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Authors
Nagy, AF
Cicerone, RJ
Hays, PB
et al.

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Simultaneous measurement of ion and neutral motions by radar and optical techniques

A. F. Nagy, R. J. Cicerone, P. B. Hays, K. D. McWatters, and J. W. Meriwether

The University of Michigan, Ann Arbor, Michigan

A. E. Belon

University of Alaska, Fairbanks, Alaska

C. L. Rino

Stanford Research Institute, Menlo Park, California

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The results of simultaneous thermospheric neutral wind and ionization drift measurements from near College, Alaska ($L = 5.6$, $\Lambda = 65°$) are presented. The neutral wind data were obtained by observing the Doppler shift of the 6300 Å atomic oxygen line with the 15-cm Fabry-Perot interferometer of the Michigan Airglow Observatory which is located temporarily at Ester Dome, Alaska. Ionization drifts were measured by the Chatanika incoherent scatter radar facility. These simultaneous measurements indicate that in the premidnight sector both the neutral wind and the ionization drift are generally westward. This westward ionization drift is consistent with the general magnetospheric convection pattern but the measured neutral wind is in a direction opposite to the diurnal pressure gradients and thus must be driven by ion drag. In the postmidnight sector the ionization drift turns eastward while the neutral wind direction turns south. Again, the ion drift is consistent with previously published results; the reasons for the absence of significant zonal neutral winds and the significant southward meridional wind in the postmidnight sector are not well understood at this time, but are probably a combination of a decrease in the ion drag force following magnetic midnight, Coriolis force, and pressure gradients due to both the diurnal and auroral heat sources.

INTRODUCTION

During the last few years it has become clear that upper atmospheric motions play an important role in determining the structure, chemistry, and energetics of the thermosphere. *Rishbeth* [1972] has recently reviewed and summarized our present understanding of these thermospheric winds. Theoretical calculations of the global neutral wind systems have most often been based on solutions of the neutral gas momentum equation, using pressure gradients obtained from models [e.g., *Geisler,* 1967; *Kohl and King,* 1967; *Challinor,* 1970; *Blum and Harris,* 1973]. The equation of motion for the neutral gas involves the ion velocity; thus, more recent calculations have attempted to solve the simultaneous momentum equations for both the neutrals and the ions. The ion velocity is strongly influenced by the presence of electric fields; however, until very recently little was known about these fields so they were ignored in most calculations. Assuming typical convection electric field values, *Fedder and Banks* [1972] and *Banks* [1972] calculated the influence of electric fields, perpendicular to the magnetic field lines, on the neutral winds. They neglected pressure gradients and their results are probably only representative of the initial response of the atmosphere to an applied electric field. Nevertheless, their work [also see *Cole,* 1971] clearly indicates that thermospheric winds are greatly influenced by electric fields of magnetospheric origin; therefore, realistic wind calculations must include these effects. Recent experimental data [*Hays and Roble,* 1971; *Rees,* 1971; *Meriwether et al.,* 1973] indicate that the actual thermospheric wind system is not described by presently published simplified calculations; the major discrepancies are related to the direction and magnitude of the wind at middle and high latitudes (e.g., measured winds blow to the west in the evenings, which is opposite to the direction obtained from calculations based on model pressure gradients).

The purpose of this brief paper is to present some results of simultaneous measurements of ionization drifts and of neutral winds in the thermosphere. By measuring these quantities simultaneously in the same locality we are attempting to determine the factors which control the respective motions. Accordingly, our discussion focuses attention on the gross features of the results, with detailed discussions to follow in a subsequent paper.

RESULTS AND METHOD OF MEASUREMENTS

The neutral wind measurements were made by observing the Doppler shift of the 6300 Å line of atomic oxygen with the six-in. Fabry-Perot interferometer of the Michigan Airglow Observatory, which is located temporarily at Ester Dome, near College, Alaska (L = 5.6, Λ = 65°). The basic facility [*Roble,* 1969; *Hays et al.,* 1969] and the general observing technique for midlatitudes have been described previously [*Hays and Roble,* 1971]. The method of scanning the line profile with the interferometer was changed in 1972 to a discrete wavelength (density) scan [*McWatters et al.,* 1973] to provide improved data quality and time resolution. Details of the modified system and data reduction method will be described in a later paper; it will suffice for the present to point out that typically it took about ten minutes to measure the wind component in a given direction. Additional explanation of the data-taking procedure accompanies the results to follow.

Motions of the ionospheric plasma were measured by the radar incoherent scatter technique. Underlying theory and general nature of this operation have been reviewed by *Evans* [1969] and *Evans* [1972]. The observations reported here were carried out with the Chatanika Radar Facility located near College, Alaska. Both the facility [*Leadabrand et al.,* 1972] and the measurement technique [*Doupnik et al.,* 1972; *Banks et al.,* 1973] have been described previously in the literature.

Figures 1 and 2 show both interferometer and radar results for the night of February 26–27, 1973 in the form of the respective zonal components of the neutral winds and ionization drifts, plotted versus universal time. Magnetic local time is also shown on the horizontal axes, as is local midnight. Figures 3

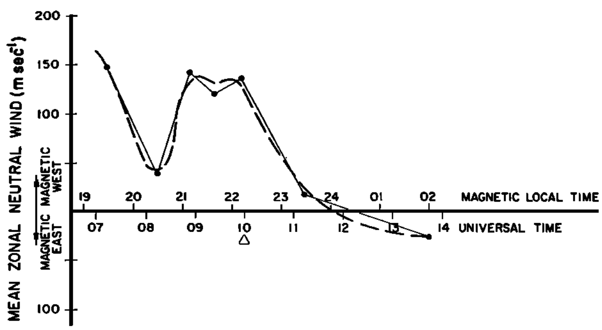

Fig. 1. Zonal (geomagnetic east-west) neutral winds measured at College, Alaska, plotted versus universal time February 27, 1973. The neutral winds were deduced from Doppler shifts of the 6300 Å atomic oxygen line observed by the Fabry-Perot interferometer of the Michigan Airglow Observatory. Each datum point corresponds to an integration of 20 min. The dashed curve is a smoothed fit to the data and was used to construct vector velocity diagrams. Δ denotes local midnight.

and 4 show the corresponding meridional components and total vectors follow in Figure 5. The data appearing in Figures 1 through 5 were gathered in the following manner. Starting at about 0700 UT both the radar and the interferometer were changing their observing directions in synchronism. We spent ten minutes making observations in each direction in the following cycle: magnetic east, west, east, west,

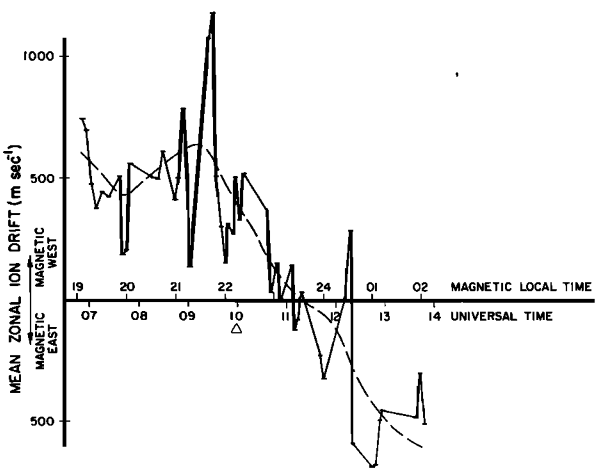

Fig. 2. Zonal (geomagnetic east-west) ionization drifts measured at College, Alaska, plotted versus universal time February 27, 1973. The ionization drifts were measured by the Chatanika incoherent scatter radar, and the data bars result from 5-min integrations (westward drifts, 230 km). The dashed curve is a smooth fit to the data and was used to construct vector velocity diagrams. Δ denotes local midnight.

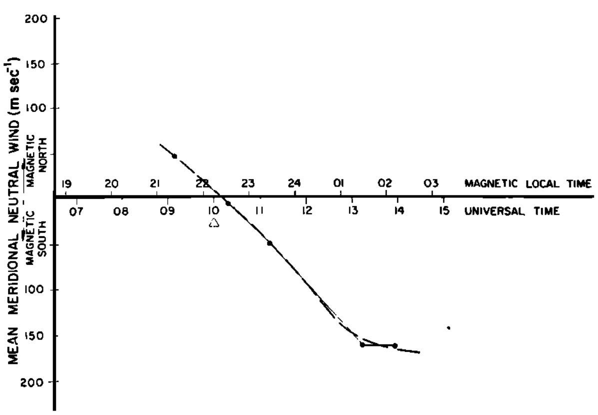

Fig. 3. Meridional (geomagnetic north-south) neutral winds measured at College, Alaska, on February 27, 1973.

zenith, north, south. The elevation angle of the radar was 70° to zenith while the elevation angle of the interferometer was 45°; thus the measured ion and neutral gas motions correspond to a spatial scale of about 150 and 400 km, respectively. Observations were carried out until about 1400 UT. The plotted radar data is of the quality and form as previously published Chatanika results [e.g., *Doupnik et al.*, 1972; *Banks et al.*, 1973], but the neutral wind data is hand-reduced and carries an uncertainty which may be as great as 50 m sec^{-1}. It should be emphasized that this is not the fundamental accuracy of the measurement, but this is the result of the data reduction scheme employed. The meridional and zonal winds plotted are obtained by measuring the difference in the Doppler shift between the north-south and east-west observations respectively. This means that the results represent a mean wind over a distance of about 400 km. Auroral 6300 Å emission originates around the 200-km region [e.g., *Rees et al.*, 1967]; therefore the measured winds are also representative of that altitude region. It should be noted that because of viscosity, the change in neutral wind speed and direction is expected to be small above about 200 km [e.g., *Rishbeth*, 1972]. The broken curve in Figure 1 represents a time-smoothing of the results and was used in replotting these data in Figure 5.

Figure 2 shows the measured zonal (magnetic west to east) ionization drifts from an altitude of 230 km (radar range gate 3, with an elevation angle of 70°). Individual data points shown on this graph are five-min integrations over a large number (about 22,500) of radar pulses. The broken curve drawn through the data envelope represents a rather gross time-smoothing of the results; this curve was used in preparing Figure 5. The motivation for drawing this curve was to display the behavior of the radar results over time scales (approximately one hr) compatible with changes in the neutral thermospheric wind velocity.

The most obvious features of the curves of Figures 1 and 2 are the following. (a) A large westward drift (about 500 m sec^{-1}) of ionization prior to magnetic midnight. This motion, driven by the $\mathbf{E} \times \mathbf{B}/|B|^2$ force, leads us to infer a northward electric field component of approximately 25 mv m^{-1}. This westward drift before magnetic midnight and the subsequent reversal toward the east are in accord with generally accepted magnetospheric convection patterns [e.g., *Axford*, 1969]. (b) Also, during the same premagnetic midnight time period one sees a large (150 m sec^{-1}) westward neutral wind. It should be noted that one would expect an opposite flow from the diurnal pressure gradients.

Figures 3 and 4 present the meridional motions measured on the same night. The major feature of Figure 3 which strikes the eye is the neutral wind blowing toward the south in the postmagnetic midnight sector. This wind attained a speed of about 150 m sec^{-1} in the early morning hours. From Figure 4 one first notes that the observed meridional motions of the ionization were rather erratic. The time-smoothed (broken) curve indicates a small southward motion before 1100 UT, then a pronounced southward flow of perhaps 300 m sec^{-1} around 1200 UT, followed by a sudden reversal to northward drifts.

Polar plots of the neutral wind and ionization drift vectors are shown in Figure 5 for the data of February 26–27, 1973. On these plots magnetic time increases in the counterclockwise direction and geo-

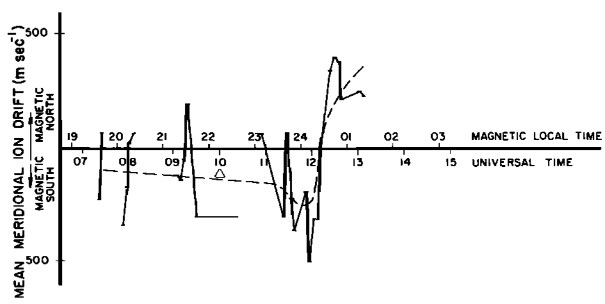

Fig. 4. Meridional (geomagnetic north-south) ionization drifts measured at College, Alaska, on February 27, 1973 (northward drifts, 230 km).

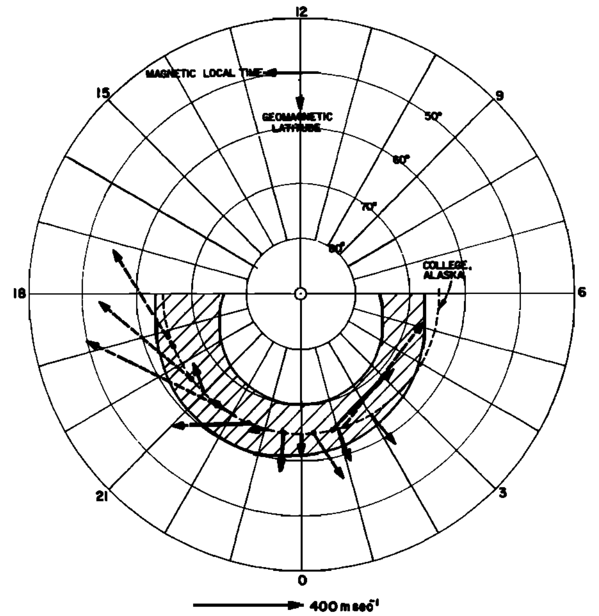

Fig. 5. Polar plots of the horizontal neutral wind (solid arrows) and ionization drift vectors (dashed arrows) measured at College, Alaska, on February 27, 1973. The velocity scale is indicated by the arrow below the figure, which corresponds to 400 m sec^{-1}. Geomagnetic latitude increases toward the origin which is the geomagnetic pole. Magnetic time increases counter-clockwise and the shaded region represents the general convection region deduced on a statistical basis by *Meriwether et al.* [1973].

magnetic latitude increases toward the origin, which is the geomagnetic north pole. Solid arrows represent the measured thermospheric neutral wind vectors and broken arrows are the measured ionization drift vectors; the magnitude of each vector is determined by comparison with the length of a 400 m sec^{-1} vector shown in the legend. The tail of each vector lies at the center of the time interval over which the vector was measured. The figure also shows the locus of College, Alaska and a general region of convection determined by *Meriwether et al.* [1973] based on electric field measurements from OGO-6 by *Heppner* [1972]. From this figure one sees an often-repeated pattern: neutral winds are westward in the dusk sector, becoming southward by magnetic midnight, afterward increasing and usually gaining some eastward component. The drift of ionization performs a similar rotation: the large westward motion present in the evening sector swings toward the south by magnetic midnight and eventually rotates toward east and north.

To show the repeatability of the neutral wind observations we display in Figure 6 neutral wind vectors measured on five nights in 1972. *Kp* indices are also noted in each three-hour interval. The thermospheric winds observed on January 22, February 25, February 28, and March 2, 1972 display the same general pattern already noted, a rotation of the wind vector from westward in the premidnight sector toward south and later to the east in the early morning hours. The observations made on February 17, 1972 show some winds which do not follow the general pattern.

While the gross features of the observations are present during each experiment on most occasions, there are certainly variations from day to day. In Figure 7 the neutral wind and ionization drift vectors observed on March 3, 1973 are shown in the same format as Figure 5. The ionization drift vectors display the oft-repeated behavior except for the northward component seen temporarily at 2100 UT. On the other hand the neutral winds are northward and even show a slight eastward orientation just before 2130 UT, after which time the more common rotation pattern is evident.

From Figure 8, data from March 22, 1973, one sees the neutral wind vector following a regular rotation pattern, westward before magnetic midnight, then to the south. But the pattern of observed ionization drifts was not that commonly recorded; the westward drifts in the premidnight sector intensified around midnight rather than reversing. It should be noted that a 1000 γ negative bay was observed at 0100 UT on the College, Alaska magnetogram *H* trace.

DISCUSSION

The major features of our simultaneous measurements of neutral thermospheric winds and ionization drift velocities are the following.

(1) In the premagnetic midnight sector the observed ionization drifts are generally directed toward the west. Around magnetic midnight a reversal to eastward drifts is commonly seen. This pattern accords with the generally accepted view of magnetospheric convection and with other radar observations [e.g., *Doupnik et al.*, 1972; *Banks, et al.*, 1973].

(2) In the premagnetic midnight sector the neutral zonal winds blow toward the west, apparently driven by the ionization motion. At the same time neutral meridional winds do not appear to be controlled by the ionization drifts which are considerably smaller than the corresponding east-west drifts. After magnetic midnight the neutral zonal winds are not

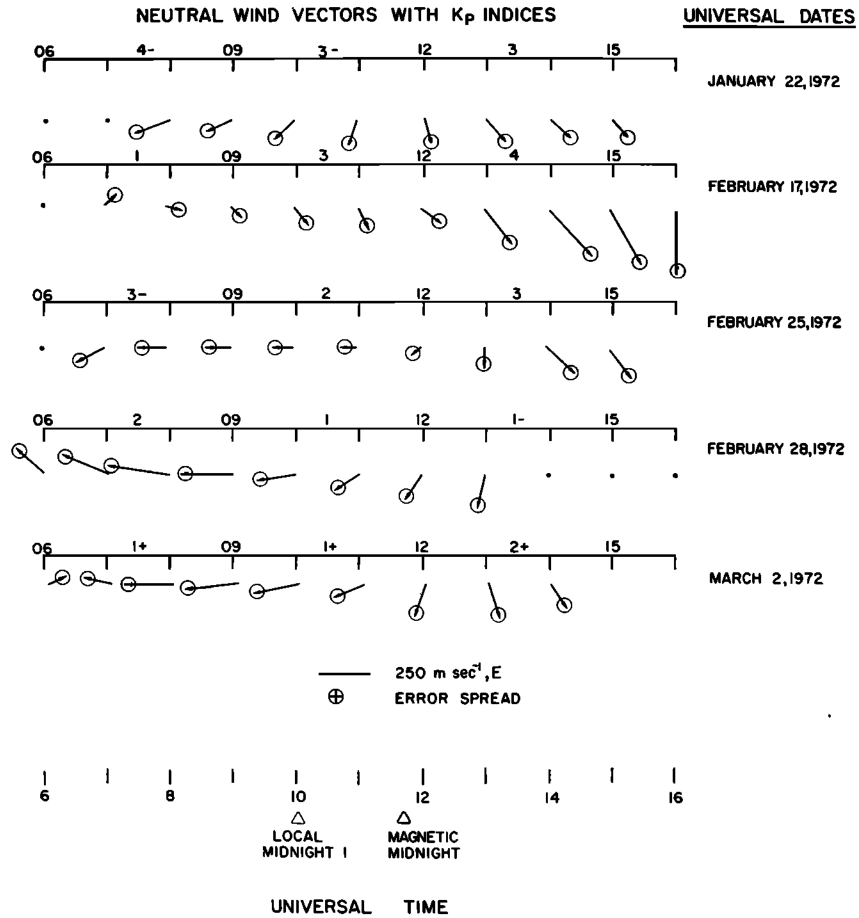

Fig. 6. Horizontal neutral wind vector measurements for a number of representative nights during the 1972 observing season at College, Alaska. The magnitude of the measured winds is proportional to the length of the arrows; the horizontal arrow in the legend near the bottom corresponds to 250 m sec^{-1}. The arrow directions represent the direction of the measured winds; magnetic north is toward the top of the figure while west is to the left. The circles at the top of each arrow indicate the uncertainty in the data, which is about 50 m sec^{-1}.

significant and do not show the same reversal exhibited by the ionization drifts. Thus, either a countervailing force reduces the extent of control exerted by the ionization drifts or the absolute strength of the ion drag force is greatly diminished around magnetic midnight. The latter would result if there were a regular sudden decrease in electron density at thermospheric altitudes, but a preliminary examination of ionospheric data does not support this suggestion. *Brekke et al.* (1973) have reported that it is common for the postmidnight eastward ionization drift to be less than the premidnight westward motion, which of course also results in a reduced drag force on the neutral gas.

(3) Significant departures from the often observed features just stated are observed, for example: the continuation and intensification of the westward ionization drift past magnetic midnight on March 22, 1973, and the neutral winds observed in the evening hours on March 3, 1973.

A complete explanation of experimental data such as that presented in this paper will probably have to consider several possible driving mechanisms acting in combination: ionization drifts due to magnetospheric convection electric fields, diurnal pressure gradients due to solar heat deposited in the thermosphere, energy input from auroral activity, both Joule heating and deposition by fast particles, and Coriolis forces. While complete quantitative explanations of the data are not possible at this time the bases of

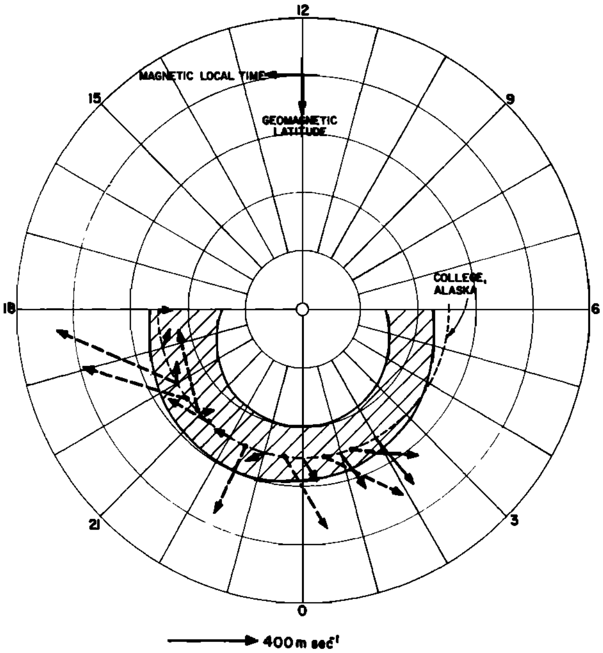

Fig. 7. Polar graphs of horizontal neutral winds and ionization drifts measured on March 3, 1973. The format is that of Figure 5.

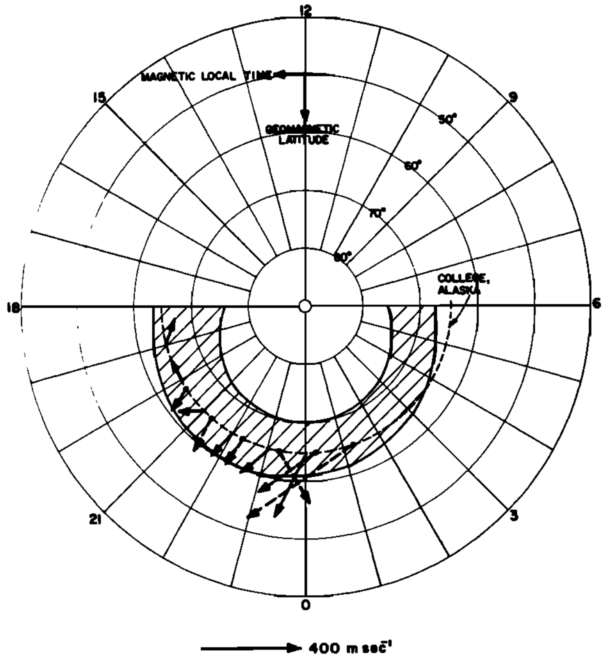

Fig. 8. Polar graphs of horizontal neutral winds and ionization drifts measured on March 22, 1973. The format is that of Figure 5.

such investigations are becoming available. For example, we have recently turned toward the model neutral atmosphere generated from OGO-6 neutral mass spectrometer data [*Hedin et al.*, 1973] and have found that one would expect neutral winds to blow toward the south beginning around magnetic midnight and increasing thereafter (B. Hinton, private communication, 1973). This prediction corresponds to the data shown, for example, in Figure 3 and is based on the total pressure gradients one computes for the College, Alaska location from the OGO-6 model atmosphere, which includes perturbation (auroral) heating and long-term average behavior.

To conclude, simultaneous measurements of neutral winds in the thermosphere and of ionization drift velocities, when properly interpreted, can be used to identify the driving forces behind the motions. Such interpretations are complicated, however, and must utilize relevant theory of neutral atmosphere dynamics, electrodynamics, and other experimental data as available, e.g., records of magnetic activity and other optical observations of auroral activity.

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