CHAPTER VI

IMAGE PROCESSING

The two SAR images are “processed” but not terrain corrected: they are not projected in a standard coordinate system, and not corrected for brightness variations due to SAR peculiarities. The images are referenced in a time domain from the perspective of the satellite and only the image corners are geo-located. Because of the side-looking nature of SAR, substantial distortions in mountainous terrain exist in the image. Rectifying the images to a geo-referenced projection allows detailed comparison of SAR images with other images and maps (Domik et al., 1986; Partington, 1998; Naraghi et al., 1983), and in addition it allows detailed comparison of image brightness to specific locations on the earth. Significant changes in glacier slope and aspect, typical of alpine glaciers (in contrast to ice sheets), can affect the brightness variation of the SAR image and potentially mask the variations caused by changes in surface character. The ERS-2 image was processed using the ASF "Terrcorr" program (ASF website, 2000). Terrcorr corrects for radiometric variation, radiometric normalization, foreshortening, and geocodes the image. Terrcorr, like all terrain correction programs cannot correct brightness variations for shadowing or layover. Their main disadvantage of terrain correction is that the image is resampled to the Digital Elevation Model (DEM) resolution, which may reduce the resolution of the final image. I found that setting up the software and running it is very time consuming.

Radiometric Calibration.

Radiometric calibration removes variations in the image caused by spatial and temporal SAR data acquisition characteristics. It consists of the computation of the difference between real radar brightness and those of a simulation (Domik et al., 1986). The real brightnesses are scaled by differences between actual and simulated values are redistributed to account for variations in surface terrain. Terrcorr corrects the following three radiometric distortions:

Removal of Center-Bias. Like a flashlight beam, when a radar pulse contacts the ground, it contains more energy at the center than at the sides, causing the backscatter to be center-biased (ASF website, 2000). A portion of this bias is corrected at the processing facility and the remainder is completed by Terrcorr. At the processing facility, the antenna gain pattern is removed from the data (removing the center-bias) and the cross-track attenuations on the signal are removed (Tom Logan, ASF, personal communication). All of the corrections in the removal of center-bias are based on a geoid model of the earth. Terrcorr completes the subsequent radiometric corrections. The theorized center bias is mathematically inverted and the result is multiplied by each range line. Using an inverted antenna gain pattern restores the noise to a flat pattern (called noise floor), which is then removed. This correction is called sigma-naught.

Range Backscatter Correction. Backscatter varies along the range due to changing incidence angle. At the far range, where the incidence angle is large, more specular reflection away from the satellite occurs (Figure 6.1). Making the uncorrected SAR image generally darker at the far range (Tom Logan, personal communication). At the ASF processing facility, the look angles are calculated across the span in range based on a geoid of the earth. These data are compared to the actual SAR signal return relative to look angle data, which are used to create a range correction vector. This vector is used to correct each line in range.

Radiometric Normalization. The incidence angle also varies with the slope of the terrain. Slopes facing the SAR beam will reflect much more energy back toward the sensor than slopes facing away (Figure 6.1). To normalize this effect, the ratio of the tangent of the local topographic incidence angle, derived for each pixel from the DEM, to the "global incidence angle," (the tangent of the center of the SAR scene to the geoid incidence angle) is applied to the data (ASF website, 2000).

Foreshortening and Geocoding.

In the process of rectifying the image to a DEM, SAR image pixels are adjusted to a DEM, which is geocoded, thus acquiring the DEM's positional coordinates. The same rectification also corrects for foreshortening by stretching pixels on foreshortened slopes facing the SAR beam and compressing the pixels on the back faces to fit the DEM.

The Digital Elevation Model.

To use the USGS DEM of the Taylor Valley in Terrcorr, it had to be converted to Universal Transverse Mercator projection in a Land Analysis System (LAS) format and an ASF metadata file created (details of all the transformations and the Internet location of LAS programs in Appendix C). The projection change was accomplished using a Geographic Information System (ArcInfo). In the same program, the DEM was then converted to an American Standard Code for Information Interchange (ASCII) format. This format allowed the header to be easily removed and the "no data" values changed from –9999 to 0 (zero). These two changes formatted the DEM to be accepted into a LAS program and converted into a LAS format. A companion file containing the metadata was created using the ASF "makeddr" program. The LAS DEM and the ASF metadata file now comprise what is hereafter called the DEM.

Terrcorr Steps.

Terrcorr is a UNIX shell program, which runs a series of subroutines that radiometrically calibrate the image and geocodes it according to the general steps described earlier. Intermediate images and temporary files are made, compared to one another, and deleted. The final result is a terrain-corrected image. Terrcorr runs through the following steps (ASF website, 2000):

1. The data are radiometrically calibrated.

2. The calibrated SAR image data are resampled to the resolution of the DEM. These data are called the preprocessed SAR image (Figure 6.2a).

3. The SAR image is truncated to the borders of the DEM.

4. The simulated SAR image is created by calculating the cosine of the angle between the local surface normal and the ray from the nominal sensor location and assigning theoretical brightness values to each pixel of the DEM. This gives the simulated SAR image the general appearance of the DEM surface illuminated from the sensor position (Figure 6.2b) (Naraghi et al., 1983).

5. Recognizable features that can be related geographically between the simulated SAR image (step 4) and the preprocessed SAR image (step 2) are correlated. The pixel offsets are calculated between the two images.

6. From the pixel offsets, a polynomial function is calculated to spatially transform (warp) the image to the simulated SAR image (Domik et al., 1986), creating the terrain corrected image (Figure 6.3a).

Details in installing and running Terrcorr are described in Appendix C.

Radarsat Terrain Correction.

Terrain-correcting ScanSAR images are difficult because the location data for individual pixels are incomplete (Ron Kwok, personal communication). The pixel size also varies in range considerably more than ERS-2 data. Because of these differences, ScanSAR could not be corrected using Terrcorr. Dr. R. Kwok at the Jet Propulsion Laboratory (JPL) in Pasadena, California corrected the Radarsat image in this thesis. The JPL terrain correction routines and Terrcorr are virtually identical in their basic operation, as JPL developed both programs. Using a template of ScanSAR pixel sizes on a geode, and the location data provided, Dr. Kwok was able to assign the pixel location data for the entire image. With this location data, the preprocessed SAR image was created, and the terrain correction was run as described above (Figure 6.4).

Peculiar Characteristics of the Corrected SAR Images.

The corrected SAR images display visual characteristics that are different from uncorrected radar and other remote sensed imagery. The outline is irregular along some edges. In mountainous areas the border irregularity is very rough. Also in mountainous terrain, the slopes facing the SAR are “smeary.”

Rough Edges. The near-range edge of the ERS-2 corrected image (southwest side) has a rough edge due to steep topography (Figure 6.5). Layover would be present in this area, but because the edge of the radar scene runs parallel to a very steep ridgeline, the top of the ridge received backscatter and the base was not illuminated. In the terrain correction this ridge was shifted northwest to its proper location, leaving a rough edge where no information was collected. In the uncorrected image this edge is a straight line and shows significant layover. In the southwest side of the ERS-2 image, next to Canada Glacier, is a black irregular region of radar shadowing from a mountaintop. The east edge of the corrected ERS-2 and Radarsat images is irregular because the DEM ends at the coastline and is removed during the "DEM clip" step of the terrain correction. On the Radarsat image (Figure 6.6) similar rough edges are present on the southern edge (near range) of the corrected image.

Smearyness on Steep Slopes. The corrected images contain parallel lines, which soften and smear the image near steep slopes. A terrain corrected image of a steep slope that has foreshortening or layover will have streaks on the slope facing the SAR (Domik et al., 1986). Slopes steeper than the SAR incidence angle (23° for these data), exhibit this smearyness error. The pixels on slopes facing the SAR must be spread to fit the simulated SAR image (*ibid*). The spreading is in the range direction. In the same way a silly-putty image of a newspaper comic strip will turn into lines when stretched too far, as SAR data is stretched it creates similar lines. Compacting the pixels into the slopes facing away from the SAR improves the image. Some streaks appear on the lee slope around Commonwealth Glacier on both the Radarsat corrected image (Figure 6.4a) and the auto-corrected ERS-2 image (Figure 6.3a). This error is probably due to DEM inaccuracies first causing poor correlation (between the simulated SAR and preprocessed SAR images) and ultimately streaking on the wrong side of the mountain in the terrain correction.

Reflector Backscatter Shape of the ERS-2 Image.

In the uncorrected ERS-2 image (Figure 6.3a), reflectors are oblong in the look direction by five pixels. The satellite-borne precision processor resolves azimuthal position better than in the range direction (Wade Albright, Quality Assurance Engineer, ASF, personal communication). At the time of image acquisition, range resolution was 19.8 m and azimuth resolution 26.6 m, with a maximum allowed deviation in range and azimuth of 30 m (ASF website, 2000). This resolution is the smallest discernable feature that can be identified by the strength of the signal. However, the pixels that are in the image are smaller than this number. Pixel spacing is just used to measure distances within an image. This image, which is referred to as a “full resolution” product, has been multi-looked (averaged) so that the pixels become square (12.5m x 12.5m). This is done because it is much easier to work with square pixels than using the resolution numbers (Wade Albright, personal communication). This is why the pixel size of the uncorrected image is 12.5 m (as indicated in the image metadata), and the resolution is 30 m (as indicated at the ASF website). This is also why there will never be a feature in an image that is represented only in one pixel. In the terrain corrected image, the oblong shape is removed because the data were resampled to the DEM resolution of 30 m (Figure 6.3). The oblong shape changed only two pixels in length because of the loss in resolution (when the data was resampled to the DEM resolution) and the pixels being averaged and generalized.

Comparison of ERS-2 Images Between Manually Correlated, and Auto-Correlated.

The auto-correlated (Terrcorr) image exhibited "smearyness" on the mountainsides sloping away from the SAR beam. Normally this correction artifact is on the slopes facing the SAR beam. This raised concern about the accuracy of the correlation, a concern shared by Tom Logan from ASF, who speculated that the DEM might contain some inaccuracies. Because of this, the terrain correction process was run twice, once allowing Terrcorr to auto-correlate, and a second time, which was manually correlated (Figure 6.7). I manually adjusted the offset to match the edges of Commonwealth Glacier between the simulated SAR image and the preprocessed SAR image. The pixel displacement from the simulated image to the preprocessed SAR image was placed in a temporary file and the program re-run with the manually calculated displacement figures (Appendix C). The manually correlated image displays the “smeariness” on the facing slopes as expected.

To quantify the differences between the auto- and manually correlated images, the distances between the reflectors was used to determine which image was most accurate (Table 6.1). From the GPS measurements on the ground, the distance between them is 2417 m (with an error in location within 1.0 cm). Because the survey error is much smaller than the resolution of the imagery, this survey distance is used without consideration of error. Measuring the distances on the SAR images was done using ENVI 3.2 computer software (**E**nviro**n**ment for **V**isualizing **I**mages Program Research Systems, Boulder, Colorado).

Table 6.1: The distance between reflectors on the ERS-2 image (m).

Survey	2417[1]	Difference
ERS auto-correlated	2431±33[2]	14
ERS manually correlated	2368±33[2]	-49
ERS uncorrected	2128±33[2]	-289

[1] this distance is accurate to within a centimeter.

[2] $error = \sqrt{(range\_resoultion)^2 + (azimuth\_resoultion)^2}$

The auto-correlated image is the closest to the survey distance, and is within the estimated error. The manually correlated image is outside the estimated error. Because Commonwealth Glacier slopes towards the SAR position, the (uncorrected) slope is slightly foreshortened reducing the distance measured on the image. Both the terrain corrections, however, adjust the distance between the reflectors to a distance within 49 m of the true distance.

To further quantify the differences between the uncorrected, auto-, and manually correlated images, the azimuth of the transect line between reflectors was examined (Table 6.2). The azimuth from the lower to upper reflector was 303.55˚ using precise GPS data. North was determined on the uncorrected images from the “scene center heading” azimuth in the image metadata, which gives the azimuth of the centerline (from bottom to top) of the uncorrected image. On the corrected image north points to the top of the image since the SAR image was rectified to the DEM, which is oriented. The reflector azimuth on the image was determined from paper copies of the image using a protractor and pencil. The terrain correction process (manual or auto) appears to work very well in azimuth accuracy (Table

6.2). The uncorrected azimuth is 12.5˚ off and is likely an error of estimating the image orientation.

Table 6.2: Azimuth of the reflectors on the ERS-2 image.

	Azimuth	Error	Difference
Survey	303.55˚	“precise”	
ERS-2 auto-corrected	302˚	±1˚	1.55
ERS-2 manually corrected	303˚	±1˚	0.55
ERS-2 uncorrected	291˚	±1˚	12.55

Although the distance between reflectors (Table 6.1) is less accurate in the manually corrected image, it is only off by 1.5 pixels (45 m). The image also *looks* better in the steep ridges to either side of the Glacier (Figure 6.7). The difference in azimuth is negligible. When I calculated the pixel offset between the simulated SAR and the preprocessed SAR image, I could *see* that I was lining up the images to within a pixel. Because of this, I have more confidence in the manually corrected image to for the Commonwealth Glacier. However, the correlation outside Commonwealth area is likely to be more accurate with the auto-correlation because that correction adjusted the offset using the data across the entire image. By manually-correlated the image using data limited to the terminus of Commonwealth Glacier and the ridgelines to either side, increased the error in other parts of the image.

A third measure of error is comparing the surveyed locations of the reflectors to the locations on the image. Using this method on the SAR images, the upper reflectors are located exactly. The lower reflectors are off by 168 m (manual) and 156 m (auto) both to the north. Using this method on the DEM and comparing the estimated location of the reflectors and the plotted location yielded an error of 400 m to the south on both reflector locations. The errors in the auto correlation are very likely due to inaccuracies in the DEM and location errors in the spacecraft position (Dr. Ron Kwok, personal communication).

Five areas are noted that indicate the terrain correction is more accurate in the manually corrected image for analysis of the Commonwealth Glacier. First, on the manually correlated image there are two bright bands that make up the slope of Mt. Falconer ridge (Figure 6.8). The lower band is not a steep slope of the ridge (Figure 6.9), but is surprisingly bright. A formal ground-truth of that area was not conducted but, from helicopter flights, the area was observed to be scattered with large boulders, which may have created a strong SAR return due to roughness. Where the slope increases over 24°, the layover (and second bright band) begins (Figure 6.9, 6.10). The auto-correlation algorithms negligibly correct this band (Figure 6.7a), smeary lines of data are in this location on the Mt. Falconer ridge, but the process is not as complete as in the manually correlated version (Figure 6.7b). Second, the bright spot from the upper reflector is smaller in the manually correlated image by one pixel. Third "King Pin" nunatak, “unnamed nunatak”, and Hjorth Hill (Figure 6.8) correspond to the shape of the DEM in the manually correlated image (Figure 6.10). Fourth, the steep cliff face at the north edge of Commonwealth Glacier mimics the shape of the DEM more accurately in the manually correlated image (Figure 6.10). Fifth, on the auto-correlated image, if the Mt. Falconer ridgeline to the west of Commonwealth Glacier is extended onto the glacier, it intercepts near the lower reflector position. Comparing to a USGS Quadrangle map this line is intercepting 1000 m too far down glacier. The mismatch is due to layover remaining in the auto-correlated image of the ridgeline. The same intercept point on the manually correlation image is 1187 m up glacier from the lower reflector, which is exactly where it should be when compared to the map.

A general comparison of the ERS-2 SAR image of Commonwealth Glacier between the manually correlated and uncorrected image (Figure 6.11) indicates that the terrain correction significantly alters the orientation, shape, and contrast on Commonwealth Glacier. The reflectors are clearly visible on both images, but the uncorrected image they stand out sharply due to the higher contrast. General features like ridgelines, nunataks, and the outline of glaciers compare easily between images. The most significant differences are the spatial adjustments of the image to fit a projection and the stretching of foreshortened slopes. There is also a brightness difference between the auto and manually corrected images.

Radarsat Image Evaluation.

The Radarsat image is a coarse image compared to the ERS-2, due to the ScanSAR mode and pixel size of 50 m, which makes analysis more difficult for small areas. The terrain corrected image contains correlation errors in steep terrain, which is shown by smeariness on the slopes facing away from the SAR beam whereas the smearyness should be on the facing slopes (Figure 6.4). Like the ERS auto-correlation, a polynomial warp function was applied to conflate the preprocessed SAR image to the simulated SAR image, creating the terrain-corrected output image. Because of the way data are collected and recorded in the Radarsat ScanSAR (as previously described), the ERS-2 data contains much more data of pixel location and is much more suitable for detailed analysis (Ron Kwok, JPL, personal communication).

Comparison of Radarsat Images Between Corrected and Un-Corrected.

The distance between the reflectors on the corrected Radarsat image is close to the surveyed distance, 15 m. The uncorrected distance is much shorter, by 207 m (Table 6.3), than the survey distance due to radar foreshortening. Because of the similar incomplete terrain correction as seen in the ERS auto-correlation image (layover still present, data correction smears on the mountain sides sloping away from the SAR beam) the same correlation errors that are likely caused by the DEM are creating similar incomplete terrain correction artifacts in the Radarsat image. Unlike the ERS-2 data, the Radarsat data is uncalibrated for error in range and azimuth. The error assigned for the corrected image was taking into account errors in distance measurements.

Table 6.3: The distance between reflectors on the Radarsat image (m).

Survey	2417±.001[1]	Difference
Radarsat corrected	2402±50[2]	-15
Radarsat uncorrected	2210[3]	-207

[1] this distance is accurate to within a centimeter.
[2] 1/2 pixel error on each reflector.
[3] errors undetermined.

The azimuth of the reflectors is compared to assess the differences between the uncorrected and corrected images (Table 6.4). Unlike the ERS-2 azimuths, the uncorrected is more accurate and the corrected image is different by 5.5˚. The uncorrected azimuth may be more accurate than the ERS-2 azimuth because, Commonwealth Glacier where the deflection was measured is closer to the center of the scene where the base azimuth is known from the metadata (Figures 5.1, 5.2). The corrected azimuth may exhibit a larger error because of the difficulties in assigning location data for individual pixels with ScanSAR data and running the terrain correction with larger degrees of estimation.

Table 6.4: Azimuth of the reflectors on the ERS-2 image.

	Azimuth	Error	Difference
Survey	303.55˚	“precise”	
Radarsat corrected	287˚	±1˚	16.55
Radarsat uncorrected	304˚	±1˚	0.45

The Radarsat ScanSAR corrected and uncorrected (Figure 6.4) images also allow general comparison. General features are cross-identifiable on both images such as Mt. Falconer Ridge, the shape and location of the terminus and sides of Commonwealth Glacier, unnamed nunatak, and the ridgeline to the north that demarks the edge of the glacier. Like the comparison between the corrected and uncorrected ERS-2 images, the spatial adjustments of the image to fit a projection are significant. Unlike the ERS-2 image there is very little brightness difference between the auto and manually corrected images. This is due to the method of radiometric normalization used.

The comparison of corrected and uncorrected Howard Glacier images is difficult. The corrected image (Figure 6.12a) contains a great deal of error due to an obtusely sloping mountainside the relative to the SAR beam (Figure 6.13). The only area that can be positively identified is the terminus and only because of familiarity of the area. Howard Glacier is somewhat easier to identify on the uncorrected image (Figure 6.12b), but the contrast between the terminus and bare earth is very low, once again familiarity of the area is necessary to properly interpret the image.