Potential for Inferring Freshwater Lake Ice Thickness by GPS Interferometric Reflectometry

M. D. Jacobson
Montana State University Billings, 1500 University Drive, Billings, MT, 59101, USA

Recently, it has been reported that the refracted, reflected and scattered signals of global navigation satellite systems (GNSS) have been successfully used to remotely sense the Earth's surface and atmosphere. For example, it has been reported that reflected global positioning system (GPS) signals can provide useful information about the land-surface composition such as snow depth. From recent snow depth studies, this promising new technique has been given the name GPS interferometric reflectometry (GPS-IR). This method is basically an L-band ground-based interferometer. Its basic mechanism is the interference between the direct (line-of-sight) signal and the multipath signals, reflected from near-ground surfaces such as snow, ice, water, etc. Here, we explore the possibility of estimating freshwater lake ice thickness. In particular, a GPS receiver is located above a frozen lake. With this setup, the received power variations with respect to the changing satellite elevation angle are calculated and measured. A case study shows potential for inferring lake ice thickness by fitting the theory to the measurements using a nonlinear least squares fitting algorithm.

Freshwater lake ice information is important in the northern hemisphere. For example, the metrological conditions in the northern latitudes may be related to the ice thickness in lakes and rivers. In addition, this lake ice information is important because the ice cover's extent and duration has a major impact on the economy of this region. In particular, lake ice cover can impede commercial navigation; interfere with hydropower production and cooling water intakes; and damage shore structures. Furthermore, the measurement of freshwater lake ice thickness is also important for ice roads in the northern latitudes. The communities in these regions depend upon the ice roads in the winter season for various supplies.

On February 13, 2009, a Trimble Lassen LP GPS L1 (1.57542 GHz) receiver was used to test the theory by placing the receiving antenna above a frozen lake. The antenna was mounted vertically with a metal plate on a tripod in order to receive the direct and ground reflected signals with equal gain. The site was located 80 km southwest of Billings, MT, USA. The measured ice thickness was approximately 39.4 cm ± 1.3 cm; the *in situ* measurements were done on the backside of the antenna. Specifically, lake ice thickness is inferred by using measured GPS signals and calculated results from an interferometric reflectometry model. The difference of these two quantities is minimized with a nonlinear least squares fitting algorithm. Only low elevation angles (≤ 25°) of received GPS signals are used in this study. The possibility of estimating lake ice thickness by using the received GPS signals from satellite PRN 10 and the GPS-IR model is demonstrated from a 1-day experiment. For this satellite, the average inferred ice thickness (38.0 cm) slightly underestimated the *in situ* measurements (39.4 cm ± 1.3 cm). GPS satellites PRN 2 and PRN 24 were also used in this study. However, signals from these satellites significantly underestimated the *in situ* measurements.

Future research will use this technique to estimate different lake ice thicknesses without snow cover and with snow cover. Also, several ice holes will be manually drilled within the antenna's first Fresnel zone in order to verify the actual ice thickness along the antenna tracks. These measurements will quantify the spatial variability of lake ice thickness which is critical for this GPS-IR technique. The height of the receiving antenna will be increased to ~ 2 m in order to reduce potential biases in estimating lake ice thickness. Future theoretical work will include two or more ice layers, variations of ice thickness in the antenna viewing area, and the antenna cross-polarization component. In summary, if estimating freshwater lake ice thickness can be accomplished by GPS-IR then it may be more cost-effective than current techniques such as radar, radiometer or manually drilling. In addition, GPS-IR may provide better spatial and temporal coverage of lake ice thickness measurements than the present techniques.