Review Article

Large-Scale Measurements of Thermospheric Dynamics with a Multisite Fabry-Perot Interferometer Network: Overview of Plans and Results from Midlatitude Measurements

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The North American Thermosphere Ionosphere Observing Network (NATION), comprising a new network of Fabry-Perot interferometers (FPIs), to be deployed in the Midwest of the United States of America is described. FPIs will initially be deployed to four sites to make coordinated measurements of the neutral winds and temperature in the Earth's thermosphere using measurements of the 630 nm redline emission. The observing strategy of the network will take into account local observing conditions, and common volume measurements from multiple sites will be made in order to estimate local vector wind quantities. The network described is expandable, and as additional FPI sites are installed in North America, or elsewhere, the goal of providing the upper atmospheric research community with a robust dataset of neutral winds and temperatures can be achieved.

1. Introduction

The thermosphere is the crucial boundary between the Earth's lower atmosphere and space. Low Earth orbiting satellites and other objects in the upper thermosphere are strongly affected by the lifting of the atmosphere that results from space weather heating events (e.g., [1–3]). In addition, space weather driven by thermospheric dynamics can cause important degradations in engineering capabilities society depends on, such as the accuracy and availability of Global Navigation Satellite Systems (GNSS) and radio transmissions (e.g., [4–7]).

Empirical models, such as the Horizontal Wind Model (HWM07, [8]) and NRLMSISE-00 [9], are useful in providing general climatologies of thermospheric parameters, but fall short in providing a realistic representation of the neutral dynamics that can be applied to space weather

forecasting. To help improve our understanding of the thermosphere/ionosphere (TI) system and its role in the bigger picture of the geospace system, understanding of the various pathways of energy transfer within the geospace system needs to be improved. These pathways include the transfer of energy from (1) the ground into the upper atmosphere by means of waves of various scales including gravity, tidal, and planetary waves; (2) space downward into the upper atmosphere through the absorption of solar energy or modification of global electric and magnetic fields during geomagnetic storm activity; and (3) the polar or equatorial regions toward the midlatitudes by traveling atmospheric disturbances (TADs) as well as tidal and planetary wave dynamics.

There are considerable challenges in being able to fully understand, much less simulate in real time, these complex physical processes of the thermosphere-ionosphere system.

FIGURE 1: Comparison of monthly-averaged thermospheric neutral winds measured over the Urbana Atmospheric Observatory (40.10 N, -88.23 E) Illinois and the results of the HWM93 [11] and HWM07 climatological models.

One of the significant problems in achieving a reasonable level of success in space weather forecasting is the lack of adequate information regarding the neutral wind behavior as a function of time and space, especially near the polar region but also at midlatitudes. Thermospheric studies are hampered by a lack of observational data that can provide a global, or even regional, view of important driving parameters. For example, optical Fabry-Perot interferometers (FPIs) instrument deployments at single sites provide only localized measurements of the thermospheric wind, temperature, and airglow brightness. Data from such isolated instruments are inherently limiting, since such measurements cannot give information on spatial extents, source regions, or even whether observed phenomena are propagating or stationary. In contrast, measurements made by orbiting satellites present a more global view of thermospheric parameters (e.g., [10]) but do not allow the exploration of the temporal evolution of the thermospheric winds over timescales of less than the ~ 90 minutes of a satellite orbit.

Based on inputs from several single-site FPI experiments, climatological models of the expected neutral wind behavior have been compiled. For example, Emmert et al. [12, 13] have compiled measurements from seven FPIs located in different regions to create climatologies of the neutral winds based on activity level, season, position in the solar cycle, and interplanetary magnetic field conditions. This type of model development demonstrates the power of multiple

stations taking data for long periods of time, albeit in an uncoordinated fashion. However, the resultant model cannot address the dynamics or the timescale of many of the features in the thermosphere.

Furthermore, the accuracy of the resultant climatology is directly dependent on the amount and quality of data used to create the model. Comparisons of the climatological neutral wind provided by HWM07 to FPI results have demonstrated that the current state-of-the-art modeling of the neutral wind climatology does not represent the actual observed neutral winds, neither on a day-by-day nor a monthly-averaged basis. Examples demonstrating this for a comparison using data obtained using an FPI located at the University of Illinois in 2008 are shown in Figure 1. Although one major reason for this discrepancy was likely the fact that the deep solar minimum conditions experienced from 2008–2010 were not represented in the database used to construct HWM07, this example highlights the need for additional measurements to improve future climatological models.

The major input forcing function of the thermosphere neutral dynamics can be traced back to solar variability, but this function may be highly modified by the extent and nature of geomagnetic activity that will produce severe polar dynamical disturbances. Large compositional changes and temperature variations are developed in the wake of such transient structures, regulating the amount of Joule heating that occurs. These disturbances travel to midlatitude

regions, and, as a consequence, they push ions up and down nonvertical geomagnetic field-lines, causing significant variability in the electron density of the ionosphere. Existing climatological neutral wind models, such as HWM07, are not sufficiently precise for these space weather modeling needs [14].

First principles models can also be used to specify the wind pattern and are frequently used to investigate thermospheric dynamics. However, due to the general lack of neutral wind measurements, there have been few direct comparisons between these types of models and wind measurements (e.g., [15–17]). Even though winds are a critical component of the model dynamics, they tend to not be validated. Other states of the model (e.g., mass density, electron density) that are well represented by data are more frequently compared and validated, even though these states are controlled by the winds. Having a richer neutral wind database made available to the community will allow modelers to better validate the winds.

Many past measurements of midlatitude dynamics with reference to the continental United States region have been reported, with the first Fabry-Perot measurements being that of Hays and Roble [18]. They reported observations of enhanced meridional winds observed in a geomagnetic storm of October 1968. Biondi and Feibelman [19] reported on the first detection of thermospheric winds from Laurel Ridge, PA, in 1968. This early work was followed up by a series of papers by Hernandez and Roble that presented results from the Fritz Peak Observatory (FPO) located in Colorado (39.9 N, 105.5 W). They showed the seasonal variations of winds and temperatures observed during geomagnetically quiet times [20], the thermospheric dynamics seen for four geomagnetic storms in 1975 [21], and the monthly climatology results seen for the period of solar minimum in 1976 [22]. The climatologies of the thermospheric winds and temperatures observed from FPO and Laurel Ridge over the period of 1973 to 1979 and 1975 to 1979 were described by Hernandez and Roble [23] and Sipler et al. [24], respectively. Comparisons of these FPO measurements for both solar minimum and solar maximum periods presented by Hernandez and Roble [25] with the Thermosphere Ionosphere Electrodynamics General Circulation Model (TIE-GCM) predictions showed reasonable agreement, suggesting that the basic driving forces for midlatitude thermospheric dynamics are reasonably well understood for quiet periods. Further studies of midlatitude thermospheric dynamics have been carried out using a Fabry-Perot located at Millstone Hill (43 N, 72 W) for quiet times [26] and for active times [27].

These studies indicate that the local thermospheric dynamics are relatively well understood, especially for quiet periods. However, there are not enough observatories currently operating that are capable of making thermospheric measurements to get an appropriate global or region view of thermospheric dynamics, particularly during active periods or to study spatial and temporal gradients in the thermosphere. For example, to investigate energy is transferred from the polar region to the midlatitudes by such traveling atmospheric disturbances (TADs), a network of FPI observatories is required.

In this paper we describe an FPI network, the North American Thermosphere Ionosphere Observing Network (NATION), that has been developed for application in the midlatitude region of the eastern continental United States in the states of Michigan, Illinois, Kentucky, and North Carolina. These four sites are intended to represent an initial deployment of what will become a larger-scale network that will eventually extend to continental and global scale in scope. Two additional sites located in New Jersey and New Mexico are already planned. The FPI instruments are already in hand and fully-operational status for the network is expected to be achieved by midsummer, 2012, upon the completion of the deployment of these instruments to these sites. One of the unique aspects of this network is the utilization of common volume points as represented by intersecting line-of-sights to observe the three components of the neutral wind vector as well as the temperature in a volume of the thermosphere on the order of 25 km laterally and 50 km vertically. Another unique aspect will be the ability to modify the observing strategy in real time depending upon the nature of cloud coverage or perhaps geophysical activity.

2. Network Instrumentation

Two types of instruments will be deployed in this network. The primary instrument is an improved version of a miniaturized CCD-based imaging Fabry-Perot interferometer that has been used successfully in recent experiments [28]. All of the initial network FPIs are variants of this design. The second instrument is an infrared cloud detector that will automatically monitor sky conditions at each observatory. This instrument is necessary for developing the real-time control infrastructure to optimize observations for the entire network, taking into account the local sky conditions at the individual sites.

The FPI instrument observes the spectral line shape of the 630 nm OI emission with a typical spectral resolution of $\lambda/\Delta\lambda \sim 310,000$. This high resolution is necessary to overcome the instrumental challenge of measuring the small quantities represented by the Doppler shift and Doppler width. A 100 ms^{-1} Doppler shift corresponds to a wavelength shift of 0.0002 nm. For a temperature of 1000 K the spectral profile full width at half peak height is $\sim 0.0033 \text{ nm}$ compared to the instrumental width of $\sim 0.0015 \text{ nm}$. The rather dim 630 nm emission is a result of the transfer of energy from the *F*-layer plasma to the neutral atmosphere by chemical reactions. These are the dissociative recombinations of the molecular ions of oxygen and nitric oxide, that is, $\text{O}_2^+ + e = \text{O} + \text{O}^*$ and $\text{NO}^+ + e = \text{N} + \text{O}^*$ that follow the production of these ions by charge exchange of O^+ and N^+ with oxygen and nitrogen atoms, respectively. The atom O^* is the excited atom that emits the 630 nm photon.

The first applications of the FPI instrument in aeronomy were based on observing only a fraction of a single order through an aperture. Scanning the source's spectral profile by changing the pressure within the etalon gap cavity or by changing the etalon gap separation provided a time series

FIGURE 2: Images ((a) and (c)) and interferograms ((b) and (d)) for 630 nm sky and HeNe laser observations made by the PARI FPI instrument. The interferograms are calculated by annular integration around the ring center of the circular pattern in each image. 500 channels of equal areas are used to generate the interferogram.

of observations of the line spectral profile that was analyzed to determine the Doppler shift and Doppler broadening. Because the 630 nm nightglow emission is weak, detection of the 630 nm emission with reasonable accuracy using these instruments required that the etalon aperture (A) is as large as 15 cm [18]. With a typical quantum efficiency (Q) of an employed photomultiplier of 5 to 10% combined with the detector observation of only a fraction (K) of an order at any one time due to the instrumental requirement of order scanning, a sensitivity quality figure (SQF) of $AQKN = 177 \text{ cm}^2 * 0.05 * 0.05 * 1 = 0.44 \text{ cm}^2$ may be computed using for K the reciprocal of the aperture finesse (~ 15).

In contrast to this, the use of a quality back-thinned CCD camera that represents the best of current CCD technology greatly enhances the SQF. Here we consider an imaging FPI system that uses an etalon aperture of 7 cm and a short focal length lens generating a ring pattern with $N = 12$ rings. In this case, the CCD camera provides much higher quantum efficiency ($\sim 90\%$ at 630 nm) than the previously used photomultipliers. When this increase is combined with the advantage of imaging of the ring pattern so that photons are continuously collected across the whole of the objective plane by all spectral elements of the spectral profile for each order, then the sensitivity is increased by nearly two orders of magnitude. Thus, K is taken as 1, Q is 0.90, and the SQF is calculated to be $SQF = \text{Area} * Q * K * N = 38.5 \text{ cm}^2 * 0.9 * 1 * 12 = 415 \text{ cm}^2$. This gain of almost a factor of 1000 is somewhat mitigated due to increased instrumental noise such as readout and dark noise, but even so, the accuracy of the observations in current-day imaging FPI measurements is much improved from the early period of scanning FPI measurements. Typically, 5 minutes

of imaging FPI observations will produce a result with 5 ms^{-1} and 15–20 K accuracy in the wind and temperature estimates as compared with $20\text{--}25 \text{ ms}^{-1}$ and 50–75 K for 15–20 minutes of integration for a scanning FPI instrument. Consequently, an imaging Fabry-Perot interferometer is much more capable of precise measurements while also becoming much more transportable (through the reduction of the required aperture diameter). The etalon components are much smaller in size and its thermal environment easier to control to achieve frequency stability.

The observation of the night sky 630 nm spectral emission by the FPI instrument produces a circular interference pattern in which a Doppler red shift produces a ring pattern that is slightly smaller in diameter for each ring, and vice versa, for a blue shift, the ring pattern features rings that are slightly larger. By annularly summing the pixels for the ring pattern, a one-dimensional set of fringes is extracted that can be analyzed to determine the Doppler shift and Doppler broadening estimates for each order. These values are used in a weighted-average sense to produce an overall estimate of the Doppler shift and Doppler broadening. Further details regarding these issues and the analysis of multiorder ring patterns are provided by Makela et al., [29].

The FPI instrument is calibrated by observing the 632.8-nm emission generated by a frequency-stabilized HeNe laser. Figures 2(a) and 2(b) illustrate an example of the ring patterns seen for sky and laser images, respectively. The broader width of the sky rings relative to the laser is indicative of the thermal broadening introduced by the moving atoms to and away from the FPI station along the line of sight. The assumption of a Gaussian distribution for these O atom speeds is an excellent assumption as there are

TABLE 1: Instrument parameters for the initial FPIs to be used in this network.

Parameter	PARI	Illinois	Michigan	Kentucky
Etalon aperture (cm)	10.0	10.0	7.0	7.0
Etalon reflectivity	78%	~80%	78%	78%
630.0 nm filter transmission	55%	TBD (~55% expected)	55%	55%
no. of orders imaged	10	10	10	10
Etalon gap	1.5 cm	1.5 cm	1.5 cm	1.5 cm
Andor CCD detector	DU-412	DU-434	iKon-934	DU-434
CCD readout noise	4 e ⁻ /pixel	3 e ⁻ /pixel	3 e ⁻ /pixel	3 e ⁻ /pixel
CCD dark signal	0.0003 e ⁻ /s/pixel	0.0004 e ⁻ /s/pixel	0.0001 e ⁻ /s/pixel	0.0004 e ⁻ /s/pixel

FIGURE 3: Map of FPI observatory sites and CV locations in the eastern continental United States for the initial NATION deployment. The FPI locations are indicated by markers within the red circles. The five loops (orange) marked L1 through L5 are the five sets of CV locations for pairs of FPI observatories. The loops L1 through L5 represent the pairs of L1 (green markers): UI and UM, L2 (dark blue markers): UM and ECU, L3 (light blue markers): UI and ECU, L4 (orange markers): UI and PARI, L5 (yellow markers), PARI and ECU.

enough collisions within the lower thermosphere to achieve thermalization [30].

Table 1 provides the instrumental details of the four Fabry-Perot observatories that are initially planned for this network. The locations are presented in Figure 3. Expansion to include additional sites in New Mexico and New Jersey is already assured and will use an instrumental design identical with that for the Kentucky and Michigan FPIs.

3. Observation and Analysis Approach for an FPI Network

Our approach to the development of a multisite FPI network located in the eastern continental United States is based upon the desire to observe vector horizontal and vertical winds as well as the neutral temperature in the thermosphere at the centroid height, ~250 km, that is characteristic of the 630 nm nightglow layer. To accomplish this, sites must share a common observing volume (CV) so that the same region

of the thermosphere can be observed simultaneously from multiple angles, allowing for the local determination of the thermospheric neutral wind vector. This approach has the advantage over a single-site observing strategy in which line-of-sight winds are obtained in the cardinal directions to infer zonal and meridional winds, as assumptions about the uniformity of the wind field are not required. In this approach, the horizontal vector winds are obtained by observing the same thermospheric volume at orthogonal look directions from two sites. This strategy also has the useful feature that vertical winds may be determined by observing the same thermospheric volume from inline, or antiparallel, look directions from two sites. Tristatic observations would allow for the full vector wind to be obtained at a single location, as demonstrated by Aruliah et al., [31].

Several different deployment scenarios can be imagined. Sites distributed in a meridional chain would have the advantage of being able to track structures propagating north-south but would be limited in east-west coverage. Similarly,

a zonal chain could track structures propagating east-west but would be limited in north-south coverage. In both cases, if observations from a site were not available due to instrumentation failure or cloud coverage, the observations from the sites sharing the CV measurement would not be terribly useful, as their line-of-sight wind measurement would be in a direction that is neither zonal nor meridional. In contrast, chains of sites distributed at 45° angles from each other will have increased coverage of both the zonal and meridional winds. Moreover, in this mode, if observations from one site are not available due to bad weather, the other CV FPI observatory will still provide geophysically meaningful wind measurements, as the individual lines-of-sights would be toward one of the four cardinal directions. Thus, although vector horizontal winds would not be possible, one component of the wind vector would still be measured. In reality, the actual deployment of instruments is constrained by available sites and infrastructure required for their operation.

Taking these considerations into account, we decided upon an initial deployment of a four-site network in which the individual nodes are distributed at approximately 45° from one another at the four sites located in the states of Michigan, Illinois, Kentucky, and North Carolina. These sites are placed near universities (University of Michigan, University of Illinois, Eastern Kentucky University, Clemson University, respectively) where students and faculty have easy access to the observatories. The locations of the sites comprising this network are shown in Figure 3. The loops labeled by L1, L2, L3, L4, and L5 each include the three common volume (CV) locations for bistatic observations by pairs of FPI instruments. For each loop marking a set of three CV locations, the central CV point is the inline point that features the azimuthal direction where each of the two FPI instruments are looking toward the other FPI site and vertical winds can be deduced. The other two points in each loop each represent a CV position where the line-of-sight measurements are orthogonal to each other. The Doppler shifts from these measurements are used to calculate the horizontal and meridional components of the neutral wind vector for that CV location.

The horizontal wind component, v_h , observed from a given FPI is calculated from the relation:

$$v_h = \frac{v_{\text{ORTH}} - w \sin \alpha}{\cos \alpha}, \quad (1)$$

where v_{ORTH} is the line-of-sight Doppler measurement, α is the elevation angle of the observation, and w is the vertical wind at observation point in the thermosphere.

The vector zonal (u) and meridional (v) wind components are calculated at the common volume locations using the relations:

$$\begin{aligned} u &= \frac{v_{h,1} \cos \theta_2 - v_{h,2} \cos \theta_1}{\sin(\theta_1 - \theta_2)}, \\ v &= \frac{v_{h,2} \sin \theta_1 - v_{h,1} \sin \theta_2}{\sin(\theta_1 - \theta_2)}, \end{aligned} \quad (2)$$

where the subscripts identify the parameters for the two FPIs participating in the measurement and θ is the azimuth

angle of the observation. The denominator of these relations is simplified to unity if the two line-of-sight directions are orthogonal to each other.

Analysis of the Doppler shifts observed for the two inline measurements, $v_{\text{IN},1}$ and $v_{\text{IN},2}$, provides an estimate for the vertical wind that is given by the relation:

$$w = \frac{v_{\text{IN},1} + v_{\text{IN},2}}{2 \sin \alpha}, \quad (3)$$

where we have assumed the two observations are made using the same elevation angle.

The determination of the Doppler shifts using the FPI requires an absolute wavelength reference. One way to obtain this reference is to make the assumption of zero vertical winds ($w = 0$). Under this assumption, observations made to the local zenith provide the zero reference and (1) is simplified somewhat and the inline measurements should be equal in magnitude but with opposite sign, making (3) zero. However, our experience has indicated that zero vertical winds are not always a correct assumption and the vertical wind calculated from inline measurements utilizing the zenith measurements as a zero wind reference is nonzero.

An alternate methodology is to utilize the frequency stabilized HeNe laser, primarily utilized to calibrate the instrument function as needed to estimate the neutral temperatures, as a zero reference. The specification for the laser indicates a stability of several ms^{-1} over the course of several hours and thus can be used to track the stability of the etalon, which may drift over several $10\text{--}100 \text{ ms}^{-1}$ over a night. In order to use the HeNe laser as a zero reference, however, the offset between the 632.8-nm HeNe wavelength and the 630 nm emission must be accounted for. This is accomplished by assuming that the *average* vertical wind is zero between 21–06 LT. With this assumption, the Doppler shift obtained by analyzing the laser interferograms can be fitted to the Doppler shift obtained by analyzing the night's zenith observations. The shifted laser is then used as the zero-Doppler reference. Example results obtained using this methodology, which will be employed in the NATION data analysis, are shown below.

Examples of the raw line-of-sight wind estimates and the results of converting to vertical and vector horizontal winds are presented in Figure 4. These results are obtained from the two-FPI experiment sponsored by the United States National Science Foundation's Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) program currently being undertaken in northeastern Brazil [28]. This figure shows uncertainties in the estimates of temperatures ranging from $\sim 20 \text{ K}$ to 100 K and $\sim 5 \text{ ms}^{-1}$ to 30 ms^{-1} . The vector wind measurements at the two CV observing points agree with each other with predominately northeasterly flow throughout the night with the magnitude of the wind reducing as the night progresses. The vertical wind measurements show values close to zero for the bulk of the night, except in the early evening when a slight downward flow is seen.

Estimates of the vector wind, as well as the spatial uniformity of this component, gained from examining the independent wind measurements made possible by the

FIGURE 4: Example of temperatures and common-volume vector neutral winds derived from data obtained from two FPI observatories located in northeastern Brazil. The left two columns show the single-site (top) temperature measurements and (bottom) line-of-sight wind observations. The right column shows the derived (top) zonal and (middle) meridional winds at the (green) north and (red) south CV locations. The bottom plot shows the derived vertical wind measurements from the (red) in-line measurements as well as local zenith measurements from (blue) Cajazeiras and (green) Cariri.

combination of the Doppler shifts observed by NATION will be used to generate an overall picture of winds in the eastern continental United States. Comparison of these “maps” with corresponding pictures of the global winds generated by a general global circulation model will help quantify the contributions to the local thermospheric dynamics generated by various physical processes such as the day-to-night pressure gradient, ion drag, and the variability introduced by gravity wave activity.

The four sites in the initial NATION deployment are described below. The geographic location of each site is given in Table 2. Each site has been chosen for having relatively good observing conditions as well as ease of access. The sites will each have Internet access, allowing for their operation as a single distributed sensing network. The typical observing strategy will be to coordinate observations of the CV locations shown in Figure 3. Typical integration times will be on the order of 3 minutes for each operation, but will

be dynamically determined based on the actual observing conditions. The sequences of observations will be specified depending on the goals of a given experiment. High temporal resolution (~ 3 minutes) could be obtained by continually observing the same common volume points. The resulting temporal resolution would allow for the tracking of dynamic features in the thermosphere, such as TADs or gravity waves. Alternately, observing all of the available orthogonal common volume locations, resulting in the largest spatial coverage, could be achieved in a sequence taking less than 30 minutes. Thus, there is a tradeoff between spatial coverage and temporal resolution.

With the integration of the Boltwood cloud sensors, we plan to develop observing algorithms that will take into account the viewing conditions at each site and modify the observing strategy accordingly. This sensor measures infrared radiation from the sky between $8\text{--}14\mu\text{m}$ using a thermopile in order to deduce the sky temperature. This is

TABLE 2: Geographic location of four initial sites to be deployed for NATION.

Site	Geographic Location
Peach Mountain, MI	42.40 N, -83.92 E
Urbana, IL	40.10 N, -88.23 E
Eastern Kentucky University, KY	37.73 N, -84.30 E
PARI, NC	35.20 N, -82.87 E

then compared to the ambient ground-level temperature. Large differences between these temperatures represent clear observing conditions. As the temperature difference decreases, the observing quality diminishes. The sensor covers a field of view of 80° , with some sensitivity out to 120° . This covers the range of elevation angles for which we expect to make measurements using the FPIs.

Once the instruments are deployed and operational, we will determine empirical thresholds of this temperature difference which result in quality data. This threshold will then be used for future operations, in real time, to determine the network's overall observing strategy. For example, if one site is determined to be clouded over, the CV observations involving that site will not be made, allowing for a higher temporal cadence for the other CV locations. In the event that no CV observations are possible from a given site due to cloud conditions at the other sites, a site would revert to a cardinal direction observing mode. We note that the Boltwood sensor may not be able to detect cirrus clouds, which are thin and cold, and that this may slightly reduce the quality of data collected in the presence of cirrus clouds. We are currently investigating alternative cloud detection techniques that may be sensitive to cirrus clouds and will investigate their utility in the development of NATION.

3.1. Observatory Locations. The Pisgah Astronomical Research Institute (PARI) is hosting the Clemson FPI instrument in an old telephone building assigned to help support the project. This area was once a NASA satellite communication station located in a valley in the Blue Ridge Mountains where radio noise was minimized due to its isolation. Because of its remote location away from any major cities, PARI is one of the best optical sites in the eastern United States.

The PARI campus is the location of a Fabry-Perot interferometer (FPI) observatory that has been operating since June 2011. This instrument has operated in the past, but a repolishing of the etalon plates combined with a new reflective coating has increased the sensitivity. The instrument now produces excellent quality results even for the weak signals from the 630 nm nightglow emission at midlatitudes. An example of the temperature estimates made using the instrument during the winter for the North, East, South, West, and zenith directions is shown in the left panel of Figure 5. This figure shows the interesting feature of a temperature peak near midnight between 23 and 00 LT. This midnight temperature maximum (MTM) is a feature that has not been reported previously for a midlatitude FPI station but is very commonly observed at

FIGURE 5: Observations of (a) temperatures and (b) winds made with the PARI FPI instrument for 23-24 November 2011.

low latitudes. It is of great interest that this feature is seen for the observations at PARI. The summer observations did not show any significant signs of this MTM structure so it is rather exciting to see this detection of the MTM peak at the latitude of PARI during the winter season.

The right panel of Figure 5 presents the winds observed on this winter night. The air at 250 km moves generally from the day side toward the nightside so during the winter we expect to see the zonal wind to be eastward, which is what is seen in Figure 5(a). This figure also shows the zonal winds to be coherent in phase and, beginning with speeds of $\sim 100 \text{ ms}^{-1}$, becoming gradually weaker during the night.

During the midnight hours there is a meridional wind component that represents the air blowing over the polar region toward the equator. Figure 5(a) shows the meridional

winds to be relatively weak reaching a maximum speed of $\sim 75 \text{ ms}^{-1}$ southward near 02-03 LT (07-08 UT).

The Fabry-Perot observatory in Kentucky will be located at the south end of the Eastern Kentucky University campus, adjacent to the astronomical observatory located at this site. Stable power and Internet will be available at the site. An FPI currently operating at Poker Flat, Alaska, will be deployed to this site in the early part of summer, 2012.

The site to be operated by the University of Michigan (UM) is located at Peach Mountain, a solar observatory that is run by the university. This site is located about 15 miles northwest of Ann Arbor, Michigan, and is situated on top of a large hill surrounded by forests and is expected to be operational in the summer of 2012. Stable power is available at Peach Mountain, and Internet access will be installed at this site.

The site to be operated by the University of Illinois (UI) is located north-east of Urbana, Illinois at the University's Upper Atmospheric Observatory field site. This site has been used extensively by faculty at the University of Illinois to test instruments before deployment at remote field sites, including testing of the FPIs currently deployed in northeastern Brazil from which the measurements in Figure 4 were made. Results from these tests are presented above in Figure 1. The observing conditions from this site are typically very good for optical measurements. Stable power and Internet connections are available. The proximity to the University of Illinois campus, an approximately 20-minutes drive, makes access straightforward. Instruments at this site are often used in the *Optical Remote Sensing* course offered to advanced undergraduate and graduate students at the University of Illinois. This FPI observatory will become operational in the May-June period, 2012.

It is important to note that the NATION concept is fully scalable and is expected to expand as additional instruments are deployed to new sites. Additional FPIs will soon be deployed in New Jersey and New Mexico, providing important longitudinal diversity to the NATION measurements that will be useful in studying, among other topics, the penetration of midlatitude tidal structure into thermospheric dynamics. Unfortunately, these sites are too far from the initial NATION chain in the Midwest to participate in common volume measurements and consequently will operate in a cardinal observing mode. As new instrumentation becomes available, a priority will be to link these two satellite observing sites to the main chain.

4. Concluding Thoughts

We have described the rationale and plans for the development of a distributed network of Fabry-Perot interferometers (FPIs) to study the thermospheric neutral dynamics of the Earth's upper atmosphere. This network will enable new insights into energy transfer across and within the thermosphere-ionosphere system and allow for the development of more robust climatological and space weather models.

The initial deployment consists of four sites in the Midwest of the United States. Each site will operate an

imaging FPI as well as a cloud sensor, used to determine the local observing conditions. The sites will be connected to the Internet and operate as a single sensor through protocols that will determine optimal common volume observing strategies. The resulting estimates of temperatures and horizontal neutral winds will be used to address the scientific questions described in this paper, although we emphasize that what is presented here is not an exhaustive list of potential scientific topics.

Finally, the network described here is a scalable model. With the addition of new instruments and sites, NATION will hopefully expand in coverage. New sites in New Jersey and New Mexico are already planned and existing FPI sites can easily be incorporated into the NATION framework. Furthermore, the NATION concept is equally applicable to other latitude regions, opening up possibilities for expanding the smaller networks of FPIs operating in other regions of the world, such as Peru and Brazil.

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