Co-located tilt and gravity observations at Conrad Observatory

Bruno Meurers, Gábor Papp, Hannu Ruotsalainen, Judit Benedek, Roman Leonhardt

Short-term (a few hours) gravity and tilt residuals at the Conrad Observatory image water accumulation on the terrain surface. Long-term (more than a few days/weeks) gravity and tilt variations are frequently observed after long-lasting rain, heavy rain or rapid snowmelt. The residuals are obviously associated with the same hydrological process but have different physical causes. While gravity is most sensitive to the gravitational effect of water mass transport, tilt residuals indicate deformation caused by surface mass loading. N-S tilts are strongly affected by strain-tilt coupling due to the cavity effect of the observatory tunnel oriented in E-W direction.

Short- and long-term gravity and tilt residual anomalies observed between April 2016 and mid of November 2018 are clearly linked to the same hydrological process: rapid water accumulation at the ground surface due to heavy precipitation (rain/snow) or water infiltration into the ground after rainfall and rapid snowmelt. Short-term (a few hours) residual anomalies can be well explained by the accumulation of precipitation on the terrain surface and in the adjacent topsoil. Gravity residuals reflect the gravitational acceleration of accumulated water/snow, N-S tilt responds to the deformation caused by the load pressure of the water mass onto the terrain surface similarly as in case of air pressure variations (Fig. 1).

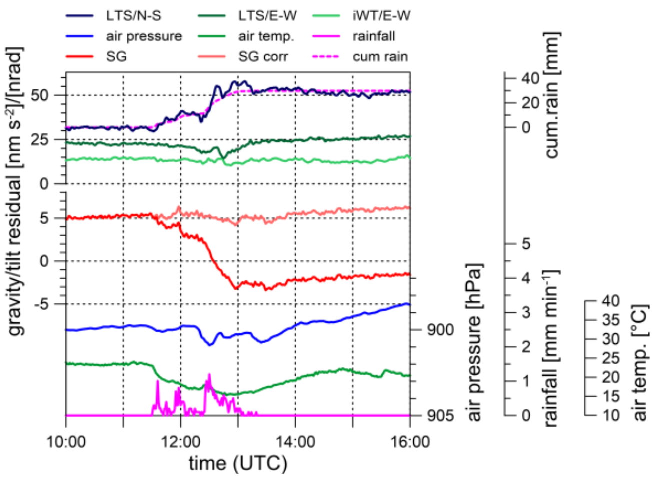

Figure 1: Effect of heavy rain on gravity and tilt at CO on July 11, 2016. Gravity and N-S tilt residuals show patterns clearly related to cumulative rain.

Slow water discharge brings the gravity residuals back to their initial level. However, particularly after long-lasting rain or rapid snowmelt, the residuals exceed the initial level remarkably due to downwards water flow (infiltration) from terrain surface into the ground until water is stored somewhere in the bedrock/soil below the SG sensor. This process probably starts as soon as the subsurface is sufficiently saturated by rain or snowmelt water and therefore needs a certain threshold to be triggered. During all of these events, strong long-term tilt anomalies appear as well with specific trends: N-S tilt shows always a steep residual drop and the E-W tilt residuals increase with much less amplitude. After 1-2 days, N-S and E-W tilts reach their maximum and then slowly decay to the previous level. This process lasts about 14 days or longer and occurs after sufficient water percolation into the subsurface, either after heavy/long-lasting rainfall or after rapid snowmelt (Fig. 2).

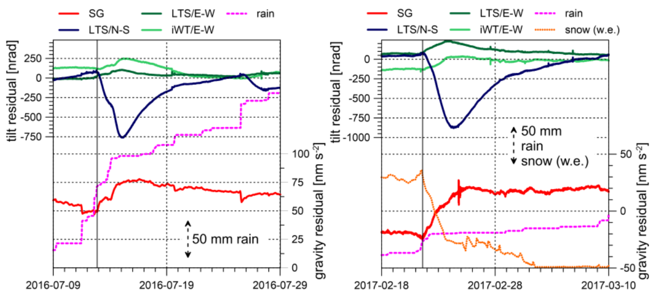

Figure 2: Long-term gravity/tilt residual signals after heavy/long-lasting rain (left) and rapid snowmelt (right).

Strain-induced tilt affects the N-S tilt considerably. Simplistic model calculations of the gravity residuals indicate high initial saturation (95%) or low porosity of the limestone rocks. Downwards water propagation has to be fast enough to store water below the SG sensor. Alternatively, a direct transport downwards along specific flow paths is required. The tilt residual anomalies can be explained by surface or subsurface deformation caused by either surface load (short-term) or water pressure changes in the adjacent fracture system (long-term).

References:

Meurers, B., Papp, G., Ruotsalainen, H., Benedek, J. and Leonhardt, R., 2021: Hydrological signals in tilt and gravity residuals at Conrad Observatory (Austria), Hydrol. Earth Syst. Sci., 25, 217–236, https://doi.org/10.5194/hess-25-217-2021.

Authors:
B. Meurers[1], G. Papp[2], H. Ruotsalainen[3], J. Benedek[2], R. Leonhardt[4]
1) University of Vienna, Vienna, Austria
2) Geodetic and Geophysical Institute, Sopron, Hungary
3) Finnish Geospatial Research Institute, Masala, Finland
4) Central Institute for Meteorology and Geodynamics, Vienna, Austria

Corresponding author:
Dr. Bruno Meurers
Department for Meteorology and Geophysics, University of Vienna
Althanstraße 14, UZA 2, 1080 Vienna, Austria
e-mail: bruno.meurers@univie.ac.at