2.4 REFERENCE FRAMES AND SOLAR SYSTEM

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EARTH ORIENTATION -
THE CURRENT AND FUTURE SITUATION

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Abstract.
Sub-milliarcsecond astrometry often requires an accurate characterization of the orientation of the Earth in a quasi-inertial reference frame. The International Earth Rotation Service (IERS) standards provide the current state of the art in the transformation between celestial and terrestrial reference systems. Improvements in the determination of Earth orientation parameters which describe this transformation continue to be made. Current and future capabilities are given.

1. Introduction

Earth orientation refers to the direction in space of axes which have been defined on the Earth. It is measured using five quantities: two angles which identify the direction of the Earth's rotation axis within the Earth (polar coordinates x and y), an angle describing the rotational motion of the Earth (UT1-UTC), and two angles which characterize the direction of the Earth's rotation axis in space (longitude of the ascending node of the Earth's orbit and obliquity of the ecliptic). With these data the orientation of the Earth in space is fully described. Anyone who must relate changing aspects of reference systems on Earth to a system in space requires information on the Earth's orientation.

2. Current Situation

Astronomical observations are made routinely by a number of observatories located around the world to monitor variations in the Earth's orientation. The International Earth Rotation Service (IERS) is the international or-

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Astronomical and Astrophysical Objectives of Sub-Milliarcsecond Optical Astrometry, 287–291.

ganization responsible for the coordination of observations of polar motion and nutation as well as astronomical time. The structure and functions of the IERS are outlined in the annual reports of the IERS, and much of the following information is taken from the *1993 IERS Annual Report* (IERS, 1994). The IERS routinely provides the information necessary to define the Conventional Terrestrial Reference System and a Conventional Celestial Reference System and relate them and their frames to each other and to other reference systems used in the determination of the Earth orientation parameters. Responsibilities of the IERS include defining and maintaining a conventional terrestrial reference system based on observing stations using high-precision techniques in space geodesy, defining and maintaining a conventional celestial reference system based on extragalactic radio sources, and relating it to other celestial reference systems, determining the Earth orientation parameters connecting these systems, collecting and archiving appropriate data and results, and disseminating the results to meet the needs of users.

The IERS consists of a Central Bureau and Coordinating Center for each of the principal observing techniques, Very Long Baseline Interferometry (VLBI), Lunar and Satellite Laser Ranging (LLR, SLR), Global Positioning System (GPS), and DORIS and is supported by organizations that contribute observations and their analyses. Coordinating Centers are responsible for developing and organizing the activities in each technique to meet the objectives of the service. The Central Bureau combines the various types of data collected by the service, and disseminates to the user community the appropriate information on Earth orientation and the terrestrial and celestial reference systems. It includes sub-bureaus for the accomplishment of specific tasks.

2.1. THE IERS REFERENCE SYSTEM

The IERS Reference System is composed of the IERS Standards and the IERS reference frames. The IERS Standards (McCarthy, 1992) are a set of constants and models used by IERS Analysis Centers for and by the Central Bureau in the combination of results. The values of the constants are adopted from recent analyses, and, in some cases, differ from the current IAU conventions. The models represent, in general, the state of the art in the field concerned.

The IERS reference frames consist of the IERS Terrestrial Reference Frame (ITRF) and IERS Celestial Reference Frame (ICRF). Both frames are realized through lists of coordinates of fiducial points, terrestrial sites or compact extragalactic radio sources. The origin, the reference directions and the scale of ITRF are implicitly defined by the coordinates adopted for the terrestrial sites. Its origin is located at the center of mass of the Earth with an uncertainty of ±10cm. The unit of length is the meter (SI). The IERS Reference Pole (IRP) and Reference Meridian (IRM) are consistent with the corresponding directions in the BIH Terrestrial System (BTS) within $\pm 0\rlap{.}''003$. The BIH reference pole was adjusted to the Conventional International Origin (CIO) in 1967, and it was then kept stable independently until 1987. The uncertainty of the tie of the BIH reference pole with the CIO was $\pm 0\rlap{.}''003$.

The origin of the ICRF is at the barycenter of the solar system. The direction of the polar axis is that given for epoch J2000.0 by the IAU 1976 Precession and the IAU 1980 Theory of Nutation. The origin of right ascensions is in agreement with that of the FK5 within $\pm 0\rlap{.}''001$.

2.2. THE EARTH ORIENTATION PARAMETERS

The IERS Earth Orientation Parameters (EOP) are the parameters which describe the rotation of the ITRF with respect to the ICRF, in conjunction with the conventional precession/nutation model. They model the unpredictable part of the Earth's rotation. x and y are the coordinates of the Celestial Ephemeris Pole (CEP) relative to the IRP, the IERS Reference Pole. The CEP differs from the instantaneous rotation axis by quasi-diurnal terms with amplitudes under $0\rlap{.}''001$. The x-axis is in the direction of IRM; the y-axis is in the direction 90 degrees West longitude. $d\psi$, $d\epsilon$ are the offsets in longitude and in obliquity of the celestial pole with respect to its position defined by the conventional IAU precession/nutation models. UT1 is related to the Greenwich mean sidereal time (GMST) by a conventional relationship (Aoki *et al.*, 1982); it gives access to the direction of the IRM in the ICRF, reckoned around the CEP axis. It is expressed as the difference UT1-TAI or UT1-UTC.

The precision of the published results depends on the delay of their availability. For the operational solutions of Earth rotation (weekly and monthly bulletins) it is of the order of one millisecond of arc. The prediction accuracy is in the range of $\pm 0\rlap{.}''005$ to $\pm 0\rlap{.}''020$ for x and y, $0\rlap{.}^{s}002$ to $0\rlap{.}^{s}15$ for UT and $0\rlap{.}''002$ for $d\psi$, $d\epsilon$ (prediction lags of 10 and 90 days). For the scientific solution of reference frames and Earth orientation, the inaccuracy is lower than $0\rlap{.}''001$ (3 cm).

Currently, accuracy appears to be limited by systematic errors, mainly in the definition of reference frames and in the observation and reduction procedures. Contributors to the IERS make use of different observing sites and perhaps different philosophies in arranging their observing programs. These differences can lead to systematic variations among the contributors' results. Also, differing models employed in the analyses of the observations by various analysts can lead to differences among the data provided to the IERS. The IERS Standards (McCarthy, 1992) are intended to provide a set of constants and models in order to minimize this problem. However, subtle differences may still lead to systematic effects. Another non-scientific concern is that, in times of dwindling budgets, resources required to operate expensive observational programs may be reduced. This situation may, in turn, cause problems which affect accuracy.

3. Future Situation

In the future we should expect that the current systematic error problems will lead to improved definitions of the reference frames. This will be accomplished in the case of the terrestrial frame by increased emphasis on collocation of observations with multiple techniques at the same locations. The celestial frame will be refined with more numerous southern hemisphere observations and efforts, already planned, for an improved radio reference frame which will be continuously updated. Improved models will also be forthcoming from efforts to understand differences between analyses. For example, a new precession/nutation model will certainly be discussed and adopted in the near future. Other refinements may be expected in modelling of site displacements due to crustal motion, glacial rebound and atmospheric loading.

Possible new concepts may also be called for as a result of advancements in accuracy. The use of the "non-rotating origin" formalism (Guinot, 1979; Capitaine, 1990) may find increased popularity as the demand for more precise definition of reference frames grows. Along with this development, a new definition of the relationship between sidereal time and solar time is likely to be accepted.

The necessity for the increasing frequency of leap seconds may lead to demands for a new definition of the second or at least a change in the relationship between UT1 and uniform time. Currently leap seconds must be inserted in the UTC time scale at the rate of approximately once per year. In the 21st century we expect this frequency to increase to almost twice per year. Users may find the current system too cumbersome for practical use and demands may grow for an alternate procedure for handling the growing difference between rotational and uniform time scales.

With improving accuracy and increased time resolution of Earth orientation parameters, refinements in geophysics will progress. Advancements in models of the Earth's interior structure will occur, and a better understanding of the relationship between the rotation of the Earth and the oceans and atmosphere will be developed. These improvements may then lead to enhancements in our ability to forecast variations in the Earth's orientation.

New observing techniques may also be developed within the next ten years providing improved determinations of the Earth's orientation. Only recently has the use of analyses of the orbits of the satellites of the Global Positioning System (GPS) provided an important improvement in the accuracy and time resolution of our determination of polar motion.

With improvements such as those listed above, it can be expected that accuracy approaching 0.01 millisecond of arc will be achievable within the next ten years.

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