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METALLIC IONS AND ATOMS IN THE UPPER ATMOSPHERE

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F49620-92-J-0092

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The main focus of research under AFOSR Grant F49620-920-J-0092 is to investigate the global and local transport of metallic ions in the upper atmosphere, in particular the layering of ionization, through use of comprehensive numerical models which account for realistic meteoric sources, chemical conversions and sinks, and transport by molecular and eddy diffusion, winds, and electric fields. The ultimate goal is to better understand the mechanisms producing ionization layers, and ultimately the seasonal, latitudinal, local time, and temporal variations in the occurrences of ionization layers. Plasma layering can affect HF communications by introducing new relection paths thus complicating the propagating modes, and presumably in extreme cases by producing blanketing effects. In addition, plasma irregularities may also accompany the sharp gradients characterizing the plasma layers.

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FINAL TECHNICAL REPORT

AFOSR Grant F49620-92-J-0092

entitled

METALLIC IONS AND ATOMS IN THE UPPER ATMOSPHERE

28 February 1994
Prof. Jeffrey M. Forbes, Principal Investigator
Center for Space Physics and
Department of Aerospace and Mechanical Engineering
Boston University, Boston, MA 02215

1. OVERVIEW

The main focus of research under AFOSR Grant F49620-92-J-0092 was to investigate the global and local transport of metallic ions in the upper atmosphere, in particular the layering of ionization, through use of comprehensive numerical models which account for realistic meteoric sources, chemical conversions and sinks, and transport by molecular and eddy diffusion, winds, and electric fields. The ultimate goal was to better understand the mechanisms producing ionization layers, and ultimately the seasonal, latitudinal, local time, and temporal variations in the occurrences of ionization layers. Plasma layering can affect HF communications by introducing new reflection paths thus complicating the propagation modes, and presumably in extreme cases by producing blanketing effects. In addition, plasma irregularities may also accompany the sharp gradients characterizing the plasma layers.

Unexpectedly, AFOSR did not fund the third year of this grant, which would have been our most productive in terms of completing a number of projects in progress. The present report therefore only covers the status of these various projects at the end of the second year.

Four separate lines of investigation were pursued under this grant:

(1) **Local Na/Na$^+$ Chemistry and Transport Simulation.** This is a high resolution two-dimensional model in the height/latitude frame for daytime conditions only, extending from 60 to 300 km. This model includes the complete photochemistry and vertical transport of all important oxygen/hydrogen/nitrogen neutral and ionized compounds, consistently coupled to the Na and Na$^+$ chemistries. Our purposes were twofold: (a) to understand the conditions necessary for the formation of Na$^+$ layers; and (b) to understand the coupling between the Na and Na$^+$ chemistries, and the formation of neutral Na layers that are observed to correlate with "sporadic" ionizations layers.

(2) **Global Fe$^+$ Transport Simulation.** This model is intended to prescribe the global distributions of winds and electric fields to simulate the distribution of Fe$^+$ around the globe. Our intent is to explain the observed E and F-region densities of Fe$^+$ using this model, and to make predictions regarding the response and recovery of global Fe$^+$ distributions in conjunction with transient events like meteor showers and geomagnetic storms.

(3) **Local Ion Layer Simulation.** This model is two dimensional in the height/local time frame, and will be used to understand the conditions necessary for the creation of ionization layers at all local times. This is a high resolution model with primary emphasis on Fe$^+$.

(4) **Observational Study Of Plasma Structure Over Millstone Hill.** During a May 28, 1992, experiment over Millstone Hill, a set of high resolution plasma density data was

obtained using new modes of radar operation and software analysis. The experiment was set up as part of a Mitre Corporation sponsored initiative to look at the effects of mid-latitude ionospheric structure on HF communications and surveillance systems. These data are being examined to characterize the plasma structures in general, and also to look for the possible presence of plasma layers that might be connected with the modeling activities above.

Initiative (1) was undertaken as a collaborative study between P.I. and Co-Investigator R.G. Roble at NCAR. The model resides at NCAR and is an extension of a previous model developed by R. Roble. (2) and (3) were undertaken as the Ph.D. Dissertation work of Mr. Leonard Carter, under the direction of the P.I. Study. (4) was pursued by Mr. Randy Godwin as part of his Ph.D. Dissertation work, under the direction of the P.I. He is supported by the MITRE Corporation for his involvement in this work.

Below, the status of work for each of these initiatives is outlined.

2. STATUS AT GRANT TERMINATION

Local Na/Na^+ Chemistry and Transport Simulation. The full sodium chemistry as recommended by Plane (*Int. Rev. Phys. Chem., 10,* 55-106, 1991) have been incorporated into the model, along with the hydrated ion chemistry scheme of Richter and Sechrist (*Geophys. Res. Lett., 6,* 183-186, 1979). In addition, a wind and electric field distribution geared to 18° latitude have been incorporated into the model. One of our intended goals was to investigate the conditions necessary to produce the descending daytime layers observed over Townesville, Australia (Wilkinson et. al., *Geophys. Res. Lett., 19,* 95-98, 1992). Only recently have we overcome some initial computational problems, and been able to produce our first baseline computation of Na and Na^+ densities.

Global Fe^+ Transport Simulation. The framework of a two-dimensional meridional-plane model was constructed, and time-dependent initial simulations performed using simplified wind and electric field distributions. All initial numerical tests were successful. Lack of funding precludes further progress.

Local Ion Layer Simulation. Fe^+ Layers were produced numerically using wind and electric field inputs typical of Arecibo, Puerto Rico. Height-time contours of Fe^+ densities are depicted in Figure 1, and illustrate the downward descent of a high-density Fe^+ layer similar to those observed by the incoherent scatter radar at Arecibo. As of 31 December 1993, a journal article describing these results was under preparation.

Observational Study of Plasma Structure Over Millstone Hill. During the 24-hour period of the Millstone Hill experiment, considerable plasma structure was observed. Figure 2 illustrates some preliminary electron density profiles for select times during the experiment. (These data are "preliminary" since they are as yet uncalibrated and corrected; however the relative variations are expected to remain intact). Note the significant structure, and in some cases, layering of the plasma (i.e., large spikes). When these data are plotted vs. time, similar structure is observed with respect to time. We believe that much of this structure is due to gravity waves. Correspondingly, we have begun to examine vertical and temporal spectra of the data, as illustrated in Figure 3. At this point our work is exploratory. We have begun, for instance, to apply band-pass filters and to perform inverse FFT's to obtain time filtered plots as in Figure 4 as well as time-filtered and space-time-filtered depictions of these data. Our goal in this initial work was to quantitatively describe, for the first time, the characteristics of plasma structure for the mid-latitude ionosphere. We had hoped to accompany this by a theoretical interpretation in terms of gravity waves, either as perturbers of the ion densities through chemical effects or through wind-shear layering effects. One question that must be addressed, for instance, is how such small-scale structures can be maintained in the topside F-region in the presence of rapid diffusion.

3. PERSONNEL

Personnel supported under this grant include:

[1.] Prof. Jeffrey M. Forbes, Principal Investigator

[2.] Mr. Leonard Carter, candidate for Ph.D. in Applied Physics

Other personnel contributing to the research under this grant, but not supported by salary:

[1.] Dr. Raymond G. Roble, Co-Investigator, NCAR/HAO

[2.] Mr. Randy Godwin (MITRE Corp.), candidate for the Ph.D. in Electrical Engineering.

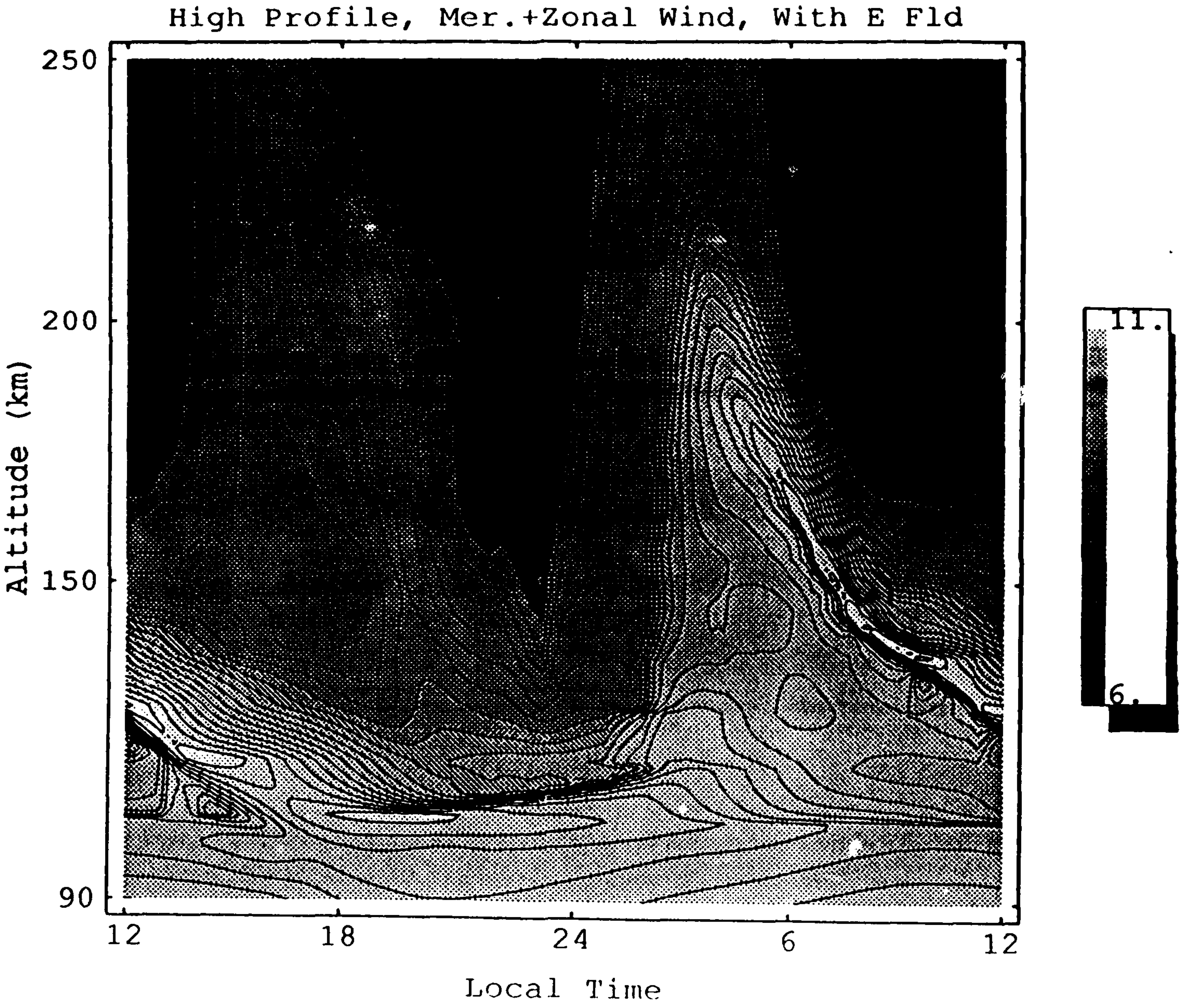
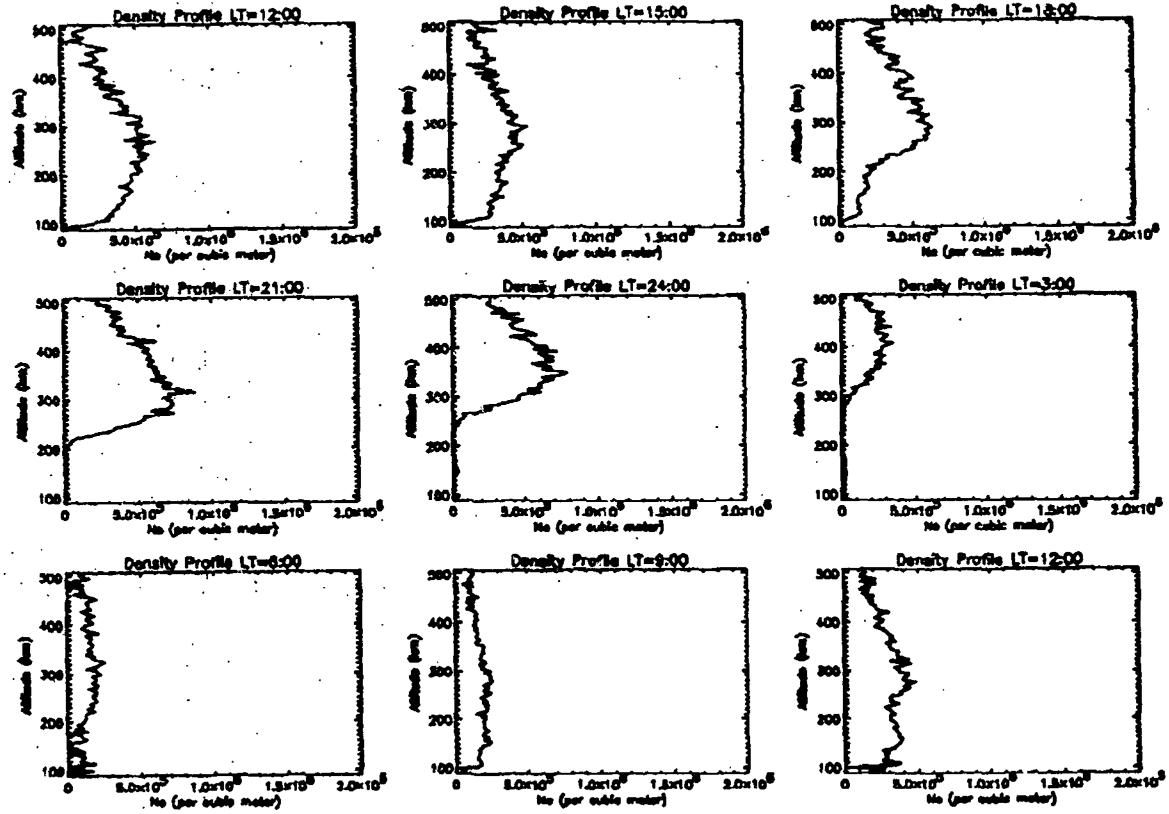


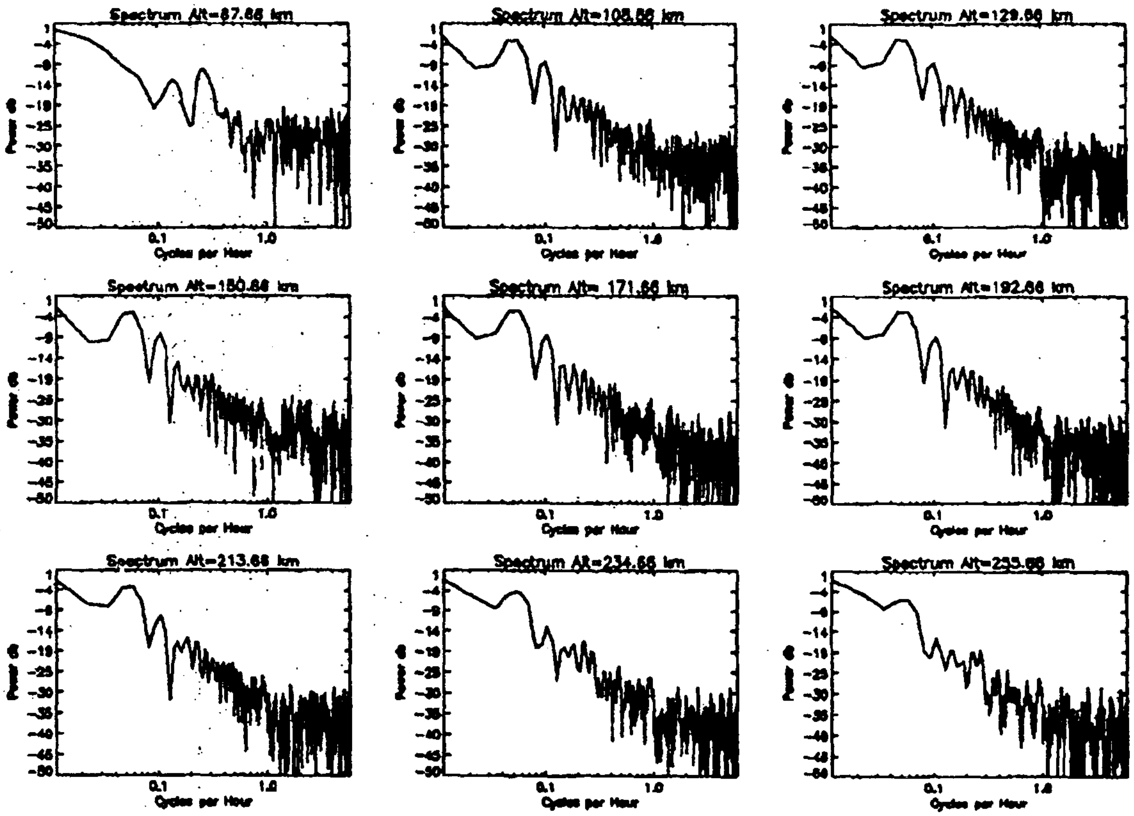
Figure 1

Contour plot of metallic ion density corresponding to high altitude deposition profile, both zonal and meridional winds, with electric field (units of log[Fe$^+$](m^{-3})).



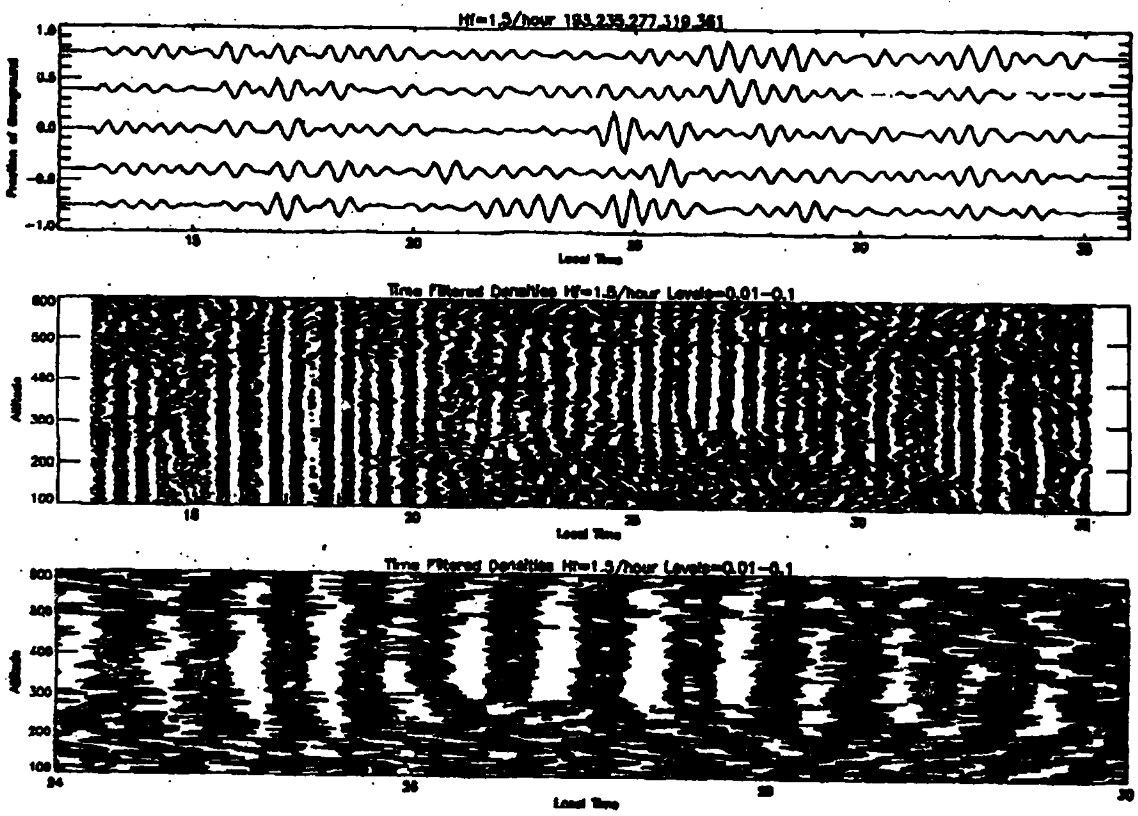
Electron Density vs Altitude for Select Times.

Figure 2



Spectrums of Density Variations for Select Altitudes.

Figure 3



Time Filtered Density Variations.

Figure 4