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In 2018, a new joint project started between NORSAR, the Institute of Geophysical Research ME of the Republic of Kazakhstan, and the Institute of Seismology of the National Academy of Sciences of the Kyrgyz Republic. The project focuses on capacity building in Central Asia in relation to technical verification of compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT), as well as on education in seismology and research for an improved seismic and infrasonic monitoring of Central Asia. During the first year, the cooperation focused on the modernization of the National Data Centers in Kazakhstan and Kyrgyzstan and training courses on interpreting and processing of seismic records conducted at the KNDC in Almaty for specialists from Kyrgyzstan, Tajikistan, and Kazakhstan. To improve the monitoring capabilities and the regional cooperation between the countries in Central Asia, the compilation of a regional bulletin has started by collecting seismic data or seismic onset readings from more than 50 stations in Central Asia. In addition, methods are under development to classify different source types (natural, man-made) of the events in the new bulletin.

On April 19, 2018 an official meeting among the Institute of Geophysical Research (IGR) ME Republic of Kazakhstan, NORSAR (Norway) and the Institute of Seismology (IS) NAS of the Kyrgyz Republic took place in Almaty. The meeting result was signing of a three-years Agreement on joint cooperation within the frame of CTBT capacity building. This project and cooperation became possible owing to financial aid and support of the Ministry of Foreign Affairs (MFA) of Norway. Already in February 2018, the IGR Data Centre in Almaty had been visited by the Norwegian Ambassador in Central Asia countries (five post-Soviet countries) Ole Johan Bjørnøy, and a representative of the Norwegian MFA, Helene Sand Andresen, in which the forthcoming project, points of common activities, relations between nuclear-test-monitoring tasks and humanitarian issues had been discussed.



Visit of Norwegian Ambassador O. J. Bjørnøy and the Norwegian MFA representative H. S. Andresen to KNDC



Signing of the joint Project

This poster presents the results obtained after one year of cooperation under this joint project. The main tasks of the project are:

1. Support of the National Data Centers in Kazakhstan (KNDC) and in Kyrgyzstan (NDC-KG).
2. Training courses for Central Asia specialists.
3. Joint research in support of cooperation among Central Asia NDCs, and creation of a regional seismic bulletin.

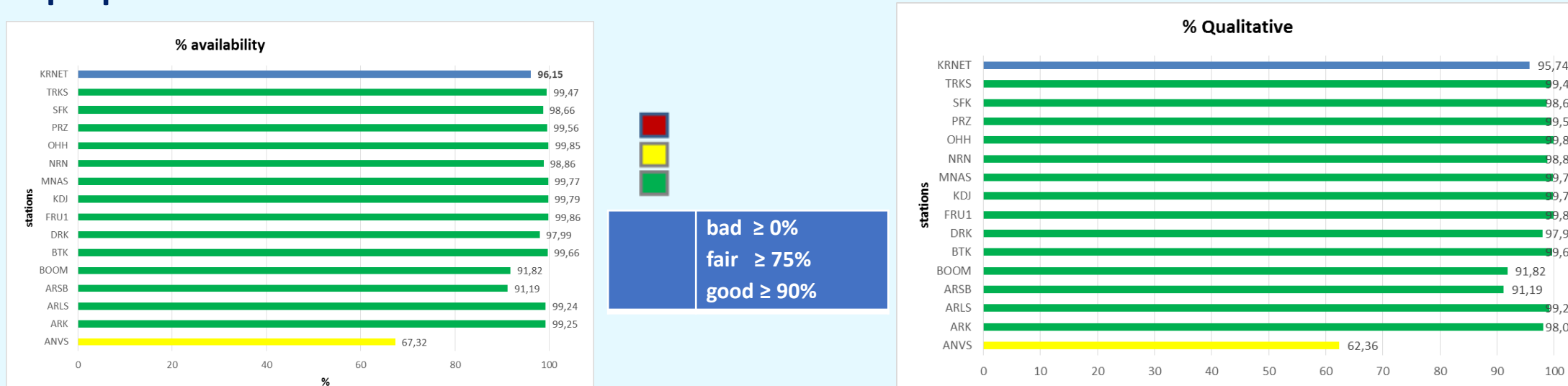
Task 1. Support of the National Data Centers in Central Asia (KNDC and NDC-KG)

Upgrade of the KNDC

During the first project year the computer equipment of KNDC has been upgraded, which allows to improve the KNDC and International Training Center capabilities.

NDC-KG upgrading

Under project support the NDC-KG infrastructure was enhanced by new powerful computers, alternative system of power supply, etc. Also seismic stations of the National Seismic Network were upgraded with new data transmission and power supply systems. All these points allow to enhance its capability significantly. Besides, all seismic bulletins of the Kyrgyz seismic monitoring system are sent to the ISC and the data are used for CTBT purposes.



Digitizing of analogue recordings of seismic events from IS NAS KR archive.

The archive of the Kyrgyz Institute of Seismology contains a lot of historical records both of earthquakes and different types of explosions (nuclear and chemical), which can be used for different CTBT related purposes. The process of saving the historical archive is divided in 2 stages: saving the archive by scanning and then digitizing the data and converting them from analogue to digital format. The archive of nuclear explosions has been completely scanned and a corresponding database was created. But, of course, the largest part of the IS archive contains earthquake records. In 2018, 65102 analogue seismograms of earthquakes with $M \geq 3.5$, which occurred on the territory of Kyrgyzstan and adjacent areas during different time periods, have been scanned. Some of them have been already digitized with the help of «WaveTrack» software.

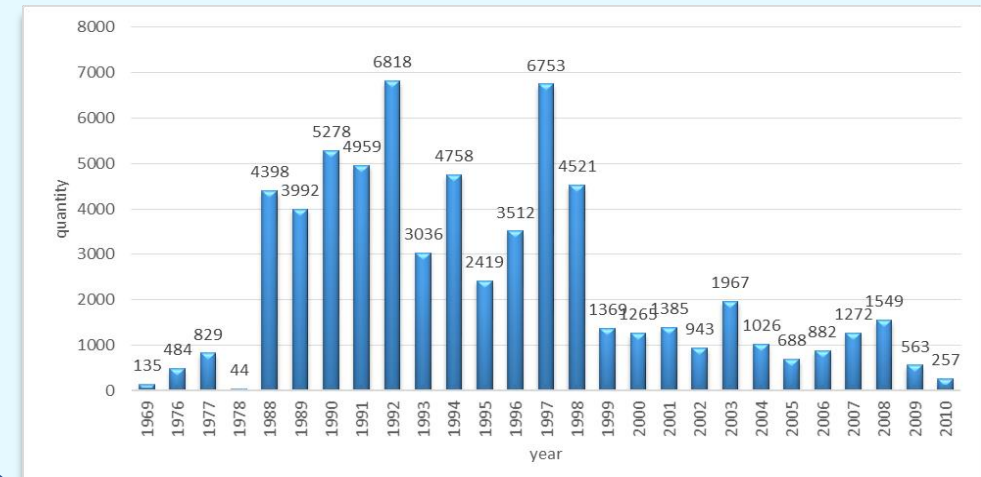
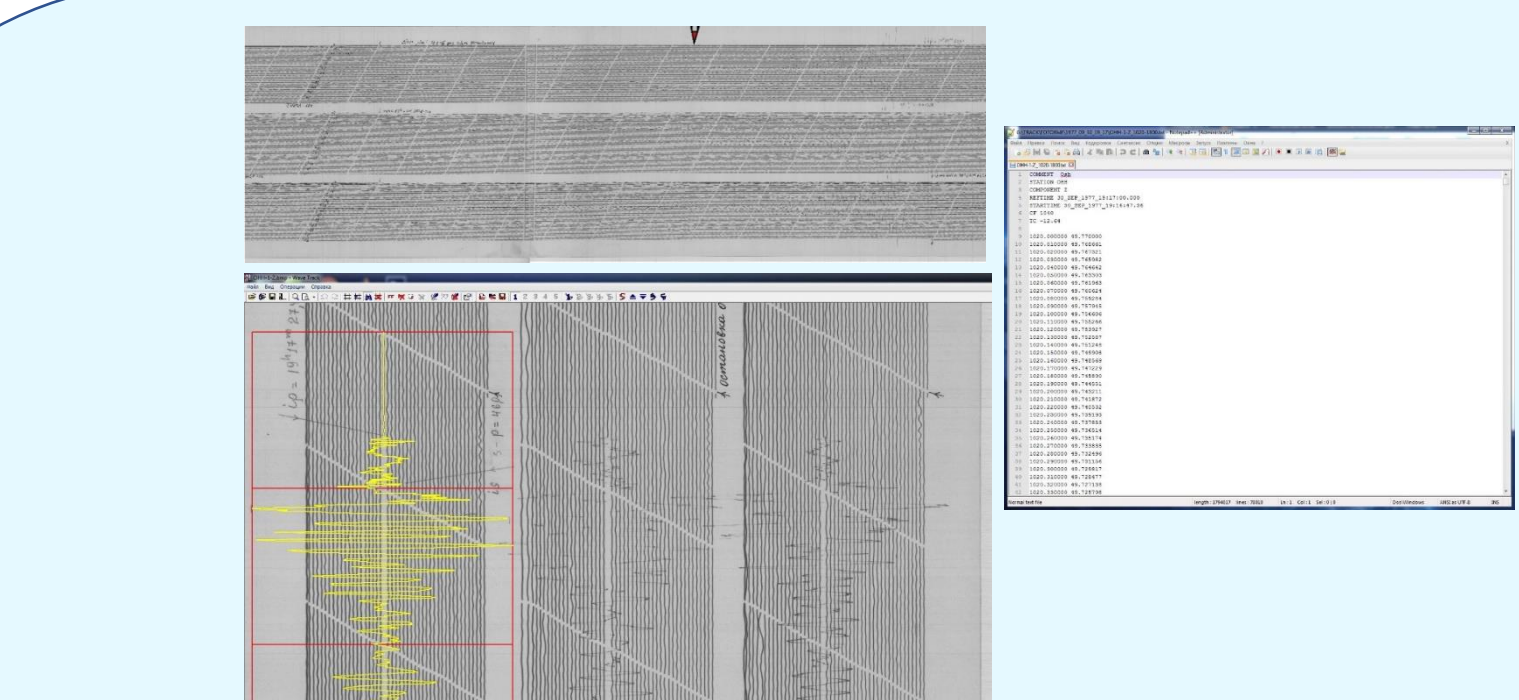


Diagram of scanned seismogram distribution



Example of the «WaveTrack» software work for the earthquake of 30.09.1977 (K=12.8, M=4.9, OHH (Osh) station)

Task 2. Training courses for Central Asia specialists

The first international training courses were conducted by the Kazakhstan National Data Centre (KNDC) in Almaty in 2010. The trainees were mainly specialists from the different NDCs of Central Asia countries of the former Soviet Union. In 2018, KNDC started a new cycle of international courses on advanced methods of interpretation and processing of digital seismograms in support of the CTBT under the project supported by the Norway MFA and NORSAR.

Between autumn 2018 and spring 2019, there were 3 one-month courses; 22 persons from 4 countries were trained – Kyrgyzstan, Tajikistan, Uzbekistan, and Kazakhstan.

The lectures and hands-on exercises were given by highly qualified personnel of the KNDC.

The courses were conducted as follows:

1. The first course was held from October 8 to November 2, 2018 and attended by trainees from Kyrgyzstan and Kazakhstan.



First 2018 Training Course

During almost the whole month, in the lecture hall and practice rooms the trainees have studied the fundamentals of seismology (seismic sources, seismic waves, seismic phases and interpretation of wave pattern, earthquake parameters) and became acquainted with data formats, with opportunities to work with data of the world data centers. Detailed discussions were stimulated on how the different countries can contribute to global and regional seismic monitoring by compilation of seismic event catalogues and bulletins. During practical exercises the trainees worked with the software for seismic records processing and tried to process data themselves – locate a source, determine magnitude, and energy class. They got knowledge on records from different types of sources – earthquakes, mining explosions, nuclear tests, as well as on possibilities to discriminate between source types by peculiarities of seismic records. During the course the trainees got information on notable scientists of the world, particularly, of the Soviet Union, geophysicist and seismologists, who contributed a lot to the most important discoveries regarding the Earth structure, and got acquainted with velocity models, and methods for source parameters determination, etc. Upon the completion of the course the trainees obtained their certificates.

2. The second courses were held from November 10 to November 30, 2018. Trainees from Tajikistan and Kazakhstan attended the courses.

All trainees from Tajikistan work at the Institute of Geology, Seismic Engineering and Seismology of the AS of the Republic of Tajikistan. The second course was also attended by new staff of Kazakhstan Data Centre and of the Institute of Geophysical Researches, who have been employed recently and just started to learn the work of waveform analysts.

A new version of ELRESS software developed by Dr. V. Asming (Kola Research Centre of RAS) for work with seismic waveforms and seismic event location was presented during the practical exercises at the first and second courses. The software options were shown: access to seismic and infrasonic data, manual processing of seismic events, analysis of location errors and velocity models discrepancies, creation of seismic events database. The principles of construction and some results of the automated system for regional seismicity monitoring NSDL dedicated for automated detection and location of seismic events were shown. All trainees obtained their certificates.



Second Training Course in 2018

3. The third course was held from April 8 to April 30, 2019; the trainees were from Uzbekistan and Kazakhstan.

The first lecture was given by N. Mikhailova, who told the trainees about the CTBT, and the International Monitoring System created for CTBT verification monitoring, about the International Data Centre, the Kazakhstan Data Centre (KNDC) and its role in global and regional monitoring.

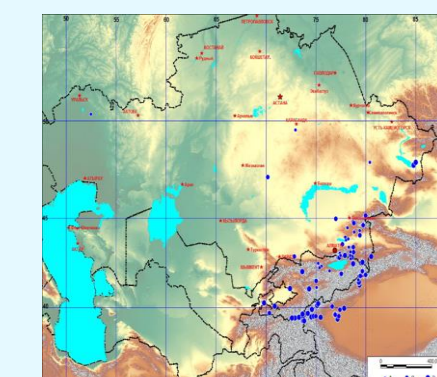


Third Training Course IN 2019

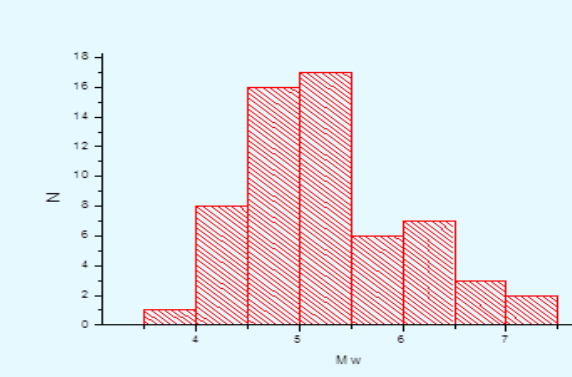
Task 3. Joint investigations in support of cooperation between Central Asia NDCs, and creation of the regional seismic bulletin

1. Joint work on study of aftershock sequences conducted by KNDC and the NDC-KG

For the investigation, 80 large and moderate crustal earthquakes ($3.7 \leq M_w \leq 7.3$) with aftershocks occurring on the territory of Kazakhstan, Kyrgyzstan and bordering regions within the territory constrained by $39.22 - 50.33^\circ$ N, $52.50 - 85^\circ$ E from 1955 to 2016 were selected. The figure below shows the map of epicenters of selected events and distribution of the selected earthquakes by magnitudes. The largest earthquakes are: Suusamyr of August 19, 1992, magnitude 7.3; Markansuu of August 11, 1974, magnitude 7.1.



The map of main shock epicenters by magnitudes. 1- $M_w < 5$; 2- $5 \leq M_w < 6$; 3- $6 \geq M_w$



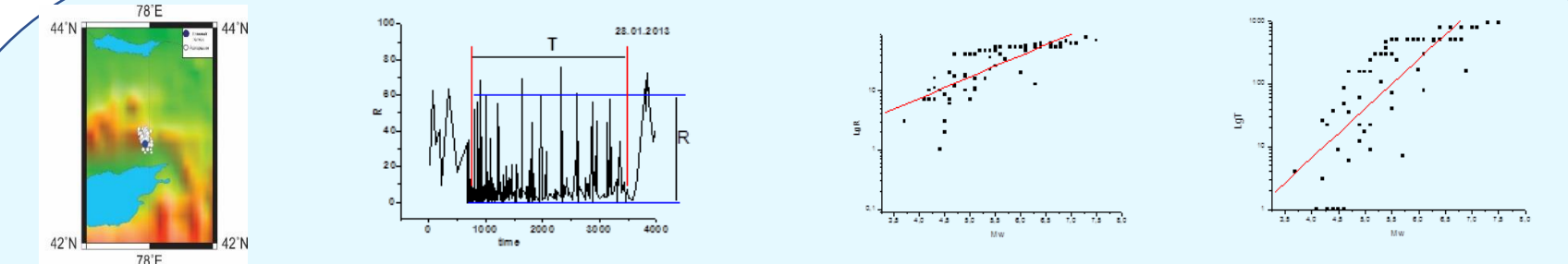
Distribution of the main shocks

Aftershock sequences were collected for all selected earthquakes based on the earthquake catalogue created under the EMCA project, the KNDC catalogue, and the IS catalogue in Kyrgyzstan. The Kazakh and Kyrgyz colleagues either combined the different catalogues for the selected sequence or chose one catalogue, most often the one representative for the territory in which the main shock happened.

The next stage of the work was studying the functions $R = f(M)$ and $T = f(M)$, where R is the mean radius of the aftershock area, T the time length of the aftershock sequence, and M the moment magnitude. To determine R_i and T_i for every i-th main-shock the following method was used: the function $r_i(t)$ shows the change of distance between the main shock epicenter and the epicenters of each considered aftershock as function of time. The graphs $r_i(t)$ were constructed by the discrete values r_j and t_j , corresponding to the place and time of j-th aftershock regarding the i-th mainshock.

For every i-th earthquake sequence the analysis was performed for the territory exceeding the area of the largest possible territory for aftershocks for a mainshock with moment magnitude $M=M_i$. The determination of the territory size was based on the values of source length L in kilometers (or rupture in the source). The estimation of T_i , i.e., selection of the time, when the aftershock activity is finished, for each graph $r_i(t)$ was made by comparison of earthquake recurrence rate within the considered area against the background seismicity level. The seismic history for every i-th event is defined by a period of 2 years. The conclusion on the size R_i was made by joint analysis of graph $r_i(t)$ and the corresponding epicenter maps.

The graphs $r_i(t)$ are very convenient and universal instruments for such analysis. They allow investigating the evolution of each aftershock sequence, estimating the spatial-temporal parameters of the aftershock area and in addition, they allow an understanding of seismic mode features during large event preparation, and determination of the time and size of cluster areas, their activation, etc.



An example for an epicentral map with mainshock and aftershocks

The graph $r(t)$ for the earthquake on 28.01.2013

Graphs: a) for the size of the focal area and b) for the duration of the aftershock sequence depending on the event magnitude M_w

This approach was applied for the analysis of all selected earthquakes, and a database of aftershock sequences from a combination of aftershock catalogues was created. The following relations were obtained after regression:

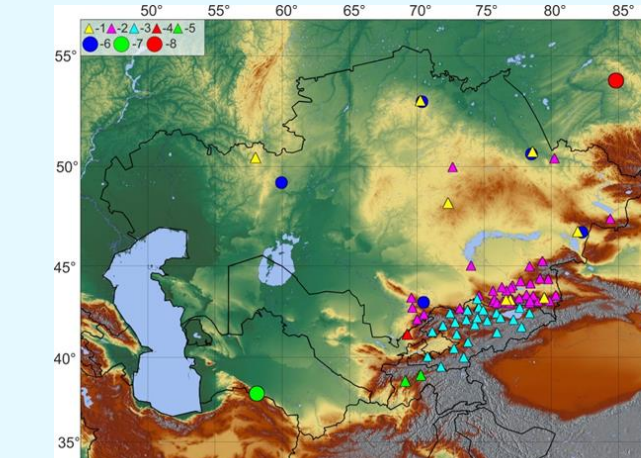
$$\lg T (\text{days}) = 0.78 \cdot M_w - 2.31, \quad \lg R = 0.36 \cdot M_w - 0.58$$

The work on the analysis of aftershock sequences is ongoing. Every event will be studied together with its focal mechanism and tectonic settings.

2. Creation of the regional bulletin for Central Asia.

One of the items of the research project is the compilation of a new and more accurate bulletin of seismic events for the territory of Central Asia. This task is implemented based on the developed technology by using results of seismic event processing from the bulletins of different seismic services. The figure below shows a map of seismic stations and arrays, whose data are used for the creation of the new regional joint bulletin.

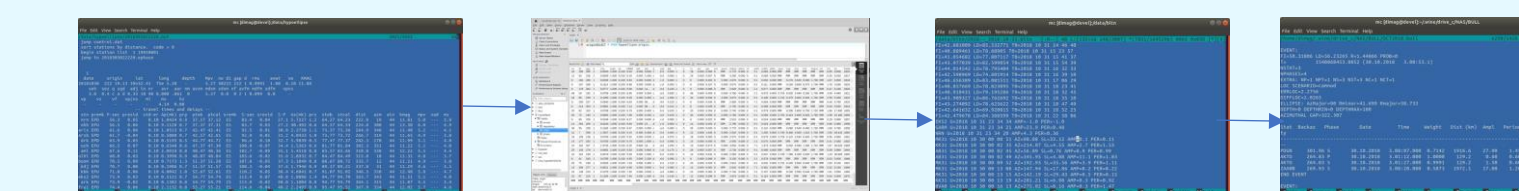
- The map of seismic stations location: (1) 3-component stations of the IGR RK; (2) 3-component stations of the SEME RK; (3) 3-component stations of the IS KR; (4) 3-component stations of Uzbekistan; (5) 3-component stations of Tajikistan; (6) seismic arrays of the IGR; (7) seismic array of Turkmenistan; (8) seismic array of Russia.



In total, 79 three-component stations and 7 seismic arrays were used for the compilation of the regional seismic bulletin.

This technology represents a set of software solutions providing an opportunity to create a joint catalogue of seismic events. The platform for this technology operation is Linux, the database server is MySQL and MongoDB, and the main programming language is Python 3.x.

The first stage in this technology operation is the process of data collection from seismic events recorded by the network of Kyrgyz, Uzbek, and Tajik stations. The data exchange is typically based on forwarding of files via e-mail. The received files are text-file bulletins of seismic events in Hypoellipse format that are automatically converted and saved in the database.



Example of initial seismic bulletin and its further conversion

Currently, there are about 950 received files containing information on about 1200 seismic events.

The next stage is joining the received data with the results of seismic event processing of the Kazakh seismic network that, in turn, is the joint bulletin and includes the results of seismic data processing by the station networks of the Institute of Geophysical Research ME RK, the Seismological Experimental-methodical Expedition of RK., IS KR, and 1 station of Turkmenistan, and 1 Russian station.

At this stage, a file is prepared in a format that contains information on seismic events from two catalogues. The file contains information on origin time (T_0), coordinates of seismic events, on arrival time of phases (for each station), amplitudes and periods of seismic waves, and values of azimuth and slowness for the seismic arrays. The file format can be read by the NAS software created by V. Asming; this software associates the received results and re-locates seismic events. The software was developed for Windows OS, however it was managed to use it under Linux OS. The software output are text bulletins of seismic events. The application of this software is the next stage in the process of the seismic event joint catalogue preparation.

In conclusion we can summarize that all points of the project under NORSAR support enhance appreciably the capacities of both KNDC and NDC-KG within the frame of CTBT cooperation.