DEFORMATION OF THE SOUTH-EASTERN BALTIC SHIELD FROM GNSS OBSERVATIONS

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ABSTRACT. The Pulkovo observatory is situated in a unique geological setting. Within only 300 kilometres from Northern Karelian Isthmus to a few kilometres south from the observatory the Archean, Paleo and Neoproterozoic, Cambrian, Ordovician, Devonian, and Carboniferous rocks are sequentially surfacing. Thus these 300 kilometres in distance correspond to 3 billion years in geologic time. The city of St. Petersburg marks a transition zone from the Baltic Shield to the East European Platform, and the observatory is built on the Baltic Klint that in turn marks a transition from Ediacaran to Devonian. Such a rich geological constitution of the region summons a need for geodynamical studies. The authors have recently gathered the GNSS observations available in the region from 1993 until present, including those made by the authors, with permanent and high quality field GNSS stations. These measurements were processed with the GIPSY software using the PPP strategy. The resulting coordinates were then adjusted for atmospheric loading corrections, and station velocities were computed. The station velocities were then used for estimation of the regional deformation field. The resulting deformation field shows a weak meridional compression and possibly a slow counterclockwise rotation of the Baltic shield with respect to the East European platform.

1. INTRODUCTION

Both the Baltic shield and the East European platform are traditionally considered as parts of one rigid Eurasian plate. Both are cratons or blocks of the ancient continental lithosphere but if the East European platform is covered by a thick layer of sedimentary rocks, the Baltic shield mostly consists of the Archean or Proterozoic rocks of igneous origin. The transition region between the two landmasses had been until recently considered seismically quiet. An interest to the region from geodynamical point of view was recently motivated by the 2004 Kaliningrad earthquake (Assinovskaya et al., 2011). The Baltic shield is also subject to the ongoing glacial isostatic adjustment (GIA). There were a few GNSS campaigns conducted in the region for the GIA investigations which concerned vertical lithospheric motions (Kierulf et al., 2014). The present study concentrates on possible horizontal movements of the regional GNSS stations. This work is a continuation of a previous study by Gorshkov et al. (2012) that did reveal a possible horizontal motion of the Baltic shield with respect to the East European platform.

The transition zone between Baltic shield and East European platform is known as the Polkanov flexure zone (Svetov and Sviridenko, 1991). The recent geological studies also suggest that this flexure zone may be subject to a stress and hence exhibit deformations. A possible mechanism of these deformation may be a layer of sediments on the East European platform that creates a load to the south of the flexure zone in contrast with the sediment free Baltic shield to the north from the flexure zone. This spatially variable load may produce both vertical and horizontal crustal motions in the border region.

Recently, there is a growing number of permanent GNSS-stations being installed and run in the region by various organizations. A few field campaigns were conducted as well. Unfortunately, not all of the stations are installed in view of proper geodetic standards. Some of them are known to be mounted on the roofs of buildings or on the steel posts so that their achievable accuracies can be restricted.

Nevertheless, there are still a substantial number of stations properly mounted that can be analysed in view of computing their velocities and regional deformations. Thus, an attempt to gather all available regional GNSS measurements and to process them in a unique framework was endeavoured as described below.

2. DATA PROCESSING

A database of GNSS observations was gathered by the authors currently including RINEX files for 38 permanent and field stations for the period from 1993 till present. Four of the permanent GNSS stations as well as all field ones were run by the authors. The rest of the data were provided by the courtesy of other organizations.

All the measurements were processed by use of the GIPSY-OASIS 6.3 software within a unique framework by the Precise Point Positioning (PPP) technique. The solution was formed with absolute antennae calibrations, IGb08 orbit and clock corrections, VMF1GRID tropospheric corrections, IERS Earth orientation parameters and solid Earth tides, GOT4.8 ocean loads, GOT4.8ac geocenter mode, and IMLS atmospheric loading corrections. As a result of the analysis the geodetic latitudes and longitudes of the stations were estimated for each diurnal series of observations.

The resulting station coordinate time series were edited for outliers as well as for jumps due to stations maintenance, changes of antennae etc. Some of the field station coordinate time series were apparently too short in time to produce a reliable velocity estimates and were excluded from the analysis. The permanent stations in the vicinity of St. Petersburg have for the present short observational history (2–3 years). At last the observations of SUUR and TORE stations were used only after relocation of these stations in 2011 year because their previous data yield considerably different velocity vector.

As a next step, a linear trend (weighted for field stations) was fitted to each of the station coordinate time series and the station velocities were computed. The ITRF 2008 plate motion model (Altamimi et al., 2012) was subtracted from the computed station velocities. Thus, the horizontal velocities for 33 stations were obtained. These velocity vectors were then used to compute the deformations with an algorithm based on (Teza et al., 2008).

3. RESULTS AND DISCUSSION

The velocities for all stations used in the analysis are shown in Fig. 1. Figure 2 is a close up of the former showing the velocities of stations in the vicinity of St. Petersburg.

The borderline between the Baltic shield and the East European platform is known to lie along the southern shores of Gulf of Finland and Ladoga lake. The main feature of the residual velocity field is slightly different average directions of the station velocities to the north from that borderline (the northern stations) and those to the south (the southern stations). It can be seen from the Figure that the southern stations tend to move more to the south than the northern ones. In other words there exists a slight clockwise rotation of the East European platform with respect to the Baltic shield.

A few exceptions to this tendency can also be seen from Figs. 1 and 2. Stations SEST, VASO and GORN in the north-western St. Petersburg are slowly moving in direction totaly different from that of the majority of the stations. Possible reasons for that peculiar movement are unknown and need further study. Nevertheless, in spite of these few exceptions the relative motion is clearly seen from Figs. 1 and 2.

Figure 3 shows a regional deformation map. It can be seen from the Figure that deformations generally reflect the velocities. Thus, the direction change of the residual station motions along the flexure zone produces a contraction along that same zone up to three nanostrains per year. This contraction is directed from south-east to north-west. A small expansion can also be seen from the Figure in a perpendicular direction, that is from south-west to north-east.

All of the above suggests that the Polkanov flexure zone, or the transition region between the Baltic shield and the East European platform is clearly geodynamically active. One can also conjecture that there is a possible counterclockwise rotation of the Baltic shield with respect to the East European platform, but this needs further studies.

In order to verify the above relative motion conjecture the algorithm of Teze et al. (2008) of deformation estimation should be developed further to include the rotation effects. In other words, a new algorithm should estimate the regional deformations together with the angular velocity components of a specific region, say the Baltic shield. This will be a subject for a further study.

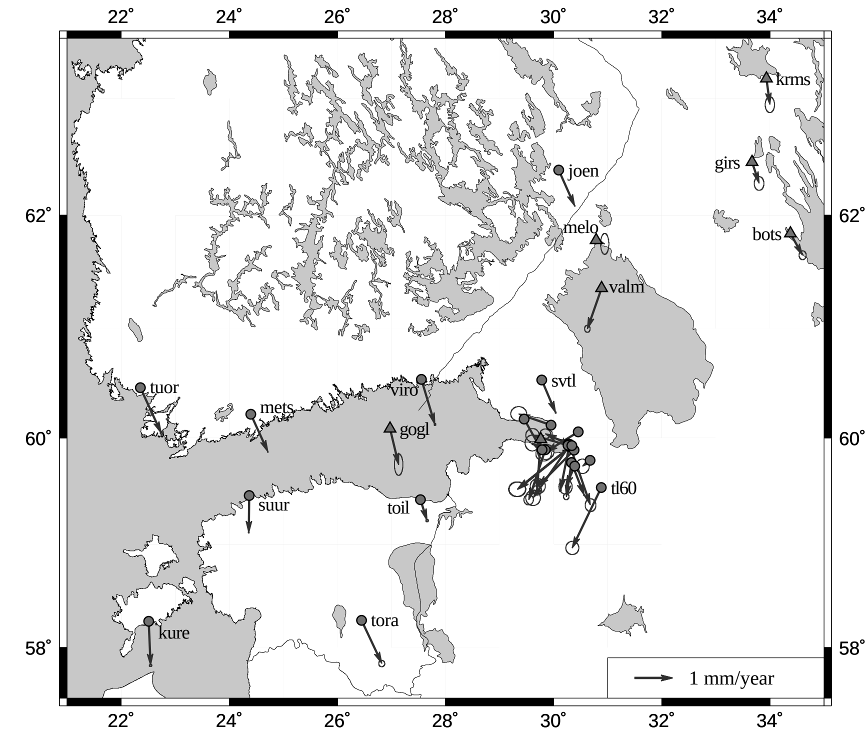

Figure 1: Residual horizontal station velocities. Permanent stations denoted with circles, field stations denoted with triangles, formal errors indicated with ellipses.

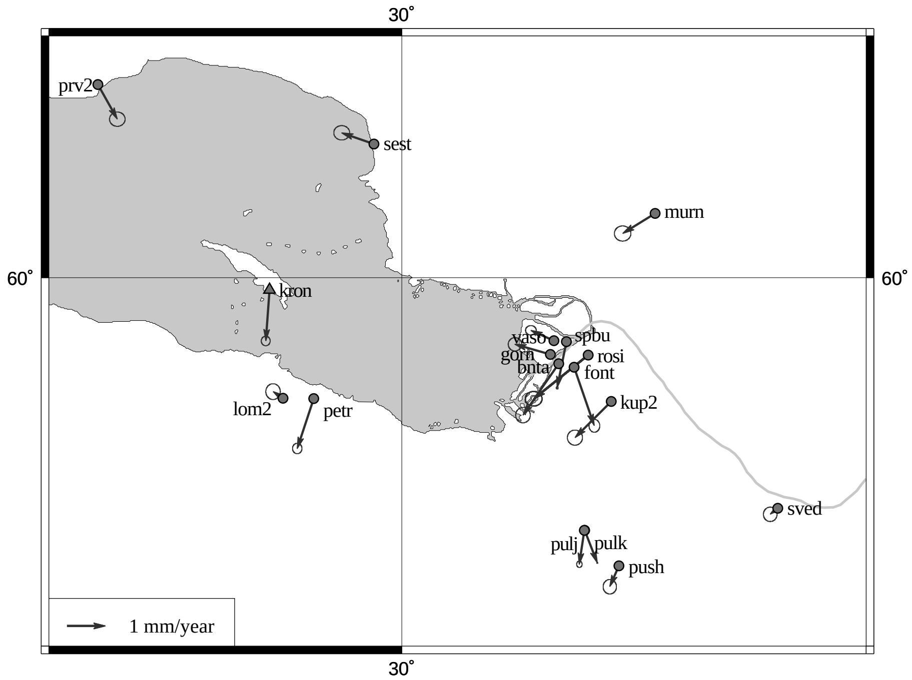

Figure 2: Residual horizontal station velocities, a close up. Permanent stations denoted with circles, field stations denoted with triangles, formal errors indicated with ellipses.

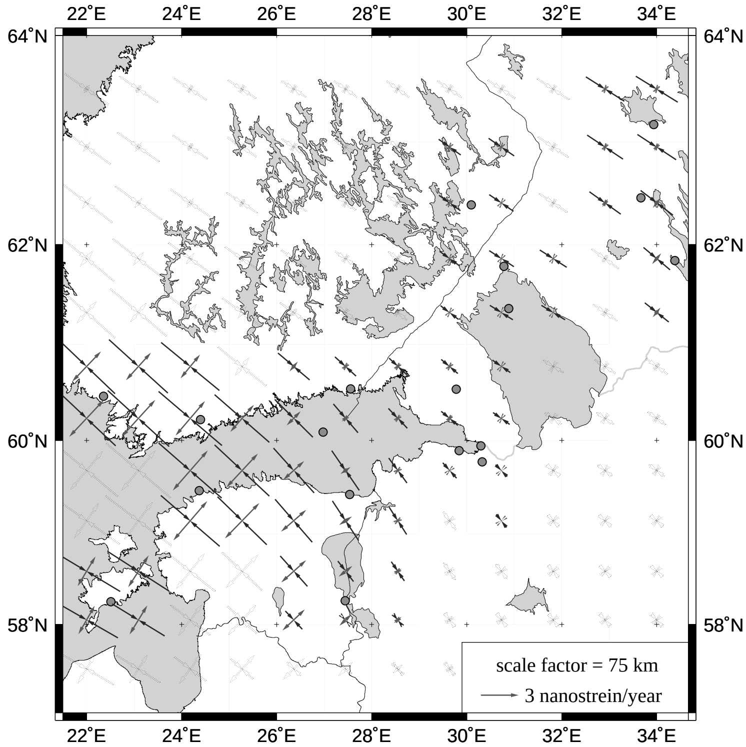

Figure 3: Horizontal deformations estimated from horizontal station velocities.

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