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ORGANIZATION OF THE NORTH EAST EURASIA REFERENCE FRAME

ОРГАНИЗАЦИЯ МЕЖДУНАРОДНОЙ КОМИССИИ ПО РЕГИОНАЛЬНОЙ ЗЕМНОЙ ГЕОДЕЗИЧЕСКОЙ ОСНОВЕ СЕВЕРО-ВОСТОЧНОЙ ЕВРАЗИИ

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Аннотация: Основная часть статьи посвящена проблеме создания и развития региональной земной геодезической основы для Северо-Восточной Евразии (NEEREF). Для решения задач предлагается создание международной научной организации. Инициатива создания Международной комиссии принадлежит Комиссии по геодезии Национального геофизического комитета Российской академии наук при поддержке ряда научно-исследовательских учреждений и организаций. Введены в действие наблюдательная сеть с основными элементами инфраструктуры, обеспечивающих совместные наблюдения, анализа данных и доступа пользователей к данным. В с татье демонтрируются возможности созданной научной организации.

Ключевые слова: Северо-Восточная Евразия, региональная земная геодезическая основа, ГНСС, международная комиссия.

Abstract: The main body of the paper deals with the problem of establishing and developing the Regional Terrestrial Reference Frame for North East Eurasia (**N**orth **E**ast **E**urasia **Re**ference **F**rame - **NEEREF**). The problem solving suggests the creation of the International Scientific Organization. The initiative for establishment of the International Commission on the Regional Terrestrial Reference Frame for North East Eurasia (**NEEREF**) launched by the Geodesy Section of the National Geophysical Committee of the Russian Academy of Sciences was supported and implemented by a number of research institutions and organizations. A unified observation network with the main infrastructure elements providing joint observations, data analysis and user data access has been put into effect. The potentialities of the created scientific organization are demonstrated.

Keywords: *North East Eurasia, Reference Frame, International Collaboration, GNSS, Permanent Observation Network.*

Background

In compliance with the principle "from the universal to the private", it may be stated that a Terrestrial Reference Frame (TRF) is the most important element of the infrastructure of the global community interactions, as well as coordination and cooperation between the regional and state formations. It is needed to be used for a large number of research and practical applications. Applying of TRF is not constrained by exclusively terrestrial tasks. It is demanded for the implementation of the satellite projects. The main quality characteristics of TRF are accuracy, density, homogeneity, stability and availability. The first three characteristics are closely interrelated. Densification and provision of the homogeneity for the observation sites of terrestrial geodetic networks is dictated by the demand for high and uniform accuracy of the coordinate reference frames for topographic surveying. High density of the reference networks is also necessary for a more reliant study of the geodynamic processes. Using a rather dense geodetic network for the study of the spatio-temporal structure of the ionosphere and troposphere is an important geophysical aspect. The density of the global terrestrial reference frame varies significantly. The major densest geodetic networks operate in such regions as the Japanese Archipelago, Western and Eastern Europe and Western North America. North East Eurasia is one of the regions least provided with regular and dense observational reference frames. Here, the area occupying tens of millions of km^2 is covered by only several tens of permanent observation networks. In the above regions with higher network density, the number of observation sites of the first level varies from hundreds to thousands. The Arctic and Circumpolar areas of the region are especially insufficiently covered by the geodetic observation techniques. The shortcomings stated, and, also, the lack of access to the observation results for a wide range of users gave an impetus for the development of arrangements on the establishment of the Regional Terrestrial Reference Frame for North East Eurasia (**N**orth **E**ast **E**urasia **Re**ference **F**rame - **NEEREF**) by analogy with those in the International Association of Geodesy (IAG) Sub-Commission 1.3 Regional Reference Frames. It is taken into consideration that a number of observation stations in the area may and should preserve their operational attributability to the acting neighboring TRF, for example, such as the European and Pacific-Asian TRFs. This will provide creating buffer zones necessary for control of independent solutions, and the possibility of obtaining the most reliable results.

The Geodesy Section [http://geodesy-ngc.gcras.ru/en/] of the National Geophysical Committee [http://ngc.gcras.ru/index_eng.html] of the Russian Academy of Sciences announced an initiative on unifying the observation networks affiliated to different national and departmental organizations into a single regional cluster. A number of meetings of the Geodesy Section held in 2012-2103 were devoted to the organizational problem solving. During this period, the texts of the Statute of the International Commission on the Regional Terrestrial Reference Frame for North East Eurasia (**NEEREF**) and the Agreement between the institutions and organizations were elaborated, and signing of the Agreement started up.

International Commission on the Regional Terrestrial Reference Frame for North East Eurasia (**NEEREF**) is a voluntary association of institutions and organizations of different ownership forms and legal structures. One of NEEREF tasks is the promotion in adhering to the recommendations of the international geodetic organizations when undertaking its activities.

The NEEREF activity as of an additional IGS cluster is intended after some year operation testing and complying with all IGS requirements and its acceptance by the IGS community. One of the long-range goals of the NEEREF network is joining GGOS.

Status of the Regional Reference Frame Commission for North East Eurasia (NEEREF)

Current data owners and analysis centers

Today, ten institutions and organizations have made a decision to participate in NEEREF activity as analysis centers. They are listed in the Table 1. with regard to their experience and expected activities.

Preliminary organization structure

It is a well-known fact that the first in the history and most developed IAG Regional Sub-Commission which provided the community with GNSS and other geodetic observation data and results is EUREF [Altamimi et al., 2009]. Therefore, NEEREF structure is established by approximate analogy with EUREF, as shown in Fig. 1. The entire research is based on the unified observation network which provides the initial observation data obtained not only by GNSS but also by other satellite and terrestrial observation techniques. The observation data are transmitted to the data centers and/or analysis centers for primary treatment and/or final solution determination. The measurement data and processing results become to be available to a wide range of users. A specialized Technical Working Group (TWG) promotes technical and scientific interaction between the centers in the unified reference frame. It develops the methods of observation and analysis, the data and analysis formats, etc., and recommends these for application. The Coordination Committee staff consists of members who are professionals and influential figures involved in strategic and political decision making. It also promotes the interaction with international organizations at the highest scientific level. It is suggested that in the future the organization should be integrated into the general structure of IAG Regional Sub-Commissions.

One of NEEREF objectives is to conduct researches not only in the frame of conventional geodetic problems but also the related geophysical ones. For example, the interaction with geomagnetic observation networks, which is significant for better understanding of the interrelationship of the terrestrial and natural external processes [Kaftan et al, 2013].

The distribution of functions between the participants and defining conditions for access to measurement data and processing results are based on free choice and the mutual arrangements concluded at the national and international levels.

Table 1.

N	Institution name	Destination for NEEREF operation	Main experience
1	Central-Asian Institute for Applied Geosciences, Bishkek, Kyrgyz Republic	GNSS data provision, regional geodynamic analysis	GNSS network operation, deformation and geotectonic study
2	Federal State Budgetary Establishment “Federal Scientific-Technical Center of Geodesy, Cartography and Spatial Data Infrastructure”, Moscow, Russia	GNSS and gravity data provision, regional coordinate solutions, quasigeoid determination, GLONASS ephemerides computation, standardization	GNSS network operation, terrestrial gravity measurement, quasigeoid research
3	Geophysical Center, Russian Academy of Sciences, Moscow, Russia	Ionosphere and magnetosphere analysis, local deformation research	Geomagnetic observation and analysis, geophysical data collection
4	Institute of Applied Mathematics, Far Eastern Branch of the Russian Academy of Sciences, Vladivostok, Russia	Regional coordinate solutions, geodynamic research	GNSS data processing, network design, ionosphere and deformation study
5	Institute of Tectonics and Geophysics, Far Eastern Branch of the Russian Academy of Sciences, Khabarovsk, Russia	GNSS data provision, geotectonic analysis	Deformation and geotectonic study
6	Moscow State University of Geodesy and Cartography, Moscow, Russia	Common observation analysis, standard development standardization	Education, geodetic research, standardization
7	Open Joint Stock Company “Roskartografia”, Moscow, Russia	Leveling data provision, standardization	Large scale geodetic measurements, standardization
8	Pulkovo Observatory, Saint-Petersburg, Russia	GNSS data provision, Earth rotation modeling	GNSS observation, Earth rotation and regional geodynamic study
9	Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, Russia	GNSS data provision, geodynamic and ionosphere analysis	GNSS observation, geodynamic and ionosphere study
10	Siberian State Geodetic Academy, Novosibirsk, Russia	GNSS data provision	Education, geodetic research, applied geodetic research

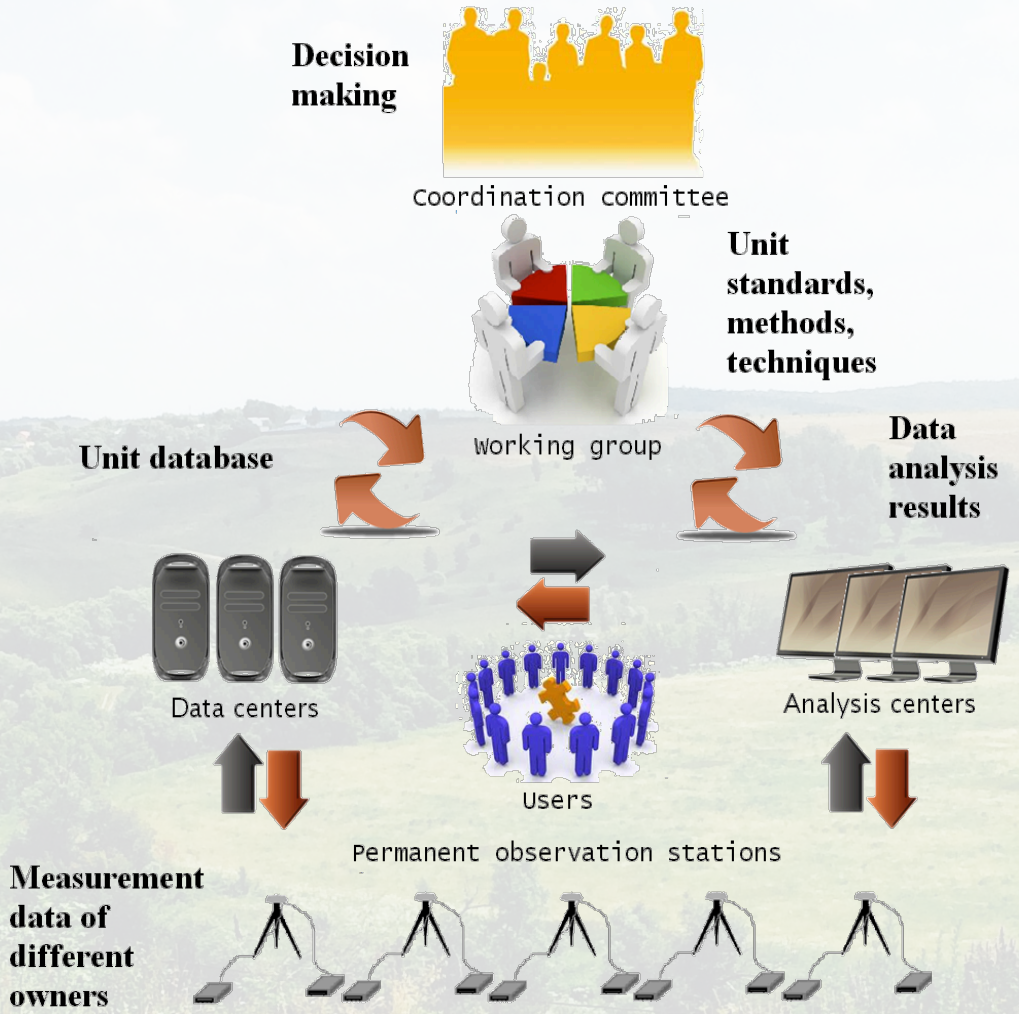

Fig. 1. Structure design of the International Commission

NEEREF rights

The Regional Reference Frame Commission for North East Eurasia (NEEREF) and its Technical Working Group (NEEREF TWG) develop harmonized recommendations on the following items:

- An appropriate set of geodetic measurement tools and special software provided for the sites involved in the creation and development of the regional reference frame NEEREF
- Monumentation and stability control of NEEREF site monuments
- The measurement modes of NEEREF stations (regimes and technical specifications)
- Defining the policy and providing the possibility for data exchange between the participants
- The structure of NEEREF data analysis centers

NEEREF goals

The main general objective of NEEREF is to provide the region of North East Eurasia with actual data and results of observations of the shape, size and gravity field of a vast area. In the first place, it is creation of the main kinematic coordinate and gravimetric reference

frame for its further densification and detalization depending on specific research and technological objectives. In this connection, let us give a preliminary list of the main research objectives set by NEEREF.

NEEREF coordinates scientific collaboration between commission participants in the field of creation and development of the North East Eurasian Terrestrial Reference Frame.

NEEREF facilitates the development of uniform coordinate, height and gravimetric systems in Eastern Europe, North and Middle Asia and Eurasia.

NEEREF realizes the joint efforts to construct and develop the unified geodetic permanent network aimed at accuracy and stability control of the North East Eurasian Terrestrial Reference Frame; to observe movements and deformation of the Earth's crust, including geophysical (seismic and meteorological) monitoring using GNSS.

NEEREF attempts to reach sufficient density of site locations and to provide the joint free access to measurement data and processing results for all NEEREF participants.

NEEREF combines efforts in creating a uniform height reference frame [see, for example, Demianov et al, 2011] and developing the common geoid model.

NEEREF creates a favorable and constructive working environment for development and exchange by modern technologies, and also for developing modern coordinate, height and gravimetric systems on the regional (sub continental) scale.

NEEREF promotes implementation of the recommendations of the international geodetic organizations in its activities for development and maintenance of the regional North East Eurasian Terrestrial Reference Frame.

NEEREF assists in expert examination of national projects for creation and development of modern national terrestrial coordinate reference systems using state-of-the-art geodetic measurement tools of GNSS, VLBI and other observation systems.

The above list of the objectives set is not exhaustive and may undergo changes. It will undergo alterations and improvements during the work according to the demands of the community and the state of the region and, also, of the planet as a whole.

NEEREF sites

NEEREF array includes the sites in compliance with the recommendations of NEEREF and its Technical Working Group (NEEREF TWG). The institutions and organizations to which they belong by right of property or on other lawful basis, signed the agreement with NEEREF on providing data for joint processing, the development of harmonized solutions with further open publication for science and international cooperation.

Presently, several tens of permanent GNSS observation stations have been prepared to operate in the unified network. Their precise number is refined and may vary depending on the tendencies of NEEREF development. Currently, the observation sites of the Federal State Budgetary Establishment "Federal Scientific-Technical Center of Geodesy, Cartography and Spatial Data Infrastructure" are recording the signals of two systems, namely GLONASS and GPS. Some of them are equipped with hydrogen masers for the use as GLONASS orbit service sites. The observation sites of the Russian Academy of Sciences and of its Far Eastern Branch are partly equipped with the receivers of these two navigation systems. The possibility of carrying out GLONASS observations suggests using the site for determining satellite ephemerides of this navigation satellite system. The sites shown on the sketch map in Fig. 2 provide static observations with recording frequency of GNSS signals - 30 s and - 1 s in some cases. The site monuments are mainly located on fundamental constructions; in some cases, these are ground monuments. Continuous observations have been carried out at the described network sites for a time span not less than a year. Separate sites have been operating for more than 20 years. Technical requirements for GNSS observations are analogous to those for IGS observations [Dow et al, 2009].

Fig. 2. Map of permanent GNSS tracking sites and geophysical observatories contributing to NEEREF
Legend. Dark blue triangles are the permanent GNSS sites of TsNIIGAiK, Pulkovo Observatory and Schmidt Institute of Physics of the Earth. Orange triangles are the permanent GNSS sites of the Far Eastern Branch of the RAS, the Russian Federation. Green triangles are the permanent GNSS sites of the Central-Asian Institute for Applied Geosciences, Bishkek, the Kyrgyz Republic. Purple triangles are the permanent GNSS sites of the Republic of Uzbekistan (under approval). Magenta and red circles are magnetic observatories and stations of the Russian Federation [Soloviev et al., 2013].

Expected and current results

Preliminary list of expected NEEREF products is the following.

- Uniform coordinate reference frame
- Weekly regional coordinate solutions
- Coordinate time series and velocity vectors
- Deformation analysis results (Fig. 4)
- Tropospheric and ionospheric characteristics (delays, maps, etc.). See Fig. 3.
- Geomagnetic observations for joint magnetosphere research
- Data for national and international use

The first kinematic coordinate reference frame of Russia is a common work result of the above mentioned Russian institutions. The coordinate solutions were obtained based on the ITRF08 catalogue. The coordinate accuracy values of daily Bernese solutions were 0.8 and 1.7 mm for the horizontal and vertical components, accordingly. The velocity vector values of the sites of the Russian Fundamental Astro-Geodetic Network (FAGS) are derived from the data of continuous GPS observations conducted in 01/2010-12/2011. The velocities are determined from the time series analysis of two-year observations. The accuracy of determination of the displacement rates obtained from the time series of daily coordinate solutions attained 0.2-0.3 and 0.4 mm/yr for the horizontal and vertical components, respectively [Gorobets et al, 2012].

Figure 3 demonstrates the models of the state of the ionosphere (fields of total electron content (TEC) values) for specific time

moments in connection with the Great Tohoku earthquake occurred on March, 11, 2011 at 05:46:23 GMT. The models are based on the data of dual-frequency GPS observations performed at the GNSS network sites of a few Russian GPS networks, IGS and Korean GPS array and GEONET data. It is observed a characteristic interference picture and decrease of TEC as a response to strong seismic event.

Figure 4 illustrates the results of deformation of the Earth's surface on the continental coast caused by the Tohoku earthquake [Baek et al., 2012]. The deformations were obtained by integrating coseismic displacement fields for China [Wang et al., 2012], Korea and the Far East of the Russian Federation. The fields were integrated using the transformation of the displacement vectors obtained from different sources. The result shows how a strong sea bottom earthquake deforms the continental earth's crust at a distance longer than two thousand kilometers from the epicenter.

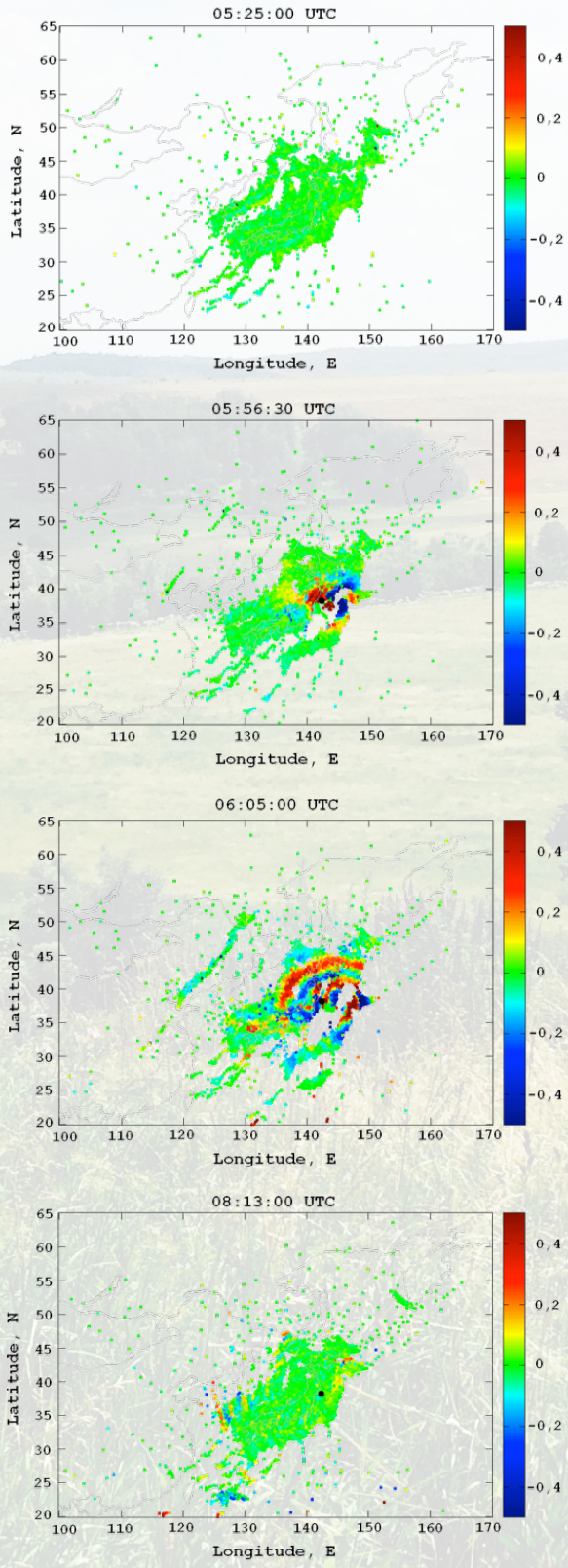

Fig. 3. Ionospheric response to the Tohoku earthquake [Shestakov et al., 2012]. Legended. Samples of filtered TEC maps showing the propagation of different scale traveling ionospheric disturbances (TIDs). Upper plot shows no any TEC perturbations before the earthquake. The next samples show large-scale coseismic and postseismic TIDs. The last figure renders the TEC conditions after the main TIDs have passed away.

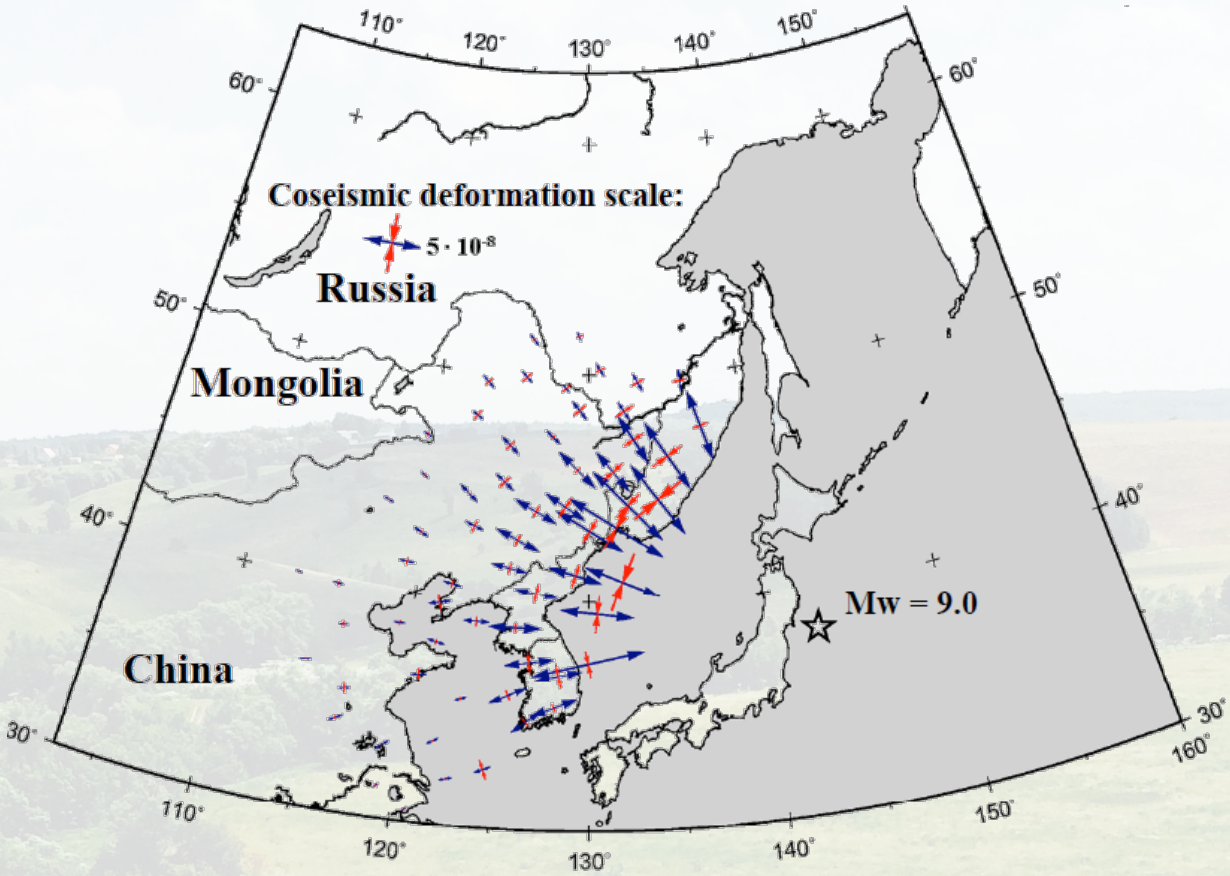

Fig. 4. Coseismic deformation due to Tohoku earthquake [Shestakov et al., 2012].
A) Coseismic displacements in the Far East of Russia obtained in this study; B) displacements in the east of China (extracted from Wang M. et al., Chinese Sci Bull, 2011); C) displacements on the Korean Peninsula (extracted from Baek et al., Terra Nova, 2011).

Concluding remarks

To date, such measures as densification of the observation networks, provision of open access to the data and products and, also, unification in the frame of the international cooperation are extremely demanded in the field of control of the Earth's geospheres. For this purpose, the scientific organization NEEREF has been established for the area of a large region. The first stage of this action has been accomplished by the preparation of the Statute and the Agreement on NEEREF. A unified permanent GNSS observation network has been created. The institutions and organizations that joined NEEREF at the first stage of establishing the International Scientific Organization, which suggests permanent expansion, possess the potentialities to fulfill the tasks planned by NEEREF including geodetic and geophysical observations to study regional variations of the geospheres using the Regional Reference Frame.

At the current stage, NEEREF can provide data and meta-data to the global international community only from the authorized part of permanent stations. All possible amounts of data will be accessible to the wide community when state official restrictions will be removed.

The future-oriented intention of NEEREF is to become a fully legitimate and capable regional cluster of ITRF.

References

1. Altamimi Z., C. Boucher, E. Brockmann, A. Caporali, W. Gurtner, H. Habrich, H. Hornik, J. Ihde, A. Kenyeres, J. Mäkinen, G. Stangl, H. van der Marel, J. Simek, W. Söhne, J.A. Torres, G. Weber, 2009, The European Reference Frame: Maintenance and Products, "Geodetic Reference Frames", IAG Symposia Series, Springer, Vol. 134, pp. 131-136, DOI: 10.1007/978-3-642-00860-3_20
2. Baek Jeongho, Young-Hong Shin, Sung-Ho Na, Nikolay V. Shestakov, Pil-Ho Park, Sungki Cho. Coseismic and postseismic crustal deformations of the Korean Peninsula caused by the 2011 Mw 9.0 Tohoku earthquake, Japan, from global positioning system data, Terra Nova, 2012, 00, 1–9, doi: 10.1111/j.1365-3121.2012.01062.x
3. Demianov G.V., Mayorov A.N., Sermiagin R.A. The joint height system establishment tasks, International scientific, technical and industrial electronic journal "Geo Science"2011, No. 1, p. 37-39
4. Dow, J.M., Neilan, R. E., and Rizos, C., The International GNSS Service in a changing landscape of Global Navigation Satellite Systems, Journal of Geodesy (2009) 83:191-198, DOI: 10.1007/s00190-008-0300-3
5. Gorobets V.P., Demianov G.V., Mayorov A.N., Pobedinsky G.G. Results of creation of the state geocentric coordinate system of Russian Federation in the frame of the Federal special purpose program GLONASS, Geodesia i Cartographia, 2012, No. 2, p. 53-57 (in Russian)
6. Kaftan V.I., N.V. Shestakov, N.P. Perevalova, M.D. Gerasimenko, S.V. Voeykov, A.B. Ishin, Yu.V. Yasyukevich, V.G. Bykov. Global navigation satellite system observation as a part of complex geophysical observation systems, Materials of the Partnership Conference "Geophysical observatories, multifunctional GIS and data mining", 30 September- 3 October 2013, Kaluga, Russia, DOI: 10.2205/2013BS012_Kaluga
7. Shestakov N.V., N.P. Perevalova, S.V. Voeykov, A.B. Ishin, Yu.V. Yasyukevich, V.G. Bykov, M.D. Gerasimenko. Investigation of coseismic displacements and ionospheric disturbances in the Far East of Russia generated by the Great 2011 Tohoku earthquake, Paper presented to EGU2013
8. Shestakov N., Takahashi H., Ohzono M., Prytkov A., Bykov V., Gerasimenko M., Luneva M., Gerasimov G., Kolomiets A., Bormotov V., Vasilenko N., Baek J., Park P.-H., Serov M. Analysis of the far-field crustal displacements caused by the 2011 Great Tohoku earthquake inferred from continuous GPS observations, Tectonophysics, 2012, V. 524-525, p. 76-86. DOI: 10.1016/j.tecto.2011.12.019
9. Soloviev A., Bogoutdinov S., Gvishiani A., Kulchinskiy R, and Zlotnicki J. Mathematical Tools for Geomagnetic Data Monitoring and the INTERMAGNET Russian Segment. Data Science Journal, 2013, V. 12, p. WDS114-WDS119, doi:10.2481/dsj.WDS-019
10. WANG Yue-Bing, JIN Hong-Lin, FU Guang-Yu, MENG Guo-Jie. Estimation of co-seismic slip distribution of the 2011 Tohoku-Oki Mw 9.0 earthquake using Yabuki & Matsu'ura's inverse method, Chinese Journal of Geophysics, 2012, V. 55, No. 4, p. 418-428