Knowledge of Locations on the Lunar Surface

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+ the LOLA Science Team

Results from LRO-LCROSS

November 16-19, 2009 + Houston, Texas

LEAG 2009
- laser altimeter precision
- pointing accuracy
- orbital knowledge

other ways to assess it:
- topographic maps
- use the data!

South Pole (~75-90S)
LOLA instrument precision

- difficult to assess from altimetry data because the Moon is rough at small scales

- Laser Ranging data can help
  - 1-way ranges from the ground to LOLA (532nm)
  - firing times and receive times are matched
  - a clock bias needs to be estimated to provide usable range data
  - single-shot 1-way sigma = 20-24cm
  ➞ 10-12cm 2-way altimetric range precision
- spacecraft attitude knowledge estimated from star trackers and gyros < 30 arcsec (3σ) ⇔ 140 μrad

- instrument pointing

thermal effects change the co-alignment between the laser beam expander and the receiver telescope
  - magnitude ~ 500 μrad (⇔25m at 50km)

- calibration in progress; related to orbital work
- NASA GSFC Flight Dynamics Facility navigates the spacecraft, and produces ‘definitive’ SPICE kernels

- requirements for those quick products are $500m$ total position and $50m$ radial

- from the LOLA perspective, orbits as advertised:
  - precise enough for Laser Ranging ($4\text{km}, 2\text{arcsec}$)
  - crossovers reasonable
- LOLA Science Team will provide orbits with higher accuracy requirements
  - 50m total position, 1m radial

- but ... POD will take time
  - use of Laser Ranging data
  - use of altimeter data in crossover analysis
  - multi-arc solutions
  - development of new gravity field solutions
  - delivery 1 year after start of mapping (Sep.2010)
- Laser pulses received at the LR telescope are timetagged by LOLA, providing very accurate 1-way ranges
- Ongoing calibration of rangewalk biases
- ~5cm precision for normal points averaged over 5s
- 96+ hours of successful LR ranging since June 30, 2009

![Graph showing residual (s) with 4th degree trend removed.](Image)

- 5-s normal points
- Individual shots, RMS~0.8ns~24cm
- Fit residual
Altimetric crossovers provide strong orbital constraints for POD
- polar orbit + slow Moon spin = very non-uniform spatial distribution of crossovers
- low-latitude crossovers important for quality of TBD LOLA reference frame

month 1 (commissioning)  

month 3 (mapping)
- altimetry is an *independent* dataset to evaluate orbits

- radial differences in mapping: $1.7 \pm 29m$

- use altimetric data to evaluate displacement error

  - along-track $\sigma \sim 193m$
  - radial $\sigma \sim 22m$

\begin{align*}
\sim 1.9\% > 500m \\
\sim 2.4\% > 50m
\end{align*}
we use LOLA’s unique 5-beam geometry to get stronger orbital constraints
Goals:

- implementation of *horizon* method

- illumination modeling can reveal shortcomings/errors of topographic models

- exploration implications, interest in LEAG audience
1 - create database of horizon elevation for whole region
2 - compare Sun elevation to horizon at each timestep

**step 1 - slow ...**
Horizon method: example

Elevation map interpolated at 291.84

Sun elevation map (deg)

Sun disc visibility ratio

step 2 - fast!
Validation: comparison to LROC WAV mosaics

ET_{J2000} \sim 307368300s

LROC WAC mosaic
(J. Oberst, F. Scholten)
Validation: comparison to LROC WAV mosaics

LOLA model output

photometric function from Gaskell et al., 2008
Validation: comparison to LROC WAV mosaics

LOLA model output
Validation: comparison to LROC WAV mosaics
- averaged over four 18.6yr cycles (1970-2044)
- 6h timestep
- good agreement with Noda et al. (2008)
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- Earth considered visible when partially occulted
- several sites show very high average illumination (>80%)
- what is still blocking their horizon?
- could this be mitigated? (towers, ...)

### Sites of max. illumination

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<th>lat.</th>
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</table>
most illuminated point at surface level (#4 in previous map)

- local surface often obstructs horizon significantly
- moving up 10m above the surface helps a lot
- (altimetry errors could still be at 10m level)
500m away

8th most illuminated point at surface level

best point at 10m altitude

- ~96% average Sun illumination!
- in 2020s, ~207 days of continuous sunlight every year
- longest ‘night’ is <2 day
- longest period of Sun occultation is ~5 days
- little can be gained by high towers (distant horizon)
Thank you