Physical modeling of hydrological gravity changes observed by the iGrav-003 superconducting gravimeter in Southeast Alaska

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Crustal uplift of 3 cm/year at a maximum has been observed in Southeast Alaska, associated with glacier melting (Larsen et al., JGR, 2007). The crustal uplift includes (1) the Earth's viscoelastic deformation due to past glacier melting and (2) the Earth's elastic deformation due to present-day glacier melting, and the two effects can be separated by simultaneous observations of crustal deformations and land gravity changes (Wahr et al., GRL, 1995). However, the land gravity data is often disturbed by hydrological variations such as soil water infiltration and groundwater flow, so they need to be corrected from the original gravity data in order to understand the gravity signals due to glacier melting quantitatively. In particular, spatiotemporal water distributions near gravity sites should be modeled accurately, because most of the hydrological gravity disturbances are dominated by time variations in attraction force due to water mass around gravimeters.

We thus modeled the local water balance and consequent gravity changes at the EGAN gravity site in Juneau, Southeast Alaska, and compared the modeled gravity with the hydrological gravity disturbances observed by the iGrav superconducting gravimeter (serial number: 003). We first estimated the spatiotemporal distributions of soil water and groundwater around EGAN using the G-WATER [3D] software (Kazama et al., JGR, 2015), and calculated the time variation in attraction force ($g_1(t)$) by the spatial integral of the water mass distributions. We also estimated the attraction effect of lake water in Auke Lake (120 m from the gravimeter; 0.65 km^2) and accumulated snow on the site facility ($g_2(t)$ and $g_3(t)$, respectively), using the observed data of lake water level and snow depth. We finally calculated the total gravity value to be $g_{cal}(t) = g_1(t) + g_2(t) + g_3(t)$, and compared $g_{cal}(t)$ with the gravity change collected by the iGrav gravimeter ($g_{obs}(t)$).

The gravity change due to underground water ($g_1(t)$) had the highest amplitude of about 4 microGal in peak-to-peak, whereas the amplitudes of both $g_2(t)$ and $g_3(t)$ are about 1 microGal. The sum of the three effects (i.e., $g_{cal}(t)$) agreed with $g_{obs}(t)$ observed from September to December 2012, in terms of rapid gravity increase during precipitation events and gradual gravity decrease after the events. However, the amplitude ratio of $g_{cal}(t)/g_{obs}(t)$ was only 30% if the small value of $\tilde{}10^{-8}$ m/s was chosen for soil permeability in modeling underground water variations; strong capillary force in the low-permeability soil leads to high steady water content, and all of precipitation cannot infiltrate into the soil during the precipitation events because of little porosity left. We thus re-calculated the underground water distributions and consequent gravity changes ($g_1(t)$) using six different permeability values, and found that the amplitude ratio of $g_{cal}(t)/g_{obs}(t)$ became the highest value of 55% when the permeability value of $1.5*10^{-6}$ m/s was used in the G-WATER modeling. The permeability value is consistent with that of glacier silt, which is assumed to spread around the EGAN gravity site. The remaining 45% difference between $g_{obs}(t)$ and $g_{cal}(t)$ may lie in soil heterogeneity and/or regional hydrological variations, so direct measurements of soil parameters around EGAN are needed in the future, in addition to gravity calculations utilizing wide-area hydrological model such as GLDAS and WaterGAP.

Keywords: hydrological gravity change, superconducting gravimeter, iGrav, glacier, soil water, groundwater