Technical Report

Millstone Hill
Thomson Scatter Results for 1970

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ABSTRACT

During 1970, the incoherent scatter radar at Millstone Hill (42.6°N, 71.5°W) was employed to measure the electron density, electron and ion temperatures, and vertical velocity of the ions in the F-region over periods of 24 hours on an average of twice per month. The observations spanned the height interval 200 to 900 km, approximately, and achieved a time resolution of about 30 minutes. This report presents the results of these measurements in a set of contour diagrams.

Commencing with the data presented in this report, a method of data reduction has been used which supersedes the older one of constructing the contour diagrams by hand. In the new method the set of points for any given parameter is matched by a two-dimensional polynomial surface in a least-squares fit. The program that carries this out is described fully in the report. By obtaining a continuous analytical description of the data with respect to height and time, machine-drawn contouring becomes possible and is now employed. The new program also provides a means of transferring the results to other users in machine-readable form. In addition, the new program yields a more repeatable smoothing of the data with respect to height and time, thereby allowing parameters that depend upon gradients (e.g., heat and particle fluxes) to be estimated more accurately.
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MILLSTONE HILL THOMSON SCATTER RESULTS FOR 1970

I. INTRODUCTION

Since 1963, incoherent (Thomson) scatter radar measurements of F-region electron densities, and electron and ion temperatures have been conducted at Millstone Hill, Westford, Massachusetts (42.6°N, 71.5°W) (Refs. 1 to 7). This paper is the eighth in a series of annual reports, and presents the results gathered in this program during the calendar year 1970. The observations reported were made for periods of 24 hours, approximately twice a month. The results obtained in earlier years have been published in the articles listed in Table I, and have been transmitted to the World Data Center A, Boulder, Colorado.

In addition to the measurements reported here of F-region electron densities, electron and ion temperatures, and vertical velocity, a number of measurements were conducted in 1970 of the electron density in the D- and E-regions of the ionosphere employing a digital filter to

<table>
<thead>
<tr>
<th>Year</th>
<th>Months Covered</th>
<th>Publication</th>
</tr>
</thead>
<tbody>
<tr>
<td>1963</td>
<td>February 1963 to January 1964</td>
<td>Ref. 1</td>
</tr>
<tr>
<td></td>
<td>March, July, August, September</td>
<td>Ref. 8</td>
</tr>
<tr>
<td></td>
<td>April, July, November</td>
<td>Ref. 9</td>
</tr>
<tr>
<td>1964</td>
<td>January through December</td>
<td>Ref. 2</td>
</tr>
<tr>
<td></td>
<td>April, July, November</td>
<td>Ref. 10</td>
</tr>
<tr>
<td>1965</td>
<td>January through December</td>
<td>Ref. 3</td>
</tr>
<tr>
<td></td>
<td>January, April, August</td>
<td>Ref. 11</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>Ref. 12</td>
</tr>
<tr>
<td></td>
<td>June, August, September</td>
<td>Ref. 13</td>
</tr>
<tr>
<td>1966</td>
<td>January through December</td>
<td>Ref. 4</td>
</tr>
<tr>
<td></td>
<td>January, March, July, September</td>
<td>Ref. 14</td>
</tr>
<tr>
<td>1967</td>
<td>January through December</td>
<td>Ref. 5</td>
</tr>
<tr>
<td></td>
<td>February, June, October, December</td>
<td>Ref. 14</td>
</tr>
<tr>
<td>1968</td>
<td>January through December</td>
<td>Ref. 6</td>
</tr>
<tr>
<td></td>
<td>October</td>
<td>Ref. 15</td>
</tr>
<tr>
<td>1969</td>
<td>January through December</td>
<td>Ref. 7</td>
</tr>
<tr>
<td></td>
<td>February, April, July</td>
<td>Ref. 16</td>
</tr>
<tr>
<td></td>
<td>September, October</td>
<td>Ref. 16</td>
</tr>
</tbody>
</table>
For these measurements, two new modes of operating the radar were developed. The E-mode provided a power profile over the altitude interval 90 to 600 km, approximately, with an altitude resolution of 15 km, while the I-mode covered the interval 65 to 130 km with 3-km height resolution. These programs afforded another improvement over the older method of operating the radar in that the repetition frequency was considerably increased, thereby providing a larger number of independent samples per second. Advantage was taken of this to try to measure rapid changes in the ionosphere introduced, for example, by Traveling Ionospheric Disturbances (TIDs) by simply repeating the E-mode runs with only 2 minutes integration. This program known as RASEM (Rapid Sequence E-Mode) was operated for eight days in 1970 and the results have been reported elsewhere.

The principle of digital clutter subtraction was later extended to measurements of the autocorrelation functions of the signals; these permitted the first measurements at Millstone of electron and ion temperatures in the E-region in which good height resolution was achieved.

The measurements of the echo autocorrelation function were accomplished by transmitting pairs of short pulses and calculating in the digital computer the correlation between samples of the echoes taken with the same spacing. This method of operation allows the height and frequency resolution of the measurements to be set independently of one another, while in the measurements reported here, the length of the single long pulse used establishes both parameters.

During 1970, three new operating modes (F, G, H) spanning the height interval 100 to 500 km were developed that employed the autocorrelation method. These became known as the "double-pulse" experiments to distinguish them from the earlier single-pulse measurements.

Double-pulse measurements were made at irregular intervals in 1970 commencing with observations conducted during a partial solar eclipse on 7 March. Results of the eclipse measurements have been reported elsewhere. Routine measurements using the double-pulse method commenced in 1971 and have been used extensively to study the propagation of thermal tides from the mesosphere into the lower thermosphere. These measurements also permit the determination of the neutral density in the lower thermosphere (in the region where ion-neutral collisions become important) and the ion composition in the F1-region, but as yet no complete reduction of these data for this purpose has been undertaken.

In this report, we present only the results of the measurements made with single long pulses. These covered the altitude interval 200 to 800 km, approximately, with a height resolution (for the measurements of temperature) of 75 km. These data can be used to deduce the temperature of the exosphere from thermal balance arguments and results obtained in this way for the period March 1969 through March 1971 have already been reported.

Section II describes the equipment, data gathering, and data reduction procedures. During 1970, these were little changed from those employed in 1969 except that a new method of data smoothing and presentation was developed that replaced the earlier manual method employed since the program began. This method of data compression is described in detail in Sec. III. Results for electron density, electron and ion temperatures, and vertical velocity are presented and discussed in Sec. IV.
II. EQUIPMENT, OBSERVING, AND DATA-ANALYSIS PROCEDURES

A. Equipment

The UHF incoherent scatter radar equipment has been described. During 1968, the spectrum analyzer portion of the receiver was replaced by one of newer design that was interfaced directly into the XDS 9300 computer. These changes are fully documented in Ref. 25 and discussed further in Ref. 7. As mentioned above, the principal changes made during 1970 were the development of the double-pulse modes for operating the equipment. A brief description of one of these (the F-mode) has been given elsewhere and a full account of the complete system is reserved for a separate report.

One other change made in (June) 1970 was the relocation of the parametric amplifier from a shelter beneath the 220-foot-diameter antenna to the room in the main building where the remainder of the receiver is located. This required extending the receiver waveguide by 330 feet. The resulting increase in the system temperature (20°K) was considered a small drawback in comparison to the greater ease with which the equipment could be adjusted. However, with the parametric amplifier in the same room as the exciter, it became necessary to exercise great care to prevent unwanted CW leakage into the receiver.

The performance of the receiver was further improved in August 1970 when the old gas discharge TR device used to protect the receiver was replaced by a new solid-state device (employing diode switches) built to a design provided by L. M. LaLonde (Cornell University). This introduced less loss and provided a faster recovery. More importantly, the new device did not suffer any of the aging problems to which the gas discharge tubes were prone, causing them to become noisy and introduce irregular variations in the noise level along the timebase.

In order to extend the measurements to low altitudes, it was also necessary to improve the transmitter switching of the beam current in the klystron amplifiers. The decay time for this with the original modulator was 200 μsec and by rebuilding the modulator deck (in August), this was reduced to about 70 μsec.

The most serious difficulty encountered with the equipment in 1970 was the loss of gain that occurred when snow collected in the 220-foot antenna to a depth of over two feet during a storm on 30 December 1969. Although the snow was removed manually during the course of the next few days, its weight (together with that of the people engaged in snow removal) aggravated the distortion of the mesh caused by a similar event the previous winter. To remedy this, a program of surface improvement was undertaken during the summer in which the wire ties holding the mesh to its supporting pipe purlins were selectively cut and the mesh retensioned. Sufficient mesh had "gathered" at the apex of the parabola to permit the removal during these operations of a 3-foot-wide span. In addition to this retensioning, the sag of the mesh between the pipe purlins (spaced 14 feet apart) was reduced by introducing a set of cables laid diagonally in orthogonal directions across the pipe purlins. These cables were separately tensioned and the mesh then tied to them.

B. Observing Procedure

During 1970, we attempted to make F-region observations twice per month for periods of 24 hours. These were carried out using the single-pulse experiment modes A to C described previously which provide the coverage indicated in Table II. Two types of measurements were conducted. In one, the experiment sequence A to C (Table II) was repeated every 30 minutes,
### TABLE II
THE NORMAL "ONE-PULSE" EXPERIMENT MODE SEQUENCE

<table>
<thead>
<tr>
<th>Mode</th>
<th>Pulse Length (μsec)</th>
<th>Height Resolution (km)</th>
<th>Sample Spacing (km)</th>
<th>Altitude Coverage (km)</th>
<th>Measured Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
<td>15</td>
<td>7.5</td>
<td>100-1000</td>
<td>Power $N_e$</td>
</tr>
<tr>
<td>B</td>
<td>500</td>
<td>75</td>
<td>30</td>
<td>150-1500</td>
<td>Power $N_e$</td>
</tr>
<tr>
<td>C</td>
<td>1000</td>
<td>150</td>
<td>30</td>
<td>300-2000</td>
<td>Power $N_e$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>450-1125</td>
<td>Power spectrum $T_e, T_i, v_z$</td>
</tr>
</tbody>
</table>

### TABLE III
THE NORMAL "TWO-PULSE" EXPERIMENT MODE SEQUENCE

<table>
<thead>
<tr>
<th>Mode</th>
<th>Pulse Length (μsec)</th>
<th>Height Resolution (km)</th>
<th>Sample Spacing (km)</th>
<th>Altitude Coverage (km)</th>
<th>Measured Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>100</td>
<td>15</td>
<td>6, 9, 15</td>
<td>90-600</td>
<td>Power $N_e$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$z &lt; 120 \text{ km}: T_i, v_{in}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$z &gt; 120 \text{ km}: T_e, T_i, v_z$</td>
</tr>
<tr>
<td>F</td>
<td>40</td>
<td>6</td>
<td>3, 6</td>
<td>105-165</td>
<td>Autocorrelation $\frac{n(O^+)}{N_e}, v_z$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$z &lt; 225 \text{ km}: T_e, T_i$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$z &gt; 225 \text{ km}: T_e, T_i, v_z$</td>
</tr>
<tr>
<td>G</td>
<td>100</td>
<td>15</td>
<td>15</td>
<td>165-315</td>
<td>Autocorrelation $\frac{n(O^+)}{N_e}, v_z$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$z &gt; 225 \text{ km}: T_e, T_i, v_z$</td>
</tr>
<tr>
<td>H</td>
<td>200</td>
<td>30</td>
<td>30</td>
<td>215-515</td>
<td>Autocorrelation $T_e, T_i, v_z$</td>
</tr>
</tbody>
</table>
thereby yielding about 50 profiles of electron density, and electron and ion temperatures during a 24-hour run. These operations were termed "regular." A second type in which the C-mode experiment was repeated four times in each sequence was employed to achieve better measurements of the vertical drift above $h_{\text{max}}F_2$. These observations were termed "drift" runs. The time to complete a cycle of measurements during the "drift" runs was 45 minutes, so that only about 30 separate density and temperature profiles were obtained in 24 hours.

The value of $N_{\text{max}}$ to be employed in the data reduction was made available in the form of a measurement of the F-region critical frequency $f_{\text{o}}F_2$ in megahertz at the start of each cycle.* This measurement was made by the radar operator, who then typed the value into the computer which stored it, along with all the other information, on magnetic tape. To make the measurement, the C-4 ionosonde was modified to permit it to be turned on and monitored remotely, as well as to have its frequency controlled by a remote frequency synthesizer. Thus, the operator would turn on the sounder and advance the frequency of the synthesizer until the ordinary return was just perceived at great range. The synthesizer dials then gave the required value of $f_{\text{o}}F_2$.

The intent of this procedure was to create a data tape that contained all the information required for processing, so that this could be carried out immediately upon completion of a run. However, the radar operators frequently encountered difficulty in reading $f_{\text{o}}F_2$ especially at night. Thus, as a rule, these real-time estimates were not employed in the data analysis; instead, they were plotted as a function of time, together with those derived from the film records and values recorded at Ottawa, Canada, Maynard, Massachusetts (if available), and Wallops Island, West Virginia. A smooth curve was then drawn through this collection of points that followed the variation at Millstone, except when this was clearly at variance with the observations at all the other stations. Values were read from this curve at 30-minute intervals and punched onto IBM cards. The recorded data were then processed employing values of $N_{\text{max}}$ for the electron-density profiles obtained by linear interpolation between the values available at half-hour intervals. The measurements made with single long pulses (modes A to C) essentially yield $N_e$, $T_e$, $T_i$, and $v_z$ over the altitude range 200 to 1000 km, approximately (Table II), and recently have been used to obtain the $H^+/O^+$ ratio at high altitudes.  

For completeness, mention should be made that the measurements made with pairs of pulses provide results at lower altitudes. Normally, a sequence of modes E through H is employed to gather data on $N_e$, $T_e$, and $T_i$ over the altitude range 100 to 500 km, approximately (Table III). However, as noted above, these data are not included in this report.

The quantities measured in each observing mode (echo power vs delay and frequency) are stored on magnetic tape for later processing. This is conducted on the XDS 9300 computer using FORTRAN programs written specifically to handle the "one-pulse" and "two-pulse" data sets. A program known as "ANALYSIS" is employed for the one-pulse data and "MUPMAP" for the multiple-pulse data.

C. Observations

The dates and times on which the "regular" and "drift" single-pulse measurements were made in 1970 are listed in Table IV. An effort was made to operate the radar in each mode for 24 hours every month. In one instance (30-31 October 1970), a large portion of the measurements

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*N_{\text{max}} = 1.24 \times 10^4 (f_{\text{o}}F_2)^2 \text{ el/cm}^3 \text{ when } f_{\text{o}}F_2 \text{ is expressed in megahertz.}
<table>
<thead>
<tr>
<th>Date</th>
<th>C*</th>
<th>EST</th>
<th>Date</th>
<th>C*</th>
<th>EST</th>
<th>Mean Kp</th>
<th>Obs†</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 January</td>
<td>Q</td>
<td>0900</td>
<td>7 January</td>
<td>Q</td>
<td>0900</td>
<td>1</td>
<td>Reg</td>
<td>Low antenna gain. Poor drift data at night.</td>
</tr>
<tr>
<td>20 January</td>
<td>1130</td>
<td></td>
<td>21 January</td>
<td></td>
<td>1200</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17 February</td>
<td></td>
<td>0930</td>
<td>18 February</td>
<td></td>
<td>0930</td>
<td>2+</td>
<td>Reg</td>
<td>Noisy TR tube. Frequency synthesizer out of lock -</td>
</tr>
<tr>
<td>23 February</td>
<td>1500</td>
<td></td>
<td>24 February</td>
<td>D</td>
<td>1500</td>
<td>3-</td>
<td>Drift</td>
<td>Poor drift data.</td>
</tr>
<tr>
<td>17 March</td>
<td>Q</td>
<td>1030</td>
<td>18 March</td>
<td></td>
<td>1030</td>
<td>2-</td>
<td>Reg</td>
<td></td>
</tr>
<tr>
<td>23 March</td>
<td>Q</td>
<td>1600</td>
<td>24 March</td>
<td>Q</td>
<td>1545</td>
<td>0+</td>
<td>Drift</td>
<td>Very quiet</td>
</tr>
<tr>
<td>14 April</td>
<td></td>
<td>0900</td>
<td>15 April</td>
<td></td>
<td>0900</td>
<td>1-</td>
<td>Reg</td>
<td></td>
</tr>
<tr>
<td>28 April</td>
<td></td>
<td>0800</td>
<td>29 April</td>
<td></td>
<td>0800</td>
<td>1+</td>
<td>Drift</td>
<td></td>
</tr>
<tr>
<td>12 May</td>
<td></td>
<td>1500</td>
<td>19 May</td>
<td></td>
<td>1500</td>
<td>1+</td>
<td>Drift</td>
<td></td>
</tr>
<tr>
<td>18 May</td>
<td></td>
<td>1500</td>
<td>11 June</td>
<td></td>
<td>0200</td>
<td>2-</td>
<td>Reg</td>
<td></td>
</tr>
<tr>
<td>10 June</td>
<td></td>
<td>1900</td>
<td>24 June</td>
<td></td>
<td>1900</td>
<td>1+</td>
<td>Drift</td>
<td></td>
</tr>
<tr>
<td>23 June</td>
<td>QQ</td>
<td>1900</td>
<td>8 July</td>
<td></td>
<td>1200</td>
<td>2-</td>
<td>Reg</td>
<td></td>
</tr>
<tr>
<td>7 July</td>
<td>QQ</td>
<td>1300</td>
<td>19 July</td>
<td>QQ</td>
<td>1100</td>
<td>1+</td>
<td>Drift</td>
<td></td>
</tr>
<tr>
<td>18 July</td>
<td>QQ</td>
<td>0830</td>
<td>13 September</td>
<td></td>
<td>1400</td>
<td>2-</td>
<td>Drift</td>
<td>Disturbed. Storm sudden commencement at 1204 EST</td>
</tr>
<tr>
<td>17 August</td>
<td>D</td>
<td>1430</td>
<td>18 August</td>
<td>D</td>
<td>1500</td>
<td>5-</td>
<td>Drift</td>
<td>on 16 August. Poor data between 1700 and 2200 EST.</td>
</tr>
<tr>
<td>24 August</td>
<td>QQ</td>
<td>1400</td>
<td>25 August</td>
<td></td>
<td>1400</td>
<td>2-</td>
<td>Drift</td>
<td></td>
</tr>
<tr>
<td>31 August</td>
<td></td>
<td>1400</td>
<td>1 September</td>
<td>D</td>
<td>1430</td>
<td>3-</td>
<td>Reg</td>
<td></td>
</tr>
<tr>
<td>16 September</td>
<td></td>
<td>0930</td>
<td>17 September</td>
<td></td>
<td>0930</td>
<td>2-</td>
<td>Reg</td>
<td></td>
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<tr>
<td>28 September</td>
<td>Q</td>
<td>1500</td>
<td>29 September</td>
<td>QQ</td>
<td>1400</td>
<td>1+</td>
<td>Drift</td>
<td></td>
</tr>
<tr>
<td>5 October</td>
<td>Q</td>
<td>1500</td>
<td>6 October</td>
<td></td>
<td>1500</td>
<td>1+</td>
<td>Reg</td>
<td></td>
</tr>
<tr>
<td>13 October</td>
<td></td>
<td>1400</td>
<td>14 October</td>
<td></td>
<td>1500</td>
<td>2-</td>
<td>Drift</td>
<td></td>
</tr>
<tr>
<td>31 October</td>
<td>Q</td>
<td>0730</td>
<td>1 November</td>
<td></td>
<td>1900</td>
<td>1-</td>
<td>Reg</td>
<td></td>
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<tr>
<td>7 November</td>
<td></td>
<td>0830</td>
<td>9 November</td>
<td></td>
<td>0800</td>
<td>2+</td>
<td>Drift</td>
<td></td>
</tr>
<tr>
<td>storm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 December</td>
<td>Q</td>
<td>1530</td>
<td>22 December</td>
<td></td>
<td>1600</td>
<td>1+</td>
<td>Reg</td>
<td></td>
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<tr>
<td>28 December</td>
<td></td>
<td>1600</td>
<td>29 December</td>
<td></td>
<td>1600</td>
<td>2+</td>
<td>Drift</td>
<td></td>
</tr>
</tbody>
</table>

*Condition:

QQ One of five quietest days in month
Q One of ten quietest days in month
D One of five most disturbed days in month

†Observations:

Data gathered and analyzed as described in Lincoln Laboratory Technical Report 477 (Ref. 23).
Reg = Regular; Drift = Drift Measurement.
was destroyed by a computer malfunction and only 11 hours of useful data were obtained. We have discarded these results in what follows. Likewise, a second short run (5 hours) on 24 November has not been included.

Beginning in 1968, a number of observations were scheduled to coincide with passes of Alouette II at the request of scientists at the NASA Goddard Space Flight Center. During 1970, there were many close passes of the satellites ISIS I, OGO VI, and Alouette II by Millstone Hill. Where possible, the regular monthly operations were scheduled to coincide with favorable passes, and Table V lists the satellite overflights of Millstone that occurred in routine operations scheduled with this in mind. The primary purpose of the measurements made during the passes of

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (EST)</th>
<th>Height (km)</th>
<th>Satellite</th>
<th>Date</th>
<th>Time (EST)</th>
<th>Height (km)</th>
<th>Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 January</td>
<td>1544</td>
<td>1060</td>
<td>OGO VI</td>
<td>18 May</td>
<td>1809</td>
<td>576</td>
<td>Alouette II</td>
</tr>
<tr>
<td>7 January</td>
<td>1544</td>
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OGO VI was to permit comparisons of electron and ion temperatures deduced by remote sounding and in situ probe measurements, and most of the results of this exercise have been reported.

During 1969, the first attempts were made to conduct coordinated measurements with Dr. J. Noxon (Harvard University) who, at that time, was measuring the 5577 Å, 6300 Å, and other emission lines from the night sky, at the Blue Hills Observatory, Boston, Massachusetts. The principal objective of this joint effort was to observe a stable auroral red (SAR)-arc, and determine if the 6300 Å emission could be accounted for in terms of impact excitation due to the
high temperature of the electrons. In this the effort proved to be disappointing, as no overhead SAR-arcs were observed. However, on three occasions (one in 1970) Dr. J. Noxon alerted us to the presence of low-latitude auroral activity and valuable optical and radar results were gathered simultaneously. These joint observations have been the subject of a separate report.²⁷

D. Data Analysis

Beginning in July 1968, the results were gathered in a manner that placed together all the quantities of interest on a single data tape so that complete machine reduction became possible. The computer programs employed are described in Ref. 25. Basically, the electron-density profiles were obtained in a way that: (1) combined measurements made with the three pulse lengths, (2) removed spurious echoes due to satellites, (3) adjusted the absolute value to yield the correct value of \(N_{\text{max}} F2\) as measured on the ionosonde, and (4) removed the dependence on altitude variations of \(T_e/T_i\) and on the Debye length. This profile was available as a graph plotted by a Calcomp plotter, and on a printout as \(\log_{10} N_e\) vs altitude.²⁵ Estimates of \(T_e\) and \(T_i\) also were provided on plots and on the printout. The values of \(T_e\) were corrected for the effects of the changing Debye length with altitude.²⁵

It should be noted that the estimates of \(T_e\) and \(T_i\) were obtained by extracting two parameters from the measured spectra, viz., the half-peak-power width (proportional to \(T_e\)) and the ratio of the peak power in the wings to that at the center frequency (proportional to \(T_e/T_i\)). These values were inserted into analytical expressions that had been obtained to represent \(T_e\) and \(T_i\) as functions of the ratio and width through scaling theoretical power spectra computed assuming only \(O^+\) ions are present and that the Debye length is extremely small. In computing these theoretical power spectra, the effects of the transmitter pulse and the finite width of the filters in distorting the measurement were included.

To correct the estimate of the electron temperature \(T_{e,\text{obs}}\) obtained in the above manner for the effect of the change in the Debye length on the spectrum, use was made of the expression²⁵

\[
T_e = T_{e,\text{obs}} \left(1 - \frac{1.62 \times T_{e,\text{obs}}}{N_e}\right)^{-1}
\]

Unfortunately, this expression holds only so long as the second term in the parentheses remains <0.3. At high altitudes, \(T_{e,\text{obs}}\) may be of the order of 2000 to 3000°K and the correction then becomes inaccurate as \(N_e\) approaches \(10^4\) el/cm³. Thus, the electron temperatures obtained near or above this level are believed to be overestimates.

The results presented in this report extend only to 900 km altitude and hence, as a rule, the daytime temperatures do not suffer from this source of error. At night, the echoes returned from altitudes where the electron density is less than \(10^4\) el/cm³ are frequently so weak that the temperatures obtained from the spectra exhibit considerable scatter and are not reliable. The automatic data compression scheme described in Sec. III usually eliminates such data points so that the contour diagrams for the electron and ion temperatures generally are left blank in these regions.

A second source of error in the temperature estimates obtained at high altitudes has been the neglect of the presence of \(H^+\) ions in the interpretation of the spectra. Recently, a computer program has been written that permits these spectra to be reanalyzed to yield estimates of \(T_{e'} T_{i'}\)
and the ratio of $O^+$ to $H^+$ ions. This program attempts to match the observed spectra computed for various temperatures and composition ratios. Unfortunately, the program is quite slow and requires several hours of computer time (using the Millstone Hill XDS 9300 computer) to analyze a single day's measurements. Accordingly, no attempt has been made to reanalyze all the 1970 results. However, based on the results obtained for five days in 1969, it appears that the temperatures below 900 km will be in error only for a short interval between midnight and sunrise and that the error will be confined largely to altitudes above 750 km. In practice, this is also the region that is suspect because of the large correction that must be made for the effect of the Debye length.

A third source of error in the temperature results is introduced (chiefly at low altitudes) by the imperfect match provided by the filters used to measure the spectra when transmitting 0.5-msec pulses (B-mode). Empirical corrections were derived to compensate for this effect and the ANALYSIS program modified to print out both the corrected and uncorrected results.

The ANALYSIS program provides a data plotting tape from which plots of $N_e$, $T_e$, and $T_i$ vs altitude are generated on a Calcomp plotter. To reduce the large number of independent profiles as well as smooth the data with respect to time (and thereby reduce some of the scatter in the measurements), it has been the custom to prepare diagrams which show, as a function of altitude and time, the variation of contours of constant density and temperature. As described previously, the first step in this process is to transfer from the vertical profiles sets of points representing particular values (of density or temperature) to their correct locations in height and time on the contour plot. These points are next connected by straight lines. The second step is to trace this "coarse" diagram using a French curve to best follow the trend of each contour. In this process the random errors from profile to profile are reduced, albeit with some smoothing of real variations.

This last step is somewhat subjective and the presence of true fluctuations from cycle to cycle introduced, for example, by TIDs makes it difficult to be consistent in the amount of smoothing one introduces.

This method of data presentation also has the drawback that it renders the results unsuited to machine processing. Consequently, we have frequently been asked to provide other users with copies of the ANALYSIS printouts. That is, although height profiles of a given parameter (or the time variation of a parameter at a given height) can be recovered from the contour diagrams, some detail is invariably lost and the operation is tedious and time-consuming.

In 1970, the hand production of contour diagrams was superseded by a method of data compression in which the results are represented in analytical form by fitting a two-dimensional polynomial expression. This is performed by the XDS 9300 computer using a program called INSCON. This is a flexible, modular FORTRAN program which also prepares contour plots from the fits and punches the parameters of the fit on IBM cards so that the smoothed results may be recovered later. INSCON is described in the next section.

III. DATA REDUCTION

A. Preparation of the Data

Prior to fitting an analytical function to the derived value of $N_e$, $T_e$, $T_i$, or $v_z$, an effort is made to eliminate bad points and assure that there are sufficient points in each height-time cell for the fit to be meaningful. INSCON reads the one-pulse (or two-pulse) data from the
master tape written by either the ANALYSIS or MUPMAP programs used to analyze the raw
data.

One-pulse electron-density data are read from the Analysis Master Tape by a subroutine.
These data are at altitudes ranging from 161 to 950 km. After these data have been read, they
are filtered to remove bad points. Density estimates between 164 and 229 km are first examined
for contamination by clutter. These data points are required to decrease monotonically with de-
creasing altitude. If this condition is not satisfied at some altitude, the data from that point
down are rejected. Since the polynomial fitting procedure requires initial guesses for the re-
jected data, the rejected densities are estimated by extrapolating linearly downward from the
two lowest accepted points. Data above 400 km are next examined to insure that the density de-
creases monotonically with height. If the density at any height is greater than at the next lowest
height, it is rejected. Rejected densities are estimated to be equal to the next lower acceptable
point. All previously accepted data are now checked to insure that $2.5 \leq \log_{10}{(N_e)} \leq 8.0$. If this
condition is not satisfied, all data at this time are now rejected.

A "box score" is now developed. This is an $M \times N$ table, where $M$ is the number of exper-
iment times and $N$ is the number of experiment altitudes. The tabulated number is 1 if the cor-
responding datum has been accepted and 0 if the corresponding datum has been rejected. The
box score is next examined to determine which regions contain too many rejected points for the
polynomial fit to be trustworthy. All box-score entries in regions where the fit is expected to
be good are set equal to 1. The table is then examined to determine if there are any time gaps
of more than two hours. If so, the tabular entries flanking the time gap are set equal to 2. The
resulting status table is then printed.

One-pulse electron temperature and ion temperature data are next read from the Analysis
Master Tape by another subroutine. These data are at 75-km intervals from 225 to 1125 km.
INSCON uses B-mode (0.5-msec pulse) data at 225, 300, and 375 km and C-mode data from 450
to 1125 km. If there is more than one set of C-mode observations, the data at each height are
averaged. No account is taken of the variation in returned power from different points within
the scattering volume. A procedure for correcting for this effect has been developed that entails
integrating the analytic expressions obtained from the INCON fit (Sec. III-G).

After the temperatures at each experimental time have been read from the Analysis Master
Tape, the B-mode data are empirically corrected for known systematic errors. The data are
then filtered to remove bad points. The corrected B-mode data are first compared with the
C-mode data to insure that the data from the two modes are reasonably consistent. The ion tem-
peratures at 450 and 525 km are averaged for each mode. If the two averages differ by more
than 20 percent, all three B-mode temperatures are rejected. The data also are checked to in-
sure that all temperatures above 825 km are greater than 1000°K and that no temperatures are
greater than 6000°K.

The rejected data are now estimated by passing a cubic through the nearest five accepted
points. An "anchor point" is then added at 150 km by extrapolating exponentially downward from
the temperatures at 225 and 300 km. This anchor is designed to prevent unreasonable behavior
of the fit near 225 km and not to provide a realistic estimate of the temperature below 225 km.

The data at 975, 1050, and 1125 km are now replaced by a linear fit. This procedure helps
to keep the final INCON fit reasonable at high altitudes. Finally, all temperatures are checked
to insure that they are less than 6000°K. As with one-pulse electron densities, the box-score
and status table are now determined and printed.
One-pulse vertical ion drift data are read from the Analysis Master Tape. These data are at 75-km intervals from 225 and 1125 km. As with one-pulse temperature data, the velocities at 225, 300, and 375 km are B-mode data, the velocities above 300 km are C-mode data, and all altitudes are "nominal" altitudes.

After the velocities at each experimental time have been read from the Analysis Master Tape, they are filtered to remove bad points. First, the velocity at any time and altitude is rejected if the temperature data at that point do not lie within the bounds specified in the discussion of one-pulse temperatures. Next, the values for any missing points are estimated by passing a straight line through the four good velocities nearest the rejected value. The velocities at 975, 1050, and 1125 km are replaced by values obtained by fitting a straight line to the velocities between 750 and 1125 km. Finally, the velocity at 900 km is replaced by a value obtained by passing a parabola through the velocities between 750 and 1050 km. This high-altitude smoothing helps to keep the final INS CON fit reasonable at high altitudes. As with one-pulse electron densities and temperatures, the box-score and status table are now determined and printed.

B. Least-Mean-Squares Polynomial Fitting

The algorithm used by INS CON to fit a two-dimensional polynomial to the input data is discussed in this section. This procedure is identical for all types of input data. A good reference on least-squares estimation is Hauck's "Foundations for Estimation by the Method of Least Squares."

Consider m experimental data \( z_1, z_2, \ldots, z_m \), each of which corresponds to a particular value \( x_1, x_2, \ldots, x_m \) of the variable \( x \). We wish to find coefficients \( b_j \) which minimize the sum of squares

\[
S = \sum_{i=1}^{m} \left( z_i - \sum_{j=1}^{M} b_j P_j(x_i) \right)^2
\]

(1)

where the \( P_j(x_i) \) are \( M \) linearly independent functions of \( x_i \). Defining \( P_{ij} = P_j(x_i) \), differentiating Eq. (1) with respect to \( b_k \) and setting \( \partial S / \partial b_k = 0 \), one arrives at the normal equations,

\[
\sum_{j=1}^{M} \sum_{i=1}^{m} b_j P_{ik} P_{ij} = \sum_{i=1}^{m} P_{ik} z_i
\]

(2)

To solve this equation for the \( b_j \), one must invert the matrix \( P^T P \) where

\[
P = \begin{bmatrix}
P_{11} & \cdots & P_{1M} \\
\vdots & \ddots & \vdots \\
P_{m1} & \cdots & P_{mM}
\end{bmatrix}
\]

If \( M \) is large, the inversion of \( P \) may be very difficult. In INS CON, \( M \) may be as large as 1024. For most choices of the functions \( P_j(x) \), the inversion of \( P^T P \) would then be completely
impractical. Suppose, however, that there exists a set of $P_j$ which satisfies the orthonormality condition for the data set under consideration, that is:

$$\sum_{i=1}^{m} P_{ik} P_{ij} = \delta_{kj}, \quad k = j$$

$$\sum_{i=1}^{m} P_{ik} P_{ij} = 0, \quad k \neq j.$$  \hspace{1cm} (4)

In this special case, the solution of the normal equations is simply

$$b_j = \sum_{i=1}^{m} P_{ij} z_i.$$  \hspace{1cm} (5)

In general, given a complete, linearly independent set of functions $P_j(x)$, a complete, linearly independent and unique orthonormal set may be derived from the $P_j(x)$ by means of the Gram-Schmidt orthogonalization procedure. If the $P_j$ are polynomials in $x$, there also exists a recursion relation for the orthonormal $P_j'$, namely

$$P_j(x) = (x - \gamma_j) P_{j-1}(x) - \delta_j P_{j-2}(x) \quad j = 1, 2, \ldots n$$

with

$$P_{-1}(x) = 0$$

$$P_0(x) = 1$$

and

$$\gamma_j = \frac{\sum_{i=1}^{m} x_i^2 P_{i,j-1}^2}{\sum_{i=1}^{m} P_{i,j-1}^2}$$

$$\delta_j = \frac{\sum_{i=1}^{m} x_i P_{i,j-1} P_{i,j-2}}{\sum_{i=1}^{m} P_{i,j-2}^2}.$$  \hspace{1cm} (6)

So far we have assumed that the data $z_i$ are functions of a single parameter $x_i$. In fact, INSCON deals with data which are functions of two variables, time and altitude. Consider then, two-dimensional polynomials in $x$ and $y$. Equations (2) through (5) are still valid if $i$ is assumed to run over all experimental points and $j$ runs over all combinations of the one-dimensional polynomials in $x$ and $y$. For a general data set, there is no recursion relation corresponding to Eq. (6). However, if the data lie on a rectangular grid, the required orthonormal polynomials are simply the products of the one-dimensional orthonormal polynomials given in Eq. (6). That is, if

$$\sum_{i=1}^{m} P_j(x_i) P_k(x_i) = \delta_{kj} \quad x_i = x_1, x_2, \ldots x_m$$
and

$$\sum_{i=1}^{n} Q_i(y_i) Q_j(y_i) = \delta_{kj} \quad y_i = y_1, y_2, \ldots, y_n \quad (7)$$

then

$$\sum_{i=1}^{m} \sum_{i'=1}^{n} P_j(x_i) P_k(x_i) Q_j(y_i) Q_k(y_i) = \delta_{kj} \delta_{k'j'} \quad (8)$$

and the desired two-dimensional orthonormal polynomials are

$$T_{jj'}(x_i, y_{i'}) = P_j(x_i) Q_j(y_{i'}) \quad j = 1, M; \quad j' = 1, N \quad (8)$$

The $M \times N$ term INSCON polynomial will then be

$$V(x_i, y_{i'}) = \sum_{j=1}^{M} \sum_{j'=1}^{N} b_{jj'} T_{jj'}(x_i, y_{i'}) \quad (9)$$

The method described above is used in INSCON. The independent variables $x$ and $y$ are time and altitude, respectively. The experimental measurements $z$ may be electron density, electron temperature, ion temperature, etc. INSCON first uses Eq. (6) to calculate one-dimensional polynomials which are orthonormal over the experimental times and altitudes, respectively. These polynomials are then combined as in Eq. (8) to form two-dimensional orthonormal polynomials. Finally, coefficients $b_{jj'}$ are evaluated by means of Eq. (5).

In practice, good data may not be present at certain times and altitudes. In this case Eq. (5) is invalid. However, the method may still be used by applying Eq. (5) iteratively. For the first iteration, a first guess based on surrounding data is used in place of the missing datum. During subsequent iterations, the fit value from the preceding iteration is used as an approximation to the missing datum. This procedure usually converges very quickly.

A further complication is the deterioration of the fit near its end points, e.g., near the lower and upper altitude limits and the earliest and latest experimental times. This is due to the well-known Runge phenomenon which often afflicts high-order polynomial interpolation and least-squares fitting. Ideally, one would like to use a basis set less subject to such difficulties; for example, piecewise polynomial functions. Unfortunately, the matrix inversion required, were such a basis set to be adopted, would be too time consuming to be practical.

An alternative approach, which has been implemented in INSCON, is the addition of "anchor points" beyond the end points of the experimental data. In general, anchor data are added at two times preceding the earliest experimental time and at two times following the latest time. The datum at each of these points is estimated by least-squares linear extrapolation of the three data points nearest in time and at the same altitude as the anchor points. The procedure used to anchor the data near the altitude limits of the experimental points varies with the type of data. In some cases additional anchor points are added by extrapolating from nearby experimental data. For example, anchor points at 150 km are used in the fits to one-pulse $T_e$, $T_i$, and $v_z$. On the other hand, at the upper altitude limit of these parameters additional data points are not added. Instead, the data at the three highest altitudes (975, 1050, and 1125 km) are smoothed before the INSCON polynomial is fit to the data. In any event, while the fit beyond the actual
data may behave reasonably due to the anchor points, it is not to be trusted. INSCON does not plot contours beyond the limits of the actual experimental data, and if an attempt is made to recover data in these regions by means of the recovery routines described in Sec. III-E, zero is returned.

For the INSCON fits to be really useful, the uncertainty of the polynomial must be known. This may easily be calculated from the punched INSCON output parameters. In general, the error bar on the polynomial fit at a given time and altitude will be less than the error bar on the corresponding experimental point.

Suppose that the variance $\sigma^2$ of the experimental data is known. Then given the INSCON error matrix $\Xi = (T^T I)^{-1}$, the uncertainties in the polynomial coefficients $b_{ij}$ may be calculated from

$$
\Delta b_{ij}^2 = \Xi_{ij} \sigma^2 .
$$

The error in the INSCON fit values $V(x_i', y_i)$ is then given by the well-known error propagation formula

$$
\Delta V(x_i', y_i')^2 = \sum_{i=1}^{m} \sum_{i'=1}^{n} \left( \frac{\partial V(x_i', y_i', x_i, y_i)}{\partial b_{ij}} \right)^2 \Delta b_{ij}^2 .
$$

The variance of the experimental data may be estimated from the scatter of the data about the INSCON fit. The INSCON output deck includes the time averaged square deviation $s_{ij}^2$ of the experimental points from the INSCON fit at each experimental altitude. This gives a reasonable estimate of the variance at any point, since the variance is much more dependent on altitude than time. We can then estimate $\sigma_{ij}^2$ by

$$
\sigma_{ij}^2 = \frac{s_{ij}^2}{m - M} .
$$

Of course, another estimate of the variation of $\sigma$ could be used in Eq. (10) based, for example, on the signal-to-noise ratio.

C. Contour Plots

After the least-squares fit to a data set has been calculated, a plotting subroutine is loaded into the computer, overlaying the data preparation subroutine. Separate subroutines exist for the types of data currently being routinely processed by INSCON. The contour plotting routines first evaluate the polynomial fit on a 121 (time) x 37 (altitude) grid. A subroutine ZCONTR is then called to find contour paths through the table. Labeling, the separation of the contours, the range of the contours, and the altitude range are fixed for each of the conventional data types. All contour diagrams have been compared with those generated by hand for 1970. In general, the agreement appears to be good, but there are differences apparently stemming from the different amounts of smoothing applied in the two methods.

D. Punched Card and Magnetic Tape Output

For each polynomial fit calculated, INSCON punches a deck of cards from which the fit may later be recovered. These cards are a convenient medium for the external distribution of selected fits, but are somewhat unwieldy in applications which require the routine processing of many INSCON fits. Consequently, new INSCON decks are transferred to a magnetic tape known
as the CONSUM tape by means of the FORTRAN program CONSUM. Each deck is stored on this
tape as one long (6949 word) record. The first two cards of each INSCON deck contain two num-
bers (FIT NO. and KDAT) which uniquely specify the fit. CONSUM first reads the new INSCON
deck and stores them on tape. A new CONSUM tape is then created from the card images of the
new decks and the old CONSUM tape. Each new fit is inserted in the new tape in proper chronolo-
gical order. If a new deck has the same two identification numbers as a fit already on the old
CONSUM tape, the old fit is replaced by the new fit. Finally, a summary of the new tape is
printed.

Several years' data may be stored on a single magnetic tape. This tape may be used in two
ways. First, if a copy of a particular fit or fits is needed for external distribution, the corre-
sponding FIT NO.s and KDATs may be punched on IBM cards and input to CONSUM. CONSUM
then scans the CONSUM tape and punches copies of the specified decks.

The INSCON summary table also includes test values which are used to assure that the
parameters on the CONSUM tape indeed correspond to the parameters calculated by INSCON.
Each time CONSUM generates a new summary tape, it evaluates the INSCON polynomial at the
earliest experimental time and lowest altitude. This value is then printed in the INSCON sum-
mary table. Comparison with the original INSCON printed output ensures the integrity of the
parameter set.

E. Recovery of Height Profiles or Time Variations

The INSCON fit to any data set may be recovered at a later time by means of the FORTRAN
recovery subroutines RCVR, RCVR1 and RCVRP. Given the INSCON fit parameters, these sub-
routines recover the polynomial representation of the data at any time and altitude within the
range of the data. The user of these routines is thereby relieved of the necessity of knowing in
detail the meaning of the INSCON fit parameters.

Given the INSCON fit parameters, the time, and the altitude, RCVR returns the value of the
polynomial fit at the specified time and altitude. The fit parameters are normally transferred
to RCVR in a labeled common block, while the time, altitude, and fit value are transferred via
the RCVR argument list. If an attempt is made to recover a fit value outside the time or alti-
tude limits of the experimental data, RCVR returns 0. If an attempt is made to recover a fit
value P in a region in which INSCON determined that the quality of the fit was questionable,
RCVR returns -P. The user must then decide whether to risk using this value, which may in
fact be a reasonable interpolated value. This procedure for indicating questionable points re-
quires that the INSCON polynomial be positive definite. To ensure this, data which may be nega-
tive are shifted upward by a constant. For example, instead of fitting the vertical ion drift v_z
directly, INSCON fits v_z + 300 m/sec. This shift is included among the INSCON fit parameters,
but must be applied by the user in his applications program. RCVR1 is similar to RCVR, but
in addition to the fit value, RCVR1 returns the time and altitude derivatives of the polynomial
fit.

RCVRP may be used if the user wants a periodic approximation to the polynomial fit rather
than the fit itself. This has proved useful in several applications. In addition to the time and
altitude, the user must specify the 24-hour period on which the periodic approximation is to be
based. RCVRP then returns values for the fit quantity and its time and altitude derivatives
based on values RCVRP obtains from RCVR1. If the experimental data span is less than 20 hours,
RCVRP makes no attempt to recover values within the gap; instead, zeroes are returned. If the
data span is more than 24 hours, RCVRP subtracts a linear trend from all recovered data. If the data span is between 20 and 24 hours, the Millstone cubic spline interpolation routine SPLN3A is used to calculate interpolated values of \( Q, \frac{\partial Q}{\partial t}, \) and \( \frac{\partial^2 Q}{\partial t^2} \) within the gap.

Two FORTRAN subroutines are available to input INSCON fit parameters to a users application program: *CREAD* reads INSCON card decks and stores the fit parameters in labeled common storage; *TREAD* searches the CONSUM tape (Sec. D) for a specified fit and stores these parameters in labeled common storage. By using one of the input routines together with one of the recovery routines, the user is able to recover INSCON fit values without having detailed knowledge of the INSCON fit parameters or the way in which they are stored on cards or tape. Detailed instructions for using these routines have been made available to some users and are contained in the Appendix of this report.

F. Vertical Gradients

By using the FORTRAN subroutines RCVR, RCVR1 and RCVRP, the INSCON fit values and their first derivatives in altitude and time may be recovered from the fit parameters punched on cards by INSCON. The recovered values may then be combined to form derived quantities such as particle or heat fluxes. While, in principle, this is very simple, there are some fairly substantial practical difficulties stemming primarily from the large amount of information contained in each set of INSCON cards. Each fit requires 6949 words of storage in the XDS 9300. As a consequence, at Millstone, programs using INSCON results usually make extensive use of the rapid access drum (RAD), and must also be segmented.

In order to make the INSCON fits more useful in view of these difficulties, a general-purpose FORTRAN program (DERQ) to calculate derived quantities has been written. All segmentation, RAD usage, and major bookkeeping are handled by general-purpose routines. To calculate a specific derived quantity or set of quantities, the user need only supply a set of data cards and a subroutine to calculate the desired quantities.

In a single run of DERQ, up to 8 different derived quantities \( DQ \) may be calculated at as many as 32 altitudes and 64 times. The \( DQs \) may be functions of as many as 16 quantities \( Q, \frac{\partial Q}{\partial t}, \frac{\partial Q}{\partial h}, \frac{\partial^2 Q}{\partial h^2} \), where \( Q \) is any quantity for which an INSCON fit exists. The necessary INSCON cards may either be read in directly as cards or read from the INSCON summary tape on which all INSCON results are ultimately stored. The latter case, the user need only specify the unique fit number which is assigned to each INSCON fit and which is listed on the summary printed after each update of the INSCON summary tape.

DERQ automatically writes an output tape which may later be used as input to INSCON if INSCON fits to the \( DQs \) are wanted. If desired, contour plots of the \( DQs \) are also automatically plotted by DERQ. These plots are produced by direct interpolation in the table of \( DQs \) calculated by DERQ and no INSCON type fit to the \( DQs \) is calculated.

G. Weighted Mean Height Correction

Measurements of electron and ion temperatures made with single long pulses represent a weighted average of the properties of the plasma illuminated by the pulse during the course of the measurement. At Millstone, a bank of filters matched to the pulse length \( T \) sec is used to explore the spectra. The return from a single electron in the ionosphere would cause the power at the output of the filter to rise linearly in a time \( T \) from zero to a peak and then fall to zero again in an equal time. Sampling the filters at any time \( t \) after the pulse has been transmitted
will permit the full power to be sampled from those electrons lying at a height \( z_0 = ct/2 \). Electrons at other altitudes \( z \) will contribute less power, i.e., their contribution will be weighted by the factor

\[
W = \left(1 - \frac{|z - z_0|}{w}\right)
\]

(13a)

where \( w = cT/2 \) is the instantaneous height interval occupied by the pulse. The electrons distributed over the altitude interval \( (z_0 - w < z < z_0 + w) \) that contribute to the estimate, yield an echo power \( P(z) \) which depends upon their number density \( N_e \), height \( z \), and electron-to-ion temperature ratio, approximately as

\[
P(z) \propto \frac{N_e}{z [1 + (T_e/T_i)z]}
\]

(14)

Since the echo power \( P(z) \) is measured in the profile measurements it is a simple matter to compute the effective or weighted height \( \bar{z} \) of the measurement

\[
\bar{z} = \frac{\int_{z_0-w}^{z_0+w} W P(z) \, dz}{\int_{z_0-w}^{z_0+w} W \, dz}
\]

(15)

provided that \( P(z) \) is known at shorter height intervals than the samples of spectra (gathered at intervals of every 75 km). Accordingly, weighted mean heights \( \bar{z} \) are computed for the 0.5- and 1.0-msec measurements from the A-mode (0.1 msec) power profile results and these are tabulated on the real-time data printout. These values of \( \bar{z} \) typically differ from values of the nominal height \( Z_0 = ct/2 \) by as much as 35 km for the C-mode (1 msec) results above \( h_{\text{max}}F2 \), where the \( N_e \) and \( z^2 \) terms in Eq. (14) cause less power to be returned from the higher altitudes. Thus, for precise work, allowance should be made for the difference between the nominal and effective pulse heights. This has been done in studies of the vertical particle fluxes, but, in general, has tended to be ignored owing to the fact that the values of \( \bar{z} \) are not stored on the real-time (RETIAS) data tape.

Accordingly, one of the first applications of DERQ has been to correct the INSICON fits to one-pulse \( T_e, T_i \), and \( v_z \) data for the inaccuracy arising from the use of nominal heights (i.e., the center of the pulse) in the initial INSICON fits. The version of DERQ which calculates this correction has been named HEQUIV. DERQ first reads the INSICON cards for \( N_e, T_e, T_i \), and \( v_z \). Values of these quantities are then recovered at all B- and C-mode nominal altitudes \( z_0 \). At each experimental time, DERQ then calculates the equivalent height \( \bar{z} \) corresponding to each B- or C-mode nominal height. The relation used is

\[
\bar{z} = \frac{\int_{z_0-w}^{z_0+w} W \frac{N_e(z)}{1 + (T_e/T_i)z} \, dz}{\int_{z_0-w}^{z_0+w} W \frac{N_e(z)}{1 + (T_e/T_i)z} \, dz}
\]

where \( z_0 \) is the nominal height and \( w \) is 75 km for B-mode data and 150 km for C-mode data. The quadratures are performed by a cubic spline interpolation, differentiation, and integration.
The experimental quantities $T_e$, $T_i$, and $v_z$ are now calculated at their nominal heights $z_0$ by using SPLN3A to interpolate between the values recovered from the original INSICON fit, and now assumed to be the correct value at the equivalent height $Z$. As discussed above, DERQ produces an output tape which contains the results of these interpolations and which can be read by INSICON which then produces new fits and a new set of contour plots. All plots for $T_e$, $T_i$, and $v_z$ given in this report are the corresponding plots after the equivalent height correction.

H. Total Electron Content

DERQ is also routinely used to calculate total electron content (TEC). This version of DERQ uses SPLN3A to integrate the measured electron density $N_e$ from 161 to 1000 km. The results at each experimental time are then tabulated. An example of the TEC results from 23-24 March 1970 is shown in Table VI.

<table>
<thead>
<tr>
<th>Time (UT)</th>
<th>TEC (161-1000 km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1611</td>
<td>3.4274E+14</td>
</tr>
<tr>
<td>1655</td>
<td>3.3502E+14</td>
</tr>
<tr>
<td>1740</td>
<td>3.0242E+14</td>
</tr>
<tr>
<td>1823</td>
<td>2.6251E+14</td>
</tr>
<tr>
<td>1908</td>
<td>2.2767E+14</td>
</tr>
<tr>
<td>1957</td>
<td>2.0151E+14</td>
</tr>
<tr>
<td>2040</td>
<td>1.8781E+14</td>
</tr>
<tr>
<td>2124</td>
<td>1.7852E+14</td>
</tr>
<tr>
<td>2208</td>
<td>1.7005E+14</td>
</tr>
<tr>
<td>2252</td>
<td>1.5992E+14</td>
</tr>
<tr>
<td>2336</td>
<td>1.4658E+14</td>
</tr>
<tr>
<td>0020</td>
<td>1.3047E+14</td>
</tr>
<tr>
<td>0103</td>
<td>1.1385E+14</td>
</tr>
<tr>
<td>0147</td>
<td>9.235E13</td>
</tr>
<tr>
<td>0230</td>
<td>8.5782E13</td>
</tr>
<tr>
<td>0314</td>
<td>7.7351E13</td>
</tr>
</tbody>
</table>

I. Uncertainties

DERQ also has been used to investigate the uncertainty of quantities derived from INSICON fits. Error bars for the INSICON fits themselves may be derived as discussed in Sec. III-B. In principle, given the INSICON polynomial coefficients and their uncertainties, the uncertainty in any quantity dependent on these coefficients also may be calculated. However, this calculation will be rather complex if the quantity whose uncertainty is sought contains derivatives of the INSICON polynomial. Examples of such quantities are the protonospheric heat flux and the divergence of the ion flux. The assumptions behind the calculation might also be called into doubt since INSICON does not necessarily provide unbiased estimates of arbitrary functionals of the INSICON fits.
An alternative procedure for investigating the uncertainty of quantities derived from INSCON fits is to use DERQ to perform a simulation study. Given the known scatter \( S \) of the original experimental data about the corresponding INSCON fit, a random number generator may be used to produce simulated data sets whose scatter about the original INSCON fit has the same magnitude and altitude dependence as the original data. INSCON fits may then be calculated for each of these simulated data sets. Each of these fits is in turn used to calculate the quantity whose uncertainty is being investigated. The results of these calculations will fluctuate about the results calculated from the original INSCON fits, providing a direct measure of the uncertainty of the derived quantity. This procedure is too time-consuming to be performed for every data set. However, by carrying the calculation out for a few representative data sets, one may determine typical uncertainties for the derived quantity.

IV. RESULTS

A. Electron Density

The electron-density contours are presented in Figs. 1(a–z) for the days and times listed in Table IV. These span the height interval 160 to 900 km and the full time of each set of observations. The contours are drawn for values \( \log_{10} N_e > 3.0 \) at intervals of \( \log_{10} N_e = 0.2 \). However, values of \( \log_{10} N_e \leq 4.0 \) at altitudes above \( h_{\text{max}} \) are not thought to be reliable.

A few general comments deserve to be made concerning Figs. 1(a–z). The results for 6–7 January and 20–21 January [Figs. 1(a) and (b)] at high altitudes at night are suspect owing to the reduced antenna gain resulting from the snowstorm damage and the existence of a noisy gas discharge tube in the TR system. Also on 17–18 August [Fig. 1(p)] the results between 1700 and 2000 EST are thought to be poor either because of external interference or a receiver malfunction. Other small outages occurred, as a consequence of transmitter or computer failures, but unless these exceeded about 1 hour [as on 12–13 May – Fig. 1(j)], the INSCON program managed to smooth through the gap.

We have described previously the two types of electron-density variation seen at Millstone on quiet days. Winter days exhibit higher daytime values of \( N_{\text{max}} \) with a single peak near noon. The layer thickness is less than in summer and \( h_{\text{max}} \) is typically \( \approx 240 \) to \( 260 \) km. Figures 1(a–c) provide good examples of this behavior. In the spring equinox, there is a rapid transition to the "summer" type of behavior, first seen in 1970 in the results obtained on 12–13 May [Fig. 1(j)]. The day-to-night variation of \( N_{\text{max}} \) is reduced in summer, largely because the daytime values appear depressed. The peak value is usually reached near ground sunset. In summer the thickness of the layer (measured by almost any criterion) is much larger than in winter and \( h_{\text{max}} \) is typically \( \geq 300 \) km. In 1970 the transition back to winter behavior occurred around the end of September [Fig. 1(t)].

We have also described particular modifications to these basic patterns caused by magnetic storms. In 1970 there appear to have been no instances when the trough was observed to move to the latitude of the station in the late afternoon as seen in 1967 and 1968, i.e., around sunspot maximum. Nor were instances of abnormally large evening increase of \( N_{\text{max}} \) observed that we have seen previously on the first day of a magnetic storm. However, it does appear that there was some manifestation of the lifting of the layer (induced by electric fields) that is responsible for this phenomenon on the evening of 17 August [Fig. 1(p)], as is evident by the very marked increase in \( h_{\text{max}} \) seen at this time and the large upward drift velocity \( v_z \) observed.
Fig. 1(a-z). Computer-drawn plots showing contours of constant log$_{10}$ $N_e$ (where $N_e$ is the electron density/cm$^3$) as functions of height and time for the measurements made in 1970 (Table IV).
Fig. 1(a-z). Continued.
Fig. 1(a-2). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
MILLSTONE HILL
14-15, APR. 1970
LOG 10 N

Fig. 1(a-z). Continued.
MILLSTONE HILL
26-29, APR, 1970
LOC 10 NE

Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. I(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
MILLSTONE HILL
05-06 OCT. 1970
LOC10NE

**Fig. 1(o-z). Continued.**
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
Fig. 1(a-z). Continued.
nighttime period of 17-18 August [Fig. 1(p)] is compared with that of the quiet day that followed
24-25 August [Fig. 1(q)]. It appears that the electron density below \( h_{\text{max}} \), \( F_2 \) remained high
\((\gtrsim 10^4 \text{el/cm}^3)\) down to lower altitudes throughout much of the disturbed night in contrast to the
quiet night. This suggests the presence of a weak ionizing flux of precipitating particles (electrons), and this interpretation is supported by the higher electron temperatures present on the disturbed night. During the day on 18 August, the density behaved much as expected, despite
the fact that this was a very disturbed period.

The observations of 31 October through 1 November were conducted jointly with the other
incoherent scatter radar facilities (St. Santin, Chatanika, and Arecibo) that participate in a pro-
gram organized by the Incoherent Scatter Working Group of Commission G (then Commission 3)
of the International Union of Radio Science (URSI). The intent was to gather observations during
a magnetically disturbed period. A class 2B flare was seen on the sun on 28 October at 0750 EST
and the joint observations were then scheduled to begin at 0900 EST on 30 October. This was
the day on which computer malfunctions marred much of the data. As it transpired, no magnetic
storm occurred and the observations were rescheduled.

On 4 November, a second 2B flare occurred on the sun at 2241 EST and this was followed
by a proton event observed by ATS-1. Unfortunately, in this instance other operations at Mill-
stone precluded our participation in the joint program prior to 0600 on 7 November. On this day,
\( N_{\text{max}} \) was very depressed until midafternoon. Normal behavior was exhibited on 8 November
[Fig. 1(x)].

The observations conducted on the evening of 9 March [Fig. 1(e)] appear to have been made
during an instance of overhead precipitation at Millstone that was responsible for a low latitude
red aura. The results for this night have been examined in considerable detail by Noxon and
Evans,27 and the reader is referred to that paper for a thorough discussion.

B. Electron Temperature

Contours of electron temperature spanning the range 225 to 900 km are presented in
Figs. 2(a-z) at 200°K intervals. In summer the electron temperature is characterized by a very
rapid increase (\(~2000°K\)) at sunrise which occurs at almost all levels in a space of 3 hours [e.g.,
Fig. 2(k)]. This rapid increase appears to commence when the solar zenith distance \( \chi \approx 105°\).
During the daytime, the electron temperature remains roughly constant at all levels until mid-
afternoon when a slow decrease to the nighttime level commences. The sunset decrease is less
rapid than the sunrise increase and extends over a 6- to 8-hour interval. At night the tempera-
ture is again roughly constant with time.

In winter the time variation of \( T_e \) is more complex. There is a marked increase at local
sunrise and \( T_e \) reaches a maximum a little after ground sunrise. Thereafter, there is often a
decline as the electron density increases [e.g., Fig. 2(b)]. At sunset there is a further decrease
which is arrested around 1700 to 1900 EST when heat from the magnetosphere is able to main-
tain the F-region temperature as the density decays [e.g., Fig. 2(y)]. The temperature may then
increase to almost its daytime value and remain at this level throughout much of the night. The
temperature usually decreases for a few hours prior to local sunrise [e.g., Figs. 2(a), 2(z)].
This decrease is thought to be caused by a density increase that commences a few hours after
midnight [e.g., Figs. 1(a), 1(z)].

The winter behavior has been explained as a consequence of heat supplied to the magneto-
sphere by photoelectrons escaping from the conjugate point which remains sunlit. During March
Fig. 2(a-z). Computer-drawn plots showing contours of constant electron temperature $T_e$ (in °K) as functions of height and time for the measurements made in 1970 (Table IV).
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
MILLSTONE HILL
23-24 FEB. 1970

Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
MILLSTONE HILL
17-18, MAR, 1970

(f)

Fig. 2(c-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2 (a-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
Fig. 2(a-z). Continued.
and October, conjugate sunrise occurs a few hours before local sunrise. Depending on the magni-

tude of the local electron density, the photoelectron flux established at conjugate sunrise

($\chi < 105^\circ$) may cause the temperature to begin increasing prior to local sunrise. Figures 2(u)

and 2(v) appear to provide clear examples of this behavior.

Anomalously high electron temperatures are associated with magnetically disturbed periods

and may be caused by heat conducted from the magnetosphere where it is generated by the decay

of ring current particles or created in situ by precipitation of soft electrons. Often it is im-

possible to distinguish between these sources except at night when, at Millstone, particle pre-

cipitation tends to fill in the valley between the E- and the F-layers. The very high temperatures

observed on 9 March [Fig. 2(c)] prior to midnight are thought to be associated with particle pre-

cipitation [cf., Fig. 1(e)]. The increase in $T_e$ after midnight is thought to be caused by conjugate

sunrise. As noted above, there is also evidence for particle precipitation during the evening

of 17 August [Fig. 1(p)] which appears to have maintained the electron temperature to high values

as late as 2200 EST.

The very low values of electron density during the daytime on 7 November caused the tem-

perature to be several hundred degrees above normal. This situation prevailed at least until

midnight. The heat flux conducted into the layer was also considerably higher on this day, sug-

gest ing that during 7 November considerable heat was being supplied to the local ionosphere by

the decay of ring current protons in the magnetosphere.

C. Ion Temperature

The ion temperature is plotted in the contour diagrams [Figs. 3(a-z)] at 100 K intervals.

At low altitudes (<350 km), $T_i$ varies in a similar fashion to the neutral temperature and values

of the exospheric temperature $T_\infty$ derived from these data have been reported by Salah and

Evans. At higher altitudes (400 to 700 km), heat supplied to the ions via coulomb encounters

with the electrons raises the ion temperature to a value intermediate between $T_\infty$ and $T_e$. With

increasing height, $T_i$ tends toward $T_e$ and begins to exhibit similar diurnal variations to those

described above.

D. Vertical Velocity

Contour diagrams for the vertical velocity $V_z$ are presented in Figs. 4(a-v). Owing to the
difficulty in extracting this parameter from the measurements, it is the first quantity to be seri-

ously degraded whenever the signal-to-noise ratio is reduced, or there are instrumental effects

which reduce the quality of the spectra. Accordingly, useful results were not obtained for this

quantity on 6-7 January, 20-21 January, 9 March and 7-9 November. On the first of these days,

there appears to have been a systematic bias in the measurements which may have been intro-

duced by the noise contributed by the poor gas discharge tube. On 20-21 January, the frequency

synthesizer employed as one of the receiver local oscillators became unlocked with the site mas-

ter frequency standard for a portion of the day, thereby introducing large errors in the drift

velocity estimates.

We have not previously attempted to present contour diagrams for $V_z$ owing to the large

scatter in the data and the seeming existence of a time-varying systematic difference in the re-

sults gathered by the B- and C-modes. The source of this difference was thought to be the use

(in 1969) of only half the B-mode filter bank for part of the year. However, analysis of data

gathered in later years suggests that it persisted when the full filter bank was back in use.
Fig. 3(a-z). Computer-drawn plots showing contours of constant ion temperature $T_i$ (in °K) as functions of height and time for the measurements made in 1970 (Table IV).
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(c-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 3(a-z). Continued.
Fig. 4(a-v). Computer-drawn plots showing contours of constant vertical velocity $v_z$ (m/sec) as functions of height and time recovered for some of the measurements made in 1970.
Fig. 4(a-v). Continued.
Fig. 4(a-v). Continued.
Fig. 4(a-v). Continued.
MILLSTONE HILL
14-15 APR 1970

Fig. 4(a-v). Continued.
Fig. 4(a-v). Continued.
Fig. 4(a-v). Continued.
Fig. 4(a–v). Continued.
Fig. 4(a-v). Continued.
Fig. 4(a–v). Continued.
Fig. 4(a-v). Continued.
Fig. 4(a–v). Continued.
Fig. 4(a-v). Continued.
Fig. 4(a–v). Continued.
Fig. 4(a-v) Continued.
Fig. 4(a-v), Continued.
Fig. 4(a-v). Continued.
Fig. 4(a-v). Continued.
Fig. 4(a-v). Continued.
Fig. 4(a-v). Continued.
Fig. 4a-v. Continued.
Fig. 4(a-v), Continued.
Here the C-mode results were employed for the nominal altitudes of >450 km. As we have
greater confidence in the C-mode results, this means that the contours drawn for the region
above ~400-km altitude are probably more reliable than those below.

The general behavior of the vertical velocity of the plasma over Millstone Hill has been dis-
cussed in a series of earlier papers. The most striking feature of the contour diagrams
is a period of large upward velocity in the region above \( h_{\text{max}} \) \( F_2 \) associated with the growth (and
thermal expansion) of the layer following sunrise. There is often a fairly well defined period of
downward velocity in this region near sunset.

During the daytime, the velocity is usually downward at all altitudes below about 500 km.
In this region, ion production exceeds loss so that ions migrate down to lower levels where the
recombination rate is higher. Above about 500 km, there is a transition to upward escaping
flux, which becomes fully developed by about 700 km. The magnitude of this escape flux in 1969
was the subject of special study. At night in summer, the drift at all levels appears to be
directed downward as the layer decays by sinking. In winter there appears to be more variabil-
ity, though the velocity tends to remain downward. The values obtained for high altitudes
 (>600 km) at night tend to be very erratic and probably these portions of the contour diagrams
should not be trusted.

The vertical velocity observed at Millstone may be represented as the sum of components
parallel to and perpendicular to the magnetic field in the north-south (N-S) meridian plane via

\[
v_z = 0.96v_{\parallel} + 0.28v_{\perp,N-S}
\]

where, in the F-region, the component perpendicular to the magnetic field is related to the east-
west (E-W) electric field in

\[
v_{\perp} = \frac{E_{E-W} \times B}{B^2}
\]

From separate measurements, it appears that on quiet days \( v_{\perp,N-S} < \pm 30 \text{ m/sec} \). Thus, with
some possible small error \( v_z \) may be taken as a measure of \( v_{\parallel} \). The velocity observed in the
vicinity of \( h_{\text{max}} F_2 \) depends upon the N-S component of the thermospheric wind and this allows
the component of the wind to be recovered from incoherent scatter measurements. Salah and
Holt have examined in detail results for two days in 1970 (23-24 March and 28-29 September)
using this approach.

An extension of this work has been the calculation of the zonal wind velocity using the ob-
served diurnal neutral temperature variation to describe the E-W pressure variation. That is,
the pressure (temperature) gradients in a local model for the neutral atmosphere (having fixed
lower boundary conditions) are simultaneously adjusted to produce the observed diurnal varia-
tion of exospheric temperature and meridional winds in the presence of the observed electron
concentrations (which establish the ion drag). This analysis has been applied to the results
reported by Salah and Holt by Roble and Antoniadis.49

More recently, Roble has combined the above neutral calculation with a photochemical
model for the ionosphere and was able to reproduce the electron density, and electron and ion
temperatures observed at Millstone on 23-24 March 1970. This appears to represent the most
complete use of information gathered by the incoherent scatter technique in testing ionospheric
theory yet attempted.
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APPENDIX
RCVR, RCVRI, RCVRP: USERS INSTRUCTIONS, LISTING
AND SAMPLE PRINTED OUTPUT

RCVR, RCVRI, and RCVRP are intended for external distribution and are, therefore, completely self-documented. The user should refer to the following listings for information on the use of these subroutines. These listings include three short test programs to test RCVR, RCVRI, and RCVRP. Each test program first calls SUBROUTINE CREAD to read the card deck generated by INSCON. RCVR, RCVRI, or RCVRP is then called to recover the INSCON fit values at the experimental times and altitudes. The user is not limited to these times and altitudes, but may use any others within the range of the data. Each recovery routine requires two or three additional subroutines:

RCVR: SET, IPL
RCVRI: SETI, IPL
RCVRP: RCVRI, SPLN3A, TRIDAG

Listings of SET, SETI, and IPL are included in this appendix. In the version of these programs intended for external distribution, the INSCON parameters are stored in a labelled COMMON block rather than blank COMMON. An abbreviated example of the printed output produced by the RCVRI test program follows the listings.
PROGRAM TEST RCVR

INCON IS A FORTRAN PROGRAM WHICH CALCULATES LEAST MEAN SQUARE

FIT TO, AND PLOTS CONTOUR DIAGRAMS OF, INCOHERENT SCATTER DATA

OBTAINED AT MILLSTONE HILL. THE FIT VALUE CORRESPONDING TO A

GIVEN TIME AND ALTITUDE MAY BE RECOVERED BY MEANS OF SUBROUTINES

CREAD AND RCVR. FOR EXAMPLE, THIS PROGRAM FIRST CALLS CREAD TO

READ THE CARD DECK GENERATED BY INCON. IT THEN CALLS RCVR TO

RECOVER THE INCON FIT VALUES AT THE EXPERIMENTAL TIMES AND

ALTITUDES.

COMMON LABEL, IDAYNO,
1  KDAT, NX, NY, NPX, NPY, XT, YT, DX, DMIN, DMAX, XMAX, XMIN,
2  YMAX, YMIN, RELTIME, SHIFT, GAMX, DELX, FACX, GAMY, DELY,
3  FACY, A, SIG, ISTAT

DIMENSION LABEL(16),
DIMENSION XT(64), YT(64), GAMX(32), DELX(32), FAXC(32), GAXY(32),
1  DELY(32), FACY(32), A(32, 32), SIG(64), ISTAT(64, 64)

C
10 CALL CREAD
C
WRITE(6,101)
C
00 20 I=1,NPX
ITIME = XT(I) + RELTIME
1FIT = ITIME + 86400) ITIME = ITIME - 86400
IHRS = ITIME / 3600
MINS = ITIME - IHRS * 3600 / 60
ITIME = 10000 + 100 * IHRS + MINS
00 20 J=1, NPY
CALL RCVR(XT(J), YT(J), P)
WRITE(6,201) ITIME, YT(J), P
20 CONTINUE
GO TO 10
C
*****FORMAT STATEMENTS*****
101 FORMAT(1H4, 4X, 4HTIME, 5X, 8HALTITUDE, 5X, 3HFIT)
201 FORMAT(5X, 14# , 5X, F10.5)
C
END

SUBROUTINE RCVR(X, Y, P)

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RCVR USES THE INCON FIT PARAMETERS STORED IN COMMON TO RECOVER
THE INCON FIT VALUE P AT TIME X AND ALTITUDE Y. KDAT INDICATES
THE TYPE OF DATA, FOR EXAMPLE ELECTRON DENSITY. THIS INFORMATION

RCV 0010
RCV 0020
RCV 0030
RCV 0040
RCV 0050
RCV 0060
RCV 0070
RCV 0080
RCV 0090
RCV 0100
RCV 0110

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IS ALSO ON THE FIRST CARD OF THE INSCON OUTPUT DECK. X IS IN
SECONDS, WITH X=0 AT THE HOUR PRECEDING THE FIRST EXPERIMENTAL
DATA(RELTME). THE SMALLEST AND LARGEST PERMISSIBLE VALUES OF
X ARE GIVEN BY XMIN AND XMAX. Y IS IN KILOMETERS AND MAY RANGE
FROM YMIN TO YMAG. IF X OR Y IS OUTSIDE THE ALLOWED RANGE, RCVR
RETURNs P=0. THE NPX EXPERIMENTAL VALUES OF X ARE STOREd IN XT.
THE NPY EXPERIMENTAL VALUES OF Y ARE STOREd IN YT. THE DATA TO
WHICH INSCON FITS AN NX BY NY LEAST MEAN SQUARE POLYNOMIAL RANGE
FROM DMIN TO DMAX, EACH TERM OF THE POLYNOMIAL IS OF THE FORM
PX(I)*PY(J)*A(J,I). THE A(J,I) ARE COEFFICIENTS OUTPUT BY INSCON.
THE PX(I) AND PY(J) ARE POLYNOMIALS WHICH ARE ORTHONORMAL OVER
XT(I) AND YT(J) RESPECTIVELY. THEY ARE DEFINED BY RECURSion
COEFFICIENTS GAMX, DELX, FACY, GAMY, DELY, FACY, IF DESIRED A
LOWER ORDER LEAST MEAN SQUARE FIT MAY BE RECOVERED BY DECREASING
NX AND/OR NY. ISTAT(J,I) IS AN NPY BY NPX ARRAY WHICH INDICATES
THE QUALITY OF THE FIT AT (XT(I), YT(J)). IF ISTAT(J,I)=1, RCVR
RETURNs P=0. LARGE TIME GAPS IN THE DATA ARE INDICATED BY
ISTAT(J,I)=2. RCVR RETURNS P=-P IF X IS WITHIN THE GAP.
SIG(J) IS THE SQUARE ROOT OF THE MEAN SQUARE DEVIATION ABOUT
THE FIT AT THE DATA AT ALTITUDE YTIJ). SHIFT IS A POSITIVE
CONSTANT WHICH IS ADDED BEFORE FITTING TO DATA WHICH TAKES ON
NEGATIVE VALUES.

COMMON LABEL, IDAYNO,
1  KDAT, NX, NY, NPX, NPY, XT, YT, DMAX, DMIN, XMAX, XMIN,
2  YMAX, YMIN, RELTME, SHIFT, GAMX, DELX, FACX, GAMY, DELY,
3  FACY, A, SIG, ISTAT

DIMENSION LABEL(15)
DIMENSION XT(64), YT(64), GAMX(32), DELX(32), FACX(32), GAMY(32),
1  DELY(32), FACY(32), A(32,32), SIG(64), ISTAT(64,64)

DIMENSION PX(32), PY(32)

IF(X LE. XMAX AND. X GE. XMIN AND.
1  Y LE. YMAX AND. Y GE. YMIN) GO TO 10
P = 0.
RETURN

10 XP = (2**X-XMAX-XMIN)/(XMAX-XMIN)
YP = (2**Y-YMAX-YMIN)/(YMAX-YMIN)
CALL SET(XP, NX, GAMX, DELX, FACX, FX)
CALL SET(YP, NY, GAMY, DELY, FACY, FY)

P = 0.
DO 20 I=1,NX
DO 20 J=1,NY

P = P + PX(I)*PY(J)*A(J,I)

P = ((DMAX-DMIN)*P-DMAX+DMIN)/2.
IF(IPL(XY) EQ. 3) P=P
RETURN

END

SUBROUTINE CREAD

C CREAD READS THE CARD DECK GENERATED BY INSCON. THE CONTENTS OF
THE CARDS ARE STORED IN BLANK COMMON INSCHILD PUNCHES

ISTAT(J,J) ONLY IF GIVEN J, EITHER THERE IS AN I SUCH THAT

ISTAT(J,J) IS NOT 0, OR J=NPY, IF NO CARD IS PRESENT FOR A GIVEN

J, READ SETS ISTAT(J,J)=1.

COMMON LABEL, IDAYNO,
1 KOAT, NX, NY, NPX, NPY, XT, YT, DMAX, DMIN, XMAX, XMIN,
2 YMAX, YMIN, RELTIME, SHIFT, GAMX, DELX, FACX, GAMY, DELY,
3 FACY, A, SIG, ISTAT

DIMENSION LABEL(15)
DIMENSION XT(64), YT(64), GAMX(32), DELX(32), FACX(32), GAMY(32)
1 DELY(32), FACY(32), A(32,32), SIG(64), ISTAT(64,64),
2 IST(64)

READ(5,101) (LABEL(I), I=1,15), IDAYNO, KOAT, NX, NY, NPX, NPY
READ(5,201) XT(I), J=1,NPX
READ(5,201) YT(J), J=1,NPY
READ(5,201) DMm, DMIN, XMAX, XMIN, YMAX, YMIN, RELTIME
N = MAX(NX,NY)
READ(5,201) GAMX(1), DELX(1), FACX(1),
1 DELY(1), FACY(1), A(1), SIG(1), ISTAT(1)
2 IST(1)

DO 10 I=1,NPX
10 READ(5,201) A(J,I), J=1,NPY
READ(5,201) SIG(J), J=1,NPY
J1 = J

20 READ(5,301) YP, (IST(I), I=1,NPX)
DO 60 J=1,NPX
IF(ABS(YT(J)-YP) +LT. +1 OR YT(J) +GE. 9999.9) G9 TO 40
DO 60 1=1,NPX
60 CONTINUE

ISTAT(J,J) = 1
G0 TO 60

50 ISTAT(J,J) = IST(I)
IF(J +EQ. NPY) RETURN
J1 = J +1
G0 TO 20
60 CONTINUE

C * * * * * FORMAT STATEMENTS * * * * *
101 FORMAT(15A4, 13X, 16/ 514)
201 FORMAT(6(1X, E12.5))
301 FORMAT(F7.1, 4X, 64/1)
C
END

SUBROUTINE SET(X, N, GAM, DEL, FAC, P)

SET CALCULATES THE FIRST N ORTHONORMAL POLYNOMIALS
P (DEFINED BY GAM, DEL, FAC) AT ARGUMENT X.

DIMENSION P(1), GAM(1), DEL(1), FAC(1)
P(1) = 1
P(2) = X - GAM(1)
DO 10 L=3,N

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FUNCTION IPL(X,Y)

IPL DETERMINES WHETHER THE INSCON FIT IS GOOD AT POINT (X,Y).

COMMON LABEL, IDAYNO,
1  KDAT, NX, NY, NPX, NPY, XT, YT, DMAX, DMIN, XMAX, XMIN,
2  YMAX, YMIN, RELTIME, SHIFT, GAMX, DELX, FACX, GAMY, DELY,
3  FACY, A, SIG, ISTAT

DIMENSION LABEL(15)
DIMENSION XT(64), YT(64), GAMX(32), DELX(32), FACX(32), GAMY(32),
1  DELY(32), FACY(32), A(32), SIG(64), ISTAT(64)

C

dx = abs(x-xt(1))
d10  i = i + 1

i f(dx * gt* dx) go to 20

10  dx = dx1

20  ip = i - 1
dy = abs(y-yt(1))
d20  j = j + 1

dy1 = abs(y-yt(j))

i f(dy1 * gt* dy) go to 40

30  dy = dy1

40  jp = j - 1

d i f(istat(jp,ip) -1) 50,60,70

50  ipl = 3

return

60  ipl = 2

return

70  ipl = 2

i f(x * gt* xt(ip) * and* istat(jp,ip+1) * eq* 2) * or* 1

x * lt* xt(ip) * and* istat(jp,ip+1) * eq* 2) ipl = 3

return

C

END

C

PROGRAM TEST RCVR1

INSCON IS A FORTRAN PROGRAM WHICH CALCULATES LEAST MEAN SQUARE FITS TO AND PLOTS CONTOUR DIAGRAMS OF INCOHERENT SCATTER DATA OBTAINED AT MILLSTONE HILL. THE FIT VALUE AND FIRST DERIVATIVE VALUES CORRESPONDING TO A GIVEN TIME AND ALTITUDE MAY BE RECOVERED BY MEANS OF SUBROUTINES CREAO AND RCVR1. FOR EXAMPLE THIS PROGRAM TESTS THE FIRST CALLS CREAO TO READ THE CARD DECK GENERATED BY INSCON. IT THEN CALLS RCVR1 TO RECOVER THE INSCON FIT VALUES AND DERIVATIVES AT THE EXPERIMENTAL TIMES AND ALTITUDES.
C
COMMON LABEL, IDAYNO,
 1 KDATA, NX, NY, NPX, NPY, XT, YT, DMAX, DMIN, XMAX, XMIN,
 2 YMAX, YMIN, RELTIME, SHIFT, GAMX, DELX, FACX, GAMY, DELY,
 3 FACY, A, SIG, ISTAT
DIMENSION LABEL(15)
DIMENSION XT(64), YT(64), GAMX(32), DELX(32), FACX(32), GAMY(32),
  DELY(32), FACY(32), A(32,32), SIG(64), ISTAT(64,64)
C
10 CALL CREAD

C
WRITE(6,101)
C
DO 20 J=1,NPX
  ITIME = XT(J) + RELTIME
  IF(ITIME.GT.86400) ITIME=ITIME-86400
  IHR = ITIME/3600
  MINS = (ITIME-IHR*3600)/60
  ITIME = 10000 + 100*IHR + MINS
  DO 20 J=1,NPY
  CALL RCVR1(XT(J), YT(J), P, PDX, PDY)
WRITE(6,201) ITIME, YT(J), P, PDX, PDY
20 CONTINUE
GO TO 10
C
10 FORMAT STATEMENTS....
  101 FORMAT(1H1, 4X, 4HITIME, 5X, 8HALTITUDE, 8X, 1HPC, 13X, 5HDPDX, 5X, 5HDPDY)
  201 FORMAT(5X, 14) 5X) F6.0, F16.5, F5.5, 4X, E12.5
C
END

SUBROUTINE RCVR1(X, Y, P, PDX, PDY)
RCV10010
C
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C
RCVR1 USES THE INSCON FIT PARAMETERS STORED IN COMMON TO RECOVER
C
THE INSCON FIT VALUE P, AND ITS DERIVATIVES WITH RESPECT TO X AND
C
Y, PDX AND PDY, AT TIME X AND ALTITUDE Y. KDAT INDICATES
C
THE TYPE OF DATA, FOR EXAMPLE ELECTRON DENSITY. THIS INFORMATION
C
IS ALSO ON THE FIRST CARD OF THE INSCON OUTPUT DECK. X IS IN
C
SECONDS, WITH X=0 AT THE HOUR PRECEDING THE FIRST EXPERIMENTAL
C
DATA(RELTIME), THE SMALLEST AND LARGEST PERMISSIBLE VALUES OF
C
X ARE GIVEN BY XMIN AND XMAX, Y IS IN KILOMETERS AND MAY RANGE
C
FROM YMIN TO YMAX. IF X OR Y IS OUTSIDE THE ALLOWED RANGE, RCVR1
C
RETURNS P=0. THE NPY EXPERIMENTAL VALUES OF Y ARE STORED IN YT, THE DATA TO
C
WHICH INSCON FITS AN NX BY NY LEAST SQUARE POLYNOMIAL RANGE
C
FROM DMIN TO DMAX. EACH TERM OF THE POLYNOMIAL IS OF THE FORM
C
PX(I)*PY(J)*A(J)*I, THE A(J)*I ARE COEFFICIENTS OUTPUT BY INSCON. RCV10020
C
140
THE PX(I) AND PY(J) ARE POLYNOMIALS WHICH ARE ORTHONORMAL OVER
XT(I) AND YT(J) RESPECTIVELY. THEY ARE DEFINED BY RECURSION
COEFFICIENTS GAMX, DELX, FACX, GAMY, DELY, FACY. IF DESIRED A
LOWER ORDER LEAST MEAN SQUARE FIT MAY BE RECOVERED BY DECREASING
NX AND/OR NY. ISTAT(J, I) IS AN NPY BY NPX ARRAY WHICH INDICATES
THE QUALITY OF THE FIT AT (XT(I), YT(J)). IF ISTAT(J, I)=1,
THE FIT IS GOOD. IF ISTAT(J, I)=2, THE FIT MAY BE BAD AND RCVR1
RETURNS P=-P. LARGE TIME GAPS IN THE DATA ARE INDICATED BY
ISTAT(J, I)=2. RCVR1 RETURNS P=-P IF X IS WITHIN THE GAP
SIG(J) IS THE SQUARE ROOT OF THE MEAN SQUARE DEVIATION ABOUT
THE FIT OF THE DATA AT ALTITUDE YT(J). SHIFT
S A POSITIVE CONSTANT WHICH IS ADDED BEFORE FITTING TO DATA WHICH TAKES ON
NEGATIVE VALUES.

COMMON LABEL, IDATNO, KDAT, NX, NY, NPY, NPY, XT, YT, DMAX, DMIN, XMAX, XMIN,
YMAX, YMIN, RELPDE, SHIFT, GAMX, DELX, FACX, GAMY, DELY,
3 FACY, A, SIG, ISTAT
DIMENSION LABEL(15)
DIMENSION XT(64), YT(64), GAMX(32), DELX(32), FACX(32), GAMY(32),
3 DELY(32), FACY(32), A(32,32), SIG(64), ISTAT(64,64)
DIMENSION PX(32), PY(32), PX1(32), PY1(32)

IF (X .LE. XMAX .AND. X .GE. XMIN) GO TO 20
P = 0
RETURN
10 XP = (2*X-XMAX-XMIN)/(XMAX-XMIN)
YP = (2*Y-YMAX-YMIN)/(YMAX-YMIN)
CALL SET1(XP, NX, GAMX, DELX, FACX, PX, PX1)
CALL SET1(YP, NY, GAMY, DELY, FACY, PY, PY1)
P = 0
PDX = 0
PDY = 0
DO 20 I = 1, NX
DO 20 J = 1, NY
P = P + PX(I)*PY(J)*A(J, I)
PDX = PDX + PX1(I)*PY(J)*A(J, I)
PDY = PDY + PX1(I)*PY1(J)*A(J, I)
20 P = ((DMAX+DMIN)*P+DMAX+DMIN)/2.
PDX = (DMAX+DMIN)*PDX/(XMAX-XMIN)
PDY = (DMAX+DMIN)*PDY/(YMAX-YMIN)
IF (IPL(X,Y)+EQ+3) P=-P
RETURN

SUBROUTINE SET1(X, N, GAM, DEL, FAC, P, P1)
SET1 CALCULATES THE FIRST N ORTHONORMAL POLYNOMIALS
P (DEFINED BY GAM, DEL, FAC) AND THEIR DERIVATIVES P1 AT
ARGUMENT X.
DIMENSION P(1), P1(1), GAM(1), DEL(1), FAC(1)
PROGRAM TEST RCVRP

INCON IS A FORTRAN PROGRAM WHICH CALCULATES LEAST MEAN SQUARE FITS TO, AND PLOTS CONTOUR DIAGRAMS OF, INCOHERENT SCATTER DATA OBTAINED AT MILLSTONE HILL. THE FIT VALUE AND FIRST DERIVATIVE VALUES CORRESPONDING TO A GIVEN TIME AND ALTITUDE MAY BE RECOVERED BY MEANS OF SUBROUTINES CREAD AND RCVRP. FOR EXAMPLE THIS PROGRAM FIRST CALLS CREAD TO READ THE CARD DECK GENERATED BY INCON. IT THEN CALLS RCVRP TO RECOVER THE INCON FIT VALUES AND DERIVATIVES AT THE EXPERIMENTAL TIMES AND ALTITUDES, A LOCAL SPLINE INTERPOLATION PROCEDURE IS USED BY RCVRP TO MAKE THE FIT VALUE AND ITS TIME DERIVATIVE PERIODIC.

COMMON LABEL, IDAYNO,
1 KDAT, NX, NY, NPX, NPY, XT, YT, DMAX, DMIN, XMAX, XMIN,
2 YMAX, YMIN, RELTIME, SHIFT, GAMX, DELX, FACX, GAMY, DELY,
3 FACY, A, SIG, ISTAT
DIMENSION LABEL(15), XT(64), YT(64), GAMX(32), DELX(32), FACX(32), GAMY(32), DELY(32), FACY(32), A(32,32), SIG(64), ISTAT(64*64)

10 CALL CREAD

WRITE(6,101)

10 DO 20 I=1,150
20 RI = I
X = 600**(RI-1) - RELTIME
IF (X < 0) X = 0.0
ITIME = X + RELTIME
IF ITIME < RE4) ITIME = ITIME - 86400
IHRs = ITIME/3600
MINs = (ITIME-IHRs*3600)/60
ITIME = 10000 + 100*IHRs + MINs
CALL RCVRP(X, YT(3), P, PDX, PDY, A, XMIN)
WRITE(6,201) ITIME, YT(3), P, PDX, PDY
20 CONTINUE
GO TO 10

***FORMAT STATEMENTS***
SUBROUTINE RCVRP(X, Y, P, PDX, PDY, IND, XS)
RCVRP USES THE INSCON FIT PARAMETERS STORED IN COMMON TO RECOVER
A PERIODIC APPROXIMATION TO THE INSCON FIT VALUE P, AND ITS
DERIVATIVES WITH RESPECT TO X AND Y, PDX AND PDY, AT TIME X AND
ALTITUDE Y. XS IS THE BEGINNING (SECONDS FROM THE MIDNIGHT
PRECEDING THE FIRST EXPERIMENTAL TIME) OF THE 24 HOUR PERIOD
ON WHICH THE PERIODIC APPROXIMATION IS TO BE BASED. IF IND=1
A PERIODIC APPROXIMATION IS CALCULATED BASED ON FIT VALUES
OBTAINED FROM RCVR1. IF IND=0 RCVRP RETURNS THE ORIGINAL
NONPERIODIC INSCON FIT VALUES

COMMON LABEL, IDAYNO,
1 KDAT, MX, NY, NFX, NPY, XT, YT, DMAX, DMIN, XMAX, XMIN,
2 YMAX, YMIN, RELTME, SHIFT, GAMX, DELX, FAXC, GAMY, DELY,
3 FACV, A, SIG, ISTAT
DIMENSION LABEL(15)
DIMENSION X(164), Y(164), GAMX(32), DELX(32), FAXC(32), GAMY(32)
1 DELY(32), FACV(32), A(32), SIG(32), ISTAT(64, 64)
DIMENSION XX(7), PP(7), PDX(7), PPX(7), PDX(7), PROXI(7), PPDY(7)
DATA W/0, , .333333, .666667, .833333, * .166667, .0, . . . USE RCVR1 DIRECTLY IF IND=0 OR THE DATA SPANS LESS THAN
1 20 HOURS*****
1 IF(IND.EQ.0 .OR. XMAX-XMIN .LT. 72000.)
1 CALL RCVR1(X, Y, P, PDX, PDY) RETURN
C
IF(XMAX-XMIN .LT. 86400.)
1 XMIN=XMIN
IF(XMAX-XMIN .GE. 86400.)
1 XMAX=XMAX
XPR = X
REPEAT 10, WHILE XPR .GT. XMIN+86400*
XPR = XPR - 86400*
10 XPR = XPR + 86400*
10 XPR = XPR + 86400*
20 XPR = XPR + 86400*
20 XPR = XPR + 86400*
20 XPR = XPR + 86400*
C
***** IF XMAX-XMIN .LT. 86400. ADD LINEAR TREND TO ALL RECOVERED
DATA*****
C
CALL RCVR1(XMIN, Y, P1, PDX1, PDY1)
CALL RCVR1(XMIN+86400, Y, P2, PDX2, PDY2)
DP = P2 - P1
PDX = PDX2 - PDX1
PDY = PDY2 - PDY1
DT = (XPR-XMIN)/86400*
CALL RCVR1(XPR, Y, P, PDX, PDY)
P = P + DP*DT
PDX = PDX + PDX*DT
PDY = PDY + PDY*DT
RETURN

***** FIND TIMES Xl AND XU, 3 HOURS BEFORE AND 3 HOURS AFTER XC:
XL = XU + 64800 (18 HOURS) +
30 Xc = XMAX + (86400 * (XMAX - XMIN)) / 2,
XL = XC - 10800,
XU = XC + 10800
- 86400

***** USE RCVR1 DIRECTLY IF X IS BETWEEN XU AND Xl*
IF( XPR < GT* XU AND XPR < LT* XL) CALL RCVR1(X,Y,P,PDX,PDY)
1
RETURN

***** CALCULATE ESTIMATES P1 AND P2 OF P(XC) AND ESTIMATES
PDY1 AND PDY2 OF PDY(XC) FROM P, PDX AND PDY AT EACH
BOUNDARY OF THE GAP*****
CALL RCVR1(XMAX, Y, P, PDX, PDY)
P1 = P + PDX*(XC-XMAX)
PDY1 = PDY
CALL RCVR1(XMIN, Y, P, PDX, PDY)
P2 = P + PDX*(XC-XMIN+86400)
PDY2 = PDY
DP = P2 - P1
DPLY = PDY2 - PDY1

***** CALCULATE PP(I) = P(xx(I)) AT TIMES Xx(I) . . . . Xx(N) WHERE
Xx(I) = XL AND Xx(N) = XU AND xx(1) . . . . xx(N-1) ARE AT HOURLY
INTERVALS BETWEEN XL AND XU. TIMES XX(I) FOR WHICH DATA
DOES NOT EXIST ARE EXCLUDED:
N = 0
DO 40 I = 1, 7
RI = I
XX(I) = XL + 3600*RI
IF(XX(I) < GT* 86400) XX(I) = XX(I) - 86400
IF(XX(I) < GT* XMAX OR XX(I) < LT* XMIN) GO TO 40
CALL RCVR1(XX(I), Y, P(I), PDX(I), PDY(I))
N = N + 1
XX(N) = XX(I)
IF(N < GT* 1 AND XX(N) < LT* XX(N-1)) XX(N) = XX(N) + 86400
PP(N) = P(I) + W(I)*DP
PDDY(N) = PDDY(I) + W(I)*DPDY
CONTINUE

40 CONTINUE

USE CUBIC SPLINE INTERPOLATION BETWEEN THE POINTS PP(XX(I)) TO
CALCULATE P(X) AND PDX(X):
RLAMO = 1.
DO = 6.*((PP(2)-PP(1))/(XX(2)-XX(1))-PDDX(I))/(XX(2)-XX(I))
RNUN = 1.
DN = 6.*(PDDX(N) = (PP(N)-PP(N-1))/(XX(N)-XX(N-1)))/
1.

IF(XPR < LT* XU) XPR = XPR + 86400
CALL SPLNN3A(N+1,XX,PP,RLAMO,DO,RNUN,DN,XPR,P,PDX,SS2,PXIN)
CALL SPLNN3A(N+1,XX,PDDY,DO,RNUN,DN,XPR,PDY,PDXY,SS2,PRXIN)
RETURN

END
16. Abstracts

During 1970, the incoherent scatter radar at Millstone Hill (42.6°N, 71.5°W) was employed to measure the electron density, electron and ion temperatures, and vertical velocity of the ions in the F-region over periods of 24 hours on an average of twice per month. The observations spanned the height interval 200 to 900 km, approximately, and achieved a time resolution of about 30 minutes. This report presents the results of these measurements in a set of contour diagrams.