Synthetic Aperture Radar detection of changes in ice and soil surfaces, McMurdo Dry Valleys, Antarctica

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INTRODUCTION

All life requires water. In the extreme polar desert of the McMurdo Dry Valleys, Antarctica, water is the limiting factor for life. This study detects the presence and distribution of water in the three major surface types found in the dry valleys: soil, perennially ice-covered lakes, and glacier surfaces. I hypothesize that three conditions must be met in order for water to be present or for melting to occur:

1. Ice must be present and near its melting point.
2. Solar radiation must be available to melt the ice.
3. The ice must be sheltered from the dry wind.

Along with these factors, sediment on or within the ice increases melting when the above conditions are met.

The region's geomorphology influences these factors that produce melting. The valleys channel the wind into predictable and reoccurring patterns. Rock outcroppings provide a source of sediment, shelter from the wind, and an area for the sediment to collect. The mountains block solar radiation from the sun, which is low in the horizon. The interaction of the geomorphology with wind, solar radiation, and ice temperature produces the overall spatial and temporal distribution of water in the dry valleys.

A primary goal of the McMurdo Long Term Ecological Research (LTER) site, which is located in the dry valleys, is to understand the processes that produce this distribution of melting and how they relate to climate (Fountain *et al.* 1999). Determining the correlation between melting in this environment and climate will provide insight to:

1. Understand the past and predict the future impact of climate change on polar glaciers.
2. Predict the impact of climate change on the simple ecosystem in the dry valleys.

3. Detect life on Mars and understand Martian geomorphology.

This study gives the keys to the past: where life came from both on Earth and Mars, and keys to the future: where the world and life will be.

The primary tool for detecting water in this study is satellite-based Synthetic Aperture Radar (SAR). I am doing a detailed analysis of seasonal change in the McMurdo Dry Valleys based on weekly SAR images from 01 August 1999 to 29 December 1999. Permanent meteorological stations located throughout the valleys have recorded meteorological variables during the acquisition of the radar images. The specific relation between the climatic variables and water distribution will be derived from this season, which had climate characteristic of the last twelve years. This will be contrasted with radar images from the 2001 – 2002 summer season. The 2001-2002 summer had a dramatic increase in temperature that produced large amounts of melting (MCM-LTER 2002).

Study Area

The McMurdo Dry Valleys is the largest ice-free region in the Antarctic. It is located in the Transantarctic Mountains near the northwest corner of the Ross Ice Shelf (color plate 1). Key features in the region include perennially ice-covered lakes, polar outlet and alpine glaciers, ephemeral streams, and sand dunes. Sand dunes are unique to this area and are cemented together by snow, which keeps them from being blown away by high winds. The lakes have a permanent ice-cover that is three to five meters thick. In the case of Lake Vanda, the bottom of the lake is 25°C all year round.

The region is a very cold and extremely dry desert. The annual temperature is -20°C and winter temperatures drop below -40°C. Precipitation in the form of snow is less than 6 cm per year (Fountain *et al.* 1999). High winds and low humidity sublimate most of the ice in the region instead of melting it. The limited amount of melt that does occur is the primary source of water for the region. Under these extreme conditions, life is still able to exist. Water is the limiting factor (Kennedy 1993).

Climate Change

The McMurdo Dry Valleys has been a US National Science Foundation (NSF) funded Long Term Ecological Research (LTER) site since 1993. The McMurdo LTER consists of Taylor Valley, Wright Valley, and Victoria Valley (color plate 2). LTER sites have been set up to study a diverse set of ecosystems throughout the world. These sites are used to discern the ecological responses of different communities to changes in weather and climate. LTER sites range from urban settings in Baltimore to remote sites such as the McMurdo Dry Valleys.

Global Change Research uses the network of LTER sites to determine how human actions are modifying global systems. There are profound global changes rapidly occurring at this time due to human actions. The LTER network of sites acts as a window into global change by providing information from different ecosystems that have different sensitivities to changes in the environment (Global Change Research 2002). The McMurdo Dry Valleys is among the most extreme deserts in the world and as part of the LTER network it plays a key role as an end member (Lyons 1998). The ecosystem in the McMurdo LTER is extremely sensitive to changes in the weather and climate. This environment is delicately balanced around the melting/freezing point of water. Small changes in the weather or climate produce disproportionately large consequences to the ecosystem. Changes in the global climate that affect Antarctica will be seen first at the McMurdo LTER (McMurdo LTER 2002).

This study intends to provide biologists with a map of the spatial and temporal distribution of water in the dry valleys. This will aid in searching for life throughout the dry valleys. The distribution of water within the glaciers will give key insight into where ice melts and how it is transported from the glacier to the streams and lakes. How the ice-covers change on the lakes is also important both for the stability of the lakes and for those that study the organism that live within the ice-cover. These physical processes are critical to the valleys ecosystem because they regulate the flow of water into the valleys.

Applications to Mars

The first scientific goal of the Mars Exploration Program is to determine if life exists on Mars (JPLb 2002). The Mars Exploration Program is using a similar strategy to look for life on Mars that this study is using to look for life in the McMurdo Dry Valleys. Life will most likely be associated with the presence of water. They have termed their strategy: "Follow the Water" (JPLc 2002). All known forms of life require water. Large amounts of ice have just recently been discovered just below the surface of Mars (JPLa 2002).

Life detected in the extreme environments of the polar deserts may provide a useful analogy to detecting life in the Martian environment (JPLd 2002). The extremely cold and dry polar deserts are the closest Earth-based analogy to the Martian environment. The polar deserts also contain subsurface ice, which is most likely similar to the subsurface water just discovered on Mars. Results from this study, which will test methods for detecting liquid water, determine the spatial distribution of liquid water in an environment analogous to Mars, and determine the underlying variables that produce the distribution, can be directly used for finding liquid water and potentially life on Mars. This study can explore both the strengths and limits of SAR imagery of extremely cold and dry conditions.

NASA is partnered with the European Space Agency to send the Mars Express spacecraft to Mars in 2003. The Mars Express will carry imaging radar to detect and map subsurface water. This mapping will give a three-dimensional distribution of where and how much water is located below the Martian surface (JPLe 2002). Similarly, NASA (2001) has announced that the Mars Scout Radar is among the ten finalists for the Mars Scout mission, which will be launched in 2006. The Mars Scout Radar is a Synthetic Aperture Radar that would be used to detect near surface moisture, ancient fluvial drainage networks, and ice structure. Information from this study could be directly used in interpreting SAR imagery of Mars.

Fundamentals of Synthetic Aperture Radar

SAR Detection. Synthetic Aperture Radar is sensitive to surface roughness, the internal structure of the material, and the dielectric constant of the imaged material. Satellite-based SAR systems send out a radar signal and detect the amount of energy reflected back to the satellite. This is called backscatter. The path the reflected energy takes depends on the geometry of the imaged surface. The material can be a specular reflector, a diffuse reflector, a volume reflector, a corner reflector, or a combination of reflectors (figure 1). The detected roughness of a surface depends on the wavelength of the radar. The amount of energy that is reflected depends on the dielectric constant of the material.

The amount of energy that is returned to the satellite depends first on the geometry of the imaged material and second on its dielectric constant. The dielectric constant of a material may cause a strong reflection but if the surface is smooth and a specular reflector, then all the energy will be reflected away from the satellite. The soil surfaces in the McMurdo Dry Valleys are extremely stable (Campbell *et al.* 1998). Changes in the backscatter from soil surfaces are related to changes in the soil's dielectric constant. Changes in backscatter from ice surfaces are a combination of seasonal changes in surface roughness and the ice's dielectric constant.

The real part of the complex dielectric constant describes the materials reflection at the surface and the imaginary part describes the material's absorption of the signal as it travels through the medium. Both ice and soil's real part of the complex dielectric constant is approximately 3. The real part of water is 80 and the imaginary part of water is 1000 (Ulaby *et al.*, 1981). The introduction of water into ice or soil increases surface scattering and blocks volume scattering.

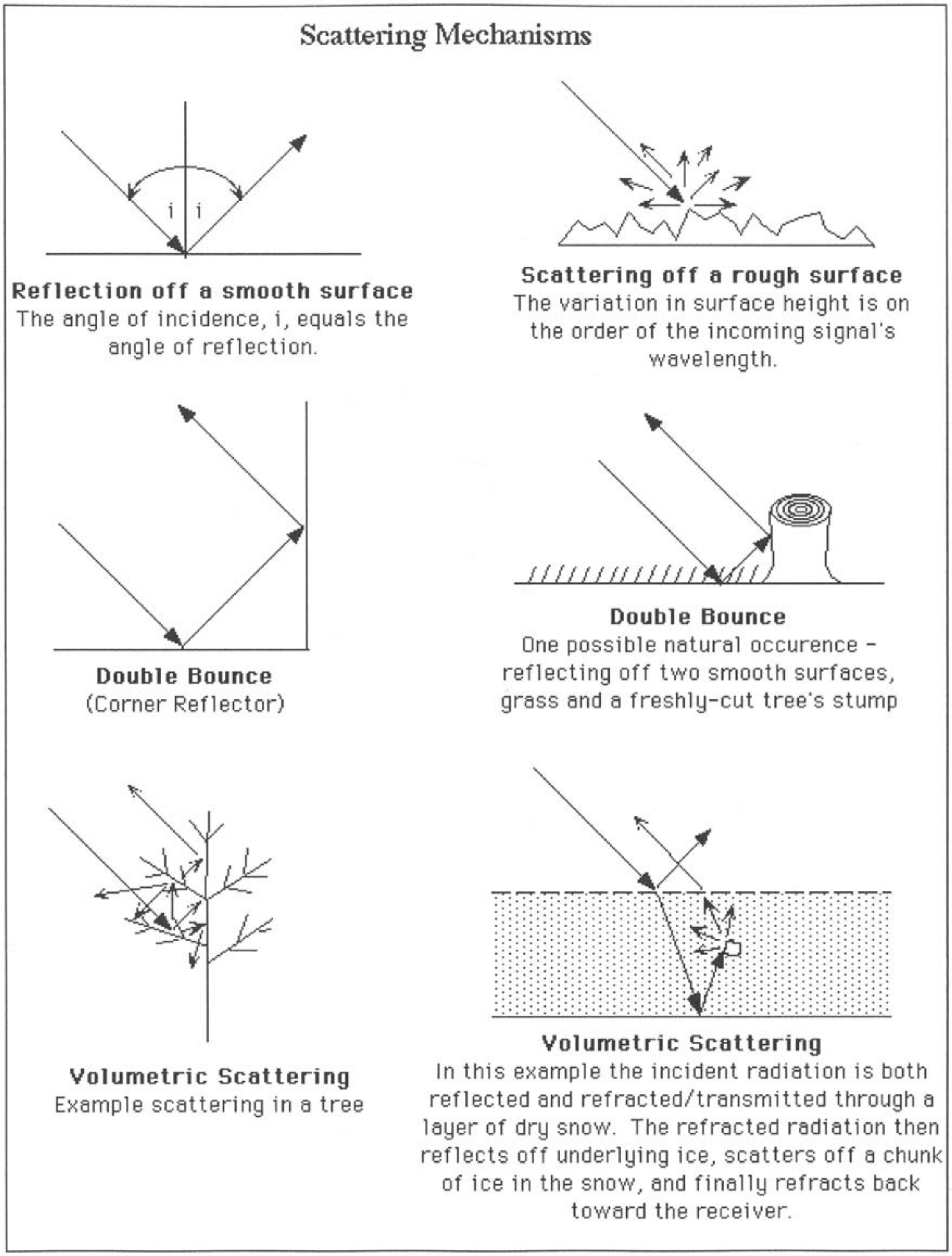

Figure 1. Scattering mechanisms for radar (Nicoll 2002).

SAR Artifacts. SAR satellites illuminate the terrain with a radar signal instead of relying on the sun to provide the energy. This allows SAR satellites to function during both the day and the night and because of the wavelength of the radar, SAR signals are unaffected by cloud cover. This is important in the McMurdo Dry Valleys because of its extreme lighting conditions. The region is also located on the Antarctic coast and is often cloud covered. Inherent in SAR systems, because it illuminates the imaged terrain, is speckle and geometric distortion.

The radar signal is in phase or coherent. This causes constructive and deconstructive interference in the backscattered signal. The radar signals are added together before being squared for power detection (Raney 1998). If the signal interferes constructively, the peaks and troughs of the backscattered radar waves are aligned. When they are combined, the measured backscatter can be greater than the power of the original signal sent from the satellite. This interference produces speckle in the image. It increases the uncertainty of the measured radiometric response of the landscape to the imposed radar signal.

SAR systems determine the distance an object is from the satellite by the amount of time it takes for the signal to travel from the satellite, to the scene, and return back. In mountainous terrain, this method produces severe distortions in the image. If the radar signal reaches the top of the mountain before reaching the bottom of the bottom, the signal from the top of the mountain is overlaid on top of the signal from the base of the mountain (figure 2). Foreshortening is similar to overlay but the top of the mountain is placed closer to the satellite but does not overlay the bottom of the mountains (figure 3). Areas behind the mountain are shadowed from the radar signal (figure 4). Examples of this distortion are in color plates 4 – 7.

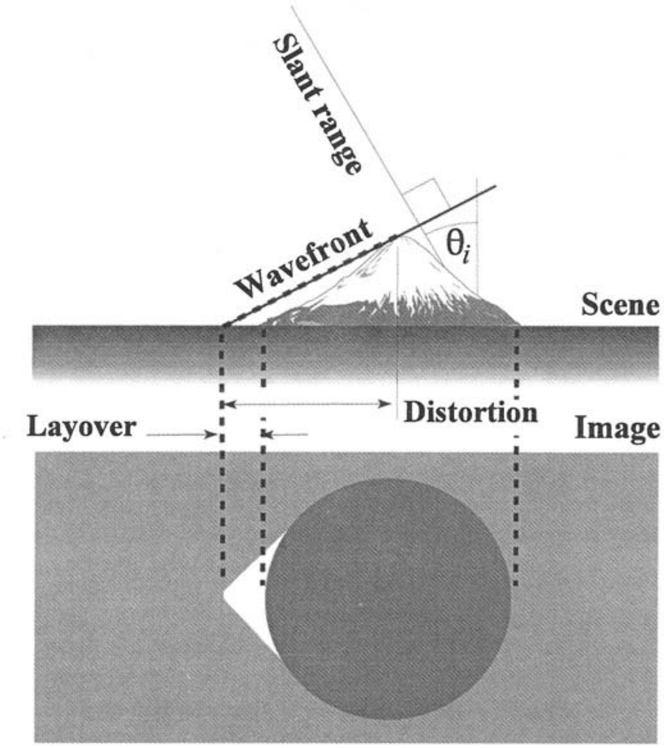

Figure 2. Absence of shadow, severe brightness distortion, and severe geometric distortion (elevation displacement and layover) for steep angles of incidence (Raney, 1998).

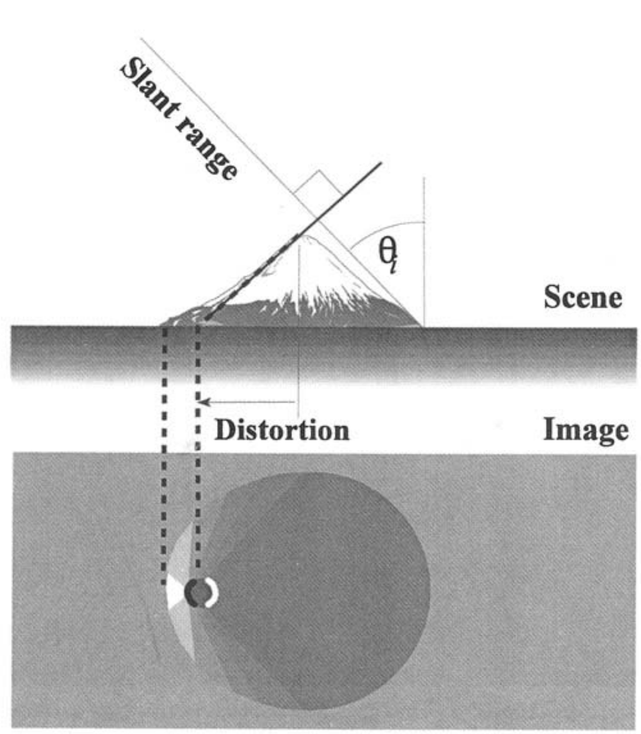

Figure 3. Darker farslope, substantial brightness enhancement on foreslope, and distortion (elevation displacement and foreshortening on facing slope) for moderate angles of incidence (Raney, 1998).

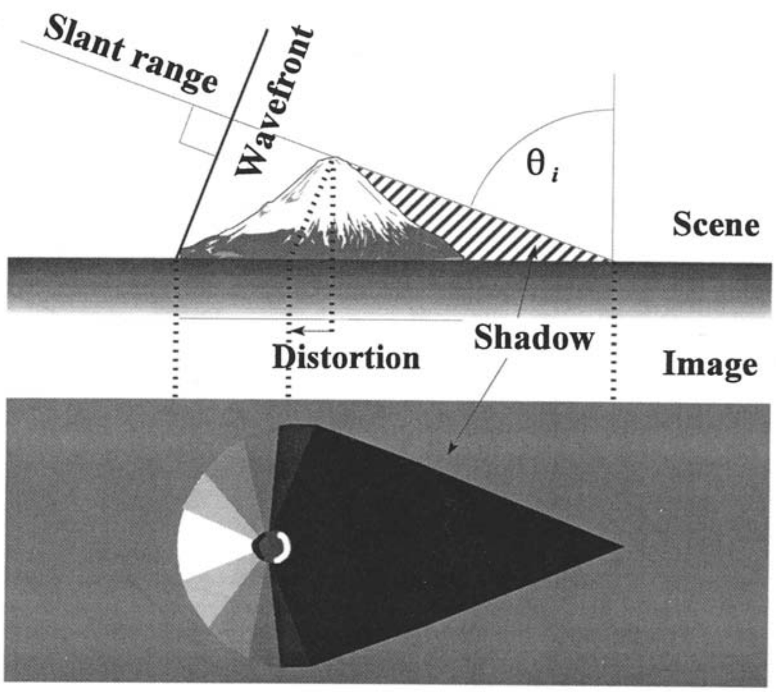

Figure 4. Large shadow, brightness enhancement, and small distortion (elevation displacement and foreshortening of facing slope) for shallow incident angles (Raney, 1998).

The radar signal is from the top of the image. The side of the mountain facing the satellite is overlaid and the side of the mountains facing away from the radar is in shadow. Glaciers facing the radar are foreshortened.

PROPOSED METHODS

Remote Sensing

There are weekly Radarsat images of the McMurdo LTER from 01 August 1999 to 29 December 1999. Radarsat is a SAR satellite that uses a horizontal copolarized signal in the C-band at a wavelength of 5.66 cm. From the 2001 – 2002 season, there are four Radarsat images and two ERS-2 images. ERS-2 uses the same wavelength radar signal but uses a vertical copolarized signal. These images need to be calibrated, corrected for geometric distortions, and suppress the speckle before using them for change detection.

The raw images are in linear amplitude and need to be converted to sigma naught values, which are measured in decibels and are a ratio of the received backscatter and the incident signal. The Alaska SAR Facility (ASF) has internally developed software tools that convert the linear amplitude images to sigma naught images using appended calibration tables.

If the satellite images are not taken with the same orientation to the scene or the same place in the sky, then geometric distortions need to be corrected for. Overlay cannot be corrected but foreshortening will occur with a different geometry based on the satellite's orientation to the scene and can be corrected for using a Digital Elevation Model (DEM). Most of the Radarsat images are taken in an ascending orbit from approximately the same position. In this case, the geometric distortions are constant between images and they do not need to be corrected.

To increase the certainty of the measured radiometric response of the scene to the imposed radar signal, the speckle in the image needs to be suppressed. Spatial resolution is exchanged for increased radiometric resolution (Raney 1998). For large areas such as the ice-covered lakes or large glaciers, the loss of spatial resolution for increased radiometric resolution increases the understanding of the area. It is unclear if loss of spatial resolution will block the detection of soil moisture since the size of the areas associated with soil moisture is near the resolution of the raw image, which is 25 meters.

The imagery is georeferenced so that it can be compared to each other. ASF tools initially georeferences the images but finer georeferencing will be completed using ground control points. The georeferencing will be analyzed for how closely the pixels correspond to one another between images and the spatial uncertainty will be measured between images.

Changes in the scene will be tracked using multi-temporal color composites. Three dates are selected and each black and white image is assigned red, green, or blue. The three images are overlaid and the colors from each associated pixel in the three images are added together. In the color composite image, areas that are black, white, or gray correspond to regions that do not change between the three dates. Areas in red correspond to areas that had a strong backscatter in the date associated with red but lower backscatter during the other two dates.

The measured backscatter of selected features will also be graphed. The variation of the backscatter with time is the features temporal radar signature. Color composites show the spatial distribution of temporal variation but they can only compare at most three dates. The temporal signature of selected features shows how a selected region varies throughout all of the SAR images.

To augment the interpretation of the SAR images, images from optical satellites taken during the same time period as the SAR images were acquired (table 1). Landsat 7 ETM+ images were purchased for 18 December 1999 and 28 December 2001. ASTER images are available for October, November, and December of 2001. ASTER has a spatial resolution of 15m and Landsat 7 has a resolution of 30m. These images can be used to detect snowpacks, streams, and changes in the ice-covered lakes and glaciers.

MODIS imagery is available for daily coverage of McMurdo LTER for the 2001 – 2002 season. AVHRR imagery is also available for daily coverage but for both the 2001 – 2002 season and also the 1999 – 2000 season. They operate at spatial resolutions of both 1km and 4km. Data from these satellites will be primarily used for their thermal bands. Meteorological stations in the McMurdo LTER measure temperature at specific points. Data from these satellites can be used to extrapolate the spatial patterns of temperature throughout the dry valleys.

Table 1. Satellite data used to detect liquid water and correlate it with proposed variables.

Satellite	**Type**	**Resolution**	**Use**
Radarsat	SAR	25m	Detect changes in liquid water and surface roughness.
ERS-2	SAR	25m	Detect changes in liquid water and surface roughness.
ASTER	Optical	15m	Detect snowpacks, streams, ice-covered lakes, glaciers.
Landsat 7	Optical	30m	Detect snowpacks, streams, ice-covered lakes, glaciers.
MODIS	Optical	1km	Extrapolate temperature measurements from met station
AVHRR	Optical	4km	Extrapolate temperature measurements from met station

Field Methods

A large amount of data exists for the 1999 – 2001 seasons from meteorological stations placed throughout the valleys (figure 5). The stations measure air temperature, soil / ice temperature, wind speed, incoming and outgoing short-wave and long-wave radiation, and humidity. Instruments were also buried at different depths in the ice-cover of Lake Bonney and measured the change in the dielectric constant. These values were converted into gravitermetric

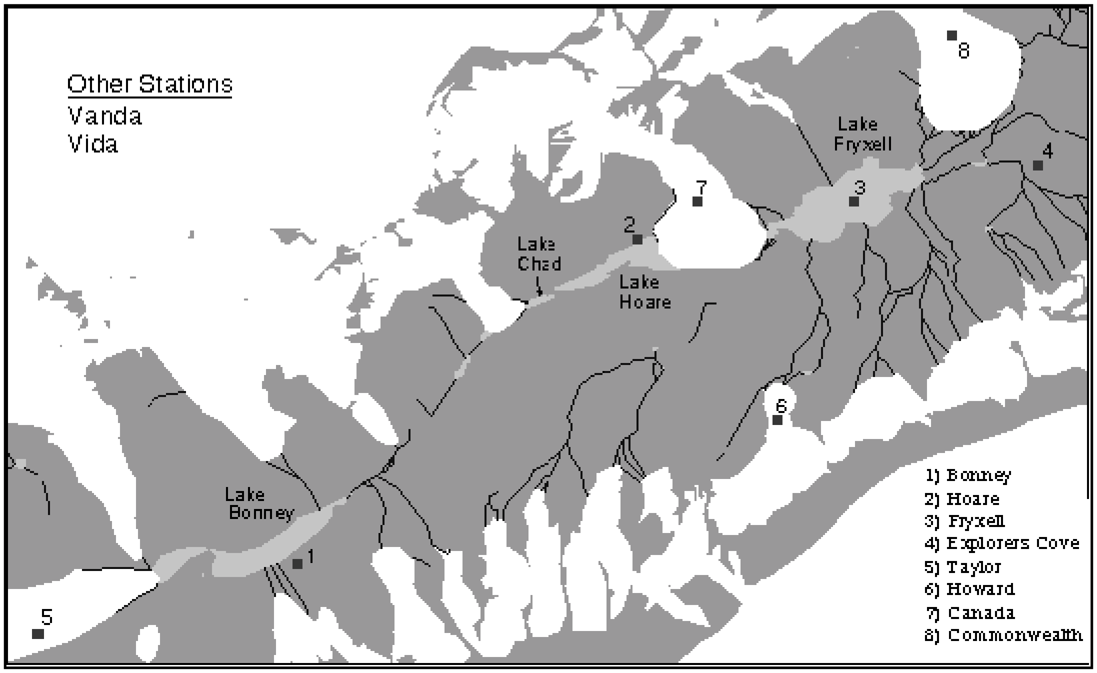

Figure 5. Locations of Meteorologic Stations in Taylor Valley (MCM-LTER, 2002).

moisture content. However, there is only very limited data available on soil moisture for the 1999 – 2001 season.

During the 2002 – 2003 field season, instruments are going to be placed in the sand dunes, which are located in Victoria Valley between Lake Vida and Victoria Lower Glacier, to measure the seasonal variation of the dielectric constant. Although these measurements will not correspond to the analyzed satellite imagery, it will provide information on general seasonal characteristics for this area. Instruments will be placed in the ablation zones of Taylor, Canada, and Commonwealth Glaciers, which are all located in Taylor Valley, to measure changes in liquid water. These instruments directly measure the change in the dielectric constant of the ice.

Surface roughness will also be measured from selected areas. Surface roughness measurements will include RMS height, correlation length, and autocorrelation function (Tansey and Millington, 2001). The surface roughness of the soils is assumed to be static. The surface roughness of the sand dunes will be measured throughout the season to determine if it is static.

The surface roughness of the ice-covered lakes and glacial ablation zones will be measured throughout the season to determine general characteristics of their seasonal variation. If permission is granted, a soil pit will also be dug in the sand dunes. The sand dunes are supposed to be cemented together with snow (Campbell and Claridge, 1987). Depth to the permafrost layer needs to be determined and the uniformity of the sand dunes needs to be ascertained.

Signature Modeling

Signature modeling needs to be developed to link physical processes with the observed backscatter signal. Using the configuration for a single band SAR system, measurements of surface roughness, and the measured dielectric constant of the medium, the Integral Equations Model (IEM) can be used to estimate the radar backscatter (Fung *et al.*, 1992). For areas that have measured values for the dielectric constant, the predicted backscatter from the IEM can be compared with the observed backscatter. The backscatter from a larger area can then be used to extrapolate the spatial distribution of changes in the dielectric constant. This assumes that the surface roughness is constant throughout the extrapolated area (Tansey and Millington, 2001).

The IEM only models backscatter from surface roughness. Volume scattering also occurs in ice surfaces and possibly the sand dunes. Multiple models exist that model volume scattering and continued investigation is required to determine which model is appropriate for this situation (Winebrenner *et al.*, 1992). Signature modeling is key in demonstrating that the proposed underlying physical processes are the cause of the detected and described distribution of moisture availability.

PRELIMINARY RESULTS & DISCUSSION

The SAR images have been acquired, calibrated, and initially georeferenced. ASTER and Landsat 7 have been acquired. ASTER images are currently being calibrated. Color plate 3 is a false color near infrared color composite from the 28 December 2001 Landsat 7 data. Rough color composites have been made from the SAR data. Color plates 4 – 7 are a subset of these color composites. Temporal signatures of selected features have been graphed based on the mode of their backscatter histograms (figures 7 and 12). The SAR images have not yet had speckle suppression techniques applied to them. Selected features include the ice-covered lakes: Bonney, Hoare, Fryxell, Vanda, and Vida; the glaciers: Taylor, Canada, and Commonwealth; and soil moisture from the sand dunes, lake edges, streams, snowpacks, and ponds.

Ice-Covered Lakes

The lakes in the McMurdo Dry Valleys either have a 3 – 5 m thick permanent ice-cover or they are completely frozen through. Lake Vida in Victoria Valley is completely frozen to its bed. The permanent ice-covers of the other lakes have a unique internal structure. The bottom half of the ice cover is composed of elongated vertical tubes (Adams *et al*, 1998). The water in the lakes is supersaturated from the release of gas from the biological activity of the lake. This forces the water to freeze to the bottom of the ice-cover in a vertically elongated fashion.

Backscatter from these different types of lakes is very different. In the winter when there is no melt, the vertical elongated ice structure and the horizontal ice-lake water interface produce a corner reflector (Jeffries *et al.*, 1994). This constructive interference pattern saturates the SAR system's backscatter sensors (figure 6). The backscatter from the lakes completely frozen is much lower because the ice-soil interface is not a dramatic change in dielectric constants.

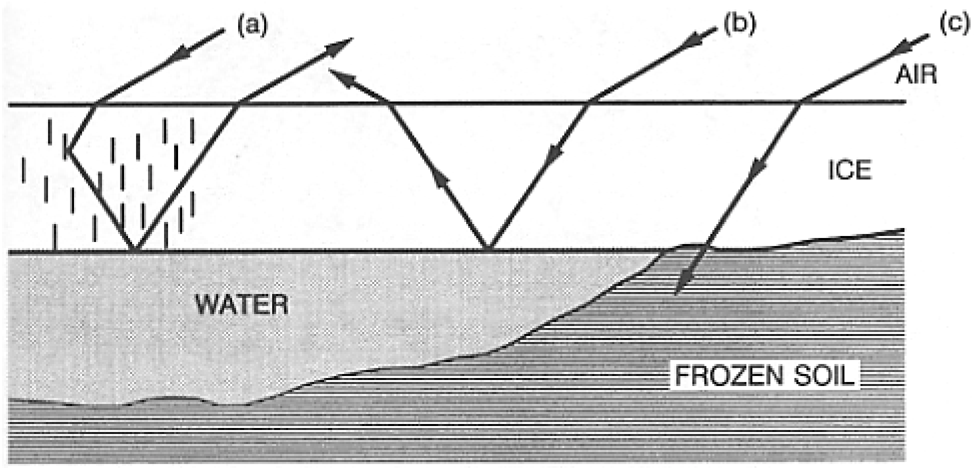

Figure 6a. Diagram showing the nature of radar scattering in a lake:
a) lake with elongated bubbles, b) bubble-free lake ice, and
c) lake with ice that is frozen to the bottom (Hall 1998).

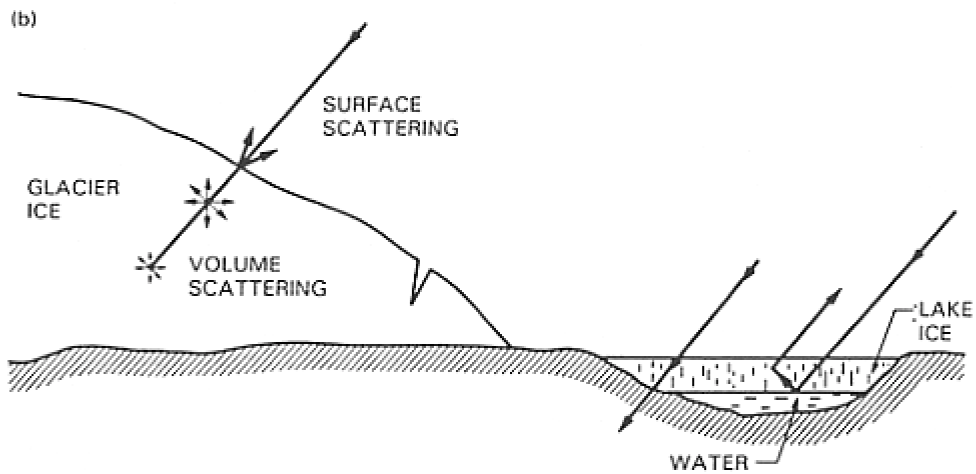

Figure 6b. Diagram comparing scattering between glacier ice and
different forms of lake ice (Lewis 1998).

Of the ice-covered lakes, the lakes of Taylor Valley have a large amount of sediment buried approximately 2m from the surface of the ice-cover (Chinn, 1993). Lake Vanda's ice-cover is almost sediment free (Fritsen *et al.*, 1998). Lake Vanda has a series of thermohaline convection cells that allows the lake to have a temperature of 25°C at its bottom without the lake overturning. The lake's ice-cover has a transmission of approximately 20% of incoming solar radiation. The first convection cell is 5m deep. This convection cell absorbs the incoming radiation over its 5m depth and redistributes that energy throughout the convection cell (Howard-Williams *et al.*, 1998). This increase in energy with an increase in solar radiation during the spring begins to melt the bottom side of the ice-cover (figures 7 – 9). This reduces the backscatter from Lake Vanda early in the season.

The lakes of Taylor Valley have a large amount of sediment and only transmit approximately 1% of the incident radiation through the ice-cover (*ibid.*). When the ice-cover in these lakes nears melting temperature, the energy absorbed from solar radiation by the sediment layer is adequate to differentially melt the ice at this depth (Simmons *et al.*, 1987). The introduction of liquid water blocks the penetration of the radar signal, removes the corner reflection, and the backscatter dramatically drops (figures 7 – 10). The backscatter at this point is only from surface roughness. As melting continues, the surface becomes rougher and the backscatter signal rebounds (figure 7, color plates 4-7).

Certain areas of Lake Hoare illustrate the limits of single band SAR systems. Areas of the lake develop extreme surface roughness from melting but do not appear to change in the color composites (color plates 4-7). The corner reflection from volume scattering is replace by corner reflection from an extremely rough surface. Ice pedestals 1m tall that are closely packed together appear in the summer when the ice-cover melts (Chin *et al.*, 1993).

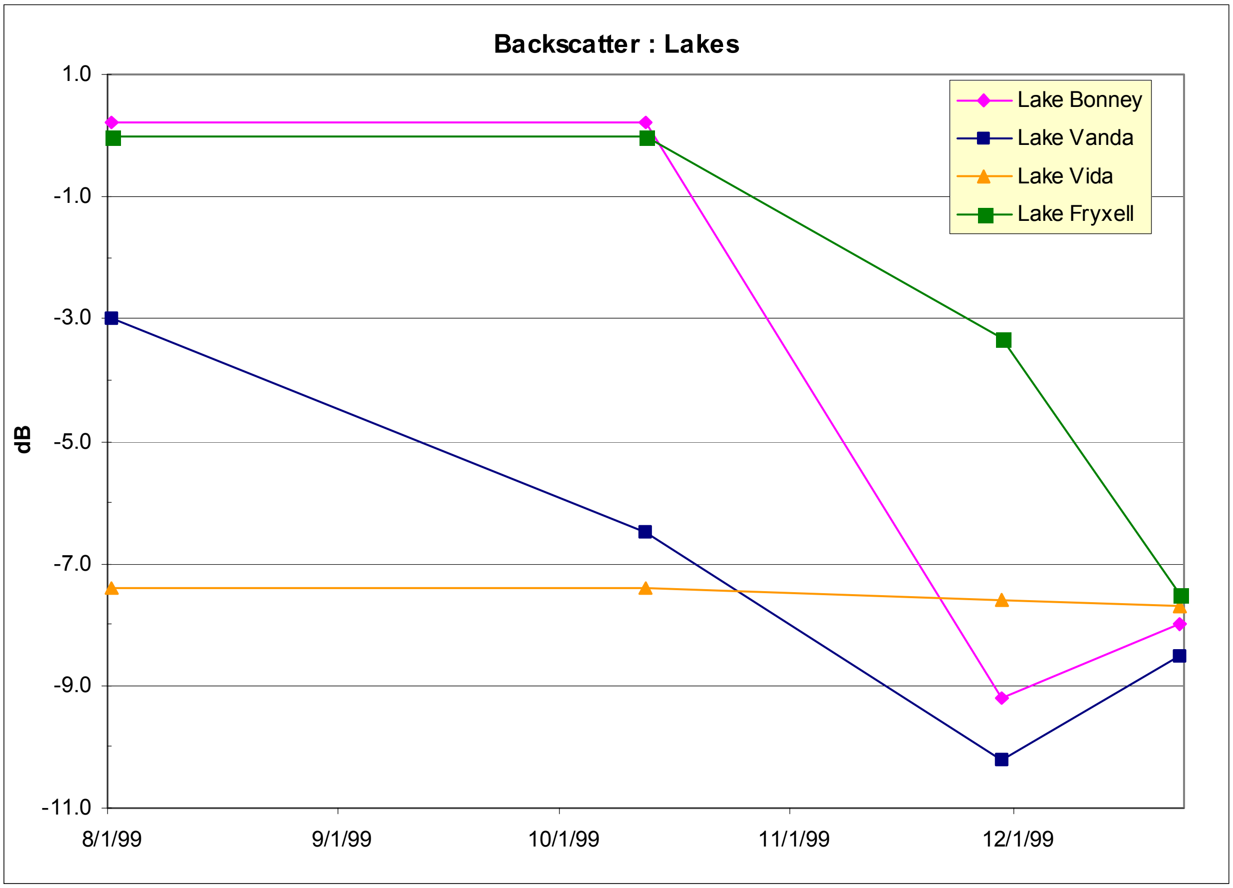

Figure 7. Backscatter temporal signatures from Radarsat images for the perennially ice-covered lakes Bonney, Fryxell, and Vanda and for the frozen Lake Vida.

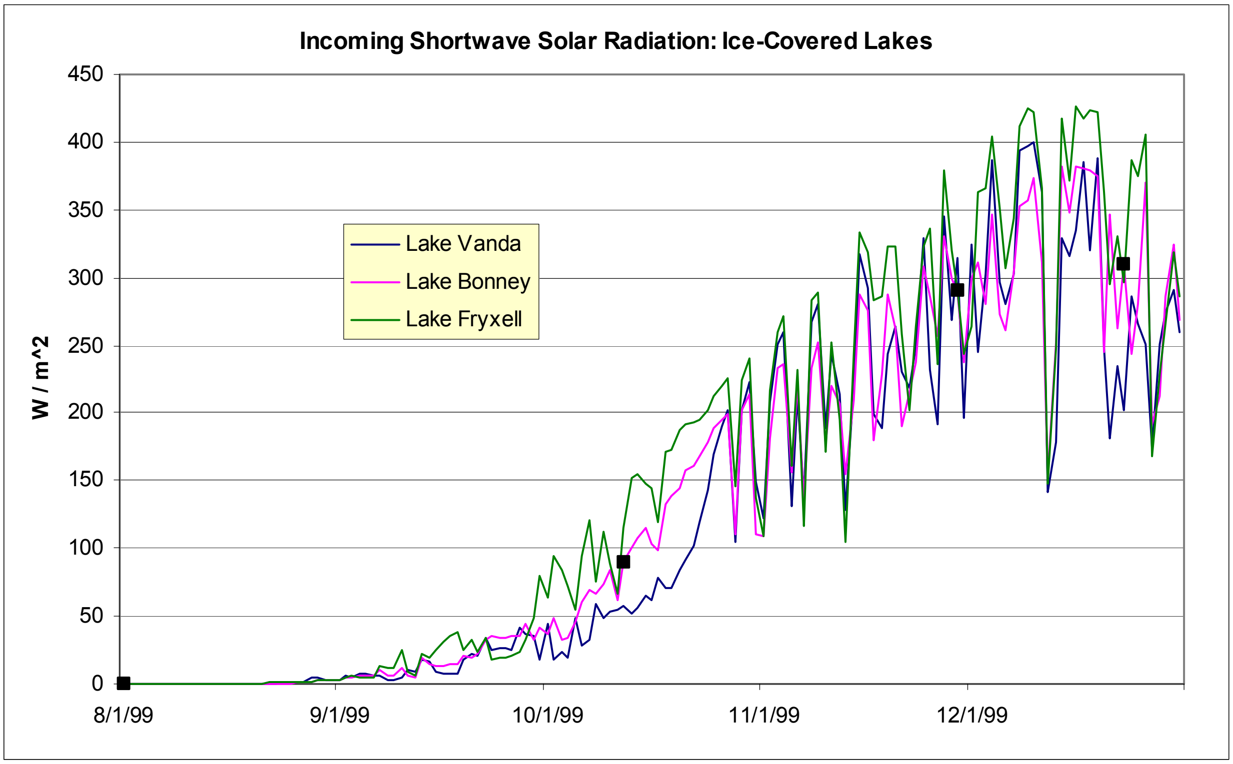

Figure 8. Radiation measurements from the lake meteorological stations (MCM-LTER, 2002). Black squares correspond to dates of measured backscatter.

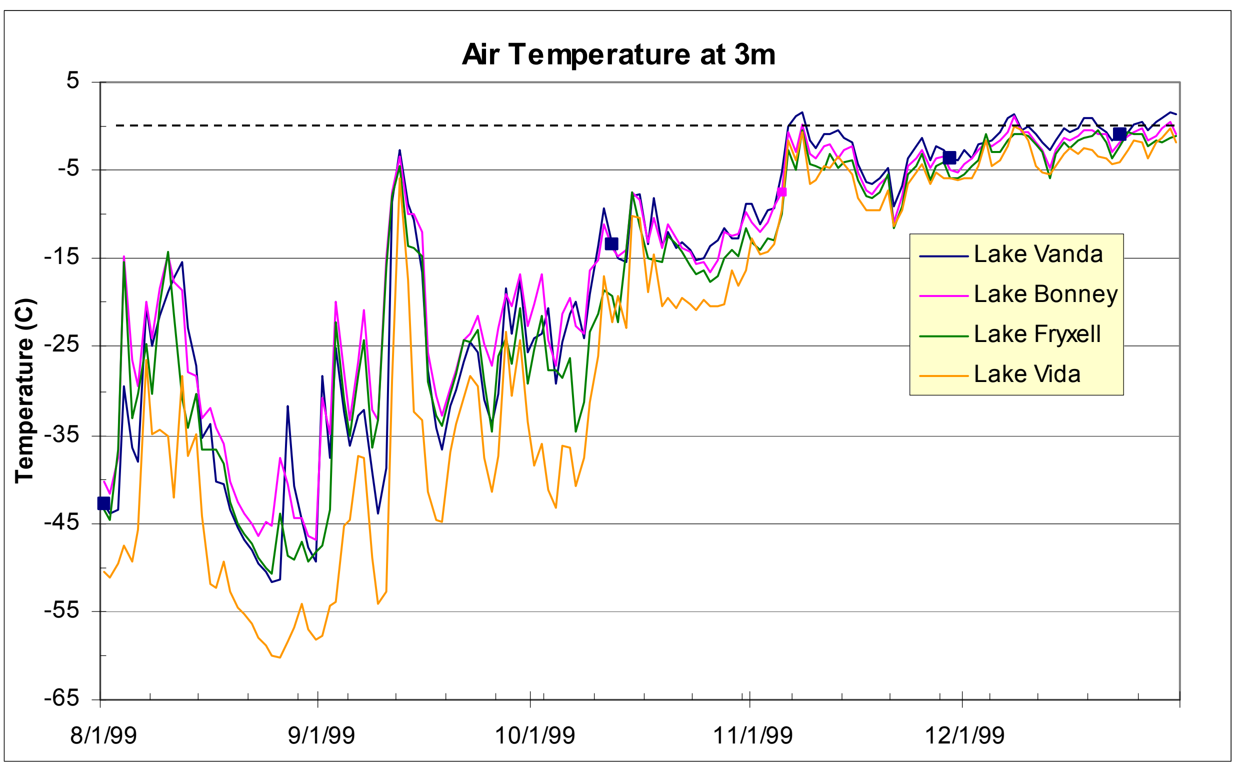

Figure 9. Air temperature measurements from the lake meteorological stations (MCM-LTER, 2002). Black squares correspond to dates of measured backscatter.

Glacier Surfaces

The ablation zone of glaciers varies primarily with the surface roughness of the ice. On Taylor Glacier, the area protected from wind by the Kukri Hills consistently gives lower backscatter values and suggests a smoother surface. With less wind, there is more energy for melting (Paterson, 2001). Melting and refreezing would produce a smoother ice surface. As well, larger sediment would fall in this area that is below and near a sediment source. This sediment causes differential melting and the formation of cryoconite holes (figure 11). Backscatter from this region is distinctly different from other areas of the ablation zone (figure 12). Differential melting would occur under similar meteorological conditions as the ice-covered lakes with a sediment layer (figures 13 and 14).

Cryoconite holes are formed by sediment that collects and melts into the ice. The top of the hole usually refreezes and leaves a hole within the ice that is filled with air, water, and sediment. If the sediment melts deep enough into the ice surface by absorbing solar radiation, it will not ablate out during the winter and will reform during the early summer. The backscatter signature labeled ‘cryoconite’ in figure 12 is an area that according to limited data has a larger density of cryoconite holes. These holes work as corner reflectors that increase the strength of the backscatter.

Detecting the location of cryoconite holes is important in determining the internal drainage system of the glacier. It is hypothesized that the holes are connected and produce a system that allows melt water to travel into the valley (Fountain, personal communication). Exposed liquid water is quickly evaporated in this dry environment and polar glaciers have an internal ice temperature of –20°C, which would not allow for the formation of englacial conduits. However, melt from the glacier flows into streams that feed the lakes in the valley.

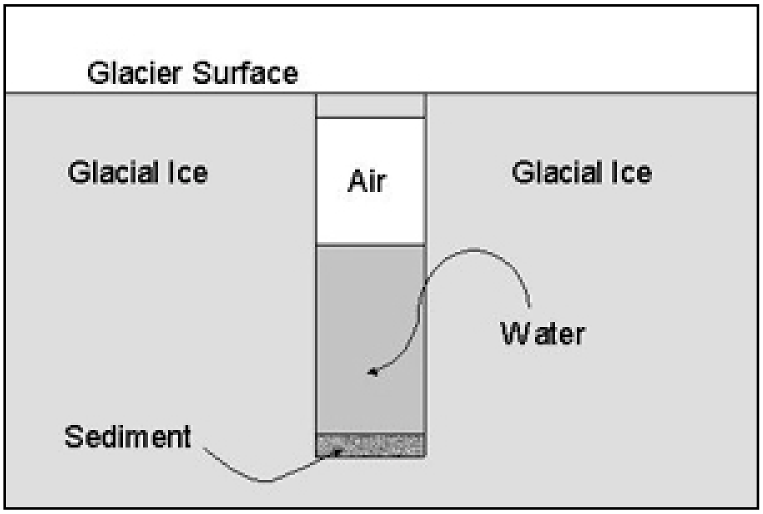

Figure 11. Diagram of a cryoconite hole (Johnston, 2002).

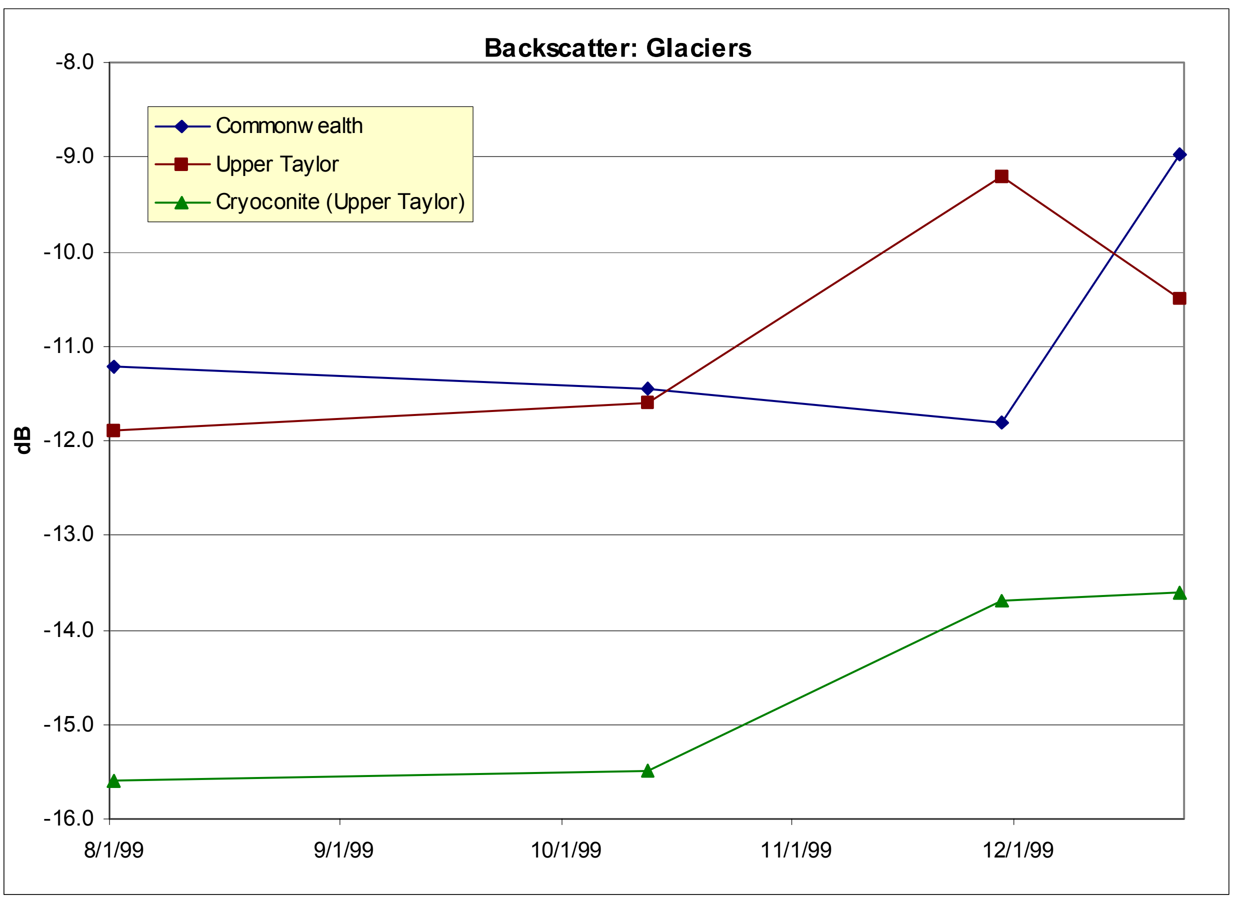

Figure 12. Backscatter temporal signature from Radarsat images of Commonwealth Glacier, Upper Taylor, and area of Upper Taylor populated with cryoconite holes.

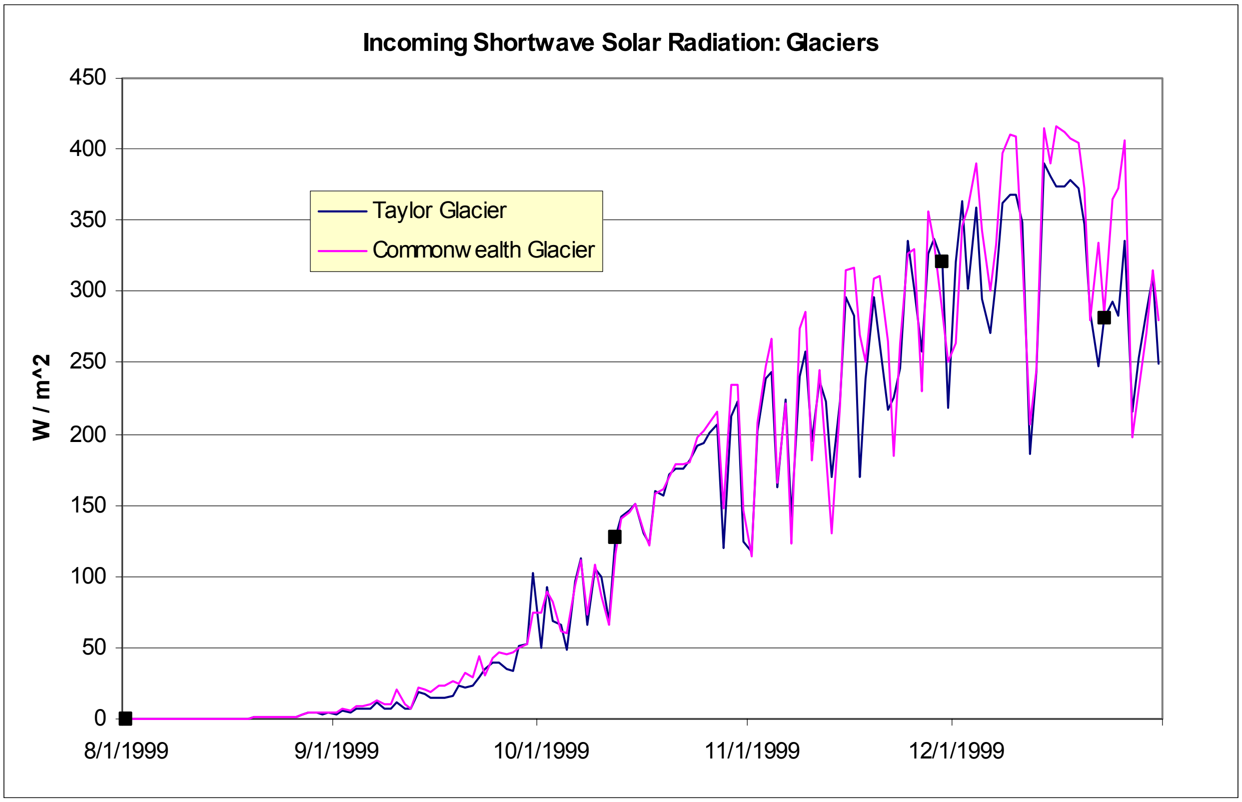

Figure 13. Radiation measurements from the glacier meteorological stations (MCM-LTER, 2002). Black squares correspond to dates of measured backscatter.

(a)

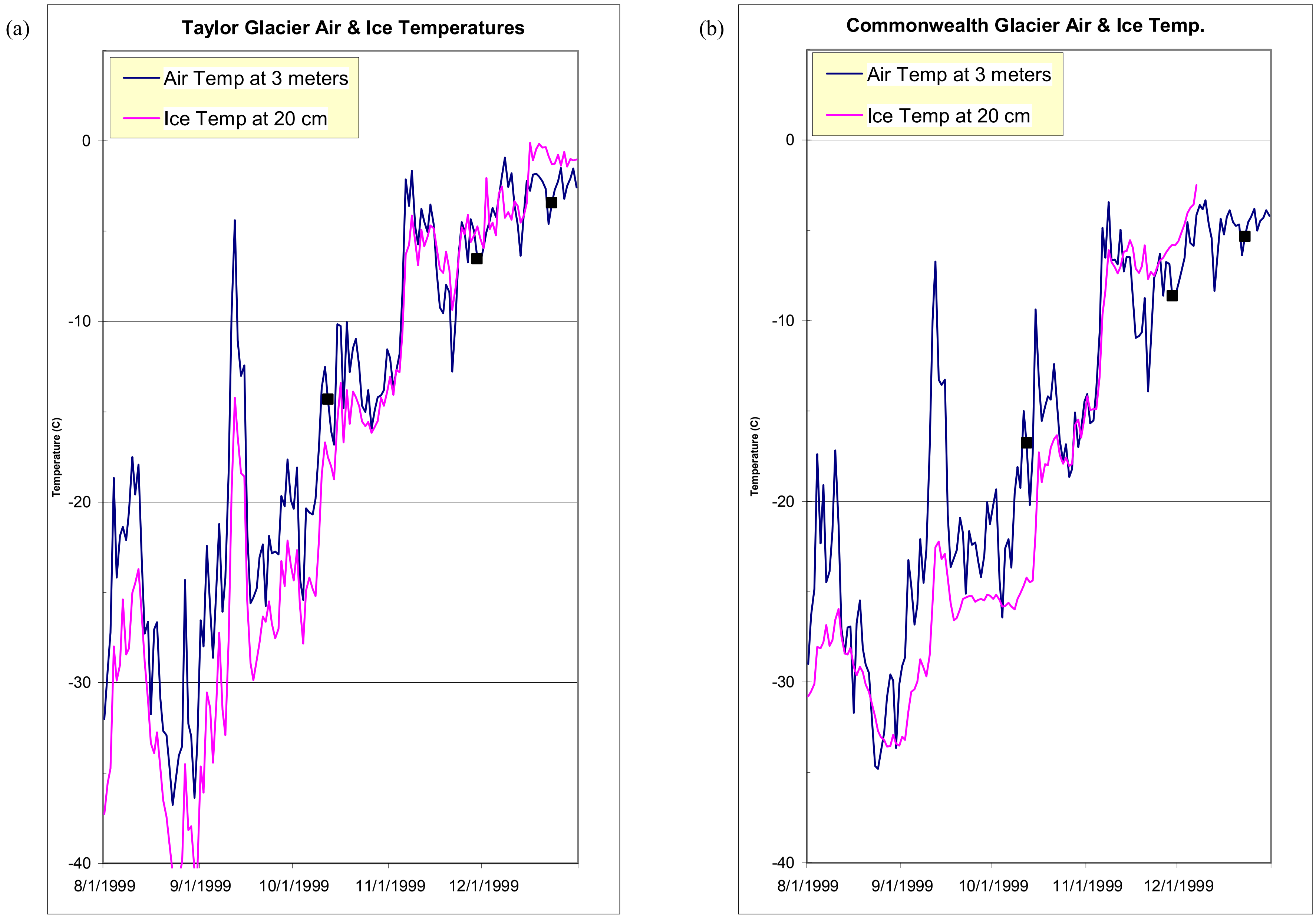

Figure 14. Air temperatures at 3 meters and ice temperatures at 20 cm for:
(a) Taylor Glacier and (b) Commonwealth (MCM-LTER, 2002).

Soil Moisture

Sand dunes. The sand dunes between Lake Vida and Victoria Lower Glacier give a higher than normal backscatter during the winter. Backscatter from sand dunes is reported in the literature as –18dB or lower (Ford *et al.*, 1998). In extremely dry conditions, radar signals are able to penetrate several meters into uniform sand. The sand dunes are cemented together with snow (Campbell and Claridge, 1987). Frozen surfaces within the sand dune and the permafrost layer could be contributing to the winter backscatter through volume scattering.

With the advent of spring, the increase of moisture from either snow within the sand dune or the permafrost layer would block radar penetration. This would reduce the backscatter to only surface scatter and backscatter values in the summer would be –18dB or below. This is what is observed (figure 15). Fieldwork in this area will confirm or deny the proposed underlying process.

Lake edges and streams. The introduction of water into soil increases the backscatter from the soil. The radar signal is only able to penetrate 5cm into the soil and surface scatter dominates the backscatter. The soil around the lakes increases in backscatter during the summer from measured values in the winter. Ground observations confirm an increase in soil moisture during the summer at the lake edges (*ibid.*).

Radarsat and ERS-2 also detect soil moisture surrounding streams. Color plate 5 shows streams flowing into New Harbor in green. During the 2001 – 2002 season, the Onyx River flows in Wright Valley from Lake Brownsworth to Lake Vanda. There are also streams and ponds that formed on the sand dunes between Victoria Lower Glacier and Lake Vida.

Snowpacks. Snowpacks accumulate during the winter from windblown snow off the Polar Plateau. During October and November, the soil absorbs energy from the short-wave solar

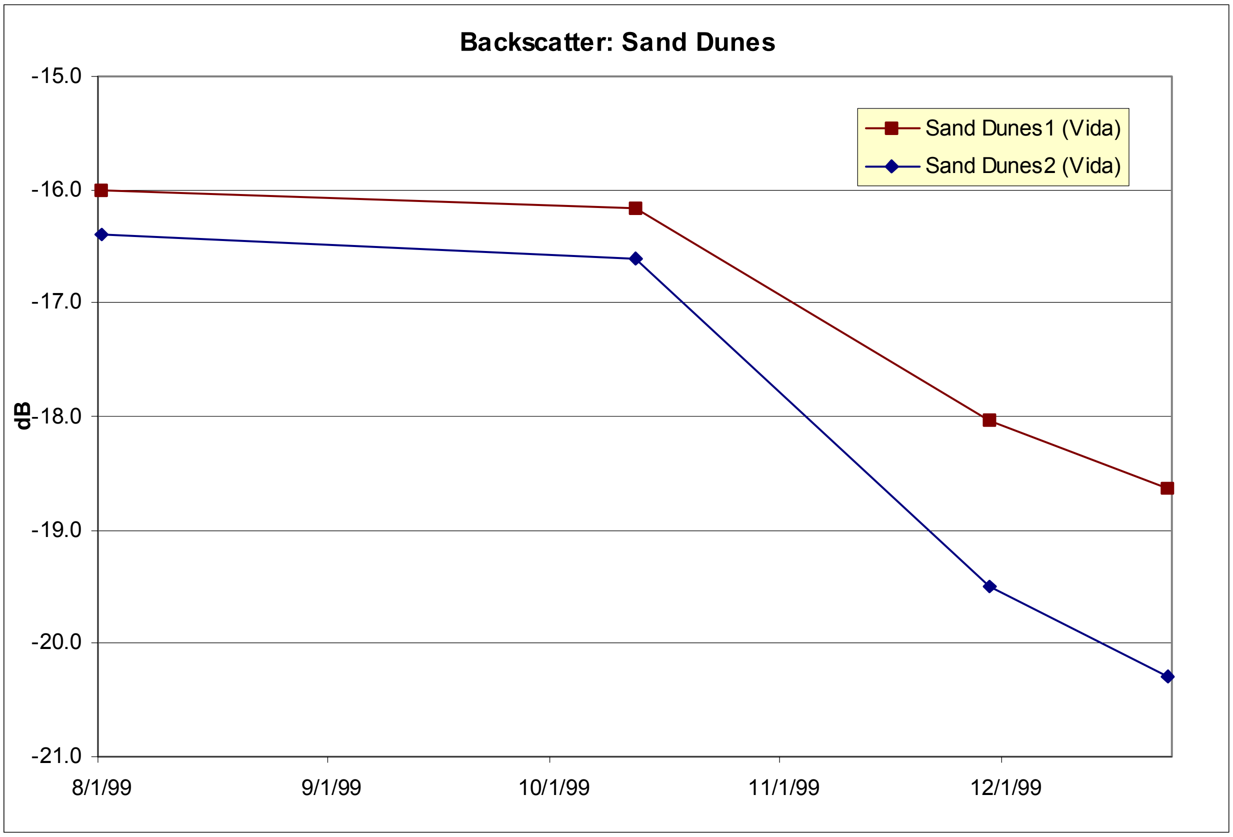

Figure 15. Backscatter temporal signature from Radarsat images of two regions in the sand dunes between Lake Vida and Victoria Lower Glacier.

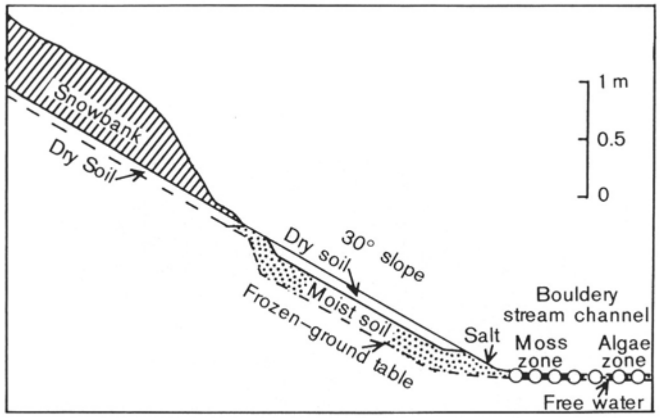

Figure 16. Melt along the edges of the snowpack from heated soil (Campbell and Claridge, 1987).

radiation and melts the edges of the snowpack (figure 16). Most of the snowpacks are completely melted by December (Gooseff *et al.*, 2002). Preliminary investigation suggests that most of the soil moisture from snowpacks is located in Taylor Valley between the Nussbaum Reigel and New Harbor. Initial investigation of color composites supports this theory.

2001 – 2002 Season

The 2001 – 2002 season produced a dramatic increase in melting. The abnormally high temperatures from 15 December 2001 to 15 January 2002 produced melt and refreezing in the accumulation zones of the glaciers (Ramage, 2000)(color plates 6 & 7). The accumulation zones during the 1999 – 2000 did not experience any change. In January, the permafrost began to melt and increased soil moisture.

EXPECTED DIFFICULTIES

The current hurdle is figuring out how to convert the radar data into a format that I can use with the software I have available to me and that I want to use. I have spent a large amount of time trying to get around this. The current software that I am using is internal software from ASF that they do not support.

The main concern I currently have is that I will be able to detect moisture and adequately describe the spatial distribution of the moisture but I will not have enough information to provide a definite explanation for what produces the distribution. I am currently uncertain the explanations for the distribution will just be suggestions. Since wind is now appearing to be such a large component, transportable meteorological stations need to be placed on the glacier to measure the difference in the wind between sheltered areas and exposed areas. It is currently too late to request the necessary equipment to install these temporary meteorological stations for this next field season.

RESEARCH SCHEDULE

Summer 2002 –	Satellite image analysis Met data analysis Correlation statistics between image and met data
Fall 2002 –	Fieldwork in the Antarctic Surface roughness measurements Probe measurements of dielectric constant Soil pit on sand dunes
Winter 2003 –	Analyze data collected from fieldwork. Write
Spring 2003 –	Write
Summer –	Write
Fall 2003 –	Defend Thesis Rewrite

ADVISOR & COMMITTEE

Advisor:	1. Andrew Fountain	
Committee:	2. Mike Emch	
	3. Keith Hadley, Heejun Chang, or Dan Johnson	
Grad Rep.:	4. Christina Hulbe	(Geology)
	Scott Burns	(Geology)

I have only asked Mike to be on my committee. I still need to ask the rest of the people.

HUMAN SUBJECTS REVIEW

I hope this is does not apply to me. Maybe I can sign a waiver saying I will not torture any virus, bacteria, or microscopic organism through my research. However, my thesis, if it works, will facilitate other people in torturing innocent organisms. Does that make me liable?

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