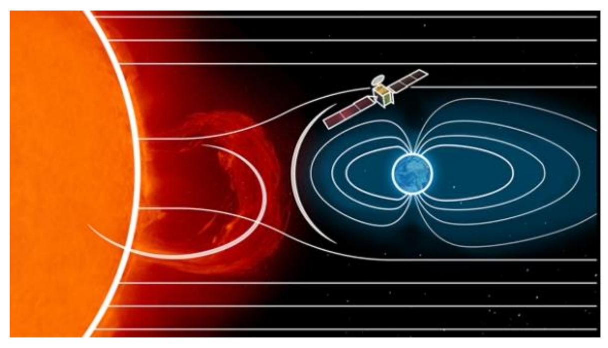

# Investigating Thermospheric Winds over Tenerife: Fabry-Perot Observations and Retrieval Method Comparisons


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## Introduction

Thermospheric winds play a vital role in transporting momentum and energy in the upper atmosphere, shaping both thermospheric and ionospheric dynamics. Understanding these winds is essential for enhancing satellite operations and communication systems. The **Fabry Pérot Interferometer (FPI)**, a remote sensing instrument that uses an etalon to generate interference patterns, is commonly employed to measure thermospheric winds through airglow emissions. **In March 2024, DLR deployed a custom-built 630 nm FPI (SOFPIT) on Tenerife** (28.29° N, 16.63° W), which has since recorded over a year of nighttime wind observations. Retrieval methods for deriving winds and temperatures were developed based on the instrument's unique characteristics. **This study introduces the SOFPIT instrument and presents two wind retrieval techniques tailored to its data.**

## Instrument

### SOFPIT Instrument

- **SOFPIT observes the 630.0 nm airglow emission** from altitudes of 200–300 km. Motion of the emitting particles causes Doppler shifts in the interference ring pattern. By analyzing these shifts and broadenings, the FPI retrieves line-of-sight wind velocity and temperature.

| Component | Specification |
|---|---|
| Sky Scanner | Views in 4 cardinal directions + zenith |
| Filter | 630 nm (red oxygen emission line) |
| Etalon | Diameter: 116 mm<br>Thickness: 15 mm<br>Reflectivity: R = 0.76 |
| Calibration | HeNe laser |
| Imaging Optics | Focal length: 300 mm |
| CCD Detector | Size: 13.312 mm × 13.312 mm<br>Resolution: 1024 × 1024 pixels |

**Tab1.** Key elements of SOFPIT

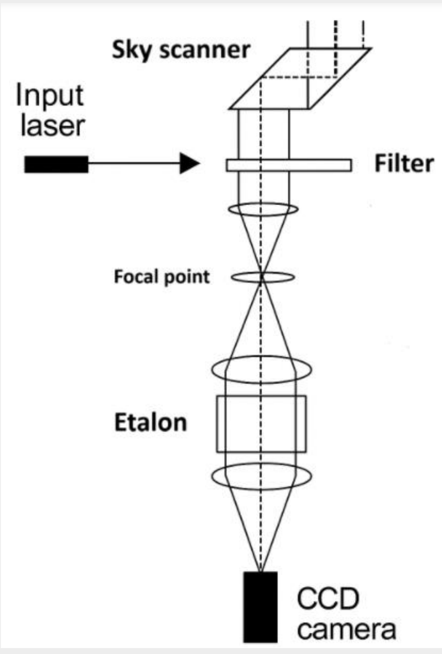


**Fig1.** Schematic diagram of SOFPIT

- A full sky scan (east, west, north, south, vertical, laser) is performed with 3.5 minutes per direction for airglow images and 0.5 seconds for the laser.

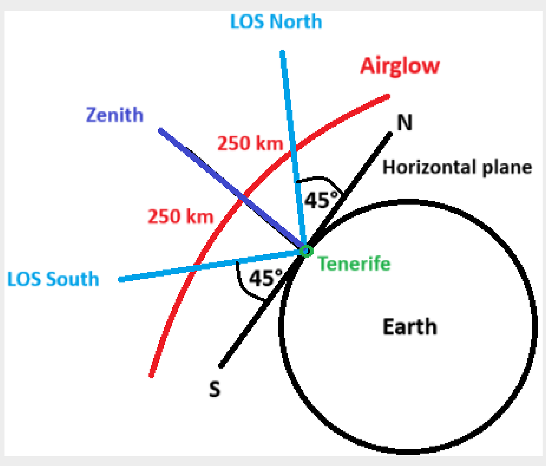


**Fig2.** Measurement geometry schematic

**Fig3.** Container with SOFPIT on Tenerife

## Data/Methods

### Shiokawa Method

**Assumptions:** Horizontal and vertical winds are uniform between two opposing viewing directions.
**Method:** Wind is derived from the shift in fringe center positions in Fabry–Perot images taken in opposite directions.
**Result:** Multiple wind estimates per image are averaged to obtain a single zonal or meridional wind value.

$$v_N = \frac{c}{\cos\theta}\frac{(r_S^2 - r_N^2)}{\left(4f^2 - (r_N^2 + r_S^2)\right)}$$

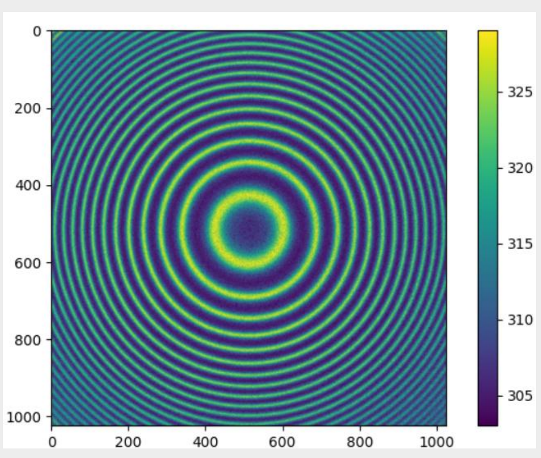

**Fig4.** Real Sky image

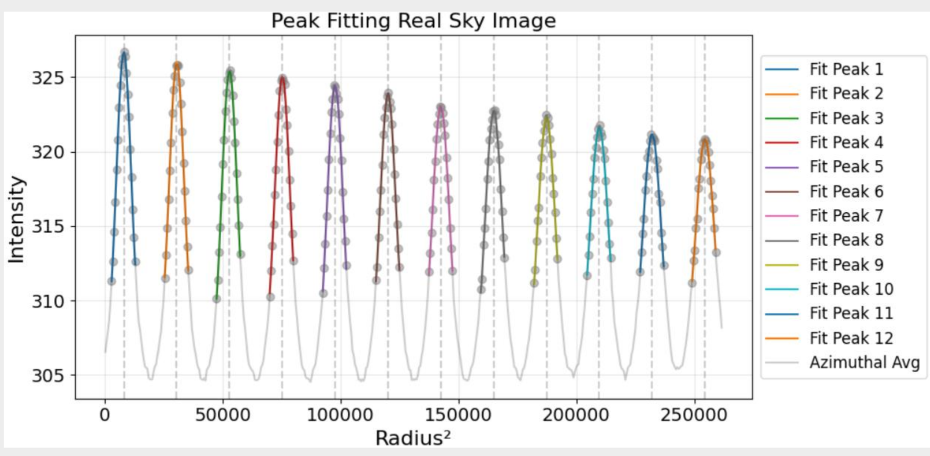


**Fig5. Shiokawa method:** Peak Detection via Azimuthal Averaging and Fitting

### Harding Method

**A. Forward model for laser calibration fringes:**

- **Assumption:** The average vertical wind is zero over the night, and vertical wind components are negligible in each individual measurement.

$$A(r,\lambda) = \frac{I}{1 + \frac{4R}{(1-R)^2}\sin(\frac{2\pi n d}{\lambda}\cos(\arctan(\frac{r}{f})))^2}$$

- Modulation in intensity for attenuations of the fringes at the edges of the CCD:

$$I = I_0(1 + I_1\frac{r}{r_{max}})$$

- Point spread function simulates optical defects via a weighted average:

$$b(s,r) = \frac{1}{\sqrt{2\pi\sigma(r)^2}} e^{\frac{(s-r)^2}{\sigma(r)^2}} \text{ with } \sigma(r) = \sigma_0 + \sigma_1 \sin\left(\pi\frac{r}{r_{max}}\right) + \sigma_2\cos(\pi\frac{r}{r_{max}})$$

Free parameters are fitted to best match the observed laser calibration fringes.

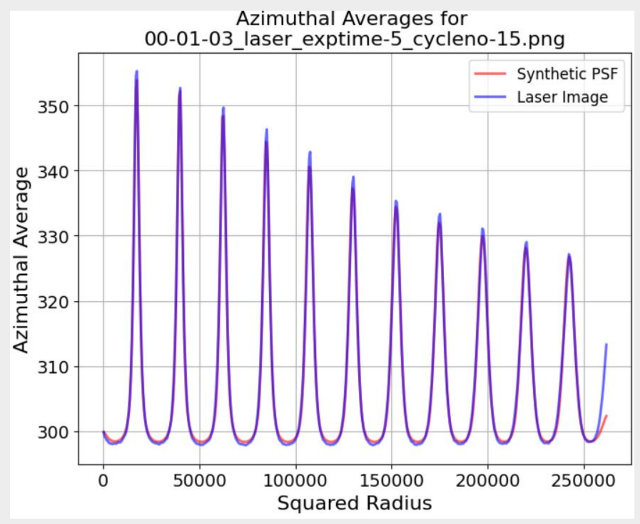


**Fig6. Harding Method:** Assessment of fit quality of the Laser model

**B. Forward model for airglow fringes:**

- The airglow model uses the same equations as for the laser, but replaces the delta function with a Gaussian source spectrum to account for thermal broadening and Doppler shifts.

$$Y(\lambda) = Y_{bg} + Y_{line} exp\left\{-\frac{1}{2}(\frac{\lambda-\lambda_c}{\Delta\lambda})^2\right\}$$

- The airglow model inputs include $\lambda_c \Delta\lambda, Y_{bg}, Y_{line}, and\ B$. These physical parameters are the target of optimization. Velocity and temperature are obtained through:

$$\lambda_c = \lambda_0(1 + \frac{v}{c}) \text{ and } \Delta\lambda = \frac{\lambda_0}{c}\sqrt{\frac{kT}{m}}$$

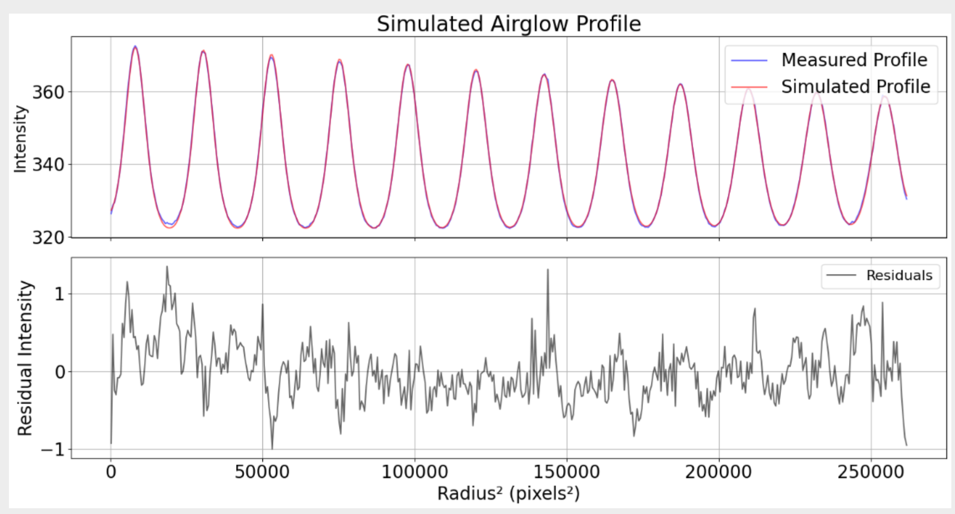


**Fig7. Harding Method:** Assessment of fit quality of the Airglow model

## Results

### Comparison Shiokawa- Harding Method

**Zonal and meridional Winds on the Night of 26–27 October 2024:**

The Shiokawa method assumes uniform winds over ~500km, while the Harding method permits to analyze each beam separately, assuming that the vertical wind is negligible in the entire volume ~500km. **The difference between the profiles indicates large-scale gradients in the wind field and increased measurement uncertainties.**

Differences in local wind conditions can cause the methods to diverge.

**The Shiokawa method wind retrieval then reflects a spatial average, as suggested by the data from this day.**

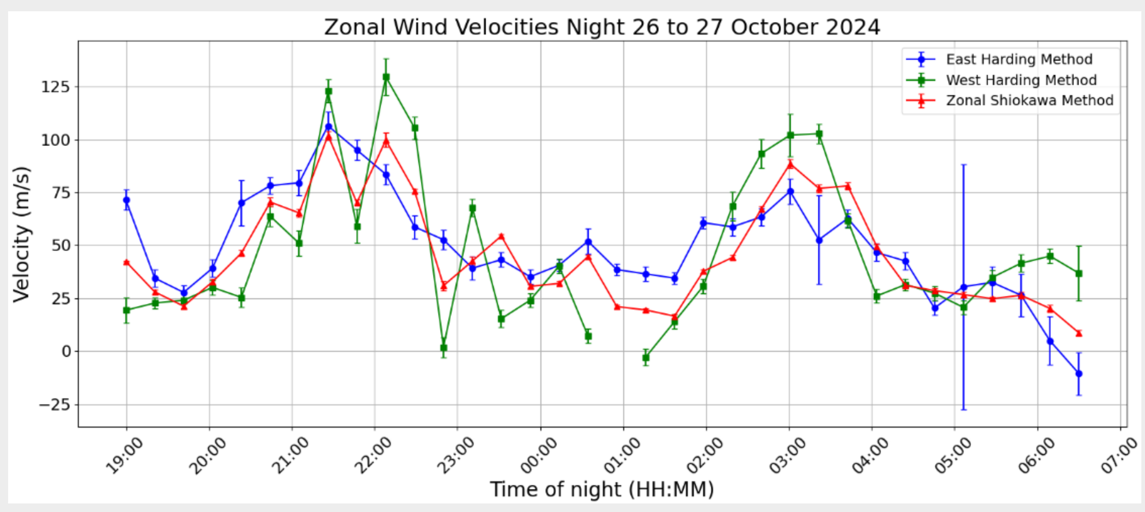


**Fig8.** Comparison of zonal winds for the 2 retrieval methods

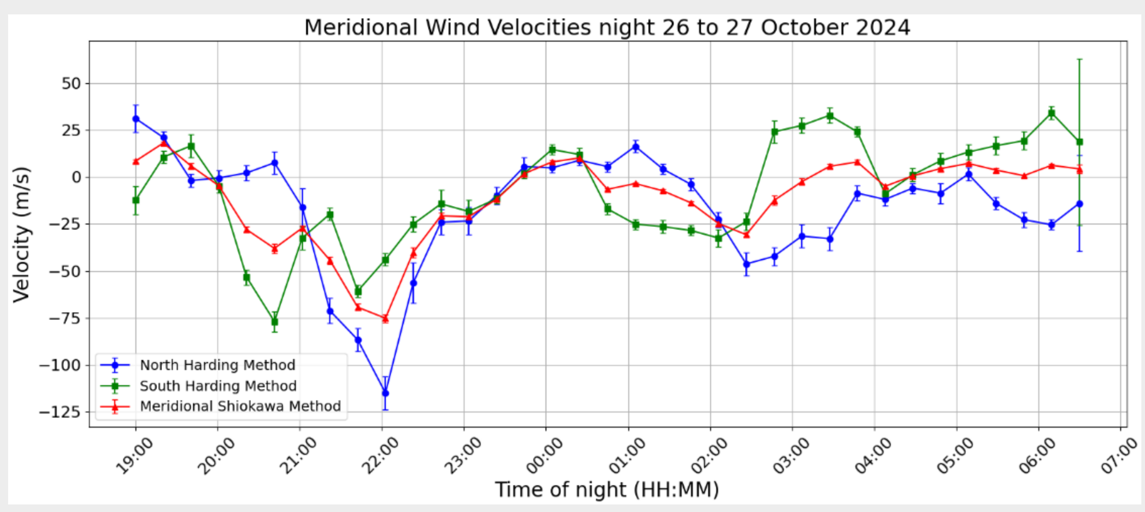


**Fig9.** Comparison of meridional winds for the 2 retrieval methods

## Conclusion/Next steps

- Although the two methods rely on different assumptions, **they yield consistent results for the presented day.**
- **Establish quality criteria for valid measurements**, e.g., by introducing a residual standard deviation threshold.
- **Evaluate how sensitive the retrieved wind velocities are to small variations in instrumental parameters.**
- **Investigate the validity of key assumptions:** negligible vertical winds over a night and horizontal wind uniformity across ~500 km.


References:

**Shiokawa, K., Otsuka, Y., Oyama, S., Nozawa, S., Satoh, M., Katoh, Y., Hamaguchi, Y., Yamamoto, Y., & Meriwether, J. W. (2012).** Development of low-cost sky-scanning Fabry-Perot interferometers for airglow and auroral studies. *Earth, Planets and Space, 64*(11), 1033–1046. https://doi.org/10.5047/eps.2012.05.004

**Harding, B. J., Gehrels, T. W., & Makela, J. J. (2014).** Nonlinear regression method for estimating neutral wind and temperature from Fabry–Perot interferometer data. *Applied Optics, 53*(4), 666–673. https://doi.org/10.1364/AO.53.000666



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