

# A new three-wavelength Fabry–Perot interferometer developed to measure the upper atmosphere at Chongyang

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## Key Points:

- A new three-wavelength Fabry–Perot interferometer (FPI) was deployed for the first time at Chongyang, China, enabling measurements of wind and temperature at multiple altitudes (87, 97, and 250 km).
- Comparative analyses with meteor radar and empirical models demonstrate the capability of the FPI to provide reasonable wind and temperature measurements.

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**Abstract:** A new three-wavelength Fabry–Perot interferometer (FPI) was developed at Wuhan University and deployed in Chongyang (114.1°E, 29.5°N), Hubei Province, China, for a short-term observation campaign to measure the temperature and wind in the upper atmosphere. The three wavelengths (892.0, 557.7, and 630.0 nm) correspond to typical emission layers at approximately 87, 97, and 250 km, respectively. A case measurement obtained on June 13, 2024, is presented together with the results from the Naval Research Laboratory Mass Spectrometer and Incoherent Scatter Radar Exosphere 2.1 (NRLMSIS 2.1), meteor radar, and Horizontal Wind Model 2014 (HWM14) for comparison, which includes the temperature, zenith wind, meridional wind, and zonal wind. The zenith winds are very weak at 87 and 97 km but exceed  $-20$  m/s at 250 km. The horizontal wind fields from the three data sources all show similar variation trends, but the FPI and meteor radar are more consistent. A multi-day comparison from June 12 to 15, 2024, reveals that the linear regression slopes between the FPI and the meteor radar are 0.92 and 0.94 at 87 km, and 1.29 and 1.07 at 97 km, indicating that the FPI and meteor radar measurements are in reasonable agreement at these altitudes. The comparative analysis indicates that the three-wavelength FPI is capable of providing reasonable measurements of wind and temperature.

**Keywords:** upper atmosphere; wind; temperature; Fabry–Perot interferometer; airglow

## 1. Introduction

The Fabry–Perot interferometer (FPI) is a high-resolution instrument used to analyze airglow and auroral emissions for the remote sensing of winds and temperatures in the upper atmosphere. It has many advantages, such as direct measurement of neutral atmospheric dynamics (neutral wind and kinetic temperature), high sensitivity, low cost, and multi-wavelength observational capability. As an independent instrument, the FPI has been widely utilized to investigate meteorological variations in wind and temperature (Makela et al., 2013; Liu X et al., 2015; Dhadly et al., 2017), the propagation of atmospheric waves (Liu X et al., 2014), plasma irregularities (Sakanai et al., 2002; Colerico et al., 2006; Chapagain et al., 2012; Liu Y et al., 2021), and so on.

To date, multiple FPIs have been deployed in China to detect neutral winds and temperatures. The first FPI deployed in China was installed at Xinglong Station (40.2°N, 117.4°E) in 2010 as part of the Meridian Project (Yuan W et al., 2010). This FPI was built by the U.S. National Center for Atmospheric Research (NCAR) and is the same as the FPI in Resolute, Canada (Wu Q et al., 2004). Since then, researchers have conducted numerous studies using data obtained from the FPI (Yuan W et al., 2013; Liu X et al., 2014; Wu Q et al., 2014; Huang C et al., 2018; Jiang GY et al., 2018; Liu YK et al., 2019; Wei YF et al., 2024). In the second year, with support from the China Meteorological Administration, another NCAR-built FPI was deployed at Kelan, China (Yu T et al., 2014; Yao X et al., 2015; Yang CJ et al., 2020). The third NCAR-built FPI was installed in Kunming, China, on the Yunnan–Guizhou Plateau in 2019, where new atmospheric phenomena were expected to be observed (Gu SY et al., 2021; Wei YF et al., 2024). Also in 2019, a new FPI was deployed at Mohe (53.5°N, 122.3°E), the northernmost space environment observatory in China. This instrument measures only the wind and temperature at 250 km, complementing the capabilities

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of the other equipment at the observation station (Li WB et al., 2021).

In recent years, China has also made significant progress in FPI technology, with several independently developed instruments demonstrating excellent performance during field tests. A scanning FPI, developed by Wuhan University, was deployed in Langfang, and its results showed good agreement with those from the nearby Xinglong FPI (Hu GY et al., 2014). In 2010, an all-sky FPI was deployed at China's Yellow River Station and operated continuously for two winters (Zhang H et al., 2013; Liu J et al., 2014). Wang HM et al. (2016) designed a tiny, low-cost ground-based FPI that observes only the 630.0 nm wavelength. In addition, Wang TC et al. (2025) developed a signal-tracking FPI that uses a frequency-stabilized He-Ne laser as a reference to obtain system parameters in real time.

This work presents the three-wavelength FPI developed independently by Wuhan University, detailing the FPI structure, key components, and operational method. Observation results obtained during the campaign are shown together with Naval Research Laboratory Mass Spectrometer and Incoherent Scatter Radar Exosphere 2.1 (NRLMSIS 2.1), meteor radar, and Horizontal Wind Model 2014 (HWM14) data for comparison. The comparison results among these datasets demonstrate that the instrument provides reasonable measurements of both temperature and wind fields.

## 2. Instrument and Method

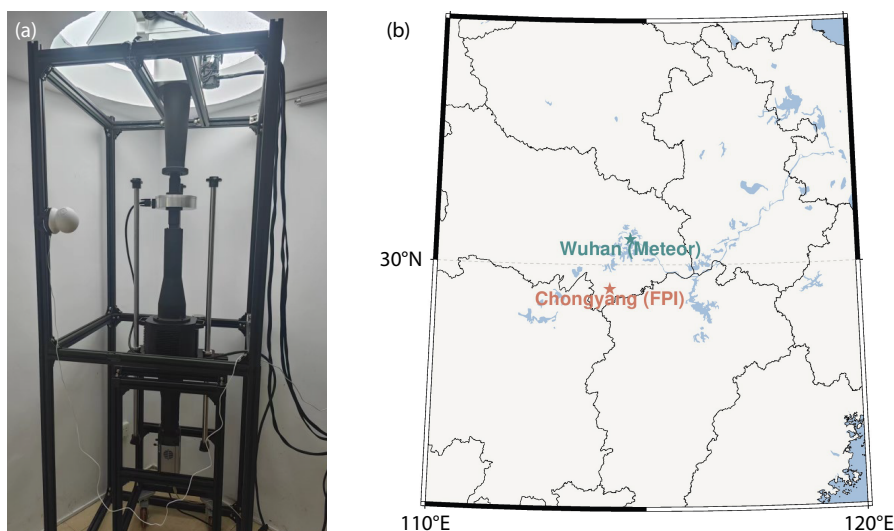
The three-wavelength FPI developed by Wuhan University, as shown in Figure 1, is installed in a temperature-controlled room maintained at 23 °C. The system consists of a sky scanner, a filter wheel, an etalon, a temperature-controlled chamber, a charge-coupled device (CCD) detector, several lenses, and a computer. The main parameters of each component are listed in Table 1. The equipment is installed in a small room with a spherical transparent dome. During routine observation, airglow emissions pass through the dome and are then directed into the subsequent

optical path by the sky scanner. The incoming light is transmitted through a selected filter in the filter wheel to isolate the target wavelength. The filtered light is then passed through the etalon, where it forms interference fringes that are focused onto the CCD detector. The computer acquires the CCD digital signal and stores it as fringe patterns, from which winds and temperatures are retrieved.

The sky scanner, mounted at the top of the FPI to adjust the observation direction, consists of a plane window, two mirrors, two stepper motors, and a two-axis rotary stage. The plane window has a diameter of 130 mm. The two stepper motors drive the rotary stage, enabling the system to point toward any selected direction. After passing through the plane window, airglow from the chosen direction is reflected by two high-reflectivity mirrors into the subsequent optical path. The pointing accuracy of the system is limited by the rotation precision of the sky scanner, which is 0.01°.

After the sky scanner, two groups of lenses are used to guide the light onto the filter. The filter in the filter wheel removes background light and environmental signals of unwanted wavelengths, which is essential for imaging. There are four symmetrically distributed slots, three of which are equipped with filters at 630.0, 557.7, and 892.0 nm, and the remaining slot is empty for laser calibration. During observations, the filter wheel positions the filter corresponding to the selected emission wavelength from the target altitude. To effectively reject background light, the filters used in this system have a full width at half maximum (FWHM) of 1.2 nm, which provides high peak transmittance to ensure sufficient signal strength.

The other two lens groups collect the filtered light from the filter and expand and collimate the optical beam before coupling it into the etalon. The etalon is one of the core components of the FPI, where the incoming light undergoes interference to form circular fringes. It consists of two parallel mirrors with a reflectivity greater than 86% and a surface flatness of  $\lambda/100$ , mounted inside a cylindrical Invar housing with a clear aperture of 100 mm.



**Figure 1.** (a) The three-wavelength FPI and (b) the geographical locations of the FPI and the meteor radar.

**Table 1.** Main parameters of the three-wavelength FPI.

| Component    | Parameter             | Specification                    |
|--------------|-----------------------|----------------------------------|
| Sky scanner  | Direction             | East, west, north, south, zenith |
|              | Field angle           | 2.5°                             |
|              | Aperture              | 130 mm                           |
|              | Rotational accuracy   | 0.01°                            |
| Filter wheel | Slot number           | 4                                |
|              | Filter FWHM           | 1.2 nm                           |
|              | Filter aperture       | 25 mm                            |
| Etalon       | Surface flatness      | $\lambda/100$                    |
|              | Clear aperture        | 100 mm                           |
|              | Etalon spacing        | 20 mm                            |
|              | Reflectivity          | >86%                             |
|              | Refractive index      | 1.000 (air)                      |
|              | Operating temperature | 30 °C                            |
|              | Temperature stability | $\pm 0.01$ °C                    |
|              | Wavelength            | 892.0, 557.7, 630.0 nm           |
|              | Operating temperature | −80 °C                           |
| CCD detector | Resolution            | 1024 × 1024                      |
|              | Sensor size           | 13.312 × 13.312 mm               |
|              | Dark current          | 0.0002 electrons/pixel/second    |

Because the etalon is highly sensitive to temperature variations, it is placed in a temperature-controlled chamber that operates continuously for 24 h and is maintained at  $30 \pm 0.01^\circ\text{C}$ , ensuring stability during the observation period. The temperature-controlled chamber provides excellent thermal insulation and uses side-mounted thermoelectric coolers for active temperature regulation, effectively minimizing the thermal drift of the etalon.

A lens group is placed immediately after the etalon to image the interference pattern onto the following detector. The CCD detector enables the FPI to image extremely weak airglow emissions. Because of the low signal intensity, the CCD detector cannot acquire clear, sharp interferograms with short exposure times and therefore requires long integration periods. A low temperature is required to reduce thermal noise generation during integration, preventing it from overwhelming the signal. The CCD detector used in this system can be cooled down to  $-80^\circ\text{C}$ , resulting in a dark current as low as 0.0002 electrons/pixel/second. Additionally, the CCD detector has a sensor size of  $13.312 \times 13.312$  mm and a resolution of  $1024 \times 1024$  pixels, which is binned to  $256 \times 256$  during routine observation.

The three-wavelength FPI operates in a fully automated mode under computer control during nighttime observations. In each observing cycle, the three-wavelength FPI sequentially measures the east, west, north, south, and zenith directions for each wavelength, and this cycle is repeated for all three wavelengths. The elevation angle for the four horizontal viewing directions (east, west, north, and south) is set to  $45^\circ$ . The exposure times are 3 minutes for the 892.0 and 557.7 nm airglow emissions and 5

minutes for the 630.0 nm emission. Therefore, the main strength of this system lies in its capability to perform sequential observations at three wavelengths, allowing near-simultaneous measurements of winds and temperatures at multiple altitudes. The trade-off is a slight reduction in temporal resolution of the observations.

The three-wavelength FPI is deployed in Chongyang, as shown in Figure 1b. Before the observation campaign, a laser is utilized for instrumental calibration during laboratory tests and equipment setup, although it is not used during the campaign. The calibration demonstrates that the FPI maintains a stable fringe line shape and etalon spacing. A short-term observation campaign was conducted from June 12 to 15, 2024. During the observation period, the daily  $A_p$  index ranged from 2 to 17, indicating geomagnetically quiet to weakly disturbed conditions, whereas the  $F_{10.7}$  index varied between 170 and 176, showing relatively stable solar activity. These conditions suggest that the thermospheric environment is generally quiet and suitable for case-based comparison and instrument performance assessment.

Figure 1b also indicates the location of the meteor radar in Wuhan, which is used for comparison with the FPI measurements. The meteor radar, located approximately 100 km from the FPI, measures horizontal wind fields in the 70–100 km altitude range with a vertical resolution of 2 km. Compared with meteor radar measurements, the FPI provides direct measurements of neutral wind and temperature at well-defined emission layers, although it is limited to clear-sky nighttime observations. Most importantly, the FPI can measure winds and temperatures at 250 km. In contrast, the meteor radar operates under most weather condi-

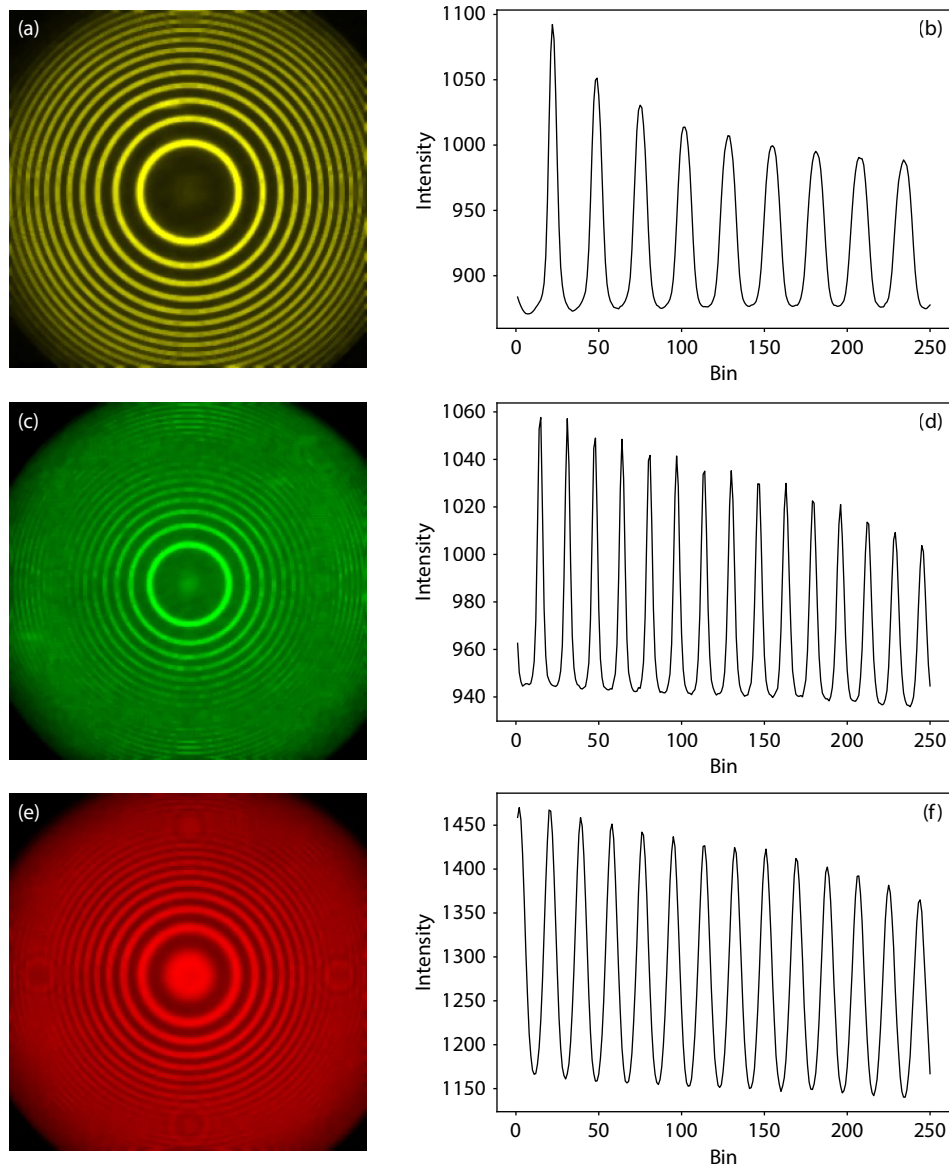
tions and has a higher spatial resolution. Although meteor radar measurements can be used to estimate temperature under certain assumptions and processing approaches, the data product used in this study does not provide temperature. Therefore, only wind measurements are compared here.

During the observation period from June 12 to 15, 2024, the instrument functioned stably without hardware interruptions. Under favorable weather conditions, several days of clear interferogram images were obtained, as shown in Figure 2. Data screening was performed to remove measurements affected by clouds, precipitation, or moonlight interference; overexposed images at the start and end of each day; and those with large retrieval errors. Data with retrieval errors exceeding 10 m/s for 557.7 and 892.0 nm and 30 m/s for 630.0 nm (for wind) or data exceeding 10 K for 557.7 nm and 30 K for 892.0 and 630.0 nm (for temperature) were removed. After the quality control, 179, 178, and 195 valid wind measurements remained for the 892.0, 557.7, and

630.0 nm emissions, respectively, and 174, 177, and 156 valid temperature measurements remained, respectively.

The airglow interferograms at 892.0, 557.7, and 630.0 nm and 1-dimensional fringes are shown in Figure 2, from which winds and temperatures were retrieved. A nonlinear regression method was utilized to retrieve winds and temperatures simultaneously, as described by Harding et al. (2014) and Wei YF et al. (2023a, b). The retrieval algorithm accounts for uncertainties such as instrument function fitting, background subtraction, line blending, and stray light, which are reflected in the error bars for each measurement. Further calculations are required to obtain the real wind from the inversion results. First, it is assumed that the wind field is uniform and constant over the short observation period. Therefore, the zero wind reference is

$$v_{\text{zero}} = \frac{v_{E0} + v_{W0} + v_{N0} + v_{S0}}{4}, \quad (1)$$



**Figure 2.** Airglow interference fringes at (a) 892.0 nm, (c) 557.7 nm, and (e) 630.0 nm, and corresponding 1-dimensional fringes (b, d, and f).

where  $v_{E0}$ ,  $v_{W0}$ ,  $v_{N0}$ , and  $v_{S0}$  are raw winds. Then, the real winds of the five directions are

$$v_E = (v_{E0} - v_{zero}) / \cos \theta, \quad (2)$$

$$v_W = (v_{W0} - v_{zero}) / \cos \theta, \quad (3)$$

$$v_N = (v_{N0} - v_{zero}) / \cos \theta, \quad (4)$$

$$v_S = (v_{S0} - v_{zero}) / \cos \theta, \quad (5)$$

$$v_Z = v_{Z0} - v_{zero}, \quad (6)$$

where  $\theta$  is the elevation angle. The meridional and zonal winds are expressed as

$$v_{merid} = \frac{v_N + v_S}{2}, \quad (7)$$

$$v_{zonal} = \frac{v_E + v_W}{2}. \quad (8)$$

In the following section, we present the wind and temperature measurements obtained by the three-wavelength FPI as well as comparisons with model outputs and meteor radar observations.

### 3. Results

In this section, the FPI measurements are evaluated with other datasets during the observation campaign. Winds and temperatures retrieved from the FPI are compared with those from the meteor radar, as well as the HWM14 and NRLMSISE 2.1 models. The primary purpose of these comparisons is to assess the performance of the FPI, rather than to investigate the differences between datasets in detail or to provide physical interpretations of the discrepancies. A representative observational case from June 13 is first presented. Subsequently, to simplify the presentation and avoid redundancy, averaged results from different data sources over the observation period are compared.

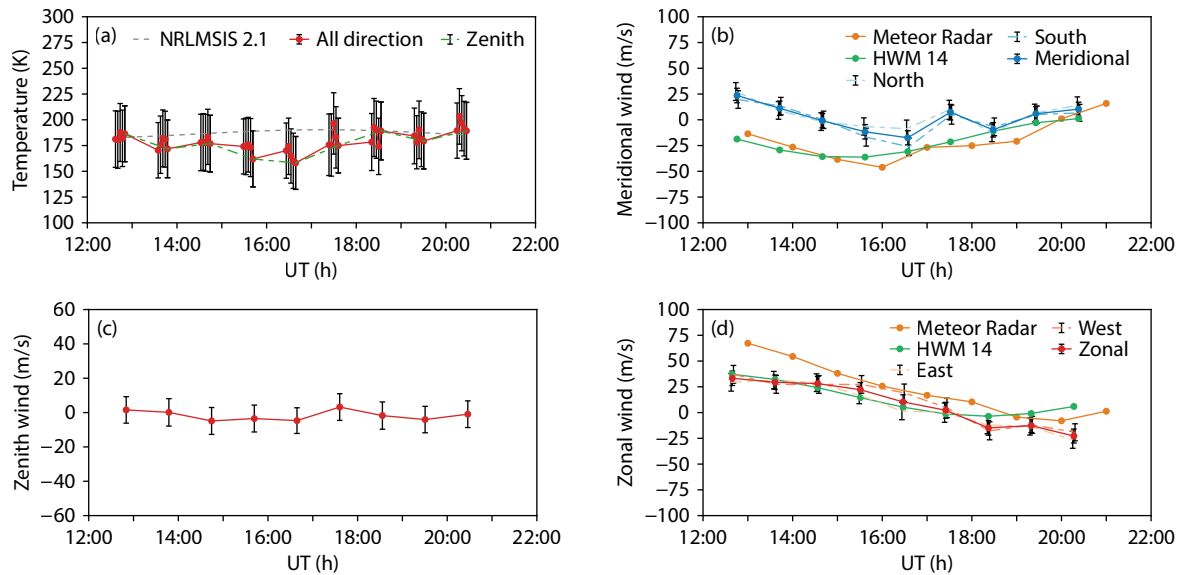
Note that the meteor radar has a higher vertical resolution, whereas the FPI measures the overall wind and temperature

across the entire airglow layer altitude. Therefore, meteor radar winds are weighted averages using Gaussian-shaped weighting factors, based on the vertical distribution of airglow. The central heights for the weighting are set to 87 km for the 892.0 nm emission and 97 km for the 557.7 nm emission, with an approximate airglow layer thickness of 6 km for both. These values correspond to the typical emission heights and vertical extents and are commonly adopted in FPI and meteor radar analyses to approximate the vertical distribution of the observed layers (Yu T et al., 2017).

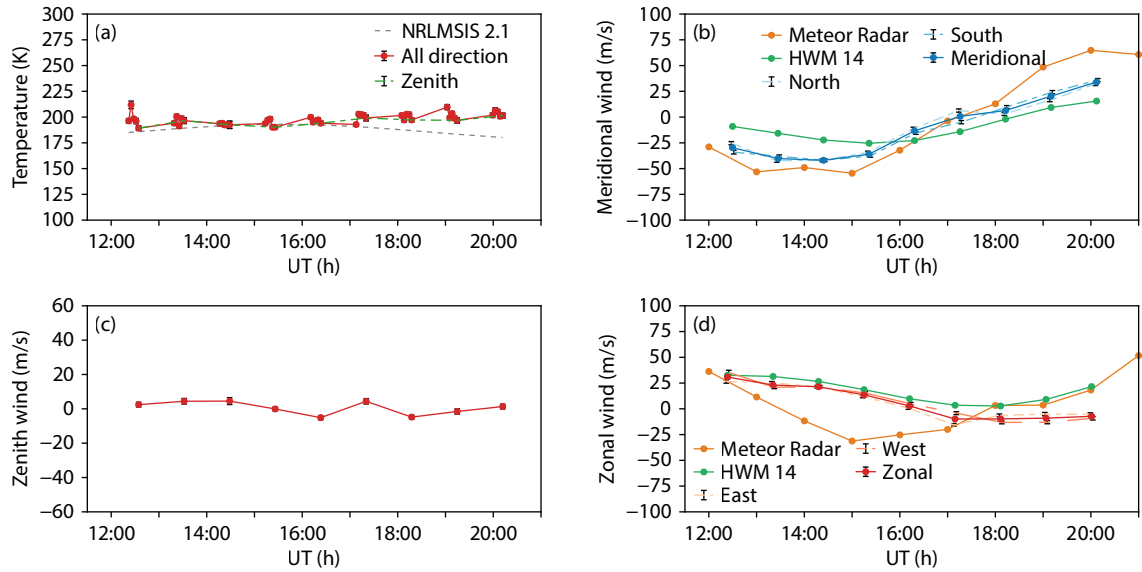
#### 3.1 A Day Case Study Comparing the FPI Measurements with the Models and the Radar

Figures 3, 4, and 5 present the wind and temperature measurement results on June 13. The retrieved winds are compared with the meteor radar and HWM14 model, whereas the temperatures are compared with the NRLMSISE 2.1 model. Horizontal Wind Model 2014 is an empirical model that lacks interannual variability; this variability is largely controlled by solar radiation and geomagnetic activity. Despite this limitation, HWM14 remains an essential data source for thermospheric winds when direct measurement data are unavailable, and it serves as an important baseline for evaluating newly deployed observational instruments. The NRLMSISE 2.1 is an empirical and global reference atmospheric model, which extends from the Earth's surface to the lower exosphere (~0–1000 km), providing neutral temperature and density profiles critical for satellite orbital decay predictions and atmospheric drag calculations.

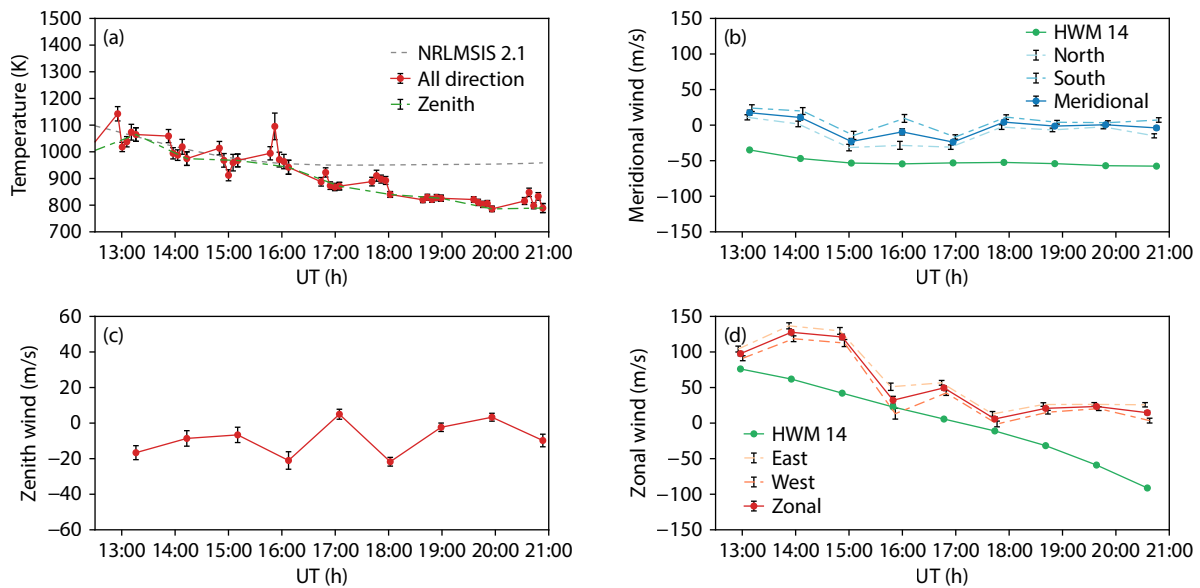
Figure 3 shows the temperature, meridional wind, zonal wind, and zenith wind at 87 km from the different models and instruments. The temperatures from the five viewing directions are all presented in Figure 3a in chronological order of observation, and they differ slightly among the five directions. When the differences in retrieval uncertainties are small, the temperatures retrieved



**Figure 3.** (a) Temperature, (b) meridional wind, (c) zenith wind, and (d) zonal wind of 892.0 nm (~87 km) on June 13, 2024. Results from the NRLMSISE 2.1, HWM14, and meteor radar are also exhibited. North, south, east, west, and zenith indicate the winds and temperatures measured by the FPI from the corresponding directions.



**Figure 4.** Same as Figure 3, but for 557.7 nm (~97 km).



**Figure 5.** Same as Figure 3, but for 630.0 nm (~250 km).

from the five viewing directions still exhibit noticeable discrepancies, indicating that the contribution of interferogram noise-induced retrieval uncertainty is limited. These discrepancies are likely attributed to the combined effects of spatial temperature differences among different sky regions and temporal temperature variations. The temperature measured by the FPI initially decreases and then increases, whereas the NRLMSISE 2.1 exhibits the opposite trend; both reach extrema at 16:30 universal time (UT). The zenith wind remains weak within  $\pm 10$  m/s throughout the night, as shown in Figure 3c. The meridional winds measured by the FPI, meteor radar, and HWM14 exhibit a generally consistent pattern, first decreasing and then increasing, as shown in Figure 3b. Around dusk, the FPI wind is approximately 25 m/s, whereas the meteor radar wind is about  $-10$  m/s. Both instruments show a rapid increase in wind speed magnitude near midnight, which occurs at about 17:00 UT for the meteor radar, earlier than for the

FPI. A consistent trend is observed in the zonal wind, as shown in Figure 3d, which converts from eastward to westward around midnight. The meteor radar wind reaches approximately 75 m/s around dusk, whereas the FPI and HWM14 are around 30 m/s. At dusk, the meridional and zonal winds between the meteor radar and the FPI show considerable differences, which may be attributed to the different altitudes of the tracers detected by the two instruments. The peak heights and thicknesses of the airglow layers change over time, whereas the meteor radar mean winds are calculated using fixed central heights and layer thicknesses.

Figure 4 presents the observation and comparison results for wind and temperature at 97 km. The temperature measured by the FPI remains near 200 K throughout the night, whereas the NRLMSISE 2.1 model exhibits a slight trend of first increasing and then decreasing. The zenith wind is also very weak, similar to the

observations at 87 km. The FPI and meteor radar show similar variations in meridional wind, both reversing from southward to northward around 17:00 UT. Compared with the FPI winds, the meteor radar shows a wider variation range, approximately  $-60$  to  $70$  m/s, whereas the HWM14 model has the smallest range. The zonal winds measured by the FPI and meteor radar show notable differences. The wind measured by the FPI decreases throughout the night and reverses direction at 16:30 UT. In contrast, the meteor radar records strong westward winds for a long period during the first half of the night, reaching its maximum value around 16:00 UT. During the first half of the night, differences in the zonal winds between the meteor radar and the FPI are larger than those in the meridional winds. These differences may be influenced by the spatial separation of the two instruments, which are approximately 100 km apart in the meridional direction.

Figure 5 presents the temperatures and winds at 250 km measured by the FPI, along with corresponding values from the NRLMSISE 2.1 and HWM14 models. The temperatures of the FPI and the model show a similar temporal variation; however, the FPI records a larger variation range of approximately 200 K during the night. The zenith wind displays a larger variation range at 250 km compared with 87 and 97 km. The zenith winds at the three altitudes exhibit similar variation patterns, reaching a maximum between 17:00 and 18:00 UT. The meridional winds for both the FPI and HWM14 gradually decrease, with mean values around 0 and  $-50$  m/s, respectively. The FPI zonal wind remains eastward throughout the night, reaching a maximum of about 130 m/s around 14:00 UT, whereas the HWM14 zonal wind converts from eastward to westward at approximately 17:00 UT.

### 3.2 Comparison of Temperature and Wind over Multiple Days

The observational data from June 12 to 15 during the campaign are analyzed, as shown in Figures 6–9. For comparison, the model and meteor radar data are processed with the same method. In addition, linear regressions of the wind measurements are performed between the FPI and the meteor radar, and between the FPI and HWM14.

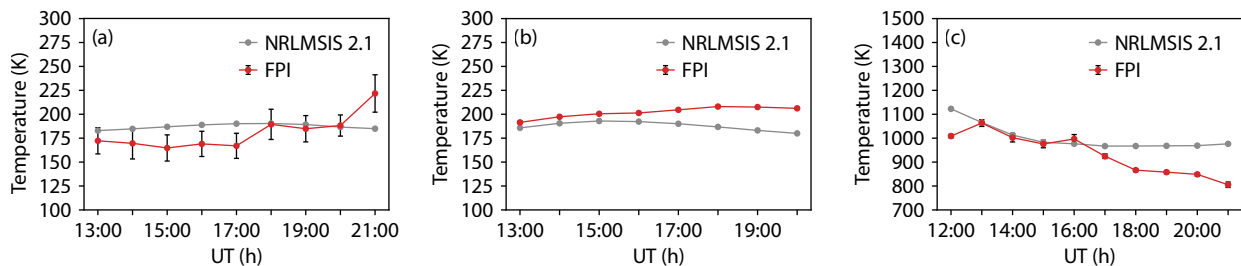
Figure 6 compares the mean temperatures derived from the FPI and NRLMSISE 2.1. Only the zenith direction temperatures are used to calculate the FPI mean temperatures, rather than temperatures from all five directions. Temperatures from the five directions differ slightly, and the model temperature corresponds to the location directly above the observatory. Using only the zenith

direction ensures a more direct comparison with the model. Although the filtering reduced the number of samples, sufficient data remained for a multi-day comparison: for the 892.0, 557.7, and 630.0 nm emissions, the number of measurements before filtering was 174, 177, and 156, and after filtering to zenith-only measurements, 34, 35, and 31 samples remained, respectively. The observation and the model fall within a similar range at altitudes of 87 and 97 km. At 250 km, both mean temperature variations exhibit an overall decreasing trend throughout the night. The visible differences between the FPI observation and the model are not unexpected. These results demonstrate that the FPI provides reasonable temperature measurements. Further validation with additional observational instruments will be carried out in future work.

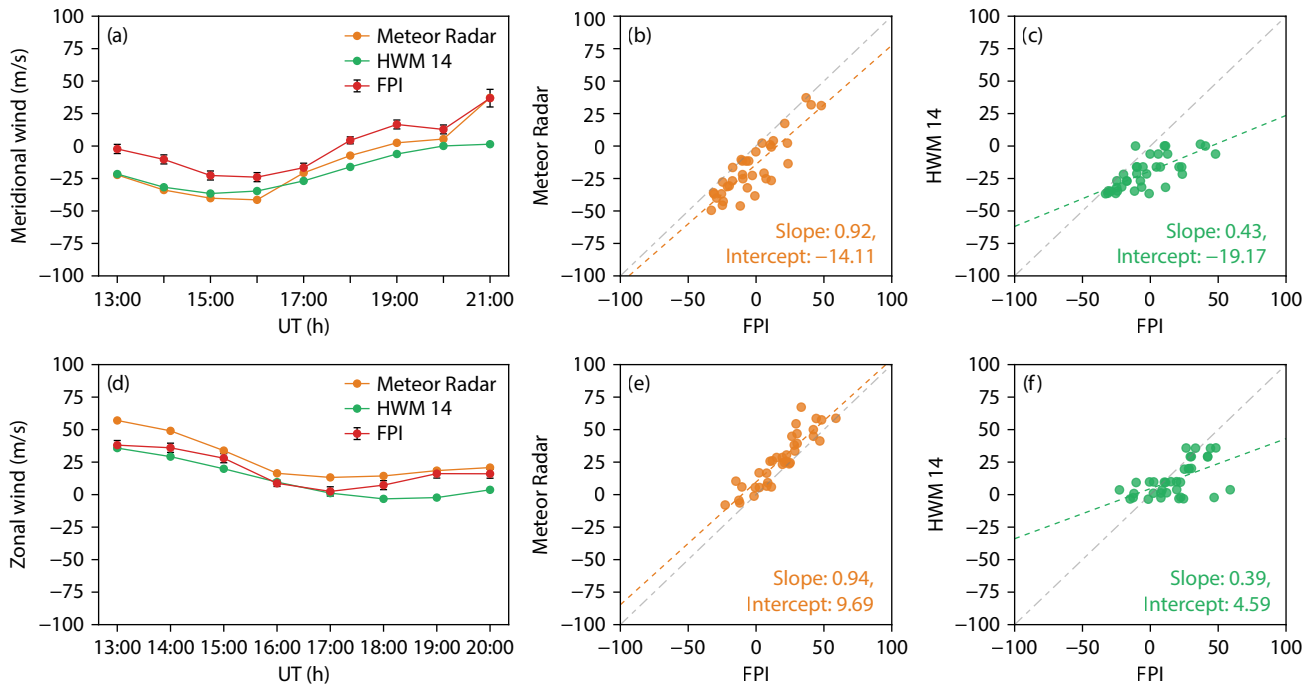
Figure 7 shows the mean winds at 87 km from the FPI, meteor radar, and HWM14, along with the linear regression between the FPI and meteor radar, and between the FPI and HWM14. The mean meridional winds from the three sources exhibit similar temporal variation patterns, but the FPI winds are generally larger than those from the meteor radar and HWM14. This result is supported by the linear regression, which shows that the regression intercept between the FPI and meteor radar is  $-14.11$  m/s and that the intercept between the FPI and HWM14 is  $-19.17$  m/s. The regression slopes are less than 1, indicating that the FPI has a larger variation range, whereas HWM14 shows the smallest. For the mean zonal wind, the meteor radar records stronger mean winds than the FPI, whereas the FPI still shows a wider variation range.

Figure 8 presents the mean winds and scatter plots of the linear regression for the comparison between different data sources at 97 km. The meridional and zonal winds of the FPI and meteor radar show closer agreement, as they exhibit smaller intercepts and slopes closer to 1. Unlike the results at 87 km, the regression slope between the FPI and the meteor radar is greater than 1, indicating that the meteor radar has a larger range of variation. In comparison, the linear regression between the FPI and HWM14 shows a relatively weak correlation.

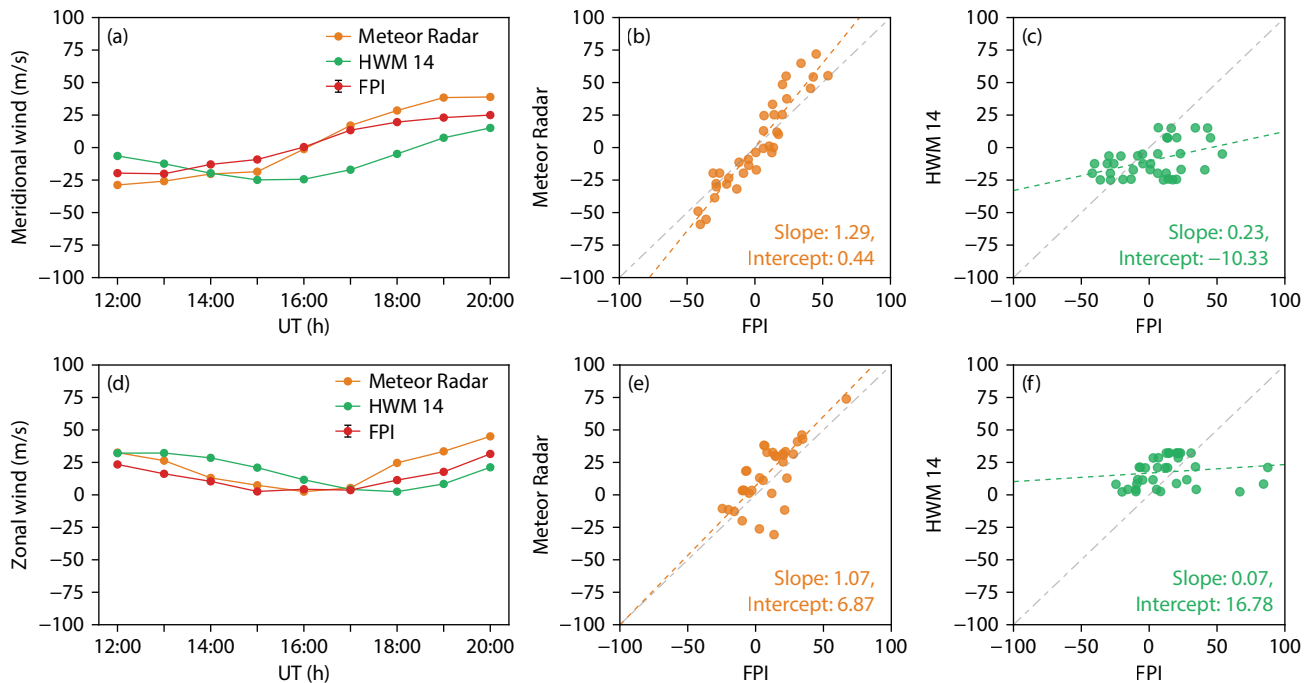
The results of the FPI and HWM14 at 250 km are shown in Figure 9. The mean meridional winds from both sources are southward, but the FPI winds are very strong in the first half of the night. For the mean zonal wind, HWM14 shows a reversal in wind direction, whereas the FPI does not. Instead, the FPI exhibits a very strong eastward wind, reaching approximately 100 m/s.



**Figure 6.** Mean zenith temperature of the FPI (at 892.0, 557.7, and 630.0 nm) and NRLMSISE 2.1 at altitudes of (a)  $\sim 87$  km, (b)  $\sim 97$  km, and (c)  $\sim 250$  km.



**Figure 7.** (a, d) Mean wind at 892.0 nm ( $\sim 87$  km) of the FPI, meteor radar, and HWM14. (b, c, e, f) Scatter plots with linear regression between the FPI and the meteor radar, and between the FPI and HWM14.

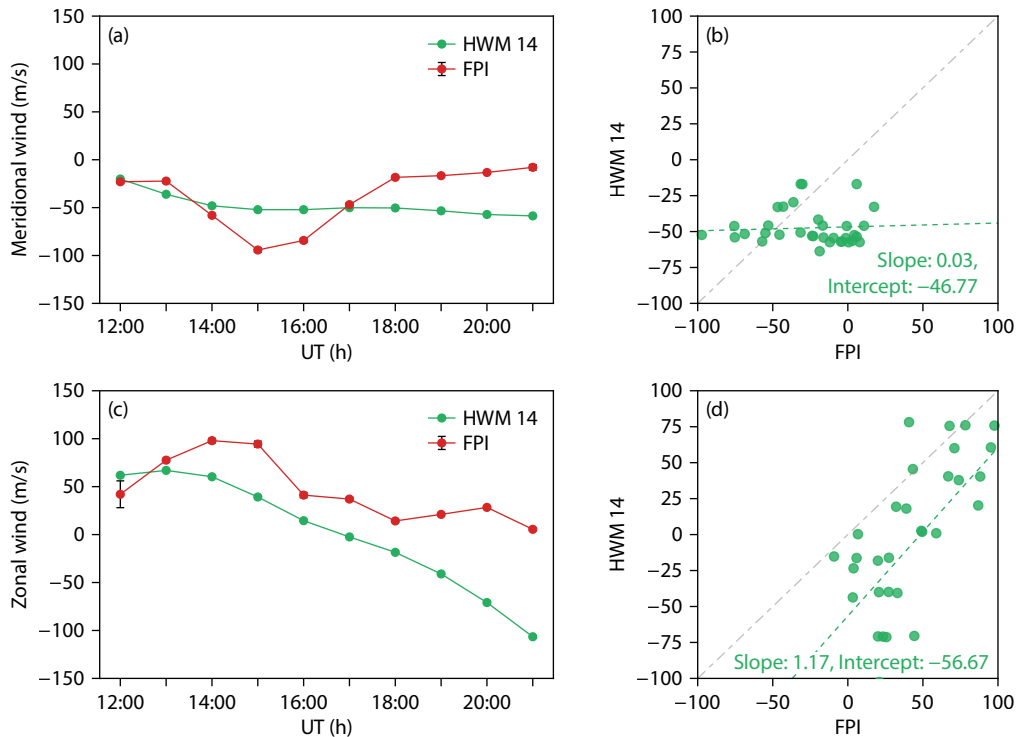


**Figure 8.** Same as Figure 7, but for 557.7 nm ( $\sim 97$  km).

#### 4. Summary

A three-wavelength ground-based FPI developed by Wuhan University is deployed in Chongyang to conduct the first observations of temperature and wind fields in the upper atmosphere. This three-wavelength FPI operates at wavelengths of 892.0, 557.7, and 630.0 nm, corresponding to the altitudes of  $\sim 87$ ,  $\sim 97$ , and  $\sim 250$  km, respectively. The structure and key components of this FPI are introduced in detail in Section 2. During the observation

period, the FPI obtained clear airglow interferograms, from which temperature and wind speeds are retrieved using a nonlinear regression method. On June 13, 2024, the temperature, zenith wind, meridional wind, and zonal wind from the FPI are presented, along with corresponding results from the NRLMSISE 2.1, meteor radar, and HWM14 for comparison. The FPI temperature variations are inconsistent with the models at 87 km but show good agreement at 97 and 250 km. The zenith wind is very weak



**Figure 9.** (a, c) Mean wind at 630.0 nm (~250 km) of the FPI and HWM14. (b, d) Scatter plots with linear regression between the FPI and HWM14.

at 87 and 97 km, within  $\pm 10$  m/s, but exceeds  $-20$  m/s at 250 km. The wind fields from the three data sources show similar variation trends, with the FPI and meteor radar showing better agreement. A multi-day comparison of winds and temperatures from June 12 to 15, 2024, and a linear regression between different data sources were conducted. At 87 km, the mean meridional and zonal winds from the three sources show very similar variations. At 97 km, the FPI and meteor radar winds are more consistent, whereas the regression slopes between the FPI and HWM14 indicate poorer agreement. The regression slopes at 87 and 97 km are less than 1 and greater than 1, respectively, indicating that the detection results of the two instruments differ at different altitudes, which may be caused by differences in the detection principles of the two instruments. At 250 km, the FPI observes extreme winds in both the southward and eastward directions, reaching approximately 100 m/s, which significantly exceed the predictions of HWM14.

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