IAU COMMISSIONS 19: ROTATION OF THE EARTH
AND 31: TIME

Report of Joint Meeting held on 1985 November 22 to consider the MERIT/COTES recommendations for a new international earth-rotation service

PRESIDENT: Session 1: D D McCarthy SECRETARY: G A Wilkins
Session 2: Y A Yatskiv

ABSTRACT. A Joint Meeting of Commissions 19 and 31 was held during the IAU General Assembly at Delhi to consider the recommendations for a new international earth-rotation service put forward by the IAU/IUGG Joint Working Groups on the rotation of the Earth and the conventional terrestrial reference system. Wilkins gave summaries of the MERIT programme of activities to monitor earth rotation and intercompare the techniques of observation and analysis and of the COTES programme to establish the basis of a new conventional terrestrial reference system. He reviewed the recommendations of the Groups, and then introduced a draft resolution of the Commissions. An amendment on the continuation of the use of the technique of optical astrometry was accepted and the resolution was then adopted without objection. Four papers on work related to the MERIT/COTES programmes were then presented. Paquet discussed the agreement in the results by different techniques for polar motion and universal time. Preuss presented a paper by Campbell and Schuh on short-period variations in earth-rotation determined by VLBI. Dickey discussed the intercomparisons between the earth-orientation parameters obtained by different techniques and then reviewed the close correlation between the length of the day and the angular momentum of the atmosphere. Finally, Vicente and Verbeiren presented new techniques for processing time and polar motion series.

## 1. REVIEW OF THE MERIT/COTES REPORT

The Chairman of the first session, D D McCarthy, Acting President of Commission 31 on Time, opened the first session of the Joint Meeting of Commissions 19 and 31 at 2 pm on Friday, 1985 November 22, during the XIXth General Assembly of the International Astronomical Union. The meeting was attended by about 60 persons.

G A Wilkins, the Chairman of the IAU/IUGG Joint Working Group on the Rotation of the Earth, drew attention to the summary report that he had prepared with I I Mueller, the Chairman of the IAU/IUGG Joint Working Group on the Establishment and Maintenance of the Conventional Terres-



*J.-P. Swings (ed.), Highlights of Astronomy, 789–795.*

trial Reference System. (This summary report has been reproduced immediately before this report on the meeting in Delhi.) He then summarised the objectives of the two working groups and the programme of activities that had been carried out during the past seven years. The MERIT programme (to monitor earth rotation and intercompare the techniques of observation and analysis) involved six different techniques of observation, namely: optical astrometry, the Doppler tracking of satellites, laser ranging to geodetic satellites (SLR) and to the Moon (LLR), and radio interferometric observations of quasars using connected-elements and very-long-baseline (VLBI) systems. The stimulus provided by the MERIT Short Campaign (in 1980) and the MERIT Main Campaign (in 1983/4) did much to foster the development of the new techniques of observation based on laser ranging and radio interferometry. The earth-rotation parameters (universal time, length of day, and the coordinates of the pole) are now determined with much higher precision and better time-resolution. The analyses of the observational data clearly demonstrated the close correlation between the rotation of the crust of the Earth (as indicated by the observed length of the day) and the angular momentum of the atmosphere. Special observations and analyses were also made to determine the coordinates of the stations and the differences between the reference systems implicit in each technique; this work represents a major contribution to the COTES programme to establish and maintain a new conventional terrestrial reference system. It is now established that the tidal motions and relative drifts of the stations must be taken into account in the determination of earth-rotation parameters and of geodetic coordinates of high precision.

The MERIT and COTES Working Groups met at the Third MERIT Workshop, which was held at Columbus, Ohio, on 1985 July 29-30, and on August 3; after reviewing the results of the campaigns they adopted three recommendations concerning the future international services for monitoring the rotation of the Earth and the adoption of new conventional terrestrial and celestial reference systems. The background to these recommendations on the reference systems is described in the paper by Wilkins in the report of the proceedings of the Joint Discussion on Reference Systems. It was recommended that the new service should be based initially on three techniques, namely VLBI, SLR and LLR, and that the general organisation of the service should be similar to that adopted during the MERIT Campaigns. In the meantime the MERIT/COTES activities should be continued to ensure the continued availability of high-quality data on earth-rotation and to provide further data for use in defining the new reference systems.

## 2. RESOLUTION ON THE EARTH-ROTATION SERVICE

The Chairman (McCarthy) asked Wilkins to introduce the draft resolution on the implementation of the MERIT/COTES recommendations that had been previously circulated to all members of Commissions 19 and 31. The preamble to the resolution recognises the success of the MERIT/COTES activities, thanks all those concerned, and endorses the report and the

recommendations. The main purpose of the resolution was to obtain the authority of the Union to proceed with the preparations for the setting up of a new service which would replace the International Polar Motion Service and the Earth-Rotation Service of the Bureau International de l'Heure. The Provisional Directing Board for the new service would be expected to put forward specific proposals for consideration at the General Assembly of the International Union of Geodesy and Geophysics in Vancouver in 1987. It would also act as the steering committee for the extension of the MERIT/COTES programme until the new service is in operation.

The Chairman then drew attention to the amendments put forward by W Markowitz and W J Klepczynski. B Guinot and I I Mueller pointed that there was a separate resolution dealing with the responsibility for leap-seconds in UTC and that the provisional Directing Board would consider this matter in its review of the functions of the new service; Klepczynski withdrew the amendment.

Paquet then introduced an amendment to insert a new clause to the effect that an optical astrometric network should be maintained for the determination of UT1. He considered that the report gave the impression that such observations were no longer of value. His view was supported by Yatskiv and others who suggested minor changes to clarify the amendment. Yokoyama considered that the amendment was not necessary since the main resolution implied that the technique would continue to be used until 1988 by which time the new techniques should be able to meet the requirements for the rapid determination of UT1. After further discussion an amended version of the original amendment was adopted without objection. The amended resolution was then put to the meeting and was adopted without objection. The text of the resolution was edited by the IAU Resolutions Committee and was adopted without objection by the General Assembly on November 28. The full text of the resolution is given as annex 3 to the Joint Summary Report.

In adjourning the meeting for tea, McCarthy drew attention to the availability of the MERIT Standards document (US Naval Observatory Circular No. 167) and to the fact that some additions were in preparation. Mueller stated that the Proceedings of the Columbus Conference would be published shortly, and that the Proceedings of the Workshop and the Catalogue of MERIT/COTES data would be published in 1986; bibliographic details are given at the end of the Joint Summary Report.

## 3. REPORT ON SESSION 2: THE ROTATION OF THE EARTH

The Chairman of the second session, Y A Yatskiv, President of Commission 19 on the Rotation of the Earth, introduced the speakers who presented papers on various aspects of the methods of analysis, the intercomparison of the series obtained by different techniques, and the interpretation of the results on the variations in the rate of rotation of the Earth and on the motion of the pole of rotation.

3.1 P Paquet presented his paper on the Agreement in Polar Motion and UT measurements during the MERIT Campaign. He had compared five series of values of the coordinates of the pole obtained during the MERIT Main Campaign (1983/4): two series were based on optical astrometric data provided by the BIH and IPMS analysis centres, and other series were based on Doppler observations of the NOVA satellite, satelllite laser ranging and VLBI. He also compared two series of UT1 obtained by optical astrometry with that obtained by VLBI.

For the polar-motion data he determined and removed the annual and Chandler components. He then fitted the residuals by a smooth curve corresponding to a Vondrak filter of approximately 30 days, formed residuals with respect to this curve, and then carried out various correlation tests between the data for the different techniques. He found that for periods greater than 30 days there is a high correlation between the residuals for the various techniques, but that for periods less than one month the series are not correlated except between the SLR and Doppler series for the x-component. He considered that the Doppler results could be further improved by the use of better models for the analysis of data from NOVA satellites.

For the UT1-data (optical astrometry and VLBI only) he removed a linear drift and found residuals from a smooth curve by the Vondrak method. He then found that the three series of residuals showed an irregular variation with a period of about 50 days, and he claimed that the IPMS results for periods over 30 days are of high quality. He confirmed the very good performance of the VLBI technique and concluded that the activity in optical astrometry should be continued.

In the ensuing discussion Feissel displayed tables of operational time series on polar motion; a considerable improvement in the SLR results as a consequence of the adoption of better models was apparent. She supported Paquet's view that the Doppler results could also be improved.

3.2 E Preuss presented a paper by Campbell and Schuh on Short-period variations of earth-rotation determined by VLBI. The VLBI observations had been made during the MERIT Campaigns, in sessions lasting only one hour on the 6000-km baseline between Westford (USA) and Wettzell (GFR); data were obtained each day over a 64-day period and for 18 days at an interval of 15 days. The data were analysed at the IRIS analysis centre at the National Geodetic Survey (USA) to determine UT1, and a spectral analysis was then carried out. Terms with periods 9.1, 13.6 and 29.2 days were found and were claimed to be in good agreement with the Yoder model of tidal effects. McCarthy commented that USNO had obtained different periods at different times of the year from analyses of daily data from the connected-elements interferometer at Greenbank (USA). Guinot stated that N Capitaine had also found that the 13-day term varied over an interval of 4 years.

3.3 J O Dickey first presented a paper by Dickey, Eubanks, Newhall, Spieth, Steppe, Sovers and Williams on work carried out at the Jet Propulsion Laboratory on Earth-orientation: analysis, intercomparisons and implications. She drew attention to the extent of the MERIT-related work at JPL: the use of the Deep Space Network (DSN) as a VLBI system to obtain regular estimates of earth-orientation; and the operation of an LLR analysis centre, including the regular production of UTO data. She also highlighted the recent advances in LLR at CERGA (Grasse, France), McDonald Observatory (Texas, USA) and Haleakala (Hawaii, USA) in both the quality and the quantity of the observational data.

An intercomparison of earth-rotation and polar-motion results from a variety of services has made it possible to evaluate the accuracy of the various measurement techniques. The period considered was from 1983.5 to 1985.0. The UT1 data from LLR and VLBI (both IRIS and DSN) agree to within their formal errors; the LLR formal errors are too large, probably reflecting an overconservative analysis. On the other hand, the formal errors given by BIH from optical astrometry are significantly too small, attributable, at least in part, to seasonal errors. Differencing the different data with respect to a smoothed IRIS multi-baseline determination, the RMS differences are 0.2, 0.4, 0.5 ms for the Westford/Wettzell VLBI, the LLR, and the DSN results, respectively. In contrast, differencing the optical data with respect to a combined space-based smoothed series gives an RMS difference of 1.2 ms. Polar motion determinations from SLR by the University of Texas and from intercontinental VLBI appear to be at least as accurate as is expected from the measurement formal errors, while the errors in the results obtained by BIH from optical astrometry and in the results obtained by the Defence Mapping Agency from the Doppler measurements of the NOVA satellite are substantially larger than can be explained by their formal errors. There are no apparent periodic systematic errors in the SLR and VLBI results, but the optical astrometric and the Doppler series show approximately annual systematic errors. The RMS difference between SLR and IRIS is about 2 milliarcseconds (mas); while the RMS differences of SLR with respect to Doppler and optical astrometry are 13 mas and 19 mas respectively for the x-component and 11 mas and 14 mas for the y-component. These results are indicative of the greatly improved performance of the new techniques.

Nutation estimates from long-duration VLBI experiments conducted by the DSN and reduced at JPL were intercompared with similar estimates from the IRIS/POLARIS data as reduced at Harvard University. The two series have an RMS difference of 1.6 mas or less. After removal of the Wahr (or IAU 1980) theory of nutation, there exist large (2 mas) annual and smaller (1 mas) semiannual oscillations, as well as linear trends (about 1 mas/year), in both obliquity and longitude. The period of the free-core nutation is about 430 d, rather than 460 d, and the damping time is about a decade; these results are consistent with interactions between core and mantle due to bumps, on the scale of 1 to 2 km, at the boundary.

In the discussion Yatskiv said that the period of 430 d has also been derived in the USSR and Dickey confirmed that the nutation corrections are consistent with those obtained by Herring.

3.4 J O Dickey then presented a paper by Eubanks, Dickey and Steppe on Atmospheric angular momentum and earth rotation. She began by drawing attention to the dramatic impact of the new technologies on the study of polar motion and of the variations in the rate of rotation of the Earth. The development of space geodesy has greatly increased the accuracy and precision of earth-orientation measurements, while the analysis of global weather data for operational weather forecasting now routinely provides high quality estimates of the atmospheric excitation of the Earth's rotation. The combination of these data types has also increased the understanding of the Earth's angular momentum balance in general and, in particular, of the atmospheric as well as the non-atmospheric excitations of earth-orientation changes.

Particular emphasis was placed on the recent data from the MERIT Main Campaign. Geodetic estimates of changes in the length of day (LOD) were compared with the corresponding meteorological excitation estimates for the period from 1983 September 1, through 1984 October 1. The geodetic excitation estimates were obtained from a Kalman smoothing of data from VLBI and LLR, while meteorological values were provided by the US National Meteorological Center (NMC) and from calculations by the UK Meteorological Office based on the results of the European Centre for Medium Range Weather Forecasting (EC). There were significant seasonal discrepancies between the EC and the NMC wind-term estimates, but seasonal errors in the pressure terms seem to be small. Changes in the EC weather-analysis software on 1984 February 1 caused a large step function change in the EC pressure term but had no observable effect on the EC wind data. The sudden jump in the pressure term was followed by a slow rebound which restored about 10% of the change over a period of 10 to 14 days. There is in general excellent agreement between the EC and NMC data (RMS difference is 0.062 ms for the wind term; 0.022 ms for the pressure term) and the geodetic LOD estimates (RMS difference is 0.072 ms for the EC pressure plus wind; 0.087 ms for the NMC pressure plus wind). Anomalously high values of atmospheric angular momentum and length of day were observed in late January 1983. This signal in the time series of these two coupled quantities appears to have been a consequence of the El-Nino equatorial-Pacific warming event of 1982-83. The atmospheric estimates from both the EC and NMC results were compared with the LOD estimates; no appreciable time delay could be detected. A combined LOD series beginning in 1962 was formed by including the modern space techniques as well as the classical optical results. Studies using the longer data sets suggest that there may have been similar LOD changes during previous El-Ninos and that some of the interannual changes in the LOD are related to the Southern Oscillation. These studies reveal a correlation of -0.5 between the interannual fluctuations in the Southern Oscillation Index and in the length of day.

Studies of the relation between the length of the day and the angular momentum of the atmosphere are being coordinated by IAG Special Study 5.98 (of which Dickey is the active chairman).

The discussion turned to the contribution of the ocean to the changes in the angular momentum of the Earth. It was recognised that the short-term changes due to the ocean are much less than those due to the atmosphere and that they are more difficult to monitor, but nevertheless it was agreed that it would be worthwhile attempting to obtain data on the oceanic contribution.

3.5 The session concluded with two short papers on new techniques for processing time and polar-motion series. R O Vicente had treated polar motion as a complex time series and had analysed data from the BIH Annual Reports for 1981-83 and also more recent data. He showed various plots and stressed the need to "be careful" in interpreting the results of the comparisons between different techniques. R Verbeiren presented a paper on the Computation of pole coordinates from the MERIT Campaign with least-squares collocations. He pointed out that the correct computation of a final set of coordinates of the pole at prespecified equidistant epochs from all available observational series is a severe statistical problem. He considered that least-squares collocation (using a technique introduced by Moritz) offers the possiblity of combining in one computational step the determinations of both the coordinates of the pole and biases in the reduction constants and reference systems. The different series are introduced with appropriate weight through the use of their covariance matrices. The application of this method to the MERIT Main Campaign shows its power by giving x, y values for every day with an accuracy of 0".004; it shows the high-level of accuracy of the SLR and VLBI results and of the determination by DMA from Doppler observations of the NOVA satellite. He considered that it also shows that the methods of classical astrometry provide good results in spite of their much higher noise level. In answer to a question he stated that he had not yet used the method for prediction purposes as the series are too short.

3.6 The Chairman (Yatskiv) closed the session at 5 40 pm by thanking all the speakers and by congratulating the coordinators and other participants on the undoubted success of the MERIT/COTES Campaigns.

REFERENCES

See the list at the end of the preceding Joint Summary Report.