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GEOPHYSICS

Typhoons and Seismicity

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Based on the application of online satellite images of cloud cover, we studied the influence of different stages of the development of typhoons on seismic processes in the Asian–Pacific region, determined the earthquake lag relative to the moment of a typhoon passage close to the earthquake epicenter, and established a link of disastrous earthquakes with typhoons.

The geographic relation between typhoons and earthquakes was understood a long time ago. Japanese seismologists believe that the abrupt pressure drop at the moment of a typhoon's passage was one of the factors that provoked the Great Tokyo Earthquake on September 1, 1923 [6].

Visher [12] theoretically substantiated the impact of the weight of an atmospheric column of typhoon upon a lithospheric plate and presumed that hurricanes can trigger an already impending earthquake in seismically unstable regions. Atmospheric pressure changes above the water's surface are conveyed into the Earth's crust by waves. Infrasound emission can be generated by the fluctuating heat release in the course of condensation accompanying the development of massive clouds [7]. The energy of a typhoon is a supplement to the tectonic potential energy.

The relation between strain processes in the Earth's crust and atmospheric pressure variations caused by typhoons is demonstrated in [8, 10]. According to [2], microvariations of atmospheric pressure are accompanied by synchronous deformation of the Earth's surface with the same periods. The average life period of typhoons is 7 days. Therefore, the response of the Earth's crust to typhoons must be of the same order.

In contrast to previous works, we used online cloud cover images transmitted every half hour from geostationary meteorological satellites, in addition to surface weather charts, to locate a typhoon in the Pacific Ocean. Space images allowed us to more precisely determine the locations of a typhoon and earthquake epicenter relative to each other.

We studied the northwestern Pacific and East Asia region (120°–170° E) extending from the Philippine Islands to Kamchatka. We plotted tracks for each of 13 typhoons. Six typhoons arrived at Kamchatka, four moved along the east coast of Honshu, two typhoons dissipated near Taiwan, and one typhoon reached the Primor'e region of Russia.

The influence of typhoons on seismicity was estimated with due account for the boundaries of lithospheric plates [1]. The regional earthquake data were taken from the Internet [11]. Only epicenters occurring within a distance comparable with the typhoon size were related to the typhoon. In order to estimate the response of the lithosphere to the atmospheric pressure fluctuations caused by a typhoon, the number of earthquakes was counted for a period of 2–4 days from the moment of the typhoon's appearance near the epicenter.

Owing to the phenomenon discovered by the author of the present communication (appearance of abnormally numerous linear cloud anomalies within an impending earthquake area), these atmospheric formations are considered indicators of tectonically and energetically active faults [3]. The appearance of such clouds in space images allowed us to immediately identify such faults in the oceanic plate within the typhoon zone.

The case study of the strongest (for the last 10 years) supertyphoon Tokage shows the passage of seismicity along its track plotted on an image received from the Goes-9 geostationary satellite on October 22, 2004, at the moment of the typhoon's location near the southeastern coast of Kamchatka. The accompanying earthquakes had a magnitude of 4.2–6.7 (the disastrous Taiwan earthquake on October 15). At that moment, a subsequent typhoon was following the earthquake above the Philippine Sea (Fig. 1).

At the initial stages of the typhoon's development, when its cloud field appeared as a whirl with the hurricane eye, earthquakes were already starting a few hours

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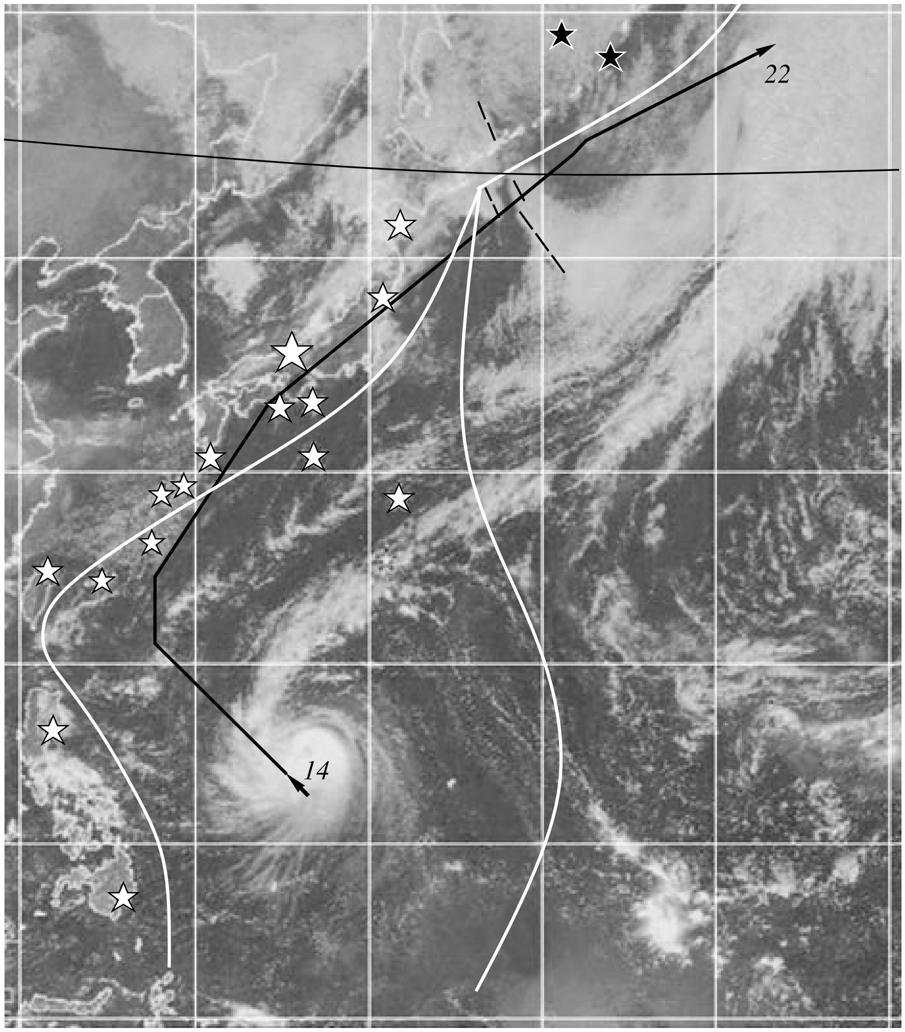

Fig. 1. Epicenters of earthquakes along the typhoon track (marked with asterisks). The large asterisk shows the Honshu epicenter ($M \geq 6.5$). The black line shows the typhoon track. The numbers designate the beginning and end of the typhoon activity period. White lines show the lithospheric plate boundaries. Linear cloud anomalies above tectonic faults in the southern Kuril Ridge are marked with dashed black lines.

after the typhoon's appearance at the periphery of its cloud field. The whirl stage is associated with high wind velocities caused by a high pressure gradient. Taking into account Visher's estimates, the pressure of the typhoon upon the plate at that moment was approximately 13×10^5 t. The typhoon above the Philippine plate induced earthquakes both within and at the boundaries of the plate. This process is best manifested when the typhoon crosses the boundaries. Earthquake foci appeared in front of the typhoon. The ability of the thinner oceanic lithosphere to intraplate deformations was proven by observations in the Indian and Atlantic Oceans [9].

At the moment when the typhoon was located above the western boundary of the plate on October 18 and 19, earthquakes with $M = 4.5$ and 4.9 were recorded in the northern Kuril Ridge at the Eurasian plate boundary (Fig. 1). In this and other similar instances, such remote seismic sources probably reflect the manifestation of typhoon-induced strains [9, 13].

The appearance of cloud anomalies at the initial stage of the typhoon was noted in many instances. In the image of November 18, 2003, faults created a cloudless corner with 175- and 700-km-long sides in the cloud field of a typhoon (Fig. 2). The ocean depth here approaches 2000 m. The Kronotskoe earthquake was preceded by a swarm of cloud anomalies above the depths of 6000 m [4].

In the subsiding typhoon with a vortex-free cloud cover, earthquake sources of October 21 and 22 were situated in the rear zone. However, this did not affect the earthquake intensity. An earthquake with $M = 6.5$ occurred in Honshu on October 23, two days after the typhoon's passage above the epicenter. On the eve of the earthquake (October 22, 01 h 25 min), an enormous 500-km-long cloud anomaly appeared above the trans-

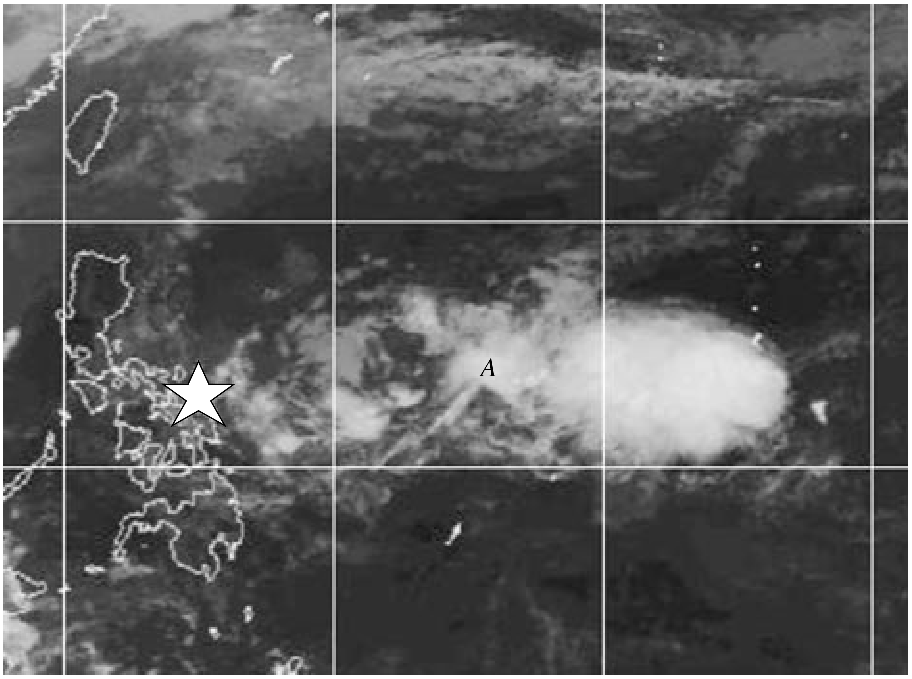

Fig. 2. Two intersecting linear cloud anomalies (marked with the letter *A*) in the typhoon cloud cover above the Philippine Sea. The asterisk marks the epicenter of the subsequent Philippine earthquake.

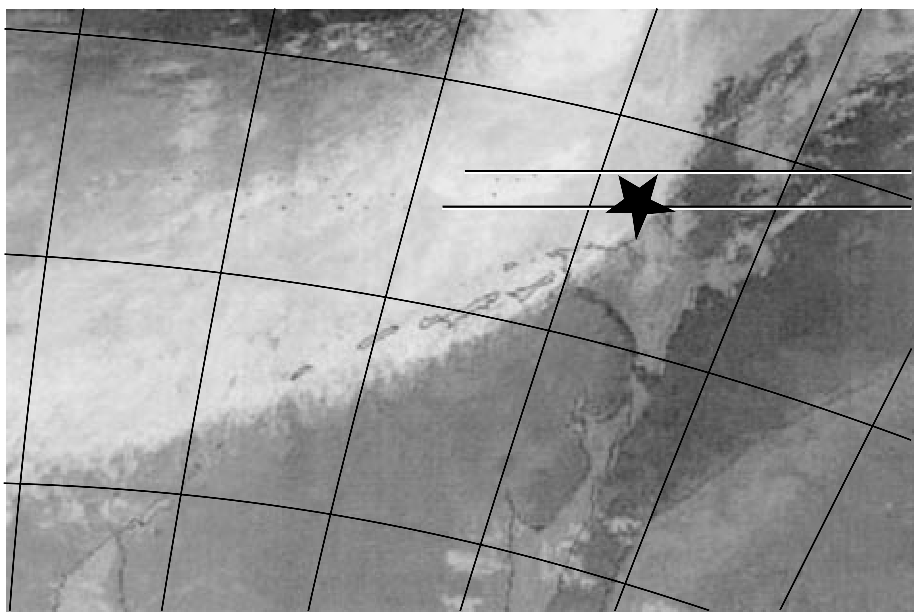

Fig. 3. The typhoon cloud cover east of Hokkaido and Honshu islands (the white massif) and two radio noise bands across the disastrous earthquake epicenter near the Hokkaido coast (marked with asterisks).

form fault in the southern Kuril Ridge. As shown in [5], the appearance of linear cloud anomalies above the faults of the Kuril–Kamchantka island arc are forerunners of earthquakes in Kamchatka and the Kuril and Japanese Islands.

An analysis of the spatiotemporal interrelation of seismicity and typhoons demonstrated that, in the initial period of two days (including the moment of the typhoon's passage), 83% of earthquakes (from a total of 89) occurred near the typhoon track in four days.

Among 13 typhoons, 46% were accompanied by earthquakes with $M \geq 6.0$. Six disastrous earthquakes ($M \geq 6.0$) occurred in the initial two days. The Hokkaido earthquake ($M = 8.1$) on September 25, 2003, occurred 2.5 days later. The space image (Fig. 3) obtained on September 22 (19 h 50 min) shows the moment of the typhoon's passage at the minimum distance from the source. Then it abruptly changed its track from northward to eastward. The seismic source shifted to the typhoon edge in the high pressure gradient area. This circumstance triggered the impact of the typhoon upon the seismic process [8, 14].

In periods of a typhoon passage, strains in the Earth's crust accompanied by earthquakes (including all the disastrous ones) were noted predominantly in the initial period of two days. The space images of cloud cover provide a more precise and vivid idea of the typhoon's position relative to seismic sources.

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