CHAPTER IV

METHODOLOGY OF THE DATA COLLECTION

Objective.

      To determine snowline position by comparing brightness variations in the two

SAR images with measured surface features on Commonwealth and Howard

Glaciers.

Experimental setup.

      Radarsat ScanSAR, and ERS-2 satellites are utilized. The axes of both glaciers

are generally parallel to the SAR look direction (Figure 4.1), while the optical depth

of the radar beam will vary considerably between the two glaciers (Figure 4.2). It is

because these two glaciers have very different incidence angles that they were

chosen. The differences in backscatter between the two glaciers may reveal

differences in mapping the position of the snowline.

      Commonwealth Glacier. The main study site for the SAR investigation was

Commonwealth Glacier (Figure 4.3). It is 52 km^2, faces to the southeast, ranges in

elevation from 100-1000 m, and is 3 km from the ocean. Its gentle slope (5°)

and broad width (~2 km) provides a large and relatively even surface to compare SAR

brightness variations. The glacier slope faces toward the SAR beam and the optical

depth (parallel to the beam direction) of the snow is close to the actual depth (Figure

4.2). Commonwealth Glacier is dotted with a network of 26 stakes across the surface

to measure mass balance (Figure 4.3). The ELA is approximately 350 m. In the

ablation zone, roughness vary from 1 cm to 5 m with the larger roughness located

near the glacier terminus (Fountain et al., 1998). Cryoconite holes are seemingly

randomly dispersed (Wharton et al., 1985) and vary in width and depth from three to

forty centimeters (Derek Mueller, personal communication). A cryoconite hole is a

hole, sometimes with a re-frozen cap, containing a layer of wind-blown sediment and

possibly (in the austral summer) water. They form by debris blowing to the glacier ice

and subsequently absorbing more solar radiation and forming a depression. The

depression collects more wind-blown debris, increasing the solar radiation absorption

and (occasionally) producing water. Snow cover in the ablation zone ranges from

traces to dune-like formations 4 to 35 cm high and covering areas from less than 1 m^2

to 20 m^2. In the accumulation zone, dry snow exists on the surface with thin ice layers

and hoar snow at depth. The accumulation zone is generally quite smooth with

roughness amplitudes typically less than a few centimeters and wavelength of 10

meters.

     Howard Glacier. Howard Glacier (Figure 4.3) is the secondary study glacier,

has similarly varying roughness and snow cover as Commonwealth Glacier, but it is

steeper; 10º in the ablation area, 10-23º in the upper part of the glacier, and 16º

overall

average. It is 8 km^2, faces to the north, ranges in elevation from 260-1000 m, and is 8

km from the ocean. The glacier faces away from the radar beam and the optical snow

depth should be much larger than the actual depth (Figure 4.2). Seventeen mass

balance stakes are found on the glacier (Figure 4.3). The ELA crosses the glacier at

approximately 500 m.

The Radarsat image was acquired through Dorothy Hall at National

Aeronautics and Space Administration (NASA). The ERS-2 image was ordered

through the NASA Earth Observation System project science office via the Alaska

SAR Facility (ASF). The image data were collected within range of the ground

receiving station at McMurdo, Antarctica, to which the data was immediately

transmitted. The data was then transferred to high-density digital tape and mailed to

ASF at the University of Alaska in Fairbanks, Alaska, where the tapes were

processed. SAR processing is complicated and computationally intensive, the

following processing summary is a general review.

First the ASF reads the tape for the processing parameters such as: sensor

name, wavelength, elevation/azimuth beam width, right or left side looking, nominal

look angle, orbit data, chirp data, attitude, and number of samples per range line

(Olmsted, 1993). Second, an array is calculated containing the best estimate of the

spacecraft's location, orientation, and rotation rates. And finally, the ASF checks the

doppler parameters, transmitted chirp (signal pulse), signal to noise ratio, and other

parameters with default values to determine if they are within limits (Olmsted, 1993;

Raney, 1998). The processing step geolocates the image (assigns geo-coordinates to

the image corners and center), computes a slant to ground range conversion vector,

applies radiometric corrections, realigns data along azimuth, and interpolates the data to a ground-based grid. The image is then either sent to the user on a 9 mm tape in the mail or (as I received it) downloaded from the ASF via the Internet.

The Digital Elevation Model.

To terrain correct the images; a Digital Elevation Model (DEM) is used (details of this process are in Chapter 6). The US Geological Survey created the DEM of the Taylor Valley (Figure 4.4). The transformations that evolve to the DEM begin with 1970 aerial photography from which 1:50,000 scale Lambert Conformal Conic maps were produced. The USGS digitized the 50 meter contour lines from this map and created a triangulated irregular network (TIN) using a Geographic Information System (ArcInfo) (Cheryl Hallam, USGS, personal communication). They converted TIN to a DEM consisting of a square grid of points at 30 m intervals and shifted the datum from the Camp Area Datum of 1962 to World Geodetic System 1984.

Surface-Based Measurements.

The mass balance stakes on Commonwealth and Howard Glaciers are measured twice annually to assess the seasonal mass change. The measured variables are: layer thickness, snow density, crystal structure, and depth to last year snow surface. I measured additional surface conditions on a transect on each glacier to provide spatially detailed data to help explain brightness variations on the SAR image.

Commonwealth Glacier. The transect, 3.5 km long, began in the ice-covered

ablation area and extended to the snow covered region just above the snowline

(Figure 4.3). To aid in identifying the transect on the SAR image, I placed two

reflectors on the ice surface along the transect 2.5 km apart (the lower reflector at the

start and the upper near the snowline). These reflectors were triangular trihedral

corner reflectors, which are known location bright spots on the SAR image (Rott and

Davis, 1993; Trevett, 1986). Reflectors were not placed on Howard Glacier because

the effectiveness of the reflectors was unknown and resources for the corner reflectors

were limited. To corner reflect; only two surfaces meeting at a 90° angle must be

pointed toward a beam (Figure 4.5a). A triangular trihedral corner reflector presents

three reflective surfaces arranged at 90-degree angles (Figure 4.5b) and requires less

precision in pointing the reflector towards the radar beam (Fuller, 1970). To enhance

identification, the reflectors were placed on glacial ice, which commonly appears dark

on a SAR image. They crossed diagonally across the ablation area to capture an

intervening bright region observed on previous SAR images. The transect then

continues beyond the second reflector, into deep, dry snow: a bright SAR region

where reflector identification would be difficult.

The reflectors need to be aimed at the location in the sky where the SAR

platform will be when it illuminates the ground. The two critical directions from the

ground, azimuth and inclination, were supplied by the ASF (Figure 4.6a). I

determined the reflector inclination angle by hanging a plumb bob off the back apex,

and adjusting the distance from the bottom point of the reflector to the plumb-bob by

tilting the reflector. This distance, can be calculated by using the sine of the desired

inclination (Figure 4.6b):

$$\text{Sin } (i) = x/h \quad (4\text{-}1)$$

$$x = h \text{ Sin } (i) \quad (4\text{-}2)$$

where i is the inclination angle, h is the height of the reflector, and x is the measured

distance from the plum bob to the bottom point of the reflector.

The Science Construction Unit of Antarctic Support Associates at McMurdo

Station built the reflectors according to specifications supplied by the ASF. They

consist of three triangular aluminum panels, backed with 1/2" plywood, and bolted to

a steel frame (Figure 4.7). At the opening of the reflectors forms an equal lateral

triangle with 8' per side; the minimum depth to the bottom point is 4'. The three

corners anchor to 2' long steel poles drilled into the ice. The anchors are covered with

snow to block the solar radiation from heating the metal and melting them out of the

ice. The bottom point of the reflector is set in a corner-shaped hole in a wooden beam,

which is chiseled into the ice to prevent it from shifting. Surveyors determined the

exact positions of the reflectors using a Global Positioning System (GPS) with post-

processing to achieve centimeter accuracy.

Along the transect, sample sites are located every 250 m yielding 11 sites over

the 2.5 km transect. Judging from previous SAR images of the area, this ensures that

sample sites will closely bracket significant brightness changes on the SAR image. I

sampled the snow conditions along the transect twice, the first time the distances

between sample sites was "chained out" by stretching out a 50 m climbing rope

between two people and repeating this five times for each sample distance (250 m).

The second sample, I used a hand-held global positioning system (GPS) and followed

the footprints from the previous transect to keep on track. The second sampling was

completed a week after the first because some measurements were not taken at each

site on the first pass. The transect continued one kilometer beyond the upper reflector

into the accumulation zone. The total transect length is 3.5 km.

Howard Glacier. On Howard Glacier I established an 850 m transect with five

sample sites and no corner reflectors (Figure 4.3). It begins in the ablation zone and

rises into deep snow. The first sample site was at stake 31 and the second was at stake

30. The other three sites were selected along the bearing lining up stake 31 and 30

and were located using GPS. The measurements on this transect give an opportunity

to compare backscatter of opposite slopes: Commonwealth Glacier faces the SAR,

while Howard Glacier faces away (Figure 4.2). On Howard Glacier it is likely to have

higher degrees of specular refection and different locations of the glacier radar zones

due to the different aspect affecting the SAR incidence angle.

The Measured Surface Variables.

The variables measured at each site included: snow temperature, ice

roughness, slope/aspect, snow depth, snow density, and snow grain size. Temperature

affects liquid water content, which increases specular reflection off snow (Avery and

Berlin, 1992; Hall, 1998; Jezek and Carsey, 1993; Mätzler, 1987). The temperatures

on the glaciers in Taylor Valley in recent years have not often reached the melting

point (Nylen, personal communication 2000). Ice and snow roughness increases radar

backscatter. Snow and ice surfaces on the study glaciers are typically smooth (< 50

cm), except near the terminus where the amplitudes reach 10 m (Fountain et al.,

1998). Surface orientation to an incident radar beam affects how the beam will reflect

and the depth of its penetration. Shallow dry snow is transparent to radar, while deeper snow will display volume reflection (Bindschadler, 1987; Hall, 1998; Jezek and Carsey, 1993). Internal density changes of the snow layers increase volume reflection (Rott and Mätzler, 1987; Shi and Doizer, 1993). Larger snow grains scatter radar more than small grains (Hall, 1998; Rott and Mätzler, 1987; Shi and Doizer, 1993). The snow grains on the study glaciers are typically small (<3 mm) (Fountain et al., 1998). In addition to measuring surface characteristics, a general description of each site includes: ratios of snow and ice cover, percentage coverage of cryoconite holes, percentage coverage of snow dunes, and crevasses.

I measured surface temperatures using a digital thermometer (accuracy within 0.1° C). For ice surfaces temperature was recorded by placing the thermometer in a small (1 - 5 mm) hole, shielding the area from the sun, and allowing the reading to stabilize within 0.5° C. By pushing the thermometer 1 - 5 mm into the snow, temporarily shielding the area from the sun, and allowing the reading to stabilize within 0.5° C an accurate snow temperature was recorded.

I measured ice surface roughness by laying a 2 m pole (the fiberglass snow depth probe was used) on the glacier surface and measuring the vertical distance from the pole to the ice surface. A folding ruler with millimeter increments was used to measure the vertical height at 5 cm intervals along the pole (Figure 4.8). On snow-covered ice, I tapped the folding ruler through the snow layers to the ice surface to obtain depth snow depth. The roughness is given as the standard deviation of values. Two sets of roughness measurements were collected at each site, one with the bar parallel to the SAR beam direction and the other with the bar perpendicular. I sighted

over a reflector and selected a landmark on the horizon of the Kurki Hills across the

valley; this gave me an approximate SAR beam direction on Commonwealth Glacier.

This landmark was then used to orient the pole. On Howard Glacier I used the

centerline axis of the glacier as the approximate SAR beam direction.

I determined the slope, relative to the SAR beam, by using the inclinometer on

a Brunton compass and an ice axe. The ice axe was laid on its side in a region that

best represents the average slope and its length (75 cm long) averages the high points

of the sample surface. I oriented the long axis of the ice axe parallel to the SAR beam

direction, and placed the Brunton compass on the shaft to measured the slope. Facing

the general fall line and comparing it to a landmark that was to the north determined

aspect. This method determined directions to only the eight cardinal directions (or

about $\pm 22.5°$).

I measured snow depth using a chimney sweep pole with centimeter intervals

marked along the shaft. The tip of the pole was a machined steel point that aided in

breaking through thin ice-crusts. Four snow depth readings were taken at each snow

site. A snow pit was dug at both reflectors, mid-way between the reflectors, and 500

m above the upper reflector. Snow stratigraphy was determined and three variables

were measured in each snow layer: density, grain size, and layer thickness. I

calculated snow density by weighing 100 cm^3 of snow; density measurements were

done for every layer thicker than 3.5 cm (due to the height of snow sample scoop).

Grain size was determined by sprinkling snow on graph paper and estimating the

average diameter. I measured layer thickness from the surface, to each layer using a

folding ruler. The area around each site, within a 50 m radius was characterized as to

relative aerial fractions of type of surface (snow, ice) and any notable features (e.g. crevasse, cryoconite holes). The fractional area of cover (e.g. snow, ice, cryoconite holes) was established by a consensus of estimates between Andrew Fountain (my thesis advisor) and myself.

I brought a calorimeter method of measuring water content of the snow to the field (Akitaya, 1985) but the snow was very dry and the error of the method high enough that reliable measurements of low moisture content were not possible.