

International Union of Geodesy and Geophysics
International Association of Geodesy

International Astronomical Union
Commissions 4, 19, 31

MERIT/COTES JOINT WORKING GROUPS

MERIT CAMPAIGN : CONNECTION OF REFERENCE FRAMES

- IMPLEMENTATION PLAN -

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FOREWORD

The constants, models and algorithms to be used in the reduction of observations of the MERIT Campaign are not included in this report. They may be found in the report on MERIT Standards, to which attention is directed.

This report was prepared by the MERIT coordinators for the Intensive Campaign and for Colocations, M. Feissel (BIH) and P. Wilson (IFAG) respectively. Contributions from R. Anderle, C. Boucher, O. Calame, W. Carter, J.O. Dickey, D.D. McCarthy, W.G. Melbourne, I. Mueller, B. Schutz, E.M. Standish, B. Tapley, J.G. Williams and K. Yokoyama are gratefully acknowledged.

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1. INTRODUCTION

1.1 Background and Objectives

This document is the plan for implementing the proposal put forward by the joint IAG/IAU Working Group on the Establishment and Maintenance of a Conventional Terrestrial Reference System) (COTES) for an attempt to connect the various terrestrial and inertial reference frames during the MERIT campaign [COTES, 1982]. The motivation for this proposal may be found in the proceedings of the MERIT Workshop held in Grasse, France [Wilkins and Feissel, 1982], in which, on page 43 there is an account of a joint meeting of the MERIT (Monitor Earth Rotation and Intercompare the Techniques of Observation and Analysis) Steering Committee and the newly formed COTES on May 21, 1981, at which

it was agreed that it would be of general benefit if the operations during project MERIT were planned in such a way as to contribute whenever possible to the establishment and maintenance of the new conventional terrestrial reference system.

The frame of the future Conventional Terrestrial System (CTS) is to be defined by an adopted set of spatial coordinates of a global network of observing stations mainly Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Lunar Laser Ranging (LLR), and their motion models, or by an equivalent way [Mueller, 1981; Kovalevsky and Mueller, 1981]. The stations will define the vertices of a fundamental polyhedron whose deformation and movement with respect to the frame of a Conventional Inertial System (CIS) is to be monitored through periodic re-observations. The main differences between this terrestrial system and that of the currently adopted CIO-BIH are that in defining the former, the stations cannot be assumed to be motionless with respect to each other, and that the observations will no longer be referred to the directions of the local plumb lines (astrometric instruments), but to other terrestrial directions (baselines). The functions of the CTS are twofold. The first, requiring only a subset of the polyhedron vertices, is to monitor the motions common to all stations (polar motion and earth

rotation) of the polyhedron with respect to the frame of a CIS. The second, involving all stations, is to monitor the internal motions (or deformations) of the polyhedron, i.e., those motions not common to all stations.

Considering that several advanced geodetic systems are available today, the problem is how to merge several networks, each one defining essentially its own reference frame, both CTS and CIS, into a common set. In order to accomplish this, several stations will need to be collocated, and short periodic variations in the earth's rotational vector need to be observed (see Section 2).

This plan for coordinated SLR, LLR and VLBI observations during the MERIT main campaign is an attempt to get answers to the following questions:

- (1) whether the most precise observational systems available at that time (i.e., third-generation lasers, and VLBI's with Mark III-type receivers) will be able to detect the systematic differences between the frames of the various Conventional Inertial Systems (CIS) and between the frames of the various Conventional Terrestrial Systems (CTS) inherent in these observations systems.
- (2) whether the above observational systems will be able to detect short periodic variations in the earth's rotational vector (and how accurately).

It is emphasized that since the aim is the establishment and maintenance of a future CTS, the plan is based only on the best SLR, LLR and VLBI systems in a network which in our view could be established by 1983/84. Important use is made of transportable SLR and VLBI systems which will be available in that time frame in Europe and the U.S.

It should also be noted that although only third-generation lasers and Mark III type VLBI are considered in this plan, other systems such as Doppler, especially when utilizing the new NOVA satellites, will also follow a similar plan for a secondary network. The Doppler systems have their own inherent CIS's and CTS's, and the establishment of the relationship between them and the others would be of scientific interest.

1.2 Resolutions

The COTES proposal was thoroughly discussed with all prospective participants and presented to the IAG General Meeting in Tokyo in May, 1982. The

IAG expressed strong support through the following resolutions:

RESOLUTION 1

The International Association of Geodesy

noting that the results to be obtained during the MERIT Main Campaign will be of long-term benefit to geodesy and its applications,

strongly endorses the proposals of the COTES and MERIT Working Groups that during the Campaign

(a) very long baseline radio interferometric and satellite and lunar laser ranging systems be used for co-located observations of high precision at the recommended sites, and

(b) observations be made intensively for a limited period to detect any short-period variations in the derived earth-rotation parameters,

and urges that the appropriate resources and facilities be made available for these activities by the countries involved.

RESOLUTION 2

The International Association of Geodesy

considering that it is important that the new terrestrial reference frame to be derived from high-precision observations during the MERIT Main Campaign should be extended and related to existing services as accurately and quickly as possible,

and urges that coordinates precise positioning observations be made during the Campaign by satellite radio-tracking systems at the Very Long Baseline Interferometric, Lunar and Satellite Laser Ranging sites as well as at a larger number of well distributed sites around the world.

The IAU subsequently endorsed both of the above resolutions at its General Assembly in Patras, August, 1982.

2. THE PRINCIPLE OF DETERMINING THE CTS AND CIS RELATIONSHIPS AND SHORT PERIODIC VARIATIONS IN THE EARTH ROTATION VECTOR

2.1 The Effect of CIS and CTS Differences on Earth Rotation Parameters

The two CIS's (and two CTS's) inherent in two different techniques are generally not exactly identical. Suppose the relation between the two CIS's is

$$(\underline{X})^{II} = R_1(\alpha_1) R_2(\alpha_2) R_3(\alpha_3)(\underline{X})^I \quad (2.1)$$

Similarly, the relation between two CTS's is

$$(\underline{x})^{II} = R_1(\beta_1) R_2(\beta_2) R_3(\beta_3)(\underline{x})^I \quad (2.2)$$

where α_i and β_i are small rotation angles about the axes "i".

The transformation from CIS to CTS is [Mueller, 1969]

$$(\underline{x})^I = S^I N P (\underline{X})^I \quad (2.3)$$

and

$$(\underline{x})^{II} = S^{II} N P (\underline{X})^{II} \quad (2.4)$$

where common nutation (N) and precession (P) matrices are assumed to be used in both techniques. The earth rotation matrix $S = R_2(-x_p)R_1(-y_p)R_3(\theta)$, in which x_p, y_p are the coordinates of the pole and θ is the Greenwich Sidereal Time.

Substituting eq. (2.1) for the last term of the right-hand side of eq. (2.4), and eq. (2.2) for the left-hand side,

$$R_1(\beta_1) R_2(\beta_2) R_3(\beta_3)(\underline{x})^I = S^{II} N P R_1(\alpha_1) R_2(\alpha_2) R_3(\alpha_3)(\underline{X})^I$$

After some reduction, neglecting second-order terms,

$$(\underline{x})^I = R_1(-\beta_1 + \alpha_1 \cos\theta + \alpha_2 \sin\theta) R_2(-\beta_2 - \alpha_1 \sin\theta + \alpha_2 \cos\theta) \cdot R_3(-\beta_3 + \alpha_3) S^{II} N P (\underline{X})^I \quad (2.5)$$

Comparing eq. (2.5) with (2.3),

$$S^I = R_1(-\beta_1 + \alpha_1 \cos\theta + \alpha_2 \sin\theta) R_2(-\beta_2 - \alpha_1 \sin\theta + \alpha_2 \cos\theta) \cdot R_3(-\beta_3 + \alpha_3) S^{II} \quad (2.6)$$

Or

$$\begin{aligned} -\Delta y_p &= -(y_p^I - y_p^{II}) = -\beta_1 + \alpha_1 \cos\theta + \alpha_2 \sin\theta, \\ -\Delta x_p &= -(x_p^I - x_p^{II}) = -\beta_2 - \alpha_1 \sin\theta + \alpha_2 \cos\theta, \\ \omega_e \Delta UT1 &= \omega_e (UT1^I - UT1^{II}) = -\beta_3 + \alpha_3. \end{aligned} \quad (2.7)$$

Thus the CTS differences (β angles) cause biases in all earth rotation parameters. Because of the modulation of the earth's diurnal rotation, the effect of CIS differences (α_1, α_2) on polar motion components are diurnal terms, while the effect of α_3 on UT1 is again a bias.

The direct way to determine all the β angles is the method of station collocation. For connections of CIS's, there are a few methods such as the use of space astrometry to connect the stellar CIS and the radio source CIS, or using differential VLBI (which, for example, was used when the Viking Mars Orbiters and a quasar were near eclipsing) to connect the planetary and radio source CIS's (see [Kovalevsky and Mueller, 1981]). These are direct approaches. One indirect method is via station collocation, i.e., using the earth as an intermediate body (see [Kovalevsky, 1980]): First by station collocation one determines the CTS difference (β angles), then through the earth rotation parameter differences one finds the CIS difference (α angles). Eq. (2.7) is the basis for connecting the two CIS's via station collocations.

2.2 Station Collocation for Determining the CTS Differences

It is obvious that using the station collocation method one can solve for $\beta_1, \beta_2, \beta_3$ directly. (β_1 and β_2 can also be determined from the biases between two sets of polar motion coordinates. (See eq. (2.7).) Suppose station i is one of the collocated stations, and $\underline{x}_i^I$ and $\underline{x}_i^{II}$ are the two sets of "geocentric" coordinates, then

$$\Delta \underline{x}_i = \underline{x}_i^I - \underline{x}_i^{II} = - \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \end{bmatrix} + \begin{bmatrix} 0 & \beta_3 & -\beta_2 \\ -\beta_3 & 0 & +\beta_1 \\ +\beta_2 & -\beta_1 & 0 \end{bmatrix} \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} + c \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} \quad (2.8)$$

where $\underline{\delta}$ is the translation vector, and c is the scale difference. Eq. (2.8) can also be seen as an observation equation. One must have at least three collocated stations to solve for the above seven unknowns. If one set of

coordinates is geocentric, and the other is not, as in the VLBI case, then there are two ways to proceed. For VLBI, $\Delta \underline{x}_{ij}$ is given between stations i and j at the ends of the VLBI baseline; by assigning one VLBI station an arbitrary position vector, the coordinates of other VLBI stations in the same network can be obtained. Eq. (2.8) is still used as the observation equation, but in this case the meaning of the translation vector is not "geocentric" difference, but it expresses how much the initial arbitrary position vector differs from the geocentric position vector. The other way is to solve eq. (2.8) for only four unknowns, namely the β 's and c , and choose one VLBI station position vector to exactly equal the geocentric position vector of the same station as determined by means of a collocated SLR or LLR.

3. DEFINITION AND REALIZATION OF REFERENCE FRAMES

This Section identifies the principal reference system related elements that will be required to intercompare earth rotation results obtained by the different techniques. For each technique, a narrative describing the process by which earth rotation results are related to the terrestrial and space-fixed reference frames is given. The information contained herein should enable the development of a set of transformation algorithms that account for the various reference systems in use when intercomparing earth rotation results. In addition, the differences in effect of adopting new precession and equinox corrections on the space techniques versus the established techniques are discussed.

3.1 Very Long Base Radio Interferometry

Through the diurnal variation of the observed phase, radio interferometry senses the true declinations and relative right ascensions of date of the observed radio sources. In addition, the direction and length of the baseline vector are obtained relative to the quasi-inertial system (CIS) defined by the angular positions of the radio sources. The zero point of the right ascension coordinate is not observed by radio interferometry. Some workers tie the right ascension of the radio source frame to a single source with an optical counterpart defined in the FK4, for example, Algol. Others use a best fit of the observed positions of the ensemble of observed radio sources with weak optical counterparts (~100 known today) to the optical positions of these sources. These optical positions are tied indirectly to the FK4 through photogrammetry to an accuracy of a few tenths arc sec. Another approach is to tie the radio source frame to the dynamical frame defined by the lunar and planetary ephemerides. This is accomplished through differential VLBI observations of planetary spacecraft. Intercomparison of radio source catalogs will probably be required unless the standard set in Appendix 1 is used.

The location of the baseline vector within a conventional terrestrial frame (CTS) is not defined by radio interferometry observations. This allows three rotational and three translational degrees of freedom of the terrestrial frame for a time series of radio interferometry observations on a given baseline. The three rotational degrees of freedom are exercised by specifying a procedure for aligning the UT1 and pole positions with the BIH. Again, some workers do this by adopting the BIH earth rotation parameters at fixed epochs; others carry out the alignment by minimizing the RMS deviations over the entire observation span (e.g., years) between their earth rotation time series and the BIH. Misalignments in right ascension between the radio source frame and the FK5 are likely to remain. Consequently, even with the UT1 systems of the radio and BIH techniques aligned, the resulting baseline terrestrial longitudes will not be exactly in the BIH defined frame. However, specification of the baseline terrestrial longitude and latitude (the latter being defined from the observed declination of the baseline and the transformations between the CIS and CTS frames) is not strictly necessary for earth rotational studies: only for study of terrestrial frames is this last step important. Also, the three translational degrees of freedom to the first order are not relevant to earth rotation studies; for computational convenience some workers fix the terrestrial coordinates of one of the radio telescopes and solve for the coordinates of the other telescopes rather than for the baselines.

3.2 Connected Elements Radio Interferometry

INTRODUCTION

Connected Element Interferometry (CEI) utilizes at least two separate radio telescopes which are used to observe the same radio source simultaneously. The signals received at each instrument are then transmitted in real time to a central location where they are correlated to find the amplitude and phase of the interferometric fringes which result. This process differs from Very Long Baseline Interferometry (VLBI) in that the length of the baselines in VLBI currently precludes the possibility of real-time correlation of the signals. Two reference coordinate systems are involved in using the CEI technique for the determination of Earth orientation. In order to understand the role of the reference coordinate systems it is useful to review the basic theory of the technique.

The signal observed at the separate antennas will be received at different times because of their different locations with respect to the radio source. This difference in the time of arrival is proportional to the dot product, $B \cdot S$, where B is the baseline vector and S is the vector directed toward the source. The baseline vector is described in the conventional terrestrial reference system while the source vector is described in the conventional inertial system. This difference in the time of arrival depends on the relative orientation of the two reference frames associated with these systems as well as the descriptions adopted for each vector within their respective frames. The reduction procedure makes use of adopted procedures to account for the rotation of the inertial system with respect to the terrestrial system. This is done through the use of the conventional expressions for precession, nutation and Greenwich mean sidereal time. The residual phases which remain after accounting for the above effects are then analyzed to determine the appropriate Earth orientation parameters (McCarthy, et al., 1980)

CONVENTIONAL INERTIAL SYSTEM

The conventional inertial reference frame used in CEI is defined by a set of adopted source positions. The sources are assumed to be at very great distances from the Earth and so no adopted models for the motions of the sources are required. Since it is known that the sources typically show time-variable structure at the level of 0.001, the sources chosen for observation are limited to those whose angular size is sufficiently small so as to minimize any effects of time-variable structure.

The source coordinates are usually adopted from previous observations made using either the same interferometer or another instrument. In the case of the Green Bank interferometer the reductions are made using positions derived from that instrument (Kaplan, et al., 1982). The coordinates are given in the usual system of right ascensions and declinations. While the observations were made in the FK4 system they are transformed to the FK5 system statistically through the use of the available procedures.

CONVENTIONAL TERRESTRIAL SYSTEM

The baseline vector is described by components derived from observations made with the instrument. It should be realized that the components are not defined in a geocentric system since the baseline can be translated without any effect on the observations. Hence, the adopted values only describe the relative orientation of one antenna with respect to the other. This relative orientation is given in a system consistent with other adopted conventions. In the case of CEI the components are chosen so that the Earth orientation parameters derived from interferometer observations over some period of time are statistically consistent with those derived from values given by the standard services of the Bureau International de l'Heure (BIH) or the International Polar Motion Service (IPMS) during that same time.

The components of the baseline vector are given in a local x,y,z coordinate system with the x and z axes lying in the plane of the local meridian of one of the antennas and with z perpendicular to the equator. The y axis, being directed toward the west for the Green Bank instrument, completes a left-handed system. The values for the components are expressed typically in nanoseconds of relative delay time although they may be given in linear measure or as direction cosines. In the case of the Green Bank interferometer the components were chosen to be consistent with BIH and are assumed to be in the BIH 1979 reference system.

3.3 Optical Astrometry

The apparent position of an observing star at the time of observation is computed on the basis of the MERIT Standards which is practically identical with IAU (1976) System of Astronomical Constants so far as the reduction of the optical astrometry is concerned. No discontinuity of UT1 will occur in this procedure. The computational algorithm is modified to include the effects which have been neglected so far. Thus the Celestial Reference Frame of the optical astrometry is the same system as the one to be used by other techniques.

The observables of the optical astrometry (latitude and/or UT0) are directly connected with the direction of the gravitational vector at the site. The gravitational vector is affected by the luni-solar attraction depending on the internal constitution of the Earth. In order to detect short periodic variations in the Earth's rotation, predictable parts of the variations of the gravitational vector due to the external forces should be corrected, namely the deflections of the vertical due to the Earth and ocean tides. Other geophysical variations after subtracting the predictable variations of the gravitational vector are supposed to be due to a crustal displacement of the site and secular variation of the gravitational vector, in addition to Earth rotation variations.

The effects of the errors in the position and proper motion of the observing catalogues are far from negligible in the observed latitude and UT0. Although these errors can be corrected to a considerable extent by an internal adjustment using the observed data themselves, it is difficult to connect the whole system to that of the fundamental catalogue like the FK4, especially for the case of PZT which usually observe faint stars of the narrow zone. The connection of the star systems to the fundamental catalogue should wait until the appearance of the FK5 which will contain fainter stars. Hence, one of the weak points of the optical astrometry in maintaining the CTS is an unknown bias of the position and the proper motion of the observing star catalogue used by each instrument. The connection of their position and proper motion system with that of the FK5, that is, a quasi-inertial system, will be one of the most important works in the future.

As to the periodic (mainly annual and semi-annual) systematic errors included in the data of each station, the correction for the refraction, as well as the elimination of periodic errors due to the catalogue errors, will be accomplished to some extent by an improvement of the environment of an observing house, as well as an improvement of the refraction table of each station.

In order to increase the precision and the accuracy of the optical astrometric observations, it is important to make effort for automatization of observation and also for improvement of the instruments, through adoption of the new technologies.

The mean latitudes and longitudes of the sites are determined using the data obtained during a certain duration. The mean coordinates thus determined define the mean north pole like CIO for the case of the ILS network, or the BIH zero meridian for UT1 determination. These origins are based on the average system of the star catalogues of the collaborating stations. Hence by the inter-comparison of the star catalogues with the FK5 or the radio source system, of course in the future, it will become possible to reduce the system of the EOP of the optical astrometry to a quasi-inertial system, or CIS.

On the other hand, it will also become necessary to connect the optical astrometric system defined by the gravitational vector to the geocentric coordinate system. Through this procedure, the optical coordinates system may be connected with those defined by other techniques.

In the near future, it will also become an important problem to determine the EOP , simultaneously with the parameters of the station displacements, as well as with other minor geophysical phenomena. When we consider the present situations which the optical astrometry has encountered, the so-called station drop-out problem is one of the serious defects in maintaining the CTS. The history of the optical astrometry is the longest among various techniques covering over 20 years. Hence these observations will provide a good example for testing such attempts to simultaneously determine station displacements together with the EOP .

It should be stressed here that for providing high-quality results to meet MERIT and COTES objectives, the stations which have supplied good data will play important roles. Especially for maintaining the CTS as stable as possible, the stations with long histories of observations are to be assigned large weights.

3.4 Lunar Laser Ranging

In the case of lunar laser ranging, the celestial reference frame is the dynamical frame defined by the lunar and planetary ephemeris system. The series of LLR observations over the past 13 years has yielded a determination of the longitude of the moon relative to the sun to $\pm 0.003''$. Thus, the zero point in right ascension of the moon is strongly tied to the zero point of the sun in the planetary ephemeris system. Furthermore, the mutual inclinations and orientations of the lunar orbit plane, the ecliptic and the dynamical equator are now known at the $0.01''$ level. LLR now provides a stronger data set than the meridian circle observations of the sun and planets for establishing the relative orientations of the ecliptic and dynamical equator. This accuracy will improve significantly as a larger fraction of the 18.6 year nodal regression period is spanned by the LLR data set. The celestial frame for LLR is thus standardized through the specification of the lunar and planetary ephemerides described in Appendix 16.* Those LLR workers adjusting the model parameters related to the lunar ephemeris should exercise care noting the rotations that accrue between the resulting lunar ephemeris and the standard.

The diurnal sinusoid in LLR provides the principal information about earth rotation. The amplitude of the sinusoid provides information about the distance of the station from the spin axis of the earth and the phase of the sinusoid provides station longitude information. For a single station, variations in the diurnal amplitudes determined from successive frames of LLR observations yield information about variations in the component of pole position along the station meridian. In practice, the observing schedule does not permit a full diurnal pass of LLR data to be taken and the resulting polar motion derived from the amplitude of the diurnal sinusoid requires accurate lunar and libration ephemerides. Variations in diurnal phase are relatively correlation free and provide a determination of the variations in UT0. For McDonald Observatory, UT1 is given by

$$UT1 = UT0 + 0.572 x + 0.142 y$$

Thus, the determined variations in UT1 are corrupted by errors in the BIH adopted values of polar motion, weakly in the case of y and more strongly in the case of x. The variation of latitude at McDonald Observatory, determined in some analyses (JPL and MIT), is dominated by the y component.

In the LLR three rotational degrees of freedom exist in the terrestrial frame. These are fixed by aligning the LLR derived UT and pole parameter series with the BIH. The UT1 systems can be aligned by deriving a longitude for the station that gives the least RMS difference in the LLR and BIH UT1 series over the entire LLR data span.

* of the Report on MERIT Standards

3.4.1 The Lunar Laser Modelling at the CERGA

INTRODUCTION

In the framework of the EROLD program and the MERIT campaign, the "Earth-Moon System" team in CERGA (Grasse) acts as the primary computing center (or operating center) for all the data available from the participating stations. The analyses of these data are performed from mathematical models constructed in CERGA for several years and in continuous evolution. These models include the computations of the observational residuals and partial derivatives with respect to the relevant parameters that affect the various motions of the lunar reflectors with respect to the observation terrestrial stations, as well as the reduction techniques of data for determination of these parameters, in particular the Earth rotation solutions. The results of this latter purpose are published regularly in the BIH issues.

This paper reports the main elements useful to these analyses, without however entering into details.

COMPUTATIONS OF OBSERVATIONAL RESIDUALS

At first, it is important to realize that the lunar range measures are not distances, but round-trip time delays, or aberration times, due to the relative motions of the lunar reflector and the terrestrial station. This fact makes the computations more complex, since for example the two parts of trip are not symmetric. However, it is sometimes more convenient (or visualizing) to give some figures in distance units, rather light-time units, although the intercomparison between them can be really made only with a conventional value for the speed of light.

Schematically, the value of a station-reflector time delay can be computed in considering the three following vectors in space :

- $\vec{SE}$: geocentric position of the terrestrial station S with respect to the center of mass E of the Earth;
- $\vec{EM}$: position of the center of mass M of the Moon from this of the Earth;
- $\vec{MR}$: selenocentric position of the considered reflector R.

Even for the only purpose of Earth rotation determination, it is necessary to take in consideration all the phenomena that can affect each of these vectors.

Generally, the observations are referred to the Coordinated Universal Time (UTC) time scale, that is the most easily available in station. For describing the rotational position of the Earth crust in space, a conversion has to be done to the Universal time UT1 in using the BIH published values of $\Delta UT = UT1 - UTC$. On the other hand, the ephemerides for the orbital motion of the Moon and the Earth are expressed in the heliocentric dynamical time (ET), as the independent variable of the gravitational theories; for this transformation, it is necessary to pass through the intermediate time scale of International Atomic Time (TAI) such that :

$$ET = UTC + (TAI - UTC) + (ET - TAI)$$

where : (TAI-UTC) is an integer number of seconds defined by international convention, and approximately,

$$(ET - TAI) = 32.18 \cdot 10^6 + 1658 (\sin E + 0.04) + 2.03 \cos \varphi [\sin (UT1 + \lambda) - \sin \lambda] + \dots$$

in microseconds, where :

E is the eccentric anomaly of the Earth clock,
 λ, φ are longitude and latitude of the clock.

For the description of the geocentric motion of the telescope at observation station, we define the reference frame as the body-fixed system based on the "true instantaneous rotation axis" and the "true equator of date", in the classical manner. The nominal coordinates of the telescope are expressed in this frame by rotations of the polar coordinates, as given in the BIH Circular D; likewise the true sidereal time is computed by application of the published values of UT1-UTC.

In addition, the Earth crust undergoes deformations due to the terrestrial tides. An optimization from the Cartright' series was constructed for this purpose. Until now, the oceanic tidal effects have not been included.

As for the orbital ephemerides, the reference frame is generally a fixed coordinate system, as for example the system represented by the mean Earth equator and equinox of 1950.0, which is used for the ephemeris so-called ECT18 (1980), constructed in CERGA, with a collaboration of the University of Texas. This new ephemeris of the solar system, by numerical integration, is based on Lunar Laser ranging data particularly. Essentially, this model includes all the relativistic acceleration terms (neglecting the fourth power of c) of each body, in the Brans-Dicke theory. The figures of the Earth and Moon are included as well as the effect of the tidal friction in the Earth. All the computations are performed in an heliocentric frame because each of the various bodies, in its heliocentric orbits, are submitted to different accelerations with respect to an inertial frame, even in the case of two near bodies like the Earth and Moon.

These heliocentric coordinates of the Earth and Moon so deduced are converted to be referred to the true equatorial system, as the geocentric position of telescope does, by application of precession, nutation and obliquity theories.

The quick-look results, obtained during the MERIT campaign, have been based on this ephemeris.

On the other hand, it is necessary to know also the selenocentric coordinates of the reflector in this same reference frame. For that, given the body-fixed mean (nominal) coordinates of the reflector and the time when the laser photon encounters it, the transformation to the mean ecliptic system of date is performed by application of a libration theory and adequate values for the physical lunar parameters. In the CERGA model, so-called EROC78, the used theory is this one due to Migus, by analytical process, for the second and third order librations. The effects due to the planetary terms are computed independently. In addition, the "free librations" are also included. The transformations to the true equatorial frame system are provided by the classical rotations.

Because of the fact that the reflector moves relatively to the station during the one-trip (and inversely during the return), it is necessary to proceed to iterations for the determination of the photon round-trip time delay.

Furthermore, we need also to take account for the Earth atmosphere, because the photons travel slower than in vacuum, so that it is necessary to apply a refraction modelling.

PARTIAL DERIVATIVES

In the course of the computation program for the observational residuals, the partial derivatives relative to the relevant parameters of motions are evaluated simultaneously. In all the cases, where it is possible, these derivatives are computed by analytical process, without hypothesis on the terms to be negligible. On other cases, for example for the initial conditions of the orbital motion, they are estimated by finite differences method.

QUICK-LOOK SOLUTIONS

The quick-look solutions for the Earth rotation determinations were computed from the basic general equation for each observation :

$$\begin{aligned} \text{residual} = & f r \cos \phi \cos \delta \sin H \delta[(UT1-UTC)^{d'} - \lambda - \alpha] \\ & + f r \cos \phi \cos H \delta A \\ & + f r \sin \phi \delta B \\ & + f r [\cos \phi \cos H \sin \delta - \sin \phi \cos \delta] \delta C \\ & + f r \delta D \end{aligned}$$

where the residual is the difference (observed - computed) value of the two-way time delay $\mathcal{D}$, and

- f : $2\Delta / \mathcal{D}$
- Δ, α, δ : geocentric distance, right-ascension and declination of the reflector, referred to the true equatorial system of date;
- r, λ, ϕ : geocentric radius, longitude and latitude of the station, referred to the instantaneous equatorial frame;
- $\delta A, \delta B, \delta C, \delta D$ representing combinations of the corrections to apply to the estimated values of parameters r, ϕ, Δ, δ .

The four unknowns $\delta A, \delta B, \delta C, \delta D$ are solved simultaneously with the Earth rotation to take account for uncertainties on the various motions, such as the orbital motion, lunar librations and so on.

3.4.2. JPL Report : LLR Earth rotation results, coordinate systems and their unification.

Earth Rotation from the JPL LLR Analysis

The rotational orientation (Universal Time and the variation of latitude at McDonald Observatory, Texas) of the earth is determined from McDonald Observatory lunar laser ranging (LLR) data. The current range data set contains 3 326 "normal" points (acquired between August 1969 and May 1982), which were constructed by the University of Texas from the individual photon returns from the Apollo 11, 14 and 15 and Lunakhod 2 retroreflectors.

The ability to accurately model the lunar orbit over the full span of the observations allows long-term studies of the variation in the earth's rotation. The JPL earth rotation results are consistent with the 1976 IAU definitions and constants. The new IAU expressions have been used for precession (Lieske et al., 1977; Lieske, 1979), nutation (Seidelmann, 1982), and Greenwich mean sidereal time (Aoki et al., 1982). In the transformation to dynamical time from IAT we use a constant offset of 32.184 sec and three periodic terms: 1.658 ms annual, 1.745 microseconds (for McDonald) daily and 1.67 microseconds monthly. The nominal planetary and lunar ephemeris, DE119/LE63, used in the reduction results from an integration based on joint fits to the lunar and planetary data. The ephemeris used an equator and equinox of B1950.0. Being on a dynamical equinox this new ephemeris has a zero point consistent with the FK5 system, since the FK5 is attempting to adjust its zero point to the dynamical equinox. See Standish (1983) for the orientation differences between different JPL ephemerides. Errors in the

ephemeris presently impose drift errors of no more than 0.1 ms/yr on UT1 and periodic errors due to the orientation of the lunar orbit plane with respect to the equator (Williams, 1982) are expected to be less than 0.15 ms. The numerically integrated lunar physical librations that were used are designated LLB12. Utilizing the new IAU expressions, the dynamical equinox, and the weighted adjustment of the mean of the LLR values of UT1 to the BIH values gives the geocentric cylindrical coordinates of the intersection of axes of the McDonald Observatory 2.7m telescope.

$$\begin{aligned}R_S &= 5\,492\,414.37 \pm 0.11 \text{ m} \\ \lambda_{\text{EAST}} &= 255.9780017 \pm 0.00000040 (\pm 0.04 \text{ m}) \\ Z &= 3\,235\,697.46 \pm 0.19 \text{ m}.\end{aligned}$$

The approach used here is to derive the Universal Time, UT1, from lunar laser data using an iterative procedure. The first stage begins with the BIH 5 day smoothed values of UT1 and polar motion on the 1979 system. Eighty-seven earth-moon parameters (including variation of latitude corrections) are solved for simultaneously by a weighted least squares fit. For the second stage, UTO corrections are obtained from the range residuals on 800 individual days. The final step involves taking the improved UT1 and performing a new least squares solution. This final solution has a weighted rms residual of 18.7 cm for the entire thirteen year data span. This is a 15% reduction from that reported previously (Dickey et al., 1982a). We find the range residual drops 10 cm when UT1 from LLR was used as compared with those solutions done with the BIH circular D value.

The daily decomposition method (Stolz et al., 1976; Harris and Williams, 1977; Shelus et al., 1977; Langley et al., 1981; Fliegel et al., 1982) relies on the fact that an error in the initial value of UT1 produces a nearly daily (25 hour) signature in the range residuals, which is clearly separable from the effects of lunar motion. In analyzing the post fit residuals, we decompose the residuals r_{ij} (the i th residual on the j th day) from two or more

observations of a single reflector during one day, separated by at least 0.05 days, to obtain weighted best fit values of the parameters A and B in the following expression:

$$r_{ij} = A_j + B_j \sin H_{ij} \cos \delta_{ij}.$$

Here, B_j is presumed to contain the correction to UTO, H_{ij} is lunar hour angle, and δ_{ij} is lunar declination. A_j reflects three errors: the variation of latitude at McDonald, the effect of systematic ranging error, and model error. The parameter B_j is a function of both the correction to the a priori value of UT1 and the component of polar motion normal to the McDonald meridian (see Fliegel et al., 1982). Although the set B_j are strictly speaking corrections to UTO, we assume here that the values of BIH polar motion plus our corrections are accurate and treat B_j as estimates of corrections to UT1. The values of UT1 and error estimates are calculated in three forms: the raw daily decomposition values, the Gaussian filtered values and the Fourier smoothed values (Dickey and Williams, 1983). Based on the comparisons of Dickey et al. (1982b) the expected error in BIH polar motion will result in average UT1-UTO errors of about 1/4 ms, but the last six years improve to 0.15 ms. Tidal terms with periods of a month or less have been removed using $k/C = 0.94$ (see Yoder et al., 1981).

The corrections to the BIH polar motion component which lies along the McDonald Observatory meridian is parameterized in terms of forty-one variables (Dickey and Williams, 1983). The observed correction to the variation of latitude $\phi(\text{LLR}) - \phi(\text{BIH})$ at McDonald prior to 1975 is systematically higher than the later data and has seasonal signatures. We have modeled these effects by multiplying a smoothed step function times a constant plus a Fourier series with eleven frequencies. Throughout the entire data span, a series with nine frequencies is considered. The latitude of McDonald and the zero of its variation of latitude are adjusted to the average BIH polar motion values since 1975. The uncertainties for this correction has been calculated. When comparing solutions obtained with and without the forty-one parameter polar motion correction, a 4 cm drop in the rms residual is seen.

Unification of Celestial and Terrestrial Coordinate Systems

Modern Ephemerides (e.g. DE200/LE200), result from simultaneous lunar and planetary integrations based on joint fits of 20 years of planetary radar and spacecraft radio tracking, roughly a century of meridian circle observations, and 13 years of lunar laser ranging (LLR). These ephemerides provide a dynamically consistent reference system that is nearly inertial. Very accurate planetary mass values exist out through Saturn. The drift with respect to an inertial frame is no more than $0.1''/\text{century}$ in ecliptic longitude for the moon about earth (about 3 m/century on the earth's surface) during the past decade. The ecliptic latitudes are considerably more stable. The sidereal mean motion of the earth is known to $+0.03''/\text{century}$ principally from radio tracking of Vikings at Mars. The ephemeris system is the key to placing the various coordinate frames used by artificial earth satellites, lunar laser ranging, planetary radar and radio tracking, and VLBI on a unified celestial coordinate system, which can be related to a unified terrestrial coordinate system. For rotation into a terrestrial frame, the obliquity of the ecliptic and the location of the equinox are required. This information comes most strongly from the LLR data and is accurate to better than $0.010''$ and $0.025''$ respectively.

The dynamical equinox can be established as the fundamental zero point of the right ascension system. In DE200/LE200, the zero point of the inertial right ascension system has been aligned with the dynamical equinox at the few milliarcsecond level, an order of magnitude better than star catalogs. This

is consistent with the FK5 equinox which also attempts to align to the dynamical equinox. The radio source catalog established by VLBI can be placed on this system via the technique of Δ VLBI applied to gravitationally anchored planetary spacecraft and nearby quasars. Alignment of the artificial satellite and the unified frames would be achieved if the artificial satellite analyses are done with an accurate source of UT1 from an inertial technique (LLR or VLBI) and if colocation is obtained with LLR stations or VLBI baselines.

The transformation into terrestrial coordinates also requires accurate knowledge of the precession and nutation of the earth. Any error in the adopted precession constant will cause systematic errors in the derived UT1 values which are technique dependent. In particular, there would be drifts between UT1 derived from LLR or VLBI observations and that derived from classical astrometric observations. It is recommended that Greenwich mean sidereal time be defined as invariant with respect to a fixed equinox. This would eliminate the discontinuities in both the VLBI and the LLR derived terrestrial longitude system and UT1 rate that would accompany changes in the precession constant. Significant measurement of the principal term of the nutation (± 0.006) has already been reported. Rapid improvement in both parameters can be expected within the next few years as the linear and the 18.6 yr signatures separate.

3.5 Satellite Laser Ranging

3.5.1 The CSR Coordinate Systems

Conventional Inertial System

The CIS adopted by the Center for Space Research is the mean equator and equinox of 2000.0. This coordinate system is realized through the specified algorithms which relate the CIS and the CTS as well as the planetary ephemerides, all of which are consistent with the MERIT Standards. This realization is achieved without adjustment of parameters associated with the DE-200 ephemerides or the IAU precession/nutation algorithms.

Conventional Terrestrial System

The origin of the CTS coincides with the origin of the CIS. Through the adoption of the MERIT Standard gravity field, GEM-L2, in which the terms (1,0) and (1,1) are zero, a necessary condition that the CTS origin coincides with the center of mass of the earth has been imposed.

The z-axis of the CTS is defined by the adopted polar motion series which was computed at MIT using a combination of techniques (King, private communication, 1983). This series has been adjusted in the CSR application so that the mean pole position is coincident with the mean BIH pole position. The x and y axes lie in the terrestrial equatorial plane, normal to the z-axis, so that a right-handed system is formed. Although the x-axis is directed toward the Greenwich meridian, the precise definition is dependent on the adopted UT1 series.

The UT1 series used during the development of the tracking station coordinates was computed at MIT using a combination of different techniques including LLR, VLBI, and Lageos (King, private communication, 1983). Corrections for tidal variations have been applied for periods of less than 40 days in a manner that is consistent with the MERIT Standards.

Tracking Station Coordinates

The tracking station coordinates obtained using the foregoing definitions of the CIS and the CTS are based on analysis of seven years of Lageos laser range data. This solution, SSC (CSR) 83 L1, was obtained using the MERIT Standards with the following exceptions: 1.) the ocean loading has not been included in the earth-tide model for station coordinates and 2.) a value of the degree three

zonal harmonic derived from long-arc analyses was used instead of the GEM-L2 value. As specified by the MERIT Standards, the $C(2,1)$ and $S(2,1)$ were also modified from the GEM-L2 values. Furthermore, it was assumed that the CTS of GEM-L2 coincided with the CTS used by the CSR as described in the previous section. Consequently, the z-axis of the gravity field is not generally coincident with the angular velocity vector of the earth.

To provide a reference meridian in the tracking station solution, the survey location of the SLR system at McDonald Observatory with respect to the LLR system has been used. This application imposes the same reference meridian as used for LLR analysis.

3.6 Doppler Tracking of Satellites

3.6.1 The NWL 9Z-2 Coordinate System

Development of Terrestrial System :

Doppler observations of Navy Navigation Satellites are used to compute orbits, pole positions and UT-1 in a coordinate system identified as NWL 9Z-2 (or NSWC 9Z-2). The system defined by the adopted coordinates of about 20 observing stations which were originally determined in a general geodetic solution for station positions, gravity coefficients and various bias parameters (Seppelin, 1974) and subsequently refined in two types of adjustments. The first adjustment was an attempt to bring the system into agreement with the CIO pole (Beuglass and Anderle, 1972), while the second type of adjustment consists of iterations between orbit solution and station coordinate solution to remove inconsistencies in relative station coordinates (e.g. Anderle, 1975). Pole position is a parameter of each two-day orbit fit.

Relationship of Terrestrial System to Others:

The original solution should have placed the origin at the center of mass of the earth and the X-axis in alignment with the BIH conventional longitude origin. However, external tests make it appear that the origin is displaced a few meters toward the north pole, probably due to model errors, and the X-axis to be rotated 0"8 from BIH origin due to misinterpretation of observatory correction in the original solution. The scale of the system was based on an earth's gravitational constant (with atmosphere) of $398601 \text{ km}^3/\text{sec}^2$ and was established inadvertently neglecting distance between antenna and center of mass of satellite. To correct for the antenna offset and to a GM of $398600.5 \text{ km}^3/\text{sec}^2$, the NWL9Z scale should be reduced by 0.4 ppm.

After this correction, Hothern (1979) reports agreement of scale with external standards of 0.1 ppm and no significant offset in the orientation of the Z axis. However, he reported that 0.8 arcseconds should be added to the longitudes. Grappo (1980) found no measurable origin error in the x, y plane by comparison between Doppler and gravimetric geoid heights, but found 4 m should be added to the Z coordinates, in reasonable agreement with Hothern's (1979) comparison with Lageos laser data.

Relationship with Inertial System:

Ephemerides are usually computed in a reference frame of the mean equator and equinox of 1950, using the precession, nutation series given the explanatory supplement of the American Ephemeris and Nautical Almanac. Values of UT-1 are based on predictions made from BIH Circular D data. Discrepancies in predicted longitudes of the node on successive orbit fits are used to determine the rate of earth's rotation; since secular and long period errors are expected due to neglect of ocean tides and determination of origin is impossible, a five parameter fit is made to BIH and Doppler results each year for origin, annual and semiannual terms and results are referenced to the BIH five parameter function (Anderle, 1980).

Other Constants:

The JPL lunar/solar ephemeris DE 96 is used with earth/moon and earth/sun ratios of 4.902796644×10^3 and $1.327125468 \times 10^{00}$, respectively. (It is entered with UTC.) Nonzero values of S_{21} , C_{21} are used which are not physically meaningful, but in aggregate with other even degree first order terms give a good representation of the effects of the earth's gravity field on the motion of the satellite. Contrary to practice at some other agencies, the earth's potential is expanded about the earth's spin axis, not the C10 pole.

Solar radiation is based on an average constant determined as a parameter in several 8 or 16-day fits (Anderle, 1971), with a cylindrical representation of the earth's shadow. An atmospheric drag scaling factor for each day is a parameter of each orbit fit. It scales a time invariant density function where log density is hyperbolic, without horizontal gradients (O'Toole, 1976), with the following constants:

$$A = .013620$$

$$B = -8.3355$$

$$C = .0001018$$

$$D = 1.083$$

$$E = 89.39$$

Solid earth tides on the potential are based on a Love number of 0.26 with zero lag. Earth tides on stations and ocean and atmospheric tides are neglected.

4. CONNECTION OF REFERENCE FRAMES

4.1 Colocated measurements (LLR, SLR, VLBI)

The necessity to perform co-located observations is implied in the title selected for the overall activities (Monitoring of Earth Rotation and the INTERCOMPARISON OF TECHNIQUES) and was urged expressly in the summary report of the chairman of MERIT on behalf of the Joint Working Group on the Determination of the Rotation of the Earth to Commissions 19 and 31 of the IAU in 1979 (G.A. Wilkins, February 1979). Since that time the simulations performed for the COTES proposal recommend specific co-locations as a foundation for various observing scenarios (COTES-proposal, Mueller et al 1982 pp. 26-28).

As a result of discussions held to date, the following co-locations are planned for the MERIT period, with those areas still in doubt shown in brackets :

Crimea	LLR	SLR	
Fort Davis/McDonald Observatory	LLR	SLR	VLBI
Grasse	LLR	SLR	
Greenbelt/Maryland Point		SLR	VLBI
Haleakala	LLR	SLR	
Madrid		SLR*	(VLBI)
Mojave		SLR*	VLBI
Monument Peak		SLR	VLBI*
Onsala		SLR*	VLBI
Orroral/Tidbinbilla	LLR	SLR	(VLBI)
Plateville		SLR	VLBI*
Quincy		SLR	VLBI*
Wettzell		SLR	VLBI

* transportable systems to be used for temporary co-colocation : SLR's are expected to observe six to eight weeks, and the VLBI's one to two days.

The problem of acquiring VLBI observations at Madrid are associated with providing an adequate feed-horn for the Deep Space Network antennae which will permit wide band S/X observations for the MK III system. Alternative solutions are under discussion but no final decision has been reached. It is not likely that these observations can take place before the last month of the campaign, but as there is no essential need to perform the laser ranging simultaneously this does not impact on the co-location plans.

Due to the distances involved between the observing sites at Greenbelt and Maryland Point a connection is being observed with the GPS system. A similar request is being made for connecting the LLR/SLR site at Orroal with the radio telescope at Tidbinbilla. There is a line of sight connection from McDonald Observatory to the radio telescope at Fort Davis.

4.2 Other colocations at MERIT sites

The use of portable Doppler receivers for point positioning at MERIT sites, in addition to fixed Doppler networks (TRANET, MEDOC), is considered as an important issue.

Doppler stations which will participate to MERIT can be divided into :

- a) permanent stations of the MEDOC network, including some TRANET stations, 4 French stations and other cooperative stations. These stations have to fulfil specifications available from the MEDOC group.
- b) global Doppler campaign during the 3 months of the MERIT intensive campaign (April-June 1984), in colocation with 2nd and 3rd generation lasers (SLR and LLR), and VLBI radiotelescopes. Specifications will be distributed by the colocated Doppler Operational Center (CDOC).
- c) other Doppler campaigns partially colocated with MERIT sites (laser, VLBI, CERI, Doppler or astrometry), providing simultaneous observations, either before (e.g. EDOC-2, ERIDOC, WEDOC-1...), or during (e.g. WEDOC-2) the MERIT campaign (Sept. 83 - Oct. 84).
- d) Doppler observations at MERIT sites, providing long series of data (over one year).
- e) other Doppler data at MERIT sites.

The data flow is the following one :

- data from (a) are collected by the GRGS/Toulouse Operation Center during the MERIT campaign, processed regularly, archived and redistributed to the analysis centers for global dynamical solutions.

Two Designated Analysis Centers (DAC) have been up to now identified :

- DMA
- GRGS Toulouse

Other DAC or Associate Analysis Centres (AAC) can be appointed later on by the coordinator for Doppler.

- data from (b) are collected by the CDOC (IGN, F), archived and redistributed to AC which will process these data either by dynamical or semi-dynamical mode. Among preliminary candidates as DAC or AAC, one can mention :
 - DMA or NSW
 - GRGS/Toulouse
 - Observatoire Royal de Belgique
 - IGN, F
 - University of Nottingham
- data from (c), (d) and (e) can be collected and archived by the CDOC. But specific AC have to be appointed. Only results have necessarily to be sent to the MERIT Coordination Center at BIH.

It is understood that any data set released to an OC will be freely available to any MERIT participant.

Finally, one must comment about the usefulness of Doppler colocation with pure astrometric sites.

Although the output information has not the same interest as for geometric positions (SLR, LLR, VLBI) the use of these data in conjunction with a homogeneous data set of absolute deflections of vertical could provide a reasonably significant value for transformation between the astrometric system and the Doppler system.

4.3 Colocation sites : Geodetic Survey requirements

Introduction

The primary purpose of "colocation" experiments is to collect a common set of measurements that can be "intercompared" to determine the systematic differences, in scale and orientation, among the various observational techniques. While conceptually simple, in practice the colocation of two or more instrumental systems is not, in the strictest sense, even possible. The physical bodies of the instruments do not permit the "reference points" of the instruments to be made coincident in space and time. It thus becomes necessary to measure the coordinates of the reference points in some well defined reference frame and reduce all of the measurements to a common point. Obtaining unambiguous, blunder-free, high accuracy measurements between the reference points and the reference marks has proven to be a difficult task, and the lack of such information has plagued the intercomparison studies.

In order to achieve the highest possible uniformity in the computations, documentation, and dissemination of the critical survey information, all surveys should be processed and adjusted through a common computer program. The program selected for this purpose is HAVAGO, developed at the National Geodetic Survey and currently operational at several locations, including NGS, Bonn University, and GRGS. The sponsoring organization of each facility which will participate in the MERIT campaign should arrange to have a proper geodetic survey of the facility, and submit the observational data in proper format to the Coordinating Center for processing through HAVAGO. Guidelines concerning the surveys, formats, and submittal schedules and procedures are presented below.

Guidelines for Surveys

A local geodetic survey must be performed at each colocation site. The complexity of a particular survey depends on the acceptable uncertainties and the separations between the instruments. Some colocation sites, such as the Wettzell Observatory, may have several instruments within tens of meters of one another, while others, such as the McDonald-HRAS complex, may extend over distances of several kilometers.

It is not the purpose of this document to design detailed survey schemes for each colocation site, but rather to provide goals, guidelines, and suggested procedures to assist in planning and making the surveys which will make the results as consistent (with regards to documentation, reference frame, accuracies) as possible.

The precise "reference point" of each instrument must be identified (e.g., the intersection of the azimuth axis with the plane containing the elevation axis of the Westford Radiotelescope) in writing and on a simple sketch, see Carter et al (79). A "primary reference mark" must be designated at each site. The location of the primary reference mark should be selected to provide the best possible accuracy of the geodetic ties to the reference points, ease of access, stability, and permanence of the mark.

The survey should be designed to achieve the most accurate determination of all three components, Δx , Δy , Δz , of the offsets of each reference point to the primary reference mark. For sites of limited extent, the goal should be to determine Δx , Δy , Δz to better than ± 5 mm. At more extended sites, a well designed and executed survey should be able to achieve ± 0.5 to ± 1.0 cm per kilometer, depending on the terrain, climate, and resources available. See for example Carter et al (79). The x , y , z values should be obtained in a coordinate system defined by the FK-4 Fundamental Star Catalog, and referred to the pole and origin of longitude using polar coordinates, and time information published by the Bureau International de l'Heure.

The final output of the survey should be the 3-dimensional, Δx , Δy , Δz , differences in locations between the "primary" mark and the instrumental reference points.

The individual observations which determine astrometric latitude, longitude, azimuth, zenith distances, lengths, etc., should be edited to eliminate outliers, and the means and standard errors computed. We caution that no corrections should be made to reduce any of the measurements to the ellipsoid - the actual observed values at each survey station are the required data.

Submittal of Survey Data

The data should be punched on standard 80 column data cards in the HAVAGO formats, as detailed in Appendix 2. The data deck, along with the supporting sketches and descriptive information should be submitted to the MERIT Coordinating Centre, attention : Martine FEISSEL, BIH, 61 Av. de l'Observatoire, F75014 Paris, preferably prior to December 1, 1983.

4.4. Intensive period of observations

A request made in the COTES proposal foresees a 3-month period of intensive observations with the objectives of detecting short period variations of the derived pole positions and short term variations of the rotation rate. Whereas the latter may be primarily associated with forces acting on the earth (e.g. changes in the mass distribution of the earth and atmosphere) the former may help to point out any misorientation of the CIS's or errors in the models adopted for precession and nutation.

The intensive observation campaign has been scheduled for all systems for the period April 1 - June 30, 1984. For those systems unable to operate intensively for the full 3-month period the month of May has been selected for the concentrated effort. For this time it will be desirable to provide 3 tracks/day/site for SLR and 4-5 hours of lunar/tracking/day. The VLBI network plans to operate daily during this period.

Finally, special attention should be given to maintaining week-end coverage throughout the period of the intensive campaign.

4.5. Data collection and treatment

At the end of the campaign, the data reduction for the connection of the terrestrial systems defined by the different networks participating in the MERIT Campaign will be performed in two steps.

In the first step, the coordinates of all the stations in a network are adjusted by the Computing Centres which compute the ERP from observations with a given technique. These centres will transmit to the Coordinating Centre the list of station coordinates, together with all relevant information on their derivation.

The second step is performed at the Coordinating Centre, where the relationships between the different terrestrial systems defined for the different networks and techniques are evaluated, and where coordinates referred to a unique terrestrial system are determined for all the stations present in the individual network adjustments. The data requested by the Coordinating Centre are as follows.

- 1 - Stations description : for all stations included in the adjustment(s), the information necessary to update the Directory of MERIT Stations, (DOMES) described in Appendix 4, according to the recommendations of section 4.3.
- 2 - For each separate global network adjustment :
 - . name of the Set of Station Coordinates (SSC) according to the naming rules of Appendix 3, and dates of the period of adjustment,
 - . name of the relevant series of ERP, according to the naming rules of Appendix 3,
 - . list of stations with derived coordinates (see Appendix 4).

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APPENDICES

1. Radio source positions.....	A 1
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Appendix 1 : RADIO SOURCES POSITIONS

The extragalactic radio sources used for geodetic VLBI observations generally have finite angular size, with complex, time varying, and wavelength dependent brightness distributions. The "effective coordinates" of the sources are therefore dependent, at the milliarcsecond level, on the configuration of the VLBI observing network, the observing frequencies, the temporal distribution of the observations, and other factors. Since the comprehensive catalogues and source structure maps which would allow the effective coordinates of the sources to be computed at the precise epoch of each observation are not available, and since the observation errors are not far below the milliarcsecond level, the practice is to include the source coordinates in the parameters to be estimated in the least squares solution performed to obtain the geodetic parameters. The resulting source position catalogues are not universally applicable and therefore it would not, at the present state-of-the-art, be useful to adopt a standard VLBI source catalogue. However, researchers may find it useful (for use as a priori values and for intercomparisons) to have the current best fitting source coordinates from ongoing observing programs.

Table 1 lists source positions derived at the National Geodetic Survey from observations collected during the MERIT short campaign and under project POLARIS, from September 9, 1980, through December 21, 1982. The nominal observing wavelength was 3.8 cm, although observations were made at 13 cm for ionosphere corrections only. The reference source, 3 C 273 B, has been used to fix the zero point of the right ascension of this catalog. The adopted right ascension of 3 C 273 B is $12^{\text{h}}29^{\text{m}}6^{\text{s}}.6997$. For more detailed information, see Robertson and Carter (1982a, 1982b).

Table 2 lists the JPL 1983-2 catalog which includes 104 extragalactic radio sources and is based on a single multiparameter fit to approximately 2400 VLBI observations extending from August 1971 to February 1980. To match the definition currently used by other VLBI groups, the value $12^{\text{h}}29^{\text{m}}06^{\text{s}}.6997$ was also adopted in this work for the right ascension of the reference source, 3C 273 B. This approach is a temporary convenience until alignment with the celestial reference frame defined by the DE200/LE200 ephemeris system is completed. For alignment of the axes of the earth-fixed frame with the CIO frame, a preliminary fit minimizes, over the span of the observations, the rms deviation of interferometrically measured UT1 and polar motion from BIH published values. In subsequent fits, the UT/PM solve-for values obtained in this fit for two strong sessions (reference days: 1979/12/20-21) are assigned as exactly known quantities. With this approach, subsequent UT/PM values and the axes of the earth-fixed frame are aligned on average with the conventional definitions in the best way provided by the data in hand. To prevent a singularity in the fit, the DSS-14 station coordinates (Goldstone, California) were held fixed at the values derived from spacecraft tracking (JPL station locations set LS111A). Thirteen of the sources solved for in the multiparameter fit are not included in this short version of the JPL 1983-2 catalog, either because the measurements were made solely on short baselines, or were judged to have inadequate redundancy. For further details see TDA Progress Report 42-73, to be dated May 15, 1983; "Radio Interferometric Determination of Source Positions, Intercontinental Baselines, and Earth Orientation With Deep Space Network Antennas - 1971 to 1980," by J. B. Thomas, O. J. Sovers, J. L. Fanelow, E. J. Cohen, G. H. Purcell, Jr., D. H. Rogstad, L. J. Skjerve, D. J. Spitzmasser.

Appendix 1 : TABLE 1 - NGS RADIO SOURCE CATALOG

Source	Rt. Asc.			(Formal) Sigma	Declination			(Formal) Sigma
	h	m	s	s	d	m	s	s
0106+013	1	8	38.7710	0.00002	1	35	0.325	0.0009
0212+735	2	17	30.8134	0.00005	73	49	32.623	0.0002
0224+671	2	28	50.0517	0.00004	67	21	3.031	0.0002
0234+285	2	37	52.4057	0.00002	28	48	8.992	0.0003
0235+164	2	38	38.9300	0.00002	16	36	59.280	0.0006
0355+508	3	59	29.7473	0.00002	50	57	50.163	0.0001
0552+398	5	55	30.8057	0.00002	39	48	49.166	0.0002
0742+103	7	45	33.0596	0.00009	10	11	12.687	0.0026
0851+202	8	54	48.8749	0.00002	20	6	30.640	0.0004
0923+392	9	27	3.0138	0.00002	39	2	20.851	0.0002
1226+023	12	29	6.6997	---	2	3	8.597	0.0009
1404+286	14	7	0.3942	0.00002	28	27	14.689	0.0003
1637+574	16	38	13.4561	0.00003	57	20	23.981	0.0002
1642+690	16	42	7.8481	0.00003	68	56	39.757	0.0002
1641+399	16	42	58.8098	0.00002	39	48	36.996	0.0002
1928+738	19	27	48.4945	0.00014	73	58	1.573	0.0009
2134+004	21	36	38.5861	0.00002	0	41	54.222	0.0010
2200+420	22	2	43.2912	0.00002	42	16	39.984	0.0002
2251+158	22	53	57.7478	0.00002	16	8	53.566	0.0005

Appendix 1 : TABLE 2 - JPL 1983-2 RADIO SOURCE CATALOGUE (J2000.0)

IAU name	Common name	Average obs. epoch	Right ascension				Declination			
			h	m	s	Error (σ)	d	m	s	Error (σ)
0008-264	P 0008-264	1980.05	0	11	1.24747	0.00039	-26	12	33.3891	0.0053
0104-408	P 0104-408	1979.43	1	6	45.10824	0.00023	-40	34	19.9640	0.0035
0106+013	P 0106+01	1978.39	1	8	38.77105	0.00011	1	35	0.3174	0.0026
0111+021	P 0111+021	1980.04	1	13	43.14505	0.00168	2	22	17.3155	0.0254
0113-118	P 0113-118	1978.85	1	16	12.52214	0.00067	-11	36	15.4375	0.0103
0133+476	DA 55	1979.14	1	36	58.59495	0.00018	47	51	29.1053	0.0013
0202+149	P 0202+14	1980.02	2	4	50.41405	0.00012	15	14	11.0461	0.0024
0224+671	DW 0224+67	1977.48	2	28	50.05199	0.00032	67	21	3.0339	0.0019
0234+285	CTD 20	1980.02	2	37	52.40585	0.00014	28	48	8.9942	0.0021
0235+164	GC 0235+16	1980.04	2	38	38.93026	0.00012	16	36	59.2767	0.0023
0300+470	DE 400	1978.39	3	3	35.24246	0.00024	47	16	16.2831	0.0019
0316+413	3C 84	1978.72	3	19	48.16043	0.00019	41	30	42.1074	0.0019
0332-403	P 0332-403	1977.84	3	34	13.65384	0.00037	-40	8	25.3969	0.0044
0333+321	NRAO 140	1977.61	3	36	30.10794	0.00016	32	18	29.3448	0.0017
0336-019	CTA 26	1979.52	3	39	30.93773	0.00013	-1	46	35.8004	0.0029
0355+508	NRAO 150	1978.60	3	59	29.74801	0.00026	50	57	50.1688	0.0022
0402-362	P 0402-362	1978.07	4	3	53.74941	0.00044	-36	5	1.9132	0.0054
0406+121	GC 0406+12	1980.03	4	9	22.00860	0.00014	12	17	39.8426	0.0055
0420-014	P 0420-01	1977.97	4	23	15.80052	0.00020	-1	20	33.0642	0.0037
0420+417	VRO 41.04.01	1979.72	4	23	56.01004	0.00026	41	50	2.7185	0.0033
0430+052	3C 120	1977.28	4	33	11.09592	0.00025	5	21	15.6142	0.0040
0434-188	P 0434-188	1980.02	4	37	1.48289	0.00057	-18	44	48.6198	0.0086
0438-436	P 0438-43	1977.87	4	40	17.17941	0.00033	-43	33	8.6054	0.0040
0440-003	NRAO 190	1976.36	4	42	38.66089	0.00051	-0	17	43.4243	0.0080
0451-282	P 0451-28	1980.02	4	53	14.64585	0.00048	-28	7	37.3195	0.0062
0528+134	P 0528+134	1980.03	5	30	56.41692	0.00012	13	31	55.1501	0.0022
0537-441	P 0537-441	1978.46	5	38	50.36073	0.00028	-44	5	8.9386	0.0037
0552+398	DA 193	1977.55	5	55	30.80616	0.00022	39	48	49.1667	0.0019
0605-085	P 0605-08	1978.96	6	7	59.69940	0.00070	-8	34	49.9881	0.0100
0607-157	P 0607-15	1978.52	6	9	40.94952	0.00025	-15	42	40.6778	0.0044
0723-008	DW 0723-00	1979.99	7	25	50.63977	0.00020	-0	54	56.5434	0.0038
0727-115	P 0727-11	1977.93	7	30	19.11287	0.00024	-11	41	12.6140	0.0043
0735+178	P 0735+17	1977.85	7	38	7.39401	0.00022	17	42	18.9934	0.0036
0738+313	OI 363	1977.01	7	41	10.70377	0.00043	31	12	0.2264	0.0054
0742+103	DW 0742+10	1978.21	7	45	33.05953	0.00013	10	11	12.6897	0.0023
0748+126	P 0748+126	1980.00	7	50	52.04562	0.00017	12	31	4.8263	0.0031
0814+425	OJ 425	1977.83	8	18	16.00000	0.00023	42	22	45.4144	0.0018
0823+033	P 0823+033	1980.01	8	25	50.33852	0.00018	3	9	24.5130	0.0033
0827+243	B2 0827+24	1979.76	8	30	52.08663	0.00034	24	10	59.8105	0.0044
0836+710	4C 71.07	1979.64	8	41	24.36807	0.00043	70	53	42.1772	0.0020
0851+202	OJ 287	1978.04	8	54	48.87506	0.00013	20	6	30.6363	0.0018
0859-140	P 0859-14	1977.80	9	2	16.83076	0.00081	-14	15	30.8847	0.0123
0859+470	OJ 499	1977.92	9	3	3.99136	0.00076	46	51	4.1266	0.0051
0923+392	4C 39.25	1978.52	9	27	3.01394	0.00013	39	2	20.8497	0.0012
0952+179	AO 0952+17	1979.98	9	54	56.82357	0.00078	17	43	31.2228	0.0126
1004+141	GC 1004+14	1980.01	10	7	41.49848	0.00047	13	56	29.5911	0.0063
1034-293	P 1034-293	1980.00	10	37	16.07921	0.00030	-29	34	2.8183	0.0042
1038+064	OL 064.5	1980.01	10	41	17.16237	0.00020	6	10	16.9218	0.0382
1040+123	3C 245	1980.03	10	42	44.60596	0.00036	12	3	31.2536	0.0049
1055+018	P 1055+01	1979.73	10	58	29.60516	0.00011	1	33	58.8174	0.0025
1104-445	P 1104-445	1977.74	11	7	8.69332	0.00047	-44	49	7.6227	0.0047
1111+149	GC 1111+14	1980.03	11	13	58.69532	0.00048	14	42	26.9449	0.0061

Appendix 1 : TABLE 2 (continued)

IAU name	Common name	Average obs. epoch	Right ascension				Declination			
			h	m	s	Error (σ)	d	m	s	Error (σ)
1123+264	P 1123+26	1980.02	11	25	53.71196	0.00019	26	10	19.9738	0.0023
1127-145	P 1127-14	1978.70	11	30	7.05233	0.00016	-14	49	27.3941	0.0033
1144-379	P 1144-379	1978.73	11	47	1.37021	0.00022	-38	12	11.0305	0.0034
1148-001	P 1148-00	1978.09	11	50	43.87056	0.00040	-0	23	54.2102	0.0064
1222+037	P 1222+037	1980.03	12	24	52.42221	0.00021	3	30	50.2808	0.0038
1226+023	3C 273	1978.62	12	29	6.69970	...	2	3	8.5914	0.0025
1228+126	3C 274	1980.04	12	30	49.42342	0.00031	12	23	28.0376	0.0043
1244-255	P 1244-255	1980.02	12	46	46.80184	0.00025	-25	47	49.2957	0.0037
1253-055	3C 279	1978.24	12	56	11.16647	0.00038	-5	47	21.5321	0.0063
1308+326	B2 1308+32	1980.02	13	10	28.66381	0.00013	32	20	43.7788	0.0015
1313-333	OP-322	1978.15	13	16	7.98528	0.00031	-33	38	59.1782	0.0041
1334-127	DW 1335-12	1977.96	13	37	39.78288	0.00028	-12	57	24.7031	0.0043
1342+663	GC 1342+663	1980.12	13	44	8.67956	0.00053	66	6	11.6365	0.0025
1354+195	P 1354+19	1980.02	13	57	4.43660	0.00017	19	19	7.3665	0.0027
1418+546	GC 1418+54	1980.13	14	19	46.59754	0.00019	54	23	14.7823	0.0015
1430-178	OQ-151	1980.05	14	32	57.68946	0.00054	-18	1	35.2438	0.0080
1502+106	OR 103	1979.35	15	4	24.97966	0.00011	10	29	39.1945	0.0023
1510-089	P 1510-08	1978.18	15	12	50.53332	0.00051	-9	5	59.8409	0.0079
1519-273	P 1519-273	1980.03	15	22	37.67552	0.00022	-27	30	10.7889	0.0035
1555+001	DW 1555+00	1976.86	15	57	51.43418	0.00033	-0	1	50.4203	0.0052
1611+343	DA 406	1977.37	16	13	41.06409	0.00025	34	12	47.9082	0.0026
1633+382	GC 1633+38	1980.04	16	35	15.49283	0.00013	38	8	4.4985	0.0013
1638+398	NRAO 512	1979.50	16	40	29.63258	0.00015	39	46	46.0278	0.0014
1641+399	3C 345	1978.28	16	42	58.80983	0.00013	39	48	36.9928	0.0012
1656+053	DW 1656+05	1978.85	16	58	33.44733	0.00061	5	15	16.4383	0.0093
1717+178	GC 1717+17	1980.07	17	19	13.04837	0.00022	17	45	6.4352	0.0037
1730-130	NRAO 530	1979.13	17	33	2.70553	0.00018	-13	4	49.5460	0.0038
1738+476	OT 465	1978.70	17	39	57.12566	0.00078	47	37	58.3768	0.0045
1741-038	P 1741-038	1977.44	17	43	58.85676	0.00027	-3	50	4.6252	0.0046
1749+701	1749+701	1979.45	17	48	32.83875	0.00060	70	5	50.7750	0.0032
1807+698	3C 371	1978.96	18	6	50.67971	0.00026	69	49	28.1088	0.0010
1821+107	P 1821+10	1980.06	18	24	2.85524	0.00013	10	44	23.7698	0.0048
1921-293	OY-236	1978.47	19	24	51.05564	0.00044	-29	14	30.1133	0.0055
1933-400	P 1933-400	1979.86	19	37	16.21675	0.00059	-39	58	1.5528	0.0061
1958-179	OY-198	1979.30	20	0	57.09073	0.00037	-17	48	57.6761	0.0055
2021+614	OW 637	1978.47	20	22	6.68158	0.00095	61	36	58.8193	0.0055
2029+547	OW 551	1980.02	20	31	47.95842	0.00040	54	55	3.1495	0.0037
2030+121	P 2029+121	1980.06	20	31	54.99410	0.00019	12	19	41.3436	0.0034
2113+293	B2 2113+29B	1979.83	21	15	29.41343	0.00015	29	33	38.3663	0.0024
2134+004	P 2134+004	1977.17	21	36	38.58616	0.00017	0	41	54.2150	0.0038
2145+067	P 2145+06	1978.52	21	48	5.45853	0.00011	6	57	38.6057	0.0023
2149+056	OX 082	1980.06	21	51	37.87530	0.00017	5	52	12.9556	0.0034
2155-152	OX-192	1978.66	21	58	6.28154	0.00072	-15	1	9.3263	0.0109
2200+420	VRO 42.22.01	1978.05	22	2	43.29125	0.00016	42	16	39.9839	0.0014
2230+114	CTA 102	1978.45	22	32	36.40897	0.00050	11	43	50.7052	0.0068
2234+282	GC 2234+28	1980.04	22	36	22.47076	0.00013	28	28	57.4168	0.0018
2243-123	OY-172.6	1979.27	22	46	18.23184	0.00014	-12	6	51.2764	0.0033
2245-328	P 2245-328	1979.55	22	48	38.68551	0.00024	-32	35	52.1861	0.0036
2251+158	3C 454.3	1977.56	22	53	57.74779	0.00015	16	8	53.5658	0.0027
2253+417	GC 2253+41	1980.11	22	55	36.70799	0.00019	42	2	52.5370	0.0030
2320-035	P 2320-035	1980.00	23	23	31.95363	0.00021	-3	17	5.0216	0.0044
2345-167	P 2345-16	1977.98	23	48	2.60846	0.00035	-16	31	12.0233	0.0052

1. TITLE CARDS. THESE ARE FOLLOWED BY A CARD WITH AN ASTERISK IN CC 1.

2. OPTION CARDS.

1	2	3	4	5	6	7	8
1234567890123456789012345678901234567890123456789012345678901234567890							
INTERNATIONAL	6378388.	297.	-100.1	200.2	300.3	-.1	.3 .5 2.3

EQUATORIAL RADIUS, RECIPROCAL OF FLATTENING AND TRANSFORMATION PARAMETERS
(3 TRANSLATIONS, METERS; 3 ROTATION ANGLES, SECONDS; & SCALE CORRECTION, PPM).
IF ELLIPSOID PARAMETERS ARE LEFT BLANK, THEY WILL BE SET TO CLARKE 1866 VALUES.

1	2	3	4	5	6	7	8
1234567890123456789012345678901234567890123456789012345678901234567890							
(FLAGS STARTING IN CC 25)							

1 IN CC 25 DENOTES THAT SEVERAL STANDPOINTS ARE PERMITTED IN A GROUP OF
RELATIVE DISTANCES.

A DIGIT IN CC 26 DENOTES THAT AVERAGE SCALE IS TO BE DETERMINED FROM RELATIVE
DISTANCES. 1/10 OF THIS IS A PRIORI STANDARD ERROR IN PPM.

1 IN CC 27 DENOTES THAT ALL ANGLES WILL BE ASSIGNED A COMMON REFRACTION UNKNOWN,
OVERRIDING ALL GROUP NUMBERS ON THE CARDS.

1 IN CC 30 SUPPRESSES COEFFICIENT OF REFRACTION CORRECTIONS TO GROUPED VERTICAL
ANGLES.

A DIGIT IN CC 31 DESIGNATES THE MAXIMUM NUMBER OF ITERATIONS. IF LEFT
BLANK, IT WILL BE SET TO 3.

A DIGIT IN CC 78 REQUESTS REORDERING OF UNKNOWNNS.

A DIGIT IN CC 79 DENOTES THAT ALL ASTRONOMIC COORDINATES WILL BE HELD FIXED
AND THEIR UNKNOWNNS OMITTED.

COLUMN 80 IS USED TO REQUEST INFORMATION ABOUT THE STRUCTURE OF THE MATRIX OF
UNKNOWNNS. 1 WILL GIVE A REORDER MESSAGE WITH NUMBER OF ELEMENTS BEFORE
AND AFTER REORDERING. 2 WILL ALSO LIST THE UNCONNECTED COMPONENTS OF THE
MATRIX. 3 WILL GIVE ALL OF THE ABOVE AND A LISTING OF UNKNOWNNS IN THE
ORIGINAL AND IN THE NEW ORDER.

3. STATION DATA CARDS. 2 CARDS PER STATION.

1	2	3	4	5	6	7	8
1234567890123456789012345678901234567890123456789012345678901234567890							
34-30121212345-175121212345	1234.123.005.004.051	STODDARD PITCHER MOUNTAIN 1871					

1 2 3 4 5 6 7 STATION NAME

1 STATION NUMBER, RIGHT JUSTIFIED.

2 PRELIMINARY GEODETIC LATITUDE.

3 PRELIMINARY GEODETIC LONGITUDE.

4 PRELIMINARY GEODETIC HEIGHT.

5,6,7 GEODETIC LATITUDE, LONGITUDE, AND HEIGHT CONSTRAINTS, IN METERS. IF ANY IS
BLANK AND THE CORRESPONDING COLUMN ON NEXT CARD (42,43,OR 44) CONTAINS 1,
THE STANDARD ERROR WILL BE SET TO 1 MM.

1	2	3	4	5	6	7	8
1234567890123456789012345678901234567890123456789012345678901234567890							
34-30121212	.3-175121212	.4	131.5	111-6378206.123	1234567.123	7654321.123	

1 2 3 4 5 6 7 8 9 ELEVATION

1 STATION NUMBER, RIGHT JUSTIFIED.

2 ASTRONOMIC LATITUDE. IF NOT OBSERVED, NORMALLY BLANK.

3 ASTRONOMIC LATITUDE CONSTRAINT, SECONDS. IF BLANK AND ASTRO LATITUDE
NOT BLANK, THE STANDARD ERROR WILL BE SET TO 0.01 SEC.

4 ASTRONOMIC LONGITUDE. IF NOT OBSERVED, NORMALLY BLANK.

5 ASTRONOMIC LONGITUDE CONSTRAINT, SECONDS. IF BLANK AND ASTRO LONGITUDE
NOT BLANK, THE STANDARD ERROR WILL BE SET TO 0.01 SEC.

6 GEODETIC LATITUDE, LONGITUDE, AND HEIGHT CONSTRAINT CODES. BLANK FOR A
FREE PARAMETER, 1 FOR A CONSTRAINED PARAMETER.

7,8,9 X, Y, Z IN AN EQUATORIAL SYSTEM. USE ONLY IF LATITUDE, LONGITUDE AND
HEIGHT ARE NOT GIVEN.

THE LAST CARD OF THIS SECTION MUST CONTAIN A NEGATIVE DIGIT IN CC 1-4.

4. ERROR OPTION CARD. DEFAULT STANDARD ERROR VALUES WHICH WILL BE USED IF
AN OBSERVATION HAS A BLANK STANDARD ERROR.

DIRECTION: 1-3 MILLIMETERS, 4-6 SECONDS.

AZIMUTH: 7-9 MILLIMETERS, 10-12 SECONDS.

RECIPROCAL VERTICAL ANGLE: 13-15 MILLIMETERS, 16-18 SECONDS.

GROUPED VERTICAL ANGLE: 19-21 MILLIMETERS, 22-24 SECONDS.

ABSOLUTE DISTANCE: 25-27 MILLIMETERS, 28-30 PPM.

RELATIVE DISTANCE: 31-33 MILLIMETERS, 34-36 PPM.

CC 37-41 ARE USED FOR INPUT OF AN ASSUMED VALUE OF COEFFICIENT OF REFRACTION
GRADIENT PER 1000 METERS OF DOWNWARD CHANGE IN ELEVATION, FOR USE WITH
GROUPED VERTICAL ANGLES. IF LEFT BLANK, THIS WILL BE SET TO 0.01.

***** NOTE *****

* IN CC 80 DENOTES AN OBSERVATION THAT IS TO BE REJECTED.

IN CC 80 DENOTES AN OBSERVATION THAT IS TO BE DEWEIGHTED.

5. DIRECTIONS.

1	2	3	4	5	6	7	8
1234567890123456789012345678901234567890123456789012345678901234567890							
431 255 3 359 59 55.56 1. .7							

FROM TO	DIRECTION	STANDARD ERROR (MM AND SECONDS)	COMMENTS
---------	-----------	---------------------------------	----------

LIST NUMBER IN 9-10, RIGHT JUSTIFIED.

DIRECTIONS MAY BE GIVEN IN ANY ORDER WITHIN A LIST.

THE LAST CARD OF THIS SECTION MUST HAVE A NEGATIVE DIGIT IN CC 1-4.

6. ASTRONOMIC AZIMUTHS. FORMAT THE SAME AS FOR DIRECTIONS, EXCEPT THAT LIST NUMBER IS LEFT BLANK.

THE LAST CARD OF THIS SECTION MUST HAVE A NEGATIVE DIGIT IN CC 1-4.

7. RECIPROCAL VERTICAL ANGLES. ONE CARD PER PAIR.

1	2	3	4	5	6	7	8
1234567890123456789012345678901234567890123456789012345678901234567890							
431 222 101 12 12.25 .5 .3 3.123 4.222 89 12 53.24 .5 .3 2.335 5.127							

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----

1 STANDPOINT.

2 FOREPOINT.

3-5 ZENITH DISTANCE.

6 STANDARD ERROR, MILLIMETERS.

7 STANDARD ERROR, SECONDS.

8 HEIGHT OF THEODOLITE.

9 HEIGHT OF TARGET.

10-16 CORRESPOND TO 3-9 IN OPPOSITE DIRECTION. ANYTHING IN CC 77-80.

THE LAST CARD OF THIS SECTION MUST HAVE A NEGATIVE DIGIT IN CC 1-4.

8. GROUPED VERTICAL ANGLES.

1	2	3	4	5	6	7	8
1234567890123456789012345678901234567890123456789012345678901234567890							
835 45 3 89 12 12.565.5.3 20.125 6.512 .12 .15							

1	2	3	4	5	6	7	8	9	10	COMMENTS
---	---	---	---	---	---	---	---	---	----	----------

1 STANDPOINT.

2 FOREPOINT.

3 LIST NUMBER. ANGLES MEASURED FROM SEVERAL STANDPOINTS MAY BE ASSIGNED THE SAME NUMBER.

4 ZENITH DISTANCE.

5 STANDARD ERROR, MILLIMETERS.

6 STANDARD ERROR, SECONDS.

7 HEIGHT OF THEODOLITE.

8 HEIGHT OF TARGET.

9 K AT THE STANDPOINT.

10 K AT THE FOREPOINT.

THE K VALUES MUST BE GIVEN FOR ALL LINES OF A GROUP OR FOR NONE.

LIST NUMBER -1 DENOTES A GROUP OF OBSERVATIONS FOR WHICH THE REFRACTION UNKNOWN WILL BE SET TO ZERO.

THE LAST CARD OF THIS SECTION MUST HAVE A NEGATIVE DIGIT IN CC 1-4.

*

9. ABSOLUTE DISTANCES.

	1	2	3	4	5	6	7	8
1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890
55 710	12345.6789	5.1.5	3.126	10.516				

1	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8

COMMENTS

- 1 STANDPOINT.
- 2 FOREPOINT.
- 3 MEASURED SLOPE DISTANCE.
- 4 STANDARD ERROR, MILLIMETERS.
- 5 STANDARD ERROR, PPM.
- 6 HEIGHT OF INSTRUMENT.
- 7 HEIGHT OF TARGET.

THE LAST CARD OF THIS SECTION MUST HAVE A NEGATIVE DIGIT IN CC 1-4.

10. GROUPED (RELATIVE) DISTANCES. FORMAT THE SAME AS FOR ABSOLUTE DISTANCES, EXCEPT THAT LIST (GROUP) NUMBER IS GIVEN IN CC 9-10, RIGHT JUSTIFIED.

THE LAST CARD OF THIS SECTION MUST HAVE A NEGATIVE DIGIT IN CC 1-4.

11. ELEVATION (ORTHOMETRIC HEIGHT) DIFFERENCES.

	1	2	3	4	5	6	7	8
1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890
123 231	-123.456	.053						

FROM TO ELEVATION STANDARD ERROR IN METERS. COMMENTS

THE LAST CARD OF THIS SECTION MUST HAVE A NEGATIVE DIGIT IN CC 1-4.

12. GEODETIC POSITION DIFFERENCES IN METERS.

	1	2	3	4	5	6	7	8
1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890
11 12	-3.122	.002	1.298	.002	30.122	.002		

FROM TO LAT. S.E. LON. S.E. HEIGHT S.E. COMMENTS

THE LAST CARD OF THIS SECTION MUST HAVE A NEGATIVE DIGIT IN CC 1-4.

13. HORIZONTAL DISTANCES. NOT OVER 100 METERS. THE SAME FORMAT AS FOR ELEVATION DIFFERENCES.

THE LAST CARD OF THIS SECTION MUST HAVE A NEGATIVE DIGIT IN CC 1-4.

14. ASTRONOMIC POSITION DIFFERENCES (TO BE THE SAME AS GEODETIC).

STATION NUMBERS IN CC 1-4 AND 5-8.

THE LAST CARD OF THIS SECTION MUST HAVE A NEGATIVE DIGIT IN CC 1-4.

15. SELECTED LINES. PUNCH STATION NUMBERS IN CC 1-4 AND 5-8. THIS WILL GIVE STANDARD ERRORS OF AZIMUTH, DISTANCE, AND VERTICAL ANGLE, DX, DY, DZ AND THEIR STANDARD ERRORS, AND GEODETIC AZIMUTH AND DISTANCE.

THE LAST CARD OF THIS SECTION MUST HAVE A NEGATIVE DIGIT IN CC 1-4.

16. NEW ELLIPSOID PARAMETERS (OPTIONAL). OMIT IF ITEM 17 IS USED.

CC 1-12: EQUATORIAL RADIUS
 CC 13-24: RECIPROCAL OF FLATTENING
 CC 25-80: ELLIPSOID OR DATUM NAME

17. COVARIANCE MATRIX FOR SELECTED STATIONS.

THE MATRIX WILL BE COMPUTED FOR COORDINATE DIFFERENCES IN X, Y, Z IN THE ORDER AS GIVEN IN THE INPUT.

CC 1-4 STATION NUMBER. STATION NAME STARTING WITH CC 25.

Appendix 3

IAU/IUGG WORKING GROUP MERIT
LABELS FOR THE SERIES OF THE
EARTH ROTATION PARAMETERS

In order to allow unambiguous reference to series of Earth Rotation Parameters (ERP) and Sets of Station Coordinates (SSC) obtained in several groups by different techniques, it is recommended

- that when a series of ERP is issued, a list of agreement or disagreement of numerical constants and models with the MERIT standards be established, together with the list of station coordinates and any other relevant parameters.
- that when a Set of Station Coordinates is issued, a list of agreement or disagreement of numerical constants and models with the MERIT standards be established, together with the label of the series of Earth Rotation Parameters used and any other relevant parameters
- that every series be labelled by its author according to the following code

ERP(AAAAAA)XX E YY

for Earth Rotation Parameters

SSC(AAAAAA)XX E YY

for Sets of Station Coordinates

where

AAAAAA = acronym of the institute producing the results
 (one to six letters)

XX = year-1900 when the series of ERP was first computed
 (or when the set of coordinates was computed)

E = the observing technique

A : optical astrometry
 D : satellite Doppler tracking
 L : satellite laser ranging
 M : Lunar Laser Ranging
 R : Radio Interferometry (CERI, VLBI)
 C : combination of techniques
 G : conventional geodesy (for SSC)

YY = serial number of the series of ERP or SSC in the year
 XX, for the technique E and the institute AAAAAA.

Appendix 4DIRECTORY OF MERIT SITES(D O M E S)1) Goals of the directory

In order to fulfil the objectives of MERIT and COTES, the MERIT Coordination Center collects 3 major types of data :

- Earth Rotation Parameters (ERP)
- Set of Station Coordinates (SSC)
- Site Description and Survey (SDS)

The first type of data has been collected from the beginning of the MERIT campaign. Now, the two remaining will be collected and entered a data base, for the following purposes :

- a) publication of a Directory of MERIT sites (DOMES)
- b) supplying of coordinates and ties between colocated instruments, in order to estimate global transformation parameters between the various reference systems and a unique set of coordinates of all stations in a new conventional terrestrial frame.
- c) publication of the various sets of coordinates

2) TerminologySite and point

A point is a basic concept of geometric geodesy to which one can provide coordinates in order to identify its location in space (-time). We consider two major types :

- points connected to tracking instruments (called S-points). Such points can be :
 - . end-points in the modelling of the "geometric" measurement, such as electrical center of an antenna, focal point of a telescope ... Such points are directly associated with the measurement, but may be moving with the mobile part of the instrument.
 - . fixed physical points on the instrument, such as intersection of axis, fixed point close to phase center on non-directive antennae.
- permanent mark points, usually established by geodetic survey teams (called M-points).

A restricted (few 100m to 10km) geographical area, where marks and instruments are colocated, even temporarily, will be called a site. Such a site is characterized by :

- its name
- its approximate location
- the list of its S- or M-points

Each M-point will be defined by a proper description.

For each S-point, we shall consider :

- type of instrument
- serial number of the instrument
- description of the point
- beginning and end dates for the settlement of the instrument
- operating agency

Project

In this context, a project is a set of (fixed or mobile) tracking stations which perform during a limited period of time, from some days to some years, with measurements planned by some organizations.

We shall distinguish between :

- space projects (laser, Doppler, VLBI ...)
- site survey projects (to interconnect instruments and permanent marks)

The major items which are related to a project are :

- designation
- period (Y-M-D of beginning and end)
- type (Doppler, LLR, SLR, VLBI, site survey ...)
- organizing agencies
- list of participating stations
- data set collected during the project
- set of analysis performed on the data by various groups
- references

Projects can be related either through a series of projects (e.g. EDOC 1, EDOC 2) or a large project divided into several smaller ones.

Block

A block is a set of points which is considered as a whole. This is, in other words, any set of points which does not belong to a unique project. For instance, the SLR stations considered in MERIT are a block. As another example, the set of stations of the NASA Directorate of Station Location is considered as a block.

A block is defined by :

- its name
- the set of its points

Solution

A solution is a set of estimated quantities resulting from the processing of some data.

It is characterized by :

- description
- agency
- date
- software used
- options used

3) Overview of data flow

The data flow is presented in the attached diagram.

4) Input data

Any document (publication, magnetic tape, computer printout ...) containing relevant information (SSC or SDS) can be sent to the MERIT Coordination Center. Two procedures are more specifically recommended :

4-1) SSC input

In this case, a sequential data set of 80-character records must be built for each set of station coordinates. Namely :

- 1 Header record (H) for identification
- 1 or several comment records (C) for description of the solution
- several coordinate records (X), one for each point

This data set should be preferably sent to the C.C. using the G.E. Mark 3 system. The producing agency will append this data set to a general input file for SSC, labelled BIHCOSTA.

The detailed format is the following (COSTA format) :

<u>H-record</u>		
(Field)	(Columns)	(Value)
1	1	H
2	3 - 20	Label of Set of Station Coordinates (SSC) (see Appendix 3)
3	21 - 80	(blank)

<u>C-record</u>		
(Field)	(Columns)	(Value)
1	1	C
2	3 - 80	Text in free format

<u>X-record</u>		
(Field)	(Columns)	(Value)
1	1	X
2	2 - 6	DOMES site number
3	7	DOMES type of point (M or S)
4	8 - 10	DOMES point number
5	11 - 20	Alternate designation
6	21 - 33	X, in metres, decimal point in column 30
7	34 - 46	Y, in metres, decimal point in column 43
8	47 - 59	Z, in metres, decimal point in column 56
9	61 - 67	Central epoch of adjusted observations (MJD, precision 0.1d, decimal point in column 66)
10	69 - 75	Time span of adjusted observations (days, precision 0.1d, decimal point in column 74)
11	81 - 86	SIG X, in metres, decimal point in column 83
12	88 - 93	SIG Y, in metres, decimal point in column 90
13	95 - 100	SIG Z, in metres, decimal point in column 97

Comments

The C-records should include a brief description of at least the following

- choice of models when they differ significantly from the MERIT standards,
- how the terrestrial system was fixed,
- what is the point of the station (instrument) for which the coordinates are computed.

The use of the DOMES site number and point number is strongly recommended.

4-2) SDS input

To update information about site description (new instrument, new geodetic tie,...), annotations of individual site description sheets generated by computer printout in DOMES (see below) will be used.

5) Directory of MERIT sites (DOMES)

This directory is a computer printout of the data base. Several parts are available :

- L1) List of MERIT sites (MERIT 5-digit site number, name, country, approximate location)
- L2) List of MERIT sites for a given technique (SLR, LLR, VLBI-CEI, Doppler, optical astrometry) by increasing MERIT number and by block number (see below)
- L3) List of MERIT sites for a specific block of project, by increasing MERIT number and by block or project number
- L4) Catalogue of site description, giving for each site its list of M- and S-points, with tridimensional corrections. This catalogue can be sorted to print sheets relevant only to a given block or project.
- L5) List of colocations
- L6) List of blocks and projects existing in the data base

Remarks about codes

- (1) The DOMES code is a 5-digit code for a site, and a 9-character code for a point.

Ex. :

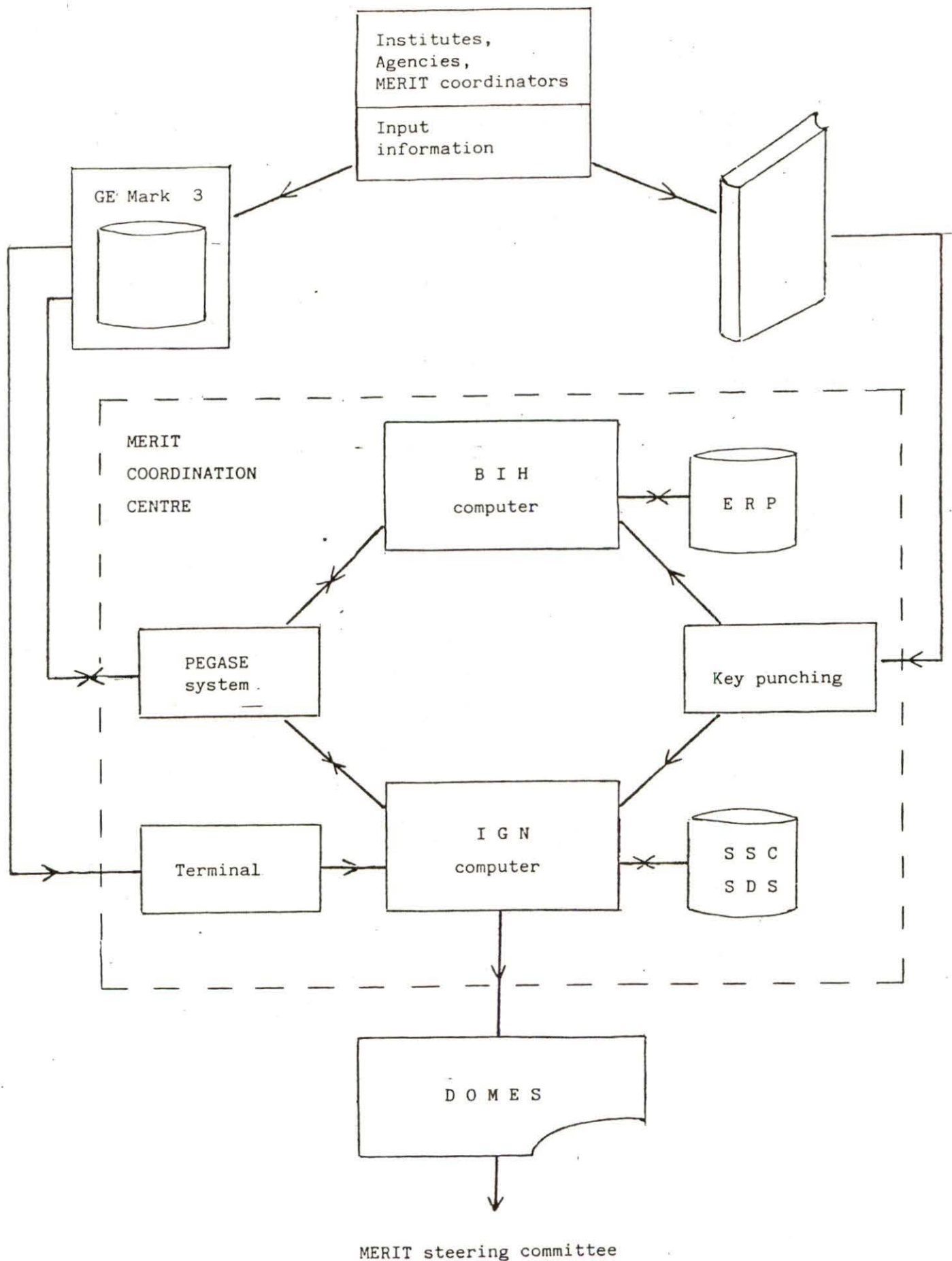
10001	Paris
10001M001	Paris meridian pillar
10001S002	Paris astrolabe

- (2) The agency code is a 6-character code given in Appendix 5. This code, which follows a proposal of NGS and DMA, is recommended by the CSTG/Sub-commission on Standards.
- (3) The country code is a 2-letter code available upon request. Same comment as (2).
- (4) The reference point can be abbreviated.

EC	electric center
IAR	intersection of axis of rotation
IPAPCDA	intersection of polar axis and plane containing declina- tion axis
TP	top of the pillar
URP	unspecified reference point

- (5) Other station codes are given in the associated block or project number (NASA, SAO, TRANET...). More details can be found in Boucher, C., 1983.
- (6) Distribution of SSC

A copy (printout, cards or magnetic tape) of the SSC data set in COSTA format is available upon request.



Appendix 5PROPOSED ACRONYMS FOR SOME INSTITUTES

BIH :	Bureau International de l'Heure 61 avenue de l'Observatoire 75014 Paris France	IGNF :	Institut Géographique National 2 avenue Pasteur 94160 St Mandé France
CERGA :	Centre d'Etudes et de Recherches Géodynamiques et Astronomiques Avenue Nicolas Copernic 06130 Grasse France	IPMS :	International Polar Motion Service International Latitude Observatory Mizusawa-Shi, Iwatae-Ken 023 Japan
CNES :	Centre National d'Etudes Spatiales 18 avenue Edouard Belin 31055 Toulouse Cedex France	JPL :	Jet Propulsion Laboratory 4800 Oak Grove Drive Pasadena, California 91109 USA
DGFII :	Deutsches Geodätisches Forschungs- institut / I München GFR	MIT :	MIT - Dept of Earth and Planetary Sciences Cambridge, Massachusetts 02139 USA
DMA :	Hydrographic/Topographic Center Geodesy and Surveys Dept WASHINGTON, D.C. 20315 USA	NGS :	National Geodetic Survey Geodetic Research and Development Laboratory, N/CG114 Rockville, MD 20852 USA
GRGS :	Groupe de Recherches de Géodésie Spatiale 18 avenue Edouard Belin 31055 Toulouse Cedex France	SAO :	Smithsonian Astrophysical Observatory 60 Garden Street Cambridge, Massachusetts 02138 USA
GSFC :	Goddard Space Flight Center (NASA) Greenbelt, Maryland 20771 USA	SFB78 :	Sonderforschungsbereich 78 (Research consortium in GFR)
CSR :	Center for Space Research Department of Aerospace Engineering University of Texas at Austin Austin, Texas 78712 USA	USNO :	U.S. Naval Observatory Washington, D.C. 20390 USA
IFAG :	Institut für Angewandte Geodäsie Richard-Strauss-Allee 1 D-6000 Frankfurt am Main 70 GFR	UTEXA :	Department of Astronomy University of Texas at Austin Austin, Texas 78712 USA
NSWC :	Naval Surface Weapons Center Dahlgren, Virginia 22448 U S A	ZIPE :	Zentral Institut für Physik der Erde 15 - Potsdam GDR
		UNOT :	University of Nottingham Department of Civil Engineering University Park NOTTINGHAM Angleterre