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GPS snow depth meter using interference between direct and reflected waves

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Multipath is the interference between direct microwaves from Global Positioning System (GPS) satellites and those reflected somewhere, and causes, e.g. measurement errors repeating every sidereal day (the orbital period of the satellites is a half sidereal day). Larson et al. (2008) attempted to infer soil moisture contents around GPS receivers by measuring the ratio between the direct waves and those reflected by the ground (the reflectivity depends on the water content near the ground). Here we report a method to measure snow depth as the change in apparent antenna height using the changing rates of the phase of the reflected waves, and compare results with AMeDAS snow depth meter observations. Larson et al. (2009) analyzed periodic variation of S/N ratio of the received signals caused by multipath. Because the GEONET RINEX data files do not include S/N ratio, here we used the phase differences (L4) between L1 and L2 carriers as another geometry-free quantity.

Elosegui et al. (1995) expressed the phase shift of received signal by multipath with four variables, namely the wave length, antenna height, elevation, and the reflectivity of the ground surface. We then converted these phases into length, and took the difference (L4) between L1 and L2. The obtained quantity is proportional to Total Electron Content (TEC), and is geometry-free, i.e. it does not depend on coordinates of GPS sites and satellites, or atmospheric delays. As the GPS satellite moves in the sky, elevation changes, and L1 and L2 phases of reflected waves also change in particular periods. The period becomes longer as the antenna becomes lower (because the change of excess path length gets slower). This enables measurement of snow depths because deep snow decreases the equivalent antenna heights.

In this study, we used data at GEONET site 950128 in Fujino, Minami-ku, Sapporo-city from February to April in 2009, and analyzed multipath components in L4 time series over two hours period before the satellite 21 sinks. Observing time window was shifted forward four minutes every day, to keep the direction of satellite same. We analyzed the spectrum of the observed short-period changes of L4, and found two frequency peaks (multipath frequency) corresponding to L1 and L2. The multipath frequencies of L1 and L2 without snow are -5 and -4 mHz, respectively, which correspond to the original GPS antenna height of 5 meters. The frequency becomes lower as snow pack develops, and the L2 frequency peak becomes lower by ~0.75 mHz when the snow depth reaches 1 meter. We separately calculated theoretical multipath frequencies to prepare the frequency-snow depth calibration curve in advance. Thus we got snow depth time series from daily multipath frequencies. The difference of reflectivity at the snow surface alters amplitudes of multipath components, but does not influence the multipath frequencies. Different calibration curves are needed for different GPS satellites or GPS sites.

We compared snow depth obtained by GPS with those measured at a nearby AMeDAS point. AMeDAS snow depth meters measure the travel time of the ultrasonic wave between the device and snow surfaces. It is located by -10 km from the GPS point, but both data agreed fairly well. There are several outliers in data, and we found that multipath peak was not cleanly identified in these cases. It might be due to anthropogenic disturbances of the snow surfaces where radio waves of the satellite 21 are reflected. We explore a way to avoid this by averaging snow depth data by a few different satellites.

References

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