Wave Activity in Thermospheric Vertical Winds and Temperatures at Subauroral Latitudes

A.L. Schmidt[1], J.W. Meriwether[1], M.B. Cooper[1], A.J. Gerrard[1], L.V. Goodwin[1], S-R, Zhang[2], G. Jeffer[1,3], C. Callie[1,3]

[1] New Jersey Institute of Technology, Newark, NJ, USA [2] Haystack Observatory, Massachusetts Institute of Technology, Westford, MA, [3]United Astronomy Clubs of New Jersey, Inc., Hope, NJ

als53@njit.edu

ABSTRACT

The need for high precision measurements of vertical winds with uncertainties less than 3-5 m/s and a temporal cadence of 1-2 min has made it exceedingly difficult to study the response of the thermosphere to gravity wave activity. Herein we present subauroral, midlatitude thermospheric wave measurements of 630 nm OI emission from a 15 cm narrow field Fabry Perot Interferometer, named the Hot Oxygen Doppler Imager (HODI). These measurements of temperature and vertical wind velocities are from a first light campaign at Jenny Jump Observatory (40.9 N, 74.9 W) located in northwestern New Jersey. The heightened sensitivity of HODI enables analysis of gravity wave behavior with uncertainties of 3-5 m/s for vertical wind speeds and 10-15 K for temperatures for two-minute exposures. Data was collected during periods of geomagnetically quiet and active conditions, and apparent wave structures were seen during both conditions. One detailed observation, taken the night of July 25, 2022, enabled the ~90-deg phase shift between vertical winds and temperatures to be inferred, as per standard gravity wave polarization relations with viscous dissipation. However, most other observations found to have little correlation between the temperature and vertical winds, which we speculate may be a result of the propagation and interaction of multiple wave events. Traveling ionospheric disturbances (TIDs) are often described as the ionospheric signature of the passage of gravity waves, and we provide comparisons of select wave events to medium scale TIDs using differential total electron count (TEC) maps.

INTRODUCTION

The Hot Oxygen Doppler Imager (HODI; pictured in Figure 1) is a 15 cm aperture Fabry-Perot Interferometer (FPI) comprised of 2 parallel, flat mirrors which can measure optical light emissions (630 nm; OI) to track the wind velocities and direction at a particular altitude of our atmosphere via Doppler shifts and widths.

Utilizing this procedure, HODI can measure horizontal and vertical wind velocities and temperatures in the thermosphere (~250 km altitude).

- Neutral vertical wave activity plays an important role in the thermosphere and the connections between the ionosphere and the thermosphere.

Figure 1: Hot Oxygen Doppler Imager with filter wheel and CCD camera (left) installed at Jenny Jump Observatory. Skyscanner which allows for the optical field of view to be directed toward any spot in the sky (left).

Variations of winds and temperatures can be studied to see the effects of gravity waves (GW) and Medium Scale Traveling Ionospheric Disturbances (MSTIDs) which are the ionospheric signature of the passage of GWs.

- MSTIDs can be studied via the change in total electron count (TEC) in the ionosphere.

In the past, the need for high precision Doppler velocity measurements of vertical winds on the scale of less than 3-5 m/s and cadence of 1-2 min. to detect GW events has made it nearly impossible to study the response of the neutral thermosphere to GW activity.

- With HODI's heightened sensitivity, we can search for possible GW behavior and events with an error typical of 3 to 5 m/s for vertical wind speeds and 10 to 15 K for temperatures for 2 min exposures.

With the measurements of **HODI's** First Light Campaign at Jenny Jump Observatory (40.9 N, 74.9 W; JJO) we can study vertical wind and temperature wave behavior during periods of quiet and active geomagnetic conditions with comparisons to MSTID events for select thermospheric wave events.

OBSERVATIONS

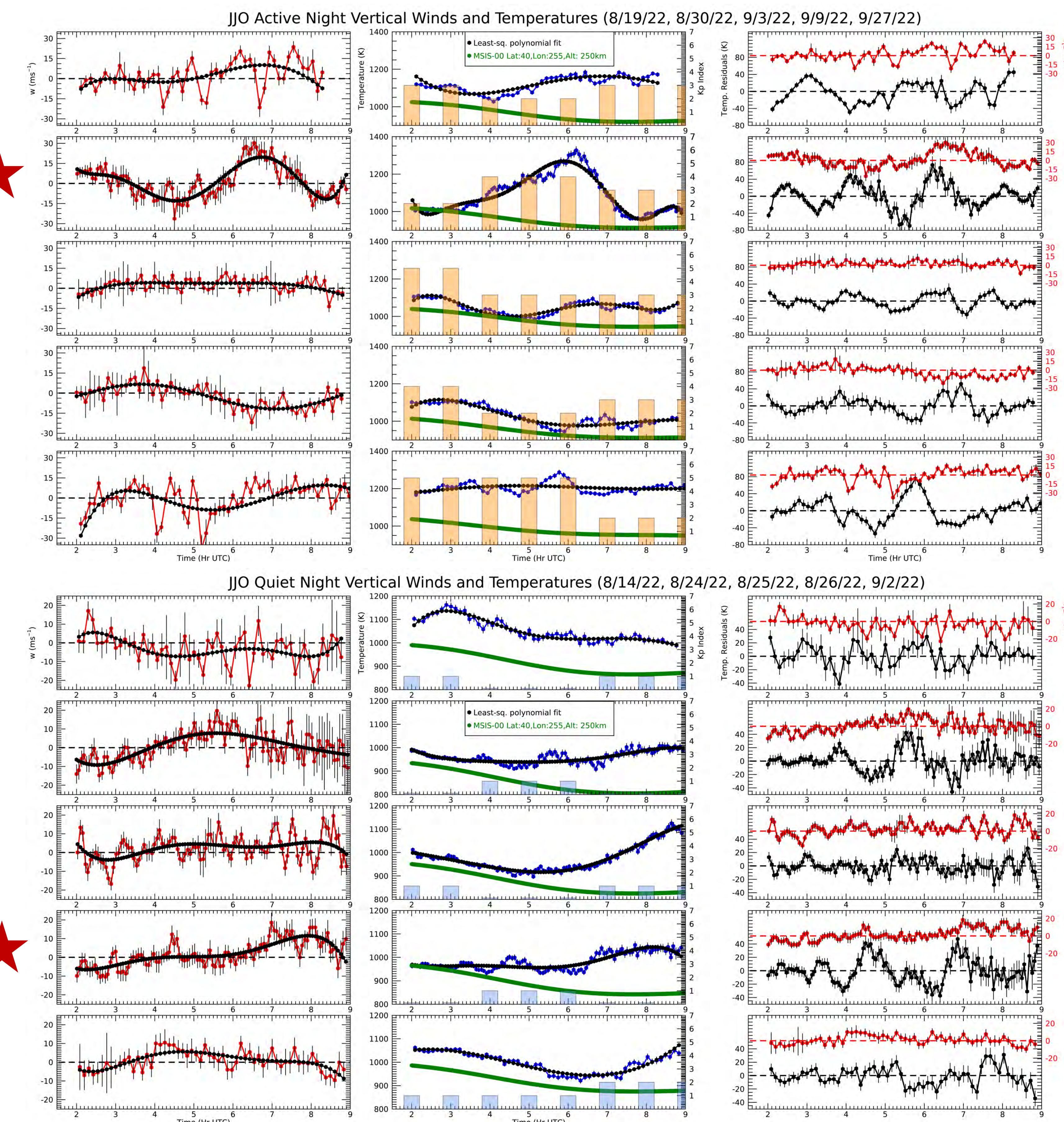

Figure 2: Observations from geomagnetically quiet (bottom) and active (top) conditions. Comparison of vertical winds (red) and temperature residuals (right, black) measured by HODI derived from the subtraction of observed temperatures (middle, blue) and a least-square polynomial fitting (middle, black). Temperatures are plotted with the NRLMSIS-00 empirical model (middle, green) and approximate kp index (bar graph).

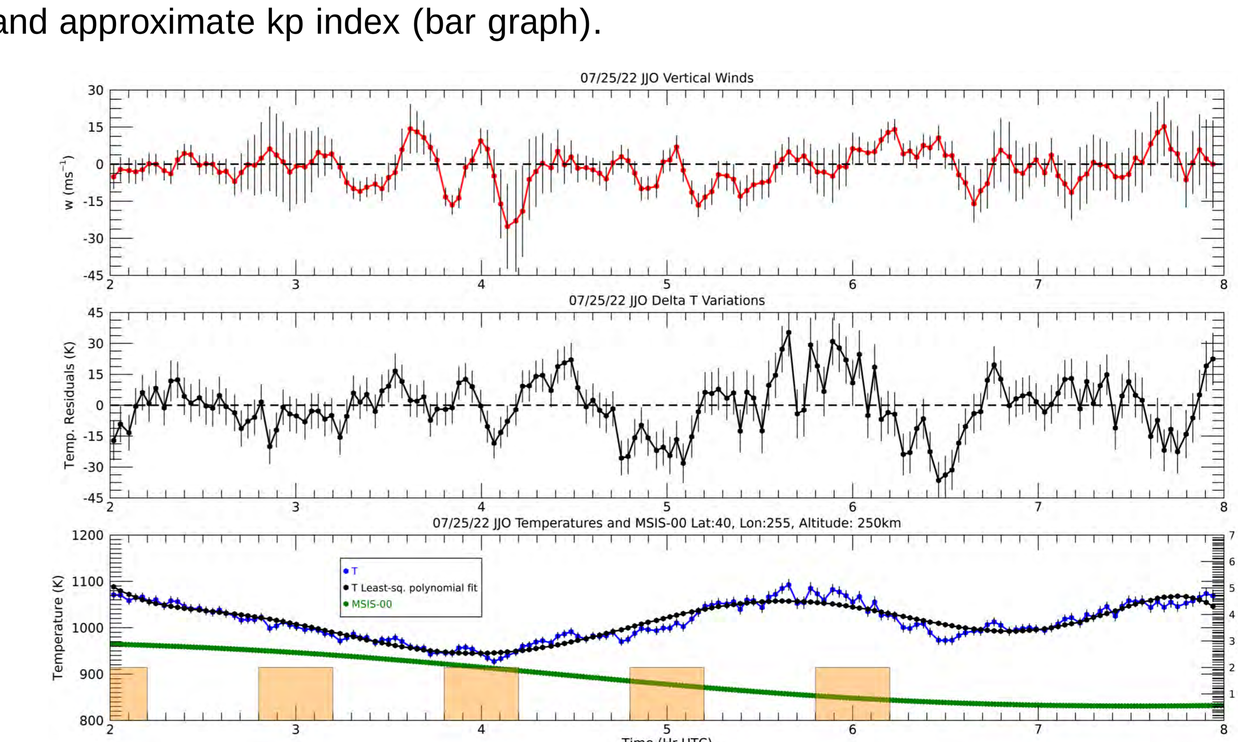

Figure 3: Potential GW event on 7/25/2022 between 03:00-04:00 UTC shown in vertical winds (top) and compared to temperature residuals (middle) derived from the subtraction of raw temperatures (bottom, blue) and a least-square polynomial fitting (bottom, black). Temperatures are plotted with approximate kp index (bar graph) and NRLMSIS-00 empirical model (bottom, green).

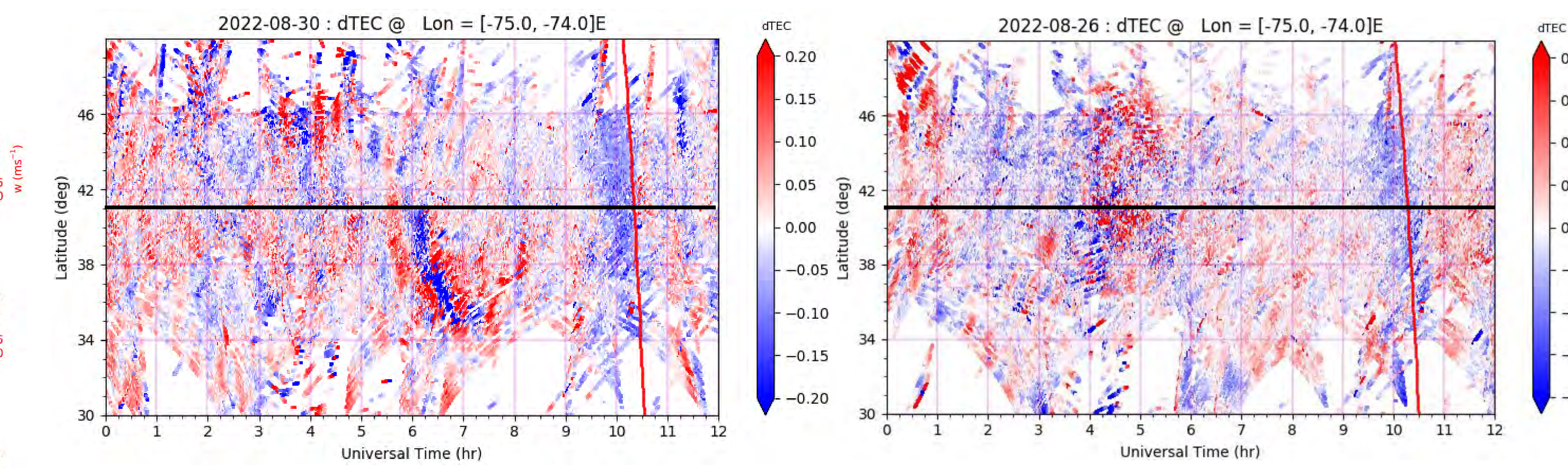

Figure 4: Differential total electron count (dTEC) for longitude [-75,-74]E with varying latitudes and times on 08/30/2022 (left) and 08/26/2022 (right). JJO approximate location (40.9 N, 74.9 W) indicated by a black line. The wind and temperature observations from HODI for these dates are starred in Figure 2.

DISCUSSION

Observations from HODI of periods of quiet and active geomagnetic conditions with clear skies (no clouds) show fluctuations in the vertical winds with larger amplitudes and enhanced temperatures during geomagnetically active times.

Observations of Interest:

- 08/30/2022 (Figure 2, top star) observations show a wave train in the residual temperatures with a period of ~2.5 hours (02:30-06:30 UTC), a lower frequency wave pattern in vertical winds, and a large upwell of 300 K in observed temperatures. A southwestward MSTID was found at ~06:00 UTC in which the decrease in dTEC corresponds to the upward flows in the vertical winds during this event. This is an active geomagnetic night.
- 08/26/2022 (Figure 2, bottom star) observations show a similar wave train in the residual temperatures with little wave behavior in the vertical winds. Some structure in the differential TEC graph can be seen. This is a quiet geomagnetic night.
- 07/25/2022 (Figure 3) observations highlight a potential GW event between ~03:00-04:00 UTC seen with high frequency oscillations in the vertical wind and temperatures.
  - Figure 5 demonstrates the phase lag of vertical wind and residual temperature. The circle-like plot is consistent with 90° wind phase lag relative to temperature with dissipation in the thermosphere.

Other than observations from 07/25/2022, no close apparent correlation between vertical wind and temperature oscillations were seen, which may be if we are observing the effects in the thermosphere of multiple GW events. More high cadence observations will be able to be taken to further probe the vertical wind and temperature fluctuations with MaxFPI, a state-of-the-art 20 cm aperture FPI.

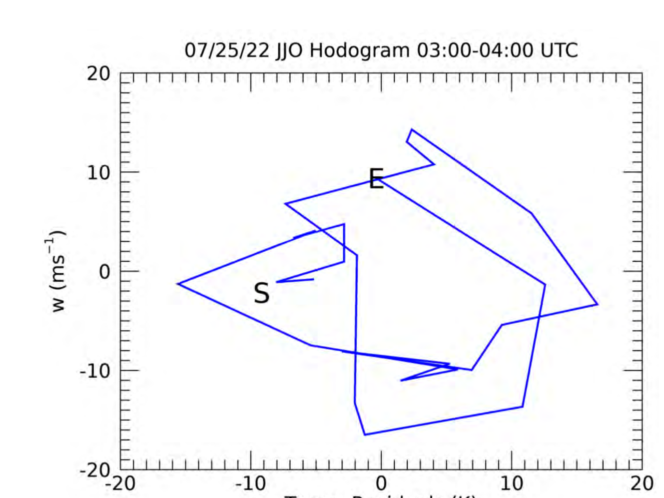

Figure 5: Analysis of phase from HODI residual temperature observations and vertical wind velocities from 03:00-04:00 UTC July 25th, 2022. S marks the start of the observations at 03:00 UTC, E marks the end of the observations at 04:00 UTC

ACKNOWLEDGEMENTS

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