Effects of transport by neutral winds on thermospheric composition in the auroral zone

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[O]/[N<sub>2</sub>] depletions seen in GUVI images following magnetic storms are presumed to arise due to uplifting of molecular species by strong vertical winds.

This is likely true. However, to understand even the local composition response within the auroral zone also requires knowledge of horizontal transport.

We illustrate this point by considering the “oxygen scaling factor” at Fort Yukon during the night of October 7, 2003.

The problem is further complicated because horizontal winds vary strongly with altitude over the height range 100-160 km.

We illustrate a new technique that can, given the right conditions, resolve this height variation by ground-based remote sensing of the nighttime auroral λ557.7-nm emission.

TIDI wind observations are now focused on lower altitudes, so that we do not expect height-resolved TIDI winds to be available above 120-km. Thus, the ground-based E-region wind measurements are now especially important for studies of composition and electrodynamics.
E-region upwelling events

Poker Flat: 02-Feb-2003, $\lambda=557.7$ nm

Zenith Velocity [m/s]

Hours UT
Four active nights in October 2003
Oxygen often does decrease over an active night.
Oxygen & aurora, October 7, 2003

Question: What was the reason for the gradual rise in oxygen scaling factor during this night?
Similar vertical winds
\( \lambda 557.7 \text{-nm} \) Doppler temperatures
What did GUVI observe?

- The next slide shows six GUVI passes spanning the period between Oct 7, 2003 and the start of the four consecutive comparison days.
- RGB colors are Red: 1304, Green: 1356, Blue: LBH-L.
- Note the decreasing dayglow during this period.
- Note also the bright dusk-side arc on the Oct 7 image.
Solar variation

- Solar x-rays@GOES-12
- SEE 133 nm

Absolute solar radio flux (1 day)
Meridional wind comparison

Oct 7

Oct 16

Oct 17

Oct 18

Oct 19
Understanding horizontal transport

On October 7, the trajectories of E-region air parcels carried them over Fort Yukon from regions inside the auroral oval. By contrast, on the comparison nights, the air parcel trajectories typically were more parallel to the oval. However, understanding these transport effects will be extremely complex, because the horizontal wind is strongly-height dependent over the altitude range in which the GUVI column-integrated $[O]/[N_2]$ is sensitive.

TIDI could possibly provide height-resolved E-region winds using the $\lambda 557.7$-nm emission, at least during sunlit conditions. However, TIDI’s operations are now focused on lower altitudes, and it is unlikely to provide routine wind data above 120-km altitude.

Fortunately, we can in some cases also derive altitude profiles of the E-region neutral winds at night, using ground-based Doppler spectra of the auroral $\lambda 557.7$-nm emission.
Temperature sky maps

02 Feb 2003

Temperature 250 [K]   Temperature 700 [K]
Inferred emission altitude
LOS wind maps

02 Feb 2003

Velocity -200 [m/s]  

Velocity 200 [m/s]
Horizontal wind component time series

Note the “noisy” wind component fits in the period 0530-0930 UT. This is because the emission altitude varied dramatically across the field-of-view. In the E-region, it is unreasonable to combine line-of-sight winds from different heights in a single fit.
Fit formulation

We model the vertical profile of horizontal wind using two polynomials – one for the meridional component and one for the zonal component.

\[
\begin{align*}
\mathbf{u}^\dagger_z & \Rightarrow u_0 + u_1 z + u_2 z^2 + u_3 z^3 + \nu \\
\mathbf{v}^\dagger_z & \Rightarrow v_0 + v_1 z + v_2 z^2 + v_3 z^3 + \nu
\end{align*}
\]

Each FPS line-of-sight wind measurement corresponds to a particular \((\theta, \phi)\) look direction, and a particular altitude \(z\) that was inferred from the Doppler temperature. Thus, for each observed wind measurement, we construct the corresponding modeled line-of-sight wind

\[
L^\dagger_{\Sigma, \delta, z} \Rightarrow \mathbf{u}^\dagger_{\delta, \Sigma} \sin \Sigma \sin \delta + \mathbf{v}^\dagger_{\delta, \Sigma} \cos \Sigma \sin \delta
\]

A simple linear least-squares (SVD) fit between the observed and modeled line-of-sight winds then gives the best choice of model parameters \(u_0, u_1, u_2, \ldots\) and \(v_0, v_1, v_2, \ldots\)
02-Feb-2003, 0700-0815 UT
Comparison with rocket data under similar conditions
Conclusions

On nights of active aurora, we usually see the oxygen scaling factor decrease, consistent with the expectation that enhanced vertical winds will transport molecular species aloft. October 7 2003 did not fit this pattern - rather, a gradual increase in atomic oxygen was observed. Higher Doppler temperatures were also observed, especially early in the night, indicating lower energy auroral precipitation. The meridional wind was more strongly equatorward on October 7, relative to the other days. Air parcels passing over Fort Yukon would have originated from inside the auroral oval. However, understanding the effects of transport on height-integrated [O]/[N₂] will require height-resolved E-region neutral winds. TIDI is now not expected to provide this as a routine data product. We have shown a ground-based technique for obtaining height resolved winds, at least under some conditions. GUVI observed a decrease in 1304 and 1356 dayglow during the 9-day period between October 7 and the comparison days.