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Monitoring Earth Orientation Variations at the Center for Orbit Determination in Europe (CODE)

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Monitoring Earth Orientation Variations at the Center for Orbit Determination in Europe (CODE)

Robert Weber, Vienna

Abstract

Since June 1992 the CODE Analysis Center of the International GPS Service for Geodynamics (IGS) has contributed to the International Earth Rotation Service (IERS) series of polar motion parameters x_p, y_p as well as length of day (LoD) estimates. The present accuracy of these LoD estimates amount to about 0.03 msec/day. Additionally and because of the special importance of global campaigns including different observation techniques (VLBI, GPS, SLR, LLR) the period of the CONT94-campaign was covered by CODE with a special LoD and polar motion data set of subdiurnal resolution.

The parameters x_p, y_p locate the Celestial Ephemeris Pole (CEP) in the terrestrial reference frame, whereas the position of the CEP in Inertial Space is defined by the IAU 1980 Theory of Nutation. Offsets relative to the CEP position as defined above have been detected by VLBI observations since 1986. Since January 1, 1994 we have determined at CODE the first derivative of these CEP offsets ($\Delta\delta\varepsilon$, $\Delta\delta\psi$) with an accuracy of 0.3 mas/day. This is a valuable contribution of the GPS to the monitoring of high frequency variations of the CEP.

This paper discusses the time development of the CODE x_p, y_p series over an interval of about 3 years and puts special emphasis on GPS-derived earth rotation parameter variations covering the CONT94 campaign. Finally first results of a spectral analysis of the $\Delta\delta\varepsilon$, $\Delta\delta\psi$ values are presented.

Zusammenfassung

Das CODE Analyse Zentrum des Internationalen GPS Dienstes für Geodynamik (IGS) ermittelt seit dem Juni 1992 täglich einen Satz von Erdrotationsparametern (ERP). Diese Serien von Polkoordinaten ($\sigma = \pm 0.2$ mas) und Schätzungen der Tageslänge (LoD, $\sigma = \pm 0.03$ m sec/Tag) werden in erster Linie dem Internationalen Erdrotationsdienst (IERS) zur Verfügung gestellt. Daneben wird vorallem internationalen Kampagnen, welche den Vergleich der Ergebnisse verschiedener Beobachtungstechniken (VLBI, GPS, SLR, LLR) erlauben, eine starke Bedeutung zugemessen. Aus diesem Grund wurde für die Dauer der im Jänner 1994 durchgeführten CONT94-Kampagne zusätzlich ein spezieller ERP-Datensatz erstellt.

Die Polkoordinaten x_p, y_p legen den Celestial Ephemeris Pole (CEP) im terrestrischen Referenzrahmen fest. Seine Lage im inertialen Raum wird durch die Nutationstheorie IAU 1980 definiert. Abweichungen von dieser vordefinierten Lage können bereits seit 1986 durch VLBI-Beobachtungen nachgewiesen werden. Seit 1. Jänner 1994 wird nun am CODE-Analysezentrum die erste Ableitung dieser CEP-Abweichungen ($\Delta\delta\varepsilon$, $\Delta\delta\psi$) mit einer Genauigkeit von 0.3 mas/Tag geschätzt. Dies stellt einen bedeutenden Beitrag von GPS zur Überwachung hochfrequenter CEP-Bewegungen dar.

Der vorliegende Artikel beschreibt die Entwicklung einer aus GPS-Beobachtungen abgeleiteten 3-jährigen Serie von Polkoordinaten und diskutiert anschließend ausführlich den für die CONT94-Kampagne erstellten Datensatz hochauflösender ERP-Schätzungen. Abschließend werden die vorläufigen Ergebnisse einer Spektralanalyse der bislang verfügbaren $\Delta\delta\varepsilon$, $\Delta\delta\psi$ - Serien präsentiert.

1. The International GPS Service for Geodynamics

In June 1992 a global GPS test campaign was started in order to prove the concept for an International Global Positioning System Service for Geodynamics (IGS). The campaign lasted for three months and was immediately followed by a pilot service which continued until the end of 1993. On January 1, 1994 the IGS took up its routine activities as an official Service of the International Association of Geodesy and later on as a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS). The primary objective of the IGS is to provide a service which supports geodetic and geophysical research activities through GPS data products [1].

These data products like satellite ephemeris, earth rotation parameters and station coordinates were based by the end of 1992 on 28 permanent GPS monitor stations [10]. Up to now the network has grown substantially and consisted of more than 60 tracking sites in May 1995 (Fig. 1). This extension of the network goes together with an evolving importance of

GPS TRACKING NETWORK OF THE INTERNATIONAL GPS SERVICE FOR GEODYNAMICS OPERATIONAL AND PLANNED STATIONS

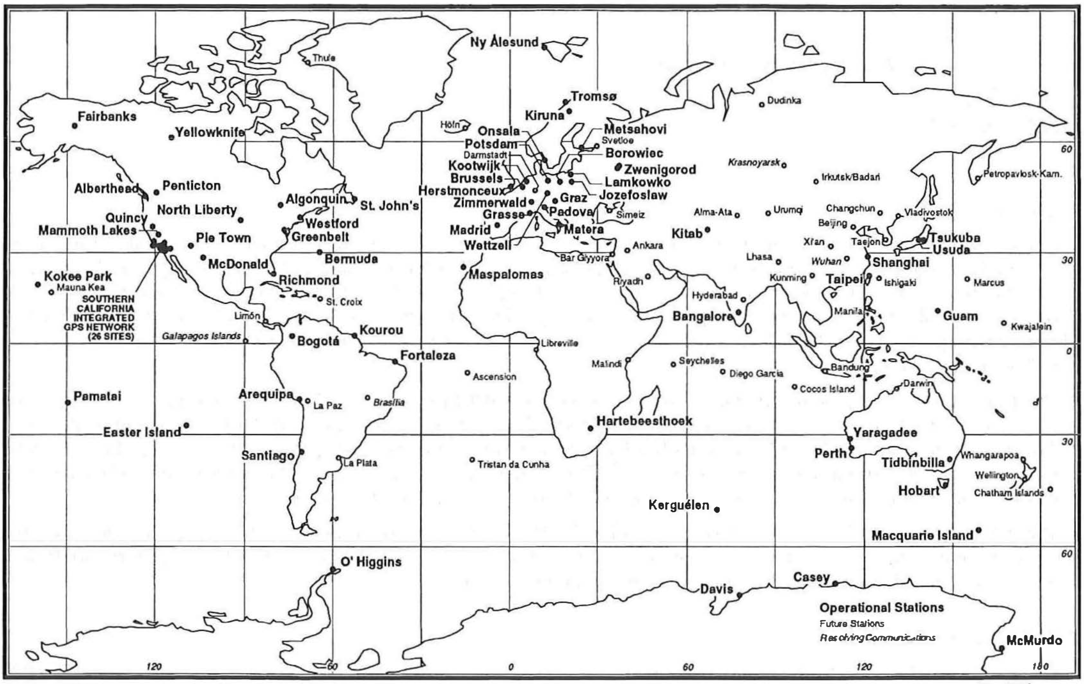

Fig. 1: IGS network of permanent tracking sites

the IGS as a provider of data sets useful for geophysical or geodynamical interpretion. Thus, GPS data is for example used nowadays to extract ionospheric information or to support the weather forecast with almost real-time tropospheric delays.

Besides the tracking stations the IGS consists of a considerable number of data- and analysis centers which are responsible for data managment and evaluation of the IGS products. Most of the results discussed in the subsequent chapters were obtained at the Center for Orbit Determination in Europe (CODE, located at the University of Berne), which acts as one (among seven) of these global analysis centers.

2. Earth Orientation Parameters

Generally the term 'Earth Orientation Parameter' (EOP) comprises a set of 5 parameters which describe the rotation of the ITRS (International Terrestrial Reference System) in the ICRS (International Celestial Reference System) in conjunction with the conventional Precession-Nutation model. On the other hand, the so-called 'Earth Rotation Parameters' (ERP) characterize a 3-parameter-subset of the EOP, namely the coordinates x and y of the CEP in the terrestrial reference frame (polar motion) and the difference UT1-UTC (respectively UT1-TAI, TAI=International Atomic Time) giving access to the direction of the IERS Reference Meridian in the Celes-

POLAR MOTION "CODE" : 21. JUNE 1993 – 1 JANUARY 1996

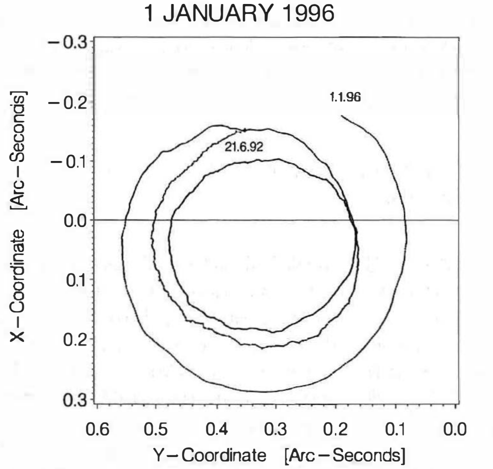

Fig. 2: Polar motion as produced by the CODE Analysis Center of the IGS

tial Reference Frame. For detailed information, see [2], [13].

The main components of polar motion are a free oscillation with a period of 1.2 years (Chandler wobble) and an oscillation which is forced by seasonal mass redistribution in the atmosphere and oceans. This variation is superimposed by a slow drift towards the west. In figure 2 GPS-based polar motion series covering a period of more than 3 years are shown. The oldest estimates date back to the start of the IGS-testcampaign in June 1992. Since then we have recognized an obvious improvement in the accuracy of the estimates. Today the accuracy of the CODE pole coordinates is believed to be of the order of about 0.2–0.3 mas.

We conclude that the GPS is very well suited to determine polar motion, provided that the terrestrial reference frame is well defined by means of the coordinates of the tracking stations.

The difference between the astronomically determined duration of the day and 86400^s atomic time is called length of day (LoD). The difference $\Delta UT1 = UT1 - TAI$ can easily be obtained by adding up LoD estimates since a change in $\Delta UT1$ is related to a change in LoD by integration (see below).

$$\Delta LoD(t) / LoD_0 = - d(UT1 - TAI) / dt \qquad (1)$$

Unfortunately, the GPS is not capable of providing absolute estimates of $\Delta UT1$. The reason is the correlation between $\Delta UT1$ and the right ascension of the ascending node of the satellite orbits. On the other hand it should be possible to solve for a drift in $\Delta UT1$ by adopting a linear model of the type

$$\Delta UT1(t) = \Delta UT1(t_0) + d(\Delta UT1) / dt \cdot (t-t_0) \qquad (2)$$

This demonstrates that the LoD may be estimated very well with the GPS. Of course, the drift parameter in (2) would be correlated again with the first derivative of the ascending node but under the assumption of a known force model, there is no need to solve for this derivative.

Figure 3 shows the LoD estimates after removal of the terms due to the fixed body tides with periods up to 35 days. These series are furthermore subject to seasonal variations mainly due to atmospheric circulation [4]. The IERS integrates the individual LoD-series (made available by different GPS-Analysis Centers) and produces a combined GPS-solution which finally effects the behaviour of the resulting IERS UT1-UTC series, especially in the high frequency range (periods shorter than about 30 days).

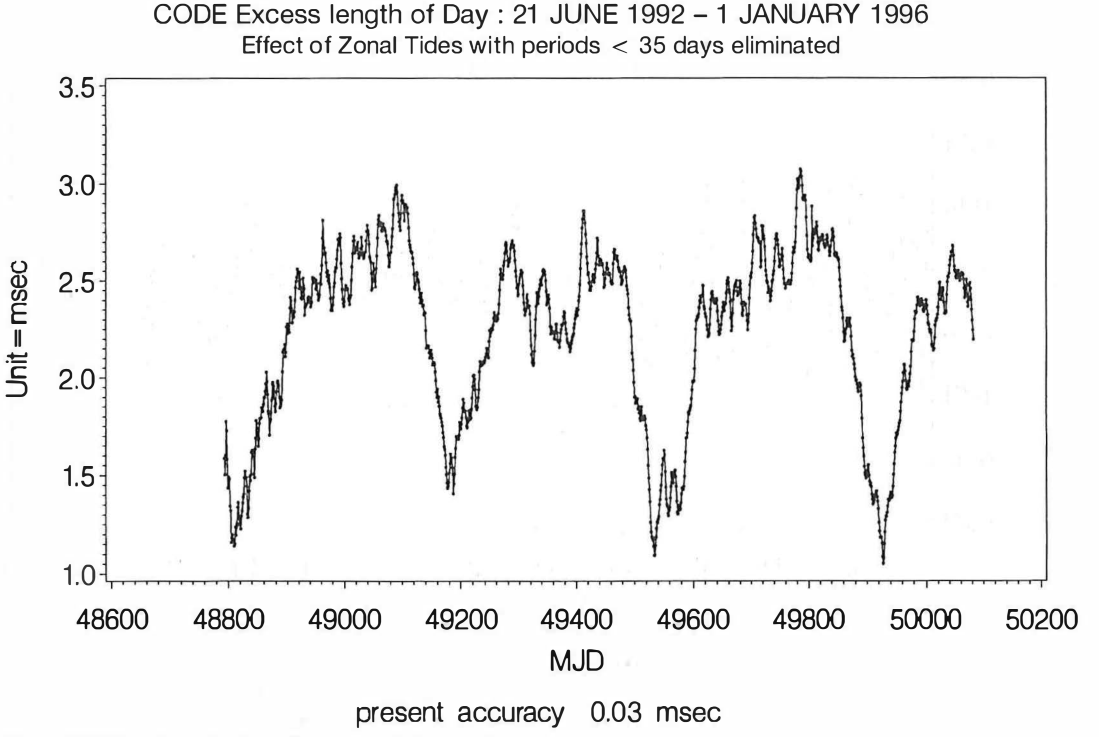

Fig. 3: CODE LoD-estimates after removal of zonal tides

3. The CONT94 Campaign

In August 1991 the International Union of Geodesy and Geophysics recognized the importance of the determination of rapid Earth rotation variations and its implication for geodynamics through a union resolution. As a result, a major campaign, called SEARCH'92 (Study of Earth-Atmosphere Rapid Changes), for subdaily measurements of Earth rotation was held in summer 1992. Measurements were performed by GPS, VLBI, SLR and LLR in order to analyze subsequently the results of the different techniques. Of course, we have to mention that high-frequency ERP-results based on GPS observations dating from 1992 suffered remarkably due to an incomplete status both of the space segment and the tracking network. Nevertheless, the outcome was really promising and a detailed description can be found in [Dickey, Feissel, 1994].

Another intensive VLBI observation campaign, lasting about 2 weeks, was performed in January 1994. This campaign was intended to serve as continuation of SEARCH'92 and was therefore called CONT94. CONT94 provided the scientific community with hourly Earth orientation measurements and a set of UT1-variations deduced from them [5]. At the CODE Analyses Center the same period was covered with GPS-based estimates of LoD and polar motion coordinates with subdiurnal resolution. First of all we used the official IGS precise ephemeris as a priori information in order to compute and save a set of daily normal equations. Afterwards these normal equations were combined to overlapping 7-day arcs and UT1 (respectively LoD) was estimated every 2 hours. Finally the results obtained from the middle days of the various arcs (Arc 1 – Arc 6) were concatenated to cover the whole period. Figure 4 shows the outcome of this procedure after the removal of lower frequencies.

A closer look at figure 4 tells us that the time series are dominated by diurnal and semidiurnal terms. There is no doubt that the oceanic tidal angular momentum can be considered to be the primary cause for these variations in the earth's rotational rate. Since, in the absence of external torques, the angular momentum of the ocean-solid earth system is conserved, changes in the ocean tidal angular momentum must be accompanied by changes in the angular momentum of the solid earth, thereby leading to changes in the solid earth's rotation. Furthermore figure 4 compares our ΔUT1 estimates with predictions obtained from two well-known tide models. The

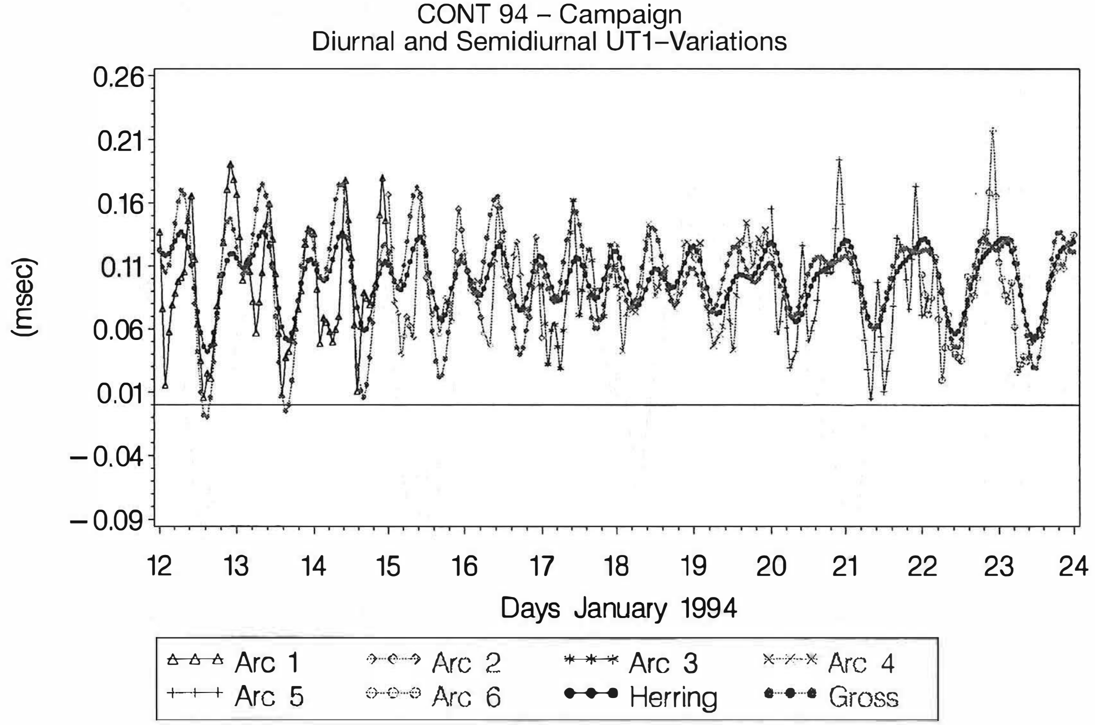

Fig. 4: Estimated diurnal and semidiurnal UT1-variations compared to model predictions

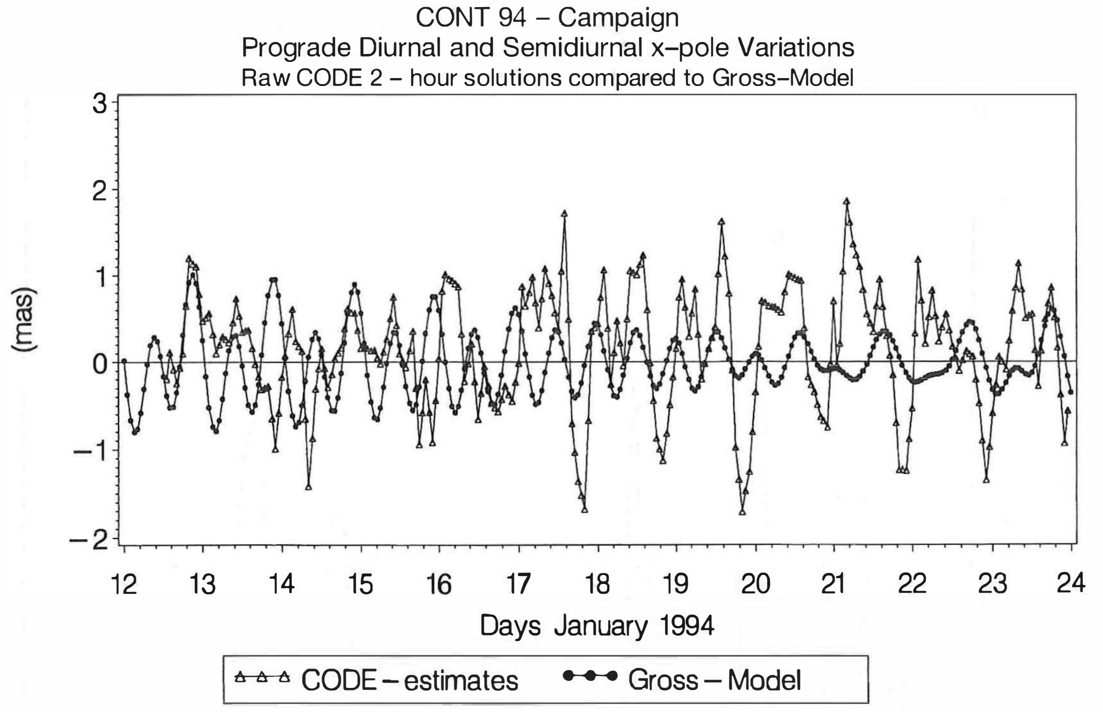

Fig. 5: Estimated x_p - variations compared to model predictions

first one (Gross model) is based on the results of Seiler [11] for the axial component of the ocean tidal angular momentum. This model can be characterized as theoretical approach, but nevertheless the evaluated series fit our estimates quite well. The other one (Herring model) is based on 1085 VLBI experiments carried out between January 1984 and June 1992 [7]. This model describes amplitudes and phase angles of about 20 tidal constituents, particularly for the main tidal lines in the diurnal (K1, O1, P1, Q1) and the semidiurnal band (K2, S2, M2, N2). Recent investigations [3], dealing with predictions according to ocean tide models based on Topex/Poseidon observations, confirm the excellent quality of the Herring model. Sometimes the amplitudes of the CODE-series seem to be overestimated by a factor of two, which could be explained by modelling problems for particular satellites.

Due to the irregular geographic distribution of the world's oceans, oceanic current and sea-level height changes can also affect the non-axial components of the earth's rotation (polar motion). Additionally, we had to keep in mind that the polar coordinates x_p, y_p specify the location of the celestial ephemeris pole (CEP) within the rotating, body-fixed terrestrial reference frame. Figure 5 outlines the estimated x_p – variations in relation to the corresponding numbers computed by means of the Gross model. There is a fairly good correspondence in the first week but the remarkable amplitude differences in the second week are subject to further investigations.

Concerning figure 5 it must be emphasized that the retrograde diurnal polar motion was already constrained to zero within the actual estimation process. A retrograde diurnal polar motion (K1 ocean tide) is not observable, because it represents a constant offset of the CEP in space and is therefore absorbed into the definition of the CEP (Nutation).

4. Nutation Offset determination by means of GPS

The present theory of nutation adopted by the IAU is based on Kinoshita's rigid earth theory [8] and Wahr's non rigid theory [12] that uses the earth model 1066A. Wahr's theory deduces the ratio of nutation amplitudes for the non-rigid earth to that for a rigid model. Soon after the adoption of the IAU 1980 Theory of Nutation VLBI-observations showed deficiencies in this theory at the level of several milliarcseconds (mas). The motion of the celestial pole relative to the IAU 1980 Theory is expressed in the Ce-

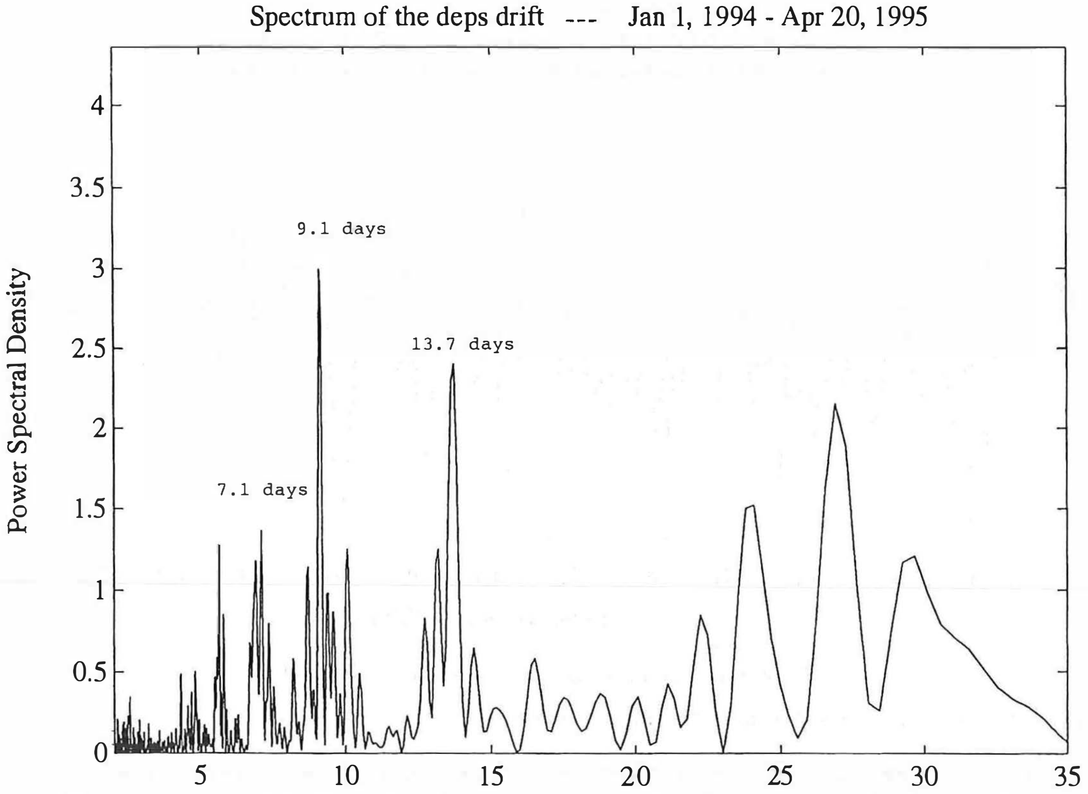

Fig. 6: Frequency analysis of the drifts in δΔε as estimated by the CODE processing center

lestial pole offset parameters Δε (Obliquity) and Δψ (Longitude), which complete in addition to the ERP the set of Earth Orientation Parameters (see chapter 2). Up to now VLBI was the only technique capable of measuring all EOP components simultaneously and accurately. In case of looking on long-period nutation this statement is also valid in the future, since VLBI is the technique with direct access to the Celestial Reference Frame. On the other hand satellite techniques should, similar to the monitoring of high-frequency variations of universal time, be able to make valuable contributions in the determination of celestial pole offset parameters, especially in the short period range. Therefore the CODE-Analysis center started (in February 1994) to derive celestial pole offset parameters based on GPS tracking data of the global IGS network. These estimates were thought to prove or reject the above mentioned idea that GPS, as a satellite technique, is able to locate the CEP in the celestial space fixed frame.

In the meantime, after a renewed computation of the January 1994 observation data, time series which cover more than 16 months, are available. Similar to LoD, there are correlations between the orbital elements (right ascension of the ascending node, inclination) and the nutation terms. Therefore only the first derivatives, the nutation offset rates in obliquity δΔε and longitude δΔψ, are accessible to the GPS. The accuracy of these daily drifts is of the order of 0.3 mas/day. Ideally we should see essentially the same frequencies as VLBI in the spectrum of our estimated drifts and furthermore get the same order of magnitude when estimating the relevant terms. Figure 6 reflects the results of a spectral analysis of the Δε - rates.

The δΔε - spectrum shows the maxima roughly at the expected periods, in particular at 7.1 , 9.1 and 13.7 days. The corresponding curve for the nutation in longitude is somewhat less convincing, but will improve with a growing time base. Analizing the δΔε- and δΔψ- series enables us to estimate amplitude corrections for some of the short period nutation terms (periods up to 35 days) relative to the IAU 1980 model. The author is therefore convinced that the GPS is able to give essential contributions in the high frequency range in future.

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The Austrian Gravity Base Net 1995

Diethard Ruess, Wolfgang Gold, Vienna

Abstract

The Austrian Gravity Network is one of the tasks of the Federal Office of Metrology and Surveying (BEV) in Vienna. A revision of the old existing network were started 1981. New stations were established and relative measurements were made with LCR gravimeters only. The neighboring networks were connected with the Austrian network. Since 1987 the absolute gravity meter JILAG-6 has been used for observations on 28 stations of the 0. order. Two different national network adjustments and an European adjustment were calculated. The results were compared and contrasted with the absolute observations. The maximum difference is less then 30 μGal, the average difference is less than 1.5 μGal.

Repeated absolute measurements twice a year have been done on a station in the Central Alps of Austria to check the stability of the gravity values. The amplitude of these results is $8 \cdot 10^{-8}$ m/s^2 (8 μGal).

1. Introduction

The Federal Office of Metrology and Surveying in Vienna has a long tradition in determining the gravity. First observations were made 1878 in Vienna with a Repsold Pendulum by Theodor R. v. Oppolzer of the k. k. Gradmessungsbüro. Further measurements were made by Robert D. v. Sterneck. The Vienna Gravity System was established and valid until 1909 when the Potsdam Gravity System was decided by the IAG. In the 50th and 60th relative measurements were possible using the relative gravimeters Nørgaard and Worden. Therefore a base station network was established and derived from the European Calibration Line which crossed Austria between Kufstein and Brenner. At the end of the 70th a lot of these base stations were lost. In 1980 four new