RADAR Titan Flyby during S30/T30

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- Sequence: s30
- Rev: 044
- Observation Id: t30
- Target Body: Titan
- Data Take Number: 131
- PDT Config File: S30_ssup_ssg_070226_pdtGH.cfg
- SMT File: s30_smt_070110.rpt
- PEF File: S30_SOPU_PORT1_070207.pef

1 Introduction

This memo describes the Cassini RADAR activities for T30 Titan flyby. This SAR data collection occurs during the s30 sequence of the Saturn Tour. This is a full radar pass. 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. Subsequent sections will show and discuss the keyword selections made for each division. Each division

CIMS ID	Start	End	Duration	Comments
044TI_T30WARMUP001_RIDER	2007-132T12:19:58	2007-132T15:19:58	03:00:0.0	Warmup for T30 inbound radiometry. REU bits included.
044TI_T30INRAD001_PRIME	2007-132T15:19:58	2007-132T18:54:58	03:35:0.0	Inbound radiometry on T30. REU bits included.
044TI_T30INSCAT001_PRIME	2007-132T18:54:58	2007-132T19:17:58	00:23:0.0	Mid latitude scatterometry of Titan, incidence angle complements T15. REU bits included.
044TI_T30INALT001_PRIME	2007-132T19:39:58	2007-132T19:53:58	00:14:0.0	Altimetry during the inbound leg of T30. REU bits included.
044TI_T30INLSAR001_PRIME	2007-132T19:53:58	2007-132T20:02:58	00:09:0.0	Low resolution SAR imaging acquired during the inbound leg of the T30 flyby. REU bits included.
044TI_T30HISAR001_PRIME	2007-132T20:02:58	2007-132T20:16:58	00:14:0.0	High resolution SAR imaging during the C/A flyby of T30
044TI_T30OTLSAR001_PRIME	2007-132T20:16:58	2007-132T20:25:58	00:09:0.0	Low resolution SAR imaging acquired during the inbound leg of the T30 flyby. REU bits included.
044TI_T30OUTALT001_PRIME	2007-132T20:25:58	2007-132T20:39:58	00:14:0.0	Altimetry during the outbound leg of T30. REU bits included.
044TI_T30OTSCAT001_PRIME	2007-132T21:03:58	2007-132T21:26:58	00:23:0.0	Mid latitude scatterometry of Titan, incidence angle complements T13. REU bits included.
044TI_T30OUTRAD001_PRIME	2007-132T21:26:58	2007-133T00:44:58	03:18:0.0	Outbound radiometry on T30. REU bits included.

Table 1: t30 CIMS Request Sequence

Division	Name	Start	Duration	Data Vol	Comments
a	Warmup	-7:50:0.0	03:05:0.0	11.0	Warmup
b	standard_radiometer_inbound	-4:45:0.0	03:26:0.0	12.3	Inbound radiometry
c	standard_scatterometer_inbound	-1:19:0.0	00:25:42.0	46.3	Inbound scatterometry raster
d	standard_scatterometer_inbound	-0:53:18.0	00:01:18.0	2.3	Inbound scatterometry raster and nadir cal
e	standard_altimeter_inbound	-0:52:0.0	00:00:6.0	0.4	Altimeter nadir cal
f	standard_sar_low_inbound	-0:51:54.0	00:00:6.0	0.7	SAR-Low nadir cal
g	standard_sar_hi	-0:51:48.0	00:00:6.0	0.7	SAR-Hi nadir cal
h	standard_altimeter_inbound	-0:51:42.0	00:19:42.0	36.6	Inbound altimetry
i	standard_altimeter_inbound	-0:32:0.0	00:12:0.0	44.6	Inbound altimetry
j	standard_altimeter_inbound	-0:20:0.0	00:20:28.0	280.0	Inbound high-rate c/a altimetry
k	standard_scatterometer_outbound	00:00:28.0	00:00:2.0	0.3	Atmospheric Probe with Chirp
l	standard_scatterometer_outbound	00:00:30.0	00:00:2.0	0.3	Atmospheric Probe with Tone
m	standard_sar_hi	00:00:32.0	00:01:58.0	27.8	Hi-SAR Turn transition, 5 beams
n	standard_sar_hi	00:02:30.0	00:13:42.0	194.0	Hi-SAR main swath
o	standard_sar_low_inbound	00:16:12.0	00:00:12.0	2.6	Low-SAR ping-pong
p	standard_sar_hi	00:16:24.0	00:00:12.0	2.8	Hi-SAR ping-pong
q	standard_sar_low_inbound	00:16:36.0	00:00:12.0	2.6	Low-SAR ping-pong
r	standard_sar_hi	00:16:48.0	00:00:12.0	2.8	Hi-SAR ping-pong
s	standard_sar_low_inbound	00:17:0.0	00:00:12.0	2.6	Low-SAR ping-pong
t	standard_sar_hi	00:17:12.0	00:00:12.0	2.8	Hi-SAR ping-pong
u	standard_sar_low_inbound	00:17:24.0	00:00:12.0	2.6	Low-SAR ping-pong
v	standard_sar_hi	00:17:36.0	00:00:12.0	2.8	Hi-SAR ping-pong
w	standard_sar_low_outbound	00:17:48.0	00:00:12.0	2.6	Low-SAR ping-pong
x	standard_sar_hi	00:18:0.0	00:00:30.0	7.1	Hi-SAR start of turn
y	standard_sar_hi	00:18:30.0	00:01:0.0	10.2	Hi-SAR turn transition to altimetry, B3 only
z	standard_altimeter_outbound	00:19:30.0	00:34:24.0	64.0	Outbound altimetry
lbrace	standard_scatterometer_outbound	00:53:54.0	00:19:18.0	48.6	Outbound scatterometry raster
vbar	standard_scatterometer_outbound	01:13:12.0	00:03:48.0	9.6	Outbound scatterometry raster
rbrace	standard_radiometer_outbound	01:17:0.0	03:18:0.0	11.8	Outbound radiometry scans
Total				832.7	

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	162885	off target	0.21	off target
b	97829	off target	0.13	off target
c	25696	off target	0.04	off target
d	16745	16791	0.02	487
e	16294	16294	0.02	499
f	16259	16259	0.02	500
g	16224	16224	0.02	500
h	16190	16190	0.02	501
i	9416	9416	0.02	789
j	5437	5437	0.01	1184
k	964	964	0.00	2686
l	965	965	0.00	2685
m	965	965	0.00	2685
n	1074	1082	0.00	2605
o	4245	4308	0.01	1392
p	4306	4368	0.01	1380
q	4367	4428	0.01	1367
r	4429	4489	0.01	1355
s	4491	4549	0.01	1343
t	4553	4610	0.01	1332
u	4615	4670	0.01	1320
v	4677	4731	0.01	1309
w	4740	4791	0.01	1298
x	4802	4852	0.01	1287
y	4960	4985	0.01	1260
z	5277	5277	0.01	1208
lbrace	16952	16952	0.02	482
vbar	23670	23810	0.03	357
rbrace	24996	25852	0.03	339

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

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

T30 has several unusual features compared to prior radar Titan flybys. The nadir track during this flyby extends into the north polar region and crosses several prior SAR swaths including T16, T17, T18, T19, T25, and T28. The T28 SAR swath was intentionally shifted to better line up with the T30 nadir track so that coincident SAR imaging and altimetry could be acquired over a majority of the SAR swath. SAR imaging is also desired on T30 to cover a target area of interest. The target area is a dark feature visible in recent ISS and VIMS data which might be a large sea. The T25 SAR swath shows large lake and sea features at the north edge of this feature, so the T30 SAR swath was pushed out to the right to cover this area. The result is a nearly even split between outbound T30 SAR imaging and inbound T30 altimetry which reaches up to the end of the T16 SAR swath overlap, but does not reach the T19 SAR swath overlap. The inbound sequence has the usual radiometry raster scans, scatterometry raster scans, and regular inbound altimetry. The inbound altimetry is continued all the way to closest approach plus about half a minute beyond. This includes a section of triple overlap with T25 and T28 SAR imaging. In this short segment (about 300 km long) SAR stereo and altimetry will both be available over the same terrain. Following the inbound T30 altimetry, the spacecraft turns to move the T30 SAR swath out over the ISS dark feature and then continues with a nominal pushbroomed SAR swath out to 18 minutes after closest approach. Following this is the usual outbound sequence of altimetry, scatterometry raster scan, and radiometry raster scans.

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 inbound altimetry, two short observations in scatterometry mode are inserted to look for echo energy coming back from the atmosphere. The very end 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 2007-05-12T12:19:58.000 (-07:49:59.8). During the warmup, the IEB will be set to collect 4-second radiometer data on all 5 beams as shown in table 4. Div's B and } cover the radiometry scans with 1-second radiometry.

5 Div's C,D, {, |: Scatterometry Raster Scans

The inbound and outbound segments have regular scatterometry raster scans (not hi-altitude imaging). The inbound scan is all at high incidence angles and uses the 9 dB attenuator throughout (div C). At the end of the scatterometry raster, the spacecraft turns to nadir pointing, and div D increases the attenuation to 15 dB for the nadir pointed scatterometry calibration measurement. The outbound scan sweeps to low incidence angles for all but the last four minutes, so the first division (div {) uses a 15 dB attenuator setting to avoid clipping, while the second division (div |) covers the last 4 minutes with the 9 dB setting. Div's C, D, { and || are shown in tables 6 and **??**

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.

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	-480.0	-470.0	yes	IEB Trigger time is usually later than this
end_time (min)	-300.0	-285.0	yes	
time_step (s)	2700.0	5400.0	yes	Used by radiometer only modes - saves commands
bem	00100	11111	yes	
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: t30 Div a Warmup block

Name	Nominal	b	rbrace	Mismatch	Comments
mode	radiometer	radiometer	radiometer	no	
start_time (min)	-300.0	-285.0	77.0	yes	
end_time (min)	-120.0	-79.0	275.0	yes	
time_step (s)	2700.0	3600.0	3600.0	yes	Used by radiometer only modes
bem	00100	00100	00100	no	
baq	don't care	5	5	no	
csr	6	6	6	no	
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	0.992	0.992	0.992	no	
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 5: t30 Div brbrace standard_radiometer_inbound block

Name	Nominal	c	d	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	-79.0	-53.3	no	
end_time (min)	varies	-53.3	-52.0	no	
time_step (s)	don't care	24.0	12.0	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 - No auto-gain, fixed attenuator set to avoid clipping
noise_bit_setting	4.0	4.0	3.0	yes	9 dB attenuator
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	30.000	30.000	no	
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 6: t30 Div cd standard_scatterometer_inbound block

6 Div's D-G: Nadir pointed Calibration

The spacecraft performs a transition from momentum wheel to thruster attitude control at higher ranges just outside of the altimeter segments. During this time, the -Z axis (high gain antenna axis) is pointed at nadir. Since the altitude is relatively high (17,000 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. The scatterometer mode data is collected at the tail end of of div D which is extended down to the start of the nadir pointed time. Div's E-G then collect data in the altimeter, SAR-Low, and SAR-Hi modes. These division parameters are shown in table 8, table 9, and table 10. 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 6 seconds worth of data which yields 24 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.

7 Div's H-J: Altimetry

The parameters used by the main altimeter segments are shown in table 11. Divisions H and I cover the usual bonus altimetry during the wheel transition time, and the regular altimetry down to 5000 km altitude. Division J covers the close approach inbound altimetry which covers time normally used for SAR imaging. The pulse parameters for these

Name	Nominal	lbrace	vbar	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	53.9	73.2	no	
end_time (min)	varies	73.2	77.0	no	
time_step (s)	don't care	8.0	8.0	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 - No auto-gain, fixed attenuator set to avoid clipping
noise_bit_setting	4.0	3.0	4.0	yes	15 dB attenuator
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	42.000	42.000	yes	
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 7: t30 Div lbracevbar standard_scatterometer_outbound block

three divisions are all the same. The main difference is the data rate. During the wheel transition time, the beam footprint moves slowly so the maximum burst period (4 sec - 30 Kbps) is used here. During the regular altimetry segment, 30 Kbps is normally also used. In this data take, there is enough data volume to double this rate to 60 Kbps and provide better sampling during the lower altitude portion. The closest approach altimetry is unusual because the spacecraft motion is parallel to the surface and the beam footprint moves at up to 6 km/s. The rapid motion opens up the possibility to do doppler sharpening on this altimetry data and obtain much better along track resolution. The along track resolution is limited by the doppler spread in the beam footprint which increases up to around 3 kHz. The 5 kHz PRF will adequately sample this, but the data rate must be increased to SAR levels to get enough looks. The altimeter mode fills more of the science data buffer so the actual data rate limit of 228 Kbps is a little lower than the SAR limit of 238 Kbps.

8 Div's K,L: Atmospheric Probe

Targetting of the nadir track ends at 30 seconds 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 L (see table 13) provides the cleanest data and the best detection threshold. If a signal is detected with div L, then div K (see table 12) provides a follow up observation with some range resolution that could discriminate the height extent of the scattering atmospheric layers.

In div L, 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

Name	Nominal	Actual	Mismatch	Comments
mode	altimeter	altimeter	no	
start_time (min)	-30.0	-52.0	yes	
end_time (min)	-19.0	-51.9	yes	
time_step (s)	don't care	2.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	7	5	yes	8 bits straight
csr	8	0	yes	0 - No auto-gain, fixed attenuator set at typical value
noise_bit_setting	2.3	3.2	yes	30 dB attenuator
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	set to produce several bursts within 6 seconds
interleave_flag	on	on	no	
interleave_duration (min)	varies	0.0	no	

Table 8: t30 Div e standard_altimeter_inbound block

Name	Nominal	Actual	Mismatch	Comments
mode	sarl	sarl	no	
start_time (min)	-19.0	-51.9	yes	
end_time (min)	-6.0	-51.8	yes	
time_step (s)	don't care	10.0	no	Set by valid time calculation
bem	11111	00100	yes	
baq	0	5	yes	8 bits straight
csr	8	0	yes	0 - No auto-gain, fixed attenuator set at typical value
noise_bit_setting	3.0	2.9	yes	22 dB attenuator
dutycycle	0.70	0.50	yes	
prf (Hz)	don't care	2300	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	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	255.000	110.000	yes	set to produce several bursts within 6 seconds
interleave_flag	on	off	yes	
interleave_duration (min)	varies	10.0	no	

Table 9: t30 Div f standard_sar_low_inbound block

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	-6.0	-51.8	yes	
end_time (min)	6.0	-51.7	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	8 bits straight
csr	8	0	yes	0 - No auto-gain, fixed attenuator set at typical value
noise_bit_setting	3.0	3.4	yes	22 dB attenuator
dutycycle	0.70	0.50	yes	
prf (Hz)	don't care	2300	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 on to preserve radiometer data during this cal
rip (ms)	34.0	34.0	no	Calculated from radiometer calibration for prior observations
max_data_rate	255.000	110.000	yes	set to produce several bursts within 6 seconds
interleave_flag	on	off	yes	
interleave_duration (min)	varies	10.0	no	

Table 10: t30 Div g standard_sar_hi block

Name	Nominal	h	i	j	Mismatch	Comments
mode	altimeter	altimeter	altimeter	altimeter	no	
start_time (min)	-30.0	-51.7	-32.0	-20.0	yes	
end_time (min)	-19.0	-32.0	-20.0	0.5	yes	
time_step (s)	don't care	14.0	10.0	10.0	no	Set by valid time calculation
bem	00100	00100	00100	00100	no	
baq	7	7	7	7	no	7 - 8 to 4
csr	8	8	8	8	no	8 - auto gain
noise_bit_setting	2.3	3.2	2.3	2.3	yes	
dutycycle	0.73	0.73	0.73	0.73	no	
prf (Hz)	5000	5000	5000	5000	no	
tro	don't care	-6	-6	-6	no	auto set to -6 except interleaved bursts where +6 is used
number_of_pulses	21	21	21	21	no	
n_bursts_in_flight	1	1	1	1	no	
percent_of_BW	100.0	100.0	100.0	100.0	no	
auto_rad	on	on	on	on	no	
rip (ms)	34.0	34.0	34.0	34.0	no	
max_data_rate	30.000	31.000	62.000	228.000	yes	
interleave_flag	on	on	off	on	yes	
interleave_duration (min)	varies	10.0	8.0	10.3	no	

Table 11: t30 Div hij standard_altimeter_inbound block

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	0.5	no	
end_time (min)	varies	0.5	no	
time_step (s)	don't care	10.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	8 bits straight
csr	0	0	no	0 - No auto-gain, fixed attenuator set for noise like data
noise_bit_setting	4.0	4.0	no	9 dB attenuator
dutycycle	0.70	0.50	yes	0.5 (allow for segmentation of atmospheric echoes)
prf (Hz)	1200	1200	no	
tro	6	2	yes	2 (one empty pri before surface echo to see atmospheric return)
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	140 Kbps - high rate to get many bursts for averaging
interleave_flag	off	off	no	
interleave_duration (min)	don't care	6.8	no	

Table 12: t30 Div k standard_scatterometer_outbound block

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	0.5	no	
end_time (min)	varies	0.5	no	
time_step (s)	don't care	10.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	8 bits straight
csr	0	0	no	0 - No auto-gain, fixed attenuator set for noise like data
noise_bit_setting	4.0	4.0	no	9 dB attenuator
dutycycle	0.70	0.73	yes	
prf (Hz)	1200	1000	yes	
tro	6	6	no	6 (need echo time before surface echo to see atmospheric return)
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	140 Kbps - high rate to get many bursts for averaging
interleave_flag	off	off	no	
interleave_duration (min)	don't care	6.8	no	

Table 13: t30 Div l standard_scatterometer_outbound block

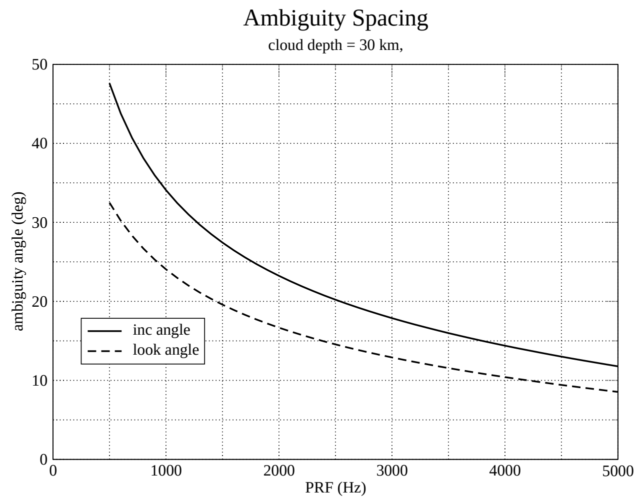

Figure 1: Range ambiguity spacing during the chirped atmospheric probe experiment (div K). This plot shows the incidence and look angles at the first range ambiguity from the center of the atmospheric scattering cloud assumed to be 30 km thick. Higher PRF's increase the spacing of range ambiguities and increase the incidence and look angles.

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 965 km and the noise equivalent normalized backscattering cross-section for a single pulse is -45 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 -51 dB. Multiplying by the cross-sectional area of the beam yields a radar cross-section of about 230 m^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 L, then div K provides some follow up with a full chirp transmission that provides about 1.6 km of range resolution. The noise floor is higher than the tone transmission because the full scatterometer mode bandwidth is used. The round trip time allows 4 pulses to be transmitted if the TRO is set to 2 and the PRF to 1200 Hz. With multiple pulses in the air, there will be range ambiguities that will also limit the detection threshold in this mode. The duty cycle is set to 0.5 to ensure adequate time domain separation of the echoes including the atmospheric segment. The scattering portion of the atmosphere is expected to lie in the first 30 km above the surface, so the single PRI of echo window time is still adequate to cover the atmospheric signal. Different processing options can be tried with this data. The division parameters are chosen to provide the most flexibility and the best detection threshold within the limits imposed by range ambiguities, thermal noise, and range compression sidelobes. The transmitted chirp is reduced to 90 percent of the usual 106 kHz because of the high doppler rate around closest approach. With a nominal scatterometer chirp of 106 kHz, the doppler shift changes enough within one second to cause frequency domain clipping. Since IEB instructions can only be issued once per second, it isn't possible to track the doppler change with a full chirp. To avoid the calibration issues that come with clipped data, we have reduced the chirp so that the entire chirp is always captured. The resulting degradation of range resolution from 1.4 km to 1.6 km should not have much adverse impact on this experiment. This issue does not arise with SAR data collections becuase the SAR modes have higher bandwidth and more doppler margin in absolute terms.

Fig. 1 shows how range ambiguity spacing is affected by the choice of PRF in div K. Lower PRF values increase the spacing of range ambiguities and lower their impact on the visibility of the atmospheric signal. In practise, look angles above a few degrees, and incidence angles above 20 degrees for the first range ambiguity have already achieved most of the benefit from the fall-off in the antenna pattern and in the surface backscattering model function. Thus, the choice of PRF is not tightly constrained. 1 kHz is used because it is the lowest PRF value that still allows the maximum pulse dutycycle of 0.7 to be maintained. This should provide the best possible SNR.

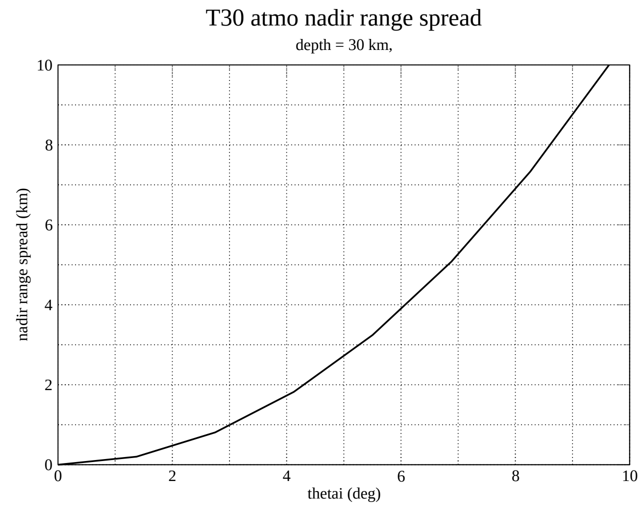

Figure 2: Range spread between the nadir point and the boresight intercept point as a function of incidence angle at the boresight intercept. This shows how surface clutter contaminates more of the lowest atmosperic range bins as the spacecraft turns away from nadir pointing.

Fig. 2 shows how the range spread between the nadir point and the boresight varies as the boresight incidence angle increases. It only takes a few degrees to shift the nadir point ambiguity into the lowest range bins (1.6 km spacing). This is the reason for conducting the atmospheric probing experiment at the very end of the nadir pointed altimeter track rather than during the turn to SAR swath pointing.

9 Div's M-Y: SAR Imaging

Div's M and Y cover the turn transitions. Div M uses all 5 beams and the full data rate because the turn transition in the north polar region is of special interest. Div Y uses beam 3 only imaging. The data rate in div Y has been reduced to 50 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 at the end. Div's O-W 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.

Targetting of the outbound pushbroom profile ends at +18 minutes. Table 14 shows the standard Hi-SAR divisions, table 15 shows two representative Low/Hi-SAR ping pong divisions, and table 16 shows the B3 only Hi-SAR division at the end. The right look option is selected here to produce a swath that will overlap the ISS dark feature which may be a sea associated with liquid bodies seen in T25.

9.1 PRF and Incidence Angle Profiles

The PRF profile and incidence angle profile (Fig. 3) 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 T30 flyby will be at 960 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. The PRF profile for this swath is reduced to 0.9 of the nominal low altitude profile. This was done to improve range ambiguity performance in the outer beam. The turn carries the swath to higher than normal incidence angles which results in higher range ambiguity levels.

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	-6.0	2.5	yes	
end_time (min)	6.0	16.2	yes	
time_step (s)	don't care	6.0	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	236.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	yes	
interleave_duration (min)	varies	10.0	no	

Table 14: t30 Div n standard_sar_hi block

Name	Nominal	o	p	Mismatch	Comments
mode	sarl	sarl	sarh	yes	
start_time (min)	-19.0	16.2	16.4	yes	
end_time (min)	-6.0	16.4	16.6	yes	
time_step (s)	don't care	6.0	6.0	no	Set by valid time calculation
bem	11111	11111	11111	no	
baq	0	0	0	no	0 - 8 to 2
csr	8	0	0	yes	8 - auto gain
noise_bit_setting	3.0	2.9	3.4	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	on	off	off	yes	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	255.000	215.000	236.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	off	yes	
interleave_duration (min)	varies	10.0	10.0	no	

Table 15: t30 Div op standard_sar_low_inbound block

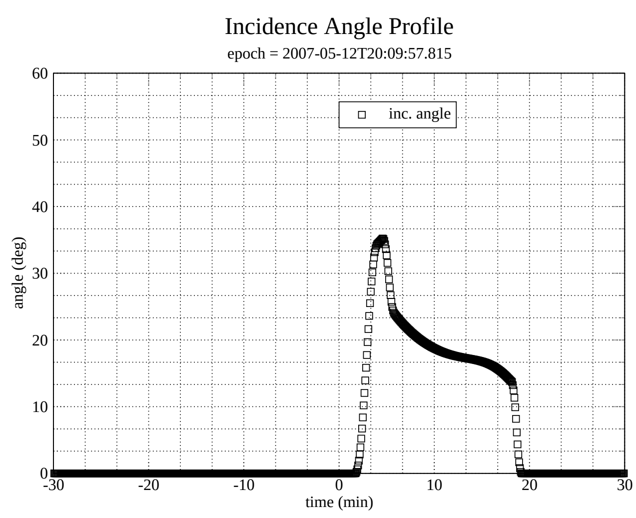

Figure 3: B3 boresight incidence angle during the time around c/a.

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	-6.0	18.5	yes	
end_time (min)	6.0	19.5	yes	
time_step (s)	don't care	6.0	no	Set by valid time calculation unless negative, then time_step is used instead
bem	11111	00100	yes	
baq	0	0	no	0 - 8 to 2
csr	8	8	no	8 - auto gain
noise_bit_setting	3.0	2.9	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	170.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	yes	
interleave_duration (min)	varies	10.0	no	

Table 16: t30 Div y standard_sar_hi block

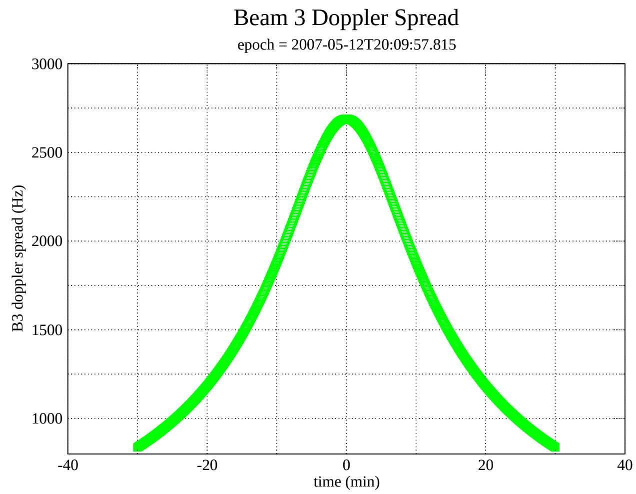

Figure 4: Nadir pointed B3 doppler spread during the time around c/a. Doppler spread is measured within the two-way 3 dB beam pattern.

9.2 SAR Resolution Performance

For all of the SAR divisions the effective resolution can be calculated from the following equations,

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

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

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

Projected range increases with decreasing incidence angle, so the range resolution varies across the swath with better resolution at the outer edge. The SAR pointing profile decreases the incidence angle as time progresses and altitude increases, so there is progressive deterioration of range resolution away from closest approach. The projected range resolution rapidly deteriorates as the incidence angle decreases toward zero at the very beginning and end of the swath.

Azimuth resolution is a function of the synthetic aperture size which is determined by the length of the receive window in each burst (assuming the receive window is always filled with echos). Azimuth resolution deteriorates less quickly because the number of pulses and the length of the receive window are increased as altitude increases which mitigates the increasing doppler bandwidth of the beam patterns. The receive window length increases to fill the round trip time until the science data buffer is filled. At this point it is no longer possible to extend the receive window, and azimuth resolution starts to deteriorate more rapidly.

10 Revision History

1. Jun 20, 2007: Fixed cfg file mismatch for PSIV delivery - minor changes
2. Apr 3, 2007: Updated for PSIV delivery - minor changes
3. Mar 15, 2007: Initial release

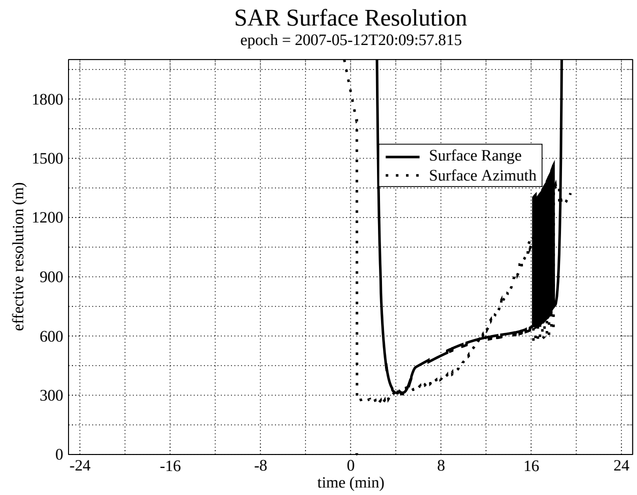

Figure 5: SAR projected range and azimuth resolution. These values are computed from the IEB parameters and are not related to the pixel size in the BIDR file. The pixel size was selected to be always smaller than the real resolution.

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