Radar generates high-resolution topographic map of the Moon

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The best topographic map of the lunar south pole, generated by radar interferometry using Goldstone Solar System Radar data, provides valuable information for lunar exploration and science.

The National Aeronautics and Space Administration’s (NASA’s) long-term exploration goals include resuming manned missions to the Moon that will culminate in a permanent manned lunar station. Before embarking on such a mission, a series of unmanned robotic missions are required to ascertain the best locations for manned exploration or a permanent lunar base. The south polar region of the Moon has attracted much recent attention because significant amounts of frozen water may be trapped in permanently shadowed regions in craters there. Knowledge concerning the lunar topography is of particular importance in planning survivable landings and locating regions accessible to exploration.

Synthetic aperture radar exploits the motion of a radar relative to a surface to create fine-resolution images essentially independent of the distance from the radar to the surface. By creating images from two spatially separated radars, an interferometric image can be derived containing topographic information. Jean-Luc Margot and co-authors used the Goldstone Solar System Radar (GSSR) in this configuration to derive topographic maps of the lunar surface at 150m spatial resolution and 50m vertical accuracy. Subsequently, in 2006, the GSSR system was upgraded to support the collection of finer-resolution imagery of the lunar surface. The topographic map described here was derived from this data.

Radar mapping of the Moon

GSSR observations on 13 September and 5 December 2006 offered two of the best opportunities to obtain high-resolution topographic maps of the near side of the Moon from either Earth-based or lunar instruments. The observations were timed so that lunar librations allowed maximal visibility of the south polar region of the Moon. This data has been used to generate a topographic map of this region with more than three times finer spatial resolution and 10 times finer vertical accuracy than previous maps.

Figure 1 depicts the GSSR imaging geometry. Imaging the south polar region of the Moon from the GSSR latitude of 34° results in near-grazing incidence angles between 85° and 90°. The footprint size, which is governed by the 70m transmit antenna pattern, is approximately 370km in the cross-range direction and nearly 630km in the range direction. Thus, over 231,000km² can be mapped with a single Goldstone observation, which is

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Figure 2. Backscatter image of the lunar south pole region obtained by the GSSR, after correcting for the antenna pattern.

Figure 3. Color-coded elevation contours are overlaid on the radar backscatter image.

typically over an hour long. Figure 2 shows the radar backscatter of the mapped region with a number of the most prominent features labeled.

To determine the 3D position of a point, we need three observations. A single synthetic aperture radar (SAR) image provides two observations, consisting of the range and Doppler to a pixel. The third observation is obtained from the interferometric combination of images. It is the phase of the derived ‘interferogram’ that contains the topographic height information. The scatterer location is a function of the baseline, velocity, and platform position vectors and the range, phase, and Doppler observables.

Figure 3 shows an elevation map generated from the September 2006 GSSR data, posted at 40m. Note that 12km of elevation variation occurs in a small region near the south pole. A number of the craters are many kilometers deep.

Geodetic control of the lunar data

Because the interferometric phase and baseline are not known to the required accuracy beforehand, fiducial points are needed to obtain cartographically-correct absolute elevation measurements. We used the United Lunar Control Network (ULCN) of 2005 for our fiducial control, derived from Clementine lidar and optical stereo elevation data. Approximately 8000 points in the ULCN 2005 database overlapped with the GSSR-derived elevation map. Points in the ULCN database have an associated vertical accuracy estimate that varies from 200m to over 4km, considerably coarser than the fine-scale error in the GSSR data, and a planimetric accuracy from hundreds of meters to several kilometers. A weighted least squares planar fit to the difference between the GSSR elevation data and the ULCN 2005 data was made for planimetric offsets of ±20km in either direction, in increments of 160m. Comparison of the Clementine data after the fit showed good correspondence between the two data sets.

Conclusion

Interferometric radar data of the Moon collected by the GSSR system in 2006 is being used to generate the most accurate topographic map of its south polar region. The final map products are expected to have a planimetric resolution of 40m and a relative vertical accuracy ($1\sigma$) of 5m. These products can be used to support scientific investigations, including the search for ice

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deposits in permanently shadowed craters on the lunar surface, and to aid in planning and exploration for future lunar missions. The absolute accuracy of these topographic maps will improve when missions like Lunar Reconnaissance Orbiter—which will carry a laser altimeter as one of the payload instruments—generate lunar elevation measurements.

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Scott Hensley is a principal engineer specializing in the design and application of radar interferometric systems. He has BS degrees in math and physics from the University of California at Irvine and a PhD in differential geometry from State University of New York at Stony Brook. Hensley has worked on numerous planetary and Earth-observing radars, including Magellan, Cassini, Spaceborne Imaging Radar (SIR-C), Shuttle Radar Topography Mission (SRTM), Airborne Synthetic Aperture Radar (AIRSAR), Geographic Synthetic Aperture Radar (GeoSAR), and Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR); for the last two, he was the principal investigator.

Eric Gurrola is a member of the technical staff who works on radar interferometric systems. He holds a PhD in electrical engineering from Stanford University. He has worked on the SRTM system and on improving the software architecture for the Repeat Orbit Interferometry Package (ROIPAC).

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Joseph Jao has an MS degree in electrical engineering from the University of Michigan and an electrical engineering degree from the University of Southern California. He is a senior electrical engineer working for JPL’s GSSR group. Jao is responsible for radar operation, data collection, and first-level image processing of data collected by the GSSR system.

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Raymond Jurgens received his BS and MS degrees in electrical engineering from Ohio University and his PhD, also in electrical engineering, from Cornell University. Jurgens has been a pioneer in Earth-based radar observations of the planets and asteroids. His scientific work has included radar observations of Venus, the Moon, and asteroids, and his engineering has primarily been devoted to the development of the GSSR. Dr. Jurgens is a member of various professional societies including the American Astronomical Society and the International Astronomical Union.

Eric De Jong heads the Solar System Visualization Project at the JPL and holds a PhD in planetary science from MIT. He has pioneered the use of advanced visualization techniques to better understand planetary bodies throughout the solar system including Venus, Mars, and the Moon.

Barbara Wilson is the chief technologist for the Exploration Systems and Technology Office at JPL, and previously served as chief technologist for JPL and for the Air Force Research Laboratory. She holds a PhD in condensed matter physics, and is a fellow of the American Physical Society (APS) and a former APS

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