Enceladus Scatterometry Rev 156

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- Sequence: s70
- Rev: 156
- Observation Id: e16
- Target Body: Enceladus

1 Introduction

This memo describes one of the Cassini RADAR activities for the s70 sequence of the Saturn Tour. A sequence design memo provides the science context of the scheduled observations, an overview of the pointing design, and guidelines for preparing the RADAR IEB. A 3-hour warmup occurs first using the parameters shown in table 4.

2 CIMS and Division Summary

CIMS ID	Start	End	Duration	Comments
156EN_E16WARMUP001_RIDER	2011-309T22:15:00	2011-310T02:57:00	04:42:0.0	
156EN_ENCELINB001_PIE	2011-310T02:57:00	2011-310T04:19:10	01:22:10.0	SOST E16 PIE.
156EN_ENCELINB002_PIE	2011-310T04:19:10	2011-310T04:50:29	00:31:19.0	SOST E16 PIE.
156EN_ENCELCA001_PIE	2011-310T04:51:29	2011-310T05:35:53	00:44:24.0	SOST E16 PIE.
156EN_ENCELOUTB001_PIE	2011-310T05:56:58	2011-310T07:21:05	01:24:7.0	SOST E16 PIE.

Table 1: e16 CIMS Request Sequence

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.

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

Division	Name	Start	Duration	Data Vol	Comments
a	distant_warmup	-6:50:0.0	04:45:0.0	17.0	Warmup
b	distant_radiometer	-2:05:0.0	00:04:0.0	0.2	Radiometer quick-steps
c	distant_scatterometer	-2:01:0.0	00:40:30.0	72.9	Radiometer/scatterometer raster scans
d	scatterometer_imaging	-1:20:30.0	00:14:30.0	65.2	Inbound Scatt imaging, global scan, pol 1
e	scatterometer_imaging	-1:06:0.0	00:31:0.0	139.5	Inbound Scatt imaging, global scan, pol 2
f	scatterometer_imaging	-0:35:0.0	00:17:0.0	76.5	Inbound closeup Scatt imaging
g	sarl	-0:18:0.0	00:05:0.0	30.0	Inbound closeup SARL imaging
h	sarl	-0:13:0.0	00:04:48.0	28.8	Inbound closeup SARL imaging
i	distant_radiometer	-0:08:12.0	00:07:29.0	0.4	Radiometer filler during c/a setup turn
j	altimeter	-0:00:43.0	00:00:17.0	4.1	inbound C/A altimeter mode imaging
k	altimeter	-0:00:26.0	00:00:11.0	2.6	C/A altimeter mode imaging
l	altimeter	-0:00:15.0	00:00:36.0	8.6	C/A altimeter mode imaging
m	altimeter	00:00:21.0	00:00:14.0	3.4	C/A altimeter mode imaging
n	altimeter	00:00:35.0	00:00:5.0	1.2	C/A altimeter mode imaging
o	distant_radiometer	00:00:40.0	00:08:20.0	0.5	Radiometer filler during c/a departure turn
p	sarl	00:09:0.0	00:13:0.0	78.0	Outbound closeup SARL imaging
q	scatterometer_imaging	00:22:0.0	00:16:0.0	72.0	Outbound closeup Scatt imaging
r	scatterometer_imaging	00:38:0.0	00:20:0.0	90.0	Outbound closeup Scatt imaging
s	scatterometer_imaging	00:58:0.0	00:20:0.0	90.0	Outbound Scatt imaging, global scan, pol 1
t	scatterometer_imaging	01:18:0.0	00:14:30.0	65.2	Outbound Scatt imaging, global scan, pol 2
u	distant_scatterometer	01:32:30.0	00:49:30.0	89.1	Radiometer/scatterometer raster scans
v	distant_radiometer	02:22:0.0	00:08:0.0	0.5	Closing radiometry
Total				935.8	

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	243837	off target	3.17	off target
b	57335	off target	0.75	off target
c	55354	55380	0.72	1360
d	35973	off target	0.47	off target
e	29285	29310	0.38	780
f	15295	15428	0.20	508
g	7748	7790	0.10	470
h	5545	5557	0.08	532
i	3448	3519	0.05	719
j	560	off target	0.01	off target
k	520	610	0.01	3102
l	504	570	0.01	3166
m	511	587	0.01	3129
n	539	665	0.01	3019
o	551	726	0.01	2971
p	3802	3840	0.05	668
q	9529	9548	0.13	447
r	16650	16720	0.22	495
s	25647	off target	0.34	off target
t	34767	34916	0.45	757
u	41464	off target	0.54	off target
v	64805	64806	0.84	1116

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)	varies	-410.0	no	
end_time (min)	varies	-125.0	no	
time_step (s)	varies	3600.0	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	0.248	0.992	yes	Kbps - set for slowest burst period
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 4: e16 Div a distant_warmup block

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. 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 Overview

This observation is the only radar observation of an icy satellite during a close flyby. The design is symmetric about close approach with SAR imaging conducted right at closest approach, high altitude SAR imaging conducted inbound and outbound with 2 global scans at two orthogonal polarizations and one closer scan, and finally a more distant scatterometry/radiometry raster scan at higher ranges. The small size of Enceladus vs Titan (250 km radius vs 2575 km radius) and the low altitude of the flyby (500 km) posed special challenges to the pointing design and the IEB design.

3.1 Pointing Design

During a normal Titan flyby with a closest approach altitude around 1000 km, the close approach time is filled with SAR imaging and lasts about 30 minutes with about 15 minutes inbound and 15 minutes outbound. The rotation rates needed to track Titan stay within the limits of the spacecraft attitude control system which allows an optimized imaging track. With the E16 flyby, the close approach and small body size require a rotation rate that exceeds the spacecraft capabilities to track the center of the body. To stay within spacecraft constraints, we designed a different kind of imaging profile for the close approach time. The objective was to maximize the number of looks during close approach imaging by slowing down the motion of the beam footprints as much as possible. To achieve this, an inertial vector description (IVD) file was manually prepared that directed the radar boresight (-Z axis of spacecraft) at the center of Enceladus at closest approach, but rotated so that the -Z axis was deflected Southward, hitting the surface at a local incidence angle of 45 degrees. The Y-axis of the spacecraft was directed towards the Saturn pole leaving the X-axis directed approximately along the spacecraft direction of motion. A maximum rate turn on thrusters about the Y-axis was assumed and directed to reduce the speed of the beam footprints across the surface. With this pointing design, the beam footprints remained on the surface from about -45 s to +45 s with respect to the close approach time. The rotation against the spacecraft motion increased the number of looks from about 1 for inertial pointing to about 3 at closest approach.

The rapid motion of the beam footprints precluded 5-beam operation. To provide adequate looks and contiguous coverage, a single beam is used. Beam 4 which is one of the outer beams is used to obtain the widest possible swath. SNR is not a constraint because the altitude of the flyby at 500 km is much lower than typical Titan flybys at around 1000 km. The main constraint on how far South the imaging track could go was range ambiguities. The desire to use one of the outer beams to achieve a larger swath made this constraint worse. Approaching the limb on both sides, the observation switches to beam 3 to avoid worsening ambguities and allow imaging for the maximum possible time.

Outside of the close approach imaging segment, the spacecraft is slewed to perform local imaging scans that target transitional terrain in the northern hemisphere while the beam footprints are still a small fraction of the apparent disk size. At higher ranges, two more imaging scans of the entire visible disk are performed with orthogonal polarizations to collect data at moderate resolution and with polarization diversity. At still higher ranges, two raster scans extending off target and collecting just radiometer and scatterometer data are performed to provide calibration context. These scans are conducted both inbound and outbound in roughly symmetrical fashion.

4 Radiometry and Scatterometry Raster Scans

Div's C and U provide for radiometry and 8-pulse scatterometry similar to standard Titan radiometry and scatterometry scans. These distant scans go at least 3-beamwidths off target to provide radiometer cold space calibration points.

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-121.0	no	
end_time (min)	varies	-80.5	no	
time_step (s)	don't care	2.0	no	Used when BIF > 1, otherwise set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	
csr	0	0	no	0 - Normal Operation, 8 - with auto-gain
noise_bit_setting	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.70	no	
prf (Hz)	varies	1200	no	Set to cover target doppler bandwidth
tro	6	6	no	6 - allows for some noise only data in time domain
number_of_pulses	varies	8	no	depends on PRF choice (can have more shorter pulses)
n_bursts_in_flight	varies	1	no	Used to increase PRF and data rate at long range
percent_of_BW	0.0	100.0	yes	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	200.000	30.000	yes	Kbps - determines burst period
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 5: e16 Div c distant_scatterometer block

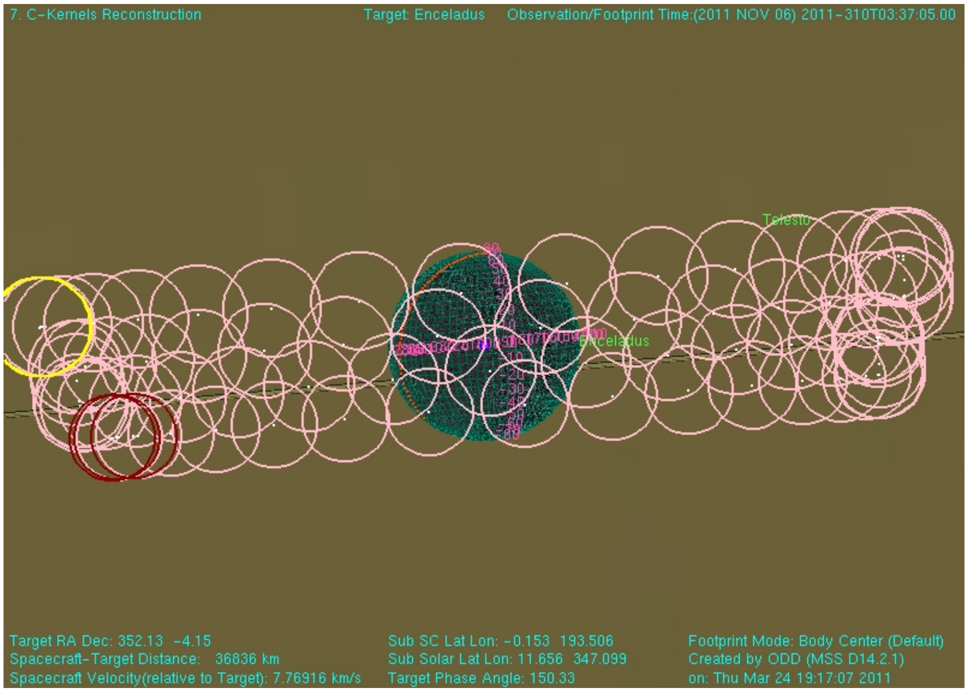

Figure 1: Beam 3 footprint during the second inbound radiometry/scatterometry scan. These scans provide calibration context for the later imaging scans.

5 High Altitude Scatterometer Imaging

Div's D and E provide for high altitude scatterometer mode imaging during the global scans. Fig. 2 shows the second inbound scan to illustrate the pointing design. A fixed PRF is used here to save on instructions while the geometry is changing slowly.

As the range decreases, the beam footprints shrink and a more focussed regional imaging scan is performed as shown in Fig. 3. Div's F,G, and H provide for scatterometer and lo-sar mode imaging during the close up scan. The PRF value of -1 indicates that an automatic PRF algorithm is used to optimize range and doppler ambiguities during this period of quickly varying geometry.

After the close up scan, division I puts the radar into radiometer mode to save data volume while the spacecraft slews off target to setup for the close approach imaging pass. The outbound side of the observation performs the same sequence in reverse (Div's O-T).

The high altitude imaging segments are designed to optimize range-doppler ambiguities, resolution, number of looks and noise-equivalent cross-section. These segments 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 in the 2 km range. For more technical details on range and doppler ambiguities, refer to the discussion in the T19 sequence design memo.

6 Close Approach Imaging

Div's J-N provide for high resolution imaging using the altimeter mode. Titan flyby's always use the hi-sar (1 MHz bandwidth) mode which provides an optimal balance between range and azimuth resolution and SNR in the 1000-4000 km ranges that are typical. The E16 flyby is much lower at an altitude of 500 km, and the altimeter mode (5 MHz bandwidth) provides a better tradeoff here. The short range means that the hi-sar mode would fill the data buffer before

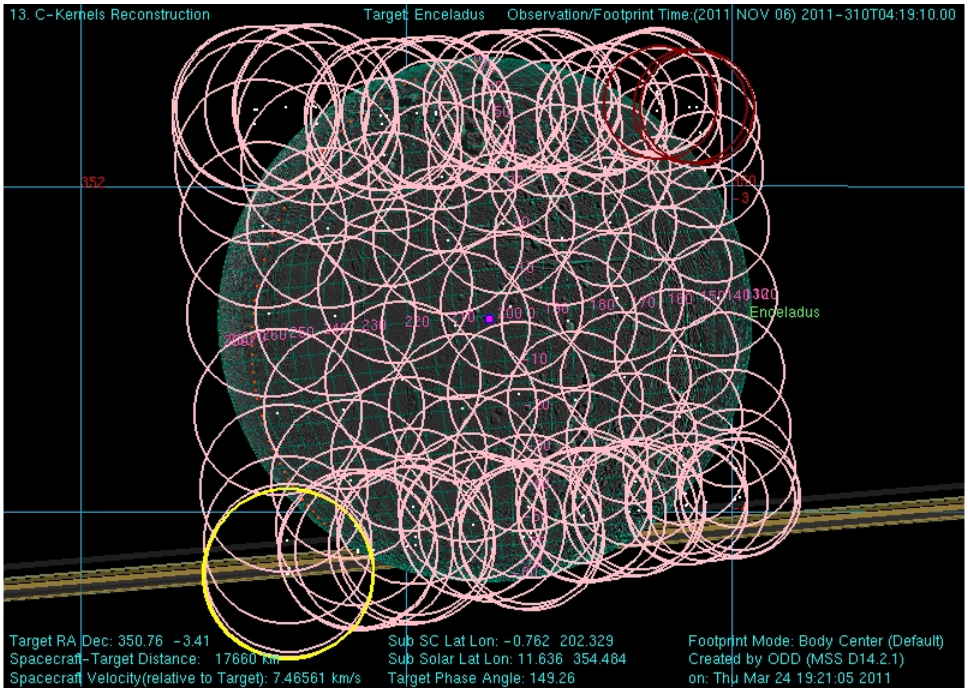

Figure 2: Beam 3 footprint during the second inbound global imaging scan. These scans are done in scatterometer mode and provide moderate resolution imaging of the entire visible disk. Scan is repeated with orthogonal polarization to provide polarization diversity.

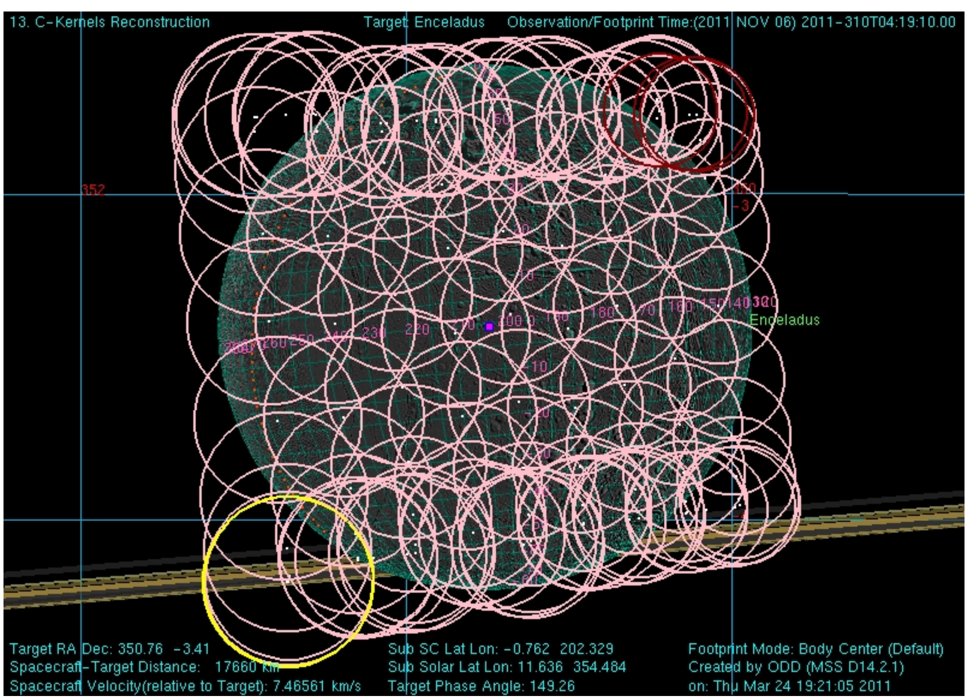

Figure 3: Beam 3 footprint during the second inbound global imaging scan. These scans are done in scatterometer mode and provide moderate resolution imaging of the entire visible disk. Scan is repeated with orthogonal polarization to provide polarization diversity.

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-80.5	no	
end_time (min)	varies	-66.0	no	
time_step (s)	varies	30.0	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	Noise like setting for scatt
dutycycle	0.35	0.35	no	
prf (Hz)	1000	1100	yes	1000 Hz is typical, set to balance range/doppler ambiguities
tro	6	6	no	
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	75.000	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 6: e16 Div d scatterometer_imaging block

Name	Nominal	Actual	Mismatch	Comments
mode	unknown	sarl	yes	
start_time (min)	unknown	-18.0	yes	
end_time (min)	unknown	-13.0	yes	
time_step (s)	2700.0	25.0	yes	
bem	00100	00100	no	
baq	don't care	0	no	
csr	6	8	yes	
noise_bit_setting	don't care	3.5	no	
dutycycle	don't care	0.70	no	
prf (Hz)	don't care	-1	no	
tro	don't care	0	no	
number_of_pulses	don't care	0	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	100.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 7: e16 Div g sarl block

the round trip time limit is reached, so azimuth resolution would be worse. Using altimeter mode provides exceptional resolution as shown in Fig. 4.

6.1 Resolution Calculation

Since SAR processing will be applied to this segment, the effective resolution can be calculated from the 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 4 shows the results from these equations for the central altimeter imaging time. The calculations are performed for the boresight of beam 4 which is the center of the swath.

7 Revision History

1. Oct 17, 2012: Final Release

Name	Nominal	Actual	Mismatch	Comments
mode	unknown	altimeter	yes	
start_time (min)	unknown	-0.2	yes	
end_time (min)	unknown	0.3	yes	
time_step (s)	2700.0	2.0	yes	
bem	00100	01000	yes	01000 use beam 4 for c/a to hit target swath
baq	don't care	0	no	
csr	6	8	yes	
noise_bit_setting	don't care	2.3	no	
dutycycle	don't care	0.70	no	
prf (Hz)	don't care	6500	no	
tro	don't care	-6	no	
number_of_pulses	don't care	0	no	
n_bursts_in_flight	don't care	1	no	
percent_of_BW	don't care	100.0	no	
auto_rad	off	off	no	
rip (ms)	34.0	34.0	no	
max_data_rate	1.000	240.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 8: e16 Div l altimeter block

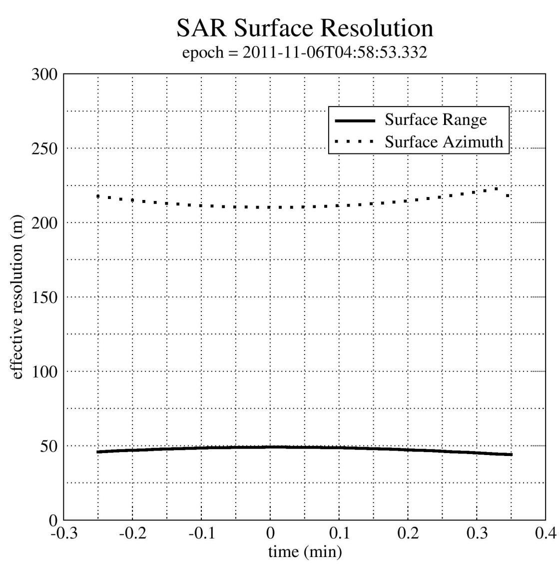

Figure 4: Close approach altimeter mode imaging projected range and azimuth resolution. These values are computed from the IEB parameters.

8 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