RADAR Titan Flyby during S36/T39

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- Sequence: s36
- Rev: 054
- Observation Id: t39
- Target Body: Titan
- Data Take Number: 157
- PDT Config File: S36_ssup_psiv1_071016_pdt.cfg
- SMT File: S36_SMT_070911.rpt
- PEF File: z0360c.pef

1 Introduction

This memo describes the Cassini RADAR activities for the T39 Titan flyby. This SAR data collection occurs during the S36 sequence of the Saturn Tour. This is a full radar pass. The SAR profile is pushbroomed on both ends. 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 through most of 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
054TI_T39WARMUP001_RIDER	2007-354T15:12:55	2007-354T18:12:55	03:00:0.0	Warmup for T39 inbound radiometry. REU bits included.
054TI_T39INRAD001_PRIME	2007-354T18:12:55	2007-354T21:27:55	03:15:0.0	Inbound radiometry of unique terrain at high latitudes contiguous with T43. REU bits included.
054TI_T39INSCAT001_PRIME	2007-354T21:27:55	2007-354T22:05:55	00:38:0.0	Inbound Scatterometry of Titan of SE terrain. Contiguous with T43. REU bits included.
054TI_T39INALT001_PRIME	2007-354T22:27:55	2007-354T22:42:55	00:15:0.0	Inbound altimetry of Titan. REU bits included.
054TI_T39INLSAR001_PRIME	2007-354T22:42:55	2007-354T22:50:55	00:08:0.0	Inbound low rate SAR of Titan. REU bits included.
054TI_T39HISAR001_PRIME	2007-354T22:50:55	2007-354T22:57:55	00:07:0.0	High rate SAR of Titan.
054TI_T39RASAR001_PRIME	2007-354T22:57:55	2007-354T23:12:55	00:15:0.0	T39 outbound ride along SAR of Titan with INMS.
054TI_T39OUTALT001_PRIME	2007-354T23:12:55	2007-354T23:27:55	00:15:0.0	Outbound altimetry of Titan. REU bits included.
054TI_T39OUTSCT001_PRIME	2007-354T23:51:55	2007-355T00:29:55	00:38:0.0	Outbound Scatterometry of Titan. Contiguous with T43. REU bits included.
054TI_T39OUTRAD001_PRIME	2007-355T00:29:55	2007-355T03:42:55	03:13:0.0	outbound radiometry of unique NW terrain. Contiguous with T43. REU bits included.

Table 1: t39 CIMS Request Sequence

Division	Name	Start	Duration	Data Vol	Comments
a	Warmup	-7:50:0.0	03:07:30.0	11.2	Warmup
b	standard_radiometer_inbound	-4:42:30.0	03:11:0.0	11.4	Inbound radiometry raster
c	standard_altimeter_inbound	-1:31:30.0	00:01:0.0	4.0	Inbound altimetry nadir cal
d	standard_sar_low_inbound	-1:30:30.0	00:00:15.0	1.4	Inbound SAR-Low nadir cal
e	standard_sar_hi	-1:30:15.0	00:00:15.0	1.4	Inbound SAR-Hi nadir cal
f	standard_scatterometer_inbound	-1:30:0.0	00:35:0.0	63.0	Inbound scatterometry raster
g	scatterometer_imaging	-0:55:0.0	00:08:0.0	33.6	Inbound scatterometer imaging
h	scatterometer_imaging	-0:47:0.0	00:02:0.0	8.4	Inbound scatterometer imaging
i	scatterometer_imaging	-0:45:0.0	00:03:0.0	12.6	Inbound scatterometer imaging
j	scatterometer_imaging	-0:42:0.0	00:01:0.0	4.2	Inbound scatterometer imaging
k	scatterometer_imaging	-0:41:0.0	00:01:0.0	3.9	Inbound scatterometer imaging
l	scatterometer_imaging	-0:40:0.0	00:06:0.0	23.4	Inbound scatterometer imaging
m	scatterometer_imaging	-0:34:0.0	00:03:30.0	10.5	Inbound scatterometer imaging
n	standard_altimeter_inbound	-0:30:30.0	00:10:30.0	18.9	Inbound altimetry
o	standard_sar_hi	-0:20:0.0	00:01:30.0	4.5	Hi-SAR Turn transition, beam 3 only
p	standard_sar_pingpong	-0:18:30.0	00:02:30.0	34.5	Inbound SAR ping-pong
q	standard_sar_hi	-0:16:0.0	00:21:0.0	296.1	Hi-SAR main swath
r	scatterometer_compressed	00:05:0.0	00:14:30.0	3.5	Compressed Scatt/Rad
s	standard_sar_low_outbound	00:19:30.0	00:00:12.0	2.2	SAR-Low, beam 1 only
t	standard_sar_low_outbound	00:19:42.0	00:00:18.0	3.2	SAR-Low, beam 1 only
u	standard_sar_hi	00:20:0.0	00:01:0.0	10.8	Hi-SAR Turn transition, beam 1 only
v	standard_scatterometer_outbound	00:21:0.0	00:00:4.0	0.6	Atmospheric Probe with Chirp
w	standard_scatterometer_outbound	00:21:4.0	00:00:2.0	0.3	Atmospheric Probe with Tone
x	standard_altimeter_outbound	00:21:6.0	00:33:24.0	60.1	Outbound regular plus bonus altimetry
y	standard_scatterometer_outbound	00:54:30.0	00:41:30.0	74.7	Outbound scatterometer raster
z	standard_radiometer_outbound	01:36:0.0	03:09:0.0	11.2	Outbound radiometry scans
Total				709.4	

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	165605	off target	0.21	off target
b	98529	98915	0.13	239
c	30561	30561	0.04	310
d	30206	30206	0.04	313
e	30117	30120	0.04	314
f	30029	30036	0.04	315
g	17631	18331	0.03	487
h	14814	15641	0.02	563
i	14112	15462	0.02	586
j	13061	14517	0.02	625
k	12711	13841	0.02	639
l	12362	13260	0.02	653
m	10276	10924	0.02	757
n	9069	9069	0.01	835
o	5538	5538	0.01	1195
p	5053	5176	0.01	1270
q	4263	4347	0.01	1417
r	1417	1905	0.01	2424
s	5376	6143	0.01	1219
t	5441	5962	0.01	1209
u	5538	5811	0.01	1195
v	5865	5866	0.01	1149
w	5887	5887	0.01	1146
x	5898	5898	0.01	1144
y	17456	17456	0.03	491
z	32161	34210	0.04	298

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	-470.0	yes	IEB Trigger time is usually later than this
end_time (min)	-300.0	-282.5	yes	
time_step (s)	2700.0	5400.0	yes	Used by radiometer only modes - saves commands
bem	00100	00100	no	
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 (Hz)	don't care	1000	no	
tro	don't care	0	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	0.248	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: t39 Div a Warmup block

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 Special Features of this Pass

T39 has one high altitude imaging segment as well as the usual inbound and outbound scatterometry scans. T39 is a partial ride-along, with regular SAR pointing on the inbound side, and ride-along SAR (with INMS prime) for the first 5 minutes after closest approach. Like T36. T39 has a sweeping turn across the surface of Titan which begins after the INMS ride-along ends, and ends at the start of outbound altimetry. Additional SAR imaging is performed during the turn. which has unusual geometry because the beams were fanned out so that doppler varied along the long axis of the non-central beams instead of the short axis as is the case in normal SAR imaging. This required an unusually high PRF (7200 Hz) to cover the doppler spread. Only beam 1 was used to balance looks and coverage. Also like T36, T39 has atmospheric probe divisions at the beginning of the outbound Altimeter observation.

4 Warmup and Radiometry

The radar warmup rider begins at 2007-12-20T15:12:55.000 (-07:44:59.8). During the warmup, the IEB will be set to collect 4-second radiometer data on all 5 beams as shown in table 4. Div B covers inbound radiometry scans. Div Z covers the outbound radiometry scans with 1-second radiometry.

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	-300.0	-282.5	yes	
end_time (min)	-120.0	-91.5	yes	
time_step (s)	2700.0	3600.0	yes	Used by radiometer only modes
bem	00100	00100	no	
baq	don't care	5	no	
csr	6	6	no	
noise_bit_setting	don't care	4.0	no	
dutycycle	don't care	0.38	no	
prf (Hz)	don't care	1000	no	
tro	don't care	0	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	0.992	0.992	no	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 5: t39 Div b standard_radiometer_inbound block

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	120.0	96.0	yes	
end_time (min)	300.0	285.0	yes	
time_step (s)	2700.0	5400.0	yes	Used by radiometer only modes
bem	00100	00100	no	
baq	don't care	5	no	
csr	6	6	no	
noise_bit_setting	don't care	4.0	no	
dutycycle	don't care	0.38	no	
prf (Hz)	don't care	1000	no	
tro	don't care	0	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	0.992	0.992	no	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 6: t39 Div z standard_radiometer_outbound block

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-90.0	no	
end_time (min)	varies	-55.0	no	
time_step (s)	don't care	30.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	5 - 8 bits straight
csr	0	0	no	0 - No auto-gain, fixed attenuator set to avoid clipping
noise_bit_setting	4.0	4.0	no	9 dB attenuator
dutycycle	0.70	0.70	no	
prf (Hz)	1200	1200	no	
tro	6	6	no	
number_of_pulses	8	8	no	
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	30.000	30.000	no	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 7: t39 Div f standard_scatterometer_inbound block

5 Div's F,Y : Regular Scatterometry

The inbound regular scatterometry raster scan is covered by div F. The inbound scan is all at high incidence angles or high altitude and uses the 9 dB attenuator throughout. The outbound regular scatterometry raster scan segment is covered by div Y.

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 scatterometry 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. The positive TRO value also guarantees noise-only data in each burst which eliminates the need to insert special noise-only bursts. The PRF of 1.2 KHz is high enough to cover the doppler spread within beam 3, so doppler sharpening could be performed.

6 Div's G-M: Scatterometry Imaging

The Scatterometry Imaging is designed to optimize range-doppler ambiguities, resolution, number of looks and noise-equivalent cross-section. The T39 inbound high altitude imaging segment is in the south polar area, and pushes the performance limits with three scan lines. The inbound imaging segment starts at 55 minutes and ends at 30.5 minutes before closest approach. Div's G-M shown in tables 9, 10, 11 and 12 provide high altitude imaging data. The separate divisions are used to track PRF variations needed to keep range and doppler ambiguities approximately evenly balanced.

The imaging divisions (G-M) push against the 7% duty cycle limit, the 32 Kbyte size of the science data buffer, the round trip time limitation, and the number of pulses that the ESS can put out. To allow the best possible azimuth resolution, the duty cycle is reduced to allow a longer pulse train while still remaining below the 7% duty cycle limit. This trades SNR for resolution as was done in T19. Resolution in these segments will be in the 1 to 2 km range.

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	54.5	no	
end_time (min)	varies	96.0	no	
time_step (s)	don't care	30.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	5 - 8 bits straight
csr	0	0	no	0 - fixed attenuator
noise_bit_setting	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.70	no	
prf (Hz)	1200	1200	no	
tro	6	6	no	
number_of_pulses	8	8	no	
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	30.000	30.000	no	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 8: t39 Div y standard_scatterometer_outbound block

Name	Nominal	g	h	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	-55.0	-47.0	no	
end_time (min)	varies	-47.0	-45.0	no	
time_step (s)	varies	30.0	30.0	no	
bem	00100	00100	00100	no	
baq	0	0	0	no	8-2 used to increase looks and duty cycle - hence SNR
csr	0	0	0	no	0 - fixed attenuator
noise_bit_setting	4.0	4.0	4.0	no	9 dB attenuator
dutycycle	0.35	0.35	0.35	no	
prf (Hz)	1000	1000	600	yes	1000 Hz is typical, set to balance range/doppler ambiguities
tro	6	6	6	no	
number_of_pulses	100	96	0	yes	100 is typical, set to fill echo buffer/round trip time
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	82.000	70.000	70.000	yes	82 is typical, set to use available data volume
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 9: t39 Div gh scatterometer_imaging block

Name	Nominal	i	j	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	-45.0	-42.0	no	
end_time (min)	varies	-42.0	-41.0	no	
time_step (s)	varies	30.0	30.0	no	
bem	00100	00100	00100	no	
baq	0	0	0	no	8-2 used to increase looks and duty cycle - hence SNR
csr	0	0	0	no	0 - fixed attenuator
noise_bit_setting	4.0	4.0	4.0	no	9 dB attenuator
dutycycle	0.35	0.35	0.35	no	
prf (Hz)	1000	500	600	yes	1000 Hz is typical, set to balance range/doppler ambiguities
tro	6	6	6	no	
number_of_pulses	100	0	0	yes	100 is typical, set to fill echo buffer/round trip time
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	82.000	70.000	70.000	yes	82 is typical, set to use available data volume
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 10: t39 Div ij scatterometer_imaging block

Name	Nominal	k	l	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	-41.0	-40.0	no	
end_time (min)	varies	-40.0	-34.0	no	
time_step (s)	varies	30.0	30.0	no	
bem	00100	00100	00100	no	
baq	0	0	0	no	8-2 used to increase looks and duty cycle - hence SNR
csr	0	0	0	no	0 - fixed attenuator
noise_bit_setting	4.0	4.0	4.0	no	9 dB attenuator
dutycycle	0.35	0.60	0.60	yes	
prf (Hz)	1000	800	1200	yes	1000 Hz is typical, set to balance range/doppler ambiguities
tro	6	6	6	no	
number_of_pulses	100	0	0	yes	100 is typical, set to fill echo buffer/round trip time
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	82.000	65.000	65.000	yes	82 is typical, set to use available data volume
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 11: t39 Div kl scatterometer_imaging block

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	sarl	yes	
start_time (min)	varies	-34.0	no	
end_time (min)	varies	-30.5	no	
time_step (s)	varies	20.0	no	
bem	00100	00100	no	
baq	0	0	no	8-2 used to increase looks and duty cycle - hence SNR
csr	0	8	yes	0 - fixed attenuator
noise_bit_setting	4.0	3.3	yes	9 dB attenuator
dutycycle	0.35	0.70	yes	
prf (Hz)	1000	1600	yes	1000 Hz is typical, set to balance range/doppler ambiguities
tro	6	0	yes	
number_of_pulses	100	0	yes	100 is typical, set to fill echo buffer/round trip time
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	82.000	50.000	yes	82 is typical, set to use available data volume
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 12: t39 Div m scatterometer_imaging block

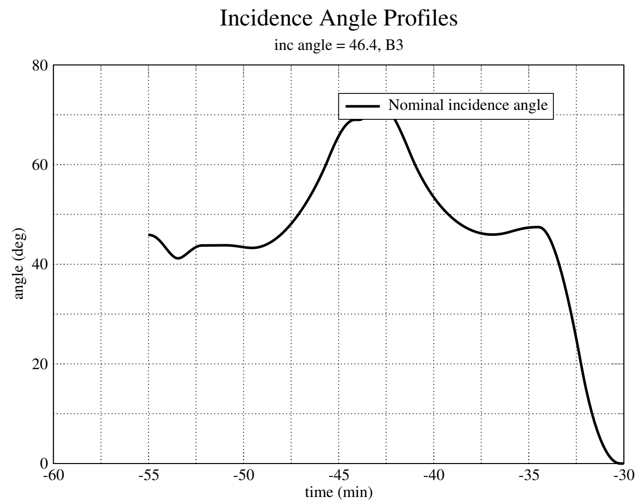

Figure 1: Incidence angle variation during Scatterometer imaging.

6.1 PRF and Incidence Angle Choices

Incidence angle variation during the imaging segment is moderate with higher values than used in normal SAR imaging. (see Fig. 1) PRF values are varied between 500 Hz and 1600 Hz in the imaging divisions. These PRF values provide for a reasonable balance between range and doppler ambiguities throughout the imaging rasters. Pixel structure is good in the low incidence parts of the imaged area which is closer to the iso-doppler point where iso-range and iso-doppler lines are nearly orthogonal. At the high incidence edge of the scan lines, the angle between iso-range and iso-doppler lines is allowed to drop to about 45 degrees. For more technical details on range and doppler ambiguities, refer to the discussion in the T19 sequence design memo.

6.2 SAR-style Scatterometer Resolution Performance

Since SAR processing will be applied to this segment, the effective resolution can be calculated from the same equations,

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

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

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 2 shows the results from these equations for the scatterometer imaging time. The calculations are performed for the boresight of beam 3 which is the center of the swath.

6.3 SNR and Looks

In scatterometer mode the noise equivalent σ_0 for beam 3 will be generally better than -8 dB in these imaging segments. The number of looks varies from a low around 10 to above 100. Looks have been sacrificed in these segments to obtain more coverage area. 8-2 BAQ is used to get more looks out of available data volume.

The resolution of this observation has been improved at the expense of SNR by reducing the pulse duty cycle below 70%, and then increasing the number of pulses until the round trip time or the science data buffer is filled. The ESS limit on the number of pulses also has reduced the duty cycle to permit filling the round trip time or buffer.

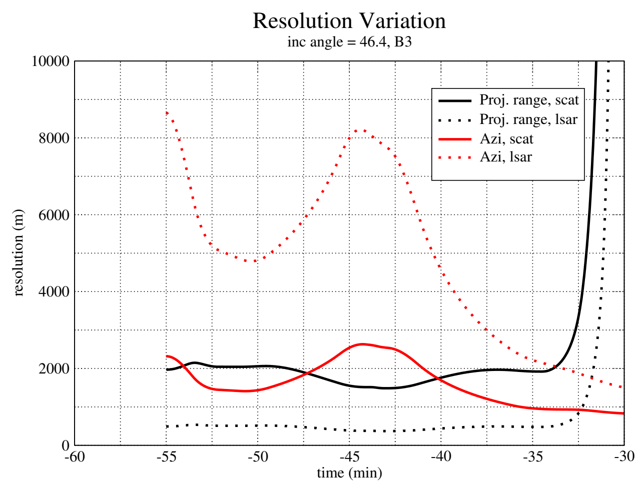

Figure 2: Scatterometer imaging projected range and azimuth resolution. These values are computed from the IEB parameters.

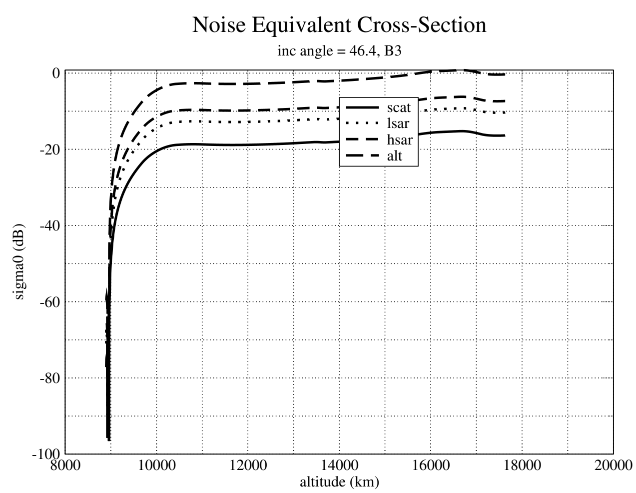

Figure 3: Noise equivalent σ_0 for the 4 possible radar modes during the scatterometer imaging time.

Name	Nominal	Actual	Mismatch	Comments
mode	altimeter	altimeter	no	
start_time (min)	-30.0	-30.5	yes	
end_time (min)	-19.0	-20.0	yes	
time_step (s)	don't care	12.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	7	7	no	7 - 8 to 4
csr	8	8	no	8 - auto gain
noise_bit_setting	2.3	2.3	no	
dutycycle	0.73	0.73	no	
prf (Hz)	5000	5000	no	
tro	don't care	-6	no	auto set to -6 except interleaved bursts where +6 is used
number_of_pulses	21	21	no	
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	30.000	30.000	no	
interleave_flag	on	on	no	
interleave_duration (min)	varies	7.0	no	

Table 13: t39 Div n standard_altimeter_inbound block

7 Div's N,X: Altimetry

The parameters used by the standard altimeter segments are shown in tables 13 and 14. The higher altitude divisions (X) cover the regular and bonus altimeter segments where the spacecraft is nadir pointed while transitioning from thrusters to momentum wheel attitude control. The IEB parameters are the same as the regular altimetry segments.

8 Div's O-U: SAR Imaging

Div's O and U cover the turn transitions with beams 3 and 1 respectively. The data rate has been reduced to 50 Kbps for div O and 180 kbps for div S to conserve data volume. This should still provide enough looks during the turn transition because only one beam is used. The SAR swath is pushbroomed on the inbound side. Div P ping-pongs back and forth every 12 seconds between Hi-SAR and Low-SAR with overlapping pixels. This provides a small increase in image quality since the two modes provide rectangular pixels with the short side in different directions. Div Q covers 16 minutes before closest approach and 5 minutes after cloasest approach. During 5 minutes after closest aproach radar is riding along INMS. Div R comes after INMS and run in scatterometer compressed mode to save data volume. Right after the INMS ridealong the beams are pointed towards nadir and imaging is done when the conditions are favourable. Div's S-U provide low-Sar and hi-Sar imaging during turn back to altimetry plane.

Table 15 shows the standard Hi-SAR divisions, table 16 shows two representative Low/Hi-SAR ping pong divisions, and table 17 shows the B3 only Hi-SAR divisions at the ends.

8.1 PRF and Incidence Angle Profiles

The PRF profile and incidence angle profile (Fig. 4) 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 T3 profiles were optimized for a 1500 km flyby. The T39 flyby will be close to 1000 km altitude, and the lower altitude profile used

Name	Nominal	Actual	Mismatch	Comments
mode	altimeter	altimeter	no	
start_time (min)	19.0	21.1	yes	
end_time (min)	30.0	54.5	yes	
time_step (s)	don't care	18.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	7	7	no	7 - 8 to 4
csr	8	8	no	8 - auto gain
noise_bit_setting	2.0	2.3	yes	
dutycycle	0.73	0.73	no	
prf (Hz)	5000	5000	no	
tro	don't care	-6	no	auto set to -6 except interleaved bursts where +6 is used
number_of_pulses	21	21	no	
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	85.000	30.000	yes	
interleave_flag	on	on	no	
interleave_duration (min)	varies	14.0	no	

Table 14: t39 Div x standard_altimeter_outbound block

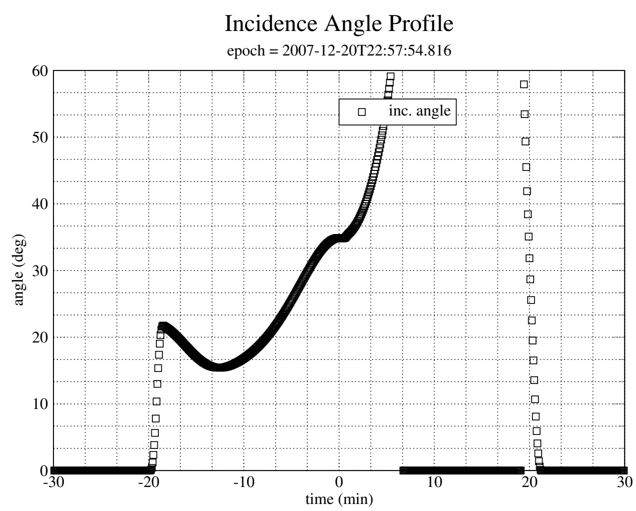

Figure 4: B3 boresight incidence angle during the time around c/a.

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	-6.0	-16.0	yes	
end_time (min)	6.0	5.0	yes	
time_step (s)	don't care	10.0	no	Set by valid time calculation unless negative, then time_step is used instead
bem	11111	11111	no	
baq	0	0	no	0 - 8 to 2
csr	8	8	no	8 - auto gain
noise_bit_setting	3.0	3.4	yes	
dutycycle	0.70	0.70	no	
prf (Hz)	don't care	0	no	RMSS follows profile
tro	don't care	0	no	
number_of_pulses	don't care	0	no	RMSS fills round trip time
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	99.0	yes	
auto_rad	off	off	no	Set off for SAR modes to allow minimum burst time
rip (ms)	34.0	34.0	no	Calculated from radiometer calibration for prior observations
max_data_rate	255.000	235.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	yes	
interleave_duration (min)	varies	10.0	no	

Table 15: t39 Div q standard_sar_hi block

Name	Nominal	Actual	Mismatch	Comments
mode	sar_ping_pong	sar_ping_pong	no	
start_time (min)	varies	-18.5	no	
end_time (min)	varies	-16.0	no	
time_step (s)	6.0	6.0	no	Set to provide overlap between Hi and Low-SAR
bem	11111	11111	no	
baq	0	0	no	0 - 8 to 2
csr	0	0	no	0 - fixed attenuator
noise_bit_setting	3.4	3.4	no	
dutycycle	0.70	0.70	no	
prf (Hz)	varies	0	no	0 - RMSS follows profile
tro	varies	0	no	
number_of_pulses	varies	0	no	0 - RMSS fills round trip time
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	off	on	yes	Set off for SAR modes to allow minimum burst time
rip (ms)	34.0	34.0	no	Calculated from radiometer calibration for prior observations
max_data_rate	230.000	230.000	no	8 to 2 reduces max data rate possible
interleave_flag	off	off	no	
interleave_duration (min)	varies	10.0	no	

Table 16: t39 Div p standard_sar_pingpong block

Name	Nominal	o	u	Mismatch	Comments
mode	sarh	sarh	sarh	no	
start_time (min)	-6.0	-20.0	20.0	yes	
end_time (min)	6.0	-18.5	21.0	yes	
time_step (s)	don't care	6.0	10.0	no	Set by valid time calculation unless negative, then time_step is used instead
bem	11111	00100	00001	yes	
baq	0	0	0	no	0 - 8 to 2
csr	8	8	0	yes	8 - auto gain
noise_bit_setting	3.0	3.4	3.7	yes	
dutycycle	0.70	0.70	0.70	no	
prf (Hz)	don't care	2200	7200	no	RMSS follows profile
tro	don't care	0	0	no	
number_of_pulses	don't care	0	0	no	RMSS fills round trip time
n_bursts_in_flight	1	1	1	no	
percent_of_BW	100.0	100.0	100.0	no	
auto_rad	off	on	on	yes	Set off for SAR modes to allow minimum burst time
rip (ms)	34.0	34.0	34.0	no	Calculated from radiometer calibration for prior observations
max_data_rate	255.000	50.000	180.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	off	yes	
interleave_duration (min)	varies	10.0	12.0	no	

Table 17: t39 Div ou standard_sar_hi block

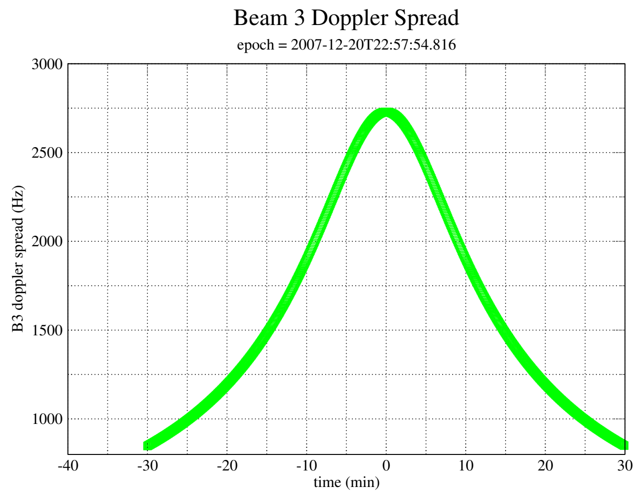

Figure 5: Nadir pointed B3 doppler spread during the time around c/a. Doppler spread is measured within the two-way 3 dB beam pattern.

at Ta will be used again here. The optimized profile maximizes usable cross-track width while avoiding gaps in the imaging swath. Unlike some previous SAR imaging passes, this pass will not include any PRF hopping which has not proven necessary.

8.2 SAR Resolution Performance

For all of the SAR divisions the effective resolution can be calculated from the same equations used in the high-altitude imaging discussion. Figure 6 shows the results from these equations 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.

9 Div's V,W: Atmospheric Probe

Targetting of the nadir track starts at 21 minutes after closest approach. Right at the end of the time when beam 3 is pointed at nadir, we have inserted two special divisions which each last two seconds to look for echo power coming from the clouds/haze in the atmosphere above the surface. This is an experiment which is best performed when beam 3 is nadir pointed near closest approach where SNR is highest and range spread within the beam is at a minimum. Div V (see table 18) provides the cleanest data and the best detection threshold. If a signal is detected with div W, then div V (see table 18) provides a follow up observation with some range resolution that could discriminate the height extent of the scattering atmospheric layers.

In div W, a single pulse is transmitted in each burst. The transmit receive offset (TRO) is set to 6 so there will be 6 PRI's of empty echo window. RMSS centers the expected surface echo in the echo window, so there will be 3 PRI's of echo window positioned to receive energy above the surface (at shorter ranges). Scatterometer mode is used to reduce

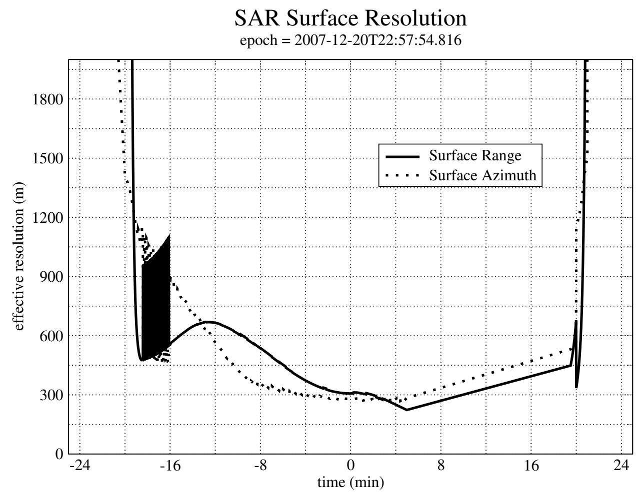

Figure 6: SAR projected range and azimuth resolution. These values are computed from the IEB parameters and are not related to the pixel size in the BIDR file. The pixel size was selected to be always smaller than the real resolution.

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	21.0	no	
end_time (min)	varies	21.1	no	
time_step (s)	don't care	10.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	5 - 8 bits straight
csr	0	0	no	0 - fixed attenuator
noise_bit_setting	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.50	yes	
prf (Hz)	1200	1200	no	
tro	6	2	yes	
number_of_pulses	8	4	yes	
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	90.0	yes	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	30.000	140.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	6.8	no	

Table 18: t39 Div v standard_scatterometer_outbound block

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	21.1	no	
end_time (min)	varies	21.1	no	
time_step (s)	don't care	10.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	5 - 8 bits straight
csr	0	0	no	0 - fixed attenuator
noise_bit_setting	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.73	yes	
prf (Hz)	1200	1000	yes	
tro	6	6	no	
number_of_pulses	8	1	yes	
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	0.0	yes	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	30.000	140.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	6.8	no	

Table 19: t39 Div w standard_scatterometer_outbound block

the noise bandwidth and provide the best possible SNR. A tone transmission is used so that doppler processing can be used to further reduce the noise bandwidth of the signal and boost SNR. This is similar to the approach used on most of the distant icy satellites. The PRF is set to 1 kHz which produces 250 samples in each PRI. In scatterometer mode, each sample corresponds to 1.2 km of range so each PRI covers 300 km of range extent in the time domain. With three PRI's of data time in front of the surface echo, the entire atmospheric column can be integrated and processed in the doppler domain to see if there is any signal coming from somewhere in the atmosphere. At the time of this observation, the range is around 5000 km and the noise equivalent normalized backscattering cross-section for a single pulse is -30 dB using these parameters. The burst rate is about 10 bursts/second, so the two seconds of data will provide 20 echo windows to be averaged together. This will provide another 6.5 dB of improvement in the noise level, so the final best possible detection threshold is about -37 dB. Multiplying by the cross-sectional area of the beam yields a radar cross-section of about 0.2 km^2. In practise, the signal will need to be several times the noise floor to provide a reliable detection.

If a reasonably strong signal is detected by div W, then div V provides some follow up with a full chirp transmission that provides about 1.6 km of range resolution. The noise floor is higher than the tone transmission because the full scatterometer mode bandwidth is used. The round trip time allows 4 pulses to be transmitted if the TRO is set to 2 and the PRF to 1200 Hz. With multiple pulses in the air, there will be range ambiguities that will also limit the detection threshold in this mode. The duty cycle is set to 0.5 to ensure adequate time domain separation of the echoes including the atmospheric segment. The scattering portion of the atmosphere is expected to lie in the first 30 km above the surface, so the single PRI of echo window time is still adequate to cover the atmospheric signal. Different processing options can be tried with this data. The division parameters are chosen to provide the most flexibility and the best detection threshold within the limits imposed by range ambiguities, thermal noise, and range compression sidelobes. The transmitted chirp is reduced to 90 percent of the usual 106 kHz because of the high doppler rate around closest approach. With a nominal scatterometer chirp of 106 kHz, the doppler shift changes enough within one second to cause frequency domain clipping. Since IEB instructions can only be issued once per second, it isn't possible to track the doppler change with a full chirp. To avoid the calibration issues that come with clipped data, we have reduced the chirp so that the entire chirp is always captured. The resulting degradation of range resolution from 1.4 km to 1.6 km should not have much adverse impact on this experiment. This issue does not arise with SAR data collections becuase the SAR modes have higher bandwidth and more doppler margin in absolute terms.

10 Revision History

1. Sep 30, 2008: Initial release

11 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