3.5.4 ICRS Centre

Introduction

The IAU has charged the IERS with the responsibility of monitoring the International Celestial Reference System (ICRS) and maintaining its current realization, the International Celestial Reference Frame (ICRF), and links with other celestial reference frames. Starting in 2001, these activities are run jointly by the ICRS Centre (Observatoire de Paris and U.S. Naval Observatory) of the IERS and the International VLBI Service for geodesy and astrometry (IVS), in coordination with the IAU Working Group on the Reference System. The present report was jointly prepared by the Paris Observatory and U.S. Naval Observatory components of the ICRS Centre.

The International Celestial Reference System (ICRS) is materialized by coordinates of extragalactic radio sources derived from VLBI observations. The access to ICRS in radio wavelengths is given by the 667 extragalactic radio sources in ICRF-Ext.1 (IERS, 1999). This extension of the initial ICRF was constructed and issued as a part of the maintenance process of the conventional celestial system and its frame (Ma *et al*., 1997, 1998). While the set of the 212 defining sources and their respective coordinates remain unchanged with respect to the first realization of the frame, more precise coordinates for sources classified as “candidate“ and “other“ in ICRF are provided in ICRF-Ext.1; 59 “new“ sources that were not included in the initial ICRF increase the number of objects in the conventional frame.

Concerning the ICRS monitoring, the location of the ICRS origin of right ascensions relative to the dynamical equinox is monitored using Lunar Laser Ranging (LLR) solutions. The location of the ICRS pole relative to the Celestial Ephemeris Pole is monitored using VLBI-derived celestial frames and time series of the celestial pole offsets.

Various investigations concerning ICRF-Ext.1 are presented, based on the contributions from VLBI analysis centres: additional sources since the construction of ICRF-Ext.1, stability analyses based on time series of source coordinates, and comparisons of the ICRF with newly computed radio source catalogues.

The link of the ICRF to the Hipparcos frame which is the primary realization of the ICRF at optical wavelengths, as well as the link with other frames as 2MASS (infrared catalogue) is also one of the fundamental objectives of the ICRS Centre. The ICRS Centre organizes and updates a database which contains VLBI celestial frame realizations achieved during the last 15 years.

Different files provide information to characterize the objects involved (radio source nomenclature, physical characteristics of radio sources, astrometric behavior of a set of sources, radio source

structure). The database is available at URL
<http://hpiers.obspm.fr/icrs-pc>,
by anonymous ftp (<hpiers.obspm.fr/icrs-pc>), and on request to the ICRS Centre (<icrs-pc@hpopa.obspm.fr>).

In the following, we explain the contents of the various tasks which are devoted to the ICRS Centre, by explaining for each of them the studies which were developed in 2001.

Task 1: Maintenance and extension of the ICRF

The VLBI observing program, which is coordinated by the IVS permanently, brings in new observations of ICRF, and prospective ICRF sources. For sake of consistency, a permanent check of the coordinates of known sources is carried out, whereas ICRS coordinates of new sources are derived.

Moreover, comparisons have been done between the ICRF and celestial catalogues produced as a result of all the observations carried out for the year 2001 by different VLBI groups. Four individual original catalogues and one combined catalogue have been received and analysed, respectively from the GSFC (Goddard Space Flight Center), the BKGI (Bundesamt für Kartographie und Geodäsie, Leipzig, and Geodetic Institute of the University of Bonn), the IAA (Institute of Applied Astronomy of the Russian Academy of Sciences, St. Petersburg), the SHA (Shanghai Observatory of Chinese Academy of Sciences) in one part, and from GAOUA (Main Astronomical Observatory of the Ukranian Academy of Sciences) for the other part. We give the corresponding rotations between the ICRF and each of these catalogues according to the three rectangular axes as well as the slopes and the bias according to the equatorial coordinates.

Notice that in the BKGI, IAA and GSFC catalogues, 23, 8 and 13 new sources respectively were observed in 2001, which are not included in the ICRF. The first extension to the ICRF, ICRF-Ext. 1, was issued by the IERS in 1998 (see the 1998 IERS Annual Report). No revision of the ICRF has been decided during 2001.

Task 2: Investigation of future realizations of the ICRS

Involvement in the celestial reference frame VLBI program continued by PC personnel in 2001, significantly increasing the number of observations of ICRF quasars in the southern celestial hemisphere and continuing an extensive observing program in the northern hemisphere. These observations may eventually result in the issuing of a second extension to the ICRF.

The northern hemisphere VLBI observing program includes a series of experiments involving the 10 VLBI stations of the U.S. National Radio Astronomy Observatory (NRAO) Very Long Baseline Array (VLBA) (see Task 3 narrative for an description of the program). Preliminary analysis of this series of experiments indicated these data had significant systematic errors of unknown origin. Additional analysis of these data by PC personnel, performed in 2001, showed that the initial concerns were unfounded, and that these data should be incorporated into the general astrometric and geodetic VLBI database.

In the coming decades, there will be significant advances in the area of space-based optical astrometry. Proposed and scheduled missions such as the National Aeronautics and Space Administration's (NASA) Space Interferometry Mission (SIM) and the European Space Agency's GAIA mission will achieve positional accuracies well beyond that presently obtained by any ground-based radio interferometric measurements. During 2001, PC personnel were involved in the Full-sky Astrometric Mapping Explorer (FAME) mission; a NASA sponsored astrometric space mission to measure the position, parallax and proper motions of 40 million stars between 5th and 15th magnitude. During 2001 the FAME project was in Phase B: the preliminary design phase. FAME's Phase B culminated in several reviews held in October, November and December of 2001, including a Preliminary Design Review, a Confirmation Assessment Review and a Confirmation Readiness Review. At the end of 2001 the FAME project was awaiting NASA Headquarters' decision on whether FAME would proceed in to Phase C (detailed design phase).

Task 3: Monitor Source Structure (2001)

Observations of International Celestial Reference Frame (ICRF) sources using the Very Long Baseline Array (VLBA), together with several geodetic antennas, continued. These observations constitute a joint program between the U.S. Naval Observatory (USNO), Goddard Space Flight Center (GSFC) and the National Radio Astronomy Observatory (NRAO) for maintenance of the celestial and terrestrial reference frames.

This program has proven highly successful, providing source images with up to twice the resolution of VLBA only observations, Earth Orientation Parameter (EOP) estimates with precision exceeding that of regular EOP observations, repeated high quality source and station position estimates, and precise positions for several phase reference sources requested by VLBA users. Results from previous observing sessions are providing some of the best astrometric/geodetic data ever obtained and are providing the basis for evaluation of the long term stability of the ICRF.

The VLBA observations taken under this program provide data suitable for imaging of the intrinsic structure of the extragalactic radio sources which make up the ICRF. Images are made at the USNO and are made available for use by anyone from the USNO Radio Reference Frame Image Database (RRFID). The RRFID can be accessed on the World Wide Web at <http://www.usno.navy.mil/RRFID/>. During the reporting period (2001), a total of

330 new images of 165 sources were added to the RRFID.

Images produced at USNO are analysed by the USNO for variability and are monitored for structural changes. Analysis of previous observations has provided valuable information on the intrinsic structure and variability of the observed sources, allowing us to characterize and classify sources based on their observed structure (Fey et al., 2001) and structural variability (Piner et al., 2002).

RRFID images are also used by various other institutions to assess the impact of source structure on astrometric position determination. The USNO and Bordeaux groups analyze the images produced by the USNO to estimate the effect of source structure on the measurement of group delay and produce a source 'Structure Index' which is a measure of the astrometric quality of a source, based on its intrinsic structure (see Fey and Charlot, 2000, and references therein). These studies have revealed a correlation between the observed radio structure and source position accuracy and stability. The assumption that such source structure errors can be minimized or removed through the application of source structure corrections has been investigated by Sovers et al. (2002). Results of this study suggest that source structure contributes significantly, but the primary contribution to astrometric error comes from the troposphere.

Task 4: Monitor coordinates to assess astrometric quality

Studies of the time stability of radio source coordinates were carried out in 2001, in the continuity of previous ones (Gontier et al., 2001). Time series of source coordinates were taken from USNO data (A. Fey, 2002). A total of about 3000 sessions are considered, involving about 700 sources and 3 million total observations. The work consisted of several steps: transforming the time series for each source into a series of differences to its mean coordinates over the period 1983.5–2002.0; transforming the difference time series of the 273 most regularly observed sources into a series of normal points at one-year intervals; analysing the time behaviour of the source coordinates, to derive a stability criteria. Another fundamental test consisted in evaluating the impact of source selection on the no-net-rotation condition of the CRF and on the determination of precession-nutation coefficients.

By selecting a sub-catalogue of 162 sources among the initial set of 273 ones, with the help of a stability criteria (Feissel, 2002) it can be shown that the year-to-year stability of the given catalogue, indicated by the amplitude of the related rotations around the three perpendicular ICRS axes, is noticeably better than for the defining sources of the ICRF catalogue. Moreover the quality of determination of the precession correction and of the obliquity rate are improved by the choice of a limiting number of sources above.

Task 5: Maintenance of the link to Hipparcos

During the report period (2001) several observational programs were ongoing. These fall into 3 categories: the densification of the reference frame at optical wavelengths, extension of the Hipparcos frame to infrared (IR) wavelengths, and the critical check on the radio to optical reference frame link itself.

The major program for the densification of the optical reference frame is the UCAC project (USNO CCD Astrograph Catalog). This all-sky survey will give 20 mas positions for stars in the 10 to 14 mag range, with a limiting magnitude of about R=16. The first release (UCAC1) was published in March 2000, containing positions and proper motions of 27 million stars on the Hipparcos Catalogue Reference System (HCRS). In September/October 2001, the astrograph was relocated from CTIO (Chile) to Flagstaff, AZ. By the end of 2001, observations over 76% of the sky were completed.

Other densification projects include the Carlsberg Meridian Circle program (Denmark, UK, Spain) of scanning the –3 to +30 degree zone, as well as a similar project from Bordeaux Observatory for the +11 to +18 degree zone. The Sloan Digital Sky Survey (SDSS) continued its deep 5-band photometric survey in areas around the galactic north pole. Astrometry is tied to the HCRS via Tycho-2 and UCAC positions.

The major program to extend the Hipparcos frame into wavelengths other than optical or radio is the 2-micron All Sky Survey (2MASS) project. IR photometry (J,H,K) has been obtained with 2 identical telescopes (north, south) for about 400 million point sources. The astrometry is on the HCRS and the average error per catalogue position coordinate is expected to be around 100 mas with much smaller systematic (zonal and magnitude dependent) errors.

Task 6: Linking the ICRF to frames at various wavelengths

The linking of the ICRF to frames at other catalogues means two different objectives:

A first objective is the compilation of the information extracted from various observational programs, concerning the extragalactic objects belonging to the ICRF catalogue. Activities of the ICRS-PC in 2001 in this topic were devoted to the cross-identification between the extragalactic sources of the ICRF and the quasars catalogues whose the list can be obtained from the CDS (Centre for Stellar Database, France). More precisely, efforts were made in adding supplementary information (redshifts, optical magnitudes etc...) for the ICRF objects, whatever their status (defining sources, candidates sources, other sources)

A second objective is the geometrical link between the ICRF catalogue and other catalogues at other wavelengths. This geometrical link can be obtained by identifying common objects (to the ICRF and to the catalogue to be linked). In this field, a comprehensive extragalactic link program is part of the UCAC project. The goal is to eventually provide a link between the ICRS and the UCAC independent of HCRS (using block adjustment procedures) and then quasi externally assess the HCRS-ICRS link. Optical positions of about 120 ICRF sources were obtained in 3 observing runs at CTIO and KPNO during 2001, supplemented with some observations from LNA (Brazil) of optically faint targets.

Task 7: Maintenance of the link to the solar system dynamical reference frame using millisecond pulsar analysis

The idea of associating pulsar timing technique with differential VLBI astrometry should provide high quality information about the position and motion of the equator, the ecliptic, the equinox of the ICRS. Although no specific project in the association above was set up in 2001, pulsar timing experiments were conducted on a regularly basis at Nançay observatory (France). Observations of pulsars with a new instrument named NBPP (Naval research Lab, Washington) have been carried out with success.

Task 8: Maintenance of the link to the solar system dynamical reference frame using Lunar Laser Ranging (LLR) analysis

The dynamical reference frame can be materialized preferentially by the dynamical ecliptic of the date or at a given epoch. The combination of VLBI data, with LLR data enables the determination, with high accuracy, of the position of the inertial dynamical ecliptic at a given epoch with respect to the ICRS. One of the fundamental parameters is the mean obliquity of the Earth, together with the position of the mean equinox, at epoch J2000.0. The position of the dynamical equinox is related to the lunar orbit through ephemerides (ELP2000, DE405 etc...), whereas the position of the mean equator at J2000.0 is implicitly given by its orientation with respect to the instantaneous equator of the date by means of the precession-nutation matrix.

Efforts were made during 2001 by the team in charge of the LLR observations at Paris Observatory (see Chapront, M., Chapront-Touzé, M., Fancou, 2002) to define the ICRS equator and origin of right ascension from the rectangular coordinates of the LLR stations in the terrestrial reference frame (through the ICRF) and the transformation from terrestrial coordinates to the J2000.0 equatorial coordinates. This last transformation has been realized according to the lunar solution S2001 (ICRS) which results from weighed fits of the semi-analytical theory ELP2000-96 of the orbital motion of the Moon to the LLR observations provided between 1970 and 2001. The precession-nutation matrix is computed via the conventional set of values recommended by IERS in particular the nutation corrections of the series EOP(C04) produced by the Earth Orientation Centre.

References

Chapront J., Chapront-Touzé M., Francou G., 2002: A new determination of the lunar orbital parameters, precession constant and tidal acceleration from LLR measurements, Astron. Astrophys. 387, 700

Fey, A.L., Boboltz, D.A., Gaume, R.A., Eubanks, T.M., Johnston, K.J., 2001: Extragalactic Radio Source Selection for Use in Directly Linking Optical Astrometric Observations to the Radio Reference Frame, AJ, 121, 1741

Fey, A., 2002, private communication; http://rorf.usno.navy.mil/solutions

Fey, A.L., Charlot, P., 2000: VLBA Observations of Radio Reference Frame Sources. III. Astrometric Suitability of an Additional 225 Sources, ApJS 128, 17

Gontier A.M., Le Bail K., Feissel M., Eubanks T.M., 2001, Stability of the extragalactic VLBI reference frame, Astron. Astrophys. 375

IERS, 1999: 1998 IERS Annual Report, Observatoire de Paris

Ma C., Arias E.F., Eubanks T.M., Fey A.L., Gontier,A.M., Jacobs C.S., Sovers O.J., Archinal B.A., Charlot P., 1997: IERS Technical Note No. 23, C. Ma and M. Feissel (eds.), Observatoire de Paris

Ma C., Arias E.F., Eubanks T.M., Fey A.L., Gontier,A.M., Jacobs C.S., Sovers O.J., Archinal B.A., Charlot P., 1998: The International Celestial reference Frame as realized by VLBI, AJ 116, 516

Piner, B.G., Fey, A.L., Milne, J., Mahmud, M., 2002: Relativistic Jet Speeds from the Radio Reference Frame Image Database: The 23 Best-Observed Sources, AAS, 200, 4501

Sovers O.J., Charlot P., Fey A.L., Gordon D., 2002, IVS2002 General Meeting Proceedings, 243, N. Vandenbergh and K.D. Baver (eds.), http://ivscc.gsfc.nasa.gov/publications/gm2002/sovers/

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