High Resolution Joint Water and Energy Balance Observation and Modeling in a Prealpine Environment

L. Hingerl1,2, H. Kunstmänner2, S. Wagner, M. Mauder, R. Rigon3
1. Karlsruhe Institute of Technology, Institute for Meteorology and Climate Research (IMK-IFU), Karlsruhe, Germany
2. University of Augsburg, Germany
3. University of Trento, Italy.

Motivation & Objectives
Water and energy fluxes at and between the land surface/subsurface and the atmosphere are intricately intertwined over a large range of space- and time-scales. Changes in either the energy balance or the water balance propagate through the connected cycles and change the respective other component. Improved understanding and prediction of the hydrological cycle and its potential changes therefore requires the joint consideration of both the water and the energy fluxes. In this work the distributed Water and Energy Budget Simulation model GEOSip was applied to the catchment of the Rott, a river in the prealpine region in southern Germany. For the validation of the model we intercompare the simulation results with observed surface/flux measurements, soil moisture and soil temperature measurements in different depths, and energy flux observations obtained by a Eddy-Covariance tower at the TERENO test site “Fendt” for the year 2010.

The GEOSip model
- High resolution, gridded, distributed water and energy budget model
- Full surface energy balance calculation (snow covered and snow-free terrain)
- Inclusion of the influence of vegetation cover on simulating turbulent fluxes and snow accumulation and melt
- Coupled blowing snow model for snow fall and redistribution
- Coupled numerical solution of the heat and water flow equations for the saturated and unsaturated soil zones
- 3-dimensional modelling of water movement with the Richards equation after Paniconi and Pumari (1994)
- Distribution of atmospheric conditions (temperature, wind, radiation) over study area [www.geotop.org]

The Rott catchment
- Part of the Danube catchment
- Catchment area: 55 494 [km²]
- Gauge elevation: 374.86 m
- Maximum elevation: 902 m
- River length: 41 km

Table 1: Mean discharge values for the gauge in Raising. Source: HNO-Steiger

<table>
<thead>
<tr>
<th>Discharge</th>
<th>Winter Summer Year unit</th>
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<tbody>
<tr>
<td>Discharge</td>
<td>Winter daily means 0.03</td>
</tr>
<tr>
<td>Discharge</td>
<td>Winter daily means 0.19</td>
</tr>
<tr>
<td>Discharge</td>
<td>Winter daily means 0.86</td>
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</table>

Meteorological Input Data:
- Hourly point measurements of:
  - Air temperature [°C]
  - Relative air moisture [%]
  - Precipitation [mm]
  - Wind speed [m/s]
  - Global radiation [W/m²]

Results
- Simulated and measured discharge at the Gauge in Raising. A Nash-Sutcliffe coefficient of 0.87 and a R² value of 0.88 indicate good congruency of simulation and measurement. One way to improve the simulations would be to minimize interpolation factors of the meteorological forcing as a result of a coarse observational network.

Conclusion
The performed modeling of the energy and water balance with the distributed model GEOSip in the Rott catchment achieved good congruency between simulations and measurements. A very high degree of accuracy was reached with the simulated daily soil moisture for the whole observational period. The simulations show the same dynamics as the measurements, but tend to overestimate the latent heat flux. This impression gets reinforced due to time steps with missing observed data because of the omitted measurements of low quality. Small time steps as displayed in the upper part of the figure show high analogy between the measured and simulated Latent Heat Flux at time steps with available observations.

Figure 1: The catchment of the Rott with the position of the discharging gauge in Raising and the TERENO test site “Fendt”

The “Fendt” site of the TERENO Bavarian Alps/pres-Alps observatory
TERENO is an interdisciplinary and long-term research programme involving six Helmholtz Association Centers. The Earth observation network of the TERENO programme covers the entire Bavarian Alps from the North German lowlands to the South Tyrolian Alps and includes the entire area of interest. The Bavarian Alps to the North German lowlands. Its objectives are to catalogue the longterm ecological, climate and energy flux observations obtained by a Eddy-Covariance tower at the TERENO test site “Fendt” for the year 2010.

Observation Equipment at the “Fendt” test site:
- Lysimeter network (36 lysimeters)
- Climate stations
- Eddy-covariance systems
- Isotope laser systems for determination of water vapour and CO2 fluxes
- TDL systems for N2O and CH4 flux measurements
- Closed chamber measuring systems for determination of CO2, N2O and CH4 fluxes at the soil atmosphere interface
- Rain radar

Figure 2: The land use (a) and the soils (b) of the Rott catchment

Figure 3: Simulated and measured discharge at the Gauge in Raising. A Nash-Sutcliffe coefficient of 0.87 and a R² value of 0.88 indicate good congruency of simulation and measurement. One way to improve the simulations would be to minimize interpolation factors of the meteorological forcing as a result of a coarse observational network.

Figure 4: Simulated and measured soil temperature for different depths in one pixel at the TERENO-observatory and soil of the observational period. The simulated soil temperatures show a good reproduction of the measured dynamics. Good congruency of the simulated temperature in 21 cm with the measured in 35 cm as well as the offset in 50 cm depth indicate a too steep simulated temperature gradient with increasing depth.

Figure 5: Simulated and measured soil heat flux for one pixel at the TERENO-observatory for a small section of the three monthly observational period. According to the used soil map, the soil type of the correspondent pixel is Histosol. More current observations demonstrate that only the upper 50 cm of the soil contains Histosol. Below the Histosol follows the same Cambisol as defined for neighboring cells on the basis of the soil map. Hence the simulated soil heat flux in Cambisol shows much better congruency to the measurements than in Histosol.

Figure 6: Simulated and measured sensible heat flux for the same pixel and time section as displayed in figure 5. The grey bars show time steps, where measurements of the sensible heat don’t meet a statistical quality criterion wherefore they are omitted in the graphic. This criterion is dependent on turbulent fluxes in the atmosphere, that’s why it is met quite seldom at night. Thus negative sensible heat fluxes as they occur at night in the simulations are difficult to verify. At the time steps with reliable measurements good accordance of the measurements to the simulations are apparent.

Figure 7: Simulated and measured latent heat flux for the same pixel as displayed in figure 6. The grey bars at upper figure show time steps with no reliable measurements as explained in figure 6. In the lower figure the latent heat flux for the whole observational period is displayed. The simulations show the same dynamics as the measurements, but tend to overestimate the latent heat flux. This impression gets reinforced due to time steps with missing observed data because of the omitted measurements of low quality. Small time steps as displayed in the upper part of the figure show high analogy between the measured and simulated Latent Heat Flux at time steps with available observations.

Figure 8: Distributed monthly means of the simulated latent heat flux for the whole observational period. The appearing patterns of more or less homogenous areas of similar mean latent heat flux values show up clearly, especially in the summer months. They shape the areas of different land types and secondarily of different soil types defined in the land use (Figure 2(a)) and soil map (Figure 3(a)). With respect to time maximum values of the latent heat flux conform with the highest position of the sun therewith the radiation maximum.

Table 1: Mean discharge values for the gauge in Raising. Source: HNO-Steiger

<table>
<thead>
<tr>
<th>Period</th>
<th>Discharge</th>
<th>Winter daily means 0.03</th>
<th>Summer daily means 0.03</th>
<th>Yearly means 0.23</th>
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<tr>
<td>Winter</td>
<td>Discharge</td>
<td>Winter daily means 0.19</td>
<td>Summer daily means 0.17</td>
<td>Yearly means 0.91</td>
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<tr>
<td>Summer</td>
<td>Discharge</td>
<td>Winter daily means 0.86</td>
<td>Summer daily means 0.86</td>
<td>Yearly means 0.91</td>
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</tbody>
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