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THE BRAZILIAN EFFORTS ON THE INVESTIGATION OF IONOSPHERIC IRREGULARITY EFFECTS ON SIR-B IMAGE PROCESSING IN THE INFORMATION EXTRACTION

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Director General

14. Abstract/Notes

Use of satellite borne synthetic aperture radar (SAR) in the L-band frequencies have been developed in recent years to obtain high resolution images of the land and ocean surfaces useful in diversified application areas. In the interpretation of the SAR images an end-to-end system with a benign propagation medium is usually assumed. However, recent investigations have revealed that the SAR images undergo severe degradation caused by propagation effects due to the ionospheric irregularities present in the radar operation medium. A proposal on "An International Investigation of Ionospheric Irregularity Effects on SIR-B Image Processing and Information Extraction" by the Naval Research Laboratory (Washington, with the principal investigator being Dr. Edward P. Szuszczewicz of the Space Plasma Division of NRL) has recently been approved by the NASA. It has the objective to investigate and quantify the effects of equatorial and auroral ionospheric irregularities on SAR images through ionospheric experiments. The present report describes briefly the Brasilian participation, as a team member, in the equatorial ionospheric investigation part of the SIR-B mission.

15. Remarks

THE BRAZILIAN EFFORTS ON THE INVESTIGATION OF IONOSPHERIC IRREGULARITY EFFECTS ON SIR-B IMAGE PROCESSING IN THE INFORMATION EXTRACTION

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ABSTRACT

Use of satellite borne synthetic aperture radar (SAR) in the L-band frequencies have been developed in recent years to obtain high resolution images of the land and ocean surfaces useful in diversified application areas. In the interpretation of the SAR images an end-to-end system with a benign propagation medium is usually assumed. However, recent investigations have revealed that the SAR images undergo severe degradation caused by propagation effects due to the ionospheric irregularities present in the radar operation medium. A proposal on "An International Investigation of Ionospheric Irregularity Effects on SIR-B Image Processing and Information Extraction" by the Naval Research Laboratory (Washington, with the principal investigator being Dr. Edward P. Szuszczewicz of the Space Plasma Division of NRL) has recently been approved by the NASA. It has the objective to investigate and quantify the effects of equatorial and auroral ionospheric irregularities on SAR images through ionospheric experiments conducted by different research groups in USA, Brazil, India, England and Peru, in coordination with the orbital passes of the Shuttle Imaging Radar (SIR-B) on board the Space Shuttle scheduled to be launched in September 1984. INPE, representing Brazil, is one of the participating groups. Results from this investigation will be useful for interpreting the SAR images and eventually to develop techniques for compensating for the image degradation suffered in the ionospheric medium.

The present report describes briefly the Brasilian participation, as a team member, in the equatorial ionospheric investigation part of the SIR-B mission.

THE BRAZILIAN EFFORTS ON THE INVESTIGATION OF IONOSPHERIC IRREGULARITY EFFECTS ON SIR-B IMAGE PROCESSING IN THE INFORMATION EXTRACTION

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1. INTRODUCTION

The Brazilian ionospheric observational efforts in support of the SIR-B mission will consist of operating the existing ground based network of instruments on specially programmed schedules. These instruments are ionosondes, VHF electronic polarimeters, meridional and east-west scanning airglow photometers and an L-band scintillation receiver. The locations of these instruments cover a wide geographic region; from the equator down to ~ 28^{o}S in latitude and from ~ 36^{o}W to ~ 56^{o}W in longitude. A detailed discussion of their locations, programed special operation schedule, preparation of the observational data set in formats appropriate for use in SIR-B image analysis, etc., will be given in the course of this report.

A good understanding of the equatorial ionosphere irregularity characteristics, such as their local time and seasonal occurrence pattern, latitudinal/flux tube extension features, spatial spectral distributions, TEC depletions caused by plasma bubble), and the irregularity patch sizes, velocities and height distribution is necessary for any reasonable assessment on the irregularity structures likely to affect SIR-B imaging. Therefore, beginning with a description of the ground based network of ionospheric instruments used for the SIR-B mission, we will proceed with a brief and rapid review on these (or many of these) different aspects of the spread F irregularities, based on accumulated data from the different ground based instruments being operated in the equatorial-low latitude locations in Brazil.

In the course of this review we will point out also relevant conditions of the ambient ionosphere and those of the irregularity structures that are likely to affect SIR-B imaging. Specific plans of data collection on the different ground based instruments will then be mentioned to be followed by a brief discussion on some proposed formats for the data presentation.

2. GROUND BASED ARRAY OF IONOSPHERIC INSTRUMENTS IN BRAZIL TO BE OPERATED IN SIR-B MISSION

The instruments locations are marked in Figure 1 and their details are given below:

Cachoeira Paulista (22^{o}S, 45^{o}W, dip-26^{o}):	one ionosonde, one VHF electronic polarimeter (136MHz), two east-west and meridional scanning 6300 Å airglow photometers.
São José dos Campos (23^{o}S, 46^{o}W, dip-26^{o}):	one VHF electronic polarimeter (136MHz), one L-band (1.541GHz) scintillation receiver.
Fortaleza (4^{o}S, 38^{o}W, dip-3.6^{o}):	one ionosonde.
Brasília (16^{o}S, 48^{o}W, dip $\sim -10^{o}$):	one ionosonde.
Belém (1.5^{o}S, 48^{o}W, dip 12^{o}):	one ionosonde.
Blumenau (28^{o}S, 49^{o}W, dip -29^{o}):	one ionosonde.

Natal
(6^oS, 33^oW, dip -10^o): one VHF electronic polarimeter (136MHz) and one VHF (254MHz) scintillation receiver.

3 - A BRIEF REVIEW OF SPREAD F IRREGULARITY OCCURRENCE CHARACTERISTICS IN BRAZIL

3.1 - LOCAL TIME, SEASONAL AND SOLAR CYCLE VARIATIONS IN SPREAD F AND F-LAYER HEIGHTS

Range spreading F-layer traces in nighttime equatorial ionograms are known to indicate presence of ionospheric irregularities in wide range of scale sizes, from meter sizes that produce VHF back scatter to amplitude scintillation producing hundreds of meter-to kilometer sizes, extending upward from the base of the F-layer. Thay occur in the post sunset hours, have generally higher intensities till around midnight and often continues till sunrise. Very often they occur in association with much larger scale (tens to hundreds of kilometer size) plasma bubbles that develop in vertically rising flux tube aligned structures above the magnetic equator. Thus, the occurrences of range spread F over locations very near and on the magnetic equator may not always indicate plasma bubble developments, whereas the presence of range spread F over locations away from equator (low latitude locations) should positively suggest development of associated plasma bubble over the equator. (Further discussion on this point using relevant observational data will be given at a later stage). These points should be born in mind while comparing the spread F irregularity data for the equatorial and low latitude locations to be presented below.

Figure 2a presents a local time versus seasonal occurrence statistics plotted in contours of iso-occurrence rates, of spread F (range spread F) over Fortaleza for 1978-79 period. Similar results for 257MHz VHF amplitude scintillation over Natal is presented in Figure 2(b) for the same period. Local time and seasonal characteristics in the occurrences of VHF scintillation and spread F are very similar. Figure

2(c) presents the spread F occurrence statistics for the low latitude location Cachoeira Paulista, in which the seasonal activity maximum of spread F is seen confined to the December-January period whereas over the equator (Figures 2(a) and (b)) the seasonal activity maximum extended into the equinoctial months as well. Also, the local time of maximum irregularity occurrences is centered around 2200LT over Cachoeira Paulista whereas over the equatorial locations it extends from ~1900LT up to ~2300LT.

Results of spread F and amplitude scintillation occurrence characteristics similar to those in the Figure 2(a), (b) and (c) are presented for the epoch 1980-81 (near the peak of the present solar cycle) in Figures 3(a), (b) and (c). The basic difference between the two sets of results is that the spread F irregularity occurrence rates showed a general rise in the later years, during the regular spread F seasons, and especially during 21-23LT.

A more direct comparison of the irregularity occurrence rates with changes in sunspot number is presented in Figure 4 for the month of October during the years from 1973-75 up to 1982 for our equatorial and low latitude locations. The main conclusions from this figure are that the spread F irregularity occurrence rates over Fortaleza could be somewhat independent of the sunspot number (being almost hundred percent occurrence rate during pre-midnight hours) in certain months (in the present case, October), and that over Cachoeira Paulista the irregularity occurrence rate could present increase with increasing sunspot number in the early hours of the night (20-21LT), whereas in the post-midnight hours this correlation could be negative. Based on this figure one could expect the following scenario of irregularity occurrence rate for the SIR-B mission period, namely, Aug-Sept 1984: The spread F irregularity structures are likely to continue to occur at the same rate over Fortaleza for nearly all the local times, whereas Cachoeira Paulista is likely to register less number of events in the early post sunset period, with perhaps a relatively increased rate in the post-midnight hours.

The height range, especially the lower limit, of the F-region irregularity occurrence should be an important point of consideration in the SIR-B mission. The base of the F-layer on nights of irregularity occurrence is somewhat higher than on the nights of non-occurrences as has been widely documented in the literature. Some typical results of such height differences presented in Figure 5(a) clearly demonstrate this effect in the pre-midnight hours for Fortaleza and Cachoeira Paulista. Figures 5(b) and (c) shows the nocturnal F-layer height variations, marked with spread F occurrences, for August and September 1982, respectively. Contour maps of virtual heights as functions of local time and season representing nights of spread F occurrences over Fortaleza and Cachoeira Paulista are presented in Figures 6(a) and (b) respectively, for the period 1980-81. (For the Aug-Sept 1984 epoch these heights are expected to be somewhat less, approximately by 50km in the pre-midnights hours).

Considering the fact that the irregularities detected in ionograms are distributed down to the F-layer base (and that the true height is ~20km less than the virtual height plotted in these figures) it can be seen that in the planned higher orbit (340km) phase of the SIR-B mission the irregularity structures from equatorial to low latitude regions are likely to affect the SIR-B imagery, whereas in the remaining lower orbit mission the irregularity structures over low latitude F-region ionosphere might continue to be an important source of interference for the SIR-B imagery. Possible effects from E-region irregularities would, of course, continue to be equally likely in both phases of the SIR-B mission.

3.2. - FLUX TUBE/LATITUDINAL EXTENSION OF SPREAD F IRREGULARITY PATCHES

Figure 7 presents a statistics of correlated occurrences of range spread F over Fortaleza and Cachoeira Paulista. It is clear from this figure that spread F could occur over the equator without its concurrent occurrences over low latitude, and that no event occurs over low latitude without a corresponding event over the equator. This shows that irregularity generation does not take place over low latitude locations independent of the conditions over the equator.

The relationship between durations of spread F events over the equator and over the low latitude plotted in Figure 8 shows that irregularities occur over low latitude only if a corresponding event over the equator has duration of 4-5 hours or more and the duration such events are linearly related at the two locations. These facts fit in well with the picture of irregularity generation over the equator in flux tube aligned structures that rise up over the equator extending the irregularities into the low latitude ionosphere. Thus it seems that for all those events in which the plasma bubble and associated irregularity structures rise up over the equator the equatorial ionogram should register spread F events for at least up to 4-5 hours.

3.3 - SCANNING AIRGLOW PHOTOMETER DIAGNOSTICS OF PLASMA BUBBLE DYNAMICS

The low latitude footprints of the vertical rise and eastward drift of the flux tube aligned plasma depletions have been studied using airglow scanning photometers over Cachoeira Paulista. Figure 9 presents a set of meridional airglow intensity profiles taken during some plasma bubble events. Southward (poleward) propagation of airglow depletion valleys usually characterizes the plasma bubble events in their development phases. Towards the end of the development phase eastward plasma bubble drift can be clearly measured using east-west scanning photometers as Figure 10 illustrates. In this figure the airglow valley meridional propagation is not clearly defined probably because these measurements represent the end of a plasma bubble development phase.

3.4 - PLASMA BUBBLE STRUCTURES (FROM TEC MEASUREMENTS) AND VHF AND L-BAND SCINTILLATION IRREGULARITIES

Equatorial ionospheric plasma bubble dynamics (as it manifests in rapid TEC fluctuations), and the dynamics of the scintillation producing irregularity structures have been monitored using VHF electronic polarimeters receiving geostationary satellite beacon at São José dos Campos and Cachoeira Paulista. Signatures in polarimeter record of TEC, and amplitude scintillation,produced by two isolated early evening plasma bubble events are presented in Figure 11. The depletions in TEC in these cases reached ~ 6-10 percent of the diurnal range in TEC, and the scintillation has a magnitude of > 7db. Examples of polarimeter records on nights of long lasting plasma bubble events are presented in Figures 12(a) and (b).On many nights severe fast fluctuations in Faraday rotation angle such as in these figures take place, rendering the TEC information irretrievable from the polarimeter records. Simultaneous VHF (136MHz) and L-band (1.541GHz) amplitude scintillations are also presented in these figures. It should be noted that the two scintillation records refer to different subionospheric regions (corresponding to GOES and MARISAT) with respect to São José dos Campos. The scintillation amplitudes at L-band are of the order of 20-30db while the VHF presents somewhat smaller scintillation amplitudes.

A statistics of the occurrences of such Faraday (fast) fluctuations and occurrences of range spread F in ionograms over Cachoeira Paulista, presented in Figure 13, clearly demonstrate the strong correlation between the occurrences of the two phenomena. Some cases of independent occurrences of events seen in this figure are obviously due to the spatial limits in horizontal and vertical directions of the irregularity structures sensed by the two different techniques.

Simultaneous receptions by two east-west spaced polarimeters (at Cachoeira Paulista and São José dos Campos) of a given geostationary satellite VHF beacon have enabled us to determine the zonal velocity component of the plasma bubble structures and scintillation producing irregularity patches. Figure 14 that presents tracings of a typical plasma bubble event, causing TEC oscillations on polarimeter recordings of VHF beacon from SIRIO, shows well-defined correlation time differences in the occurrences of ΔTEC features over the two sites. Such time differences have been used to determine the zonal velocities of the plasma bubble with their associated spatial structures. An example of the local time variations in plasma bubble zonal velocities representing average summer conditions in 1981-82 is presented in Figure 15. Similar plasma bubble zonal velocity determinations have also been carried out using the east-west scan photometer measurements over Cachoeira Paulista (not shown here).

4. PLANNED OPERATIONAL SCHEDULE, FOR THE SIR-B MISSION, OF THE GROUND BASED INSTRUMENTS IN BRAZIL

As equatorial ground based part of the SIR-B program, special measurements of ionospheric parameters will be carried out during orbital passages over (or near) any one of the ground observational sites that was shown in the Figure 1. The specifics of these measurement are as follows:

- Ionosondes

At Cachoeira Paulista and Fortaleza vertical soundings will be carried out with a maximum resolution of up to one ionogram/ minute during the space shuttle passages.

The ionosondes at Brasília, Blumenau and Belém could provide ionograms at a maximum resolution of one ionogram/3 minutes.

Besides the above schedules for the space shuttle passages, more frequent soundings (than the regular quarter hourly and half hourly soundings) will be carried out during the general SIR-B mission window.

- Airglow photometers

Meridional and east-west scanning 6300 Å photometers will be operated in their routine mode which will permit detecting plasma bubble irregularities within ± 75^{0} from vertical in the two scanning planes. Airglow profiles in these planes are taken at a rate of one per 4 minutes.

- Polarimeters

Polarimeter recordings of TEC using 136MHz beacon from GOES-3 satellite received at São José dos Campos and Cachoeira Paulista will be carried out at the usual time resolution, namely at a recording paper chart speed of 6cm per hour.

Amplitude channels of the polarimeters will be recorded at increased time resolution (of the order of 60 times faster) for spectral analysis of the amplitude scintillation data.

- L-band satel-lite beacon

Amplitude recordings of the 1.541GHz MARISAT beacon will be carried out at normal resolution, and also at fast speed that would permit spectral analysis of the amplitude scintillation data.

5. DATA PRESENTATION FORMATS UNDER CONSIDERATION

Ionosonde Data: The relative degrees of range spreading in ionograms and the heights of the ambient F-layer base, as well as the critical frequencies and heights of the F-layer peak density, are important inputs for correlating with SIR-B imageries. We intend to present these data set in the format of Figure 16, for all the 5 ionosonde locations. Figure 16 presents range spread F index values (representative of the relative degree of irregularity strenght) as a function of the sounding frequency and local time. The virtual height of the F-layer base and that of 3MHz plasma frequency are also plotted versus local time in the same figure. (Attempts will be made to provide reduced true height curves instead of the virtual heights).

Data on sporadic E-layer characteristics will also be provided, giving informations on whether they are range spreading type or not, and values of their blanketing and top frequencies.

Scanning Photometer Results: Meridional and east-west airglow intensity profiles will be prepared in mosaic forms such as those presented in Figures 9 and 10.

Polarimeter, and L-Band Amplitude Scintillation, Data: Total electron content variations with local time will be prepared on all days of the SIR-B mission.

Short period (of the order of minutes) fluctuations in nighttime TEC records at the two polarimeters locations (during spread F events) that represent plasma bubble horizontal structure movements, (see the example in Figure 13), will be subjected to correlation analysis. The correlation times of these structures and those of scintillation patches at the two subionospheric locations will be used to determine the zonal (usually eastward) velocities of the plasma bubble and associated irregularity structures as function of local time.

Spectral analysis of the ΔTEC fluctuations will be undertaken to determine dominant horizontal scale sizes (10's of kilometers) in the plasma bubble structures.

Spectral determinations of the 1.541GHz and 136MHz amplitude scintillation producing irregularities will be undertaken and spatial scale sizes of these irregularities will be established using the velocities determined above.

ACKNOWLEDGEMENTS

Many of the figures presented in this report have not been published yet and some of them have been provided to us by our colleagues. The spread F distribution for 1978-79 period over Cachoeira Paulista was prepared by Inez S. Batista, and spread F and scintillation results for the period 1980-81 for Fortaleza, Natal and Cachoeira Paulista were provided by Osman Rosso Nelson. We express our thanks for their help.

We are greatful to Dr. Nelson J. Parada, Director of INPE, and Dr. Ivan J. Kantor, head of the Department of Geophysics and Aeronomy, for their help and encouragement.

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FIGURE CAPTIONS

Figure 1 - Geographic distribution of ionospheric instruments locations in Brazil for observations during the SIR-B mission. These locations are São José dos Campos, Cachoeira Paulista, Natal, Fortaleza, Belém, Brasília and Blumenau (see the text for details). Also shown in the figure are the iso-dip lines and magnetic meridional directions.

Figure 2 - (a) Range Spread F irregularity occurrence distribution over Fortaleza plotted in occurrence percentages as functions of local time and month for the year 1978-79.
(b) Amplitude scintillation occurrence percentages at 254MHz over Natal plotted as functions of local time and month for 1978-79. All scintillation events are included in this statistics.
(c) Range spread F irregularity distribution over Cachoeira Paulista plotted in occurrence percentages as function of local time and month for 1978-79. On the right hand side of the figure is plotted the evening vertical rise velocity peak (namely, the prereversal peak) of the F-layer over Fortaleza as monthly averages for the same period. (From Medeiros et al., J.G.R., 88, 6253-6258, 1983).

Figure 3 - (a) Range spread F occurrence distribution over Fortaleza for the period 1980-81, as in the Figure 2(a).
(b) 254MHz amplitude scintillation occurrence distribution over Natal for 1980-81 as in the Figure 2(b).
(c) Range spread F occurrences distribution over Cachoeira Paulista for the period (1980-81) as in the Figure 2(c).

Figure 4 - Range spread F irregularity occurrences over Fortaleza (the magnetic equator) and Cachoeira Paulista (-28^{o} dip) plotted as function of years from 1973-75 up to 1982, and for different local times. The lowest frame in this figure represents the sunspot number variation during the same period.

Figure 5 - (a) a - The mean nocturnal variations of the virtual heights of the base of the F-layer (h'F), for a group of 6 days when range spread F was absent (dashed line) and present (solid line), over Fortaleza.

b - The same representation as in (a) but for Cachoeira Paulista (taken from Abdu et al., J.G.R., 88, 4861-4868, 1983).

(b) Virtual height of the F layer base, and that of 3 MHz plasma frequency, for all available days of August 1982. The vertical marking adjacent to some of these h'F curves represent occurrences of range type spread F in the ionograms.

(c) Similar results as in (b) for September 1982. Range spread F was present in most nights in September.

Figure 6 - (a) Seasonal and local time distribution of the virtual heights of the F-layer base over Fortaleza for the night hours during 1980-81.

(b) Seasonal and local time distribution of the virtual heights of the F-layer base over Cachoeira Paulista for the night hours during 1980-81.

Figure 7 - (a) Percentages of the four possibilities of relative occurrences of range type spread F over Fortaleza and Cachoeira Paulista. The four possible combinations of range spread F occurrences are indicated by combination of "yes" and "no" representing occurrence and nonoccurrence respectively of the spread F marked against the station names, F_Z and C.P. (Abdu et al., J.G.R., 88, 4861-4868, 1983).

Figure 8 - (a) Histogram showing the duration of range type spread F events over Fortaleza plotted against the mean durations of the corresponding events over Cachoeira Paulista.

(b) The number of range type spread F events present in each 1 hour time interval, considered in the part (a) of the figure. (Abdu et al., J.G.R., 88, 4861-4868, 1983).

Figure 9 - (a) Meridional profiles of 6300Å airglow intensity obtained from meridional scanning photometer over Cachoeira Paulista. The airglow valley propagation is predominantly on the southern portion of the scanning range in the upper part (namely during the earlier hours) and in the northern portion of the scanning range in the lower part (namely during later hours) in this figure. (b) An example of a long duration event in which the airglow valley propagates from approximately the zenith up to the southern end of the scanning range. This event represents the vertical growth over the magnetic equator and in the vicinity of the magnetic meridian of Cachoeira Paulista, of a westward tilted plasma bubble.

Figure 10 - (a) Meridional profile of 63000Å airglow valleys taken simultaneously with east-west scan measurements over Cachoeira Paulista presented in (b). (b) 6300Å airglow intensity profiles measured by east-west scan photometers. Eastward propagating valleys representing corresponding bubble eastward drift can be seen from 2130LT onward.

Figure 11 - Polarimeter recording, of the Faraday rotation angle (ϕ) representing the total electron content in the ionosphere (TEC), on 136MHz SIRIO VHF veacon received at São José dos Campos (upper part). The two identical records have a phase difference of 90^o between them. The lower record represent amplitude of the 136MHz beacon. Two isolated plasma bubble events at ~21-2120 LT and at 2215-2305 LT marked by 6-10% depletions in TEC and ~10 db peak to peak amplitude scintillation were registered on this night.

Figure 12 - (a) VHF polarimeter recordings of TEC (upper part) and amplitude scintillation (middle part) on 136MHz beacon from GOES-3, and amplitude scintillation on 1.541GHz MARISAT beacon (lower part) received at São José dos Campos. The scintillation peak-to-peak amplitude at 1.541GHz was 20-30 db and that of 136MHz was of the order of 10 db.

(b) Another example of VHF and GHz scintillation during an extended plasma bubble event during which the Faraday rotation fast fluctuation causes the TEC information irretrievable from the phase recordings.

Figure 13 - A statistical representation of the occurrence of Faraday rotation angle (TEC) fluctuations registered at São José dos Campos and Cachoeira Paulista on GOES-3 VHF beacon and range type spread F over Cachoeira Paulista for all days of December 1981, plotted as function of local time between 18LT and 06LT. /\/\ represents oscillations in clean TEC traces (namely, without rapid fluctuations). /\/\ represents oscillations in TEC superimposed with rapid fluctuations of small amplitude, ---- represents small amplitude fluctuations in Faraday rotation angle without well-defined oscillations in TEC, and —— represents strong fluctuations in the Faraday rotation angle. The lowermost line (——) for each day represents occurrences of range type spread F. The letter "C" represents failure of data.

Figure 14 - Tracings of Faraday rotation angle records (and amplitude scintillation intervals) on SIRIO VHF beacon received at São José dos Campos (solid line) and Cachoeira Paulista (broken line) on the night of 6-7 January 1983.

Figure 15 - Mean eastward velocities of Faraday rotation angle fluctuations, namely, structures in plasma bubbles, presented as a function of local time, representing the summer months of 1981-82 (marked by solid triangles). Also shown are the eastward F-region bulk plasma velocities measured by Jicamarca radar (taken from Fejer et al., J.G.R., 86, 215-218, 1981), and eastward velocities of VHF scintillation patches measured using closely spaced antennas over Natal (Yeh et al., J.G.R., 86, 7527-7532, 1981).

Figure 16 - Plots of h'F and h'_3 (the virtual height of 3MHz plasma frequency) for Fortaleza and Fernando de Noronha on the magnetic equator.
Range spread F developments at the two stations are shown in the inset which has a vertical frequency scale and horizontal time scale. The solid vertical lines in those figures represent presence of satellite traces in the ionograms. The numbers 1, 2, 3 represent degree of range spreading in the ionogram for spreading ranges of $\leq$ 100km, from 100 to 200km, and > 200km respectively.

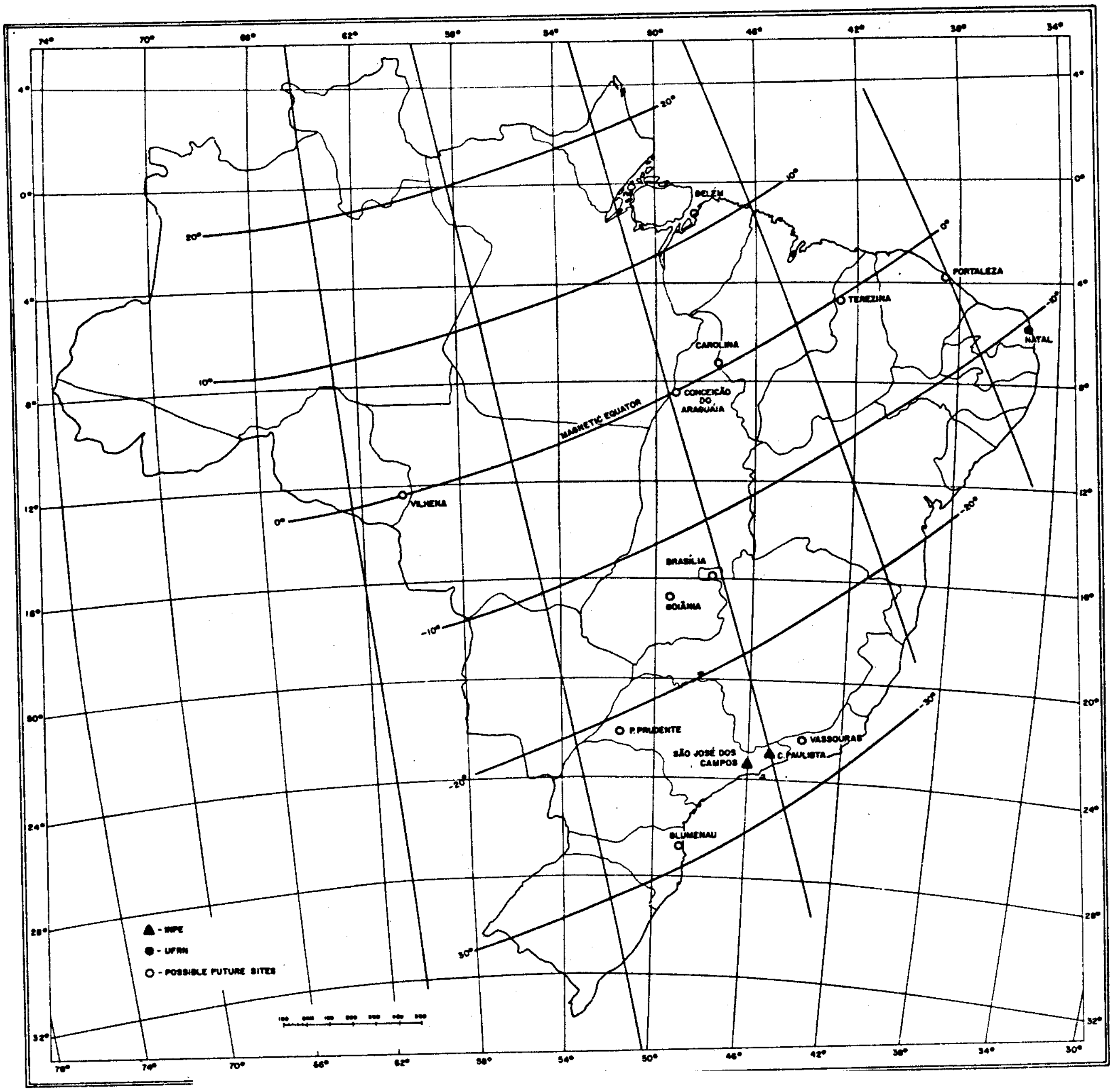

BELÉM
FORTALEZA
TEREZINA
NATAL
CAROLINA
CONCEIÇÃO DO ARAGUAIA
MAGNETIC EQUATOR
VILHENA
BRASÍLIA
GOIÂNIA
P. PRUDENTE
VASSOURAS
SÃO JOSÉ DOS CAMPOS
C. PAULISTA
BLUMENAU
- INPE
- UFRN
- POSSIBLE FUTURE SITES

Figure 1

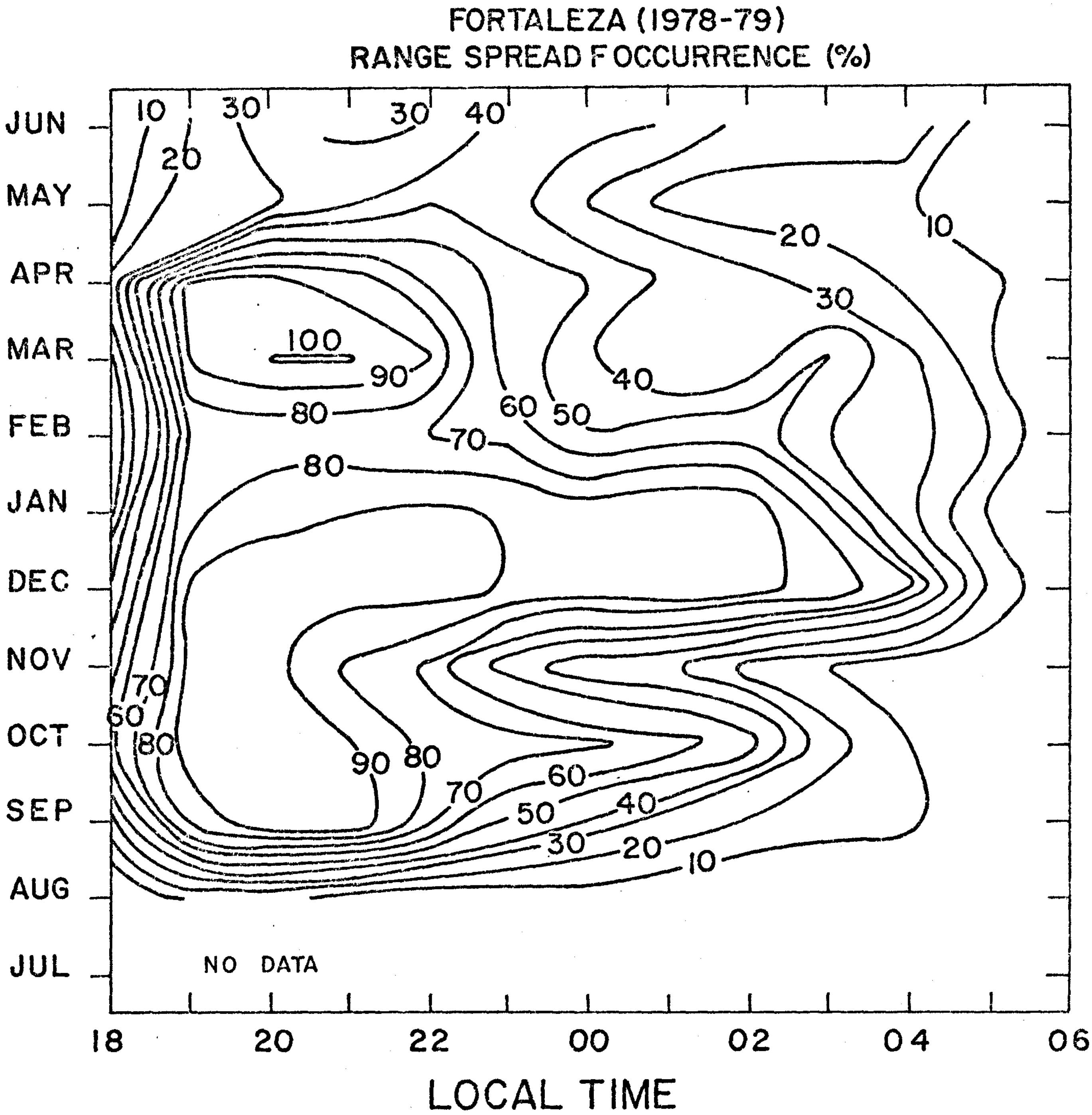

FORTALEZA (1978-79)
RANGE SPREAD F OCCURRENCE (%)
JUN
MAY
APR
MAR
FEB
JAN
DEC
NOV
OCT
SEP
AUG
JUL
NO DATA
18
20
22
00
02
04
06
LOCAL TIME
10
20
30
40
50
60
70
80
90
100

Figure 2(a)

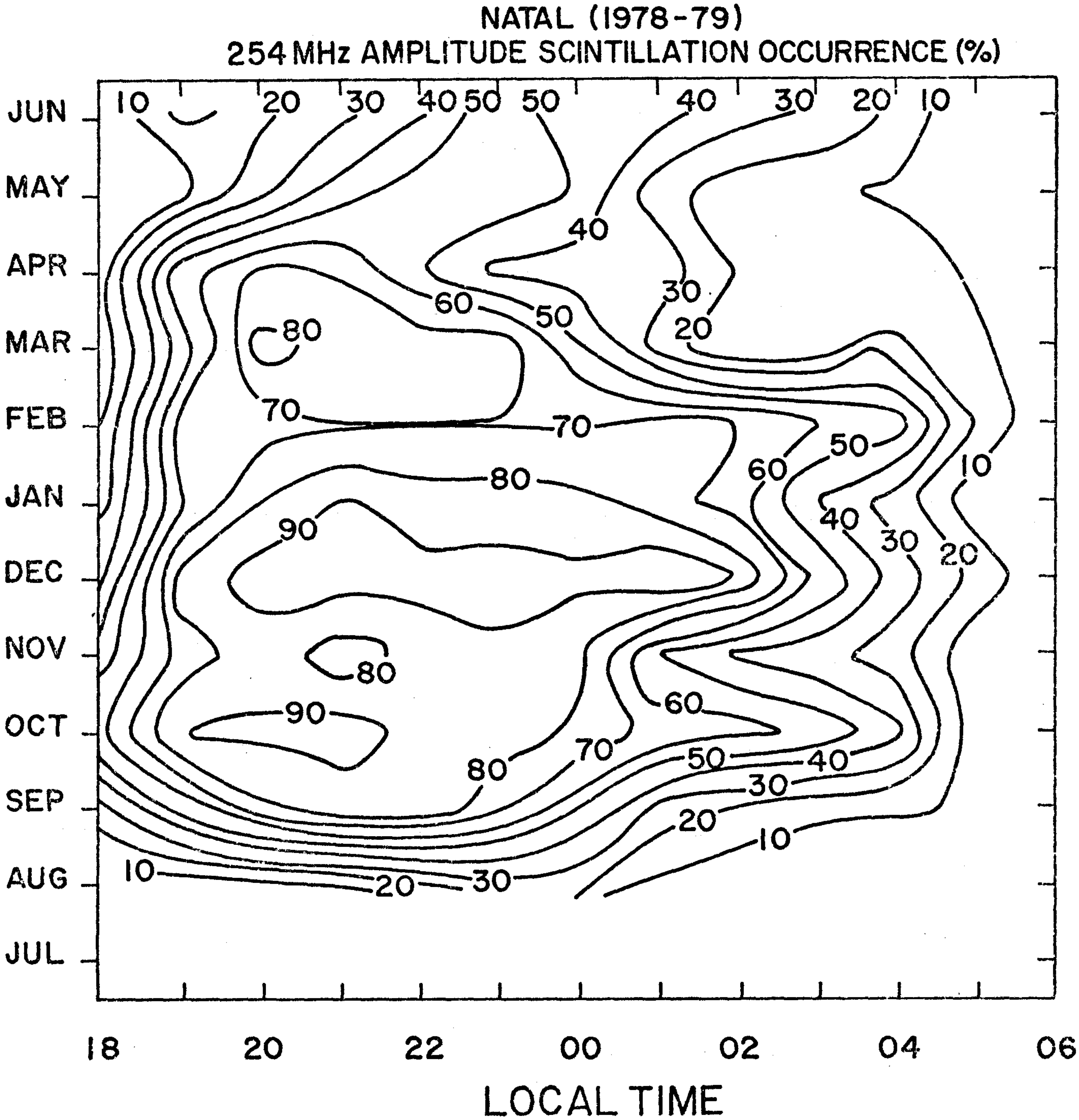
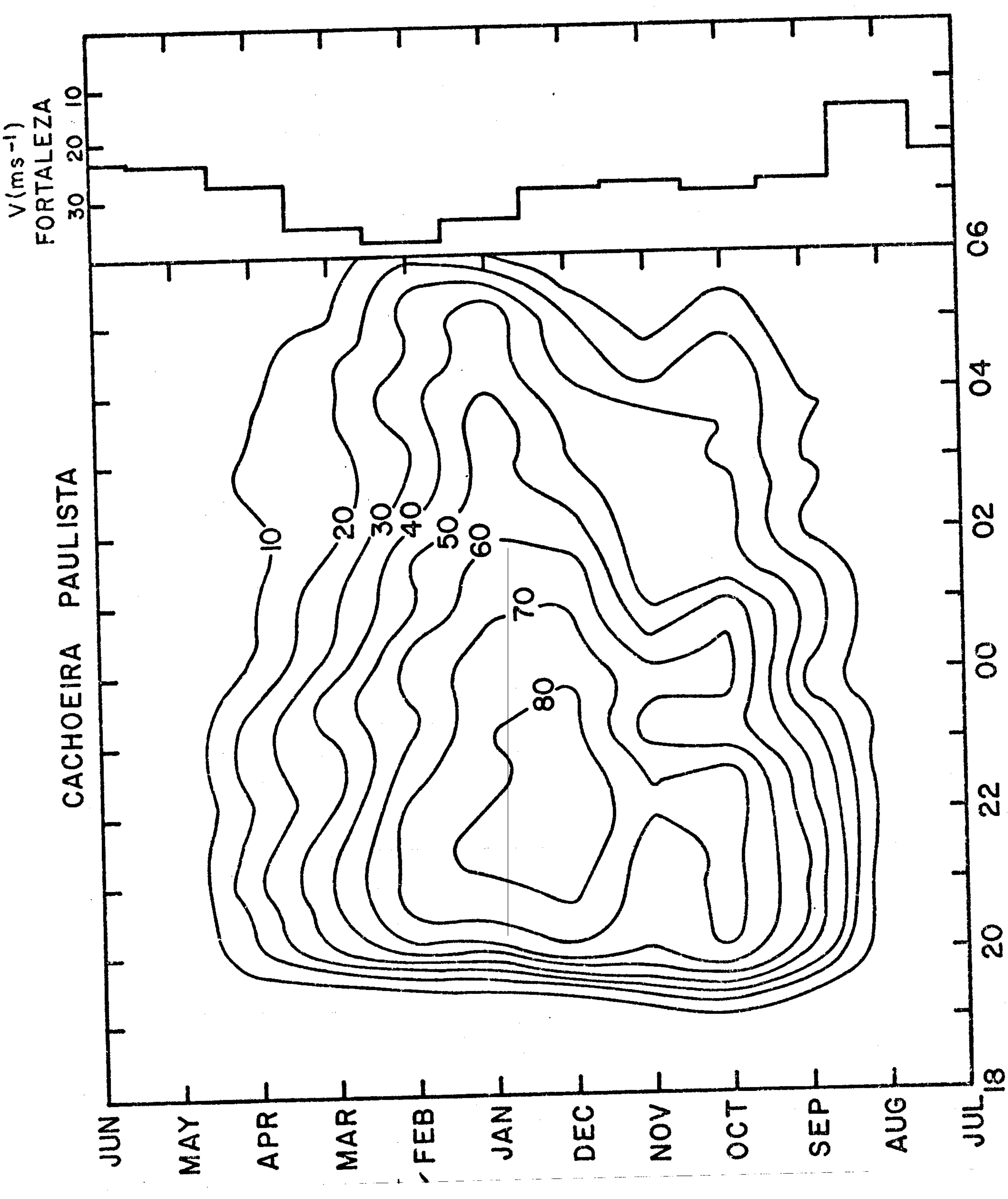

NATAL (1978-79)
254 MHz AMPLITUDE SCINTILLATION OCCURRENCE (%)
JUN
MAY
APR
MAR
FEB
JAN
DEC
NOV
OCT
SEP
AUG
JUL
18
20
22
00
02
04
06
LOCAL TIME

Figure 2(b)


CACHOEIRA PAULISTA
V(ms-1)
FORTALEZA
10
20
30
10
20
30
40
50
60
70
80
LOCAL TIME
18
20
22
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JUN
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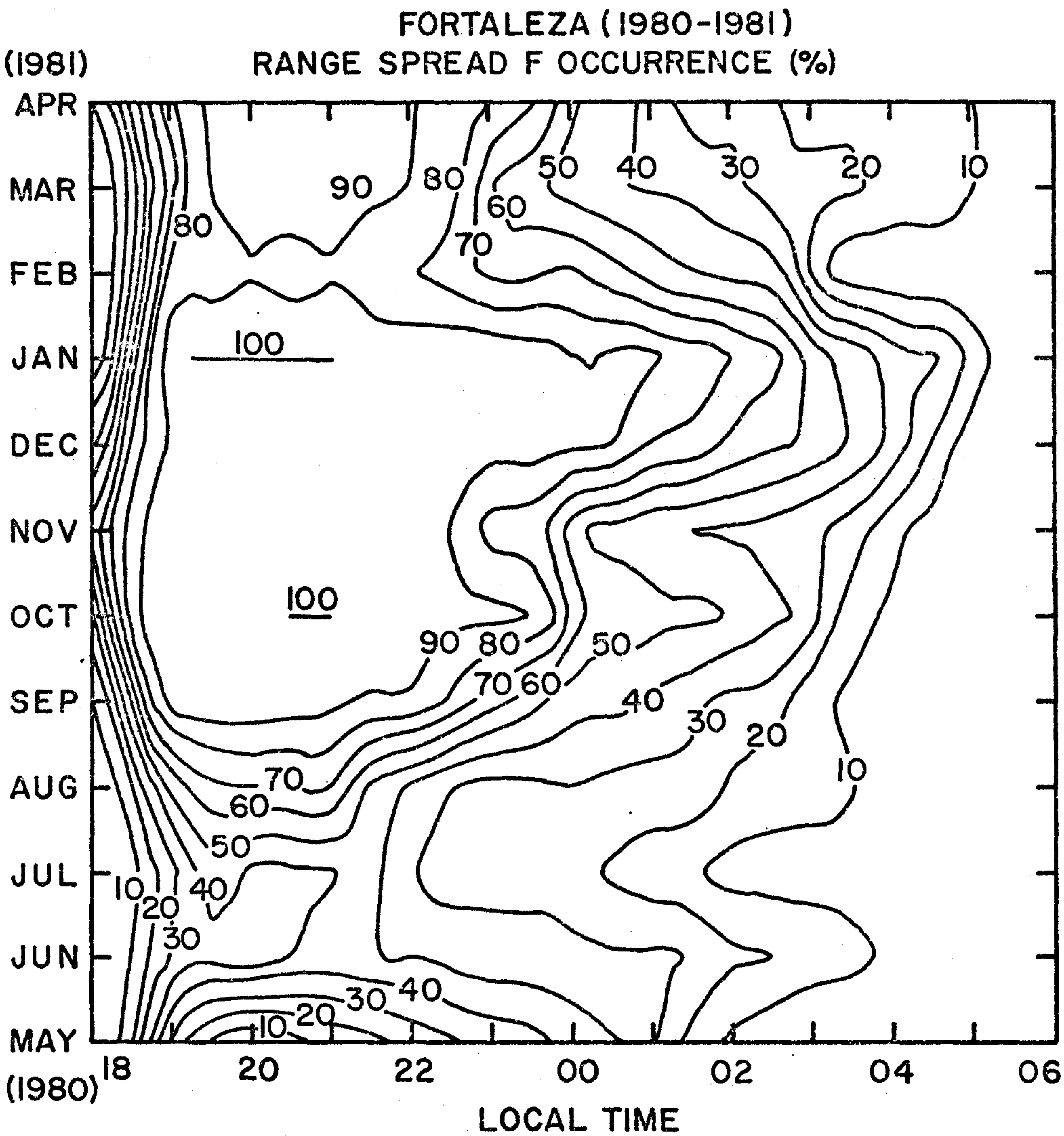
AUG
JUL

Figure 2(c)


FORTALEZA (1980-1981)
RANGE SPREAD F OCCURRENCE (%)
(1981)
APR
MAR
FEB
JAN
DEC
NOV
OCT
SEP
AUG
JUL
JUN
MAY
(1980)
18
20
22
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LOCAL TIME
100
100
90
80
70
60
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40
30
20
10

Figure 3(a)

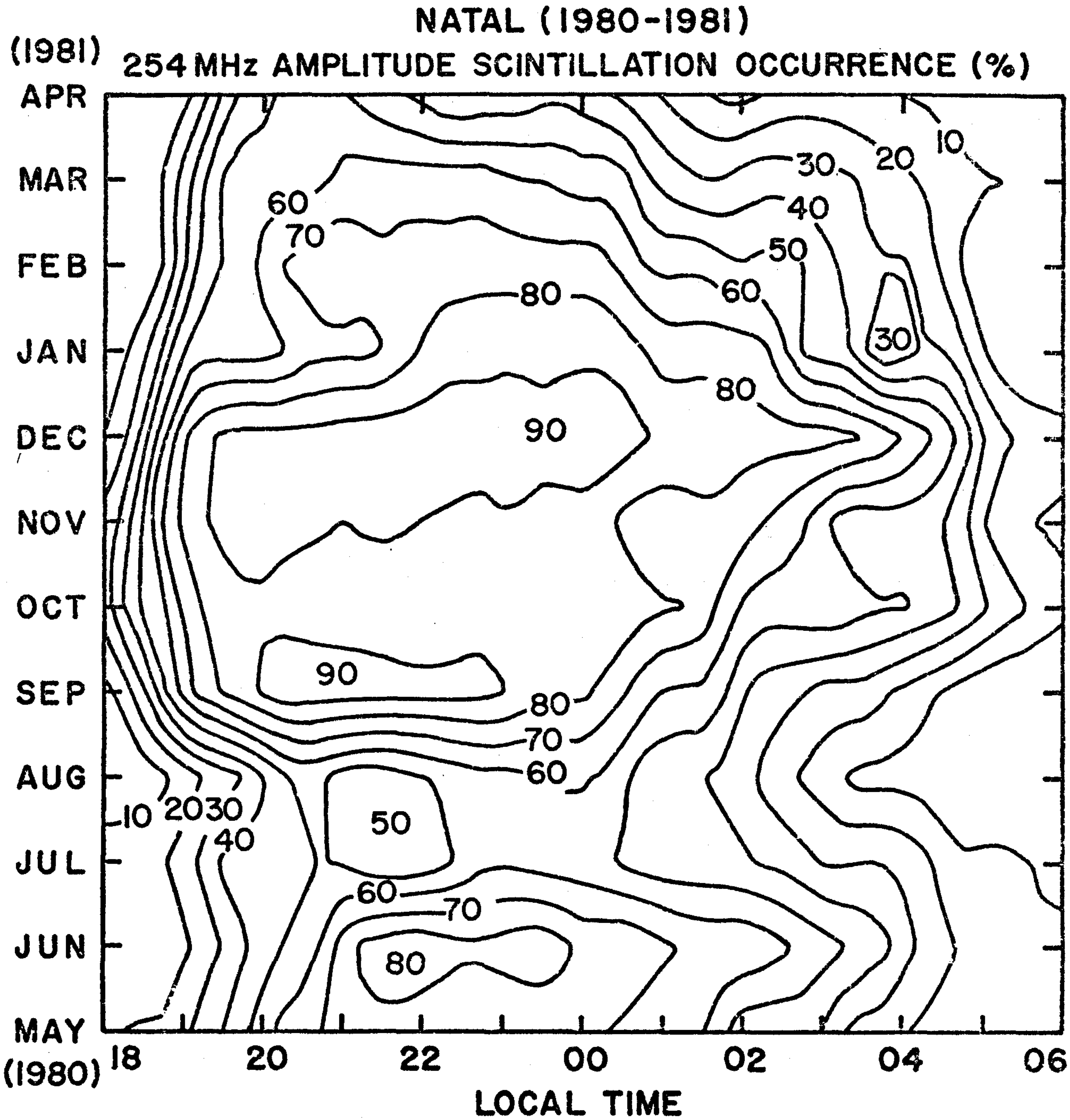
NATAL (1980-1981)
254 MHz AMPLITUDE SCINTILLATION OCCURRENCE (%)
(1981)
APR
MAR
FEB
JAN
DEC
NOV
OCT
SEP
AUG
JUL
JUN
MAY
(1980)
18
20
22
00
02
04
06
LOCAL TIME
10
20
30
40
50
60
70
80
90

Figure 3(b)

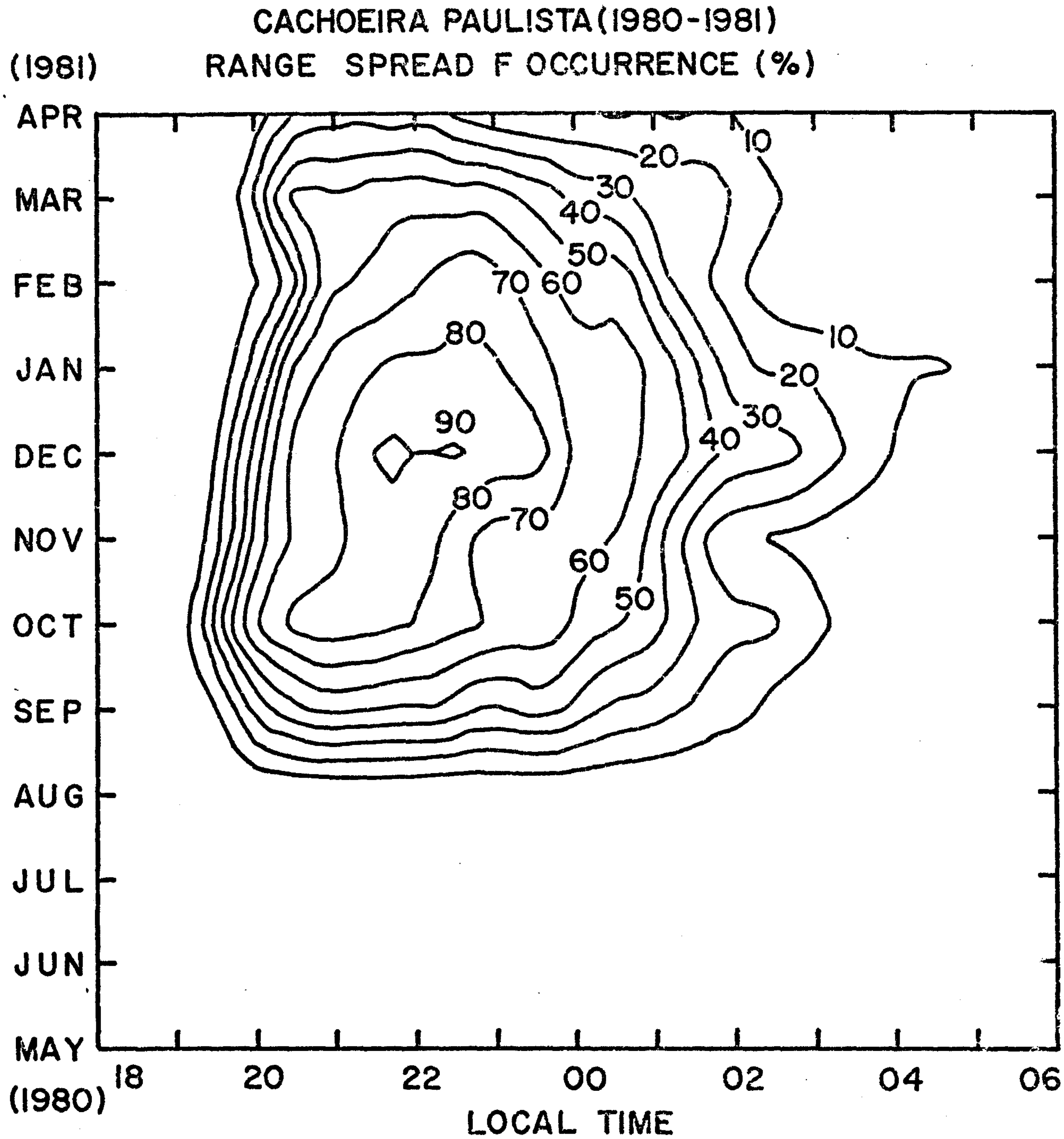
CACHOEIRA PAULISTA (1980-1981)
RANGE SPREAD F OCCURRENCE (%)
(1981)
APR
MAR
FEB
JAN
DEC
NOV
OCT
SEP
AUG
JUL
JUN
MAY
(1980)
18
20
22
00
02
04
06
LOCAL TIME
10
20
30
40
50
60
70
80
90

Figure 3(c)

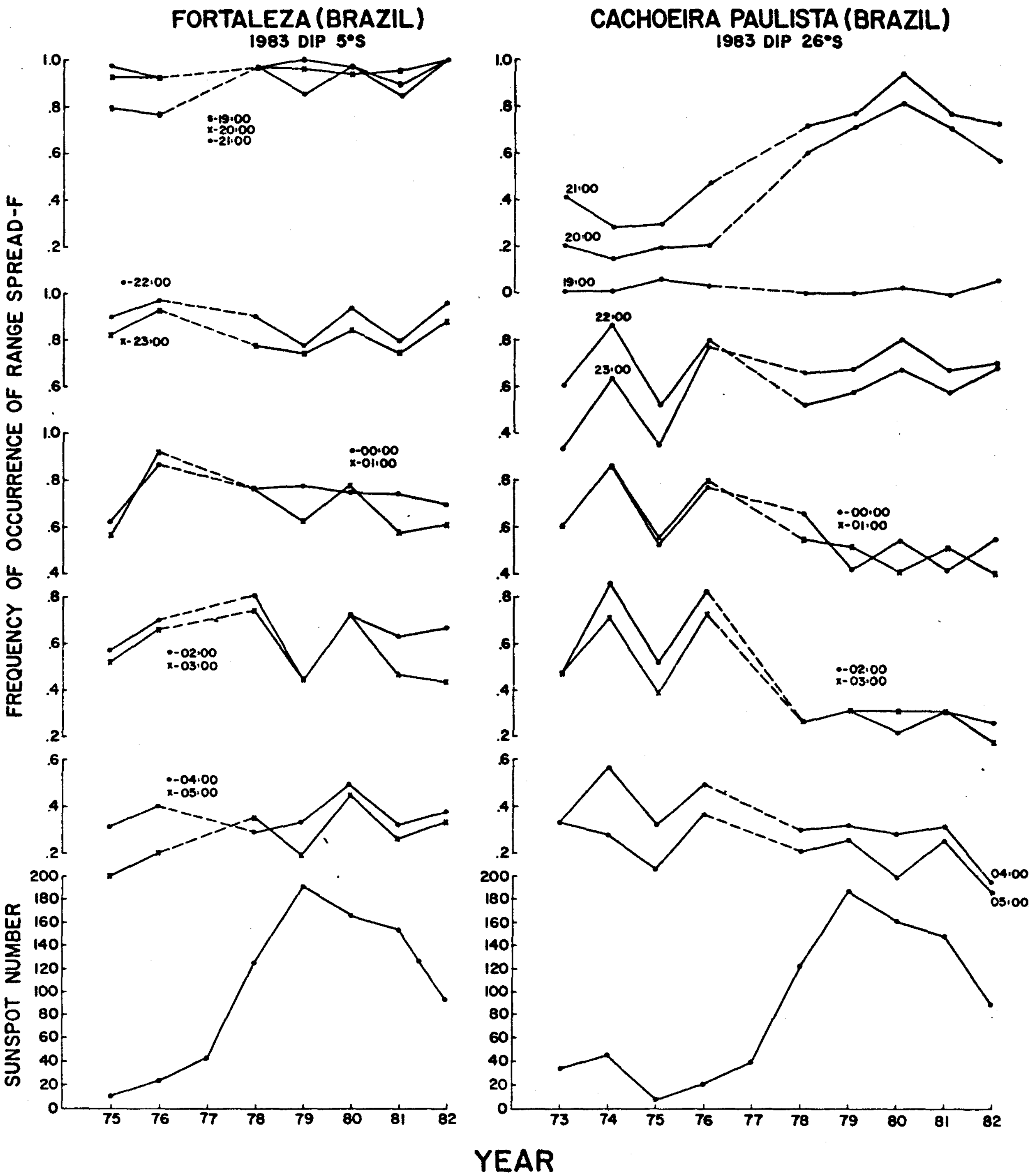
FORTALEZA (BRAZIL)
1983 DIP 5°S
CACHOEIRA PAULISTA (BRAZIL)
1983 DIP 26°S
FREQUENCY OF OCCURRENCE OF RANGE SPREAD-F
SUNSPOT NUMBER
•-19:00
x-20:00
•-21:00
•-22:00
x-23:00
•-00:00
x-01:00
•-02:00
x-03:00
•-04:00
x-05:00
21:00
20:00
19:00
22:00
23:00
04:00
05:00
YEAR

Figure 4

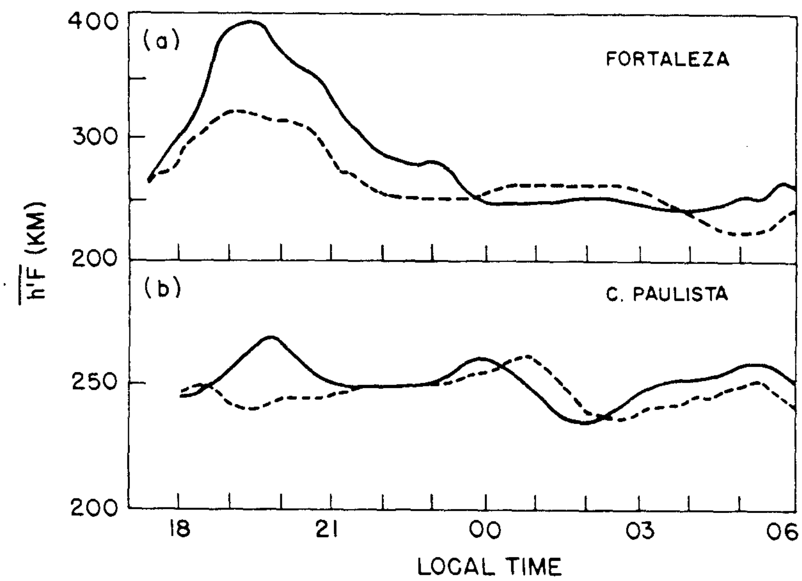
400
300
200
250
200
(a)
FORTALEZA
(b)
C. PAULISTA
h'F (KM)
18
21
00
03
06
LOCAL TIME

Figure 5(a)

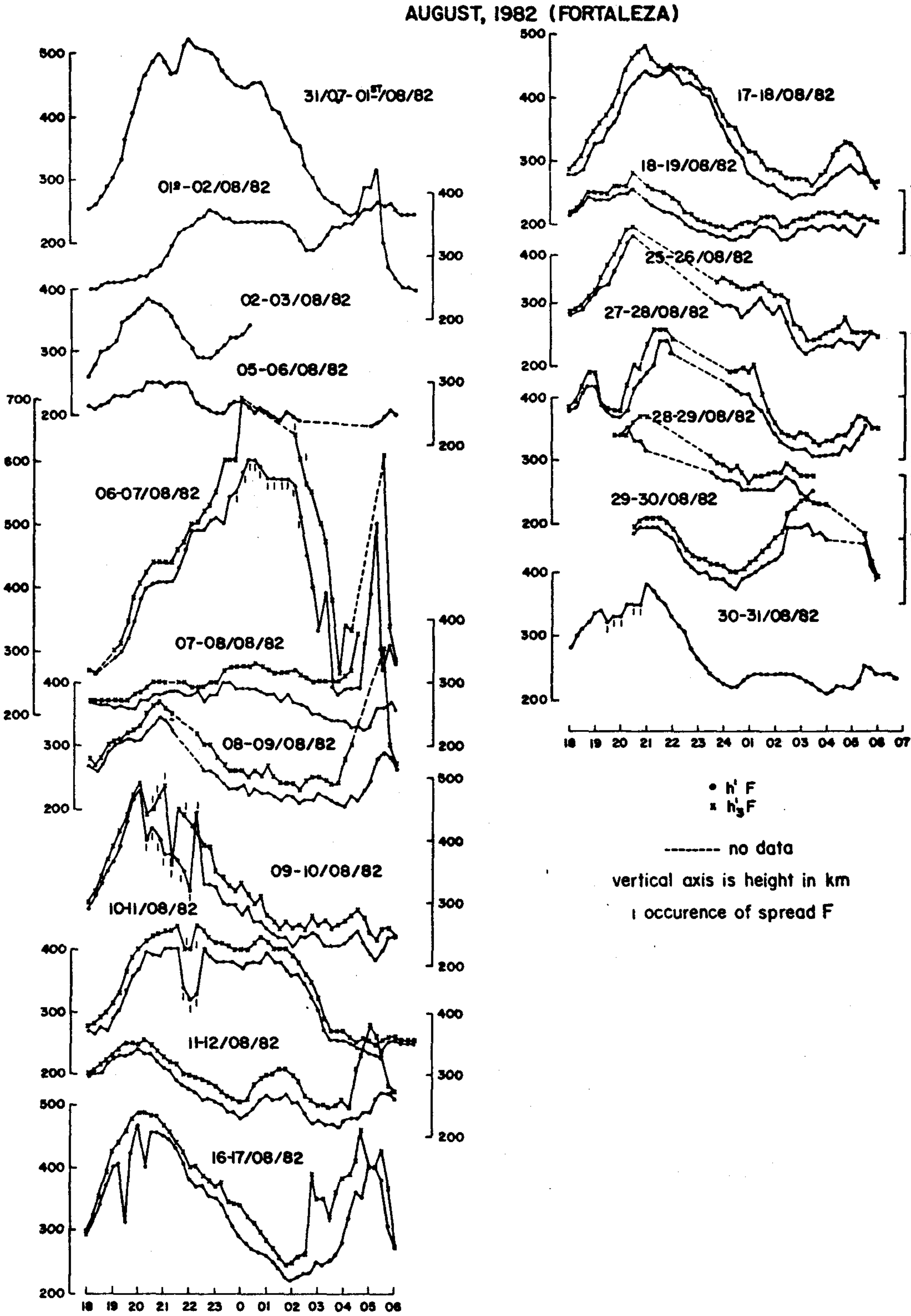
AUGUST, 1982 (FORTALEZA)
31/07-01st/08/82
01º-02/08/82
02-03/08/82
05-06/08/82
06-07/08/82
07-08/08/82
08-09/08/82
09-10/08/82
10-11/08/82
11-12/08/82
16-17/08/82
17-18/08/82
18-19/08/82
25-26/08/82
27-28/08/82
28-29/08/82
29-30/08/82
30-31/08/82
18 19 20 21 22 23 0 01 02 03 04 05 06
18 19 20 21 22 23 24 01 02 03 04 05 06 07
• h' F
x h'3F
-------- no data
vertical axis is height in km
ı occurence of spread F

Figure 5(b)

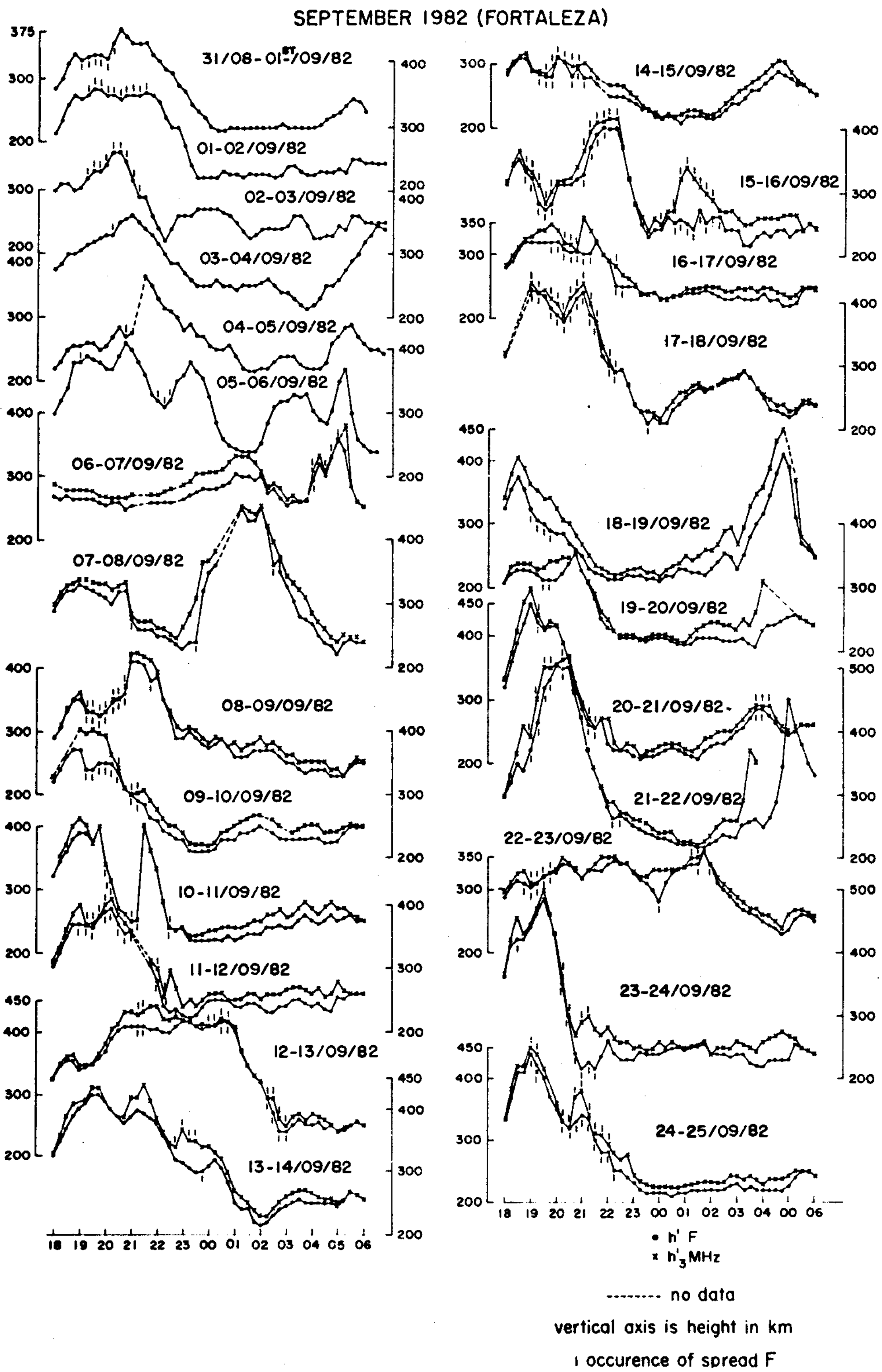
SEPTEMBER 1982 (FORTALEZA)
31/08-01ST/09/82
01-02/09/82
02-03/09/82
03-04/09/82
04-05/09/82
05-06/09/82
06-07/09/82
07-08/09/82
08-09/09/82
09-10/09/82
10-11/09/82
11-12/09/82
12-13/09/82
13-14/09/82
14-15/09/82
15-16/09/82
16-17/09/82
17-18/09/82
18-19/09/82
19-20/09/82
20-21/09/82
21-22/09/82
22-23/09/82
23-24/09/82
24-25/09/82
• h' F
× h'3MHz
-------- no data
vertical axis is height in km
ı occurence of spread F

Figure 5(c)

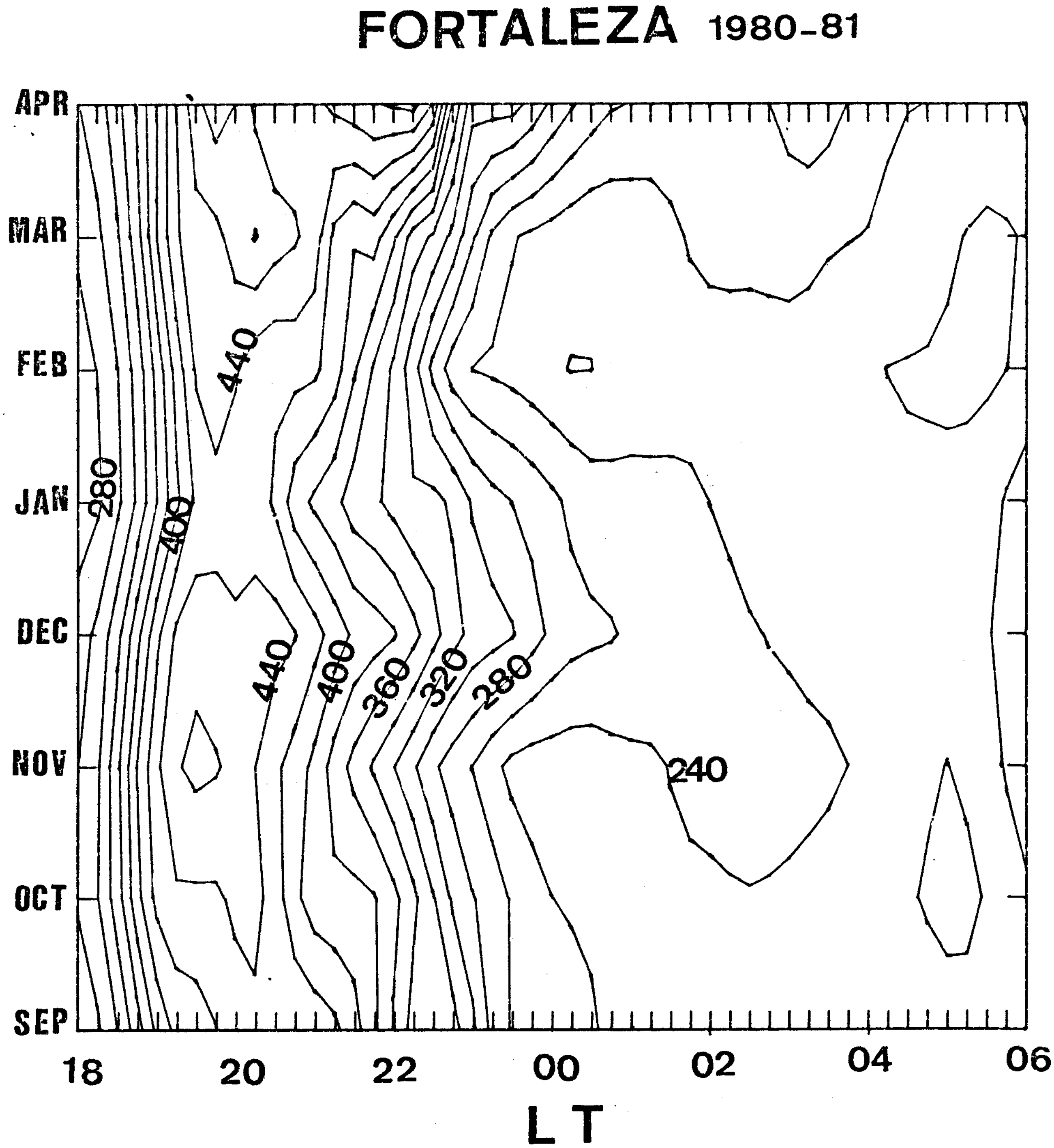
FORTALEZA 1980-81
APR
MAR
FEB
JAN
DEC
NOV
OCT
SEP
440
280
400
440
400
360
320
280
240
18
20
22
00
02
04
06
L T

Figure 6(a)

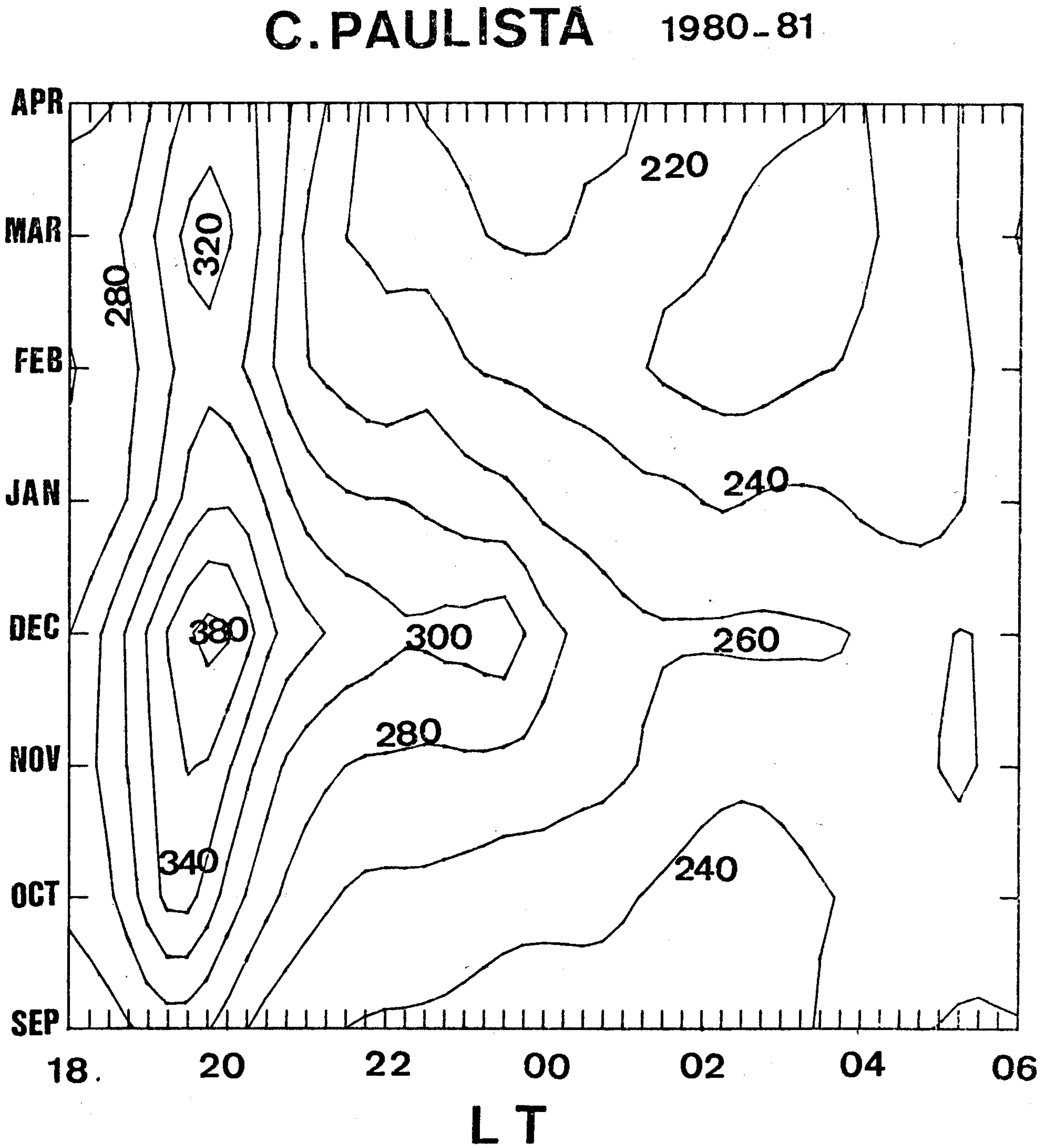
C.PAULISTA 1980-81
APR
MAR
FEB
JAN
DEC
NOV
OCT
SEP
18.
20
22
00
02
04
06
LT
220
320
280
240
380
300
260
280
340
240

Figure 6(b)

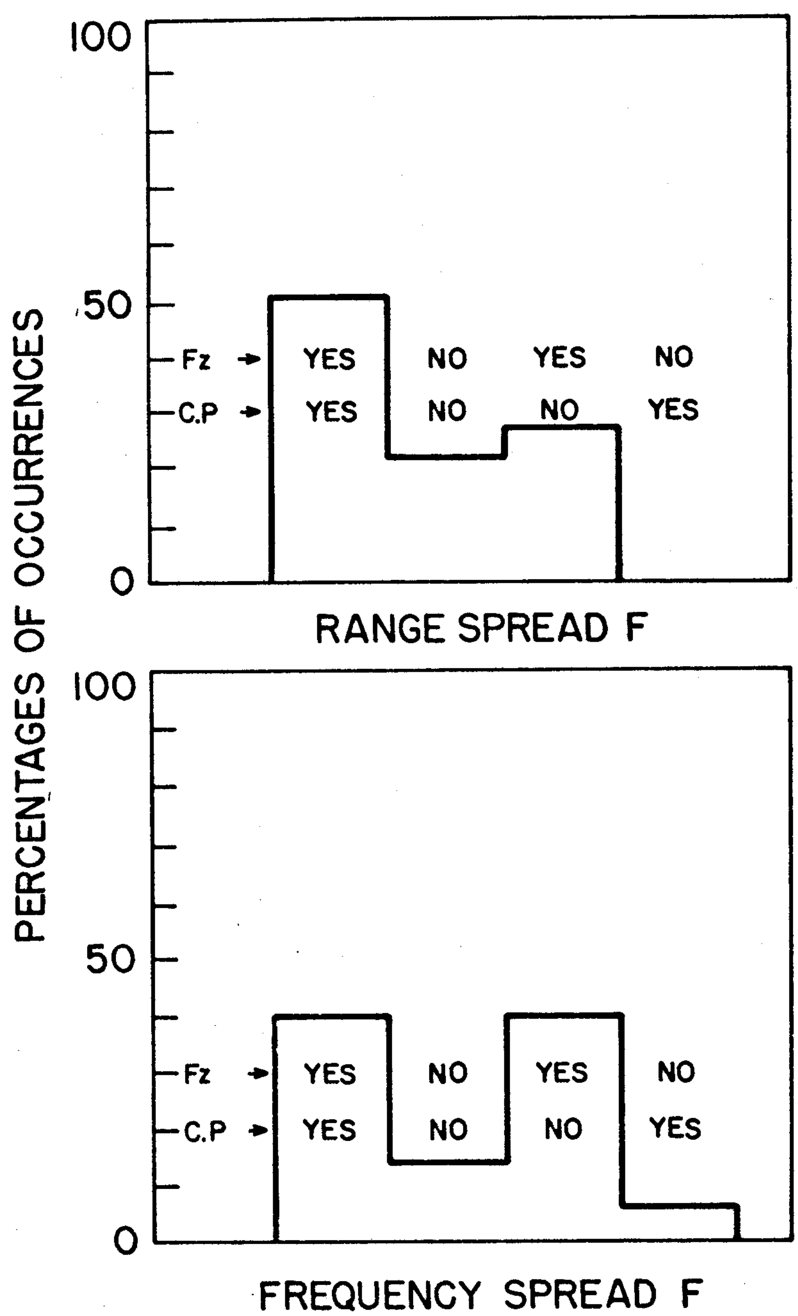
100
50
0
Fz →
C.P →
YES
YES
NO
NO
YES
NO
NO
YES
RANGE SPREAD F
PERCENTAGES OF OCCURRENCES
100
50
0
Fz →
C.P →
YES
YES
NO
NO
YES
NO
NO
YES
FREQUENCY SPREAD F

Figure 7

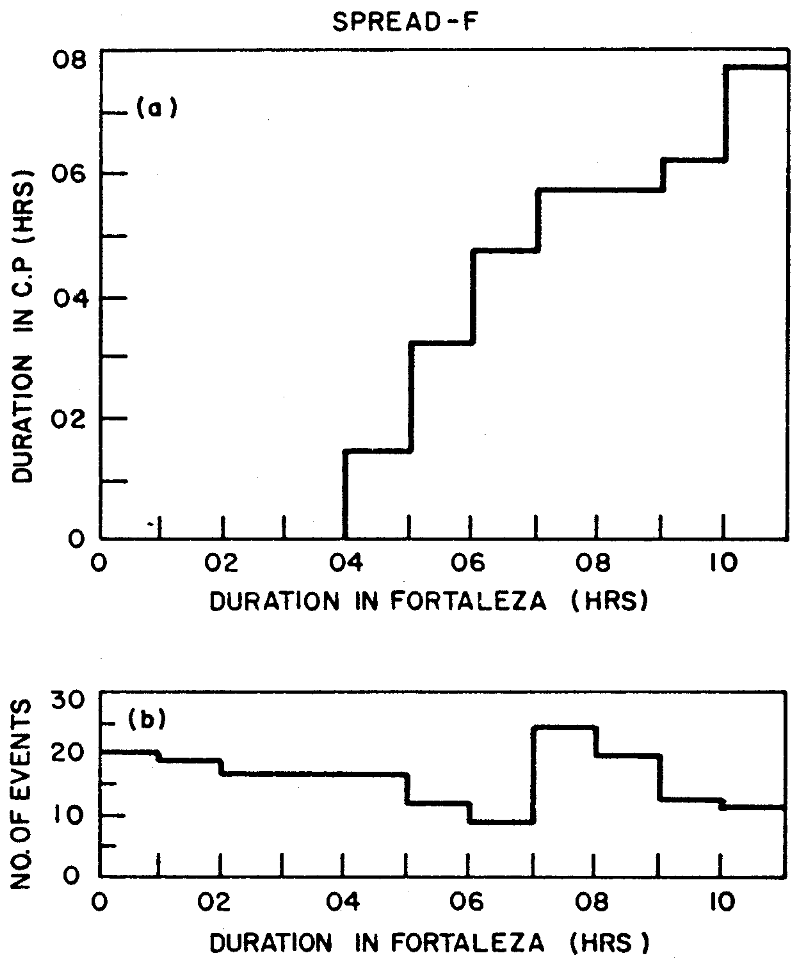
SPREAD-F
(a)
DURATION IN C.P (HRS)
08
06
04
02
0
0
02
04
06
08
10
DURATION IN FORTALEZA (HRS)
(b)
NO. OF EVENTS
30
20
10
0
0
02
04
06
08
10
DURATION IN FORTALEZA (HRS)

Figure 8

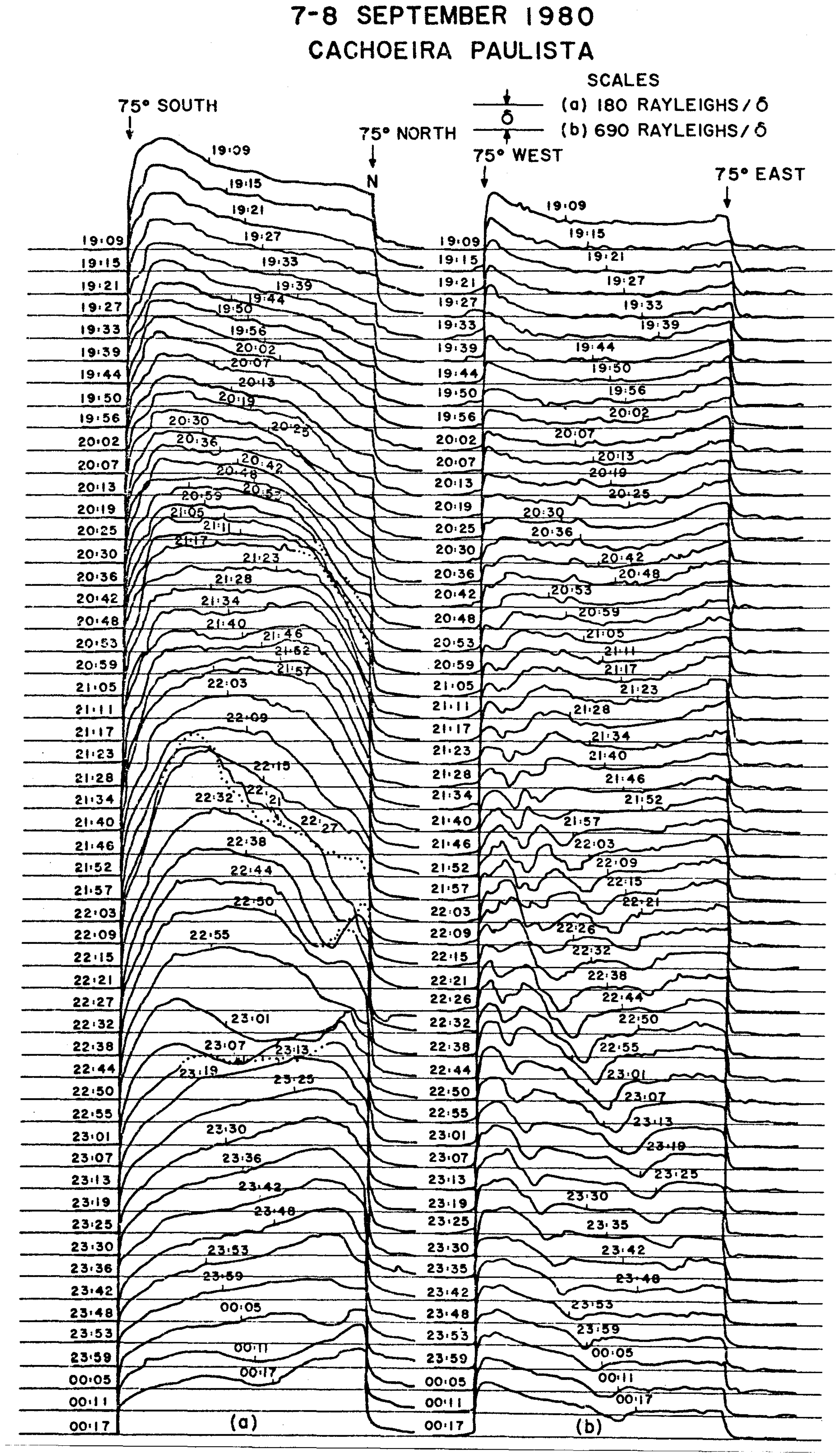
7-8 SEPTEMBER 1980
CACHOEIRA PAULISTA
SCALES
(a) 180 RAYLEIGHS/δ
(b) 690 RAYLEIGHS/δ
δ
75° SOUTH
75° NORTH
N
75° WEST
75° EAST
(a)
(b)

Figure 10

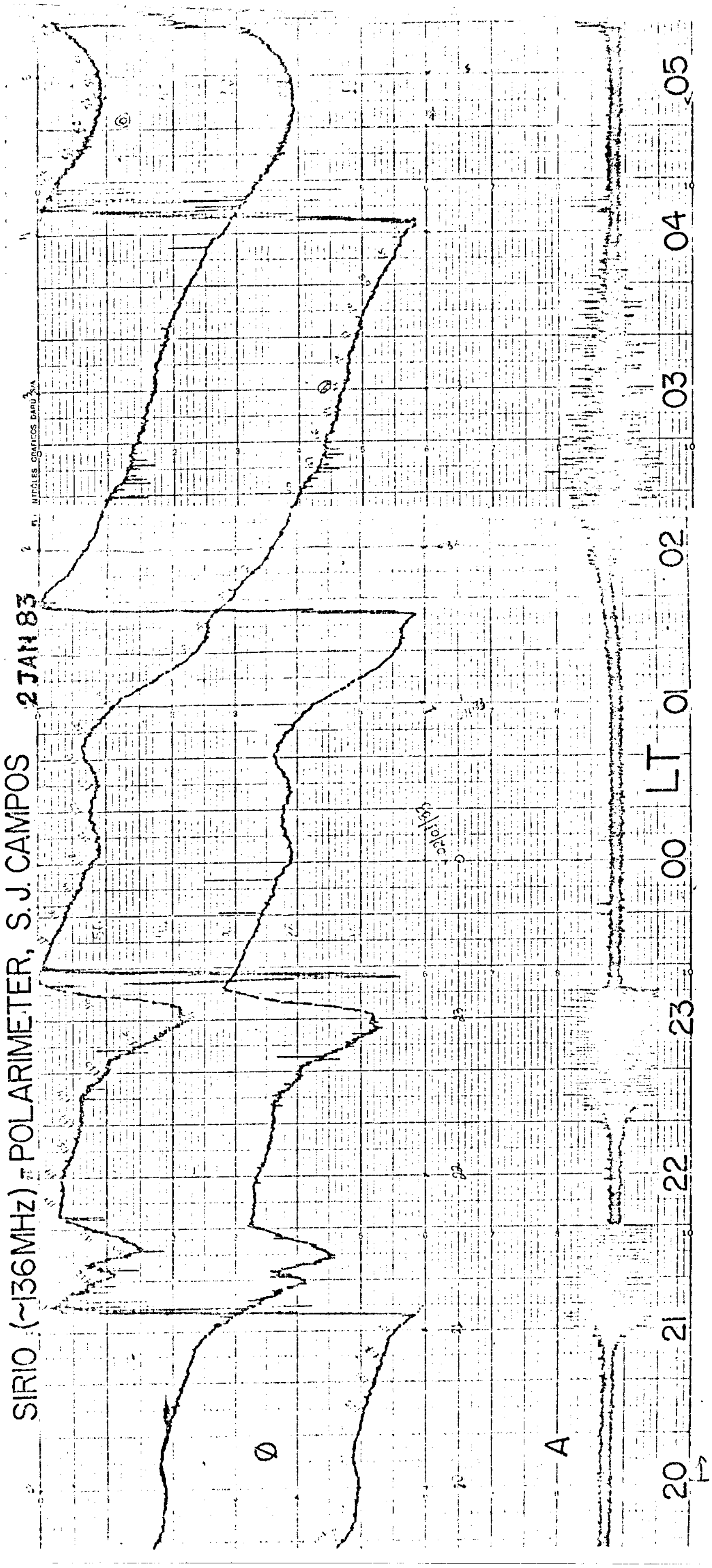
SIRIO (~136MHz) - POLARIMETER, S.J. CAMPOS
2 JAN 83
Ø
A
20
21
22
23
00
01
02
03
04
05
LT

Figure 11

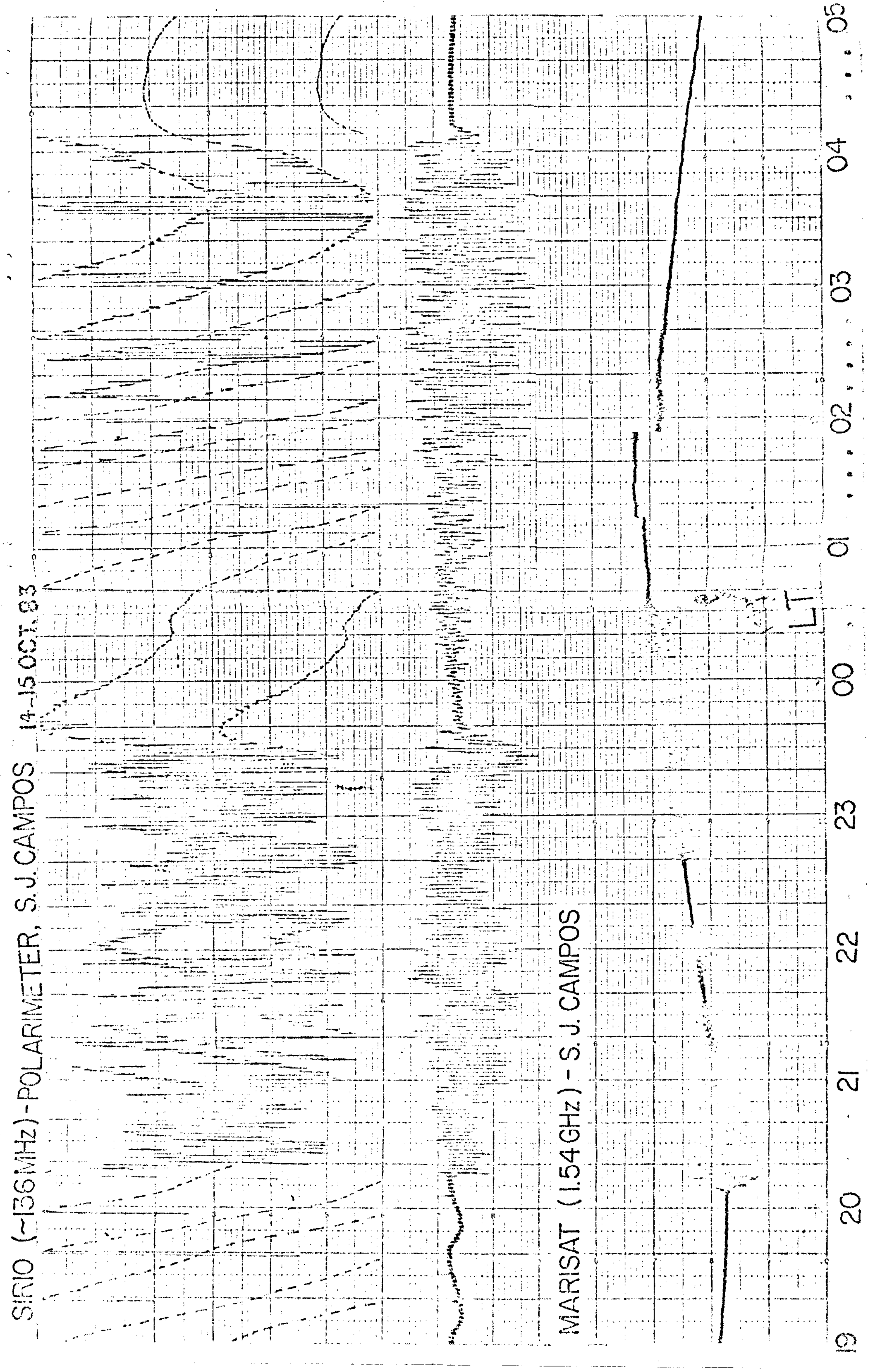
SIRIO (~136MHz)-POLARIMETER, S.J.CAMPOS 14-15 OCT. 83
MARISAT (1.54GHz) - S. J. CAMPOS
LT
19
20
21
22
23
00
01
02
03
04
05

Figure 12(a)

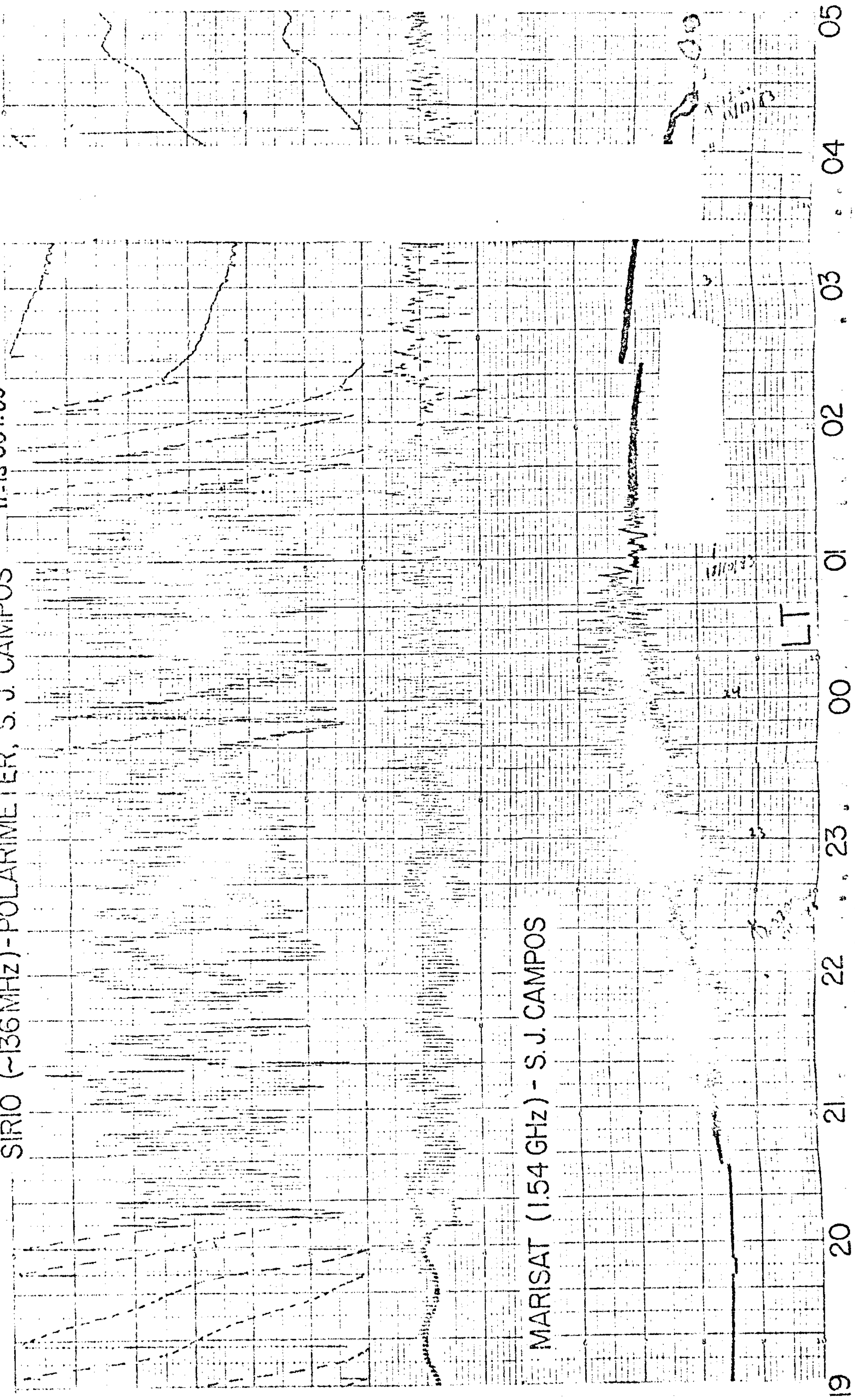
SIRIO (~136 MHz) - POLARIMETER, S. J. CAMPOS
17-19 OCT. 83
MARISAT (1.54 GHz) - S. J. CAMPOS
LT
19
20
21
22
23
00
01
02
03
04
05

Figure 12(b)

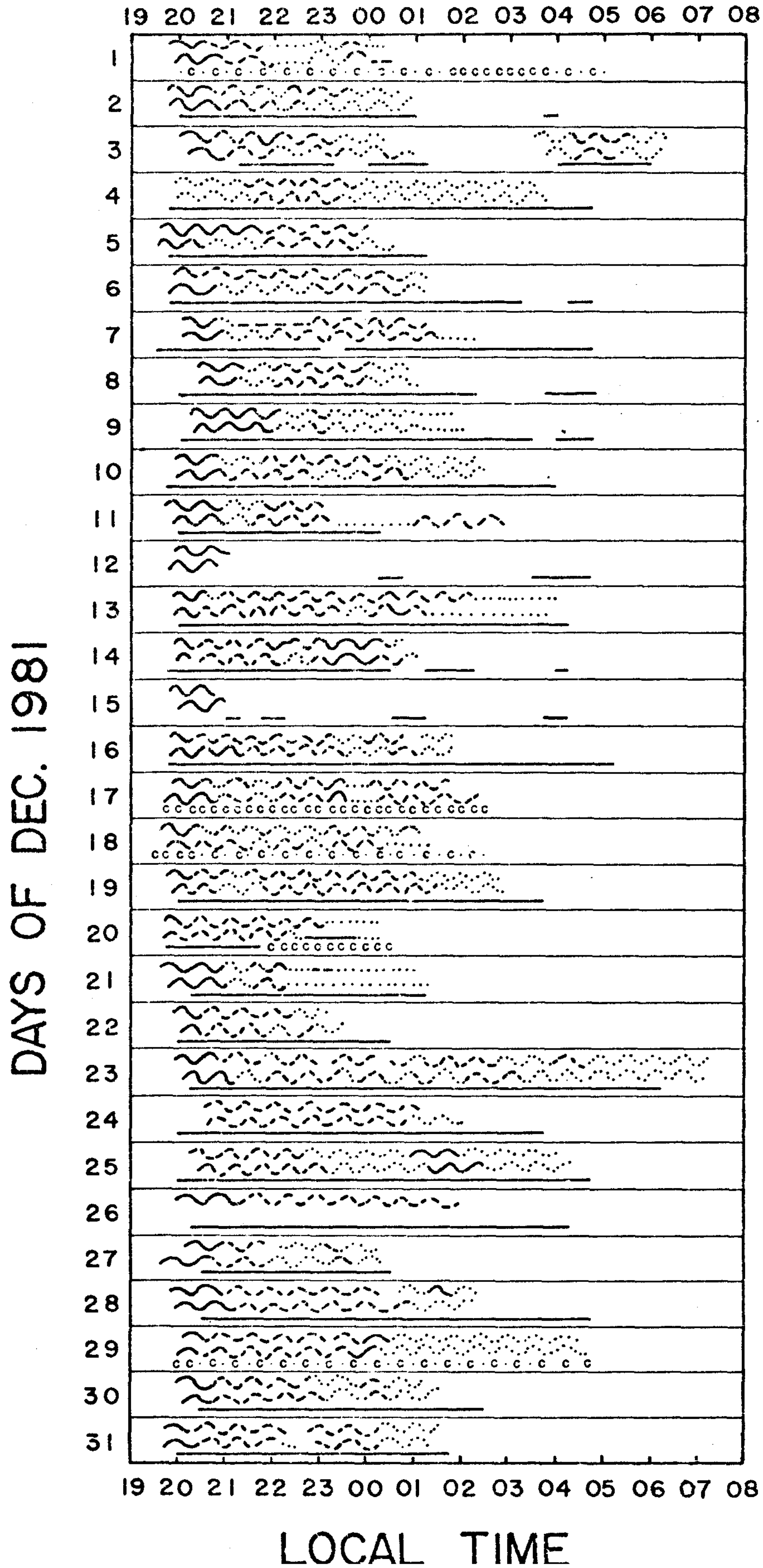
19 20 21 22 23 00 01 02 03 04 05 06 07 08
DAYS OF DEC. 1981
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
LOCAL TIME

Figure 13

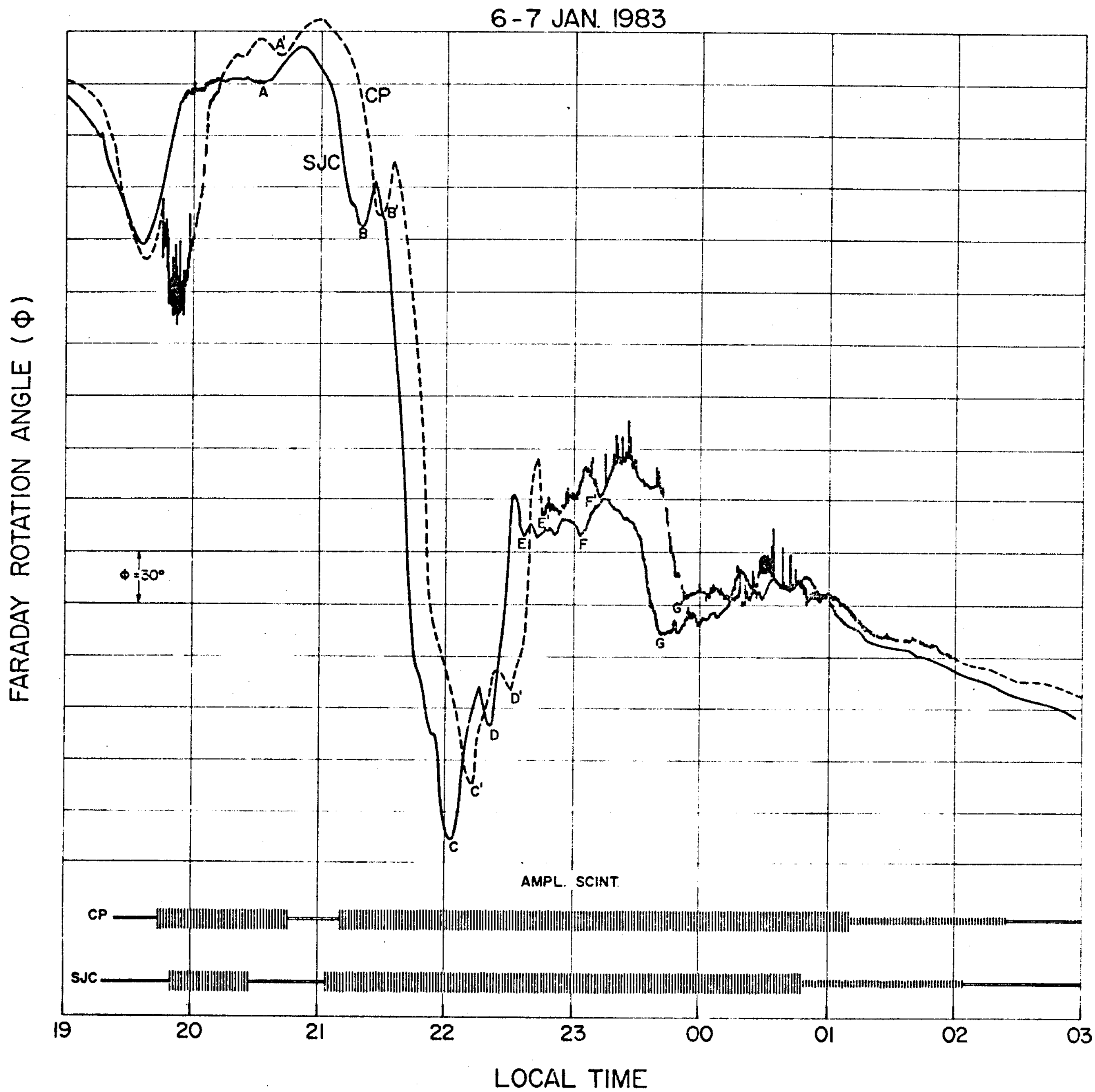
6-7 JAN. 1983
FARADAY ROTATION ANGLE (Φ)
Φ = 30°
CP
SJC
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
AMPL. SCINT.
CP
SJC
19
20
21
22
23
00
01
02
03
LOCAL TIME

Figure 14

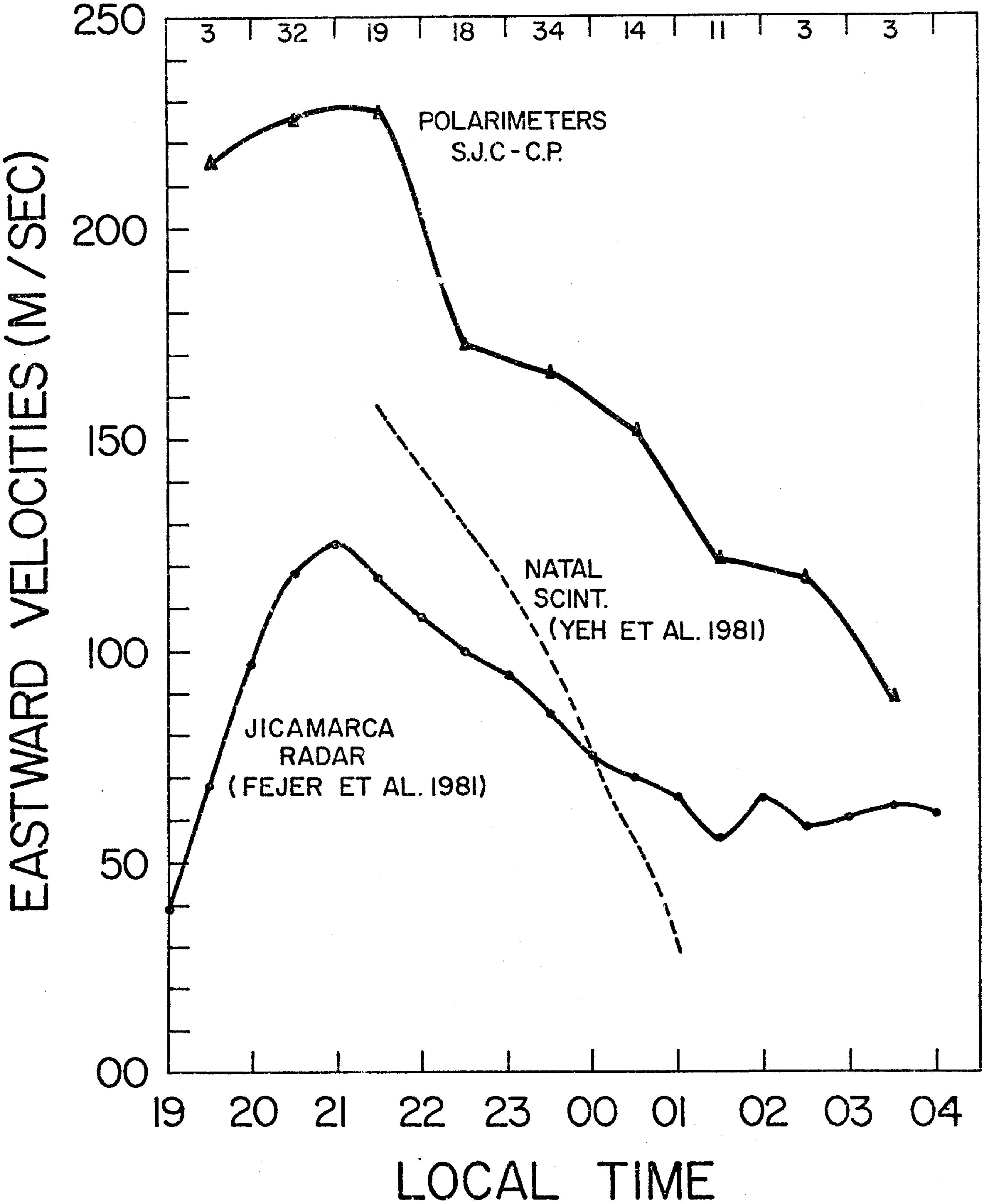
250
200
150
100
50
00
3
32
19
18
34
14
11
3
3
EASTWARD VELOCITIES (M / SEC)
POLARIMETERS
S.J.C - C.P.
NATAL
SCINT.
(YEH ET AL. 1981)
JICAMARCA
RADAR
(FEJER ET AL. 1981)
19
20
21
22
23
00
01
02
03
04
LOCAL TIME

Figure 15

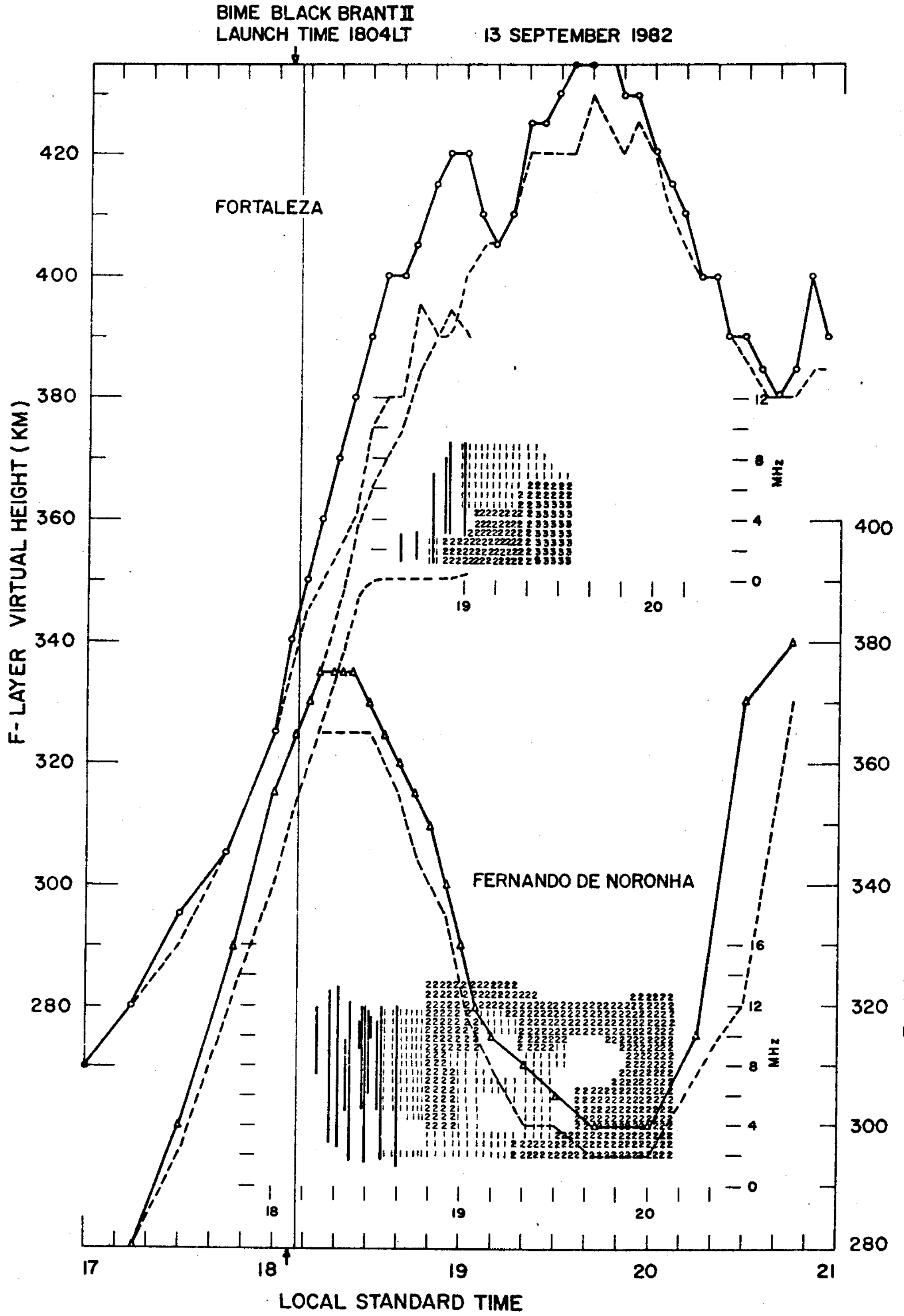
BIME BLACK BRANT II
LAUNCH TIME 1804LT
13 SEPTEMBER 1982
FORTALEZA
FERNANDO DE NORONHA
F- LAYER VIRTUAL HEIGHT (KM)
LOCAL STANDARD TIME
MHz

Figure 16