Atmosphere and Lithosphere Interaction Could Triggered the 2023 Mw 7.8 Turkey Earthquake

Victor Volkov[1], Mstislav Dubrov[2](✉), Igor Larionov[3], Jan Mrlina[4], Vaclav Polak[4], Dmitriy Aleksandrov[2], and Sergey Golovachev[2]

[1] Shmidt Institute of Physics of the Earth RAS, Bolshaya Gruzinskaya 10, Moscow 123995, Russia
[2] Fryazino Branch of Kotel'nikov Institute of Radioengineering and Electronics RAS, Vvedensky 1, Fryazino, Moscow Region 141190, Russia
mnd139@ire216.msk.su
[3] Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS, Mirnaya 7, Paratunka, Kamchatka Region 684034, Russia
[4] Institute of Geophysics CAS, Bocni II/1401, 14131 Praha, Czech Republic

Abstract. Comprehensive data analysis of atmospheric and cyclonic activity based on worldwide meteorological and oceanology data as well as the comparison with tilts and strains precise measurements by far distanced instruments have been performed. The earlier proposed model of earthquakes triggering due to atmosphere, ocean and lithosphere interaction was confirmed. The interaction develops as successively arising hurricanes (typhoons) activity in form of spatial-temporal swings of the lower pressure areas over the tectonic plates. The process started 1–2 months before the 2023 Mw 7.8 Turkey earthquake and after some cyclones reduction, it resumed. It was at this time that a major seismic shock occurred. This study considers the cyclones interaction in the Indian Ocean, North Atlantic Ocean and Mediterranean Sea during December 2022–January 2023. Excitations of Indo-Australian, African, Eurasian and Arabian tectonic plates progressed as NW-SE spatial and temporal swings over seismogenic area and were accompanied by tilt-baric and strain-baric disturbances detected by instruments installed in Central and East Europe and Far East regions. Tilt-baric effects of 1.2 mas/hPa and strain-baric events were observed for the most intensive cyclones 2–7 weeks before the earthquake.

Keywords: Tiltmeter · Strainmeter · Tropical Cyclone · Earthquake Triggering

1 Introduction

Temporal and spatial correlations between the strongest tropical cyclones (typhoons, hurricanes) and earthquakes were detected and discussed during recent decades. Different physical mechanisms of relationship between these two main natural disasters, which are similar in order of realized energy in the environment, has been considered in a number of publications [1–4].

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The connection of major earthquakes and typhoons in the northwestern part of the Pacific Ocean was demonstrated by means of satellite images of cloud covers accompanying the earthquakes occurring [1]. The intra-annual analysis of cyclogenesis in this most active basin allowed the seasonal dynamics of seismicity to be proposed [2].

The triggering of slow earthquakes as well as common earthquakes due to typhoons passage similarly to the passage of teleseismic waves from large regional events has been shown in [3] and [4].

Another model of a physical link between the two hazard types suggested the rocks erosion induced by very wet tropical cyclones [5]. Although this approach required the long time delays (from a few months up to few years) between tropical cyclone passage and earthquake happening [5].

Most of the studies mentioned above [1, 2, 5] are based entirely on statistical comparison of seismic catalogues data and typhoons (hurricanes) services information. The applying instrumental methods, such as the borehole strain-meters [3], laser interferometers [4] and tiltmeters [6] to detect accompanying earth deformations, promoted the observed phenomena investigation sufficiently.

The results of many years of experimental searching [7–9], and [10] allowed uncovering a physical entity of the interrelated processes. The proposed model assumes an atmosphere, ocean and lithosphere interaction to be a possible drive of triggering mechanism of major earthquakes [11]. We have described this process as successive development of cyclonic activity and arising hurricanes (typhoons) in form of a specific spatial-and-temporal motions of lower pressure areas over the Earth's tectonic plates.

The process starts 4–7 weeks before an earthquake and after some cyclonic activity descending it resumes wherein it was at this time that occurring a power seismic shock becomes highly probable. Investigation of the decade 1997–2007 major earthquake series showed that duration of the above period of cyclones system swinging within earthquake preparation continuance can increase up to 1–2 months for the strongest M 8–9 seismic events.

This study considers the initiation of powerful Turkey earthquake (6 February 2023) that could be a result of tropical cyclones interaction in the Indian Ocean and extra tropical windstorms in North Atlantic Ocean and Mediterranean Sea.

2 Earthquakes and Tropical Cyclones Interrelation Background

There are distinct physical justifications for coupling these two most terrible disasters on the globe.

Solar irradiation amounts the substantial part of atmosphere-ocean interactive energy releasing in tropical cyclones activity. We have shown [10] the daily energy outcome of a powerful tropical cyclone (Category 5 SSHWS) can reach the value about $1.5 \cdot 10^{19}$ J, which is equivalent to the energy released by a strong earthquake of $M_W > 8.3$.

An active zone of this rotating geophysical "engine" can spread over 10^3 km that is an order of size of a preparation zone of large regional earthquake. Lower pressure disturbs earth crust and being at vicinity of fault zone close to failure can trigger an earthquake.

A common period of tropical cyclone development including its highest activity phase alternates from a few days up to a few weeks. It is just the period, which characterizes the time scale of short-term earthquake precursors. Disturbances in atmosphere and lithosphere caused by powerful tropical cyclone (typhoon, hurricane) in the World Ocean are spread over wide areas.

In this way, typhoons and hurricanes are usually accompanied by a variety of earthquake precursory phenomena, including abnormal behavior of ultra-wideband (0.002 MHz–3 Hz) Earth's oscillations, which are available to be recorded at far distances up to 1,000–10,000 km.

Although not all of these phenomena may be due to earthquake preparation processes in the Earth's crust or mantle, at the same time, they are detected and studied for a long time included classic authors [12] and our earlier publications [8, 9].

3 Analysis of the 2022–2023 Tropical Cyclogenesis Preceding the 2023 Mw 7.8 Turkey Earthquake

Tropical cyclones transition from the Northern Hemisphere to the southern one in the end of November and the beginning of December 2022 was characterized by the calm condition period in one and a half weeks duration that was observed in atmosphere and World Ocean [13–15] and [16]. This was about two months before 06.02.2023 Turkey earthquake.

Meanwhile, tropical cyclones activity moved from NW Pacific to the Indian Ocean and sometime later, to the Southern Pacific. Last system of the 2022 Eastern and Central Pacific hurricanes dissipated on October 23 and last system of the 2022 Atlantic hurricane season dissipated in the northeastern Caribbean Sea on November 11. A series of extra tropical cyclones of the 2022–2023 European windstorm seasons succeeded the cyclonic activity in North Atlantic Ocean (Table 1).

Severe tropical storm MANDOUS, which developed in the Bay of Bengal on 6 December 2022, was the first notable system (after tropical cyclone ASANI, 7–12 May 2022) for this round of cyclonic activity in the North Indian Ocean [14]. Arising of the succeeded low pressure events have progressed as NW-SE spatial and temporal swings of cyclonic disturbances between Atlantic and Indian Ocean basins during December 2022–January 2023 (see Fig. 1).

Extra tropical cyclone EFRAIN from North Atlantic hitting the Iberian Peninsula and France was the most intense, strongest storm of the 2022–2023 European windstorm season (955 hPa ~ C2, SSHWS). Cyclone EFRAIN came after tropical storm MANDOUS in the Indian Ocean. Tropical storm PAKHAR (the last system of the 2022 NW Pacific

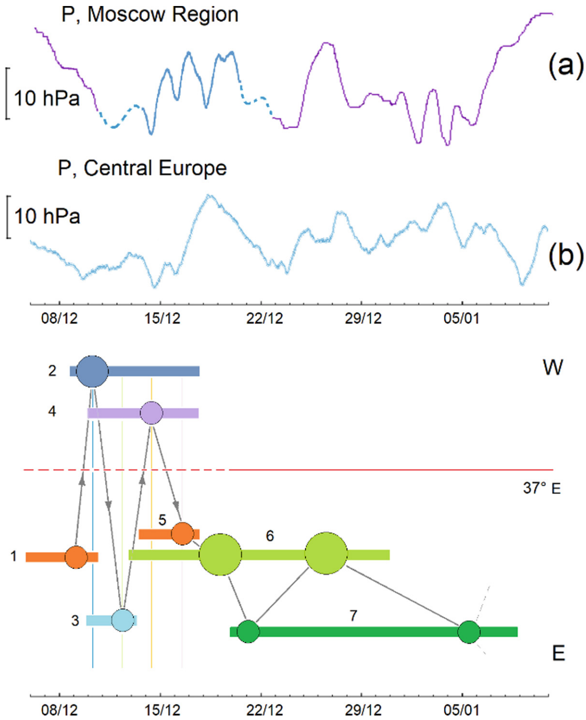

Fig. 1. Atmospheric pressure variations in Moscow Region (a) and Central Europe (b) during December 2022–January 2023; 1…7 – tropical cyclones in the Indian Ocean and European windstorms in North Atlantic (see Table 1), circles denote the time intervals in the lowest pressure of cyclones

typhoon season) succeeded the cyclone EFRAIN, GAIA came after PAKHAR and so on, as shown in Fig. 1 and Table 1.

These spatially and temporary swinging the lower pressure systems excited the Indo-Australian, African and Eurasian tectonic plates bordering around the Arabian tectonic plate (Fig. 2). It is important that spatial distribution of cyclones active zones formed triangular patterns having the epicenter of impending earthquake near their medians (marked by star in Fig. 2).

This period of cyclonic activity has ended by swinging between tropical cyclone DARIAN (C4 SSHWS) and tropical storm ELLIE excited the eastern part of the Indo-Australian tectonic plate [15]. The atmospheric condition was featured by stochastic air pressure variations without any sign of synchronizing or correlation of signals recorded at spatially distanced observational points (Fig. 1).

Some cyclonic activity weakening happened in 9–13 January 2023. This pause was fulfilled by very rare subtropical cyclone in the Southern Atlantic that moved from the Brazilian coast toward the African tectonic plate.

The next round of cyclones development started 14.01.2023 (Table 1). Extra tropical cyclone FIEN occurred in Northern Atlantic and tropical storm IRENE in Southern

Table 1. Tropical cyclones in the World Ocean and European windstorms in North Atlantic and Mediterranean Sea during December 2022–February 2023 [13–15] and [16]

No	Name	Category (SSHWS)	Duration	Basin
1	MANDOUS	TS[1]	06–10 December	North Indian Ocean
2	EFRAIN	ETC2[1]	10–17 December	Northern Atlantic
3	PAKHAR	TS	10–12 December	NW Pacific
4	GAIA	ETC	10–17 December	Northern Atlantic
5	ARB 03	TS	14–17 December	North Indian Ocean
6	DARIAN	C4	13–21–30 December	SW Indian Ocean
7	ELLIE	TS	20 December–8 January	Aust. Indian Ocean[2]
8	HALE	TS	07–08 January	Southern Pacific
9	Subtropical ccl	STC	07–10 January	Southern Atlantic
10	FIEN	ETC1	14–20 January	Northern Atlantic
11	IRENE	TS	14–19 January	Southern Pacific
12	GE’RARD	ETC2	15–17 January	Northern Atlantic
13	CHENESO	C2	16–29 January	SW Indian Ocean
14	HANNELORE	ETC1	19–28 January	Mediterranean
15	DINGANI	TL(C2)[1,3]	27 January–9 February	Aust. Indian Ocean
16	FREDDY	C1	04–14 February…[4]	Aust. Indian Ocean
17	BARBARA	ETS[1]	05–08 February	Mediterranean
18	GABRIELLE	C2	05–10 February…[5]	Aust. Indian Ocean

[1] TS – Tropical storm; ETC(S)–Extra tropical cyclone (storm); TL – Tropical low
[2] Australian region cyclone
[3] DINGANI – Tropical Low; 9 – 15 February– C2 SSHWS, SW Indian Ocean
[4] FREDDY –C1; 14 February–15 March – C5 SSHWS, SW Indian Ocean
[5] GABRIELLE – 10–11 February, Southern Pacific

Pacific basin. Another cyclone – European windstorm GE’RARD developed next day and tropical cyclone CHENESO (C2 SSHWS) formed 16.01.2023 in SW Indian Ocean.

The above swinging of three tectonic plates (I, II, III) surrounding the Arabian plate (IV) resumed. This process became more severe when Mediterranean “hurricane” [16] – Medicane HANNELORE was involved on 20.01.2023 (see left Fig. 3). The HANNELORE’s competition with tropical cyclone CHENESO in SW Indian Ocean was their alternate impacts up to the end of January 2023. The less intensity of cyclone HANNELORE (C1 SSHWS equivalent) was more than compensated by its proximity (Mediterranean and Balkans) to the region of upcoming disaster – epicenter location was near 37.2° N and 37.0° E. The next tropical cyclones DINGANI, FREDDY and GABRIELLE arising in the Indian Ocean went to the eastern part of the Indo-Australian

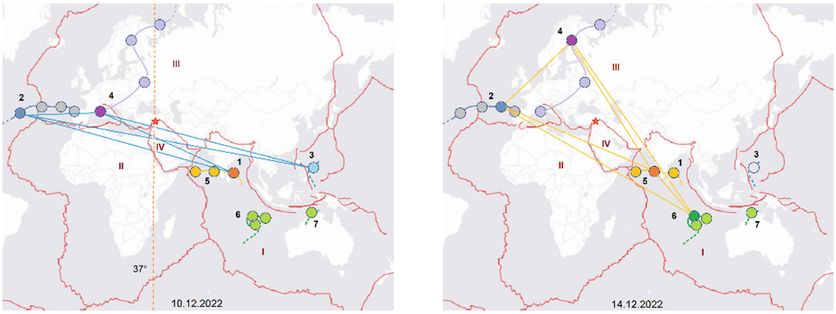

Fig. 2. Tracks and spatial distribution of active zones (1…7, see Table 1) for tropical cyclones in the Indian Ocean and European windstorms in North Atlantic. The lower pressure areas (bright circles) excite tectonic plates: I – Indo-Australian, II – African, III – Eurasian and IV – Arabian on 10 and 14 December 2022

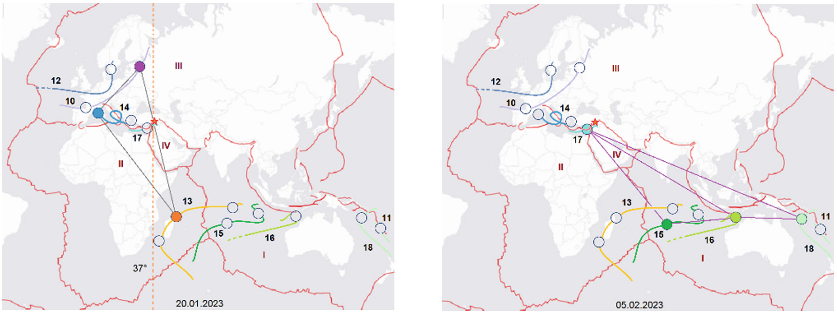

Fig. 3. The same as Fig. 2 on 20 January and 5 February 2023

tectonic plate in the very beginning of February (Fig. 3, right).Meanwhile, the Mediterranean storm BARBARA affected directly the area of the 6 February 2023 Turkey earthquake, preceded for tens hours the main Mw 7.8 shock (t_0 = 01 h 17 m 35 s UTC) and accompanied all the strong aftershocks.

4 Tilt-Baric and Strain-Baric Processes Preceding and Accompanying the 2023 Mw 7.8 Turkey Earthquake

The Earth's deformations (tilts and strains) and atmospheric pressure variations were monitored at three observational points: in Central Europe (Geophysical Observatory Pribram), Moscow Region (testing site Fryazino) and Kamchatka peninsula (observational site Karymshina). Instruments installations, measuring techniques and precision characteristics were described in detail in our previous publications [6–8, 10] and [11].

As noted above, atmospheric pressure variations were random during December 2022 without any sign of coherency between the signals recorded at the observational points Pribram and Fryazino spatially distanced by 1600 km. That was the period when the windstorms and tropical cyclones started the NW-SE swinging between Northern

Atlantic (European areas) and Indian Ocean basin. That was 1.5–2 months before the 2023 Mw 7.8 Turkey earthquake.

A different situation developed 2–3 weeks before this earthquake. The high degree of correlation and even signs of synchronizing could be distinguished between the wideband tilt-baric and strain-baric processes recorded at observational points being 1600–8100 km apart (Fig. 4, Fig. 5, and Fig. 6).

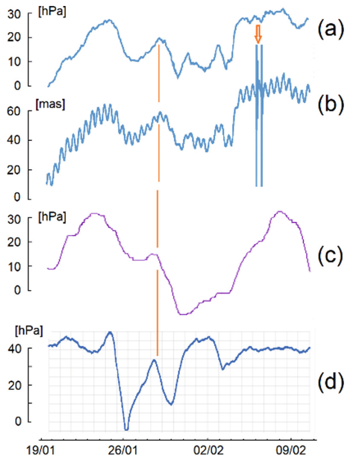

Fig. 4. Ultra-long period tilt-baric variations in Pribram (a, b), Fryazino (c) and Karymshina (d) 1–2 weeks before the 2023 Mw 7.8 Turkey earthquake (denoted by arrow)

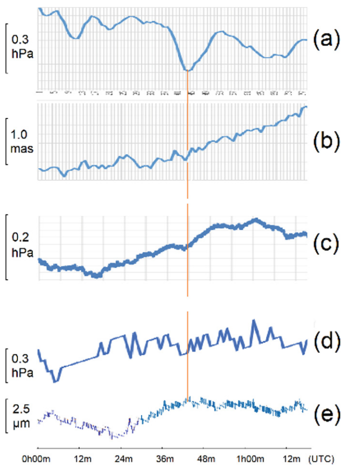

Fig. 5. Long-period tilt-baric and strain-baric variations in Pribram (a, b), Fryazino (c) and Karymshina (d, e) 1 h before the 2023 Mw 7.8 Turkey earthquake

Strong correlation (R_P ~ 0.8–0.9) was observed between NS component of tilts and atmospheric pressure variations with characteristic periods about 20–100 h that recorded in Pribram (Fig. 4 a, b). The value of tilt-baric variations reached the level of a few tidal amplitudes wherein tilt-baric coefficient was near 1.2 mas/hPa. Good conformity of baric variations at ultra-long periods up to 400 h was seen under 1600 km distance (observational points Pribram and Fryazino) and kept in part up to 8100 km in Karymshina point (Fig. 4 c, d). The direct estimations of correlation coefficient are hugely intricate due to wave shapes blur under their propagation at far distances.

The long period 5–20 min tilt-baric and strain-baric variations appeared by less clear correlation features 1–1.5 h before earthquake though some consistency of recorded baric strokes were noted at distanced points (Fig. 5 a-e). The strain-baric coefficient for strainmeter in Karymshina point was evaluated to be about (2–3) $\cdot$ 10^{-8} hPa^{-1} (Fig. 5 d, e; the linear thermal trend 2.4 K/h was removed).

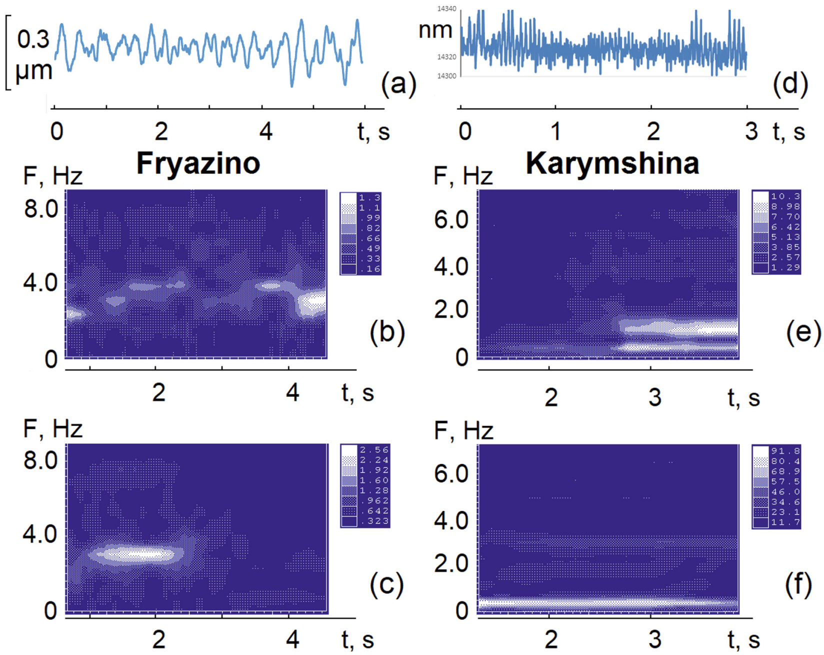

Fig. 6. Micro-seismic oscillations in Fryazino (a) and Karymshina (d) and their time-frequency diagrams 1 min (b, e) and few seconds (c, f) before the main Mw 7.8 shock (t_0 = 01 h 17 m 35 s UTC) of the 2023 Turkey earthquake

A special behavior of micro-seismic oscillations in 1–10 Hz band were recorded by the two distanced laser strainmeters (Fryazino and Karymshina) just before the 2023 Mw 7.8 Turkey earthquake (Fig. 6 a-f). The synchronization phenomenon of high frequency microseisms, which we observed before strong seismic events earlier [7, 10], appeared this time clearly. The speckle structure of time-frequency diagram (2–4 Hz, Fryazino) and spectral pick splitting (0.4–1.2 Hz, Karymshina), which were seen 1 min before earthquake (Fig. 6 b, e), collapsed into narrow bands in 3.1 Hz (Fryazino) and 0.4 Hz (Karymshina) respectively a few seconds preceding the main shock (Fig. 6 c, f).

5 Conclusion

The comparative analysis of atmosphere condition, cyclonic activity in the World Ocean and wideband Earth's deformations (tilts and strains) reveal the three geospheres interaction could be a trigger of the 2023 Mw 7.8 Turkey earthquake. The newly developed methods and original techniques have been applied in this study. The spatially distributed at distances 1600–8100 km tilt meters and laser strainmeters allowed the ultra-long periods up to 400 h variations and micro-seismic oscillations in 1–10 Hz band to be analyzed. Their behavior has been connected with time intervals preceding earthquake for one minute and up to the hundreds hours. The obtained result will be useful in earthquake prediction application.

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