DOI: 10.18721/JPM
УДК 534.2

RECORDING TYPHOONS' INFRASONIC DISTURBANCES BY LASER STRAINMETERS

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In the paper, the field studies of powerful infrasonic disturbances in the range of «voice of the sea» (7–9 Hz) caused by tropical cyclones (typhoons) in the southeastern region of the Far Eastern Federal District (Russia) and the water area of the Sea of Japan have been presented. Event monitoring was carried out using the laser-interference measuring complex located permanently in the south of Primorski Krai. The dynamic spectrograms of the observable events were analyzed and their connection with various meteorological phenomena, such as wind and sea waves, was traced. Using the satellite data, a connection between the distribution of the area of typhoon influence in the region and the observed infrasound excitation was found. The conclusions were drawn regarding the correlation between the exhibition of the «voice of the sea» microseisms and the initiation of primary and secondary microseisms, as well as the one between the «voice of the sea» microseisms' disappearance and the corresponding end of primary microseisms. No dependence of the signal level on the wind speed in the area of the measuring range location was established.

Keywords: infrasonic wave, laser strainmeter, typhoon, voise of sea

Citation: V.A. Chupin, G.I. Dolgikh, E.S. Gusev, Recording typhoons' infrasonic disturbances by laser strainmeters, St. Petersburg Polytechnical State University Journal. Physics and Mathematics. 12 (1) (2019) 107–116. DOI: 10.18721/JPM.12110

РЕГИСТРАЦИЯ ИНФРАЗВУКОВЫХ ВОЗМУЩЕНИЙ ТАЙФУНОВ ЛАЗЕРНЫМИ ДЕФОРМОГРАФАМИ

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В статье приводится описание натурных наблюдений мощных инфразвуковых возмущений в диапазоне «голоса моря» (7 – 9 Гц), вызванных прохождением тропических циклонов (тайфунов) в юго-восточном районе Дальневосточного федерального округа России и акватории Японского моря. Регистрация каждого события выполняется с помощью лазерно-интерференционного измерительного комплекса, стационарно расположенного на юге Приморского края. Проанализированы динамические спектрограммы наблюдаемых событий и прослежена их связь с метеорологическими явлениями, такими как ветер и морские волны. При использовании спутниковых данных найдена взаимосвязь распределения области влияния тайфунов в регионе с наблюдаемым инфразвуковым возбуждением. Сделаны выводы о взаимосвязи проявления микросейсм «голоса моря» с возникновением первичных и вторичных микросейсм, а также хорошей корреляции между исчезновением микросейсм «голоса моря» и соответствующим прекращением первичных микросейсм. Установлено отсутствие зависимости уровня сигнала от скорости ветра в области расположения измерительного полигона.

Ключевые слова: инфразвуковая волна, лазерный деформограф, тайфун, голос моря

Ссылка при цитировании: Чупин В.А., Долгих Г.И., Гусев Е.С. Регистрация инфразвуковых возмущений тайфунов лазерными деформографами // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2018. Т. 12. № 1. С. 117–127. DOI: 10.18721/JPM.12110

Introduction

Cape Shultz is a Marine Experimental Station of the V.I. Il'ichev Pacific Oceanological Institute of the Far Eastern Branch of the Russian Academy of Sciences (POI FEB RAS) that is constantly monitoring a whole range of indicators of the seismo-acoustic and hydrological cycles. The station records variations in the deformation of the Earth's crust (using coastal laser strainmeters), variations in atmospheric pressure (using laser nanobarographs), variations in hydrospheric pressure (using special laser meters) and variations in wind speed (at the meteorological station). Processing of synchronized experimental data for these phenomena revealed low-frequency seismo-acoustic disturbances in the range of 7–9 Hz (the frequency band of the so-called "voice of the sea") in coastal areas of Primorsky Krai.

Excitation of seismic signals in this frequency range is associated with tropical cyclones passing near the measurement site. These natural phenomena significantly affect the life of the Far Eastern Region of the Russian Federation.

The voice of the sea, i.e., high-frequency infrasound (in the range from a few to tens and more Hz) was first hypothesized to exist in [1], suggesting that the mechanism for this phenomenon was wind flowing around large ocean waves. An alternative mechanism by which this infrasound might occur was proposed in [2], where acoustic noise from sea waves crashing on rocky shores was considered. Ref. [3] argued that infrasound was generated by standing surface waves and that the resulting stratification of such properties of the atmosphere as wind speed and temperature affected the given parameters of infrasonic waves. Such standing waves are formed through non-linear interaction between progressive surface waves.

Numerous studies, including [4], recorded primary and secondary microseisms resulting from progressive and standing sea waves acting on the ocean floor. The mechanism of generation of secondary microseisms, i.e., small-amplitude oscillations of the Earth's surface with the period equal to the half-period of progressive sea waves, was described in [5]. Similar acoustic signals in the atmosphere were called microbaroms [6], and the theory describing the conditions in which they occur was developed in [7–9]. Microbaroms and secondary microseisms are formed as a result of non-linear effects from interaction of two progressive counter-propagating sea waves with a double period. Experimental data related to storms were analyzed in [10], suggesting that microbaroms and secondary microseisms have the same source. Deformation disturbances caused by a passing typhoon and lying in the frequency range of the voice of the sea were reported for the first time in [11].

These natural phenomena present a serious threat, which is why comprehensive study of the physics of such processes, as well as study of their dynamic features are very urgent tasks.

Measuring system and experimental data

This paper discusses both our own experimental data and those obtained by Japanese researchers. We collected and studied the following information:

Studies of the Japan Meteorological Agency on movement of tropical cyclones for 2010–2018 [12];

images from the Japanese satellite Himawari-8 [13], which make it possible to visually monitor the region of distribution of the cyclonic vortex with an accuracy up to 1 h;

results of our measurements using a laser strainmeter;

experimental data from our meteorological station.

Variations in the deformation of the Earth's crust were recorded using laser strainmeters from a hardware and software system located at the Cape Schultz site of POI FEB RAS. The system was deployed to study the origin, evolution and transformation of oscillations and waves in sound and infrasound ranges, their interaction with each other and with geospheric inhomogeneities of different scales [14].

Two laser strainmeters were located at Cape Shultz, Sea of Japan. Coordinates of the objects were 42.58°N, 131.157°E. These two devices were positioned so that they represented a two-coordinate laser strainmeter with (almost) mutually perpendicular measuring arms [15]. Each strainmeter was assembled by the unequal-arm Michelson scheme using a frequency-stabilized helium-neon laser. One of the strainmeters had a 52.5 m long measuring arm and was oriented north-south at an angle of 18° (198°); the other was 17.5 m long and was oriented north-south at an angle of 110° (290°). The first one was located at a depth of 3–5 m from the Earth's surface in a hydrothermally isolated room 67 m above sea level, and the second at a distance of 70 m from the first one at a depth of 3–4 m from the Earth's surface. The angle between the measuring arms of the strainmeters was 92°. The interferometric methods used allow to record the variation in length l of the measuring arm of each strainmeter with an accuracy $\Delta l = 0.01$ nm in the frequency range from 0 (roughly) to 1000 Hz. The sensitivity of the laser strainmeter with an arm length $l = 52.5$ m is $\Delta l/l \approx 0.2 \cdot 10^{-12}$, and that of a la-ser strainmeter with an arm length $l = 17.5$ m is approximately $0.6 \cdot 10^{-12}$.

Air temperature and humidity, atmospheric pressure, wind speed and direction are measured at the meteorological station. Data on variations of these quantities are recorded with a resolution of 1 Hz.

The readings from laser strainmeters and from the meteorological station are submitted to the laboratory room, where preliminary processing (filtering and downsampling) of the obtained data is performed, the information is then recorded on physical media of the hardware and software system with an experimental data base subsequently organized.

We have initially analyzed the database of typhoons in the northwestern Pacific Ocean that directly affected the Far Eastern region of Russia. We have selected four typhoons as typical examples of these effects. The names of the typhoons and the time intervals for their duration are given in Table. Based on the data of the Japan Meteorological Agency, we have compiled a composite map for the tracks of the given typhoons (Fig. 1), indicating the semi-daily time intervals of their movement in Japan Standard Time (JST), which corresponds to UTC+09, i.e., +9 hours relative to Universal Time Coordinated.

As follows from Fig. 1, the tracks of the given typhoons passed near the measurement site and generated the observed seismo-acoustic disturbances in the range of the "voice of the sea". Images from the Japanese satellite Himawari-8 were used to visually monitor the location of the "eyes" of the typhoons, their leading edges and "tails".Experimental data and analysis

We used data from one laser strainmeter as the most representative, as well as the measured variations in the magnitude of wind speed obtained at the meteorological station. Processing the readings from the strainemeter for the given observation periods, we obtained spectrograms of the "voice of the sea" range were obtained (Fig. 2). Spectrograms of the range of microseisms induced by sea wind waves and ripple acting on the seabed were also obtained (Fig. 3). Fig. 4 shows data on the variation in wind speed in the given observation periods.

Below we have analyzed the data provided for each typhoon in Fig. 1–4 in detail. Images from the Japanese satellite Himawari-8 were also used.

Typhoon Bolaven (B). According to the data from the strainmeter, noise in the range of 1.0–2.5 Hz, as well as narrow-band oscillations with central frequencies around 5.3, 9.1 and 107 Hz occurred at 03:25 UTC on August 28. The "eye" of the typhoon was located in the Yellow Sea and extended to the Korean Peninsula. South/southwest wind at the speed of 1–2 m/s was recorded at Cape Schulz

After noise first appeared, its range gradually expanded to 1.0–4.5 Hz, with an increase in signal levels, and reached its maximum at 2:53 pm (August 28). Amplification of oscillations with central frequencies of 9.1 and 10.7 Hz was observed. The typhoon then tracked over Primorsky Krai (Russia), with its strong tail located in the north of the Yellow Sea; thick tails of the typhoon were located above the Sea of Japan. The wind changed to southeast at Cape Shultz, acquiring a speed of 14–16 m/s.

Table

Time intervals used for processing observation data for typhoons

Notation	Name of typhoon	Period of time
B	Bolaven	28.08. 2012–31.08.2012
S	Sanba	17.09. 2012–31.08.2012
M	Matmo	26.07. 2014–27.07. 2014
Ch	Chan-hom	12.07. 2015–15.07.2015

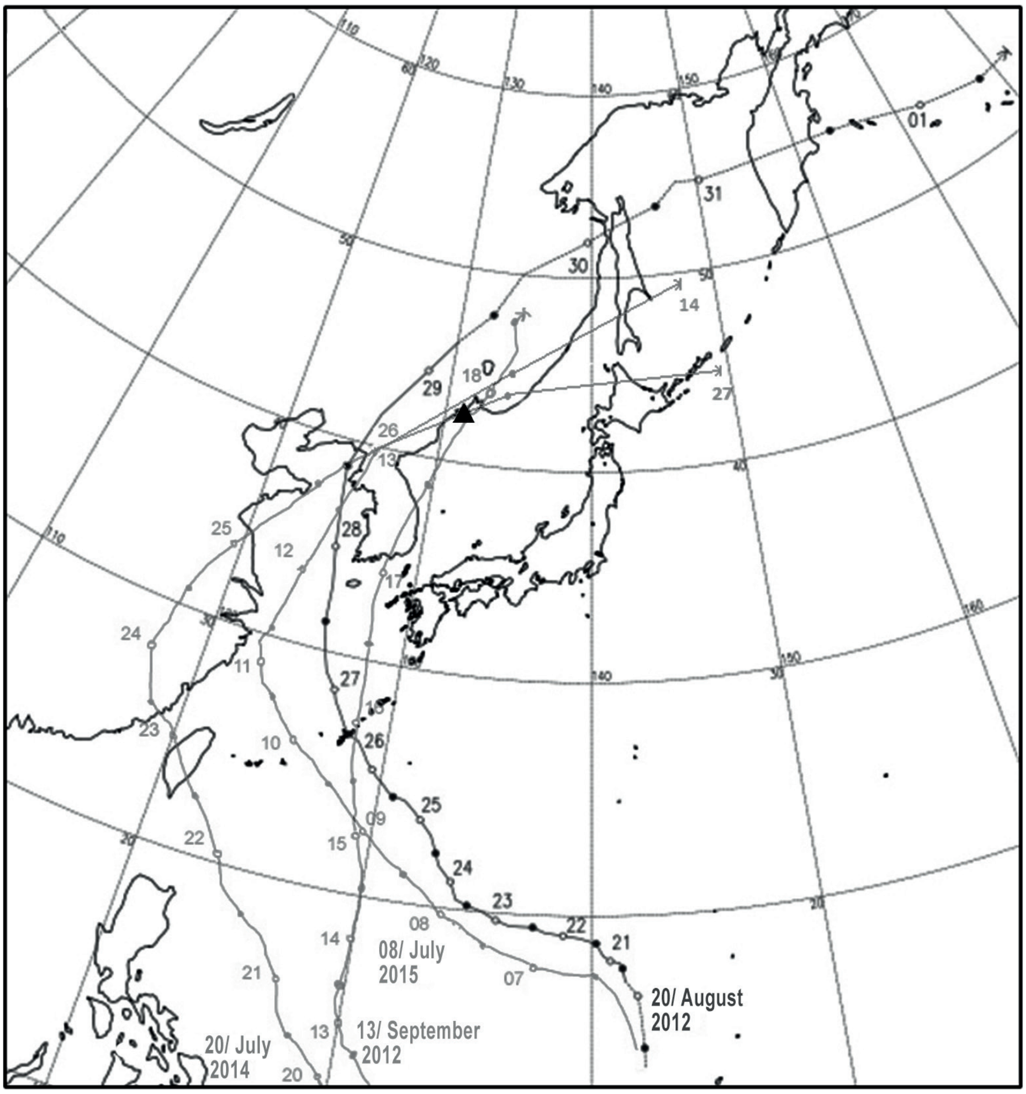

Fig. 1. Composite map of trajectories of given typhoons
compiled based on data from Japan Meteorological Agency.
The figure shows the semi-daily time intervals of typhoon movement by Japanese Standard Time (JST), the numbers correspond to the recording dates (see Table and explanations in the text);
the triangle indicates the location of the survey site.

The noise level remained constant in the range of 1.0–4.5 Hz until 19:26 on August 28. The intensity of signals with the same central frequencies (9.1 and 10.7 Hz) then either amplified or attenuated periodically. The main, central part of the typhoon nearly left Primorsky Krai, moving to China and Khabarovsk Krai. Only a small tail of the typhoon remained in the south of Primorsky Krai and in the northeast of the Sea of Japan. Southeast wind at a speed of 16–18 m/s was recorded at Cape Schulz.

The noise level kept falling until 22:10 on August 28, its frequency range of 1.0–4.5 Hz narrowed back to 1.0–2.5 Hz. The level of oscillations with central frequencies of 9.1 and 10.7 Hz decreased, however, strong oscillations occurred in the frequency range of 6.5–9.3 Hz with a central frequency of about 8.0 Hz (referred to as the “voice of the sea” microseisms below). The typhoon remained in the north of Primorsky Krai, China and Khabarovsk Krai. Tails of the typhoon tracked to the east and northeast of the Sea of Japan. However, a strong leading edge of another typhoon, whose “eye” was located over Taiwan,

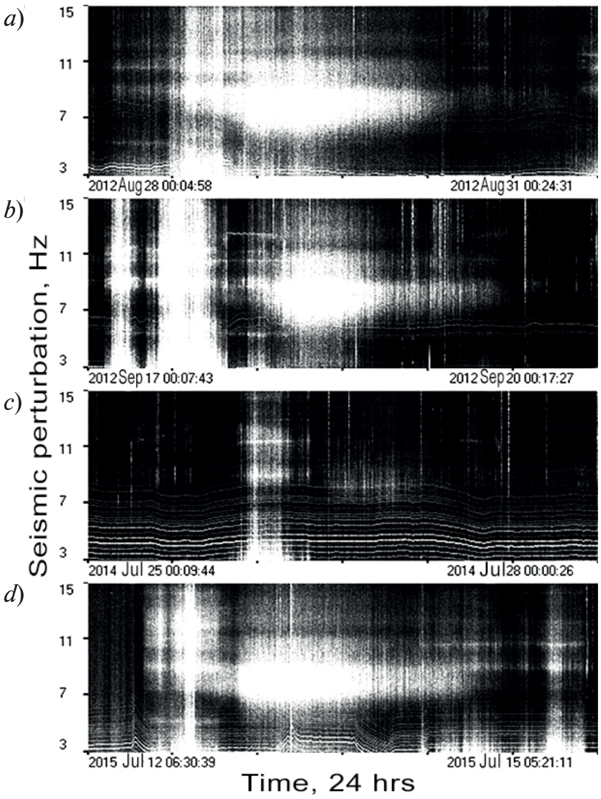

Fig. 2. Spectrograms (dynamics of seismo-acoustic disturbances) for "voice of sea" range, obtained using coastal laser strainmeter, for typhoons B (*a*), S (*b*), M (*c*) and Ch (*d*) (see Table)

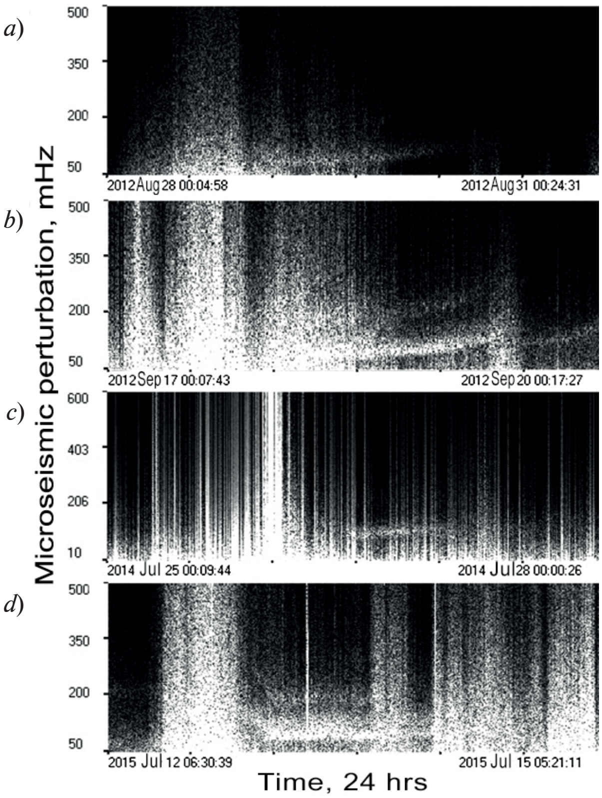

Fig. 3. Spectrograms (dependences of variation in sea disturbance over time) for range of microseisms caused by impact of sea wind waves and ripple, obtained using coastal laser strainmeter, for typhoons B (*a*), S (*b*), M (*c*) and Ch (*d*) (see Table)

penetrated the Sea of Japan from the Korean Peninsula. Southeast wind at a speed of 20–25 m/s was blowing at Cape Schulz.

The widest frequency range of the sea voice microseism was reached at 06:00 on August 29 (6.5–9.5 Hz, white core). At that time, the typhoon raged over China, Mongolia, and the Khabarovsk Krai. Primorsky Krai was almost entirely outside the zone of the typhoon. Small tails were observed off the Japanese coast and in the north of the Sea of Japan. The strongest southeast wind at a speed of 33 m/s was recorded at Cape Schulz.

The main core of the sea voice microseism was not observed at 18:00 on August 29. Both the Primorsky Krai and the Sea of Japan were outside the typhoon zone. The eye of a new typhoon was observed in the south of the Yellow Sea; its leading edge tracked over the Korean Peninsula. West wind with a speed of 8–10 m/s was blowing at Cape Schultz.

Low-frequency noise was not recorded in the range of 1.0–2.5 Hz. The intensity of oscillations in the range of 6.5–9.3 Hz decreased with time, the oscillation frequency range also narrowed to 7.5–8.5 Hz. The given oscillations almost completely attenuated by 23:30 on August 30. The typhoon was located in the Sea of Okhotsk. Northwest wind at a speed of 2–4 m/s was blowing at Cape Schulz.

The laser strainmeter readily recorded the primary and secondary microseisms. Primary microseisms with a period of about 12 s were first recorded by the device at approximately 23:00 on August 28, and their period then gradually decreased to 5 s (20:30 on August 30). Secondary microseisms with a period of about 6 s were readily recorded by the strainmeter at about the same time (11:00 pm on August 28). The period and intensity of secondary microseisms gradually decreased, and they were virtually absent in the recordings from 00:30 on August 30. Up to this point, their period was about 4 s, while the period of primary microseisms was about 8 s.

Thus, the moment when strong oscillations occurred in the frequency range of 6.5–9.3 Hz almost coincided with the time when strong

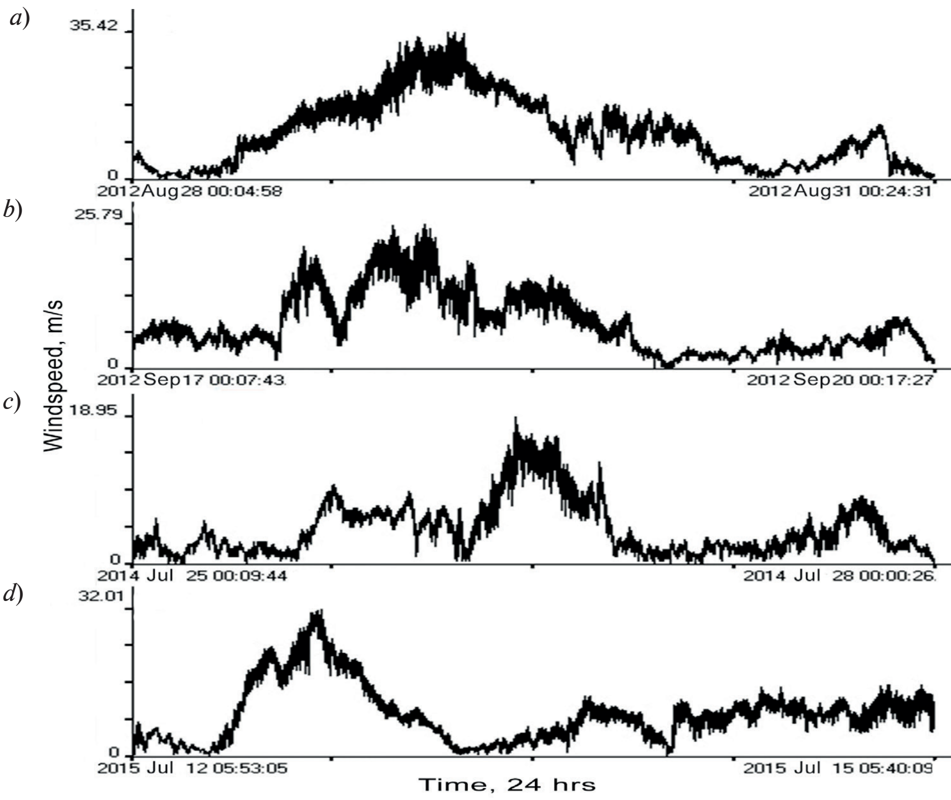

Fig. 4. Variations in wind speed over time.
Experimental data were obtained at meteorological station
for typhoons B (*a*), S (*b*), M (*c*) and Ch (*d*) (see Table)

primary microseisms evolved. The period and intensity of primary microseisms were reduced and barely recorded by the device starting from 20:30 on 30 August. Somewhat later (23:30), practically no oscillations were recorded in the range of 7.5–8.5 Hz. Notably, the speed range of the local wind for the same observation period (August 28, 10:10–August 30, 23:30), i.e., during the period when sea voice microseisms appeared and disappeared, increased from 20–25 to 32–33 m/s, and then gradually dropped to 2–4 m/s. The widest frequency range of sea voice microseisms was observed at 6:00 on August 29. Only typhoon tails were recorded at Cape Schulz during the same period of observations.

Typhoon Sanba (S). Noise increased at 02:20 on September 17, leading to an increase in all spectral components and expanded individual frequency ranges. For example, the range from 1.0–2.5 Hz gradually expanded to 1.0–4.5 Hz. Oscillations were observed in narrow frequency ranges with central frequencies of 9.1, 10.7, and 11.3 Hz. At 11:00 on the same day, the eye of the typhoon tracked to the south of the Korean Peninsula. The leading edge of the typhoon covered the entire Korean peninsula, Primorsky Krai, north and northwest of the Sea of Japan, Sakhalin and Sea of Okhotsk, expanding to Kamchatka. As the noise level reduced, the intensity of these disturbances fell and almost disappeared at 07:15 on September 17. At 07:00 the typhoon's eye tracked to the north of the Korean Peninsula. Northeast wind at a speed of 6–8 m/s was blowing at Cape Schulz (2:20).

Noise with a central frequency of 5.3 Hz appeared at 08:20 on September 17. The eye of the typhoon was localized on the shelf of the Sea of Japan, off the coast of South Korea. The leading edge of the typhoon covered Primorsky Krai, Sakhalin, the Sea of Okhotsk, Kamchatka, the northern and western parts of the Sea of Japan. Northeast wind at a speed of 5–6 m/s was blowing at Cape Schulz.

The main zone of the typhoon moved to Khabarovsk Krai, China, Mongolia, the north and the central part of Primorsky Krai at 20:00 on September 17. The eye of the typhoon left the south of Primorsky Krai. A tail of the typhoon was observed in the center of the Sea of Japan; only a small tail remained on the shelf of the Korean Peninsula. Northeast wind at a speed of 13–16 m/s was rising at Cape Schultz.

Noise in the range of 1.0–4.5 Hz and oscillations in narrow bands with central frequencies of 5.3, 9.1 and 10.7 Hz appeared at 22:35 on September 17. Oscillations with a central frequency of 11.3 Hz were weak. The typhoon nearly left Primorsky Krai. The eye of the typhoon was located on Sakhalin. A tail at the center of the Sea of Japan and a smaller one off the coast of the Korean Peninsula were observed. Northeast wind at a speed of 20–23 m/s was raging at Cape Schultz.

Microseisms of the voice of the sea appeared about 00:10 on September 18; the frequency range at its maximum was from 6.0 to 9.5 Hz with a central frequency (by intensity) of 8 Hz. Oscillations of the sea voice microseism were strongly attenuated by 18:00 on September 18 and were almost untraceable until 10:00 on September 19 (their central frequency was about 8.5 Hz). The locations of the typhoon's eye and its leading edge were almost unchanged, and its tail was in the center of the Sea of Japan. A weak tail of the typhoon extended along the coast of the Korean Peninsula with access to Cape Schulz. A small atmospheric depression was observed in the Yellow Sea, reaching the south of Primorsky Krai through the north of the Korean Peninsula. Northeast wind at a speed of 18–21 m/s (00:10), then northwest wind at a speed of 6–9 m/s (September 18, 18:00) and then north wind at a speed of 3–4 m/s (September 19, 10:00) was blowing at Cape Schultz.

The central part of the sea voice microseism reduced in intensity at 18:00 on September 18. The tail of the typhoon covered the north of the Korean Peninsula, the southern coasts of Primorsky Krai and the Sea of Japan near Korea; this tail subsequently disintegrated, forming a whirlwind. The front of the new typhoon spread through the island of Hokkaido to the north and then to the island of Sakhalin.

Virtually no sea voice microseisms were detected at 10:00 on September 19.

Strong primary microseisms with a period of about 12 s and secondary microseisms with a period of about 6 s appeared at about 23:30 on September 17. Their period then decreased. Secondary microseisms were barely recorded by the laser strainmeter around 03:50 on September 20. Their period fell to 4.2 s, and the period of primary microseisms at that time was about 8.5 s. The amplitude of primary microseisms recorded by the laser strainmeter at 07:30 on September 19 was greatly decreased. Their period was equal to about 7.5 s.

Thus, the time when the sea voice microseisms occurred (00:10, September 18) nearly coincided with the time when the primary microseisms with a maximum period of 12 s arrived (23:30, September 17). Secondary microseisms had a maximum period of 6 s. The wind speed at Cape Schultz was about 18–21 m/s. Sea voice microseisms greatly attenuated by 18:00 on September 18. The wind speed dropped to 6–9 m/s by this time. The sea voice microseisms attenuated completely by 10:00 on September 19. The wind speed dropped to 2–3 m/s at Cape Schultz. The frequency of primary microseisms decreased to 7.5 Hz and was poorly detectable by 7:30 on September 19. Secondary microseisms were not observed.

Typhoon Matmo (M). The weakest manifestations of the given signals in the low-frequency range could be observed on the spectrograms of infrasound disturbances generated by this typhoon, starting to evolve on July 26, 2014 around 10:00 and having approximately the same intensity during the entire time interval that these signals were observed. The center of the typhoon was in the Sea of Japan near Hokkaido at 45°N during this period. Peak frequency was 7.8 Hz. The disturbances attenuated completely at 23:00 on July 26.

Typhoon Chan-hom (Ch). Noise in the range of 1.0–2.5 Hz appeared at 15:00 on July 11. The eye of the typhoon was located in the south of the Yellow Sea, its front occupied the Korean Peninsula and extended to the south of Primorsky Krai. South wind at a speed of 6–8 m/s was blowing at Cape Schultz.

The noise in the range of 1.0–2.5 Hz amplified and expanded to the range of 1.0–4.5 Hz at 14:00 on July 12. The eye of the typhoon covered the north of the Korean Peninsula, and its leading edge (whirlwind) extended from the north of the Yellow Sea to China, Khabarovsk Krai, Primorsky Krai and the center of the Sea of Japan, passing through the southern islands of Japan to the Pacific Ocean. Southeast wind at a speed of 10–12 m/s was blowing at Cape Schultz.

Noise in the frequency range of 1.0–4.5 Hz continued at 14:30 on July 12. Oscillations with central frequencies of 5.3, 9.1 and 10.7 Hz were observed. Southeast wind increased to a speed of 15–19 m/s at Cape Schultz.

The eye of the typhoon was in the south of Primorsky Krai at 17:20 on July 12. The typhoon did not affect the Sea of Japan along the coast of the Korean Peninsula. Southeast wind at a speed of 17–20 m/s was raging at Cape Schultz.

Strong sea voice microseisms were observed in the frequency range from 7 to 9 Hz at 02:50 on July 13 (no other oscillations were observed). The frequency range of the sea voice microseism then rapidly expanded to 6–11 Hz (06:00 on July 13). The frequency range of the sea voice microseism narrowed to 7–9 Hz and disappeared at 10:00 on July 14. The eye of the typhoon was located in the north of Primorsky Krai, while the center, south and west of the Sea of Japan were not covered by the typhoon. The tail of the typhoon extended in an arc across the Yellow Sea, the Korean Peninsula, the center of Primorsky Krai, the eastern part of the Sea of Japan and the Japanese Islands and moved south into the Pacific Ocean. Southeast wind at a speed of 9–11 m/s was blowing at Cape Schultz.

Weak signals with center frequencies of 9.1 and 10.7 Hz appeared at 04:20 on July 14. The tail of the typhoon was located in the north of the Primorsky Krai, while the south of the Primorsky Krai was not covered by the typhoon. Northwest wind at a speed of 9–11 m/s was blowing at Cape Schultz.

The weak background of the sea voice microseism completely disappeared at 23:18 on July 14. The typhoon left the Primorsky Krai and the Sea of Japan. A slight atmospheric depression extended in the Sea of Japan along the Korean Peninsula. Northeast wind at a speed of 8–11 m/s was blowing at Cape Schultz.

The signals with the central frequencies of 9.1 and 10.7 Hz disappeared at 03:45 on July 15 but the signals with the central frequencies of 9.1 Hz reappeared from time to time. The atmospheric situation remained virtually unchanged. Northeast wind at a speed of 10–14 m/s was blowing at Cape Schultz.

The strainmeter recorded primary microseisms with a period of about 7.2 s and secondary microseisms with a period of about 3.7 s at about 03:00 on July 13. Their periods gradually increased with time, and reached, respectively, 10.5 and 5.3 s at about 05:30 on July 13. They were readily detected by the strainmeter, and their periods remain unchanged until 8:00 pm on July 13. The secondary microseisms then disappeared in the noise, while the primary ones with a period of about 10 s could be detected until 04:30 on July 14. Their period was slightly reduced to 9.3 s by this time.

Thus, the time when the sea voice microseisms appeared (July 13, 02:50) almost coincides with the time when the primary microseisms with a maximum period of 7.2 seconds arrived (03:00 on July 13). The toric period microseisms are characterized with 3.7.The wind speed at Cape Schultz was about 9–11 m/s. The frequency range of the sea voice microseism then rapidly expanded to 6–11 Hz (06:00 on July 13), which is associated with an increase in the periods of primary and secondary microseisms. The periods of these microseisms reached 10.5 and 5.3 s, respectively, by 05:30 on July 13. Secondary microseisms could not be detected at all around 20:00 on July 13. Primary microseisms were readily detected by the laser strainmeter until 04:30 on July 14. Sea voice microseisms disappeared at about 10:00 on July 14.

Conclusion

Analysis of the data we have obtained for each typhoon, as well as images from the Japanese satellite Himawari-8 allowed us to draw the following conclusions.

The time when sea voice microseisms were recorded with a laser strainmeter almost exactly (taking into account the complexity of visual detection by spectrograms) coincides with the time when primary and secondary microseisms were obtained with the same device.

Disappearance of sea voice microseisms is well correlated with the disappearance of primary microseisms and is poorly correlated with the disappearance of secondary microseisms.

The moment when the wind reaches maximum speed does not always coincide in time with the moment when the maximum microseisms of the sea voice are observed.

The study was carried out with partial financial support from the Russian Foundation for Basic Research (Grant no. 18-05-80011 “Dangerous Phenomena”) and the Program “Far East”.

REFERENCES

[1] **V.V. Shuleykin,** O golose morya [On the voice of the sea], Doklady of the USSR Academy of Sciences. 3 (8) (1935) 259–263.

[2] **M. Garces, J. Aucan, D. Fee, et al.,** Infrasound from large surf, Geophys. Res. Lett. 33 (2006) L05611(1–4).

[3] **V.G. Perepelkin, S.N. Kulichkov, I.P. Chunchuzov, I.A. Repina,** On experience in recording the voice of the sea in the water area of the Black Sea, Izvestiya. Atmospheric and Oceanic Physics. 51 (6) (2015) 716–728.

[4] **G.I. Dolgikh, S.G. Dolgikh, S.N. Kovalev, et al.,** Experimental estimate of a relation between sea wave energies and the Earth's crust microdeformations, Acta Geophysica. 55 (4) (2017) 607–618.

[5] **M.S. Longuet-Higgin,** A theory of the origin of microseism, Phil. Trans. R. Soc. London, Ser. A: Math. Phys. Sci. 243 (857) (1950) 1–35.

[6] **H. Benioff, B. Gutenberg,** Waves and currents recorded by electromagnetic barographs, Bull. Am. Meteorol. Soc. 20(10) (1939) 421–426.

[7] **E.S. Posmentier,** A theory of microbaroms, Geophys. J. R. Astron. Soc. 13 (1967) 487–501.

[8] **L.M. Brekhovskikh, V.V. Goncharov, V.M. Kurtepov, K.A. Naugolnykh,** The radiation of infrasound into the atmosphere by surface waves in the ocean, Izv. Acad. Sci. USSR, Atmos. Oceanic Phys. 9(9) (1973) 899–907.

[9] **R. Waxler, K.E. Gilbert,** The radiation of atmospheric microbaroms by ocean waves, J. Acoust. Soc. Am. 119 (5) (2006) 2651–2664.

[10] **W.L. Donn, B. Naini,** Sea wave origin of microbaroms and microseisms, J. Geophys. Res. 78 (21) (1973) 4482–4488.

[11] **G.I. Dolgikh, E.S. Gusev, V.A. Chupin,** The nature of the "Voice of the sea", Doklady Earth Sciences. 481 (1) (2018) 912–915.

[12] Data of the Japan meteorological agency on the movement of tropical cyclones for 2010–2018, URL: http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/besttrack_viewer_2010s.html.

[13] Himawari 8 Data Archive, GMS/GOES9/MTSAT Data Archive for Research and Education, URL: http://weather.is.kochi-u.ac.jp/archive-e.html.

[14] **G.I. Dolgikh, V.E. Privalov,** Lazernaya fizika. Fundamentalnyye i prikladnyye issledovaniya [Laser physics. Fundamental and applied research], Dalnauka, Vladivostok (2016).

[15] **G.I. Dolgikh, S.N. Kovalev, I.A. Koren, V.V. Ovcharenko,** A two-coordinate laser strainmeter, Izvestiya, Physics of the Solid Earth. 34 (11) (1998) 946–950.

Received 14.11.2018, accepted 28.11.2018.

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СПИСОК ЛИТЕРАТУРЫ

1. **Шулейкин В.В.** О голосе моря // Доклады Академии наук СССР. 1935. Т. 3. № 8. С. 259–263.

2. **Garces M., Aucan J., Fee D., Caron P., Merrifield M., Gibson R., Bhattacharyya J., Shah S.** Infrasound from large surf // Geophys. Res. Lett. 2006. Vol. 33. L05611. P. 1–4.

3. **Перепёлкин В.Г., Куличков С.Н., Чунчузов И.П., Репина И.А.** Об опыте регистрации «голоса моря» в акватории Черного моря // Известия РАН. Физика атмосферы и океана. 2015. Т. .51 6 №. С. 728–716.

4. **Dolgikh G.I., Dolgikh S.G., Kovalev S.N., Ovcharenko V.V., Chupin V.A., Shvets V.A., Yakhovenko S.V.** Experimental estimate of a relation between sea wave energies and the Earth's crust microdeformations// Acta Geophysica. 2017. Vol. 55. No. 4. Pp. 607–618.

5. **Longuet-Higgin M.S.** A theory of the origin of microseism // Philosophical Transactions of the Royal Society of London. Ser. A. Mathematical and Physical Sciences. 1950. Vol. 243. No. 857. Pp. 1–35.

6. **Benioff H., Gutenberg B.** Waves and currents recorded by electromagnetic barographs // Bull. Am. Meteorol. Soc. 1939. Vol. 20. No. 10. Pp. 421–426.

7. **Posmentier E.S.** A theory of microbaroms // Geophys. J. R. Astron. Soc. 1967. Vol. 13. Pp. 487–501.

8. **Бреховских Л.М., Гончаров** В.В., Куртепов **В.М., Наугольных К.А.** К вопросу об излучении инфразвука в атмосферу поверхностными волнами в океане // Известия АН СССР. Физика атмосферы и океана. 1973. Т. 9. № 9. С. 899–907.

9. **Waxler R., Gilbert K.E.** The radiation of atmospheric microbaroms by ocean waves // J. Acoust. Soc. Am. 2006. Vol. 119. No. 5. Pp. 2651–2664.

10. **Donn W.L., Naini B.** Sea wave origin of microbaroms and microseisms // J. Geophys. Res. 1973. Vol. 78. No. 21. Pp. 4482–4488.

11. **Долгих Г.И., Гусев Е.С., Чупин В.А.** Деформационные проявления «голоса моря» // Доклады Академии наук. 2018. Т. 1 № .148. С. 95–98.

12. Данные Японского метеорологического агентства о движении тропических циклонов за 2010 – 2018. http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/besttrack_viewer_2010s.html.

13. Himawari 8. Data Archive. GMS/GOES9/MTSAT Data Archive for Research and Education. http://weather.is.kochi-u.ac.jp/archive-e.html.

14. **Долгих Г.И., Привалов В.Е.** Лазерная физика. Фундаментальные и прикладные исследования. Владивосток: Дальнаука, 2016. 352 с.

15. Долгих Г.И.**, Ковалев С.Н., Корень И.А., Овчаренко В.В.** Двухкоординатный лазерный деформограф // Физика Земли. 1998. № 11. С. 76–81.

Статья поступила в редакцию 14.11.2018, принята к публикации 28.11.2018

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