

Tectonics of the terrestrial lithosphere in spherical harmonics

A V Mokhnatkin^{1,2}, S D Petrov², V L Gorshkov^{1,2},
N V Shcherbakova^{1,2}, S S Smirnov^{1,2} and D A Trofimov²

¹ Main Astronomical Observatory, Russian Academy of Sciences, St.Petersburg, Russia

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

E-mail: artspace3@mail.ru, s.d.petrov@spbu.ru, vigor@gao.spb.ru

Abstract. According to the classical tectonics theory, lithosphere is divided into more than twenty plates that are considered as absolutely rigid. However, modern astronomical and geodetic observations reveal disagreements with the standard theory. First of all, there are already more than two hundreds plates and newer ones are still being discovered. Then, it was found out that lithospheric plates can not be regarded as absolutely rigid, since they are evidently subject to deformations. This work is aimed at expansion of velocities of the global geodetic network stations into vector spherical harmonic series on the assumption of division of the velocity field into toroidal and poloidal components. Spherical harmonics up to fourth degree are obtained for corresponding components and a preliminary attempt of their geophysical interpretation is submitted.

1. Introduction

Current plate motion models are used for construction of the terrestrial reference system and are based on fitting of the plate rotation parameters to velocities of individual stations [1]. There are several ways to find high precision site coordinates and, accordingly, their velocities, such as Global Navigation Satellite Systems (GNSS), Very Long Baseline Interferometry (VLBI), Satellite or Lunar Laser ranging. In order to facilitate the lithospheric motion models, plates are considered as absolutely rigid bodies, moving along the spherical Earth surface, though at the same time plates have internal deformations, which are indicated by significant values of residual velocities after the motion model reduction. The problem of the reference system selection also remains for stations velocities as the lithosphere is considered generally to be fixed for the global models. Despite the accepted conception of plate boundaries as infinitely thin areas, which follows from the representation of lithospheric plates as absolutely rigid objects, observations indicate extended boundaries, which are subject deformations. These plate motion issues come from assumptions made for modern purely kinematic models. Current empirical models can be improved if internal deformations would be added to the station velocities interpretations. However, the question of the general lithospheric motion laws is still open, but nowadays it is possible to use the spherical harmonics to search for features in motion of lithospheric blocks.



2. GNSS station velocity data

Horizontal velocities with respect to the International Terrestrial Reference Frame (ITRF2008) of more than two thousand stations computed by Jet Propulsion Laboratory (USA)¹ were used as input data. This data set includes positions and velocities of most of the world GNSS stations with open access to their observations. The orbits of GPS satellites and their clock offsets were calculated in the IGS08 system by use of roughly 80 global GPS receivers, GIPSY software package were used for postprocessing. The station velocities were computed after breaks were rejected from series of position observations according to the chi-squared statistic. The velocities for 2490 stations were used, four of them excluded from further consideration as they were situated on a glacier and have a very high annual velocity value in horizontal projection. The rest stations velocities are represented in Fig. 1.

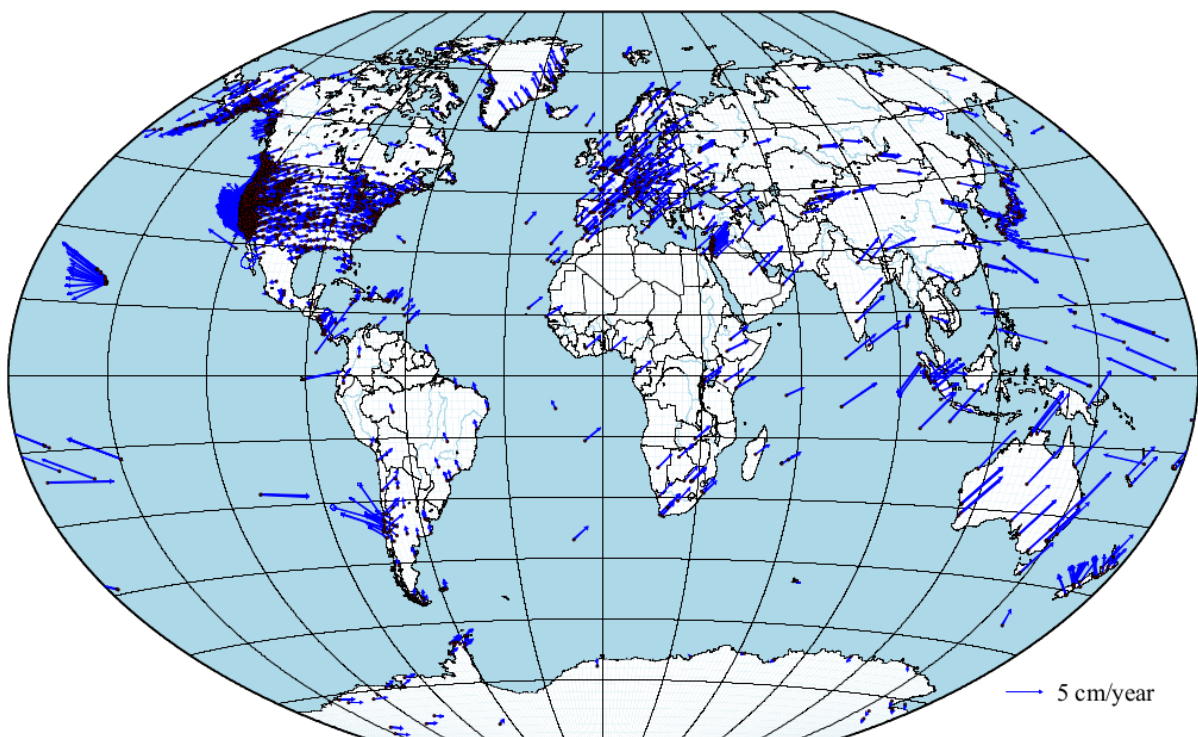


Figure 1. Horizontal velocities of 2486 GNSS stations by JPL

3. Vector spherical harmonics

The vector decomposition into series of spherical harmonics can be done based on the Helmholtz theorem for irrotational, poloidal and toroidal components of the velocity vector. The Helmholtz representation was used by previous authors [2] for horizontal velocities in the hotspot reference frame. We accepted that the zonal and meridional velocity field of stations is solenoidal and considered it on the sphere as the sum of toroidal and poloidal components. All this components are expanded into series of scalar spherical harmonics using expressions similar to the case in [3]. The proposed method imposes restrictions on the vector field, it does not need to be solenoidal – spreading zones, for example, obviously are areas of divergence of the vector velocity field. Nevertheless, proposed method is formal and has demonstrative physical interpretation.

¹ <http://sideshow.jpl.nasa.gov/post/series.html>

4. Results

The results are shown in Fig. 2-5. Meridional and zonal velocity components for spherical functions up to degree four are shown in Fig. 2. Some notable features of lithospheric tectonics can be seen there, such as a relatively high value of the Australian plate velocity. The velocity field for spherical harmonics of degree one is shown in Fig. 3. It can be seen that the distribution of the zonal velocity has a pronounced dipole structure. Velocity fields for spherical functions of degree two and three are respectively shown in Fig. 4 and Fig. 5, which exhibit that the velocity distribution has a more meridional character than zonal.

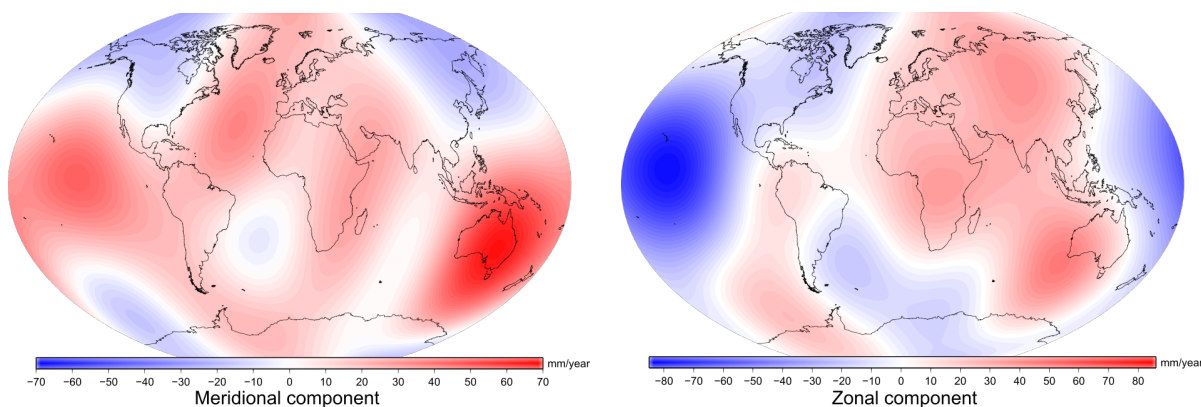


Figure 2. General meridional and zonal velocity components

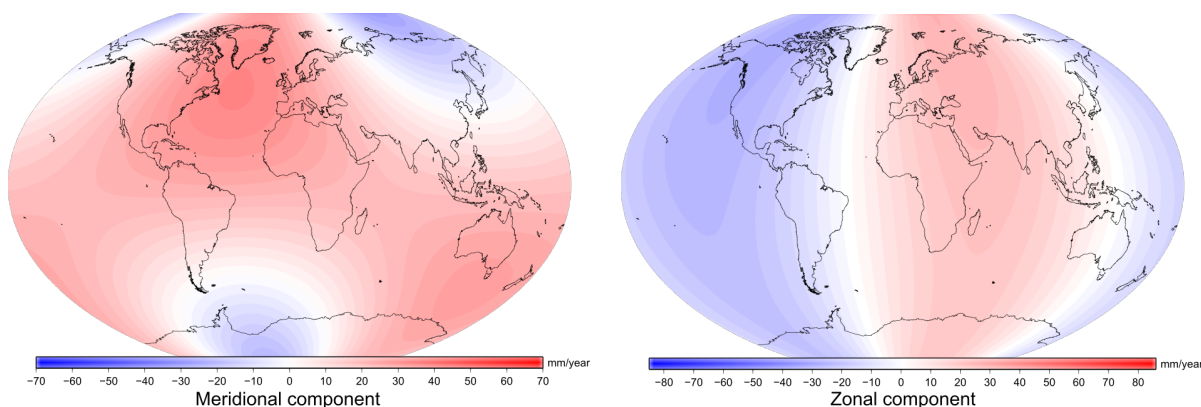


Figure 3. Meridional and zonal velocity components of degree one

5. Conclusions

An expansion of GNSS station velocities into series of spherical harmonics was performed. The results for poloidal and toroidal velocity components are generally consistent with the known features of the lithospheric tectonics. They yielded a visual representation of the large-scale lithospheric tectonics. The aim of further research is tectonophysical interpretation of the results, the elicitation of possible linkages of large-scale tectonic motions and the geoid variations. This research has been supported by the SPSU Grant nr. 6.37.343.2015.

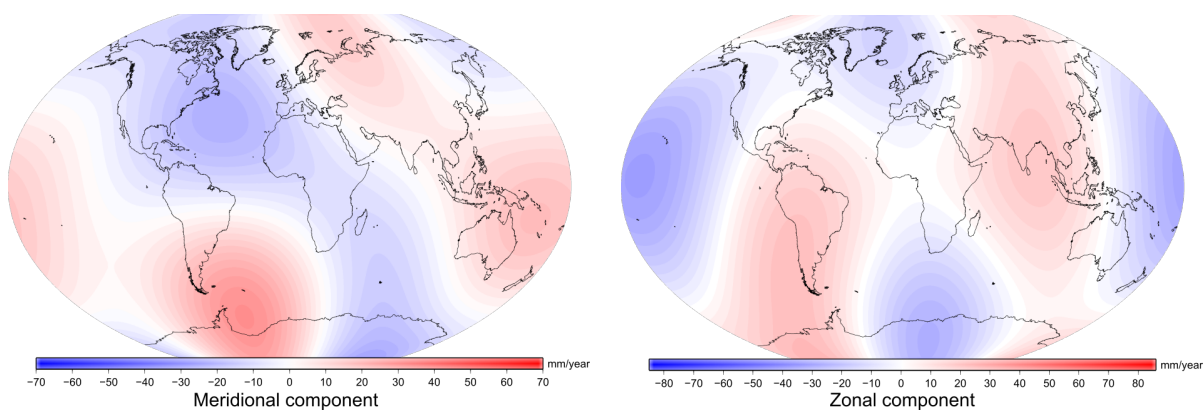


Figure 4. Meridional and zonal velocity components of degree two

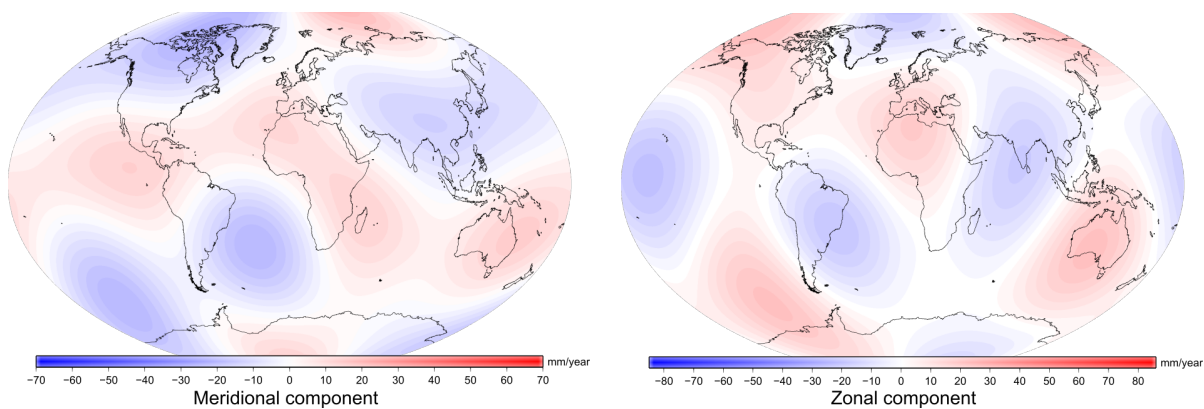


Figure 5. Meridional and zonal velocity components of degree three

References

- [1] Altamimi Z, Métivier L and Collilieux X ITRF2008 plate motion model *J. Geophys. Res.* 2012 Vol. **117** Issue B7
- [2] Bercovici D and Wessel P A continuous kinematic model of plate-tectonic motions *Geophys. J. Int.* 1994 **119** 595-610
- [3] Vityazev V V and Tsvetkov A S UCAC4: Stellar kinematics with vector spherical functions *Astron. Nachr.* 2010 No. **8** 760-764