RADAR Titan Flyby during S21/T15

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- Sequence: s21
- Rev: 025
- Observation Id: t15
- Target Body: Titan
- Data Take Number: 86
- PDT Config File: S21_ssup_psiv1_060413_a_pdt.cfg
- SMT File: s21_ssup_060426.rpt
- PEF File: z0210c.pef

1 Introduction

This memo describes the Cassini RADAR activities for the eighth Titan flyby on which RADAR data will be acquired. This data collection occurs during the s21 sequence of the Saturn Tour. A sequence design memo provides the science context of the scheduled observations, an overview of the pointing design, and guidlines for preparing the RADAR IEB.

Like T4, this RADAR data collection includes only radiometry and scatterometry. RADAR will not operate at the closest approach time, therefore no altimeter or SAR data can be collected. After the two inbound radiometry scans, there will be a small scatterometry segment that sweeps about 10 beamwidths at an incidence angle around 35 degrees. This segment will provide data that can be processed into higher-resolution scatterometry coverage. All of these scans are executed on momentum wheel control.

2 CIMS and Division Summary

Each RADAR observation is represented to the project by a set of requests in the Cassini Information Management System (CIMS). The CIMS database contains requests for pointing control, time, and data volume. The CIMS requests show a high-level view of the sequence design. Table 1 shows the CIMS request summary for this observation. Although the CIMS requests show Low-SAR intervals, in reality the radar will be operated in Hi-SAR mode throughout this flyby.

The CIMS requests form the basis of a pointing design built using the project pointing design tool (PDT). The details of the pointing design are shown by the PDT plots on the corresponding tour sequence web page. (See https://cassini.jpl.nasa.gov/radar.) The RADAR pointing sequence is ultimately combined with pointing sequences from other instruments to make a large merged c-kernel. C-kernels are files containing spacecraft attitude data.

A RADAR tool called RADAR Mapping and Sequencing Software (RMSS) reads the merged c-kernel along with other navigation data files, and uses these data to produce a set of instructions for the RADAR observation. The

CIMS ID	Start	End	Duration	Comments
025OT_WARM4TI15001_RIDER	2006-183T01:20:48	2006-183T04:20:48	03:00:0.0	Warmup for RADAR observation of Titan.
025TI_T15RADIOM001_PRIME	2006-183T04:20:48	2006-183T08:20:48	04:00:0.0	Radiometry of Titan. -Z scanned over Titan. Y axis controlled for different polarizations.

Table 1: t15 CIMS Request Sequence

Division	Name	Start	Duration	Data Vol	Comments
a	Warmup	-8:00:0.0	02:45:0.0	2.5	Warmup
b	scatterometer_compressed	-5:15:0.0	00:05:0.0	2.1	Slewing on target, 5-beams
c	standard_radiometer_inbound	-5:10:0.0	01:50:0.0	6.5	Inbound Rad scan 1
d	scat_compressed	-3:20:0.0	01:55:0.0	21.4	Inbound Scatt/Rad scan 2
e	scat_compressed	-1:25:0.0	00:00:18.0	0.1	On-target Receive only
f	standard_scatterometer_inbound	-1:24:42.0	00:13:18.0	45.5	Hi-Res Scat, 8-2
g	standard_sar_low_inbound	-1:11:24.0	00:00:18.0	3.6	Low Sar, 8-2
h	standard_scatterometer_inbound	-1:11:6.0	00:00:18.0	1.0	Hi-Res Scat, 8-2
i	standard_sar_low_inbound	-1:10:48.0	00:00:18.0	3.6	Low Sar, 8-2
j	standard_scatterometer_inbound	-1:10:30.0	00:00:18.0	1.0	Hi-Res Scat, 8-2
k	standard_sar_low_inbound	-1:10:12.0	00:00:18.0	3.6	Low Sar, 8-2
l	standard_scatterometer_inbound	-1:09:54.0	00:00:18.0	1.0	Hi-Res Scat, 8-2
m	standard_sar_low_inbound	-1:09:36.0	00:00:18.0	3.6	Low Sar, 8-2
n	standard_scatterometer_inbound	-1:09:18.0	00:00:18.0	1.0	Hi-Res Scat, 8-2
o	standard_sar_low_inbound	-1:09:0.0	00:00:18.0	3.6	Low Sar, 8-2
p	standard_scatterometer_inbound	-1:08:42.0	00:00:18.0	1.0	Hi-Res Scat, 8-2
q	standard_sar_low_inbound	-1:08:24.0	00:00:18.0	3.6	Low Sar, 8-2
r	standard_scatterometer_inbound	-1:08:6.0	00:00:18.0	1.0	Hi-Res Scat, 8-2
s	standard_sar_low_inbound	-1:07:48.0	00:00:18.0	3.6	Low Sar, 8-2
t	standard_scatterometer_inbound	-1:07:30.0	00:00:18.0	1.0	Hi-Res Scat, 8-2
u	standard_sar_low_inbound	-1:07:12.0	00:00:18.0	3.6	Low Sar, 8-2
v	standard_scatterometer_inbound	-1:06:54.0	00:00:18.0	1.0	Hi-Res Scat, 8-2
w	standard_sar_low_inbound	-1:06:36.0	00:00:18.0	3.6	Low Sar, 8-2
x	standard_scatterometer_inbound	-1:06:18.0	00:00:18.0	1.0	Hi-Res Scat, 8-2
y	standard_scatterometer_inbound	-1:06:0.0	00:11:0.0	72.6	Scat, 8-8
Total				192.7	

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	157126	off target	0.20	off target
b	102156	off target	0.13	off target
c	100498	off target	0.13	off target
d	64102	off target	0.08	off target
e	26217	26726	0.04	449
f	26118	26627	0.04	450
g	21766	22202	0.03	512
h	21668	22106	0.03	513
i	21570	22010	0.03	515
j	21472	21914	0.03	517
k	21374	21819	0.03	518
l	21276	21723	0.03	520
m	21178	21628	0.03	522
n	21080	21532	0.03	524
o	20982	21437	0.03	525
p	20885	21342	0.03	527
q	20787	21247	0.03	529
r	20689	21152	0.03	531
s	20591	21057	0.03	533
t	20493	20962	0.03	535
u	20395	20868	0.03	537
v	20298	20773	0.03	538
w	20200	20679	0.03	540
x	20102	20584	0.03	542
y	20004	20490	0.03	544

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	-480.0	no	IEB Trigger time is usually later than this
end_time (min)	-300.0	-315.0	yes	
time_step (s)	2700.0	2700.0	no	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	0.250	0.248	yes	Kbps - actual data rate may be less
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 4: t15 div_a Warmup block

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 each division. Subsequent sections will show and discuss the keyword selections made for each division. Each division table shows a set of nominal parameters that are determined by the operating mode (eg., distant scatterometry, SAR low-res inbound). The actual division parameters from the config file are also shown, and any meaningful mismatches are flagged.

3 Warmup and Overview

The radar warmup rider begins at 2006-07-02T01:20:48.000 (-07:59:58.8). During the warmup, the IEB will be set for slow speed radiometer only data as shown in table 4. Division B cycles all 5 beams as the spacecraft slews onto Titan to collect information about spill-over sidelobes. The instrument operates in compressed scatterometer mode during this time to collect off-target receive only data in the scatterometer bandpass and in radiometer mode. These data provide a calibration reference point. The compressed mode keeps the data volume down while still collecting a large amount of integration time.

4 Div's C,D: Compressed Scatterometry and Radiometry Scans

There are two radiometry scans in this observation. The first is radiometry only, while the second also includes compressed scatterometry. The compressed scatterometry obtained during the radiometry scans follows the same

Name	Nominal	Actual	Mismatch	Comments
mode	scat_compressed	scatterometer	yes	
start_time (min)	varies	-315.0	no	
end_time (min)	varies	-310.0	no	
time_step (s)	don't care	5400.0	no	Set by valid time calculation
bem	00100	11111	yes	
baq	3	3	no	3 - PRI summation
csr	1	1	no	1 - receive only antenna measurement
noise_bit_setting	4.0	4.0	no	9 dB setting used by all low SNR scatterometry
dutycycle	0.70	0.70	no	
prf (Hz)	1200	1202	yes	
tro	don't care	6	no	automatically set to 6
number_of_pulses	150	150	no	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	no	
percent_of_BW	100.0	0.0	yes	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	8.000	4.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 5: t15 div_b scatterometer_compressed block

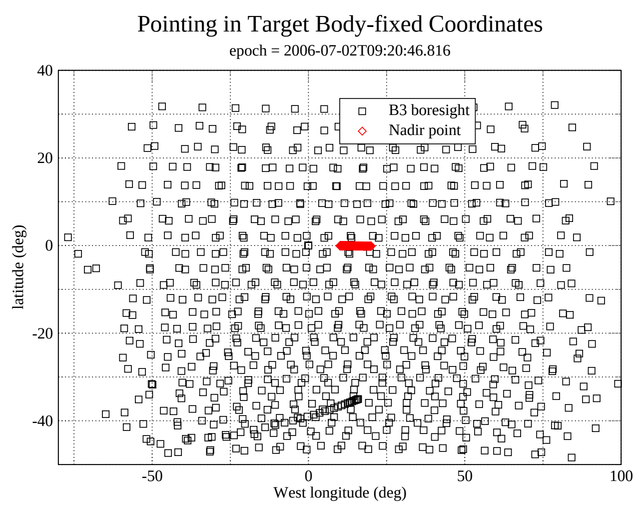

Figure 1: Scans in target body-fixed coordinates

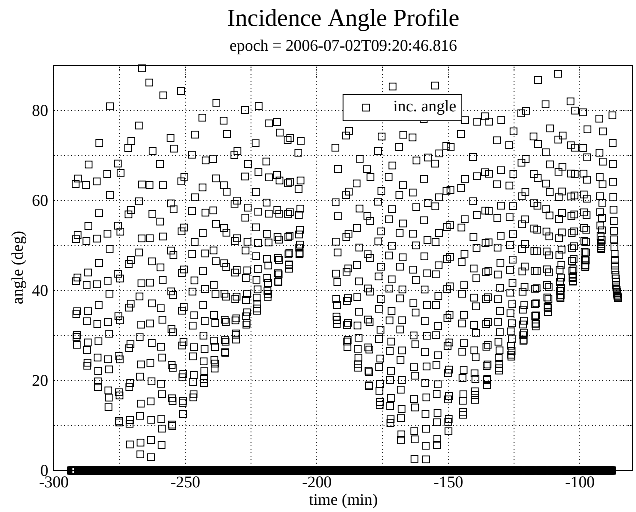

Figure 2: Incidence angle variation during scan

constraints and considerations confronted in the T7 design. The on-board summation (compressed scatterometry) keeps the data rate down to about 5 Kbps. Immediately following the radiometry scans, a short receive only division replicates Div B to provide the parameters and some on-target data.

5 Div's F-X: High Altitude Imaging

From -85 min to -65 minutes, the pointing design slews beam 3 about 10 beamwidths around the normal iso-doppler attitude for an incidence angle of 35 degrees. This design allows for a high altitude imaging segment with performance characteristics from segment B of the high altitude imaging presentation made at the T13 science team meeting (see high altitude imaging memo and presentation on radar web page under CRST meetings). Div F covers the first 13 minutes with a scatterometer division that pushes against the 7% duty cycle limit. Resolution in this segment will be about 3.5 km by 2.5 km. Div's G-X then alternate scatterometer mode (same params as div F) with SAR-Low divisions that also push the 7% duty cycle limit and the 32 Kbyte science data buffer. The SAR-Low divisions run at a higher data rate of 202 Kbps vs 57 Kbps for the scatt divisions. The alternating divisions are 18 seconds long each so that each provides overlapping looks of the illuminated area. The 5 minutes of alternating modes will provide a test case to try out resolution enhancing processing. Table 8 and 9 show the scatterometer and low-sar parameters used.

5.1 PRF and Incidence Angle Choices

RMSS does not support all of the SAR options in scatterometer mode, so this high-res scatterometer profile uses a constant incidence angle (see Fig. 3) and PRF. The PRF value is set to 1 KHz to adequately space the range and doppler ambiguities. Doppler ambiguities occur at intervals equal to the PRF, so the PRF needs to be set higher than the doppler spread within the beam footprint. The doppler spread during divisions F-X varies from about 600 Hz to about 620 Hz as range varies from 26000 km to 20000 km. At the same time the PRF needs to be low enough to keep the range ambiguities outside of the beam footprint. Assuming a locally flat surface, range ambiguities have an angular spacing of,

$$\alpha = \frac{c}{2Rf_p \tan\theta_i}, \tag{1}$$

where α is the angular spread from the spacecraft position, c is the speed of light, θ_i is the incidence angle, R is the range to the surface, and f_p is the PRF. If we set the angular spread equal to the beamwidth θ_{bw}, then f_p should lie between the two limits,

$$f_p(max) = \frac{c}{2R_{\mathrm{max}}\theta_{\mathrm{bw}} \tan\theta_i} = 1230Hz, \tag{2}$$

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	-300.0	-310.0	yes	
end_time (min)	-120.0	-200.0	yes	
time_step (s)	2700.0	2700.0	no	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	1.000	0.992	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 6: t15 div_c standard_radiometer_inbound block

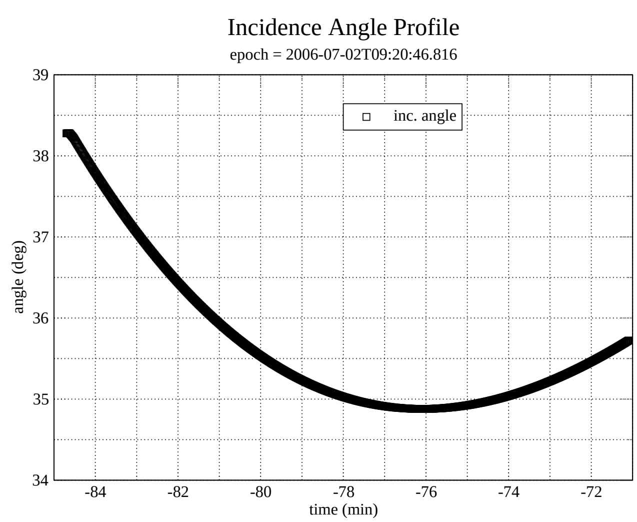

Figure 3: Incidence angle variation during Div's F,G

Name	Nominal	Actual	Mismatch	Comments
mode	scat_compressed	scat_compressed	yes	
start_time (min)	varies	-200.0	no	
end_time (min)	varies	-85.0	no	
time_step (s)	don't care	4.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	3	3	no	3 - PRI summation
csr	1	0	yes	1 - receive only antenna measurement
noise_bit_setting	4.0	4.0	no	9 dB setting used by all low SNR scatterometry
dutycycle	0.70	0.70	no	
prf (Hz)	1200	2000	yes	
tro	don't care	6	no	automatically set to 6
number_of_pulses	150	135	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	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	8.000	3.100	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 7: t15 div_d scat_compressed block

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-84.7	no	
end_time (min)	varies	-71.4	no	
time_step (s)	don't care	4.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	5	0	yes	5 - 8 bits straight
csr	8	0	yes	8 - auto gain
noise_bit_setting	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.60	0.70	yes	
prf (Hz)	1200	1000	yes	
tro	6	6	no	
number_of_pulses	8	70	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	57.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 8: t15 div_f standard_scatterometer_inbound block

and

$$f_p(min) = \text{max doppler spread} = 620Hz, \tag{3}$$

where R_{max} is 26000 km, θ_{bw} is 6 mrad for beam 3, and θ_i is about 38 degrees at 26000 km. For divisions F-X, the PRF is set in the middle at 1000 Hz to balance the spacing of the range and azimuth ambiguities.

5.2 SAR-style Scatterometer Resolution Performance

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

$$\delta R_g = \frac{c}{2B_r \sin\theta_i}, \tag{4}$$

$$\delta x = \frac{\lambda R}{2\tau_{rw} v \sin\theta_v}, \tag{5}$$

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

5.3 SNR and Looks

Noise performance will be better in this segment than it was in the T12 high altitude imaging because of the lower altitude range. In scatterometer mode the noise equivalent σ_0 for beam 3 will be better than -10 dB, and in low-sar mode it will be better than -5 dB. The number of looks will vary from 160 to 200 in scatterometer mode. The low-sar

Name	Nominal	Actual	Mismatch	Comments
mode	sarl	sarl	no	
start_time (min)	-19.0	-71.4	yes	
end_time (min)	-6.0	-71.1	yes	
time_step (s)	don't care	6.0	no	Set by valid time calculation
bem	11111	00100	yes	
baq	0	0	no	0 - 8 to 2
csr	8	0	yes	8 - auto gain
noise_bit_setting	2.0	4.6	yes	
dutycycle	0.73	0.70	yes	
prf (Hz)	don't care	1000	no	RMSS follows profile
tro	don't care	0	no	
number_of_pulses	don't care	36	no	RMSS fills 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	255.000	202.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	yes	
interleave_duration (min)	varies	10.0	no	

Table 9: t15 div_g standard_sar_low_inbound block

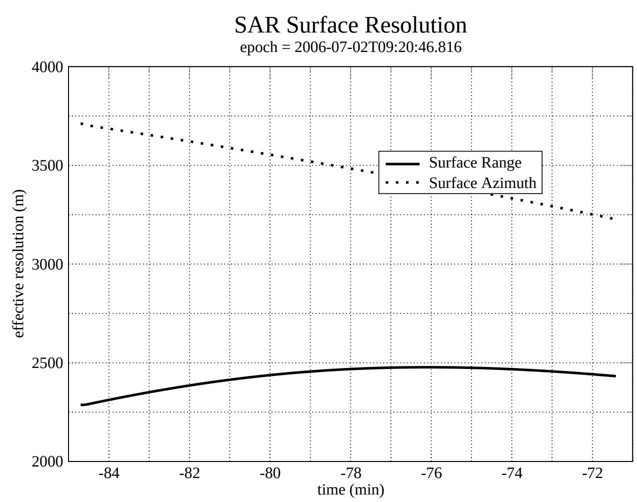

Figure 4: Div F: Projected range and azimuth resolution. These values are computed from the IEB parameters.

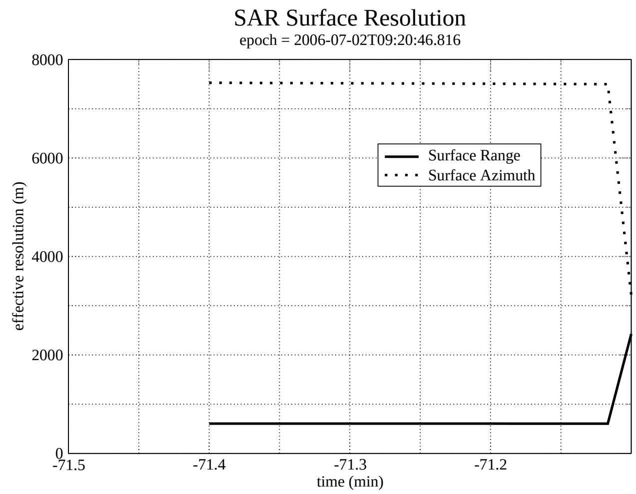

Figure 5: Div G: Projected range and azimuth resolution. These values are computed from the IEB parameters.

divisions will add many more looks with better range resolution, but worse azimuth resolution. 8-2 BAQ is used to get more looks out of available data volume, and to allow the low-sar mode to push the 7% duty cycle limit.

The resolution of this observation could be improved at the expense of SNR by reducing the pulse duty cycle below 70%, and then increasing the number of pulses until the science data buffer is filled. The ESS limit on the number of pulses may kick in before the science data buffer can be filled. Future designs may want to make this tradeoff depending on the desired balance between SNR and resolution, so this option should be tested.

6 Revision History

1. May 11, 2006: Initial release

7 Acronym List

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