The global continental water balance using GRACE spaceborne gravimetry and high-resolution consistent geodetic-hydrometeorological data analysis – Phase II

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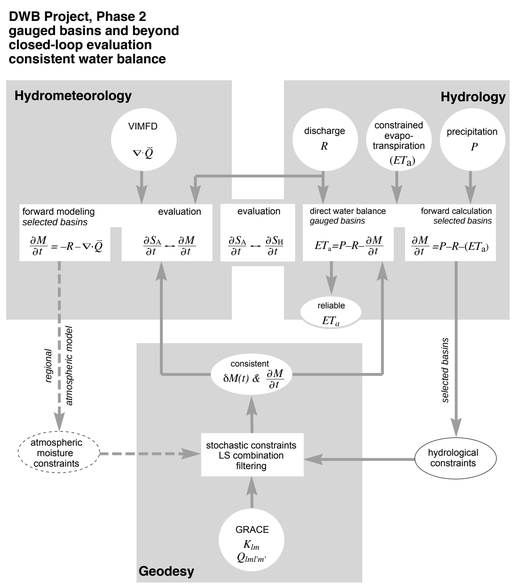
DirectWB

Lessons learned from Phase I

- The identification of areas and times of constrainable water balance ($ET_\mathrm{a} \approx 0$) provides a sound basis for the evaluation of GRACE and hydrometeorological mass change rates by hydrological groundbased measurements under different climatic and physiographic conditions.
- The use of monthly residuals in data comparisons increases sensitivity due to the elimination of the mean seasonal behaviour and thus allows for a detailed investigation of uncertainties.
- Atmospheric moisture flux divergence provides an independent data source. Respective hydrometeorological data usually fit much better to hydrological data than GRACE – especially for high latitudes. This allows to separate contributions from climatic variations and intrinsic errors.
- Experience in the choice of filtering methods and with the respective handling of huge variance-covariance matrices for GRACE Level-2 products plays an essential role for an adequate compatibility with hydrometeorological and hydrological data.
- Regional modelling of moisture flux seems to improve consistency with meteorological and hydrological data.

Phase II Objectives

- Quantification of the accuracy of continental water balance on the basis of geodetic, hydrological, and hydrometeorological data.
- Improvement of GRACE-derived storage change by hydrological constraints in sequential estimation framework
- Implementation of EOF-based filters in filter bank and systematic analysis of its effectiveness to GRACE-based mass estimates.
- Forward modelling and evaluation of regional atmospheric moisture fluxes and related storage changes for additional catchments using also 10-day and short-arc regional GRACE solutions.
- Investigation of water budget closure in the regional atmospheric model for pilot regions.
- Direct determination of monthly actual evapotranspiration ET_a for gauged catchments.
- Development of a regionalization approach for ET_a based on climatic and physiographic conditions.
- Evaluation of hydrological and atmospheric model approaches.
- Evaluation of potential use of atmospheric moisture constraints in sequential estimation framework.

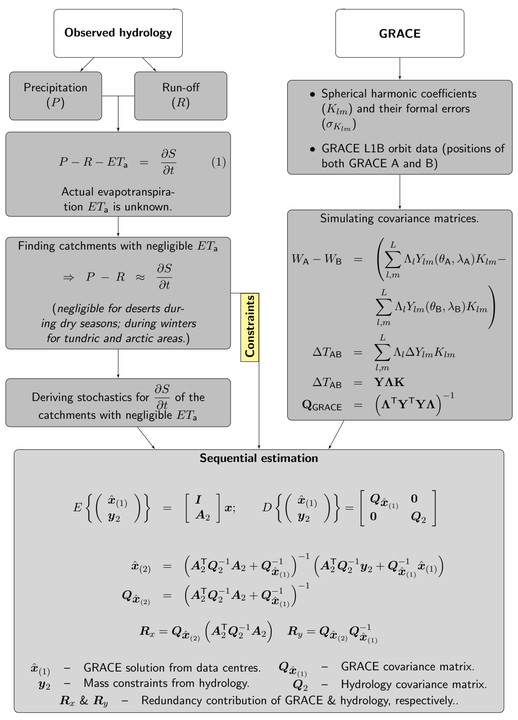


Geodesy

Motivation & Objectives

- GRACE derived mass change rates are often unrealistic when compared to selected catchments where hydrological mass change rates are known (cf. Phase I).
- Reliable hydrology mass change rates can be used as stochastic constraints *to improve the accuracy of GRACE mass change rates*. Since GRACE errors are highly correlated the constraints will "leak" outside the confines of the constrained catchments.
- *A sequential estimation scheme will be used to stochastically constrain GRACE mass change rates with hydrological mass change rates.* A proof of concept has already been created and presented at European Geosciences Union General Assembly meeting, Vienna, 2008.

Constraining GRACE with observed hydrology



- Use of Kaula-type power law for temporal gravity changes, developed in phase 1, as a weak constraint in the sequential estimation scheme.
- Investigation of the time evolution of the Kaula-type power law.
- Determination of the appropriate domain for parameterization in the sequential estimation scheme.
- Use of simulated GRACE variance-covariance information for sequential estimation, when there is lack of complete variance-covariance information for GRACE.
- Addition of inter-catchment correlations to the stochastic hydrological constraints.
- Evaluation of the suitability of atmospheric constraints in the sequential estimation scheme..

Other activities & Outlook

- Maintenance of the filter bank from phase 1.
- Addition of EOF-based filters to the filter bank.
- Evaluation of central difference methods and the artificial correlations induced by them between the statistically independent monthly GRACE data.
- Computation of a proof of concept for a simple Kalman filtering scheme.

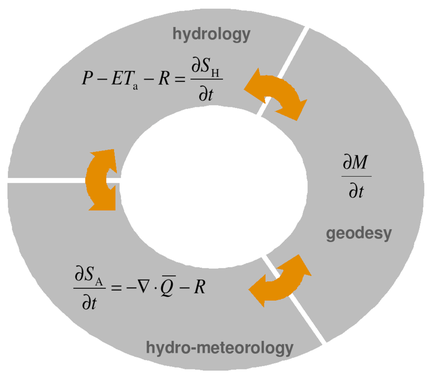
Hydrology

Motivation & Objectives

- For a reliable direct determination of monthly ET_a from the closure of the water balance there is need for a high quality quantification of errors in GRACE mass change rates on basin scale
- Differences between modelled and measured mass changes cannot be uniquely assigned to instrument errors or to insufficient hydrological model approaches at the moment.
- Due to considerable variations in ET_a hydrological and atmospheric models cannot be used as a reference for the evaluation of a seasonally variable, continental gravity signal (PILPS, AMIP studies)
- The only reliable basis for an evaluation of GRACE measurements on large scales are areas and times of known water storage changes by groundbased measurements.

Methods

- Areas and times of constrained water balance i.e. limited ET_a (high latitude / altitude regions) and hydrological inputs (deserts)
  - Improvement of selection schemes using additional climatic data (temperature, humidity etc.)
  - Selection of areas and times with large mass change rates and limited ET_a (snow accumulation / melt) to bridge the gap between small and large signals
- Independent data from atmospheric moisture flux (partly model based) :
  - Need for evaluation versus groundbased measurements
  - Quantification of moisture flux uncertainty versus constrained water balance
  - Direct comparability of $\frac{\partial S_\mathrm{A}}{\partial t}$ with GRACE $\frac{\partial M}{\partial t}$ (without constraints on ET_a).



  - Use of VIMFD = $P - ET_\mathrm{a}$ for independent determination of ET_a
  - Use of VIMFD and GRACE $\frac{\partial M}{\partial t}$ for determination of R in ungauged catchments
- Statistical characteristics of GRACE, atmospheric and hydrologic data and their mutual relationship:
  - Specific spatial properties of signals and residuals
  - Separation of signals and residuals with respect to climatic variations and intrinsic error
  - Quantification of impacts from filters and basin properties (areas, shape, latitude)
  - Formulation of new stochastic approaches of geodesy to improve the regional GRACE signals.

Outlook

Impacts of climatic and physiographic conditions (land use, soil, topography) and state of water storage on direct ET_a :

- Evaluation of existing hydrological models
- Evaluation of global / regional atmospheric models
- Development of a regionalization scheme for direct ET_a
- Evaluation of ET_a forecasts at gauged catchments
- Evaluation of runoff forecast for ungauged catchments (Phase III).

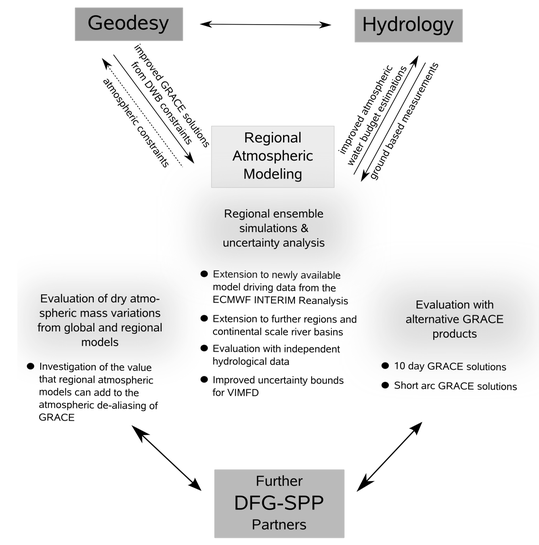
Hydrometeorology

Motivation & Objectives

Insufficient consideration of regional conditions (topography, land use) within global atmospheric models :

- Forward modelling, evaluation and validation of atmospheric water budgets and use of the approach with continental scale river basins.
- Comparison of $\frac{\partial S_\mathrm{A}}{\partial t}$ and $\frac{\partial S_\mathrm{H}}{\partial t}$ for regional and global datasets
- Evaluation of atmospheric water budgets with independent hydrometeorological data and quantification of VIMFD uncertainties.

Methods



- Extended evaluation
  - Forward modelling, evaluation and validation of atmospheric water budgets and extension of the approach to additional continental scale river basins
  - Comparison of $\frac{\partial S_\mathrm{A}}{\partial t}$ and $\frac{\partial S_\mathrm{A}}{\partial t}$ for regional and global datasets
  - Evaluation of atmospheric water budgets with independent hydrometeorological data and quantification of VIMFD uncertainties
  - Closure of modelled joint atmosphere- land surface water balance
- Regional atmospheric simulations
  - New ECMWF Reanalysis data (available in 2009) will be evaluated with the hydrometorological approach
  - The potential of FDDA (four dimensional data analysis) to further improve atmospheric water balances is assessed
  - In the WRF model runoff is produced at the lower model boundary, hence the model's internal water budgets will be evaluated where possible (discharge observations)

Other activities & Outlook

- Unquantified effects of temporal and spatial resolution in GRACE signals
  - Comparison of atmospheric water budgets with innovative GRACE products like 10-day solutions from GFZ or regional short-arc GRACE solutions from University Bonn
- Air mass variations
  - Quantification of the differences that emerge from global and regional fields of vertically integrated atmospheric mass
  - Provision of high resolution pressure fields for the de-aliasing of regional GRACE solutions (Uni Stuttgart; Uni Bonn) and for the atmospheric de-aliasing of groundbased gravitational measurements (superconducting gravimeters, GFZ Potsdam)
- Continuation of the joint atmosphere land-surface water balance approach and comparison to products 1) with higher spatial and temporal resolutions and 2) of upcoming missions like GOCE
- Evaluation of the suitability of atmospheric mass constraints for the Direct Water Balance approach

Phase III Outlook

- Evaluation of direct water balances for all investigated catchments and climatic zones.
- Use of atmospheric moisture constraints in the sequential estimation framework.
- Determination of runoff from ungauged catchments from gravimetric, hydrological, and hydrometeorological data.
- Global determination of monthly runoff from land masses.
- Analysis of short-term trends and anomalies in observed temporal mass variations with respect to climatic variations as contribution for the separation of mass signals from geophysics.