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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Hydrological Signals in Tilt and Gravity Residuals at Conrad Observatory (Austria)" *by* Bruno Meurers et al.

Anonymous Referee #2

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This study reports on the effects of precipitation and snowmelt events on the recordings of a gravimeter and of tiltmeters that are located in an underground observatory. In both instrument types, signals related to these events can be recognized with different amplitudes and evolution in time. With this comparative analysis, the study makes a potentially valuable contribution to HESS in illustrating how geodetic monitoring methods might be of use for unraveling hydrological processes and water storage dynamics. However, in this perspective and to make the manuscript more accessible to the hydrological community, I suggest a revision of the manuscripts in particular with respect to the following:

In its present form, the manuscript does not make sufficiently clear how environmental processes such as variations in hydrological state variables (water storage) or water

fluxes may translate into the observation of the monitoring devices used here, i.e., gravimeters and tiltmeters. Given that the hydrological community is hardly familiar with gravimeters, and even less with tiltmeters, large part of the interpretation of the monitoring data presented in this study remains unclear or inconclusive to the reader as the basic idea behind these instruments is not sufficiently laid out.

Thus, I suggest to include in a revised version of the manuscript an introductory part that illustrates the measurement principle of gravimeter and tiltmeters and the influencing factors, and sets up general hypothesis how hydrological dynamics might be seen by these instruments, probably also highlighting in which way the instruments react differently to the same process. On these grounds, in the results and discussion chapters of the manuscript, explaining and discussing the observations at the Conrad Observatory can then be more clearly presented in particular with respect to the following issues:

- "Gravity and tilt residuals are associated to the same hydrological process but have different physical causes." (Abstract,). What exactly are the physical causes that makes the difference between the instruments if the fundamental hydrological process is the same?

- The "cavity effect" is mentioned in several instances throughout the manuscript as an influencing factor (abstract, line 177, line 229, line 262) but it is not further explained. What is it about and how can it influence the observations? How can thus the statement "Because the tunnel axis is oriented in E-W direction, the N-S component corresponds to the tilt perpendicular to the tunnel axis and therefore is extremely sensitive to cavity effects." (line 177) be explained?

- Additional explanations to the two points before may also shed more light on "…because tilt is affected by the topography and by geometry and size of the cavity where the tilt meters are installed" (line 33). This sentence is not intelligible by its own for someone who is not familiar with tiltmeters.

- Line 227: "However, at long periods the air pressure signal in the tilt meter time series is due to geophysical/geodynamical reasons which are probably dominated by deformation due to air pressure loading." Also the gravimeter should be sensitive to loading effects that are associated with vertical displacements, right? Can this be jointly analyzed? More basically, even the term 'loading' might need to be explained for a hydrological reader.

- "Newtonian acceleration" Newtonian effect" (line 230, line 241) on the gravimeter needs to be explained with respect to water storage (mass) variations. Also, what is the difference to the 'Newtonian tilt effect' (line 243) seen by tiltmeters?

- Line 257: "… the observed total N-S tilt offsets as function of cumulative rain or the surface pressure load exerted by cumulative rain at the end of the respective rain event." Does a spatially uniform rain event cause a tilt signal? Probably not because also the surface pressure load is uniform? Thus, a tilt signal indicates spatially non-uniform rainfall?

- Line 262: "The short-term N-S tilt response is therefore interpretable as pure deformation effect (strain induced tilt) due to surface load, which is probably enhanced by the cavity effect." What does strain-induced tilt mean? How does this relate to the "cavity effect"?

- Line 274: "Therefore, deformation due to surface loading rather than due to pore pressure changes explains the observed short-term tilt signal." This statement is not clear a another effect is introduced that has not been explained before: how and why due pore pressure changes cause tilt signals? How do pore pressure changes relate to water storage changes that occur during a rainfall event?

- Line 298: "… a clear systematic tendency of the source azimuth (340° to 350°) is indicated." What does this mean? Needs some general introduction or explanation.

- Line 347: "It is not the physical source, but the hydrological process, which links the

residual anomalies of gravity and tilt." This statement is not clear. Is a hydrological process different from a physical source? What does this imply?

Other comments:

- Data section 2: I assume that there are no soil moisture or groundwater level data available at the observatory site or close to it? Is there a nearby river gauging station (or a smaller creek gauge) of which the discharge data could be used for comparing to the overall hydrological response of the study area?

- The manuscript ends rather abruptly. I suggest adding a concluding paragraph on what has been learned from this combined setup of gravimeters and tiltmeters towards their potential for unraveling water storage dynamics and hydrological processes, what are the limitations, what are additional observations that may be needed to disentangle ambiguities in these observations, or similar aspects.

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