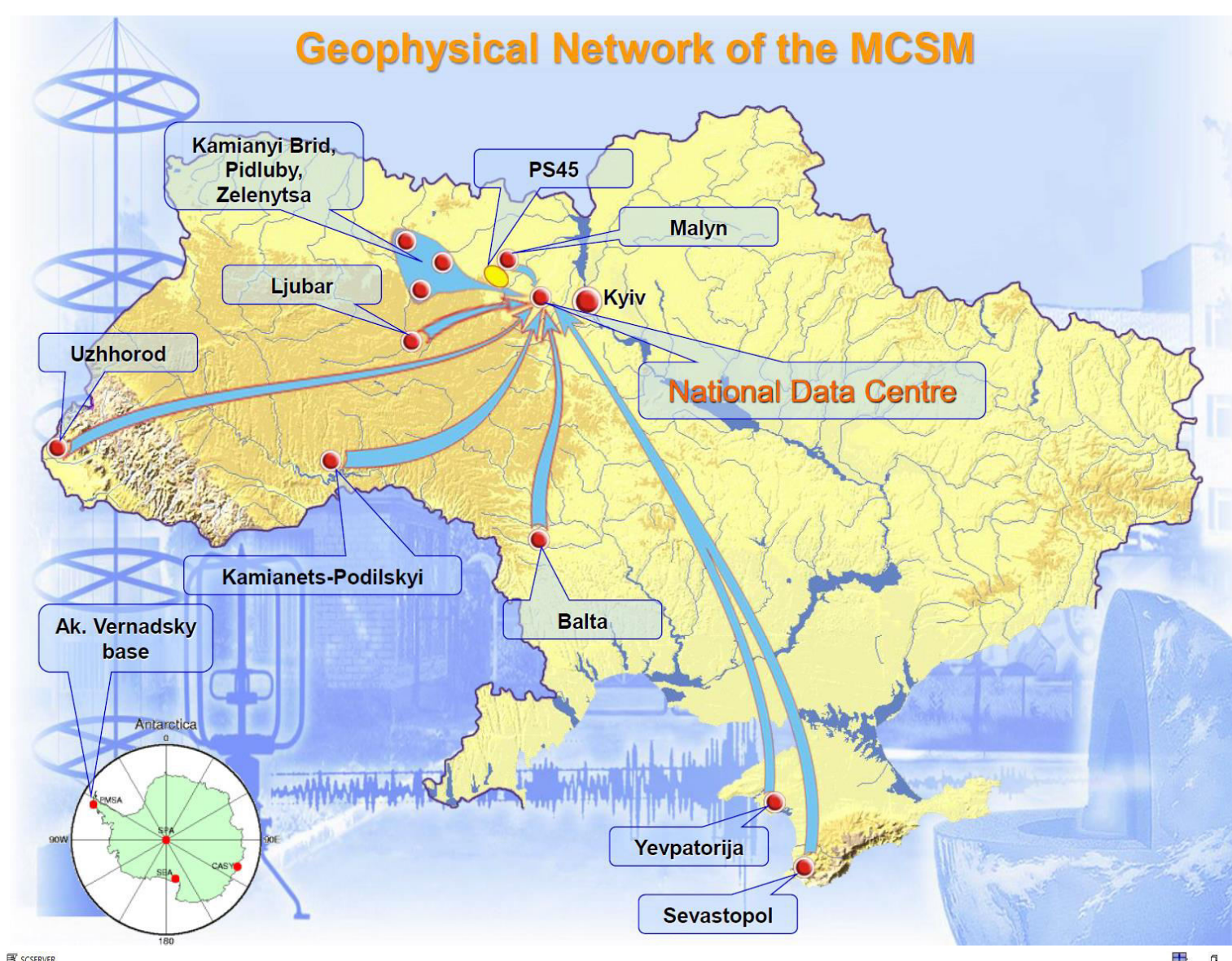
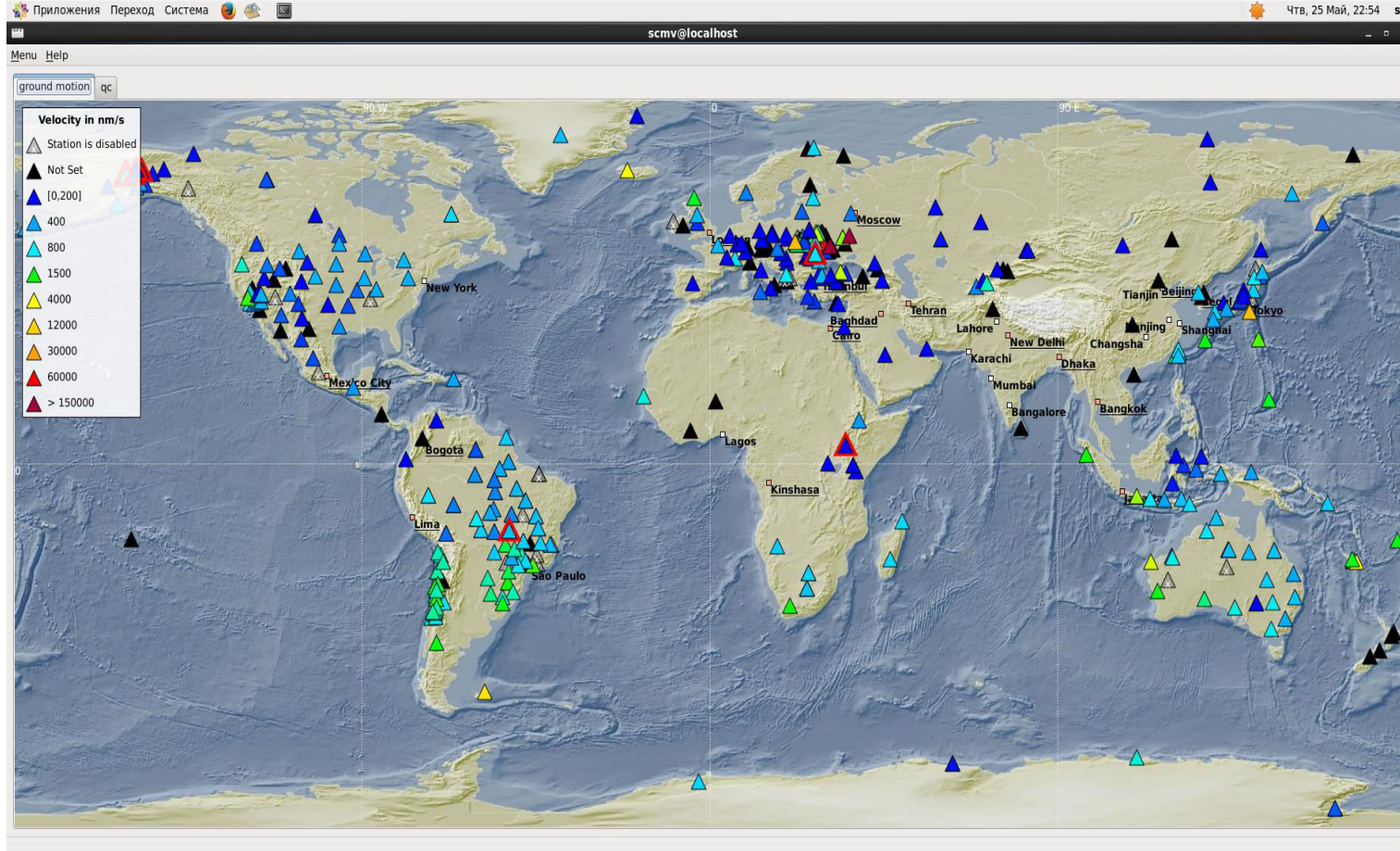
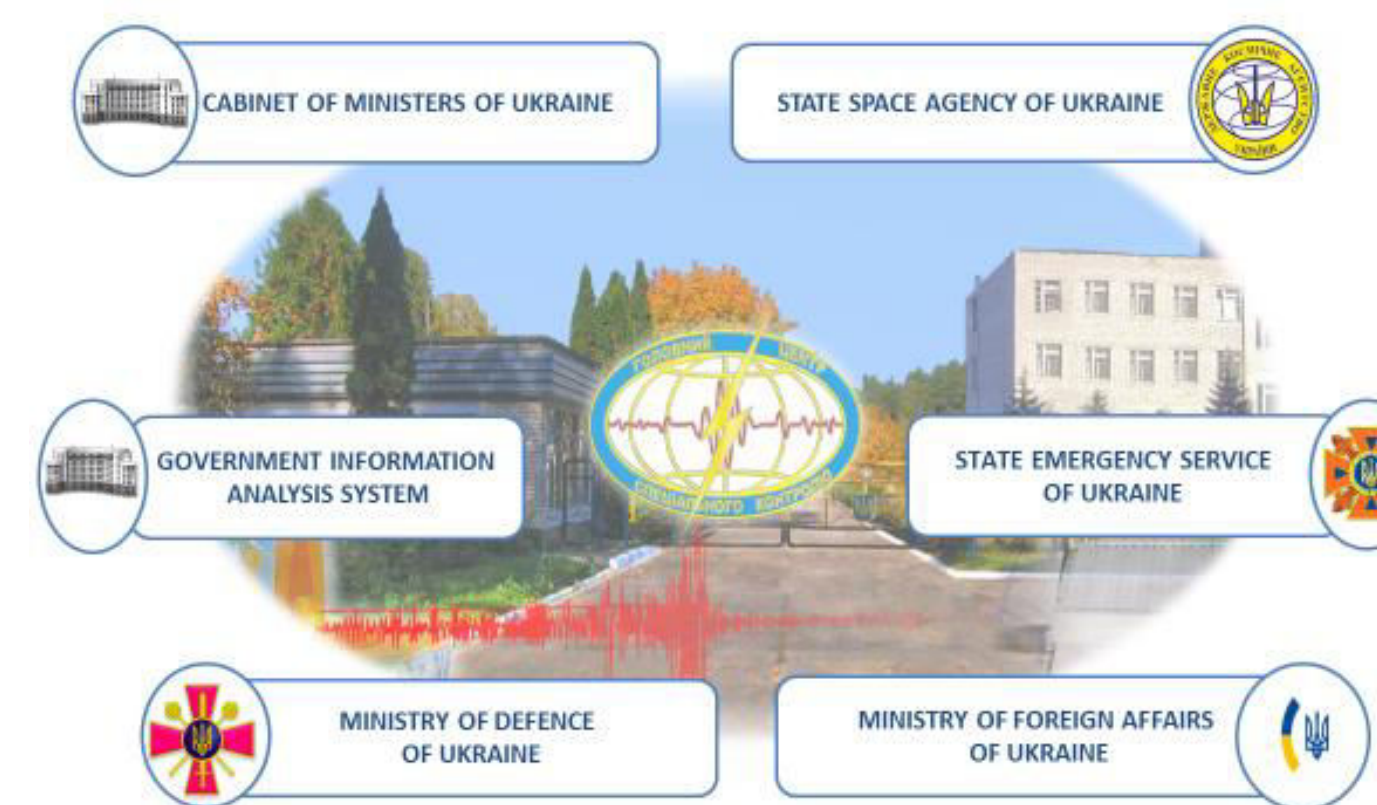


Registration of events from DPRK test site in 2016 by facilities of Main center of special monitoring

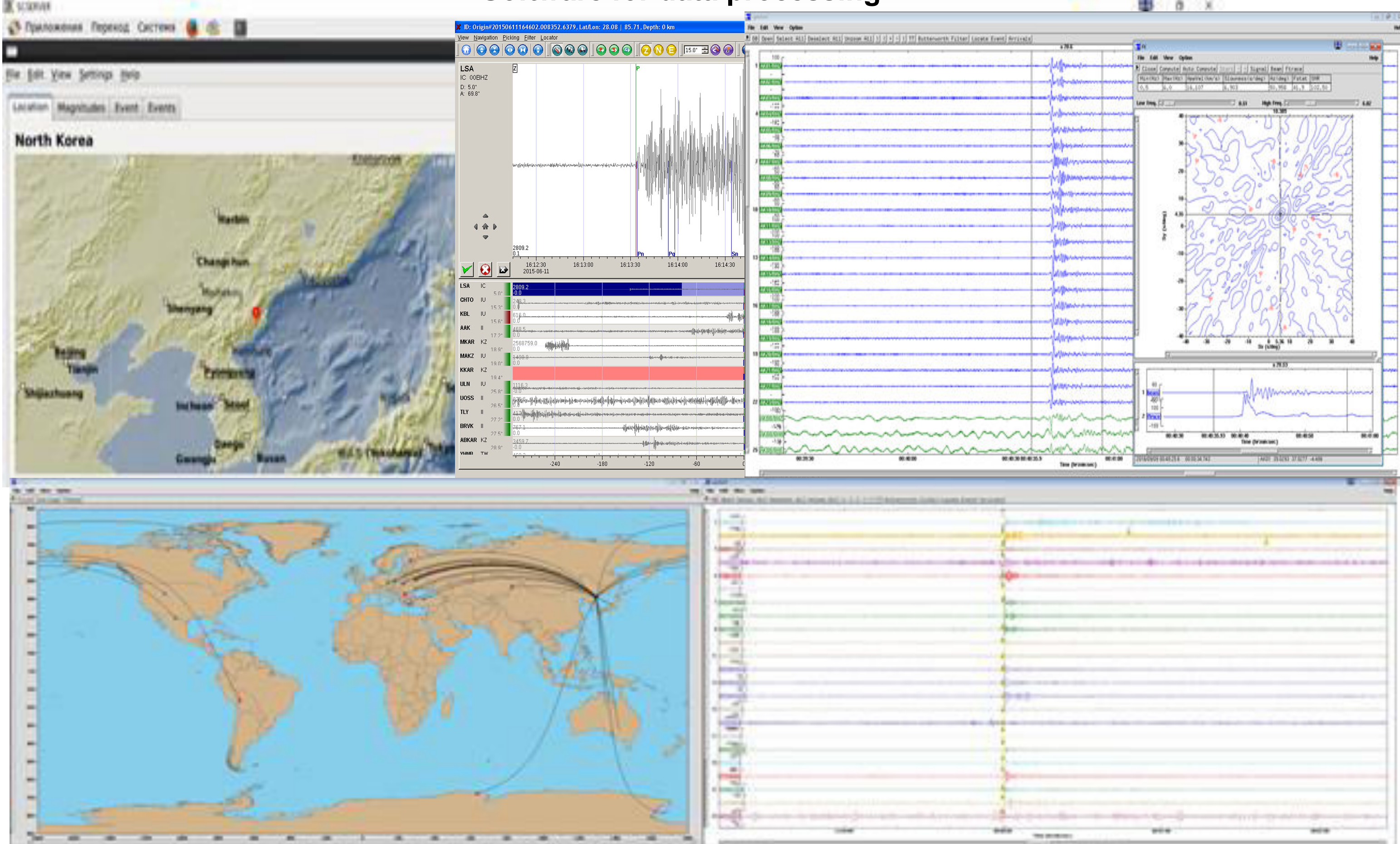
Both events in 2016 from DPRK test site were confidently registered by all national stations including primary IMS station PS45. Due to a limited time to make a decision about event in addition to the data from national network the data from global networks were also used. For data processing were used SeisComp3, Geotool from ENIAB package and some local software to estimate depth and energetic parameters, cross-correlation analysis and determine the nature of event/



GOVERNMENT USERS OF MCSM INFORMATION



Software for data processing



Results of events processing

Event from DPRK test site on 06 January 2016

SeisComp3 automatic detector
(first origin at 01:33:37)

Time: 01:30:03
Lat. 41,23 N
Long. 128,95E
Depth 10 km
mb - 5,3

Manual processing by on-duty analyst (01:45)

Time: 01:30:02
Lat. 41,3 N
Long. 129,1 E
Depth 0 km
mb - 5,2

Estimated power 18 kt

Event from DPRK test site on 09 September 2016

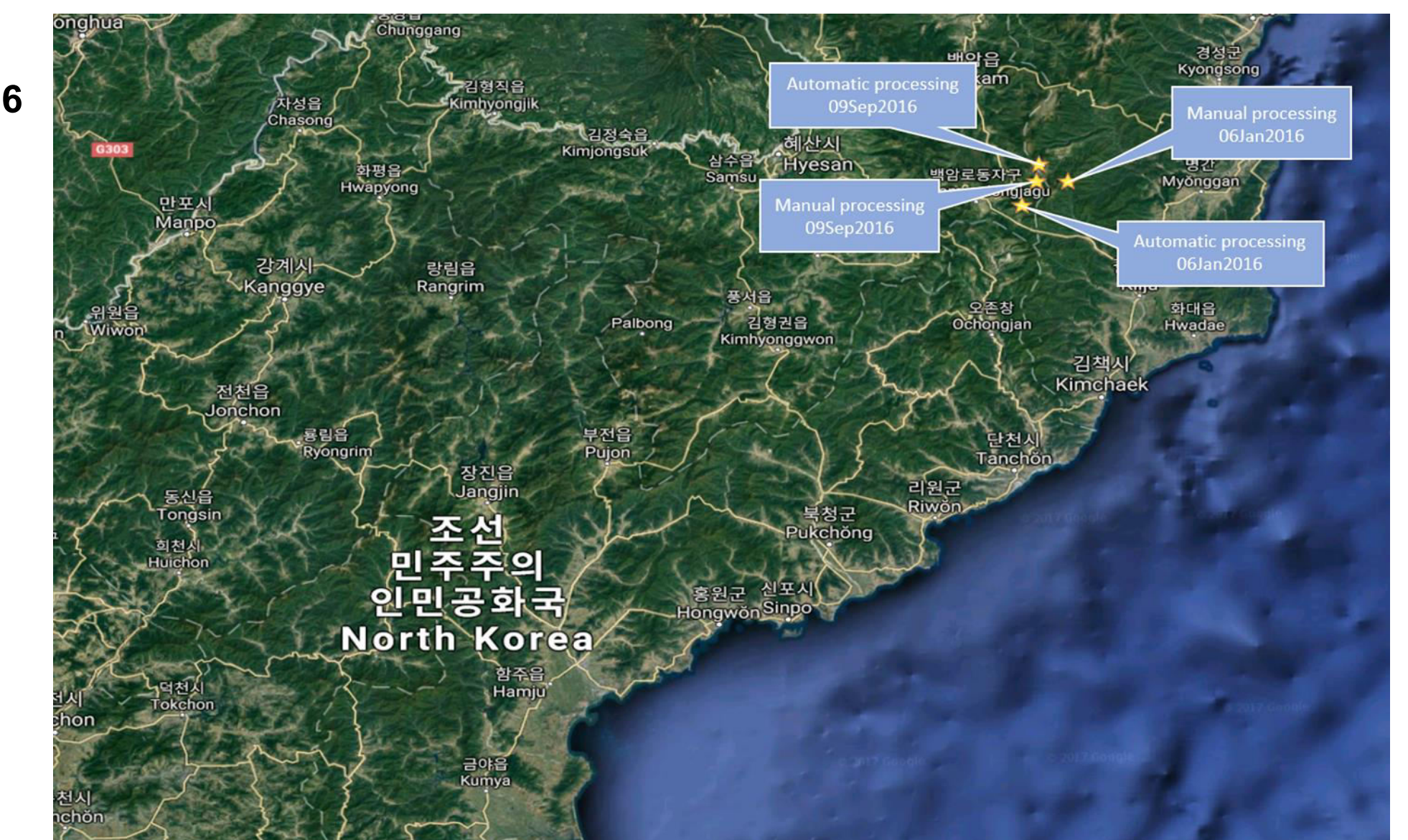
SeisComp3 automatic detector
(first origin at 00:33:25)

Time: 00:30:03
Lat. 41,35 N
Long. 129,01 E
Depth 10 km
mb - 5,1

Manual processing by on-duty analyst (00:38)

Time: 00:30:01
Lat. 41,3 N
Long. 129, E
Depth 0 km
mb - 5,3

Estimated power 25 kt



Determining of event nature

To solve the problem of identifying seismic signals from explosive events, we use method that is based on differences in the amplitude of envelope signals from earthquakes and explosions as a function of frequency. At the first stage of the implementation of this method, the normalized values of the amplitudes of the seismic envelope are calculated in the frequency range from 1 to 18 Hz:

$$F_i = \frac{S_i}{\bar{S}}$$

F_i – the normalized value of the amplitude of the envelope of the wave fragment (signal or background) for the frequency i ; S_i – amplitude of the envelope of the wave fragment (signal or background) for the frequency i ;

$$S_i = \sum_{k=1}^N G_{ik}$$

N – duration of the signal (background) sample. Estimation of the total energy of the wave fragment (signal or background section) is as follows:

$$\bar{S} = \sum_{i=1}^{18} S_i$$

In order to take into account the background conditions in the area of the seismic station at the time of arrival of the seismic signal, the distribution of the amplitudes of the envelope of the wave fragment for the portion of the microseismic background preceding the seismic signal.

The next step is to determine the ratio of the amplitudes of the envelopes of seismic signals and background areas preceding them at the corresponding frequency:

$$K_i = \frac{F_i^e}{F_i^b}$$

K_i - ratio of the amplitudes of envelopes of seismic signals and the background sections preceding them at a frequency i ; F_i^e – normalized value of the envelope amplitude of a seismic signal at a frequency i ; F_i^b – The normalized value of the envelope amplitude for the background section preceding the seismic signal at the frequency i .

To obtain a numerical coefficient that unambiguously characterizes the nature of the seismic source, we find the sum of the values of K_i for frequencies i in the range 1 – 9 Hz (where the maximum values of K_i are concentrated for earthquakes) and for frequencies i in the range 10-18 Hz (where the maximum values of K_i are concentrated for explosions), after which we calculate their ratio K .

$$K = \frac{\sum_{i=1}^9 K_i}{\sum_{i=10}^{18} K_i}$$

The decision on the nature of the source of the seismic disturbance is made on the following values: $K > 1.05$ - "explosion"; $0.95 < K < 1.05$ - "uncertainty zone"; $K < 0.95$ - "earthquake".

Additional analysis

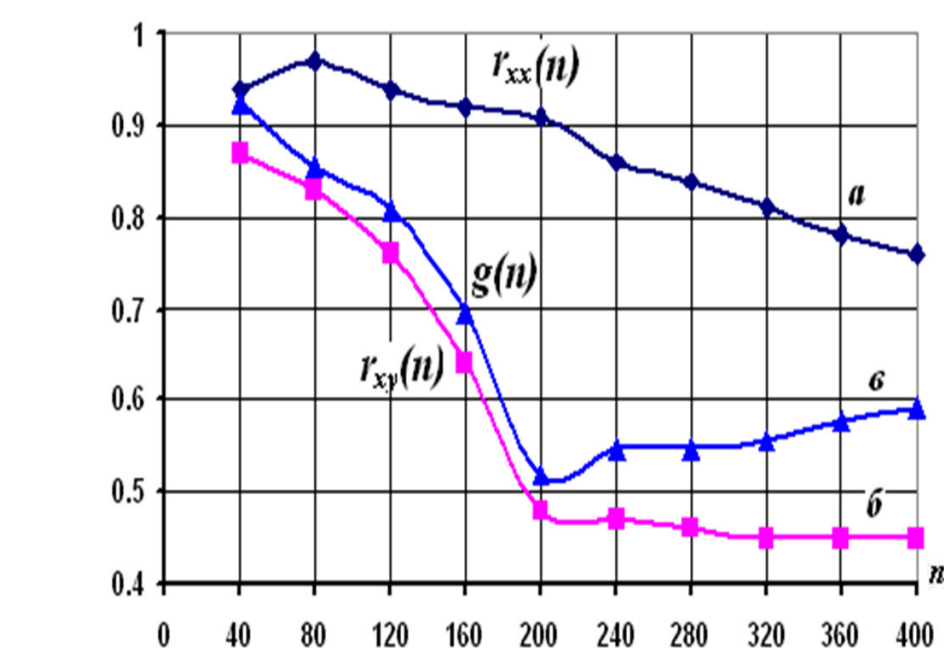
Cross-correlation analysis

Identification of the seismic signal from the UNE from the DPRK TS is performed by determining the degree of cross-correlation between the first arrivals of the registered seismic signal and the previously recorded signal from the UNE from the DPRK TS selected as the reference.

$$\hat{r}_{xy} = \frac{R_{xy}}{\sqrt{\bar{D}_x \cdot \bar{D}_y}}$$

\hat{R}_{xy} – an estimate of the value of the correlation moment between the signals $x(t)$ and $y(t)$; \bar{D}_x , \bar{D}_y – estimates of dispersion $x(t)$ and $y(t)$ respectively.

Determination of the duration of the seismic signal recording section for the implementation of the correlation schema for detecting the signal from the UNE from the DPRK TS is performed by searching for the minimum of the function of the ratio of the cross-correlation coefficients $g(n)$ for signals from UNEs and earthquakes.



$\hat{r}_{xx}(n)$ – cross-correlation coefficient between the reference signal and signals from DPRK TS UNE; $\hat{r}_{xy}(n)$ – cross-correlation coefficient between reference signal and signals from earthquakes in region of Honshu Island.

As a reference, the signal from the UNE on 09.10.2006 was used. The cross-correlation coefficient $\hat{r}_{xx}(200)$ between the signals from DPRK TS UNE and the reference signal: 0.91 for the explosion on May 25, 2009, 0.96 for the explosion on February 12, 2013, 0.98 for the explosion on January 6, 2016 and 0.94 for the explosion on September 09, 2016.

Conclusions

The information about the both events were processed very quickly and forwarded to superior authorities. Results of processing showed that events location occurred at the region of DPRK test site. Differences between automatic and manual location are about 14 km for 06 January and 5 km for 09 September. Additional analysis confirm that events had explosion nature and cross-correlation coefficients were 0.98 for the explosion on January 6, 2016 and 0.94 for the explosion on September 09, 2016 in relation to signal from DPRK UNE on 09 October 2006. Simultaneous use of several methods allows to identify both events with high reliability as underground nuclear explosions