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Coordinated Studies of Magnetospheric/Ionospheric Coupling and Dynamics in the Diffuse Aurora

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Introduction

The results of the studies carried out under the grant are described in detail in the following publications:

Larsen, M. F., T. R. Marshall, I. S. Mikkelsen, B. A. Emery, A. Christensen, D. Kayser, J. Hecht, L. Lyons, and R. Walterscheid, Atmospheric Response in Aurora experiment: Observations of E and F region neutral winds in a region of postmidnight diffuse aurora, *J. Geophys. Res., 100,* 17299-17308, 1995.

Larsen, M. F., and R. L. Walterscheid, Modified geostrophy in the thermosphere, *J. Geophys. Res., 100,* 17321-17329, 1995.

C. D. Odom, M. F. Larsen, A. B. Christensen, P. C. Anderson, J. H. Hecht, D. G. Brinkman, R. L. Walterscheid, L. R. Lyons, R. Pfaff, and B. A. Emery, ARIA II neutral flywheel-driven field-aligned currents in the postmidnight sector of the auroral oval: A case study, *J. Geophys. Res., 102,* 9749-9459, 1997.

Larsen, M. F., A. B. Christensen, and C. D. Odom, Observations of unstable atmospheric shear layers in the lower E region in the post-midnight auroral oval, *Geophys. Res. Let., 24,* 1915-1918, 1997.

Christensen, A. B., J. H. Hecht, R. L. Walterscheid, M. F. Larsen, and W. E. Sharp, Depletion of oxygen in aurora: Evidence for a local mechanism, *J. Geophys. Res., 102,* 22273-22277, 1997.

The objective of the Atmospheric Response in Aurora (ARIA) experiment was to measure the response of the E-region neutral flow to substorm activity in the post-midnight sector of the auroral oval. To this end, neutral wind profiles were obtained from a series of four sets of rocket flights using the chemical release technique. The measurements covered conditions ranging from quiet to disturbed. A consistent feature of the observed winds in disturbed conditions is the presence of an E-region jet located between approximately 110 and 120 km altitude.

The profiles presented here show that the neutral wind speeds near 110-120 km altitude increase and the hodographs become more elongated or linear in response to higher magnetic activity levels. The wind speeds decrease and the hodographs become more circular as the activity level decreases.

The presence of a wind maximum implies shears both above and below. The observations consistently show larger shears below the peak and smaller shears above. In fact, the bottom-side shears during disturbed conditions have Richardson numbers close to or below the critical value of 0.25 suggesting that the flow is highly unstable in that height range. The instability is expected to produce waves, turbulence, and enhanced diffusivity.

Description of the Experiments

The wind measurements cover quiet (ARIA IV), moderate (ARIA I), moderate to high (ARIA III), and high (ARIA II) activity levels. The four sets of launches were carried out from the Poker Flat Research Range in Alaska in the post-midnight sector of the auroral oval. In each of the disturbed cases, the measurements were made after one hour of forcing associated with a substorm event, and the Alaska magnetometer chain showed maximum currents located between the launch site and the impact point for the rockets which was approximately 250 km north of the rocket range. The maximum magnetometer deviations varied between approximately zero for the quiet case to approximately 1000 nT for the most disturbed case. The four sets of measurements are described below:

ARIA IV: November 1995 (low magnetic activity)

Figure 1 and Figure 2 show the wind profile and hodograph, respectively, for the quiet-time launch on November 24, 1995, in the height range between 90 and 140 km. The local time of the release was within one hour of the local times of the disturbed releases described later. Conditions had been quiet for several days prior to the launch with no substorm activity and Kp values of 2 or less throughout the period. The height variations of the winds were oscillatory and the rotation of the wind vector direction was uniform with height with a hodograph that was nearly circular. The shape of the hodograph and the wind magnitudes are consistent with the results from modeling studies which analyzed the interaction between the high-latitude E-region forcing and the tidal modes propagating upward from the mesosphere and found nearly circular hodographs in the regions characterized by weak auroral forcing.

The largest shears in the observed winds occurred between 105 and 110 km, but the Richardson numbers were greater than 0.5 at all heights. The values from MSIS model for the date and time of the release were used together with the magnitude of the observed shear to calculate the Richardson number profiles. The critical value for instability is 0.25.

ARIA II: February 1994 (high magnetic activity)

Conditions during the February 12, 1994, launch were the most disturbed of the cases discussed here with magnetometer deflections exceeding 1000 nT. The launches occurred after approximately one hour of substorm activity in the post-midnight sector. The maximum currents were located between the upleg and downleg portions of the flight. The observed wind profile from a downleg release is shown in Figure 3 along with the corresponding hodograph in Figure 4 for the altitude range between 90 and 140 km. A jet is evident in the lower E region with peak winds near 115-km altitude. The magnitude of the wind was greater than 250 m/s and the shear on the bottom side exceeded 300 m/s over an altitude range of 5 km. The Richardson number in the height range was close to 0.20, i.e., below the critical value. The shear on the topside of the jet was smaller, and the upper altitudes were stable. Figure 4 shows that the hodograph had become elongated above 105 km, again in agreement with the modeling for the regions in which the upward-propagating tides are strongly affected by the auroral forcing in the lower E region.

ARIA I: March 1992 (moderate magnetic activity)

The March 3, 1992, data represent an intermediate case. As in the previous case, the launch was carried out approximately one hour after the commencement of a substorm in the post-midnight sector. The maximum magnetometer deflections in the vicinity of Poker Flat were close to 500 nT and the strongest currents were located in the region north of Poker Flat between the upleg and downleg segments of the flight. The observed wind profile and the corresponding hodograph for the altitude range from 90 to 140 km are shown in Figure 5 and Figure 6, respectively. The magnitude of the wind increased with altitude above 130 km, as would be expected due to the effects of the Pedersen drag during disturbed conditions. However, there was also an enhancement of the wind in the lower E region with a peak wind speed of approximately 125 m/s near 115 km. The wind vector rotated clockwise with height. The bottom-side shear associated with that peak was close to 200 m/s between 110 and 115 km. The observed shear produces a minimum Richardson number of 0.5 which is above the critical value. The hodograph is nearly circular and is most similar to the hodograph for the quiet-time case but has some elongation.

ARIA III: February 1995 (moderate to high magnetic activity)

The February 2, 1995, data is the second intermediate case with activity levels between those in the March 1992 and February 1994 cases. The wind profile and hodograph are shown in Figure 7 and Figure 8, respectively, for the height range between 90 and 140 km. Again, the jet is evident in the lower E region with a larger shear below the peak and a more gradual change in the magnitude with height above the peak. The wind vector rotated clockwise with height, as in the previous case. The largest shear occurred between 105 and 110 km and exceeded 230 m/s over 2.5 km. The MSIS temperature values and the observed winds produced a minimum Richardson number near 0.20, i.e., below the critical value. The hodograph in this case is elongated and deviates significantly from the circular shape evident in the quiet-time profile.

Summary

The E-region wind data from the post-midnight sector of the auroral oval consistently show the presence of a jet in the lower E region during disturbed conditions. The wind speeds generally increase with increasing magnetic activity and the shears on the bottom side become more unstable as the conditions become more disturbed.

The observed rotation of the winds with height, evident in the hodographs, is likely associated with the modification of the upward propagating tides by the auroral forcing. In fact, the hodograph for low magnetic activity was nearly circular which is strongly suggestive of a tidal mode, as shown by simulations. The low activity wind profile had a height variation closest to that expected for dominant tidal forcing. Higher activity levels produced larger deviations from this simple pattern with hodographs that were elongated or nearly linear in the extreme case.

The lower E-region jet is of interest since it implies a strong circulation and significant horizontal transport in a narrow height range. Furthermore, the unstable shears on the bottom side of the jet imply the existence of Kelvin-Helmholtz waves. The end product of the growth and decay of these waves is turbulence and enhanced eddy diffusivity. Enhanced diffusion is expected to increase the vertical transport in the region where the unstable shears occur. The ARIA composition measurements made during the same experiments show evidence for the importance of a local mechanism for producing the observed composition changes in the lower thermosphere. Enhanced vertical diffusion on the bottomside of the jet should produce a decrease in the oxygen density in the region of the shear by enhancing the transport of oxygen to lower altitudes. The sensitivity of the optically deduced O depletion is weighted toward altitudes of significant auroral emission which includes the region of the shear.

The small characteristic vertical scale of the jet feature and the instability of the bottom side make it unlikely that the dynamics of the feature are adequately represented in the general circulation models. The vertical scale of the jet is approximately 10 km or less which is at the limit of the model resolutions in the lower E region. Also, unstable shears are damped or smoothed in the simulations in order to keep the integrations stable. Furthermore, the unstable waves and turbulence produced by the unstable shears are not resolvable in the models, although it may be possible to parameterize the process with an empirical scheme.

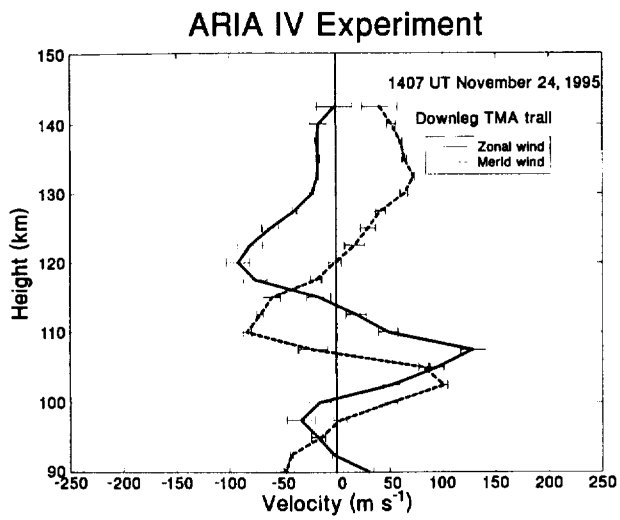

Figure 1

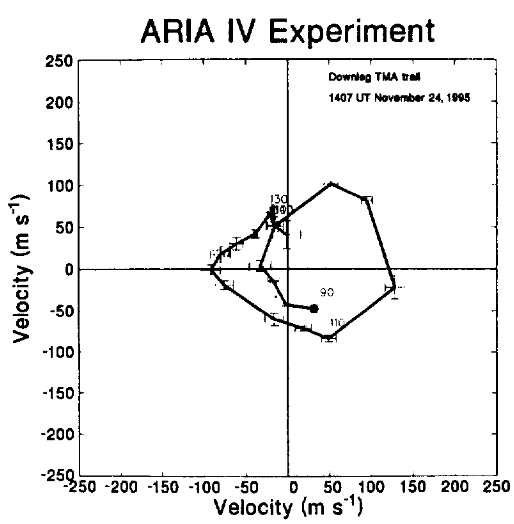

Figure 2

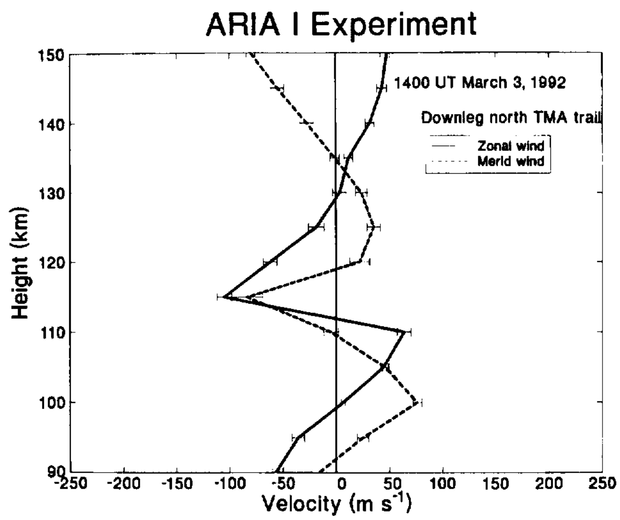

Figure 5

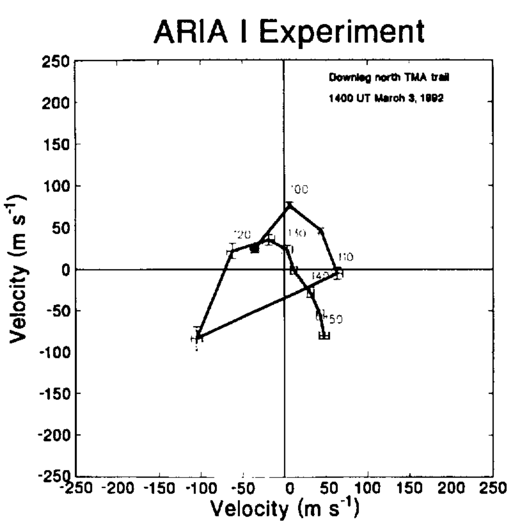

Figure 6

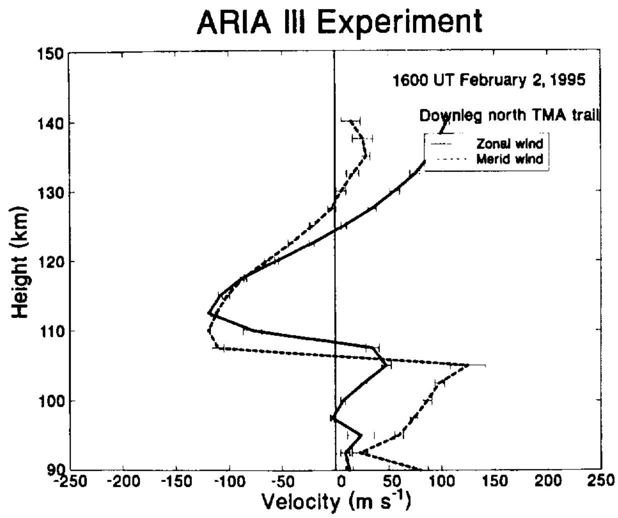

Figure 7

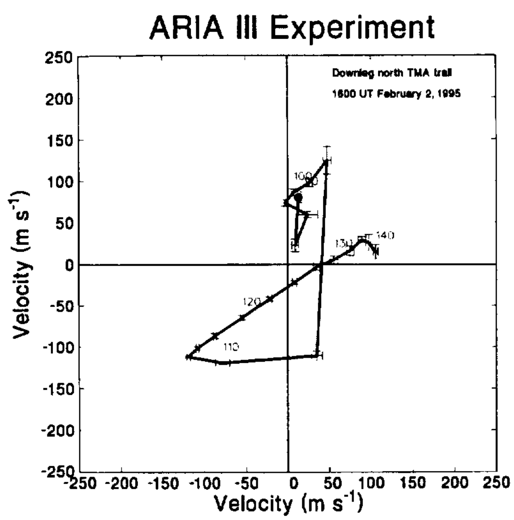

Figure 8