

Variations of seismic activity caused by the Chandler Wobble

*Elena Blagoveshchenskaya*¹, *Evgenia Lyskova*^{2*}, and *Konstantin Sannikov*²

¹SPbF IZMIRAN, St.Petersburg, Russia

²St.Petersburg State University, St.Petersburg, Russia

Abstract. The problem of the correlation of the global dynamic phenomenon "Chandler wobble" with the local dynamics in different parts of the Earth's crust and lithosphere is wide of the solution. In this study, an attempt was made to approach the solution by analyzing the temporal variations of local seismic activity in the restricted geospace volumes (GSV) within the uniform seismoactive regions. The driver of Chandler wobble is the deep mantle – the most hard and most massive Earth's layer, whose large inertia tensor value is able to keep up Chandler's specific rotation of the Earth for a long time. We use the geocentric coordinate system where daily rotation is absent. In this system Chandler wobble is very slow rotation of the Earth around the current equatorial axis (the pole of which is denoted as EP14). Probably, this slow rotation can influence on the seismic events in the GSV. This influence is proposed to determine by the some statistical parameter EP14gsv that indicates the most typical position EP14 on equator when the most part of the earthquakes have occurred in the given GSV. For some geospace volumes the distribution indicates certain longitudes, where the number of seismic events is maximal or minimal.

1 Introduction

The Polar Motion (PM) is a complex phenomenon. It is influenced by many factors and therefore it contains many components. The most significant components are the annual (seasonal) and Chandler component with a period of 428–435 days. These two periodic components are relatively easy to distinguish in observations of latitude and therefore they have been repeatedly studied by many authors [1–7]. The presence of annual harmonics is explained by seasonal movements of air and water masses in the atmosphere and hydrosphere [3, 7].

The Chandler oscillation is an oscillation of a complex structure and is most often associated with a period of free nutation, the presence of which was theoretically predicted by L. Euler at the end of the 18th century. Assuming the Earth to be a rigid body and assuming that it is not affected by external forces, Euler showed that the axis of rotation should describe a cone around the main axis of inertia of the Earth's spheroid. In Euler's

* Corresponding author: e.lyskova@spbu.ru

calculations, the period should have been less than a year (about 10 months, about 305 days) [3, 5, 7].

Astronomers were busy isolating this periodic component until 1891 – the time when Chandler, having analyzed numerous latitudinal observations accumulated by then, showed that PM consists of two components with periods of about 14 months (Chandler period) and about 12 months (seasonal, annual component) and proved that in the astronomical definitions of latitude it is necessary to introduce a systematic correction related to PM [8].

PM appear at any point of the globe as polar variations of latitude in such a way that points located on the same meridian at the same time have the same deviation of their latitude from its average value over many years. The deviation can reach 0.3'' of the arc of a large circle.

Polar Motion with a periodicity of 12 and 14 months reflects the interaction between the Earth's shells and the moving atmospheric shell excited by solar radiation. It is believed that the atmosphere provokes a deviation of the axis of rotation of the Earth from the axis of its greatest moment of inertia, which leads to free nutation with a period of 14 months [3]. Redistribution of energy in the system "Sun – atmosphere – elastic solid Earth" may also affect the Earth's crust (lithosphere) [5]. However, the question of how this effect is manifested on the dynamics of the earth's crust (layered, fractured, laterally extremely heterogeneous) and whether there is any effect has hardly been studied.

Mansinha and Smylie in 1967 have presented some observational evidence in support of the hypothesis that large earthquakes can excite the Earth's natural wobble and produce the observed secular polar shift [9]. The simplest model of the effect of earthquakes on the Polar Motion takes the displacement fields to be established as a step function at the time of the earthquake. The effect would be a step-function shift in the secular pole and nearly an equal and opposite change in the pole path, thus producing a second-order discontinuity in the pole path [10]. In this model the pole would proceed at a uniform rate along a circular arc centered at the secular pole until the exact time of the earthquake. At the time of the earthquake, the secular pole would shift and the pole would proceed at a uniform rate along a new circular arc centered at the new secular pole [11]. There appear to be some premonitory signs of large earthquakes in the pole path.

Although earthquakes are generated by forces that cause slow movement of tectonic plates for millions of years [12], it often turns out that the distribution of earthquakes in time is not random, but has some quasiperiodicity [13, 14]. It can be assumed that the moment of the earthquake, when an already stressed state in the future earthquake source zone has formed, is under "trigger" influence of relatively weak variable in time forces that are not related to tectonics. In some cases, these forces can somewhat speed up the moment of an earthquake, and in some, delay it depending on the direction of stresses or strains that they possibly create in addition to tectonic stresses, thus imposing its rhythm on seismic events. It can also be assumed that stresses in the Earth's crust arising in connection with the movement of the pole, in some seismically active areas can manifest themselves precisely in the form of such an "induced" rhythm.

In this paper, we study the question: if there is an influence of the Chandler Wobble on the weak and medium local seismic activity in the restricted geospace volumes within the uniform seismoactive regions, and what is the mechanics of this influence.

2 Data and Methods

The study of the possible influence of Chandler wobble on the Earth's seismicity can be attributed to interdisciplinary research, since we use the astronomical data on Polar Motion, the basic principles of the mechanics of a rigid body rotation, the basic principles of Plate tectonics and the data of world seismological networks.

The Earth's rotation can be represented as the vector sum of two rotations: rotation around an axis passing through the N (mean geographic pole of the Earth) and rotation around a current equatorial axis with pole EP moving counterclockwise along the equator with a period equal to the Chandler's period about 14 months (Fig. 1).

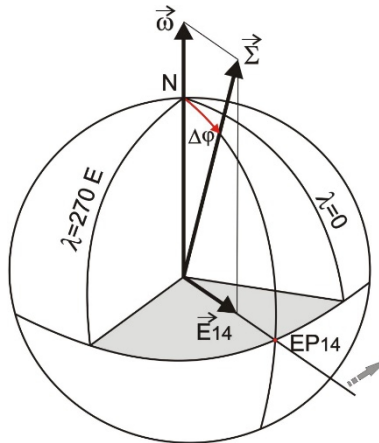


Fig. 1. Rotation of the Earth $\vec{\Sigma}$ can be represented as the sum of two components: the daily rotation of the Earth $\vec{\omega}$ around the geographic pole N and the Chandler rotation \vec{E}_{14} around the pole EP_{14} ; $\Delta\varphi$ – the Chandler variation of latitude on the given meridian.

We use the geocentric coordinate system where daily rotation is absent. In this system Chandler wobble is the very slow rotation of the Earth (as the whole) around the current equatorial axis (the pole of which is denoted as EP14). The pole moves along the equator eastwards and EP14(t) passes the whole cycle from 0 to 360° during the time about 14 months (430 days) and for each time t_i we can specify the position of the equatorial axis $\lambda_i = EP14(t_i)$. We suppose that this slow rotation can influence on the seismic events in the geospace volumes. This influence is proposed to determine by the some statistical parameter EP14gsv that indicates the most typical position of the EP14 on equator when the most part of the earthquakes have occurred in the given geospace volume (GSV). Thus, for a given GSV, it is possible to estimate the number of seismic events in different phases of the cycle of EP14 and to pick out the certain longitudes, where the number of seismic events is maximal (or minimal).

Taking the EP14 as the pole of current axis of Chandler rotation, we have the right to expect an stresses increasing in the earth's crust and mantle at a distance of 90° from this pole (red line in the Fig. 2). Fig. 2 demonstrated the counterclockwise rotation of the Earth in the moment when EP14 is situated at the Greenwich Meridian. The resulting additional stresses can be expected to serve as a trigger mechanism and lead to variation of seismic activity in different regions of the Earth.

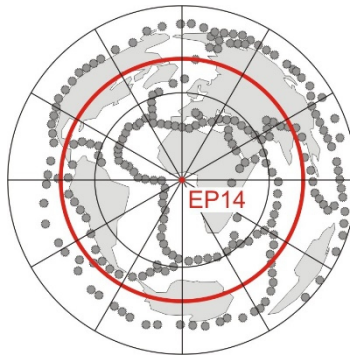


Fig. 2. Rotation of the Earth in the moment when EP14 is situated at the Greenwich Meridian ($\lambda=0$, $\varphi=0$). The red line marks a great circle at the distance of 90° from EP14.

The data on Polar Motion were taken mainly from [4]. Pole coordinates were recalculated to the “system of mean Pole position for an epoch of observation (according to the system by A.Ya. Orlov), and PM secular variations were removed. The most direct method of removing the annual components is Fourier filtering. As a result, we get just the amplitude of Chandler wobble as a function of time. The astronomical latitude variations at the Greenwich Meridian ($\lambda=0$) as a time function is plotted in Fig. 3 by the dashed line. It’s maximum amplitude is about $0.279''$ for the time range from 1965 to 1990 years. The latitude variations at Chandler period are marked by solid line, the maximum amplitude is $0.204''$ ”.

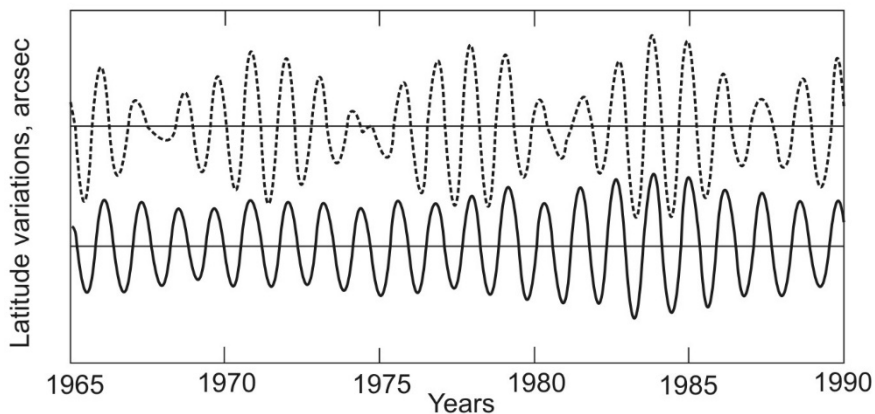


Fig. 3. The astronomical latitude variations (dashed line) and the latitude variations at Chandler period (solid line) at the Greenwich Meridian ($\lambda=0$).

We investigated the effect of the Chandler Wobble on seismicity in the different GSV over the globe, but the most noticeable and interesting results were revealed for GSV within uniform seismoactive regions (according to [12, 15]). These GSV presented in the Fig. 4 (1 – West Indian ocean ridge, 2 – Southern part of the East Pacific ridge, 3 – South of mid-Atlantic ridge) have some similar characteristics: 1) location in the Southern Hemisphere in the zones of the Mid-Ocean Ridges in the same range of latitudes (from 5 S to 50 S); 2) extended submeridional strike.

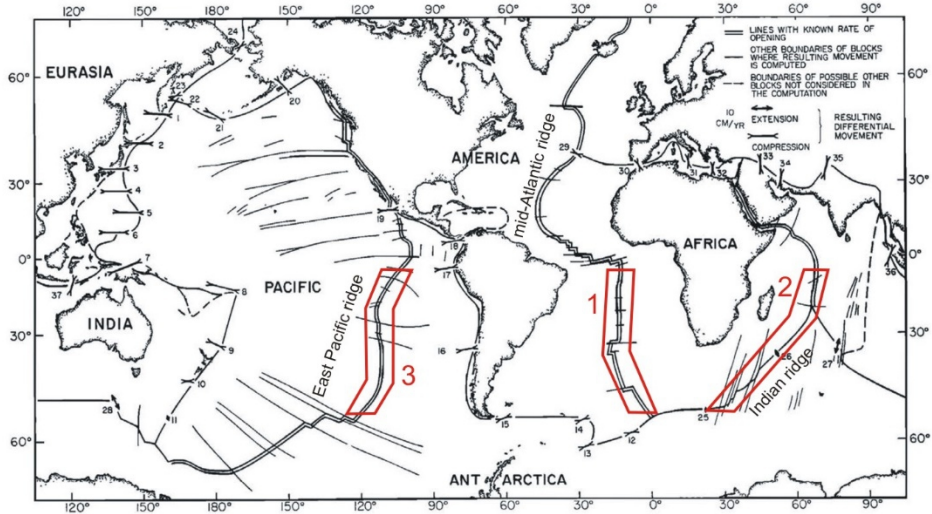


Fig. 4. Plate boundary map (according to [15]) and geospace volumes: 1 – South of mid-Atlantic ridge, 2 – West Indian ocean ridge, 3 – Southern part of the East Pacific ridge.

Data on week and medium seismicity for each GSV were taken from USGS catalog (<http://earthquake.usgs.gov>) from 1965 to 1990 years. The control histogram (number of events in 0.1 year) with the step 0.1 year (gray bars in Fig. 5) is used as the basis both for constructing the time series of seismic activity and for the series of seismic activity variations. We removed events associated with aftershocks, swarms and other «group events». The long periodic trend was also removed. We are interested in the variations of seismicity for each region relative to the average value, so just such variations we associate with the influence of the Chandler Wobble. To do this, we subtracted the floating average (blue line) from the time series obtained at the previous stage and then calculated an alternating series describing the variation of seismic activity (red line).

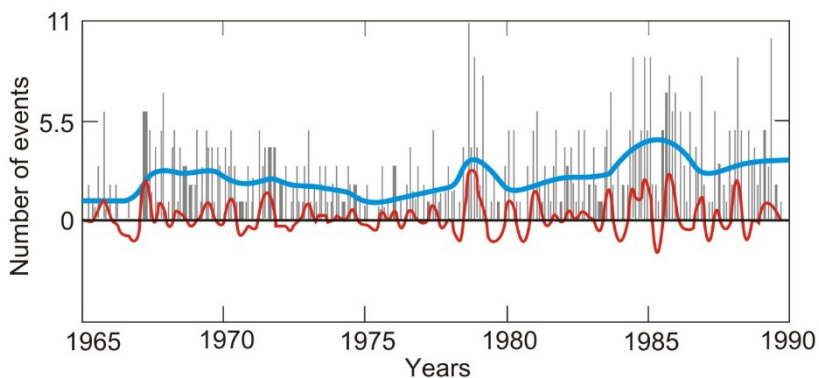


Fig. 5. Seismic activity: gray bars denote the number of events in 0.1 year with the step 0.1 year; blue line – floating average; red line – seismic activity variations.

3 Results

The obtained variations of seismic activity make it possible to study the nature of seismicity in both the time and frequency domains. To reveal the prevailing periods in the seismic activity variations, for different geospace volumes (South of mid-Atlantic ridge; West Indian ocean ridge; Southern part of the East Pacific ridge) the Fourier spectra were calculated. The results are shown in the Fig. 6 and represented in Table 1. On the spectra, maxima are clearly distinguished, which are in the range of periods corresponding to the Chandler oscillations. Also, maximums corresponding to various harmonics of seasonal pole oscillations are clearly visible on the spectra. Period corresponding to maximum spectral amplitude in the Chandler's period band T_{\max} is also presented in the Table 1.

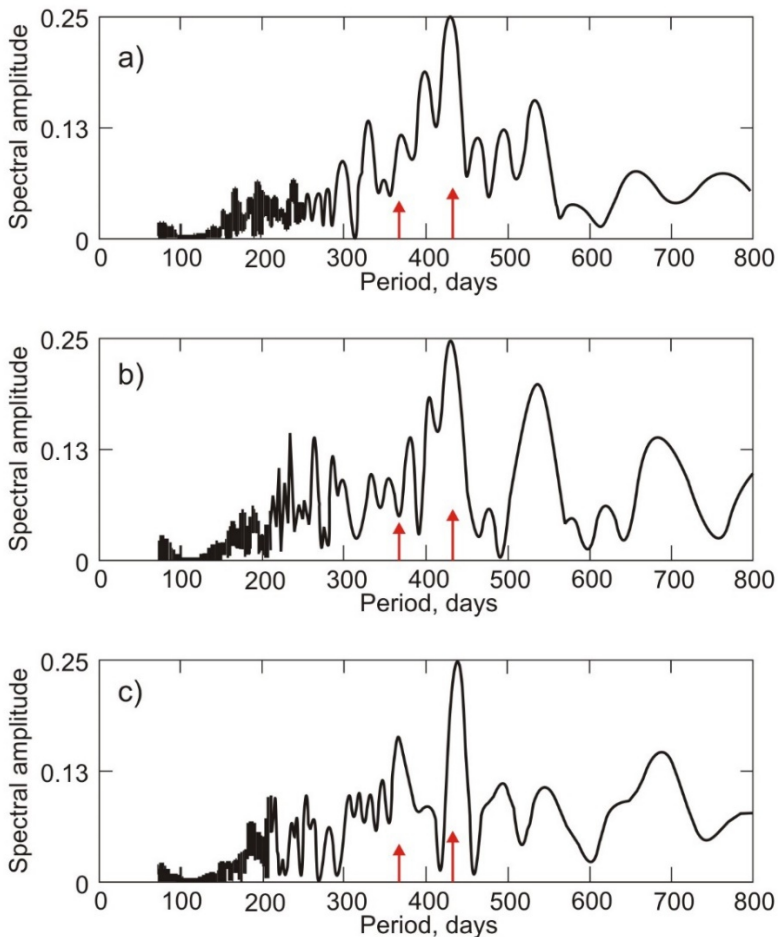


Fig. 6. Spectra of seismic activity variations for geospace volumes: a – South of mid-Atlantic ridge; b – West Indian ocean ridge; c – Southern part of the East Pacific ridge. The red arrows show the periods corresponding to the annual (seasonal) and Chandler components of the Polar Motion.

In order to identify the relationship between latitude variations of the Chandler component and seismic activity variations in the time domain, it was proposed to use Pearson's correlation. For this, latitude variations were recalculated for each meridian that the pole EP14 has passed. Then, the Pearson correlation coefficient was calculated between seismic activity variations and latitude variations at a given meridian. The meridian at which the maximum correlation was achieved was designated EP14gsv. The examples of the best correlation between seismic activity and latitude variations for different geospace volumes are shown in the Fig. 7. Variations of seismic activity in a given geospace volume are marked by red solid line, and the latitude variations for EP14gsv – by blue dashed line. Thus, it was found that for “South of mid-Atlantic ridge” the maximum correlation was achieved when the position of EP14 is equal $\lambda=26^{\circ}$; for “West Indian ocean ridge” when $\lambda=319^{\circ}$; for “Southern part of the East Pacific ridge” when $\lambda=92^{\circ}$ (see Table 1). The obtained correlation coefficients belong to the range of 0.41–0.5. In this way, it is possible, in accordance with the Chaddock table, to characterize the relationship between the Chandler latitude variations and the seismic activity variations as moderate.

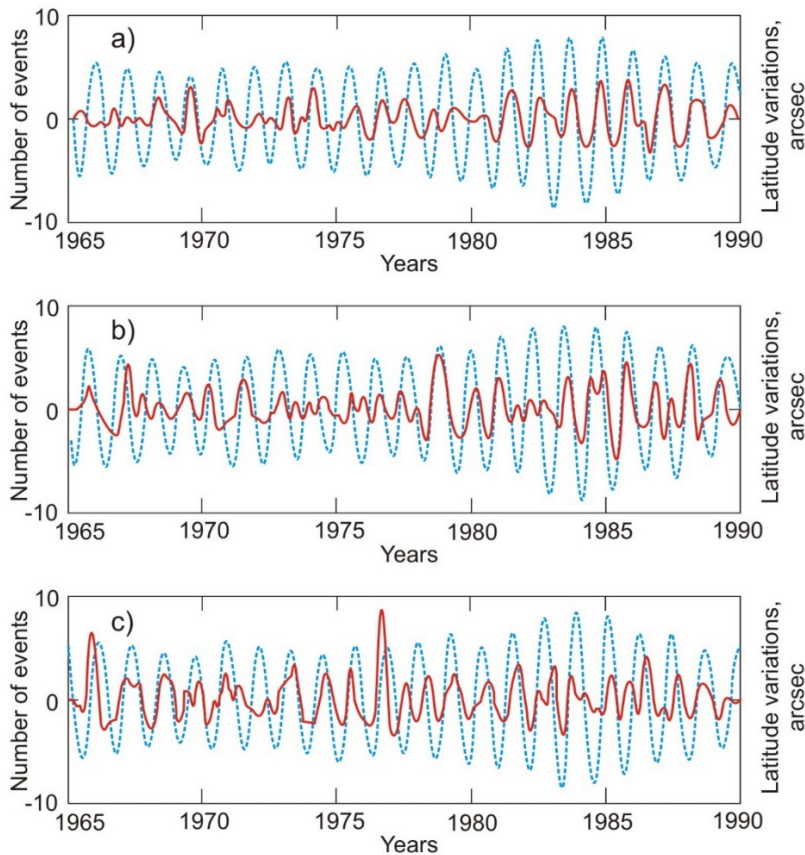


Fig. 7. The examples of the best correlation between seismic activity and latitude variations for geospace volumes (shown in Fig. 4): a – for South of mid-Atlantic ridge; b – for West Indian ocean ridge; c – for Southern part of the East Pacific ridge. Variations of seismic activity in a given geospace volume are marked by red solid line, and the latitude variations for EP14gsv – by blue dashed line.

Table 1. Geospace volumes and their parameters.

No	GSV location	Number of events	EP14gsv, deg.	Pearson's correlation coefficient	T_{\max}
1	South of mid-Atlantic ridge	495	26	0.50	429
2	West Indian ocean ridge	652	319	0.45	427
3	Southern part of the East Pacific ridge	653	92	0.41	436
4	West Indian ocean ridge and Southern part of the East Pacific ridge	1305	15	0.25	423
5	West Indian ocean ridge and South of mid-Atlantic ridge	1147	343	0.56	429

Also, the influence of the position of the EP14 pole on variations in seismic activity is presented in the diagrams (Fig. 8). In this case, only seismic events were taken into account when the EP14 pole has passed the certain meridian. A similar operation was carried out for each meridian in the range of 0–360 degrees. For convenience, the average was subtracted from the obtained diagrams and normalization was performed.

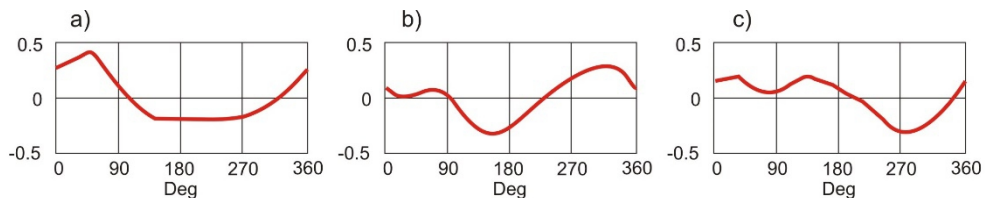


Fig. 8. The diagram illustrating how the number of seismic events changes when the pole EP14 passed the values from 0° to 360° : a – for South of mid-Atlantic ridge; b – for West Indian ocean ridge; c – for Southern part of the East Pacific ridge.

From the Fig. 8 it can be seen that the maximum variations of seismicity for the South of mid-Atlantic ridge λ belongs to the range $20^{\circ}\text{W}–80^{\circ}\text{E}$ and for the West Indian ocean ridge $\lambda = 250^{\circ}\text{E}–340^{\circ}\text{E}$. These values are in good agreement with the position of the pole obtained using Pearson's correlation $\lambda = 26^{\circ}\text{E}$ and $\lambda = 319^{\circ}\text{E}$ (Table 1).

As for the Pacific Ocean, the presence of a local minimum at the location of the EP14 pole ($\lambda=92^{\circ}\text{E}$), demonstrates that a good correlation between the Chandler latitude variations and seismicity variations does not necessarily lead to an increase in seismicity.

If we consider the West Indian ocean ridge and Southern part of the East Pacific ridge together, it turns out that the amplitude in the spectrum corresponding to the Chandler period significantly decreases and becomes comparable with the amplitude of the annual component. You can also see a decrease in the correlation coefficient. This is probably due to the fact that their EP14gsv lie approximately on opposite meridians.

An interesting result is obtained if we consider together the southern environment of Africa, that is, the West Indian ocean ridge and the South of mid-Atlantic ridge. The correlation coefficient becomes even higher on the 17W meridian, which is close to the longitude of the rotation pole of Africa, obtained by Minster and Jordan as 22W [16].

4 Conclusion

The problem of the correlation of the global dynamic phenomenon Chandler wobble with the local dynamics in different parts of the Earth's crust and lithosphere is wide of the solution. In this research, an attempt was made to approach the solution by analyzing the temporal variations of local seismic activity in the restricted geospace volumes within the uniform seismoactive regions.

This study describes a method that allows us to identify the relationship between weak and medium seismicity with the Chandler Wobble. It is proposed to determine the statistical parameter EP14gsv that indicates the most typical position of the EP14 on equator when the most part of the earthquakes have occurred in the geospace volume.

The most noticeable and interesting results were revealed for GSV within uniform seismoactive regions, connected with definite tectonic structures. These GSV can be characterized by similar characteristics: 1) location in the Southern Hemisphere in the zones of the Mid-Ocean Ridges in the same range of latitudes (from 5 S to 50 S); 2) extended submeridional strike. In the spectra, maxima are clearly distinguished, which are in the range of periods corresponding to the Chandler Wobble.

Joint consideration of two GSVs (West Indian ocean ridge and Southern part of the East Pacific ridge, No 4 in the Table1) demonstrates the absence of significant maxima in the spectrum at the Chandler period. Apparently, because their EP14gsv have maxima on opposite meridians. For the GSVs around the south of the African Plate (West Indian ocean ridge and South of mid-Atlantic ridge, No 5 in the Table1), the total EP14gsv defines a 17W meridian close to the pole of rotation of the African Plate [16].

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