Exploring Nocturnal Canopy Advection in Complex Terrain Through Active Heating Fiber Optics: Unraveling Temperature Dynamics and Airflow Patterns

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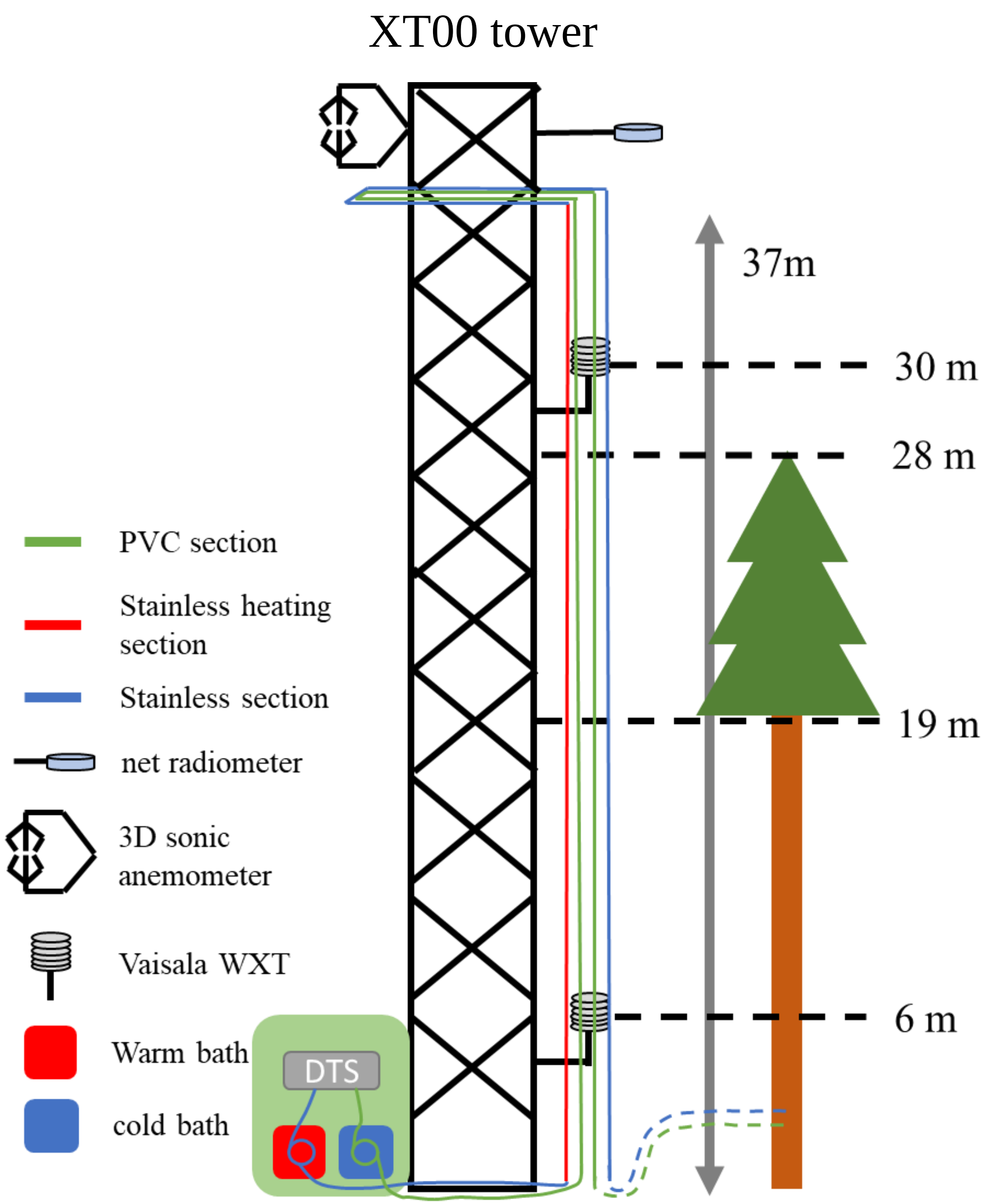
Abstract

Nocturnal advection significantly influences the accurate estimation of net ecosystem exchange (NEE). This phenomenon is prevalent in Taiwan's subtropical montane forests, introducing a potential bias when relying solely on eddy covariance data for carbon budget calculations. From the preliminary analysis, the wind speed can be well estimated through the temperature difference between the heated and unheated fiber optical.The derived five-minute average wind speed exhibits a high coefficient of determination (R^2) of up to 0.94. In the current study, a fiber observational setup consisting of a 38 m vertical section has been implemented to investigate temperature dynamics and airflow in complex terrain. The wind speed profile can be well reflected from the preliminary data analysis. Insights gained through this approach contribute to a better understanding of the nocturnal canopy advection model, offering valuable corrections to NEE estimates.

Introduction & Method



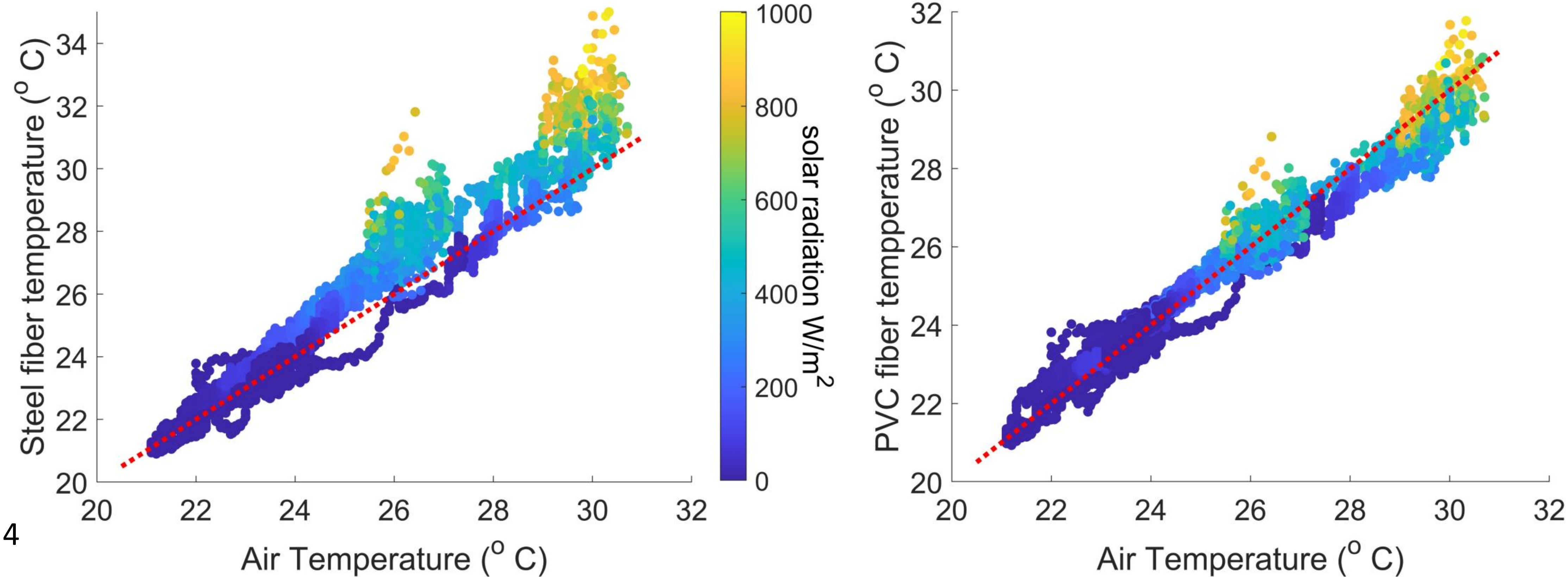
Nocturnal advection significantly influences the accurate net ecosystem exchange (NEE) estimation. This phenomenon is prevalent in Taiwan's subtropical montane forests, introducing a potential bias when relying solely on eddy covariance data for carbon budget calculations. Exploring higher temporal and spatial resolution monitoring technologies is thus crucial to assessing the detailed atmospheric process within the forest. This study used distributed temperature sensing (DTS) to explore vertical distributions of air temperature and wind speed and their temporal variation, mainly focusing on nocturnal processes.

A 38 m vertical fiber optical was deployed to monitor temperature changes and air movement dynamics over complex terrain in a Japanese cedar plantation of the Experimental Forest of the National Taiwan University in Xitou, Taiwan. The fiber array consists of fibers coated with PVC (outer diameter 0.9 mm) and stainless steel (outer diameter 1.2 mm), with two segments of fiber spliced inside the shed of the XT00 tower, making the two fibers the same circuit. The stainless steel-coated fiber was connected to a direct current source for heating at the profile of the XT00 tower. The heated and unheated stainless steel-coated fibers were used to estimate wind speed.

High-resolution Distributed Temperature Sensing (Ultima DTS M, Silixa) was conducted in double-ended mode with a spatial resolution of 0.254 m, connecting the fiber's start and end points to two different channels. The laser light alternates between the two channels every 4 seconds, with an average temperature output every 10 seconds.

Air Temperature observation characteristics

In terms of air temperature observation, the temperature measured by PVC-coated fiber optical is similar to the air temperature of WXT. It may be affected only when the solar radiation is greater than 800 W/m^2, while the stainless coated fiber is susceptible to interference from solar radiation. The measured temperature will increase with the increase of solar radiation. Therefore, if only observe the air temperature, it is recommended to use PVC-coated fiber for measurement.

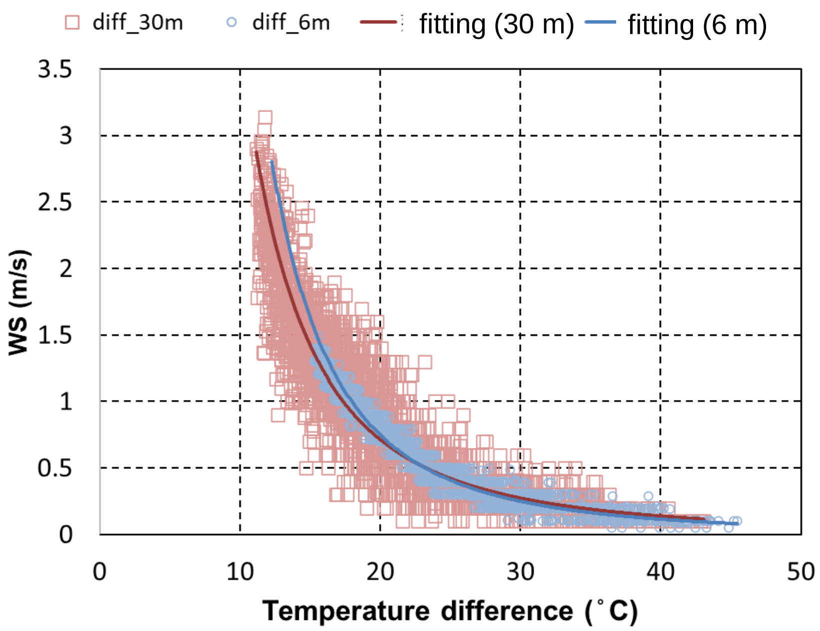


Wind Speed Estimate

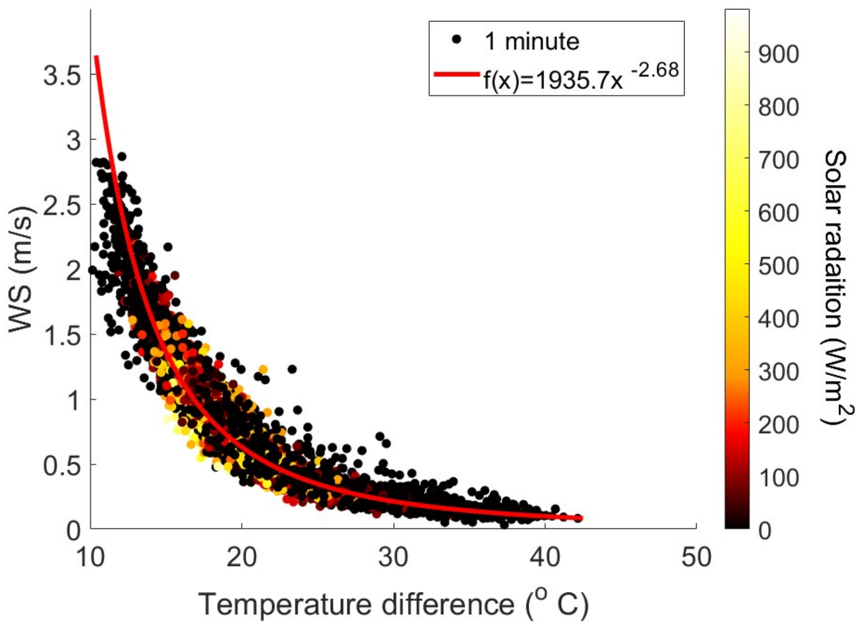
- This study utilized the relationship between the temperature difference of heated and unheated fiber optics at a height of 30 m and the wind speed measured by an anemometer at the same height to estimate wind speeds at various heights along the fiber. The same relationship was also evaluated at a 6-m height to verify the validity of this method across the height.

- Observed data indicates that the relationship between the temperature differences and wind speeds can be represented by the equation $y = ax^b$ with consistent regression performance at different locations and different solar radiation intensities.. Converting the temperature difference at a 6-m height into wind speed and comparing it with observed wind speeds demonstrated a certain level of accuracy.

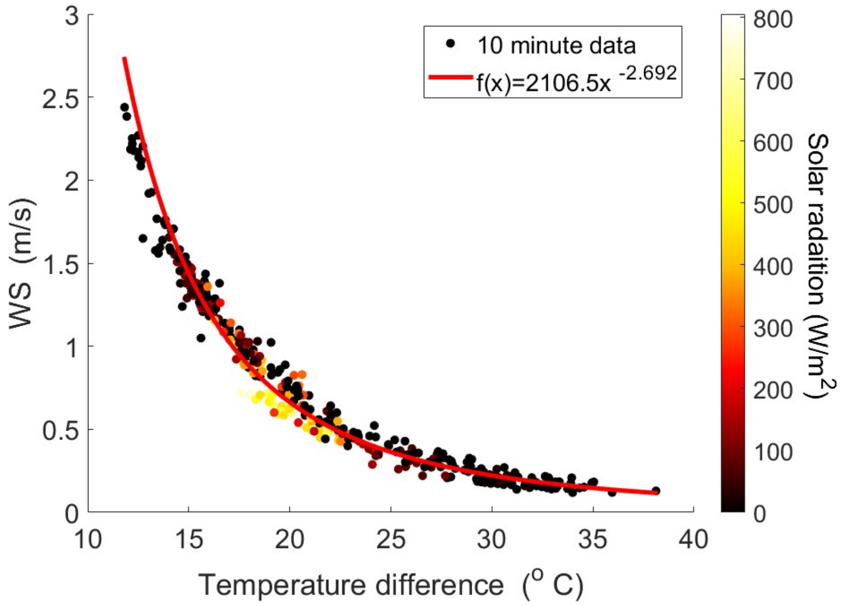
- Still, the estimated values tended to overestimate at low wind speeds and underestimated at high wind speeds.



Average ten seconds



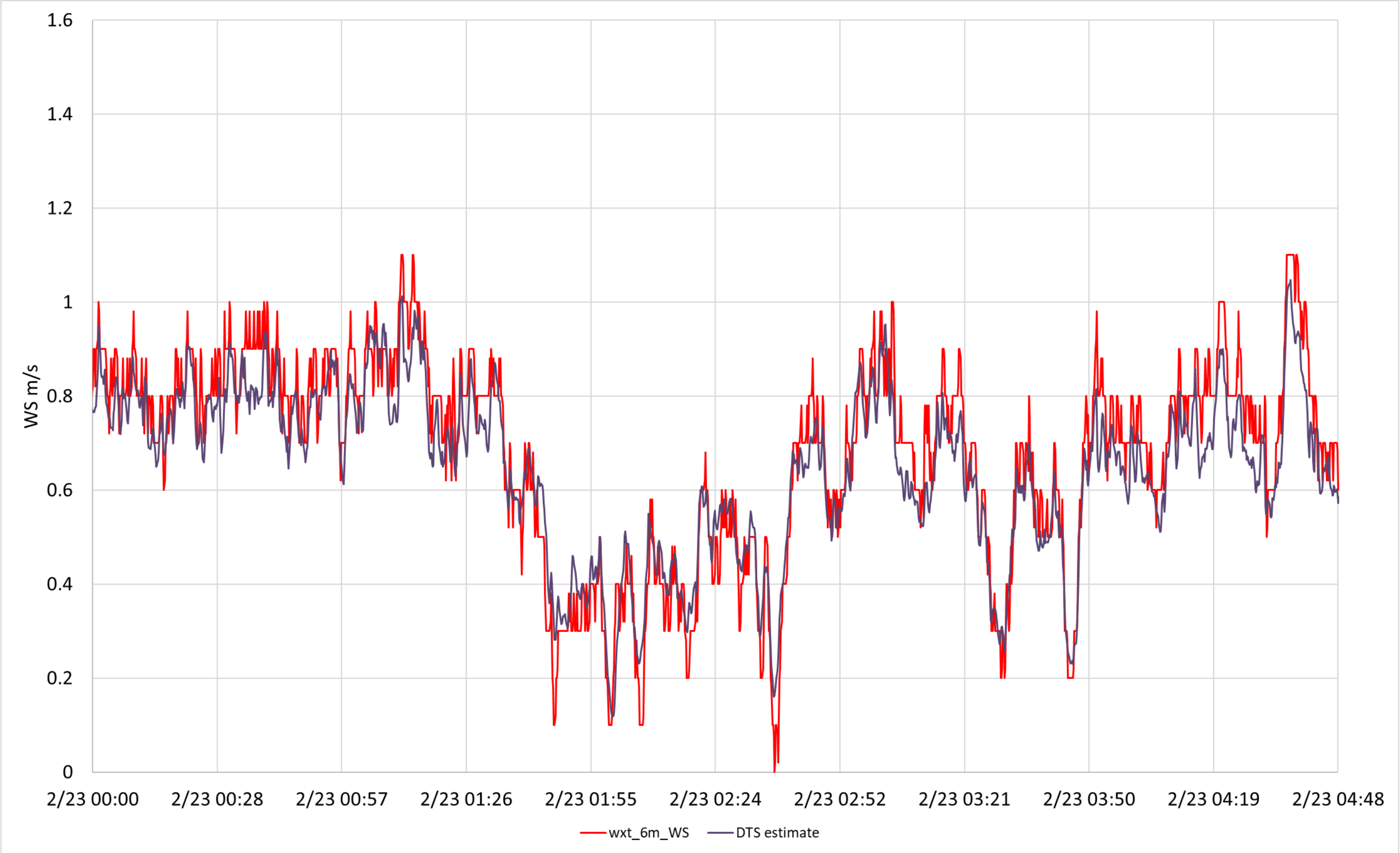
Average one minute



Average ten minute

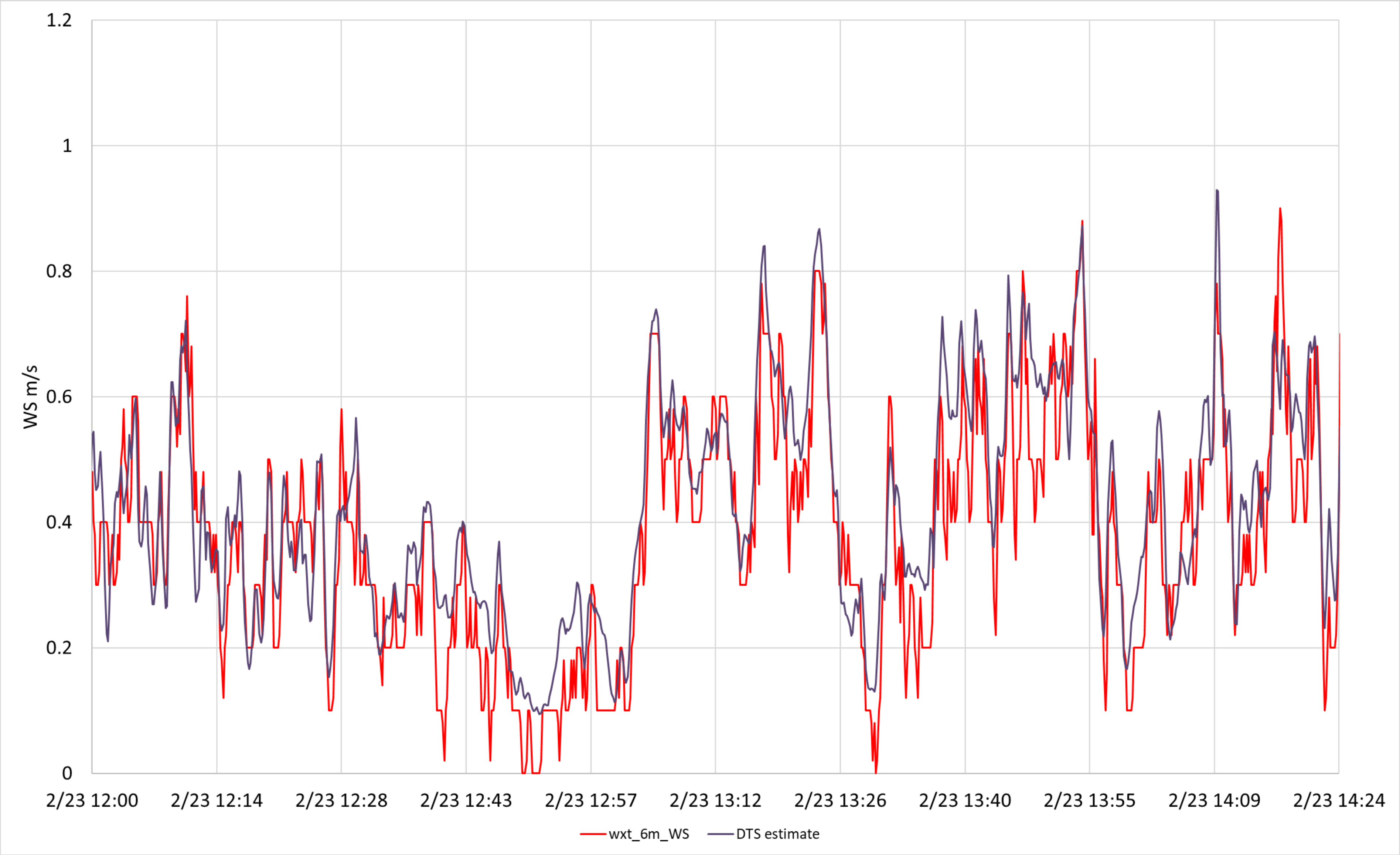
Nighttime

Average ten seconds



Daytime

Average ten seconds



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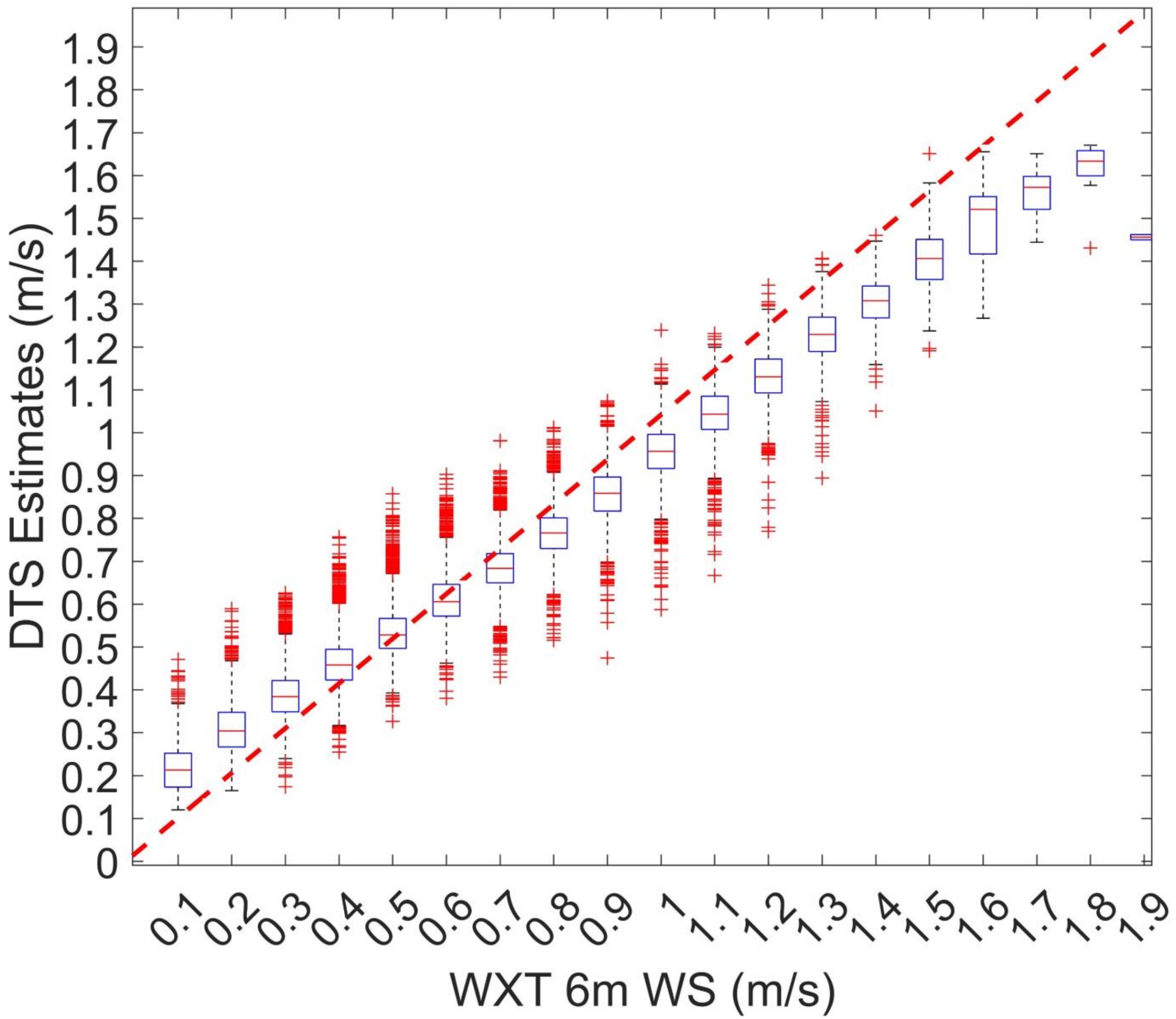


Turbulence Intensity

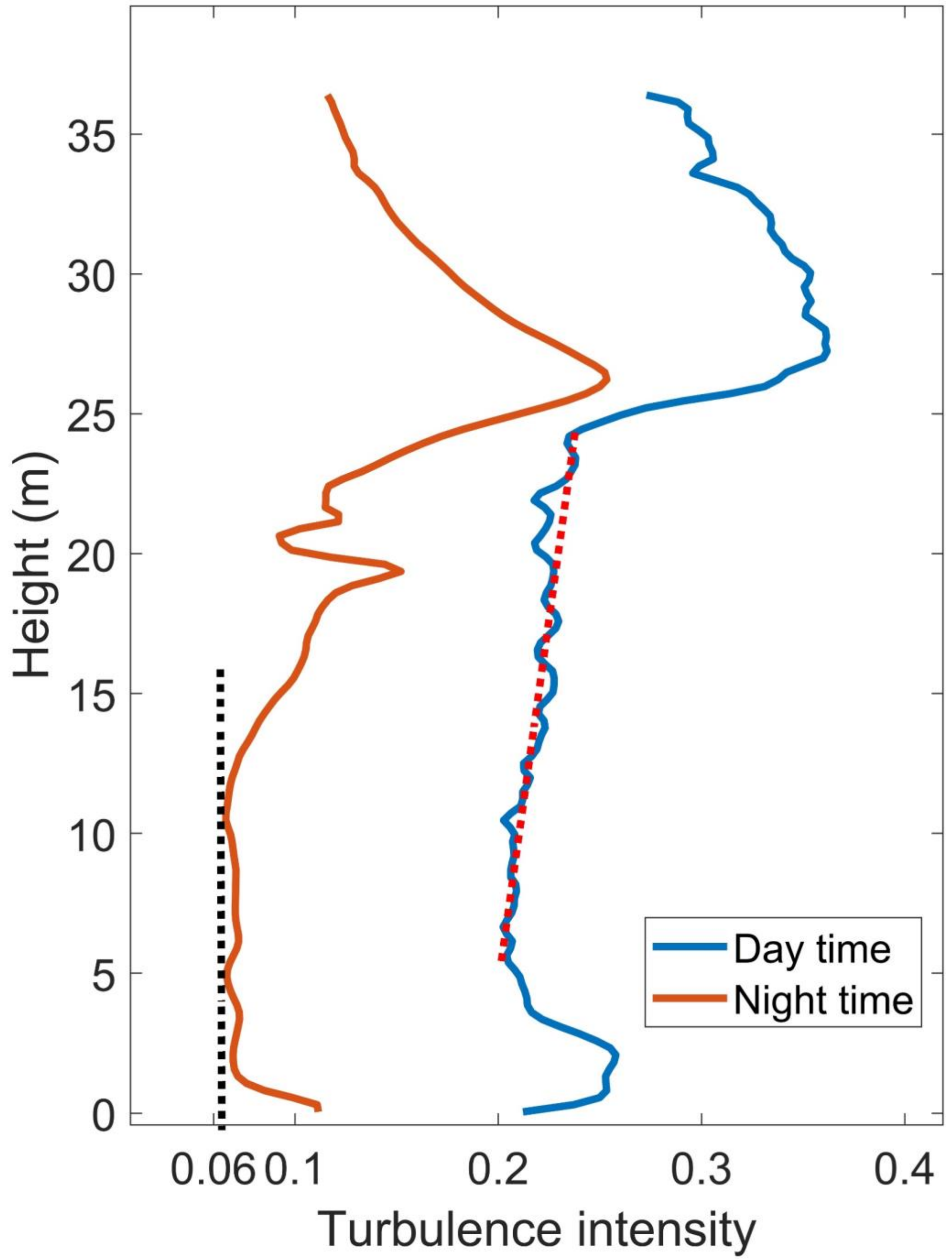
$$TI = \frac{\sigma_U}{\overline{U}}$$

- $\overline{U}$ and σ_U were evaluated every five minutes using the wind speed estimated from DTS at various heights, and the vertical profiles of TI were obtained in the daytime and nighttime.

- In the daytime, the TI under the canopy decreased monotonically with the depth of the trunk space. On the other hand, the TI at night was generally lower than in the daytime, showing a constant layer with $TI \approx 0.06$ with height near the surface, which is attributed to nocturnal advection. Therefore, we use $TI < 0.06$ as the threshold for nocturnal advection.

- The rough canopy and the area near the ground surface exhibit higher turbulence intensity due to the increased disturbances from airflow passing through. This phenomenon diminishes with distance from the rough surface, and is well represented by the turbulence intensity profile.

- During the day, the fiber was located on the leeward side of the house, hence the data for the first 5 meters were disturbed.



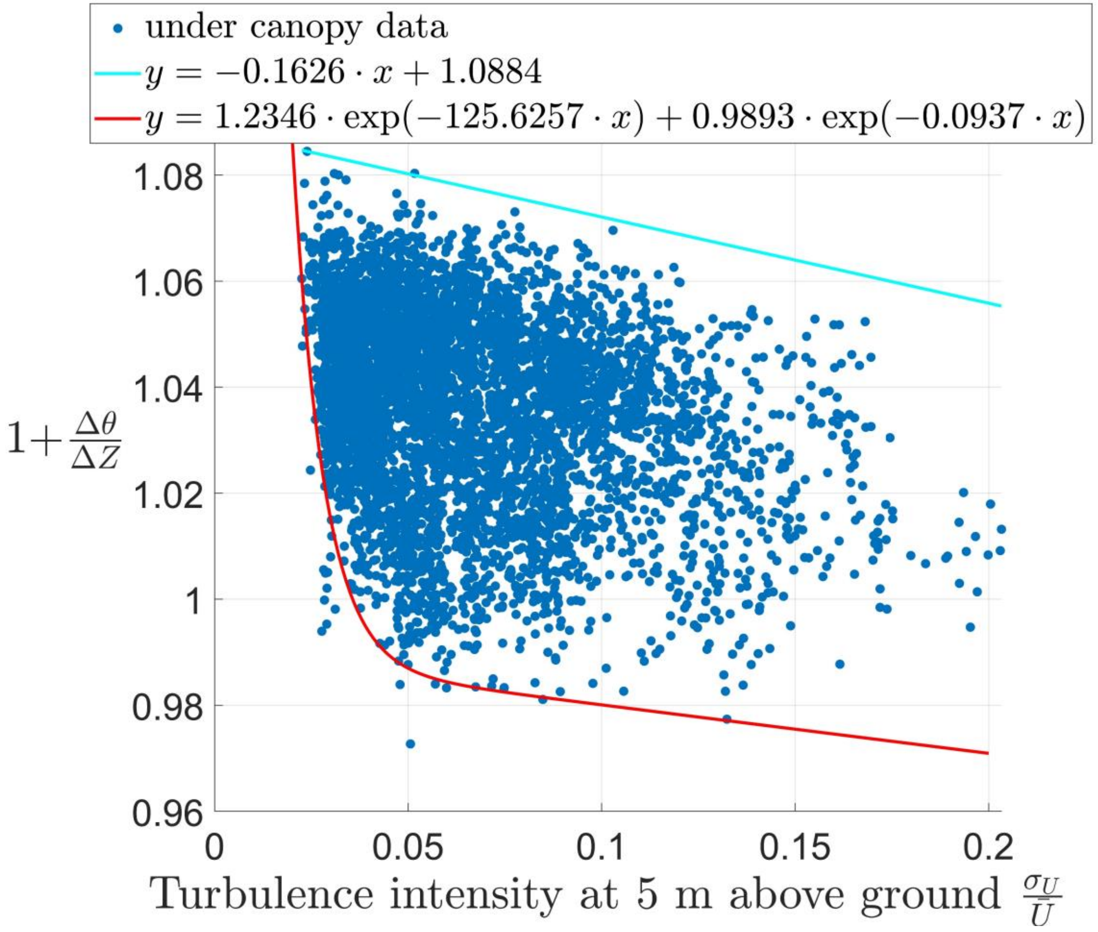
Temperature gradient

- The scatter plot visually represents the relationship between turbulence intensity and temperature gradient. The Pearson correlation coefficient for this dataset is approximately -0.277, indicating that the temperature gradient decreases slightly as turbulence intensity increases, although the relationship is not strong.

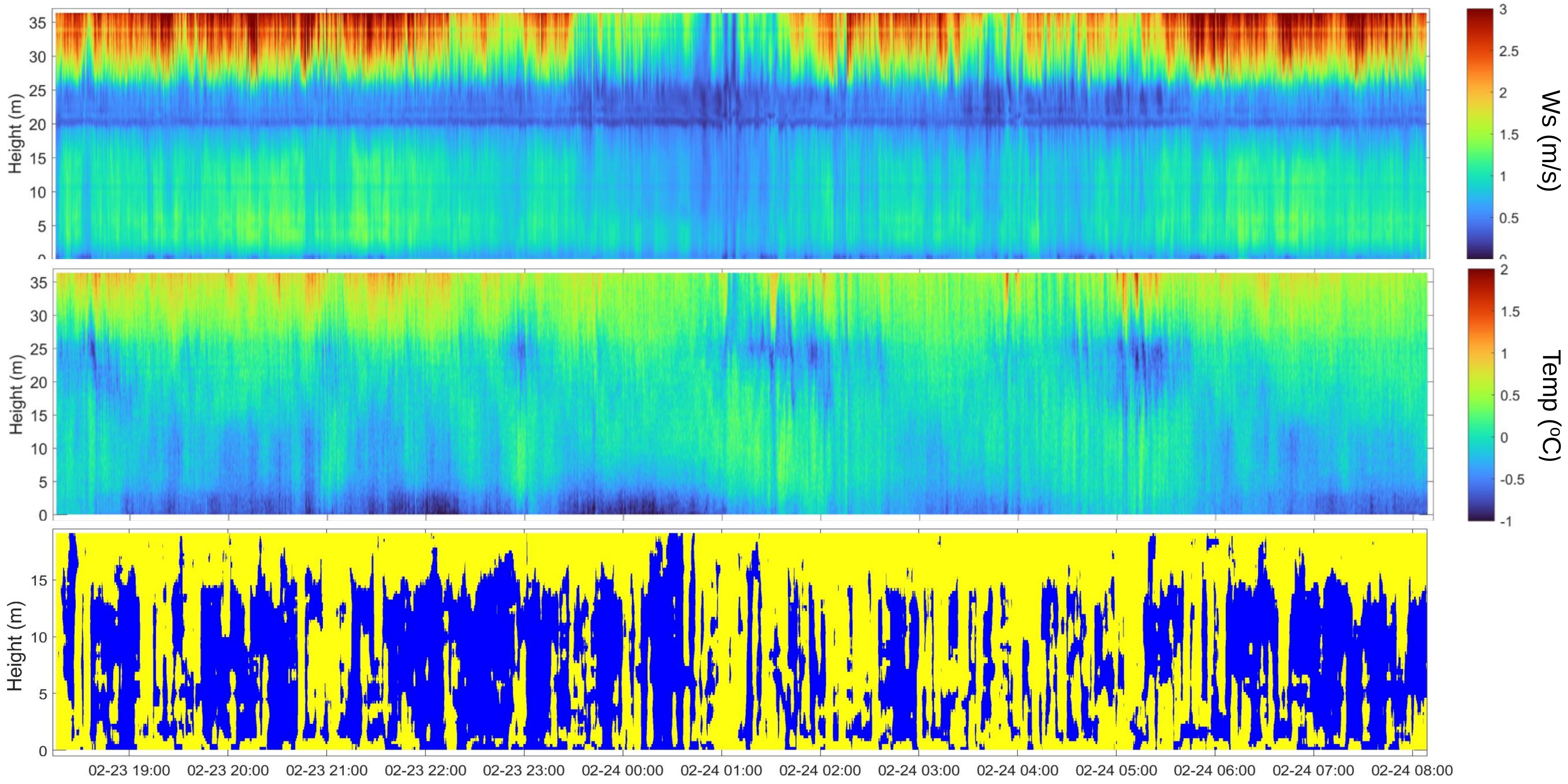
- When the turbulence intensity is less than 0.05, the lower bound of the temperature gradient varies with the turbulence intensity, indicating that at this time, the turbulence cannot effectively mix the gases. When the intensity exceeds 0.05, the relationship between the two declines. The upper bound of the temperature gradient decreases with increasing turbulence intensity.

- Linear regression is using the overall data fitting, with the starting point set at the place of maximum gradient.

- Exponential regression is using the minimum values of the temperature gradient in different turbulence intensities for fitting.



The nocturnal advection accounted for approximately 42% of the nighttime from February 23 to 24.



(a) Wind speed profile estimated by DTS. (b) Vertical profile of the deviations of potential temperature measured by DTS, indicating the vertical un/uniformity in the temperature profile at different times. (c) Turbulence intensity under the canopy, with blue for $TI<0.06$, and yellow for $TI \geq 0.06$.

Conclusions

- Using the temperature difference between heated and unheated fiber optical can effectively estimate the wind speed value.
- Quantifying the turbulence intensity at different heights through wind speed profiles provides different methods for analyzing nighttime advection.
- Turbulence intensity under the canopy exhibits a negative correlation with temperature gradient changes and reflects a similar constant to the turbulence intensity profile.
- Applying Distributed Temperature Sensing (DTS) in complex forest environments allows for effective assessment of nighttime canopy temperature dynamics and airflow patterns.