

UPDATE FOR 2019 FROM THE IAU WORKING GROUP ON CARTOGRAPHIC COORDINATES AND ROTATIONAL ELEMENTS. Al Conrad¹, Brent Archinal², and the IAU Working Group on Cartographic Coordinates and Rotational Elements, ¹Large Binocular Telescope Observatory (University of Arizona, Tucson, AZ, USA aconrad@lbto.org), ²U. 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”) of the International Astronomical Union (IAU) has, after most IAU General Assembly (GA) meetings, issued a report recommending 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 and our report published in 2018 [1] covering 2012-2015. The WG encourages input and is available to assist users, instrument teams, and missions. See our website [2] 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 [3], LGCWG [4]) and individual missions. We also plan to coordinate with two newer related organizations, IAU Commission A3 on Fundamental Standards, and the NASA Mapping And Planetary Spatial Infrastructure Team (MAPSIT) [5]. Input from such organizations has been welcomed by the WG and the fre-

quency of interaction highlights the strong need for such organizations at mission, space agency, and international levels. As pointed out at the 2012 IAU General Assembly [6] 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, and missions to understand and follow IAU recommendations.

General Changes: Following extensive discussion, substantial updates have been incorporated by the WG into our new report [1]. An overview follows. *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 the orientation of Saturn.

Changes for Specific Bodies: Please see the current report [1] for details and complete citations. The orientation model for Mercury has been updated based on MESSENGER results. Formulas for the Earth’s orientation (previously given for comparison purposes only) have been removed to avoid confusion over their accuracy. The MGCWG has recommended new orientation models for Mars [7] and Phobos and Deimos, which the WG in turn has recommended for use; in addition, more precision in longitude for Mars is provided by fixing the position of the Viking 1 lander. Neptune’s rotation model has been updated based on new results. The previously online only WG recommended orientation model for (4) Vesta is repeated along with additional explanatory material. Individual members of the WG worked with Dawn mission personnel to arrive at a suitable way to update the existing orientation model for Ceres. New or updated orienta-

tion values are recommended for (52) Europa, and (2867) Šteins. The declination of the pole of (243) Ida has been corrected. Orientation data were added for comet 9P/Tempel 1 based on the Stardust NExT flyby, for 19P/Borrelly based on the DS1 flyby and subsequent ground-based measurements, for 103P/Hartley 2 based on the EPOXI flyby, and for 67P/Churyumov-Gerasimenko based on the pre-perihelion approach mapping from the Rosetta orbiter. The size of the Sun was updated per an IAU Resolution. Size recommendations for Mercury, (1) Ceres, and the radii for (134340) Pluto and Charon have also been updated based on recent mission results and papers. The recommended radius for Titan is returned to its previous value. Size information has been updated for 13 other Saturnian satellites and added for Aegaeon. Sizes are given for (16) Psyche and (52) Europa, and the size of (25143) Itokawa has been corrected.

Other recommendations: We repeat our previous recommendations that planning and efforts be made to make controlled cartographic products. We now recommend 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 point out that for planets and satellites planetographic systems have generally been historically preferred over planetocentric systems; 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, (486958) 2014 MU69, Toutatis, Bennu, and Ryugu.

We will also consider updating the recommendations for lunar coordinates. At the 2018 IAU GA, the X2 Cross-Division A-F Commission Solar System Ephemerides recommended, and the WGCCRE informally concurred, that a new WG should be set up to consider issues related to such updates [8]. 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. In any case the WGCCRE is willing to collaborate with such a new WG and consider any recommendations if available in a timely manner.

For Mars, the recommended orientation model could be updated to that of Konopliv et al. [9] as formulated by Jacobson et al. [10], since this model is based on additional data and improved over the previously recommended system [7]. A separate issue has also been raised that the new systems [7, 9/10] 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” [7]. Based on community input, a decision may then need to be made by e.g. the MGCWG and WGCCRE, as to whether some correction in longitude needs to be made to these newer models, and perhaps whether such a change should be made in advance of the next report.

Future Projects: The WG has over time received multiple requests for some type of (e.g. database) summary of model recommendations made since the formulation of the WG in 1976. 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 sufficient 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 [11, 12]. We encourage volunteers to become WG members and help with our efforts. Our membership is open to all. Contact the authors for additional information.

Acknowledgements: Funding for B. Archinal has been provided via a NASA-USGS Interagency Agreement on Planetary Spatial Data Infrastructure.

References: [1] Archinal et al. (2018) *CMDA*, 130:22, doi 10.1007/s10569-017-9805-5. [2] <http://astrogeology.usgs.gov/groups/IAU-WGCCRE>. [3] Duxbury et al. (2002) *ISPRS*, 34, pt. 4, <http://astrogeology.usgs.gov/groups/ISPRS>. [4] Archinal and the LGCWG (2009) *LPS XL*, #2095. [5] Radebaugh et al. (2017), LEAG Annual Meeting, #5053. [6] Meech et al. (2012) *Inquires of Heaven*, no. 10, p. 6, <http://www.astronomy2012.org/ih>. [7] Kuchynka et al. (2014) *Icarus*, 229, 340. [8] IAU Commission X2 Triennial Report 2015-2018, <http://map.tinyurl.com/IAUX2-2018report>. [9] Konopliv et al. (2016) *Icarus*, 274, 253. [10] Jacobson et al. (2018) *PSS* 152, 107. [11] Archinal et al. (2018) *PSIDA Conf.* #6047. [12] Archinal et al. (2018) 42nd *COSPAR* #PEX.1-0021-18.