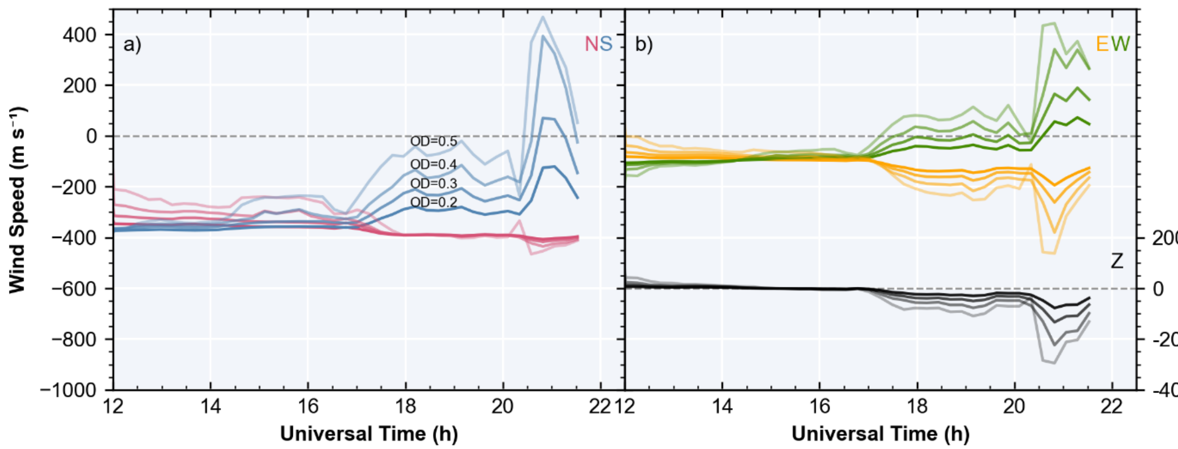
Dear Referee #1,

We are deeply grateful for your thoughtful review. Your suggestions and insights have greatly improved our work. We have addressed every comment and detailed our responses below. Following your suggestions, we have revised the Introduction, the scattering-model description, and the Discussion to improve clarity and accuracy. All corresponding revisions in the manuscript are highlighted in purple.

We note your expectation that wind-speed fluctuations should decrease from U_LOS_S to U_LOS_Z to U_LOS_N. Our simulation reproduces this order while the observations do not. Below, we want to clarify the scattering mechanism and discuss the remaining simulation–observation discrepancy briefly.

The post-scattering speed change is indeed direction-dependent, **as detailed in Section 4.1, "Core working principle of the scattering model"**. There, we show the simulated horizontal LOS speed variations (Fig. 7 of the manuscript) together with the proportion of scattered light (Fig. 8). In short, the wind-speed fluctuation for any direction depends on (1) its geometry relative to the brighter airglow patch and (2) whether its LOS speed sign matches that of the brighter patch.

Unfortunately, simulation–observation discrepancies remain: (1) the model underestimates scattering-induced deviations in all directions (case of Oct.), and (2) the north-looking winds are unexpectedly larger than simulated and depart from the expected U_S > U_Z > U_N ordering (case of May). These discrepancies point to either model underestimation of scattering or extra non-scattering effects. We have refined the model on multiple aspects to reduce its underestimation and explored possible non-scattering effects. However, with no ISR or other neutral-wind measurements available in the study region, quantifying these non-scattering contributions remains hard. **We have summarized the possible influencing factors in Section 4.2, "Errors of the scattering model"**. In short, for discrepancy (1), only optical depth tuning has so far appreciably reduced the model's underestimation. When the optical depth is artificially increased to a higher value, the model outputs more significant wind-speed fluctuations and more closely matches the Oct. observations (0.2 in practice). The optical depth used in the manuscript is a daytime observation obtained ~180 km from Siziwang, and thus carries substantial uncertainty. The figure below shows the simulated results for Oct. 10^{th} under different optical depths.



For discrepancy (2), we suspect the north-looking line of sight picks up non-neutral Doppler shifts from embedded auroral emissions. **That is discussed at the end of Section 4.2.** Because of multiple uncertainties in the input fields, the simulation can hardly match the observations numerically at present. Nevertheless, it reproduces the observed wind-speed trends and is therefore useful for examining the scattering mechanism. For now, we can only list and discuss the potential issues that arise between the model and the observation. A quantitative verification will require additional aerosol and radio measurements that await future work.

Below are our responses:

Comment #1: *L70: "During two geomagnetic storms with visible auroras" > "During two geomagnetic storms on May 10th and Oct. 13, 2024 with visible auroras"*

Response #1: Thank you for this helpful suggestion. We feel sorry for not specifying the storm dates in the introduction. We have revised **L70 to:** **"During two geomagnetic storms on May 10th and October 10th, 2024, with visible auroras".**

Comment #2: *L72-73: "The observations were unaffected by moonlight or clouds, and the interferometer retrieval errors were acceptable." How did you confirm these?*

Response #2:

To keep the Introduction concise, we deferred the complete data-screening criteria to Section 3.1, L177–180. Thank you for highlighting the potential confusion. We have now added a forward reference **at L73** **"…(see Section 3.1)"** to guide readers directly to these details.

The screening criteria are (1) excluding cases where the angle between the moon and the line of sight is less than 30 degrees, (2) excluding cases where large-area thick cloud coverage is visible in DCAI, and (3) excluding data with standard errors greater than 50 $m \cdot s^{-1}$. We computed the moon's position with PyEphem (https://rhodesmill.org/pyephem/index.html). As the cloud sensor at Siziwang was not yet operational in 2024, we reviewed the all-sky imager DCAI and excluded any intervals where excessively thick clouds obscured the field of view.

Comment #3: *L139: "The LOS speed is used directly instead of the Doppler shift, assuming a constant background temperature." This sentence requires revision. I have two comments: (1) To my knowledge, the LOS speed is derived from the Doppler shift measured by the optical interferometer. In this process, the Doppler shift seems more like a "direct" measurement rather than the LOS speed itself. (2) I find it unclear why the assumption of a constant background temperature is necessary. This should be more explicitly addressed in the text.*

Response #3:

Thank you for the insightful suggestion. With the instrument thermal drift kept under control and elastic scattering assumed, we skip the chain fringe-shift > frequency-shift > LOS speed and simulate each ray directly with its LOS speed. The Doppler shift remains implicit and need not be computed explicitly. Every incident ray from the airglow layer is mapped straight to its LOS speed. This approach is outlined in Response #4.

However, during storms, the thermosphere heats rapidly, broadening the emission line and increasing the retrieval uncertainty. We are concerned that spatial temperature gradients near the auroral zone may further enlarge the deviation between simulation and observation. Thus, we highlighted the limitation in the previous manuscript. Indeed, wind-speed retrieval itself is insensitive to thermosphere temperature. The latter merely affects the retrieval uncertainty. We have now revised the relevant statements to minimize any possible misinterpretation:

L139: "(2) The LOS speed is used directly instead of the Doppler shift, assuming a constant background temperature." **to "(2) The Doppler shift is replaced by LOS speed, with every incident ray from the airglow layer mapped directly to its corresponding LOS speed."**

Remove L141-145: "We directly use LOS speed instead of Doppler shift, primarily neglecting the interference fringe recognition errors caused by spectral broadening due to temperature variations. During auroral events, FPI observations show similar neutral temperatures in all directions, with the northward direction occasionally being about 300 K higher (not shown here). Overall, the temperature at mid-latitudes is uniform at the 500 km spatial scale, and the variations caused by spectral line broadening can be neglected."

Background temperature is added to Discussion (4.2) as a possible source of error:

"We also considered the potential influence of thermospheric temperature. FPI data show uniformly elevated thermospheric temperatures in these two storms, with the northward view occasionally about 300 K warmer than the others (not shown here). Because our scattering model does not yet include temperature effects, we cannot quantify

how much scattering biases the FPI temperature measurements. In the study of Harding et al. (2017b), wind simulations are temperature-independent, while temperature retrieval relies on the wind. Likewise, we substitute the LOS speed for the Doppler shift and ignore temperature-induced spectral broadening. In principle, thermospheric temperature influences retrieval uncertainty, not the wind speed itself. We remain cautious that ignoring this uncertainty could introduce extra bias if a horizontal temperature gradient is present, but incorporating it would markedly raise the computational cost and remains a task for the future.”

L352-353: “In the model, we assume that without considering temperature-related spectral broadening, stronger light rays dominate interference fringe identification” **to “In the model, we assume that stronger light rays dominate interference fringe identification”**

L491-493: “Ignoring the background temperature gradient, LOS speeds can directly correspond to Doppler shifts to simplify the simulation of the Doppler distribution.” **to “To simplify simulation, the model directly uses LOS speeds corresponding to Doppler shifts.”**

Comment #4: *L140: “After binning different LOS speeds and computing the corresponding scattered light intensity, contaminated LOS speeds are calculated via weighted average, simplifying the wind simulation.” The procedure for "binning different LOS speeds" is unclear to me. Is it similar to pixel binning, a technique used in digital camera sensors?*

Response #4:

This is different from pixel binning. The specific method is described at the end of Appendix A (L490–498). In short, (1) We converted the assumed horizontal wind to the LOS speed at each viewing angle on the airglow layer, ignoring the effect of earth curvature. (2) We slice the airglow layer by LOS speed. Each bin spans less than ±40 m s^{-1}. We simply take its mean speed V_{sc}. (3) At each run, we illuminate a single bin to simulate the scattered intensity I_{sc} seen from all angles on the ground (all rays share that bin’s LOS speed). (4) At each viewing angle, the post-scattered LOS speed is computed as an intensity-weighted average (including both direct (V_{dr}, I_{dr}) and scattered components) according to the following equation:

$$V = \frac{V_{dr} I_{dr} + \sum_k V_{sc}(k) I_{sc}(k)}{I_{dr} + \sum_k I_{sc}(k)}$$

Because the detailed method is given in the appendix, the main-text description may appear too vague. We have now made it more specific:

L140-141: “(3) After binning different LOS speeds and computing the corresponding scattered light intensity, contaminated LOS speeds are calculated via weighted average, simplifying the wind simulation.” **to “(3) After slicing the airglow layer into several bins by LOS-speed, the model illuminates one bin per run, records its scattered intensity, then merges all bins with an intensity-weighted average to yield the post-scattered LOS speed.”**