INTERNATIONAL ASTRONOMICAL UNION (IAU)
DIVISION A AND F / WORKING GROUP
CARTOGRAPHIC COORDINATES AND ROTATIONAL ELEMENTS

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REPORT TO IAU FOR 2022-2023

1. Introduction

The main activity of the IAU Working Group on Cartographic Coordinates and Rotational Elements (hereafter, WG) is to make recommendations regarding the creation and maintenance of cartographic planetary coordinate systems and frames. The agreed-upon recommendations are produced approximately in conjunction with each IAU General Assembly and are published as a report in the journal *Celestial Mechanics and Dynamical Astronomy*. Our most recent main report was published in February 2018 (Archinal et al., 2018) with corrections published in 2019 (Archinal et al., 2019).

2. Main Report

Our efforts to compile the next version of that report have progressed more slowly than we would like. However we plan to return to doing our main report in 2023. We expect to include routine updates (Archinal and WG, 2021a and 2021c) 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, Venus, the Moon, Mars, Jupiter, Saturn, the Saturnian satellites, Ceres, 67P/Churyumov–Gerasimenko, Arrokoth, Bennu, and Ryugu. We also expect to clarify the (geodetic) usage of the terms “system” and “frame” and comment further on the usage of planetographic vs. planetocentric coordinates.

Lunar Orientation Overall: Regarding lunar orientation, as this report is being drafted, we have heard from personnel at the U. S. National Geospatial-Intelligence Agency (NGA) (personal communication, e-mail of 2023 March 10 from Nicholas Makley and e-mail of 2023 April 10 from Trevor Garner) and possibly other groups are planning to use a principal axis (PA) system-based reference frame for the Moon as part of their work to develop a lunar reference system (Garner, 2022). The total shift involved is approximately 860 meters with components in both longitude and latitude. This would not follow past practice where all lunar cartographic products throughout history have always been placed in a mean Earth/polar axis (ME) system reference frame, as previously recommended by the WG. The total difference between the two systems amounts to a quite significant 860 meters on the lunar surface. We are in communication with those involved to try to understand their plans and need for such a change. We are concerned about such a large change and hope that it could be avoided. If it moves forward, such a transition would require many if not all existing lunar data and mapping products to be converted at great cost in both funding and personnel time. Significant confusion could arise (including for navigation near the lunar surface) due to the likely resulting simultaneous use of the two systems.

Lunar Orientation Update: Meanwhile, the WG has been considering whether an update should be made to our recommendations regarding lunar orientation. Various groups (e.g., the Joint LEAG-MAPSIT SAT, 2021) have recommended an update based on a newer Jet Propulsion Laboratory (JPL) lunar ephemeris, and in preparation for upcoming missions. A directly related issue is whether to finally base the ME frame directly on a no-net-rotation-based lunar laser ranging (LLR) solution for retroreflector coordinates rather than on a specific lunar ephemeris as is done currently. Abstracts and presentations on this topic have been

made by the WG (Archinal and WGCCRE, 2022; Archinal and WGCCRE, 2023a) and are planned (Archinal and WGCCRE, 2023b and 2023c).

Mars Orientation Update: For Mars, the orientation mode currently recommended by the WG could be updated to a newer mode based on Konopliv et al. (2016). However, a separate issue is that both the currently recommended model and the newer model under consideration appear to have a ~100-m offset in longitude at the fundamental epoch of J2000.0 relative to the system previously recommended in Archinal et al. (2011). Separate from the WG, Mayer and Archinal (2023) have proposed how the Mars orientation model could be revised to reverse this offset and maintain a consistent system of longitude between models. It is possible that their recommendations could be considered for adoption by the WG and others.

Given the importance and urgency of updating both the lunar and Mars orientation models, the WG also might consider separately publishing an abbreviated "main" report addressing those models, and then returning to doing a longer main report covering the rest of the Solar System.

3. Membership

The WG began operation in 1976. In recognition of the continued need for the WG, it became a "Functional Working Group" of the IAU in 2016, with an institutional scope and purpose in providing a service that naturally extends beyond the IAU triennial cycle (IAU Executive Committee, 2016). The WG currently comprises 15 members from 5 countries, with membership lengths from 5 to 47 years. Brent Archinal (U.S. Geological Survey) serves as the current Chairman, and Al Conrad (Large Binocular Telescope Observatory) serves as the Vice-Chairman. C. Acton has stepped down after 11 years of valuable service that we have appreciated.

The WG is always looking for volunteers to join, particularly to help with each new report. Some individuals have recently expressed an interest in joining the WG, but we have been delayed (and apologize to them for those delays) in incorporating them into the WG. We plan to follow up with them soon. However, additional members are also welcome. Our membership is open to all who wish to help with our work. We hope to increase our membership, expertise, and available time to work on our main report and respond to community requests and inquiries.

4. Community Inquiries

The WG Chair and many of the WG members spend significant time answering questions from NASA, the NASA Planetary Data System, missions, mission instrument teams, journal editors, individual researchers, and the public, on various issues related to planetary coordinate systems. As already noted, there are ongoing open questions about the coordinate systems for the Moon and Mars. Some of our members have provided information to international archiving organizations such as the European Space Agency's Planetary Science Archive, the Japan Aerospace Exploration Agency's and Russian Space Research Institute's archiving arms, as well as the International Planetary Data Alliance; and to planning organizations such as the NASA Mapping and Planetary Spatial Infrastructure Team (MAPSIT) advisory group. The WG cooperates with other IAU components, such as IAU Commission A1 Astrometry and the X2 Cross-Division A-F Commission Solar System Ephemerides. WG members also have often been asked to review papers and plans for data archives regarding coordinate system issues.

5. Concern About Support as a Functional WG

We repeat our past comments, in that in recent years the WG has been concerned that it is becoming over-extended, particularly due to the greatly increasing number and complexity of community inquiries. The time needed to respond to such inquiries have resulted in delays of our most recent reports relative to the preferred triennial schedule of IAU activities. We have

(as noted above) planned to address this partly by increasing membership, especially as experienced personnel retire. However, it also may be necessary to consider whether an actual service (perhaps analogous to the International Earth Rotation and Reference Systems Service) is needed to perform some of the community support functions of the WG. One of us (Archinal) receives NASA funding for a portion of his work, but it may be necessary for the WG to seek additional support, perhaps from international space agencies, to continue to address community requests and increased demands for input. The WG is considering these issues, but community input is welcome as we proceed. A discussion of the overall issues involved has been presented as input to the NASA Planetary Science and Astrobiology Decadal Survey (Paganelli et al., 2020) and at other venues (Archinal and the WGCCRE, 2020a, 2020b, 2021a, 2021c; Archinal et al., 2020).

6. Publications and Meetings

The WG has continued to make its efforts and activities known via its website (https://www.usgs.gov/centers/astrogeology-science-center/science/iau-wgccre) and by various publications and community presentations. Specifically:

- We plan to again in 2023 publish our main report to the planetary community, or as noted above consider publishing an interim report with lunar and Mars orientation recommendations and then our main report.
- The WG will make brief annual reports such as this to the IAU and Divisions A and F on our activities. We are also willing to continue to make oral reports at the General Assembly Division meetings, such as in 2021 for Division F (Archinal and the WGCCRE, 2021b) and in 2022 for Division A.
- To make our work better known and encourage adherence to the recommendations in our main report, we will continue to submit abstracts to and make presentations at various planetary science meetings, describing the activities of the WG and our reports. See the various references herein for examples of those submissions and presentations.

7. Closing remarks

Our highest priority is to add new members and continue on to completing our main report. We will continue to address questions from the planetary community regarding planetary coordinate system issues and continue to further increase community awareness of our work with abstracts and presentations at appropriate scientific meetings. Inquiries from the community have increased greatly in recent years from individuals, editors, instrument teams, missions, and space agencies. We expect to accommodate this increased workload in part by moving forward with an increased WG membership, but are open to and see a need to consider other possibilities regarding the long-term operation of the WG or some new organizational structure with a similar purpose.

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