Iapetus Scatterometry Imaging

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July 16, 2007

- Sequence: s33
- Rev: 049
- Observation Id: ia_049_3
- Target Body: Iapetus

1 Introduction

This memo describes one of the Cassini RADAR activities for the s33 sequence of the Saturn Tour. A sequence design memo provides the science context of the scheduled observations, an overview of the pointing design, and guidlines for preparing the RADAR IEB. This IEB is for a unique Iapetus scatterometer imaging observation around Sep 10 2007.

2 CIMS and Division Summary

CIMS ID	Start	End	Duration	Comments
049OT_WARMUP4IA001_RIDER	2007-253T08:44:53	2007-253T11:05:40	02:20:47.0	Warmup for scatterometry and simultaneous radiometry of icy satellite.
049IA_SCATTRAD001_PRIME	2007-253T11:05:40	2007-253T12:30:40	01:25:0.0	Point -Z axis at target and execute raster scan(s) centered on target. Obtain simultaneous scatterometry and radiometry.

Table 1: ia_049_3 CIMS Request Sequence

Each RADAR observation is represented to the project by a set of requests in the Cassini Information Management System (CIMS). The CIMS database contains requests for pointing control, time, and data volume. The CIMS requests show a high-level view of the sequence design.

The CIMS requests form the basis of a pointing design built using the project pointing design tool (PDT). The details of the pointing design are shown by the PDT plots on the corresponding tour sequence web page. (See

Division	Name	Start	Duration	Data Vol	Comments
a	distant_warmup	-5:25:0.0	02:25:0.0	2.2	Warmup and initial radiometry
b	distant_warmup	-3:00:0.0	00:05:30.0	0.3	Initial radiometry
c	distant_scatterometer	-2:54:30.0	00:00:30.0	1.5	Scatterometer Off target
d	scat_compressed	-2:54:0.0	00:02:30.0	7.5	Scatterometer rcv-only 8-8 off to on target
e	distant_scatterometer	-2:51:30.0	00:16:0.0	105.6	Scatterometer Imaging 8-2
f	distant_scatterometer	-2:35:30.0	00:00:12.0	1.3	Scatterometer Imaging 8-8
g	distant_scatterometer	-2:35:18.0	00:03:42.0	24.4	Scatterometer Imaging 8-2
h	standard_altimeter	-2:31:36.0	00:00:3.0	0.7	Nadir pointed altimetry
i	standard_altimeter	-2:31:33.0	00:00:3.0	0.7	Nadir pointed altimetry
j	distant_scatterometer	-2:31:30.0	00:25:36.0	169.0	Scatterometer Imaging 8-2
k	distant_scatterometer	-2:05:54.0	00:00:12.0	1.3	Scatterometer Imaging 8-8
l	distant_scatterometer	-2:05:42.0	00:01:42.0	11.2	Scatterometer Imaging 8-2
m	scat_compressed	-2:04:0.0	00:04:0.0	12.0	Scatterometer rcv-only 8-8 on to off target
n	distant_radiometer	-2:00:0.0	00:10:0.0	0.6	Radiometer
Total				338.2	

Table 2: Division summary. Data volumes (Mbits) are estimated from maximum data rate and division duration.

Div	Alt (km)	Slant range (km)	B3 Size (target dia)	B3 Dop. Spread (Hz)
a	45116	off target	0.21	off target
b	24758	off target	0.11	off target
c	23987	off target	0.11	off target
d	23917	off target	0.11	off target
e	23567	23887	0.11	109
f	21326	21655	0.10	118
g	21298	21636	0.10	118
h	20780	20781	0.10	120
i	20773	20773	0.10	121
j	20766	20767	0.10	121
k	17188	17536	0.08	142
l	17160	17524	0.08	142
m	16923	17279	0.08	144
n	16365	off target	0.08	off target

Table 3: Division geometry summary. Values are computed at the start of each division. B3 Doppler spread is for two-way 3-dB pattern. B3 size is the one-way 3-dB beamwidth

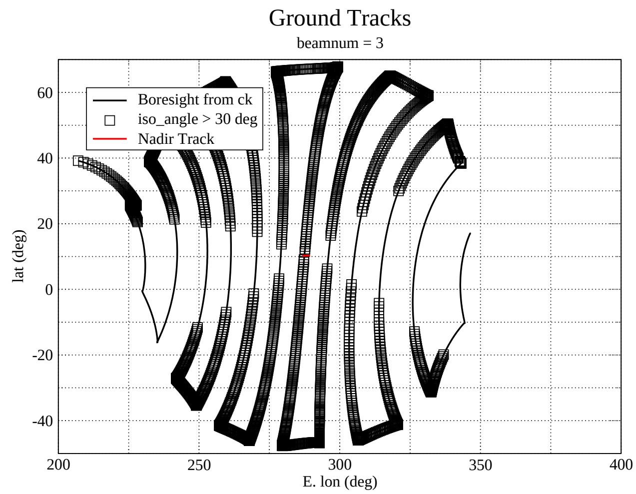

Figure 1: Scan in target body-fixed coordinates. Symbols mark portions of the scan where the angle between iso-range and iso-doppler lines are greater than 30 degrees. These areas are most favorable for imaging.

https://cassini.jpl.nasa.gov/radar.) The RADAR pointing sequence is ultimately combined with pointing sequences from other instruments to make a large merged c-kernel. C-kernels are files containing spacecraft attitude data.

A RADAR tool called RADAR Mapping and Sequencing Software (RMSS) reads the merged c-kernel along with other navigation data files, and uses these data to produce a set of instructions for the RADAR observation. The RADAR instructions are called an Instrument Execution Block (IEB). The IEB is produced by running RMSS with a radar config file that controls the process of generating IEB instructions for different segments of time. These segments of time are called divisions with a particular behavior defined by a set of division keywords in the config file. Table 2 shows a summary of the divisions used in this observation. Subsequent sections will show and discuss the keyword selections made for each division. Each division table shows a set of nominal parameters that are determined by the operating mode (eg., distant scatterometry, SAR low-res inbound). The actual division parameters from the config file are also shown, and any meaningful mismatches are flagged.

3 Special Features of this Observation

This observation is a unique icy satellite radar opportunity. At around 20,000 km range, this is the only radar observation of an icy satellite that permits synthetic aperture imaging. The range and viewing geometry make it most similar to the high-altitude imaging performed on some of the Titan flyby's (eg., T25 and T29). Scatterometer mode is used to obtain the longest echo window time and therefore the best doppler resolution. Scatterometer mode is also favored because it has the smallest noise-power bandwidth and hence the best SNR. Unlike the high-altitude Titan observations, this observation will scan the entire visible disk of the target (see Fig. 1). Thus, the viewing geometry varies widely, and imaging performance will vary significantly over the disk. In some parts of the scan, normal SAR imaging will not be possible because the iso-range lines and iso-doppler lines will be nearly parallel. The following sections describe the design in more detail.

4 Div's A,B,N: Radiometry

Radiometry data is always acquired by the radar even during active mode operations, so this observation will collect a unique passive data set covering the visible hemisphere of Iapetus. The IEB is optimized for the scatterometry imaging, but the radiometer collection works out to have reasonable efficiency. For most of the scan, each burst integrates 245 ms out of a 600 ms burst period which yields a collection efficiency of 40 percent. Scan rates are much lower than for normal Titan radiometry, so multiple bursts can be averaged without much beam smearing. Div's A, B, and N

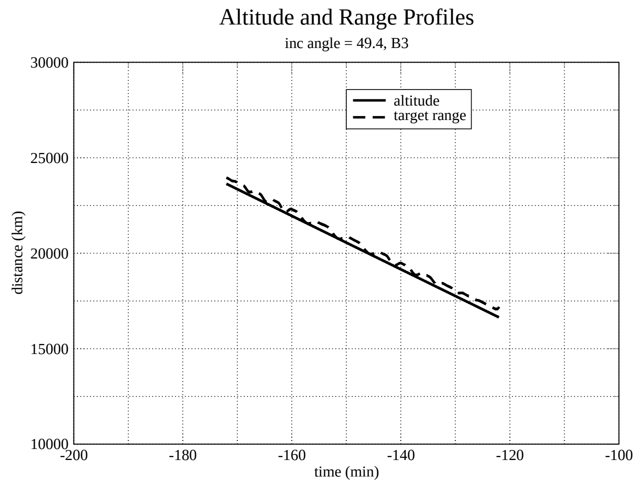

Figure 2: Altitude and range to the boresight point

will collect radiometer only data while the beam looks at cold space which provides bounding calibration references. These division parameters are summarized in table 4.

5 Div's C,D,M: Scatterometer Receive Only Measurements

To aid in calibrating the scatterometer data, receive only data is collected during the turn onto the target at the beginning of the scan, and again during the turn off of the target at the end of the scan. Div's D and M (see table 6) set the parameters for these. Data is collected in 8 bit straight mode with the 9 dB attenuator setting which is used throughout this observation. Div C is a short active division while pointing off target. This forces the ESS to power up before the scan begins. These measurements can be used to determine system gain and receiver noise temperature for the scatterometer mode at the start and end of the scan. The division PRF and number of pulses (1202 Hz and 150 respectively) are chosen to fill the science data buffer. Table 6 shows the division parameters.

6 Div's H-I: Altimetry

The scan of Iapetus passes over the nadir point in the middle and altimetry is programmed for 6 seconds centered on the nadir crossing. This provides 10 bursts of high-bandwidth altimetry which will be used to measure the range to the target with about 35 m resolution. The altimeter waveform also may reveal some information about the nature of the surface.

Division parameters are shown in table 7. The interleave option is used which means that one of the 10 bursts will have some empty PRI intervals that can be used to verify the start of the pulse echo train. The maximum doppler spread in Div h is 121 Hz which comes from rotation and spacecraft motion. The PRF needs to be higher than the doppler spread to support potential range-doppler processing, and is set by division parameter to 5000 Hz. The division parameters match the usual altimeter parameters used on Titan. With this PRF, the range amiguity spacing is 30 km while Iapetus is 718 km in radius. The range-spread of the beam depends on where it is pointed. For target centered pointing the cosine law can be applied to solve the geometry. At 20780 km range, the range-spread is 3 km. Thus, range ambiguities will not be an issue.

7 Div;s E-G,J-L: Iapetus Imaging Scatterometry

The remaining divisions collect imaging data across the scan lines. A typical imaging division is shown in table 8. Just like regular Titan SAR, 8 bits to 2 bits BAQ is used to increase the efficiency of the data collection. Reducing the raw data per burst by a factor of four allows the burst period to be shortened by a factor of four while maintaining the same

Name	Nominal	a	b	n	Mismatch	Comments
mode	radiometer	radiometer	radiometer	radiometer	no	
start_time (min)	varies	-325.0	-180.0	-120.0	no	
end_time (min)	varies	-180.0	-174.5	-110.0	no	
time_step (s)	varies	9600.0	60.0	3600.0	no	Used by radiometer only modes - saves commands
bem	00100	11111	00100	00100	yes	
baq	don't care	5	5	5	no	
csr	6	6	6	6	no	6 - Radiometer Only Mode
noise_bit_setting	don't care	4.0	4.0	4.0	no	
dutycycle	don't care	0.38	0.38	0.38	no	
prf (Hz)	don't care	1000	1000	1000	no	
tro	don't care	0	0	0	no	
number_of_pulses	don't care	8	8	8	no	
n_bursts_in_flight	don't care	1	1	1	no	
percent_of_BW	don't care	100.0	100.0	100.0	no	
auto_rad	on	on	on	on	no	
rip (ms)	34.0	34.0	34.0	34.0	no	
max_data_rate	0.248	0.248	0.992	0.992	yes	Kbps - set for slowest burst period
interleave_flag	off	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	10.0	no	

Table 4: ia_049_3 Div abn distant_warmup block

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-174.5	no	
end_time (min)	varies	-174.0	no	
time_step (s)	don't care	6.0	no	Used when BIF > 1, otherwise set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	
csr	0	0	no	0 - Normal Operation, 8 - with auto-gain
noise_bit_setting	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.38	yes	
prf (Hz)	varies	1200	no	Set to cover target doppler bandwidth
tro	6	6	no	6 - allows for some noise only data in time domain
number_of_pulses	varies	8	no	depends on PRF choice (can have more shorter pulses)
n_bursts_in_flight	varies	1	no	Used to increase PRF and data rate at long range
percent_of_BW	0.0	100.0	yes	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	200.000	50.000	yes	Kbps - determines burst period
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 5: ia_049_3 Div c distant_scatterometer block

Name	Nominal	d	m	Mismatch	Comments
mode	scat_compressed	scatterometer	scatterometer	yes	
start_time (min)	varies	-174.0	-124.0	no	
end_time (min)	varies	-171.5	-120.0	no	
time_step (s)	don't care	6.0	6.0	no	Set by valid time calculation
bem	00100	00100	00100	no	
baq	3	5	5	yes	5 means 8 bits straight - not using the compressed mode here
csr	1	1	1	no	1 - receive only antenna measurement
noise_bit_setting	4.0	4.0	4.0	no	9 dB setting used by all low SNR scatterometry
dutycycle	0.70	0.38	0.38	yes	
prf (Hz)	1200	1200	1200	no	
tro	don't care	6	6	no	automatically set to 6
number_of_pulses	150	50	50	yes	Set with the PRF to fill the science data buffer - Only 2 PRI's worth of data are downlinked.
n_bursts_in_flight	1	1	1	no	
percent_of_BW	100.0	0.0	0.0	yes	
auto_rad	on	on	on	no	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	8.000	50.000	50.000	yes	
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 6: ia_049_3 Div dm scat_compressed block

Name	Nominal	h	i	Mismatch	Comments
mode	unknown	altimeter	altimeter	yes	
start_time (min)	unknown	-151.6	-151.6	yes	
end_time (min)	unknown	-151.6	-151.5	yes	
time_step (s)	2700.0	6.0	6.0	yes	
bem	00100	00100	00100	no	
baq	don't care	7	7	no	
csr	6	0	0	yes	
noise_bit_setting	don't care	4.7	4.7	no	
dutycycle	don't care	0.73	0.73	no	
prf (Hz)	don't care	5000	5000	no	
tro	don't care	-6	-6	no	
number_of_pulses	don't care	21	21	no	
n_bursts_in_flight	don't care	1	1	no	
percent_of_BW	don't care	100.0	100.0	no	
auto_rad	off	on	on	yes	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	1.000	220.000	220.000	yes	
interleave_flag	off	on	off	yes	
interleave_duration (min)	don't care	7.0	7.0	no	

Table 7: ia_049_3 Div hi standard_altimeter block

data rate. This increases the number of looks by a factor of four as long as the 7 percent limit on the burst duty cycle isn't exceeded. In this observation, there is not enough data volume to push this limit and the actual burst duty cycle runs around 3.8 percent. The drawback to using 8-2 BAQ is the loss of noise only data at the margins of each burst. To make up for this, two divisions (F,K) of 8 bit straight data are inserted during the relatively slow moving turn-arounds at the ends of two scan lines. In these locations, there are a large number of looks to spare, and these divisions will provide some usable noise-only data.

Doppler spread shown in Fig. 3 is relatively low due to the slow flyby speed of 2 km/s. This leads to a low PRF selection of 357 Hz. Using this PRF, Fig. 4 shows that range and doppler ambiguities are well spaced over the entire scan. The plot shows ambiguity ratios that include just the beam gain ratio which is the dominant factor. The incidence angle varies across scan lines as shown in Fig. 5 which leads to variation in range resolution and noise equivalent cross-section as shown in Figs. 6 and 7.

8 Revision History

1. Jul 16, 2007: Initial Release

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-171.5	no	
end_time (min)	varies	-155.5	no	
time_step (s)	don't care	6.0	no	Used when BIF > 1, otherwise set by valid time calculation
bem	00100	00100	no	
baq	5	0	yes	0 means 8-2 BAQ - increases look efficiency
csr	0	0	no	0 - Normal Operation, 8 - with auto-gain
noise_bit_setting	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.21	yes	max allowed by the ESS while filling the echo buffer
prf (Hz)	varies	357	no	selected to balance range and doppler ambiguities across the scan
tro	6	6	no	6 - allows for some noise only data in time domain
number_of_pulses	varies	0	no	0 means calculate to fill round trip time or buffer
n_bursts_in_flight	varies	1	no	Used to increase PRF and data rate at long range
percent_of_BW	0.0	100.0	yes	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	200.000	110.000	yes	selected to use available data volume
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 8: ia_049_3 Div e distant_scatterometer block

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-155.5	no	
end_time (min)	varies	-155.3	no	
time_step (s)	don't care	6.0	no	Used when BIF > 1, otherwise set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	5 means 8 bits straight - collects noise only data at margins
csr	0	0	no	0 - Normal Operation, 8 - with auto-gain
noise_bit_setting	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.21	yes	max allowed by the ESS while filling the echo buffer
prf (Hz)	varies	357	no	selected to balance range and doppler ambiguities across the scan
tro	6	6	no	6 - allows for some noise only data in time domain
number_of_pulses	varies	0	no	0 means calculate to fill round trip time or buffer
n_bursts_in_flight	varies	1	no	Used to increase PRF and data rate at long range
percent_of_BW	0.0	100.0	yes	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	200.000	110.000	yes	selected to use available data volume
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 9: ia_049_3 Div f distant_scatterometer block

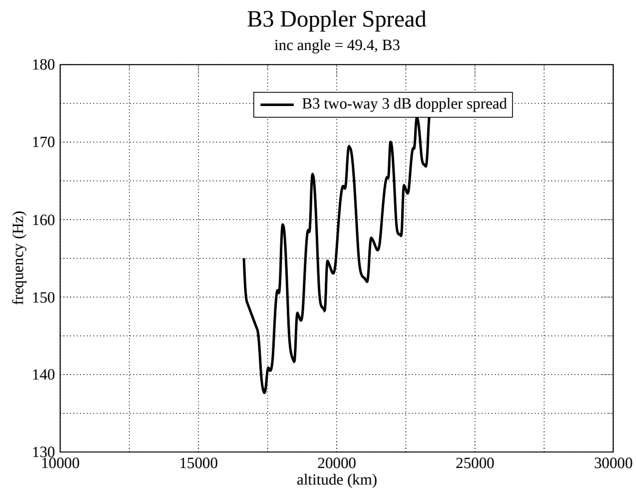

Figure 3: Doppler spread within beam 3 two-way main lobe.

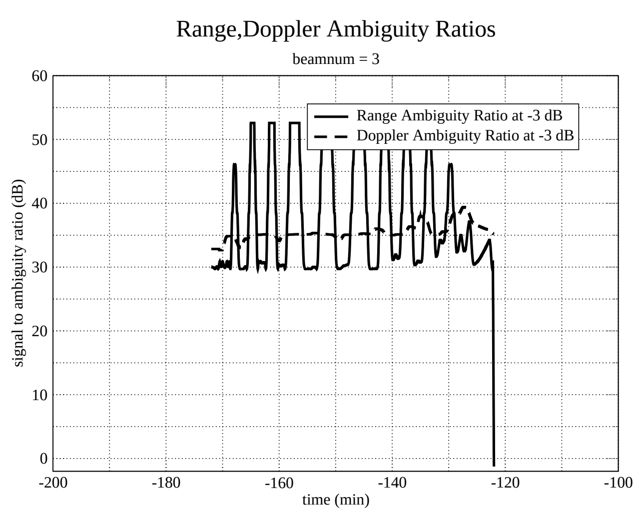

Figure 4: Beam gain ambiguity ratios computed at the -3 dB contour level in the gain pattern. Only the nearest ambiguity which dominates is included.

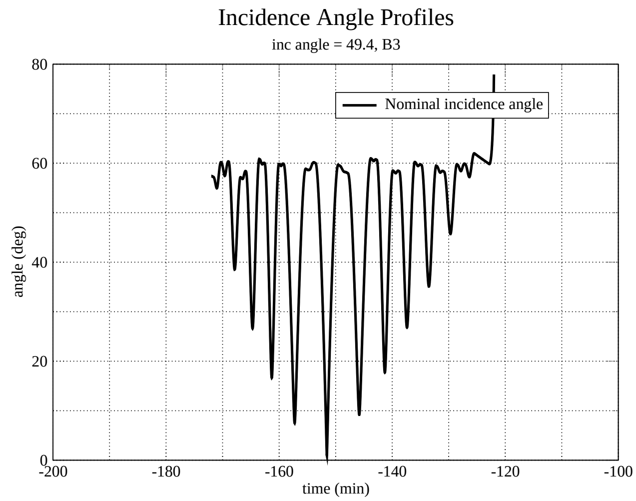

Figure 5: Incidence angle variation across the scan.

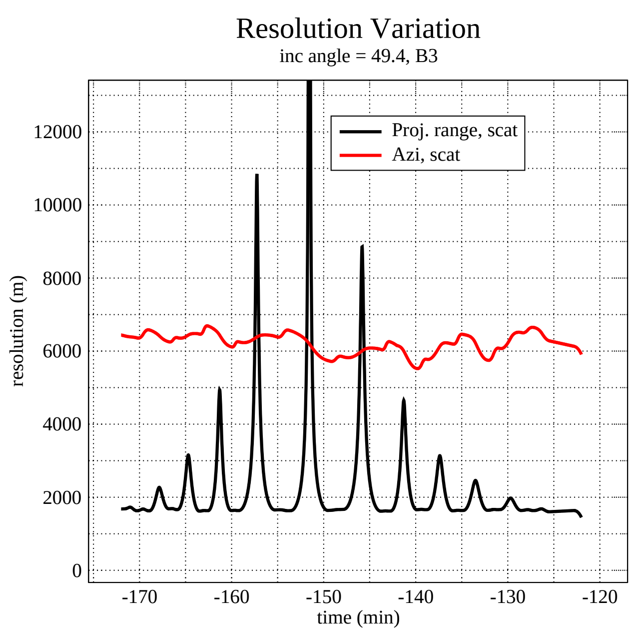

Figure 6: Range and doppler resolution variation across the scan. Azimuth (doppler) resolution is relatively coarse due to the very small doppler spread within the beam which traces back to the slow flyby speed. Range resolution varies considerably due to the variable projection effect. At low incidence angles, the range bin set by the chirp bandwidth spreads across more surface distance and resolution is worse while SNR is better due to higher pixel area.

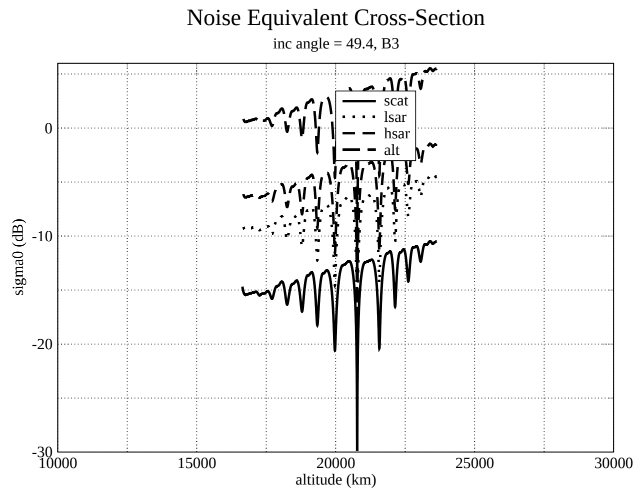

Figure 7: Noise equivalent cross-section variation across the scan. Scatterometer mode provides the best noise floor becuase it has the smallest noise bandwidth. Variation across scan lines occurs because the pixel area increases at lower incidence angles where range resolution deteriorates due to geometric projection.

9 Acronym List

ALT	Altimeter - one of the radar operating modes
BAQ	Block Adaptive Quantizer
CIMS	Cassini Information Management System - a database of observations
Ckernel	NAIF kernel file containing attitude data
DLAP	Desired Look Angle Profile - spacecraft pointing profile designed for optimal SAR performance
ESS	Energy Storage System - capacitor bank used by RADAR to store transmit energy
IEB	Instrument Execution Block - instructions for the instrument
ISS	Imaging Science Subsystem
IVD	Inertial Vector Description - attitude vector data
IVP	Inertial Vector Propagator - spacecraft software, part of attitude control system
INMS	Inertial Neutral Mass Spectrometer - one of the instruments
NAIF	Navigation and Ancillary Information Facility
ORS	Optical Remote Sensing instruments
PDT	Pointing Design Tool
PRI	Pulse Repetition Interval
PRF	Pulse Repetition Frequency
RMSS	Radar Mapping Sequencing Software - produces radar IEB's
SAR	Synthetic Aperture Radar - radar imaging mode
SNR	Signal to Noise Ratio
SOP	Science Operations Plan - detailed sequence design
SOPUD	Science Operations Plan Update - phase of sequencing when SOP is updated prior to actual sequencing
SSG	SubSequence Generation - spacecraft/instrument commands are produced
SPICE	Spacecraft, Instrument, C-kernel handling software - supplied by NAIF to use NAIF kernel files.
TRO	Transmit Receive Offset - round trip delay time in units of PRI