Karlsruhe Institute of Technology

TERENO
Terrestrial Environmental Observatories

REKLIM
Helmholtz-Verbund
Regionale Klimaänderungen

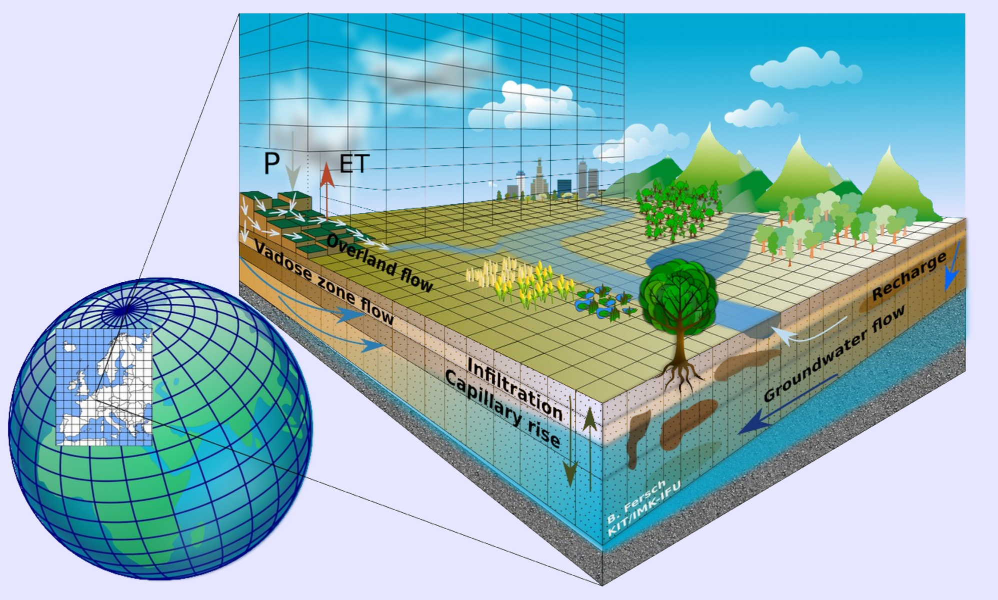
KIT-Campus Alpin
IMK-IFU: Atmospheric Environmental Research

Coupled Modeling of Groundwater-Soil-Atmosphere Interaction in the TERENO Pre-Alpine Region

Benjamin Fersch (fersch@kit.edu), Sven Wagner, Matthias Mauder, and Harald Kunstmann

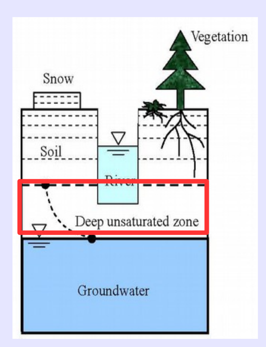
Cross-Compartment Coupled Regional Water Balance Modeling

- The interaction between groundwater and soil-moisture and its implications for the exchange of water and energy with the atmosphere has recently gained increasing attention, especially when groundwater levels are shallow.
- Most of the current land-surface-models (LSMs) like the Noah-LSM of the WRF-ARW model neglect the process of interaction between the groundwater and the unsaturated soil.
- Being the lower boundary for regional atmospheric simulations, the state of the upper soil layers directly connects to the water and energy exchange intensity at the land surface.
- Under certain conditions, in comparison with free-drainage LSMs, groundwater induced patterns of soil moisture distribution can lead to different atmospheric states and dynamics in regional simulation models.
- This study investigates the impact of groundwater soil-moisture coupling on the soil moisture characteristics and the land-surface water budgets of the Noah-LSM. Observations from TERENO are used for model driving and evaluation.



Overview of the major processes that can be captured in a fully coupled model approach.

Groundwater (Phreatic Zone) Enabled Noah-Land-Surface-Model



- The moisture interaction between phreatic and vadose zone is realized by an additional model layer that holds the properties of an imaginary deep unsaturated zone.
- The intensity and direction of the flux between the lowest model soil layer and the groundwater depends on the moisture state of the vadose zone, the distance to the hydraulic head and differs for different soil types.
- In this study, two different approaches are examined for the description of saturated-unsaturated zone interaction:

1) Richard's model with fixed-head lower boundary condition

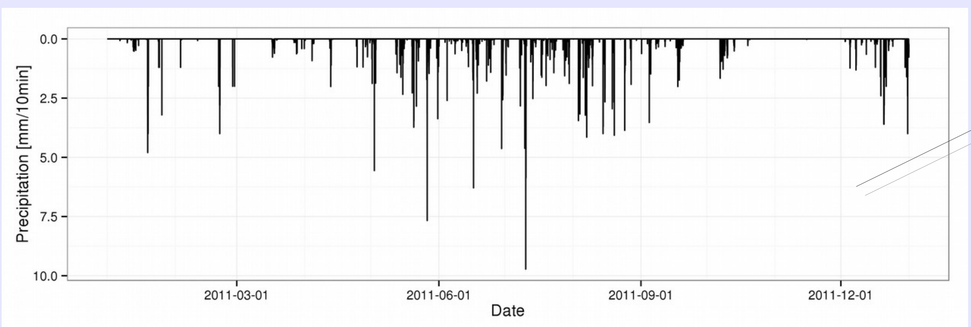
- This method is based on the work of Zeng et al. (2009), and De Rooij (2010) and it uses the soil moisture based Richard's equation.
- The new bottom boundary condition is calculated by specifying the hydraulic head at the bottom of the LSM assuming hydrostatic equilibrium in the deep unsaturated zone.

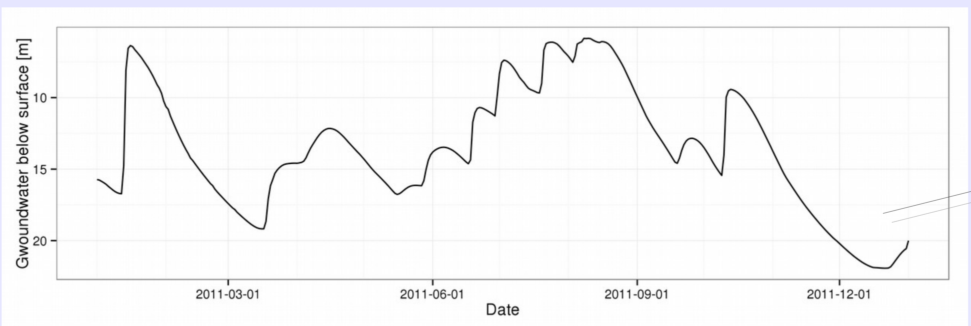
2) Darcy flow approximation for lower boundary fluxes

- The approach applies the method developed by Bogaart et al. (2008).
- The net flux (up or down) between groundwater and the lowest soil layer of the LSM is calculated with the Darcy equation.
- The equations are parametrized for the soil moisture content and the distance to the groundwater level.

Application Study for TERENO Pre-Alpine Site Graswang

TERENO climate/covariance station Graswang with soil moisture sensor array placed below



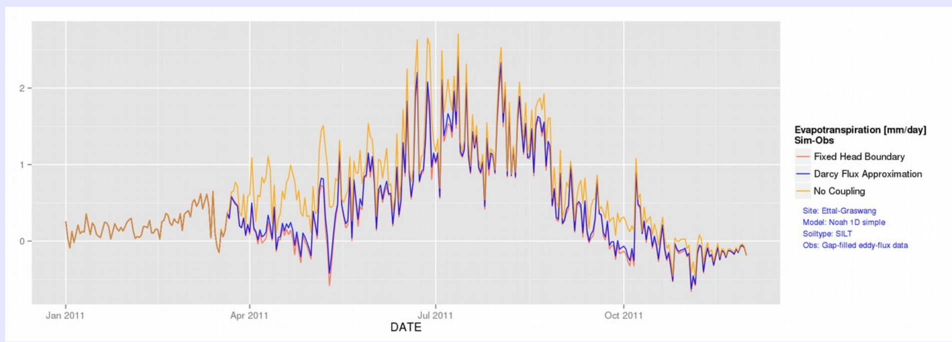


Model input from climate station (TERENO) and nearby groundwater well (Wasserwirtschaftsamt Weilheim)

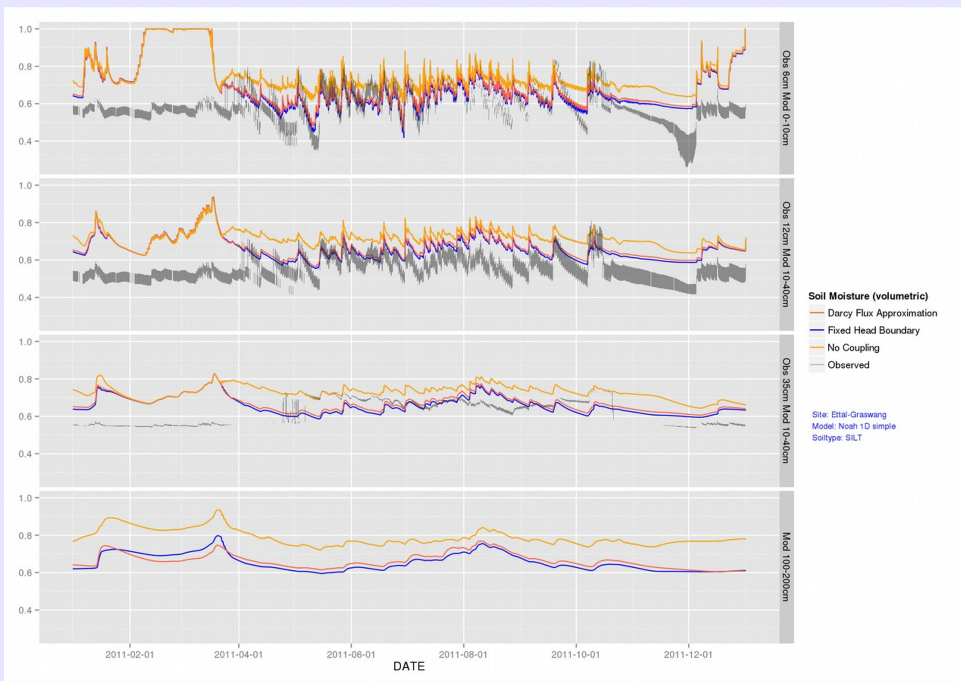
Observations for Model Driving

- Wind speed
- Wind direction
- Temperature
- Humidity
- Pressure
- Shortwave radiation
- Longwave radiation
- Precipitation

Noah-LSM 1D with GW coupling



Changes in simulated evapotranspiration between coupled and uncoupled simulations.



Changes in simulated soil moisture content between uncoupled and coupled model configuration. Due to a calibration problem, the range of the moisture observations is shifted and increased. For comparison the simulation results are therefore scaled by a factor of 2.1.

Integration Into Distributed Regional Atmospheric Model System WRF

- The coupled LSM has been implemented into the Weather and Research Forecasting Model WRF in combination with a 2D distributed groundwater model.
- Currently, feedback studies for the distributed model system are evaluated out in a meso-scale application at China's Poyang Lake region (WRF-HMS) and in a catchment-scale application at TERENO Alpine/Pre-Alpine in combination with the WRF-Hydro modeling system (http://www.ral.ucar.edu/projects/wrf_hydro/).

Bogaart, P. W., Teuling, A. J., & Troch, P. A. (2008). A state-dependent parameterization of saturated-unsaturated zone interaction. Water Resources Research, 44(11), W11423.
De Rooij, G. H. (2010). Comments on "Improving the Numerical Simulation of Soil Moisture-Based Richards Equation for Land Models with a Deep or Shallow Water Table". Journal of Hydrometeorology, 11, 1044-1050.
Zeng, X., & Decker, M. (2009). Improving the numerical solution of soil moisture-based Richards equation for land models with a deep or shallow water table. Journal of Hydrometeorology, 10(1), 308-319.