LAKE ICE THICKNESS ESTIMATION USING GPS

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ABSTRACT

Reflected signals from natural and man-made features affect the reception quality for land-base Global Positioning System (GPS) receivers. The sum of the direct line-of-sight signal and the reflected signals constitute the total received signal at the receiver. These reflected signals can provide useful information about the land-surface composition such as soil moisture, ground electrical characteristics, snow depth or ice thickness [1] – [9]. Here, we explore the possibility of estimating lake ice thickness by using the GPS L1 frequency [10]. In particular, a GPS receiver is located above a frozen reservoir. 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.

Lake ice thickness measurements are important for two major reasons. First, these measurements improve the understanding and forecasts of the winter lake ecosystem. This is important because ice cover impacts the water balance of the lakes, lake flora and fauna by affecting energy and mass transfers from lakes and to the lakes. Furthermore, the duration and extent of ice cover on large lakes like the Great Lakes has a major impact on the economy of the region by impeding and eventually stopping commercial navigation, interfering with hydropower production and cooling water intakes, and damaging shore structures. Second, these measurements provide crucial control and monitoring information for ice roads. Ice roads play a crucial role of supplying northern communities with medical and other supplies in the winter season. Furthermore, these ice roads fuel the economy by supplying machinery, tools and fuel to various work sites. These sites exist primarily for the exploration and extraction of oil, gas, and diamonds.

A simple model depicting a water surface covered by dielectric layers is used to determine the relative received power at a GPS receiver. This model includes a vertically mounted hemispherical directional antenna with no sidelobes, a flat dielectric layer(s) of infinite extent above water, and uniform plane waves with a monochromatic frequency. The total field is the sum of the direct and specularly reflected signals at the right-hand circularly polarized antenna.

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 snow-covered 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 on Cooney Reservoir, approximately 80 km southwest of Billings, MT. This reservoir is approximately 3 km^2 in size and it freezes over in the winter season. The measured ice thickness was approximately 39.4 cm $\pm$ 1.3 cm. The measurements were collected throughout the day with partly cloudy skies with an average snow and ice temperature of $-2.2\,^\circ$C. A 0.3 cm thick snow layer was on top of the frozen reservoir. The liquid reservoir water temperature was at 0° C.

The theoretical model for this ice thickness range shows general agreement with three different GPS satellite measurements. These comparisons show that this technique may have enough sensitivity to discriminate different ice thickness values. The possibility of using GPS signals to estimate lake ice thickness is explored further by doing two theoretical comparisons. First, we compare the effects of different snow layer thicknesses on the received power as a function of elevation angle with a fixed ice-layer thickness. This theoretical comparison shows that the snow depth can be a significant factor in the received power pattern. In fact, the snow depth could limit the usefulness of this GPS technique in determining the ice thickness. Therefore, the snow layer needs to be included in this ice layer model when snow is present.

Second, we compare the effects of different ice layer thicknesses on the received power at two different elevation angles. In this comparison, a receiving antenna is fixed at a given height above a 0.3 cm thick snow layer on top of an ice layer with a variable thickness which is located above a water surface. The correct ice layer thickness is obtained by using the received power difference at two distinct elevation angles, the first deep fade's power value and the first deep fade's elevation angle location. Other sets of measurements might be appropriate for inferring the correct ice thickness. For example, inferring ice thickness might be possible by using the first deep fade's elevation angle value and a least squares fit between theory and measurement over a specified elevation angle range.

With the above encouraging results, the simulated power variations with respect to elevation angle for a particular snow-covered ice layer thickness could be fitted to the measured power variations. The resultant computed power variations might have the necessary information to infer an approximate lake ice thickness. If this technique is viable, then GPS signals could provide a new and economical technique for estimating lake ice thickness for tens of centimeters.

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