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Error calculation and analysis for an improved wind retrieval method based on the ground-based Fabry–Perot interferometer measurements

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Abstract

A ground-based Fabry–Perot interferometer (FPI) fabricated by American National Center for Atmospheric Research (A-NCAR) was deployed in Kelan (111.6° E, 38.7° N), in middle of China, to observe OH 892.0 nm, OI 630.0 nm, and OI 557.7 nm airglow emissions for wind retrieval of mesospheric and thermospheric atmosphere using a method based on the convolution of the source profile and instrumental function. Based on the instrument, wind velocities were retrieved using another retrieval method but improved in both noise reduction and choice of interference fringes, which can reduce the disturbance of bad fringes and advance the retrieval precision. The retrieval results were subsequently compared with the FPI wind products, and good agreement was found between them. The averaged deviations of wind velocities between the two retrieval methods depend on airglow intensity with 5.7 m/s for 892.0 nm emission, 6.18 m/s for 630.0 nm emission, and 3.66 m/s for 557.7 nm emission, respectively. Then, a new method was proposed for error calculation by considering the influence of airglow intensity, CCD dark noise, background emissions, and data processing, which can steadily evaluate the precision and reliability of wind retrieval. The relationships between errors derived from the two retrieval methods and airglow intensity were compared and analyzed. It is found that the variation of errors is inversely correlated with the variation of airglow intensity.

Keywords: Wind velocity retrieval; Fabry–Perot interferometer (FPI); Error analysis; Mesospheric and thermospheric atmosphere

1. Introduction

The observations of the neutral winds are used for studying the dynamics and behavior of the mesospheric and thermospheric atmosphere and for developing forecasting capabilities for the space environment. Fabry–Perots (FPIs) have been used to measure mesosphere and thermosphere neutral winds for many years. They monitor the Doppler shift of mesosphere and thermosphere nightglow emissions, from which the neutral wind is deduced. To date, wind measurements using Fabry–Perot interferometers from the ground have been studied for several decades by many scientists (Rees et al., 1984; Killeen and Roble, 1988; Niciejewski et al., 1994; Hernandez and Roble, 1995; Nakajima et al., 1995; Aruliah et al., 1996; Dyson et al., 1997; Plagmann et al., 1998; Biondi et al., 1999; Shiokawa et al., 2001, 2003, 2012; Wu et al., 2004).

For the wind retrieval of those ground-based FPIs, two main methods were proposed and used widely. One method was originally developed for the analysis of data obtained from the multi-channel FPI which was on board the Dynamics Explorer 2 spacecraft (Killeen and Hays,

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1984). The retrieval error of the method has been validated within 3 m/s for space satellite measurements (Killeen et al., 2006) and within 6 m/s for ground measurements (Wu et al., 2004). This method was developed and used by A-NCAR for wind retrieval of FPI in Kelan. Therefore, we refer to it as A-NCAR method for simplicity in this paper.

Another method was proposed firstly by Shiokawa et al. (2001) for the ground-based measurement based on the assumption of uniform wind in two opposite directions (distance ≈ 500 km), which is suitable for low- and mid-latitude wind retrieval. Based on the method, wind velocities were retrieved using two interference fringes for a two-channel FPI in 2003. The retrieval results were compared with wind measurements of MU radar with maximum differences of ~20 m/s for 557.7 nm airglow and ~40 m/s for 630.0 nm airglow (Shiokawa et al., 2003). Meanwhile, the wind error was estimated by considering airglow intensity and CCD dark noise. Then, wind was retrieved using 10 fixed fringes based on four FPIs, and the results were compared with each other (Shiokawa et al., 2012). However, the method may lead to a large wind deviation from the true value because of disturbance of one or several bad fringes (Fig. 10, Shiokawa et al., 2012). The wind error was also calculated in that paper by use of standard error of 10 wind velocities of 10 interference fringes, which can reveal the variation of airglow intensity but with much more uncertainties. The reason is that the error estimation is very sensitive to the wind velocities of one or several bad fringes which may be caused by random stray lights, background emissions, or data processing.

An improvement of the latter retrieval method was carried out, and the results were validated by comparing with FPI wind products which were calculated using A-NCAR method. The retrieval errors were also re-calculated. All of the studies were based on observations of a FPI which was deployed in Kelan to observe the nightglow emissions at wavelengths of OH 892.0 nm, OI 557.7 nm and OI 630.0 nm to obtain the wind at heights around 87 km, 97 km and 250 km, respectively (Yu et al., 2014). The FPI measures the Doppler shift of the airglow emissions in a zenith direction and four azimuthal directions of east, west, north, and south with a zenith angle of 45° (Fig. 1, quoted from Yu et al., 2014). The FPI sky-scanner is sequentially steered to the five directions (zenith, eastward, westward, southward, and northward) to observe the airglow emissions with three minutes exposure time for 892.0 nm and 557.7 nm emissions and five minutes for 630.0 nm emission. Therefore, it takes roughly 50 min to detect the airglow at three wavelengths during one measurement cycle, and the wind results are derived at an hour. The originally observed data of the FPI is shown in Fig. 2.

The methodology and improved data processing method are presented in Section 2. The result comparisons are given in Section 3. Finally, the error analysis is shown in Section 4.

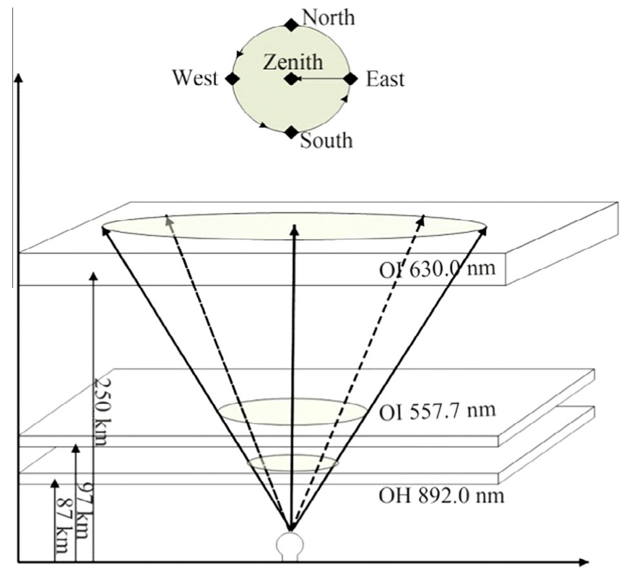

Fig. 1. The diagram of the ground-based Fabry–Perot observation (Yu et al., 2014).

2. Methodology and data processing

As shown in Fig. 2, the equal inclination interference fringes are formed when the airglow emissions enter into the FPI. Therefore, the interference order can be derived from the radius of fringe peak finally after series of transformations (Shiokawa et al., 2001):

$$m_i = \frac{2\mu t}{\lambda_0\left(1-\frac{v}{c}\sin\theta\right)}\left(1-\frac{r_i^2}{2f^2}\right) \tag{1}$$

where m is the interference order, subscript i presents the number of fringe from the center to the edge, μ is the refractive index, t is the etalon spacing, λ_0 is the central wavelength of the airglow without the Doppler shift, r is the fringe peak radius in one observation direction, f is the focal length, c is the light speed, $\theta = 45°$ is the view zenith angle, and v is horizontal wind velocity. Assuming that the vertical wind velocity was negligible and that wind velocity was uniform between the two opposite directions holding in all areas except for high-latitude auroral zones (Smith, 1998), zonal and meridional wind velocity can be derived from the radiuses of eastward/westward and northward/southward fringe peaks respectively. The equations are shown as follows:

$$V_N = \frac{c}{\sin\theta}\frac{r_S^2 - r_N^2}{4f^2 - (r_S^2 + r_N^2)} \tag{2}$$

$$V_E = \frac{c}{\sin\theta}\frac{r_W^2 - r_E^2}{4f^2 - (r_E^2 + r_W^2)} \tag{3}$$

where r_N and r_S are the radiuses of the northward and southward fringe peaks, respectively. r_E and r_W are the radiuses of the eastward and westward fringe peaks, respectively.

Based on Eqs. (2) and (3), wind velocity can be derived from the fringe radius determination calculated using