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INFRARED AND IONIZATION STRUCTURE
OF THE POLAR MESOSPHERE

James C. Ulwick
Kay D. Baker
Allan J. Steed

AFOSR-TR. 88-1182

Center for Space Engineering
Utah State University
Logan, UT 84322-4140

August 1988

FINAL REPORT
Grant AFOSR-85-0163
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CENTER FOR SPACE ENGINEERING

UTAH STATE UNIVERSITY UMC 4140 LOGAN, UTAH 84322



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different characteristics in the peak scattering region. Spectra of the spatial density fluctuations have been derived from the campaign results. In the region of most intense backscatter, the power is up over the whole frequency range by almost 5 orders of magnitude. A comparison between the measured radar echo power and the calculated echo power based on the in situ rocket measurements gives very good correspondence. Several results from the spectra which are in agreement with present theories for mesospheric dynamics and its interaction with the electron gas are as follows:

1. The electron fluctuation spectrum displayed both a Kolmogorov inertial subrange and a viscous subrange characterized by an inner scale for turbulence.
2. A neutral density fluctuation strength of 1% integrated was estimated over the range from 1 m to 700 m, a result in agreement with other mesospheric observations.
3. The inner scale size for the electron gas varies with the energy dissipation rate in a manner predicted by classical turbulence theory.
4. The 50 MHz scattering signal is in qualitative agreement with the in situ measurements.

Some of the more controversial results we have found are:

1. The microscale for turbulence in the electron gas is much smaller than expected.
2. The electrons seem to behave as a passive scalar but one with a large Schmidt number. This in turn may be due to an anomalously high ion mass.
3. The fact that strong high latitude mesospheric scatter occurs at all for a 50 MHz radar is due to the unusual character of the electron spectrum.
4. For weak electron density gradients the electron spectrum has a Kolmogorov form, but for the case of strong gradients, the spectrum is steepened. *(See fig 1)*

In addition to these results we have found evidence for an outer vertical scale near 700 m in the large scale organization of electrons by the neutral dynamics just above the mesopause. Imbedded in these large scale electron density oscillations we found peaks in the short wavelength fluctuations ($\lambda \approx 3$ m) which occur when the electron density was at a local minimum. Analysis of the interaction with the neutral gas shows that the turbulence is strongest when the neutral gas was moving upward, with weaker short scale irregularities found when the perturbation velocity was downwards.

AFOSR Program Manager: James G. Stobie, Lt Col, USAF

AFOSR-TR- 88-1182
COMPLETED PROJECT SUMMARY

TITLE: Infrared and Ionization Structure of the Polar Mesosphere

PRINCIPAL INVESTIGATOR: Prof. James C. Ulwick
Department of Electrical Engineering
Utah State University
Logan, UT 84322

INCLUSIVE DATES: 19 March 1985 - 15 May 1988

GRANT NUMBER: AFOSR-85-0163

COST AND FY SOURCE: \$109,534, FY85; \$100,231, FY86; \$94,218, FY87

SENIOR RESEARCH PERSONNEL: Dr. Kay D. Baker
Dr. Michael Kelley

JUNIOR RESEARCH PERSONNEL: Mr. Glenn Berg

PUBLICATIONS:

"Mesospheric Minor Species Determinations from Rocket and Ground-Based IR Measurements," J.C. Ulwick, K.D. Baker, D.J. Baker, A.J. Steed, W.R. Pendleton Jr., K. Grossmann, and H.G. Bruckelmann, J Atmos Terr Phys, 49, 855 (1987).

"Measurements of Odd Oxygen in the Polar Region on 10 February 1984 During MAP/WINE," P.H.G. Dickinson, G. Witt, A. Zuber, D. Murtagh, K.U. Grossmann, H.G. Bruckelmann, P. Schwabbauer, K.D. Baker, J.C. Ulwick, and R.J. Thomas, J Atmos Terr Phys, 49, 843 (1987).

"Comparison of Simultaneous MST Radar and Electron Density Probe Measurements During STATE," J.C. Ulwick, K.D. Baker, M.C. Kelley, B.B. Balsley, and W.L. Ecklund, J Geophys Res, 93, 6989 (1988).

"Large and Small Scale Organization of Electrons in the High Latitude Mesosphere: Implications of the STATE Data," M.C. Kelley and J.C. Ulwick, J Geophys Res, 93 (1988).

"Comparison of Simultaneous MST Radar and Electron Density Probe Measurements in the Polar Mesosphere," J.C. Ulwick, SPIE, 874, 260 (1988).

ABSTRACT OF OBJECTIVES AND ACCOMPLISHMENTS:

The primary objective of this project was the investigation of the spatial and temporal structuring and photochemistry of the infrared airglow and the dynamic processes that modify the physical and radiative properties of the polar mesosphere. The approach was to conduct ground-based mesospheric/stratospheric/tropospheric (MST) radar measurements and rocket-borne probes together with other investigations in campaigns to obtain a coordinated data base.

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Rockets containing dc probes were launched at Poker Flat, Alaska in two different campaigns to measure electron density irregularities with high spatial resolution. They were launched at times when the MST radar showed regions of intense backscatter in the mesosphere. Large changes and strong gradients in the electron density were observed in the region of most intense backscatter. The electron density profiles in general show different characteristics in the peak scattering region. Spectra of the spatial density fluctuations have been derived from the campaign results. In the region of most intense backscatter, the power is up over the whole frequency range by almost 5 orders of magnitude. A comparison between the measured radar echo power and the calculated echo power based on the in situ rocket measurements gives very good correspondence. Several results from the spectra which are in agreement with present theories for mesospheric dynamics and its interaction with the electron gas are as follows:

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SUMMARY

The primary objective of this research is the investigation of the spatial and temporal structuring and photochemistry of the infrared airglow and the dynamic processes that modify the physical and radiative properties of the polar mesosphere. The approach is data analysis, interpretation and publication of past as well as present investigations and participation in ground and rocket campaigns to achieve the objectives above. With respect to the data analysis, during this reporting period five papers have been published. Two of these on the photochemistry of the infrared airglow and three on structure and properties of the cold summer polar mesopause. During the reporting period, participation in five successful measurement campaigns significantly broadened the data base for present and future research. Two campaigns involving radar and rocket probes, MISTI 1 (Mesospheric Ionization Structure and Turbulence Investigation - Alaska, July 86) and MAC SINE (Middle Atmospheric Cooperation/Summer in Northern Europe - Norway, July 87) were conducted to study dynamical processes, winds, waves and turbulence in the high latitude structured summer middle atmosphere. Infrared ground measurements coupled with radar measurements were made in the MISTI 2 campaign (Alaska, August 86) to study noctilucent clouds - hydroxyl relationships. In MAC EPSILON (Norway, October 87), the campaign planned as a case study of turbulence of the non-summer middle atmosphere involving many rocket salvoes and ground-based techniques, infrared ground measurements were made of the hydroxyl radiation intensities and rotational temperatures. Most recently ground-based infrared measurements were made in support of the Air Force Geophysics Laboratory MAPSTAR (Middle Atmospheric Periodic Structured

Atmospheric Radiance - Colorado, June 88) program. These campaigns have produced an extensive data base that promises to significantly advance the understanding of the ionization and infrared structuring of the polar mesosphere.

1.0 RESEARCH OBJECTIVES

The primary objective of this research is the investigation of the spatial and temporal structuring and photochemistry of the infrared airglow and the dynamic processes that modify the physical and radiative properties of the polar mesosphere.

Utah State University proposed:

1. To complete the analysis and interpretation of the data from the very successful USU participation (AFOSR sponsored) in the STATE (June 83) and MAP/WINE (Feb 84) campaigns.
2. To conduct a small rocket campaign in conjunction with mesospheric/stratospheric/tropospheric (MST) radar observations to investigate spatial and temporal polar summer turbulence.
3. To use USU state-of-the-art infrared instrumentation for observations under different atmospheric conditions, different diurnal conditions and different seasons.

The approach for the field measurement programs (2 and 3 above) was to participate in campaigns with other investigators to develop a more thorough understanding of mesospheric structuring and airglow.

2.0 STATUS OF RESEARCH

With respect to the analysis and interpretation of the data from the STATE and MAP/WINE campaigns, these have been completed. The Annual Technical Report for this Grant for the period 15 March 1986 - 15 March 1987 gives details about the papers resulting from this work. The following are a list of the publications:

STATE

1. "Comparison of Simultaneous MST Radar and Electron Density Probe Measurements During STATE," J.C. Ulwick, K.D. Baker, M.C. Kelley, B.B. Balsley, and W.L. Ecklund, J Geophys Res, 93, 6989 (1988).
2. "Large and Small Scale Organization of Electrons in the High Latitude Mesosphere: Implications of the STATE Data," M.C. Kelley and J.C. Ulwick, "J Geophys Res, 93 (1988).

MAP/WINE

3. "Mesospheric Minor Species Determinations from Rocket and Ground-Based IR Measurements," J.C. Ulwick, K.D. Baker, D.J. Baker, A.J. Steed, W.R. Pendleton Jr., K. Grossmann, and H.G. Bruckelmann, J Atmos Terr Phys, 49, 855 (1987).
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MISTI

5. "Comparison of Simultaneous MST Radar and Electron Density Probe Measurements in the Polar Mesosphere," J.C. Ulwick, SPIE Vol 874, 260 (1988).

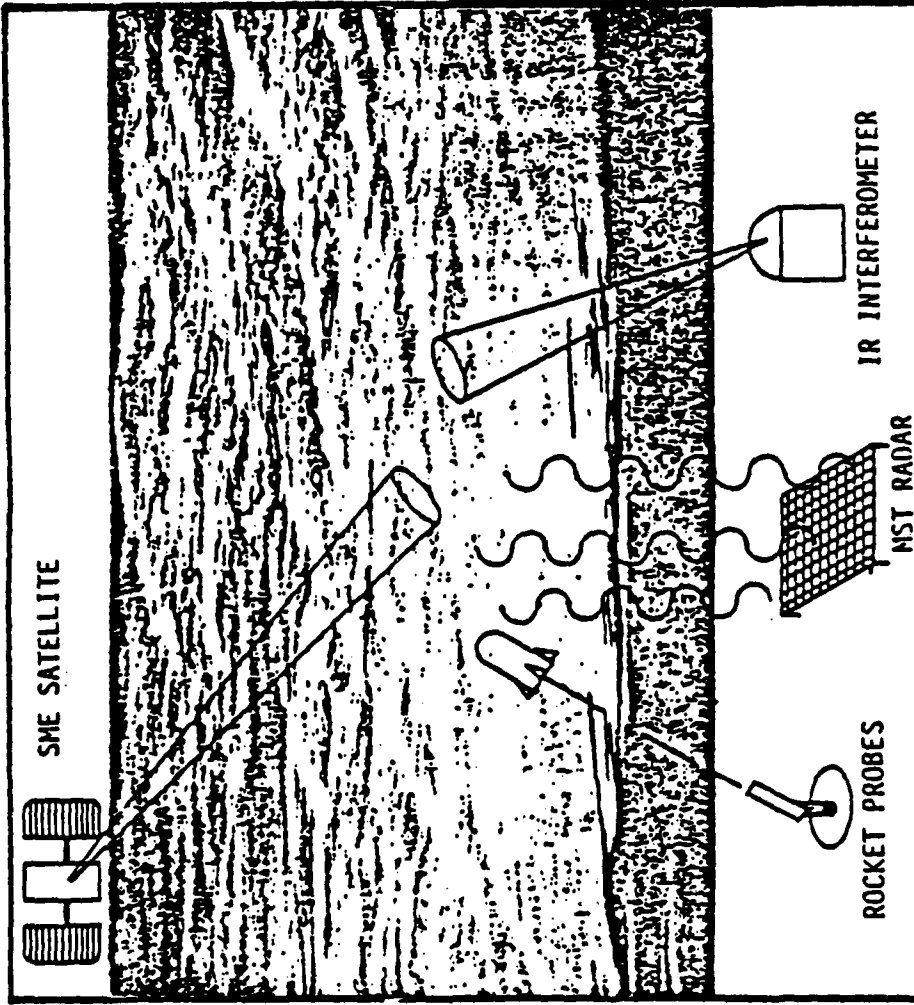
The summer conditions in the high latitude middle atmosphere are known to be in marked contrast to the winter conditions. The direction of the mean zonal and meridional flow in the stratosphere is reversed and runs from east to west and from north to south, the stratopause is warmer and the mesopause colder than during winter, and the variability of the temperature is believed to be smaller in the summer than in winter. MST radar measurements at Poker Flat, Alaska have shown strong backscattered signals from the mesospheric region over about 40% of the time during the summer months indicating strong turbulence.

As a follow-on to the STATE campaign, Utah State University conducted a campaign called MISTI (Mesospheric Ionization Structure and Turbulence Investigation) in July/August 1986 at the Poker Flat Rocket Range, Alaska. One of the objectives of the campaign was to launch a rocket when radar observations indicated strong turbulence in the mesosphere and when the SME (Solar Mesospheric Explorer) satellite UV optical experiment was viewing over Poker Flat Rocket Range. In the summer of 1982 a continuous operation of the Ultraviolet Spectrometer Experiment (UVS) began on the Solar Mesospheric Explorer (SME) spacecraft. This experiment provided a series of measurements over five summer seasons. Thomas and McKay established that thin Polar Mesospheric Clouds (PMC) are regularly observed over the summer polar region at an altitude of 82-88 km. The upper limit of particle diameters of PMC ice particles from the UVS-results is 0.14 microns and the probability of PMC-appearance in July is close to 40% at 65-70°N increasing with latitude to values as high as 80% around 80°N. Further, the Poker Flat MST Radar measurements have shown that there is a relatively narrow and surprisingly

intense echoing layer centered at about 86 km which was present only during summer months. These authors also pointed out that the occurrence of the strong summertime echoes corresponded well with the height, latitude, and seasonal occurrence of polar mesospheric or noctilucent clouds.

Figure 1 gives a cartoon representation of the MISTI program. Five rocket payloads were launched during the campaign during periods where strong backscatter signals from the MST radar were present. In Table No. 1 and No. 2, the results of the program are summarized. Note that all of the rocket launches took place in the morning. This was because better coordination with the satellite passes could be achieved and there was less local air traffic which could hold up the launch if the aircraft was in the launch corridor. On two of the days two rockets were launched within six hours (#241 and 242) and within four hours (#243 and 240). Furthermore, note that in the first instance, the echo altitude went up in time and in the second instance the echo altitude came down. Both probes on the heavy payload worked so in this campaign an absolute calibration of the DC probes was possible - a major objective of the campaign because the STATE results did not have an absolute calibration. In figures 2 and 3, the MST radar signal-to-noise in db are shown for each of the rocket launches, the measured electron density and direction of launch relative to the radar antenna directions.

Timing a rocket launch to a satellite overpass is very difficult. On some days the passes might be too far to the east or west of the rocket range to be useful, the weather might be too poor to allow visible observation that no local aircraft were in the launch corridor as required by the FAA, and



MISTI CAMPAIGN

(MESOSPHERIC IONIZATION/INFRARED STRUCTURE AND TURBULENCE INVESTIGATION)

Figure 1

TABLE NO. 1

<u>ROCKET</u>	<u>NO.</u>	<u>TYPE</u>	<u>LAUNCH (DAY #)</u>	<u>TIME (UT-LOCAL-MST)</u>
1	239	L	7-27-86(208)	1700UT--0900ADT--0700MST
2	241	H	7-29-86(210)	1142UT--0342ADT--0142MST
3	242	M	7-29-86(210)	1758UT--0958ADT--0758MST
4	243	L	8-02-86(214)	1220UT--0420ADT--0220MST
5	240	M	8-02-86(214)	1650UT--0850ADT--0650MST

TABLE NO. 2

<u>ROCKET #</u>	<u>APPOGEE</u>	<u>PURPOSE</u>	<u>ECHO(HT./db)</u>	<u>RESULTS</u>
239	96.7	Hi MST Echos	86-89/25	Probe failure
241	95.8	Lo MST Echos	81-83/27	Success
242	95.0	Mid MST Echos	83-86/32	Success
243	100.9	Hi MST Echos	85-88/37	Success
240	100.2	SME Overpass	83-86/19	Success

Note: L is light payload; M is mid weight payload; H is heavy.
H had impedance and DC probes -- L and M just DC probes.
NASA rocket numbers are 15.239 etc.

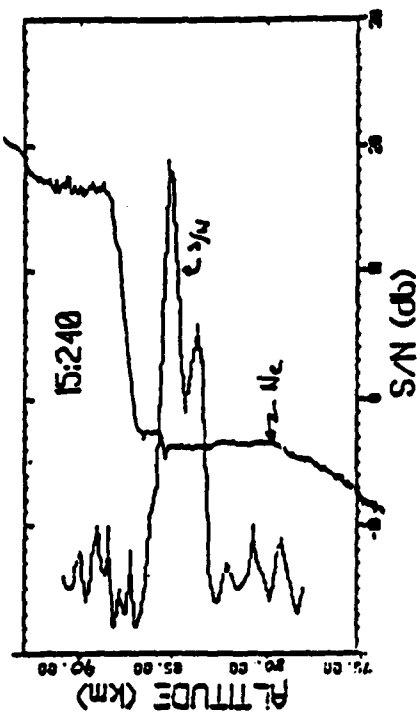
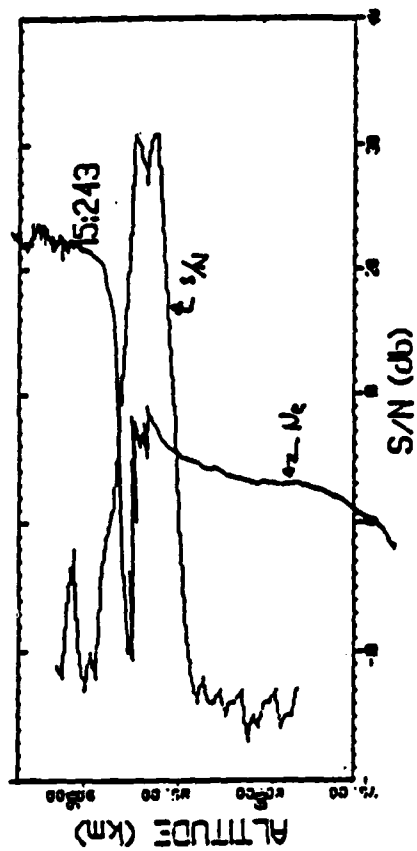
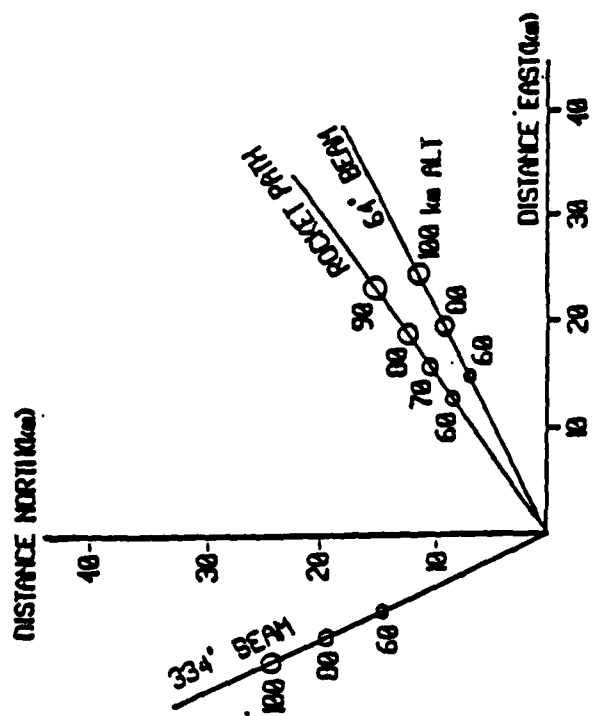
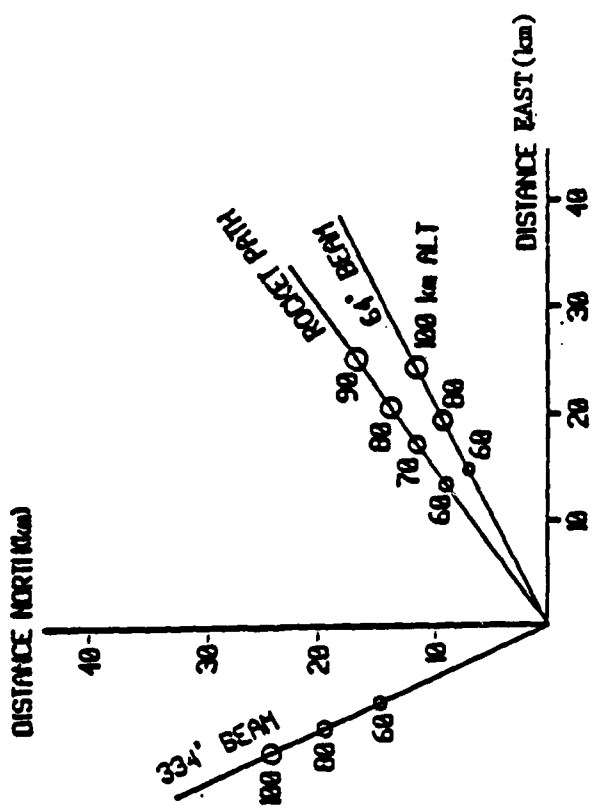


Figure 2

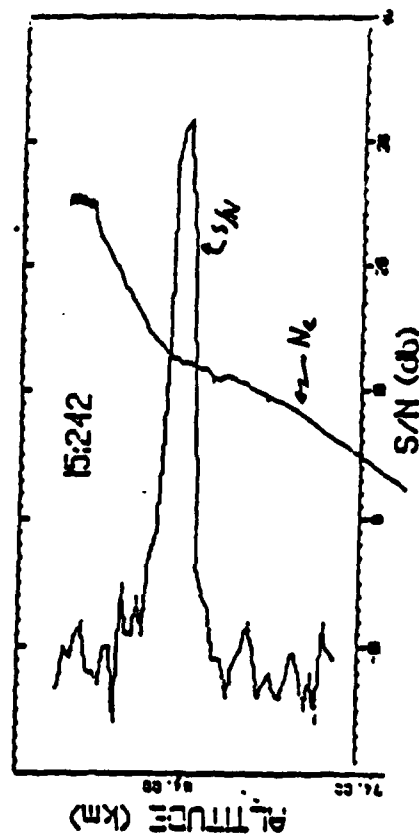
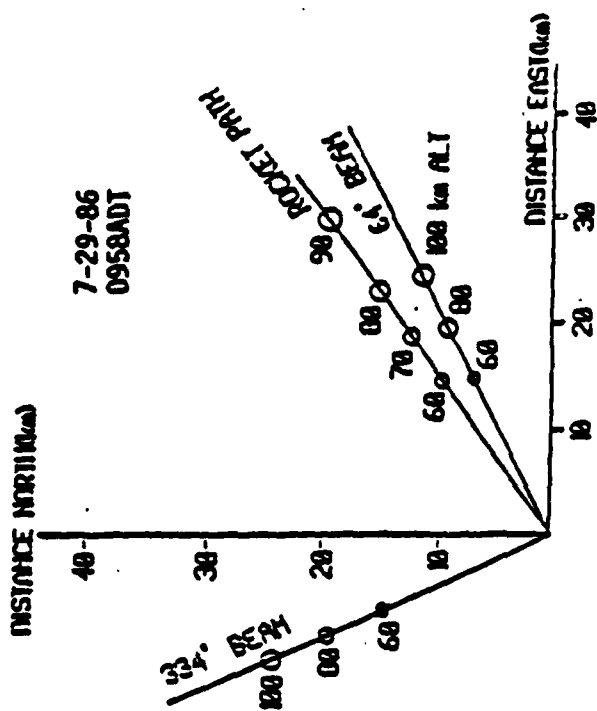
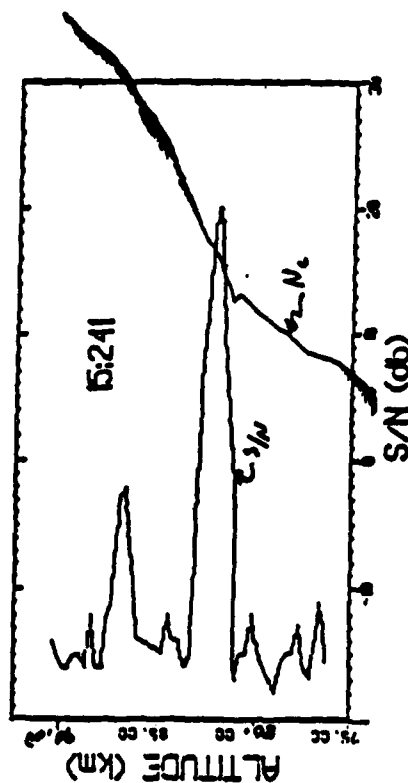
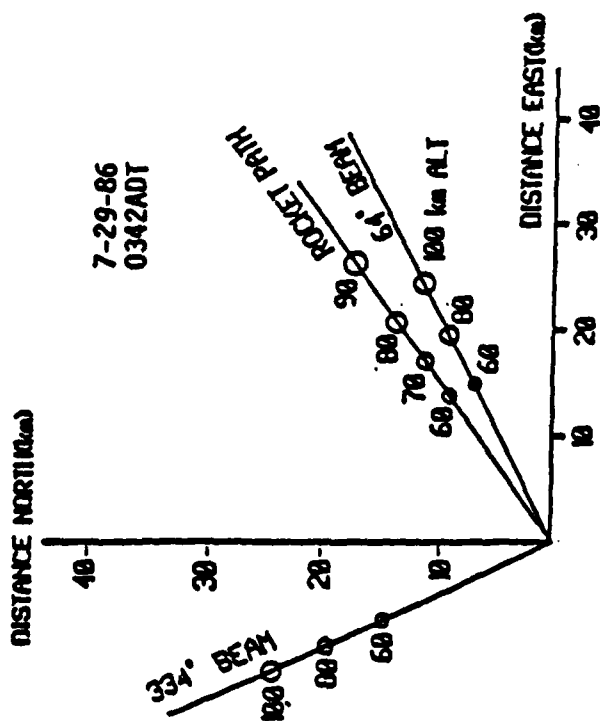


Figure 3

aircraft presence on good days could delay launch well past a satellite overpass. Therefore, the launch on the second of August was most fortuitous. The echoes as recorded by the MST radar were not the strongest at the time of the rocket launch and satellite overpass but the geometry was excellent as can be seen in Figure 4, with the radar, the satellite and the rocket all viewing pretty close to the same region of the mesosphere.

Figure 5 shows the electron density profile obtained by the rocket during the satellite overpass (Rocket #240) and the profile from a rocket fired about 4 hours earlier. The latter (Rocket #243) shows a large region of electron depletion and a very narrow large 'bite out' of electrons near 87 km with structure superimposed as in the STATE 3 results. The radar signal-to-noise (S/N) backscatter was very strong (over 30 db) in contrast to the S/N associated with Rocket #240 which was about 19 db. The electron density profile here shows again a broad area of electron depletion and a strong gradient at 87 km but no 'bite out'. Preliminary inspection of the SME data also indicates a very weak layer which is consistent with the rocket and satellite observations. Further analysis of this data will be done and published at a later date.

The MAC SINE Campaign described in more detail in Appendix B of the Annual Technical Report March 1987, was conducted in June and July 1987 at the Andoya Rocket Range in Norway. USU participated by launching four instrumented Super Arcas rocket payloads almost identical to the ones flown in the MISTI 1 Campaign. This campaign combined radar, lidar, and optical ground based measurements with meteorological rockets for winds, temperature,

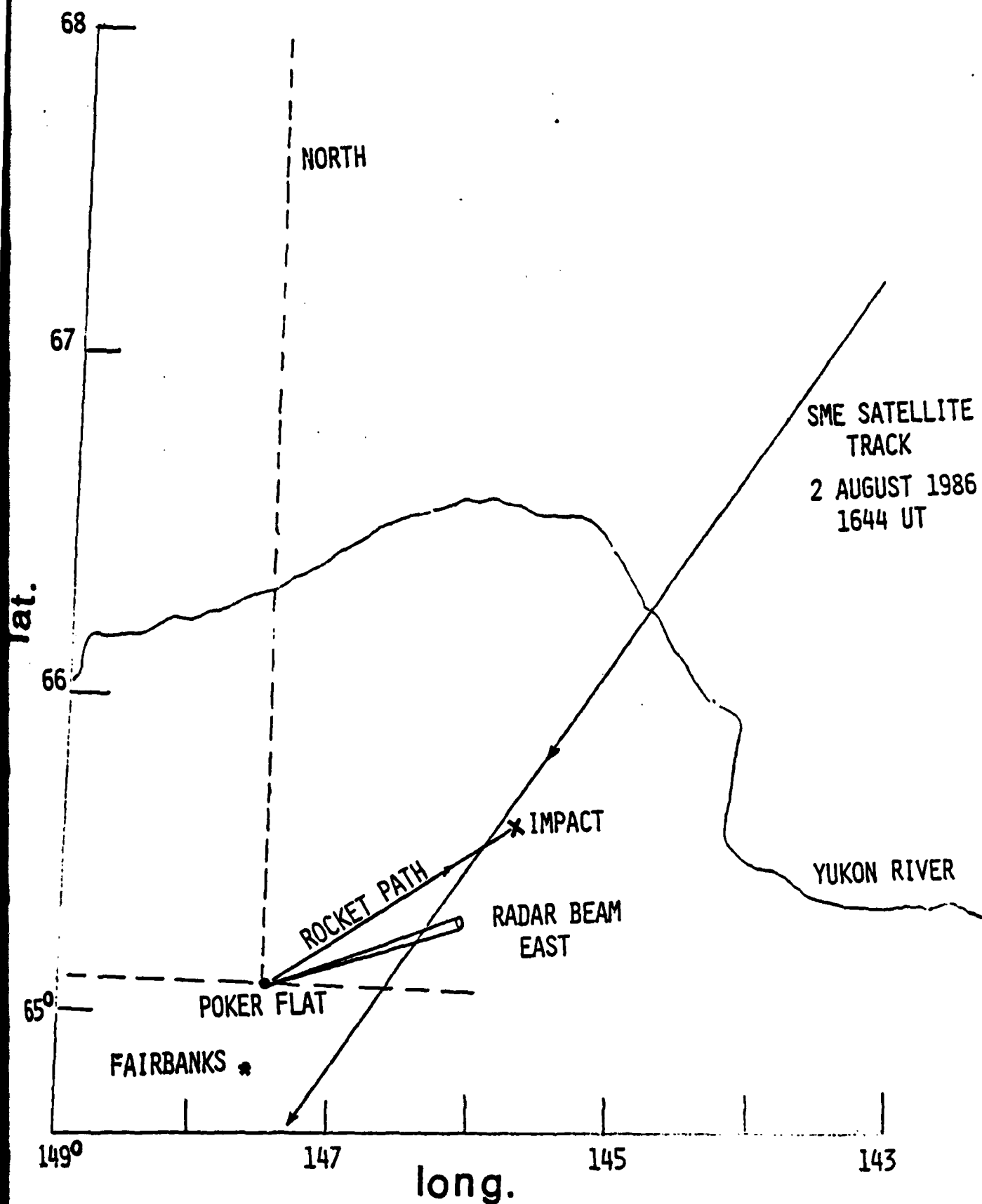


Figure 4

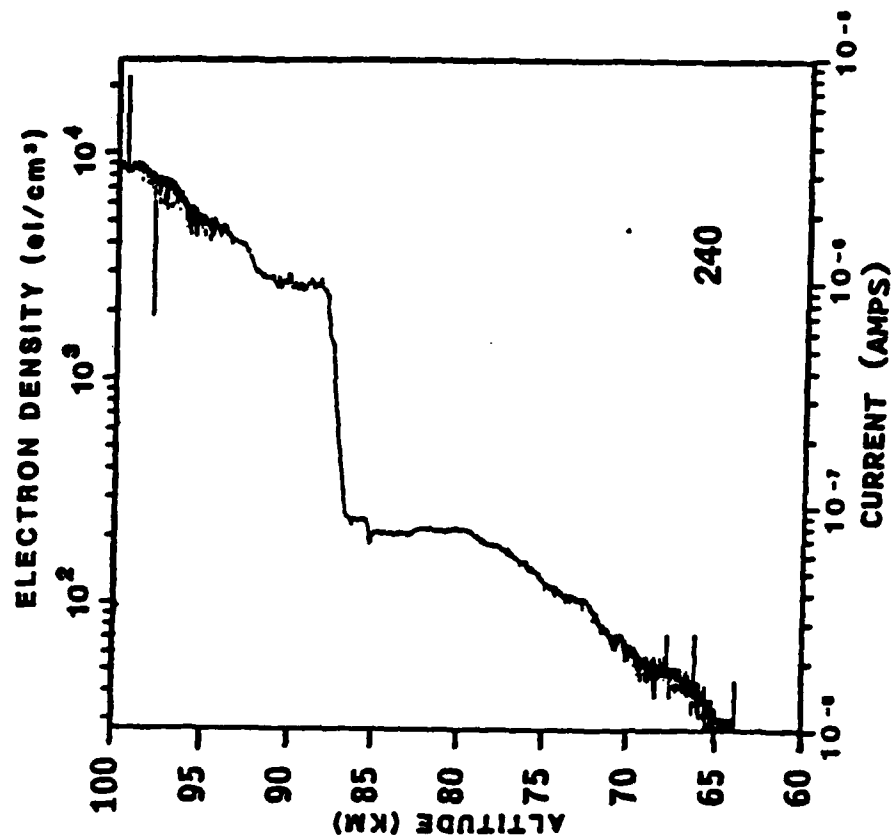
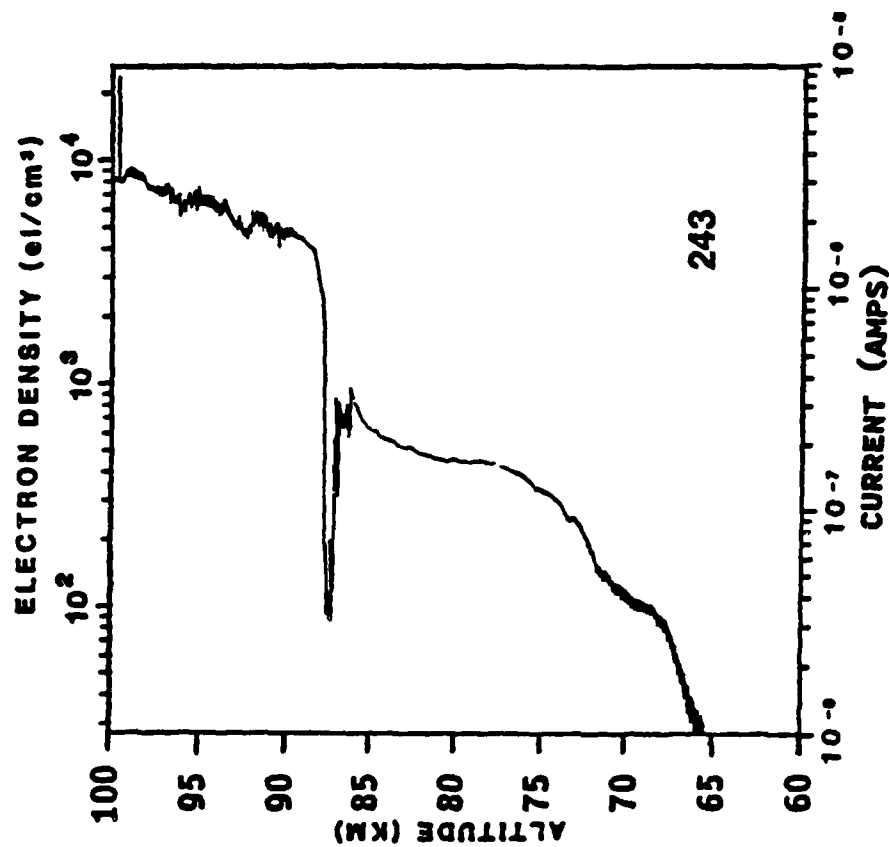


Figure 5. Electron density profiles from MISTI campaign. Rocket #243 launched on 8-02-86 at 0420 local daylight time and Rocket #240 on the same day about four hours later.

and density measurements and the USU Super Arcas ionization probe measurements. Of particular importance was the turbulent/gravity wave salvo to make detailed studies of mesospheric ionization structure, waves, turbulence and winds by rocket and ground measurements for a coordinated investigation of gravity waves and their role in generating turbulence and the structure in the mesospheric scattering region. Table 3 summarizes the rocket results from the Salvo with USU payloads underlined.

TABLE 3

Turbulence/Gravity Wave Salvo
Tuesday, 14 July 1987

<u>Rocket No.</u>	<u>Launch Time</u> (UT)	<u>Experiment (Measurement*)</u>	<u>Remarks</u>
<u>S-SA1/L</u>	08:00	DC Probe (Ne S)	Success
S-F18	08:11	Falling Sphere (T)	Poor Sphere
S-F19	08:32	Falling Sphere (T)	Success
S-C17/L	08:52	Chaff (W)	Success
<u>S-SA2/H</u>	09:29	DC and RF Probes (Ne S)	Success
S-C18/L	09:43	Chaff (W)	Success
S-C19/H	10:19	Chaff (W)	Success
S-F20	11:02	Falling Sphere (T)	Success
S-C20/L	11:30	Chaff (W)	Success
S-C21/L	12:03	Chaff (W)	Success
<u>S-SA3/H</u>	12:55	DC and RF Probes (Ne S)	Success
S-C22/L	13:07	Chaff (W)	Failure

* Measurement: 'Ne S' - electron density structure
'T' - temperatures
'W' - winds

In addition the Sousy MST radar and the PRE (partial reflection experiment) radar (as well as other ground measurements) were made during the whole period. The mesospheric conditions (from Sousy measurements) went from very dynamic and turbulent to very quiet conditions by the time the last two rockets were launched. We, therefore, have a most unique data set for the study of the cold summer turbulent polar mesosphere.

The fourth USU rocket was launched on 15 July with EISCAT, MST and PRE radar support, LIDAR measurements and temperature and chaff rockets into the most intense disturbance (over 70 db in S/N by the MST radar) of the summer. Preliminary examination of the USU probe results show ascent and descent electron density profiles similar to STATE 3 and MISTI #243 results, i.e., a deep "bite-out" in the electron density near 85 km. The simultaneous EISCAT measurement could be very important in verifying the contention by Kelley and Ulwick, 1988 that heavy water cluster ions in the cold summer mesosphere are responsible for the strong radar backscatter at 50 MHz not observed at other latitudes and that in the presence of these ions, the enhanced, turbulence-driven spectrum of the ionization irregularities could extend to considerably shorter wavelengths than that of the neutral turbulence itself. Since the mechanism of Kelley and Ulwick, 1988 predicts a substantial shift of the inertial subrange of the electron gas to smaller scalar, we might perhaps observe enhanced turbulent scattering at the EISCAT 224 MHz VHF radar, in which case, of course, the data could not be analyzed as incoherent scatter due to random thermal motion only.

USU has already participated in a MAC SINE/MAC EPSILON Investigators Preliminary 2 day workshop. It is very apparent that the campaigns were very successful and a special issue of JATP will be requested (as with MAP/WINE) for publication of the results. USU will participate in four (4) papers as described in the Data Analysis Section. In October 1988 USU will host the 2nd Investigators Meeting expected to be attended by 10 European and 14 American scientists that participated in the MAC campaigns. This will be a workshop wherein determination of final papers will be accomplished.

USU participated in three campaigns where infrared measurements were made with ground-based experiments: MISTI 2, MAC EPSILON and MAPSTAR.

The MISTI 2 campaign was conducted from 3 to 21 August 1987. Measurements of the OH nightglow intensity and rotational temperature were made by interferometers pointing at the region that the two MST radar antennas were measuring. In addition, simultaneous observations of Noctilucent Clouds (NLC) were made over the interferometer site by photographic and low light TV cameras located at a site about 230 km to the south. Since the altitude of the OH emission (85 km) is about the same as NLC's, study of its intensity and temperature has provided information on the atmospheric conditions during NLC displays. Preliminary results were presented at the Fall AGU meeting and the abstract was included in Appendix B of the Annual Technical Report. A paper is being prepared for publication as described in the Data Analysis Section.

The MAC EPSILON campaign (again, see Appendix B for details) was a combined rocket and ground measurement program conducted at Andoya Rocket Range,

Norway from 12 October to 15 November 1987. USU participated in the campaign under the present grant as part of the AFGL MAPSTAR program, also funded by AFOSR. We had the following experiments operating at the Optics Site at the Andoya Rocket Range, Norway during the MAC EPSILON Campaign:

Michelson Interferometer: By measuring the vibrational-rotational spectrum of the excited OH molecules in the near infrared spectrum (1.05-1.60 μm), it is possible to calculate the rotational temperatures at the mesopause (Baker, et al., 1985). It is generally accepted that the rotational states of OH^+ are in thermal equilibrium with the atmosphere at least up to a height of 110 km. Thus, the rotational temperature reflects the actual mesopause kinetic temperatures. The observations of temporal and spatial variations of the mesopause temperature is utilized to study mesosphere dynamics.

Fixed Radiometer: This instrument is coaligned with the interferometer to provide intensity variations of O_2 (Δg) and OH^+ (3,1) bands.

Scanning Radiometer: An IR radiometer is mounted on an optical pointing system that can be controlled by a PDP 11/73 computer to control the instrument scan. Various preprogrammed modes allow elevation and azimuth scanning to map out structure in the OH^+ as has been observed by the near IR video system of MAP STAR (this video system will be looking over Andoya from Finland during MAC EPSILON).

Three Photometers: Two photometers (4278A and 6300A) will be coaligned with the interferometer field-of-view and another (5577A) coaligned with the scanning radiometer.

Quick look results showed that the interferometer, the fixed radiometer, scanning radiometer and the photometers all functioned well during the campaign. Measurements were made during the night rocket Salvo and at many other nights during the campaign. Figures 6 and 7 show rotational OH temperatures and intensity measurements during one of the nights indicating the variability and structure - and the good correlation between the measurements. These results will be part of a paper planned to be published with MAC EPSILON results as described in the Data Analysis Section.

The acronym MAPSTAR stands for Middle Atmosphere Periodic Structure Associated Radiance. The purpose of this program is to study the wavelike patterns seen in IR emissions of the OH airglow from 95 km altitude. Primary interest centers on the gravity wave sources producing the patterns and the mechanism of the emissions. This is an Air Force Geophysics Laboratory program conducted for AFOSR. We participated in the May-July 1988 campaign which included three separate measurement periods. The IRFWI interferometer and radiometer described under MAC EPSILON operated to provide excellent data. A workshop will be held 28 and 29 September 1988 wherein the experimenters will present their results and publications of the data will be discussed.

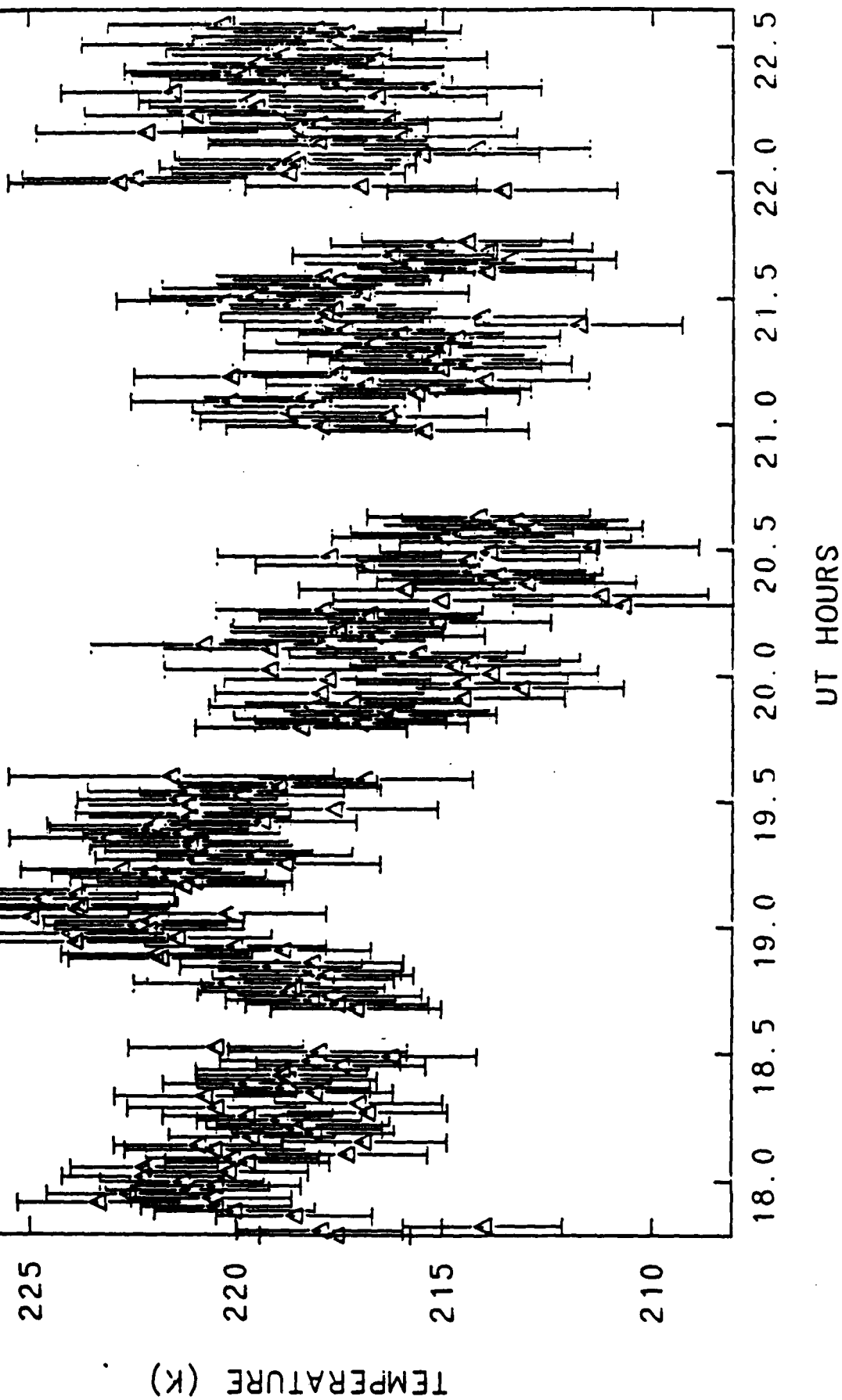


Figure 6

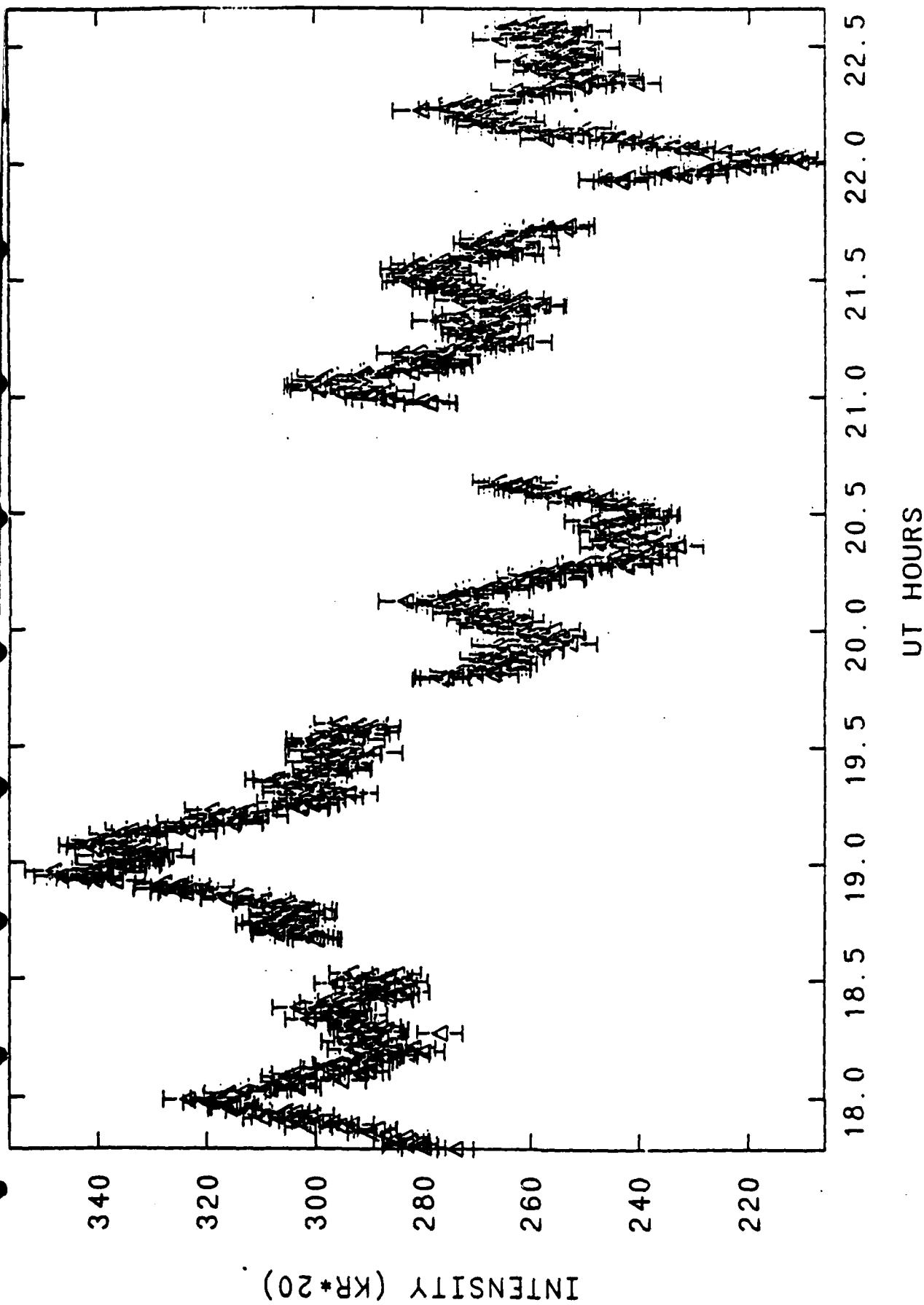


Figure 7

3.0 DATA ANALYSIS

As discussed in Section 2.0 STATUS OF RESEARCH, five papers were listed that were published during the contractual period. Here will be presented the manuscripts in preparation and planned for publication.

1. "Hydroxyl Nightglow Intensity and Temperature Measurements in the Presence of Noctilucent Clouds," M. Taylor, R. Lowe, and J.C. Ulwick, likely Journal, JGR.
2. "Small Scale Structures Observed in Situ in MAC SINE," J.C. Ulwick, M.C. Kelley, B. Inhester, and E. Thrane, likely Journal JATP Special MACSINE/EPSILON Issue.
3. "Consistency of Rocket and Radar Measurements of Radar Parameters," B. Inhester, J.C. Ulwick, M.C. Kelley, and T. Blix, likely Journal JATP Special MACSINE/EPSILON Issue.
4. "Scattering and Reflection Mechanisms," M.C. Kelley, J. Rottger, J.C. Ulwick, and B. Inhester, likely Journal JATP Special MACSINE/EPSILON Issue.
5. "Gravity Wave Dynamics - EPSILON," D. Fritts, U. Hoppe, F. Manson, P. Espy, and J.C. Ulwick, likely Journal JATP Special MACSINE/EPSILON Issue.
6. "Structuring of Summer Polar Mesosphere Electrons by Neutral Atmospheric Turbulence," J.C. Ulwick and M.C. Kelley, likely Journal, JGR.

PROFESSIONAL PERSONNEL INVOLVED

Utah State University: J.C. Ulwick
K.D. Baker
A.J. Steed
P. Espy

Cornell University: M.C. Kelley

NASA: B.B. Balsley

Univ of Wuppertal(FRG): G. Grossmann
H. Bruckelmann