Intern Report: Volker Kaltenborn

Summary of my summer internship
from March 25th to June 30th, 1995 at the

Alaska SAR Facility (ASF)

This summary is dedicated to all ASF people, who are working for high-quality satellite image products.
I want to say special thanks to Tom and Shery George for their hospitality during my first days in Alaska, and of course Jason Williams, my supervisor, for his patience and inspiration regarding my work.
It is very hard to leave .....

Volker Kaltenborn

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1. Introduction

The European Remote Sensing Satellite ERS-1 was launched in 1991 by ESA (European Space Agency). The satellite is configured to highlight applications in land resources, including geology, geomorphology, glaciology, and land cover monitoring. Studies of sea ice, glaciers, and permafrost will play an important role in understanding global climate changes.

ERS-1 is a C-Band (5.3 Ghz) Synthetic Aperture Radar system, with a sun-synchronous orbit in an altitude of 785 km above ground, and an inclination of 97.5 degrees. It covers the same point on the earth every 35 days. Due to the satellite imaging geometry, data are not available north of approximately 88.4 degrees north latitude or south of approximately 79 degrees south latitude.

In 1995 the Alaska SAR Facility will handle data from two new satellites, ERS-2 and RADARSAT. ERS-2 will be a copy of ERS-1, and will likely fly the same orbit as ERS-1 35 day repeat cycle with a one-day separation between the spacecraft.

2. Task

In preparation for the ERS-2 launch it was my task to characterize ERS-1 data.

In the past a lot of image data was analyzed at different times, with different versions of calibration software and different SAR-processor adjustments. To get more exact state-ments about the ERS-1 SAR-system and in order to provide a good reference for compa-rison of ERS-1 and ERS-2 data I had to reanalyze a huge number of images using one calibration software version and one constant SAR-processor adjustment.

My task was structured in the following steps:

- searching for all processed image data in the archive catalog system
- searching for unprocessed images to fill in time gaps
- ordering all images
- analyzing all images
- summarize all calibration data in a database
- evaluate and represent the results
- other activities

2.1. Searching for the images

For the analysis of SAR data with regard to the calibration features the SAR Facility mostly uses a corner reflector array located near Delta Junction.

The first step for me was to find out which ERS-1 satellite tracks cover the corner reflector array at all. I used the ESA PC program " DESC " to do this. This program provides the orbit numbers of ERS-1 tracks covering a fixed point on the earth (for example Delta Junction : 64.19 degrees north 147.89 degrees west). These orbit numbers include both processed and unprocessed images.

The second step was to get the orbit numbers of all processed images. These orbit numbers I found out in the ACS (archive catalog system) database. Then I put all orbits in time order to make sure that the data consistently cover the time from March 1992 to March 1995. That was important to get a reasonable database for the following statistical analysis. I noticed that the already processed images did not completely fill out the time period. Therefore it was further necessary to process a lot of images to fill out the time gaps. After this there remained a time gap from the 7th of February 94 to the 7th of April 94. For this time were neither ascending nor descending images available.

2.2. Ordering the images

To order the images I logged into the SANTA host, which allows access to the ACS.

The reprocessing parameters are all the same except for the gain. To prevent saturation of the corner reflector impulse responses I used a processor gain of -18 dB. The actual SAR processor version was AASP 04.4000.

All together I ordered 140 full resolution ERS-1 images for reprocessing, 85 for descen-ding and 55 for ascending orbits. This includes 22 originally unprocessed images. This produced a data quantity of 140 times 64 Mbytes (!). All images fitted on 25 8mm cartridge tapes with a data capacity of 4.5 Gbytes.

2.3. Analyzing the images

This part of my work took the most time.
For analyzing of the images I used the calibration workstation (Sun Sparcstation 2).

The first step was always to create a 1024 pixels x 1024 pixels x 8 bits/pixel low-resolution image running the scrunch program on the full-resolution SAR image with 8192 pixels x 8192 pixels x 8 bits/pixel.
The next step was to start the disa calibration software running on the UNIX workstation. The actual disa version was 1.04. After these preparations I could start the calibration calculations.

2.4. Summarizing of the calibration results

I summarized the calibration results in a Microsoft EXCEL 5.0 database.
For performing the statistics analysis and for creating the charts I used EXCEL as well.

3. Characterization of ERS-1 data

In order to meet the user requirements for retrieving parameters using ERS-1 SAR images, it is necessary to carefully estimate the errors arising from the quality of the SAR data, their calibration, and the accuracy of the applied retrieval algorithms. The calibration team performs routine calibration analysis to ensure that the data being distributed meets the specifications of the Official Calibration Plan. My characterization of ERS-1 data mainly refers to the geometric calibration and the radiometric calibration of the SAR images.

3.1. Geometric Calibration

The geometric fidelity of the SAR data is critically important for many scientific applications (e.g. geologic mapping). Geometric distortion arises from platform ephemeris errors, errors in the estimate of the target height, and signal processing errors. The geo-metric calibration is the process of measuring the various error sources and characterizing them in terms of the calibration accuracy parameters.

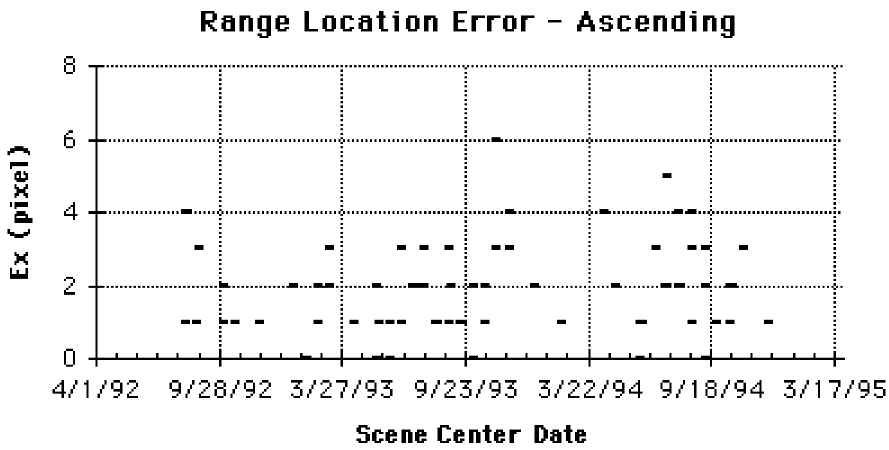
One parameter can be the absolute location error. It is the uncertainty in the estimate of any image pixel to a given coordinate system. In our case are these the latitude and longitude of the corner reflectors measured by using differential GPS (Global Positioning System). These coordinates are compared to the coordinates of the peak pixel in the corner reflector impulse response. The corner reflector positions are found by calculating the image corners so that the reflector locations will fit their true position with a minimum square error.

In the following graphs (1-6) one pixel corresponds to 12.5 m. That is the value for the pixel spacing of an ERS-1 full-resolution image. The GPS accuracy is +/- 3 m by our estimates.

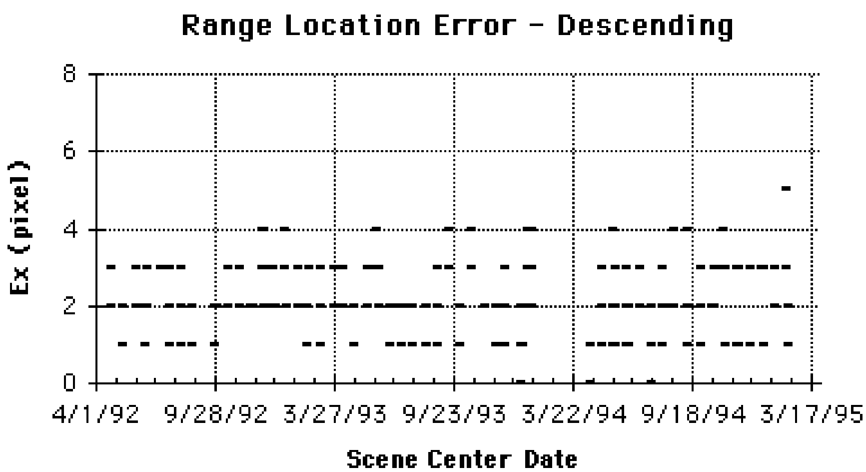
3.1.1. Range Location Error Ascending/Descending

Graph 1 and 2 show the range location error (cross-track error) for the ascending and descending satellite tracks. The value

Ex (pixel) is calculated as the difference of the accurately measured GPS location of the reflectors and the position of the reflectors determined from the satellite data (CEOS file - Committee on Earth Observing Satellites) in cross-track direction.



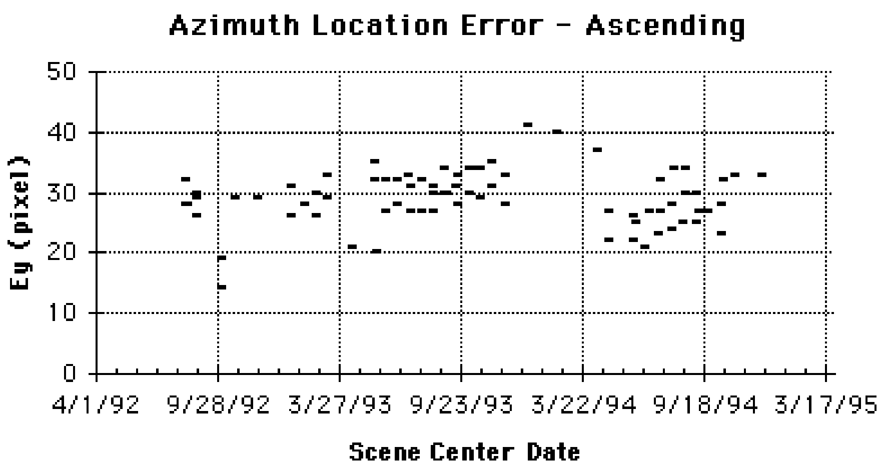
Graph 1



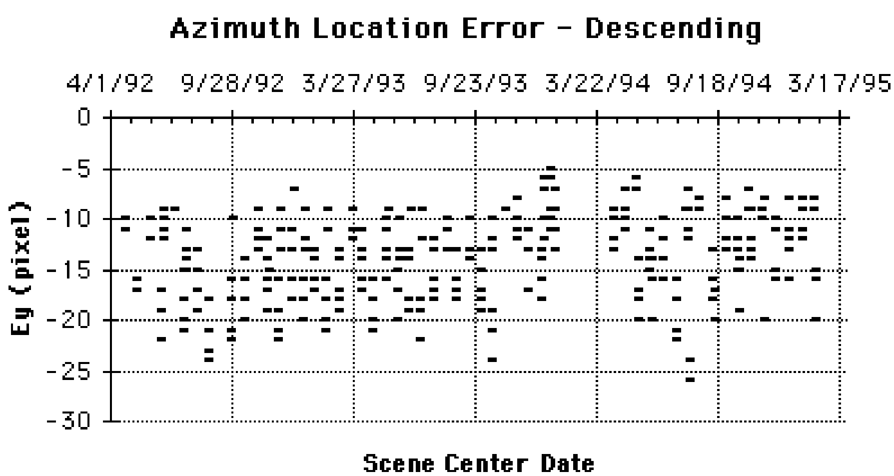
Graph 2

<u>3.1.2. Azimuth Location Error Ascending/Descending</u>

Graph 3 and 4 are showing the azimuth location error (along-track error). The value Ey (pixel) is calculated as the difference of the accurately measured GPS location of the reflectors and the position of the reflectors determined from the satellite data (CEOS file) in along-track direction.



Graph 3

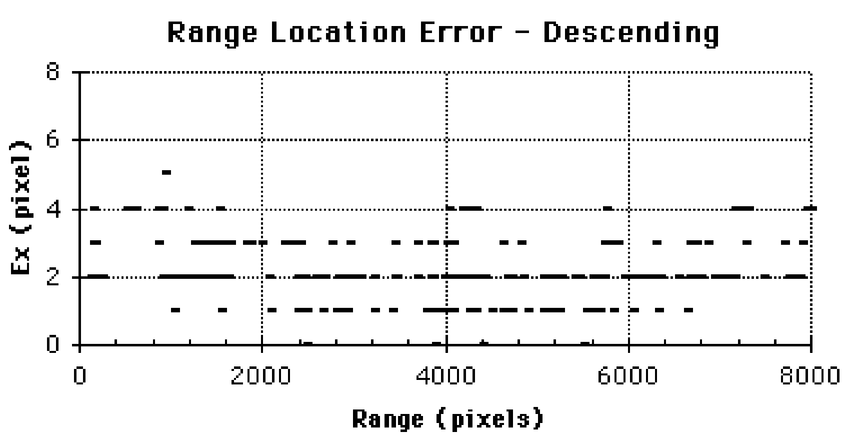


Graph 4

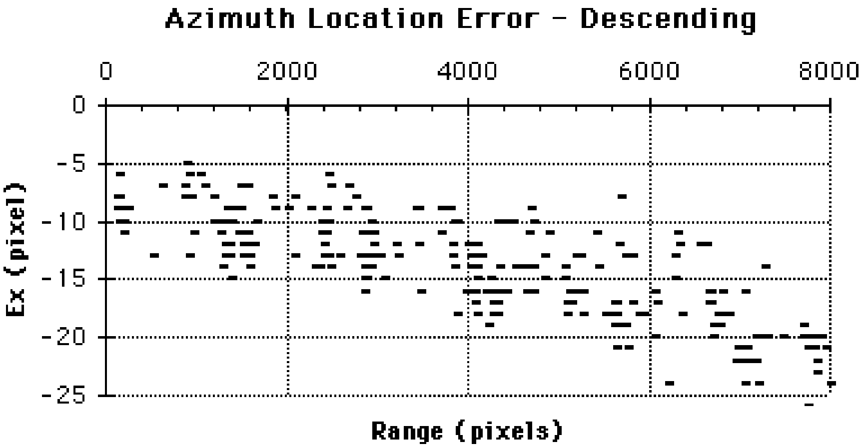
Normally the range/azimuth location errors should show a distribution around zero. In our case this is not so. Both errors have an offset which could be reduced with another SAR processor adjustment.

3.1.3. Range/Azimuth Location Error versus Range

Graph 5 and 6 are showing the location errors (descending) as a function of range (pixels).



Graph 5



Graph 6

Whereas the range location error does not show dependence on the range (pixels) the azimuth location error is a function of range (pixels). The mean near range azimuth location error (< 1500 pixels) is -124.78 m (9.98 pixel), the mean far range azimuth location error (> 6500 pixels) is -246.2 m (19.7 pixel).

3.1.4. Other Errors

Two images Rev Id 167959100 (E1/S/08024.01) and 170448100 (E1/S/08797.01) both ascending showed an uncommon high range location error of - 127 to -157 pixels. This corresponds to an position error of 12.5 m (pixel spacing) times pixels, about -1.587 km to -1.962 km. The reason for this is probably a window position error, a known processing error.

These images were taken out of the statistical calculations.

3.1.5. Error Statistics

The following table shows statistical calculations with regard to the absolute calibration errors.

Error	mean	sdev	meandev	# meas
Range Location - Descending	27.19 m	11.16 m	0.67 m	274
Range Location - Ascending	23.36 m	16.12 m	1.85 m	76
Azimuth Location - Descending	-124.78 m	52.82 m	3.19 m	274
Azimuth Location - Ascending	363.32 m	57.64 m	6.61 m	76

Table 1

The mean value and the standard deviation of the geometric errors are within the limits set forth in the official calibration plan.

3.2. Radiometric Calibration

Radiometric calibration is the process of characterizing the performance of the SAR system in terms of its ability to measure the amplitude and phase of the backscattered signal. The process can be divided in an internal and an external calibration. Whereas the internal calibration is injecting specific signals into the radar data stream the external calibration is using signals originating from, or scattered by, ground targets. In our case we use corner reflectors with a known radar cross section.

There exists a big variety of calibration error sources in the end-to-end system performance. Sources are the sensor as well as the downlink and the ground processor. Here are a few examples for possible error sources:
sensor:
-effects of the atmospheric propagation (attenuation, Faraday rotation, group delay),
-radar antenna (distortion in the phased array because of large temperature variation),
-sensor electronics,
downlink:
-stability of platform (influence on Doppler parameter estimation)
processor:
-SAR correlator can produce matched filtering errors
Because of the uncertainty in the characterization of each element the current calibration only determines if the expected system performance meets the defined specifications in the official calibration plan.

The most important radiometric calibration parameters are :
-radiometric correction factor K
-resolution (range/azimuth)
-peak side-lobe ratio (range/azimuth) PSLR
-integrated side-lobe ratio (range/azimuth) ISLR

Other calibration features are the Equivalent Sigma Naught (NES0), antenna pattern, number of looks, and histograms.

3.2.1. Radiometric correction factor K

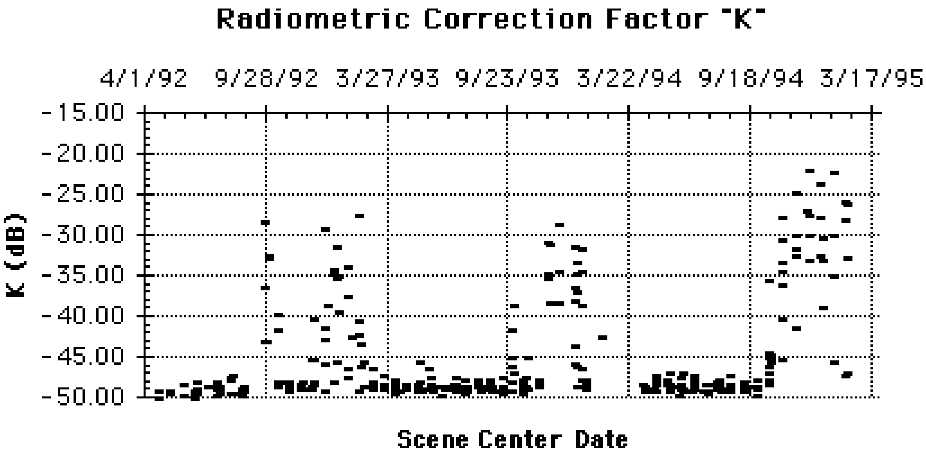
The full-resolution SAR images consist of pixels, each with an 8 bit digital number (DN) representing a scaled amplitude of the backscattered signal. If the processor is correctly adjusted the radiometric calibration factor K gives a functional dependence between each pixel's DN value and the real backscatter σ_0. The equation is:

$$\sigma_0 = K \cdot DN^2$$

In the calibration process the K value computed from the image is taken to be compared to the CEOS K value, a fixed value which is supplied with all images. The CEOS value is based on the known radar cross section of the corner reflector. For detailed calculations see [2].

3.2.1.1. K value versus overflight date

Graph 7 shows the K value versus the time period from April 92 to March 95. It is remarkable, that the K value in the summer is nearly constant, whereas in the winter the K value varies between -22 dB to -50 dB. The reason for this effect is the influence of snow in the corner reflectors. In the time between 09/18/94 and 03/17/1995 the maintenance of the reflectors was irregular (only one trip!).
The summer period 1993 had originally four uncommonly bad K values between -30 dB and -36 dB. All values concerned corner reflector DJ5. The reason was a farmer who moved the corner reflector on his field. The four values were taken out of the statistics.



Graph 7

Table 2 concludes the differences of the K value between summer and winter.

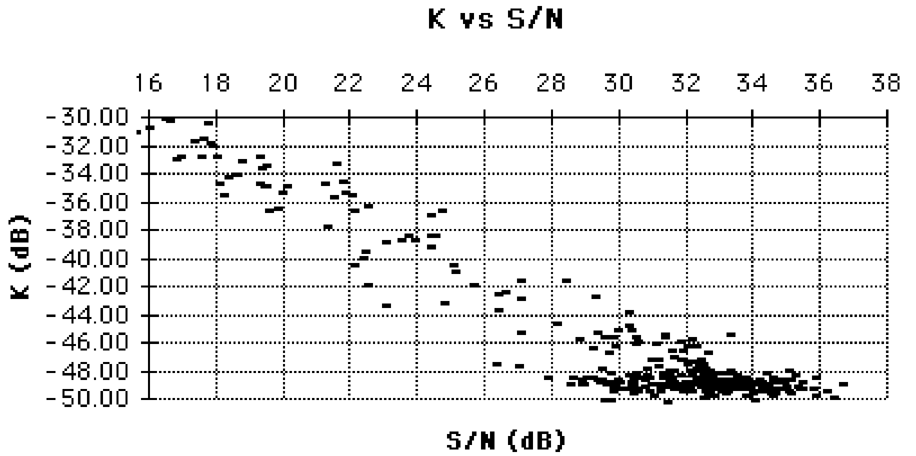
K value	mean	sdev	meandev	# meas
summer (04/01-09/30)	-48.35 dB	2.73 dB	0.19 dB	198
winter (10/01-03/31)	-41.59 dB	7.79 dB	0.63 dB	152
overall	-45.42 dB	6.46 dB	0.35 dB	350

Table 2

The summer K value keeps the alert level of the absolute K value of -49.2 dB (+/- 2 dB). Standard deviation (+/- 1 dB) and winter K value are not as demanded. To improve the results the maintenance in the winter months should be expanded. I recommend at least two times a month.

<u>3.2.1.2. K value versus S/N</u>

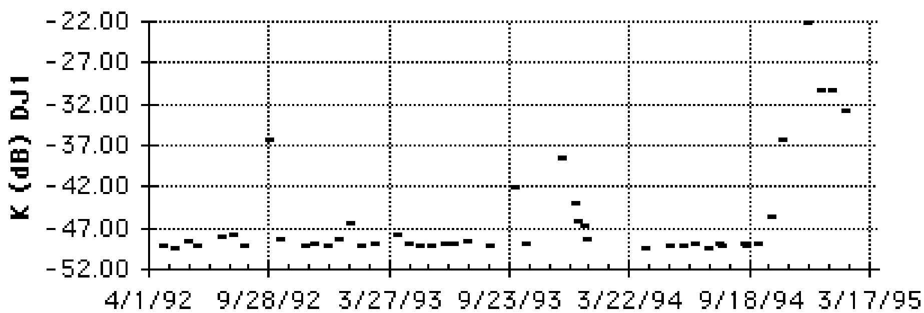
An other interesting relationship exists between the K value and the S/N (signal to noise ratio). The S/N ratio of the impulse response of a corner reflector is calculated as the difference between the corner reflector power and the average background power. To find the power values FFT oversampling is used and an integration over the entire response is done [2].
The higher the S/N ratio the closer the K value keeps the specified value (see Graph 8).

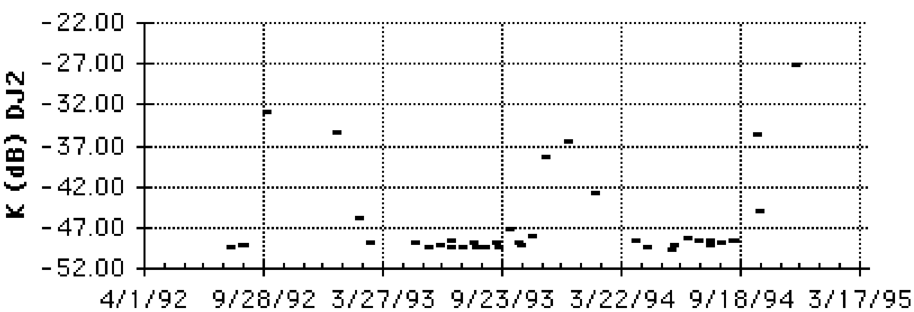


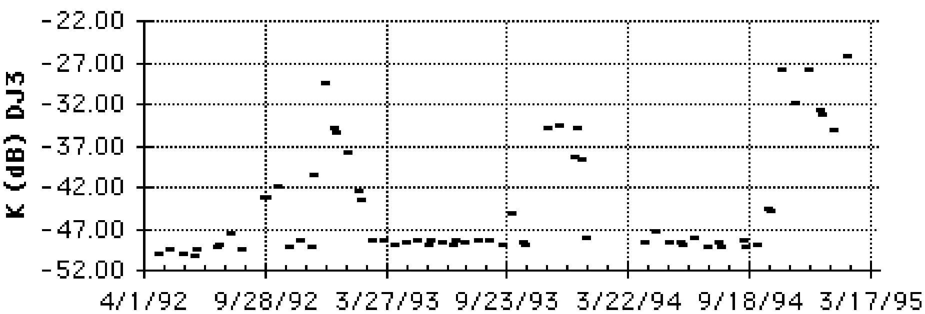
Graph 8

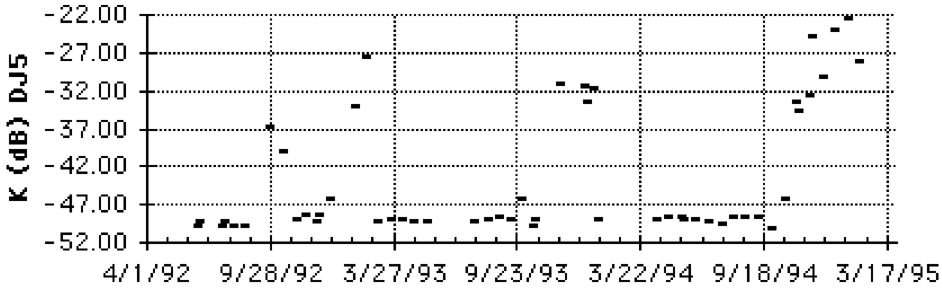
<u>3.2.1.3. Comparison of K values between corner reflectors</u>

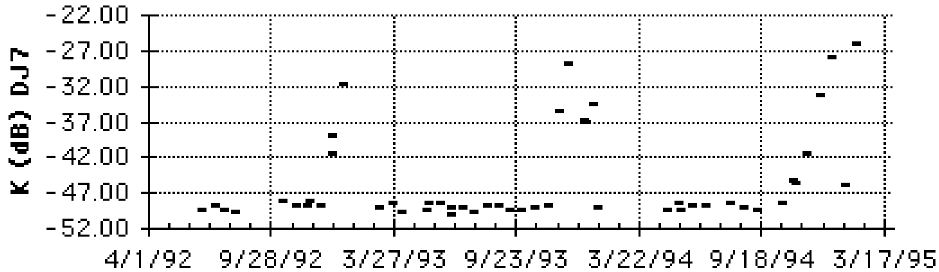
The following graphs are showing the quality of the different corner reflectors with regard to the K value.

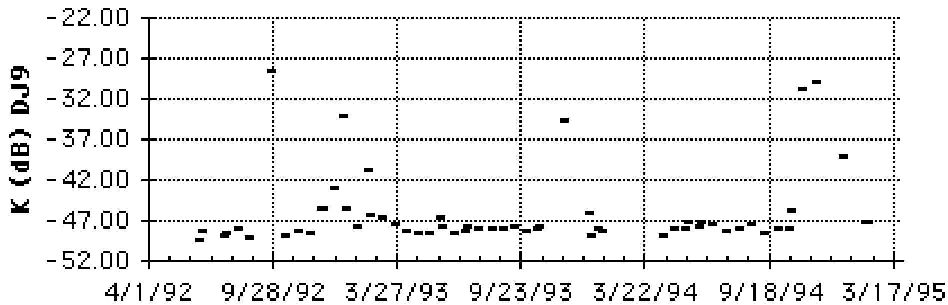


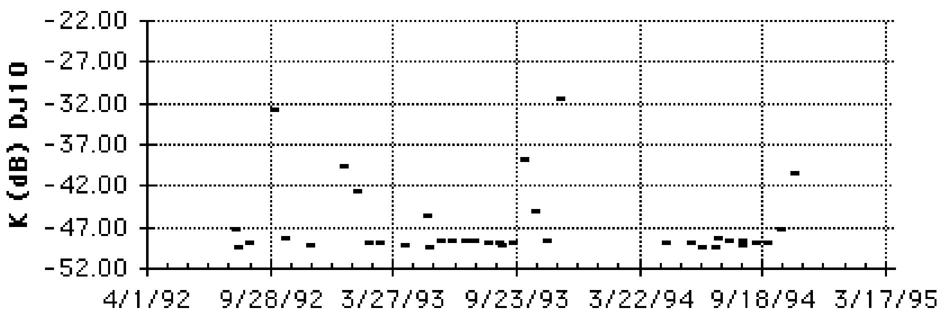












In table 3 are summarized the statistical results for the corner reflectors. The summer values include all measurements between April 1st and September 30th. It is remarkable that the overall and summer K values of all reflectors differ by at least 2 dB (except DJ9 and DJ10).

CR #	mean K value	sdev K value	meandev	# meas
1 (overall)	- 46.06 dB	6.24 dB	0.91 dB	47
1 (only summer)	- 48.31 dB	2.75 dB	0.53 dB	27
2 (overall)	- 46.44 dB	5.55 dB	0.89 dB	39
2 (only summer)	- 48.46 dB	3.13 dB	0.60 dB	27
3 (overall)	- 44.43 dB	6.81 dB	0.84 dB	66
3 (only summer)	- 48.56 dB	1.54 dB	0.26 dB	36

5 (overall)	- 43.46 dB	8.72 dB	1.21 dB	52
5 (only summer)	- 48.64 dB	2.52 dB	0.49 dB	26
7 (overall)	- 45.37 dB	6.67 dB	0.94 dB	50
7 (only summer)	- 49.19 dB	0.44 dB	0.09 dB	24
9 (overall)	- 46.17 dB	4.81 dB	0.63 dB	59
9 (only summer)	- 47.61 dB	3.49 dB	0.62 dB	32
10 (overall)	- 46.90 dB	4.53 dB	0.74 dB	37
10 (only summer)	- 47.84 dB	3.71 dB	0.73 dB	26

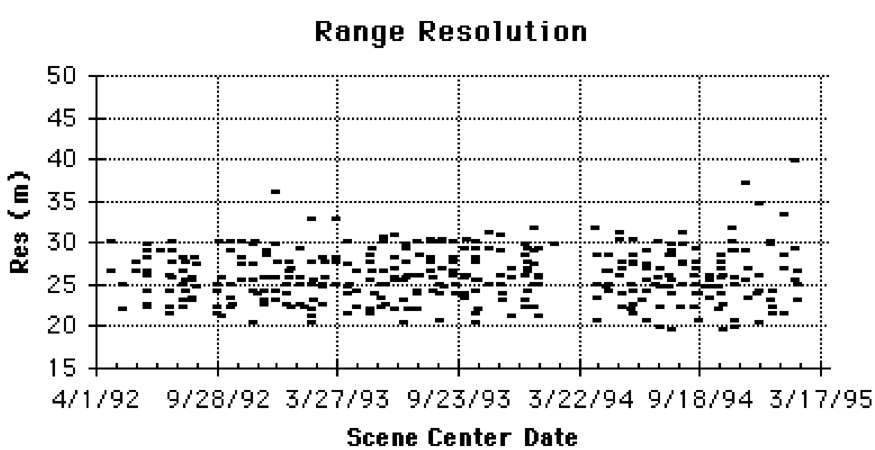
Table 3

3.2.2.Resolution (Range/Azimuth)

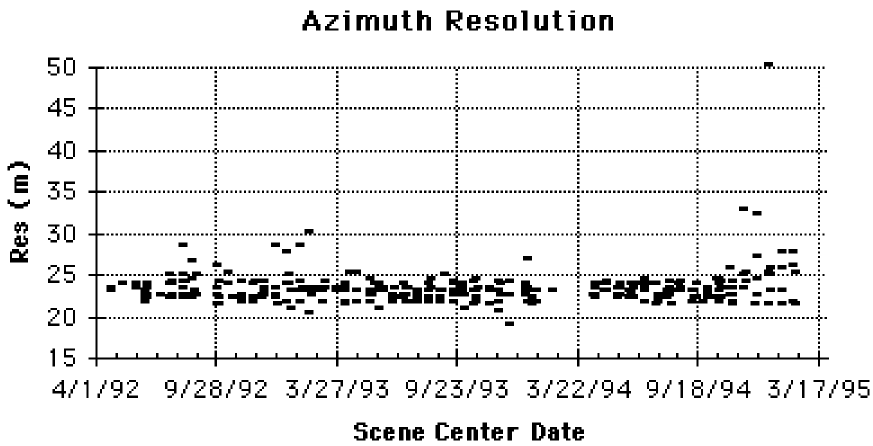
The range/azimuth resolution is the minimum range/azimuth separation of two points that can be distinguished as separate by the system.

The range resolution is limited by the pulse duration. The shorter the pulse duration the higher the resolution can be, but a shorter pulse duration would not produce a sufficient echo signal to noise ratio (SNR). To improve both high resolution and a high SNR the satellite uses the pulse compression technique.
The azimuth resolution is limited by the radar beam angle. Two targets on the ground can be resolved only if they are not both in the radar beam at the same time. An improvement of the azimuth resolution would require a huge antenna length in the along-track dimension, which is quite impractical. Instead of this is used the synthetic aperture radar (SAR). The key observation dates from 1951, and is attributed to Wiley (1965). He observed that two point targets, at sligthly different angles with respect to the track of the moving radar, have different speeds at any instant relative to the platform. Therefore, the reflected radar pulse will have two distinct Doppler frequency shifts [1].

The measurement of the resolution is based on the 3-dB width of the target impulse response along the range or azimuth axis. It is defined as the distance between the 50% points on both sides of the peak of the signal power. The calibration software does a 2-dimensional FFT of the local region of pixels around the point target by zero padding and then taking the inverse FFT [2].
Graphs 9 and 10 are showing the results for the range and azimuth resolution.

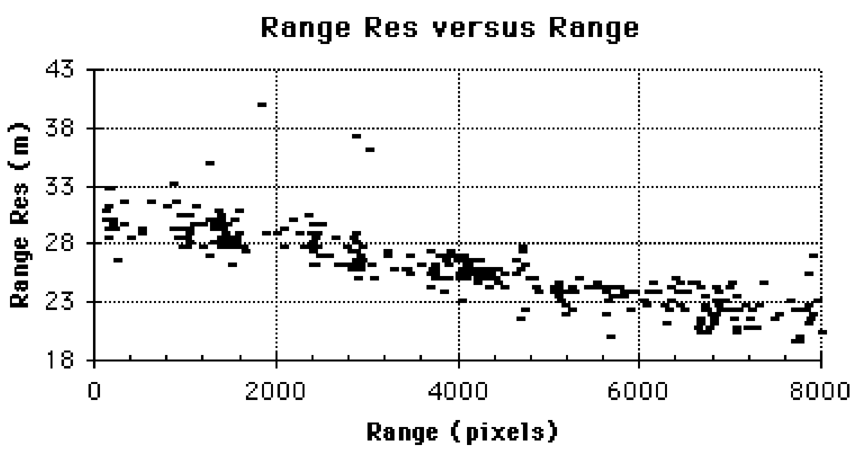


Graph 9

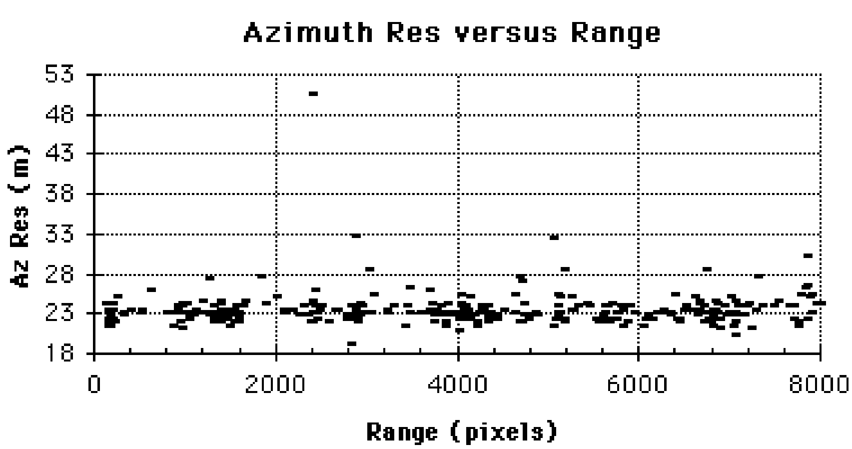


Graph 10

Graph 11 and 12 show the resolutions versus range (pixels). Whereas the azimuth resolution is independent from the range we can divide the range resolution in a far and near range resolution. The near resolution is larger than the far range resolution. The reason for this is the different incidence angle of near and far distant targets with respect to the satellite.



Graph 11



Graph 12

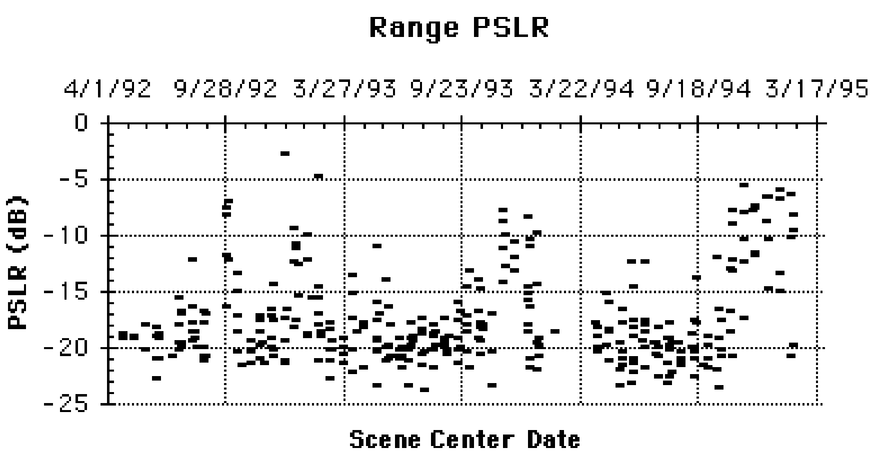
In table 4 are compared the results of the statistical analysis to the requirements in the calibration plan. The values of the calibration plan are essentially achieved.

Resolution	mean	stdev	meandev	# meas
Near range (pixel <1500)	29.50 m	1.51 m	0.17 m	76
Near range (calibration plan)	28 m	+/- 1m		
Far range (pixel >6500)	22.20 m	1.49 m	0.19m	62
Far range (calibration plan)	22 m	+/- 1 m		
Azimuth	23.35 m	2.07 m	0.11 m	350
Azimuth (calibration plan)	23 m	+/- 1 m		

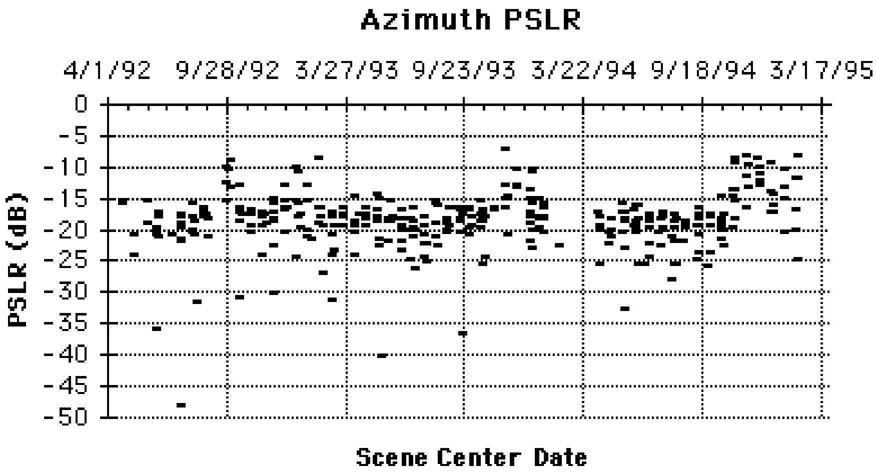
Table 4

3.2.3. Peak to side-lobe ratio (PSLR)

The PSLR indicates the ability of the radar to detect weak targets. It is the ratio of the largest sidelobe value (outside the specified mainlobe region) to the mainlobe peak. The PSLR is found by first doing a FFT interpolation of the local region around the point target response. Then the mainlobe peak and the first sidelobe peak are located.
Graph 13 and 14 are showing the range/azimuth PSLR versus overflight time.



Graph 13



Graph 14

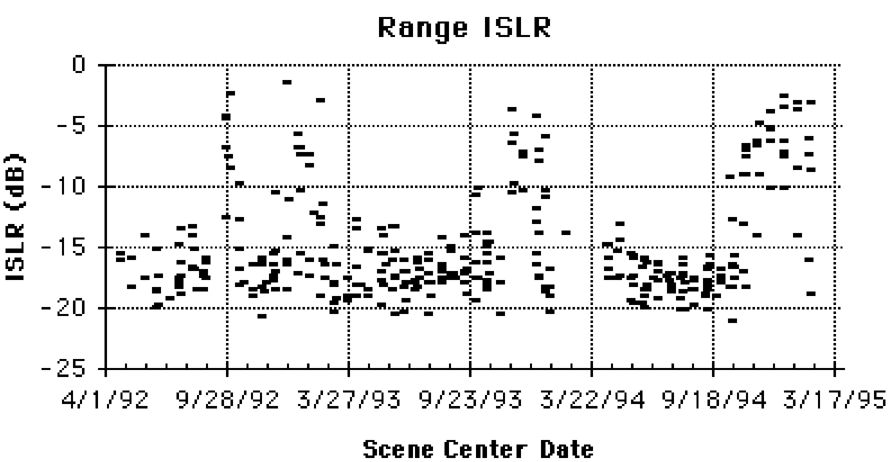
Table 5 concludes the PSLR measurements.

PSLR	mean	sdev	meandev	# meas
Range	-17.48 dB	4.57 dB	0.24 dB	350
Range (calibration plan)	-15.00 dB	+/- 1 dB		
Azimuth	-18.62 dB	4.56 dB	0.24 dB	350
Azimuth (calibration plan)	-18.00 dB	+/- 1 dB		

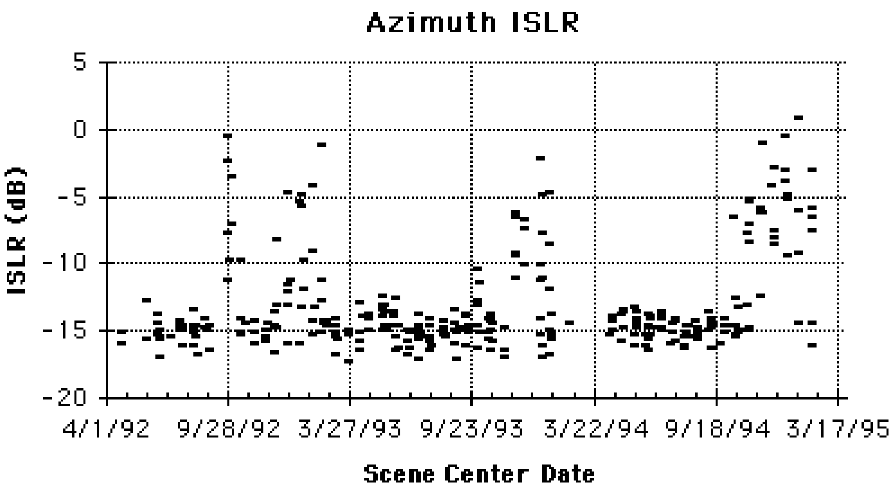
Table 5

3.2.4. Integrated side-lobe ratio (ISLR)

The ISLR is a measure of how much energy is leaking from the mainlobe of the impulse response function of the target. It is the integrated sidelobe to mainlobe power ratio. Graph 15 and 16 show the range/azimuth ISLR versus overflight time.



Graph 15



Graph 16

Table 6 concludes the calculated results.

ISLR	mean	sdev	meandev	# meas
Range	-15.20 dB	4.33 dB	0.23 dB	350
Range (only summer)	-16.75 dB	2.66 dB	0.19 dB	198
Azimuth	-13.08 dB	4.15 dB	0.22 dB	350
Azimuth (only summer)	-14.24 dB	3.50 dB	0.25 dB	198
Cal.Plan	-13.00 dB			

Table 6

The difference of the values between summer and winter is remarkable again.

3.2.5. NES0

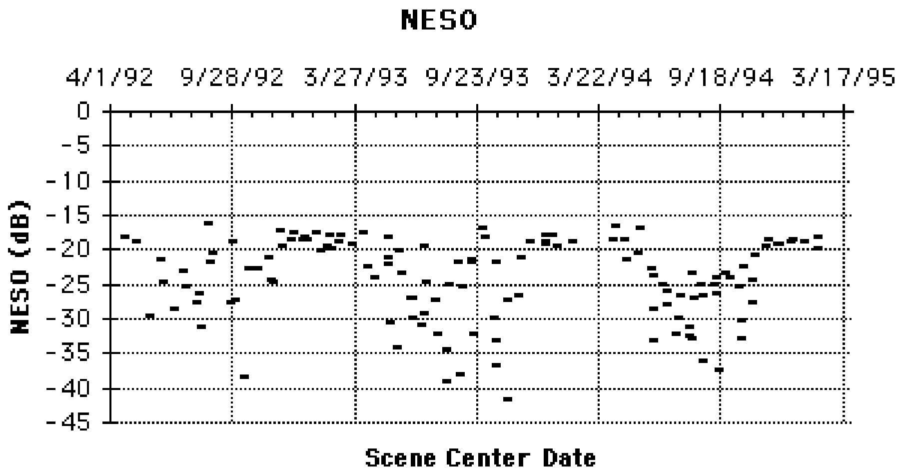
The Noise Equivalent Sigma Zero (NES0) describes the amount of noise in the SAR system. It is the lowest level where signals can be measured. The value is found by locating a region which is black (e.g. a lake). The program disa calculates an average DN value over the small region (radius 4) and converts the DN value into the σ_0 value. The equation is:

$$\sigma_0^{dB} = K_0^{dB} + 20\log(DN) - G_{image}^{dB}$$

K_0 ...radiometric correction factor for 0 dB gain image

G_{image} ...gain for the image (-18 dB)

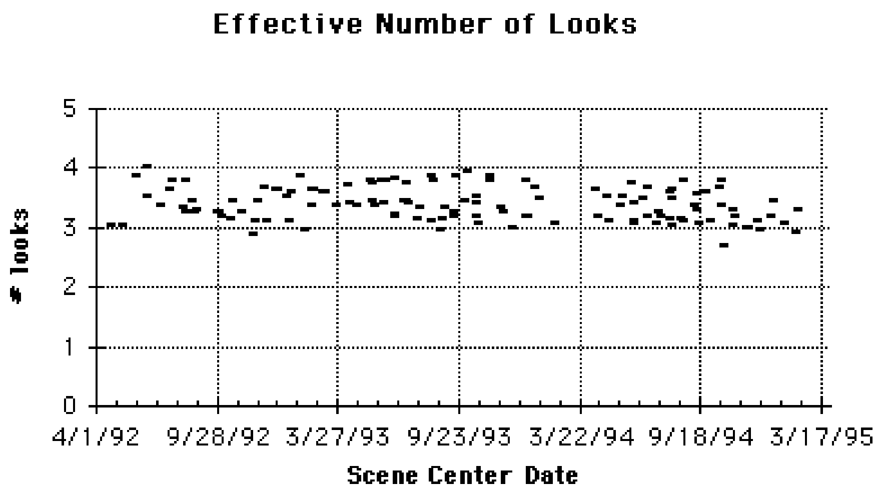
Graph 17 shows the NES0 distribution. The calculated mean value is -24.29 dB. This meets the specified value of -23 dB (+/-2 dB) perfectly.



Graph 17

<u>3.2.6. Number of looks</u>

The number of looks is a setting in the SAR processor, which cannot be directly measured. Instead of this is measured the effective number of looks. The program calculates the value from the point target resolution. The effective number of looks is the measured azimuth resolution divided by the theoretical 1 look resolution (along track length of the real SAR antenna divided by two) [2].



Graph 18

The values of the calibration plan for the mean (3.5) and standard deviation (+/- 0.3) are perfectly achieved (mean # of looks 3.38, standard deviation 0.28).

<u>4. Other activities</u>

An important role in the life of a calibration intern is the maintenance of the corner reflec-tors. They are used for the calibration of SAR images. Because of their very high and known radar cross section (RCS) they produce a bright dot on the image. There are two corner reflector arrays outside of Fairbanks.

Two maintenance trips took us to the corner reflector array near Delta Junction 120 miles southeast of Fairbanks. The reflectors are distributed in an area of 100 km x 100 km. There currently exist seven corner reflectors, five used for descending and two used for ascending images. These reflectors are constantly maintained at least once a month because this array is usually used for the satellite calibration. All reflectors were in very good condition, so we had to do only slight corrections.

Another maintenance trip took us to the second corner reflector array at Toolik Lake. The Toolik Field Station is located about 400 miles north of Fairbanks (68.38 degrees north, 149.38 degrees west) in the arctic tundra. The array consists of six corner reflectors around the research station. Because of the difficult climate conditions above the arctic circle (frozen soil, heavy storms, snow showers in July...) and the long distance has this been the first maintenance trip since two years. In spite of it the reflectors were in a quite good condition. Beside the normal measurements like front edge heading, inclination and front edge level we had to tighten the cables, knock in loose iron bars, and remove dirt.

5. References

[1] John C. Curlander, Robert N. Mc Donough, "Synthetic Aperture Radar"
John Wiley & Sons Inc.,1991.

[2] Jason Williams, "Calibration of SAR data from the Alaska SAR Facility"
Alaska SAR Facility, 1993.

[3] Norvang Madsen, "Specification of the Single Point Target analysis module."
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[4] Jason Williams "Calibration/Validation Plan" Version 1.0
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6. Special remarks regarding my internship

Experiences at work:

The first weeks were a little bit difficult because of the language problems and the search for a room, which was supported by the GI employees. The working atmosphere was outstanding. The guidance by my supervisor, J. Willams, was unique. I enjoyed my work very much. A problem was the small velocity of our MAC computers. We solved this by ordering a new one. In spite of it we had a lot of fun beside the hard work. A special highlight were the maintenance trips to the corner reflectors. I liked it very much.

Free time:

I brought a small ham radio station with me to Alaska. I met personally many of my hamfriends who I knew before only from the ham radio in Germany. A had a lot of fun in working pileups (ham radio jargon for many contacts in a short time) into Europe and the US westcoast.

I was very impressed by the overwhelming mountains and the beautiful nature of this land.

Recommandations for the next summer interns:

Although I was the first summer intern (maybe provisionally the last), who rode the snowmachine, I cannot recommend bringing lots of warm winter clothes to Alaska. The summer here has been surprisingly hot almost as hot as in Germany (plus mosquitos!).
An important thing is to have a good medical insurance. Sometimes it can happen that your chief gets the "Chicken Pox", which you have never had or you were unprepared stung by a bee. Suddenly you will find yourself in a hospital with a huge bill.

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If you have any comments, please EMAIL me!
