Processing of altimetric data of CASSINI mission

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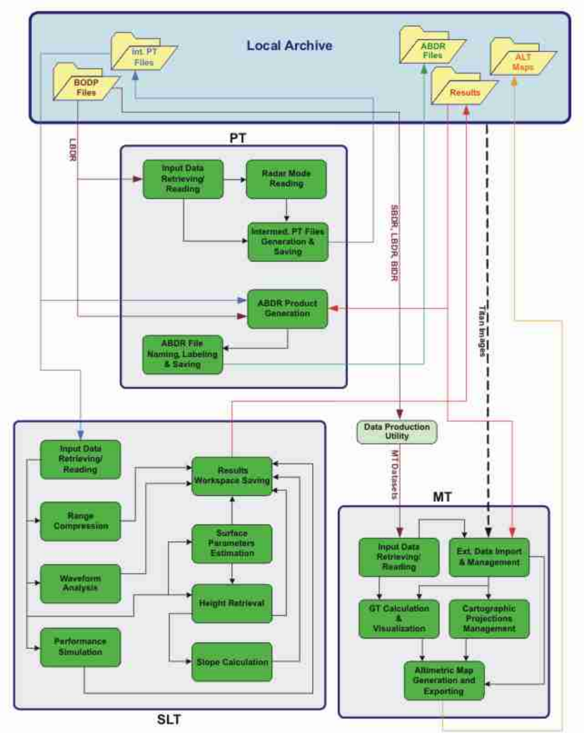
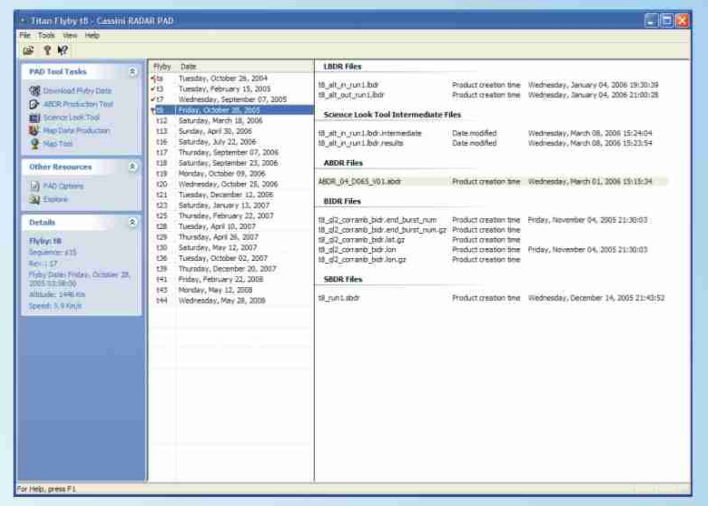
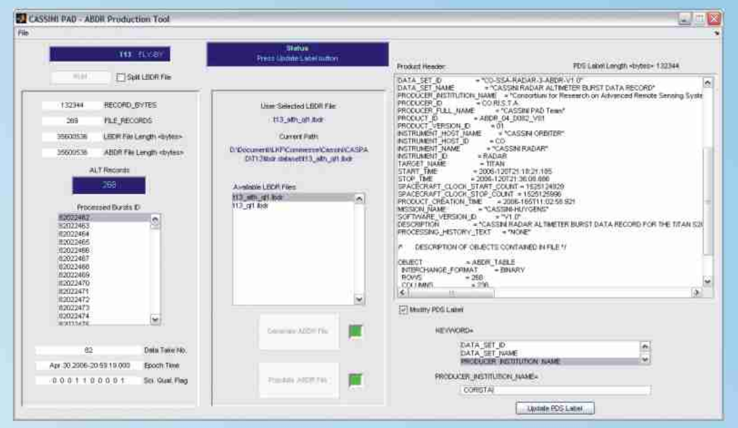
PAD Tools Architectural Design





PAD Framework

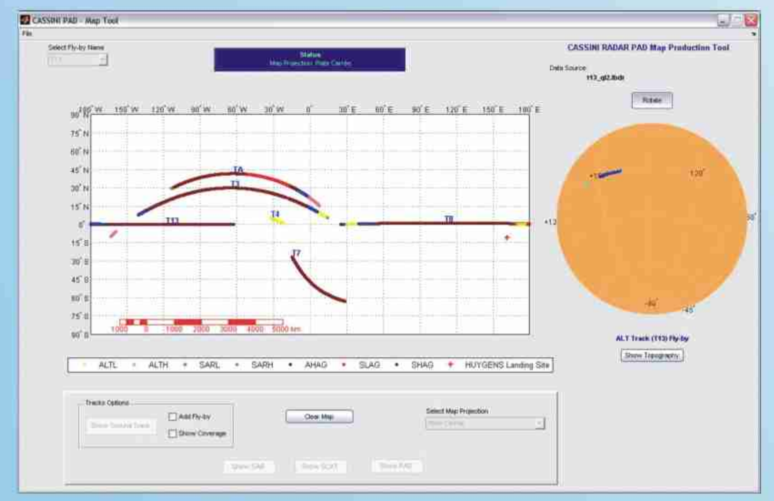
The main functionality of the PAD Framework software is to give users a global vision of the status of all the operations that can be made on the BODP files within the Cassini Radar PAD. It provides easy access to all system functionalities. Users can select the flyby to operate and start any operation available for the processing of telemetry files.



ABDR Production Tool

The off-line ABDR Production Tool (PT) retrieves the input LBDR files by managing a list of LBDR files locally stored, allowing user to select the input file (see Figure 4, showing an example of PT GUI). After interactive selection of the LBDR file to be processed, the tool proposes to start the creation of subsets of the input LBDR product (intermediate PT Files) each containing only data records pertinent to one of the *active* Cassini Radar operational modes, i.e. Altimeter, SAR and Scatterometer mode. These files are created for internal use and stored into the local archive in both binary and ASCII format, in order to be accessed by SLT.

The PT allows user to perform the generation of the ABDR product starting from the selected LBDR file. Moreover, user is allowed to interactively modify selected keywords into ABDR PDS label.
An ABDR file is produced which contains records for only the two periods (one inbound, one outbound) in which the radar is in altimeter mode, by filling in automatically all the appropriate data fields in the Science Data Segment with the values obtained from SLT processing, and by filling the end of each record in the LBDR file with the values resulting from range compression of sampled echoes data counts (i.e. the altimeter profile), starting from SLT results files. When LBDR processing is terminated, the ABDR PT stores the new file into the local archive along with a report file. Data contained into the ABDR product shall be validated by using SLT functionalities, before submission to the local file server.



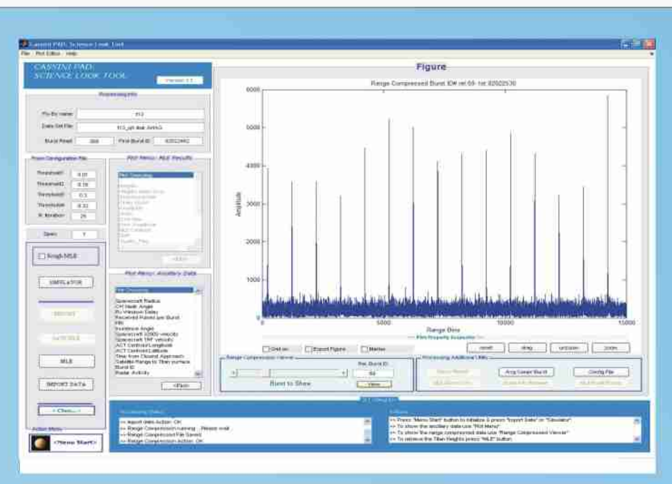
Map Tool

The off-line PAD Map Tool (MT) is a graphical application that allows users to visualize and navigate through Titan's 2D and 3D maps, finalized to the analysis of their informative content, as immediate instrument of interpretation of scientific data (see Figure 6, showing an example of MT GUI). From the point of view of scientific surveying, altimetric maps could be confronted and joined with maps obtained by radiometric surveys and with the analysis made by other instruments onboard the Cassini Spacecraft, in order to provide a global vision, as far as it is possible, of the characteristics of Titan's surface.

The purpose of MT is the production of altimetric regional maps obtained by visualization of sub-satellite ground-tracks and overlapping of data collected along tracks to a pre-existent map of Titan, over the region illuminated by the Cassini Radar in high-resolution ALT mode, for each Titan fly-by. Hence, Titan's maps represent the final results of data processing. The realization of the altimetric map can be accomplished by referencing the radar altimetry profile with respect to the surface of Titan.

The Titan's altimetric maps are generated starting from SBDR, LBDR and BIDR data files, and from output data produced by the SLT (e.g. the topographic profile with information about the surface slope, etc.) which could be superimposed to referenced images of Titan surface in a given projection. The content of SBDR, LBDR and BIDR data files is extracted by means of a *Data Production Utility*, which saves all relevant information needed to produce MT datasets (map internal files) containing satellite geometry, Scatterometer, Radiometer and SAR data, which becomes then available to Map Tool for visualization.

The SLT output data needed to MT procedures execution are retrieved from the local archive or database. Titan's images (e.g. Mercator albedo maps from HST, ESO, etc, images acquired by optical observation by the Cassini ISS, etc.) to be used as map background, shall be made available, for example by the Cassini Ground System at JPL/NASA, and shall be also stored in the local database. All maps produced by the Map Tool are stored into the local archive, for further distribution.



Science Look Tool

The off-line Science Look Tool (SLT) is in charge to perform the altimetric processing. It is a graphical application including procedures and algorithms designed to check and simulate the performances of the Cassini Radar Altimeter through calculation, visualization and plotting of relevant parameters (see Figure 5, showing an example of SLT GUI). The SLT uses an intermediate BODP file produced by the ABDR Production Tool, stored into the local archive, and it automatically performs range compression of sampled data.

The SLT evaluates the altimeter profile range start, altimeter profile range step and altimeter profile length required for the PT ABDR production functionality, starting from compressed data. Each compressed burst is typically constituted of 15 chirp pulses. In order to reduce the speckle, a single pulse is obtained by averaging all the received pulses within the burst. Hence, each compressed burst becomes an array containing only one averaged pulse-compressed echo. The averaged bursts are stored into internal memory as bi-dimensional arrays.

The range compressed data are used to perform waveform analysis and final altitudes estimate by using different altimetry models previously implemented. In addition, the tool permits user to simulate the performances of the Cassini Radar Altimeter, thus allowing obtaining a complete analysis of ALT data from a scientific perspective.

In order to infer the significant geophysical parameters describing the surface's topography from the altimetry data, a Maximum Likelihood Estimator (MLE) has been implemented to be enclosed in the developed algorithm. The Maximum Likelihood Estimator algorithm is based on fitting averaged bursts with a theoretical model describing the Radar Impulse Response. The algorithm is able to select automatically which is the best theoretical model to be used during the processing. The selection is based on threshold criteria related to the current value of the off-nadir angle, in order to cope with the expected occurrence of near-nadir measurements along the hyperbolic trajectory followed during the flyby. All the performances have been numerically evaluated: this method ensures the best fitting of data, thus reducing the errors in heights estimation.

The SLT Tool allows users to specify the default processing parameters by using a Configuration File containing:

- threshold values for off-nadir angles
- minimum number of MLE iterations
- first attempt values
- thresholds for MLE Error Reducing Procedure, etc.

The SLT provides several auxiliary functionalities that allow the user to obtain the complete monitoring of both processing and results. On user request, the SLT provides 2-D or multi-plots of S/C and Radar ancillary data, processing results and algorithm configuration. All the results can be exported (i.e. printed/saved) by user. In addition, on user request, a report file in xml format is generated containing all the results produced by the SLT, e.g. relevant processing parameters, MLE procedure results, relative elevations of Titan's surface vs. along-track distance (i.e. topographic profiles), altimeter waveforms vs. range bins, ancillary data (e.g. observation geometry and orbital parameters vs. time, instrument data, etc.), surface parameters vs. along-track distance, etc. It will be used by scientists for further validation of data, which is propaedeutical to ABDR production.

Altimetry models :

- Nadir Model
- Off-Nadir Model derived by using Brown's Asymptotic form for PFS function
- Off-Nadir Model derived by using Prony's method to approximate the PFS function

For small off-nadir pointing angles the followed approach entails the approximation of the flat surface response by a series of exponentials using the Prony's method: for each exponential term in the series, the convolution can be integrated in closed form to yield a rather simple function of exponentials

$$IR(\tau)=\sum_{i=1}^{N} IR_i \Longleftrightarrow IR_i(\tau)=C_i \exp[-K_a\tau]\exp[K_i\tau]*\exp[-K_C\tau^2]$$

For high off-nadir pointing angles, the PFS can be evaluated asymptotically by using the Laplace's method and, since the surface height distribution and the pulse response are very narrow with respect to the flat surface response, the IR can be simply written as the product of the following terms

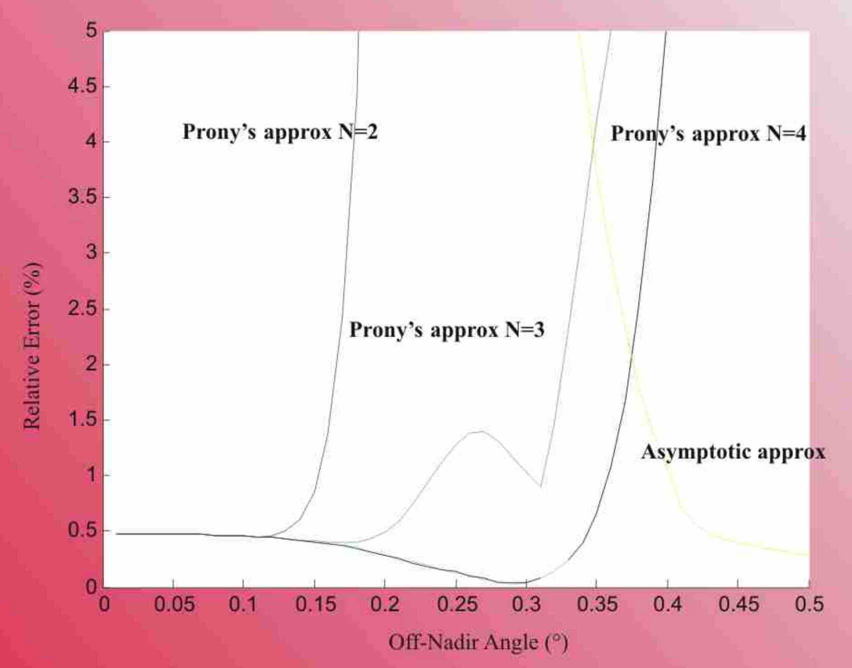
$$IR(\tau)\big|_{\xi\neq 0}=P_{FS}(\tau)\cdot\sigma_P\left[1+erf\left(\frac{\tau}{\sqrt{2}\sigma_C}\right)\right]=$$

$$=A\sigma^0\exp\left(-\frac{4}{\gamma\left(1+\varepsilon^2\right)}(\sin\xi-\varepsilon\cos\xi)^2\right)\cdot\sqrt{\frac{2\pi}{a+2b}}\cdot\sigma_P\left[1+erf\left(\frac{\tau}{\sqrt{2}\sigma_C}\right)\right]\quad \tau\geq 0$$

The system Impulse Response can be evaluated by convolution of PFS with height probability density function and system point target response assuming gaussian distribution and constant backscattering coefficient within antenna footprint:

$$\begin{cases} P_h(\tau)=\dfrac{1}{\sqrt{2\pi}\sigma_h}\dfrac{c}{2}\exp\left(-\dfrac{\tau^2}{2\sigma_h^2}\dfrac{c^2}{4}\right) \\ P_p(\tau)=\dfrac{P_T T}{\sqrt{2\pi}\sigma_p}\exp\left(-\dfrac{\tau^2}{2\sigma_p^2}\right)\end{cases}$$

$$IR(\tau)\big|_{\xi=0}=K\sigma^0\frac{1}{2}\sqrt{\frac{\pi}{2}}\exp\left(\frac{\delta^2}{2}\right)\exp\left(-\frac{\delta}{\sigma_C}\tau\right)\left[1+erf\left(\frac{\tau}{\sqrt{2}\sigma_C}-\frac{\delta}{\sqrt{2}}\right)\right]$$



Altimetric profiles for TA, T3 and T16 Titan's flybys flown respectively on 26 Oct. 2004, 15 Feb. 2005, 22 July 2006