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GEOPHYSICAL INSTITUTE

OF THE

UNIVERSITY OF ALASKA

ANALYSIS OF DATA ACQUIRED ON THE 1968 AIRBORNE AURORAL EXPEDITION

Final Report

Grant NGR-02-001-048
Supplement No. 1

August 1968 - June 30, 1970

Prepared For

National Aeronautics and Space Administration

Approved by:

Gerald J. Romick
Principal Investigator

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ABSTRACT

The analysis of data from both the 1968 and 1969 NASA Airborne Expeditions has covered the general areas of spectral variability of both aurora and airglow emissions in a wide range of latitudes and longitudes. Much of the analysis is still incomplete and under study but some trends seem noteworthy, i.e.,

a) The ratio of λ4278 N_2^+/λ5577 [OI] seems to be constant across at least one discrete auroral form.

b) The λ5001-λ5006 N II emissions appear to be due to direct dissociation ionization and excitation of N_2.

c) The mid-day sector of the auroral oval and polar cap shows zones of electron precipitation (as deduced from the λ6300/λ4278 ratios with latitude)

   1) >3 kev in the oval associated with λ6300/λ4278 ratios $\lesssim 1$

   2) <1 kev in the magnetosphere cusp region associated with λ6300/λ4278 ratios > 10

   3) discrete earth-sun aligned auroras over a < 1 kev background in the polar cap.

d) The boundary between the oval and polar cap on the dayside is interpreted as the boundary between open and closed field lines.

e) The boundary region seen on the night side where the λ6300/λ4278 ratio changes rapidly with latitude is also interpreted as the boundary between the open and closed field lines on the nightside.

f) The discrete earth-sun aligned auroras seen in the open field line polar cap region on the day side have a similar appearance to some rayed auroras seen on the night side both in terms of characteristic particle energy spectra as well as visual appearance, and this may

imply that the acceleration of auroral particles for these type discrete arcs is not in the tail region but is a near-earth phenomena.

g) The clarification of problems in auroral conjugacy, northern latitude limit of pulsating aurora, and other morphological effects may be explained by the determination of the instantaneous night time latitude of the boundary between open and closed field lines.

h) Airglow OH measurements show no appreciable change with latitude or longitude but do show diurnal changes.

ANALYSIS OF DATA ACQUIRED ON THE
1968 AIRBORNE AURORAL EXPEDITION

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INTRODUCTION

During the 1968 NASA Airborne Auroral Expedition, the Geophysical Institute, supported by NASA Grant NGR 02-001-048, operated a scanning photometer onboard the NASA CV 990 aircraft. Data was acquired on 11 of the 12 flights on which the instrument was onboard the aircraft. A preliminary inspection of the data indicated that a detailed analysis of the data was warranted so additional funds were requested and partially provided under a supplement to NASA Grant NGR 02-001-048, in September 1969. Soon after that date the 1969 NASA Airborne Auroral Expedition occurred (December, 1969). The Geophysical Institute again operated a scanning photometer on 15 flights funded under NASA Grants NGR 02-001-058 and NGR 02-001-060. Preliminary analysis and data reduction from the 1969 airborne expedition was included under the analysis funding for the 1968 expedition with the understanding that further funding would become available for the completed analysis of the data from both airborne expeditions. Unfortunately, such a continuation of funding has only recently become available due to NASA budget limitations and consequently much analysis of the data from the two expeditions is still in an uncompleted form. Because of more pronounced scientific interest, analysis of data from the 1969 expedition has taken precedence over that from the 1968 expedition.

Some of the results were discussed in the Spring 1970 AGU meeting (Romick, 1970a; Brown, 1970) and elaborated further in the Fall 1970 AGU meeting (Romick, 1970b). In addition, this grant has also provided some support for the OH airglow analysis reported in the Master's thesis (to be awarded in the summer of 1971) of R. Henderson (1971) on data acquired from the 1969 expedition. Publication of the midday auroral observations is in progress (Romick and Brown, 1971). This final report will summarize those data that have been reduced and analyzed from both the 1968 and 1969 NASA airborne expeditions.

1968 AIRBORNE AURORAL EXPEDITION

The Geophysical Institute operated a four filter meridian type scanning photometer onboard the CV 990 aircraft on 11 of 12 flights (Table I). The instrument had a 1° field of view and a clear scanning field out of one of the top windows from approximately 10° to one side of the geographic zenith to 60° on the other side in a direction perpendicular to the flight path of the aircraft. The data were recorded on seven FM tracks of an onboard NASA-14 track tape recorder as well as on 35 mm film.

One of the specific problems attacked on this expedition was the study of the relative intensity of the λ4278 (N_2^+), λ5577 [OI] and λ5001-5006 [N II] emissions across the horizontal width of a narrow auroral arc.

The original plan was to look at the ratio of these emissions in various brightness and width arcs in order to determine the frequency of the narrow cone of λ5577 emission noted by Romick and Belon (1967), Murcray (1967) and others and whether it occurs in any particular phase of the substorm. This will hopefully shed light on the possible excitation mechanism for the λ5577 [OI] emission. The N II emissions at λ5001-5006 to a first order approximation should be directly proportional to the N_2^+ emission and will, among other uses, indicate whether the horizontal ionization profile within the arc can be assumed constant in all ions at all heights. This is, of course, important in the interpretation of the meaning of the λ5577 and λ4278 ratio.

The sequence of ASC (all-sky camera) photographs in Fig. 1 illustrate a zenith arc selected for this study and its changes during the one minute between 0636 UT and 0637 UT March 3, 1968. An intense investigation of all of the 1968 data revealed only a few cases where arcs were stable enough to allow the detailed investigation of the relative emissions even though the photometric data for all three emissions were acquired within two seconds or less. The photometric data shown in Fig. 2(a) is a plot of intensity versus zenith angle for one set of scans taken in a 2 second interval starting at 063640 UT on March 3, 1968. The ratio obtained from these data (Fig. 2(b)) for $\lambda 4278/\lambda 5577$ is 1/5.5 and $\lambda 4278/\lambda 5001$-5006 is 13/1 and within the accuracy of this particular scan is reasonably constant over the form. However, continuation of the analysis is obviously needed to determine whether the scatter observed in Fig. 2 is due to the random noise or whether it is due to actual changes in the signal due to a horizontal or altitude dependence of these ratios. The data reduction to date has covered 60 individual scans for this particular auroral form and specific conclusions must await the completed analysis of more than the one scan depicted in Fig. 2. Note, however, that the $\lambda 4278$ $(N_2^+)/\lambda 5001$-5006 (N II) ratio of 13 obtained in Fig. 2 is very close to the ratio (14.5) obtained through the laboratory measurements of the ratio of the total emission cross sections of the $\lambda 3914$ $(N_2^+)/\lambda 5001$-5006 (N II) lines (assuming $\lambda 3914$ $(N_2^+)/\lambda 4278$ $(N_2^+) = 3$) reported by Srivastava (1969). This closeness implies that all of the observed N II in the aurora was created by direct dissociative ionization and excitation of N_2 by electron impact, i.e., $N_2 + e \rightarrow N^{+*} + N + 2e$.

Other individual auroral forms such as indicated in Fig. 3 are also present in the flight data and should be analysed before definite conclusions can be published.

Table 1

Operational Resumé

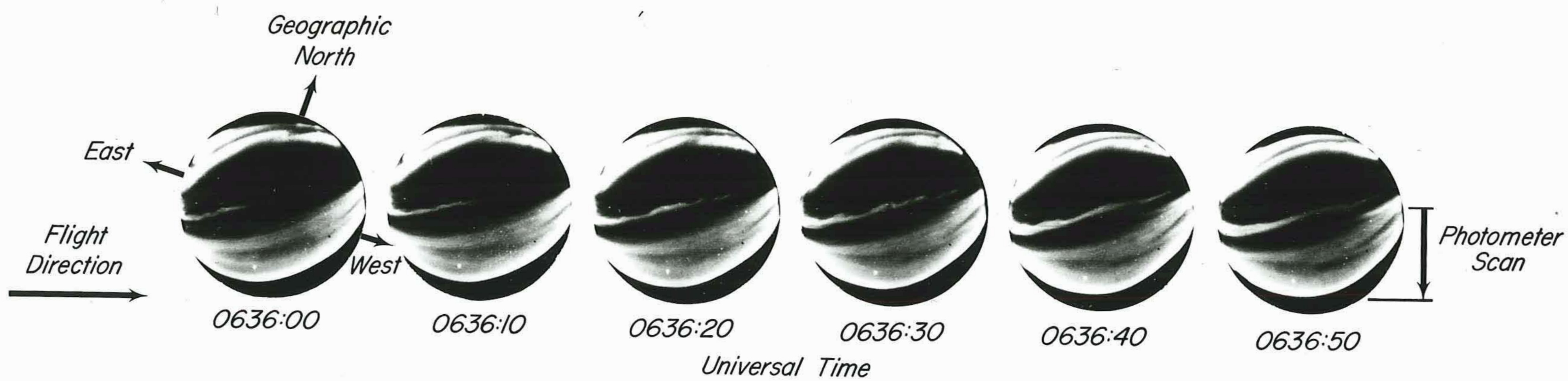
1968 (UT) Date	Flight No.	UT Time On	UT Time Off	Mode of Operation	Field of View
February 21	14	0930	1100	Scanning 1/2 rps	2°
February 22	15	No operation ------------------------------			
February 23	16	1030	1105	Scanning 1/2 rps	2°
February 25	17	0200	0504	Scanning 1/2 rps	2°
February 26	18	0207	0648	Scanning 1/2 rps	2°
February 27	19	0307	0726	Scanning 1 rps	1°
February 29	20	0352	0800	Scanning 1 rps	1°
March 3	21	0530	1015	Scanning up to 4 rps	1°
March 4	22	0950	1028	Zenith 5577 only	1°
March 6	23	0610	1038	Scanning 1 rps	1°
March 8	24	0534	1005	Scanning 1 rps	1°
March 9	25	0554	1013	Scanning 1/2 rps	1°

Continuous data was acquired within the times indicated except for short periods during the changing of the magnetic tape.

NASA 1968 Auroral Airborne Expedition

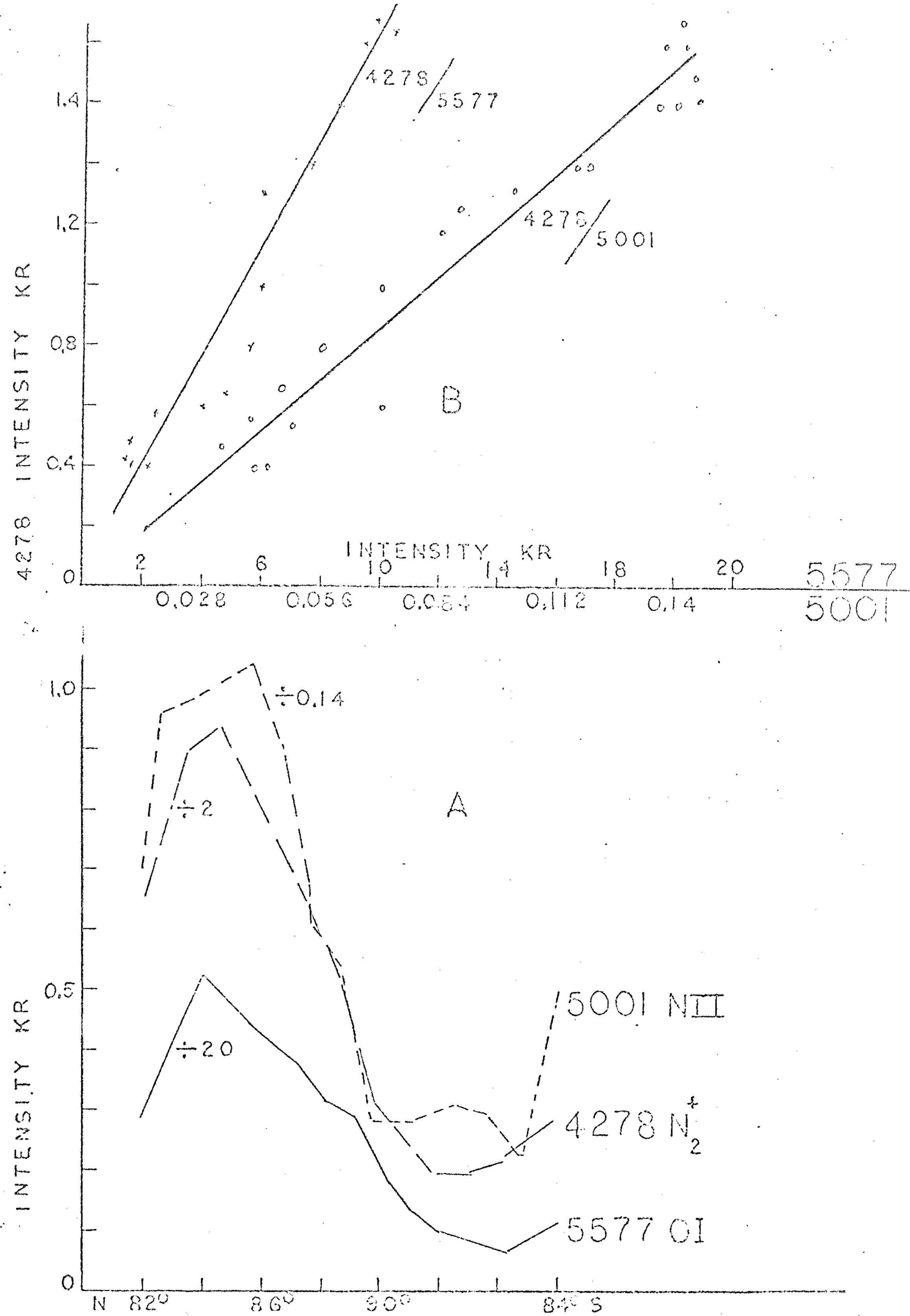
Flight Number 21

3 March 1968



dp Latitude 68.6°

Fig. 1 Development of a narrow zenithal auroral arc as seen on all-sky camera exposures taken every 10 seconds starting at 0636 UT March 3, 1968 when the NASA Convair 990 was at dp latitude 68.6°.



. 2 a) Intensity versus zenith angle in the wavelengths λ5001-5006 (N II), λ4278 (N_2^+) and λ5577 [OI] at 063640 UT March 3, 1968.
b) Intensity of λ5001-5006 N II and λ5577 [OI] plotted against the intensity of λ4278 (N_2^+) from Fig. 2-a.

1969 NASA AIRBORNE EXPEDITION

The Geophysical Institute of the University of Alaska operated an eight filter scanning photometer onboard the 1969 NASA auroral airborne expedition. The instrument was operated under two NASA Grants divided between aurora and airglow studies. The auroral experiment (under NASA Grant 02-001-060) was directed towards the acquisition of two kinds of information. The first concerned studies on the enhancement of the N_2^+ 1NG system through resonant scattering of sunlight. The second concerned the horizontal distribution within discrete auroral forms of the λ5577 OI emission relative to that of the N_2^+ 1NG bands under sunlit and midday conditions.

Little data on sunlit aurora were obtained but the observations of midday aurora are of special interest due to the paucity of information available regarding their spectral characteristics, relative emission height variation and general height range.

The airglow experiment under NASA Grant 02-001-058 had as its primary goal the study of the geographical distribution of the emission intensities of the hydroxyl (OH) and related airglow emission features, particularly at high latitudes. These data were to be analysed to determine the relative importance of atmospheric dynamical processes including those of a meteorological origin as well as possible variations from the basic hydrogen-ozone reaction excitation mechanism. In addition, the occurrence of sudden increases in the intensity of the OH emissions due to the presence of active aurora was to be verified and firmly established.

The initial ferry flight of the expedition to Ft. Churchill, Canada, occurred on November 24, 1969 and the return ferry flight took place on December 18, 1969. Table II is a resumé of the data flights carried out between those dates and indicates the mode of operation of the scanning

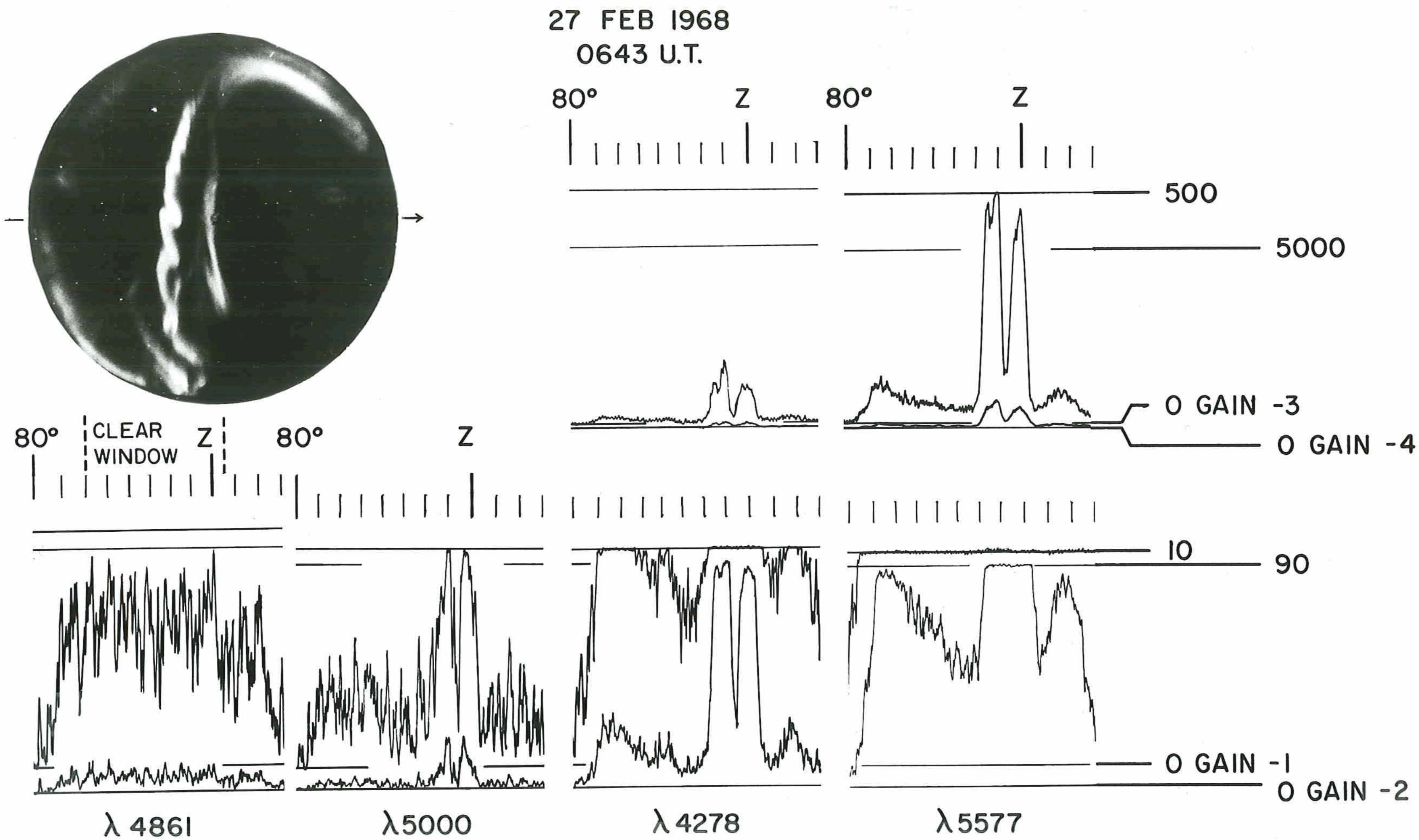


Fig. 3 Original data showing the photometric observation of the aurora illustrated in the all-sky camera photograph. The weak emissions of Hβ (λ4861) and N II/λ5001-5006 give deflections on gain 1 and 2 only. The stronger emissions OI(λ5577) and N_2^+(λ4278) appear on gains 3 and 4 also. The size of the clear window aperture through which the photometer observed is indicated directly below the ASC photograph. The arrows on the ASC photograph indicate the direction of the photometer scan.

photometer and the various wavelengths monitored as a function of time during each flight.

The same type of scanning photometer was used on the 1969 expedition that was used during the 1968 expedition except for electronic modifications.

From a knowledge of the operational characteristics of the basic optical system when used at shorter wavelengths for other types of auroral and airglow studies, a decision was made to use pulse-counting signal detection techniques. In order to retain flexibility under a variety of possible observational conditions, and also to interface smoothly with the existing analog recording instrumentation, the raw pulse data were converted to analog voltage levels. These were then passed into four separate amplifiers that resulted in four separate decades of signal level which were available simultaneously, ranging from 0 - 200 cps to 0 - 200,000 cps. In operation, pulse pile-up occurred at approximately 40,000 cps. A manual multipole switch placed a load resistor chain across the anode of these same four amplifiers if analog detection were desired over the range of 10^{-7} to 10^{-4} amperes full scale. This feature was used successfully for a short period during a day-to-night transitional flight which occurred during passage from Ft. Churchill to Bodø, Norway.

The remaining modifications were minor, consisting for the most part of installing a 1° resolution shaft encoder assembly on the optical field of view scanning system, reprogramming the filter wheel movement circuitry for positive filter identification and stop-motion movement, and general construction for aircraft mounting. The field of view was 0.5° and was scanned through a top window of the aircraft having a clear field of view from 10° to one side of the geographic zenith to 50° on the other side perpendicular to the flight path of the aircraft.

Table II

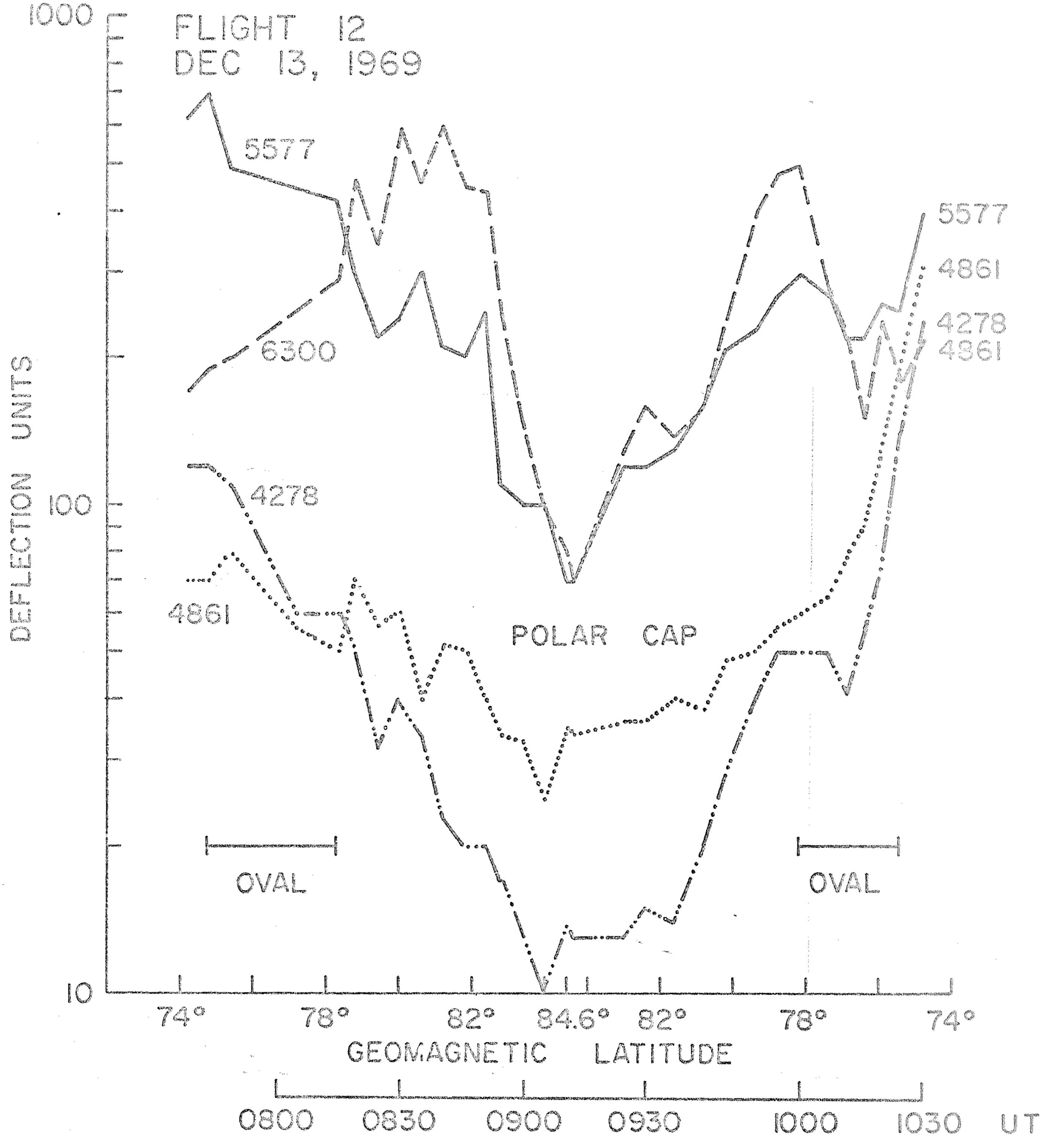
Operation Resumé

1969 Date UT	Flight	Mode of Scanning	Operation Zenith	Time Interval U.T.	Recording Mode Tape	Recording Mode Chart	Channel Wavelength 1	2	3	4	5	6	7	8
	1	x	x	Test Flight		x								
Nov. 24	2		x	0806-1231		x	4278	5893	5577	6300	8630	7250	8345	9350
Nov. 26	3		x	0042-0133	x	x	4278	7250	4861	6772	8911	8630	8345	9350
		x		0133-0239	x	x								
			x	0239-0307	x	x								
		x		0307-0319	x	x								
			x	0319-0437	x	x								
		x		0437-0611	x	x								
Nov. 27	4		x	0033-0225	x	x	4278	7250	6772	8911	8630	8345	9550	4861
		x		0225-0230	x	x								
			x	0230-0450	x	x								
		x		0450-0532	x	x								
Nov. 29	5		x	0225-0620	x	x	4278	7250	6772	8911	8630	8345	9350	4861
Dec. 3	6		x	0513-0536	x	x	4278	7250	6772	8911	8630	8345	9350	4861
		x		0536-1025		x								
Dec. 4	7		x	0450-0930	x	x	4278	7250	6772	8911	8630	8345	9350	4861
	8		x	0610-0640	x	x								
Dec. 5		x		0640-0756	x	x								
			x	0756-0850	x	x								
		x		0850-1000	x	x								
			x	1000-1127	x	x								
Dec. 7	9		x	0515-0600	x	x	4278	7250	6772	8911	8630	8345	9350	4861
		x		0600-0744	x	x								
			x	0744-1016	x	x								
Dec. 8	10			0745-1245		x	4278	7250	6772	8911	8630	8345	9350	4861
Dec. 11	11			1850-2135	x	x	4278	7250	6772	8911	8630	8345	9350	4861
		x		2135-2230	x	x								
Dec. 13	12	x		0630-1130	x	x	5577	4278	5000	4861	6300	8911	8345	8630
Dec. 14	13	x		0530-1030	x	x	5577	4278	5000	4861	6300	8911	8345	8630
Dec. 16	14		x	0120-0203	x	x	5577	4278	5000	4861	6300	8911	8345	8630
		x		0203-0550	x	x								
			x	0550-0553	x	x								
		x		0553-0804	x	x								
Dec. 18	15	x		0817-0933	x	x	5588	4278	9350	4861	6300	8911	8345	8630
			x	0933-1028	x	x								
		x		1028-1426	x	x								

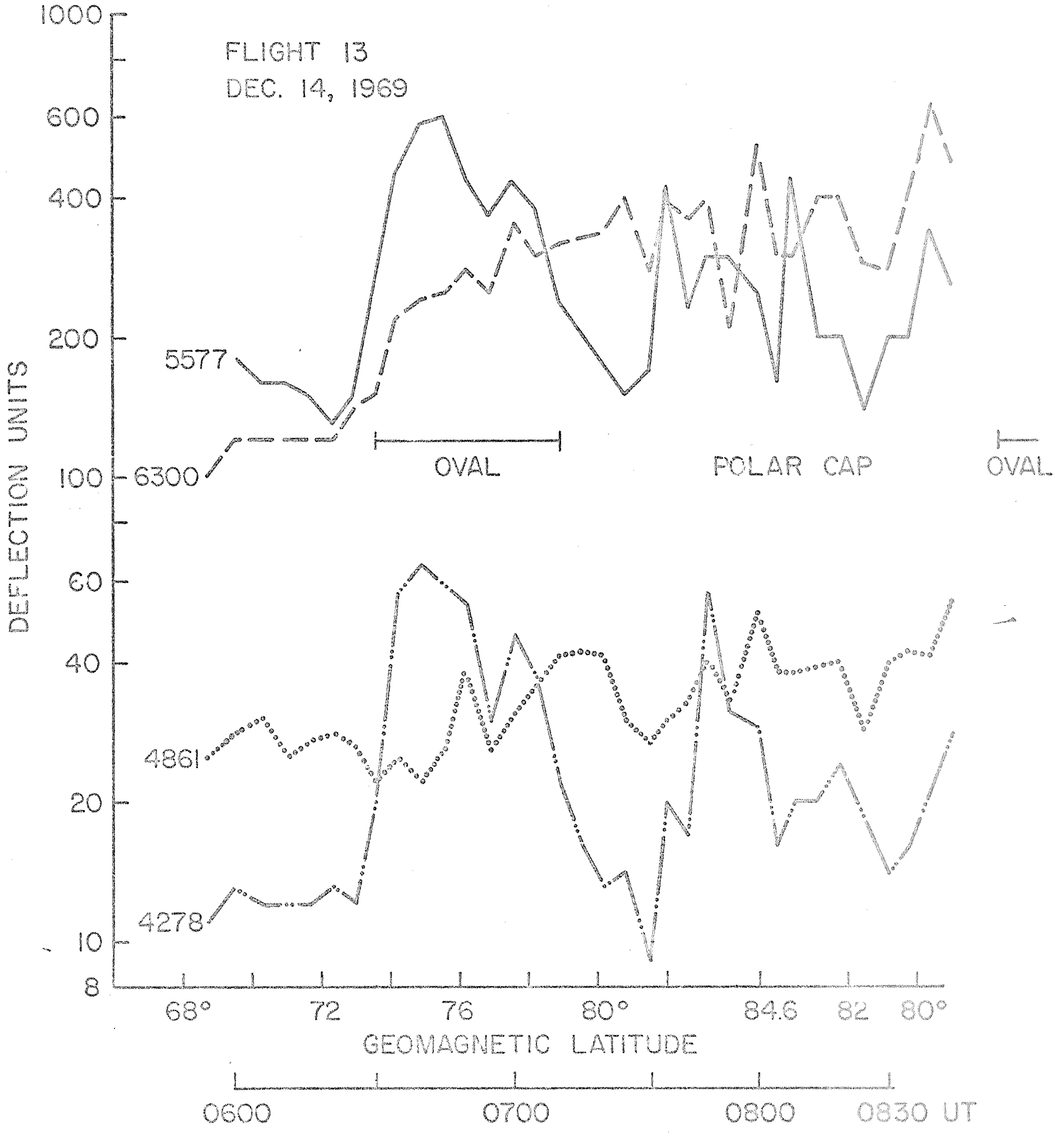
AURORAL STUDIES

The main emphasis in the analysis of the auroral data from the 1969 expedition has been concerned with the two flights which covered the noon sector of the auroral oval. Two interesting features which were observed on these flights were (1) the high λ6300[OI] to λ4278(N_2^+) ratios which indicate the presence of very soft incident particles and (2) the occurrence of discrete stable auroral arcs which are aligned almost in the direction of the sun (Romick and Brown, 1971). These have a similar description to those reported by Gustafsson (1967).

Figs. 4 and 5 show plots of the zenith intensity, obtained from each sky scan, versus latitude (or time) for Flight No. 12 on December 13, 1969 and Flight No. 13 on December 14, 1969. Indicated on each figure is the approximate position of the auroral oval during the flight. The magnetic activity during both of these flights was very low, $K_p \sim 1$ on December 13, 1969 and $K_p \sim 0$-1 on December 14, 1969. The maximum intensity (λ5577) of the aurora at the zenith reached approximately 3 kR with off-zenith intensities going as high as 15 kR. One feature noticeable on both flights is the relatively large signal in λ5577[OI] and λ4278(N_2^+) which decreased as the flight path crossed the auroral oval. In contrast, the λ6300 OI signal increased across the oval into the polar cap. All of the discrete aurora observed occurred poleward or at the poleward edge of the oval on both flights. The high λ6300[OI] to λ4278(N_2^+) ratios observed are characteristic of soft particle precipitation which loses most of its energy at high altitude (>150 km) where not only is λ6300 OI only partially quenched but the O to N_2 ratio is high. Thus these flights appear to indicate a relatively hard ($\geq$ 3 kev) uniform particle flux precipitating equatorward



3. 4 Zenith intensities in arbitrary units for the 4 emissions λ5577, λ6300 [OI], λ4861 Hβ and λ4278 (N_2^+) on Flight 12, Dec. 13 UT 1969.



;. 5 Zenith intensities in arbitrary units for the 4 emissions λ5577, λ6300 [OI], λ4861 (Hβ) and λ4278 (N_2^+) on Flight 13, Dec. 14 UT, 1969.

and into the position of the statistical auroral oval, producing a relatively uniform glow or weak broad arcs. On the poleward side a soft particle flux ($\leq$ 1 kev) appears, which increases as one proceeds at least partially towards the polar cap. In addition, discrete auroral forms which appear to have typical characteristic energies (2 kev) appear within the more uniform soft particle precipitation. This description matches very well the particle data obtained in the same region by Hoffman and Berko (1970) and Heikkila and Winningham (1971). Some of these discrete arcs observed on Flight No. 13, December 14, 1969, are shown in Figures 6, 7 and 8, which are composite photographs of all-sky camera data and photometer data taken of these discrete arcs. Figure 9 is a map of the arc orientation and position of the observations along the flight path. Figure 10 shows the observation geometry for one view (0812;30 UT) of the stable arcs. Figure 11 gives the best fit of the observed intensity versus zenith angle data to the height variation for these arcs. This data indicates that these rayed arcs are produced by incident particle spectra which, based on an exponential spectra, have characteristic energies near 2 kev and are thus very similar to the same type auroral arc observed in the evening or midnight sector of the auroral oval. The only difference is the orientation of these arcs with respect to the L-shell configuration since, as seen in Fig. 9, they lie almost along geomagnetic longitude lines and in the direction of the sun. Winningham (1970) and Winningham and Heikkila (1971) have discussed the penetration of the magnetosheath plasma to low altitudes during the daytime from data from the ISIS-1 satellite. The region at the poleward edge of the oval in Figs. 4 and 5 where the λ6300 emission begins to become enhanced coincides with the latitude limit of closed geomagnetic field lines in the dayside magnetosphere. As stated by Winningham (1970)

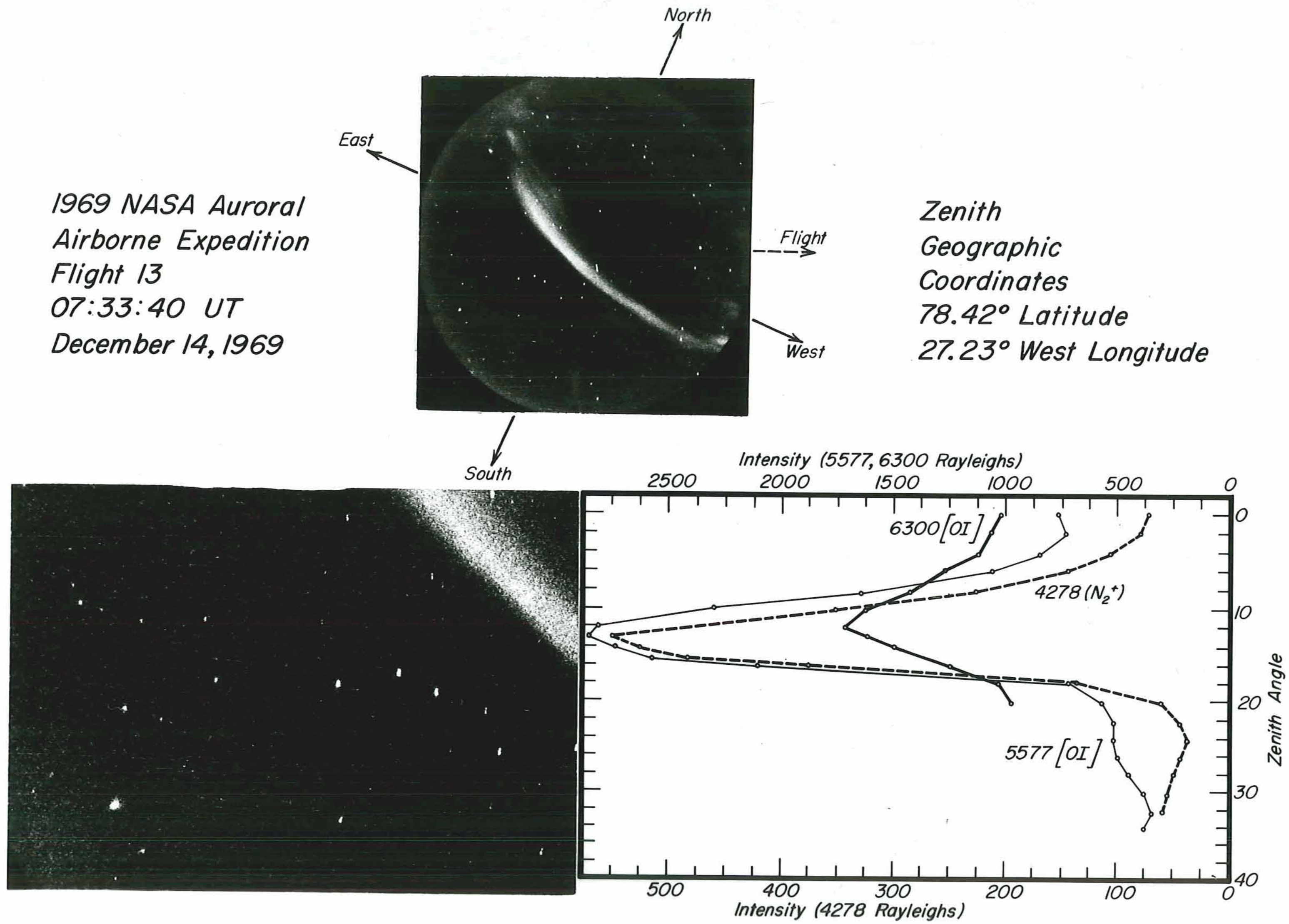


Fig. 6 Composite photograph of the all-sky camera and scanning photometer data for the midday polar cap aurora on Flight 13 at 073340 UT Dec. 14, 1969.

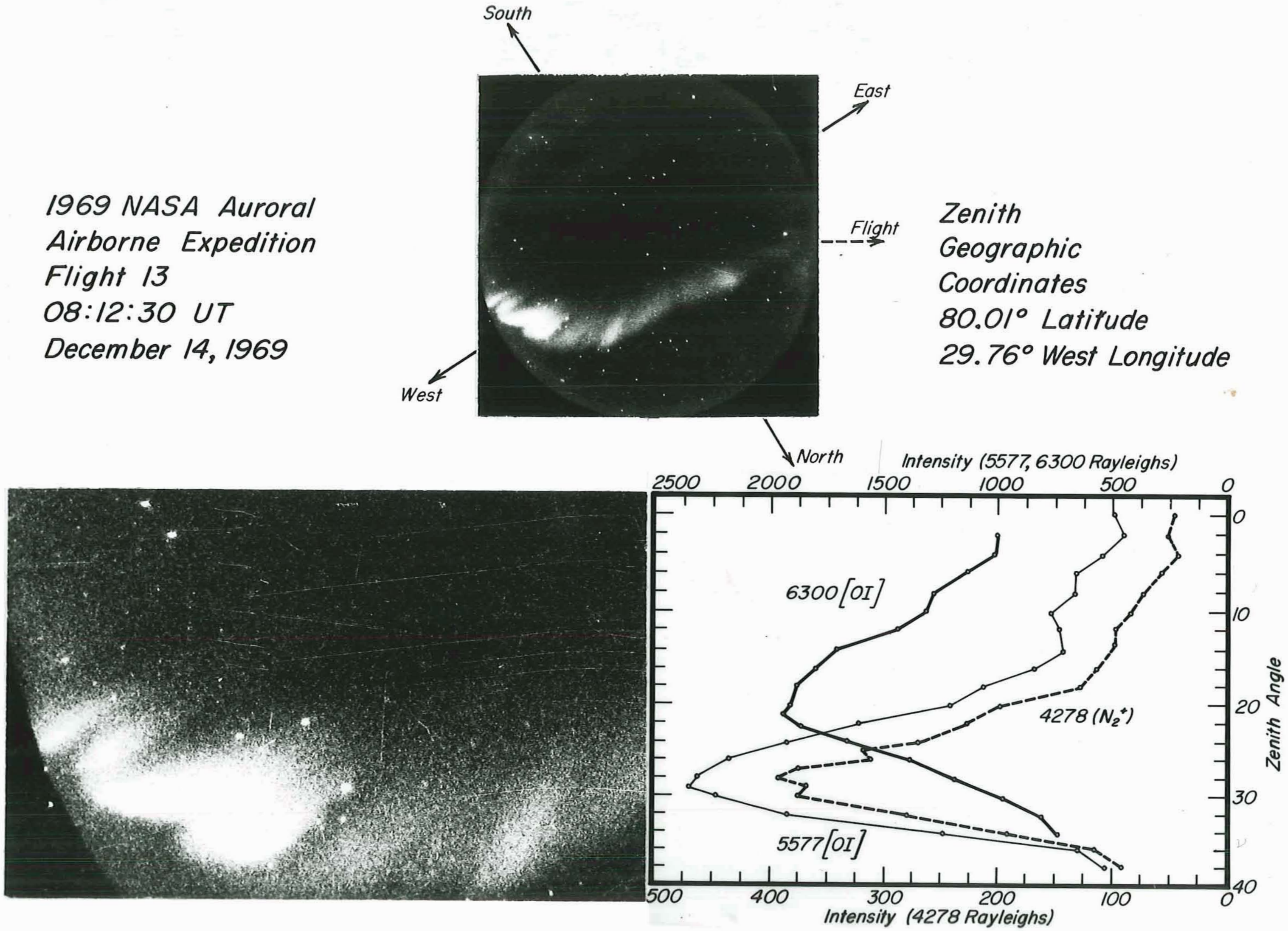


Fig. 7 Composite photograph of the all-sky camera and scanning photometer data for the midday polar cap aurora on Flight 13 at 081230 UT Dec. 14, 1969.

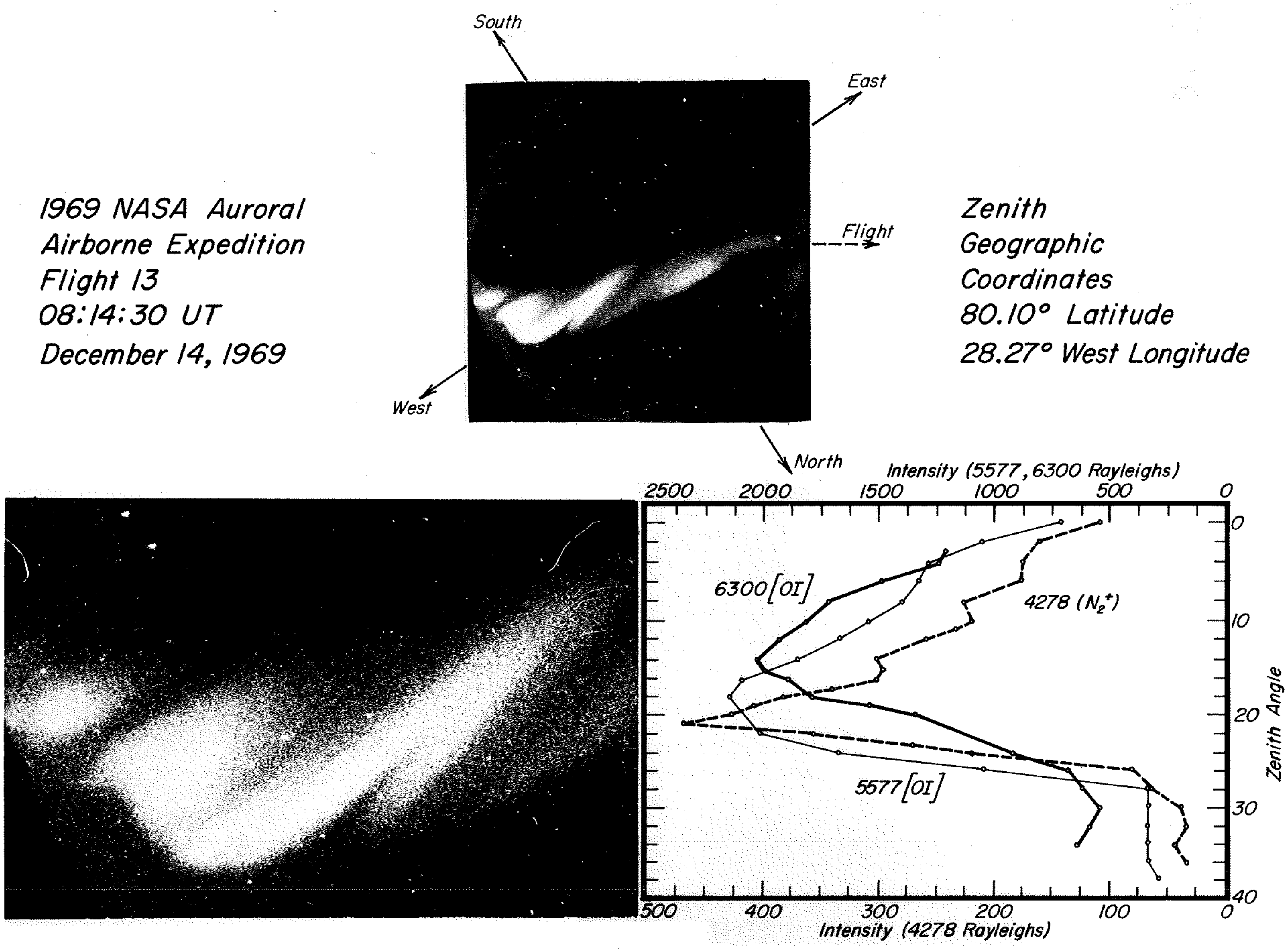
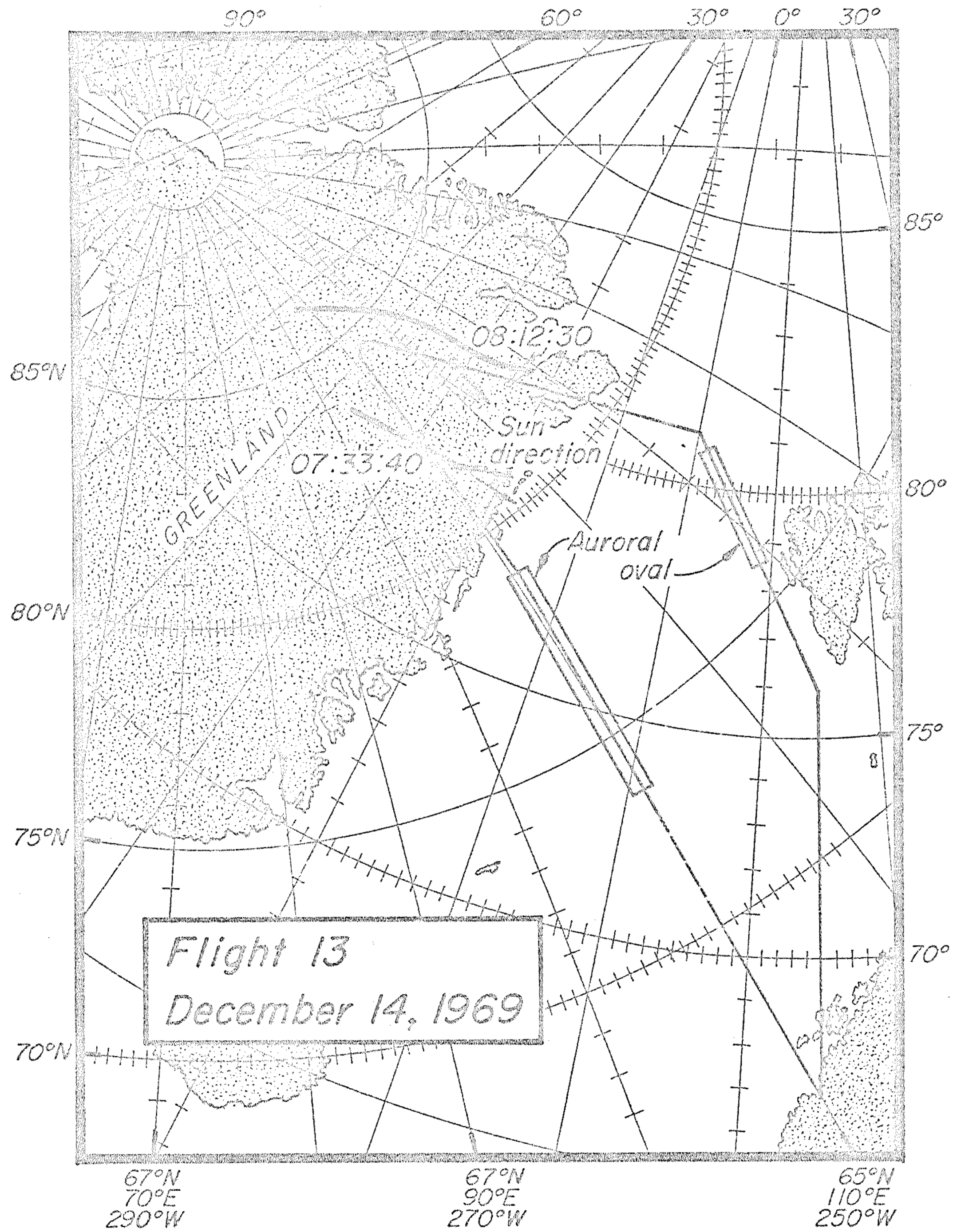


Fig. 8 Composite photograph of the all-sky camera and scanning photometer data for the midday polar cap aurora on Flight 13 at 081430 UT Dec. 14, 1969.



g. 9 Flight path and orientation of polar cap aurora on Flight 13, Dec. 14 UT, 1969.

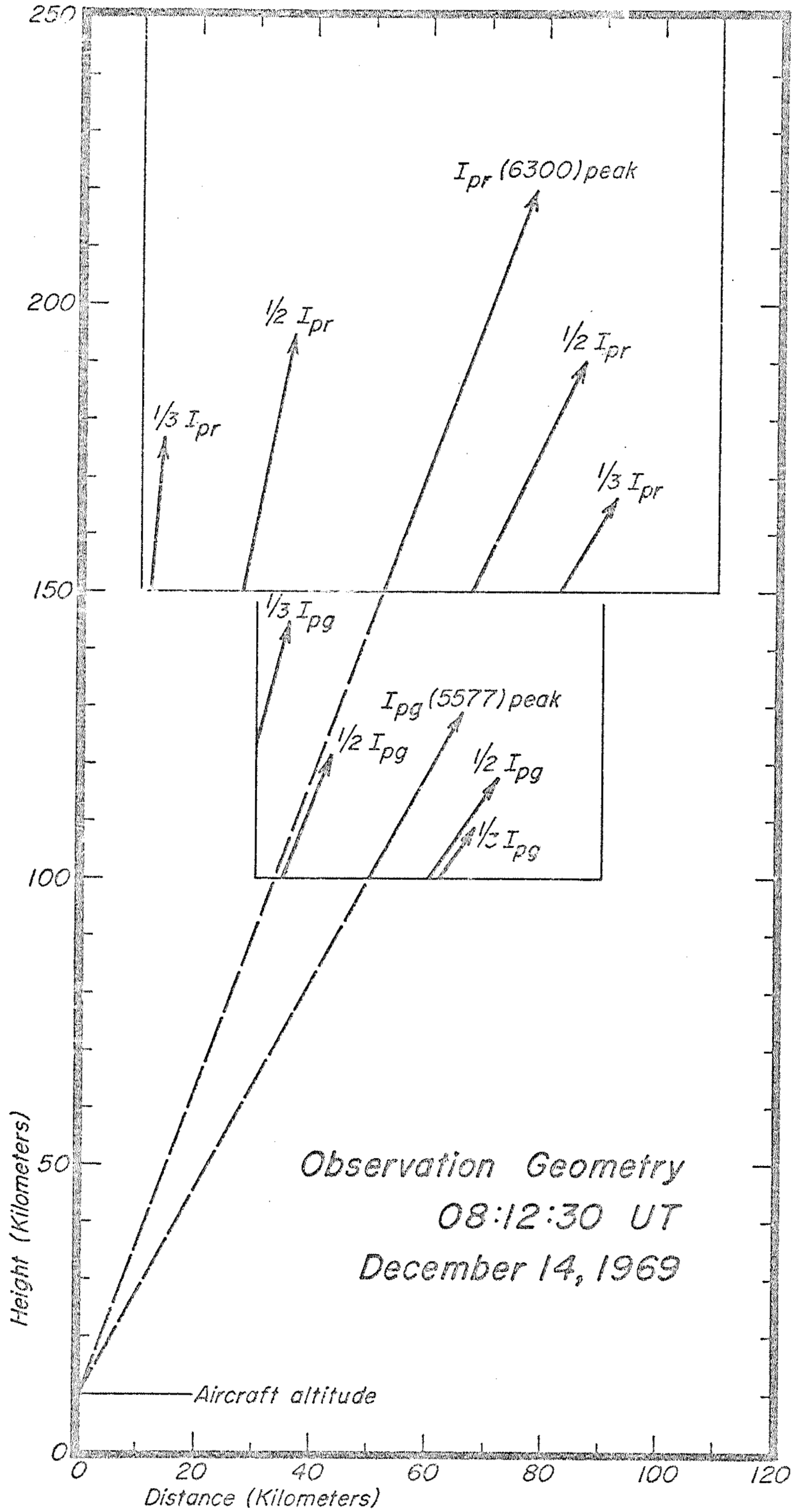


Fig. 10 Observation geometry from the aircraft of the aurora seen in Fig. 7.

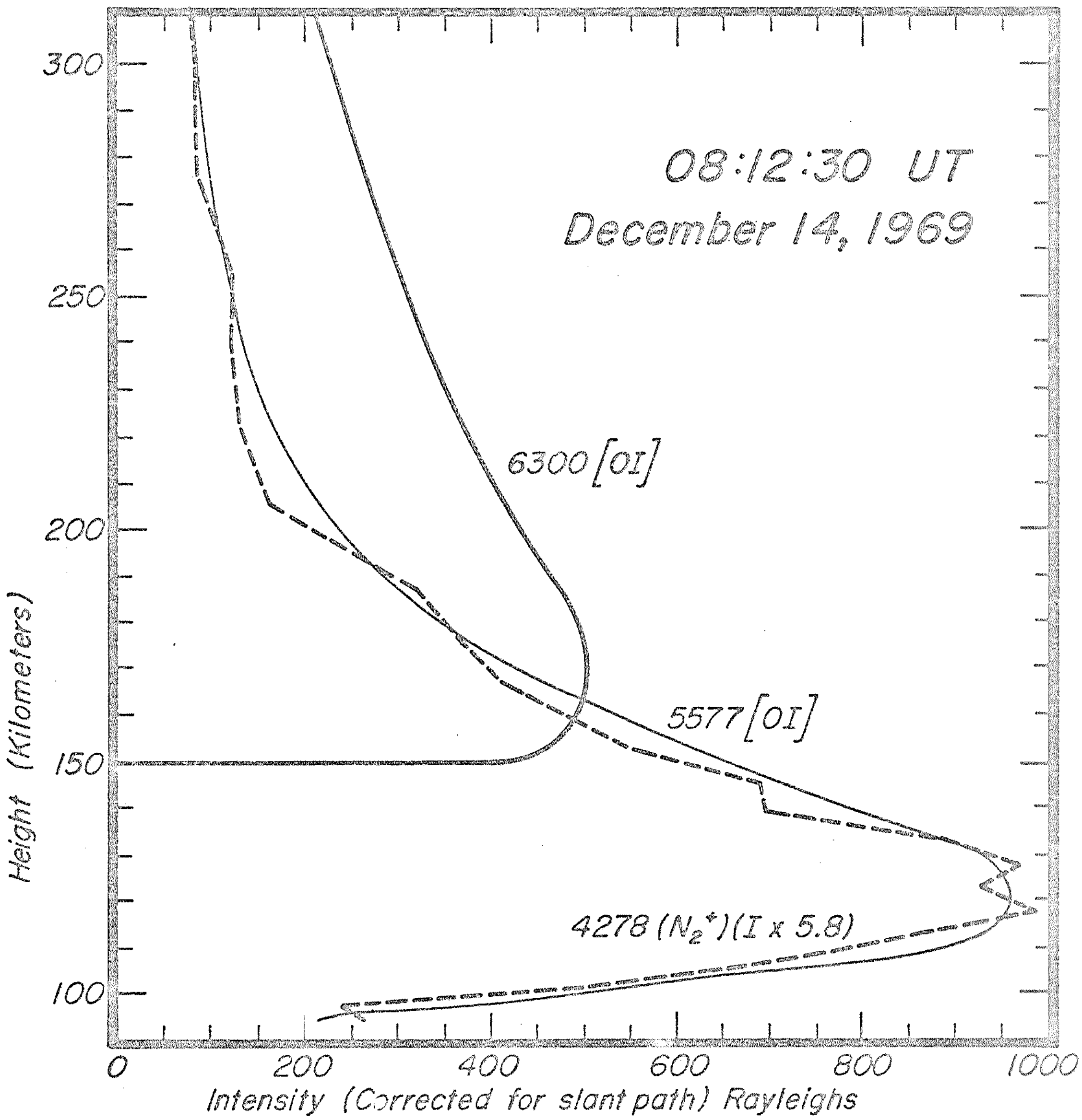


Fig. 11 Intensity vs. altitude profiles for various auroral emissions in the auroral arc shown in Fig. 7.

"this boundary can be identified through a sharp decrease in the flux of electrons of somewhat higher energy ∿ 10 kev". He further goes on to show that, above this latitude, fluxes of low energy (< 1 kev) electrons are observed. His description fits our observations presented in Figs. 4 and 5. Eather and Mende (1971) have also come to this conclusion in their analysis of similar data. Thus the discrete arcs seen in Figs. 6, 7 and 8 must originate from field lines well above the limit of the last closed field lines and come directly from the tail region of the magnetosphere.

In the analysis of conjugate nighttime auroral data, Belon et al. (1969) found that detailed conjugacy depends upon the latitude of the aurora and the level of geomagmetic activity. It is suggested in these analyses that in auroral arcs poleward of major activity there appears to be poor conjugacy possibly as low as dp latitudes near 69°.

If this lower variable latitude is the latitude of the limit of closed field lines on the nightside, then it too may be characterized by a change in the characteristics of particle flux which may be determined by the change in the background λ6300/λ4278 ratio similar to that observed on the dayside. Indeed, the statistical results of Eather (1969) from results of the 1968 NASA Airborne Expedition indicate a rapid change near 72° invariant latitude (approximate latitude 73°) for the λ6300/λ4278 ratio which implies that averaged over the 22 flights the latitude limit of the closed field lines is near 72°. This latitude may shift with activity since Eather's plot was obtained only when all data were combined. Thus it represents an average latitude for the average of the activity which occurred over these flights. Sharp and Johnson (1968), from satellite data, show a displacement of the peaks in the hard and soft zones on the dayside; although the separation was not pronounced on the nightside, they seemed to be able to detect a softening of the electron spectrum towards the pole. It appears that the boundary between these hard and soft zones is the region of the last closed field lines and is the poleward limit of the auroral oval. It migrates in latitude both on the evening and dayside due to the level of magnetic activity, i.e., it moves equatorward as the activity increases. The region of sharp $\lambda 6300/\lambda 4278$ does change in latitude as observed by Eather and Mende (1971) using statistical results of the 1969 NASA Airborne Expedition. Here, the region on the nightside moved poleward from that indicated in the 1968 data. This movement fits with the change in average activity between the two expeditions. In addition, the access of the solar wind particles into the dayside is easier than on the nightside (causing a hardening of the nighttime spectra due to gradient drift), thus explaining the larger observed $\lambda 6300$ OI enhancement on the dayside than on the nightside, the softer flux in the dayside soft region compared to the nighttime soft region and the difficulty in separating the two zones on the nightside. This concept may also at least in part explain the poleward limit of pulsating auroral displays.

In addition, the conjugate studies (Belon et al., 1969) and the results of the NASA flights (Eather, 1969; Eather and Mende, 1971) imply that the auroras in the oval are on closed field lines and are not associated directly with magnetospheric tail plasma. Such a conclusion is contrary to the interpretation of satellite data by Zmuda et al. (1970).

Perhaps, although somewhat premature at this stage in the analysis, the fact that the discrete arcs observed in the dayside have the same appearance and precipitating energy spectra as other similar arcs seen on the nightside implies that they all have the same acceleration mechanism regardless of the origin of the particles, i.e. the acceleration of the particles is carried out close to the earth rather than in the tail region. Thus one expects similar aurora even on the nightside both above and below the limiting closed field lines, but only those below need be close to conjugate in the Southern Hemisphere. Obviously, further work needs to be done to substantiate these ideas, but if they are true, the λ6300/λ4278 ratio as a function of latitude may allow the determination of the position of the boundary between the open and closed field lines at any time and at any degree of activity.

AIRGLOW STUDIES

High Latitude OH and O_2 Intensities

The average intensities of the (6-2), (7-3), (8-4) hydroxyl bands and the O_2 (0-1) atmospheric band during low auroral activity at latitudes 48.6°N, 58.5°N and 71.6°N are summarized in Table III. In order to determine times of low auroral activity, the auroral emissions λ4278 (N_2^+ 1NG) and λ4861 (Hβ) were monitored. The points chosen for the calculation of the average intensities found in Table III were taken from aircraft flights on nights when the general intensity levels of λ4278 and λ4861 were low. In particular, the points were chosen at times when there were no bright discrete auroras at the zenith. The average auroral background as measured by λ4278 and λ4861 for the three latitudes are given in Table IV.

Latitude Variations

When these average values were plotted as a function of geographic latitude, as in Fig. 12, it appeared at first that there was a slight latitude effect. However, the average times for the observations at

Table III

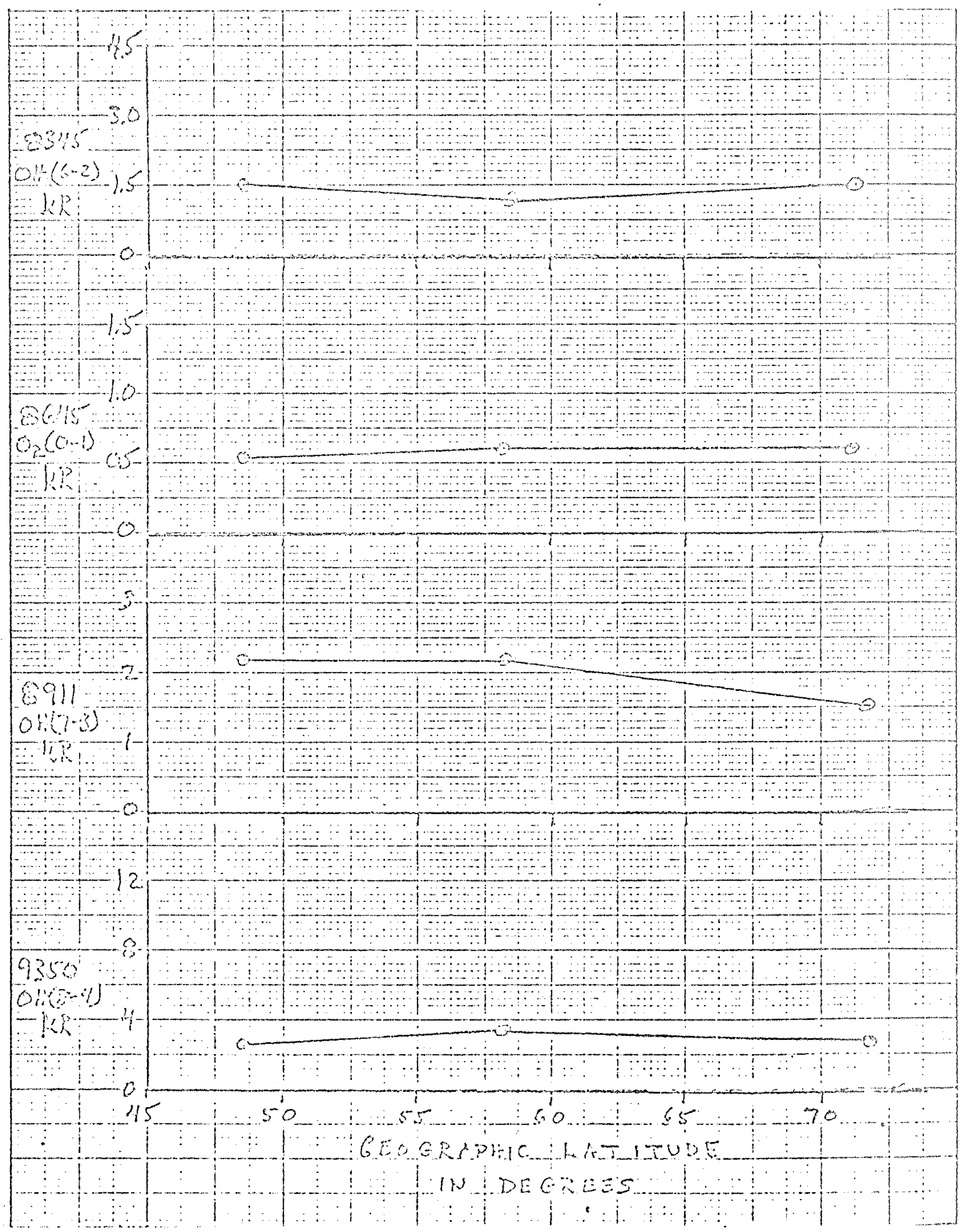
Average OH and O_2 Zenith Intensities and Ranges

Geographic Latitude	Emission	Transition	Wavelength (A)	Average Intensity	Range of Intensities
48.6°N	OH	6-2	8345A	1500 R	1400-1600 R
48.6°N	OH	7-3	8911A	2200 R	2000-2500 R
48.6°N	OH	8-4	9350A	2500 R	2000-2600 R
48.6°N	O_2	0-1	8645A	550 R	500-650 R
58.5°N	OH	6-2	8345A	1200 R	1100-1500 R
58.5°N	OH	7-3	8911A	2200 R	2100-2300 R
58.5°N	OH	8-4	9350A	3000 R	2700-3200 R
58.5°N	O_2	0-1	8645A	600 R	550-700 R
71.6°N	OH	6-2	8345A	1500 R	1400-1600 R
71.6°N	OH	7-3	8911A	1500 R	1400-2000 R
71.6°N	OH	8-4	9350A	2500 R	2300-3000 R
71.6°N	O_2	0-1	8645A	600 R	550-650 R

Table IV

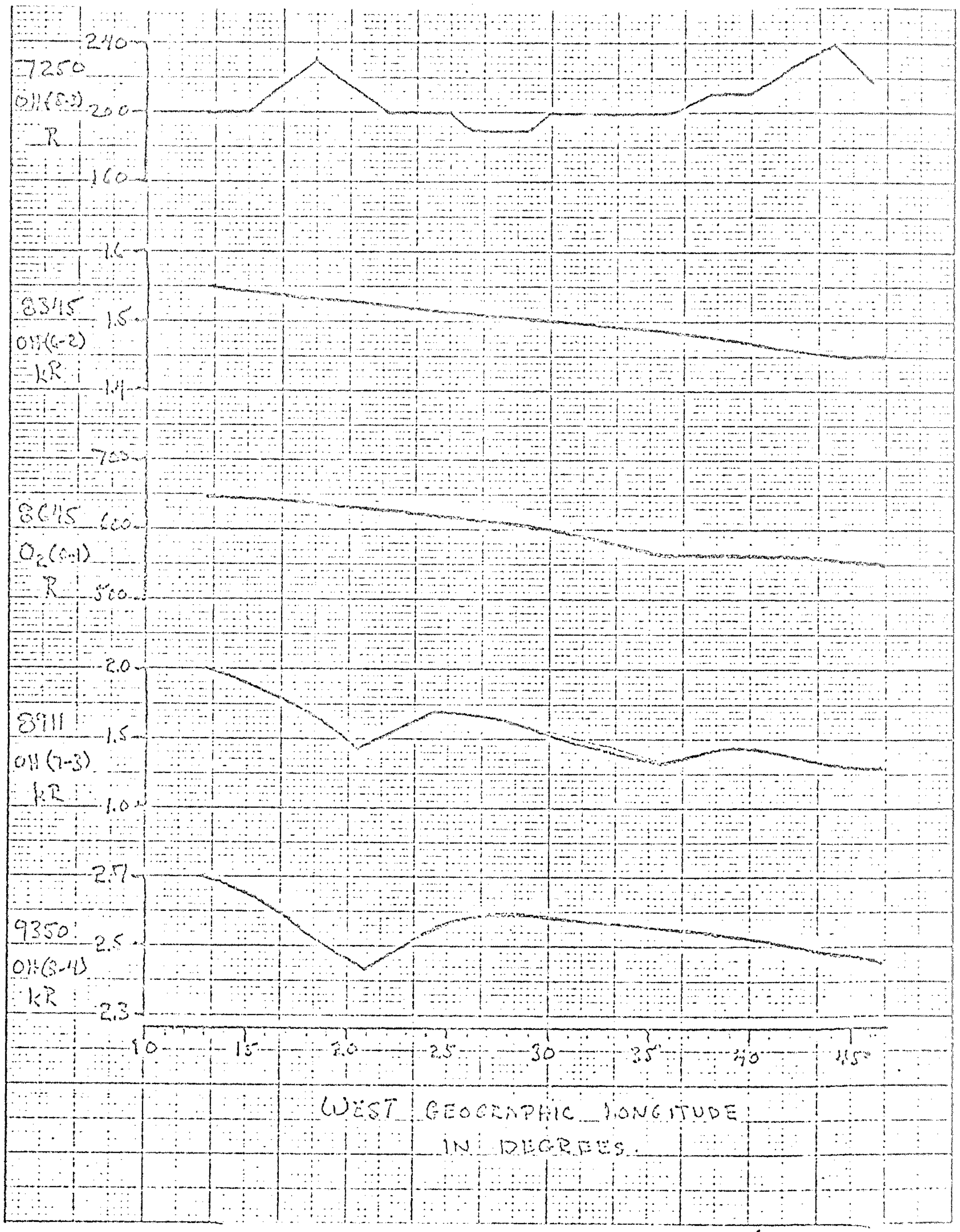
Average Auroral Background Intensities and Ranges

Geographic Latitude	Emission	Wavelength (A)	Average Intensity	Range of Intensity
48.6°N	N_2^+ 1NG	4278	20 R	10-30 R
48.6°N	Hβ	4861	0 R	0 R
58.5°N	N_2^+ 1NG	4278	30 R	20-40 R
58.5°N	Hβ	4861	10 R	10-60 R
71.6°N	N_2^+ 1NG	4278	30 R	20-60 R
71.6°N	Hβ	4861	10 R	10-50 R

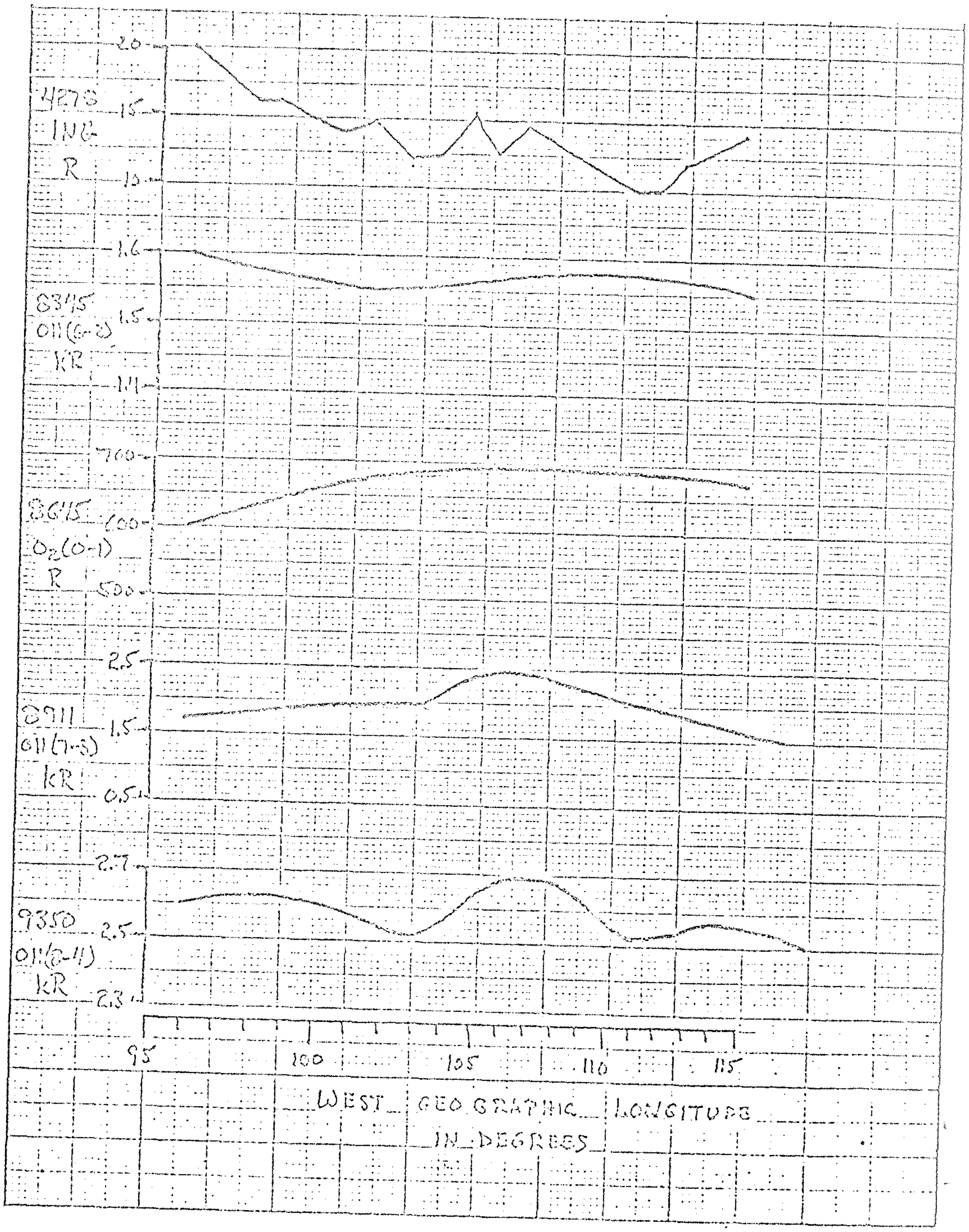


ȝ. 12 Intensity variation with geographic latitude of various airglow infrared emissions.

the latitudes were 0500 LT, 0041 LT and 1845 LT for 48.6°N, 58.5°N and 71.6°N respectively. The diurnal investigations of Bertheir (1955) at low latitudes and the current investigation at high latitudes described in this report suggest that the same type of temporal behavior occurs in both regions. Since the average latitudinal intensity values covered a rather large diurnal period, the average diurnal variations were compared with the deviations found in Fig. 12. The changes shown in Fig. 12 easily fit into the intensity ranges found for the diurnal variation. Therefore the existence of a significant latitude effect is doubted for the range of latitude from 48.6°N to 71.6°N during December. Most of the systematic investigations of the effects of latitude on OH have taken place in the range from 40°N to 50°N (Huruhata, 1963; Kodama, 1963), thus the above conclusion stands almost alone. Shefov (1969) presents a graph indicating little or no latitude variation in the range from 40°N to 65°N in November and a slight increase in intensity with latitude in December. In order to make his graph, Shefov has to assume that the OH emissions in the Northern and Southern Hemispheres are similar in behavior. He makes this assumption in the face of the growing importance of horizontal transport processes and the work of Webb (1967) indicating that the upper atmospheric circulation systems for the Northern and Southern Hemispheres are different. At middle latitude Barbier (1957) found a slight increase in OH intensity with increasing latitude while Noxon (1964) observed a decrease. Shefov (1969) finally concluded that, since latitudinal variations seem to change from month to month, all of the types of variations mentioned above might be observed.



g. 13 Intensity variation with geographic longitude of various airglow infrared emissions.



g. 14 Intensity variation with geographic longitude of various auroral emissions and airglow infrared emissions.

Longitude Variations

Since almost no data are available on longitudinal variations, Figs. 13 and 14 are unique. Figure 13 shows a portion of Flight No. 11 from Ft. Churchill, Canada to Bodø, Norway. The graphed portion of the flight is entirely within the polar cap region within a latitudinal range of 0.58°. Despite the 33° change in longitude, the average OH and O_2 levels remained unchanged. The auroral background throughout this time remained fairly uniform, as indicated on the graph. Figure 14 is compiled from a constant local time section of Flight No. 15. The fluctuations in the intensity are due to the increased auroral intensity at the zenith. This part of the flight took place inside the auroral oval. Again, no particular pattern was established over the 18° change in longitude.

Diurnal Variations

The diurnal variations that were observed fell into four types. They were: (1) a minimum at or before local midnight, (2) a maximum during the night, (3) constant from local midnight to about 0400 LT, followed by a sharp decrease and (4) constant through the night. Types (1) and (2) were observed most often with each being seen as often as the other. Type (3) was observed once as was type (4). Although he claimed no seasonal dependency, Elvey (1943) presented examples of type (1) (minimum at or before midnight) that all occurred in winter and examples of a decreasing intensity throughout the night that all occurred in the spring or summer. Type (2) (maximum at night) was seen most frequently by Rodionov and Pavlova (1949) and Radionov (1950). Armstrong (1956), unlike Elvey, observed type (2) in winter. He also observed type (4) (constant throughout the night). The results of 103 observations made throughout the year by Bertheir (1955) also showed type (1) (minimum near midnight) as the predominant type. Bertheir also observed a sharp decrease around 0400 LT on long nights (winter). Bertheir, observing at a latitude of 44°N, observed some of the same types of diurnal changes as one reported in this paper for high latitudes. Therefore, since there seems to be no general latitude effect on the intensity of either OH or O_2 in December, the data indicate that OH and O_2 both at high and at low latitudes during this month are very similar both in form and intensity.

OH Enhancements

The question of auroral enhancements of OH has been discussed for some time (Brown and Belon, 1969; Isaksen et al., 1968). Any increase in the concentrations of atomic hydrogen or ozone helps produce more excited molecules of OH through the reaction

$$H + O_3 \rightarrow OH^* + O_2 \qquad (1)$$

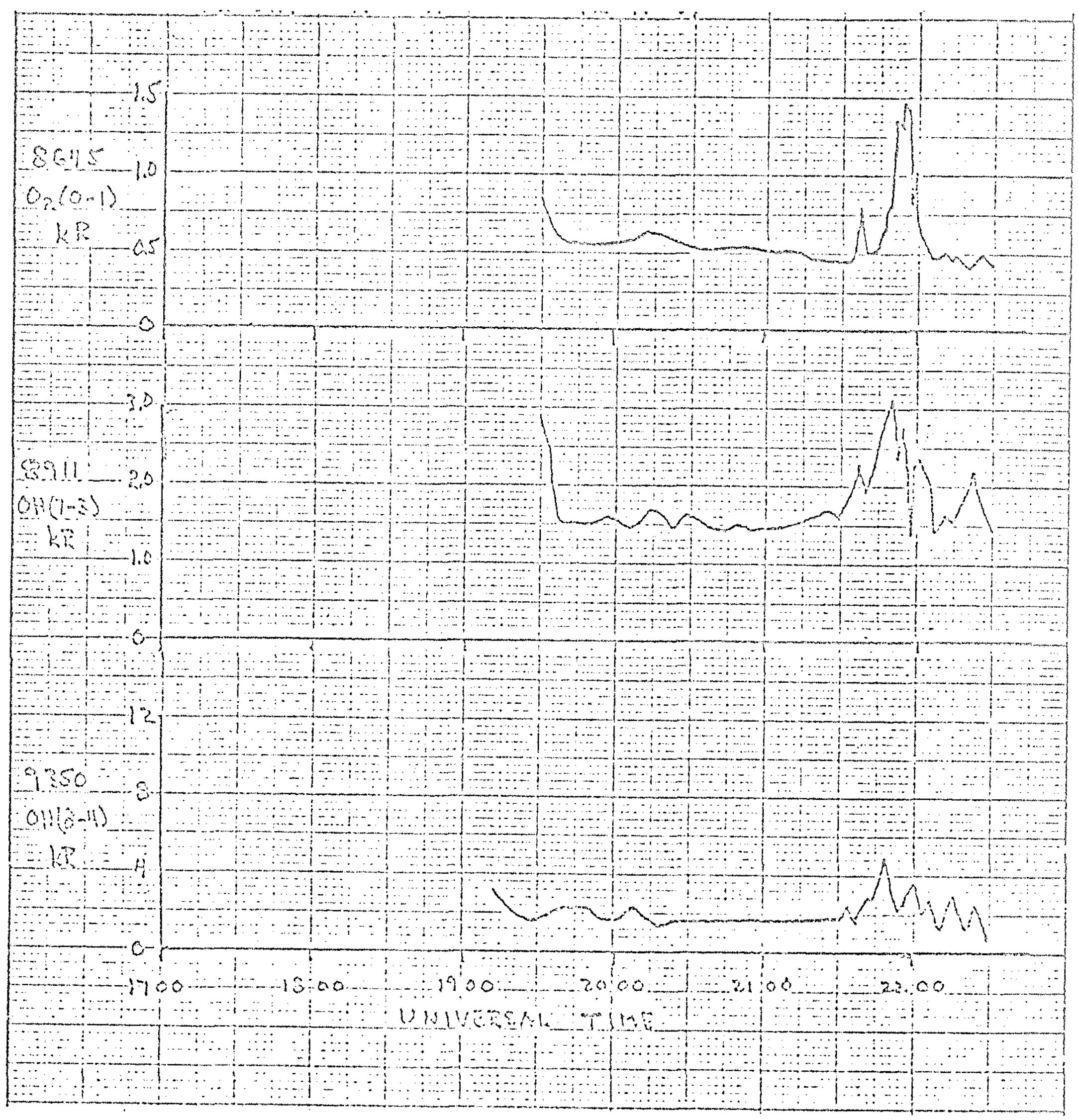
One of the first suggestions, that the concentration of ozone might be increased by intense auroras, was made by Murcray (1957). Although his attention was focused solely on the emission intensity enhancements of the 9.6μ band of ozone, the bulk of which arises from around 30 to 35 km level, the implications for higher altitudes is apparent. Recently Gattinger (1969) suggested that not only ozone is enhanced but also atomic hydrogen, which causes a further increase in OH intensity. Atomic hydrogen is stored as OH and HO_2 at night. The importance of atomic oxygen is illustrated by the two fast reactions (Gattinger, 1969)

$$OH + O \rightarrow H + O_2 \qquad (2)$$

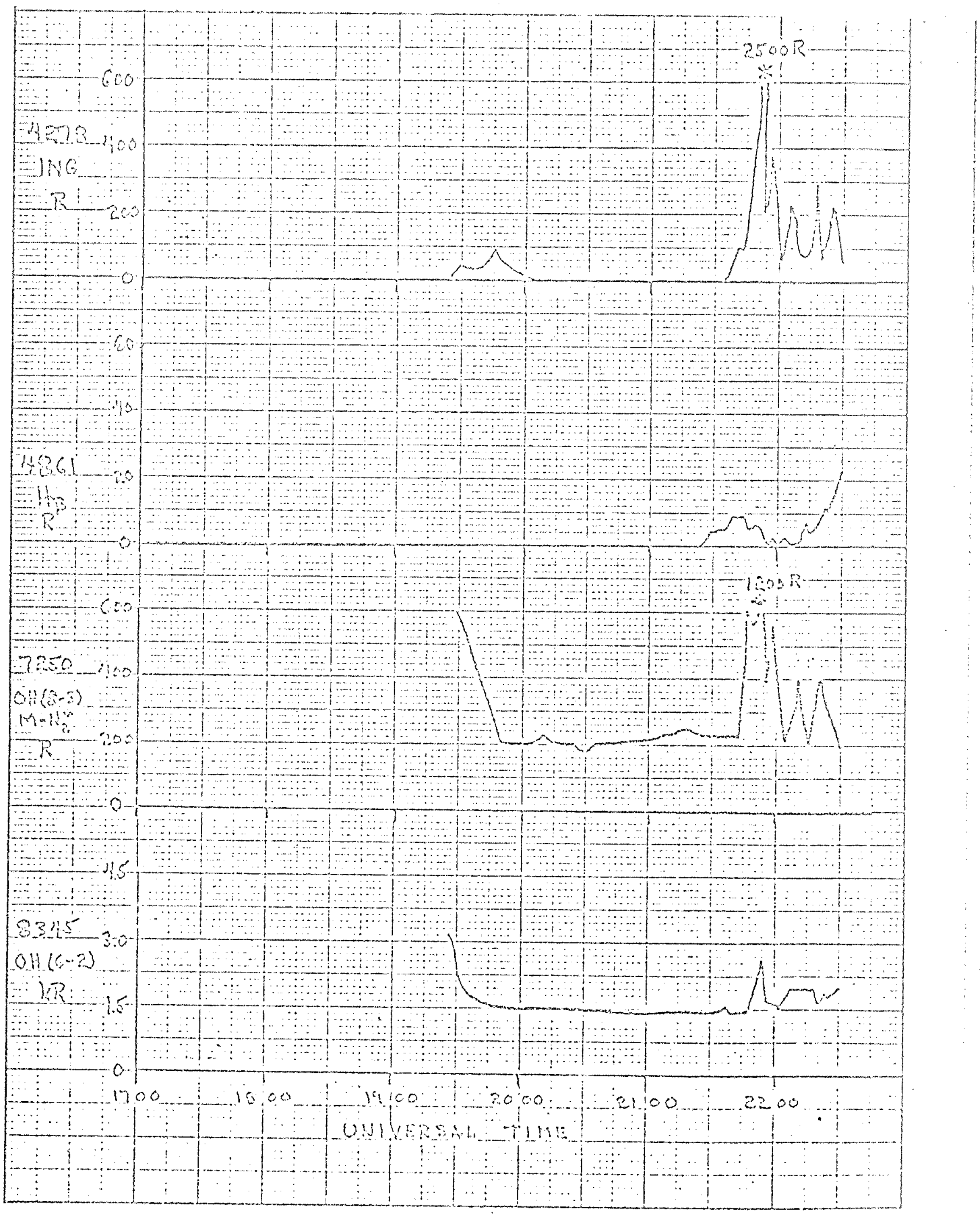
and

$$HO_2 + O \rightarrow OH + O_2 \qquad (3)$$

which may liberate atomic hydrogen if the concentration of atomic oxygen is enhanced by an intense aurora.



15 Temporal variation of some airglow infrared emissions on Flight 11, Dec. 11 UT, 1969.



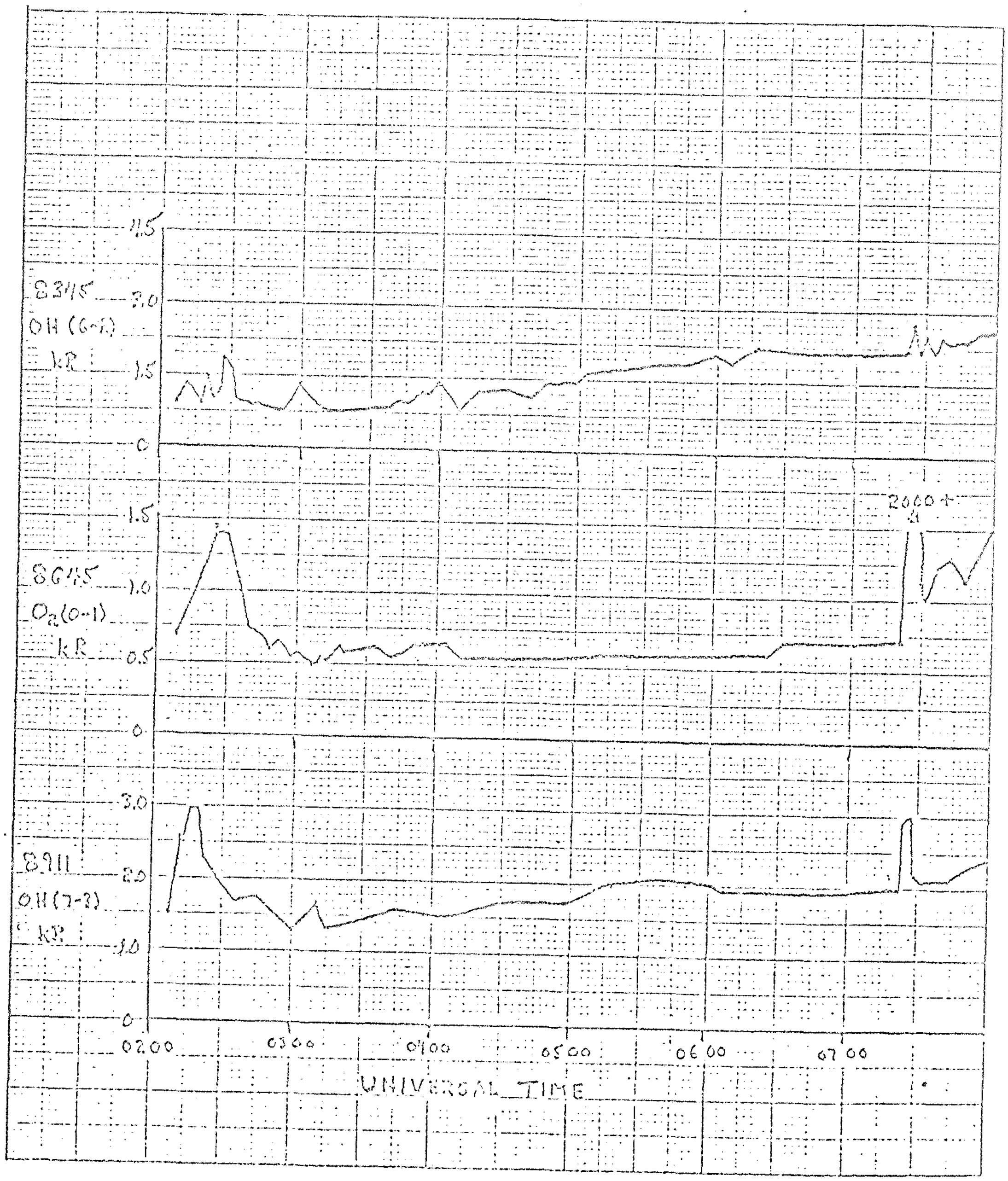
16 Temporal variation of some auroral emissions and airglow infrared emissions on Flight 11, Dec. 11 UT, 1969.

Since ozone is dissociated by sunlight with O_2 ($^1\Delta g$) molecules being produced, the auroral enhancement of atomic oxygen might be verified by observing the intensity of the infrared atmospheric oxygen system, as has been suggested by Gattinger (1969). Any increase in ozone due to added atomic oxygen should be reflected by an increased intensity of the infrared atmospheric oxygen system at dawn.

Auroral Enhancements of OH

Two different types of enhancements were observed in the course of the current investigation. The first type occurs at or near the time of an intense aurora and is characterized by a quick rise and fall of intensity with the corresponding auroral changes. The second is a general increase in OH intensity over a three- or four-hour interval. During this interval there were no intense auroras at the zenith, and the general intensity level of the auroral background remained unchanged.

An example of the first type of enhancement is the λ9350 (8-4) band of OH shown for Flight No. 11 in Fig. 15 (flight from Ft. Churchill, Canada to Bodø, Norway). Figure 16 shows the auroral activity at the same time. The enhancements occur at 2148, 2200, 2206, 2217 and 2224 UT. These enhancements ranged from a factor of 2.0 to a factor of 3.0. This type of enhancement is definitely aurorally associated and might be explained by the increase in atomic oxygen as indicated by Gattinger (1969). The auroral intensity as measured by λ4278 (N_2^+ 1NG) was 2500 R. The λ9350 emission was chosen since the filter pass band allowed only a negligible amount of aurorally excited emissions to pass through the filter. Therefore, all of the changes in intensity were due to an enhanced OH signal. (Recent (spring 1971) high wavelength resolution (5A) spectral measurements indicate the presence of an as yet unidentified auroral emission feature within the



17 Temporal variation of some airglow infrared emissions on Flight 14, Dec. 16 UT, 1969.

passband of the 9350A filter. Thus auroral enhancements of OH based on observations of the emissions near 9350A may be subject to reinterpretation.)

Anomalous Enhancement

The second type of enhancement occurred on Flight No. 14 from Bodø to Ft. Churchill (Fig. 17). The increase can be seen for the OH emissions λ8911 (7-3) and λ8345 (6-2) beginning near 0400 UT. The overall increase in λ8345 emission was by a factor of 2.7. Again, during this period of increase the auroral background was almost constant and had an average intensity of 20 R as measured by λ4278. The explanation for this type of enhancement is either in an as yet unknown excitation process that can be enhanced by weak auroral precipitation or by high altitude meteorological effects. High altitude neutral winds and circulation systems, as described by Hook (1970) and Webb (1967), might be very important in transporting atomic oxygen, molecular oxygen, ozone, or any other constituent horizontally and vertically. Under the proper transport processes, the concentrations of O, O_2 and O_3 could be changed in such a way as to produce an increased OH intensity.

Further Studies

Further investigations should begin with a concerted effort to confirm the results presented here on OH intensity variations with latitude, longitude, and local time. These studies should take place at high latitudes where seasonal effects are more pronounced, making the annual variations easier to delineate. Once the OH intensity variations have been clearly established, then the causes of the changes might be found by studying the variations in the concentration of atomic oxygen due to local, diurnal, seasonal or meteorological effects. A solution to the enhanced seasonal effects might be found in the latitudinal transport of atomic oxygen proposed by Kellogg (1961), Young and Epstein (1962).

The temporal and spatial variations of atomic oxygen due to auroral or meteorological effects should also be investigated with reference to enhancements of the OH intensity. As was pointed out by Gattinger (1969), the importance of atomic oxygen can not be over-emphasized.

DISCUSSION AND CONCLUSION

The data obtained on board both the 1968 and 1969 NASA auroral expeditions have provided much information on the details of airglow and auroral spectral morphology in different parts of the auroral oval and polar cap at various local times. These data, although only partially analyzed, have shown that

a) some discrete arcs may have a constant $\lambda 4278(N_2^+)/\lambda 5577[OI]$ ratio across their horizontal width;

b) most of the $\lambda 5001$-$\lambda 5006$ N II appears to come from direct dissociative ionization and excitation of N_2;

c) the midday sector of the auroral oval and polar cap shows zones of electron precipitation (as deduced from the $\lambda 6300/\lambda 4278$ ratios with latitude)

   1) >3 kev in the oval associated with $\lambda 6300/\lambda 4278$ ratios $\lesssim 1$

   2) <1 kev in the magnetosphere cusp region associated with $\lambda 6300/\lambda 4278$ ratios > 10, and

   3) discrete earth-sun aligned auroras over a < 1 kev background in the polar cap;

d) the demarcation between the oval and polar cap is the boundary between the open and closed field lines;

e) the instantaneous background $\lambda 6300[OI]/\lambda 4278(N_2^+)$ ratio may allow the determination of the boundary between open and closed field lines on the night side at any given time or degree of magnetic activity;

f) some of the discrete arcs in the polar cap are very stable in time and align more closely with the sun and along geomagnetic longitudes rather than along L-shells;

g) there are discrete arcs in regions of precipitation associated with the field lines open to the magnetospheric tail particles and consequently auroral acceleration mechanisms may be more closely associated with the earth than the tail region, and

h) the OH airglow seems to be constant with latitude and with longitude between 48.5° and 71° but does become enhanced at times not necessarily associated with particle precipitation.

These results certainly justify the overall concept of these airborne expeditions and point towards areas where further analyses of the existing data should be pursued as well as indicating the need for further observations of certain emissions at different degrees of magnetic activity and at different local times.

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