CHAPTER I

INTRODUCTION

The possibility of global climate change has caught the attention of both the scientific community and the public. Increasing levels of atmospheric carbon dioxide, affected by human activity, may be causing increasing global temperatures (Crowley, 2000; Watson, 1996). The phenomenon of the El Niño-Southern Oscillation (ENSO), the development of a cap of warm ocean water along the coast of Peru that blocks the upwelling of cold water (Sarachik, 1997), and how it affects weather around the planet have become a common concern in our society. Global Circulation Models (GCMs) have been developed to predict climate change, and the global warming trend is predicted to continue (Crowley, 2000; Watson, 1996). This temperature increase is believed to be melting glaciers and contributing to the rise in sea levels (O'Farrell et al., 1997; Oerlemans and Wegener, 1989).

Antarctica plays a critical role in global climate variation. Because of its large size and low temperatures, Antarctica is one of the largest energy sinks on earth (Tzeng et al., 1993). Ocean surface currents and subsiding flows circulate warmer water to Antarctica and cold water towards the equator (*ibid*). Latitudinal temperature gradients control meridional atmospheric flow that moves atmospheric heat and moisture to the pole (*ibid*).

To predict changes in the Antarctic Ice Sheet, GCMs are coupled with ice sheet models (Marsiat, 1996; Verbitsky and Saltzman, 1995). Because the response time between snowfall and glacier advance or retreat movement is so long, ice sheets will rarely obtain equilibrium (Fastook and Prentice, 1994). A warming Antarctica, however, may not contribute water to the oceans via melting, because it may also increase snow precipitation due to the atmosphere's increased ability to carry moisture to the continent (Budd et al., 1994; Fastook and Prentice, 1994; Krinner and Genthon, 1997; O'Farrell et al., 1997).

A vital parameter in ice sheet models is mass balance (Budd et al., 1994; Fastook and Prentice, 1994; Marsait, 1996; Van De Wal, 1996). Mass balance is the difference between mass gain (snowfall) and mass loss (ablation) over the whole ice body (Patterson, 1994). Because the atmosphere drives most of these processes, mass balance is a proxy measure of the climate (*ibid*). Changes in glacier and ice sheet mass balance are one of the most important components for predicting global sea level (Ohmura et al., 1996; Oerlemans, 1989; Oerlemans, 1992).

Mass balance changes are measured over a single year. These year-to-year changes in mass affect the position of the terminus after some lag time depending on the thickness, length, and temperature of the glacier (Patterson, 1994). The changes in advance or retreat of glaciers and ice sheets are responses to multiple past mass changes that occurred over different time scales (*ibid*).

The equilibrium line altitude (ELA) of a glacier is the dividing line between the region of yearly net mass accumulation (the accumulation zone) and the region of yearly net mass loss (the ablation zone): at this line, the mass balance is zero, or at equilibrium (Patterson, 1994). The ELA moves up or down due to changes in meteorology (snowfall, latent and sensible heat). The ELA responds only to meteorological variations whereas terminus variations are a result of meteorology and ice dynamics. Thus, the ELA is an important variable in climate studies, energy balance studies, and runoff modeling. For temperate glaciers the transient snowline may be different than the ELA, but on Antarctic (polar) glaciers the snow line *is* the ELA (*ibid*). This is because of melt on a polar glacier. The sub-freezing, dry atmosphere sublimates the snow in place.

One of the most attractive techniques for tracking the ELA in Antarctica is satellite synthetic aperture radar (SAR). SAR has several benefits: it covers broad areas; it has a long wavelength allowing it to image through clouds; and it is self-illuminating allowing it to image in darkness. Therefore SAR has an all-weather, day/night capability, which is an attractive feature for imaging Antarctica because of the frequently cloudy skies near the continental margins and darkness throughout the austral winter. Compared to ground measurements, SAR is an inexpensive approach to monitoring the ELA position.

Although the US Navy has used radar (**RA**dio **D**etection and **R**anging) since 1934 for object detection (Ulaby et al., 1981), specific questions as to exactly how it interacts with different surfaces are now in the forefront of research. Various researchers have noted penetration of radar energy into snow surfaces (Bindschadler, 1998; Bindschadler et al., 1987; Fahnestock et al., 1993; Jezek, 1993a; Partington, 1998; Rott et al., 1993; Rott and Davis, 1993).

The penetration depth of SAR in dry snow was theoretically estimated to be 20 m (Ulaby et al., 1981); however, field studies comparing the SAR image with measured penetration are lacking. Because of penetration of radar energy into dry snow, the thinner snow margins are not detected, causing underestimation of the full extent of snow cover and could cause up-slope displacement of the ELA.

This thesis demonstrates a methodology for estimating the location of the ELA using SAR. This work has two important applications. First, defining the ELA on the Antarctic Ice Sheet will be more easily investigated on a large scale. Second, the McMurdo Long Term Ecological Research (LTER) project in Taylor Valley, Antarctica, will benefit by using SAR to monitor the ELA on more glaciers. The McMurdo LTER is part of a long-range collaborative investigation focusing on ecological processes. The entire LTER consists of 21 sites, one of which is in the McMurdo Dry Valleys (including Taylor, Wright and Victoria Valleys) (Figure 1.1) (Harris, 1998; Moorhead and Priscu, 1998). Currently five glaciers in the valley are monitored by field measurements, but with SAR a more complete picture of the variation in the ELA will be acquired. Since the valley's microbial communities depend on the influx of liquid water, understanding how the climate could change in this valley and estimating the corresponding levels of biotic activity will allow researchers to further understand how life exists in one of the most extreme environments on earth.

Additional applications of this research may be applied to the Martian Polar Ice Caps. Earth-bound radar imagery of the Martian Polar Ice Caps has shown the cap to be very heterogeneous (i.e. very fractured and lumpy) and thus very reflective (Muhleman et al., 1995). A Magellan-type mission (which mapped Venus in 1990-1994 using a SAR) to Mars may resolve similar glacial zones discussed in this thesis.