HYDROLOGICAL INDUCED EARTH ROTATION VARIATIONS FROM STAND-ALONE AND DYNAMICALLY COUPLED SIMULATIONS

R. DILL, M. THOMAS, C. WALTER
Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences
Telegrafenberg, D-14473 Potsdam
e-mail: dill@gfz-potsdam.de

ABSTRACT. The impact of continental water mass redistributions on Earth rotation is deduced from stand-alone runs with the Hydrological Discharge Model (HDM) forced by ERA40 re-analyses as well as by the unconstrained atmospheric climate model ECHAM5. The HDM is attached in three different approaches to the atmospheric forcing models. First, ECHAM5 and its embedded land surface model generates directly runoff and drainage appropriate for the subsequent processing with HDM, like it is realized in the dynamically coupled model system ECOCTH, too. Second, an intermediate Simplified Land Surface scheme (SLS) is used to separate ERA40 precipitation into runoff, drainage, and evaporation. Third, precipitation and evaporation are used as input for the Land Surface Discharge Model (LSDM), which estimates runoff and drainage internally for its HDM-like discharge scheme. The individual models are validated by observed river discharges. The induced rotational variations represent mainly the different forcing from precipitation-evaporation and trends from inconsistent mass fluxes. The dynamical coupling of atmosphere and ocean has only a subordinated influence.

1. HYDROLOGICAL MODEL APPROACHES

Water mass redistributions within the global hydrological cycle affect the Earth's rotation and its gravity field, especially on seasonal to interannual timescales. Since Earth rotation variations and particularly Length-of-Day are sensitive for deficiencies in the global water balance, consistent mass exchanges among the atmosphere, oceans and continental hydrology are mandatory for realistic simulations of hydrospheric induced global integral Earth parameters. The continental water mass redistributions have been simulated with the Hydrological Discharge Model (HDM) from the Max-Planck-Institute for Meteorology (MPI-M) in Hamburg (Hagemann & Dümenil, 1998a) which has been applied in three different configurations (Fig. 1).

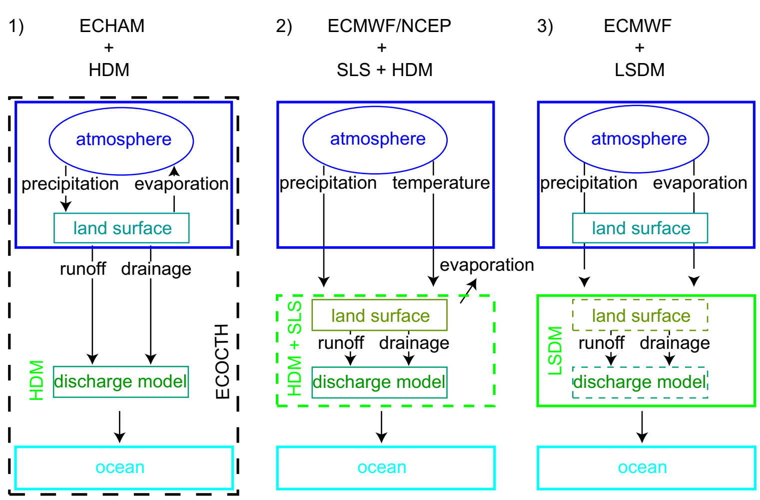

Figure 1: Three approaches to pass the input from the atmospheric models to the hydrological discharge model HDM.

HDM classifies the lateral water flow processes into three parallel types of flows. Water produced within a catchment, reaching the land surface by rain or snowmelt, enters the HDM as surface runoff or groundwater drainage. Surface runoff feeds the fast overland flow. Groundwater drainage is passed laterally as slow base flow. The water is transferred from gridcell to gridcell by the river flow network. Retention of water in each flow process is represented by a cascade of equal linear reservoirs with spatially distributed lag times depending mainly on topography. Wetlands and lakes are included by an extended renewal rate concept (Hagemann & Dümenil, 1998b). Within the DFG project TH864/3 the initial version of HDM has been improved to calculate hydrological angular momentum (HAM) functions and low degree gravity coefficients.

Since HDM exclusively describes the lateral flow processes, it requires input data separated in runoff and drainage. To split precipitation into snow accumulation, soil moisture, runoff, groundwater drainage, and evaporation a land surface model is interposed between atmosphere and HDM (Fig. 2). Most atmo-

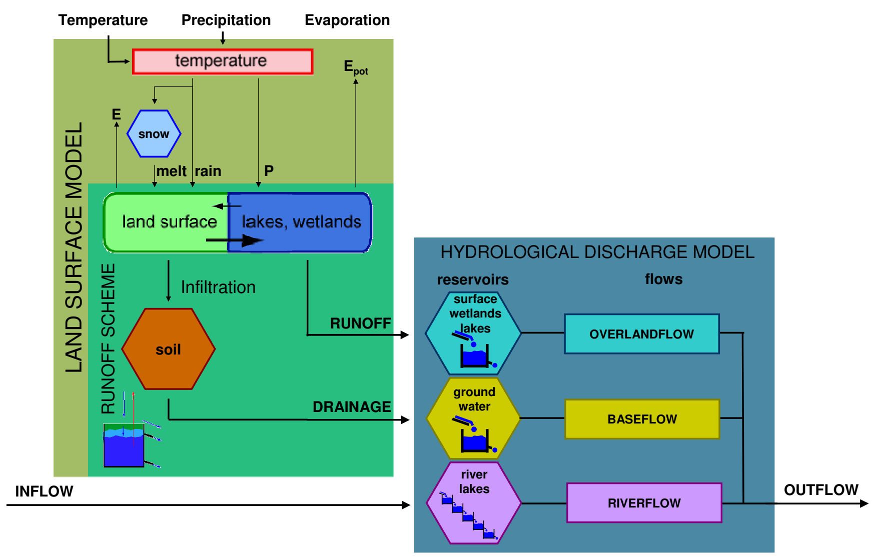

Figure 2: Connecting land surface model to hydrological discharge model HDM via runoff and drainage.

spheric models comprise their own land surface model to obtain correct atmosphere-land boundary conditions. Unfortunately, the weather models from the European Centre for Medium-Range Weather Forecasts (ECMWF) and the National Centers for Environmental Prediction (NCEP) do not provide appropriate runoff and drainage data for HDM. Only the output from the atmospheric climate model ECHAM fits directly for HDM (approach 1). The dynamically coupled model ECOCTH (ECHAM+OMCT+HDM) follows also approach 1. To use HDM with atmospheric data from ECMWF's re-analyses ERA40 or analogous data from NCEP the Simplified Land Surface scheme (SLS; Hagemann & Dümenil, 2003) has been implemented (approach 2). SLS processes precipitation and temperature to generate runoff, drainage and also its own evaporation estimates. In long term studies the SLS+HDM combination exposes several deficiencies concerning mass conservation. Consequently, a new model setup, based on SLS and HDM, has been developed. This Land Surface Discharge Model (LSDM; Dill, 2008) ensures internally consistent water mass fluxes between land surface and HDM. Further, it implies the incorporation of glaciated regions, the option to import evaporation rates from the weather model, and conservative mass exchanges among the connected Earth's sub-systems and models avoiding standard interpolation schemes. It turned out that evaporation rates consistent with precipitation are crucial in the atmosphere-land coupling. Estimating precipitation and evaporation within two different land surface models, as in approach 2, provokes critical errors in the global water budget due to unsynchronized land surface water balances. Therefore, LSDM operates with evaporation rates from the same atmospheric model as precipitation (approach 3). Compared to the simple temperature based evaporation modelling in SLS the ECMWF evaporation benefit notable from the more sophisticated treatment of wind, radiation, and humidity in their land surface scheme TESSEL (Beljaars & Viterbo, 1999). The ECMWF evaporation correlates higher to local precipitation events and can compensate precipitation overestimations.

2. DISCHARGE VALIDATION

The continental discharge of HDM strongly depends on the atmospheric forcing, primarily on the precipitation data. This dependency is more pronounced in models using the SLS land surface module for evaporation (approach 2) than in models using ECHAM runoff and drainage (approach 1) or the ECMWF's evaporation (approach 3). ECHAM and ECMWF comprehend a much more complex land surface modelling. The monthly precipitation means of atmospheric weather models indicate generally a slight overestimation compared to observed climatological values from the Global Precipitation Climate Centre (GPCC). In contrast, the climate model ECHAM produces too low annual precipitation amplitudes, i.e., only 40% of that suggested by GPCC, coming along with less variability. In total, the correlation of monthly mean precipitation rates from GPCC with NCEP is 0.9, with ECMWF 0.8 and with the unconstrained climate model ECHAM 0.4. Detailed analyses of all atmospheric forcing fields can be found in Walter (2008).

Due to the lack of globally distributed water storage measurements the HDM has been validated indirectly by comparing modelled river discharges with in-situ river runoff observations from the Global Runoff Data Centre (GRDC) at 142 selected stations. In general, HDM shows a very good agreement for all Arctic river catchments. In contrast, some African rivers are not satisfactorily reproduced due to especially high evaporation rates and anthropogenic influences not represented by the atmospheric nor by the hydrological model (e.g., irrigation, dams). The various atmospheric forcing data result in significant differences in the simulated river discharges. Forcing with re-analyses data from ECMWF or NCEP naturally leads to more realistic discharges than simulations driven by the climatological ECHAM data. The coupled model ECOCTH produces slightly lower annual runoff amplitudes than the corresponding ECHAM5+HDM stand-alone simulations. In Middle- and South-America, in the Congo basin and in the monsoon regions of South-East-Asia these differences reach up to 20%. A comprehensive verification based on statistical analyses has been done by Griesbach (2004).

3. HYDROLOGICAL ANGULAR MOMENTUM (HAM)

Unlike the oceanic angular momentum (OAM) and the atmospheric angular momentum (AAM) the HAM time series are dominated by mass variations, the matter term, while relative motions of water masses in rivers are subordinated. Contributions from the motion term come mainly from seasonal variations in river flows with magnitudes three orders lower than the matter term. The most significant annual amplitudes in HAM reflect the different magnitudes of the precipitation forcing fields. Differences in the corresponding phases might be associated with the use of different land surface models resulting in diverse snow melting seasons and soil moisture capacities.

Inconsistencies in the hydrological modelling appear as long-term trends in the HAM functions. Fig. 3 gives the three components of the HAM matter term ERA40 forced simulations using approach 2 and 3. The positive trend in SLS+HDM (blue) is eliminated when using LSDM. ECHAM5+HDM or ECOCTH results show less seasonal variability in HAM but they are also free of linear trends. Daily updated HAM functions and low degree gravity coefficients from LSDM, forced by ERA40 and operational ECMWF analyses, are routinely produced and can be accessed via anonymous FTP from:

FTP.GFZ-POTSDAM.DE public/ig/dill.

4. CONCLUSIONS

The hydrological discharge model HDM is capable of reproducing continental water mass variations on a global scale. On seasonal time scales the good agreement of modelled gravity field variations with estimates based on GRACE observations suggest that the HDM realistically represents variations of continental water mass storage. Using the HDM in a closed model system to simulate water mass exchanges among the three Earth subsystems atmosphere, ocean and continental hydrosphere offers the possibility to assess deficiencies in the global hydrological cycle, in particular inconsistencies in the mass fluxes between the sub-models are detected by long term trends in the hydrological angular momentum functions caused by accumulated water mass losses. We recommend the use of inter-coordinated atmospheric forcing fields and a mass-conservative remapping to obtain well balanced mass fluxes among atmosphere and land surface. The ECOCTH (approach 1) and the LSDM model (approach 3) satisfy these requirements for the generation of long term global geodetic parameters. However, over glaciated regions both models

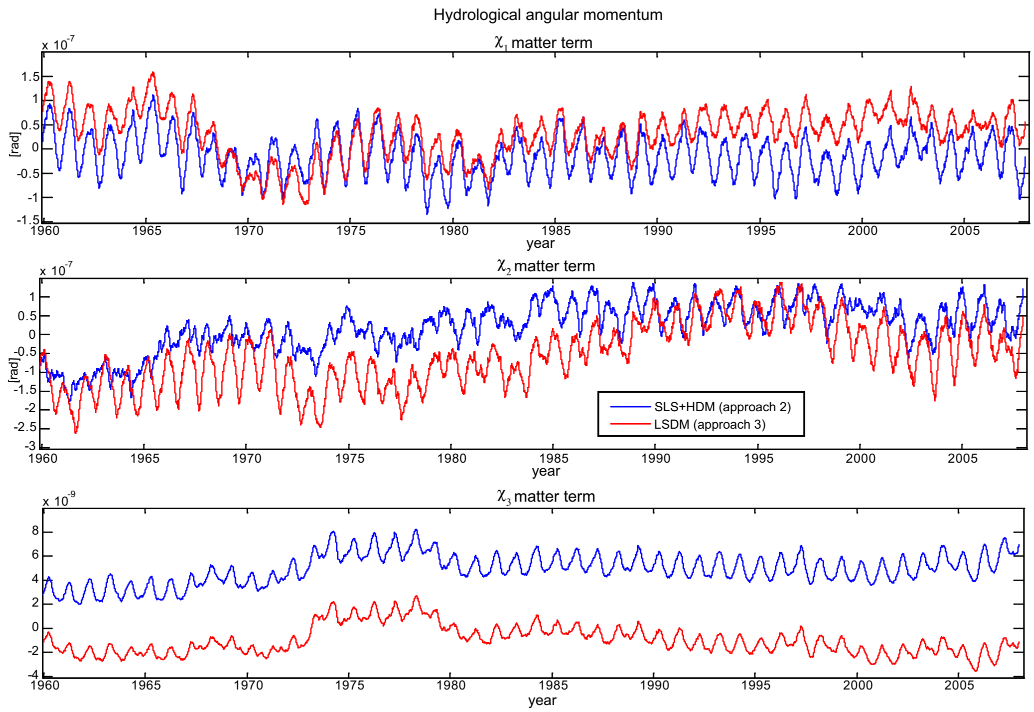

Figure 3: Three components of HAM matter term, simulated with ERA40 forced SLS+HDM (approach 2) in blue and LSDM (approach 3) in red.

still suffer from the absence of a sophisticated ice model. The dominant impact on continental water mass distributions arises from atmospheric forcing conditions, mainly from the precipitation-evaporation budget. Forced simulations with reanalysis data from atmospheric weather models have naturally a more realistic real-time relation than unconstrained atmospheric climate models, such as ECHAM5 and ECOCTH. The dynamical coupling of atmosphere and ocean in ECOCTH has only subordinated influence on the continental hydrosphere resulting in a slightly lower variability and better seasonal time relation compared to ECHAM5 forced HDM stand-alone simulations.

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