

UPDATE FOR 2020 FROM THE IAU WORKING GROUP ON CARTOGRAPHIC COORDINATES AND ROTATIONAL ELEMENTS. Brent Archinal¹, and the IAU Working Group on Cartographic Coordinates and Rotational Elements, ¹U. S. Geological Survey (2255 N. Gemini Drive, Flagstaff, AZ 86001, USA).

Overview: Approximately every 3 years since 1979, the Working Group on Cartographic Coordinates and Rotational Elements (hereafter the “WG”) a functional WG of the International Astronomical Union (IAU) has, after most IAU General Assembly (GA) meetings, issued a report. It includes recommendations on coordinate systems and related parameters (body orientation and shape) that can be used for making cartographic products (maps) of Solar System bodies. These recommendations, which are open to further modification when indicated by community consensus, are intended to facilitate the use and comparison of multiple datasets by promoting the use of a standardized set of mapping parameters. This abstract is intended to draw attention to the WG’s efforts in 2019-2020, our report published in 2018 [1], and a 2019 correction publication [2]. The WG encourages input and is available to assist users, instrument teams, missions, and space agencies. See our website [3] for additional information.

Operation of WG: The Working Group consists of 17 volunteers, including C. Acton, B. Archinal (Chair), A. Conrad (Vice Chair), T. Duxbury, D. Hestroffer, J. Hilton, L. Jorda, R. Kirk, S. Klioner, J.-L. Margot, K. Meech, J. Oberst, F. Paganelli, J. Ping, K. Seidelmann, D. Tholen, and I. Williams. We are always looking for volunteers to join the WG to help with each new report following the IAU GA. The WG looks at new determinations of coordinate systems (e.g., body sizes and orientations) that preferably have been published in refereed papers, and makes recommendations as to which to use, based where possible on consensus decisions.

As a volunteer organization, the WG has no resources to verify results or conduct its own research so it relies only on published results and community input. For this reason, it is sometimes not possible to recommend one set of results over another. The WG cannot verify or “bless” any results. The WG has no “enforcement” powers, but tries, in reflecting the long-term planetary community consensus, to make persuasive recommendations.

The WG does not deal with issues related to the formats of mapping products; such issues have largely been left to individual map developers, archiving organizations such as the NASA Planetary Data System (PDS), the International Planetary Data Alliance, or the NASA Mars Geodesy and Cartography and Lunar Geodesy and Cartography Working Groups (MGCWG [4], LGCWG [5]) and individual missions. We also are coordinating with two newer related organizations, IAU Commission A3 on Fundamental Standards, and the NASA Mapping And Planetary Spatial Infrastructure Team (MAPSIT) [6]. Input from such organizations is welcome by the WG and the frequency of in-

teraction highlights the strong need for such organizations at mission, space agency, and international levels. As pointed out at the 2012 IAU General Assembly [7] a substantial body of IAU recommendations exist that have been developed over many decades of input by IAU members, national space agencies, and other institutions. Care should be taken to follow such recommendations or to present well-reasoned arguments why they should be changed. The IAU and its Working Groups stand ready to help authors, journal editors, instrument teams, and missions to understand and follow IAU recommendations.

In general, during its 44-year history, the WG has not been directly involved in holding broad scientific meetings. However, in 2019 the WG, with other components of the IAU, including Division A Commissions, submitted a proposal to the IAU to hold a symposium in 2021 at the IAU General Assembly in Busan. The proposed title is “Reference systems and their ties with the rotation of the Earth and other Solar System bodies.” This would be the first such meeting to our knowledge to broadly discuss the theory and practical aspects of *both terrestrial and planetary* reference systems, frames, and body rotation.

The 2018 published report: Our current report [1, 2] is available on our web site [3] and the CMDA site. Summaries and additional details are also available in our abstracts from previous meetings since 2018. As an overall summary though we note general changes. *First*, the WG has reworded and clarified its recommendations regarding updating longitude. *Second*, mission and community input indicate a need for the WG to differentiate between planetary body shapes and sizes for image projection and scientific modeling vs. a reference surface for elevation and map scale. Long-accepted values for the latter are documented for the Moon and (now recommended for) Titan. *Third*, after considerable input from the community, including from New Horizons mission personnel, the discussion of terminology for the poles (hemispheres) of small bodies has been modified, e.g. to indicate that following community practice, cardinal directions can still be used informally or as shorthand for directions on small bodies (which formally have only positive and negative directions). *Fourth*, updates to the orientation models of Jupiter and Saturn are not recommended at this time, as we await community consensus on a model for Jupiter and results from the Cassini mission regarding Saturn.

See the report (and corrections) for details of changes regarding specific bodies, such as Mercury, Mars [8], Phobos and Deimos, Neptune, Ceres, Pluto and Charon. Asteroids Psyche, Europa, Šteins, and Itokawa, as well as several comets are also included.

In 2019 we also published [2] corrections to the report, which primarily corrected the equation for the spin orientation of Phobos.

In the report we repeated our previous recommendations that planning and efforts be made to make controlled cartographic products. We recommended that common formulations should be used for orientation and size and that historical summaries of the coordinate systems for given bodies should be developed. We pointed out that planetographic systems have generally been historically preferred over planetocentric systems for planets and satellites; and that in cases when planetographic coordinates have been widely used in the past, there is no obvious advantage to switching to the use of planetocentric coordinates.

Outlook for the Next WG Report: We are currently compiling our next overall report, associated with the 2018 IAU GA. We expect there will be routine updates to recommended orientation and size models resulting from processing or reprocessing of various planetary datasets, e.g. with improvements possible for various bodies such as Mercury, Jupiter, Saturn, Saturnian satellites, Ceres, 67P/Churyumov-Gerasimenko, Arrokoth, Toutatis, Bennu, and Ryugu.

Although lunar ephemerides currently seem to provide the orientation of the Moon with an accuracy of several meters, updates from various groups based on new lunar laser ranging (LLR) solutions continue to be made and improvements should be considered. Another issue is whether to finally base the mean Earth/polar axis (ME) lunar system directly on no-net rotation based LLR solutions for retroreflector coordinates rather than on a specific lunar ephemeris as is done currently. At the 2018 IAU GA, the X2 Cross-Division A-F Commission Solar System Ephemerides recommended [9] that a new WG should be set up to consider issues related to such updates. However, it appears at this time that such a WG has not yet been created, and updates will not be ready for our next report. The *WGCCRE urges that such a WG should be formed to consider these issues of lunar orientation, either by the IAU or (like the now inactive LGCWG) by NASA.*

For Mars, the recommended orientation model could be updated to that of Konopliv et al. [10] as formulated by Jacobson et al. [11], since this model is based on additional data and improved over the previously recommended system [8]. A separate issue has also been raised that the new systems [8, 10/11] seem to have a ~100 m offset in longitude at the fundamental epoch of J2000.0 relative to the previous recommended system. Clarification is needed as to the cause of this offset, given e.g. the intent that “the definition adopted in this paper does not change the position of the prime meridian” [8]. Based on community input, a decision may then need to be made by the MGCWG and WGCCRE, as to whether some correction in longitude should be made to these newer models, and perhaps

whether such a change should be made in advance of the next report.

A related concern is that Tom Duxbury has stepped down from his leadership of the MGCWG and currently no one else has agreed to coordinate this activity. The WGCCRE has relied heavily on the MGCWG in the past regarding decisions related to the coordinate systems for Mars and its satellites. *We strongly recommend that the planetary community, including NASA and/or other space agencies reinvigorate the MGCWG so that it can discuss and make recommendations or findings regarding not just the coordinate system issues, but other mapping issues, as it has successfully since the 1990s.* The WG may attempt to address the longitude issue itself, but due to resource issues has not been able to do so in a timely way without the help of the MGCWG.

Future Projects: The WG has over time received multiple requests for a summary of model recommendations made since the formulation of the WG in 1976 as a table or database. We have also received suggestions that the WG extend the recommendations in its reports about establishing and updating coordinate systems. These and perhaps other projects may be undertaken given enough volunteer effort.

Request for Input: The WG desires continued input from the planetary community, especially regarding the systems for specific bodies, the operation of the WG, our proposed question submitting process, and posting of updates via the WG website. We regularly provide summaries (such as this one) and make meeting presentations to make the community aware of our work [12,13]. We encourage volunteers to become WG members and help with our efforts. Our membership is open to all. Contact the authors for additional information.

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References: [1] Archinal et al. (2018) *CMDA 130:22*, doi 10.1007/s10569-017-9805-5. [2] Archinal et al. (2019) *CMDA, 121:12*, doi 10.1007/s10569-019-9925-1. [3] <http://astrogeology.usgs.gov/groups/IAU-WGCCRE>. [4] Duxbury et al. (2002) *ISPRS 34*, pt. 4, <http://astrogeology.usgs.gov/groups/ISPRS>. [5] Archinal and the LGCWG (2009) *LPS XL*, #2095. [6] Radebaugh et al. (2019), EPSC-DPS Meeting, #EPSC-DPS2019-951. [7] Meech et al. (2012) *Inquires of Heaven* no. 10, p. 6, <http://www.astronomy2012.org/ih>. [8] Kuchynka et al. (2014) *Icarus*, 229, 340. [9] IAU Commission X2 Triennial Report 2015-2018, <http://map.tinyurl.com/IAUX2-2018report>. [10] Konopliv et al. (2016) *Icarus 274*, 253. [11] Jacobson et al. (2018) *PSS 152*, 107. [12] Archinal et al. (2019) 4th Planetary Data Workshop, #7062. [13] Archinal et al. (2019) IAG Symposium G01, #IUGG19-1604.