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Review paper

EARTH ROTATION OBSERVATIONS AND THEIR GEOPHYSICAL IMPLICATIONS

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SUMMARY: This paper reviews the precision of the measurements of the Earth rotation fluctuations realized during the last decades; particularly the observations performed during the last ten years allow to constrain theoretical Earth models, which include mantle inelasticity and normal mode resonances, with realistic parameters such as the dynamical flattening of the Earth in agreement with the observed Free Core Nutation (FCN), the observed degree 2 of the geoid (J2) and the observed precession constant. The precision obtained nowadays by the observations requires to take into account the effects of the atmosphere and oceans on nutations and precession.

The contributions of the world GPS tracking network to classical geodesy and short term Earth rotation variations are also reviewed; for observation of Earth Orientation Parameters (EOP), the importance of such a network requires collaboration of observatories and geodetic institutes concerned with space geodesy , Earth rotation monitoring, local or global geophysics.

1. INTRODUCTION

During the last 25 years and more particularly since 1989, the measurements of the Earth orientation in space and of the relative positions on Earth were dramatically improved. Till 1970, the classical astronomical methods were the only ones allowing to measure the three Earth rotation parameters with a precision of the order of 0"01. Fundamental stars catalogues provided the external reference.

In the beginning of the seventies, thanks to space geodesy, new external references were used such as the orbital plane of the Moon or of artificial satellites and the position of quasars.

Starting in 1972, space geodesy, based on the observations of Transit satellites, contributed to the Polar Motion with a higher weight than the astronomical methods (Fig. 1); the interest of the last ones decreased rapidly with the development of Laser ranging of satellites like Lageos (SLR) or of the Moon (LLR) and mainly by the deployment of a world network based on Very Long Base Interferometry observations (VLBI).

In 1988, the new techniques conducted the scientific community to set up the International Earth Rotation Services (IERS) which replaced the Bureau International de l'Heure (BIH) and the International Latitude Service (ILS); this new international Service turned in operation on January 1988. More recently a new world network based on the Global Positioning System (GPS), has been deployed; it is composed of about 200 stations, which contribute to the evaluation of polar motion and Earth rotation rate. The network is managed by the International Geodynamics Service (IGS) (Beutler *et al*, 1995); it contributes to IERS since 1993. The precision of ab-

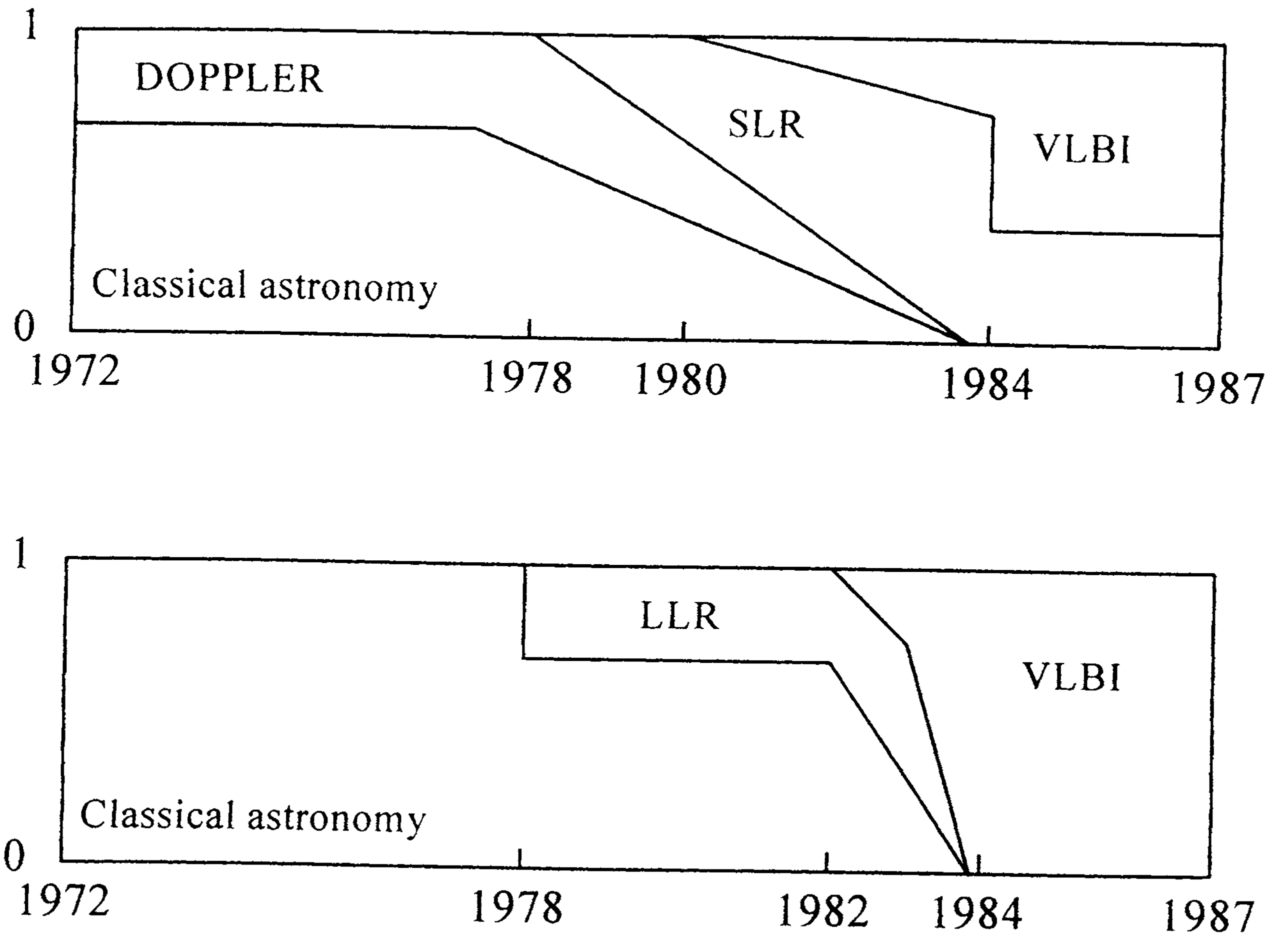

Fig. 1. *For the period 1972-1987, relative weight of the various techniques contributing to the determination of the Earth rotation parameters: the figures are related to the polar motion (top), and angular velocity of the Earth (bottom).*

solute positioning with GPS reflects its capabilities for the measurements of Earth rotation parameters; it is at the level of few centimetres while in differential positioning, the precision is of the order of 10^{-9} in horizontal displacements and 1 centimetre in altitude over distances up to 2000 km. The actual relative contribution to Earth rotation measurements, as given in Fig. 2, let appear the main role of VLBI and GPS techniques.

In Fig. 3 the evolution of the precision is given both for the polar motion and the angular Earth rotation (UT); it is remarkable and it must be pointed out that the actual precision is of the order of 0"0001 or better.

Such a precision is an incomparable input to study some geophysical properties of the Earth and at the same time it imposes to remove carefully the known effects perturbing the measurements at that level of precision; among these effects let us indicate the atmospheric and ionospheric refractions, the station displacements due to the continental drift, the station height variations due to oceanic and atmospheric loading. An important example of interesting geophysical aspects that can be approached from Earth orientation observations, is the radius and flattening of the outer core. The response of the Earth to the attraction of external bodies contains indeed a lot of information because it is related to the Earth interior. The dynamical flattening of the Earth is another interesting example because it is related to the precession; the mantle inelasticity, the normal mode resonances, the effects of the atmosphere and oceans on the nutations, the precession and obliquity rate are other examples. We shall review some of these topics but let us first view the most well known fluctuations of the Earth Rotation Parameters (ERP) at different time scales.

2. THE POLAR MOTION OR THE LATITUDE VARIATIONS

Variations of the position of the Earth rotation pole were first recognized at the end of the nineteen century. In 1887 Chandler published the results of latitude observations performed in Cambridge during the period 1884-1885 from which he brought out

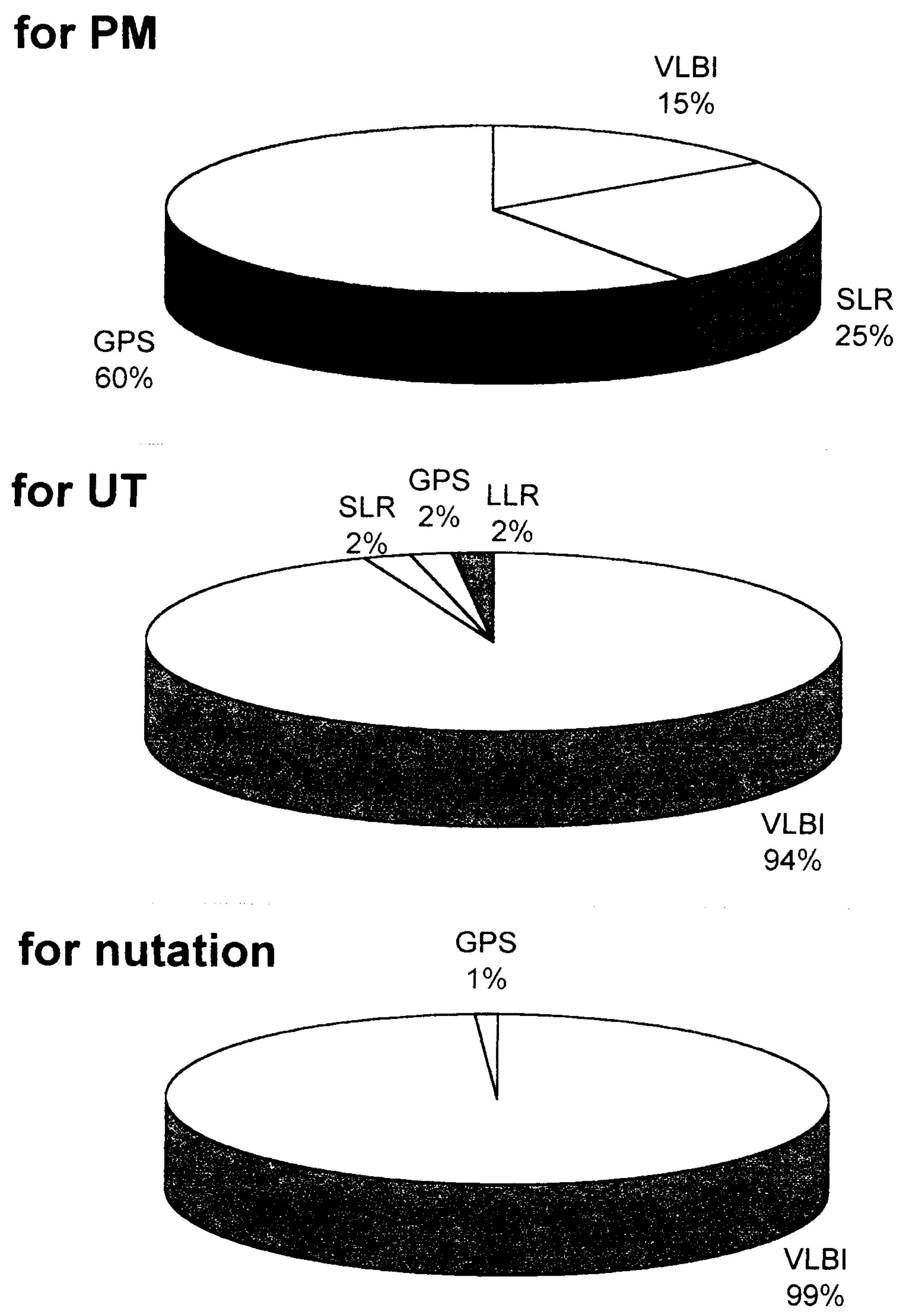

Fig. 2. *In 1996, relative weight of the techniques contributing to the determination of the Earth rotation parameters: the figures are related to the polar motion (top) angular velocity of the Earth (middle), nutation (bottom).*

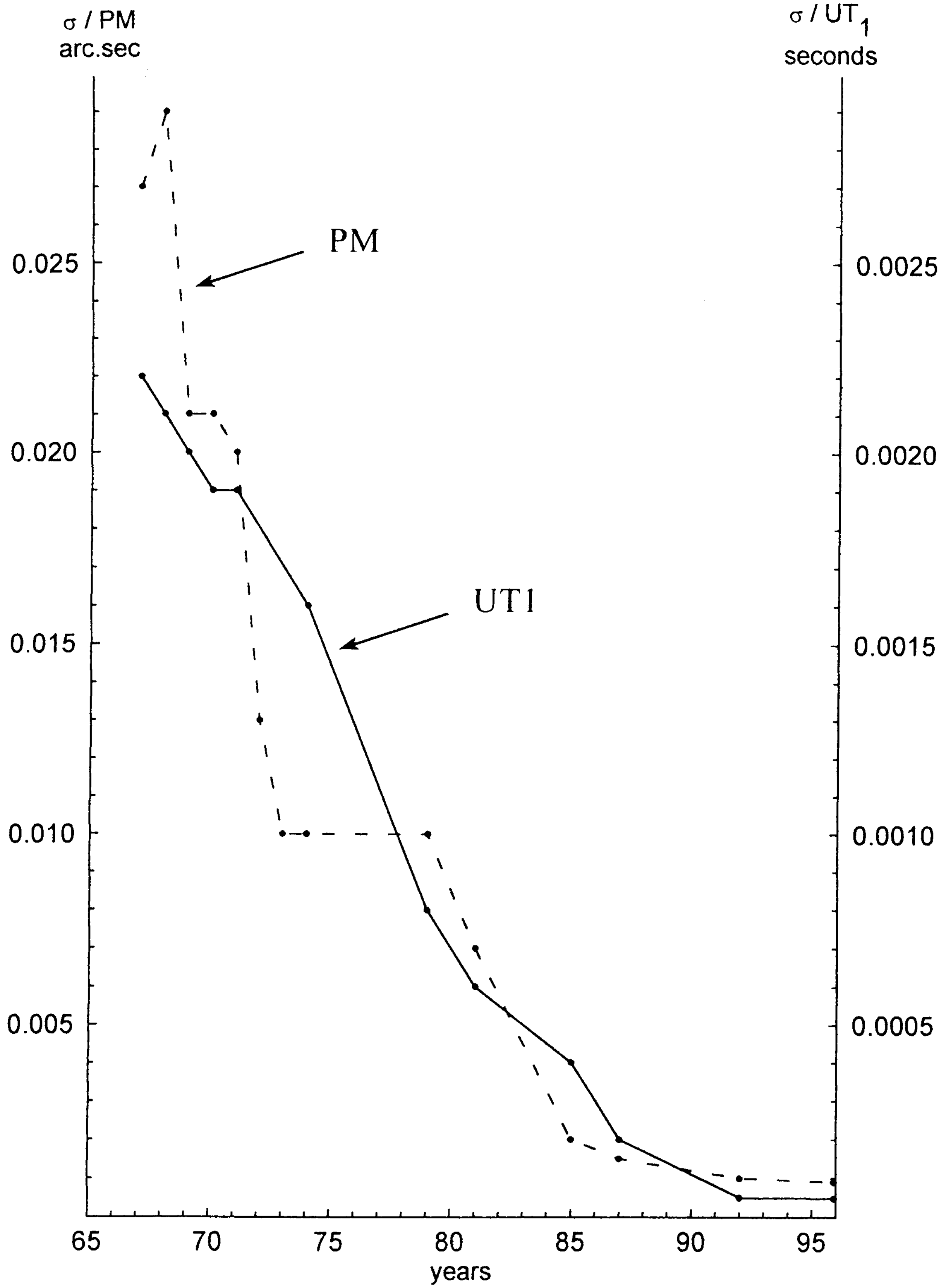

Fig. 3. *Evolution of the precision of the polar motion and angular velocity measurements of the Earth.*

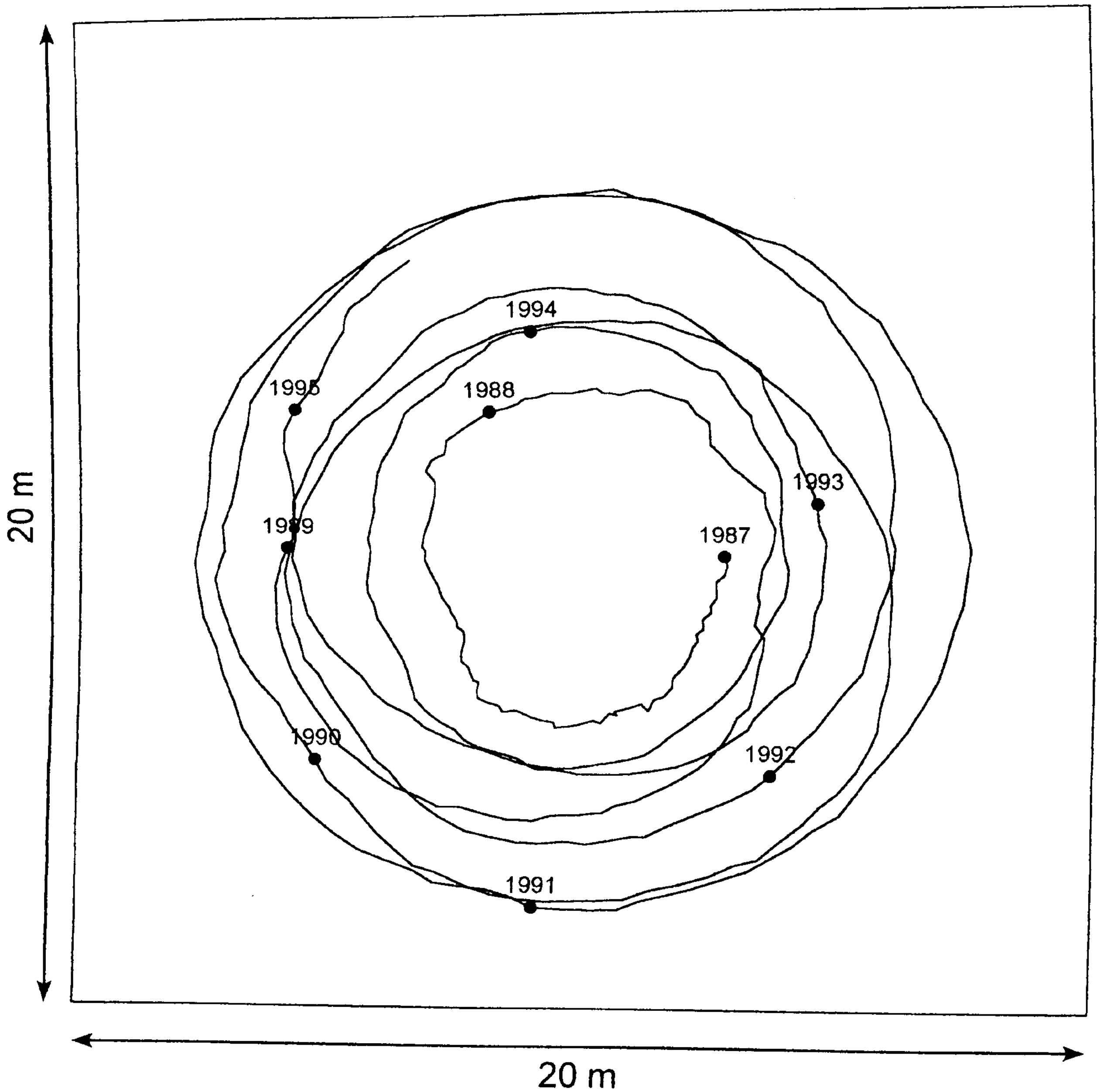

Fig. 4. *Polar motion as observed during the period 1987-1996.*

changes of the latitude. During the same period, Küstner observed a change in the latitude of the Observatory of Berlin. In 1891, Chandler analyzing observations obtained in Potsdam, Pulkovo, Berlin, Prague, identified two components in the change of latitude; the first one at 427 days and a second one corresponding to an annual variation (Chandler 1891, 1892). Newcomb (1892) explained the lengthening up to 427 days, from the theoretical value (305 days) predicted by Euler in 1827, as a consequence of the elasticity of the Earth.

The total amplitude of the motion is variable with time (due to the modulation between two periods) and the maximum amplitude is 0"3; it corresponds to a displacement of the Earth pole at the surface of the Earth of about 20 meters. The coordinates of the pole are reported in a cartesian coordinates system (x, y); the plane (x, y) is tangential to the Earth, the origin being the Conventional International Origin (Fig. 4).

In addition to the modulation between the annual and the Chandler periods which induces a time variation of the circular polar motion, there is a variation of the annual and the Chandler motions according to the epoch analyzed; the Chandler period (427 days) could change by an amount as large as plus or minus 10 days. To explain the lengthening of the Euler period (305 days), besides the elasticity of the Earth as advocated by Newcomb, other main contributors are the inner core (Jeffreys 1948), the oceans (Newcomb 1892), the inelasticity of the mantle (Dehant and Zschau, 1989) which changes the period by amounts of - 50, + 29, + 8 days respectively (Fig. 5).

Due to energy dissipation, the polar motion is supposed to damp over a relatively short period; this is indicated by a low damping factor Q of which the estimation (50 to 400) corresponds to low damping time which is contradictory with the fact that the polar motion is going on over geological time (0oe 1978). The nature of the excitation mechanism is still unknown although several sources were unsuccessfully investigated during the last decades: internal mass shift (Munck and McDonald, 1960), earthquakes (Chao and Gross, 1987), atmospheric mass motion (Hide 1984), ground water (Chao 1988). All these potential candidates are one or two order of magnitude too weak to keep the polar motion going; evidently each of them contributes to the motion and probably all of them should be considered together.

3. THE ANGULAR VELOCITY OF THE EARTH

In 1937, after removing the polar motion described above, seasonal fluctuations of the angular velocity of the Earth rotation were brought out by Stoyko. Starting in 1952, the monitoring of these irregularities were of primary importance to determine the astronomical time scale given by the transit of celestial bodies across the meridian; it is only at the IAU General Assembly of Dublin (1955) that the variations of the local meridian due to polar motion and the Earth rotation fluctuations were taken into account for time determination. The amplitudes of the angular velocity changes are ranging from a few tenths of one millisecond several thenths of a second (Lambeck 1990).

Thanks to the Temps Atomique International (TAI) adopted as the reference time scale since 1967, variations of the Earth angular rotation are now measured with an one day resolution while the precision is of the order of 0.0001 s.; let us remind that the time which would be displayed by a clock adjusted on the Earth rotation, corrected for the change of meridian due to the Polar Motion, is known as UT1 (Universal Time). The observations measure the quantity TAI-UT1 which is the difference between the atomic time and the time based on Earth rotation.

In Fig. 6 differences TAI-UT1 are given for the last 25 years. The main reason of the long term trend is the difference of duration between the seconds adopted for TAI and that one realized by the Earth rotation.

In Fig. 6 a solid line is superposed to the long term drift; the solid line represents the Temps Universel Coordonné, (UTC) used for civilian purposes. UTC is generated from TAI clocks on which jumps of one second are applied to keep public time scale (UTC) in an agreement better than 0.9 second with a clock referenced to the Earth rotation; on 1 January 1996, the cumulated value of TAI-UTC = 30 seconds. After removing the long term drift from TAI-UT1, irregular variations of the Earth rotation can clearly be seen (Fig. 7); those irregularities being not predictable, they must be observed. The irregularities can be subdivised in three categories analyzed below.

3.1. Decadal variations

In Fig. 7 large scale variations appear; their amplitude is of the order of a few tenths of a second and the period is ranging from 8 to 12 years. They are known as the decadal variations; although the transfer process is not well understood, geophysicists agree that they reflect long term time variation of motions in the liquid core of the Earth with exchange of angular momentum between the core and the mantle. According to Hide *et al.* (1996), the core fluxes induce a pressure torque on the Core Mantle Boundary (CMB) topography. This torque can be computed, on the one hand, from the core fluxes deduced from surface magnetic data using some hypotheses (as the frozen flux approximation or the geostrophic approximation), and on the other hand from CMB topography either determined by seismologists, or derived from mantle convection model. The amplitude of the torque is unfortunately too large. Other mechanisms as electromagnetic or viscous coupling at the CMB has then also been advocated. Recently Greff-Lefftz et al (1996) have computed the gravitational torque acting at the CMB (gravitational interaction between core and mantle) and have shown that it is a right candidate to decrease the total effect. An other possibility might be related to overevaluation of the topographic (pressure) torque: the presence of a D" layer at the bottom of the lower mantle would reduce the topography a lot.

3.2. Seasonal and short period variations

By seasonal and short period variations we refer to phenomena whose periods are ranging from a few days to a year. In order to let clearly appear such variations, the excess to 86400 seconds of the length of day (LOD) is computed according the expression

$$[\ LOD(i) = [(UT1\ -\ TAI)(i\ -\ 1)\ -\ (UT1\ -\ TAI)(i)]/\Delta t.]$$

Such a series of LOD(i) is represented in Fig. 8 (top) for the period 1990-1995. The irregularities observed in this curve result from many contributions having two main origins:

- change of the tensor of inertia of the solid Earth due to its deformations in response to the attraction of external

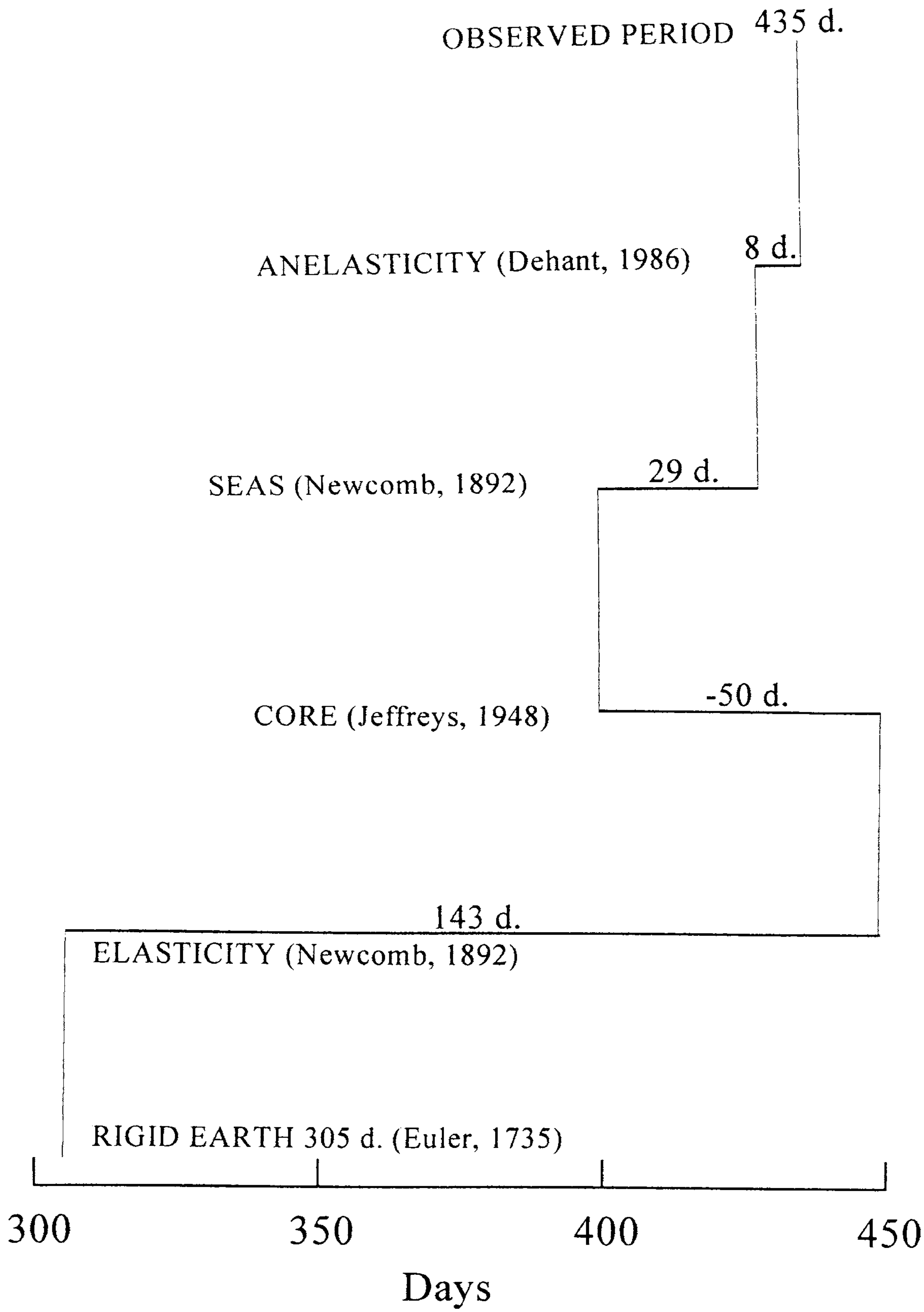

Fig. 5. *Influence of the physics of the Earth on the polar motion period.*

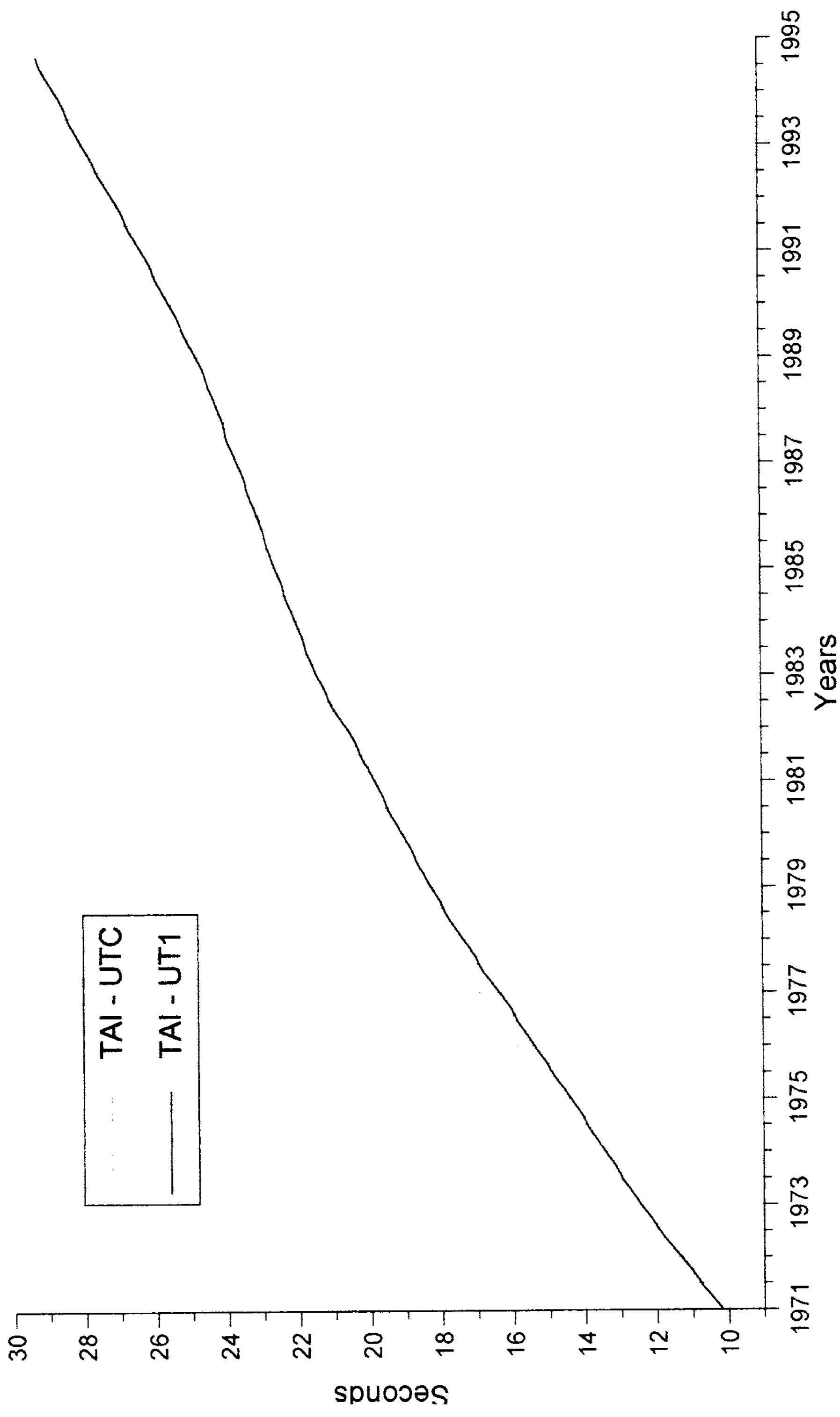

Fig. 6. *The broken line is the difference between the Temps Atomique International (TAI) and a clock referenced to the Earth rotation (UT1); it represents the Earth rotation variations. The solid line is the Temps Universel Coordonné, (UTC) deduced from TAI on which jump of one second are applied from time to time.*

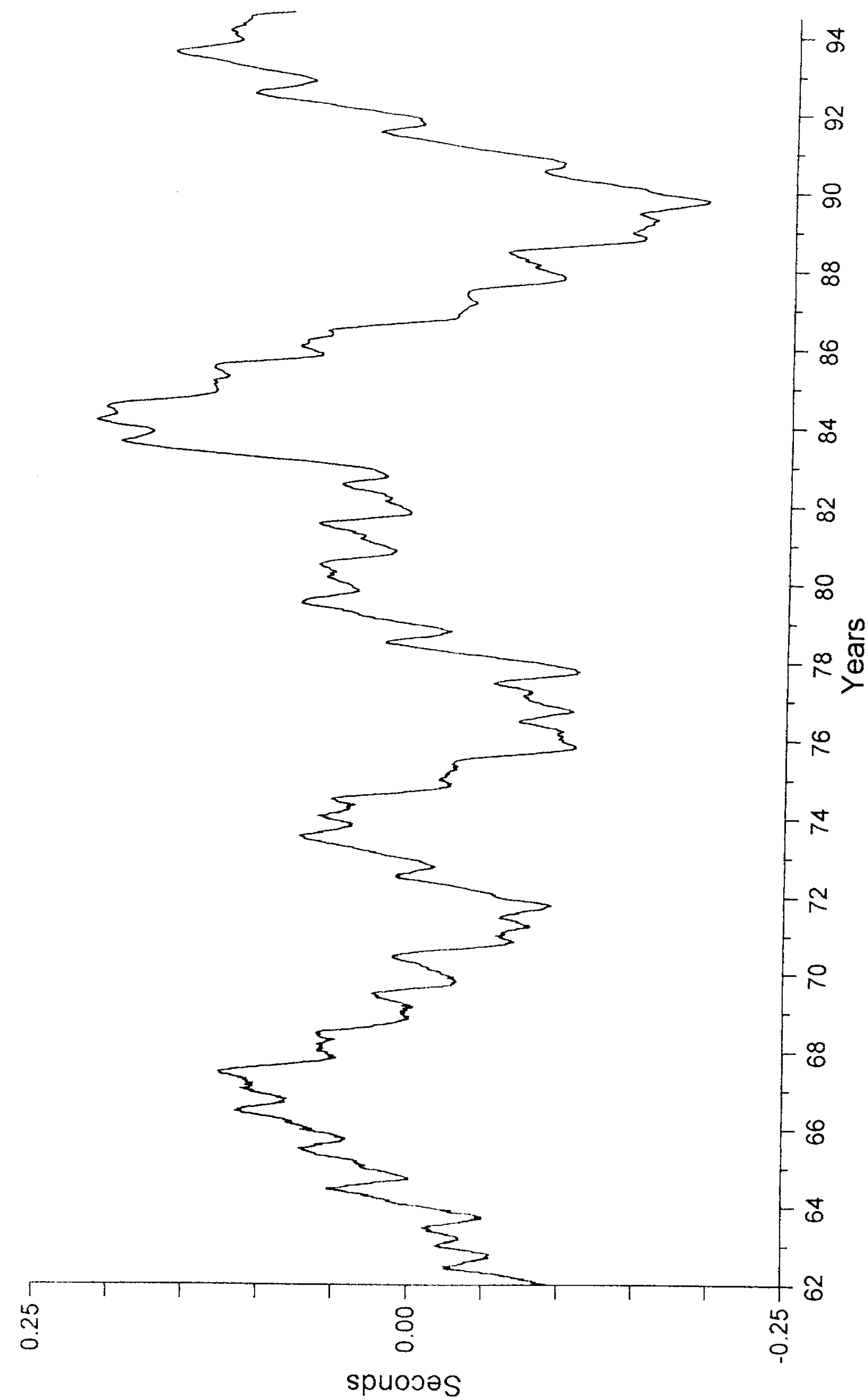

Fig. 7. *Residuals of TAI-UT1 after removing the long term drift. It lets appear large decadal oscillations.*

bodies; this is called the tidal effects on the length-of day (lod);

- exchange of angular momentum between the solid Earth and the atmosphere.

3.2.1. Variations due to changes of the tensor of inertia

Let us first consider the tidal phenomenon, implying a change of the tensor of inertia; these tidal effects are associated with solid Earth deformations which in turn, induce Earth rotation variations with amplitude as large as 0.001 s and period ranging from a few days to the secular slowing-down of the Earth rotation.

The tides being generated by the Sun and the Moon, their period is known with high precision but the amplitudes and the phases are depending on the rheological properties of the Earth and thus are to be measured. The mantle inelasticity amplifies the tides and introduces a delay in the Earth response. In particular the secular slowing down of the Earth rotation is mainly the consequence of a permanent phase lag in the deformation of the inelastic equatorial bulge due to the Moon attraction; its amplitude is estimated at 2 milliseconds per century (0.02 msec/yr).

The inelastic rheological parameters are presently not yet well determined from the theoretical point of view; thus Earth rotation observations provide complementary information to that obtained by seismology, nutation data, tidal records and satellite geodesy. Periodic variations of TAI-UT1 due to tidal deformation, from 5 to 6790 days, are given by Yoder *et al.* (1981).

As the solid Earth tides, oceanic tides do also generate variations in TAI-UT1 (Brosche *et al*, 1989; Dickman 1991); the amplitudes were estimated by Brosche *et al.* (1991), from VLBI observations.

The LOD variations generated by solid Earth tides are given in Fig. 8 (middle); if they are removed from the LOD measurements (Fig. 8-top), one gets a less noisy signal as given in Fig. 8 (bottom).

3.2.2. Variations due to exchange of angular momentum

The origin of the signal given in Fig. 8 (bottom) is mainly the consequence of an exchange of angular momentum between the solid Earth and the zonal atmospheric motion (Barnes *et al*, 1983); as it will be seen later it is responsible for most of the yearly UT1 variations while most of the remaining energy is provided by weaker variations detected between 14 and 122 days, 2.2 years. The International Earth Rotation Service provides a series of Effective Atmospheric Angular Momentum (EAAM); this series gives the LOD variations induced by changes of the Atmospheric Angular Momentum; let us call these computed changes of the Earth Rotation LOD_{AAM}. For the period 1976-1996, this series is represented in Fig. 9 (top, light line), and the real observed changes of the Earth rotation, called LOD_{IERS}, are also given in the same Fig. 9 (top, solid line). From the LOD_{AAM}, the LOD_{IERS} curve is easily recognized because it contains, over the short periodic fluctuations, the longer periodic components, including the decadal ones.

To remove the long term trend and the rapid variations (less than 6 months) from the original data, a double filtering by the Wittaker-Robinson-Vondrak (WRV) method is applied; the filtering parameters are chosen to be $\varepsilon = 10^{-15}$ and $\varepsilon = 10^{-8}$ (Wittaker and Robinson 1946; Vondrak 1969). The resulting smoothed curve presented in Fig. 9 (bottom) clearly shows the annual component in each series of data; by comparing the maxima of the two curves, one sees that 90% of EAAM is sufficient to explain the Earth rotation variations. Besides the two main seasonal components at one year and 6 months which are known since the years 1950's, increasing of precision in the observation allowed to bring out other components with period close to 50 days (Langley *et al*, 1981), 30, 60 days (Djurovic and Pâquet, 1988), 122 days (Djurovic 1970; Djurovic and Pâquet, 1989), 2.2 years (Iijima *et al*, 1966; Djurovic and Pâquet 1993).

All these Earth rotation variations are related with exchanges of angular momentum with the atmosphere. The following question can then be addressed: from where is the atmosphere excited? In several analyses performed by Djurovic and Pâquet (1988, 1989, 1990, 1991, 1994b, 1995), Djurovic et al (1994a), Gu Zhen-Nian *et al.* (1995) the authors conclude that the atmosphere excitation is related to solar activity which oscillates with the same periods. Several indices, evidence of the solar activity, exhibit all or some of the oscillations indicated above; among these indices let us point out that of the Wolf number, the apparent sunspot areas, the solar corona index, 10.7 cm solar flux, the solar irradiance. It is important to point out that the measurement of the last index has been collected from satellite; it is a measurement quite independent of any perturbations that the atmosphere could introduce. The interface between the Sun and the Earth atmosphere are the solar wind and the interplanetary magnetic field which exhibits also oscillations around 50 and 120 days; these series of observations obtained from satellite are covering only 2 to 3 years and are too short to detect signals at longer periods.

A very interesting feature on the solar origin of the oscillations observed in the Earth rotation is the fact that they are also observed in the geomagnetic index (Aa) which is known to respond to the fluctuations of the solar activity. Details about these analyses are given in Djurovic and Pâquet (1988, 1989, 1990, 1991, 1994b, 1995), Djurovic *et al.* (1994a), Gu Zhen-Nian *et al.* (1995). An other oscillation, around 5 years, has been recently indicated by Dickey *et al.* (1994). From an analysis of Djurovic and Pâquet (1996) similar oscillation is detected in solar activity and geomagnetic index but it does not exist in the atmospheric angular momentum. To excite the Earth rotation the mechanism that could be advocated seems again the solar activity which perturbs the geomagnetic field and consequently the Earth rotation.

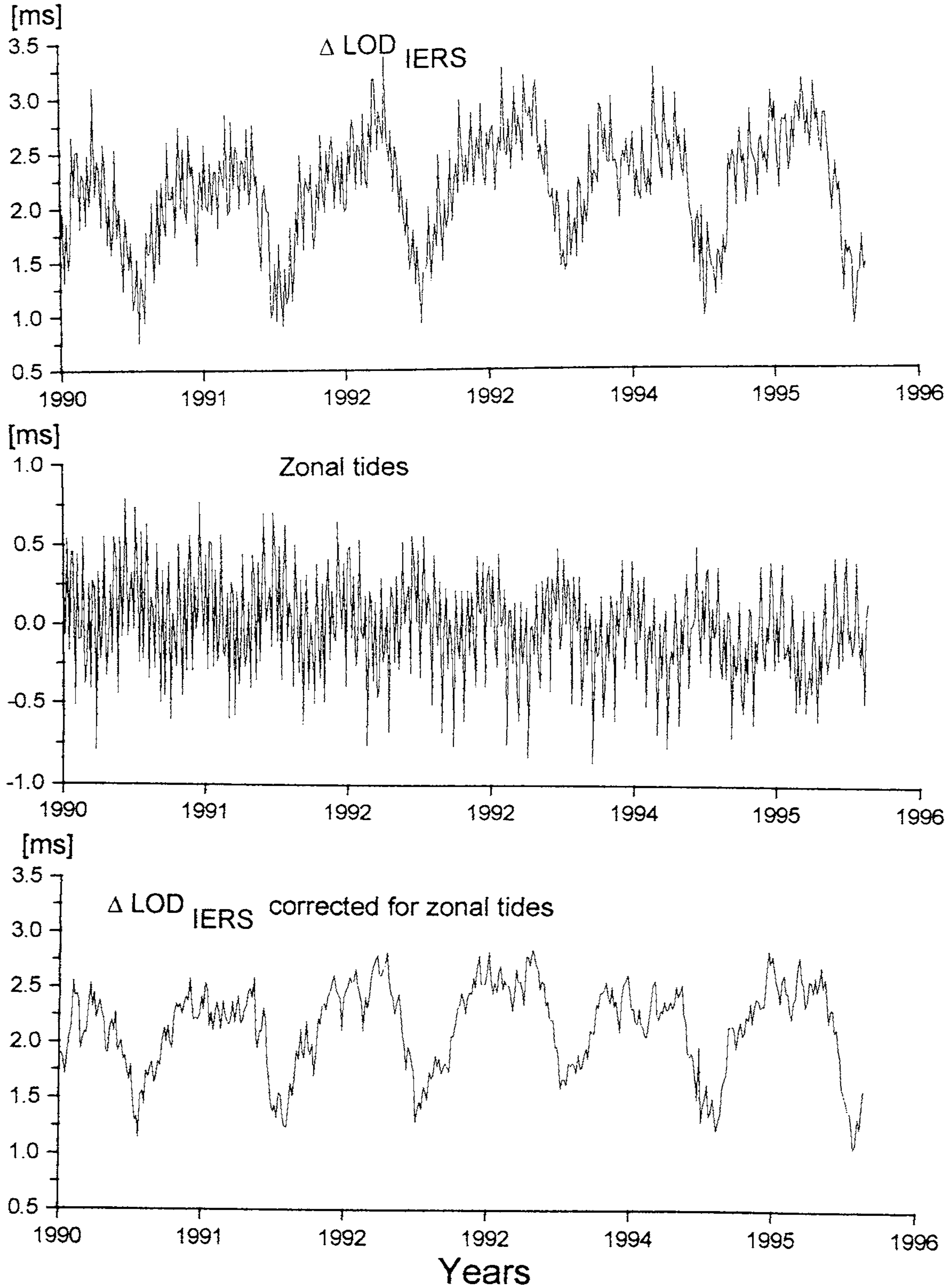

Fig. 8. Top: *Excess of the observed length of day (LOD).*
Middle: *Excess of length of day generated by the zonal tides.*
Bottom: *Differences between the series represented on top and middle of figure 8.*

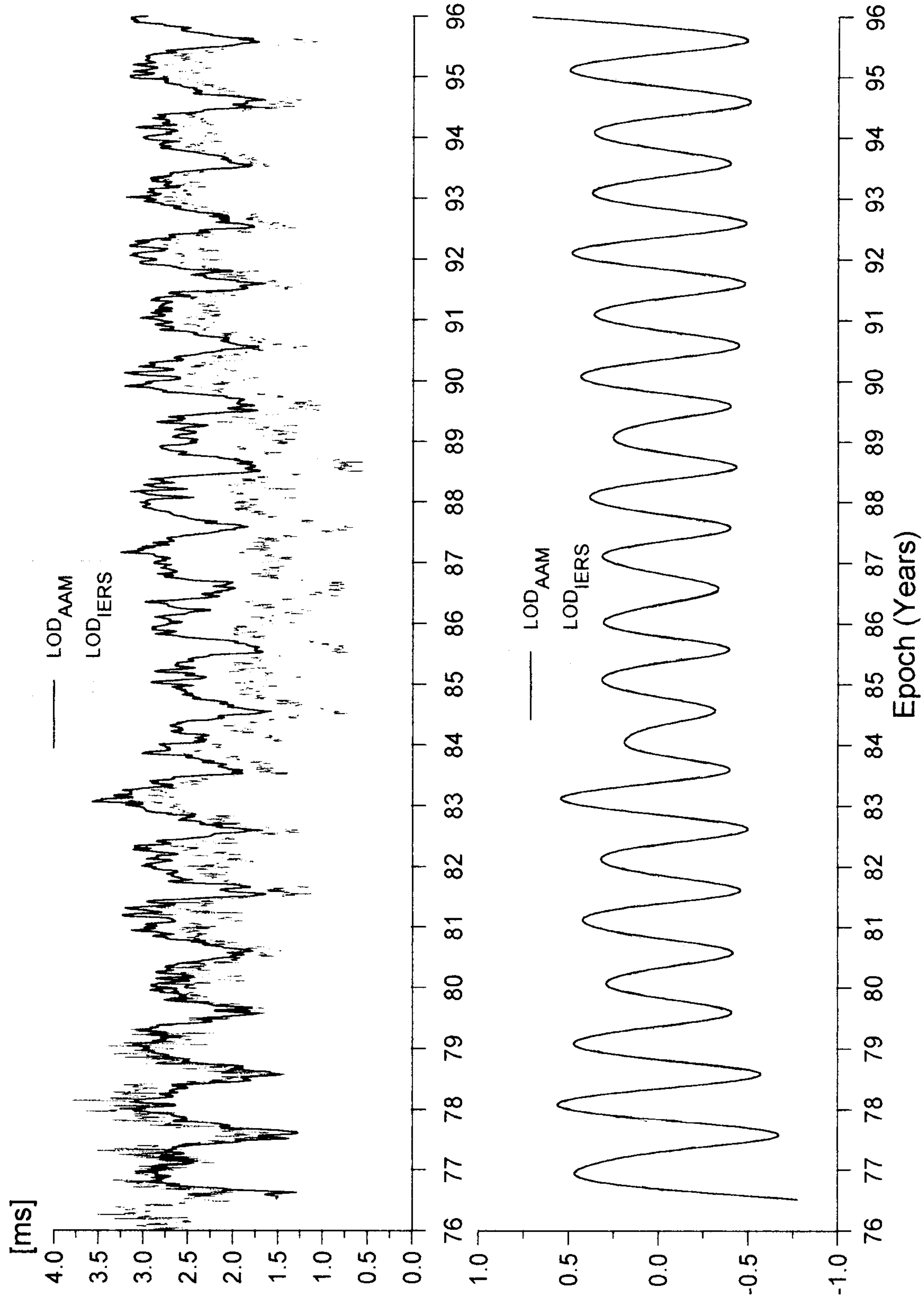

Fig. 9. Top: *Excess of the length of day* LOD_{AAM} *as deduced from the Effective Atmospheric Angular Momentum and* LOD_{IERS} *as observed by astronomical and geodetic techniques.*

Bottom: *Double filtering of* LOD_{AAM} *and* LOD_{IERS} *to isolate the annual component of both signals.*

In addition an independent experience confirms the link between the solar activity and the state of the ionosphere at periods given above, (Dehant and Pâquet, 1983, Pâquet *et al*, 1989, Warnant, 1996). In these papers the authors analyze geodetic coordinates measured for several years from a ground station (Brussels), belonging to a world geodetic network in charge of the determination of precise satellite orbits by radiotechniques. They found that the geodetic height let appear significant apparent oscillations at periods of 4 months, one year and 11 years; the apparent station height variations are induced by the unmodeled perturbations acting on the propagation of radio signals and mainly originated from ionospheric refraction; the physical state (the total electronic content) of this last one is depending on the solar activity.

4. SPACE MOTION OF THE EARTH ROTATION AXIS

The instantaneous positions of the rotation axis of the Earth change in space; this motion is known as astronomical precession and nutation. The gravitational torque responsible for these motions is due to the attraction of the Earth by the Moon, Sun and planets; the response of the Earth to these forces must be based on a model of the Earth interior structure. At the present level of precision of the observations, such a model does not yet exist; indeed although modern theories represent nutations for a rigid Earth by series of several hundreds of terms whose the periods are ranging from a few days to 18 2/3 years (and even larger for the planetary effects) and amplitudes from 0"0001 to 17"2 (amplitude of the main nutation in longitude at 18 2/3 years), observations still disagree with the theory for a non rigid Earth with differences of the order of a few milli-arc seconds (mas). In consequence the theory must be improved and in particular, the Earth transfer function accounting for the actual Earth interior should be improved.

Figure 10 is an example of time evolution of the actual differences between the adopted IAU theoretical nutation series and the observations.

What are the improvements of the adopted nutation model that could be foreseen ? Two research domains are now in progress (1) new series of nutations for a solid Earth have been developed (Souchay & Kinoshira, 1996; Roosbeek & Dehant, 1996; Hartman& Soffel, 1996) (2) improvements in our knowledge of the physics of the Earth are leading to new Earth's transfer function computations for nutations. In the next paragraphs we shall review some of these two aspects.

4.1. Series of nutations for a rigid Earth

Series to compute the nutations of the real Earth are deduced from the convolution of series computed for a rigid Earth. Several authors address this problem using different approaches, each one having its own advantages or disadvantages.

Kinoshita and Souchay (1996) as well as Roosbeek and Dehant (1996) use an analytical approach based on ephemerides given in the frequency domain by celestial mechanics. They have a truncature level of 0.005 mas and 0.001 mas respectively and an internal precision of 0.001 mas and 0.0001 mas respectively which provides for the non rigid Earth a precision of 0.05 mas.

Perturbations of the solid Earth which are taken into account are the direct and indirect planetary effects, the tri-axiallity of the Earth, the Moon contributions of degree 3 and 4 to perturbation of the Sun (J3 and J4), geodetic nutations, on the Earth-Moon position, perturbation of the Moon orbit due to the shape of the Earth and the action of planets (J2 tilt and planetary tilt), second order effects as the effect on nutations of the nutations themselves.

Another approach is followed by Hartmann and Soffel (1996). They use a numerical approach called the spectral method because the global effects are first computed as a time series on which a Fourier transform is applied to get a representation in terms of frequencies. In that case the nutations series are deduced from the tidal potential as given in Melchior (1983). The ephemerides used for the tidal potential and thus for the nutations are the ephemerides DE200 (Standisch and Williams 1981). The perturbating effects of these series of nutations are those which are contained in DE200. The truncature level is 0.45 mas and the internal precision is 0.01 mas.

The main difference between the analytical and the numerical approaches is the following. The analytical method starts from a basic problem whose solution is known; the perturbations of the basic problem are added step by step. The effects of each perturbation and the frequency of each nutation are estimated precisely. By contrast, the spectral method, based on existing numerical series, contains in one step all the perturbations which are present in the numerical ephemeris used; moreover the frequency of each nutation is not defined with a precision as good as that one obtained by the analytical method.

4.2. Geophysical parameters probed to improve nutations

The nutations series adopted by IAU in 1980 are based on a rigid Earth model (Kinoshita 1977) and the Earth model 1066 A of Gilbert and Dziewonski (1975); the transfer function from the rigid Earth to a more realistic Earth model has been computed by Wahr (1981).

It is an ellipsoidal Earth, in uniform rotation, oceanless, with an elastic solid mantle, a liquid core (mean radius 3485 km) and an elastic solid inner core (mean radius 1217 km).

The differences between the observed and the computed of the main nutations are given in Table 1.

Table 1. Differences between theoretical and observed nutations

Period			Theoretical	- observed (mass)
18 2/3	years	prograde	- 1180.40	- 1180.55
		retrograde	- 8021.92	- 8024.82
9.6	years	prograde	85.76	86.13
		retrograde	3.74	3.62
1	year	prograde	25.69	25.65
		retrograde	- 31.04	- 33.04
6	months	prograde	- 549.05	- 548.47
		retrograde	- 24.54	- 24.59
13.7	days	prograde	- 94.12	- 94.22
		retrograde	- 3.67	- 3.64

In order to get a better agreement between theoretical and observed values, on the one hand, one needs a better modelling of the effects of Earth surface phenomenon, essentially ocean loading and current, atmospheric coupling, and, on other hand, one needs a better understanding of phenomenon related to the interior of the Earth such as the increase of the flattening of the core, the core-mantle coupling, the inelasticity of the mantle, or new Earth's normal modes.

In order to improve the knowledge of the Earth, besides the nutations, geophysicists have also access to information from seismology and Earth tides. In particular, there is the important knowledge of the free core nutation (FCN) period. It is mainly the consequence of the elliptical shape of the fluid core of which the axis of rotation does not coincide with the mantle rotation axis; in that case, fluid motions in the core produce a torque at the CMB (Core Mantle Boundary) which will induce a motion of the mantle. From nutation theory a signal should be observed at a period of 460 days. From a stacking of both kinds of observations (tides and nutations), Defraigne *et al.* (1994 and 1995) have determined the value of the FCN period which is about 30 days less than the theoretical value based on an Earth in hydrostatic equilibrium. Herring *et al.* (1986), (see also Gwinn *et al*, 1986) noted that a small change of the value of the FCN would produce a significant change in the amplitude of the annual nutation without affecting significantly values at the frequencies; they showed that the residuals of the annual nutations could be explained by a departure of 490 ± 110 m of the equatorial CMB from its hydrostatic equilibrium. Analyzing nutations series, Herring *et al.* (1991) determined that the period of FCN should be at 430 days to explain the residuals of the annual nutations; the amplitude of the residual signal at that nutation period is of the order of 2 mas. This value reduces by a factor of 10 when the FCN period matches the departure of the CMB from its hydrostatic equilibrium suggested by Herring *et al.* (1986).

It is very interesting to note that the same value has been obtained by analyzing gravity tides recorded by superconducting gravimeters alone (Neuberg *et al.* 1987).

5. THE INTERNATIONAL GPS GEODYNAMICS SERVICE

The contributions of GPS in the observation of Earth rotation parameters and other geophysical parameters are really impressive; this is the reason why the last paragraph will be dedicated to the organization of the world GPS tracking and data analysis networks. IGS (International GPS Geodynamics Service) is based on the observations of the GPS satellites by a world network of about 200 stations.

Initiated in 1992, it is operational since 1994. A great number of scientific institutions (> 100) contributes to IGS; the aim is to collect information for the study of the Earth, both from the geodynamical and geophysical aspects i.e.: precise ephemerides of GPS satellites, Earth rotation parameters, world and regional ground deformations, geodetic networks, sea level monitoring, ionosphere; more recently studies are conducted to use GPS to measure the humidity content in the atmosphere (Bevis and Businger 1996). The great success of such a service is the consequence of the international collaboration to share the tasks between partners; they are organized on different levels: permanent tracking stations, network for data collection, network for data analysis; a Central Bureau takes care of the coordination while a Governing Board defines the objectives of the Service (refer to a series of papers published by Gendt and Dick 1996).

Besides the world network of permanent stations, IGS supports regional networks as for example, the EUREF network (European Reference Network - Fig. 11). The interrelations between the world and regional networks are given in Fig. 12 (Bruyninx *et al.*, 1996).

The IGS analysis centers compute precise orbits of all GPS satellites together with the Earth rotation parameters; they also deduce the station coordinates of the permanent stations (Global Network Solution). The data of regional networks (densification of the world network) are processed through their regional (local) analysis centers; they benefit of the precise ephemerides computed by IGS and thus compute the station coordinates of the regional network in the same reference system as that one realized by IGS.

In our point of view, to participate in such a regional network is mandatory for countries interested in studies related to local or regional geodetic networks, seismology, crustal deformations, ionospheric perturbations..., new applications of GPS are extending from year to year.

The conditions imposed on a permanent IGS station are given in Gurtner (1995); let us just indi-

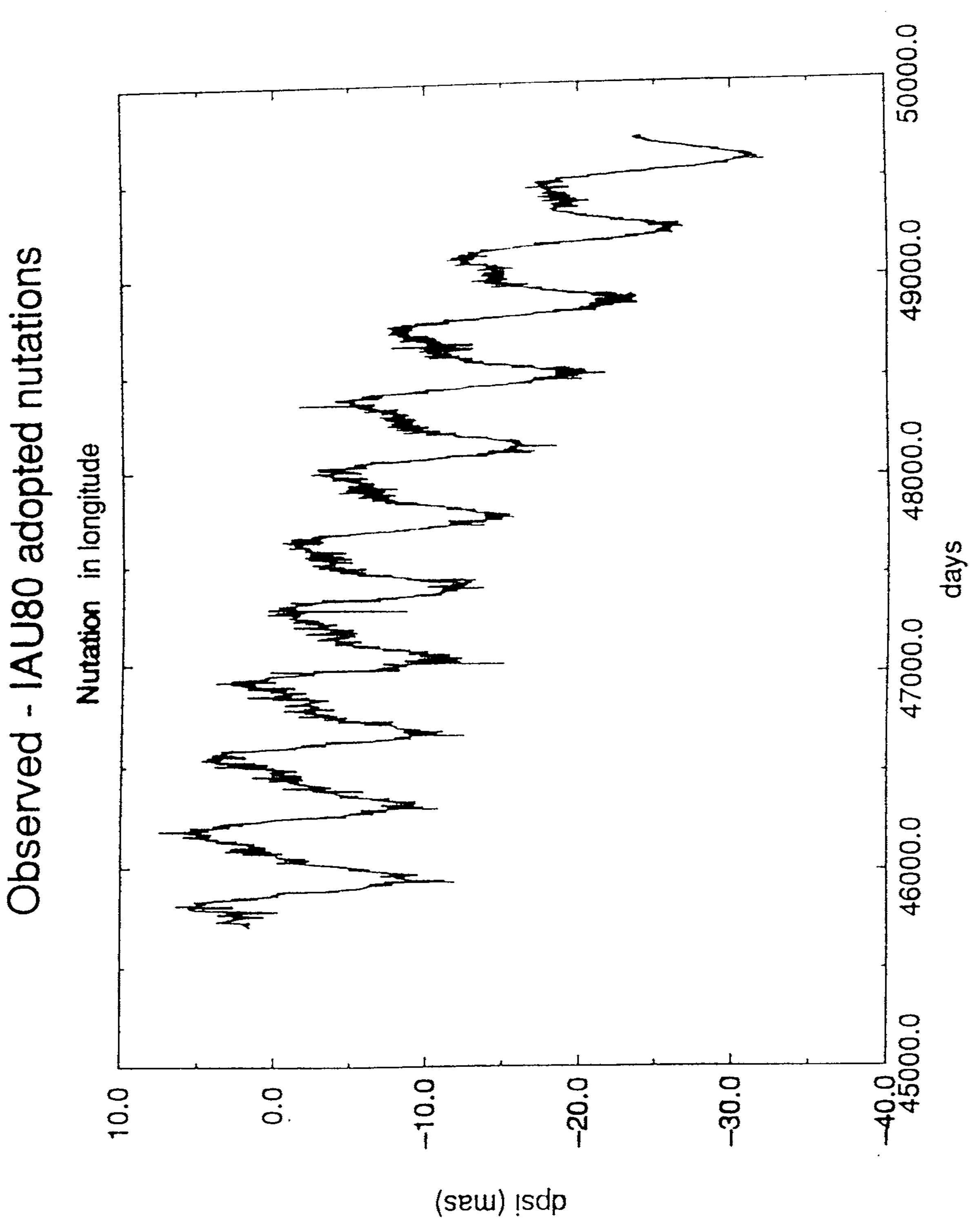

Fig. 10. *Actual differences between the observed nutations and the computed one. The trend is due to the contribution of the precession.*

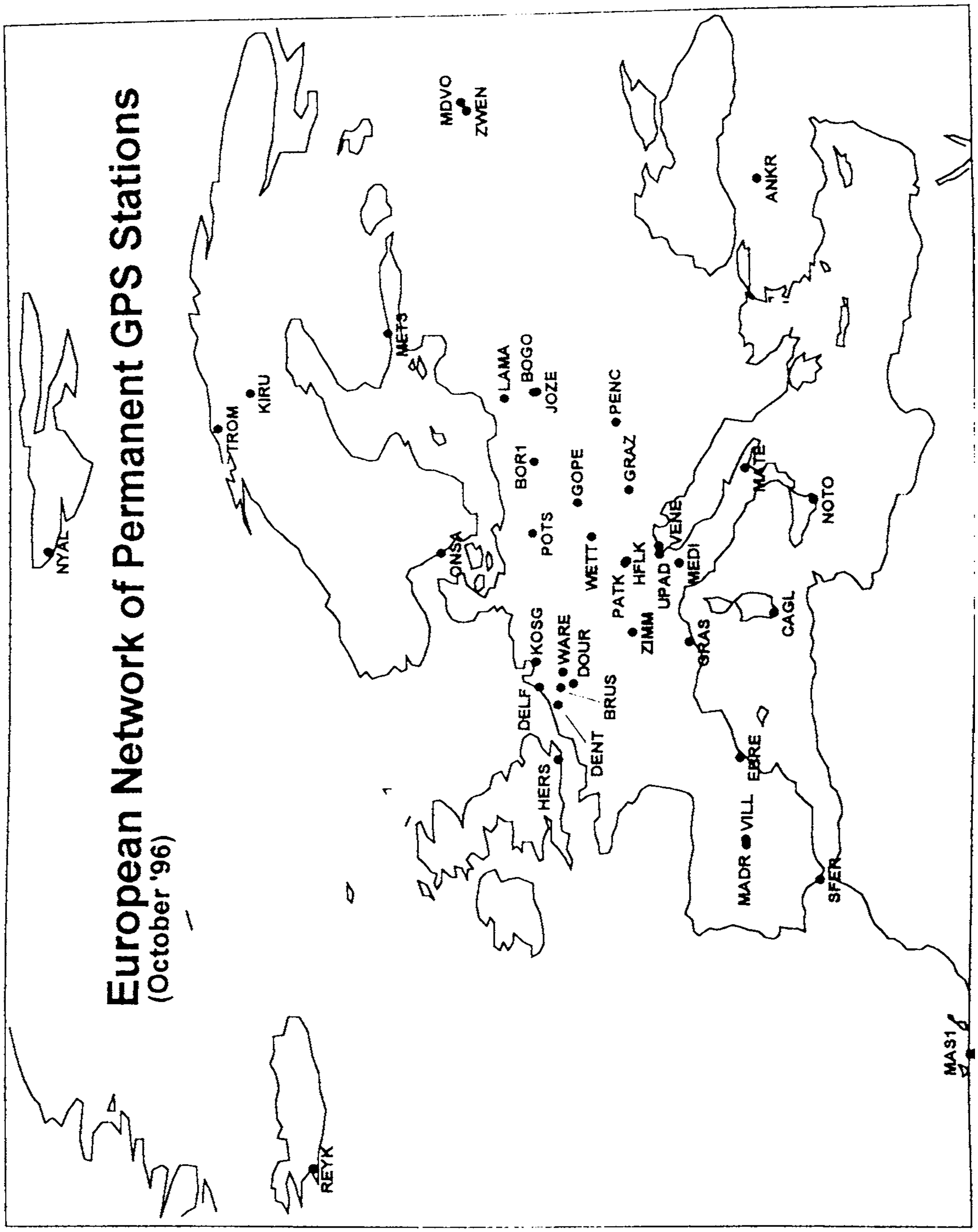

Fig. 11. *European Reference (EUREF) network.*

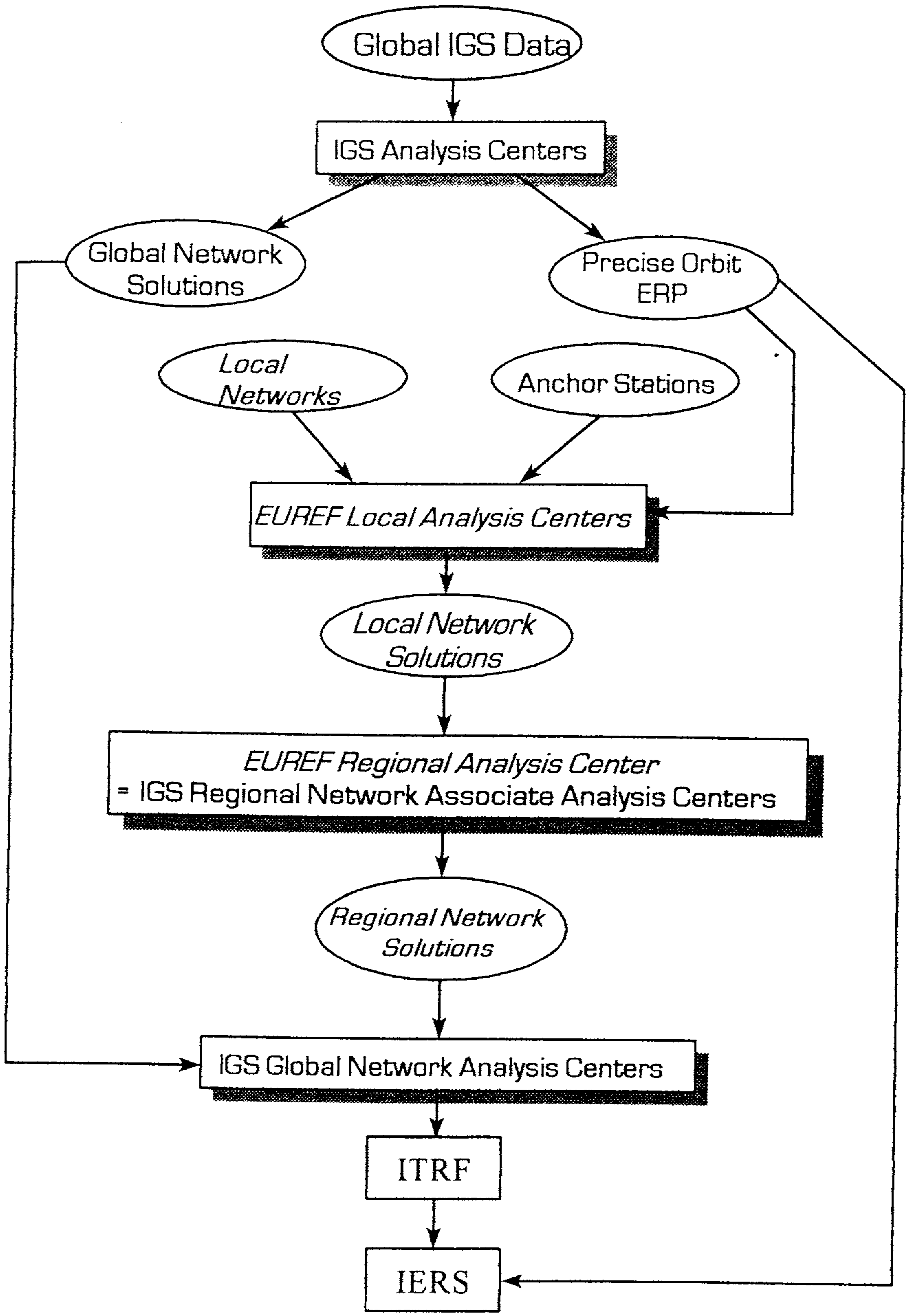

Fig. 12. *Relations between the networks EUREF and International Geodynamic Service (IGS).*

cate that such a station must benefit of the support of other observations as: permanent observations in gravimetry, time and frequency reference stations, meteorological observations, fulfil standard requirements with respect to stability and long-term maintenance ...

Let us point out that meteorological observations are required not only to estimate the atmospheric refraction which perturbs radio signals, but also to compute the ground deformations due to the atmospheric loading. In Europe, over distances of a few hundred to several thousand kilometres, the vertical displacements between stations can reach 3 to 4 centimetres as a consequence of the atmospheric pressure distribution (Sun 1995).

6. CONCLUSION

Earth rotation variations and the space motion of the Earth rotation axis are evidence of phenomena which concern both external and internal geophysics. New insights into the interactions between the Sun and the Earth are qualitatively described but new researches are still to be initiated to understand the mechanisms.

The inputs of precession and nutations and the knowledge of the internal structure of the Earth are very complementary; results of Earth rotation studies provide constraints to seismologists as for example the size of the core and the hypothesis of the non-hydrostatic equilibrium at the CMB.

The contribution of VLBI is well known for those studies; since 1992 the Global GPS Geodynamic Service (IGS) provides very valuable inputs mainly for the short term events. Moreover the outputs of IGS concern a very broad field of applications, which is extended from year to year; it makes it mandatory and it is recommended to equip observatories and the main geodetic reference marks with GPS stations.

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ПОСМАТРАЊА ЗЕМЉИНЕ РОТАЦИЈЕ И ЊИХОВЕ ГЕОФИЗИЧКЕ ИМПЛИКАЦИЈЕ

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Прегледни рад

Овај рад представља један преглед прецизности мерења флуктуација Земљине ротације током последњих деценија; конкретно посматрања обављена током последњих десет година дозвољавају ограничавање слободе у креирању оних модела Земље који укључују нееластичност омотача и резонанције нормалне моде са реалним параметрима, као што су динамичка спљоштеност Земље у сагласности са посматраном Слободном Нутацијом Језгра (СНЈ), посматрани степен 2 геоида ($J2$) и посматрана константа прецесије. Прецизност која се добија из данашњих посматрања захтева узимање у обзир ефеката атмосфере и океана на нутације и прецесију.

Доприноси светске мреже праћења (GPS) класичној геодезији и краткорочне варијације Земљине ротације су такође дати у овом прегледу; за посматрање Параметара Земљине Оријентације (ПЗО) важност једне овакве мреже захтева сарадњу опсерваторија и геодетских института у вези са космичком геодезијом, мониторисањем Земљине ротације, локалном или глобалном геофизиком.