# 11
# TPW and Polar Motion as due to an asymmetrical Earth expansion

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The possibility of a link between asymmetrical Earth's expansion and Polar Motions (PM) is investigated, searching for possible mechanisms of inner and/or surface material displacement, which can lead to the observed Chandler Wobble (CW; Eulerian free oscillation) and its secular drift. While the main result of this work is the identification of the possible cause of PM in the diffuse emplacement of new mass in and under the triple point zones, the problem of the continuous excitation of the CW is still not resolved. Only a qualitative argument in favour of a cause of the CW's excitation by the not uniformity in time (from short, tens of years, to long time scale), low frequency noise or pulsations, of the diapirical flow of mantle material is proposed. The inversion of paleogeography towards geodynamics is performed, and the result is found that the PM's current parameters can be prolonged in the current geological past up to 100 Myr, reproducing with satisfactory approximation the more reliable true polar wander path and its slowing down around 50 Myr, which was detected by Besse and Courtillot (1991, 2002). The very long pulsation of the expansion rate – a fundamental new acquisition supporting a pulsating tectonic activity of the Earth (see the «Half Spreading Map of the Ocean Floors»; fig. 5.19 in McElhinny and McFadden, 2000, based on Müller *et al.*, 1997) – could be the cause of the modern undetectability of the effects of the Earth's expansion on LOD and on geodesy. This is because of the minimum of the half spreading rate and tectonic activity occurring today – and the consequent minimum variation of radius and inertial moment –, and because the possible compensating effects due to differentiation of the mantle and core, with consequent accretion of the inner core still underway today.

## 11.1. Introduction

Many discussions have raised the expanding Earth hypothesis from the birth of the ocean-floor expansion framework in the sixties (Carey, 1988). At the time, the two global tectonic ideas, global expansion and sea-floor expansion, overlapped and went to a neat separation only with the formulation of the plate tectonic paradigm. The argument that played a major role in the decision of the scientific community in favour of the constant radius theory was the belief that a substantial increase in size of the planet should have had an observable effect on its rotational dynamics (Runcorn, 1964). A doubling of the Earth's radius should have had as consequence a nearly halved length of the day in the Palaeozoic, which was not confirmed from the palaeontologic data. The expanding Earth was excluded on these bases, and also today this opinion is repeated on well-documented review papers on paleorotation of our planet (Williams, 2000).

My aim is to re-discuss the relation of some Earth's rotation parameters if an expansion of the planet is hypothesized.

## 11.2. Preliminary analysis

The rotation pole is today drifting towards 76°-79°W at a speed of more than 10 cm/yr (3.3-3.5 marcs/yr) (Dick *et al.*, 2000; Dickman, 2000; Schuh *et al.*, 2001). The continental drift does not seem

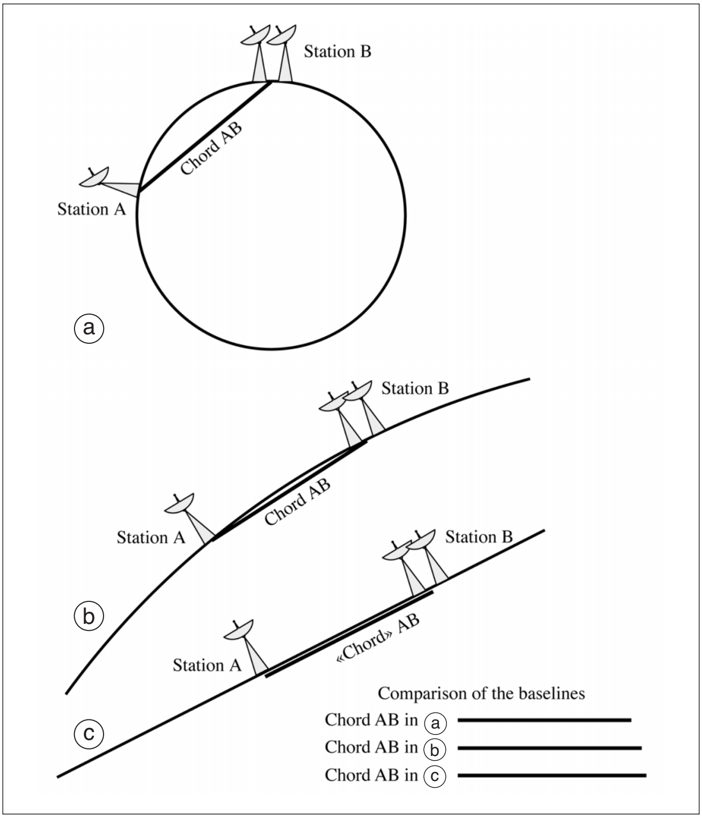


**Fig. 11.1a-c.** Problematic VLBI baseline evaluation. All the parabolic antennas shown in a), b), c) are oriented at the same angle in the celestial reference frame. The radius of the Earth is assumed to increase from a) to b) to c), from an initial value of $R$=6371 km to a final one of $R=\infty$. Both antennas in the VLBI station B have the same angle with respect to the local terrestrial reference frame. Albeit the chords from site A to site B increase passing from a) to c) – see the comparison – if the observer is not aware of the radius increase he can reach wrong conclusions in processing the data, namely that because in (c) the three antennas have the same angle in the local terrestrial reference frame then the distance of station A from station B is null. An unrecognized spurious contraction of the baselines hides the real Earth's expansion. It is evident that a vicious circle, difficult to avoid, is present, and that a new computation methodology should be found.

able to operate such rapid latitude variation, because it is more effective on longitudinal variations. It is simple to put this situation in relation to the expanding Earth theory.

If a radius of 3300 km is assumed (Scalera, 2001) in Triassic, ≈220 Myr ago, then my estimated annual rate of radius increase is

$$\frac{dR}{dt} = \frac{(6370 - 3300)\,\text{km}}{220\,\text{Myr}} \cong 14.0\ \text{mm/yr}\,.$$

This value is an average upon the entire geological time window. The recent global minimum expansion rate (map of fig. 5.19 in McElhinny and McFadden, 2000, based on Müller *et al.*, 1997) could hinder the geodetic revelation of unambiguous global expansion, because the minimum phase of the pulsation – very evident in the map – could give place to a minimum of the tectonic activity, which could lead to a near-zero rate of global expansion.

The accurate or not-accurate selection of the geodetic stations on which to ground the search for a radius variation can also have an influence in the difficulty to detect geodetically this minimum or near-zero rate of expansion. This possibility is supported by an earlier analysis of space tracking data in searching for change of Earth dimensions, which, using LAGEOS and VLBI data for stable non-orogenic continental regions, has indicated an increase in the Earth's radius of +4.15±.27 mm/yr (Gerasimenko, 1993). A more recent reprocessing of the NASA VLBI baseline data (NASA GSFC solution number 1122, June 1999) using only the condition that each point of the network does not change its height more than ±4.0 mm/yr has given a value of the possible radius variation of 0.2 mm/yr (Gerasimenko, 2003). This smaller value could be due to the use of the NASA baseline solution as they are, albeit their evaluation may be affected by spurious effects. Indeed, in fig. 11.1a-c an argument is shown that relates Earth's expansion to a spurious baseline contraction.

In any case, the situation of the global scale geodetic measurements is still characterized by a variety of conflicting results, positive and negative, which do not allow them to be used in supporting or confuting with certainty the expansion tectonics. Only reasonable assumptions can be made, waiting for the important condition that a greater number of station could cover in the next decennia the Southern Hemisphere.

Then Gerasimenko's earlier results – with its careful station selection – may be could be considered near the actual recent value, while the maximum of expansion rate – in the McElhinny and McFadden (2000) map – in the Early Cretaceous time could correspond to a Cretaceous radius gradient of few centimetres per year. I then can only assume here that today the Earth pulsation is in a mini-

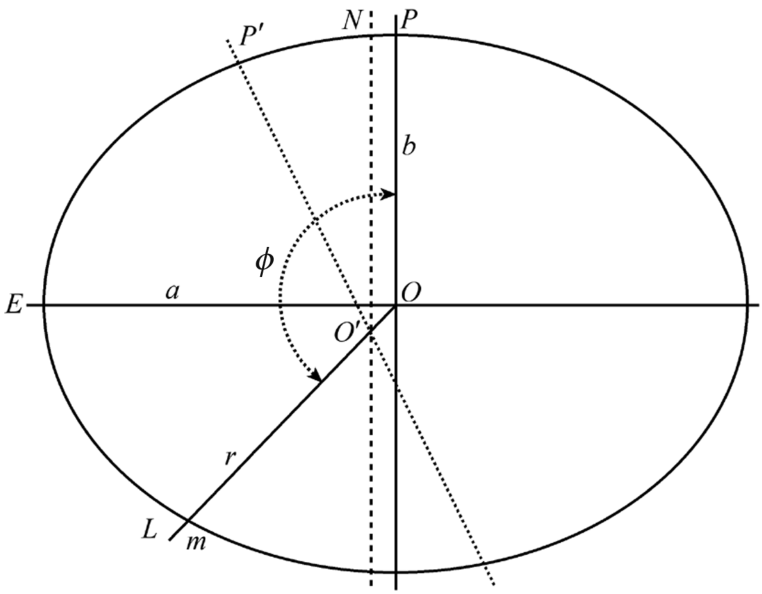


**Fig. 11.2.** If a mass $m$ is inserted in a point of latitude $L$ (colatitude $\phi$), a displacement of the geocenter from $O$ to $O'$ happens, with a displacement of the principal axis of inertia from $P$ to $P'$. The contribution of $NP$ to the total PM is opposite in the two hemispheres.

mum and as consequence I can conservatively assume that today the radius increase rate is 7 mm/yr, a value very near to that of +4.15±.27 mm/yr found by Gerasimenko (1993), and probably a rate still very difficult to be ascertained without ambiguity by the geodetic method.

If a completely asymmetrical growth of the planet radius of 0.7 cm/yr, 1.4 cm/yr in diameter, centred on an equatorial point, is assumed, then a pole displacement of 0.7 cm/yr will be observed in the direction of that longitude (fig. 11.2). This value of the polar displacement is evidently not sufficient, one order of magnitude less, to explain the real polar displacement of more than 10.0 cm/yr (Dickman, 2000; Schuh *et al.*, 2001). The conclusion is that effective displacements or depositions or subtractions of mass happen in some non-equatorial Earth regions, surface areas or deep volumes, or both, which have preponderant effects on the polar motion with respect to the effects of the pure equatorial asymmetrical volume variation.

## 11.3. More quantitative considerations

In the case of a rigid Earth (Schiaparelli, 1883, 1891), it is possible to prove referring to fig. 11.2 and neglecting higher order smaller terms, that when a mass $m$ is added to the Earth mass $M_E$ in a point $L$ at a colatitude $\phi$ in the Northern Hemisphere (with $B$ and $A$ the polar and equatorial moment of inertia, respectively)

$$PP' \cong \frac{br^2 m}{2(B-A)} \cdot \sin(2\phi) - r\frac{m}{M_E}\sin\phi. \tag{3.1}$$

In eq. (3.1) the term

$$NP = -r\frac{m}{M}\sin\phi$$

(in fig. 11.2 the situation for an addition of mass in the Southern Hemisphere is shown because more interesting in the expanding Earth geodynamics, and in this case the sign of $NP$ must be «+») arises from the displacement of the centre of mass from $O$ to $O'$ and is normally neglected (Schiaparelli, 1891) because it is considered small in comparison with the first term if the mass transport on the Earth happens with a roughly casual spatial distribution and with a probability nearly equal zero to happen very near to the equator. Then, the relation to compute the inertial pole displacement in the rigid case is

$$PP' \approx W \cdot r\frac{m}{M_E} \cdot \sin(2\phi) \quad \text{with} \quad W = \frac{M_E br}{2(B-A)} \cong 460$$

(the value of $W$ was assumed 506 in the classic works of Schiaparelli).

If a more realistic viscoelastic behaviour of the Earth is taken into account (Lambeck, 1980, 1988; Spada, 1992, 1997) the introduction of the Love numbers $k$ leads to a similar relation

$$PP' \approx \frac{br^2 m(1+k')}{2(B-A)} \cdot \sin(2\phi).$$

Considering that the factor $(1+k')$ assumes values smaller than 1 with $k'$ ranging nearly linearly from a surface value $k'=-0.30$ to an upper-lower mantle boundary value $k'=-0.45$, the viscoelastic formula leads to numerical values for $PP'$ few tens percent smaller than the values in the rigid case. I will adopt the rigid case framework in these simplified considerations, because the rheology of the inner Earth's materials is still not well known, because the true viscoelasticity of the Earth's interior, if the planetary expansion is true, should be derived from a specific variable radius model, and because the probable absence of mantle convection in the expanding Earth framework leads towards a more rigid behaviour of the planet as a whole.

## 11.4. Where the displacement happens

The direction of the polar motion is ≈79°W. This fact has been variously interpreted, invoking different geological processes but only the hypothesis of the glacial rebound (Peltier, 1976; Peltier and Jiang 1996; Sabadini *et al.*, 1982) has found more general consensus because the Northern Canadian Shield and Siberia were once covered by ice caps – on whose real extent an ongoing debate is active today (Clark e*t al.*, 2001).

Near the same direction the Nazca Plate and a superplume are located (fig. 11.3a,b), in the Southern Hemisphere, at a latitude of ≈30°S. This superplume, revealed by seismology by global tomographic methods (Su *et al.*, 1992, 1994; and others) could be interpreted as the main expression of the asymmetrical global expansion.

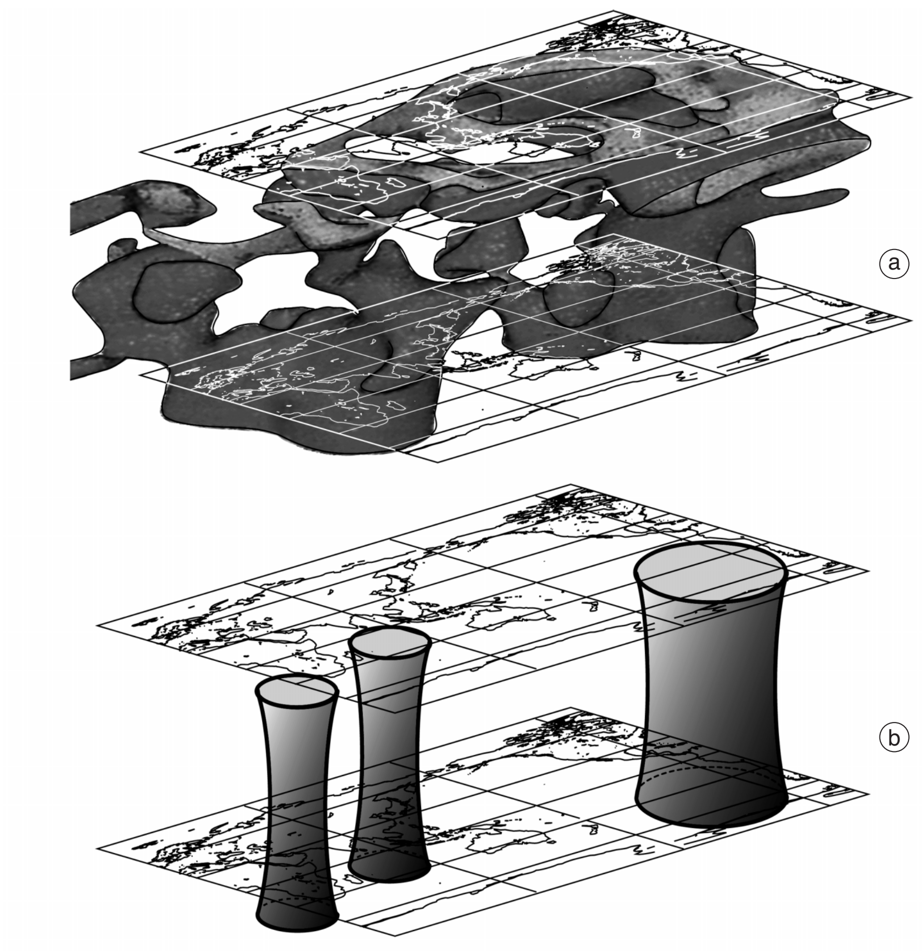


**Fig. 11.3a,b.** a) The global pattern of the mantle flow as revealed by the global seismic tomography (from web site source and Su *et al.*, 1992, 1994). b) The major upwelling of mantle material sketched under the Bouvet, Indian and Pacific triple points, with pipes which section is proportional to the observed ocean floor expansion rate.

I have then to test, with some rough computations, under which limits on mass accretion this situation is relevant for an expanding Earth. I do not still consider, in this section, the possibility that a cosmologically induced increase in mass, with a still unknown physical process, happens, with spherical symmetrical distribution, in the Earth deep body. I consider then only a rough model in which progressively, in a geological time scale, a part of the Earth's mass is asymmetrically expelled from the deep interior of the planet, rising vertically in the main tomographically revealed superplumes, like a diapiric process (Scalera, 2002). No hypothesis is made on the composition and progressive differentiation of this slow mass flow.

For example, if a mass $m=10^{-11}$ $M_E$ ($M_E$= Earth's mass) was annually added on the geographic point 30°S, 79°W, near Nazca, the following PM drift would be obtained:

$$PP' \approx W \cdot r \frac{m}{M_E} \sin(240°) \approx -2.5\, cm/yr.$$

A factor, 4 or 5, applied to $10^{-11} M_E$ is then sufficient to reach the value of the observed annual drift of ≈10.0 cm/yr.

In fig. 11.4 the real path of the mean rotation pole from 1900 to 1990 is shown, superimposed (in a different scale) on the Lambert equivalent polar plot of the geography. The mean direction of the


**Fig. 11.4.** The secular drift of the rotation Pole – the red path with arrow – is shown superimposed to the geography. A rough vectorial sum, neglecting the different latitude, is represented in black broken lines among the three major hypothesized contributions to PM provided by the Nazca, South Atlantic and Indian triple points, which are sketched in fig. 11.3b. A ratio of 1/4 is assumed between South Atlantic and Pacific vector magnitude as well as between Indian and Pacific vector. With those simplified assumptions the resultant vector – in solid black arrow – is in good agreement with the observed averaged PM secular drift.

PM is directed slightly eastward from the Nazca triple point (the above mentioned 79°W *versus* the triple point longitude of ≈115°W), and this means that one must take into account the other two main rising of mantle material in the Atlantic Ocean, the South Atlantic Bouvet triple point, and in the Indian Ocean triple point, which are sketched in fig. 11.3a,b. If a ratio of 1/4 between each of the other two minor expanding rate and the Pacific expansion rates is assumed, and if the different latitude of the three emplacing point is neglected, the vectorial sum of the three contribution give a resulting vector in good longitudinal agreement with the observed PM mean drift vector (fig. 11.4).

## 11.5. The need for an increase in mass?

A number of papers have been dedicated to, or have mentioned, the problem of a possible change in the Earth's inertia moment (Runcorn, 1964; Burša, 1984; Williams, 2000 and cited references), but all of the authors have made explicitly or implicitly the assumption that a volumetric expansion is associated necessarily with an increase in the inertial moment and then a strong increase in the LOD should be observed, more pronounced with respect to the paleontological data indication.

On the other hand, an increase in mass of only one or few parts on 100 billions per years, asymmetrically emplaced, appears insufficient to take into account a many-fold increase of the Earth's volume during the time lapse from Palaeozoic to Recent – a lapse of 300 Myr. A difference of orders of magnitude is present. Then, in the expanding Earth framework, the mass increase deduced from secular polar motion, or radially unbalanced mass displacement, should be considered only a small portion of the new absorbed mass. The unbalanced mass could also derive from the contrast of density between the quick expansion of the basaltic Pacific Hemisphere with respect to the slower expansion of the Continental Hemisphere. Only a small percent of the total mass increase should be considered unbalanced and the possibility is not excluded of a concomitant chemical differentiation of the total accreted mass, with the heavier chemical compounds dropping towards the core-mantle boundary and the inner core.

Assuming a simplified situation with an expanding Earth retaining its average density during geological time, an estimate of the annual mass increase is possible on the basis of the variable-radius paleogeographical reconstruction, adopting an initial radius $r$=3000 km

$$\frac{dM_E}{dt} = \frac{[M_E - (5.5\ \mathrm{g/cm^3} \cdot 4/3\pi r^3)]}{300\ \mathrm{Myr}} = 1.78 \cdot 10^{19}\ \mathrm{g/yr}$$

which is in the magnitude order of $10^{-9}$ of the Earth's mass $M_E$=5.9736·$10^{27}$ g, *versus* an annual asymmetrically emplaced mass $m$ (evaluated from polar motion) of few parts of 100 billion

$$\frac{dm}{dt} = K \cdot 5.97 \cdot 10^{16}\ \mathrm{g/yr}$$

with the adimensional value of $K$ ranging around 4÷5, to reach the value of the observed secular polar drift. Assuming the value of $K$=4, it is possible to compute the value of the ratio of the accreted mass emplaced asymmetrically

$$\frac{dm/dt}{dM_E/dt} \cong 1.34 \cdot 10^{-2}.$$

The asymmetrically unbalanced emplaced mass should then be around 0.02 the annual total mass increase, which has been roughly evaluated from the paleogeography and from simplified assumptions on the density, and without taking into account other possible significant contributions to the inertial pole motion due to material flow on the surface or in the interior of the planet (Peltier, 1981; Sabadini *et al.*, 1983; Spada *et al.*, 2000).

## 11.6. The slowing down of the Earth

While the asymmetrically emplaced $m$ must contribute to the slowing down of the Earth's spin, the more consistent total mass increase $dM_E/dt$ can also contribute to the slowing down, but could well give place and contribute to a more general differentiation process which also involves the pre-existing mantle and fluid core and which influences the Earth's rotation with a positive contribution to the spin acceleration, a process which compensates the slowing down.

It is possible to try to evaluate the upper limit of the inertial moment variation produced by the asymmetrically extruded mass, $\cong 24{\cdot}10^{16}$ g. It is clearly unrealistic to hypothesize a displacement from the bottom of the mantle to the Earth surface. The mass is slowly displaced distributed on a large section of a vertical column, the area of which is difficult to evaluate. Then I can suppose that only a vertical upward displacement of few centimetres or millimetres per year could really happen distributed on large ocean-floor-ridge area, because this is the only way do not conflict with the geodetic observations, a conflict which could become unavoidable assuming larger rates.

All the following considerations should be considered largely conjectural because we do not know absolutely how the total accreted mass $1.78{\cdot}10^{19}$ g/yr and the pre-existing mass, in ongoing differentiation, contribute to the variation of the thickness of the different Earth's strata and redistribution of the inertial moment.

I can evaluate the slowing down of the Earth in the simplified idealized case of an injected mass, say $24{\cdot}10^{16}$g, in the Nazca triple point. The inertia moment variation due to the idealized extrusion of the asymmetrical emplaced mass is

$$\Delta I = 24 \cdot 10^{16} \cdot (R\cos(30°))^2 = 7.6 \cdot 10^{30}\ \mathrm{gm}^2$$

which is small, nearly $10^{-10}$ times, with respect to the Earth polar inertia moment $8{\cdot}10^{40}\mathrm{gm}^2$. This means that an equivalent value should be compensated by differentiation in the mantle and in the liquid core. Applying the law of the conservation of the angular momentum $I_1\omega_1{=}I_2\omega_2$, it is possible to evaluate $\omega_2$, and the annual angle of delay with respect to an unaffected Earth.

$$\omega_2 = \omega_1 \cdot \frac{I_1}{I_2} = 7.292114999 \cdot 10^{-5}\ \mathrm{rad/s}$$

which is different from $\omega_1{=}7.292115{\cdot}10^{-5}$ (the actual Earth spin) only on the nineth decimal ($\omega_1 - \omega_2$ is in the order of $10^{-15}$) and the annual angular delay is only in the order of $10^{-15}$ geographical degree. The lengthening of the day, ΔLOD, is in the order of magnitude of 1÷2 ms/cy. Indeed, the computation gives

$$\Delta\mathrm{LOD} \cong 1.74\ \mathrm{ms/cy}$$

which is in the same magnitude order of – and only 0.66 ms less than – the ΔLOD computed by taking into account reasonable tidal friction (≅2.4 ms/cy; see fig. 11.6a,b); and only slightly greater then the secular ΔLOD evaluated from ancient eclipses (≅1.4 ms/cy; Stephenson, 1997; see fig. 11.6a,b). This numerical agreement should be object of deep reflection.

But it is the time to evaluate the variation of inertial moment to be compensated if a spherically symmetric shell of material, thickness 1 cm, is symmetrically emplaced eventually by a spherical radial 1 cm growth of the core-mantle boundary. Assuming 3.0 g/cm$^3$ the Earth average surface density and 5.0 g/cm$^3$ the mean lower mantle density, 2.0 g/cm$^3$ the difference between the mantle and the upper mantle-lithosphere density, and finally 5.0 g/cm$^3$ the difference between the mantle and the fluid core density, in this oversimplified Earth model the annual increase in mass is in the right magnitude order, $10^{-9}$ of the Earth mass. The variation of moment of inertia can be evaluated from the assumed values with the sum of three contributions

$$\Delta I = \Delta I_{\text{surf}} + \Delta I_{700\text{ km}} + \Delta I_{2900\text{ km}} .$$

The computation takes into consideration the spherical redistribution of the volumes as $1/r^2$, and gives an annual angle of delay of the mantle with respect to the inner core in the order of magnitude of $10^{-3}$ geographical degree. In both cases, for asymmetrical and symmetrical mass emplacements, the annual angle of superrotation of the core due to effects of an expanding Earth is small in comparison to the range of the seismologically detected angles, 0.1°-3.0°, and probably in the range of the non-detectability by seismological methods (Song and Richards, 1996; Su *et al.*, 1996; Nataf, 2000; Vidale *et al.*, 2000).

The ΔLOD, in this symmetrical emplacement case, rises to a value in the order of magnitude of few tens of milliseconds per century, while the observed value is around 2.4 ms/cy. In the best case of a symmetrical contribution to the expansion of few millimetres per year, I have obtained a secular ΔLOD of 20.0 ms/cy. The hypothesis must then be made of a still active geochemical differentiation in the mantle and in the liquid core, which could compensate, at least partially, the slowing down due to the expansion. This means a transport of mass from the mantle and the fluid core toward the inner core surface. The annual inertial moment to be compensated is of the order of magnitude of $10^{-9}$ of the Earth's moment, but no modelization of the requested mass transport exists up to now. A differentiation of the type here requested has been recently proposed in the theoretic geodynamo modelisation of the Earth interior, where the mechanism able to sustain the material flow in the convection tubular cells is the solidification heat released by the iron which is deposited on the surface of the inner core (Buffet *et al.*, 1996; Kutzener and Christensen, 2000).

Also it should be remembered that at least a partial contribution to the compensation of the slowing down could be provided by the variation of the $J_2$ geoidal coefficient due to the global glacial rebound (Argus *et al.*, 1999).

## 11.7. True polar wander and expanding Earth

Albeit the existence and meaning of a true polar wander has intrigued the geophysical community from the beginning of paleomagnetism (Goldreich and Toomre, 1969; McElhinny, 1973), no definitive linking of this phenomenon with other geophysical processes has been found. The discussion about TPW has been very lively in recent years (Cottrell and Tarduno, 2000; Prevot *et al.*, 2000; Sager and Koppers, 2000).

An explanation of the TPW has been sought in the global pattern of the convective cells, not considering the fact that mantle convection and hot spot concepts are incompatible. The synthetic path derived from these modelisations of the mantle convection (Richards *et al.*, 1997) is in overall disagreement with the observed path (if we accept the «hot spot» frame as at least a rough approximation of a really fixed terrestrial reference frame). Other models (Steinberger and O'Connell, 1997) try to put in relation the TPW to the advection of mantle density inhomogeneities. This kind of modelisation reaches a greater similarity between the true and the computed TPW, but cannot avoid other problems.

The modern TPW, namely the Polar Motion (PM) – the secular drift of the rotation pole observed today by astrogeodetic methods –, is explained not with the same modelisation of the global convection used for the TPW's explanation, but with the influence of the so called glacial rebound (Peltier, 1976; Sabadini *et al.*, 1982; Peltier and Jiang, 1996). The main difficulty in this view is the estimation of the extension and thickness of the paleo-icecaps on Canadian and Siberian shields respectively (Clark *et al.*, 2001). Moreover the glacial rebound can sustain a TPW only for a few million years or, more realistically, fraction of a million years, while TPW is active on a hundreds of million year time scale. This is an unacceptable double or multiple explanation of the same phenomenon.

The hypotheses I have made as concerns the influence of the superplumes on the global dilatational geodynamics (Scalera, 2001) and my palaeogeographic reconstructions are in favour of a slow

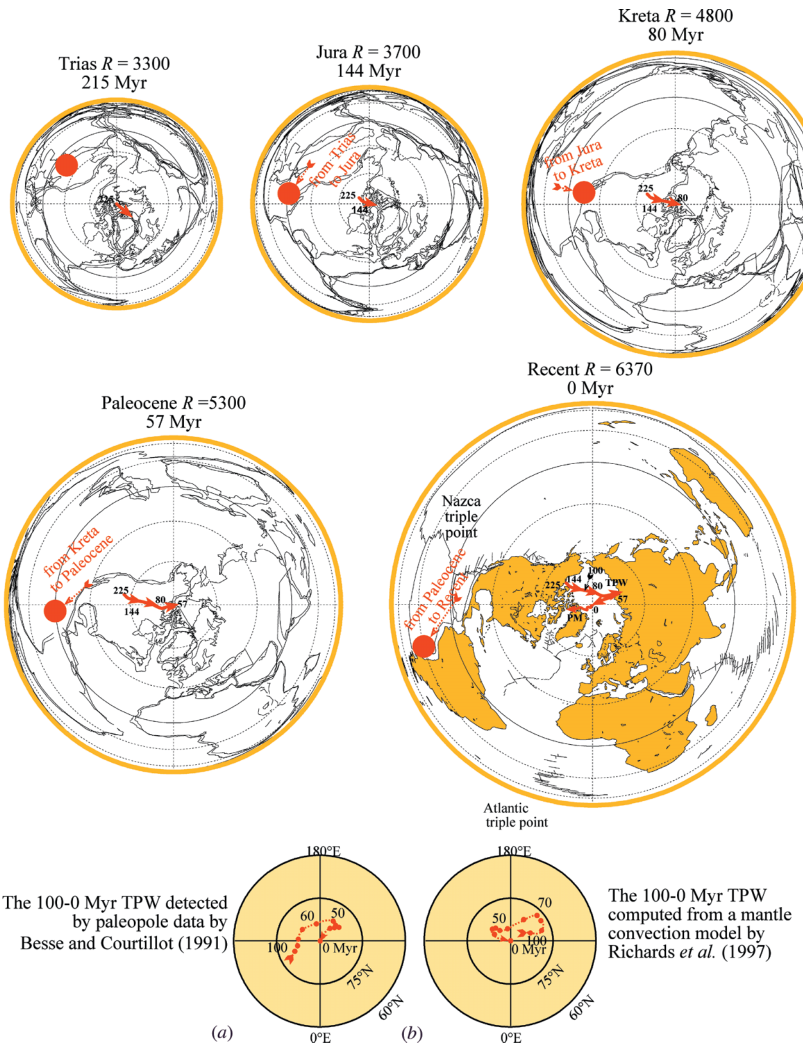


**Fig. 11.5.** The reconstruction of the possible True Polar Wander (TPW) as it come from the asymmetric expanding Earth interpretation. The meaning of the series of maps is that a joined inversion of the data upon which the paleogeography has been reconstructed (paleontologic, geomorphologic, paleomagnetic, etc., data) has been provided. The red-filled circles are the estimated positions of the resultant of a vectorial sum of the contributions of mass emplacements due to the triple points (*e.g.*, see fig. 11.4 for Recent). In the segments of the path which is approaching and passing the equator (from Cretaceous to Palaeocene) or passing and leaving the equator (from Palaeocene to Recent), a corrective factor $q$=0.3 has been applied to the modern drift rate (more than 1° for Myr) of the rotation pole. In (*a*) the observed TPW by Besse and Courtillot is represented, in (*b*) the synthetic TPW from a convective mantle model by Richards *et al.* (1997) is redrawn. Considering that the paleogeographical maps was not constructed with attention to the TPW and that we do not know all the different factors of damping of the PM drift rate, and that the hot spot reference frame is not a guaranteed optimal fixed frame in the planetary dilatation framework, the overall good agreement of the reconstructed and observed TPW – on the actual PM rate basis – is a new evidence favouring the expanding Earth geodynamics.

drift, through geological time, of the Pacific superplume (fig. 11.3a,b) from its Triassic position near Asia, Northern Hemisphere, towards its actual Southern Hemisphere position, near Nazca triple point (see the succession of maps in fig. 11.5). Both the pattern and ages of the Western Pacific Ocean floor volcanism and the Darwin Rise appear as the trace of the slow south-eastern displacement of the superplume. This migration from north-west to south-east, passing the equatorial line, should have had also other detectable geodynamic consequences, namely in the data of TPW and PW.

Also in this case I made a simplified assumption to try, at least roughly, to reproduce the already known paths of the true polar wander (Andrews, 1985; Besse and Courtillot, 1991, 2002). I assume:

1) The modern observed polar motion is the actual modern expression of the true polar wander, and the actual rate of drift (little more then 10 cm/yr, equivalent to nearly one geographical degree every million years) can be applied, with corrective factors, to the geological past.

2) The epoch of the equator crossing of the superplume is assumed around 50 Myr.

3) A corrective factor $q<1$ should be applied to take into account the slowing down of the PM as the accreted mass flow approaches the equator. The slowing down is influenced by the factor $\sin(2\phi)$ which has a maximum if $\phi=\pi/4$. The Nazca triple point is today at 32°S and then I can assume $q=1/3$ for the lapse of time from the crossing of the equator up to the present time.

4) From Triassic to Recent time, fluctuations of the tectonic activity have happened (McElhinny and McFadden, 2000) with a minimum today and a maximum at 25-30 Myr and so on. In the present paper I do not apply any corrective factor for this because the correlation of the maximum spreading rate to the intensity of the superplume rising, albeit possible, may be largely conjectural.

With these four assumptions I am able to reconstruct the TPW path going back in the geologic time from the Recent to the Palaeocene 57 Myr and then from Palaeocene back to Cretaceous, Jurassic, and finally Triassic. In the paths from Recent to Palaeocene and from Palaeocene to Cretaceous I apply the corrective factor $q=1/3$ because of the reasoning explained in the above point (3). Coming further back in geological time I hypothesize a prolonged permanence of the superplume very near to the equator to reproduce the small observed rate of drift of the common North Pole of the continents in my paleogeographic reconstructions and in literature (Besse and Coutillot, 2002).

The resulting reconstructed TPW in fig. 11.5 can be compared with the observed TPW of Besse and Courtillot (1991) from 100 Myr to 0 Myr (see the left drawing *a* in the box in fig. 11.5). It is noticeable that the magnitude and the oscillating path of the observed TPW, with turning point near 50 Myr, albeit roughly, is fairly reproduced by my paleogeographic series of reconstructions with simple assumptions on diapiric rise of mantle materials. A further advantage is that it is possible to represent in the same figures the TPW and the PM as one the prolongation of the other. Finally, I trust in the possibility to better fit the real TPW path by taking into account the different contribution of the other ocean-floor expansions.

My geodynamical inversion of paleogeographical reconstruction is more in agreement with the advective model proposed by Steinberger and O'Connell (1997), which takes into account the rising of the low-density zone of the mantle as revealed by seismic tomography and the plate motion in the tertiary. But the results of Steinberger and O'Connell (1997) present a nearly constant rate of TPW (see the equal intervals every 10 Myr in their fig. 11) and cannot explain the slowing down of the TPW near the inversion point at 50-40 Myr, which is evident in the shortening length of the intervals near the inversion point in the Besse and Courtillot TPW evaluation. This is explained in my diapiric model, in the expanding Earth framework, because the PM rate decreases and becomes zero under the influence of the $\sin(2\phi)$ factor as the adding of mass approaches and crosses the equator.

## 11.8. Chandler Wobble excitation and damping

In this section, only a brief and incomplete account of the possibility to excite the Chandler Wobble only by asymmetrical emplacement of mass will be provided. It is well known (Lambeck, 1979, 1980, 1988) that to solve the problem of the Earth's rotation, the Liuville equation, a generalization of the Euler equation to a non-rigid body, must be solved. A linearised form of the Liuville equation is derived from a more complete form neglecting terms that are very small (Spada, 1992)

$$\frac{j}{\sigma}\frac{dm/dt}{dt} + m = \Psi.$$

The notation is complex and $m = jm_x + m_y$, and $\Psi$ is the excitation function of the polar motion, which is proportional to the position of the rotation pole in the *x-y* plane.

The solution of the Liuville linearised equation is

$$m = m_o e^{j\sigma_o t}$$

which, if represented in the plane $m_x$-$m_y$, describes a cycloid around the shifting pole of rotation $\Psi$ (Spada *et al.*, 1999). The problem of this solution, in the presence of damping (internal friction due to viscosity of the Earth), is that the amplitude of the coils of the Chandler component was progressively attenuated by a damping factor, usually an exponential, and the cycloid transforms in a linear path (see fig. 2.7 in Spada, 1992). The motion – on a sufficient lapse of time – resolves in a straight line without the circular Chandlerian motion. What is the cause of the Chandler motion still remains unexplained in the absence of other excitation sources.

A plethora of hypotheses could be formulated to avoid this impasse:

1) Some special non-linear terms should be added to the Liuville equation that makes possible a concomitant excitation of the Chandler Wobble.

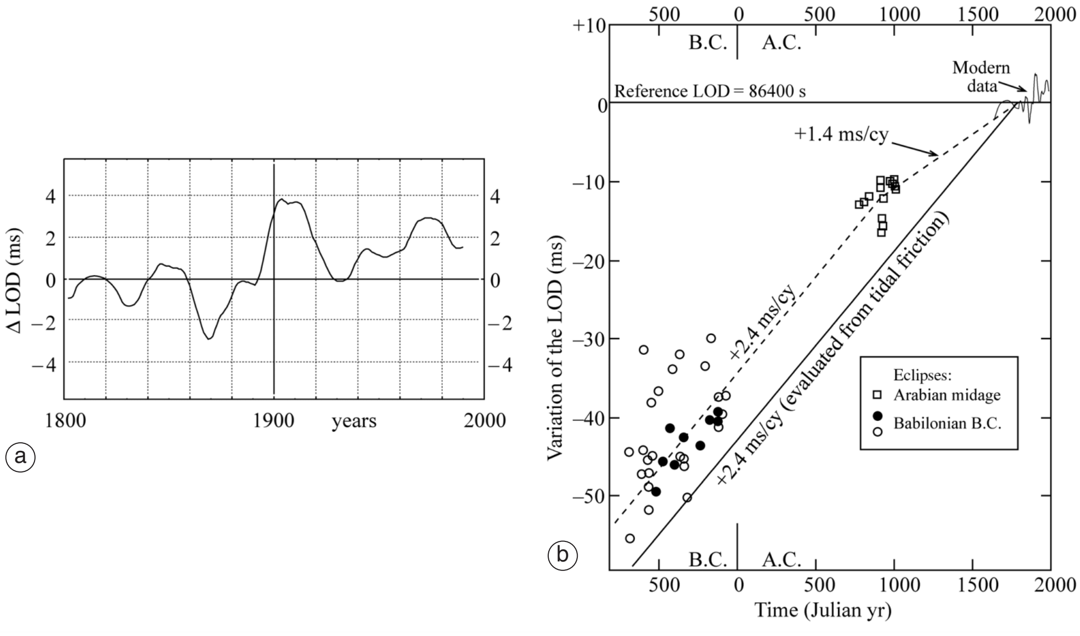


**Fig. 11.6a,b.** The secular variation of the Length Of Day (LOD): a) in the short term, from the last two century data (data from Morrison, pers. comm.); b) in the deep historical time (data from Stephenson, 1997).

2) The influence of strong earthquakes on excitation of the Chandler Wobble.

3) The role of other surface mass transport (erosion-sedimentation) (Spada *et al.*, 2000) and of geo-fluid circulation (Chao *et al.*, 2000; Gross *et al.*, 2003; Seiz *et al.*, 2004).

4) The continuous asymmetrical mass emplacement which results in a consequent continuous variation of the inertial moment as well as in a never-ending propensity of the new inertial axis to remain more or less far from the figure axis – in dependence from the balancing between the viscosity damping and the intensity of the continuous excitation caused through the outpouring mass.

No indication in favour of point 1) emerges from literature. The influence of collective action of earthquakes 2) is hypothetical if not disproved (Spada, 1997). Also 3), the role of the currents in geo-fluids is still an open problem (Gross *et al.*, 2003; Seiz *et al.*, 2004) while the erosion and sedimentation geological process (Spada *et al.*, 2000) has a negligible effect on PM, and acts in a different direction. Then, among the items of this incomplete list I prefer point 4) with possible small but not negligible contribution to the excitation process coming from the irregularities of the mass displacements in the Earth's interior. This, because the data series of the Length Of Day (LOD) presents the right characteristics of irregular variations. As can be seen in fig. 11.6a,b (Jordi *et al.*, 1994; Stephenson, 1997; Scalera, 1999; in fig. 11.6a data from Morrison, pers. comm.) strong irregular oscillations of the LOD are typically on periods of few decades and on longer lapses of time as witnessed by ancient eclipses (Stephenson, 1997). And, as a further element of disturbance, the Markowitz oscillation (near three decades in periods) is superimposed on the secular PM path (Markowitz, 1970; Poma *et al.*, 1987). The concomitant presence of these phenomena could be an indication that irregular mass displacements happen in the interior of the Earth's body, which asymmetrically displaced parts can continuously excite the Chandler Wobble against the continuous viscous damping. This asymmetrically displaced mass may well be in relation to the major superplumes diapirical expansion and to the overall Earth's dilatation. In any case the entire matter deserves a more careful investigation, in connection with possible consequences of the different expansion models on the surface gravity of the Earth (Scalera, 2004).

Finally it should be considered that this mechanism of continuous excitation of the Chandler Wobble by slow asymmetrical exhumation of planetary mass, can be naturally prolonged in the deep interior of the Earth, providing a possible explanation of the double peak spectrum of the Chandler Wobble (McCarthy, 1974; Guo *et al.*, 2005; among others). It is sufficient to imagine a process of asymmetrical slow rising of mass from the depth of the outer core and an asymmetrical emplacement of this mass on the core-mantle boundary. Core rotation models has been already developed in this direction (Rogister and Valette, 2004) but the expanding Earth geodynamics provides the further opportunity – also in this double peak Chandler subject – to achieve an unified view.

## 11.9. Conclusions

The rising material exhumed by the Pacific superplume (Su *et al.*, 1992, 1994) in the Nazca triple-point region could be, at least partially, but mostly, responsible for the secular drift of the rotation Pole position.

The needed annual rate of exhumed material can be computed starting from the actual value of the PM secular rate of $\cong$10.0 cm/yr. This annual asymmetrically exhumed material, $\cong 24 \cdot 10^{16}$ g, is able to decelerate the Earth spin just in the right observed magnitude order and value ($\cong$1.7 ms/cy *versus* $\cong$1.4 ms/cy observed from eclipses and $\cong$2.4 expected from tidal friction). This astonishing numerical agreement is the concluding step of a path that leads from global expansion palaeogeography to the possible NW-SE migration of the region of the maximum ocean-floor expansion rate, to the observable effect of this on current PM and to the needed amount of new emplaced mass in that region able to drive the observed PM. As a matter of fact, the same evaluated annual rate of emplaced mass is finally able to decelerate the Earth spin in the right order of magnitude. If an expanding Earth the-

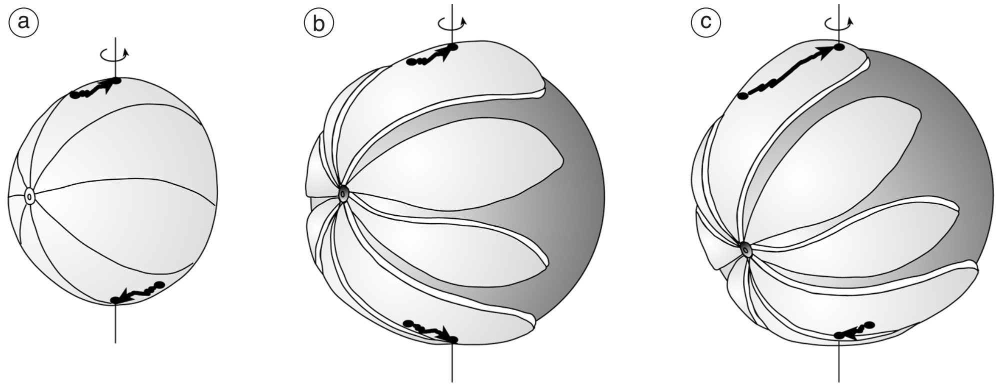


**Fig. 11.7a-c.** a) The secular polar motions for North Pole and South Pole are symmetrical on a constant size Earth. b) If Earth is asymmetrically expanding with the expansion centred on an equatorial point, the first term of the Schiaparelli's eq. (3.1) is zero and only the second term, linked to the geocentre prevails. In the perfectly equatorial mass emplacement shown in b) the northern and southern PM paths drift towards the zone of maximum expansion at equal rate. c) If the emplacement of new mass is at intermediate latitude – in this case southern latitude – the length of the Northern and Southern path of the polar secular motion are the sum or the difference of the first and the second term of eq. (3.1) respectively, and then have different lengths. The influence of the small second term of eq. (3.1) is important to detect the expansion of a planet, but on the Earth the databank, from 1850 to 2003, contains only the data of the Northern Hemisphere. Today the integration of this databank with the few years old geocentre databank could be helping to detect expansion (fig. 11.7a-c is redrown on the basis of Owen, 1981).

ory is adopted which does not state a cosmological-caused increase in mass, this numerical coincidence is admittedly very significant and it deserves a deeper analysis.

In the case of an increasing mass expanding planet, the decoupling of mantle and core due to the effect of the expansion cannot lead to easily seismological observable effects like a superrotation of the core, because only an annual decoupling angle of $10^{-3}$ geographical degree is expected.

The slowing down of the Earth, and the consequent secular increase in LOD, which should be expected from a variation of the inertial moment due to the volumetric expansion of the planetary body, could be compensated by an equivalent decrease of the inertial moment if a differentiation of the mantle and of the liquid core is ongoing. It is possible to estimate that a deposition of mass upon the inner solid core able to compensate an annual increase in inertia moment of the same magnitude order of the symmetrically emplaced mass, in the order of $10^{-9}$ of the Earth's inertial moment, is sufficient to assure no dramatic change of the LOD through geological time.

Contributions to the Chandler Wobble excitation could arise from the continuous diapirical rising of the mantle material at the triple points of Pacific, Atlantic and Indian oceans. Other irregular or periodical processes, if of adequate intensity, could contribute to the Eulerian period excitation, while the main contribution should be assumed coming from expansion process.

The observed path of TPW in the last 100 Myr can be explained assuming that the actual astrogeodetically observed PM is governed by the same physical process active in the geological past. The oscillation of the TPW path observed from 100 Myr to the Present is well reproduced also in the slowing down from 100 Myr to 50 Myr, and the next acceleration from 50 Myr to the Recent, with the simple assumption of a migration of the major expansion zone of the Pacific from north of the equator to the present southern position around Nazca triple point: this migration can be deduced from variable radius paleogeographic reconstructions.

An unified view of many geodynamical phenomena is achieved by the expanding Earth. In fact also the double peak spectrum of the Chandler Wobble can be explained by the same process of asymmetrical outpouring and emplacement of deep material on the top of the mantle – at the oceanic triple point zones – and on the top of the outer core – in still not well-defined zones.

The approach to the part-per-billion level in the definition of the Earth's shape by the continuous improvement of the ITRF, namely the international terrestrial reference frame (Altamimi *et al.*, 2001), will be very important in discriminating the possibility and the current rate of the Earth expansion. But the global variation of the radius should enter into the computational methods of the ITRF, because on the contrary, the risk exists to attribute all the altitude variations to physical phenomena, like global isostatic rebound adjustment (Argus *et al.*, 1999), which can have only a substantial but limited part in the trend of the data. All those high precision geodetic goals could be better achieved by a denser network of geodetic bench mark in the Southern Hemisphere.

With regard to this, it is worthwhile recalling that the need for a southern astrogeodetic station was first recognized around a century ago (see Darwin, 1911, p. 266; Cecchini, 1928; Proverbio, 1996) with the aim of establishing the reality of the Chandler Wobble. A few southern observatories worked for two years and found a wobble symmetrical with respect to the northern one. The work of Carlo Chandler was confirmed, but the short lapse of time of observation – due to a number of reasons, cultural, political, social, which are also active today – prevented the possibility to detect the secular drift rate of the southern pole, which – according to the presence of the second term *NP* in the Schiaparelli's eq. (3.1) – in the case of an asymmetrically expanding Earth must be different from the northern rate (fig. 11.7a-c). And then the scientific world has missed an opportunity – already virtually available and reliable some decennia ago – to easily establish or disprove the expansion tectonics.

Finally, albeit dependently on the expansion model adopted – fast or slow expansion; expansion with inner change of phases or with mass creation –, some astronomical problems are still unsolved, like the length of the year in the increasing mass cosmological models, the possibility to reconcile an expanding Earth with the Earth rotational mechanics is an important step on the way to increasing trust in this old idea (see the collection of historical and scientific paper in Scalera and Jacob, 2003).

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