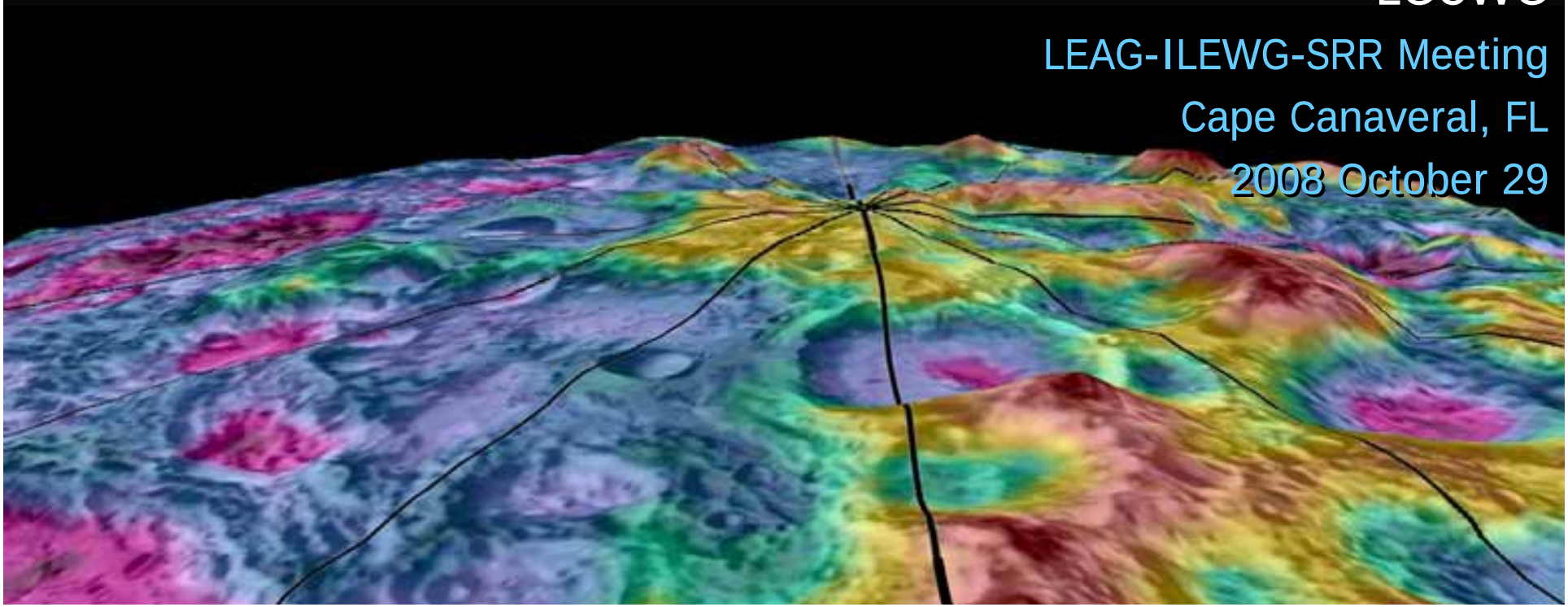
# *International Standards and the NASA Lunar Geodesy and Cartography Working Group*

Presented by Jeff Plescia
for Brent Archinal
LGCWG

LEAG-ILEWG-SRR Meeting
Cape Canaveral, FL
2008 October 29



## *Outline*

- Addressing Questions of this Meeting
- Identified Needs
  - Example: differences due to coordinates confusion/errors
- LGCWG Operation/Activities
- Membership
- Current work
  - General Lunar Coordinates standards
  - Lunar mosaicking recommendations
  - DEM evaluation recommendations
- Continuing work

# *Addressing Meeting Questions*

1. What technologies need to be developed now for human return to the Moon (and beyond)?
   - Mapping technologies to access, register (geodetically control), and use all lunar datasets, such as visible, multispectral, and radar imaging and lidar
2. What are the critical elements for robotic development, habitats, and hazard prevention?
   - Important initial one is acquisition and registration of mapping data for planning, resource location, safe landing and surface operations, and surface development
3. How can international standards be developed and different agency technology/R&D roadmaps be coordinated?
   - The LGCWG is attempting to lead the development and coordination of lunar coordinate and mapping standards, as we describe here

# *Identified Needs*

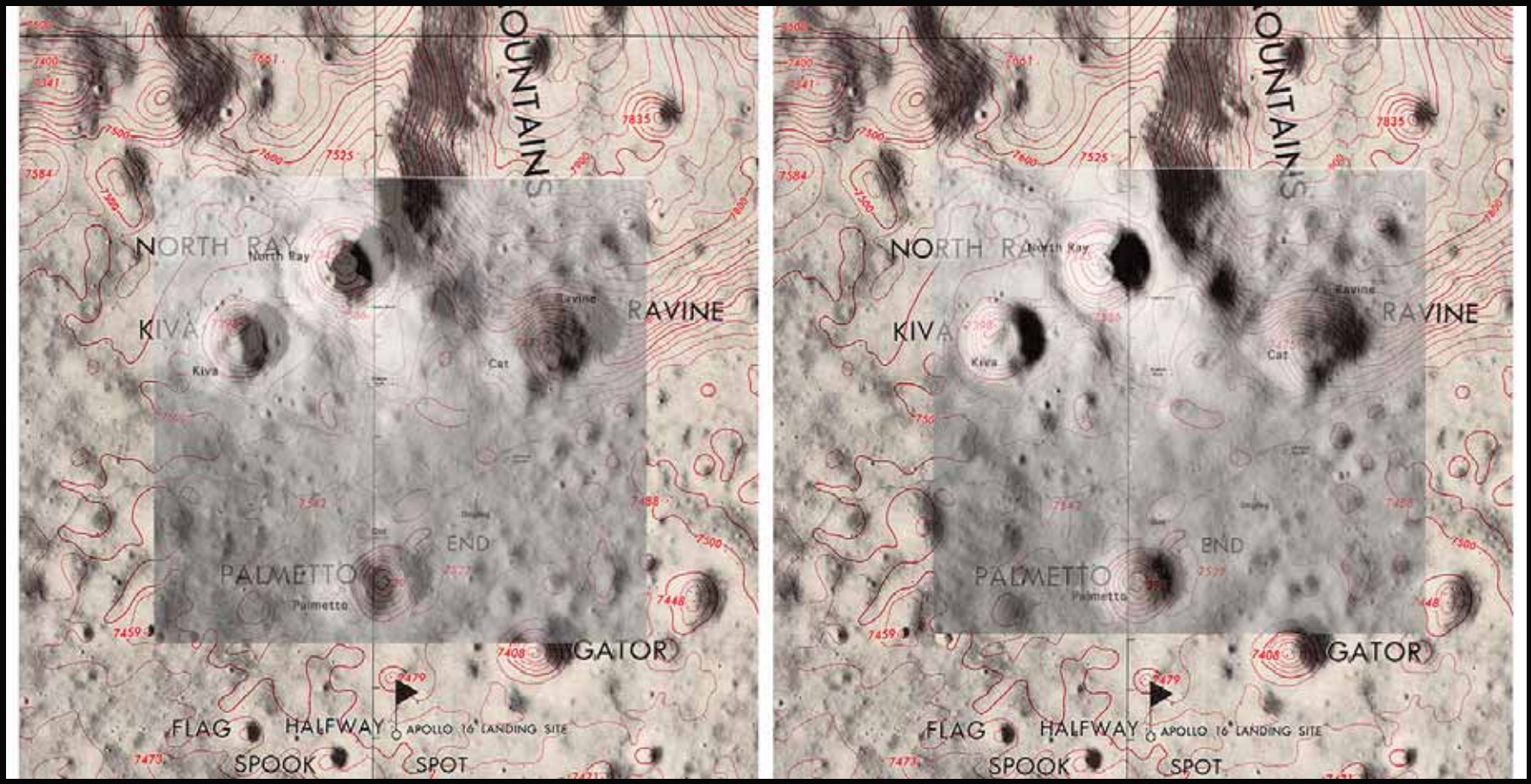
- Lunar reference coordinate system and frames standards
  - Mean Earth/polar axis vs. Principal Axis systems
  - Frames creation / ties to Lunar Laser Ranging coordinates
  - Lunar reference shape
  - Lunar gravity
- Common cartographic standards
  - Creation of lunar data products
  - High and low level data formats
  - Archiving requirements
- Image processing requirements and standards
  - Large image file formats
  - Camera/sensor calibration and modeling
  - Control networks
- Cooperation within and across all missions and space agencies

# *Example: Horizontal Coordinate Differences*

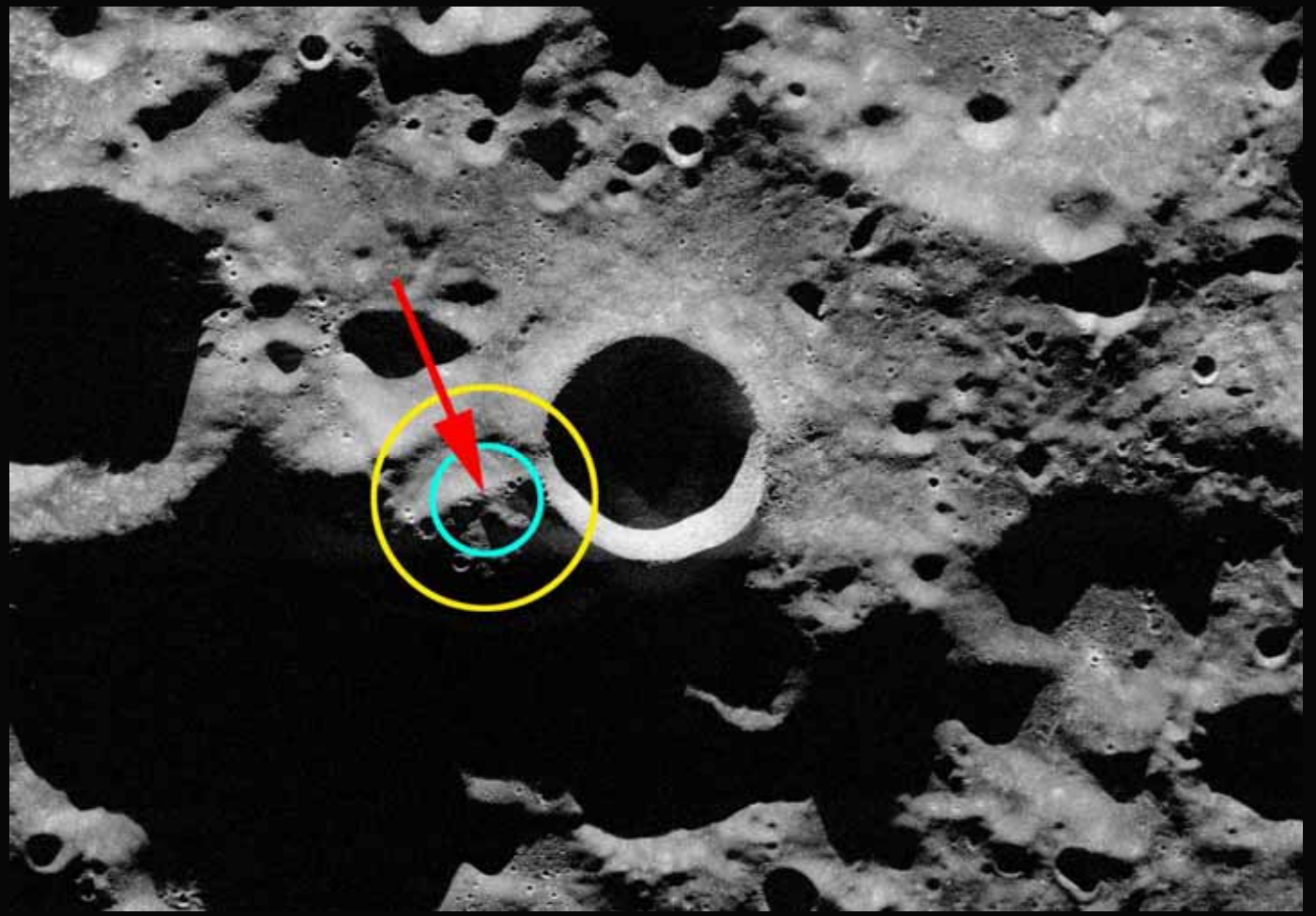
Below are possible coordinate differences, due to standards confusion or errors of difference systems and frames

| | *Size* | *Comments* |
|---|---|---|
| CLCN vs. ULCN 2005 frame | 7 km ave. to > 20 km | Original Clementine products |
| Spacecraft ephemeris/pointing | 5-10 km | Apollo |
| Spacecraft ephemeris/pointing | few 100 m to 3 km | Clementine |
| ULCN 2005 frame accuracy | few 100 m to 3 km | Estimate only |
| ME vs. PA system | <860 m | 560 m in longitude at equator |
| Old IAU ephemeris vs DE 421 | ~105 m | Closed formulae vs. ephemeris |
| Spacecraft ephemeris/pointing | 100-300 m? | prelim. Chang'E-1, Kaguya, C-1 |
| Spacecraft ephemeris/pointing | 50-100 m? | preliminary LRO |
| Spacecraft ephemeris/pointing | 30-50 m? | final LRO |
| DE 421 vs. DE 403, PA system | ~30 m | PA depends on gravity field def. |
| DE 421 accuracy, ME system | 5-10 m | ME tied to LLR frame |
| LLR frame | <10 cm | 4 retroreflectors |

# *Why Should You Care?*




# *Why Should You Care?*



# *LGCWG Operation/Activities (1)*
## *(from group charter)*

Consider comments and recommendations from the U.S. and international community, make decisions by consensus of core membership

Follow or recommend changes to basic lunar standards of the IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements

Otherwise define and extend geodetic / cartographic requirements as needed

Activities include:

- Recommend common geodetic and cartographic standards for use by NASA components
- Provide such standards for possible use by international missions and space agencies
- Recognize and make recommendations on the use of updated lunar reference frames
- Define lunar gravity field standards and updates
- Define updates to lunar shape model
- Define other image processing requirements
- Define product requirements
- Assist PDS and/or IPDA with archiving requirements

# *LGCWG Operation/Activities (2)*

- Created in late 2007
- Under NASA Lunar Precursor Robotic Program, but to provide for general NASA support and encourage international cooperation
- Patterned after successful Mars WG (MGCWG), Tom Duxbury, chair
- Operating with telecons and occasional meetings, meeting presentations (e.g., here)
- Forum for discussing data processing plans, new products
- However, input & participation encouraged from anyone with interest
  - Participation in telecons is open
  - Meeting summaries available on request
- Web site coming
- If you wish to be on e-mail list / participate in telecons, contact:
  - barchinal (at) usgs.gov
  - Address is on abstract
- Following are
  - Membership
  - Activities/issues addressed so far

# *Lunar Geodesy and Cartography Working Group Invited Membership*

Core membership:

Brent Archinal – USGS – Chair

Chuck Acton – JPL/NAIF
Ben Bussey – JHU/APL
Bruce Campbell – Smithsonian
Anthony Cook – University of Aberystwyth, UK
Daniela Despan – Observatoire de Paris (SMART-1 processing)
N. S. Gopinath – ISRO (Chandrayaan-1)
Randy Kirk – USGS
Frank Lemoine – GSFC
Juergen Oberst – DLR Germany
Mark Robinson – ASU
David Smith – GSFC
Ted Sweetser – JPL (Constellation Standards Coordinate Systems)
James Williams – JPL
Jixian Zhang – Chinese Acad. of Surveying & Mapping (Chang'e project leader for lunar geodesy & cartography)

Kaguya representative (invited)

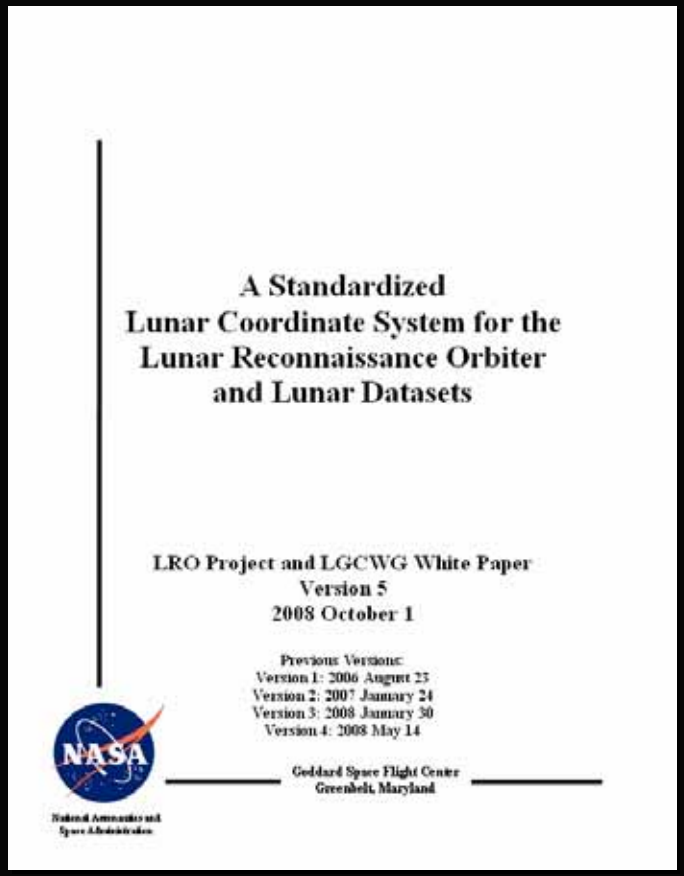
Ex Officio membership:

Mark Nall – MSFC – LPRP Program
Ray French – MSFC – LPRP Program
Jeff Plescia – JHU/APL – LPRP Program
Mike Wargo – NASA – ESMD
Gordon Chin – GSFC – LRO Associate Project Scientist
Rich Vondrak – GSFC – LRO Project Scientist
Tony Colaprete – ARC – LCROSS
Kelly Snook – NASA – SMD
Wendell Mendell – JSC – Constellation
Lisa Gaddis – USGS – Planetary Data System
Zach Crues – JSC

Revised 2008 April 14

# *Lunar Coordinates White Paper*

- General lunar coordinates standards reference
  - Affirms IAU WGCCRE recommended use of the mean Earth/polar axis (ME) coordinate system
  - Recommends use of either LLR coordinates, or JPL DE 421 ephemeris and Euler angles to define ME frame
- Originally created by LRO Project
  - Input from USGS, NAIF, project, instrument teams
- LGCWG
  - Rather than create new standard/document…
  - Have revised jointly with LRO project
- Current version available soon from:
  - LRO web site, library page http://lunar.gsfc.nasa.gov/library/451-SCI-000958.pdf



A Standardized
Lunar Coordinate System for the
Lunar Reconnaissance Orbiter
and Lunar Datasets

LRO Project and LGCWG White Paper
Version 5
2008 October 1

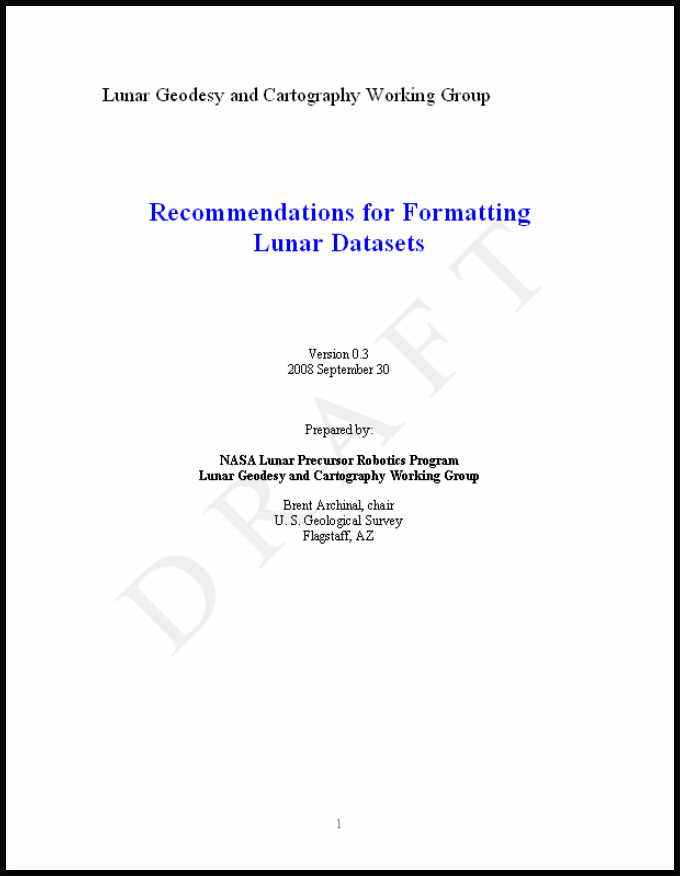
Previous Versions:
Version 1: 2006 August 23
Version 2: 2007 January 24
Version 3: 2008 January 30
Version 4: 2008 May 14

NASA

Goddard Space Flight Center
Greenbelt, Maryland

# *Lunar Mosaicking Recommendations*

- Recommendations for formatting lunar datasets
- Trying not to get preoccupied with file (tile) size issues
- Contents
  - Definitions
  - Coordinate system and frame guidelines
  - Tiling schemes, projections
  - Use 1°/2n per pixel resolution for global products
  - Image conventions
  - Examples
- LGCWG created late in process, but has helped with defining LRO (RDR) products
- Should be most useful for Lunar Mapping and Modeling Project products for Constellation use
- Available to international missions
- Current draft available from
  - http://tinyurl.com/Lunardata0809



Lunar Geodesy and Cartography Working Group

**Recommendations for Formatting Lunar Datasets**

Version 0.3
2008 September 30

Prepared by:

**NASA Lunar Precursor Robotics Program**
**Lunar Geodesy and Cartography Working Group**

Brent Archinal, chair
U. S. Geological Survey
Flagstaff, AZ

DRAFT

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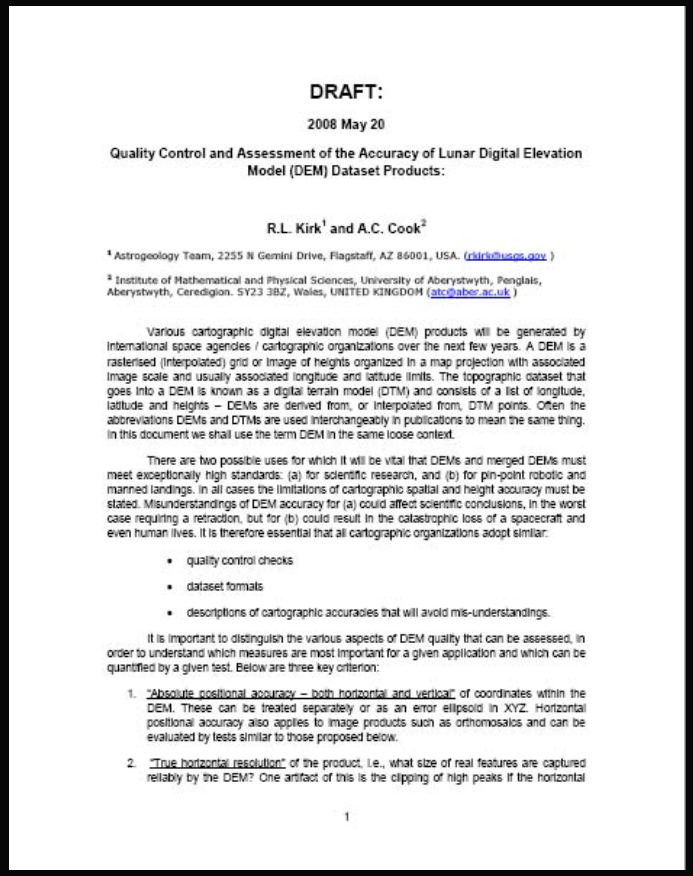
# *DEM Assessment*

- Guidelines for accessing accuracy, quality of lunar DEMs
- Related to lunar mosaicking recommendations
- Mostly developed by R. Kirk (USGS) and A. Cook (Univ. of Aberystwyth)
  - Being reviewed by LGCWG
- Several methods for evaluating DEMs
  - Mostly intended for local to regional mapping
  - Some ideas for checking global DEMs
  - In practice level of assessment would likely depend on use of data
- Current draft available at:
  - http://tinyurl.com/LunarDEMs0809



**DRAFT:**

2008 May 20

**Quality Control and Assessment of the Accuracy of Lunar Digital Elevation Model (DEM) Dataset Products:**

R.L. Kirk[1] and A.C. Cook[2]

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[2] Institute of Mathematical and Physical Sciences, University of Aberystwyth, Penglais, Aberystwyth, Ceredigion. SY23 3BZ, Wales, UNITED KINGDOM (atc@aber.ac.uk )

Various cartographic digital elevation model (DEM) products will be generated by international space agencies / cartographic organizations over the next few years. A DEM is a rasterised (interpolated) grid or image of heights organized in a map projection with associated image scale and usually associated longitude and latitude limits. The topographic dataset that goes into a DEM is known as a digital terrain model (DTM) and consists of a list of longitude, latitude and heights – DEMs are derived from, or interpolated from, DTM points. Often the abbreviations DEMs and DTMs are used interchangeably in publications to mean the same thing. In this document we shall use the term DEM in the same loose context.

There are two possible uses for which it will be vital that DEMs and merged DEMs must meet exceptionally high standards: (a) for scientific research, and (b) for pin-point robotic and manned landings. In all cases the limitations of cartographic spatial and height accuracy must be stated. Misunderstandings of DEM accuracy for (a) could affect scientific conclusions, in the worst case requiring a retraction, but for (b) could result in the catastrophic loss of a spacecraft and even human lives. It is therefore essential that all cartographic organizations adopt similar:

- quality control checks
- dataset formats
- descriptions of cartographic accuracies that will avoid mis-understandings.

It is important to distinguish the various aspects of DEM quality that can be assessed, in order to understand which measures are most important for a given application and which can be quantified by a given test. Below are three key criterion:

1. "Absolute positional accuracy – both horizontal and vertical" of coordinates within the DEM. These can be treated separately or as an error ellipsoid in XYZ. Horizontal positional accuracy also applies to image products such as orthomosaics and can be evaluated by tests similar to those proposed below.
2. "True horizontal resolution" of the product, i.e., what size of real features are captured reliably by the DEM? One artifact of this is the clipping of high peaks if the horizontal

1

# *Continuing Work*

- Finish circulating and finalizing current documents
  - Collecting input from PDS, international missions
  - Later, revise when necessary
- Continue to address Constellation, community needs
  - Possibly develop recommendations on registering (controlling) datasets
  - Continuing LMMP work
  - Working with international missions
- Operationally
  - Continue meeting presentations
  - Place material and other lunar coordinates info on web site
  - Continued telecons, possible meetings, but dependent on need

*Thank you.*

# *Example: Vertical Coordinate Differences*

Below are possible coordinate differences, due to standards confusion or errors of difference systems and frames

| | *Size* | *Comments* |
|---|---|---|
| Sphere vs. actual | -11 to +12 km | ULCN 2005 min/max |
| ULCN 2005 topo accuracy | <100 m to sev. km | ULCN 2005 EVP |
| Incorrect reference sphere | 400 m | IAU r = 1738.4 km vs. 1738 km |
| Ellipsoid vs. sphere | 400 m | Clementine LIDAR r vs IAU r |
| Laser Altimeter | ~1 km? (orbit) | Apollo (1 m res) |
| LIDAR | 130 m (orbit) | Clementine (40 m res) |
| LELA | 50 m? (orbit) | Chang'E-1 (5 m res) |
| LALT | 50 m? (orbit) | Kaguya (5 m res) |
| LLRI | 50 m? (orbit) | Chandrayaan-1 (5 m res) |
| LOLA | 50 m? (orbit) | preliminary LRO (1 m res) |
| LOLA | ~2 m (orbit) | final LRO (1 m res) |
| LLR frame | <10 cm | 4 retroreflectors |

# CHARTER

## *Lunar Geodesy and Cartography Working Group*
## *Lunar Precursor Robotic Program*

Provide support for US Lunar Precursor Robotic Program (LPRP) Office

- Reports to the NASA Outpost Science and Exploration Working Group through Tony Lavoie (Marshall Space Flight Center) – LPRP Office Program Manager
- Transcends all NASA Lunar Mission Development (A - D) and Implementation (E ) Phases

Consider comments and recommendations from the U.S. and international community, make decisions by consensus of core membership

Follow or recommend changes to basic lunar standards of the IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements

Otherwise define and extend geodetic / cartographic requirements as needed

Activities include:

- Recommend common geodetic and cartographic standards for use by NASA components
- Provide such standards for possible use by international missions and space agencies
- Recognize and make recommendations on the use of updated lunar reference frames
- Define gravity field standards and updates
- Define updates to shape model
  - Sphere size, elevation (potential) model
- Define other image processing requirements
  - Large image file formats
  - Camera/sensor calibration and modeling
  - Control networks
- Define product requirements
  - Controlled, semi-controlled, uncontrolled
  - Mosaic vs. projected images, mosaic resolution
- Assist PDS and/or IPDA with archiving requirements
  - Data formats, including digital mosaic standards (projections, map conventions, scales, etc.)

Original version, 2007 October 19

# *Activities so far (details)*

- Created in late 2007
- 8 telecons, and meeting/telecon at LPSC, meeting summaries
- General coordinates issues addressed:
  - Have affirmed IAU WGCCRE (and LDWG) recommended use of the mean Earth/polar axis (ME) coordinate system for the Moon for creation of cartographic products
  - Recommended use of the JPL DE 421 ephemeris to specify the initial lunar body-fixed frame in the principal axes system, with associated Euler angles, to define a ME frame
  - Informal current gravity model recommendation of using LP155P, A. Konopliv et al.'s update to their published LP150Q – formal recommendation later after new models appear
  - Working jointly with LRO project to maintain Lunar Coordinates White Paper (see slide above)
- Have reviewed Constellation coordinate standards
- Developing recommendations or a standard for creating lunar mosaics and global map products (see slide above)
- Developing recommendations for assessing lunar digital elevation models (see slide above)
- Planning web site for distributing information and recommendations on lunar mapping standards and conventions
- Meeting presentations (NLSI, COSPAR, here)
- Serving as forum for announcing new lunar data products (e.g. ephemeris, Lunar Orbiter mosaic)
- Providing an opportunity to discuss data processing plans

# *The Need for Control of Image Datasets*

- Only way to connect/register/compare data at known levels of precision and accuracy to common coordinate system
- Data cannot be compared with confidence and synergistic value of datasets lost otherwise
- Users always want best precision and accuracy possible and want to know what it is
  - important for mineralogic, geologic, and scientific investigations
  - *critical* for landing and landed operations
  - lander maneuvering costs and danger (including loss of mission) rise significantly with uncertainty. C.f. Apollo 11, 12, 15 landing problems
- Best way to remove seams for qualitative work
- Necessary for proper orthometric projection of data (registration of images to topography)
- Necessary for registration of multispectral data
- Necessary for photometric correction of data
- Note that usually considered “expensive”, but not so relative to the cost of data collection, or worse, the inability to use the data or the loss of a mission

=> The value of data sets increases synergistically/exponentially when controlled, so it is essential that this work be planned for and done with new lunar data

# *Useful References –*
## *Lunar Coordinates, Mapping, Topography*


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