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AN ELECTRON TEMPERATURE ANOMALY IN THE EQUATORIAL IONOSPHERE

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Abstract:

Elevated electron temperature regions detected first by KYOKKO Satellite in 1978 and later, more extensively,during the 17-month observational period by HINOTORI Satellite are found to be closely associated with the ionization crests of the equatorial anomaly(EIA), also known as Appleton anomaly. This phenomenon which we will call equatorial electron temperature anomaly (EETA) occur predominantly in the equinoctial months of March- April and September- October. The elevated electron temperature is found to get enhanced during high solar radio (F10.7 cm) flux. It is a predominantly nighttime phenomenon and shows maximum amplitude around 21 LT. We present a mechanism for its occurrence that is based on the plasma transport pattern of the evening equatorial ionosphere resulting from the sunset electrodynamic processes.

1-Introduction

In 1978 the Japanese satellite,KYOKKO, encountered regions of elevated electron temperatures over low latitude ionosphere, during several of its eccentric orbit. In some cases the temperature enhancement, with respect to the expected nighttime background temperatures, exceeded 2000 K (Oyama and Schlegel, 1984). In the example shown in Fig.1 KYOKKO had a northbound pass at an inclination of 73°, and enhanced electron temperature (T_e) that reached the order of 1500K above the expected background level(indicated by the broken interpolation line) was observed from magnetic latitude -30° to 7° (lower panel). This electron temperature enhancement occurred in the same region where the electron density was high (upper panel). Even though the electron density instrument reached saturation in this region (due to the bias level applied to the sensor electrode) a close association of the T_e enhancement with large electron densities is clearly seen. We observed some 16 cases of T_e enhancement, out of all of the KYOKKO passes,all of which occurred during March 1978, within the height range of 600 -900 km and in the general vicinity of the latitude range mentioned above.

In 1981, HINOTORI was put into an orbit that was nearly equatorial (with inclination of 31°) and circular at a height of ~ 600 km, and the phenomenon of the T_e enhancement was again recognized. During the 17-month mission period of HINOTORI this phenomenon was repeatedly observed. The details of the morphological feature to be described in this paper clearly demonstrate the association of the T_e enhancements with the equatorial ionization anomaly (EIA) crests in the evening hours. A mechanism is suggested that invokes the role of the equatorial ionosphere sunset electrodynamics in producing the observed T_e enhancements. Brief descriptions of the T_e probe used in these measurements are given in Oyama and Abe,1987 (and refereneces therein) and Oyama et al.,1991.

2- Morphology of the Hot Region

Fig.2 shows the electron density (upper panel) and the electron temperature (lower panel) measured by HINOTORI on its revolution 3599. The two hatched regions in the T_e profile represent enhancements of ~600K and ~ 1000 K at the magnetic latitudes of 8° and -9° respectively, with respect to the background T_e values as well as with the IRI (International Reference Ionosphere, Bilitza, 1990) prediction shown by the broken line. These regions coincide exactly with the two electron density crests of the equatorial anomaly in the upper panel. (The T_e enhancement at ~05LT of ~ 1500K with respect to the background is a sunrise associated phenomenon). The electron density latitude profile characterized by a trough at the magnetic equator straddled by two crests on either side is clearly reflected in the T_e latitude profile as well. We thus identify an equatorial electron temperature anomaly (EETA) associated with the equatorial ionization anomaly (EIA). (For details on the EIA see, Hanson and Moffet, 1966; Moffet, 1979; Walker and Chan, 1989.)

2.1- Global Distribution of the Hot Region

All the cases of T_e enhancements that occurred in exact coincidence with the electron density crests , such as in the example of Fig.2 were identified in a large number of HINOTORI passes in the evening-premidnight local time sector where anomalous T_e increases were more often observed. The corresponding trajectory segments are marked as solid lines in Fig.3 with the T_e maxima marked by triangles. The magnetic equator is shown by a dashed line . As we can see, the hot regions are distributed predominantly at latitudes away on either side of the magnetic equator, and not on it. Though not shown separately these are also the locations of the EIA crests. The reason for the occurrence of relatively smaller data statistics in the longitude region of 130° - 180° is the fact that the satellite was located in this longitude region when it was accessed from the Kagoshima tracking station and the time of accessing was devoted for the recovery of data stored at other longitudes.

2.2- Seasonal Dependence

The cases of T_e enhancements >200K are plotted at latitudes of their occurrences in the upper panel of Fig.4 versus the day of the year. In this figure the bigger the triangles are, the larger are the T_e enhancements. We can clearly see that the excess temperatures are concentrated in the equinoctial months of March-April, (around the day 90), September- October (around the day 270) and the March- April of the following year (around the day 450). Their occurrences in the equinoctial months are independent of the solar F 10.7 cm flux values plotted in the lower panel. Further, there are clear cases of T_e enhancements that seem to be related to the solar F 10.7 cm flux values exceeding ~150 units. The T_e enhancements around the days 128, 320, 345 and 400 represent such cases. A few cases of elevated T_e regions that occurred at latitude slightly away from that of the EIA have not been included in this study.

2.3- Association with Groundbased EIA Diagnostics

Ionograms over Cachoeira Paulista (45° W, 22.5°S) in Brazil were studied for the days when HINOTORI flew over Brazil. Although the region surveyed by the ionosonde is not excactly the same as that of the satellite passes, their proximity (in some cases by field line connection) could make a comparison with ionosonde data very valuable in the way of identifying the phenomenon. In Fig.5 we have plotted the F- layer peak density ,(that is the critical frequency, foF2) and the peak height parameter,hpF2, for a few consecutive days, of the HINOTORI passes. The Dst index values for these days are also shown in the top panel of the figure. The daytime equatorial anomaly produces maximum foF2 values over Cachoeira Paulista around 17-18 LT. Followed by a short lived decrease in the electron density there is a resurgence of the EIA starting at approximately 20 LT.The hpF2 values of the bottom panel that decrease in the afternoon hours show increases again starting at 18 LT. This is produced by the well known prereversal enhancement of the evening equatorial electric field (see for example,Woodman 1970; Fejer et al., 1979). Such enhancements in the electric field have earlier onset and higher amplitude over the magnetic equator (for example, over Fortaleza, in Brazil , Abdu et al, 1992) than over Cachoeira Paulista. Also marked as vertical bars in the bottom panel of Fig.5 are the T_e enhancements observed during consecutive HINOTORI passes over regions in the vicinity of Cachoeira Paulista. (Their local times refer to the longitudes of their occurences that are in the vicinity of 45°W). Maximum ΔT_e values observed (that is, deviation from the background)varied from 800K to 1200K. The T_e enhancements occurring in the general vicinity of the EIA peaks and very near in time to the onset of the evening vertical drift enhancements on all these days support the association between the EIA and the EETA. (On 31 May for which the longitude of T_e observation was some 30°east of Cachoeira Paulista, a shift by 2 hrs in the local times of the observations will make the T_e values fall within the above description). However, these T_e enhancements did not occur at the same locations as those of the EIA crests but were displaced a little towards higher latitudes in the HINOTORI orbits. They are being investigated as a solsticial class of events influenced by transequatorial meridional winds, as the preliminary result from a theoretical model study (to be published) shows. These types of events are not included in the present morphological study.

2.4- Dependence of the Hot Plasma Region on Local Time, and of the T_e on Electron Density

The maximum values of the temperature deviations in the hot region (ΔT_e) are plotted in Fig.6 versus local time from 18 LT to 02 LT when they are more often encountered. Although significant scatter in the data points exists we can see a tendency for the ΔT_e to first increase starting from 18 LT to reach a maximum value near 21 LT and then to decay towards midnight and beyond. The former (rising) part of the plot is due to the continuing influence of the daytime temperature into the nighttime in such a way that the ΔT_e, with respect to an otherwise decaying nighttime (background) temperature, shows up as an increasing function of time. The modified temperature itself starts its decay from 21 LT onward resulting in the second part of the plot. Fig.7 shows a plot of the maximum electron densities in the equatorial anomaly against the associated maximum ΔT_e. The dependence of the latter as an increasing function of the electron density is clearly brought out in this figure.

3- A Mechanism for the Elevated Electron Temperatures

We suggest that the hot and dense plasma regions, that characterise the electron temperature anomaly (EETA), could be resulting from the transport of the dayside hotter plasma into the cooler nightside ionosphere through sunset electrodynamic processes. It is a well-known fact that the equatorial ionospheric plasma undergoes rapid upward drift around sunset hours just before the nighttime reversal to downward of the drift (Woodman, 1970; Fejer et al.,1979). For theoretical/ model interpretation of the phenomenon,see Rishbeth, 1971; Heelis et al.,1974; Farley et al., 1986; Haerendal et al.1992). The prereversal enhancement electric field that drives the upward drift arises from the interaction with the geomagnetic field of an eastward blowing neutral wind in the presence of a longitudinal gradient in the E layer Pederson conductivity. The evening zonal wind, as well as the plasma drift, is strongly eastward near and above ~ 300 km and in the height region of our interest covered from the lowest altitude of the HINOTORI observation,of around 570 km, to the height region of 600-900 km where most of the KYOKKO observations were made (Tsunoda et al.,1981; Abdu et al.,1985;Fejer et al., 1991; Sobral and Abdu, 1991; Sahai et al.,1992;) . In this height region large upward and eastward drifts characterise the evening ionosphere plasma dynamics. The vertical drift velocities are of the order of 40-60 ms^{-1} in the equinoctial months (Fejer et al.,1979; Abdu et al., 1992). The corresponding eastward drift is of the order of 150-200 ms^{-1} (Fejer et al., 1991; Abdu et al., 1985). Thus hotter plasma from the dayside evening sector drifting upward and eastward participating in the evening equatorial plasma fountain could contribute to the enhanced electron temperature associated with the EIA. In its superrotating frame of reference the local time change experienced by the hotter plasma is ~1.3 times faster (for an eastward velocity of around 150 ms^{-1}) than in the corotating case. This means that the ΔT_e peak around 21 LT could be produced by the hotter plasma that drifted from the vicinity of the 17-18LT meridian. Due to the decay in the background nighttime temperature the ΔT_e increases till 21 LT after which the decay of the modified nighttime temperature sets in. A schematic representation of these processes is sketched in Fig.8.

4- Discussion and Conclusions

The morphology of the EETA that we discussed in Section 2 seems to be well explained on the basis of the plasma transport pattern of the evening equatorial ionosphere. Their occurrence coincident with the latitudinal position of the EIA crests in the equinoctial months of March-April and September- October (Fig.4) is very significant. The thermospheric zonal wind (blowing away from the subsolar point) is generally strongest in the evening hours of these months (Hedin et al.,1991) . This situation is conducive to large amplitudes of the evening (prereversal) zonal electric field (vertical drift) enhancement (Batista, et al., 1986; Farley et al., 1986) as well as of the vertical electric field, (zonal plasma drift), thus contributing to the mechanism for elevated electron temperatures as discussed in Section 3. It is further interesting to note that the solar F 10.7 cm flux controls both the vertical and zonal equatorial plasma drifts in the evening hours as discussed by Fejer et al.,1991. For example, an increase of the flux unit from 100 to 200 could result in 100 percent increase in the yearly averaged vertical drift and by as much as 50 percent in the zonal plasma drift velocity. Therefore large increase in the F 10.7 cm flux should produce, according to our explanation for the EETA mechanism, hot plasma of the ionioization anomaly as is indeed observed in Fig.4. The events centered around the days 320, 340 and 400, that do not fall stricly in the equinoctial months, are good examples of this effect. Anomalous neutral wind and temperature distributions (identified as Equatorial Temperature and Wind Anomaly - ETWA) associated with the EIA have been reported from the analysis of DE 2 (Dynamic Explorer) data by Raghavarao et al.,1991. We believe that the physical mechanism that produces the EETA involves different/additional processes than that are invoked for the ETWA.

To conclude, a study on the morphological features of the hot plasma region observed by HINOTORI satellite demonstrates that these regions are in fact closely associated with the well known equatorial ionization anomaly in the post sunset hours . They occur predominantly in the equinoctial months. They also occur for large intensities of solar F 10.7 cm flux.The characteristic features of the EETA suggest that they could be produced by the vertical and eastward transports of hotter day- side plasma well into the nighttime ionosphere as part of sunset electrodynamic processes. The presently used theoretical/numerical ionospheric models do not predict the EETA, understandably, because they do not include realistic electron temperature and the effects of zonal plasma drift. In order to verify this transport phenomenon, we need to measure simultaneously the electron and ion temperatures and densities, vertical and horizontal plasma drifts, polarization electric field, neutral wind and ion composition at various altitudes from ~400 km up to 1000 km. Such measurements could be accomplished by a multiple tethered satellite mission for which we are presently carrying out feasibility studies.

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Figure Captions:

Fig.1- Elevated electron temperatures detected by KYOKKO satellite in 1978. The different curves of electron densities in the top panel corresponds to the different bias voltages applied to the density measuring(current collecting) sensor. The thick line represents most realistic value. The two curves of the bottom panel correspond to the T_e values calculated corresponding to two amplitudes of the oscillator signals applied to the T_e sensor(see Oyama, 1991).

Fig.2- The electron density (upper panel) and electron temperature (lower panel) measured by HINOTORI during its revolution no.3599. The two EIA peaks centered around the magnetic equator at 4:10 UT covering the local time interval 17 -23 LT have associated with the elevated electron temperatures (shaded region) with respect to the background temperature and the IRI representation (broken line) . The T_e enhancement around 05:11 LT is sunrise effect .

Fig.3- Locations marked in solid lines of elevated electron temperature along HINOTORI trajectory segments,the maximum value of T_e being indicated by triangles. The dashed curve is the magnetic equator.

Fig.4- Occurrence of hot plasma regions marked at geomagnetic latitude (upper panel) versus number of days starting from 1st of January 1981 (one month and 20 days before the HINOTORI mission) till the end of the HINOTORI data on 11 June 1982. Increasing sizes of the plotted triangles indicate increasing T_e deviation (up to 1200K).The lower panel shows the solar F 10.7 cm flux diurnal averages for the same period.

Fig.5- Top panel: Dst values from 26 to 31 May 1981 for which ionospheric parameters over Cachoeira Paulista (45°W,22.5°S) in Brazil are plotted on the middle panel for foF2 and bottom panel for hpF2 (a representative parameter for the F2 layer peak height). The solid lines represent quiet day mean values and the dots are values for each day.

Bottom panel:The electron temperature enhancements observed by HINOTORI satellite in the vicinity regions of Cachoeira Paulista with scale on the right hand side.

Fig.6- T_e deviation in the center of the hot region (with respect to the background values) plotted as a function of local time during evening-nighttime period .

Fig.7- The electron densities in the anomaly crest plotted versus the corresponding T_e deviations from the back-

ground.

Fig.8-A sketch of the plasma drift near sunset into the nightside shown in the equatorial plane above 350 km. The vertical upward component of the plasma drift reverses to downward near 21 LT meridian whereas the eastward drift is a maximum around this hour and then decrease towards later hours. The EIA fountain diffusion is shown in the magnetic meridional plane at 21 LT. Idealized EIA density straight line contours are shown in the F layer horizontal plane. In the upper panel the T_e is shown decaying into nighttime values (broken line) in an ideal situation of zero eastward plasma drift.The eastward and upward plasma drifts maintain the T_e value high till 21 LT after which it steadily decreases thus producing a peak in ΔT_e (with respect to the broken line background value) around 21 LT similar to the actual results plotted in Fig.6.

List of References

Abdu, M.A., I.J.Kantor, I.S.Batista, and E.R. de Paula, East-West plasma bubble irregularity motion determined from spaced VHF polarimeters: Implication on velocity shear in the zonal F region bulk plasma motion, Radio Sci., 20, 111-122, 1985.

Abdu, M.A., I.S. Batista, J.H.A.Sobral, B.G.Fejer, and E.P.Szusz czewicz, Equatorial F-region dynamo electric field height/latitude structure: Solar cycle dependence from SUNDIAL data set, STEP symposium /5th COSPAR colloqium, John Hopkins University, 24-28 Aug. 1992..

Batista, I.S., M.A.Abdu, and J.A.Bittencourt, Equatorial F- region vertical plasma drift: Seasonal and longitudinal asymmetries in the American sector, J. Geophys. Res., 91, 12055- 12064, 1986.

Bilitza, D. International Reference Ionosphere 1990, URSI-COSPAR, Report NSSDC/WDC-A- R&S, 90-22, Lanham, Maryland,20706, 155p, 1990.

Farley, D.T., E. Bonelli, B.G. Fejer, and M.F.Larsen, The prereversal enhancement of the zonal electric field in the equatorial ionosphere, J. Geophys. Res., 91, 13723- 13728, 1986.

Fejer, B.G., D.T.Farley, R.F. Woodman, and C.Calderon, Dependence of equatorial F region vertical drifts on season and solar cycle, J.Geophys. Res., 84, 5792- 5796, 1979.

Fejer, B.G., E.R. de Paula, S.A. Ganguly, R.F.Woodman, Average vertical and zonal plasma drifts over Jicamarca, J. Geophys. Res., 96, 13901- 13906, 1991.

Haerendel, G., and J.V. Eccles, The role of the equatorial electrojet in the evening ionosphere, J. Geophys. Res., 97, 1181-1192, 1992.

Hanson W.B., and R.J. Moffet, Ionization transport in the equatorial F- region, J.Geophys. Res., 71, 5559- 5572, 1966.

Hedin, A.E., M.A.Biondi, R.G.Burnside, G. Hernandez, R.M. Johnson,T.L. Killeen,C. Mazaudier, J.W. Meriwether, J.E.Salah, R.J. Sica, R .W. Smith, N.W.Spencer, V.B. Wickwar, and T.S.Virdi, Revised global model of thermospheric winds using satellite and ground-based observations, J. Geophys. Res., 96, 7657-7688,1991.

Heelis, R.A. P.C. Kendall, R.J. Moffet, D.W. Windle, and H.Rishbeth, Electrical coupling of the E and F regions and its effects on the F region drifts and winds, Planet. Space Sci., 22, 743-756, 1974.

Moffet, R.J., The equatorial anomaly in the electron distribution of the terrestrial F- region, Fun. Cosmic Phys., 4, 313- 391, 1979.

Oyama,K.-I. and K.Schlegel,Anomalous electron temperature above the South American Magnetic Anomaly,Planet.Space Sci.,32,1513-1522,1984.

Oyama, K.-I., Electron temperature measurements carried out by the Japanese scientific satellites,Adv. Space Res., 11, (10), 149-158,1991.

Oyama, K. -I, and T.Abe, Anisotropy of electron temperature in the ionosphere, Geophys. Res. Lett. 14, 1195- 1198, 1987.

Raghavarao,R., L.E. Wharton, N.W. Spencer, H.G. Mayr, and L.H. Brace, An equatorial temperature and wind anomaly (ETWA), Geophys. Res. Lett.,18, 1193- 1196, 1991.

Rishbeth, H., Polarization fields produced by winds in the equatorial F region, Planet Space Sci., 19, 357- 369, 1971.

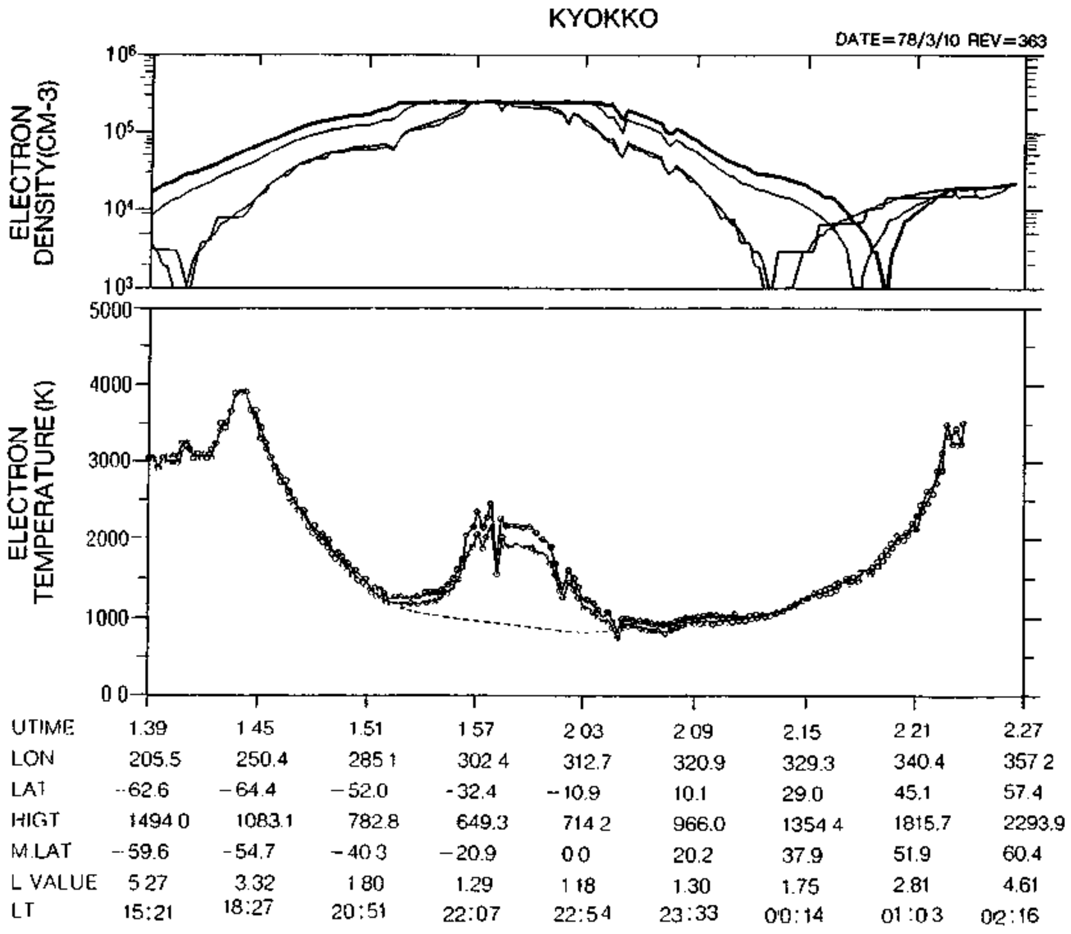
Sahai.Y., H.Takahashi, N.R. Teixeira, P.R. Fagundes, B.R. Clemsha, and J.A. Bittencourt, Observations of thermospheric winds at 23°S,Planet.Space Sci.,40,1545-1549,1992.

Sobral, J.H.A., and M.A.Abdu, Solar activity effects on the equatorial plasma bubble zonal velocity and its latitude gradient as measured by airglow photometers, J. Atmos. Terr. Phys., 53, 729- 742, 1991.

Tsunoda, R.T., R.C. Livingstone, and C.L. Rino, Evidence of velocity shear in bulk plasma motion associated with the post-sunset rise of the equatorial F layer, Geophys. Res., Lett., 8, 807- 810, 1981.

Walker, G.O., and Chan, H.F., Computer simulation of seasonal variation of the ionospheric equatorial anomaly in East Asia under solar minimum condition, J. Atmos. Terr. Phys., 51, 953-974, 1989.

Woodman, R.F., Vertical drift velocities and east- west electric fields at the magnetic equator, J. Geophys. Res., 75, 6249-6259, 1970.



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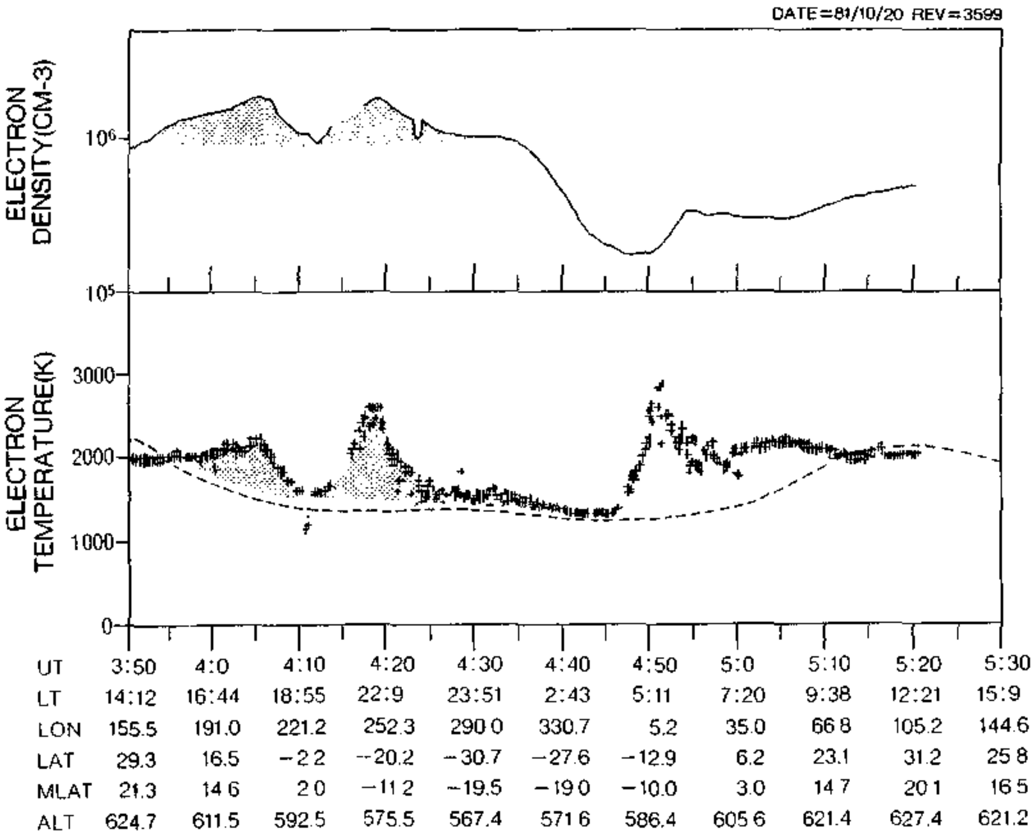

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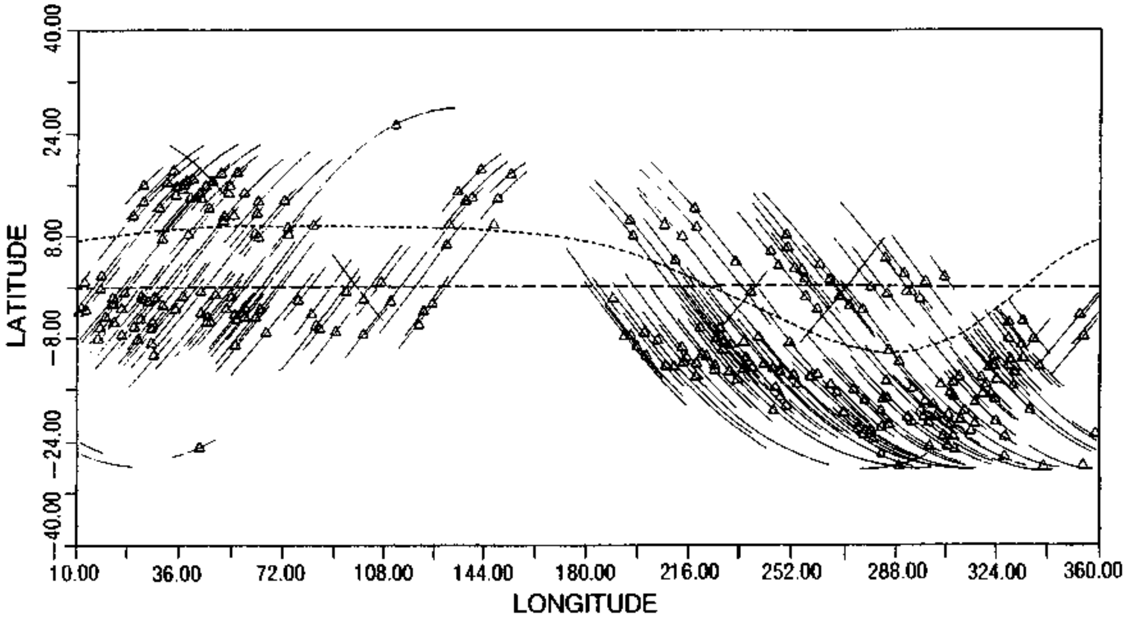

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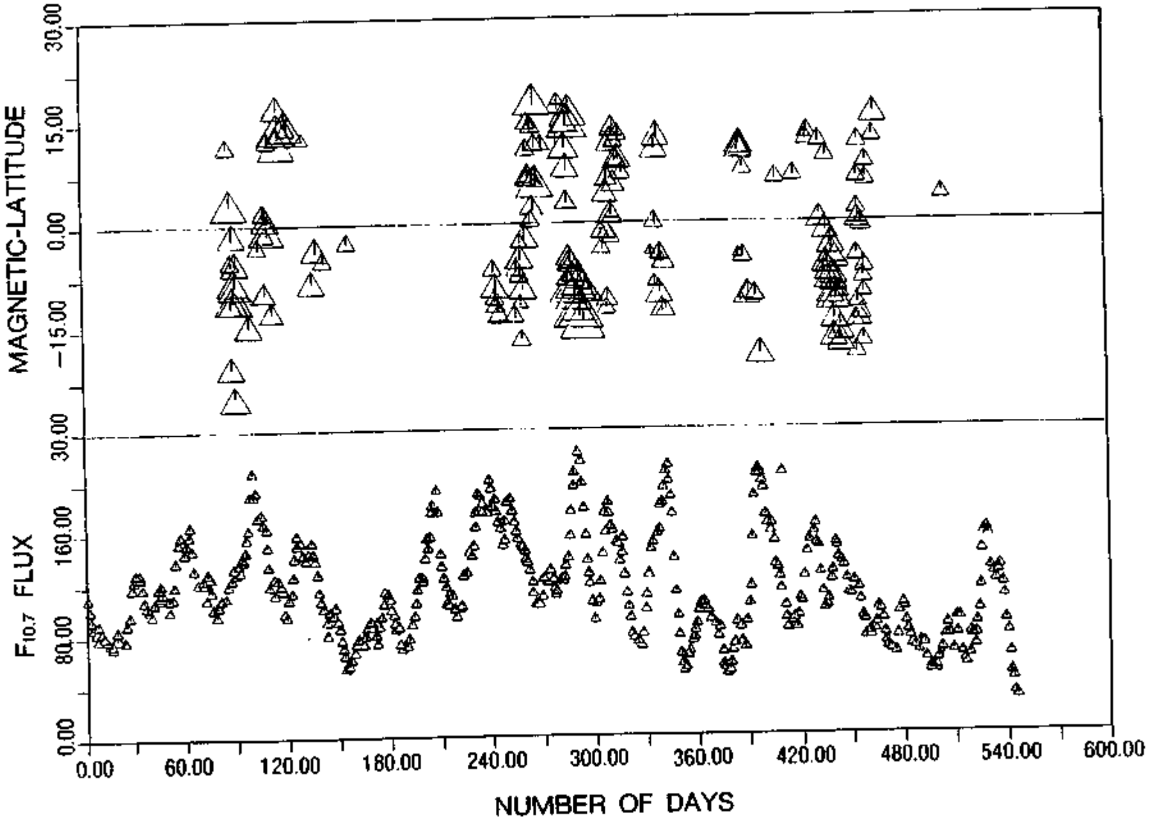

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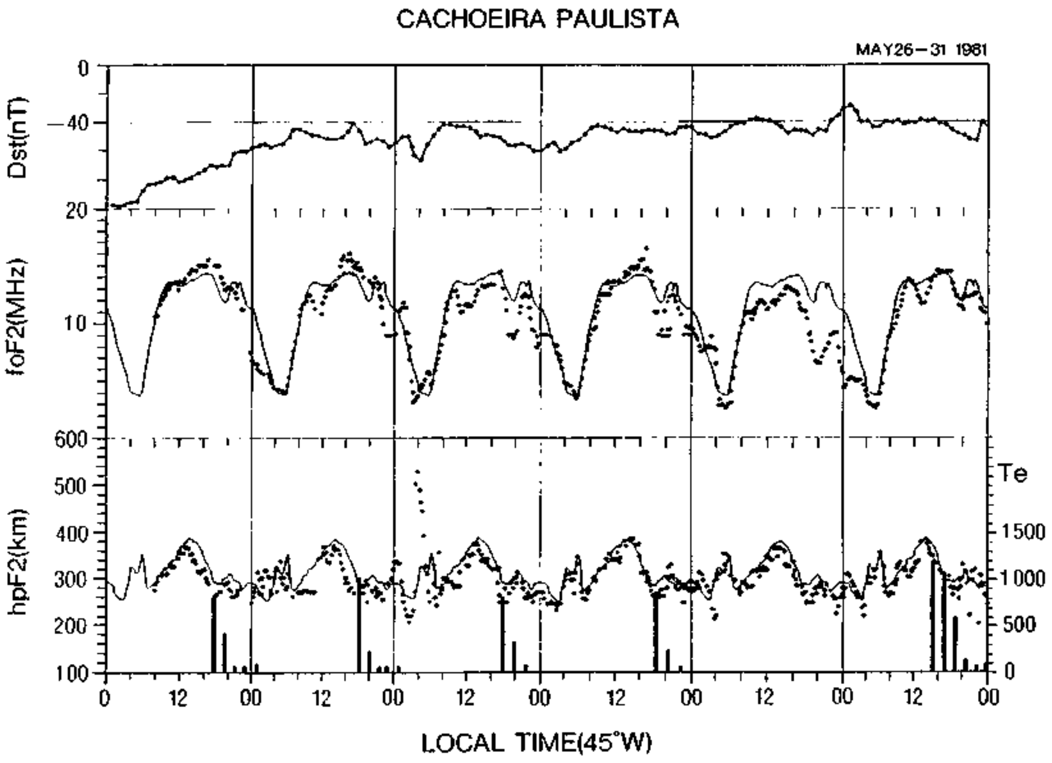

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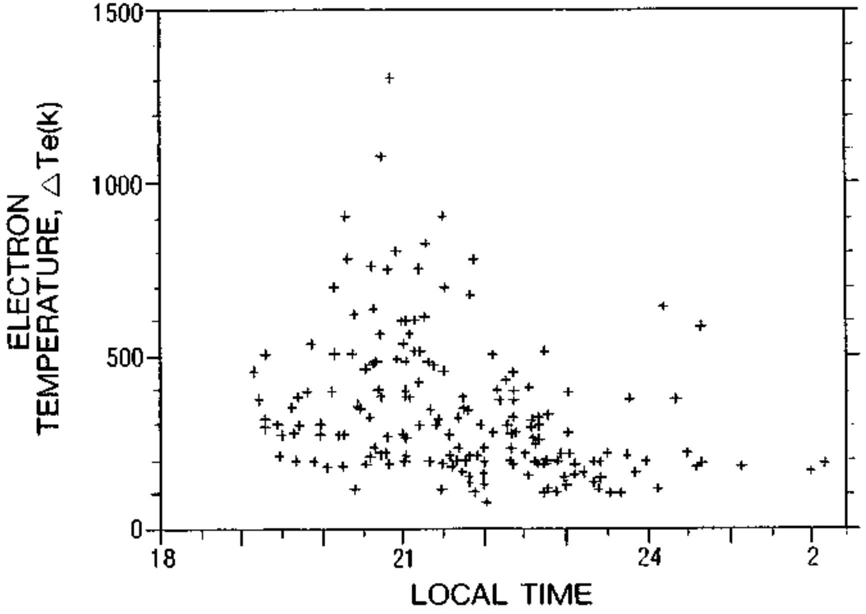

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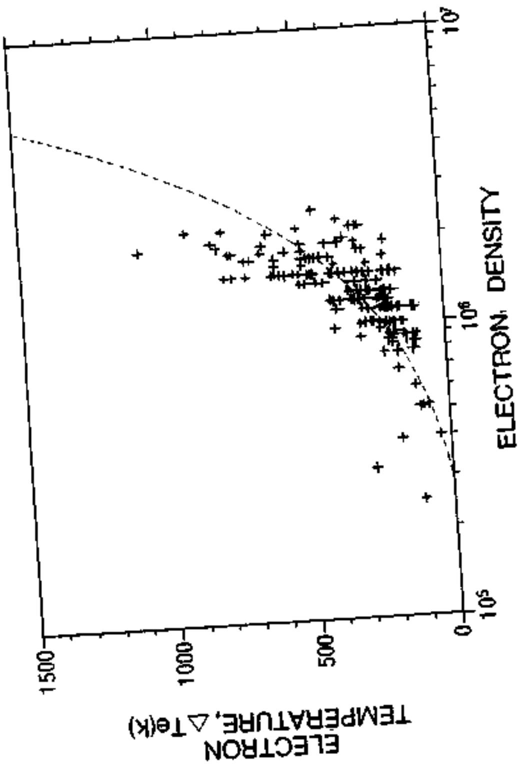

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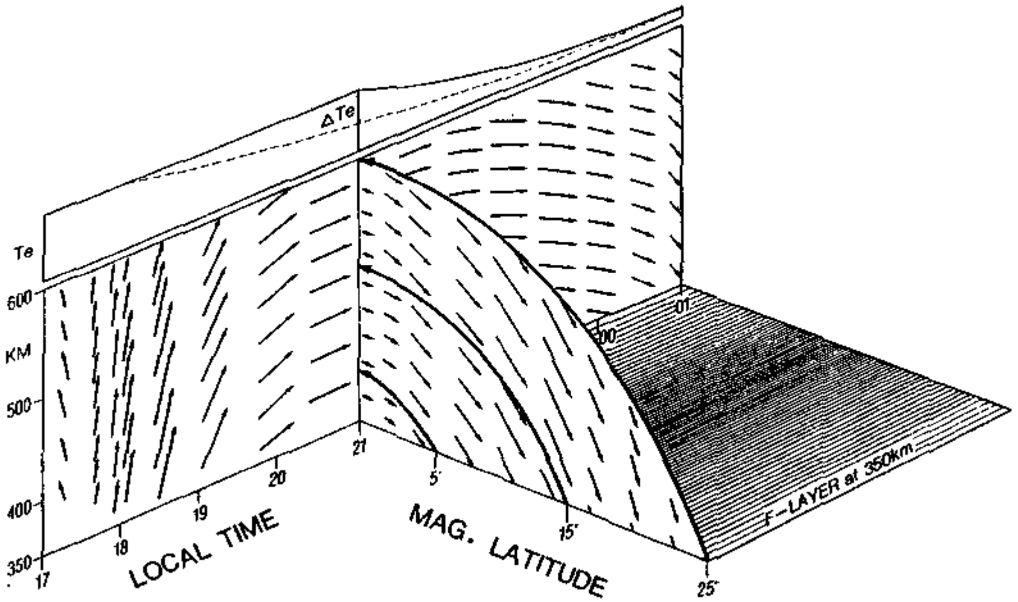

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