Synthetic Aperture Radar (SAR) can provide useful images in situations where passive optical imaging cannot, either because the microwaves used can penetrate atmospheric clouds, because active imaging can "see in the dark," or both. Past planetary applications of SAR have exploited its cloud-penetrating abilities. The NASA Magellan mission of the early 1990s used S-band SAR to image nearly all of the surface of Venus at 150 m resolution. More recently, the Ku-band RADAR instrument on the NASA/ESA Cassini spacecraft has revealed >22% of the surface of Saturn's giant moon Titan at resolutions of 300 to 1500 m, with additional images to be obtained over the next few years. Beginning in 2008, closely related instruments on two lunar orbiters will use polarimetric radar to image the permanently shadowed areas of the lunar poles and search for subsurface ice deposits. The Mini-RF "Forerunner" instrument on the ISRO Chandrayaan-1 probe will image the entire polar areas in S band with 150 m resolution. The NASA Lunar Reconnaissance Orbiter (LRO) Mini-RF radar will have the same capability, plus X-band imaging and a 15-m resolution "zoom mode" in both bands, though only limited samples of data in each mode will be obtained in the prime mission.

We have participated in data analysis for all four of these planetary imaging radars, focusing on the generation of map products. We describe the techniques for radargrammetry (precisely analogous to photogrammetric analysis of passive optical images, but respecting the geometric principles by which radar images are formed) that we have developed and applied to these datasets. This work encompasses both the production of controlled image products by bundle adjustment (solution for improved image orientation parameters and ground coordinates of features, based on measurements of corresponding features in the images) and the production of digital topographic models (DTMs) by automated and/or manual identification of dense sets of image correspondences. SAR images can actually be preferable to optical images of comparable resolution for geodetic control, because they are unaffected by errors in instrument pointing. Stereo DTM production with radar, though the best source of topographic data in some situations, can be challenging because of the unavoidable coupling between viewing geometry and illumination (i.e., stereo images necessarily have differing illumination, making correspondences harder to identify) and the presence of coherent speckle noise..

We utilize a commercial stereo software package (SOCET SET ® from BAE Systems) for planetary radargrammetry. The USGS planetary cartography software ISIS is used in a supporting role, to ingest the images and supporting data from archival formats and prepare them for use in SOCET SET. Key functions provided by SOCET SET include multi-sensor bundle adjustment, flexible automated image matching for DTM production, and interactive measurement of control points and editing of DTMs based on stereoscopic display of the images with overlaid graphics. A "sensor model" that calculates the relation between ground coordinates and image coordinates is needed to make use of these capabilities. Each planetary radar has individual peculiarities that require us to develop our own sensor model specific to it. These models are based rigorously on the physics of radar image formation, but they differ greatly in complexity. The Mini-RF sensor model now under development is the simplest, because the images are available in a "Level 1" format that corresponds directly to the observed quantities: the time at which a feature is observed at zero Doppler shift (i.e., in a plane perpendicular to the flight track) and range from the spacecraft at that time. Given a model of the flight trajectory, it is a simple geometrical calculation to relate the latitude-longitude-height coordinates of any point to these image coordinates..

Our sensor models for the Magellan and Cassini radar images are considerably more complex, because these products have been map projected to "Level 2" surface coordinates. It is necessary to reverse this projection process and reconstruct Level 1 coordinates of a feature before relating these Level 1 coordinates to surface position as for Mini-RF. In this two-step calculation, it is crucial to use the same trajectory and surface model used by the mission to produce Level 2 data when reconstructing the Level 1 coordinates. An improved (adjusted) trajectory and surface elevation may be used in the second step of the process. The sensor models are made even more complex by our desire to work with mosaics as well as single images for Magellan. For Cassini, even single image strips must be handled as mosaics because they contain data from the instrument's five overlapping beams. Thus, it is necessary build and use a database that describes which image or beam each pixel originates from, as well as the assumed spacecraft trajectory and surface height for that location.

We have demonstrated our ability to use these tools to map large areas of Venus with Magellan stereo images by producing DTMs of two 12°x12° quadrangles (about 0.7% of the surface, out of ~17% imaged in stereo with same side illumination). The 675-m grid spacing of the stereo DTMs improves on Magellan altimetry by more than an order of magnitude. DTMs requiring only moderate amounts of editing can be produced if the automatic matching process is "seeded" with a limited number of manual measurements along topographic breaklines. Opposite-side stereo has also been found to be useful in the venusian lowlands, where relief is subdued. We are just beginning to produce stereo DTMs of Titan from Cassini data. The results are highly consistent with other sources of information such as altimetry where they can be compared, and are providing useful contstraints on Titan's organic inventory and surface processes. We look forward to presenting early results from the Forerunner SAR at the ISPRS Congress.