Features of some interacting tropical cyclones in the Indian Ocean after the Mount Pinatubo eruption

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Abstract— *The features of the impact of some tropical cyclones (TC) in the Indian Ocean on the environment after the eruption of Mount Pinatubo are considered. The 1992 North Indian Ocean cyclone season was unofficially the most active year on record for the basin, with 13 TC developing. It was shown that TC-05B, closing the chain of 10 TC before its destruction over the North Bay of Bengal, showed anomalous thunderstorm activity and contributed to the emergence of TC Aviona in South Indian Ocean. The strongest in season-92 TC-10B and TC Forrest, apparently, caused an earthquake in the Indian Ocean. At the same time, the strongest typhoons Hunt and Gay from 1979 to 2015 simultaneously developing in the Pacific Ocean caused the Burma Plate earthquake. Experimental data of anomalous features of the ionosphere during these events were obtained using the satellite Cosmos-1809.*

Keywords— Indian Ocean, Tropical Cyclone, Pinatubo.

I. INTRODUCTION

The problem of the movement of several interacting tropical cyclones and their impact on the environment is complex. It was previously shown that two tropical cyclones, at a distance of less than 1,400 km from one another, begin to rotate around a common center and converge [1]. Currently, meteorology typically uses a modified ETA model: North American Mesoscale Forecast System (NAM) [2] or Weather Research and Forecast Model (WAR) [3] to predict the development of tropical cyclones. Manipulating the vast datasets and performing the complex calculations necessary to modern numerical weather prediction requires some of the most powerful supercomputers in the world. Examples of such calculations and detailed references are presented in the series of works by the authors [4].

Further studies showed that the nonlinear dynamics of internal gravity wave (IGW) structures of the dissipative ionosphere in the presence of a heterogeneous zonal wind can create both monopole vortices in the form of a tropical cyclone and a vortex path along the zonal wind [5, 6]. IGW can occur both in multiple lightning discharges and in the structures of a developed tropical cyclone [7-9]. The flow of atmospheric air over obstacles such as islands or isolated mountains sometimes gives birth to von Karman vortex streets [10]. The significant role of the structure of the lower stratosphere in the development of a tropical cyclone was noted in [11] and in separate sections of the annual reports of the Joint Typhoon Warning Center (JTWC) by J.C. Sadler. The structure of the equatorial stratosphere is associated with the development phase of the quasi-biennial oscillation (QBO) [12, 13].

Analysis conducted by the authors according to the Cosmos-1809 satellite showed that a month after the eruption of Mount Pinatubo 12-Jun-91 [14], the plasma density of the upper ionosphere near the equator decreased approximately two times, and a continuous sequence of typhoons was observed in the western Pacific [15, 16].

In 1992, the cyclonic activity of the world's oceans, characterized by the Accumulated Cyclone Energy (ACE) index, increased by 50% [15]. TCs achieved the highest activity in September-November 92, when up to 10 TCs simultaneously developed. At this time the eastern phase of QBO was observed in the lower stratosphere [12]. IGW acoustic effects from numerous strong aftershocks of the Landers-92 earthquake and from underground nuclear tests (UNT) on the Nevada Test Site (NTS) on the atmosphere contributed to the development of a chain of interacting TCs in accordance with the theoretical conclusions of Aburjania [16-18].

One of the authors' research results was the detection of the dependence of the earthquake occurrence during the intensification of TCs of the fifth category: Andrew (August), Bonnie and Charley (September) in the Atlantic Ocean, and Gay and Hunt (November) in the Pacific Ocean. Earthquakes occurred on the southern border of the American Plate in the South Sandwich Islands on August 24 (M = 6.1), September 24 (M = 5.5 and 5.6) and November 21 (M = 6.6) (Table 1). A possible mechanism for the occurrence of earthquakes is associated with the raising of tectonic plates in the zone of the “eye” of TC and lowering the opposite edge of the plate, what is suggested in the presentation of the report [18].

The effects of the development of the Indian Ocean TCs in 1992, interacting with Pacific typhoons in the eastern wind phase of the lower stratosphere are considered in this paper as well as individual earthquakes, the occurrence of which may be associated with TC 10B and Forrest impact on the Indian Plate.

II. FEATURES OF THE HIGH IONOSPHERE OVER THE INDIAN OCEAN 24-SEP-92

In the middle of September, 92 tropical cyclones were observed only in the Pacific Ocean and nowhere more [19]. The names of these tropical cyclones were Typhoon Ted and Hurricane Roslin. September 17, before the autumnal equinox when the eastern zonal wind occurred in the lower stratosphere three Tropical Depression (TD) Bonnie, Seymour and Tina were formed near the American continent [11]. Bonnie formation was associated with a deep invasion of a cold front along the east coast of America. Tropical waves after crossing the Americas were upgraded into TD Seymour and Tina. TD Seymour reached hurricane strength on the 19th. TD Tina was alive from September 17 to October 11. This is the record for the eastern Pacific Ocean.

The further development of TCs is in good agreement with the ideas of Aburjania [5, 6] about the formation of the Rossby-Aburjania wave from the TC chain diverging from the San Andreas Fault. The additional acoustic impact from the nuclear test experiment (NTE) Hunter Trophy on September 18 led to an increase of Bonnie, Seymour, Tina and Ted intensity, as well as to the organization of TC Val in the western Pacific Ocean. September 21, with further self-organization of the Rossby-Aburjania wave TC Charley and Danielle arose in the Atlantic Ocean to the east of the San Andres fault, and TC 05B appeared in Indian Ocean on the other side of the wave. Fig. 1 shows the dynamics of the TC development in the Indian Ocean and the western Pacific Ocean. Moments of the NTE are marked by arrows in Fig. 1.

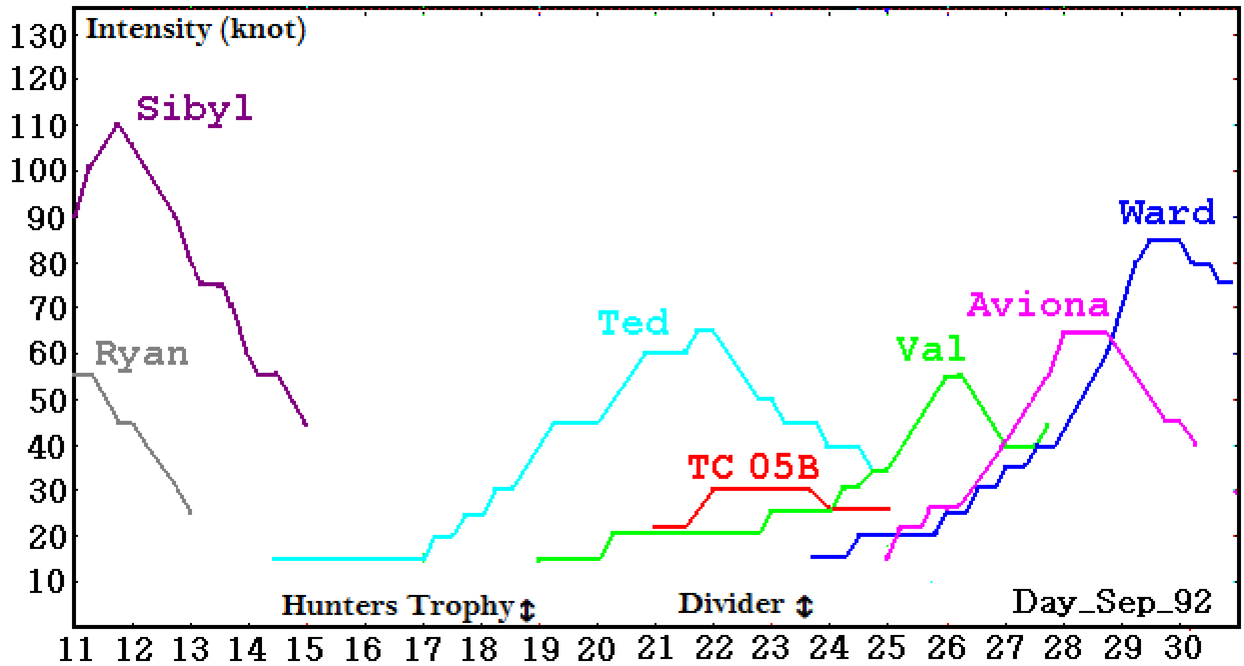

FIGURE 1. Dynamics of TCs in the western Pacific and Indian Oceans in September 1992.

After the next NTE Divider held on September 23, the trajectories of five tropical cyclones in eastern Pacific and Atlantic oceans changed dramatically, TC 05B and typhoon Ted dissipated, and a new TC Ward was born in the western Pacific [18]. TC 05B moved westward over the northern Bay of Bengal. It hit near the Indian/Bangladesh coastline on the 23rd as a depression, and dissipated 2 days later over India [19]. The India Meteorological Department report does not contain information on TC 05B [20].

Cosmos-1809 satellite measurements 24-Sep-92 revealed an abnormally large thunderstorm activity over India and the emergence of a new TC Aviona in the South Indian Ocean. The satellite had an altitude of about 960 km, a period of ~ 104.1 min, an inclination of ~ 82 °, a shift in the next orbit in longitude of ~ 26.1 °, and a change in local time of ~ 36 sec. Satellite in the passive mode measured: electron density Ne and its fluctuation dNe, electron temperature Te, two components of a large-scale electric field, amplitudes of electromagnetic plasma oscillations in frequency channels f = 140, 450, 850, 4600 Hz and 15 kHz with a width Δf = f / 8. All this made it possible, by comparing the measurement data at neighboring orbits, to determine local and global sources of ionosphere disturbances.

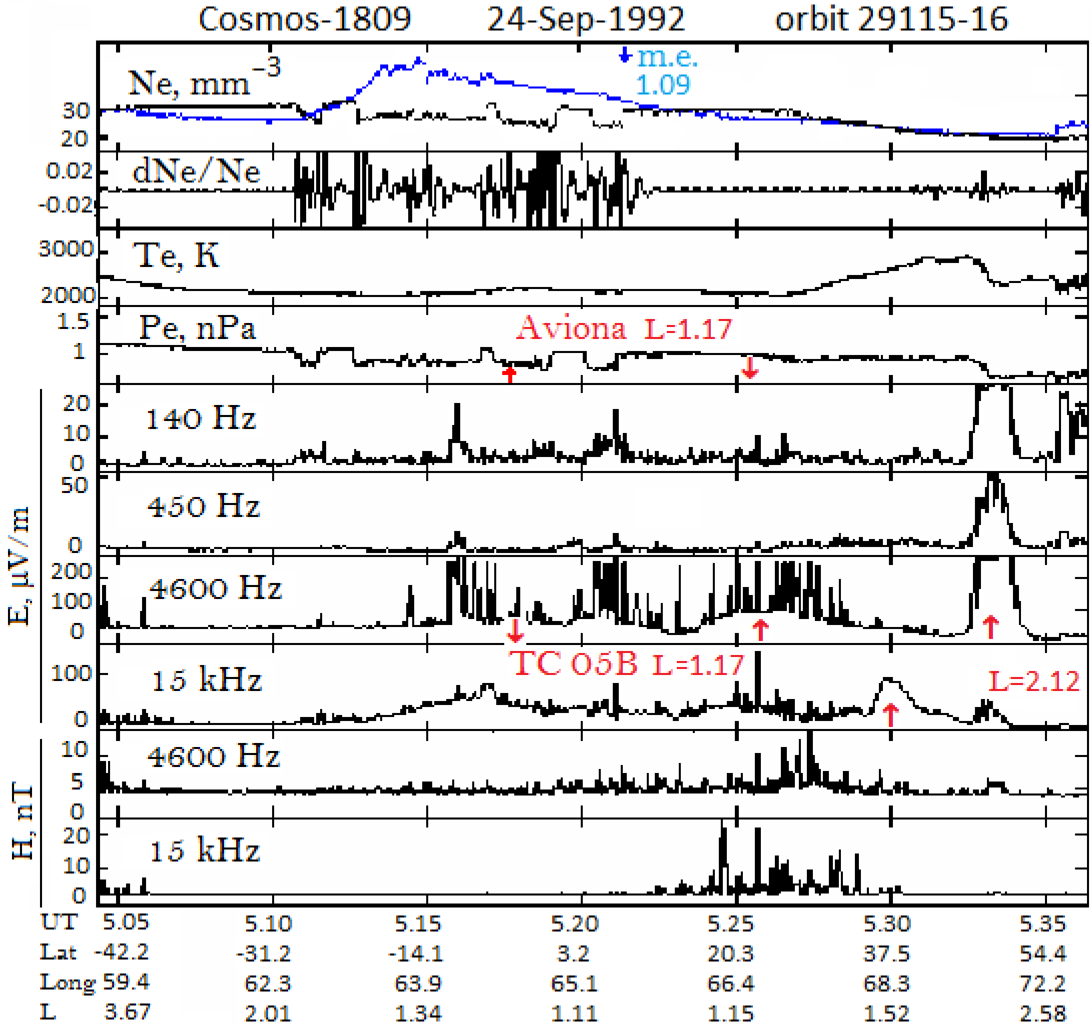

FIGURE 2. Cosmos-1809 measurement data in the morning sector (LT ≈ 10) west of the Indian peninsula and near the Aviona TC origin center (73 E, 5 S).

In Fig. 2, the satellite's passage through the latitude of the TC 05B center (21.7 N, 89.0 E) is marked on the E4600 panel with the up arrow and the same path in the magnetically conjugated region (L = 1.17) is indicated by the down arrow. Narrow peaks in the channels of 4600 Hz register the magnetosphere passage of whistles from lightning discharges. The maximum intensity of these signals is located near the lower hybrid frequency (LHR), which is usually located in the channel band of 4600 Hz. The magnetosphere passage of VLF signals from the VLF transmitters was studied jointly with the Cosmos-1809 and DE-1 satellites [21]. Usually, signals in the whistle mode deviate from the magnetic field from the region of entry into the ionosphere to the caustic with large L – shells. And if a duct is formed along a magnetic field with a lower density, then the signal is captured. Above the TC 05B (the zone of whistlers entering the ionosphere), both electric and magnetic components were observed. When the whistle propagates beyond the magnetic equator (indicated by a blue down arrow in Fig. 2), it has only the E component near the LHR, which is perpendicular to the magnetic field. September 24, the high density of whistling signals was observed only at this orbit. At the previous orbit passing between TC 05B and Ted only ascending whistlers were observed and the density was 2-3 times less.

The appearance of individual Ne cavities with dNe fluctuations of up to 4–5% over the incipient TC at the stage of amplification of the tropical disturbance (TD) was observed from the Cosmos-1809 satellite in several cases [8]. However, there are several such caverns south of the magnetic equator and above TD Aviona. They are filled with descending whistlers that displaced part of the plasma to the east. The blue curve on the Ne panel shows the plasma density distribution along 29114-15 orbit on the same L-shells.

Additionally Fig. 2 shows the electron gas pressure Pe = NekTe, where k is the Boltzmann constant (panel No. 4). The equilibrium of Pe in the cavities is established due to the interaction of electrons with developed Langmuir turbulence where Ne fluctuations reach 4% (panel No. 2). At 5:33 UT, the satellite entered the region of strong oscillations in the vicinity of the LHR (channel 4600 Hz) near the cyclotron frequency of hydrogen (channel 450 Hz) and the cyclotron frequency of helium (channel 140 Hz). Sharp decrease in Pe also occurs here. This region is associated with a traveling ionospheric disturbance (TID) from an earthquake in Iran (29.8 N, 51.1 E; M = 5.1) September 23 at about 22 UT. The development of disturbances in the ionosphere in the low-frequency range was considered in detail by M. Hayakawa [22]. The Cosmos-1809 satellite recorded the dynamics of similar disturbances from the acoustic effects of underground nuclear explosions [23].

It should be noted that at 5:30 UT a strong signal only in the 15 kHz channel is associated with the satellite passing over the zone of influence of one of the Radio Engineering Navigation Range finder (RSDN-20; 39.5 N, 62.7 E) transmitters on the ionosphere, one of whose frequencies f = 14.88 kHz falls into the channel band. The Russian RSDN-20 stations are nicknamed ALPHA.

The features discussed in this section did not stand out after 11 hours on orbit 29122, passing in the unlit ionosphere along the west coast of India.

III. TC 10B AND FORREST ENVIRONMENTAL EFFECTS

In autumn 1992 El Niño-Southern oscillation is formed in the Pacific Ocean. In November, a short-term anomaly of the east wind arose in the lower stratosphere [12]. In this period the strongest TCs are observed which are shown in Fig. 3. Iintensity and trajectory of movement of the TCs show that:

1. TC Forrest and TC 10B interacted under the influence of the monsoon on November 12-16.
2. Typhoons Gay, Hant and Forrest interacted on November 16-22.

Only one (TC10B of November 11-17) of the 12 cyclones formed over the North Indian Ocean affected the weather over Indian peninsula [20]. Under the influence of this weather system, wide spread very heavy rainfall occurred in the coastal districts of Tamilnadu and Kerala. Forrest was the only TC of 1992 to track from the western North Pacific, across the South China Sea, and into the Bay of Bengal. It reached a maximum intensity of 125 kt (230 km/h) in the Bay of Bengal over a day after it had recurved. Hunt was part of a three storm outbreak with Forrest and Gay. As Hunt intensified, it brushed by Guam, moved into the Philippine Sea, and later recurved. After recurvature, the typhoon played an important role in the extremely rapid weakening of Gay which was approaching the southern Mariana Islands. Typhoon Gay was the most intense TC since Typhoon Tip in 1979 to Hurricane Patricia in 2015. JTWC estimated its peak winds of 295 km/h (160 knot) and a minimum barometric pressure of 872 mb [19].

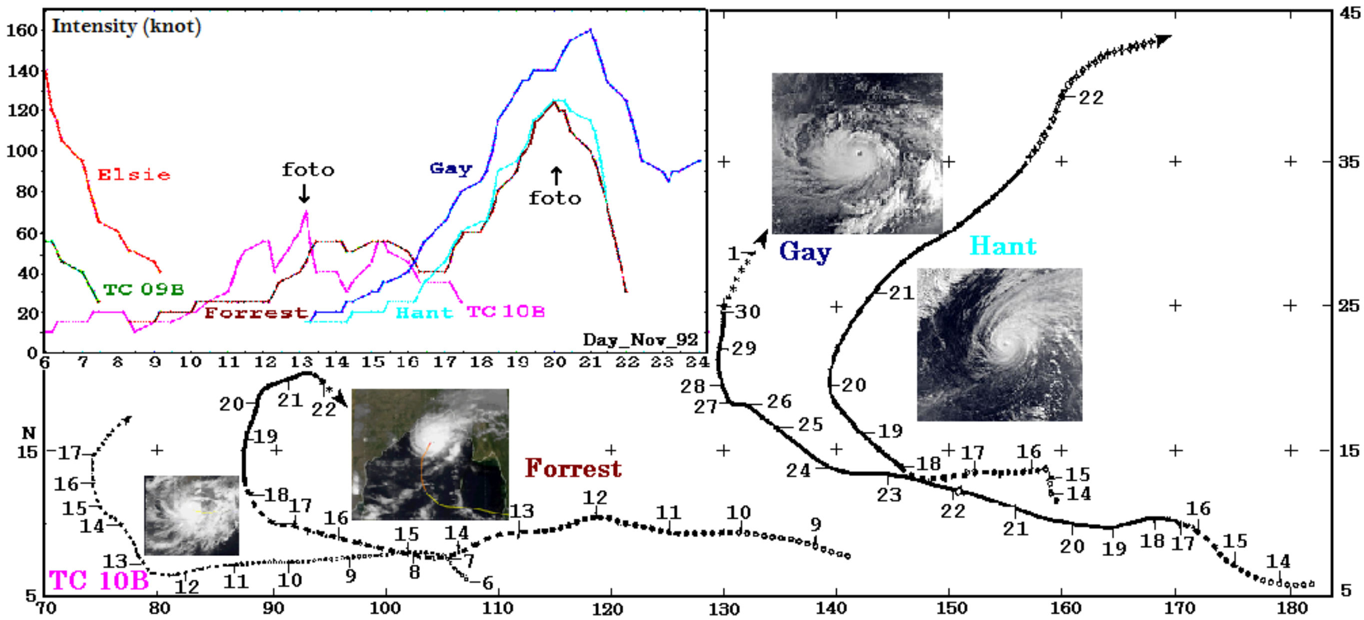

FIGURE 3. Trajectories and intensity of tropical cyclones in November 1992.

Two maps are shown in Fig. 4 on which measurements of the amplitude of the electric (green curve) and magnetic (blue) components of the plasma oscillations obtained from the Cosmos-1809 satellite in the frequency channels of 4600 Hz in the morning sector on November 14 and 16 are plotted. The ordinate axis of the first curve on the left is aligned with the 123.4 E meridian, whose plane at the equator crosses the 29816 orbit at 21:33:22 UT 13-Nov. The subsequent curves are shifted by 26.1 in longitude and 104.1 minutes in time. Correspondingly, the ordinate axis is aligned with the 84.0 E meridian, whose plane at the equator crosses orbit 29845 at 23:54:26 UT on November 15. Due to the inclination of the orbit the descending orbits at a latitude of 45 N pass of about 4.8 west of the longitude of the equator, and at a latitude of 45 S pass east of about 4.8. All curves are plotted in the same scale, which is shown at the top right.

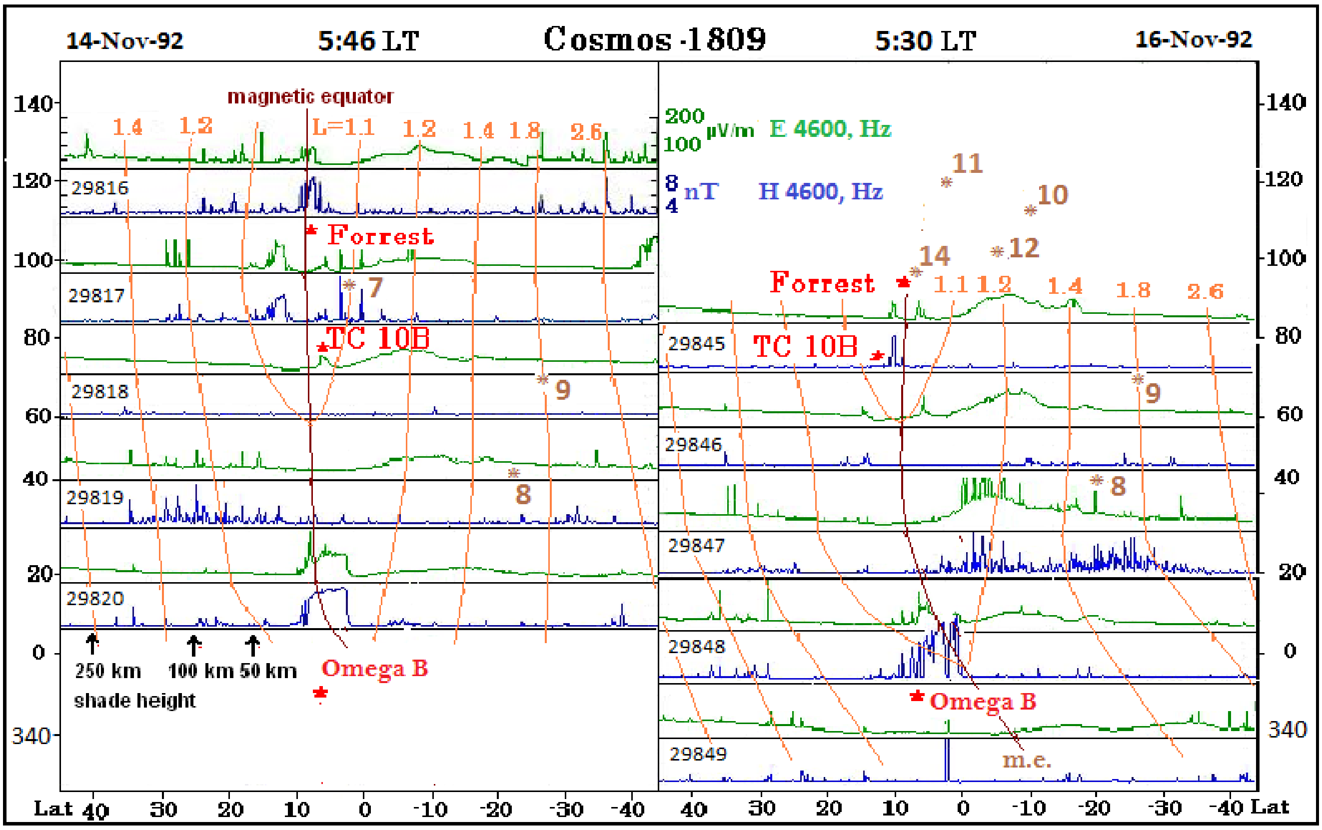

FIGURE 4. Measurement data of the amplitudes of the electric (green) and magnetic (blue) components of the plasma oscillations recorded in the frequency channels of 4600 Hz at 5 consecutive downward orbits. The horizontal axis of the E-component coincides with the longitude of the orbit at the equator. The brown stars with the number mark the centers of earthquakes from Table 1. The orange lines on the maps with the number at the top are the magnetic L-shells at the height of the satellite.

Cosmos-1809 satellite data at 4600 Hz channels most representatively illustrate, taking into account measurements by other instruments, the features of the upper ionosphere over powerful natural and technogenic sources [23]. A comparison of the signals on November 14 and 16 over Forrest, the intensity of which did not change, and the TC 10B indicates:

1. The intensity of plasma oscillations near LHR is highly dependent on the height of the solar shadow. On November 14, the shadow whose height below the satellite, shown in Fig. 4, November 16, shifted ~ 15 degrees latitude south. Therefore, in a less illuminated ionosphere, the signal is weaker.
2. The strong electric and magnetic component in orbit 29816 which passed 15 degrees east of Forrest, is associated with LHR excitation in the perturbed ionosphere above the TC similarly to the situation considered in [8]. In orbit 29817 which passed 18 degrees to the east from the TC 10B which was located 2 degrees south of the magnetic equator a stronger LHR perturbation was observed in the magnetically conjugated ionosphere due to the action of the terminator. On orbit 29845 passing between Forrest and TC 10B the formation of a magnetosphere channel which contains e / m oscillations of the whistling mode and electrostatic oscillations in the conjugated ionosphere is observed. In orbit 29846 west of the TCs over the TIDs, which arose after the terminator passed over the TCs, a well-formed cavity was observed.

3. Two spaced peaks in orbit 29817 near the equator are associated with earthquake No. 7 of Table 1. Ten hours before the earthquake, the TC 10B increased to 70 kt into the Bay of Bengal, while Forrest increased to 55 kt into South China Sea. The combined impact of TCs on the Indian Plate and Philippine Plate was transmitted to the Burma Plate where an earthquake occurred in the southeast ledge under East Sameule, Sinabang. Exactly the same earthquake occurred 2-Nov (No. 6, Table 1) while TC 09B passing into the Bay of Bengal and Super Typhoone Elsie passing into South China Sea. These earthquakes did not have a pre-shock and aftershocks this indicates a sharp change in the impact on seismic plates.
4. Another TCs geometry was observed on November 22, when Forrest (85 kt) was in the north of the Bay of Bengal and Gay (to 145 kt) crossed the Marinas Trench and entered the Philippine Sea. The result was a deep earthquake in the middle of the eastern border of the Burma Plate (middle of the Nicobar Islands arc). Earlier on 16 November Forrest was near this fault but there was no earthquake.
5. On November 15, TC 10B into the Arabian Sea and Forrest into the Andaman Sea synchronously intensified to 55 kt (100 km / h) and an earthquake occurred in the Indian Ocean Triple Junction of 4.7 M_w.
6. On November 14, a satellite in orbit 29819 passed over the focal point of an earthquake in Madagascar. According to the entire set of satellite instruments, 3 hours before the earthquake, precursors stood out here, examples of which are considered in the monograph [22]. On November 16, after an earthquake in orbit 29847, a highly disturbed region stands out to the west of the earthquake source. Indonesian earthquakes under No. 10-12 in Table 1, the centers of which are indicated on the right half of Fig. 4 belong to the class of ordinary earthquakes.
7. The lower part of Fig. 4 shows the change in the ionosphere parameters depending on the position of the terminator above the Omega B transmitter, which effectively affects the E-layer of the ionosphere. Each Omega station transmitted a sequence of three very low frequency (VLF) signals (10.2 kHz, 13.6 kHz, 11.333... kHz in that order) plus a fourth frequency which was unique to each of the eight stations. The duration of each pulse (ranging from 0.9 to 1.2 seconds, with 0.2 second blank intervals between each pulse) differed in a fixed pattern, and repeated every ten seconds. These features are in good agreement with the parameters of the perturbed lower ionosphere from the occurrence of acoustic pulses during earthquakes and the development of the TC.

TABLE 1
SPECIFIC NUCLEAR TEST EXPERIMENTS AND EARTHQUAKES IN SEPTEMBER – NOVEMBER 1992.

No.	Date 1992	UT h : m	Epicenter N / E	M_w	Depth km	Area / Name
1	18-Sep	17:00	37.2 / -116.2	3.8	2.3	NTS / Hunters Trophy
2	23-Sep	15:04	37.0 / -116.0	4.2	1.83	Nevada Test Site / Divider
3	23-Sep	21:59	29.8 / 51.1	5.1	35.0	Southern Iran
4	24-Sep	00:52	-59.5 / -26.0	5.5	21.2	South Sandwich Islands region
5	24-Sep	21:49	9.8 / 92.8	4.3	72.9	Nicobar Islands, India region
6	02-Nov	01:41	2.1 / 95.7	4.7	33.0	Simeulue, Indonesia
7	13-Nov	16:01	2.4 / 96.3	5.3	33.0	Simeulue, Indonesia
8	14-Nov	05:55	-23.0 / 45.8	5.0	22.9	Madagascar
9	15-Nov	07:02	-26.2 / 70.9	4.7	10.0	Indian Ocean Triple Junction
10	15-Nov	15:57	-11.5 /115.0	5.0	33.0	South of Bali, Indonesia
11	18-Nov	00:36	1.6 / 118.0	4.9	33.0	Kalimantan, Indonesia
12	18-Nov	21:26	-7.3 / 106.2	5.3	48.2	Java, Indonesia
13	21-Nov	22:40	-56.7 / -26.4	6.6	20.1	South Sandwich Islands region
14	22-Nov	07:48	7.1 / 94.1	4.5	96.1	Nicobar Islands, India region

IV. CONCLUSION

1. After the Pinatubo eruption, TC enhancement in the Indian Ocean correlated with the development of Pacific typhoons was observed with an east wind in the lower stratosphere.

2. The earthquakes in Simeulue, Indonesia were caused by the joint intensification of TCs into the Bay of Bengal and into South China Sea on November 02 and 13.
3. Earthquakes in Nicobar Islands, India region occurred after August 4, Super Hurricanes Janis and November 22 Gay crossed Marinas Trench and entered the Philippine Sea. Earthquakes in this area also occurred after intensification of the global TCs chain September 24 and intensification of TCs in the South Pacific Ocean and South Indian Ocean December 8, 10 and 27.
4. The earthquake in Indian Ocean Triple Junction November 15 occurred after the synchronous amplification of TC 10B into the Arabian Sea and Forrest into the Andaman Sea. According to the Centennial Earthquake Catalog, it was the only earthquake with M_w>2.5 in the region during the period of November 11-22. It is assumed that it was associated with the rise of the Indian Plate in the zone of development of two TC and the lowering of the edge of the Indian Plate in a node with two adjacent plates.
5. Probably December 25, 2004, the intense tropical cyclone Chambo to 80 kt (150 km / h) in central South Indian Ocean lifted the southern edge of the Indian Plate. The eastern edge of the Indian Plate plummeted beneath the Burma Plate, the mega earthquake of 9.1 M_w and the Boxing Day Tsunami occurred. This situation requires further detailed consideration and refinement of the forecast of such events [24].

CONFLICT OF INTEREST STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict.

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