RADAR Titan Flyby during S14/T7

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- Sequence: s14
- Rev: 014
- Observation Id: t7
- Target Body: Titan
- Data Take Number: 59
- PDT Config File: S14_ssup_psiv1_050720_pdt.cfg
- SMT File: s14_2005-07-05.rpt
- PEF File: z0140c_full.pef

1 Introduction

This memo describes the Cassini RADAR activities for the 4th Titan flyby on which SAR data will be acquired. This SAR data collection occurs during the s14 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.

2 CIMS and Division Summary

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. Table 1 shows the CIMS request summary for this observation. Although the CIMS requests show Low-SAR intervals, in reality the radar will be operated in Hi-SAR mode throughout this flyby.

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 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. Table 3 shows a summary of some key geometry values for

CIMS ID	Start	End	Duration	Comments
014OT_TI7WARMUP001_RIDER	2005-250T07:08:46	2005-250T07:37:46	00:29:0.0	Warmup in preparation for SAR. Radiometer calibration data collected.
014TI_TI7P1ALT001_PRIME	2005-250T07:37:46	2005-250T07:45:46	00:08:0.0	Collect altimetry data while maintaining nadir pointing.
014TI_TI7P2LRES001_PRIME	2005-250T07:45:46	2005-250T07:54:16	00:08:30.0	Low Resolution Synthetic Aperture RADAR (SAR) Imaging.
014TI_TI7P3HRES001_PRIME	2005-250T07:54:16	2005-250T08:07:16	00:13:0.0	High Resolution Synthetic Aperture RADAR (SAR) Imaging.
014TI_TI7P4LRES001_PRIME	2005-250T08:07:16	2005-250T08:15:46	00:08:30.0	Low Resolution Synthetic Aperture RADAR (SAR) Imaging.
014TI_TI7P5ALT001_PRIME	2005-250T08:15:46	2005-250T08:39:46	00:24:0.0	Collect altimetry data while maintaining nadir pointing.
014TI_TI7P6RAD001_PRIME	2005-250T09:48:46	2005-250T13:20:46	03:32:0.0	Outbound Radiometry of Titan.

Table 1: t7 CIMS Request Sequence

each division. 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 Warmup

The radar warmup rider begins at 2005-09-07T07:08:46.000 (-01:03:11.8) and lasts for 29 min. The short warmup is ok since there is no inbound radiometry, and the active modes need less warmup time. During the warmup, the IEB will be set for 1 s bursts of radiometer only data as shown in table 4. All 5 beams are cycled to gather cross-calibration data from the SAR beams while looking at cold space. This data will be used to cross-calibrate the slightly different loss paths used by each of the beams during SAR radiometry.

4 Div's B-D: Standard Altimeter-SAR-Altimeter Sequence

From -0:23:0.0 to 05:21:0.0, the instrument will operate following a truncated RADAR mode sequence. Only altimetry and SAR are performed, while the inbound radiometry and both inbound and outbound scatterometry are omitted. A rotation around the spacecraft Z-axis is performed outside of the SAR interval to reduce CIRS heating. Tables and figures show the parameters and designs during these divisions. Refer to previous Titan flyby sequence design memos for the standard performance tradeoff analyses.

Division	Name	Start	Duration	Data Vol	Comments
a	Warmup	-0:52:0.0	00:29:0.0	1.7	Warmup
b	standard_altimeter_inbound	-0:23:0.0	00:06:30.0	19.5	Inbound altimetry
c	standard_sar_hi	-0:16:30.0	00:03:30.0	44.1	Hi-SAR at reduced data rate
d	standard_sar_hi	-0:13:0.0	00:26:0.0	374.4	Hi-SAR at highest data rate possible
e	standard_sar_hi	00:13:0.0	00:03:0.0	37.8	Hi-SAR at reduced data rate
f	standard_altimeter_outbound	00:16:0.0	00:23:0.0	69.0	Outbound altimetry
g	standard_scatterometer_outbound	00:39:0.0	01:46:0.0	0.0	8-0 Scatt/Radiometry during non-radar pointing
h	scat_compressed	02:25:0.0	01:21:0.0	13.1	Outbound compressed scatt and radiometry
i	standard_scatterometer_outbound	03:46:0.0	00:38:0.0	0.0	8-0 Scatt/Radiometry inbetween rasters
j	scat_compressed	04:24:0.0	00:57:0.0	23.9	Outbound compressed scatt and radiometry
Total				583.6	

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	15807	15807	0.02	507
b	6244	6244	0.01	1076
c	4255	4256	0.01	1393
d	3262	3312	0.01	1632
e	3262	3312	0.01	1632
f	4109	4109	0.01	1424
g	11458	11458	0.02	670
h	47337	off target	0.06	off target
i	74882	off target	0.10	off target
j	87815	off target	0.11	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

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	-480.0	-52.0	yes	IEB Trigger time is usually later than this
end_time (min)	-300.0	-23.0	yes	
time_step (s)	2700.0	540.0	yes	Used by radiometer only modes - saves commands
bem	00100	11111	yes	
baq	don't care	5	no	
csr	6	6	no	6 - Radiometer Only Mode
noise_bit_setting	don't care	4.0	no	
dutycycle	don't care	0.38	no	
prf (KHz)	don't care	1.00	no	
number_of_pulses	don't care	8	no	
n_bursts_in_flight	don't care	1	no	
percent_of_BW	don't care	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	0.250	0.992	yes	Kbps - actual data rate may be less
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 4: t7 div_a Warmup block

Name	Nominal	b	f	Mismatch	Comments
mode	altimeter	altimeter	altimeter	no	
start_time (min)	-30.0	-23.0	16.0	yes	
end_time (min)	-19.0	-16.5	39.0	yes	
time_step (s)	don't care	2.0	2.0	no	Set by valid time calculation
bem	00100	00100	00100	no	
baq	7	7	7	no	7 - 8 to 4
csr	8	8	8	no	8 - auto gain
noise_bit_setting	2.0	2.0	2.0	no	
dutycycle	0.73	0.73	0.73	no	
prf (KHz)	5.00	5.00	5.00	no	
number_of_pulses	21	21	21	no	
n_bursts_in_flight	1	1	1	no	
percent_of_BW	100.0	100.0	100.0	no	
auto_rad	on	on	on	no	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	30.000	50.000	50.000	yes	leaving as much data for SAR as possible
interleave_flag	on	on	on	no	
interleave_duration (min)	varies	2.7	10.0	no	

Table 5: t7 div_bf standard_altimeter_inbound block

Name	Nominal	c	d	e	Mismatch	Comments
mode	sarh	sarh	sarh	sarh	no	
start_time (min)	-6.0	-16.5	-13.0	13.0	yes	
end_time (min)	6.0	-13.0	13.0	16.0	yes	
time_step (s)	don't care	2.0	2.0	2.0	no	Set by valid time calculation unless negative, then time_step is used instead
bem	11111	11111	11111	11111	no	
baq	0	0	0	0	no	0 - 8 to 2
csr	8	8	8	8	no	8 - auto gain
noise_bit_setting	2.0	2.0	2.0	2.0	no	
dutycycle	0.73	0.73	0.73	0.73	no	
prf (KHz)	don't care	0.00	0.00	0.00	no	RMSS follows profile
number_of_pulses	don't care	0	0	0	no	RMSS fills round trip time
n_bursts_in_flight	1	1	1	1	no	
percent_of_BW	100.0	100.0	98.0	100.0	yes	
auto_rad	off	off	off	off	no	Set off for SAR modes to allow minimum burst time
rip (ms)	34.0	34.0	34.0	34.0	no	Calculated from radiometer calibration for prior observations
max_data_rate	255.000	210.000	240.000	210.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	on	off	yes	
interleave_duration (min)	varies	10.0	25.0	10.0	no	

Table 6: t7 div_cde standard_sar_hi block

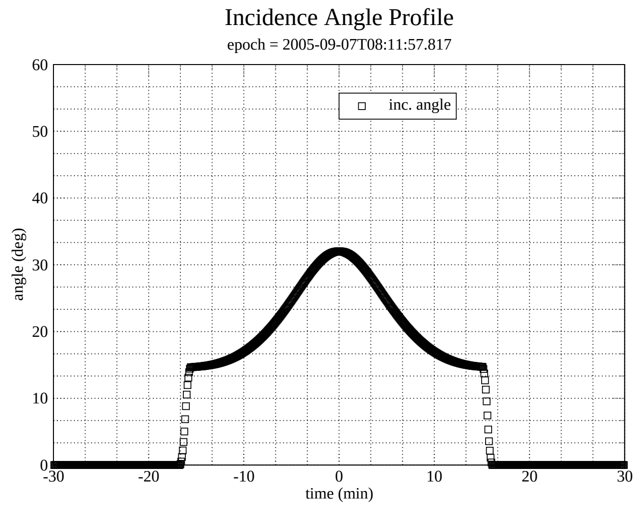

Figure 1: B3 boresight incidence angle during the time around c/a.

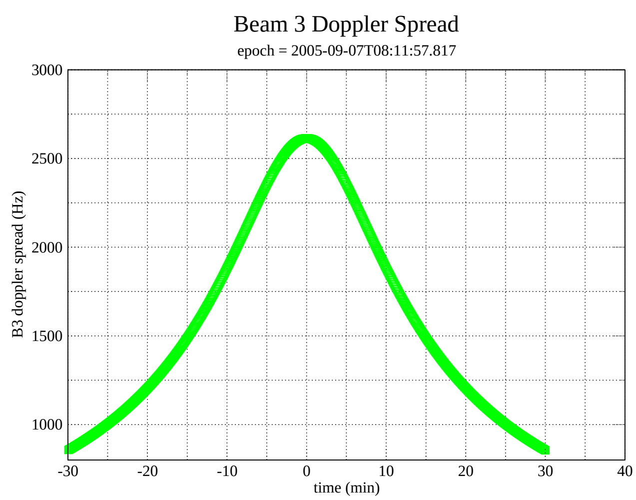

Figure 2: Nadir pointed B3 doppler spread during the time around c/a. Doppler spread is measured within the on-way 3 dB beam pattern.

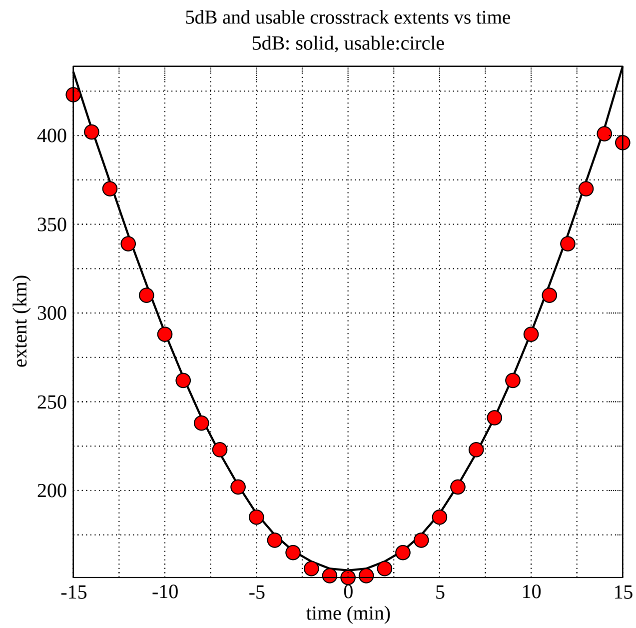

Figure 3: Usable cross track coverage predicted for the parameters in Div's C-E and the 950 km PRF and incidence angle profiles. Usable image area must have a signal to ambiguity ratio of at least 14 dB, a noise equivalent σ_0 of at least -10 dB, and a one way antenna gain of at least -5 dB relative to the beam maximum gain. The large drop at the ends are due to the absence of beams 2 and 4 which are offset from beams 1, 3, and 5.

4.1 PRF and Incidence Angle Profiles

The PRF profile and incidence angle profile (Fig. 1) are optimized for maximum usuable imaging coverage. The Ta profiles were produced for a 950 km flyby which is the most common SAR flyby altitude. The Ta flyby was at 1200 km c/a altitude, however, the same PRF and incidence angle profiles still give the same performance. The flyby altitude for T7 was raised to 1075 km to avoid the possibility of tumbling the spacecraft. The SAR divisions (c-e) will use the same PRF and incidence angle profiles as were used for Ta.

Figures 3 and 4 show the SAR image coverage performance expected from the pulse parameters in divisions C-E and the PRF and incidence angle profiles applied to this flyby geometry. Calculation of ambiguities assumes a Venus backscatter model for the Titan surface. Once actual data on the Titan backscatter response is obtained, this calculation can be updated. However, it is unlikely that changes in the model function will have much affect on the selection of parameters. Most of the constraints come from the evolution of the flyby geometry, the shape and position of the beam patterns, and the location of range ambiguities.

4.2 PRF Hopping

The central SAR division puts a PRF hop in the PRF sequence at the beginning and end of the division. Thus, there will be a PRF hop at about + and - 13 minutes from closest approach. The PRF hop provides data to resolve potential integer ambiguities in future processing. If navigation performance continues to improve, PRF hopping may be removed. The only penalty to including PRF hopping is a potential 1 second gap in the SAR data due to the need to line up instructions on sclk boundaries. This is not an issue away from closest approach where there are many looks.

4.3 Data Rate

The T7 allocation is not quite enough to cover the whole SAR imaging swath at the max data rate possible. Two three minute divisions are created at the ends to lower the data rate and stay within the overall allocation.

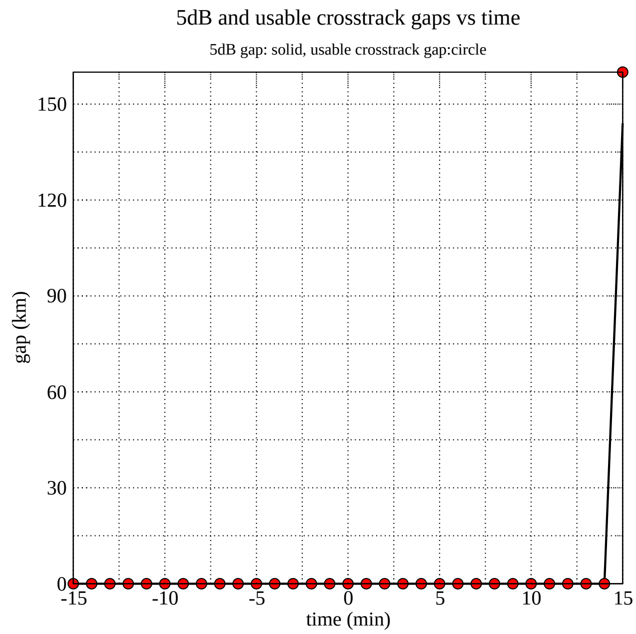

Figure 4: Extent of gaps in the cross-track coverage which do not meet the usable imaging criteria. These gaps occur when the PRF and incidence angle profiles are not optimized for the flyby geometry. The leading cause of gaps is the azimuth offset between beams 2 and 4 and beams 1, 3, and 5. The offset causes beams 2 and 4 to lead/lag the other beams on the surface. Thus they pass with a different incidence angle which can lead to gaps unless the incidence angle profile is adjusted to avoid this problem.

4.4 SAR Resolution Performance

For all of the SAR divisions the effective resolution can be calculated from the following equations,

$$\delta R_g = \frac{c}{2 B_r \sin\theta_i}, \tag{1}$$

$$\delta x = \frac{\lambda R}{2 \tau_{rw} v \sin\theta_v}, \tag{2}$$

where δR_g is the projected range resolution on the surface, c is the speed of light, B_r is the transmitted chirp bandwidth, θ_i is the incidence angle, δx is the azimuth resolution on the surface, λ is the transmitted wavelength, R is the slant range, τ_{rw} is the length of the receive window, v is the magnitude of the spacecraft velocity relative to the target body, and θ_v is the angle between the velocity vector and the look direction. Figure 5 shows the results from these equations for the T7 flyby using the parameters from the IEB as generated by RMSS. The calculations are performed for the boresight of beam 3 which is the center of the swath.

Projected range increases with decreasing incidence angle, so the range resolution varies across the swath with better resolution at the outer edge. The SAR pointing profile decreases the incidence angle as time progresses and altitude increases, so there is progressive deterioration of range resolution away from closest approach. The projected range resolution rapidly deteriorates as the incidence angle decreases toward zero at the very beginning and end of the swath.

Azimuth resolution is a function of the synthetic aperture size which is determined by the length of the receive window in each burst (assuming the receive window is always filled with echos). Azimuth resolution deteriorates less quickly because the number of pulses and the length of the receive window are increased as altitude increases which mitigates the increasing doppler bandwidth of the beam patterns. The receive window length increases to fill the round trip time until the science data buffer is filled. At this point it is no longer possible to extend the receive window, and azimuth resolution starts to deteriorate more rapidly.

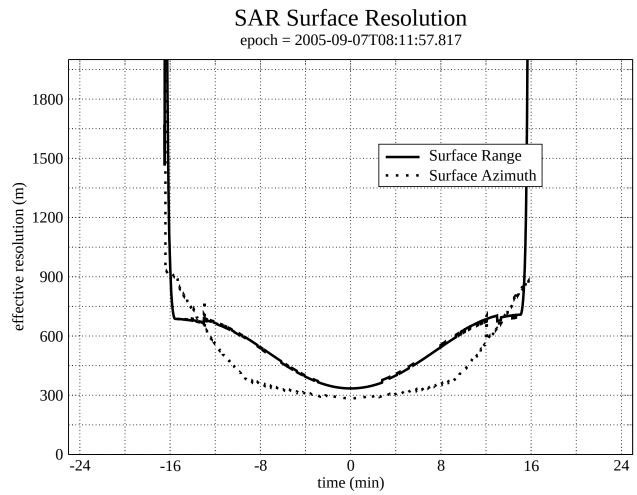

Figure 5: SAR projected range and azimuth resolution. These values are computed from the IEB parameters and are not related to the pixel size in the BIDR file. The pixel size was selected to be always smaller than the real resolution.

5 Div's G,I: Scatterometry/Radiometry During Telemetry Hole and Turn Transitions

At the end of outbound altimetry, pointing and telemtry modes are switched to the ORS instruments. During this time, the radar will remain powered and under the control of a scatteromter division (G) with the block adaptive quantizer (BAQ) set to 8 bits to 0. The 8 to 0 BAQ setting drops all of the echo data, but keeps the radiometry data. This keeps the radar transmitting, but with a low data rate. During the last 15 minutes, the telemetry mode will switch to radar compatible mode, and we will begin to receive these data packets again. All 5 beams are cycled here to gather more radiometer cross-calibration data while looking at cold space. Division G ends after the first few radiometry raster scans where the scatterometer data is not expected to be valuable. This helps to conserve some data volume. Division I also provides 8 to 0 BAQ scatteromtry and radiometry during the turn between the two raster scans. Again, this is done to save data volume.

6 Div's H,J: Outbound Compressed Scatterometer and Radiometer Scans

The T7 radar observation ends with two wheel driven radiometry scans with orthogonal polarizations. Compressed scatterometry data is also collected. Figures 6 show the altitude and range for the raster scans from the PDT ckernels. Figure 7 shows the incidence angle coverage of the scans.

The IEB instructions for this scatterometry/radiometry block are generated by RMSS under the control of the set of config parameters shown in table 8. Although not shown in table 8, scatterometer mode operations use a transmit-receive window offset (TRO) of 6 which makes the echo window 6 PRI's longer than the number of pulses transmitted. This is done to increase the valid time for an instruction by letting the pulse echos walk through the longer echo window before the range-gate needs to be updated. This is particularly important during Titan raster scans where the number of instructions needed to track the varying range can exceed the number available if a smaller TRO value is used. For compressed scatteromtry during radiometry scans, it will not be possible to track the range gate all of the time. SAR and altimetry have priority, so the range gate tracking in this division will be limited by the number of instructions left over after serving the needs of the higher priority modes.

As with T3, auto-gain will not be used for the T7 compressed scatteromtry scan. Instead, a fixed attenuator value will be used to keep the signal on-scale over the whole raster scan. During the T4 observation, the scatterometry scan showed some saturation with a 15 dB attenuator setting at about 20000 km range. In the T7 radiometry scans, the range at the start is about 40000 km. Since the scan starts at the limb, the incidence angle stays above 40 degrees until about 60000 km. Thus, the signal will be 12 dB lower and saturation should not be a problem with a 9 dB attenuator

Name	Nominal	g	i	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	39.0	226.0	no	
end_time (min)	varies	145.0	264.0	no	
time_step (s)	don't care	8.0	8.0	no	Set by valid time calculation
bem	00100	00100	00100	no	
baq	5	2	2	yes	8 to 0 to dump un-needed echo data
csr	8	0	0	yes	8 - auto gain
noise_bit_setting	4.0	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.60	0.60	0.60	no	
prf (KHz)	1.20	1.20	1.20	no	
number_of_pulses	8	8	8	no	
n_bursts_in_flight	1	1	1	no	
percent_of_BW	100.0	100.0	100.0	no	
auto_rad	on	on	on	no	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	30.000	4.000	2.700	yes	
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 7: t7 div_gi standard_scatterometer_outbound block

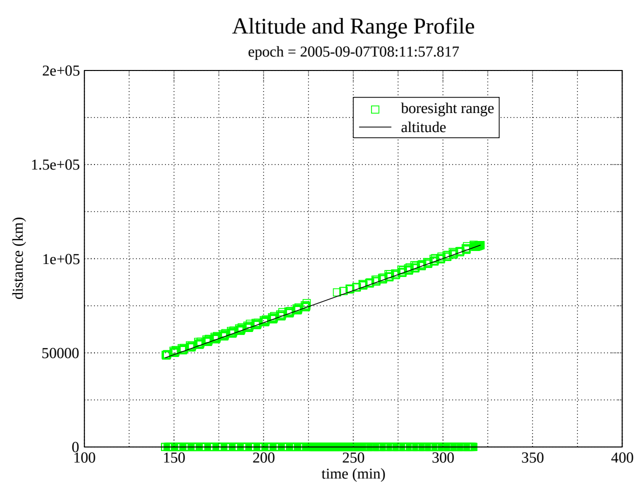

Figure 6: Altitude and range during radiometry/scatterometry scans

Name	Nominal	h	j	Mismatch	Comments
mode	scat_compressed	scat_compressed	scat_compressed	yes	
start_time (min)	varies	145.0	264.0	no	
end_time (min)	varies	226.0	321.0	no	
time_step (s)	don't care	8.0	8.0	no	set to keep instruction count below 500 limit
bem	00100	00100	00100	no	
baq	3	3	3	no	3 - PRI summation
csr	8	0	0	yes	0 - No auto-gain, fixed attenuator set to avoid clipping
noise_bit_setting	4.0	4.0	4.0	no	9 dB attenuator
dutycycle	0.60	0.60	0.60	no	
prf (KHz)	1.20	2.00	2.50	yes	set to control data volume and receive window position
number_of_pulses	90	150	150	yes	Set to the largest number that the ESS can supply - Only 2 PRI's worth of data are downlinked.
n_bursts_in_flight	1	1	2	yes	
percent_of_BW	100.0	100.0	100.0	no	
auto_rad	on	on	on	no	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	6.000	2.700	7.000	yes	leaving as much data for SAR as possible
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 8: t7 div_hj scat_compressed block

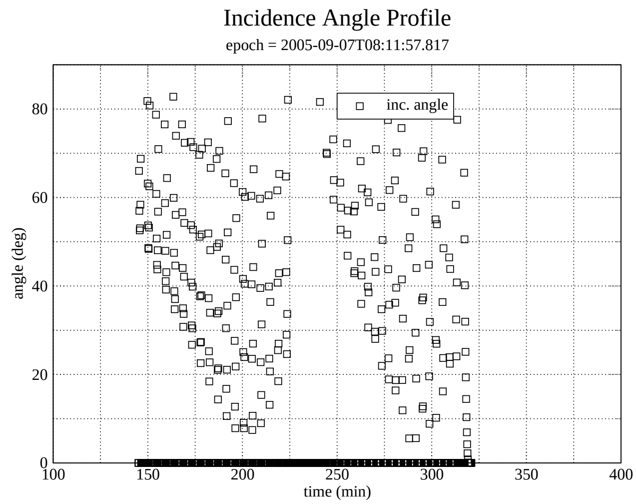

Figure 7: Incidence angle variation during radiometry/scatterometry scan

setting. The 9 dB attenuator setting matches the noise-like setting used on all of the distant scatterometer observations.

7 Revision History

1. Jul 28, 2005: Initial release

8 Acronym List

AL	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