Multi-Squint Radar Sounder Processing

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The impact that rapid changes in the Greenland and Antarctic ice sheet could have on sea level rise is substantial. During the last decade, monitoring the dynamics of these ice sheets has become an important scientific priority and remote sensing has played a crucial role in monitoring ice sheet topography, surface velocities, and melting events for these remote regions. These measurements, however, are limited to the ice surface. In order to prove the interior of the ice sheet over wide areas, the only viable technique to date is to use low-frequency (10's to 100's of MHz) radar sounders. These sounding measurements are critical for determining the depth of the ice sheet, internal layering, and the potential presence of liquid water, which could lubricate ice stream motion.

Given the importance of radar sounders, innovative processing techniques for coherent processing of these data to maximize the amount of information that can be extracted have been proposed recently by Legarsky and Gogineni, Peters at al., and Heliere et al. . Although different in some of the implementation details, all of these techniques aim at increasing the azimuth resolution by compensating the depth-dependent target azimuth phase history over longer synthetic apertures than that allowed by unfocused synthetic aperture processing (or coherent pre-summation). A common characteristic of these techniques is that they all synthesize an aperture whose look direction is in the nadir direction, i.e., the most direct direction to the basal layer. Another common characteristic is that they attempt to maximize the aperture size (and hence reduce the clutter and improve the azimuth resolution), given the constraint of platform motion and ice sheet topography.

While improving azimuth resolution is useful, we argue that it should not be the main criterion used to judge the improvements that coherent sounder data processing can bring. Unfocused data processing results in single-look azimuth resolutions on the order of ~50 m to ~75 m, which is sufficient for most ice sheet studies. The real use of increased resolution is the ability to incoherently average the image to reduce radar speckle by taking additional radar "looks". Speckle noise reduction is particularly important for radar sounders, since the signal-to-noise rat can be close to 1 due to surface clutter or ice attenuation. Since radar noise is multiplicative, feature recognition for radar data in low signal-to-noise conditions can often be done as long as K_p , the ratio between the σ_0 standard deviation to the σ_0 median value, is small. This quantity will decrease as $N^{-1/2}$, where N is the number of independent looks.

A possible way of maximizing looks is to process as large an aperture as possible and average the resulting image incoherently to obtain a lower resolution image with smaller K_p. Low-frequency radar sounders typically have an antenna pattern with very large beam width in the along-track direction, so potentially very large aperture can be formed. However, there are several practical reasons that limit the maximum size of the synthetic aperture:

- Low-flying aircraft can have significant motion (at the wavelength level) during a synthetic aperture, and motion compensation of the data becomes problematic if this motion departs significantly from a straight line.
- An even more important effect is due to the roughness of the air-ice interface at the wavelength level. Uncompensated variations of the topography of this interface will introduce phase errors in the signal to be compressed, which will reduce the resolution and coherent compression gain.
- Finally, near nadir incidence, internal ice layers, water bodies, or flat basal regions can be quite specular exhibit significant variability in the angular variability of the radar cross-section, limiting the gains that coherent processing can give to the effective beam width of the scatterer, rather than the antenna beam width.

In this paper, we advocate a different approach to extracting the maximum amount of information from radar sounder data. The approach utilizes the fact that wide sounder along-track antenna beam width will allow the interrogation of targets from many different along-track incidence angles. For each point of interest in the radar beam, we form many small (i.e., on the order of the unfocused SAR aperture length) apertures and focus each aperture on it by doing coherent back-propagation, including ray bending by the ice interface. The advantages of this process over the conventional approach which maximizes the aperture length are:

- By forming short apertures, the problems associated with aircraft motion and, more importantly, surface roughness (which is hard to correct for) are minimized.
- For each target of interest, one can derive an angular cross section variability curve. This curve can then be used to characterize the surface roughness and mean slope. Of great interest is the identification of scatterers which have a very narrow specular peak, indicating a very smooth interface, possibly due to the presence of liquid water.
- The different looks, which are co-located due to the back-propagation process, can be combined incoherently to reduce speckle noise. For targets with small angular variations in the cross section, such as the basal layer, this will result if a less noisy image. For highly specular target, such as internal ice layers, combining the images from multiple angles will allow the tracking of tilting layers. In conventional processing, these layers are only visible when they are perpendicular to the synthetic beam look direction.

In this presentation, we give a description of the processing approach for ideal data followed by some of the limitations introduced by aircraft motion and the ice interface. Finally, applications of the technique to estimate the angular characteristics and improved imagery of the surface, basal, and internal layers for data collected over the North East Ice Stream of the Greenland ice sheet are presented. Emphasis is given on the use of this technique for the improved detection of liquid water at the basal layer.