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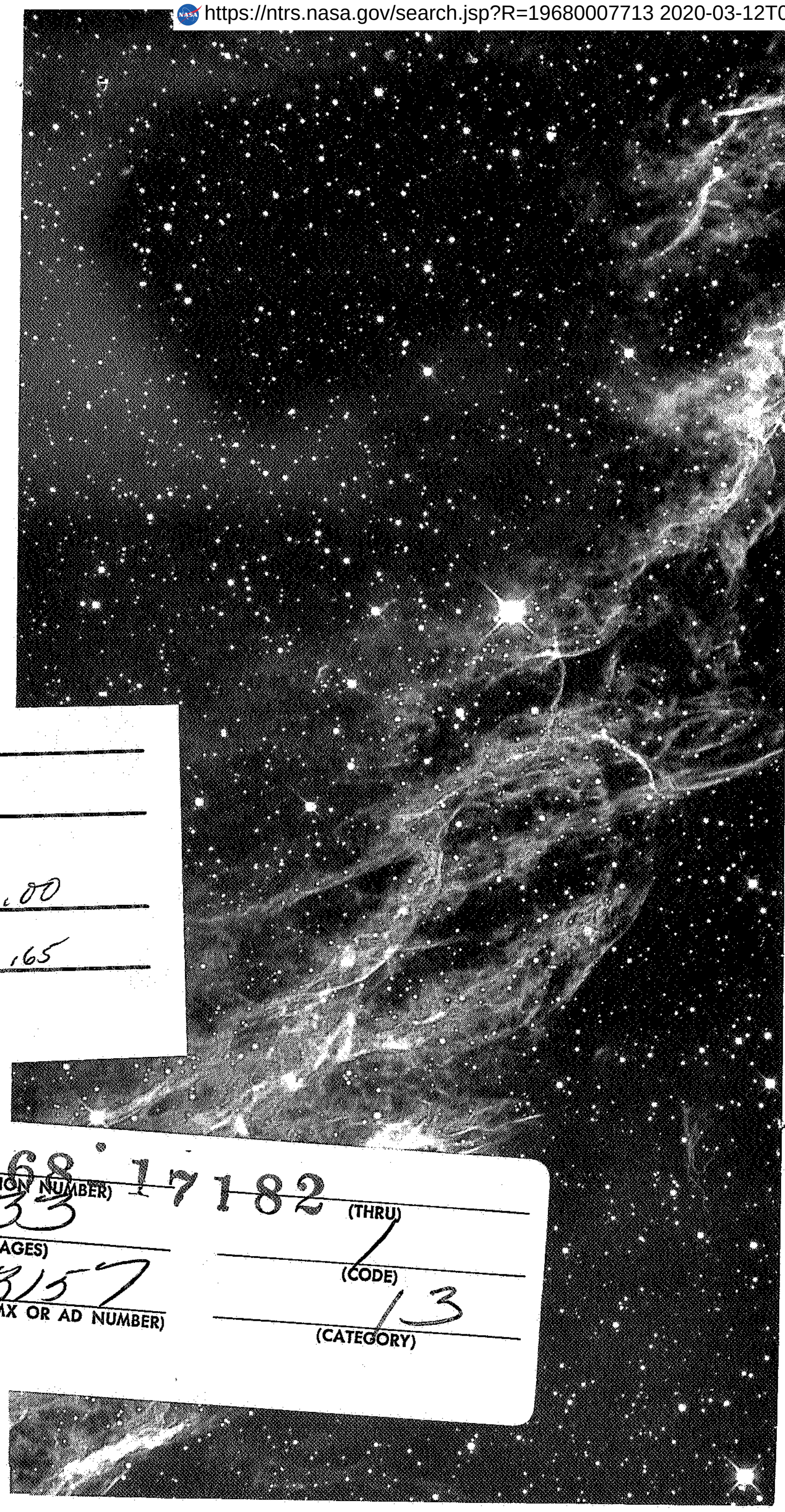

Final Report

NIGHTGLOW OBSERVATIONS DURING NASA'S MOBILE LAUNCH EXPEDITION NO. 1

Contract No. NASr-65(11)/14-003-911

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Final Report

NIGHTGLOW OBSERVATIONS DURING NASA'S MOBILE LAUNCH EXPEDITION NO. 1

by

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FOREWORD

This final report describes the nightglow observations conducted by IIT Research Institute as part of NASA's Mobile Launch Expedition No. 1. Continuum compensated observations of the atmospheric emissions $[OI]_{21}$ λ6300 Å, $[OI]_{32}$ λ5577 Å, and N_2^+ (0-1) λ4278 Å were made at the zenith and at elevation angles of 75° and 85°. In addition, observations of the continuum near 6200 Å, 5477 Å, and 4178 Å were made at the zenith. Data was obtained on 63 nights representing the totality of nights at sea less one. The observing period extended from sunset to sunrise.

The instrumentation is described and the observing procedure outlined. The data obtained are summarized and sample records are presented. Diurnal variations and latitude effects in the 5577 Å and 6300 Å zenith intensities have been examined and the results, which have been published, are discussed. First attempts at correlating the red line intensity with h'F and f_0F_2 through Barbier's formula have been made and the results are presented. The phenomenology of the red line emission is discussed in terms of the results of these measurements.

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NIGHTGLOW OBSERVATIONS DURING NASA'S MOBILE LAUNCH EXPEDITION NO. 1

1. INTRODUCTION

As part of the International Quiet Sun Year (IQSY) 1964-1965, NASA organized Mobile Launch Expedition No. 1 for the study of the equatorial electrojet and ionospheric phenomena in the latitude range from 35°N to 60°S. The expedition, carried out from the U.S.N.S. Croatan, consisted of a number of complementary rocket probe and ship-based experiments for investigating the interrelationships between optical, radio, and magnetic phenomena during the period of the quiet sun.

The night airglow, which is an optical manifestation of photochemical processes occurring in the ionosphere, was monitored as part of this expedition. The IIT Research Institute (IITRI) provided photometric instrumentation and an observer for these ship-based airglow measurements. The Environmental Sciences Service Administration (ESSA) provided complementary ship-based ionosonde instrumentation. These two sets of simultaneous measurements provided a valuable opportunity for obtaining a deeper understanding of the complex processes responsible for the night airglow.

A similar set of airglow observations was previously carried out from aboard the U.S.N.S. Eltanin (Davis and Smith 1965) during an expedition along the Pacific coast of South America in 1962. The airglow measurements described here confirmed the Eltanin results and provided information on the variation of the airglow behavior throughout the solar cycle.

This expedition ran from Feb. 15, 1965 to May 3, 1965. Airglow observations were made on a total of 63 nights. This report describes the results of these observations and presents the results of preliminary analyses concerning the phenomenology of the 6300 Å nightglow.

2. BACKGROUND

The airglow consists of nonthermal radiation (Chamberlain 1961) emitted by the Earth's atmosphere. Of particular interest here are the atomic oxygen emissions at 5577 Å ($^1S \rightarrow {}^1D$) and 6300 Å ($^1D \rightarrow {}^3P$). Numerous photochemical reactions can be invoked as mechanisms for the generation of these emissions, however, no single mechanism or well defined combination of mechanisms can explain all of the spatial, temporal, and seasonal variations of the airglow. The problem is further complicated by the vague distinction between airglow and aurora and the fact that magnetic disturbances and particle bombardment influence these missions. Thus, the 4278 Å emission (normally absent in the night airglow) which is characteristic of auroral activity was also observed.

The Mobile Launch Expedition may be considered to be a controlled experiment since measurements are made along a constant of longitude. Several such expeditions have previously been conducted. Of particular interest are those carried out aboard the Soya (Nakamura 1959), the U.S.N.S. Eltanin (Davis and Smith 1965), the R.S.A. (Greenspan and Stone 1964) and on several aircraft (Barbier et al. 1961).

3. INSTRUMENTATION

The photometer used in these measurements consists of an objective lens and aperture defining a 3° field of view, followed by a collimating lens and a narrow-band interference filter. A reflecting chopper deflects the beam, which is incident normal to the filter, onto a secondary mirror which returns the light through the filter at an oblique angle. The oblique beam results in an equivalent transmission band displaced approximately 100 Å below the emission wavelength. The signal from this displaced transmission band can be made nearly equal to the contribution from continuum radiation in the transmission band containing the line. Thus, the difference in the signals from the direct and oblique beams is due solely to the line emission. Three-color operation is obtained by automatically cycling one of the three filters (4278 Å, 6300 Å, and 5577 Å) in front of the RCA-7265 photomultiplier tube every 20 seconds. A servo system automatically adjusts the gain of the photometer allowing measurements over seven decades of intensity. [redacted]

[redacted]

An opaque movable screen placed between the chopper and interference filter can be adjusted to block out either the normal or oblique beam. Thus, measurements can be made of the line emission plus continuum, the pure continuum, or the difference which gives the spectrally pure line emission. The noise level of the system can be measured by blocking the entrance aperture.

Four photometers were installed aboard the Croatan for this expedition. The continuum compensated emissions were observed at the zenith and at elevation angles of 75° and 85° from the bow of the ship. The inclined orientation provides for the intersection of the 75° and 85° photometer sight lines with the 90 and 300 km altitude levels, respectively, at a location roughly 45 miles ahead of the ship. Thus, a stable localized enhancement should appear separated by approximately 2 hours on the zenith and inclined instruments due to the ship's motion. The fourth instrument monitored the zenith night sky continuum.

The four photometer telescopes were mounted in a single axis gymbal to remove the effect of the ship's roll. The instruments were installed on the port side of the flight deck near the bow of the ship as shown in Figure 1. The associated electronics and recording apparatus were installed in an active space below the flight deck as shown in Figure 2.

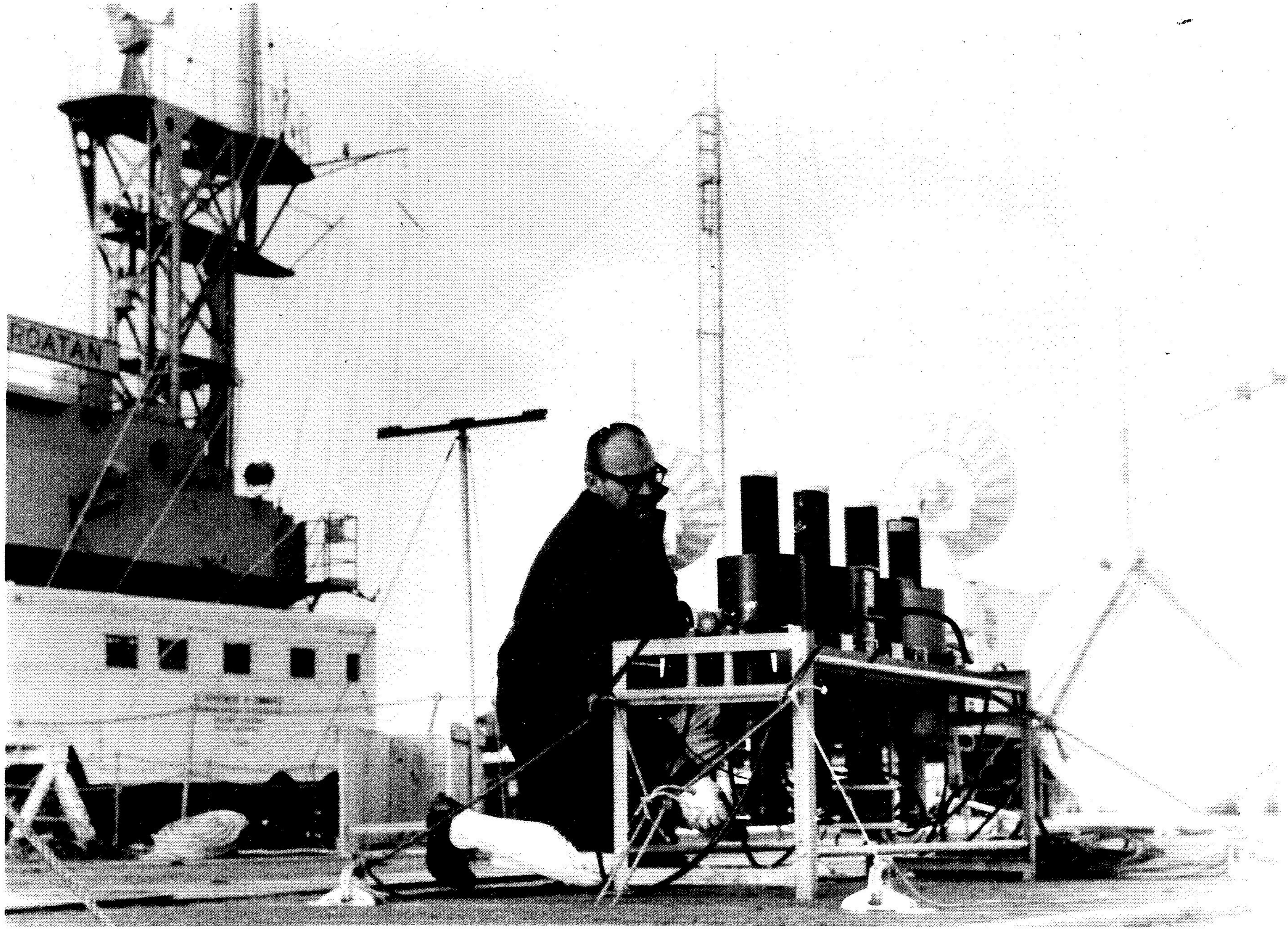

FIGURE I. DECK MOUNTED PHOTOMETERS

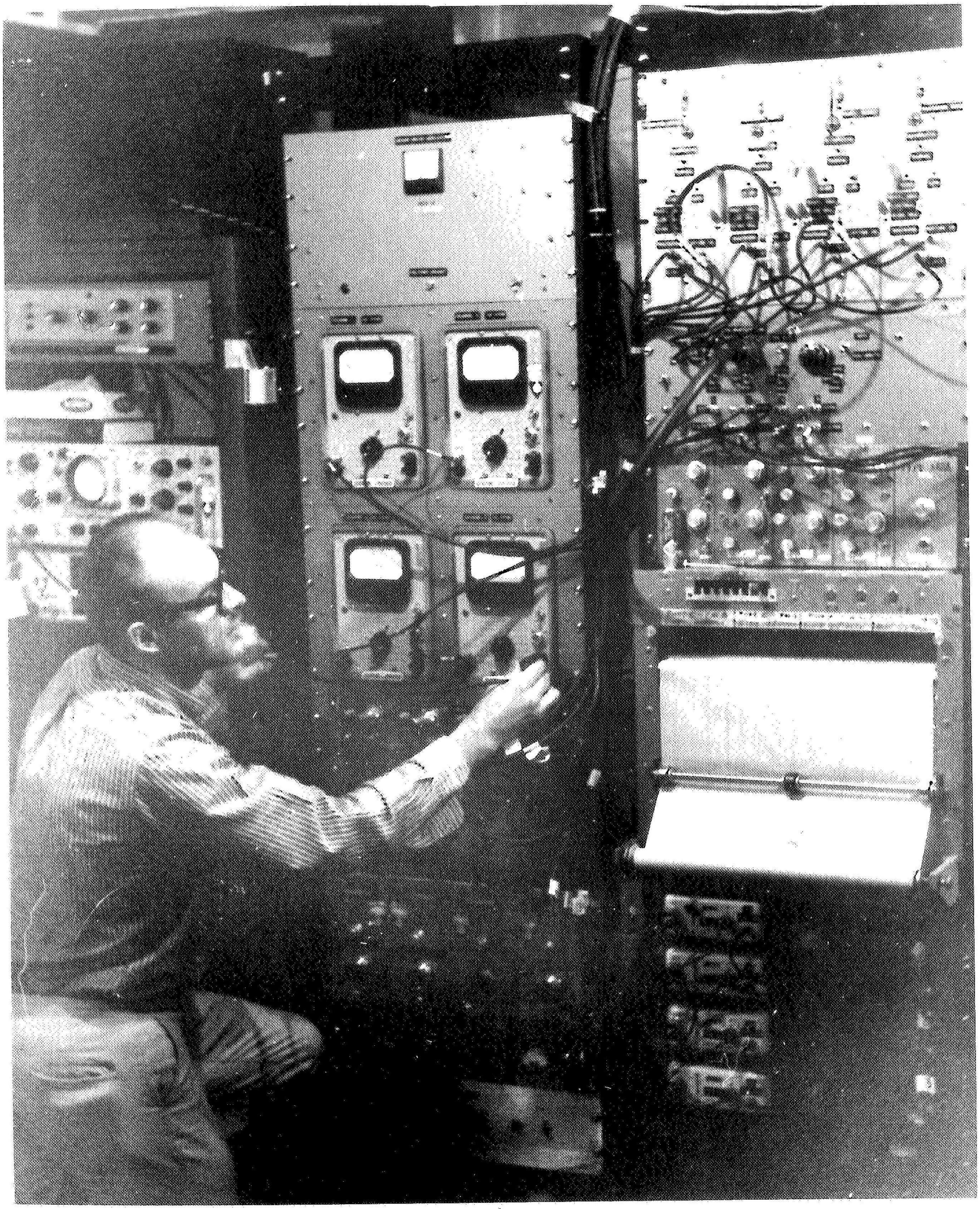

FIGURE 2. DATA RECORDING INSTRUMENTATION

4. OBSERVATIONAL PROGRAM

The observational program called for routine measurements of the nightglow intensity from sunset through sunrise, for each night of the expedition, independent of sky or moon conditions. This was accomplished with the exception of the several nights spent in port and one night at sea when the recorder was damaged. The distribution of the observations were as follows:

Location		Nights of Data
Wallops Island area	Feb. 15-Feb. 26	9
Wallops to Panama Canal	Feb. 27-March 4	5
Canal to Lima, Peru	March 6-March 13	7
Equatorial launch area	March 15-March 30	14
Lima to Talcahuano, Chile	April 1-April 7	6
Southern leg	April 8-April 19	10
Valparaiso, Chile to Canal	April 20-April 27	7
Canal to U.S.A.	April 28-May 2	5
	Total nights	63

The photometers were calibrated (set against a stable reference) three times each night; prior to the commencement of observations, in the middle of the run, and prior to shutdown. Cloud and moon conditions were frequently noted on the chart record as were any unusual occurrences such as rocket launches. Time reference marks were automatically recorded from the launch control timing systems. The ship's position and heading were obtained from the ship's log.

Arrangements were made to have the deck area surrounding the photometer darkened during observations. Any violations were reported and recorded.

The four photometers were oriented in the same manner described in the instrumentation section. The color sequence, 4278 Å - 6300 Å - 5577 Å was completed once each minute; each observation occupied 20 seconds. All four instruments were cycled simultaneously. The orientation of the four instruments was maintained throughout the expedition with the exception of the Wallops Island observations and the last observing night. In those instances all instruments simultaneously observed the continuum compensated zenith emission for the purpose of intercalibration.

5. DATA SUMMARY

Data of varying quality were obtained on 63 nights during the expedition. The map in Figure 3 shows the mean location of the ship on these nights. The dots indicate the nights on which the best data were obtained. These data were used in the analyses described in the following sections. The crosses indicate nights during which cloud cover or moon conditions produced substantial contamination. A reasonably good latitude distribution exists for the clear sky data with the exception of the southern leg. Moon conditions were mainly responsible for the loss of this data; this fact should be considered in the planning of future expeditions. The points enclosed in circles indicate nights during which midnight

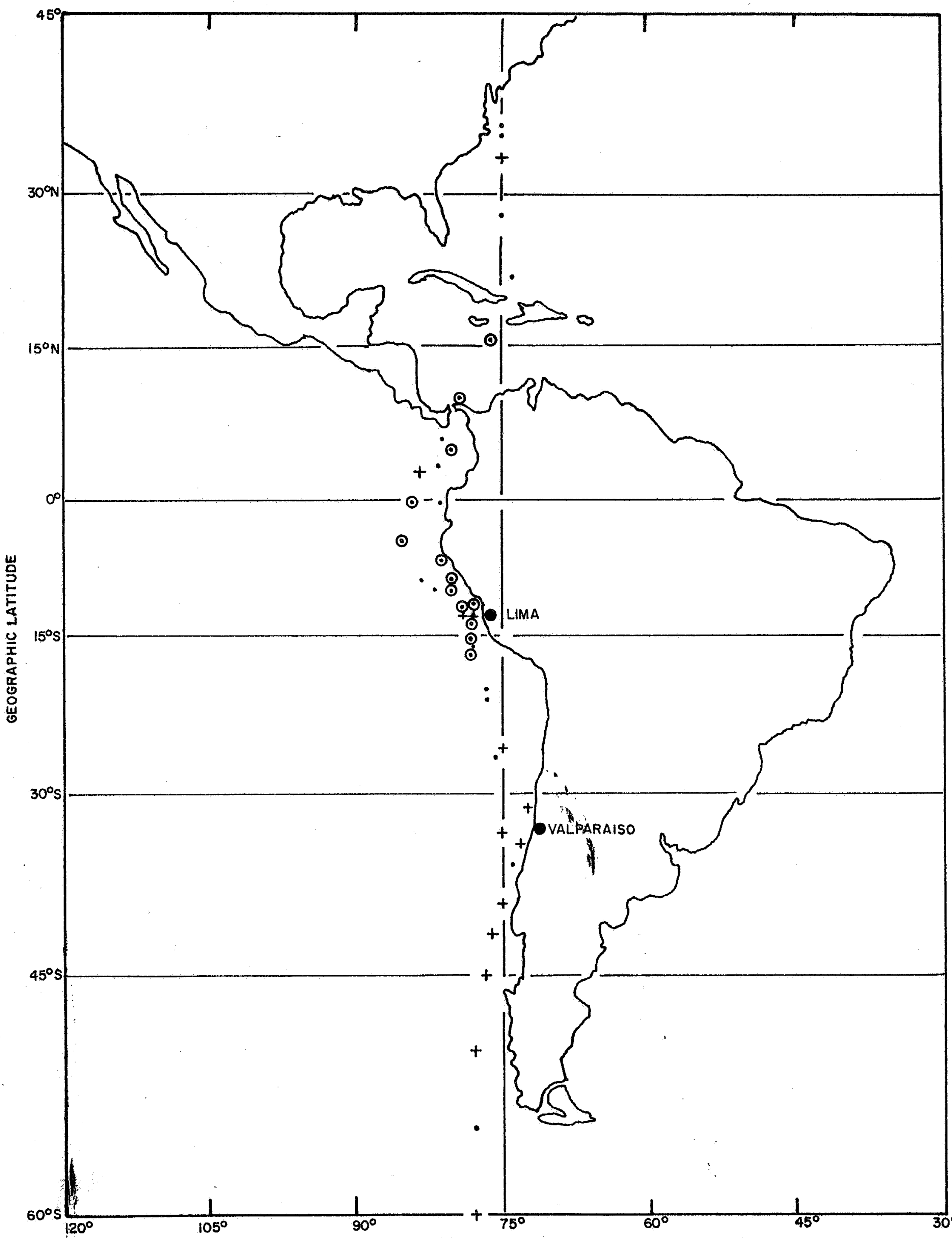

FIGURE 3. MEAN LOCATION OF THE U.S.N.S. CROATAN ON NIGHTS WHEN AIRGLOW OBSERVATIONS WERE MADE.

enhancements in the 6300 Å intensity were observed. These events were restricted to the latitude range between roughly 15°N and 15°S geographic latitude and will be discussed further in subsequent sections of this report.

Table 1 summarizes the airglow observations obtained during the expedition. The date at which the observation began and the mean latitude and longitude during the night are given in addition to the sky condition. The local time of moonrise (↑) or moonset (↓) is indicated as is the lunar phase. The columns under "instruments" indicate the operative (X) or inoperative (-) status of the individual photometers. All four photometers were in zenith operation during the first several nights. The remarks column indicates unusual events or explains absence of data.

6. SYNOPTIC DESCRIPTION OF THE 6300 Å NIGHTGLOW NEAR 78° WEST LONGITUDE

Subsequent to the initial data reduction, the first analysis considered the local and average diurnal variations and the latitude variations in the zenith nightglow intensities. These results were presented at the NASA 1965 Launch Expedition Review Symposium at the University of Illinois and at the annual meeting of the American Geophysical Union (see Trans. Am. Geophys. Un. 47, 77 (1966)).

The 6300 Å observations were studied first and the results were published in the Journal of Atmospheric and Terrestrial Physics 28, 739-745 (1966). [redacted]

Table I

AIRGLOW OBSERVATION LOG -
MOBILE LAUNCH EXPEDITION NO. 1

Date	Position		Sky Conditions	Moon Local Time	Instruments				Remarks
	Lat.	Long.			Zenith	75°	85°	Cont.	
Feb. 18	36°N	75°W	--	↑ 2053	-	-	-	-	Test run
19	36°N	75°W	--	↑ 2157	-	-	-	-	
20	36°N	75°W		↑ 2259	X	←	←	←	Photometer Intercalibration Green enhancement
21	36°N	75°W		↑ 2347	X	←	←	←	
22	36°N	75°W		↑ 0100	X	←	←	←	
23	36°N	75°W	Clear	↑ 0159$^{\Sigma}$	X	←	←	←	
24	36°N	75°W	Overcast, storm	↑ 0253	X	X	X	X	
25	36°N	75°W	Mostly overcast	↑ 0345	X	X	X	X	
26	36°N	75°W	Clear	↑ 0433	X	X	X	X	Green enhancement
27	35°N	75°W	Clear	↑ 0507	X	X	X	X	Green enhancement
28	28°N	75°W	Mostly clear	↑ 0528	X	X	X	X	Green enhancement
Mar. 1	22°N	74°W	Mostly clear	↑ 0602	X	X	X	X	
2	16°N	76°W	Mostly clear	↑ 0643	X	X	X	X	Red & green enhancements
3	11°N	79°W	Partly overcast	↑ 0716$^{\Omega}$	X	X	X	X	Red enhancement
4	--	--	--	--	-	No	Run	-	Passing through canal

Δ First quarter; o Full moon; Σ last quarter; Ω new moon.

Table I (Cont'd)

Date		Position		Sky Conditions	Moon Local Time	Instruments				Remarks
		Lat.	Long.			Zenith	75°	85°	Cont.	
Mar.	5	--	--	--	--		No	Run		At anchor in Balboa
	6	6°N	81.5°W	Mostly overcast	↓ 2105	X	X	X	X	Red enhancements
	7	2°N	83.5°W	Partly overcast	↓ 2153	X	X	X	X	
	8	1°S	84°W	Partly overcast	↓ 2238	X	X	X	X	Red and green enhancement
	9	5°S	84.5°W	Partly overcast	↓ 2316	X	X	X	X	Red enhancement
	10	9°S	83°W	Mostly overcast	↓ 0003$^{\Delta}$	X	X	X	X	
	11	10.5°S	82°W	Partly overcast	↓ 0103	X	X	X	X	
	12	12°S	78.5°W		↓ 0158	X	X	X	X	Moon
	13	--	--	--	--	-	No	Run	-	In Callao Harbor
	14	--	--	--	--	-	No	Run	-	In Callao Harbor
	15	12.5°S	78°W		↓ 0513	X	X	X	X	Moon
	16	13°S	78°W	Mostly overcast	↓ 0610	X	X	X	X	Moon
	17	13°S	78°W	Mostly overcast	↑ 1834^{o}	X	X	X	X	Moon
	18	13°S	78°W	Clear	↑ 1926	X	X	X	X	Moon
	19	13°S	78°W	Partly clear	↑ 2007	X	X	X	X	Moon
	20	13°S	78°W	Mostly clear	↑ 2049	X	X	X	X	
	21	13°S	77.5°W	Mostly overcast	↑ 2136	X	X	X	X	
	22	13°S	78°W	Partly clear	↑ 2217	X	X	X	X	
	23	12°S	78°W		↑ 2303					
	24	10°S	79.5°W	Partly clear	↑ 2343	X	X	X	X	Red enhancement
	25	9°S	80°W	Partly overcast	↑ 0048$^{\Sigma}$	X	X	X	X	Red enhancement

Table I (Cont'd)

Date		Position		Sky Conditions	Moon Local Time	Instruments				Remarks
		Lat.	Long.			Zenith	75°	85°	Cont.	
Mar.	26	12°S	79°W	Partly clear	↑ 0132	X	X	X	X	Red enhancement
	27	15°S	78°W	Partly overcast	↑ 0220	X	X	X	X	Red enhancement
	28	14°S	78°W	Mostly overcast	↑ 0315	X	X	X	X	Red enhancement
	29	--	--	--	--	-	No Run		-	In Callao Harbor
	30	--	--	--	--	-	No Run		-	In Callao Harbor
	31	--	--	--	--	-	No Run		-	In Callao Harbor
Apr.	1	12°S	78°W	Partly overcast	↑ 0640	X	X	X	X	
	2	16°S	77.5°W	Mostly overcast	↓ 1849Ω	X	X	X	X	
	3	21.5°S	76.5°W	Mostly overcast	↓ 1927	X	X	X	X	
	4	27.5°S	75.5°W	Mostly overcast	↓ 1959	X	X	X	X	
	5	33°S	74.5°W	Overcast, rain	↓ 2035	X	X	X	X	
	6	36°S	74°W	Partly overcast	↓ 2111	X	X	X	X	
	7	--	--	--	--	-	No Run		-	At Talcahuano Harbor
	8	42°S	76.5°W	Mostly overcast	↓ 2248	X	X	X	X	
	9	--	--	--	-- Δ	-	No Run		-	Repairing recorder
	10	50°S	78°W	Overcast, rain	↓ 0031	-	X	-	X	
	11	55.5°S	78°W	Overcast, rain	↓ 0136	X	-	-	X	
	12	59.5°S	78°W	Overcast	↓ 0303	X	-	-	X	
	13	59.5°S	78°W	Mostly overcast	↓ 0438	X	X	-	X	
	14	55°S	78°W	Mostly overcast	↓ 0601	X	-	X	X	
	15	50°S	78°W	Mostly overcast	↓ 0712○	X	-	X	X	

Table I (Cont'd)

Date	Position Lat.	Position Long.	Sky Conditions	Moon Local Time	Instruments Zenith	75°	85°	Cont.	Remarks
Apr. 16	44.5°S	76.5°W	Overcast, rain	↑ 1803	X	-	X	X	
17	39°S	75°W	Mostly overcast	↑ 1836	X	-	X	X	
18	34°S	72.5°W	Partly overcast	↑ 1925	X	-	X	X	
19	--	--	--	--	-	No Run		-	In Valparaiso Bay
20	31.5°S	72.5°W	Clear	↑ 2055	X	-	X	X	
21	26°S	75°W	Clear	↑ 2156	X	-	X	X	
22	20°S	77°W	Partly clear	↑ 2301	X	-	X	X	
23	13.5°S	79°W	Partly overcast	↑ 0025^{Σ}	X	-	X	X	
24	7.5°S	81°N	Partly overcast	↑ 0117	X	-	X	X	Red enhancement
25	1°S	81°W	Mostly overcast	↑ 0209	X	-		X	
26	5.5°N	80°W	Mostly overcast	↑ 0301	X	-	X	X	
27	--	--	--	--	-	No Run		-	Going through Canal
28	11°N	79°W	Mostly clear	↑ 0420	X	-	X	X	
29	16°N	76°W	Clear	↑ 0450	X	-	X	X	
30	22°N	74°W	Partly clear	↑ 0536	X	-	X	X	
May 1	29.5°N	74.5°W	Mostly overcast	↓ 1855^{Ω}	X	-	X	X	
2	33.5°N	75°W		↓ 2013	X	←—	——	——	Calibration data

[redacted]

At the time of publication, the re-calibration of the photometers had not been completed and the intensities were reported as recorded signal levels in volts. The appropriate calibration for use with the following results is:

$$Q(6300\ \text{Å}) = 65 \pm 4\ \text{Rayleighs/volt.}$$

7. SYNOPTIC DESCRIPTION OF THE 5577 Å NIGHTGLOW

The results of the 5577 Å observations were published in the Journal of Atmospheric and Terrestrial Physics 29, 239-250 (1967) and in a paper intended as a companion to that presented in the previous section of this report. [redacted]

8. CORRELATION OF THE [OI]$_{21}$ INTENSITY AND IONOSPHERIC PARAMETERS BY MEANS OF BARBIER'S SEMI-EMPIRICAL FORMULA

Barbier (1957) discovered that the red line intensity in tropical regions could be related to the ionospheric parameters h'F and f_0F_2, the height and the maximum electron density of the F-layer, respectively. This relationship can be expressed analytically by Barbier's semi-empirical formula

$$Q = A + B\ (f_0F_2)^2\ \exp\ [(h'F - 200)/H]$$

where Q is the zenith 6300 Å intensity, H is the O_2 scale height and A and B are constants (for a given night at least). This expression is derived from the assumption that $O(^1D)$ atoms are produced by dissociative recombination of O_2,

$$O_2^+ + e \rightarrow O(^1D) + O$$

and that the O_2 molecules are distributed exponentially with height, as

$$N = N_o e^{-Z/H} \quad .$$

Peterson (Roach and Cole 1965) has shown that the right-hand term in Barbier's formula results from the integration of a simplified form of an expression for the 6300 Å emissivity based on dissociative recombination of O_2^+ and NO^+.

The semi-empirical formula has been used with good success in tropical regions especially in the early part of the night. Examples of such studies have been reported by Barbier et al. (1962), Carman (1965), etc. Definition of the latitude range in which the Barbier formula holds, and studies of possible systematic departures with latitude are crucial to the understanding of the physical processes responsible for the airglow. This expedition has provided one of the best opportunities thus far, for resolving these questions.

Correlation studies have been completed for all nights when good quality airglow and ionosonde data were available. These studies were performed with the IBM 7094 computer at IITRI. Examples of observed and calculated diurnal profiles for three nights are shown in Figures 4, 5, and 6.

Figure 4 shows the results for the pre-midnight portion of the night of Feb. 27/28, 1965. The red line was very stable while the green line showed post-midnight enhancement. Sky conditions were very clear. Comparison of ionosonde and photometer data yielded A = 40, B = 20, and H = 36 with a correlation coefficient of 0.93.

Figure 5 illustrates the results for the early night of April 24/25, 1965. The data again showed a red midnight enhancement. Latter part of night was cloudy and moonlit. For the first portion of the night we obtained A = 65, B = 9.3, and H = 36 with a correlation coefficient of 0.91.

Figure 6 shows data for the entire night of April 29/30, 1965. Considering the entire night we obtained A = 160, B = 9, and H = 15 with a correlation coefficient of 0.56. Letting A = 70 and H = 36 throughout the night, then B = 20 produces a good fit in the early part of the night and B = 10 fits the latter portion. Thus, B seems to have decreased by about a factor of 2 between 3 and 7 hours G.M.T. Similar effects have been found for Maui data.

Since all of the nights considered exhibited reasonably good degrees of correlation with Barbier's formula, we decided to attempt to reproduce the entire 6300 Å excitation pattern (see Section 6) at once. Since the excitation pattern represents averages of average values, it was necessary to prepare the ionosonde data in a corresponding manner. The input data for these analyses thus consists of corresponding isophote,

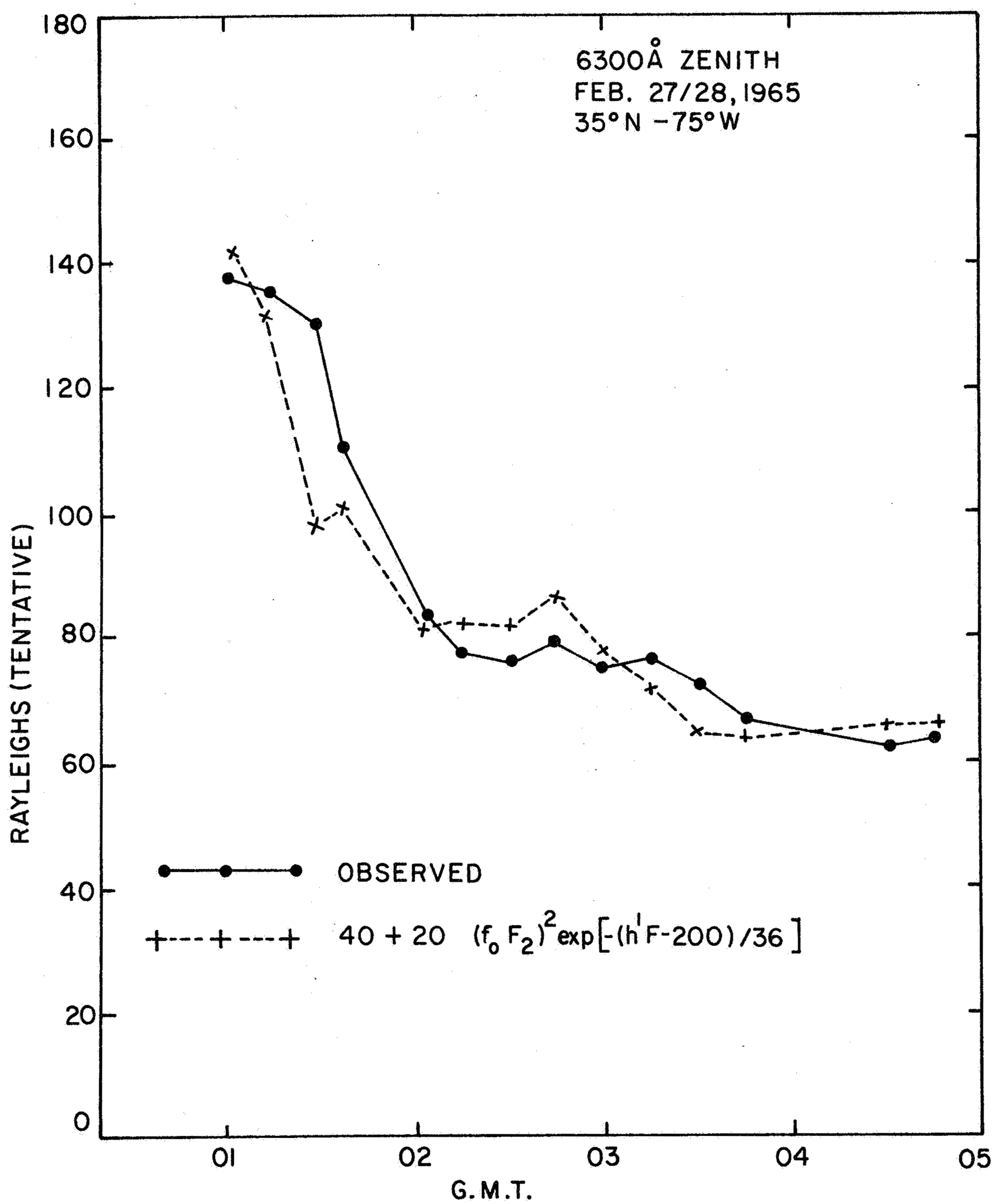

FIG. 4. CALCULATED AND OBSERVED RED LINE INTENSITIES FOR FEB. 27/28, 1965.

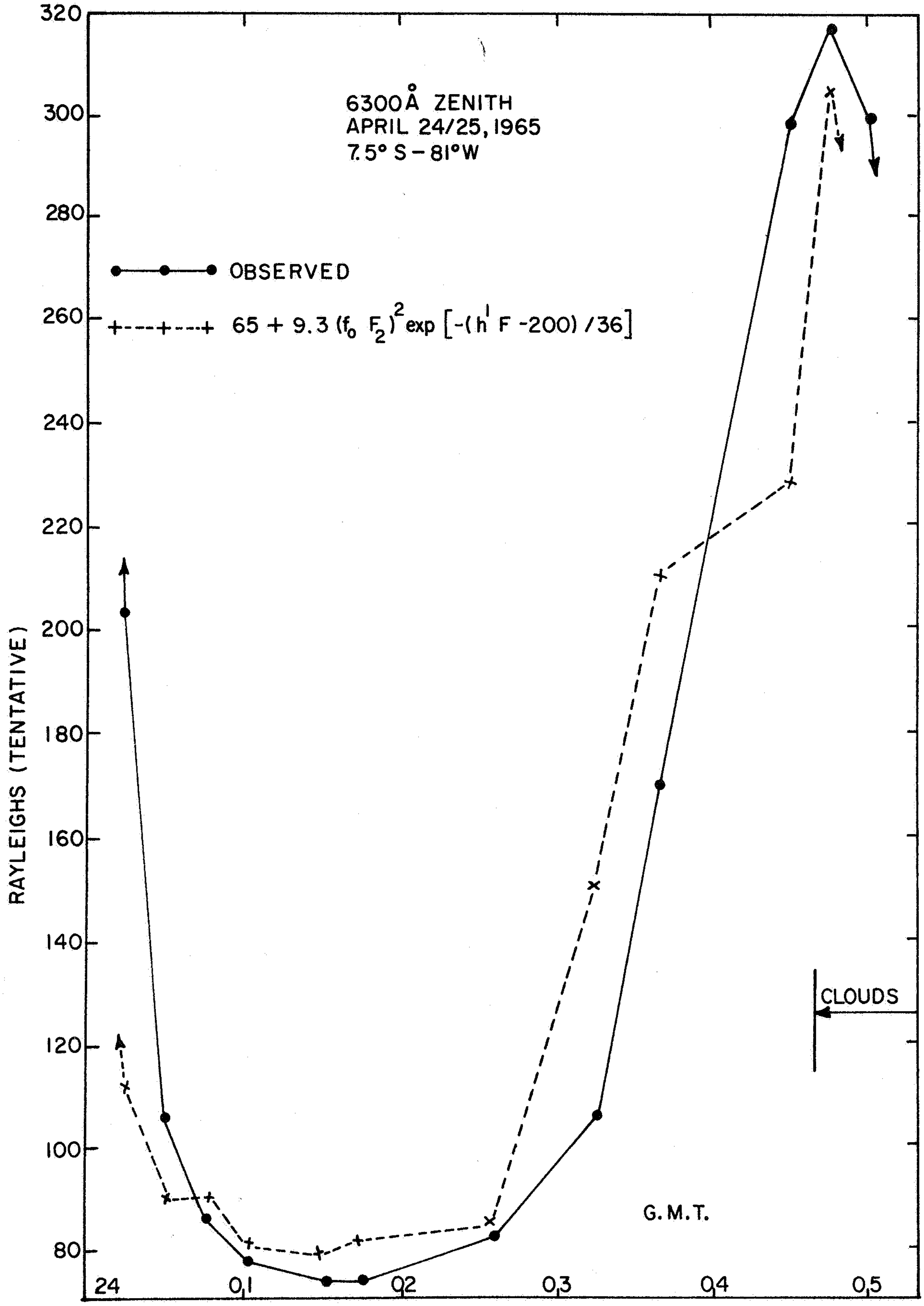

FIG. 5. CALCULATED AND OBSERVED RED LINE INTENSITIES FOR APRIL 24/25, 1965.

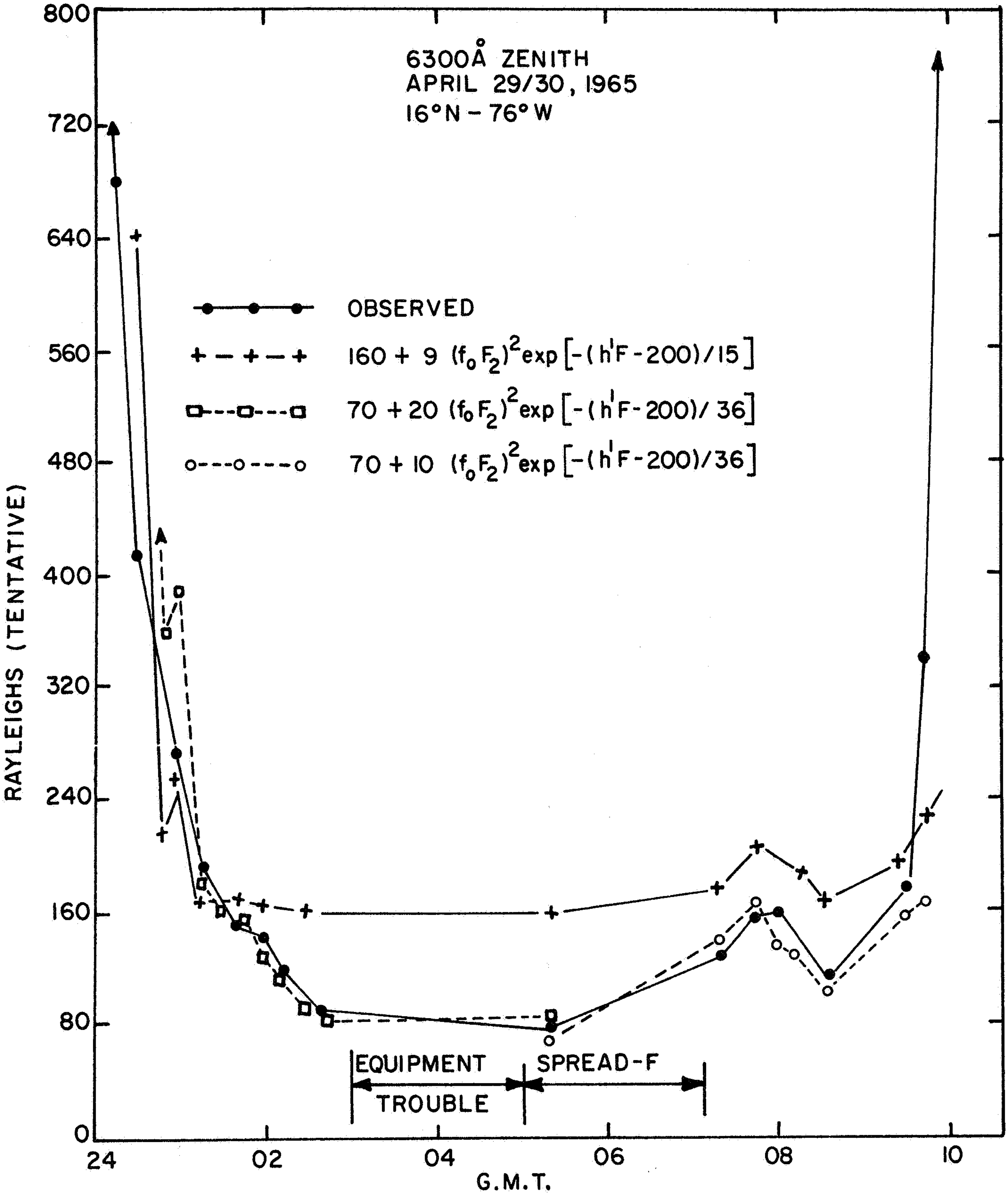

FIG. 6. CALCULATED AND OBSERVED RED LINE INTENSITIES FOR APRIL 29/30, 1965.

isofreq and isoheight plots which are shown in Figures 7, 8, and 9. These plots have been prepared by selecting the average value of the appropriate parameter for each square on a 10° latitude by one hour longitude grid. A similar set of isoplots have been prepared on a 5° latitude by one half hour longitude grid, however, those will not be discussed here.

The overall Barbier correlation studies have been performed in several ways. The most meaningful of these involves the application of Barbier formulas to each longitude sweep at constant latitude. This corresponds to a sample at each 10° of latitude on the grid used in Figures 7, 8, and 9. The results of this correlation are illustrated by the calculated isophote plot contained in Figure 10 where the O_2 scale height has been kept constant at 40 km. Correlation coefficients ranged from 0.717 to 0.990 for individual latitudes, an average value for the correlation coefficient being 0.850.

Other techniques tested for the overall Barbier correlation included constant latitude correlations selecting scale heights giving optimum correlation at each value of latitude, and simultaneous point to point correlation over the entire night sky. In the latter case the anti-solar point maximum (see Section 6) appears shifted towards the equator. The overall correlation in this case was 0.722 for a scale height of 48 km.

As a result of the excellent degree of overall correlation illustrated in Figure 10 we can conclude that

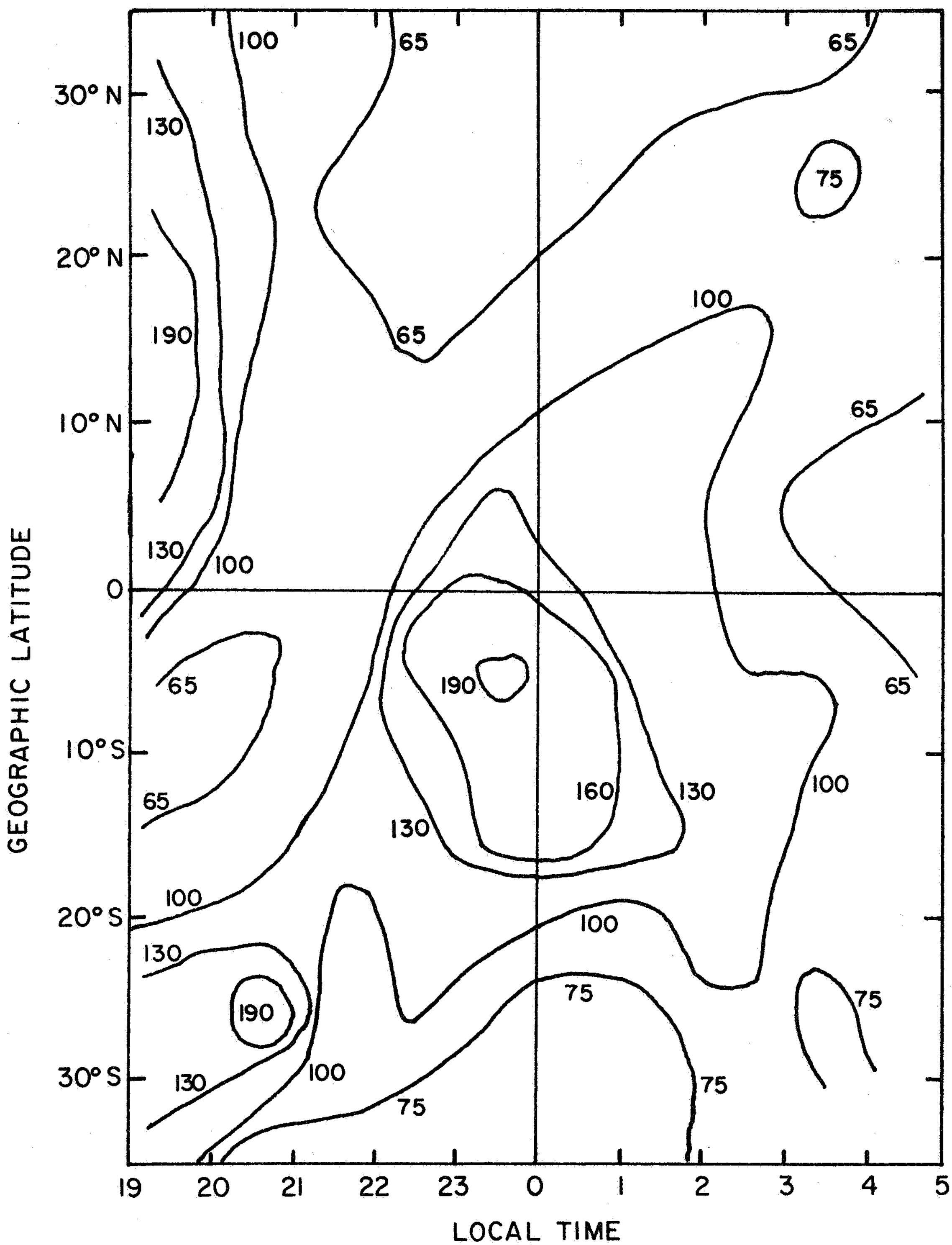

FIG. 7. OBSERVED ISOPHOTE PATTERN FOR THE 6300Å NIGHTGLOW

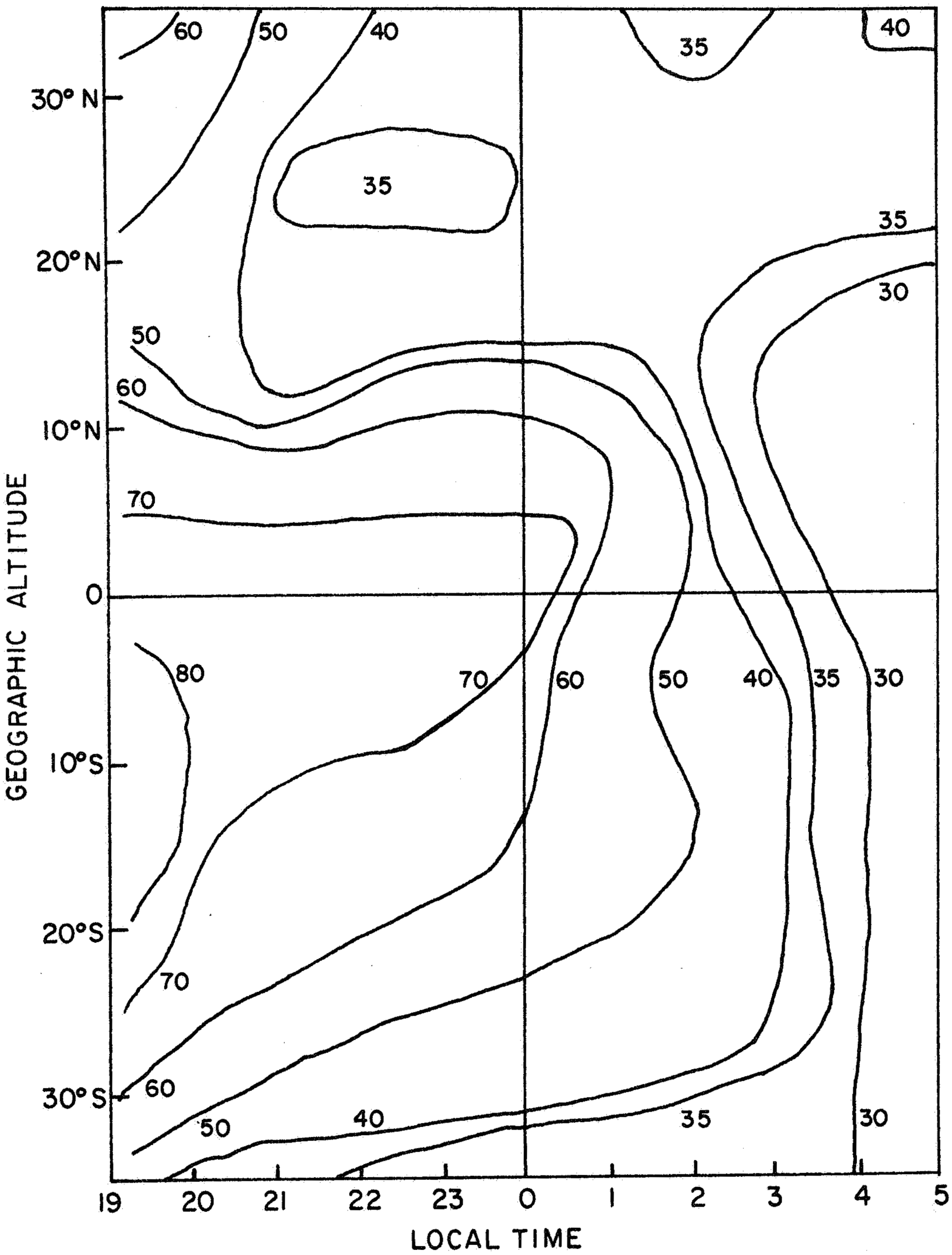

FIG. 8. OBSERVED ISOFREQ PATTERN FOR NIGHTTIME f_0F_2

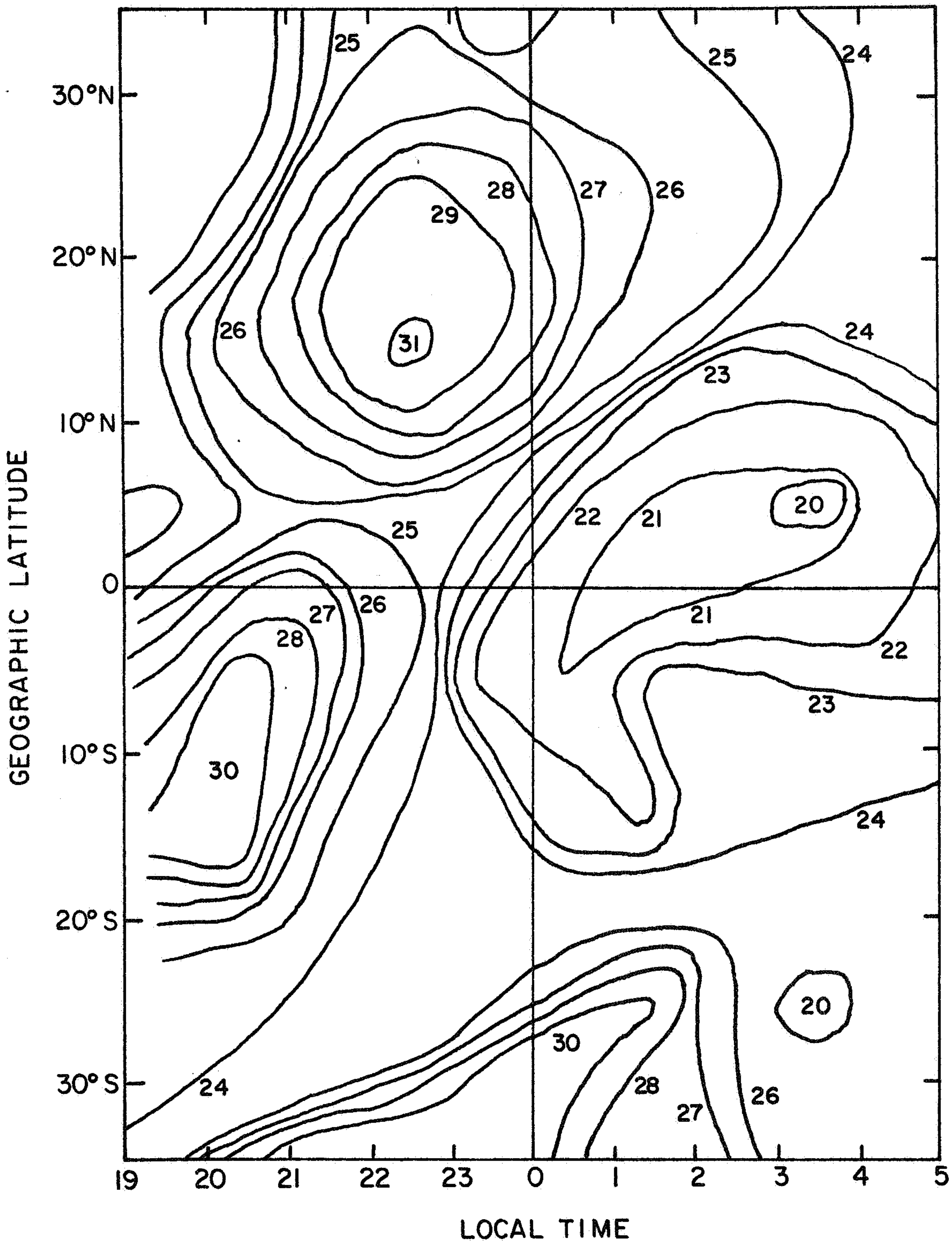

FIG. 9. OBSERVED ISOHEIGHT PATTERN FOR NIGHTTIME h'F

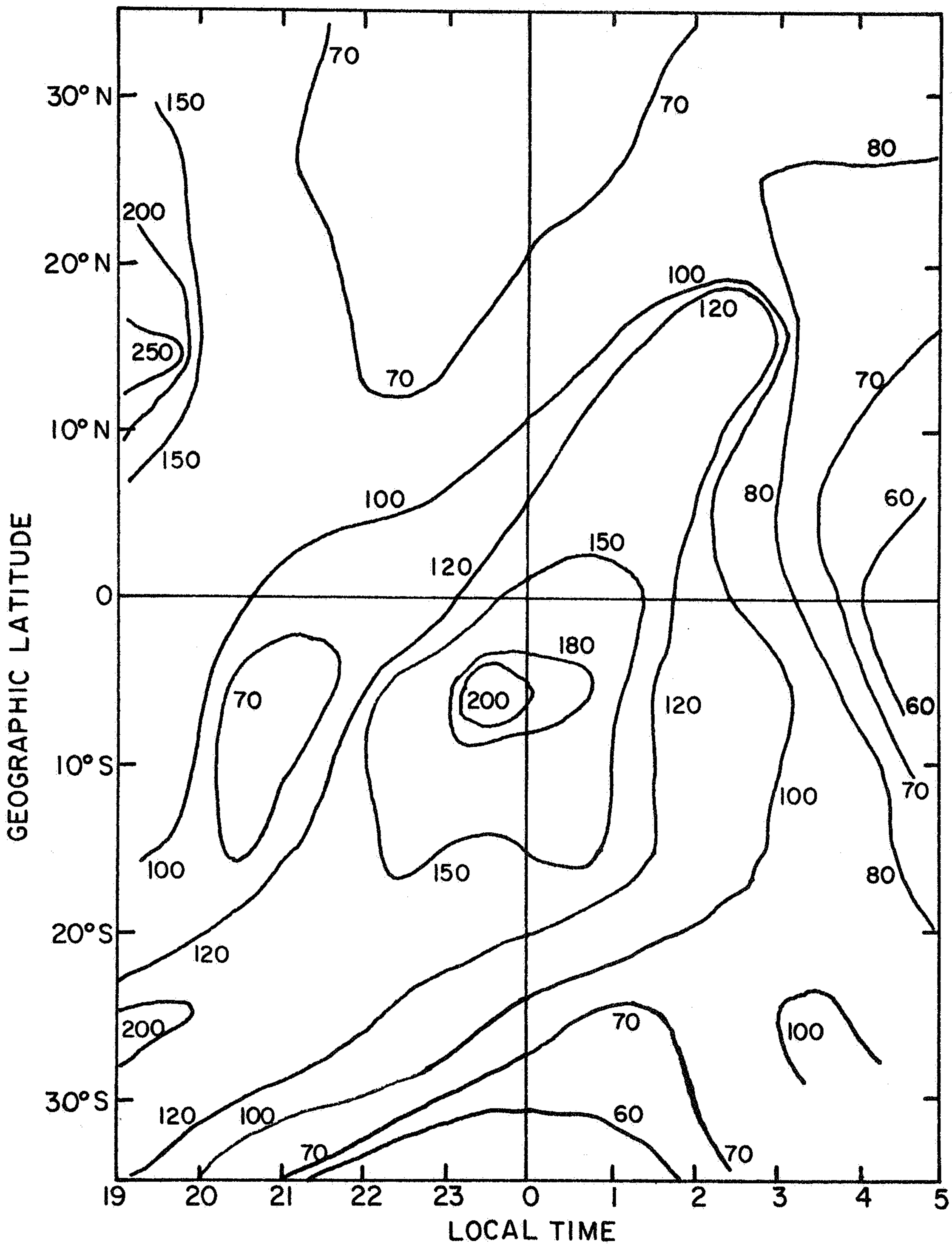

FIG. 10. CALCULATED ISOPHOTE PATTERN FOR 6300Å NIGHTGLOW. (BARBIER FORMULA BY LATITUDE FOR H = 40KM)

dissociative recombination is the dominant final mechanism responsible for the $[OI]_{21}$ emission over the latitude range covered by the expedition. This result per se does not imply anything about providing the energy for maintaining dissociative recombination.

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(References relating to reprints contained in Section 3, 6, and 7 are not included here.)

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