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# IONOSPHERIC RESEARCH



Scientific Report 445

## A STUDY OF THE CONDITIONS NECESSARY FOR THE ONSET OF MID-LATITUDE SPREAD F

by

Gieb N. Zinchenko

August 3, 1976

*The research reported in this document has been supported by The National Aeronautics and Space Administration under Grant No. 39-009-003 and the International Research Exchange Board.*

IONOSPHERE RESEARCH LABORATORY

University Park, Pennsylvania

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## ABSTRACT

A series of observations is described of ionospheric conditions associated with the initiation of spread F in the mid-latitude ionosphere. The morphology of spread F at Puerto Rico was investigated. Data from 7 nights was examined for Arecibo, five with spread F and two without. The relative height of the F-layer maximum and the vertically integrated Pedersen conductivity, the relation between E and F region conductivities, the coupling lengths between the E and F regions, and vertical and horizontal gradients of electron density were examined. At Millstone Hill 13 nights were examined for all of which spread F was observed. The EW and NS velocities and the vertical velocities and the electric ion temperature ratio were examined.

## Chapter 1
## INTRODUCTION

There is considerable interest in the study of the mechanisms for the production of irregularities in the mid-latitude ionospheric F-region. Such irregularities cause scintillation of satellite signals and fading of high frequency radio communications. They have been observed for many years on ionosondes as a spread in the echoes referred to as "spread F". Attempts have been made to characterize the phenomena as "range spreading" when the echoes appear to be multiple echoes with a spread in echo delay that is almost independent of frequency and "frequency spreading" when the effect is observed as a spread in the maximum ordinary or extraordinary critical frequency. It is believed that both types of spread F are caused by similar irregularities and that the length scale, orientation, and the intensity of the fluctuation is responsible for the difference in appearance on ionosonde traces. The behavior of spread F is different in the equational, mid-latitude and high latitude ionospheres and the instability mechanisms appear to be different.

Several mechanisms have been proposed to explain mid-latitude spread F based on different plasma instability mechanisms such as those of Reid (1968), Perkins (1973) and McDonald et.al. (1975). In each of these papers assumptions have been made about the instability mechanism, and the conditions necessary for growth. In this paper attention will be paid to the geophysical conditions observed at the time of initiation of mid-latitude spread F to allow both the correctness of the assumptions about conditions for onset of spread

F and about the validity of the assumptions made in the treatments that may affect the calculation of growth rates. The data used in this study are from Arecibo and Millstone Hill incoherent scatter sounding facilities which provide data on the electron densities, electron and ion temperatures, and ion drift velocities that can be used to deduce important parameters of the electric field and neutral wind systems.

## Chapter II
## DESCRIPTION OF THE DATA BASE

The Millstone Hill facility is a typical mid-latitude facility with geographic coordinates 42.6°N; 288.5°W; and geomagnetic coordinates 54.09°N; 356.86° and has an L parameter of 3.12. Singleton (1975) has presented a model of spread F incidence at such stations.

The Arecibo Observatory is in a rather unique position because of the very different geographical coordinates of its conjugate location, Zinchenko and Nisbet (1976). It has geographic coordinates 18.50°N; 293.17°E; geomagnetic coordinates 29.99°N; 02.38°E; and an L parameter of 1.43.

The Singleton (1975) model shows a deep minimum in spread F incidence at 30° magnetic latitude. Spread F is seen, however, at Arecibo, Mathews and Harper (1972). It was first decided to do a small study of ionosonde data at Puerto Rico for three years of varying solar activity to determine the morphology of spread F at that site. Figure 1 shows the percentage of nights on which spread F was observed in 1959, 1960 and 1961 and the Zurich Sunspot Number $R_z$ for this period. It is apparent that there is a large winter maximum, minima at the equinoxes and a summer maximum that is much smaller at high solar activity than it is when the sunspot number is lower. Under low sunspot conditions it is seen that the probability of seeing spread F on any night was of the order of 90% in January (Figure 2).

Figure 3 shows the local time variation of spread F at Arecibo. It can be seen that it is a night time phenomenon. It starts around the

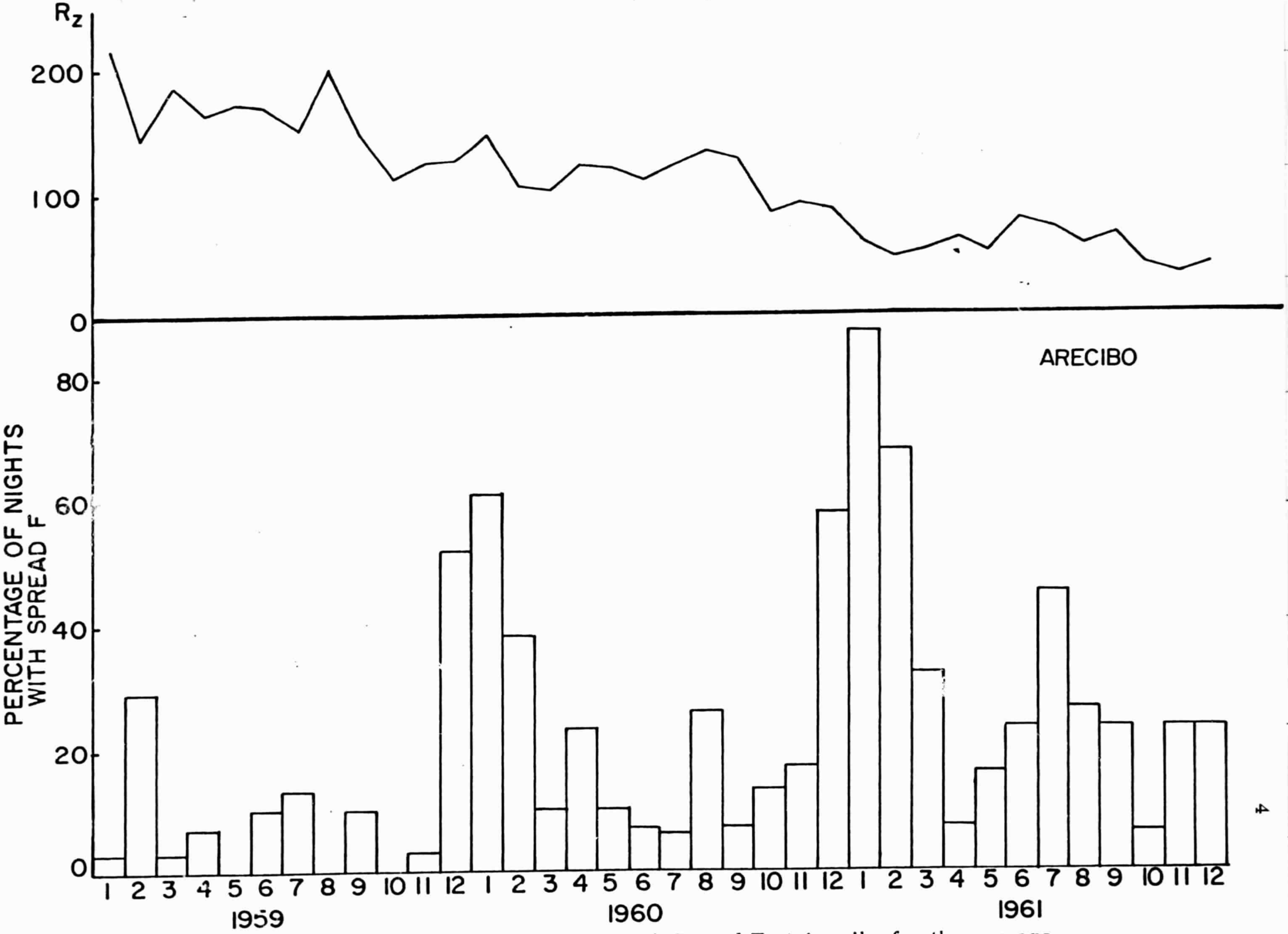
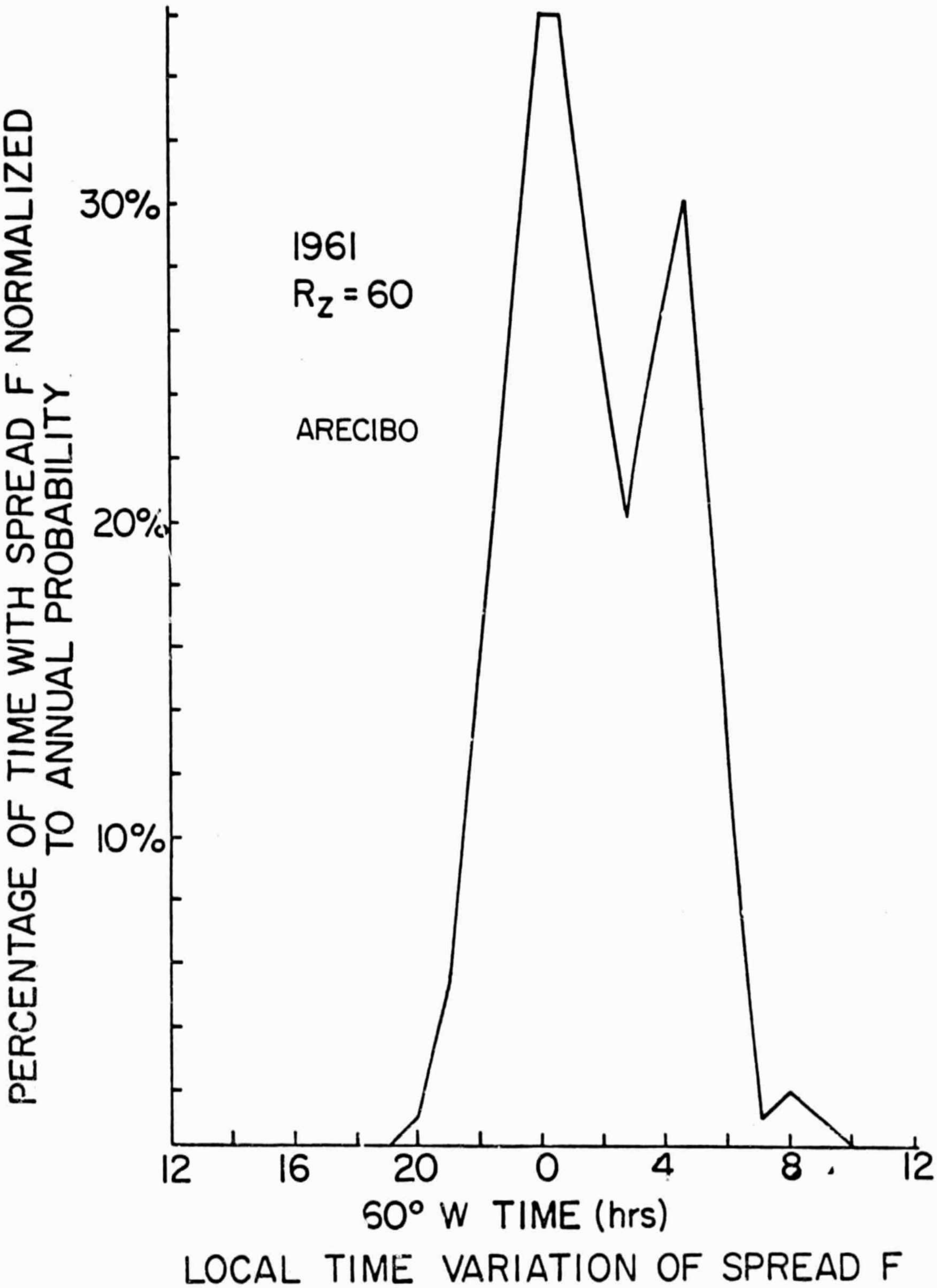



Figure 1: Monthly percentage of nights with Spread F at Arecibo for three years (1959, 1960, 1961) and monthly index of sunspot activity.




LOCAL TIME VARIATION OF SPREAD F AT ARECIBO

Figure 2: Percentage of time with Spread F versus local time normalized to annual probability, Arecibo 1961.

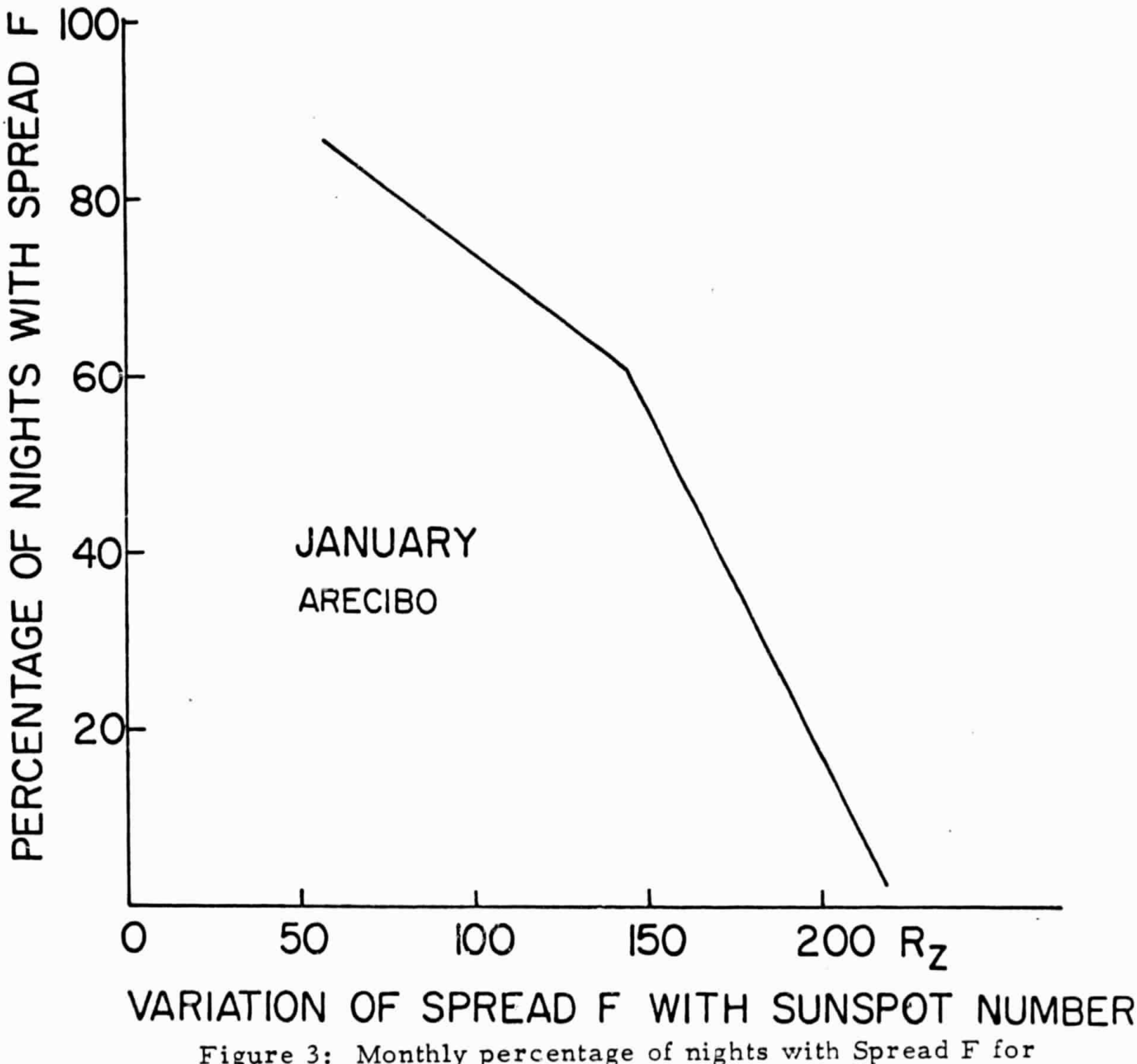



Figure 3: Monthly percentage of nights with Spread F for January as a function of sunspot number, Arecibo.

time of local sunset, reaches a maximum around midnight and there is a minimum which appears at about the same time as the post midnight collapse. After the collapse then there is another maximum and spread F dies away at dawn. The post midnight decrease in spread F occurrence at mid-latitudes has been discussed previously by Glover (1960) and Bowmann (1975).

Table 1 gives the times of onset of spread F and the solar and geomagnetic conditions for the Millstone observations. Table 2 gives similar data for the Arecibo observations.

In our study we have used 13 nights when spread F was observed at Millstone Hill, 5 nights during which spread F was observed at Arecibo and 2 nights on which it was not observed for comparison.

Data available from Millstone Hill were the drift velocities at the level of 300 km in North-South, East-West and vertical directions (L. Carpenter, V. Kirchhoff, 1975); $h_M F_2$; $N_M F_2$; and electron and ion temperatures at the level of 300 km. The data from Arecibo included the profiles of electron density, electron and ion temperatures, Pedersen, Hall, and direct conductivities, different components of drift velocities, horizontal and vertical gradients of electron density, and $h_M F_2$ and $N_M F_2$. The data used in this analysis were not obtained specifically to study spread F and so the full potentialities of the instruments for an investigation of this type were not employed.

## Table 1

### Millstone Hill

| Date | Nov. 21, 1968 | July 20, 1971 | Jan. 27, 1972 | March 24, 1972 | July 26, 1972 | Dec. 6, 1972 |
|---|---|---|---|---|---|---|
| Day Number | 326 | 201 | 27 | 84 | 208 | 341 |
| Time of the onset of spread F | 03.59 | 04.01 | 04.29 | 07.06 | 19.16 | 04.45 |
| geomagnetic and solar conditions | $\Sigma K_p = 12.33$<br>$F10.7 = 137.1$<br>$\overline{F}10.7 = 146.4$<br>$R_z = 84$ | $\Sigma K_p = 7$<br>$F10.7 = 115.0$<br>$\overline{F}10.7 = 111.1$<br>$R_z = 91$ | $\Sigma K_p = 24$<br>$F10.7 = 122.6$<br>$\overline{F}10.7 = 127.0$<br>$R_z = 92$ | $\Sigma K_p = 26.66$<br>$F10.7 = 127.4$<br>$\overline{F}10.7 = 127.7$<br>$R_z = 109$ | $\Sigma K_p = 25$<br>$F10.7 = 116.9$<br>$\overline{F}10.7 = 127.7$<br>$R_z = 77$ | $\Sigma K_p = 5$<br>$F10.7 = 80.1$<br>$\overline{F}10.7 = 102.2$<br>$R_z = 18$ |

| | Dec. 7, 1972 | Feb. 12, 1974 | Feb. 13, 1974 | Apr. 16, 1974 | Apr. 16, 1974 | July 15, 1974 | July 16, 1974 |
|---|---|---|---|---|---|---|---|
| ber | 342 | 43 | 44 | 106 | 106 | 196 | 197 |
| e of onset pread | 04.15 | 20.00 | 22.45 | 00.30 | 20.45 | 23.30 | 22.00 |
| mag- c and r ditions | $\Sigma K_p = 18$<br>$F10.7 = 89.8$<br>$\overline{F}10.7 = 102.2$<br>$R_z = 24$ | $\Sigma K_p = 35.66$<br>$F10.7 = 78.5$<br>$\overline{F}10.7 = 81.1$<br>$R_z = 22$ | $\Sigma K_p = 27.33$<br>$F10.7 = 79.3$<br>$\overline{F}10.7 = 81.1$<br>$R_z = 48$ | $\Sigma K_p = 7$<br>$F10.7 = 85.3$<br>$\overline{F}10.7 = 114.2$<br>$R_z = 77$ | $\Sigma K_p = 7$<br>$F10.7 = 85.3$<br>$\overline{F}10.7 = 114.2$<br>$R_z = 77$ | $\Sigma K_p = 9$<br>$F10.7 = 82.8$<br>$\overline{F}10.7 = 92.5$<br>$R_z = 49$ | $\Sigma K_p = 17.33$<br>$F10.7 = 88.4$<br>$\overline{F}10.7 = 92.5$<br>$R_z = 54$ |

**Table 2**

**Arecibo**

| te | Sept. 17, 1974 | Sept. 18, 1974 | Nov. 9, 1974 | Apr. 15, 1975 | May 18, 1975 | Jun. 2, 1975 | Jan. 20, 1976 |
|---|---|---|---|---|---|---|---|
| y mber | 260 | 261 | 313 | 105 | 138 | 153 | 20 |
| me of onset spread | 21.50 | 20.56 | No $F_s$ | 18.31 | 19.45 | No $F_s$ | 19.00 |
| omag- tic and lar nditions | $\Sigma K_p = 6.70$<br>$F10.7 = 99.3$<br>$\bar{F}10.7 = 85.7$<br>$R_z = 71$ | $\Sigma K_p = 20.10$<br>$F10.7 = 99.1$<br>$\bar{F}10.7 = 86.1$<br>$R_z = 66$ | $\Sigma K_p = 34.40$<br>$F10.7 = 80.4$<br>$\bar{F}10.7 = 92.8$<br>$R_z = 7$ | $\Sigma K_p = 14.70$<br>$F10.7 = 69.2$<br>$\bar{F}10.7 = 72.0$<br>$R_z = 0$ | $\Sigma K_p = 16.00$<br>$F10.7 = 67.1$<br>$\bar{F}10.7 = 70.8$<br>$R_z = 8$ | $\Sigma K_p = 31.40$<br>$F10.7 = 70.9$<br>$\bar{F}10.7 = 69.9$<br>$R_z = 11$ | $\Sigma K_p = 18.70$<br>$F10.7 = 77.1$<br>$\bar{F}10.7 = 75.4$<br>$R_z = 16$ |

# Chapter III
## EXPERIMENTAL RESULTS AND ANALYSES

As has been noted by many authors such as W. Calvert (1962) and R. K. Misra (1973) spread F always starts during periods when the F-layer is high. This means that the transverse conductivity of the F-layer which is proportional to the neutral density will be small at these times. Perkins (1973) suggested that the inverse relation between the height of the F-layer and the integrated Pedersen conductivitv causes the electrical support mechanism to be unstable. To illustrate this point Figures 5 to 11 show the calculations of F-layer integrated Pedersen conductivity versus local time for seven nights at Arecibo. In these figures we have plotted as a dashed line the height of the maximum of the layer using an inverted scale. The integrated Pedersen conductivity in the F-layer is shown with solid lines calculated from the Arecibo measurements. These figures illustrate quite well the inverse relationship between the integrated conductivity and the height of the main peak. This is valid both for the nights with spread F (Figures 5 to 9) and without spread F (Figures 10 and 11). The drift velocities can be used to determine the electric field which plays an important role in supporting the night-time F-layer and in triggering the instabilities. The drift velocity components in the north-south, east-west and vertical directions at the level of 300 km for the times of spread F onset have been analyzed. The results can be summarized as follows:

1. For the onset of spread F it seems to be necessary to have a westward component of drift velocity.

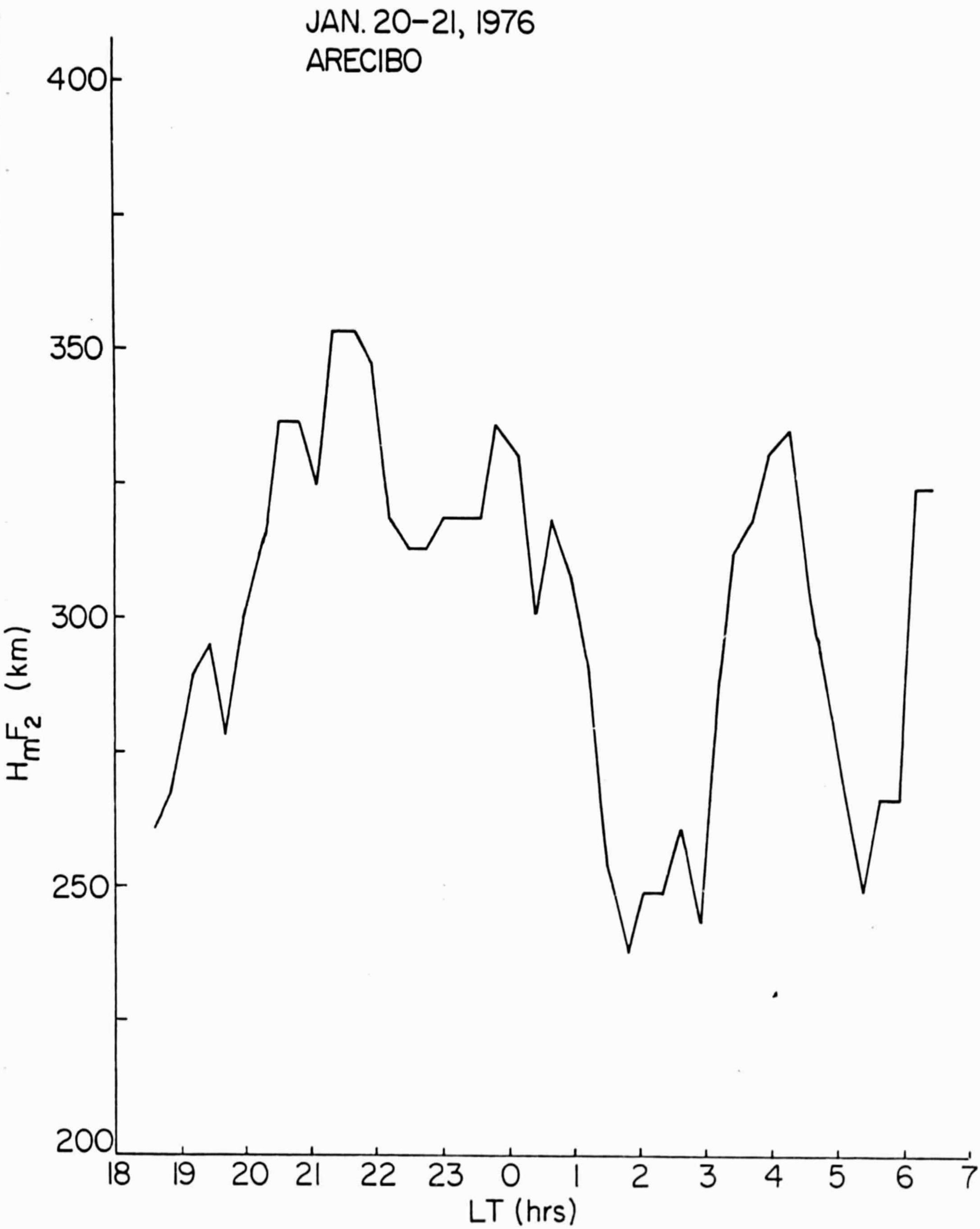



Figure 4: Time variation of the height of main peak for the night of 20-21 Jan. 1976, Arecibo.

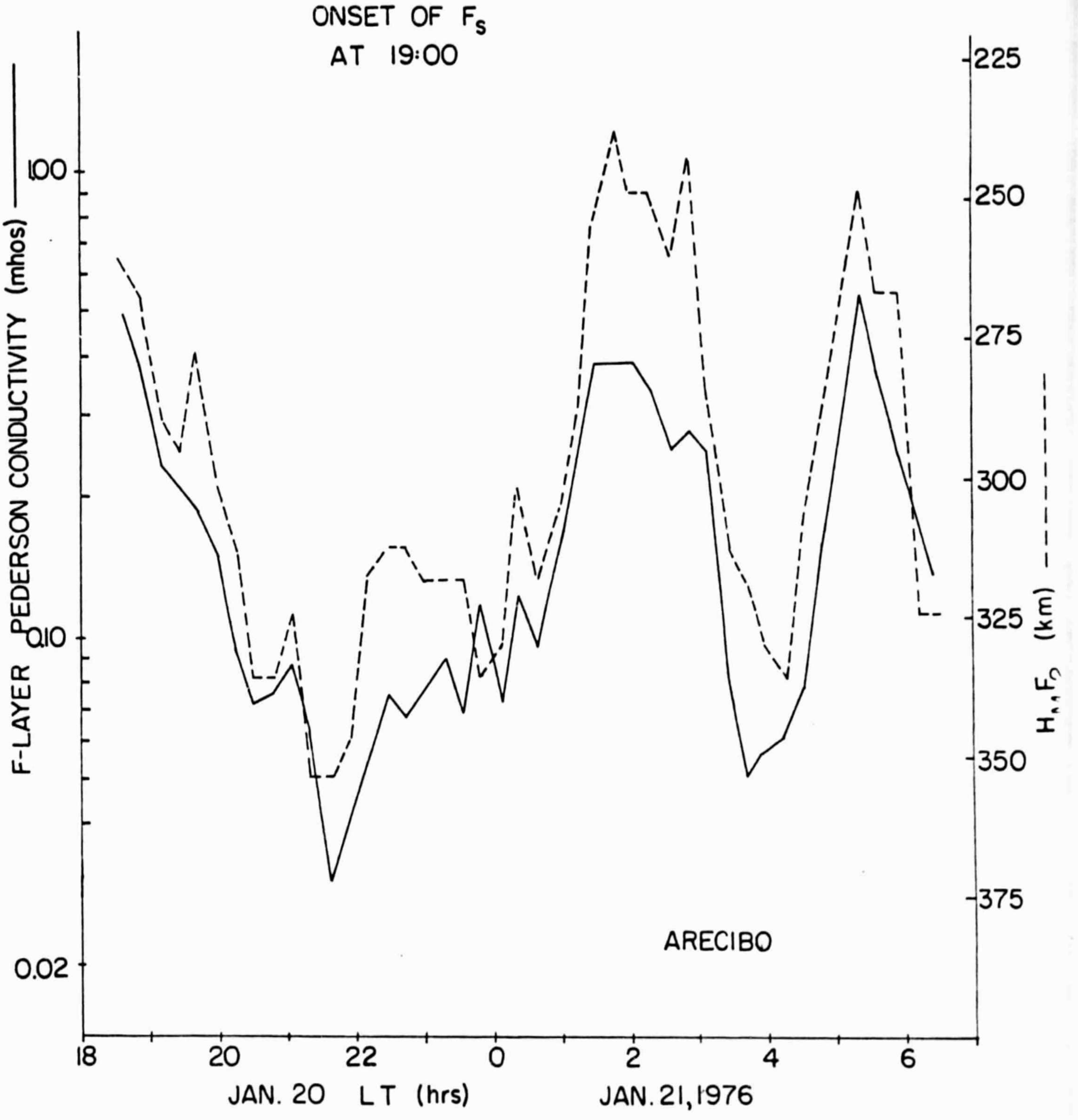



Figure 5: Time variations of the integrated F-layer Pedersen conductivity and the height of the main peak, Arecibo, 20-21 Jan. 1976.

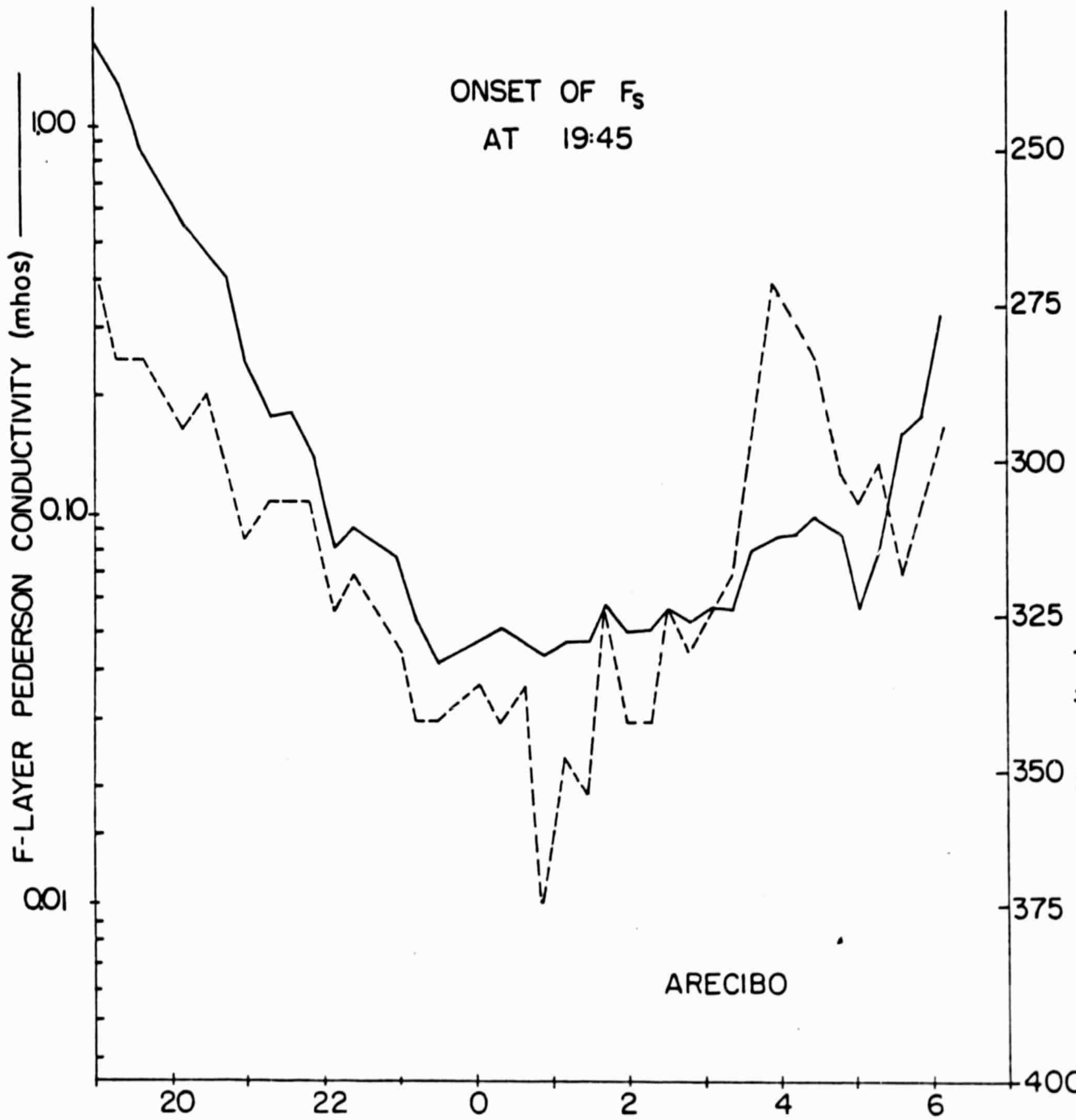



Figure 6: Time variations of the integrated F-layer Pedersen conductivity and the height of the main peak, Arecibo, 18-19 May, 1975.

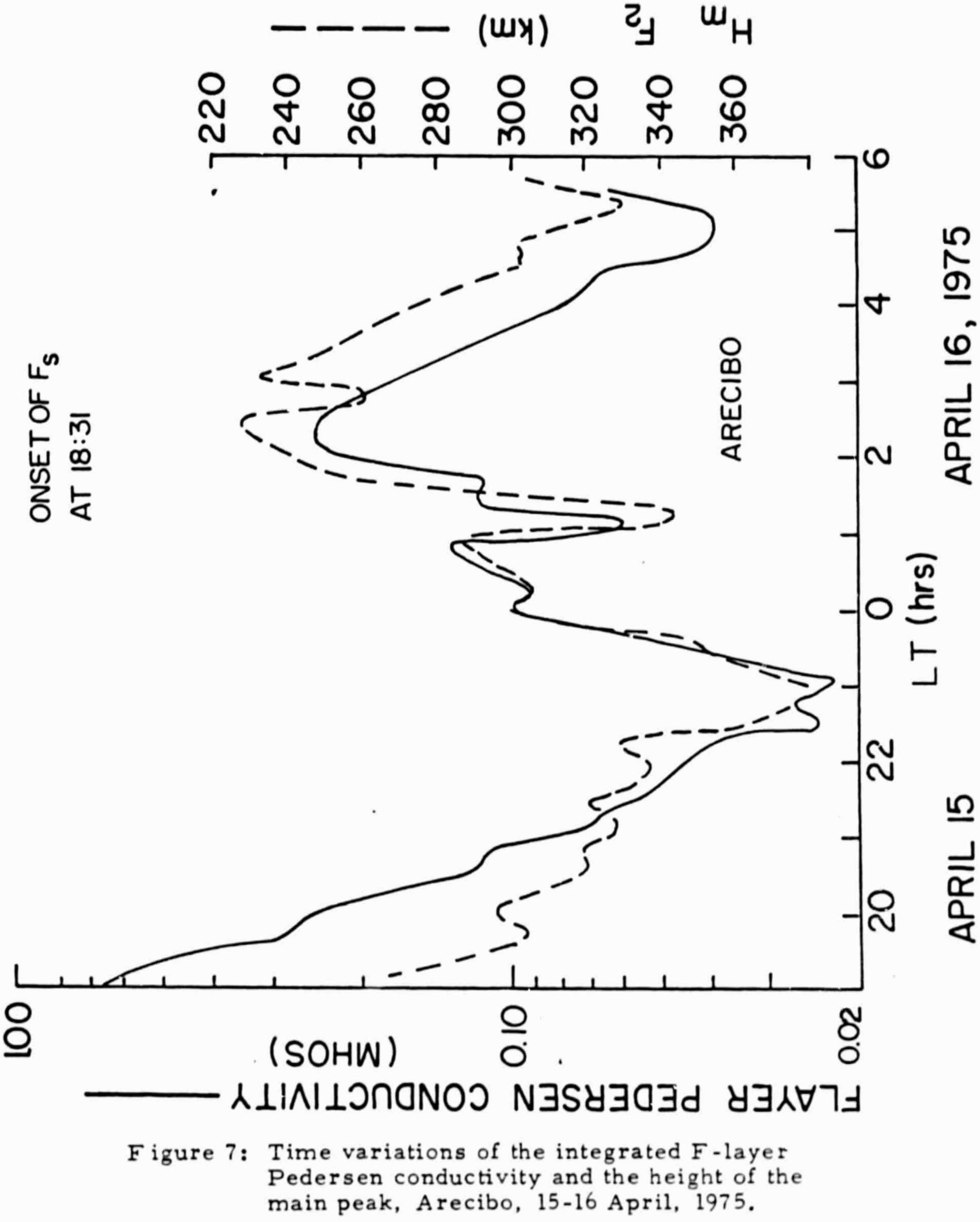



Figure 7: Time variations of the integrated F-layer Pedersen conductivity and the height of the main peak, Arecibo, 15-16 April, 1975.

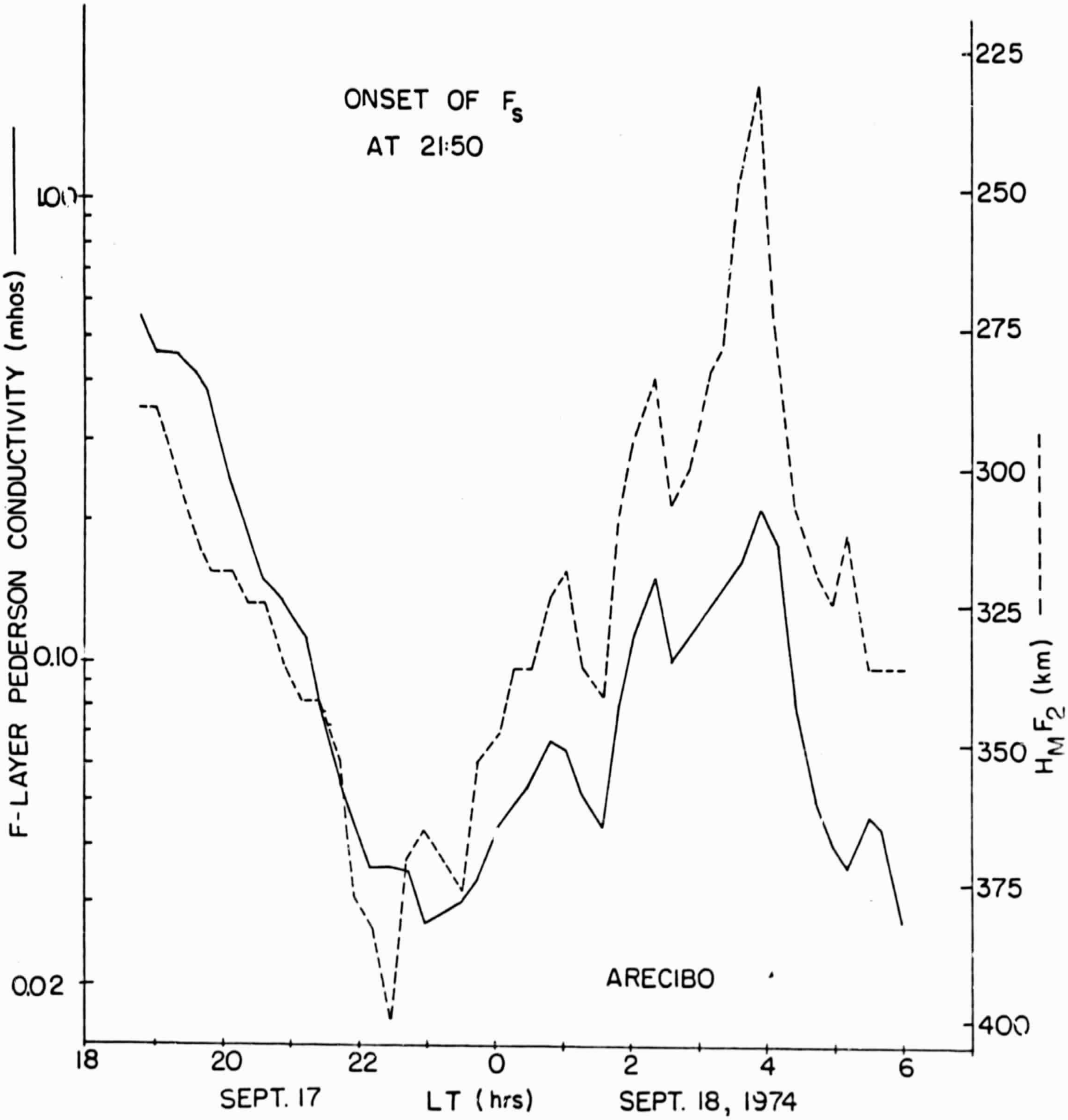



Figure 8: Time variations of the integrated F-layer Pedersen conductivity and the height of the main peak, Arecibo, 17-18 September, 1974.

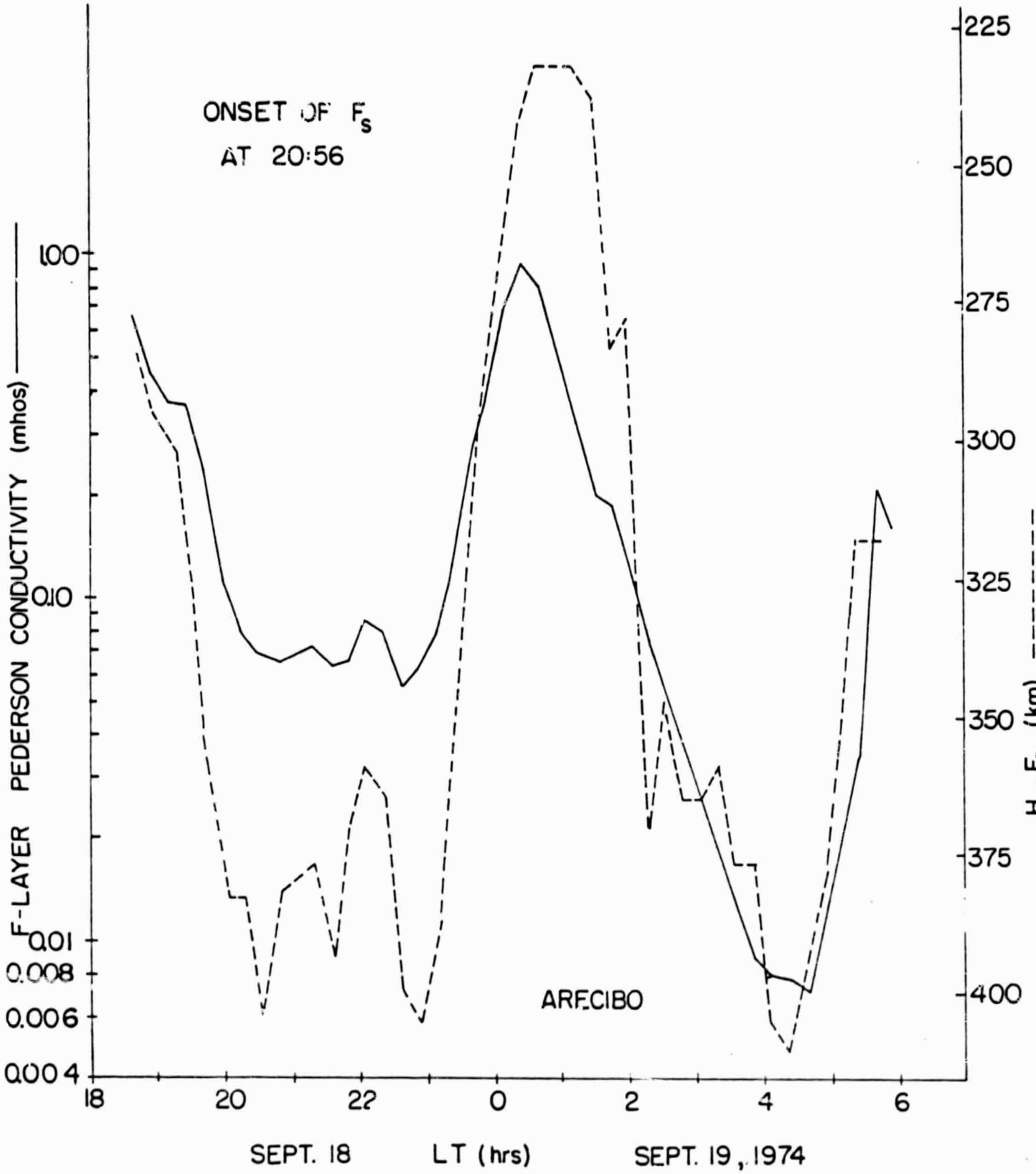



Figure 9: Time variations of the integrated F-layer Pedersen conductivity and the height of the main peak, Arecibo, 18-19 September, 1974.

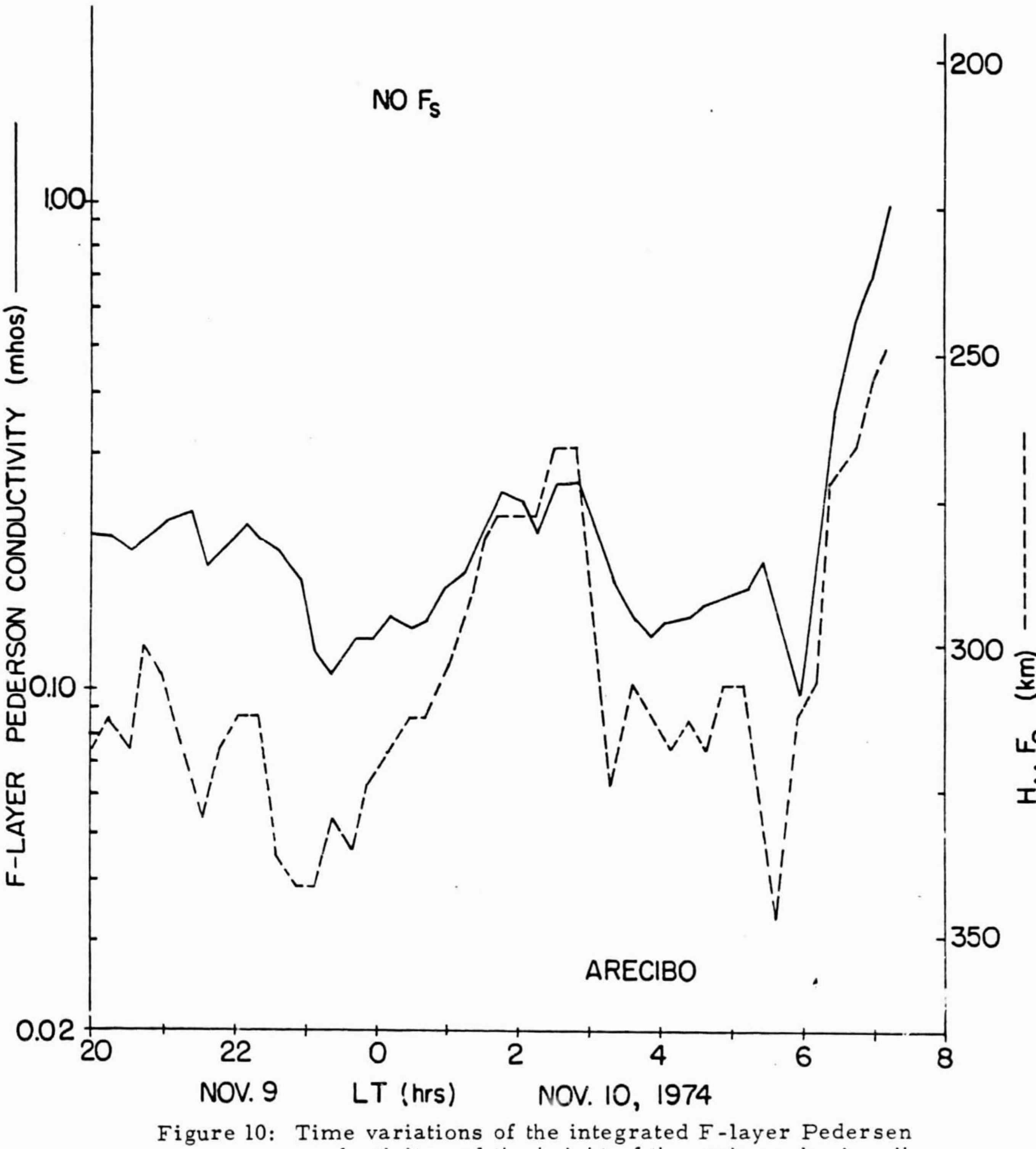



Figure 10: Time variations of the integrated F-layer Pedersen conductivity and the height of the main peak, Arecibo, 9-10 November, 1974.

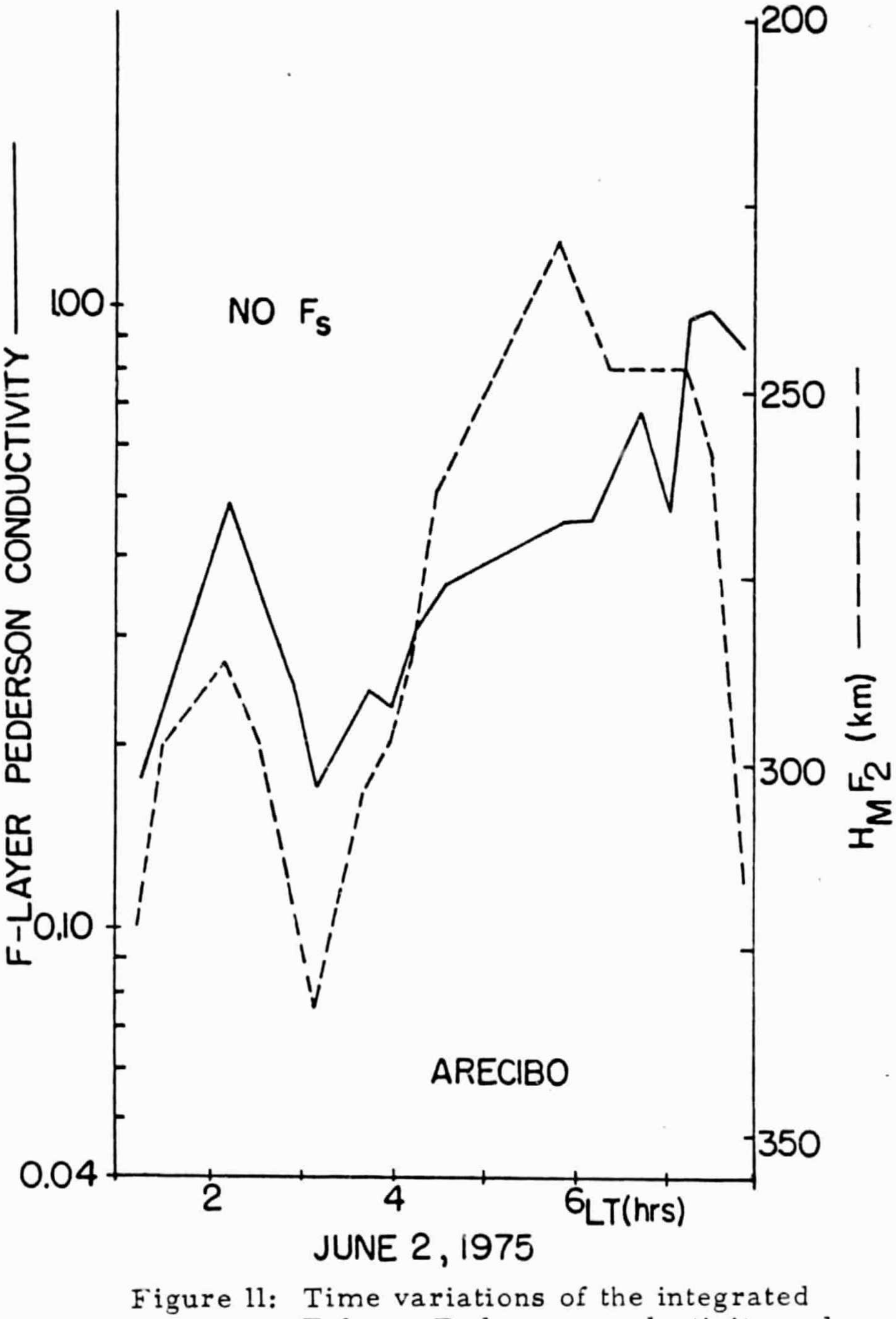



Figure 11: Time variations of the integrated F-layer Pedersen conductivity and the height of the main peak, Arecibo, 2 June, 1975.

2. For all days analyzed with spread F the downward component of drift velocity is present while spread F is starting.

3. Average values of drift velocities' components observed at the onset of spread F were:

$$\overline{V}_{N-S} = 9 \text{ m sec}^{-1}$$

$$\overline{V}_{W} = 49 \text{ m sec}^{-1}$$

$$\overline{V}_{Down} = 18 \text{ m sec}^{-1}$$

As mid-latitude spread F is essentially a night-time phenomenon it is usually assumed in the theories such as those of Perkins (1973) that the ionospheric plasma is in thermal equilibrium. While this is true for much of the night since the spread F usually starts soon after the local sunset it was found at the times of spread F onset that Te was not equal to Ti. The ratio Te/Ti varied from 1.4 to 2.0 with an average value Te/Ti = 1.6. It should be noted however that this disagreement between experimental values of Te/Ti and the theoretical assumption is not vital for most mechanisms suggested but will only slightly change the calculated gorwth rate.

More important for the validity of the mechanisms is the relation between the conductivities of E and F layer. To decide which of these regions is responsible for originating the instabilities causing the spread F it is necessary to determine which conductivity dominates the night-time ionosphere during spread F conditions, if the conductivities of the E and F-layers are comparable, and how strong is the coupling between these regions. By such checks it is possible to test the validity of neglecting the conductivity of one of these regions as it has been done by Perkins (1973) with respect to E-region conductivity. It is also possible to examine whether electric fields due to irregularities triggered in the E-region can be coupled to the F-region to produce spread F.

Figures 12 to 16 show the behavior of integrated F-region Pedersen conductivity and E-region Pedersen and Hall conductivities during five nights with spread F at Arecibo. From these figures and Table 2 it is apparent that E-region conductivities either dominate or are comparable with the F-region Pedersen conductivity during most of the nights when spread F was observed.

Figures 17 and 18 show the behavior for two nights at Arecibo when there was no spread F. During the most of the nights without spread F the F-region Pedersen conductivity is really considerably larger than the E-region Pedersen conductivity but smaller than the E-region Hall conductivity.

In analyzing these data it is thus necessary to consider to what extent the F-region is coupled to the E-region with its higher conductivities and to the conjugate ionosphere.

In local winter at Arecibo at the time spread F starts the conjugate ionosphere is sunlit and so the integrated Pedersen conductivity there would be expected to be quite large. Figure 19 shows the coupling length between E and F-region calculated from high resolution measurements made at Arecibo. Frequently during the night at Arecibo the electron densities become quite small in the trough between the E and the F-region. The parameter of

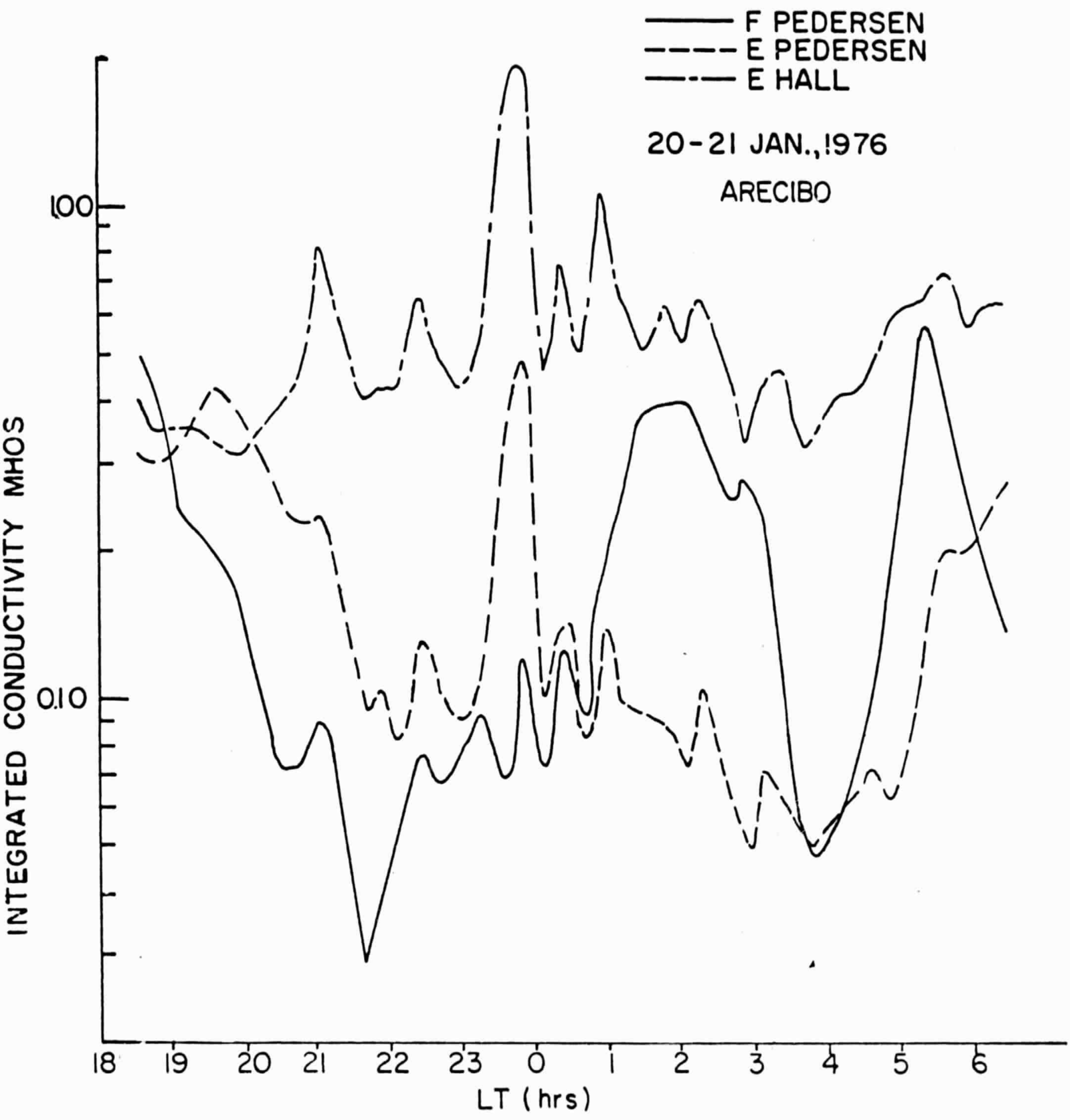



Figure 12: Time variations of integrated F-layer Pedersen and E-layer Pedersen and Hall conductivities, Arecibo, 20-21 January, 1976.

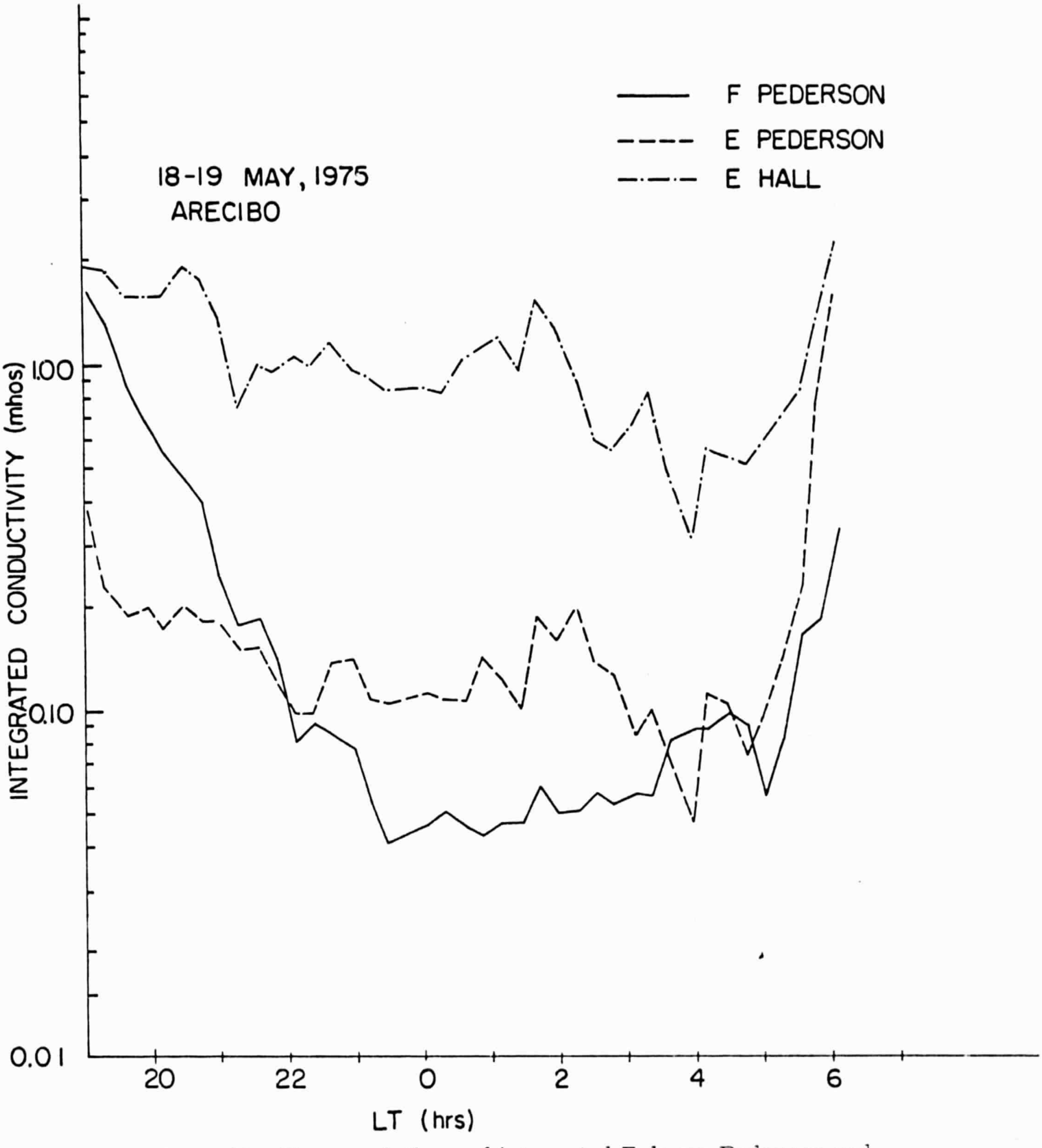



Figure 13: Time variations of integrated F-layer Pedersen and E-layer Pedersen and Hall conductivities, Arecibo, 18-19 May, 1975.

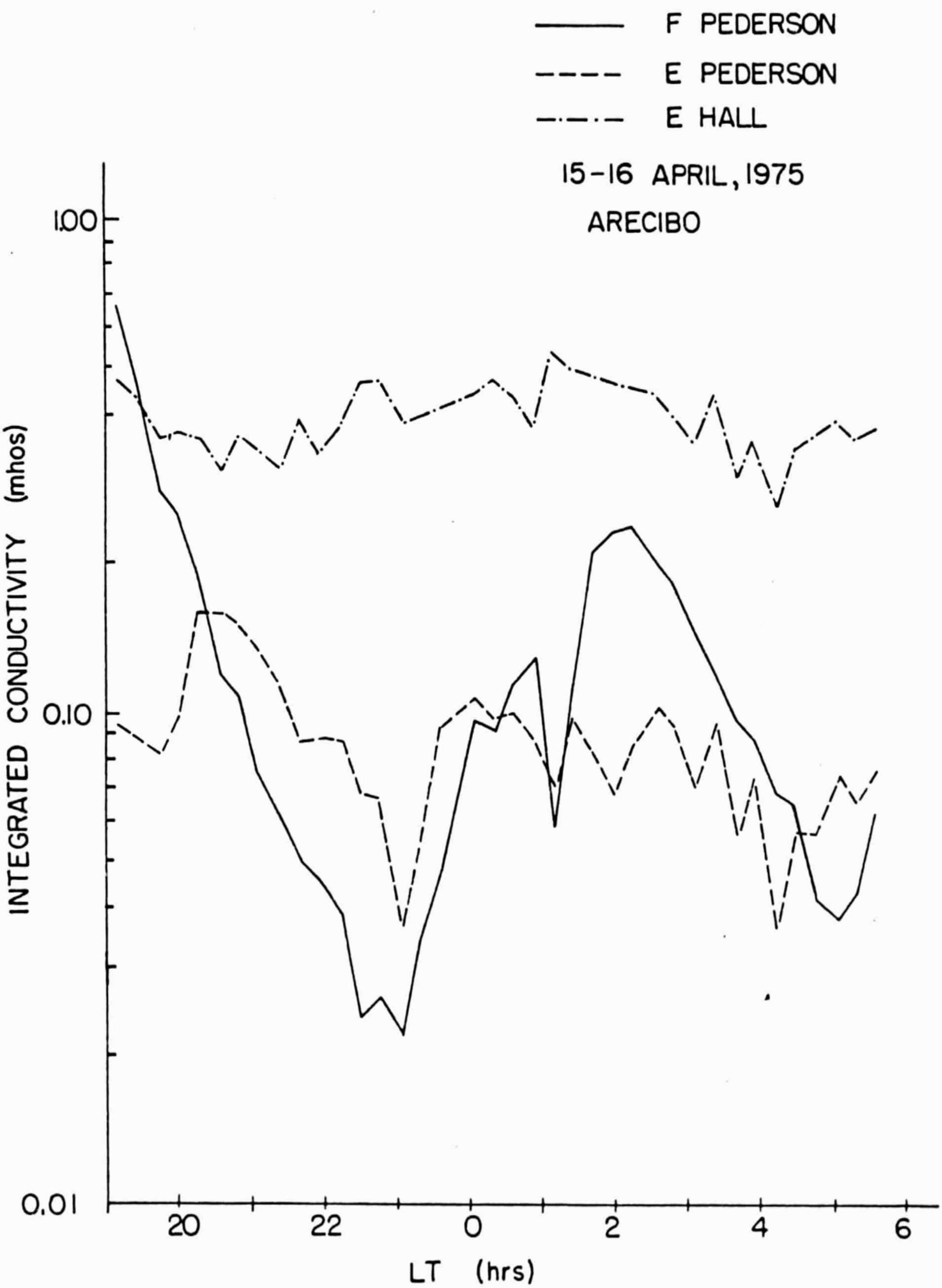



Figure 14: Time variations of integrated F-layer Pedersen and

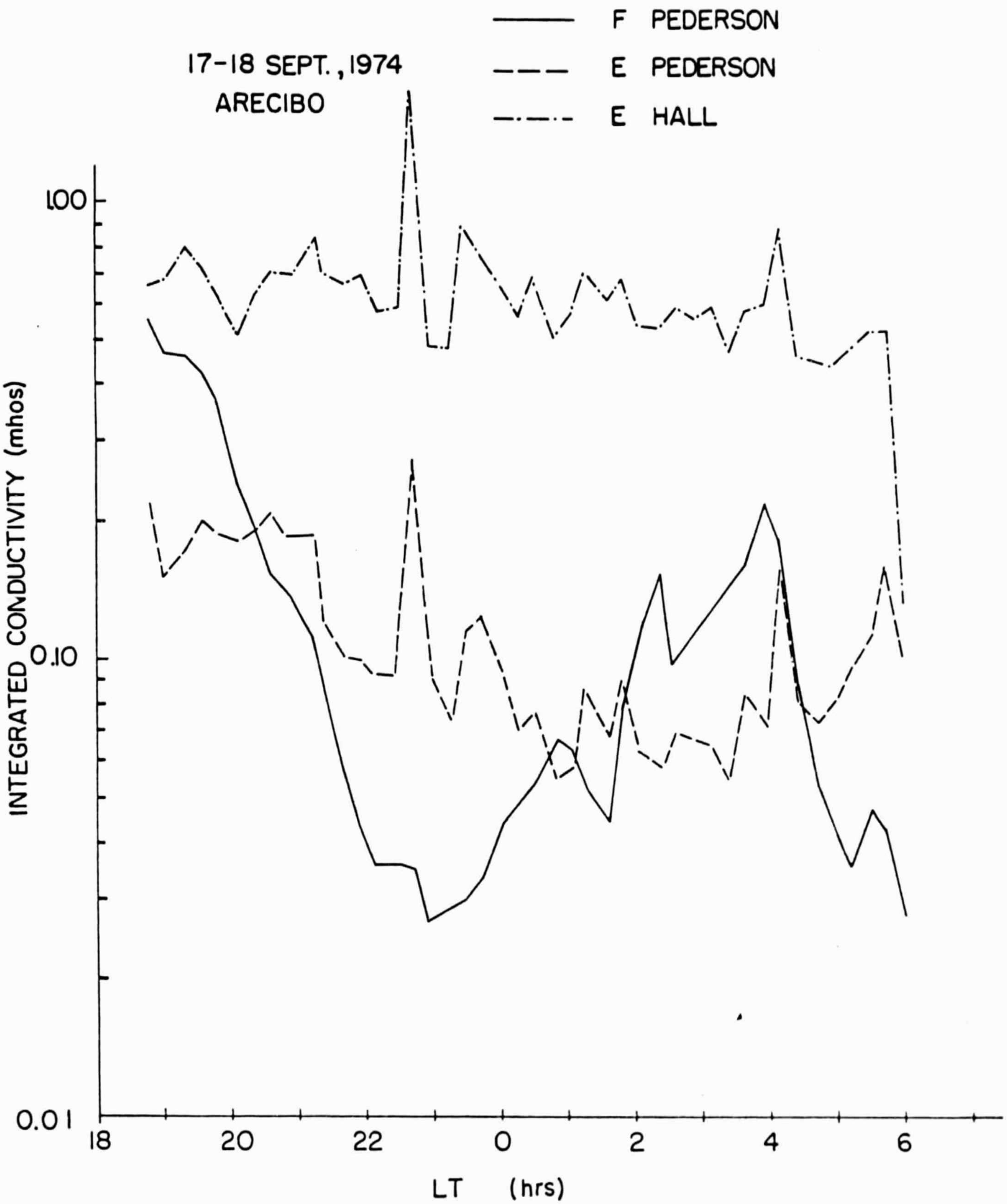



Figure 15: Time variations of integrated F-layer Pedersen and E-layer Pedersen and Hall conductivities, Arecibo, 17-18 September, 1974.

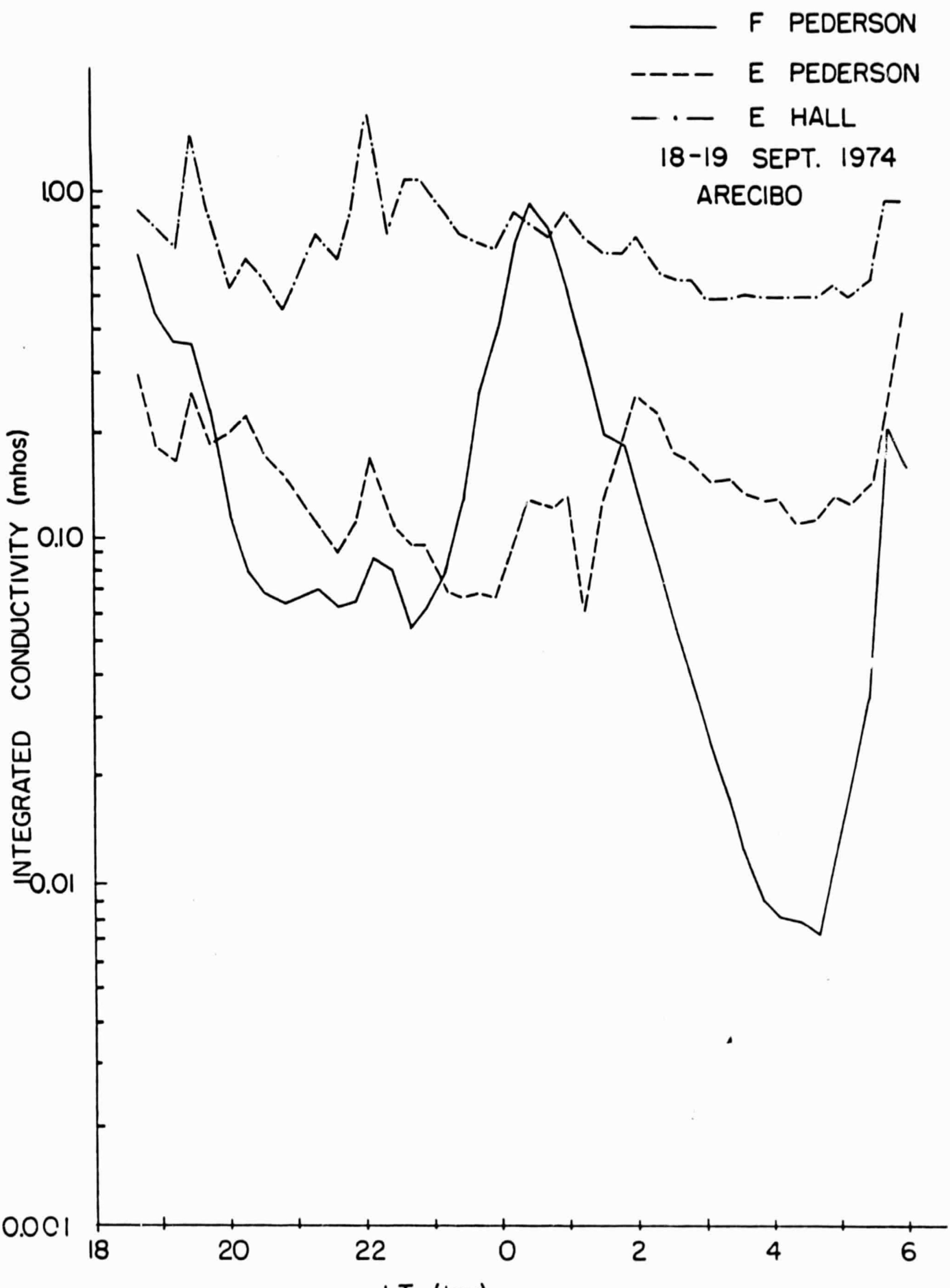
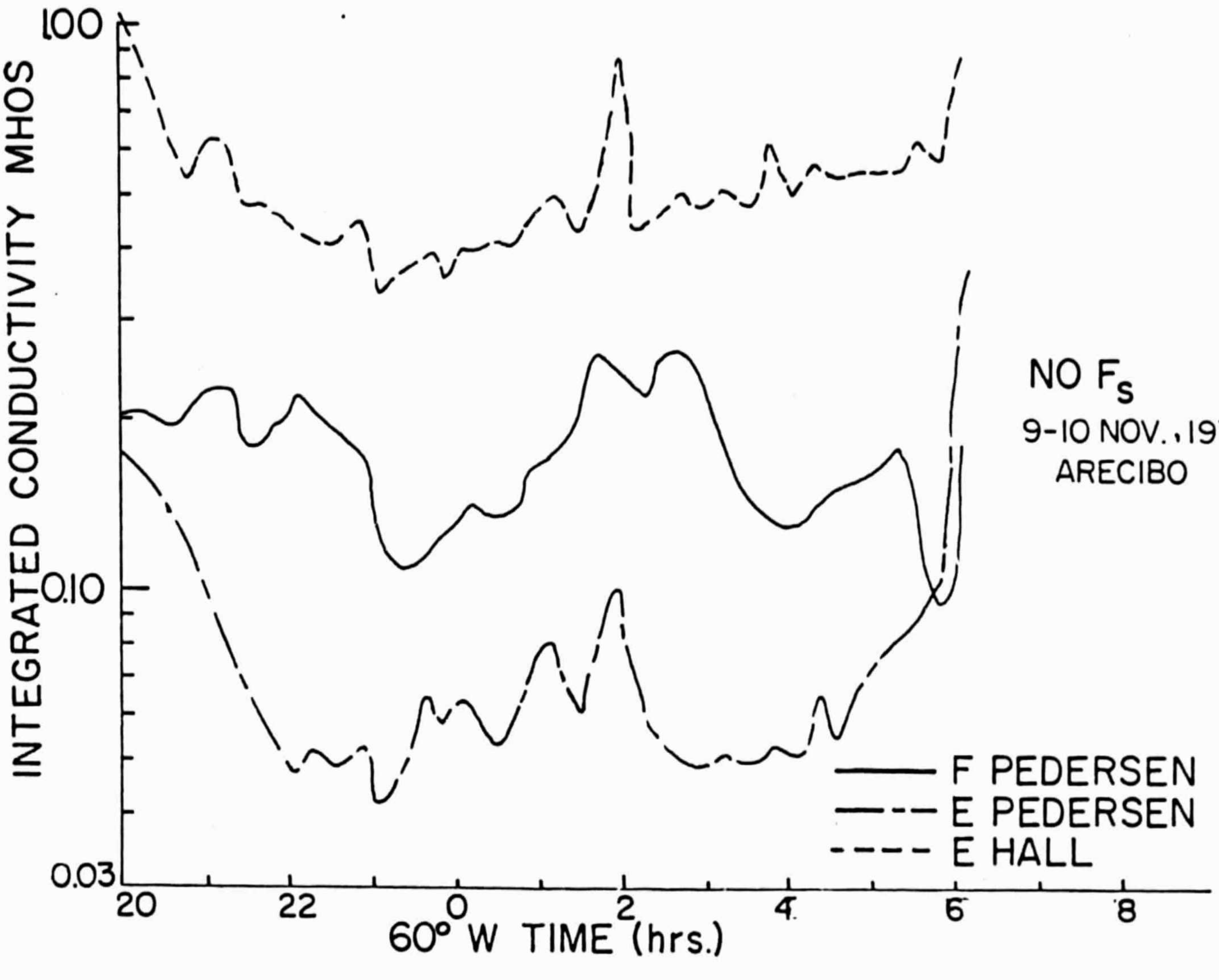



Figure 16: Time variations of integrated F-layer Pedersen and E-layer Pedersen and Hall conductivities, Arecibo.




HEIGHT INTEGRATED CONDUCTIVITIES FOR E&F REGION

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Figure 17: Time variations of integrated F-layer Pedersen and E-layer Pedersen and Hall conductivities, Arecibo, 9-10 November, 1974.

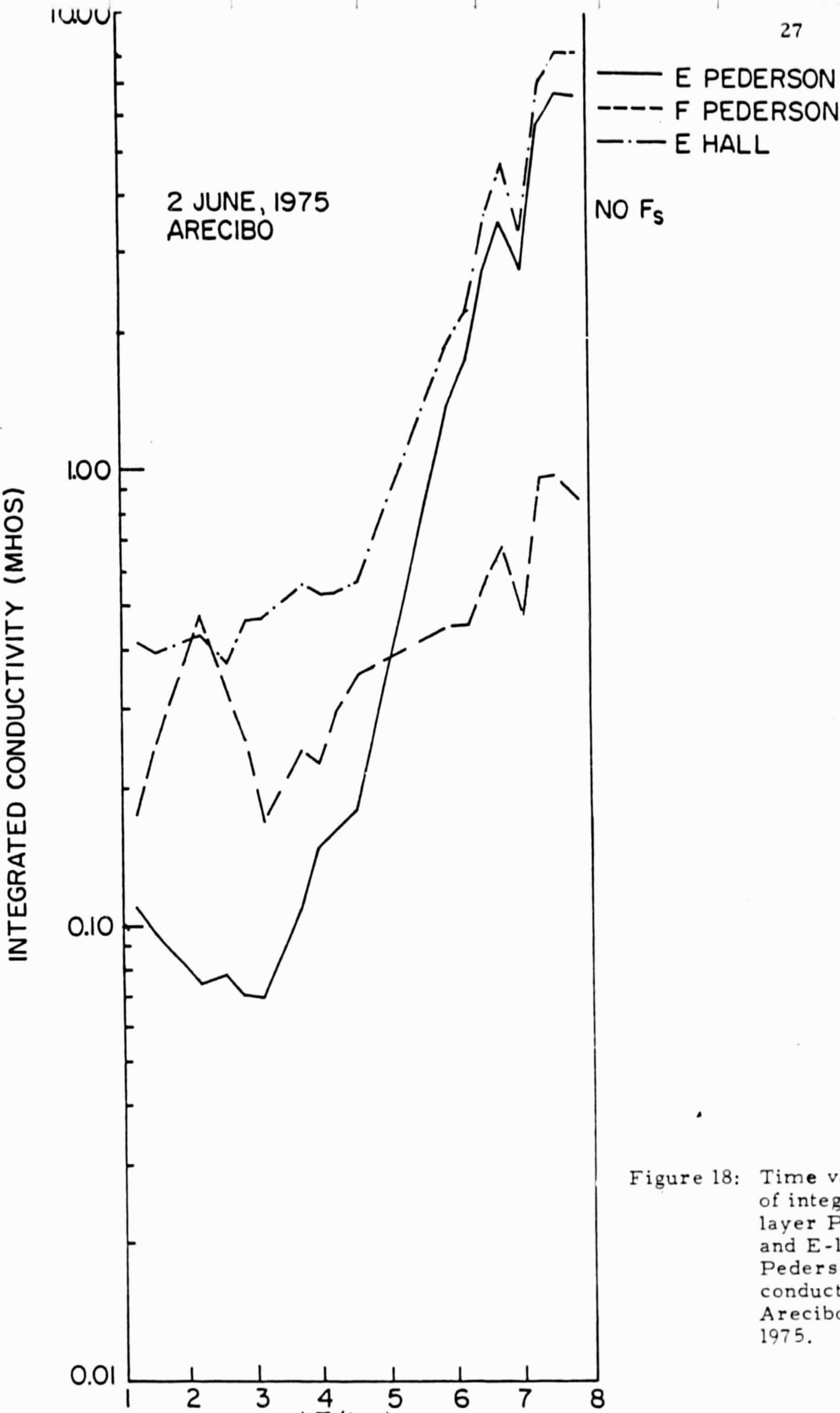


Figure 18: Time variations of integrated F-layer Pedersen and E-layer Pedersen and Hall conductivities, Arecibo, 2 June, 1975.

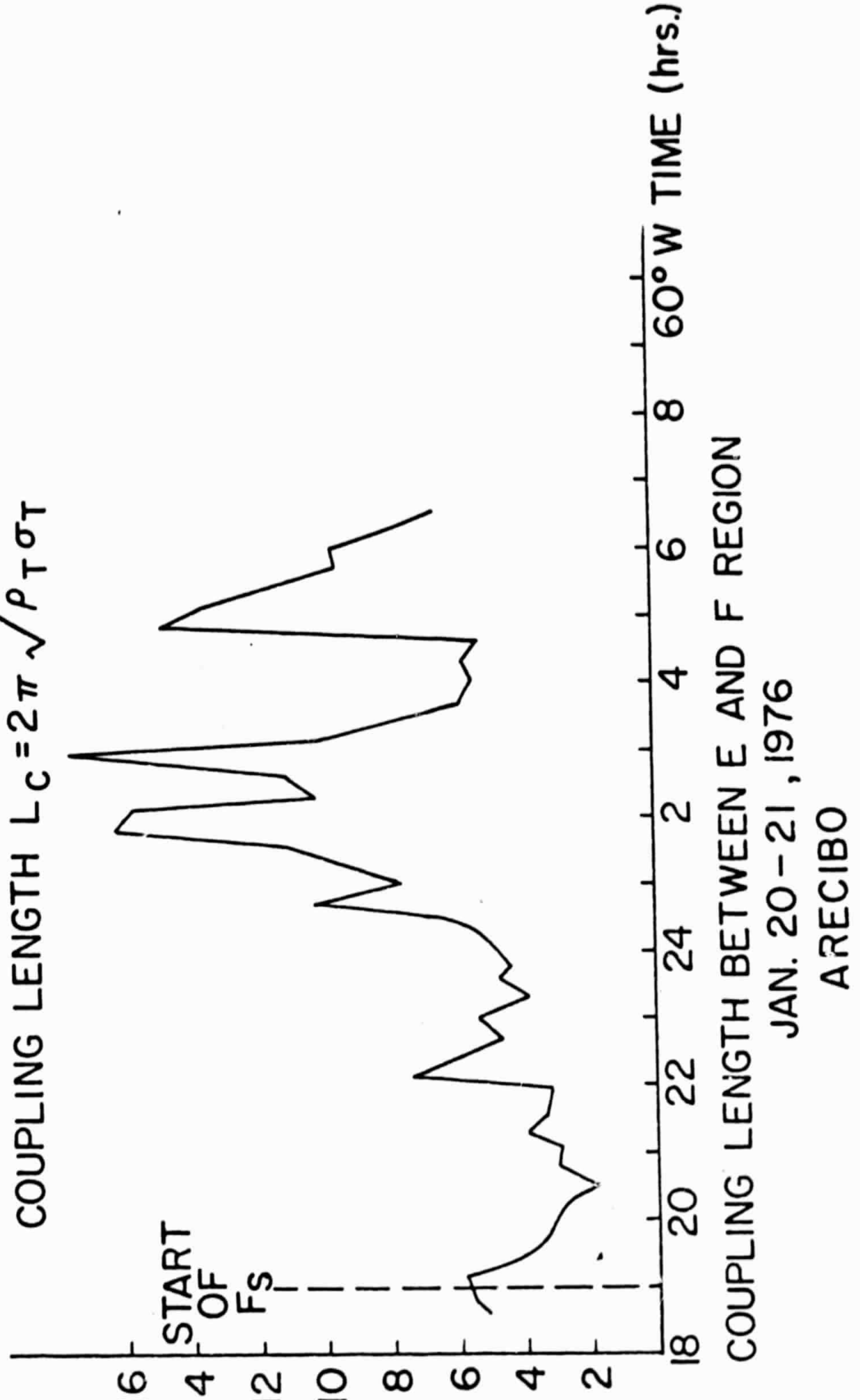


Figure 19: Coupling length between night-time E and F layers, Arecibo, 20-21 January, 1976.

importance in determining whether two regions are coupled is the coupling length shown at the top of Figure 1 (Zinchenko and Nisbet, 1976). The coupling length is the wave-length of a sinusoidal density perturbation which would result in the electric field being attenuated by a factor of two in the coupled region. When the wave-length of the perturbation is small compared to the coupling length the two regions can be considered to be isolated and when the wave-length of the perturbation is large compared to the coupling length the two regions can be considered to be coupled to each other. As can be seen a coupling length at the time spread F started was about 6 km and the minimum coupling length during the night was of the order of 2 km. The coupling length to the conjugate ionosphere has also been estimated (Zinchenko and Nisbet, 1976). The calculations made it appear that the coupling length to the conjugate ionosphere must be of the order of 2 km. It would thus appear that in theories predicting the onset of spread F, the F-region can be considered to be isolated from the E-region and the conjugate ionosphere for perturbations of wave-length much smaller than 2 km and to be directly coupled to these regions at much longer wavelengths.

It should be noted here that according to Mathews and Harper (1972) the range spreading type of spread F is believed to be caused by the large-scale tilts or gradients of tens of km scale size in the ionosphere and so at least for this type of spread F the possible influence of perturbations originally triggered in the conjugate ionosphere or even the E-layer cannot be excluded from consideration.

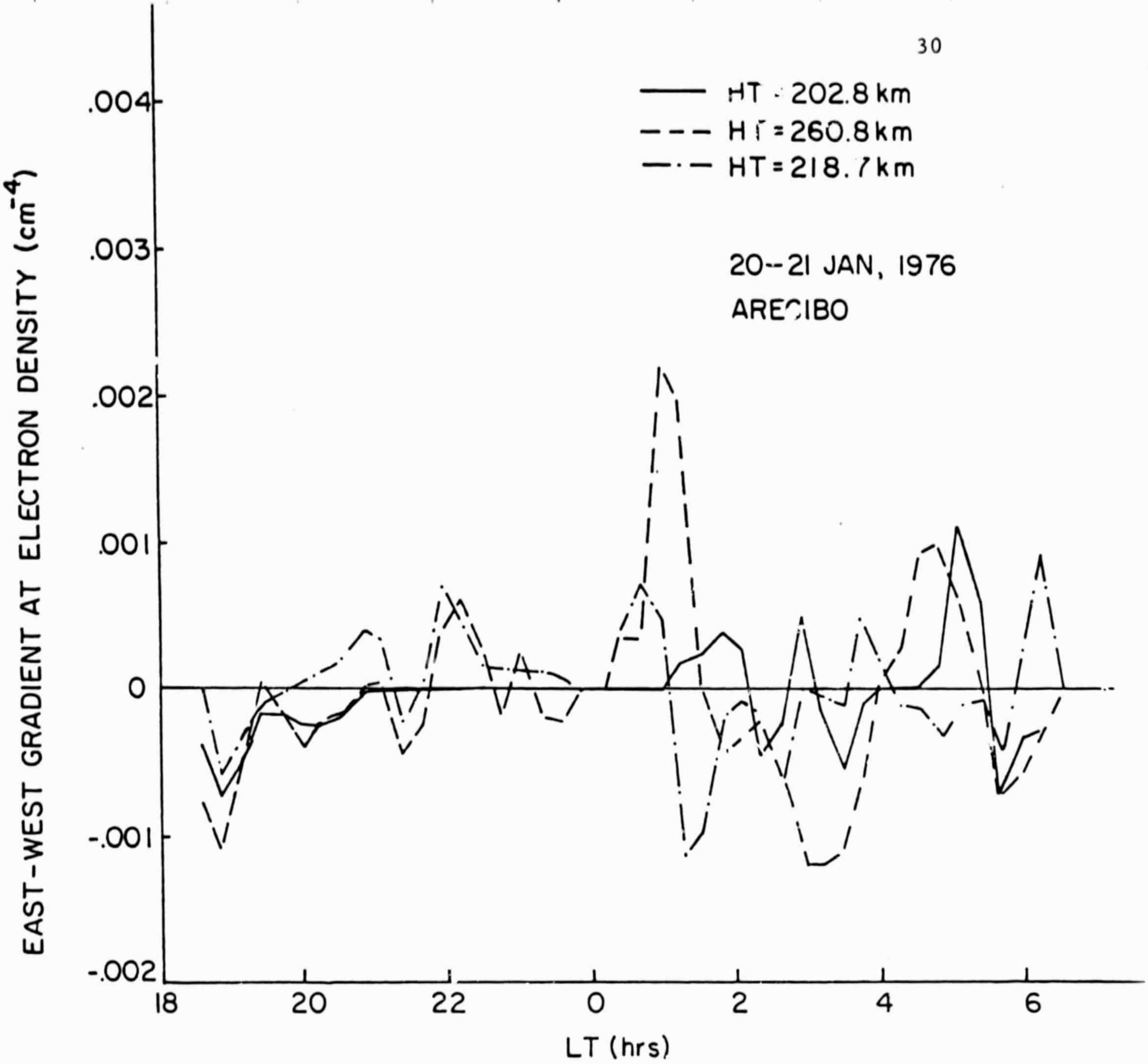


Figure 20: East-west gradient of the electron density at three levels (202.8; 260.8 and 318.7 km), Arecibo, 20-21 January, 1976.

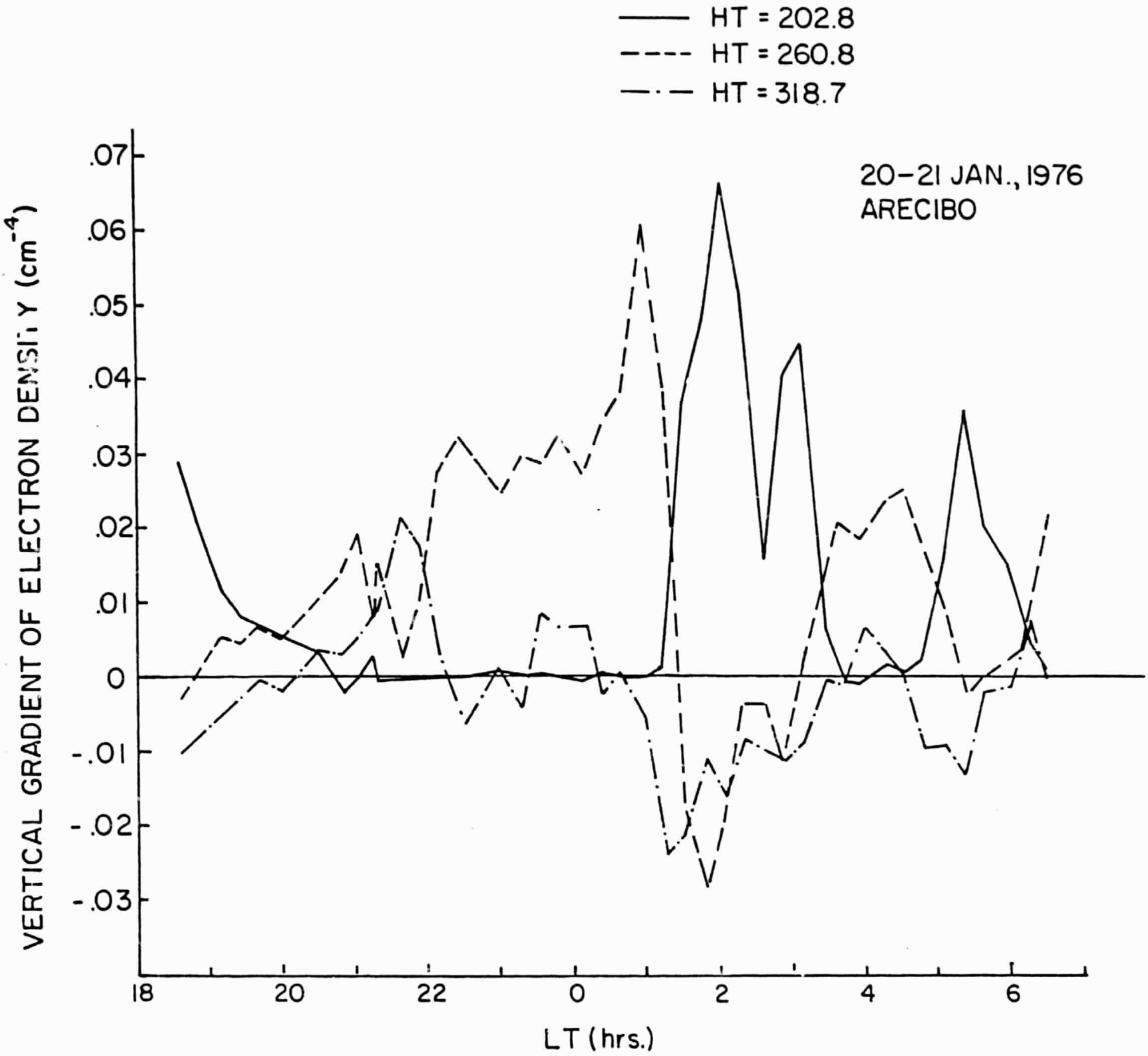


Figure 21: Vertical gradient of electron density at three levels (202.8; 260.8 and 318.7 km), Arecibo, 20-21 January, 1976.

It may be speculated that if the coupling between conjugate ionospheres is high then the rather high occurrence of spread F at Arecibo can be explained as being due to its conjugate point which is located at geographical latitude around 50$^{\circ}$, where according to Singleton (1975) the occurrence of spread F is much higher. Moreover with the same assumption we can consider the summer maximum in the occurrence of spread F at Arecibo could result from the winter maximum "transported" from the conjugate ionosphere in the southern hemisphere.

The model given by McDonald, et al. (1975) assumes an east-west gradient in the equilibrium Pedersen conductivity. Figures 20 to 21 show the values of east-west and vertical electron density gradients for three heights measured by R. Harper at Arecibo for the night with rather strong spread F. As was shown by Imel (1976) these experimentally measured values of the east-west gradient are too small to give a realistic growth rate.

Figure 21 shows the vertical electron density gradients for three heights measured by R. Harper at Arecibo for the same conditions as shown in Figure 20. Imel (1976) has shown that in the region where the gradient is large and positive, it is possible to have a gradient instability of the type discussed by Reid (1968). However, growth times are rather long.

Chapter IV

## CONCLUSIONS

This study has been directed toward checking the real ionospheric conditions at the time of initiation of spread F. For this purpose ionospheric measurements made earlier at two incoherent scatter facilities, Arecibo and Millstone Hill, were used.

The importance of using actual ionospheric parameters in the theories predicting the onset at spread F has been demonstrated. It has been shown in this study the ionospheric conditions accompanying the onset of spread F includes the presence of drifts with average magnitudes of 9 m $sec^{-1}$ in north-south direction, 49 m $sec^{-1}$ in westward direction and 18 m $sec^{-1}$ directed down. At the onset of spread F the ionospheric plasma is not in thermal equilibrium and the average magnitude of the ratio Te/Ti is 1.6.

It has been shown that during most nights with spread F the conductivities of the E-layer cannot be neglected and the coupling between the night-time E and F-region is rather strong for the perturbations of a scale larger than 3 km.

Large scale horizontal gradients measured at Arecibo and used in calculations of the growth rate predicted by the model of McDonald, et al. (1975) yield growth times that are far too long to be realistic (Imel, 1976).

In future experiments at Arecibo it is necessary to measure with good time and space resolution the winds, drift velocities, temperatures, electron density, horizontal and vertical gradients, dimensions and orientation of small-scale irregularities. The high time resolution is especially important because even during nights of rather strong spread F periods are observed when the instability disappears, and then reappears soon after.

Additional information about irregular ionospheric parameters which can be obtained by the simultaneous in situ measurements on satellites can be very useful. The simultaneous measurement of the airglow intensities made at the same facility can provide valuable information about the size and orientation of inhomogenities.

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