Lunar Pole Illumination and Communications Statistics Computed from GSSR Elevation Data

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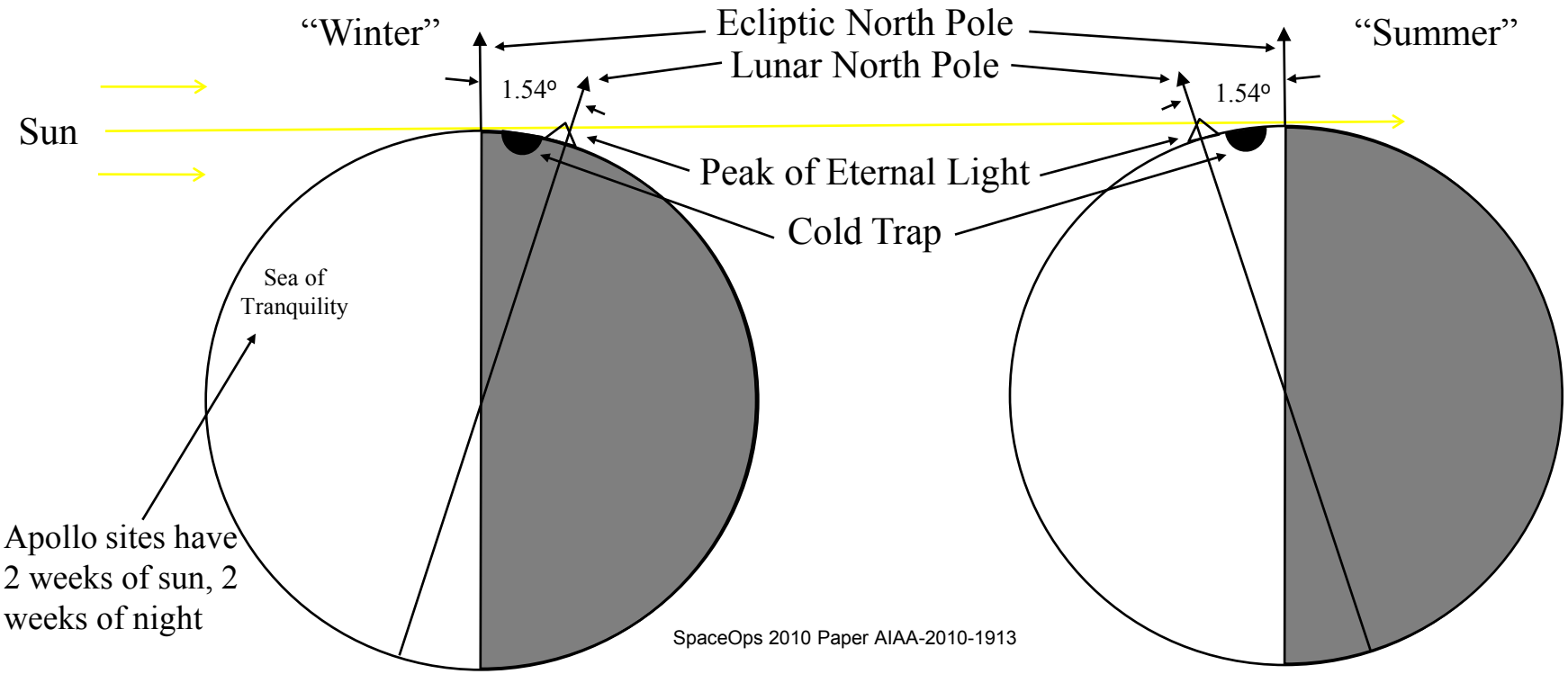
Introduction

- The paper examines the poles of the moon for potential human base locations.
- Sites evaluated based on quantitative values for:
  - Solar illumination
  - Earth communications
- This work was part of the SCiP studies for NASA's Constellation Program.
  - SCiP became SCaN, Spacecraft Communications and Navigation studies.

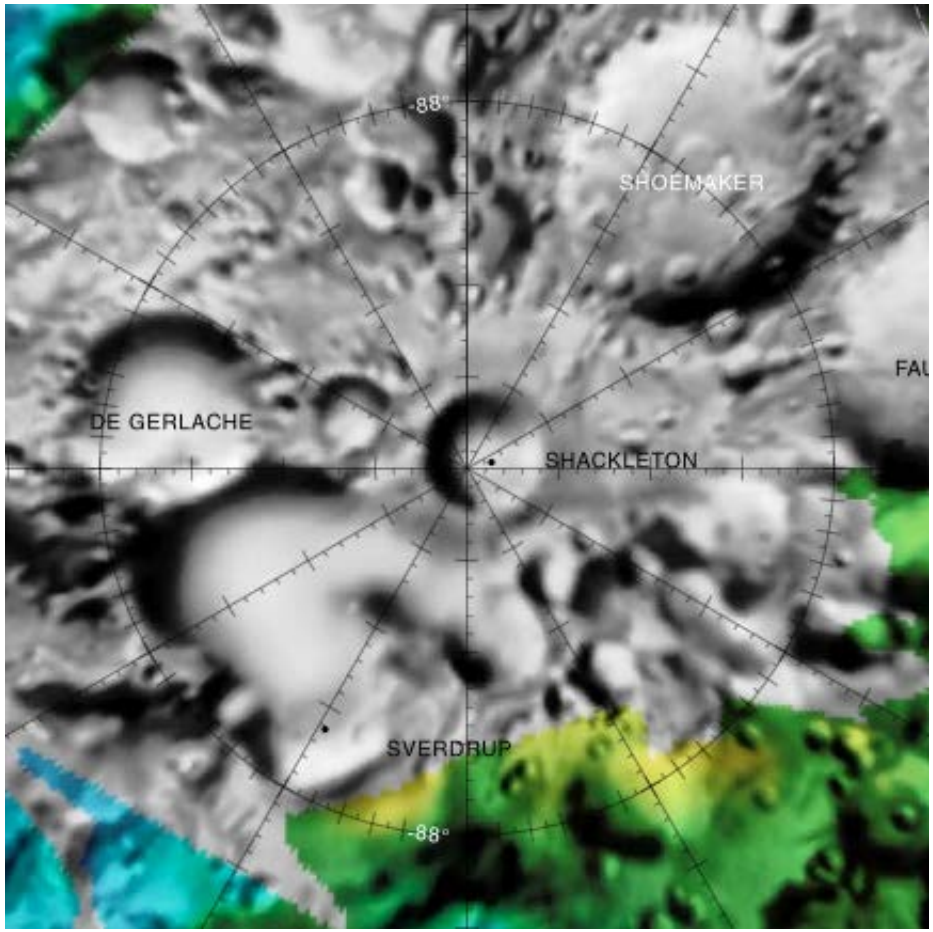
Why Put Lunar Bases at the Poles?

- **The Moon's axial tilt from ecliptic normal is only 1.54 degrees.**
- **This means the lunar poles could have 2 resources:**
  - **1) Water ice accumulated in permanently shaded polar 'cold traps'**
    - **LCROSS and Chandrayaan missions confirmed water ice.**
  - **2) Increased solar power at 'Peaks of (almost) Eternal Light'**
    - **Tall, isolated peaks near poles could see 1.54 degrees below the horizon.**
    - **Peaks would have continuous light and photovoltaic power.**



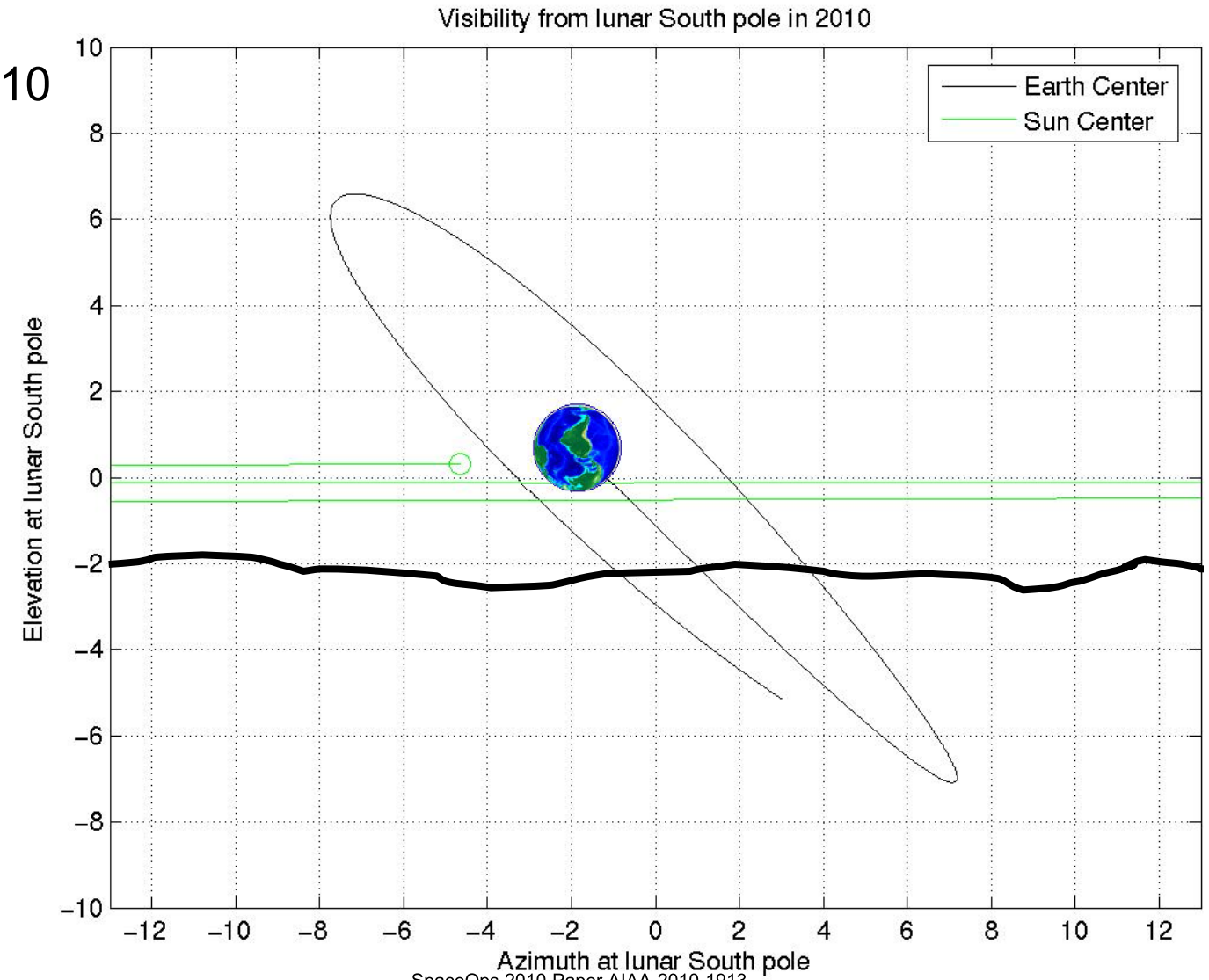
Polar Bases Could Become Self-Supporting

- Ice + power = drinkable water & oxygen & H^2 fuel propellant.
- Downside: Direct to Earth communication at poles is limited.
- Studies are focusing on Shackleton Crater at lunar South pole.



View From the Pole

January, 2010

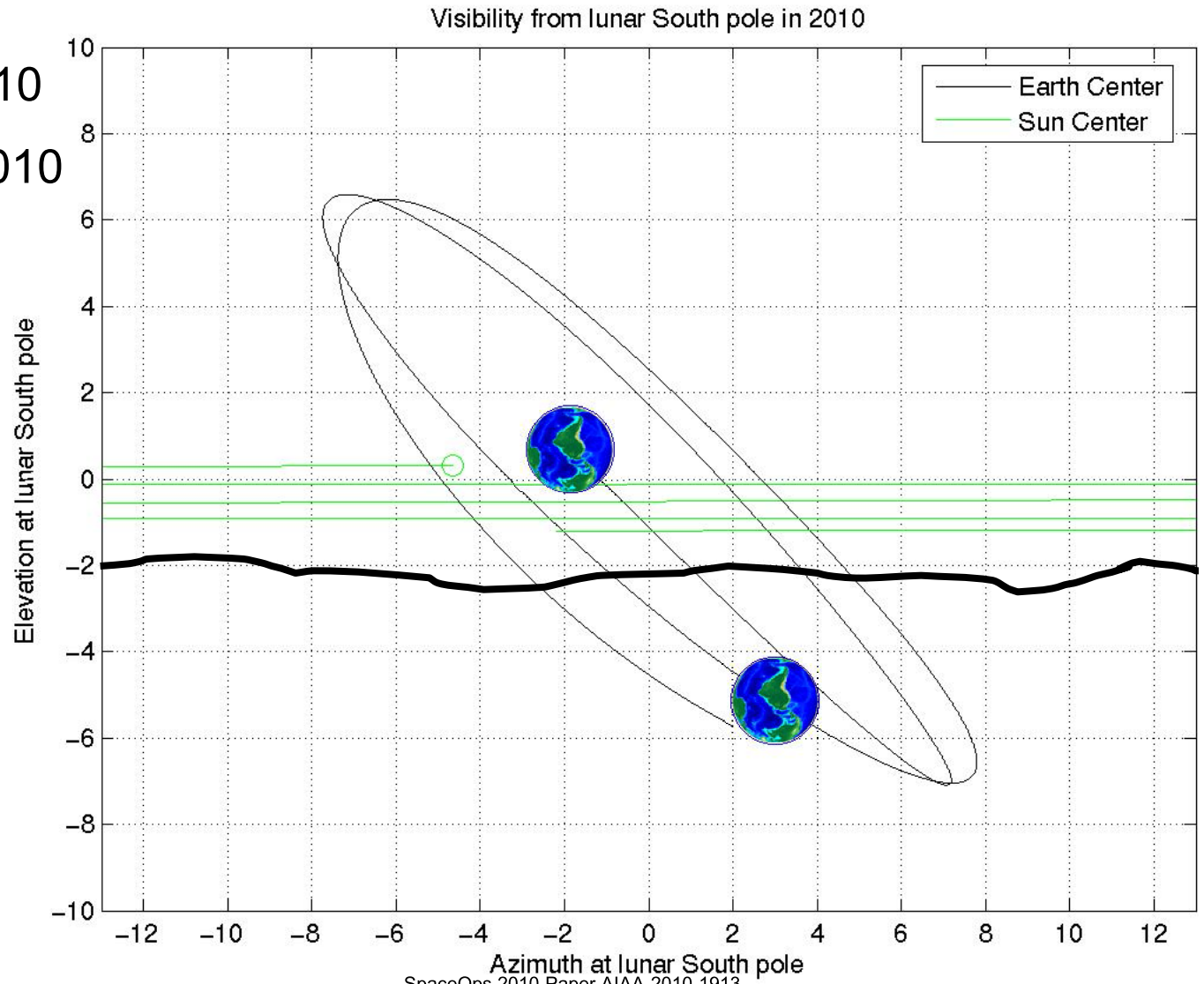


Local Horizon

View From the Pole

January, 2010

February, 2010



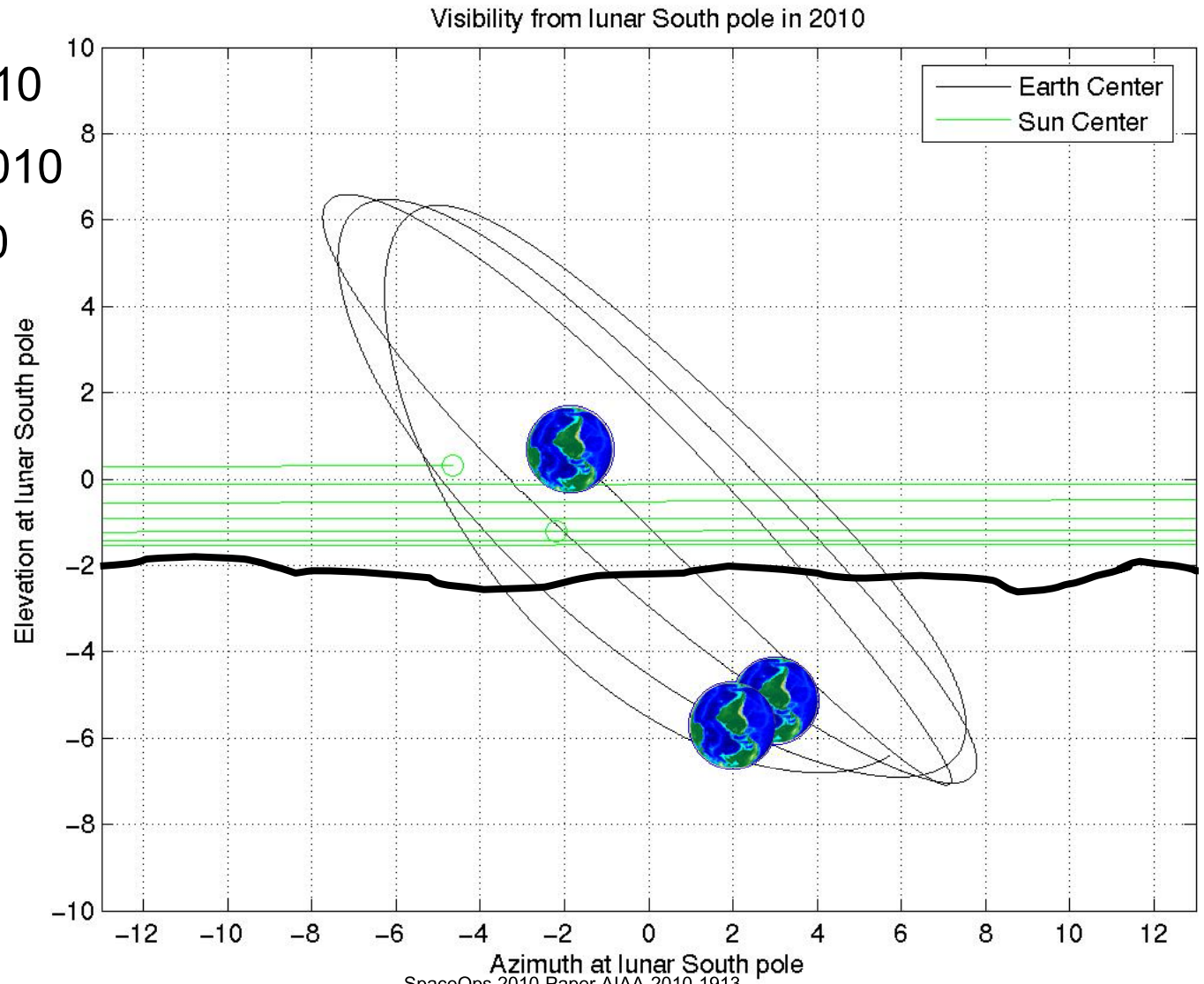
Local Horizon

View From the Pole

January, 2010

February, 2010

March, 2010



Local Horizon

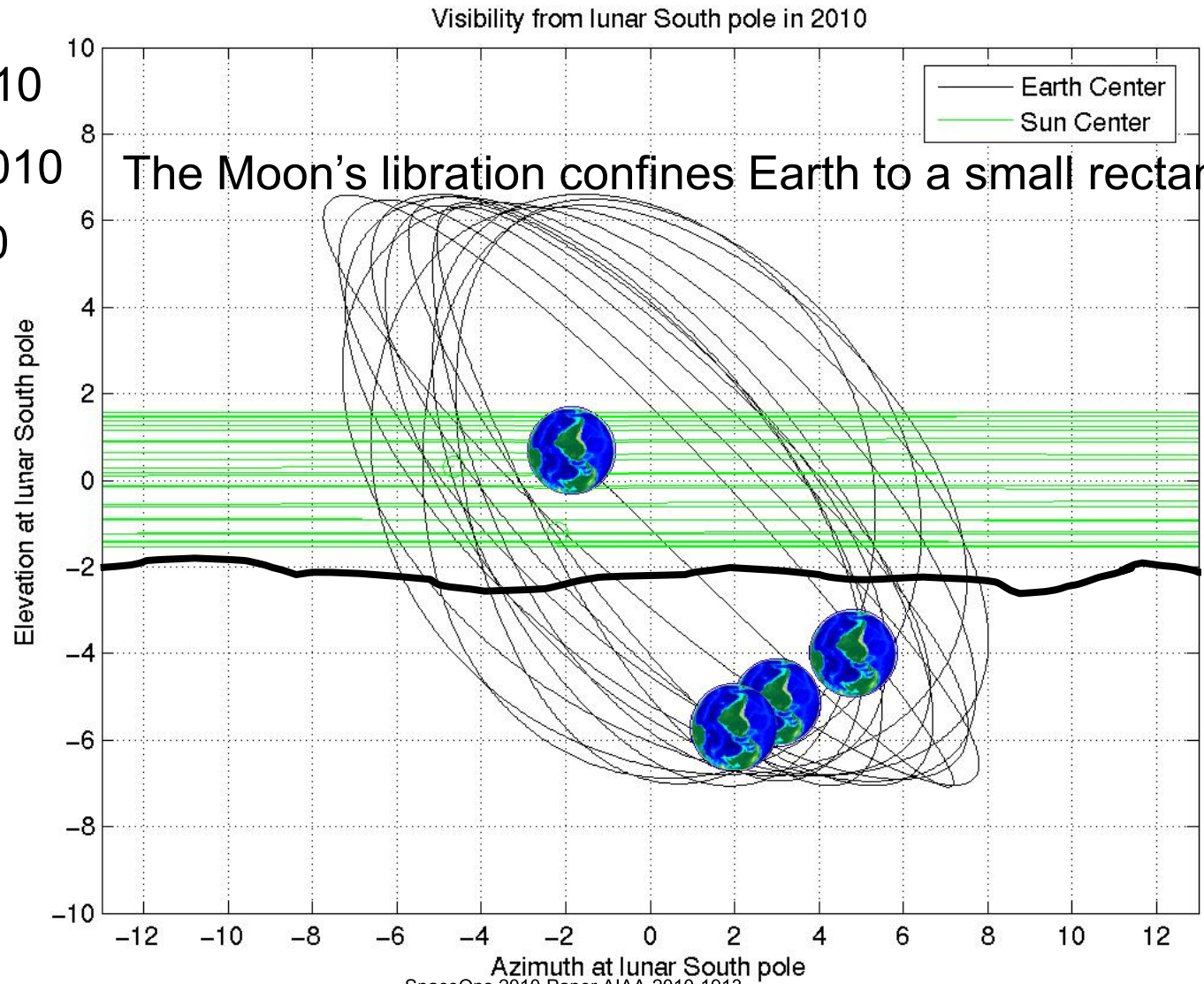
View From the Pole

January, 2010

February, 2010

March, 2010

All Year



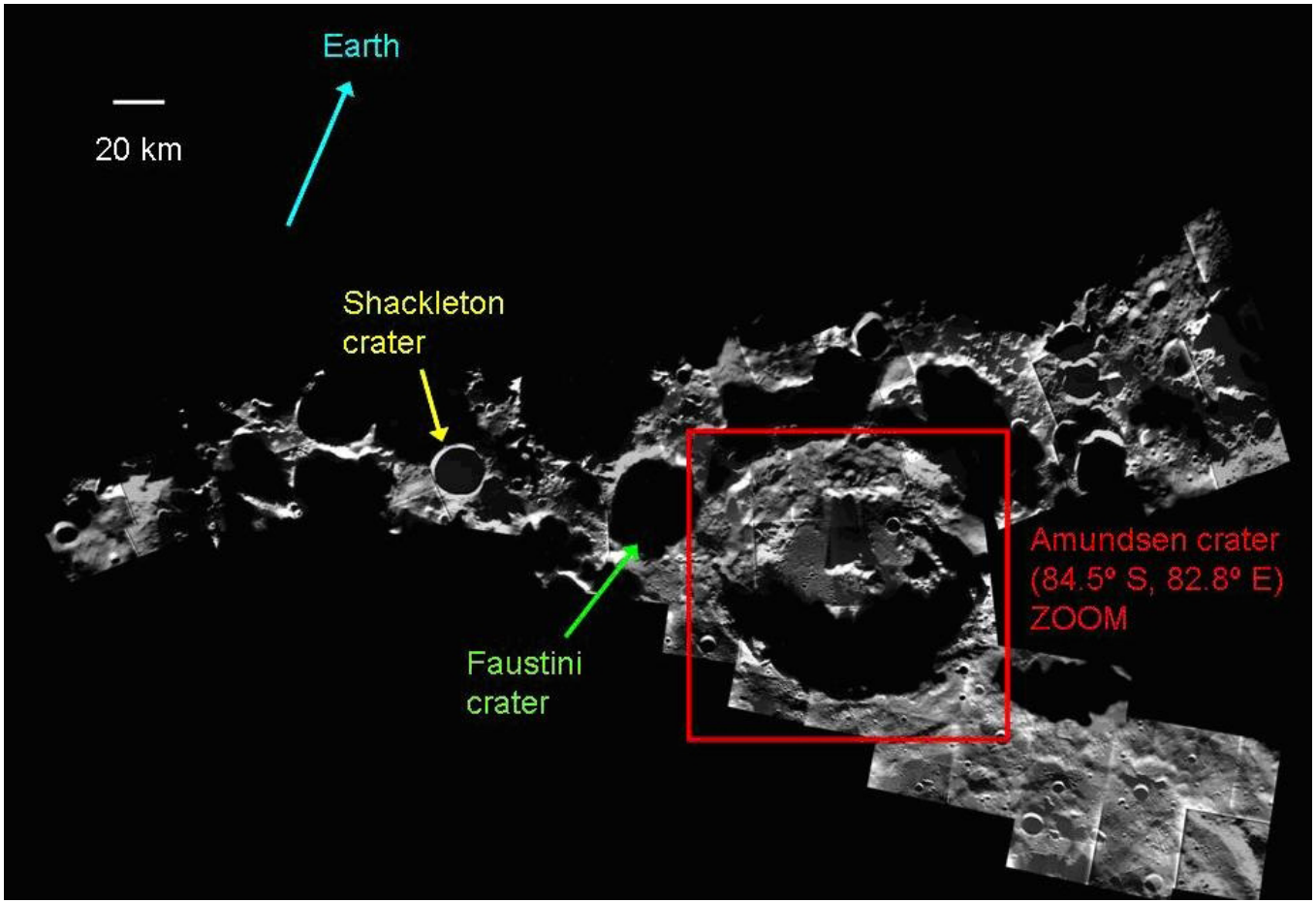
Local Horizon

Selecting a Good Base Location

- Look for tall peaks near each pole.
- Compute the local horizon mask from elevation data.
- Convert horizon mask to selenographic (lat, long) coordinates.
- Find locations with a horizon mask that:
  - Stays below -2 degrees, giving constant sunlight.
  - Has few obstructions of Earth's rectangular confining box.
- You just need accurate lunar elevations, to make the horizon mask.

Current Pictures of Lunar Poles are limited

- **This SMART-1 photo montage covers the pole, *but***
  - **Elevations have to be interpreted.**
  - **Coverage limited by Solar illumination, mission duration.**

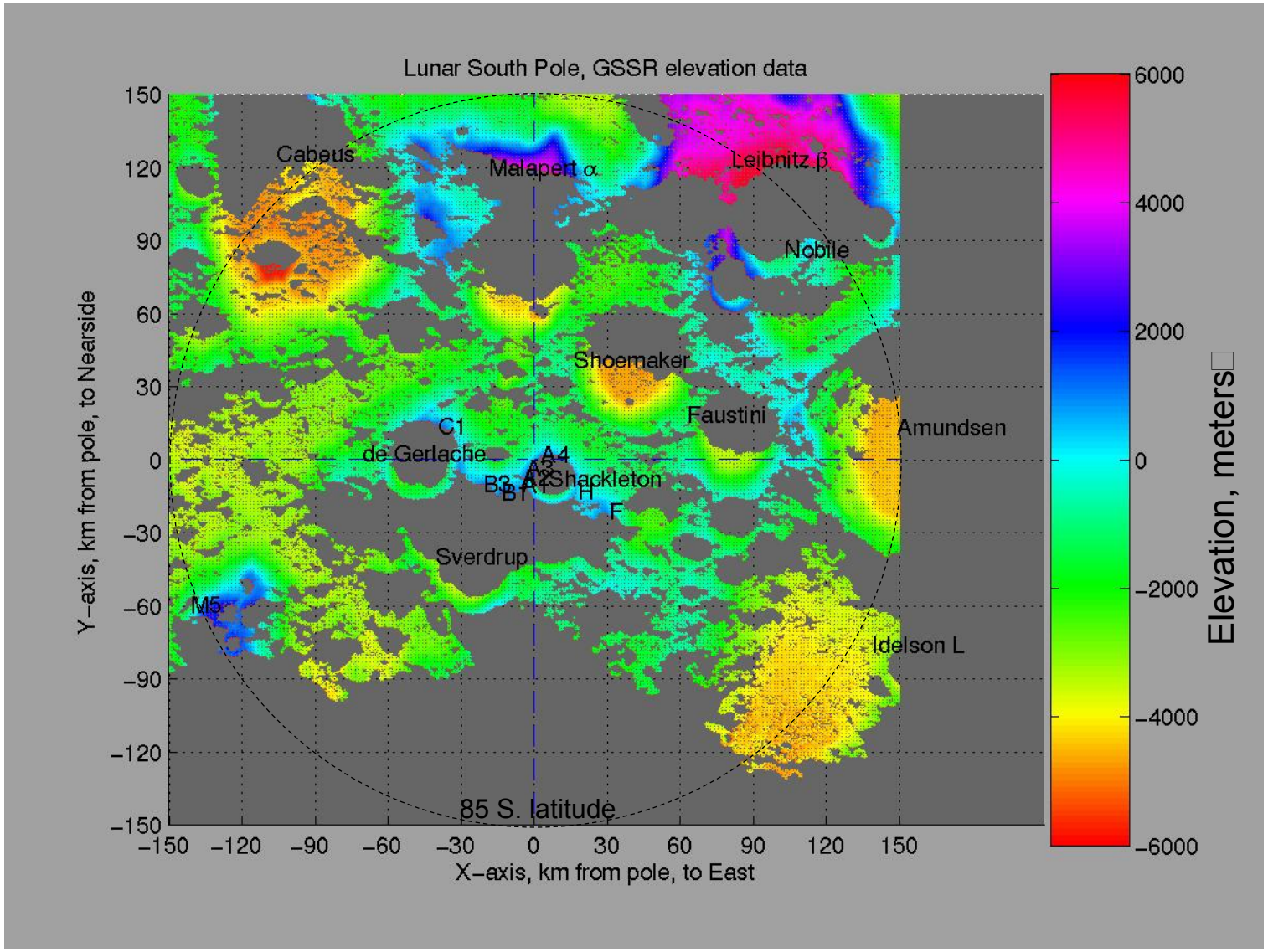


Courtesy of ESA's SMART-1 webpage

RADAR Directly Measures Elevation

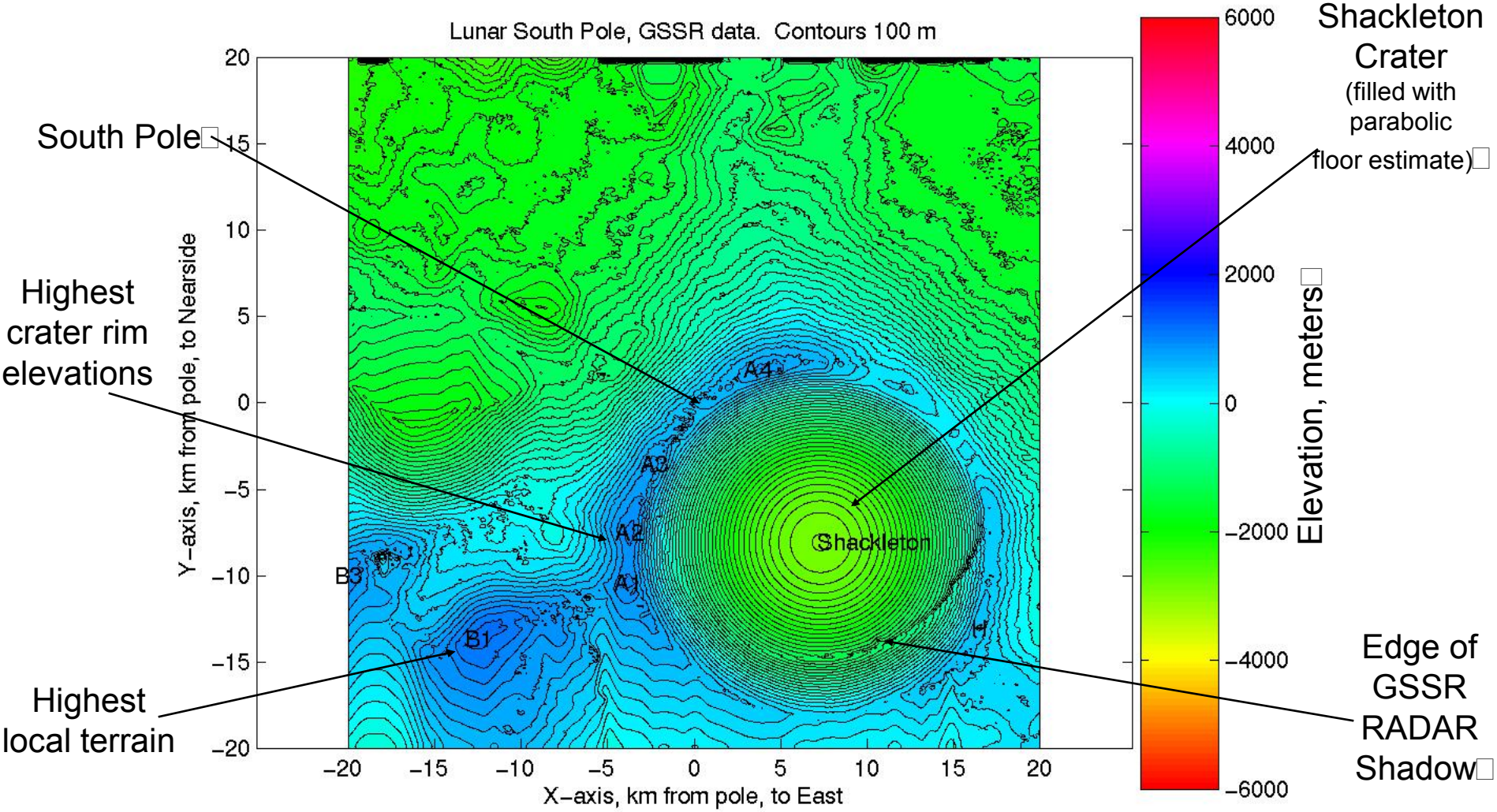
- JPL's Goldstone Solar System Radar (GSSR) team measured lunar South pole elevations in 2006.
  - They produced a Digital Elevation Model with 40m horizontal resolution.
  - The Model covers over 100 km radius around the pole, minus RADAR shadow areas.
- GSSR able to see into polar 'cold traps'
  - Earth was at 6 degrees elevation as seen from lunar South pole. This favorable viewing is due to lunar librations.
  - GSSR can not directly detect ice.
- Elevation data was processed into horizon masks:
  - Confirm areas that are permanently shaded.
  - Find peaks of illumination, and illumination metrics.

GSSR Elevations, lunar South pole

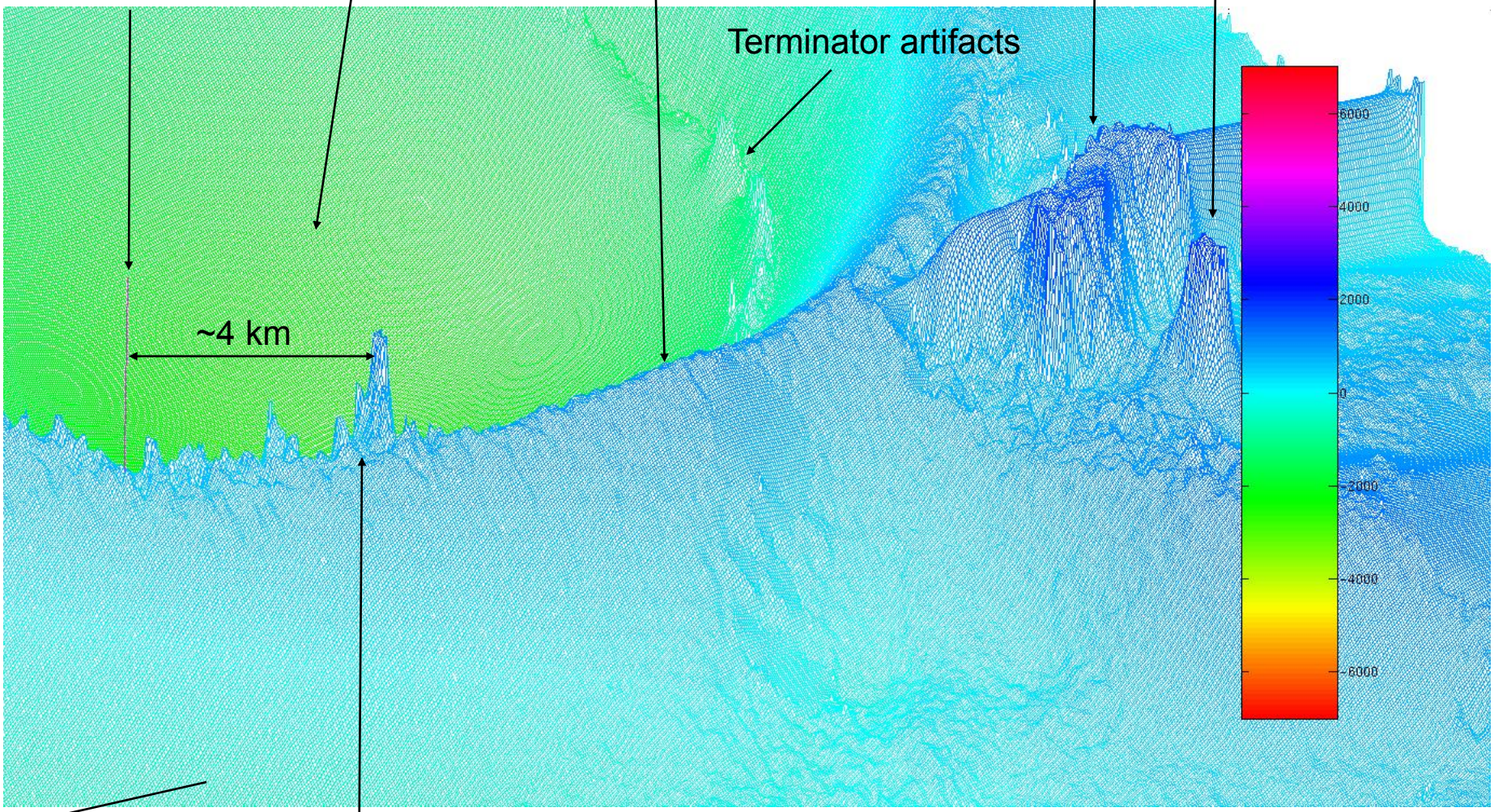


Topographic Map of Shackleton Crater

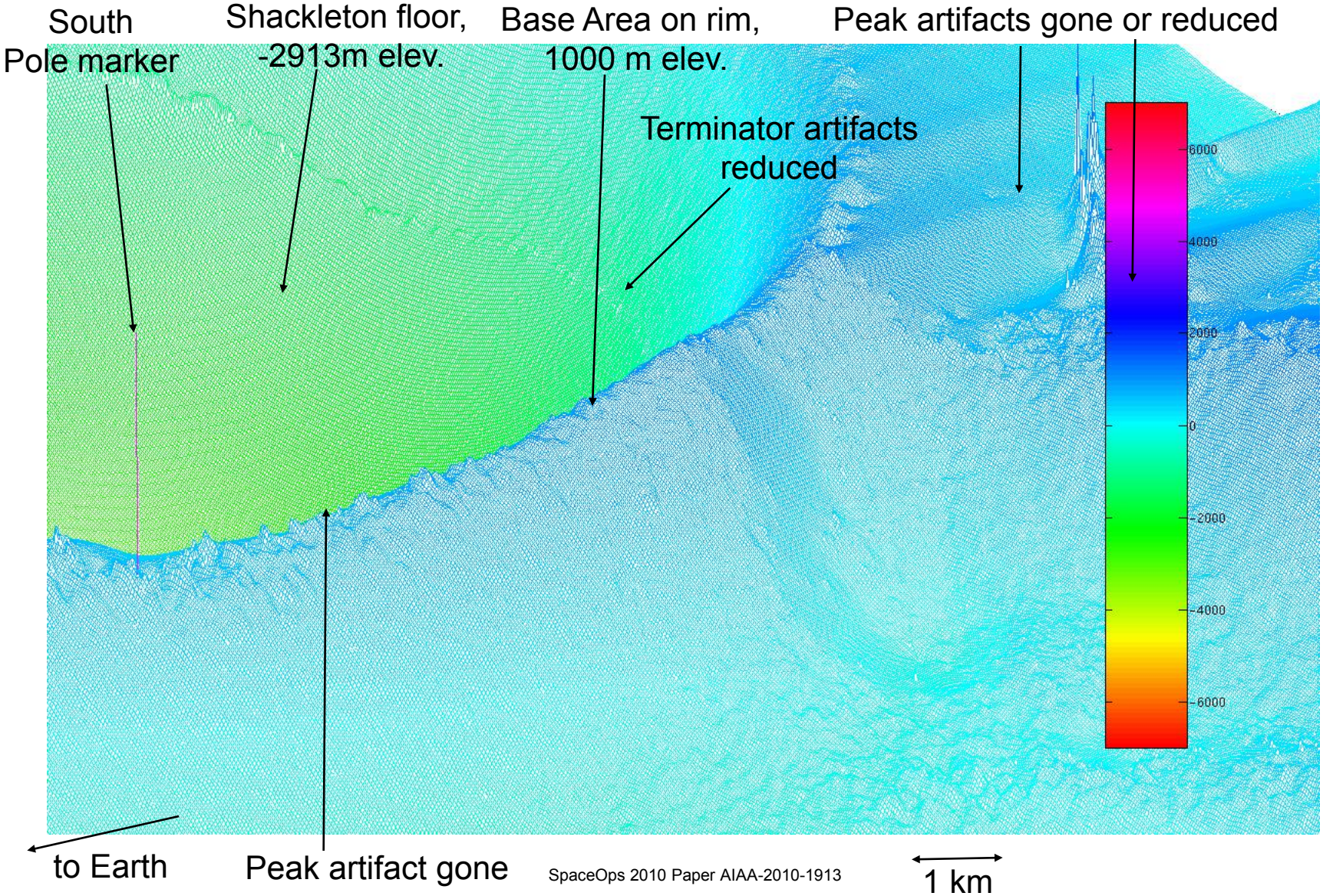
Letters show favorable base sites



40m Resolution Grid, with Artifacts



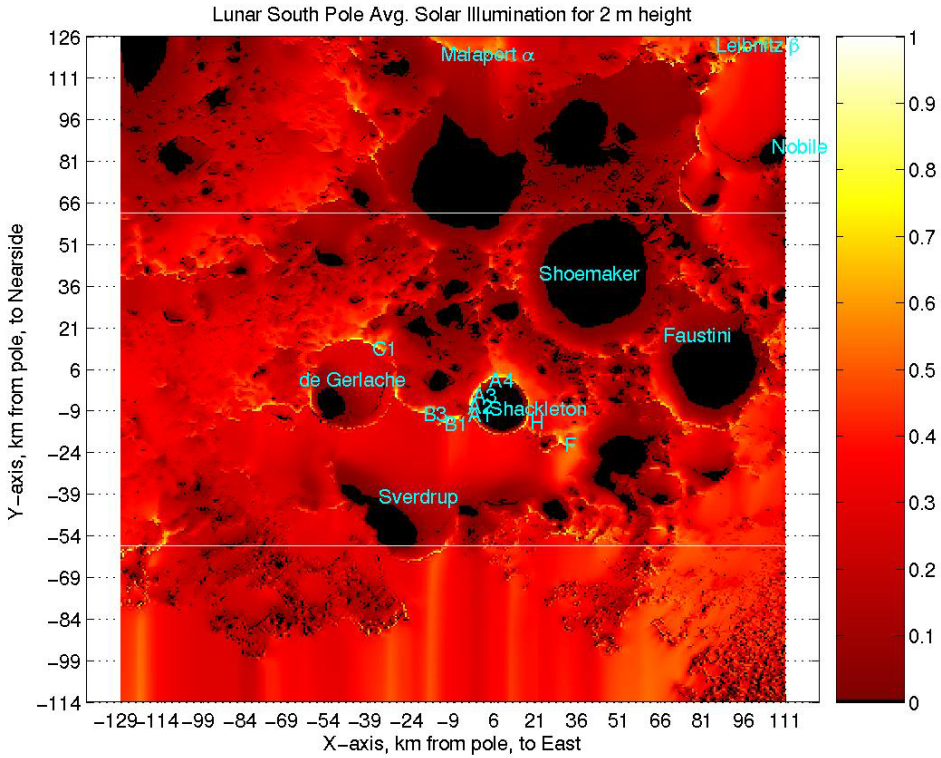
Artifacts Removed

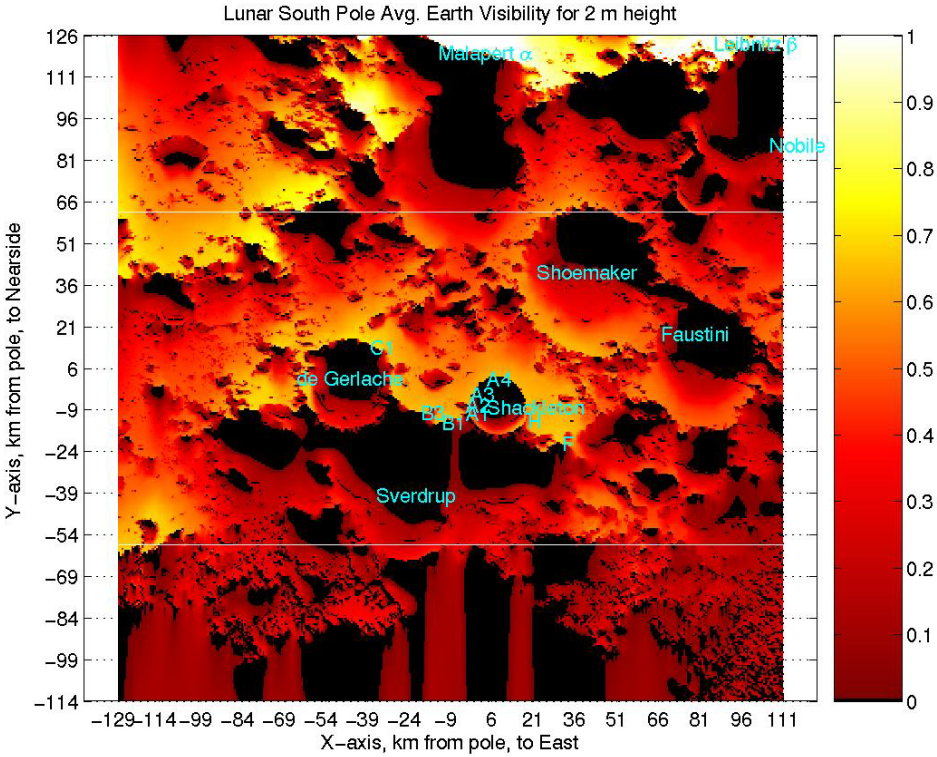


Lunar Base Communications Study

- Purpose: Determine the Direct To Earth (DTE) communications availability at polar bases
  - First, find base locations with good solar illumination.
  - Then, compute solar illumination and DTE metrics.
- Methodology
  - Get new 40 meter resolution elevation data from GSSR group
    - Provided the lunar South pole elevation data for lunar studies.
    - Also provided a 1997 lunar North pole data at 600m resolution.
  - Remove artifacts and fill in shadows in elevation model.
  - Create coarse maps at 600m resolution of solar illumination and DTE visibility. For each 600 m pixel in the grid:
    - Compute horizon mask of lunar surface for 2m tall viewer.
    - Convert horizon mask from azimuth/elevation to selenographic lat/long.
    - Assume a uniform distribution for sun positions within the libration boundaries defined by rectangle in lat/long.
    - Compute the percent of bounding rectangle covered by horizon mask.
  - Pick coarse map sites with most illumination, create medium map of 2 km x 2 km at 40 m resolution.
  - Select medium map sites with most illumination for 'fine resolution' analysis at 40-meter resolution.

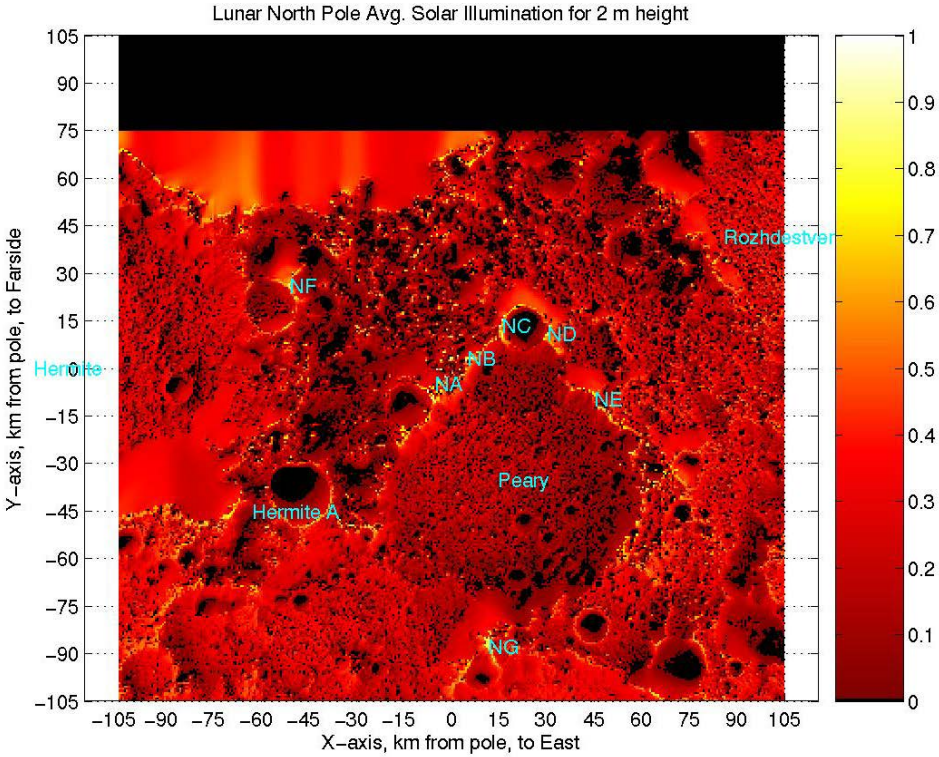
Coarse Results, Lunar South Pole

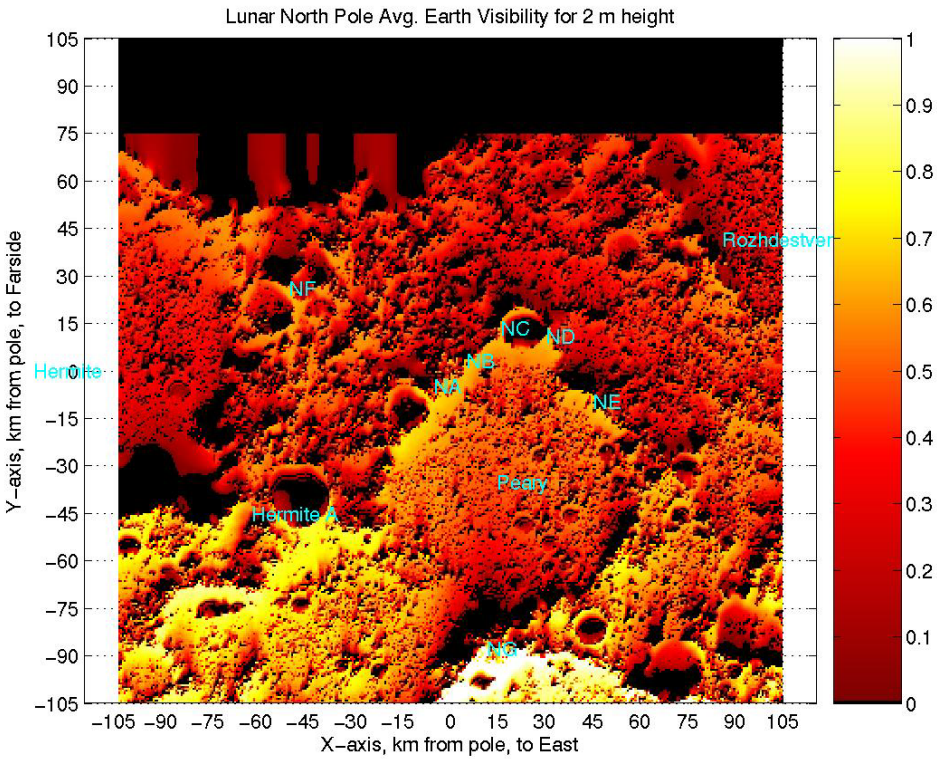




Results are for a multi-year average illumination

Coarse Results, Lunar North Pole

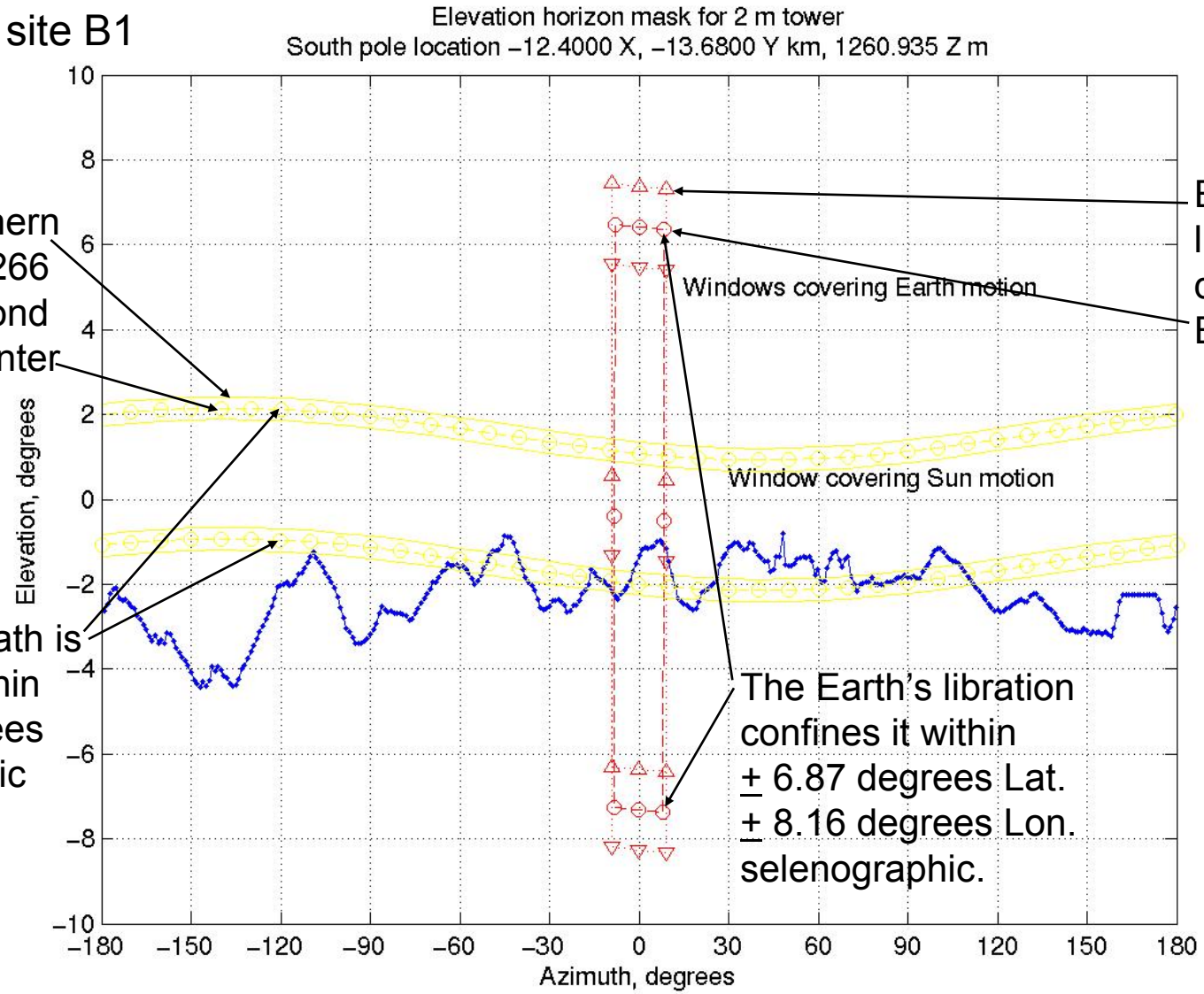




Results are for a multi-year average illumination

Fine resolution Horizon Mask, Az/Elev

South pole site B1



Solar Southern limb is 0.266 degree beyond Solar center

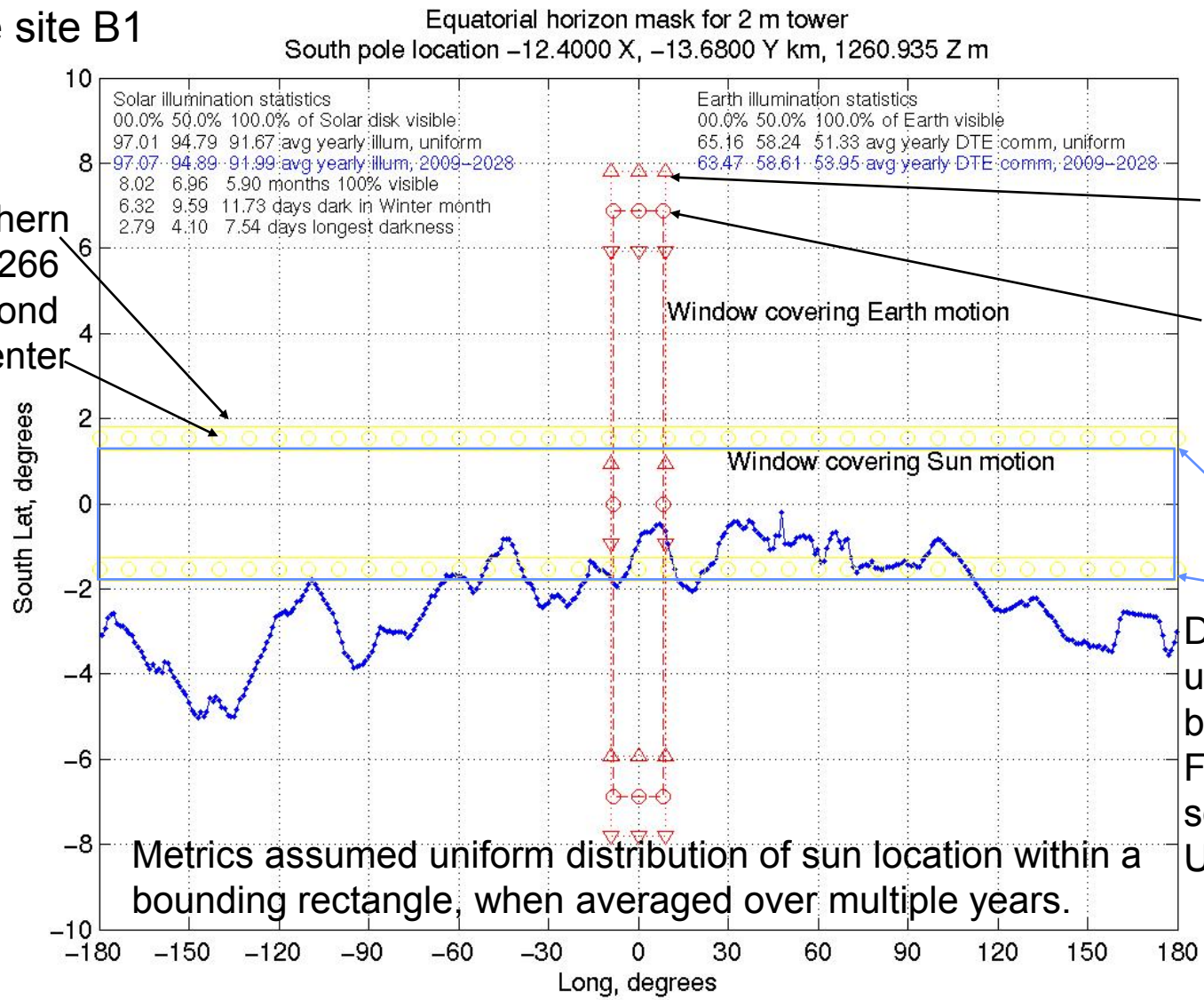
Earth Southern limb is 0.95 degree beyond Earth center

The Sun's path is confined within ± 1.54 degrees selenographic Latitude.

The Earth's libration confines it within ± 6.87 degrees Lat. ± 8.16 degrees Lon. selenographic.

Fine resolution Horizon Mask, Lat/Lon.

South pole site B1



Solar Southern limb is 0.266 degree beyond Solar center

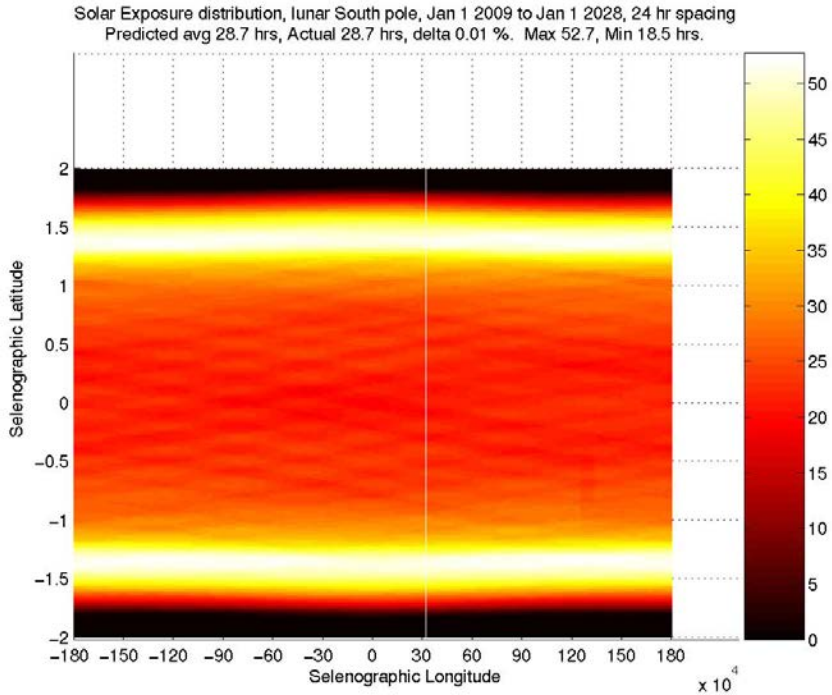
Earth Southern limb is 0.95 degree beyond Earth center

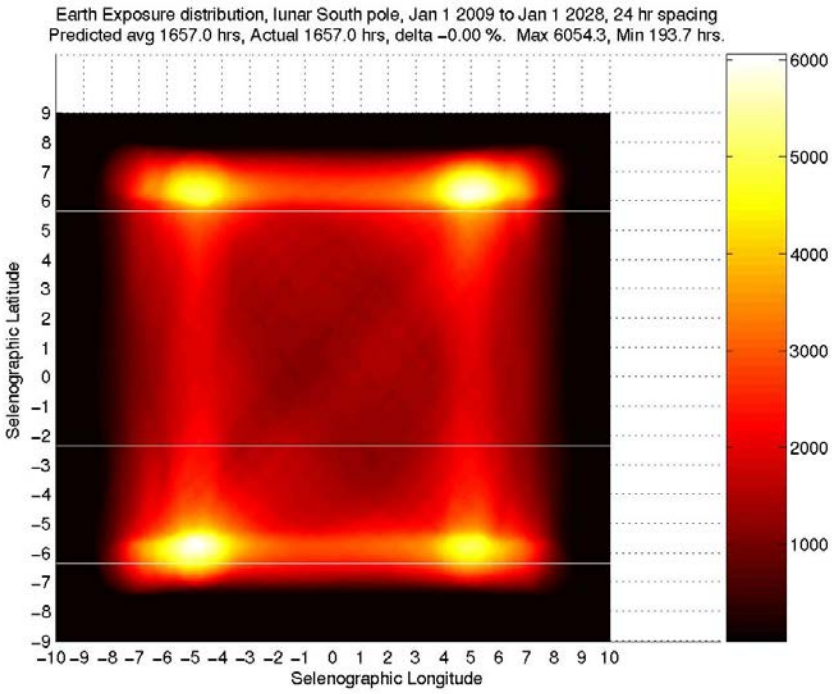
Different metrics use different bounding areas. For 100 % of solar disk visible, Use this area.

Metrics assumed uniform distribution of sun location within a bounding rectangle, when averaged over multiple years.

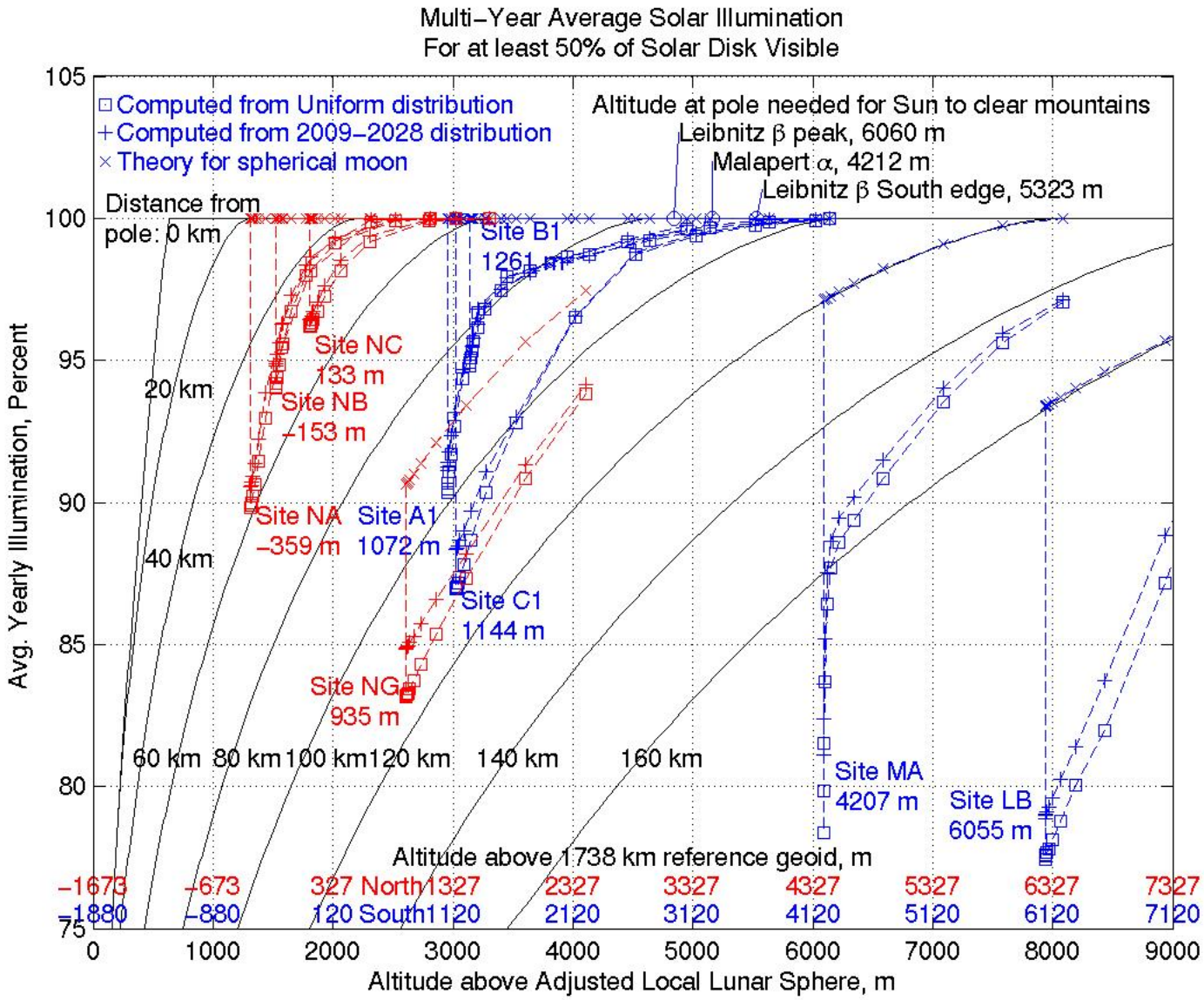
Re-evaluate Bases With Ephemeris Data

- **Metrics were also computed using a multi-year average of sun / Earth ephemeris locations.**
  - **Ephemeris used 24-hour spacing for years 2009-2028.**
  - **Data was integrated to make selenographic lat/long exposure distribution, to replace uniform distribution.**
  - **Results agree with simple uniform distribution to within 5%.**

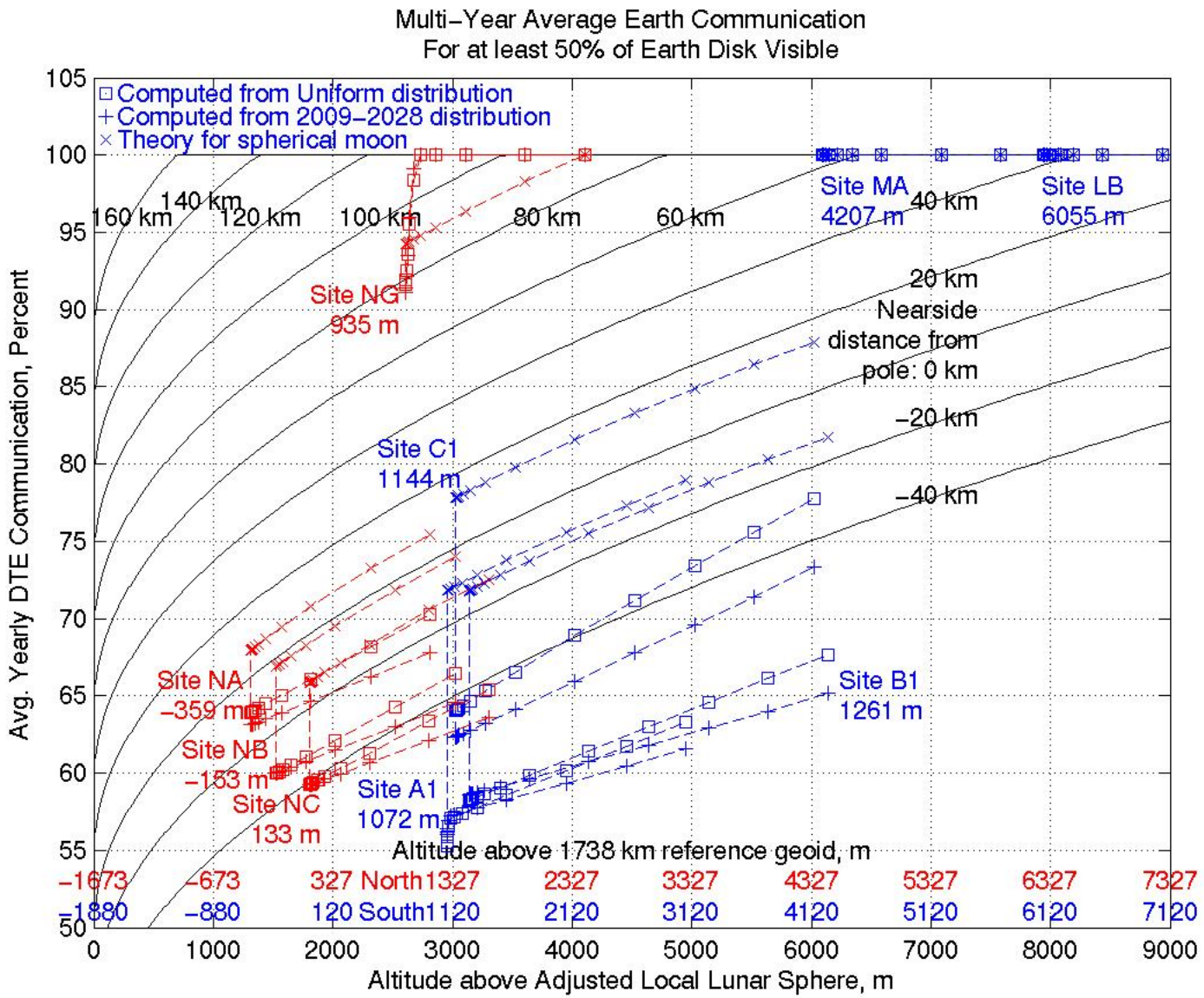




Towers help, but aren't a feasible solution

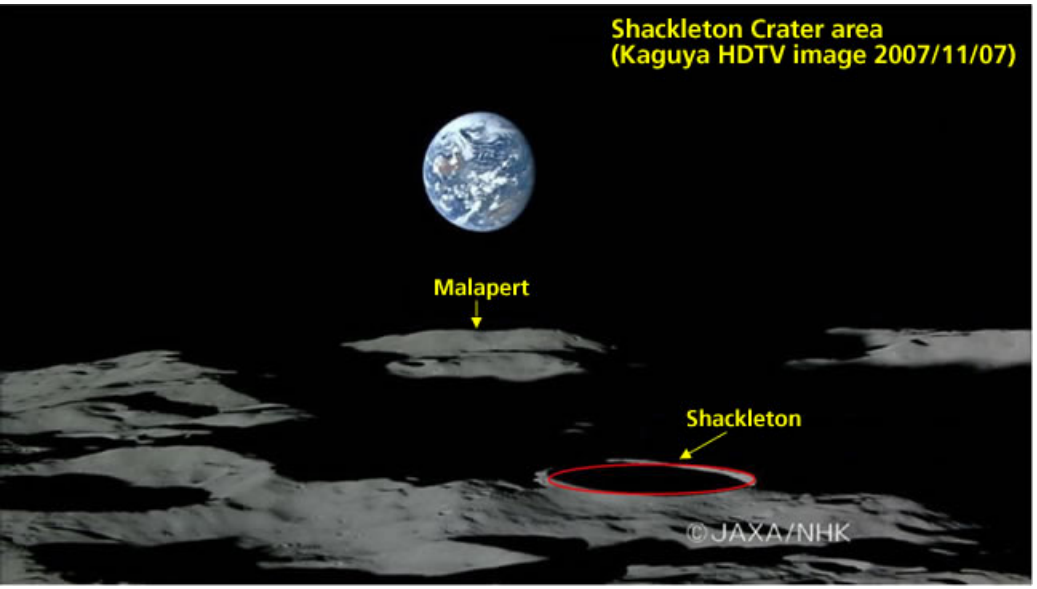


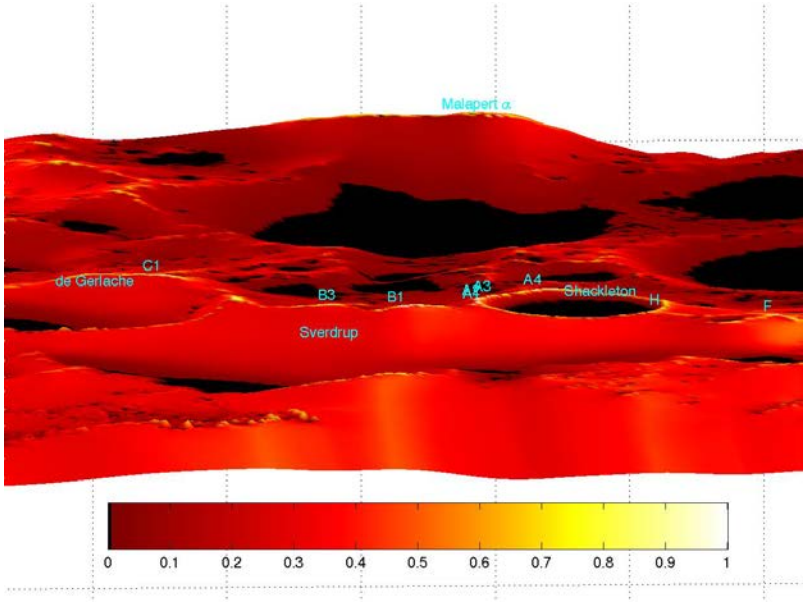
Southern Mountains have 100% DTE comm.



Comparison with Spacecraft Images

- Kaguya image of lunar South pole, 11/07/2007 [courtesy of SELENE mission website, http://wms.selene.jaxa.jp]
- Multi-year avg. of solar illumination, same view. Derived from GSSR elevation data.
- Views of terrain are very similar, except for RADAR shadow.



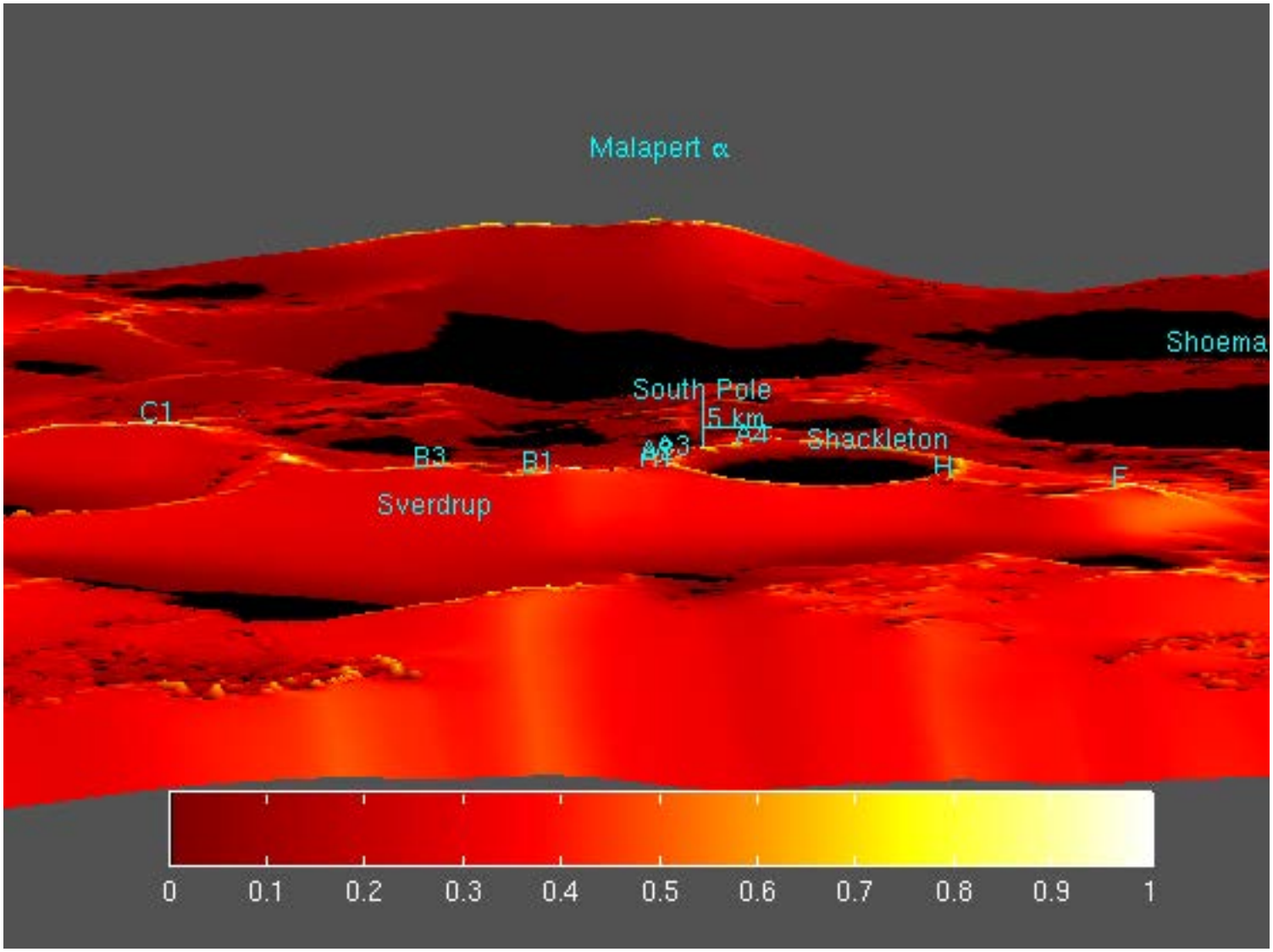


Summary

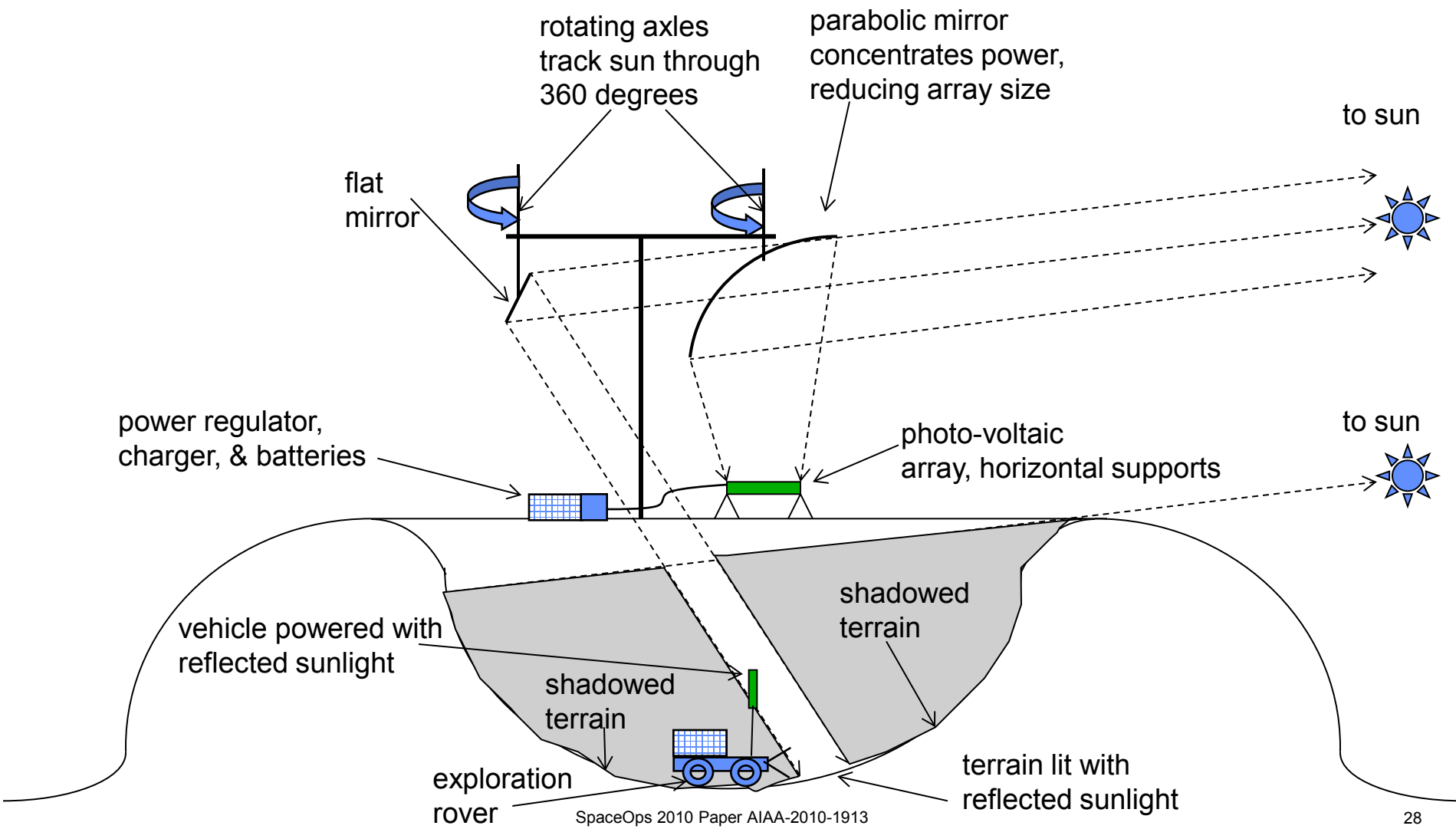
- GSSR elevation data agrees well with lunar photos.
- Using multi-year approximations of Earth and Sun motions simplified illumination calculations.
  - Results agreed with ephemeris-based average illuminations for the most favorable base locations.
- There are several illumination metrics to consider:
  - Days of darkness / continuous light. % of disk covered.
- No site at either pole has 100% solar illumination.
- Base sites with 90%+ solar have only 60% Earth Communication availability.
  - This bolsters the case for lunar relay satellites.
  - A South pole base should consider a mountain relay
    - Malapert α peak and Leibnitz β have continuous relay to Earth.
    - Each peak has 9+ days of darkness in Winter.

Backup Material

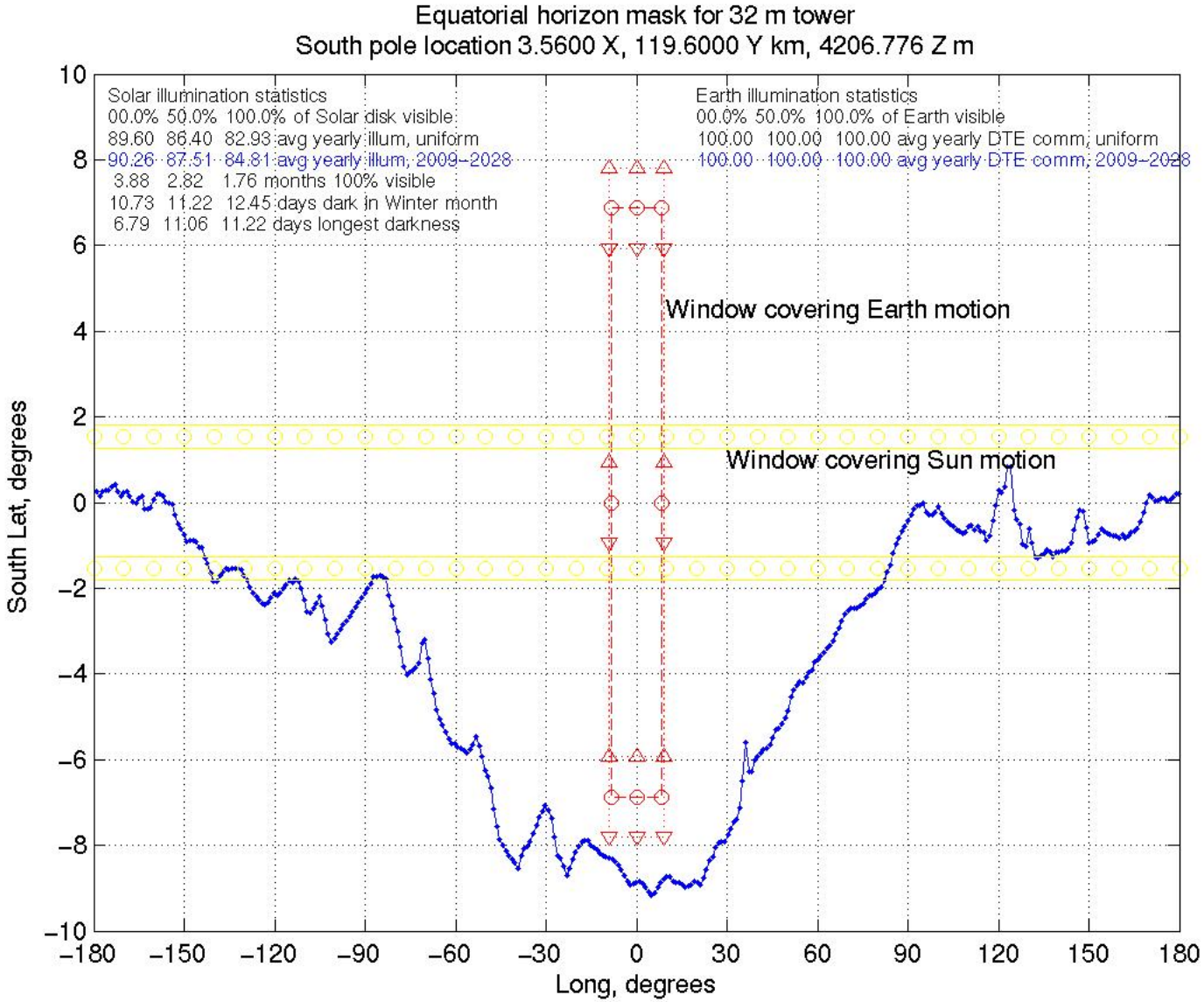
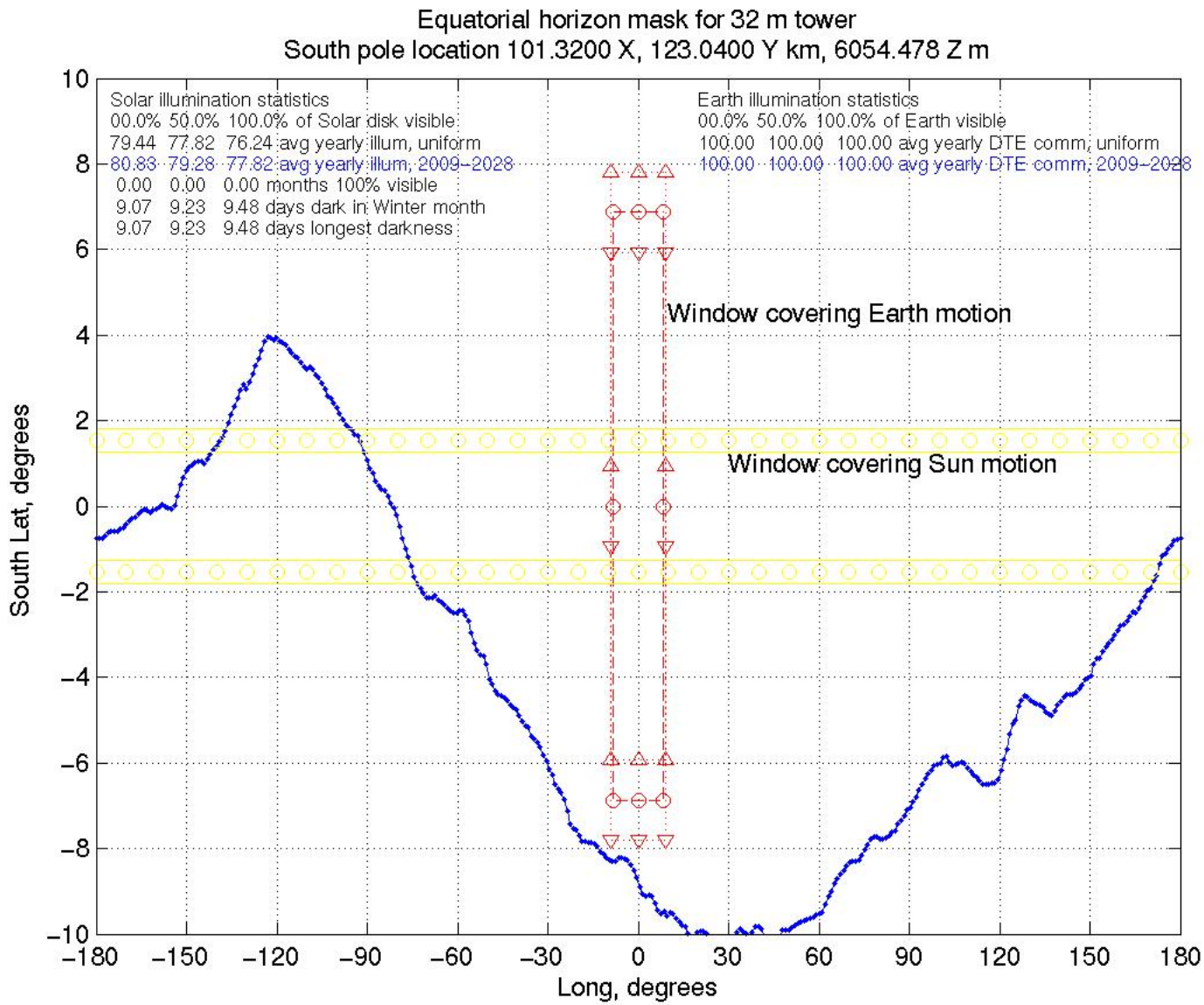
Flyover of lunar South pole sites



Heliostat design puts array flat on surface



Malapert α Peak



Leibnitz β Peak