Measurements of Hot Air in Alaska
John Meriwether, Professor of Physics, Clemson University

Research focus: “Which way does the wind blow, how fast, and how hot?”

The answer to this question is needed for the study of the ion-neutral coupling at high latitudes.

Russ Hedden (Clemson undergraduate physics major) and I undertook a whirlwind tour of central Alaska last October to install 3 FPIs to establish a network that would supplement AMISR and Mark Conde’s all-sky imaging observations.
Why a FPI network?

- Phenomena that matter in the upper atmosphere occur over a wide range of spatial scales, some being global in extent.
  - Extended coverage in longitude as well as latitude needed to obtain tidal phases and to study effects that might be dependent upon magnetic declination
- Several sites desirable for certain local studies
- Many observatories desirable for global coverage
Barium chemical release produces ion and neutral clouds that can be tracked to determine ion drift and neutral wind direction and speed.

These results illustrate the importance of plasma convective forcing in controlling the behavior of the polar thermosphere.

Meriwether et al., 1973
The aurora offers a great opportunity to measure line-of-sight Doppler shifts with great accuracy using a Fabry-Perot interferometer.
The 630 nm emission of O is found as a layer between 200 and 300 km.
How do we measure the wind speed and direction at 250 km?

Fabry-Perot Interferometer
2 French physicists invented the concept of the Fabry-Perot interferometer and did extensive work with the instrument in the period of 1897-1902. Fabry was the theorist who thought of the instrumental concept. Perot built the apparatus as he was very mechanically talented; the first etalon was capable of mechanical adjustment over three orders.
An interference pattern is formed on the screen for a spectral line source.

The interference results from the union of multiple beams generated by reflections between the two surfaces.

The objective lens is thus the most important element of the interferometer optics!
Another example of the FPI etalon

This Biondi etalon chamber was used in pressure scanning at Laurel Ridge, PA, and was attached to the front end of the Calgary optical frame to achieve an imaging system installed at Poker Flat, Alaska, last October.
The FPI line shape given by this formula for the amplitude $A(x)$ is called an Airy function.

$$A(x) = \frac{1}{2\pi} \left[ \frac{(1 - R^2)}{1 - 2R \cos x + R} \right],$$

$$X = 4\pi \mu t (\sigma - \sigma_0) \cos \theta$$

$X$ refers to the phase of the ring pattern.
A one dimensional interferogram featuring Doppler broadening and Doppler shift.
Paul Hays and I moved MAO from Ann Arbor to Ester Dome, Alaska, and we operated this FPI for two winters (Manual operations required!)
The Fabry-Perot interferometer observe the Doppler shift and Doppler broadening of the auroral red emission.

This example illustrates a meridional wind of \(~250\, \text{ms}^{-1}\).
First MAO results at high latitudes
First high latitude ISR-FPI observations show strong indication of ion-neutral coupling.

From Nagy et al.[1974]

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].
Averaged DE winds for quiet and active periods
- note twin cell pattern for dusk and dawn sectors
Vorticity and divergence patterns derived from DE winds

Ratio of vorticity to divergence decreases for increasing magnetic activity.

More energy goes into the divergent flow as a result of the particle and Joule heating generated by the greater activity.

Observing winds and plasma drifts with the AMISR tristatic FPI and the AMISR radar provides means for a localized study of divergence and vorticity variations as well as thermospheric joule heating.
Paul Hays brought me back to Michigan to take over the Michigan FPI observatory and I added new ones.
Measurements of thermospheric winds by FPI observatories located at Sondrestrom and Thule illustrate the sensitivity of polar dynamics to $F_{10.7}$ and IMF By parameters (from Killeen et al., 1995)
All-sky imaging of the thermospheric wind field is possible to obtain line-of-sight Doppler shift measurements for various directions.
Inferring Horizontal Wind Vectors

Doppler imaging only directly measures line-of-sight wind components. We infer the underlying vector field by fitting a model of the form:

\[ H_x = u_0 + x \frac{\partial u}{\partial x} + y \frac{\partial u}{\partial y} \]
\[ H_y = v_0 + x \frac{\partial v}{\partial x} + y \frac{\partial v}{\partial y} \]

This fit is used to "fill in" the vector components perpendicular to our line-of-sight. In all figures presented here, the line-of-sight components are shown directly as measured.
The AMISR radar located at Poker Flat, Ak provides once again the capability of studying the ion-neutral coupling in Alaska.
The AkFPI network was funded to support AMISR for ion-neutral coupling studies using the three stations of Poker, Ft. Yukon, and Eagle.

Primary purpose would be to observe thermospheric wind vectors at common volume points: finally doing the determination of a wind vector the way physicists should!
Three common volume points would be observed in sequence so that three neutral wind vectors are determined.

The AMISR would provide similar coverage re the 3 CV points.

Additional points N, E, Z for each FPI would be included to get a more extended view of the dynamics.

With 90 s for each point, the cadence would be ~12 minute (including dark and laser images)

Vorticity would be calculated for the triangle shown using Stokes theorem.

Variations of vorticity and divergence would be particularly interesting during substorm activity.
First light for the FYU instrument

Note: complete 2D image not shown

He-Ne laser calibration

Nightglow 630-nm image
exposure time, 300 seconds
Results from MiniME Arecibo observations.
MTM enhancement evident near midnight (4 UT)
Analysis, PARI observations

Analysis is based upon laser determination of line shape and Levingberg Marquardt NLLQ algorithm.

Averaged winds, 21-22 Sept 2006

Analysis based upon individual fringes
Russ moves the FPI optics carefully!

The FPI is raised to its mount

Ready to take data
Ft. Yukon FPI
Last we go to Eagle. But where is it?

The airport at Eagle

The SkyScanner has arrived at Eagle
MiniME at Eagle
First results, Poker FPI

Four other directions are not included.

Exposure time is 120 s per image.
Eastward observations (5 directions between 75 deg to 115 deg)

W and T uncertainties 2-3 ms$^{-1}$ and 6-8 K

Influence of meridional component evident as az angle increases

Between 10 and 15 UT, increase is a result of the red shift associated with the meridional wind

On the same night, we had measurements toward four CV points.
Some scenes from Alaska and special thanks to Russ Hedden and Brian Turpin for their hard work in Alaska!