The improved hydrological gravity model for Moxa observatory, Germany

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Hydrological situation around the observatory Moxa

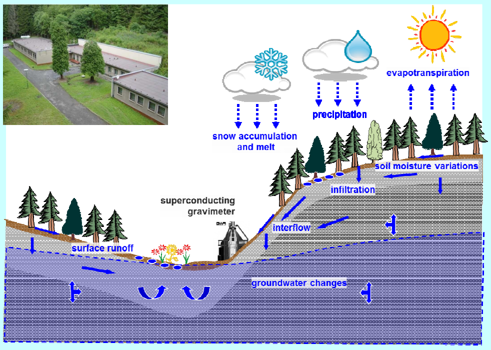

Fig. 1: Sketch of the hydrological situation in the Silberleite valley: precipitation causes mass movements above and below the sensor level of the SG. In addition, different flow paths are active for water transport from the hills to the valley (after Weise and Jahr 2015).

Introduction and aim of this study

The gravity variations observed by the super conducting gravimeter (SG) CD-034 at Geodynamic Observatory Moxa were compared with the GRACE results some years ago. Esp. at the location Moxa strong hydrological induced gravity signals are playing a decisive role, which has to be considered in the interpretation of the SG residual data. The basis of the correction model is a local hydrological model of the catchment of the small creek in the valley surrounding the observatory, which has been developed in cooperation with hydrologists. The transfer of the areal hydrological mass information to a 3d-gravimetric model has enabled the successful hydrological correction by Naujoks et al. (2010).

During the last three years the time series of the existing hydrological model were extended in period. In addition, the combined hydrological-gravimetrical modeling could be clearly enhanced. On the one hand, the direct surrounding of the gravimeter and the observatory building has been inserted into the gravimetric model in more detail, including mass changes above the gravimeter sensor in the soil layer on the observatory roof and the snow layer on top of the roof and topography. On the other hand, the model was extended for ground water. Both provisions clearly improve the hydrological correction, which is obvious from the increased correlation with results provided by the gravity data from the satellite mission GRACE (Weise and Jahr 2015).

Hydrological model

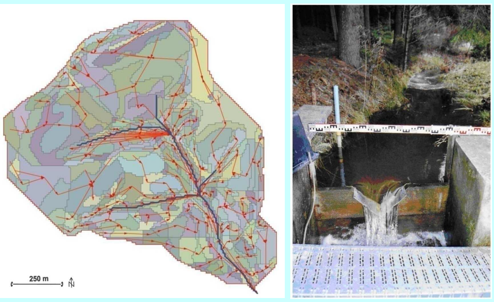

Fig. 2: The hydrological model around the Geodynamic Observatory Moxa. Left: The model consists of hydrological response units (HRUs) according to soil parameters and slope, discharging downhill along the given fluid paths (red arrows). Right: In front of the observatory building the runoff of the creek Silberleite is observed at the small weir. In addition, several divers installed in shallow drillholes distributed over the model area are measuring soil moisture changes (after Naujoks et al. 2010).

Modeling of local hydrology

Conceptual model J2000
Exemplarily for 3 soil horizonts
Modeling of water content in soil in HRUs
-> densitiy changes
Surface water DPS
Mid pore storage MPS
Large pore storage LPS

Input:
Snowmelt SM
Precipitation P
Throughfall TF/interception

Output:
Surface runoff SQ
Subsurface flow SSQ
Evapotranspiration ET
Flow into groundwater PERC
Comparison modeled vs. observed runoff

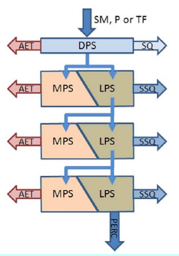

Fig. 3: Strategy of hydrological modeling (after Eisner 2009)

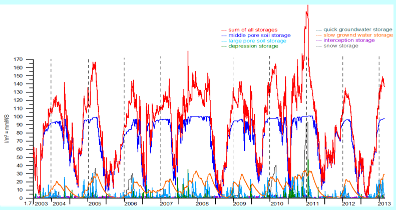

Fig. 4: Temporal change of model content in water storages

Hydrological gravity modeling

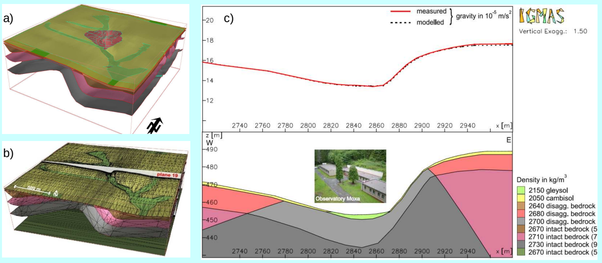

Fig. 5: 3d-gravity model IGMAS for hydrological density changes. a) model area with HRUs, b) model planes connected by triangulation with plane 19 crossing the observatory; c) plane 19: underground structures and measured vs. modeled gravity (Naujoks et al. 2010).

In a first step a 3d-gravity model was developed on the base of Bouguer gravity values and geological underground information (Naujoks et al. 2010) using the software IGMAS (Schmidt et al. 2011). The model describes the geological structures by 38 vertical planes whereas the direct vicinity of the observatory is much higher resolved (Fig. 6).

The results of the hydrological modeling are inserted by continuously changing densities dependent on the water content. In time steps of 1 hr the gravity effect due to water mass changes in the upper model units is calculated for the location of the superconducting gravimeter SG resulting in the hydrological induced gravity time series for correction of the local hydrological effect in the SG recording.

Modeling of local vicinity

The most recent finding beyond the work of Naujoks et al. (2010) is - after correction of the conversion to density:
the considerable more detailed modeling of the immediate SG-vicinity and observatory building is crucial and leads to improved results (Fig. 6):

- snow is stored on the roof above the SG;
- the plastic cover reduces humidity in the soil cover to ~30%
- building acts as shield -> humidity variations under SG estimated with ~10% of soil humidity
- improved geometry next to SG and topography
- slow ground water (up to 30 mmWC seasonal) included, partly in soil layer and deep layer which lets vanish the before apparent phase shift against satellite data.

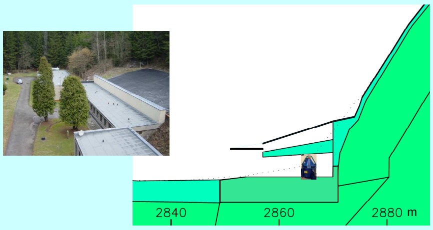

Fig. 6: Detail from gravimetric 3d-model through observatory

Modeled hydro-correction and SG-residuals

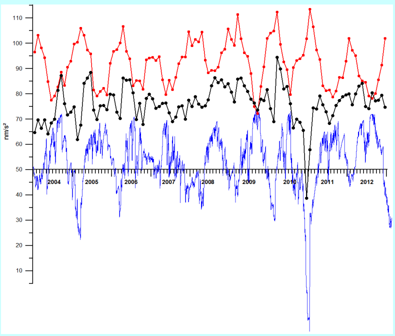

Fig. 7: Local hydrological effect 2004-2012 from combined hydrological and 3d-gravity modeling at SG site (blue) with seasonal variations, SG-gravity residuals (monthly) observed (black) and after hydrological reduction (red)

Hydrological reduced SG residuals compared with GRACE

The observed SG gravity residuals, reduced for tides, 3D-atmospheric masses, and drift in the range of 20 nm/s² to max. 57 nm/s² are without clear seasonal content. After subtracting the modeled local hydrological effect a seasonal signal of 30 - 40 nm/s² shows maxima in winter and minima in summer (Fig. 7).

The general agreement with satellite observations and with the global hydrological model GLDAS in magnitude and in phase is much improved (Fig. 8).

Agreeing structural details with GRACE e.g. in winter 2007/8 and 2008/9, and with GLDAS in autumn 2010 and 2011, and in summer 2005 and 2009 (minima) support the similar origin.

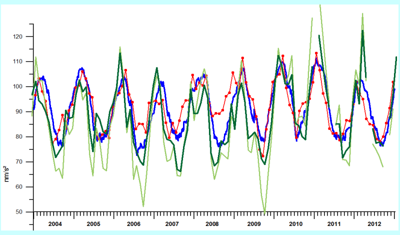

Fig. 8: Monthly gravity variations reduced for local hydrological effect (red; Fig. 7) compared with the global hydrological model GLDAS (blue, hourly samples) and to satellite data from GRACE (RL5 JPL) which are Gauss filtered (R=1000km, dark green) and DDK1 anisotropic filter (light green, Kusche 2007) is applied.

Modeling short-term events

A great challenge is the hydrologic induced gravity modeling of heavy rain events (Fig. 9) and/or the snow melting process. These short-term rainfall events start with sudden gravity decrease due to mass above the SG agreeing in amplitude and time. However, it is evident that the relaxation is to slow and not perfectly running back. Several models of flow of quick ground water in the slope show that, obviously, the model cannot describe the quick flow process of ground water within the slope under the observatory.

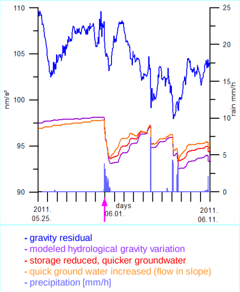

Fig. 9: Example of short-term gravity changes after heavy rainfall with three modeled versions of the hydrological induced gravity effect.

Conclusions:

1) Snow is stored on the roof of the observatory and on the ground above the SG,
2) Due to the plastic cover soil humidity in the roof soil coverage is reduced to 30 % (not zero)
3) Building acts as a shield leading to reduced variation of humidity beneath the observatory/SG, in clefts, estimated 10 %
4) Topography has been improved
5) Geometry next to SG is adapted more specific, e.g. pillar height, thickness of basement, height of rooms, cover layer in the roof
6) Constant thickness of units next to the SG is set for exact conversion of water storage to density change
7) Slow ground water has been included (up to 30 mmWC). The equivalent density change has been included in the gravimetric model partly in the soil layer and partly in the deeper layer. The impact in the seasonal amplitude of gravity change at the SG site is about 20 to 30 %. The apparent phase shift against the satellite data vanished after including the slow ground water.

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