Thermospheric Dynamics: Past informs present

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NCAR/TN-308+STR
NCAR TECHNICAL NOTE

February 1988

The First Cedar Data Base Report

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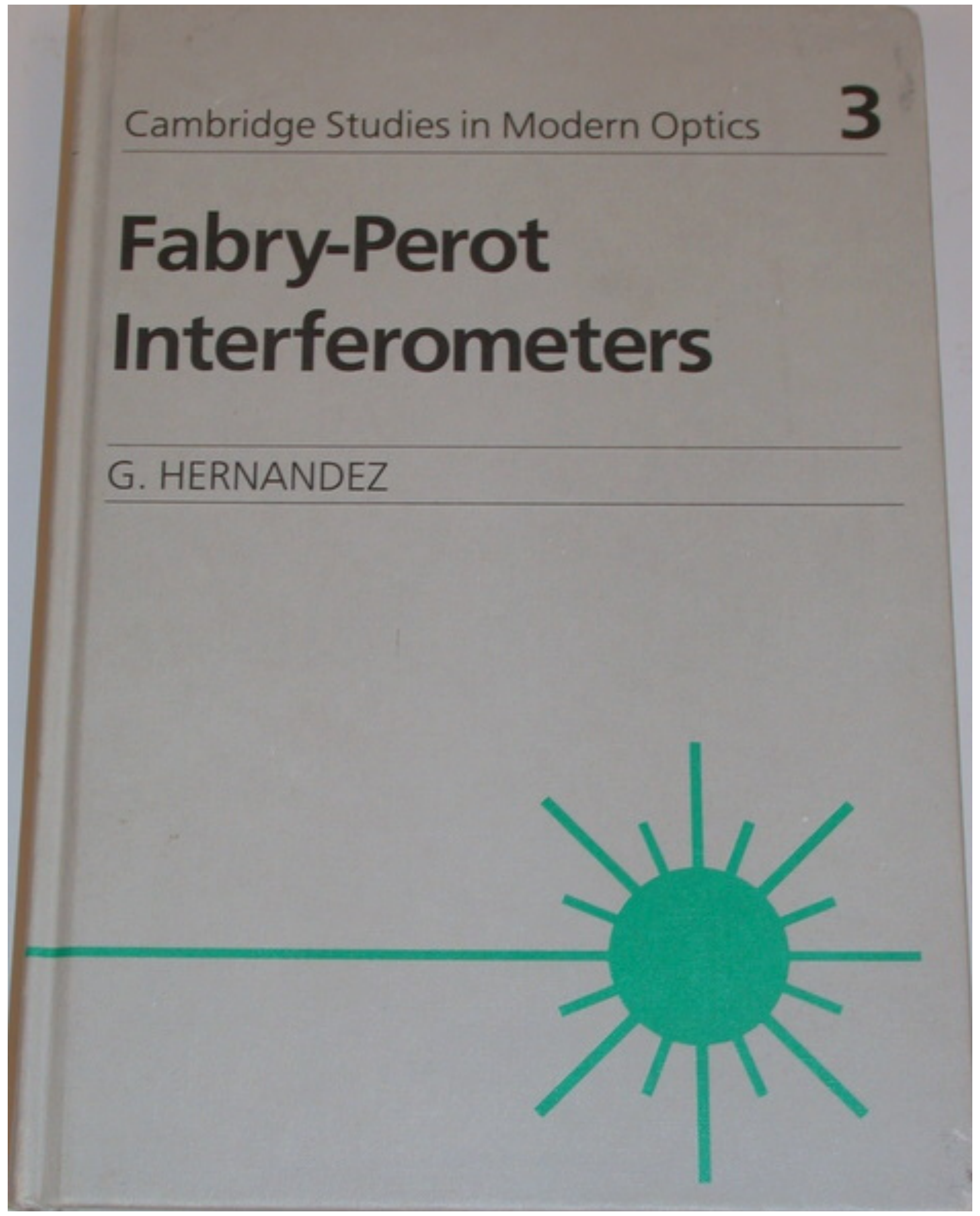
HIGH ALTITUDE OBSERVATORY

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
BOULDER, COLORADO

Best Source on the FPI

- 1986: G. Hernandez, *Fabry-Perot Interferometers,* Cambridge Studies in Modern Optics
- Proud to have been Gonzalo's mentee
- This tome is the ultimate deep dive into the FPI
- He was "the perfectionist's perfectionist"



Selective History of Auroral FPI measurements

- 1955: Dave Wark used a FPI brought to College by C.T. Elvey to measure the width of the 15,867 cm^{-1} (630 nm) line in twilight and aurora
  - He obtained a temperature of 710±50 K in twilight, 730±80 K in aurora.
  - Wark concluded the emission layer height was ~210 km.
  - First imaging work
- 1961: Nilson and Shepard obtained temperatures in auroral structures using the 17,924 cm^{-1} (557.7 nm)
  - Gordon Shepard has made many innovative instruments during his 50+ year career, including the first “digital array” FPI for auroral measurements

History

1972: Hays, Meriwether, and Roble bring a FPI to Ester Dome and measure winds using the red line.

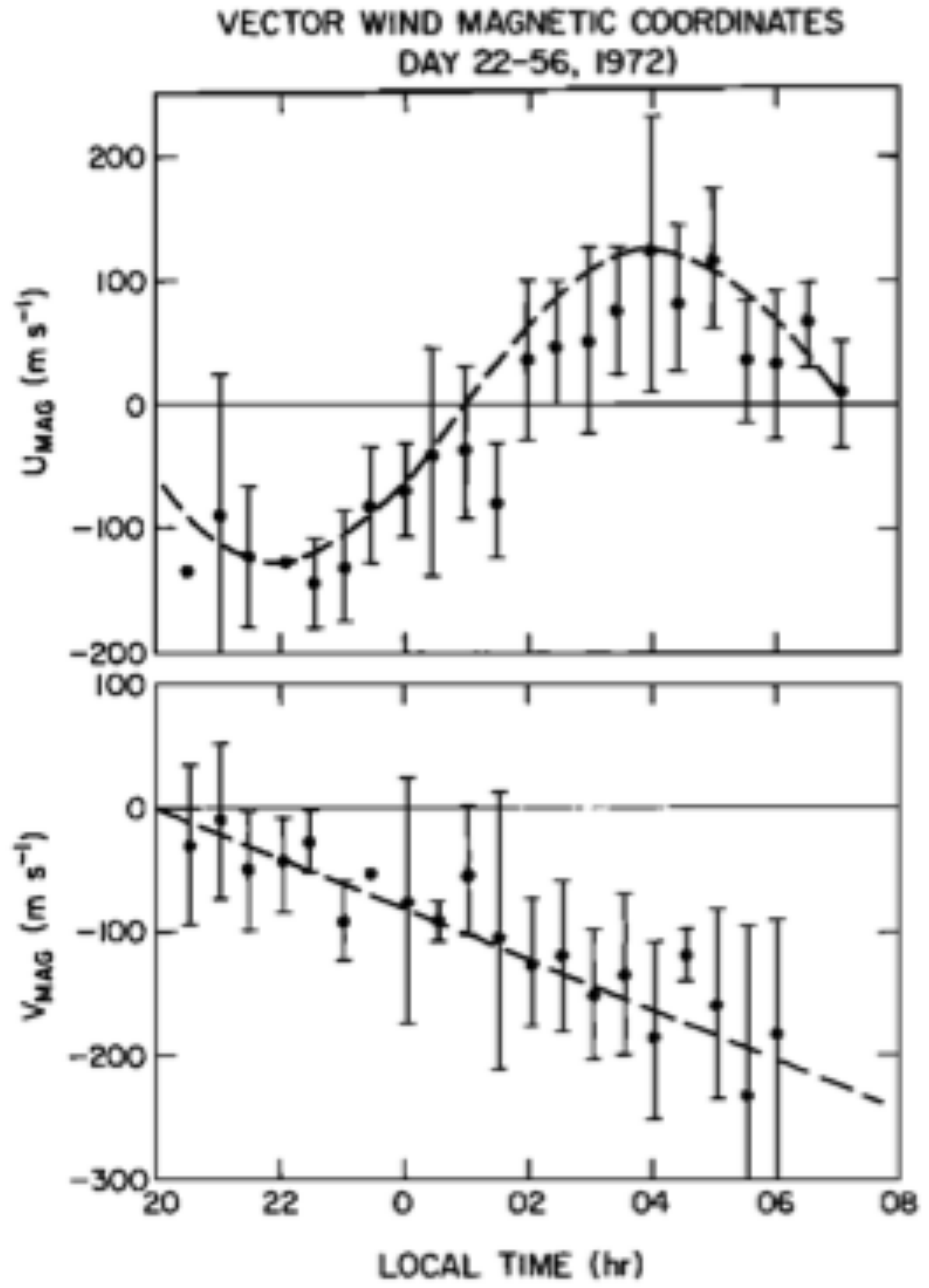


Fig. 1. Half-hour averages and standard deviations of measured neutral wind components over Ester Dome, Alaska, during January and February 1972. The zonal and meridional wind components in meters per second are plotted in geomagnetic coordinates as a function of local time. The average wind is shown as the dot, and the bar indicates the standard deviation of the measured wind value in the half-hour interval. The dashed curve is an average curve used to represent the data in the analysis. The wind components are positive eastward and northward.

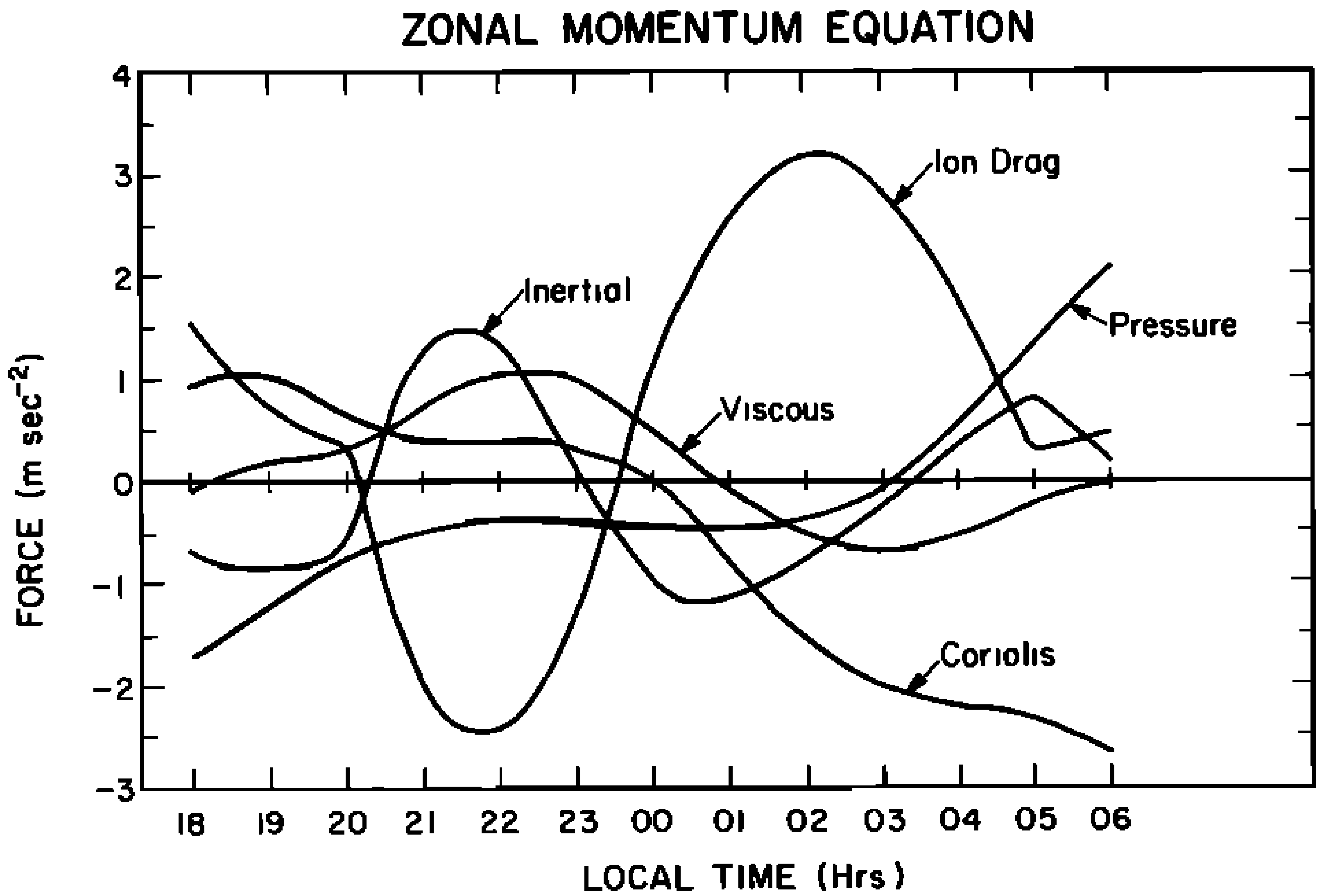


Fig. 12. Balance of forces in the zonal momentum equation at 250 km during the night.

(Hays, P. B., Meriwether, J. W., & Roble, R. G. Nighttime thermospheric winds at high latitudes. *J. Geophys. Res*., 84(A5), 1905-1913, doi:10.1029/JA084iA05p01905)

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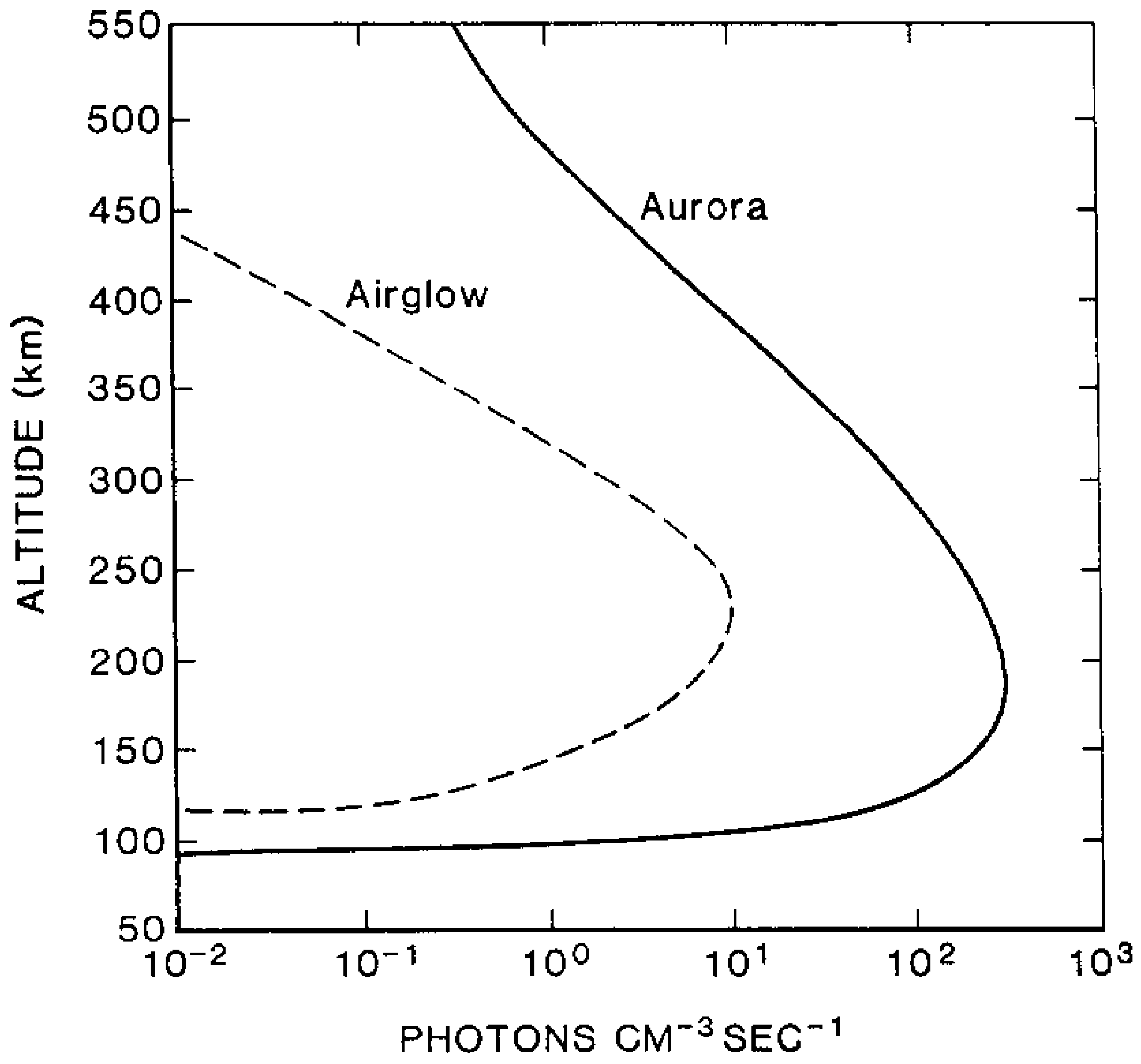
The Height Problem

- Passive remote sensing has poor vertical resolution
- Red line emission is broad and variable
- This was used to argue temperature wasn't useful
    - What about wind shear? (viscosity)
    - Temperature is hard, not useless



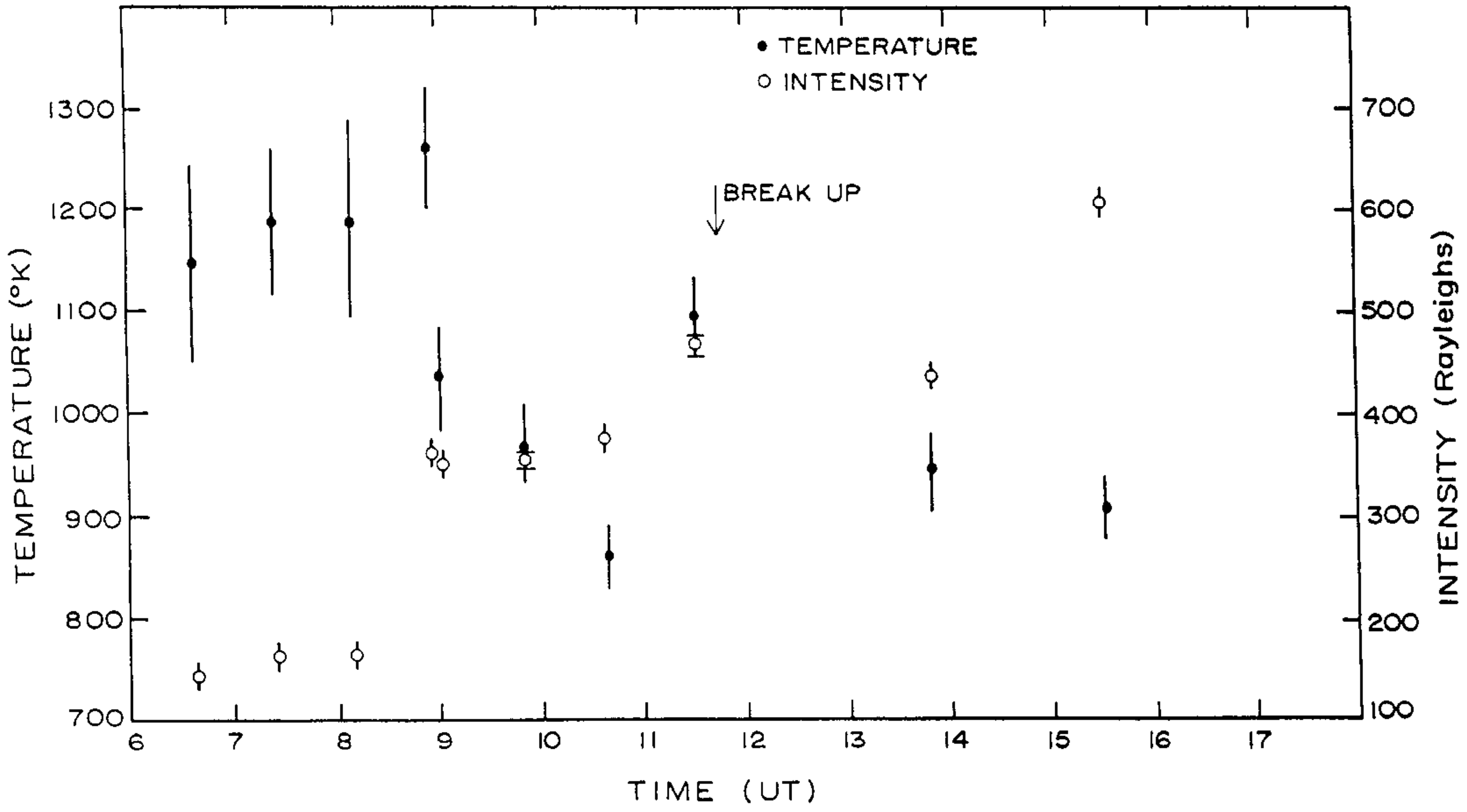


FIG. 3. FABRY–PEROT SPECTROMETER MEASUREMENTS OF TEMPERATURE AND INTENSITY IN THE GEOGRAPHIC ZENITH.
The bars through the points are plus and minus one standard deviation. The intensity uncertainty is the statistical error of the measurement.

Sica, R. J., Rees, M. H., Roble, R. G., Hernandez, G., & Romick, G. J. (1986). The Altitude Region Sampled by Ground-Based Doppler Temperature-Measurements of the OI 15867 K Emission-Line in Aurorae. PLANETARY AND SPACE SCIENCE, 34(5), 483-488.

Constant SNR scanning

- Auroral variability is fast
- We take for granted now videos which show the OI emissions lagging behind the precipitation.
- First colour cameras to show this were a big deal
- We compensated by using the time to achieve a constant SNR as opposed to a constant sampling interval.

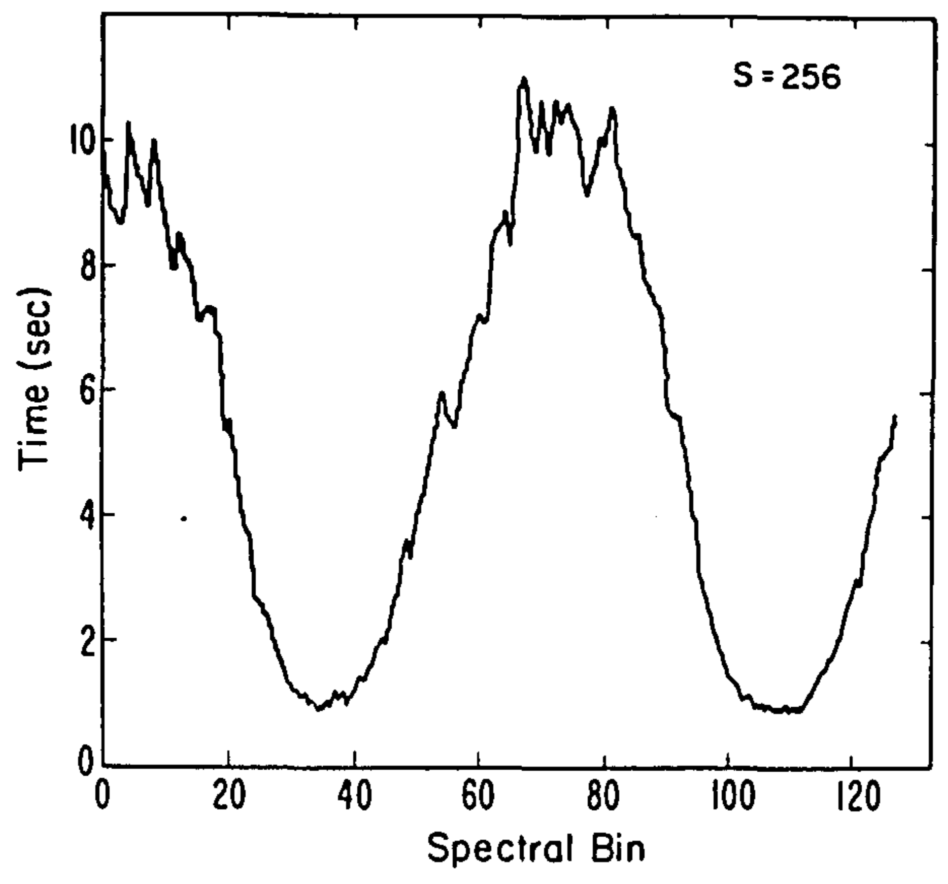


Fig. 1. Recorded times of measurement as a function of spectral bin (630-nm auroral emission).

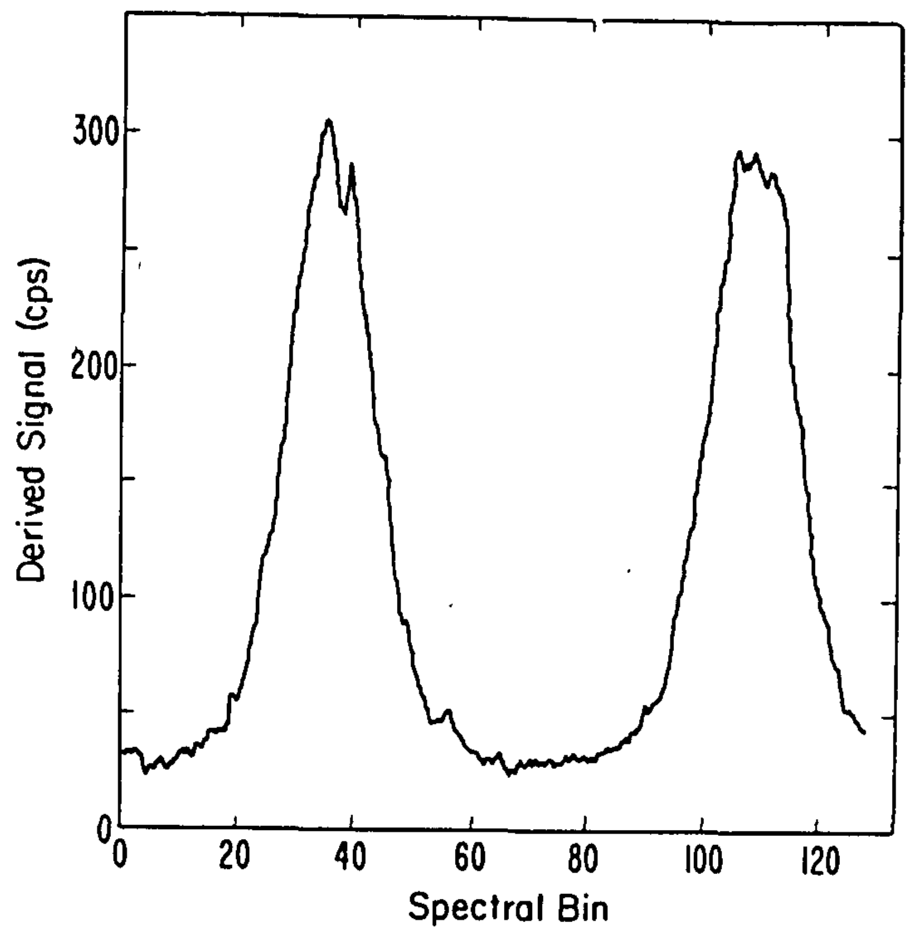
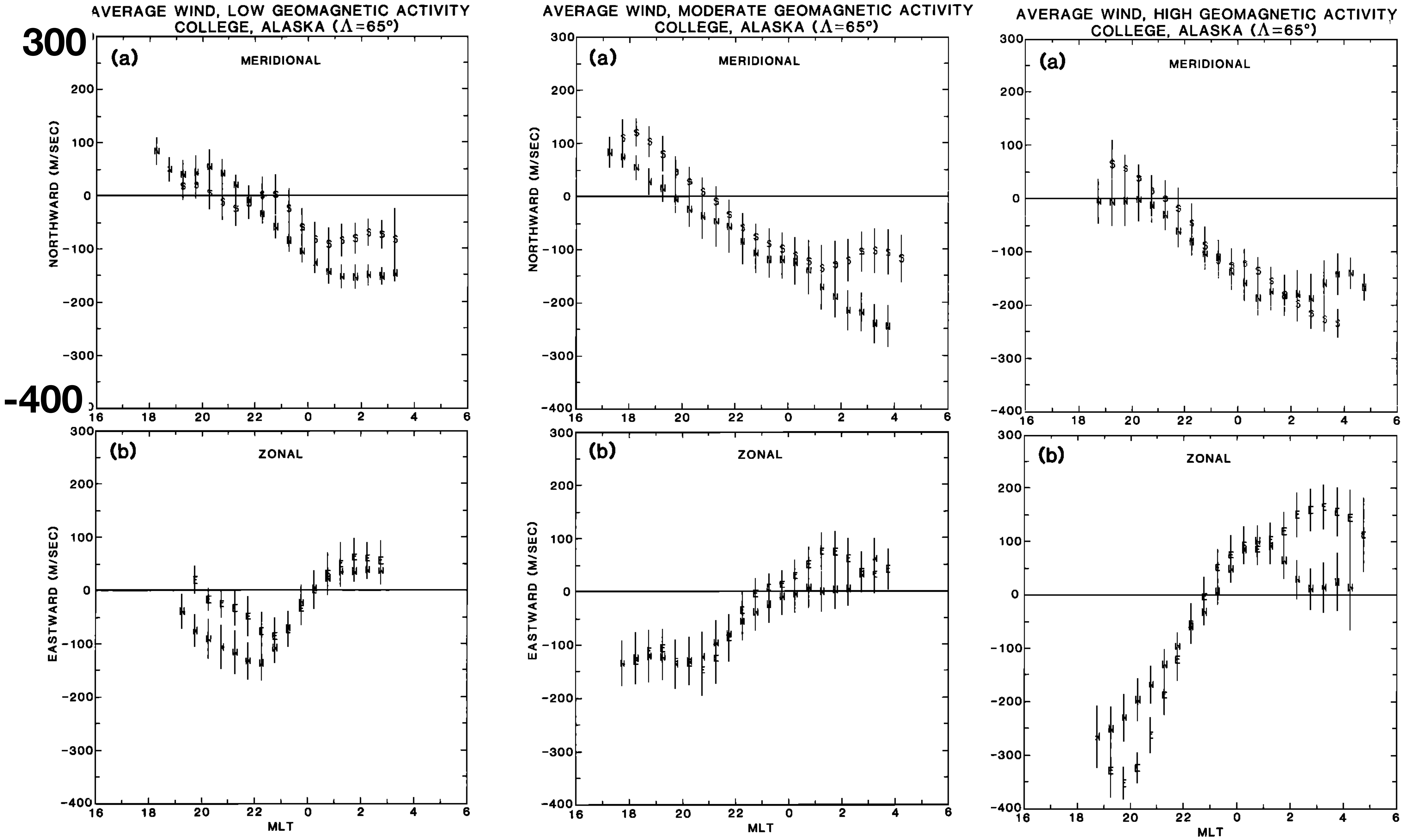


Fig. 2. Reconstructed line profile from the measurement shown in Fig. 1.

Hernandez, G., Sica, R. J., & Romick, G. J. (1984). Equal-noise spectroscopic measurement. Applied Optics, 23(6), 915-919.

Average Horizontal Winds



- 10 - Low, 25 - Moderate, 9 - High activity nights

Sica, R. J., Rees, M. H., Romick, G. J., Hernandez, G., & Roble, R. G. (1986). Auroral-zone thermospheric dynamics 1. Averages. Journal of Geophysical Research-Space Physics, 91(A3), 3231-3244.

Average Vertical Winds

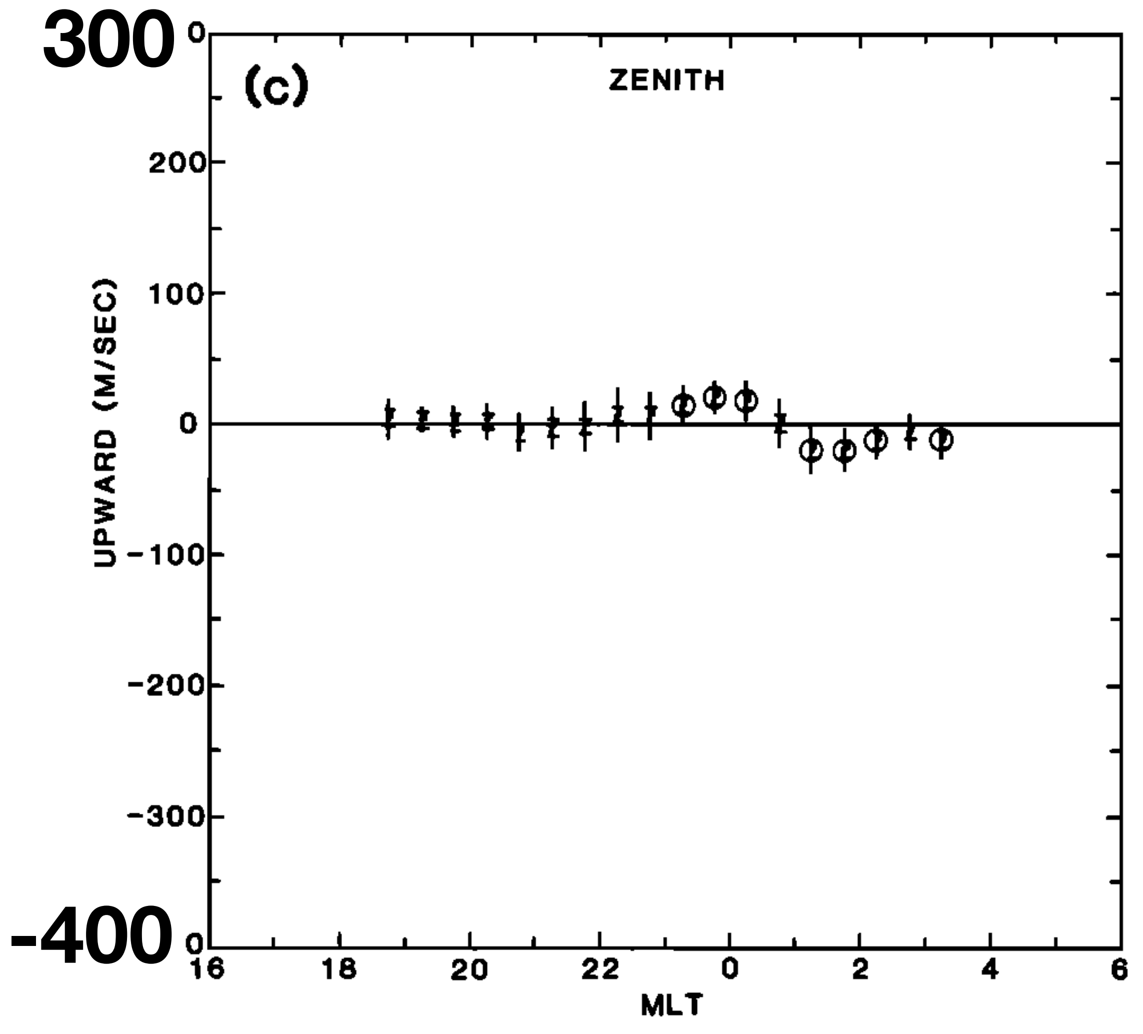


Fig. 5. Diurnal variation of the average wind components in geomagnetic coordinates for low geomagnetic activity in (*a*) the meridional direction, (*b*) the zonal direction, and (*c*) the geomagnetic zenith.

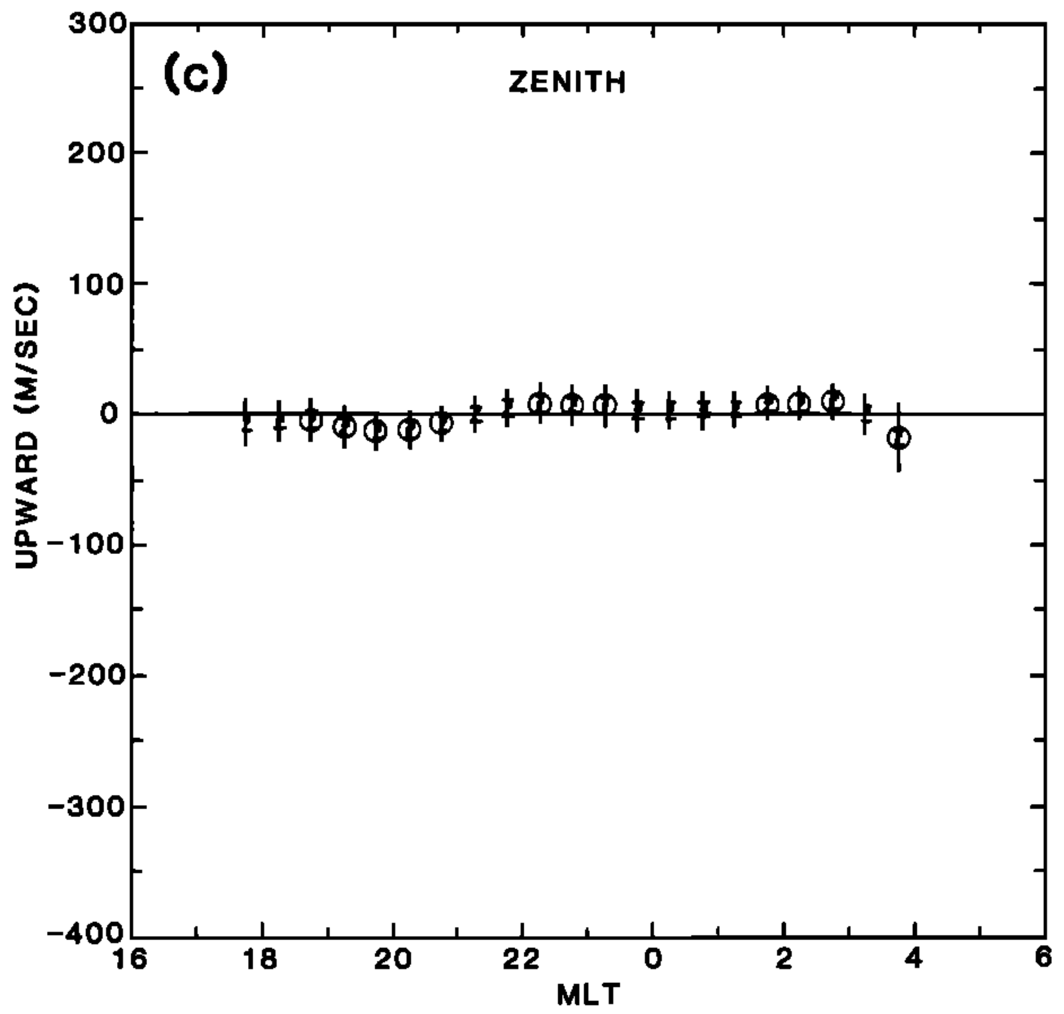


Fig. 6. Average wind components for moderate geomagnetic activity and in geomagnetic coordinates for (*a*) the meridional direction, (*b*) the zonal direction, and (*c*) the geographic zenith. For the zenith measurements, the circled points are different from the mean at the 95% confidence level as determined from Student's *t* test.

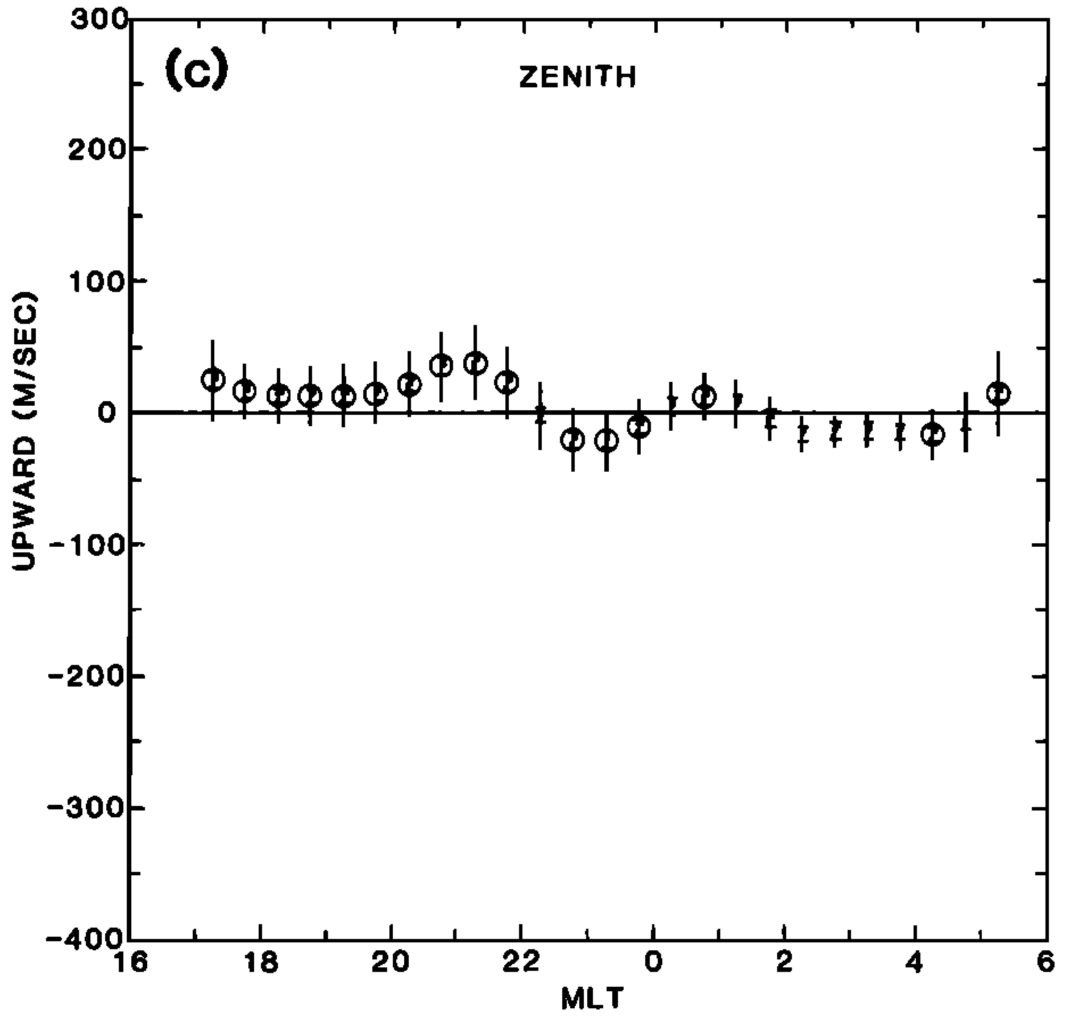
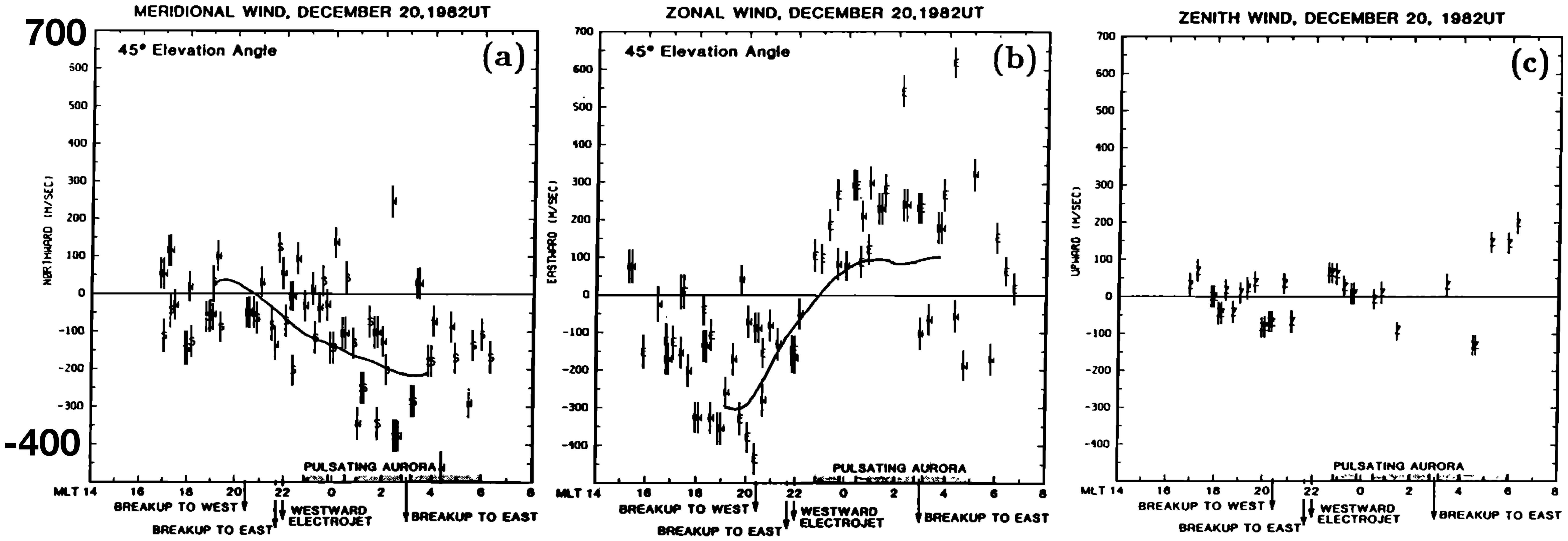


Fig. 7. Average wind components for high geomagnetic activity and in geomagnetic coordinates for (*a*) the meridional direction, (*b*) the zonal direction, and (*c*) the geographic zenith.

- Note on systematics. We used a single frequency HeNe laser measured against the 18,857 cm^{-1} (530 nm) neon line; over many hours the "wind" was always less than 20 m/s.
- We lumped the systematic into the random for a total uncertainty in all plots.

Normal Means Substorms

- Substorms define the steady state in the auroral zone, much like thunderstorms define the ITZ (intertropical convergence zone)



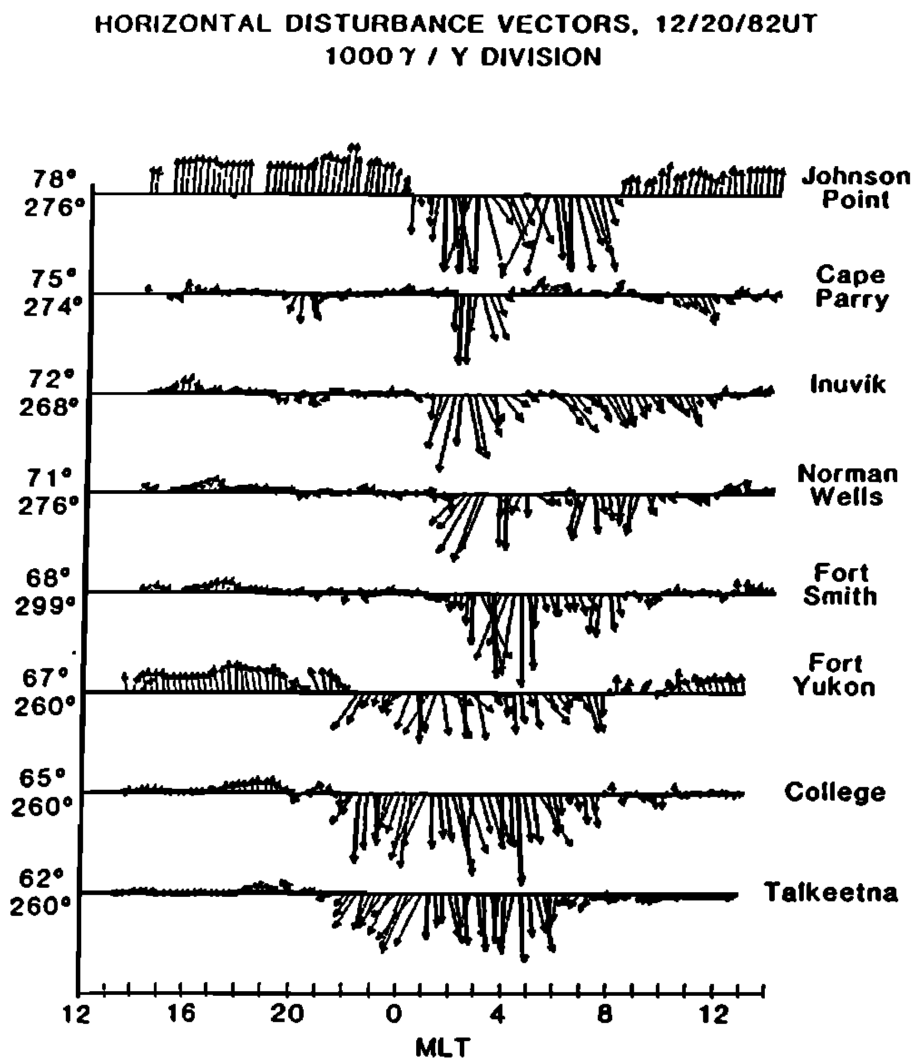
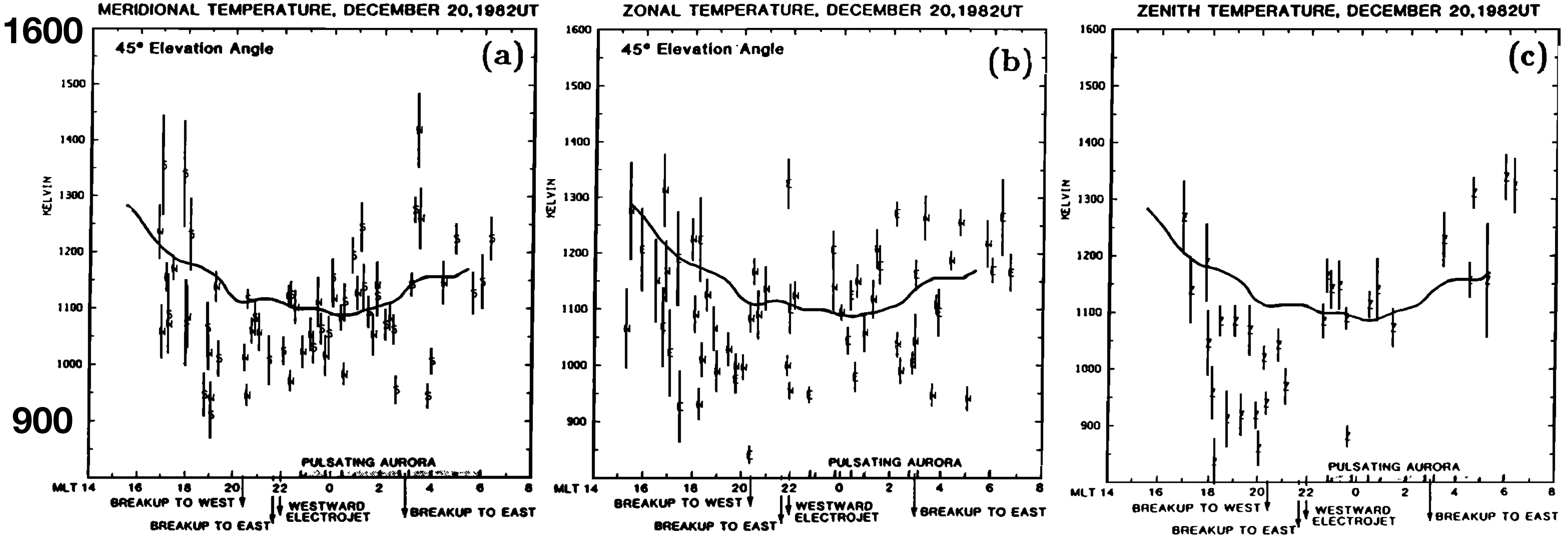


Fig. 2. Horizontal magnetic disturbance vectors for local IMS stations on December 20, 1982, UT. The distance between station zero lines corresponds to 1000 γ.

Fig. 1. Wind measurements on December 20, 1982, UT, (*a*) meridional, (*b*) zonal, and (*c*) zenith. The coordinate system employed has northward, eastward, and upward positive. The zonal measurements are shifted in magnetic local time (MLT) to the time at the point of observation for an assumed 225 km emission layer. The solid line is the high geomagnetic activity wind average from paper 1. The uncertainty of the line is about ±30 m/s.

Sica, R. J., Hernandez, G., Romick, G. J., Rees, M. H., & Roble, R. G. (1986). Auroral-zone thermospheric dynamics 2. individual nights. Journal of Geophysical Research-Space Physics, 91(A12), 13593-13611.

Temperature Response to Precipitation



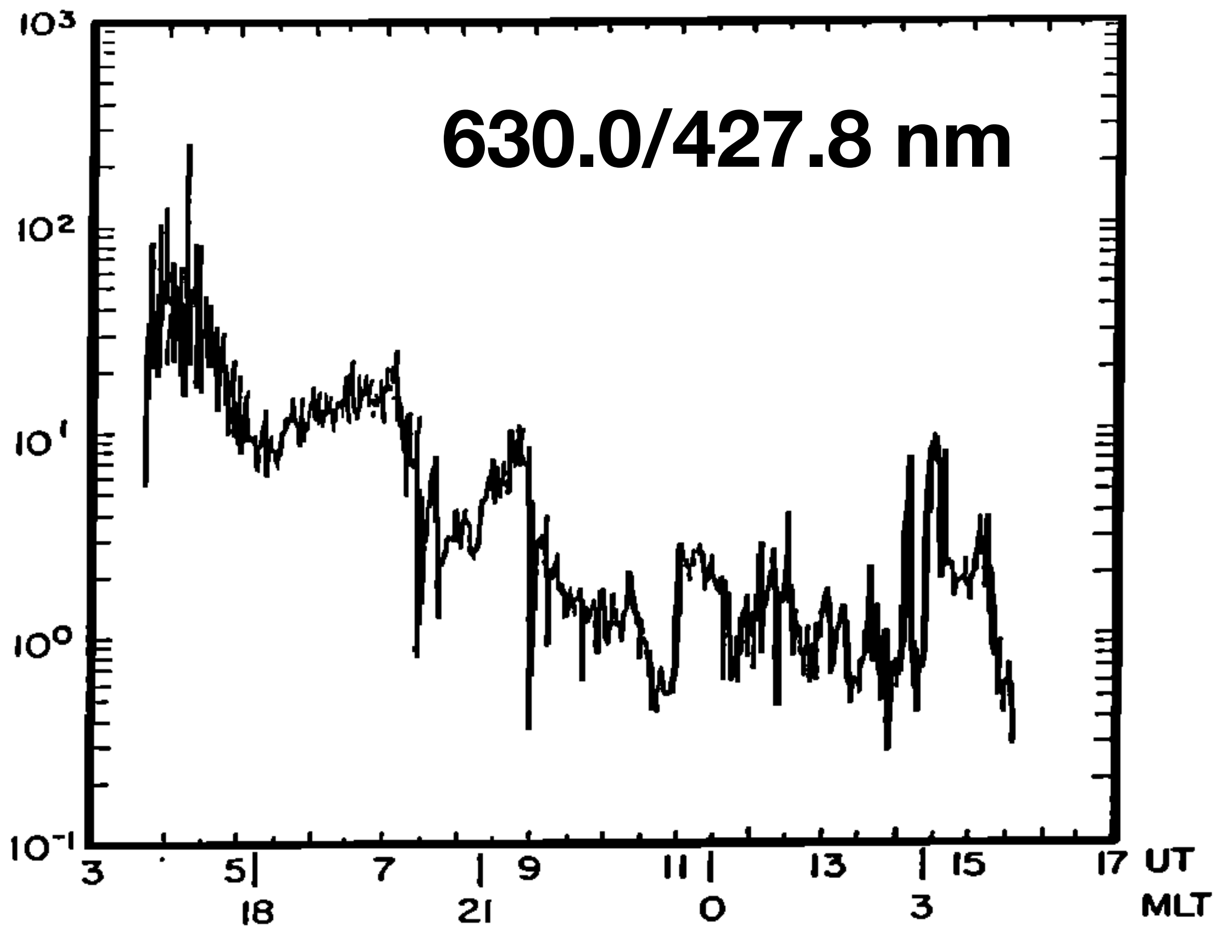
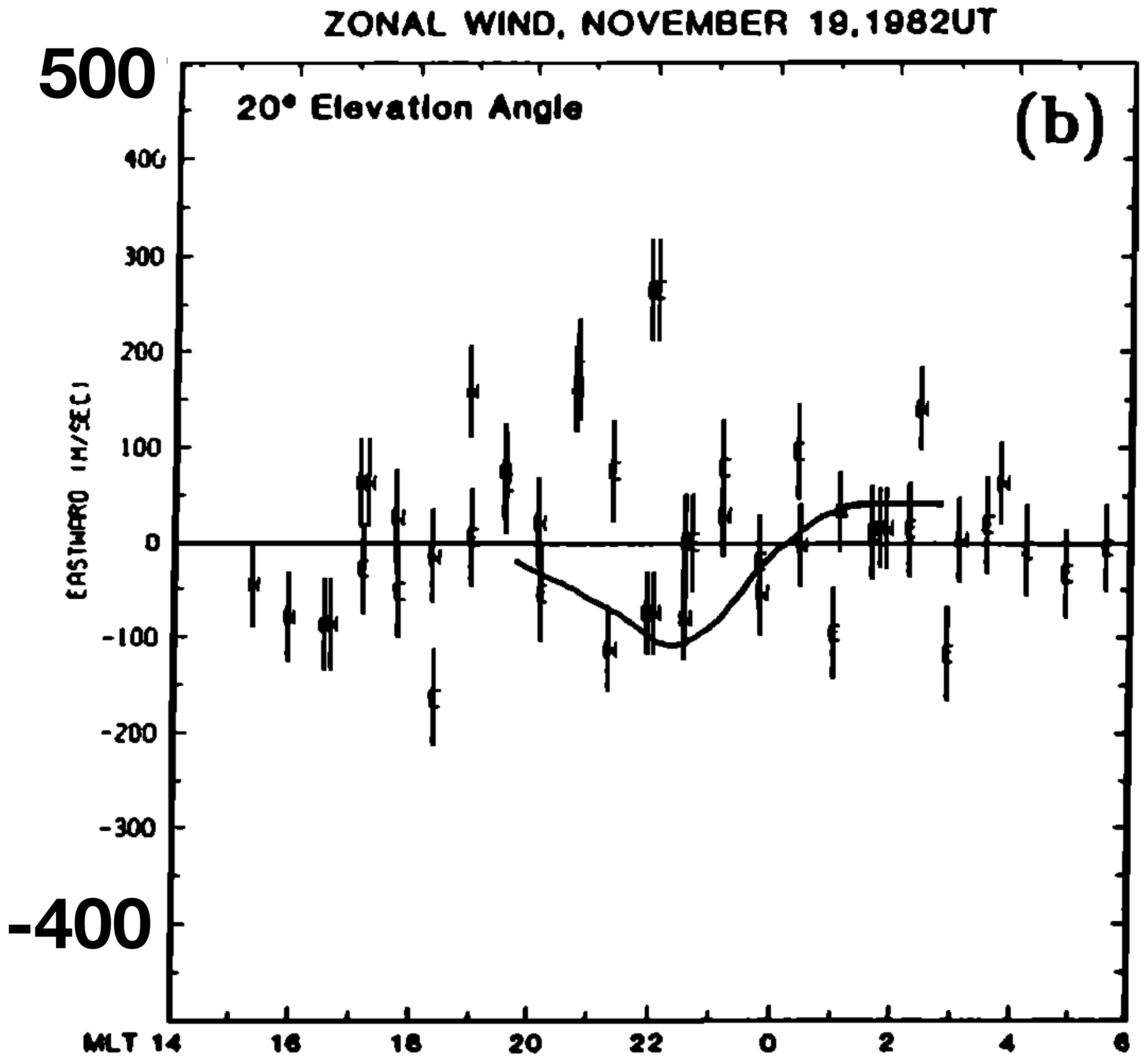


Fig. 4. The ratio of 15867 K to 23368 K emission rates in the College magnetic zenith calculated from intensity measurements obtained with a tilting-filter meridian-scanning photometer on December 20, 1982, UT.

“Disturbed” Conditions

- Here disturbed means no substorm.
- “Wave” in vertical winds until…
- A substorm comes along and smooths out the flow.



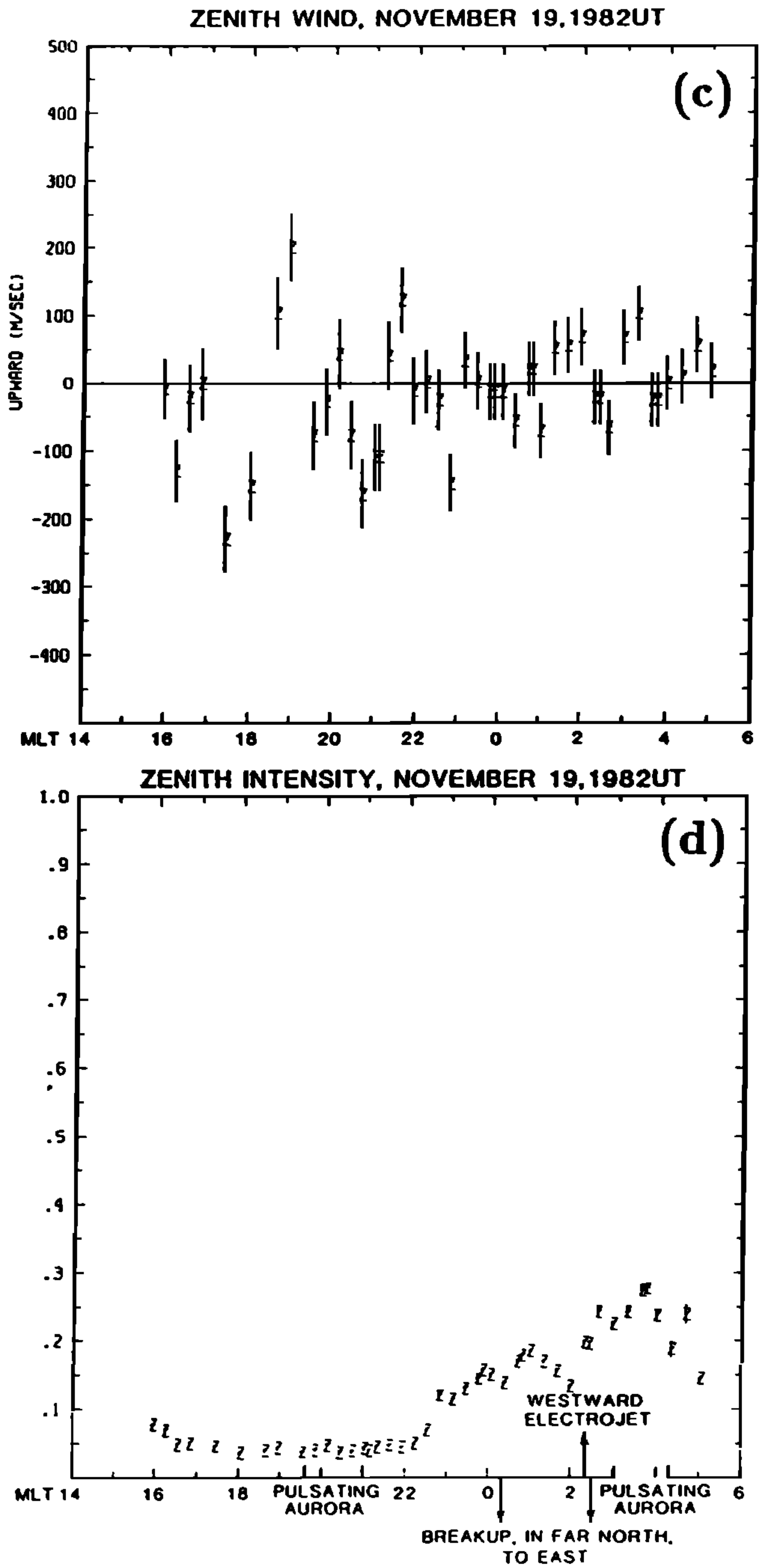


Fig. 15. (continued)

Interesting Variations with B_y

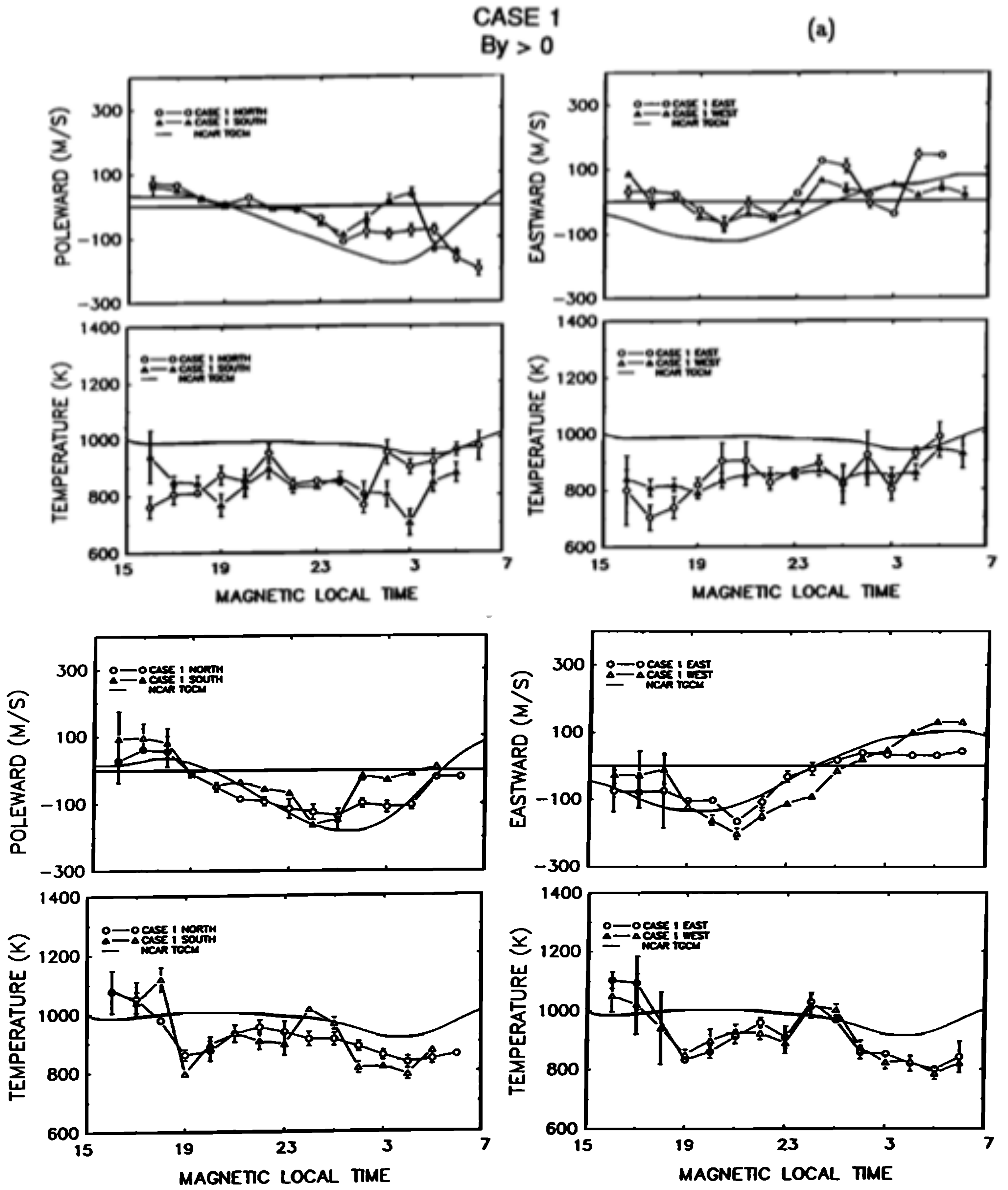
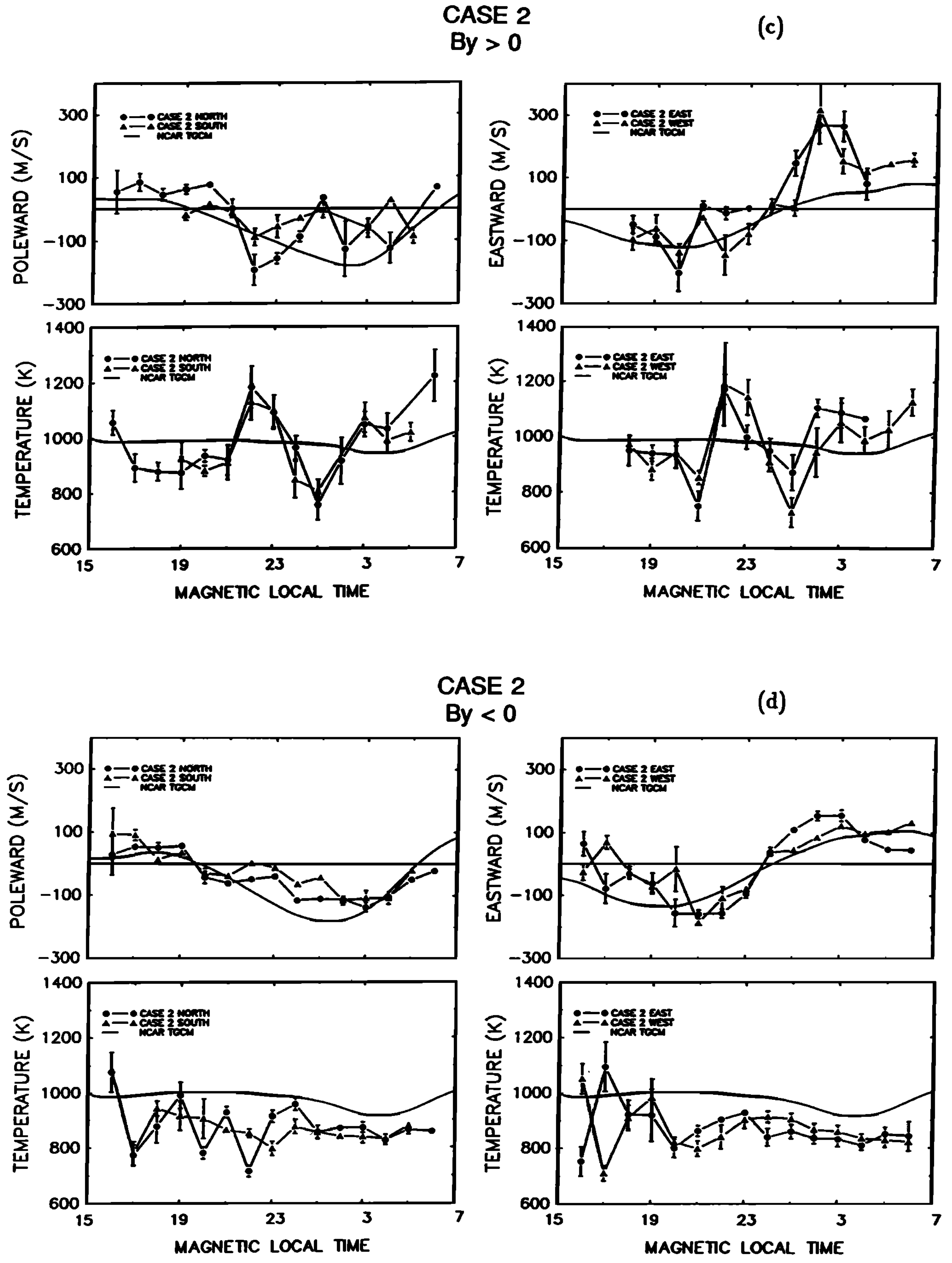


Fig. 2. Individual components of the wind and temperature averages for B_y positive and negative for cases 1 and 2. The measurements were obtained in the magnetic dipole north, south, east, and west. The bar through the measurements is two root-mean-square deviations of the average in length. The predictions of the NCAR TGCM at a height of about 225 km are also shown for the grid point nearest College.



Sica, R. J., Hernandez, G., Emery, B. A., Roble, R. G., Smith, R. W., & Rees, M. H. (1989). The control of auroral-zone dynamics and thermodynamics by the interplanetary magnetic-field dawn-dusk (Y) component. Journal Of Geophysical Research-Space Physics, 94(A9), 11921-11932.

Ion Energy Balance

- The impetus behind CEDAR was GBOA
- Initially poor synergy between optical and radar techniques
- Fortunately that is in the distance past (scientifically)
- I believe there have been quite a few significantly better studies like this since.

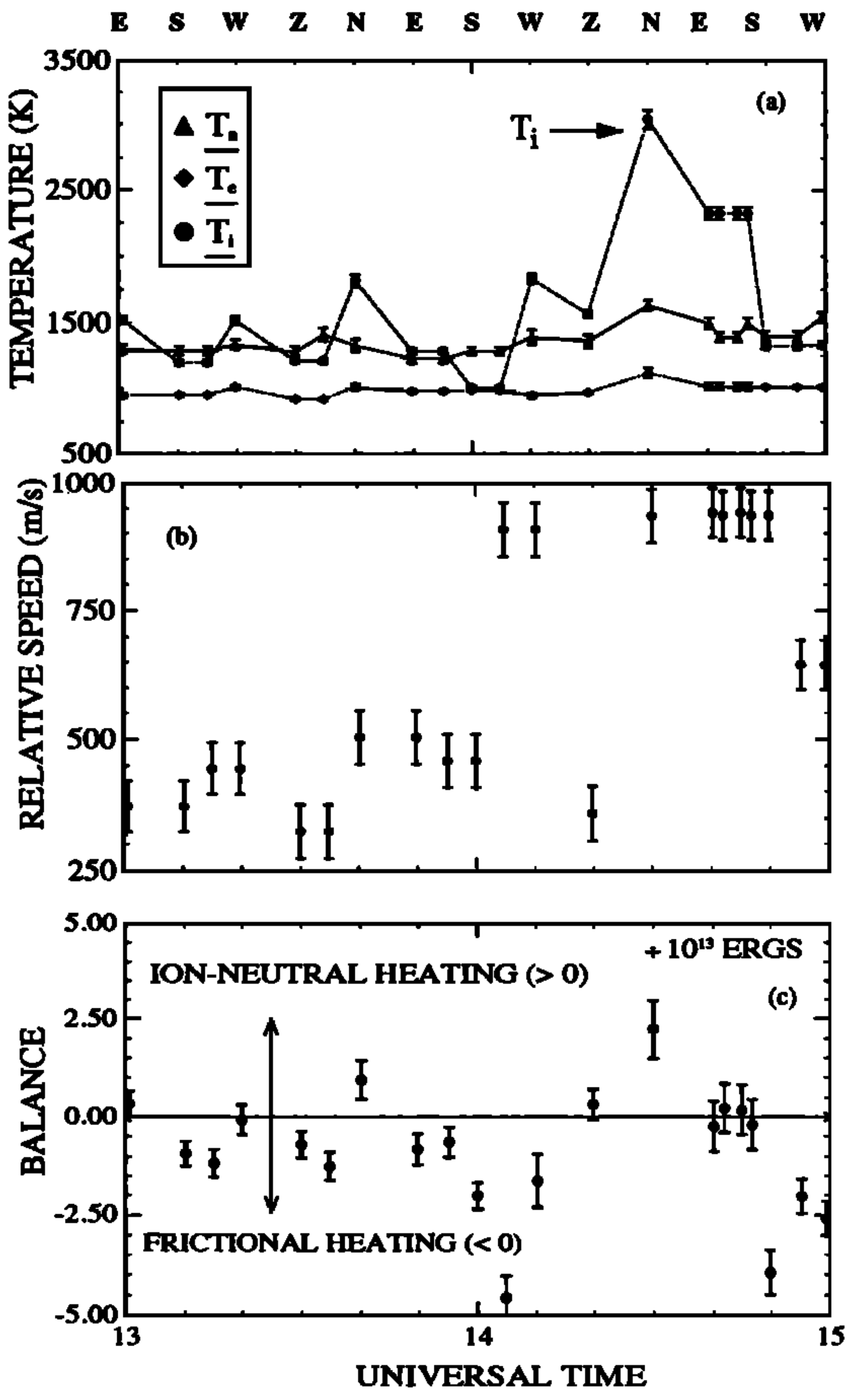


Fig. 8. Balance calculations for an NO^+ ionosphere, assuming the Fabry-Perot Red spectrometer measurements are sampling a 630.0-nm-emitting region whose centroid is at 161 km. *(a)* Neutral, ion and electron temperature measurements; *(b)* relative ion-neutral speed; *(c)* ion energy equation balance. In Figure 8*c*, ION-NEUTRAL HEATING (> 0) means that points above the zero-line have an excess of ion-neutral heating relative to frictional heating; FRICTIONAL HEATING (< 0) means that points below the zero line show an excess of frictional heating relative to ion-neutral heating. Electron-ion heating was negligible during this period.

Sica, R. J., St. Maurice, J. P., Hernandez, G., Romick, G. J., & Tsunoda, R. (1993). Computations of local ion energy-balance in the auroral-zone. Journal of Geophysical Research-Space Physics, 98(A9), 15667-15676.

OEM for profiles?

- Everything about the optimal estimation method in 15 s
- Data
  - FPI intensity scan
  - Red line intensity
- Forward model:
  - Volume emission profile
  - Instrument function
- Retrieve
  - Volume emission profile
  - Weighted temperature

Summary

- Auroral substorms define the steady state for the auroral zone
- Relaxation from the steady state “stagnates” the flow
- Neutral atmosphere responds rapidly to the magnetosphere: so focus on the relation to morphology.
- Temperature measurements are useful, and their interpretation improved, possibly using inverse modelling.
- Don’t forget the green line.
- Use an alkali metal lidar in the upper mesosphere & lower thermosphere. With the green line could validate the inverse model.