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Hydrology and Earth System Sciences Discussions

Interactive comment on "The benefits of gravimeter observations for modelling water storage changes at the field scale" *by* B. Creutzfeldt et al.

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Dear Ty Ferré,

We would like to thank you for your positive review and for your comments on our paper. We believe that they helped to substantially improve the manuscript and we responded to all comments.

Comment: This paper falls neatly in the framework of coupled hydrogeophysical analysis, which we have discussed in some recent papers (Hinnell et al., 2010; Ferré et al., 2009). In this case, the authors present compelling evidence of the advantage of elim-

inating independent geophysical inversion in favor of incorporating a gravity forward model into hydrologic investigations.

Answer: We are including a short discussion of coupled hydrogeophysical analysis in the introduction (P2225 Z16): "Different strategies exist to parameterise/calibrate a hydrological model with geophysical measurements. Frequently, geophysical data are integrated into a hydrological model by inverting the geophysical data to estimate the spatial distribution of geophysical properties. Hydrological quantities are then derived from the estimated geophysical properties and the hydrological model is parameterised/calibrated based on these quantities (uncoupled hydrogeophysical inversion). Contrary to that, a coupled hydrogeophysical inversion framework, as presented by Ferré et al. (2009), directly infers hydrological quantities from geophysical measurements. Geophysical data are interpreted for hydrological research by coupling hydrological and geophysical models during inversion (Hinnell et al., 2010; Rings et al., 2010; Rucker, 2009). For this study, this means in practice that we use (1) a hydrological model with a certain parameter set to calculate the WSC, (2) a geophysical model to calculate the gravimeter response to these WSC and (3) the SG data to assess the parameter set by comparing them to the modelled gravity response."

Comment: My only question regards their comparison with a lysimeter While I agree that this represents the best available method to measure water exchange under spatially uniform conditions, there is the question of whether the lysimeter's measurement scale is representative at the field scale. The authors mention this in the final two paragraphs of the conclusions, but I think that a more developed discussion of the advantages and challenges of using gravity under spatially heterogeneous conditions would round out the paper nicely. For example, could they describe how they could test for the impacts of heterogeneity using their current modeling framework?

Answer: Based on this comment and also to take into account the comments of the other reviewers, we will explain in more detail why we focus on the water storage distribution only over depth neglecting lateral variability (P 2229 L21): "As a simplifying

assumption to approximate the complex and open hydrological system, we consider water storages to vary over depth, neglecting lateral variability of water storages. This assumption was motivated by the fact that at the scale relevant for the gravimeter, the variability of WSC over depth is much more important than the lateral variability of WSC. This is given because water storages are controlled by the driving processes like infiltration, evaporation, plant water uptake, deep drainage, groundwater recharge or groundwater discharge, as well as by internal properties of the system such as soil hydraulic properties or macropores. At the scale relevant for the gravimeter, these first order controls of water storages differ significantly over depth, whereas a lateral continuity is given for most of the processes and landscape features."

Hence, it would be difficult to consider lateral variability of WSC using a generalised and simplified conceptual model. The results of this study indicate that SG measurements, too, can neither resolve the detailed and complex process nor the high spatial variability of WSC. In this context, SG measurements are in accordance with the nature of conceptual models. However, we agree that spatial variability of WSC and the scale issue need to be addressed in gravimeter studies and we will extend the discussion of spatial variability (P2241 L20): "In this context, gravimeters might contribute to upscale point measurements to the field scale and will narrow the gap to the catchment scale. Hence, temporal gravity measurements should also be investigated in the context of the lateral variability of water storages. For example, as a next step at the Geodetic Observatory Wettzell, the spatial variability of water storages will be investigated along the hillslope using a physically-based hydrological model in a coupled hydrogeophysical inversion framework. Additionally, different concepts of spatio-temporal variability and stability (e.g., Western et al., 2004; Vereecken et al., 2007; Teuling and Troch, 2005; Brocca et al., 2010; Grayson and Western, 1998; Kachanoski and de Jong, 1988; Vachaud et al., 1985; Famiglietti et al., 2008) should be evaluated in the context of gravity observations (e.g., Glegola et al., 2009). These theories were developed and tested based mainly on near-surface water storage, but only very few studies used data from deeper zones (e.g., Pachepsky et al., 2005; Kachanoski and de Jong, 1988). So,

it might be problematic to apply them directly to gravity measurements. At the same time, this reveals the potential of gravity measurements to test the developed theories of spatio-temporal variability in combination with different spatial scales not only for near-surface water storages but also for the whole hydrological system."

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