RADAR Titan Flyby during S99/T126

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- Sequence: s99
- Rev: 270
- Observation Id: t126
- Target Body: Titan
- Data Take Number: 285
- PDT Config File: S99_sip_port3_170103_pdt.cfg
- SMT File: S99_170207.smt
- PEF File: z0990bGH.pef

1 Introduction

This memo describes the Cassini RADAR activities for the T126 Titan flyby. This SAR data collection occurs during the S99 sequence of the Saturn Tour. This is a nearly complete radar pass with a close approach altimetry track over the northern lake district of Titan. A sequence design memo provides the science context of the scheduled observations, an overview of the pointing design, and guidlines for preparing the RADAR IEB.

2 CIMS and Division Summary

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

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

A RADAR tool called RADAR Mapping and Sequencing Software (RMSS) reads the merged c-kernel along with other navigation data files, and uses these data to produce a set of instructions for the RADAR observation. The RADAR instructions are called an Instrument Execution Block (IEB). The IEB is produced by running RMSS with a radar config file that controls the process of generating IEB instructions for different segments of time. These segments of time are called divisions with a particular behavior defined by a set of division keywords in the config file. Table 2 shows a summary of the divisions used in this observation. Table 3 shows a summary of some key geometry values for each division.

CIMS ID	Start	End	Duration	Comments
270TI_T126WRMUP001_RIDER	2017-111T20:53:07	2017-112T00:08:07	03:15:0.0	
270TI_T126INRAD001_PRIME	2017-112T00:08:07	2017-112T03:53:07	03:45:0.0	
270TI_T126INSCT001_PRIME	2017-112T03:53:07	2017-112T04:56:07	01:03:0.0	
270TI_T126IHSAR001_PRIME	2017-112T04:56:07	2017-112T05:37:07	00:41:0.0	
270TI_T126INALT001_PRIME	2017-112T05:38:07	2017-112T05:53:07	00:15:0.0	
270TI_T126RASAR001_PRIME	2017-112T05:53:07	2017-112T06:08:07	00:15:0.0	
270TI_T126RASAR002_RIDER	2017-112T06:00:07	2017-112T06:08:07	00:08:0.0	
270TI_T126OTSAR001_PRIME	2017-112T06:08:07	2017-112T06:26:07	00:18:0.0	
270TI_T126OTALT001_PRIME	2017-112T06:26:07	2017-112T06:38:07	00:12:0.0	
270TI_T126OHSAR001_PRIME	2017-112T07:00:07	2017-112T07:38:07	00:38:0.0	
270TI_T126OTSCT001_PRIME	2017-112T07:38:07	2017-112T08:43:07	01:05:0.0	
270TI_T126OTRAD001_PRIME	2017-112T08:43:07	2017-112T12:08:07	03:25:0.0	

Table 1: t126 CIMS Request Sequence

3 Observation Sequence

T126 is a complex radar flyby befitting its position as the last close radar Titan flyby of the mission. The observation starts with two radiometer scans that sweep all the way off the limb as shown in figure 1. Following the radiometry scans, we have inbound scatterometry and high altitude scatterometer imaging scans over areas just north of Xanadu. These areas were not previously covered by any form of SAR imaging, so we are picking up more coverage with these segments. Figure 2 shows the layout of all the segments of this observation. The inbound high altitide imaging is shown by the blue and cyan raster scans.

After the inbound scatterometer imaging, the spacecraft turned to nadir for a standard inbound altimeter track, and then turned off target to align for an INMS observation. The radar acquired ride-along SAR imagery starting about 5 minutes prior to closest approach. In figure 2, the ride-along SAR imagery is shown as a red strip heading north from the Xanadu area. Around closest approach, the radar became the prime pointing instrument again, and the spacecraft was commanded to turn to nadir for a close altimetry track over a region of many small methane lakes in the north polar region. Figure 3 shows the beam 3 boresight surface intercept as a series of yellow triangles. Atmospheric probe measurements were inserted just before the nadir track begins (at 2.5 minutes from c/a) and just after it ends (at 4.5 minutes from c/a) to take advantage of the opportunity for close range atmospheric sounding. Between 2.5 minutes and 4.5 minutes from c/a, the radar collected high data rate altimetry with a high attenuator setting to avoid saturating echoes from the methane lakes (see table 4). This segment was designed to do sounding of the lakes and explore their bathymetry.

Following the close approach altimetry, the spacecraft turned back to do outbound SAR imaging as shown in figure 3. This SAR coverage overlapped numerous previous northern hemisphere SAR swaths. Then the spacecraft turns back to nadir for a standard outbound altimeter track with another atmospheric probe measurement inserted just before reaching nadir pointing. After finishing the outbound altimetry track, the spacecraft turns off-target in a long turn before coming back on target for an outbound high altitude imaging scan at high northern latitudes, and a contiguous outbound scatterometry scan at somewhat lower latitudes. As shown in figure 2, these two scans are joined together and provide coverage of a large previously unobserved (by SAR imaging) area. Data rates are kept high to support imaging for part of the scatterometry raster scan as shown in table 5.

After these final imaging and scatterometry raster scans, the spacecraft performs two outbound radiometry scans with the usual polarization offset between them.

4 Mode Specific Operation and Performance

Many details of standard radar sequencing during the 4 main modes (Radiometry, Scatterometry, Altimetry, and SAR) have been discussed in previous sequence memos for prior observations. Refer to these for details. Some selected performance highlights are illustrated in figures and explained in the following subsections.

Division	Name	Start	Duration	Data Vol	Comments
a	Warmup	-9:20:0.0	03:25:0.0	12.2	Warmup
b	standard_radiometer_inbound	-5:55:0.0	00:05:0.0	0.3	radiometer quick-steps
c	standard_radiometer_inbound	-5:50:0.0	03:32:0.0	12.6	radiometer raster
d	scatterometer_imaging	-2:18:0.0	00:28:0.0	60.5	Inbound scatt imaging
e	scatterometer_imaging	-1:50:0.0	00:39:0.0	140.4	Inbound scatt imaging
f	scatterometer_imaging	-1:11:0.0	00:42:24.0	152.6	Inbound scatt imaging
g	standard_altimeter_inbound	-0:28:36.0	00:08:50.0	17.5	Inbound altimetry
h	standard_sar_hi	-0:19:46.0	00:01:46.0	5.3	SAR Turn transition transition from scat, beam 3 only
i	scatterometer_compressed	-0:18:0.0	00:11:0.0	2.0	Compressed Scatt/Rad while turning on,off-target
j	standard_sar_hi	-0:07:0.0	00:02:0.0	6.0	SAR Turn transition transition from scat, beam 3 only
k	standard_sar_hi	-0:05:0.0	00:07:22.0	101.7	Inbound Ride-along SAR Swath
l	standard_scatterometer_outbound	00:02:22.0	00:00:4.0	0.6	Atmospheric Probe - Tone
m	standard_scatterometer_outbound	00:02:26.0	00:00:2.0	0.3	Atmospheric Probe - Chirp
n	standard_altimeter_outbound	00:02:28.0	00:01:58.0	26.0	Close approach high rate altimetry
o	standard_scatterometer_outbound	00:04:26.0	00:00:4.0	0.6	Atmospheric Probe - Chirp
p	standard_scatterometer_outbound	00:04:30.0	00:00:2.0	0.3	Atmospheric Probe - Tone
q	standard_sar_hi	00:04:32.0	00:11:28.0	151.4	SAR Outbound Swath
r	standard_sar_hi	00:16:0.0	00:02:30.0	33.0	SAR Outbound Swath
s	standard_sar_hi	00:18:30.0	00:00:42.0	1.7	SAR during turn transition to nadir, beam 3 only
t	standard_scatterometer_outbound	00:19:12.0	00:00:4.0	0.6	Atmospheric Probe - Tone
u	standard_scatterometer_outbound	00:19:16.0	00:00:2.0	0.3	Atmospheric Probe - Chirp
v	standard_altimeter_outbound	00:19:18.0	00:08:54.0	17.6	Outbound altimetry
w	scatterometer_compressed	00:28:12.0	00:10:0.0	1.8	Compressed Scatt/Rad during turn off,on-target
x	scatterometer_imaging	00:38:12.0	00:14:48.0	35.5	Outbound scatt imaging
y	scatterometer_imaging	00:53:0.0	00:27:0.0	97.2	Outbound scatt imaging
z	scatterometer_imaging	01:20:0.0	00:10:0.0	36.0	Outbound scatt imaging
lbrace	scatterometer_imaging	01:30:0.0	00:20:0.0	72.0	Outbound scatt imaging
vbar	scatterometer_imaging	01:50:0.0	00:45:0.0	97.2	Outbound scatt scan
rbrace	standard_radiometer_outbound	02:35:0.0	03:25:0.0	12.2	Outbound radiometry scans
Total				1095.1	

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	179481	off target	0.23	off target
b	113293	off target	0.15	off target
c	111675	off target	0.14	off target
d	42938	off target	0.06	off target
e	33846	34320	0.05	269
f	21196	21959	0.03	389
g	7625	7625	0.01	883
h	4947	4947	0.01	1195
i	4435	5445	0.01	1282
j	1691	2681	0.01	2103
k	1359	1720	0.00	2280
l	1068	1068	0.00	2462
m	1073	1073	0.00	2459
n	1075	1075	0.00	2457
o	1281	1281	0.00	2326
p	1290	1290	0.00	2321
q	1294	1294	0.00	2318
r	3869	3935	0.01	1394
s	4579	4638	0.01	1256
t	4782	4782	0.01	1221
u	4801	4801	0.01	1218
v	4811	4811	0.01	1217
w	7501	7501	0.01	894
x	10644	off target	0.02	off target
y	15382	16441	0.02	507
z	24112	24738	0.03	350
lbrace	27355	28464	0.04	316
vbar	33846	34198	0.05	268
rbrace	48458	48462	0.06	216

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

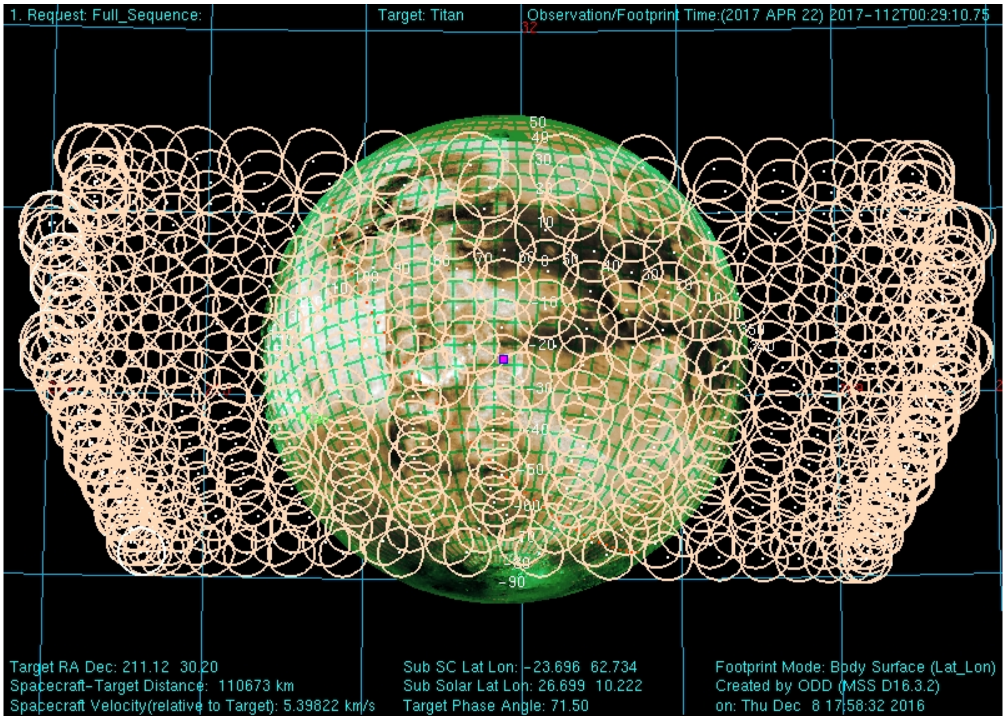

Figure 1: Inbound Radiometer Scan of Titan.

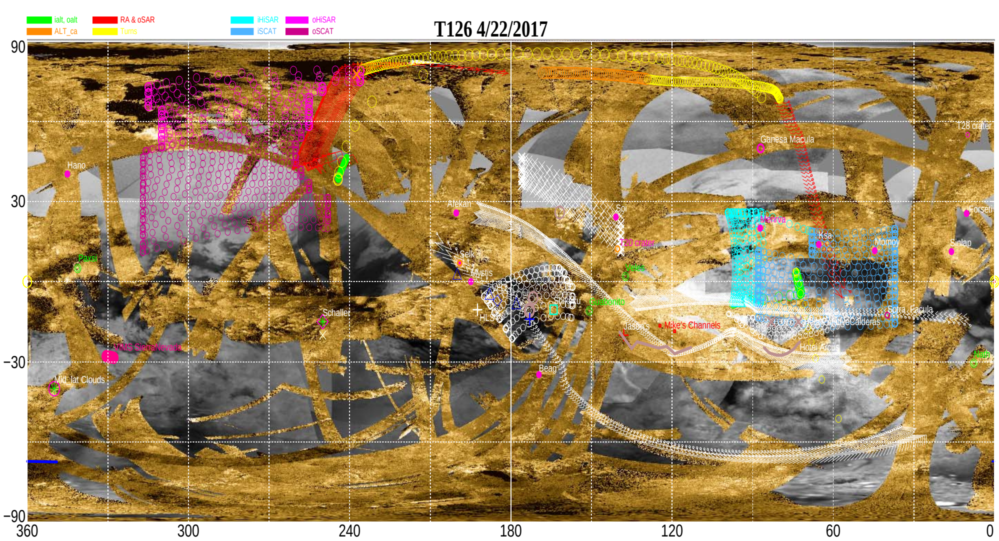

Figure 2: Coverage areas overlaid on Titan map showing prior optical and radar imaging.

Name	Nominal	Actual	Mismatch	Comments
mode	altimeter	altimeter	no	
start_time (min)	19.0	2.5	yes	2.5 - start of c/a track
end_time (min)	30.0	4.4	yes	4.4 - end of c/a track
time_step (s)	don't care	30.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	7	7	no	7 - 8 to 4
csr	8	0	yes	0 - fixed attenuator to avoid saturation
noise_bit_setting	2.0	-2.1	yes	-2.1 - 62 dB attenuation
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	220.000	yes	220 - highest rate possible
interleave_flag	on	on	no	
interleave_duration (min)	varies	5.0	no	

Table 4: t126 Div n standard_altimeter_outbound block

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	80.0	no	
end_time (min)	varies	90.0	no	
time_step (s)	varies	50.0	no	
bem	00100	00100	no	
baq	0	0	no	8-2 used to increase looks and duty cycle - hence SNR
csr	0	0	no	0 - fixed attenuator
noise_bit_setting	4.0	4.0	no	9 dB attenuator
dutycycle	0.35	0.55	yes	0.55 - stay under limits
prf (Hz)	1000	-1	yes	-1 signals ambiguity optimization for imaging
tro	6	6	no	
number_of_pulses	100	0	yes	0 signals to fill the 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	60.000	yes	60 - using available data volume
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 5: t126 Div z scatterometer_imaging block

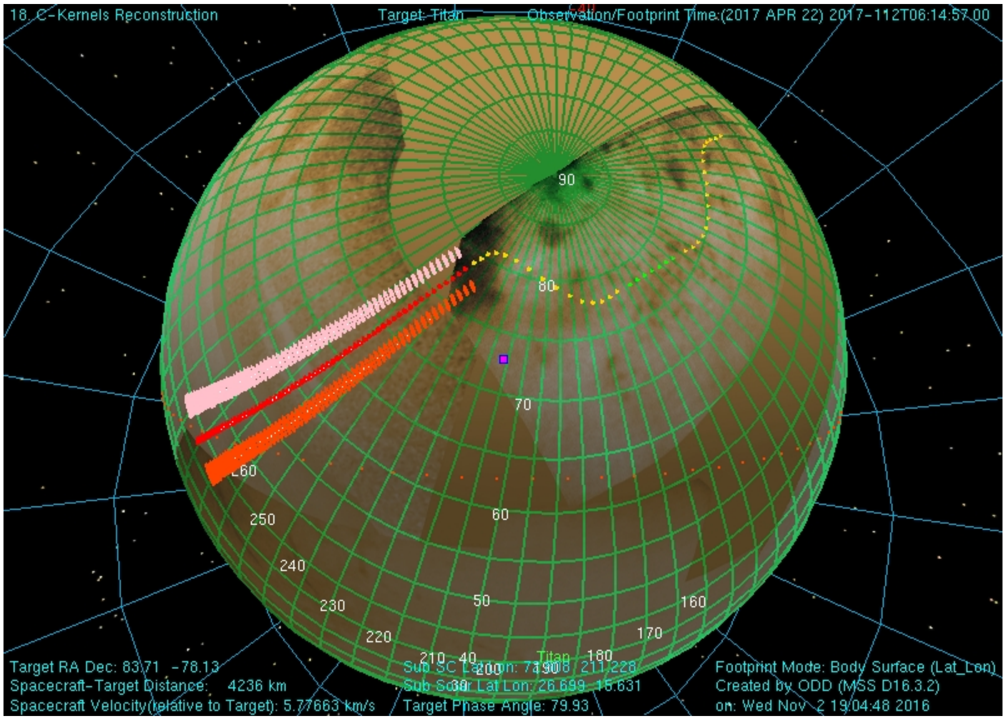

Figure 3: Beam 3 boresight (yellow triangles) during the close approach altimetry track and associated turns, and outbound SAR imaging swath (red and violet symbols) shown on Titan north polar map.

4.1 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 4 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 and during the close approach altimetry segment.

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.

5 Revision History

1. Apr 12, 2018: Final release

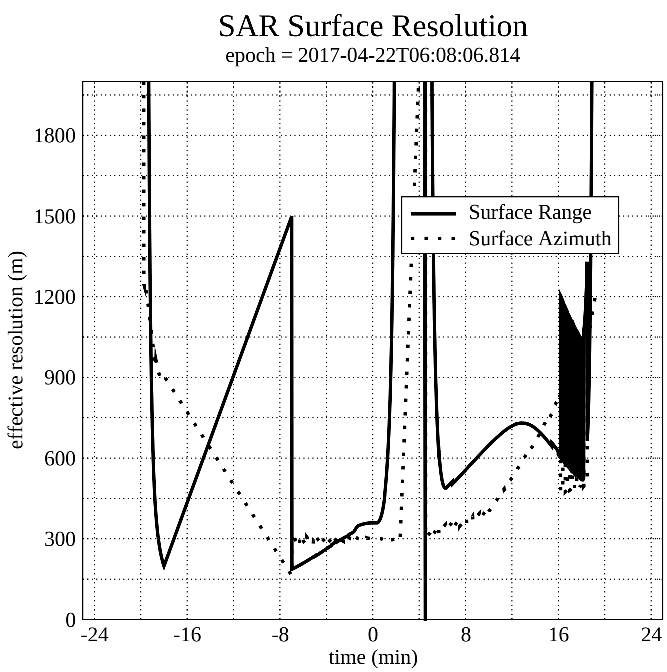

Figure 4: SAR projected range and azimuth resolution. These values are computed from the IEB parameters and are not related to the pixel size in the BIDR file. The pixel size was selected to be always smaller than the real resolution.

6 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