Research of the Meteotsunamis Impact in the Coastal Zone

A. Zaytsev[1], S. Dolgikh[2], and M. Zaytseva[3](✉)

[1] Special Research Bureau for Automation of Marine Researches, FEB of Russian Academy of Sciences, 25 Gorky Street, Yuzhno-Sakhalinsk, Russian Federation
[2] V.I. I'lichev Pacific Oceanological Institute FEB of Russian Academy of Sciences, 43 Baltiyskaya Street, Vladivostok, Russian Federation
[3] Nizhny Novgorod State Technical University Named After R.E. Alekseev, 24 Minin Street, Nizhny Novgorod, Russian Federation

aizaytsev@mail.ru

Abstract. The paper presents an analysis of the meteotsunami event, which occurred on 6'th September, 2022. An abnormal change in pressure was registered at the marine scientific experimental base of Pacific Oceanological Institute "Schulz cape". This event caused large waves in the coastal point Preobrazhenie. Wave heights at this time reached 1 m. Interestingly, this event did not lead to strong excitement in neighboring points. Numerical modeling was performed, the causes of abnormal amplification in the coastal point of Preobrazhenie were determined.

Keywords: numerical modeling · meteotsunami · air pressure · full-scale measurements

1 Introduction

The cause of large waves, which are sometimes observed on the coast, is associated with spatial and temporal changes in atmospheric pressure. Since low atmospheric pressure leads to a static increase in the water level of a part of the marine region, and high atmospheric pressure leads to a static decrease in the water level of another zone (reverse barometer law), the water level in the sea is distorted. The resulting waves can be amplified due to the resonant properties of coastal morphology. The generation of long waves by atmospheric disturbances (meteorological tsunamis) in different countries is called differently: "rissaga" (Belerik Island), "marubbio" (Sicily), "milghuba" (Malta), "abiki" (Nagasaki Bay) and "Seebär" (Baltic Sea). An overview of meteotsunami is given in articles [1, 2]. Meteorological long waves have the same wave period as conventional tsunamis (a few minutes to 2–3 h), they can cause loss of life and a devastating effect in coastal zones, just like conventional tsunamis. For meteotsunami, source mechanisms such as spatial and temporal pressure distributions, atmospheric gravitational waves are important. Figure 1 show the cases of meteorological observations.

One of the interesting similar tsunami events was observed on June 23–27, 2014 in the Mediterranean and Black Seas from Spain to Ukraine. [3] describes this event. The first destructive wave was observed in Siutadella (Spain) with a height of 1 m on June 23. After 2 days, tsunami-like tsunami waves were observed in the Adriatic Sea. June 25, the

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Fig. 1. Cases of meteocunes in the oceans [1]

strongest waves with heights up to 3 m. Recorded in Vela Luke Bey. On the same day, a tidal wave of 1.5 m hit Matsara del Vallo. Then on June 26, the maximum 1-m wave was noticed in the Adriatic Sea. Finally, on June 27, 2014, waves 1–2 m high suddenly came to the Odessa coast on a calm and sunny day. In general, during these events, significant earthquakes in the Mediterranean and Black Sea regions were not recorded. Therefore, atmospheric disturbances are assumed to be a possible cause of such events.

2 6'th September 2022 Meteotsunami Event

At 6'th September 2022, an abnormal atmospheric disturbance was registered at the marine scientific experimental base of Pacific Oceanological Institute "Schulz cape" (Fig. 2). It has characteristics refers to meteotsunami.

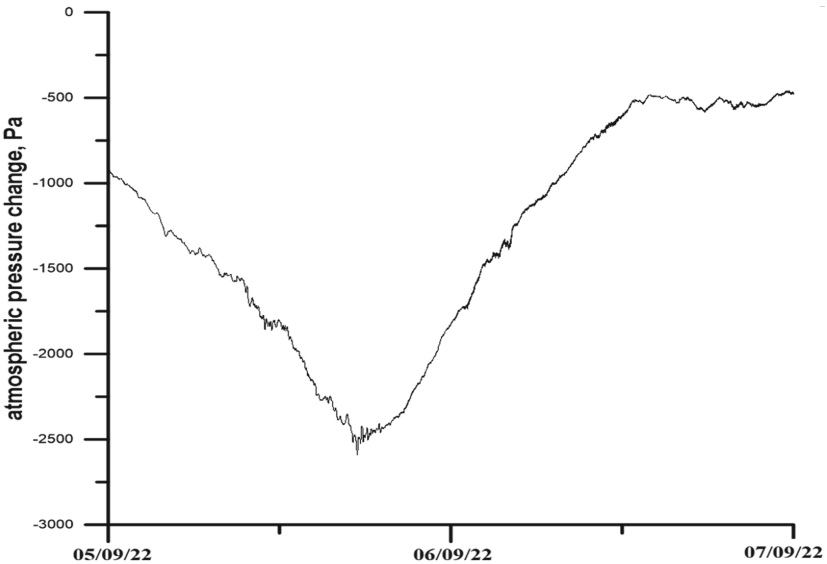

Fig. 2. Instrumental recording of the change in atmospheric pressure during 05/09/22–07.09.22 Shultz cape station.

In connection with this event, the task was set to study this phenomenon with a probable assessment of its manifestation in neighboring geospheres (atmosphere, hydrosphere, earth's crust) and with the determination of the primary source [4]. Pressure distribution for this region at 6/09/2022 (Fig. 3), obtained from the GFS/NCEP/US National Weather Service [5], shows that an abnormally low pressure front passed at Japan sea. A low pressure value (about 20 hPa) was also registered at "Schulz cape" station (Fig. 2).

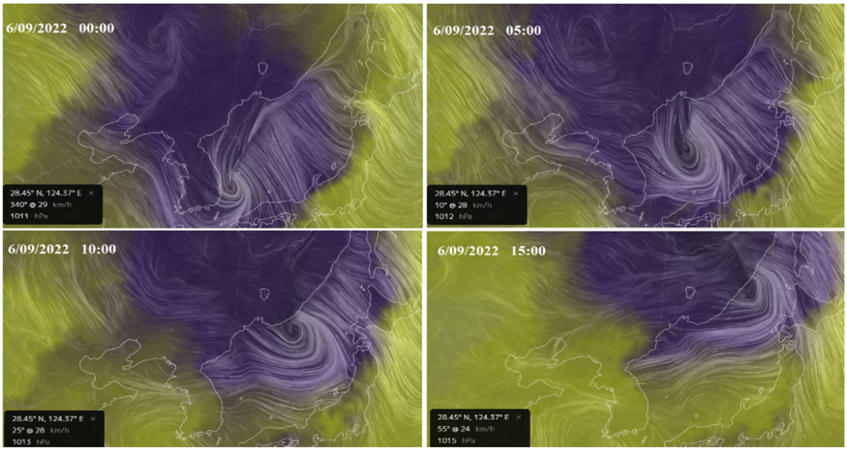

Fig. 3. Parameters and trajectory of 06.09.2022 Typhoon (GFS/NCEP/US National Weather Service).

Figure 4 shows the records of sea level changes at the points located along the 06/09/22 cyclone movement. It is worth noting that at the points Vladivostok and Nahodka the wave heights do not exceed 10 cm, but at the point Preobrazhenie we can see waves with heights up to 1 m taking into account the tide.

3 Numerical Simulation

For numerical simulation of generation and propagation of long waves caused by atmospheric disturbances, we used computational complex NAMI-DANCE_P [7]. Model equations include atmospheric impact term. This mathematical model has been used many times for simulation of long waves of atmospheric origin. It passed the tests and was approved on analytical and laboratory experiments [8]

$$\begin{aligned}&\frac{\partial M}{\partial t}+\frac{1}{R\cos\theta}\frac{\partial}{\partial\lambda}\left(\frac{M^2}{D}\right)+\frac{1}{R\cos\theta}\frac{\partial}{\partial\theta}\left(\frac{MN\cos\theta}{D}\right)+\frac{gD}{R\cos\theta}\frac{\partial\eta}{\partial\lambda}\\&+\frac{gn^2}{D^{7/3}}M\sqrt{M^2+N^2}+\frac{D}{\rho}\frac{1}{R\cos\theta}\frac{\partial p_{atm}}{\partial\lambda}=fN,\end{aligned}\tag{1}$$

$$\begin{aligned}&\frac{\partial N}{\partial t}+\frac{1}{R\cos\theta}\frac{\partial}{\partial\lambda}\left(\frac{MN}{D}\right)+\frac{1}{R\cos\theta}\frac{\partial}{\partial\theta}\left(\frac{N^2\cos\theta}{D}\right)+\frac{gD}{R}\frac{\partial\eta}{\partial\theta}\\&+\frac{gn^2}{D^{7/3}}N\sqrt{M^2+N^2}+\frac{D}{\rho}\frac{1}{R\cos\theta}\frac{\partial p_{atm}}{\partial\theta}=-fN,\end{aligned}\tag{2}$$

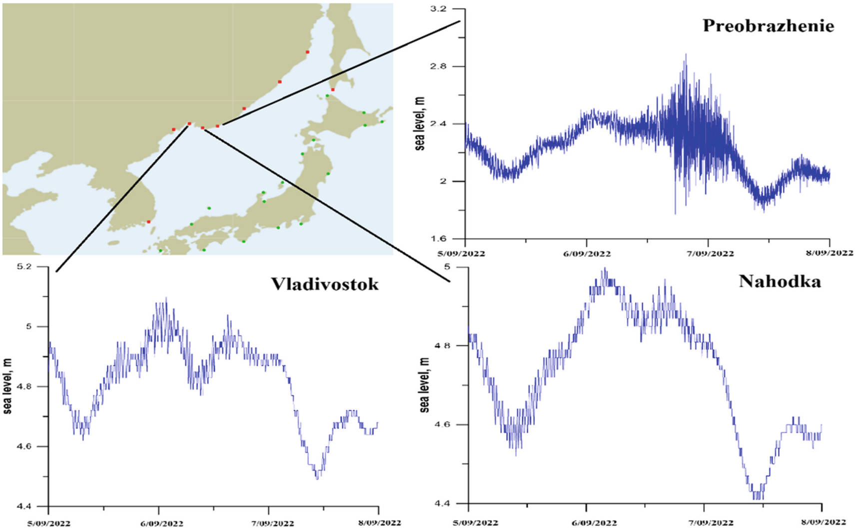

Fig. 4. Sea level station record of 06.09.2022 Typhoon [6].

$$\frac{\partial \eta}{\partial t}+\frac{1}{R\cos\theta}\left[\frac{\partial M}{\partial \lambda}+\frac{\partial}{\partial \theta}(N\cos\theta)\right]=0, \tag{3}$$

where η- the displacement of the water surface, t is time, M and N are the components of the discharge fluxes along the coordinates λ and θ, $D = h\ (\lambda, \theta) + \eta$ - the total depth of the basin and $h\ (\lambda, \theta)$ is the undisturbed water depth, g is the gravitational constant. f - Coriolis parameter ($f = 2\Omega\ \sin\theta$) and Ω - Earth rotation frequency (rotation period 24 h), R – the radius of the Earth. P_{atm} is the value of atmospheric pressure in Pascal, which is taken from meteorological maps usually transmitted to consumers at intervals of one hour. Pressure distribution maps with an interval of 1 h are available on the NASA website [https://gemini.gsfc.nasa.gov/aplo]. For calculations, these maps were interpolated in time in order to have a pressure field at each time.

To use the available meteorological information (GFS/NCEP/US National Weather Service), a digital pressure map was built for period from the 5'th to the 7'th of September 2022. The movement of the cyclone and the impact on the water surface were computed for 24 h using the NAMI-DANCE_P numerical program. Comparative analysis of water surface displacement at observation points (Nahodka, Preobrazhenie, Vladivostok) was performed. The results of the simulation show good convergence with natural instrumental measurements of sea level change. In Vladivostok and Nahodka points, there were small sea level displacements within 10 cm height, as well as according to the registration data (Fig. 4). At the Preobrazhenie point, we can observe fluctuations in height up to 0.5 m. The results of the numerical simulation show good agreement with the real data in this point station (Fig. 5).

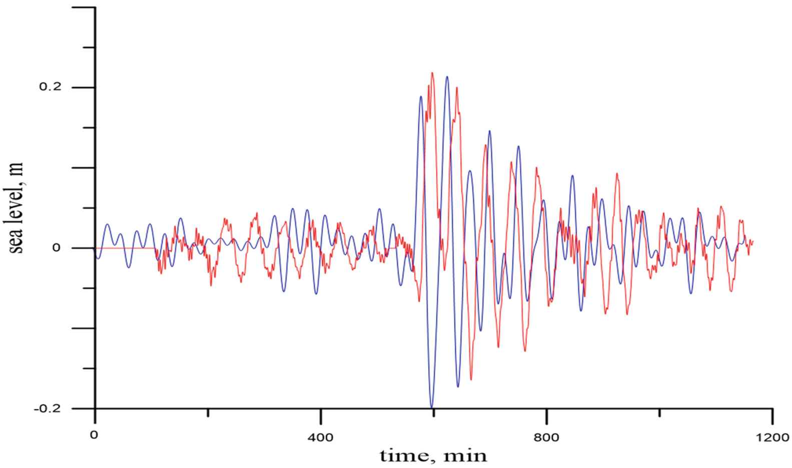

Fig. 5. Sea level change at the Preobrazhenie point (blue - measurement, red - numerical simulation)

Note anomalous values of sea level change altitudes at the Preobrazhenie point station obtained during numerical modeling and observation are more than five times higher than the value at neighboring stations (Vladivostok and Nahodka). This phenomenon can be explained by the peculiarity of the coastline structure at the Preobrazhenie point (Fig. 6). The station is located inside an elongated bay, the entrance to which is located in a southeast direction. I.e. in the direction of 06/09/2022 cyclone movement. And presumably in this place there was a physical mechanism for focusing the surface waves generated by the change in atmospheric pressure. This result should be of interest in the design of coastal infrastructure in the region.

Fig. 6. Map of Preobrazhenie station (red arrow – sea level record station)

4 Conclusion

The reasons for this study were to explain the physical mechanisms of an abnormal sea level change at the Preobrazhenie point during 06/09/2022 cyclone event. Numerical modeling was performed using the access meteorological information and the sampled mathematical model NAMI-DANCE. The results showed good agreement with the real records and this allowed the analysis of the distribution of wave heights along the coast from this event. This phenomenon can be explained by the peculiarity of the coastline structure at the Preobrazhenie point. And presumably in this place there was a physical mechanism for focusing the surface waves generated by the change in atmospheric pressure. This result should be of interest in the design of coastal infrastructure in the region.

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References

1. Pattiaratchi, C.B., Wijeratne, E.M.S.: Are meteotsunamis an underrated hazard? Phil. Trans. R. Soc. **A 373**, 20140377 (2015)
2. Monserrat S., Vilibic I., and Rabinovich A. B.: Meteotsunamis: atmospherically induced destructive ocean waves in the tsunami frequency band., Nat. Hazards Earth Syst. Sci. 2006. V. 6, P. 1035–1051
3. Sepic, J., Vilibic, I., Rabinovich, A.B., Monserrat, S.: Widespread tsunami-like waves of 23–27 June in the Mediterranean and Black Seas generated by high-altitude atmospheric forcing., Scientific reports. 5 (2015)
4. Dolgikh, G.I., et al.: A laser nanobarograph and its application to the study of pressure-strain coupling Izvestiya. Phys. Solid Earth. **40**(8), 683–691 (2004)
5. https://www.ncei.noaa.gov/products/weather-climate-models/global-forecast
6. http://www.ioc-sealevelmonitoring.org/
7. Zaytsev, A., Kurkin, A., Pelinovsky, E., Yalciner, A.C.: Numerical tsunami model NAMI-DANCE Science of Tsunami Hazards. **38**(4), 151–168 (2019)
8. Dogan, G.G., et al.: Long wave generation and coastal amplification due to propagating atmospheric pressure disturbances. Natural Hazards **106**(2), 1195–1221 (2021)