A pilot project on the comphrensive diagnosis of earthquake precursors on Sakhalin Island: Experiment results from 2007

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Introduction

Last year's research clearly revealed the existence of specific variations in the atmosphere and ionosphere parameters during the buildup, or preparation, period leading to an earthquake (M > 5) in the area where it was about to take place. The characteristic dimensions of the earthquake preparation area are defined by $R = 10^{0.43M}$, where R is the radius of a preparation area and M is the magnitude of an earthquake (Pulinets and Boyarchuk, 2004).

The appearance, major morphology characteristics, and correlation of the atmosphere and ionosphere anomalies are explained in terms of a lithosphere-atmosphere-ionosphere (LAI) coupling (LAIC) model which has been developed recently (Pulinets and Boyarchuk, 2004; Pulinets *et al.*, 2006a; Pulinets, 2007).

The most active seismic region in Russia is the Far East where more than 500 earthquakes of varying intensity have taken place in the last 10 years (Fig. 1).

In 2007 the decision to conduct a comprehensive experiment using different types of experimental data was realized by the completion of the first stage of a pilot project to test navigation equipment with the signals of Russian and foreign space navigation systems to diagnose the precursors of strong earthquakes.

The main goal of the experiment was the verification and validation of methods and algorithms of data acquisition, processing and distribution based on existing Russian and foreign navigation, meteorological and resource satellites, and helio-geophysical *in-situ* information in seismic active region of the Russian Far East using the scientific principals of Pulinets and Boyarchuk (2004), Pulinets *et al.* (2006a) and Pulinets (2007).

It was first necessary to carry out a registration of the different atmosphere and ionosphere (Fig. 2) parameters described by the LAIC model for the pilot project. A comprehensive approach can lead to a new reliable earthquake short-term forecast prediction method using even a single parameter of atmosphere or ionosphere registration.

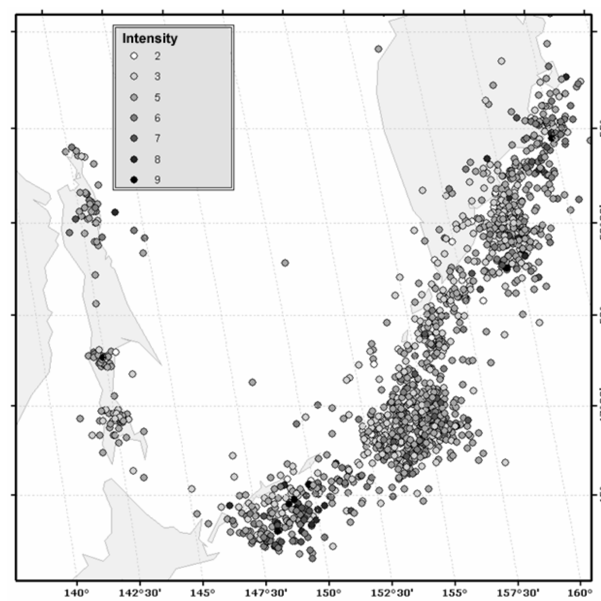

Fig. 1 Earthquake distributions on Sakhalin Island, Kamtchatka and the Kuril Islands region in 1994–2004 (data taken from the Russian Geophysical Survey).

During the experiment on August 2, 2007 at 02:59 UTC, an earthquake took place, with epicenter coordinates 46.55°, 141.81° and M = 6.3 near Nevelsk city, Sakhalin Island. Thus the current research is directed to the study of anomaly phenomena in different media prior to this seismic event.

Experimental Data and Joint Analysis

Comprehensive analysis of meteorology data for a series of recent strong earthquakes (Pulinets *et al.*, 2006a,b) that have taken place in the world reveals the temporal dynamics of surface air temperature and humidity. The most sensitive parameter is the daily temperature range (the difference between minimum

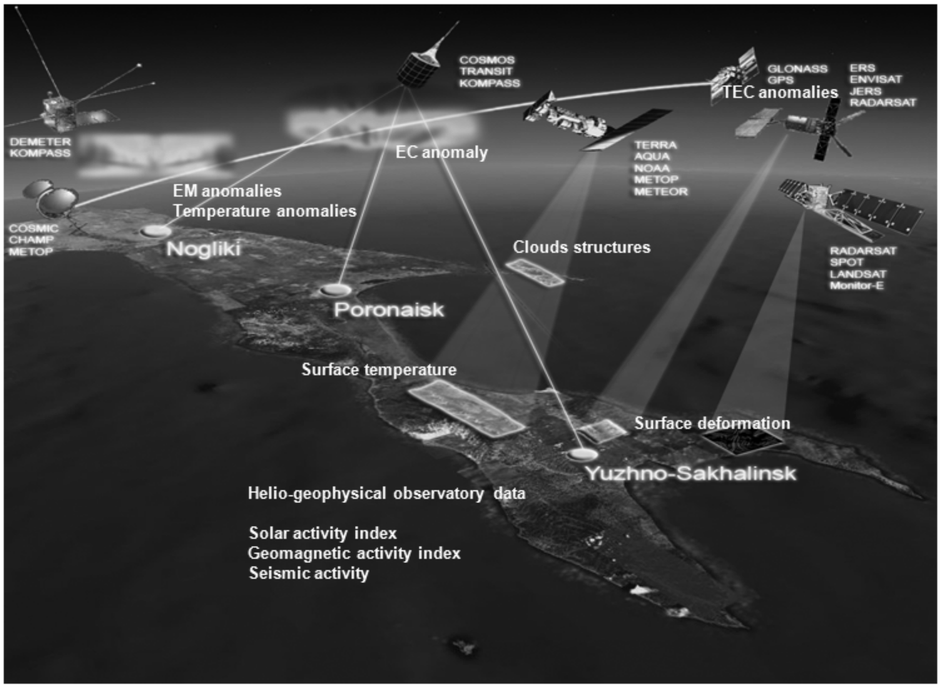

Fig. 2 The scheme of a comprehensive monitoring system of earthquake precursors in different media from space.

and maximum values). Approximately 5–7 days before an earthquake, this parameter usually reaches the local maximum and then decreases to the event moment. The maximum of the daily temperature range coincides with the minimum of the air humidity at the same time.

The temperature and humidity variations from standard meteorology observations were analyzed for the period of July–August in 2007. It can be seen (Fig. 3) that neither surface air temperature nor humidity demonstrate anomalous values. These parameters are within the limits of monthly variations but the variation corresponds to a typical form (simultaneous but opposite variations of the temperature and humidity expressed by the ellipse in Figure 3) for different earthquakes and the time range of the temperature maximum and humidity minimum is 4 days before the earthquake. It can be seen that the maximum daily temperature range occurred on July 29–30 whereas the humidity minimum was on July 30.

Anomalous cloud structures formed over the area of earthquake preparation were also analyzed. The linear cloud structures, corresponding with the fault system and tectonic plate borders, were distinguished in meteorological data by American satellites. The inset in the left hand panel of Figure 4 represents the structure of tectonic plates in the Sakhalin and Japan areas, and the rest of the panel is the image taken on July 30, 2007 by the TERRA satellite. It can be seen that the cloud cover is cut along the tectonic border, across Sakhalin Island (marked with an ellipsis). The right hand panel shows an image taken by AQUA on July 31. Inside the area marked with an ellipse one can clearly distinguish the thread-like cloud lying almost over the epicenter of the future earthquake. The dimensions of the cloud structures and their locations show the scale of tectonic activity before the earthquake and confirm the conclusion of Pulinets and Dunajecka (2007) that tectonic activity increases not only near the epicenter of a future earthquake but also on the tectonic borders. This example shows another important factor: the gases emanating into the atmosphere from tectonically active structures takes place both in the earth and in the ocean and the short-term precursors of earthquake activity can be successfully registered over the ocean surface too. The results of the analysis for the outgoing infrared radiation (OLR) from satellite radiometers, of 10–12 μm (Ouzounov *et al.*, 2007; Fig. 5), support the evidence discussed above. Because of the existence of the atmospheric transparency window in these wavelength ranges, the radiance is not absorbed by clouds and special data processing technology allows us to measure OLR under the clouds to approximately 12 km height.

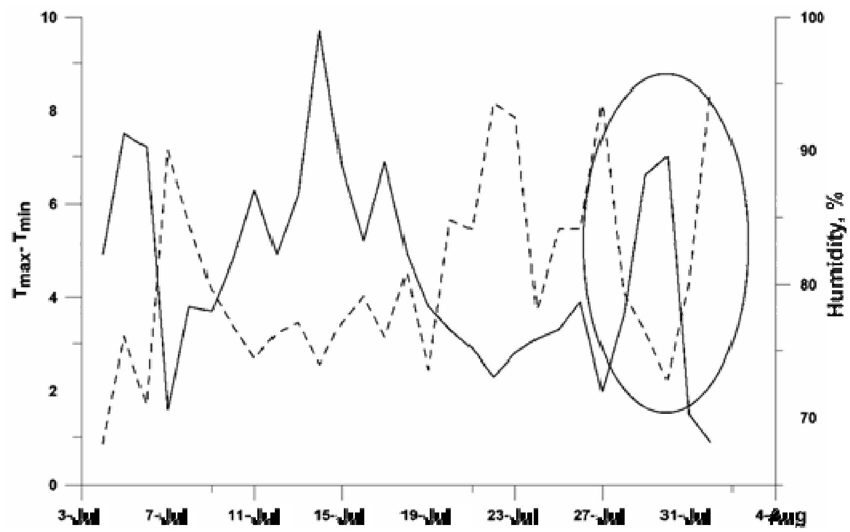

Fig. 3 The daily temperature (solid line) and humidity (dashed line) range change in Nevelsk city (Sakhalin Island) before the M6.3 earthquake of August 2, 2007. Simultaneous but opposite variations in temperature and humidity are shown by an ellipse.

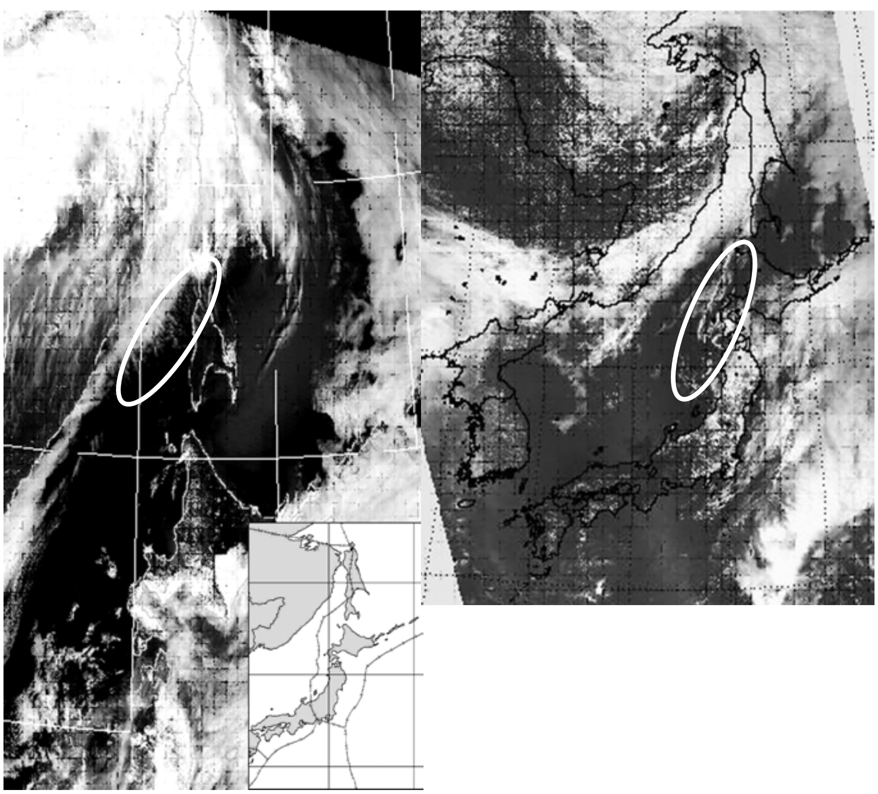

Fig. 4 Anomalous cloud structures marked by an ellipse (left panel) July 30, 2007 from TERRA data and (right panel) July 31, 2007 from AQUA data. The satellite data were taken from Institute of Industrial Science, University of Tokyo, Japan.

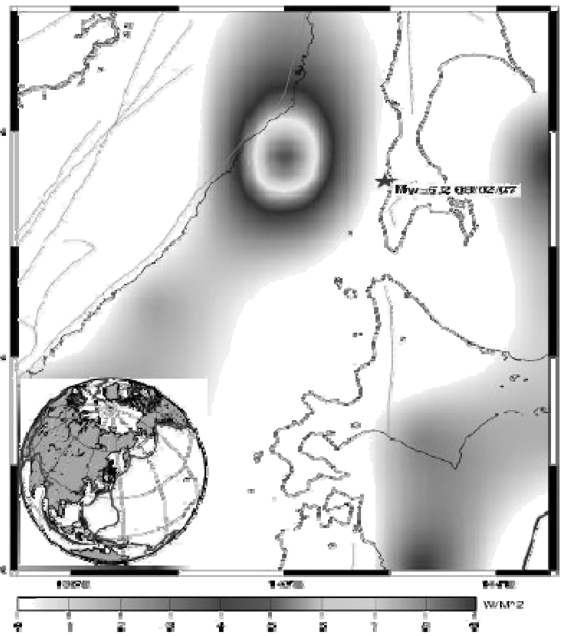

Fig. 5 OLR distribution (W m^{-2}) off Sakhalin Island using AIRS data from the AQUA satellite (Granted by D. Ouzounov).

The variations of total electron content (TEC) for three different GPS stations in the study region were calculated for July–August 2007. The geomagnetic disturbance analysis (Dst index, bottom panel in Figure 6) shows almost quiet geomagnetic conditions in the region. On July 12 and 14 there were small geomagnetic disturbances of less than 50 nT. Nevertheless, the regional ionosphere variability calculation method of Pulinets *et al.* (2007) is used to distinguish the possible seismology caused by ionosphere variations. This method allows us to reveal ionosphere variations in difficult geomagnetic conditions. The result is represented in the upper panel of Figure 6. A week before the earthquake (from July 24 to 31, marked by arrows), an increase of the seismic activity was observed. The second maximum after the earthquake is caused by after-shocks observed during the longer time period.

The regional ionosphere variability index running average curve has three local maxima in the period before the seismic event: July 24, 28 and 30. Tomography reconstructions of the vertical electron concentration distribution in the ionosphere showed the anomalies just in these days. These anomalies are represented in Figure 7. The figures were reconstructed by the phase-different method (Kunitsyn and Tereshchenko, 2001) during night satellite communication sessions (Fig. 7a, b, and c, respectively). Tomography reconstruction for the undisturbed ionosphere conditions is represented in Figure 7d.

The reconstructions for July 24 and 28 can be interpreted as a spreading horizontal wave disturbance with wavelength about 200 km. This could be an acoustic-gravity wave induced by an electric field anomaly according to Hegai *et al.* (1997). The reconstruction on July 30 can be interpreted as a ring-like structure with a minimum over the epicenter of the future earthquake.

In addition to the parameters discussed above, lithosphere plate dynamics were analyzed as a result of an experiment conducted in the Far East region using GPS data of the International Ground Station (IGS) network, located in Yuzhno-Sakhalinsk (Russia) and Shintotsukawa (Japan) (Fig. 8).

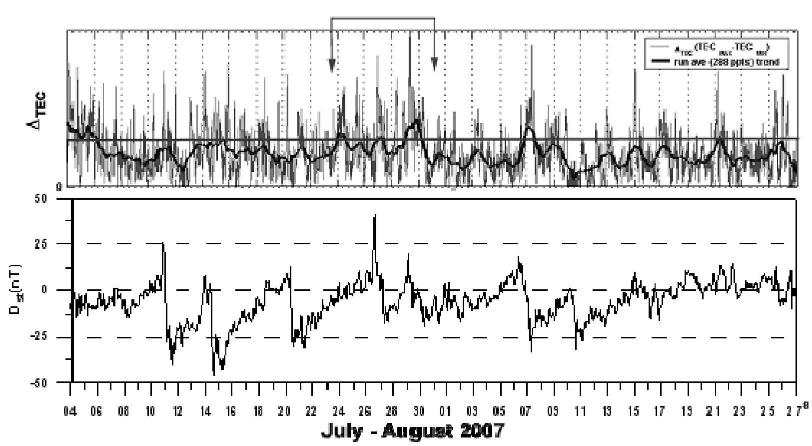

Fig. 6 The regional ionosphere variability index (upper panel), by GPS data (July–August 2007). Bottom panel is the Dst index for the same time period in July and August 2007.

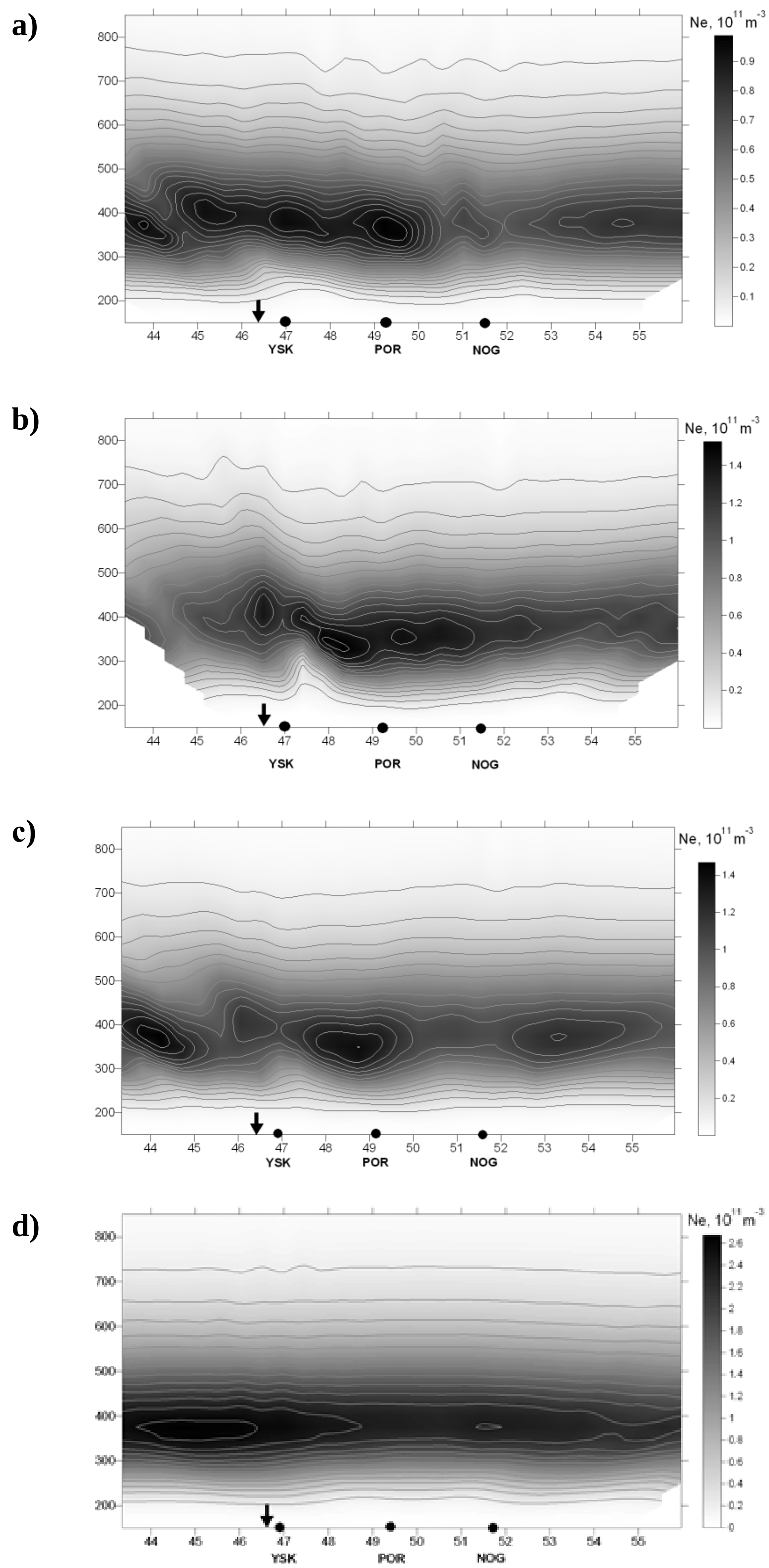

Fig. 7 Vertical distribution of ionosphere electron concentrations reconstructed from the signals of Russian low-orbit navigation satellites. (a) July 24, 2007, (b) July 28, 2007, (c) July 30, 2007, and (d) July 27, 2007. Panel d, having undisturbed ionospheric conditions, is shown for comparison.

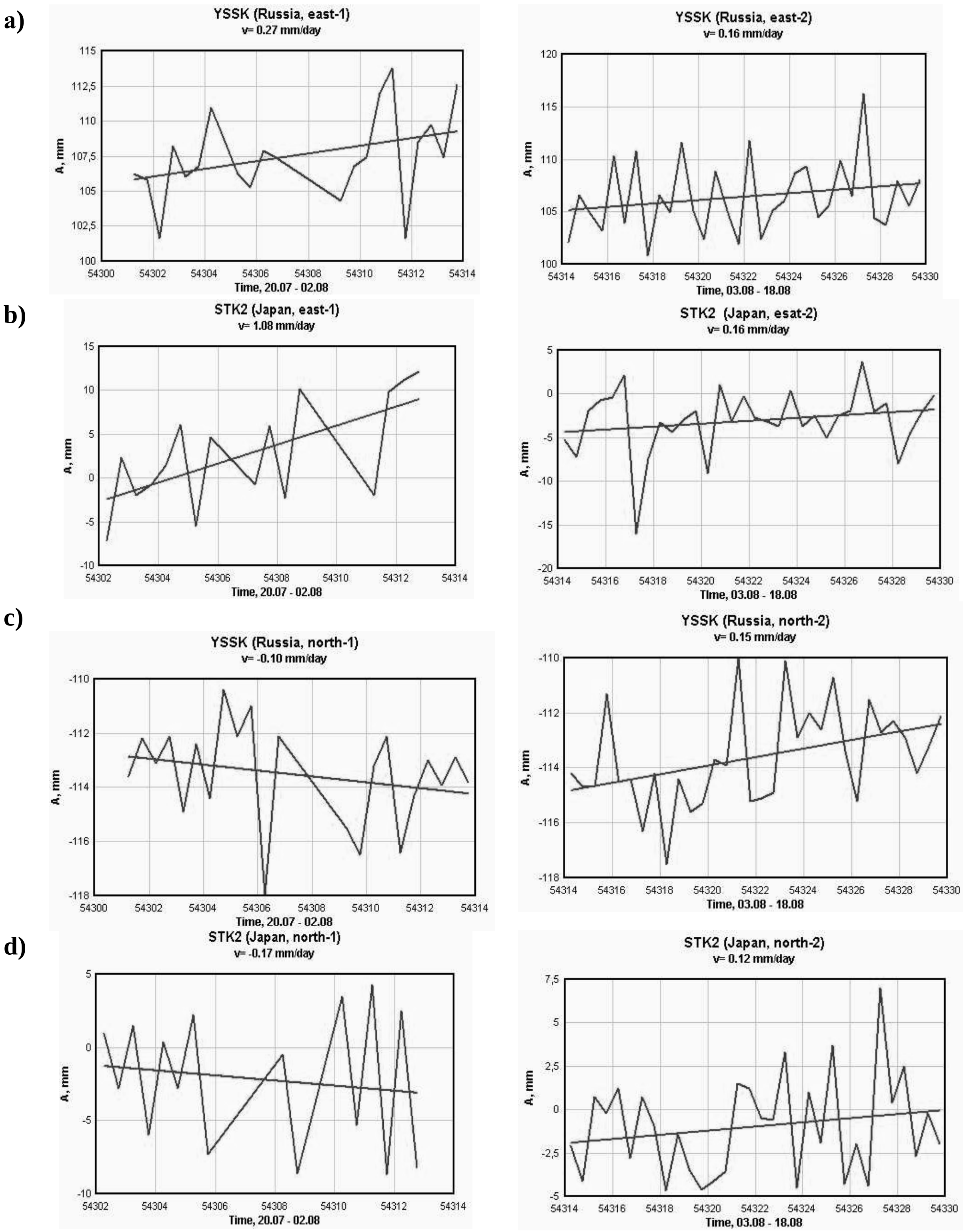

Fig. 8 IGS GPS station displacement (in mm) calculated for stations located in Yuzhno-Sakhalinsk (Russia) and Shintotsukawa (Japan) before (left column) and after (right column) the earthquake. Panels a and b show the horizontal component of displacement in Yuzhno-Sakhalinsk (YSSK) and Shintotsukawa (STK2), respectively. Panels c and d show the vertical component of displacement in Yuzhno-Sakhalinsk and Shintotsukawa, respectively.

As can be seen, the patterns in IGS station displacement velocity changes cannot be considered good earthquake precursors. However, the displacement velocity is almost the only directly measured parameter characterizing the processes taking place in the Earth's crust.

Preliminary analysis of the IGS stations' coordinates shows that the sign for the vertical component of velocity displacement changed to the opposite sign after the earthquake (Fig. 8c and d). Similar behavior is typical both for the Yuzhno-Sakhalinsk and Shintotsukawa stations. For the horizontal component, (Fig. 8a and b) there is a significant decrease in velocity in the lithosphere plate after the earthquake, similar to the results of Carlson and Langer (1989).

Conclusions

The major portion of the scientific program of a comprehensive experiment carried out in a pilot project is mostly completed. Information describing the atmosphere and ionosphere state was collected and analyzed. The anomalies of the parameters characterizing the LAI system were revealed, confirming the LAIC model represented in Pulinets and Boyarchuk (2004), Pulinets *et al.* (2006a) and Pulinets (2007). It is necessary to note that there was a time coherency in the appearance of all anomalies registered during the week from July 24 to 31 before the earthquake took place on August 2.

From gathered information and from the analysis of retrospective earthquake supplementary data, it can be concluded that the morphology of the registered variations of atmosphere and ionosphere parameters before the earthquake of August 2007 on Sakhalin Island completely corresponds to the indications that were revealed before for strong earthquakes around the world. Nevertheless, the successful realization of the experiment only expresses the necessity to intensify international efforts in the framework of the current research. Because of the transboundary nature of the phenomena being studied – the signatures of the earthquake precursors in different media measured on the territory of just one country (Russia or Japan), cannot provide the whole picture, but must be a collaborative effort between the two countries. In the case of Russian tomography chain prolongation to the Japanese territory (Mombetsu and Obihiro cities), the accuracy of the vertical distribution of the ionosphere electron concentration reconstruction will significantly increase due to the amount of data sources increasing. Thus, at the same time, the reliability of ionosphere earthquake precursor diagnostics will increase.

Acknowledgement

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