ANNUAL REPORT OF THE CODE PROCESSING CENTER OF IGS FOR 1992

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1. INTRODUCTION

General Remarks

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

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

The CODE Processing Center

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

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

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

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

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

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

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

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

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

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

Side issues will be :

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

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

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

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

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

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

2. ANALYSIS CHARACTERISTICS

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

Automated Data Flow, Processing Scheme, and Technical Aspects

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

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

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

```
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 Intervals at AIUB (Official CODE orbits)

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

The force model

Earth's Potential and related Information :

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

Gravitation by sun/moon :

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

Radiation Pressure Modelling

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

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

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

Table 1. Satellite Specific Data

SATELLITE SPECIFIC DATA

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

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

Light <--> Shadow Changes

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

Problem if the sun is in the orbital plane:

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

Solid Earth Tides :

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

General Relativity :

Taken into account according to IERS standards.

System of Orbit Integration :

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

Our realization of the ITRF

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

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

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

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

Orbits:

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

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

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

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

Characteristics of the routine solutions

Table 3 : Solution Characteristics for NG SERIES and EU SERIES

(a) Global Solution

```
-----------------------------------------------------------------------------
Agency               : CODE
Solution Identifier: "NG"

Orbit Arc Length     : 3 days, overlapping
Orbit Parameters     : Osculating Keplerian Elements (6 per arc & satellite)
                       direct radiation pressure p0 (on top of ROCK Models,
                       compare Table 1) and y-bias.

Troposphere           :4 zenith delays per day and station, at present virtually
unconstrained

Fixed Coordinates    : KOSG, MADR, MATE, TROM, WETT, ONSA, KOKB, ALGO,
                       FAIR, GOLD, YELL, RCM2, CANB, YAR1

Earth Rotation       : Each 3-day solution is divided into 3 one-day intervals.
Parameters             x, y, and UT1-UTC are modeled as polynomials of degree 0
                          (on top of the most recent pole distributed by the IERS
                        Rapid Service) within each one-day interval. No continuity
                        conditions were imposed. The UT1-UTC estimate of the first
                       day is fixed to the a priori value (from the RAPID service)
```

(b) European Solution

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----------------------------------------------------------------------------
Agency:               CODE
Solution Identifier: "EU"

Orbit Arc Length:     3 days, overlapping
Orbit Parameters:     Osculating Keplerian Elements (6 per arc & satellite) direct
                      radiation pressure p0 (on top of ROCK Models, compare
                      Table 1) and y-bias.

Troposphere:          4 zenith delays per day and station, at present virtually
                      unconstrained

Fixed Coordinates:    a) during the 1992 IGS Campaign: NONE (only a priori cons-
                      traints according Table 4)
                      b) during the IGS Pilot Service: WETT is kept fix together
                      with the other global sites of Table 2.

Earth Rotation:       Each 3-day solution is divided into 3 one-day intervals.
                      Parameters x, y, and UT1-UTC are modeled as polynomials of
                      degree 0 (on top of the most recent pole distributed by the
                      IERS Rapid Service) within each one-day interval. No conti-
                      nuity conditions were imposed. The UT1-UTC estimate of the
                      first day is fixed to the a priori value (from the RAPID
                      service)
----------------------------------------------------------------------------
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Table 4: A priori constraints on the European coordinates during the 1992 IGS Campaign

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

3. RESULTS

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

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

3.2 Coordinates

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

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

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

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

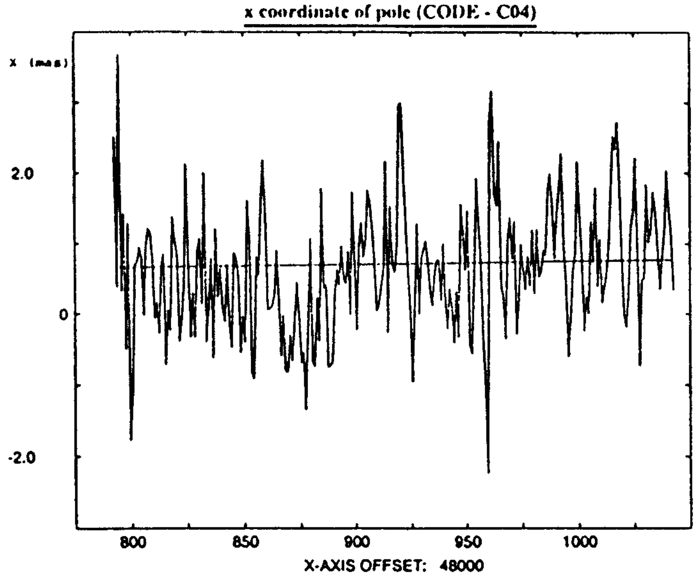
- Scale, translation and orientation of EU P 92 is the same as ITRF.

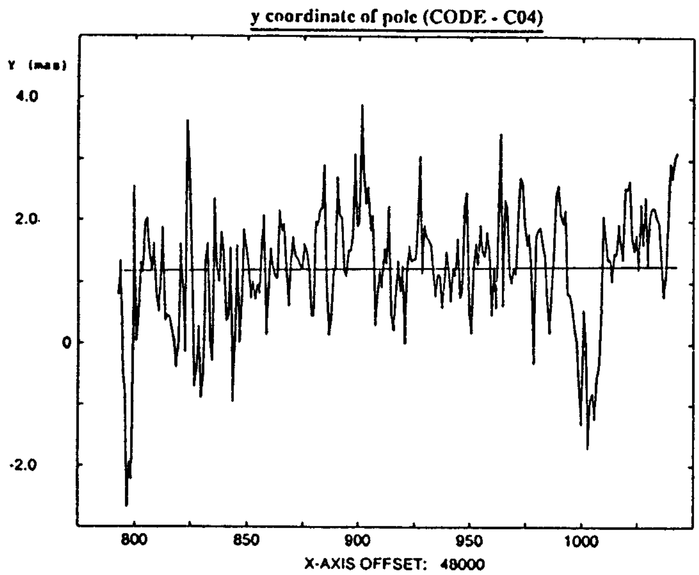
These results were handed over to the IERS.

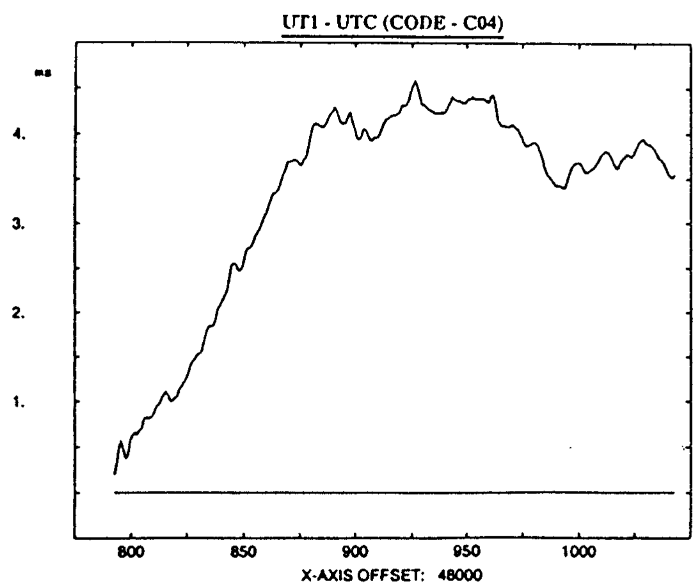
To confirm these coordinates, a second coordinate set is estimated with data since the beginning of the IGS Pilot Service (WETT is kept fix together with other global distributed sites of Table 2, all European stations are free):

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

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







Figures. 2a, 2b, 2c

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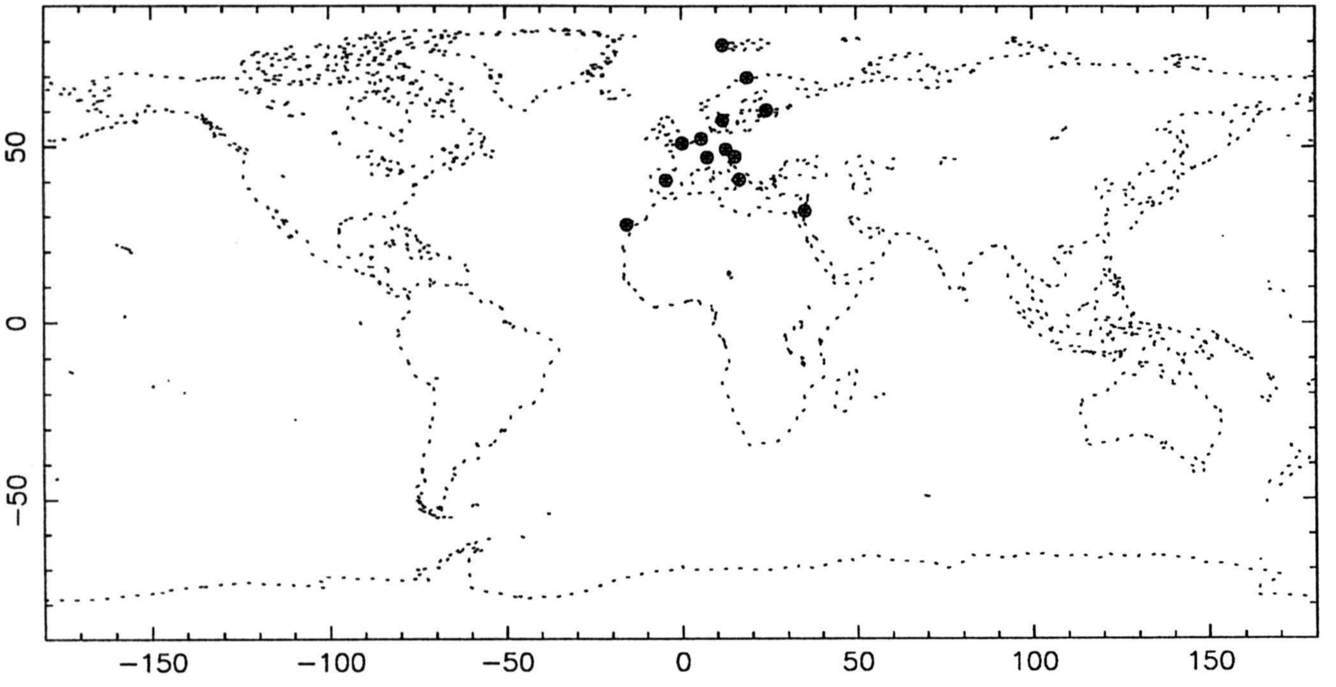

Distribution of the 13 sites of the terrestrial frame SSC(CODE) 92 P 01.

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

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

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