Evaluation of the land surface scheme HTESSEL with satellite derived surface energy fluxes at the seasonal time scale.

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1. Introduction

A problem often reported in numerical regional climate studies is a systematic summer drying that results in too dry and too warm simulations of summertime climate in southeastern Europe (*Hagemann et al.* 2004). This summer drying is associated with a strong reduction of the hydrological cycle, dry soils, strong evaporation stress and reduced precipitation. Precipitation and evaporation are coupled processes, but these models often overemphasize the positive feedback. Presumably, land surface processes play an important role in this feedback, and their representation may be subject to improvement.

Lenderink et al. (2003) pragmatically reduced a summer continental dry bias in the KNMI regional climate model RACMO2 by enhancing the soil reservoir depth in the land surface scheme (LSS). Yet, it is unclear how realistic this solution is, and whether it is still valid when extrapolating to changing climate conditions.

Here we evaluate the LSS HTESSEL and modifications therein with satellite inferred evaporation estimates during a single growing season. Focus is on the Transdanubian region in Hungary, a region that was found particularly sensitive to summer drying in previous integrations with RACMO2. The modifications that are examined relate to soil water issues, i.e. water storage capacity, water stress in vegetation covered soils, and water supply from groundwater. In the evaluation, we focus on the model ability to reproduce the range of evaporative responses seen in the observations. Details can be found in *Wipfler et al.* (in prep).

2. HTESSEL reference version

In the LSS TESSEL (Tiled ECMWF Scheme for Surface Exchange over Land; *van den Hurk et al.,* 2000) and its successor Hydrology-TESSEL, introduced in ECMWF IFS cy33r1 (*Balsamo et al.* 2009), the tiled land surface in each atmospheric model grid cell is partitioned between bare soil, low and high vegetation, intercepted water, shaded and exposed snow deck. For each tile a separate surface energy balance is calculated. Total fluxes are calculated as area weighted averages over the tiles. The soil heat flux G serves as upper boundary condition to a 4-layer vertical column with fixed depth (2.89m) using a standard diffusion scheme. Sensible (H) and latent heat (LE) fluxes from each tile are calculated applying a commonly used resistance analogy. Of relevance to this study is the sensitivity of evaporation to soil moisture content which strongly affects the seasonal evolution of evaporation in water-constrained conditions. This is controlled by the so called water stress function

$$f_2^{-1} = (\theta - \theta_{pwp})/(\theta_{cap} - \theta_{pwp})$$

with θ denoting the actual root density weighted column average soil water content, while θ_{pwp} and θ_{cap} are soil moisture content at permanent wilting point and field capacity (in units m^3/m^3).

The hydrology of a snow free land grid cell is depicted in Figure 1. Precipitation accumulates in the interception

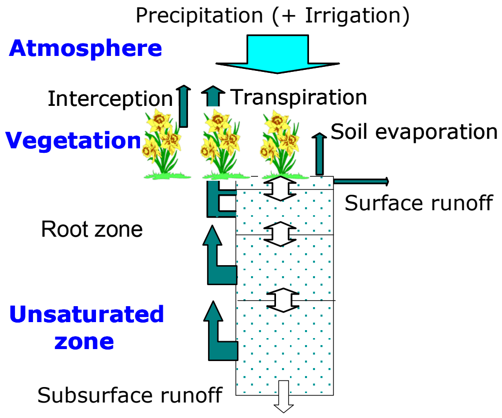

Figure 1. Schematic representation of the water component of the (H)TESSEL land-surface scheme.

reservoir until it is saturated. Excess precipitation is partitioned between surface runoff and infiltration into the soil column. Soil water flow is described by the diffusivity form of the Richard' equation using the same 4-layer mesh as for soil temperature. The hydraulic conductivity and diffusivity are described with the analytical functions proposed by van Genuchten. Free drainage is assumed at the bottom of the soil column. Excess water leaves the domain as surface or subsurface runoff. Capillary rise of groundwater is not considered, nor is horizontal exchange of soil water.

3. Modifications to HTESSEL

A parameter analysis with a detailed soil-water-atmosphere model showed that the evaporative responses of HTESSEL to a controlled forcing are particular sensitive to i) the characteristics of the water stress function, ii) soil column depth, and iii) the treatment of the lower boundary condition. In addition it was indicated that a finer mesh of the soil column yields improved convergence. Based on these findings we have investigated the following modifications:

i) formulation of the water stress function f_2 in terms of the more commonly used soil water pressure head:

$$\tilde{f}_2^{-1} = (\psi - \psi_{pwp})/(\psi_{cap} - \psi_{pwp})$$

with ψ_{pwp} and ψ_{cap} set to -15 and -0.1 bar.

ii) introduction of additional spatially variable soil depths classes with shallower depths to account for rocky material in the soil. In the region of interest about 30% of the area is found to have a soil depth of 1 meter or less.

iii) inclusion of extra water storage to represent the presence of a shallow ground water table. This acts as an additional supply of moisture. In the region of interest about 40% of the area is potentially affected by a shallow water table.

In addition, the number of soil layers was doubled to 8.

4. Evaporation estimates from SEBAL

Maps of evaporation have been derived by application of the energy-partitioning algorithm SEBAL (Surface Energy Balance Algorithms for Land, *Bastiaanssen et al.* 1998) on the basis of MODIS images. Information at pixel scale (1km) is aggregated to 0.25^o to match the typical RCM resolution. The temporal resolution is about one week, primarily determined by the occurrence of cloud free scenes. Figure 2 shows the SEBAL inferred evaporative fraction averaged over the growing season of 2005. The accuracy of the evaporation estimates is 3-5% on a seasonal basis.

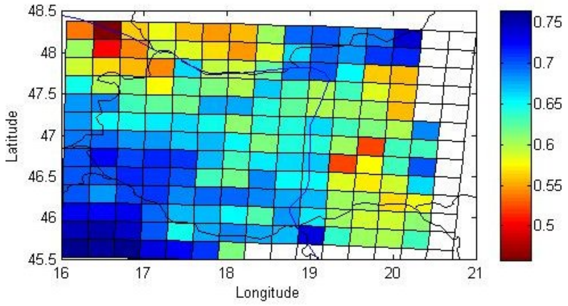

Figure 2. SEBAL inferred evaporative fraction across Hungary for the growing season of 2005

5. Experimental setup

HTESSEL standalone versions are set up across the domain of interest and forced with 3-hourly fluxes of precipitation, incoming radiation and near surface meteorological fields from a RACMO2@25km hindcast run driven by ECMWF operational analyses. Weekly total amounts of precipitation and incoming short wave radiation are scaled with the observed amounts used to constrain the SEBAL algorithm, for consistency. Incoming radiation has been calibrated with in-situ measurements, while precipitation amounts have been inferred from TRMM estimates.

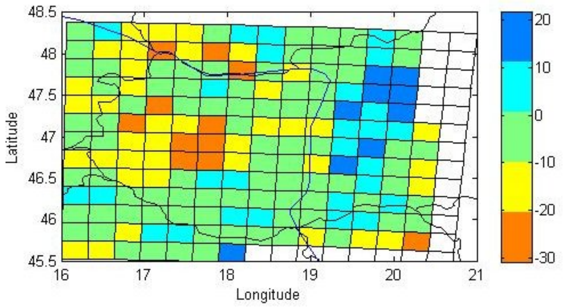

Figure 3. Relative difference in seasonal evaporative fraction between HTESSEL and SEBAL.

6. Results and Conclusions

The difference in seasonal evaporative fraction between HTESSEL and SEBAL is shown in Fig.3. The areas with underprediction are found to match reasonably well with areas where P-E accumulated over the season is negative. It is yet unknown whether this points to a model inadequacy or to a problem with irrigation as a missing source term. Figure 4 shows a scatter plot of ranked evaporative fraction obtained from integrations with HTESSEL (reference and modified versions) against ranked SEBAL evaporative fraction. The reference version follows the SEBAL range of variability reasonably well, but with a tendency of underestimating the low amounts. Modifying the water stress clearly results in increased seasonal evaporative fractions, especially in the higher end of the distribution. Shallower soil depths produce lower values of evaporative fraction, in particular in the central part of the distribution. Inclusion of capillary rise from a shallow ground water table shows little impact. The combination of all three modifications yields a marginally improved result in the lower part of the distribution (fraction smaller than 0.60), but in the higher end the combined result is strongly dominated by the modification in water stress.

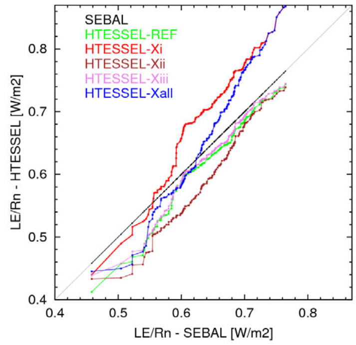

Figure 4. Ranked evaporative fraction from HTESSEL compared to SEBAL

7. Outlook

HTESSEL has been implemented in RACMO2. Integrations of the present-day European climate are ongoing The evaluation assessment will focus on the seasonal cycle and interannual variability of land surface feedbacks

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References

Bastiaanssen, W.G.M., M. Menenti, R.A. Feddes and A.A.M. Holtslag: The Surface Energy Balance for Land (SEBAL): Part 1 formulation, *J. Hydrology*, 212-213, 198-212, 1998

Balsamo, G., P. Viterbo, A. Beljaars, B. van den Hurk, M. Hirschi, A.K. Betts and K. Scipal, A revised hydrology for the ECMWF model: Verification from field site to terrestial water storage and impact in the ECMWF-IFS, Tech. Memo. 563, 28 pages, 2008.

Hagemann, S., B. Machenhauer, R. Jones, O.B. Christensen, M. Déqué, D. Jacob and P.L Vidale, Evaluation of water and energy budgets in regional climate models applied over Europe. *Climate Dynamics*, 23, pp. 547-567, 2004

Lenderink, G, B. van den Hurk, E. van Meijgaard, A. van Ulden, and H. Cuijpers: Simulation of present-day climate in RACMO2: First results and model developments, KNMI Tech. Report 252, pp. 24, 2003.

Van den Hurk, B.J.J.M., P. Viterbo, A.C.M. Beljaars and A.K. Betts: Offline validation of the ERA-40 surface scheme; ECMWF Tech. Memo. 295, 2000.

Wipfler, E.L, K. Metselaar, J. C. van Dam, R A. Feddes, E. van Meijgaard, L.H.. van Ulft, B. van den Hurk, S. J. Zwart and W.G.M. Bastiaanssen, Seasonal evaluation of the ECMWF land surface scheme against remote sensing derived energy fluxes of the Transdanubian region in Hungary, *in preparation*