RADAR Titan Flyby during S40/T43

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May 14, 2008

- Sequence: s40
- Rev: 067
- Observation Id: t43
- Target Body: Titan
- Data Take Number: 166
- 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 T43 Titan flyby. This SAR data collection occurs during the S40 sequence of the Saturn Tour. This is a mostly complete radar pass with the normal inbound activities plus an extra high altitude imaging segment, and the normal outbound activities except for radiometry scans. 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

CIMS ID	Start	End	Duration	Comments
067TI_T43WARMUP001_RIDER	2008-132T23:46:58	2008-133T05:12:58	05:26:0.0	Warmup for radiometry
067TI_T43INRAD001_PRIME	2008-133T05:12:58	2008-133T08:31:58	03:19:0.0	Inbound radiometry of unique SE terrain. Contiguous with T39. REU bits included.
067TI_T43INSCAT001_PRIME	2008-133T08:31:58	2008-133T09:09:58	00:38:0.0	Inbound Scatterometry of unique SE terrain of Titan. Contiguous with T39.
067TI_T43INALT001_PRIME	2008-133T09:10:58	2008-133T09:46:58	00:36:0.0	Inbound altimetry of Titan T43.
067TI_T43INLSAR001_PRIME	2008-133T09:46:58	2008-133T09:54:58	00:08:0.0	Inbound low rate SAR of Titan. REU bits included.
067TI_T43HISAR001_PRIME	2008-133T09:54:58	2008-133T10:08:58	00:14:0.0	High rate SAR of Titan.
067TI_T43OULSAR001_PRIME	2008-133T10:08:58	2008-133T10:16:58	00:08:0.0	Outbound low rate SAR of Titan. REU bits included.
067TI_T43OUTALT001_PRIME	2008-133T10:16:58	2008-133T10:31:58	00:15:0.0	Outbound altimetry of Titan. REU bits included.
067TI_T43OUTSCT001_PRIME	2008-133T10:53:58	2008-133T11:51:58	00:58:0.0	outbound Scatterometry of unique NW terrain of Titan. Contiguous with T39. REU bits included.

Table 1: t43 CIMS Request Sequence

Division	Name	Start	Duration	Data Vol	Comments
a	Warmup	-10:15:0.0	05:28:0.0	19.5	Warmup
b	standard_radiometer_inbound	-4:47:0.0	00:01:0.0	0.1	Inbound radiometry
c	standard_radiometer_inbound	-4:46:0.0	03:01:0.0	10.8	Inbound radiometry raster scans
d	standard_scatterometer_inbound	-1:45:0.0	00:52:54.0	95.2	Inbound scatterometry raster
e	standard_sar_low	-0:52:6.0	00:00:18.0	1.6	Inbound SAR-Low nadir cal
f	standard_sar_hi	-0:51:48.0	00:00:18.0	1.6	Inbound SAR-Hi nadir cal
g	standard_altimeter_inbound	-0:51:30.0	00:00:18.0	1.2	Inbound altimetry nadir cal
h	scatterometer_imaging	-0:51:12.0	00:02:54.0	17.4	Inbound scatterometer imaging
i	scatterometer_imaging	-0:48:18.0	00:00:54.0	5.4	Inbound scatterometer imaging
j	scatterometer_imaging	-0:47:24.0	00:02:54.0	17.4	Inbound scatterometer imaging
k	scatterometer_imaging	-0:44:30.0	00:07:30.0	40.5	Inbound scatterometer imaging
l	scatterometer_imaging	-0:37:0.0	00:02:42.0	9.7	Inbound scatterometer imaging
m	scatterometer_imaging	-0:34:18.0	00:03:18.0	12.9	Inbound scatterometer imaging
n	scatterometer_imaging	-0:31:0.0	00:00:48.0	4.8	Inbound scatterometer imaging
o	standard_altimeter_inbound	-0:30:12.0	00:10:12.0	18.4	Inbound altimetry
p	standard_sar_hi	-0:20:0.0	00:01:30.0	18.0	Hi-SAR Turn transition, all 5 beam
q	standard_sar_pingpong	-0:18:30.0	00:02:30.0	34.5	Inbound ping-pong
r	standard_sar_hi	-0:16:0.0	00:32:0.0	451.2	Hi-SAR Main Swath
s	standard_sar_pingpong	00:16:0.0	00:02:12.0	30.4	Outbound ping-pong
t	standard_sar_hi	00:18:12.0	00:02:18.0	27.6	Hi-SAR Turn transition to altimetry, all 5 beams
u	standard_scatterometer_outbound	00:20:30.0	00:00:4.0	0.6	Atmospheric Probe with Chirp
v	standard_scatterometer_outbound	00:20:34.0	00:00:2.0	0.3	Atmospheric Probe with Tone
w	standard_altimeter_outbound	00:20:36.0	00:09:24.0	16.9	Outbound altimetry
x	standard_altimeter_outbound	00:30:0.0	00:22:0.0	39.6	Outbound bonus altimetry
y	standard_scatterometer_outbound	00:52:0.0	00:54:0.0	97.2	Outbound scatterometer raster
z	standard_radiometer_outbound	01:46:0.0	00:04:0.0	0.2	Closing radiometer
Total				972.9	

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	216517	off target	0.27	off target
b	100142	100142	0.13	272
c	99786	99786	0.13	272
d	35414	off target	0.05	off target
e	16643	16679	0.02	539
f	16538	16573	0.02	542
g	16432	16467	0.02	544
h	16326	16361	0.02	547
i	15304	16160	0.02	575
j	14987	16078	0.02	584
k	13968	15057	0.02	617
l	11344	12651	0.02	724
m	10406	11282	0.02	773
n	9266	9510	0.01	843
o	8991	8991	0.01	862
p	5561	5561	0.01	1213
q	5076	5186	0.01	1288
r	4286	4357	0.01	1434
s	4286	4370	0.01	1434
t	4980	5097	0.01	1304
u	5725	5725	0.01	1189
v	5746	5746	0.01	1186
w	5757	5757	0.01	1185
x	8923	8923	0.01	867
y	16609	16609	0.02	539
z	35773	37053	0.05	316

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

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

T43 has one high altitude imaging segment as well as a usual inbound scatterometry scan segment. The inbound high altitude imaging has four scan lines. It covers the southwestern area of Xanadu between the T13 and T41 main swaths. 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 very beginning 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 SAR swath is left-looking and has been tweaked with incidence angle offsets to hit the VIMS snail and to provide better altimeter track crossings. At the beginning a small negative incidence angle offset was applied, and in the middle section a positive incidence angle offset was applied to center the VIMS snail in the swath. The details of each of these data collections are described in the following sections.

4 Warmup and Radiometry

The radar warmup rider begins at 2008-05-11T23:46:58.000 (-10:14:59.8). During the warmup, the IEB will be set to collect 1-second radiometer data on beam 3 as shown in table 4. Div C covers inbound radiometry scans.

5 Div's E-G: 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, 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 E-F collect data in the SAR-Low, SAR-Hi modes.The altimetry mode data is collected at by div G. These division parameters are shown in table 6, table 20 and table 8. 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 Div D,Y: Regular Scatterometry

The inbound regular scatterometry raster scan is covered by div D. 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 is covered by div Y. The scans are shown in Figs. 1 and 2.

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

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	-480.0	-615.0	yes	IEB Trigger time is usually later than this
end_time (min)	-300.0	-287.0	yes	
time_step (s)	2700.0	9600.0	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: t43 Div a Warmup block

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	-300.0	-286.0	yes	
end_time (min)	-120.0	-105.0	yes	
time_step (s)	2700.0	4800.0	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: t43 Div c standard_radiometer_inbound block

Name	Nominal	Actual	Mismatch	Comments
mode	unknown	sarl	yes	
start_time (min)	unknown	-52.1	yes	
end_time (min)	unknown	-51.8	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 6: t43 Div e standard_sar_low block

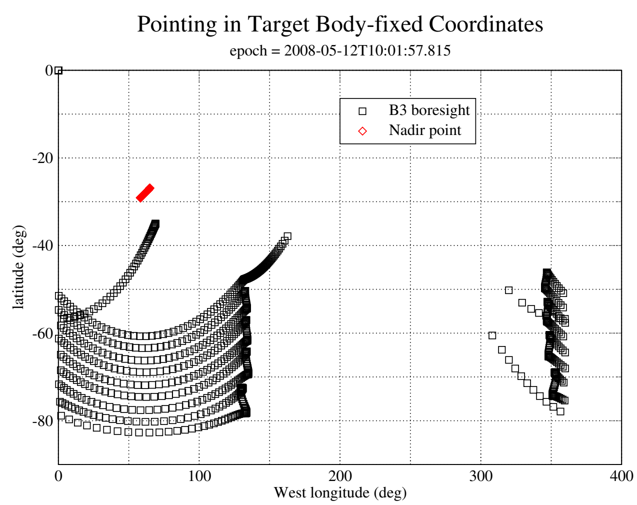

Figure 1: Inbound Scatterometry scan in target body-fixed coordinates

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	-6.0	-51.8	yes	
end_time (min)	6.0	-51.5	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 7: t43 Div f standard_sar_hi block

Name	Nominal	Actual	Mismatch	Comments
mode	altimeter	altimeter	no	
start_time (min)	-30.0	-51.5	yes	
end_time (min)	-19.0	-51.2	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	5000	no	
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 8: t43 Div g standard_altimeter_inbound block

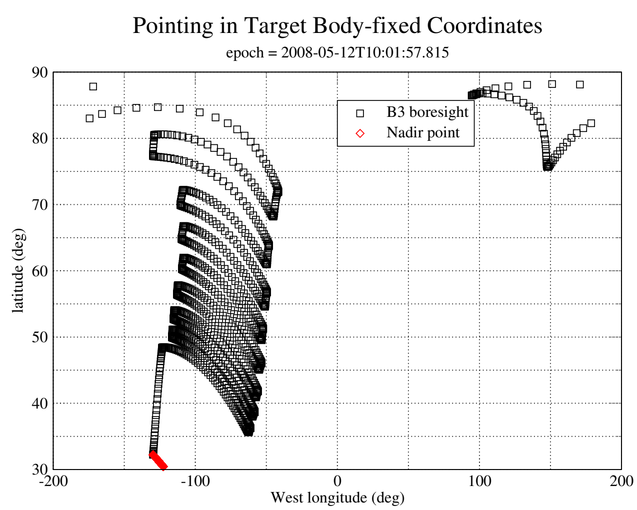

Figure 2: Outbound Scatterometry scan in target body-fixed coordinates

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-105.0	no	
end_time (min)	varies	-52.1	no	
time_step (s)	don't care	40.0	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 9: t43 Div d standard_scatterometer_inbound block

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 H-N: Scatterometry Imaging

The T43 high altitude imaging segment uses to cover more area at expense of looks. Div's H-N shown in tables 11,12,13 and 14 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 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 about 2 km by 1.8 km.

7.1 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. 3) The PRF value is set to provide for a reasonable balance between range and doppler ambiguities throughout the imaging rasters. For technical details on range and doppler ambiguities, refer to the discussion in the T19 sequence design memo.

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	52.0	no	
end_time (min)	varies	106.0	no	
time_step (s)	don't care	40.0	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 10: t43 Div y standard_scatterometer_outbound block

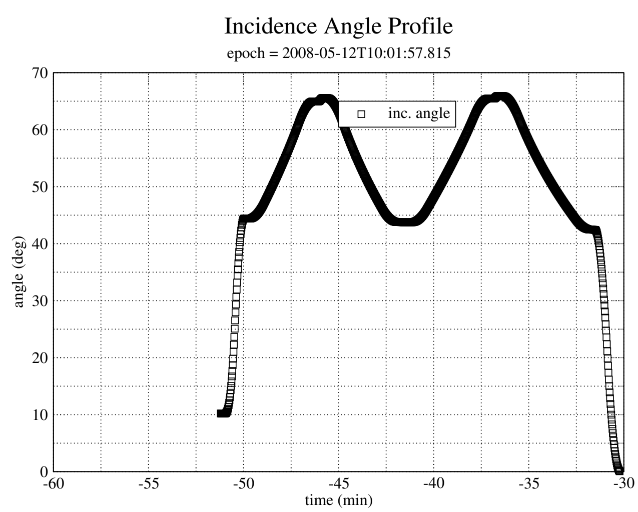

Figure 3: Incidence angle variation during Div H-N

Name	Nominal	h	i	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	-51.2	-48.3	no	
end_time (min)	varies	-48.3	-47.4	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	800	yes	1000 Hz is typical, set to balance range/doppler ambiguities
tro	6	6	6	no	
number_of_pulses	100	96	76	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	100.000	100.000	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: t43 Div hi scatterometer_imaging block

Name	Nominal	j	k	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	-47.4	-44.5	no	
end_time (min)	varies	-44.5	-37.0	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	0.45	yes	
prf (Hz)	1000	650	800	yes	1000 Hz is typical, set to balance range/doppler ambiguities
tro	6	6	6	no	
number_of_pulses	100	0	57	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	100.000	90.000	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 12: t43 Div jk scatterometer_imaging block

Name	Nominal	l	m	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	-37.0	-34.3	no	
end_time (min)	varies	-34.3	-31.0	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	0.70	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	60.000	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 13: t43 Div lm scatterometer_imaging block

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	sarl	yes	
start_time (min)	varies	-31.0	no	
end_time (min)	varies	-30.2	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	100.000	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 14: t43 Div n scatterometer_imaging block

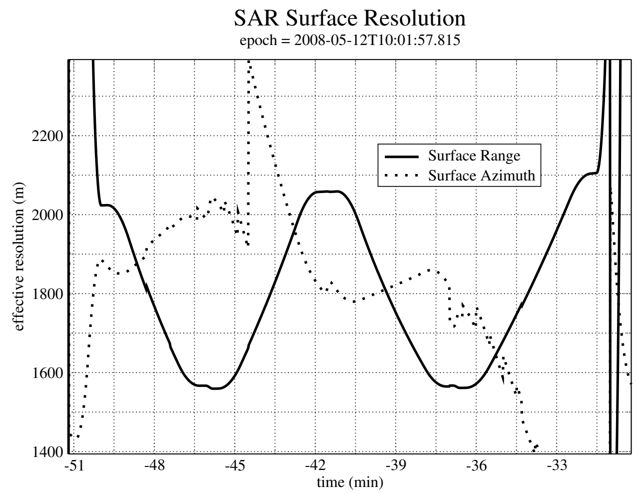

Figure 4: Div H-N: Projected range and azimuth resolution. These values are computed from the IEB parameters.

7.2 SAR-style Scatterometer Resolution Performance

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

$$\delta R_g = \frac{c}{2B_r \sin\theta_i}, \quad (1)$$

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

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 4 shows the results from these equations for divisions H-N. The calculations are performed for the boresight of beam 3 which is the center of the swath.

7.3 SNR and Looks

In scatterometer mode the noise equivalent σ_0 for beam 3 will be generally better than -13 dB in these imaging segments. The number of looks varies from a low around 20 to above 100. 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.

8 Div's O,W,X: Altimetry

The parameters used by the main altimeter segments are shown in tables 15 and 16. The higher altitude division (X) cover the 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.

9 Div's P-T: SAR Imaging

Div's P and T cover the turn transitions with all 5 beams. The data rate has been reduced slightly to 200 Kbps to conserve data volume. This should still provide enough looks during the turn transition because only one beam is

Name	Nominal	o	w	Mismatch	Comments
mode	altimeter	altimeter	altimeter	no	
start_time (min)	-30.0	-30.2	20.6	yes	
end_time (min)	-19.0	-20.0	30.0	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 15: t43 Div ow standard_altimeter_inbound block

used. The SAR swath is pushbroomed at both ends. Div's Q,S ping-pong 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 R covers the 32 minutes centered on closest approach. Hi-SAR is used throughout to obtain the best resolution possible. Targetting of the outbound pushbroom profile ends at +18.2 minutes. Table 17 shows the standard Hi-SAR divisions, table 18 shows the two ping pong divisions, and table 19 shows the Hi-SAR divisions at the ends.

9.1 PRF and Incidence Angle Profiles

The PRF profile and incidence angle profile (Fig. 5) 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 T43 flyby will be close to 1000 km altitude, and the lower altitude profile used 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.

9.2 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 7 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

Name	Nominal	Actual	Mismatch	Comments
mode	altimeter	altimeter	no	
start_time (min)	19.0	30.0	yes	
end_time (min)	30.0	52.0	yes	
time_step (s)	don't care	16.0	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 16: t43 Div x standard_altimeter_outbound block

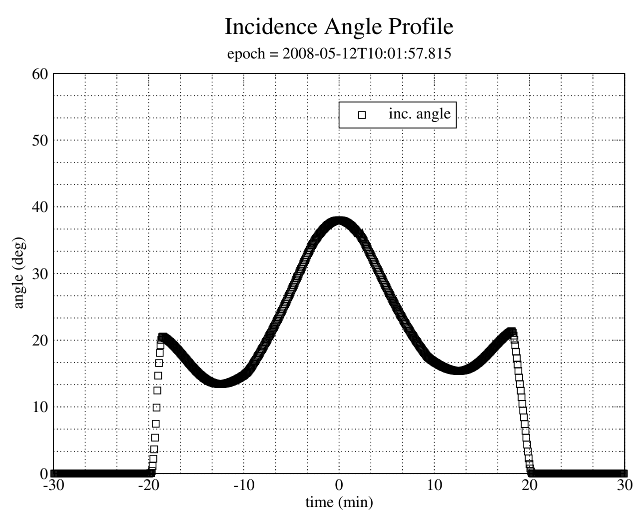

Figure 5: B3 boresight incidence angle during the time around c/a.

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	-6.0	-16.0	yes	
end_time (min)	6.0	16.0	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	100.0	no	
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 17: t43 Div r standard_sar_hi block

Name	Nominal	q	s	Mismatch	Comments
mode	sar_ping_pong	sar_ping_pong	sar_ping_pong	no	
start_time (min)	varies	-18.5	16.0	no	
end_time (min)	varies	-16.0	18.2	no	
time_step (s)	6.0	6.0	6.0	no	Set to provide overlap between Hi and Low-SAR
bem	11111	11111	11111	no	
baq	0	0	0	no	0 - 8 to 2
csr	0	0	0	no	0 - fixed attenuator
noise_bit_setting	3.4	3.4	3.4	no	
dutycycle	0.70	0.70	0.70	no	
prf (Hz)	varies	0	0	no	0 - RMSS follows profile
tro	varies	0	0	no	
number_of_pulses	varies	0	0	no	0 - 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	230.000	230.000	230.000	no	8 to 2 reduces max data rate possible
interleave_flag	off	off	off	no	
interleave_duration (min)	varies	10.0	10.0	no	

Table 18: t43 Div qs standard_sar_pingpong block

Name	Nominal	p	t	Mismatch	Comments
mode	sarh	sarh	sarh	no	
start_time (min)	-6.0	-20.0	18.2	yes	
end_time (min)	6.0	-18.5	20.5	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	11111	11111	no	
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	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	200.000	200.000	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 19: t43 Div pt standard_sar_hi block

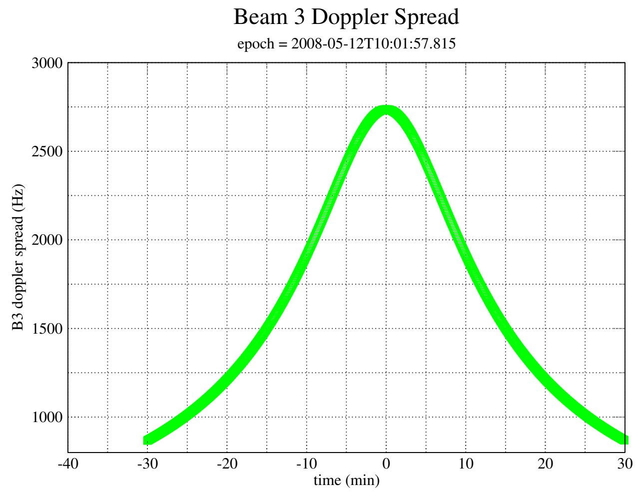

Figure 6: Nadir pointed B3 doppler spread during the time around c/a. Doppler spread is measured within the two-way 3 dB beam pattern.

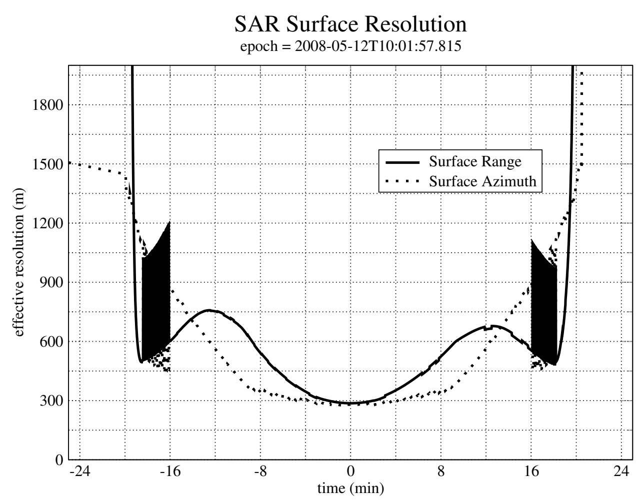

Figure 7: SAR projected range and azimuth resolution. These values are computed from the IEB parameters and are not related to the pixel size in the BIDR file. The pixel size was selected to be always smaller than the real resolution.

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	-6.0	-51.8	yes	
end_time (min)	6.0	-51.5	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 20: t43 Div f standard_sar_hi block

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.

10 Div's U,V: Atmospheric Probe

Targetting of the nadir track starts at 20.5 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 U (see table 21) provides the cleanest data and the best detection threshold. If a signal is detected with div V, then div

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	20.5	no	
end_time (min)	varies	20.6	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 21: t43 Div u standard_scatterometer_outbound block

U (see table 21) provides a follow up observation with some range resolution that could discriminate the height extent of the scattering atmospheric layers.

In div V, 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 V, then div U 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

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	20.6	no	
end_time (min)	varies	20.6	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 22: t43 Div v standard_scatterometer_outbound block

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.

11 Revision History

1. May 14, 2008: Initial release

12 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