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Response of the Lower Equatorial Ionosphere to Strong Tropospheric Disturbances

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Abstract—A morphological analysis of the results of sounding the lower equatorial ionosphere (the *D* region) in the region of action of strong tropospheric vortex disturbances (tropical cyclones, TC) is presented in this work. Based on the rocket sounding of the lower ionosphere at Thumba rocket site (8° N, 77° E) in May–June 1985 and on the satellite monitoring of TC in the northern Indian Ocean, it is demonstrated that a sharp depletion (by a factor of 2–4) of the electron concentration at altitudes of 60–80 km could be a response of the ionosphere during the TC active phase. In this case the lower boundary of the *D* region rose by several kilometers (not more than 5 km), and the temperature in the region of the stratopause slightly (by 2°–3°) increases. It is assumed that internal gravity waves (IGWs) generated by TC cause the effect on the lower ionosphere.

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1. INTRODUCTION

Studying the global energy transport, which is a very important problem of the physics of the Earth's atmosphere, is based on the investigation of the processes and mechanisms of interaction between various atmospheric layers. The problem of interaction of such layers as troposphere, stratosphere, mesosphere, and ionosphere was considered in many publications, which demonstrate an integrity (including the thermodynamic one) of the Earth's atmosphere [Vanina and Danilov, 2001]. Depending on the location of the impact source, the interaction of such layers is possible both from below and from above. The waves (planetary, tidal, gravity) propagating upward, penetrating through the systems of zonal winds, and reflected from these winds are considered as a physical basis of the influence from below. Intense dynamical processes in the troposphere are considered as a source of these waves, and the transmission characteristics depend on the thermodynamic regime of the middle atmosphere. Many investigators showed that the interaction between meteorological and ionospheric fields is most evident in the extratropical winter atmosphere [Danilov et al., 1987]. In this paper we, on the contrary, study the equatorial tropical zone of the troposphere–stratosphere–mesosphere–ionosphere system.

It is known that the whole spectrum of powerful dynamical phenomena is originated in the tropical zone of the atmosphere. The most intense of these phenomena are TCs, which are possible potential sources of the influence from below. Catastrophic atmospheric vortices, which originate near the equator and develop in the tropical zone of the Earth's atmosphere, present a peculiar mechanism of effective heat effluence under such atmospheric conditions, when the action of ordinary mechanisms (the main mechanisms are turbulent convection and global circulation) becomes evidently insufficient. Thus, the catastrophic atmospheric vortex systems play an important (and possibly determining) role in the formation of the temperature regime of the Earth (the greenhouse effect), removing excess heat and preventing the atmosphere (its tropical part) and the surface ocean layer in the tropical zone from strong overheating [Balebanov et al., 1997; Sharkov, 1997, 2006].

The aim of this paper is to find the response to the impact of the intense energy released during the TC active phase on the adjacent troposphere and stratosphere, which, in turn, possibly influence the lower ionosphere. The data of the rocket sounding of the ionosphere and satellite monitoring of the tropical cyclogenesis were used to solve this problem.

2. DATABASE OF ROCKET SOUNDING OF THE IONOSPHERE

The measurements considered in this paper were conducted by the Central Aerological Observatory (CAO) of the State Committee on Hydrometeorology at Thumba equatorial rocket site (8° N, 77° E). The initial data are part of the database, the description of which can be found in [Borisov et al., 1981; Kokin et al., 1988]. The CAO database is based on the bank of electron concentration [*e*] measurements on board the M 100B meteorological rockets using the probe

Table 1. Solar and geophysical information accompanying rocket flights in May–June 1985

Flight no.	Flight date	Flight time (UT)	Zenith angle χ, deg	$F_{10.7}$	*Kp*	*Ap*	*Dst*, nT
46	May 1, 1985	1134	71	81	3	10	34
47	May 8, 1985	1155	76	84	3	8	5
48	May 16, 1985	1154	76	95	2	11	19
49	May 22, 1985	1135	71	83	1	5	3
50	May 29, 1985	1155	75	73	0	4	4
51	June 5, 1985	1137	70	84	1	5	1
52	June 19, 1985	1158	74	72	1	3	8
53	June 27, 1985	1216	77	70	2	13	13

Table 2. Meteorological information accompanying rocket flights in May–June 1985

Flight no.	Temperature, °C			Velocity, m/s					
	*T*75	*TSp*	*T*30	*Vx*80	*Vy*80	*Vx*60	*Vy*60	*Vx*30	*Vy*30
46	–108	3	–33	–	–	–5	33	–2	17
47	–92	–3	–40	–	–	0	12	0	–1
48	–99	–8	–38	2	–100	12	–6	1	3
49	–	–7	–39	–	–	–	–	–3	5
50	–104	–5	–41	–16	–62	13	21	–5	–5
51	–101	–9	–42	–22	–90	–10	27	1	–3
52	–88	–12	–45	–	–	–5	–42	2	3
53	–	–	–	–	–	–	–	–	–

method, which is based on the application of the Langmuir electrostatic probe. The probe was installed at the top end of the meteorological payload of the rocket, which protected this probe from the influence of electric and magnetic fields of the rocket itself [Pakhomov, 1981]. The probe method has systematic errors, which are revealed by comparing the measurements, performed using this method, with the most accurate measurements made using the Faraday rotation method. The estimated standard error of an individual measurement of the electron concentration (the CAO databank) is ~35% [Knyazev et al., 1994]. During the routine atmospheric sounding, the temperature sensors and the equipment for measuring wind parameters were also installed on board meteorological rockets.

3. VARIATIONS IN THE ELECTRON CONCENTRATION VERTICAL PROFILE IN MAY–JUNE 1985 AGAINST A BACKGROUND OF TROPICAL TROPOSPHERIC DISTURBANCES

Attempts to model the behavior of the equatorial *D* region for various solar and geomagnetic conditions were undertaken repeatedly [Knyazev et al., 1994; Watanabe and Oyama, 1995]. However, these papers did not consider the possible influence of tropical cyclones on the equatorial ionosphere. In this work we try to find this influence. At the first stage, we will analyze available solar, magnetic, and meteorological information obtained during the rocket flights, when [*e*] was measured before, during, and after TCs in May–June 1985.

The heliogeomagnetic conditions during eight rocket flights, carried out in May–June 1985, is shown in Table 1. The 3 h planetary geomagnetic index (*Kp*) was selected for the time of measurements, whereas the low-latitude hourly *Dst* index was taken for 1200 UT. It was mentioned above that the CAO database contains meteorological data also obtained during rocket flights. Table 2 shows accompanying meteorological information for the flights (see Table 1), including: the temperature at a altitude of 75 km (*T*75), the temperature at the stratopause level (*TSp*), the temperature at an altitude of 30 km (*T*30), the zonal component of the wind velocity *Vx* ($Vx < 0$ and $Vx > 0$ for the westerly and easterly winds, respectively), and the meridional component of the wind velocity *Vy* ($Vy < 0$ and $Vy > 0$ for the southerly and northerly winds, respectively) at altitudes of 30, 60, and 80 km.

Figure 1 shows the vertical profiles of the electron concentration measured during the flights (see Table 1).

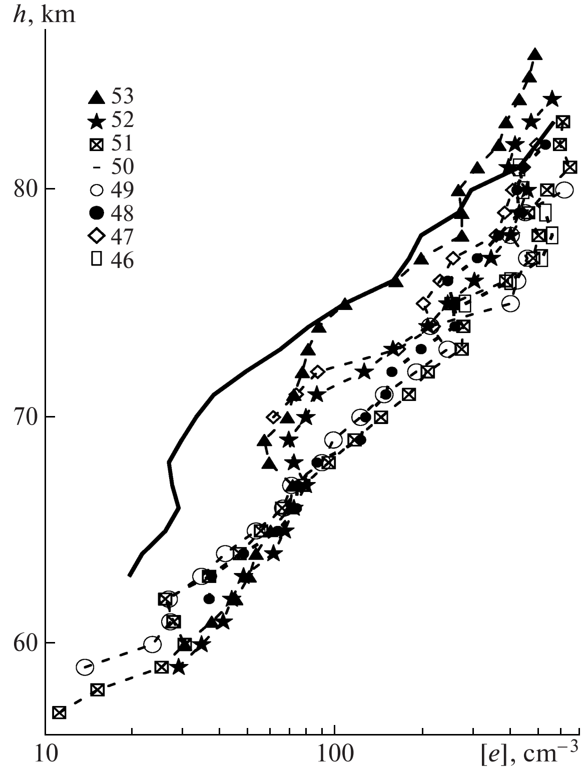

Fig. 1. Vertical profiles of the electron concentration $[e](h)$ obtained in May–June 1985 at the Thumba rocket site.

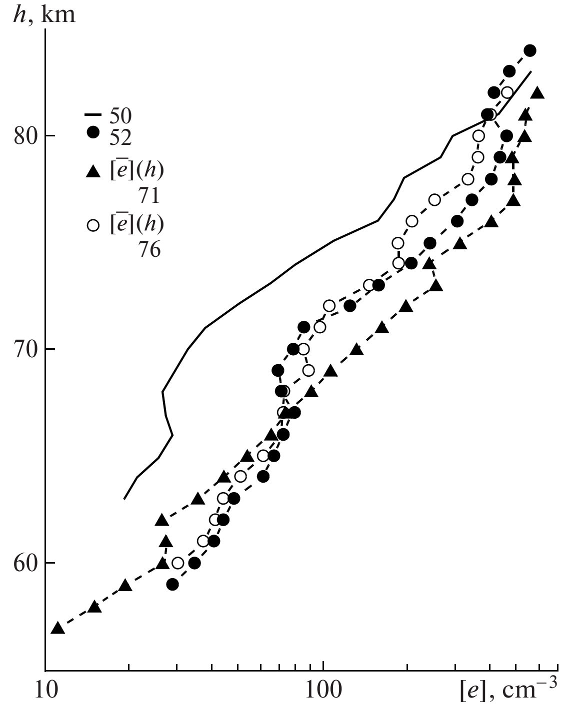

Fig. 2. Vertical $[e](h)$ profiles obtained during isolated flights (50 and 52) and averaged for fixed zenith angles.

All flights, except one, were carried out near UT noon. Correspondingly, the values of the solar zenith angle χ are slightly scattered ($\bar{\chi} = 73° \pm 4°$). The values of the solar activity index ($\bar{F}_{10.7} = 82.5 \pm 12.5$) and the geomagnetic activity index ($\bar{A}p = 8 \pm 5$ and $\bar{K}p = 1.5 \pm 1.5$) indicate that solar and geomagnetic conditions were quiet during the flights. The [e] profiles (Fig. 1) should be comparable with the averaged profile, obtained by Knyazev et al. [1993, 1994] at the same Thumba rocket site at low solar activity ($\bar{F}_{10.7} = 78 \pm 9$, $\bar{R} = 20$, $\bar{A}p = 15$, and $\bar{\chi} = 71 \pm 2°$).

Since we actually have two groups of flights at $\chi \sim 71°$ (flights 46, 49, and 51) and at $\chi \sim 76°$ (flights 47, 48, and 53), we will construct the statistical mean profiles for these groups. The profiles of flight 50, obtained during the active phase of a tropical cyclone at $\chi = 75°$, and flight 52, obtained at $\chi = 74°$ (the nearest flight to flight 50 according to the values of χ) remained unchanged. Figure 2 presents the results of such a representation. If we exclude from the consideration the anomalous electron concentration profile obtained during flight 50, we will obtain self-consistent data: under the daytime conditions at low solar and geomagnetic activity, the [e] value in the ionosphere decreases with increasing χ due to the absorption of the ionizing radiation [Knyazev et al., 1993, 1994].

4. EVOLUTION DATA ON TCS IN MAY–JUNE 1985

We consider information on the available cyclones during May–June 1985 over the northern Indian Ocean [Pokrovskaya and Sharkov, 2001]. TC No. 8501-01B originated at 1200 UT on May 22, 1985, in the Bay of Bengal at 16° N at a distance of 800 km eastward of the Indian coast at the stage of a tropical depression (TD). The wind velocity and pressure at the cyclone center were 15 m/s and 996 mbar, respectively. Moving northwestward, On May 23, 1985, TD changed into a tropical storm (TS), and the pressure decreased to 992 mbar. The storm slowly drifted northeastward and gradually intensified. On May 24, 1985, at a distance of 200 km southward of the Bangladesh coast, this storm changed into the stage of a strong tropical storm (STS), when the wind velocity and pressure were 31 m/s and 985 mbar, respectively. Approaching the coast, the storm weakened, crossed the coastline on May 25, and quickly dissipated over Bangladesh territory.

The next TC (No. 8502-02A) originated on May 27, 1985, over the Arabian Sea at 16° N at a distance of 700 km westward of the Indian coast. The wind velocity and pressure became 15 m/s and 1002 mbar, respectively. Drifting northeastward, TC changed into

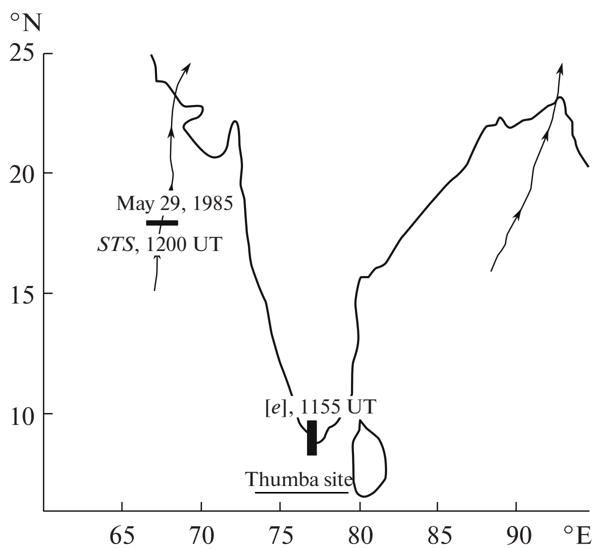

Fig. 3. Motion of TC Nos. 8501-01B and 8502-02A and the position of the Thumba rocket site in the horizontal projection.

TS on May 28, and the pressure decreased to 996 mbar. On May 29, 1985, at a distance of 300 km from the coast, TC changed into STS and the wind velocity and pressure were 26 m/s and 990 mbar, respectively. Approaching the coast, the storm gradually weakened, crossed the coastline at 1800 UT on May 31 at the stage of TD, and disintegrated over the Pakistan territory on June 1, 1985.

The traces of tropical cyclones Nos. 8501-01B and 8502-02A and the location of the Thumba rocket site are presented in Fig. 3 in geographic coordinates. The location of TC No. 8502-02A at 1200 UT on May 29, 1985, is specially marked. We remind that the rocket measurements on this day were conducted at 1155 UT. Thus, we have almost synchronous data on the tropospheric, stratospheric and mesospheric, and lower ionospheric parameters.

5. METEOROLOGICAL SITUATION IN MAY–JUNE 1985

As is known, a breaking of the wind system is observed in the stratosphere, mesosphere, and troposphere during the equinox periods: the eastward circulation in winter changes into the westward circulation in summer. In the Northern Hemisphere, the reversal begins near March at polar latitudes and ends later (near May) closer to the equator. The circulation scheme is more complicated in the equatorial zone.

In this work we only compare the meteorological parameters for May–June 1985, noting the principal differences during such a short period, when the influence of the seasonal factor can be neglected. We will analyze the meteorological situation during the flights (according to Table 2).

Meridional and zonal wind velocity components. Unfortunately, the data for an altitude of 80 km are available only for three flights (from May 16 to June 5, 1985). At this altitude the northerly wind had high velocities (62–100 m/s). At an altitude of 60 km, the wind was southerly and slower, except the situation on May 16 and June 19. A weak southerly wind prevailed at an altitude of 30 km; however, on May 8 and 29 and on June 5, the wind was weak and northerly.

At an altitude of 80 km, the easterly wind was observed on May 29 and June 5 (we note again that the data for this level were obtained only during three flights). At an altitude of 60 km, the easterly wind was observed from May 1 and June 5. At an altitude of 30 km, a weak westerly wind was periodically replaced by a weak easterly wind (on May 1, 22, and 29).

It is clear that the wind regime at levels of 30, 60, and 80 km in May–June 1985 constantly changed except a stable strong northerly wind at an altitude of 80 km. On May 29, the wind measured during flight 50 was northeastward at the lower and upper levels (30 and 80 km, respectively) and was southeastward at the middle level (60 km). On May 29, the wind at various altitudes was either moderate or weak.

Thermal regime. The temperature at 75 km altitude generally increased during the period in question. Two interesting periods of abrupt warming (near May 8) and cooling (near May 29 and June 5) are distinguished. In May–June, the temperature gradually decreased at the stratopause altitude (around 50 km) but slightly increased on the threshold of tropical disturbances on May 22 and more strongly increased on May 29 (Fig. 4). The temperature decreased at an altitude of 30 km but slightly increased prior to cyclonic disturbances.

The behavior of the temperature in May–June 1985 at all levels is shown in Fig. 4. As was already noted, TC in May–June 1985 were observed on May 22–25 and on May 28–June 1 over the northern Indian Ocean. TCs were located 8°–15° northward of the Thumba rocket site and 10° eastward and about 11° westward of this site in the first and second cases, respectively.

6. RESULTS AND DISCUSSION

Internal gravity waves propagate upward along an inclined trajectory; therefore, the effects in the upper atmosphere can manifest themselves not only at a distance of many hundreds of kilometers from the tropospheric source but also a few days after their generation [Danilov et al., 1987]. One of the intense sources of such waves can be TC. We assume that IGWs originating in this case can reach even the topside ionosphere. Figure 1 shows a substantial difference in the vertical distribution of [e] during TC in the active phase as compared to the conditions without TC or with TC in the depression phase.

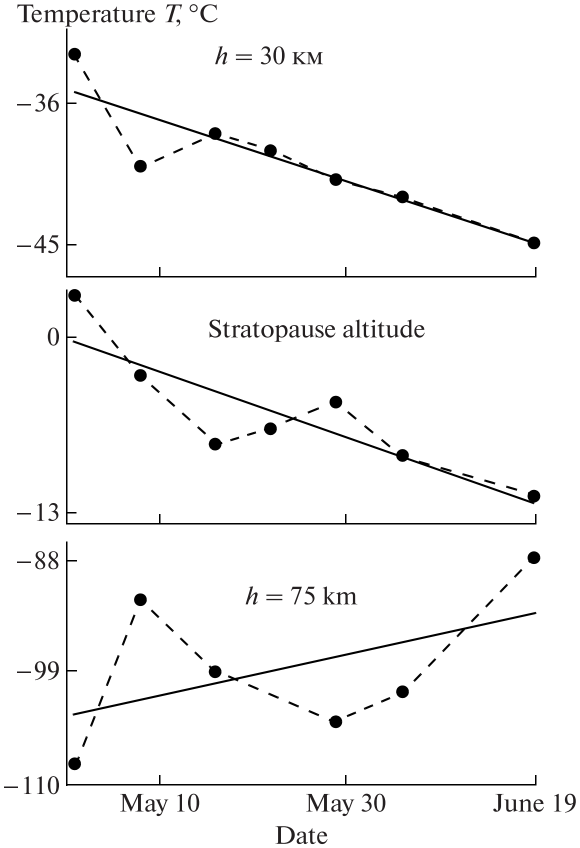

Fig. 4. Variations in the atmospheric temperature at various altitudes in May–June 1985.

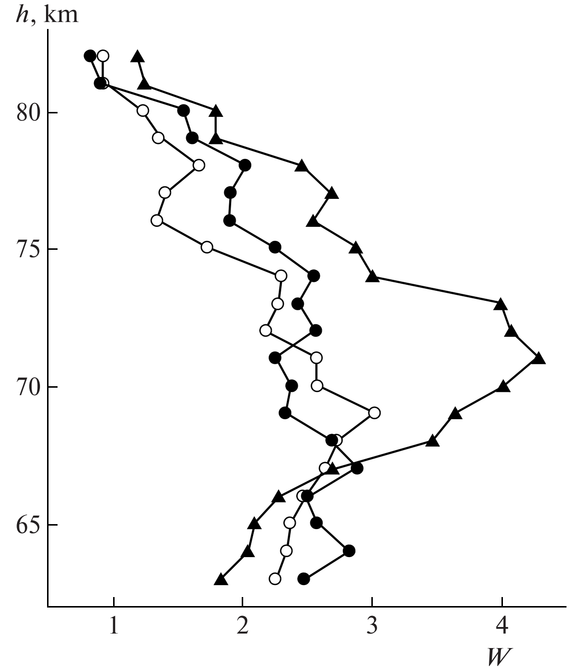

Fig. 5. Ratio of the $[e](h)$ profiles (from Fig. 2) to the $[e](h)$ profile obtained during the TC active phase (flight 50).

If we try to find W (the ratio of the electron concentration on the profiles in Fig. 2 to $[e]$ on the flight 50 profile), a decrease in the $[e]$ value in the lower D region will be a factor of about 2–4 (Fig. 5) at altitudes of 60–80 km. The mechanism of such a decrease in the electron concentration (measured at the peripheries of active TC) in the lower ionospheric D region is possibly explained by the influence of the tropospheric disturbance via IGWs. The wind regime at altitudes of the stratosphere and mesosphere on May 29 considered above did not prevent the penetration of IGWs generated by TC. IGWs affect the content of neutrals. For example, Nerushev [1995] paid special attention to the wave mechanism of excitation of periodic variations in the total ozone content and vertical ozone distribution under the action of IGWs generated by developing TC. It is known that electron concentration decreases with increasing ozone concentration [Danilov and Vlasov, 1973; Pakhomov and Knyazev, 1988]. Consequently, if the ozone concentration $[O_3]$ increased at altitudes 60–80 km, this would lead to a depletion of $[e]$ at these altitudes. Unfortunately the authors have no experimental data on the ozone content needed to confirm this fact.

It is evident that substantial differences were not revealed in the upper D region (at altitudes ≥80 km). We note that the influence of a tropical disturbance via the entire complex chain of interactions is realized rather quickly (during about half a day or even quicker). Based on the results of the ground-based artificial acoustic electromagnetic (relatively weak) excitation of the ionosphere (almost "instantaneous") [Ramkumar et al., 2006; Rapoport et al., 2004], we can assume that such a possibility of "rapid" excitation also exists under natural conditions. Certainly, to specify the channels (with their quantitative evaluation) of the influence on the behavior of the lower ionosphere it is necessary to perform a detailed analysis. The authors plan to carry out such an analysis in the future.

Thus, based on a synchronous analysis of the series of rocket measurements of the electron concentration and thermodynamic parameters of the lower ionosphere in the equatorial region and on the remote sensing data on tropical cyclogenesis in the northern Indian Ocean, we for the first time experimentally registered a decrease in $[e]$ in the D region at the distance of about 1000 km (in the horizontal projection) from the nucleus of a tropical cyclone in the active phase. A decrease in electron concentration is maximal (on average, a factor of 3–4) at altitudes of 71 ± 3 km. In this case the lower boundary of the D region ascends by a few kilometers (not more than 5 km). During the action of TC, the temperature also slightly increased (by about 3°) at the stratopause altitude.

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