CORRELATION BETWEEN TROPICAL CYCLONES AND THE IONOSPHERE PARAMETERS ABOVE AUSTRALIA

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Abstract

Advanced international investigations of the correlation between tropical cyclones (TCs) and the ionosphere are connected with extreme difficulties of proving the action of possible mechanisms of TC effect on the ionosphere. Powerful surges of charged particles and neutrals, internal gravity wave (GW) radiation and low-frequency electromagnetic wave radiation from central points of TCs to considerable altitudes and distances are a manifestation of TC action mechanisms. The authors of this presentation analyse the ionosphere parameters, received in the process of satellite remote sensing above TC and at a certain distance from it. Cyclones, being examined in the paper, functioned above the Indian Ocean and the Pacific Ocean in 2011-2013.

1.INTRODUCTION

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 from strong overheating of the atmosphere (of its tropical part) and the surface ocean layer in the tropical zone.

Studying the global energy transport, which is a very important problem of the physics of the Earth’s atmosphere, is based on the various atmospheric layers interaction processes and mechanisms investigations. 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. 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. In this paper, on the contrary, we continue our studying of the equatorial tropical zone system «troposphere–stratosphere–mesosphere–ionosphere».

Advanced international investigations of the correlation between tropical cyclones (TCs) and the ionosphere are connected with extreme difficulties of proving the action of possible mechanisms of TC effect on the ionosphere. TCs are the greatest troposphere disasters. Powerful surges of charged particles and neutrals, internal gravity wave radiation and low-frequency electromagnetic wave radiation from central points of TCs to considerable altitudes and distances are a manifestation of TC action mechanisms.

The aim of this presentation is the analyse of the ionosphere parameters, received in the process of satellite remote sensing above TC and at a certain distance from it. Cyclones, being examined in the paper, functioned above the Indian Ocean and the Pacific Ocean in 2011-2013.

2.IONOSPHERE & TROPICAL CYCLONE

The of atmospheric–ionospheric interactions study is one of the most interesting and perspective applied directions in geophysics. Because of its nature, being a product of ionization of various neutral gas components, the Earth's ionosphere rapidly enough (for example, at heights of the E layer, the characteristic time of a reaction to changes in the ionization rate by auroral discrete type electrons is a few seconds) reacts to changes in space radiation and also in the composition of the neutral atmosphere. Respectively, deviations in the behaviour of ionospheric parameters due to atmospheric events (thunderstorms, cyclones, tornadoes, hurricanes, etc.) are detected.

2.1. HISTORICAL FACTS

1.The radio transmissions strength (received via the E-layer) varied with the occurrence of cyclones and anticyclones (below the propagation path).
2.The ionisation density of the E-layer & the under-lying surface pressure patterns: direct relation.
3.Thunderstorms , tornados, tsunamis and earthquakes have all been observed to cause atmospheric gravity waves which affect the ionosphere.
4. It might reasonably be expected that typhoons would also affect conditions in the ionosphere through both the atmospheric GWs from their strong convective towers and the associated synoptic - scale motions in the stratosphere and ionosphere. Tsutsui and Ogawa (1974) used a high frequency Doppler sounder to determine vertical motions in the ionosphere as typhoon Helen crossed Honshu (Japan) on 16-17 Sept. 1972. They observed GWs at their sounding frequencies of 5 and 8 MHz.
5.G.J.Bell repeated the experiments at Hong Kong with Gherzi's cooperation but found no such simple correlation. The strong synchronous seasonal change in the frequency of occurrence of air masses (or of high and low pressure) and of the echoes suggests a relationship. For example, in winter echoes from the F- layer prevail as does high pressure and Siberian air. Whereas in June and July one expects and finds, neither F-echoes nor Siberian air. It is the transition months which test the theory, and it is then that the one to one relationship fails. In both May and September, for example, the returns (on 6 MHz) on days with Pacific (tropical maritime) air prevailing were distributed; E 15%, F1 30% and F2 55%.
6.Gherzi (1946) was the first to suggest that ionospheric soundings could be used as an aid for weather forecasting and for predicting the movement of typhoons. But much of this work was based on misconceptions and some of his claims on this subject have not stood up to scrutiny.
7. As early as in the 1950s, Bauer [Bauer, 1958] studied ionosphere responds in the passage of hurricanes and found that foF2 would rise and reach the maximum when hurricanes were closest to the observation station.
8. Observations have shown that the passage of tropical storms can lead to perturbations in the plasma drift [Bishop et al., 2006]

Relationships between meteorological and ionospheric phenomena come about through vertical motions in the ionosphere induced by underlying large scale weather systems or from gravity waves which originate from the surface or upper troposphere. The amplitude of gravity waves (GWs)of certain frequencies increases exponentially a with height because of the decreasing density. The growth factor is given, if by the square root of the ratio of the atmospheric density at source and at the height of interest. A displacement at the earth's surface of a few centimetres can originate an atmospheric GW which will grow in amplitude to several kilometres at ionospheric levels. Growth factors of 10^4 to 10^5 are typical. The layers of constant electron density move up and down with oscillatory motions similar to the acoustic pressure wave itself.

This phenomenon has been proposed as a method for detecting tsunamis. Normal ocean waves do not generate acoustic waves which grow exponentially with height because their periods are well below the Brunt-Vaisala period of the atmosphere (about 300s) and their speeds are much less than the speed of sound (330 m/s); a combination which gives rise to atmospheric waves which quickly fade with height weakly ionised layers) were transmitted from Shanghai at 6 MHz - a frequency which would not normally be reflected at the E layer - and were returned by the E, or layers depending on whether Pacific (tropical maritime), Siberian or Tropical (equatorial) air masses were affecting the station.

2.2.POSSIBLE WAYS "TC – IONOSPHERE" INTERACTIONS

There are some possible ways of TC-ionosphere interactions:

1. TCs would affect conditions in the ionosphere through both the atmospheric GWs from their strong convective towers and the associated synoptic-scale motions in the stratosphere and ionosphere. (G.J.Bell,1981).
2. An effect of external electric currents on the global atmosphere-ionosphere el. circuit may be one of possible mechanisms of interaction between atmospheric and ionospheric components. External currents with a horizontal scale of about one hundred of kms may be related to the vertical large - scale convection of the cloudy atmosphere in the zone of a TC and to the charge separation in this region. The electric field disturbance arises due to perturbation in the atmosphere – ionosphere electric circuit generated by the upward transport of charged water drops and aerosols in TC convection zone (Isaev et al, 2006).
3. GWs generated at tropospheric altitudes propagate to the F-region. GWs generated from storms break near 100 km and produce secondary waves that continue to propagate upward GWs modulate the E-region plasma producing polarization fields that map to F-region altitudes. Strong convection cells produce a wide spectrum of GWs. GWs increase in amplitude with increasing altitude and may become unstable. Only waves propagating at the certain angles and with the correct amplitude can reach thermospheric altitudes. Once in the thermosphere, only those waves oriented to the magnetic field in a particular manner may produce ionospheric disturbances (dr.Rebecca Bishop, PSL/SSAL, 30 March 2012)

3. THE INVESTIGATIONS OF THE CORRELATIONS BETWEEN TROPICAL CYCLONES AND THE IONOSPHERE

In spite of the fact that searches for the results of the tropical cyclone–ionosphere interaction have been performed since the middle of the previous century, the number of publications on this problem is small. Certainly, it is not only related to the deficit of corresponding data, but to the absence of a reliable theoretical mechanism of such interaction. Nevertheless, searches in this direction are continuing (to a substantial degree, in the publications of Chinese scientists) (see, for example, [Tian et al., 2010]).

In fact, the question of the "TC-ionosphere" interaction was posed many years ago by foreign ionospheric scientists. As early as in the 1950s, Bauer studied ionosphere responds in the passage of hurricanes and found that foF2 (the critical frequency of the *F*2 layer) would rise and reach the maximum when hurricanes were closest to the observation station.

3.1.CHINESE RESEARCH

The article [Tian, et al., 2010] includes an overview (which we present below) of the Chinese scientific papers in the "TC-ionosphere" interaction area. With the analysis of ionospheric responses to TC around Hainan Island, Shen [Shen, 1982] found that TCs had specific effects on ionospheric foF2, which lie on the distance of TCs, and foF2 decreased obviously when typhoons landed. In the paper [Liu, et al., 2006 a, 2006 b] was confirmed the Shen's conclusion, and discussed in detail the possible impacts due to the distances between the observation stations and TC, and the differences of the winds violent interactions with land and sea surface. Generally speaking, the TC will lead to short increase in foF2 before landing and long decrease about a day after landing [Yu, et al., 2009]. TC can also inspire gravity waves which can propagate upward to the ionospheric height and thus have impacts on the ionosphere. Tsutsui and Ogawa [Tsutsui and Ogawa, 1973] confirmed TCS inspired some mesoscale TID using HF Doppler observations. Huang, et al., 1985], [Xiao S., et al., 2006], и [Xiao Z., et al., 2007] all came to the conclusion that TC could affect the ionosphere according to their Doppler observations.

At present, the study of the lower atmosphere and ionosphere (or the upper atmosphere) coupling focuses mainly on the fluctuation mechanism that gravity waves are inspired in lower atmosphere and propagate to the ionosphere. However, this propagation is very difficult. In the paper [Shen, 1982] was proposed an assumption that moving turbopause would be a possible mechanism of the lower atmosphere and ionosphere coupling, but the further investigation was not made.

3.2.RESEARCH OF THE TC – IONOSPHERE IN IKI RAN

1.Authors of this article have been working on the problem "TC - ionosphere" interaction for a few years. In the pioneering paper they [Vanina-Dart and others, 2007a, 2007b,2008] used a database of the measurements from the Central Aerological Observatory (CAO) in the equatorial rocket site Tumba (8 ° N, 77 ° E). The period May-June 1985 was taken as the basis for analysis. The database contains information about 8 rocket flights (during TCs and without). We can see the profiles of the electron density [e], measured at the time of these launches in Figure 1. As we can see, one of the profiles(the solid line) has decreased [e] values below 75 km altitude. It happened when tropical cyclone was in an active phase to the north – west (68°E,18°N) of the Thumba site.
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.

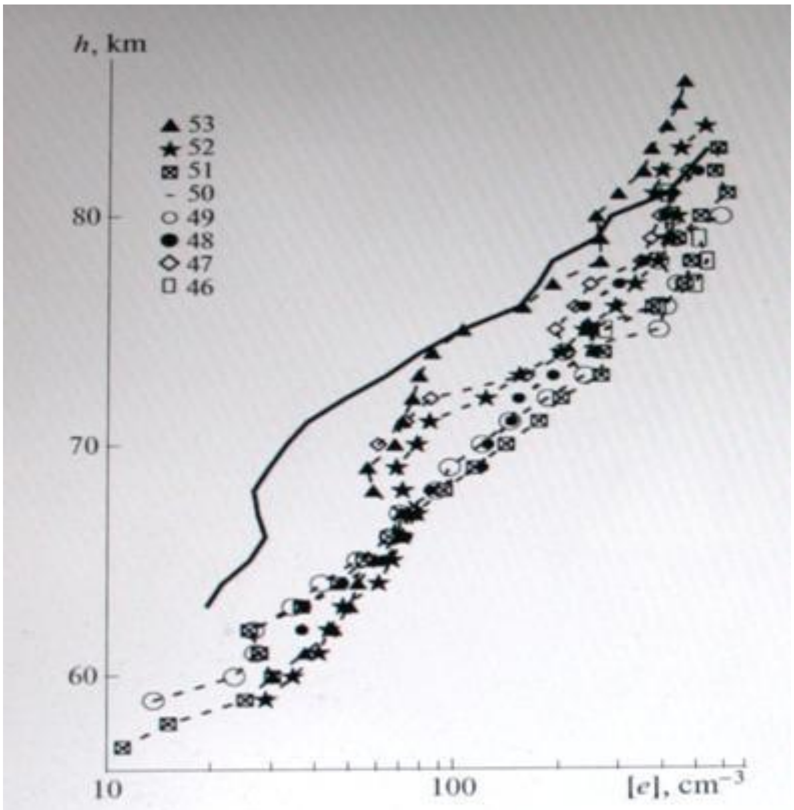

Figure 1: **Vertical profiles of the electron concentration (e)[h] obtained in May-June 1985 at the Thumba rocket site.**

The goal of the paper [Vanina-Dart et al., 2011] is to search for possible influences of TCs on the topside ionosphere on the basis of tomography data obtained on Sakhalin Island in 2007. Observations were conducted over three points located at the same meridian: Yuzhno-Sakhalinsk (47°

N, 142° E), Poronaisk (49° N, 143° E), and Nogliki (51° N, 143° E). The data used in this paper were obtained by the method of phase-difference tomography.

2.The peculiar feature of the ionospheric tomography method based on signals of low-orbiting navigation systems gives a possibility to reveal the variations in the ionospheric electron concentration caused, for example, by the propagation of strong cyclones in the Earth's troposphere. It principally could not be done using global satellite navigation systems—GLONASS and GPS. Unlike phase tomography, where the total phase is an integral value, the phase-difference method is more sensitive to relatively small irregularities of the electron concentration, which provide an insignificant input into the phase and a more substantial input into its derivative. It should be noted that a TC is not a point-instantaneous disturbance, but should be considered as an "extended" and lasting disturbance. It is reasonable to search for a ionospheric response in the zone over an acting TC. We will conventionally call this zone "broadband." The localization of this zone (10°–20° westwards or eastwards from the TC location) depends on the disturbance propagation direction.

Figure 2 shows an illustrative situation of falling values of ionospheric parameters (shows the latitude dependence of the foF2 on November 20, 2007: the solid lines show the experimental data and the dashed - the model calculated by the IRI-2007), when the TC was located near latitude (138^0E), but much further south (12^0N).

On the basis of the performed analysis of the data obtained by the phase-difference tomography method in the first half of November 2007 on Sakhalin Island, the authors of this paper came to the following conclusion: The possible response of the topside ionosphere localized over a tropical cyclone zone (in the given case, by 25°–30° northwards and by 5°–20° eastwards) at a distance from ~3800 to 5500 km is a change in its parameter *foF*2 by on average no more than 10–20%. Nevertheless, it is a substantial response at such distances from the disturbance source. A decrease or, vice versa, an increase in *foF*2 is related to the "delay" of the measurement moment relative to the beginning of TC action. The complexity of a morphological analysis of the given event is that a tropical cyclone is a "broadband" (in the longitudinal and, to a lesser degree, in the latitudinal directions) and lasting disturbance source.

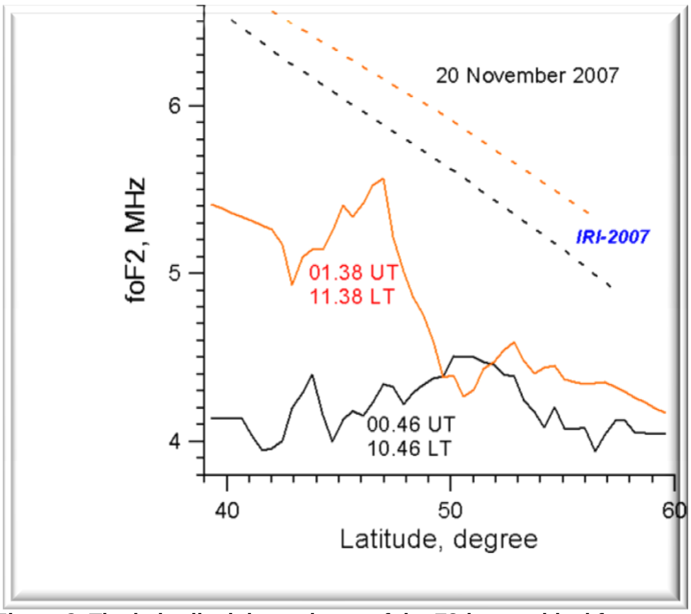

Figure 2: **The latitudinal dependence of the F2-layer critical frequency.**

3.In paper [Vanina-Dart and Sharkov, 2012, 2013], the authors have continued to search for a tropical cyclone reply to the upper ionosphere using data of TEC (total electron content of the ionosphere in a column with a cross section of 1 cm^2) above the Australian continent during the period of the most powerful TC YASI. The powerful TC YASI had been over the north-western part of Australia in late January and early February 2011. On the eve of its "invasion" to the land the hazard service predicted disaster due to its proximity to the shores of Australia. Queensland authorities even evacuated the local population. Super cyclone YASI struck between the towns of Innisfail (geographic coordinates: 17^0 S 146^0 E) and Cardwell (95 km to the south of Innisfail) about midnight local time (14.00 UT 2 February 2011) and caused them serious harm. The TC crossed the coast near the famous Australian resort of Mission Beach (17^0S, 146^0 E). Wind gusts were estimated by meteorologists to reach 290 km/h and left behind significant damage. The sea level rose by 7 meters. Part of the coastal infrastructure was destroyed (up to 300 m from the beach), some of the area flooded. Hurricane-force winds were accompanied by heavy thunderstorms. The TC eye was 35 km. A width of the path of the TC along the coast was 650 km.

Every 15 minutes ionospheric maps can be obtained from the site of the Australian Ionospheric Prediction Center. These depict the region 10^0 to 50^0 S and from 110^0 to 180^0 E. The major parameter from these maps is TEC (total electron content in the ionospheric column section 1 m^2). The climatic disturbances TEC map was obtained from the same source. The TEC climate model is based on empirical orthogonal functions (EOF), derived from the analysis of TEC for a 30-day period at 15 minutes intervals. The function is decomposed into basic predictors. Typically, the most significant are the first four EOF, which can decode nearly 95% of the observed variation within 30 days. The TEC deviations map include the time of day, day of the year, the season and the solar cycle.

4. Information about The Australian region TC tracks during season 2012-2013 is presented in the Figure 3 and about Kp indices in the Figure 4.

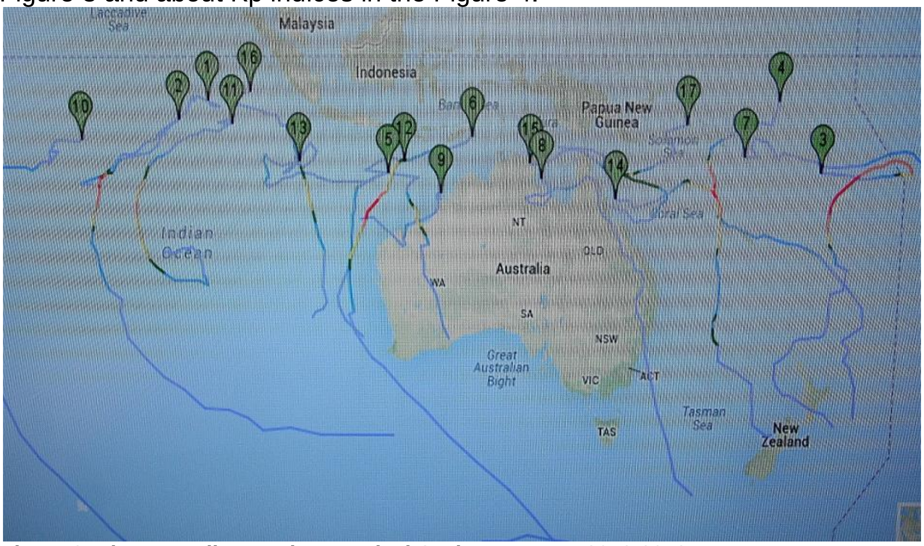

Figure 3: The **Australian Region Tropical Cyclone season 2012-2013.**

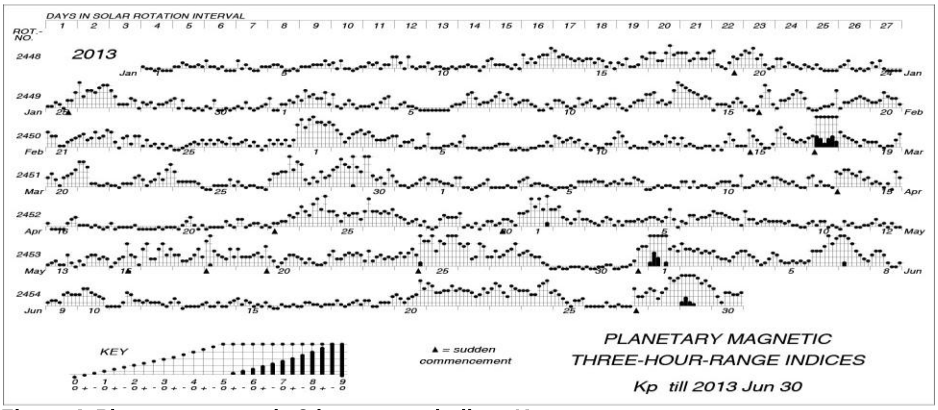

Figure 4: **Planetary magnetic 3-hour-range indices Kp.**

Cyclone Name	Map ID	Cyclone Number	Basin	Date Range (UTC)	Min CP	Max Winds
BOLDWIN	1	1302	SIO	16.11.12 – 26.11.12	982	55
CLAUDIA	2	1303	SIO	03.12.12 – 16.12.12	937	115
EVAN	3	1304	SPAC	09.12.12 – 26.12.12	929	125
FREDA	4	1305	SPAC	25.12.12 – 07.01.13	941	110
MITCHELL	5	1306	SIO	26.12.12 – 31.12.12	989	45
NARELLE	6	1308	both	04.01.13 - 24.01.13	937	115
GARRY	7	1310	SPAC	14.01.13 - 29.01.13	959	85
OSWALD	8	1311	both	17.01.13 - 30.01.13	993	35
PETA	9	1312	SIO	19.01.13 - 26.01.13	996	35
FELLENG	10	1313	both	22.01.13- 11.02.13	937	115
GINO	11	1315	SIO	07.02.13 – 18.02.13	956	90
RUSTY	12	1317	SIO	20.02.13 – 02.03.13	952	95
201318	13	1318	SIO	19.02.13 – 04.03.13	993	40
SANDRA	14	1319	SPAC	04.03.13 – 17.03.13	941	110
TIM	15	1320	SPAC	09.03.13 – 20.03.13	982	55
VICTORIA	16	1322	SIO	04.0.13 – 13.13.03	967	75
ZANE	17	1323	SPAC	24.04.13 – 02.05.13	974	65

Table 5: **The Australian Region Tropical Cyclones information (season 2012-2013).**

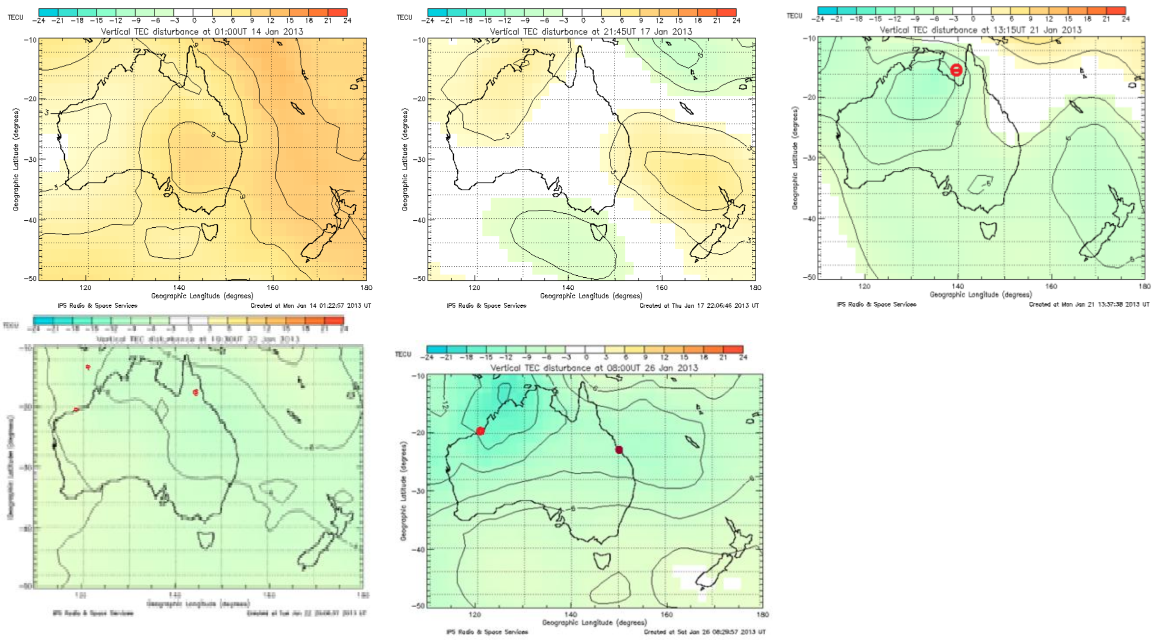

***Figure 6*: TEC disturbances maps 14.01.2013 (01.00UT), 17.01.2013 (21.45UT), 21.01.2013 (13.15UT), 22.01.2013 (10.30UT), 26.01.2013 (08.00UT)**

There were 3 TCs above Australia (Narelle, Oswald, Peta) in January 2013. In this article we presented only 5 examples of TEC disturbances maps. The red spots (Figure 6) are demonstrating the TC location. We can see different areas with different changing of the electron concentration decreasing.

4. Conclusion

In general, we can state the following. From the inception of TC to full grown activity can be observed a corresponding growth of ionospheric parameters (100%). Next, the picture changes. The ionospheric parameters begin to fall (50%) above the TC localization area and around. We believe that the influence of a TC on the ionosphere shows a cyclic pattern and zonal increases and decreases of electrons content which slowly spread over time.

We support the main conclusion of many papers about "TC-ionosphere" interaction "It might reasonably be expected that typhoons would also affect conditions in the ionosphere through both the atmospheric GWs from their strong convective towers and the associated synoptic -scale motions in the stratosphere and ionosphere"(G.J.Bell).

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