

**PLANETARY ORBITAL RADAR PROCESSING AND SIMULATION SYSTEM.** M.R. Perry (mperry@psi.edu)<sup>1</sup>, D. C. Hickson<sup>2</sup>, G. A. Morgan<sup>1</sup>, M.B. Russell<sup>1</sup>, F. J. Foss II<sup>3</sup>, G.M. Nelson<sup>1</sup>, P.C. Sava<sup>3</sup>, B.A. Campbell<sup>4</sup>, A.J. Kopf<sup>5</sup>, and N.E. Putzig<sup>1</sup>. <sup>1</sup>Planetary Science Institute, Lakewood, CO 80401, <sup>2</sup>Colorado School of Mines, <sup>3</sup>Freestyle Analytical and Quantitative Services, LLC, <sup>4</sup>Smithsonian Institute, <sup>5</sup>U.S. Naval Observatory.

**Introduction:** The Planetary Orbital Radar Processing and Simulation System (PORPASS) will revolutionize the processing and simulation of planetary orbital radar sounding data by bringing the typically esoteric subject into a more public sphere. Although orbital radars have added greatly to our understanding of planetary surfaces and subsurfaces, processing of raw radar data is often poorly documented and difficult to implement, leaving researchers to rely on results from standardized processing pipelines (e.g., products stored on the Planetary Data System (PDS) or equivalent archives) that may not be well-suited to specific scientific goals. This situation, combined with a lack of publicly available radar processors, means that the processing of radar data has been largely limited to instrument teams or radar scientists who are intimately familiar with orbital radar datasets, limiting the number of potential collaborations and isolating the field.

The overarching goal of PORPASS is to enhance mission legacy by providing custom processing and analysis of planetary radar datasets beyond the life of any particular mission, ensuring data and code longevity and relevance as well as opening the door to the next generation of researchers. PORPASS will facilitate and strengthen current and future scientific investigations that use planetary radar data, provide an avenue for citizen science and education endeavours, and enable greater collaboration and understanding within the planetary science community.

*Long-term vision:* The long-term vision for PORPASS is to develop an expansive system that incorporates disparate datasets spanning a variety of radar instrumentation. This development plan will be carried out in four stages. Stage 1 (presently funded) will establish PORPASS and start separating custom processing and simulation of orbital radar data from mission funding, beginning with data from the Mars Reconnaissance Orbiter (MRO) Shallow Radar (SHARAD), Mars Express (MEx) Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS), and Selenological and Engineering Explorer (Selene) ‘Kaguya’ Lunar Radar Sounder (LRS). Stage 2 will expand the scope of PORPASS by incorporating processing and simulation capabilities for Cassini RADAR, Lunar Reconnaissance Orbiter (LRO) Mini-RF, and Magellan planetary radar imaging data. Stage 3 will further expand the scope of PORPASS by incorporating processing and simulation capabilities of Earth-based telescopic radar data such as from the Arecibo and Goldstone DSS Observatories.

This presentation focuses on the currently funded Stage 1 work, which consists of the development of two primary software applications and a Geographic Information System (GIS) integrated into a single web interface.

**Generalized Radar Sounder Processor:** The heart of PORPASS will be the development of a generalized radar sounder processor (GRaSP). Most modern sounder systems rely on synthetic aperture radar (SAR) processing to enhance along-track resolution and boost the effective signal-to-noise ratio. Despite the similarities across radar systems, instrument teams devote a substantial amount of time and effort in designing and enhancing new SAR processing systems specific to each new instrument. All modern radar sounder processors typically range compress the data either onboard (e.g., LRS and some modes for MARSIS) or on-ground (e.g., SHARAD and some modes for MARSIS), but they differ in whether and how they correct for ionospheric distortion (where applicable), apply SAR processing, and redatum the data acquired from orbit.

The development of GRaSP will focus around four main modules: data input/output, fast-time processing, slow-time processing, and output/imaging modules.

*Data Input/Output Module.* While the PDS has standardized many planetary data sets, differences in either the PDS format or in the structure of radar data make it necessary to develop a module that standardizes the disparate datasets into a format easily digestible by GRaSP. Furthermore, with the ongoing adoption of new standards (PDS4), modules will need to be developed to read and convert data in both PDS3 and PDS4 formats. We will develop modules that read the PDS labels for each radar dataset to determine which follow-on submodules to use to format the data appropriately for input to and output from GRaSP. The output will be standardized data and orbital parameters encapsulated in the HDF5 data structure that will ensure proper processing within the subsequent GRaSP modules.

*Fast-time Processing Module.* “Fast-time” is defined as the range-delay time (i.e., direction of travel for the emitted signal). Processing in this dimension includes frame-by-frame signal-processing submodules such as range compression, ionospheric distortion correction, and range migration (i.e., the alignment of the individual frames due to changes in the spacecraft orbital parameters).

*Slow-time Processing Module.* “Slow-time” is the elapsed time along the direction of spacecraft travel (i.e., along-track). Processing in this dimension includes

synthetic-aperture processing submodules such as additional presumming (i.e., adding or stacking together of data records to increase the signal-to-noise ratio), Doppler processing, and final fine-range redatuming, focusing, and migration (i.e., aligning the frames in the azimuthal direction to ensure continuity).

**Output Module.** As an added benefit to users, all data exported from PORPASS will be in PDS4 format, however, the archival of the derived products will be the responsibility of users. This module will create the fully processed radargrams (TIFFs), browse images (i.e., lower resolution JPEG images useful for quick inspection), map-view ground track figures plotted over digital elevation models (DEMs) as well as delimited files describing orbital parameters and other useful instrument diagnostics (i.e., solar array gimbal angles, transmit and receive temperatures, etc.).

**Orbital Radar Simulator (OaRS):** The interpretation of radar data is complicated by assumptions and inferences about subsurface structure and composition. Most assumptions are grounded in geology and geologic history, but as with all geophysical data, interpretations can be ambiguous. Simulations of the electromagnetic propagation of radar waves through a modeled subsurface are often employed to reduce uncertainties in interpretations.

Due to the complex nature of the problem, most radar simulators are simplified to increase computational efficiency, resulting in either simple 1D simulators [1-4] or more advanced, but still simplified 2D simulators [5-7]. Simulators that predict only the arrival of radar returns based on surface topography ("clutter" simulators) have also been employed to assist investigators in determining whether a noticeable signal in radar data is actually from the subsurface and not a return from an off-nadir surface feature [8-9].

While there is no shortage of radar simulators mentioned in the available literature, most are specific to particular instruments and have either been lost to time or are not made publicly available due to institutional restrictions or personal preferences of the developers.

The development of OaRS will focus around two main modules: the model-building module and the simulation module.

**Model Building Module.** The model-building module will construct virtual physical environments appropriate for radar simulations. Submodules will include spacecraft orbital parameters and instrument configuration, instrument emission patterns, the space environment including a modeled ionosphere where applicable, surface topography, and free-form (i.e., independent of surface topography) subsurface stratigraphy and material properties. The modular design will provide the flexibility for OaRS to incorporate new virtual environments and modules for

new spacecraft and instruments as they are proposed and developed.

**Simulation Module.** This module will produce simulated radar data that will be formatted in a manner consistent with the input/output modules of GRaSP. The computational framework of this module will include physics specifications, numerical discretization, and computational methods submodules. This will allow for the most realistic model case and most accurate propagation physics, which is necessary to accurately model the radar returns, and will include simplifying switches to toggle appropriate time and space discretization and computational methods "on" or "off" depending on simplifying model parametrization and/or physics assumptions.

**Website and GIS Application:** The development of the web application will focus on building the web architecture in a modern full-stack framework with full GIS capability and enhanced security protocols.

The GRaSP and OaRS applications will use and produce data sets for the visualization of scientific analysis and for quality control purposes. We intend to develop flexible visualization tools for extracting 1D, 2D, 3D, and 4D graphical renderings through these datasets in user-specified orientations. For example, a 1D view might consist of a single frame of data or a model profile at one location taken from a simulated radar data set. A 2D view might be a radargram acquired along an orbital track. A 3D view might be a tri-axial perspective "chair" view through a 3D model [10]. A 4D view (movie) might be a fast-time simulation of radar propagating through a 3D model.

**Testing, Validation, and Launch:** Individual development and integration of the various codes is expected to be completed by the end of 2022 followed by a testing and validation stage with an official launch of PORPASS slated for the 54th Lunar and Planetary Science conference in March 2023.

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