WORKSHOP ON RADIO PROPAGATION IN THE TROPICS

International Centre for Theoretical Physics
Trieste, Italy, 1-12 November 1982

RADIO PROPAGATION IN SOUTH AMERICA

S. M. Radicella

National Programme of Radiopropagation
Argentina

Lectures Scheme

1.- Reference Data (2 lectures)
 1.1.- The ionosphere over the South America Continent
 1.2.- The troposphere over the South America Continent
2.- Ionospheric radiopropagation (1 lecture)
3.- Tropospheric radiopropagation (1 lecture)
4.- Case studies (2 lectures)

INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONES: 224281/2/3/4/5/6
CABLE: CENTRATOM - TELEX 460392-I

SMR/98 - 26

AUTUMN COURSE ON GEOMAGNETISM, THE IONOSPHERE
AND MAGNETOSPHERE

(21 September - 12 November 1982)

RADIO PROPAGATION IN SOUTH AMERICA

S.M. RADICELLA

PRONARP
J. Alvarez 1218
1414 Buenos Aires
Argentina

RADIO PROPAGATION IN SOUTH AMERICA

S. M. RADICELLA
National Programme of Radiopropagation
ARGENTINA

1. REFERENCE DATA

1.1. The ionosphere over the South American continent.

The ionosphere over the South American region shows unique characteristics due to the excentricity of the geomagnetic field and the inclination of its axis with respect to the geographic one (Fig. 1.1 and 1.2) The low values of B in the area of the South Atlantic facilitate intense low latitude precipitation of energetic particles from the radiation belts. This precipitation changes the aeronomic conditions at the lower ionosphere heights, where during nighttime there is evidence of increased ionization due to particle effects. The separation between the geographic and the geomagnetic equators in the south american continent affects the time variations of the ionospheric parameters, in particular the seasonal changes of the F region.

Both peaks of the so called "equatorial anomaly" of the F region ionization lies essentially over the equatorial and southern hemisphere portion of the continent.

The ionosphere of the region, as shown by the ionograms, can be seen in the "Atlas of Ionograms for the South American Region" prepared by González and Kurbán (1981).

Table 1.1 gives the location, geographic cordinates and type of observation made of the ionospheric stations active at present time in South America.

1.1.1. Average conditions and normal variations.

1.1.1.1. F region:

The F region over the south american region is strongly controlled by the well known geomagnetic equatorial anomaly first discovered by Appleton (1946). The crests of the anomaly at a longitude around the 70°W meridian, are located over Tucumán and Bogotá (4.5°N, 74.2°W) approximately.

The behaviour of the "fountain effect" that originate the anomaly is dependent on the solar activity and its variable strenght regulates the diurnal and seasonal variations of F region parameters at low and middle latitudes, as was shown by Radicella and Cosio de Ragone (1964) for a year of high solar activity. These authors used mainly data from 11 stations of the South and North American continents, but checked the control of the equatorial anomaly over the seasonal variation of foF2 with data from 14 additional stations of the African-European sector.

Representative diurnal variations of the maximun electron density obtained from foF2 are shown in Fig. 1.3 and 1.4 (Martinez de Garat and Manzano, 1981) for a year of low solar activity and summer. The development of the equatorial anomaly starting near noon and reaching its apex around 16.00 for that season is easily seen in the figures. The peak moves toward nighttime for the equinoctial period when the equatorial anomaly is more pronounced and more symmetrical with respect to the geomagnetic or dip equator. Seasonal variations of foF2 are well described by the graphs shown by Radicella and Cosio de Ragone (1964)(Fig. 1.5, 1.6 and 1.7). The subequatorial peaks are more extended in latitude during equinoxes and at noon. The foF2 peak is higher over South America and the latitudinal gradients of the isolines are more pronounced at 18.00 and midnight.

A semianual variation with equinoctial maxima is observed from +60° to -60°of magnetic dip at noon and reduces its latitudinal extention to ±50° at midnight. The amplitude of the seasonal variation has a minimum over the Dip equator region.

Lascano (1981) made a detailed study of foF2 and h'F data obtained at Tucumán from July 1957 to December 1970. Fig. 1.8 shows diurnal variation of foF2 for summer, equinoxes and winter. Once more the nighttime peaks at high solar activity and equinoxes are clearly seen over this station at the crest of the equatorial anomaly. A comparison of diurnal seasonal and solar activity variations between Tucumán and Buenos Aires, outside the crest, is shown in Fig. 1.9 also taken from Lascano (1981).

The diurnal development of the southern crest of the equatorial anomaly at latitudes around Tucumán has been analysed by Grimolizzi et al. (1978) using total electron content (TEC) data obtained from the low orbiting satellite INTASAT Faraday rotation records for the equinoctial period of 1975 (Fig. 1.10 and 1.11). A comparison is made in the same paper with data obtained by De Mendonca et Al (1969) using records from Sao José dos Campos. The results obtained using TEC values confirm the conclusions on the diurnal variations of the equatorial anomaly crest of ionization obtained using ionosonde data (Fig. 1.12).

Manzano et al. (1981) have found that the middle latitude trough of the F region ionization observed using topside sounders is also seen at nighttime over the south american continent using data from bottom side ionosondes (Fig. 1. 13). Its latitude corresponds to lower L values than those observed from satellites. These authors also found a pedestal of increased ionization at latitudes still somewhat far from the auroral oval (fig. 1.14). They relate the presence of the trough and the pedestal to the existence of the particles precipitation region in the South Atlantic.

BE-B Satellite data obtained at Tucumán where used by Ríos et al.(1975) to study ionospheric satellite scintillations at 40 MHz. Their comparison with data from Ghana (dip angle -8.50)(Fig. 1.15) show that at the latitude of Tucumán scintillation appears during all day while at Ghana, much closer to the geomagnetic equator, the phenomenon is clearly a nighttime one. It must be also remembered that data from the equatorial location of Huancayo again show only nighttime scintillation and Haifa data -that correspond to the northern crest of the equatorial anomaly in the African-European sector- are similar to those obtained at Tucumán. Ríos et al. (1975) suggest the influence of the equatorial anomaly dynamics on the scintillation behaviour.

1.1.1.2. E region:

It is well known that normal E region follows closely the Chapman photochemical theory of ionization layer formation. The maximum electron density in the layer -represented in the ionograms by the critical frequency foE- is then a function of geographical position, local time, month of the year and solar activity. To describe it, the mathematical expression of the function given by Muggleton (1975) can be used:

$$(foE)^4 = S\ B \cos^m \chi_{noon} \cos^p \chi \ , \qquad (1)$$

where χ is the solar zenith angle, χ_{noon} is its value at noon, S and B are

function of solar activity and geographical position respectively, m is latitude dependent and p is considered a constant for non equatorial latitudes. When solar activity dependence is eliminated, equation (1) reduces to:

$$(foE)^4 = A \cos^p \chi \ , \qquad (2)$$

where: $$A = B \cos^m \chi_{noon} . \qquad (3)$$

Appleton (1963) discovered that A varies seasonally, meaning a second order variation of the maximum electron density in the E region not described by the Chapman theory. Kouris and Muggleton (1973 a, 1973 b) [from now on: K-M] have analysed in detail A and p behaviour using median values of foE from 45 ionospheric stations and one solar cycle. Their work only considers three stations from South America: Huancayo, Concepción and Port Stanley.

González et al. (1982 a) have studied foE for 1971 and 7 stations: Huancayo, Tucumán, San Juan, Buenos Aires, Concepción, Port Stanley and Argentine Islands by using a more refined method of data analysis, that make possible to utilyze only one year of data with similar results than those of K-M. Fig. 1.16 shows the seasonal variation of A in full lines for all the stations. Broken lines correspond to K-M results. Fig. 1.17 displais B values as a function of latitude. Dots are by K-M and crosses by González et al. (1982). Fig. 1.18 shows m values in the some way.

The more refined data analysis -based on the use of hourly values of foE matched with correponding solar zenith angle, elimination of extreme values with statistical criteria of selection of zenith angle intervals and normalization by monthly values of solar activity- allowed González et al. (1981) to detect a significant latitudinal variation of p, that is displaied in Fig. 1.19.

The results described appears to be a good representation of foE behaviour over the south american sector.

1.1.1.3. Sporadic E:

Different types of layers and structures of ionization are observed around 100-120 Km, overimposed to the normal E region. As a whole, they are called sporadic E. The parameter read in the ionograms that better represents the maximum electron density of the sporadic E is the blanketing frequency fbEs, as was shown by several authors (Rawer, 1962; Reddy and Rao, 1968; Whitehead, 1972 and Smith and Mechtly, 1972). Particularly for radiopropagation uses it is important to define the behaviour of this parameter.

Giraldez (1979 a) have shown -using data of 17 years from 4 south american stations: Sao Paulo, Tucumán, Buenos Aires and Port Stanley- that it is possible to describe fb as a function of solar activity, solar zenith angle and latitude. Giraldez (1979 b) also shows that the prediction equation obtained using south american data is valid on a world wide basis.

The expression used is:

$$fbEs = A\ F\ (R)\ \cos^{0.25} \chi\ F(\chi_i, \lambda) \quad , \qquad (4)$$

where the proportionality constant is A = 3.844, λ is the geographic latitude, and

$$F\ (R) = 1 + 1.737 \times 10^{-3}\ R \quad , \qquad (5)$$

and

$$F\ (\chi_i, \lambda) = \exp\ (-\lambda - \phi)^2 / S(\chi_i) \quad , \qquad (6)$$

where ϕ, the latitude factor, is given by:

$$\phi = 150^\circ\ (\cos \chi - \cos^2 \chi - \cos^3 \chi /9) + 7^\circ \quad , \qquad (7)$$

and

$$S(\chi_i) = 2.525 \times 10^3\ (\cos \chi)^{-0.73} \quad , \qquad (8)$$

Fig. 1.20 and 1.21 shows examples of observed and predicted values of fbEs using equation (4), for different locations in the southern hemisphere.

It must be commented that the empirical expression given by Giraldèz (1979 b) -that reproduces well enough median values of fbEs- has been obtained considering the physical principles involved in the formation of Es ionization. The dependence on R and χ takes into account that fbEs tends to follow foE behaviour and the function of latitude makes allowance of the special nature of Es formation: the action of neutral wind-shears at E region heights and solar tides.

When sporadic-E predictions are considered it must be kept in mind that only general average patterns can be reproduced and that it is not possible to predict individual day conditions.

A more recent paper by González et al. (1982 b) analyses the behaviour of fbEs using data from 11 stations in South and North America, for a year of minimum solar activity: 1964 ($\bar{R}$ = 10), and a year of high solar activity: 1967 ($\bar{R}$ = 94). Published monthly median values where corrected and unified taking into account rules of ionograms scaling, that considere the relation between fbEs and foE, now generally accepted. Their results show some marked differences with those of Matsushita and Reddy (1967). The main one is concerned with a symmetry with respect to the geomagnetic equator found by them and not mentioned before (Fig. 1.22). As a result of this work, corrections are being introduced in the Giraldez method of fbEs predictions in order to consider the geomagnetic influence together with the solar-latitudinal one.

1.1.1.4. D region:

It is known that D region heights in the ionosphere, below 90 Km, cannot be explored using the normal HF vertical pulse ionosonde.

Data on the behaviour of that region can be obtained by sounding it with pulses at fixed frequency or other ionospheric absorption techniques (Rawer,1975). From these only integrated values of the product of electron density and collision frequency are acquired. Additional information can be obtained using long or short distance measurements of phase and amplitude of VLF signals. Both in the Sao Paulo area and at Tucumán, rutine records of the VLF Omega-Argentina station (43.20°S, 65.4°W) signals are made. Average conditions show that the nighttime reflection heights are lower in the southern portion of South America (Fig. 1.23) than what is observed in other middle latitude regions. This fact is related with the expected nighttime ionization by particle precipitation in that region.

A comparison of winter ionospheric absorption by the fixed frequency pulse method at a middle latitude station in Europe: Lindau (51.65°S, 10.12°E) and at equivalent station in South America: Ushuaia, have been made by Schwentek et al. , 1981. At the latter station the absorption is larger, indicating a real asymmetry between northern and southern hemispheres (Fig. 1.24). The observed difference is greater than the expected one due to the differences of solar photon radiation and to geomagnetic conditions at the two stations considered.

1.1.2. Ionospheric storms.

1.1.2.1. F region:

It is well known that the F region of the ionosphere is very sensitive to the occurrence of magnetic storms and substorms.

The results obtained by Martinez de Garat and Manzano, (1981), that analyse southern hemisphere F region response to the strong magnetic disturbances of August 1972 using ionosonde data; show evidences of Travelling Ionospheric Disturbances (TID) that propagates with speeds of 400 to 1000 m/sec. The "impact area" is located in the auroral zone of the nighttime south american sector and the storm travels north in the continent, toward north-east reaching the north of Aus tralia and also more slowly toward east arriving to southern Australia. It must be taken into consideration that this clear behaviour corresponds to a period of almost unusual strong geomagnetic activity. Kp index was 7 to 9 during 24 hours after the Sudden Commencment (SC) of the storm. Other results of Martinez de Ga rat and Manzano (1981) show important differences between foF2 storm values in the south american sector and in Australia (Fig. 1.25 and 1.26). This result make necessary to check carefully the existing theory of ionospheric storms in the F region.

Manzano et al. (1981) have studied the response of the F region to the storm of March 26, 1976 over the continent. Their results confirm the existence of latitudinal transport of ionization from high latitudes toward the equator.

Another geomagnetic storm effect in the F region was analysed by Kurbán et al. (1981). The behaviour of F region over the South American Continent was studied for the storm of April 4, 1967. An essentially positive phase lasted for more than two days.

Magnetic storms appear to affect also the TEC values as it can be seen in Fig. 1.27 (Ezquer et al. , 1981) where data obtained at Tucumán from the geosta tionary ATS-5 satellite signals are shown for the period covering the SC of July 25, 1981. The some figure shows geomagnetic characteristics recorded at Trelew. Around two hours after the SC a large increase of the TEC value that lasts very shortly is observed. After that a period of more than 12 hours of strong perturb ations in the geomagnetic field is corresponded by strong alterations of TEC val ues.

1.1.2.2. Lower ionosphere:

Electron density fluctuations of sporadic E associated with large F reg ion TID have been analysed by Giraldez (1980). This author finds that at Es heights the disturbance represented by gravity waves started at high latitudes in the south american sector and travels toward the equator with velocity between 250 and 600 m/s. Fig 1.28 shows the relation between F region and E region disturbances.

D region response to the magnetic storms have been investigated by Perés (1981) using data from ionospheric absorption, for Ushuaia and Kergulen, both stations in the southern hemisphere. Fig. 1.29 shows the effect of the geomagnetic storm started with the SC of April 1, 1976. An increase of ionization at Kergülen (L = 3.7) is seen almost inmediately and lasts for several days after the SC. At Ushuaia (L = 1.7) the effect appears only after some days. The normal ionization at this station is attributed to transport of plasma from the southern auroral zone. Similar effects are observed and discussed for the geomagnetic storm of March 25, 1976.

Abdu et al. (1981) and Pintado and Radicella (1982) have shown the effect of geomagnetic storms on VLF signals in the area of the South Atlantic where particle precipitation is expected to be enhanced during geomagnetic disturbances. Fig. 1.30 shows the VLF paths under study and Fig. 1.31 displais the results by Pintado and Radicella (1982) for the storm of December 19, 1980. The results obtained by the two groups coincides in showing nighttime increase of ionization during the recovery phase of the storm, that can be associated to an increase of particle precipitation along tha propagation path of the VLF signals.

1.1.3. Figures Captions.

Fig. 1.1 The isomagnetic map for B, computed on the basis of the International Geomagnetic Reference Field 10/68. From Akasofu and Chapman (1972).

Fig. 1.2 The isomagnetic map for I, computed on the basis of the International Geomagnetic Reference Field 10/68. From Akasofu and Chapman (1972).

Fig. 1.3 Diurnal variations of Nm F2 as function of geomagnetic latitude in South America, for November and December 1975.

Fig. 1.4 Diurnal variations of Nm F2 as function of geomagnetic latitude in South America, for January and February 1975.

Fig. 1.5 Isolines of foF2 median values as function of geographic latitudes and month of the year in the American Continent, for 00.00 LMT and 1959.

Fig. 1.6 Isolines of foF2 median values as function of geographic latitudes and month of the year in the American Continents, for 12.00 LMT and 1959

Fig. 1.7 Isolines of foF2 median values as function of geographic latitudes and month of the year in the American Continents, for 18.00 LMT .

Fig. 1.8 Diurnal variations of foF2 median values obtained at Tucumán for summer, equinoxes and winter as function of the year, from 1957 to 1970.

Fig. 1.9 Comparison of the diurnal variation of foF2 median values ob tained at Tucumán and Buenos Aires for summer, equinoxes and winter for years of maximum (1957-58), medium (1960-61) and low (1963-64) solar activity.

Fig. 1.10 Average daytime TEC values for different hours as function of geographic latitude, obtained at Tucumán from INTASAT low orbiting satellite signals, for equinoctial months in 1975.

Fig. 1.11 Average nighttime TEC values for different hours as function of geographic latitude, obtained at Tucumán from INTASAT low orbiting satellite signals for equinoctial months in 1975.

Fig. 1.12 Comparison of average nighttime TEC values obtained by de Mendonca et al. (1969) for the equinoxes of 1966 in Sao José dos Campos and over Tucumán for the equinoxes of 1975.

Fig. 1.13 Monthly median values of foF2 for September 1971 as function of latitude and time, for the South American region. The middle latitude trough of ionization is seen.

Fig. 1.14 Average values of foF2 for quiet days of March 1976 as function of latitude and time, for the south american region. The middle latitude trough and pedestal of ionization are seen.

Fig. 1.15 Comparison of average diurnal variation of the percentage of time when scintillation index excceds a given value, for the Tucumán and Ghana 1967 winter. The experimental points for Ghana are taken from Koster (1968).

Fig. 1.16 Seasonal variation of A obtained by González et al. (1982) in full lines and those by K-M in broken lines for the South American stations.

Fig. 1.18 Latitudinal variation of B values. Dots are taken from K-M for all the stations and crosses are obtained by González et al. (1982) for South American stations.

Fig. 1.18 Latitudinal variation of m values for the 75°W meridian stations. Dots are taken from K-M and crosses are obtained by González et al. (1982).

Fig. 1.19 Latitudinal variation of p for the South American stations.

Fig. 1.20 Observed hourly median values (dots) and predicted values (full lines) of fbEs for stations of the South American region.

Fig. 1.21 Observed hourly median values (dots) and predicted values (full lines) of fbEs for stations of the North American region.

Fig. 1.22 Isolines of fbEs as a function of time of day and latitude in the American Continents, for a year of low (1964) and one of high solar activity (1967).

Fig. 1.23 Seasonal variation of Δ h, the day to night difference of the reflection height for 12.9 KHz signals transmitted from Omega Argentina and received at Tucumán (experimental). The lower portion of the figure shows the computed Δ h using IRI79 electron density model for middle latitude D region. The upper part displais monthly mean values of the solar activity index R and χ (From Radicella and Pintado: private communication).

Fig. 1.24 Ionospheric absorption at a constant solar zenith angle = 78.5° as a function of time for winter in the southern hemisphere (Ushuaia) and in the northern hemisphere (Lindau). Pulsed fixed frequency of 1.73 MHz.

Fig. 1.25 Time variations of foF2 and h'F for the South American sector during the geomagnetic storms of August 3-6. The control day curve (dashed lines) is obtained averaging data from the 11 quietest days. Kp and AE indices are shown for the period involved.

Fig. 1.26 Time variations of foF2 and h'F for the Australian sector during the geomagnetic storms of August 3-6. The control day curve (dashed lines) is obtained averaging data from the 11 quietest days. Kp and AE indices are shown for the period involved.

Fig. 1.27 TEC values obtained at Tucumán using ATS-5 geostationary satellite signals are shown together with geomagnetic variations at Trelew (43.25°S, 65.30°W), for the July 25, 1981 geomagnetic storm.

Fig. 1.28 Relative minima of foF2 (dots) and maxima of foEs (crosses) as a function of time and latitude for December 15, 1965. Vertical arrows indicate station location.

Fig. 1.29 Absorption by the single pulsed frequency method measured at

Ushuaia and riometer absorption data from Kergülen for the period 1-8 April 1976. The lower part of the figure shows Dst and Kp indices.

Fig. 1.30 Southern hemisphere particle precipitation zones from Seward (1973). Black heavy lines show the propagation paths from Abdu et al. (1981) and Pintado and Radicella (1982).

Fig. 1.31 Hourly values of fase (ϕ) and amplitude (A) recorded at Tucumán for December 17-27, 1980 (full lines) together with monthly median values (dotted lines). Kp and Dst indices are also shown.

1.1.4. References:

ABDU, M.A.; BATISTA, I.S.; RIZZO PIAZZA, L. (1981) J. Geophys. Res. 86, 7533.

AKASOFU, S.I. and CHAPMAN, S. (1972) "Solar-Terrestrial Physics" Oxford University Press.

APPLETON, E.V. (1946) "Two anomalies in the ionosphere", Nature, 157, 691.

APPLETON, E.V. (1963) "A seasonal anomaly in the ionospheric E-layer", J. Atmos. Terr. Phys., 25, 577.

EZQUER, R.G.; MANZANO, J.R. and ORTIZ de ADLER, N. (1981) "Fuertes incrementos de contenido electrónico total y densidad electrónica, en condiciones geomagnéticas diferentes", Reunión Nacional de Física, 1981, San Luis, Argentina.

GIRALDEZ, A.E. (1979 a) "Predicción de las frecuencias de apantallamiento fbEs de las capas Es en latitudes medias en el sector sudamericano", GEOACTA 9, 1, 195, Buenos Aires.

GIRALDEZ, A.E. (1979 b) "Daytime sporadic-E blanketing frequency prediction", SOLAR-TERRESTRIAL PREDICTION PROCEEDINGS, Vol. IV, NOAA, Boulder.

GIRALDEZ, A.E. (1980) "Evidence of gravity at E-region heights", Geophys. Res. Letters, 7, 2. 170.

GONZALEZ, M.M. de; MOYANO, C.E. and DUHAU, S. (1982 a) "Variaciones de la frecuencia crítica de la región E en los registros de la red sudamericana de sondadores", GEOACTA 11, no 2, Buenos Aires.

GONZALEZ, M.M. de; RADICELLA, S.M.; ABARCA, O. and GONZALEZ, R. (1982 b) Morfología de las capas E esporádicas en las américas", Informe de Proyecto, Comisión de Geofísica IPGH, México.

GONZALEZ, M.M. de and KURBAN, L.L. (1981) "Atlas of Ionograms for the South American Region", PRONARP, Argentina.

GRIMOLIZZI, O.M.L.; LAGORI, J.F.; MANZANO, J.R.; RIOS, V.H. and LASCANO, J.V. (1978) "Contenido electrónico total sobre Tucumán para el período equinoccial de 1975 a partir de señales del satélite INTASAT", REVISTA GEOFISICA, no 8, 85, IPGH, México.

KOSTER, J.R. Progress Report no 3, Departament of Physics, University of Ghana.

KOURIS, S.S. and MUGGLETON, L.M. (1973 a) "Diurnal variation in the E-layer ionization", J. Atmos. Terr. Phys., 35, 133.

KOURIS, S.S. and MUGGLETON, L.M. (1973 b) "World morphology of the Appleton E-layer seasonal anomaly", J. Atmos. Terr. Phys., 35, 141.

KURBAN, L.; GONZALEZ, M.M.de; CEJAS, R.; MARTINEZ de GARAT, A.C. and MANZANO, J.R. (1981) "Desarrollo de una tormenta ionosférica esencialmente positiva a lo largo de la red sudamericana de sondadores", GEOACTA, 11, no 1, 103, Buenos Aires.

LASCANO, J.V. (1981) "Análisis del comportamiento de la región F sobre Tucumán durante un ciclo solar", GEOACTA, 11, no 1, 219, Buenos Aires.

MANZANO, J.R.; LASCANO, J.V.; TOLEDO, B.; KURBAN, L.; GONZALEZ, M.M. de and PERELLO, R. (1980) "Evidencia de la presencia de la garganta de densidad electrónica en los registros de los sondadores de la red sudamericana", GEOACTA, 10, no 2, 53, Buenos Aires.

MANZANO, J.R.; PINTADO, O.I.; EZQUER, R.G. and MARTINEZ de GARAT, A.C. (1981) "Acoplamiento de la alta y baja ionósfera durante la tormenta geomagnética del 26 de marzo de 1976", GEOACTA, 11, no 1, 23, Buenos Aires.

MARTINEZ de GARAT, A.C. and MANZANO, J.R. (1981) "Respuesta hemisférica de la ionósfera a las fuertes perturbaciones magnéticas de agosto de 1972", GEOACTA 11, no 1, 339, Buenos Aires.

MARTINEZ de GARAT, A.C. and MANZANO, J.R. (1982) "Là Ionósfera de Base en el Hemisferio Sur", (sent for publication).

MATSUSHITA, S. and REDDY, C.A. (1967) "A Study of Blanketing Sporadic E at Middle Latitudes", J. Geophys. Res., 72, 2903.

de MENDONCA, F.; KANTOR, I.J. and CLEMENSHA, B. (1969) "Low Latitude Ionospheric Electron Content Measurements During Half a Solar Cycle", Scientific Report LAFE-84, INPE, Sao José dos Campos.

PERES, M. (1981) "Storm after effects observed at Ushuaia and Kergulen", J. Atmos. Terr. Phys., 43, 12, 1279.

PINTADO, O.I. and RADICELLA, S.M. (1982) "Respuesta de la ionósfera inferior a tormentas geomagnéticas", (sent for publication).

RADICELLA, S.M. and COSIO de RAGONE, A.H. (1964) "Seasonal Variations of foF2 and the Equatorial Anomaly", Universidad Nacional de Tucumán, Argentina.

RAWER, K. (1962) "Structure of Es at temperate latitudes", IONOSPHERIC SPORADIC E, 292, E.K. Smith and S. Matsushita (Ed.) McMillan Co., New York.

REDDY, C.A. and RAO, M. (1968) "On the physical significance of the Es parameters fbEs, fEs and foEs", J. Geophys. Res., 73, 215.

RIOS, V.H.; SAUVAGE, A.M. and MANZANO, J.R. (1975) "Analysis of scintillation phenomena produced over Tucumán, for the 1965-1968 period", SPACE RESEARCH XV, Akademie Verlag, Berlin.

SCHWENTEK, H.; ELLING, W. and PERES, M. (1980) "Asymmetry in the winter anomalous behaviour of absorption at midlatitudes in the northern and southern hemispheres", J. Atmos. Terr. Phys. 42, 545.

SEWARD, F.D. (1973) "The geographical distribution of kev electrons above the earth's atmosphere", Rep. UCRL-51466, Univ. California Lawrence Livermore Lab., Livermore.

SMITH, L.G. and MECHTLY, E.A. (1972) "Rocket observations of sporadic-E layers", Radio Sci., 7, 367.

WHITEHEAD, J.D. (1972) "The structure of sporadic-E from a radio experiment", Radio Sci., 7, 355.

TABLE 1.1

IONOSPHERIC OBSERVATION SITES

IN SOUTH AMERICA (1982)

LOCATION NAME	GEOGRAPHIC COORDINATES Lat. S	Long.W	TYPE OF OBS.
FORTALEZA	3.70°	38.80°	B01
NATAL	5.70°	35.20°	B11
JICAMARCA	11.95°	76.85°	B03
HUANCAYO	12.00°	75.30°	B01
CACHOEIRA PAULISTA	22.70°	45.02°	B01,B06,B08,B13
SAO JOSE DOS CAMPOS	23.23°	45.85°	B06,B11,B13
ATIBAIA	23.50°	46.50°	B13
TUCUMAN	26.90°	65.40°	B01,B06,B11,B13
BLUMENAU	28.16°	49.14°	B01,B08,B13
SAN JUAN	31.50°	65.50°	B01
BUENOS AIRES	34.50°	58.50°	B01,B07
CONCEPCION	36.60°	73.00°	B01
PORT STANLEY	51.70°	57.80°	B01
USHUAIA	54.80°	68.30°	B01,B08

TYPE OF IONOSPHERIC OBSERVATION CODE (FROM WDC-A codes)

B01 Ionosphere Vertical Soundings
B03 Incoherent Scatter Soundings
B06 Total Electron Content - Satellite Beacons
B07 Absorption - Method A-1 (pulse echo)
B08 Absorption - Method A-2 (riometers)
B11 Ionospheric Scintillations from Beacon Satellites
B13 Whistlers and VLF emissions.

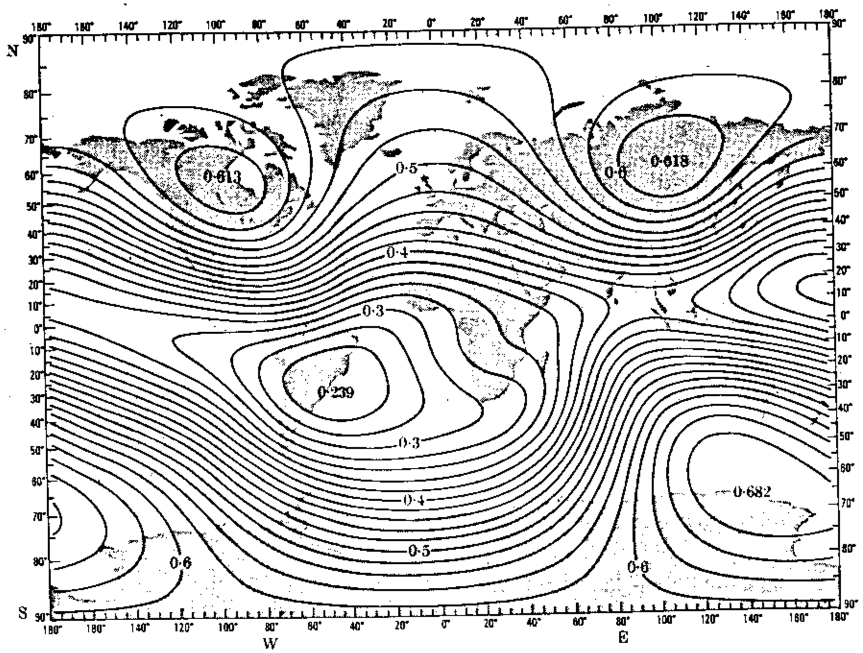
N
S
W
E
0·613
0·618
0·5
0·6
0·4
0·3
0·239
0·3
0·4
0·5
0·6
0·682
0·6

Fig. 1.1

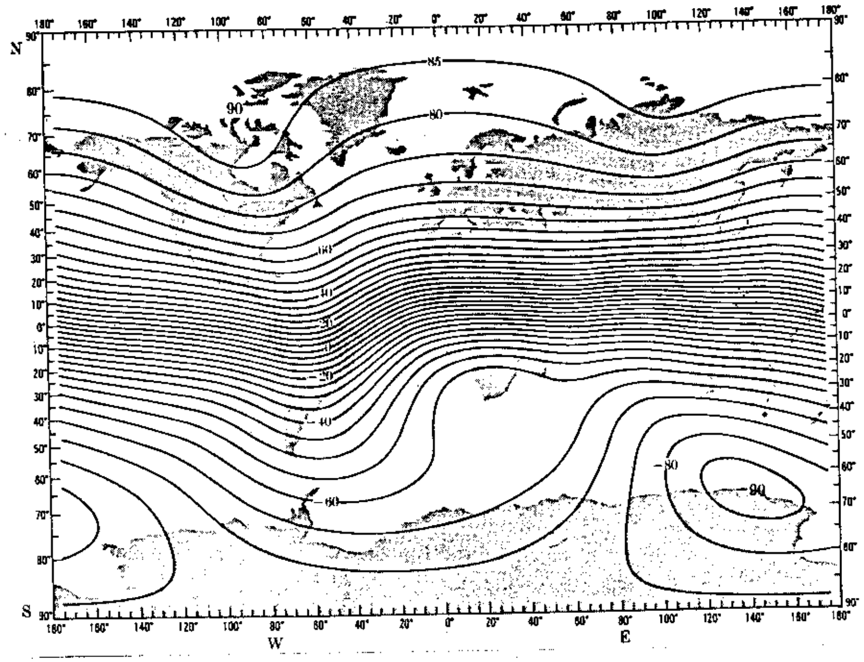
N
S
W
E
85
80
90
60
40
80
90
60

Fig. 1.2

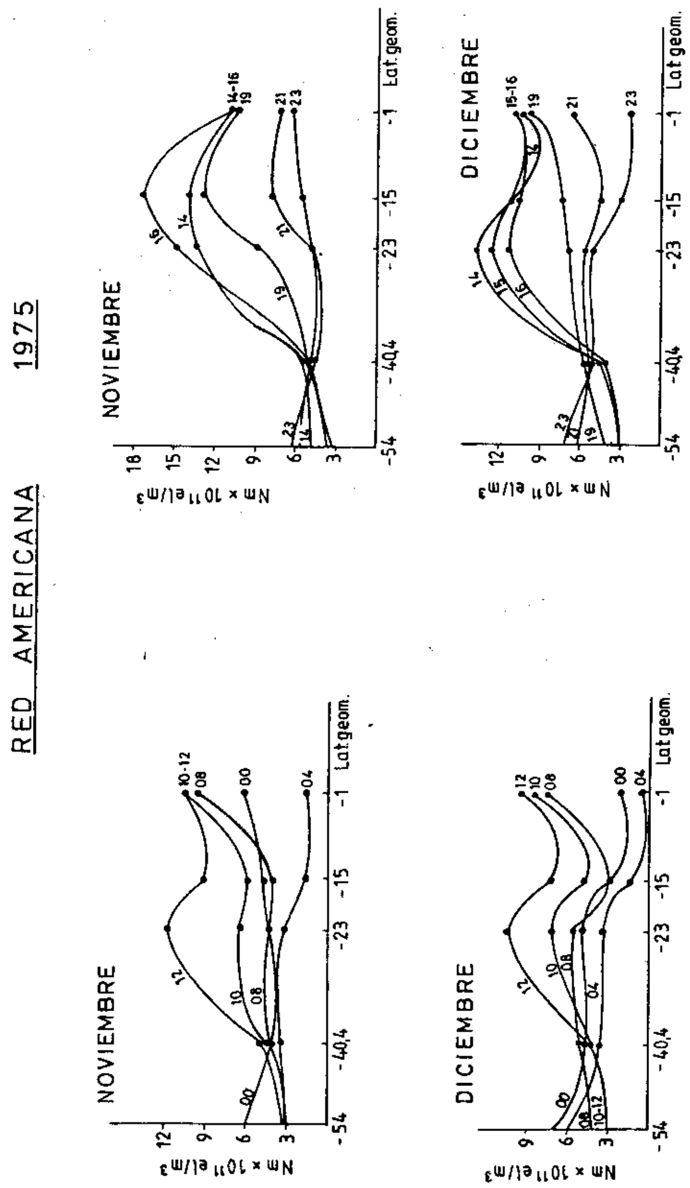
RED AMERICANA 1975
NOVIEMBRE
DICIEMBRE
Nm × 10¹¹ el/m³
Lat geom.

Fig. 1.3

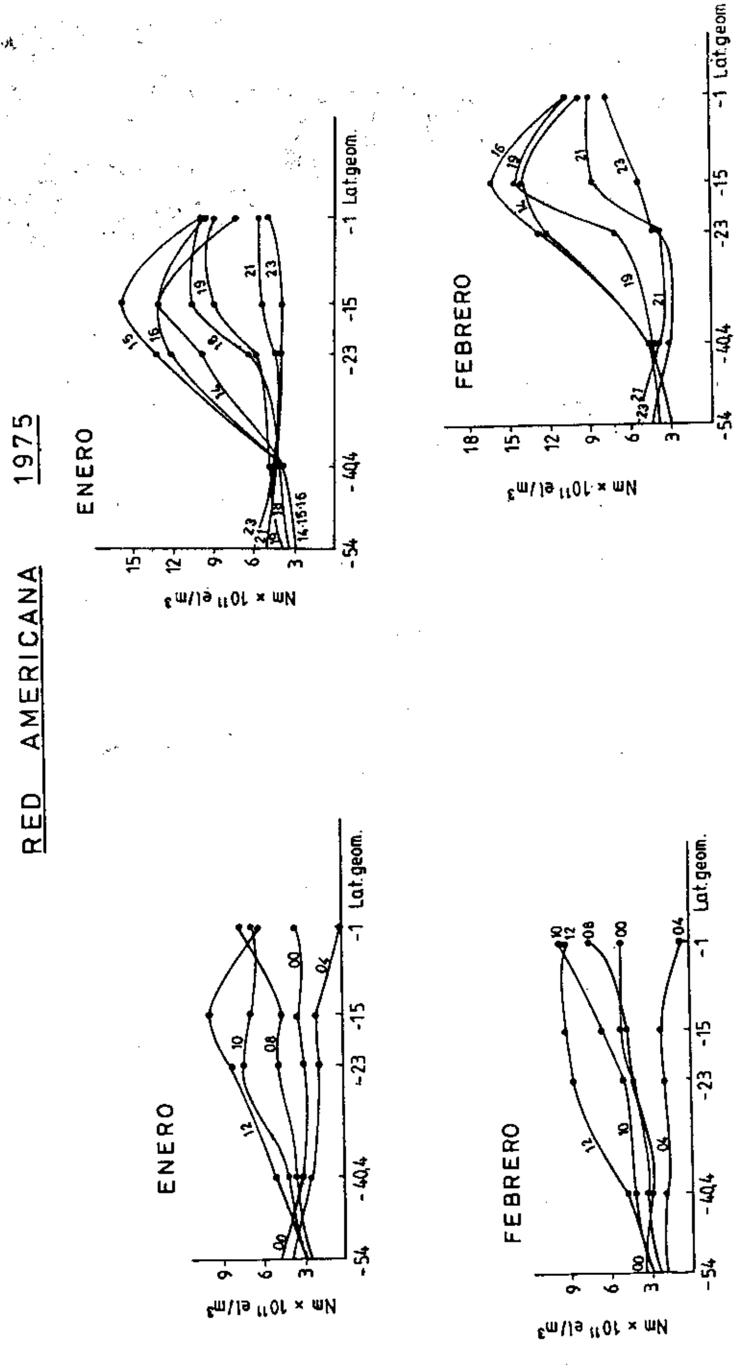
RED AMERICANA 1975
ENERO
FEBRERO
Nm × 10¹¹ el/m³
Lat geom.

Fig. 1.4

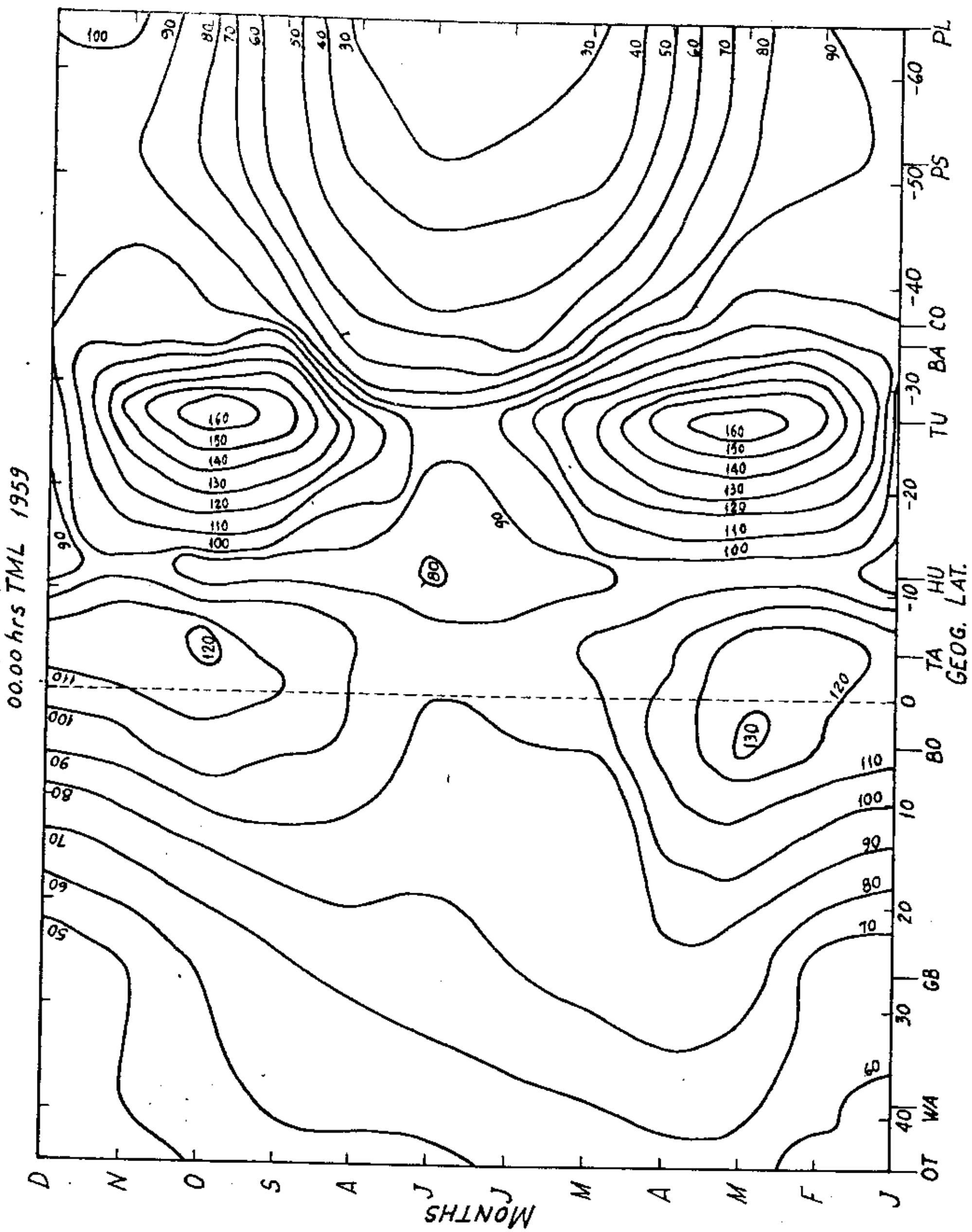
foF2 (med.)
00.00 hrs TML 1959
MONTHS
GEOG. LAT.
D N O S A J J M A M F J
PL PS CO BA TU HU TA GB WA OT

Fig. 1.5

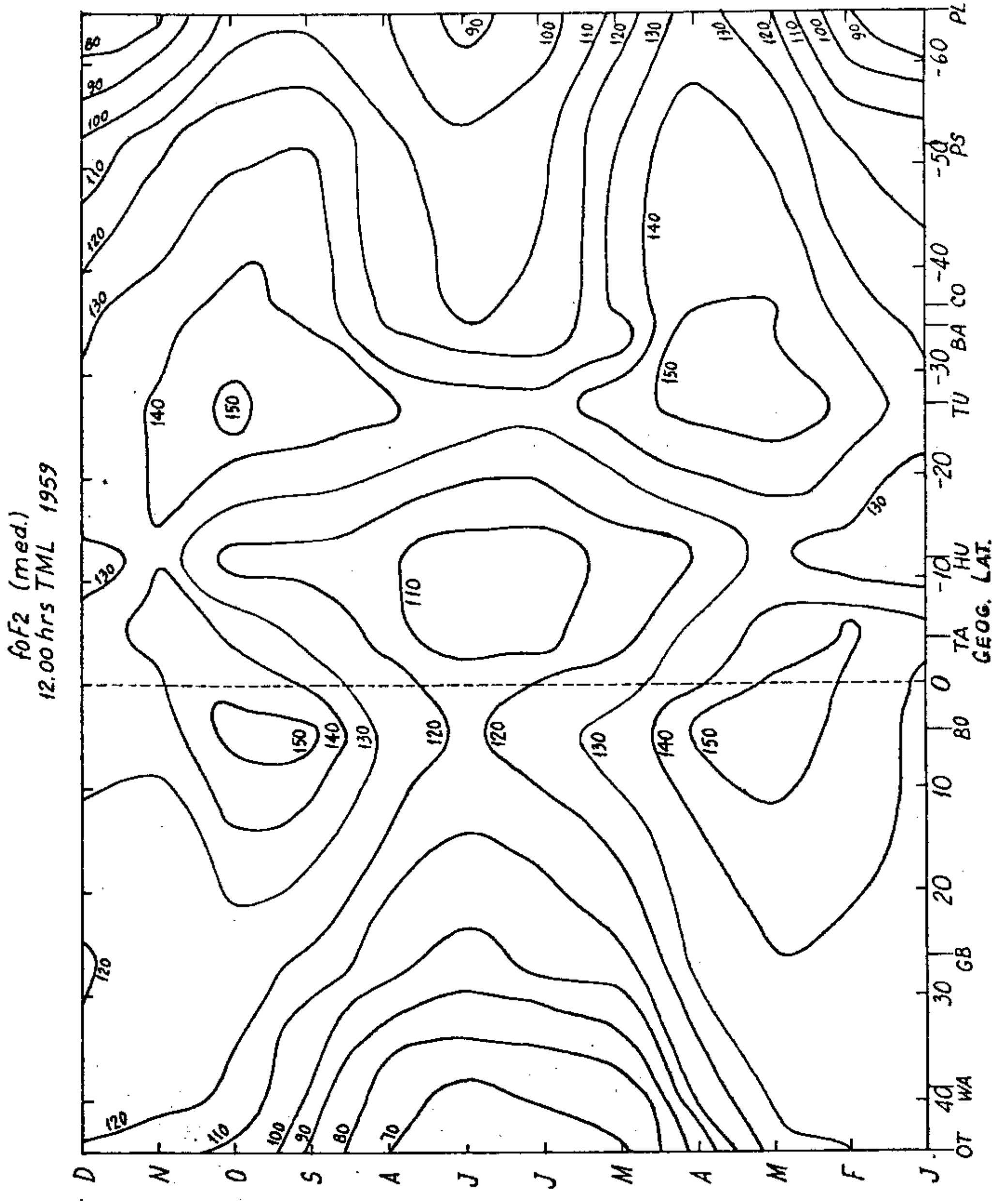
foF2 (med.)
12.00 hrs TML 1959
GEOG. LAT.
D N O S A J J M A M F J
PL PS CO BA TU HU TA GB WA OT

Fig. 1.6

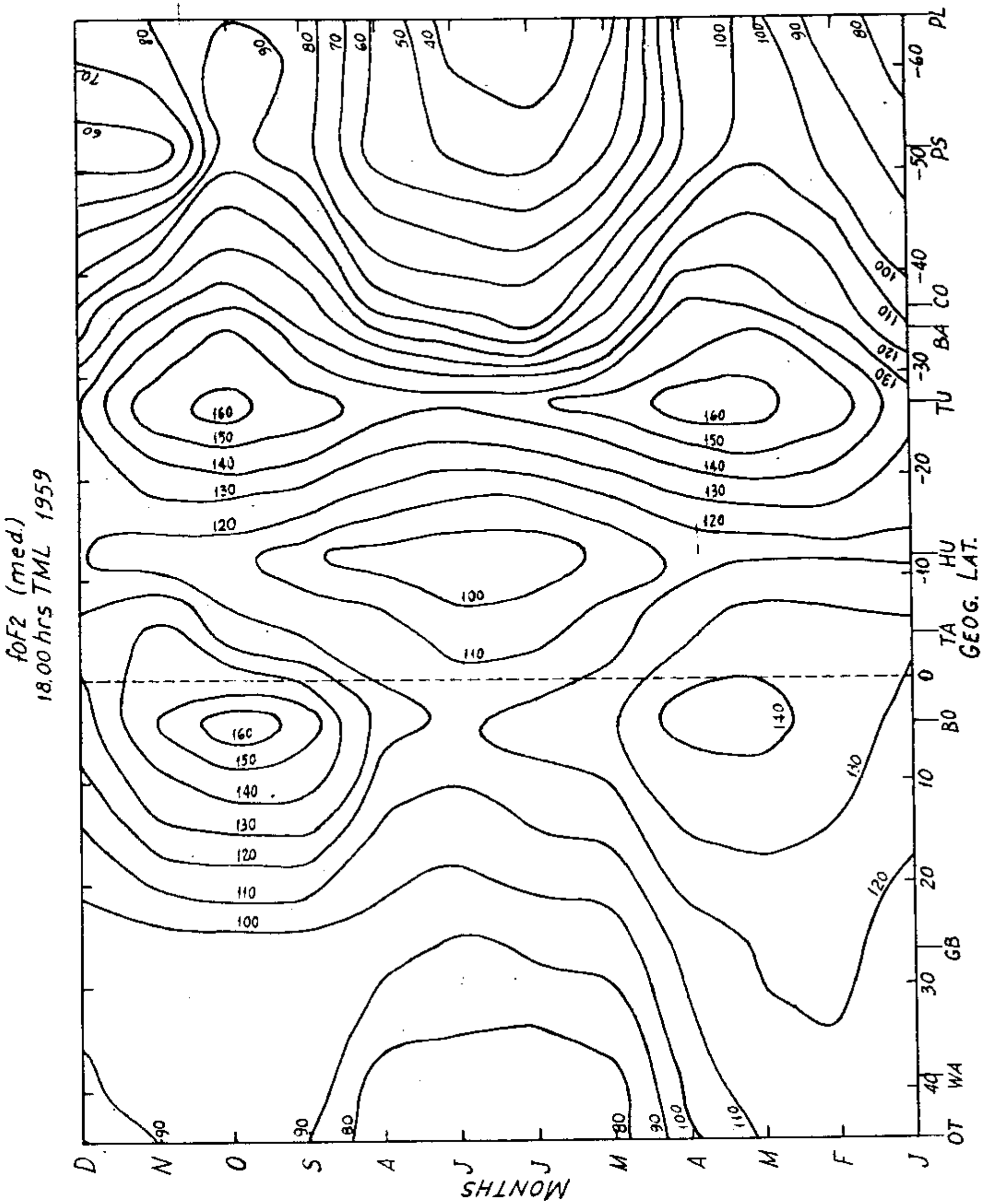
foF2 (med.)
18.00 hrs TML 1959
MONTHS
GEOG. LAT.
D N O S A J J M A M F J
PL PS CO BA TU HU TA BO GB WA OT

Fig. 1.7

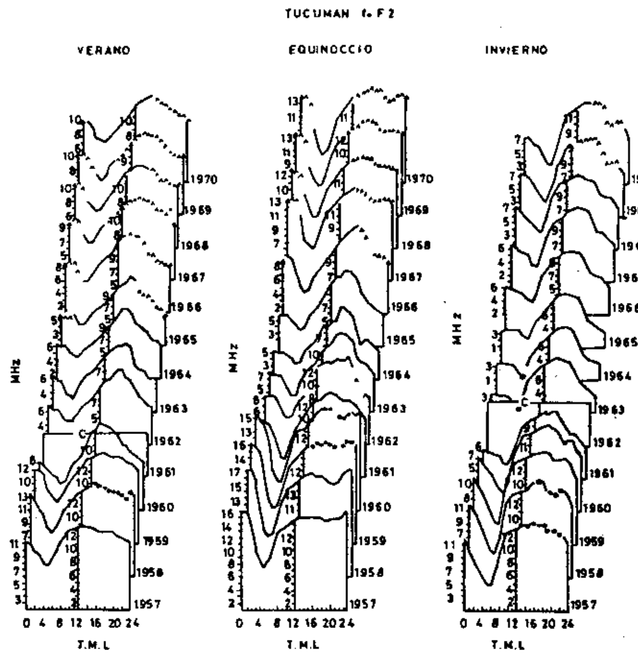
TUCUMAN f0F2
VERANO
EQUINOCCIO
INVIERNO
MHz
T.M.L

Fig. 1.8

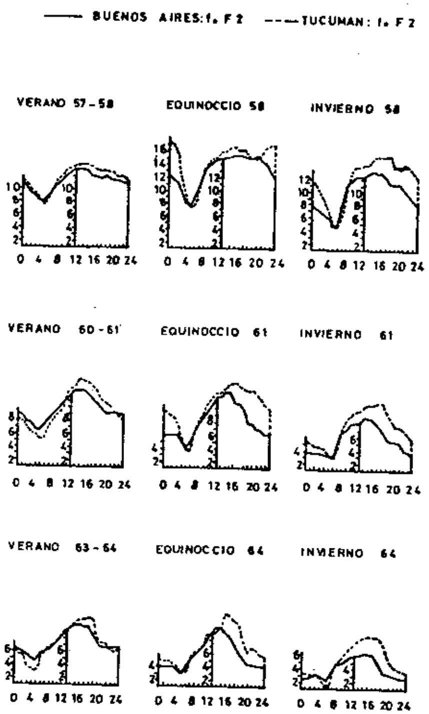

Fig. 1.9

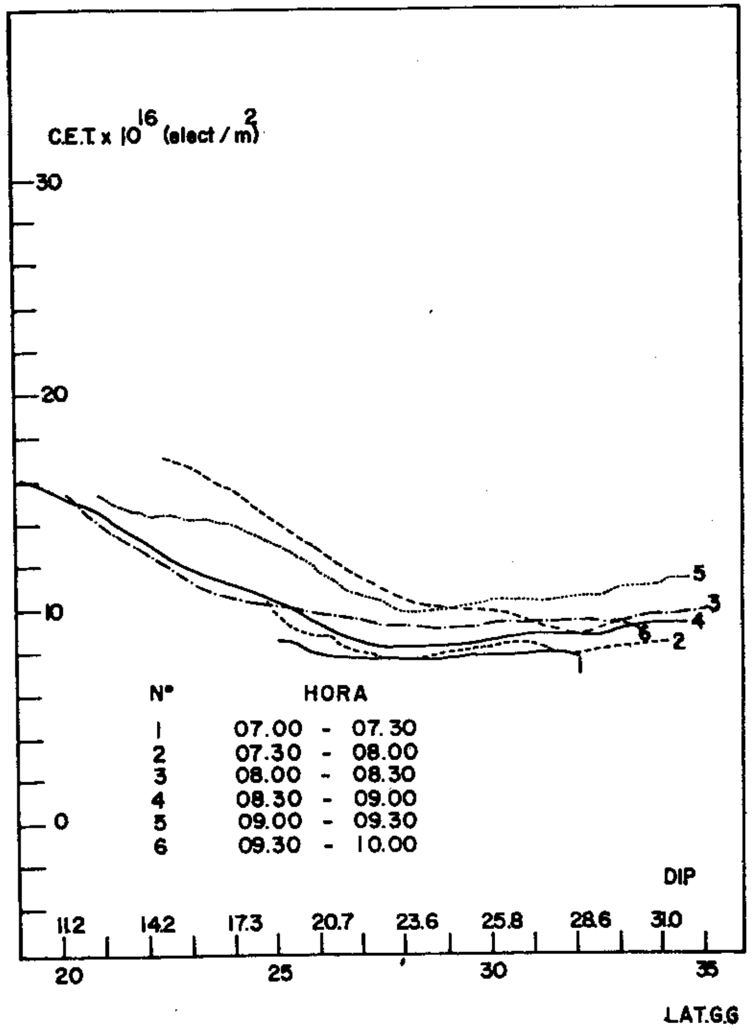

Fig. 1.10

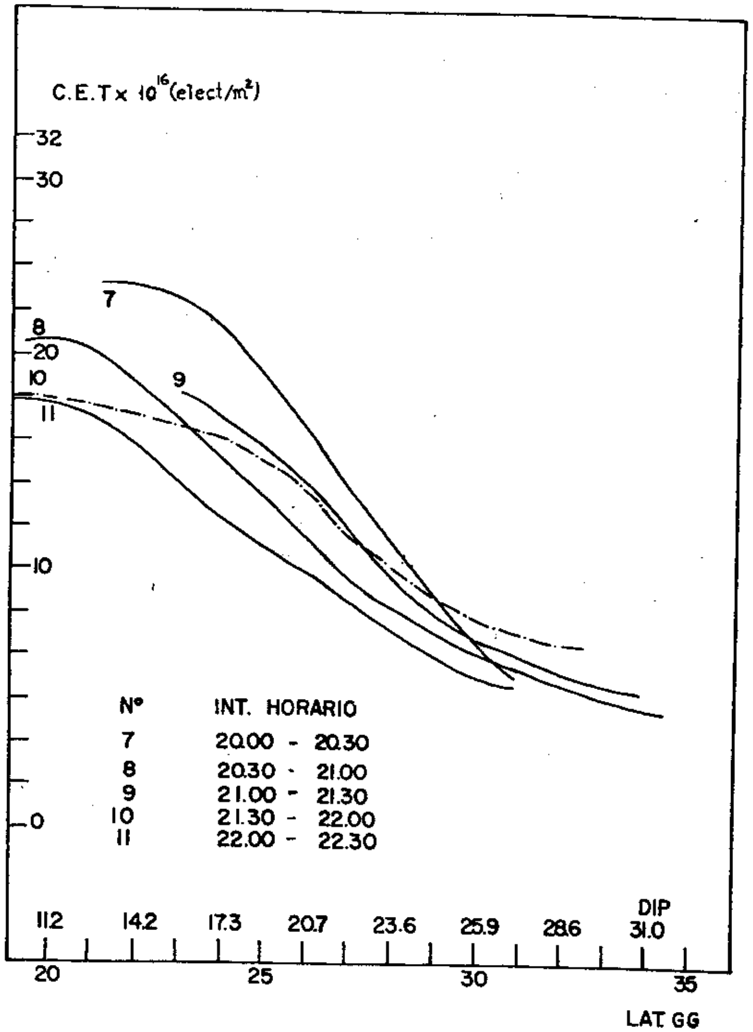

Fig. 1.11

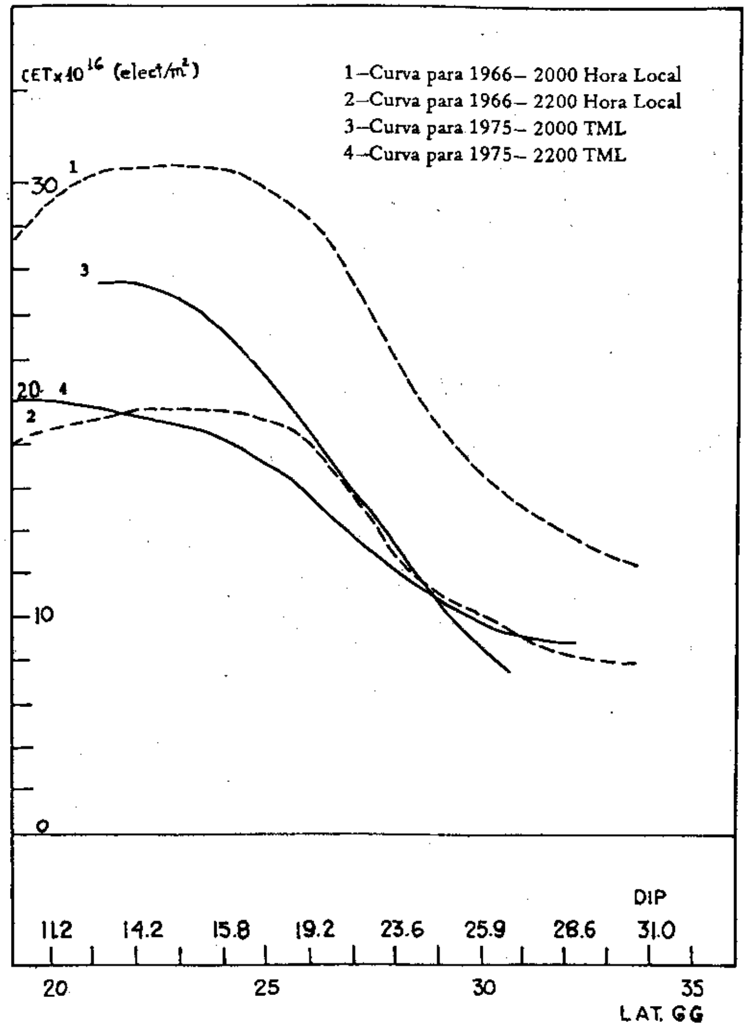

Fig. 1.12

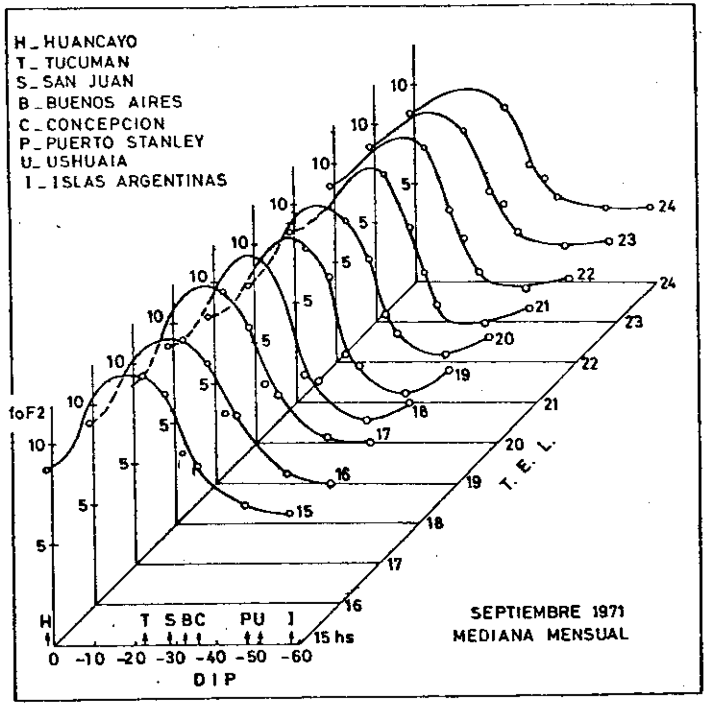

Fig. 1.13

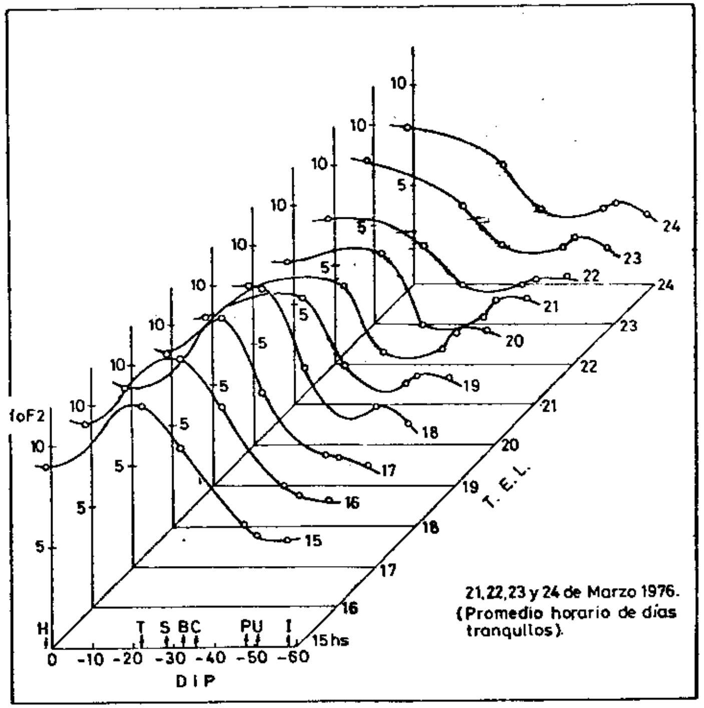

Fig. 1.14

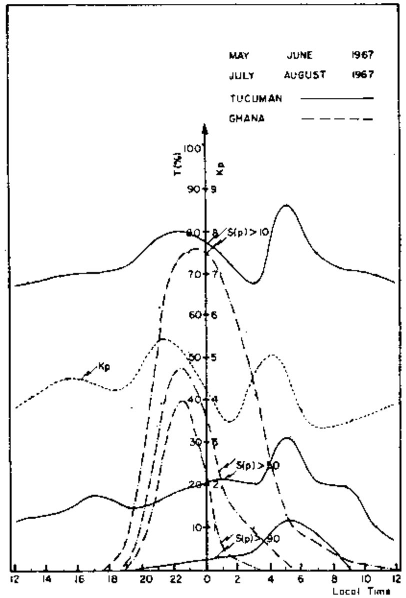

Fig. 1.15

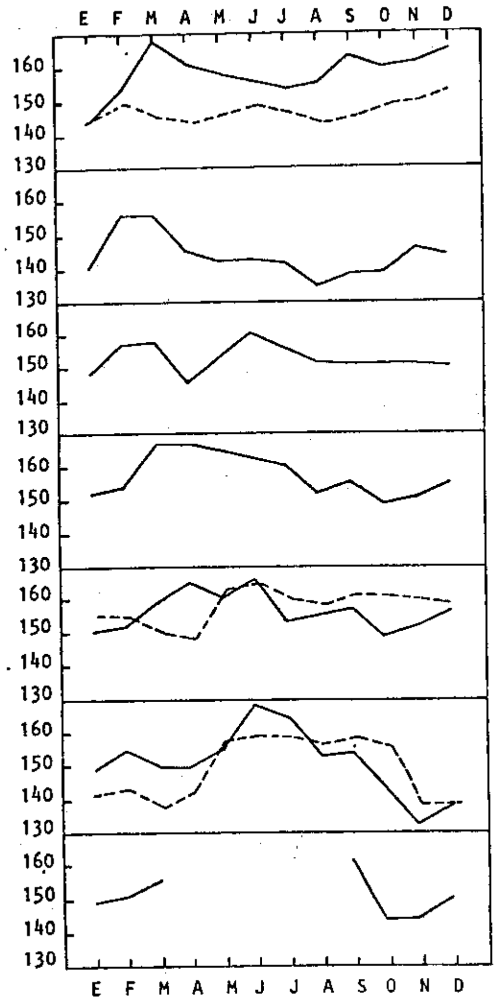

Fig. 1.16

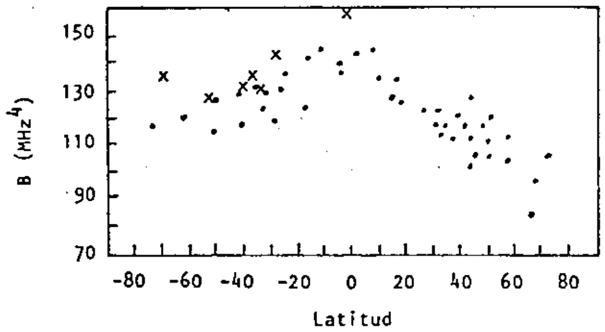

Fig. 1.17

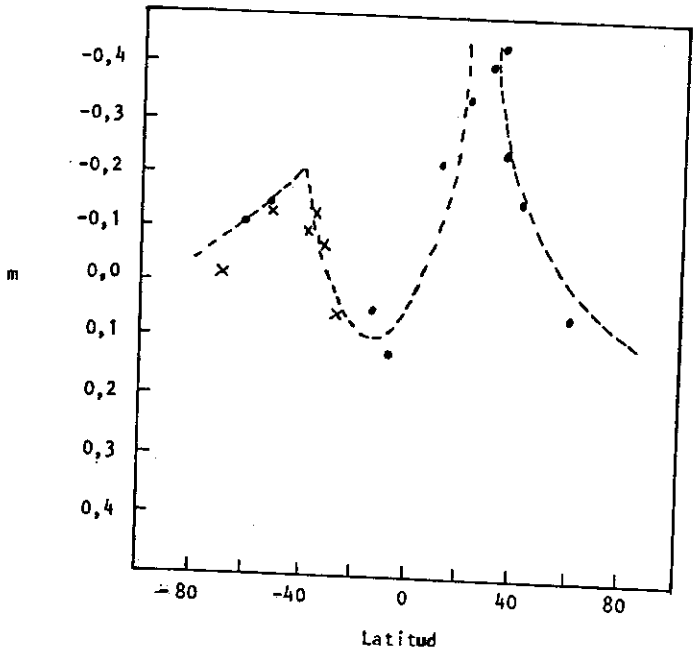

Fig. 1.18

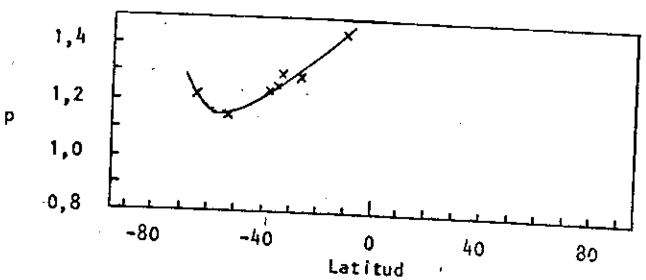

Fig. 1.19

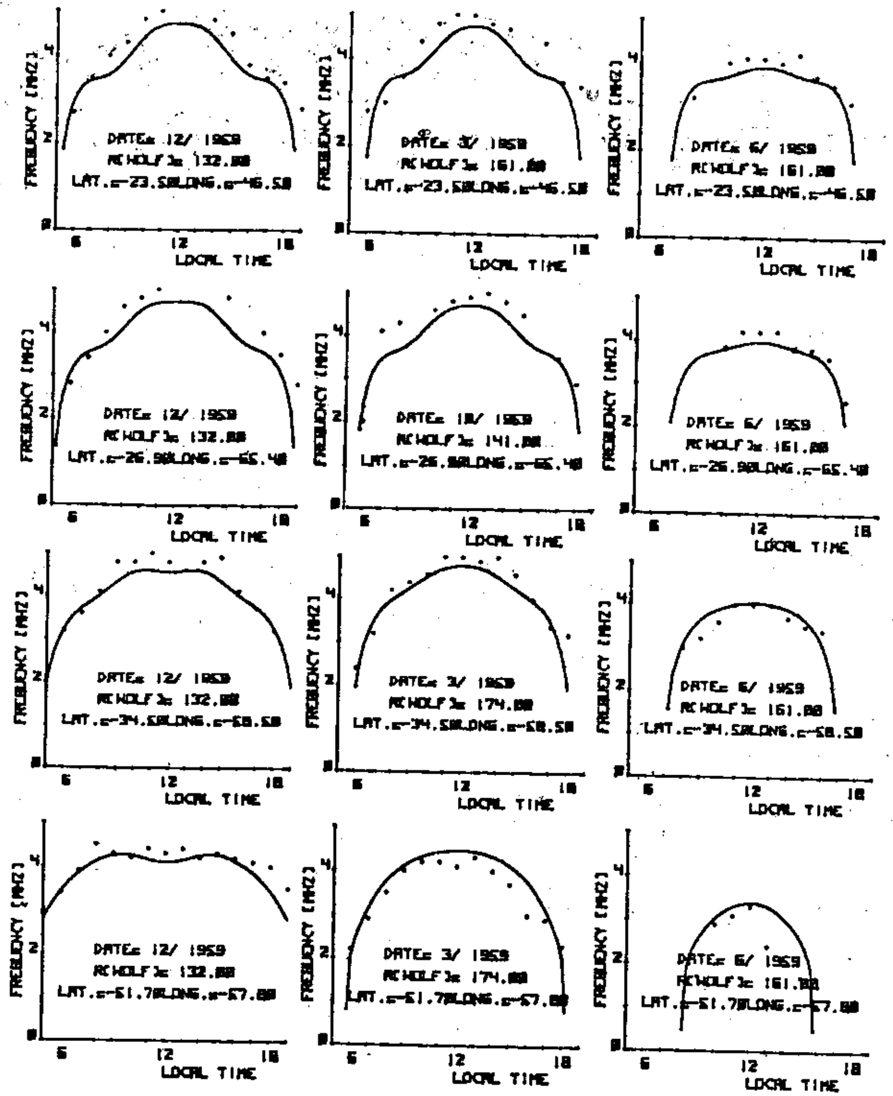

Fig. 1.20

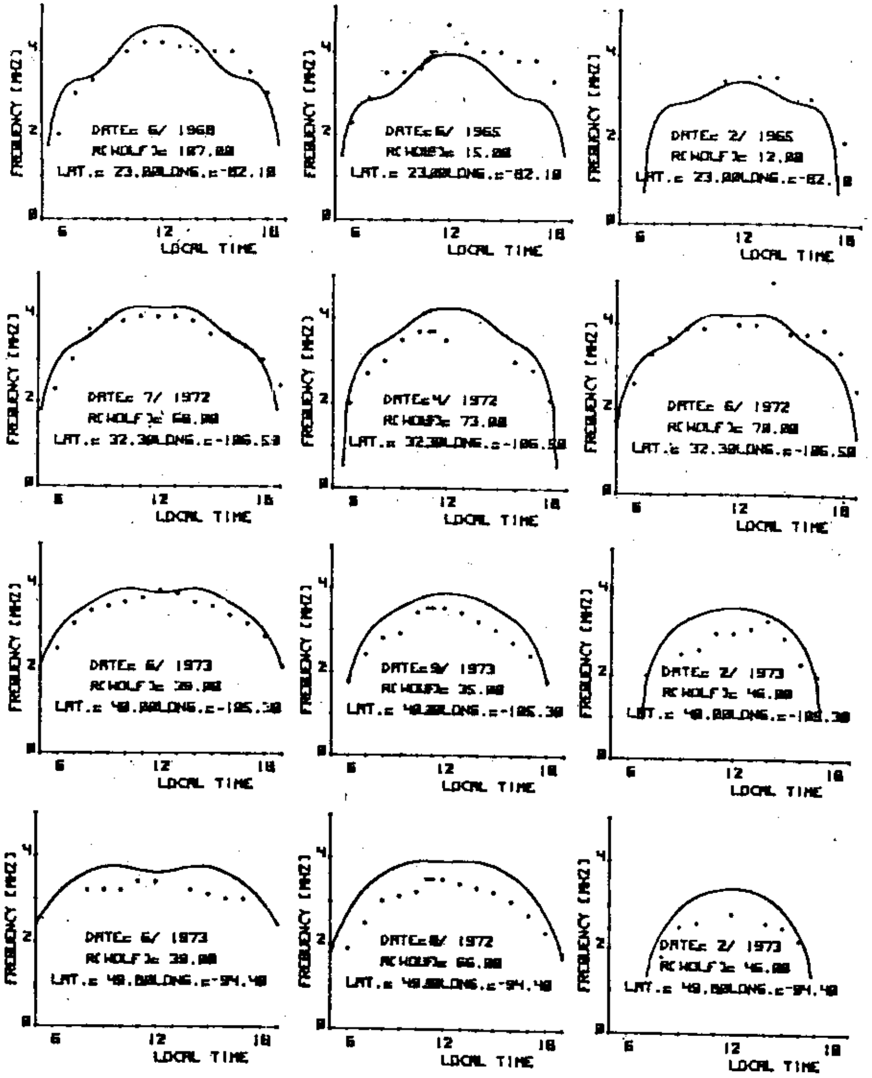

Fig. 1.21

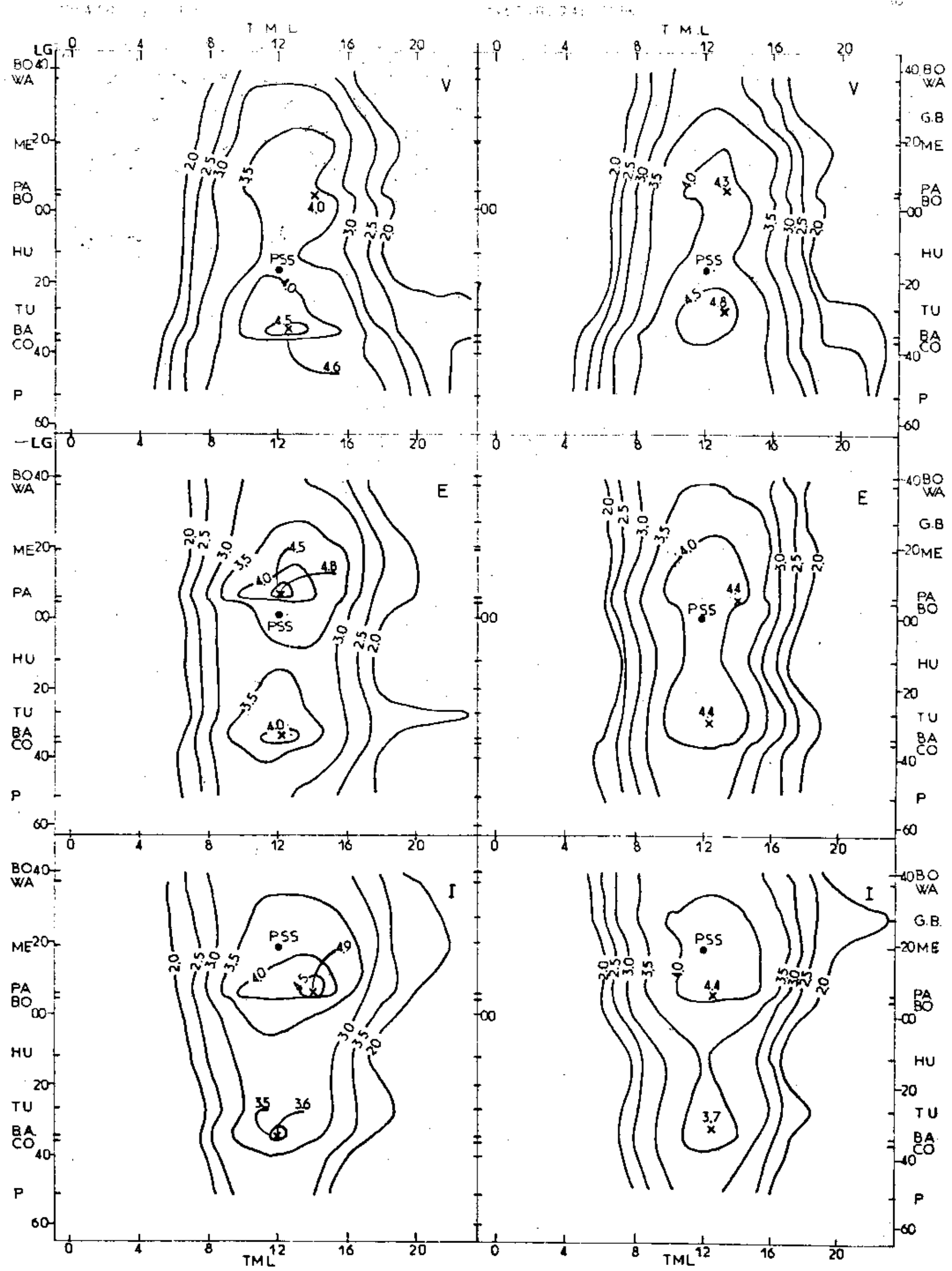

Fig. 1.22

VARIACION ESTACIONARIA DE LA ALTURA DE REFLEXION

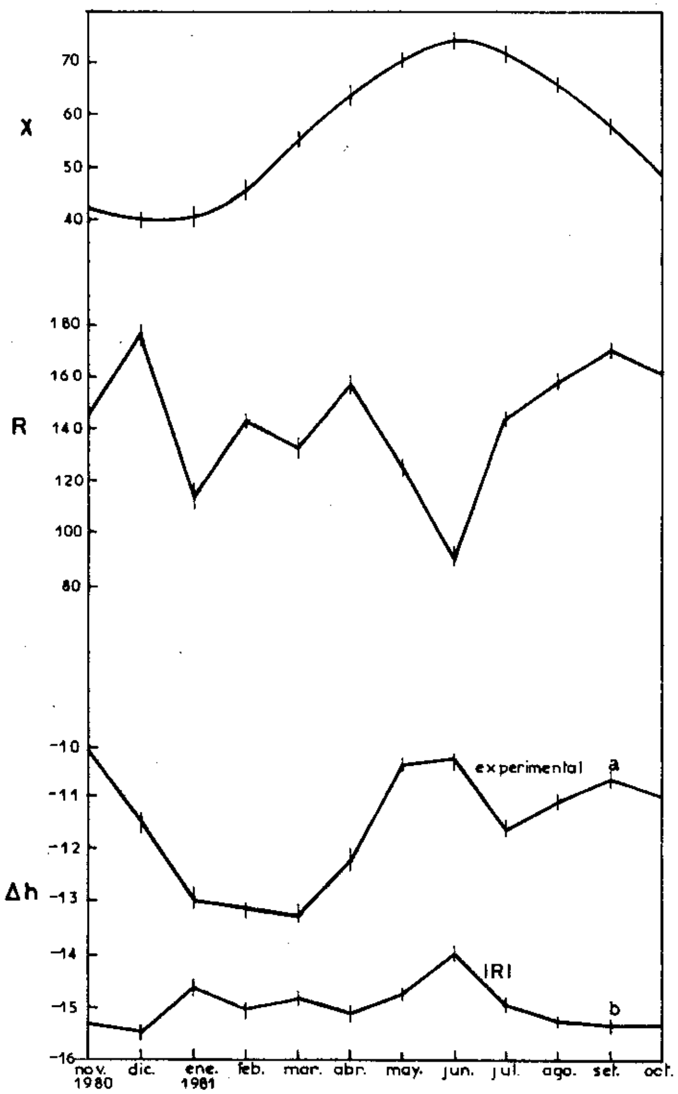

Fig. 1.23

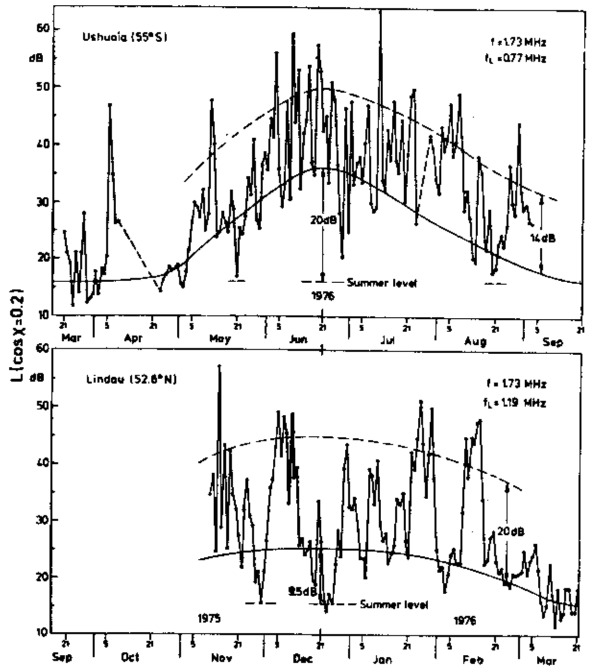

Fig. 1.24

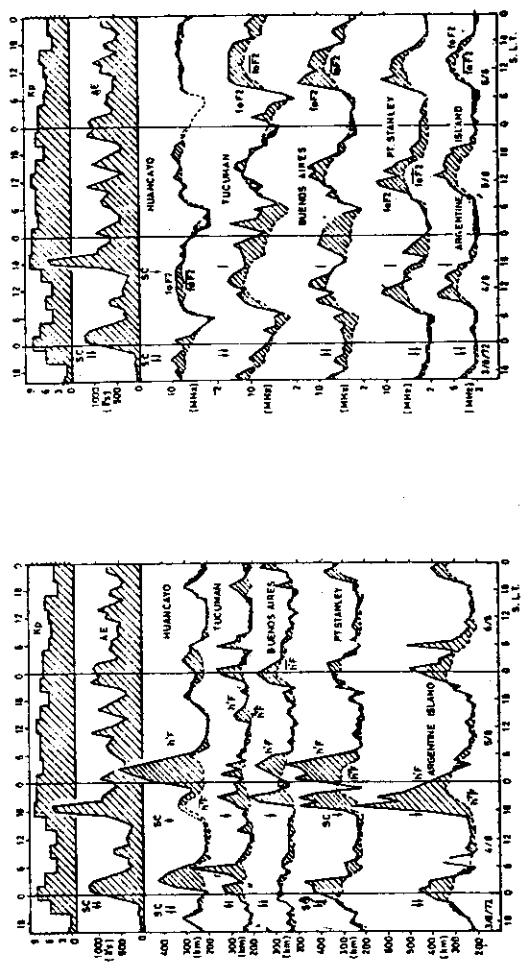

Fig. 1.25

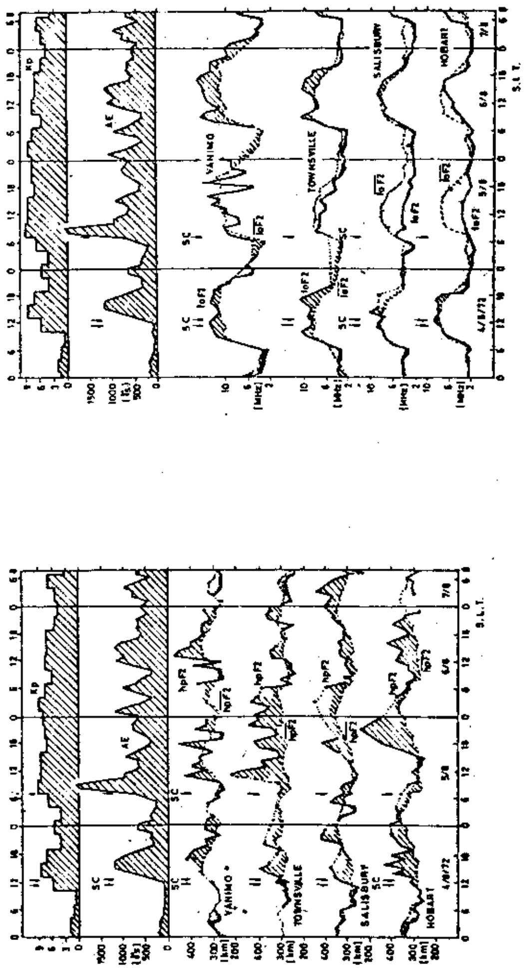

Fig. 1.26

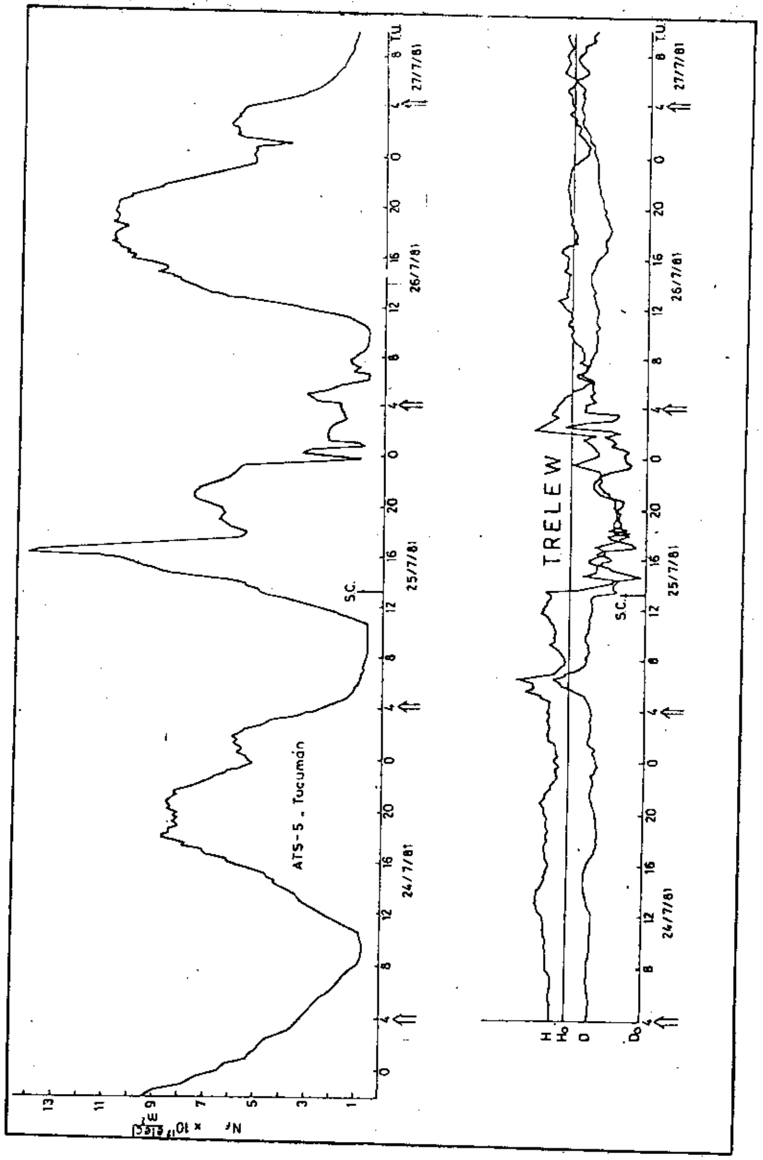

Fig. 1.27

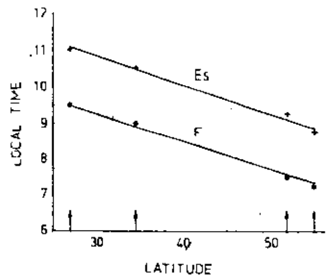

Fig. 1.28

Storm after-effects observed at Ushuaia and Kerguelen

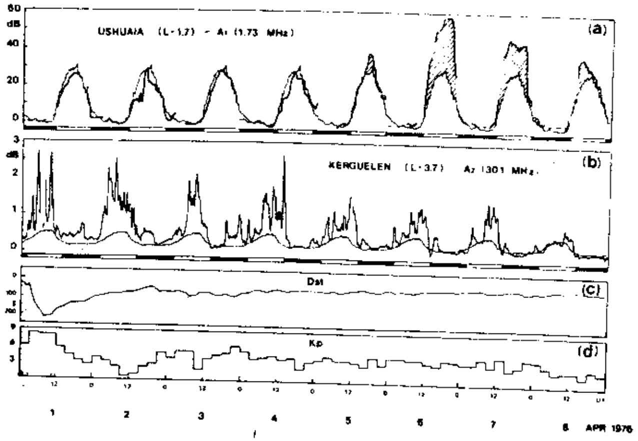

Fig. 1.29

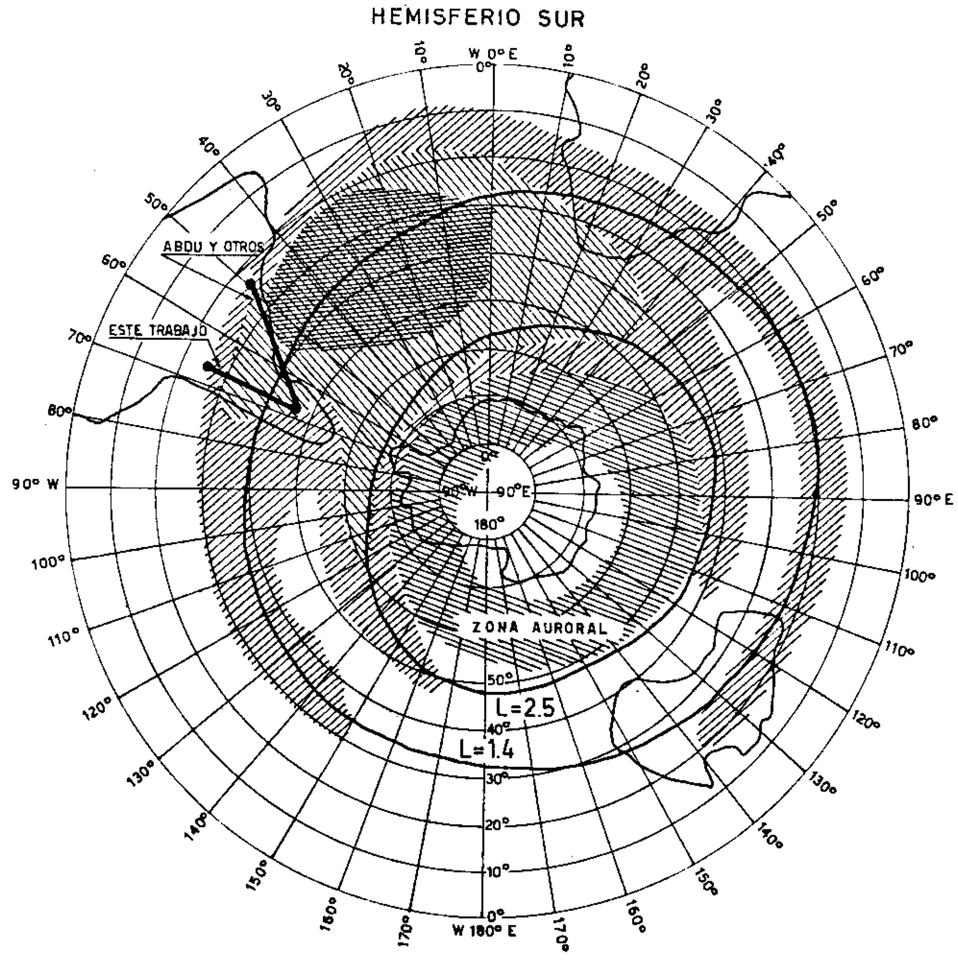

Fig. 1.30

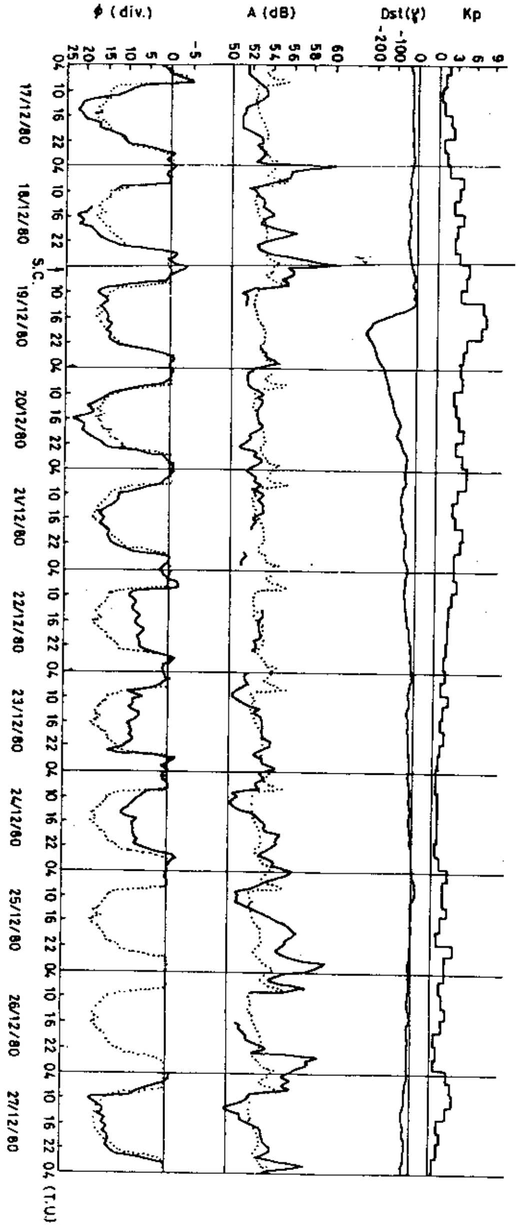

Fig. 1.31