

CONSIDERATIONS ON UPDATING THE LUNAR REFERENCE FRAME. Brent Archinal¹ and the IAU Working Group on Cartographic Coordinates and Rotational Elements, ¹U. S. Geological Survey, Astrogeology Science Center (2255 N. Gemini Drive, Flagstaff, AZ 86004, USA; barchinal@usgs.gov).

Introduction: The IAU Working Group on Cartographic Coordinates and Rotational Elements (WGCCRE) has made past recommendations regarding the lunar reference frame [1]. Over the last 2 years both the Artemis III SDT report [2] and the LEAG-MAPSIT LCDP SAT report [3] have included recommendations for an updated lunar reference frame (LRF). Park et al. [4] have published new Solar System ephemeris results that include a new lunar laser ranging (LLR) solution and lunar orientation ephemerides. The latter includes the DE440 ephemeris in the ME frame (defined below), which is compatible with their earlier DE421 ME frame recommended for use by the WGCCRE. Besides NASA's interest in improving the lunar frame, the USA National Geospatial-Intelligence Agency is considering the creation of a Lunar Reference System, which would incorporate a LRF definition [5]. An improved LRF would be of use to many nations and commercial endeavors that are undertaking missions to the Moon.

Given these recent activities and interest on the LRF, and the expected increase in lunar missions by the USA and other nations, both robotic and human, the WGCCRE is considering updating the recommendations on a LRF in its next main report or a separate report. The purpose of this abstract and an earlier abstract and presentation [6] is to solicit input for such a recommendation.

Background: Two different coordinate systems have long been in use for the Moon. These are the Mean Earth/polar axis (ME, sometimes MER for Mean Earth/Rotation) and the Principal Axis (PA) systems. In brief, ME is defined by having 0° longitude in the mean direction of the Earth and an equator defined by the mean direction of the lunar pole, whereas PA is defined by the axes of the principal moments of inertia of the Moon (e.g., see [1]). The WGCCRE previously has recommended the use of the JPL DE421 ephemeris, rotated to an ME frame for defining lunar coordinates.

Issues to Consider: The Moon is one of few bodies in the Solar System without a specific longitude defining feature. After many years of discussion, it may be time to finally use an LLR solution to define the LRF, following long-standing IAU and WGCCRE recommendations [1, p. 7]. Currently a particular such LLR solution is already the underlying basis for the DE421 ME frame. So, such a solution and similar future improved solutions could instead serve to

directly define the frame in the ME system, and in practice would match in a no-net rotation sense to the existing recommended DE421 ME frame.

Separately, the lunar orientation model could now be specified by using the JPL DE440 ephemeris in the ME frame. The new JPL solutions use substantially more available data, and improved modeling compared to the previous (2008) DE421 solution. Differences from the previous model are less than 1 meter during the period 1900–2050. See Figure 1. Differences in the underlying LLR solutions are < 1.5 meters. Such differences are unlikely to be noticeable in the positioning of data products except at the highest current levels of accuracy. This update would nevertheless help to prepare for the best future accuracy, by reducing one source of error.

The current JPL products are the most likely data sources for updating the lunar frame in the near term, as they appear to include the most recent LLR solution and ephemeris results. Eventually, updates would need to consider LLR solutions and ephemerides from other sources, possibly in some sort of combined solutions.

In the meeting presentation, we will present the benefits of making an update and weigh them against the burden of changing the established definition.

Request for input: The WGCCRE is requesting feedback from the lunar community on these issues. Is using (the current new JPL) LLR solution to define the LRF appropriate for both high and low accuracy users and products? Is using the DE440 ephemeris in the DE421 ME frame appropriate as a new lunar orientation model? Are there other LLR and lunar ephemeris solutions that could be considered for use in this process? Feedback to the lead author is welcome, preferably by the time of or at the LPSC. We hope to complete the next version of our main WGCCRE report by the end of this year and possibly include an update for a recommended lunar frame definition.

References: [1] Archinal et al. (2018) *Report of IAU WGCCRE...*, CMDA 130:22. [2] NASA (2020) *Artemis III Sci. Def. Team rep.* SP-20205009602, <https://www.nasa.gov/sites/default/files/atoms/files/artemis-iii-science-definition-report-12042020c.pdf>. [3] LEAG-MAPSIT Special Action Team (2021) *Final Report of the Lunar Critical Data Products SAT*, <https://doi.org/10.5281/zenodo.7236426>. [4] Park et al. (2021) *The JPL Planetary and Lunar Ephemerides DE440 and DE441*, *Astron. J.* 161(3), 105. [5] Garner, T. (2022), *Developing a Lunar Reference System for*

Navigation Safety, ION International Technical Mtg. [6] Archinal et al. (2022) PSIDA Meeting, <https://www.cosmos.esa.int/web/psida-2022/conference-programme> (see final links on page).

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acknowledge the important work of Park et al. [4] that is part of the discussion here.

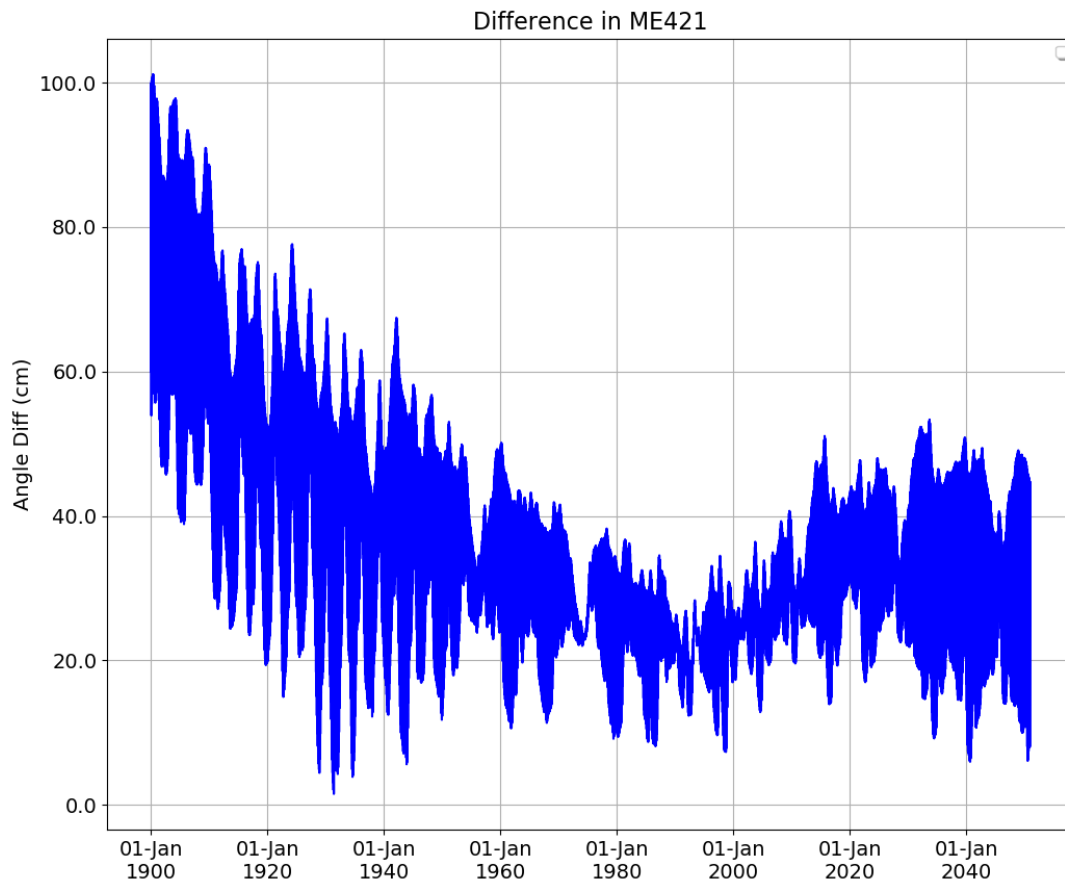


Figure 1: Total difference (all axes) between the JPL DE421 and the JPL DE440 lunar orientation ephemerides in the ME system, from 1900 to 2050. The entire vertical axis covers 100 cm. *Image Credit: Ryan Park, JPL; via Boris Semenov, JPL/NAIF.*