Large scale groundwater modeling for the Rhine Meuse basins

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There are too many models in these basins.

There are abundant data, but we still say there are no enough data available.

***... but ...** Do we have a model for the entire basins?*

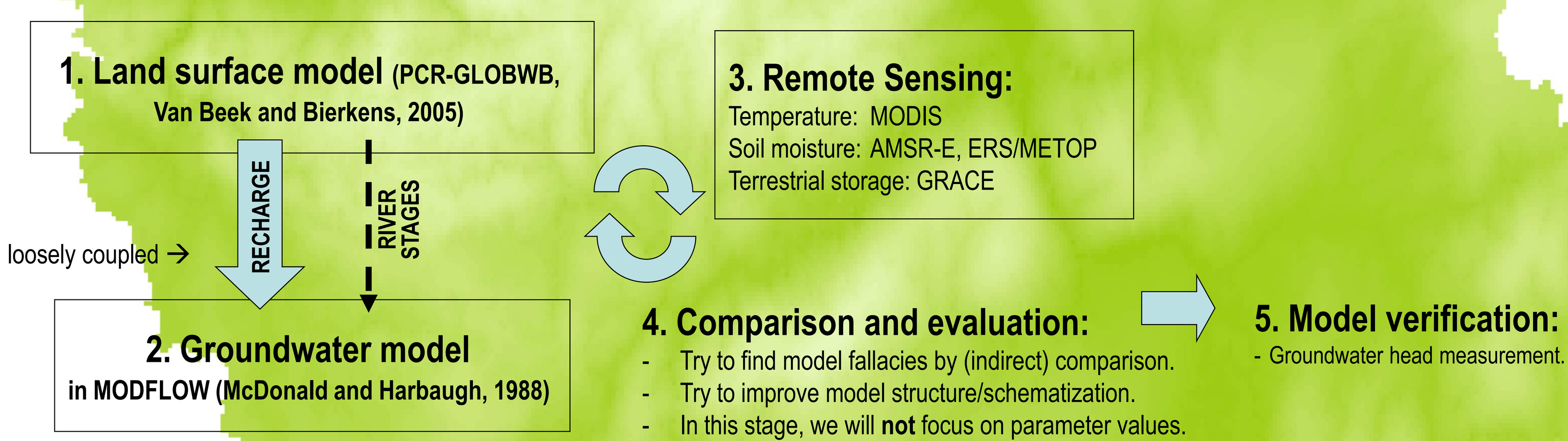
Can we make a model by using globally available datasets?

Purpose:

The basic idea is to use globally available datasets to build large scale groundwater models for data-poor regions and furthermore to improve such models by using data from remote sensing information. We use the Rhine-Meuse basins as the test bed, because they contains ample data for verification.

General Methodology: (see the diagram below)

We start by building a **land surface model** to estimate groundwater recharge and river discharge in the basins. The land surface model is based on the PCR-GLOBWB model (Van Beek and Bierkens, 2005, see the box on the right). Then, a groundwater model of the Rhine-Meuse basins is built using the MODFLOW model code (McDonald and Harbaugh et al, 1988). This groundwater model is only one layer model based on the global lithological map of Dürr et al (2005). Both land surface and groundwater model has the resolution of 30 arc-second (about 1 km in the equator).



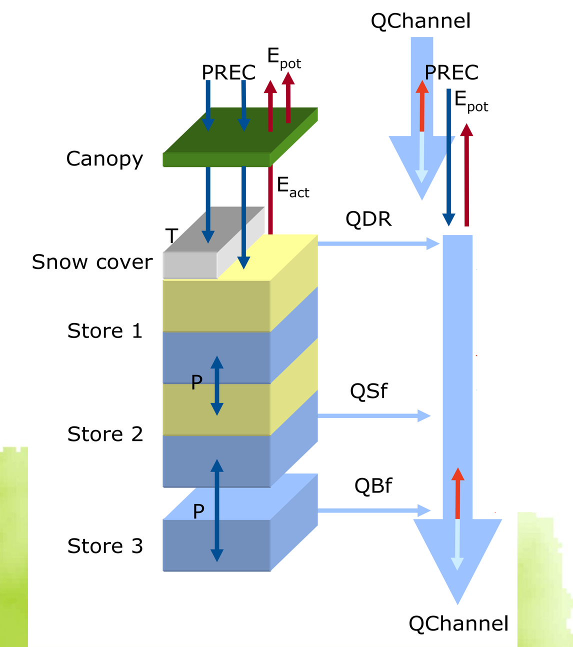
The **groundwater model** is forced by the recharge and channel discharge as calculated from the land surface model. The land surface model itself is forced with climatological data from the ECMWF operational archive analysis (http://www.ecmwf.int/) for the period of 2000-2006, which most remote sensing data are available. To spin up the model, the monthly CRU datasets (Mitchell and Jones, 2005 and New et al, 2002) that are downscaled into daily resolution based on the ERA40 reanalysis data (Uppala et al, 2005) are used for the simulation in the period of 1970-1999.

Next, we will derive some information from remote sensing. Some thoughts that have been drawn are:

1. We will use the **MODIS surface temperature** time series to calculate maps of averages winter and summer surface temperature. Locations where this difference is small indicate zones with shallow water tables. Alternatively, we can also calculate a map of the temporal standard deviation of surface temperatures. Locations with small standard deviations are expected to have shallow water tables.
2. We will use the **soil moisture** products (e.g. **AMSR-E** and **ERS/METOP**). Using the similar way as mentioned in the first point, we can detect the occurrences of shallow groundwater table. Moreover, we can identify groundwater recharge areas because they should be associated with wet soils.

By comparing the model results and aforementioned information (from remote sensing), we can **identify model fallacies**. Based on such fallacies, we will try to improve the model structure and schematization. At the end, the results of improved model will be compared to the observed piezometric heads.

Model structure:



The **land surface PCR-GLOWB** model (Van Beek and Bierkens, 2005) is a distributed model written in the meta-language of the PCRaster package. There are two upper soil stores (1 and 2) and a groundwater store (3) in the model.

The drainage components corresponding to each stores are direct runoff (QDR), interflow (Qsf), and baseflow (Qbf). By routing all of these drain components through a drainage network, channel discharges can be known.

The evaporation (E) consists of interception, bare soil evaporation, and plant transpiration (T). The evaporation in open water bodies, such as lakes and wetlands, is also consideted. The water exchange between soil stores (P) consists of capillary rise and percolation/recharge.

Loosely coupling to MODFLOW:

The groundwater store in the PCR-GLOBWB is a simple linear reservoir. In this research, we try to replace it by a MODFLOW groundwater model. As the initial attempt, we perform a loosely coupling procedure as follows:

1) Firstly, the PCR-GLOBWB is used to calculate river discharges and groundwater recharges.
2) Then, a MODFLOW groundwater model is built and forced by the groundwater recharges and channel or river discharges calculated from the PCR-GLOBWB.

Progress:

The early versions of the land surface and groundwater models have been assembled. Although the models are only based on the globally available datasets, the results are promising (see the box below). The river discharges from the land surface model are quite reasonably well compared to the measurement data.

From the current groundwater model output, we can also identify seasonal and long term trend variations. However, some unrealistic trends are also identified. In some locations, the model is not able to capture seasonal variations. We hypothesize that this may be due to too little groundwater recharge provided by the land surface model. Further investigation is still in progress at this moment.

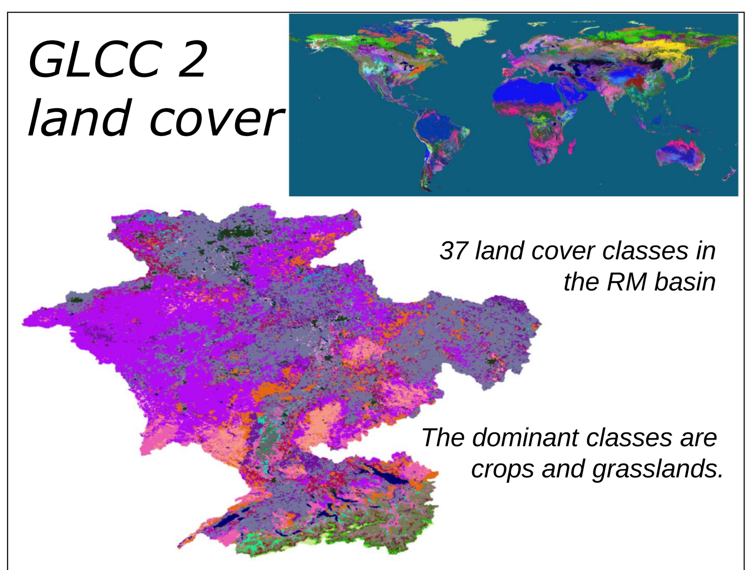
Future work:

Surely, we will try to improve the current land surface and groundwater models and to fulfill all plans that have been drawn in the methodology section. These includes attempts to use remote sensing information to find model fallacies.

As part of the long term plans of this research (until August 2012), the future work will include:

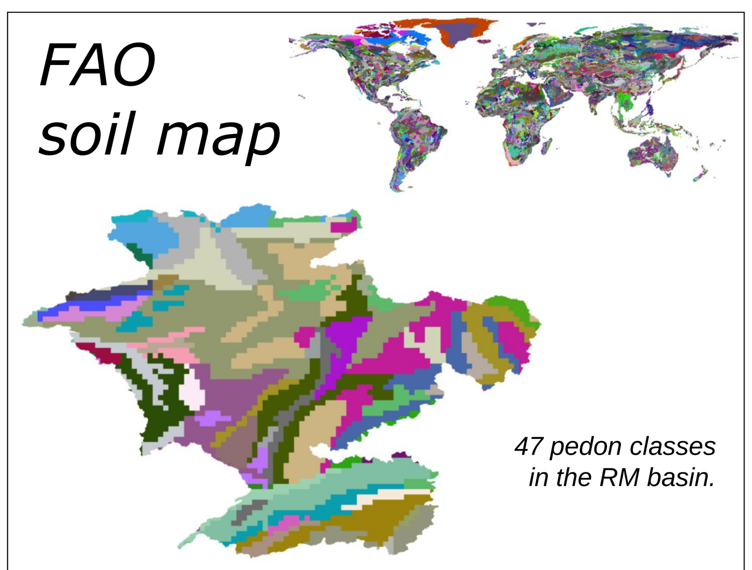
- **Dynamic (fully) coupling** between the land surface model and the groundwater model.
- **Model calibration**. After having a fully coupled model, we will do a calibration procedure to adjust model parameters.

GLCC 2 land cover



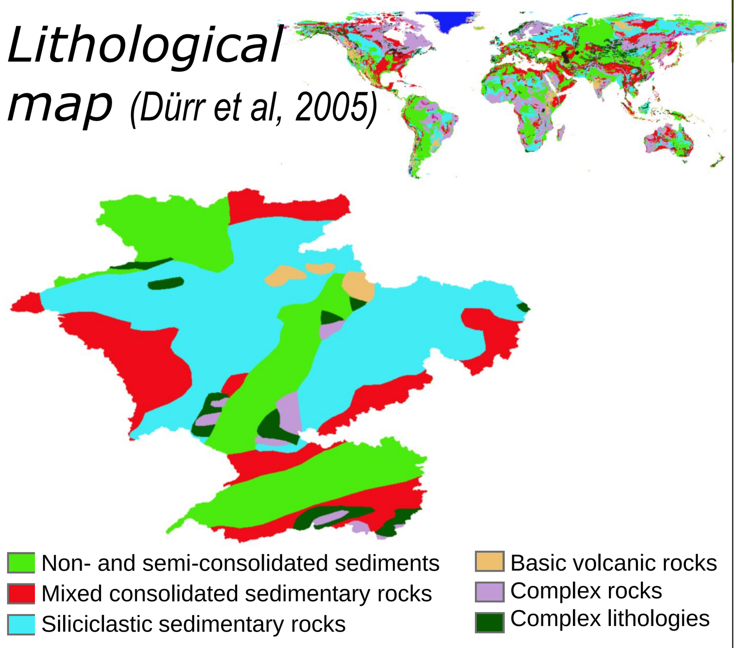
The GLCC map version 2 (http://edc2.usgs.gov/glcc/glcc.php) is used to characterize the land cover. The parameters based on this map are fractional vegetation covers, leaf area indexes, and (plant-available) soil water holding capacities. These parameters are used in canopies (interception) and upper sub-soils.

FAO soil map



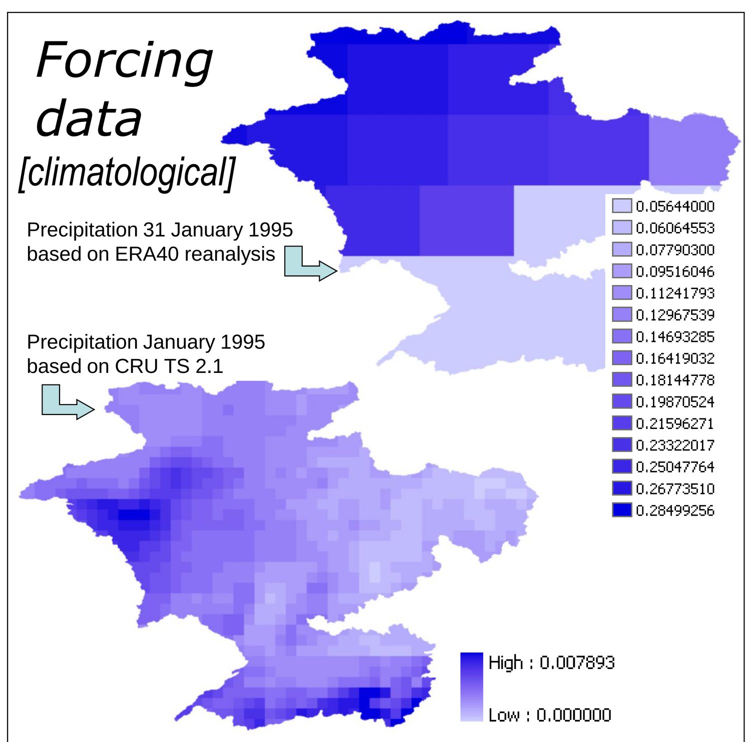
The FAO map is used to parameterize the upper sub-surface compartments of the land surface model.
Some parameters based on this map are moisture contents, hydraulic conductivities, soil depths, and storages.

Lithological map (Dürr et al, 2005)

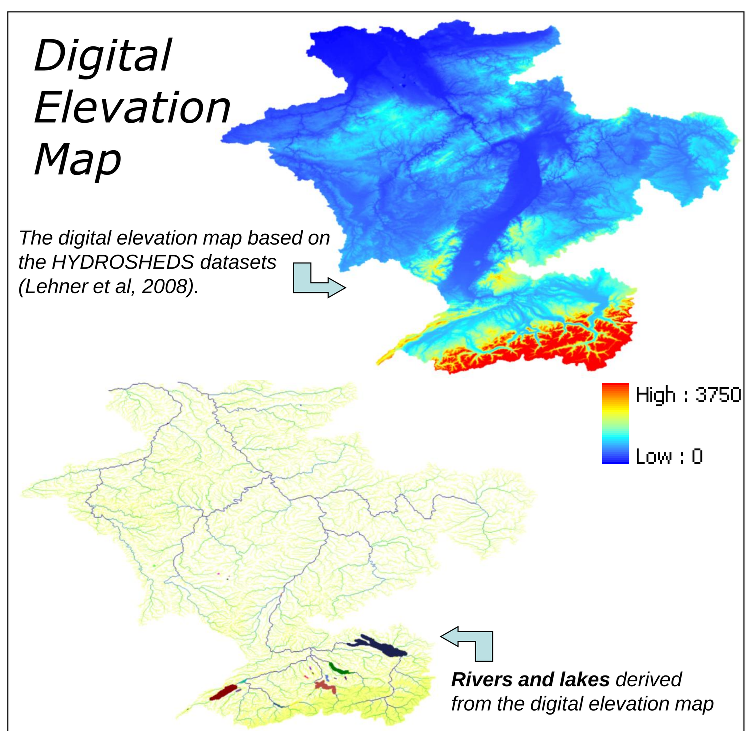


This simple lithological map will be used to parameterize the groundwater model (transmissivities and storage coefficients).

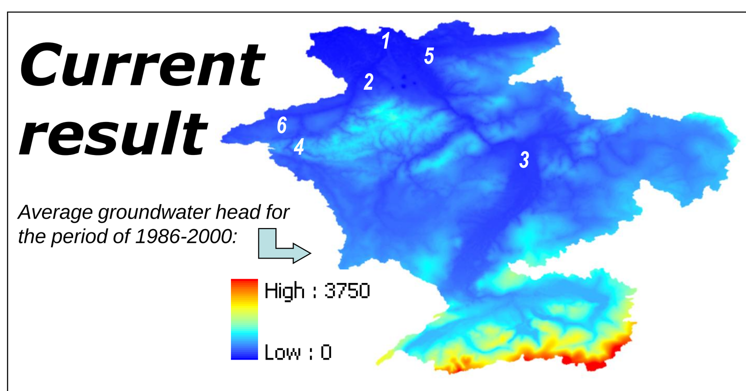
Forcing data [climatological]



Digital Elevation Map



Current result



Overview of the current MODFLOW groundwater model:

The current version is still a very simple model. There is only one layer in the MODFLOW model. At this moment, we still assume **one homogenous layer** with the transmissivity kD = 100 m^2/day and the storage coefficient = 15%.

The no-flow **boundary condition** is implemented surrounding the basins. In big lakes (e.g. Bodensee, Zurichsee, Neuchatel, Lucerne, etc.), we assume the constant water level condition.

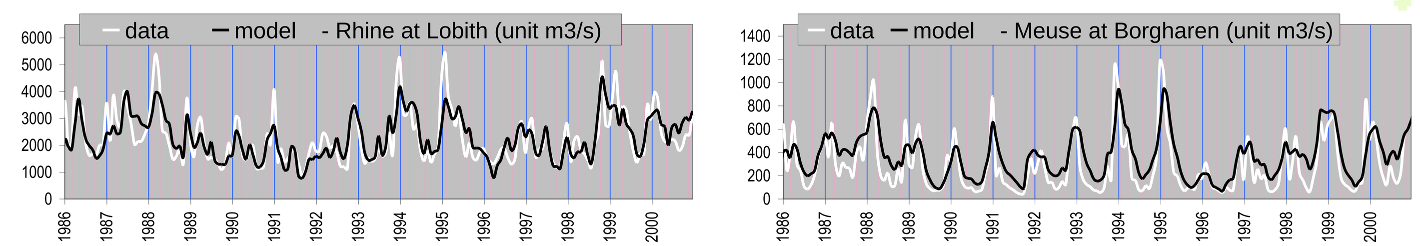
We employ the river package (**RIV**) to simulate the discharges calculated from the land surface model. The river dimensions and hydraulic properties are derived from the digital elevation map and bankfull discharge condition analysis based of the land surface model output. The river stages are calculated by using the Manning formula.

The recharge package (**RCH**) is used to simulate the capillary rise and recharge calculated from the land surface model.

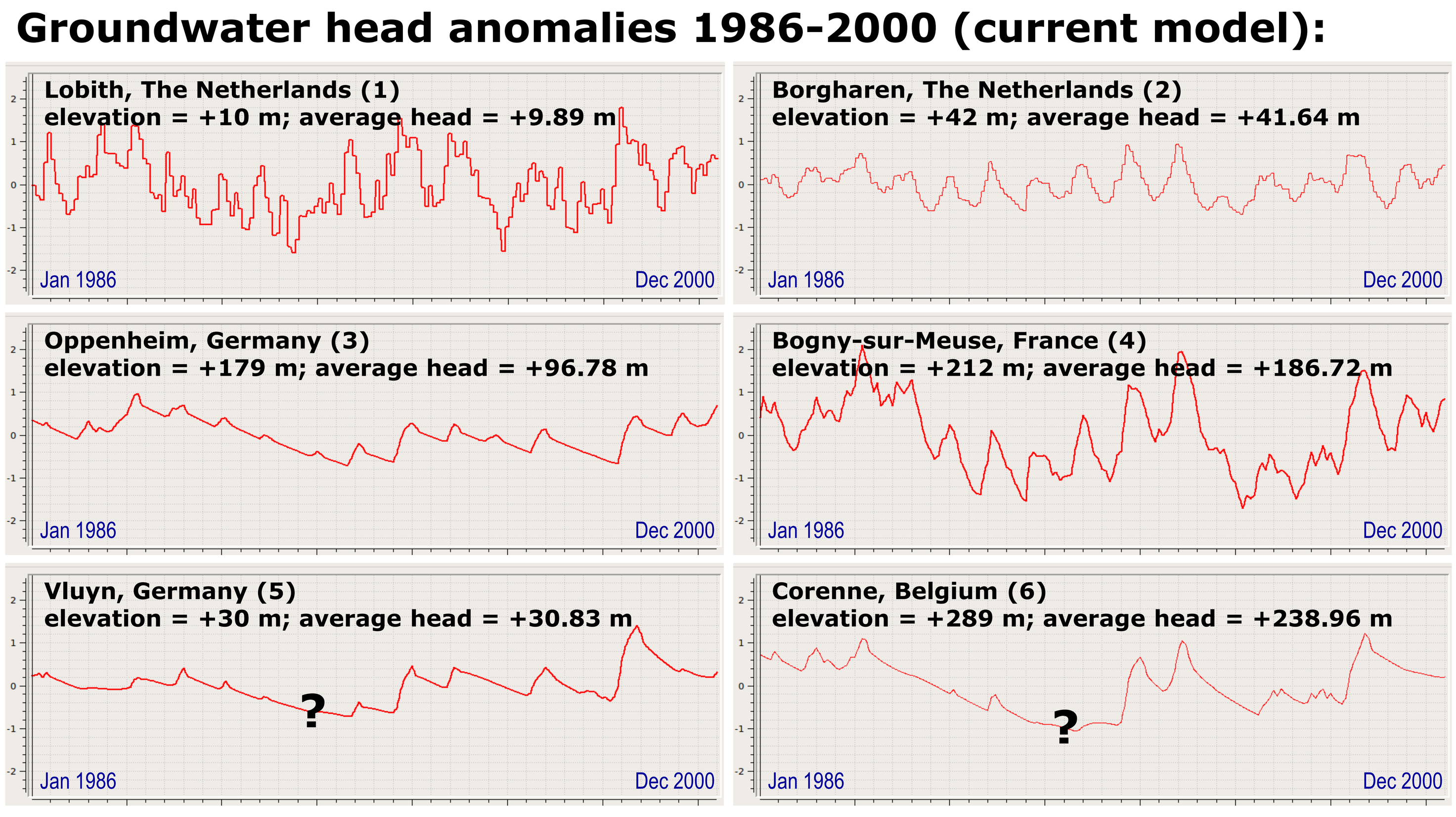
As the **initial condition**, we use the output of the steady state simulation. The steady state simulation itself is forced by the average groundwater recharge and average river discharge between 1986-2000 (from the land surface model output).

The **stress period** during transient simulation is a month (28-31 days), while the **time step** is about a week (7-8 days).

River discharges 1986-2000 (current model):



Groundwater head anomalies 1986-2000 (current model):



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