The Cryosphere Discuss., 6, C1997–C2001, 2012
www.the-cryosphere-discuss.net/6/C1997/2012/

The Cryosphere Discussions

TCD
6, C1997–C2001, 2012

Interactive Comment

Interactive comment on "Ground penetrating radar detection of subsnow liquid overflow on ice-covered lakes in interior Alaska" *by* A. Gusmeroli and G. Grosse

A. Gusmeroli and G. Grosse

agusmeroli@alaska.edu

Received and published: 29 October 2012

We would like to thank Drs A. Heilig and S.E. Hamran for their constructive reviews. Both reviewers address technical details that need to be incorporated and will improve our manuscript. Heilig comments are particularly important. He pointed out that (i) our determination of radar reflectivity is faulted because we did not correct for geometric spreading. He also noticed that (ii) the dielectric properties of slush that we use in our model (Table 1 and Figure 6) are inaccurate. (i) Our response for this was published in our short comment [http://www.the-cryosphere-discuss.net/6/C1558/2012/tcd-6-C1558-2012.pdf]. The suggested corrections do not change the main discovery of our study: the presence of subsnow water coincides with drastic changes in (albeit corrected) radar reflectivity. This is because the thickness of the snow-layer is generally uniform and the geometric correction affects flooded and unflooded areas . (ii) This comment affects the assignment of dielectric parameters listed in Table 1. Here we have attempted a simple modeling exercise to quantify the dielectric properties (and the water content) of the slush. It is important to include correct parameters and therefore we will incorporate AH comment with a paragraph which will discuss the dielectric properties of slush following the suggested framework. However, corrections in this respect will only slightly change the numbers in Table 1 and Section 4.1. Detailed answers to all reviewers comments (excluding editorial) are listed below. I thank editor and reviewers again for their help in evaluating and discussing our work with us. Yours sincerely, Alessio Gusmeroli and Guido Grosse. Fairbanks, Alaska.

REVIEW BY ACHIM HEILIG AH: The manuscript by Gusmeroli and Grosse: "Ground penetrating radar detection of sub- snow liquid overflow on ice-covered lakes in interior Alaska", is an interesting feasibility study for the application of ground-based GPR in detecting these overflows. They could show that as soon as water is present at the snow-ice interface, signal amplitudes at this interface increase significantly and thereby allow for overflow detection. I recommended reconsidering this manuscript after major revisions mainly just because I have concerns about the processing applied on the radar data and because the determination of the effective dielectric permittivity values of the so called "slush" is wrong. This error has an influence on the modeling results and thereby will change the conclusion after correction as these values go directly into the model. AG: http://www.the-cryosphere-discuss.net/6/C1558/2012/tcd-6-C1558-2012.pdf AH: (1) I recommend applying a proper processing on all the radar data. At least you must compensate for divergence losses (gain), if you compare reflection amplitudes originating from different distances to the radar transmitter. This comparison is pretty much the basis of the presented work. As snow depths do not vary that much, you might not see a huge difference on SLO/ noSLO values but on page 3087 line 1-10 you discuss various ice thicknesses and the magnitude of reflection. Spherical divergence losses are a contributing factor and after compensation you might receive different results. AG: http://www.the-cryosphere-discuss.net/6/C1558/2012/tcd-6-C1558-2012.pdf AH: (2) The determination of the effective dielectric permittivity is wrong (page 3086, L10- 13). "Slush" is not a 2 phase dielectric medium, you have to apply a 3-phase mixing formula! Snow already consists of 2 phases (air, ice) and after water percolated through the snowpack (or in your case flows into the snowpack) you have to deal with 3 phases. Mitterer et al (2011) for example discuss these circumstances in detail. You definitely want to apply a formula in way like this: eps_eff=(theta_w*eps_wËĘbeta+(1- n)eps_iËĘbeta+(n-theta_w)*eps_aËĘbeta)ËĘ(1/beta) (e.g. Perla, 1991; Roth et al., 1990). The parameters have to be set in accordance to the prevailing conditions. Further- more, volumetric liquid water content of theta_w=0.3 is really high, you are already in the funicular regime. AG: We will discuss the dielectric properties of slush following the framework suggested and we will correct the numbers in Table 1 and the estimates of water content provided in Section 4.1 AH: (3) The methodology needs to be revised. You do not explain how the spectral amplitude was calculated in the manuscript. There is a short hint in a figure caption, however, this needs to be explained in the methodology AG: This was also pointed out by SH. In the revised manuscript we will include more details about the processing steps. AH: (4)I would like to see the occurrences of SLO in the overview maps you plotted. A spatial distribution along the radar transects might help the reader to identify spots of SLO on those lakes. AG: Sure, we will plot the spatial occurrence of SLO. AH: (5)Your figure arrangement is very confusing. Please try to be consistent (clockwise, counterclockwise...). AG: Also SH made the same point. We will be consistent in the revised manuscript. AH: (6) You got confused by this arrangement by yourself for Fig 2 (p.3084 l.1-10). The figure references are random within this section. AG: Thanks for pointing this out. We will correct accordingly. AH: (7)A radar wave speed of v=0.21m/ns in dry snow corresponds to a density of roh_s=507 kg/mËĘ3, which is unusual for seasonal snow, especially for those shallow snow depths. Have you measured density? If so please present data. Otherwise on a frequently used

TCD
6, C1997–C2001, 2012

snow-machine track it might be possible. Please discuss. AG: Thanks for the comment. This is just a scale to put things a little more into context in Figure 2b. We will use a slightly higher speed here. REVIEW BY SVEIN HAMRAN SH: The paper lacks an explanation of how the radar signal processing is done. It is mentioned in section 2 that the only processing done was de-wow. AG: This was also pointed out by Heilig. Specifically he recommended to correct all the radar amplitudes for geometric spreading. We will include this correction in the revised manuscript and provide two sentences in which we list the processing stream that we used.

SH: Later in figure 5 it is mentioned that the lower plot shows the intensity of the reflection measured using the peak amplitude of the Fast Fourier Transform. It is not clear what you mean by this. What is "spectral amplitude". Normally the reflected signal strength is measured by calculating the envelope of the radar trace and picking the max signal strength at the position of the reflector. The envelope can be calculated using a Hilbert-transform. A Hilbert-transform can be calculated using an FFT. In the text it is said that the peak amplitude of the FFT is used. I do not understand how this can work. The amplitude of the FFT of the radar trace will be dominated by the strongest reflector. In the data presented it seems to be the air snow interface that is the strongest reflector. AG: I agree on the reviewer point. This needs to be clarify. What we did is extracting the waveforms of the snow-ice reflector across the radar profiles. Then we calculated the FFT (for the snow-ice reflection, not entire trace). In the revised manuscript we will provide more details on how the reflection strength was measured. SH: In figure 6 a model of the snow/ice/slush geometry is presented together with some simulation results. The simulations were done using a package called MATGPR. It is said that this is based on a FTDT code. Please include an explanation of how the simulation was done. How was the antennas simulated, as a point source? Is the simulation done in 2D or 3D? The geometry shown in figure 6 is very simple with only plane interfaces between the different layers. A simple analytical model could apparently also have been used. AG: We used a 2D simulation, the antenna was simulated as point source. We will include more details about MATGPR in the revised version. SH: I find the ordering and referencing to the figures a bit confusing. There is a lot of A, B, C, 1a, 1b ..., d, e and f ... It is not easy to follow what is being referenced and in what order. AG: Sure, we will clean this ordering (such a comment was also made by Heilig). SH: At the end I will just add a small comment on radar terminology. A GPR is a Ground Penetrating Radar. A GPR may use an impulse as the transmitted waveform as is the case in all commercially GPR systems. A GPR may also use a FMCW waveform. If a FMCW radar looks into the subsurface of the ground it is a GPR. So when you speak of either a GPR or a FMCW radar you basically speak of a GPR in both cases. AG: Sure, this will be modified and made consistent throughout in the revised manuscript.

Interactive comment on The Cryosphere Discuss., 6, 3079, 2012.