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Hydrological modeling of gravity change associated with groundwater flow: application to Isawa Fan in northern Japan

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Gravity observation is one of the most effective methods in monitoring solid-earth activities (such as crustal deformations and volcanic activities), because mass redistributions associated with the activities can be detected as time variations of gravity value. However, the gravity variations are often masked by gravity disturbances originating from groundwater redistributions (i.e. groundwater disturbances). The groundwater disturbances must be effectively modeled and corrected in order to discuss the solid-earth activities with the observed gravity data.
Kazama and Okubo (2009) modeled the groundwater disturbance by simulating groundwater flow with hydrological physics. They found that the hydrological modeling can reproduce the time variation of the groundwater disturbance, such as gravity increase during rainfalls and gravity decrease after rainfalls. However, they showed the hydrological modeling only at Asama volcano, and they did not verify the effectiveness of the modeling at every area.
In order to verify the reproducibility of the hydrological modeling, we chose Isawa Fan (Ohshu city, Iwate prefecture) as the test area, because we can easily observe groundwater distributions and the gravity disturbance owing to the shallow water level (about 5 m from ground surface).
We observed groundwater and gravity at National Astronomical Observatory on Isawa Fan since 2008, and found that soil moisture, water level and gravity value increased simultaneously during rainfalls, associated with the water mass increase in surface soil.
We then simulated the time variations of groundwater distributions and gravity disturbance according to the hydrological modeling by Kazama and Okubo (2009) as follows. [1] We solved the diffusion equation of soil moisture for spatiotemporal moisture variation between ground surface and water level. [2] We then calculated the gravity value originating from groundwater (i.e. groundwater disturbance) with the integration of the estimated soil moisture distribution.
As a result, the time variation of the estimated moisture was consistent with the observed moisture within observation error range, in steep increase during rainfalls and exponential decrease after rainfalls. In addition, the estimated groundwater disturbance reproduced the observed gravity change (steep increase during rainfalls and linear decrease after rainfalls) within 1 micro-gal (RMS). However, the discrepancy became larger between observed and estimated gravity changes in snowfall season, showing the need for more accurate modeling of land water distributions, such as snow cover distribution and snow-groundwater interaction.

Keywords: gravity change, groundwater flow, Isawa Fan, superconducting gravimeter, snow cover