Calibrating a large-scale groundwater model using spaceborne remote sensing products: a test-case for the Rhine-Meuse basin

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Calibration of large-scale groundwater models is difficult due to a general lack of groundwater head measurements. The calibration becomes even more complex if the basin covers several countries with different observation systems and different base maps, or if calibration must be done in developing countries with poor data availability.

In this study, we present and discuss a novel approach for calibrating a large-scale groundwater model using various satellite remote sensing products without using groundwater head data. The study area is the combined Rhine-Meuse basin located in Western Europe and covering a total area of around 200.000 km2. For this basin an extensive groundwater head database is available. However, calibration of the groundwater model was carried out using only remote sensing products while the head data were solely used for model validation. The groundwater model itself uses as input only global datasets so that the modeling procedure is portable to other areas on the globe including data poor environments such as developing countries.

Our hydrological model consists of two parts:

(1) the land surface model, which conceptualizes the upper first meter of the unsaturated zone soil layer; and
(2) the MODFLOW-based groundwater model simulating the saturated horizontal flow in the deeper layer.

Both model parts together simulate the dynamic interaction between surface water and groundwater bodies, and between the unsaturated soil and the saturated groundwater zone. We ran the model for the period 1960 to 2008. Calibration is carried out by adjusting aquifer characteristics and soil physical parameters determining flow in the unsaturated zone.

State variables used in calibration is the unsaturated zone/soil moisture storage and total terrestrial water storage. Two promising remote sensing products are considered: for soil moisture the European Remote Sensing (ERS) scatterometer derived Soil Water Index (SWI) products and for total basin-average water storage the GRACE monthly gravity field solutions. Time series of ERS-SWI are available from 1992 onwards. GRACE data are available from 2002 to 2008. The time series are used because our previous studies showed a strong correlation between timeseries of remote sensing products and timeseries of groundwater head measurements. We used the time series of GRACE to constrain anomalies of total basin water storage including groundwater, unsaturated zone/soil moisture, canopy, surface water, and snow storages. Finally, the resulting groundwater head of the calibrated model is verified to available groundwater head measurement data.

Results are very promising and suggest that it is possible to calibrate and constrain large-scale groundwater models using satellite remote sensing derived products. Comparing uncalibrated and calibrated model simulations with observed groundwater head data, we conclude that important model improvements can be made by integrating models with remote sensing products, particularly for areas with shallow water tables. We argue that, in the absence of groundwater head measurement data, satellite remote sensing products are useful products for calibrating groundwater models.