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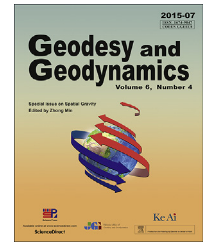

Evidences of the expanding Earth from space-geodetic data over solid land and sea level rise in recent two decades

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ABSTRACT

According to the space-geodetic data recorded at globally distributed stations over solid land spanning a period of more than 20-years under the International Terrestrial Reference Frame 2008, our previous estimate of the average-weighted vertical variation of the Earth's solid surface suggests that the Earth's solid part is expanding at a rate of 0.24 ± 0.05 mm/a in recent two decades. In another aspect, the satellite altimetry observations spanning recent two decades demonstrate the sea level rise (SLR) rate 3.2 ± 0.4 mm/a, of which 1.8 ± 0.5 mm/a is contributed by the ice melting over land. This study shows that the oceanic thermal expansion is 1.0 ± 0.1 mm/a due to the temperature increase in recent half century, which coincides with the estimate provided by previous authors. The SLR observation by altimetry is not balanced by the ice melting and thermal expansion, which is an open problem before this study. However, in this study we infer that the oceanic part of the Earth is expanding at a rate about 0.4 mm/a. Combining the expansion rates of land part and oceanic part, we conclude that the Earth is expanding at a rate of 0.35 ± 0.47 mm/a in recent two decades. If the Earth expands at this rate, then the altimetry-observed SLR can be well explained.

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1. Introduction

Whether the Earth is expanding is a controversial problem in science. Although many scientists hold the opinion that during the geological time the Earth remains stable without obvious expanding or contracting [1,2], many paleontological, paleomagnetic, paleoclimatological, geological and geodetic evidences support the expanding Earth hypothesis [3–9].

Wilson [10] declared that the Earth is expanding based on geological evidences and Wegener's continental drift hypothesis. Creer [11] concluded that the Earth's radius R_E was 0.55R at the early Precambrian (ca. 3800 million years (Ma) ago) and increasing ever since. Carey [4,12] suggested that the Earth was expanding within the ocean-floor expansion framework. Scalera [13,14] believed the Earth was expanding at a rate of few millimeters or fraction of millimeter per year from a series study of three palcogeographical reconstructions for the Paleocene. Gerasimenko [15] obtained a possible radius increase of 0.2 mm/a based on the analyses of LAGEOS and Very Long Baseline Interferometry (VLBI) data for stable nonorogenic continental regions. Our previous study [16] suggests that the Earth is expanding at a rate about 0.2 mm/a in recent decades based on space-geodetic data and temporal gravity data. In that study we did not use the sea level rise evidences.

In the present study, we use two kinds of evidences to further estimate the Earth expansion rate. First, based on the space-geodetic data of 629 space-geodetic stations under the International Terrestrial Reference Frame (ITRF) 2008 (including stations of GPS, SLR, VLBI, Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)) covering a period about 20 years [17–19] (All of the ITRF2008 files and results are available at the ITRF web site: http://itrf.ign.fr/ITRF_solutions/2008/), we found that the Earth's radius was increasing at a rate of about 0.24 mm/a [16]. However, this evidence only suggests that the solid part of the Earth is expanding.

The second evidence is the observation of sea level rise (SLR). Current observations show that the global mean SLR is at a rate of about 3.3 ± 0.4 mm/a from 1993 to 2009 [20] or 3.2 ± 0.4 mm/a from 1993 to 2013 [21]. It is mainly attributed to ice cap melting and temperature change of the sea. However, the Earth expansion may also contribute to the SLR, for the ice cap melting and temperature increase could not close the observed amount of SLR, namely, the SLR caused by the ice cap melting plus the thermal expansion is not balanced to the observed SLR by altimetry. In this study, to improve our previous study [16], we use SLR evidence to further estimate the Earth expansion rate.

2. Evidence from space-geodetic data

The Earth's volume will increase if the Earth is expanding. Since the topography variation on the Earth's surface cannot be well modeled by the current distribution of space-geodetic stations, we consider the average vertical velocity of the Earth's surface rather than the actual volume of the Earth. First, a Delaunay triangulation Irregular Network [22,23] is set up by all of the geodetic stations. The average vertical velocity of the Earth's surface could then be calculated as [16].

$$v_G = \frac{\sum_{i=1}^{N} P_i v_i}{\sum_{i=1}^{N} P_i}, \quad P_i = \frac{S_i}{\sigma_{v_i}^2} \tag{1}$$

where v_G is the expanding rate of the Earth, v_i the representative vertical velocity of the ith triangle, N the number of triangles, S_i the spherical area of the ith triangle, $\sigma_{v_i}^2$ the variance of the ith triangle, P_i the weight of v_i. Here P_i is proportional to the area S_i of the ith triangle, and inversely proportional to the variance $\sigma_{v_i}^2$ of v_i.

The velocity of each triangle v_{tr} is calculated by [16]

$$v_{tr} = \frac{1}{3}(v_D + v_E + v_F) \tag{2}$$

where v_D, v_E and v_F are vertical velocity of three nodes of this spherical triangle.

The data used are from ITRF2008, including coordinates and velocities of 1572 stations distributed over solid land (see Fig. 1). Of these sites, some sets of records actually refer to the same stations but in different time periods. In our calculations, the velocity and position of any one of such kinds of stations are determined by continuation of the corresponding data set over the whole time periods. Besides, many stations from different techniques locate in a very small area. These stations are merged to one station. The velocity and position of this new station is the average value of all the stations locating in this small area. After above handling, we have 845 stations left [16].

Absolute values of vertical velocities of some stations are relatively large. We consider that a too large vertical velocity should be related to local events rather than global expansion. Such stations are removed from our calculations. Stations locating in orogen belts are also removed since these vertical velocities of these stations are more likely related to local deformations but expansion. The information of orogen belts is provided by Bird [24]. After removing the above mentioned stations, 629 stations are used in our calculations based on DTIN. Details are referred to Shen et al. [16].

Post glacial rebound (PGR) is a possible reason for the vertical movement of the station. Based on the data released from website (http://grace.jpl.nasa.gov/data/pgr/) [25], the estimated average uplift rate v_u of the whole surface of the Earth caused by the PGR is only $v_u = (5.69 \times 10^{-6} \pm 1.09 \times 10^{-4})$ mm/a. To obtain a more reasonable result of the influence of PGR on the uplift of the surface of the Earth, it is necessary to calculate the uplift rate for each space-geodetic station. In our study [16], we expand the grid data of uplift rate of the lithosphere into spherical harmonic coefficients, and then the uplift rate resulted from PGR could be calculated by the following equation

$$v_{PGR} = \sum_n \overline{C}_{n0}^P \overline{P}_{n0}(\theta) + \sum_n \sum_m \left(\overline{C}_{nm}^P \cos m\lambda + \overline{S}_{nm}^P \sin m\lambda\right) \overline{P}_{nm}(\theta) \tag{3}$$

where $\overline{C}_{n0}^P$, $\overline{C}_{nm}^P$ and $\overline{S}_{nm}^P$ are spherical harmonic coefficients obtained from grid values of uplift rate from PGR model [25], $\overline{P}_{n0}(\theta)$ and $\overline{P}_{nm}(\theta)$ are normalized Legendre functions defined in geophysical convention.