RADAR Titan Flyby during S40/T44

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- Sequence: s40
- Rev: 069
- Observation Id: t44
- Target Body: Titan
- Data Take Number: 167
- PDT Config File: S40_ssup_psiv1_080227_pdt.cfg
- SMT File: S40_2008-02-25.rpt
- PEF File: z0400c.pef

1 Introduction

This memo describes the Cassini RADAR activities for the T44 Titan flyby. This SAR data collection occurs during the S40 sequence of the Saturn Tour. This is an almost complete radar pass with just the inbound radiometry scans missing. The SAR profile is pushbroomed on the outbound side. 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

CIMS ID	Start	End	Duration	Comments
069TI_T44WARMUP901_RIDER	2008-149T03:24:32	2008-149T06:24:32	03:00:0.0	Warmup for altimetry
069TI_T44INSCAT901_PRIME	2008-149T06:33:32	2008-149T07:54:32	01:21:0.0	
069TI_T44INALT901_PRIME	2008-149T07:54:32	2008-149T08:09:32	00:15:0.0	Inbound altimetry of Titan. REU bits included.
069TI_T44INLSAR901_PRIME	2008-149T08:09:32	2008-149T08:17:32	00:08:0.0	Inbound low rate SAR of Titan. REU bits included
069TI_T44HISAR901_PRIME	2008-149T08:17:32	2008-149T08:31:32	00:14:0.0	High rate SAR of Titan.
069TI_T44OTLSAR901_PRIME	2008-149T08:31:32	2008-149T08:39:32	00:08:0.0	Outbound low rate SAR of Titan. REU bits included.
069TI_T44OUTALT901_PRIME	2008-149T08:39:32	2008-149T08:54:32	00:15:0.0	Outbound altimetry of Titan. REU bits included.
069TI_T44OUTSCT901_PRIME	2008-149T09:16:32	2008-149T10:03:42	00:47:10.0	
069TI_T44OUTRAD901_PRIME	2008-149T10:03:42	2008-149T13:29:32	03:25:50.0	

Table 1: t44 CIMS Request Sequence

shows a summary of the divisions used in this observation. Table 3 shows a summary of some key geometry values for 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

Data volume for this pass was cutback from the nominal value because of DSN allocation changes to support the Phoenix landing on Mars. Due to this restriction, no hi-altitude imaging was performed, and data rates were reduced from normal values in several places. Most of the main SAR swath was preserved at the nominal rate so that its coverage of the sharp emission/backscatter boundary observed in prior radiometry and scatterometry scans will have the best quality possible. The start of the SAR swath is delayed to -15.5 min, so there is no inbound pushbrooom or ping-pong section. At the start of the inbound altimetry, some special nadir pointed calibration observations are inserted in all four modes to collect some data useful for radiometric cross-calibration. At the end of the outbound altimetry, two short observations in scatterometry mode are inserted to look for echo energy coming back from the atmosphere. The lowest altitude part of the nadir pointed boresight time is used for this observation because it minimizes the intrusion of surface echo power and maximizes SNR due to the low range. The details of each of these data collections are described in the following sections.

4 Warmup and Radiometry

The radar warmup rider begins at 2008-05-28T03:24:32.000 (-04:59:59.8). During the warmup, the IEB will be set to collect 1-second radiometer data on beam 3 only as shown in table 4. The outbound radiometry scans (see Fig. 1) also use these parameters as shown in table 5.

Division	Name	Start	Duration	Data Vol	Comments
a	Warmup	-5:05:0.0	03:15:0.0	11.6	Warmup
b	standard_radiometer_inbound	-1:50:0.0	00:18:30.0	1.1	Inbound radiometry
c	standard_altimeter_inbound	-1:31:30.0	00:01:0.0	4.0	Inbound altimetry nadir cal
d	standard_sar_low	-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	00:00:15.0	1.1	Inbound scatterometry nadir cal
g	scatterometer_compressed	-1:29:45.0	00:25:45.0	6.2	Inbound scatterometry raster scan (compressed)
h	standard_scatterometer_inbound	-1:04:0.0	00:33:0.0	39.6	Inbound scatterometry raster scan (reduced data rate)
i	standard_altimeter_inbound	-0:31:0.0	00:14:0.0	25.2	Inbound altimetry
j	standard_sar_hi	-0:17:0.0	00:01:30.0	3.6	Hi-SAR Turn transition, beam 3 only
k	standard_sar_hi	-0:15:30.0	00:05:30.0	75.9	Inbound standard Hi-SAR
l	standard_sar_hi	-0:10:0.0	00:20:0.0	276.0	Hi-SAR Main Swath
m	standard_sar_hi	00:10:0.0	00:06:0.0	60.5	Outbound reduced data rate Hi-SAR
n	standard_sar_pingpong	00:16:0.0	00:02:6.0	18.9	Outbound reduced data rate ping-pong
o	standard_sar_hi	00:18:6.0	00:02:54.0	7.0	Hi-SAR Turn transition to altimetry, beam 3 only
p	standard_scatterometer_outbound	00:21:0.0	00:00:4.0	0.6	Atmospheric Probe with Chirp
q	standard_scatterometer_outbound	00:21:4.0	00:00:2.0	0.3	Atmospheric Probe with Tone
r	standard_altimeter_outbound	00:21:6.0	00:31:24.0	56.5	Outbound regluar plus bonus altimetry
s	standard_scatterometer_outbound	00:52:30.0	00:17:30.0	14.7	Outbound reduced data rate scatterometer raster
t	standard_scatterometer_outbound	01:10:0.0	00:30:0.0	14.4	Outbound reduced data rate scatterometer raster
u	standard_radiometer_outbound	01:40:0.0	03:25:0.0	12.2	Outbound radiometry scans
Total				631.9	

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	106416	off target	0.14	off target
b	37179	37179	0.05	340
c	30614	30614	0.04	382
d	30259	30259	0.04	385
e	30171	30171	0.04	386
f	30082	30082	0.04	386
g	29994	30011	0.04	387
h	20879	22044	0.03	500
i	9369	9369	0.01	923
j	4791	4791	0.01	1476
k	4338	4417	0.01	1571
l	2825	2892	0.01	2005
m	2825	2892	0.01	2005
n	4488	4573	0.01	1538
o	5130	5255	0.01	1412
p	6047	6047	0.01	1265
q	6068	6068	0.01	1262
r	6079	6079	0.01	1260
s	16830	16830	0.02	588
t	23000	23291	0.03	465
u	33633	34253	0.05	359

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

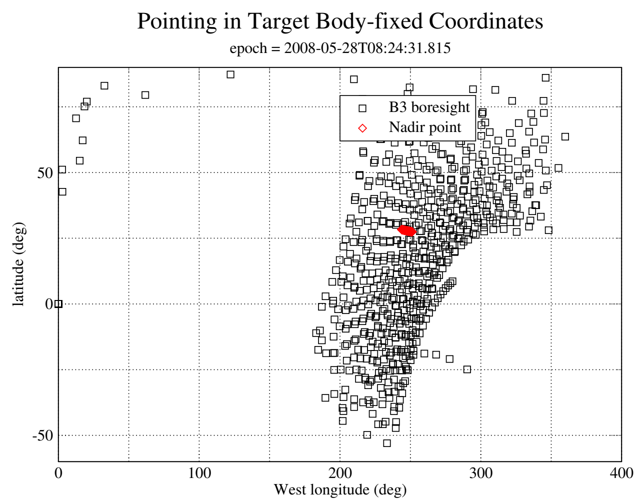

Figure 1: Radiometry scans in target body-fixed coordinates

Name	Nominal	a	b	Mismatch	Comments
mode	radiometer	radiometer	radiometer	no	
start_time (min)	-480.0	-305.0	-110.0	yes	IEB Trigger time is usually later than this
end_time (min)	-300.0	-110.0	-91.5	yes	
time_step (s)	2700.0	7200.0	240.0	yes	Used by radiometer only modes - saves commands
bem	00100	00100	00100	no	
baq	don't care	5	5	no	
csr	6	6	6	no	6 - Radiometer Only Mode
noise_bit_setting	don't care	4.0	4.0	no	
dutycycle	don't care	0.38	0.38	no	
prf (Hz)	don't care	1000	1000	no	
tro	don't care	0	0	no	
number_of_pulses	don't care	8	8	no	
n_bursts_in_flight	don't care	1	1	no	
percent_of_BW	don't care	100.0	100.0	no	
auto_rad	on	on	on	no	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	0.248	0.992	0.992	yes	Kbps - actual data rate may be less
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 4: t44 Div ab Warmup block

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	120.0	100.0	yes	
end_time (min)	300.0	305.0	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: t44 Div u standard_radiometer_outbound block

Name	Nominal	Actual	Mismatch	Comments
mode	altimeter	altimeter	no	
start_time (min)	-30.0	-91.5	yes	
end_time (min)	-19.0	-90.5	yes	
time_step (s)	don't care	2.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	7	5	yes	7 - 8 to 4
csr	8	0	yes	8 - auto gain
noise_bit_setting	2.3	3.2	yes	
dutycycle	0.73	0.73	no	
prf (Hz)	5000	4800	yes	
tro	don't care	-6	no	auto set to -6 except interleaved bursts where +6 is used
number_of_pulses	21	18	yes	
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	66.000	yes	
interleave_flag	on	on	no	
interleave_duration (min)	varies	0.0	no	

Table 6: t44 Div c standard_altimeter_inbound block

5 Div's C-F: Nadir pointed Calibration

The spacecraft performs a transition from momentum wheel to thruster attitude control at higher ranges just outside of the inbound scatterometer segments. During this time, the -Z axis (high gain antenna axis) is pointed at nadir. Since the altitude is relatively high (31,000 km), the spacecraft motion is mostly in the range direction and the beam footprint moves very slowly on the surface. We are taking advantage of this to collect a few bursts of echo power in each of the four active modes while looking at essentialy the same target area. The purpose of this is to provide data useful for cross-calibrating the four modes which each pass through a separate receive path with its own gain and noise level. Div's C-F collect data in the altimeter, SAR-Low, SAR-Hi and scatterometer modes. These division parameters are shown in table 6, table 7, table 8 and table 9. The calibration data are all collected in 8 bit straight mode. The altimeter division uses the same PRF and dutycycle values as the usual science collections. The attenuator is set to 30 dB to match the typical value in regular altimetry collections. The interleave flag is turned on with a very short interleave duration to ensure that all of the bursts have some noise only data in addtion to the echo data. The two SAR divisions use a lower PRF override value to avoid an RMSS error when the round trip time allows for more than 255 pulses. The actual number of pulses is limited by the science data buffer. Each mode collects 18 seconds of calibration data. The beam footprint only moves a few percent of its size during this time so the calibration data is all based on essentially the same backscattering level. These data will also provide a measurement of the zero range delay for all of the modes.

6 Scatterometry Scans

The first 25 minutes of the inbound scatterometry scan are collected using the compressed scatterometry mode which sums data on board to save data volume. The last 33 minutes are then collected in the regular 8-bit straight mode, but at a reduced data rate of 20 Kbps which still provides for overlapping burst footprints. The data volume savings here are used to preserve the SAR imaging data rate later on. The inbound scan is all at high incidence angles or high altitude and uses the 9 dB attenuator throughout. The parameters for these two divisions are shown in table 10.

Name	Nominal	Actual	Mismatch	Comments
mode	unknown	sarl	yes	
start_time (min)	unknown	-90.5	yes	
end_time (min)	unknown	-90.2	yes	
time_step (s)	2700.0	10.0	yes	
bem	00100	00100	no	
baq	don't care	5	no	
csr	6	0	yes	
noise_bit_setting	don't care	2.9	no	
dutycycle	don't care	0.50	no	
prf (Hz)	don't care	1200	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	off	on	yes	
rip (ms)	34.0	34.0	no	
max_data_rate	1.000	90.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 7: t44 Div d standard_sar_low block

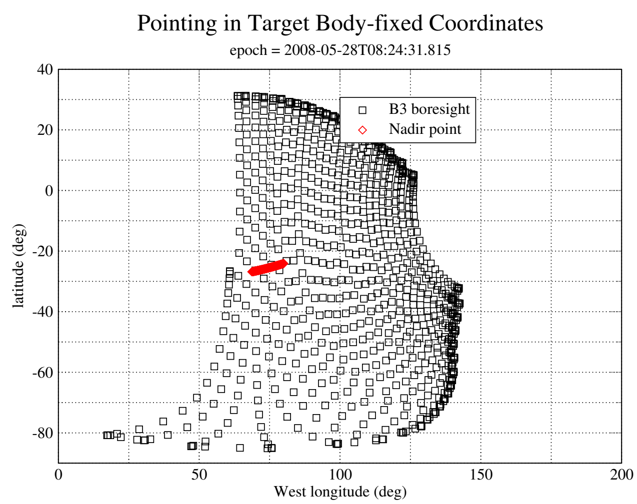

Figure 2: Inbound scatterometry scan in target body-fixed coordinates

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	-6.0	-90.2	yes	
end_time (min)	6.0	-90.0	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	00100	yes	
baq	0	5	yes	0 - 8 to 2
csr	8	0	yes	8 - auto gain
noise_bit_setting	3.0	3.4	yes	
dutycycle	0.70	0.50	yes	
prf (Hz)	don't care	2000	no	RMSS follows profile
tro	don't care	0	no	
number_of_pulses	don't care	8	no	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	255.000	90.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	yes	
interleave_duration (min)	varies	10.0	no	

Table 8: t44 Div e standard_sar_hi block

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-90.0	no	
end_time (min)	varies	-89.8	no	
time_step (s)	don't care	30.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	5	0	yes	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	0.35	yes	
prf (Hz)	1200	1000	yes	
tro	6	6	no	
number_of_pulses	8	96	yes	
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	70.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 9: t44 Div f standard_scatterometer_inbound block

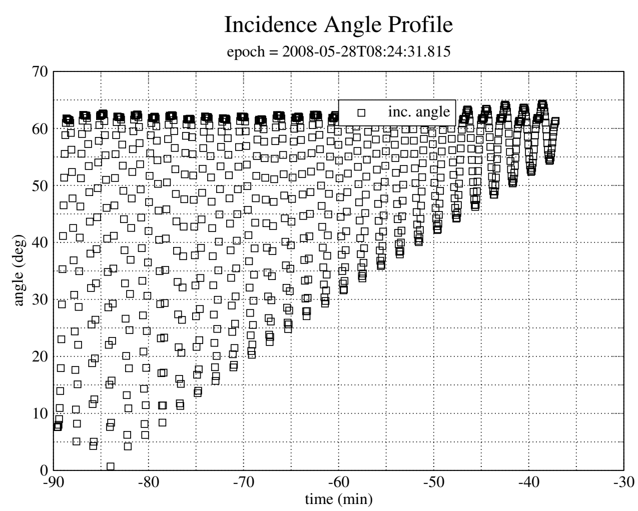

Figure 3: Inbound scatterometry scan incidence angle variation

Name	Nominal	g	h	Mismatch	Comments
mode	scat_compressed	scat_compressed	scatterometer	yes	
start_time (min)	varies	-89.8	-64.0	no	
end_time (min)	varies	-64.0	-31.0	no	
time_step (s)	don't care	30.0	22.0	no	Set by valid time calculation
bem	00100	00100	00100	no	
baq	3	3	5	yes	3 - PRI summation
csr	1	0	0	yes	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	don't care	0.70	0.70	no	
prf (Hz)	1200	1200	1200	no	
tro	don't care	6	6	no	automatically set to 6
number_of_pulses	150	84	8	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	100.0	100.0	no	
auto_rad	on	on	on	no	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	8.000	4.000	20.000	yes	
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 10: t44 Div gh scatterometer_compressed block

Name	Nominal	s	t	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	52.5	70.0	no	
end_time (min)	varies	70.0	100.0	no	
time_step (s)	don't care	40.0	40.0	no	Set by valid time calculation
bem	00100	00100	00100	no	
baq	5	5	5	no	5 - 8 bits straight
csr	0	0	0	no	0 - fixed attenuator
noise_bit_setting	4.0	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.70	0.70	no	
prf (Hz)	1200	1200	1200	no	
tro	6	6	6	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	14.000	8.000	yes	
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 11: t44 Div st standard_scatterometer_outbound block

The outbound regular scatterometry raster scan is covered by div's S and T shown in table 11. The outbound scan is slower and the data rate has been further reduced in this scan to save data volume.

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.

7 Div's I,R: Altimetry

The parameters used by the main altimeter segments are shown in tables 12. The tail end of division (r) cover the bonus altimeter segment where the spacecraft is nadir pointed while transitioning from thrusters to momentum wheel attitude control. These burst rates in these divisions are already as slow as can be commanded (4 sec), so these data rates are the same as prior altimetry observations.

8 Div's J-O: SAR Imaging

Div's J and O cover the turn transitions with beam 3 only. The data rate has been reduced to 40 Kbps 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 outbound end. Div N 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's K-M cover the 32 minutes centered on closest

Name	Nominal	i	r	Mismatch	Comments
mode	altimeter	altimeter	altimeter	no	
start_time (min)	-30.0	-31.0	21.1	yes	
end_time (min)	-19.0	-17.0	52.5	yes	
time_step (s)	don't care	16.0	16.0	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	2.3	2.3	2.3	no	
dutycycle	0.73	0.73	0.73	no	
prf (Hz)	5000	5000	5000	no	
tro	don't care	-6	-6	no	auto set to -6 except interleaved bursts where +6 is used
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	30.000	30.000	no	
interleave_flag	on	on	on	no	
interleave_duration (min)	varies	7.0	14.0	no	

Table 12: t44 Div ir standard_altimeter_inbound block

approach. Hi-SAR is used throughout to obtain the best resolution possible. Targetting of the outbound pushbroom profile ends at +18.2 minutes. Table 15 shows the standard Hi-SAR divisions, table 14 shows the ping pong division, and table 13 shows the B3 only Hi-SAR divisions at the ends. The data rate after 10 minutes past c/a is reduced (div's M,N) due to data volume cutbacks for this observation. The inbound half of the SAR swath is favored because it covers an area of strong contrast in radiometry and scatterometry maps obtained in prior flyby's.

8.1 PRF and Incidence Angle Profiles

The PRF profile and incidence angle profile (Fig. 4) are optimized for maximum usable 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 T44 flyby will be close to 1400 km altitude, and the higher altitude profile used at T3 will be used again here. The optimized profile maximizes usable cross-track width while avoiding gaps in the imaging swath.

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

Name	Nominal	j	o	Mismatch	Comments
mode	sarh	sarh	sarh	no	
start_time (min)	-6.0	-17.0	18.1	yes	
end_time (min)	6.0	-15.5	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	00100	yes	
baq	0	0	0	no	0 - 8 to 2
csr	8	8	8	no	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	0	0	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	40.000	40.000	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 13: t44 Div jo standard_sar_hi block

Name	Nominal	Actual	Mismatch	Comments
mode	sar_ping_pong	sar_ping_pong	no	
start_time (min)	varies	16.0	no	
end_time (min)	varies	18.1	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	150.000	yes	8 to 2 reduces max data rate possible
interleave_flag	off	off	no	
interleave_duration (min)	varies	10.0	no	

Table 14: t44 Div n standard_sar_pingpong block

Name	Nominal	k	l	m	n	Mismatch	Comments
mode	sarh	sarh	sarh	sarh	sar_ping_pong	yes	
start_time (min)	-6.0	-15.5	-10.0	10.0	16.0	yes	
end_time (min)	6.0	-10.0	10.0	16.0	18.1	yes	
time_step (s)	don't care	10.0	10.0	10.0	6.0	no	Set by valid time calculation unless negative, then time_step is used instead
bem	11111	11111	11111	11111	11111	no	
baq	0	0	0	0	0	no	0 - 8 to 2
csr	8	8	8	8	0	yes	8 - auto gain
noise_bit_setting	3.0	3.4	3.4	3.4	3.4	yes	
dutycycle	0.70	0.70	0.70	0.70	0.70	no	
prf (Hz)	don't care	0	0	0	0	no	RMSS follows profile
tro	don't care	0	0	0	0	no	
number_of_pulses	don't care	0	0	0	0	no	RMSS fills round trip time
n_bursts_in_flight	1	1	1	1	1	no	
percent_of_BW	100.0	100.0	100.0	100.0	100.0	no	
auto_rad	off	off	off	off	on	yes	Set off for SAR modes to allow minimum burst time
rip (ms)	34.0	34.0	34.0	34.0	34.0	no	Calculated from radiometer calibration for prior observations
max_data_rate	255.000	230.000	230.000	168.000	150.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	off	off	off	yes	
interleave_duration (min)	varies	10.0	10.0	10.0	10.0	no	

Table 15: t44 Div klmn standard_sar_hi block

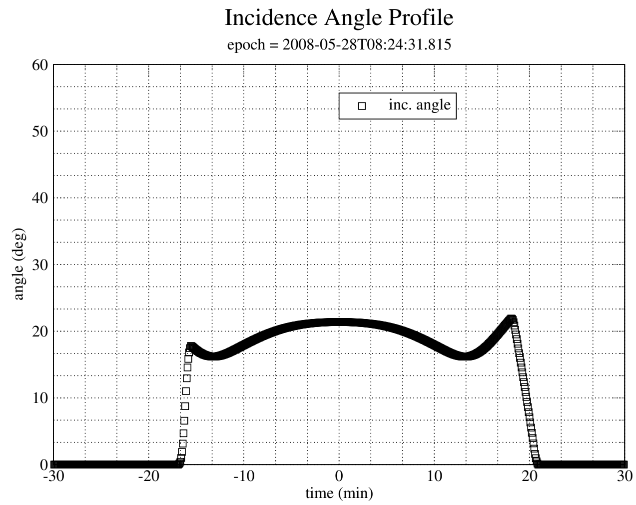

Figure 4: B3 boresight incidence angle during the time around c/a.

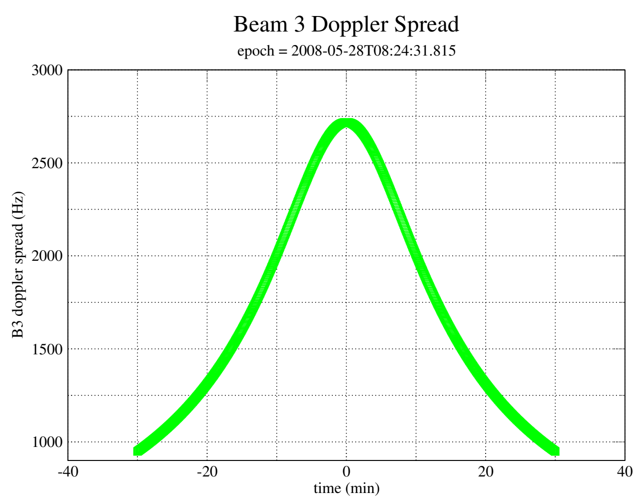

Figure 5: Nadir pointed B3 doppler spread during the time around c/a. Doppler spread is measured within the two-way 3 dB beam pattern.

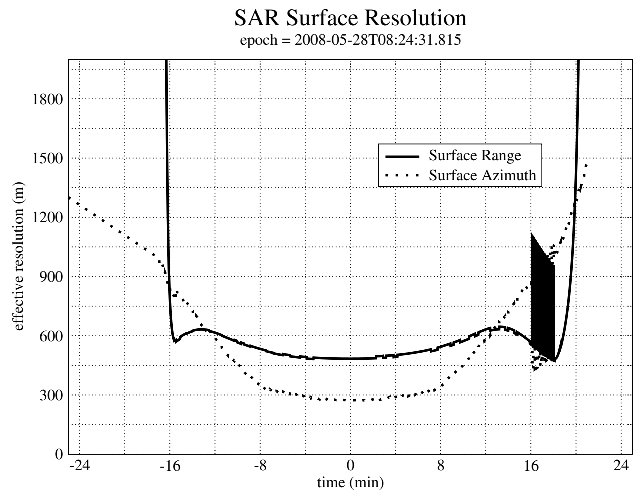

Figure 6: SAR projected range and azimuth resolution. These values are computed from the IEB parameters and are not related to the pixel size in the BIDR file. The pixel size was selected to be always smaller than the real resolution.

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 P,Q: 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 p (see table 16) provides the cleanest data and the best detection threshold. If a signal is detected with div q, then div p (see table 16) provides a follow up observation with some range resolution that could discriminate the height extent of the scattering atmospheric layers.

In div Q, a single pulse is transmitted in each burst. The transit 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 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 Q, then div P 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

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 16: t44 Div p 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 17: t44 Div q standard_scatterometer_outbound block

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. May 27, 2007: 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