GSSR High Resolution Imagery and Topography of The Lunar South Pole Region. Scott Hensley*, Eric Gurrola*, Leif Harcke*, Nick Marechal†, Lawrence Weintraub†, Martin Slade*, Kevin Quirk*, Barbara Wilson*, Sang-Ho Yun*, Walter Szeliga*, Meera Srinivasan*, Clement Lee*, Richard Dickinson†, Ronald Bloom†, Grant Karamyan†, Anneliese Lilje†, Joseph Jao*, Eric De Jong*. *Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr. Pasadena CA, 91109. †The Aerospace Corporation, El Segundo, CA. (Scott.Hensley@jpl.nasa.gov)

Introduction: Mapping the Moon's topography using Earth based radar interferometric measurements by the Goldstone Solar System Radar (GSSR) has been done several times since the mid 1990s. In 2008 we reported the generation of lunar topographic maps having approximately 4 m height accuracy at a horizontal posting of 40 m [1]. Since then GSSR radar has been improved to allow 40 MHz bandwidth imaging and consequently obtained images and interferograms with a resolution of about 4 m in range by 5 m in azimuth. The long synthetic aperture times of approximately 90 minutes in duration necessitated a migration from range/Doppler image formation techniques to spotlight mode processing and autofocusing methods. The improved resolution imagery will permit the generation of topographic maps having 15 m spatial resolution with about same height accuracy.

Hardware Upgrade: The GSSR radar system consists of a series of transmitting and receiving antennas located near the Goldstone Lake Bed in the Mojave Desert of California. The GSSR interferometric observations of the Moon involve transmitting an X-band (3 cm wavelength) signal on the 70 m antenna, DSS 14, and receiving on two 34 m antennas (DSS 13 and 25) that have an interferometric baseline of 13 km. Previous interferometric data collected by the GSSR system employed a continuous transmitting Pseudo-Random Noise (PN) phase-coded waveform of length 131070. The time interval between each 180° phase shift, called a chip, is 0.125 ms which results in a total transmitted code duration of 16.4 ms. This is greater than the lunar range depth (11.6 ms), thereby allowing polar imagery to be collected without range ambiguities. This chip length gives a range resolution of 18.75 m. Several waveform options were considered for increasing the range resolution of the GSSR system with special care devoted to insuring the out of band emissions would meet NTIA requirements and that were compatible with the 500 kW klystron used for the transmitted signal.

Based on the waveform studies a 40 MHz linear frequency modulated waveform (LFM), or chirp waveform, was selected. With this transmitted waveform imagery with a range resolution of 3.75 m is possible,

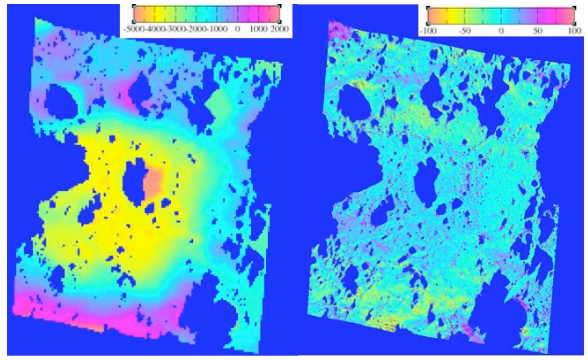

Figure 1. *On the left is a GSSR 40 m resolution topographic map generated from the 5 m imaging mode of the GSSR radar of a 100x100 km tile containing the Cabeus crater and the LCROSS impact site. On the right is an elevation difference map of the GSSR elevation data and the LRO lidar data. The elevation difference standard deviation in this tile was 23.7 m.*

however in practice to reduce sidelobes the matched filter is amplitude weighted resulting in an effective range resolution of 4.25 m. By collecting 90-minute synthetic apertures it is possible to generate imagery with comparable cross-track or azimuth resolution of 5 m.

After testing the hardware modifications to the GSSR hardware, three acquisitions using the increased 40 MHz bandwidth LFM waveform were acquired of the south polar region of the Moon: May 22, 2009 for 180 min (2-90 min apertures), July 15, 2009 for 360 min (4-90 min apertures) and November 1, 2009 for 360 min (4-90 min apertures). See [2] for more details.

Processing Improvements: The finer resolution of the modified GSSR system and the accompanying migration through resolution cells during a synthetic aperture called for spotlight, rather than delay-Doppler, imaging techniques. A new pre-processing system supports fast-time Doppler removal and motion compensation to a point. A spotlight imaging technique which compensates for phase errors due to i) out of focus-plane motion of the radar and ii) local topography, has been implemented and tested. Using an appropriately chosen lunar elevation reference good focusing is obtained without autofocus, however, for the 90 minute synthetic aperture times required for 5 m resolution topographic effects cause defocusing that is compensated by autofocus.

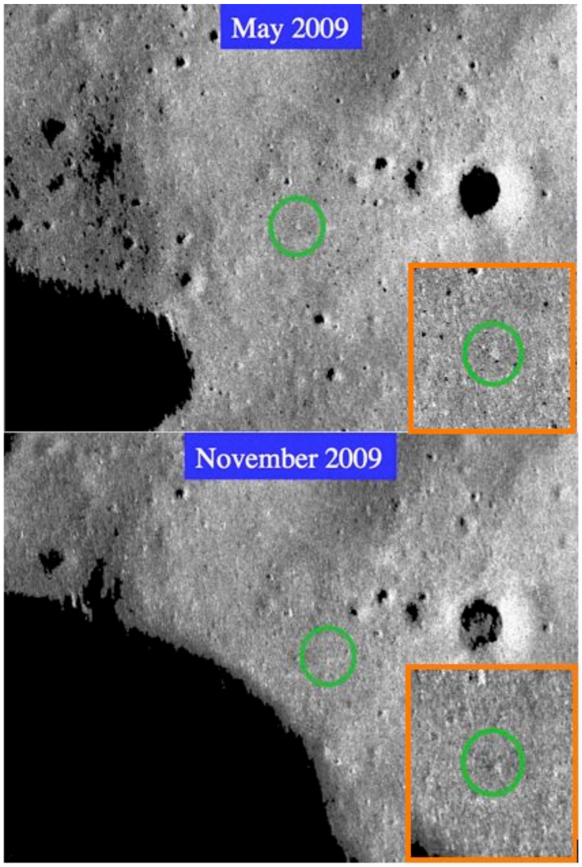

Figure 2. *GSSR 5 m resolution imagery collected in May and November of 2009 that bracket the LCROSS impact event on the moon. The green circles indicate the putative LCROSS impact point detected in the GSSR imagery. Images are approximately 6.25x4.65 km. Orange boxes enclose zoomed in views of the impact area.*

Elevation Products and LRO Comparison: Using interferometric data acquired by the GSSR radar high resolution topographic maps of the lunar surface can be generated. Radar data of the Moon collected by the upgraded GSSR system in 2009 are being used to generate high accuracy topographic maps of its south polar region. The final map products are expected to have a planimetric resolution of 20 m (posted at 15 m with 15 m resolution imagery) and a relative vertical accuracy (1σ) of 3-5 m. Figure 1 shows a elevation map generated for a 100x100 km tile around LCROSS impact site that is posted at 40 m and a comparison with LRO lidar data which was used for cartographic control. The elevation standard deviation was 23.7 m that is larger than the LRO (3-6 m) or GSSR (11-15 m) elevation precisions estimated from the interferometric correlation. The larger difference is attributed to some LRO orbit to orbit errors visible in the difference map that range from 10-50 m and some low frequency along-track distortion between the two height maps.

Even with the advent of the Kaguya and LRO topographic data sets there is still value from having the capability to generate topographic maps using the GSSR radar. Lidar based topographic maps from LRO and Kaguya have excellent height accuracy, however they will only be able to generate topographic maps with 20 m postings within a small region (about a degree) about the pole and will have around 1 km postings near the equator. The improved GSSR radar can generate topographic maps with 20 m postings (4 m imagery) anywhere on the near side of the Moon with an elevation accuracy that depends on the number of synthetic apertures mosaicked to make the map product.

LCROSS Impact: Figure 2 shows full resolution 5 m orthorectified imagery from the GSSR radar collected in May and November of 2009 that bracket the LCROSS impact onto the lunar surface in Cabeus crater. Circled in green is the putative impact point detected in the GSSR imagery and the orange inset boxes show a zoomed in view of the impact point. The impact point detected in the GSSR imagery is in good agreement with the impact location identified by the LCROSS impact team.

The ability to detect small impacts on the lunar surface using earth based imaging assets opens up the possibility of an GSSR based observatory to monitor impacts on the near side of the moon either via amplitude of coherent change detection. Data from such an observatory could help refine meteor impact rates and identify landslide or other disturbance events.

References:

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[2] S. Hensley, E. Gurrola, L. Harcke, M. Slade, K. Quirk, M. Srinivasan, C. Lee, S. Yun, J. Jao, B. Wilson, E. De Jong, N. Marechal, L. Weintraub, R. Dickinson, R. Bloom, G. Karamyan, A. Lilje, Lunar Topographic Mapping Using A New High Resolution Mode For The GSSR Radar, Proceeding of Radarcon2010, Washington DC, May 2010.

Acknowledgement: The work reported here was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. The authors would like to thank The Aerospace Corporation for supporting the work through its Independent Research and Development Program.