

L. I. MOROZOVA

CLOUDS

as forerunners

OF EARTHQUAKES

The screen formed by banks of clouds can appear in the seismically active region at any stage of an earthquake. The Sea of Okhotsk. Photo taken from the Terra satellite (NASA/GSFC, Rapid Response)

The atmospheric clouds of meteorological nature have no clear line boundaries; it is hence understandable why linearly extensive banks of clouds found on the satellite images made in the beginning of the space era provoked interest of the scientific community in this phenomenon. A comparative analysis of the photos and maps of the earth's crust faults has shown that the cloud anomalies were related with the geological structure, namely with the faults of the earth's crust. Though the nature of the unusual phenomenon is not clear yet, the information accumulated allows of practical applications, namely, indicating seismically active regions



Lidia I. MOROZOVA, Candidate of Geography, senior researcher of the Laboratory of Natural Geophysical Fields, the Institute of Petroleum Geology and Geophysics SB RAS (Novosibirsk). She is the author and co-author of 42 scientific papers and one patent

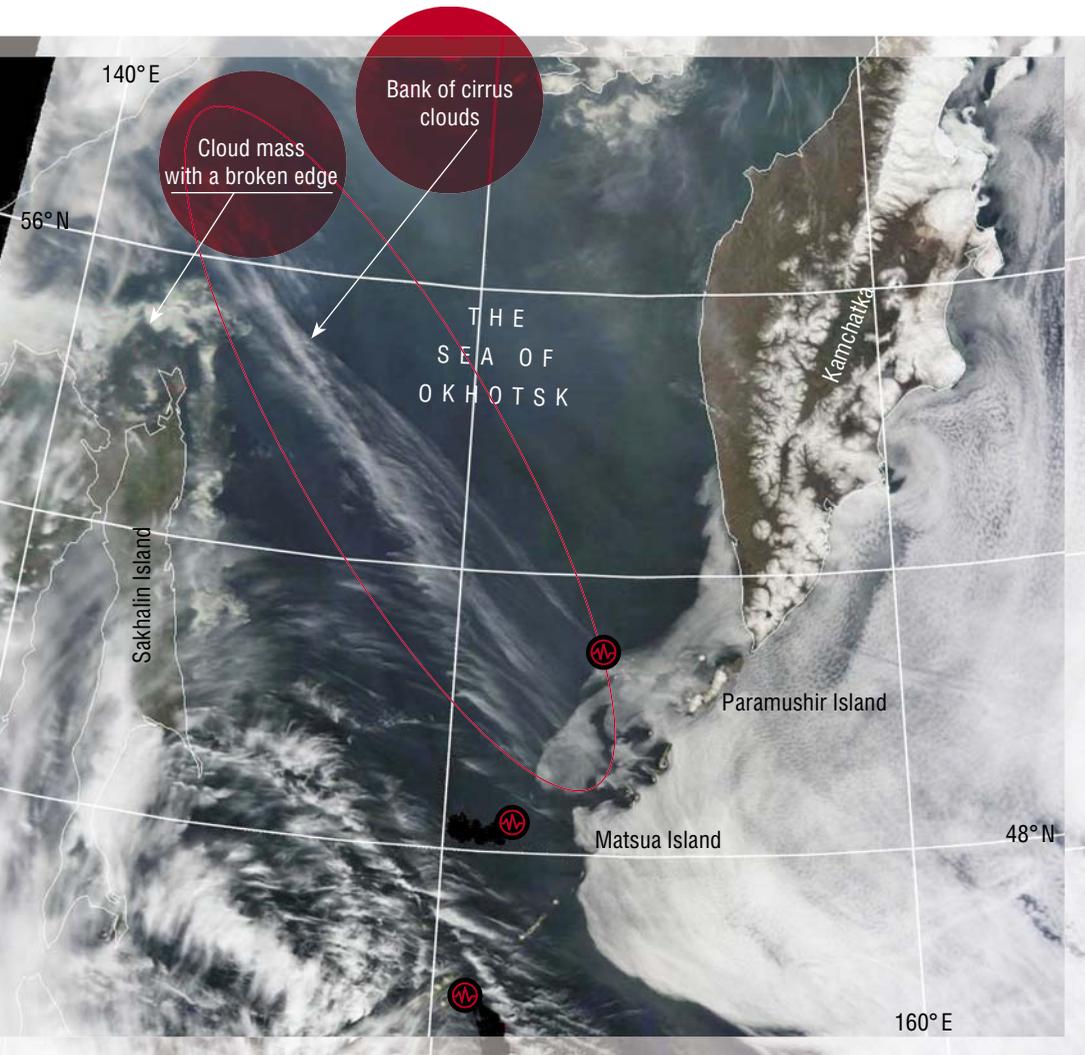
In the first half of the 20th century, French geologist A. Schlumberger, doing field studies in the Alps, and outstanding Russian geologists I.V. and D.I. Mushketovy, working in Central Asia, discovered cloud banks not be blown away by the airstream which were formed over the *earth's crust faults*.

Though there was no convincing explanation of the physical principles underlying this phenomenon, it later (in the 1970s) found wide use in space geology. On the images of the Earth taken from the outer space, the cloud boundaries were sufficiently clear to carry out a mapping of faults in the shelf zones of the continents. The famous geologist P.V. Florensky used the images of cloud banks to find petroleum regions in the mid-Volga Region and on the peninsula of Mangyshlak in the Caspian Sea.

Satellite observations revealed that linear clouds can be several hundred and even thousand kilometers long. Another natural phenomenon was discovered shortly, commensurable in its meaning with the former but opposite in its nature – thinning out of clouds over faults (Morozova, 1980). The latter phenomenon can show in two ways: either as a narrow cloud gap (canyon) in a continuous cloud cover or by forming a clear-cut fixed linear border of a cloud massive coming over a fault. *Linear cloud anomalies* (LCA) is a common name given to these three types of unusual cloudiness.

Key words: earthquake forecasting, lithosphere-atmosphere coupling, the linear cloud anomalies, satellite images

© L.I. Morozova, 2012



An extended bank of cirrus clouds of the upper layer of atmosphere (at the height of 12—14 km) appeared over an earth crust fault under the Sea of Okhotsk. On the following day, a chain of strong underground seismic shocks occurred on the Kuril Islands; in two weeks, the volcano on Matsua Island erupted. The broken edge of the cloud mass to the north of Sakhalin Island reflects a geodynamic interaction of a group of short faults. *The photo taken from satellite Terra (NASA/GSFC, Rapid Response) on May 31, 2009*

— earthquake focus

Before an earthquake

On the one hand, this phenomenon obviously cannot be caused by the atmospheric processes alone, since LCA are connected with the geology of a locality: they copy the configuration of the earth's crust faults. On the other hand, there exist a great many faults, while only some of them are reflected in cloudiness: appearing and vanishing from time to time, they live for some minutes or several hours, or sometimes even for longer than a day. According to Academician F.A. Letnikov (2002) from the Institute of the Earth Crust SB RAS, the reason for this is that faults influence the atmosphere only in the periods of their tectonic and energetic activity.

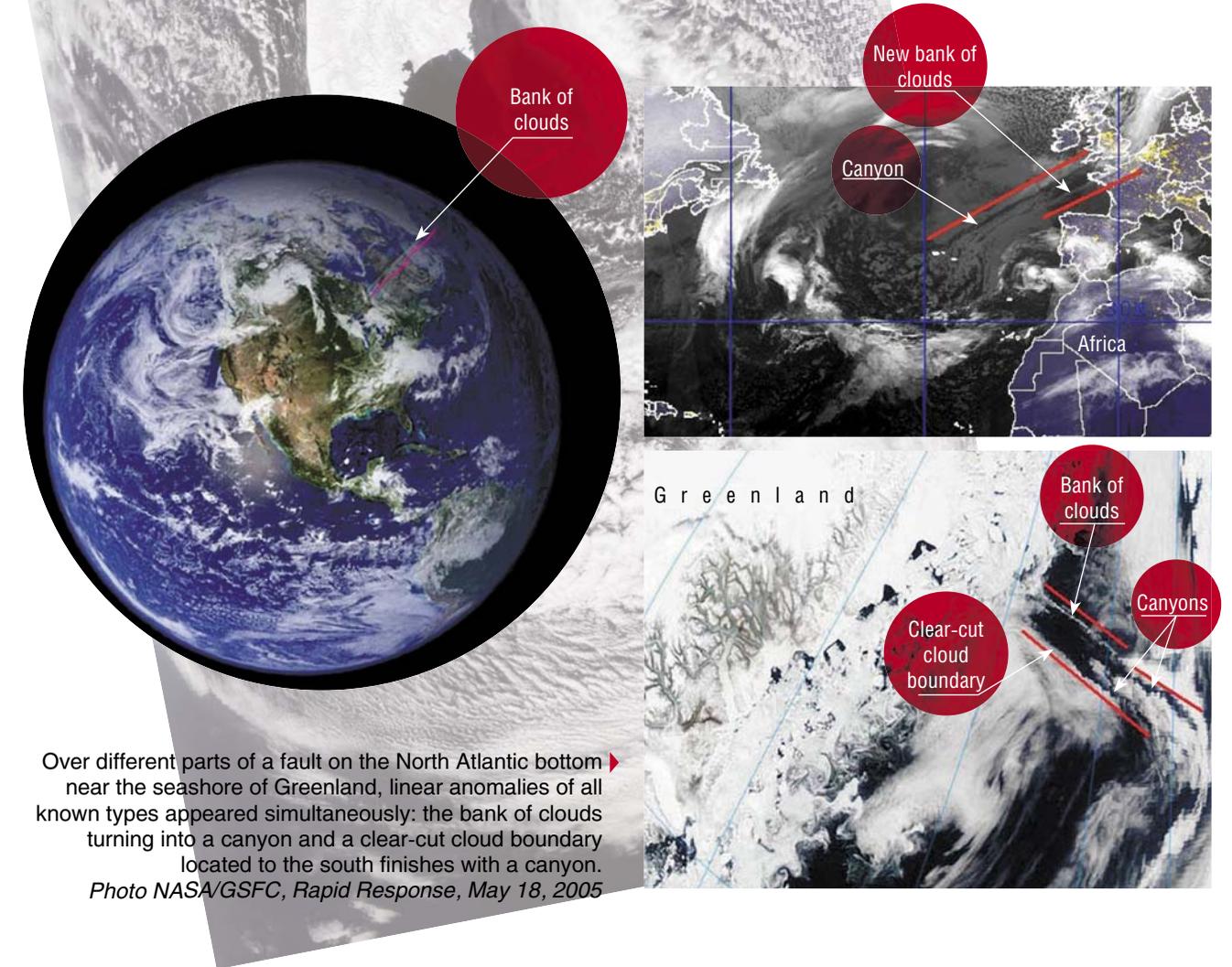
In other words, linear cloud anomalies are of lithospheric nature, and their advent signalizes an activation of geodynamic processes. Such processes are often followed by an earthquake. Hence, LCA monitoring is yet another way to forecast a coming disaster.

From the time when the wide scientific community got access to meteorological satellite images (for example, on the Russian Federal Space Agency site) up to now, enough information has been accumulated to establish a correlation between a forthcoming earthquake and a certain cloud condition. Thus, it was found that a swarm of LCA emerges a few hours (or sometimes one or two days) before an earthquake (Morozova, 2008).

It can happen that in the same image both banks and canyons appear over different faults or over different parts of the same fault. Evidently, geodynamic activity can lead both to cloud generation and cloud degradation depending on the condition of the atmosphere.

Dynamics of cloud disruption by an emission from a fault can be illustrated by the photos of the cyclone coming from the continent to a seismically active region, which occurred in March 2011 off the Japanese coast. While the cyclone

A bank of clouds spread over the North Atlantic: from the Newfoundland Peninsula to the Baltics (*on the left*). On March 9, 2011, a canyon 3,000 km long formed parallel to this bank length. Another bank of clouds appeared over the Bay of Biscay (*to the right*). *The photos taken from satellite at a geostationary orbit (NASA/GSFC, Rapid Response) and from satellite MultiSat (Naval Research Laboratory, Marine Meteorology Division, Monterey, CA)*



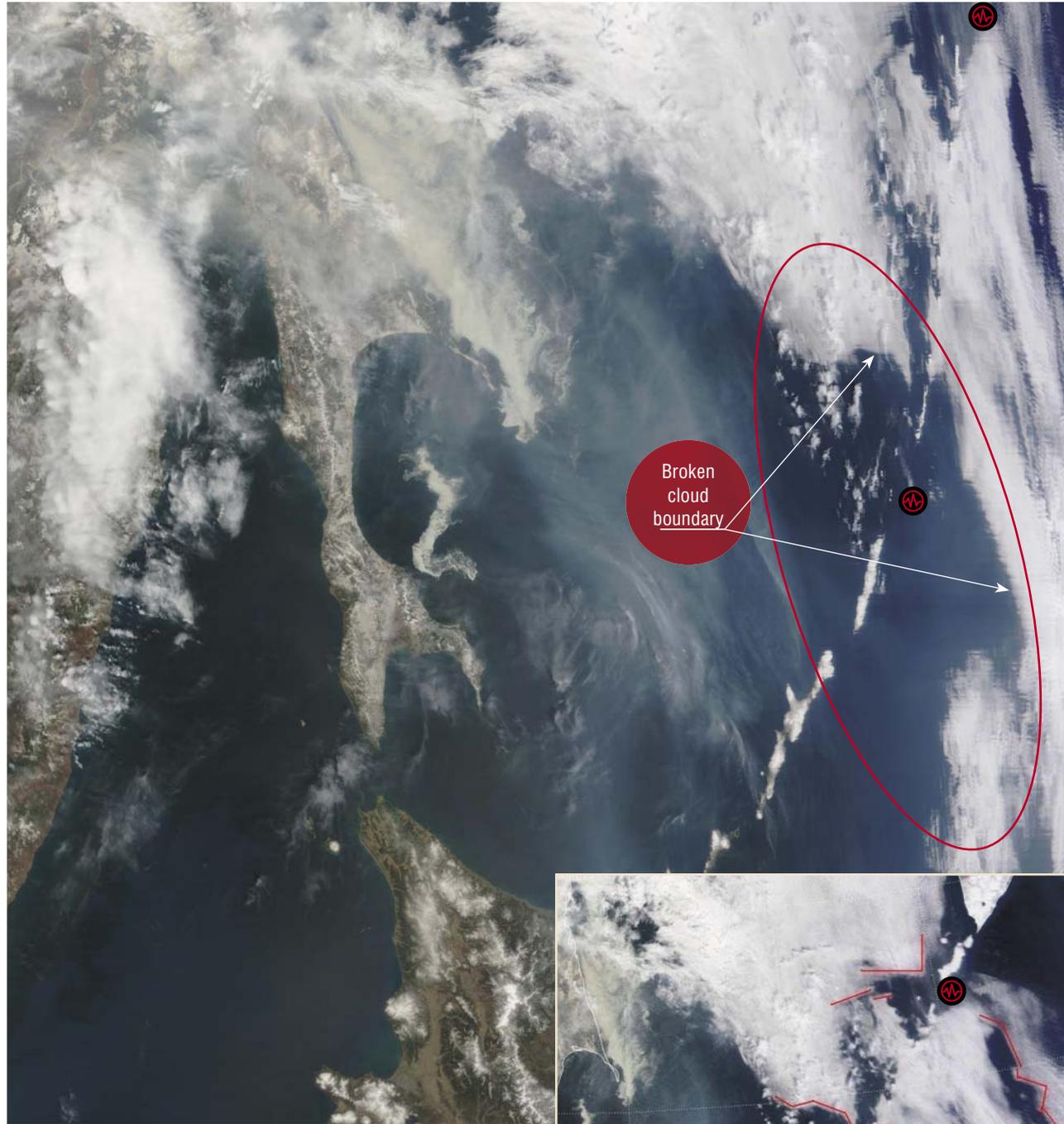
Over different parts of a fault on the North Atlantic bottom near the seashore of Greenland, linear anomalies of all known types appeared simultaneously: the bank of clouds turning into a canyon and a clear-cut cloud boundary located to the south finishes with a canyon. *Photo NASA/GSFC, Rapid Response, May 18, 2005*

was out of that area, its vortex cloud field had a typical round shape with a fuzzy edge. As the cyclone was moving towards the seismic zone and came to be affected by the emission from the linear fault of the earth crust, a vertical wall, depicted in the image as a sharp linear boundary of cloudiness, rose in the cloud field of the cyclone.

Apart from the LCA caused by lithospheric faults, forerunners of earthquakes can be cloud ranges of non-atmospheric nature appearing at the seismic center before a shock. They are supposed to result from fluid emission from the earth interior. These "earthquake clouds" tend to emerge before a shock and after it and keep their position in space as long as several hours or several days. For example,

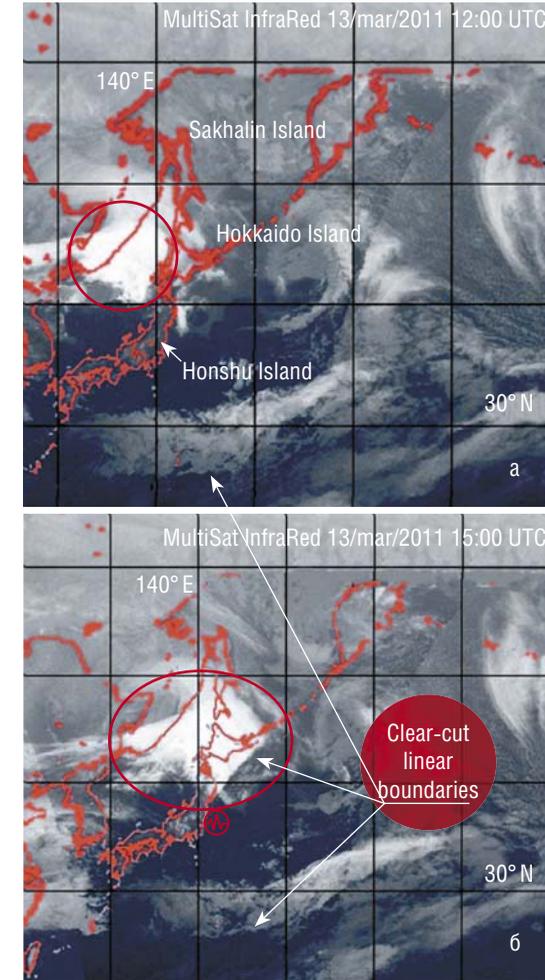
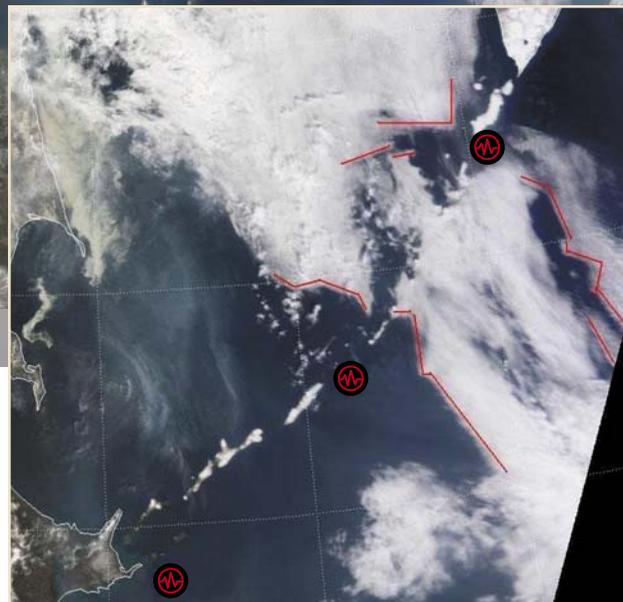
during the disastrous earthquake that occurred in China on May 12, 2008 a short bank of such clouds appeared a day before the first shock over an active fault near the epicenter and could be observed for over a month which was a sign of an increased seismic activity.

Anomalous cloud phenomena can also appear as a result of technogenic earthquakes: inducing seismicity initiates fault activation; faults hence become sources of intense emission. For instance, immediately after an underground nuclear explosion, LCA were observed near this area; they continually vanished and emerged over the following two weeks. During nuclear weapon tests in North Korea, LCA appeared mainly over the faults of the sea bed in the blast



☞ – earthquake focus

The formation of clear-cut angular cloud boundaries in the northern part of the Kuril Islands preceded the earthquakes that occurred throughout the island range (on May 2, there was an earthquake on the Kuril Islands, on May 3, near the island of Hokkaido). *The photo taken from satellite Terra (NASA/GSFC, Rapid Response) on April 30, 2009*



While the cloud field of the cyclone was out of the seismic zone during the series of earthquakes that occurred in Japan on March 11—14, 2011, it had a traditional round shape (a). Three hours later (b) the cyclone reached an active fault and the south-eastern boundary of cloudiness became anomalously straight-line. *The photo taken from satellite MultiSat (Naval Research Laboratory, Marine Meteorology Division, Monterey, CA), on March 13, 2011*

A cloud of unusual configuration hung over Sea of Japan for three hours. This “earthquake cloudiness” resulted from an emission of fluids from the depths. At the same time, a linear anomaly appeared over the small islands southward of Kiushu.

The photo taken from the geostationary satellite NASA on March 28, 2011. (Naval Research Laboratory, Marine Meteorology Division, Monterey, CA)

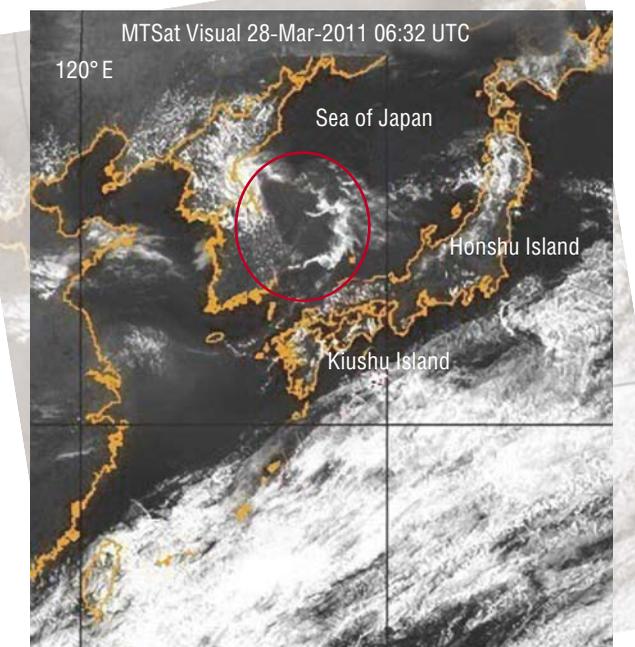
effect areas. Importantly, launching a ballistic missile equals to a small nuclear explosion, as far as the effect on the earth’s crust is concerned.

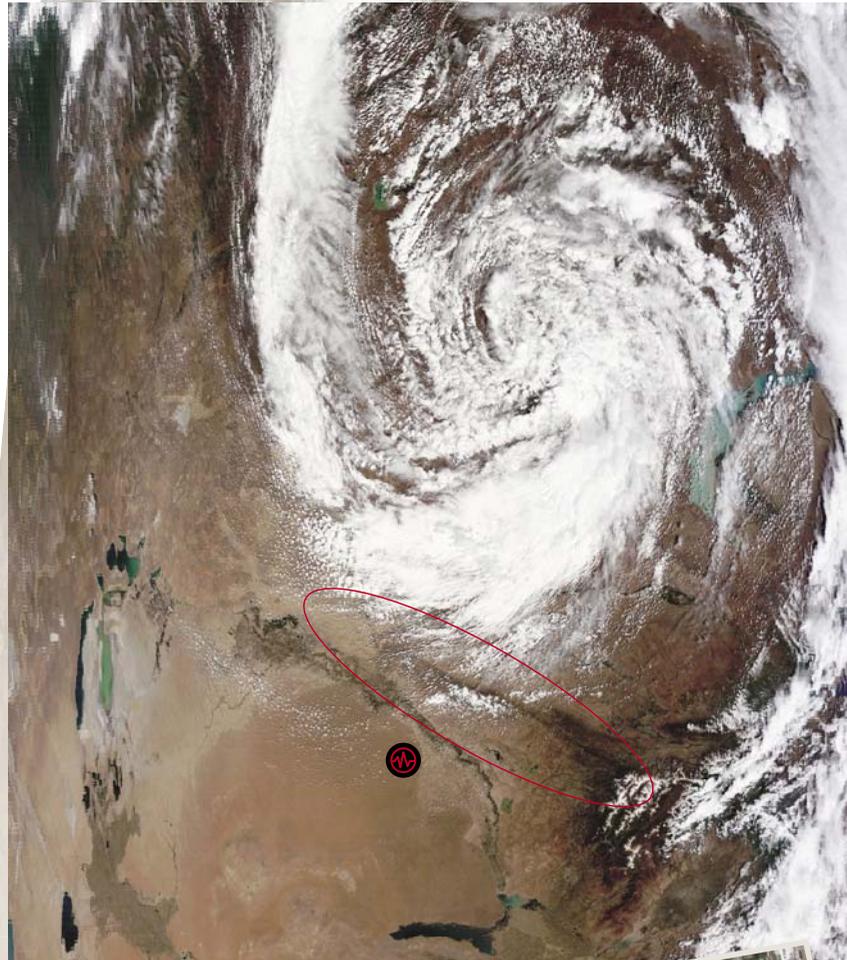
In this manner, LCA satellite monitoring allows of global monitoring of powerful weapon tests at their sites, even when the weather is cloudy. Such monitoring is optimal because it is informative, ecologically safe and cost-effective.

Cloud fluster

Mountain ranges and rock masses create noticeable distortions in airstream distribution and cloudiness. Due to relief heterogeneity on the lee-side of ridges, parallel banks of clouds emerge. In meteorology, this phenomenon is known as *orographic* cloudiness. As an airstream crosses a mountain range, waves form on its lee-side. Within upward cold streams of these waves, banks of clouds arise, while in the warm downward streams cloudless spots originate. The same waves appear in the atmosphere behind islands in the ocean and can be easily seen on the satellite images.

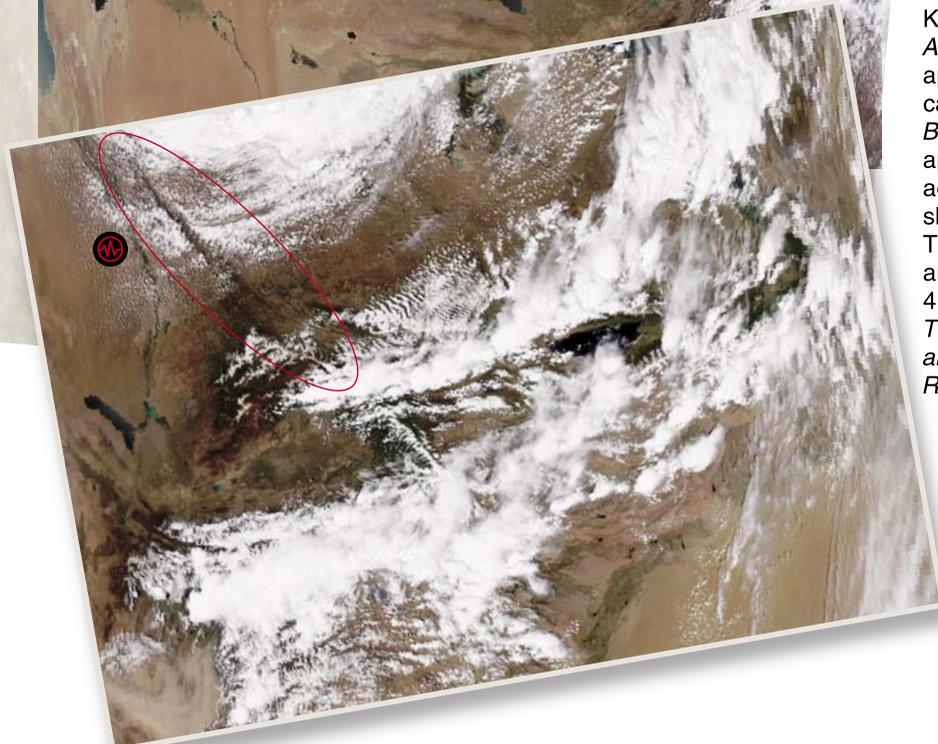
If orographic clouds spread along an airstream in the same direction, banks of seismic clouds overlap, making a mesh. A similar configuration of cloud fields occurred near the Kuril Islands during the recent disastrous earthquake in Japan; this phenomenon cannot derive from an orographic influence or from a temperature inhomogeneity over the





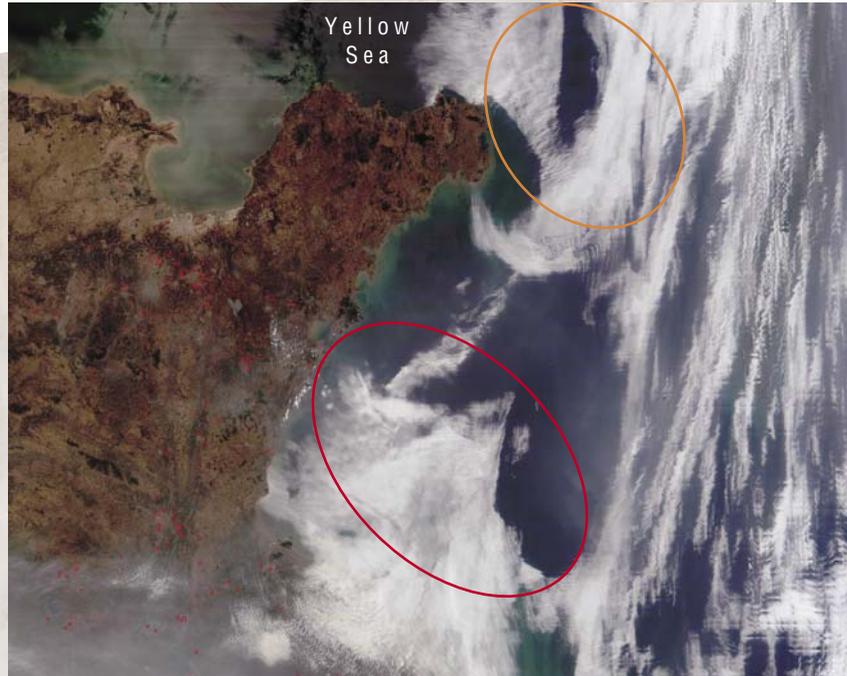
water surface. This configuration remained in place no longer than two hours, after which the mesh was replaced by latitude-oriented cloud stripes, stretching along the geographical parallel, from west to east. Such a rapid change in the atmosphere was probably attributable to the high power of the lithospheric processes.

On August 23, 2011, a major earthquake occurred in Virginia, USA, 140 km away from the national capital. Two types of cloud forerunners that appeared a day before the first underground shock could be treated as a sign of the forthcoming accident. Over the earthquake region, wider cloudless canyons emerged against the background of the cloud stripe mesh. Moreover, at the same time LCA

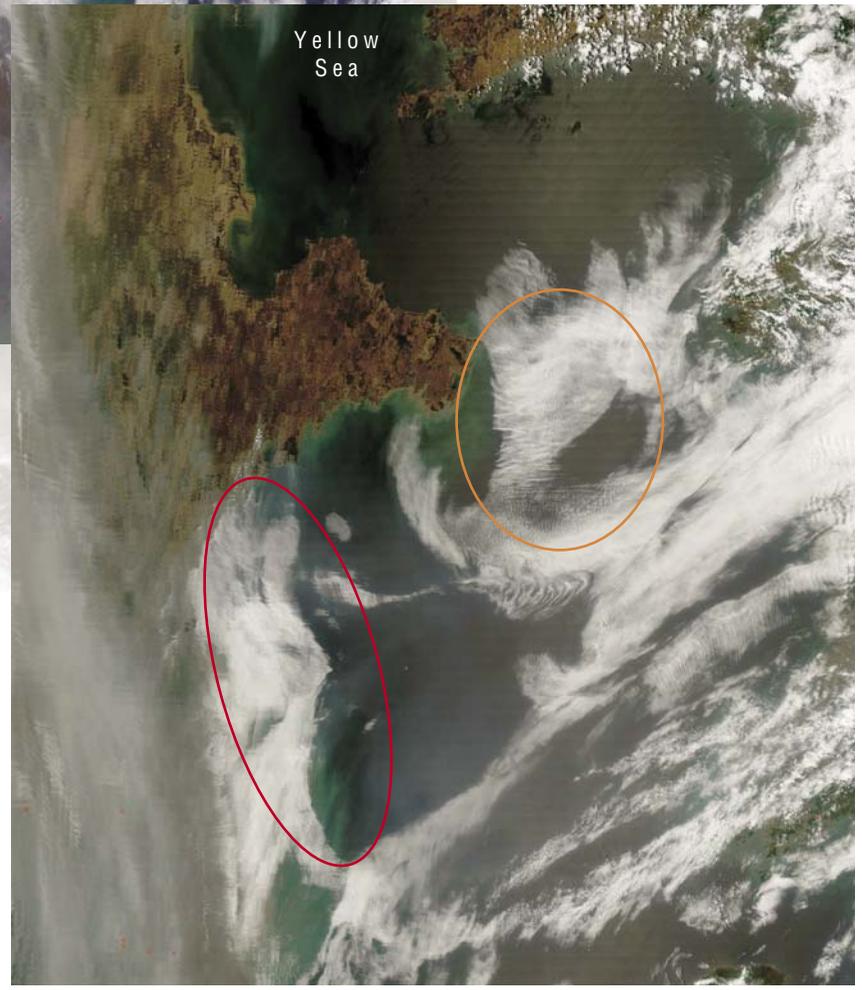


May 31, 2009.
 Disruption of cumulonimbus clouds in the form of a canyon took place over the Thalasso-Fergana Fault in Kazakhstan.
Above – a revolving cloudy spiral is approaching the fault over which a canyon is forming.
Below - as the cloudy spiral is approaching the fault, the canyon acquires an increasingly distinct shape.
 Two weeks later, on June 16, an earthquake with the magnitude of 4.5 took place near the fault.
 The photos taken from satellites Terra and Aqua (NASA/GSFC, Rapid Response)

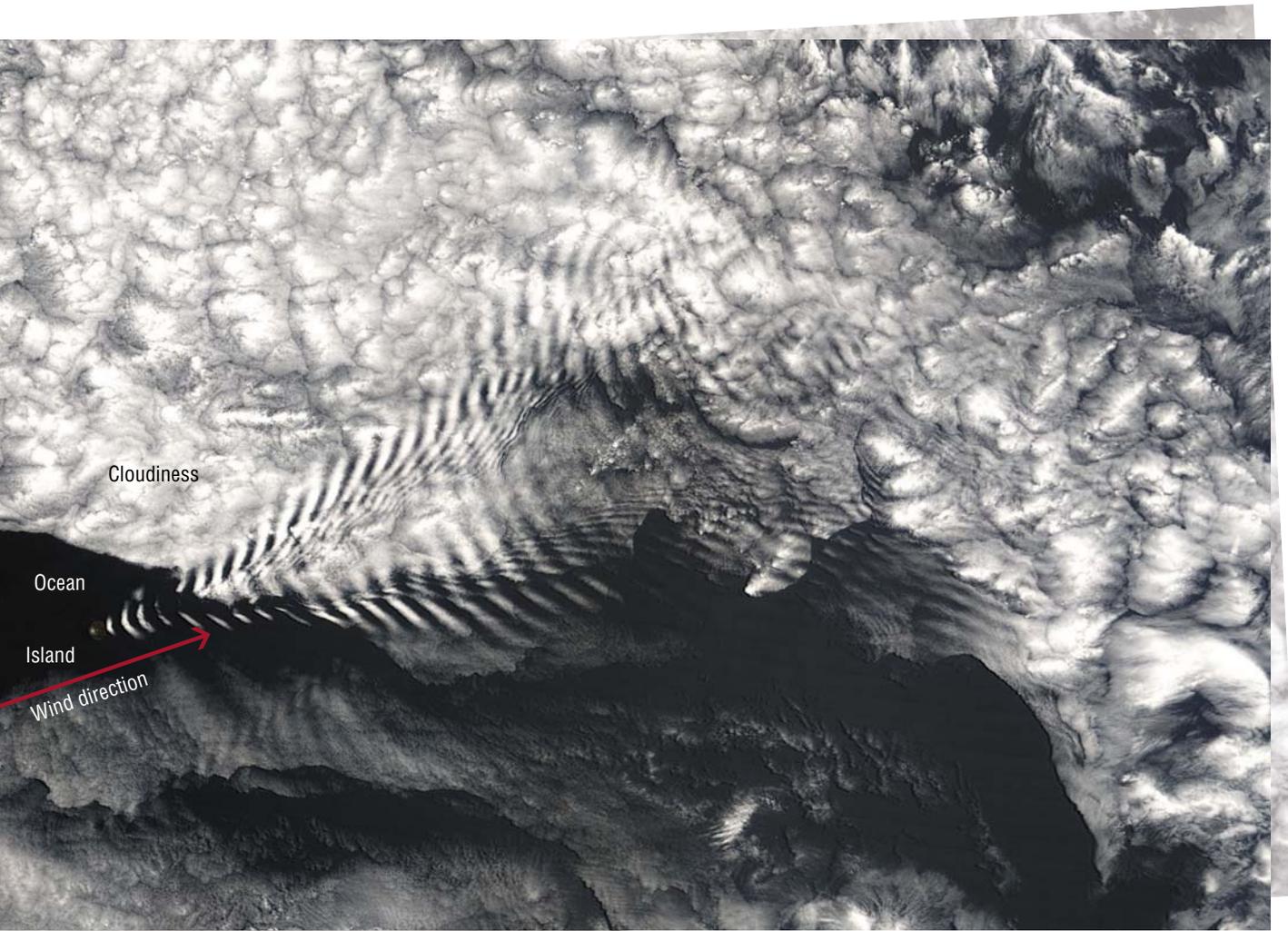
 – earthquake focus



The launch of short-range nuclear missiles from the western shore of Korean Peninsula caused an activation of the sea bottom faults, which were reflected on the cloud masses as anomalously linear edges (*above*).
 To the right – though the atmospheric clouds have changed their position, the existing anomalies remain.
 The photos taken from satellites Terra and Aqua (NASA/GSFC, Rapid Response) on May, 29, 2007



could be observed as far as hundreds of kilometers away from that region, over the Atlantic Ocean – notably, the epicenter of the earthquake was located on the continuation of a land projection of one of these anomalies.
 The appearance of the two types of cloud anomalies can be interpreted as a short-term forerunner of an earthquake that can happen in a region. Statistical data analysis has showed that the probability of a seismic event taking place after such a sign is 77 %.



Sometimes, upon the leeward side of the island, orographic waves arise caused by the relief roughness. The photo by NASA, Visible Earth

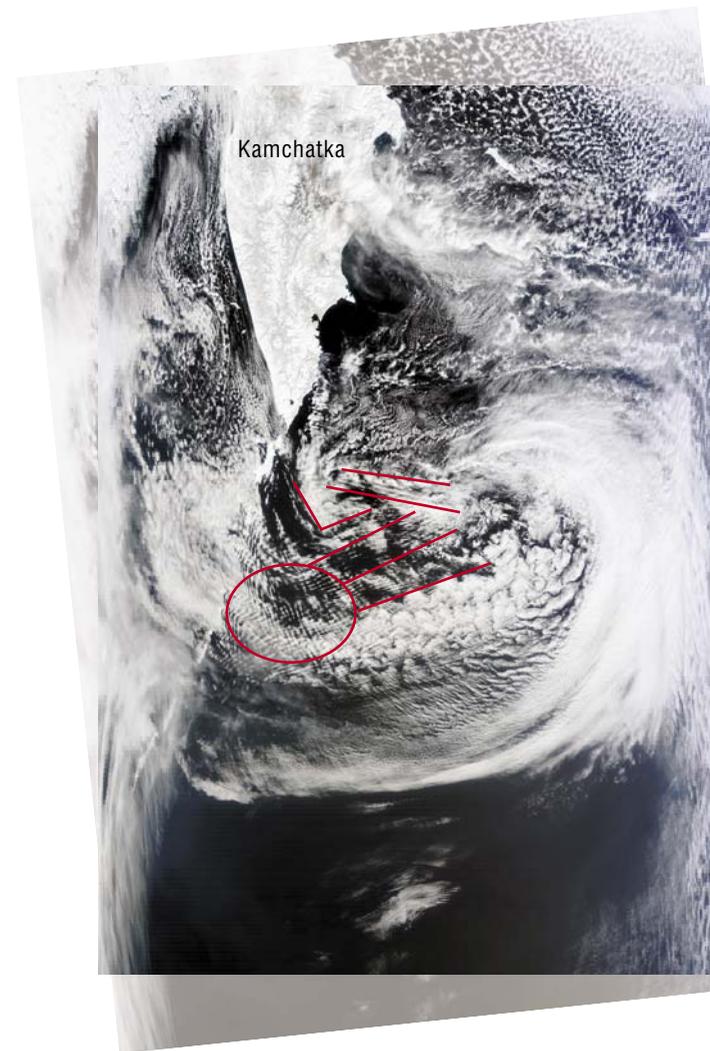
Orbit guards

The territory (or the water area) influenced by seismic process can be immense. Hence, it is possible to make a reliable forecast of a major earthquake only in the regions equipped with a system of continuous monitoring of forerunners, simultaneously covering an area with a minimum radius of 500 kilometers. Regretfully, the existing geophysical monitoring nets can only cover about one-tenth of this area. At the same time, the radio coverage zone of a satellite center is many thousand kilometers, which is why LCA satellite monitoring seems to be the most appropriate tool to survey global seismic activity. The distant sounding of the Earth from satellite orbits produces sufficiently accurate data of the atmosphere parameters, in particular, the vertical and horizontal dimensions of cloud

masses. This suffices to produce a correct idea of the global and local changes in the atmosphere-lithosphere system in various time and spatial scales.

On gridded satellite images, LCA dislocation allows us to determine the geographical position of seismically active faults. Its changes with time make it possible to estimate the direction and propagation velocity of the stresses in the earth's crust, both locally and globally. Small-scale images taken from high-orbit satellites show an area covering several tectonic plates, which allows of tracing their interaction.

Luckily, the existing global satellite system supplying data for weather forecast can successfully perform seismic monitoring. Regulations of the orbital cloud-cover

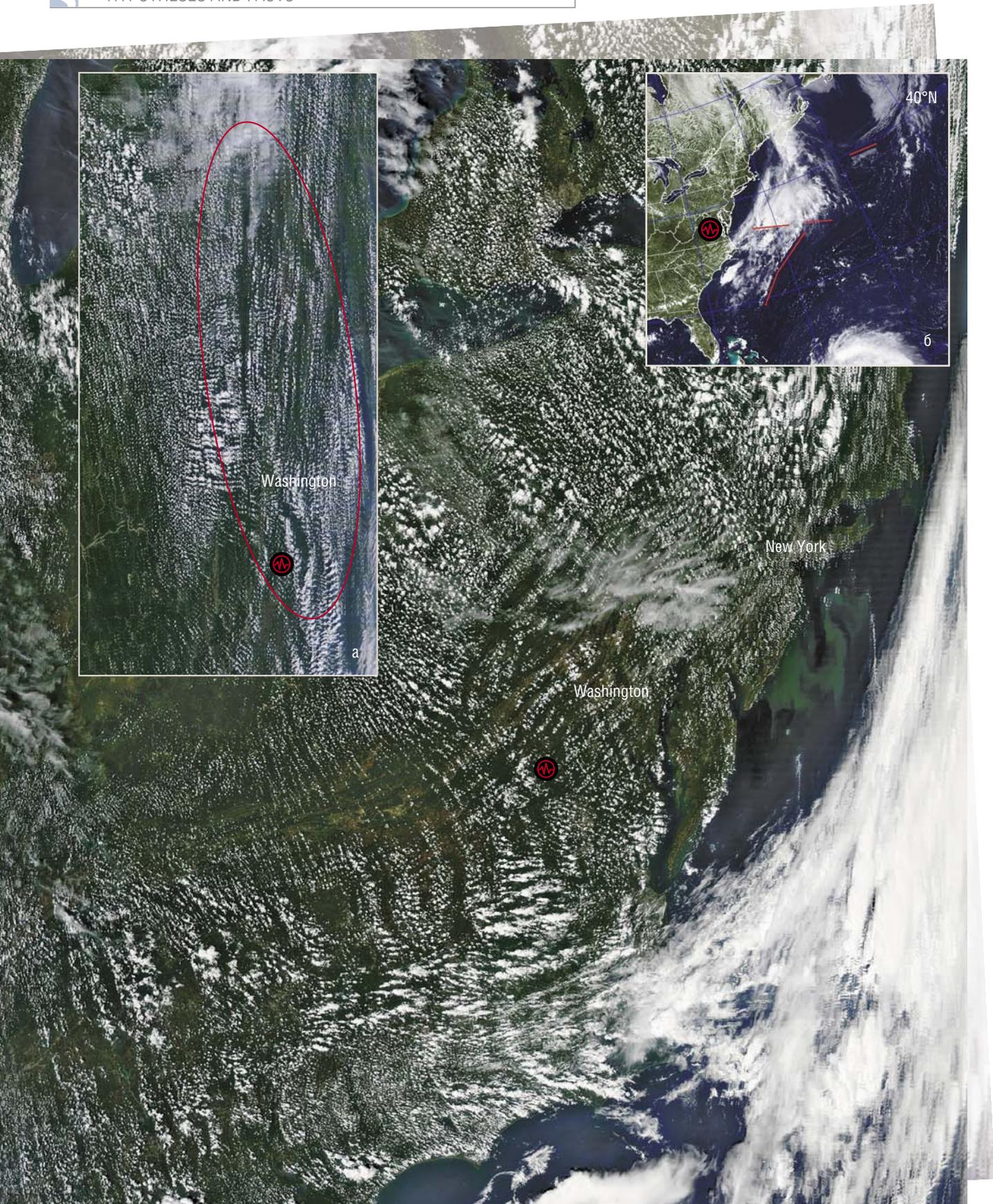


observations are convenient for LCA prompt recording. Data from satellites come on-line, data processing rate is quite high – therefore, the result can be received in a matter of minutes.

An analysis of the Earth's satellite images can provide information on the processes occurring in Earth's spheres within a wide time and spatial spans. Thus, small-scale images from the satellites flying around the planet at distant circular orbits are distinguished by the field of view.

Such photos enable us to analyze the atmosphere dynamics and lithosphere processes connected with it over an immense territory. Several dozens of geostationary satellites can transmit images from the orbit 36,000 km above the Earth of any place at the Earth's surface at hour

The “mesh” clouds formed near the northern part of the Kuril Ridge after the earthquake in Japan testified that seismic activity in the region persisted (left). Indeed, though an hour and half later cloud stripes of latitudinal orientation replaced the mesh (right), earth shocks continued during the next three days. The photos taken from satellites Terra and Aqua (NASA/GSFC, Rapid Response), on March 11, 2011



or half-hour intervals. Large-scale photographs from the satellites Terra and Aqua are currently used to map small, local LCA and to study the types of clouds constituting LCA.

Unfortunately, LCA satellite monitoring can reliably predict only the region and the time of the beginning of an earthquake (accurate to a day). In order to determine the exact location of the earthquake epicenter, complementary methods are needed. The immediate goal is to organize the synchronous recording and coprocessing of LCA and seismic fields with a view to improving the earthquake forecasting methods.

Since remote areas and water areas occupy a large part of Russia, further development of the satellite methods for natural phenomena and disasters monitoring is a crucial task of today's science. Further research into the discovered atmosphere geoinicator of seismic processes will bring practical benefit and expand knowledge about the nature of this phenomenon. The development of a new scientific field will allow us to open a new page in the study of seismicity, fault tectonics, and in the ecological monitoring of underground nuclear explosions.

◀ A day before the earthquake, on August 23, there appeared a “mesh” of cloud stripes over the state of Virginia, USA. Against its background, two wider canyons showed up, joining at an angle (a). Two hours later, the canyons vanished while the mesh-like structure persisted for some time. The photos taken from satellites Terra and Aqua (NASA/GSFC, Rapid Response), August 22, 2011. Simultaneously, LCA appeared over the faults of the Atlantic Ocean bottom (b). (Naval Research Laboratory, Marine Meteorology Division, Monterey, CA)

☞ – earthquake focus

References

Avenarius I. G., Bush V. A., Treshhov A. A. *Ispol'zovanie kosmicheskikh snimkov dlja izuchenija tektonicheskogo stroenija shel'fov // Geologija i geomorfologija shel'fov i materikovykh sklonov. M.: Nauka, 1985. S. 163–172.*

Letnikov F. A. *Sinergetika sredy obitaniya cheloveka. Atlas vremennykh variacij prirodnykh, antropogennykh i social'nykh processov / Pod red. A. G. Gamburceva. T. 3. M.: Janus-K, 2002. S. 69–78.*

Morozova L. I. *Projavenie Glavnogo Ural'skogo razloma v pole oblachnosti na kosmicheskikh snimkah // Issledovanie Zemli iz kosmosa, 1980. № 3. S. 101–103.*

Morozova L. I. *Sputnikovyj monitoring: otobrazhenie i vyjavlenie geojekologicheskikh anomalij i katastrof v Dal'nevostochnom regione Rossii // Inzhenernaja jekologija, 2008. № 4. S. 24–28.*

Sidorenko A. V., Kondrat'ev K. Ja., Grigor'ev Al. A. *Kosmicheskie issledovanija okruzhajushhej sredy i prirodnykh resursov Zemli. M.: Znanie, 1982. 78 s.*

Florenskij P. V. *Kompleksgeologo-geofizicheskikh i distancionnykh metodov dlja izuchenija neftegazonosnykh oblastej. M.: Nedra, 1987. 205 s.*

Morozova L. I. *Satellite Meteorological Images as Carriers of Information on Seismic Processes // Geol. of Pac. Ocean. 2000. Vol. 15. P. 439–446.*

Shou Z. *Precursor of the largest earthquake of the last forty years // New Concepts in Global Tectonics Newsletter. 2006. No. 41. P. 6–15.*

The satellite images testified earthquake imminence in Japan <http://www.roscosmos.ru/main.php?id=2nid=15949>