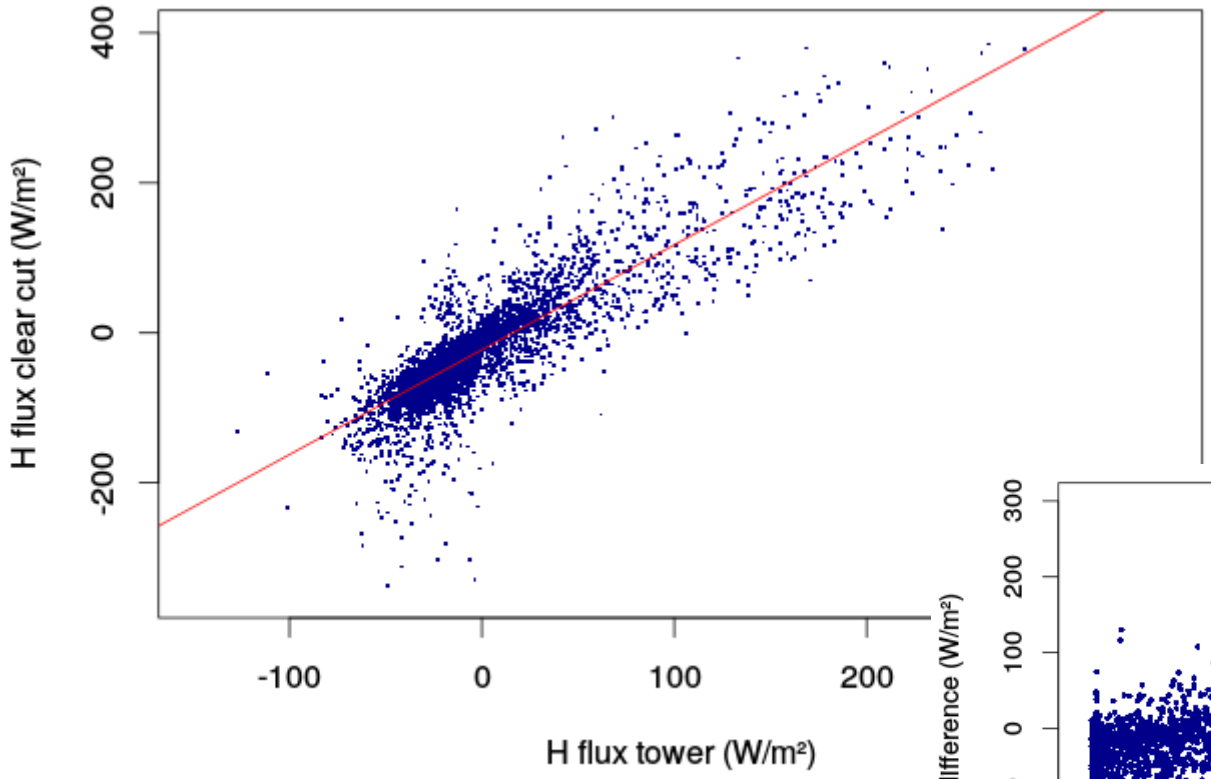
Preliminary post-deforestation results

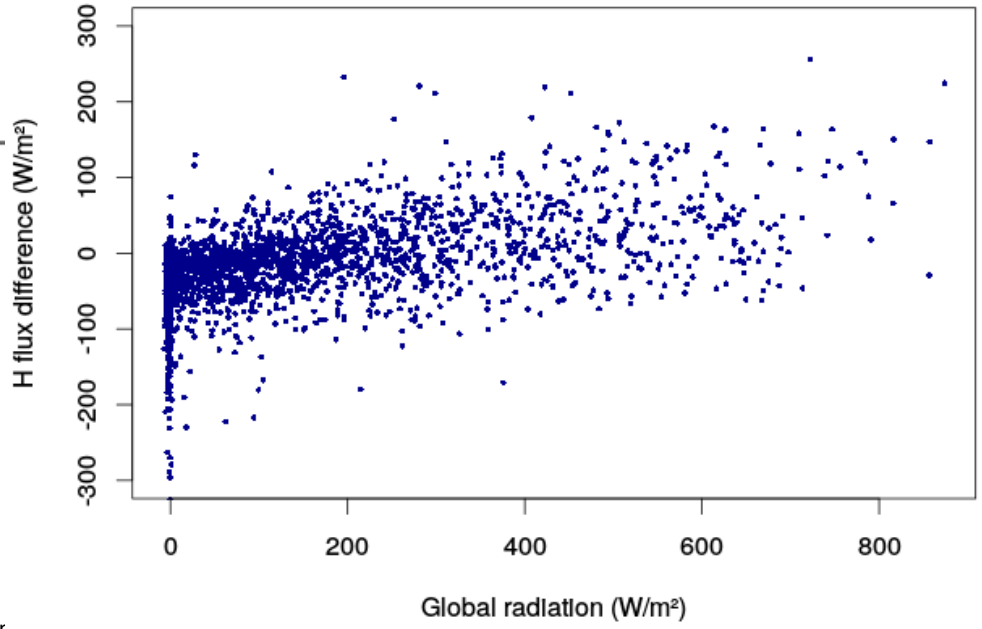




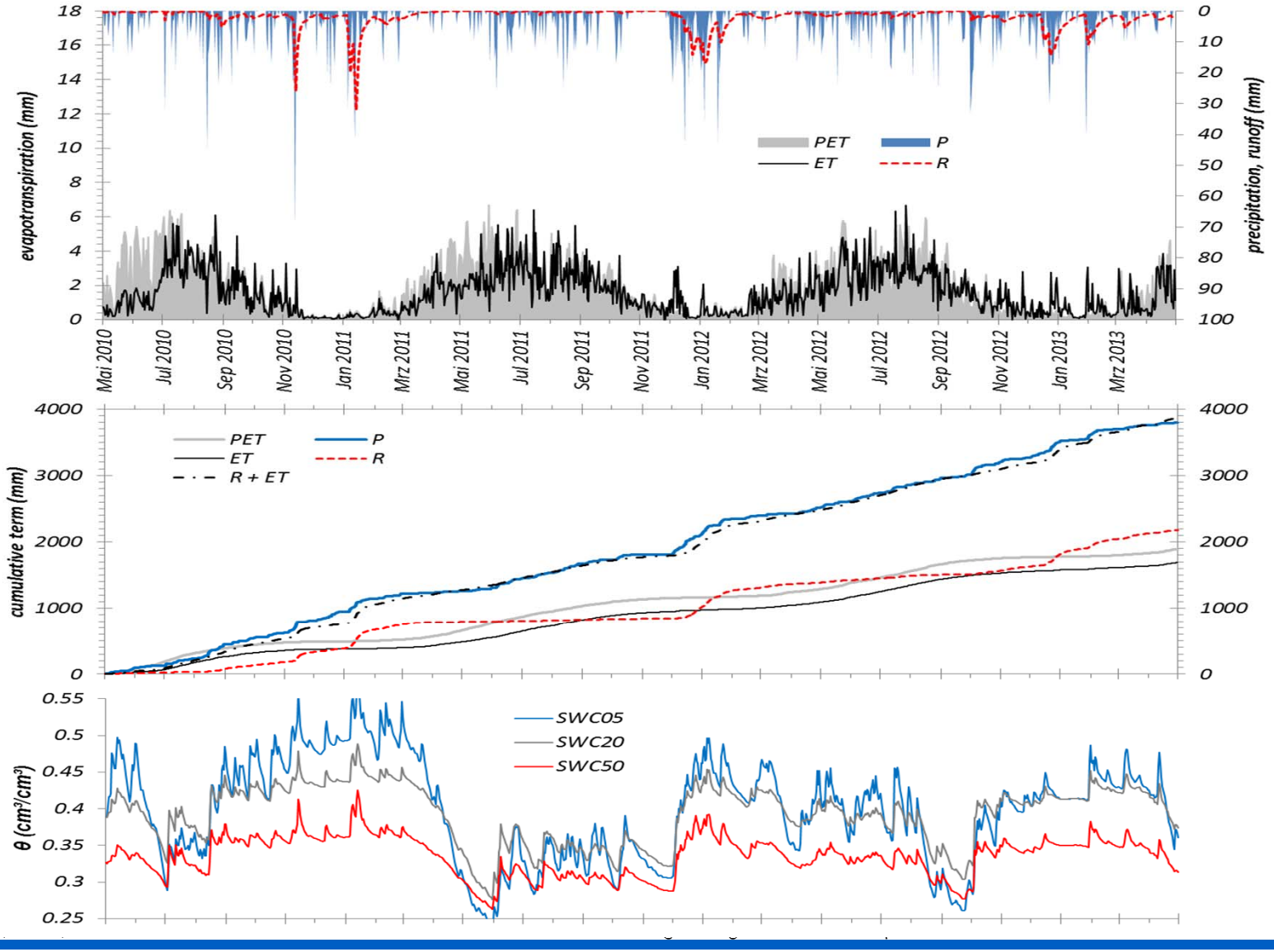


½ year of parallel measurement





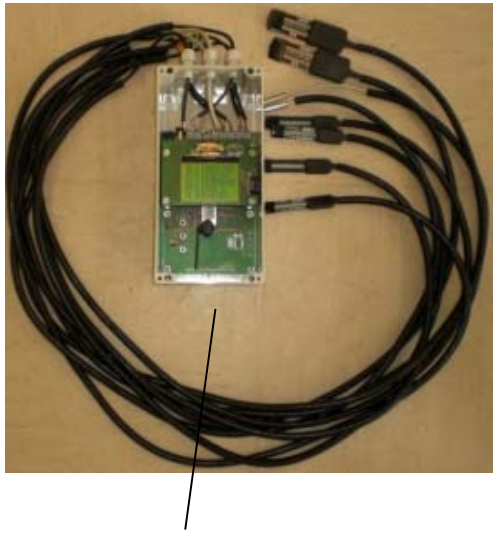
3 years of water balance data (2010-2013)



Water storage terms

$$S = (S_{aqu}) + S_{vad} + S_{sur} + S_{veg} + S_{int}$$

aqu = aquifer
vad = vadose zone including the litter layer
sur = surface (water body or snow pack)
veg = vegetation
int = canopy intercepted water

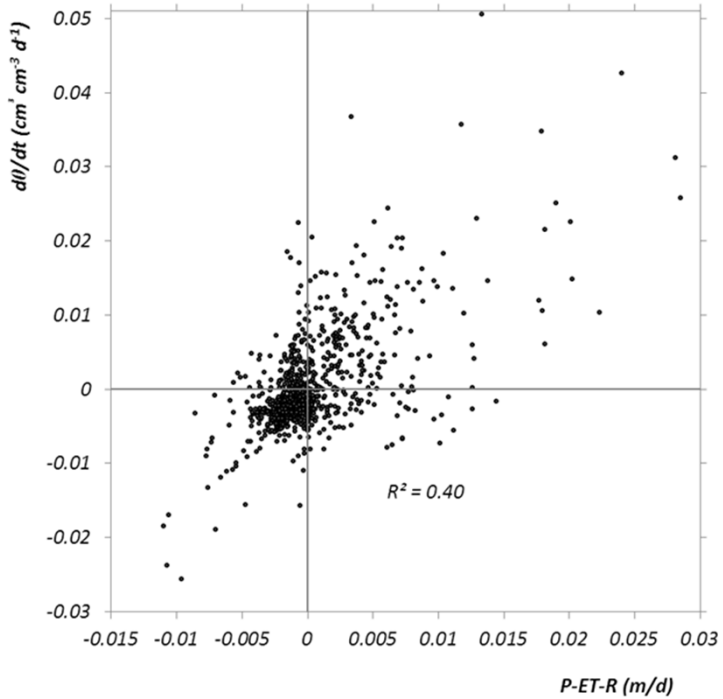


$$S_{vad}(t) = \Sigma\, ci\, \theta\,(i,t) + \varepsilon$$

- **Three-dimensional domain is defined by the catchment boundaries**
- ***θ (i,t)*** **soil water content**
- c_i **empirical estimate of the representative volume of measurement** ***i***
- **ε is the part of** S_t **not represented well by the measurements**

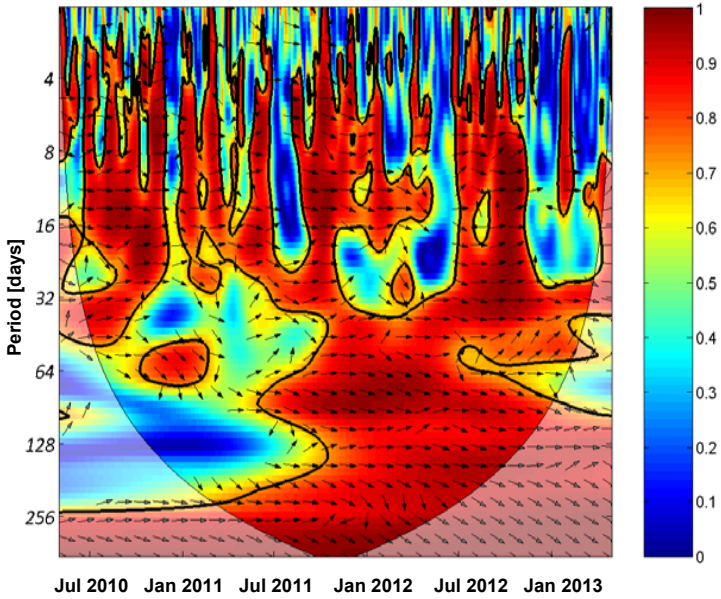
Relationship between ΔS and ΔSWC

ΔSWC (derivative of SWC at 50 cm) versus storage term change ΔS:



→ Scatter is related to random errors in each of the terms P, R, ET and θ as well as the unaccounted water storage terms S_{sur}, S_{veg} and S_{int}

Wavelet coherence between ΔS and ΔSWC at 50 cm:



→ On short time scales (< 7 days) low coherence

→ On longer time scales seasonal break downs of coherence

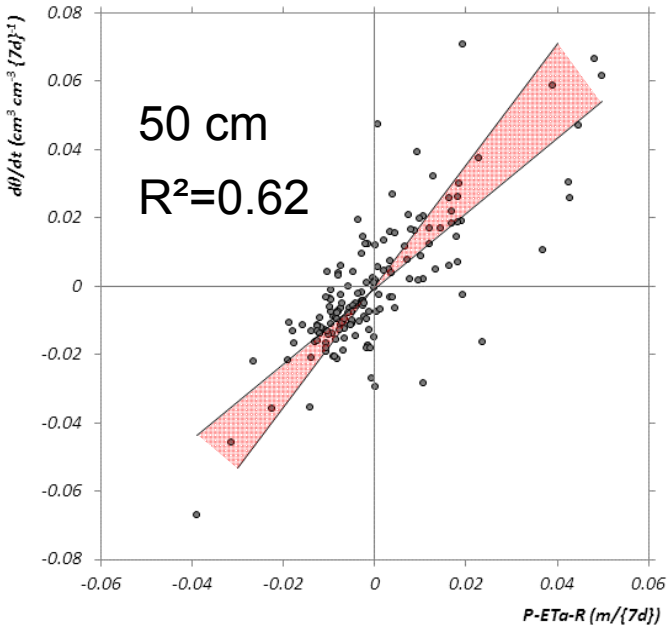
ΔSWC versus ΔS at weekly scale

→ Explained variance increased for all sensors

→ The slope coefficient provides an estimate for c_i

→ Stepwise multiple regression yields:

$$P - R - ET = \Delta S = 0.13\frac{d\theta_{5cm}}{dt} + 0.86\frac{d\theta_{50cm}}{dt} \quad R^2 = 0.63$$



→ θ_{5cm} represents the uppermost 13 cm

→ θ_{50cm} represents the remainder of the uppermost ~ 1 m

Temporal versus spatial variance

A matrix of 327 measurement locations and 1096 days are used for the decomposition according to:

$$\theta(t,i) = \bar{\tilde{\theta}} + \tilde{\theta}'(t) + \bar{\theta}'(i) + \varepsilon(t,i)$$

Residual fluctuations in space and time

Total variance: $\sigma^2 = \sigma^2_t + \sigma^2_i + \sigma^2_{res}$

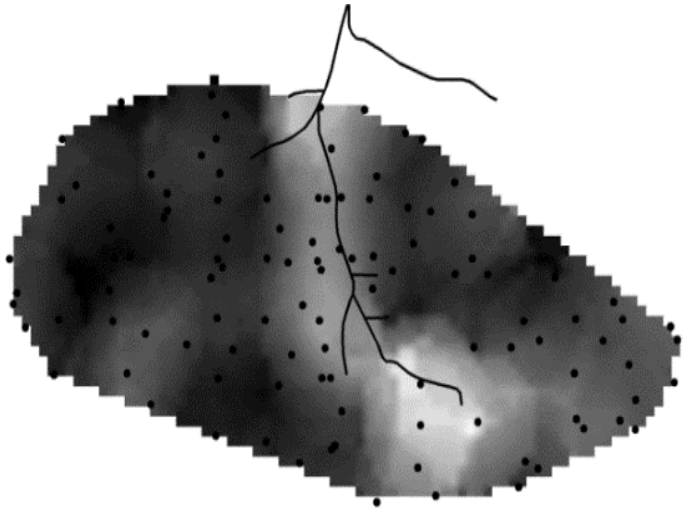
Temporal variance σ^2_t = 13.8 %

Spatial variance σ^2_i = 73.4 %

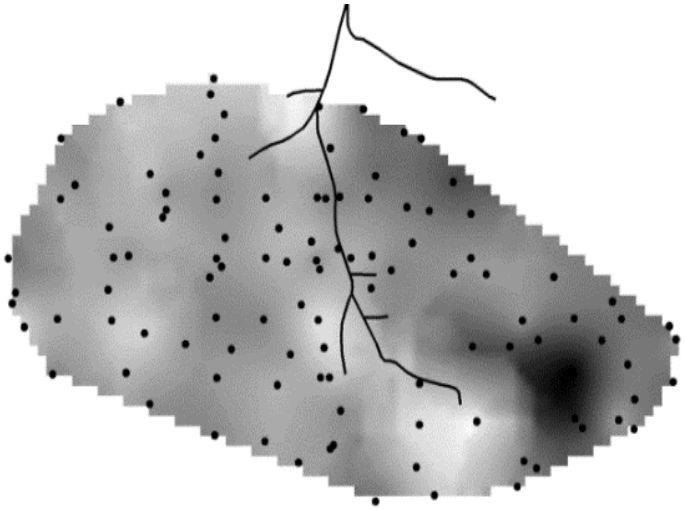
Residual variance σ^2_{res} = 12.5 %

Results EOF Analysis (SWC at 5 cm)

EOF1



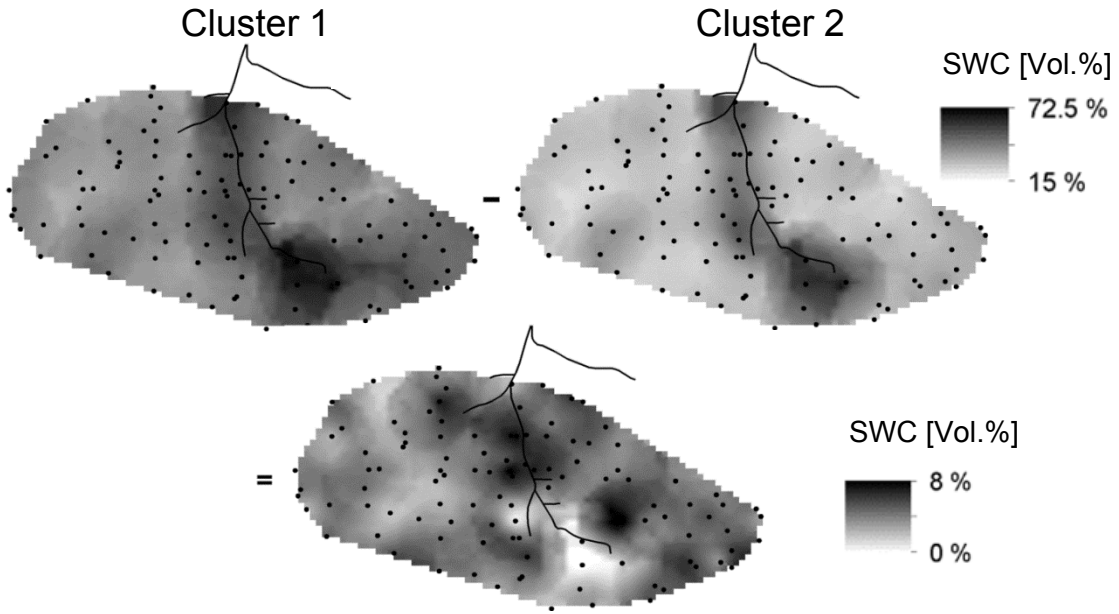
EOF2



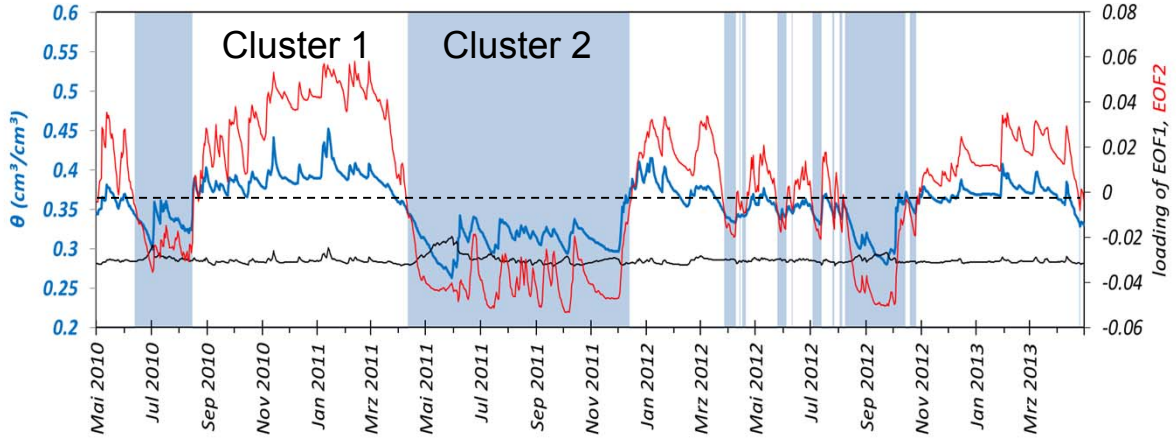
- EOF1 and EOF2 describe 92% of the total spatio-residual variance
- Loadings of EOF1 always negative sign
  - pattern unchanged but different strength
- Loadings of EOF2 occurred with both signs
  - pattern changed depending on average soil moisture

Cluster Analysis on top of EOFs

- The difference between both clusters reveals distinct differences in both SWC pattern
- Smallest differences between both cluster maps are found in permanently wet areas



- The time series of the prevailing cluster and spatially averaged soil water content reveals a switching of SWC pattern at a mean SWC of 35 Vol.%



Conclusions

- Water balance closed within certainty range of measurements
- Spatially averaged soil water contents (esp. at 50 cm) explained most of the residual variance of the water balance on week-to-week timescale
- The spatial pattern of soil water content changed between wet and dry periods at a threshold of about 0.35 m^3/m^3

Further reading:

Graf, A., H.R. Bogena, C. Drüe, H. Hardelauf, T. Pütz, G. Heinemann and H. Vereecken. (under review): Spatiotemporal relations between water budget components and soil water content in a forested tributary catchment. Water Resour. Res.

Bogena et al. (under review): Integrated investigation of the effects of deforestation on water, energy, and matter fluxes using a terrestrial observatory approach. Submitted to SCIENCE CHINA Earth Sciences.

Stockinger, M., Bogena, H., Lücke, A., Diekkrüger, B. , Weiler, M. and Vereecken H. (under review): Seasonal Soil Moisture Patterns Control Transit Time Distributions in a Forested Headwater Catchment. Water Resour. Res.

Thanks a lot for your attention!

… there will be an excursion to the Wüstebach catchment …

Study questions

To characterize the system state prior to a deforestation,

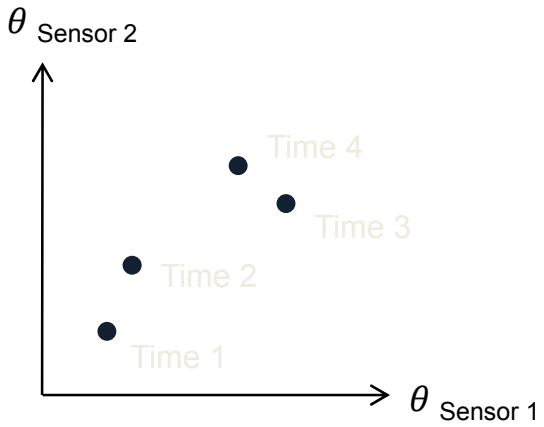
1) Can the long-term catchment water balance be closed by monitoring data (including measured ET)?

2) Can distributed soil water content measurements within the catchment act as a proxy for the storage term?

3) Are those variations in soil water storage a mere result of the varying average and variance parameters of a single pattern?

Combined EOF/Cluster Analysis

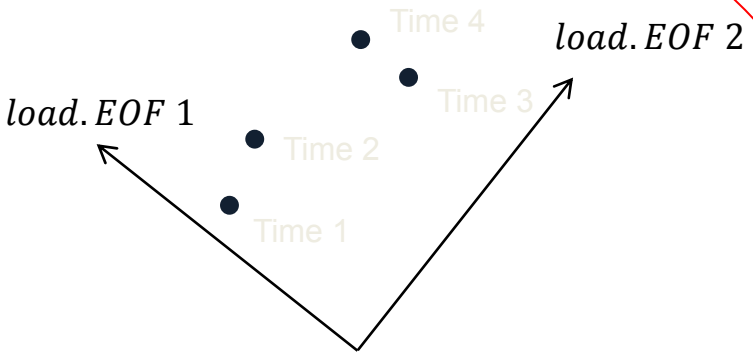
Original data



Soil moisture observations are converted into a set of linearly uncorrelated variables

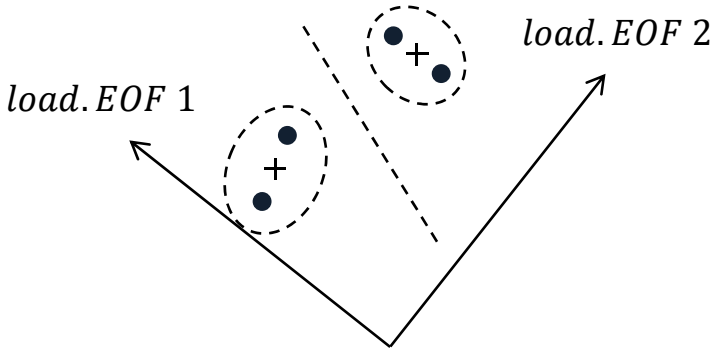
The first EOF accounts the largest possible variance

EOF analysis



Transformation from EOF space into non-orthogonal, soil moisture fields

Cluster analysis



Long-term water balance closure

$$P = R + \cancel{D} + ET + \Delta S$$

P = areal average of precipitation

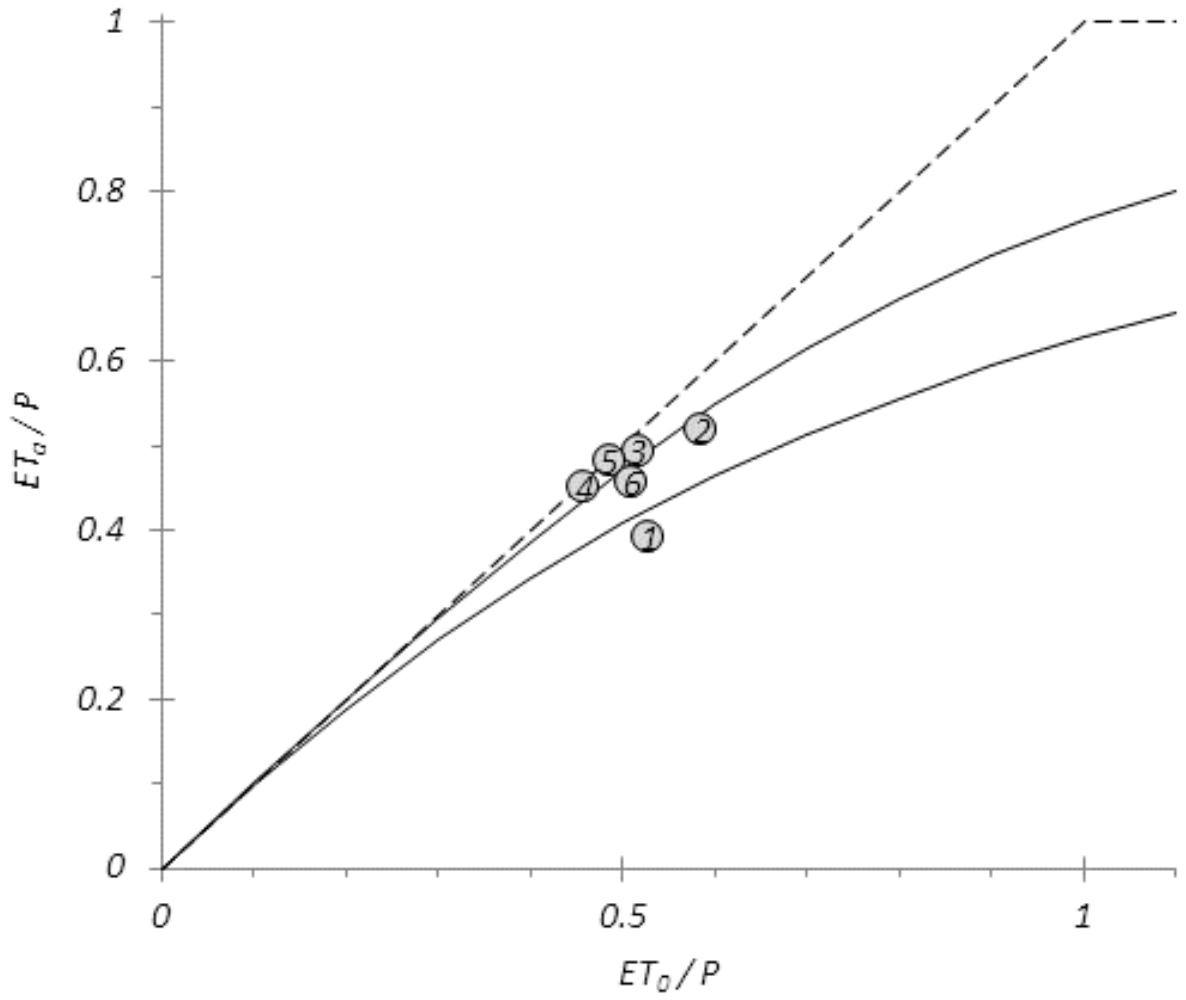
R = runoff

D = deep percolation

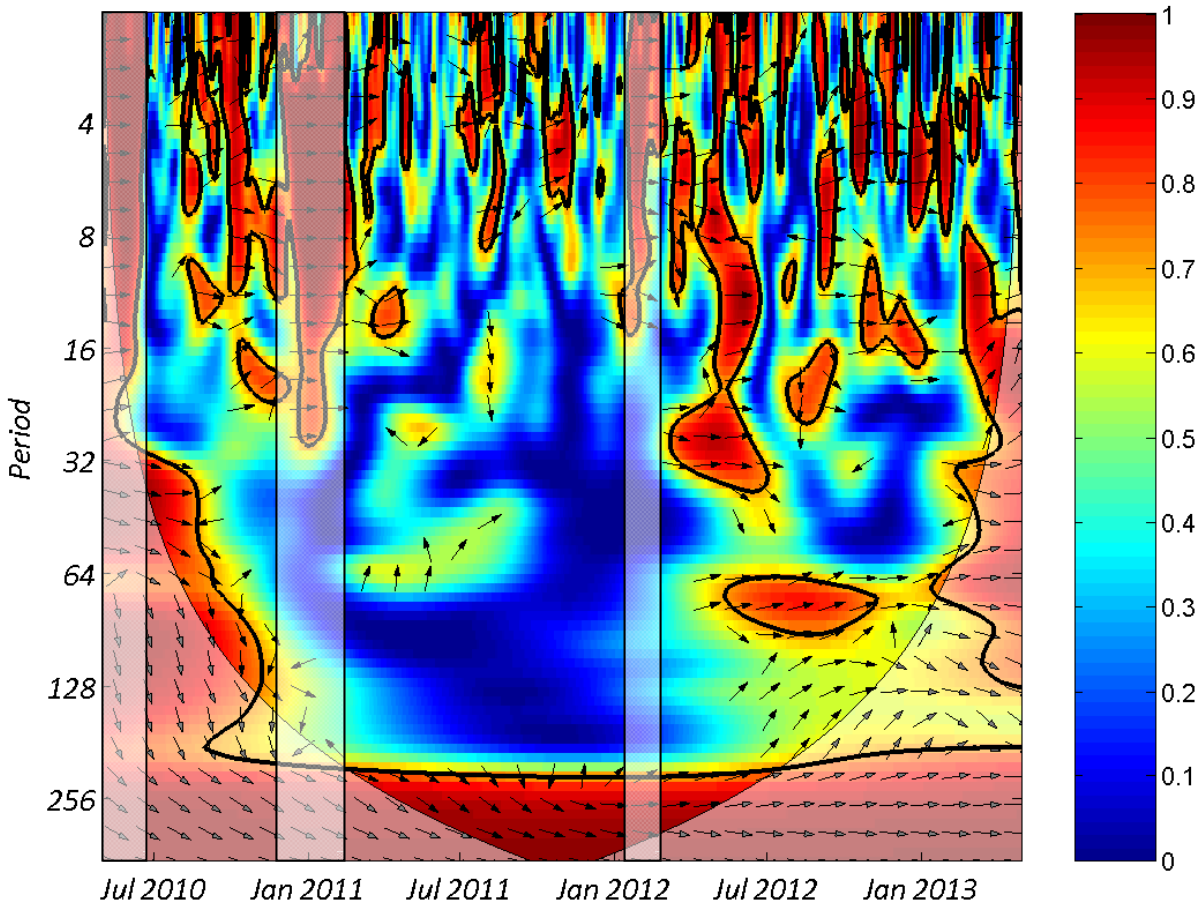
ET = areal average of actual evapotranspiration

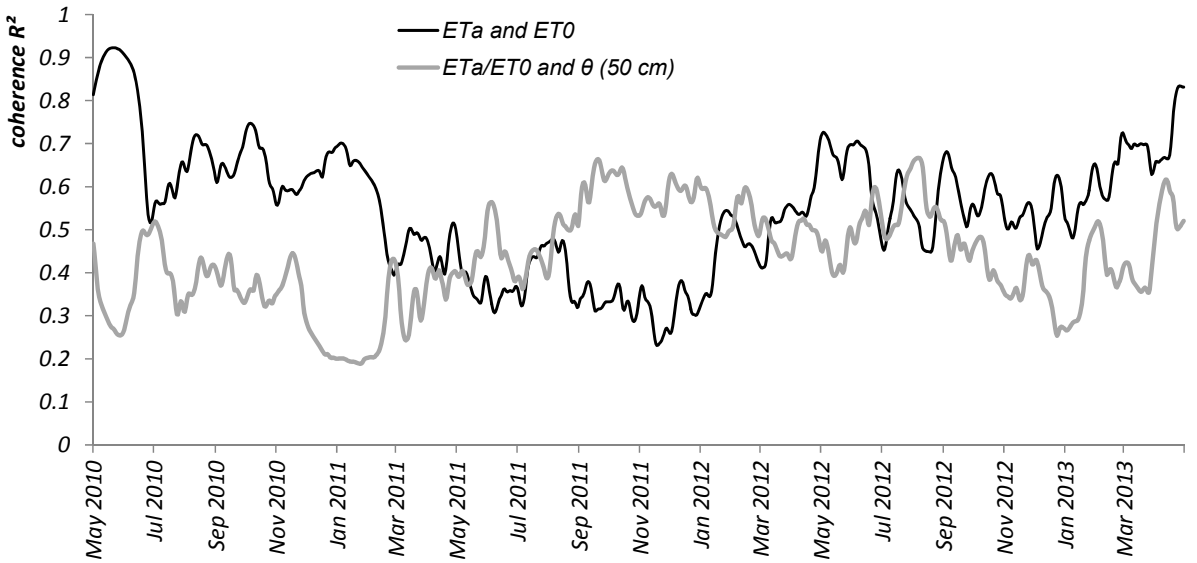
ΔS = storage term

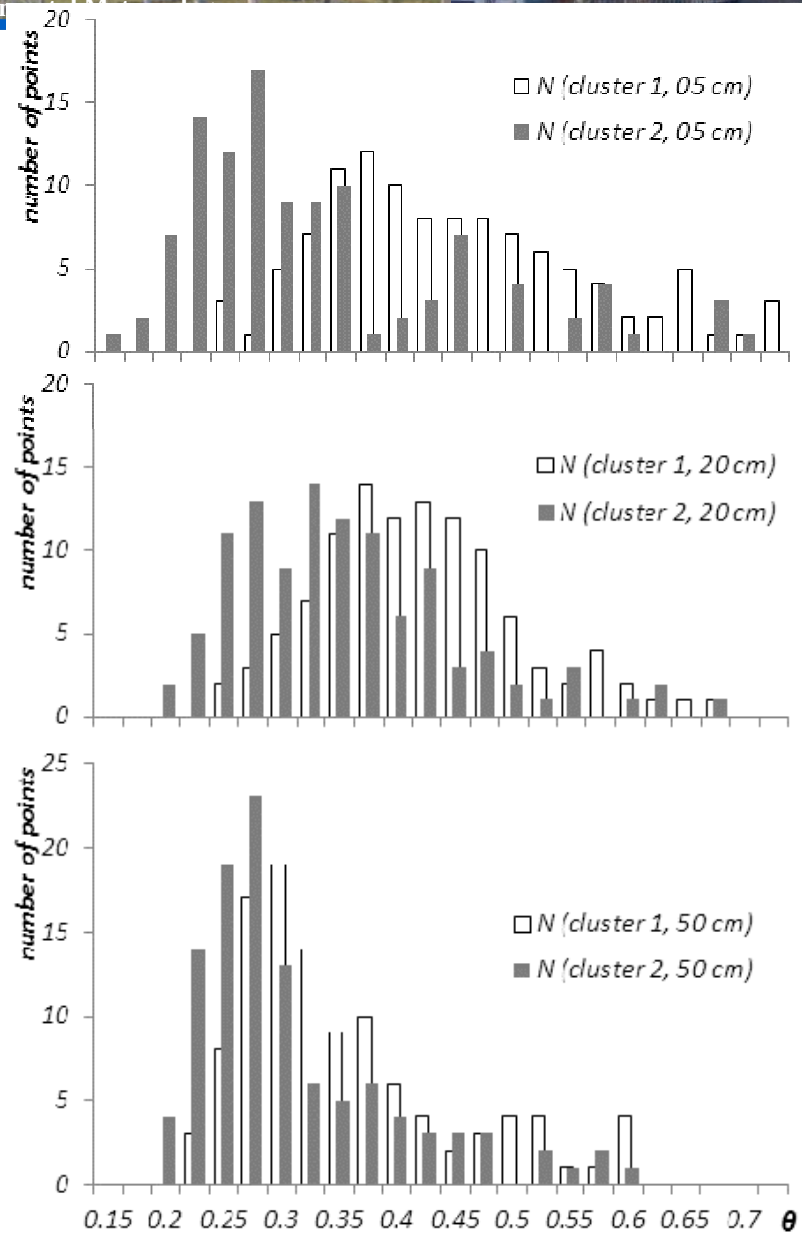
- The Shale bedrock has a very low conductivity (10^{-9} to 10^{-7} m s^{-1}), thus we assume deep percolation to be negligible
- Residual of the 3-years period was 2% of precipitation
- Precipitation was partitioned in 44 % ET_a and 56 % runoff


1
0.8
0.6
0.4
0.2
0
0
0.5
1
ET_a / P
ET_0 / P
1
2
3
4
5
6

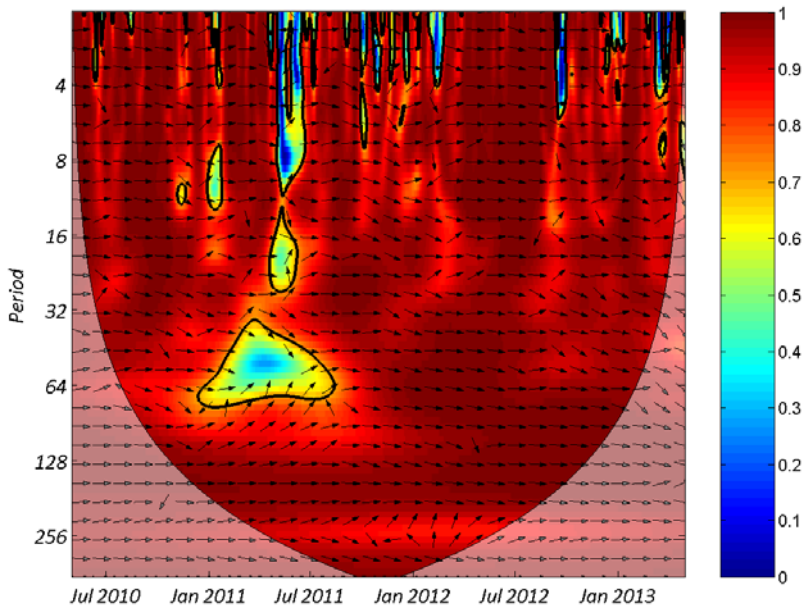
ET vs. PET


Period
4
8
16
32
64
128
256
Jul 2010
Jan 2011
Jul 2011
Jan 2012
Jul 2012
Jan 2013
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

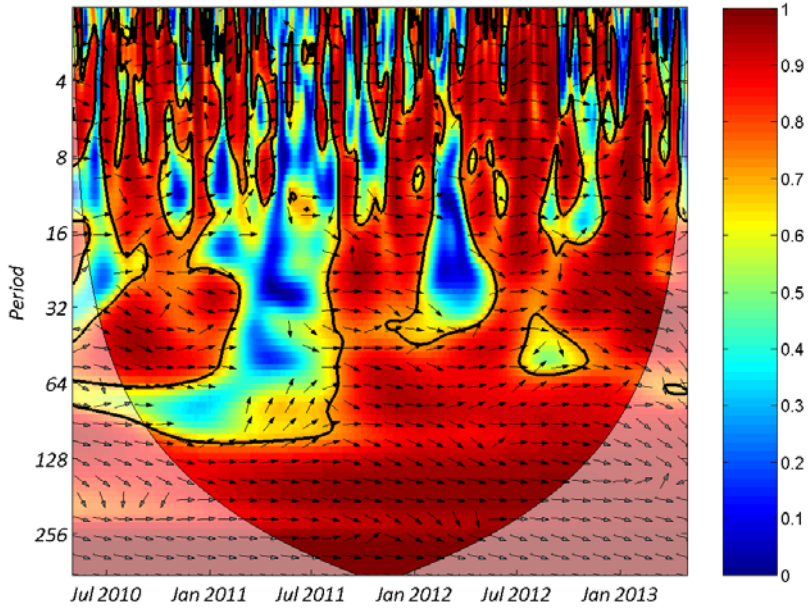

coherence R²
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ETa and ET0
ETa/ET0 and θ (50 cm)
May 2010
Jul 2010
Sep 2010
Nov 2010
Jan 2011
Mar 2011
May 2011
Jul 2011
Sep 2011
Nov 2011
Jan 2012
Mar 2012
May 2012
Jul 2012
Sep 2012
Nov 2012
Jan 2013
Mar 2013


number of points
N (cluster 1, 05 cm)
N (cluster 2, 05 cm)
number of points
N (cluster 1, 20 cm)
N (cluster 2, 20 cm)
number of points
N (cluster 1, 50 cm)
N (cluster 2, 50 cm)
0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7 θ

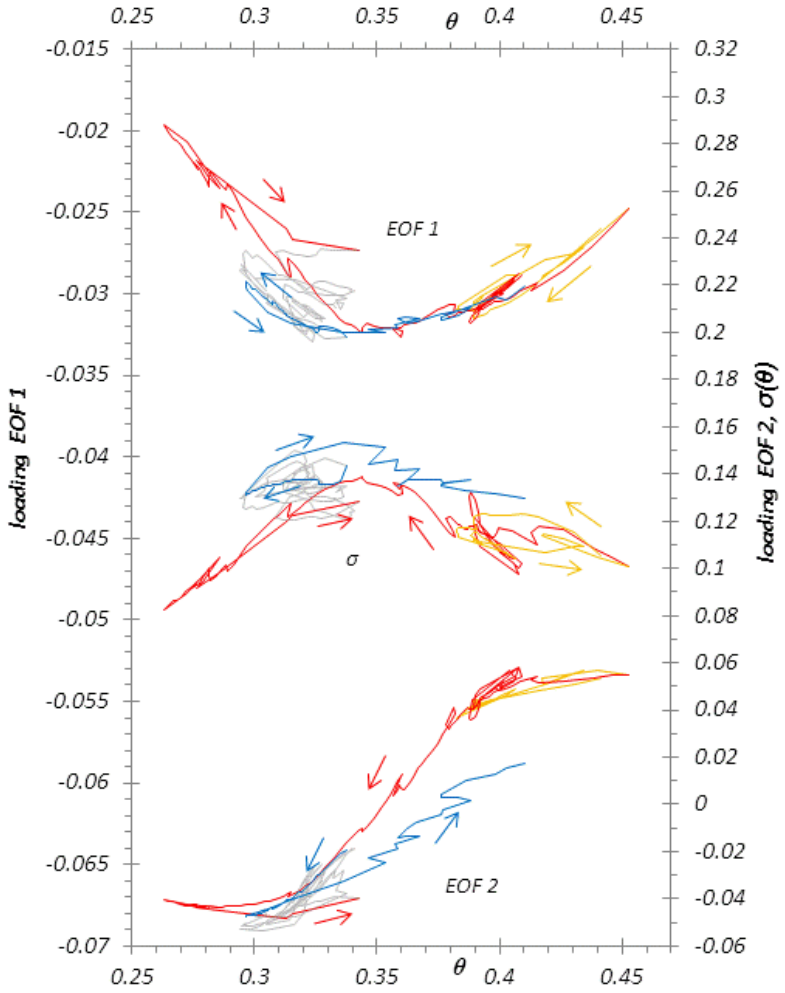
Loading(EOF2) vs. SWC



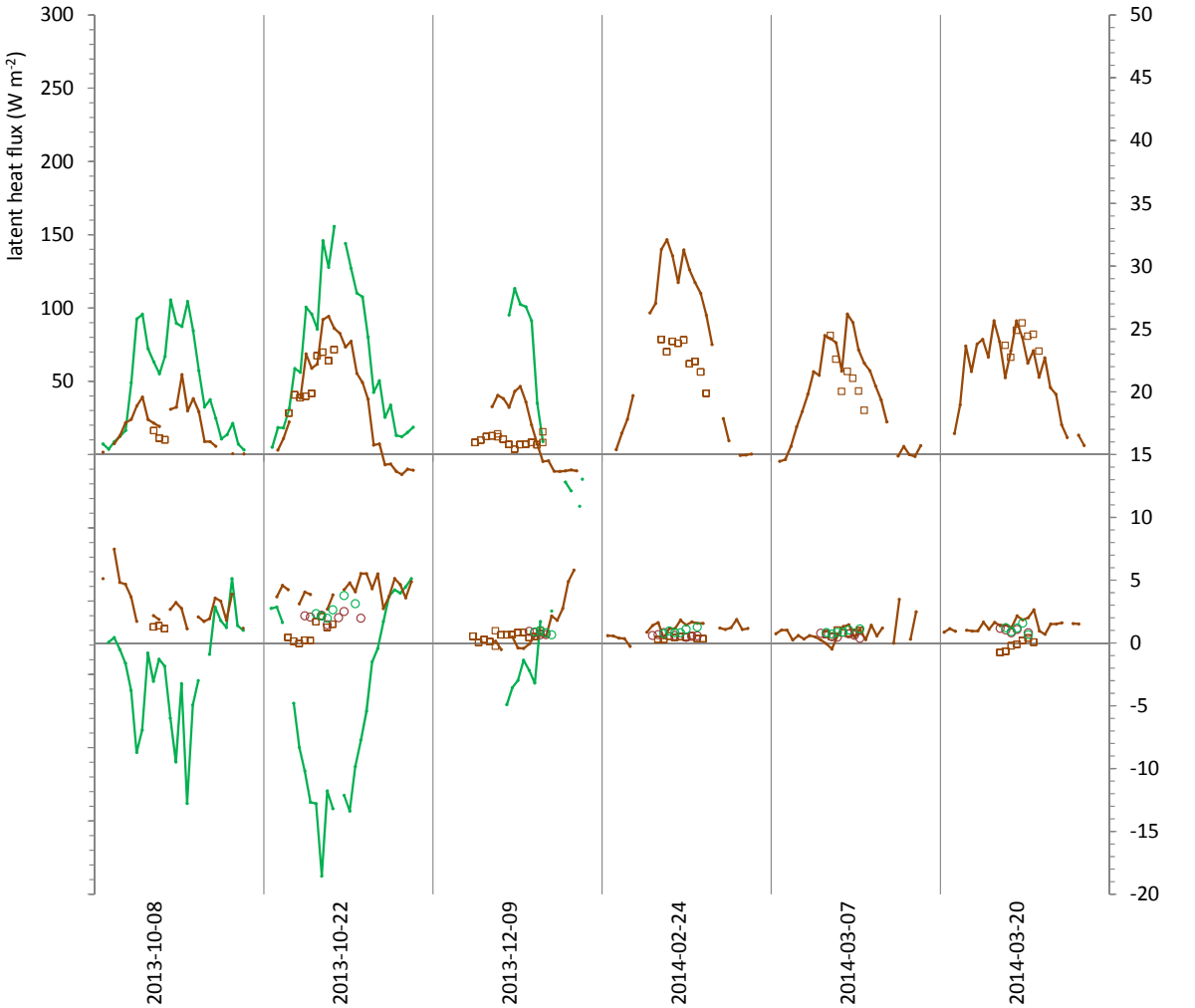
5 cm

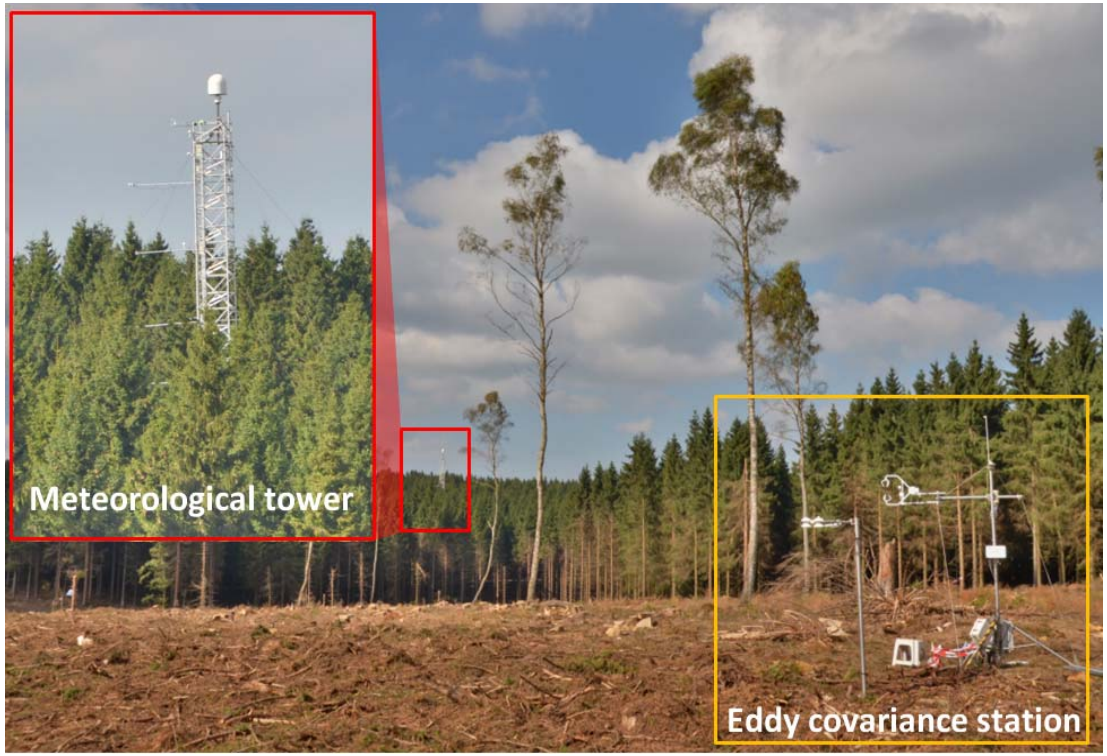


50 cm


0.25
0.3
0.35
θ
0.4
0.45
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
-0.045
-0.05
-0.055
-0.06
-0.065
-0.07
0.32
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
loading EOF 1
loading EOF 2, σ(θ)
EOF 1
σ
EOF 2

Wüstebach (Wald)




Meteorological tower
Eddy covariance station