GLOBAL POSITIONING SYSTEM

FOREWORD

In 1990 the IERS Directing Board set up an interim Technique Coordinating Centre for GPS to evaluate its potential for EOP applications and to encourage broader participation in the use of the technique. The GIG'91 Campaign (see 1991 IERS Annual Report) was a first attempt at coordinating on an international basis the efforts of a number of participants in deploying a globally distributed network of GPS tracking stations. The campaign was executed over three-week period in Jan-Feb 1991. Its primary purpose was to collect tracking data with sufficient strength to evaluate the accuracy of the GPS ephemeris products, the tracking station locations and the EOP information.

As a result of these IERS activities and partially out of recognition of the enormous potential of GPS, if properly coordinated, a small working group was formed in early 1990 with the goal of establishing a permanent GPS service operated through the cooperative efforts of a number of organizations and agencies under IAG auspices. The objectives of the International GPS Geodynamics Service (IGS) are to provide to the scientific community GPS data products with the highest accuracy, reliability and integrity that is economically feasible. The working group organized a three-month campaign, IGS'92, which started in June 1992. This campaign initiated the effective operation of the IGS, including the setting up of a close cooperation between IERS and IGS.

Since the IGS'92 campaign the network of GPS stations has largely remained intact and continued to make continuous observations; it also has grown considerably. As a result there is a continuing effort by a number of analysis centers to process the data on an ongoing basis and to generate GPS satellite ephemerides, station locations and velocities, and EOP results. A total of eight GPS Analysis Centers have contributed their Earth orientation and terrestrial frame results to the IERS Central Bureau and sub-Bureau for Rapid Service and Predictions.

In parallel, the future cooperation of IERS with the International GPS Geodynamics Service (IGS) was discussed in detail by the two services. The final agreement is that the IERS will rely on IGS for the GPS observations and their organisation, and that in turn the IGS rules will make provision for the interfacing of its participants with IERS, including direct interaction of the GPS Analysis Centres with the IERS Central Bureau and Sub-bureau for Rapid Service and Predictions.

The global Earth rotation and terrestrial frame results described in this section are based on observations collected since 1991 and analysed during 1992 in this context.

Several sets of station coordinates have been computed by the Terrestrial Frame Section of the IERS Central Bureau, at IGN, and proposed to the IGS analysis centers to be used in their orbit computation. They are referred to in some of the analysis descriptions published in these volume. These sets are:

1) SSC(IERS) 92 C 02 (epoch 1992.5): 1st version sent in IGS Mail #33 on 1 July 1992. This set has been computed by referring the ITRF91 coordinates to epoch 1992.5 using its velocity field and adding the local ties between GPS and SLR-VLBI reference points. These local ties concern only GPS points which are not originaly in the ITRF91.

2) SSC(IERS) 92 C 03 (epoch 1992.5): 2nd version sent in IGS Mail #65 on 12 August 1992. This set has been computed using the same procedure as in 1. Some stations have been added or updated.

3) SSC(IERS) 92 C 04 (epoch 1992.5): 3rd version sent in IGS Mail #90 on 9 September 1992. This set has been computed using the same procedure as in 1. Some stations have been added or updated.

4) SSC(IERS) 93 C 01 (epoch 1992.6): 4th version which was presented at the IGS Workshop in Bern and is published in the proceedings of this Workshop. This set has been computed in two steps. In the first step a global combined GPS solution has been computed using five GPS solutions provided by five analysis centers: JPL, SIO, CSR, CODE and EMR. In the second step the global combined GPS solution has been combined with the ITRF91 at epoch 1992.6.

5) SSC(IERS) 93 C 02 (epoch 1993.06): 5th version (included in IGS Mail #236, 5 April 1992). It is extracted from SSC(IERS) 93 C 01, containing the 12 selected sites as decided at the IGS Workshop in Bern. It is shifted to 1993.06 epoch using the ITRF91 velocity field.

W.G. Melbourne
GPS Coordinator

ANNUAL REPORT OF THE CODE PROCESSING CENTER OF IGS FOR 1992

EOP(CODE) 92 P 04
SSC(CODE) 92 P 01, 02

G. Beutler, M. Rothacher, W. Gurtner, T. Springer, E. Brockmann, S. Fankhauser, S. Botton, L. Mervart, U. Wild, A. Wiget

1. INTRODUCTION

General Remarks

Today we are looking back to about eight months of processing the observations of the IGS Core network (IGS=International GPS Geodynamics Service). Our contribution to this service started around 21 June 1992, the start of the 1992 IGS Test Campaign, and it was never stopped since. In the initial phase the emphasis had to be put on the development and perfection of the routine processing. Data flow, automatic (pre-)processing, and routine quality control were set up, program bugs had to be fixed, human interactions were minimized. In the second priority the physical modeling was improved and checked parallel to the routine processing. This first phase is over about now. The emphasis in the second phase will lie on the critical analysis of the used models and on the development of long-term analysis capabilities.

It is worth mentioning that in this first phase we developed the mental and technical capacity of processing on a very high accuracy standard permanent GPS tracking data. The same is true for the six other IGS processing centers that were active since 21 June 1992. This fact undoubtedly is of highest importance for fundamental astronomy, global and regional geodynamics in future.

The CODE Processing Center

CODE (Center for Orbit Determination in Europe) is one of the processing centers of the International GPS Geodynamics Service (IGS). Four institutions are collaborating under this label :

- The Swiss Federal Office of Topography (L+T)
- The French Institut Geographique National (IGN)
- The German Institute for Applied Geodesy (IfAG)
- The Astronomical Institute of the University of Berne (AIUB)

All mentioned institutions are supporting CODE either by manpower or financially. It was agreed within CODE that only a long term committment makes sense in this field of science. Therefore, after having seen during the 1992 IGS Test Campaign (21 June - 23 September 1992) that the human, hard- and software resources were about adequate, CODE continued operating after the official end of the 1992 IGS

Test Campaign (21 June - 23 September 1993). Today CODE is one of the processing centers of the IGS Pilot Service (intermediary IGS Service starting on 1 November 1992 and ending when the "final" IGS Service will be established by IAG).

The processing center is located at the AIUB, where the computations are done on a cluster of VAX computers. The Bernese GPS Software Version 3.4+ is used. The "+" indicates that the official version of the Bernese Software had to be gradually updated to meet the requirements of the routine processing.

In IGS terminology Processing Centers are meant to produce orbits on a regular, preferably daily, basis. The delay between observation and availability of orbits should essentially be driven by the time it takes to make observations available at the IGS network centers (CDDIS, the Crustal Dynamics Data Information System of NASA, IGN, the Institut Geographique National, and SIO, Scripps Institution of Oceanography).

This was exactly the understanding of the task at CODE : Since 21 June 1992 an uninterrupted series of orbits, earth rotation parameters, coordinates, and miscellaneous results is being generated. It is worth mentioning that CODE results were delivered to CDDIS and IGN for every day (non-AS days and AS days, AS = Anti-Spoofing) since 21 June 1992. The results were sent on a weekly basis, the delay so far was on the order of 7-10 days.

In 1992 the accuracy of CODE results was significantly deteriorated under AS, which could be attributed to a mal-functioning of the ROGUE receiver under AS. This was disappointing for us, because processing and pre-processing schemes at CODE should give results of comparable quality independent of AS (see below).

It is remarkable how the understanding of the project was developing at CODE since the beginning of the operations : In the proposal to IGS we wrote (May 1991) :

- the main purpose is the computation of GPS orbits for the entire system.
- the emphasis will lie on regional orbits over Europe.

Side issues will be :

- earth rotation parameters
- regional ionosphere models for Europe
- satellite clock parameters

It was planned to process the observations of about 12-15 stations, where more than half of them should lie in Europe.

This original concept had to be modified rather quickly : It became evident that highest quality orbits could only be produced, if earth rotation parameters with 1 mas accuracy or better were generated together with the orbits; it was not possible to rely on predictions stemming from other space techniques. Due to these facts and due to the circumstance that the ERPs were analysed very rapidly by IERS agencies (Central Bureau and the IERS Rapid Service), ERPs became of primary interest already in the routine operations. Also it became clear that 12-15 stations were not enough; today the data of about 30 stations are routinely analyzed. Even now we feel that the scarcity of

stations in South America, Africa, former Soviet Union, and India is one of the most important accuracy-limiting factors of our (and other centers) analyses.

Although we will not discuss all aspects mentioned in our original proposal, we would like to point out that we are still following these topics :

- during the 1992 Test Campaign we were producing free-network solutions for Europe. The results were handed over to the IERS.

- we were and are producing local ionosphere models for Europe. We could demonstrate that these models together with our CODE orbits allow ambiguity-resolution baseline by baseline (Mervart *et al.*, 1993). Analyses of this kind demonstrate the usefulness of the IGS concept for the "normal" user.

2. ANALYSIS CHARACTERISTICS

The summary given here is based on the papers (Rothacher *et al.*, 1992) and (Gurtner *et al.*, 1992) presented at the IAG Symposium No 112 in Potsdam.

Automated Data Flow, Processing Scheme, and Technical Aspects

The incoming data are sent to CODE via FTP by IGN and IfAG. In a first step data files are decompressed, the a priori orbits are generated (based on broadcast orbits), the receivers are synchronized to GPS time (using either C/A- or P-code), single difference files are formed, then the phase single difference files are screened. It is important to know that it is not necessary to use the P-code in our pre-processing scheme. If it is available we usually run a program which cleans the wide-lane on the zero-difference level using the Melbourne/Wuebbena linear combination of phase and code. If (under AS) the P-code is not available, this pre-processing part is simply skipped. Afterwards the single difference phase observations are screened, where the ionosphere-free linear combination L3 and the wide-lane L5 are checked for discontinuities. If the code/phase linear combinations were screened previously, we may use a program switch which will assume that L5 is clean already. If discontinuities are encountered, it is checked whether they can be safely removed by adding integer numbers of cycles in the individual carriers. If this is not the case, new ambiguities are set up. Through this procedure we perhaps set up too many ambiguities, but we have the advantage that the procedure may be used under AS too.

In a second step one-day solutions are computed. During the first few months we used these solutions for pure data quality checks. Later on we became aware that these solutions already are of a remarkable quality. Therefore, since 25 July 1992 we are keeping track of the earth rotation parameters x and y. It is planned to compare them to our 3-days series in future.

In the third step 3-days solutions are produced. All results leaving CODE are based on these 3-days solutions. We generate one such solution for each day, which means that we are working with overlapping orbits. The principle is shown in Figure 1.

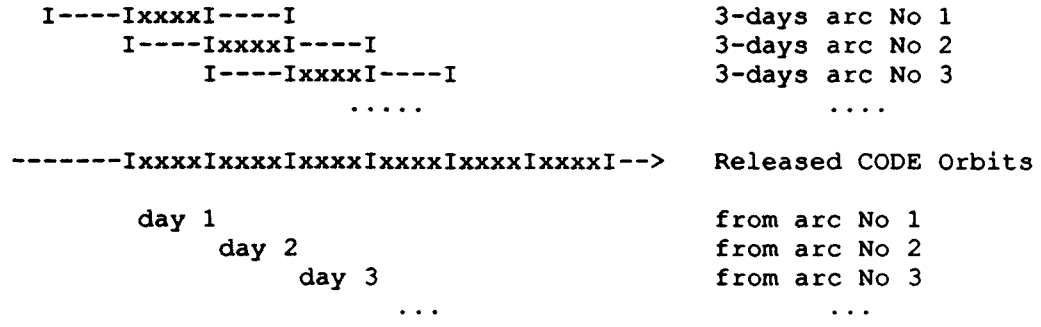


Figure 1: Processing in Overlapping Intervals at AIUB (Official CODE orbits)

During the 1992 IGS Test Campaigns steps 2 and 3 of our analysis were done separately for the European sites and for the Global sites. With the beginning of the IGS Pilot Service the separate European solution was discontinued, but all European stations were incorporated into the Global solution. We are now routinely producing two different solutions : one solution with fixing a certain number of stations (among them are 5 European sites, see Table 2) to their official ITRF coordinates, in a second program run we are processing exactly the same observations, but we are leaving all European sites (apart from Wettzell) unconstrained. In this way we are still producing "free" European solutions.

The force model

Earth's Potential and related Information :

- GEM-T3 (8,8) model (including the non-zero terms C21, S21 (!)) as specified in the IERS standards (Mc Carthy, 1992)
- GM=398.6004415 10^{12} m^2/s^2
- Equatorial Radius of the earth a = 6378137.0 m

Gravitation by sun/moon :

at present we are using analytical approximations for the recommended JPL DE-200 series. The differences to the DE-series are not important for the arc-lengths (maximum of three days) which we are using at present. For long term analyses (a few months) the differences might become relevant. This is why we will incorporate the DE-200 in the near future into our routine processing scheme too.

Radiation Pressure Modelling

We use the Rock4, Rock42 models according to Fliegel (1992). In this model the satellite masses must be used. In Table 1 we give the masses we use at present as a priori values. These a priori models are left unchanged in our processing.

We may solve, however, for a direct radiation pressure parameter dp0 (pointing from the sun to the satellite) and for a y-bias parameter p2.

Table 1 also contains the input parameters for the Rock models and other satellite specific data which are used in our processing.

Table 1. Satellite Specific Data

SATELLITE SPECIFIC DATA

PRN	BLOCK NO.	ANTENNA OFFSETS (M) DX	DY	DZ	MASS (KG)	DP0 (1.E-8)	P2 (1.E-9)	ROCK MODEL (T=1,S=2)	
1	3	0.2794	0.0000	1.0259	975.	0.0000	0.0000	2	ok
2	2	0.2794	0.0000	1.0259	878.2	-0.8596	0.8249	2	ok
3	1	0.2100	0.0000	0.8540	521.8	-0.1098	0.2328	2	ok
6	1	0.2100	0.0000	0.8540	453.8	-0.1600	0.7385	2	off
8	1	0.2100	0.0000	0.8540	440.9	0.0000	0.0000	2	off
9	1	0.2100	0.0000	0.8540	462.6	0.0000	0.0000	2	off
11	1	0.2100	0.0000	0.8540	522.2	-0.2749	-0.5216	2	ok
12	1	0.2100	0.0000	0.8540	519.8	-0.1856	0.2371	2	ok
13	1	0.2100	0.0000	0.8540	520.4	-0.4206	-0.6902	2	ok
14	2	0.2794	0.0000	1.0259	887.4	-0.8120	0.8043	2	ok
15	2	0.2794	0.0000	1.0259	885.9	-0.7188	0.6608	2	ok
16	2	0.2794	0.0000	1.0259	883.2	-0.7046	0.4846	2	ok
17	2	0.2794	0.0000	1.0259	883.2	-0.6821	0.6294	2	ok
18	2	0.2794	0.0000	1.0259	883.2	-0.7657	0.0000	2	ok
19	2	0.2794	0.0000	1.0259	883.2	-0.8262	0.4905	2	ok
20	2	0.2794	0.0000	1.0259	887.4	-0.9558	0.3691	2	ok
21	2	0.2794	0.0000	1.0259	883.9	-0.7674	0.3047	2	ok
22	3	0.2794	0.0000	1.0259	975.	0.0000	0.0000	2	new
23	3	0.2794	0.0000	1.0259	972.9	0.3138	0.3932	2	ok
24	3	0.2794	0.0000	1.0259	975.	-0.7518	1.0852	2	ok
25	3	0.2794	0.0000	1.0259	975.	-1.0015	0.9704	2	ok
26	3	0.2794	0.0000	1.0259	975.	0.0000	0.0000	2	new
27	3	0.2794	0.0000	1.0259	975.	0.0000	0.0000	2	new
28	3	0.2794	0.0000	1.0259	975.	-0.1438	0.1147	2	new
29	3	0.2794	0.0000	1.0259	975.	0.0000	0.0000	2	new
30	3	0.2794	0.0000	1.0259	975.	0.0000	0.0000	2	next
31	3	0.2794	0.0000	1.0259	975.	0.0000	0.0000	2	next
32	3	0.2794	0.0000	1.0259	975.	0.0000	0.0000	2	new

BLOCK NUMBER: BLOCK I = 1, BLOCK II = 2, BLOCK IIA = 3, BLOCK IIR = 4

Light <--> Shadow Changes

We assume instantaneous light <--> shadow transits. The corresponding transit times are computed by indirect interpolation, the numerical integration is initialized at these points (to allow for discontinuities of the forces at these times).

Problem if the sun is in the orbital plane:

The rules which are given by Fliegel (1992) to compute the orientation of the satellites (x-, y-, and z- axes) ask for very rapid rotations by the angle of 180 deg of the spacecraft around the z-axis at two points in the orbit in this case. This may cause numerical problems. The same problem of course occurs in reality. One should know how the GPS satellites actually behave under these circumstances. Experience shows that the orbit modelling is usually more delicate if these situations occur.

Solid Earth Tides :

Implemented according to the IERS standards (Mc Carthy, 1992).

General Relativity :

Taken into account according to IERS standards.

System of Orbit Integration :

J2000.0. The IAU 1980 models for precession and nutation are used. The corrections $d\psi$, $d\varepsilon$ distributed by the IERS bulletins were not used so far.

Our realization of the ITRF

Table 2 gives the list of tracking stations we keep fixed in our analysis. The corresponding site eccentricity information can be found in IGS Mail No 90. The used coordinates are VLBI and SLR coordinates in the ITRF system according to the IGSMAIL No 90.

In addition it is important to note that we apply the deformations due to the solid earth tides (Mc Carthy, Chapter 7, Eqn.6) before using a station position at a special time t.

Table 2: Fixed stations ,*): these stations are not any more fixed since the beginning of the IGS Pilot service

```
Fixed stations in the processing (Global set):
                          1.   KOSG 13504M002
                          2.   MADR 13407S010
                          3.   MATE 12734S001 *)
                          4.   TROM 10302M002
                          5.   WETT 14201S004
                          6.   ONSA 10402S002
                          7.   KOKB 40424S001 *)
                          8.   ALGO 40104S001
                          9.   FAIR 40408S002
                         10.   GOLD 40405M013
                         11.   YELL 40127M001
                         12.   RCM2 40499M002
                         13.   CANB 50103S010
                         14.   YAR1 50107M001
```

Miscellaneous Modelling components

Orbits:

A pseudo-stochastic orbit modelling capability was introduced around January 1993. The principle is the following : At predetermined times (e.g. six times during the day (equidistant spacing)) impulse-changes may be solved for, where it is again possible to constrain those changes. The resulting orbital trajectory is, but its first derivative is not continuous. A series of 'stochastic' solutions over a time interval of months is available now. The results are interesting, the only real problem seems to be the long-term stability of the UT1-UTC estimates. Residual difficulties with cases where no or only few observations are available still exist. These solutions are not part yet of the official CODE results.

Troposphere:
Modelling tropospheric refraction is a crucial element. We use an a priori model based on the Saastamoinen theory. In addition we may introduce for each site a number n of troposphere parameters (zenith delays) per day. These parameters may be constrained in two different ways, (a) by imposing a priori weights (thus constraining their absolute variations), (b) by imposing a priori weights to the difference of subsequent troposphere parameters. This allows us to model the troposphere in many different ways, e.g. as a random walk with predetermined characteristics. (For more information see Rothacher (1992)).

Earth Rotation Parameters:
In the parameter estimation program the total time interval covered by observations may be divided into smaller time intervals, so called partial intervals. Within each partial interval the pole may be modeled as a polynomial in time, where the polynomial degree (separately for x, y, and UT1-UTC) has to be specified by the user. It is possible to ask for a continuous pole at the partial interval boundaries.

Ambiguity parameters:
Ambiguity parameters (at least one per day and satellite, in general it is necessary to introduce more (after breaks, losses of lock)).

Characteristics of the routine solutions

Table 3 : Solution Characteristics for NG SERIES and EU SERIES

(a) Global Solution

Agency	: CODE
Solution Identifier	: "NG"
Orbit Arc Length	: 3 days, overlapping
Orbit Parameters	: Osculating Keplerian Elements (6 per arc & satellite) direct radiation pressure p0 (on top of ROCK Models, compare Table 1) and y-bias.
Troposphere unconstrained	:4 zenith delays per day and station, at present virtually
Fixed Coordinates	: KOSG, MADR, MATE, TROM, WETT, ONSA, KOKB, ALGO, FAIR, GOLD, YELL, RCM2, CANB, YAR1
Earth Rotation Parameters	: Each 3-day solution is divided into 3 one-day intervals. x, y, and UT1-UTC are modeled as polynomials of degree 0 (on top of the most recent pole distributed by the IERS Rapid Service) within each one-day interval. No continuity conditions were imposed. The UT1-UTC estimate of the first day is fixed to the a priori value (from the RAPID service)

(b) European Solution

Agency:	CODE
Solution Identifier:	"EU"
Orbit Arc Length:	3 days, overlapping
Orbit Parameters:	Osculating Keplerian Elements (6 per arc & satellite) direct radiation pressure p0 (on top of ROCK Models, compare Table 1) and y-bias.
Troposphere:	4 zenith delays per day and station, at present virtually unconstrained
Fixed Coordinates:	a) during the 1992 IGS Campaign: NONE (only a priori constraints according Table 4) b) during the IGS Pilot Service: WETT is kept fix together with the other global sites of Table 2.
Earth Rotation:	Each 3-day solution is divided into 3 one-day intervals. Parameters x, y, and UT1-UTC are modeled as polynomials of degree 0 (on top of the most recent pole distributed by the IERS Rapid Service) within each one-day interval. No continuity conditions were imposed. The UT1-UTC estimate of the first day is fixed to the a priori value (from the RAPID service)

Table 4: A priori constraints on the European coordinates during the 1992 IGS Campaign

Constaint on	East and North-Coordinates	Up-Coordinate
WETTZELL:	0.02 m	0.05 m
all other Stations:	0.05 m	0.10 m

3. RESULTS

3.1 Earth Rotation Parameters: EOP(CODE) 92 P 04

Figures 2a, 2b, and 2c contain the differences of our NG pole with respect to the C04 pole as computed by the IERS Central Bureau in Paris. The straight solid line shows the correction that should be applied (IERS Annual Report, 1991, Table II-3) to the C04 pole to be comparable with GPS estimates. With the exception of a short time interval in January 1993 (reason to be found) the agreement is satisfactory in x and y, there are significant differences however in our integrated UT1-UTC values. This is not too surprising in view of the fact that GPS is only capable of measuring the derivative of the UT1-UTC curve.

3.2 Coordinates

During the 1992 Test Campaign we produced free-network solutions for Europe. Independently from the processing of the globally distributed stations we performed solutions only with European stations. The European coordinates got weak constraints (see Table 4). Let us point out that the introduced constaints (Wettzell) are really weak.

For 115 3-day solutions (overlapping) (Days 171-285) residuals to the ITRF coordinates are analysed (after 6 Parameter Helmert transformation (3 Rotations, 3 Translations)).

The mean coordinate set EU P 92 SSC(CODE) 92 P 01 has the following properties:

- The sum of the residuals (after 6-Parameter Helmert transformation of each 3-Day Solution to EU P 92) of each coordinate is zero.

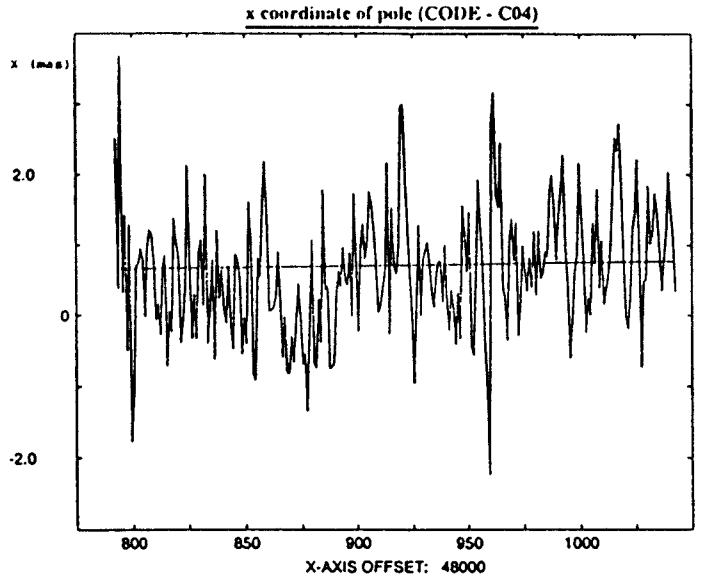
- Scale, translation and orientation of EU P 92 is the same as ITRF.

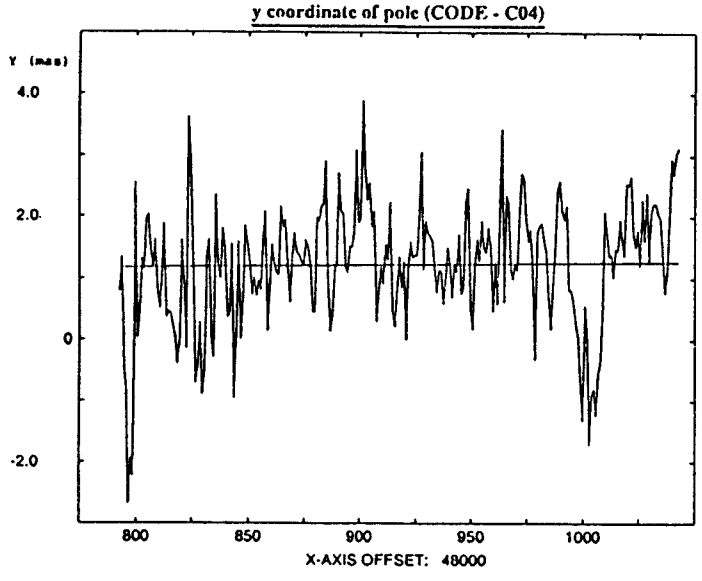
These results were handed over to the IERS.

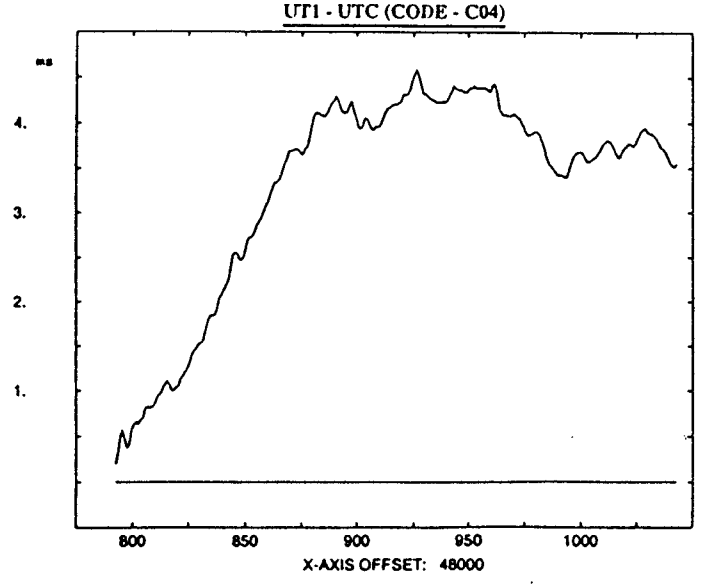
To confirm these coordinates, a second coordinate set is estimated with data since the beginning of the IGS Pilot Service (WETT is kept fix together with other global distributed sites of Table 2, all European stations are free):

Combining 119 3-day Solutions (day 312 (1992)- day 063 (1993)) with the full variance covariance matrix to a mean coordinate set gives coordinate set EU P 92-2 SSC(CODE) 92 P 02. No helmert transformation is necessary for this proceeding.

The consistency of these different coordinate sets, due to the used data (only European data -- global supported data) and due to the computation (Residual analysis after Helmert transformation -- Least square adjustment with full variance covariance matrix) is proved with a helmert transformation of EU P 92 and EU P 92-2. With one exception (TROM North direction) all residuals are below the 1 cm level.







Figures. 2a, 2b, 2c

References

Rothacher, M., *et al.*, 1992: Results of the Center for Orbit Determination in Europe (CODE) during the IGS 1992 Campaign, *IAG-Symposium No. 112*, Potsdam.

Gurtner, W., *et al*, 1992: Automated Data Flow and Processing at the Center for Orbit Determination in Europe (CODE) during the 1992 IGS Campaign, *IAG-Symposium No. 112*, Potsdam.

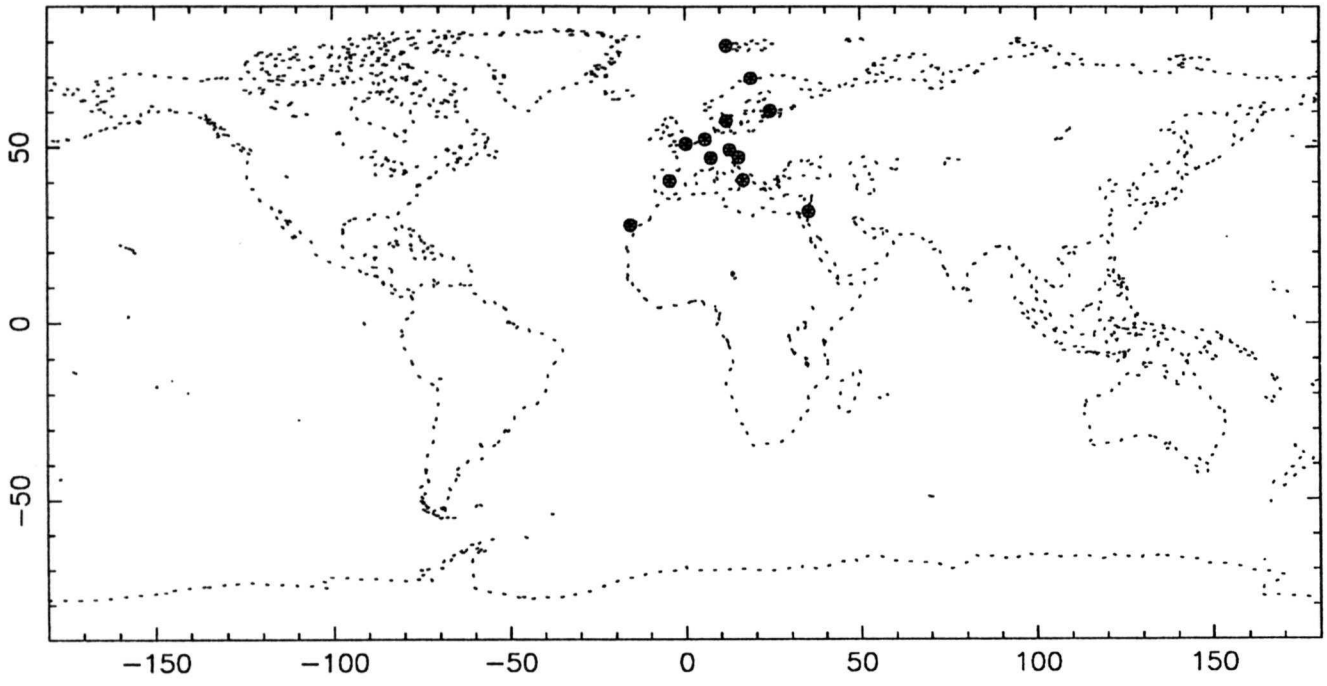
Mervart, L., *et al* 1993: Ambiguity Resolution using Results of the International GPS Geodynamics Service (IGS), paper submitted.

Rothacher, M., *et al* , 1992: Orbits of Satellite Systems in Space Geodesy, Ph. D. thesis, *Geodaetisch-geophysikalische Arbeiten in der Schweiz*, Volume **46**.

McCarthy, D.D., 1992: IERS Standards, *IERS Tech. note 13*, Observatoire de Paris, Paris.

IERS 1992: *IERS Annual Report 1991*, Observatoire de Paris, Paris.

Fliegel, H.F., *et al.*, 1992: Global Positioning System Radiation Force Model for Geodetic Applications, *J. Geophys. Res.*, **97**, No B1, 559.



Distribution of the 13 sites of the terrestrial frame SSC(CODE) 92 P 01.

EOP(CODE) 92 P 04 From Jun 1992 to Jul 1993

Number of measurements per year and median uncertainties
Units : 0.001" for X, Y; 0.0001s for UT1

YEAR	X		Y		UT1	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	196	0.10	196	0.10	196	0.07
1993	196	0.08	196	0.07	196	0.05

SITE COORDINATES FROM THE CENTER FOR SPACE RESEARCH SOLUTION CSR 92 P 03

M. M. Watkins, B. E. Schutz, and P. A. M. Abusali
Center for Space Research, University of Texas at Austin, Austin TX

Mean positions for all sites processed at the University of Texas Center for Space Research were adjusted using a noncontiguous 54 day subset of the data span from the IGS campaign in Weeks 650 through 662. The solution is fiducial free, so no sites were held fixed. The resulting site positions were corrected for geocenter motion in order to coincide with the CSR92L01 (which defines ITRF91) geocenter and frame orientation.

The a priori polar motion and UT1 were derived from Lageos laser ranging (constrained by IRIS VLBI at periods > 60 days) produced operationally at UTCSR for inclusion into the IERS rapid service bulletins.

The force and measurement models used for this solution conform generally to the IERS/IGS Standards, with the following exceptions:

1) The mean gravity field was TEG-2, a state of the art gravity field computed at the University of Texas Center for Space Research.
2) The ocean tide model was an enhanced version of the Schwiderski model extrapolated to include 80 consituents complete through degree and order 20, assuming admittances which vary linearly with frequency.
3) The solid tide model has been expanded to include third degree and fourth degree terms.
4) The geogravitational constant, GM, was 398600.4415 km^3/s^2.

Notes concerning the interpretation of the coordinates:

(1) The corrected antenna heights of 5.203 m at Ny Allesund and of 9.754 m at Hartebeesthoek have been used.

(2) The epoch of 1992.6 is reported because it is the (rounded) mean of the data used to adjust the sites, however, no tectonic velocities were modelled in the adjustment in order to achieve this exact epoch uniformly for each site.

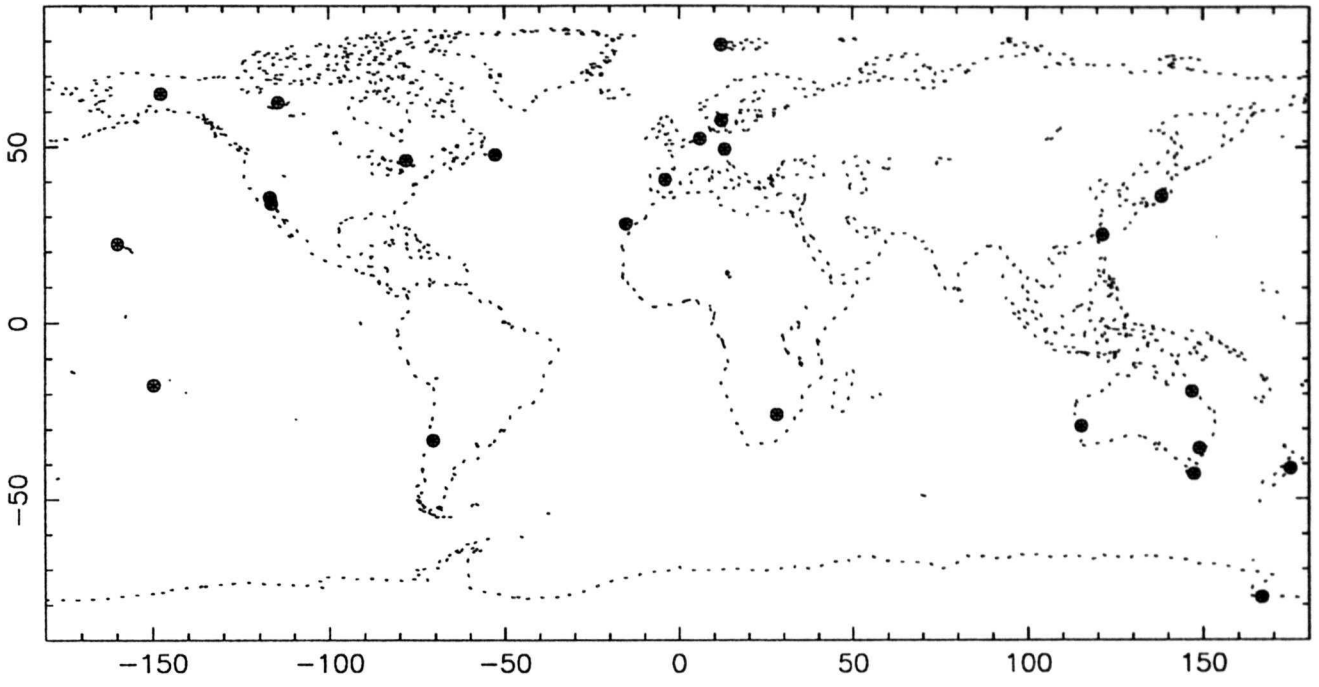
(3) The position for Pinyon spans the Landers earthquake, but with 7 days before and 38 days after, so the position will agree more closely with postquake positions from other groups, but may be slightly in error because of this.

(4) Usuda data after day 222 was not included in the solution, so the position reflects the position over the period from days 173-222, and does include the anomalous position afterwards.

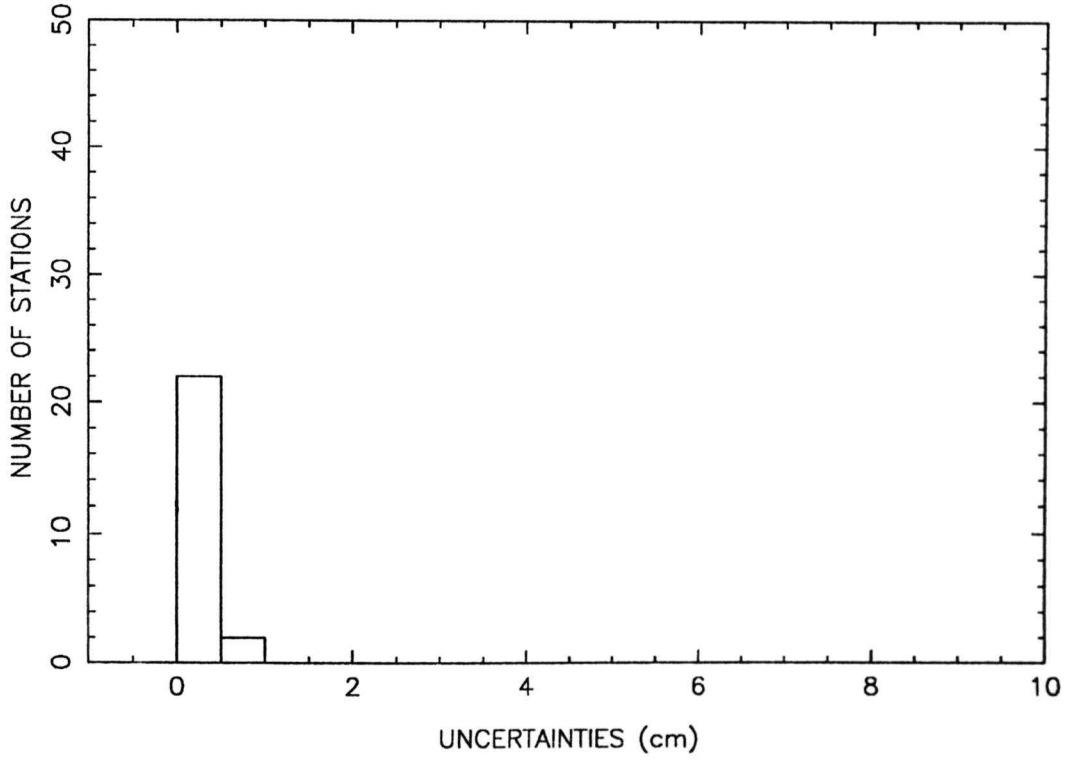
IERS(1993) Technical Note No 14.

Summary description of the terrestrial system attached to the set of station coordinates SSC(CSR) 92 P 03

1 - Technique:	GPS
2 - Analysis Center:	CSR
3 - Solution Identifier:	(CSR) 92 P 03
4 - Software Used:	MSODP1/LLISS
5 - Relativity Scale:	Geocentric (LE)
6 - Permanent Tidal Correction on station:	Tidal correction has nonzero mean. Positions do not reflect true mean.
7 - Tectonic Plate model:	Adjusted
8 - Velocity of light (C) :	299792458 m/sec
9 - Geogravitational constant (GM) :	398600.4415 km^3/s^2
10 - Reference Epoch :	1992.6
11 - Adjusted Parameters:	
Coordinates:	Epoch 1992.6 position for sites in cartesian coordinates solved globally for entire data span.
Phase Ambiguities:	Adjusted where necessary.
Orbit:	Epoch position and velocities, Rock4 Scale parameter, Y bias adjusted daily.
EOP:	Fixed to UTCSR operational series
12 - Definition of the origin:	Geocentric, C10 = C11 = S11 = 0.0
13 - Definition of the orientation:	System oriented to agree with ITRF91 in rotation and translation
14 - Constraint for time evolution:	None due to short time span



Distribution of the 24 sites of the terrestrial frame SSC(CSR) 92 P 03.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 24 stations of the terrestrial frame SSC(CSR) 92 P 03.

GPS DATA PROCESSING AT THE EMR ANALYSIS CENTRE EMR 93 P 01

J. Kouba, J. Popelar, P. Tetreault, R. Ferland and F. Lahaye
Geodetic Survey Division (GSD), Surveys, Mapping and Remote Sensing Sector (SMRSS), Energy Mines and Resources (EMR), 615 Booth St., Ottawa, Ont. K1A OE9

Since August 1992 the GSD's Master Active Control System (MACS) Centre has been reducing GPS data from six Canadian ACS stations augmented by up to 12 stations of the International Geodynamics GPS Service (IGS) global core station network. The GIPSY II/ OASIS GPS software system developed by the Jet Propulsion Laboratory has been adopted for daily processing. The GIPSY II processing has been highly automated using UNIX script to consolidate and integrate procedures into a single run. Eleven stations were constrained at the IGS coordinates (Table 2) and adopted constants, gravity and radiation pressure models conform to the IGS/IERS standards (Boucher *et al.*, 1992; McCarthy, 1992) The global ocean loading model due to Pagiatakis (1982) has been adopted. The submitted EMR EOP series starts on July 27, 1992 and does not include days with Anti Spoofing (AS).

The EMR processing is based on undifferenced phase and smoothed pseudorange data at 5 minutes sampling intervals using 15 degree elevation angle cut off. Both phase and pseudorange observations are considered uncorrelated and weighted according to sigmas computed from the following exponential model:

$$\sigma(E) = \sigma_0 + \sigma_1 e^{-(E/E0)}$$

where E is the elevation angle in degrees and the constants are: $E_0 = 20$, $\sigma_0 = 4$ mm, $\sigma_1 = 15$ mm for phase measurements at all stations; $\sigma_0 = 180$ and 780 mm for pseudoranges at most stations. Some stations (e.g. PAMA, STJO, YELL) have higher pseudorange noise due to multipath and are being weighted accordingly. We have also enhanced the GIPSY II software to allow different weighting of satellites, data segment deletion and corrections of biases. This proved to be useful for data reduction when AS satellites can be down weighted, deleted or bias corrected.

We have adopted 24h arcs without any data overlap. For each 24h arc the initial a priori state vector is taken from the previous day solution and propagated to the beginning of the current day making the estimation process self contained. Broadcast orbits are used only when introducing a new satellite, or after a large gap such as those due to early hardware problems associated with AS tracking. Using the preceding arc solution is not only more accurate than the broadcast orbit initialization, but it also offers a self check on daily solutions and a quick indication of orbit errors and/or problems relating to a particular satellite. The differences between the state vector estimation for successive days are typically below 1m and values larger than 1.5m are usually reported in the weekly summary files. In most cases larger differences

have been found for eclipsing satellites. This approach also facilitates another type of orbit modelling and estimation of DUT1. By assigning a priori orbit sigmas of 1m and 0.5 mm/s in fact approximates a random walk stochastic process with daily updates and sigmas of $1m/day^{0.5}$ and $(.5mm/s)/day^{0.5}$. This is due to the fact that the other sigmas are much smaller, typically below 10 cm and 0.03 mm/s. As a consequence of the colinearity between DUT1 and R. A. of the ascending orbit nodes, the estimated DUT1 contains both the DUT1 changes as well as the orbit node errors common to all satellites with sigmas and correlation characteristic of a random walk process, i.e. the covariance between day i and i+1 is

$$\sigma^2_{i,i+1} = \sigma^2_{i,i}$$

The variance $\sigma^2_{i,i}$ increases approximately with $i^{0.5}$, where i is the number of days since the DUT1 initialization. DUT1 is initialized the first non AS day of the GPS week using the most current USNO/IERS Bull. A values. The summary of estimated parameters, their a priori values and sigmas are listed in Table 1.

Table 1 : Summary of estimated parameters, a priori values and sigmas

Parameters	type	a priori values	a priori sigmas
StationX,Y,Z	constant	IGS/ITRF91 (1992.5)	50m (fixed .002-.02m)
Pole x,y	"	IERS/USNO Bull. A	3m
DUT1	"	"	3m ; fixed/reset every week
Trop. Z. dely	"	2.0m	.2m
Satell. states	"	prev. day solution	1km, .005m/s or 1m, .0005m/s
Sol. rad. Gx,Gz	"	1.0	.1 (10%)
Sol. rad. Gy	"	0	1.0 10E-9 m/s^2
Init. phase amb.	"	0	300000km
Trop. bias	random w.	0	.01m/sqrt(1h)
Station clock	w. noise	0	1s (ALGO H-Maser fixed)
Satell. Clock	"	0	0.001/.0001s for Block I/II

The orientation and to a large extend the scale of the EMR orbit/EOP solutions are nominally those of ITRF91 (epoch 1992.5) as realized through the set of up to 11 stations (Table 2) constrained at the ITRF91 coordinates which are primarily based on VLBI solutions. Also the DUT1 prediction is derived from VLBI DUT1 solutions/ For this submission the DUT1 estimations has been reinitilized by using the final values (FV) of IERS/NOES Bull. A, to ensure agreement with the Bull. A.

The reported EOP sigmas are the formal sigmas as estimated by the adjustment. As experienced from the repeatability of position solutions the formal sigma may be too optimistic, and need to be multiplied by a factor of 2 or 3.

Table 2: IGS/IERS station coordinate set used in EMR GPS processing:
(ITRF91 system epoch: 1992.5)

Station	IGS Code	DOMES	X (KM)	Y(km)	Z(km)	L1 m	L2-L1 m
Contrained Stations: 2mm - ALGO: 10mm - TROM, WETT, MADR; 20mm - all others							
Algonquin	ALGO	40104M002	918.129616	-4346.071224	4561.977800	0.1919	-0.0185
Fairbanks	FAIR	40408M001	-2281.621327	-1453.595775	5756.961976	0.1939	-0.0185
Goldstone	GOLD	40405S031	-2353.614083	-4641.385406	3676.976471	0.0779	-0.0185
Hartebee.	HART	30302M002	5084.625404	2670.366499	-2768.494039	9.8319	-0.0185
Madrid	MADR	13407S012	4849.202506	-360.329179	4114.913003	0.0779	-0.0185
Mcmurdo	MCMU	none	-1310.69525	310.468880	-6213.363449	5.0679	-0.0185
Santiago	SANT	41705M003	1769.693228	-5044.574103	-3468.321138	0.1709	-0.0185
Canberra	TIDB	50103S017	-4460.996091	2682.557181	-3674.444005	0.0779	-0.0185
Tromsoe	TROM	10302M003	2102.940451	721.569379	5958.192072	2.5510	-0.0185
Wettzell	WETT	14201S020	4075.578683	931.852634	4801.569980	0.0779	-0.0185
Yarragad.	YAR1	50107M004	-2389.025331	5043.316830	-3078.530926	0.1509	-0.0185
Yellowkn.	YELL	40127M003	-1224.452369	-2689.216048	5633.638286	0.1949	-0.0185
Unconstrained Stations							
A. Head	ALBH	40129M003	-2341.332759	-3539.049484	4745.791405	0.2079	-0.0185
Holberg	none	none	-2503.040302	-3188.233327	4908.701573	0.1979	-0.0185
Kokee Pk.	KOKB	40424M004	-5543.838080	-2054.587522	2387.809570	0.1709	-0.0185
Pamatai	PAMA	none	-5245.195148	-3080.472201	-1912.825643	8.4979	-0.0185
Penticton	DRAO	40105M002	-2059.164587	-3621.108390	4814.432423	0.1959	-0.0185
Prince Al.			-1050.708041	-3680.985753	5085.127839	0.0779	-0.0185
Calgary (Priddis)			-1659.60276	-3676.725778	4925.493699	0.1889	-0.0185
St. Johns	STJO	40101M001	2612.631359	-3426.807033	4686.757736	0.2399	-0.0185

References

Boucher, C., Altamimi, Z., Dufour, J.P., and Fagard, H., 1992: The IERS terrestrial reference frame and its extensions by IGS and DORIS, presented at NASA DOSE meeting, GSFC Greenbelt, Md, Oct.

McCarthy, D.D. (ed), 1992: *IERS Tech. Note 13*, Observatoire de Paris, Paris.

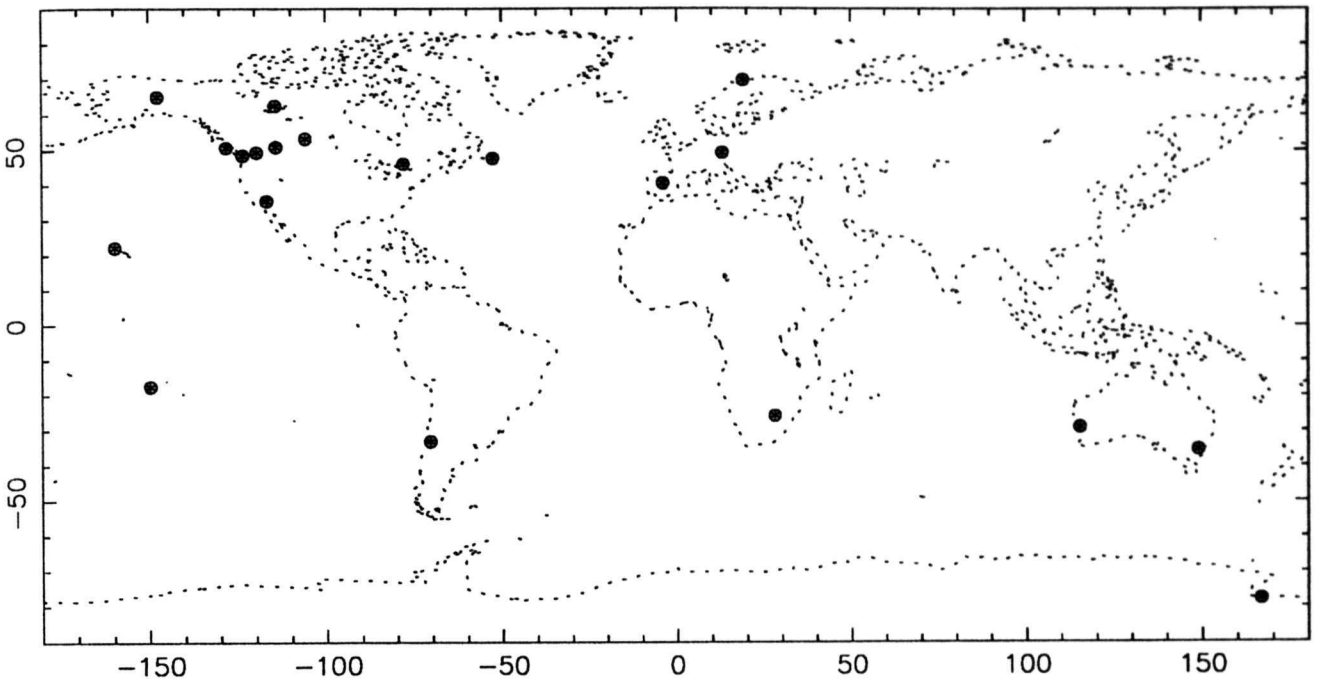
Pagiatakis, S.D., 1982: Ocean loading, body tides and polar motion effects on very long baseline interferometry, UNB Technical Rep. No. 2, Dept. of Surv. Engineering, Univ. of New Brunswick, Fredericton, N.B.

Summary description of the terrestrial system attached to the set of station coordinates SSC(EMR) 93 P 01

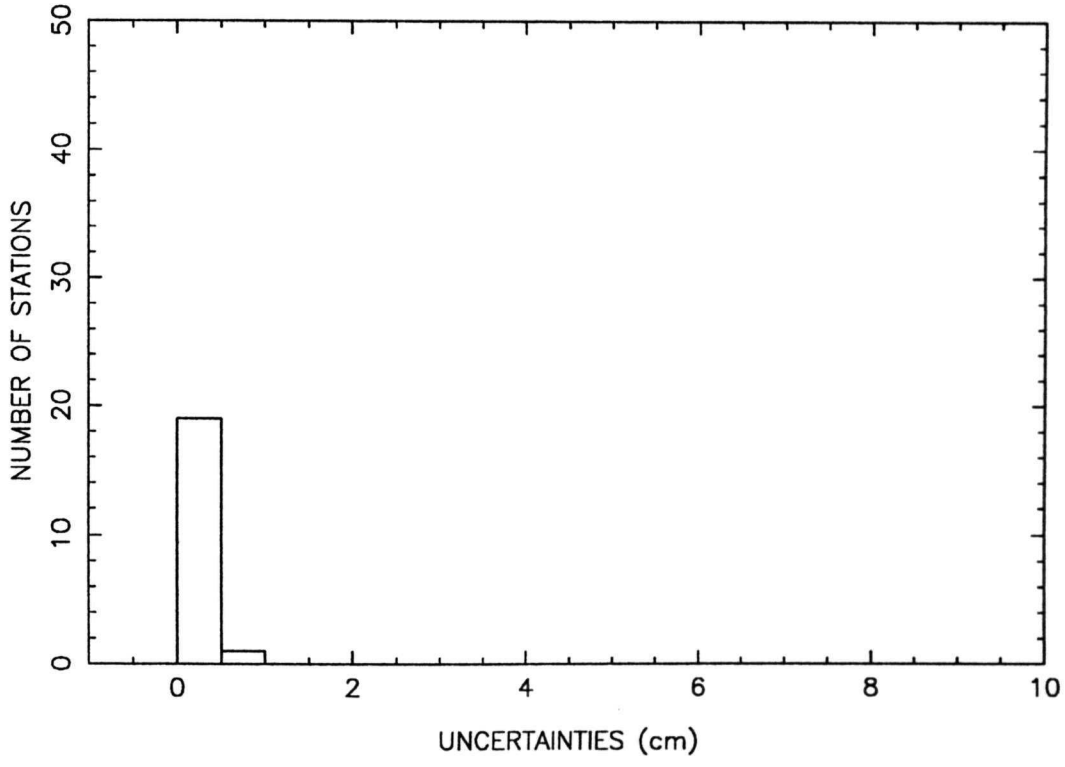
1 - Technique:	GPS
2 - Analysis centre:	Geodetic Survey Division (GSD), SMRSS, EMR
3 - Solution identifier:	EMR 93 P 01
4 - Software used:	GIPSY/OASIS II (UNIX)
5 - Relativity scale:	LE
6 - Permanent Tide correction:	none
7 - Tectonic plate model :	none, single epoch
8 - Velocity of light:	299792458 m/s
9 - GM:	389600.4414 km^3/s^5
gravity model:	GEMT3(8,8) +C21+S21
10 - Reference epoch:	1992.79

11 - Adjusted parameters:
- undifferenced phase and smoothed pseudorange data > 15 degrees @ 5 min
- single day (24h) arc with 6 IC and 3 rad. parameters per satellite (up to 21sat.)
- trop. zenith delay corr. parameter augmented with random walk stoch. process
- initial phase ambiguity parameters (1 for each satellite/station pass or initial phase)
- station positions X,Y,Z, up to 19 stations. ALGO, FAIR, GOLD, HART, TROM, WETT, YELL, MADR, MCMU, SANT, TIDB and YAR1 are constrained
- x, y pole position, once a day (DUT1 fixed/solved; DUT1, x, y apriori sigma=3m)
- station clock biases once per each epoch/station (except for ALGO h. maser which provides the time reference) with sigma 1 s
- satellite clock biases once per each epoch/satellite with 1 ms or 0.1ms sigma.

12 - Origin:	Nominally ITRF91
13 - Orientation:	" "
14 - Constraint for time evolution:	none



Distribution of the 20 sites of the terrestrial frame SSC(EMR) 93 P 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 20 stations of the terrestrial frame SSC(EMR) 93 P 01.

EOP(EMR) 93 P 01 From Jul 1992 to Dec 1992

Number of measurements per year and median uncertainties
Units : 0.001" for X, Y; 0.0001s for UT1

YEAR	X		Y		UT1	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	113	0.22	113	0.19	77	2.10

DAILY EARTH ORIENTATION PARAMETERS AND GROUND STATION POSITIONS FROM ROUTINE IGS92-CAMPAIGN PROCESSING

EOP(ESOC) 92 P 02
SSC(ESOC) 93 P 01

J.M. Dow, T.J. Martin-Mur (1), J. Feltens (2), C. Garcia-Martinez (1)
ESA/European Space Operations Centre, Robert-Bosch-Str. 5,
D-6100 Darmstadt, Germany
(1) GMV at ESOC; (2) mbp at ESOC

The GPS group at ESOC has been participating in the IGS service from June 21 1992. We are using double-differenced phase observables to estimate the IGS products (EOP's and precise orbits) and to obtain the observation equations for other geodetic parameters. For this processing we use BAHN, the standard ESOC orbit determination and geodetic parameter estimation program, also used for other precise orbit determinations (Lageos, ERS-1). We also have a program for multiarc processing that uses the observation equations generated by BAHN to produce estimates of geodetic parameters.

Description of the EOP-solution EOP(ESOC) 92 P 02

GPS data acquired since the beginning of the IGS'92 campaign at 21 June 1992 have been analyzed to obtain orbits, earth orientation parameters and positions of participating ground stations. The incoming IGS data is evaluated on a daily basis, EOPs are determined for 24-hour-intervals. The initial values are taken from IERS Bulletin A. For the period of 21 June 1992 to 14 November 1992, UT1 has been fixed to the IERS Bulletin A values. Since 15 November, the rate of change of the difference between UT1 and TAI has been included as additional unknown EOP parameter into the estimation process.

The terrestrial reference frame is defined by fixing a set of 11 ground stations, whose coordinates are provided in the ITRF91 (IERS Terrestrial Reference Frame, *IERS Tech. Note 13*) and are referred to epoch 1992.5. These coordinates have been provided in "IGS site information and coordinates", (Boucher and Altamimi, IGS Mail 33). These coordinates have been updated and distributed several times and in the meantime the coordinates of IGS Mail 90 are used (for a detailed history see Table 2). The names of the 11 fixed stations are listed in the under point 11.

NNR-NUVEL1 plate motion has been used for the station velocities, as recommended by IERS standards. No ocean loading has been applied to the ground stations and no relativity corrections to propagation or/and acceleration have been calculated (see point 15 in the summary).

The celestial frame is defined by standard J2000.0, and celestial pole offsets from IERS Bulletin A are included.

For a detailed desciption of the models used at the beginning of the ESOC-IGS evaluations at 21 June 1992 and the history of changes since then until today, see Tables 1 and 2. Results were obtained for all days, including those when anti-spoofing was applied.

Table 1. Models and constants used

The routine of IGS evaluations started at 21 June 1992 (IGS Mail 51)

- Velocity of Light: c = 299792.458 km/s
- Earth Gravitational Constant: GM = 398600.4415 km^3/s^2
- Mean Equatorial Earth Radius: Ae = 6378.137 km
- Solid Earth Tidal Love number.: h = 0.6090
- Solid Earth Tidal Shida number.: l = 0.0852

GPS data handelling
- GPS double-differenced phases, ionosphere-free combination, sampling rate 6 min, 10 degrees elevation cutoff; IGS data evaluation on a daily basis, i.e. 24-hour-arcs

Satellite force model
- Geopotential, GEM-T3 (n = 8, m = 8 plus C21 = -0.17 10^{-9} and S21 = 1.19 10^{-9})
- Solar Third Body Attraction
- Lunar Third Body Attraction
- Solid Tides, k2 = 0.300, phi = 0, Wahr frequency dependent corrections
- Ocean Tides, Schwiderski; n = 6, m = 2, 11 tidal constituents
- Non-Gravitational: Solar Pressure + Thermal Emission: Fliegel *et al.* (1992), models T10 for BLOCK I and T20 for BLOCK II/II-A
  Y-bias acceleration
- All active GPS satellites are included

Ground stations
- Coordinates referred to ITRF91 at epoch 1992.5 (IGS Mail 33)
- station velocities are modelled with NNR-NUVEL1 model

Earth orientation parameters
- IERS Bulletin A, UT1 held fixed

Other parameters
- atmospheric modelling according to Willmann Model

Table 2. History of changes since beginning of the IGS evaluations at 21 June 1992 (only valid for EOP solution EOP(ESOC) 92 P 02)

9 August 1992 (IGS Mail 78): An updated set of ITRF91 ground station coordinates has been adopted from IGS Mail 65. The epoch remains at 1992.5.

18 August 1992 (IGS Mail 108): Data evaluation in 30-hour-arcs i.e. the arcs start 3 hours before - and end 3 hours after the central day. So overlaps of 6 hours between successive days are obtained.

3 September 1992 (IGS Mail 93): An updated set of ITRF91 ground station coordinates has been adopted from IGS Mail 90. The epoch remains at 1992.5.

20 September 1992 (IGS Mail 114): A priori constraints are given to the estimated parameters:

- Satellite	position:	± 100 m
	velocity :	± 10 cm/sec
	ROCK4(2) scaling factor :	± 5 % deviation from value 1
	Y-bias :	± 0.2 10^{-5} (Newton)
- EOPs	xp :	± 5 mas
	yp :	± 5 mas
- Station	position :	± 20 cm
	atm. zenith delay :	± 20 cm

11 October 1992 (IGS Mail 123): Elevation cutoff has been changed from 10 degrees to 20 degrees.

15 November 1992 (IGS Report 27): The data evaluation span was set back to 24-hour. As additional unknown, we started to evaluate rate of change of the difference between UT1 and TAI. The a priori constraint for this parameter was set to 0.5 ms/day.

Description of the station coordinate solution SSC(ESOC) 93 P 01

A total of 33 days have been used to produce a multiarc solution for the station coordinates. These days span the Epoch'92 period and another 23 additional days in November and December of 1992. Only non anti-spoofing days have been used for this solution.

Summary description of the terrestrial system attached to the solution EOP (ESOC) 92 P 02

1 - Technique: GPS
2 - Analysis Center: ESA/European Space Operations Centre (ESOC)
3 - Solution identifier: EOP(ESOC) 92 P 02
4 - Software used: GPSOBS/BAHN-Version 5
5 - Relativity Scale: Local Earth
6 - Permanent tidal correction on station: To be added to listed coordinates
7 - Tectonic plate model : NNR-NUVEL1 plate motion model
8 - Velocity of light (c) : 299792.458 km/s
9 - Geogravitational constant (GM) : 398600.4415 km^3/s^2
10 - Reference epoch : 48960.5 (mean between 3 Sep 1992 and 6 Mar 1993)
11 - Adjusted parameters : On daily basis (24-hour arc), for the a priori constraints see above.

Satellite parameters per Spacecraft:
- one orbital state X, Y, Z, $\dot{X}$, $\dot{Y}$, $\dot{Z}$ at start epoch
- one scaling factor for solar pressure T10 or T20 model
- one Y-bias acceleration

Station related parameters per ground station:
- ground station positions (if not member of the fixed stations)
- every 3 hours an atmospheric zenith delay parameter (Willmann Model)
- Double-difference phase ambiguities as real-valued parameters

Earth orientation parameters (EOPs):
- one set of pole coordinates xp,yp and d(UT1R-TAI)/dt per day

Parameters to be kept fixed:

Satellite parameters per Spacecraft:
- solar pressure scaling factor GX and GZ in spacecraft body fixed x- and z-axis are kept fixed with value 1.0

Station related parameters per ground station:
- ground station position X,Y,Z of the following sites: Algonquin, Fairbanks, Goldstone, Hartebeesthoek, Madrid, Matera, Onsala, Santiago de Chile, Wettzell, Yaragadee and Yellowknife.

12 - Definition of the origin : Geocentre through gravity model (C10 = C11 = S11 = 0)
13 - Definition of the orientation : by fixing the ITRF91-coordinates of the above ground stations
14 - Constraint for time evolution : NNR-NUVEL1 plate motion model
15 - Deviations from IERS standards:
- The velocities of all ground stations are taken from NNR-NUVEL1 plate motion model
- no relativity corrections to propagation or/and acceleration
- no station ocean loading

EOP(ESOC) 92 P 02 From Jun 1992 to Mar 1993

Number of measurements per year and median uncertainties
Units : 0.001" for X, Y; 0.0001s for D

YEAR	X		Y		D	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	194	0.28	194	0.28	47	0.45
1993	65	0.29	65	0.28	65	0.46

Summary description of the terrestrial system attached to the set of station coordinates SSC (ESOC) 93 P 01

1 - Technique: GPS
2 - Analysis Center : ESA/European Space Operations Centre (ESOC)
3 - Solution identifier : SSC(ESOC) 93 P 01
4 - Software used : GPSOBS/BAHN-Version 5/MULTIARC
5 - Relativity Scale : Local Earth
6 - Permanent tidal correction on station : To be added to listed coordinates
7 - Tectonic plate model : NNR-NUVEL1 plate motion model
8 - Velocity of light (c) : 299792.458 km/s
9 - Geogravitational constant (GMo) : 398600.4415 km^3/s^2
10 - Reference epoch : MJD 48805.0 1992.5
11 - Adjusted parameters :

On daily basis (24-hour arc):

Satellite parameters per Spacecraft:
- one orbital state X, Y, Z, $\dot{X}$, $\dot{Y}$, $\dot{Z}$ at start epoch
- one scaling factor for solar pressure T10 or T20 model
- one Y-bias acceleration

Station related parameters per ground station:
- every 3 hours an atmospheric zenith delay parameter (Willmann Model)
- Double-differced phase ambiguities as real-valued parameters

For the whole campaign:

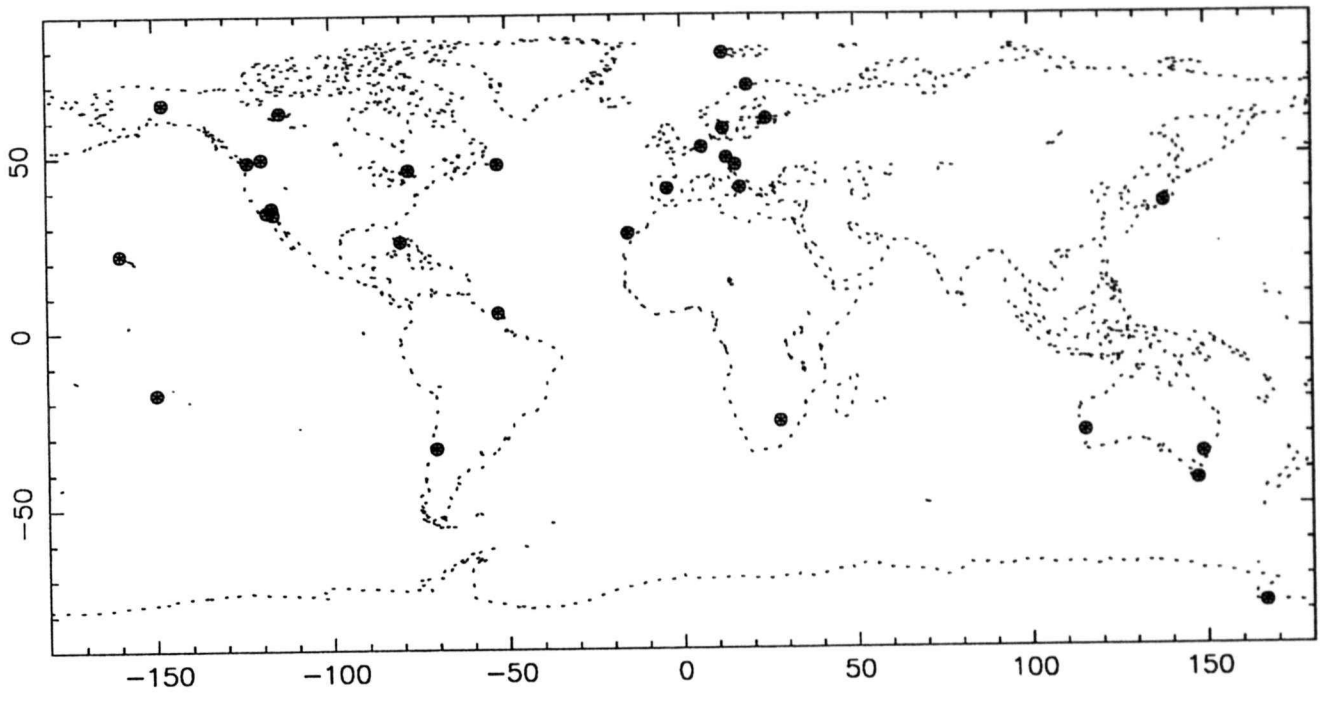
Station related parameters per ground station:
- ground station positions

Parameters to be kept fixed:

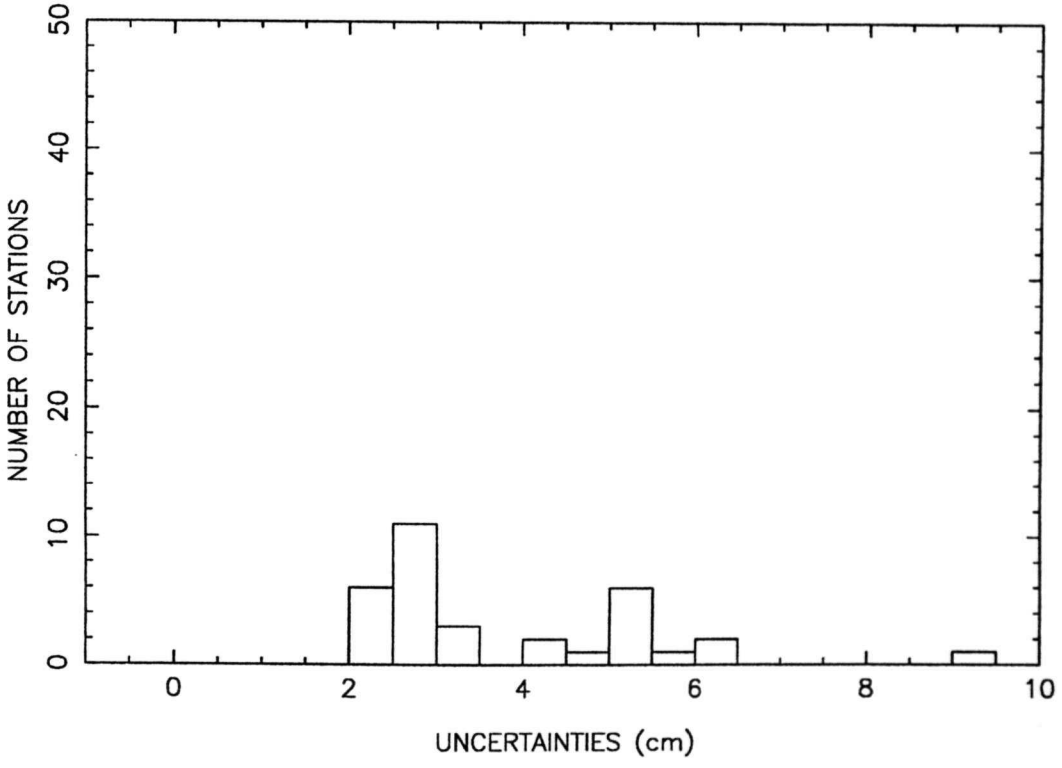
Satellite parameters per Spacecraft:
- solar pressure scaling factor GX and GZ in spacecraft body fixed x- and z-axis are kept fixed with value 1.0

EOP values:
- from IERS Rapid Service.

12 - Definition of the origin : Geocentre through gravity model (C10 = C11 = S11 = 0)
13 - Definition of the orientation : the EOP's are fixed to IERS Bulletin A, 12 stations are constrained in longitude and latitude with a priori uncertainty of 5 cm. These stations are: Madrid, Kootwijk, Matera, Onsala, Metsahovi, Tromso, Wettzell, Algonquin, Yellowknife, Albert Head, Goldstone and Fairbanks. The initial coordinates used are those from IGS Mail 90.
14 - Constraint for time evolution : NNR-NUVEL1 plate motion model
15 - Deviations from IERS standards:
- The velocities of all ground stations are taken from NNR-NUVEL1 plate motion model
- no relativity corrections to propagation or/and acceleration
- no station ocean loading



Distribution of the 30 sites of the terrestrial frame SSC(ESOC) 93 P 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 33 stations of the terrestrial frame SSC(ESOC) 93 P 01.

EARTH ORIENTATION PARAMETERS FROM THE JET PROPULSION LABORATORY USING GPS

EOP(JPL) 92 P 02

J.F. Zumberge, G. Blewitt, D. Jefferson, M. B. Heflin, and F.H. Webb
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA.

Since 1992 June 21, GPS data from a globally-distributed network of Rogue GPS receivers have been analyzed with GIPSY/OASIS-II software to give daily estimates of a variety of parameters, including those related to Earth orientation.

The measurements consist of undifferenced dual-frequency (1.2276 and 1.5742 GHz) carrier phase and P-code pseudorange. For both carrier phase and P-code, linear combinations of the individual frequencies provide the ionosphere-free phase and pseudorange. Data noise values for these are taken to be 1 cm and 1 m, respectively. Data below 15 degrees elevation are not used. The phase data are decimated to 6 minutes (5 min beginning 1992 Sep 05, and 10 min beginning 1993 Feb 04), and the P-code data are carrier-smoothed over the same interval.

Data corresponding to each GPS day are analyzed in 30-hour batches (24 hours prior to 1992 Sep 28) centered on GPS noon. GPS time is a constant offset from TAI time, and currently differs from UTC by 8 sec.

Estimated parameters are satellite state vectors, receiver coordinates, zenith wet troposphere delay at each receiver site, station and satellite clock offsets, carrier phase ambiguities, and earth orientation. Daily solutions contain 800-1200 solved-for parameters. The rms post-fit residulas for the phase measurements are typically a few mm. Those measurements with more than 5 cm post-fit residual for phase, or 5 m for pseudorange, are considered outliers and excluded.

The Williams solid Earth tide model is used. Pole tide and ocean loading are not modeled.

The Earth's gravity field is described by the GEM-T3 multipole expansion using terms up through degree and order 8. IERS-recommended values for C21 and S21 of $-0.17\ 10^{-9}$ and $1.19\ 10^{-9}$ are also used. The value of GM is taken as 398600.4415 km^3/s^2. Beginning with 1992 November 18 JGM1_8x8 gravity field is used.

Nominal values of the 9-component state vector for each GPS satellite [3 parameters each for position, velocity, and solar radiation pressure (srp)] are from the broadcast ephemeris (digital information included in the GPS signal which contains satellite almanacs whose accuracies vary from 10 to 1000 m). Weak a priori constraints of 1 km and 10 mm/s for position and velocity, respectively, are imposed. The ROCK4 model is used for srp. Beginning on 1992 Sep 06, in addition to the constant components, colored noise parameters are included for srp, with a 4-hour time constant.

IERS(1993) Technical Note No 14.

Table 1 GPS Receiver Sites Used in EOP(JPL) 92 P 02

ALGO* Algonquin Park	Canada (Ontario)
ALBH Alberthead	Canada (British Columbia)
DRAO Penticton	Canada (British Columbia)
FAIR* Fairbanks	U.S. (Alaska)
GOLD Goldstone	U.S. (California)
HART* Hartebeesthoek	South Africa
HARV Harvest	U.S. (California)
HERS Herstmonceaux	U.K.
JPLM Jet Propulsion Lab	U.S. (California)
KOKB* Kokee Park	U.S. (Hawaii)
KOSG Kootwijk	Netherlands
KOUR Kourou	French Guiana
MADR* Madrid	Spain
MASP Maspalomas	Canary Islands
MATE Matera	Italy
METS Metsahovi	Finland
MCMU McMurdo	Antarctica
NYAL Ny Alesund	Norway
ONSA Onsala	Sweden
PAMA Pamatai	Tahiti
PGC1 Victoria	Canada (British Columbia)
PINY Pinyon Flat	U.S. (California)
RCM2 Richmond	U.S. (Florida)
SANT* Santiago	Chile
SCRI Scripps	U.S. (California)
STJO St. Johns	Canada (Newfoundland)
TAIS Taiwan	Taiwan
TIDB Canberra	Australia
TROM* Tromso	Norway
USUD Usuda	Japan
WETB Wettzell	Germany
YAR1* Yaragadee	Australia
YELL Yellowknife	Canada (NW Territories)

*Indicates fiducial site.

Table 1 contains a list of sites used in 1992. Receiver locations are modeled as constant over each analysis day. Locations of fiducial sites (ALGO, FAIR, MADR only through 1992 Jul 18, add HART, KOKB, SANT, TROM, and YAR1 for 1992 Jun 05, 08, 11, and from 1992 Jun 19 onwards) were assumed known. Prior to 1992 Jul 19, the epoch used was 1992 Jul 01. From Jul 19 through Nov 18, the epoch was 1992 Aug 01. From Nov 18 through Nov 30, the epoch was Nov 01. Changes in assumed locations of fiducial sites are based on corrections and/or updates to site-tie information as well as plate motion as described by Boucher & Altamimi in International GPS Geodynamics Service mail message #90. Beginning on 1992 Dec 01, we update fiducial locations at the beginning of each month.

Non-fiducial sites are solved for as constant parameters for each analysis day.

The wet troposphere zenith delays at each site are modeled as a random walk in time with a 1 cm^2/hour variance derivative, and are mapped to satellite elevations using the Lanyi mapping function. Their nominal values are 0.1 m at every site and are estimated with 500-m a priori constraints.

The zenith dry delays are assumed fixed for every site, and are also mapped to satellite elevations using the Lanyi mapping function. Prior to 1992 Nov 18, the zenith dry delay was assumed to be 2 m at every site. Beginning with 1992 Nov 18, this was changed to 2.3 m x exp (-H/Ho), where H is the height of the site and Ho = 8621 m. Because the wet and dry delays are nearly degenerate parameters, the estimated wet delay in fact represents the combined delay which deviates from the nominal wet+dry.

Clocks for all but one station and satellite are estimated as a white-noise process with updates at each new time datum. One maser-based clock is chosen as a reference. Prior to 1993 Jan 06, this was the clock at FAIR. Beginning 1993 Jan 06 and later, the reference clock site was changed to ALGO. These clocks are generally believed accurate to better than 1 μsec.

The carrier phase ambiguities are estimated as real-valued parameters.

Nominal values for X and Y polar motion and UT1R-UTC, as well as the rates for these quantities, are obtained for each analysis day from the IERS Bulletin B predicted values. Estimates of polar motion are weakly (5-m) constrained, while UT1R-UTC is tightly constrained (0.01 mm) to be the nominal.

The X- and Y- pole biases with respect to IERS Bulletin B Final change abruptly on Jul 19 when we began using 8 fiducials. We have therefore adjusted the estimates prior to and including 1992 Jul 18 by -0.000095" for X and -0.001643" for Y to account for this step.

Prior to and including Aug 29, the deviation from nominal of polar motion was modeled as piecewise constant, with new estimates every UTC day. So that we would be less sensitive to errors in the a priori rates, we estimated rate terms beginning 1992 Aug 30.

The UT1R-UTC values use GPS-measured LODR (our first series). LODR is integrated to form UT1R-UTC values. The series was initialized with the IERS Bulletin B value on 1992 Jun 01. The series is very weakly forward filtered using an IERS Bulletin B value every 60 days. This was unnecessary for this submission, but the intent is to produce a continuous time-series which will not, in principle, ever diverge from the IERS series more than a few milliseconds (worst case). The forward running filter has an exponential response with a 60-day time constant. This weak filtering changes LODR by an insignificant amount on any given day. We intend to use this filter for routine processing, starting with the last point of this submitted series, and submit weekly reports on UT1R. For missing days, LODR was interpolated before integration. These days have an error of 0.99999s assigned to the UT1R value. Errors for days for which we have a true LODR solution actually refer to LODR, and not UT1R.

1992 Sep 14, Sep 21, Oct 05, and Oct 19 were deleted because these were Mondays during which Anti-Spoofing (encryption of P-code) was implemented for the first ten hours of the day, and the formal errors for the daily estimates are several times larger than usual.

The values for 1992 Jul 26 through 1992 Aug 8 result from our re-processing of the IGS Epoch '92 period, and reflect the current, more-sophisticated analysis strategy.

Summary description of the terrestrial system attached to the solution EOP(JPL) 92 P 02

1- Technique :	GPS
2- Analysis Center :	JPL
3- Solution identifier :	EOP(JPL) 92 P 02
4- Software used :	GIPSY/OASIS-II
5- Relativity scale :	Local Earth
6- Permanent tide correction on station :	No
7- Tectonic Plate Model :	No model assumed. Station coordinates updated at discrete reference epochs given below using ITRF91 velocities given by SSC(IERS) 92 C 04.
8- Velocity of light :	299792458 m/s
9- GM :	$3.986004415\ 10^{14}\ m^3/s^2$
10- Reference epoch :	1992 Jul 01, Aug 01, Nov 01, and Dec 01 for fixed site positions.
11- Adjusted parameters : (all reset every UTC midnight)	Station X, Y, Z, except for fiducials (ALGO FAIR HART KOKB MADR TROM SANT YAR1). Daily pole X, Y at noon. Daily X and Y rates. Daily UT1R-UTC rate (LODR). GPS epoch states reset daily: X, Y, Z, Vx, Vy, Vz as constant; solar radiation pressure Gx, Gy, Gz estimated as constant plus colored process noise with 4-hr correlation time. Gx and Gz biases are lumped (100% correlated), but process noise not lumped.

Zenith troposphere biases as random walk process noise of 1 cm per sqr. root hour.
Station and satellite clocks as white process noise (one site chosen as reference)
Carrier phase ambiguities as real valued (not bias-fixed)

12- Definition of origin: ITRF91 (8 sites held fixed)

13- Definition of orientation: ITRF91 (8 sites held fixed)

14- Constraint for time evolution: Fixed coordinates reset at reference epochs given above according to SSC(IERS) 92 C 04 (IGS mail message #90).

EOP(JPL) 92 P 02 From Jun 1992 to Jan 1993

Number of measurements per year and median uncertainties
Units : 0.001" for X, Y; 0.0001s for UT1

YEAR	X		Y		UT1	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	176	0.17	176	0.18	164	0.60
1993	30	0.14	30	0.16	30	0.50

GEOCENTRIC SITE COORDINATES FROM THE JET PROPULSION LABORATORY USING GPS

SSC(JPL) 93 P 01

G. Blewitt, M. B. Heflin, Y.Vigue, F.H. Webb, J.F. Zumberge, and D. Jefferson
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA.

GPS data spanning 1992 June 01 to 1993 Feb 17 from a globally-distributed network of Rogue receivers have been specially analyzed with GIPSY/OASIS-II software in order to estimate geocentric site coordinates. SSC(JPL) 93 P 01 is a more refined, self consistent analysis than the Earth orientation solution, EOP(JPL) 92 P 02, which was produced as part of a rapid service. Unlike the fiducial approach that was taken for EOP(JPL) 92 P 02, all station coordinates were free to adjust in SSC(JPL) 93 P 01. In addition, note that SSC(JPL) 93 P 01 includes a reanalysis of earlier data in order to apply improved estimation strategies developed later in the year. The reanalysis is still in progress, hence this solution contains a data gap from 1992 September 01 to 1993 January 01, which will be filled in future submissions.

Details of the models are given in the description of EOP(JPL) 92 P 02. Data from 1992 June 01 to 1992 Aug 30 were reanalyzed, a very important change being the introduction of stochastic solar radiation parameters to absorb systematic force model errors on the GPS satellites. While degrading the computed uncertainty in locating the geocenter, this strategy effectively reduces systematic bias in the geocenter location, leaving a statistical error which tends to average down in time. Our studies show a net translation between SSC(JPL) 93 P 01 and ITRF91 at the subcentimeter level, indicating the level of accuracy for locating the geocenter.

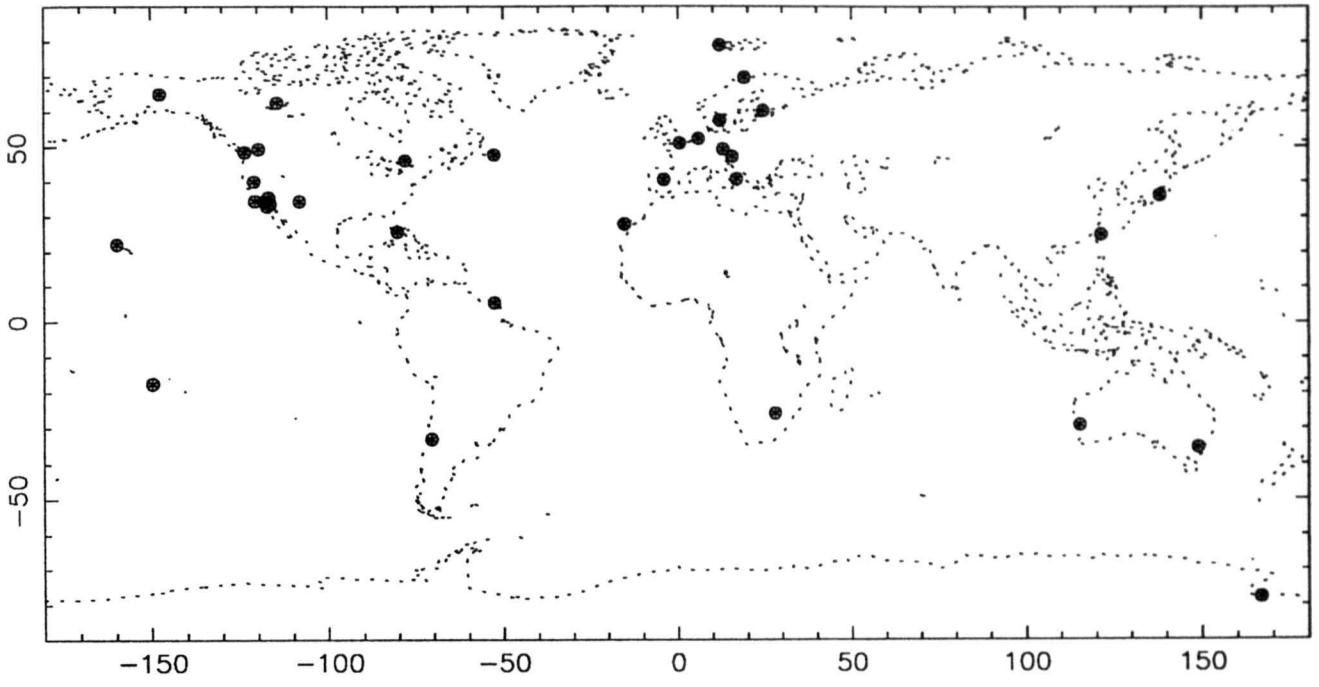
The orientation of SSC(JPL) 93 P 01 was fixed by applying the estimated rotation angles into SSC(IERS) 92 C 04. Since the Earth orientation solution EOP(JPL) 92 P 02 used 8 sites fixed to the coordinates in SSC(IERS) 92 C 04, the pole series ought to be consistent with SSC(JPL) 93 P 01 coordinates. Small inconsistencies may be present due to station coordinate errors in ITRF91 for those stations (and their local ties) held fixed in EOP(JPL) 92 P 02. As an indication of the level of this inconsistency, the RMS difference between coordinates in ITRF91 and SSC(JPL) 93 P 01 is approximately 1.4 cm. Given that there were 8 fiducial sites in EOP(JPL) 92 P 02, we might therefore expect the orientation inconsistency to be at the level of 0.2 mas. Although the same Earth orientation parameters were also freely estimated in SSC(JPL) 93 P 01, a current software limitation prevents us from back substituting the final coordinate solution to derive daily polar motion estimates in the same reference frame. This will be corrected for future submissions, thus eliminating the current need for a separate Earth orientation and station coordinate solution.

Time evolution is such that stations move with ITRF91 velocities as reported in SSC(IERS) 92 C 04 (IGS mail message number 90). For some sites in California, station coordinates are estimated independently for pre -and post- earthquake

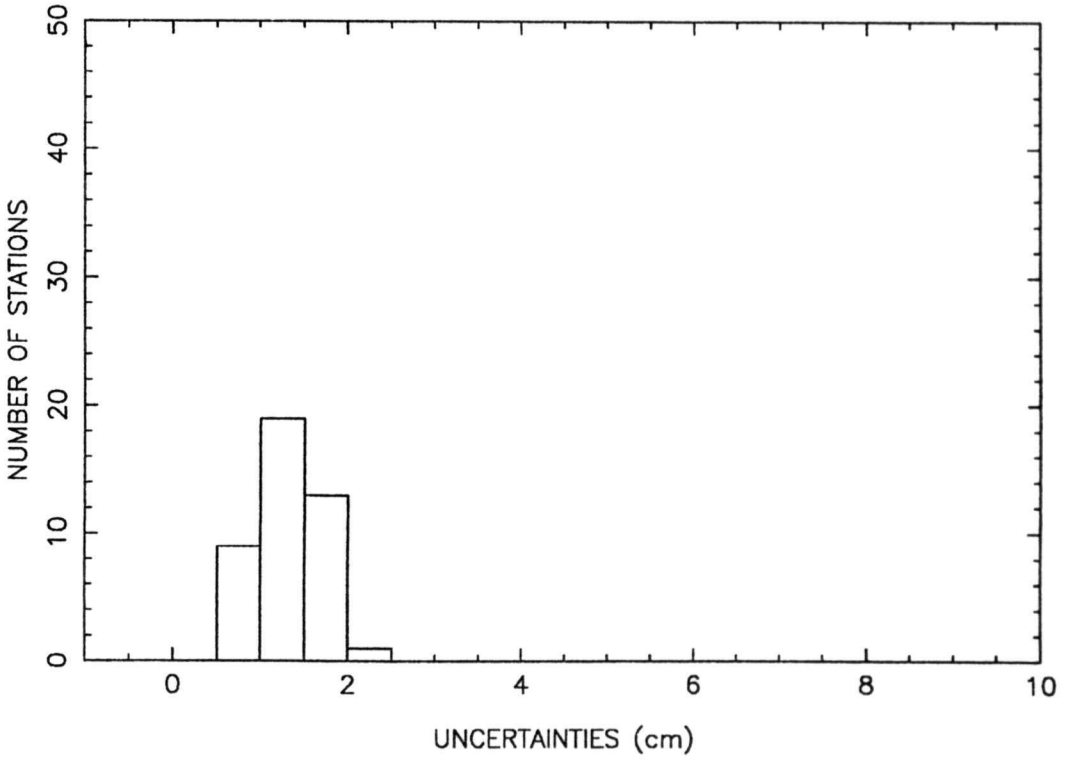
positions (1992 June 28 Landers earthquake). The receiver at Usuda, Japan, is estimated independently 3 different times because the antenna was moved twice during this time period. Moreover, its starting location (USU2) is different than the location during the GIG'91 experiment of January-February 1991 (as in ITRF91).

Summary description of the terrestrial system attached to the set of station coordinates SSC(JPL) 93 P 01

1- Technique :	GPS
2- Analysis Center :	JPL
3- Solution identifier :	SSC(JPL) 93 P 01(JPL identifier: JGC9302)
4- Software used :	GIPSY/OASIS-II
5- Relativity scale :	Local Earth
6- Permanent tide correction on station :	No
7- Tectonic Plate Model :	ITRF91 site velocities.
8- Velocity of light :	299792458 m/s
9- GM :	$3.986004415\ 10^{14}\ m^3/s^2$
10- Reference epoch :	1992.5
11- Adjusted parameters :	All station X, Y, Z with loose a priori standard deviation of 10 m (ITRF91 is nominal). Multiple estimates for sites which moved suddenly either due to earthquakes or antenna relocation. Daily pole X, Y at noon. Daily X and Y rates. Daily UT1R-UTC rate (LODR). GPS epoch states reset daily: X, Y, Z, Vx, Vy, Vz as constant; solar radiation pressure Gx, Gy, Gz estimated as constant plus colored process noise with 4-hr correlation time.Gx and Gz biases are lumped (100% correlated), but process noise not lumped. Zenith troposphere biases as random walk process noise of 1 $cm/hr^{1/2}$. Station and satellite clocks as white process noise (one site chosen as reference) Carrier phase ambiguities as real valued (not bias-fixed)
12- Definition of origin:	Geocenter: C10=C11=S11=0. (All sites free to adjust).
13- Definition of orientation:	Applied 3 rotation angles to align solution with ITRF91 at the reference epoch, using SSC(IERS) 92 C 04 coordinates for 22 sites.
14- Constraint for time evolution:	Stations velocities fixed to according to ITRF91 as given by SSC(IERS) 92 C 04.



Distribution of the 35 sites of the terrestrial frame SSC(JPL) 93 P 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 42 stations of the terrestrial frame SSC(JPL) 93 P 01.

1991-1993 SIO POLAR MOTION SERIES SIO 93 P 01

Yehuda Bock, Peng Fang, Keith Stark, Scripps Institution of Oceanography.

Definition of Terrestrial Reference Frame:
(described in detail in IGSMAIL #168)

Origin: Nominally ITRF91
Orientation: Nominally ITRF91
Reference epoch: 1992.836
Station coordinates: Given on IGS mail #168
Station Velocities: IERS ITRF91 values given in IGS mail #90.
Relativity Scale: Terrestrial
Velocity of light: 299792458.0 m/s
Permanent tidal correction: None

Analysis Strategy:

(1) GAMIT weighted least squares analysis

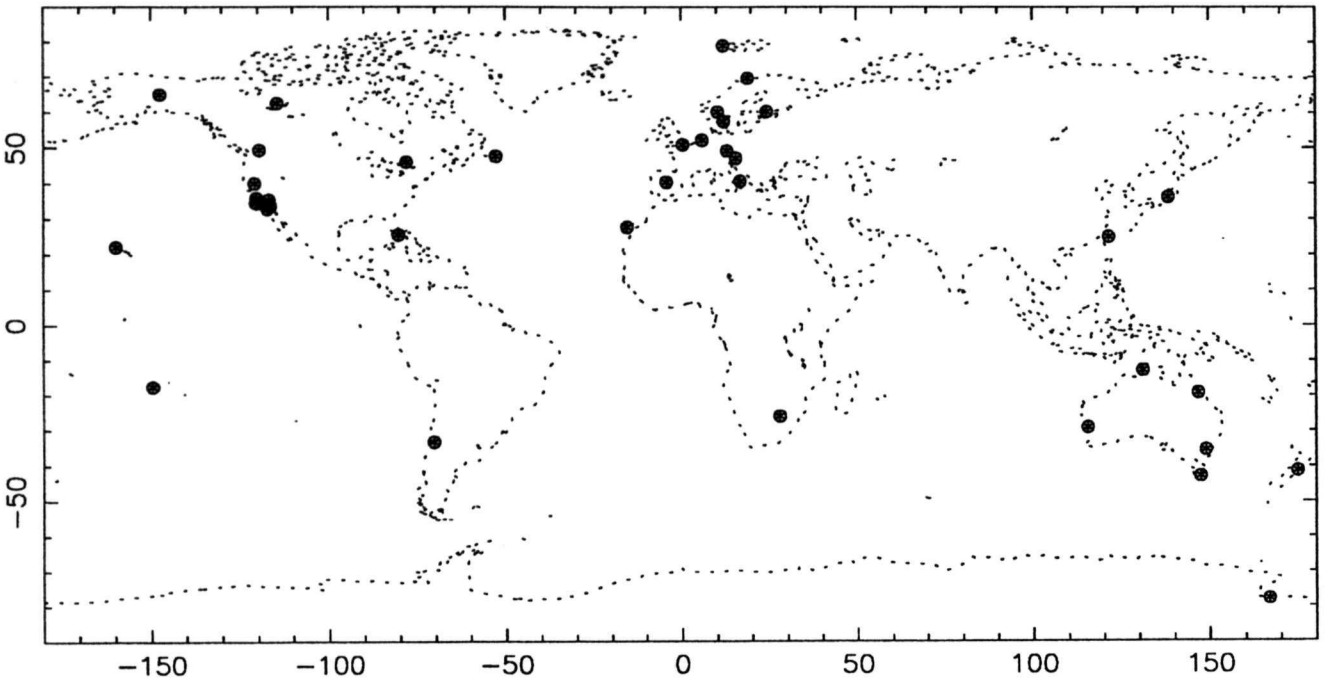
(a) Double-difference phase data
(b) Single day orbit arcs, 6 ICs and 2 radiation parameters per satellite-per-day
(c) One-per-day-per-station zenith tropospheric parameter,
(d) Bias parameters, one for each independent double difference combination.
(e) All parameters are given loose constraints in the daily GAMIT adjustment and the adjusted parameters and corresponding variance-covariance matrix for station and orbital parameters is recorded on auxiliary file for GLOBK processing.

(2) GLOBK Kalman Filter analysis

(a) Input auxiliary files from daily GAMIT solutions.
(b) Station positions with ± 10 m constraints at stations other than: ALGO, FAIR, KOKB, KOSG, MADR, MASP, MATE, MCMU, METS, ONSA, PAMA, DRAO, TIDB, TROM, WTZ1, YAR1, YELL. For these stations constraints of ± 0.001 m for horizontal components, and ± 0.005 m for height.
(c) In forward filter estimate station coordinates for all sites using constraints described in (b), to realize reference frame
(d) In back filter estimate daily orbital parameters and X and Y pole positions that are consistent with positions determined in forward filter. (No estimate is made of UT1-AT since these deviations are absorbed into the orbital parameters).

References: Dong, D., and Bock, Y., 1989: *J. Geophys. Res.*, **94**, 3949-3966.
Herring, T.A., Davis J.L., and Shapiro, I.I., 1990: *J. Geophys. Res.*, **95**, 12561-12583.

IERS(1993) Technical Note No 14.



Distribution of the 38 sites of the terrestrial frame SSC(SIO) 93 P 01.

EOP(SIO) 93 P 01 From Aug 1991 to Jul 1993

Number of measurements per year and median uncertainties
Units : 0.001" for X, Y

YEAR	X		Y	
	Nb	Sigma	Nb	Sigma
1991	140	0.39	140	0.43
1992	325	0.19	325	0.20
1993	205	0.09	205	0.10