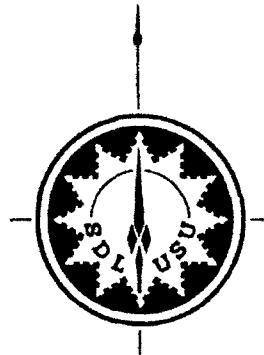AD-A265 360

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FINAL REPORT FOR
GRANT N00014-91-J-1883

## POLAR MESOSPHERIC WAVES AND STRUCTURE

James C. Ulwick
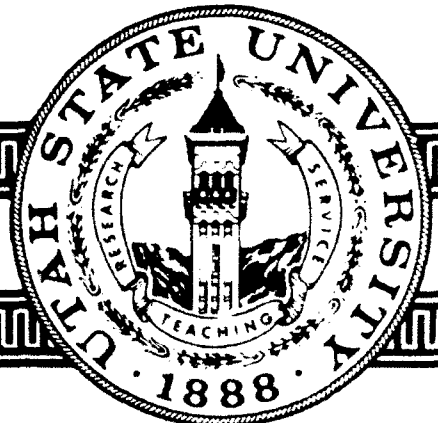
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## SPACE DYNAMICS LABORATORY
### UTAH STATE UNIVERSITY LOGAN, UTAH 84322-4140

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# FORWORD

The Department of the Navy/Office of Naval Research awarded Grant No. N00014-91-J-1883 to Space Dynamics Laboratory/Utah State University. SDL/USU used rocket and radar measurements from the MAC SINE campaign to conduct a detailed study of mesopheric ionization structure waves, turbulence, and wind. SDL/USU investigated the role of gravity waves in generating turbulence in the mesopheric scattering region.

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## SUMMARY

This report discusses a quantitative comparison of rocket observations of electron density fluctuations and simultaneous 53.5 MHz radar measurements that were obtained during the MAC/SINE campaign in Northern Norway. Two of the three rockets launched during the Turbulence/Gravity Wave salvo were flown during conditions that allowed a detailed investigation. A large part of the data from these rocket flights indicate that the radar reflectivity is about 10 dB enhanced over what would be expected from the rocket observations in the case of isotropic electron density fluctuations. The observations can be reconciled under the assumption of an anisotropic turbulence. Assuming a simple model spectrum for the electron density fluctuations, we derive a relation between the rocket and radar observation that covers the whole range from isotropic turbulent scatter to Fresnel-scatter at horizontal density stratifications. For the observed data set, an anisotropy which typically corresponds to a ratio of horizontal to the vertical coherence length of about 10 is consistent with the comparison of rocket and radar observations. A similar anisotropy is found also from the observed aspect sensitivity of the radar echoes. The variation of the anisotropy with height and time shows an anticorrelation with the turbulence level of the mesosphere as deduced from the spectral width of the radar echoes. The anisotropy is found to maximize in heights where density displays deep "bite-outs". These depletion in the electron density were independently observed by a Langmuir and an admittance probe on board the rocket.

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## INTRODUCTION

The earlier rocket/radar studies of the now-called Polar Mesospheric Summer Echoes (PMSE) in the STATE campaign led to the discovery that the electron density fluctuations spectrum in the polar summer mesosphere extends to scales much smaller than the Kolmogorov microscale. A comparison with simultaneous rocket probes published by Ulwick et al. [1988] showed that the electron density fluctuation spectrum was also elevated enormously at short wavelengths relative to the low latitude spectrum of Royrvik and Smith, 1984. At $\lambda=3$ m the polar summer spectrum was at least five orders of magnitude higher than near the equator. (See Figure 1). The polar summer mesospheric radar and rocket results, in fact, were in excellent quantitative agreement. In a sense, we now "understand" the huge polar summer radar echo cross section as being due to strong fluctuations in the electron density at 3 m. The question remains, however, as to why should these 3 m structures exist in a passive scaler when the viscous cutoff for neutral turbulence is at several tens of meters.

Subsequent efforts have focused on questions concerning how such an extension could occur. In two papers [Kelley et al., 1987; Kelley and Ulwick, 1988], we proposed the notion that the Schmidt number (Sc) for the passive scaler electrons must be elevated and suggested several experiments which might be able to test the hypothesis. The idea is that if Sc = v/D is large, where v is the neutral viscosity coefficient and D is the electron diffusion coefficient, then the plasma can exhibit structure at smaller scales than the neutral fluid which drives the structuring process [Batchelor, 1959]. We further argued that somehow heavy positive ions could reduce D and hence increase Sc. We also pointed out that (1) there might be enhanced scatter even at
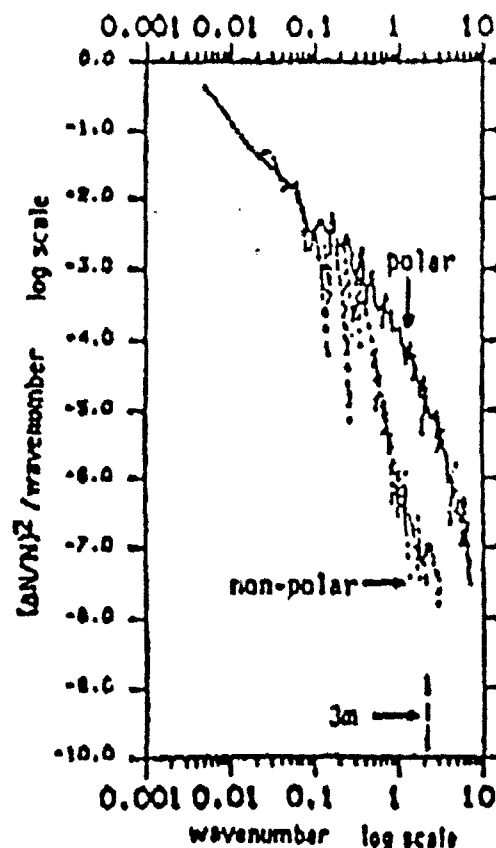
Figure 1. Power Spectral Density. This figure shows that the power spectral density of the electron fluctuations in the polar summer mesosphere can be orders of magnitude higher than observed in the low latitudes.

224 MHz which is measurable at EISCAT, and (2) very narrow incoherent scatter spectra should occur at frequencies high enough that turbulent scatter is absent. Both of these predictions turned out to be true [Röttger et al., 1989; Hall et al., 1990]. The recent work of Cho et al., 1992, shows that a likely candidate for enhancing Sc is the existence of charged aerosols in sufficient number that, for the strongest scattering events, roughly half of the charge is tied up on aerosols rather than as free electrons. A rocket/radar campaign was conducted in 1987 on the polar summer mesosphere to address some of the above questions. The next section describes the program and accomplishments.

## SUMMARY OF WORK ACCOMPLISHED

The MAC SINE Campaign was conducted in June and July 1987 at the Andoya Rocket Range in Norway. USU participated by launching four instrumented NASA Super ARCAS rocket payloads. This campaign combined radar, lidar, and optical ground based measurements with meteorological rockets for winds, temperature, and density measurements and the USU Super ARCAS ionization probe measurements. Through rocket and ground measurements, the turbulent/gravity wave salvo made detailed studies of mesospheric ionization structure, waves, turbulence and winds; therey performing a coordinated investigation of gravity waves and their role in generating turbulence and the structure in the mesospheric scattering region. Table 1 summarizes the rocket results from the Salvo with USU payloads underlined.

The Super ARCAS rockets carried probes for the measurement of electron density fluctuations similar to those in previous PMSE studies. Briefly, an electron dc probe was operated at a fixed +3V bias as before but a sweep mode was added to provide vehicle charging information in electron density "bite-out" regions thought to be responsible for the edge scattering process. In addition, previous measurements showed that the dc probe data indicated deeper depletions than did the rf probe results in the "bite-out"; a result which we feel has important information concerning the origin of these "bite-outs". The collected current is converted to a 16-bit digital number and transmitted to the ground at a rate near 5500 bytes/s to provide high spatial resolution data. We include in two of our payloads an rf capacitance probe for measurement of the absolute electron density. This probe has been used in several mesospheric investigations (e.g. Harris et al., 1983), and details of a description of the probe are contained

### Table 1.  Turbulence/Gravity Wave Salvo

### Tuesday, 14 July 1987

| Rocket No. | Time (UT) | Launch (Measurements)* | Experiment Remarks |
|---|---|---|---|
| S-SA1/L | 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 |
| S-SA2/H | 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 |
| S-SA3/H | 12:55 | DC and RF Probes (Ne S) | Success |
| S-C22/L | 13:07 | Chaff (W) | Failure |

*Measurement:    Ne S - electron density structure
T - temperature
W - winds

in this reference.  Briefly, an RF generator generates 3.0 MHz and the oscillator outputs are fed through an rf bridge to one-half of the instruments dipole antenna and the guard electrode.  The ac ground return for this dipole is the rocket body.  When immersed in the ionospheric plasma, the dipole can be equated to a simple parallel RC circuit with values of R and C dependent upon electron density of the ionospheric medium.  As these values change due to changes of electron density of the plasma, imbalances in the RF bridge circuitry result.  These changes are amplified and synchronously detected, and are commutated to form the output of the probe.

During the time of the rocket launches and in between, the mobile SOUSY-VHF radar system was operated at 53.5 MHz in a 6-beam mode looking sequentially into the vertical, towards NE, NW and SW with a 4° angle and towards N and W at 5.6° angle off-zenith.  The integration time for each single beam measurement was about 10 s, so that a full beam cycle took about 1 minute.  The range resolution was $\Delta r = 300$ m and a height range from 60 to 100 km was covered.  The radar was operated at a peak transmitter power of $P_t = 75$ kW, which is about half the maximum possible power.  The lower power mode was chosen in order to reduce the possibility of a transmitter failure during its continuous operation for the time of the MAC/SINE campaign of more than a month.  A list of the other radar parameters and a further description of the radar system can be found in Czechowsky et al., 1984.  Figure 2 shows the geometry of the rocket and radars at Andoya, Norway.   The mesospheric conditions (from Sousy measurements as shown in Figure 3) went from very dynamic and turbulent to very quiet conditions by the time the last rocket was launched.  In Figure 4, we show the comparison of the ascent rocket density and the Sousy radar reflectivity for the TGW salvo (a, b and c) and for the
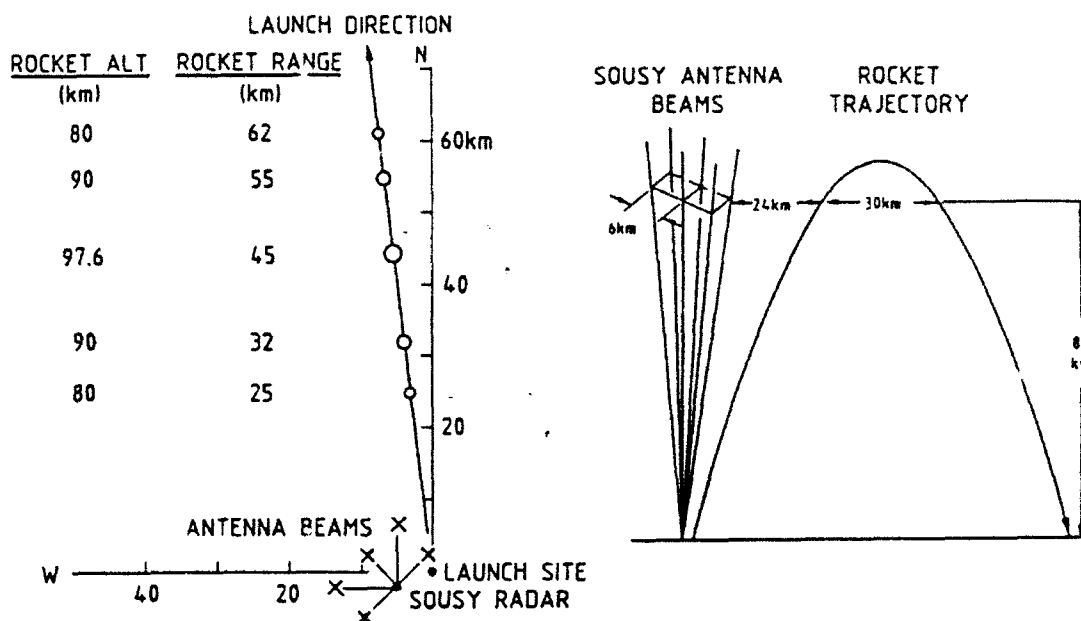
Figure 2. Relative Location of the Super ARCAS Rocket Trajectories and the SOUSY Antenna Beams. There are six antenna beams of the SOUSY radar pointing vertically, towards NE, NW and SW with 4° off-zenith angle and towards N and W with 5.6° off-zenith angle. The left part of the figure is a view from the top. The crosses denote the horizontal coordinates of the radar beams at a height of 85 km; the open circles give the rocket position at the indicated height. The right part of the figure shows a side view of the beam configuration and the rocket trajectory.
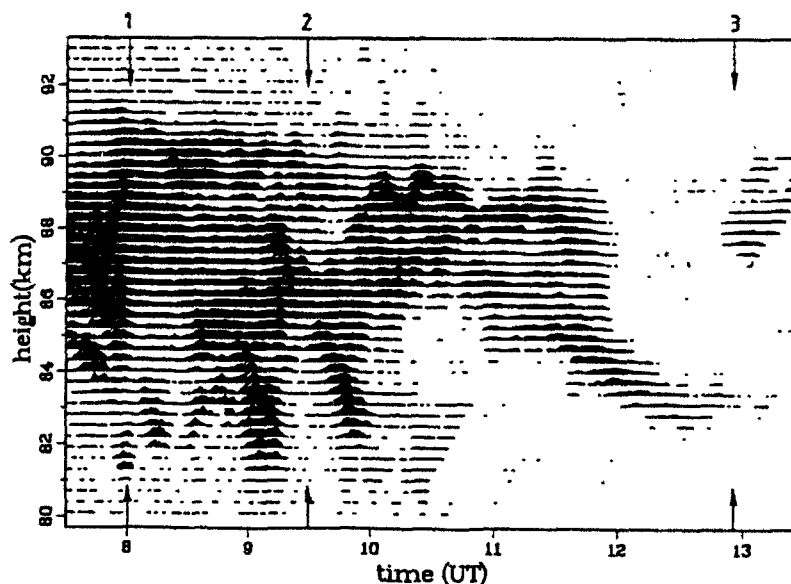
SOUSY VHF − 14 July 1987



Figure 3. Relative Echo Intensity. This figure shows the relative echo intensity observed in the vertical SOUSY beam during the time of the Turbulence/Gravity Wave salvo. The distance from one range gate to the next is 300 m. The height of the grey-shading within each range gate is proportional to the logarithm of the echo intensity in the height such that a grey-shading over a full range gate corresponds to a signal-to-noise ratio of 40 dB. The launch times of the Super ARCAS rockets are indicated by arrows above the abscissa.
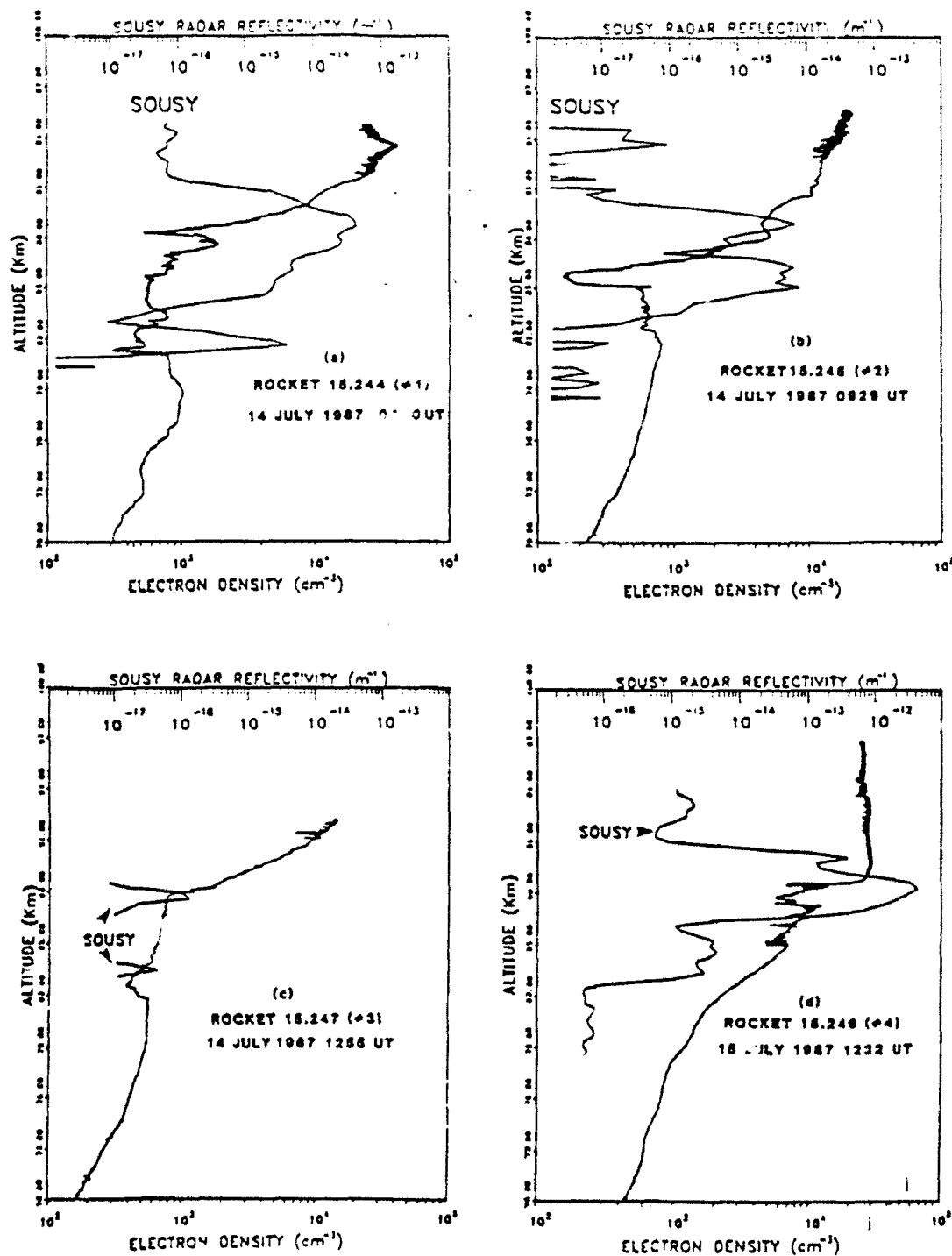
Figure 4. Ascent Rocket Electron Density Profiles and SOUSY Radar Reflectivity. This figure shows a comparison of the ascent rocket electron density profiles from the dc probes and the SOUSY radar reflectivity observed simultaneously in the northward beam for the four MAC/SINE rockets. Panels (a)-(c) show the results of the TGW salvo flights No. 1-3, respectively; panel (d) displays the results of the EISCAT salvo.

EISCAT salvo. We, therefore, have a most unique data set for the study of the cold summer turbulent polar mesosphere.

Using these results, we report about a quantitative comparison of rocket observations of electron density fluctuations and simultaneous 53.5 MHz radar measurements that were obtained during the MAC/SINE campaign in norther Norway. Out of three rockets launched during the Turbulence/Gravity/Wave salvo, two were flown during conditions that allowed a detailed investigation. A large part of the data from these rocket signals indicate that the radar reflectivity is about 10 dB enhanced over what would be expected from the rocket observations in the case of isotropic electron density fluctuations. The observations can be reconciled under the assumption of an anisotropic turbulence. Assuming a simple model spectrum for the electron density fluctuations, we derive a relation between the rocket and radar observations that cover the whole range from isotropic turbulent scatter to Fresnel-scatter at horizontal density stratifications. For the observed data set, an anisotropy which typically corresponds to a ratio of the horizontal to the vertical coherence length of about 10 is consistent with the comparison of rocket and radar observations. A similar anisotropy is found also from the observed aspect sensitivity of the radar echoes. The variation of the anisotropy with height and time shows an anticorrelation with the turbulence level of the mesosphere as deduced from the spectral width of the radar echoes. The anisotropy is found to maximize in heights where the electron density displays deep "bite-outs." These depletions in the electron density were independently observed by a Langmuir and an admittance probe on board the rockets.

The simultaneous measurement of electron density from two quantitatively different

measurement techniques--one is a dc type Langmuir probe and the other an rf capacitance probe--

on two different rocket flights showed that the two agree _except_ in the region of intense radar

backscatter where the Langmuir probe shows a more intense bite-out than does the C-probe (See

Figure 5). The most intriguing explanation of this result is that the +3V positive bias on the

Langmuir probe is not sufficient to repel massive positively charged aerosol particles in the
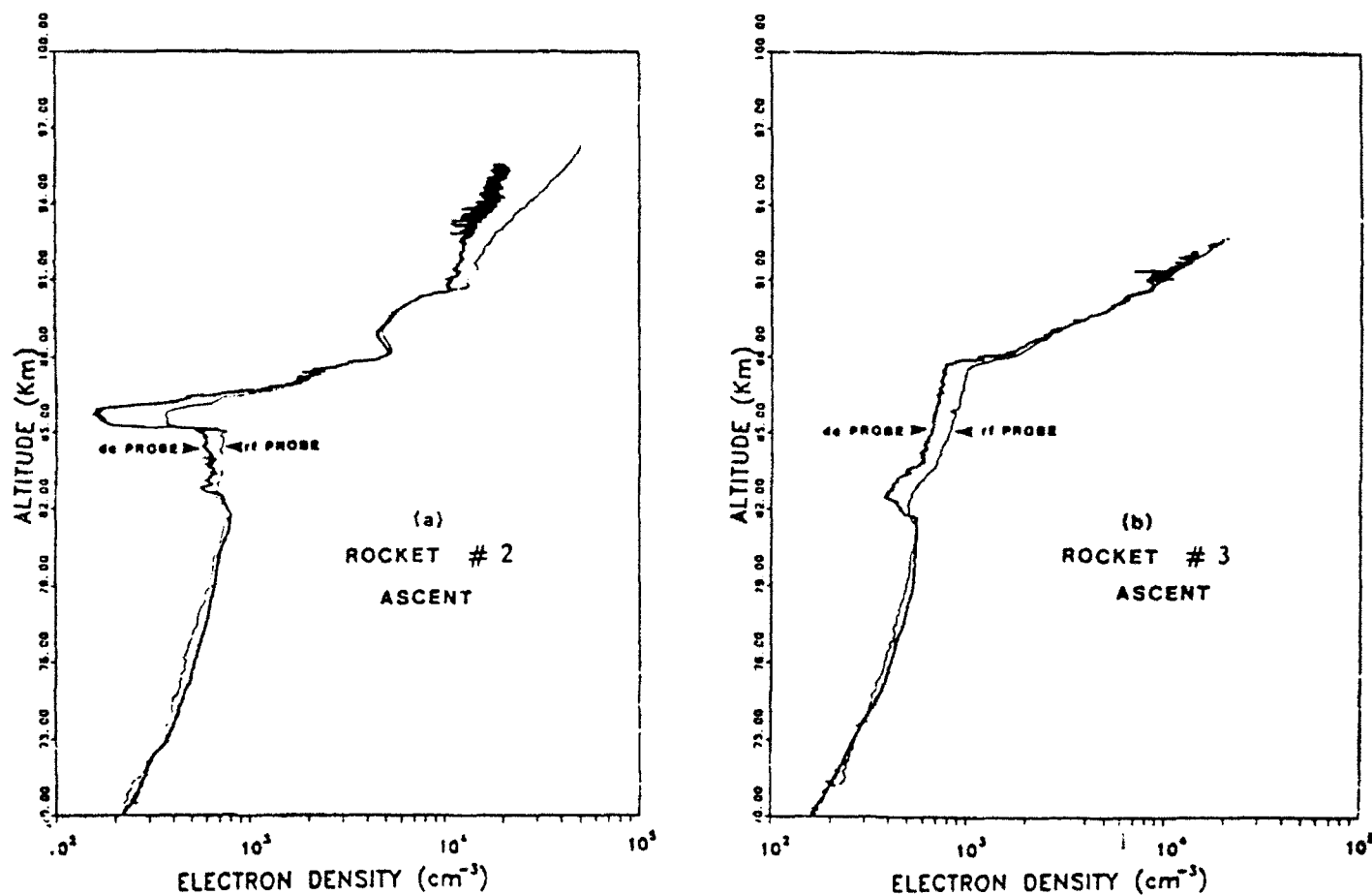


Figure 5. Superposition of the dc Probe Electron Currents to Corresponding Electron Densities. This figure shows the superposition of the dc probe electron currents to a best fit to the corresponding electron densities from the RF probes for the second (a) and third (b) rocket flight of the TGW salvo. The resulting conversion factor to obtain the electron density from the dc probes is $4.5 \times 10^9$ electrons/(cm$^3$ ampere) and is nearly identical for both rockets.

rocket frame of rest. Although cluster ions were first suggested, it now appears that positively charged aerosols are more likely to be responsible [Havnes et al., 1990; Cho et al., 1991]. The advantage of this theory is that it can explain other features as well--the enhanced incoherent scatter levels at 933 MHz and 1230 MHz [Röttger et al., 1989; Cho, private conversation, 1991]; the bizarre reports of downward mean winds in the PSM [Balsley and Riddle, 1984]; the evidence for specular reflection even at 3 m backscatter wavelengths [Czechowsky et al., 1988]; and the electron density bite-outs co-located with the radar echoes [Ulwick and Kelley, 1988].

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 (see Figure 4). Simultaneous observations of polar mesospheric summer echoes (PMSE) were made with two different frequency radars during the launch of a sounding rocket designed to measure the fluctuations in the electron density in the same height range. The cross-section for radar backscatter deduced from the rocket probe data under the assumption of isotropic turbulence is in reasonable agreement with the measured signals at both 53.5 MHz with the mobile Sousy radar and 224 MHz with the EISCAT VHF radar, which correspond to backscatter wavelengths of about 3 m and .75 m respectively. Some controversy exists over the relative roles of turbulent scatter versus specular reflections in PMSE. A number of characteristics of the data obtained in this experiment are consistent with nearly isotropic, intense meter scale turbulence on this particular day. Since equally compelling arguments for the importance of an anisotropic type mechanism have been presented by other experimenters studying PMSE, we conclude that both isotropic and anisotropic

mechanisms must operate. We have found the inner scale for the electron fluctuation spectrum, which corresponds to the diffusive subrange for that fluid, and have compared it to the inner scale for the neutral gas. The latter was found from the Kolmogorov microscale which in turn depends on the energy dissipate rate in the gas. We found the dissipation rate from the spectral width of the 53.5 MHz backscatter signal diffusive subrange was found to occur at a wavelength of a factor of about ten times smaller that the viscous subrange. This corresponds to a Schmidt number of about 100. High Schmidt numbers have been reported in recent measurements of the diffusion coefficient of the electrons in this height range made with the EISCAT incoherent scatter radar. About 15 minutes after the rocket flight, an extremely high radar reflectivity was found with the Sousy system. We have been able to reproduce this high level theoretically by scaling the rocket data with an increase in the neutral turbulence energy dissipation rate by a factor of 14 as deduced from the Sousy spectral width, an increase in the electron density which is consistent with riometer data, and a 33% decrease in the electron density gradient scale length which is hypothesized. We also estimate the radar reflectivity at 933 MHz and conclude that signals in excess of thermal scatter levels would have occurred at the peak of the event studied provided that the inner scale of the electron fluctuation spectrum decreases at least as fast as $e$-1/4, which is the case for neutral turbulence.

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