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.

```
--------------------------------------------------------------------------
          I----IxxxxI----I                         3-days arc No 1
               I----IxxxxI----I                    3-days arc No 2
                    I----IxxxxI----I               3-days arc No 3
                             .....                       ....

        -------IxxxxIxxxxIxxxxIxxxxIxxxxIxxxxI-->  Released CODE Orbits

                day 1                              from arc No 1
                     day 2                         from arc No 2
                          day 3                    from arc No 3
                                 ...                     ...
--------------------------------------------------------------------------
```

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.

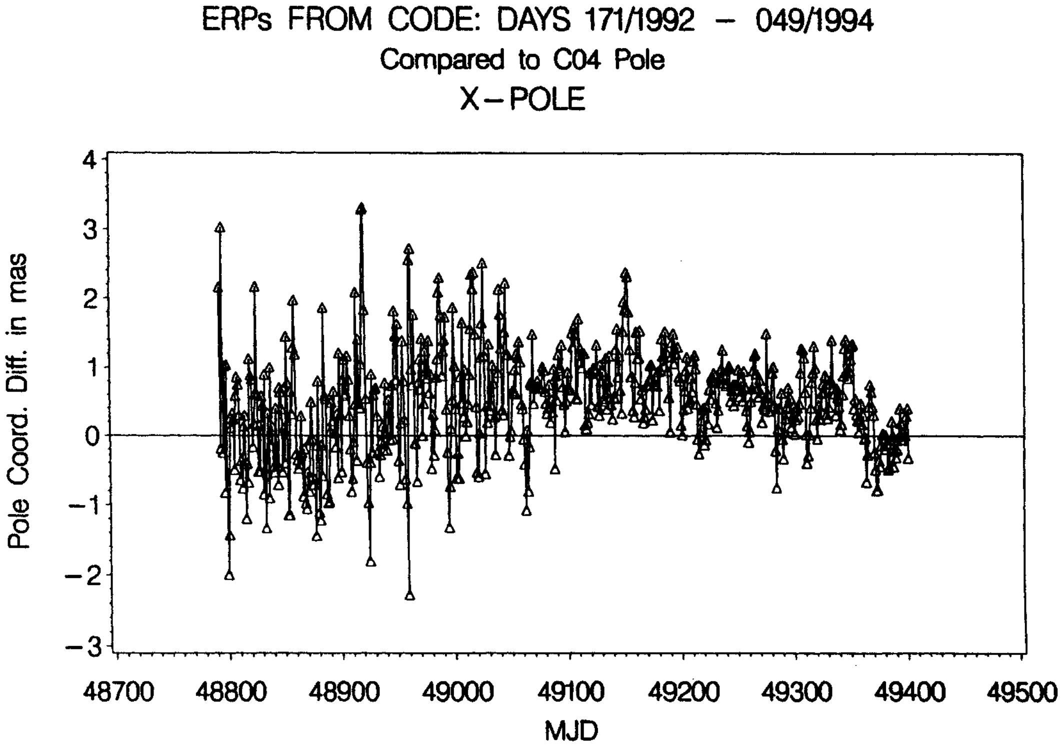

Figure 2a : Daily CODE Pole Estimates - C04 Pole Series (x-component)

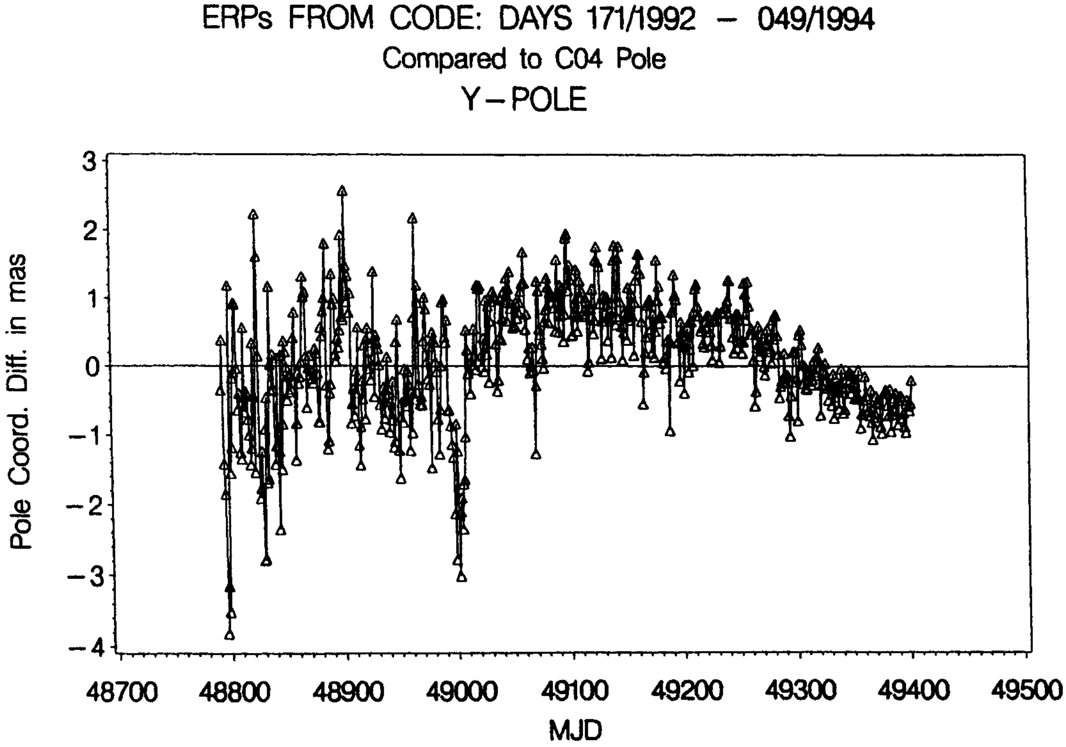

Figure 2b : Daily CODE Pole Estimates - C04 Pole Series (y-component)

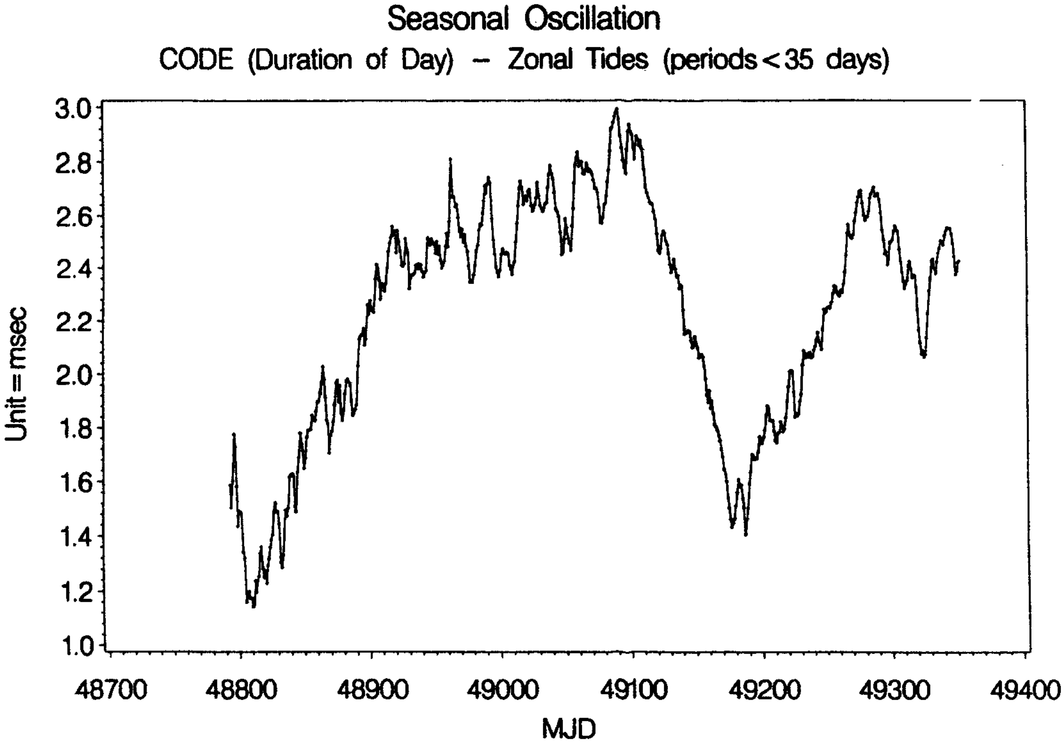

Figure 3a : Daily CODE Excess Day Length Values freed from zonal solid earth tides (periods shorter than 35 days)

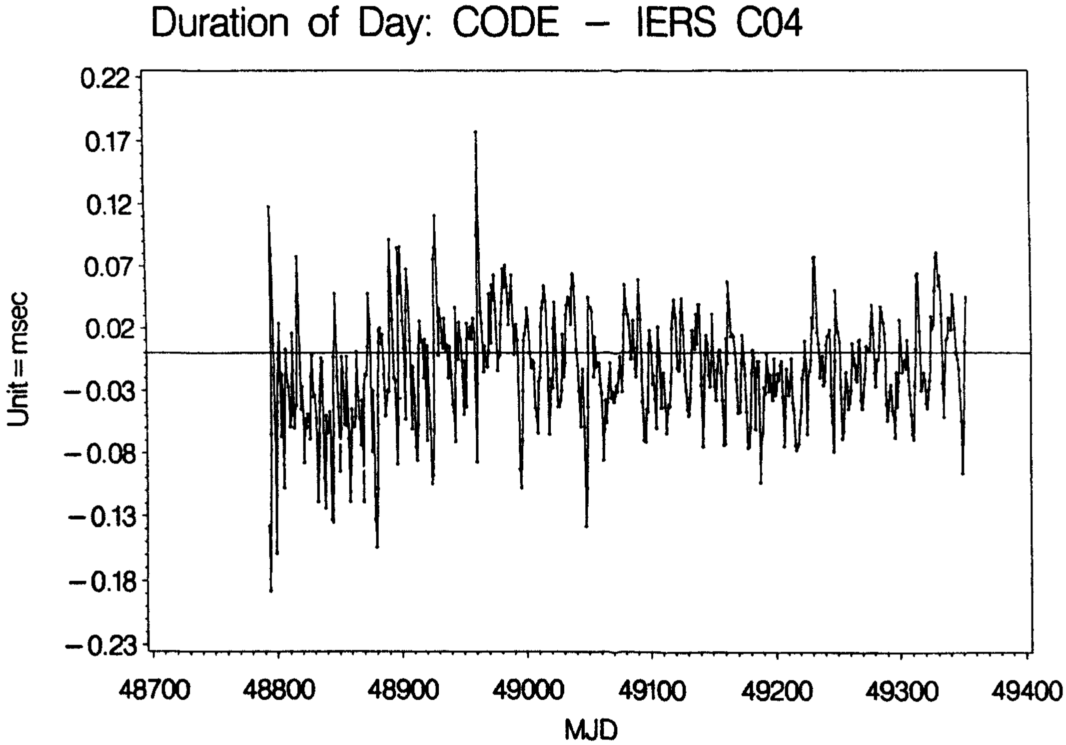

Figure 3b : CODE estimates - IERS C04 Series (Length of day)

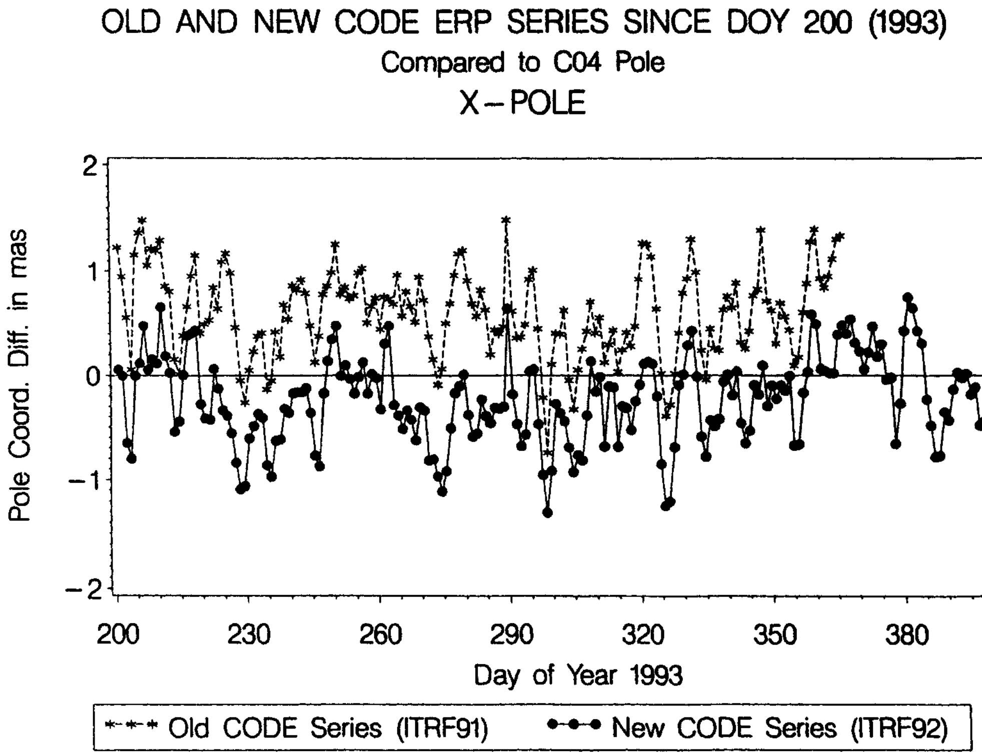

Figure 4a : CODE Estimates using the ITRF 91 of Table 1 - C04 Pole Series (*) and CODE Estimates using the ITRF 92 of Table 1 - C04 Pole Series (.) x-component

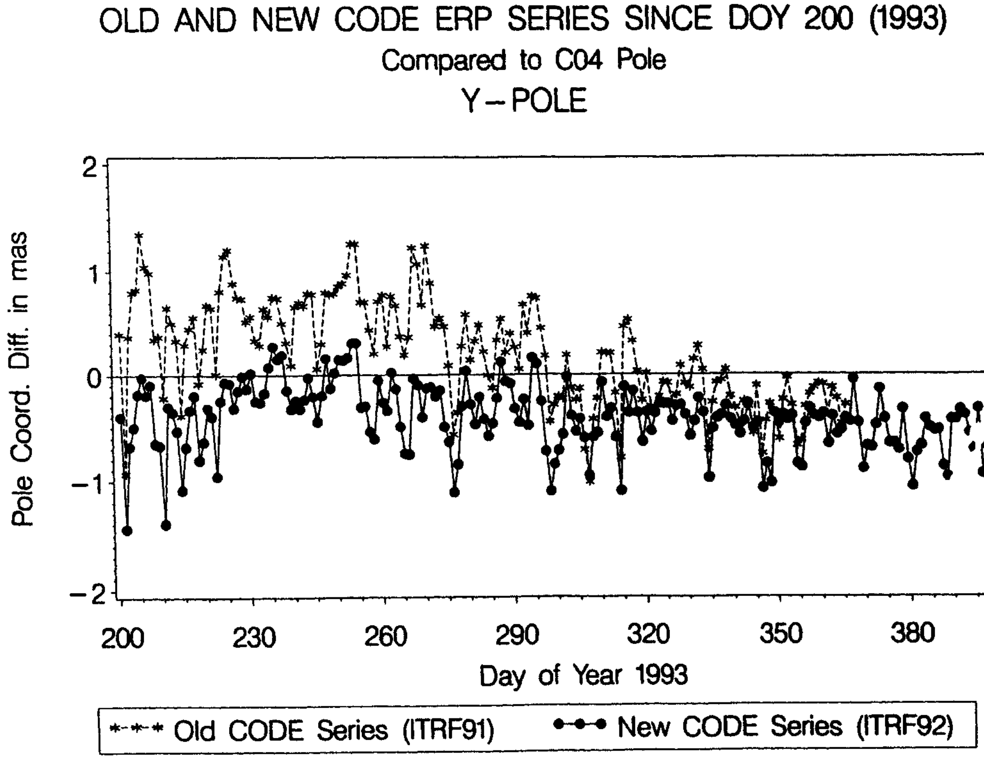

Figure 4b : CODE Estimates using the ITRF 91 of Table 1 - C04 Pole Series (*) and CODE Estimates using the ITRF 92 of Table 1 - C04 Pole Series (.) y-component

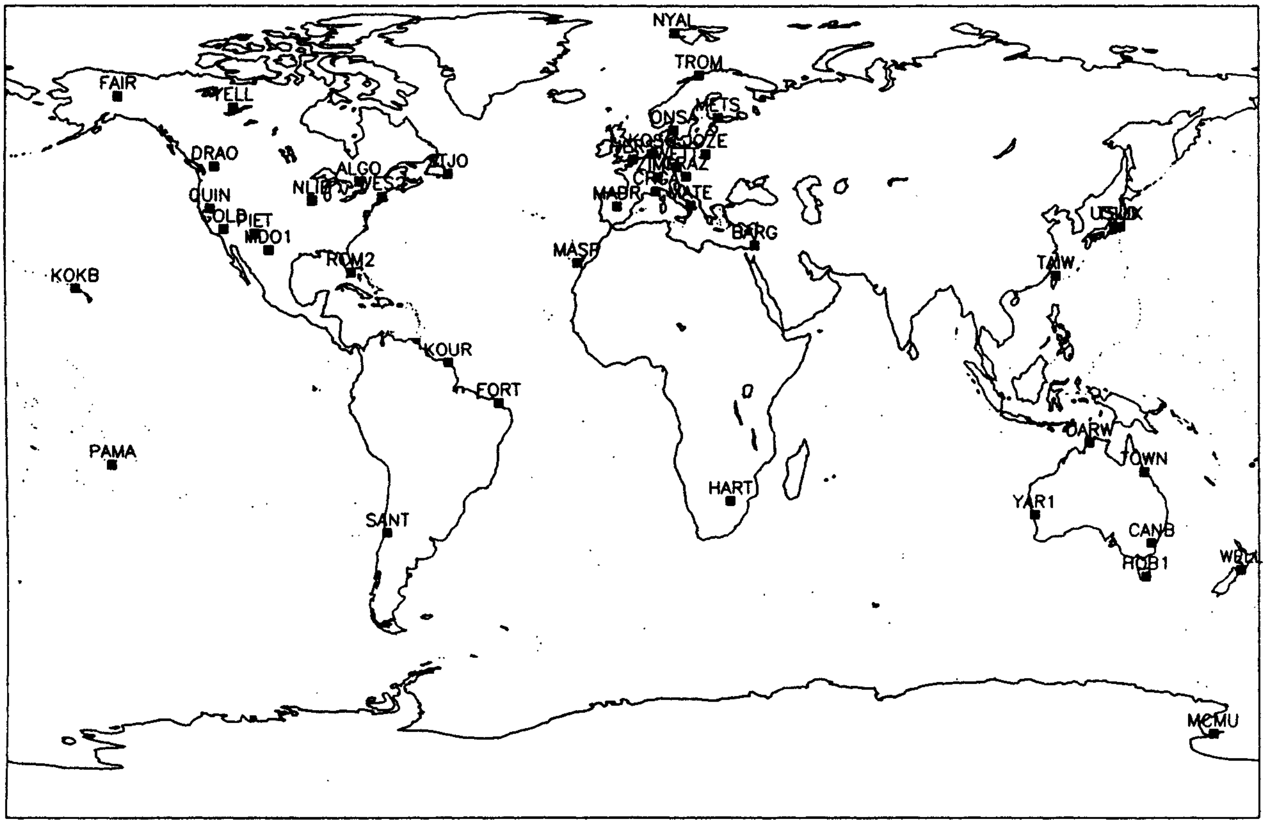

Figure 5 : IGS Core Stations used by the CODE Processing Center in 1993.

References

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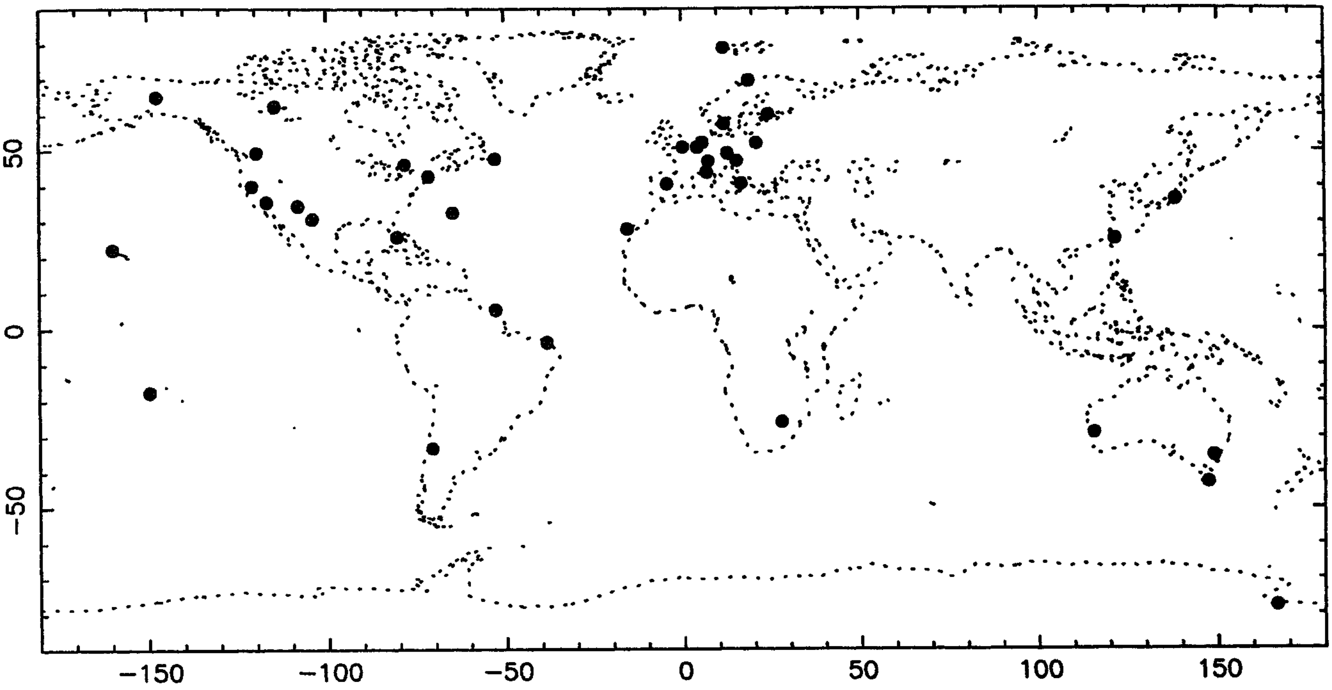
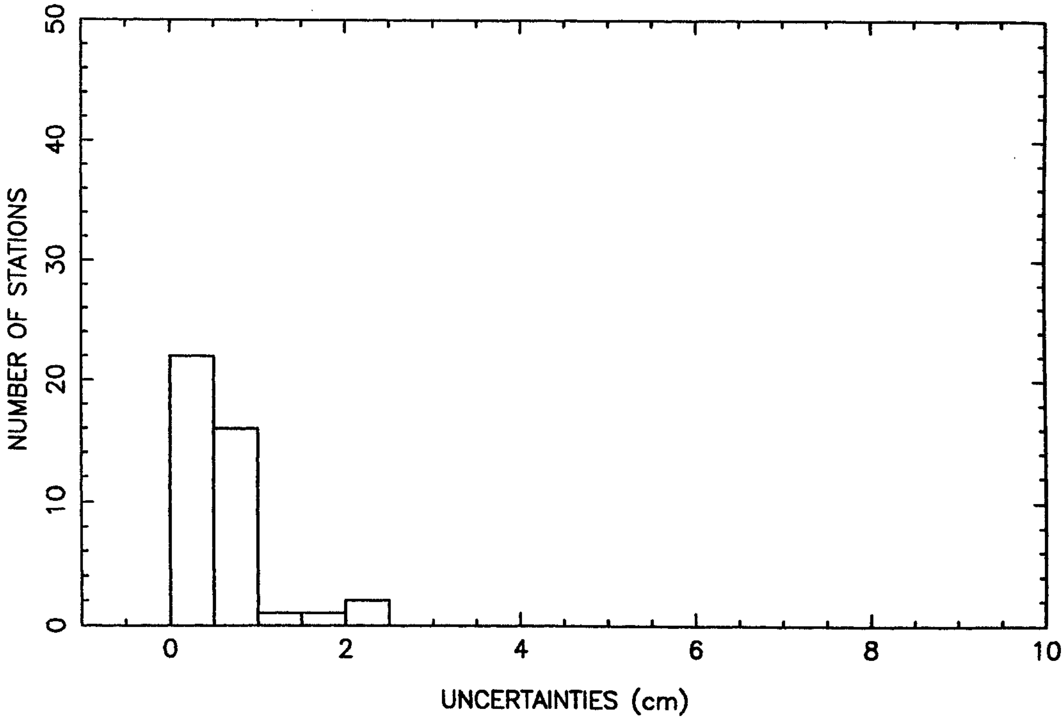
Summary description of the solutions CODE 94 P 01 and P 02

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