THE HYPOTHESIS ON THE EARTH'S EXPANSION IN THE LIGHT OF SPACE GEODESY RESULTS

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ABSTRACT
The hypothesy on the Earth's expansion is shortly reviewed in this article. Its quantification based on the Blinov theory is performed and compared with recent results of space geodesy methods. These results based on measurement interpretation lead us to rejection of the Blinov hypothesis, but considering measurement itself – if we use strict statistical criteria – we cannot decide if the Earth expands or not.

KEYWORDS: space geodesy, geodetic reference systems, Earth's expansion theory, plate tectonics

1. SPACE GEODESY MEASUREMENTS – GENERAL SITUATION

There have always been many arguments against the hypothesis on the Earth's expansion based on results of various space geodesy methods. Many conlusions have claimed that all modern observations exclude the value of 2.5 cm/year, although this value is still claimed by supporters of the expansion theory (Tab 1). Opponents of Earth Expansion Therory are trying to close the discussion saying that the expansion (or substraction, with the same probability) of the Earth, if it exists, must be much smaller than 1 cm/year. Space geodesy insists that statistically-significant vertical changes were detected for none tectonic plate.

There are more controversies between expansion theory and plate tectonics that refer to space geodesy measurements. They include two main parts: the first one is based on the selection, age and related precisison of data used to prove each theory; the second one is in interpretation of these measurements discussed in this article.

Yet another problem, that refers to space geodesy measurements, is related to principles of space geodesy techniques themselves. Especially the VLBI, its principles and assumptions, has often been misunderstood in many ways. The VLBI is a purely geometrical method that uses as a constant only the speed of light in vacuum – a frequent mistake is based on the assumption that space geodesy applies some

Table 1 Annual increments of the Earth's radius

PRESENT ANNUAL INCREMENTS OF THE EARTH'S RADIUS ACCORDING TO EXPANSION THEORIES			
AUTHOR	year	Increment [cm/year]	METHODS
Le Pichon	1968	2.7	Calculation of the increase in the Earth's circumference
Koziar	1980	2.6	Measurements of the increase in the Earth surface
Blinov	1987	2.4	Astronomical and satellite geodesy
Parkinson	1988	2.08 ± 0.8	Satellite geodesy SLR
Robaudo & Harrison	1993	min. 1.8	Space geodesy VLBI
Maxlow	1995	2.2	Measurement of the increase in the Earth surface
			From Koziar: Space geodesy and expanding earth

constant radius before any measurement starts. The condition of a zero vertical movement is implemented into the geodetic models after measurements. Among other reasons, why vertical movements are often studied separately, is that the measured horizontal movements are significantly higher than the vertical ones. In regards to vertical movement studies, it is important to underline that space geodesy techniques are geometrical methods – they give true Cartesian coordinates so it is possible to study height changes on a global scale more precisely than ever.

Still supporters of the Earth‘s expansion theory insist that all space geodesy methods including the VLBI apparently underestimate the Earth‘s expansion. The Earth‘s expansion theory today also claims (Koziar, 1993, 1994) that maybe not the measurements themselves, but their interpretion may be wrong.

A review of basic principles of space geodesy techniques follows. Recent space geodesy articles, which study vertical movements and their impact in detail, are listed in References so that the measurements will be left out and we will concern with the kinematic models resulting from space geodesy technologies.

2. REFERENCE FRAMES

The geodetic reference frame is based on results of space geodesy techniques. Primary core stations are observed by the VLBI, LLR, SLR, GPS and DORIS; their network is densified by regional GPS networks. The history of the International Terrestrial Reference Frame (ITRF) starts in 1984 with the ITRF88 and ends with ITRF2000. In our case, we used the ITRF2000 reference frame. A short description of its genesis of this frame follows in the next section.

2.1. REFERENCE FRAME ITRF2000

The reference frame ITRF2000 – see Boucher et al. (2004) – as a part of the reference system ITRS2000 was constructed by means of these space geodesy techniques:

- VLBI – Very Long Baseline Interferometry (rms error 2-3 cm for two station distance) – determination of directions and distances between radiowave source (quasars); baselines between two stations are determined. Resulting networks have to be conected to at least one known point, because only relative coordinates can be obtained.
- SLR, LLR – Satellite Laser Ranging and Lunar Laser Ranging - (rms 2-3 cm for station coordinates) – distances between a station and a satellite (Moon) is measured. Station coordinates are determined by solving the dynamic task of satellite geodesy. This methods produces absolute (geocentric) values of station coordinates.
- DORIS (rms 3-4 cm for relative station coordinates) – rate of a distance between a station and a satellite is measured (Doppler principle). This method is primarily focused on determination of a precise satellite position. Station coordinates are determined by solving the dynamic task of satellite geodesy, but problem with the scale of the whole network exists.
- GPS – Global Positioning system (rms 0.5 cm for relative station coordinates) – distances between a satellite and a station is measured (phase distancemeter principle). Station coordinates are determined by solving combined geometric and dynamic tasks of satellite geodesy. This method produces absolute (geocentric) values of station coordinates and their change in time (velocities).

The ITRF2000 is based on the combination of station coordinates collected by analysis centers in „set of station coordinates“ – SSC, obtained from the analysis of different above mentioned space geodesy techniques. Every SSC contains coordinates of a selected set of stations in different observation epochs. The following SSC were used:

- VLBI – 3 SSC with coordinates for the epoch 1979 – 1999
- LLR – 1 SSC with coordinates for the epoch 1977 – 2000
- SLR – 7 SSC with coordinates for the epoch 1976 – 2000
- GPS – 6 SSC with coordinates for the epoch 1991 – 2000
- DORIS – 2 SSC with coordinates for the epoch 1992 – 2000

Used SSC were completed by data from space geodesy regional campaigns or data from multi-techniques, used for determination of the Earth‘s gravity field models (i.e., GRIM5). Final coordinates were determined by combination of the SSC by means of a 7-parameter Helmert transformation for positions and 7-parameter Helmert transformation for velocities. A crucial role is played by „collocation stations“, where observations with more than one space technique are performed.

Differences in the rate of scale factor (which is closely connected to changes of the shape of the Earth) is important for our study. The maximum differences in the rate of scale between individual SSC was estimated 0.087 x 10^{-8}/year, i.e., 5 mm/year.

While the scale and the scale rate of the ITRF2000 was determined/defined from a weighted average of VLBI and SLR solutions, the origin of the frame is defined as a weighted average of SLR solutions. The orientation of the frame depends upon a selection of the ITRF sites with high (geodetic) quality data and the condition for rotation: the ITRF97 at the 1997.0 epoch and for rotation rates: no-net-rotation w.r.t. NNR-NUVEL1A. The criteria retained for the site selection are:

- continuously observed during at least 3 years

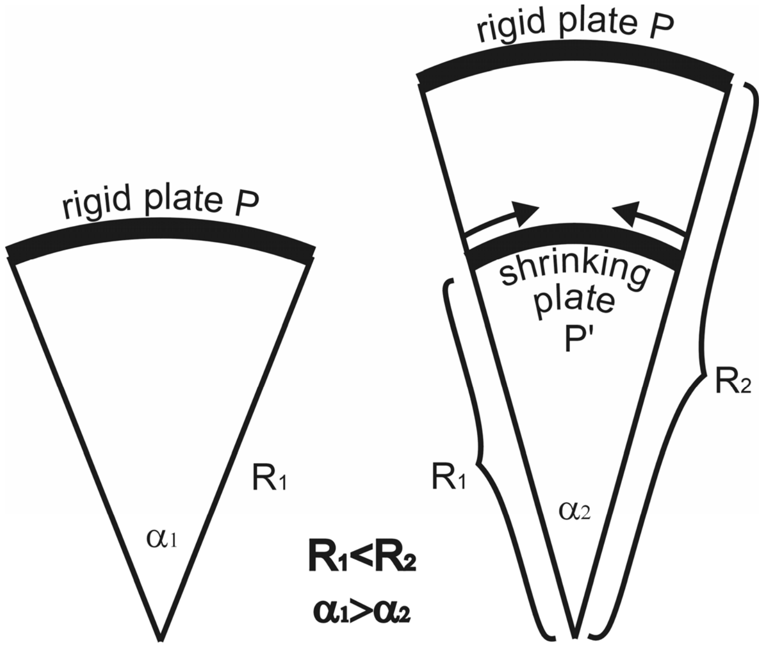

Fig. 1 Blinov's principle

- location far away from plate boundaries and deformation zones
- velocity accuracy (as a result ofthe ITRF combination) better than 3 mm/y
- velocity residuals less than 3 mm/y for at least 3 different solutions

Based on the ITRF2000 preliminaty analysis, the site selection was performed using the above criteria that yielded 54 sites.

It is necessary to emphasise that final results come from solutions combined by above mentioned methods, that measurements are processed in networks and then they are succesfully densified by other GPS measurements.

Geophysical models included in the ITRF models determine relative plate motions between the rigid interiors of the tectonic plates (main plates are African, Antarctican, Arabian, Australian, Caribbean, Cocos, Eurasian, Indian, North American, Nazca, Pacifician, Philippine Sea and South American). Computation inputs for the plate motion determination are the magnetic time scale (revised in 1994 for the NUVEL-1A), spreading rates (as recorded by magnetic-reversal seafloor-crust anomalies averaged over the last 3 million years), transform-fault azimuths, and earthquake slip-vectors.

The base theory reflected is the plate tectonics – horizontal plate movements are described by the Euler poles. In such a way, an absolute movement of each plate is determined by vector of angular velocity $\boldsymbol{\omega}$.

The ITRF2000 results show for some plates significant disagreement between the geophysical model NNR-NUVEL-1A and space geodesy results – regional site velocity difference between two sites may exceed 3mm/y. Angular velocities of tectonic plates, which would be estimated using the ITRF2000 velocities, may significantly differ from those predicted by the NNR-NUVEL-1A model. This difference is significant but the models are still so close that (Drewes et al., 2001) corrected the NUVEL model on the basis of the geodetic measurements.

The first goal of this article is to demonstrate that a possible expansion of the Earth based on the geophysical model NNR-NUVEL-1A and geodetic model APKIM2000 is significantly smaller than that one introduced by expansion theory. Second goal is to show that greater expansion suggested by expansion theory would have to be noticed already as larger errors in space geodetic measurements colliding with plate tectonics theory.

3. EXPANDING THEORY – SHORT DESCRIPTION

Short description of this theory is based on articles supporting expansion theory from (Koziar, 1993, 1994). Geological and geophysical parts are ommitted here. This paragraph concentrates on the geometric description of a tectonic plate movement model as the most important point for geodesy.

The kinematic model for tectonic plates in expansion theory differs namely from the plate tectonics in basic ideas. Expansion theory considers rigid plate resting on isotropically extending basement. In this way, geographical coordinates of all points change but one stable point of transformation is gravity centre. In this point, transformation can be considered but comparison using gravity centre points will equally be evident and more transparent. So these important points will serve for comparison of both geometrical model difference.

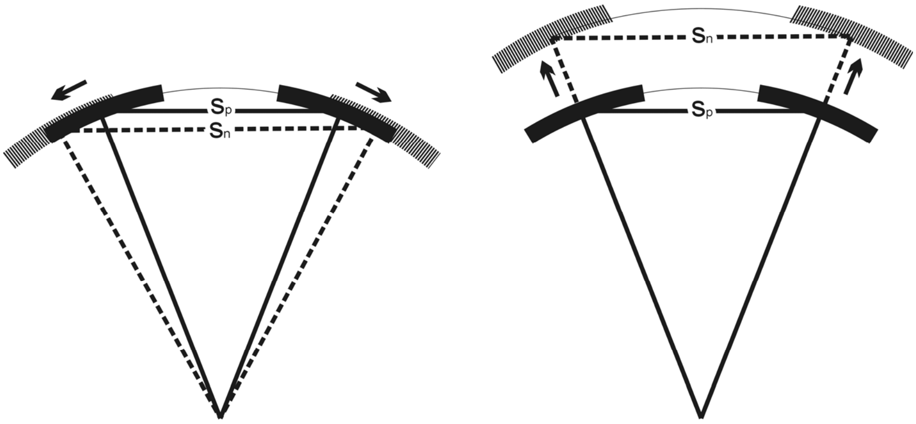

Fig. 2 Vertical interpretation – principle

Table 2 Changes of plate gravity centers

PLATE GRAVITY CENTERS DISTANCE YEAR CHANGE			
Plate 1	Plate 2	NNR-NUVEL-1a (distance change) [m/y]	APKIM2000 (distance change.) [m/y]
PCFC	AUST	-0.067	-0.069
AUST	AFRC	0.021	0.021
AUST	ANTA	0.053	0.052
AFRC	ANTA	0.006	0.006
PCFC	ANTA	0.001	-0.003
SOAM	ARFC	0.029	0.026
SOAM	ANTA	-0.007	-0.003
SOAM	NOAM	-0.002	-0.002
PCFC	NOAM	-0.005	-0.002
AFRC	NOAM	0.011	0.011
AFRC	EURA	-0.007	-0.002
PCFC	EURA	-0.042	-0.043
NOAM	EURA	0.009	0.008
AUST	EURA	-0.037	-0.033

BLINOV'S PRINCIPLE

We are going to concentrate on the idea of the so-called "apparent contraction". "On the expanding Earth, a craton (plate) is stretched only inconsiderably. So the central angle between two points on it is decreasing. If the reduced angle is reffered to the non-increased radius, the distance between two points will be apparently diminished and the whole plate will be apparently shrunk." (Koziar, 1994). The principle is illustrated on Fig 1.

This may be applied to angle measurements (e.g. paleomagnetism) but geodetic models combine more technologies. It also obviously leads us to the question related to plate tectonic borders and to disallovance of subduction type borders existence. This is not discussed here more.

4. COMPARISON OF TWO MODELS

We will concentrate on the idea introduced in the previous paragraph. The main idea of comparing both plate tectonics movement models is that distance between two points changed by the model may be (accorging to the Earth's expansion theory) well measured by means of space geodesy, but wrongly fixed - Fig 1. So the plate tectonics model annual change of the distance is not taken as a horizontal motion, but it is interpreted as a change of the Earth's radius. This simple idea is demonstrated on Fig. 2–on its left side where s_p is the original distance and s_n is the new distance determined by the model (Tab 2 – NNR-NUVEL-1A, APKIM2000)) and interpreted as a vertical change on the right-hand side of Figure 2. It can be expressed by the formula:

Table 3 Comparison of different vertical motion

COMPARISON OF GEOPHYSICAL, GEODETIC AND EXPANSION MODELS					
Plate 1	Plate 2	NNR-NUVEL-1a (vert.interpr.) [cm/y]	APKIM2000. (vert. interpr.) [cm/y]	KOSTELECKÝ, ZEMAN (ITRF2000 – measured) [cm/y]	
				Plate 1	Plate 2
PCFC	AUST	-4.88	-5.05	-0.02	0.07
AUST	AFRC	1.39	1.39	0.07	-0.05
AUST	ANTA	6.59	6.42	0.07	0.37
AFRC	ANTA	0.38	0.34	-0.05	0.37
PCFC	ANTA	0.05	-0.26	-0.02	0.37
SOAM	ARFC	2.93	2.65	0.10	-0.05
SOAM	ANTA	-0.11	-0.22	0.10	0.37
SOAM	NOAM	-0.13	-0.14	0.10	-0.08
PCFC	NOAM	-0.46	-0.22	-0.02	-0.08
AFRC	NOAM	0.64	0.65	-0.05	-0.08
AFRC	EURA	-0.65	-0.21	-0.05	-0.04
PCFC	EURA	-2.44	-2.55	-0.02	-0.04
NOAM	EURA	0.72	0.61	-0.08	-0.04
AUST	EURA	-2.83	-2.55	0.07	-0.04

$$\Delta r_{ij} = r_{n,ij} - R = R\left(1 - \frac{s_{p,ij}}{s_{n,ij}}\right) \; (\approx +2.6\text{cm?})$$

where Δr_{ij} is the change of the Earth's radius as a result of the vertical interpretation, R is the original Earth's radius, $r_{n,ij}$ is the new radius obtained from the above equation.

14 vectors between centres of gravity of the main tectonic plates (between each two points i, j) are interpeted in this way. The gravity centres were estimated approximately with respect to the precision with which they are known. Annual changes of the distance were computed from the geophysical models NNR-NUVEL-1A and APKIM2000 (see Drewes, 2001). The APKIM2000 is built on the same principle as the NUVEL but uses space geodesy measurements.

Using the following formula for a one-year period, we get directly the desired change of the spatial distance $s_n = v \cdot t$.

$$\mathbf{v} = \boldsymbol{\omega} \times \mathbf{r}$$

$$v'_x = \omega_y z - \omega_z y, \; v'_y = \omega_y x - \omega_x z, \; v'_z = \omega_z y - \omega_y x$$

where $\boldsymbol{\omega}$ is an angular velocity vector of the plate done by the model, $\mathbf{r}$ is the radius and $\mathbf{v}$ is the vector of instant velocity described for the Cartesian coordinates.

Values of the Earth's radius change induced by the described vertical interpretation are in Tab 3 for both used models (NUVEL and APKIM). They are compared with the vertical change determined directly from space geodesy measurements via the reference frame ITRF2000 – (Kostelecký and Zeman, 2003, 2004). In these contributions, global horizontal and vertical movements were computed for individual tectonic plates from the velocity vectors published for the ITRF2000 by transformation of (X, Y, Z) geocentric coordinates and (dX/dt, dY/dt, dZ/dt) geocentric velocities to the ellipsoidal components: geographical latitude φ, geographical longitude λ, ellipsoidal height H and their time derivatives (velocities) dφ/dt, dλ/dt and dH/dt. The time derivatives dH/dt (our main interest) were computed for individual plates as a weighted mean value of dH/dt for the individual stations. We know that this individual changes can be „contamined" by local motion (i.e., Scandinavian uplift in Europe). Local motions then influence the dispersion of a resulting mean value of dH/dt. For the whole globe, the estimated value dH/dt = -0.0002 ± 0.0088 m/year was computed from 447 stations. The second problem, yet not resolved, is whether the distribution of the space geodesy stations sufficiently represents the global motion.

Following graphs display main results from Tab 3. Values in Figs. 3 and 4 illustrate the differences between the change of the Earth's radius from „vertical interpretation of horizontal motion" vs. space geodesy measurements from the ITRF2000.

The central zone of both graphs bordered by solid lines (± 5mm) underlines general accuracy of space geodesy measurements. The cross line inside this zone represents vertical changes studied by means of the ITRF2000 (Kostelecký and Zeman, 2003, 2004). 14 points connected by the dashed line shows results of the „vertical interpretation" studied in this article. Each short dashed line connecting two points represents tectonic plate. The point value between two

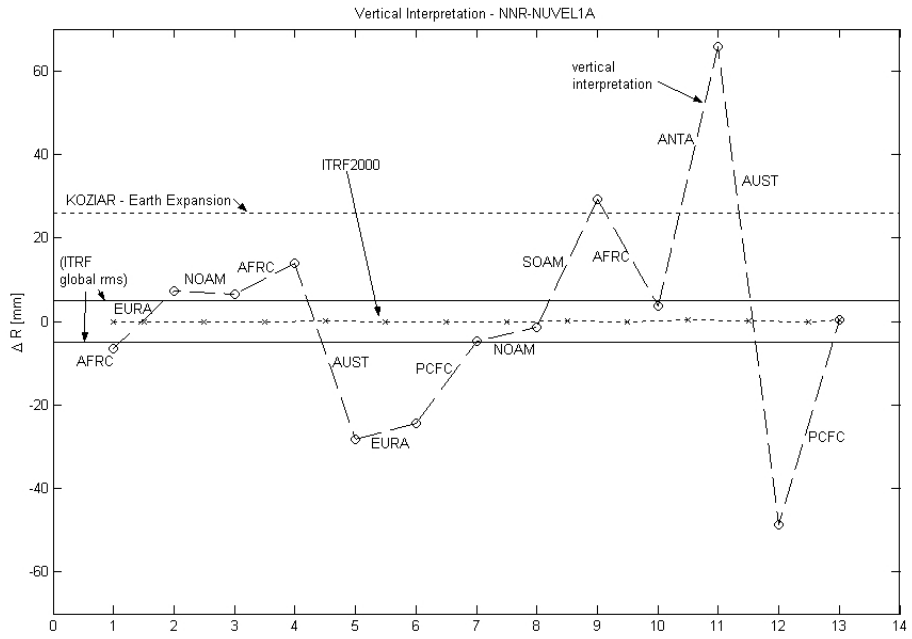

Fig. 3 Vertical interpretation of NNR-NUVEL-1A compared with „measured“ value from ITRF2000

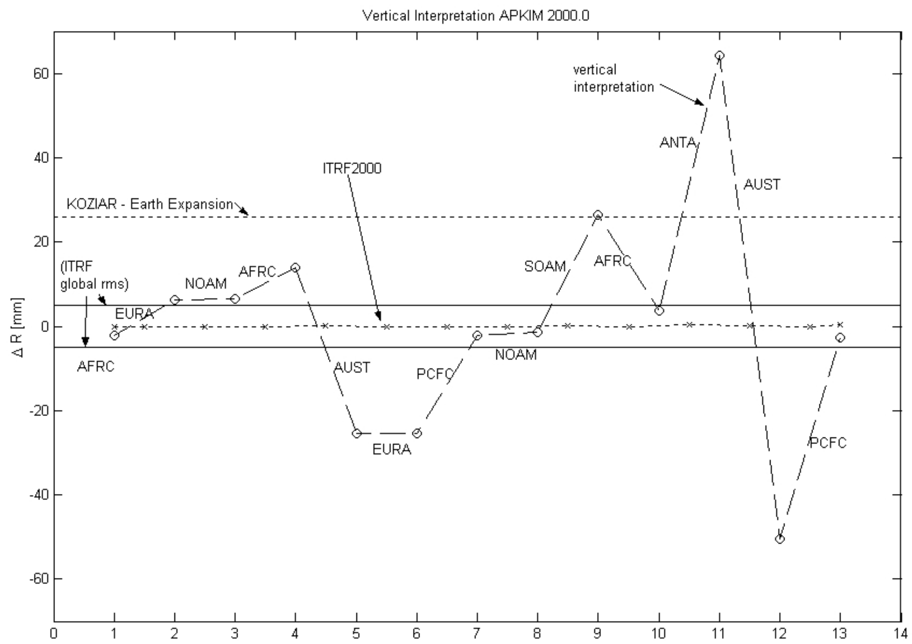

Fig. 4 Vertical interpretation of APKIM2000 compared with „measured“ value from ITRF2000

adjacent plates then shows values of the uplift/decline of the adjacent plates in order to fulfil Blinov's principle while not denying all modern results of space geodesy.

5. CONCLUSIONS

We focused on the comparison of numerical differences between the models NNR-NUVEL-1A and APKIM2000 vs. Earth's expansion theory model by using the models itself, i.e., without using measured data directly. With the actual models, the accuracy of the differences are so significant that one of the described (Blinov) models is injustifiable. As shown in Tab 3, vertical interpretations give values in centimetres. They are both positive and negative and they show no tendency to be homogenous.

Such values show differences systematically exceeding present measurement results. So in the case, when the plates do not move horizontally, and we only "force" them to do so by geophysical models, we see errors. They should have approximatelly the same size as the vertical interpretation values, i.e., about ± 0.5-5 cm.

Burša (1993) showed that the recent LLR data and the long-term decrease observed in the angular velocity of the Earth's rotation do not support expansion hypothesis. Burša and Hovorková, 1994 demonstrate that "no realistic origin of the internal energy of the internal energy of the Earth required for expansion can be found in the Earth-Moon-Sun system in the last 450 milion years".

In contrary, we think that we cannot deny the Earth's expansion hypothesis on the basis of the present space geodesy measurements due to their accuracy. Results from (Kostelecký and Zeman, 2003, 2004) gave a value for dH/dt to be approximately 0 ± 1 cm/y with the statistical probability of 67 %. If we take a more strict statistical criterium, we can say that dH/dt = 0 ± 2.5 cm/y with the 99 % probability. The value of 2.5 cm/y is a "critical" value from Tab 1 for the Earth's expansion supported by different authors, i.e., present results of the space geodesy methods cannot be used to prove if the Earth expansion appears or not!

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