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TERENO
TERRESTRIAL ENVIRONMENTAL OBSERVATORIES

In-Situ soil moisture and its relation to remotely sensed retrievals

Heye Bogena, Carsten Montzka and Harry Vereecken

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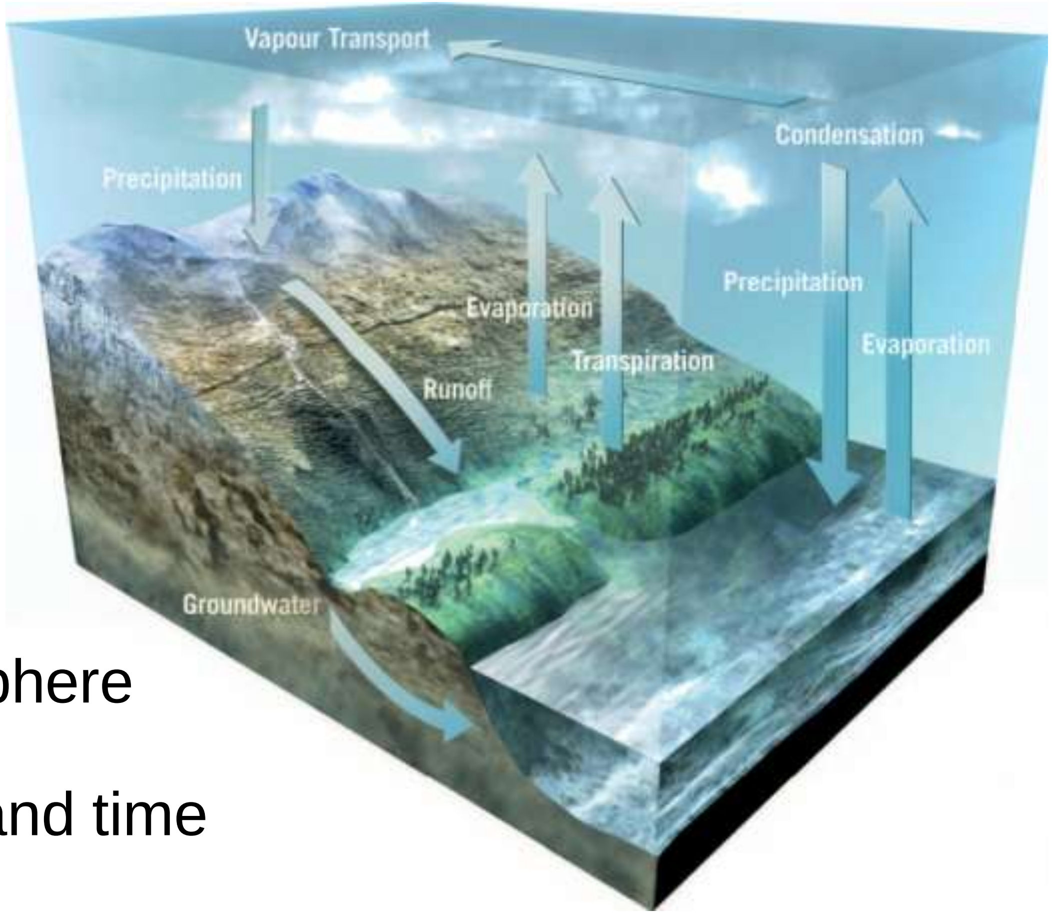
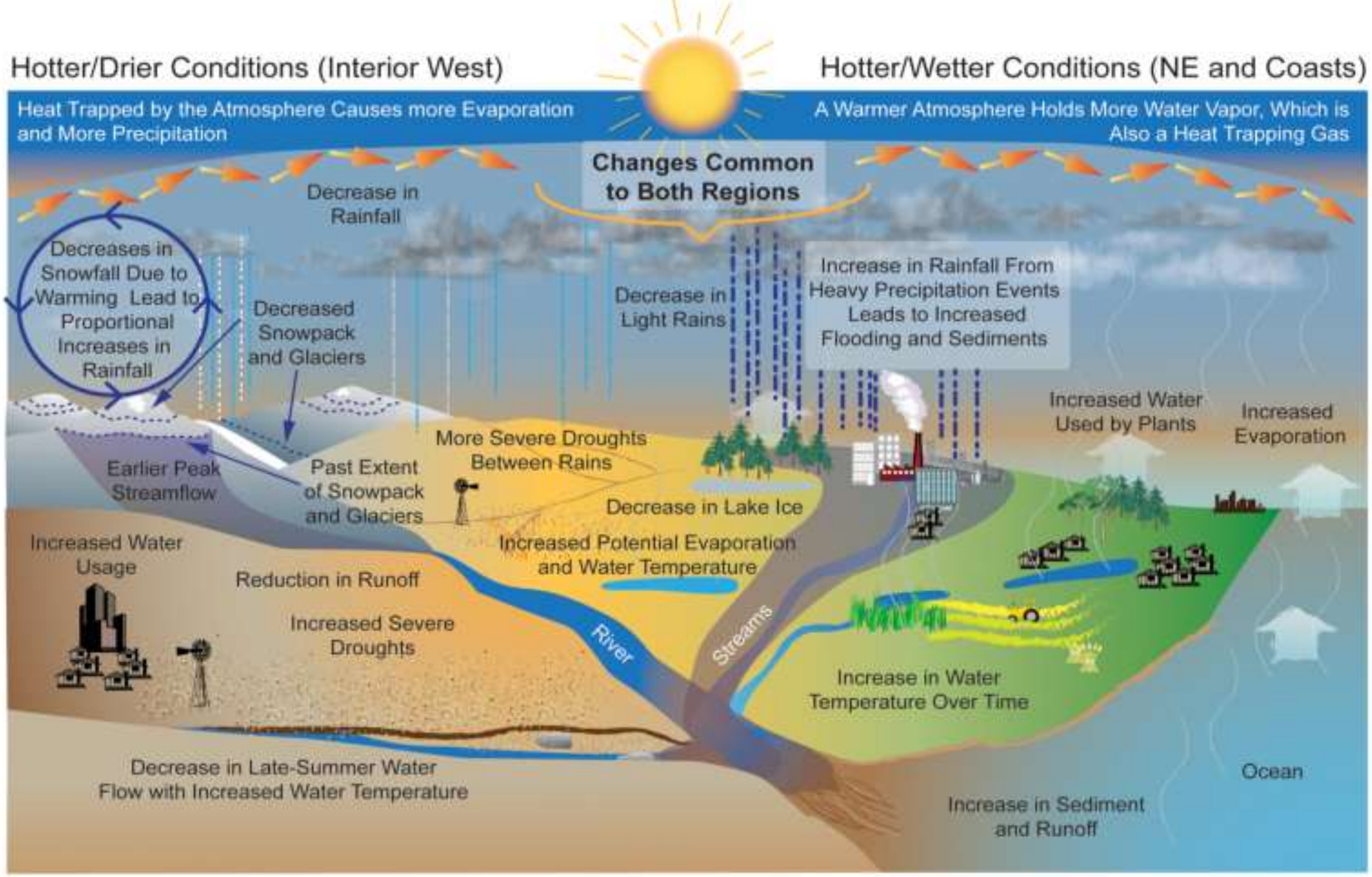
Soil moisture



Soil moisture is:

- A key variable in the global water cycle
- Controlling the exchange of water and energy between land and atmosphere
- Highly variable in space and time
- However still not routinely measured (e.g. DWD)

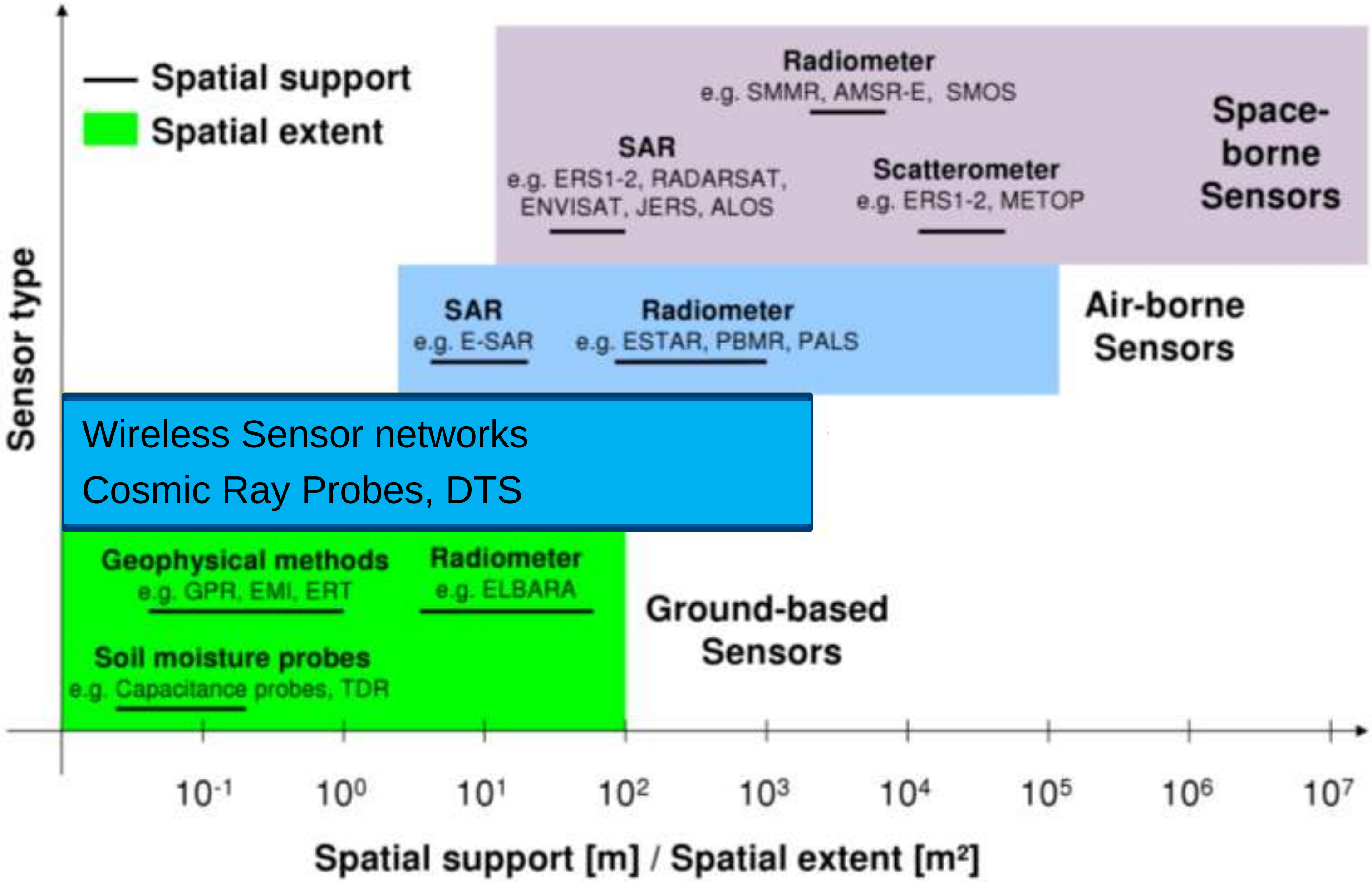
Global Change Effects



NOAA/NCDC

The water cycle exhibits many changes as the earth warms. Wet and dry areas respond differently.

Available measurement techniques



— Spatial support
🟩 Spatial extent

Space-borne Sensors

Radiometer
e.g. SMMR, AMSR-E, SMOS

SAR
e.g. ERS1-2, RADARSAT, ENVISAT, JERS, ALOS

Scatterometer
e.g. ERS1-2, METOP

Air-borne Sensors

SAR
e.g. E-SAR

Radiometer
e.g. ESTAR, PBMR, PALS

Wireless Sensor networks
Cosmic Ray Probes, DTS

Ground-based Sensors

Geophysical methods
e.g. GPR, EMI, ERT

Radiometer
e.g. ELBARA

Soil moisture probes
e.g. Capacitance probes, TDR

Soil moisture remote sensing

global

regional

local

Data assimilation

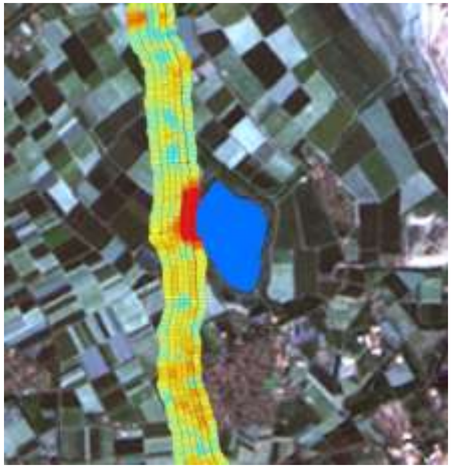
Cal/Val activities

Satellites (e.g. SMOS)

⇒ continuous monitoring

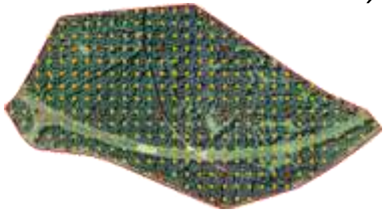
Airborne campaigns

EMIRAD, PLMR, SAR
⇒ momentary imaging



PLMR Rur Campaign 2008

Test sites



Radiometer and Sensor Networks (SoilNet)
⇒ long-term continuous monitoring

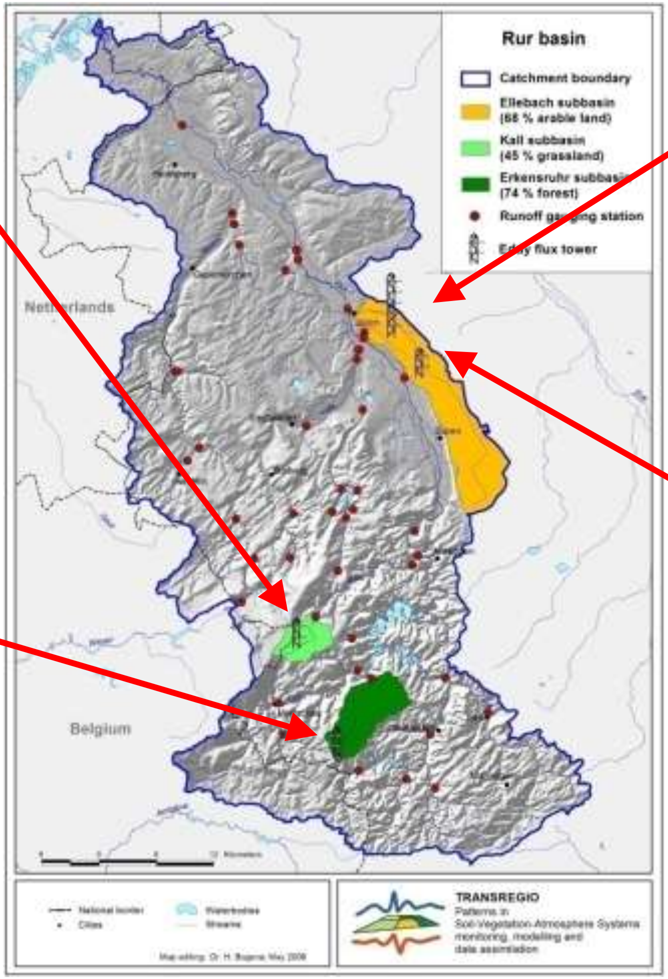
The Rur catchment and its test sites

Grassland test site „Kall“

- Eddy Correlation station
- Soil moisture sensor network
- Soil temperature measurements
- Soil CO_2 flux measurements

Forest test site “Wüstebach”

- Eddy Correlation station
- Soil moisture sensor network
- Soil temperature measurements
- Groundwater monitoring
- Runoff and solute monitoring
- Soil CO_2 Flux measurements



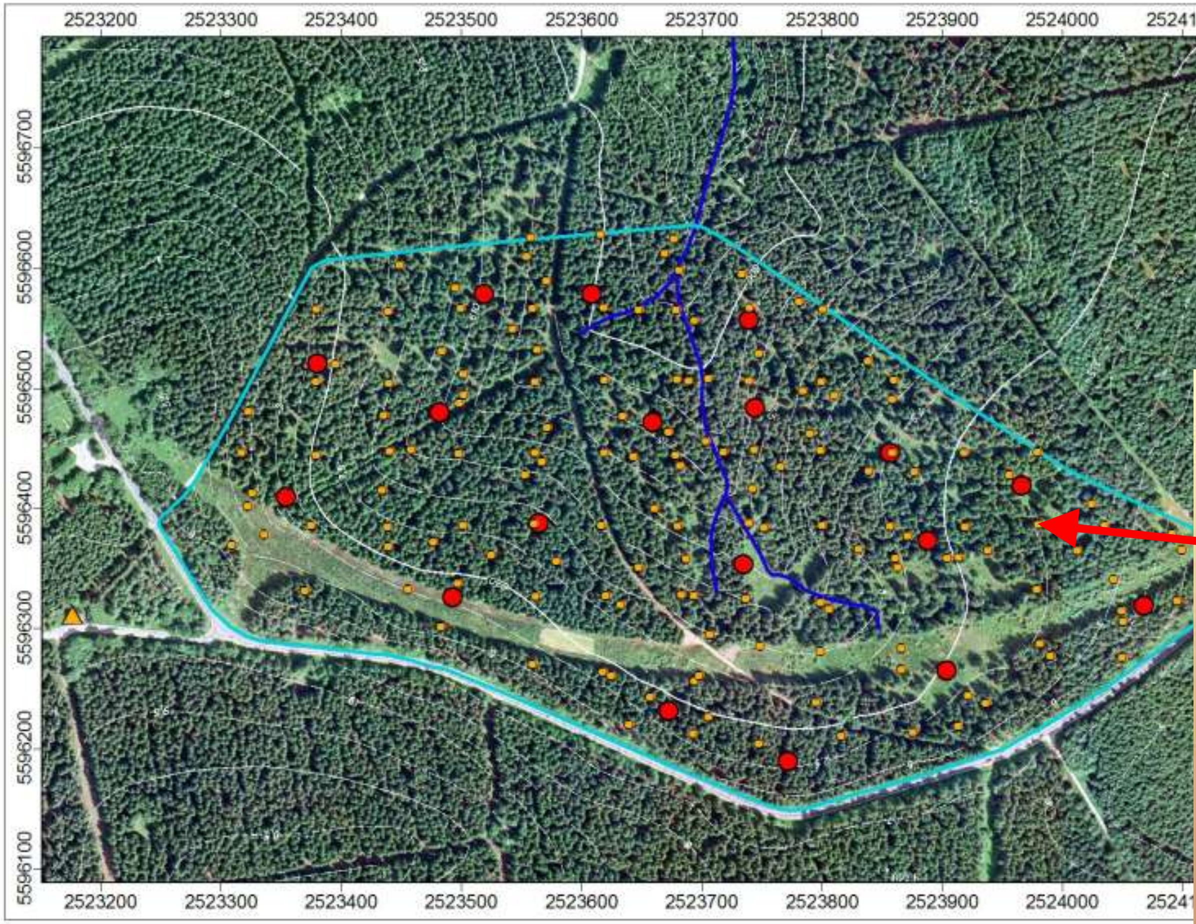
X-band Doppler Weather Radar

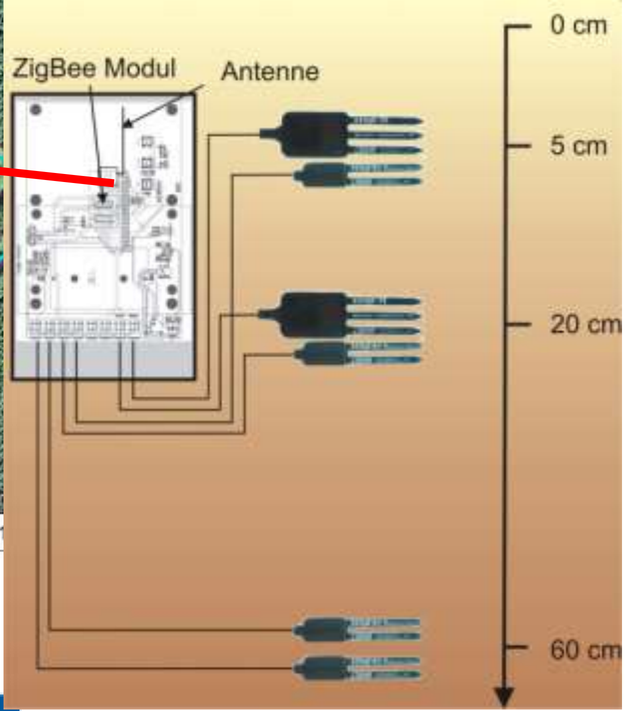
Agricultural test site „Selhausen“

- Eddy Correlation station
- Soil moisture measurements
- Soil temperature measurements
- Soil CO_2 flux measurements
- Ground-based remote sensing
- LIDAR

SoilNet instrumentation at the TERENO research station Wüstebach

150	Sensor units
18	Router units
900	Soil moisture sensors
300	Temperature sensors





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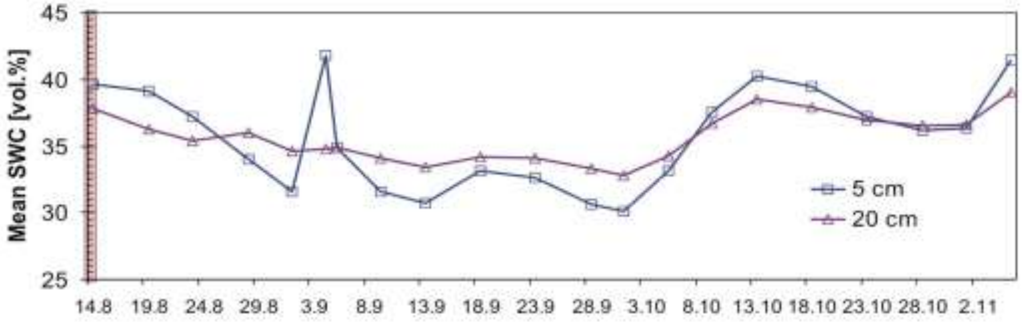
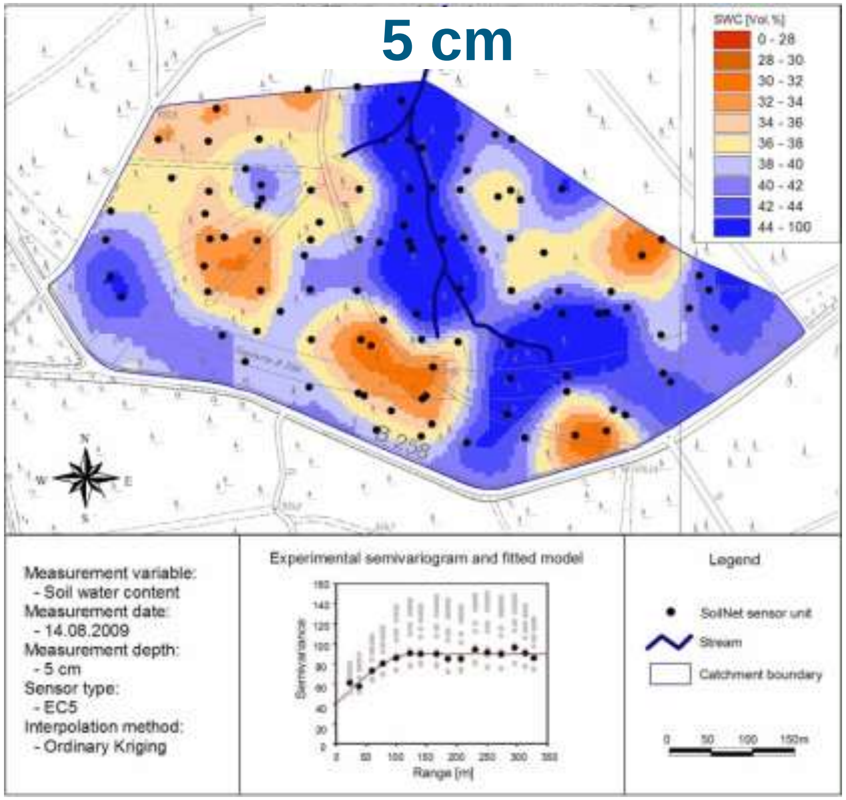
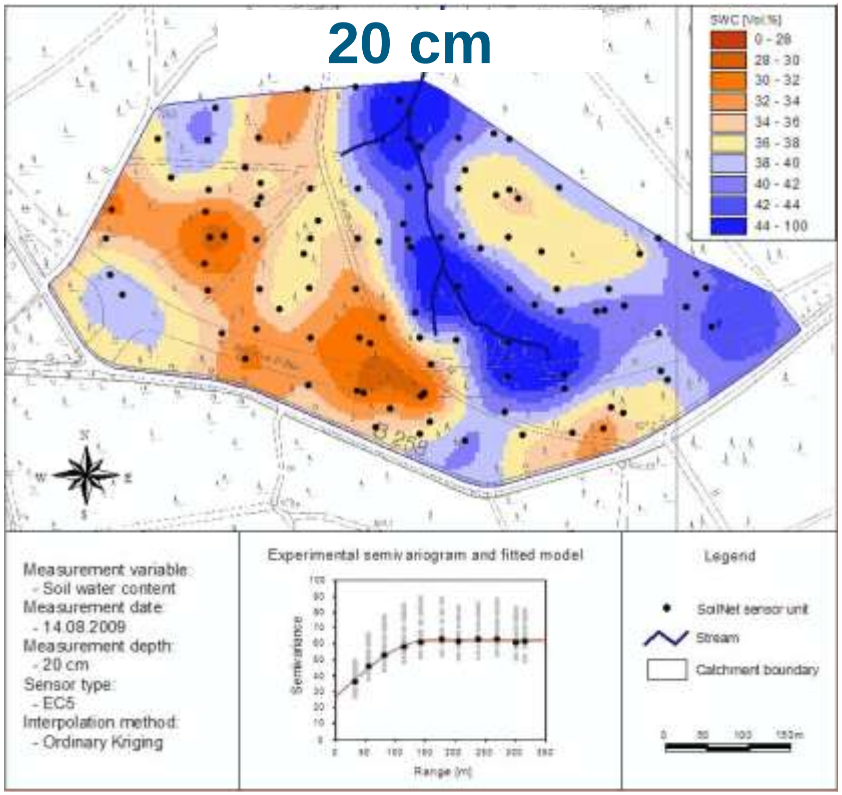
Soil moisture pattern between August and November 2009



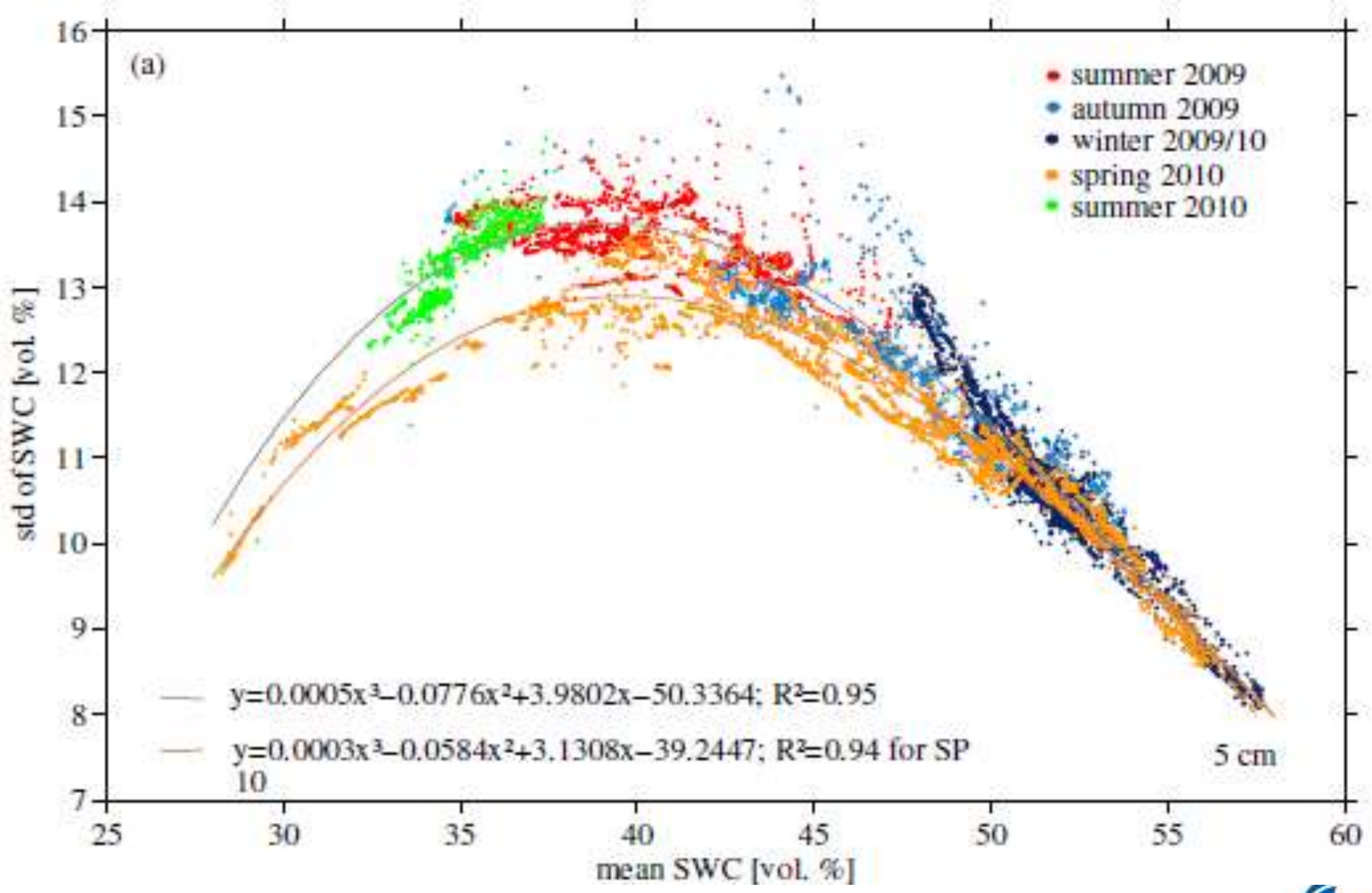


Measurement variable:
- Soil water content
Measurement date:
- 14.08.2009
Measurement depth:
- 5 cm
Sensor type:
- EC5
Interpolation method:
- Ordinary Kriging



Measurement variable:
- Soil water content
Measurement date:
- 14.08.2009
Measurement depth:
- 20 cm
Sensor type:
- EC5
Interpolation method:
- Ordinary Kriging

Relationship between mean soil water content and its standard deviation in 5 cm depth



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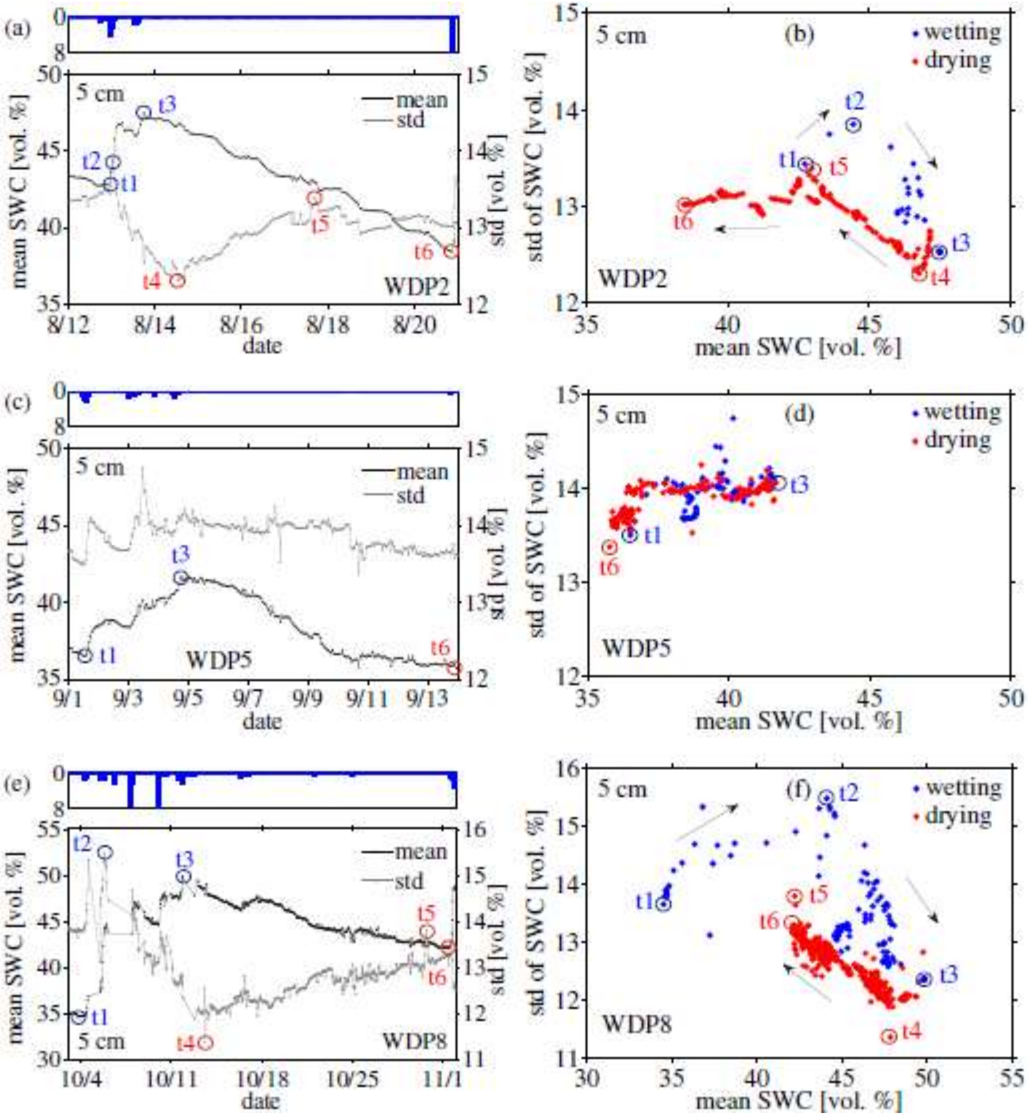
Event dependent hysteretic behaviour



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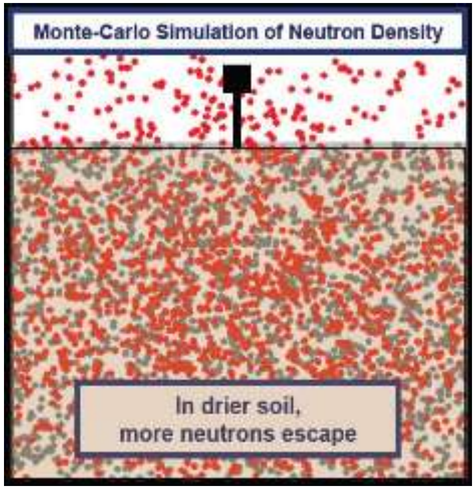
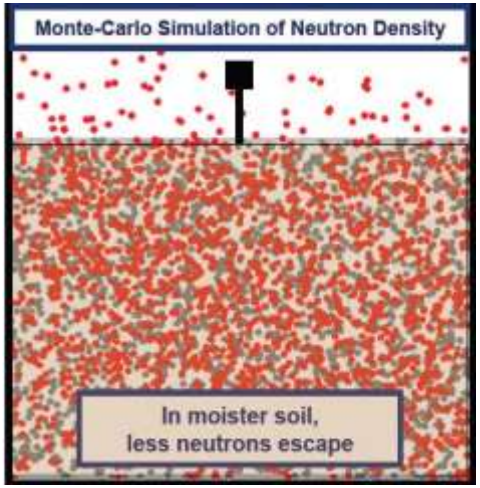
Cosmic Ray Probes

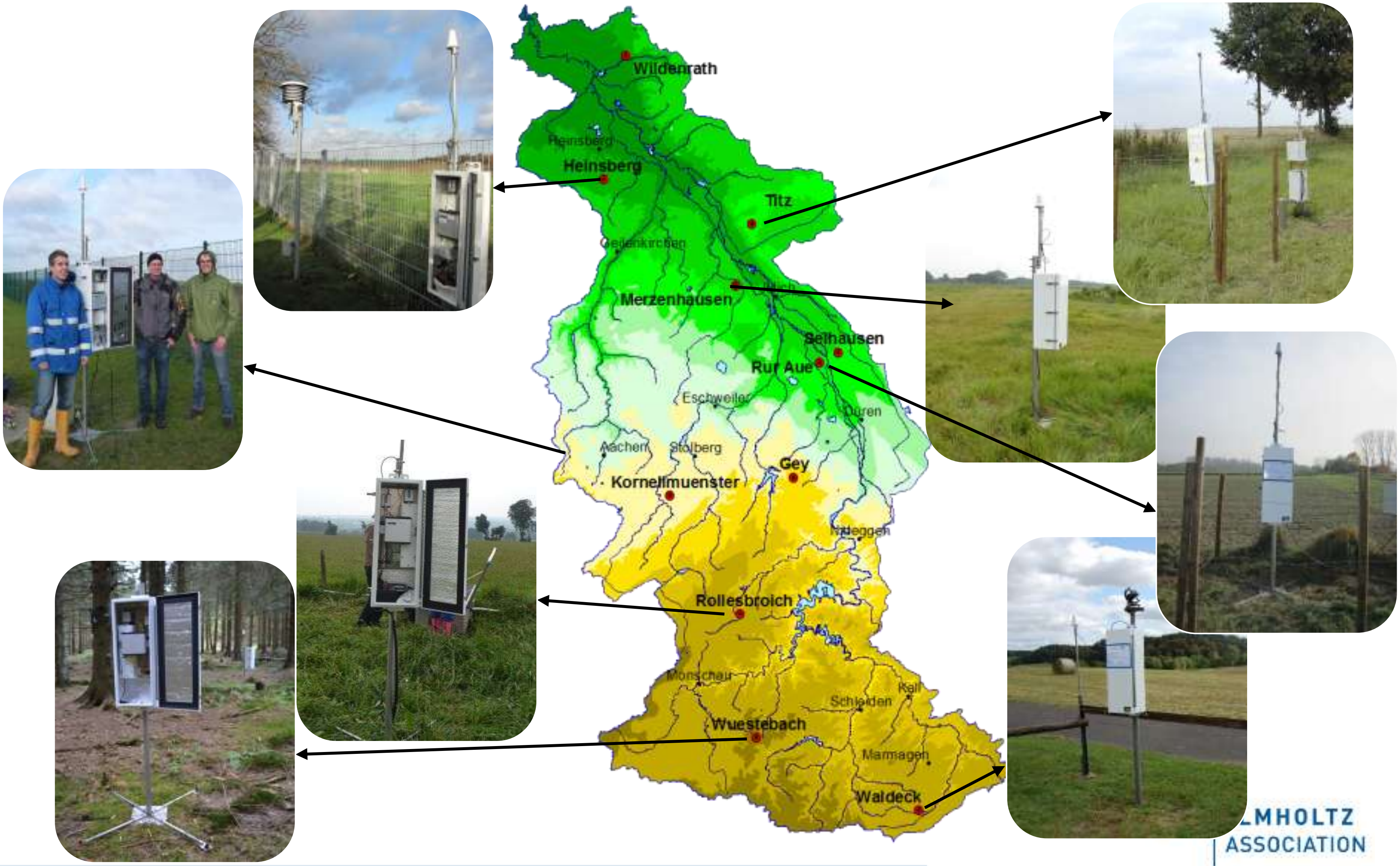
- Cosmic rays lead to emission of neutrons by soil nuclei in the top soil.
- CR Neutrons lose energy primarily through collisions with hydrogen
- Continuous measurement of neutron flux to estimate soil moisture at hourly resolution
- Large Footprint (about 350 m radius)





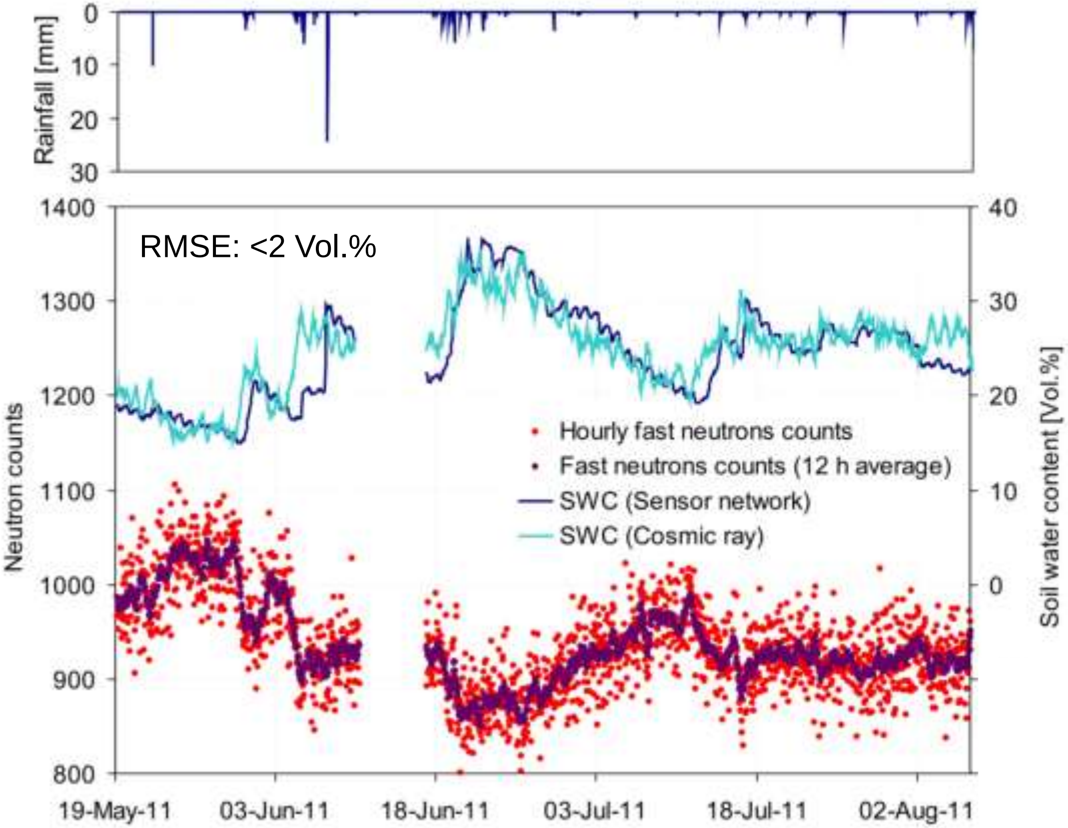
Cosmic ray probe in the field of Rollesbroich (May 2011)

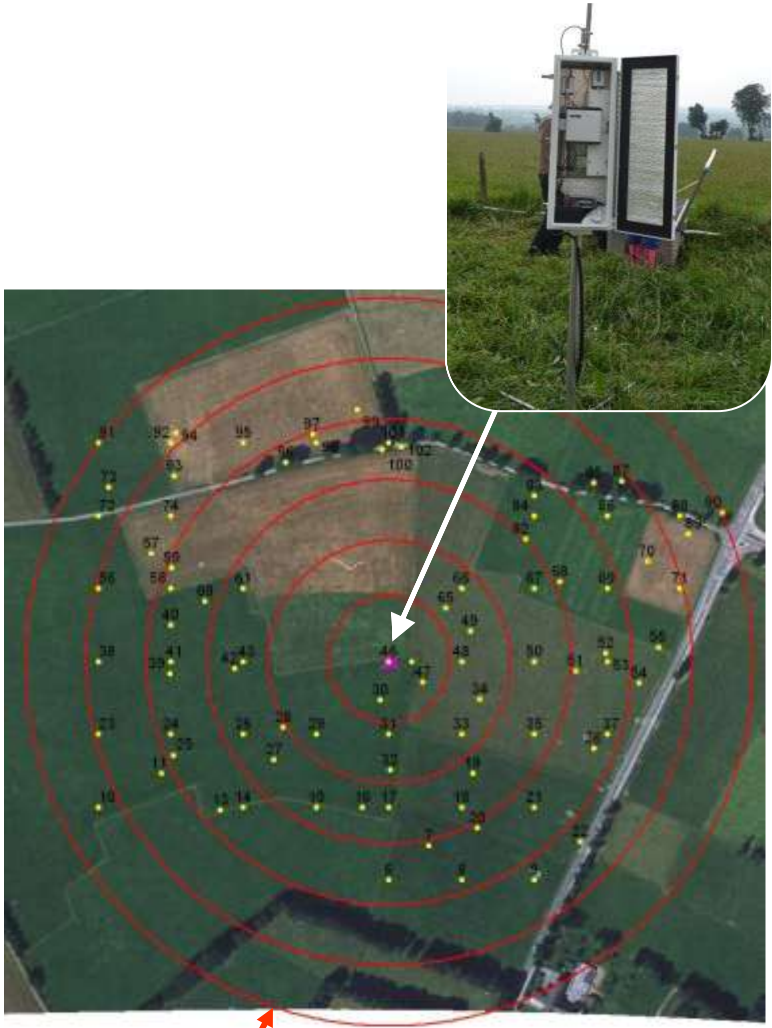
Cosmic Ray monitoring network in the Rur Catchment



Calibration results: Grassland test site Rollesbroich

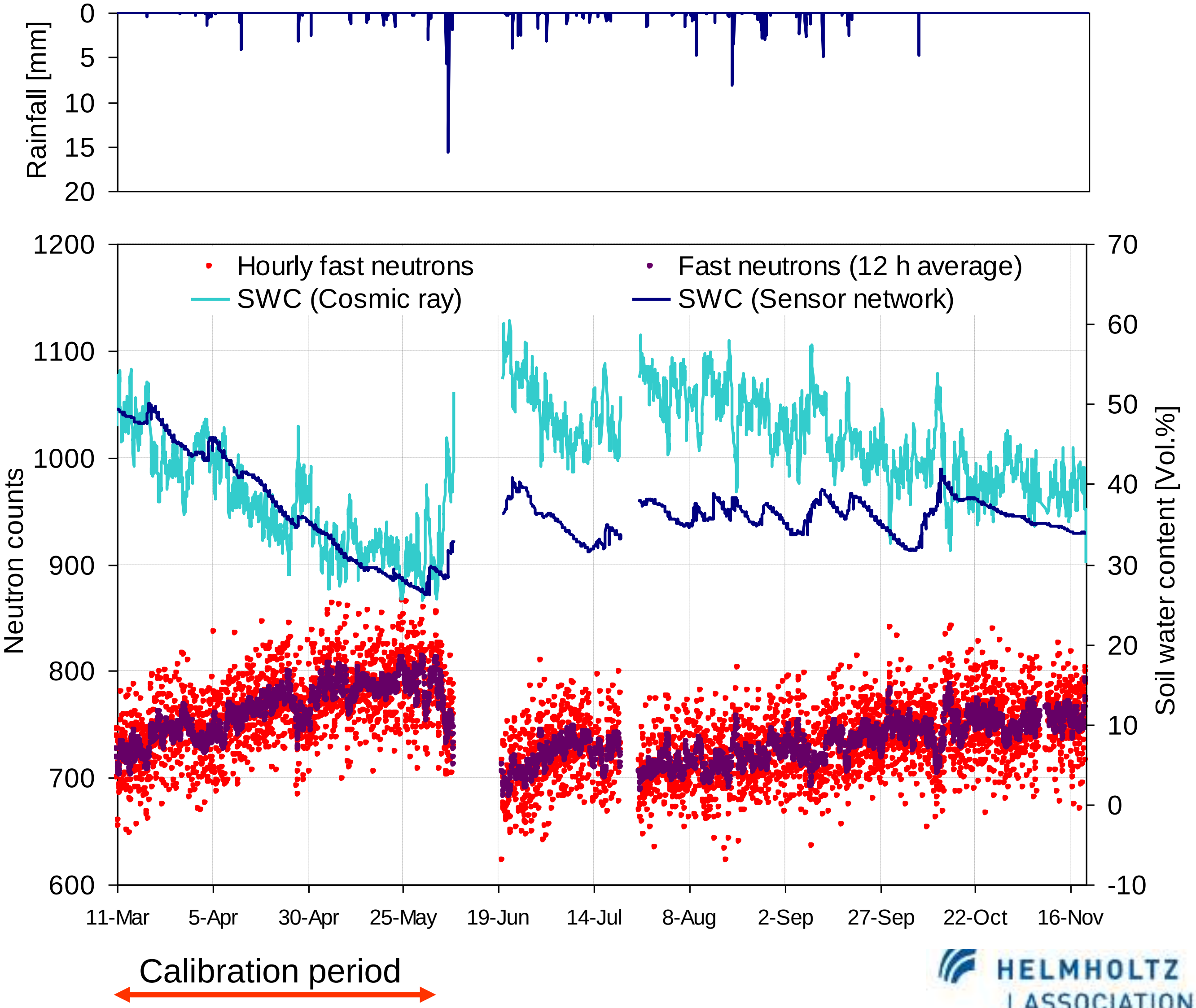
83 soil moisture stations (5, 20 and 50 cm)





300 m radius

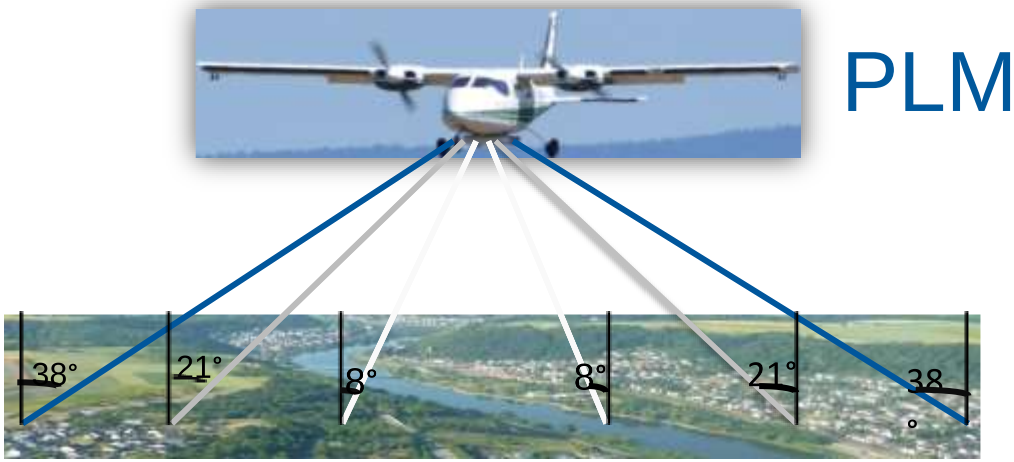
Calibration results: Forest test site Wüstebach



RMSE
(calibration period):
2.93 Vol.%

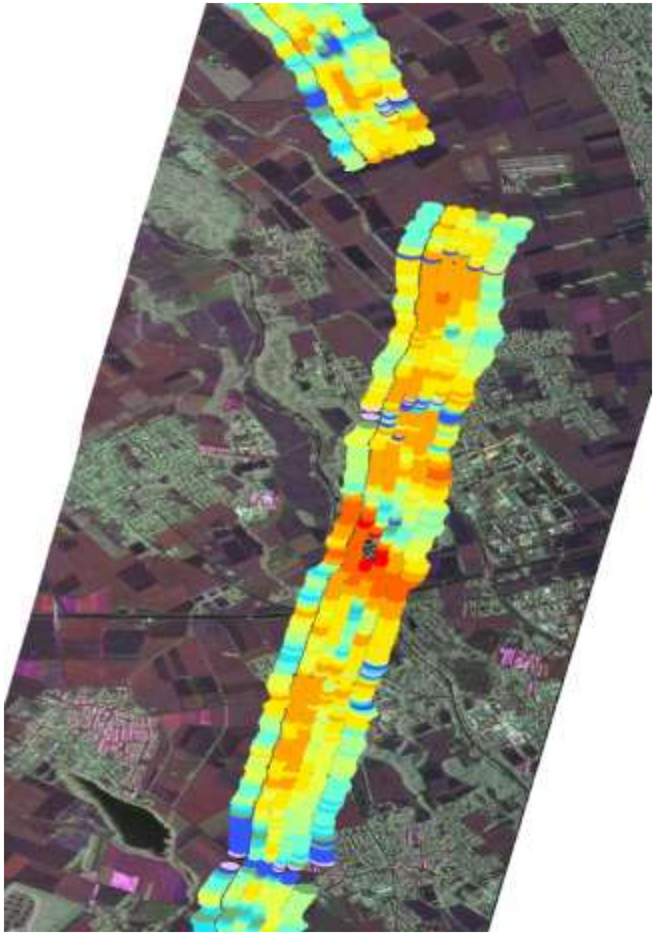
RMSE
(remaining period)
9.47 Vol.%

Passive and active microwave sensors the 2011 campaign



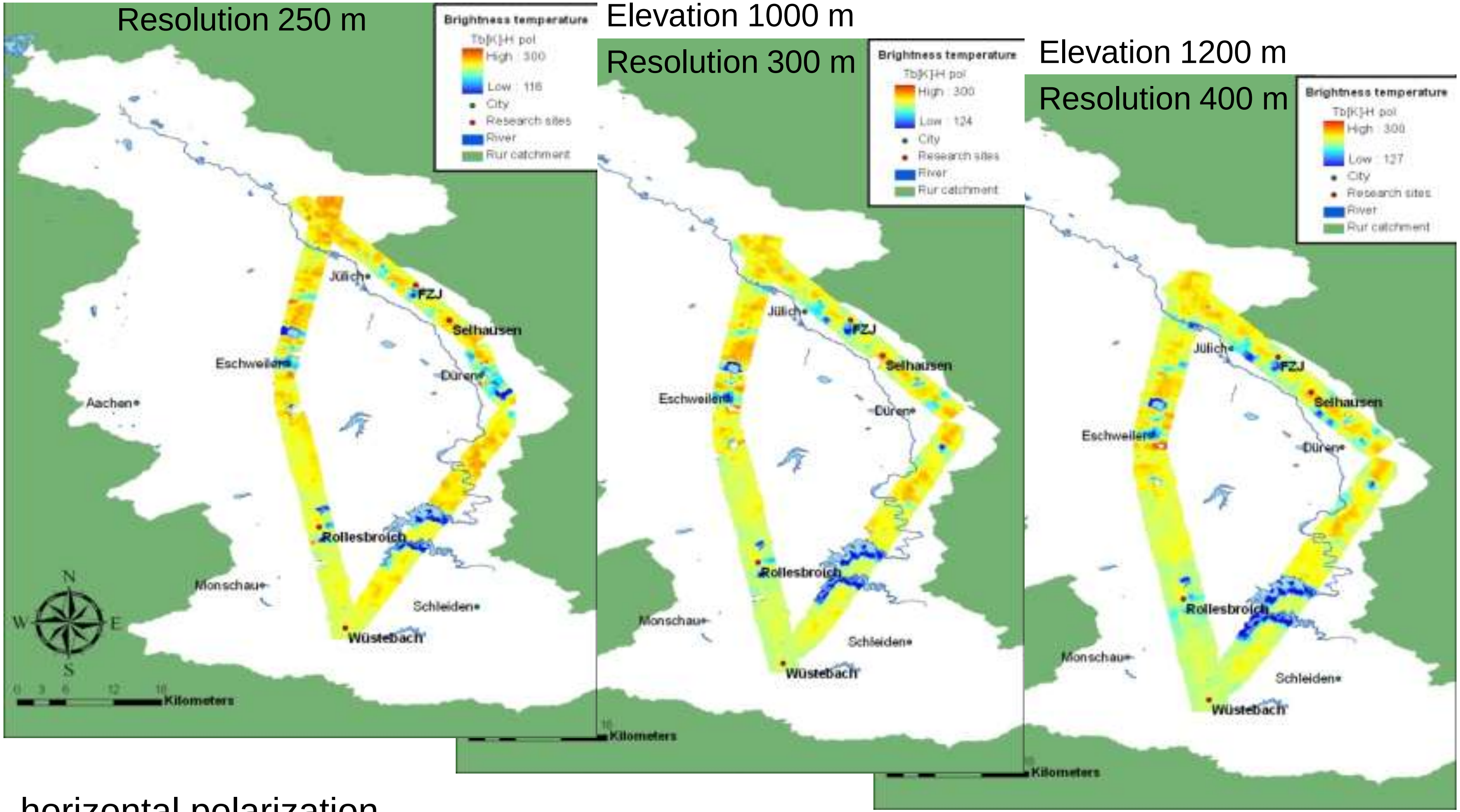
PLMR

F-SAR



F-SAR overlayed with unprocessed PLMR data

Multi-resolution TB for the Rur catchment



Elevation 700 m

Resolution 250 m

Elevation 1000 m

Resolution 300 m

Elevation 1200 m

Resolution 400 m

horizontal polarization

Multi-resolution TB for the Rur catchment

Elevation 700 m

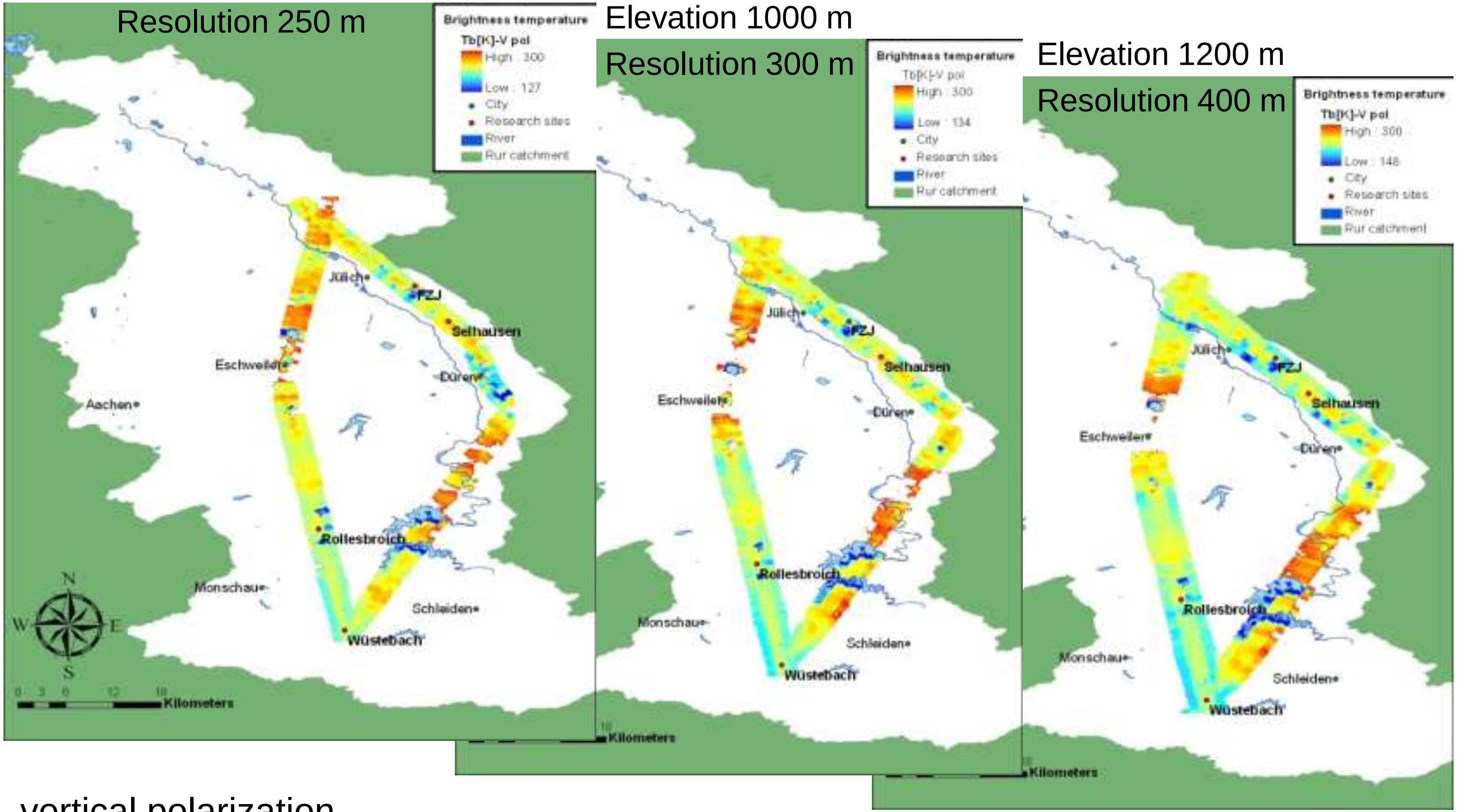
Resolution 250 m

Elevation 1000 m

Resolution 300 m

Elevation 1200 m

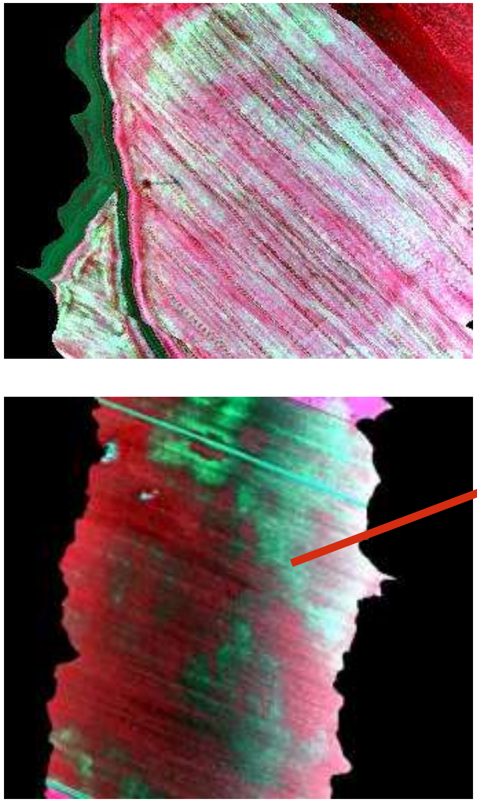
Resolution 400 m



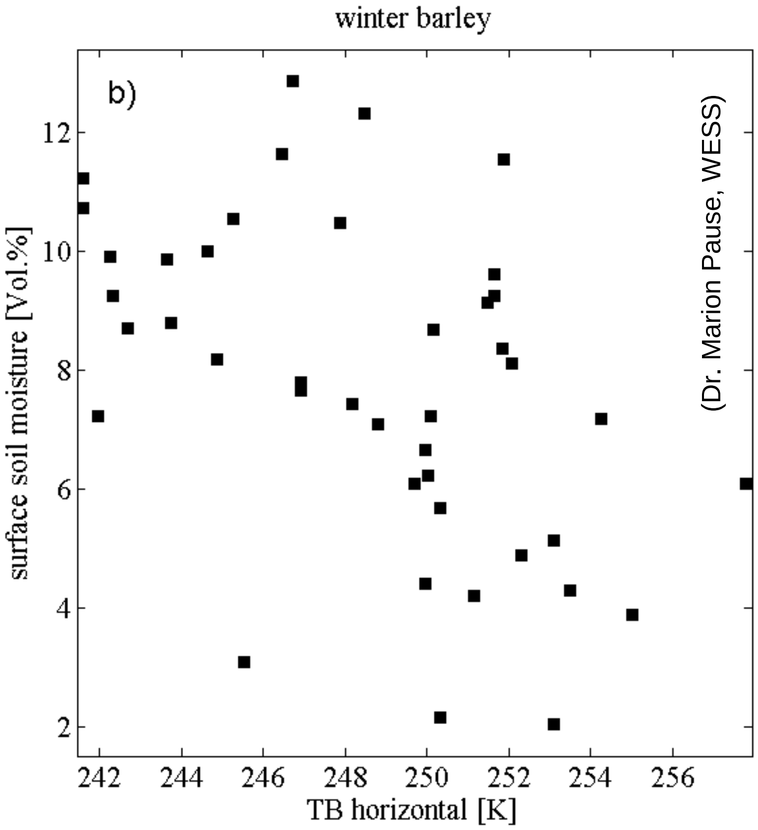
vertical polarization

PLMR brightness temperature vs. surface soil moisture

Test site: Grossbardau (TERENO Central German Lowland Observatory)



AISA CIR image: Lausch/ Pause UFZ)

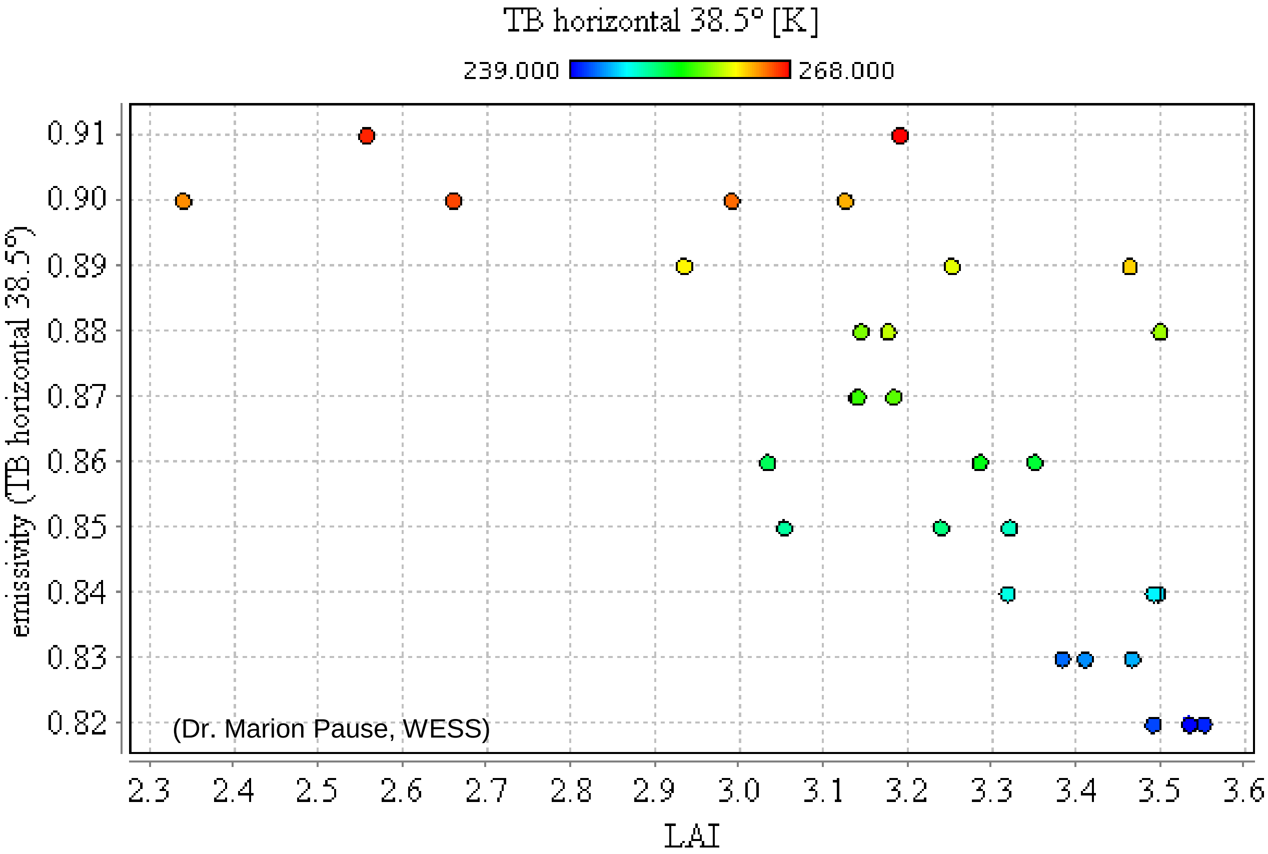


(Dr. Marion Pause, WESS)

→ Spatial distribution of vegetation parameters from AISA data!

PLMR brightness temperature vs. LAI

winter barley (fruit development)

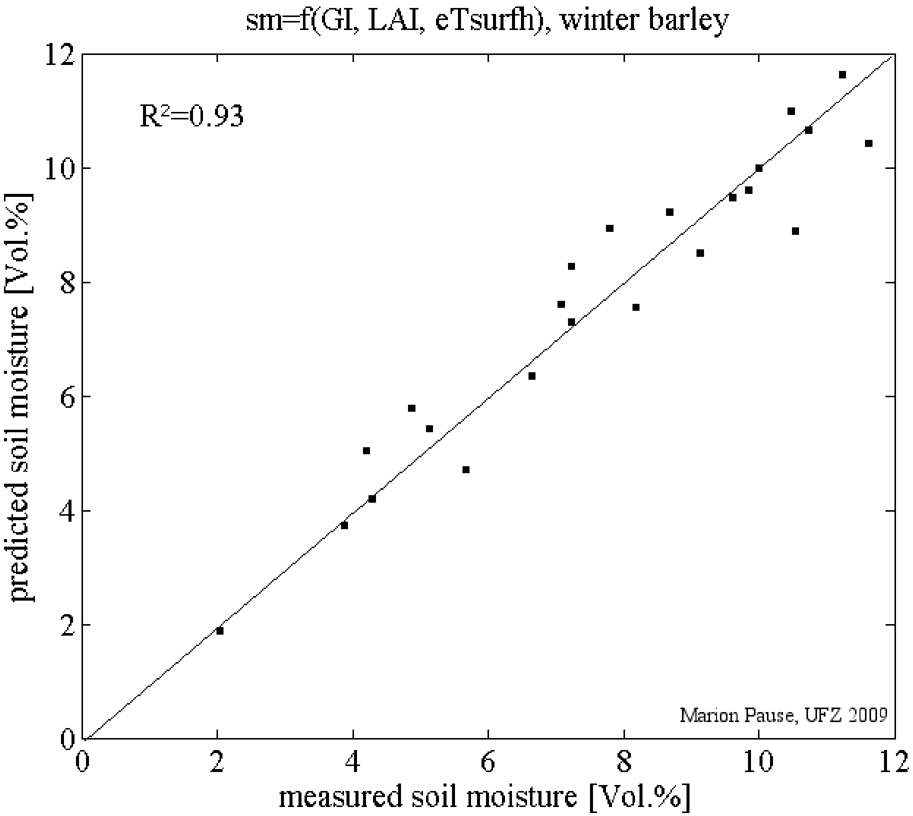


(Dr. Marion Pause, WESS)

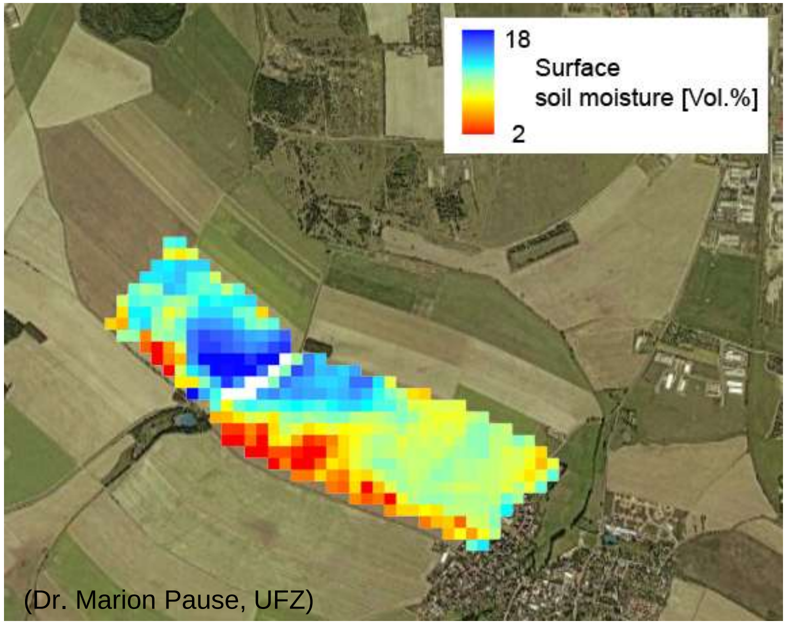
Test site: Grossbardau

(TERENO Central German Lowland Observatory)

Application of multi-variate regression



Marion Pause, UFZ 2009



(Dr. Marion Pause, UFZ)

SMAP validation campaign with simultaneous use of passive and active microwave sensors

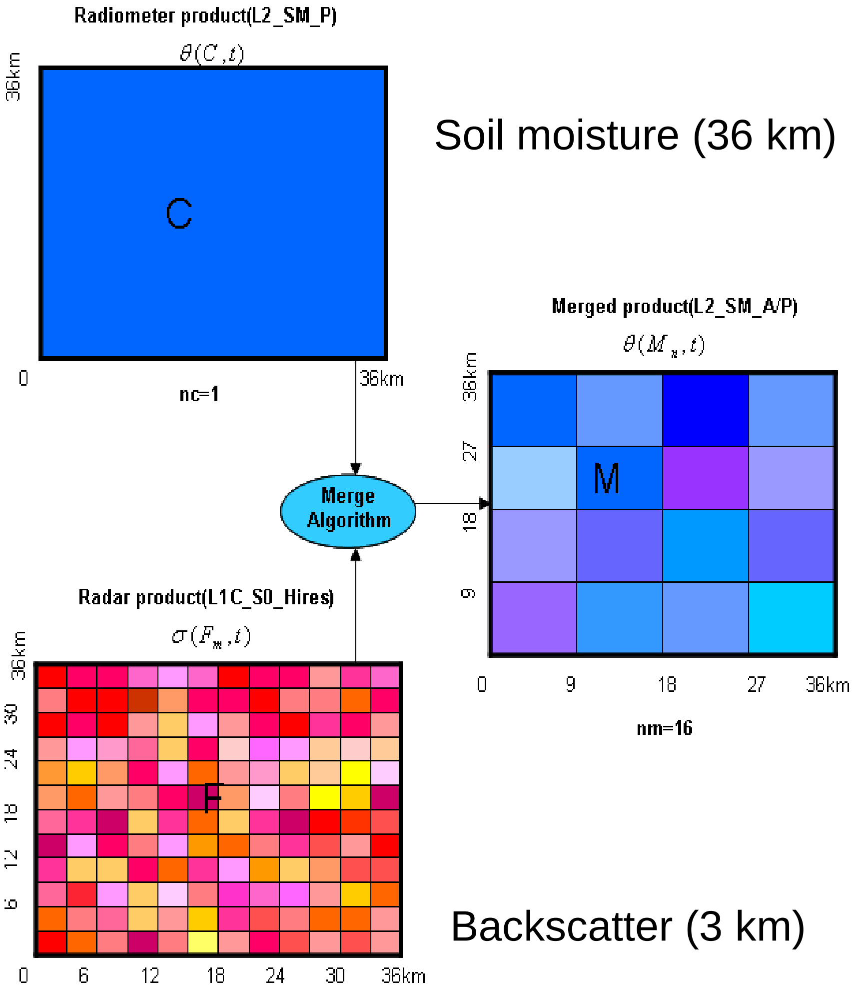
Combination of PLMR2 and DLR F-SAR onboard a Dornier DO228 aircraft

+ IR-camera
+ Hyperspectral camera

- F-SAR is able to operate in 4 frequency bands (X, C, L and P)
- Dual (F-SAR) channel operation

- Polarisation: Dual linear (V and H)
- Incidence angles: +/- 8°, +/-22°, +/- 38° @ pushbroom

PhD study of Sayeh Hasan: Airborne active and passive microwave data fusion for soil moisture retrieval (DFG)

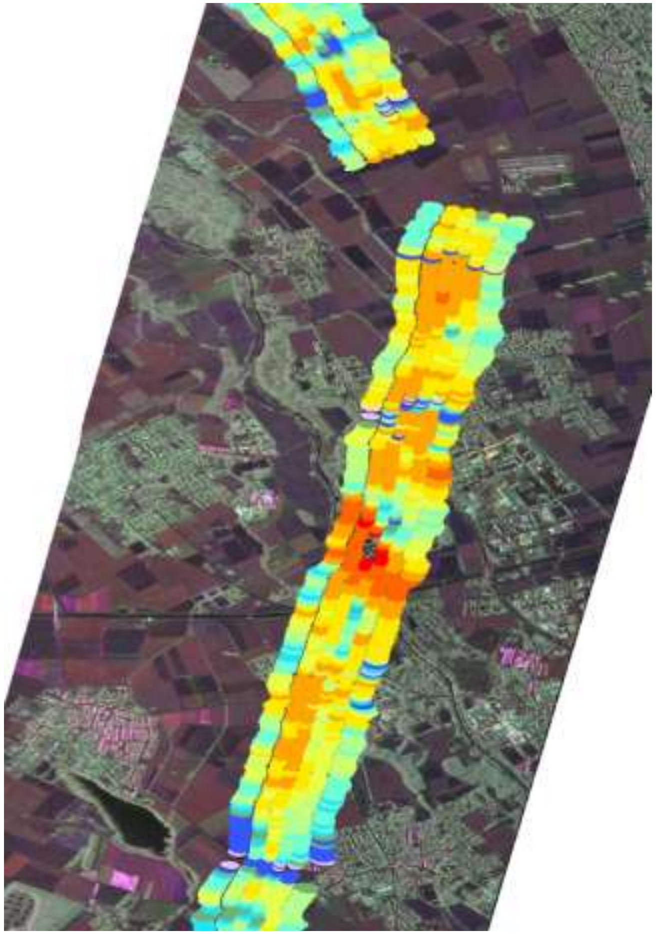


Soil moisture (36 km)

Soil moisture (9 km)

Backscatter (3 km)

Das, Entekhabi and Njoku 2011



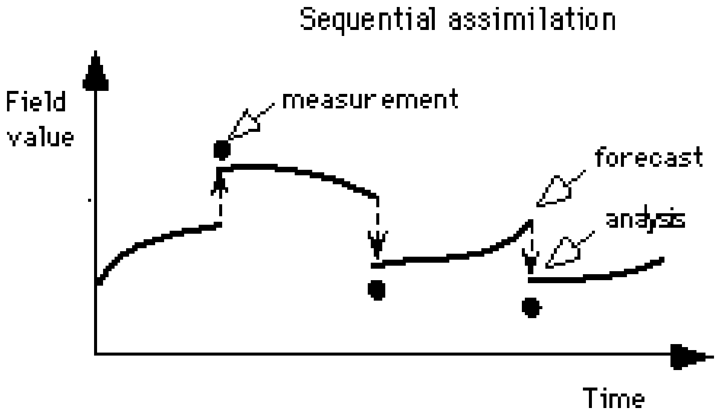
F-SAR overlayed with unprocessed PLMR data

Data assimilation techniques to predict hydrological fluxes from soil moisture measurements

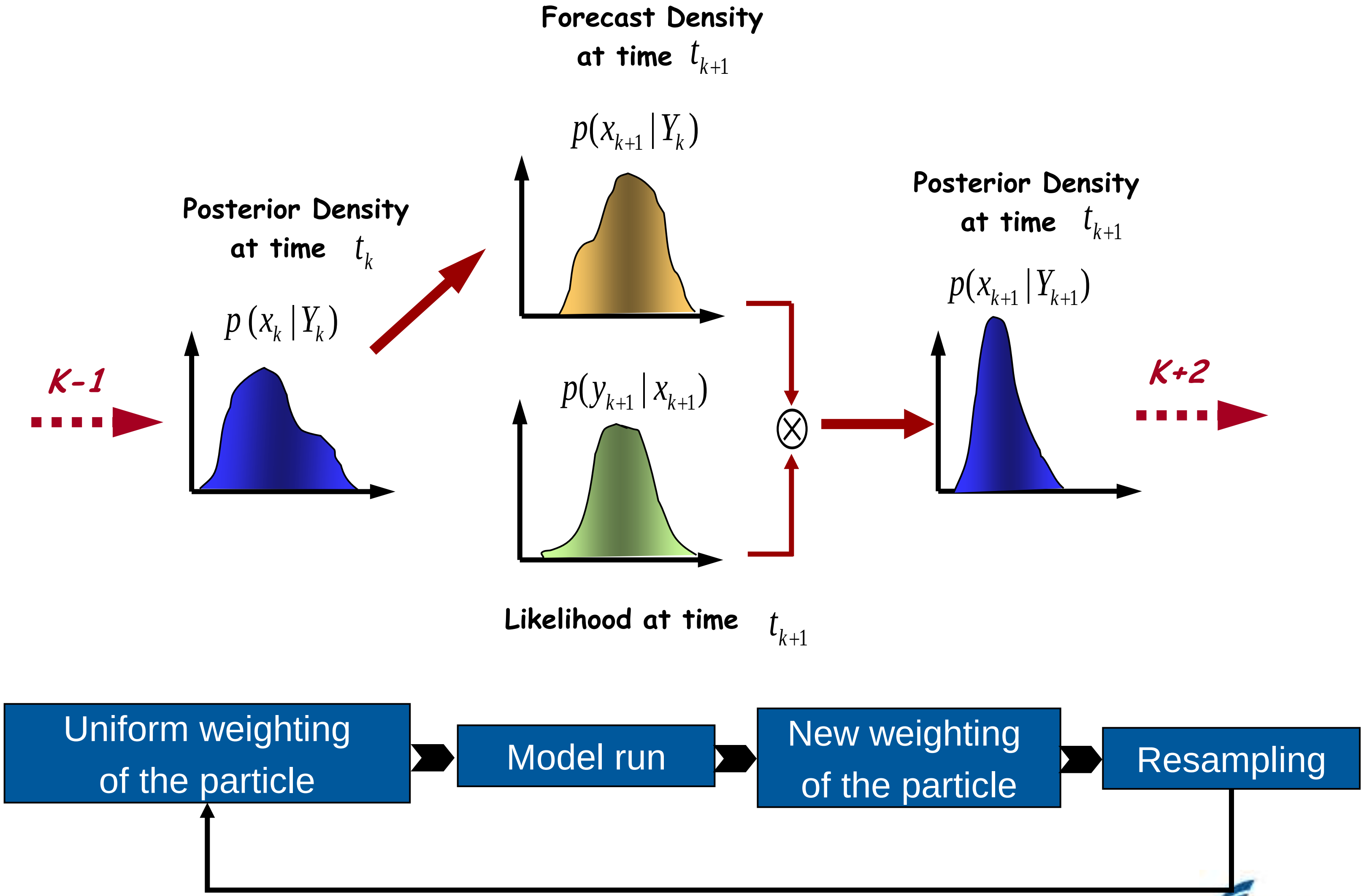
Optimal combination of observations and model predictions e.g. Ensemble Kalman Filter, Particle Filter

Particle Filter:
Sequential Monte Carlo

Sequence:



Particle Filter



Forecast Density at time t_{k+1}

$p(x_{k+1}|Y_k)$

Posterior Density at time t_k

$p\,(x_k\,|Y_k)$

K-1

Posterior Density at time t_{k+1}

$p(x_{k+1}|Y_{k+1})$

K+2

$p(y_{k+1}|x_{k+1})$

$\otimes$

Likelihood at time t_{k+1}

Uniform weighting of the particle

Model run

New weighting of the particle

Resampling

HYDRUS 1D lysimeter experiment

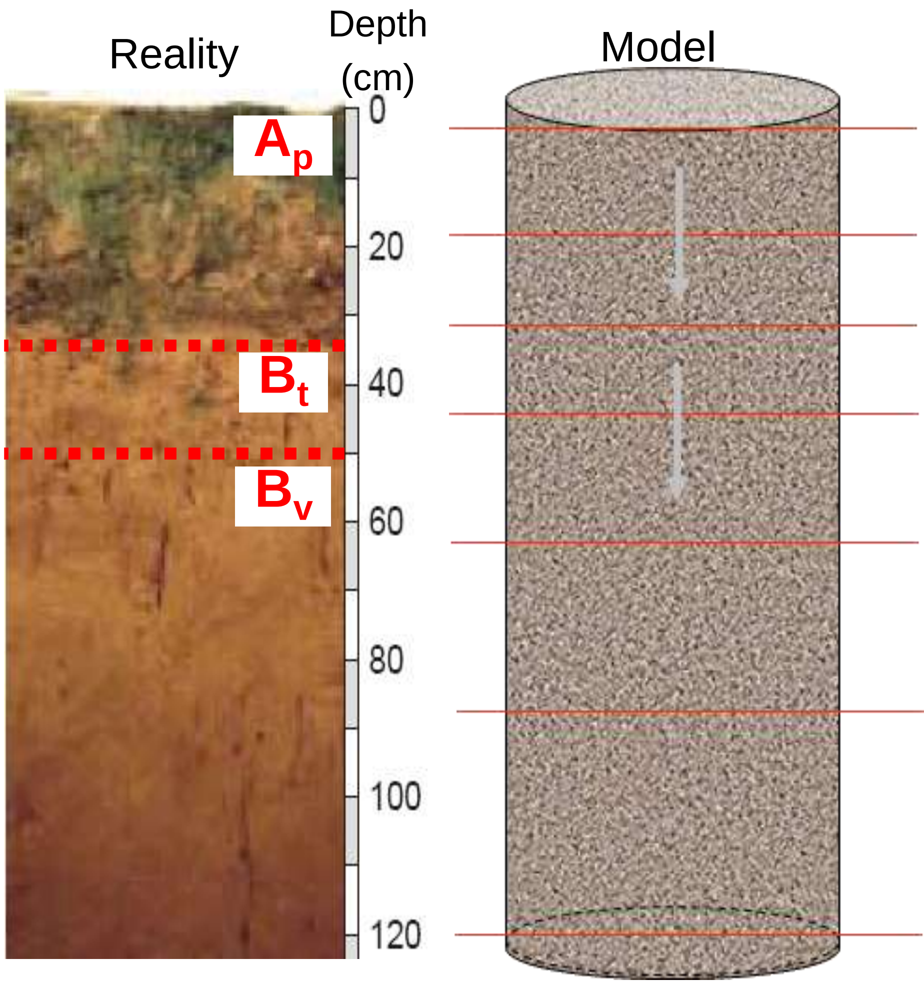
- 1-D physical finite elements model solves Richards equation numerically:

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}\left[k(h)\left(\frac{\partial h}{\partial z}-1\right)\right]-Q$$

- Soil hydraulic properties are parameterised using the Mualem-van Genuchten model
- 1 day temporal resolution
- 3 soil layers

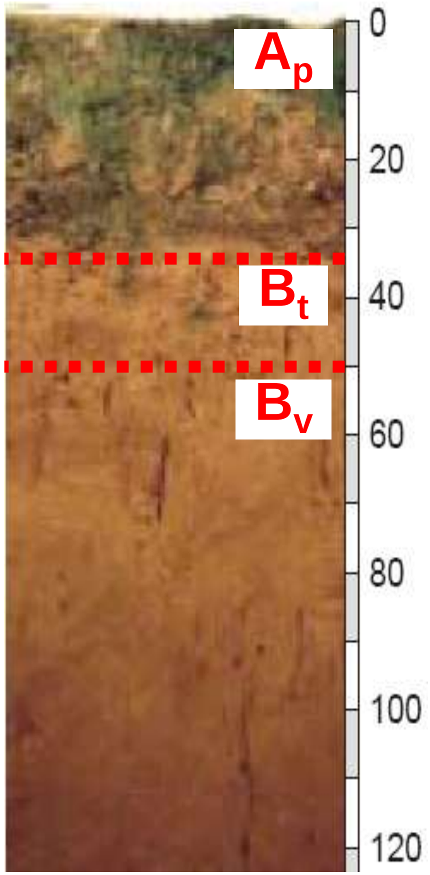
Assumptions:

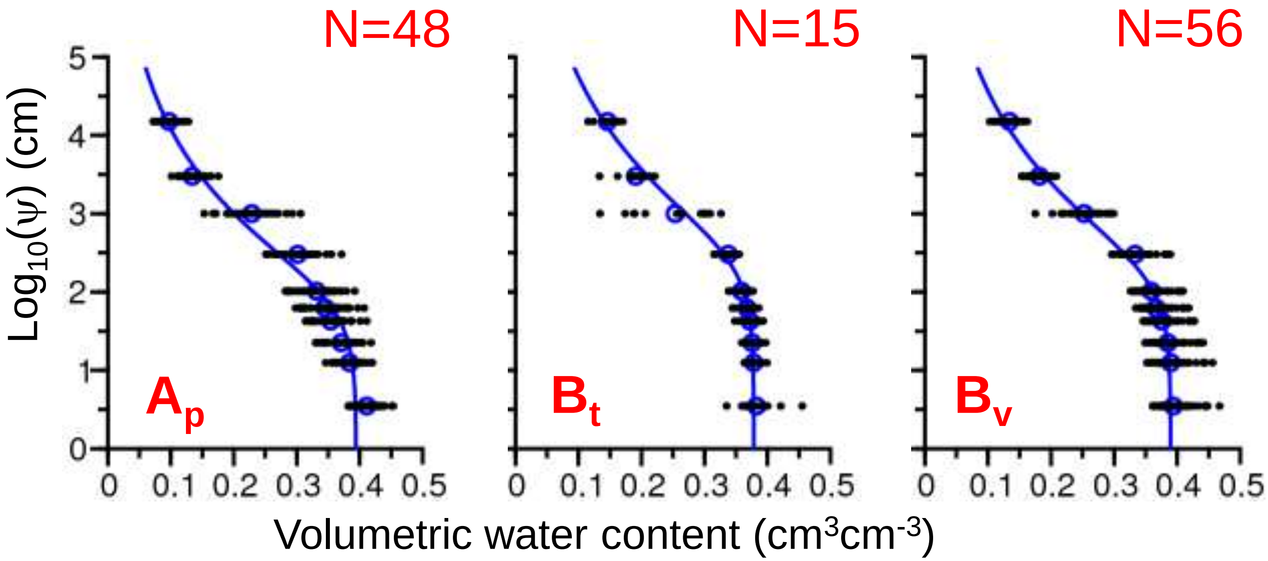
- Vapour flow is negligible
- No macropore flow
- No hysteresis



*Simunek et al. (2006)

Soil moisture observations in lysimeters





Van Genuchten (1980): $S_e = \left[1+(\alpha|\psi|)^n\right]^{1/n-1}$

		θ_r	θ_s	α	*n*	*Ks* *cm/h*
	A_p	0	0.394	0.0105	1.28	9.21
Depth (cm)	B_t	0	0.378	0.0031	1.26	0.73
	B_v	0	0.390	0.0051	1.26	0.36

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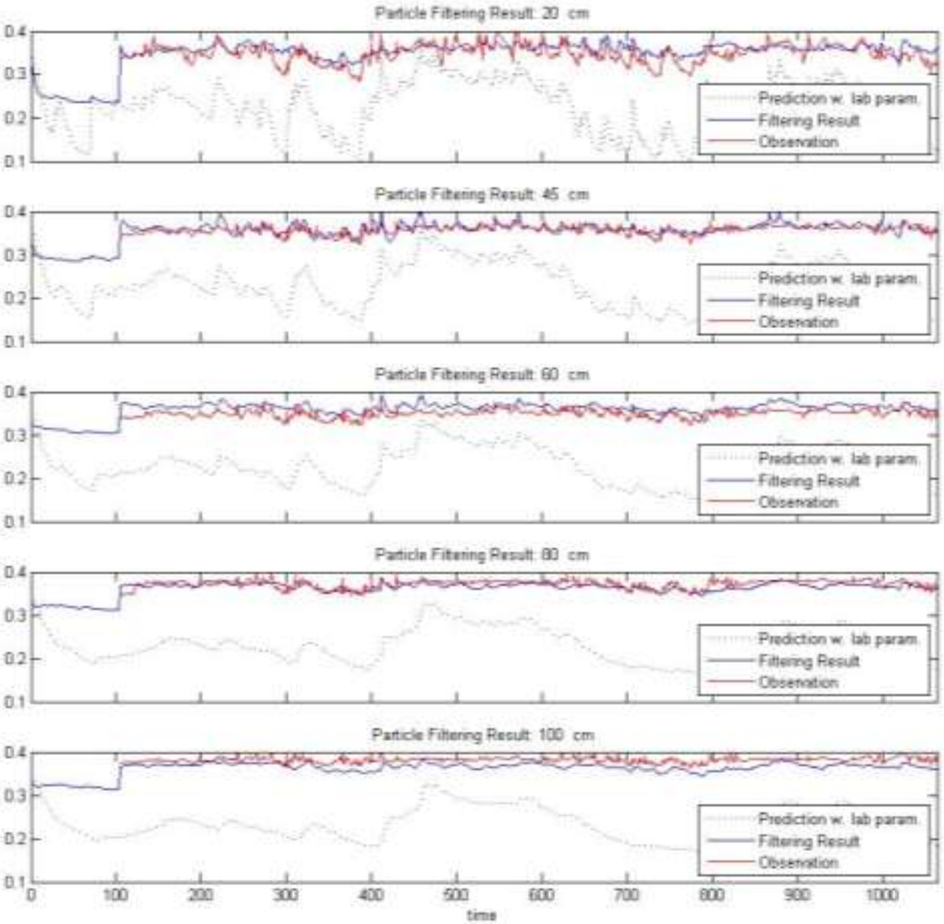
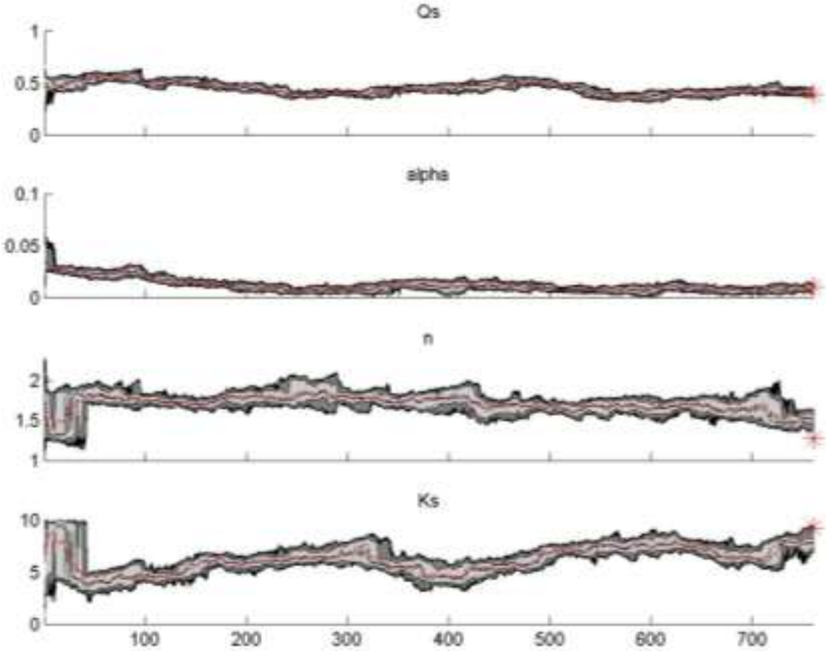
Particle Filtering – Soil water content

Soil water content



Optimised MvG parameter:



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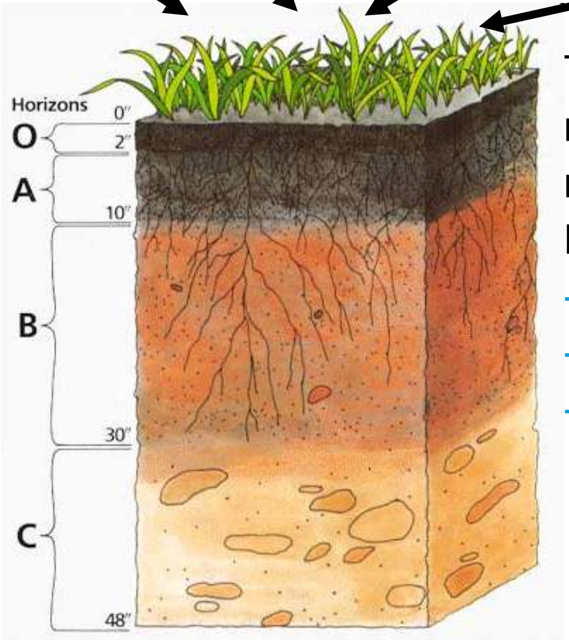
Soil moisture observations

Measuring a soil volume:

Surface to 5 cm depth



⇒ Assimilation

Top soil moisture measurements with microwave radiometry in L-Band (1 - 2,6 GHz)
- groundbased (ELBARA)
- airborne (PLMR, EMIRAD)
- spaceborne (SMOS, ALOS)

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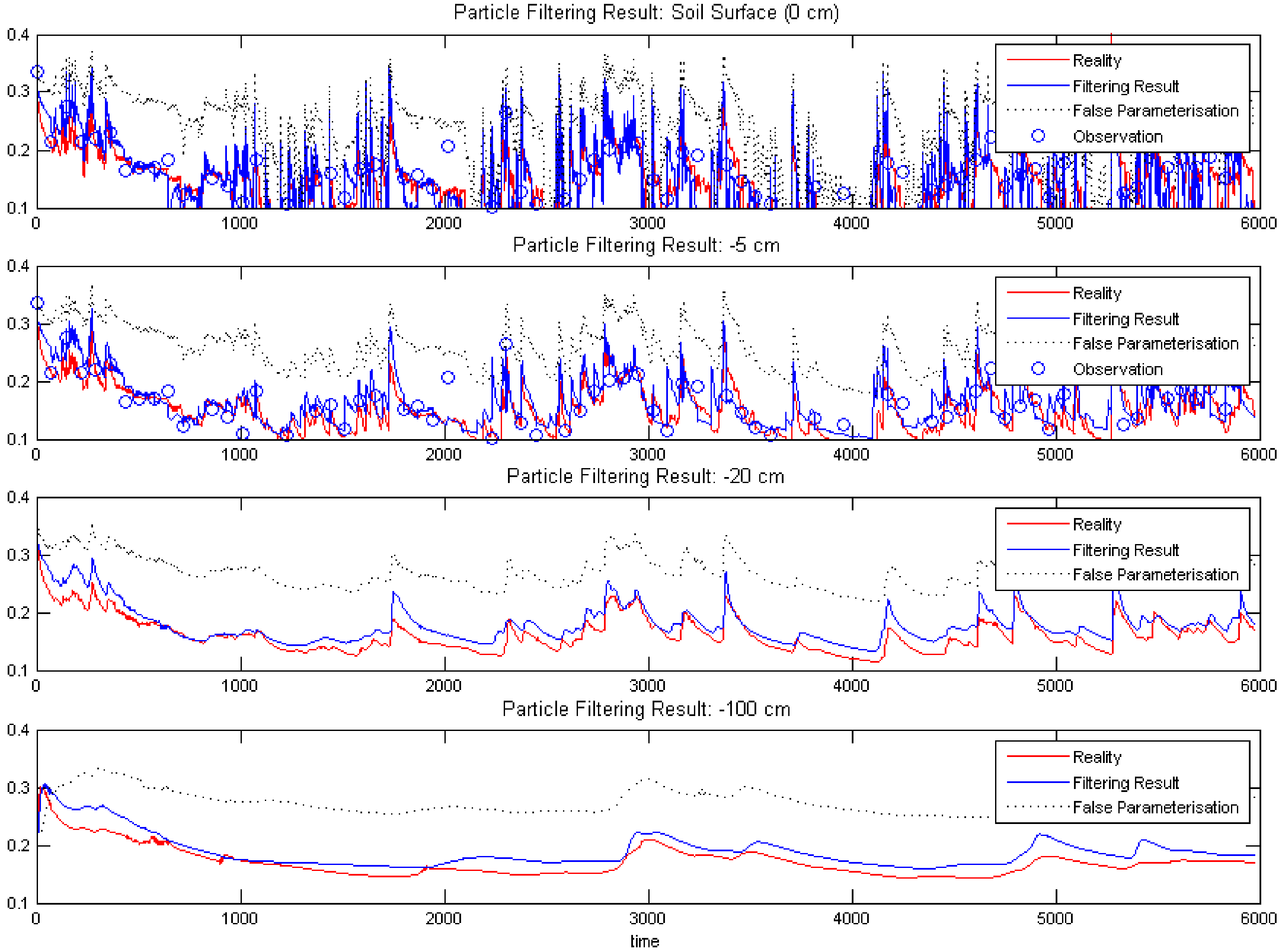
State and param. update (loamy sand)

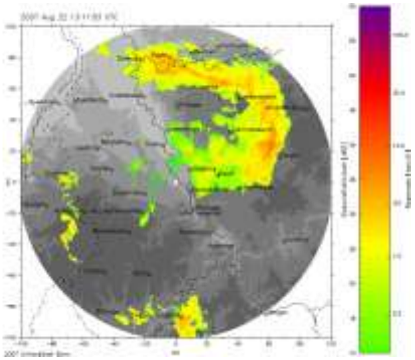


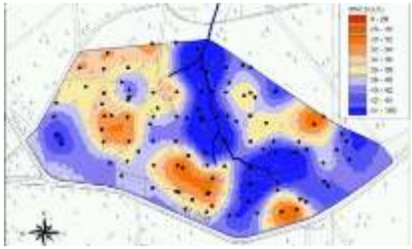
Conclusions

- Wireless sensor networks can be used to analyse soil moisture variability at the headwater catchment scale
- Wireless sensor network data can be used to analyze Cosmic Ray probe foot print measurements
- Airborne passive radiometer data has to be combined with additional data (e.g. LAI) to increase the quality of soil moisture retrieval
- A active/passive retrieval algorithm helps to increase spatial resolution of radiometer soil moisture data
- Data assimilation methods provide a unique means of combining soil moisture measurements and models to predict soil water fluxes

Prediction of hydrological states and fluxes

Real-time monitoring





Assimilation

Real-time communication

Assimilation

Weather model

(Local model)

2-way couplig

Hydrological model

Supercomputer JUROPA/JUGENE

Prediction of hydrological fluxes and states