CHAPTER VIII

DISCUSSION AND CONCLUSIONS

Glacier surfaces in Taylor Valley are generally radiometrically smooth and appear dark in the SAR image over most of the ablation zone. The snow zone images are brighter because of the volume reflection from the entire depth of snow penetrated by the SAR beam. Researchers theorized that SAR penetrates dry snow to depths of one or more meters (Bindschadler et al., 1987; Bindschadler, 1998; Fahnestock et al., 1993; Forster et al., 1996; Jezek et al., 1993b; Lucchitta et al., 1995; Partington, 1998; Rott et al., 1993; Rott and Davis, 1993). Because of the predicted SAR penetration, the apparent location of the (SAR) snowline would be misplaced upslope compared to the actual position. Because of the spatial scale of the ice sheets, the comparatively small misplacement of the snowline is not considered. On the scale of small alpine glaciers (~5 km^2), however, misplacement of the snowline could be important. Surprisingly, the SAR inferred and actual snowlines on Commonwealth Glacier are very close to each other. This correspondence is likely due to enhanced volume reflection and can reveal the presence of snow depths of only 15 cm deep. Enhanced volume reflection results from layers of different densities acting as a specular reflective surfaces (Mätzler and Schanda, 1984; Tsang et al., 1985; Ulaby et al., 1981). Reflection off internal layers increases the path length the beam travels (Ulaby et al., 1981), creates more opportunity to scatter in the snow, and increases total reflection. Therefore thin, dry snowpacks with no internal layers will not be visible in SAR imagery. This result indicates that the snowline may be detected with some certainty around the coastline of Antarctica as long as polar conditions are maintained.

Results from snowline mapping using SAR on Howard Glacier are inconsistent with the results from Commonwealth Glacier. The glacier only appeared on the Radarsat image because the ERS-2 scene did not cover that part of the valley. The aspect and slope of Howard Glacier faces away from the SAR beam at a sharp incident angle of about 10-23º. The entire glacier imaged dark with some tonal variation to indicate the transition from the snow to ice surfaces. The terrain correction degraded the resolution of the image sufficiently that it was nearly impossible to use. The steep slopes facing away from the SAR created both difficulties reassigning pixel locations in the terrain correction, and increased specular reflection on the snow layers limiting penetration, volume reflection, and displacing the snowline up-glacier. The uncorrected image was useful for making general interpretations, but the lack of geocoding makes precise analysis unreliable.

Howard Glacier illustrates the limitation of estimating snowline on steep slopes facing away from the sensor. In this case, imagery from another look direction or uncorrected analysis is required. Taking account of this limitation, SAR can map snowlines in dry snow and be a useful instrument for tracking snowline changes over broad regions. Problems with glaciers sloping steeply away from the SAR platform are readily visible on the image.

Once an ELA is established using SAR, its variability can be measured over time and interpretations on changes on temperature and snowfall can be made. This information can be used to verify ice sheet models and GCMs as to their validity. Furthermore, the predictive aspects of GCMs would improve with a broader range of data around the entire coastline of Antarctica. Antarctica, because of its large size and low temperatures, it is one of the largest energy sinks on earth (Tzeng et al., 1993) and it plays a critical role in GCMs due to its significant influence on global climate. Questions about global warming and El Niño-Southern Oscillation could well come closer to a resolution with more complete ELA data from the Antarctic coastline.

Ice covered lakes in Taylor Valley early in the year, are radiometrically bright (Figure 7.25). Later in the year, they become difficult to discern (Lake Fryxell) using SAR. The lakes are very rough (>1 m) and well above the wavelength of the SAR (5.66 cm). In the austral spring, there is little or no meltwater in the surface cavities of the lake; however, later in the year substantial pools of water develop both in the cavities and just below thin layers of ice. I fell in one pool on Lake Hoare in January and measured it to be chest deep (1.5 m). This water is the likely cause of the seasonal change in backscatter, absorbing the radar and inhibiting backscatter (Hall, 1998).

The “hook” on Commonwealth Glacier, has only been identified on SAR imagery and is not reported in other investigations. It is brightest in the austral spring 1996 and fades in the fall. The hook is not visible in the January 6, 1993 Landsat 6 image, the November 1993 air photos, was not noted on helicopter over flights, nor noted while walking over the glacier surface. Because of lack of SAR imagery for the austral spring of 1999, it is not known if the hook is a SAR feature that is fading from 1996, or if it is a seasonal (austral spring) SAR feature. Further study of the persistence and causative surface properties of this feature is warranted.

Experiences and Recommendations.

The Terrcorr terrain correction program took months of work. I had problems formatting the DEM, setting the terrain correction program up in the computer, and understanding how to work the esoteric command language. However, once Terrcorr is set up and run once, the time it takes to run other SAR images are on the order of hours. For this study it was a benefit to have the data geolocated allowing detailed image pixel to glacier surface comparisons. The analysis of the SAR brightness with radiometric corrections gave the analysis a basis to the shape of the DEM and not simple radar backscatter from a geoid. Furthermore, for making maps with SAR, terrain correction is necessary to rectify the shape of the glacier to a map projection. For the analysis on Commonwealth Glacier it would have been a much lower detail and more ambiguous without the terrain correction. However, for change detection analysis, if similar SAR look angles and orientations are used, and the orientation of the glacier is facing the SAR—terrain correction is not necessary.

I found the corner reflectors were very effective, brightly appearing against the dark background of the glacier ice on the SAR images. They provided known points on the SAR image, located the transect, and added scale. Without the corner reflectors, the detailed analysis of SAR brightness to snow measurement locations would have contained so much error to negate any conclusions. Corner reflectors are infrequently used as a ground reference in SAR analysis, however, they are relatively easy to construct and as little as two reflectors add two known points and scale to the SAR image, which was quite useful to this study.

Corner reflectors could be used on snow but they would be much more difficult to identify. If old SAR images are available, the reflectors could be placed where the image shows a dark region. A single reflector randomly placed in the snow zone would be lost in the brightness patterns.

Recommendation for Future Work.

This investigation answered some questions but it has also posed more. There are a number of things that could be further investigated:

- Define the snowline using a GPS and compare its location with a current SAR image.
- Compare the visible snowline from air photos or a Landsat image taken at same time as SAR data.

- Dig snow pits all along the snowline to compare SAR brightness to shallow snow depths.
- Make a seasonal analysis of the Commonwealth Glacier “hook” area to determine the glacier characteristics that create the unusual backscatter.
- Compare SAR imagery with other glaciers in the valley with a GPS snowline positions and snow stake data.
- Compare the SAR snowline on Taylor with a GPS track of the snowline.
- Convert the SAR data to decibels for more precise analysis of backscatter.
- Examine other glaciers along the Antarctic coastline for similar results to verify the practicality for large-scale snowline analysis.

As the dynamics of the interaction of radar with earth materials continues to be investigated, the uses for SAR will continue to expand. Its unique characteristics imaging through inclement weather and in darkness add practicality to this sensor for many locations on the earth. The possibility of mapping the snowline using SAR across large areas of Antarctic coastline offers a great volume of new data that could be used in GCMs. More accurate GCMs could answer the critical question of global warming and its impact on humanity. The future of SAR will undoubtedly bring smaller pixel sizes and multi-polarizations increasing resolution both spatially and in materials differentiation. The science of SAR is rapidly developing, giving cartographers, geographers, environmental scientists, and climatologists new perspectives to model and interpret the earth.