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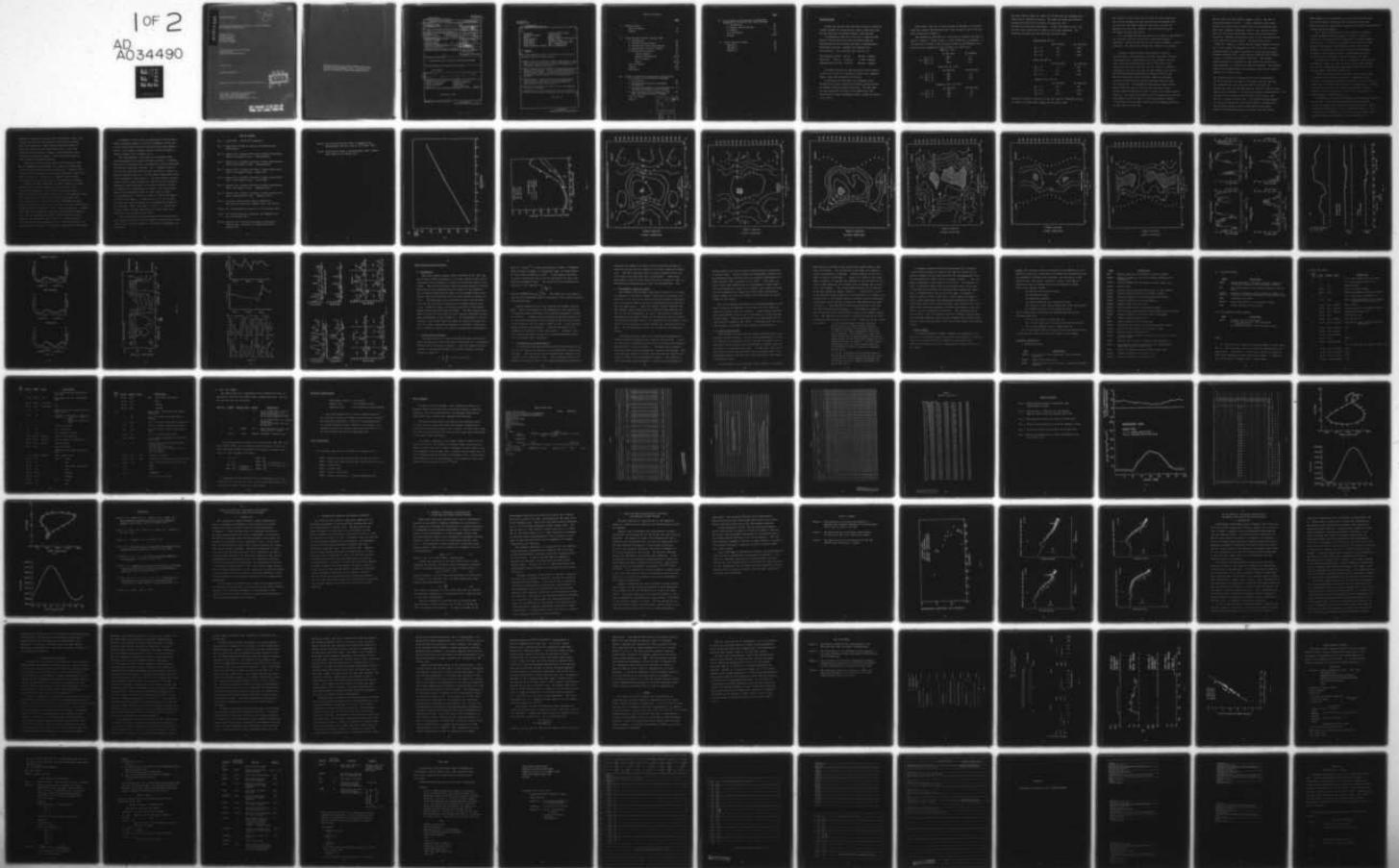
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STUDY AND ANALYSIS OF TOTAL ELECTRON CONTENT AND SCINTILLATION DATA

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October 1976

Scientific Report No. 1

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><br>(See reverse side)  |                         |   |                                  |

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19.

|                            |                                 |
|----------------------------|---------------------------------|
| Ionosphere                 | Scattering Domain (weak)        |
| Irregularity Region        | Scintillation                   |
| M-Value                    | Signal Analysis                 |
| Model Equations            | Spectral Index of Scintillation |
| Plasmasphere               | Sporadic-E ( $E_{sq}$ )         |
| Power Spectra              | Total Electron Content (TEC)    |
| Radar Echoes               | Type 1 Irregularities           |
| Scattering Domain (strong) | Type 2 Irregularities           |

20. ABSTRACT

This report embodies a study of Ionospheric Scintillations as considered from the following aspects:

- 1) Overall view of scintillations using a large data base, and also the detailed, individual magnetic storm picture. Solar flux level, seasonal variation, invariant latitude, and irregularity region are discussed.
- 2) Total Electron Content measurements through Faraday Rotation and Group Delay Methods. Results of employment of these techniques are discussed. The M-factor, for conversion of Faraday Rotation angles is studied, and associated use of it is displayed through a program for which documentation is included.
- 3) Characteristics of scintillations in the weak and strong scatter regimes. Results on the frequency dependence of scintillations, power spectra, and autocorrelation of amplitude fluctuations are discussed.
- 4) Daytime VHF scintillations. Type 1, type 2, and  $E_{sq}$  irregularities are discussed.
- 5) A modification to the Signal Analysis Package, previously developed, is described. Application for use on the CDC 6600

*E sub sq*

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I.

SCINTILLATIONS

During this period, work was done to focus on both the overall picture of scintillations using a large data base and the detailed, individual magnetic storm picture.

In conjunction with this first aim, a high-latitude model of scintillation has been developed using the observations of the existing data base of Narssarssuaq, Greenland, Goose Bay, Labrador and Sagamore Hill, Massachusetts. The available data consists of:

|               |                   |                   |
|---------------|-------------------|-------------------|
| Narssarssuaq  | 9/17/68 - 9/1/74  | 146,700 + samples |
| Goose Bay     | 1/1/72 - 12/31/74 | 71,000 + samples  |
| Sagamore Hill | 12/1/69- 11/30/74 | 148,000 + samples |

The model consists of equations which yield scintillations at 137 MHz as a function of local time, magnetic index, solar flux and month of the year.

A validation of this model was attempted using Millstone Hill data obtained by observing scintillations at 400 MHz tracking Transit satellites. The data base for the comparison was that in the publication "The Millstone Hill Radar Propagation Study: Scientific Results " by J. Evans.

Since Evans' data was in the  $S_4$  format at 400 MHz, a conversion using weak scatter relationships must first be made to dB at 137 MHz. This is plotted in Figure 1.

The measured  $S_4$  (400 MHz) as a function of invariant latitude is shown in Figure 2. These values, in three different  $K_p$  groupings, at the invariant latitude of Narssarssuaq, Goose Bay and Sagamore Hill, along with the conversion to dB (137 MHz) are shown below.

NSSQ ( $\Lambda = 63^\circ$ )

|                        | $S_4$ (400 MHz) | dB (137MHz) |
|------------------------|-----------------|-------------|
| $K_p \leq 1+$          | .0375           | 2.5         |
| $2_0 \leq K_p \leq 3+$ | .05             | 3.6         |
| $K_p \geq 4_0$         | .0775           | 6.3         |

Goose Bay ( $\Lambda = 60^\circ$ )

|                        | $S_4$ (400 MHz) | dB (137 MHz) |
|------------------------|-----------------|--------------|
| $K_p \leq 1+$          | .025            | 1.5          |
| $2_0 \leq K_p \leq 3+$ | .030            | 1.9          |
| $K_p \geq 4_0$         | .055            | 4.0          |

Sagamore Hill ( $\Lambda = 54^\circ$ )

|                        | $S_4$ (400 MHz) | dB (137 MHz) |
|------------------------|-----------------|--------------|
| $K_p \leq 1+$          | .016            | .8           |
| $2_0 \leq K_p \leq 3+$ | .018            | 1.0          |
| $K_p \geq 4_0$         | .021            | 1.2          |

This data used by Evans was taken in 1972-1973 and was averaged over local time to include all passes. The model dB values are obtained by using the local time equations developed for each station for 3 particular  $K_p$  values. A solar flux level of  $S_f = 108$  was used since solar flux in 1972-73 was of this magnitude. The resulting averages over all hours and all months are:

Narssarssuaq ( $63^\circ \Lambda$ )

|             | dB (137 MHz) | $S_4$ (400 MHz) |
|-------------|--------------|-----------------|
| $K_p = .5$  | 2.5          | .0375           |
| $K_p = 2.5$ | 4.0          | .053            |
| $K_p = 5.0$ | 6.3          | .0775           |

Goose Bay ( $60^\circ \Lambda$ )

|             | dB (137 MHz) | $S_4$ (400 MHz) |
|-------------|--------------|-----------------|
| $K_p = .5$  | .3           | .012            |
| $K_p = 2.5$ | 1.6          | .026            |
| $K_p = 5.0$ | 4.8          | .063            |

Sagamore Hill ( $54^\circ \Lambda$ )

|             | dB (137 MHz) | $S_4$ (400 MHz) |
|-------------|--------------|-----------------|
| $K_p = .5$  | .55          | .014            |
| $K_p = 2.5$ | .75          | .0155           |
| $K_p = 5.0$ | 1.23         | .022            |

The model dB values (converted to  $S_4$ ) are shown as individual points in Figure 2 to facilitate comparison with Evans' data.

The results of Evan's data and the model dB values predicted are in good agreement for both Narssarssuaq and Sagamore Hill. At Goose Bay, the model values are much lower for the low magnetic activity case, somewhat lower for the case  $K_p=2.5$  and higher for the case  $K_p=5.0$ .

It is believed that the position of the trough is approximately the invariant latitude of Goose Bay under quiet magnetic conditions, moving farther south as the level of magnetic activity increases. The model data of Goose Bay reflects this picture.

Using this same data base, the seasonal variation of data taken at Narssarssuaq, Greenland, Goose Bay, Labrador, and Sagamore Hill, Massachusetts was also examined. Contour plots have been generated using month of the year versus time of day for each individual station. There is a further breakdown of the data into low and high magnetic index groups. For the Narssarssuaq observations, (Figures 3 and 4) the 350 km. intersection point is  $63^\circ \text{N}$ . There are striking seasonal contrasts between summer and winter data for both low and high  $K_p$ . The December-February period shows uniform mean SI for both low and high  $K_p$  with relatively little diurnal pattern although the level is raised for higher magnetic activity. The April-June contours show a strong diurnal pattern with higher mean SI for  $K_p=4-9$ . Peak scintillation appears  $\sim 2300$  LST while the lowest levels are noted during the months of April-June at 08-13 LST.

For the Goose Bay observations, Figures 5 and 6, the 350 km. intersection point is  $60^\circ \Lambda$ . A higher elevation angle shows smaller mean scintillation indices than the Narssarssuaq data. Under quiet magnetic conditions,  $K_p=0-3$ , very low mean indices exist for the period of November-January with little diurnal variation. Maximum scintillation occurs in the March-May period with a definite diurnal pattern. The peak values occur  $\sim 2100$  LST. However, at Goose Bay the higher magnetic activity case is not simply an enhancement of the low  $K_p$  case as occurs at Narssarssuaq. For  $K_p=4-9$ , minimum SI occurs for the period December-February with a small diurnal variation which reaches a peak  $\sim 1-2$  hours after magnetic midnight. The maximum activity occurs in the months of July-August with peak values also occurring  $\sim 1-2$  hours after magnetic midnight. The seasonal maximum and minimum though distinguishable, are not as sharply defined as at Narssarssuaq.

The seasonal pattern for Sagamore Hill (at an intersection of  $53^\circ \Lambda$ ) differs from that of the higher latitude stations. The irregularities are mainly confined to the hours of darkness for both low and high magnetic activity, with the peak daily values occurring  $\sim 1-3$  hours after magnetic midnight, (Fig. 7&8) For  $K_p=0-3$ , the seasonal minimum occurs in May-August; for  $K_p=4-9$ , it occurs in April-June. The seasonal maximum appears to take place during the equinoctial months; February-April and September-November, with an extension of the highest contours throughout the period July-April when  $K_p$  is high.

These Sagamore Hill observations are felt to be mid-latitude for the  $K_p$  indices considered while both Narssarssuaq and Goose Bay show the sensitivity to magnetic variations characteristic of high latitude stations.

For a more complete view of scintillations, a detailed picture examining individual magnetic storms is needed in addition to the overall picture provided by seasonal contours and the model. To this end, a magnetic storm atlas has been proposed including all the magnetic storms in the period November 1971-December 1972, as noted in the atlas produced by Mendillo and Klobuchar (1974). As prototype, data was collected for the magnetic storm of October 18-19, 1972.

On October 18, 1972 at 1746 UT, a magnetic storm commenced. The magnetic index,  $K_p$ , very low prior to the storm, reached  $K_p=3$  at SSC, peaked at  $K_p=5 \sim 0000$  UT October 19, then fell to  $K_p=3$  again  $\sim 1500$  UT on October 19.

Figure 9 is a plot of the 15-minute scintillation index as observed at Narssarssuaq, Goose Bay, Sagamore Hill and College. Narssarssuaq and Goose Bay exhibit a slightly delayed storm rise at 2030 and 2200 UT October 18 respectively. College scintillation responds with medium scintillation  $\sim 0830$  UT October 19, while Sagamore Hill shows only a sharp burst of scintillation  $\sim 2330$  UT October 18.

In Figure 10 is seen the Narssarssuaq and Ottawa magnetograms, and the Dst. Both magnetograms show moderate disturbance levels, peaking in the period 0000-1200 UT October 19. The Dst reaches a maximum value of  $-75 \gamma$  at 0900 UT October 19. This, combined with a moderate  $K_p$  index, points to the irregularity region developing slowly from a quiet day picture to a

moderately expanded version and then fading again. Thus, the College data does not show moderate scintillation activity until the irregularity region becomes developed enough to reach the latitude of its intersection point. Also, the College SI seems to show a seasonal response pattern, with the equinox response to magnetic storms differing from the winter dramatic disturbance pattern.

The total electron content plots of Narssarssuaq, Goose Bay and Sagamore Hill of October 18-19 (Fig. 11) reveal only slightly enhanced values at SSC on October 18. Nighttime TEC values show the increased TEC occurring during many nights with magnetic activity. In addition to somewhat higher values, spiky areas of activity are seen in the polarization records.

There is no clear indication in these records of a trough (DMSP pictures are not available for this period). The scintillation boundary, except for a brief period between 2330 UT October 18 and 0030 UT October 19, in the nighttime along the 75th meridian lies between Goose Bay and Sagamore Hill. This short period is seen in the contour map (Figure 12) just prior to 2400 October 19. At the same time, the 50% scintillation contour reaches a minimum of  $\sim 56^\circ \Lambda \sim 0400$  UT October 19. Perhaps the trough lies between the latitudes of Goose Bay and Sagamore Hill, but the synchronous satellite records cannot be used to determine the trough position in this case. The increase in scintillation index at Sagamore Hill at 2330 UT on October 18 is accompanied by an increase in TEC on the Sagamore Hill TEC records.

In addition to the local time component of scintillation shown by magnetic storms, a storm time component can be seen in the scintillation increases occurring during some magnetic storms. Data taken at various stations during the magnetic storms of August 1972 illustrate this.

For large magnetic storms when the plasmopause moves well equatorward of its usual quiettime location, a stormtime component of scintillations is recognizable at many midlatitude stations with invariant latitudes  $<60^\circ$ . Figures 13 and 14 show the Dst index and scintillations observed at stations of varying invariant latitudes. The Dst index reached peak values  $\sim -100\gamma$  on August 4-6 and August 9. The high latitude stations exhibit high SI values during these periods but the stormtime component is more noticeable at the lower latitude stations of Sagamore Hill, Aberystwyth and Lindau. Even though these stations are separated 6 hours in local time, all show scintillation peaks  $\sim 0400$  UT on August 4,  $0000$  UT on August 5 and  $0500$  UT on August 6. These occur at times of Dst index increases and large TEC depletions at Sagamore Hill (Mendillo and Klobuchar, 1974). On August 9  $\sim 1200$  UT, a similar peak occurs at these stations even though the local time of the stations is in the morning-noon sector.

The joint study of the general patterns of scintillation, when combined with the individual magnetic storm analysis should yield a more accurate picture of scintillation development and occurrence.

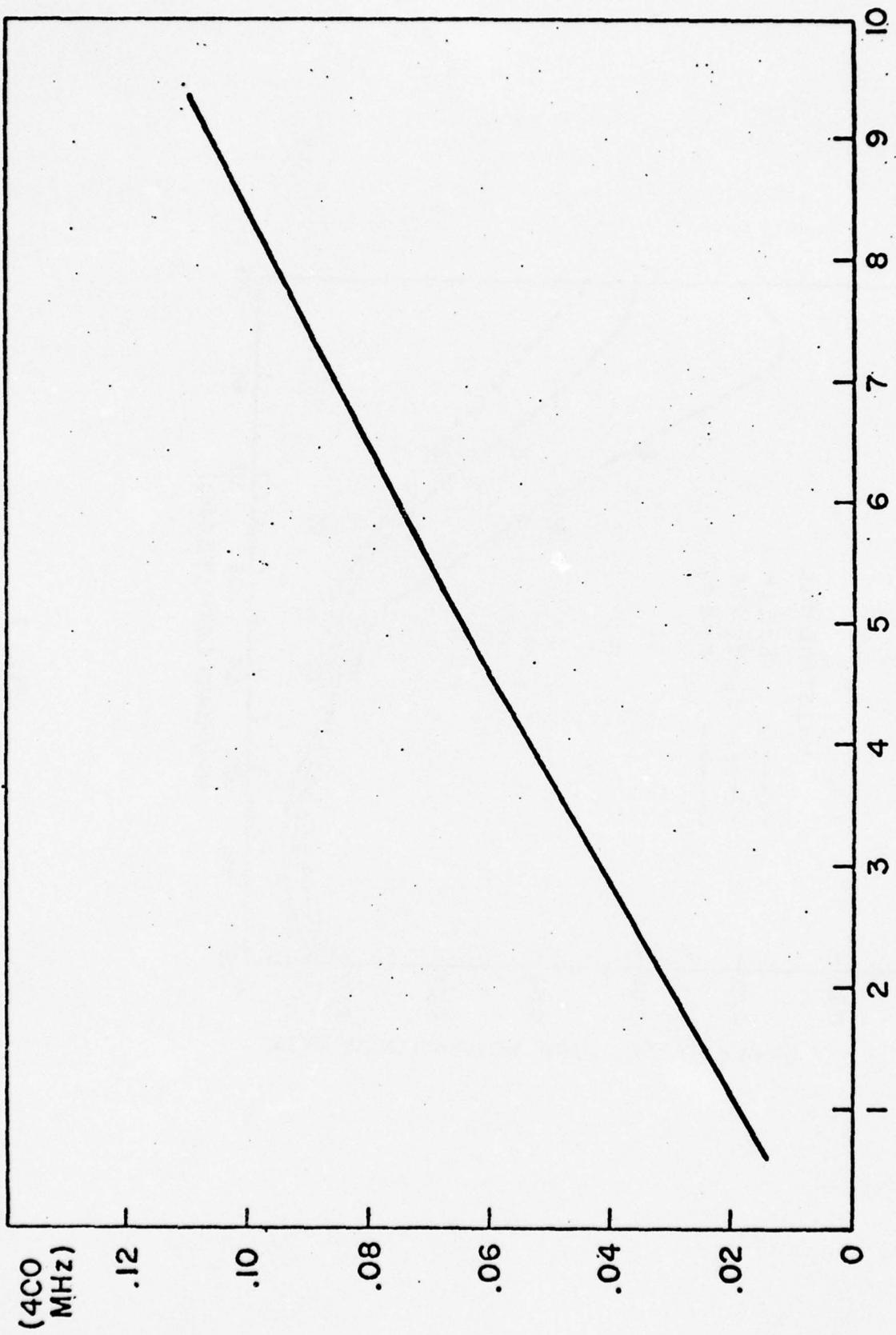
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Fig.13 Dst and Scintillation Index at Sagamore Hill,  
Narssarssuaq, and Goose Bay on 3-10 August 1972.

Fig.14 Scintillation Index at Narssarssuaq, Wales, Athens,  
and Lindau on 3-10 August 1972.

S4



dB (137 MHz)  
FIG. 1

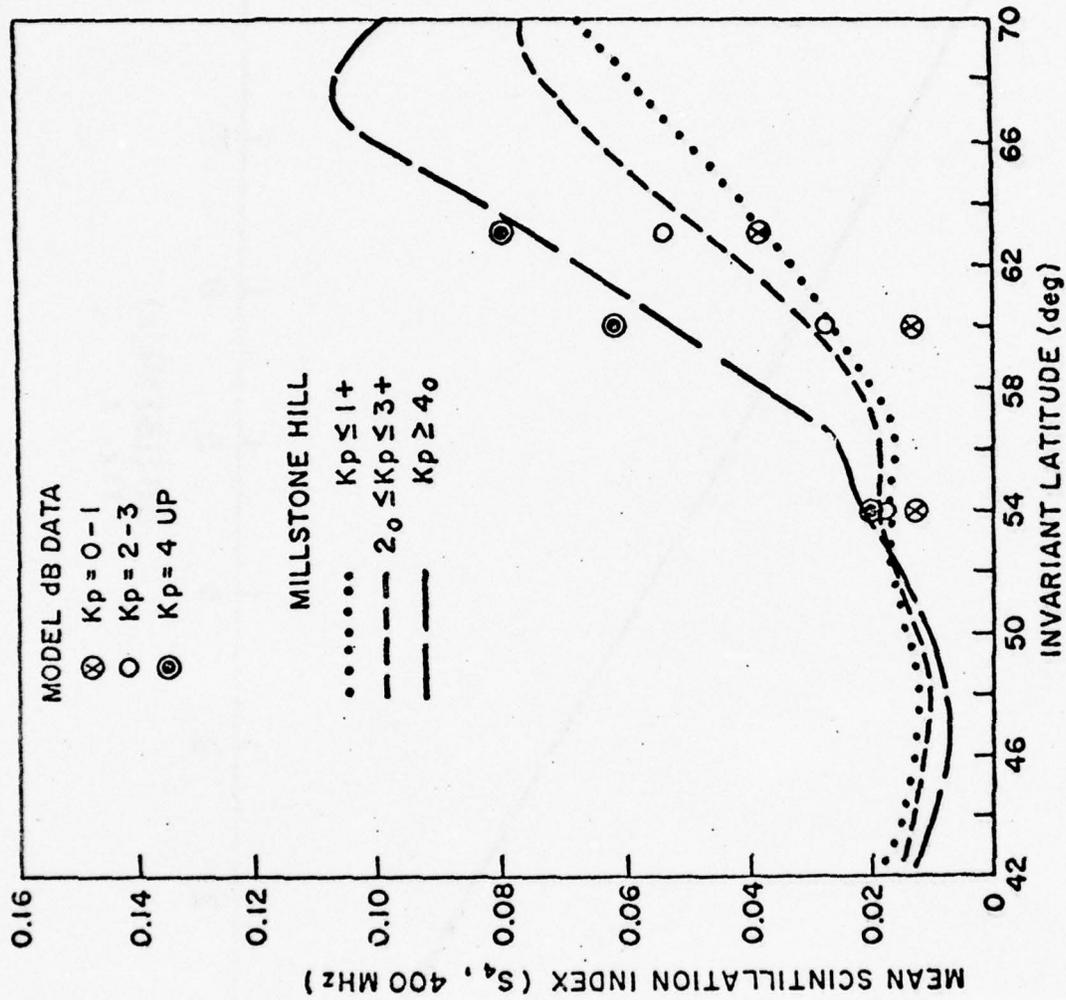
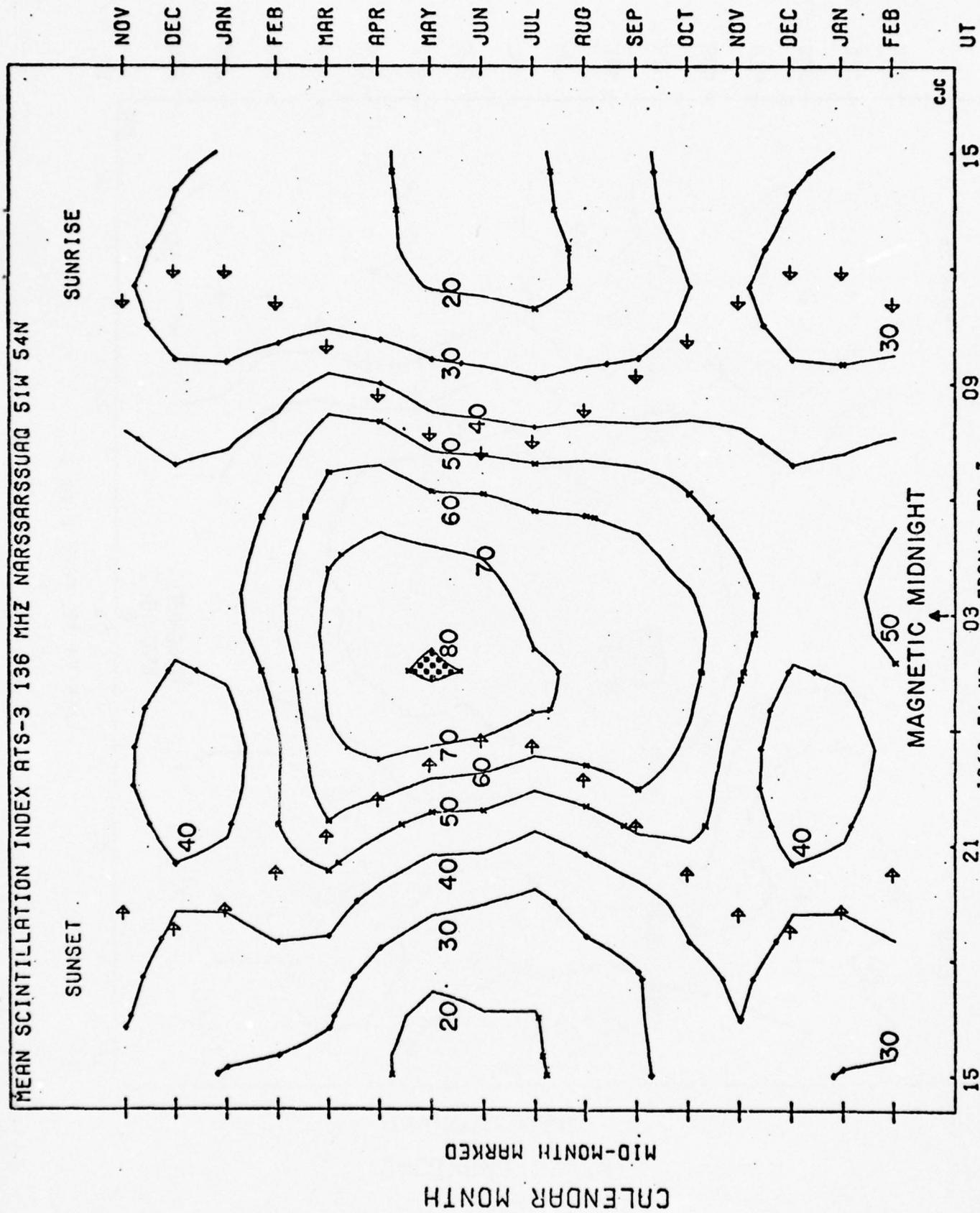


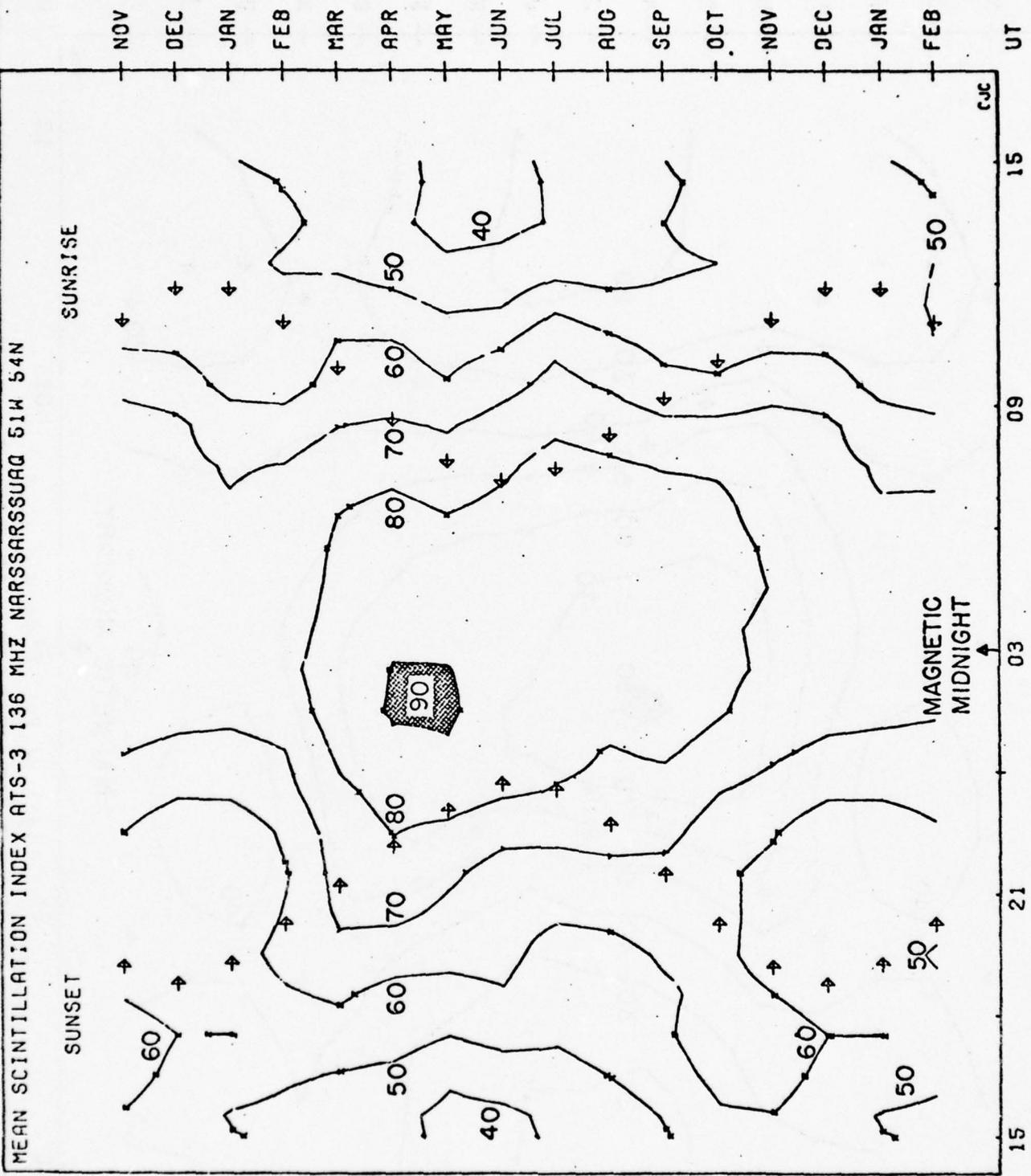
Fig. 2

MEAN SCINTILLATION INDEX ATS-3 136 MHZ NARSSARSSUAQ 51W 54N



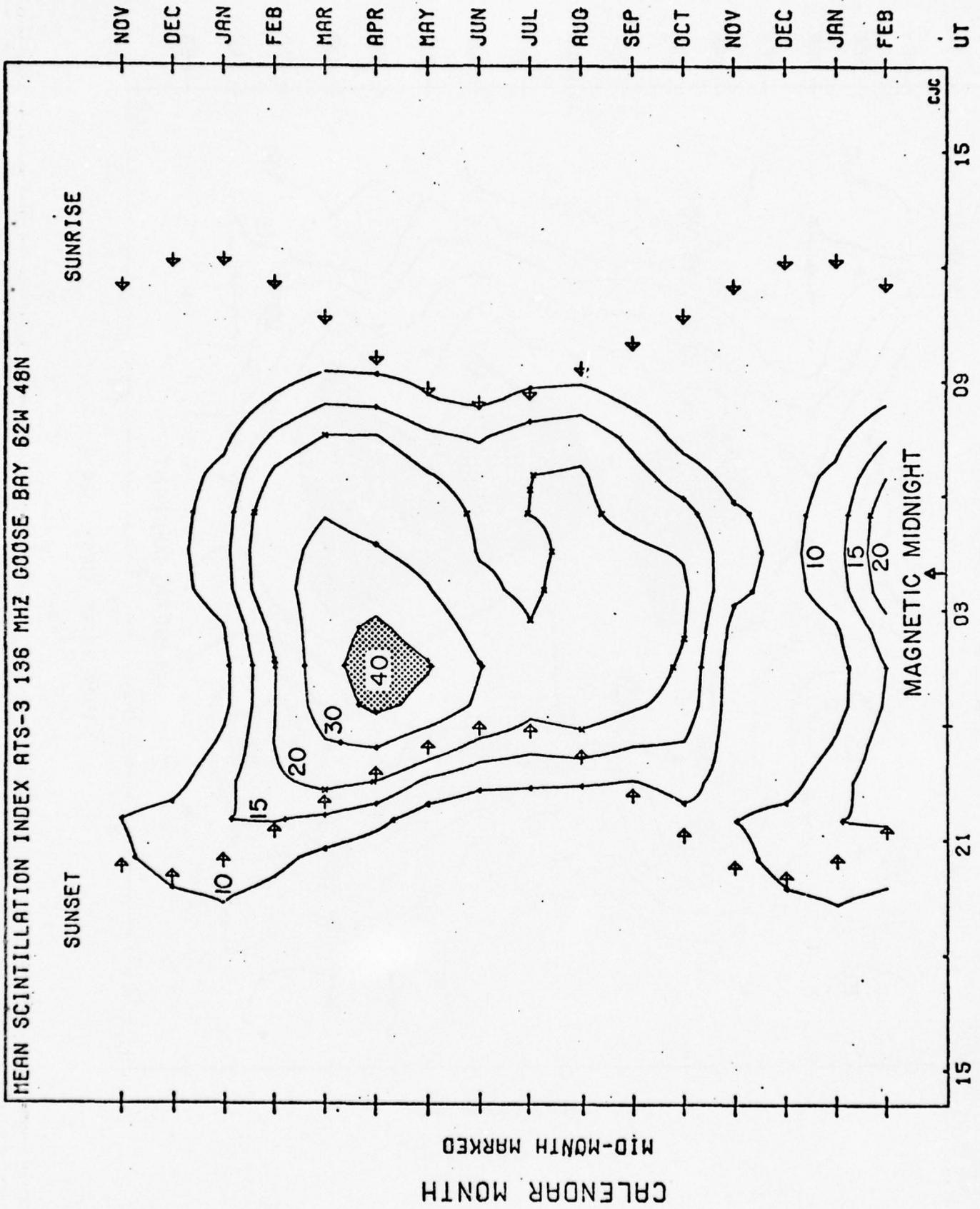
1968-74 KP FROM 0 TO .3

Fig. 3



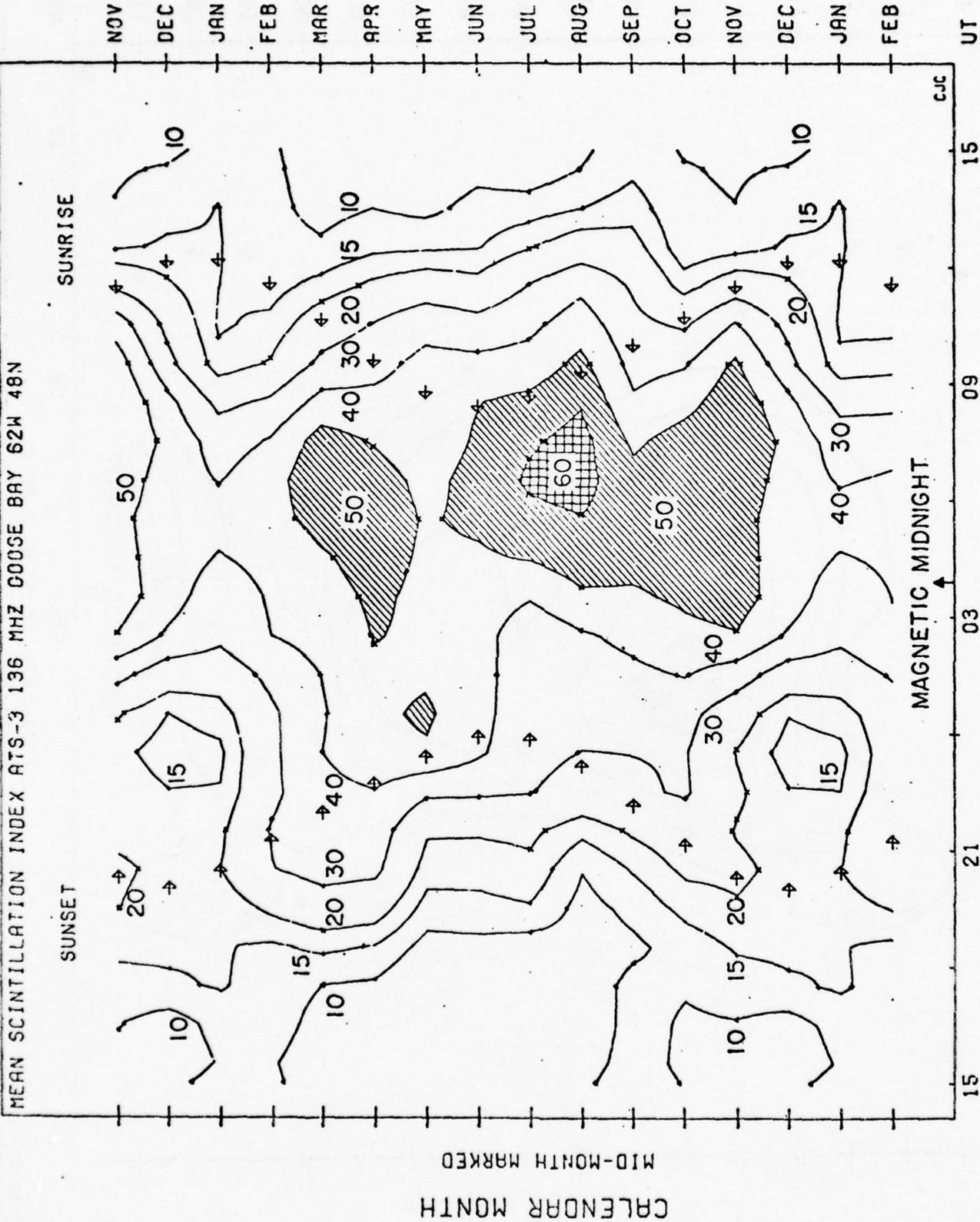
CALENDAR MONTH  
MID-MONTH MARKED

1968-74 KP FROM 4 TO 9  
Fig. 4



1971-1974 KP FROM 0 TO 3

Fig. 5



1971-74 KP FROM 4 TO 9

Fig. 6

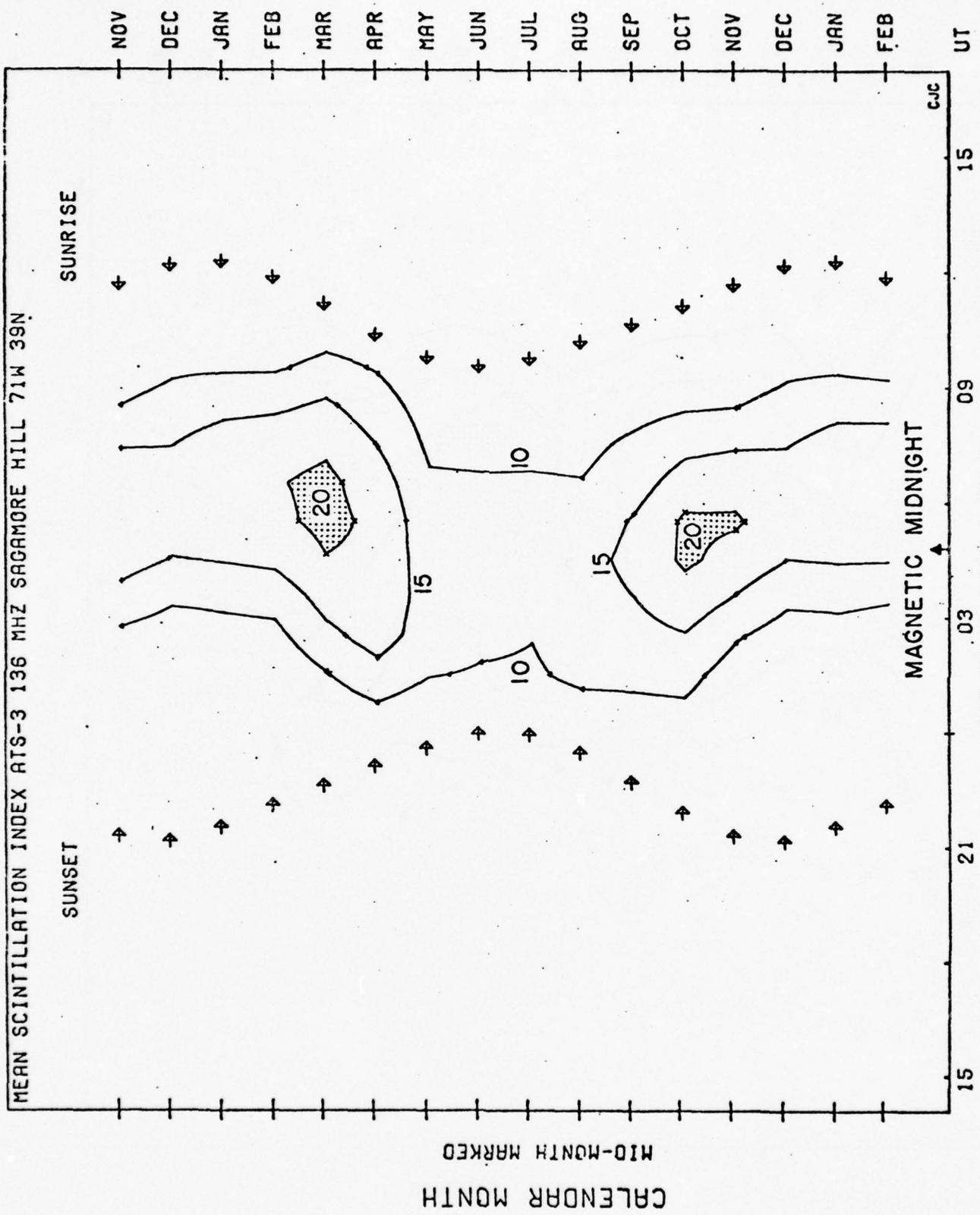
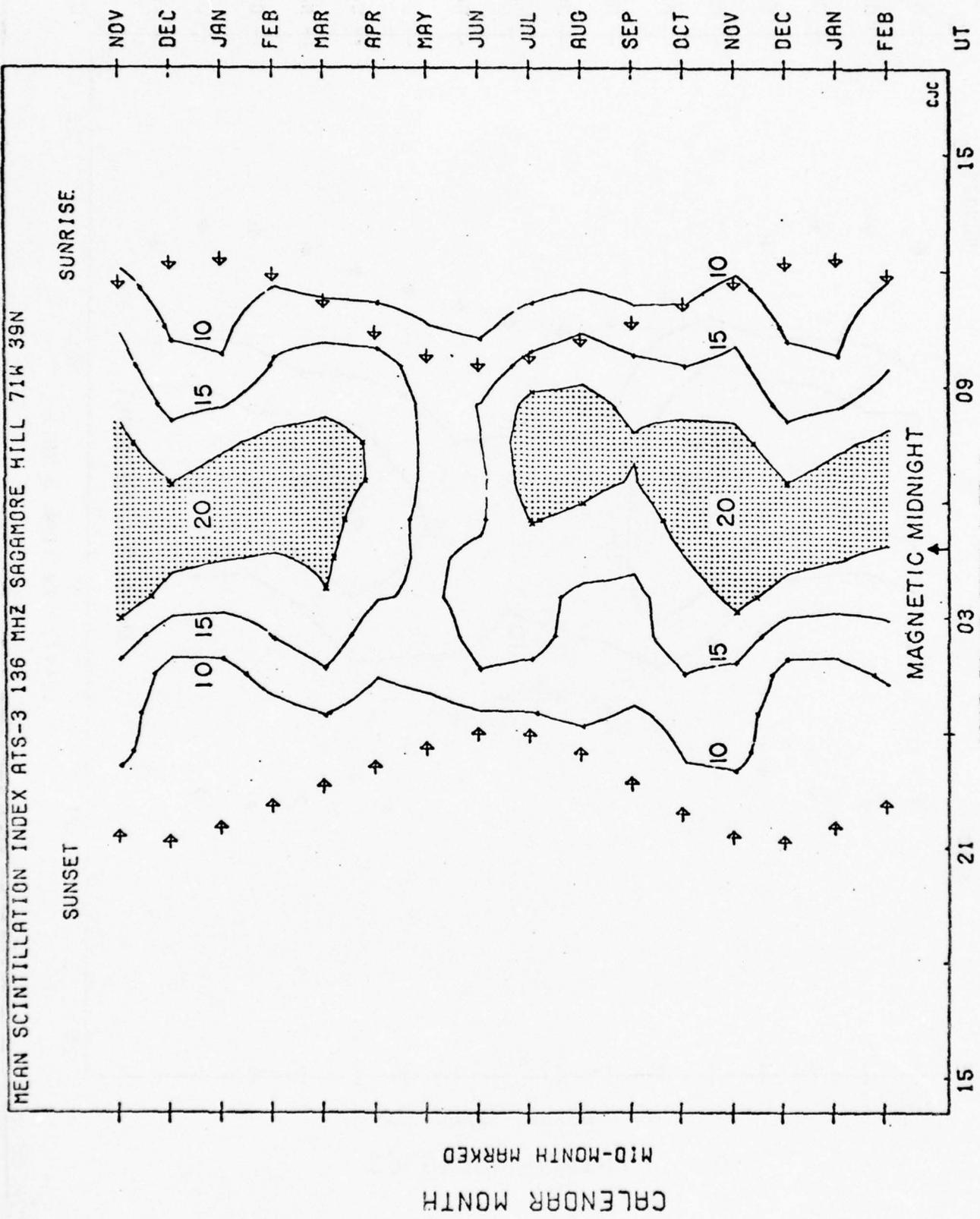
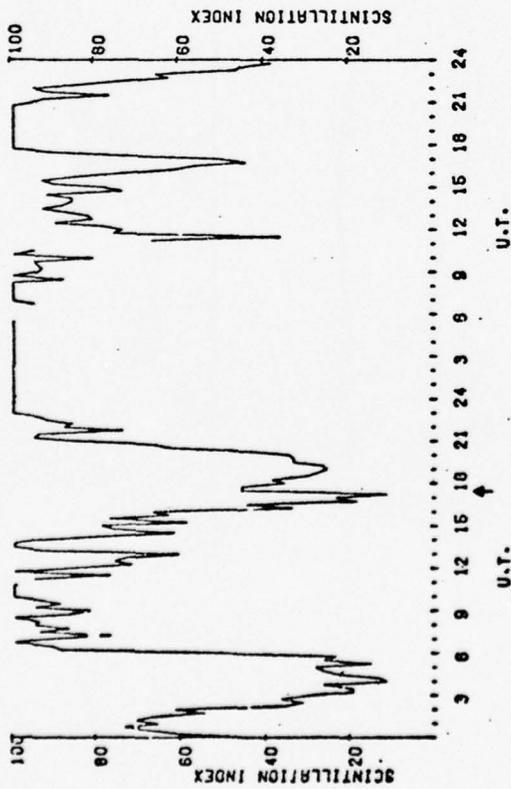


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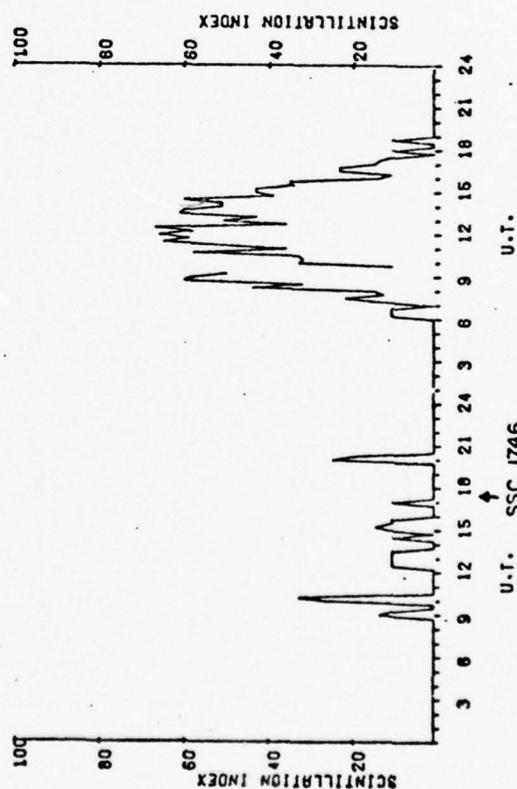
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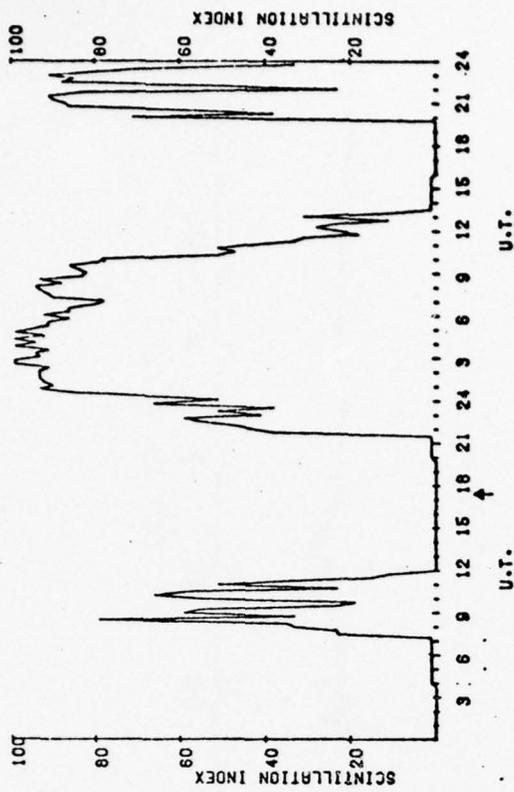
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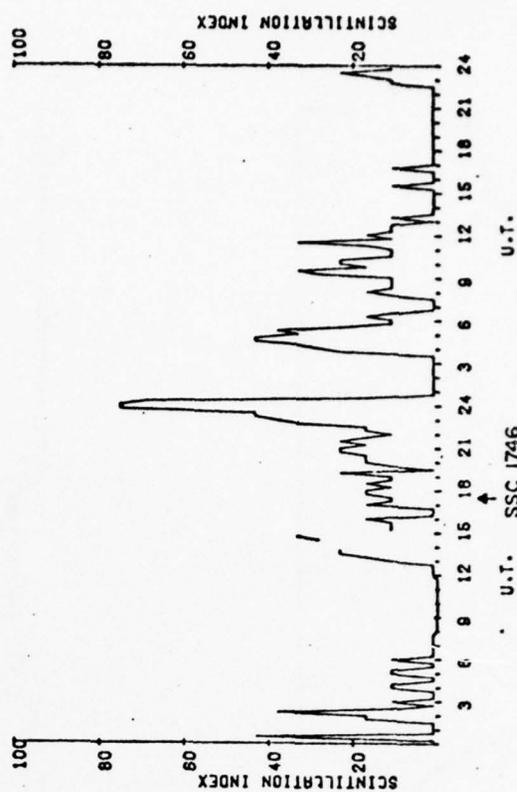
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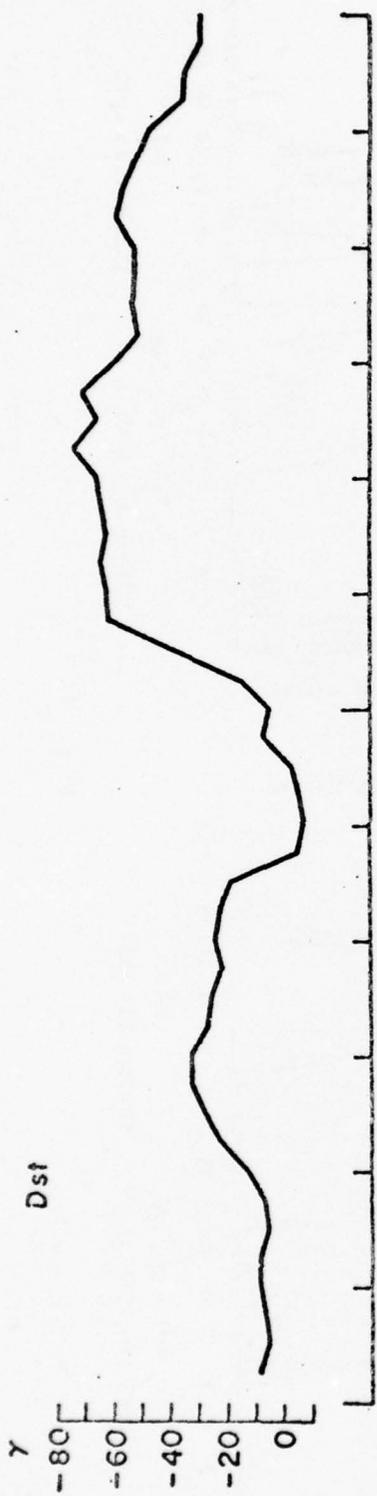
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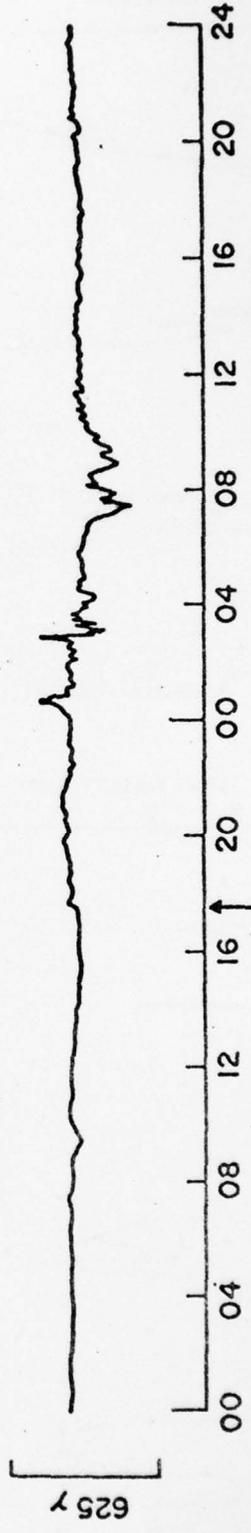
Fig. 9



Narssarssuaq  
H - Component



Ottawa  
H - Component



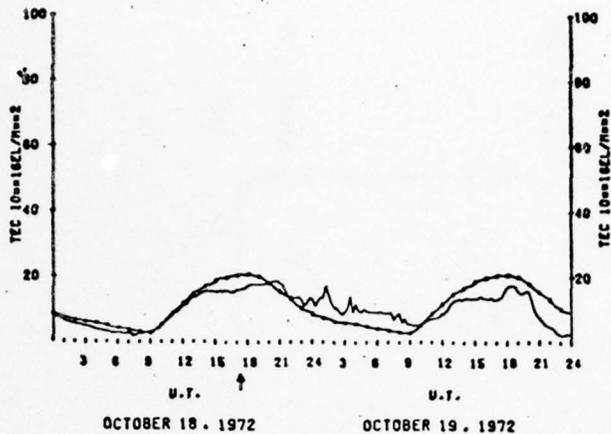
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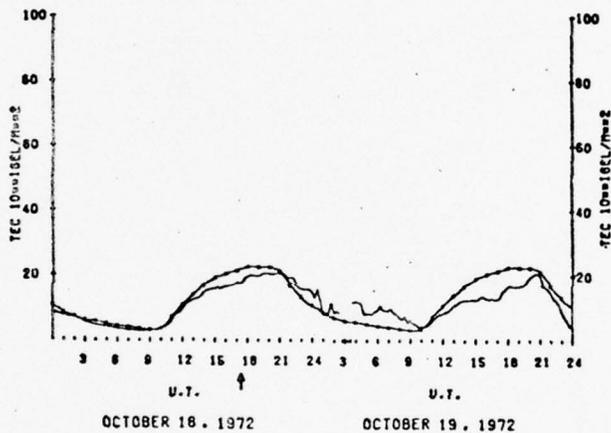
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1746 UT

Fig. 10

NARSSARSSUAQ, GREENLAND



GOOSE BAY, LABRADOR



HAMILTON, MASS.

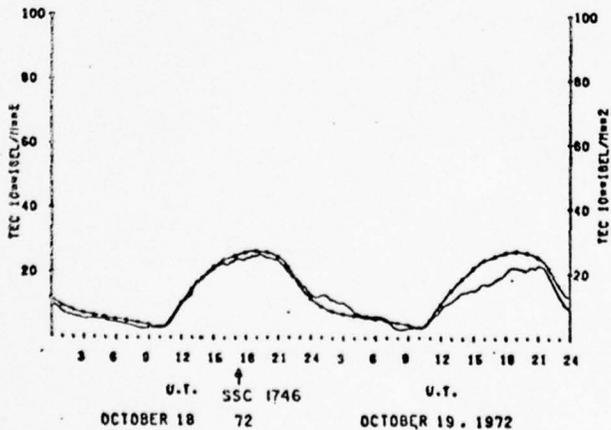


Fig. 11

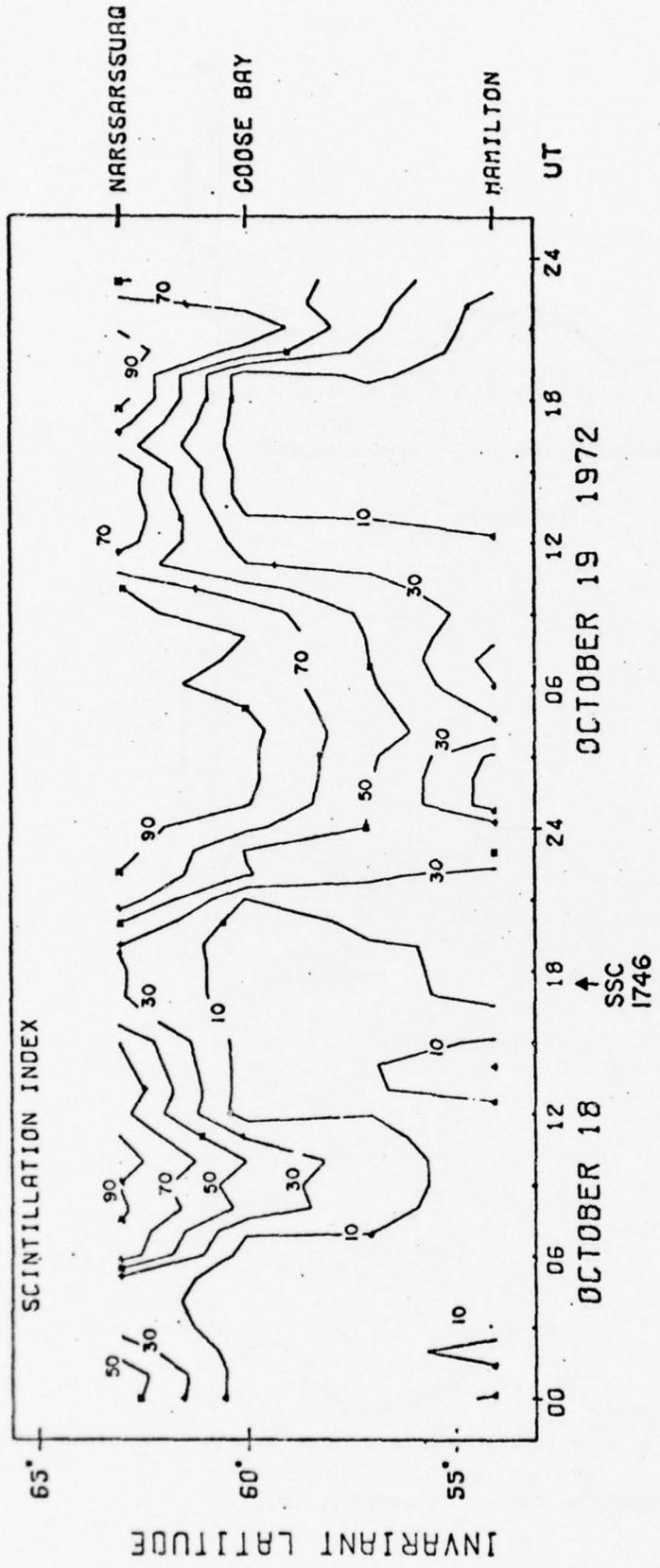


Fig. 12

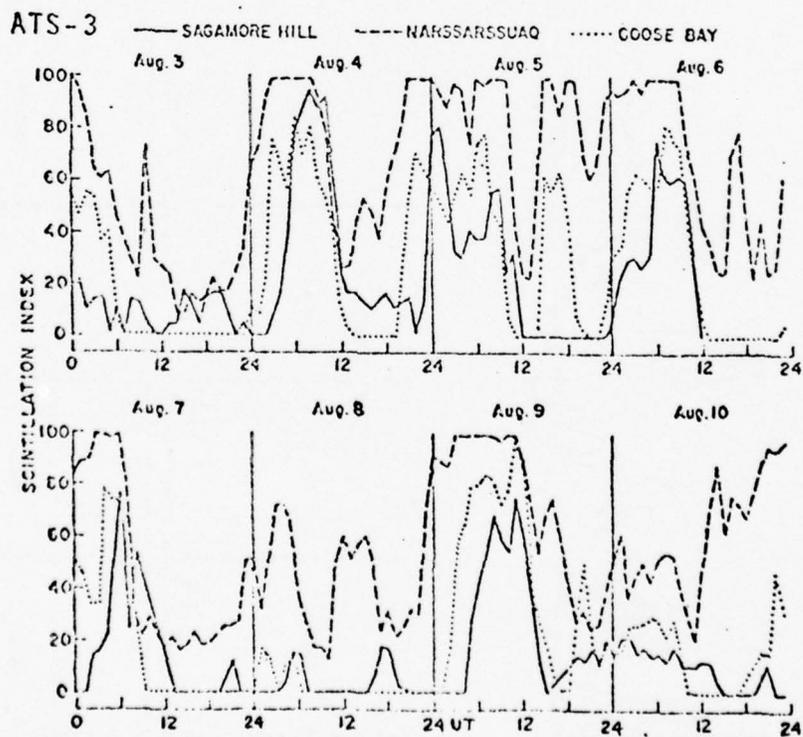
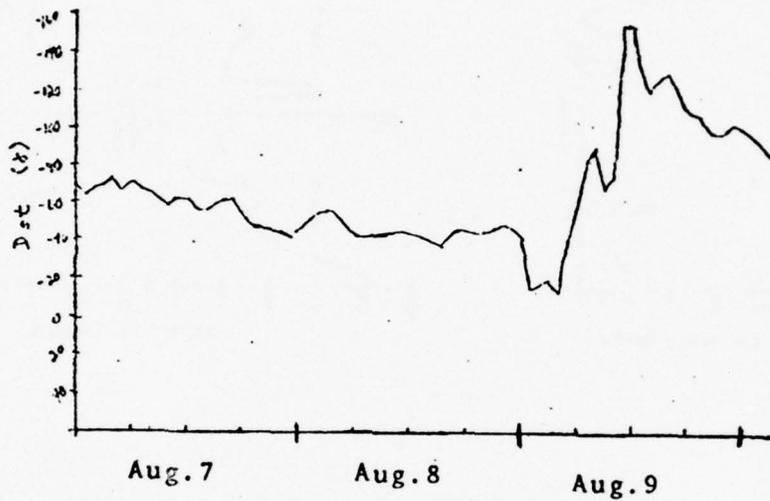
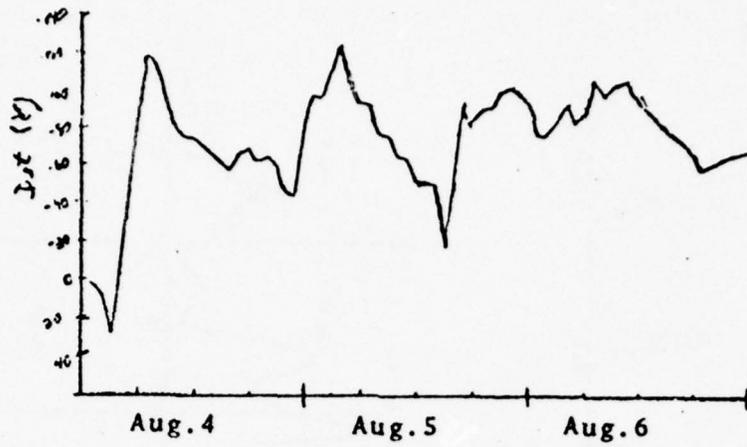
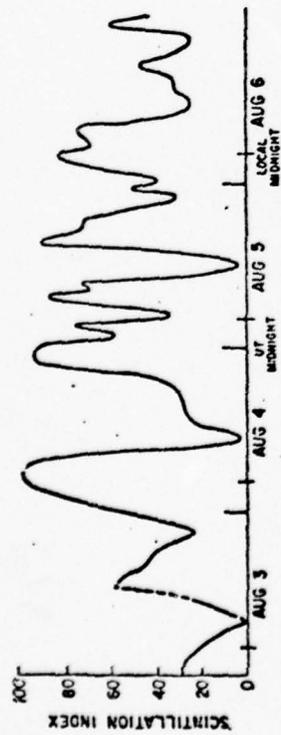
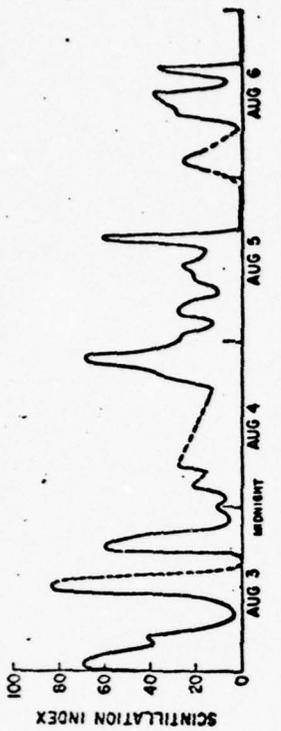
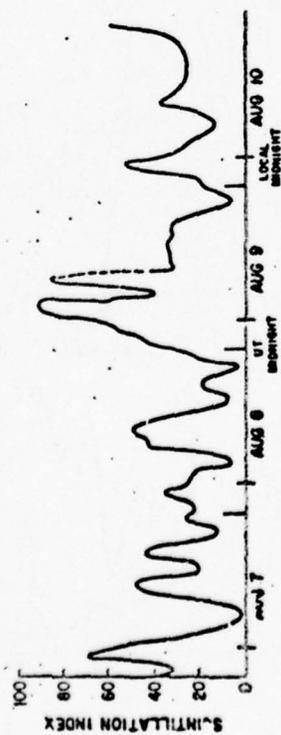


Fig. 13



SCINTILLATION INDEX, NARSARSUAQ, GREENLAND FOR LES-6



SCINTILLATION INDEX, WALES, FOR I2F2

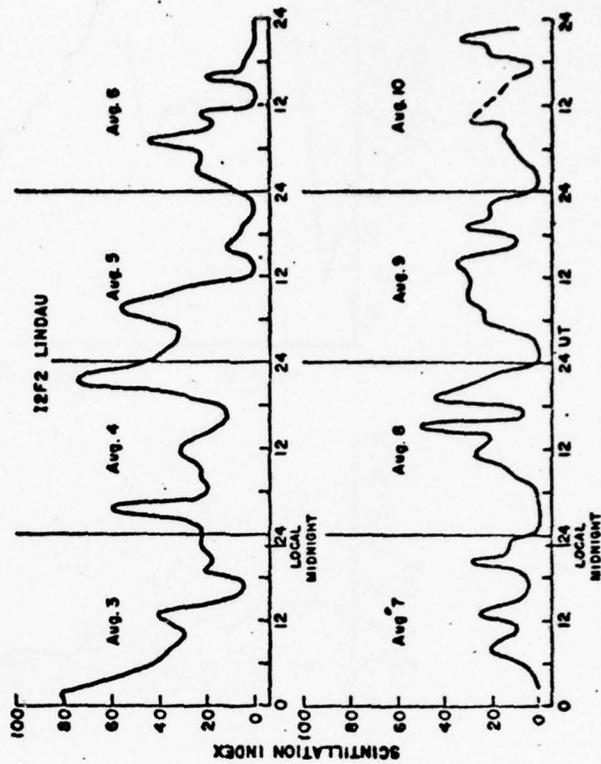
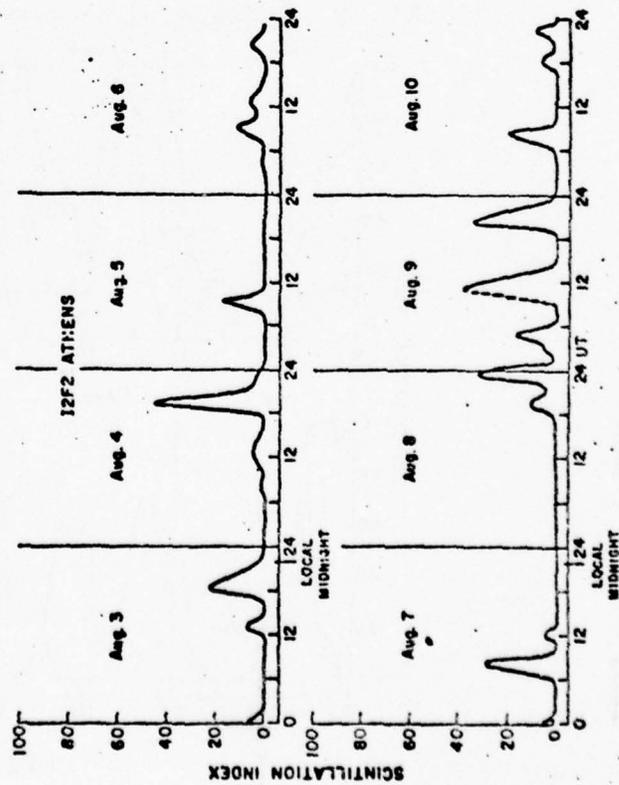
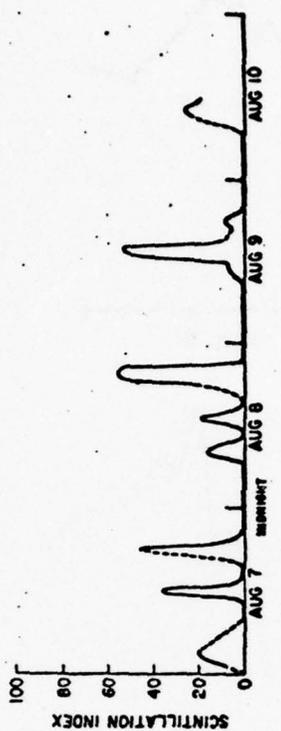


Fig. 14

## II.

### Total Electron Content Studies

#### 1. Introduction

The total electron content (TEC) is defined as the total number of free, thermal electrons in a vertical column of unit area of ionosphere from the ground to a height well above the peak of ionization. The use of artificial satellite beacons permits continuous monitoring of the integrated electron content of the ionosphere. This is done by measuring the effect of the ionosphere upon radio signals transmitted from the satellite and received at ground stations. TEC measurements have been made by many stations around the globe for many years by employing the Faraday rotation technique. Since the launch of the ATS-6 satellite in 1974 another method of obtaining TEC became available. The Radio Beacon Experiment on board ATS-6 provided the first reliable differential group delay measurements of the ionosphere. The plasmaspheric electron content is the content above the height at which the Faraday rotation of a signal propagating through the ionosphere is negligible and is found by comparing the Faraday and group delay measurements.

#### 2. Faraday Rotation Method

The polarization of a plane polarized VHF radio wave emitted from a geostationary satellite rotates continuously as it propagates through the non-isotropic ionosphere. The total amount of polarization,  $\Omega$ , encountered between the satellite and the receiving station is given by,

$$\Omega = \frac{k}{f^2} \int_0^h B \cos \theta \sec \chi N dh$$

where  $K = 2.36 \times 10^{-5}$ ,  $f$  = observing frequency in Hertz,  $B$  = magnetic field strength in gammas,  $\theta$  = propagation angle,  $\chi$  = zenith angle,  $N$  = local electron density in  $e1/m^2$ . If the quantity  $B \cos \theta \sec \chi$  is slowly varying with time it may be replaced by its mean value along the propagation path. The equation of total polarization rotation is then simplified to,

$$\Omega = \frac{K \bar{M}}{f^2} N_F$$

where  $\bar{M} = \overline{B \cos \theta \sec \chi}$  and  $N_F = \int_0^{h_F} N dh$ . The height  $h_F$  is the height above which the remaining amount of rotation is less than the absolute experimental error.

Several problems occur in the reduction of Faraday rotation data. One is the problem of n-pi ambiguities in the data which is discussed along with general TEC reduction techniques in Cantor et al (1975). Another is the assurance of absolute rotation values where the orientation of the transmitted VHF wave with respect to the satellite spin axis must be known as well as the reference polarization of the polarimeter. Absolute calibration of all equipment is essential to valid measurements. Klobuchar (1973) has estimated the total polarization rotation measurement error to be not better than  $\pm 10$  degrees.

### 3. Differential Group Delay Method

An alternative method of measuring the electron content along the line of sight to the satellite is the differential group delay technique. This method has been reviewed by many authors including Evans (1976) and Davies (1976). This technique measures the difference in transit times of two signals propagating through the

ionosphere by comparing the phase of the modulation envelope between the carrier and its sideband at two widely separated frequencies. The ATS-6 satellite carries a multi-frequency beacon and is an ideal source for this type of measurement. Group delay measurements using the ATS-6 beacon have been recorded at Hamilton, Massachusetts during the period June, 1974 through April, 1975.

#### 4. Plasmaspheric Electron Content

The Faraday rotation effect described in Section II is strongly dependent on the earth's magnetic field which is inversely proportional to the cube of the distance from the center of the earth. Also, the electron density decreases exponentially with altitude above the peak density. These two factors together indicate that the Faraday rotation method yields a measure of the electron content of the lower ionosphere,  $N_F$ , and is insensitive to electrons encountered in the upper regions of the satellite-station ray path. The group delay method, however, is independent of the magnetic field and gives the integrated electron content,  $N_T$ , along the entire ray path. The plasmaspheric content,  $N_p$ , is found by subtracting  $N_F$  from  $N_T$ .

The ATS-6 satellite allows for simultaneous measurements of Faraday rotation and group delay along the same ray path. A plot of simultaneous Faraday/group delay data as observed from Hamilton, Massachusetts is shown in Figure 1. The upper plot in Figure 1 shows the monthly median plasmaspheric variation for November, 1974. A scatter plot (Figure 2) for the same period can be used for statistical studies of the plasmaspheric content. Yeh (1976) has found that under normal geomagnetic conditions the plasmaspheric

content exhibits very little diurnal variation and is essentially a constant value. Initial studies of plasmaspheric contents during geomagnetically active periods have produced contradictory results (Soicher, 1976, and Davies et al, 1975). Yeh (1976) and Davies (1976) have reported that the plasmasphere becomes depleted during geomagnetic storms and is steadily replenished by plasma from the ionosphere for several days after sudden commencement. Further studies of storm time effects will yield rates of replenishment of this region.

One of the problems encountered in deriving plasmaspheric contents is that  $N_p$  is sometimes of the order of  $0.1 N_T$ , thus very accurate  $N_T$  and  $N_p$  values are required. A main factor contributing to uncertainties in  $N_p$  is due to variations in the  $\bar{M}$  value conversion factor. Another consideration is at what height the  $\bar{M}$  value should be computed (Yeh, 1976). Variations here are due to uncertainties in the shape of the ionospheric  $N_e(h)$  profile.

##### 5. $\bar{M}$ - Value Determination

The  $\bar{M}$  factor is used to convert Faraday rotation angles in integrated electron contents. For an ideal geostationary satellite in a perfectly synchronous orbit with orbital inclination and eccentricity exactly equal to zero the  $\bar{M}$  value is indeed a constant and needs to be determined only once. In real life, even if the ideal orbit is initially achieved it will soon decay due to the perturbing forces of the sun, moon, and variations in the earth's gravitational field.

An inclination in the satellite's orbit results in a diurnal

oscillation in latitude of the sub-satellite point around a mean value of latitude. Any ellipticity in the orbit will produce a similar oscillation in longitude. Several examples of this are shown in Figure 3 and Figure 5. Figure 3 is a plot of the actual hourly variation in latitude and longitude of the sub-satellite position of I2F3 which has an inclination of 6.6 degrees and eccentricity of .002 degrees. The corresponding  $\bar{M}$  values for an observer at Luning, Taiwan are shown in Figure 4. A plot of the sub-satellite position of ATS-3 which has an inclination of 5.9 degrees and eccentricity of .002 degrees appears in Figure 5 and the corresponding  $\bar{M}$  values for an observer at Hamilton, Massachusetts are shown in Figure 6. The amplitude of the diurnal variation in  $\bar{M}$  value for I2F3 as observed from Luning is  $\pm 8.8\%$  from the constant mean value which would traditionally be used in the Faraday computation. The amplitude of the diurnal variation in  $\bar{M}$  value for ATS-3 as observed from Hamilton is only  $\pm 5.5\%$ . There are several effects

to be noted:

- 1.) For a geostationary satellite observed from a station at middle or high latitudes the relative change in the  $\bar{M}$  value with time is smaller than other experimental errors and can be ignored. For observes in or near equatorial regions the relative change in  $\bar{M}$  value is large and use of the traditional constant  $\bar{M}$  value conversion factor is invalid. An actual value of  $\bar{M}$  appropriate to the time of observation must be calculated if one is to obtain a reasonable measure of  $N_F$ .

- 2.) As the inclination of the orbital plane of the satellite increases with time the sub-satellite position will have greater latitudinal oscillations and thus a larger fluctuation in  $\bar{M}$  value will occur.

A computer program has been developed which will calculate a satellite's position as a function of time for a given set of orbital elements and will also calculate the corresponding  $\bar{M}$  value for an observer at a given station as shown in Table 1. This program is described in more detail in Section VI. The program provides a relatively simple corrective procedure which can be used by the monitoring stations for obtaining more accurate TEC values. This is accomplished by use of a look-up table, an example of which is given in Table 2 and Table 3, which converts Faraday rotation angles expressed in the polarimeter polarization channel strip chart units of pi's and millimeters into corrected TEC values. These tables have been designed to minimize the amount of time and effort that is required of an observer. The conversion tables are currently in use at observing stations in Athens, Greece / Goose Bay, Labrador / Hamilton, Massachusetts / Kennedy Space Flight Center, Florida / Ramey Air Force Base, Puerto Rico / Osan, Korea and Lunping, Taiwan.

#### Program Support

A satellite ephemeris program, LOKANGL, was developed by the Analysis and Simulation Branch of the Air Force Geophysics Laboratory. Under this Contract (F19628-76-C-0003) the program has been modified and expanded to aid in improving the accuracy of reported TEC values.

OUTPUT: For any given satellite-station pair the program will calculate the satellite's orbit and will produce the sub-satellite and sub-ionospheric latitudes and longitudes, the satellite's right ascension and declination, elevation, azimuth, and range as a function of time as observed from the user specified station.

Other output options include:

- (1) Position and velocity vectors
- (2) Sub-satellite data
- (3) Osculating Elements
- (4) Table of  $\bar{M}$ -values as a function of time
- (5) Conversion table (TEC (constant  $\bar{M}$ ) to TEC (varying  $\bar{M}$ ) )
- (6) Faraday rotation to TEC conversion table

Any of these output options may be generated from one of the following input sets:

- (1) A 2-card orbital element data set
- (2) A 2-card input set of position and velocity vectors
- (3) A 5-card SPADATS orbital element data set

The 5-card SPADATS orbital element set has been used exclusively and only this input set will be described in this report.

## FUNCTIONAL DESCRIPTION

### I. Ephemeris program

| <u>NAME</u> | <u>DESCRIPTION</u>  |
|-------------|---|
| LOKANGL     | main program- reads input data- calls necessary routines      |
| CONVRT      | reads 2-card element set                                      |
| DELEM       | reads position-velocity vector + converts to SPADATS elements |

| <u>NAME</u> | <u>DESCRIPTION</u>  |
|-------------|---|
| DREV        | obtains change per revolution in orbital elements   |
| NUMINT      | computes changes per rev due to drag by Simpsons rule integration                               |
| INTGND      | supplies NUMINT with integrands for each integ. step  |
| DENSEL      | density model   |
| OSCTMN      | converts osculating position-velocity to mean elements  |
| PVTELM      | converts position-velocity to orbital elements  |
| MNTOSC      | converts elements to osculating position-velocity   |
| ELMTPV      | converts elements to position-velocity  |
| SHPRDC      | computes short periodic terms   |
| KEPECN      | converts mean anomaly to eccentric anomaly  |
| SPSETC      | sets constants and program initializations for all routines                                     |
| SPRFCO      | computes refraction correction due to atmosphere  |
| NEW         | converts units of output data   |
| CRMXA       | prints heading on each output page  |
| SPTRAN      | transformation matrix and station coordinates routine   |
| SPROU       | prints out BDC and/or binary ephemeris tapes  |
| MULTIP      | performs matrix multiplication  |
| JDATE       | converts Gregorian date to Julian date-limits Jan 1,1950 to Dec 31,1999                         |
| CDATE       | converts Julian date to Gregorian date-same limits  |
| WRSTA       | reads $\bar{M}$ -value and TEC conversion table output options and prints ephemeris predictions |
| WRTAP       | extracts lookangle predictions from binary tape   |
| ANGLE1      | reduces an angle to interval $-\pi$ to $+\pi$   |
| ANGLE2      | reduces an angle to interval 0 to $2\pi$  |

## II. M-VALUE ROUTINES

| <u>NAME</u>         | <u>DESCRIPTION</u>   |
|---------------------|--|
| MGEOS               | CALLED FROM WRSTA, calculates $\bar{M}$ -value as function of satellite position, calls necessary routines       |
| GEO                 | sets initializations and performs geometric calculations   |
| FIELDG }<br>FIELD } | calculate geomagnetic field, updates the POGO coefficients to time of observation, prints $\bar{M}$ -value table |
| HOUR                | calculates hour angle  |
| HEADER              | prints AFGL header on every page of output   |
| HEAD                | prints heading on $\bar{M}$ -value table   |

## III. TEC CONVERSION TABLE ROUTINE

| <u>NAME</u> | <u>DESCRIPTION</u>   |
|-------------|--|
| TABLE       | produces the following output<br>(1) TEC (constant $\bar{M}$ ) to TEC (varying $\bar{M}$ )<br>conversion table<br>(2) Faraday rotation to TEC conversion table |

### INPUT

The input which is required by program LOKANGL is of two forms. One is a series of input cards which are to be submitted with the program deck. The other is an input tape (tape 2) on which the POGO (8/69) geomagnetic field coefficients reside. A sample of the control deck is included later in this report.

# I. INPUT CARD FORMAT

| <u>CARD NO.</u> | <u>COLUMN</u> | <u>FORMAT</u> | <u>UNITS</u>         | <u>DESCRIPTION</u>  |
|-----------------|---------------|---------------|----------------------|---|
| 1               | 1             |               |                      | "5" = 5 card element set to be used   |
| 2               | 1             |               |                      | "1" = first card of element set   |
|                 | 4-7           | A4            |                      | satellite name  |
|                 | 46-48         | I2            |                      | year of orbital elements  |
|                 | 49-51         | F3.0          |                      | Julian day number of orbital elements   |
| 3               | 1             |               |                      | "2" = second card of element set  |
|                 | 9-13          | F5.0          |                      | Epoch = fractional part of orb element date; = 0.0 if epoch = 0hr U.T.                  |
|                 | 23-31         | F9.4          | degrees              | Mean anomaly  |
|                 | 32-40         | F9.4          | degrees              | Right Ascension of ascending node ( $\Omega$ )  |
|                 | 41-49         | F9.4          | degrees              | Argument of Perigee ( $\omega$ )  |
|                 | 50-58         | F9.4          |                      | Eccentricity (e)  |
|                 | 59-67         | F9.4          | degrees              | Inclination (i)   |
| 4               | 9-19          | E11.8         | revs/day             | Mean motion = $1440 \cdot (\text{mins/day}) / \text{period}$<br>$(\text{mins/rev}) = n$ |
|                 | 21-31         | E11.9         | rev/day <sup>2</sup> | $\dot{n}/2$   |
|                 | 33-40         | E8.5          | deg/day              | $\dot{\Omega}$  |
|                 | 42-49         | E8.5          | deg/day              | $\dot{\omega}$  |
|                 | 51-58         | E8.5          |                      | $\dot{e}/\text{day}$  |
|                 | 60-67         | E8.5          | deg/day              | $\dot{i}$   |
| 5               | 1             |               |                      | "4" = fourth card of orbital element set  |
|                 | 9-19          | E11.8         | rev/day <sup>3</sup> | $\ddot{n}/6$  |
|                 | 21-31         | E11.8         | rev/day <sup>4</sup> | $\ddot{\dot{n}}/24$   |
|                 | 33-40         | E8.5          | rev/day <sup>2</sup> | $\ddot{\Omega}/2$   |
|                 | 42-49         | E8.5          | rev/day <sup>2</sup> | $\ddot{\omega}/2$   |

| <u>CARD NO.</u> | <u>COLUMN</u> | <u>FORMAT</u> | <u>UNITS</u>          | <u>DESCRIPTION</u>  |
|-----------------|---------------|---------------|-----------------------|---|
| 6               | 1             |               |                       | "5" = fifth card of orbital element set   |
|                 | 9-19          | E11.8         | E.R.                  | Semi-major axis (a) E.R.=earth radii  |
|                 | 21-30         | E10.7         | E.R./day              | $\dot{a}$   |
|                 | 32-41         | E10.7         | E.R./day <sup>2</sup> | $\ddot{a}/2$  |
| 7               | 1-3           | I3            |                       | number of stations requesting look angle output   |
|                 | 4-6           | I3            |                       | if number of stations 1, code in column 6: 0= output as function of time<br>1= output as function of time |
| 8               |               |               |                       | station parameters  |
|                 | 1-5           | I5            |                       | I.D. of station   |
|                 | 8             | I3            |                       | "2" = geodetic system   |
|                 | 9-23          | E15.8         | degrees               | station longitude (+W)  |
|                 | 24-38         | E15.8         | degrees               | station geodetic latitude (+N)  |
|                 | 39-53         | E15.8         | meters                | station height  |
|                 | 61-72         | 2A6           |                       | name of station   |
| 9               |               |               |                       | start and stop times of ephemeris table   |
|                 | 1-15          | E15.8         | seconds               | print interval (t)  |
|                 | 17-18         | I2            |                       | start month   |
|                 | 20-21         | I2            |                       | day   |
|                 | 23-24         | I2            |                       | year (last two digits)  |
|                 | 26-29         | F4.1          |                       | hour  |
|                 | 31-34         | F4.1          |                       | minutes   |
|                 | 36-41         | F7.3          |                       | seconds   |
|                 | 43-44         | I2            |                       | end month   |
|                 | 46-47         | I2            |                       | day   |

| <u>CARD NO.</u> | <u>COLUMN</u> | <u>FORMAT</u> | <u>UNITS</u> | <u>DESCRIPTION</u>   |
|-----------------|---------------|---------------|--------------|--|
| 9               | 49-50         | F4.1          |              | end year (last two digits)   |
|                 | 52-55         | F4.1          |              | hour   |
|                 | 57-60         | F4.1          |              | minutes  |
|                 | 62-67         | F4.1          |              | seconds  |
| 10              |               |               |              | print codes all=0 when look angles requested   |
|                 | 2             | I2            |              | =0; =1 to print position/velocity vectors  |
|                 | 4             | I2            |              | =0; =1 to print sub-satellite position   |
|                 | 6             | I2            |              | =0; =1 to print osculating elements  |
|                 | 8             | I2            |              | =0; =1 to print station observation data   |
|                 | 9-10          | I2            |              | =0; =1 to write binary tape  |
|                 | 11-13         | E15.8         |              | =1.0; single correction of range for refraction  |
| 11              | 16            | I1            |              | output options for $\bar{M}$ -value and Conversion Tables<br>"0"= $\bar{M}$ -value table only<br>"1"= $\bar{M}$ -value and Faraday to TEC Conversion Tables<br>"2"= all tables |
|                 | 33-38         | F6.2          | MHz          | operating frequency  |
|                 | 52-55         | F4.1          | MM           | Polarization reference value(millimeters   |
|                 | 60-63         | I4            |              | Year of requested $\bar{M}$ -value prediction  |
| 12              | 1-3           |               |              | "END"  |
|                 | 5-6           |               |              | "OF"   |
|                 | 8-14          |               |              | "PROBLEM"  |
| 13              | 1             |               |              | "9" = end of all input   |

## II. INPUT TAPE FORMAT

The POGO (8/69) set of geomagnetic field coefficients must be attached to the local file TAPE2 before program execution. The format for this file is as follows;

| <u>CARD NO.</u> | <u>COLUMN</u> | <u>VARIABLE NAME</u> | <u>FORMAT</u> | <u>DESCRIPTION</u>  |
|-----------------|---------------|----------------------|---------------|---|
| 1               | 1             | J                    | I1            | =0 if coefficients were derived using oblate earth<br>≠0 if coefficients were derived using spherical earth |
| 1               | 2             | K                    | I1            | =0 if coefficients are Schmidt normalized<br>≠0 if coefficients are Gauss normalized                        |
| 1               | 4-9           | TZERO                | F6.1          | epoch for which coefficients were derived = 1960.0  |
| 1               | 10-72         | AID                  | 10A6,A3       | Alphabetic identification   |

Each succeeding card contains the variables N,M, GNM, HNM, GTNM, HTNM, GTTNM, HTTNM, in the following format (2I3,6F11.4) where GNM, HNM, GTNM, HTNM, GTTNM, and HTTNM are the spherical harmonic coefficients in units of gamma ( $10^{-5}$  gauss).

$$\begin{array}{l}
 N = n+1 \\
 M = m+1 \\
 \left. \begin{array}{l}
 GNM = g_n^m \\
 HNM = h_n^m
 \end{array} \right\} \text{spherical harmonic coefficients} \\
 \left. \begin{array}{l}
 GTNM = \dot{g}_n^m \\
 HTNM = \dot{h}_n^m \\
 GTTNM = \ddot{g}_n^m \\
 HTTNM = \ddot{h}_n^m
 \end{array} \right\} \text{time derivatives at the epoch date}
 \end{array}$$

Termination of the coefficient set is accomplished by a flag card where N is set equal to zero. A list of the POGO (8/69) coefficient file is given in Table 4 of this report.

## EXECUTION REQUIREMENTS

Core memory required = 110 K octal  
Compile time = 17.9 decimal seconds  
Execution time = 8.7 seconds per station/month

Since this program will be used to produce output tables for many stations each month one would like to minimize the execution requirements. One way of accomplishing this is to store the binary object code as a user-library, thus avoiding the need for compiling the program each time it is use while greatly reducing the operating costs.

## TAPE REQUIREMENTS

The following tapes must be included on the program card:

TAPE1 : output tape containing the  $\bar{M}$ -value and TEC tables  
TAPE2 : input tape containing the POGO (8/69) coefficient set  
TAPE3 : scratch tape  
TAPE4 : scratch tape  
TAPE5 : input ; card reader  
TAPE6 : output; line printer ; contains ephemeris data

## USE OF PROGRAM

In order to use the Faraday to TEC conversion correctly an observer should first verify that the station location, operating frequency, satellite being observed, and reference polarization value match those listed on the computer table headings.

The observer then turns to the page of the conversion tables with the proper pi-value and finds the millimeter reading which matches the polarization channel chart reading. He then scans across the table to find the final TEC value in the column which corresponds to the time of the observation.

For example, referring to the sample output in Table 3 one can easily see that for an observer at Luning, Taiwan monitoring the satellite IS2F3 which has a nominal longitude of -161.9 degrees east, on a frequency of 136.44 MHz, with a reference polarization value of 13.5 millimeters during the month of September, 1976, a polarization chart reading of  $2\pi$ , 15 millimeters at 14 hrs universal time corresponds to a TEC value of  $13.8 \times 10^{16}$  el/m<sup>2</sup>.

SAMPLE CONTROL DECK

2535 JOHANSON

JJLOR, T90, CMI 10000.  
ATTACH, JL1B, JMJLIBX2939, ID=JOHANSON.  
ATTACH, TAPE2, POGOX2939, ID=JOHANSON.  
LIBRARY(JL1B)  
LDSET (PRESET=ZERO)  
LOKANGL.  
REWIND, TAPE1.  
COPY, TAPE1, OUTPUT.  
EXIT.  
7/8/9

5  
1 12F3 076127  
2 0.0 55.8347 54.0444 298.4900 .0019999 6.61364  
3 1.002989, .0134 0.0268  
4  
5 6.6096106

1 1  
47 -121.17 25.0 LUNPING  
3600. 09 15 76 00.0 00.0 00.000 09 15 76 23.0 00.0 00.000

0 0 0 0 01.0  
OUTPUT OPTION =1 FREQUENCY =136.44 BETAR =13.5 1976 LUN  
END OF PROBLEM

9  
6/7/879

TABLE I

K-VALUE OUTPUT

LOOK ANGLES FOR A GEOSTATIONARY SATELLITE (EQUATORIAL ORBIT) AS A FUNCTION OF SATELLITE LATITUDE AND LONGITUDE.

| DATE               | STATION       | LATITUDE        | E-LONGITUDE | PROG   | SEC     | Z     | G     | FLCY | AZIM | RANGE | HOUR ANGLE | DECLIN | ALPHA |     |          |
|--------------------|---------------|-----------------|-------------|--------|---------|-------|-------|------|------|-------|------------|--------|-------|-----|----------|
| SEPTEMBER 15, 1976 | TAIWAN        | 25.00           | 121.00      | ANGLE  |         |       |       |      |      |       | MR         | MIN    | SEC   | DEG | MIN      |
| TIME (UT)          | SUB-SATELLITE | SUN-IONOSPHERIC | H           | PROP   | SEC     | Z     | G     | FLCY | AZIM | RANGE | MR         | MIN    | SEC   | DEG | MIN      |
|                    | LAT           | E-LONG          | LAT         | E-LONG |         |       |       |      |      |       |            |        |       |     |          |
| 0 0                | 4.3           | -161.0          | 23.5        | 130.5  | -23419. | 106.5 | 2.022 | 3.60 | 4.7  | 91.5  | 41229.     | 18     | 19    | 41  | 0 38.0   |
| 1 0                | 2.8           | -161.9          | 23.1        | 133.9  | -30711. | 109.5 | 2.837 | 3.95 | 4.2  | 92.9  | 41278.     | 18     | 20    | 6   | -0 30.1  |
| 2 0                | 1.2           | -162.0          | 22.6        | 139.3  | -32438. | 110.5 | 2.852 | 4.34 | 3.6  | 94.5  | 41359.     | 18     | 20    | 38  | -2 30.7  |
| 3 0                | -0.6          | -162.1          | 22.0        | 139.8  | -33022. | 111.5 | 2.855 | 4.71 | 3.0  | 96.1  | 41380.     | 18     | 21    | 10  | -4 16.0  |
| 4 0                | -2.2          | -162.2          | 21.3        | 140.2  | -33222. | 112.5 | 2.876 | 5.04 | 2.3  | 97.7  | 41431.     | 18     | 21    | 34  | -5 59.1  |
| 5 0                | -3.8          | -162.3          | 20.8        | 140.7  | -33504. | 113.4 | 2.885 | 5.34 | 1.7  | 99.1  | 41478.     | 18     | 21    | 46  | -7 32.8  |
| 6 0                | -5.1          | -162.3          | 20.2        | 141.1  | -33924. | 114.1 | 2.890 | 5.55 | 1.1  | 100.3 | 41521.     | 18     | 21    | 41  | -8 50.7  |
| 7 0                | -6.0          | -162.2          | 19.6        | 141.5  | -34557. | 114.6 | 2.893 | 5.73 | .6   | 101.2 | 41554.     | 18     | 21    | 20  | -9 47.4  |
| 8 0                | -6.5          | -162.1          | 19.5        | 141.6  | -35093. | 114.8 | 2.894 | 5.74 | .3   | 101.5 | 41576.     | 18     | 20    | 47  | -10 19.0 |
| 9 0                | -6.5          | -161.9          | 19.5        | 141.9  | -35620. | 114.8 | 2.895 | 5.69 | .1   | 101.5 | 41583.     | 18     | 20    | 9   | -10 23.2 |
| 10 0               | -6.2          | -161.8          | 19.7        | 142.0  | -36279. | 114.5 | 2.895 | 5.74 | .2   | 101.1 | 41571.     | 18     | 19    | 33  | -9 59.7  |
| 11 0               | -5.4          | -161.7          | 20.0        | 141.8  | -37035. | 114.1 | 2.894 | 5.61 | .6   | 100.3 | 41541.     | 18     | 19    | 6   | -9 20.1  |
| 12 0               | -4.2          | -161.6          | 20.5        | 141.5  | -37950. | 113.4 | 2.892 | 5.42 | .9   | 99.2  | 41454.     | 18     | 18    | 52  | -7 58.1  |
| 13 0               | -2.7          | -161.6          | 21.1        | 141.0  | -39050. | 112.6 | 2.887 | 5.15 | 1.5  | 97.9  | 41433.     | 18     | 18    | 51  | -6 24.4  |
| 14 0               | -1.1          | -161.6          | 21.7        | 140.4  | -40350. | 111.6 | 2.877 | 4.84 | 2.3  | 96.4  | 41364.     | 18     | 19    | 1   | -4 47.3  |
| 15 0               | .7            | -161.7          | 22.4        | 139.5  | -41834. | 110.7 | 2.863 | 4.47 | 3.1  | 94.8  | 41283.     | 18     | 19    | 16  | -3 11.6  |
| 16 0               | 2.4           | -161.7          | 22.9        | 139.2  | -43524. | 109.7 | 2.845 | 4.08 | 3.9  | 93.3  | 41228.     | 18     | 19    | 30  | -1 18.6  |
| 17 0               | 3.9           | -161.5          | 23.4        | 135.7  | -45452. | 108.3 | 2.827 | 3.71 | 4.6  | 91.9  | 41174.     | 18     | 19    | 39  | 0 18.8   |
| 18 0               | 5.1           | -161.2          | 23.8        | 132.2  | -47648. | 108.1 | 2.811 | 3.34 | 5.1  | 90.7  | 41136.     | 18     | 19    | 39  | 1 32.1   |
| 19 0               | 6.0           | -161.8          | 24.2        | 138.0  | -50223. | 107.6 | 2.800 | 3.13 | 5.5  | 89.8  | 41116.     | 18     | 19    | 30  | 2 27.9   |
| 20 0               | 6.5           | -161.7          | 24.2        | 137.9  | -52854. | 107.3 | 2.784 | 2.89 | 5.6  | 89.3  | 41115.     | 18     | 19    | 17  | 2 58.3   |
| 21 0               | 6.6           | -161.7          | 24.2        | 137.9  | -55610. | 107.2 | 2.795 | 2.91 | 5.6  | 89.3  | 41130.     | 18     | 19    | 5   | 3 11.2   |
| 22 0               | 6.2           | -161.6          | 24.1        | 138.0  | -58579. | 107.4 | 2.802 | 3.10 | 5.4  | 89.6  | 41159.     | 18     | 18    | 58  | 2 36.4   |
| 23 0               | 5.4           | -161.6          | 23.9        | 138.3  | -61766. | 107.9 | 2.813 | 3.32 | 5.1  | 90.4  | 41198.     | 18     | 19    | 1   | 1 45.8   |

FOR A SATELLITE AT THE EQUATOR...

G=0 -161.9 22.1 139.8 -31035. 111.1 2.865 4.60 3.0 95.5 41426. 18 20 6 -3-41.7 -64.7

MSAT=12F3 FREQ=136.440 DELET=7.00 DEVAR=13.5

Copy available to DDC does not permit fully legible reproduction

TABLE 2

TEC CONVERSION TABLE OUTPUT

CONVERSION TABLES FROM REFERENCE POLARIZATION CHANNEL CHART READINGS TO FINAL T.E.C. VALUES

\*\*\*\*\* WARNING \*\*\*\*\*  
 \* \* \* \* \*  
 \* MAKE CERTAIN THAT STATION, SATELLITE, FREQUENCY,  
 \* MONTH, AND REFERENCE POLARIZATION VALUE ARE CORRECT  
 \* BEFORE USING THESE TABLES.  
 \* \* \* \* \*

TO OBTAIN THE REFERENCE POLARIZATION VALUE:

1. INITIALLY ADJUST THE POLARIZATION CHANNELS FOR 45 MILLIMETERS (DIVISIONS) DEFLECTION.
2. CONNECT A SIGNAL GENERATOR INTO R.F. SWITCH INPUT "B" WITH INPUT "A" TERMINATED WITH A MATCHED LOAD.
3. READ REFERENCE POLARIZATION VALUE ON POLARIZATION REFERENCE CHANNEL.

DIFFERENCES BETWEEN THE ACTUAL REFERENCE POLARIZATION VALUE AND THAT LISTED IN THE TABLE HEADINGS CAN BE ACCOMMODATED BY ONE OF THE FOLLOWING:

1. TAKE THE DIFFERENCE BETWEEN THE ACTUAL REFERENCE POLARIZATION VALUE AND THE COMPUTER LISTED VALUE. ADD THIS VALUE TO THE FINAL CHART READINGS BEFORE LOOKING UP FINAL T.E.C. IN THE FOLLOWING TABLES.
2. NEW TABLES WITH CORRECT VALUES MAY BE OBTAINED FROM AFGL-L10 BY NOTIFYING THEM OF THE CORRECT REFERENCE POLARIZATION VALUE (IN MILLIMETERS).



TABLE 4

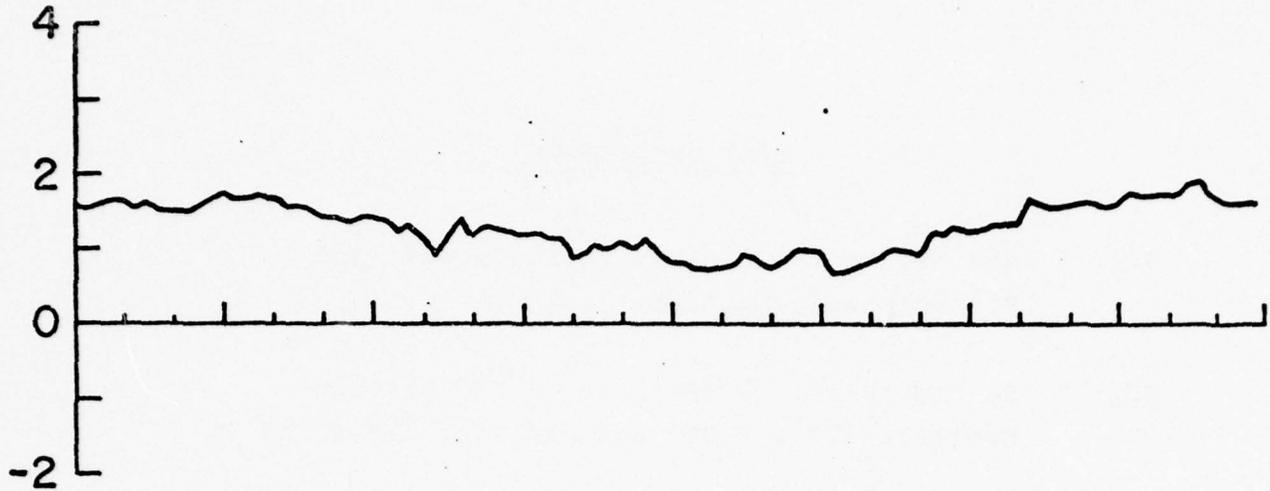
POGO (E/69) COEFFICIENT SET

| 00 | 1560.0       | PCCO(E/69) |          |          |      |      |
|----|--------------|------------|----------|----------|------|------|
| 2  | 1-30470.P320 | -0.0       | 26.E223  | -0.0     | -0.0 | -0.0 |
| 2  | 2-2170.2336  | 5757.0859  | 10.0325  | 2.2485   | -0.0 | -0.0 |
| 3  | 1-1542.4E51  | -0.0       | -23.6564 | -0.0     | -0.0 | -0.0 |
| 3  | 2-2989.3350  | -1979.3044 | 1.4984   | -6.6426  | -0.0 | -0.0 |
| 3  | 3-1555.9304  | 266.0750   | 7.9161   | -28.3228 | -0.0 | -0.0 |
| 4  | 1-1333.3594  | -0.0       | -7.2364  | -0.0     | -0.0 | -0.0 |
| 4  | 2-1982.5684  | -424.8779  | -11.4175 | 4.4887   | -0.0 | -0.0 |
| 4  | 3-1282.1541  | 241.6939   | 0.8416   | -0.9585  | -0.0 | -0.0 |
| 4  | 4-833.6372   | -173.6776  | 3.2653   | 1.7665   | -0.0 | -0.0 |
| 5  | 1-564.6553   | -0.0       | -1.5687  | -0.0     | -0.0 | -0.0 |
| 5  | 2-810.7571   | 134.4438   | -1.1772  | 3.6897   | -0.0 | -0.0 |
| 5  | 3-506.E203   | -303.6641  | -5.3583  | 5.6356   | -0.0 | -0.0 |
| 5  | 4-357.E0E3   | 19.3889    | 1.0208   | -1.0901  | -0.0 | -0.0 |
| 5  | 5-224.7370   | -276.3591  | 8.3367   | -2.0537  | -0.0 | -0.0 |
| 6  | 1-237.4645   | -0.0       | 3.5940   | -0.0     | -0.0 | -0.0 |
| 6  | 2-356.5618   | 5.0910     | 0.5769   | 2.3359   | -0.0 | -0.0 |
| 6  | 3-249.7766   | 107.9608   | -0.2723  | 4.0147   | -0.0 | -0.0 |
| 6  | 4-14.3464    | -107.2727  | -3.2611  | -4.2427  | -0.0 | -0.0 |
| 6  | 6-75.7366    | 117.0501   | 5.0440   | -5.0275  | -0.0 | -0.0 |
| 6  | 5-149.7288   | -108.2535  | -1.0817  | 0.6315   | -0.0 | -0.0 |
| 6  | 6-75.7366    | 117.0501   | 5.0440   | -5.0275  | -0.0 | -0.0 |
| 7  | 1-44.7689    | -0.0       | 0.1186   | -0.0     | -0.0 | -0.0 |
| 7  | 2-59.3958    | -7.6247    | 0.3830   | -0.6497  | -0.0 | -0.0 |
| 7  | 3-3.6751     | 118.1291   | 2.3535   | -2.3806  | -0.0 | -0.0 |
| 7  | 4-232.3608   | 58.3039    | 1.2792   | 2.4867   | -0.0 | -0.0 |
| 7  | 5-9.5710     | -18.1037   | -2.7692  | -1.6966  | -0.0 | -0.0 |
| 7  | 6-1.9681     | -27.0357   | 0.0831   | 2.3390   | -0.0 | -0.0 |
| 7  | 7-83.0814    | 0.1058     | -1.2965  | -2.5932  | -0.0 | -0.0 |
| 8  | 1-79.2588    | -0.0       | -1.5993  | -0.0     | -0.0 | -0.0 |
| 8  | 2-51.5829    | -54.4392   | -0.2631  | -1.6805  | -0.0 | -0.0 |
| 8  | 3-0.2746     | -21.2277   | 0.7227   | -1.1414  | -0.0 | -0.0 |
| 8  | 4-8.9470     | -8.6502    | 0.8573   | 0.5781   | -0.0 | -0.0 |
| 8  | 5-33.4968    | 5.5250     | 0.8359   | 1.2319   | -0.0 | -0.0 |
| 8  | 6-3.2699     | 15.0558    | -0.5747  | 0.6359   | -0.0 | -0.0 |
| 8  | 7-10.0034    | -23.6011   | 1.0100   | 0.4034   | -0.0 | -0.0 |
| 8  | 8-3.9274     | -27.8326   | -1.3952  | 0.6037   | -0.0 | -0.0 |
| 9  | 1-9.9028     | -0.0       | 0.1883   | -0.0     | -0.0 | -0.0 |
| 9  | 2-3.1867     | 9.8124     | 0.2709   | 0.0110   | -0.0 | -0.0 |
| 9  | 3-5.6134     | -16.2349   | 0.3290   | 0.3866   | -0.0 | -0.0 |
| 9  | 4-16.5215    | 9.9281     | 0.8273   | -1.0603  | -0.0 | -0.0 |
| 9  | 5-3.2876     | -18.8807   | 0.4170   | -0.0866  | -0.0 | -0.0 |
| 9  | 6-4.5906     | 10.6028    | -0.0007  | -0.4919  | -0.0 | -0.0 |
| 9  | 7-11.5698    | 20.6160    | 0.4934   | 0.5618   | -0.0 | -0.0 |
| 9  | 8-4.9906     | 10.6028    | -0.0007  | -0.4919  | -0.0 | -0.0 |
| 9  | 9-11.9698    | 20.6160    | 0.4934   | 0.5618   | -0.0 | -0.0 |
| 9  | 10-10.1946   | -0.1734    | 0.7337   | -0.6709  | -0.0 | -0.0 |
| 9  | 11-18.6983   | -20.7359   | -1.4755  | -0.0795  | -0.0 | -0.0 |
| 10 | 1-9.5694     | -0.0       | 0.1661   | -0.0     | -0.0 | -0.0 |
| 10 | 2-9.3443     | -25.3560   | -0.0791  | 0.4840   | -0.0 | -0.0 |
| 10 | 3-3.0948     | 12.8425    | -0.4572  | 0.4232   | -0.0 | -0.0 |
| 10 | 4-11.9937    | 3.1355     | -0.0917  | 0.1703   | -0.0 | -0.0 |
| 10 | 5-15.2921    | -2.4809    | -0.3723  | -0.4054  | -0.0 | -0.0 |
| 10 | 6-0.7382     | -2.0734    | -0.0282  | -0.2177  | -0.0 | -0.0 |
| 10 | 7-0.8367     | 7.2581     | -0.4837  | 0.2051   | -0.0 | -0.0 |
| 10 | 8-0.3897     | 12.7127    | 0.5370   | 0.0107   | -0.0 | -0.0 |
| 10 | 9-6.2269     | 4.6771     | -0.1324  | -1.1328  | -0.0 | -0.0 |
| 10 | 10-3.7603    | 0.7433     | 0.3251   | 0.1563   | -0.0 | -0.0 |
| 11 | 1-1.6855     | 0.0        | -0.0265  | 0.0      | 0.0  | 0.0  |
| 11 | 2-2.8307     | 2.8873     | -0.0756  | -0.1371  | 0.0  | 0.0  |
| 11 | 3-1.2560     | 3.4969     | 0.1663   | -0.3725  | 0.0  | 0.0  |
| 11 | 4-1.5793     | -0.6889    | -0.0662  | 0.5148   | 0.0  | 0.0  |
| 11 | 5-2.1593     | 6.6194     | -0.1231  | -0.0206  | 0.0  | 0.0  |
| 11 | 6-9.3895     | -5.0403    | -0.3321  | 0.0435   | 0.0  | 0.0  |
| 11 | 7-8.6777     | 1.0199     | -0.3308  | -0.1912  | 0.0  | 0.0  |
| 11 | 8-0.2722     | -2.8203    | -0.2116  | 0.0687   | 0.0  | 0.0  |
| 11 | 9-2.3784     | 2.1396     | 0.2742   | 0.3863   | 0.0  | 0.0  |
| 11 | 10-0.0938    | 4.2055     | 0.4915   | -0.5333  | 0.0  | 0.0  |
| 11 | 11-5.2727    | -8.7786    | -0.7501  | 0.3076   | 0.0  | 0.0  |

LIST OF FIGURES

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- Fig. 4  $\bar{M}$  Value for Observation of I2F3 for Lunping, Taiwan.
- Fig. 5 Sub-Satellite Position of ATS-3 on 15 June 1976.
- Fig. 6  $\bar{M}$  Value for Observation of ATS-3 from Hamilton MA on 15 June 1976.

SLANT PLASMASPHERIC  
ELECTRON CONTENT



NOVEMBER 1974

HAMILTON

----- GROUP DELAY DATA  
————— FARADAY ROTATION DATA

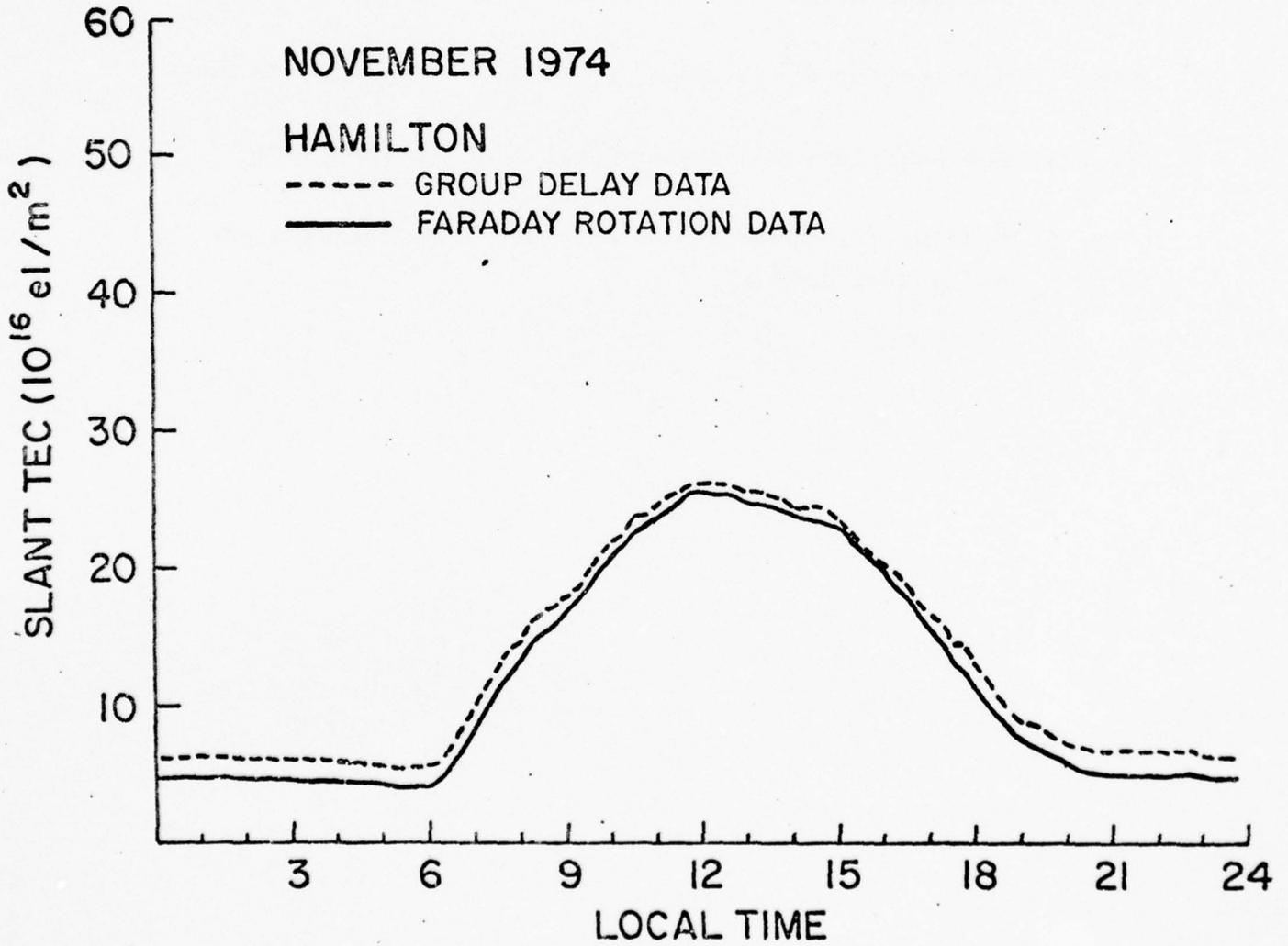


Fig. 1



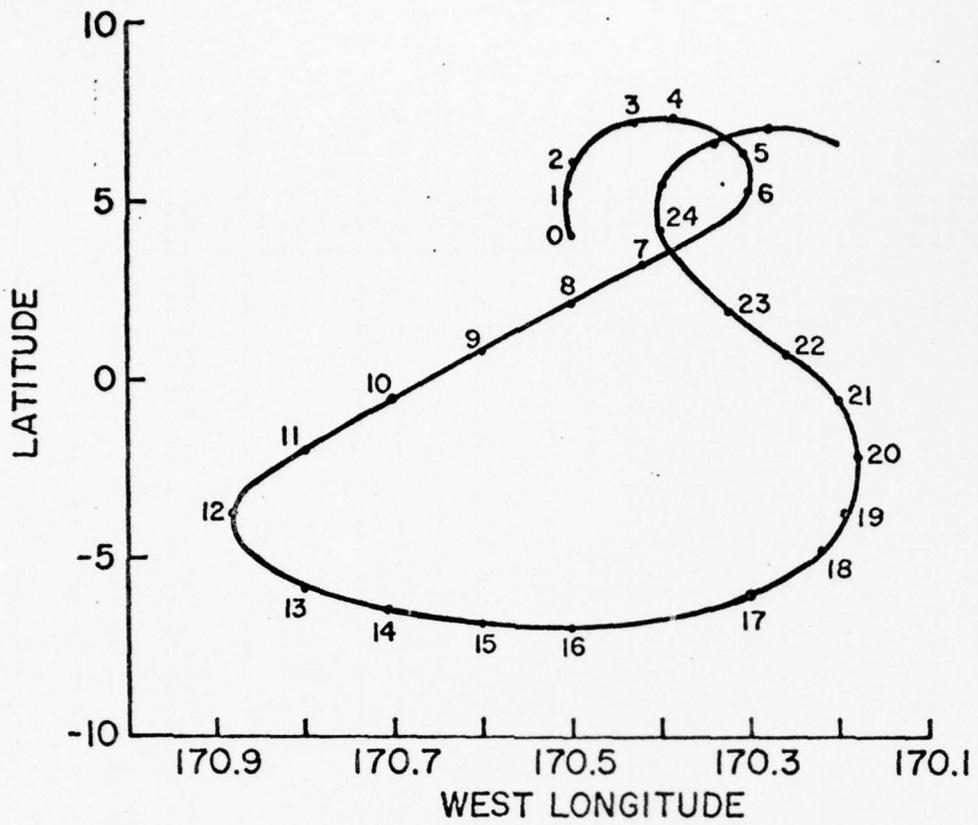


Fig. 3

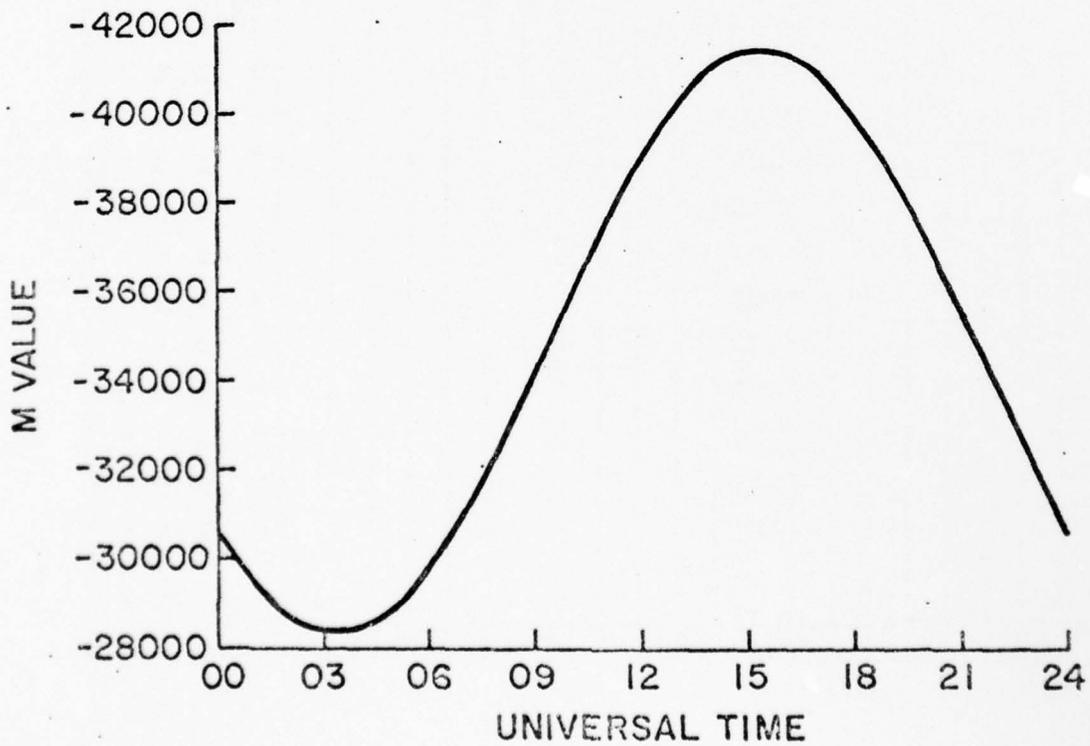


Fig. 4

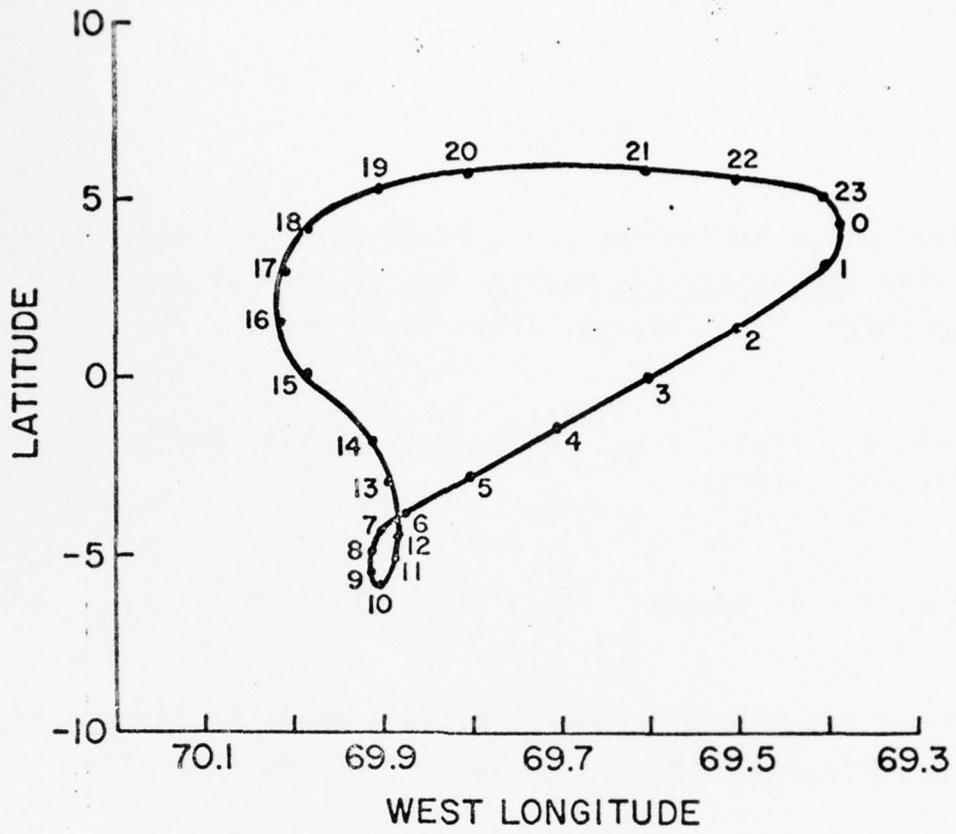


Fig. 5

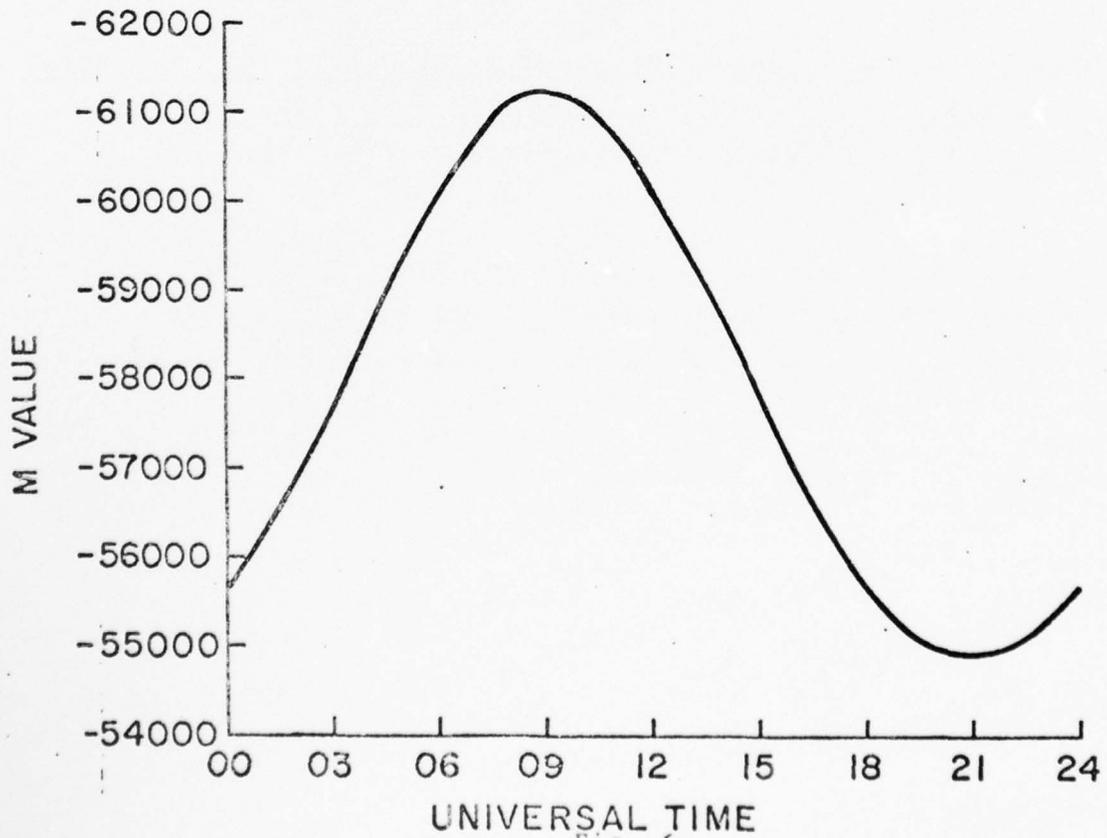


Fig. 6

## REFERENCES

- Cantor, C.J., MacKenzie, E.M., Vesprini, R.L., Hagan, M.P.,  
Data Reduction and Analysis in the Area of Satellite  
Studies, Final Report, AFCRL-TR-75-0493, 1975.
- Davies, K., Fritz, R.B., Grubb, R.N., Jones, J.E., Radio Sci.,  
10, 785, 1975.
- Davies, K., J. Geophys. Res., 81, 2825, 1976.
- Evans, J.V., Satellite Beacon Contributions to Studies of the  
Structure of the Ionosphere, Boston MA, June 1976.
- Klobuchar, J.A., et al., Total Electron Content Studies of  
the Ionosphere, AFCRL-TR-73-0098, 1973.
- Koster, J.R., Ionospheric Research Using Satellites, The Total  
Electron Content of the Ionosphere Over Legon for the  
Year 1972, AFCRL-TR-74-0414, 1973.
- Poletti-Liuzzi, D.A., Yeh, K.C., Lin, C.H., Simulation and  
Measurement of the Plasmaspheric Electron Content,  
Proceedings of COSPAR Satellite Beacon Symposium, 1976.
- Soicher, H., Nature, 259, 33, 1976.

### III.

## SIGNAL STATISTICS OF IONOSPHERIC SCINTILLATION IN THE WEAK AND STRONG SCATTER REGIMES

### 1. INTRODUCTION

For a successful design of ground to space communication links, a knowledge of ionospheric scintillations at a desired frequency as well as the fine structure of the fluctuations is required. At mid-latitudes where the amplitude fluctuations are small, ground based scintillation measurements in conjunction with the well-developed weak scattering theories allow predictive systems of scintillations to be successfully built. On the other hand, in the equatorial region, where strong irregularities extend over several hundred kilometers, amplitude fluctuations as large as 25 dB in the VHF range and even 2 dB at frequencies as high as 6 GHz are often observed. The deleterious effects of such intense scintillations on communication links are indeed very formidable. In view of the paucity of experimental data defining the structure of ionospheric scintillations in the strong scatter regime and the fact that scattering theories in this domain are not fully developed, it has not been possible to develop a successful predictive system of scintillations in the equatorial region for use in communication engineering.

In this report, we present such a study of the characteristics of ionospheric scintillation in the weak and strong scatter regimes. Results on the frequency dependence of scintillations, power spectra and autocorrelation intervals of amplitude fluctuations in the two scattering domains are discussed.

## 2. OBSERVATIONAL MATERIAL AND METHOD OF ANALYSIS

The study has been based on simultaneous amplitude scintillation measurements of 137 and 360 MHz transmissions from ATS-6 carried out at Huancayo, Peru. The data used in the study correspond to a high level of scintillation activity and were recorded over the interval 2215-2400 LT on Nov. 1, 1974 and 2018-2333 LT on Nov. 4, 1974. In order to study the behavior of the wavelength dependence of scintillation, low fluctuation level scintillation data obtained at Sagamore Hill Radio Observatory, Hamilton, Mass., have also been used. Sagamore Hill data were obtained from ATS-5 transmissions at 137 and 412 MHz on April 12 and May 18, 1973. The data were recorded on FM analog tape which was later digitized at the rate of 6 samples/second. From each 15-minute data block from Huancayo and every 5-minute block from Sagamore Hill, the  $S_4$  index of scintillation has been derived which is defined as the second moment of intensity normalized to the average intensity. The 137 and 360 MHz scintillation data recorded at Huancayo have also been processed to obtain the autocorrelation intervals and the power spectrum of scintillations by the use of FFT algorithm.

### 3. FREQUENCY DEPENDENCE OF SCINTILLATION IN THE WEAK AND STRONG SCATTER REGIMES

From channel modelling considerations there is considerable interest in the study of frequency dependence of scintillation as it provides an estimate of scintillation at a desired frequency by extrapolating scintillation measurements at another frequency. Recent in-situ measurements at F-region heights indicate that the power spectral density of the irregularity wavenumber spectrum exhibits a power law form with one-dimensional spectral index  $\alpha_1 \sim 2$ . The dependence of three-dimensional irregularity power spectral density  $\Phi_N(k)$  on the irregularity wavenumber  $k$  may thus be represented as;

$$\Phi_N(k) = k^{-p} \quad (1)$$

where  $p = \alpha_1 + 2 \sim 4$  for F-region irregularities.

It has been shown that in the weak scatter limit or small amplitude fluctuations, the above form of irregularity spectrum yields a frequency dependence of  $S_4$  index of scintillation as;

$$S_4 \propto f^{-(p+2)/4} \propto f^{-\eta} \quad (2)$$

Thus the exponent  $\eta$  for the frequency dependence of scintillation is related to the spectral index  $p$  of three-dimensional irregularity wavenumber spectrum as;

$$\eta = \frac{p+2}{4} \quad (3)$$

For F-region irregularities if we assume that  $p \approx 4$  the exponent for wavelength dependence  $\eta$  is expected to have a value of about 1.5 for weak scintillations.

Based on Sagamore Hill observations of 137 and 412 MHz scintillations of ATS-5 transmissions on April 12 and May 18, 1973, we obtained the exponent  $\eta$ . In order to examine if the

weak scatter conditions are violated we studied the variation of  $\eta$  with  $S_4$  index at 137 MHz, corresponding to the lower limit of the frequency pair. Most of the observation points pertained to  $S_4 < 0.4$  at 137 MHz conforming to weak scatter limit. The data of April 12, 1973 yielded a median value of  $\eta \sim 1.2$  while May 18, 1973 data yields  $\eta \sim 1.5$ . These values of  $\eta$  correspond to spectral indices varying between 3.8 to 4.0 which is very close to that obtained from in-situ measurements of F-region irregularity power spectrum.

The frequency dependence of scintillation in the regime of strong amplitude fluctuations was studied by the use of scintillation measurements at Huancayo with ATS-6 transmissions at 137 and 360 MHz. It may be observed that the exponent  $\eta$  progressively decreases with increasing  $S_4$  in the strong scatter regime. For  $S_4 > 0.9$ ,  $\eta \sim 0$ , indicating thereby that scintillations become invariant of wavelength for very strong scattering.

Numerical solutions to the problem of multiple scattering indicate that scintillations gradually saturate as scattering conditions become stronger. In the case of our two frequency (137/360 MHz) observations, scintillations saturate first at lower frequency while the scintillation index of the higher frequency still registers an increase with increasing strength of scattering. This explains the observed progressive decrease of  $\eta$  index with  $S_4$ . Finally, when the scattering becomes so strong as to drive both 137 and 360 MHz to the saturated scintillation regime, frequency-independent scintillation ( $\eta \approx 0$ ) should result. The experimental results may thus be explained in the framework of multiple scatter theories.

#### 4. POWER SPECTRUM SCINTILLATIONS IN THE WEAK AND MULTIPLE SCATTER REGIMES

The power spectrum of scintillations in the equatorial region was studied and its variation with scintillation activity was examined.

Figures 2 and 3 illustrate the characteristics of power spectrum of scintillations at 137 and 360 MHz over two 15-minute intervals. The spectra in Figure 2 were obtained when the  $S_4$  indices at 137 and 360 MHz were 0.36 and 0.13 respectively and the case therefore corresponds to weak scatter conditions. The noise and frequency resolution error bars as computed at 0.1 Hz are indicated in the diagram. The spectral structure around 1 Hz corresponds to satellite spin modulation. It may be observed that the spectra are characterized by a relatively flat portion and then a linear roll-off portion. The spectral slopes of the roll-off portions correspond to  $f^{-3.6 \pm 0.5}$  and  $f^{-2.3 \pm 0.5}$ . If we consider the spectral slope to be approximately 3, then from weak scatter theory an irregularity power spectral index of 4 is obtained in agreement with in-situ measurements of F region irregularities

Figure 3 illustrates the power spectrum of scintillations when multiple scatter conditions prevailed at both frequencies, the  $S_4$  indices at 137 and 360 MHz being 0.95 and 0.84 respectively. The marked variation of the spectral features in this case as compared to that under weak scatter domain, illustrated in the previous diagram, is evident. The flat portion of the spectrum extends to much higher frequency and the slopes of the roll-off portions become very steep as strong scattering is

encountered. The frequency extension of the flat portion indicates that the noise band becomes more white in the strong scatter case and is more red in the weak scatter condition.

A close examination reveals that the limiting frequency of the flat portion is higher at 137 MHz as compared to 360 MHz. The results were confirmed independently by determining directly the autocorrelation intervals at the two frequencies. That the autocorrelation interval is shorter at lower frequency as compared to the higher frequency is opposite to what is expected under weak scatter theory.

From a knowledge of irregularity velocity, the autocorrelation intervals may be transferred to autocorrelation distance. This result has important implications in space diversity systems. We find that for combating weak scintillations the space diversity at lower frequencies is to be larger than that required at higher frequency but the reverse situation will hold when strong scintillations are encountered.

## LIST OF FIGURES

- Figure 1. The variation of the power law exponent,  $\eta$ , defining the frequency dependence of scintillations ( $f^{-\eta}$ ), with  $S_4$  index at 137 MHz.
- Figure 2. The power spectra of amplitude scintillations at 137 and 360 MHz when scattering is weak.
- Figure 3. The power spectra of scintillations at 137 and 360 MHz when scattering is strong.

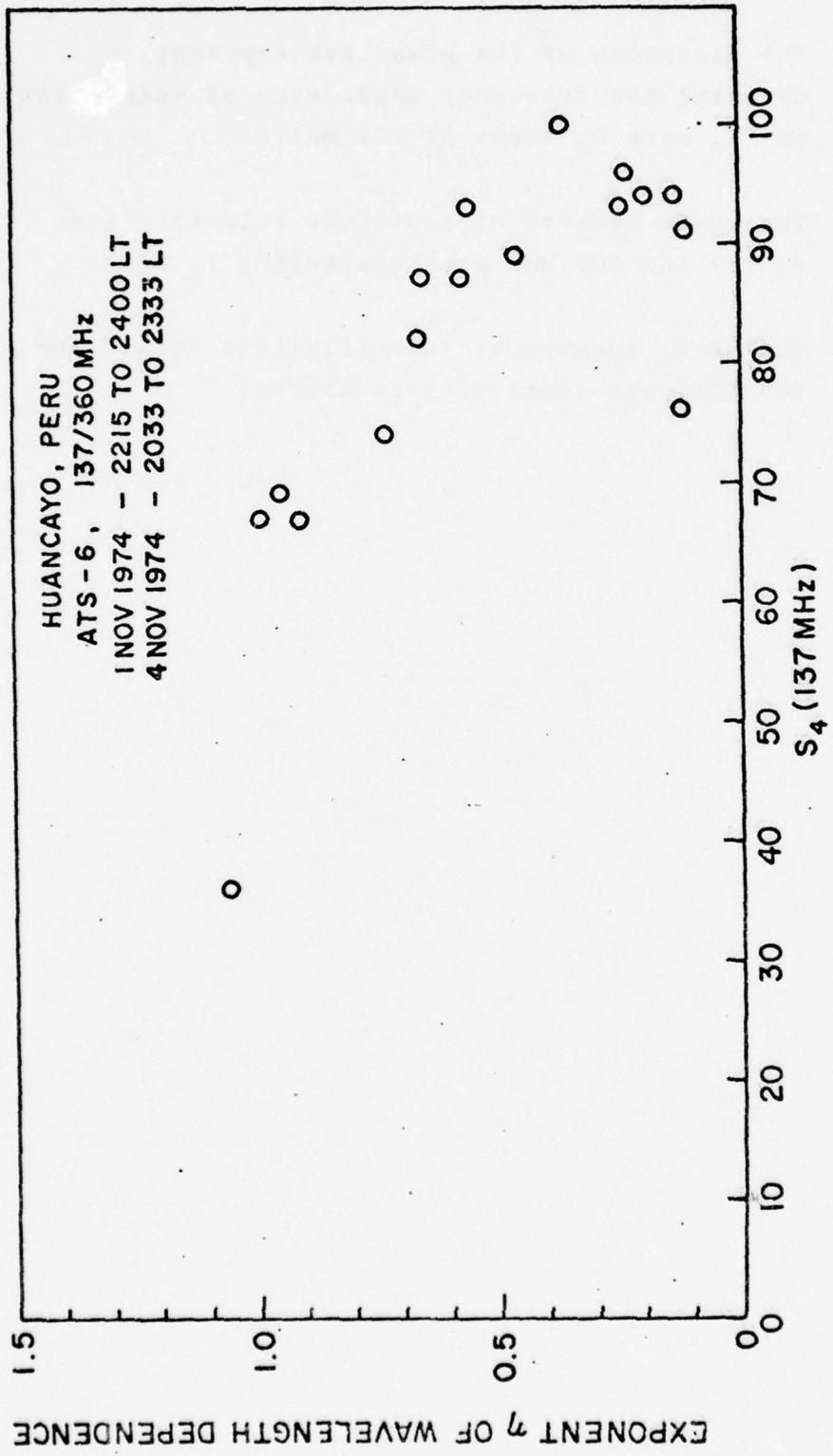
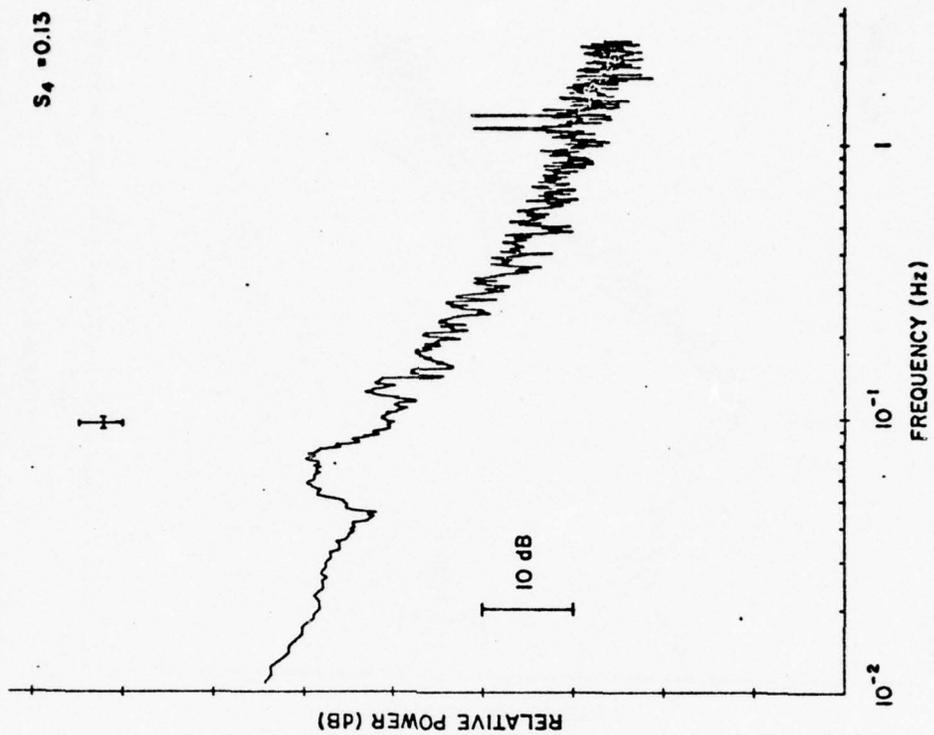


Fig. 1

HUANCAYO, ATS-6/360 MHz NOV. 1, 1974 2345-2400 LT

$S_4 = 0.13$



HUANCAYO, ATS-6/137 MHz NOV 1, 1974 2345-2400 LT

$S_4 = 0.36$

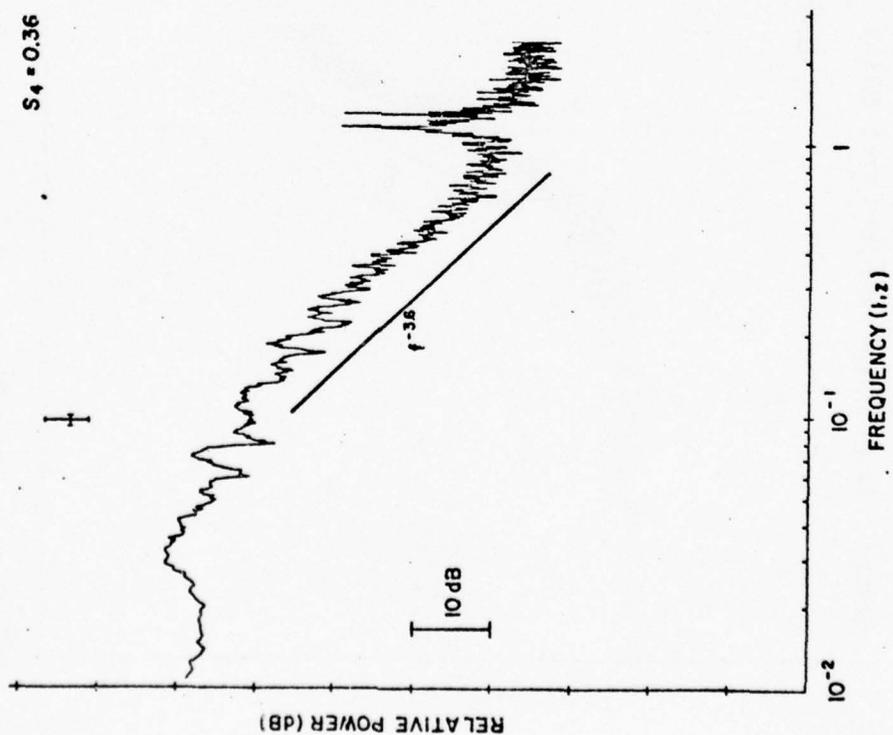
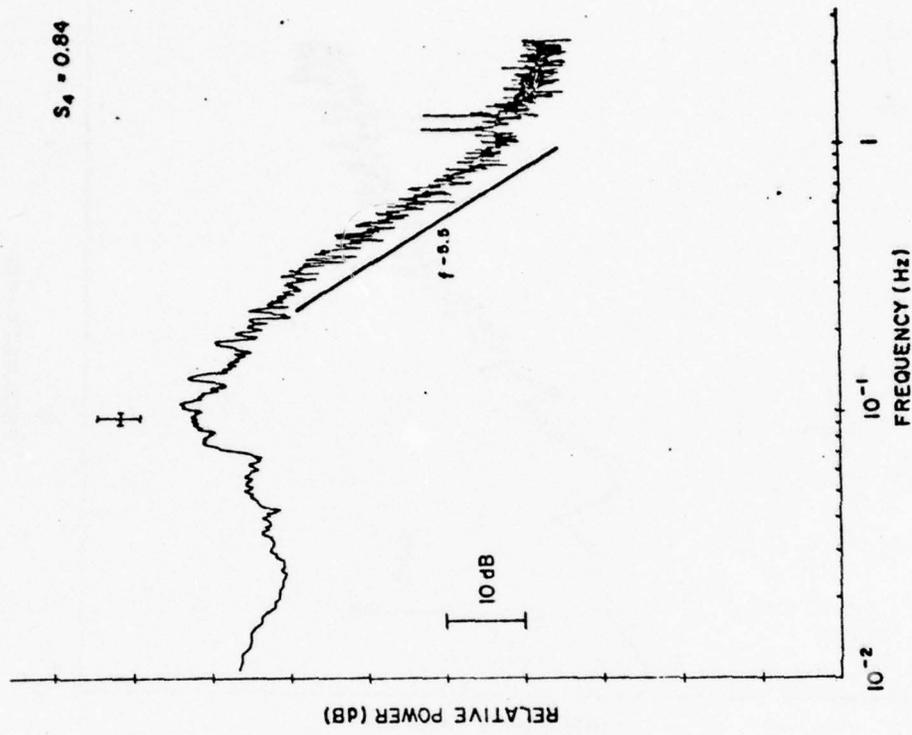


Fig. 2

HUANCAYO, ATS-6 / 360 MHz NOV. 1, 1974 2300-2315 LT

$S_4 = 0.84$



HUANCAYO, ATS-6 / 137 MHz NOV. 1, 1974 2300-2315 LT

$S_4 = 0.95$

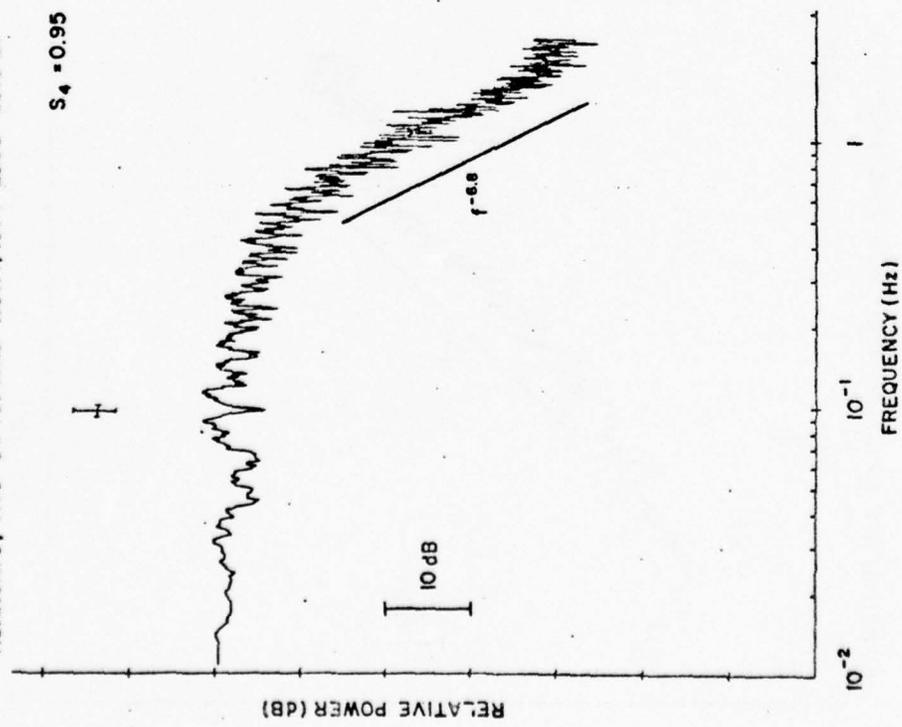


Fig. 3

#### IV.

### ON THE NATURE OF ELECTROJET IRREGULARITIES RESPONSIBLE FOR DAYTIME VHF SCINTILLATIONS

#### 1. INTRODUCTION

Scintillation measurements made at Huancayo, Peru by the use of 41 and 140 MHz transmissions of ATS-6 indicate that scintillation is almost a regularly occurring phenomenon during daytime near the magnetic equator. In view of the much lower level of daytime scintillation as compared to nighttime, the characteristics of daytime scintillation have remained unexplored whereas equatorial nighttime scintillation has been extensively studied. The most viable portion of the equatorial ionosphere where plasma density irregularities are generated during daytime corresponds to the electrojet region which is to be associated with the observed daytime scintillations.

The nature of electron density irregularities with meter wavelength present in the equatorial electrojet has been extensively explored, experimentally, by the radar spectral techniques and theoretically in the light of plasma instability mechanisms. These studies reveal the existence of two distinct types of meter wave irregularities, namely, types 1 and 2. Type 1 irregularities are considered to be generated by a modified two-stream instability when the electron drift velocity relative to the ions exceeds the ion-acoustic velocity of about 360 m/sec. Type 2 irregularities, on the other hand, are generated by gradient drift instability mechanism when the electron drift velocity exceeds a velocity of about 30 m/sec in a region of steep density gradient.

In view of the fact that a backscatter radar is sensitive to half the transmitted wavelength, sweep frequency radars have been operated over the frequency range of 15-150 MHz to study the

electrojet irregularities with wavelengths ranging between 10m - 1m. These studies indicate that the long wave irregularities correspond to type 2 generated by gradient drift instability mechanism whereas short wave irregularities correspond to type 1 being generated by two-stream instability mechanism. In an effort to extend the study of electrojet irregularities to wavelengths longer than those explored by radar measurements, the features of equatorial sporadic-E ( $E_{sq}$ ) in relation to radar measurements have been recently explored. The sporadic-E signature on ionograms corresponds typically to 30-80m irregularity wavelengths. It has been found that the long wave  $E_{sq}$  irregularities are related to type 2 meter wave irregularities which are generated by the gradient drift mechanism. This indeed conforms to the theoretical predictions. Recent theoretical studies show that the gradient drift mechanism generates still longer irregularity wavelengths in the kilometer range. From experimental as well as theoretical standpoint there exists considerable interest in exploring the long wavelength end of electrojet irregularities.

The present report based on VHF scintillation measurements and ionograms obtained at Huancayo as well as NOAA oblique VHF radar measurements made at Jicamarca attempts such a study of the characteristics of electrojet irregularities. It is known that scintillations arise from irregularities with wavelengths of the order of Fresnel dimension of the exploring wavelength at the irregularity height. For ATS-6 observations from Huancayo the Fresnel dimensions at 41 and 140 MHz with 110km slant range of the electrojet region correspond to 1km and 0.5km respectively. The study of  $E_{sq}$  on ionograms obtained at Huancayo provided

simultaneous information on 30-80m irregularity wavelengths whereas 50 MHz oblique radar backscatter measurements carried out at Jicamarca reveal the existing types of irregularities at 3m wavelength. This study, therefore, covers the wide range of irregularity wavelength from a few meters to about a kilometer in the equatorial electrojet.

## 2. RESULTS AND DISCUSSIONS

On normal days, the onset of scintillations occur immediately before 0800 LT and continue until about 1800 LT. Around noontime, scintillations attain maximum daytime level which can be as large as 13 dB peak to peak at 41 MHz and a few dB even at 140 MHz. On some occasions, the nighttime F-region scintillation continues through the early morning hours to merge with the daytime scintillation. On these days it is impossible to determine the onset time of daytime scintillation. On some other occasions, the onset of post-sunset F-region scintillation takes place before the daytime scintillation event has ceased completely.

Figure 1 indicates the time intervals over which both the NOAA oblique VHF radar detected electrojet irregularities and scintillations were recorded at Huancayo. On a few days scintillation measurements at 41 MHz only were available and on some others scintillation measurements at 140 MHz only could be made. The shading for these different measurements have been indicated in the diagrams. The breaks in the bar diagrams indicate either no observations were made during the period or no satellite transmission was available. During the period February 1-8, 1975, scintillations are observed only when 50 MHz radar is also able to detect electrojet irregularities. In view of the higher

frequency, scintillations at 140 MHz are detected slightly after the radar detects the presence of electrojet irregularities. Similarly, the cessation of scintillation activity at 140 MHz occurs earlier than the cessation of radar echo. We shall later provide estimates of irregularity amplitudes required to give measurable scintillation at 140 MHz. This will indicate that the irregularity amplitudes need to be larger than some threshold level to give measurable 140 MHz scintillation. It is interesting to note that on February 4, the electrojet irregularities are absent during the major part of the day as indicated by the radar measurements and scintillations are also conspicuous by their absence. The weak irregularities detected by the radar between 1500 and 1800 LT are not sufficiently strong to cause 140 MHz scintillation. Scintillation at 140 MHz observed on February 1 immediately prior to 2000 LT without any associated radar echo is attributed to the post-sunset F region irregularities. On this day, the nighttime scintillation at 140 MHz occurred at 1945 LT and continued until 0445 LT on the next day. Between February 18 and March 5, 1975, scintillation measurements could be made at the lower frequency of 41 MHz and it may be noted that the time synchronism between the radar echo and scintillation is excellent. The weak irregularity amplitudes which become detectable with the radar give rise to immediate scintillation effects at the lower frequency.

The comparative study of radar echoes and VHF scintillations illustrated by Figure 1 indicate that daytime scintillation is caused by electrojet irregularities and that the irregularities with wavelengths of the order of a km (corresponding to Fresnel dimensions) as explored by scintillation measurements co-exist

with the short-wavelength (3m) irregularities detected by the 50 MHz radar.

We shall next illustrate the behavior of q-type sporadic-E ( $E_{sq}$ ) echoes on February 20 in relation to 41 MHz scintillation and VHF radar echo. Figure 2 shows that both the scintillation activity and radar echo corresponding to type 2 ceased at 1820 LT. The bottom panel of this figure shows the ionogram sequence between 1800 and 1830 LT. The presence of  $E_{sq}$  echoes in the first two frames may be observed but in the final frame obtained at 1830 LT,  $E_{sq}$  is seen to have disappeared. Such a correlation between these events is found to exist on other days also. It shows that VHF scintillation, type 2 radar echo and  $E_{sq}$  echoes appear and disappear together. An extensive study of  $E_{sq}$  echoes in relation to type 2 radar echoes has been recently carried out. Our results establish the fact that type 2 irregularities are synchronized not only with the appearance of irregularities at 30-80m wavelengths as viewed by  $E_{sq}$  echoes on ionograms but with kilometer wavelength irregularities as well which cause 41 MHz scintillations. Thus this correlative study indicates that type 2 irregularities cover about a 3-decade range in wavelength.

The radar observations provided information on the nature of electrojet irregularities observed at 50 MHz. It has been established that both type 1 and type 2 are equally important in giving 50 MHz radar backscatter echoes whereas at frequencies higher than 50 MHz, type 1 irregularities predominate and radar echoes at lower frequencies are dominated by type 2 irregularities. The present 50 MHz radar observations yield the time

evolution of type 1 and type 2 irregularities and also provide the strength of either type of echo simply as weak or strong. Figure 3 shows the time variation of scintillation index SI at 140 MHz and the evolution of type 1 and type 2 irregularities as observed by the 50 MHz radar. The levels 1 and 2 marked in NOAA radar plots represent respectively the presence of weak or strong type 2 irregularities whereas levels 3 and 4 correspond respectively to weak and strong type 1 irregularities. On February 2, 140 MHz scintillation becomes discernible at 0915 LT when the radar echo reveals the presence of strong type 2 and weak type 1 echo. At 1210 LT when the radar echo indicates the cessation of type 1 irregularities and presence of type 2 irregularities only, the scintillation index does not show any change. This implies that the presence or absence of type 1 irregularities do not introduce any marked variation of the scintillation level indicating thereby that VHF scintillation activity is related to type 2 irregularities.

The lower data set obtained on February 4 shows an unusual day with no electrojet irregularities and consequently no scintillation during the major part of the day. The sporadic appearance of radar echo between 1600-1920 LT corresponding mostly to weak type 2 is not associated with scintillation activity at 140 MHz. The absence of scintillation activity on that day as well as any type 2 irregularities during the major part of the day may be related to a reversal of electric field at E-region heights. On a normal day, the E-region electric field near the magnetic equator is eastward, an upward Hall electric field is generated which in the presence of an upward

plasma density gradient generates type 2 irregularities. The generation of these irregularities is inhibited when the electric field reverses its direction to become westward. The reversal of the electric field, termed as counter-electrojet, has been diagnosed from a decrease in horizontal magnetic field intensity and has been shown to be correlated with the disappearance of  $E_{sq}$  echoes and decrease of signal intensity in transequatorial VHF scatter links.

During the development phase of VHF scintillations, a scintillation index (SI) of about 50% at 41 MHz typically corresponds to moderately strong type 2 echoes at meter wavelengths. The SI index of 50% corresponds to the theory based  $S_4$  index of about 0.25. A knowledge of  $S_4$  index allows us to compute the electron density deviation in the irregularities of realistic assumptions can be made regarding the irregularity layer thickness (L), layer height (z) and irregularity power spectrum. The slant range (z) of electrojet region to Huancayo for ATS-6 observations during the period was about 110 km. The thickness (L) of this layer over which the irregularities are assumed to be distributed undiminished in magnitude is considered as 5 km. We have also assumed that the 3-dimensional irregularity power spectrum has a spectral index of 4 in agreement with other experimental and theoretical results. The outer scale of the irregularity has been taken as 2 km in keeping with the numerical studies of type 2 irregularities. We find that  $S_4$  index of 0.25 at 41 MHz may be observed when the electron density deviation of the irregularities is  $\Delta N = 6 \times 10^9 \text{ m}^{-3}$ . This corresponds to irregularity amplitudes of 6% and 3% respectively for ambient

ionization density of  $10^{11}$  and  $2 \times 10^{11} \text{ m}^{-3}$  corresponding to critical frequencies of 3 and 4 MHz. At 140 MHz, similar level of  $S_4$  is attained only if the irregularity amplitudes increase by a factor of about 5. Theoretical studies of type 2 irregularities indicate that when the amplitude of type 2 irregularities in the tens of meter wavelength range attains a level of about 4% under the linear theory of gradient drift instability, shorter wavelength irregularities in the meterwave range may be generated through non linear cascading mechanism. Our computations of irregularity amplitudes based on VHF scintillation measurements indicate that when the r.m.s. irregularity amplitude in the kilometer wavelength range is found to be of the order of 5%, the 50 MHz radar is able to detect simultaneously the presence of type 2 irregularities. The highest level of  $S_4$  index at 41 MHz during daytime is found to be of the order of 0.5, which is found to correspond to an electron density deviation  $\Delta N = 1.6 \times 10^{10} \text{ m}^{-3}$  with the above assumed parameters. This value corresponds to r.m.s. irregularity amplitudes of 16% for ambient ionization density of  $10^{11} \text{ m}^{-3}$ .

For a power law type of irregularity power spectrum, the scintillation index ( $S_4$ ) is expected to have a power law variation with frequency. Assuming that such a power law variation exists, we defined the spectral index ( $\eta$ ) of scintillation as

$$\eta = \frac{\log (S_{4_1} / S_{4_2})}{\log (f_2 / f_1)}$$

where  $S_{4_1}$  and  $S_{4_2}$  are the scintillation indices ( $S_4$ ) at  $f_1$  and  $f_2$

respectively. From simultaneous daytime scintillation measurements at 41 and 140 MHz the spectral index  $\eta$  is obtained. Figure 4 indicates the variation of  $\eta$  with  $S_4$  index at 41 MHz. It is found that for  $S_4$  varying between 0.2 to 0.4,  $\eta$  varies between 0.6 to 1.2. For weak scattering spectral index of scintillation related to the spectral index ( $p$ ) of the irregularity power spectrum as  $\eta = \frac{p+2}{4}$ . Thus the results indicate that during the development or decay of type 2 irregularities, the irregularity power spectrum is very flat but attains a spectral index of about 3 when the irregularities are fully developed. It should be emphasized that the Fresnel dimensions of 41 and 140 MHz at the electrojet height corresponds to 0.5 km and 1 km respectively. Thus the derived spectral indices of the irregularities correspond to the above wavelength range which is close to the outer scale of type 2 irregularities.

### 3. SUMMARY:

The study reveals that daytime VHF scintillations are generated when  $E_{sq}$  echoes appear on ionograms and 50 MHz radar detects type 2 electrojet irregularities. Since VHF scintillations are sensitive to kilometer wavelength irregularities,  $E_{sq}$  monitors 30-80m wavelength irregularities and 50 MHz radar detects 3m wavelength irregularities, it may be concluded that type 2 irregularities covering the wavelength range of a few meters to a few kilometers co-exist. We have also found that during periods when the radar does not detect any electrojet irregularity, neither  $E_{sq}$  nor VHF scintillation is observed.

With the time scale of our measurements, it is not possible to locate the time period when non-linear cascading mechanism starts to generate meter wave irregularities, the theoretically predicted time interval being of the order of a second.

We have shown that when type 2 meter wave irregularities and VHF scintillations are simultaneously observed the irregularity amplitudes ranging between 4% to 16% (for ambient ionization density of  $10^{11} \text{ m}^{-3}$ ) at kilometer wavelengths are obtained. Further in the wavelength range of 0.5-1 km corresponding to the Fresnel dimensions of scintillation measurements, the spectral index of the irregularity power spectrum indicates a variation with irregularity amplitudes. At low levels of scintillation, the power spectrum is very flat but confirms to a power law spectral exponent of about 3 when fully developed. The observed evolution of irregularity spectrum corresponds to wavelengths in the vicinity of outer scale of type 2 irregularities which is typically assumed to lie in the range of 2-3 km.

## LIST OF FIGURES

- Figure 1. Association of daytime VHF scintillation in the VHF radar echo from electrojet irregularities.
- Figure 2. The association of the appearance and disappearance of q-type sporadic-E echoes with daytime scintillation and VHF radar echo.
- Figure 3. The co-existence of kilometer wavelength electrojet irregularities explored by scintillation measurements with 3m irregularities causing 50 MHz radar echo.
- Figure 4. The variation of power law exponent  $\eta$  defines the frequency dependence of scintillation ( $f^{-\eta}$ ) with scintillation index  $S_4$  at 41 MHz.

□ 41 MHz SCINTILLATION  
 HUANCAYO, PERU  
 ▨ 140 MHz SCINTILLATION  
 HUANCAYO, PERU  
 □ 50 MHz NOAA RADAR  
 BACKSCATTER

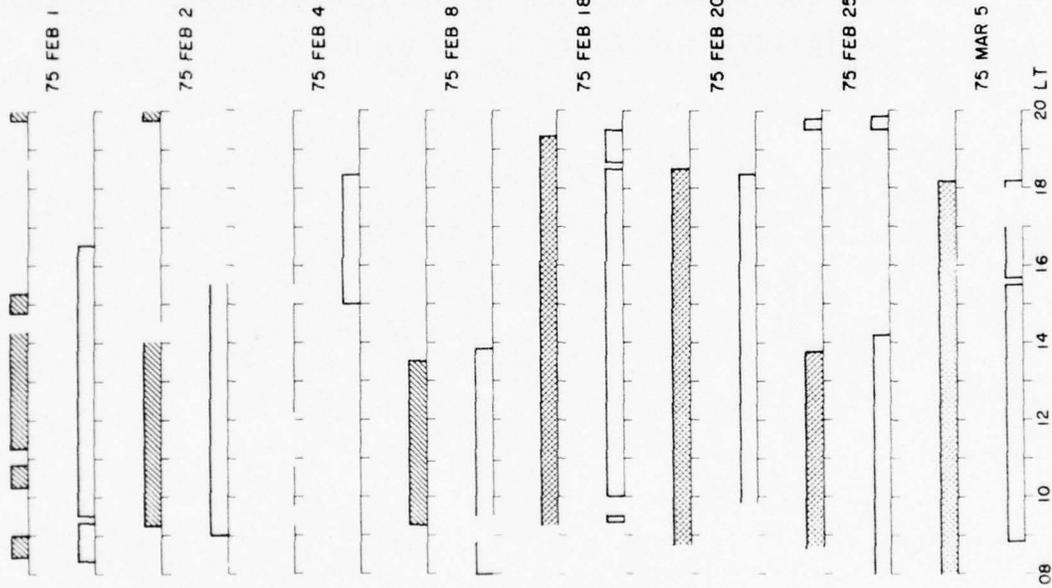


Fig. 1

41 MHz SCINTILLATION  
 VHF RADAR ECHO

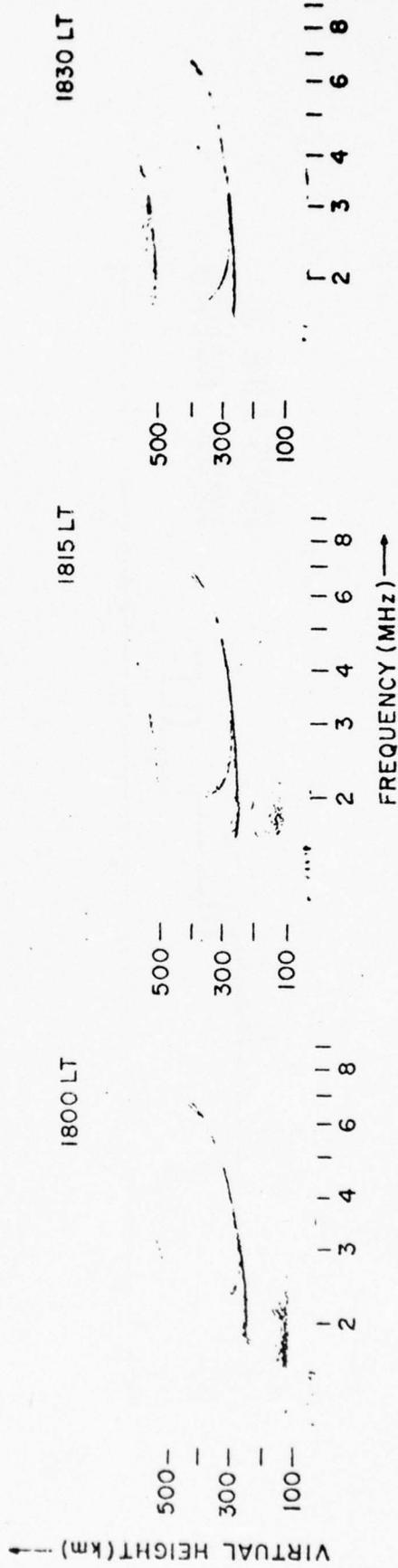
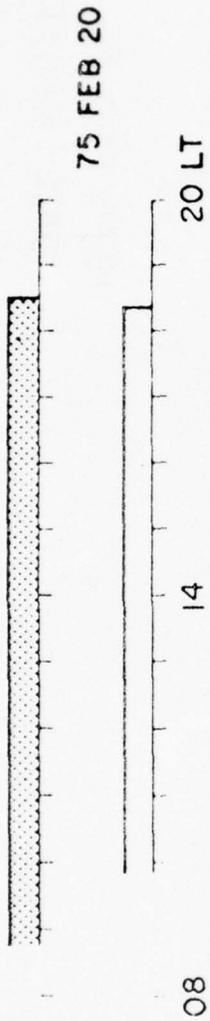
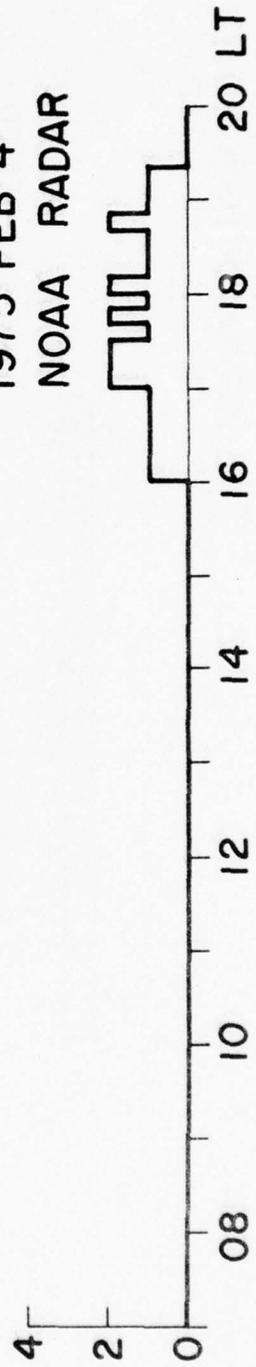
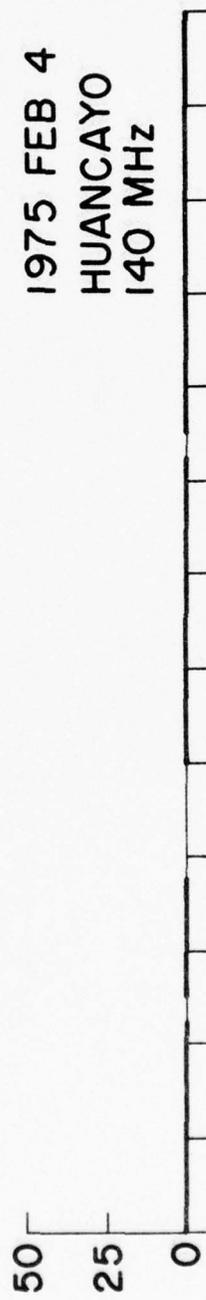
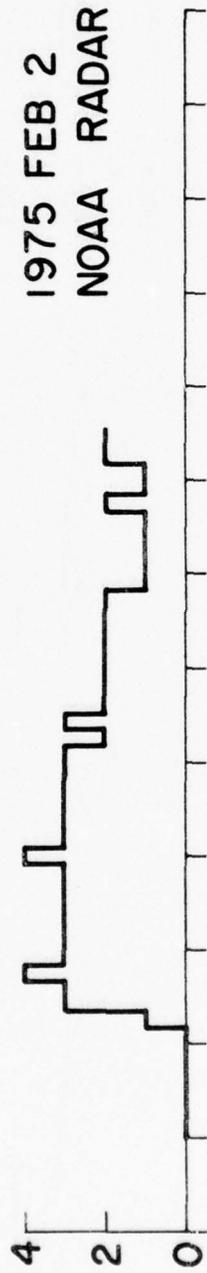
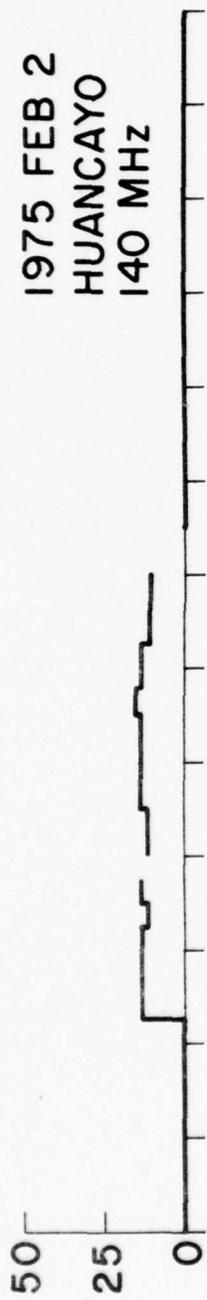


Fig. 2



SI

Fig. 3

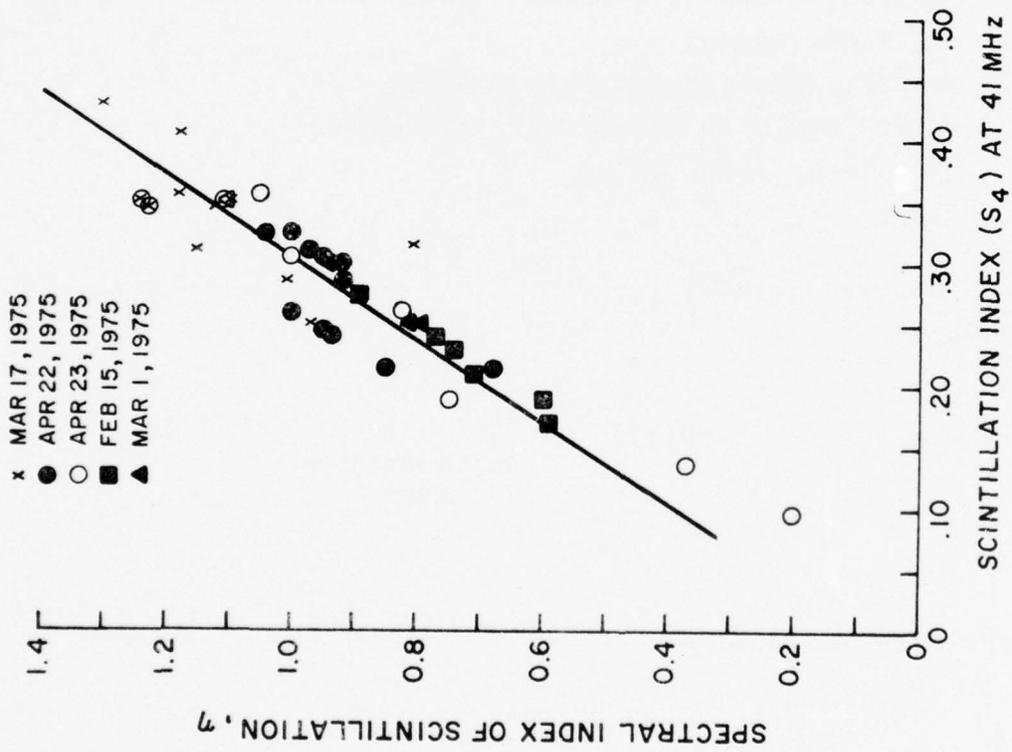


Fig. 4



T<sub>1</sub>, T<sub>2</sub> are start and end time of digitization for this file

R<sub>1</sub>, R<sub>2</sub> are start and end time (real time of data acquisition for this file)

T<sub>i</sub>, R<sub>i</sub> are of the form hhhmss

Here cals follow

Update - update cal file

#### Calibration Cards (H option)

Card 1 - Channel number, identification (I2,A10) - b2360MHZ

Card 2-n -- digitized count level, dB level free format separated by blank or comma. Need not be one level per card. Calibrations are entered with high signal first and nondecreasing signal strengths. All dB levels are normalized to 0 dB high signal

Example:

128,0,100,1,90,2 is normalized to

128 0

100 - 1

90 - 2

Calibrations can be added at either end.

Example:

140,-2,135,-1

128,0,100,1,90,2

85,3 is normalized to

140 0

135 - 1

128 - 2

100 - 3

90 - 4

85 - 5

Card n+1 { blank } end of { channel }  
          {-g }                    { calibrations }

If no calibrations are entered  
(i.e., n+1=2) dB=level.

Examples:

- 1) Existing cal file  
T37,C2,F3
- 2) To add new file or redefine old file with previously defined calibrations  
T37,C2,F4=1800.30,1815.05,200,400,U
- 3) To use new calibrations but not to redefine  
T37,C2,F3=1800,1900,200,400,H  
cals

It should be noted that calibrations are catalogued under tape and calibration number. Any redefinition of calibrations for any file under that tape and calibration number, redefines calibrations for all files.

Control Cards

Control cards are free form concatenations of option selections of the form

Option or Option = parameter list

(options are separated by commas)

Parameter lists have the following forms:

- a) OFF turn the option off for all channels
- b) none " " " on " " "
- c)  $n_1, \dots, n_k$   
turn the option off for channels  $n_i$ , off for other channels
- d) hhmm.ss time
- e)  $d_1$  number
- f)  $dB_1, dB_2$  dB levels limits for dwell analysis
- g)  $t_1, \dots, t_n$   
times for dwell analysis

| <u>options</u> | <u>parameter<br/>list types</u> | <u>meaning</u>   | <u>default</u> |
|----------------|---------------------------------|--|----------------|
| END            |                                 | end of control cards   |                |
| CHANS          | a,b,c                           | restrict analysis to<br>these channels   | 1,2,...,10     |
| CDF            | a,b,c                           | CDF's on these channels  | OFF            |
| DWELL          | a,b,c                           | dwelt time analysis<br>for these channels  | OFF            |
| MSG            | a,b,c                           | message reliability<br>statistics for these<br>channels  | OFF            |
| DATA           | a,b,c                           | plot data for these<br>channels  | OFF            |
| SPECTRA        | a,b,c                           | plot smoothed power<br>spectra for these<br>channels   | OFF            |
| RAW            | a,b,c                           | plot raw power spectra<br>for these channels   | OFF            |
| AUTO           | a,b,c                           | perform autocorrelation<br>for these channels  | OFF            |
| CROSS          | a,b,c*                          | perform cross-correlation<br>for these channels  | OFF            |
| CORR           | e                               | correlation limit for<br>plotting of auto and<br>cross-correlations.<br>CORR=0 - plot all<br>CORR=2 - suppress plots | 0.3            |
| SECONDS        | e                               | number of seconds (real<br>time) in each period of<br>analysis   | 900            |
| PERIODS        | e                               | number of periods to<br>analyze  | 999            |
| REWIND         |                                 | rewind data tape   |                |
| SKIP           | b,e                             | skip d,(or 0) files on<br>data tape after skipping<br>to end of current file<br>if not already there                 |                |

| <u>options</u> | <u>parameter list types</u> | <u>meaning</u>  | <u>default</u>   |       |           |            |     |   |     |   |   |    |   |    |   |    |    |   |    |    |   |    |    |    |    |           |  |
|----------------|-----------------------------|---|--|-------|-----------|------------|-----|---|-----|---|---|----|---|----|---|----|----|---|----|----|---|----|----|----|----|-----------|--|
| START          | d                           | real time start of data analysis                            | current real time on data tape or start of current data file   |       |           |            |     |   |     |   |   |    |   |    |   |    |    |   |    |    |   |    |    |    |    |           |  |
| CLEAR          |                             | all analysis options and all channels off                   |  |       |           |            |     |   |     |   |   |    |   |    |   |    |    |   |    |    |   |    |    |    |    |           |  |
| NTH            | e                           | use every n'th point  | 1  |       |           |            |     |   |     |   |   |    |   |    |   |    |    |   |    |    |   |    |    |    |    |           |  |
| DBS            | f                           | dB range for dwell times and message reliability analysis   | -10 to +5  |       |           |            |     |   |     |   |   |    |   |    |   |    |    |   |    |    |   |    |    |    |    |           |  |
| TIMES          | g                           | time ranges for dwell time and message reliability analysis | <table border="1"> <thead> <tr> <th><math>t_n</math></th> <th><math>t_{n+1}</math></th> <th><math>\Delta t</math></th> </tr> </thead> <tbody> <tr> <td>.25</td> <td>1</td> <td>.25</td> </tr> <tr> <td>1</td> <td>6</td> <td>.5</td> </tr> <tr> <td>6</td> <td>10</td> <td>1</td> </tr> <tr> <td>10</td> <td>20</td> <td>2</td> </tr> <tr> <td>20</td> <td>40</td> <td>5</td> </tr> <tr> <td>40</td> <td>60</td> <td>10</td> </tr> <tr> <td>60</td> <td><math>t_{max}</math></td> <td></td> </tr> </tbody> </table> <p>all times in sec.</p> | $t_n$ | $t_{n+1}$ | $\Delta t$ | .25 | 1 | .25 | 1 | 6 | .5 | 6 | 10 | 1 | 10 | 20 | 2 | 20 | 40 | 5 | 40 | 60 | 10 | 60 | $t_{max}$ |  |
| $t_n$          | $t_{n+1}$                   | $\Delta t$  |  |       |           |            |     |   |     |   |   |    |   |    |   |    |    |   |    |    |   |    |    |    |    |           |  |
| .25            | 1                           | .25   |  |       |           |            |     |   |     |   |   |    |   |    |   |    |    |   |    |    |   |    |    |    |    |           |  |
| 1              | 6                           | .5  |  |       |           |            |     |   |     |   |   |    |   |    |   |    |    |   |    |    |   |    |    |    |    |           |  |
| 6              | 10                          | 1   |  |       |           |            |     |   |     |   |   |    |   |    |   |    |    |   |    |    |   |    |    |    |    |           |  |
| 10             | 20                          | 2   |  |       |           |            |     |   |     |   |   |    |   |    |   |    |    |   |    |    |   |    |    |    |    |           |  |
| 20             | 40                          | 5   |  |       |           |            |     |   |     |   |   |    |   |    |   |    |    |   |    |    |   |    |    |    |    |           |  |
| 40             | 60                          | 10  |  |       |           |            |     |   |     |   |   |    |   |    |   |    |    |   |    |    |   |    |    |    |    |           |  |
| 60             | $t_{max}$                   |   |  |       |           |            |     |   |     |   |   |    |   |    |   |    |    |   |    |    |   |    |    |    |    |           |  |

\* Cross correlation channel list consists of sublists separated by semicolons. The first channel in the sublist is correlated with the remaining channels. The last sublist may be terminated by a comma or end of card.

For example:

CROSS=1,2,3;2,3,4

or

CROSS=1,2,3;  
2,3,4

or

CROSS=1,2  
3;2,3,4

will yield cross-correlations of channel 1 vs 2+3 and 2 vs 3+4, while

CROSS=1,2,3  
2,3,4

will yield cross-correlations of 1 vs 2,3, and 4.

## TITLE CARD

A title card is any card that cannot be mistaken for a calibration card or control card. Care should be taken not to use a control card option word as the first word of a title.

Processing begins after each title card is recognized.

### Example:

To run 4 fifteen-minute data samples on channels 1,3,4 on data tape OS1, file three starting at 415. Statistics wanted are only print statistics including those for correlations. Further, one hour samples of smoothed spectra and autocorrelations, decimated 4 to 1 are wanted for the fourth file of the tape. Cross-correlations are wanted only for channel 1+2 versus the rest, and are to be plotted only if greater than 0.4. There are 5 channels on the tape. The calibrations are catalogued as tape 17, calibration 1, files 2 and 3. Plots are to be off line, red ink.

### Deck

CANTOR, CM11000, T500.  
VSN, TAPE1=050001.  
REQUEST, TAPE1, HY, S. (OS0001/NORIN6)  
ATTACH, SIG, SIGNALYSISX3828, ID=CANTOR.  
CALL, I=SIG, P=OFFRED.  
7/8/9  
  
T17, C1, F2  
PERIODS=4, SKIP=2, START=415,  
CHANS=1, 3, 4, CDF, DWELL, MSG  
AUTO, CROSS, CORR=2, END  
TITLE FOR FIRST SAMPLE RUN  
T17, C1, F3

PERIODS=999,SECONDS=3600  
NTH=4,SKIP,CLEAR,SPECTRA,AUTO,  
CROSS=1,2,3,4,5;2,3,4,5,CORR=0.4,END  
TITLE FOR SECOND SAMPLE RUN  
6/7/8/9

FOLLOWING THIS SECTION ARE:

CALIBRATION ERROR MESSAGES (3 pages)

ERROR MESSAGES

APPENDIX 1 - Catalogued Procedures on  
File SIGNALYSISX3828

APPENDIX 2 - Calibration File Format

APPENDIX 3 - Control Card Decoder

including

Sample Main Program,  
Functions  
Sample Output

|        |        |        |        |        |        |        |        |        |        |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 000100 | 000100 | 000100 | 000100 | 000100 | 000100 | 000100 | 000100 | 000100 | 000100 |
| 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     |
| 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     |
| 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     |
| 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     |
| 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     |
| 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     |
| 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     |
| 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     | 00     |

MAIN

CONTROL

T37,C2,F3=2113,2120.30,3300,0500,H

CHANNEL 1

137 MHZ

- 221, 0
- 215, 1
- 208, 2
- 201, 3
- 193, 4
- 188, 5
- 179, 6
- 171, 7
- 164, 8
- 156, 9
- 149, 10
- 141, 11
- 133, 12
- 125, 13
- 117, 14
- 109, 15
- 101, 16
- 94, 17
- 87, 18
- 79, 18
- 73, 21
- 67, 21
- 61, 22
- 55, 23
- 50, 24
- 45, 25
- 40, 26
- 36, 27
- 33, 23
- 30, 29
- 28, 30
- 27, 31
- 26, 32
- 25, 33
- 24, 34

CALIBRATION ERROR MESSAGES (1 of 3)

~~CHANNEL 1 POSSIBLE ERROR IN CALIBRATION~~

|     |      |
|-----|------|
| 24  | -34. |
| 25  | -33. |
| 26  | -32. |
| 27  | -31. |
| 28  | -30. |
| 30  | -29. |
| 33  | -28. |
| 36  | -27. |
| 40  | -26. |
| 45  | -25. |
| 50  | -24. |
| 55  | -23. |
| 61  | -22. |
| 67  | -21. |
| 73  | -20. |
| 79  | -18. |
| 87  | -18. |
| 94  | -17. |
| 101 | -16. |
| 109 | -15. |
| 117 | -14. |
| 125 | -13. |
| 133 | -12. |
| 141 | -11. |
| 149 | -10. |
| 156 | -9.  |
| 164 | -8.  |
| 171 | -7.  |
| 179 | -6.  |
| 186 | -5.  |
| 193 | -4.  |
| 201 | -3.  |
| 208 | -2.  |
| 215 | -1.  |
| 221 | -0.  |

CALIBRATION ERROR MESSAGES (2 of 3)

Copy available to BDC does not  
permit fully legible reproduction

CHANNEL 2  
 360 MHZ  
 215,0  
 198,1  
 181,2  
 165,3  
 148,4  
 133,5  
 118,6  
 103,7  
 89,8  
 76,9  
 65,12  
 56,11  
 50,12  
 46,13  
 42,14  
 39,15  
 37,16  
 35,17  
 34,18  
 33,20  
 32,22  
 31,24  
 -9

CHANNEL 2                      ERROR IN CALIBRATION

|     |       |
|-----|-------|
| 31  | -24.  |
| 32  | -22.  |
| 33  | -20.  |
| 34  | -18.  |
| 35  | -17.  |
| 37  | -16.  |
| 39  | -15.  |
| 42  | -14.  |
| 46  | -13.  |
| 50  | -12.  |
| 56  | -11.↑ |
| 65  | -12.↑ |
| 76  | -9.   |
| 89  | -8.   |
| 103 | -7.   |
| 118 | -6.   |
| 133 | -5.   |
| 148 | -4.   |
| 165 | -3.   |
| 181 | -2.   |
| 198 | -1.   |
| 215 | -0.   |

STOP                                      CALIBRATION ERROR MESSAGES (3 OF 3)

ERROR MESSAGES

Further Explanation

REWIND, START=245, CDF, END  
NO TIME FOUND FOR DATA SEARCH

No tape specified  
before manipulation

T37, C2, F3  
3 10 FILE FULL OR CALS. NOT FOUND  
T37, C2, F3

T37, C2, F3  
REWIND, START=245, END  
HIT END OF INFORMATION ON TAPE 1

T37, C2, F3  
REWIND, START=1200, END  
HIT END OF FILE LOCKING FOR 12 0 0

T37, C2, F3  
PERIODS=3, SECONDS=311, CDF, END  
PARAMETERS OR CALS MISSING

----- Periods misspelled.  
----- Title card assumed

T37, C2, F3  
PERIODS=3, SECONDS=303, CDF, END  
\*  
PARAMETER ERROR IN FIELD ENDING WITH \*.

APPENDIX 1

Catalogued Procedures on File SIGNALYSISX3828.

ALL INFORMATION CONTAINED  
HEREIN IS UNCLASSIFIED

~~\*ONRED.~~

~~DISPOSE,PLOT,\*PL.~~

~~ATTACH,LG1,DECDBINX2944, ID=CANTOR,MR=1.~~

~~COPYL,LG1,LGO,LG2.~~

~~UNLOAD,LG1,LGO.~~

~~ATTACH,PEN,ONLINEPEN.~~

~~LIBRARY,PEN.~~

~~ATTACH,TAPE10,CALIBX2944, ID=CANTOR,PW=CJC.~~

~~LG2.~~

~~EXTEND,TAPE10.~~

~~EXIT.~~

~~EXTEND,TAPE10.~~

~~\*OFFRED.~~

~~DISPOSE,TAPE30,\*LR.~~

~~ATTACH,LG1,DECDBINX2944, ID=CANTOR,MR=1.~~

~~COPYL,LG1,LGO,LG2.~~

~~UNLOAD,LG1,LGO.~~

~~ATTACH,PEN,OFFLINEPEN.~~

~~LIBRARY,PEN.~~

~~ATTACH,TAPE10,CALIBX2944, ID=CANTOR,PW=CJC.~~

~~LG2.~~

~~EXTEND,TAPE10.~~

~~EXIT.~~

~~EXTEND,TAPE10.~~

~~\*OFFBLACK.~~

~~DISPOSE,TAPE30,\*LL.~~

~~ATTACH,LG1,DECDBINX2944, ID=CANTOR,MR=1.~~

~~COPYL,LG1,LGO,LG2.~~

~~UNLOAD,LG1,LGO.~~

~~ATTACH,PEN,OFFLINEPEN.~~

~~LIBRARY,PEN.~~

~~ATTACH,TAPE10,CALIBX2944, ID=CANTOR,PW=CJC.~~

~~LG2.~~

~~EXTEND,TAPE10.~~

~~EXIT.~~

~~EXTEND,TAPE10.~~

~~\*ONBLACK.~~

~~DISPOSE,PLOT,\*OL.~~

~~ATTACH,LG1,DECOBINX2944, ID=CANTOR, MR=1.~~

~~COPYL, LG1, LG0, LG2.~~

~~UNLOAD, LG1, LG0.~~

~~ATTACH, PEN, ONLINEPEN.~~

~~LIBRARY, PEN.~~

~~ATTACH, TAPE 10, CALIBX2944, ID=CANTOR, PW=CJC.~~

~~LG2.~~

~~EXTEND, TAPE 10.~~

~~EXIT.~~

~~EXTEND, TAPE 10.~~

~~\*NOPLOT.~~

~~ATTACH, LG1, DECOBINX2944, ID=CANTOR, MR=1.~~

~~COPYL, LG1, LG0, LG2.~~

~~UNLOAD, LG1, LG0.~~

~~ATTACH, PEN, ONLINEPEN.~~

~~LIBRARY, PEN.~~

~~ATTACH, TAPE 10, CALIBX2944, ID=CANTOR, PW=CJC.~~

~~LG2.~~

~~EXTEND, TAPE 10.~~

~~EXIT.~~

~~EXTEND, TAPE 10.~~

## APPENDIX 2

### Calibration File Format

Catalogued calibrations reside on a CDC 6600 mass storage file. See the CDC FORTRAN Extended manual for general definitions and usage details. The defining parameters for a particular calibration are type number and calibration number, referred to hereafter as a calibration id. Each calibration id may have associated with it up to twenty files. Calibration id's are numerically indexed in the main file index in the order of receipt, except that additions or changes to an existing calibration id overwrite it. Up to one hundred calibration id's may be catalogued.

The following is a description of the calibration file structure.

#### Main Index Structure

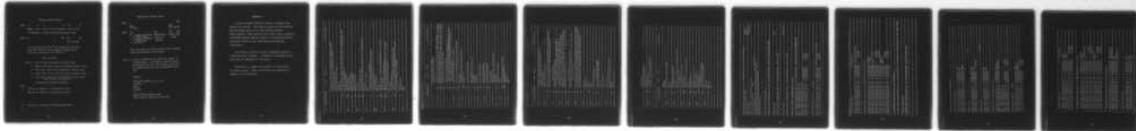
| Word |                                   |
|------|-----------------------------------|
| 1    | Pointer to control record 1       |
| 2    | Pointer to calibration subindex 1 |
| ...  | ...                               |
| 2n-1 | Pointer to control record n       |
| 2n   | Pointer to calibration index n    |
| 2n+1 | 0                                 |
| ...  | ...                               |
| 200  | 0                                 |

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END  
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2-77

### Control Record Format

|      |       |      |  |            |   |    |
|------|-------|------|--|------------|---|----|
| Word | 1     | 2    | 3  | 7          | 8 | 12 |
|      | Tape# | Cal# | File id #1 (5 words)                         | File id #2 |   |    |
|      |       |      | Calibration id from calibration control card |            |   |    |

|      |    |   |   |    |    |             |
|------|----|---|---|----|----|-------------|
| Word | 13 |   |   | 97 | 98 | 102         |
|      | .  | . | . | .  | .  | File id #20 |

All variables in the control record are strictly positive floating point numbers except that a null file id consists of -999.0's.

### File id Format

- Word 1 - File # from calibration control card
- 2 - Start time (tape) from calibration control card
- 3 - End time (tape) from calibration control card
- 4 - Start time (real) from calibration control card
- 5 - End time (real) from calibration control card  
(Time formats are hhmm.ss)

### Calibration Subindex Structure

|      |  |
|------|--|
| Word |  |
| 1    | Pointer to channel 1 calibration record  |
| 2    | Pointer to channel 2 calibration record  |
|      |  |
|      |  |
|      |  |
|      |  |
|      |  |
| 10   | Pointer to channel 10 calibration record |
| 11   | 0  |

### Calibration Record Format

|      |                                       |             |            |
|------|---------------------------------------|-------------|------------|
| Word | 1                                     |             | 256        |
|      | dBs                                   |             | dBs        |
|      | 1 count                               |             | 256 counts |
| Word | 257                                   | 258         | 259 260    |
|      | 0 if signal decreases<br>with counts. | #characters | Alpha from |
|      | 1 if signal increases<br>with count   | alpha in    | input      |
|      | -1 see Note 1                         | 259-260     |            |

dB's are  $\leq$  for all counts except that original input calibrations are positive.

Note 1. A null calibration on input will result in setting  $dB_i = i$ . Calibrations should not be catalogued this way, but various statistics on uncalibrated data can be generated this way.

Example:

```
T999,C999,F999=t1,t2,r1,r2,H
1137MHZ
blank
2256MHZ
-9
DATA,SPECTRA,START=r1,END
QUICK LOOK AT SPECTRA OF RAW DATA.
```

### APPENDIX 3

As part of Signal Analysis Package, a control card decoder was written. This relies heavily on two functions NUM and IFIELD which are of more general interest. Taken together, these functions will scan a card, stripping off EDITOR defined sequence numbers if desired, and return individual fields on the card between user defined terminators.

The field is returned either as alphabetic array or a floating point variable. In addition, the length of the field and the terminator is available.

Following is a sample main program, the functions, and sample output. Usage instructions are contained in comments to the functions.

```

1  PROGRAM MAIN(INPUT,TAPE6=INPUT,OUTPUT,TAPE5)
   DIMENSION Ibuff(8),Jbuff(80),Iterm(4)
   COMMON/IFLOXYZ/IT
   DATA ITERM/1H,1H,0,0/
   REWIND 5
   PRINT 100
100  FORMAT(*IFOLLOWING IS INPUT CARD DECK. TERMINATORS ARE*
1     1,* COMMA AND EQUAL.*)
101  FEAD(6,101)IBUFF
102  FFORMAT(8A10)
2     IF(EOF(6))99,2
2     KR1E(5,101)IBUFF
109  PRINT 109,I3UFF
   FFORMAT(1X,8A10)
15     GO TO 1
99     DO 3 I=1,2
   IF(I.EQ.2)PRINT 102
102  FFORMAT(*1BLANK HAS BEEN ADDED AS A TERMINATOR.*)
   REWIND 5
20     FEAD(5,101)IBUFF
   N=0
   NMAX=NUM(IBUFF,-80,JBUFF)
5     NCHAR=IFLO1(JBUFF,IBUFF,N,NMAX,ITERM)
   IE(1,EO,GO IO 3
25     IF(NCHAR)6,7,8
7     PRINT 105,IT
   GO TO 5
105  FFORMAT(* NULL FIELD TERMINATED BY **A1,1H**
6     NCHAR=-NCHAR
30     PRINT 106,IT,NCHAR,IBUFF(1)
106  FFORMAT(* FLOAT FIELD TERMINATED BY **A1,1H**
1,13,* CHARACTERS.*,E12.4)
   GO TO 5
8     NQ=(NCHAR+9)/10
35     PRINT 107,IT,NCHAR,(IBUFF(IT),IT=1,NQ)
107  FFORMAT(* ALPHA FIELD TERMINATED BY **A1,1H**
1,13,* CHARACTERS.*,1X,8A10)
   GO TO 5
3     ITERM(3)=1H
40     STOP
   END

```

```

1      FUNCTION_NUM(I,IBUFF,N,JBUFF)
      DIMENSION IBUFF(8),JBUFF(80)

C      FUNCTION_NUM TAKES A "CARD" IN A10 FORMAT IN IBUFF,
C      PLACES IT IN JBUFF IN A1 FORMAT IN JBUFF AND RETURNS THE NUMBER
C      OF CHARACTERS LESS TRAILING BLANKS
C      PLACES IT IN JBUFF IN A1 FORMAT IN JBUFF AND RETURNS THE NUMBER
C      OF CHARACTERS LESS TRAILING BLANKS
C      IBUFF=INPUT CARD A10 FORMAT
C      N=NUMBER OF CHARACTERS IN IBUFF (TYPICALLY 80).
C      IF N IS NEGATIVE, EDITOR FORMAT SEQUENCE NUMBERS IN 73-80
C      ARE REMOVED IF THE PROGRAM DETERMINES THAT AN EDITOR
C      FORMAT CARD WAS INPUT.
15     JBUFF=OUTPUT CARD IMAGE IN A1 FORMAT

C      NUM=NUMBER OF CHARACTERS LESS TRAILING BLANKS
C      NN=IABS(N)
C      DECODE(NN,100,IBUFF)(JBUFF(I),I=1,NN)
C      FORMAT(80A1)
C      NNN=NN
C      STRIP TRAILING BLANKS
C      GO 1 I=1,NN
C      IF(JBUFF(NN).NE.1H)GO TO 2
C      NNN=NNN-1
C      CONTINUE
C      NUM=NNN
C      EDITOR_FORMAT_CHECKS
C      IF(N.GT.0)GO TO 99
C      IF(NN.NE.78)GO TO 99
C      SEQUENCE_NUMBER_CHECK
C      DO 3 I=73,78
C      J=JBUFF(I)
C      IF(J.GE.1HJ.AND.J.LE.1H9)GO TO 3
C      GO TO 99
C      CONTINUE
C      CARD_IS_EDITOR_FORMAT
C      NN=72
C      GO TO 4
C      PRINT 102,(JBUFF(I),I=1,NNN)
C      PRINT 100
C      RETURN
C      END
50

```

```

1  FUNCTION IFIELD(JBUFF,ABUFF,N,NMAX,IYERM)
    DIMENSION JBUFF(80),IYERM(80),IFMT(3)
    COMMON/IFLDXYZ/L
    DATA IFMT/2H(F,1H ,3H.0)/

5  C  FUNCTION IFIELD SCANS A CARD AND RETURNS A FIELD,ALPHABETIC
    C  CR_NUMERIC, TERMINATED BY USER DEFINED TERMINATORS.
10 C  CALLING SEQUENCE
    C  JBUFF=INPUT ARRAY, A1 FORMAT.
    C  ABUFF=OUTPUT, EITHER ALPHA (A1) OR FLOATING POINT.
    C  ALSO USED AS INPUT BUFFER FOR ENTRY IFLD1.
15 C  N=STARTING POSITION IN ARRAY JBUFF, SHOULD BE SET TO
    C  ZERO ORIGINALLY BY MAIN PROGRAM, MAINTAINED BY IFIELD.
    C  NMAX=MAXIMUM NUMBER OF CHARACTERS. OUTPUT OF FUNCTION NUM
    C  IYERM=ARRAY OF TERMINATION CHARACTERS, LAST ONE MUST BE ZERO.
    C  EXAMPLE: DATA IYERM/1H ,1H ,0/

20 C  ENTRY POINTS
    C  IFIELD-DO NOT READ NEXT CARD IF N>NMAX
    C  IFLD1-READ NEXT CARD IF NECESSARY (END OF CARD TERMINATES A
    C  FIELD IN ANY CASE).

25 C  FUNCTION VALUE IS THE NUMBER OF CHARACTERS IN THE FIELD, POSITIVE
    C  IF ALPHABETIC, NEGATIVE IF FLOATING POINT. 0 IF NULL OR END OF
    C  COMMON BLOCK /IFLDXYZ/CONTAINS THE FIELD TERMINATOR. END OF
    C  CARD TERMINATOR IS A FORCED COMMA, END OF FILE IS ZERO.
    C
30 C  IFLQ=0
    GO TO 25
    ENTRY IFLD1
    IFLQ=1
    NN=0
    M=N+1
    MM=M
    IF(M.GT.NMAX)GO TO 66

35 C
    C  ILEAD IS LEADING BLANK SWITCH
    C  INUM IS ALPHA/NUMERIC SWITCH
    C  INUM=0
    GO 1 I=M,NMAX
    N=N+1
    I=JBUFF(I)
    LEADING BLANK CHECK
    IF(I=0.OR.L.NE.1H )GO TO 4
    GO TO 1

45 C
    C  ILEAD=1
    C  TERMINATOR CHECK
50 C

```

```

DO 2 J=1,80
IF(ITERM(J).EQ.0)GO TO 5
IF(L.EQ.ITERM(J))GO TO 3
2 CONTINUE
55 C NUMERIC CHECK
IF(L.GE.1H0.AND.L.LE.1H9)GO TO 1
IF(L.EQ.1H.CR.L.EQ.1H-)GO TO 1

```

FUNCTION IFIELD 7474 OPT=1 FJN 4.5 +414 3

```

INUM=1
1 CONTINUE
C END OF CARD ON FALL THROUGH
L=1H,
N=N+1
3 NN=N-M
C NN=NUMBER OF CHARACTERS
55 IF(NN.EQ.0)GO TO 6
NN1=N-1
ENCODE(NN,10,ABUFE(1))(J8UFF(U),J=H,NN1)
IF(INUM.NE.0)GO TO 5
C GET F. FORMAT
70 ENCODE(10,101,IFMT(2))NN
100 FORMAT(80A1)
101 FORMAT(I1C)
C ENCODE(NN,IFMT,ABUFE(1))ABUFF(1)
NN=-NN
75 IFIELD=NN
105 FORMAT(1X,8A10)
RETURN
66 IF(IFLQ.EQ.0)GO TO 6
C READ NEXT CARD
80 FEAD(5,106)ABUFF
106 FORMAT(8A10)
IF(EOF(5))61,67
C NOTE CHECK FOR EDITOR CARDS
67 NMAX=NUM(ABUFF,-80,JBUFF)
N=0
85 GO TO 25
61 L=0
GO TO 6
END

```

FOLLOWING IS INPUT CARD DECK. TERMINATORS ARE COMMA AND EQUAL.

THIS IS AN EDITOR CARD

THIS IS NOT

NOR IS THIS

SHOW MULTIPLE TERMINATORS,,1,2,3

SHOW MULTIPLE BLANKS 1,2,3

LONG BLANK LEAD

7.2,5.978,2.3

REWIND,START=315,CDF=1,2,3,SPECTRA,DATA=3,3,0,3.

NON-COMMA TERMINATOR AS LAST CHARACTER

END OF CARD DECK

000100

100

000100XX

THIS IS AN EDITOR CARD

ALPHA FIELD TERMINATED BY "," 22 CHARACTERS. THIS IS AN EDITOR CARD

THIS IS NOT

100

ALPHA FIELD TERMINATED BY "," 75 CHARACTERS. THIS IS NOT

NOR IS THIS

000100XX

ALPHA FIELD TERMINATED BY "," 80 CHARACTERS. NOR IS THIS

SHOW MULTIPLE TERMINATORS,,1,2,3

ALPHA FIELD TERMINATED BY "," 25 CHARACTERS. SHOW MULTIPLE TERMINATORS

NULL FIELD TERMINATED BY ","

NULL FIELD TERMINATED BY ","

NULL FIELD TERMINATED BY ","

FLOAT FIELD TERMINATED BY "," 1 CHARACTERS. 1.0000

FLOAT FIELD TERMINATED BY "," 1 CHARACTERS. 2.0000

FLOAT FIELD TERMINATED BY "," 1 CHARACTERS. 3.0000

SHOW MULTIPLE BLANKS 1,2,3

ALPHA FIELD TERMINATED BY "," 26 CHARACTERS. SHOW MULTIPLE BLANKS 1

FLOAT FIELD TERMINATED BY "," 1 CHARACTERS. 2.0000

FLOAT FIELD TERMINATED BY "," 1 CHARACTERS. 3.0000

LONG BLANK LEAD

7.2,5.978,2.3

ALPHA FIELD TERMINATED BY ", " 44 CHARACTERS. LONG BLANK LEAD

FLOAT FIELD TERMINATED BY ", " 5 CHARACTERS. 5.9780

FLOAT FIELD TERMINATED BY ", " 3 CHARACTERS. 2.3000

REWIND, START=1,2,3, SPECTRA, DATA=3,3.0,3.

ALPHA FIELD TERMINATED BY ", " 6 CHARACTERS. REWIND

ALPHA FIELD TERMINATED BY "= " 5 CHARACTERS. START

FLOAT FIELD TERMINATED BY ", " 3 CHARACTERS. 315.0000

ALPHA FIELD TERMINATED BY "= " 3 CHARACTERS. CDF

FLOAT FIELD TERMINATED BY ", " 1 CHARACTERS. 1.0000

FLOAT FIELD TERMINATED BY ", " 1 CHARACTERS. 2.0000

FLOAT FIELD TERMINATED BY ", " 1 CHARACTERS. 3.0000

ALPHA FIELD TERMINATED BY ", " 7 CHARACTERS. SPECTRA

ALPHA FIELD TERMINATED BY "= " 4 CHARACTERS. DATA

FLOAT FIELD TERMINATED BY ", " 1 CHARACTERS. 3.0000

FLOAT FIELD TERMINATED BY ", " 3 CHARACTERS. 3.0000

FLOAT FIELD TERMINATED BY ", " 2 CHARACTERS. 3.0000

NON-COMMA TERMINATOR AS LAST CHARACTER=

ALPHA FIELD TERMINATED BY "= " 38 CHARACTERS. NON-COMMA TERMINATOR AS LAST CHARACTER

END OF CARD DECK

ALPHA FIELD TERMINATED BY ", " 16 CHARACTERS. END OF CARD DECK

BLANK HAS BEEN ADDED AS A TERMINATOR.

THIS IS AN EDITOR CARD

ALPHA FIELD TERMINATED BY " " 4 CHARACTERS. THIS  
ALPHA FIELD TERMINATED BY " " 2 CHARACTERS. IS  
ALPHA FIELD TERMINATED BY " " 2 CHARACTERS. AN  
ALPHA FIELD TERMINATED BY " " 6 CHARACTERS. EDITOR  
ALPHA FIELD TERMINATED BY " " 4 CHARACTERS. CARD

THIS IS NOT 100

ALPHA FIELD TERMINATED BY " " 4 CHARACTERS. THIS  
ALPHA FIELD TERMINATED BY " " 2 CHARACTERS. IS  
ALPHA FIELD TERMINATED BY " " 3 CHARACTERS. NOT  
FLOAT FIELD TERMINATED BY " " 63 CHARACTERS. 100.0000

NOR IS THIS 000100XX

ALPHA FIELD TERMINATED BY " " 3 CHARACTERS. NOR  
ALPHA FIELD TERMINATED BY " " 2 CHARACTERS. IS  
ALPHA FIELD TERMINATED BY " " 4 CHARACTERS. THIS  
ALPHA FIELD TERMINATED BY " " 68 CHARACTERS.

SHOW MULTIPLE TERMINATORS...1,2,3

ALPHA FIELD TERMINATED BY " " 4 CHARACTERS. SHOW  
ALPHA FIELD TERMINATED BY " " 8 CHARACTERS. MULTIPLE  
ALPHA FIELD TERMINATED BY " " 11 CHARACTERS. TERMINATORS  
NULL FIELD TERMINATED BY " "  
NULL FIELD TERMINATED BY " "  
NULL FIELD TERMINATED BY " "  
FLOAT FIELD TERMINATED BY " " 1 CHARACTERS. 1.0000  
FLOAT FIELD TERMINATED BY " " 1 CHARACTERS. 2.0000  
FLOAT FIELD TERMINATED BY " " 1 CHARACTERS. 3.0000

SHOW MULTIPLE BLANKS 1,2,3

ALPHA FIELD TERMINATED BY " " 4 CHARACTERS. SHOW  
ALPHA FIELD TERMINATED BY " " 8 CHARACTERS. MULTIPLE  
ALPHA FIELD TERMINATED BY " " 6 CHARACTERS. BLANKS  
FLOAT FIELD TERMINATED BY " " 5 CHARACTERS. 1.0000  
FLOAT FIELD TERMINATED BY " " 1 CHARACTERS. 2.0000  
FLOAT FIELD TERMINATED BY " " 1 CHARACTERS. 3.0000

LONG BLANK LEAD

7.2,5.978,2.3

ALPHA FIELD TERMINATED BY " " 4 CHARACTERS. LONG  
ALPHA FIELD TERMINATED BY " " 5 CHARACTERS. BLANK  
ALPHA FIELD TERMINATED BY " " 4 CHARACTERS. LEAD  
FLOAT FIELD TERMINATED BY " " 28 CHARACTERS. 7.2100  
FLOAT FIELD TERMINATED BY " " 5 CHARACTERS. 5.9780  
FLOAT FIELD TERMINATED BY " " 3 CHARACTERS. 2.3000

REWIND, START=315, CDF=1,2,3, SPECTRA, DATA=3,3,0,3.

ALPHA FIELD TERMINATED BY " " 6 CHARACTERS. REWIND  
ALPHA FIELD TERMINATED BY " " 5 CHARACTERS. START  
FLOAT FIELD TERMINATED BY " " 315.0000  
ALPHA FIELD TERMINATED BY " " 3 CHARACTERS. CDF  
FLOAT FIELD TERMINATED BY " " 1 CHARACTERS. 1.0000  
FLOAT FIELD TERMINATED BY " " 1 CHARACTERS. 2.0000  
FLOAT FIELD TERMINATED BY " " 1 CHARACTERS. 3.0000  
ALPHA FIELD TERMINATED BY " " 7 CHARACTERS. SPECTRA  
ALPHA FIELD TERMINATED BY " " 4 CHARACTERS. DATA  
FLOAT FIELD TERMINATED BY " " 1 CHARACTERS. 3.0000  
FLOAT FIELD TERMINATED BY " " 3 CHARACTERS. 3.0000  
FLOAT FIELD TERMINATED BY " " 2 CHARACTERS. 3.0000

NON-COMMA TERMINATOR AS LAST CHARACTER=

ALPHA FIELD TERMINATED BY " " 9 CHARACTERS. NON-COMMA  
ALPHA FIELD TERMINATED BY " " 10 CHARACTERS. TERMINATOR  
ALPHA FIELD TERMINATED BY " " 2 CHARACTERS. AS  
ALPHA FIELD TERMINATED BY " " 4 CHARACTERS. LAST  
ALPHA FIELD TERMINATED BY " " 9 CHARACTERS. CHARACTER

END OF CARD DECK

ALPHA FIELD TERMINATED BY " " 3 CHARACTERS. END  
ALPHA FIELD TERMINATED BY " " 2 CHARACTERS. OF  
ALPHA FIELD TERMINATED BY " " 4 CHARACTERS. CARD  
ALPHA FIELD TERMINATED BY " " 4 CHARACTERS. DECK