GLOBAL POSITIONING SYSTEM

ANNUAL REPORT OF THE CODE ANALYSIS CENTER FOR 1993

EOP(CODE) 94 P 02, P 03
SSC(CODE) 94 P 01, 02

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1. Introduction

CODE (the Center for Orbit Determination in Europe) is one of at present seven processing centers of the International GPS Service for Geodynamics (IGS). CODE is a collaboration of

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

The processing center is located at the AIUB. The computations originally were performed on a cluster of VAX computers. During 1993 most of these VAX machines were replaced by ALPHA processors, one being reserved for IGS processing only (the other ALPHAs and VAXes are also used for other projects of the institute or by other institutes of the university of Berne). The Bernese GPS Software Version 3.5+ is used for processing. The "+" indicates that this version is in constant development to meet the requirements of a steadily growing workload of the routine processing (Table 1).

Table 1. Workload of the daily "three-days" CODE solutions

Solution Characteristic	DATE (mm yyyy)			
	06 1992	01 1993	06 1993	12 1993
Number of Satellites	19	21	23	26
Number of Stations	25	28	33	38
Number of Observations	50'000	60'000	110'000	180'000
Number of Parameter	2000	2300	4700	6200

The contribution of CODE to the IGS started on 21 June 1992. There are uninterrupted series of orbits, earth rotation parameters (ERPs), and station coordinates available from CODE since that time. To the best of our knowledge there never were delays longer than about two weeks before our products could be made available to the scientific community.

According to our 1992 annual report delivered to the IERS the emphasis in 1993 should be "on the critical analysis of the physical models and on the development of long-term analysis capabilities". Actually we focused our development and test activities on (1) the orbit model, (2) the stacking of normal equation systems to compute e.g. free network solutions (and the associated velocity field), (3) the optimization of ERP estimation. The progress made in these fields and initial results are summarized in the following sections.

In 1992 the CODE results were significantly affected by AS (Anti-Spoofing). This was due to a mal-functioning (under AS) of the principal receiver in the network. The problem was fixed around the end of 1992; only minor difficulties were encountered in our processing of AS data since that time. We had the impression that the overall performance of the IGS network was satisfactory in 1993. Since 31 January 1994 AS seems to be turned on permanently. It is still difficult to say how much the quality of our results is influenced by AS. At present we believe that the "damage" is of the order of 10% except for the coordinates of stations in the auroral zone, which, at some times, had to be excluded from our routine processing due to the receiver problems.

2. CODE Analysis Characteristics

The general characteristics of our processing were given in Beutler *et al.* (1993b). Here we focus on the changes and the progress made since that time. Detailed information may be found in Rothacher *et al.* (1993), Brockmann *et al.* (1993), Mervart *et al.* (1993), and Beutler *et al.* (1993a).

AUTOMATIC PROCEDURES AT CODE

The processing scheme was modified several times during 1993. At present we proceed as follows: At regular intervals of a few hours an automatic procedure checks whether the data of the day to be processed are available at CODE (sent by IGN) or at the closest IGS Global Data Center. If this is the case, processing of the day is started. In a first step the data are translated from RINEX to the internal (binary) Bernese format. Inconsistencies (wrong file names, wrong station names, "new" antenna heights) are sorted out. This step may need user interaction. Then the pre-processing (single-difference formation, code processing, phase-cleaning) is done with the best orbit information available at that time; today this is usually a one-day extrapolation of our latest three-days solution (see below). Then a first one-day solution is produced. The primary result is a first improved orbit. Afterwards the phase pre-processing is repeated (with this improved orbit) and this time all cycle-slips should be safely removed. If this is not possible, new ambiguities are set up. The principal difference between AS and non-AS processing resides in the number of ambiguities which have to be set up in this step. Again a one-day solution, this time including the estimation of earth rotation parameters is performed. If the solution is acceptable the next three-days solution (Figure 1) is produced in two iteration steps. Two iteration steps are required to guarantee not to run into linearity problems.

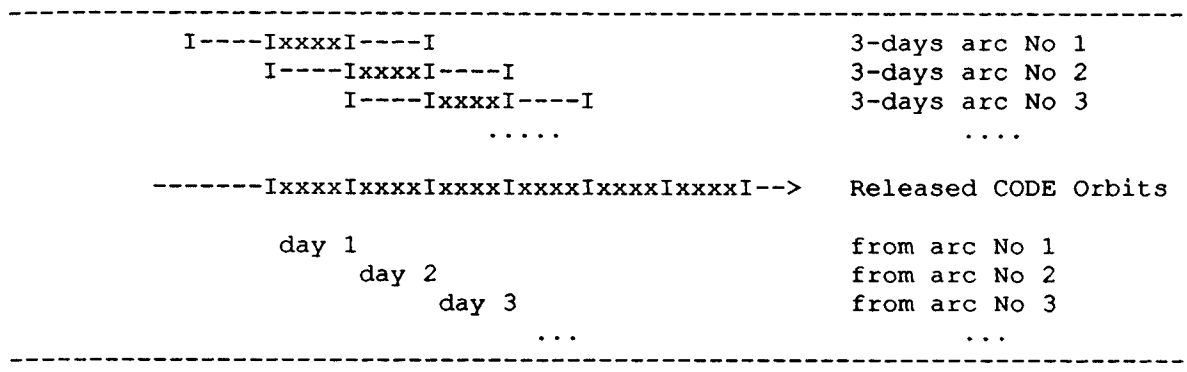

Figure 1: Processing in Overlapping 3-days Intervals

THE FORCE MODEL

The principal features did not change since 1992 (Beutler *et al.*, 1993b). Two minor, but important improvements concerning the orbit model for the eclipsing satellites took place in 1993: (1) As described in the 1992 Annual Report, the GPS space-crafts which are in deep eclipse theoretically have to rotate very rapidly by 180 deg around the space vehicles' z-axis twice during the revolution. The numerical problems in processing caused by this phenomenon were sorted out once and for all in 1993. There are clear indications, however, that there is a "real" attitude problem of the eclipsing satellites in the first 20 to 30 minutes after they leave the earth's shadow. (2) The pseudo-stochastic orbit model was used for the eclipsing satellites in our routine processing since 14 June 1993. At predetermined times (at present twice per day) impulse-changes are estimated for these satellites. The resulting orbit is continuous, but its first derivative is not. This change was made after several months of extensive tests. A priori constraints are put on these parameters to prevent damage in the case where (almost) no observations of the eclipsing satellites are available.

THE MODEL FOR THE ERPS

Our parameter estimation program allows to model x, y, and UT1-UTC as a series of polynomials of user defined degree where the individual polynomials refer to user defined connected time intervals. So far we always divided the 3-days interval of our "final" solutions into three one-day bins, and modeled each pole component x, y, and UT1-UTC as a polynomial within each bin. Prior to 14 June 1993 a pure offset for each component (polynomial degree = 0) was estimated. Afterwards the polynomial degree 1 was used; in addition we asked the pole coordinates to be continuous at the day-boundaries. So, before the mentioned date we modeled each component of the pole by 3 parameters in every three-days solution, afterwards by 4 (formally 6 parameters (3 x (1 offset + 1 drift per day)). The main reason for this change was to make our estimates compatible with the a priori model for the pole (which is continuous). Therefore, after 14 June 1993, it was possible to iteratively improve the pole coordinates in the final two processing steps (3-days-solutions). We mention that for UT1-UTC we put a heavy weight either on the a priori value of the first day (before 14 June 1993) or on the 0-degree coefficient of the first day (after 14 June 1993). It is thus clear that we are "only" able to determine the first derivative of the UT1-UTC curve.

By integrating the resulting first derivatives of consecutive days it is formally possible to reconstruct UT1-UTC starting from an arbitrary initial value.

STACKING CAPABILITIES

The "interesting part" of the normal equation system (NEQ-systems) of each 3-days solution is stored together with the necessary logistics information in a file for later use. The newly developed program ADDNEQ (Brockmann *et al.*, 1993) is then used to combine as many of these NEQ systems as required to produce consistent sets of station coordinates, pole positions, and satellite orbits. To a certain extent the models may be modified in ADDNEQ: the pole model may e.g. be simplified in ADDNEQ (only one polynomial per pole component over three days), station velocities may be set up, a change from one terrestrial reference frame to the other (e.g. from ITRF 91 to ITRF 92) is possible, "free network solutions" by removing constraints and by introducing system conditions may be produced. The program again generates a correct variance-covariance matrix for the estimated parameters. The NEQ-systems of our three days solutions have been stored every third day since April 1,1993 (doy 091), every day since July 23, 1993 (doy 200).

OUR REALIZATION OF THE ITRF IN 1993.

Table 2 gives the list of tracking stations we kept fixed in our analyses in 1993. The set marked ITRF 91 obviously refers to the International Terrestrial Reference Frame 1991 (Boucher *et al.*, 1992). The coordinates, velocities, and the eccentricities are available in IGS mail No.90. Our orbits and the ERP series from 1 November 1992 to 31 December 1993 delivered to the IGS Global Data Centers (CDDIS, IGN, SIO) are based on this realization of the ITRF reference frame. On 1 January 1994 we switched to the ITRF 92 (Boucher *et al.*, 1993) in our routine processing. From this time onwards our results at CDDIS, IGN, and SIO are based on the set "ITRF 92" of fixed sites in Table 2. We had to change the fixed sites according to the list selected at the 1992 IGS analysis centers workshop (Kouba, 1993, section "Conclusions and Recommendations"). The coordinates, and corresponding velocities may be found in IGS mail No.430, the site eccentricities are stored in the CBIS (Central Bureau Information System; file: localtie.tab). Thanks to the stacking procedure described above it was possible to re-process the larger part of the 1993 solutions using the ITRF 92 coordinate set and the new station list given in Table 2 (see section 3) with program ADDNEQ. In addition we note that the deformations due to the solid earth tides (Mc Carthy, 1992, Chapter 7, eqn. 6) are added when a set of station coordinates is used in our processing.

Table 2. List of Sites kept fixed in 1993 Processing and in 1994.

ITRF 91 Set	ITRF 92 Set
KOSG 13504M002 *)	KOSG 13504M003
MADR 13407S010	MADR 13407S012
TROM 10302M002	TROM 10302M003
WETT 14201S004	WETT 14201M009
ONSA 10402S002	HART 30302M002
ALGO 40104S001	ALGO 40104M002
FAIR 40408S002	FAIR 40408M001
GOLD 40405M013	GOLD 40405S031
KOKB 40424S001	KOKB 40424M004
YELL 40127M001	YELL 40127M003
RCM2 40499M002	SANT 41705M003
CANB 50103S010	TIDB 50103M108
YAR1 50107M001	YAR1 50107M004

*) unconstrained after 23 July 1993.

MISCELLANEOUS MODELLING COMPONENTS

Attempts were made to improve the model for the GPS force field beyond the 1992 IERS standards. For this purpose the program ORBIMP was developed. The program interprets the satellite positions of the daily IGS precise orbit files as (pseudo-) observations. "Long" arcs (up to 14 days) were formed using consecutive IGS orbit files. In particular Colombo's empirical resonance forces, a generalized radiation pressure model, pseudo-stochastic velocity changes, albedo radiation pressure, and the resonance terms of the earth's gravity field were considered as candidate forces. Only the generalized radiation pressure model led to a substantial improvement (Beutler *et al.*, 1993a). It is planned to use this improved force model in the routine processing after further extensive tests in future. The program ORBIMP also may be used to check the orbit quality of different IGS processing centers. It is used at present in the process of IGS orbit combination, see e.g. Kouba (1994), theory in Beutler, Kouba, and Springer (1993).

Mervart *et al.* (1993) showed that the quality of CODE orbits is sufficient to allow ambiguity resolution (wide- and narrow-lane) on the single baseline level with baseline-lengths up to about 1000 km. Ambiguity resolution and a subsequent orbit improvement step will be implemented in the near future into our routine processing.

3. Results

EARTH ROTATION PARAMETERS

Figures 2a and 2b show differences of the x and y components of our pole estimates with respect to the C04 pole SERIES of the IERS Central Bureau. We clearly see a quality improvement of our estimates from originally about 1 mas per coordinate to now about 0.3 mas. The "discontinuity" at the end of 1993 (MJD 49352) marks the transition from the ITRF 91 to the ITRF 92.

Figures 3a and 3b show the length-of-day estimates of the CODE processing center after removing the zonal solid earth tides and the difference between our estimates and those extracted from the IERS C04 ERP series (which is completely independent of our series). These figures clearly prove that GPS is capable of estimating the length-of-day (with a one day resolution) with a precision of about 0.03 msec. We attribute the quality of our estimates to the length of our satellite arcs (three days).

Figures 4a and 4b demonstrate that the set of fixed coordinates used (see Table 2) is important: Both curves show differences between our solutions and the C04-series. They are based in one case on our realization of the ITRF 91, in the other on our realization of the ITRF 92 system. We clearly see the superiority of our ITRF 92 series.

COORDINATES

Two "free network solutions" could be produced using the program ADDNEQ. The NEQ-systems of 91 3-days solutions covering the time period from 1 April 1993 to 31 Dec 1993 were used for this purpose. The solutions' characteristics are given in the summary description below, the station distribution in Figure 5. In the first set of coordinates (A3) the station velocities were constrained to the ITRF 92 values, in the second case (B3) the station velocities are solved for. We are aware of the fact that a nine month time interval is too small to derive reliable station displacements. We include this solution to allow an optimal combination with coordinate series produced by other analysis centers.

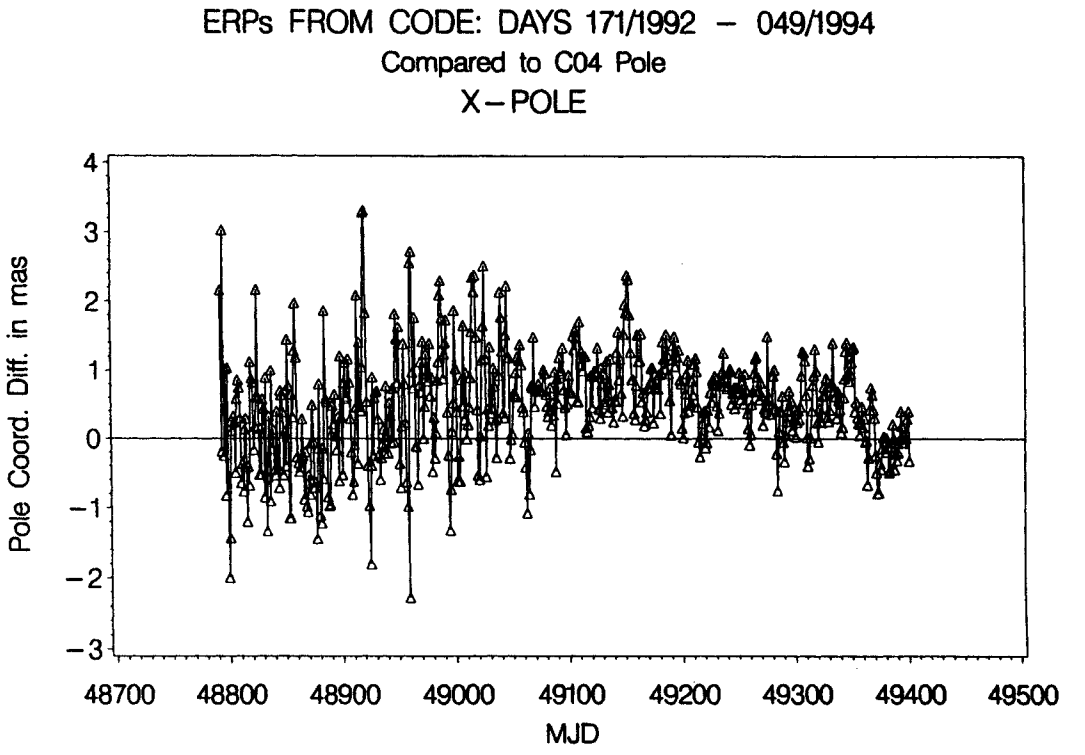

Figure 2a : Daily CODE Pole Estimates - C04 Pole Series (x-component)

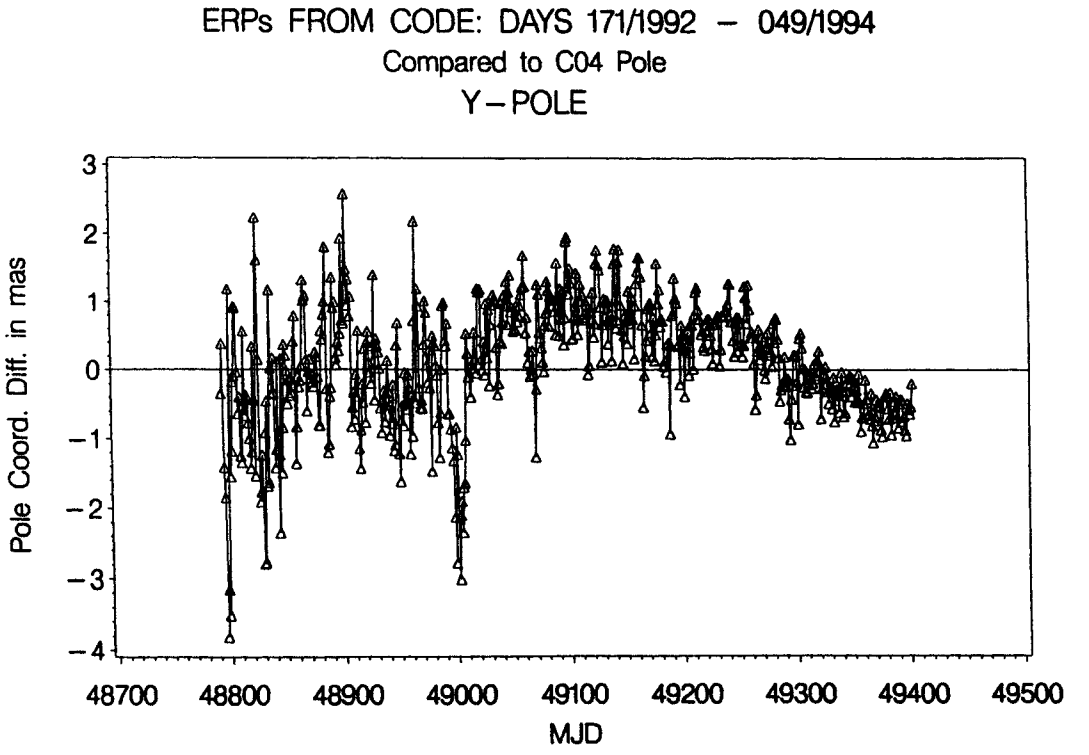

Figure 2b : Daily CODE Pole Estimates - C04 Pole Series (y-component)

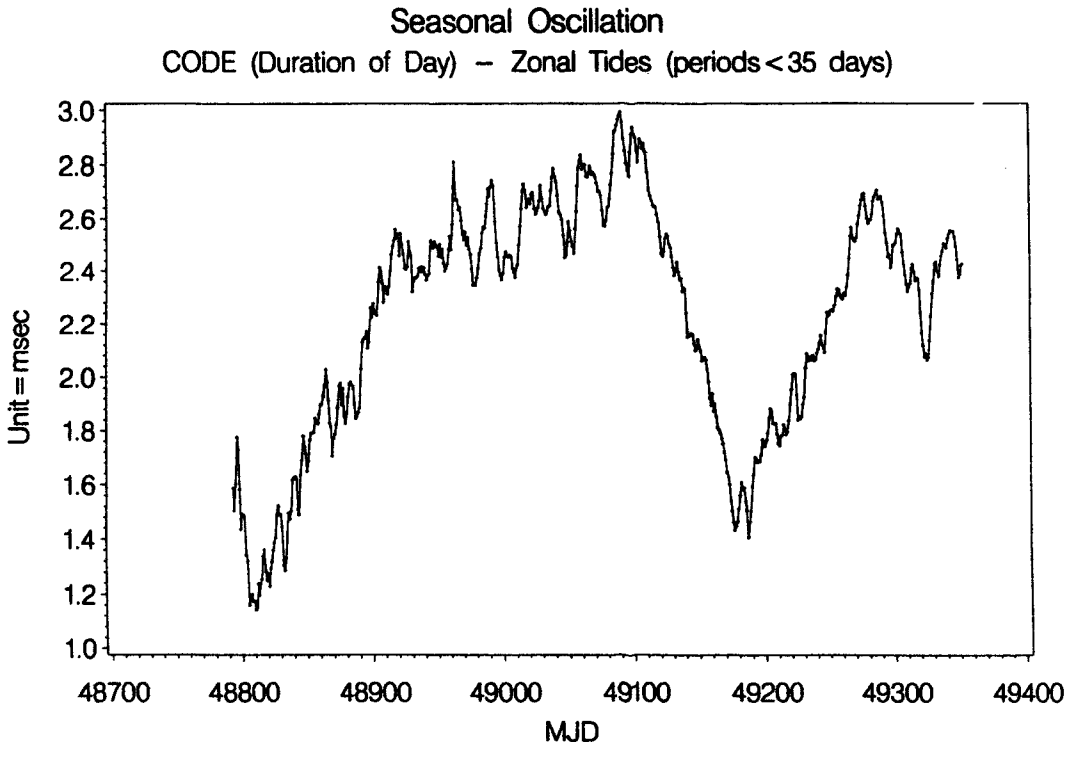

Figure 3a : Daily CODE Excess Day Length Values freed from zonal solid earth tides (periods shorter than 35 days)

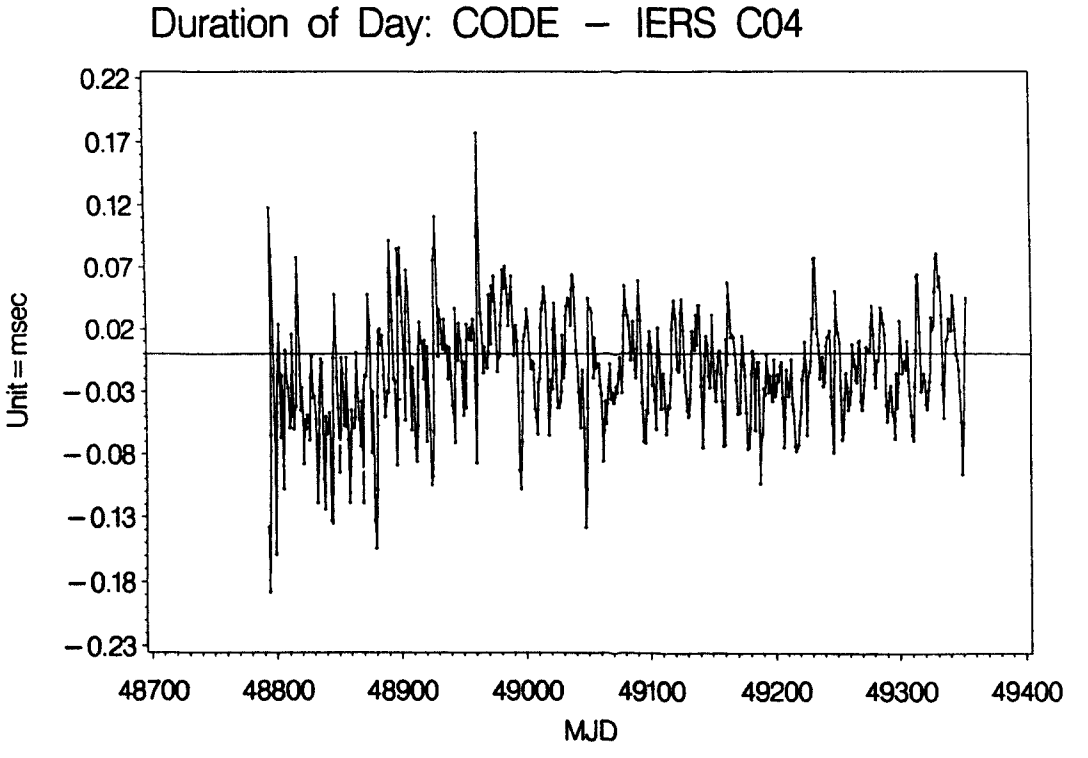

Figure 3b : CODE estimates - IERS C04 Series (Length of day)

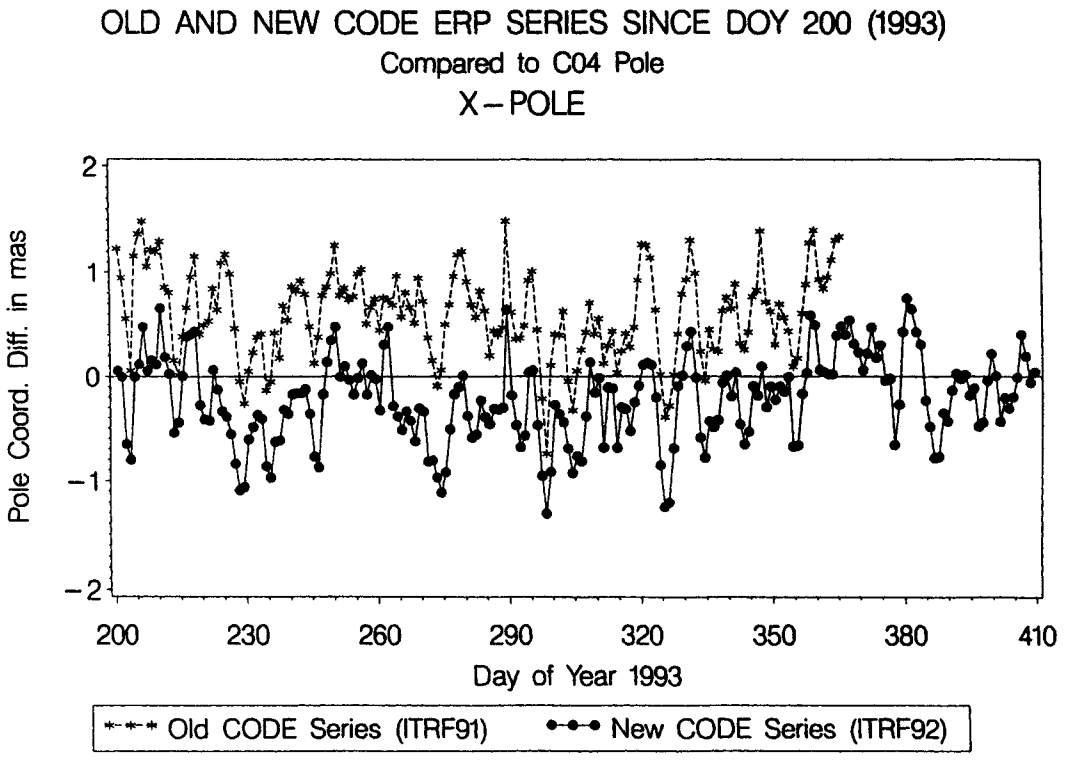

Figure 4a : CODE Estimates using the ITRF 91 of Table 1 - C04 Pole Series (*) and CODE Estimates using the ITRF 92 of Table 1 - C04 Pole Series (.) x-component

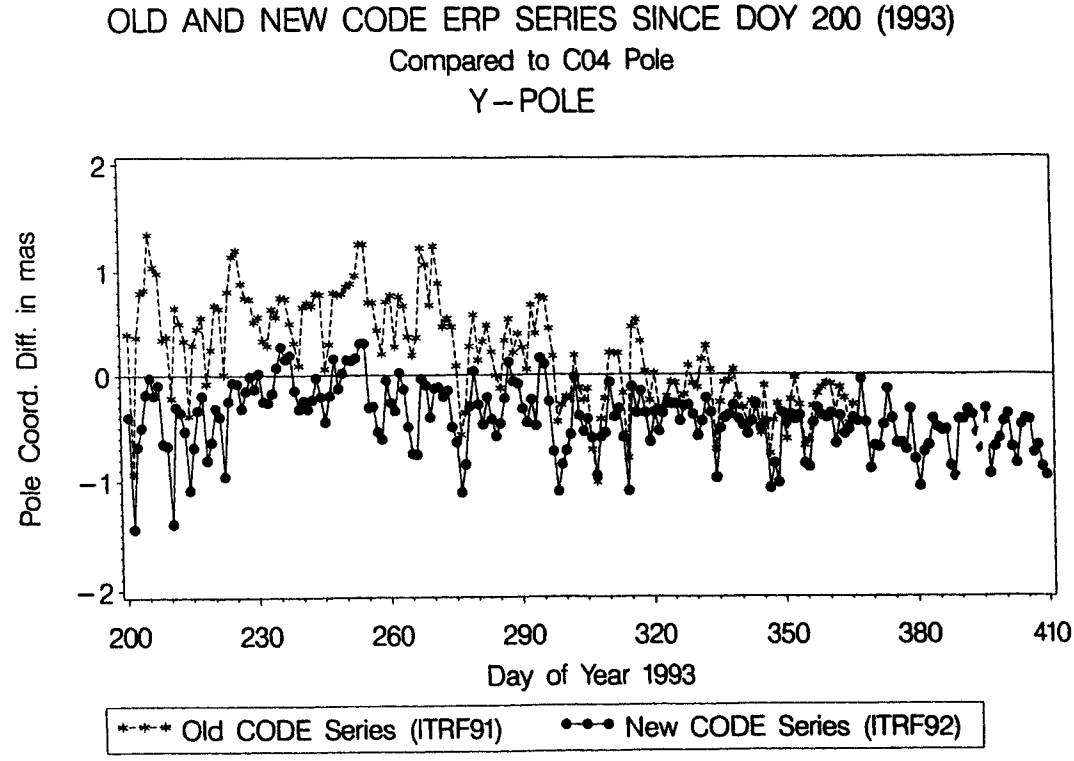

Figure 4b : CODE Estimates using the ITRF 91 of Table 1 - C04 Pole Series (*) and CODE Estimates using the ITRF 92 of Table 1 - C04 Pole Series (.) y-component

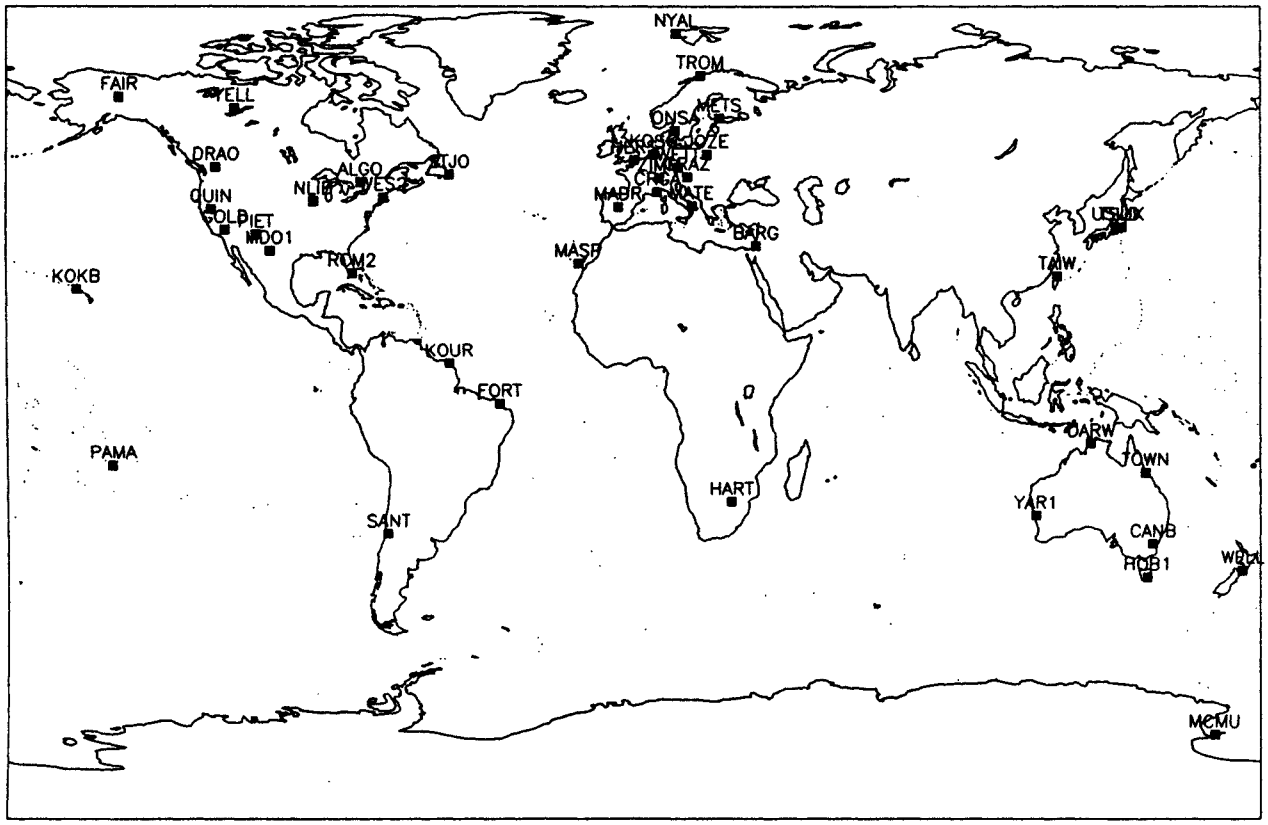

Figure 5 : IGS Core Stations used by the CODE Processing Center in 1993.

References

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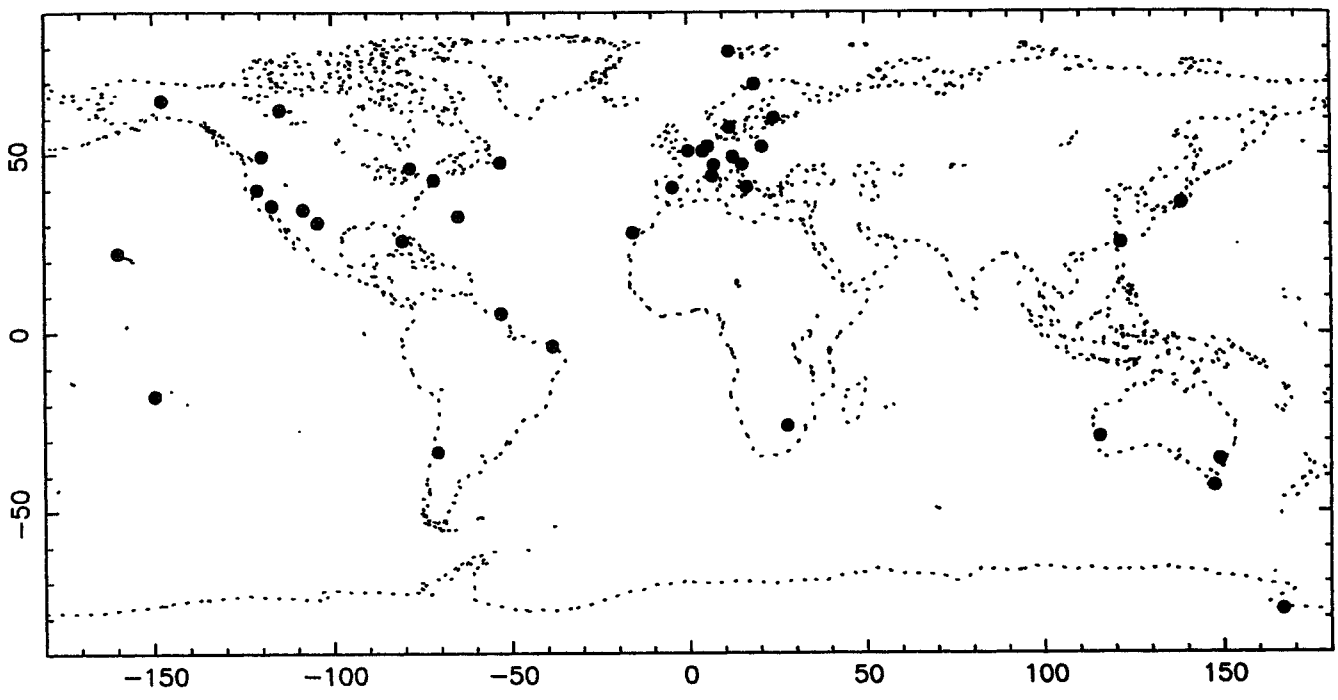
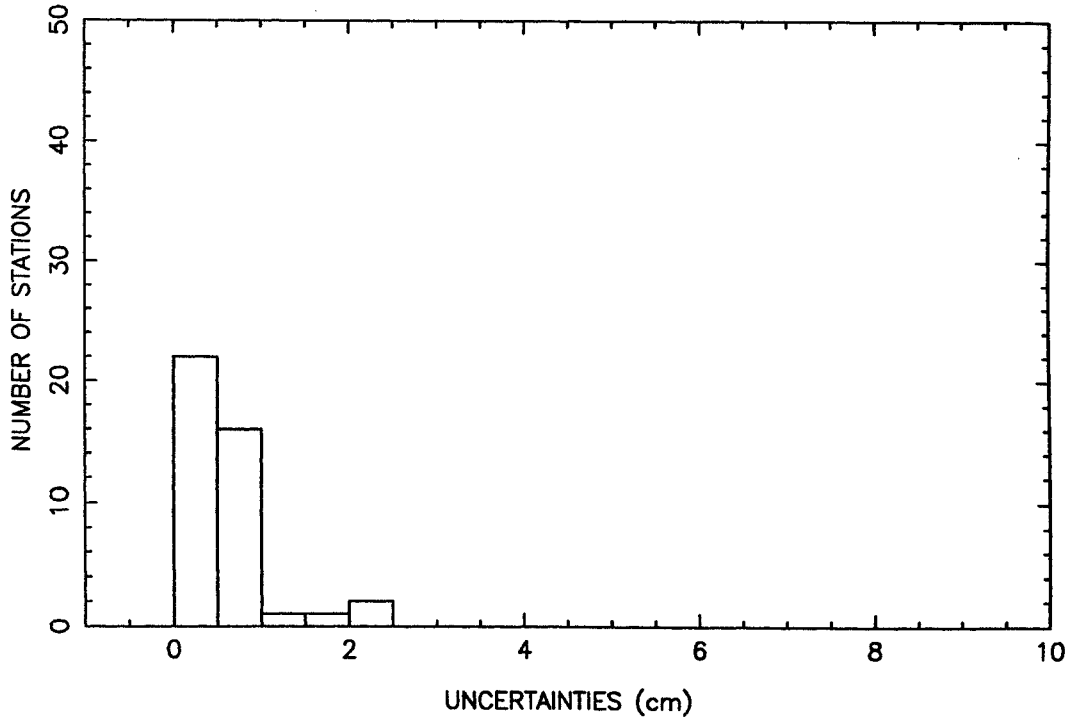
Summary description of the solutions CODE 94 P 01 and P 02

1 - Technique :	GPS
2 - Analysis Center :	CODE
3 - Solution identifier :	(a) A3 (94 P 01) (b) B3 (94 P 02)
4 - Software used :	Bernese GPS Sogftware, Version 3.5+
5 - Relativity Scale :	Local Earth
6 - Permanent tidal correction on station :	according to IERS standards
7 - Tectonic plate model :	ITRF 92 velocity model
8 - Velocity of light (C) :	299792458 m/sec
9 - Geogravitational constant (GMo) :	398.6004415 10^{12} m^3/sec^2
10 - Reference epoch :	15 Aug 1993 for both solutions
11 - Adjusted parameters :	- 6 Keplerian osculating elements, direct radiation pressure, and y-bias for each satellite and each 3-days arc, - pseudo-stochastic impulse changes (twice per day) for eclipsing satellites, - 4 tropospheric zenith delays per day and station, - ERPs as polynomials of degree 1 for each day (continuity at the day boundaries), - initial phase ambiguity parameters, - geocentric coordinates for each site, and, for solution (b) B3, velocity for each site.
12 - Definition of the origin :	no translation with respect to the official 13 IGS ITRF 92 stations
13 - Definition of the orientation :	no rotation with respect to the official 13 IGS ITRF 92 stations
14 - Constraints for time evolution :	(a) ITRF 92 Velocity Field (b) 1m/yr for north,east-components, 0.1mm/yr for up-component, for 28 stations. Wettzell fixed on ITRF 92 vel.



Distribution of the 39 sites of the terrestrial frame SSC(CODE) 94 P 01.



Distribution of the uncertainties (quadratic mean of δx, δy, δz) for the 42 stations of the terrestrial frame SSC (CODE) 94 P 01.

EOP(CODE) 94 P 02 From Jun 1992 to Dec 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	195	0.10	195	0.10	195	0.07
1993	364	0.06	364	0.06	364	0.06

EOP(CODE) 94 P 03 From Jul 1993 to Feb 1994

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
1993	166	0.05	166	0.05	166	0.06
1994	50	0.04	50	0.04	50	0.06

1993 GPS DATA PROCESSING AT THE EMR ANALYSIS CENTRE

EOP(EMR) 92 P 04
SSC(EMR) 94 P 02, 03, 04

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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. Twelve 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 is identical with our weekly submissions during 1993 and starts on January 1, 1993. All days are included even those with Anti Spoofing (AS) turned on.

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:

$$\sigma(E) = \sigma_0 + \sigma_1 e^{-E/E_0}$$

where E is the elevation angle in degrees and the constants are: E_0=20, σ_0=4 mm, σ_1=15 mm for phase measurements at all stations; σ_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. For AS data the pseudorange observations were down weighted by assigning very large sigmas (100 m).

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. 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 1 m and values larger than 1.5 m 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/sqrt(day) and (0.5 mm/s)/sqrt(day). 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 var(i,i+1)= var(i,i).

The variance var(i,i) increases approximately with the sqrt(i), 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 the 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 12 stations constrained at the ITRF91 coordinates which are primarily based on VLBI solutions (see the list of constrained stations in the summary description below). Also the DUT1 which is initialized once a week, usually on Sunday or the first non AS day of the week using the most current IERS/NOES Bull.A predictions is derived from VLBI DUT1 solutions.

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.

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Summary of solutions SSC (EMR) 94 P 02, 03 and 04

1 - Technique:	GPS
2 - Analysis centre :	Geodetic Survey Division (GSD), SMRSS , EMR
3 - Solution identifier:	1993 EMR Annual submission
4 - Software used:	GIPSY/OASIS II (UNIX)
5 - Relativity scale :	LE
6 - Permanent Tide corr:	none
7 - Tectonic plate mod.:	none, 3 epochs
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:	1993.21, 1993.5, 1993.83
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 26sat.); - 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 18 stations. - 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 1ms or.1ms sigma.
12 -origin:	Nominally ITRF91
13 -orientation:	" " "
14 -Constraint for t. evolution:	none

Summary of solution EOP (EMR) 92 P 04

1 - Analysis centre: Geodetic Survey Division (GSD), SMRSS , EMR

2 - Solution identifier: Annual submission

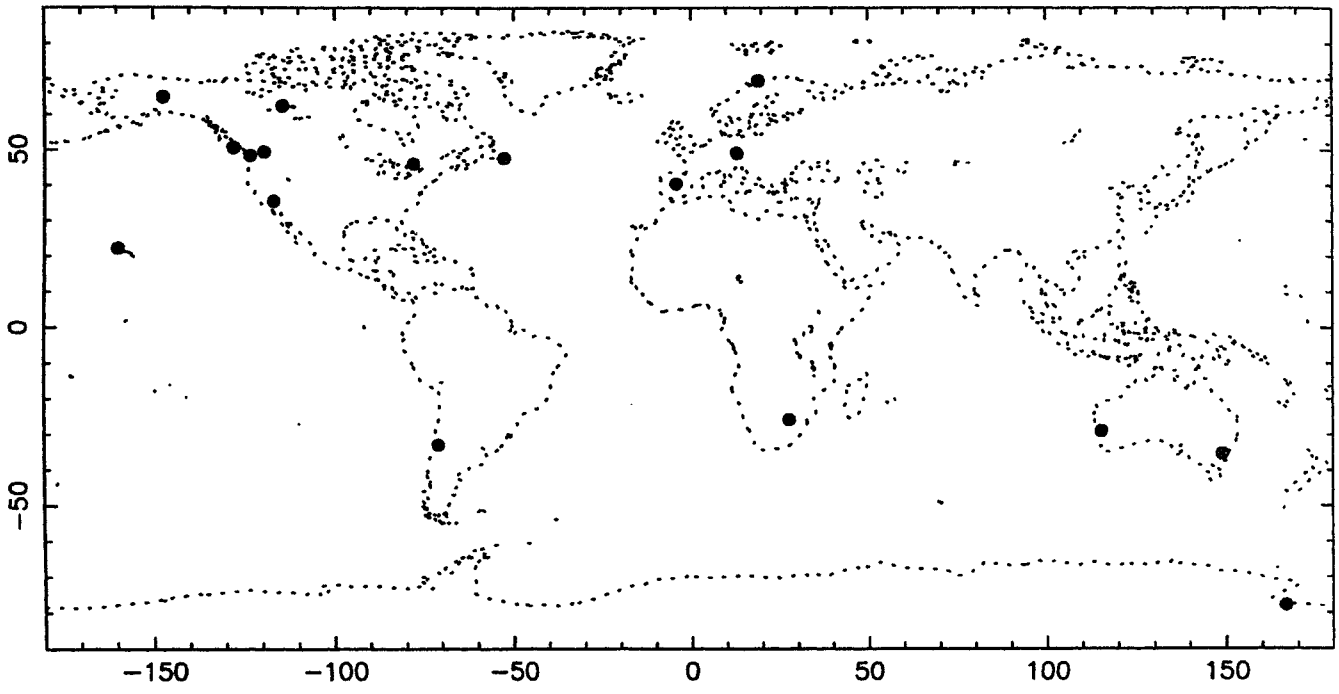
3 - Software used : GIPSY/OASIS II (UNIX)

4 - Definition of Terrestrial frame:

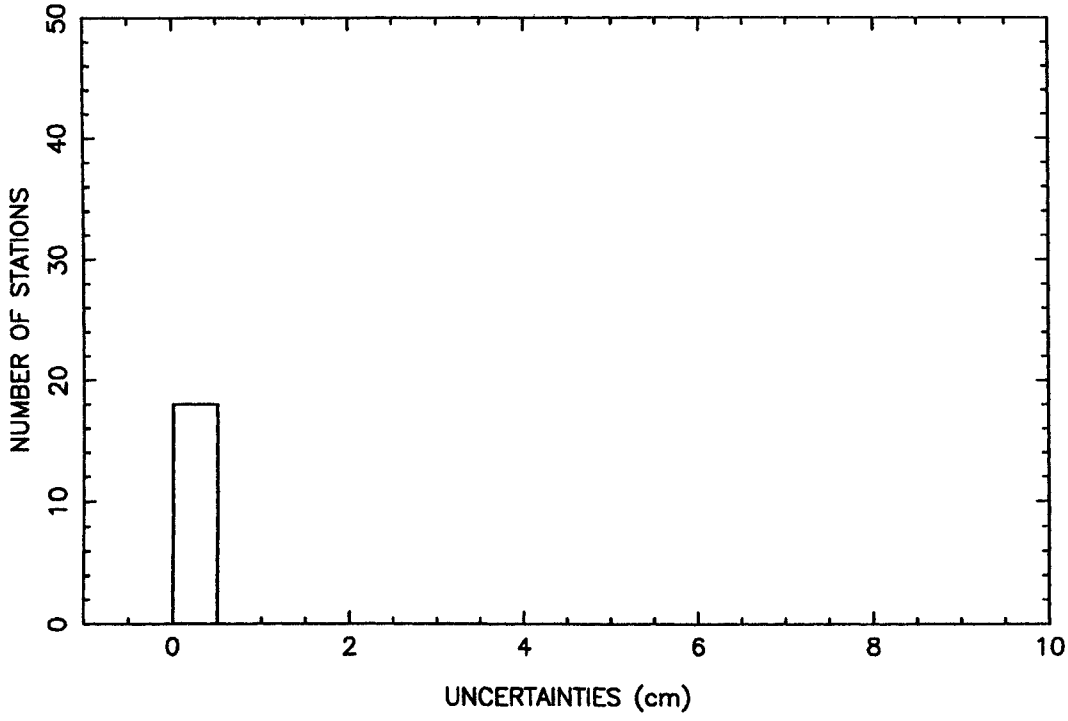
origin:	Nominally ITRF91
orientation:	" "
reference epoch:	1992.5
velocity of light :	299792458 m/s
GM:	398600.4414 km^3/s^5
gravity model:	GEMT3(8,8) +C21+S21
permanent tide corr:	None
ocean loading :	Pagiatakis, global model

5 - 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 (20sat.)
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, SANT, TROM, WETT, YELL, MADR, MCMU, TIDB and YAR1 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 1ms or .1ms sigma



Distribution of the 17 sites of the terrestrial frame SSC(EMR) 94 P 02.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 18 stations of the terrestrial frame SSC(EMR) 94 P 02.

EOP(EMR) 92 P 04 From Oct 1992 to Jan 1994

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	64	0.22	64	0.18	41	2.40
1993	365	0.21	365	0.17	265	2.20

ANNUAL REPORT FROM THE ESOC ANALYSIS CENTRE FOR 1993

EOP(ESOC) 92 P 02
SSC(ESOC) 94 P 01

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The ESOC contribution to the IERS for 1993 consists of a daily Earth Orientation Parameter solution, EOP(ESOC) 92 P 02, and a GPS station coordinate solution, SSC(ESOC) 94 P 01. The EOP solution has been obtained with the daily processing of GPS data for the IGS and the station coordinate solution has been obtained from 21 two day arcs of GPS observation equations from 1993.

1. DESCRIPTION OF THE EOP(ESOC) 92 P 02 SERIES FOR 1993

1.1 Daily IGS processing at ESOC

GPS data from every day of 1993 have been used to obtain orbits, Earth Orientation Parameters, and as of November 28, satellite clock biases. The incoming GPS data from about 24 stations is evaluated on a daily basis and EOPs are determined for 24 hour intervals. The initial values are taken from IERS Bulletin A predictions. RINEX observation files are the input of the GPSOBS program, that checks for cycle slips, obtains initial estimates for clock biases, obtains independent double differenced phase observations and prepares the inputs for BAHN, our orbit and geodetic parameter estimation program. BAHN makes an adjustment estimating orbits, positions of some stations, tropospheric parameters, measurement biases, receiver clock biases and EOPs. If precise satellite clock biases are needed GPSOBS can also obtain them in post processing using code and carrier phase observations and fixing the values of earth fixed orbits, tropospheric parameters and position of stations to those obtained by BAHN. Daily solutions are grouped in GPS week batches and sent to the IERS to be used in the IERS EOP combination.

1.2 Models and constants used

- Terrestrial reference frame

It is defined by fixing a set of 11 to 13 ground stations to the values given by the IERS and by using a velocity field that was NNR-Nuvel1 up to March 13 1993 and ITRF92 from March 14 1993. The geocentre is defined through the gravity model (C10 = C11 = S11 = 0).

- Integration of the equations of motion

This is done in the standard J2000.0 celestial frame. The relativity scale is that of the local Earth.

- Transformation between terrestrial and celestial reference frames

The IERS standards are used to transform from celestial frame to the terrestrial reference frame, including celestial pole offset from IERS Bulletin A. EOP's are modelled as constant during every UTC day, with a constant pole position (xp, yp). UT1 was modelled with a constant UT1 rate up to October 30 1993, and from October 31 1993 a constant value of UT1 regularized (UT1R) rate was used, so the UT1 rate could have the variations during the day predicted by the difference between UT1 and UT1R. The parameter that is provided to the IERS is the Length Of the Day (LOD), and as of October 31 LODR. UT1 series can be reconstructed from LOD or LODR values when a initial value is given.

- Basic constants

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_2	= 0.6090
Solid Earth tidal Shida number:	l_2	= 0.0852

- GPS data handling

The basic observable for BAHN is double-difference of carrier phases, using the ionospheric free combination. The elevation cutoff angle is 20 degrees and IGS evaluation was done using 24 hour arcs up to April 3 1993 and 48 hour arcs from April 4 1993. The 48 hours include the central day and two periods of 12 hours before and after.

- 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 + radiation emission models from Fliegel, T10 for Block I satellites and T20 for Block II/ IIA satellites. A constant scale factor and a Y-bias are estimated for every arc.

- Corrections to the measurements

Satellite centre of mass correction: For Block I satellites, in body fixed, dx = 0.210 m, dz = 0.854 m. For Block II satellites, dx = 0.279 m, dz = 1.026 m.
Ionospheric correction: Through the use of L3 ionospheric free combination.
Tropospheric correction: Zenith delay estimated linearly in 3 hour intervals up to April 3 1993. From April 4 1994 zenith delay and shape factor estimated linearly in 6 hour intervals.
Receiver L3 antenna phase centre correction: A vertical offset from the antenna reference point of 0.050 m for Rogue/MiniRogue antennas and of 0.082 m for TurboRogue antennas.

Antenna heights and local ties: from IGS Mail 90 up to March 13 1993, from IGS Mail 160 from March 14 1993 up to December 26 1993, from the localtie.tab file maintained at the IGS Central Bureau from December 27 1993.

1.3 Results

The EOP series obtained by ESOC for 1993 have been weekly sent to the IERS.

Table 1: Initial values and constraints used. When two values of constraint appear, the first was used up to April 3, 1993 and the second from April 4, 1993.

Parameter	Initial value	A priori constraint
Satellite position at epoch	From previous day orbit	100 m
Satellite velocity at epoch	From previous day orbit	0.1 m/s , 1 m/s
ROCK4 scaling factor	1.0 (0.88 for PRN# 23)	0.05 , 0.1
Y-bias	0.0	2e-6 N , 1e-6 N
xp, yp	IERS Bulletin A	5 mas , 100 mas
LOD / LODR	IERS Bulletin A	0.5 ms/d , 6 ms/d
Station position	ITRF91 / ITRF92	0.2 m , 50 m
Total tropos. zenith delay	2.1 m	0.2 m
Ambiguities	0.0	3e-8 m

Table 2: History of changes for 1993

Date	MJD	Description of change
Mar. 7	49053	New station coordinates SSC(ESOC) P 01 used. Before the station coordinate set from IGS Mail 90 was used.
Mar. 14	49060	New station coordinates and velocities from the ITRF91 used. Before the velocities were derived from the NNR-Nuvel1 model.
Apr. 4	49081	48 hour arc used for orbits adjustment. New a priori constraints.
Sep. 12	49242	Receiver clock biases estimated. Before these biases were supposed to be zero. Intial values obtained from GPSOBS and used with an a priori constraint of 1 microsecond.
Oct. 31	49291	LODR estimated instead of LOD. Improved UT1 modelling as a consequence. More passes and observations used. Implemented the capability of excluding manoeuvering satellites from affecting the EOP estimate.
Dec. 26	49347	New station coordinates and velocities from the ITRF92.

2.DESCRIPTION OF THE GPS STATION COORDINATE SOLUTION SSC(ESOC) 94 P 01

2.1 Input data

- Sites included

The stations that were included in the analysis were those stations that the ESOC/IGS Analysis Centre was using in January of 1994 for the daily IGS processing. They included all the 13 stations that are kept fixed for daily IGS processing, all the ESA receivers and additional receivers to obtain an evenly distributed tracking of the GPS satellites. All these stations are equipped with Rogue, MiniRogue, or TurboRogue precise geodetic GPS receivers connected to stable atomic frequency standards. The stations used are listed in the Table 3.

Table 3: Stations used in the station coordinate solution

Domes number	Name	IGS code	Operator	Receiver type	Tectonic plate
10302M003	Tromso	TROM	SK	Rogue	Eurasia
10403M002	Kiruna	KIRU	ESOC	TurboRogue	Eurasia
12734M008	Matera	MATE	ASI/Telespazio	Rogue	Eurasia
13407S012	Madrid	MADR	JPL/DSN	Rogue	Eurasia
13504M003	Kootwijk	KOSG	DUT	Rogue	Eurasia
14201S020	Wettzell	WETT	IfAG	Rogue	Eurasia
21729S007	Usuda	USUD	JPL	Rogue/TurboR.	Eurasia
23601M001	Taipei	TAIW	IES/AS	Rogue	Eurasia
30302M002	Hartebeesthoek	HART	SAC/CNES	Rogue	Africa
31303M001	Maspalomas	MASP	ESOC	MiniRogue	Africa
40104M002	Algonquin	ALGO	NRCan	Rogue	North America
40127M003	Yellowknife	YELL	NRCan	MiniRogue	North America
40405S031	Goldstone	GOLD	JPL/DSN	Rogue	North America
40408M001	Fairbanks	FAIR	JPL	Rogue	North America
40424M004	Kokee Park	KOKB	JPL	Rogue	Pacific
40499M002	Richmond	RCM2	NOAA	Rogue	North America
40499S018	Richmond	RCM5	NOAA	TurboRogue	North America
41602M001	Fortaleza	FORT	INPE/NOAA	TurboRogue	South America
41705M003	Santiago	SANT	JPL	Rogue	South America
50103M108	Tidbinbilla	TIDB	JPL/DSN	Rogue	Australia
50107M004	Yarragadee	YAR1	JPL	Rogue	Australia
50133M001	Perth	PERT	ESOC	TurboRogue	Australia
66001M001	McMurdo	MCMU	JPL	Rogue	Antarctica
92201M003	Pamatai	PAMA	CNES	Rogue	Pacific
97301M210	Kourou	KOUR	ESOC	MiniRogue	South America

- Arcs included

The periods of data used were:

Seven two day arcs from January 17th 1993 to January 30th 1993, using 21 GPS satellites.

Seven two day arcs from July 4th 1993 to July 17th 1993, using 23 GPS satellites.

Seven two day arcs from December 19th 1993 to January 1st 1994, using 26 GPS satellites.

Neither anti-spoofing was activated nor satellites were manoeuvered during these three periods. Not all the stations were available during these six weeks. The actual stations used for every arc are listed in Table 4. Kokee Park (KOKB) was excluded from the December Analysis because it did not produce good data for some days.

Table 4: Data spans used

IGS	January 1993							July 1993							December 1993						
code	17	19	21	23	25	27	29	04	06	08	10	12	14	16	19	21	23	25	27	29	31
TROM	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
KIRU											**	**	**	**	**	**	**	**	**	**	**
MATE	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
MADR	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
KOSG	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
WETT	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**					**
USUD	**	**	**	**	**	**	**						**	**	**	**	**	**	**	**	**
TAIW	**	**		**	**	**	**	**	**	**	**	**	**		**	**	**	**	**	**	**
HART	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
MASP	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
ALGO	**	**	**	**	**	**	**		**	**	**	**	**	**	**	**	**	**	**	**	**
YELL	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
GOLD	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
FAIR	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
KOKB	**	**	**	**	**	**	**	**	**	**	**	**	**	**							
RCM2				**		**	**	**	**	**	**		**	**							
RCM5															**	**	**	**	**	**	**
FORT															**	**			**	**	**
SANT	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
TIDB	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
YAR1			**	**	**	**	**	**	**	**	**	**			**	**	**	**	**	**	**
PERT															**		**	**	**	**	**
MCMU					**		**	**		**	**	**		**							
PAMA	**	**	**	**	**	**	**								**	**	**	**	**	**	**
KOUR	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**

- Initial station coordinates

Initial station coordinates were obtained from the ITRF92 station coordinate solution, as listed in IGS Mails 421 and 430. Station positions were calculated at the different epochs using the velocities of the ITRF92. To obtain the velocities of those stations not included in the ITRF92 (KIRU, FORT, PERT) and also for TROM and YELL the NNR-Nuvel-1 velocity field was used. Coordinates for stations not listed in these mails (KIRU, RCM5, FORT, PERT) were obtained from the average estimates from one week of IGS processing. Local ties and antenna heights were obtained from the file localtie.tab maintained by the IGS Central Bureau.

- Observation equations

The parameters that were estimated in the generation of the observation equations were:

Satellite position and velocity for the start of each arc and a scale radiation pressure and a y-bias for each arc.
Tropospheric biases, modelled linearly in 6 hour intervals.
Measurement biases for the double difference phase observations.
Receiver clock biases and drifts, as needed.

Observation equations were also obtained for other parameters, fixing for each arc their value to some initial value:

Earth rotation parameters, with initial values from the IERS Bulletin B.
Station coordinates.

- Normal equations

Normal equations were obtained from the observation equations eliminating those parameters that were not of interest for subsequent processing. The only parameters kept were station coordinates and earth orientation parameters.

2.2 Data analysis

- Free network solutions

First station coordinate solutions were obtained separately for every arc in order to verify the quality of the data from each arc. These solutions were then compared with three two week solutions for January, July and December. Only observability problems were found for one or two stations for a couple of arcs, but they were solved by combining these arcs with other with better observability for those stations. Then a global solution was obtained and compared with the two week solutions to obtain an estimate of the repeatability of the solutions. All these solutions were obtained fixing the ERP values to the initial IERS Bulletin B values and without using any other additional constraint, so they can be considered "free network" solutions. Table 5 compares the two week solutions with each other and with the global free network solution.

Table 5. Discrepancies after 7 parameter transformation.

First set	Second set	rms of East discrepancies (cm)	rms of North discrepancies (cm)	rms of Height discrepancies (cm)
Jan. solution	Jul. solution	1.8	1.2	3.7
Jul. solution	Dec. solution	3.3	1.5	3.7
Jan. solution	Dec. solution	3.9	1.3	3.1
Global solution	Jan. solution	1.6	0.7	1.9
Global solution	Jul. solution	1.4	1.1	2.5
Global solution	Dec. solution	2.6	0.7	1.7

Typical accuracy based in repeatability can be estimated to about 2.2 cm east, 1.0 cm north and 2.5 cm vertical for the two week solutions and about 1.3 cm east, 0.6 cm north and 1.5 cm vertical for the global solution. When the global free network solution is compared with the initial values (mostly ITRF92), the results are those shown in Table 6.

Table 6. Comparison of the global free network solution with the initial values after a seven parameter transformation to obtain the new coordinates in the same reference

	centre offset			rotations				residual rms		
	x	y	z	x	y	z	scale	East	Nor.	Hei.
reference set	(cm)	(cm)	(cm)	(mas)	(mas)	(mas)	(ppm)	(cm)	(cm)	(cm)
All stations	-0.25	-7.15	17.88	-1.55	-0.61	-10.10	0.000	1.2	1.1	3.1
ITRF92	-0.33	-6.90	17.59	-1.67	-0.68	-10.17	0.001	1.2	0.9	3.3
IGS fiducial	0.07	-6.88	17.29	-1.63	-0.57	-9.95	0.000	0.9	0.6	3.0

The comparison shows agreement with the initial coordinates to about 1 cm horizontal and 3 cm vertical. All the initial coordinates, those obtained from the IERS as well as those obtained from one week of IGS results, seem to be equally accurate. There is no significant difference between the accuracy of the 13 stations that are used as fiducial sites for the daily solution and the other sites.

- Discussion on constraints

As we see in Table 6 a free network solution can be shifted and rotated with respect to the reference solution. The biggest shift is always for the GPS solutions that we have obtained a z axis displacement and the biggest rotation is, as expected for a satellite based solution, a z rotation. We would like to have our solution in the same reference as the original ITRF92 set without having to post-process the coordinate set. This can be done using constraints for the station coordinates that stabilize our system without changing the relative position of the stations. Another additional problem is that free network solutions do not provide a credible estimate of the accuracy of the coordinates. Calculated absolute accuracies are as big as 7 meters for the longitude of some stations in the global free network solution. Two kinds of constraints will be used. The first will be a so called seven parameter constraint, that constrains the displacements of a group of stations so the average shift, rotation or scale are kept unchanged. The second, needed to obtain estimates of the accuracy, is a loose a priori constraint for every component of a group of stations so that the system is stabilized.

- Solution SSC(ESOC) 94 P 01

For this solution the following constraints were applied:

Earth rotation parameters were fixed to the IERS Bulletin B values.

The origin and z rotation of the system defined by the set of 13 stations that are fixed for the daily solution were constrained to be zero. X and y rotation were not fixed because it would conflict with fixing the centre of the system and the position of the pole. The scale factor is well determined and does not need to be fixed.

All the station coordinates were loosely constrained to the a priori values with 1 m for every component.

2.3 Results

- Effect of constraints

The first thing that has to be analyzed is how the constraints that have been applied have affected the solution. For that we compare in Table 7 the constrained solution with the free network solution, with the initial coordinates and with the initial coordinates of the set of fiducial stations

Table 7. Comparison of the SSC(ESOC) 94 P 01 with reference sets after a seven parameter transformation to obtain the new coordinates in the same reference

	centre offset			rotations				residual rms		
	x	y	z	x	y	z	scale	East	Nor.	Hei.
reference set	(cm)	(cm)	(cm)	(mas)	(mas)	(mas)	(ppm)	(cm)	(cm)	(cm)
Free network	-0.02	6.49	-17.23	-0.17	-0.15	9.74	0.000	0.5	0.3	1.0
Initial set	-0.27	-0.66	0.65	-1.72	-0.76	-0.36	0.001	1.5	1.1	2.8
IGS fiducial	-0.02	0.02	0.01	-1.80	-0.75	-0.21	0.001	1.2	0.8	2.9

The comparison with the free network set shows that the constraints have effects that are smaller than the repeatability of the solution, so we can say that the adjustment is not over-constrained. The x and y rotations are basically the same as in the free network solution, because they are fixed by fixing the pole position to the IERS Bulletin B values. The discrepancy with the ITRF92 in these two rotations, that we can see both in the comparison with the initial set and the fiducial set, can be explained using the predicted biases and slopes given in the 1992 IERS Annual Report (p. II-17). The offset at 1993.5 should be 0.34 0.5 for xp and 1.53 0.5 for yp. These offsets make the IERS EOP series consistent with the IERS terrestrial reference frame. The comparison with the IGS fiducial set shows that the origin and z rotation constraint has worked as expected, fixing the origin of the system and the rotation about the z axis. In addition, the sigmas of the solution have now values that are closer to those expected by the repeatability, so the 1 m constraint has produced the desired effect without overconstraining the system.

- Accuracy of the solution

Agreement with the set of initial coordinates, basically ITRF92, is in the same order of magnitude as the accuracy of the solution based on repeatability. In Table 8 three measurements of the accuracy of the solution are compared.

Table 8. Accuracy estimates

Measurement of accuracy	East estimate (cm)	North estimate (cm)	Height estimate (cm)
Repeatability	1.3	0.6	1.5
Comparison with ITRF92	1.5	1.1	2.8
Average formal uncertainties	3.7	1.5	3.2

The formal uncertainties seem to be pessimistic, specially for the East accuracy.

- Velocity field

To check whether the velocity field may need improvement for some sites, we have compared the discrepancies of the two week solutions with respect to the global solution, after a seven parameter transformation, with the formal uncertainties for each site. If the discrepancies were higher than the formal uncertainties we could suspect that the velocities might be not well determined, but all the discrepancies are well within 3 sigma of the estimates, so an improved velocity field solution does not seem possible with this data set.

Summary description of the solution SSC(ESOC) 94 P 01

1 - Technique: GPS
2 - Analysis Centre: ESA / European Space Operations Centre (ESOC)
3 - Solution identifier: SSC(ESOC) 94 P 01
4 - Software used: GPSOBS/BAHN-V5/MULTIARC
5 - Relativity Scale: Local Earth
6 - Permanent tide correction on station: To be added to listed coordinates
7 - Tectonic plate model: ITRF92 + NNR-Nuvel1
8 - Velocity of light (c): 299792.458 km/s
9 - Geogravitational constant (GMo): 398600.4415 km^3/s^2
10 - Reference epoch: 1994.0
11 - Adjusted parameters:

On a two day basis:

Satellite parameters per spacecraft:

- one orbital state at start epoch.
- one scaling factor for radiation pressure ROCK4 T10 or T20 models.
- one Y-bias acceleration.

Station related parameters per ground station:

- every 6 hours an atmospheric zenith delay parameter and a shape parameter.
- clock biases and clock drifts as needed.
- double-differenced 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:

- radiation pressure scaling factors Gx and Gz fixed to 1.0.

Station related parameters per ground station:

- site velocities from ITRF92 or NNR-Nuvel1 when the site is not listed in the ITRF92.

EOP values

- from the IERS Bulletin B.

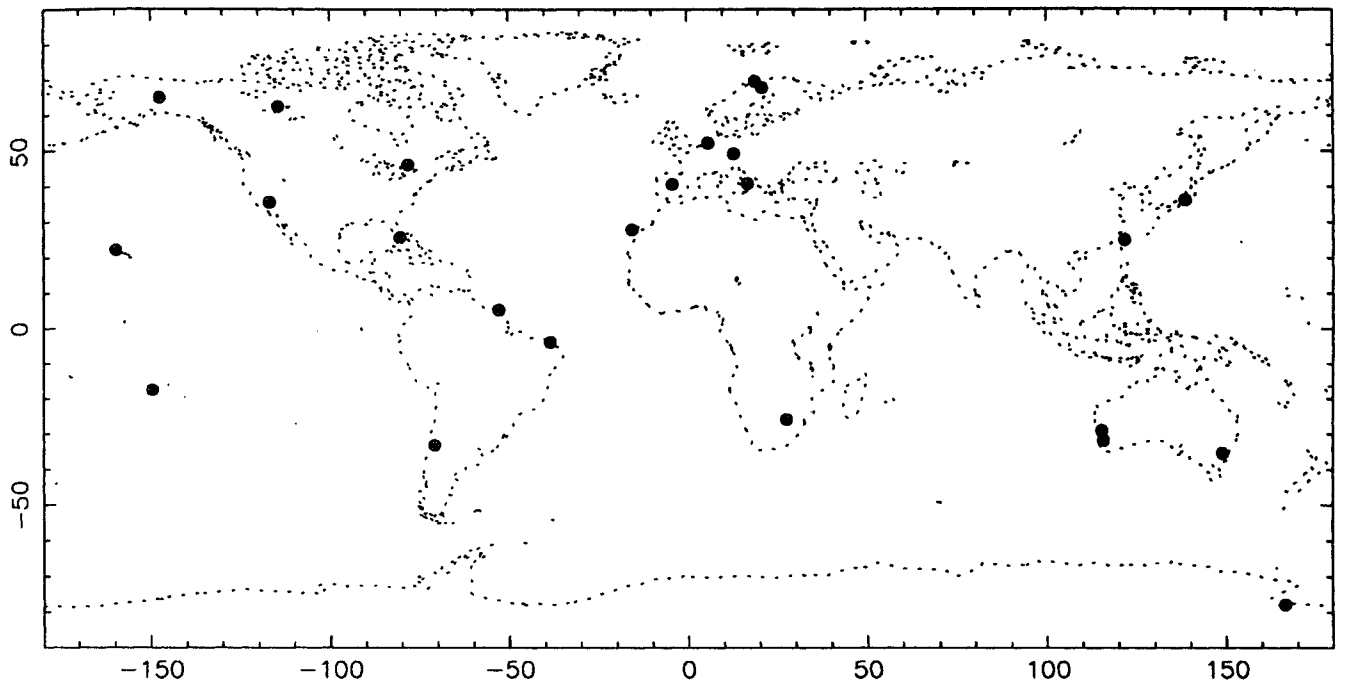
12 - Definition of the origin: Origin of a set of 13 fiducial stations constrained to be the same as that of the ITRF92. These stations are: Madrid, Kootwijk, Wettzell, Tromso, Hartebeesthoek, Yarragadee, Tidbinbilla, Kokee Park, Fairbanks, Goldstone, Yellowknife, Algonquin and Santiago.

13 - Definition of the orientation: the EOP's are fixed to IERS Bulletin B, the rotation about the z axis of the set of 13 fiducial stations constrained to be the same as that of the ITRF92.

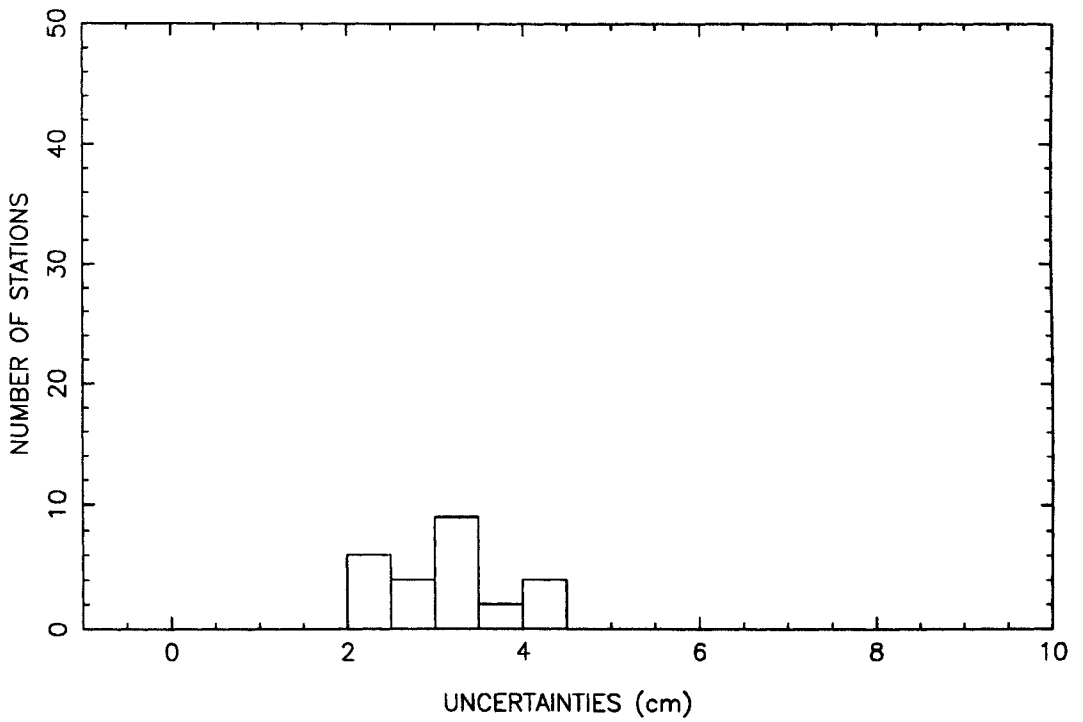
14 - Constraint for time evolution: ITRF92 and NNR-Nuvel1 plate motion model

15 - Deviations from the IERS standards:

- no relativistic corrections to propagation or/and acceleration.
- no station ocean loading.



Distribution of the 24 sites of the terrestrial frame SSC(ESOC) 94 P 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 25 stations of the terrestrial frame SSC(ESOC) 94 P 01.

Summary description of solution EOP(ESOC) 92 P 02

1 - Technique: GPS
2 - Analysis Centre: ESA / European Space Operations Centre (ESOC)

3 - Solution identifier: EOP(ESOC) 1993
4 - Software used: GPSOBS/BAHN-V5
5 - Relativity Scale: Local Earth
6 - Permanent tide correction on station: To be added to listed coordinates
7 - Tectonic plate model: ITRF92 + NNR-Nuvel1
8 - Velocity of light (c): 299792.458 km/s
9 - Geogravitational constant (GMo): 398600.4415 km^3/s^2
10 - Reference epoch: 1993.5
11 - Adjusted parameters:

Satellite parameters per spacecraft:
- one orbital state at start epoch.
- one scaling factor for radiation pressure ROCK4 T10 or T20 model.
- one Y-bias acceleration.

Station related parameters per ground station:
- every 6 hours an atmospheric zenith delay and a shape parameter.
- clock biases and clock drifts as needed.
- double-differenced phase ambiguities as real-valued parameters.
- ground station positions for stations that are not fixed

Earth Orientation Parameters (EOPs):
- one set of pole coordinates xp, yp and LODR per day.

Parameters to be kept fixed:

Satellite parameters per spacecraft:
- radiation pressure scaling factors Gx and Gz fixed to 1.0.

Station related parameters per ground station:
- site velocities from ITRF92 or NNR-Nuvel1 when the site is not listed in the ITRF92
- The coordinates of 13 fiducial stations are fixed to the ITRF92 values. These stations are: Madrid, Kootwijk, Wettzell, Tromso, Hartebeesthoek, Yarragadee, Tidbinbilla, Kokee Park, Fairbanks, Goldstone, Yellowknife, Algonquin and Santiago

12 - Definition of the origin: Geocentre through gravity model (C10 = C11 = S11 = 0).
13 - Definition of the orientation: By fixing the coordinates of 13 fiducial stations to the ITRF92 values.
14 - Constraint for time evolution: ITRF92 and NNR-Nuvel1 plate motion model
15 - Deviations from the IERS standards:
- no relativistic corrections to propagation or/and acceleration.
- no station ocean loading.

EOP(ESOC) 92 P 02 From Sep 1992 to Dec 1993

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	100	0.26	100	0.26	47	0.45
1993	359	0.15	359	0.16	359	0.21

EARTH ROTATION PARAMETERS AND STATION COORDINATES FROM GPS DATA

EOP(GFZ) 94 P 02, 03,
SSC(GFZ) 94 P 01

G. Gendt, G. Dick, W. Mai, Ch. Reigber, Th. Nischan
GeoForschungsZentrum (GFZ) Potsdam

A global Set of Station Coordinates (SSC(GFZ) 94 P 02) and Earth Rotation Parameters (ERP(GFZ) 94 P 02) have been computed by GFZ from the 1993 global GPS data set and with the GPS analysis Software package EPOS.P.V2. Some details of the analysis are described below.

Data

The initial data acquired at the GFZ-IGS Center are the 30 sec RINEX data from 29 IGS pilot service stations collected at the network data centers CDDIS and IGN.

For the analysis itself undifferenced ionospheric free phases with a sampling rate of 6 minutes were used. P-code data entered into the analysis to preset the ambiguities. The identified ambiguities were constrained to the expected P-code accuracy. Consecutive data segments of 32 hour were formed to carry out the solutions including a quality assessment in overlapping orbital segments.

Analysis

Data from 29 globally distributed ROGUE receivers went into the solution. The solution was obtained by using GFZ EPOS.P.V2 Software package, which is adapted to the IERS- Standards with the few exceptions indicated below. The adjusted parameter set results from a HELMERT blocking. For each parameter the time resolution can be chosen freely. Normal equations were combined into a yearly system to derive the global station position solution SSC(GFZ) 94 P 01. In this solution the station motions were not solved but fixed to the NUVEL-1 motion values.

The Earth Rotation Parameters (pole coordinates and length of day) were adjusted as daily values (first 24 hours of each session). These values are nearly independent from day to day. 12 hour pole values were determined in addition.

Reference Frame

CIS:	mean equator and equinox of J2000.0
Precession:	IAU 1976
Nutation :	IAU 1980
Tectonic plate model :	NNR NUVEL-1
Solid earth tides :	Wahr-model, h2=0.609, l=0.0852,permanent tide included
Ocean loading site displacement :	not applied

Dynamic Model

Gravity field:	GEM-T1 GM : 398600.4400 km^3/s^2
Velocity of light :	299792.458 km/s
Earth tides :	Wahr-model
Ocean tides :	Schwiderski-model
Corrections to rotational deformations:	C(2,0), C(2,1), S(2,1)
Indirect perturbation of oblateness of the Earth:	applied
Third body effects:	Sun, Moon, Jupiter, Venus
Solar radiation:	ROCK4 and ROCK42, including thermal reradiation (T10, T20 formulation of Fliegel [1992])
Relativistic equation of motion :	no
Tidal variations in UT1:	zonal tides with periods < 35 days

Measurement Model

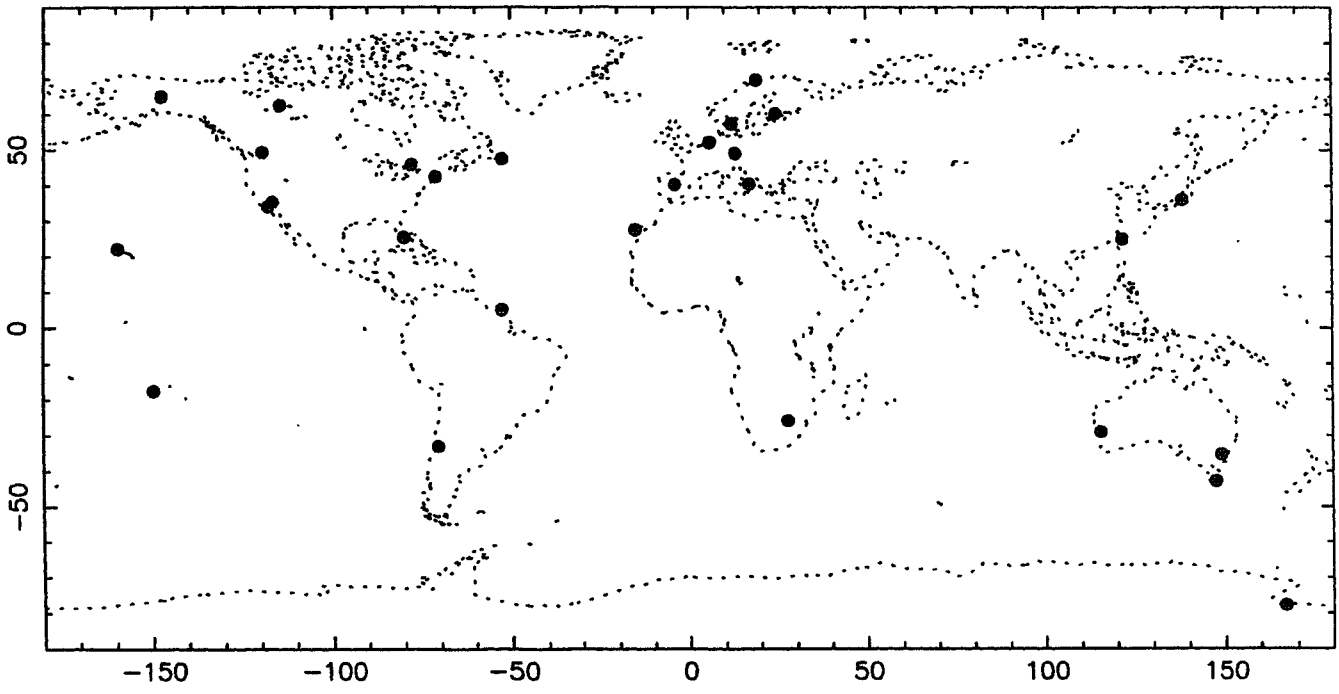
Tropospheric model :	Saastamoinen
Relativistic clock corrections :	applied
Center-of-mass corrections :	IERS Standards
GPS space vehicle masses :	from Fliegel et al. [1992] and Feltens [1991]

Solve for parameters are:

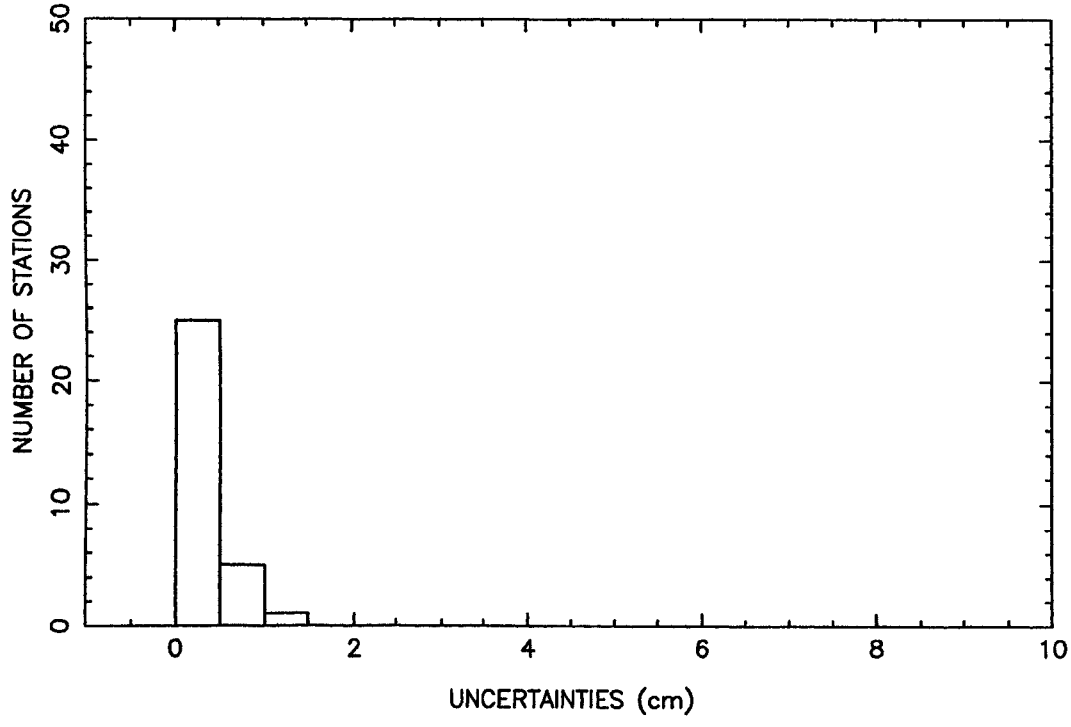
Satellite state :	32h interval
Reflectance coefficient and y-bias:	32h interval
ERP (pole and LOD) :	24h interval
Tropospheric zenith path delay:	4 h interval
Ambiguities	
Epoch time parameters	

Summary description of the terrestrial system attached to the set of station coordinates SSC (GFZ) 94 P 01

1 - Technique :	GPS
2 - Analysis Center :	GFZ
3 - Solution identifier :	SSC(GFZ) 94 P 01
4 - Software used :	EPOS.P.V2
5 - Relativity Scale :	no
6 - Permanent tidal correction on station :	yes
7 - Tectonic plate model :	NNR NUVEL-1
8 - Velocity of light :	299 792 458 m/s
9 - Geogravitational constant (GMo) :	398600.4400 km^3/s^2
10 - Reference epoch :	49170 (1993.5)
11 - Adjusted parameters :	STATION COORDINATES - radius, longitude and latitude ORBIT - 6 orbital parameters - reflectance coefficient and y-bias every 32 hours EOP - daily x, y and LOD OTHER - Tropospheric zenith path delay at 4 hours intervals - Ambiguities - Epoch time parameters
12 - Definition of origin :	C(1,0)=C(1,1)=S(1,1)=0
13 - Definition of orientation :	aligned to ITRF91 by similarity transformation
14 - Constraint for time evolution :	fixed NNR-NUVEL-1



Distribution of the 28 sites of the terrestrial frame SSC(GFZ) 94 P 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 31 stations of the terrestrial frame SSC(GFZ) 94 P 01.

EOP(GFZ) 94 P 02 From Jan 1993 to Jan 1994

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1993	360	0.04	360	0.03	360	0.04

EARTH ORIENTATION RESULTS FROM THE JET PROPULSION LABORATORY USING GPS

EOP(JPL) 92 P 03

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G Blewitt,
The University of Newcastle upon Tyne, Newcastle, England

The Satellite Geodesy and Geodynamics Group in JPL's Tracking Systems and Applications Section has continued its regular analysis of data from a globally-distributed network of Rogue GPS receivers. Using the GIPSY/OASIS-II software, estimates of a variety of parameters, including those relating to earth orientation, are made every day.

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, during periods when anti-spoofing (AS) is not in effect. Data below 15 degrees elevation are not used. The phase data are decimated to 5 minutes for 93 Jan 01 - Feb 03, 10 min for Feb 04 - Oct 30, and 7.5 min beginning Oct 31. The P-code data are carrier-smoothed over the same interval.

Data corresponding to each GPS day are analyzed in 30-hour batches centered on GPS noon. Estimated parameters are satellite state vectors and solar radiation pressure, receiver coordinates, zenith wet troposphere delay at each receiver site, station and satellite clock offsets, carrier phase ambiguities, and earth orientation. A typical day's analysis of 40 stations and 26 satellites contains ~57,000 phase measurements, from which ~1550 parameters are determined (parameters allowed to vary stochastically are counted only once). The rms post-fit residuals 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; it differs from the IERS standards by an insignificant amount. Pole tide and the Love number variation at K1 frequency are modeled beginning Apr 01 (*IERS Technical Note 13*). Ocean loading is modeled beginning Nov 04 (Scherneck, H -G, 1991, A parametrized solid earth tide model and ocean tide loading effects for global geodetic baseline measurements, *Geophys. J. Int.*, **106**, pp 677-694; private communication between Scherneck and JPL).

The Earth's gravity field is described by the JGM1 8x8 multipole expansion using terms up through degree and order 8. The value of GM used is 398600.4415 km^3/s^2. Beginning Apr 13 the JGM2_12x12 gravity field is used [Nerem, R S, *et al.*, Gravity model development for TOPEX/Poseidon: Joint Gravity Models 1 and 2, *J. Geophys. Res.*, submitted, 1994].

Nominal values of the parameters for each GPS satellite [3 each for position and velocity, and two for solar radiation pressure (srp)] are from the broadcast ephemeris. Weak a priori constraints of 1 km and 10 mm/s for position and velocity, respectively, are imposed. The T10-T20 solar radiation pressure model is used for srp [Fliegel, H.F., Gallini, T.E., and Swift, E.R., Global Positioning System Radiation Force Models for Geodetic Applications, *J. Geophys. Res.*, **97**(B1), 1992].

Table 1 contains a list of sites from which data were used in the analysis. The number of calendar days in 1993 for which data from each site were used is also listed, together with the median (over the year) daily value of the rms post-fit residual.

Parameters are first estimated without fiducial constraints, and the station estimates and covariance are set aside. (Such daily free-network solutions form the basis for SSC(JPL) 92 P 01.) The locations of eight sites (denoted with "*" in Table 1) are then held fixed in each day's analysis to provide a reference frame for GPS satellite ephemerides and earth orientation. Up through Oct 22, locations of the fiducials are updated at the beginning of each month. Beginning Oct 23, they are updated daily. Positions and velocities are ITRF 91 [SSC(IERS) 92 C 04]. Beginning Dec 20 and later (except Dec 25), we begin to use 13 fiducials (additional five denoted with "." in Table 1) and ITRF 92. Based on two days in 1994 analyzed both ways, we observe a shift in X pole of -0.825 ± 0.005 mas and a shift in Y pole of -0.035 ± 0.175 mas (ITRF 92 - ITRF 91). 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. The zenith dry delay is assumed to be 2.3 m * 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 Jan 06, this was the clock at FAIR. Beginning 1993 Jan 06 and later, the reference clock is at ALGO, except on a few days when ALGO data were not available. These clocks are generally believed accurate to better than 1 μsec. The carrier phase ambiguities are estimated as real-valued parameters.

Table 1. GPS Receiver Sites Used in EOP(JPL) 92 P 03

site	country	JPL ID	rms (mm)	days
Alberthead	Canada	ALBH	5.2	347
Algonquin Park	Canada	*ALGO	4.1	364
Bermuda	North Atlantic	BRMU	6.1	255
Tdibinbilla	Australia	.CANB	5.1	361
Mammoth Lakes	Unites States	CASA	5.0	273
Fairbanks	United States	*FAIR	4.5	337
Fortelaza	Brazil	FORT	6.2	184
Greenbelt	United States	GGAO	4.3	81
Goldstone	United States	.GOLD	3.5	361
Graz	Austria	GRAZ	4.0	306
Hartebeesthoek	South Africa	*HART	5.1	357
Harvest	United States	HARV	5.2	359
Herstmonceux	United Kingdom	HERS	3.8	273
Hobart	Australia	HOBA	4.8	229
Jet Propulsion Lab	United States	JPLM	4.5	351
Kiruna	Sweden	KIRU	8.7	122
Kokee Park	United States	*KOKB	6.3	342
Kootwijk	Netherlands	.KOSG	3.6	350
Kourou	French Guiana	KOUR	7.4	330
Madrid	Spain	*MADR	4.9	364
Maspalomas	Canary Islands	MASP	5.0	348
Matera	Italy	MATE	4.0	295
McMurdo	Antarctica	MCMU	4.7	213
McDonald	United States	MDO1	4.7	182
Metsahovi	Finland	METS	3.4	343
Ny Alesund	Norway	NALL	4.3	278
North Liberty	United States	NLIB	4.5	296
Onsala	Sweden	ONSA	3.9	345
Pamatai	Tahiti	PAMA	9.1	246
Penticton	Canada	PENT	4.0	338
Pietown	United States	PIE1	4.8	326
Pinyon	United States	PINY	4.1	109
Quincy	United States	QUIN	5.2	325
Richmond	United States	RCM2	6.9	215
Richmond	United States	RCM4	6.2	62
Richmond	United States	RCM5	4.8	18
Santiago	Chile	*SANT	6.1	356
St. John's	Canada	STJO	4.8	361
Taipai	Taiwan	TAIS	5.2	344
Tromso	Norway	*TROM	3.8	357
Usuda	Japan	USUD	4.8	317
Vandenberg	United States	VNDP	4.1	295
Westford	United States	WEST	4.8	273
Wettzell	Germany	.WETB	4.4	327
Yaragadee	Australia	*YAR1	4.1	338
Yellowknife	Canada	.YELL	3.9	360

* Indicates fiducial site for entire year.
• Indicates fiducial site beginning Dec 20 (except Dec 25).

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. Beginning Jul 11, we tightened the a priori constraints on the polar motion rate parameters to properly reflect the data strength for determining these quantities and the accuracy of the IERS Bulletin B predictions. (This applies also to Jul 07, but not to Jul 15.) LODR is estimated with a very loose a priori constraint.

All days in 1993 were analyzed, including 45 for which our AS strategy was in effect. AS periods are Feb 20-21, Feb 26 - Mar 01, Mar 31, Apr 19 - Apr 24, Apr 28 - May 03, May 06, Jun 05 - 09, Sep 17 - Sep 20, Sep 24 - Sep 28, Oct 29 - Oct 31, Nov 03-06, Nov 08-09, Nov 26, and Dec 07.

Our AS analyses exclude data below 20 degrees elevation angle. In the first half of 1993, pseudorange data were used during AS but with a 500-m data noise (increased from 1 m). Beginning with the Sep AS period, we stopped using pseudorange altogether in the parameter estimation phase of each day's analysis. Finally, beginning Oct 29, we reduced the amount of allowed stochastic variation in satellite radiation pressure parameters to a negligible level when processing data acquired during periods of AS. [Our AS strategy improves significantly in 1994.] Using Space 93 (R. Gross, submitted to IERS), we have estimated that our formal errors for pole coordinates are underestimated by a factor of 2.42 for non-AS days, and 6.38 for AS days.

For the 353 days prior to our adjustment to the new 13-station ITRF 92 reference frame, we have compared our polar motion and LODR series with those from Space 93 (using scaled formal error weighting) and IERS Bulletin B Final Values, respectively. The results are in Table 2.

Table 2: Comparison of this work with Space 93 (polar motion) and IERS Bulletin B Final values (LODR)

	weighted mean difference	weighted standard deviation
X pole (mas)	0.669	0.430
Y pole (mas)	1.432	0.274
LODR (msec)	-0.007	0.151

Pole weights are $1/(s^2)$, where s is 2.42 times the formal error for non-AS days, and 6.38 times the formal error for AS days. The LODR result is unweighted and excludes all AS days as well as 8 outliers for which the discrepancy exceeds 0.5 msec.

Acknowledgment. The work described in this report was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

EOP(JPL) 92 P 03 From Nov 1992 to Jan 1994

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

YEAR	X		Y		DR	
	Nb	Sigma	Nb	Sigma	Nb	Sigma
1992	39	0.16	39	0.15	39	0.50
1993	365	0.14	365	0.15	365	0.50

SITE COORDINATES AND VELOCITIES FROM THE JET PROPULSION LABORATORY USING GPS

SSC(JPL) 94 P 01

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G. Blewitt
University of Newcastle upon Tyne

Coordinates and velocities for 41 globally distributed sites have been computed using GPS data spanning three years from January 22, 1991 through September 16, 1993. Velocity estimates for all sites are provided for the first time (Heflin *et al.*, 1993). A no-fiducial approach was used whereby all site positions and velocities were estimated, preserving the independence of the GPS solution and avoiding the possibility of systematic errors which can be caused by fiducial constraints. The four step analysis process is described below.

1. Estimate

All daily site positions were estimated using weak constraints of 10 m to 1 km for each site component. The 10 m constraint is used only for sites with well known nominal values. The GPS data span three years from January 22, 1991 through September 16, 1993 but not all sites are present for the entire time span and there is a gap where no analysis was carried out between February 13, 1991 and May 31, 1992. A typical site has data spanning about one year. Daily solutions after January 17, 1993 were products of the standard IGS processing performed at JPL. A detailed description of the strategy used is provided in the summary of EOP(JPL) 94 P 03. The number of receiver sites and satellites has increased significantly since 1991 and the analysis strategy has also evolved with time. The most significant improvements include estimation of LODR and a stochastic treatment of the satellite forces due to solar radiation pressure (Vigue *et al.* ,1993).

2. Combine

All daily solutions were combined using a standard least-squares constant-velocity model to obtain a single set of positions and velocities. Full covariance matrices were used when combining the daily solutions.

3. Constrain

Instead of using the fiducial approach, we choose to apply fourteen internal constraints to the combined covariance matrix. Internal constraints are not new and the basic idea is to fix several linear combinations of positions and velocities at their estimated values instead of fixing some number of position and velocity components at externally provided values. Internal constraints offer two significant advantages. First, they allow the GPS estimates to remain independent of other techniques and second, they avoid the possiblity of systematic effects which can be caused if there are errors in the fiducial coordinates or velocities. We have built upon the internal constraint method of Vanicek and Krakiwsky (1987) and have generalized their approach to include fourteen internal constraints and allow those constraints to be non-zero so that the final matrix is fully invertible, allowing it to be combined with other solutions.

4. Transform

We estimate seven traditional Helmert parameters and their rates to transform the GPS solution into ITRF92. The three rotations, three translations, and one scale ensure no net offset with respect to ITRF92 while the corresponding rates ensure no net drift.

Solution SSC(JPL) 94 P 01 represents a significant improvement over our previous submissions because of the increased time span of data and because all velocities are estimated. A number of geophysically interesting signals are present in this solution, including global tectonic motion, deformation in plate boundary zones, displacement due to the Lander's earthquake, volcanic uplift at CASA, and a possible detection of glacial rebound at Algonquin Park. Sites in the northern hemisphere have WRMS values 2-3 times better than those in the southern hemisphere. The overall CHI^2/DOF is 0.34, indicating that the errors as stated are too conservative by about a factor of 1.7 and the mean residual WRMS values over all sites are 6 mm, 9 mm, and 14 mm for latitude, longitude, and height respectively.

Acknowledgements. This research was partially carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. We thank the numerous institutions and individuals who operate the GPS constellation and global receiver network.

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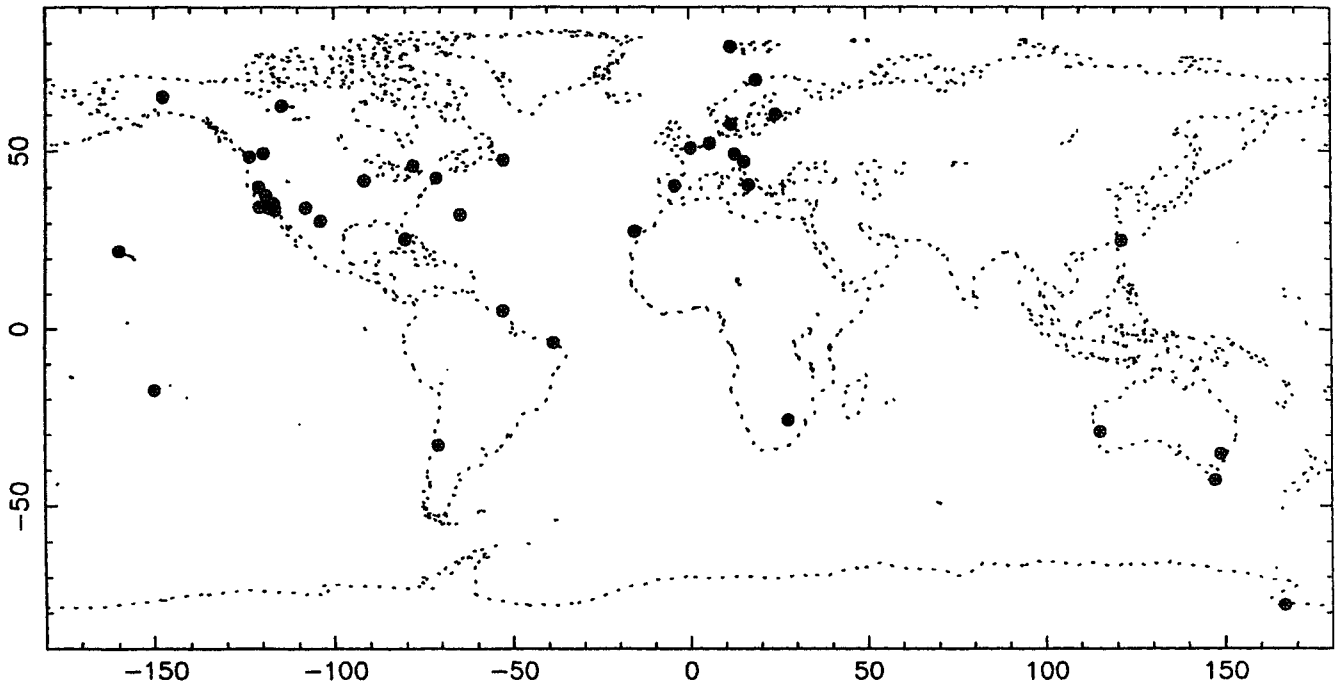
Vanicek, P., and Krakiwsky, E., 1986: Geodesy, the concepts, Elsevier Science Publishers B. V., The Netherlands, 271P381.

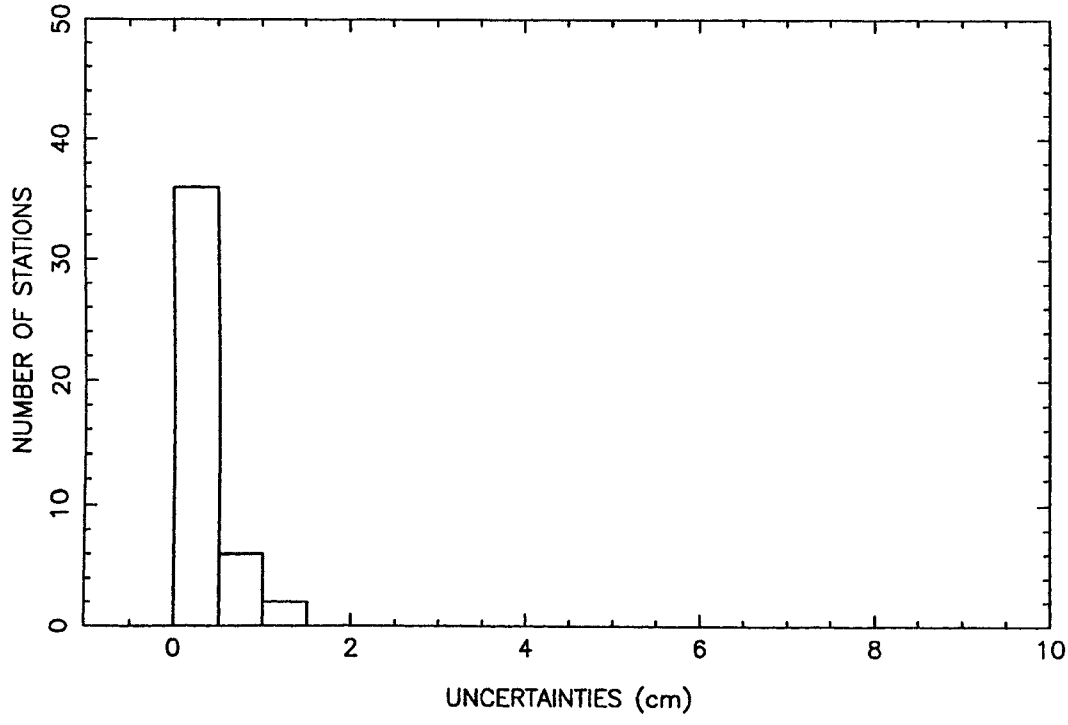
Vigue, Y., Lichten, S., Muellerschoen, R., Blewitt, G., and Heflin, M., 1993: Improved Treatment of GPS Force Parameters in Precise Orbit Determination Applications, Paper AAS 93P159, AAS/AIAA Spaceflight Mechanics Meeting.

Summary description of the terrestrial system attached to the set of station coordinates and velocities SSC(JPL) 94 P 01:

1 - Technique:	GPS
2 - Analysis Center:	JPL
3 - Solution identifier:	SSC(JPL) 94 P 01 (JPL Identifier JGC9401)
4 - Software used:	GIPSY
5 - Relativity scale:	Local Earth Scaled into ITRF92
6 - Permanent tide correction on station:	No
7 - Tectonic plate model:	None
8 - Velocity of light:	299792458 m/sec
9 - GM:	$3.986004415\ 10^{14}\ m^3\ s^{-2}$
10 -Reference epoch:	1992.5
11 -Adjusted parameters:	All station coordinates X, Y, Z PMX, PMY, and LODR All satellite epoch states Three stochastic solar pressure parameters per satellite Random walk zenith tropospheric delays for each site All clocks except one Real valued carrier phase ambiguities
12 - Definition of origin:	Translated into ITRF92
13 - Definition of orientation:	Rotated into ITRF92
14 - Constraint for time-evolution:	All velocities estimated Fourteen parameter transformation ensures no net drift with respect to ITRF92



Distribution of the 40 sites of the terrestrial frame SSC(JPL) 94 P 01.



Distribution of the uncertainties (quadratic mean of σ_x, σ_y, σ_z) for the 44 stations of the terrestrial frame SSC(JPL) 94 P 01.

NOAA EARTH ORIENTATION TIME SERIES FROM GPS OBSERVATIONS

NOAA 94 P 02, 03, 04

M.S. Schenewerk, G.L. Mader, W. Kass, R. Dulaney, D. Pursell

DESCRIPTION OF ANALYSIS PROCEDURES

Daily terrestrial site coordinates and a time series of polar motion parameters have been estimated using tracking data from a subset of the International GPS Service (IGS) tracking network selected to provide timely data, global coverage, and a consistent set of GPS antennas. The a priori ephemerides were created with ARC, an orbit integrator program, provided by the Massachusetts Institute of Technology. ARC employs an eleventh order Adams-Moulton predictor-corrector to produce satellite positions and partial derivatives to the initial conditions at 22.5 minute intervals. The constants used in the program were defined in the IERS standards [McCarthy, 1989]. An 8x8 gravity field taken from the GEM-L2 model were used from January 1, 1993 to November 30, 1993; thereafter, an 8x8 gravity field from the GEM-T2 [Marsh *et al.*, 1989] were used. A simplified ROCK4T model [Columbo, 1989] for the satellite radiation pressure, ad hoc Y-bias, and the related partial derivatives were used throughout 1993. Conversion between inertial and earth-centered, earth-fixed coordinates uses the IGS Rapid Service Earth Orientation Values provided by the National Earth Orientation Service (NEOS), and nutation values generated from IAU 1980 Theory of Nutation [Seidelmann, 1982; Wahr, 1981]. In routine production initial conditions taken from the previous day's adjusted ephemeris are used, although any precise or broadcast ephemeris can provide these.

The creation of databases, the identification and removal of cycle slips, and orbit adjustment were accomplished using software developed at NOAA. The program PAGE3 combined the a priori ephemerides from ARC with tracking data in a least-squares adjustment to produce the adjusted ephemerides, polar motion, and other estimates. 24 hours of tracking data were used for each set of daily estimates. A 15 degree observation elevation cutoff was imposed. Dual frequency phase data were combined to produce an ionosphere-free, double-differenced observable. Double-differencing effectively removes all clock errors. S/A, which manifests itself as a satellite clock error, is therefore also removed with this technique. A daily neutral atmosphere path length correction derived from the Saastamoinen dry atmosphere [Saastamoinen, 1972] plus the Chao wet atmosphere [Chao, 1972] zenith corrections combined with the Center for Astrophysics 2.2 mapping function [Davis *et al.*, 1985], and an Earth tide correction [Melchior, 1978] for the tracking sites are applied. No atmospheric or ocean loading corrections were applied. Sites coordinates, all satellite positions and velocities, scale factors for the radiation pressures, Y- biases, and tropospheric delays, phase bias values, and adjustments to the Earth's rotational pole position were estimated.

From January 13, 1993 to November 30, 1993, the following 13 sites with well determined coordinates [Bock, 1992] were held fixed:

Algonquin, Canada,
Kokee Park, HI, USA,
Matera, Italy,
Metsahovi, Finland,
Taiwan, Tai-Shi,
Wettzell, Germany,
Yellowknife, Canada.
Fairbanks, AK, USA.
Kootwijk Obs., Netherlands,
McMurdo, Antarctica,
Onsala, Sweden,
Tromso, Norway,
Yarragadee, Australia,

The coordinates for these fixed sites were updated on April 30, 1993 [Bock, 1993] and resulted in a break in the polar motion time series. On December 1, 1993, the set of 13 tracking sites and coordinates selected by the IGS to be held fixed or tightly constrained were implemented resulting in a second break in the polar motion time series. The coordinates for these sites are consistent with the ITRF91. These 13 sites are:

Algonquin, Canada,
Goldstone ,CA, USA,
Kokee Park, HI, USA,
Madrid, Spain,
Tidbinbilla, Australia,
Wettzell, Germany,
Yellowknife, Canada.
Fairbanks, AK, USA,
Hartebeesthoek, S. Africa,
Kootwijk Obs., Netherlands,
Santiago, Chile,
Tromso, Norway,
Yarragadee, Australia,

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EOP(NOAA) 94 P 02 From Jan 1993 to Apr 1993

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

YEAR	X		Y	
	Nb	Sigma	Nb	Sigma
1993	104	0.09	104	0.09

EOP(NOAA) 94 P 03 From Apr 1993 to Nov 1993

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

YEAR	X		Y	
	Nb	Sigma	Nb	Sigma
1993	215	0.10	215	0.10

EOP(NOAA) 94 P 04 From Dec 1993 to Dec 1993

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

YEAR	X		Y	
	Nb	Sigma	Nb	Sigma
1993	31	0.08	31	0.09

Summary description of the solutions EOP (NOAA) 94 P 02, 03 and 04

1 - Technique :	GPS, Double-differenced phase
2 - Analysis center :	NOAA
3 - Solution identifier :	Daily
4 - Software used :	ARC orbit integrator; PAGE3 for data analysis
5 - Relativity Scale :	Terrestrial site coordinates are geocentric
6 - Permanent tidal correction on station :	No correction is applied to remove the zero-frequency displacement introduced by the solid Earth tide model.
7 - Tectonic plate model :	ITRF92 velocity field (combined solution from SLR and VLBI estimates) for all fixed sites except for TROMSO, YELLOWKNIFE, and SANTIAGO from December 1, 1993 - December 31, 1993 where the NNR-NUVEL1 is used.
8 - Velocity of light (C) :	299792458. m/s
9 - Geogravitational constant (GMo) :	$3.9860044451 \times 10^{14}\ m^3/s^2$ January 13, 1993 - November 30, 1993; $3.98600436 \times 10^{14}\ m^3/s^2$ December 1, 1993 - December 31, 1993.
10 - Reference epoch :	48829.5 January 13, 1993 - November 30, 1993; 48850.6 December 1, 1993 - December 31, 1993.
11 - Adjusted parameters :	XYZ geocentric station coordinates for all non-fixed sites; pole X and Y coordinates; 1 tropospheric scale factor; double differenced phase biases. All parameters estimated once per day.
12 - Definition of the origin :	Origin specified by the combined solution from SLR and VLBI estimates.
13 - Definition of the orientation :	not applicable
14 - Constraint for time evolution :	Origin specified by the combined solution from SLR and VLBI estimates.

1991-1993 SIO POLAR MOTION SERIES

SIO 93 P 01

The implementation of this series is described in IERS Technical Note No 14, p. P-43.

EOP(SIO) 93 P 01 From Aug 1991 to Jan 1994

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	332	0.19	332	0.20
1993	365	0.09	365	0.09