IERS TECHNICAL NOTE 22

IERS missions, present and future

Report on the 1996 IERS Workshop

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Errata
for the IERS Conventions (1996), IERS Technical Note No 21.

1. p. 2: In the Errata from Technical Note 13, Pearblossum should be Pearblossom.
2. p. 12: In the second full paragraph, relevent should be relevant.
3. p. 15: COCO x rotation -0.009705 should be **-0.010425**. EURA z rotation 0.003135 should be **0.003153**.
4. p. 16: After the "Compute the new coordinates" comment, ORY should be OMY(IPSIT), ORZ should be OMZ(IPSIT), and ORX should be OMX(IPSIT).
5. p. 18: In the last reference, Follkner should be Folkner.
6. p. 19: For 1/f, 298.25645 should be 298.2564**2**.
7. p. 35: In the second ful paragraph, micorarcsecond should be microarcsecond.
8. p. 36: i=1,106 has been removed from the summation and in Table 5.4
   the B_i" term -12.7 should be **12.7** on line 5,
   the B_i" term 1.4 should be **-1.4** on line 10.
9. p. 39: Liekse should be Lieske.
10. p. 41: In the first partial paragraph, "(see below)Consequently" should be "(see below). Consequently".
11. p. 42: In the last paragraph, "because the contribution" should be "because there is no closed expression for the contribution".
12. p. 44: In the last paragraph, "are below cutoff and are not listed." should be "are below cutoff (except for K_1, as given above) and are not listed."
13. p. 50: Sckweizerbart'sche Verlagabuchhandlung should be Schweitzerbart'sche Verlagsbuchhandlung.
14. p. 51: In the Roosbeek reference, in press should be 126, pp. 197-204.
15. p. 56: In the second paragraph, sperical should be spherical.
16. p. 64: In the last paragraph, the upside-down question mark is removed.
17. p. 70: In the Rabbel and Zschau reference, Statis should be Static.
18. p. 71: Sckweizerbart'sche Verlagabuchhandlung should be Schweitzerbart'sche Verlagsbuchhandlung.
19. p. 73: In the first paragraph, corected should be corrected.
20. p. 79: In the first paragraph, atomspheric should be atmospheric.
21. p. 80: In the Mendes and Langley reference, Navigations should be Navigation.
22. p. 81: In the first paragraph under Global Positioning System, Fliegel *et al.* (1992), (Gallini and Fliegel, 1995) are recommended should be Fliegel *et al.* (1992) Gallini and Fliegel (1995) and Fliegel and Gallini (1996) are recommended.
23. p. 82: In the Fliegel and Gallini reference, in press should be 33, No 6, pp. 863-866.

Note:
As of 15 January 1997, all changes listed above have been made to the electronic version. The up-to-date files are accessible via

- anonymous ftp maia.usno.navy.mil (192.5.41.22)
  directory conventions
  file errata for the list of corrections,

- the NEOS World Wide Web page (http://maia.usno.navy.mil).

The policy on changes is to make the changes to the electronic version as soon as possible.

Contents

IERS Technical Notes

This series of publications gives technical information related to the IERS activities, e.g. reference frames, excitation of the Earth rotation, computational or analysis aspects, models, etc. It also contains the description and results of the analyses performed by the IERS Analysis Centres for the Annual Report global analysis.

Back issues still available

No 14: P. Charlot (ed.) Earth orientation, reference frames and atmospheric excitation functions submitted for the 1992 IERS Annual Report.*[Superseded by T.N. 17]*

No 15: C. Boucher, Z. Altamimi and L. Duhem. ITRF92 and its associated velocity field

No 16: J.O. Dickey and M. Feissel (eds.). Results from the SEARCH'92 Campaign

No 17: P. Charlot (ed.). Earth orientation, reference frames and atmospheric excitation functions submitted for the 1993 IERS Annual Report.*[Superseded by T.N. 19]*

No 18: C. Boucher, Z. Altamimi, L. Duhem. Results and Analysis of the ITRF93

No 19: P. Charlot (ed.). Earth orientation, reference frames and atmospheric excitation functions submitted for the 1994 IERS Annual Report

No 20: C. Boucher, Z. Altamimi, M. Feissel, P. Sillard. Results and Analysis of the ITRF94

No 21: D.D. McCarthy (ed.). IERS Conventions (1996)

No 22: C. Reigber and M. Feissel (eds). IERS missions, present and future. Report on the 1996 IERS Workshop

Future issues

No xx: C. Boucher, P. Sillard. Evolution of realization of global reference systems from space techniques and their links with ITRF

No xx: C. Ma and M. Feissel (eds). Definition and realization of the International Celestial Reference System

FOREWORD

The IERS was created in 1987 by the IAU and the IUGG, replacing the Bureau International de l'Heure (BIH) and the International Polar Motion Service (IPMS), as a result of the ten-year international MERIT Campaign. The IERS started its activities in January 1988.

IERS was given the missions to define and maintain a terrestrial reference system based on the most precise space geodesy techniques at this time, to define and maintain a celestial reference system based on the directions of extragalactic radio sources and its tie to other celestial reference frames, and to monitor the Earth's orientation, i.e. the parameters that connect the terrestrial and the celestial reference systems as a function of time.

When operation began, the observational techniques available for these tasks where Very Long Baseline radio Interferometry (VLBI), Lunar Laser Ranging (LLR) and Satellite Laser Ranging (SLR). The Directing Board included representatives of the Coordinating Centres for these observing techniques, of the Central Bureau, and of IUGG, IAU and FAGS (Federation of Astronomical and Geophysical Data Analysis Services).

According to the Terms of Reference of the service, "the Directing Board exercises general control over the activities of the service, including modifications to the organisation and participation that would be appropriate to maintain efficiency and reliability, while taking full advantage of the advances in technology and in theory". The main decisions of the Directing Board in the first eight years of activity were the setting up of permanent monitoring of global atmospheric dynamical parameters in 1989, the adoption of the Global Positioning System (GPS) as an additional observing technique in 1989-93 and of DORIS (Doppler Orbitography by radio positioning integrated on satellite) in 1994-96, and the redefinition of the VLBI contributions in 1995-96.

In 1995, the IERS had achieved its primary missions, by providing globally distributed terrestrial and celestial references and the Earth's orientation with an accuracy equivalent to about one centimeter on the surface of the Earth.

After the initial IERS observing techniques reached maturity, new and powerful techniques were introduced. The environnement in Earth sciences - including funding aspects - evolves rapidely. The consideration of expectations and frustrations as well as the recognition of achievements led the Directing Board to organize a general public evaluation of the service, that would encompass a review of current operation, and advice on possible extensions to better meet new and future needs for global references. In December 1995 they decided that the 1996 IERS Workshop would be dedicated to this review, after a period of preliminary discussion. The discussion was organized under six topics, each analyzed by Topic Coordinators helped by a small group. The Topics were as follows.

1: Assessment of current missions
2: Astronomical reference frames
3: Vertical references, incl. geoid, sea level, etc.
4: Topography and crustal deformations
5: Unification of regional reference systems
6: Earth rotation dynamics and geophysical fluids

The Topic Coordinators prepared draft reports with recommendations and distributed them in advance to the IERS Workshop. The latter took place at Paris Observatory, 14-16 October 1996, with program and participants as given at the end of this volume. The draft reports and recommendations were discussed in detail during the workshop and then finalized by the Topic

Coordinators, taking into account the results of the discussions. The final texts are those published in this volume.

The lively discussions that took place in this context were extremely productive in that a number of important aspects were put forward or given increased emphasis. While some extensions of activities in the fields of astronomy, geodesy and geophysics were recommended, the Workshop also recognized the success of IERS in providing timely and accurate data on Earth rotation, and in the establishment and maintenance of accurate terrestrial and celestial reference frames.

The IERS Directing Board started to work on the implementation of the recommendations, at and between the two DB meetings already held in October and in December 1996. The major aspects of the foreseen evolution are as follows.

- Maintaining the International Celestial Reference Frame (ICRF) based on VLBI-derived directions of extragalactic radio sources, and of the tie of the Hipparcos galactic reference frame, as will be recommended by the IAU Working Group on Reference Frames to the 1997 IAU General Assembly. This activity will be performed in concertation with an IAU Working Group on reference frames.

- Coordinating the use of astronomical observations for tying the Solar System reference frames to the ICRF.

- Monitoring the global geophysical fluids that influence both the ground measurements and the Earth's rotation, an extension of the current activity on atmospheric data.

- Monitoring the motion of the Earth's centre of gravity.

- Fostering the provision of global vertical terrestrial references and of global horizontal references for the monitoring crustal deformations, in close cooperation with the International Association of Geodesy.

- Enhancing the role of Coordinators and extending their field of responsability to general themes of importance to IERS.

- Getting organized to interact with the Working Groups set up by IAU, IAG and IUGG on topics relevant to IERS missions.

- Strengthening the development and maintenance of the IERS Conventions.

- Developing or improving technical abilities for the global combination of products from analyses of the various observing techniques, and fostering internal competition within IERS on this aspect.

- Extending formally the Directing Board membership to better represent all components of IERS activities.

- Polling the IERS distribution lists to check the various types of users and their specific requirements.

The whole endeavour of reviewing IERS and making it evolve owes much to the dedication of the scientists that accepted to work on the requested evaluations and then took account of the input of the Workshop participants to finalize the documents in this volume. The IERS Directing Board is most thankful to these colleagues for their strong contributions. It is doing its best to use as efficiently as possible the momentum they created.

Christoph Reigber
Chairman
IERS Directing Board

THE INTERNATIONAL EARTH ROTATION SERVICE: CURRENT MISSION AND RECOMMENDATIONS FOR THE FUTURE

G. Beutler, Astronomical Institute, Berne
I. I. Mueller, The Ohio State University, Columbus
J. Vondrak , Astronomical Institute, Prague

1. INTRODUCTION

The six topics discussed at the Paris Workshop (October 1996) are listed in Table1.

Table 1. Topics of the 1996 IERS Workshop

Topic	Description	Topic Coordinators
1	Assessment of current missions	G. Beutler, I. Mueller
2	Astronomical reference frames	J. Kovalevsky, M. Standish
3	Vertical references, incl. geoid, sea level, etc	C. Boucher, B. Carter
4	Topography and crustal deformations	B. Engen, J.B. Minster
5	Unification of regional reference systems	W. Augath, J. Manning
6	Earth rotation dynamics and geophysical fluids	V. Dehant, C. Wilson

One of the duties of the Coordinators was to prepare a position paper with a small team of experts. The team for Topic 1 is that of the authors of the present report.

According to the instructions received the following questions had to be adressed (Table 2).

Table 2. Questions to be addressed under Topic 1. Assessment of Current Mission.

Number	Question
1.1	International Terrestrial Reference Frame (users, requirements, access)
1.2	International Celestial Reference Frame (users, requirements, access)
1.3	Earth Orientation Information (users, requirements, access)
1.4	IERS Conventions (Standards) (update rate, software for users)
1.5	Assessment of the structure of the IERS (Directing Board, Coordinating Centers, Bureaus, etc.)
1.6	Extension of IERS Missions

Obviously our Topic is the only one which is not primarily of a technical nature. In Topic 1 the organizational aspects are studied and modifications to the structure may be recommended. It is clear that our recommendations must be broad enough to accomodate any changes that might emerge from Topics 2 to 6.

The only question reaching in our opinion into the other fields is No 1.6, Extension of the IERS Mission. Without making the attempt to solve the other Topic Coordinators problems we would like that the following considerations are taken into account:

(1) We believe that the IERS should be a cooperative service shared by Astronomy, Geodesy and Geophysics. The three components should be kept in a balance.

(2) We believe that the global character of the service should be retained, without going too much into details that might be covered by other existing services like the IGS, PSMSL, IGeS, ICET, IGB or regional organizations. With reference to Table 1 we believe that

- the establishment and maintenance of the Astronomical Reference Frame must continue to be one of the primary responsibilities of the IERS

- only the global aspects of Topic 3 should be within the IERS responsibility (this is the case today),

- Topic 4 looks like a regional problem which should be addressed by IERS users in close cooperation with the ITRF section of the IERS,

- Topic 5 is a very desirable goal to achieve, but obviously the responsibility to perform such a task cannot be taken away from the government bodies responsible for mapping and cartography.

(3) We believe that instead, the IERS should revise its products to better serve these communities. The IERS must be a service in support of the national geodetic institutions (responsible for regional networks) with the IERS products, but should not make the attempt to replace them.

(4) In summary we believe that only Topics 1, 2 and 6 and the global aspects of Topic 3 are clearly within the IERS responsibilities. This is certainly true in view of the Terms of Reference as they are today (Appendix A).

(5) From the point of view of Space Geodesy, the IERS is the multi-technique service par excellence. It is e.g., clear from the outset that VLBI cannot produce a geocenter, neither can GPS or SLR produce UT1 and nutation series with good long-term stability. This multitechnique aspect should be given more emphasis in future. We would even argue that everything that does not involve at least two space geodetic techniques does NOT deserve the label "IERS". The exception to this statement is of course the celestial reference frame - at least in its present realization.

If we adopt this principle as an axiom we would have the perfect argument for a continuation of the optical reference frames - based today on the HIPPARCOS catalogue and new Earth-and space-based CCD astrometry techniques.

A first look at our task (Topic 1) made it clear that most of the questions that we have to address were already dealt with in detail at workshops held in the 1980's. In particular we would like to draw attention to the Airlie Workshop (Walters, 1984), to the Erice Workshop (Mueller and Zerbini, 1989), and, last but not least, to the Coolfont Report (NASA, 1991). It cannot be the task of our position paper to reproduce these studies; on the other hand it is clear that we have to base our considerations on these reports and to try to take into account the changes that took place since - of course only insofar as they are relevant to the IERS.

We notice moreover that most of the aspects of Question 1.2, International Celestial Reference Frame (users, requirements, access) would better be dealt within the frame of Topic 2, Astronomical Reference Frame. We will thus only address this issue when necessary in the context of the other issues of the present report.

The program for the 1996 IERS Workshop in Paris was distributed through the IERS Gazette (distribution list containing about 500 addresses). It is thus not surprising that we obtained spontaneously a few individual and voluntary comments and suggestions regarding our work. These contributions are appreciated and taken into account in this report. We decided to ask for additional comments from experts in the field such as the extended IERS Governing Board and others.

A first version of this position paper was made available to all workshop participants well before the beginning of the workshop. This distributed version served as the basis for the sessions devoted to Topic 1. As expected, the paper and its recommendations attracted much attention and created very useful and sometimes controversial discussions at the 1996 IERS Workshop. The attempt was made at the workshop to come up with a revised set of recommendations which seemed to reflect the general opinion of the workshop participants.

The last step consisted of thoroughly revising the position paper for Topic 1 after the 1996 IERS Workshop in Paris. Let us mention in particular, that Section 4 was completely rewritten to reflect the discussions at the Paris Workshop and to contain the adopted recommendations.

The revised version of the position paper is structured as follows:

Section 2: Current Situation of the IERS
Section 3: User Requirements
Section 4: Recommendations

2. CURRENT SITUATION OF THE IERS

Charter and Structure

Let us briefly review the Charter of the IERS as contained in the Terms of Reference. The current version was made available to us by Martine Feissel, Director of the Central Bureau and secretary of the IERS Directing Board, and is contained in Appendix A of this report.

The IERS Terms of Reference are short and clear: the IERS is responsible for the definition and maintenance of the Celestial and Terrestrial Reference Systems and for the determination of the Transformation Parameters between the reference frames of these systems. The latter part obviously consists of time series for polar motion, UT1, and precession/nutation. In addition the IERS is responsible for organising operational activities, management of data and results.

The IERS consists of the Central Bureau, Coordinating Centers and the Directing Board. According to Martine Feissel (private communication) the IERS Central Bureau is organized in the following way:

The Central Bureau is a joint effort of Paris Observatory and Institut Géographique National. The seat of the Central Bureau is at Paris Observatory. The work on Earth orientation and reference frames is performed by sections of the Central Bureau, as listed in the Table3.

Table 3. Organization of the IERS Central Bureau

Section	Institute	Head
Celestial reference frame	Observatoire de Paris	F. Arias
Terrestrial reference frame	Institut Geographique National	C. Boucher
Earth orientation	Observatoire de Paris	D. Gambis

The activity (Direction plus the three sections) add up to a workload of 7 man-years per year. It is performed by a total of 12-15 persons.

The Central Bureau is responsible for combining the various types of data and to disseminate the information on the appropriate information on Earth orientation and the two reference frames.

There are two IERS Sub-Bureaus, the Sub-Bureau for Rapid Service and Predictions (U.S. Naval Observatory), and the Sub-Bureau for Atmospheric Angular Momentum (NOAA, Washington) to accomplish well-defined tasks.

The Coordinating Centers are responsible for developing and organizing the activities within each technique. At present there are five Coordinating Centers (for VLBI, LLR, GPS, SLR, DORIS).

The IERS Directing Board is composed of representatives of

- the Central Bureau,
- all Coordinating Centers,
- IAU, IAG/IUGG, FAGS.

According to the current director of the Central Bureau, Sub-Bureau representatives and representatives of the Central Bureau Sections were also treated de facto as members of the Directing Board. More information concerning the work of the IERS components may be found in Appendix B (using the year 1996 as an example).

Products

Appendix C contains the list of regular publications of the IERS with some explanations as described in the IERS Annual Reports, Appendix D contains the distribution list for these reports. Most of the material is available in paper form and in electronic versions.

This aspect is in particular true and important for IERS Bulletins A and B.

The IERS Annual Reports contain the necessary information for the best current realizations of the ITRS and the ICRS as well as an evaluation of the time series for the transformation parameters between the two frames.

Not explicitly in the list, but probably one of the most important and outstanding products of the IERS, are the IERS Standards, or, as they are called today, the IERS Conventions. So far three versions of the Standards/Conventions were prepared and made publicly available (McCarthy, 1989, 1992, 1996).

3. USER REQUIREMENTS

The IERS, as probably each service, makes well defined products available to a broad variety users. Let us adopt for the following considerations a simplified scheme by introducing three types of users:

- Standard Users (SUs) of the IERS products. Government agencies like topographic services, navigation/geodetic services, geological services etc., are considered as SUs.

- Internal Research oriented Users (IRUs) directly involved in the work (technologies) of the IERS. In this category are e.g., scientists in the VLBI, SLR or GPS Analysis Centers who contribute directly to the IERS products.

- External Research oriented Users (ERUs) not involved in the operation of the IERS. Typical ERUs are researchers addressing fundamental issues related to the stability of the Earth, i.e., the temporal deformations and the variable rotation of the Earth on a variety of time scales.

The common requirement of the SUs and IRUs is the availability of correct transformation parameters (albeit with different levels of accuracy) between their respective terrestrial and astronomical frames of reference in use, while the ERUs are more interested in studies of the driving mechanisms of the transformation parameters (precession, nutation, polar motion and UT1) and/or in modeling them.

The SUs astronomical frame of reference is directly tied to their observations (e.g., stars in astronomical positioning) and they require IERS to provide transformation parameters based on internationally adopted reference systems so that they can provide coordinates which refer to an internationally adopted terrestrial frame.

The IRUs astronomical (inertial) frame is technique dependent (e.g., defined by a catalogue of radio sources or by the ephemerides of artificial satellites) and the transformation parameters have to be consistent with the technique dependent terrestrial frame as defined by the adopted coordinates of selected observatories or tracking stations. The transformation parameters usually are part of the solutions producing source coordinates (VLBI) or satellite ephemerides and station coordinates, and therefore the IRUs generally do not depend on the IERS to the same extent as the other users do. An exception is the quasi-daily measurement of UT1 by VLBI which benefits from independent determinations of polar motion by other techniques and which is used in turn by satellite geodetic IRUs.

Because the astronomical and terrestrial frames may be different for different techniques, the resulting transformation parameters may be different for different IRUs and their comparison or combination into a single series as a separate undertaking (primarily for the use of the ERUs) is a necessity. In any case the combined series (possibly several of them) should be made available through the IERS publications.

The ERUs requirements essentially are the same as those of the IRUs, except that there is neither the need nor the wish to deal with the IRUs individual series. Using current IERS combined products is problematic for various reasons, however (e.g., because of constraints inherent in the IERS products due to the current weighting and/or smoothing procedures) and at present they need access to one or more individual series more suitable for their specific applications.

In summary, one might say that the SUs and the ERUs are typical IERS users and that the IRUs are IERS "insiders". How to serve all user types? One option for the IERS would have been to generate different types of products for different types of users. This idea was not supported, however, by the majority of the participants of the 1996 IERS Workshop. A broad consensus was reached, instead, that the IERS should meet the most demanding requirements in one series of products which would then satisfy all types of users (ERUs, IRUs, and SUs). This was considered as a logical continuation of the policy pursued so far by the IERS.

In order to recognize these most demanding requirements we will elaborate on specific research requirements, based on the programmatic documents mentioned above (NASA, 1991, pp. 14-15; Walters, 1984, pp. 36-37).

As mentioned above the primary scientific objectives are related to the stability of the Earth, i.e., the temporal deformations and variations in Earth rotation on a variety of time scales. The challenge at the moment is to separate the noise from the signals and this is where multiple techniques become important, and where fundamental analyses that do not force results to pre-conceptions of the Earth behavior are needed.

The scientific objectives include the following (see also Topic 6 report):

- To observe and understand the interactions of air and water (oceans, ground water, ice) with the rotational dynamics of the Earth, and their contribution to the excitation of Earth rotation variations, over the time scales of hours to centuries.

- To observe and understand the effects of the Earth's crust and mantle on the dynamics and excitation of Earth rotation variations, over the same time scales.

- To observe and understand the effects of the Earth's core on the rotational dynamics of the Earth and excitation of Earth rotation variations over time scales of a year and longer.

- To establish, refine and maintain terrestrial and astronomical reference frames.

These objectives reflect the unique strength of studying Earth rotation variations to provide an absolute reference frame for geodynamics; provide global measures of mass redistribution and deformation due to hydrological and meteorological variability, tectonic activity, mantle convection, glacial melting, sedimentation and erosion; constrain the rheology of the lithosphere through observation of Earth rotation variations at the time of earthquake activity; study physical properties of and motions within the inaccessible core; and constrain magnitudes of viscous, magnetic, and pressure torques acting on the core mantle boundary.

The ERU goals include the following:

- Measurement of the rotation vector of the Earth with at least 0.1 mas precision and a temporal resolution nominally 4-6 times a day.

- Improve analysis and modeling capabilities to a level commensurate with the above spatial and temporal resolution.

- Geophysical, oceanographic and atmospheric data for the interpretation of the rotational and deformation data.

- Ties between the celestial and terrestrial reference frames at the few mm level.

- Plate motion measurements for at least three sites per major plate with auxiliary data such as gravity, seismic information at least at the key sites.

In closing, it should be pointed out that

- there never have been measurements on a global scale with the accuracy and time resolution now possible,

- large scale effects (such as pressure loading) deform the Earth more easily than small scale effects and that the response is very long wavelength. Therefore global (at least continental) scale measurements are more likely to see the effects than small scale measurements.

- there are many phenomena that ERUs expect to see (as deviations from steady state motion) but there are likely many that we do not know about yet, which is why the ERUs want as few constraints as possible on the data analysis,

- there is so much data that it is difficult for any one center to process it all.

4. RECOMMENDED FUTURE DEVELOPMENT

The current structure of the IERS was presented in Section 2: we have the Central Bureau consisting of the Celestial Frame Section (Observatoire de Paris), the Terrestrial Frame Section (IGN), and the Earth Orientation Section (Observatoire de Paris); currently there are two Sub-Bureaus and five Coordinating Centers (CCs). Figure 1 gives an impression of this structure. We made the distinction between two levels (not in a hierarchical sense), the Central Bureau Level and the Coordinating Center Level.

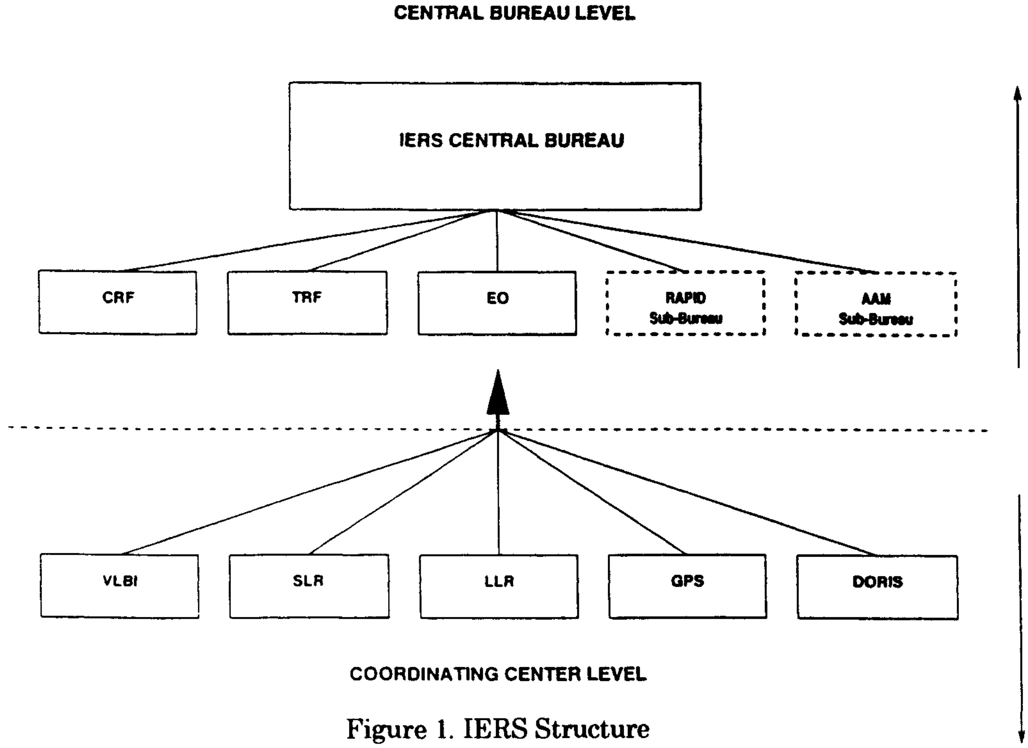

Figure 1. IERS Structure

We believe that this structure proved its usefulness in the past. We believe moreover that there is no obvious reason for dramatically changing the now existing IERS components, namely Central Bureau and Sub-Bureaus, Technique Coordinators, and Directing Board.

Before offering our specific recommendations for the future development of the IERS, it is useful to consider some broad themes that we expect will be increasingly important, namely

- improved communications,
- distributed combination efforts, and
- an even more dynamic evolution than in the past.

First, global instantaneous communication techniques have undergone revolutionary changes since the founding of the IERS. This creates the opportunity for faster and easier ways to exchange information among groups and individuals worldwide. Naturally, the IERS has taken advantage of this revolution in many ways, as reflected partly by the distribution modes used for IERS products presented in Appendix D. E-mail, ftp file transfers, and WWW-pages are routinely used to facilitate information exchange among all components of the IERS and its users. We acknowledge these developments and encourage the IERS Central Bureau to lead in the exploitation of new technologies. For example, feedback of results from combinations to the Analysis Centers could be improved in frequency and comprehensiveness. Likewise, the Analysis Centers and the proposed specialized (Combination) Centers (see Recommendation 3, below) should provide full and timely information concerning the technique solutions to the IERS Central Bureau and the Sub-Bureaus.

Second, the ability to transfer large data files easily between groups makes if feasible for combination efforts to be efficiently distributed among more groups than the Central Bureau alone. The value of multiple combination efforts has been demonstrated already by the IGS for GPS. We propose to encourage similar technique-specific combinations for the other techniques in the IERS. The Coordination Centers are asked to organize these. In addition, we believe that new multi-technique combination groups within the IERS structure would stimulate a "friendly competitive" environment that would ensure the best possible approaches emerge.

Finally, the more dynamic environment that we envision for the IERS will allow the organization to evolve naturally in response to rapidly changing conditions. It is clear that new techniques will soon contribute to the IERS which must be evaluated thoroughly and efficiently. We believe the multi-lateral comparison and coordination efforts proposed below will enhance this possibility.

We propose that specialized Analysis Centers are created to study state-of-the-art combination of results stemming from different space techniques to complement the existing IERS structure together with the already existing centers (Recommendation 3). It is left to the IERS Directing Board whether these new Analysis Centers will be considered as Analysis Centers (and represented by a Coordinating Center on the corresponding level in Figure 1), as Sub-Bureaus, or even as Central Bureau Sections (on the corresponding level in Figure 1.

We also propose to create a Network Coordination Group and we encourage the IERS to consider the creation of one or more new Coordinating Center(s) e.g., for monitoring the fluid angular momentum (geophysical fluids) (see Recommendation 2, below).

Let us now present our commented recommendations. We will always start with the recommendation(s) first and let the explanations follow.

Recommendation 1: Each Coordinating Center (CC) should strengthen overall control of observations,quality control, and data processing for products of interest to the IERS (coordinates, EOP series,etc.) in accordance with the IERS Terms of Reference. Combinations of individual solutions into technique specific products are strongly encouraged.

When the IERS started working in 1988 there was no strong coordination within each technique (possibly with the exception of VLBI, where the observations had to be coordinated very closely). The work within each technique was more of development-type rather than that of a full fledged service. The procedure thus adopted by the IERS was simple: the IERS Central Bureau and the Sub-Bureaus worked directly with each individual group generating and/or processing data for a single technique and it had access to each individually generated series of coordinates, EOPs, etc. The role of the Coordinating Center was that of a spokesman for these groups in the IERS Directing Board.

Meanwhile a number of developments within and outside the IERS took place: we have seen the development of the IGS with a clear structure, namely the Central Bureau, several Analysis Centers, the Analysis Center Coordinator, Global, Regional, Operational Data Centers, and, last but not least, a truly global network of about 100 stations. The IGS, as the name implies, is itself a service with a well-defined list of official products that are based on the products of the individual IGS Analysis Centers and that are expressed in the IERS System, according to the IGS Terms of Reference.

The DORIS group is organized very much along the same lines as the IGS. The VLBI links to the IERS were considerably improved lately by the call for participation issued by the IERS in 1995. The SLR group, as the second rather old established IERS contributor, at present considers modifications pointing to the direction given in Recommendation 1 to keep the technique competitive.

We conclude that this process of change on the level of the individual techniques should be reflected in a modified role of the Coordinating Centers (CCs).

Recommendation 1 has to be passed on from the IERS Directing Board to each single CC. There should be a clear signal coming from the IERS Directing Board that strong, service-like contributions are expected from each CC. Although the CCs are contributing to the work of the IERS, they need not be IERS components (e.g., the IGS).

At present there are five IERS CCs, namely for VLBI, LLR, SLR, GPS, and DORIS. The IERS Directing Board may wish to re-consider this structure from time to time.

Recommendation 2: Coordinating Centers should be formed to promote the collection of other types of information relevant to EOPs such as atmospheric excitation functions, information on ocean circulation, global water level changes, etc.

There are observation techniques inside and outside the scope of space geodesy which are of importance for the IERS. Such techniques should be represented by a CC-type of organization and on the CC-level, organized in the sense of Recommendation 1, and represented by a Coordinating Center (Technique Coordinator).

We think in particular of observations concerning the atmospheric excitation function, of ocean currents, etc., where it should be possible to define clear products to be generated regularly. A good part of the activities considered in Topic 6 (Table 1) might fall into this category.

Recommendation 3: Combination of products from the various CCs shall be performed by at least two IERS Components such as Sub-Bureaus, specialized Analysis Centers, Central Bureau Sections. The Central Bureau should disseminate the state-of-the-art combined solutions and provide the official IERS products. The criteria for the selection or production of this official solution will be determined by the IERS Directing Board.

We believe that many institutions actually are interested today and should get involved in combining solutions performed at different centers. We conclude that such combinations must be studied within the IERS, and that the IERS should make the attempt to get as many experts and institutions involved as possible.

The above Recommendation is one of the important results of the Paris workshop which evolved slowly from the originally proposed text. After long discussions it was generally acknowledged that it is important

- to foster the collaboration of new research groups interested in combining the results stemming from all different techniques contributing to the IERS,
- to continue resp. maintain unique series of official IERS products for all types of IERS users,
- and that the IERS Directing Board is responsible for selecting resp. giving the directions for producing these official products.

Recommendation 4: It is desirable to form a Network Coordination Group to consider issues of network design, colocation, local ties, site quality, etc. as previously recognized and accepted by the IERS Directing Board.

All major space techniques contributing today to the IERS (VLBI, SLR, LLR, satellite microwave systems) will be relevant in future, too. The IERS thus must be interested not only in well organized technique-specific networks, but also in a close coordination and colocation of the networks.

This recommendation is a reminder that the IERS Directing Board should actually create the Committee on IERS Network Design and Implementation (CINDI) as announced in the minutes of the IERS DB Meeting, Tuesday, 11 July 1995 in Boulder. It was generally acknowledged that the IERS must be vitally interested in a well established and collocated ground tracking network.

Recommendation 5: Members of the Directing Board should include representatives of CCs, Sub-Bureaus, sections of the Central Bureau, selected Combination Centers (see Recommendation 3), the Director of the Central Bureau, and representatives of IAU, IAG/IUGG, and FAGS.

As stated in Section 2 representatives of Sub-Bureaus and Central Bureau Sections were considered de facto members of the IERS Directing Board. The above recommendation would change this de facto into a real membership. The recommendation also asks that the newly created group of Combination Centers (Recommendation 3) has (at least) one representative on the Board.

Recommendation 6: The IERS Conventions should be updated periodically at reasonable intervals. They should reflect state-of-the-art at the time of publication. In all cases, they should be consistent with the IAU and IUGG resolutions on reference systems (at present, the resolutions adopted in 1991). The IERS Conventions should be considered one of the IERS products for the use of the internal and external researchers. An IERS unit such as a Sub-Bureau shall be formed to maintain the IERS Conventions.

It was mentioned in Section 2 that the IERS Conventions (previously Standards) are a document of outstanding importance for the IERS and its users on all levels. The Directing Board should give this document a high priority. The conventions should appear in paper and electronic versions.

Recommendation 7: The IERS Central Bureau should continue its excellent work necessary to develop and make available information on the ITRF, the ICRF, and the transformation parameters between them. The Central Bureau should poll its distribution list to identify the various types of users and their specific requirements.

It became clear at the Paris workshop that the IERS Central Bureau is considered responsible for making available the information on the ITRF, the ICRF and the consistent transformation parameters. There were long discussions concerning the user types and the number of users within each type. It seems appropriate that the IERS distribution lists and the user requirements are carefully analysed in order to come up with a better understanding of the needs of "IERS customers".

Recommendation 8: The above Recommendations are intended to further enhance and improve the widely acknowledged excellent work performed by the IERS.

ACKNOWLEDGEMENTS:

The authors express their gratitude to Tom Herring and Kurt Lambeck for their review of the manuscript and their useful comments. Martine Feissel's effort in providing the material for the Appendices is also acknowledged with thanks. Valuable inputs by Jim Ray before, during and after the Workshop are also very much appreciated.

Many lively, animated, and sometimes controversial discussions took place during the sessions devoted to Topic 1. We acknowledge all contributions which were taken into account to the extent possible in the above revised version of the position paper.

Last but not least we express the likely feelings of all attendants of the 1996 IERS Workshop by thanking the IERS Central Bureau as the local organizer of the 1996 IERS Workshop for the cordial hospitality we could experience in Paris.

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APPENDIX A: IERS TERMS OF REFERENCE

The International Earth Rotation Service (IERS) was established in 1987 by IAU and IUGG and it started operation on 1988 January 1st. It replaces the International Polar Motion Service (IPMS) and the Earth rotation section of the Bureau International de l'Heure (BIH); the activities of BIH on time are continued at Bureau International des Poids et Mesures (BIPM). IERS is a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS).

IERS should provide the information necessary to define a Conventional Terrestrial Reference System and a Conventional Celestial Reference System and relate them as well as their frames to each other and to other reference systems used in the determination of the Earth orientation parameters.

IERS is responsible for :

- defining and maintaining a conventional terrestrial reference system based on observing stations that use the 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, the terrestrial and celestial coordinates of the pole and universal time;
- organising operational activities for observation and data analysis, collecting and archiving appropriate data and results, and disseminating the results to meet the needs of users.

IERS consists of a Central Bureau and Coordinating Centres for each of the principal observing techniques, and is supported by many other organisations that contribute to the tasks of observation and data processing.

The Coordinating Centres are responsible for developing and organising 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 can include Sub-Bureaux for the accomplishment of specific tasks. The Central Bureau decides and disseminates the announcements of leap seconds in UTC and values of DUT1 to be transmitted with time signals.

The Directing Board is composed of representatives of

- the International Astronomical Union,

- the International Association of Geodesy/International Union of Geodesy and Geophysics,
- the Federation of Astronomical and Geophysical Data Analysis Services
- the Central Bureau,
- each of the Coordinating Centres.

The chairperson is a member of the Directing Board, elected by the Board for a term of four years, with the possibility of reelection for one additional term. He/she coordinates the activity of the Directing Board. He/she is the official representative of the Service at the meetings of IAU, IAG/IUGG, FAGS, and other outside organisations.

The Directing Board exercises general control over the activities of the service, including modifications to the organisation and participation that would be appropriate to maintain efficiency and reliability, while taking full advantage of the advances in technology and in theory. Most decisions are expected to be made by consensus or by a simple majority vote. Changes in the structure, membership and chairmanship of the Directing Board can be made at any time by a two third majority.

The secretariat of the Board is provided by the Central Bureau. The function includes the distribution of papers and the compilation of the annual administrative and financial reports.

The Board shall meet annually and at such other times as shall be considered appropriate by the Chairperson or at the request of two members.

APPENDIX B: WORK PERFORMED BY THE IERS IN 1996

The data analysis which yields the values of the Earth Orientation Parameters (EOP) published by IERS includes several steps, which are summarized below.

1. Observations by the VLBI, LLR, GPS, SLR and DORIS networks.

2. Analyses (quick-look and refined) by the IERS Analysis Centres. The quick-look results include only the Earth orientation information. They are transmitted weekly in parallel to the Rapid Service Sub-Bureau and to the Central Bureau. The refined results include, in addition, information on the reference frames. They are transmitted yearly to the Central Bureau, and published in issues of the IERS Technical Notes.

3. General analysis of IERS Celestial Reference Frame (ICRF), IERS Terrestrial Reference Frame (ITRF) and EOP by the Central Bureau, based on the refined results. This adjustment, performed yearly, provides the basis for determining the systematic corrections to be added to the individual series for the following year in order to bring them into the IERS Reference System; these corrections are used in step 4. The general results are described and published in the IERS Annual Report, Part II.

4. Determination of EOP by the Central Bureau in the form of normal and smoothed values at five-day and smoothed values one-day intervals. This involves the application of the systematic corrections determined in step 3 and statistical weighting. The results are published in the monthly Bulletin B with a delay of thirty days between the date of publication and the last date of the standard solution.

5. Determination of EOP by the Rapid Service Sub-Bureau in the form of smoothed solutions at one-day intervals. This involves the application of systematic corrections and statistical

weighting. The results are published in Bulletin A with a delay of about two to five days between the date of publication and the last available date with estimated EOP. The analyses of the Sub-Bureau for Rapid Service and Predictions are described in the IERS Annual Report, part III.

6. Prediction of EOP. Bulletins A and B provide predictions of the EOP for up to ninety days. In addition, the Rapid Service Sub-Bureau issues each week predictions at monthly intervals for one year in advance. The predictions use similar algorithms, based on seasonal filtering and autoregressive processing for x, y, UT1 and on an approximate, modelled correction for the celestial pole offsets.

APPENDIX C: IERS PUBLICATIONS IN 1996

Weekly Bulletin A	Earth orientation parameters (x,y, UT1, $d\psi$, $d\varepsilon$): Rapid Service, prediction. First issue covering observation dates in the last week in 1987.
Monthly Bulletin B	Earth orientation parameters (x,y,UT1, $d\psi$, $d\varepsilon$) combined solution and individual series. Information on UTC time scale. First issue covering observation dates in January 1988.
Annual Reports	Earth orientation parameters, terrestrial and celestial frames of the IERS Reference System: combined solutions and analysis of individual results. First issue, Report for 1988, published in July 1989.
Special Bulletin C	Announcement of the leap seconds in UTC.
Special Bulletin D	Announcement of the value of DUT1 to be transmitte with time signals.
Technical Notes on	Reports and complementary information of relevance to the work of IERS Earth orientation and the reference systems.

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 a fraction of one millisecond of arc. The prediction accuracy is in the range of 0.005-0.020" for x,y, 0.002-0.015s for UT and 0.002" for $d\psi$, $d\varepsilon$ (prediction lags of 10 and 90 days). For the scientific solution of reference frames and Earth orientation, the inaccuracy is lower than 0.0003" (1 cm).

The IERS publications are airmailed. Bulletin A is prepared and distributed by the Sub-Bureau for Rapid Service and Predictions; the other publications are prepared and distributed by the Central Bureau. Bulletins A and Bulletin B are also distributed by e-mail and available on anonymous FTP (File Transfer Protocol), see Section V. The Sub-Bureau for Rapid Service and Predictions makes available various results on a Bulletin Board (see Section III).

APPENDIX D: DISTRIBUTION AND USERS OF IERS CENTRAL BUREAU PUBLICATIONS IN 1996

Distribution of IERS publications in 1996 [and 1988] (1)

Publication	Interval	Contents	Airmail		e-mail		ftp/www(3)	
			1996	1988	1996	1988	1996	1988
Bulletin B	monthly	Earth orient.	120	[360]	170	[0]	Yes	[No]
Bulletin C(2)	6 months	UTC time steps	80	[250]	220(2)	[0]	Yes	[No]
Bulletin D	8/year	UT1-UTC (0.1s)	50	[140]	150	[0]	Yes	[No]
Annual Rep.	yearly	Global anal.	400	[500]			part	[No]
Tech. Notes	2-3/year	Add. analyses	300	[200]			part	[No]
IERS Conv.	3-4 years	Models,...	1300	[1000]			Yes	[No]
Gazette	20/year	News			600	[0]	Yes	[No]

Notes 1. The distribution lists were revised in 1988 and 1996
2. Bulletin C is widely reproduced in national publications on Time
3. Dictinct users of the Central Bureau ftp,www site: 30/day , 400/month

Types of uses of IERS publications in 1996 [and 1988]

	1996	1988	Users Type
1. Space geodesy, reference frames	45%	[20%]	IRU, ERU
2. Operational reference	25%	[40%]	SU
3. Time service activities	10%	[20%]	SU
4. Geophysical investigations	10%	[10%]	ERU
5. Libraries, students	10%	[10%]	SU, ERU

ASTRONOMICAL REFERENCE FRAMES

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INTRODUCTION

The essential problem to be dealt with by the topic "Astronomical Reference frames" is to study what should be the involvment of IERS in the analysis, maintenance, and construction of celestial reference frames for all useful spectral domains. This should be done taking advantage of the competence of other groups or individuals, but respecting their areas of activity.

We note that the IAU Working Group on Reference Frames (WGRF) met in early October 1996. They discussed the key issues of this report and then, after some modification, agreed with the contents of this report.

We also note the completion of the first realization of the IAU International Celestial Reference Frame (ICRF). This catalogue of approximately 600 radio sources has now been finalized. As such, the future IERS involvement in this area concerns maintenance and upkeep.

An important proposal which affects several of the topics is that a Consultative Group should be appointed by the IAU to advise the IERS on matters concerning celestial reference frames. This Consultative Group is to begin its function at the time when the existing WGRF will have concluded its present work. It could be the successor of the WGRF.

1. MAINTENANCE OF THE ICRF

It is considered that the maintenance of the ICRF must be one of the three major objectives of IERS, together with the maintenance of the ITRF and their time-variable relations. Any decision on the definition of the system is of the sole responsibility of IAU, so that the reference system (ICRS) is to remain untouched. However, individual positions of the sources must continue to be improved. This means that:

i) All primary sources must be regularly observed in a coordinated manner as well as their structure.

ii) Other ICRF sources must also be occasionally re-observed and the evolution of their structure systematically analyzed, so that a stock of potential primary sources be updated.

iii) The list of primary sources must be modified whenever they are found to become inadequate, and new primary sources must be added accordingly, without modifying the representation of the system. This requirement will need some theoretical thoughts and possibly additional definitions.

iv) The number of sources of the ICRF must not be limited. A densification of the catalogue with new sources is very desirable.

The role of IERS should be to promote and coordinate observations, to decide upon their frequency, to update the various lists of sources, and to decide upon the time when such modifications become effective, according to the evolution of the requirements. IERS will be supported in these activities by the Consultative Group defined in the Introduction.

2. OPTICAL REFERENCE FRAMES AND THEIR LINK TO THE ICRS

The objective is to follow the accuracy with which the optical primary catalogue (now Hipparcos, later ...) represents the ICRS, to promote observations for its maintenance and, if felt necessary, to increase the quality of the link.

At present, the most significant contributions for determining the optical-ICRF frame tie are VLBI and MERLIN observations of Hipparcos radio stars with respect to the ICRS radio sources. A coordinated observation program should be promoted. Contributions from ground-based optical astrometry should also be considered and, if alternate methods are available, they should similarly be promoted.

In addition to the promotion of these programs, the role of the IERS should be to analyze the results and make a list of stars that are thought to be the best representatives of the ICRS in optical wavelengths (some kind of primary stars for ICRS). It should promote observation programs and either organize them or stay in close contact with the people responsible for them (e.g., in case of a new astrometric satellite). The IERS must be helped in this work by the Consultative Group.

3. OTHER OPTICAL CATALOGUES

It is important that other catalogues represent also the ICRS and that the accuracy be maintained into the future. There should be a continuous check on the most used ones (PPM, TYCHO as well as new ones that will be constructed using Hipparcos and other new or old data).

It should, however, not be the role of the IERS to provide the checks. It could do the comparisons between the catalogues, but the main task would be to centralize the results and give some kind of recognition to the links that would be considered as the most significant. At this level, the important parameters to be publicized are the accuracy and the biases of the link including their dependence upon time.

4. REFERENCE FRAMES BASED IN OTHER WAVELENGTHS AND UPON OTHER OBJECTS

It would be useful to investigate the necessity of extending the ICRS into the infra-red and microwave spectral domains. The Consultative Group should consider the analyses of catalogues of objects in other wavelengths (e.g., IRAS) and frames based upon other objects. In such cases, where there would naturally be other specialists involved, the Consultative Group should serve only to encourage and promote the establishment of the appropriate frame-tie, determined by the specialists themselves.

In general, other catalogues (such as IRAS) are nominally based upon an existing optical reference catalogue (e.g., FK4 or FK5) and would automatically be tied to the ICRS by an exisiting or future more accurate optical link (FK4 or FK5-ICRS). However, if such a link does not exist or if the accuracy of the other catalogue exceeds that of the catalogue to which it is referenced, then it would become necessary to establish a direct link to the ICRS (ICRF or its optical counterpart).

5. POSITIONS AND MOTIONS OF THE EQUINOX AND OF THE ECLIPTIC

The dynamical reference system, as realized by the ephemerides of the major bodies in the solar system, is no longer based upon the mean equator and mean dynamical equinox, nor upon the mean dynamical ecliptic. Instead, the most recent ephemerides are based directly upon the ICRF. However, the equinox and ecliptic do remain important concepts in a number of applications, such as analytical derivations of precession and nutation, etc. Therefore, it is necessary to make an effort to know the relation between the ICRF and the best determinations of the equator and ecliptic.

The instantaneous positions and motions of the equinox and ecliptic are inherent within the planetary ephemerides. The determination of their means at a given epoch, however, requires some later analysis. Further, there are two different definitions of the ecliptic. Therefore, uncertainties in the locations of the mean equinox and ecliptic arise from different ephemerides, different methods of analysis, and the differing definitions of the ecliptic itself. The IERS should analyze and monitor these differences, make available the different determinations, and present an estimation of the uncertainties of the results.

6. MILLISECOND PULSAR TIMINGS

Information from the timings of millisecond pulsars is useful for determining the Earth's orbit and for orienting the whole inner planetary system onto the ICRF. These objects have now been observed, measured, and analyzed for well over a decade by specialists outside of the IERS, and there is no reason to believe that their activity will not continue into the future. The IERS, however, can certainly encourage the observation of the millisecond pulsars in order to ensure their continued support.

In a lesser role, the IERS could assist in the collection and distribution of the analyses and results of those more actively involved in the studies of the millisecond pulsars.

7. IERS CONVENTIONS

All information present in the IERS Conventions is of interest to astronomy, This includes numerical standards, celestial reference frames, transformations between systems, and relativistic models. All should continue to be carefully followed and updated. The important point here is the availability to the astronomical community in a timely manner. The IERS is to establish and maintain coordination with the IAU WGAS (Working Group on Astronomical Standards) and, in particular, with SOFA (Standards of Fundamental Astronomy). Certainly, the IERS must maintain its own set of standards as it has done in the past. However, when possible without sacrificing accuracy or efficiency, these standards should be chosen to conform with those of the IAU WGAS. In all cases, they should be consistent with the IAU resolutions on reference systems (at present, the IAU and IUGG resolutions adopted in 1991).

VERTICAL REFERENCES

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with contributions of

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INTRODUCTION

This report was prepared by several contributors to stimulate discussions on Topic 3 on Vertical References at the IERS Workshop, held in Paris on 14 to 18 October 1996. This topic is rather important to the extent that many issues can be included under such a title and that several opposite points of view have been expressed on what IERS should do or not do in this area.

Just to illustrate this statement, here are the items mentioned as possible subjects of discussion of Topic 3 in the Workshop announcement as written by the IERS Directing Board:

- should IERS make an effort to put tide gauges in the ITRS?
- does IERS want to maintain a geoid?
- issues related to the geopotential;
- tidal variations and surface loadings;
- should IERS monitor the motion of the geocenter?

CONCEPTS AND TERMINOLOGY

We mention here the various concepts which can be referred to in this broad and somewhat fuzzy concept of vertical references. They belong to several disciplines which obviously can be relevant to this subject: geodesy, but also solid earth geophysics, oceanography and atmospheric science.

We can then view that vertical references are all surfaces close to the Earth's boundary which have some geometric, physical or practical interest:

- ellipsoid (E) which is a geometrically defined surface in a specific terrestrial reference system;
- geoid (G) which is an equipotential surface of the Earth's geopotential;
- sea surface (S) which is the ocean-atmosphere boundary;
- land topographic surface (T).

We could have also considered sea floor as the solid earth-ocean boundary. As it is still a very specific domain of Marine Geodesy, we did not consider it in this report. This attitude may have to be revised in the future.

Several common characteristics can be considered for these surfaces:

- Time variations: all these surfaces except E have some time variations at various levels both in the spatial and time domain.

- Physical modeling: some surfaces can be expressed through a physical model: G as equipotential of the geopotential, S as boundary of hydrodynamical equations...

- Realizations: the concepts of ideal definition and realization already applied for celestial and terrestrial systems can be also efficiently applied to these surfaces. Without giving a thorough insight of this topic, we mention here some ideas:

  - these surfaces can have various mathematical expressions: grids, contour lines, spherical harmonic expansions or other types of numerical approximation;

  - the definition itself can be done in various ways, for instance G can be ideally defined either by giving a particular point which belongs to this equipotential or by giving the potential value W_o;

  - in the case of G, Physical Geodesy offers the choice of slightly different surfaces: quasi-geoid, co-geoid;

  - the actual complete model is currently mapped into a simpler regularized model by applying some corrections (relativity, tides...). This can be done in slightly different ways whence various ideal definitions (in particular for S and G).

- Use as reference surface for height: these surfaces can be used to define various height systems for both scientific and practical uses: surveying, hydrography, mapping, reduction of gravity data, DTM.

Besides a pure conceptual point of view, the joint study of these surfaces (vertical references) is justified by the two by two connections realized by various types of measurements or numerical determinations. Here is a list of such connections:

- global or regional geoid determination, whatever technique, provide an E-G link;
- positioning of a point located on land topography with a space technique in a well defined reference system provides an E-T connection;
- positioning of a floating buoy with a space technique in a well defined reference system provides an E-S connection;
- spirit leveling on land benchmarks provides a G-T connection;
- satellite radar altimetry with precise orbits in a terrestrial reference system provides an E-S connection;
- coastal tide gauge recording provides a T-S connection;
- hydrodynamical modeling provides a G-S connection.

This very partial and schematic review has hopefully shown the variety of the topic.

EXISTING ACTIVITIES IN THIS AREA

It is out of the scope of this report to establish an extensive inventory of the groups which are already working in parts of this area. We have nevertheless considered it useful for non specialists to list some significant works at international level:

International activities

- the UNESCO International Oceanographic Commission (IOC) which is driving the GLOSS program (a network of 200 tide gauges with high standards including geodetic monitoring);

- IAPSO with its Commission on sea level and tides, to which is linked an ad hoc group common with IAG on Geodetic fixing of tide gauges (W.E. Carter, chairman);
- ICL has a panel on sea level (S. Zerbini, chairman);
- Permanent Service on Mean Sea Level (PSMSL) involved in many activities (GLOSS...). It is a FAGS service like IERS and IGS. A joint project IGS/PSMSL on installing IGS stations at tide gauges has been initiated;
- International Hydrographic Organization (IHO) for vertical datums for hydrography;
- Global Change/IGBP related activities.

IAG activities

In addition to the IAG umbrella on IERS, IGS and PSMSL, we can quote:

- Commission X on Global and Regional Networks (C. Boucher) in charge of leveling networks, with in particular a WG on Unification of Vertical datums (W. Kearsley);
- SSG 1.153 Precise marine positioning, surface and seafloor (D. Egge);
- CSTG WG on Fundamental Reference and Calibration Network, FRCN (G. Beutler);
- Special Commission 6 WEGENER (S. Zerbini);
- Commission XII on Geoid (H. Sunkel) with its International Geoid Service, IGeS (F. Sanso);
- Commission V Earth tides (H.G. Wenzel);
- Special Commission 3 Fundamental Constants (E. Groten);
- Special Commission 8 Sea level and ice sheets (W. Carter).

Bilateral or regional (e. g. European) activities

- DMA/GSFC global earth model with IAG validation group (M. Sideris);
- Science groups of the US/French satellite radar altimetric mission; TOPEX/POSEIDON and of the ESA ERS missions, as well as future ones (JASON...);
- European projects including geodetic fixing of tide gauges: SELF I and II, EUROGAUGE, HIBISCUS, Baltic Sea Project, EPTN, EUVN, Euro-GLOSS, EOSS...

IERS and a Global Vertical Datum

A first possible contribution of IERS would be to provide a realization of a Global Vertical Datum (GVD) which would be to some extent a logical extension of ITRF. IERS would consequently determine and disseminate as a new product an estimate of the height in the GVD for each ITRF station.

This implies several actions:

1) to extend the IERS Conventions in order to include a definition of a GVD: choice of a geoid and of a related height system, consistency within all IERS conventions (for instance tides);

2) to develop methods of realization and the relevant organization within IERS, taking into account existing groups (in particular working on geoid models or in leveling networks). We simply quote some progressive methods:

a) use of a global geopotential model (DMA/GSFC approach) to which the ITFS section of the IERS/CB has already worked in the IAG validation group;

b) combined use of a with ITRF ellipsoidal heights, regional leveling data and gravity data. This requires an access to a reliable data base of levelling data at ITRF sites and of course suitable gravity data;

c) more general combination using regional geoid models, satellite altimetry and other relevant data.

Another important aspect to be considered is the potential contribution of fundamental atomic clocks to this topic. They are direct sensors of the absolute geopotential through the relativistic gravitational effect on frequency.

A real question asked by several people is: why IERS should go into this business? Many groups have spend many efforts on the various aspects, as shown above. They have produced significant results and they know well what are the critical problems to solve!

During the discussion, several possible contributions from IERS were mentionned:

- in the definition of consistent specifications (which do not exist presently);
- by publishing a global realization at ITRF sites (which goes in the direction of FCRN stations);
- in the preparation of the future contribution of new techniques such as atomic clocks.

Finally, it was recommended to establish within IAG a working group on this topic through a cooperation of Commissions X (networks) and XII (geoid), with IERS as well as IAPSO representatives.

ITRF and geodetic fixing of tide gauges

The need to have a high quality and well distributed network of mixed permanent GPS and tide gauge stations is now well established (see GLOSS and IAPSO/IAG ad hoc group). As already mentionned, IGS and PSMSL are actively preparing a workplan.

Consequently, and through IGS, this net will be naturally expanding the ITRF network. Furthermore, IERS should consider whether some ITRF stations without GPS system could also be considered for colocation with tide gauges (for instance DORIS for which this was investigated and even recommended in the frame of TOPEX/POSEIDON). Definitively there is a need for clear specifications on the relative contributions of each contributing technique to this task: VLBI, SLR, GPS and DORIS... They are NOT identical, both on global level (datum) and individual station height quality!

In order to reach these objectives, there is a definite need for up-to-date standards for tide gauge fixing. The existing IAPSO/IOC/PSMSL documents are good for tidal recording but need to be developped on the geodetic aspects. It was recommended that the IAPSO/IAG working group previously mentionned should prepare technical specifications more detailed and up to date on the geodetic aspects than the already published reports. This group should take benefit of experts in this field.

IERS should be closely associated to that in order to contribute with its own competences to the fulfilment of the scientific/technical objectives identified above.

Global geopotential models

Active groups are working in this subject. Presently, they have impact on IERS activities through the physical modeling adopted by analysis centers for dynamical techniques. IERS Conventions are already dealing with this point.

The establishment of an IERS realization of a Global Vertical Datum would clearly create a new link to the geopotential models.

Vertical motions of the Earth crust

The vertical component of the position of a point linked on the land topographic surface is affected by a variety of motions. Besides special motions (we mean some active zones, or motions linked to seismicity or volcanism, or land subsidence), the main causes are tidal responses and various loadings (atmosphere, ice, groundwaters).

Here the present questions are:

a) improvement of the models and of their consistency in the IERS Conventions;
b) effective use by the groups participating to IERS;
c) how IERS results could improve these models?
d) need of available ancillary data for accurate corrections, in particular global surface atmospheric pressure;
e) better local monitoring of ITRF sites and intercomparison with other data such as gravimetry or clocks (a question for the FRCN group?)

It was therefore recommended that these points should be discussed by the CSTG group on Fundamental Reference and Calibration Network.

Motion of the Geocenter

ITRS is presently defined as geocentric (including oceans and atmosphere). It is recognized that a correction model is needed to remove from the instantaneous station position on the crust the motion effect coming from the motion of the geocenter, in particular seasonal effects produced by the mass redistribution of oceans and atmosphere. Such a model still needs to be adopted for IERS Conventions.

Furthermore, dynamical techniques are currently realizing the geocenter through the adoption of a rigorously geocentric geopotential. The quality obtained for short term series (e. g. monthly) for SLR and now GPS (and potentially DORIS) should make feasible the determination of the geocenter coordinates as a set of parameters, similarly to EOP series.

A related problem is also to realize ITRF through a time series with a purely kinematical equation for time evolution. One may also think of revising the geocentric definition of its origin. These questions are presently discussed by the IERS WG on ITRF datum (J. Ray).

It was recommended that this group should continue and furthermore establish a pilot experiment on the determination of the geocenter by combined use of several time series from several techniques.

In addition, it was required that some geophysical models or estimations should be collected (tidal part, atmospheric and oceanic circulations).

CONCLUSIONS

The general goal of this report was to investigate the topic of vertical references in order to show that it is altogether important, interdisciplinary and widely opened. As many groups are already working on some aspects, the aim was to identify which specific contributions IERS could make in the short term in order to improve the whole topic.

We do not expect to have reached a definitive review of the subject. We hope nevertheless that the statements of this report and its recommendations will help to undertake some fruitful activities for various users, according to the missions that a Service such as IERS has.

TOPOGRAPHY AND CRUSTAL DEFORMATIONS

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INTRODUCTION

Deformations of the Earth's crust change the topography of the planet. Natural geodynamic processes span a very large range of time scales. Earthquakes may shift the position of sites by several centimeters horizontally and vertically in a few seconds. Continents and tectonic plates move relative to each other by several cm per year. This process has continued for millions of years but may or may not be well described by continuous linear motion. Post-glacial rebound effects, which are mainly vertical, take place over several thousands years between ice ages. They are regional and affect the extended polar caps of our planet. The topography of a coastal nation may change significantly as the accumulated vertical motion may add to several hundreds meters. The collection of natural changes that occur in the surface layers of our planet constitutes a challenge to the IERS because the terrestrial reference frame of observing sites must be continuously maintained and updated. The ITRF product is a conceptual as well as a realized basis that can be used for measuring topography and crustal deformations.

THE ITRF AND ITS RELATION TO TOPOGRAPHY AND CRUSTAL DEFORMATIONS

Topography is the surface features of the planet. The ITRF is a small, select set of points on the surface whose positions are known at some epoch(s) with particular accuracy. These points form the conceptual and realizable framework on which the topography of the planet can be defined and measured.

Crustal deformation is the change in topography arising from the accumulation of strain. It can be measured through the ITRF from the velocities of the ITRF points. Most of the velocity of an ITRF point does not come from deformation, however. The underlying system is based on the simplifying assumption of rigid tectonic plates whose modeled rotations carry the surface points along horizontally without strain. The difference between the modeled velocity and the ITRF velocity at a point arises from a mixture of deformation, model error, and observation/analysis error. Other geophysical and geodetic information is required to make the best interpretation.

A strong, reliable, well-understood ITRF is the basis for measuring topography and crustal deformation on a global scale. The ITRF is formed by combining position and velocity results from different space geodetic techniques, each having different systematic errors, spatial distribution, and temporal distribution. Collocation is the most important means by which information from different space geodetic techniques is integrated into a unified system and is the primary method for assessing the accuracy of the ITRF. Because fixed SLR and VLBI systems have generally been located for reasons other than collocation and because mobile SLR and VLBI systems have not been extensively operated for some time, the collocation between these techniques includes a number of points of lower quality. The situation with GPS collocation is potentially better, but some of the best SLR/VLBI sites do not now have GPS or have not had long, reliable GPS occupations. Many VLBI sites are also GPS sites today, but some historical VLBI sites were occupied by mobile equipment so their current quality is declining and the collocation with GPS is weak.

The use of more than one measurement technique at an observatory requires the instrument monuments or reference points to be tied together, e.g., by local geodetic survey. The quality of these local surveys may be the current limiting factor in combining space geodetic results. It would be wise to repeat such measurements from time to time to check for possible movement of monuments. This would involve a local reference network at the site. Some observatories have been built in areas of geophysical or geological activity. It may be required to considerably extend the survey area around such sites to establish if any instrument monument has movements deviating from the others. Some observatories carry out control surveys regularly, and they should be encouraged to make results available to serve the IERS and its users. Similarly local geological and geophysical information would be useful to show whether movement is consistent with expectation.

The ITRF is not static and must be continuously updated. The ITRF is defined by positions at a reference epoch and velocities, both with uncertainties. The precision of a site position at a specific epoch is a function of the error at the mean observation epoch, the error of the velocity, and the time interval between the mean and specific epoch. The quality of sites no longer occupied deteriorates as the mean observation epoch recedes into the past. This is a problem with old SLR and VLBI sites. Mobile SLR and VLBI systems could be used in the future to reobserve old sites to provide a new, longer time interval for determining velocities. Sites currently acquiring space geodetic data need to continue in order to avoid future degradation.

Recommendation 1: The IERS should make a strong effort to promote the collocation of observations, accurate local surveys, and continued (re)observations at TRF sites in order to strengthen the ITRF.

SITE HISTORY

The ITRF is a good set of site positions and velocities, but at some locations the velocities are not yet adequately known. It is desirable to know in greater detail the station history with time. Such information would reveal: 1) the time intervals for which data are available, i.e., site life time and occurrence of data breaks, 2) overlapping of periods of data for different observing techniques, and 3) episodic and other nonlinear motion present at the site. This information would allow both IERS analysts and external scientific users to evaluate the importance of each site. It is possible for analysis centers to provide this information today, and they should be encouraged to give it in a way consistent with a realization of ITRF, such as ITRF94. The time series of site positions derived by an analysis center may not be in exact agreement with ITRF94 because of difference due to data or frame definition, but the site velocities inferred from the time series should be consistent with the analysis center's own realization of ITRF. The IERS web should establish links to analysis centers to announce the existence of such information.

Recommendation 2: The IERS should encourage the analysis centers to provide time series of ITRF site positions and make this information available through the IERS web site.

UNEXPECTED STATION BEHAVIOR

The ITRF is realized by station positions and velocities. It is assumed that velocities remain constant with time, which may not be true for all sites. Counterexamples are given by observations around the earthquakes near Fort Ord and Landers. Recognition and identification of such episodic and other nonlinear motion is essential to obtaining the goal of a strong ITRF. The previous history of site positions and velocities (together with confidence information) should enable analysis centers to determine if motion components for a site at a specific epoch or some interval deviate significantly from expectations. The information is also of interest to the geophysical community. To identify causes of abnormal station behavior may require multidisciplinary efforts. The IERS should encourage and promote such studies. It is appropriate to notify the users of ITRF by means of messages on the IERS web pages and active links to detailing information.

Recommendation 3: The IERS should encourage the analysis centers to report deviating behavior of ITRF sites at the 5 sigma level or above and to attempt to identify the cause of such behavior. IERS should make such information available on the IERS web site.

UNIFICATION OF REGIONAL REFERENCE SYSTEMS

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The Topic 5 question set for discussion the IERS review was: What should be the role of IERS in unifying the national datums into ITRS ?

The definition of global reference systems is a permanent international scientific task, which is suitably undertaken by IERS, but at the national level, the realization of the global system can only be done by, or in conjunction with the respective individual national survey agencies. This report is prepared from their point of view.

1. REQUIREMENTS OF NATIONAL REFERENCE SYSTEMS

Every national administration needs to maintain a uniform national geodetic reference system and a realization for the whole country. The establishment of a fixed national datum requires the definition of a set of coordinates at a particular epoch, preferably within a global reference system. Due to the costs involved in establishing or changing this fundamental datum, every government is interested in preserving a long life for the declared datum to gain maximum utility in respect to :

accuracy,
point density,
access to the data,
actuality of coordinates due to crustal movements.

There are varying accuracy requirements for national datums; from countries in Europe, where centimeter accuracy is required; to the large number of developing countries throughout the world which do not have such a high immediate accuracy requirement. Whilst IERS can promote the tools to facilitate the establishment and subsequent unification of national datums into regional and global systems, the choice of required accuracy level remains with the national agency. But for IERS to meet the full range of options required, the highest level of accuracy must be met by the provision of a 1cm reference frame.

In practice GPS will be used by countries in virtually every case to establish ITRF (or WGS84) points for a national datum, whether it is to upgrade existing terrestrial trig networks or to establish new geodetic frameworks.

Where a fixed IRTF epoch is used to determine a coordinate data set to establish a national datum, the crustal motion velocities of fundamental sites also need to be monitored in scientific solutions. The fixed datum can then be subsequently upgraded when the crustal movement from the ITRF epoch has become significant to the national agency, or data can be transformed to different epochs using published IERS values. Where a fixed epoch approach is not suitable for establishing a national datum, due to significant differential motions across the country, the problems are more complex and will require more frequent revision of the national datum or maintenance of a dutum in a kinematic mode. Two strategies therefore need to be considered :

Stable areas

The reference system is established at a certain epoch and the values of all coordinates in the datum and geodetic network are kept fixed. In that case, the reference system moves in the same way as the plate. This solution fulfills the requirements of a large number of national users, due to the fact that they only work in their national system.

Unstable areas

In unstable areas the user of a reference frame can encounter problems with differential or abnormal (non linear) movements of points within the datum set of coordinates or extended geodetic network. Where the movements of the reference points are larger than the internal accuracy of the geodetic network, constant remeasurement of either the whole country or the unstable parts may be required to continually redefine the datum epoch.

2. UNIFICATION OF NATIONAL AND REGIONAL REFERENCE SYSTEMS

Although most users of national reference systems work only in local areas, there are also important requirements, which can only be fulfilled within a regional (ie continental) or a global system such as:

- internal infrastructure projects (highways, railways, water ways),
- navigation of cars, vessels,
- spatial data bases,
- geographic information systems,
- land information systems,
- global navigation of ships and airplanes.

For these purposes reference systems beyond local national borders have to considered, defined and realized. From the economic point of view it would be desirable if all requirements could be fulfilled within one global system, so that data can be readily integrated without overlap or duplication. So an orderly approach to integrate or unify national systems into regional networks must be developed. Where national datums are established within IRTF then it is possible to meet these requirements using IERS values.

3. NATIONAL AND REGIONAL REQUIREMENTS ON GLOBAL REFERENCE SYSTEMS AND THEIR REALIZATIONS.

The highest accuracy definition and realization of a global reference system for national use should be on the 1cm level, as this can be achieved by users of modern GPS techniques over the whole country. The global system must then be realized at least on the same accuracy level to support long life aspects of a national datum.

It is desirable that at least three ITRF points be established in each national datum. Additionally permanent geodetic trackers (such as GPS) should be established to monitor the crustal motion applicable to that national datum.Iin areas of high tectonic activity the movement of the respective plates need to be monitored to evaluate the expected useful life of an established datum.

4. REQUIREMENTS OF IERS

There are a number of requirements of IERS in order to facilitate the orderly unification of national datums:

- For IERS to maintain 1cm global solutions a point density of 20-30 fundamental permanent, collocated techniques sites, well distributed over the continents is essential.
- Additional densification (such as is being undertaken by IGS) of a large number of permanent geodetic regional stations is needed, to facilitate establishment of national datums within ITRF.
- A further epoch densification is required at the border of continents and plate/microplates to monitor differential velocities.
- To facilitate transformations between epoch values of the kinematic ITRF, the frequency of published solutions should be used to allow a linear interpolation between such epochs.
- There should be minimal time delays between computation and publication of these values IERS conventions should be made readily available for use by national agencies and for regional solutions.
- Time series of coordinate positions, velocities and transformation parameters between the epochs should be available electronically through IGS or IERS.

5. RECOMMENDATIONS

Recommendations to the Directing Board from the Topic 5 review group are.

IERS should :

1. Provide a consistent global reference frame, and transformations between ITRF solutions, based on a homogeneously distributed network of stations at the highest possible level of accuracy.

2. Maintain the coordinates and velocities of a homogeneously distributed global network of accurate permanent stations, and parameters, so that any agency can undertake a national ITRF based datum.

3. Encourage national agencies to establish their precise national datums within ITRF so that these datums can be linked into regional or continental solutions.

EARTH ROTATION DYNAMICS AND GEOPHYSICAL FLUIDS

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INTRODUCTION

The IERS efforts to coordinate the monitoring of Atmospheric Angular Momentum (AAM) have been very successful. The purpose here is to consider whether the efforts should extend to other geophysical fluids, such as the oceans, core, and groundwater. We propose that this extension is appropriate and necessary to fulfill the fundamental missions of the IERS, but that any newly proposed activities should not adversely impact the current ones by diluting existing resources. Furthermore, extensions of IERS activities should use existing services (as for instance, the FAGS services); and, existing special study groups (SSG) or existing working groups (WG) should not be overlooked. We are persuaded that there are competent existing services from which the IERS would gain, but that there is probably not enough exchange with the IERS. There, the IERS can play a pioneering role by creating and appointing coordinators acting as link-agents, who bridge the information towards the IERS or towards other bodies. These persons should have a background which permits them to understand the interests of the two bodies.

On the other hand, if there is no competent service or WG or SSG capable of answering particular points addressed by the IERS, then it may be worthwhile creating this activity within the frame of the IERS in the form of a new sub-bureau (SB) or coordinating center (CC). The success of a SB or CC will depend critically on the level of activity and interest of the individuals. Careful selection should lead to little additional work for IERS personnel. Delay in establishing a center may be preferable to an early effort that lacks sufficient level of interest and commitment.

In this report, one will find suggestions to create a new sub-bureau (SB) or coordinating center (CC), as well as sub-sections (that we also call sub-bureaux in the text) of this SB or CC, i.e. we consider an extension of the present Sub-Bureau for the Atmospheric Angular Momentum. This extension could be seen as considering the SBAAM as a sub-section of the new CC (which could be at the same location). In this report, we discuss the necessity of an extension, but we will not discuss the structure itself, neither the incorporation of this structure as part of the present IERS structure. This is discussed in the report related to Topic 1.

A long term goal of the IERS effort should be to make issues and data related to global scale geodetic quantities, Earth's rotation, and reference frame, more visible within the Earth Sciences Community. We should have as a goal that all those who model geophysical fluids (atmosphere, ocean, core fluxes, mantle convection fluxes, ice, snow, ground water) will be concerned with, and examine the performance of their model using predictions of geodetic quantities such as nutation, LOD (length-of-day) and polar motion. That is, we want scientists outside the IERS to consider geodetic quantities as useful measures. This is the case, for instance, for geodetic measures related to some parameters relevant to the SEDI (Study of the Earth Deep Interior) community, as well as for geodetic measures related to global climate quality which should be considered just as temperature, pressure, rainfall, etc are normally.

Assessment of current mission: users of, requirements for and access to AAM.

There is no doubt that the AAM computations should be continued. The availability of estimates from numerical weather prediction models of the atmosphere's angular momentum has enabled a wealth of scientific investigations and contributed to improve tracking and navigation of interplanetary spacecraft. The Sub-Bureau for Atmospheric Angular Momentum (SBAAM) has played an important role in these endeavors by being an advocate for the estimation of AAM by the various operational weather prediction centers and by collecting, archiving, and disseminating the AAM estimates. At present, the angular momentum of the atmosphere about three axes, related to the excitation of Earth rotation and polar motion, is computed and provided on a near-real time basis by the U.S. National Centers for Environmental Prediction (NCEP, formerly NMC, the National Meteorological Center). The sub-bureau also acts to collect and distribute AAM data from other large world meteorological centers. Both analysis and forecast values are treated in this way. These activities constitute important missions of the SBAAM. For a complete description of the SBAAM activities, see Annex 1.

Since AAM can be expected to continue to play a key role in future Earth rotation studies, the present activities of the SBAAM should not only be continued but might be expanded upon. Some thoughts in this area have been discussed and transmitted directly to the SBAAM. They are summarized as follows:

(1) new meteorological data and parameters could be added,

(2) not only AAM approach but also the torque approach should be considered,

(3) new atmospheric data centers must be included,

(4) combination of AAM estimates would be useful,

(5) extended period of AAM estimates would also be useful,

(6) the impacts of the atmosphere on precession-nutation should be computed,

(7) in order to improve the availability of the SBAAM data, a ftp-system should be implemented,

(8) together with more documentations.

Note that some of the recommendations are already underway or done. The SBAAM is providing an important service to the scientific community and deserves greater recognition. These suggestions should not be taken as criticisms but rather as constructive comments designed to enhance the strength of the SBAAM. Possible mission extension: should IERS take some part in the coordination of the monitoring of global fluids (terrestrial water, ocean currents, core currents) ?

Given the success of the sub-bureau for AAM, we consider whether other sub-bureaux should be created for quantities such as ocean angular momentum (OAM), ocean tidal angular momentum (OTAM), or core angular momentum (CAM). If such sub-bureaux were to be created, what would be their role, who would be the leaders, and who would be their customers? One difficulty we see here is that unlike AAM, no operational centers exist for the computation of OAM, OTAM, or CAM. In the case of AAM, operational weather prediction centers running atmospheric general circulation models already existed when the SBAAM was created. Thus, there was a role for a sub-bureau to collect the AAM values produced from the products of these existing operational weather prediction centers. This is not the case for OAM, OTAM, or CAM where the ocean general circulation, ocean tides, and core flow models, respectively, are run by research rather than operational groups. Is this distinction important? Is it appropriate for the IERS to advocate, collect, and archive quantities from research rather than operational groups?

We think that the distinction between collecting quantities from research rather than operational groups is important when discussing what the role of such sub-bureaux should be, but not in discussing whether or not such sub-bureaux should be created. We think that it would be a service to the research community to have such sub-bureaux advocating, collecting, and archiving OAM, OTAM, and CAM, and hence we would encourage the IERS to expand in this direction by creating such sub-bureaux, even though their only customers will be from the research community. (The customers of the SBAAM include not only research groups but also operational groups.) However, since the sub-bureaux for OAM, OTAM, and CAM will be collecting results from research rather than operational groups, they will need to be more aggressive in their role. Since the SBAAM collects results from operational centers, once the collection mechanism has been initiated, it can passively and automatically archive the results as they arrive. However, sub-bureaux for OAM, OTAM, and CAM must establish and maintain active contacts with the relevant research groups in order to ensure that the OAM, OTAM, and CAM are computed and sent to the sub-bureaux every time the ocean general circulation, tide, and core flow models are run. Thus, organizations willing to support such active sub-bureaux must be found if they are to be established. We give in Annex 2 some propositions for these eventual sub-bureaux. We give there the main tasks (the list is probably not exhaustive) that we see for the SBOAM, SBOTAM, and SBCAM, as well as for additional ones like the sub-bureaux for geocenter and gravitational field, or for water vapor, or for ionospheric TEC.

The next question we see is: should separate sub-bureaux for OAM, OTAM, and CAM be established, or should they and the SBAAM be combined into, say, one sub-bureau for Angular Momentum (SBAM)? If combined into one overarching sub-bureau, would all its parts need to be at the same hosting organization, or could its subparts (sub-sub-bureaux?) be located at different organizations where the relevant expertise resides? If separate sub-bureaux are established, we suggest that each have World-Wide Web homepages through which their archives can be accessed by anonymous ftp and with hot links to each of the other sub-bureaux homepages as well as with the IERS homepage. Thus a virtual SBAM can be created from geographically separate groups. Geophysical fluid monitoring pertaining to nutations.

We give in Annex 3 a description of the scientific situation concerning nutations. We summarize here the conclusions:

(1) It is absolutely necessary to continue VLBI observations. There, the proposed new VLBI/CORE continuous measurement of Earth rotation with the anticipated improvements in precision and temporal resolution would play an important role.

(2) There is also an important effect of the atmosphere on nutations. It is thus necessary to collect, archive and disseminate values of the x- and y- components of the AAM and/or values of the x- and y- components of the atmospheric torques acting on the Earth. Because nutations are quasi-diurnal in the TRF, short time intervals and long time span are necessary. Not only the effects at particular forced nutation frequencies should be considered, but also eventual excitation of Earth normal modes. Another interesting extension is to compute the effects of the atmosphere on sub-daily polar motion and prograde diurnal polar motion (retrograde diurnal polar motion corresponding to nutation).

(3) The ocean tide effects due to ocean heights as well as the ocean currents have a contribution to nutations far above the observational standard deviation. Thus, a SB or a CC or a coordinator for OTAM would be helpful. The situation is somewhat different compared to the atmosphere, because models rather than an operational unit are the basic tools. However the models are constantly evolving, requiring communication to the IERS and new calculations of geodetic effects.

(4) Mantle mass anomalies and the associated boundary displacements might play an important role in the nutation phenomena. Here, the observed precession and nutation can produce numerical values of parameters useful for the seismic community.

Recommendation - Propositions

This discussion contains suggestions to establish coordinators or eventually sub-bureaux (or coordinating centers) for OAM, OTAM, CAM, geocenter variations, gravitational field models, and water vapor, and ionospheric TEC, all of which would greatly expand the scope of the IERS. If capable host institutions can be found for the suggested new coordinating centers (or sub-bureaux), then we suspect that the IERS can absorb these new sub-bureaux fairly easily. However, the new activities should in no way jeopardize the quality of the existing IERS programs which have been extraordinarily successful in providing timely and accurate data on Earth rotation, and in establishment and maintenance of terrestrial and celestial reference frames.

Summary of recommendations

(1) keep SBAAM and make recommendations for strengthening this SB;

(2) examine currently existing organizations dealing with geophysical fluids, seeking existing data and computational models such as numerical and/or hydrodynamical ocean models; this could be done by the use of existing WGS or SSGs, or by nominating a coordinator, or by calling for a new coordinating center (or sub-bureau); this organizer or organization would create coordinated links with relevant bodies or research groups, eventually within a larger organization;

(3) create a SB or a CC for angular momentum related to geophysical fluids pertaining to the Earth orientation parameters as well as any parameters relevant for the space geodesy technics; this SB or SB would deal with different sub-SB or sub-CC;

(4) create a www page and links to associated ftp sites for the IERS and AM-related sub-bureau.

Annex 1 - Description of the current activities of SBAAM

The meteorological data used in SBAAM calculations consist of motion terms, calculated from the wind vector (zonal wind and meridional wind) and the mass term, calculated from the surface pressure of the atmosphere. Integrations to different vertical levels in the atmosphere may be available. The above data are typically available on a six-hourly basis, which usually makes diurnal signatures evident. The most complete vertical extent of the data spans the atmosphere between 10 and 1000 hPa, or approximately 99% of the mass of the atmosphere.

The approximate effect of the ocean mass redistribution is considered in the calculations of AAM by the inclusion of two options: modeling with either a perfect inverted barometer or with the total absence of an inverted barometer relationship. Because indications are that the true nature of the atmosphere/ocean relationship falls somewhat in between these two options, the investigation of alternate approaches to the inverted barometer issue is most appropriate, including the use of ocean dynamic models. Other quantities, related to the global momentum of the atmosphere, are values of the zonal mean wind, zonal mean temperature, and spherical harmonics of surface pressure, all of which can be calculated from the reanalysis fields.

Recently data from a historical atmospheric "reanalysis" has become available to calculate angular momentum for historical periods, starting in the mid-80's to the present, but eventually to include one or two decades earlier. Within the meteorological community, these efforts are designed to incorporate any data not included in the original operation results, but also to perform the computations with a fixed numerical scheme. Such series are more continuous, and are available to those users who wish to study the atmospheric component of the Earth's dynamic system, momentum exchange with the solid Earth and the ocean, and the momentum as a climate parameter. Angular momentum studies of these reanalysis data sets should lead to understanding processes on a number of time scales, including those on interannual, seasonal and intraseasonal.

Annex 2 - Scientific activities pertaining to IERS and related to possible sub-bureaux.

(1) Ocean Angular Momentum. One very interesting extension we see for the IERS is to create a SBOAM (Sub-Bureau for Ocean Angular Momentum). A separate group dealing specifically with tides is discussed below. Indeed, the role of the oceans in Earth rotation, after the effects of the atmosphere, is important, particularly for short time scales (subdaily and daily periods) as well as medium time scale (daily to yearly periods). The data-poor oceans have delayed an "operational" oceanography modeling program relative to meteorology, but we believe things are moving quickly towards use of models and data assimilation as is currently done for the atmosphere. There have been many groups that have turned out preliminary results for OAM based on oceanic General Circulation Models (GCM). Model results indicate observable effects on the LOD, and substantial contributions to the excitation of seasonal polar motion; at shorter time scales, oceanic excitation can be as important as atmospheric excitation. Both mass redistributions and fluctuating currents contribute importantly to variability in OAM. While the inverted barometer approximation has been the focus of previous OAM calculations, in reality, the issue is much more complicated, involving also wind forcing and oceanic currents, and a proper accounting will require the use of oceanic numerical models. As we approach operational capabilities for OAM prediction, a sub-bureau should be in place to provide information to the IERS. Possible future operational centers include US Navy, NCEP, and NASA Goddard Space Flight Center.

(2) Ocean tidal angular momentum. Most early works have been based on Schwiderski's tide model, but Topex/Poseidon (T/P) diurnal/semidiurnal tide models, or oceanic hydrodynamic models are now available. However, there are still some important tidal waves missing in these computations, for instance, in the diurnal frequency band, the psi_1 wave is important because it is near the Free Core Nutation (FCN) Resonance, but it is not determined in present ocean models. Continued refinement of tide models is expected with present and future altimetry missions. A coordinator position for tide models and angular momentum predictions seems

appropriate. There is no comprehensive method for observing global tidal currents in the way that altimetry now observes elevations. Thus, dynamical assumptions about the ocean will always play an important role, either in purely hydrodynamic models or in models that attempt to combine elevation (and possibly current) observations with theory. Assimilation methods that bring out explicitly this combination of data and theory and allow for quantitative testing of dynamical assumptions are an important development. Already, however, the NASA Goddard group have shown that the new Topex/Poseidon ocean tide models are in better agreement with Earth-rotation measurements than earlier models, including the pioneering estimates from the Brosche/Seiler model predictions. The agreement for eight major tidal components (4 diurnal and 4 semidiurnal) between T/P model predictions and long-term Earth rotation observations is remarkable, both in amplitude an phase. In fact, the T/P models can explain as much as 90% of the observed sub-daily variance in UT1, and about 60% variance in polar motion, during the intensive VLBI Earth rotation measurement campaign CONT94. This success paves the way for further study of non-tidal excitations sources, such as AAM, OAM, Earth libration, and atmospheric thermal "tides". A breakthrough can be anticipated with the proposed new VLBI/CORE continuous measurement of Earth rotation with the anticipate improvements in precision and temporal resolution. In addition the ocean tide effects due to ocean heights as well as ocean currents make a contribution to nutations far above the observational standard deviation. Thus, a SB or a CC or a coordinator for OTAM would not only be helpful for Earth's rotation but also for precession/nutation. The situation is somewhat different compared to the atmosphere, because models rather than an operational unit are the basic tools. However, the models are constantly evolving, requiring communication to the IERS and new calculations of geodetic effects.

(3) Terrestrial water (ground water, snow, and ice). There have been some calculations on the effect of continental water and on the effect of man-made reservoirs and underground water storage. All these estimates are quite uncertain, incomplete, and suffer from lack of global data, but all suggest that water storage on land, in its various forms, produces observable polar motion and variations in other geodetic parameters such as center of mass and station coordinates. While the present data are poor in quality and coverage, the inclusion of the water cycle in global climate and general circulation models is underway, meaning that in the near future we should expect assimilated model predictions of soil moisture, river discharge, snow and ice cover, and change in underground storage, which should permit more accurate estimates.

(4) Core angular momentum. There appear to be clear correlations between variations of the length-of-day at decade time scales and the parameters of the geomagnetic field. The link can be explained by the fact that the core velocity field and the magnetic field are directly related one another, and that the core angular momentum, related to that velocity field, is transmitted to the mantle. The mechanism for transferring core angular momentum to the mantle (coupling at the core-mantle boundary) is uncertain. It has been suggested that the main mechanism is a topographic coupling (also called pressure torque or mountain torque; core fluxes pushing on the bumps of the Core-Mantle Boundary (CMB)). Early numerical studies predicted a torque which is about 50 times too large, although recent revisions accounting for an additional gravitational torque have reduced the discrepancy to only a factor of 5. The other possible mechanisms of core-mantle coupling are viscous coupling or electro-magnetic coupling at the CMB. The core situation remains uncertain for several reasons: the models predicting the bumps are incomplete, the connection between surface magnetic observations and the CMB field is uncertain, the theoretical approximations like geostrophy, may be inappropriate, and the core viscosity is not well known. The geomagnetic community is active, and interested in these matters. The recent numerical simulations of the geodynamo and the seismological discovery of an inner core rotation should stimulate interest in the geomagnetic community to interact with the IERS.

(5) Geocenter and gravitational field. Satellite techniques such as SLR and GPS can, in principle, determine the location of the Earth's geocenter which will vary in response to Earth system mass fluxes, and hence analysis of geocenter variations provides information about these mass fluxes. Thus, in principle a sub-bureau to advocate, collect, and geocenter determinations would provide a service to the research community and we suggest that one be established. However, care must be taken to ensure that the quantities being archived are properly

documented so that users know how they were determined. Geocenter studies are still in their infancy and many questions have not yet been resolved. Numerous organizations produce global gravitational field modelsparticularly of the static field, but also of time-varying components of the field. Accurate static gravitational field models are required for a number of reasons, not the least of which are satellite missions such as altimetry and Synthetic Aperture Radar (SAR) Interferometry. Having an archive of the available gravitational field models would be a service to the user community by providing "one-stop shopping" for them. Time variable gravity and geocenter variations can both be computed in principle from the same air and water surface load variations used in angular momentum calculations. The gravity and mass center variations involve simply other surface integrals (spherical harmonics). Hence we suggest that a simple extension of activities related to angular momentum would be to calculate other spherical harmonics of mass load variations (air and water), besides those related strictly to angular momentum.

(6) Water Vapor (Zenith Path Delay). Radiometric techniques such as VLBI and GPS (and DORIS, PRARE, ...) routinely estimate the zenith path delay of radio signals through the atmosphere. These path delay estimates are a function of the weighted temperature and water vapor content of the atmosphere and hence may provide important measurements for climate and weather prediction models, especially of the integrated water vapor. The results are important to geodetic measurements, specifically to the problem of correcting Synthetic Aperture Radar (SAR) Interferometry data, as well as to climate and weather studies. Additional GPS occultation results (as in GPS Met) are available and likely to be more prevalent in the future (The GPS Met satellite is in orbit now and is operated by UCAR/UNAVCO/JPL. It uses the GPS signals observed from a low-orbit satellite to measure travel time delays through the atmosphere, providing a very uniform measure for the whole earth of 'limb soundings' or occultation measurements giving temperature/water vapor. It is very complimentary to the ground based solutions from GPS or VLBI because it provides a vertical profile through the atmosphere, whereas the GPS or VLBI results are a vertically integrated profile.). Because path delay data are of interest in geodetic observations, as well as to a wider community, this is an area of possible study and coordination by the IERS. However this must be closely coordinated with related activity by the IGS, perhaps via a joint IERS/IGS sub-bureau established for this purpose.

(7) Ionosphere TEC (Total Electron Content). An additional aspect of the atmosphere that is of interest for radio-signal analyses is the Total Electron Content (TEC) of which abnormal values can largely perturb the measurements. This is particularly important for the near future because we are now in a minimum of the solar activity which will increase rapidly in a couple of years. In addition, ionospheric perturbations as scintillation effects and Traveling Ionospheric Disturbance (TID) produce irregular variations in the signals and consequently in the deduced quantities as station position vectors. On the other hand, the TEC can be deduced from radio-signal observations and abnormal behaviours of the atmosphere can be pointed out. These observations are important for the ionosphere scientific community. Because the ionosphere state is important for the geodetic community as well as the atmospheric community, this is also an area of possible coordination of IERS. As for the water vapor, this must be closely coordinated with related activities in IGS.

(8) Mantle fluxes. Mantle convection induces mass heterogeneities inside the mantle (as well as associated mass anomalies every where else). Down going slabs associated with plate tectonics are part of that process. These mass anomalies induce spatial variations in the gravity field at the Earth's surface, which is important for satellite geodesy. Mass heterogeneities also induce variations in the Earth's moments of inertia, and thus in the global dynamical flattening. This parameter can also be derived from the observation of precession. The comparison of both kinds of measures can lead us to a better knowledge of the Earth's interior, of the precession constant, of the plate tectonics, and of the gravity field. There is a second parameter related to mantle convection and which is of great importance for nutations, the core flattening. Indeed, the core flattening is one of the parameters which enter the equation for the Free Core Nutation. The FCN is an Earth's normal mode related to the fact that one can excite an angle between the instantaneous rotation axis of the core and the instantaneous rotation axis of the mantle. Precise

VLBI measurements (as well as precise tidal measurements by using superconducting gravimeters) can be used to derived the "observed" value of the FCN from the induced resonance in the Earth's response. The observed value that is deduced from the combined data is 434 sidereal days in inertial space, while the value associated with the adopted IAU 1980 nutation is 460 days (this value is associated with a spherical Earth uniformly rotating initially in hydrostatic equilibrium). A small increase of the core flattening corresponding to an increase of the core equatorial radius with respect to the polar radius of only about 500 meters would explain this difference. Here, mantle convection can play an important role is refining this explanation. Indeed, the CMB displacement associated with the mantle convection fluxes are in agreement with an increase of the core flattening, and so, a decrease of the FCN period. Here, because mantle convection lateral heterogeneities are not yet precise enough for geodesic observation (we would need to know the CMB boundary displacement at about a few meters for instance), the seismic community can benefit from the constraints derived from VLBI precession/nutation observations.

Annex 3 - Scientific description and examination of the geophysical fluids pertaining to nutation.

Theoretical models for nutations are at a crossroads, because observations are now accurate enough to observe interesting discrepancies with existing theories. Among the important problems are: the "geophysical nutations" which are called like this because they are particularly sensitive to changes in the Earth's transfer function (as the 18.6 year nutations for instance), and the value of the precession constant. For example, if one considers a theoretical constraint on the relation between the 9.3 year, the 18.6 year nutations and the precession, one obtains a correction to the precession constant (derived from the IAU 1976 adopted precession and discussed in the WG report on the nutation model adopted by the IAU in 1980) of -3.1 mas/year. If we do not use the constraint, we obtain -3.0 mas/year. This illustrates the necessity of continuing the observations of the nutations to understand long period nutations. There are also differences at the level of tenths of mas in the 13.66 day nutation among different observations, and peaks in the residual spectrum at 5 and 7 days. There is an effect of the atmosphere on the prograde annual nutation, as well as an excited FCN above the standard deviation of the observations. These effects need to be observed. All of these questions emphasize the need to continue VLBI observations for both short and long period nutation studies. There is no good link between the terrestrial and celestial reference frames if the nutations are not accurately determined, and to that aim, it is absolutely necessary to continue the VLBI observations. Activity within the VLBI community to organize effectively continuous observations is encouraging and important. A. Effect of the atmosphere

(1) For atmospheric fluctuations, most operational numerical weather prediction centers already submit to the SBAAM, AAM values computed at 6-hour intervals. The GSFC DAO reanalysis has provided products as often as every 3-hours, and even hourly values are possible. Close cooperation with the modeling groups, a future focus of the SBAAM, can thus provide the basic data to calculate atmospheric contributions.

(2) There is an important impact of the atmosphere on the nutations, in particular, on the prograde annual nutation. There are differences between the most recent theories and the observations at the level of the tenth of milliarc second (mas). This is above the noise of the observations (some hundredths of mas). The SBAAM already archives the data needed to compute atmospheric effects on nutation, namely, the x- and y-components of the AAM (wind and pressure terms separately) at 6-hour intervals. It would be easy to extend the work of the AAM sub-bureau by computing the effect from the first and second components of the angular momentum of the atmosphere on the nutations. A torque approach has been used by several authors, but they only computed by using spherical harmonics expansions. These torques are not only the pressure torque acting at the Earth surface, but also the gravitational torque (which is counterbalancing an important part of the pressure torque) and the friction torque (which is very small). The resulting torque predicts effects on nutation which are too large with respect to the differences between the recent geophysical nutation theories and the observations.

(3) There could be an important atmospheric effect at the K_1 sidereal diurnal frequency. This is related to the atmospheric excitation at the one-solar-day period modulated by an annual period and which gives then a one-sidereal-day period (K_1) in the terrestrial frame. There is a corresponding impact on the precession. The atmospheric pressure torque acting on Earth gives an effect of a few mas/year. Again the pressure torque is not the only one acting on the solid Earth, the gravitational torque and the friction torque are supposed to decrease it (again probably one order of magnitude). Nevertheless, even for one order of magnitude less, this could be important for the determination of the general precession, the precession constant and the Earth dynamical flattening.

(4) In the observations there is some energy around the Free Core Nutation (FCN) period. It is thought that there is an excitation of this normal mode. While it is probably not possible to explain it entirely from a purely luni-solar excitation, it is suspected that it is excited by the atmosphere because there is sufficient energy in the broad-band variability of the atmosphere to excite it.

(5) It has been shown from intensive VLBI campaigns that the semi-diurnal and diurnal polar motion (the retrograde part corresponds to the nutations) can be obtained. While this is thought to be related to the oceans, it is suspected that there is an atmosphere-ocean interaction. See next point.

Summarizing these points, an important extension for the AAM-sub-bureau would be to compute the effects of the atmosphere on the nutations. The SBAAM already archives the basic data needed to compute atmospheric effects on nutation, namely, the x- and y-components of the AAM (wind and pressure terms separately) at 6-hour intervals. This is not a simple matter and will need a lot of additional input mainly because nutations are usually studied in the frequency domain. Another interesting extension is to compute the effects of the atmosphere on sub-daily polar motion, and on prograde polar motion, although it is generally believed that the oceans are responsible for an important part. B. Effect of the oceans.

(1) Ocean heights: The Wahr and Sasao (1981) corrections for the effects of the ocean heights on the nutations have become the accepted method but have not been adopted by the IAU. The ocean effects are not completely described by this approach because the currents may indeed play an important role, as discussed below. Wahr and Sasao used Schwiderski's ocean tide models but since then, the Topex/Poseidon mission has produced many new ocean tide models derived from satellite altimetric data, ocean loading effects gravity data, finite element modeling and/or on ocean hydrodynamics. Validation and testing of these models can be coordinated with other FAGS services as the ICET (International Center for Earth Tides). The Topex/Poseidon community has also devoted much work to validation of these new tidal height models, primarily because of their crucial role in other oceanographic investigations that use altimetry. In the open ocean, the new T/P models have been shown to be significantly more accurate than any models existing before 1992. These conclusions rely on comparisons to in situ tidal observations with island gauges and with ocean-bottom pressure recorders, as well as on variance-reduction tests with independent altimeter data (e.g., Andersen *et al.*, 1995; Shum *et al.*,1996). The story, however, is somewhat different in shallow and marginal seas. In such areas, the tides are spatially very complex, and the large spacings between altimeter ground tracks have precluded any great improvements. Because the tides in these areas are also large, they may alias into spatial harmonics that cause nutation. Thus, there is still important work to do in improving tidal elevation models in shallow seas.

(2) Ocean currents: Some authors have already computed the effects on the retrograde diurnal polar motion using the angular momentum approach, finding the currents to be as important as the heights (or maybe a little bit less). It would be valuable to compute currents from Topex/Poseidon or other recently available ocean model mentioned above. The corresponding effects on nutations are above the noise level of the observations for some of the geophysical nutations and need to be incorporated. In summary, the effect of ocean tides on the nutations deserves the attention of a sub-bureau or coordinator of OTAM to collect and archive the angular momenta carried by the diurnal tidal currents and height changes. The situation is somewhat

different compared to the atmosphere, because models rather than an operational unit are the basic tool. However the models are constantly evolving, requiring communication to the IERS and calculations of geodetic effects. C. Effect of mantle convection.

We may consider the mantle to be another geophysical fluid that plays an important part in the nutations. The mantle undergoes convection, implying that the Earth's interior properties are not spherically symmetric, but the Earth contains mass anomalies: there are places in the mantle where the density is high (where there is a mass accumulation producing down-going motion) and places where the density is low (there is a mass deficit associated with upwelling). This induces variations in the moment of inertia and consequently of the computed dynamical flattening. There is a difference between the dynamical flattening derived from the observed precession and the one derived from the hydrostatic equilibrium of the Earth based on the spherical properties given by seismologists. Here the IERS can not benefit yet from the seismic observations which are not yet well constrained in the lower mantle and at the 670 km depth (boundary between the lower mantle and the upper mantle), but rather can give some constraints to the seismologists as the observed dynamical flattening of the Earth. The VLBI nutations can also be used to derive the FCN period from the resonance effects that the FCN induces in the forced nutations. An increase of the core flattening corresponding to an increase of the core equatorial radius of about 500 meters is proposed for explaining the difference between the observed and the computed FCN periods. This could also be used as a constrain for the seismological models of the Earth's interior.

1996 IERS Workshop - Recommendations to the Directing Board

Topic 1 - Missions

Recommendation 1: Each Coordinating Center (CC) should strengthen overall control of observations, quality control, and data processing for products of interest to the IERS (coordinates, EOP series, etc) in accordance with the IERS Terms of Reference. Combinations of individual solutions into technique specific products are strongly encouraged.

Recommendation 2: Coordinating Centers should be formed to promote the collection of other types of information relevant to EOPs such as atmospheric excitation functions, information on ocean circulation, global water level changes, etc.

Recommendation 3: Combination of products from the various CCs shall be performed by at least two IERS components such as Sub-Bureaus, specialized Analysis Centers, Central Bureau Sections. The Central Bureau should disseminate the state-of-the-art combined solutions and provide the official IERS products. The criteria for the selection or production of this official solution will be determined by the IERS Directing Board.

Recommendation 4: It is desirable to form a Network Coordination Group to consider issues of Network Design, Colocation, local ties, Site Quality, etc. as previously recognized and accepted by the IERS Directing Board.

Recommendation 5: Members of the Directing Board should include representatives of CCs, Sub-Bureaus, sections of the Central Bureau, selected combination centers (see Rec. 3), the Director of the Central Bureau, and representatives of IAU, IAG/IUGG, and FAGS.

Recommendation 6: The IERS Conventions should be updated periodically at reasonable intervals. They should reflect the state-of-the-art at the time of publication. In all cases, they should be consistent with the IAU and IUGG resolutions on reference systems (at present, the resolutions adopted in 1991). The IERS Conventions should be considered one of the IERS products for the use of the internal and external researchers. An IERS unit such a Sub-Bureau shall be formed to maintain the IERS Conventions.

Recommendation 7: The IERS Central Bureau should continue its excellent work necessary to develop and make available information on the ITRF, the ICRF and the transformation parameters between them. The Central Bureau should poll its distribution list to identify the various types of users and their specific requirements.

Recommendation 8: The above Recommendations are intended to further enhance and improve the widely acknowledged excellent work performed by the IERS.

Topic 2 - Astronomical reference frames

Executive summary of recommendations

IERS tasks

To monitor the evolution in time of the instantaneous positions and motions of the equinox and ecliptic and, in particular, to provide for planetary ephemerides, the mean ecliptic and equinox in the ICRS system.

a - To provide the maintenance of ICRF; this includes promoting and coordinating observations, monitoring source structures and updating the catalogue.

b - To assess the accuracy with which the main astrometric catalogues in various wavelengths represent ICRS and monitor the evolution of the links. This task is primarily to be performed on the Hipparcos Catalogue as the primary optical reference frame.

c - To monitor the evolution in time of the instantaneous positions and motions of the equinox and ecliptic and, in particular, to provide for planetary ephemerides, the mean ecliptic and equinox in the ICRS system.

d - To assist in the collection and distribution of observations of millisecond pulsars.

e - For these tasks, IERS will be assisted by a Consultative Group appointed by the IAU.

In addition, Topic 2 supports recommendation 6 of Topic 1 stating that the IERS Conventions should be consistent with the IAU resolutions on reference systems (at present, the IAU and IUGG resolutions adopted in 1991).

Topic 3 - Vertical References

Recommendation 1: Considering the critical contribution of IERS for vertical reference issues by defining and realizing primarly the International Terrestrial Reference System (ITRS), we recommend IERS

- to propose IAG to establish a joint working group between its Commission X (networks) and its Commission XII (geoid) on the consistent utilization of space geodetic heights, geoid models and leveling to obtain a unified vertical datum;

- to appoint an IERS representative in this WG;

- to suggest IAG to invite also a IAPSO representative for tide gauge issues.

Recommendation 2: Considering the various problems related to the realization of a proper geodetic fixing of tide gauges and the necessity to fully exploit the improving quality of the vertical component of the ITRF and its densifications, such as the IGS one, we recommend

- that the IAPSO/IAG Working group on Geodetic fixing of tide gauges be asked to prepare technical specifications on these issues;

- that this WG would ensure that these specifications be prepared with the contribution of several geodetic experts in this field.

Recommendation 3: We recommend that an IAG CSTG group deal with various topics with potential impact on IERS in a near future. We have specifically identified two subjects of this kind:

a) the use of ground based atomic clocks as sensors of the geopotential and consequently ask the FRCN group to include a representative of this community;

b) the definition and realization of a pilot experiment to detect some geophysical signals from a specific subnetwork of ITRF stations. IERS should draft such a proposal and submit it to the group. This experiment should include:

- a global design of this subnet taking into account the individual quality of sites and the structure of expected signals,

- a small group of scientifically interested persons who would take part to this design and to the analysis of results (we can mention postglacial rebound, tidal effects...),

- a procedure to guarantee that the participating stations will accept to apply the established specifications, in particular concerning some monitoring issues to be defined in more details (local surveys, evaluation of the stability of the instruments and monuments...).

Recommendation 4: Considering the present day capability of several IERS techniques to monitor the motion of the geocenter, we recommend

a) to support strongly the proposal to launch a pilot experiment on this issue as announced by the WG on ITRF datum;

b) to obtain as soon as possible geophysical estimated of this motion for the following contributions:

- atmosphere,
- tides,
- oceanic circulation.

The existing or new relevant IERS Sub-bureaux should take this action

Topic 4 - Crustal Deformations

Recommendation 1: The IERS should make a strong effort to promote the collocation of observations, accurate local survey and continued (re)observations at the TRF sites in order to strengthen the ITRF.

Recommendation 2: The IERS should encourage the analysis centres to provide time series of ITRF site positions and make this information available through the IERS Web site.

Recommendation 3: The IERS should encourage the Analysis Centers to report deviating behavior of ITRF sites at the 5 sigma level or above, and to attempt to identify the cause of such behavior. IERS should make such information available on the IERS Web site.

Topic 5 - Unification of national datums

Recommendation 1: Provide a consistent global reference frame, and transformations between ITRF solutions, based on a homogeneously distributed network of stations at the highest possible level of accuracy.

Recommendation 2 : Maintain the coordinates and velocities of a homogeneously distributed global network of accurate permanent stations, and parameters, so that any agency can undertake a national ITRF based datum.

Recommendation 2 : Encourage national agencies to establish their precise national datums within ITRF so that these datums can be linked into regional or continental solutions.

Topic 6 - Global geophysical fluids

Recommendation 1 : We recommend that the IERS DB strengthen the present Sub-bureau for AAM. The IERS should be aware that this Sub-bureau could be enlarged sometime in the future.

Recommendation 2 : We recommend that the IERS DB start the procedure for creating a WG to evaluate the existing ocean tide models, working towards recommending an IERS standard which includes parameters related to Earth orientation, gravity, geocenter motion, and other parameters of interest to IERS.

Recommendation 3 : We recommend that the IERS DB request that the IAG SSG5.173 investigate the status of global ocean models related to Earth orientation, gravity, geocenter motion, and other parameters of interest to IERS. We recommend that the IERS DB asks this SSG to investigate the possibility to introduce a specific algorithm within the existing ocean models to compute EOP, gravity and geocenter motion.

Recommendation 4 : We recommend that the IERS DB encourages the CC for space geodesy techniques to archive and make available water vapour estimates.

Recommendation 5: The IERS DB should expect that, in the long term, the global hydrological cycles will be part of the global climate models.

Recommendation 6: We recommend that the IERS DB encourages the establish-ment of contact with the SEDI community for getting core parameters relevant to Earth's rotation.

Recommendation 7: After the IERS DB accepts these recommendations, they should be publicized in the litterature such as a paper in EOS.

IERS Workshop at Paris Observatory,
14-18 October 1996

PROGRAM

Monday 14 October

9:00-10:30 IERS extended Directing Board
Conveners: C. Reigber, M. Feissel

11:00-12:30 IERS extended Directing Board + Topic Coordinators
Conveners: C. Reigber, M. Feissel

---------------------- START OF 1996 IERS WORKSHOP ----------------------

13:00-14:00 **Registration.**

14:00-15:30 Topic 1(a): Assessment of current missions
Conveners: G. Beutler, I. Mueller

16:00-17:30 Topic 2: Astronomical reference frames
Conveners: J. Kovalevsky, M. Standish

Tuesday 15 October

9:00-10:30 Topic 3: Vertical references, incl. geoid, sea level, etc.
Conveners: C. Boucher, B. Carter

11:00-12:00 Topic 4: Topography and crustal deformations
Conveners: B. Engen, B. Minster

12:00-12:30 Topic 5: Unification of regional reference systems
Conveners: W. Augath, J. Manning

14:00-15:30 Topic 6: Earth rotation dynamics and geophysical fluids
Conveners: V. Dehant, C. Wilson

16:00-17:30 Topic 1(b): Assessment of current missions
Conveners: G. Beutler, I. Mueller

Wednesday 16 October

9:00-12:00 Group discussions

14:00-16:30 General discussion and conclusions
Convener: C. Reigber

------------------------ END OF IERS WORKSHOP ------------------------

Friday 18 October

14:00-15:30 IERS extended Directing Board + Topic Coordinator
Conveners: C. Reigber, M. Feissel

16:00-17:30 IERS extended Directing Board
Conveners: C. Reigber, M. Feissel

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