114 年第三十九屆天氣分析與預報研討會

分散式光纖溫度感測技術在大氣觀測的應用

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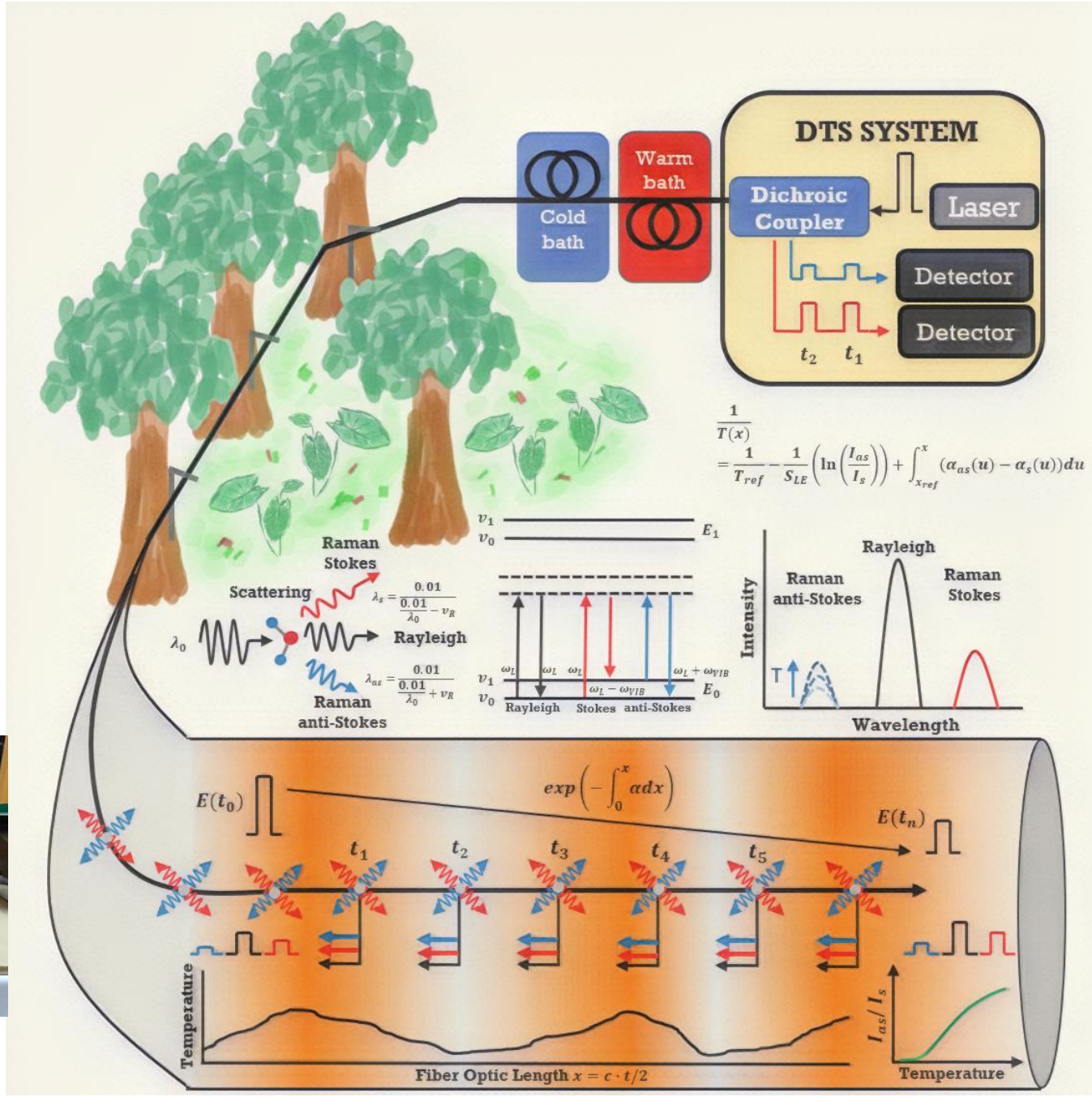
Outline

- **Introduction Fiber Optic Distributed Temperature Sensing**
- **Characteristics of Air Temperature Measurements**
- **Wind Speed Estimation**
- **Application in Forests**

Introduction Fiber Optic Distributed Temperature Sensing

(Model M ULTIMA, Silixa, London, UK)



Types of fiber optics used

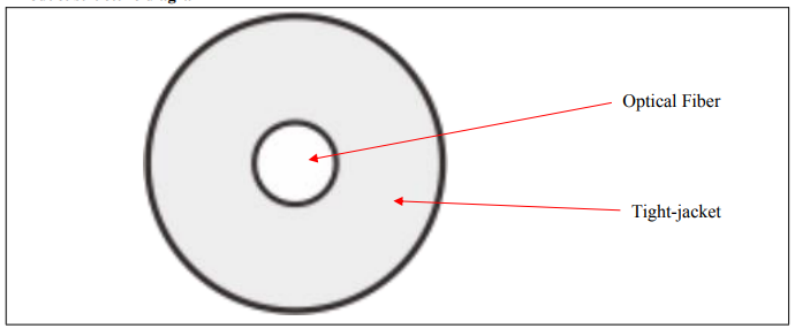
FO-STL

Product name:	Stainless steel tube optical cable	
		
Item	Parameter	Remarks
Outer Steel Tube Material	304	
Outer steel pipe diameter (mm	1.2±0.02	
Outer steel pipe wall thickness (mm)	0.18±0.05	
Ointment Filling Rate	30%	
Fiber count 2	2	
Fiber type	OM3 50/125 multimode	
Fiber attenuation 1300nm	<0.6dB/km	
Fiber attenuation 850nm	<2.8dB/km	
Operating temperature	-40~80℃	
Tensile force (long term/short term)	250/500N	
Flattening cursh force (long term/short term)	2000/4000N	
Weight	4.8kg/km	
Packaging	4km/400mm/DRUM	

FO-PVC

1 Core Optical Fiber Cable

Product structure diagram



Construction

1. Optical Fiber
2. Tight-jacket Diameter：0.9±0.05mm

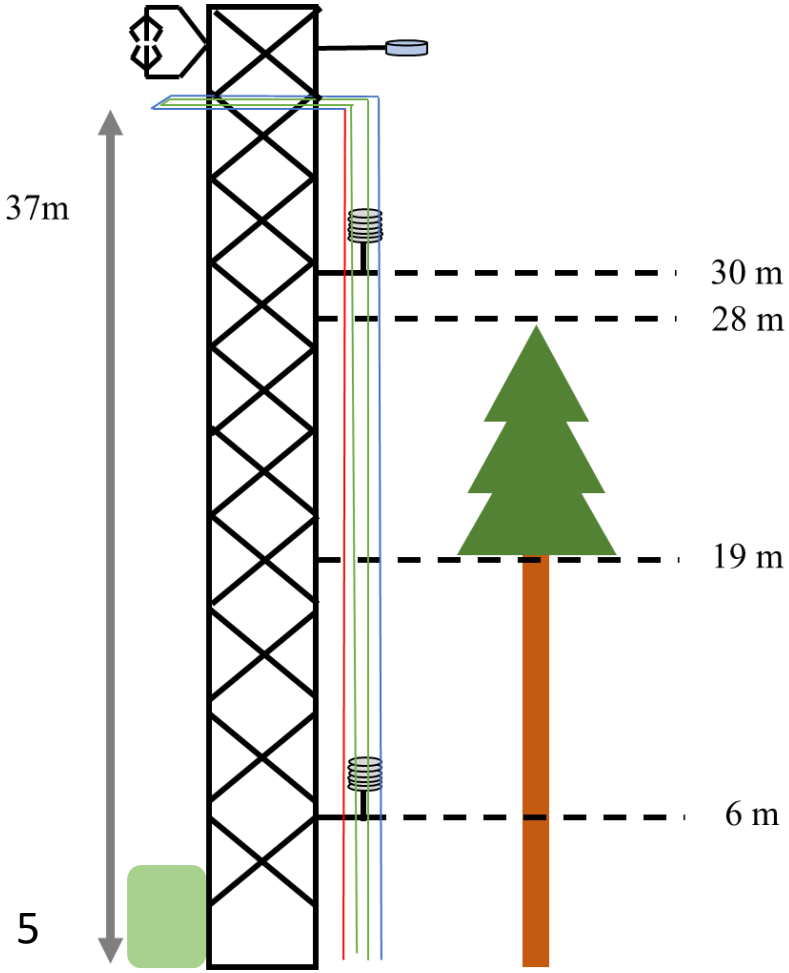
Parameters of fiber

Optical fiber type	Unit	SM G652D	SM G657A2	MM 50/125	MM 62.5/125	MM OM3
Waveband	nm	1310/1550	1310/1550	850/1300	850/1300	850/1300
Attenuation	dB/km	0.36/0.24	0.36/0.24	3.5/1.5	3.5/1.5	3.5/1.5

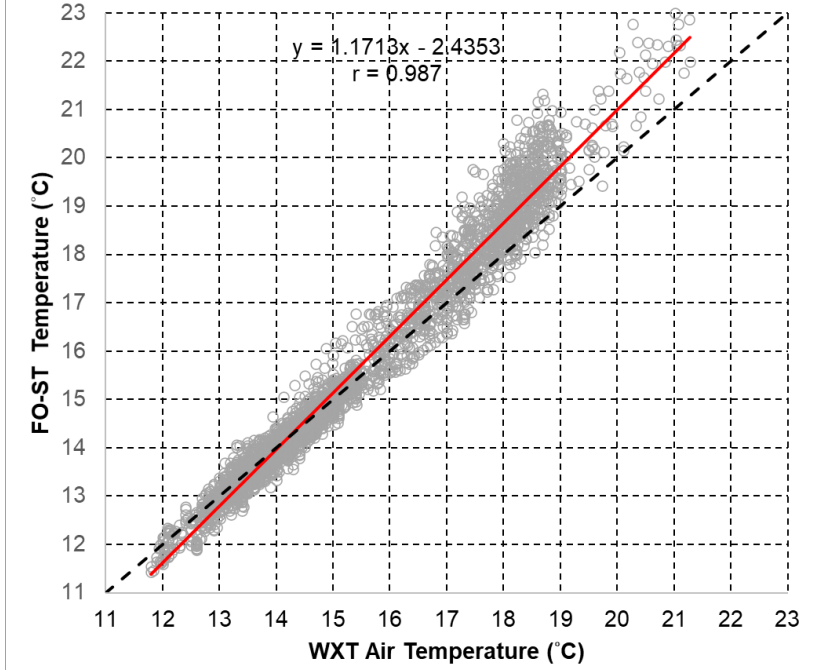
Product parameters

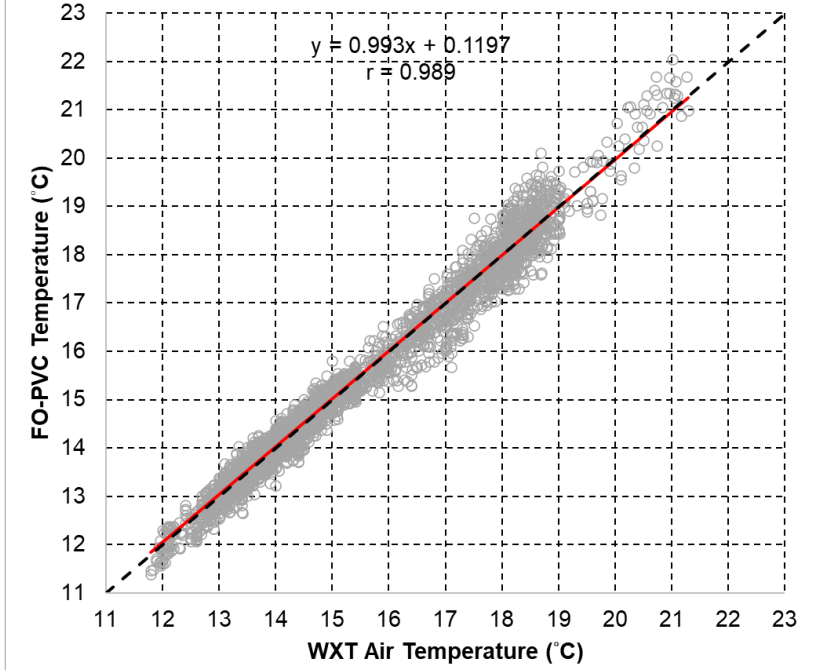
Performance	Long-term	Short-term
Min. Bending Radius	20mm (Dynamic)	10mm(Static)
Storage and operating temperature	−20℃ − +70℃	

Characteristics of Air Temperature Measurements

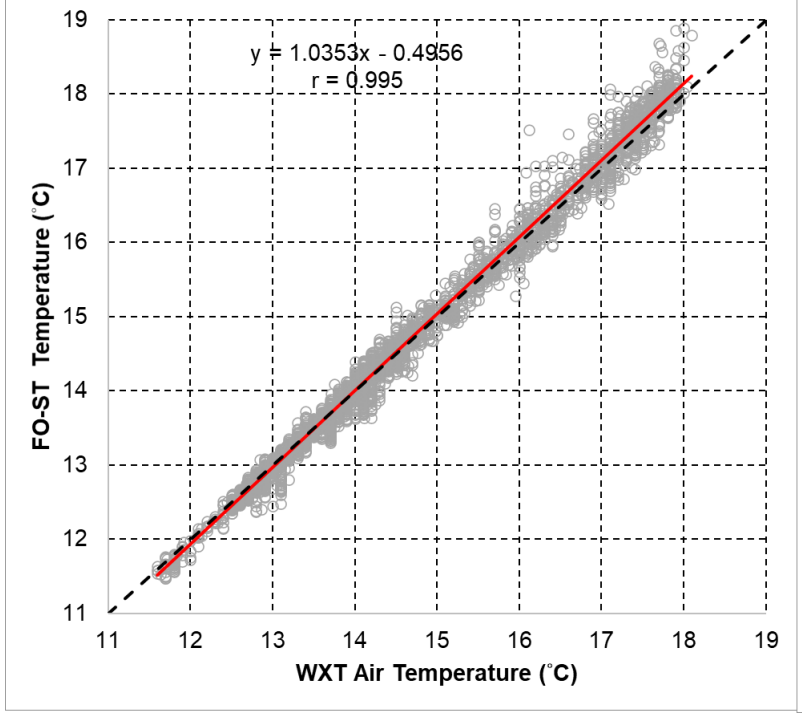


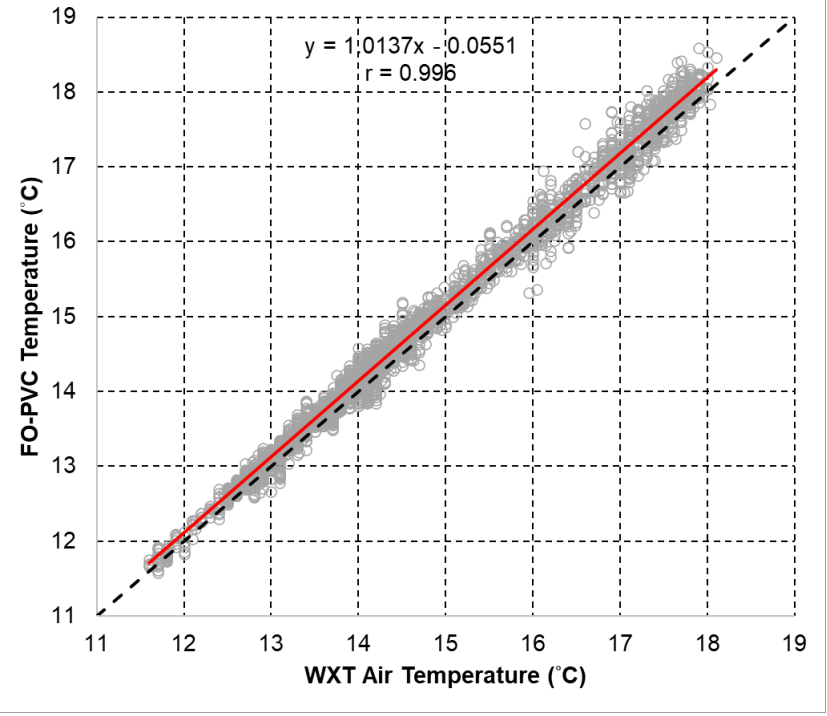
Above Canopy



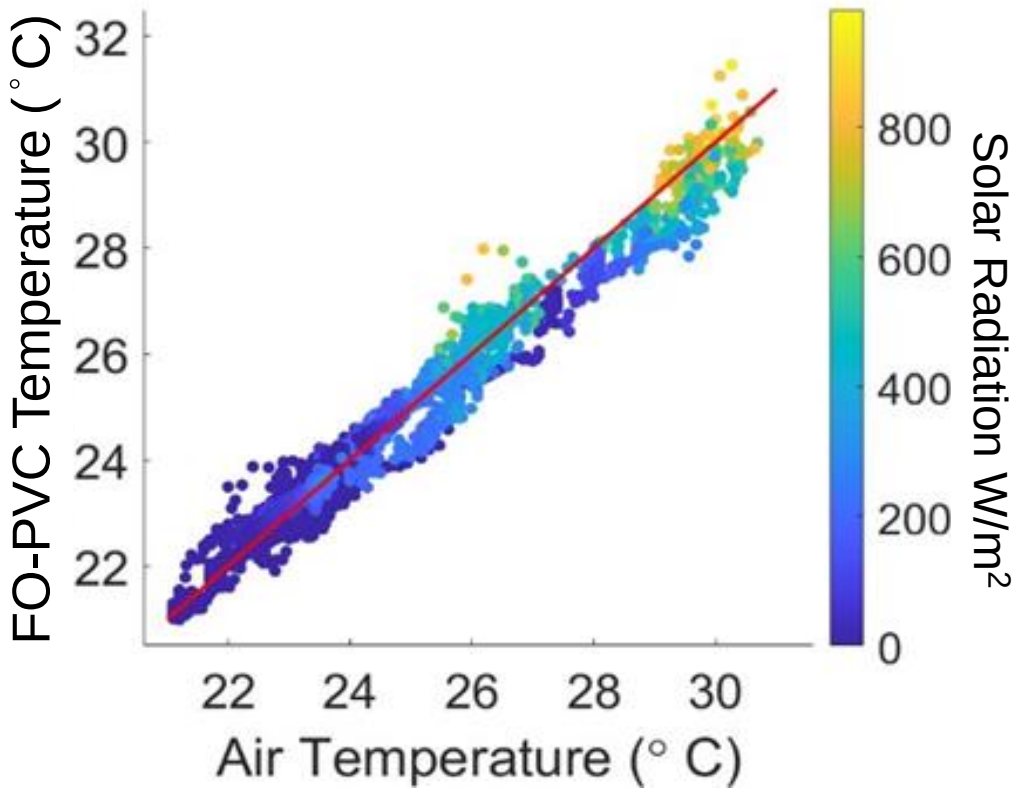


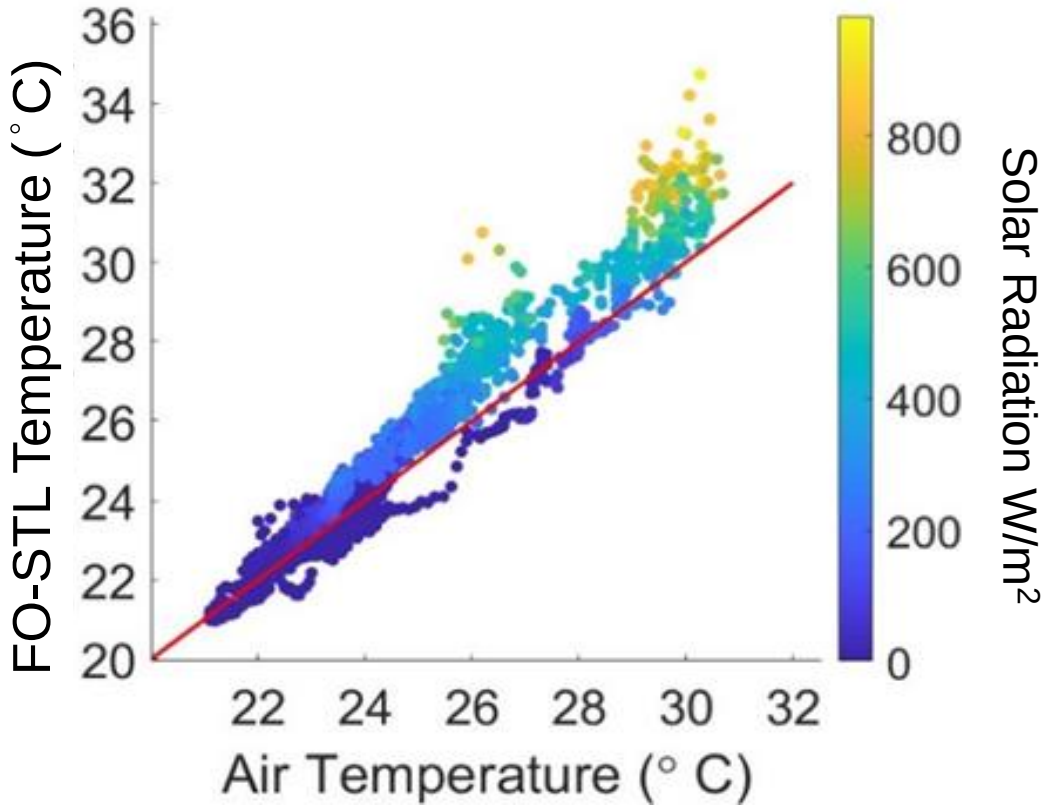
Within Canopy



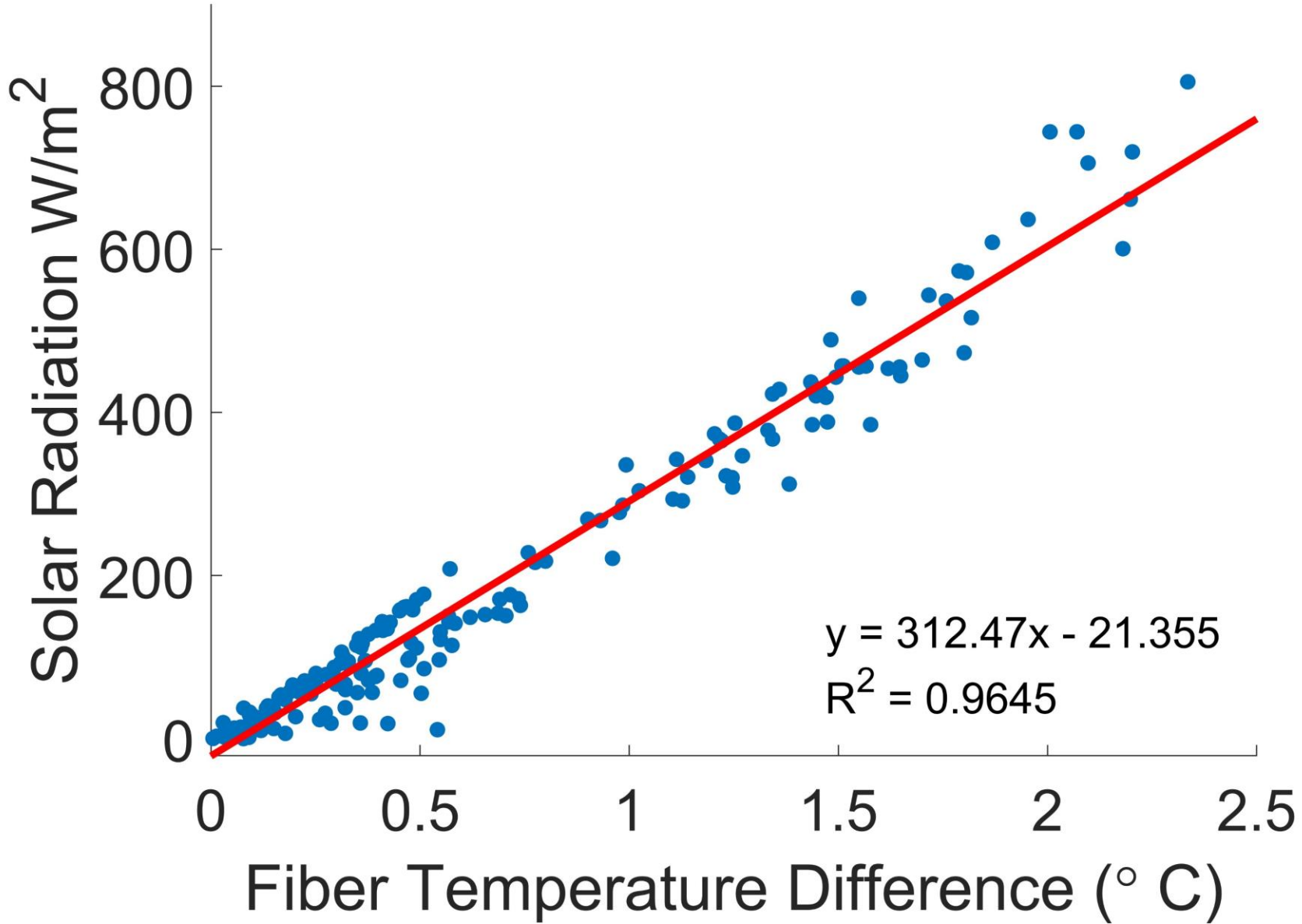


Effect of Solar Radiation

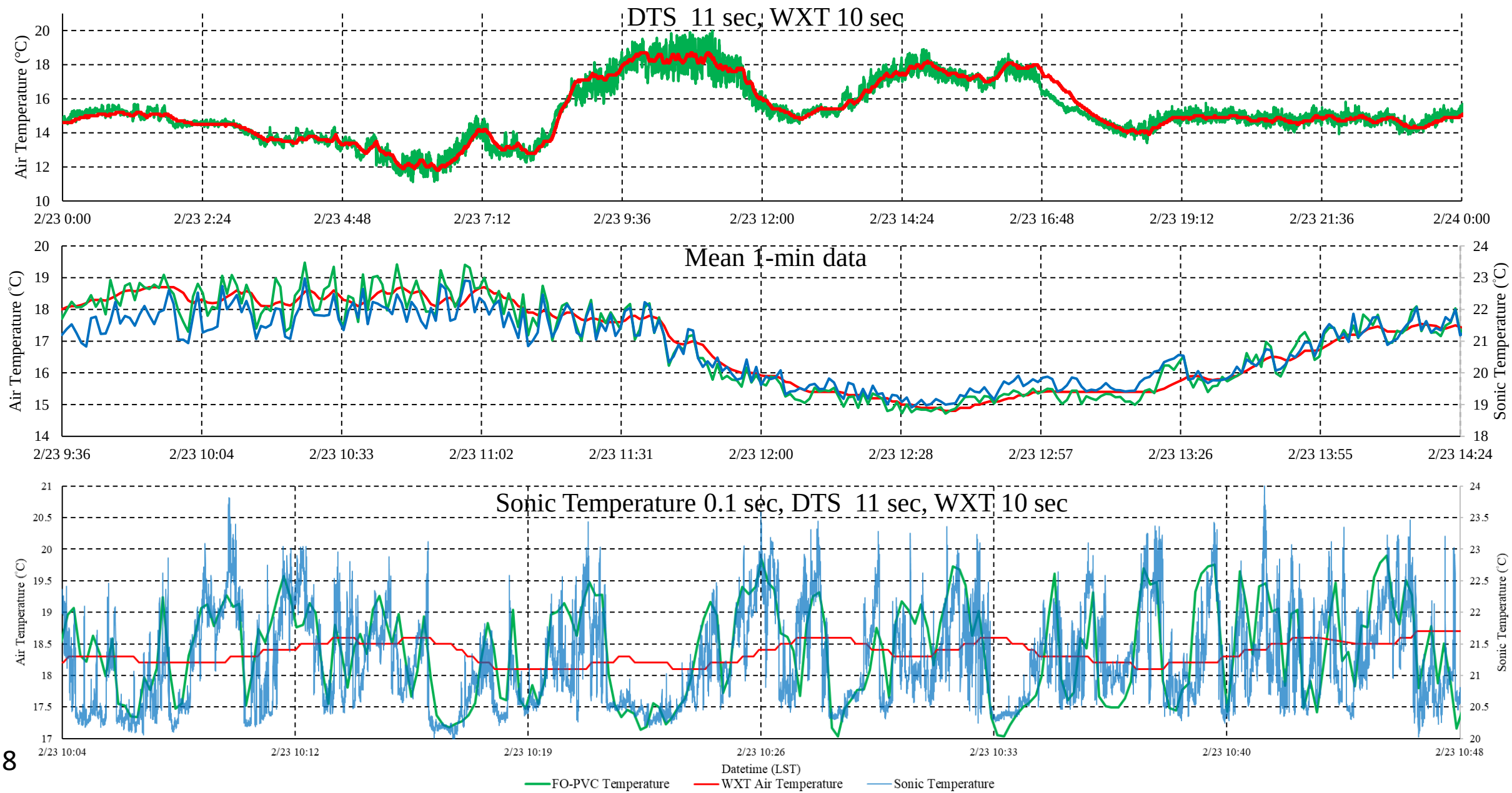




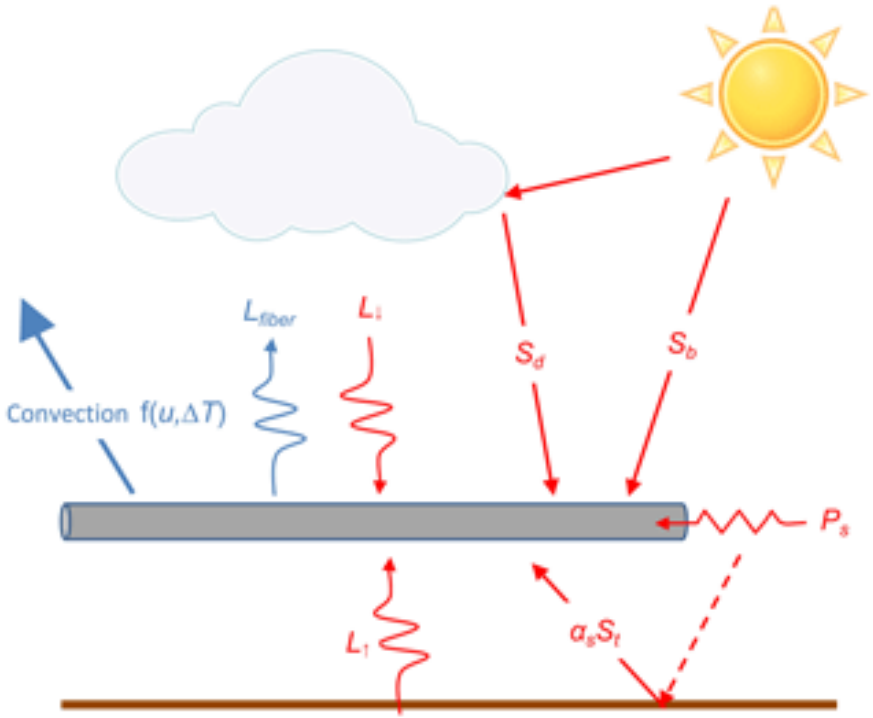
Solar Radiation and Temperature Difference Between Two Types of cables



Variation of Air Temperature Over Time

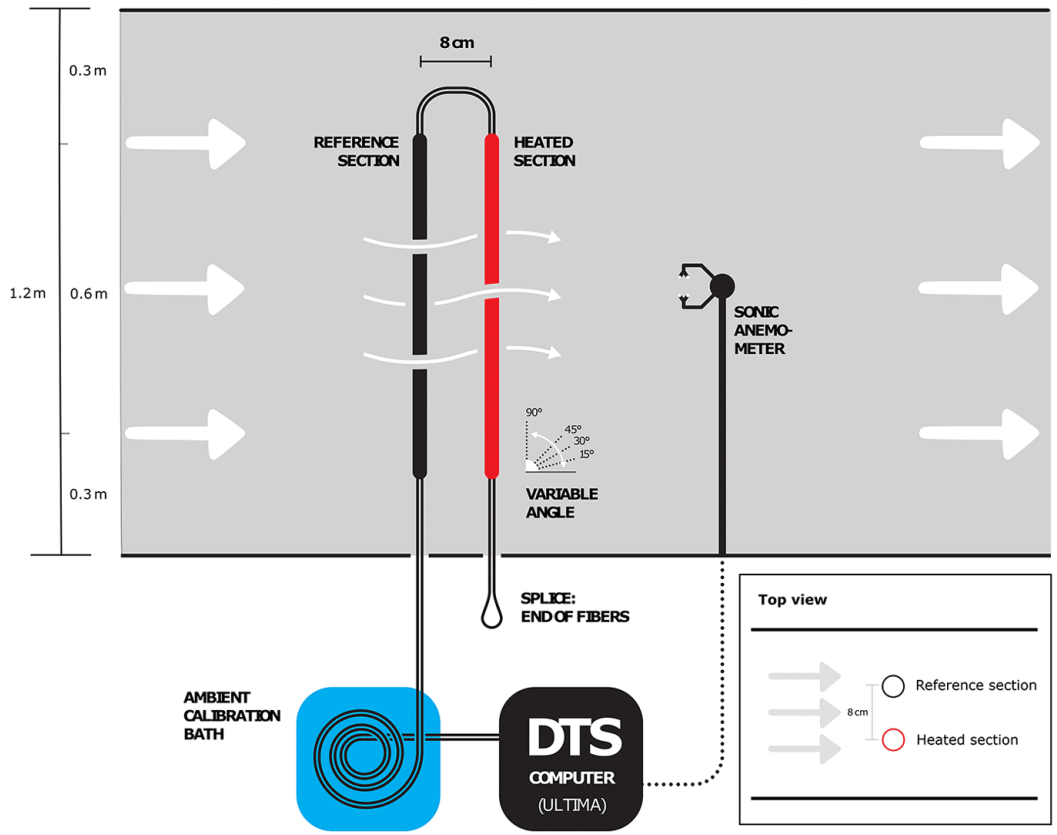


Wind Speed Estimation Using DTS



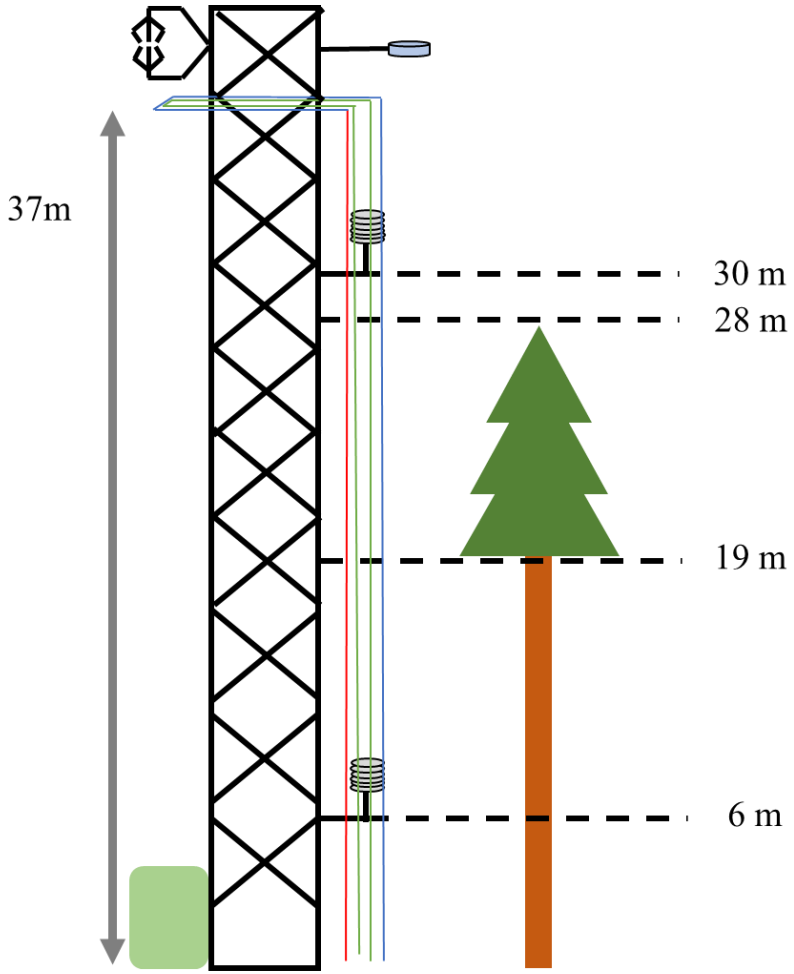
$$U_N = \left(\frac{0.5\ P\ \pi^{-1} r^{-1} + \left(\bar{S}_b + \bar{S}_d + \rho\bar{S}_t\right)(1-a) + \left(\bar{L}_\downarrow + \bar{L}_\uparrow\right)\varepsilon - \varepsilon\sigma T_s^4 + \frac{1}{2} c_p \rho r \frac{dT_s}{dt}}{-C(2r)^{m-1} Pr^n \left(\frac{Pr}{Pr_s}\right)^{\frac{1}{4}} K_A v^{-m} (T_s - T_f)} \right)^{\frac{1}{m}}$$

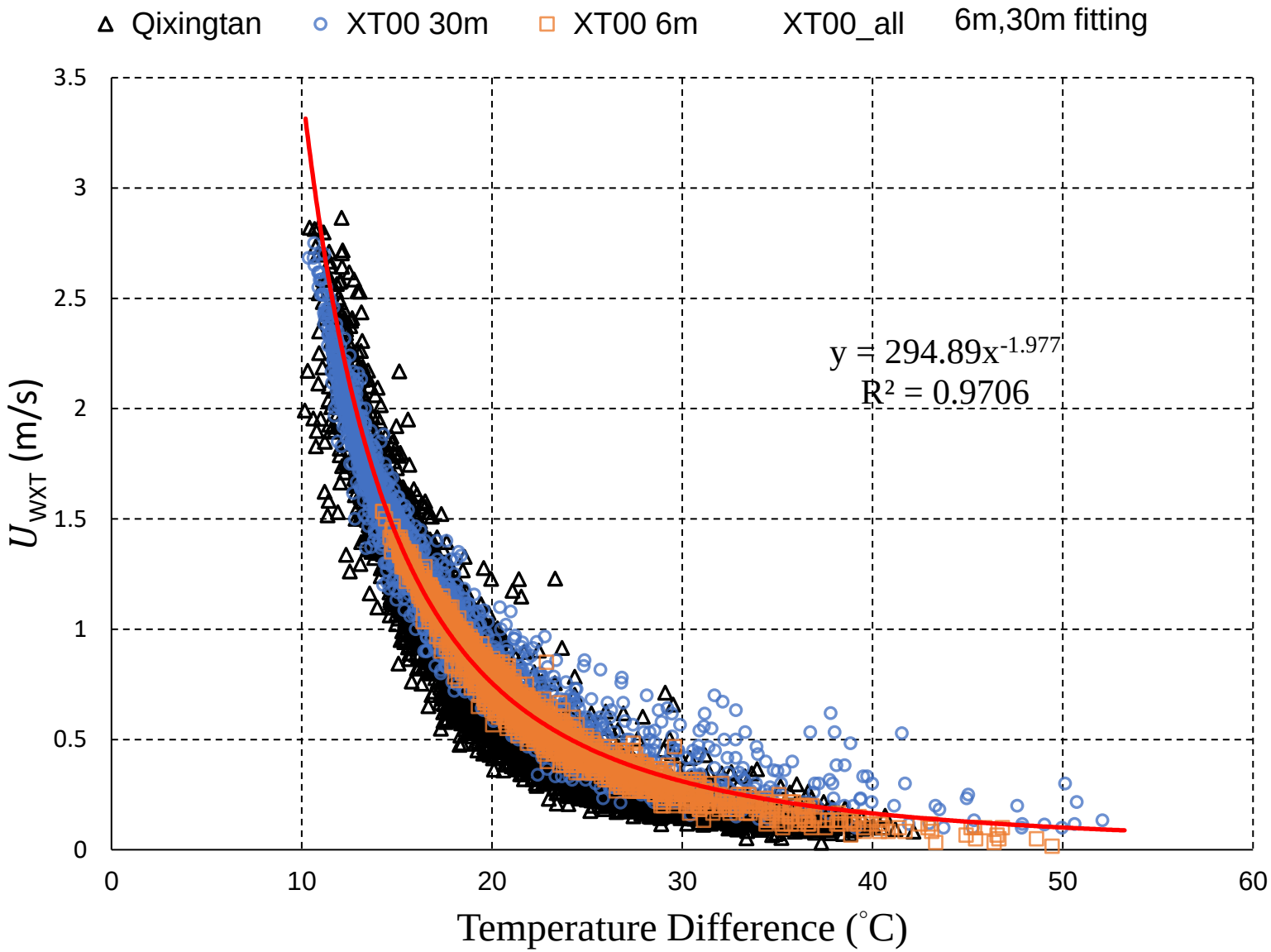
(Sayde et al., 2015)



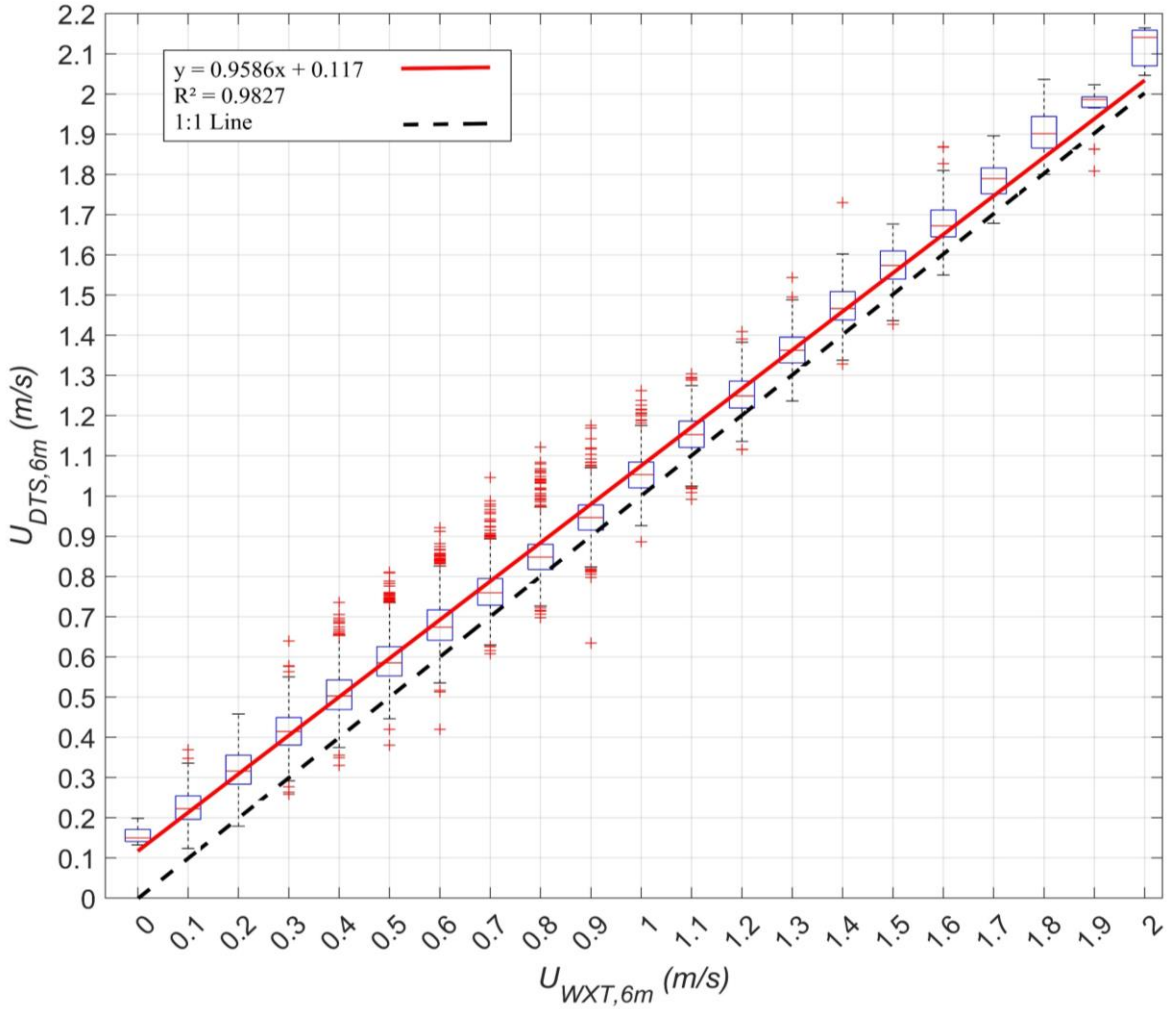
(van Ramshorst et al., 2020)

Relationship between wind speed and temperature difference





Accuracy of Estimating Wind Speed



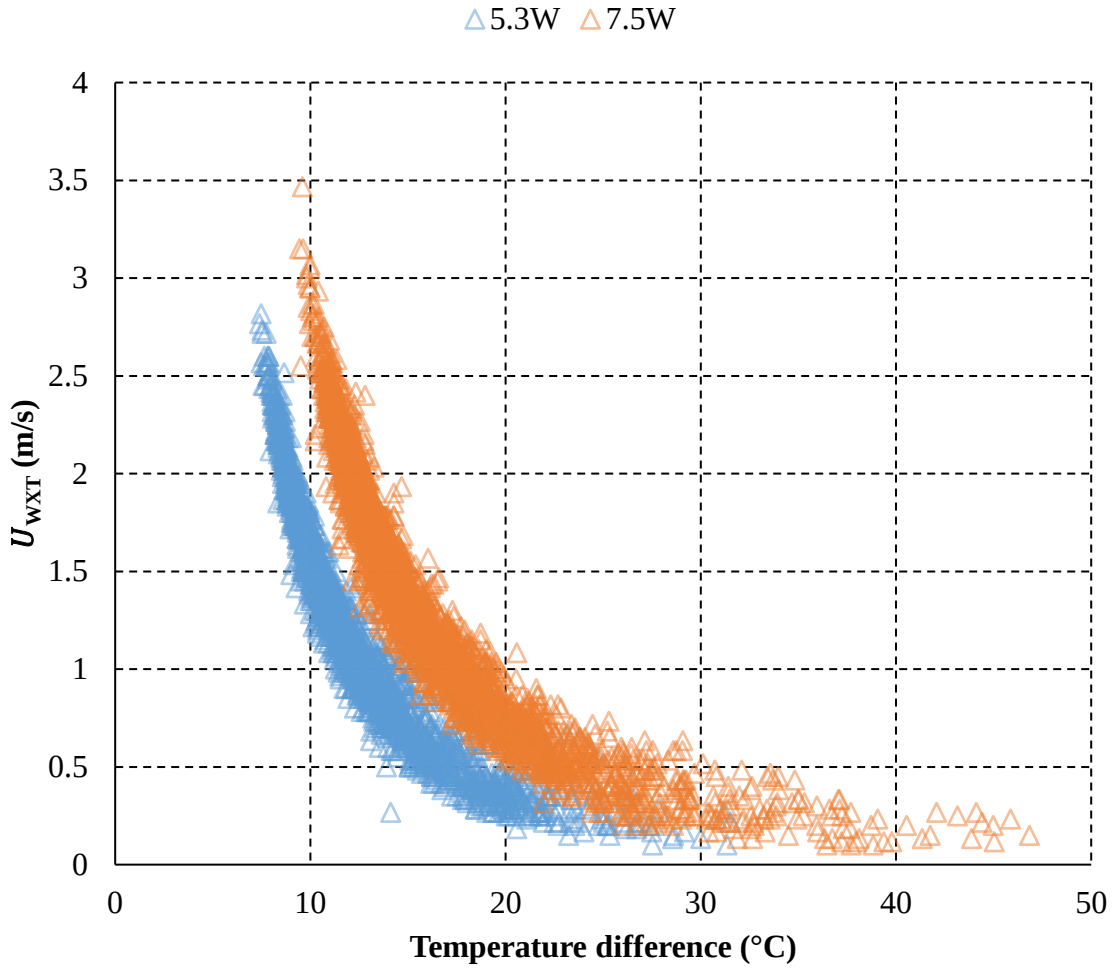
$$y = 294.89x^{-1.977}$$

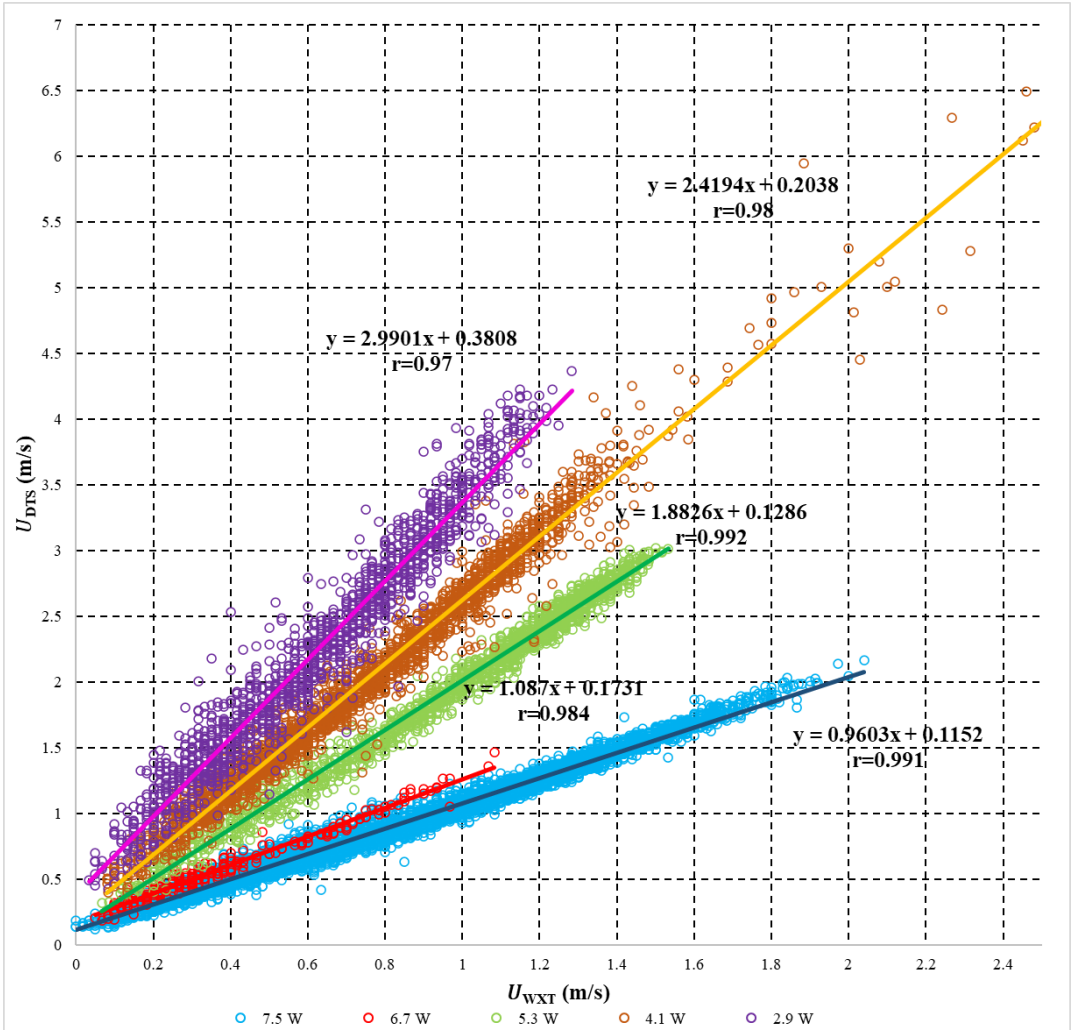
Average of the range 25%-75% is about 0.07 m/s

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|U_{\text{n DTS,6m}} - U_{\text{n WXT,6m}}\right|$$

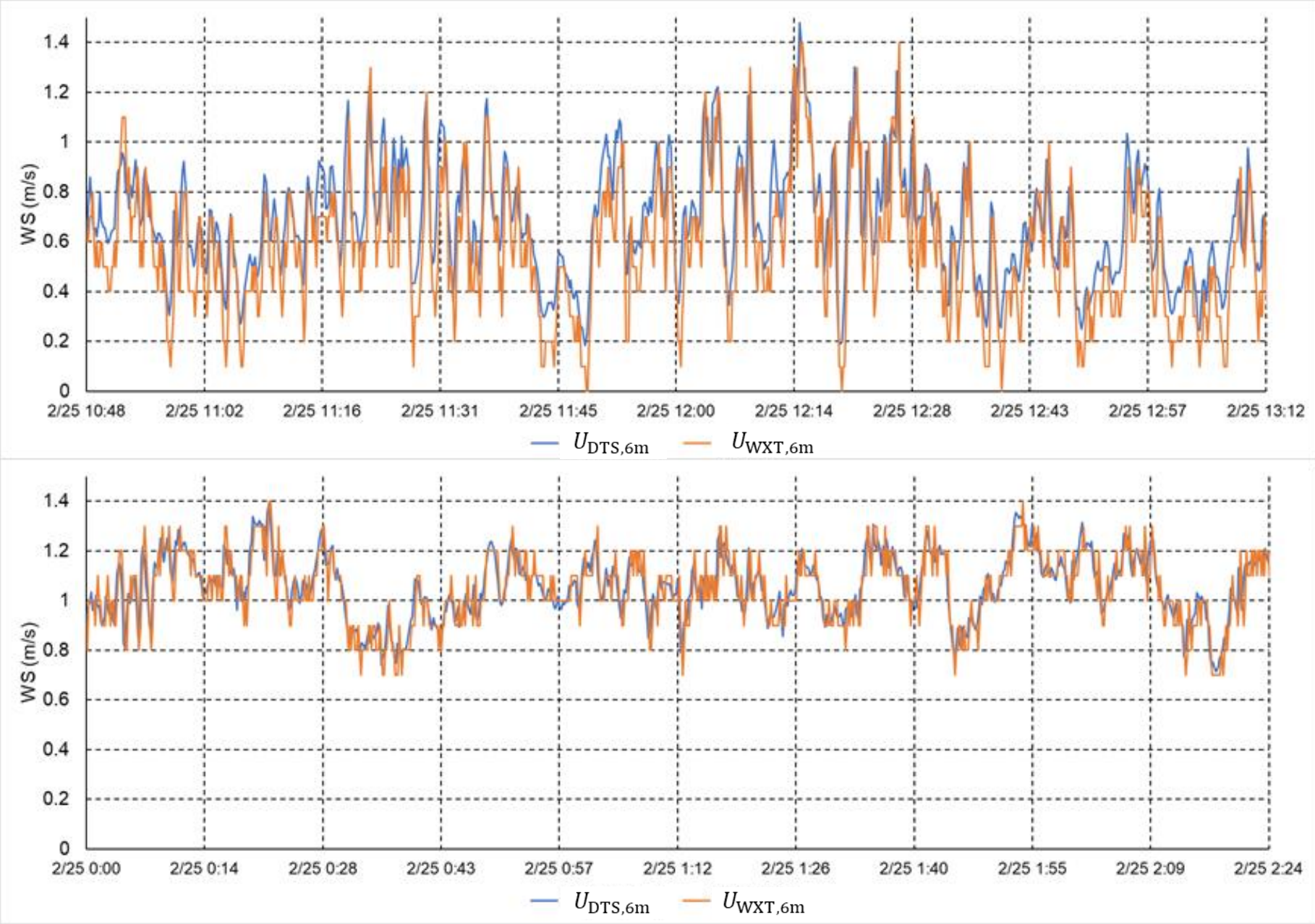
WS(m/s)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
MAE(m/s)	0.16	0.13	0.13	0.12	0.11	0.10	0.09	0.07	0.06	0.06	0.07	0.06	0.06	0.07	0.08	0.09	0.09	0.09	0.10	0.09	0.10

DTS wind speed and WXT for different heating powers

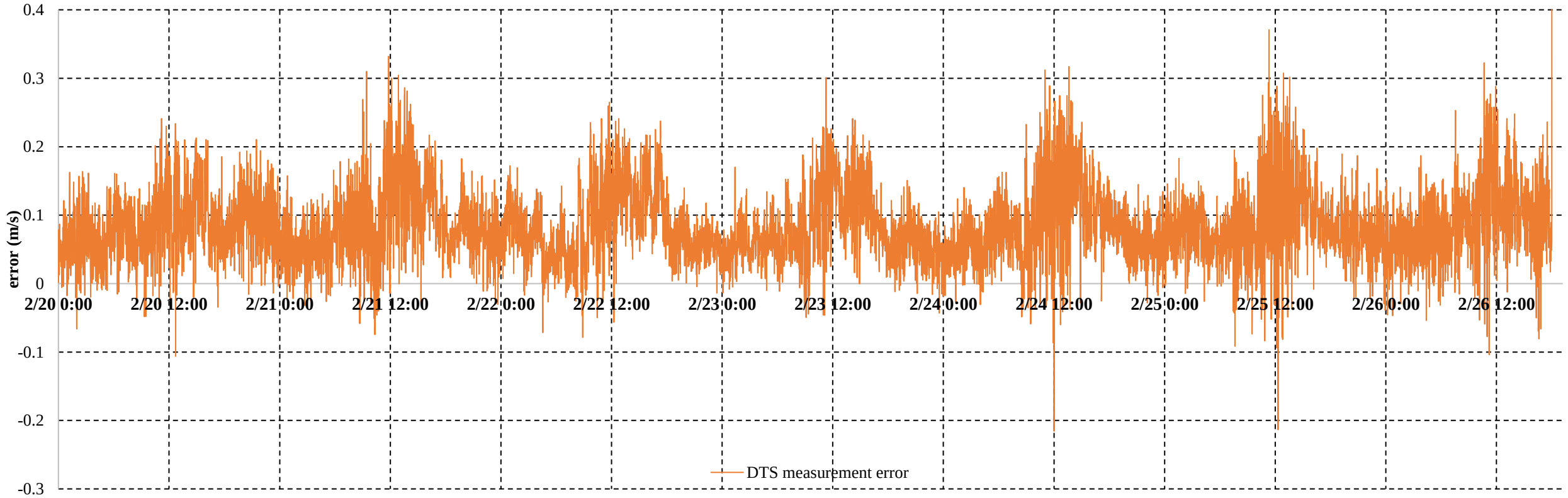




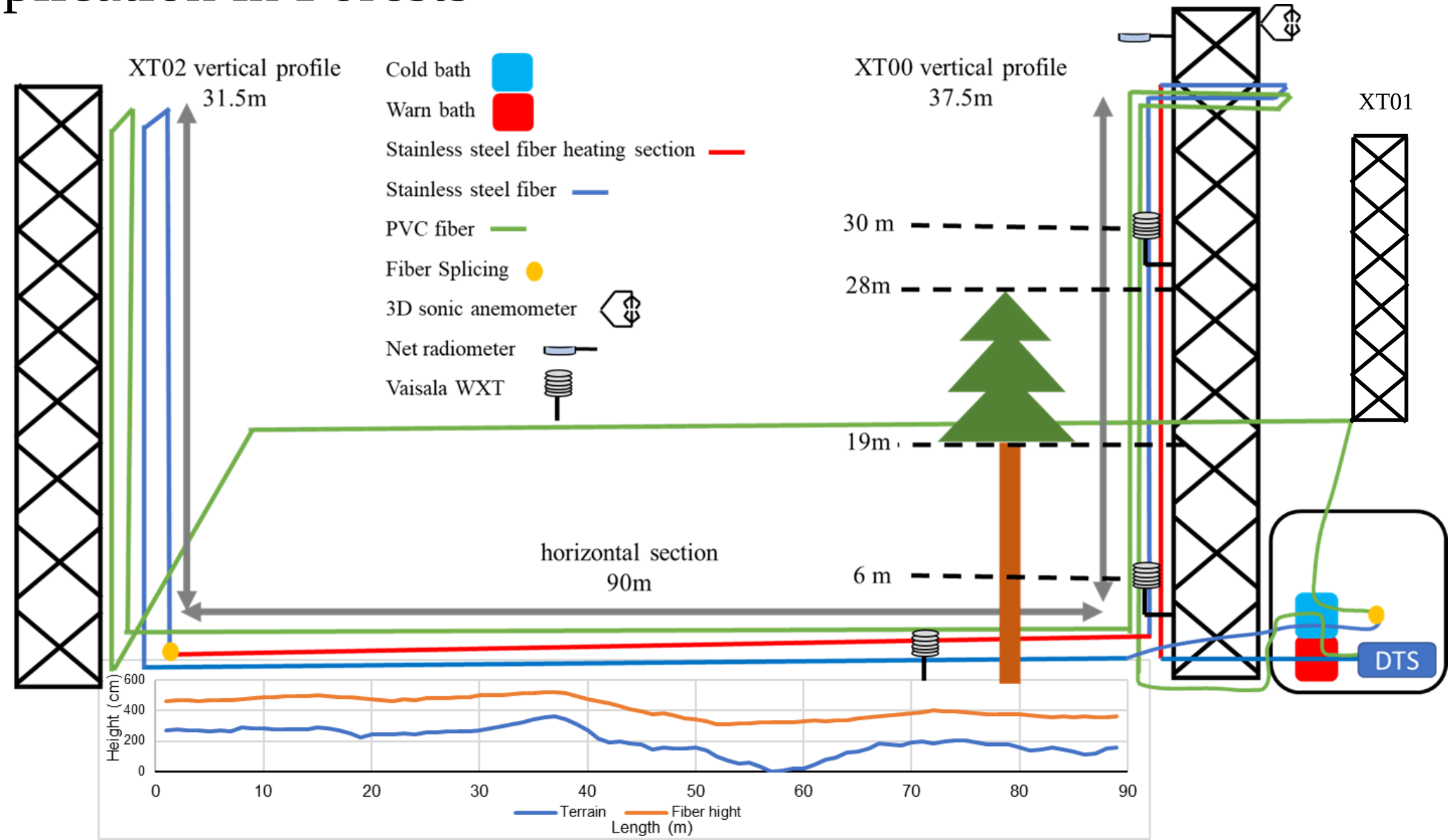
Examples of temporal variations in $U_{\mathrm{WXT,6m}}$ and $U_{\mathrm{DTS,6m}}$ on a ten-second average



Variation of Error Over Time

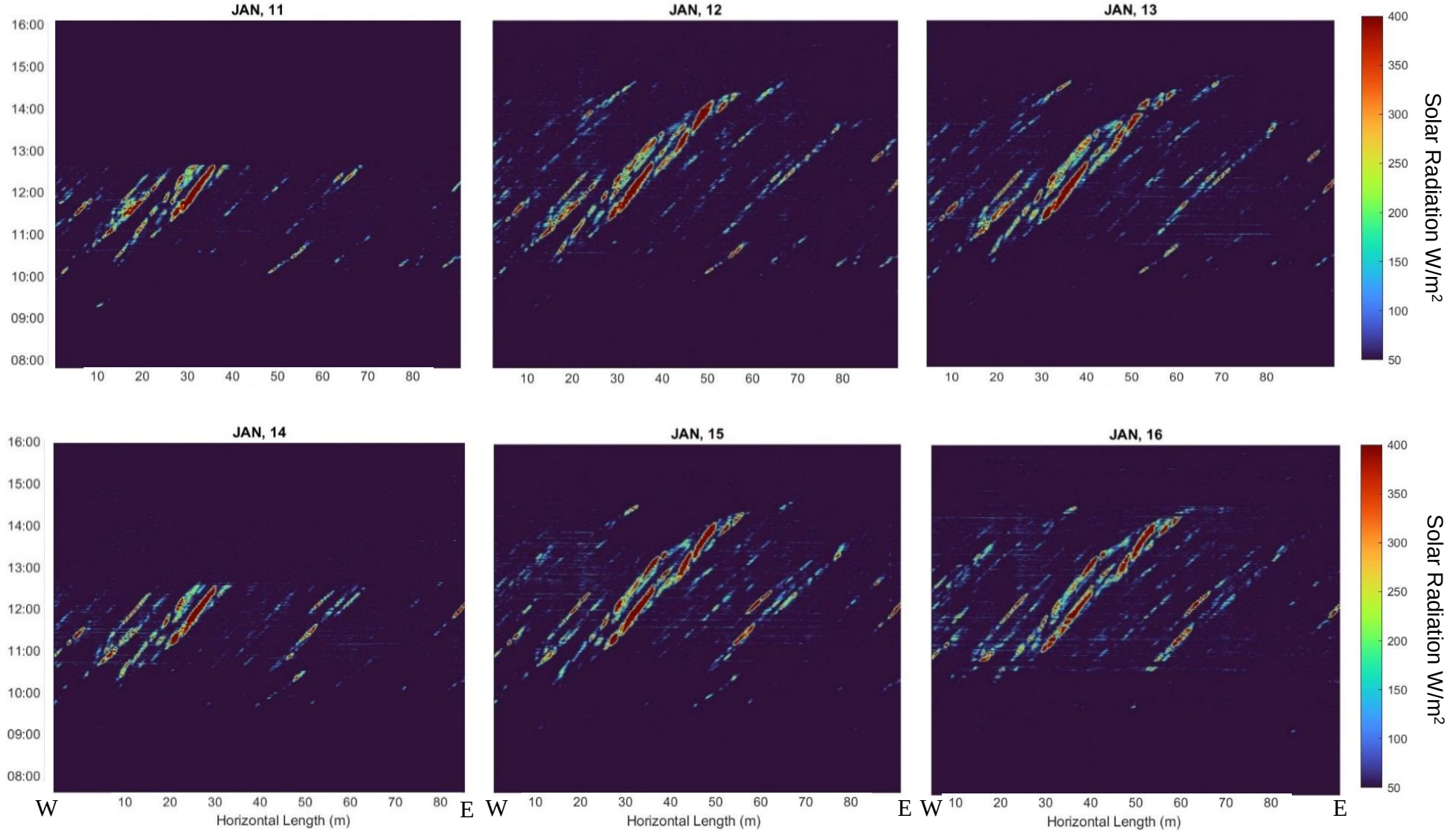


Application in Forests

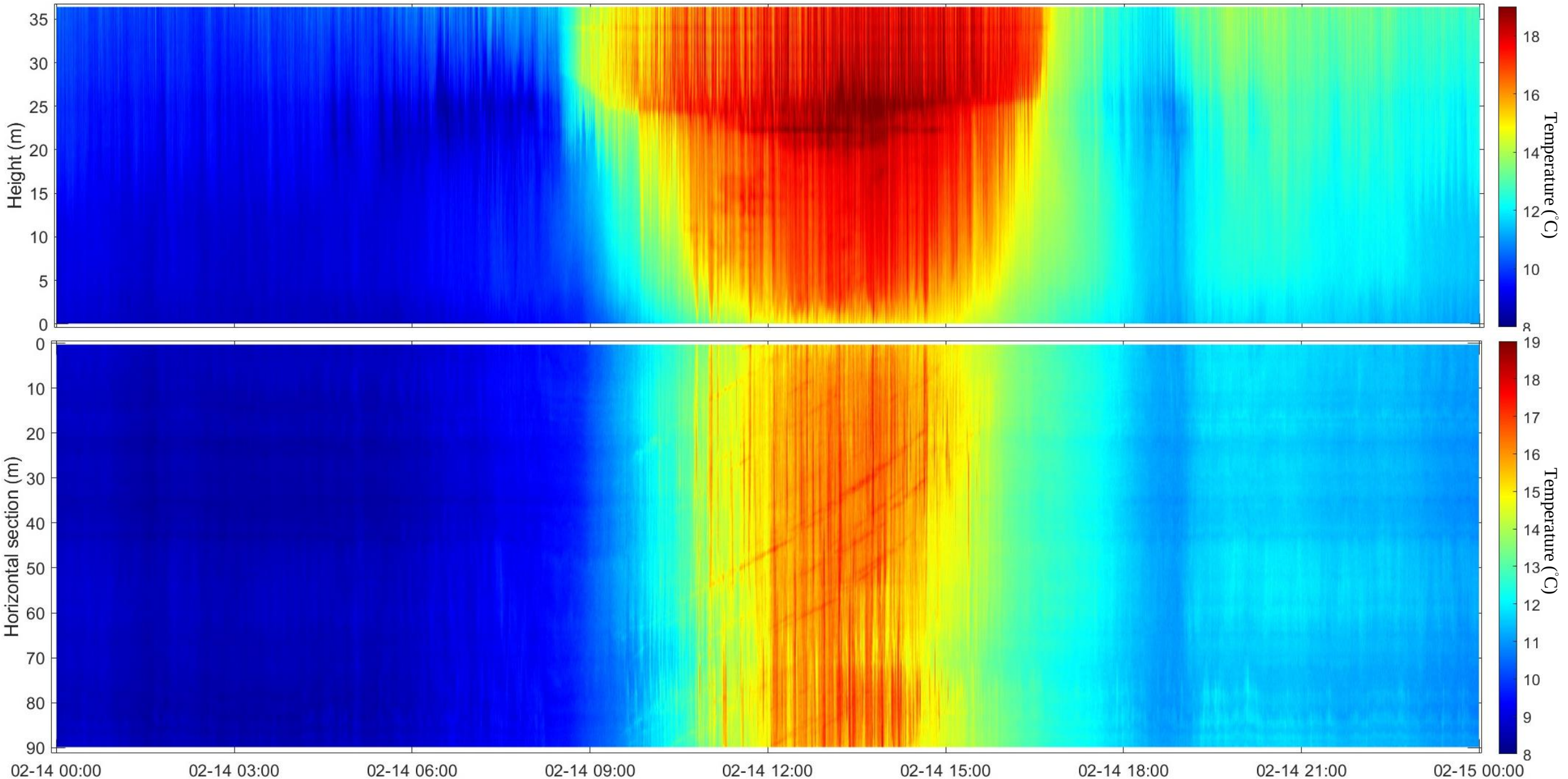



Sunfleck Distribution on the Forest Floor

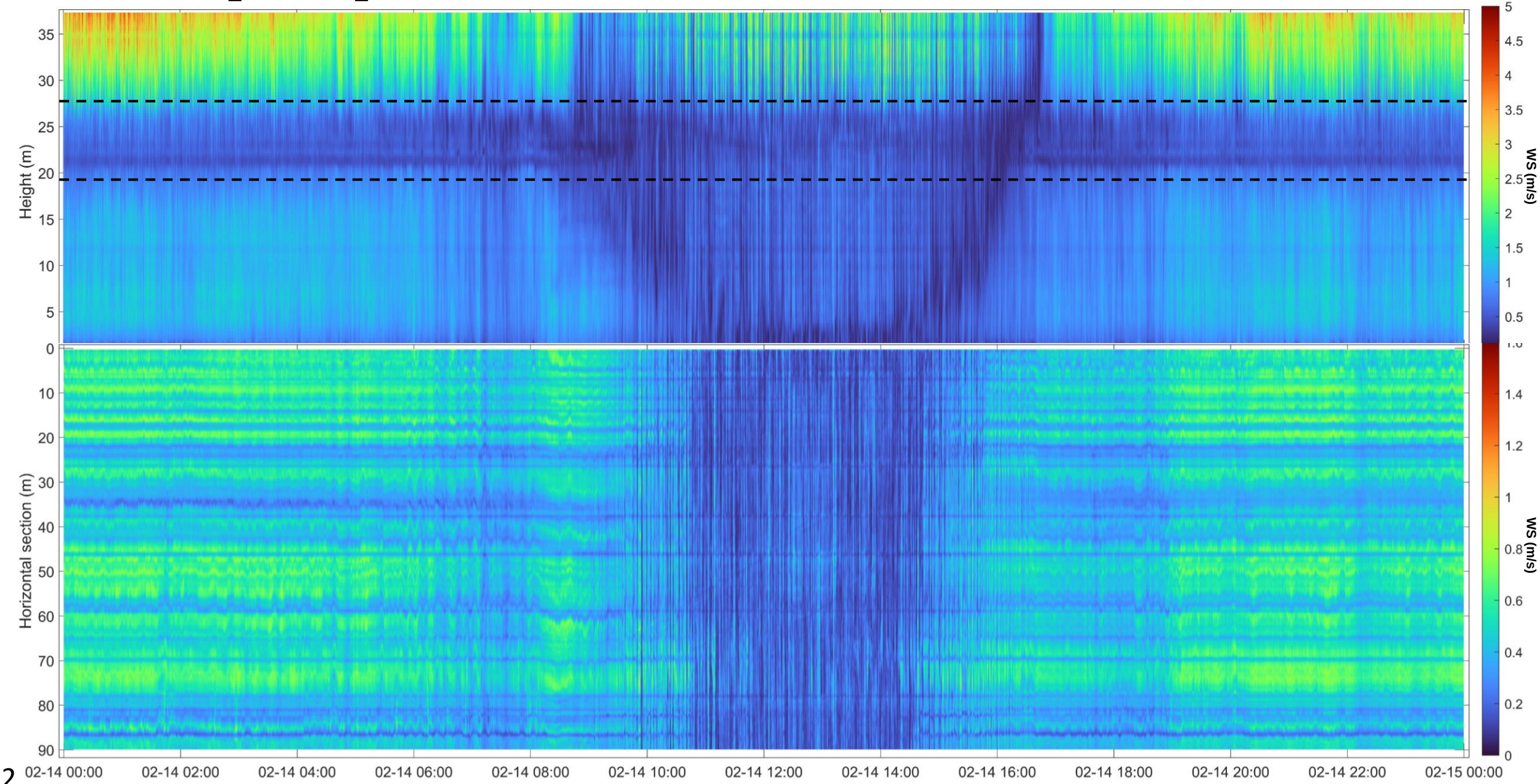
Spatio-Temporal Distribution of Sunflecks



Temperature profile



Wind speed profile



Air Temperature Responses of Fiber Optic Cables

Significant differences in temperature responses using fiber optics with different coatings were observed.

FO-STL Cables:

1. Highly sensitive to changes in solar radiation.
2. Faster heat conduction due to metallic materials.
3. Larger diameter compared to FO-PVC cables.

FO-PVC Cables:

1. Less affected by solar radiation.

Comparison with Sonic and WXT Air Temperatures

1. Temperature variations of FO-PVC and FO-STL cables were closer to the sonic temperature.
2. Under sunlight-free conditions, the temperature difference between WXT air temperature and DTS varied within ±1°C.

Correlation with Solar Radiation:

1. A linear positive correlation was observed between the temperature difference and the intensity of solar radiation for stainless and FO-PVC cables.
2. This correlation can help future studies observe the spatial distribution of solar radiation intensity in areas with high variability.

Limitations and Future Considerations:

1. Current instrument limitations prevent the estimation of radiation intensity using this method in ideal environments.
2. The influence of long-wave radiation on temperature differences has not been fully verified, representing only a general trend.

Estimating Wind Speed

1. Unlike previous methods that estimate wind speed using energy balance, this study estimates wind speed based on the temperature difference between heated and unheated FO-STL cables.
2. The relationship between temperature difference and wind speed showed a similar response under different environmental conditions.
3. Wind speed estimated by regression equations tended to be overestimated by about 0.16 m/s at low wind speeds due to the limitation of the exponential equation.
4. Changes in estimated wind speed corresponded well with sonic anemometer data on a 10-second timescale.