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K.F. Wakker

REPORT BY THE SUBCOMMITTEE ON INTERCOMPARISON AND MERGING OF GEODETIC DATA

TOPEX/POSEIDON SCIENCE WORKING TEAM

TU Delft
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1. INTRODUCTION

During the first TOPEX/POSEIDON (T/P) Science Definition Team (SDT) meeting at the NASA Jet Propulsion Laboratory (JPL) on November 10-13, 1987, a Subcommittee on Intercomparison and Merging of Geodetic Data (SIMGD) was formed. The members of this Subcommittee are listed on the previous pages.

As chairman of this Subcommittee I have sent out a letter in December 1987, which addressed a few relevant topics and asked the members of the SIMGD for their comments about these topics and about other items that they considered important to be discussed within the Subcommittee. From the comments received a first paper has been compiled, which was presented by R. Rummel during the second T/P SDT meeting at CNES, Paris, on May 3-6, 1988. During the Chapman Conference on Progress in the Determination of the Earth's Gravity Field held at Ft. Lauderdale, Florida, September 13-16, 1988, the majority of the SIMGD members met and I presented a paper dealing with some standing items and problems concerning topics of relevance to the Subcommittee. After that meeting some additional information was provided by the SIMGD members.

From the comments received on both papers, the discussions during the Paris and Ft. Lauderdale meetings and the additional material received, a first draft report was compiled, which was discussed within the SIMGD on February 20 and 23, 1989, and presented at the first T/P Science Working Team (SWT) meeting at JPL, February 21-24, 1989. It was realized that a number of topics discussed in that report do not fit into the original terms of reference of the SIMGD. They were, however, included because the Subcommittee wanted to give its opinion about these topics. On the other hand, it was recognized that many details of topics which do belong to the terms of reference were not yet covered. These have to be defined and worked out in the next couple of years.

An updated version of the February 1989 report, which also reflected conclusions reached during the first SWT meeting and developments which have taken place since that meeting, was presented at the second SWT meeting on October 17-20, 1989, at OMP, Toulouse. From the discussions at that meeting and information provided after the meeting the present report was compiled. It is the final version of the full report by the SIMGD and future recommendations and suggestions will be distributed as separate notes.

It is realized that a number of recommendations listed in this report have already been adopted by the T/P Project. They are still included for the sake of completeness. For convenience, in this report a number of additional abbreviations will be used. The term 'NASA' will be used to indicate the cooperating US groups in the T/P Project Team, the term 'CNES' to indicate the cooperating French groups in that Team, and the notation 'SSG' to indicate the Science Steering Group.

2. REFERENCE ORBIT

A major conclusion from the second T/P SDT meeting in Paris was the recommendation for a new orbit parameters window (orbit design space). After analyses performed by JPL and consultation of the T/P SSG, the T/P Projects Scientists have recommended a new reference orbit and a new mission design space, which were accepted by the T/P Project in the second half of 1988. The characteristics of that reference orbit were a semi-major axis of 7713.6 km, a reference altitude of 1335.5 km, an eccentricity of 0.00044 and an inclination of 65.105°. This 10-day repeat frozen orbit would give a descending pass overflight of Bermuda and an ascending pass overflight of Lampedusa. These islands in the North-Atlantic and the Mediterranean were considered for altimeter calibration sites using satellite laser ranging equipment.

Early in 1989 it was decided that the NASA and CNES calibration sites will be the Harvest Oil Tower off the California coast at Point Conception, and an area about midway between the Lampedusa and Lampione islands in the Mediterranean (Section 4). Therefore, two new reference orbits have been proposed that overfly these verification sites. Both are 10-day 127-revolutions frozen repeat orbits. The orbits are characterized by an altitude and inclination of 1334.9 km and 64.45°, or 1336.3 km and 66.10°, respectively. The pros and cons of these orbits have been discussed extensively at the second T/P SWT meeting in Toulouse, and the second orbit has been selected as the new reference orbit. The mean eccentricity of this orbit is about 0.0001, while the perigee remains frozen over the north pole region. Work continues on further tuning the reference orbit so that it satisfies all mission requirements.

3. TRACKING

Operational orbit determination will be performed by the NASA Goddard Space Flight Center (GSFC), based on short-arcs of S-band tracking data acquired by the Tracking and Data Relay Satellite System (TDRSS). These orbits will not be accurate enough to be used in the altimeter data processing. However, TDRSS could potentially be useful as a backup tracking system for precision orbit determination, if the data are acquired over longer arcs and are taken in the non-destruct mode. Therefore:

- *It is recommended that for parts of the T/P mission long arcs of non-destruct mode TDRSS tracking data be acquired and that these data be available for precision orbit determination.*

Since the TRANET beacon has been removed from the original spacecraft design, the precise tracking systems which will be carried by the spacecraft are: a laser retroreflector array, a DORIS receiver and a GPS receiver. The NASA part of the T/P Project has decided that laser tracking will be the prime precision orbit data source. The GPS tracking mode is considered a proof of concept experiment. The global laser ranging network will consist of about 25-30 systems in the early 1990's, of which about 10 will be operated by NASA. Most of the stations have already been operational for many years. The French DORIS network will consist of about 50 globally distributed ground-based transmitters providing a near-continuous tracking of T/P. The network will be (almost) operational in 1990 and the DORIS tracking concept will be tested and validated beginning in 1990 using SPOT-2 tracking data. The first DORIS SPOT-2 tracking data have actually been acquired on February 3, 1990. Since then, many passes have been tracked with a measurement noise level of around 0.3 mm/s.

The DORIS network is controlled by France and more-or-less dedicated to the T/P mission, so there is no question of availability of this network. However, for the laser tracking the situation is completely different. In addition to T/P these lasers may have to track a variety of other satellites, including LAGEOS-1, LAGEOS-2, LAGEOS-3, STARLETTE, AJISAI, STELLA, ETALON-1, ETALON-2, SALT, ERS-1, during the early 1990's. More than half of the available laser systems will be operated by countries other than the US or France. Considering the importance of the availability of a sufficient number of globally distributed laser tracking systems for T/P, the following recommendations are made.

- *It is recommended that the T/P Project establish the global laser tracking requirements in terms of system locations, operation periods and tracking schedule.*

- *It is recommended that the NASA laser network fully support the T/P mission.*

- *It is recommended that the T/P Project take the initiative to convince the international laser systems community to consider T/P a high-priority tracking target and to track T/P according to predetermined schedules.*

- *It is recommended that the T/P Project start negotiations with each interested laser system group in an early phase to determine the goods and services which they may require in return for their guaranteed participation in the tracking.*

The goods and services mentioned in the last recommendation may include e.g. the loan of hardware that facilitates more-efficient tracking or data transmission, or software that enables the laser system to track more satellites within the same operational period. In any case, formal agreements will be necessary to guarantee the tracking of T/P by these systems.

The European laser system groups have established the EUROLAS organization, which is chaired by F. Barlier (CNES/CERGA). Because of the high concentration of laser systems in Europe only a few of these systems have to track T/P at any time. Therefore:

- *It is recommended that the T/P Project contact the EUROLAS organization to negotiate an agreement about the T/P tracking by European laser systems.*

The GPS receiver on board of T/P will have the capability of tracking six GPS satellites simultaneously and of providing precise tracking data. However, the extremely precise GPS tracking concept developed for T/P should be considered a flight experiment. A GPS precision orbit determination team has been set up, which consists of members of JPL and the Center for Space Research at the University of Texas (UT/CSR). The major objectives of this team are to establish the inherent accuracy of T/P orbits derived from the GPS-based tracking system and to develop most of the capability to use this tracking system in an operational mode, if its accuracy and cost-effectiveness are proven. The present plan is to collect, edit and archive the tracking data acquired by the T/P GPS receiver and by GPS receivers of a so-called fiducial network on earth over the first two years of the mission. The evaluation of the data will probably be confined to a subset of approximately 90 days. After this analysis has been performed by JPL and UT/CSR, and the validity and accuracy of the GPS tracking system has been established, the GPS tracking data could be made available to other groups.

The SIMGD recognizes the enormous potential of this GPS tracking experiment for the T/P mission and future earth observation missions and therefore the following recommendations are made.

- *It is recommended that a considerable effort be spent in preparing, executing and evaluating the T/P GPS tracking experiment.*

- *It is recommended that a full set of GPS tracking data be collected during the T/P mission, and that all groups are encouraged to process these data for the computation of precise T/P orbits and the development of T/P gravity models.*

Because of the experimental nature of the tracking concept, the GPS tracking data should not be applied to compute the T/P orbits on the Geophysical Data Record (GDR) during the 3-years baseline mission. If the GPS precision orbit determination team has proved the validity and accuracy of the GPS tracking concept:

- *It is recommended that the GPS tracking system be upgraded into a fully operational one for a possible extended mission phase.*

As there are strong indications that it will indeed be proved that the GPS system offers a very attractive tracking option:

- *It is recommended that all actions be taken to establish an international global fiducial network of top-quality GPS receivers and to coordinate the tracking data exchange and processing.*

In relation to the latter recommendation, it is stressed that the Project should be prepared to negotiate with participating international GPS tracking groups their access to the T/P GPS data and the GPS data acquired by other stations.

The SIMGD has understood that, according to the NASA-CNES T/P Memorandum of Understanding (MOU), the DORIS tracking data will not be available to NASA for the computation of precise orbits, but will only be used by CNES for precise orbit computations. This strict separation of laser and DORIS tracking data and the application of only subsets of tracking data for the computation of precise GDR orbits is considered by the SIMGD a situation that may conflict with the extremely high orbit accuracy requirements. Therefore, the following recommendations are made.

- *It is recommended that no effort be spent to try to change the NASA/CNES MOU, but the US and French teams who are responsible for the computation of the T/P GDR orbits should strive for optimal cooperation and tracking data exchange on a working level.*

- *It is recommended that both the NASA and the CNES teams working on the T/P precise orbit determination base their computations on all available laser and DORIS tracking data, after the DORIS tracking systems have been fully calibrated relative to the laser systems.*

For scientific purposes various groups of investigators will compute T/P orbits of high accuracy. These orbits may become available months or even years after the acquisition of the tracking data and should be considered science products. To enable investigators to compute these precise orbits, the following recommendations are made.

- *It is recommended that the T/P laser, DORIS and GPS tracking data be released to all interested T/P investigators after the DORIS and GPS tracking concepts have been fully validated.*

- *It is recommended that, in order to familiarize investigators with the detailed characteristics of the DORIS and GPS tracking data, the investigators be supplied with limited subsets of DORIS SPOT-2 tracking data and T/P GPS tracking data taken during the initial validation period.*

The combined use of all existing tracking data will yield orbits of highest accuracy and will allow a full comparison of the orbit computation results. In addition, repeated computations of orbits over the same time interval, but applying various combinations of subsets of all existing tracking data, would contribute significantly to the assessment of the real accuracy of the orbits and the applied models (Section 10).

Tides gauges may provide an interesting tracking concept. When the position (in particular the radial component) of a tide gauge is accurately known in a geocentric reference frame, a combination of altimeter measurements over the tide gauge and the tide gauge reading can be used to monitor the radial orbit error. However, it is believed that the applicability of this tracking option is very limited, and the viability of the concept still has to be proved. Thus, this option should presently be considered a scientific experiment. The tide gauges information is, however, very important for the absolute positioning of altimetric sea surfaces (Section 7).

4. ALTIMETER CALIBRATION

The pre-launch T/P performance expectations have to be verified after the satellite is placed in orbit. This verification phase has been fixed to the first 6 months of the mission. After this phase the verification activities will not necessarily be stopped, but will in any case be reduced. Several experiments will support the verification of the overall T/P system, including regional validation campaigns. A major role will be played by NASA and CNES verification sites, each equipped with various instruments to determine precisely all external phenomena which affect the altimeter measurement, and to perform a detailed engineering verification of both the TOPEX and the POSEIDON altimeter.

In January 1989, NASA and CNES published their verification plans, which were discussed during the first and second T/P SWT meetings. The verification sites are the Harvest Oil Tower off the California coast at Point Conception (NASA) and an area midway between the Lampedusa and Lampione islands in the Mediterranean (CNES). Both verification plans assume laser tracking of T/P as it overflies the verification sites.

For the NASA site, the radial position of the satellite will be derived from tracking data acquired by existing laser systems, which are located on land along the west coast of the USA, relatively close to the verification site. The CNES verification plan assumes the availability of a French ultra-mobile laser system (SLUM), optimized for (near-)vertical ranging and altimeter calibration, at Lampedusa. In case that laser system will not be available on time, the existing German (MTLRS-1) or Dutch (MTLRS-2) mobile laser ranging systems are planned to perform the calibration.

Considering the extreme importance of a thorough altimeter calibration, the SIMGD makes the following recommendations.

- *It is recommended that NASA and CNES make a detailed joint calibration plan, which should focus on the methods and techniques to be adopted to calibrate the altimeter. This calibration should include the measurement time tagging.*

- *It is recommended that both the NASA and the CNES verification site be used for the calibration of both the TOPEX and the POSEIDON altimeters.*

- *It is recommended that full guarantees be negotiated with the German and the Dutch authorities for use of their lasers, which are backup systems for the French SLUM, even if the T/P launch date slips.*

- *It is recommended that for regional altimeter verification efforts maximum use be made of regions which are covered by both a dense network of DORIS tracking systems and by laser tracking systems.*

If the onboard altimeter electronics indicate a long-term drift in the altimeter system, repeated altimeter calibrations would be needed. But even if no indications of altimeter drift are present, a yearly calibration of the altimeter by the laser systems is still advisable.

- *It is recommended that, in order to verify that no long-term drift in the altimeter systems have occurred, the calibration be not only performed during the first months of the mission, but also repeated a few times during the entire mission. This requires that for all calibration periods the same lasers, or lasers which have been calibrated relative to the previous laser systems, will be used.*

5. STANDARDIZATION OF CONSTANTS AND MODELS

The adoption of well-defined standards and models by all groups working with T/P data is extremely important. Otherwise, the detailed comparison and assessment of results obtained by different groups will be difficult or even impossible. Although this Subcommittee only deals with orbit and geodetic aspects of the T/P mission, it is stressed that this concept of developing standards should be pursued in all fields of T/P data processing.

The T/P satellite will accommodate both a NASA and a CNES altimeter, which basically will be operated independently by NASA and CNES. These agencies will only process the data from their own altimeter, from the original raw measurements to the quantity that is included in the GDR, and will compute their own orbits and corrections to be included in the GDR. On the US side, the major groups involved in the orbit work are at the NASA GSFC, UT/CSR and the Colorado Center for Astrodynamics Research (CCAR) at the University of Colorado, Boulder. These groups have some agreements on using a common set of parameters and models. They basically follow the MERIT standards, originally established in 1983 by an international working group, chaired by W. Melbourne (JPL), for earth rotation investigations and satellite geodesy [1], which are extended and updated with improved values for the T/P mission. On the French side, a CNES team is preparing its orbit computation activities. This team will also apply the updated MERIT standards.

Within the International Earth Rotation Service (IERS) organization, a special working group chaired by D. McCarthy (USNO) has prepared an improved system of standards for constants, models and reference frames [2]. This system is based largely on the MERIT standards and the 1985 update [3] of these standards, with revisions being made to reflect improvements in constants and models since these standards were published. In addition, the Commission for the International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG) has promoted standards for the processing of laser and GPS data for geodetic and geophysical purposes.

Because both altimeters should be considered supplementary instruments in a common oceanographic mission, which asks for an unprecedented orbit accuracy:

- *It is recommended that the best constants and models be adopted by NASA and CNES. The standard should follow the existing CSTG/SLR and CSTG/GPS standards and the forthcoming IERS standards as close as possible.*

- *It is recommended that each group involved in the generation of the T/P GDR's fully document their standard for the constants and models that will be applied consistently throughout the mission. These documents should be made available to T/P investigators before the mission.*

In the next Section, a survey of candidate T/P standards proposed by the NASA GSFC, UT/CSR and CNES is presented. In Sections 7 to 9 some elements of these standards will be discussed. In the selection process, which has to lead to the adoption of the final T/P standard, it is essential to make maximum use of the expertise available in the various investigator teams. Therefore:

- *It is recommended that updated versions of the T/P standards applied by NASA and CNES be circulated among the investigators for comments. These comments should be taken into account in the selection procedure that will lead to a final standard that has to be frozen a few months before launch.*

6. CANDIDATE STANDARDS

The processing of T/P tracking data by NASA GSFC, UT/CSR, CCAR and CNES will be performed by their respective software systems GEODYN, UTOPIA and ZOOM. Some characteristics of the reference frame, force and measurement models proposed to be applied in these, and other, software systems are listed on this and the following pages. The information was received from C. Shum (UT/CSR) in December 1989, and represents the results of discussions between S. Klosko (NASA GSFC/ STX), F. Nouel (CNES) and C. Shum. The proposed T/P standards are largely based on the draft IERS standards, which are also listed for comparison.

REFERENCE FRAME

Model	IERS Standard	Proposed T/P Standard
Conventional Inertial System (CIS)	J2000 S.I. units	Same
Precession	1976 IAU	Same
Nutation	1980 IAU	1980 IAU with corrections
Planetary ephemerides	JPL DE-200	Same
Conventional Terrestrial System (CTS)	IERS	IERS
Polar Motion	IERS	IERS 3-day time series
UT1-TAI	IERS	IERS 3-day time series
Plate motion	Minster-Jordan AM0-2	Minster-Jordan AM0-2 Epoch: 1984.0 or TBD
$\bar{C}_{21}$, $\bar{S}_{21}$-mean values	$\bar{C}_{2,1} = -.17 \times 10^{-9}$ $\bar{S}_{2,1} = 1.19 \times 10^{-9}$	TBD
-rates	None	TBD

FORCE MODELS

Model	IERS Standard	Proposed T/P Standard
GM	398600.440 km^3/s^2	398600.4405 km^3/s^2
Geopotential	GEM-T1 $\dot{J}_2$ = -2.8 x 10^{-11}/year	T/P model (TBD) $\dot{J}_2$ = -2.8 x 10^{-11}/year Permanent tide treatment according to IERS
GM and R_e for geopotential scale	398600.440 km^3/s^2 6378137 m	398600.4405 km^3/s^2 6378136.3 m
n-body	Sun, Moon and all planets except Pluto JPL DE200/LE200	IERS or TBD
Solid Earth tides Frequency independent	$k_2 = 0.3$ $\delta = 0°$	IERS
	Zero frequency tide not included	IERS
	Honkasalo correction applied to J_2	IERS
Frequency dependent	Wahr's theory	IERS
Ocean tides	11 constituents 55 coefficients max. degree = 6 one order per species	T/P model (TBD) Possible yearly solutions for S_a
Rotational deformation	$\Delta\bar{x}_p$ and $\Delta\bar{y}_p$ from polar motion series $k_2 = 0.3$ $k_0 = 0.942$	IERS Include effects for $\bar{C}_{20}$ Δl_{od} (TBD)

FORCE MODELS (continued)

Model	IERS Standard	Proposed T/P Standard
Relativity	Central body (Earth) perturbation	IERS
Solar radiation	Solar constant = 4.5605E-6 N/m^2 at 1 AU	IERS
	Conical shadow model for Earth and Moon, $R_e = 6402$ km $R_m = 1738$ km R_s no standard	IERS, with $R_s = 696000$ km
Atmospheric drag	No standard	DTM (TBD)
	No standard for solar flux and geomagnetic index	Daily flux and K_p (3hr or daily, TBD) 1.85-day lag for flux lag for K_p (6.7 hr, or TBD)
Earth radiation pressure	No standard	Albedo & infrared 2nd degree zonal model
Satellite parameters	Cross-sectional area for some satellites C_D and C_R estimated	Realistic geom. model (TBD) C_D and C_R estimated

MEASUREMENT MODELS

Model	IERS Standard	Proposed T/P Standard
Laser range	No standard	Full light-time solution
Troposphere	Marini & Murray	IERS
Relativistic correction	Applied	IERS
Doppler (DORIS)	No standard	Range difference
Troposphere	No standard	TBD
Relativistic correction	No standard	Applied
Ionosphere (higher order)	None	TBD
Reference ellipsoid	a_e = 6378137 m 1/f = 298.257	a_e = 6378136.3 m 1/f = 298.2564
Site Displacement		
Induced permanent tide	Not removed	IERS
Geometric tides		
Frequency independent	h_2 = 0.6090 l_2 = 0.0852 $\delta = 0°$	IERS Site dependent?
Frequency dependent	K_1 only	IERS
Ocean loading	Table of values	IERS + updates
Rotational deformation	Variations from polar motion series h_2 = 0.6090	IERS

MEASUREMENT MODELS (continued)

Model	GEOSAT GDR	Proposed T/P Standard
Altimeter		Instantaneous height above sea surface
Geoid (low degree and order)	None	T/P gravity field (TBD)
Geoid (high degree and order)	OSU78	TBD
Reference ellipsoid	'Zero' surface: a_e = 6378137 m 1/f = 298.257	'Mean' surface: a_e = 6378136.3 m (or TBD) 1/f = 298.2564 (or TBD)
W_0	None	Corresponds to mean surface (TBD)
Ocean tide	Schwiderski 11 constituents 1° x 1° gridded time series	TBD
Earth tide		
Frequency independent	MERIT	IERS
Frequency dependent	K_1	K_1
Polar motion	None	IERS
Quasi-stationary sea surface topography	None	Spherical harmonics to (10 x 10), (or TBD)
Barotropic	Inverse barometer	TBD
Ionosphere	Single-frequency altimeter GPS model	Dual-frequency altimeter Measured
Troposphere		
Dry	FNOC	Same
Wet	FNOC or SMMR	TBD
Significant wave height bias	JHU/APL 85	TBD

7. REFERENCE SYSTEM

It is very important that the earth orientation parameters (precession, nutation, polar motion) and the geocentric coordinates of all tracking systems involved in the T/P mission form a consistent and highly accurate set of models. CNES has selected as the initial DORIS Terrestrial System (DTS) the BTS-87 system as published in the BIH Annual Report for 1987. An improved version of this terrestrial system will also be adopted for the IERS standards. Consequently, the following recommendations are made.

- *It is recommended that the IERS earth rotation parameters and terrestrial reference system be adopted. These are state-of-the-art solutions from SLR, LLR, VLBI and Doppler measurement techniques and are consistent with modern nutation theories.*

- *It is recommended that the a-priori coordinates of the DORIS and laser tracking systems, and of the GPS fiducial stations, be determined relative to a single recent high-quality reference system.*

It is emphasized that the computation of these a-priori coordinates may require pre-launch tracking campaigns and collocation experiments between laser, DORIS and GPS systems. It is the opinion of the SIMGD that these activities are the responsibility of the T/P Project.

Shortly before or during the early phase of the T/P mission it will be necessary to establish a final set of station coordinates, for which the following recommendations are made.

- *It is recommended that the final coordinates of the DORIS and laser systems, and of the GPS fiducial stations, be determined relative to a single geocentric reference frame that is consistent with the IERS earth rotation parameters. The effects of plate motions on the station coordinates should be accounted for.*

- *It is recommended that the T/P investigators be supplied with the a-priori and operational tracking system coordinates.*

Tide gauges may contribute orbit information (Section 3), and certainly will yield valuable information to tie an altimetric sea surface to the adopted reference frame, to improve global tide models and, in the long run, to monitor sea level changes. For these scientific goals the position of the tide gauges should be known accurately, which leads to the following recommendation.

- *It is recommended that the T/P Project take the initiative to tie a number of suitably located accurate tide gauges to the global geocentric reference frame applied for the tracking system coordinates before the start of the mission.*

For the determination of the geodetic positions of these tide gauges relative to reference points of the geocentric reference frame, GPS receivers should preferably be used. In order to maximize the scientific return of a tide gauge precise positioning campaign, this effort should be done in cooperation with the Global Level Of the Sea Surface (GLOSS) project, and the Permanent Service for Mean Sea Level (PSMSL) data bank.

- *It is recommended that the tide gauges, of which the geocentric positions will be determined accurately by GPS measurement campaigns, be selected from the GLOSS tide gauges network, and that the derived geocentric coordinates be stored in the PSMSL data bank.*

Before and during the T/P mission various groups probably will derive tracking system or tide gauge coordinates and will submit these to the T/P Project for transformation into the unified geocentric reference frame. To enable the proper use of these coordinates:

- *It is recommended that all sets of station and tide gauge coordinates delivered to the T/P Project be accompanied by a full description of the measurement techniques, as well as of the models and processing methods applied to determine the coordinates.*

An example of a suitable description document was received from C. Boucher (IGN/GRGS) in August 1988 and is reproduced on pages 32-35 of this report.

8. GRAVITY MODEL

For the last several years, NASA GSFC has been developing gravity models of ever increasing accuracy for T/P orbit determination. At the moment, three T/P models are available, ranging from GEM-T1, which is based upon ground tracking data from 17 unique satellites and is complete to order and degree 36, up to GEM-T3, that has been derived from ground tracking data from 31 satellites, satellite-to-satellite tracking data between GEOS-3 and ATS-6, surface gravimetry data and altimetry data from GEOS-3, SEASAT and GEOSAT, and which is complete to order and degree 50.

Preliminary versions of a T/P gravity field model have also been produced at UT/CSR. The TEG-1 model includes ground tracking data from 14 satellites, global surface gravity anomaly data and altimetry data from SEASAT and GEOSAT. The PTGF4 and PTGF4A gravity models are the products of more recent developments at UT/CSR. The PTGF4 model includes tracking and GEOSAT altimeter cross-over data, and is complete to order and degree 36, plus additional selected coefficients up to order 43 and degree 50. The PTGF4A model includes the data set of PTGF4 plus direct altimeter data from SEASAT and GEOSAT, and surface gravity data. The model is complete to order and degree 50.

These model development activities at NASA GSFC and UT/CSR will continue and will culminate in a joint pre-launch T/P gravity model. Extensive work on gravity field modeling is also being pursued at other US and European institutes since many years. Because of the extreme T/P orbit accuracy requirements, the following recommendation is made.

- *It is recommended that a few months before the launch of T/P the best gravity model available at that time be adopted as the starting point for the gravity model tuning during the first six months of the T/P mission.*

For a long time the topic of including non-T/P altimeter data (GEOS-3, SEASAT, GEOSAT, SALT, ERS-1) in the development of the pre-launch T/P gravity model has been discussed. The concern is that the use of altimetry data would generate an undesirable correlation between the orbit errors and the dynamic ocean topography. Those in favor of the inclusion of altimeter data have argued that not using these data would mean that significant information about the earth's gravity field is neglected. By properly processing satellite tracking data, altimetry data and surface gravity data in a joint solution, involving simultaneous adjustments of the gravity model, dynamic ocean topography model and tide model, it is argued that the aliasing of oceanographic signals into the gravity model can be minimized. It has also been argued that as long as no dedicated gravity field satellite mission (like the European ARISTOTELES mission) has flown, such a joint solution is the only way to develop gravity models of the high accuracy level required for the T/P mission.

In June 1989, the NASA Project Scientist L. Fu (JPL) sent a letter to members of the T/P SWT, explaining promising results in this field obtained by the T/P Precision Orbit Determination Task Group (PODTG). In this letter it is suggested that the technique of including non-T/P altimetry data in the gravity field development be accepted, and the T/P SWT was invited to discuss this matter. Because the highest possible orbit accuracy level is required, and the analyses by the PODTG have already yielded very promising results, the SIMGD came to the following recommendation:

- *It is recommended that non-T/P altimeter data be used to develop the pre-launch T/P gravity model.*

Although the pre-launch gravity model will be quite accurate, the extreme orbit precision requirements will undoubtedly require a gravity model tuning process. It is understood by the SIMGD that this tuning will be accomplished through the incorporation of T/P laser, DORIS, may be altimeter (cross-over) and possibly TDRSS data into the model. An important issue concerns the inclusion of T/P altimeter measurements in the gravity field tuning process. While this would probably improve the T/P orbit accuracy, the danger exists that some of the oceanographic signals to be measured by T/P will be aliased into the gravity field solution. Therefore:

- *It is recommended that T/P altimeter measurements not be used in the development of the gravity model that will be applied for the generation of the T/P orbits on the GDR.*

After the six months period of gravity model tuning, the increasing tracking data sets will undoubtedly be used to generate a series of improved gravity models. To keep an internal consistency of the GDR's:

- *It is recommended that the best gravity model available six months after launch be adopted as the standard for all groups involved in generating the GDR's.*

- *It is recommended that all other T/P (tailored) gravity models developed during the mission be considered science products and should not be used for the generation of the T/P GDR orbits.*

When the T/P GPS tracking concept has been fully validated (Section 3), the GPS data will undoubtedly be used in the development of gravity models. It is expected that these data will provide significant information about the lower degree and order harmonics of the gravity field. All improved gravity models developed by the NASA and CNES teams, and by other groups, are extremely important for the evaluation of the true accuracy of the standard model and of the orbit. If it turns out that the T/P gravity field modeling activities during and after the mission have resulted in a gravity model that yields significantly improved orbits, that model and the associated orbits should be made available to the T/P investigators. In order to limit the reprocessing efforts both by the Project and by the investigators:

- *It is recommended that, if a significantly improved T/P gravity model is developed, this model should be made available to interested investigators. In addition, investigators should receive tapes with the new orbits for the entire mission duration, and the associated interpolation software to extract the information for all records on the GDR.*

9. TIDE MODEL

Tide models have to be applied in the generation of the T/P GDR for two different purposes. First, they will be used in the orbit determination process to compute the tide-induced changes in the geocentric positions of tracking systems and to compute the tidal forces acting on the satellite. In this way the tide models affect the orbit included on the GDR. Secondly, a tide model will be used to derive the ocean surface geometric tidal correction on the GDR. According to the draft GDR baseline (Section 11), the GDR will contain separately the (geometric) solid-earth tide, the ocean tide and the ocean loading effect on the solid-earth tide. Both the applied solid-earth and ocean tide models may include equilibrium and non-equilibrium components.

For the orbit computation there seems to exist no controversy about the solid-earth tidal force model, and about the geometric solid-earth tide and ocean loading models to be applied for the correction of the tracking system coordinates. The selection of a high-quality ocean tide model, however, seems to be more problematic. Therefore, the following recommendation is made.

- *It is recommended that the T/P Project take initiatives to guarantee that at the launch of T/P a high-quality ocean tide model is available that is suited for orbit computation purposes.*

For the tide correction on the T/P GDR an ocean tide model of highest quality should be applied. At present, in most analyses the applied model for the geometric correction at the ocean surface is based on the 1980 global Schwiderski model. It is understood that the T/P Tide Gauges Subcommittee will recommend that only a global tide model and no regional models should be applied to compute this correction for the T/P GDR. Therefore the following recommendations are made.

- *It is recommended that the T/P Project take the initiative to organize a study on the generation of a new global ocean tide model to be applied for the computation of the geometric correction on the T/P GDR. In the derivation of this model modern tide gauge measurements and GEOSAT altimeter data should be included.*

- *It is recommended that during the T/P mission extensive tide gauge measurement campaigns be organized to verify the ocean surface geometric corrections on the GDR.*

In May and October 1988 letters were received from J. Wahr (University of Colorado) dealing with three tidal effects. These effects may be described as (1) the radial displacement of the ocean surface due to the incremental centrifugal force caused by polar motion (pole tide), (2) a correction of the Love number h in the solid-earth tide model to account for differences in the value of this Love number at various important diurnal and semi-diurnal frequencies, and (3) a solid-earth deformation in response to atmospheric loading. During the first T/P SWT meeting in February 1989 this matter was discussed in detail by J. Wahr, S. Klosko (GSFC/STX) and C. Shum (UT/CSR). The outcome was that (1) is already modeled in the relevant software systems, that (2) is already part of the IERS standards, and that (3) is not to be modeled for T/P.

Another important issue concerns the treatment of the so-called permanent tidal deformation. The SIMGD has agreed during the second T/P SWT meeting to define a way in which the permanent tide may be treated consistently in the T/P orbit computation, altimeter data referencing, mean sea surface definition and geoid definition. This activity has resulted in a report written by R. Rapp, Ohio State University (OSU) [4].

- *It is recommended that the T/P Project take notice of this report and take all actions required to guarantee that the permanent tide is treated in the correct way.*

10. MODEL AND ORBIT INTERCOMPARISON

For some years the experts at NASA GSFC, UT/CSR and CCAR, who are the US teams responsible for the precise orbit determination of T/P, have worked together to define a common set of geophysical models and constants. A candidate set of such T/P models and constants is tabulated on pages 12-16 of this report. These groups use two different software systems: GEODYN and UTOPIA, which have been developed independently and have been in use for many years to compute very precise satellite orbits. A thorough software comparison effort is performed regularly. When using precisely the same input data and models, the criterion for agreement between GEODYN and UTOPIA has been established to be 3 mm in the radial direction for 10-day orbital arcs.

The French ZOOM software will apply models which are very similar to the models incorporated in the GEODYN and UTOPIA software systems, and the ZOOM software will be calibrated with respect to GEODYN and UTOPIA [5]. Differences in models and orbits will be made available to the T/P investigators by CNES. The SIMGD considers it realistic to assume that the differences between the ZOOM and GEODYN orbits will be somewhat larger that the differences between the UTOPIA and GEODYN orbits and therefore makes the following recommendation.

- *It is recommended that the T/P Project take all actions required to guarantee that the models applied by CNES and NASA agree as closely as possible, and that the differences between the CNES and NASA orbits, when computed from the same tracking data, are as small as possible.*

Until the launch of T/P, the US intercomparison efforts for the GEODYN and UTOPIA software systems will continue. This work will include real data analysis, using tracking data from other satellites, and the application of a series of well-defined tests and comparison techniques developed over the years by the NASA GSFC. Given the enormous importance of the pre-launch model and software calibration and validation activities:

- *It is recommended that the T/P Project take all actions required to guarantee that the pre-launch model and software calibration and validation activities by NASA and CNES are continued at a level that is required to satisfy the mission goals.*

During the first month in orbit, an intensive verification of the geophysical parameters produced by T/P will start, which will last for about five months. During this period various precise orbit determination verification activities will be performed by NASA GSFC and UT/CSR. Concerning this phase of the mission:

- *It is recommended that the final report presenting the verification results for both the precise orbit and the geophysical parameters obtained by the US team during the first six months in orbit, and a similar report by the CNES team, be made available to the T/P investigators.*

After this verification phase the GDR production phase will begin. On the US side, NASA GSFC is responsible for processing the tracking data and producing an ephemeris file which satisfies the orbit accuracy requirements. The T/P Project at JPL will produce the GDR which contains the orbit information. UT/CSR is responsible, while working in concert with NASA GSFC, for verification of the orbit determination accuracy. Throughout the duration of the mission the accuracy of the orbit and the geophysical parameters will continually be monitored using various well-defined techniques. As this will undoubtedly also hold for the CNES activities, the following recommendation is made.

- *It is recommended that reports presenting the NASA and CNES verification results for both the orbit and the geophysical parameters be made available to the investigators on a regular basis throughout the entire mission duration.*

A basic question in relation to the topic of intercomparison is whether there are significant altimeter hardware, tracking system technology and precision orbit determination technology exchange restrictions existing between NASA and CNES, which may jeopardize a full intercomparison of orbits and models. In the discussion presented in this report this aspect is completely ignored, but clarification of this point should be a high priority item for discussion.

11. BASELINE GDR

In May 1989 a draft of the T/P GDR baseline, prepared by P. Callahan (JPL), was published and circulated among members of the T/P SWT for comments [6]. This document gives parameters and their definitions, as well as other auxilliary information. This draft GDR baseline includes a number of parameters which were recommended for inclusion by the SIMGD. In subsequent Sections of the present report some issues of the draft GDR baseline will be addressed.

12. GEOID AND MEAN SEA SURFACE

At the second T/P SDT meeting in Paris, the SIMGD has stressed the importance of having a good long-wavelength geoid, a mean sea surface and cross-track geoid gradients on the GDR. Since then, this point of view has repeatedly been brought to the attention of the T/P Project.

The purpose of including an accurate mean sea surface derived from GEOS-3, SEASAT, GEOSAT, SALT and possibly ERS-1 altimeter data is that this reference surface may be used to identify blunders in the data. This mean sea surface will serve the purpose of removing bad points much better than an artificial mathematical filter. The justification of the inclusion of a geoid needs more explanation. It is recalled that the major goal of the T/P mission is the measurement of the difference between a mean sea surface derived from T/P altimetry and the marine geoid. It is true that a really accurate and detailed geoid will only become available after a dedicated gravity field mission has flown, such as the ARISTOTELES mission presently studied in Europe. However, at the time of the launch of T/P, there will be available geoid models which are quite accurate for the longer wavelengths. When these geoid models are based on the lower-degree terms of a gravity model derived from satellite tracking data and gravimetry only, they are very well suited to study the long-wavelength oceanographic features. For the study of shorter-wavelength features, it is unavoidable for the time being that geoid models are used which have been developed by also incorporating altimeter data. Although this may seem to be a difficult procedure, various numerical experiments have already demonstrated that it may produce valuable results, if the parameter estimation process is properly designed (Section 8).

The inclusion of cross-track geoid or mean sea surface gradients on the GDR is important to identify areas where high cross-track gradients occur, which may hamper some altimeter data analysis techniques, or to apply the gradients in other analysis techniques to interpolate over slight offsets of successive near-repeat tracks. These gradients should preferably be derived from the high-quality mean sea surface mentioned above.

These issues were extensively discussed during both T/P SWT meetings in Pasadena and Toulouse. At the last meeting it was decided to make the following recommendations:

- *It is recommended that the T/P GDR contain fields with the undulation of a detailed mean sea surface derived from previous altimeter missions, the cross-track gradient of this surface and a high-quality 360 by 360 potential coefficients geoid model.*

- *It is recommended that at the common harmonic degrees the 360 by 360 potential coefficients geoid model be identical with the potential coefficients gravity model used for the computation of the T/P orbits on the GDR. The development of these potential coefficients models should be done to minimize the corruption by oceanographic signals.*

In January 1989 a message was received from V. Zlotnicki (JPL), raising a question from the T/P Project about which group outside the Project would supply the mean sea surface gradients and in what form and under what schedule. The Project would prefer two grids, one of the slopes normal to the nominal ascending tracks, one for the descending tracks. In this way the Project can treat this quantity just like the fields of atmospheric pressure, etc., which will come complete, except for the final interpolation, from operational sources. At the first T/P SWT meeting in February 1989, C. Shum (UT/CSR), C. Koblinsky (NASA GSFC) and R. Rapp (OSU) have expressed their willingness to support the Project in computing grids of highly accurate cross-track mean sea surface gradients.

- *It is recommended that the T/P Project ask for support by the above mentioned persons for the computation of the cross-track sea surface gradients grids.*

The draft GDR baseline (Section 11) includes fields for the geoid height above the reference ellipsoid, the sea surface height above this ellipsoid as computed from a high-resolution mean sea surface model, and the cross-track sea surface gradient from this model.

13. ALTIMETER OPERATION SCHEDULE

According to the present T/P mission plan the CNES altimeter will operate for about 1 out of every 20 days. Concerning this aspect the following recommendation is made.

- *It is recommended that immediately after the initial system verification and calibra-*

tion phase, a continuous 10-day arc of NASA altimeter data be collected, followed by a continuous 10-day arc of CNES altimeter data. During these two periods laser, DORIS and GPS tracking observations should be recorded.

These data should be made available to the NASA and CNES teams and to all interested investigators. A detailed intercomparison of results produced by all groups may be used for an extensive validation of all hardware and software aspects. It is believed that there is important tracking system, altimeter and geophysical information in a complete repeat cycle, which may not be visible in shorter 1-day arcs. To detect long-term variations in tracking system and altimeter characteristics (Section 4):

- *It is recommended that such double continuous NASA and CNES altimeter data arcs, having a length of one repeat cycle, be also planned for a few other periods during the T/P mission.*

- *It is recommended that for an area of well-known oceanographic characteristics, which is adequately covered by laser and DORIS tracking systems, a number of NASA and CNES altimeter data acquisition periods be planned, distributed over the entire T/P mission.*

14. ALTIMETER MEASUREMENT RATE

The original standard for the NASA GDR was that it would contain one record every three seconds, whereas the standard for the CNES GDR was to have one record approximately every second. Because the T/P mission aims for high-precision results, the SIMGD stated at the second SDT meeting in Paris that the interval of 3 s, during which the satellite will traverse a distance of about 20 km, is too large. It was recommended that the record should contain 1 s averaged sea surface heights and preferably also a series of fully-corrected altimeter heights at a suitably selected higher rate (e.g. 10 per second), if the overall system design would allow this. All corrections and auxilliary data need only be computed at a one per second rate. This means that the values of the corrections for the 10 heights are the same as those applied to the one-per-second height.

- *It is recommended that, in addition to the one-per-second averaged sea surface height and all associated corrections, each record of the GDR also contain a series of 10-per-second fully-corrected altimeter heights.*

The recommendation for including the 10-per-second altimeter heights in the GDR has been formally submitted by the Project Scientists to the T/P Project for consideration by March 1989. The draft GDR baseline (Section 11) includes these quantities.

15. FLAGS AND LAND-SEA MAP

The fact that T/P will carry two altimeters, and that the US altimeter has an internal redundancy, leads the SIMGD to make the following recommendation.

- *It is recommended that a flag in the GDR indicate which of the two altimeters has produced the measurement, and which Ku-string of the US altimeter was active.*

To facilitate the extraction of good quality data over water or ice the following recommendations are made.

- *It is recommended that a flag in the GDR indicate whether the data is considered by the T/P Project as suspect data due to hardware anomalies.*

- *It is recommended that the T/P Project produce a document with suggestions for the altimeter data editing criteria to be adopted by a user.*

- *It is recommended that a flag in the GDR indicate whether the measurements are taken over water, over ice or over land. Measurements over coastal zones, rivers and in-land lakes should be flagged as measurements over water.*

The latter recommendation requires the application of altimeter return pulse shape analysis techniques and the availability of a good quality shoreline data base. Concerning this last topic, information has been received from R. Rapp (OSU) and B. Tapley (UT/CSR). Rapp has pointed out that the Naval Surface Weapons Center (NSWC) has developed an improved land/ocean mask, using the CIA World Data Bank II shoreline information, and that the Defense Mapping Agency (DMA) has recently developed an improved World Vector Shoreline (WVS) data base [7]. Tapley has mentioned a paper by C. Shum et al., dealing with the computation of a global land-sea map from shoreline information [8].

- *It is recommended that the T/P Project ask for support by the above mentioned persons to create a highly-accurate land-sea map.*

The draft GDR baseline (Section 11) reserves fields for flags to indicate whether there is land within a predefined radius from the measurement point, whether the water vapor content along the altimeter path is greater than a predefined value, whether the radiometer brightness temperatures are consistent with the presence of ice, and whether the waveforms are consistent with a return from the ocean surface.

16. MERGING OF GDR'S

The T/P satellite design does not allow the simultaneous operation of both the NASA and the CNES altimeter. Therefore, the two altimeters have to be operated separately, and in the present planning the CNES altimeter will be operated for about 5 percent of the time. Basically, two separate series of measurements will be produced. In fact, not only two series of measurements will be produced, but two completely separate GDR's, as NASA and CNES are responsible for filling the entire records of a GDR for the time periods that their national altimeter is active.

This means that those investigators who want to use the TOPEX and POSEIDON altimeter data simultaneously, have to merge the data on the two separate GDR's themselves. A disadvantage of this situation is that various investigator teams have to perform the same merging activity, which leads to the conclusion that it would be preferable if the T/P Project would perform the merging and distribute the merged datasets to the investigators.

Within the SIMGD a long discussion has been carried on about the orbit discontinuities introduced when the two GDR's are merged, and about a possible preference of having both the NASA and the CNES orbit on each record. Concerning the discontinuities, the conclusion was reached that the discontinuities will be very small as CNES will apply (about) the same constants and models as NASA (Section 6), and because the CNES ZOOM software system will be fully calibrated against the US GEODYN and UTOPIA software systems (Section 10). It should also be realized that discontinuities can never be prevented completely, as the orbit of the satellite will be determined from independent tracking data arcs with a length of about 10 days, and as the two altimeters are different instruments built according to different specifications. It is understood, however, that the T/P Project will place these discontinuities over land. The availability of the NASA and CNES orbit on the same record was finally decided not to be recommended, because this leaves the decision about what orbit to be selected for the data analysis to the investigator, who generally is not an orbit mechanics expert, and because the differences between both orbits will be small for the reasons mentioned above. Therefore the following recommendation is made.

- *It is recommended that, in addition to the separate TOPEX and POSEIDON GDR's, a combined GDR be made available, where the two separate GDR's are merged in chronological order. A flag should indicate which altimeter is active, but during the merging no modifications should be made to the records.*

Both NASA and CNES will undoubtedly also compute T/P orbits for the periods that their national altimeter is not active. To support those investigators who wish to process the CNES and NASA altimeter data simultaneously, but who prefer to use exclusively the NASA or the CNES orbit:

- *It is recommended that separate tapes be made available with continuous NASA and continuous CNES orbits, as well as the associated software to extract the orbit information at the times on the records of the T/P merged GDR.*

To ensure that one can properly merge the two GDR's into a continuous internally consistent data set, continuous files of a number of altimeter measurement corrections as computed from NASA and CNES models have to be available, at least if these models differ. Examples of these corrections are: sea level pressure data, tide elevations, ionospheric electron content, and wet tropospheric data.

- *It is recommended that NASA and CNES archive the values of relevant corrections computed from their models for the entire mission, regardless of which altimeter is on, and that these data are available to interested investigators.*

17. CROSS-OVER DATASET

The computation of the exact locations of all altimeter height cross-overs and of the cross-over differences is a lengthy numerical process, in particular for a mission duration of three or more years as planned for T/P. To support those investigators who are not in a position to regularly compute the cross-overs:

- *It is recommended that a separate T/P altimeter cross-over data set be made available once a year, where for each cross-over within each 10-day repeat period the (interpolated) GDR's of corresponding ascending and descending tracks are included in one record.*

If this is not possible, an alternative cross-over dataset should be produced, which consists of a small series of records from the original GDR around each nominal cross-over point. The interpolation required to find in each series the actual cross-overs is then left to the investigator.

During the second T/P SWT meeting in Toulouse, UT/CSR has offered to generate a dataset with all cross-over times and locations, and to make this dataset available to all investigators.

- *It is recommended that the T/P Project accept this offer by UT/CSR and take all actions required to archive and distribute that dataset.*

18. CATALOGS AND HANDBOOK

From the T/P Mission Description document it is understood that a number of catalogs and records will be produced by the US and French TOPEX and POSEIDON Data Information Facilities, and that these will be accessible to the investigators. For the investigations with the altimeter data the most important are the TLM, SDR and GDR catalogs, the Precision Orbit Record catalog, Ascending Node/Rev Record and Orbital Elements Record catalog. Concerning the catalogs the following recommendation is made.

- *It is recommended that, in addition to the catalogs mentioned, a catalog that specifies the exact times when orbit maneuvers have occurred be produced and made accessible to the investigators.*

To support an investigator to process the T/P GDR's in the correct way the following recommendation is made.

- *It is recommended that before the start of the mission a user handbook be published with a clear and detailed description of the information content of the GDR's. This handbook should also include a complete worked out example, in order to avoid any obscurity about the proper sign of corrections to be applied.*

19. DATA PROCESSING PREPARATION

The SIMGD considers it essential that the investigators can check and validate their processing techniques and software systems before the mission. For this reason the following recommendations are made.

- *It is recommended that investigators be provided with a set of simulated T/P data in the standard format about six months before launch of T/P.*

- *It is recommended that during the system verification and validation phase interested investigators be provided with the Interim Geophysical Data Record (IGDR) as soon as these data become available, and that the T/P Project should encourage all investigators to process these data and to intercompare the results produced by various teams.*

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21. APPENDIX

On the following pages a summary sheet for the description of the terrestrial system attached to a set of station coordinates, contributed by C. Boucher, has been reproduced.

SUMMARY SHEET FOR THE DESCRIPTION OF THE TERRESTRIAL SYSTEM ATTACHED TO A SET OF STATION COORDINATES

-=-=-=-=-=-

1 - Technique :

2 - Analysis Center :

3 - Solution identifier :

4 - Software used :

5 - Relativity scale :

6 - Permanent tidal correction on station :

7 - Tectonic plate model :

8 - Velocity of light (C) =

9 - Geogravitational constant ($GM_{\oplus}$) =

10 - Reference epoch =

11 - Adjusted parameters :

12 - Definition of the origin :

13 - Definition of the orientation :

14 - Constraint for time evolution :

Contributed by C. Boucher, International Association of Geodesy, Special Study Group 5.123.

GUIDELINES TO FILL UP THE SUMMARY SHEET

-=-=-=-=-=-

1 - Technique

Select the type of technique : SLR, LLR, VLBI, GPS, DORIS, PRARE, Doppler, Combined ...

2 - Analysis Center

Name or usual acronym of the Analysis Center
Ex. : GSFC, CSR, NGS, DMA, DGFI, JPL, DUT, IFAG, GRGS, SO, CFA, MIT, BIH ...

3 - Solution identifier

Ex. : SL7.1, SSC(NGS)87R01, SV3 ...

4 - Software used

Name, such as : GEODYN, UTOPIA, CALC, MASTERFIT ...

5 - Relativity scale

SSB : solar system barycentric (usual for VLBI or LLR)
LE : local Earth (usual for SLR)

6 - Permanent tidal correction or station

This effect on coordinates is :

$$X \text{ (at epoch t)} = X_0 + \Delta X_{perm} + \Delta X_{periodic} \text{ (at t)}$$

Yes will mean that both ΔX_{perm} and $\Delta X_{periodic}$ have been used, so that the output position is X_0.

No means that only $\Delta X_{periodic}$ is applied, or no correction at all. Then, the output position is $X_0 + \Delta X_{perm}$

We recall that ΔX_{perm} is mainly a vertical effect, of :

$$\Delta h_{perm} = -0.121 \left(\frac{3}{2}\sin^2\phi - \frac{1}{2}\right) \text{ (m)}$$

7 - Tectonic plate motion model

Indicate the type of model used (if any)
Ex. : AMO-2, AM1-2 ...

8 - Velocity of light

Value used, in m/s
Currently 299 792 458
Previous value 299 792 500

9 - Geogravitational constant

Value used for $GM_{\oplus}$, including the atmosphere. In SI units ($m^3 \times s^{-2}$)

The current recent values are :

$$GM_{\oplus} = 3.9860\ 0440 \times 10^{14}\ m^3 s^{-2}$$

Previous value (MERIT) :

$$GM_{\oplus} = 3.9860\ 0443 \times 10^{14}\ m^3 s^{-2}$$

They are usually expressed in a local Earth frame. In barycentric frame, the value is different :

$$GM^B_{\oplus} = GM^L_{\oplus}\ (1 - 1.5 \times 10^{-8})$$

$$\simeq GM^L_{\oplus} - 6 \times 10^6 m^3 s^{-2}$$

10 - Reference epoch

If any, e.g. for coordinates

11 - Adjusted parameters

List of adjusted parameters in the least squares solution. They can be either free or constrained with an a priori variance.

Examples of lists :

$X_o \quad Y_o \quad Z_o$

$X_o \quad Y_o \quad Z_o \quad \dot{X} \quad \dot{Y} \quad \dot{Z}$

$X_o \quad Y_o \quad Z_o \quad \dot{\lambda} \quad \dot{\phi}$

$\lambda_o \quad \phi_o \quad h_o \quad \dot{\lambda} \quad \dot{\phi}$

$\lambda_o \quad \phi_o \quad h_o \quad \dot{\lambda} \quad \dot{\phi} \quad \dot{h}$

$X_o \quad Y_o \quad Z_o \quad \Omega_x \quad \Omega_y \quad \Omega_z$

$X_o \quad Y_o \quad Z_o \quad L_{X_k} \quad L_{Y_k} \quad L_{Z_k}$

$X_k \quad Y_k \quad Z_k$

We have assumed the general physical model for station positions :

$$X = X_o + \dot{X}(t - t_o) + L_k$$

with in some case $\dot{X} = \Omega \wedge X_o$

12 - Definition of the origin

How the origin is defined.
For instance, in dynamical techniques, this is the geocenter through $C_{10} = 0$, $C_{11} = 0$ and $S_{11} = 0$.

In VLBI, a station position is held fixed to some values (at some epoch or always).

13 - Definition of the orientation

How the orientation is defined.
For instance, by adopting at a given epoch ERP values, or equivalently two latitudes and one longitude.

14 - Evolution with time

How the system evolves with time, especially in orientation.
Examples :

- fixed plate motion model
- Tisserand condition
- constrained to an a priori model

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