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GEOPHYSICS

Application of the Thermal Effect of the Atmosphere Ionization for Remote Diagnostics of the Radioactive Pollution of the Atmosphere

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We study the interaction processes of the radioactive isotopes of cesium-137 (^{137}Cs) and iodine-131 (^{131}I) with the boundary atmospheric layer. Energetic electrons emitted by ^{137}Cs (electronic energy 170.8 keV) and ^{131}I (electronic energy 970 keV) and the products of their secondary fission produced by the collision ionization of molecules of atmospheric gases lead to the formation of a large number of initial ions. The initial ions participate in chemical reactions, and simultaneously, they are subjected to hydration and association of water vapor molecules. This process is called ion ageing. In the case of a sharp increase of the ionization rate as occurs during reactor accidents at atomic power stations, hydration of ions acquires an explosive character (in the literature, this process is called ion-induced nucleation), and large ion clusters with a size of a few microns are formed. The ion hydration and the subsequent coagulation of nano-particles are accompanied by the release of thermal energy (latent evaporation heat) because association of water molecules to the ions is equivalent in its energetic efficiency to condensation. The theoretical estimates and the data of experimental measurements showed that the heat flux released during ionization of the atmospheric boundary layer under significant radioactive pollution is sufficient for recording anomalous heat fluxes using the means of remote sounding (infrared radiometers) installed on satellites. The measurements are carried out in the range of wavelengths 8–12 μm, which is transparent for the clouds. This makes such measurements independent of the weather. In this paper, we give examples of heat flux recording after the accidents at the Three Mile Island (United States) and Chernobyl atomic power stations, and also show the dynamics of the thermal anomaly over atomic station Fukushima–1 (Japan) as a result of the accidents caused by the catastrophic earthquake near Sendai on March 11, 2011.

NATURAL RADIOACTIVITY OF THE EARTH AND THERMAL ANOMALIES

Natural radioactivity of the Earth is the main source of the surface atmospheric layer ionization. It is mainly caused by outcropping of uranium fission products to the surface [1, 2]. Radon gives the main contribution to the ionization process because it is transported to the surface by the migration of gases in the Earth's crust [3]. Fluids also contribute to ionization. The maximum activity of radon emanation is recorded over the tectonic fractures of the Earth's crust [4]. During the preparation of earthquakes, the radon radiation level increases multiple times [5]. Investigation of the air surface layer ionization by radon during earthquake preparation allowed us to reveal that the thermal anomalies observed before the earthquakes are a result of the latent evaporation heat release during hydration of ions formed during ionization of the atmospheric gases by radon [6]. Further improvement of the multidisciplinary model of the links in the lithosphere–atmosphere–ionosphere system allowed us to obtain the main parameters of the thermal anomalies generated during preparation of strong earthquakes [7]. The flux of longwave infrared radiation varies from a few to a few tens of W/m^2. It is seen from Fig. 1, which presents the dynamics of longwave infrared radiation dynamics over the epicenter of the Sumatra earthquake of December 26, 2004, that three days before the earthquake, the flux exceeded 80 W/m^2 [8]. Successful results of the satellite monitoring of thermal anomalies before earthquakes, which has been carried out over the last five years, give grounds to consider the problem of the possibility of

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recording the thermal anomalies generated as a result of accidents on the atomic power stations if we take into account the identity of the physical mechanism and high ionization level in the emissions of radioactive substances during accidents at atomic power stations.

RADIOACTIVE POLLUTION AND THE POSSIBILITY OF CONTROL

The accidents with damage to the atomic reactor in the United States (Three Mile Island, 1979) and in the Soviet Union (Chernobyl, 1986) brought forward the burning issue about the safety of nuclear technologies and the possibilities of objective independent control of the level of radioactive pollution caused by the emissions of radioactive substances into the atmosphere or to the Earth's surface [9]. Special attention should be focused on the problems of nuclear safety in the location of atomic power stations in the seismic active regions of our planet. The problems of nuclear power engineering in Japan and inadequate approaches of the TEPCO controlling company became an object of the peer attention of the world community not for the first time. In July 2007, after a strong earthquake near Niigata city, an accident occurred similar to the accident at the Fukushima power station: leakage of polluted water and emission of radioactive gas into the atmosphere with the further emergency shutdown of the nuclear reactor on the world's largest Kashiwazaki-Kariwa nuclear power plant [10]. Since it was a one-time emission and the infrastructure of the power station was not seriously damaged, the incident remained known only to the specialists. The catastrophic tsunami of March 11, 2011, broke the life support systems of the Fukushima-1 nuclear power plant, in particular, the reactor cooling system, while the earthquake caused cracks in the protective shells of the reactors of the first and second power plant blocks. As a result, several hydrogen explosions occurred that led to the emission of fission products into the atmosphere, in particular, radioactive cesium and iodine and radioactive leakage of polluted water into the ocean together with purposeful draining due to the overfilling of the reservoirs. The situation was aggravated by the fact that the information about the radiation level changed by a few orders of magnitude within a day, which provided evidence either about inadequate actions of the personnel or deliberate concealment of the real situation at the station. Taking into account the unfavorable development of the situation, the consequences of the accident could have a global character. An independent information source was needed that could provide estimation of the radioactive pollution level. The measurements of the thermal radiation over the nuclear station became such a source. These measurements used a modified recording technology for infrared outgoing longwave radiation (OLR) described in [8]. The first attempts at recording the thermal radiation over a nuclear plant during an accident were made in [11]; they resulted in a positive outcome. Figure 2 shows examples of thermal anomalies recorded after the accidents on nuclear power plants in the United States (Three Mile Island, 1979, left panel) and in the Soviet Union (Chernobyl, 1979, right panel).

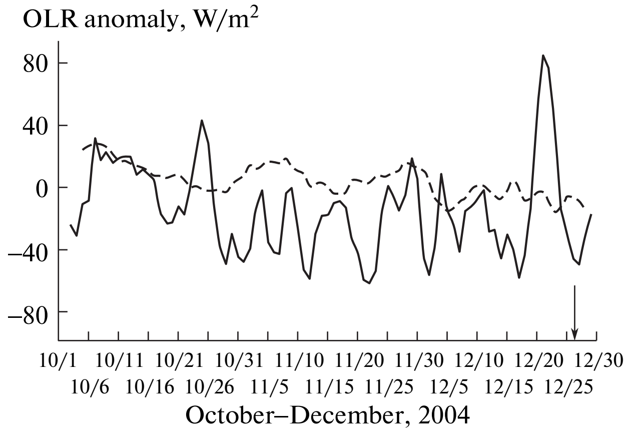

Fig. 1. Dynamics of infrared longwave radiation recorded by the *NOAA-15* satellite from October 2004 to January 2005 (solid line) and mean flux over the same point over the period 2001–2004 plus the root-mean-square deviation (dashed line). The arrow denotes the time of the earthquake.

The results presented in Fig. 2 demonstrate that the application of monitoring thermal anomalies in the OLR range opens new capabilities for independent control of the radioactive pollution of terrains and the atmosphere in the case of such accidents.

DYNAMICS OF OLR ANOMALIES OVER THE FUKUSHIMA NUCLEAR POWER PLANT (JAPAN) AFTER THE ACCIDENT

The first hydrogen explosion occurred on March 12. However, it is likely that it did not cause significant emissions of radioactive substances into the atmosphere, unlike the second explosion, after which a significant increase in the radiation background was recorded. This is seen from the data of the radiation doses recorded at the Kurihama station not far from Fukushima (Fig. 3, thin curve) [12].

The second explosion occurred on March 21. This was the maximum in the dynamics of the radioactive pollution around the nuclear station. The thermal spot over the Fukushima station on March 21 based on the data of the AVHRR instrument installed on the *NOAA-15* satellite (United States) is shown in Fig. 4. It is seen that the level of the infrared longwave radiation reaches 14 W/m^2. After March 21, the thermal flux gradually decreased, which corresponds to a decrease in the level of the radioactive pollution over the station.

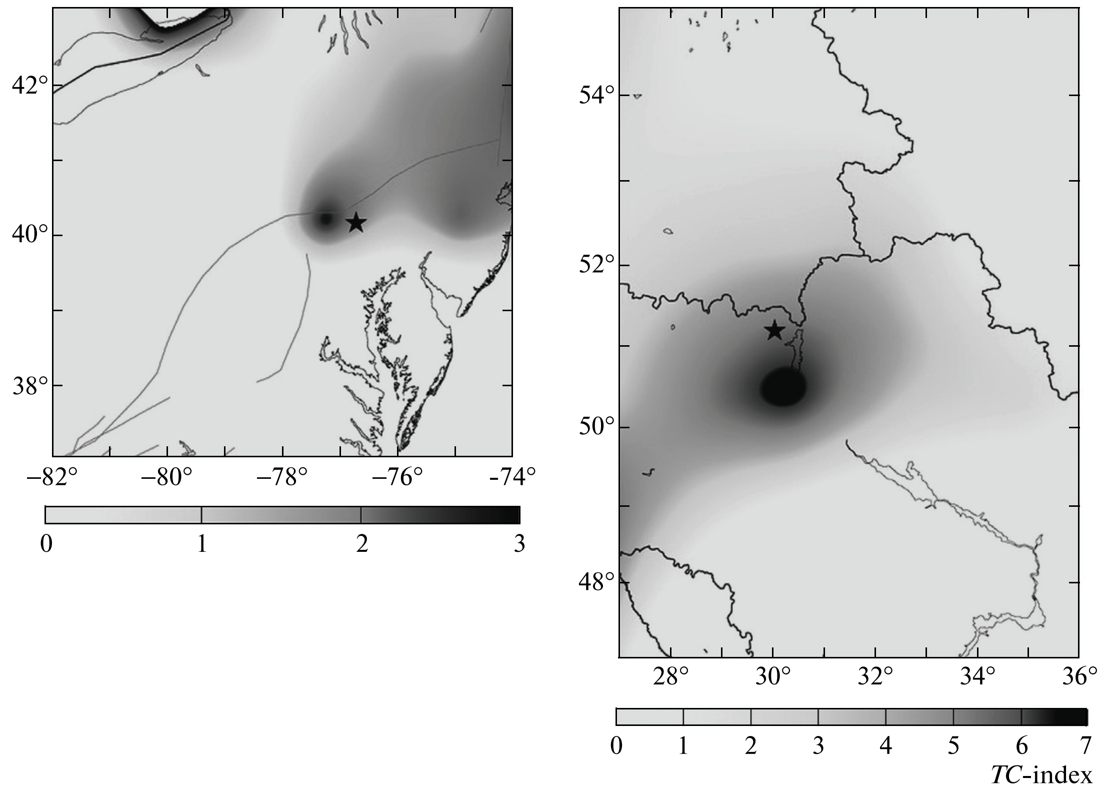

Fig. 2. Thermal anomaly (OLR) based on the NOAA/AVHRR data recorded after the accident at the Three Mile Island nuclear power station (United States) on March 28, 1979 (left panel). Thermal anomaly (OLR) recorded after the accident at the Chernobyl nuclear power station (Soviet Union April 26, 1986.

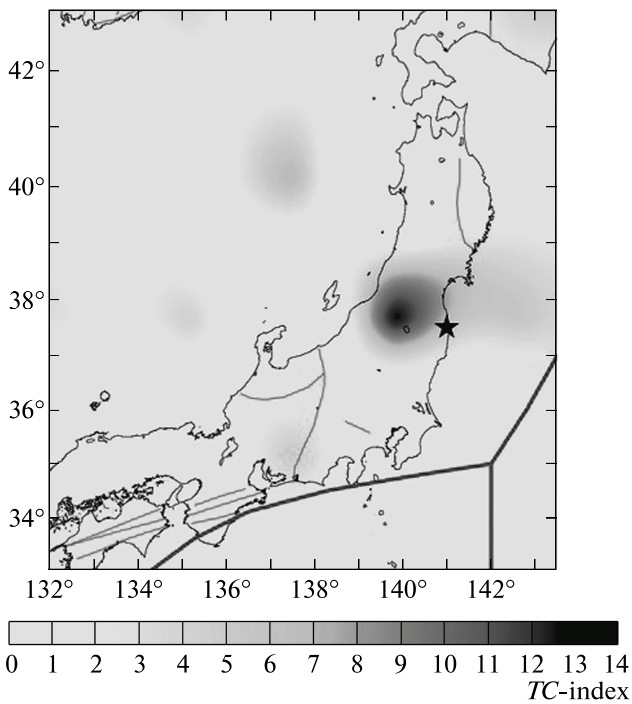

Fig. 3. Dynamics of the variation in the flux of the infrared outgoing longwave radiation (OLR) over the Fukushima power station (heavy line) based on the NOAA–15/AVHRR satellite data during the period March 11–13, 2011, and the effective radiation dose based on the observations on land [12].

The dynamics of the OLR flux over the Fukushima nuclear station on March 11–31, 2001, is shown in Fig. 3 (heavy curve). The periods of a sharp increase in the OLR flux precisely correspond to the radiation emissions (thin curve), which is an argument supporting the suggested mechanism of generation of thermal anomalies by means of ionization of the surface atmospheric layer and subsequent water vapor condensation on the ions with the release of the latent evaporation heat.

Thus, we demonstrated the possibility of independent control of radioactive pollution of the environment using satellite monitoring of the thermal anomalies over the polluted areas. We suggest an ionization mechanism of the surface atmospheric layer as the physical mechanism of the generation of such anomalies. It was developed for the case of the thermal anomalies recorded before strong earthquakes. The level of the infrared outgoing longwave radiation flux (OLR) over the Fukushima station based on the *NOAA-15* satellite data reached 14 W/m^2, which is comparable with the values recorded before strong earthquakes. The difference in the methods of data processing was in the data filtration. Transient fluxes were filtered out for the nuclear station data to accumulate the information about the motionless source. Despite low resolution of the AVHRR instrument (2 degrees), the applied method allowed us to record reliably the ther-

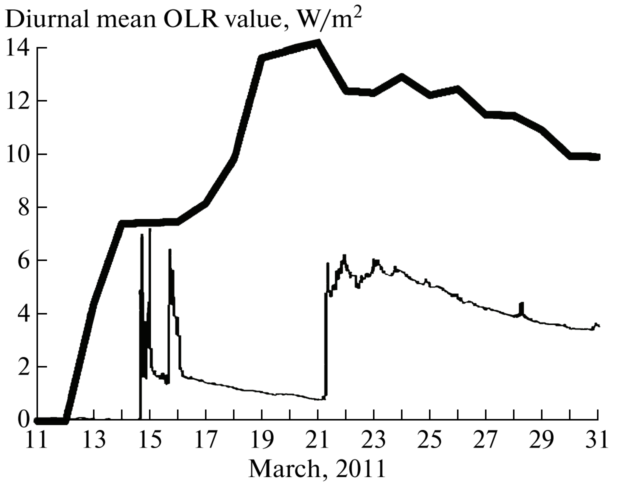

Fig. 4. The flux of infrared outgoing longwave radiation (OLR) over the Fukushima power station based on the NOAA–15/AVHRR satellite data.

mal anomalies, which gives us the possibility to improve the suggested method in the future using infrared radiometers with a higher spatial resolution.

REFERENCES

1. Y. Ikebe, J. Earth Sci **18**, 85–93 (1970).
2. N. P. Laverov, V. I. Kazanskii, and A. I. Tugarinov, *Evolyutsiya uranovogo rudoobrazovaniya (Evolution of the Uranium Ore Formation)* (Atomizdat, Moscow, 1978) [in Russian].
3. L. F. Khilyuk, G. V. Chillingar, J. O. Robertson, Jr., and B. Endres, *Gas Migration. Events Preceding Earthquakes* (Culf, Houston, 2000).
4. A. A. Spivak, in *Geofizika mezhgeosfernykh vzaimodeistvii (Geophysics of Inter-Geospheres Interactions)* (Geos, Moscow, 2008), pp. 235–246 [in Russian].
5. C.-Y. King, W. Zhang, and B.-S. King, Pageoph. **141**, 111–124 (1993).
6. S. A. Pulinets, D. Ouzounov, A. V. Karelin, et al., Phys. and Chem. Earth **31**, 143–153 (2006).
7. S. A. Pulinets and D. Ouzounov, J. Asian Earth Sci **41**, 371–382 (2011).
8. D. Ouzounov, D. Liu, C. Kang, et al., Tectonophysics **431**, 211–220 (2007).
9. N. P. Laverov, V. I. Velichkin, V. I. Mal'kovskii, et al., in *Izmenenie okruzhayushchei sredy i klimata: prirodnye i svyazannye s nimi tekhnogennye katastrofy (Changes in the Environment and Climate: Natural and Related Man-Caused Catastrophes)* (IGEM RAN, Moscow, 2007), pp. 139–175 [in Russian].
10. D. Cyranoski, Nature **448**, 392–393 (2007).
11. S. Pulinets and D. Ouzounov, Abstr. NH24A-04. AGU Fall Meeting (A), (AGU, San Francisco, 2010).
12. http://www.mext.go.jp/english/

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