Karlsruher Institut für Technologie

KIT-Campus Alpin
IMK-IFU: Atmospheric Environmental Research

TERENO
Terrestrial Environmental Observatories

Coupled Simulation of Groundwater-Soil-Atmosphere Interaction for the TERENO Pre-Alpine Region (Topic 4)

Benjamin Fersch, S. Wagner, M. Mauder, H. Kunstmann

REKLIM
Helmholtz-Verbund Regionale Klimaänderungen

Reklim Workshop, Bad Honnef, 16.-18. April 2013

Institute for Meteorology and Climate Research (IMK-IFU), Garmisch-Partenkirchen, Germany

Motivation

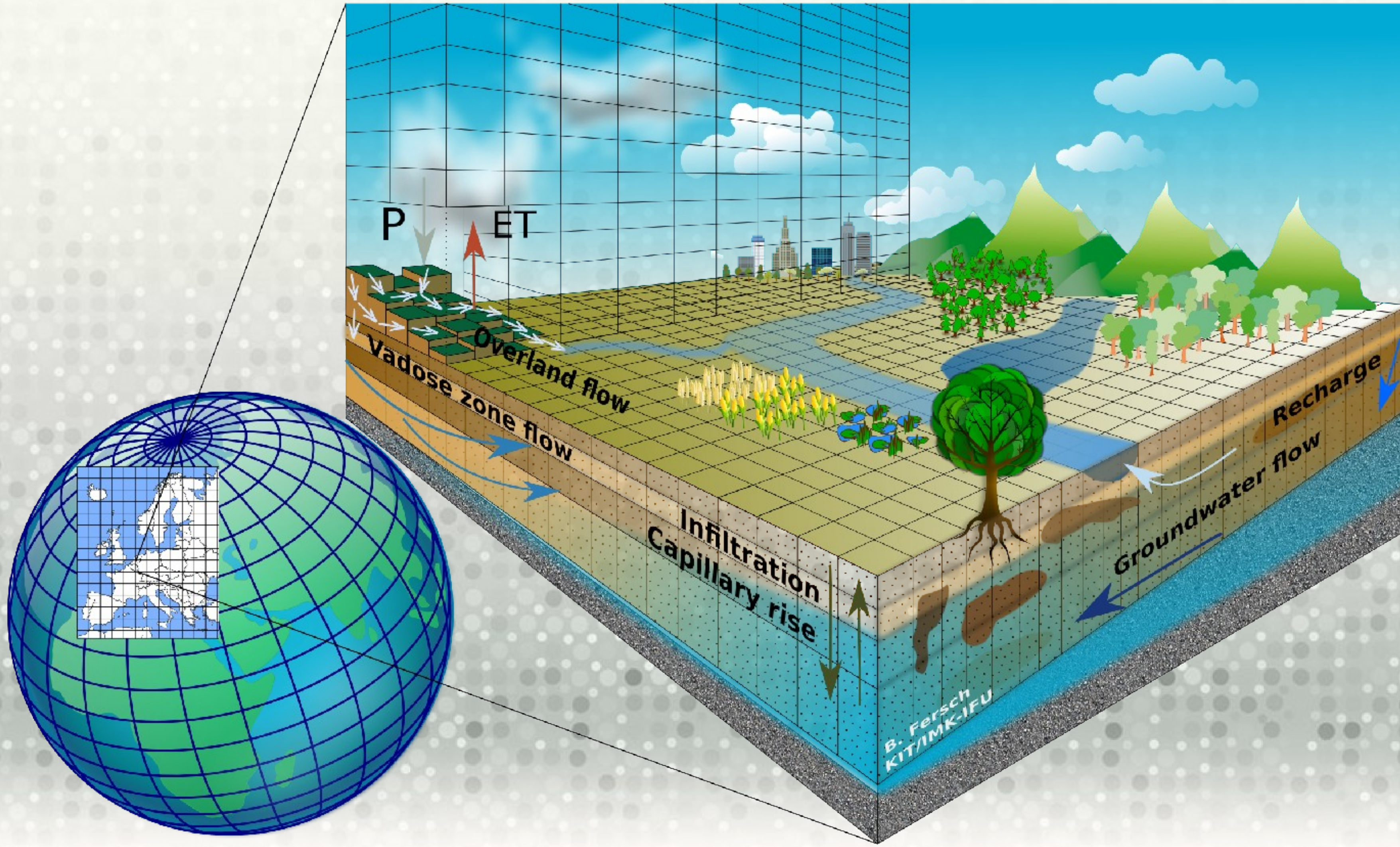
- Closed expression of the regional water balance in dynamic model system
  - Regional atmospheric modeling studies focus usually on the prediction of temperature and precipitation
  - Coupling to hydrological models is typically realized in a one way mode and by using bias correction
  - Such approaches violate the closure of the water balance of the full system from the subsurface via the surface to the atmosphere

Motivation

Karlsruher Institut für Technologie

- Towards fully coupled cross-compartment hydrological-atmospheric model systems
    - Consider effects of lateral redistribution of surface water
        - Reinfiltration
        - Runoff routing
    - Account for subsurface processes of the vadose and the phreatic zone
        - Percolation to the groundwater
        - Capillary rise to root layers
        - Horizontal transport
    - Provide feedback capability from the subsurface via the surface to the atmospheric model and vice versa

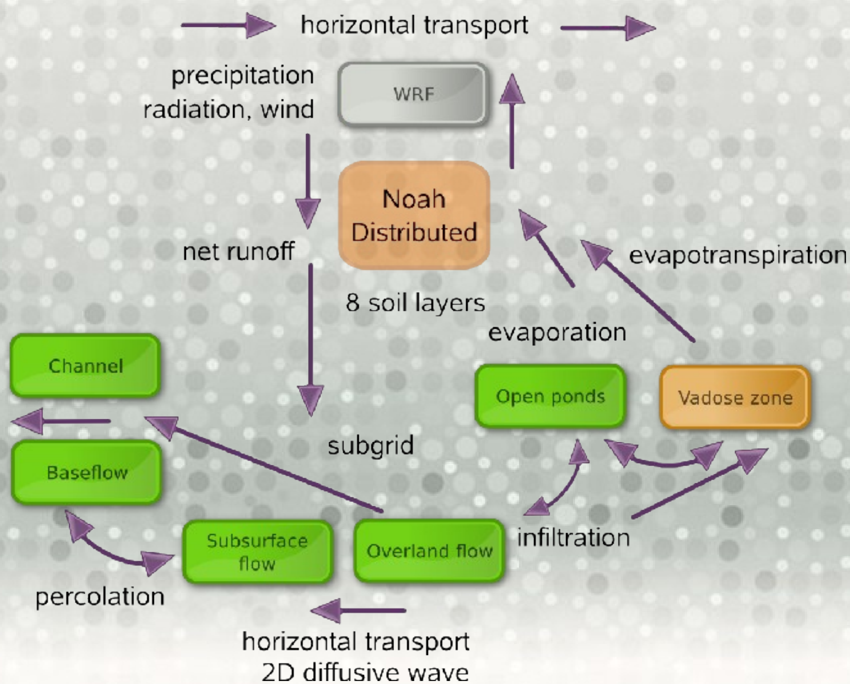
Coupled Atmosphere-Hydrology Model System

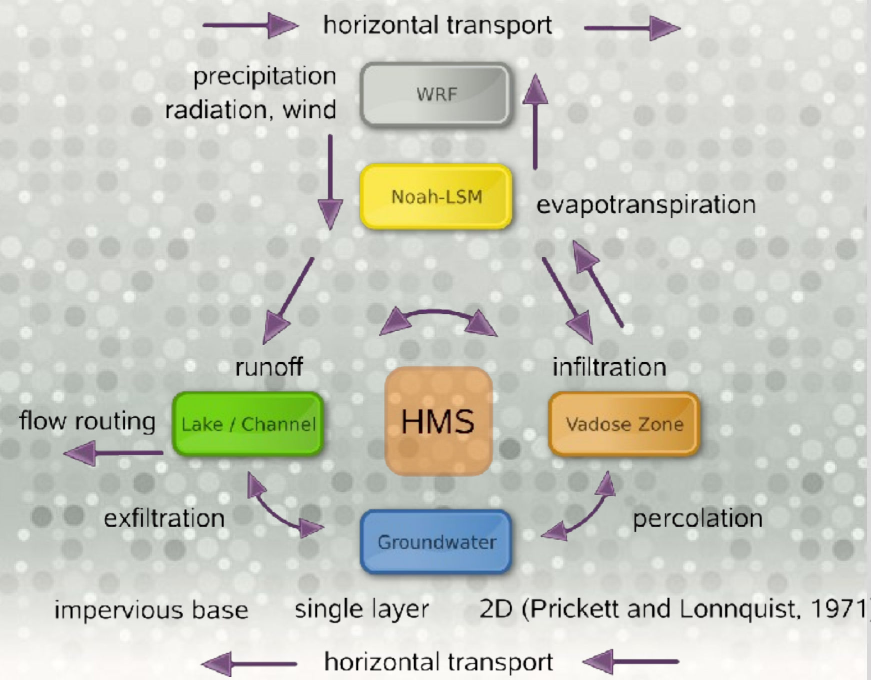


Coupled Atmosphere-Hydrology Model Systems

KIT
Karlsruher Institut für Technologie

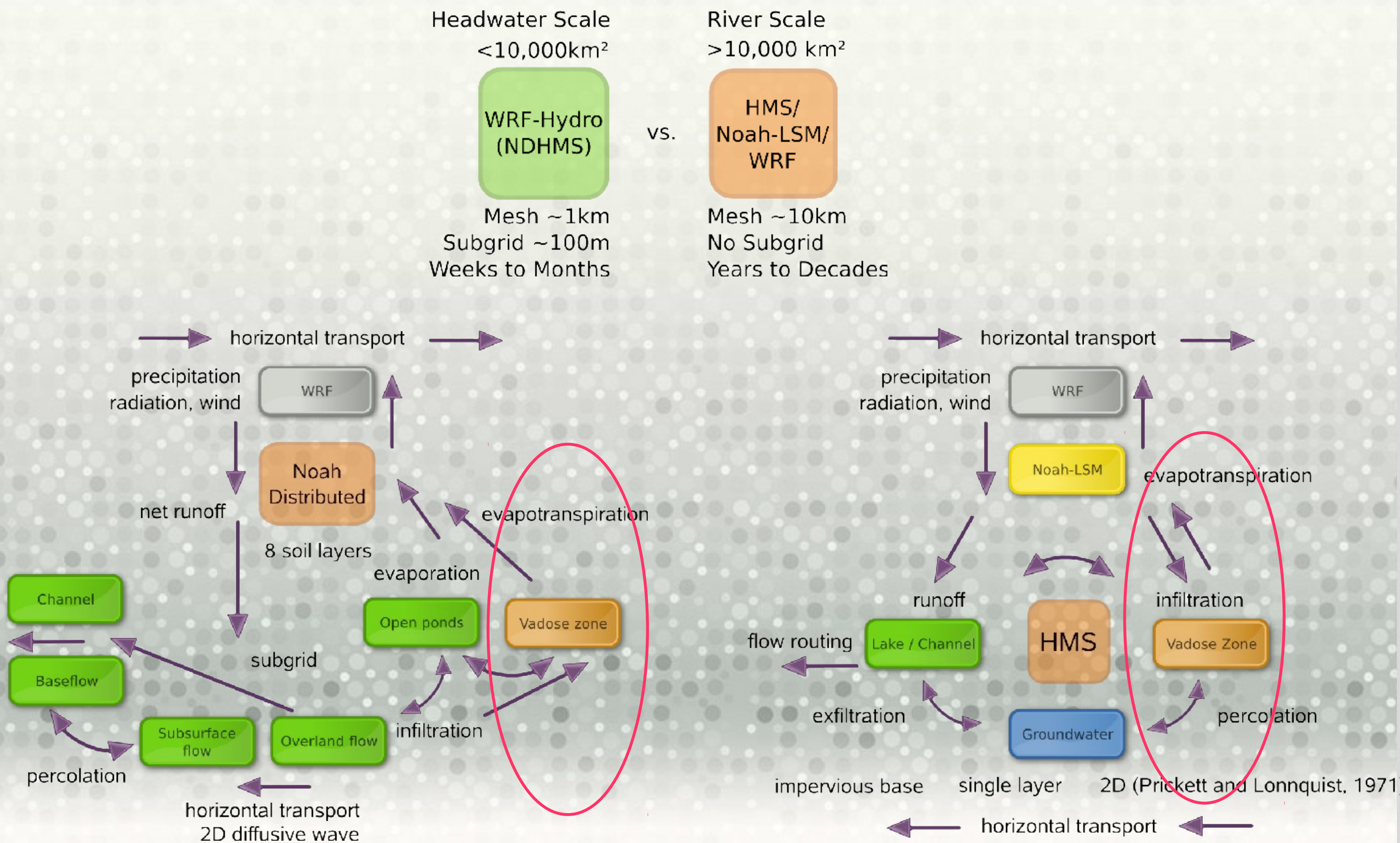
Headwater Scale <10,000km²		River Scale >10,000 km²
WRF-Hydro (NDHMS)	vs.	HMS/ Noah-LSM/ WRF
Mesh ~1km		Mesh ~10km
Subgrid ~100m		No Subgrid
Weeks to Months		Years to Decades





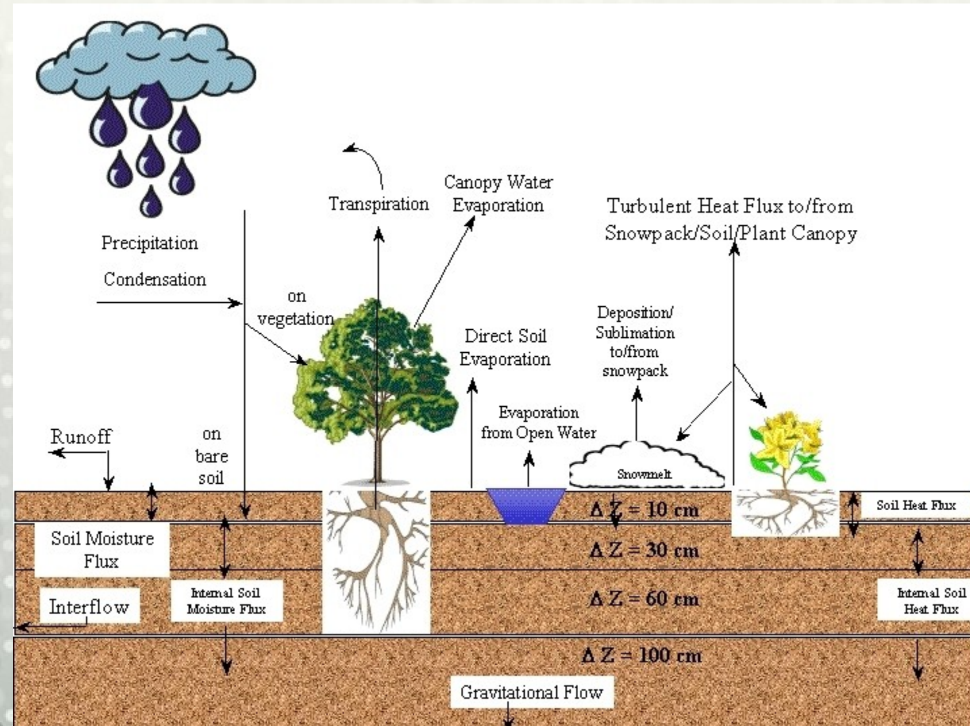
Coupled Atmosphere-Hydrology Model Systems

KIT Karlsruher Institut für Technologie



Common Land-Surface-Description in Regional Atmospheric Models

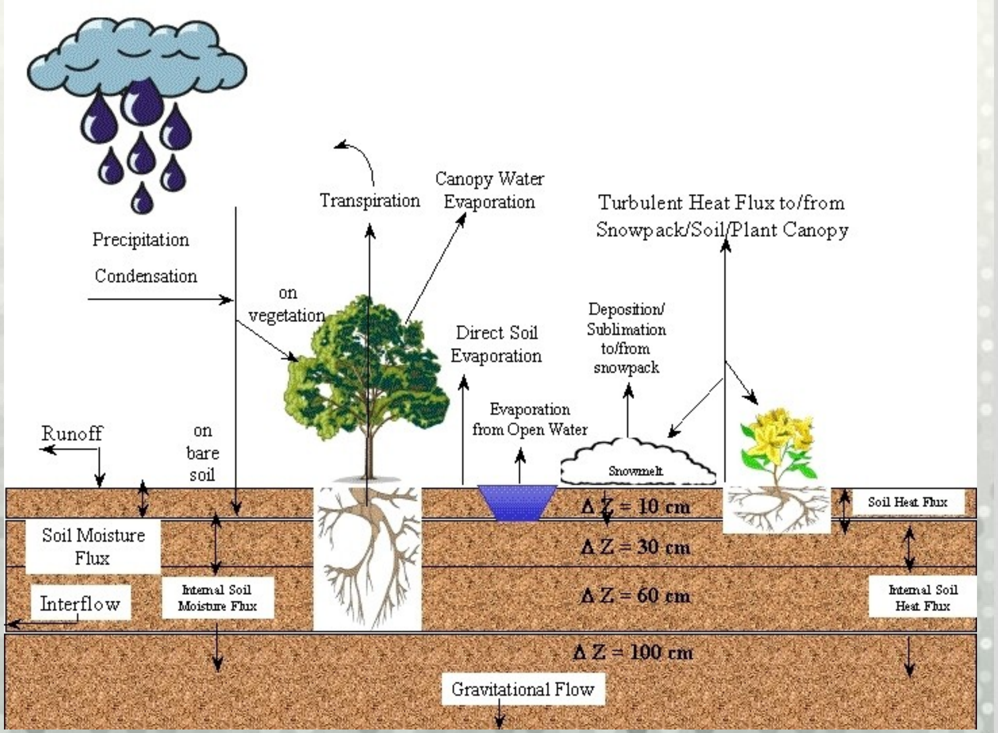
- Standard column approach in LSMs
  - Only vertical transport of moisture and energy is considered
  - Infiltration excess and bottom drainage terms act as sink term with no possibility of returning
  - Lower model boundary is defined by a downward gravitation driven flux



(Unified Noah / OSU Land Surface Model © NCAR)

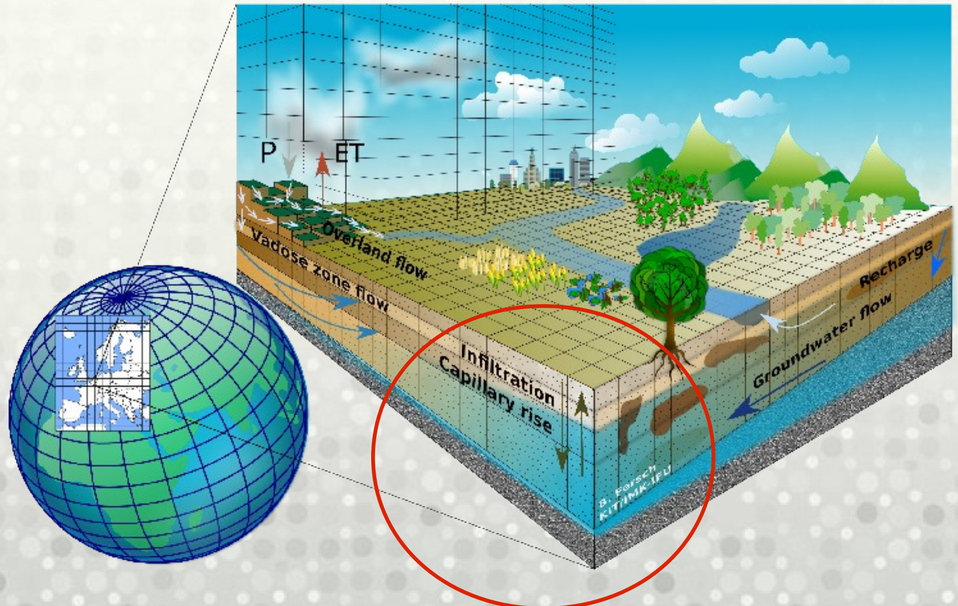
Common Land-Surface-Description in Regional Atmospheric Models

- Standard column approach in LSMs
  - No **lateral redistribution** of surface and subsurface water in the LSM
  - No **interaction** between **unsaturated** and **saturated** zone
  - **Mutual non-linear interaction of a closed water cycle cannot emerge**



(Unified Noah / OSU Land Surface Model © NCAR)

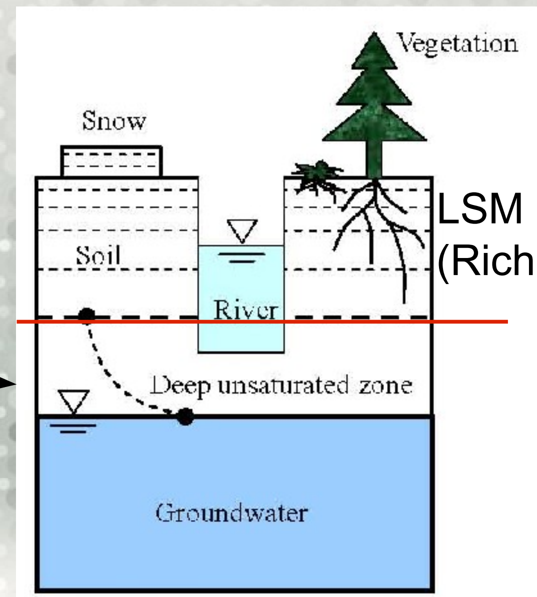
Coupled atmosphere-hydrology model systems



Description of moisture transport

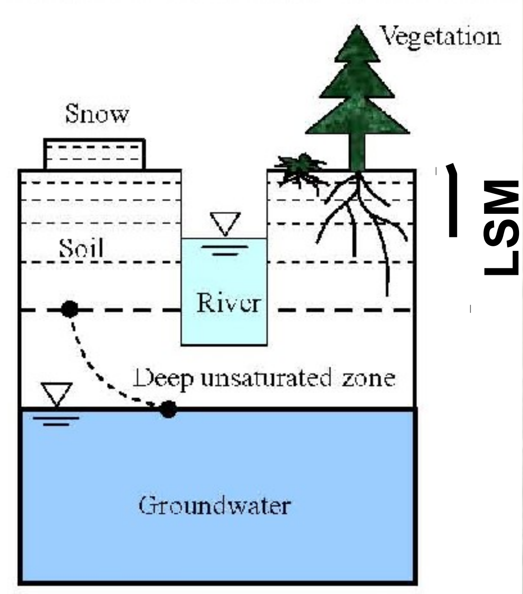
LSM
(Richard's eq.)

GW-Head
Variable lower boundary



Groundwater Coupling Approach

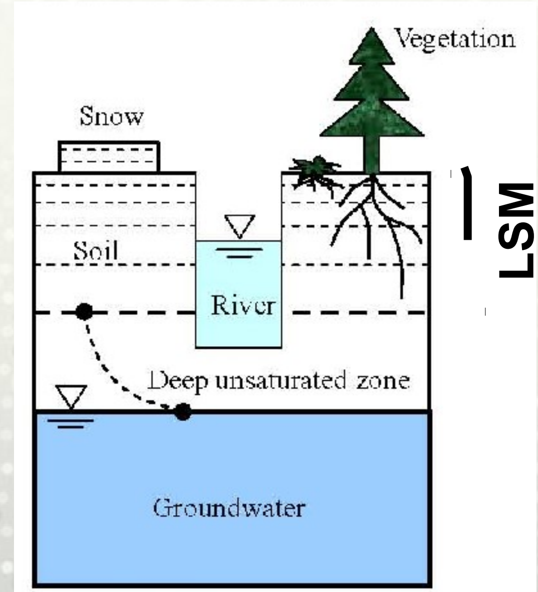
- Approach 1: Richard's equation with fixed-head boundary condition (based on Zeng et al. (2009), De Rooij (2010)
  - Free drainage boundary condition of the LSM is replaced by bottom boundary condition which assumes an equilibrium soil moisture distribution of the deep unsaturated zone
  - The new bottom boundary condition is calculated by specifying the hydraulic head at the bottom of the LSM
  - New boundary condition realized with additional layer below the bottom of the Noahl-LSM
  - Soil moisture content of additional layer depends on the distance to the hydraulic head
    - fully saturated, hydraulic head above or equal layer
    - partly saturated, hydraulic head within layer
    - unsaturated, hydraulic head below layer

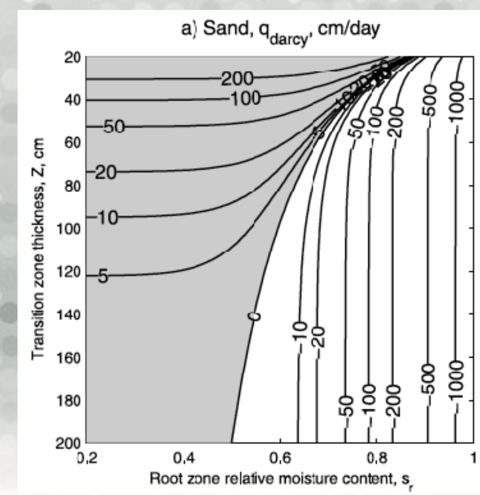


Groundwater Coupling Approach

Karlsruher Institut für Technologie

- Approach 2: Darcy flux boundary condition (based on Bogaart et al. 2008)
  - Assumes a quasi steady-state moisture profile between groundwater head and the lowest soil layer of the LSM
  - Darcy equation is used to describe flow through this transition zone depending on the relative saturation at the bottom of the LSM and on the thickness of the transition zone
  - Parametrization that approximates net Darcy flux q_{darcy} for different thicknesses of the transition zone and different values of saturation for the lowest LSM soil layer
  - Approximation available for the 12 soil classes of Clapp & Hornberger (1978)

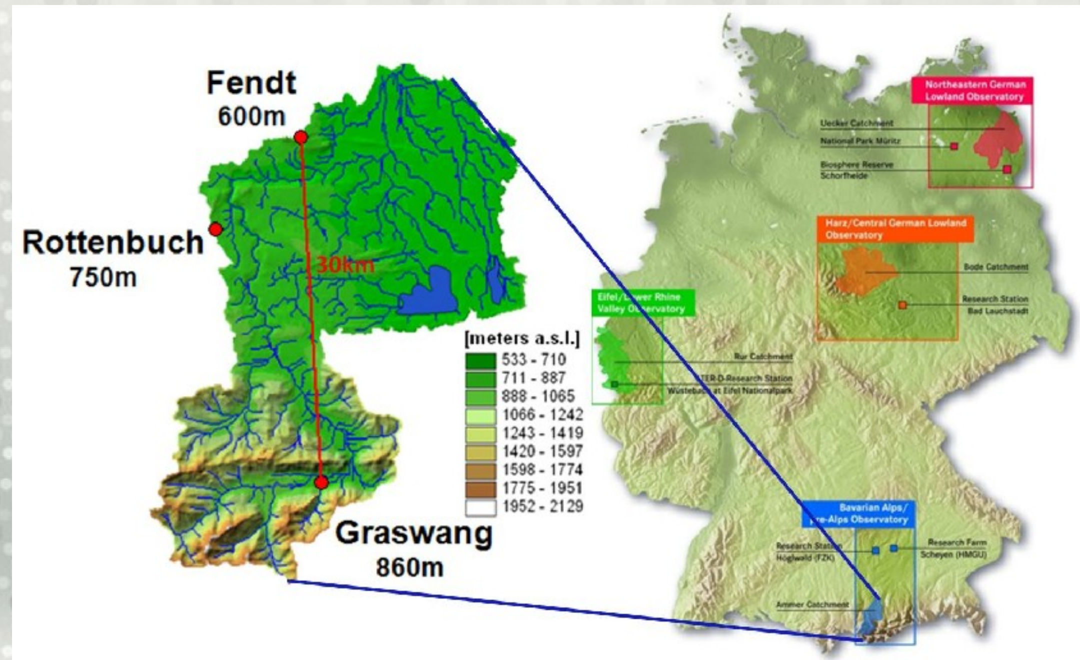




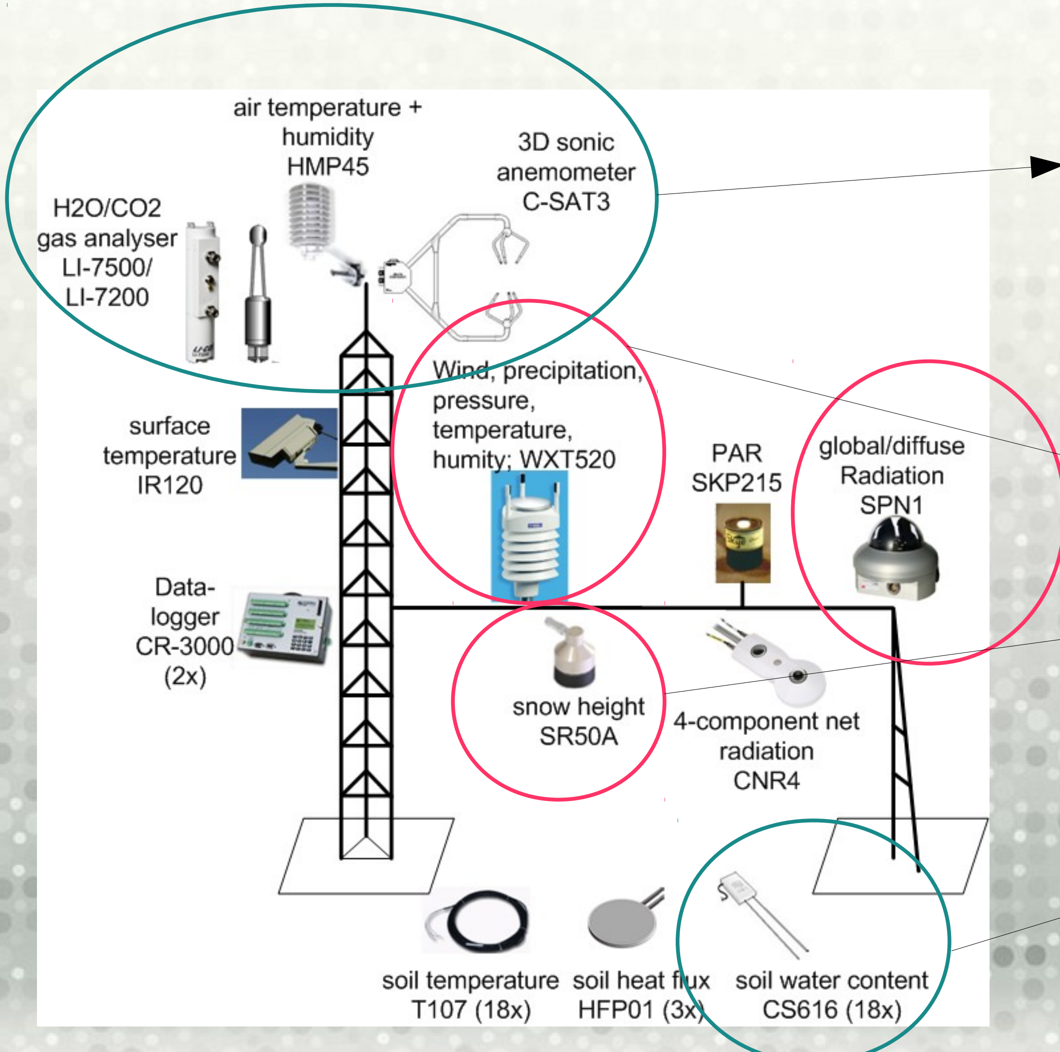
Proof of Concept – 1D Groundwater Coupling Study with the Noah-LSM and TERENO DATA

Karlsruher Institut für Technologie

- The validity of the coupling approaches can hardly be analyzed in a distributed (2D) application
- 1D – stand-alone study is performed for a well measured site of the terrestrial environmental observatory (TERENO) pre-alpine
- Linder valley of the Ammer catchment
- Grassland, influenced by temporarily shallow groundwater table



Data at TERENO Climate Station Graswang



Time-series of eddy-flux evapotranspiration for evaluation

Noah-LSM stand-alone model driving

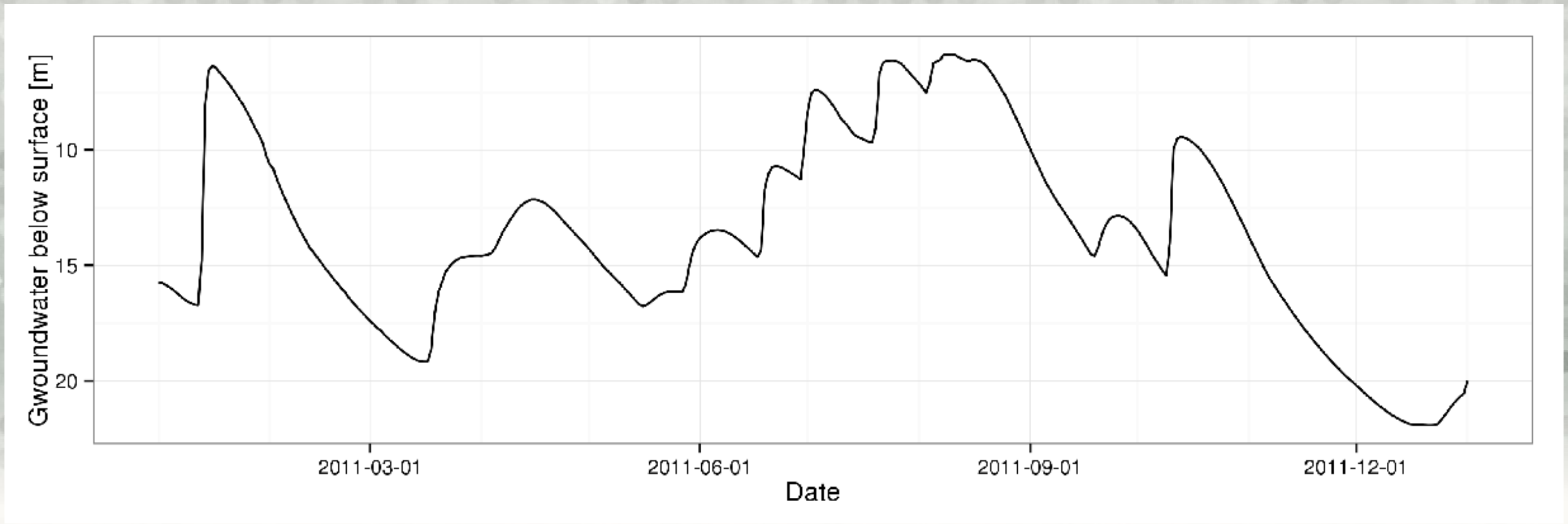
Time-series of soil-moisture for evaluation

Data Source: TERENO Site Graswang

Karlsruher Institut für Technologie

TERENO
TERRESTRIAL ENVIRONMENTAL OBSERVATORIES

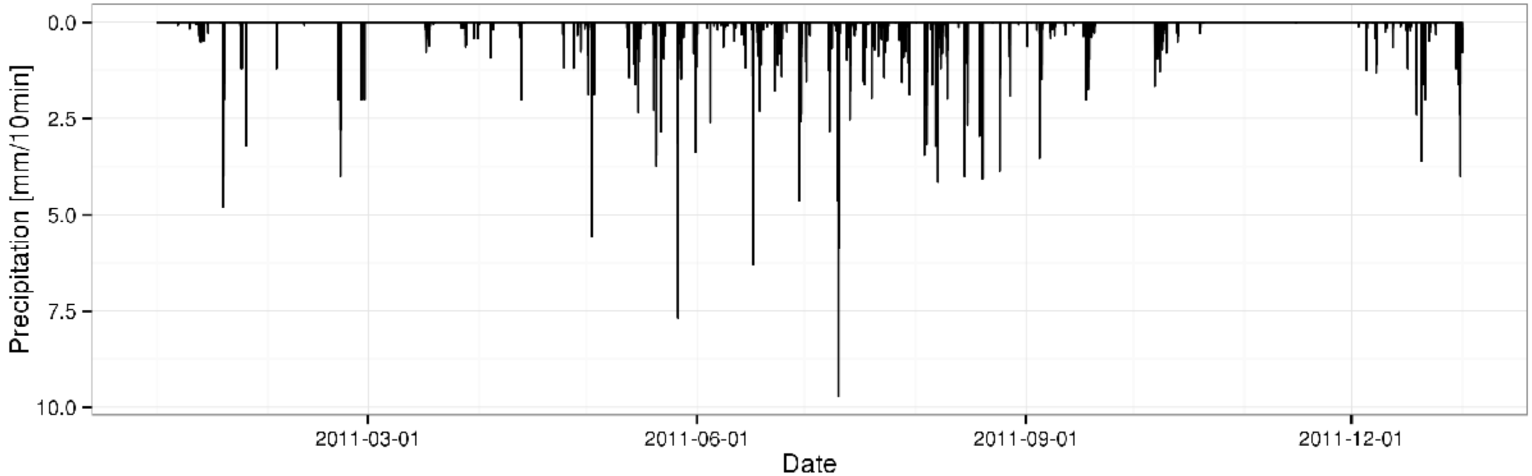
Data Source: Groundwater Head Time-Series from the Local Water Authority (WWA Weilheim)

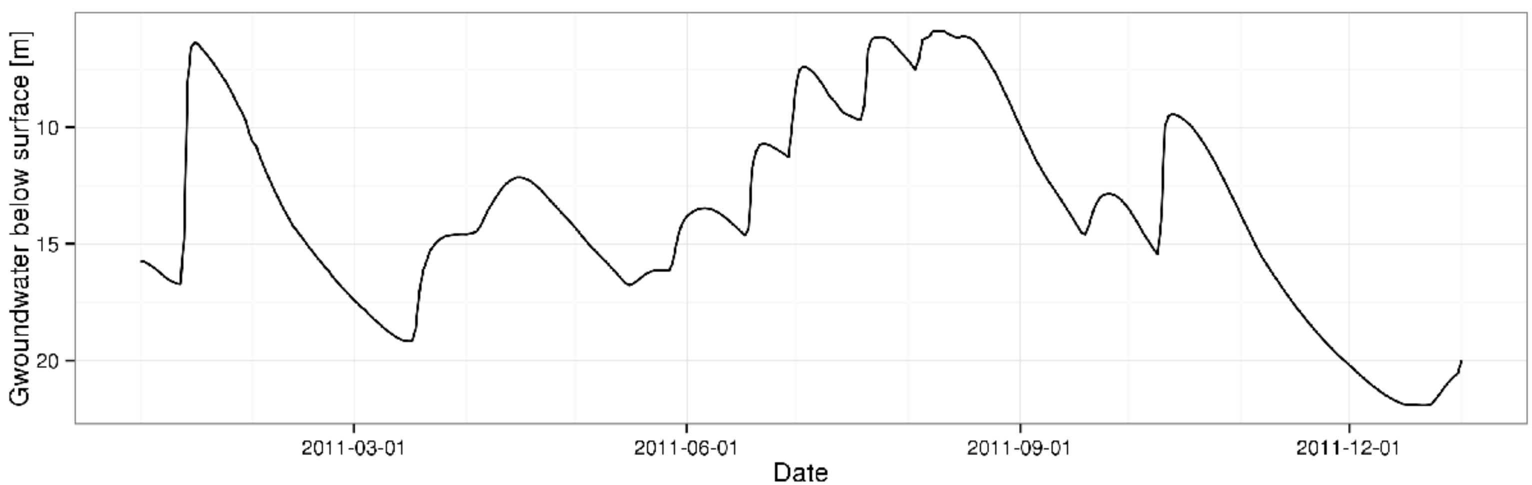


REKLIM Helmholtz-Verbund Regionale Klimaänderungen

KIT-Campus Alpin

Data Source: Groundwater Head Time-Series from the Local Water Authority (WWA Weilheim)



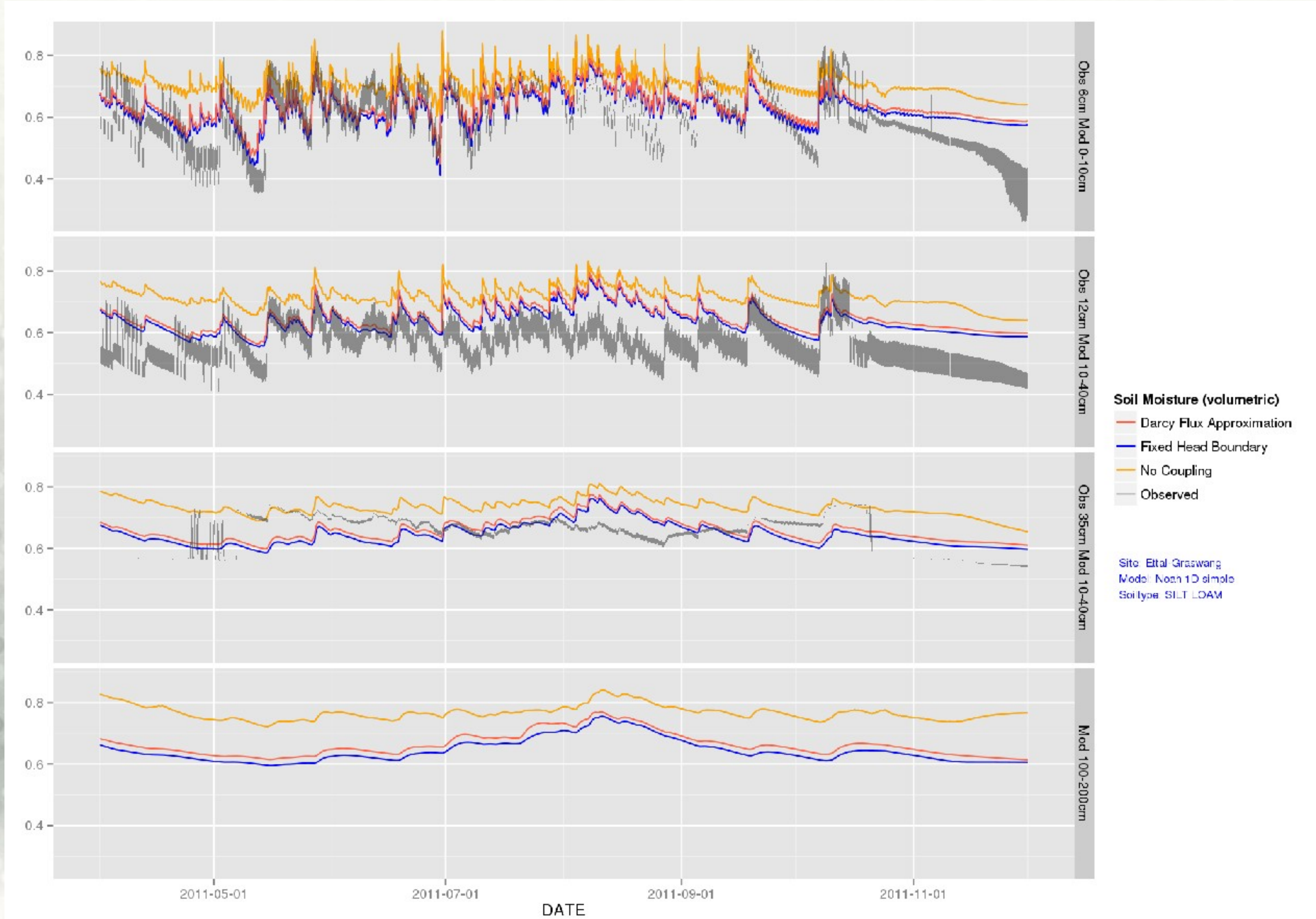


Configuration Noah-LSM for 1D Study

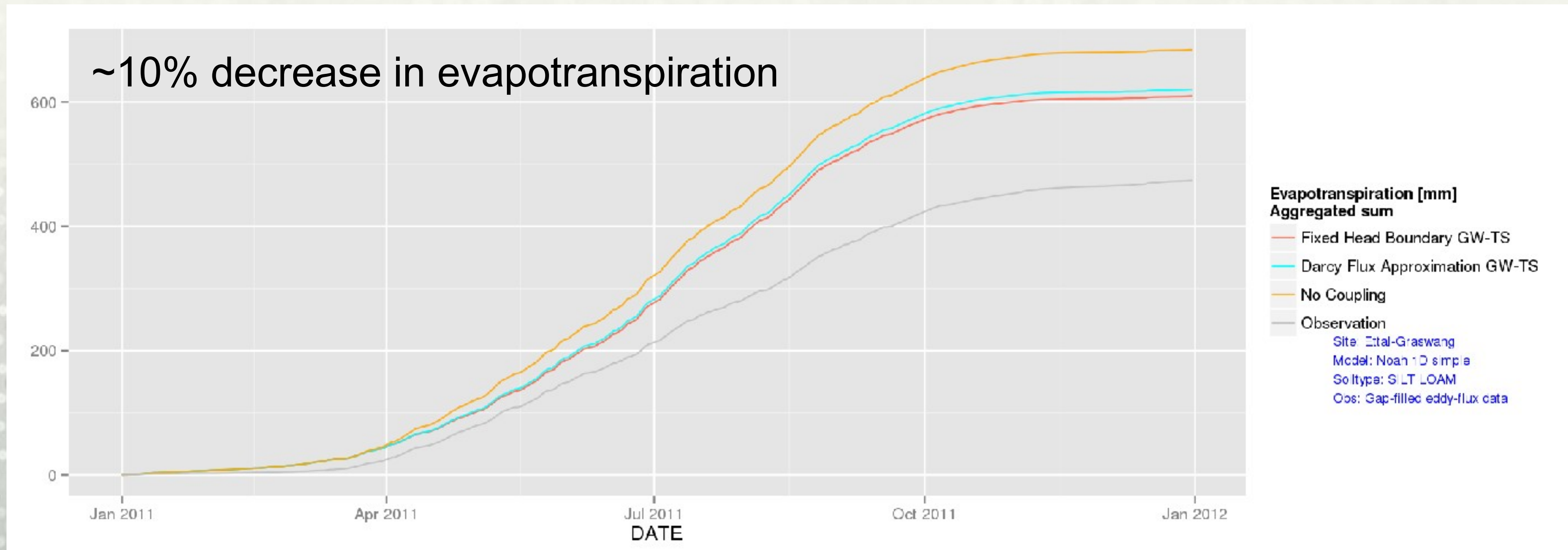
Karlsruher Institut für Technologie

- Noah-LSM 1D, simple-driver, V.3.3
- Simulation period: 2010-07-01 to 2011-12-31 (half year of spin-up)
- Simulation time-step: 10 minutes
- Soil-type 4, silt loam
- Vegetation / land-use: grassland (USGS 7, modified)
- Monthly update of albedo, LAI, vegetation fraction, and roughness length
- 4 soil layers, 0-10, 10-40, 40-100, 100-200 cm (standard setup)
- Modes: Uncoupled, fixed-head-boundary and darcy-flux coupling with time-variant and constant (-7m) groundwater head

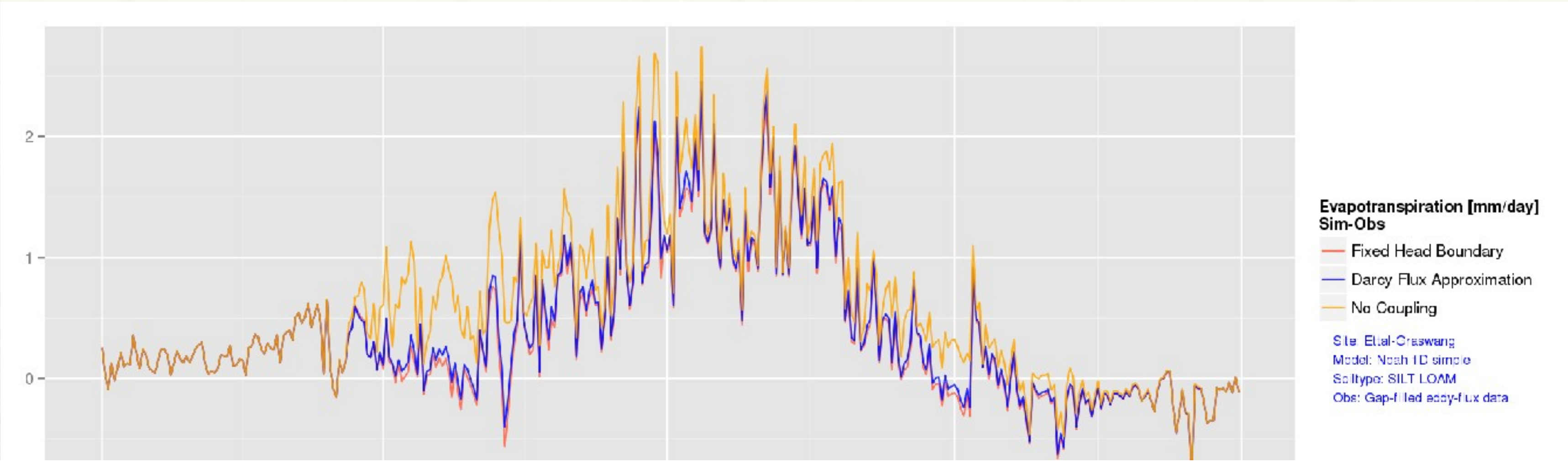
Impact of Coupling on Soil Moisture Dynamics

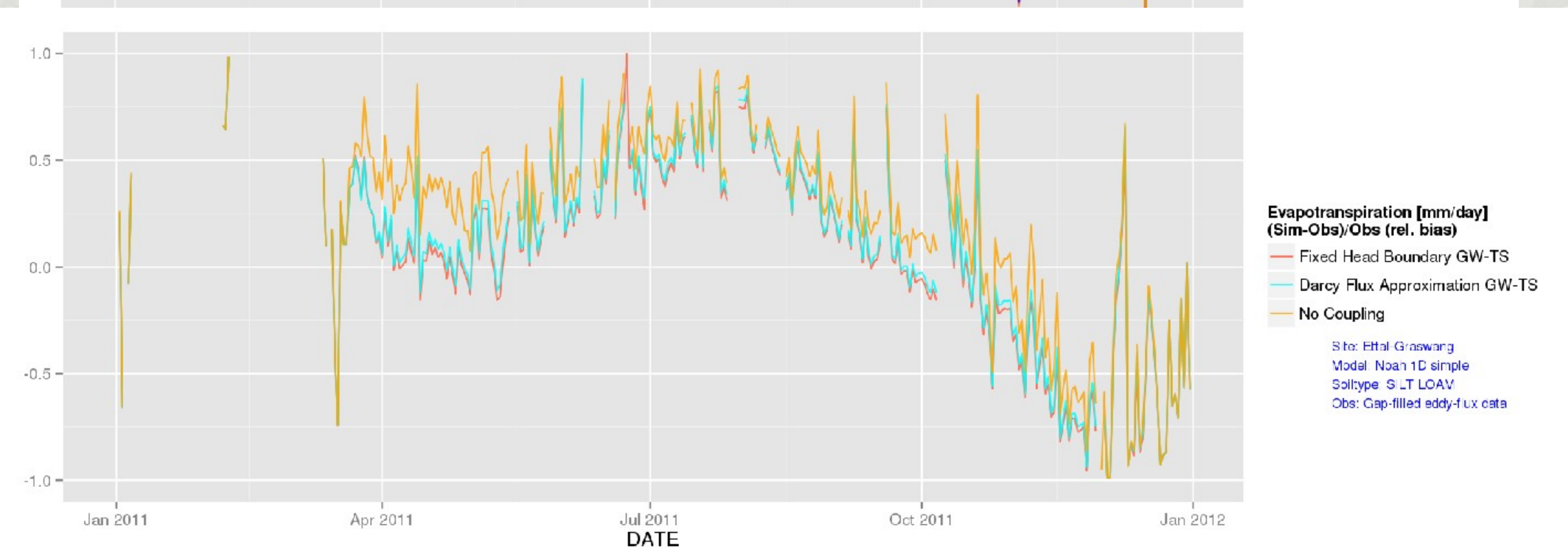


Impact of GW-Coupling on Evapotranspiration

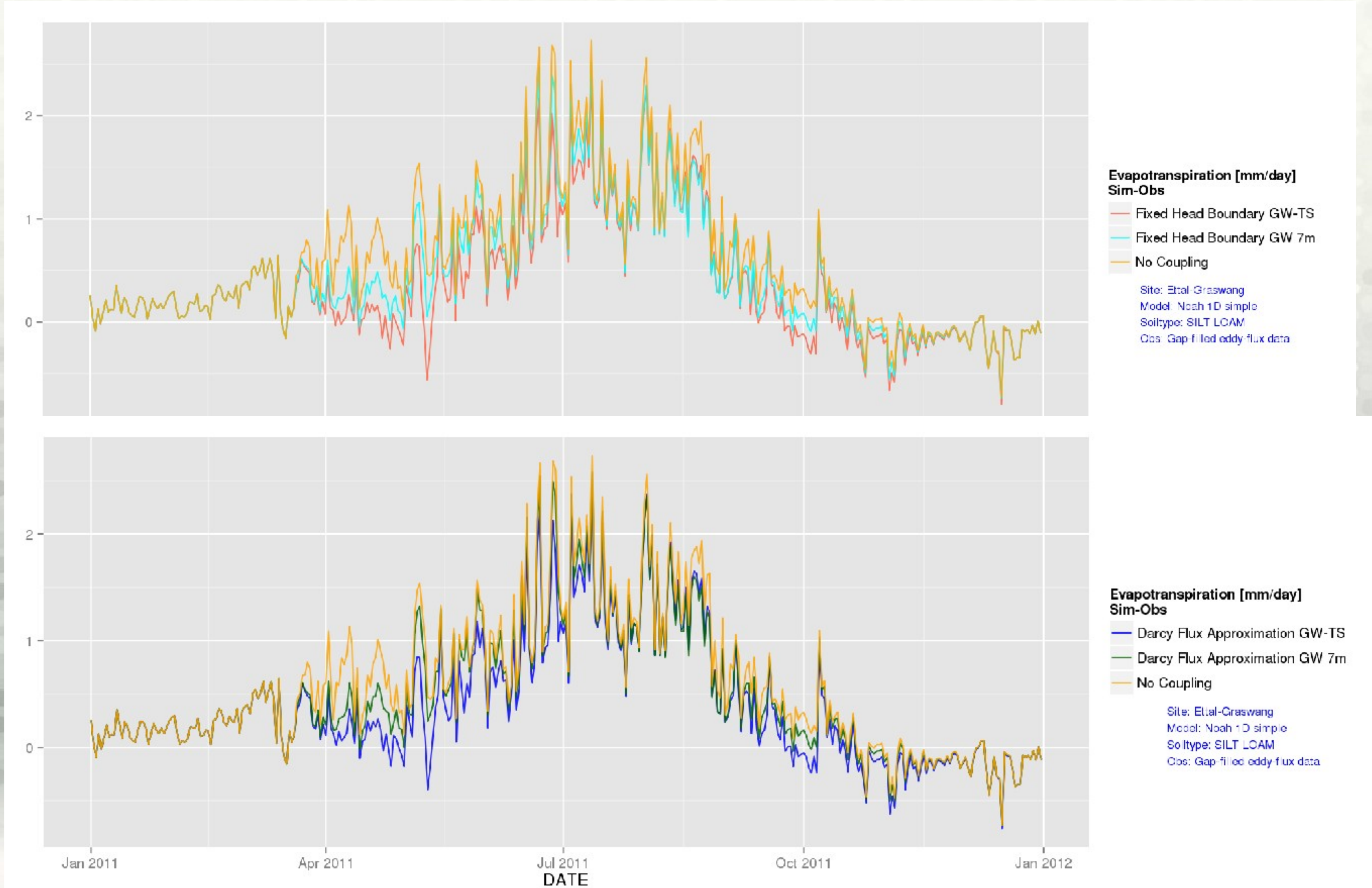


Daily Bias of Evapotranspiration

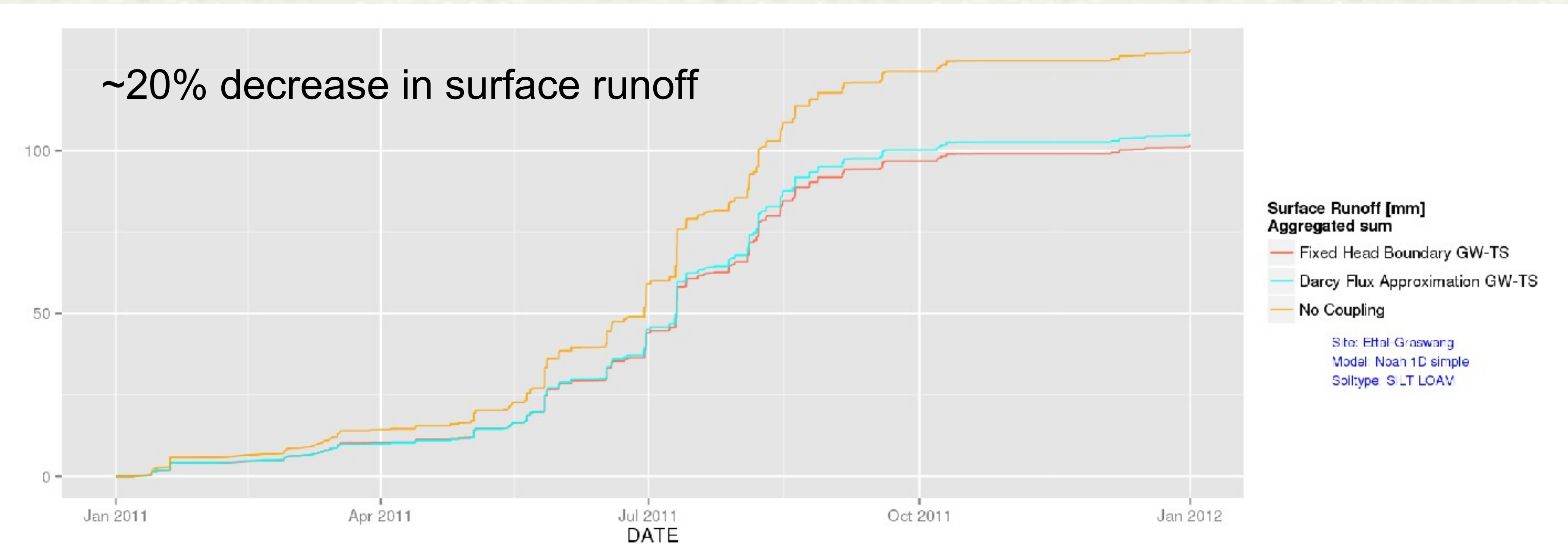




ETa, Comparison Static vs. Variable GW - Head



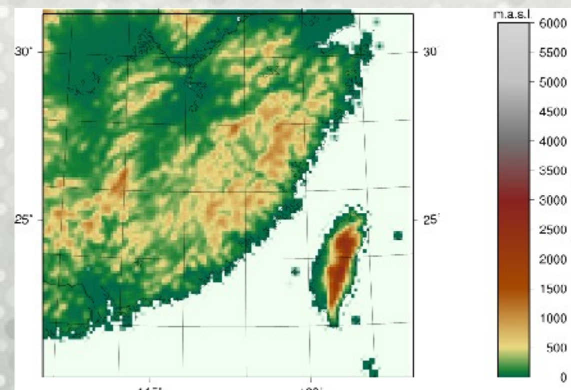
Impact of GW-Coupling on Infiltration Excess



Distributed Model Systems WRF-Hydro & WRF-HMS

Karlsruher Institut für Technologie

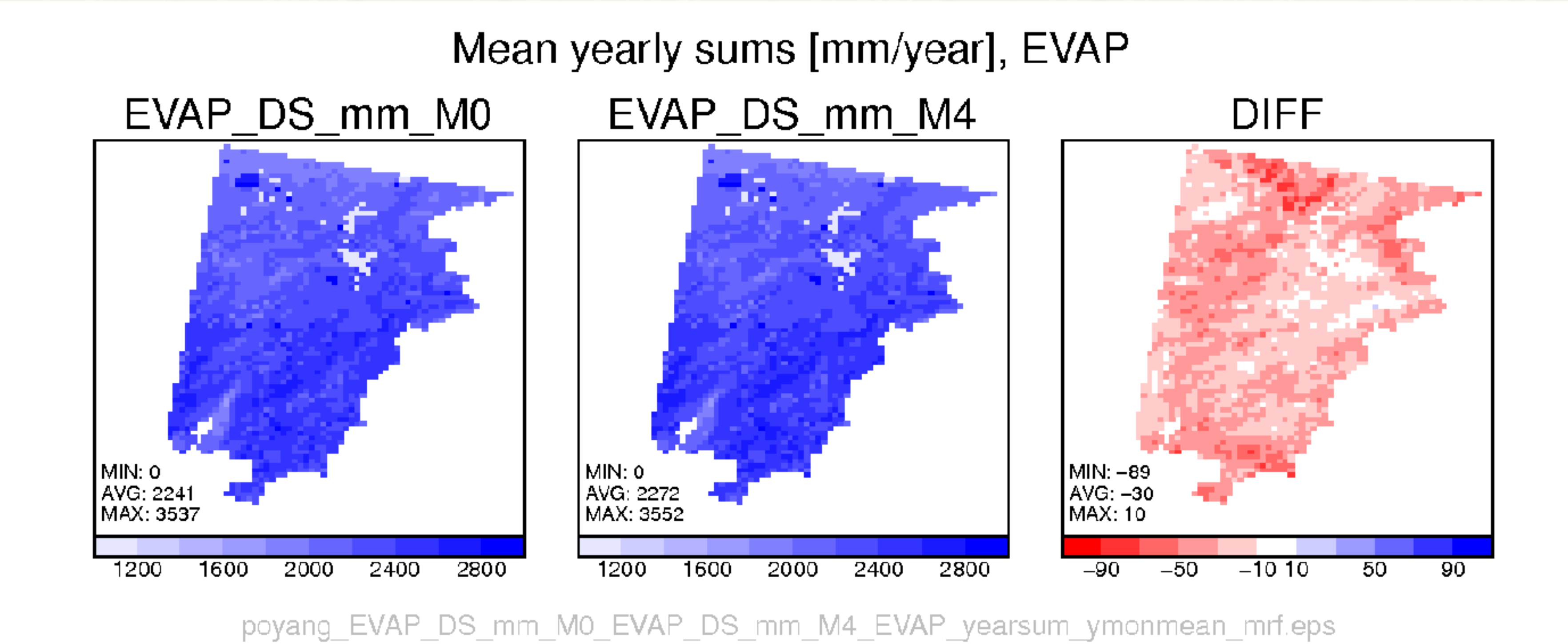
Headwater Scale <10,000km²		River Scale >10,000 km²
WRF-Hydro (NDHMS)	vs.	HMS/ Noah-LSM/ WRF
Mesh ~1km Subgrid ~100m Weeks to Months		Mesh ~10km No Subgrid Years to Decades



Process Study and Forecast Application

Climate and Long Term Application

Distributed Application, HMS-WRF, Poyang Lake Region, China



Difference in potential evaporation for groundwater coupled HMS-WRF simulation.

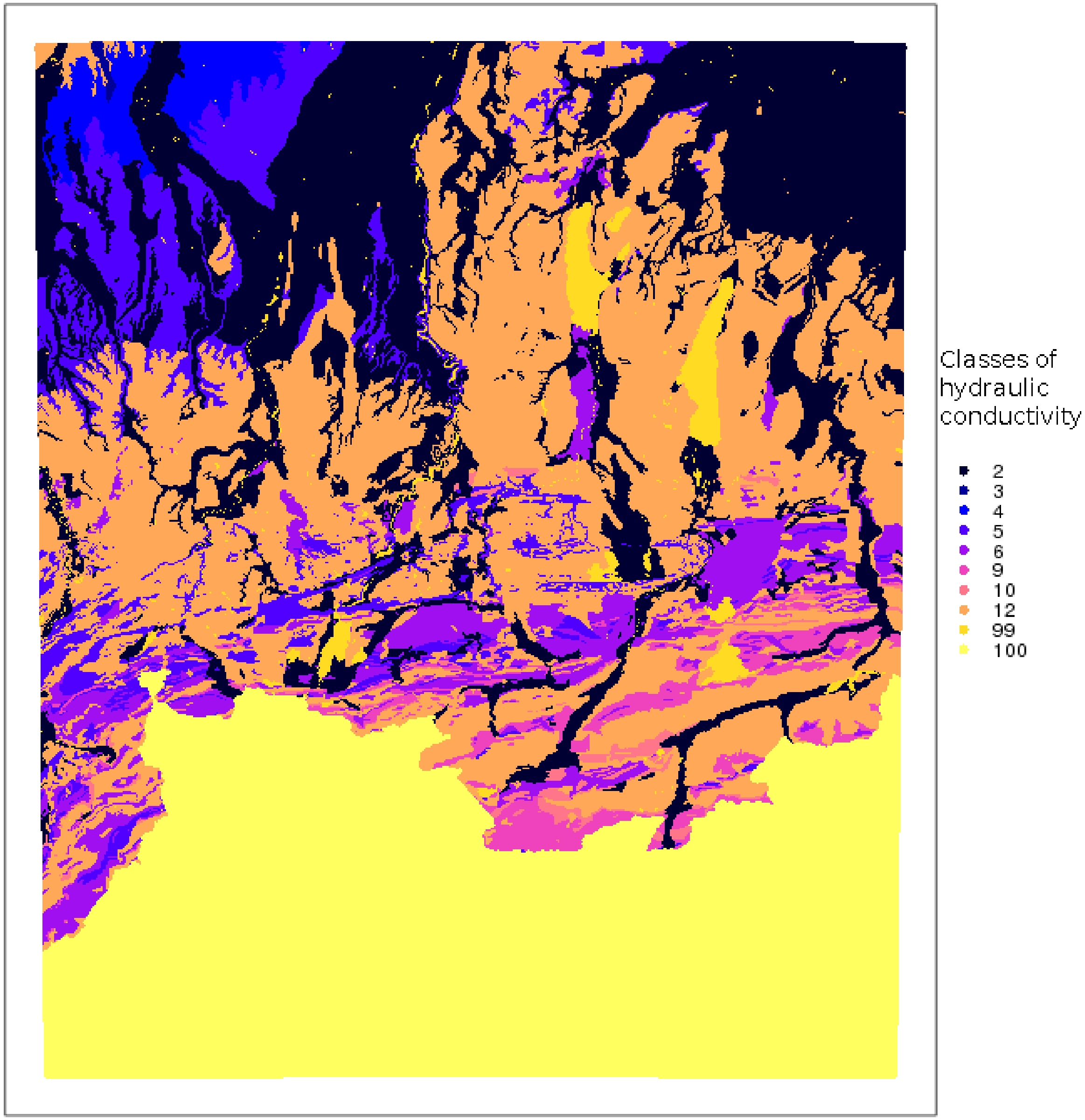
Summary & Conclusion

Karlsruher Institut für Technologie

- Lower boundary condition for LSM Richard's equation important for simulation of near-surface soil moisture field
- For 1D column study with TERENO input data, improvement of soil moisture states of the upper LSM soil levels
- Groundwater coupling impacts also evapotranspiration and surface runoff with considerable amounts

Outlook

- Additional comparison of 1D Study for other TERENO sites throughout Germany (but groundwater is not monitored for most of the observatories)
- Application of a groundwater enabled version of the model system WRF-Hydro for the Ammer catchment (incl. 2D groundwater model)
- Distributed application requires distributed hydrogeological information about saturated conductivity, porosity, and thickness for aquifers → approximation strategy
- Validation of coupled simulations with respect to soil moisture patterns (sensor networks, ACROSS, remote sensing products)


Classes of hydraulic conductivity
2
3
4
5
6
9
10
12
99
100