SCIENCE PRODUCTS OF THE LUNAR ORBITER LASER ALTIMETER. E. Mazarico[1], M.K. Barker[1], G.A. Neumann[1], K. Jha[2], M.H. Torrence[3], M.T. Zuber[4] and D.E. Smith[4]. [1]NASA Goddard Space Flight Center, Greenbelt, MD (erwan.m.mazarico@nasa.gov); [2]Sigma Space Corp., Lanham, MD; [3]Stinger Ghaffarian Technologies, Inc., Greenbelt, MD; [4]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA.

Introduction: The Lunar Reconnaissance Orbiter (LRO) has been in a low-altitude polar orbit around the Moon since 2009, mapping it with seven science instruments [1]. The quality of the instruments originally selected to acquire datasets to prepare a human return to the Moon and the length of the mission (more than 8 years) make the LRO data a keystone of lunar science. The Lunar Orbiter Laser Altimeter (LOLA) [2,3] instrument onboard significantly improved the topographic knowledge about the lunar surface thanks to its high sampling rate (28 Hz) five-beam configuration, but it has also allowed other scientific measurements. Higher-level data derived from quantitative analysis have also been developed by the LOLA team, either already or about to be archived at the NASA Planetary Data System (PDS). Here, we review and describe the main data products from the LOLA instrument.

Individual profiles: The data acquired by the instrument over each LRO orbit are recorded as individual products. These are calibrated and geolocated using reconstruction orbit and attitude information. These Reduced Data Records (RDR) give profiles of groundtrack position, range, lunar elevation, pulse return energy, but also contain key instrument settings such as detection thresholds and background noise counts, for each of the five channels.

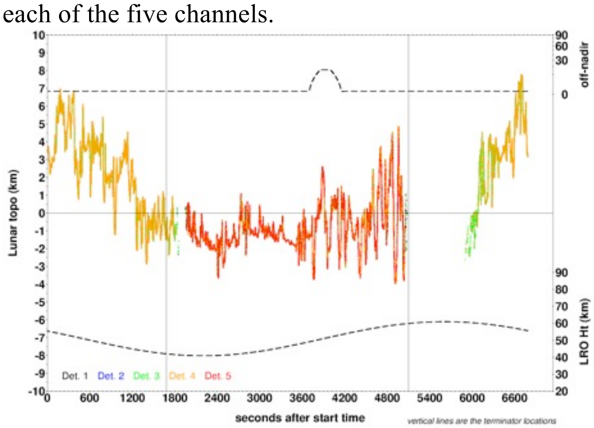

Figure 1. Altimetric profile of orbit 5709 (2010/09/20).

Topographic maps: As with MOLA at Mars, the LOLA gridded maps (also known as Digital Elevation Models, or DEMs) constructed from all the profiles are of most interest to the planetary community. These are archived in cylindrical and polar projections at a number of spatial resolutions. Rather than topography, these products actually describe elevation (or shape), as no geoid correction is applied. The difference is not as important as on Mars however, given the smaller variations (and thus effect on gravitational slopes; ; max. <0.2°/km near northwestern rim of Orientale) and the lack of hydrological transport. Despite more than 37,000 orbits, the narrow individual profiles do not sample the entire surface. A slew campaign in 2010-2011 reduced the size of the coverage gaps between tracks, but interpolation is still required at the highest resolutions. Count maps archived alongside DEMs can help assess the possible impact of sampling and interpolation on various kinds of analysis.

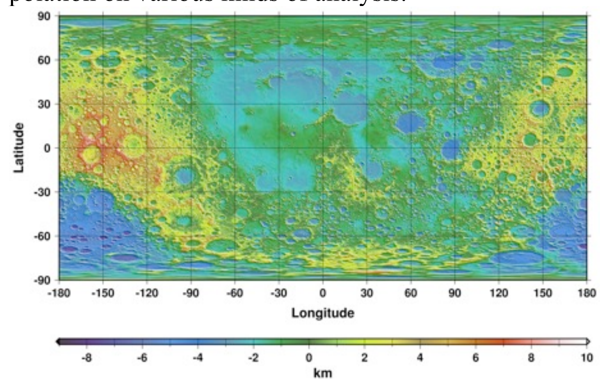

Figure 2. Global cylindrical map of lunar topography.

The LOLA team combined the geodetically-accurate LOLA data with the Kaguya stereo camera data, with excellent spatial coverage below 60° latitude, to produce the SLDEM2015 topographic map [4], the best topographic product for the Moon as of today and well suited for most studies.

Spherical Harmonics: The joint analysis of gravity and topography can be powerful to infer properties of the lunar interior, particularly its crust (thickness, density, porosity), and spectral-domain studies are often favored. Spherical harmonics expansion to degree and order 2050 were created from the global maps. A special version in the Principal Axes frame (instead of the Mean Earth frame for all other products) is intended for use with the GRAIL gravity spherical harmonic coefficients [5].

Slope and Roughness: The expression of geologic features and processes lead to complex surface topography, and the slope and roughness properties at various baselines are important to decipher them. LOLA measures these in different ways and at different lengthscales. The long LOLA profiles of each beam give one-dimensional slopes and roughness, while each five-beam LOLA footprint provides two-dimensional sub-50m slope and roughness information [6]. The return pulse shapes also relate to sub-footprint baseline roughness (~5-15m depending on LRO altitude). Finally, slope and slope azimuth at a given baseline can be directly computed from a DEM at that scale. The latest PDS delivery will include these maps.

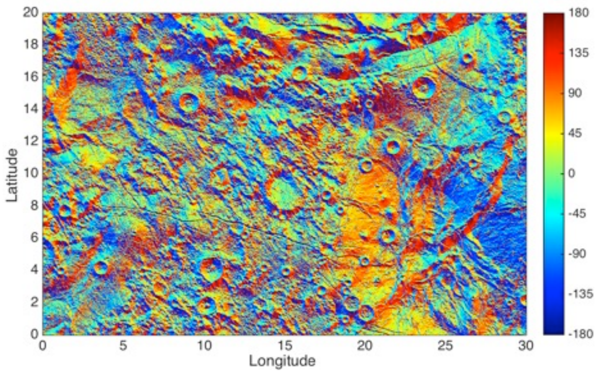

Figure 3. Slope azimuth at ~500-m baseline.

Active radiometry: The measurement of the return pulse energy by the LOLA detector can be used to calculate the surface reflectance at zero phase angle (normal albedo), after correction for the range to the surface and calibration of the detector response [7]. This calibration was especially difficult because of the 'LOLA thermal anomaly' behavior near the poles and on the nightside, but individual profiles of calibration surface reflectance have been archived and combined into polar maps showing enhanced signal attributed to water frost [8,9].

Passive radiometry: The LOLA flight software allows automatic threshold adjustment to target a false-alarm rate, typically small (1-2%) in altimetric operations. In 2013, the thresholds were reconfigured to record 10,000's noise counts per second to allow passive radiometry measurement of the surface-reflected solar photons. This mode is used when LOLA is out of range, due to LRO's elliptical polar orbit, mostly in the northern hemisphere. In combination with the active measurements of normal albedo, these passive data allowed the estimation of the lunar phase function at 1064 nm to contribute to the understanding of surface photometry and physical properties [10]. Calibrated passive radiometry will soon be archived at PDS as individual orbit products.

Illumination conditions: The LOLA topographic maps were used to survey the areas of permanent shadow in the lunar polar regions [11]. Maps of average solar illumination and average Earth visibility were similarly derived and archived. In addition, the solid angle of sky visibile from the surface was computed, as it can be useful in studies dealing with external sources (starlight [12], solar wind, etc.).

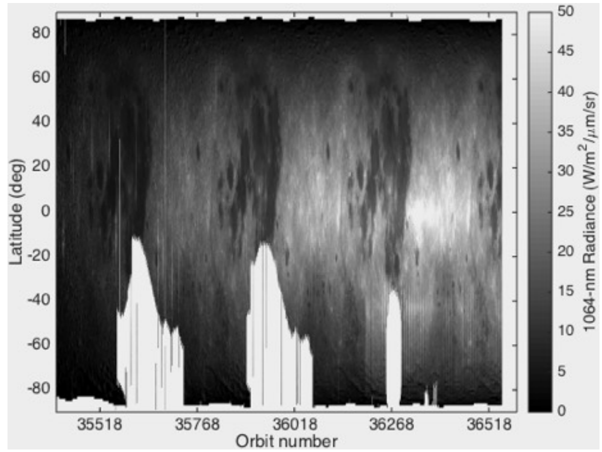

Figure 4. Three months of passive radiometry in 2017.

Laser Ranging: The LOLA spot-1 detector is connected through fiber optics to the High-Gain Antenna to receive 532-nm laser pulses from ground stations and provide precise 1-way laser ranges for orbit determination [13,14] (from 2009 to 2014, now archived).

Others: Several other products related to special activities by LOLA will be discussed. Since the LRO 3rd extended science mission (ESM3), the LR telescope has been regularly used to observe in geometrical configurations not possible from the nadir deck. A campaign of observations of the terminator close to the surface was performed to detect Apollo 15-like enhancements in dust forward-scattered light just before sunrise or after sunset [15]. The LRO spacecraft also slewed on a few occasions to point LOLA towards a NIR telescope near GSFC and perform asynchronous two-way ranging, useful for instrument pointing correction, pulse shape characterization and clock calibration.

Conclusions: The LOLA instrument provides a rich dataset. Beyond the primary topography products, the analysis of ancillary data recorded by LOLA and new operational modes implemented by the LOLA and LRO teams have expanded the set of studies possible. We will describe these datasets and experiments, and highlight the resulting archives now at PDS.

References: [1] Chin G. et al. (2007) SSR, 129. [2] Smith D.E. et al. (2010) GRL, 37. [3] Smith D.E. et al. (2017), Icarus, 283. [4] Barker M.K. et al. (2016) Icarus, 273. [5] Lemoine F.G. et al. (2014) GRL, 41. [6] Rosenburg M.A. et al. (2011) JGR, 116. [7] Lucey P.G. et al. (2014) JGR, 119. [8] Zuber M.T. et al. (2012) Nature, 486. [9] Fisher E.A. et al. (2017) Icarus, 292. [10] Barker M.K. et al. (2016b) Icarus, 273. [11] Mazarico E. et al. (2011) Icarus, 211. [12] Gladstone G.R. et al. (2012) JGR, 117. [13] Zuber M.T. et al. (2010) SSR, 150. [14] Mao D. et al. (2017) Icarus, 283. [15] Barker M.K. et al. (2018) LPSC, submitted.