Patterns in Soil-Vegetation-Atmosphere Systems

Monitoring, Modelling and Data Assimilation

Introduction and Overview

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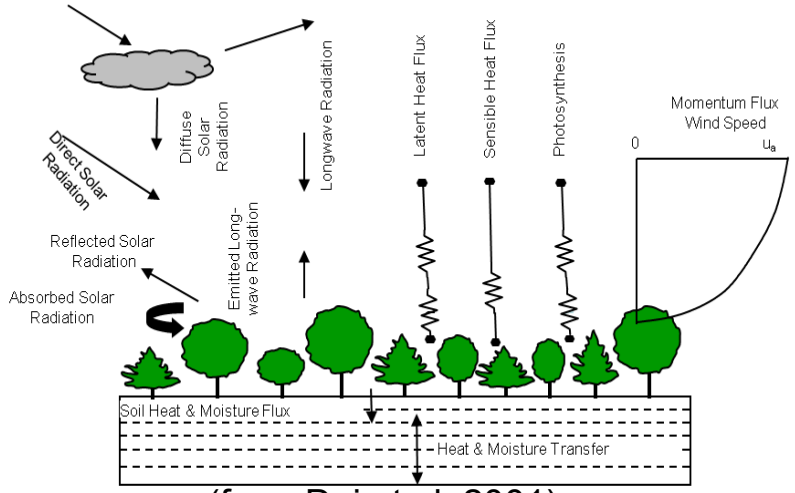
Significance

- The **land surface** is a key component of the **climate system**
  - Radiation exchange and transformation
  - Carbon exchange and storage
  - Moisture exchange and storage
  - Heat exchange and storage
  - Momentum exchange

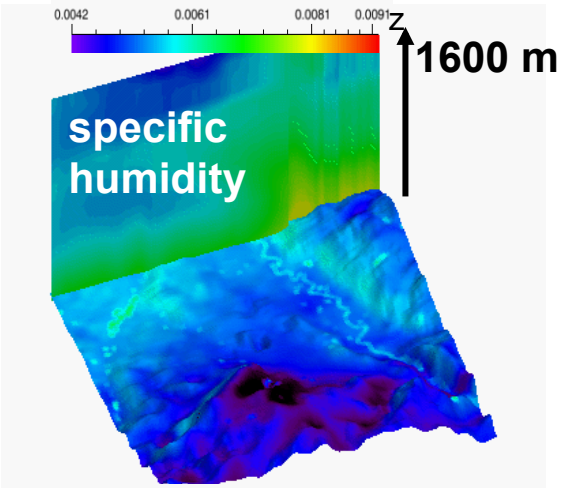


(from Dai et al. 2001)

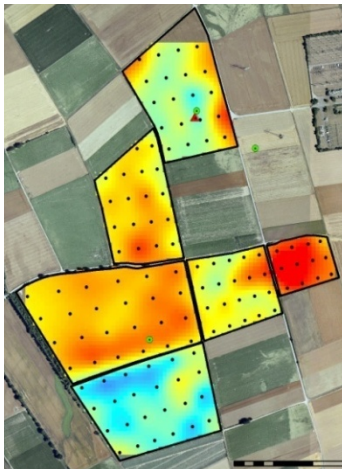
- **All processes are coupled** via common state variables and via the balance equations for energy, mass and momentum.

- Thermodynamics requires that the land surface **dissipates the incoming energy** as efficiently as possible - and **at all scales...**

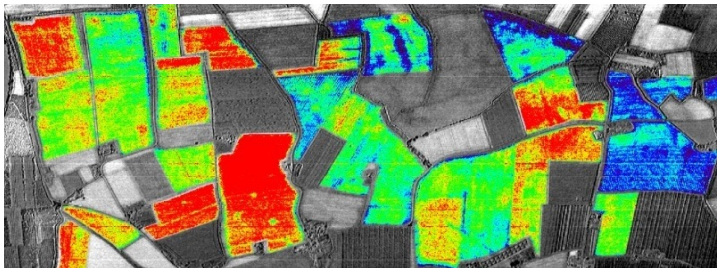
…resulting in patterns and structures



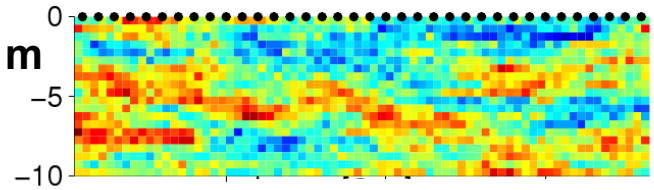
surface temperature



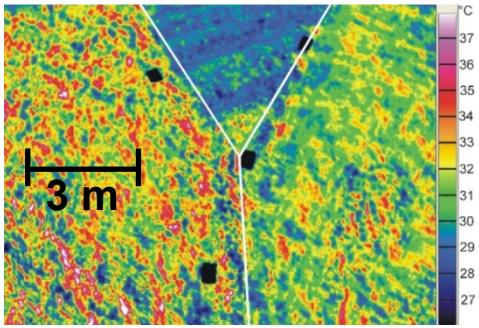
Soil moisture



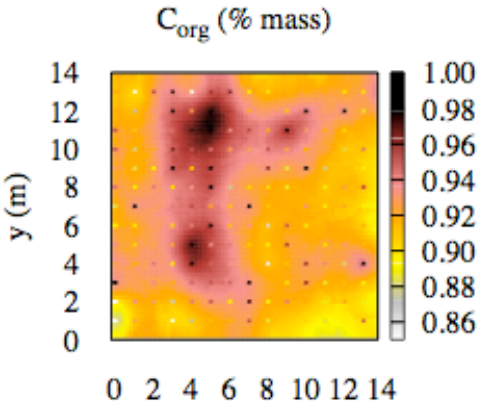
sun induced fluorescence



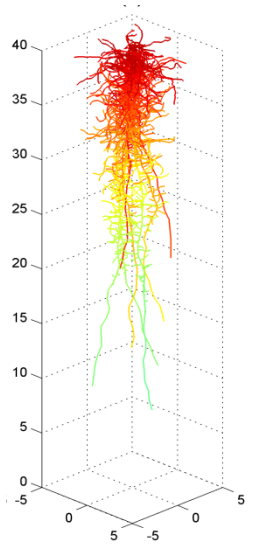
soil resistivity

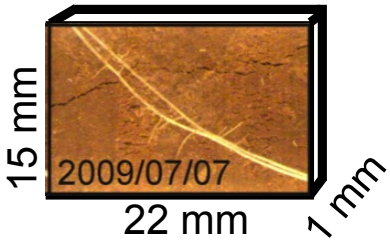


land surface temperature



% soil organic carbon





TR32 Research Paradigms

- **Characterisation of structures and patterns will**
  - lead to a **deeper** qualitative and quantitative **understanding** of the SVA system,
  - and ultimately to **better predictions** of the SVA state.

- Progress can only be achieved by linking experiments and theory via **model-observation integration**.

What are our options?

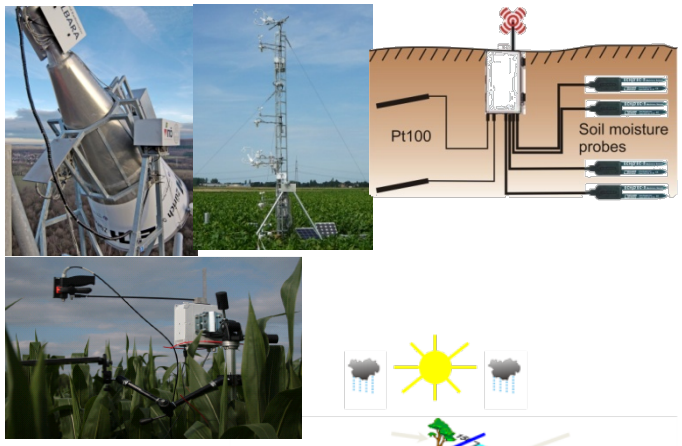
- **Parameterize variance (patterns)** at small scales (upscaling, grid filter, coarse graining, etc.)

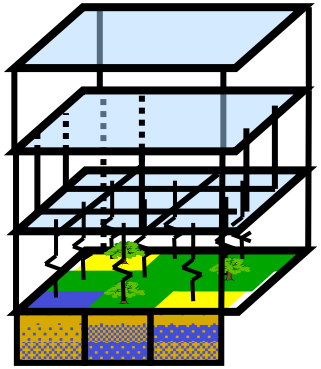
- **Resolve variance (patterns)** explicitly over orders of magnitude (e.g., from meters to kilometers)

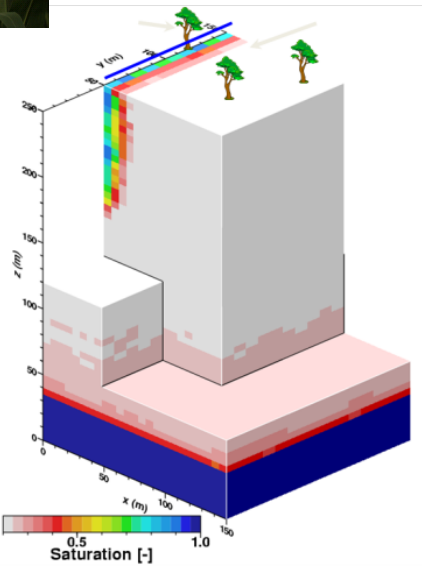
- The second option requires parallel codes and massively parallel computer resources.
  - Simulations provide results that can be used to e.g., understand observations and test upscaling techniques (improve parameterizations).

Specific Goals

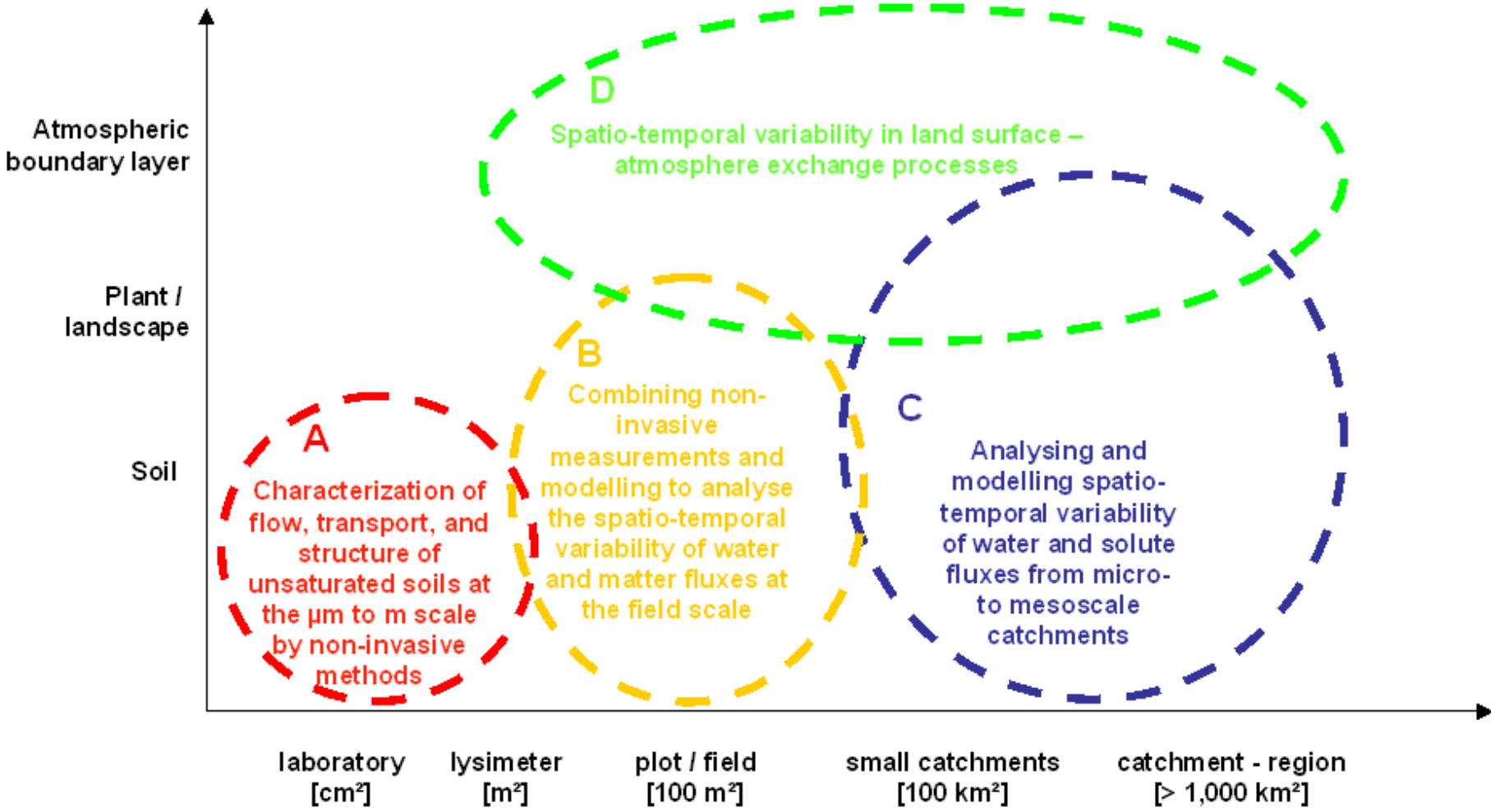
- Suitable **sensors/strategies** to measure state variables and exchange processes of momentum, water, heat and carbon in the SVA system
- **Integrated models** from the groundwater to the atmosphere for both the m- and km-scale
- Methods to **bridge the scale gaps** in measurements and modelling **via explicit consideration of patterns**
- Fusion of integrated models and observations via **data assimilation and inverse theory**







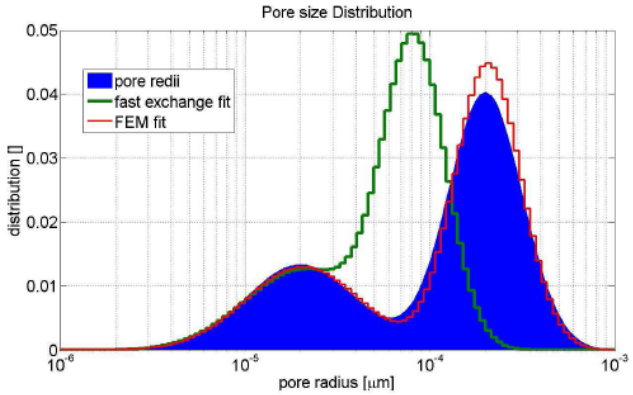
TR32 Organisational Structure



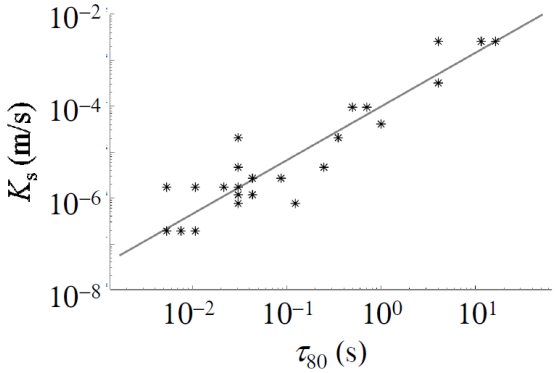
Cluster A

NMR and SIP sense the very small soil scales in the laboratory by model-data integration

- pore size distribution and connectivity



- hydraulic conductivities of the soil

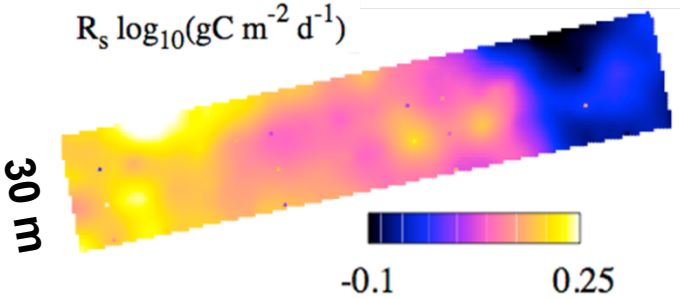


- Slim-line **field logging tool** measures pores plus conductivities by NMR relaxometry

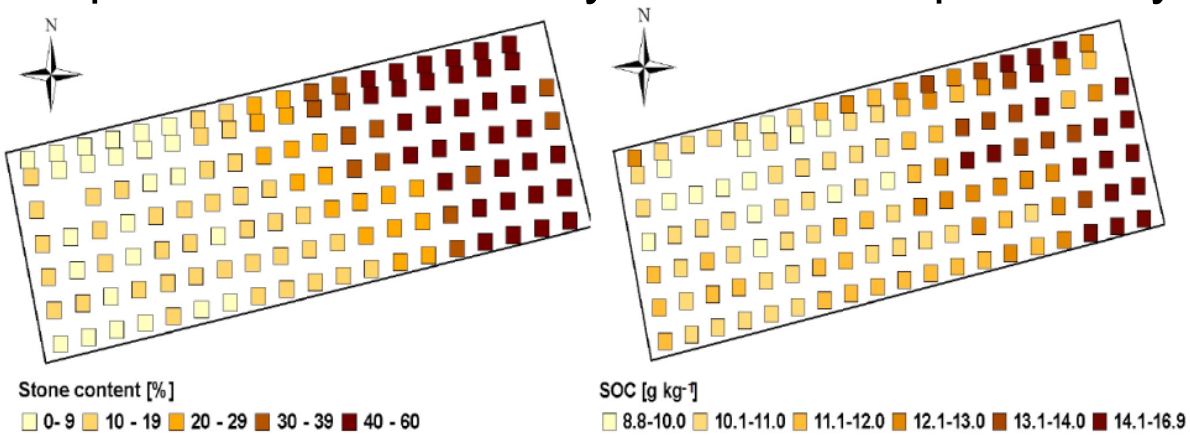
Cluster B

Patterns of soil-carbon, evapotrans-piration and respiration in the field

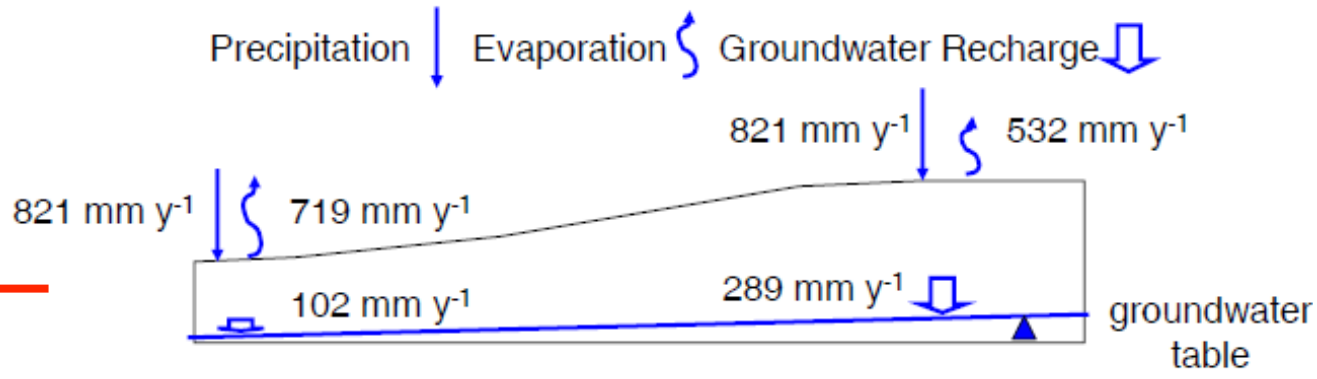
- soil respiration a function of soil moisture and temperature



- carbon pools differentiated by MIRS and explained by soil structure

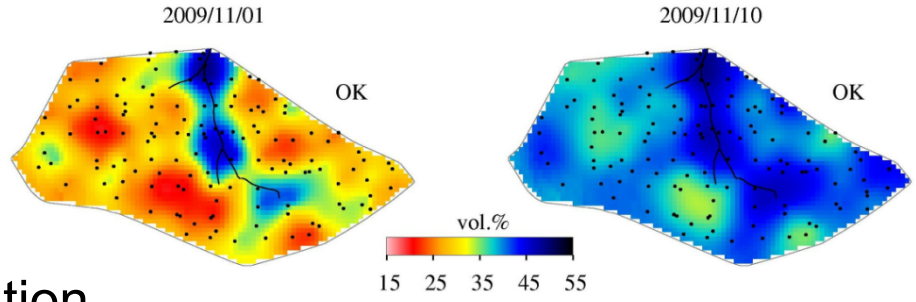


- Groundwater table influences bare soil evaporation.

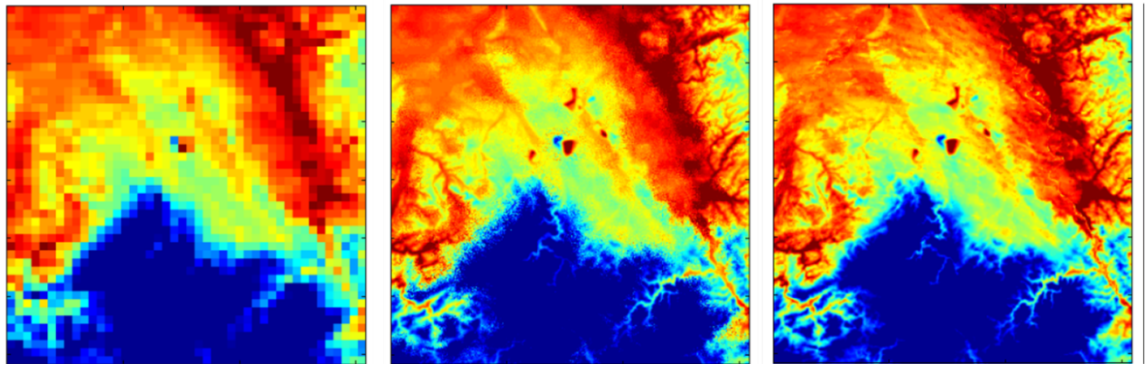


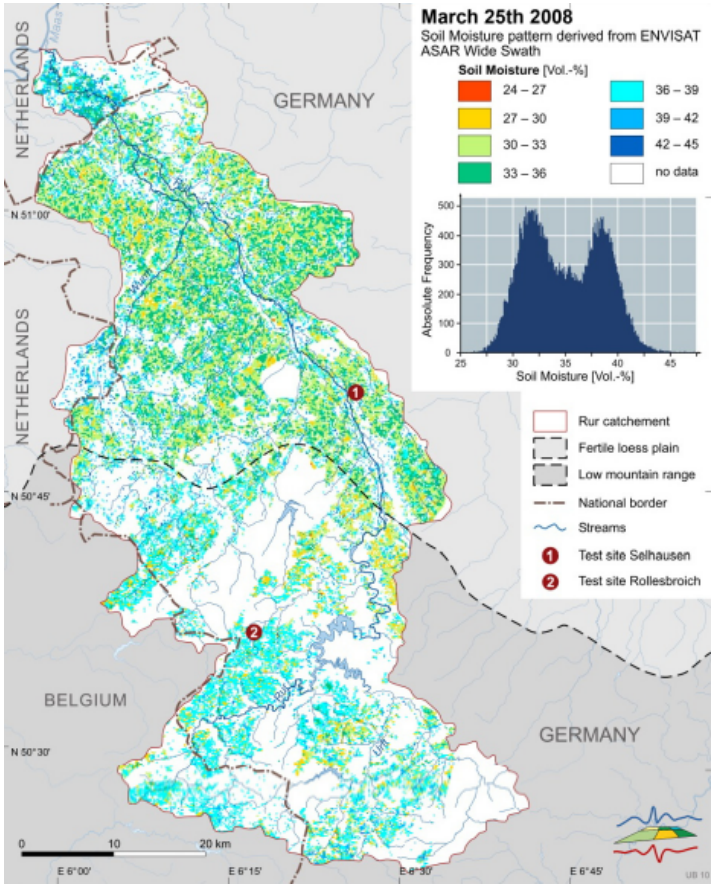
Cluster C

Catchment-scale measuring and integrated modeling of exchange processes



- Monitored 3D soil moisture distribution successfully modeled and related to soil structure
- Soil moisture is retrieved from satellites and used to initialize SVAT-models
- Near-surface sub-scale atmospheric patterns included in integrated model.

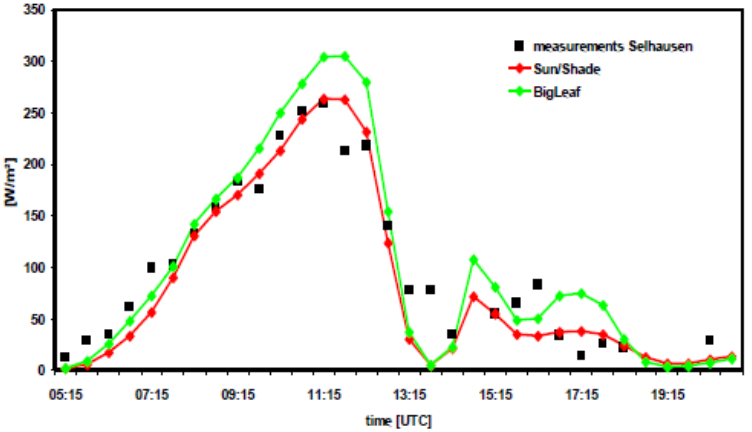




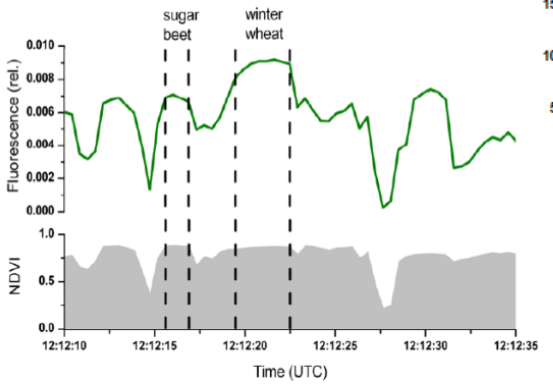
Cluster D

Atmospheric boundary-layer

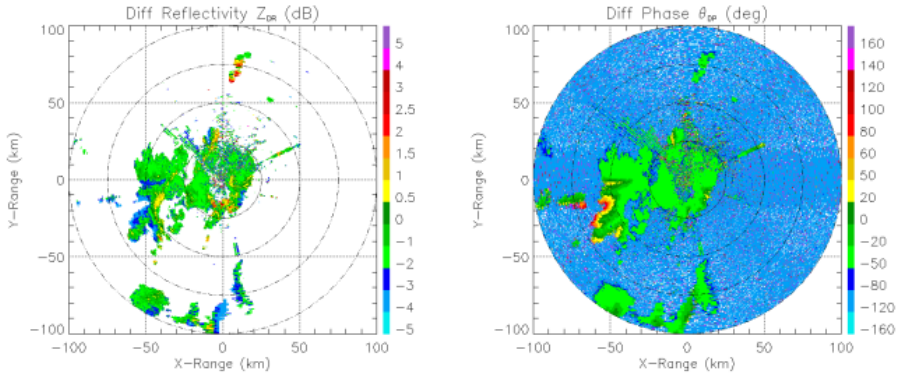
- Modelling and measuring of boundary layer CO_2-H_2O covariances

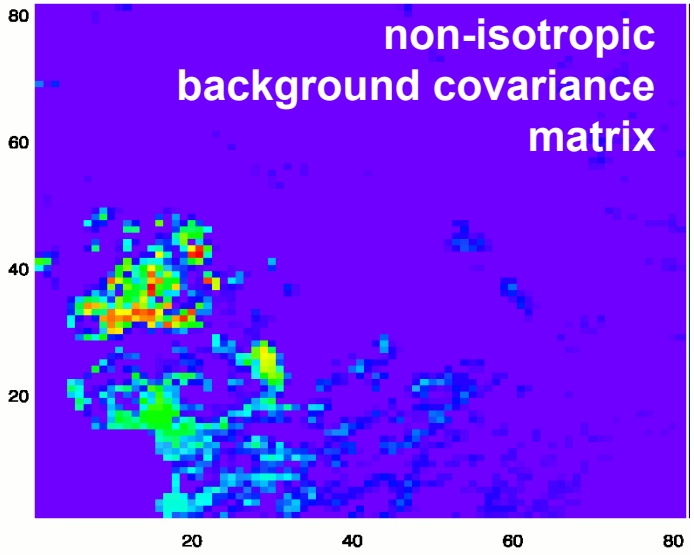


- Plant state from sun-induced fluorescence



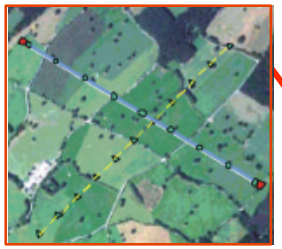
- 4DVar data assimilation now possible in CLM
- New radar retrieves rain in melting layer





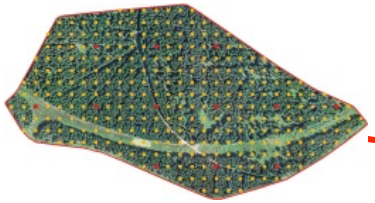
The Rur catchment and its measurement infrastructure coordinated by a cross-cutting group and a central service project (phase 2)

Testgebiet “Rollesbroich”

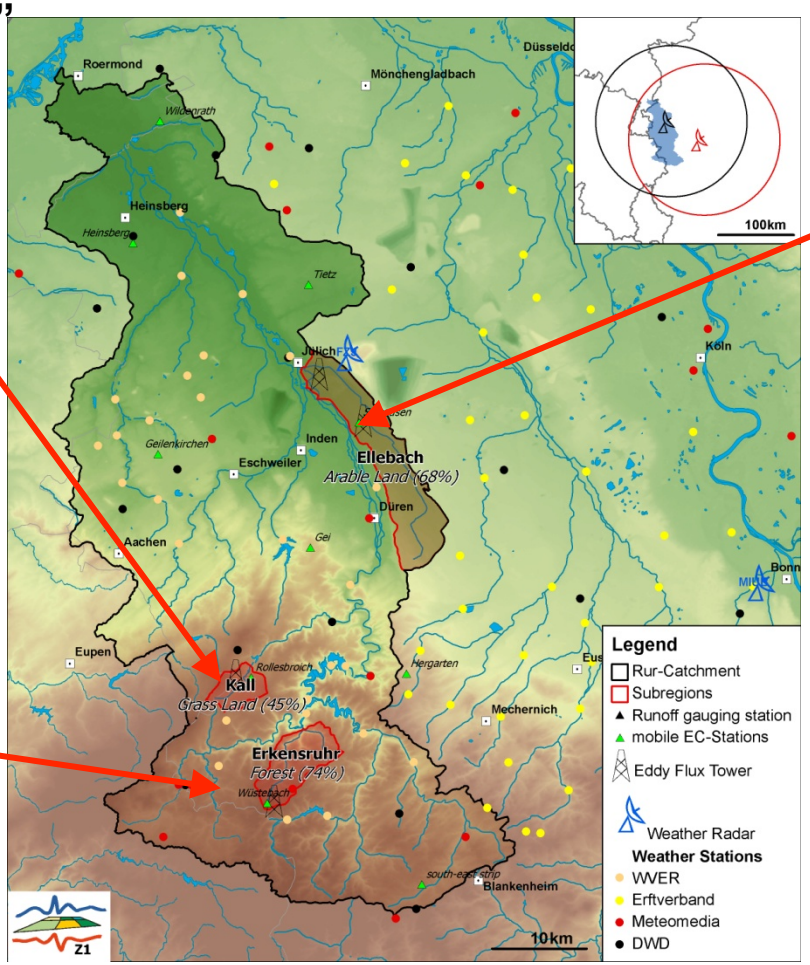


- Eddy Correlation Station
- Soil moisture measurements
- Soil CO_2 flux measurements

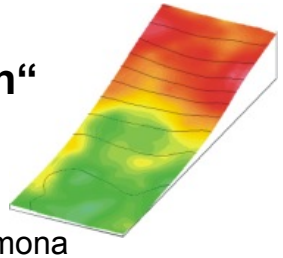
Testgebiet “Wüstebach”



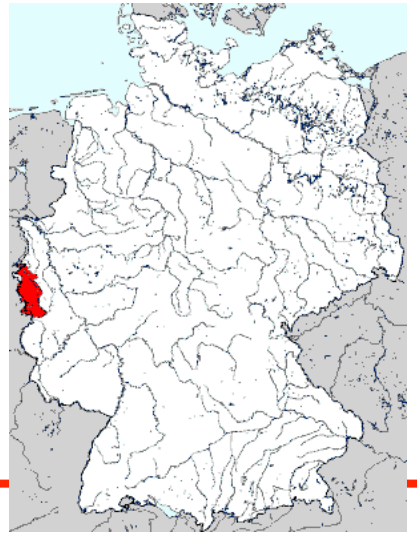
- Eddy Correlation Station
- soil moisture sensor network
- groundwater monitoring
- Discharge and solute concentration
- Soil-CO_2 flux measurements



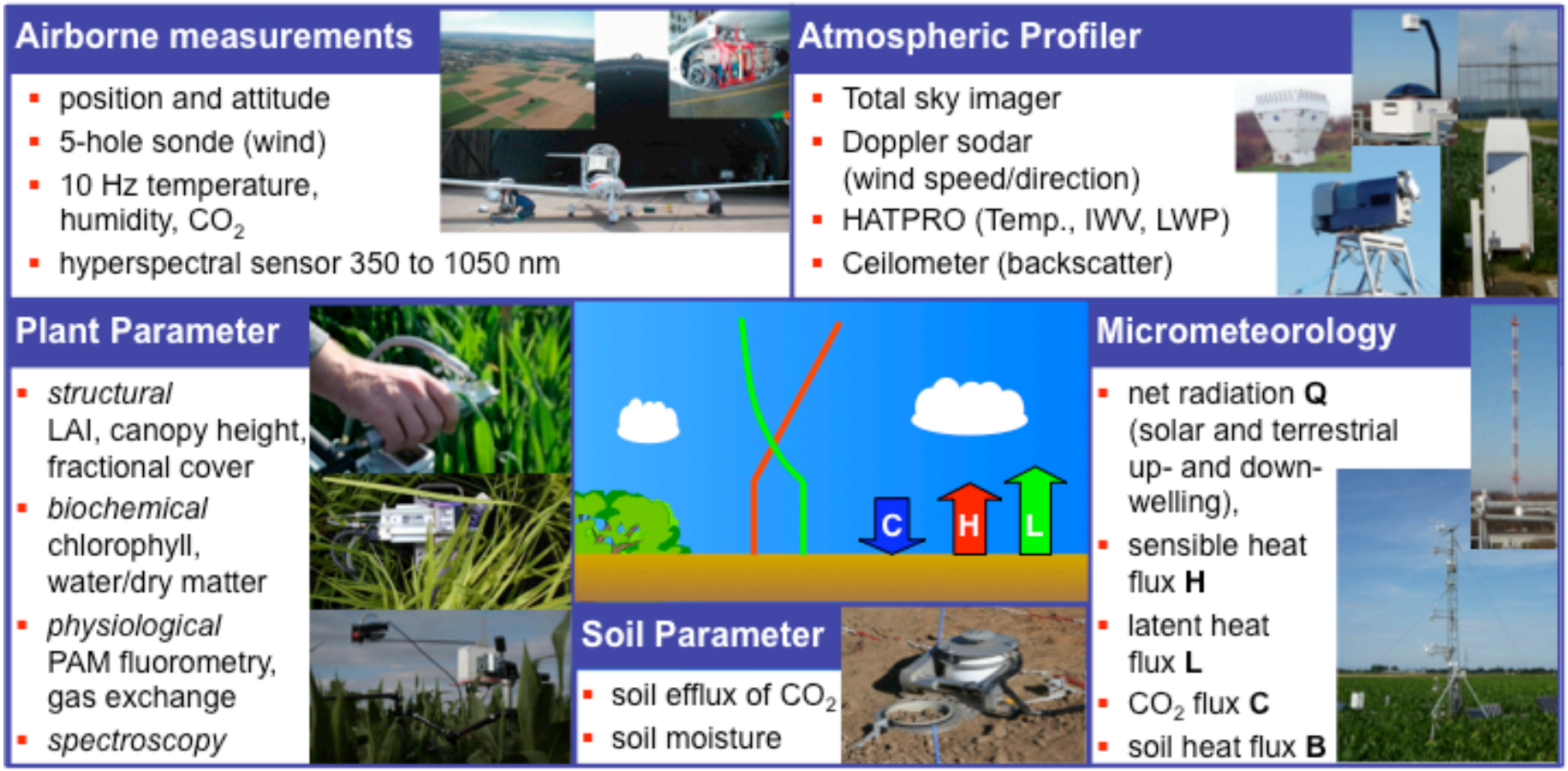
Testgebiet „Selhausen“



- Airborne
  - MetAir Dimona
  - small remote planes
- Captive ballons
- Ground remote sensing
  - active/passive micro waves
  - Lidar, Szintillometer etc.
- Eddy Correl. & profile stations
- Soil CO_2 flux measurements
- Soil moisture measurements

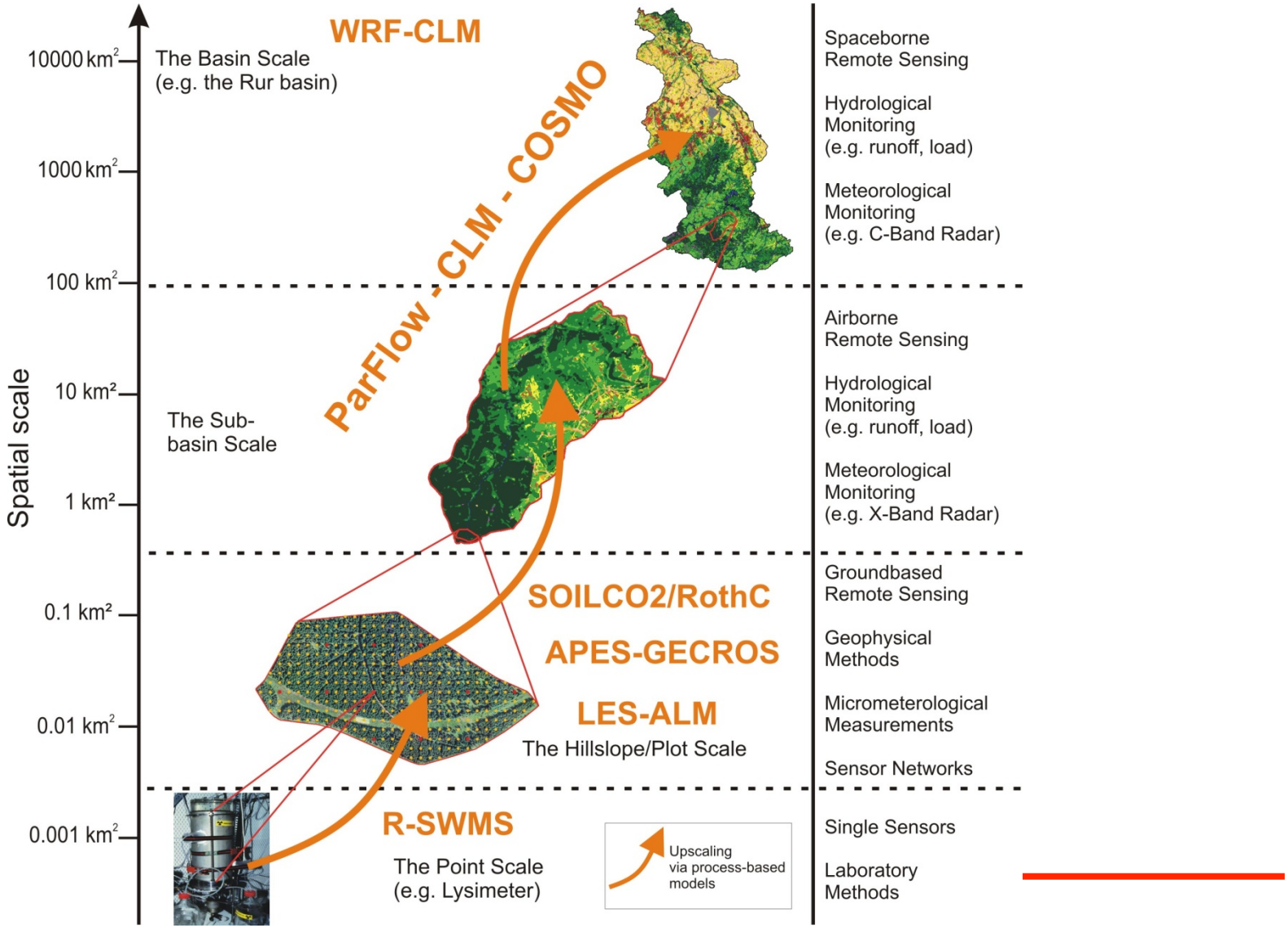


Experimental characterization of patterns using various methods across multiple scales

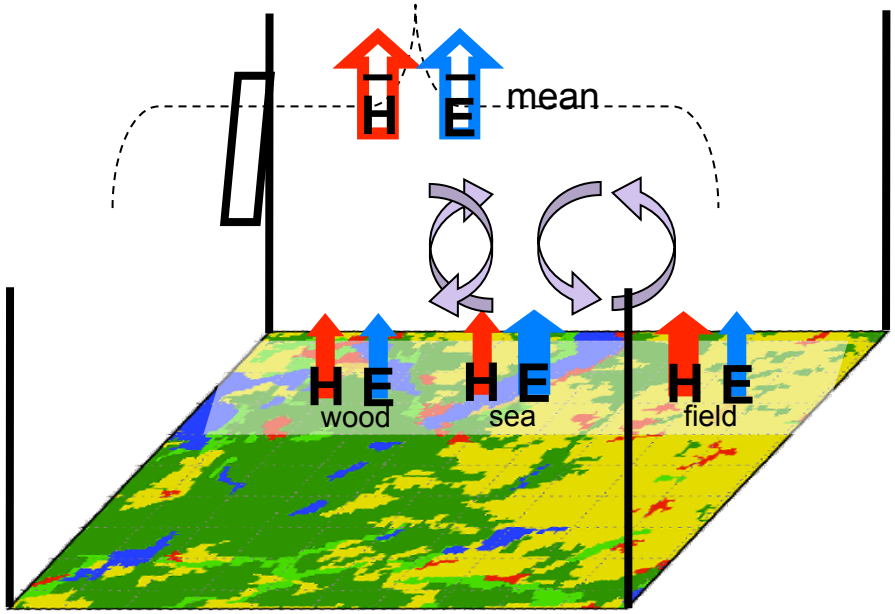


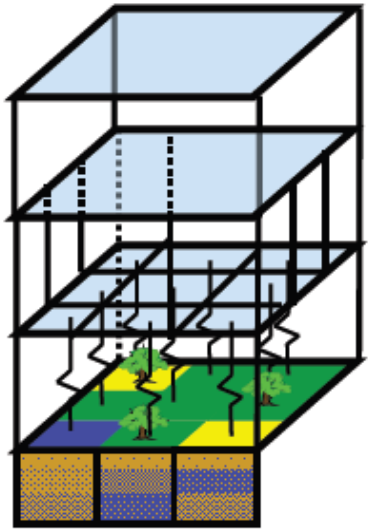
Schween, Crewell et al., 2010

Modeling strategy coordinated by a cross-cutting group and a central service project (phase 2)



Scale consistent two-way coupling of land surface and atmosphere



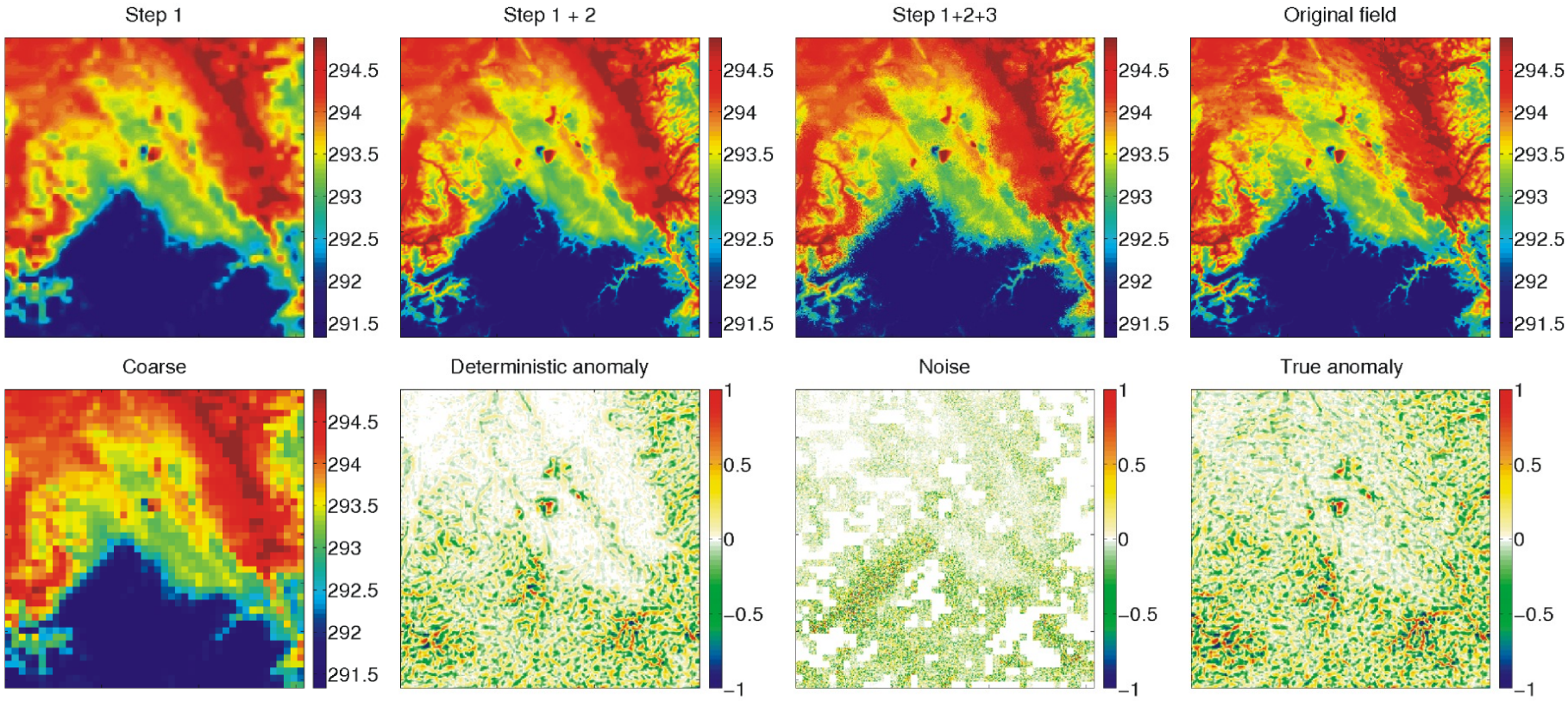


- Aggregation effects because of simplified averaging laws
- Dynamic effects because of induced atmospheric circulation

(Schomburg et al. 2010)

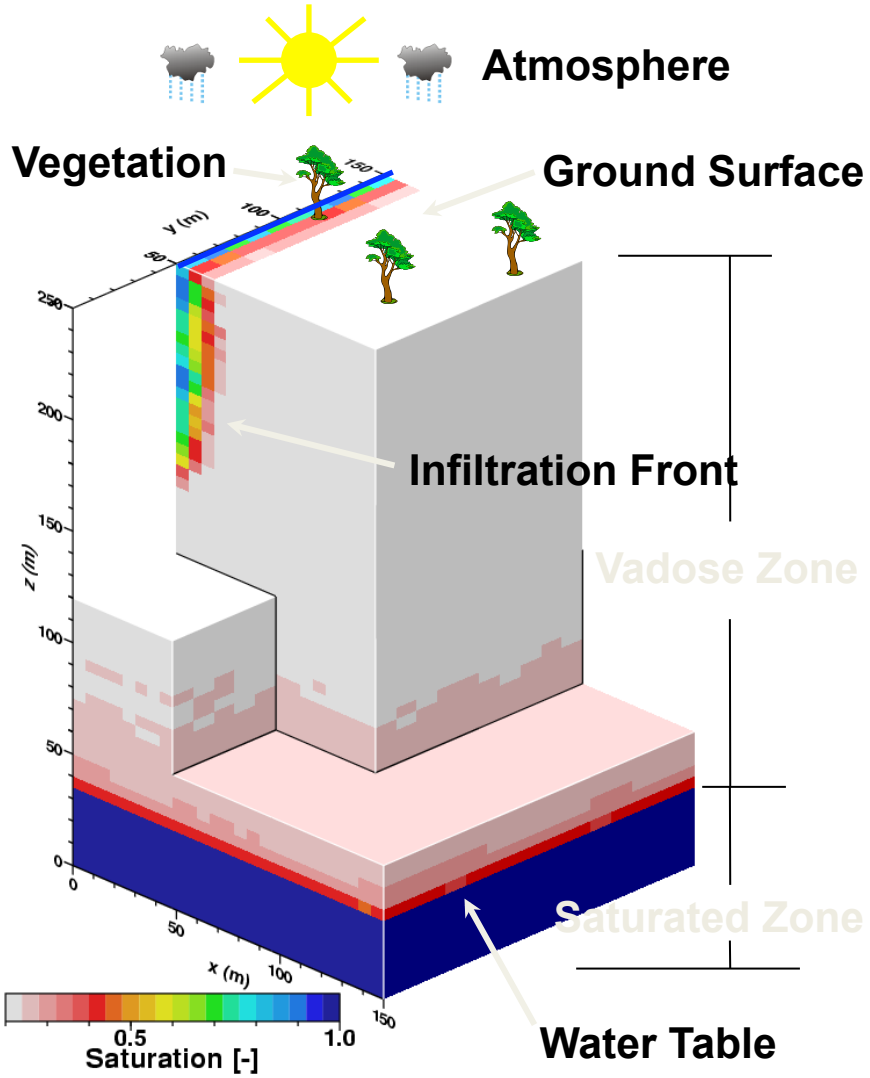
Downscaling of atmospheric variables

- Spline smoothing of the field
- Deterministic downscaling based on various rules (topography, land use)
- Addition of spatially correlated (structured) noise (Schomburg et al. 2010)



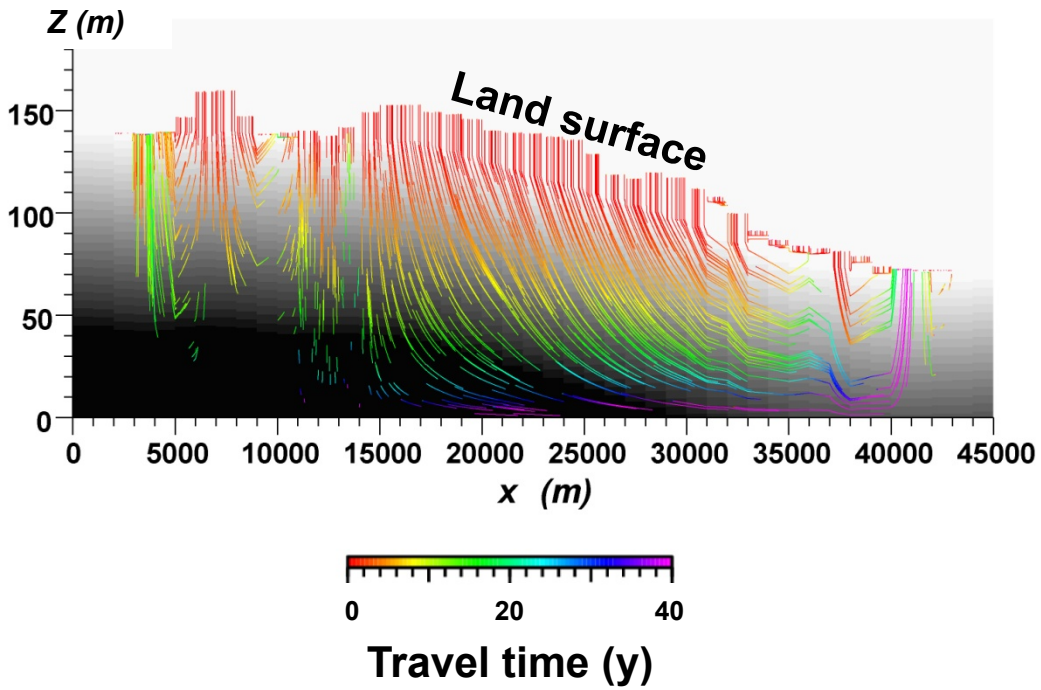
Integrated, parallel simulation platform ParFlow-CLM

- **3D** variably saturated subsurface **flow** and E transport (Jones & Woodward, 2001; Kollet et al., 2009)
- Integrated land surface and also atmospheric model (e.g., Kollet & Maxwell, 2008)
- Integrated **overland flow** (Kollet & Maxwell, 2006; Maxwell & Kollet, 2008; Frei et al., 2009)
- Efficient multigrid preconditioned **linear and nonlinear solvers**
- **Parallel**; **designed for HPC** which enables large-scale, high-resolution simulations

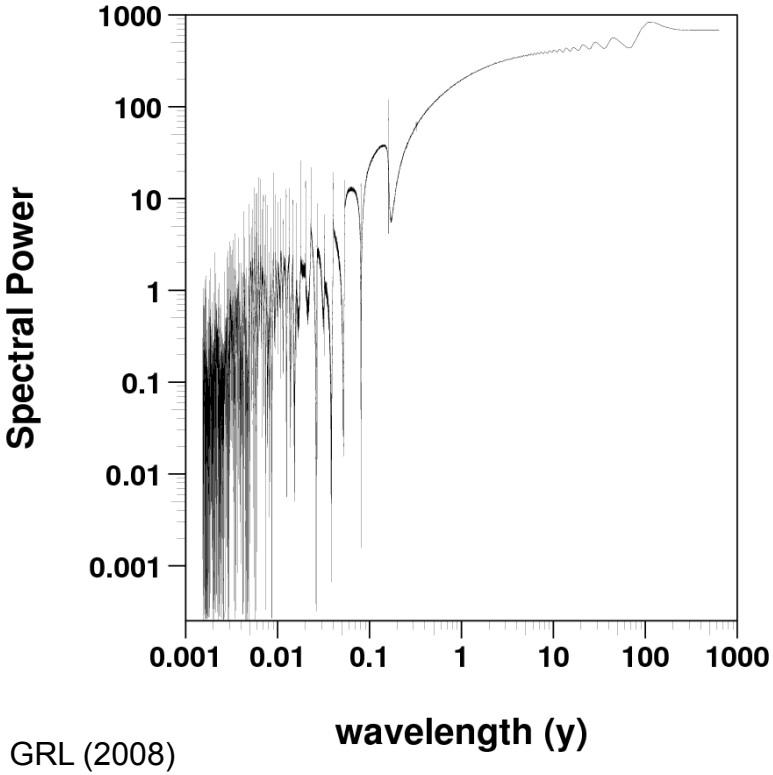


Simulation of pathways and residence time distributions is able to reproduce fractal scaling

Pathways

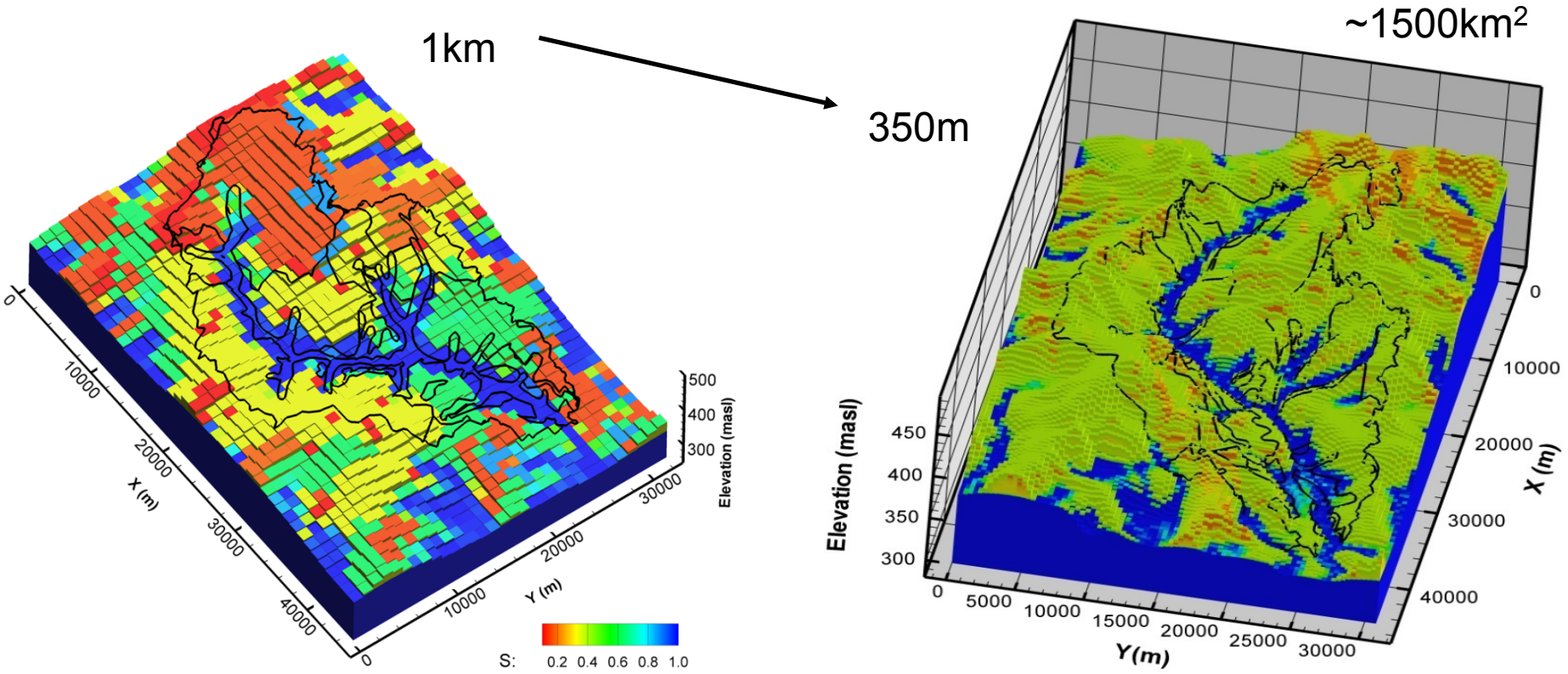


Residence Times



Kollet & Maxwell, GRL (2008)

Increasing resolution results in more realistic soil moisture fields: Little Washita, OK, USA



Kollet & Maxwell, WRR (2008)

High resolution atmospheric modelling and data assimilation

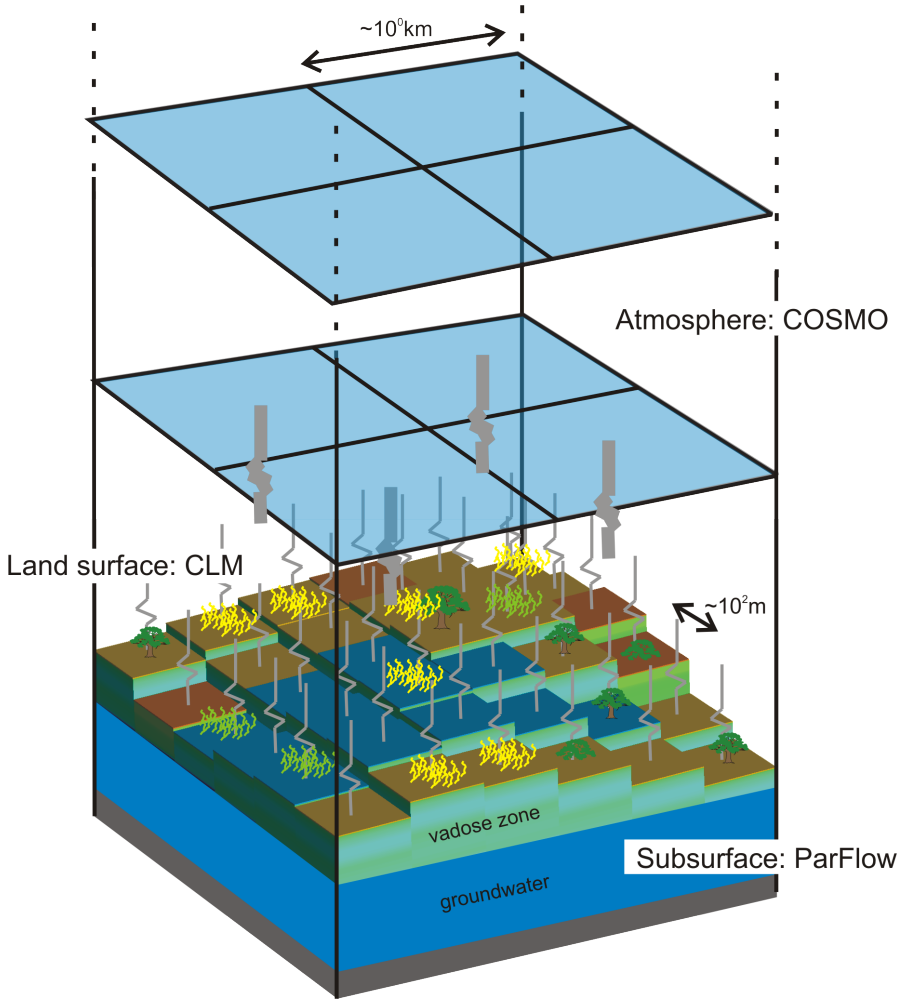
High resolution modelling

- **Coupled LES-CLM** modelling including vegetation
- COSMO-NRW: **operational COSMO** model runs with **1km resolution**

Ensemble Kalman filter

- for data assimilation of COSMO-NRW (Data Assimilation Research Testbed (DART))
- for inversion of hydrological parameter of CLM-ParFlow

COSMO-CLM-ParFlow Coupling

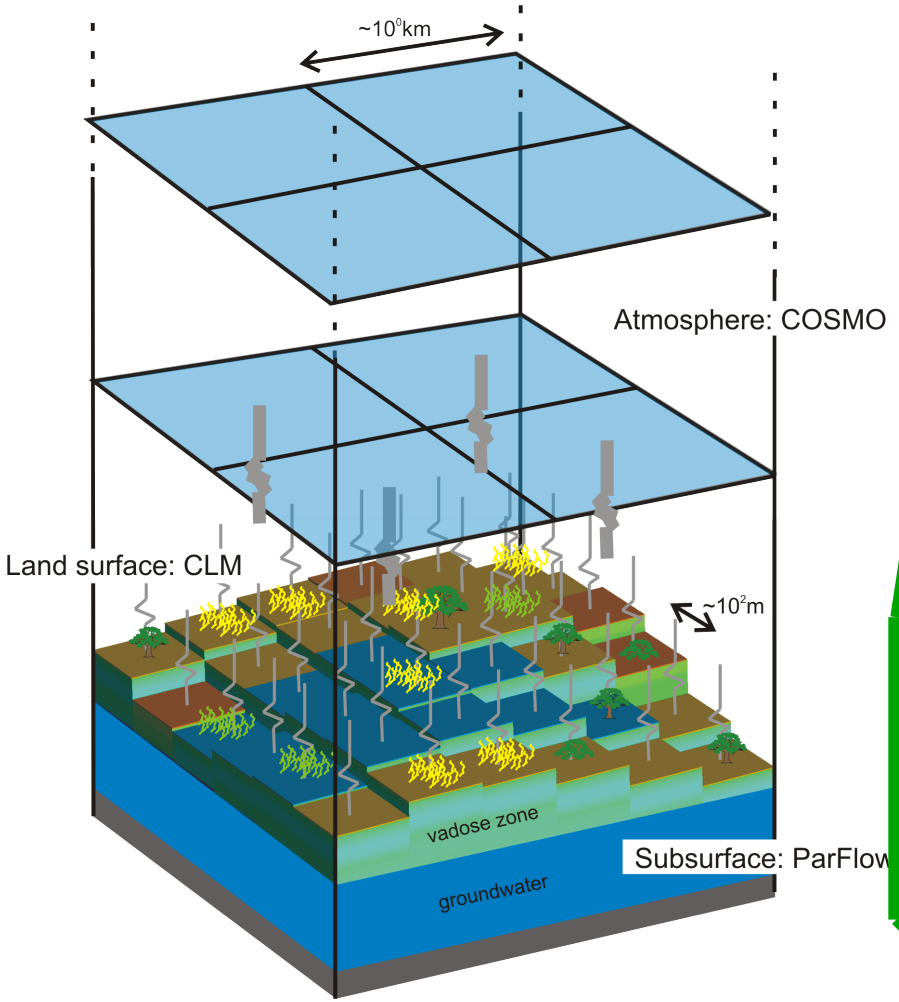


COSMO-CLM interactions, regulated by a **coupler** including:

-Mosaic approach
- Deterministic downscaling (topography, pressure)
- CO_2 Fluxes (soil respiration, soil storage)
- etc…

In order to **include Structures and patterns influences**

Improvements of CLM parameterizations



- Implement Additional PFT (forest,…)

- Time dependent plant physiological parameters (crop modelling)

- Root parameterisation

- New parameterisation of soil evaporation

- Parameterisation of soil hydraulic & vegetation properties

Summary and Outlook

- TR32 project focuses on **exchange soil-atmosphere** for momentum, moisture, energy and CO_2…

  … at all scales

- TR32 **cumulates expertise** in hydrology, crop system processes, soil physics, meteorology and land surface interactions

- TR32 develops a **model suite - COSMO-CLM-ParFlow** – in order to centralize the improvements of soil-atmosphere exchange within the project…

  … nevertheless we are **open community**

- Further information: **www.tr32.de**