Dynamic implications of temporal gravity changes over Himalaya-Tibet

Carla Braitenberg[1]

[1] Department of Mathematics and Geosciences, University of Trieste, berg@units.it

The time variations of gravity observed with satellite GRACE or with terrestrial measurements are due to the combination of ice-volume changes and hydrologic mass changes, that add to the effects of vertical crustal movements and tectonic mass changes. The vertical crustal movement is expected to generate a long-term effect, the hydrologic and ice-mass changes being both seasonal and long-term. The superficial mass variations generate a load variation which induces vertical isostatic crustal accommodation. Apart from the glacial isostatic response, vertical movements can be generated also by tectonic effects: exhumation typically in areas of plate convergence, and subsidence due to sediment compaction, post-seismic movements or subduction. At the Himalayan orogen the ongoing uplift has been measured by GPS, and rates of a few mm/yr are typical. The horizontal convergence rates are much greater, in the order of several cm/yr. As crustal material is not destroyed, it implies that the crustal material contributes to crustal thickening, which according to the isostatic degree of compensation is divided into topographic uplift and crustal root thickening.

These different mechanisms of mass transfer generate a change in the gravity field combined to different extents of changes in the topography. The observation of this mass transfer would give a useful constraint on understanding the mountain building process. In this study first a review of the observed gravity variations and geometry variations is given, based on published results. It is found that depending on the authors, contrasting conclusions are found regarding the interpretation. The gravity changes have been determined using satellite GRACE as well as through absolute gravity observations. These two data sets differ substantially, as the first gives a spatially averaged result with wavelengths typical of the spatial resolution of the GRACE satellite, whereas the repeated absolute measurements are point-like observations.

For the Tibetan plateau GPS observations give evidence that horizontal convergence is 3-4 times the uplift rate. The absolute gravity rate at Lhasa set at the South-Eastern border of the plateau is -1.97 ± 0.66 microGal/yr, and when corrected for the observed uplift and assumed erosional denudation remains negative at a rate of -1.56 ± 0.67 microGal/yr (Sun et al., 2011). The residual negative gravity rate has been interpreted as the observation of crustal thickening, in terms of Moho deepening, at a rate of 2.3 ± 1.33 cm/yr (Sun et al., 2009). Alternatively, Matsuo and Heki (2010), determine the gravity change from GRACE observations for 2003-2009 and attribute the yearly and long term gravity change to hydrologic effects which are concentrated at the outer border of the Tibet plateau, estimated to 47±12 Gigaton/yr ice-loss. These authors mention the uncertainty in the contribution of isostatic or tectonic uplift, but think the hydrologic effect to be preponderant in their observations. The GRACE observations were filtered with a Gaussian filter of radius 400km to reduce short wavelength noise. Yi and Sun (2014) extend the analysis of the GRACE satellite observations to 10 years.

Uplift may have the cause of a glacial isostatic movement, of crustal thickening, or a combination of both effects. The difference resides in the mass variations at Moho level: for crustal thickening the Moho is deepened, producing a negative gravity effect; in case of glacial isostatic accommodation the Moho is uplifting, and it produces a positive gravity effect. This signal adds to the positive gravity effect of the uplift, which increases the superficial mass. We here calculate simulations for the Tibet plateau, assuming different geometries and rates for crustal thickening and uplift rates and compare them with the published gravity changes. The simulations quantify the wavelengths and change rates of the expected gravity signal. Another product of the simulations is the so called “viscous ratio”, which is defined as the ratio between terrestrial gravity change rate from absolute gravity observations and the observed uplift, which

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in southern Alaska is between -0.1 to -0.2 microGal/mm (Sato et al., 2012), whereas in Tibet at the Lhasa station is much lower, -2.5 microGal/mm (Sun et al., 2009; 2011). This difference could be an indicator of the different mechanisms which are affecting the crust-mantle contact. The simulations contribute to define the requirements to future gravity missions apt to contribute to a better understanding of the genesis of the Tibet plateau.

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