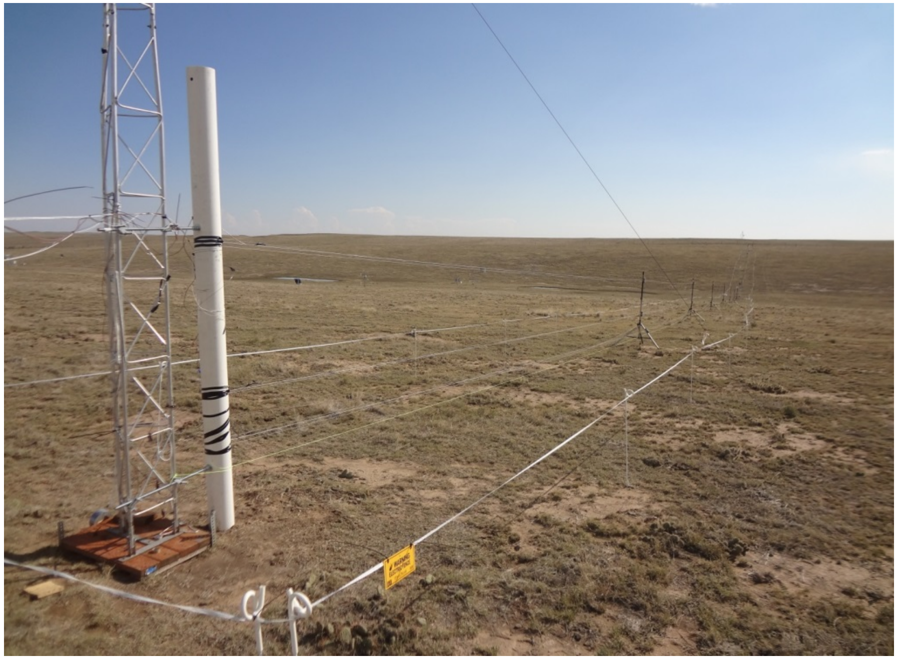
Towards Multi-Scale Tracking of Water Movement Across the Soil-Plant-Atmosphere Continuum Using Fiber Optic Distributed Temperature Sensing

Chadi Sayde



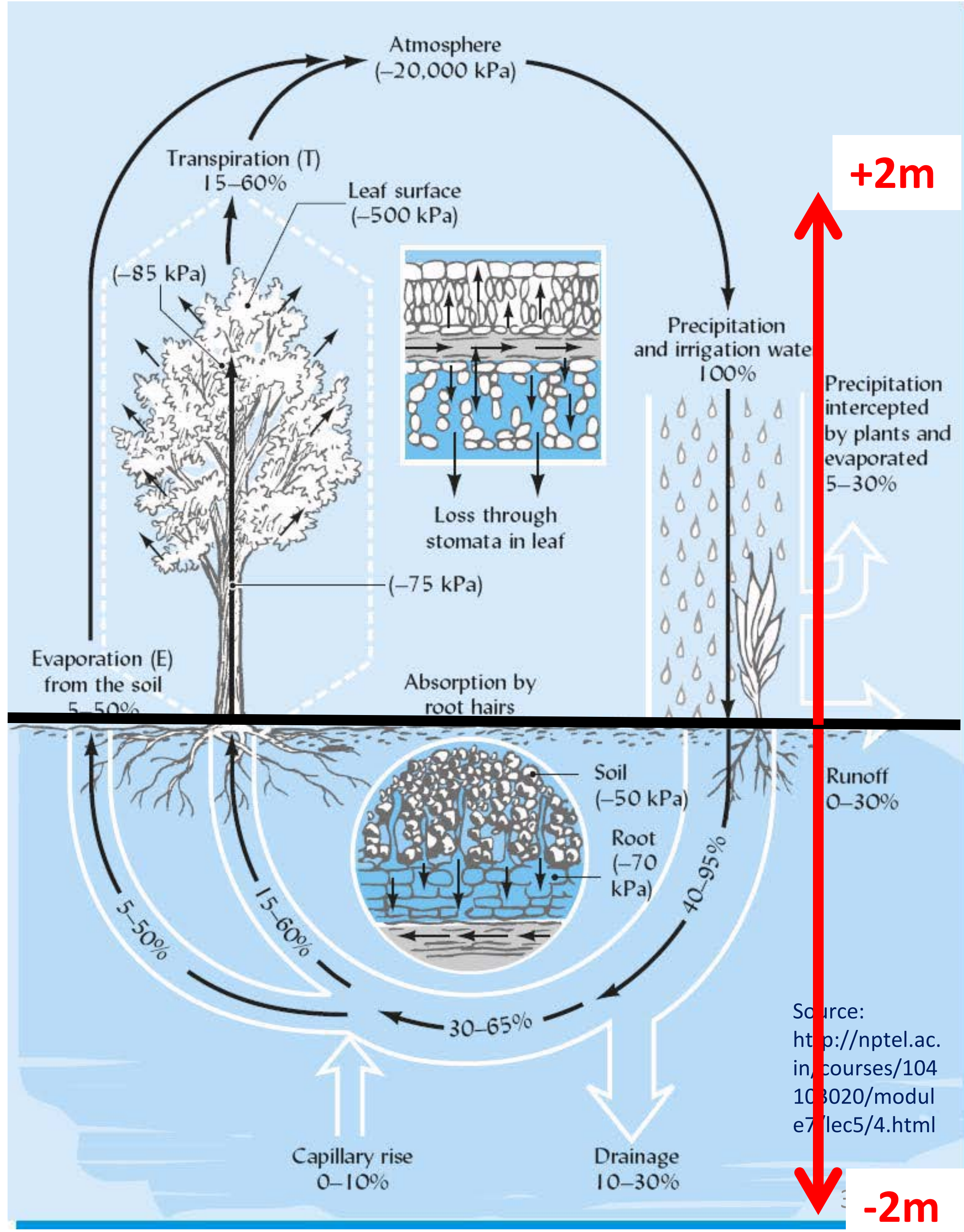
MOISST Workshop
Stillwater - May 23, 2017

- **Oregon State University:** John Selker, Daniel Moreno, Chad Higgins, Robert Predoza
- **Delft Technical University:** Suzan Steel-Dunn, Dong Jianzhi
- **Oklahoma State University:** Tyson Ochsner and team
- **University of Nevada – Reno:** Scott Tyler
- **University of Beyreuth:** Chris Thomas

Water is generally free to move across the **plant-soil**, **soil-atmosphere**, **and plant-atmosphere** interfaces it is necessary and desirable to view the water transfer system in the three domains of soil, plant, and atmosphere as a **whole** ...”

John R. Philip (1966)

- **soil-Fiber Optics:** Soil Water <**1 h** , **0.1 m**, **10 km**
- **air-Fiber Optics:** atmospheric fluxes **1 s, 0.1 m**, **10 km**



Source: http://nptel.ac.in/courses/104103020/module7/lec5/4.html

Soil - Fiber Optics: Measuring soil moisture content

Actively heated

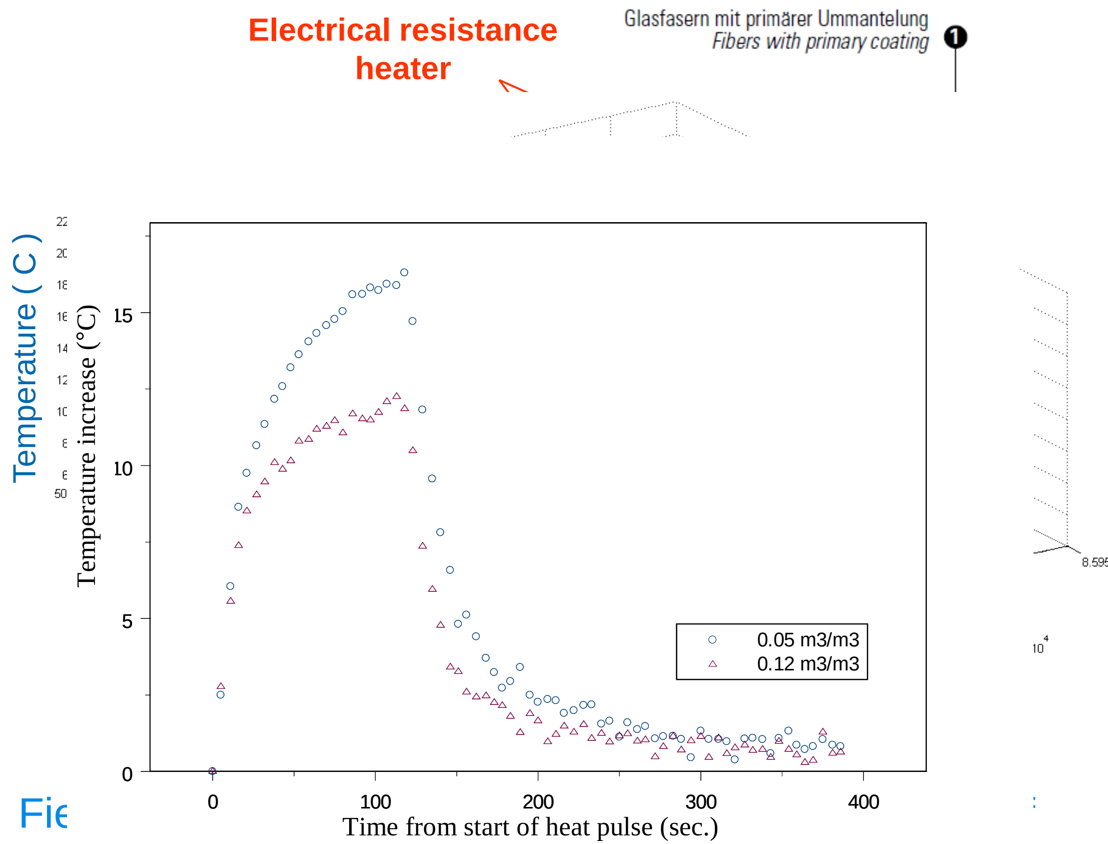
Heat injected in soil along fiber optic cable

↓

DTS reads temperature changes during heat pulse along fiber optic cable

↓

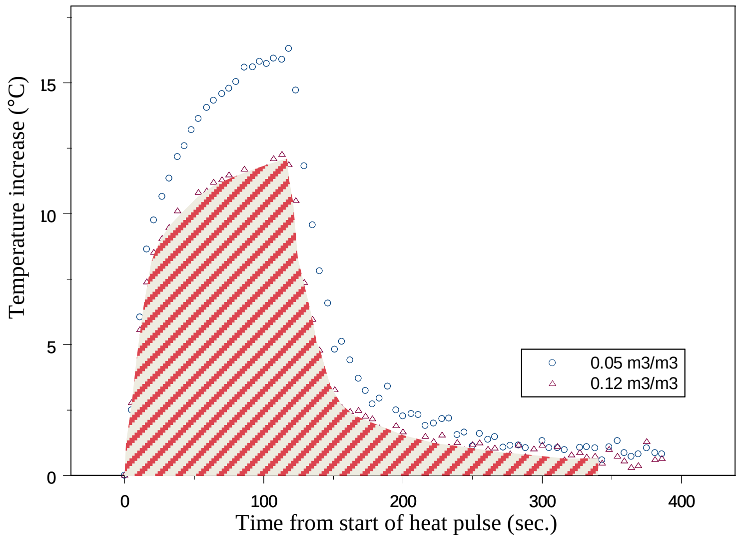
Soil water content inferred from thermal response of soil to the heat pulse

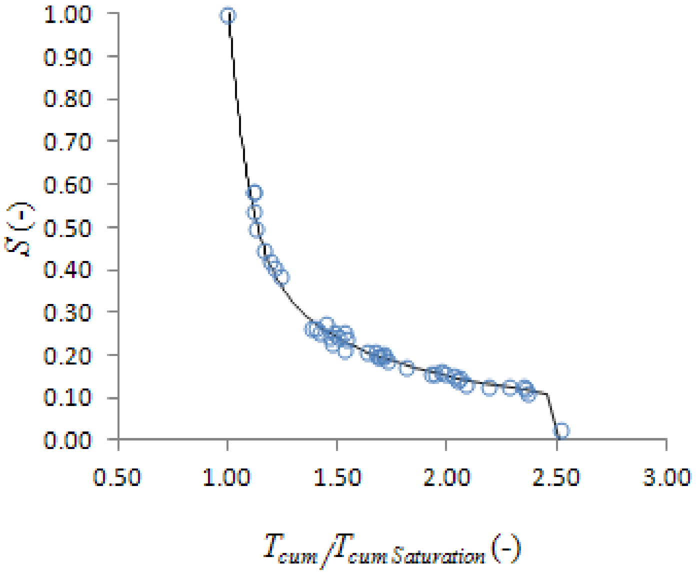


Heat Pulse Interpretation:

The Integral Method

$$T_{cum} = \int_{t_0}^{t_j} \Delta T \, dt$$





T_{cum} is the cumulative temperature increase

t_0 is the time to start of a heat pulse

t_j is the total time of integration

ΔT is the temperature increase over ambient tempera

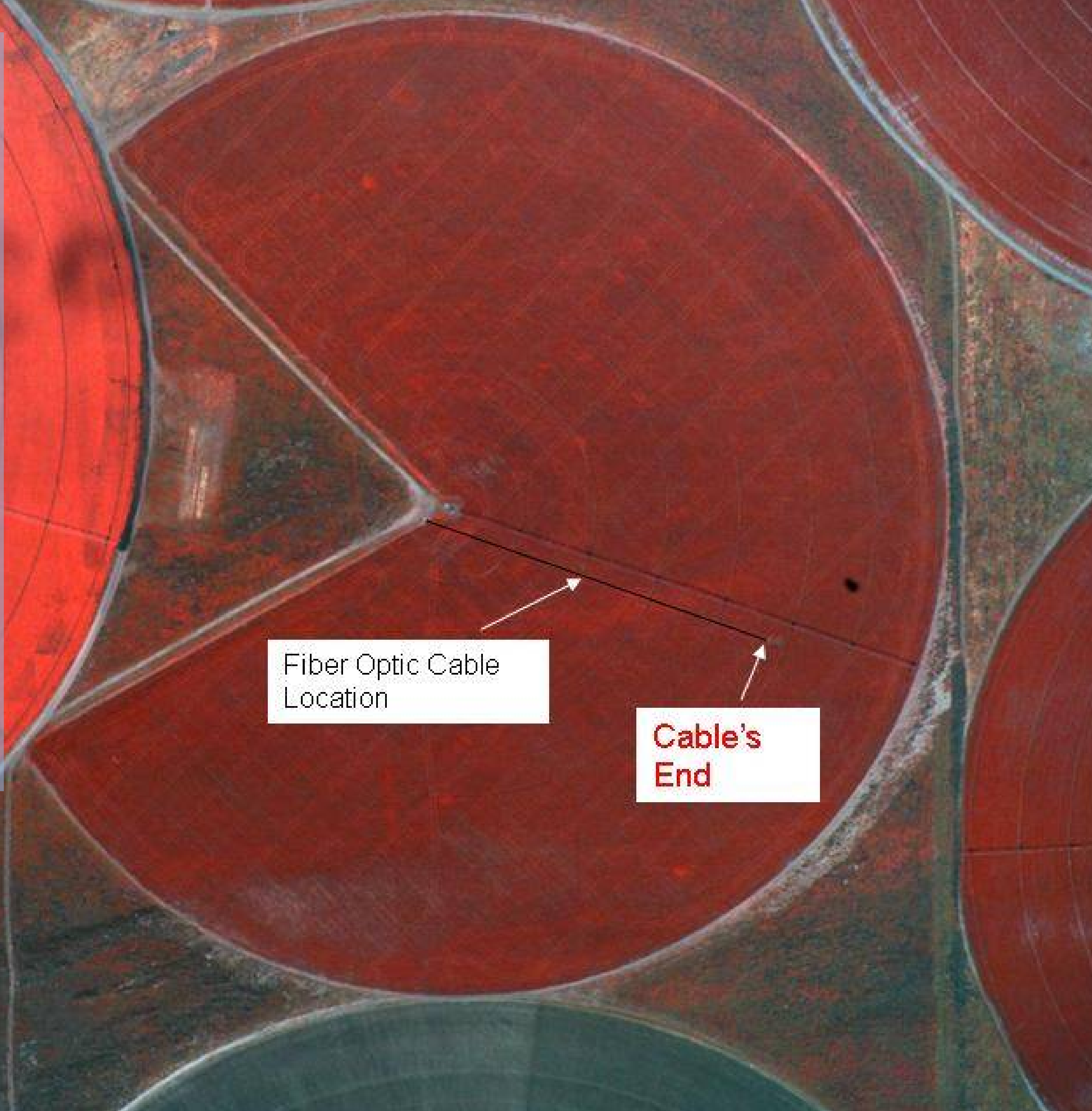
Field Test

- 750 m of fiber optic cable installed in an agricultural field in Echo, Oregon

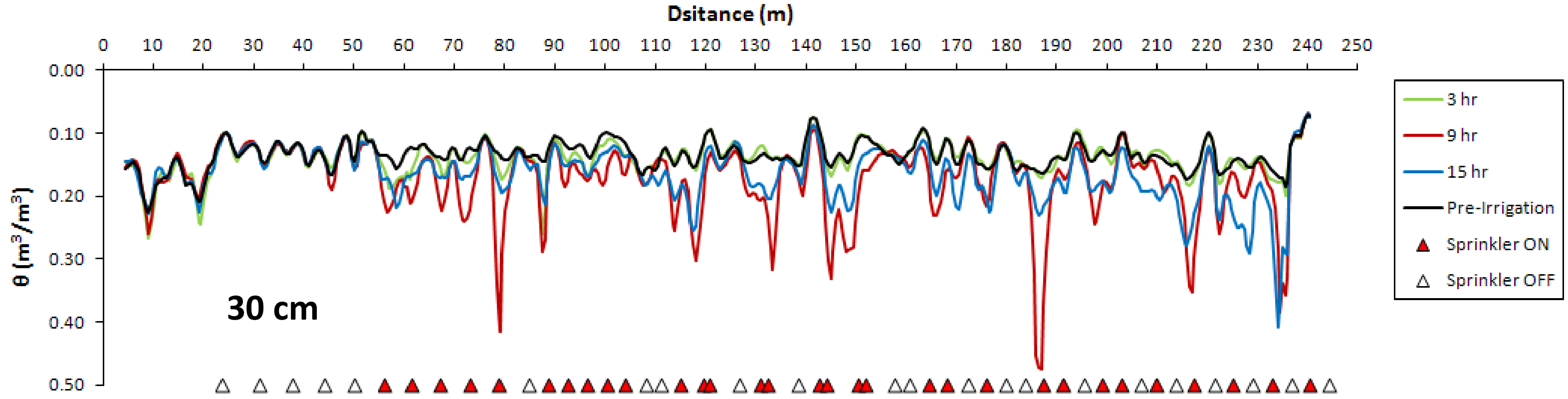
- Fiber optic cables installed simultaneously at 3 depths: 30, 60, and 90 cm

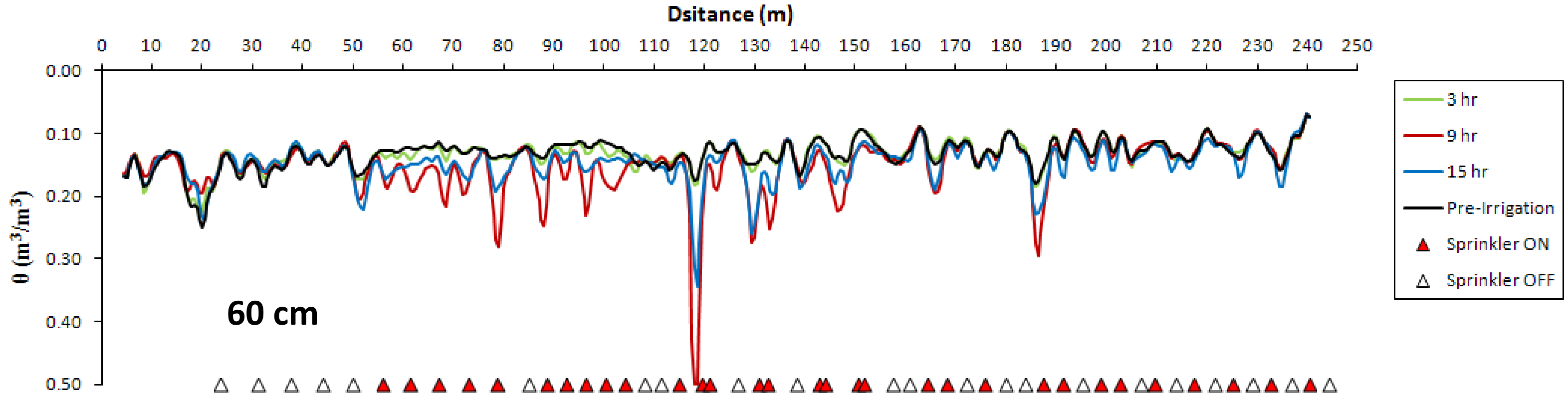
- The field is irrigated by a center pivot system

- Soil type: Sandy loam

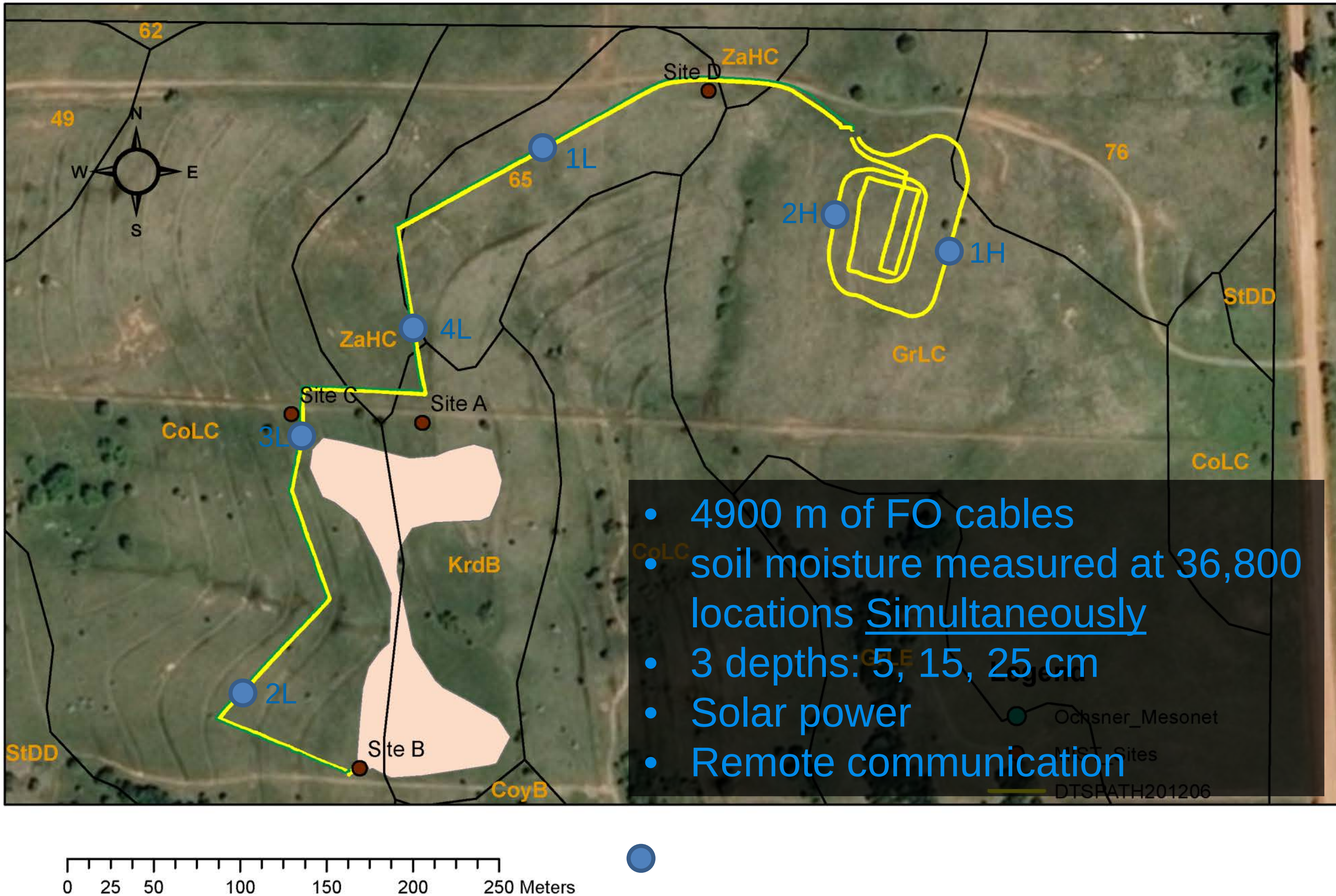


Imposed water application variability at the surface

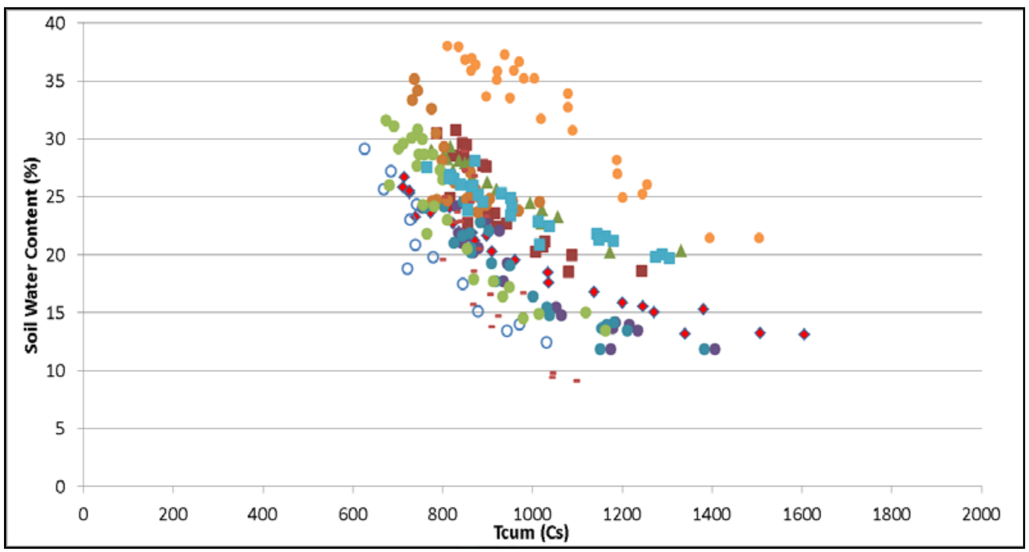




Fiber Optics Cable Path



- 4900 m of FO cables
- soil moisture measured at 36,800 locations <u>Simultaneously</u>
- 3 depths: 5, 15, 25 cm
- Solar power
- Remote communication



Spatial variability of soil thermal properties

Novel Distributed Calibration Model

- Kersten function (*Ke*) can be found at **any location** and for the **whole** soil moisture range from *Tcum* at dry and at saturation:

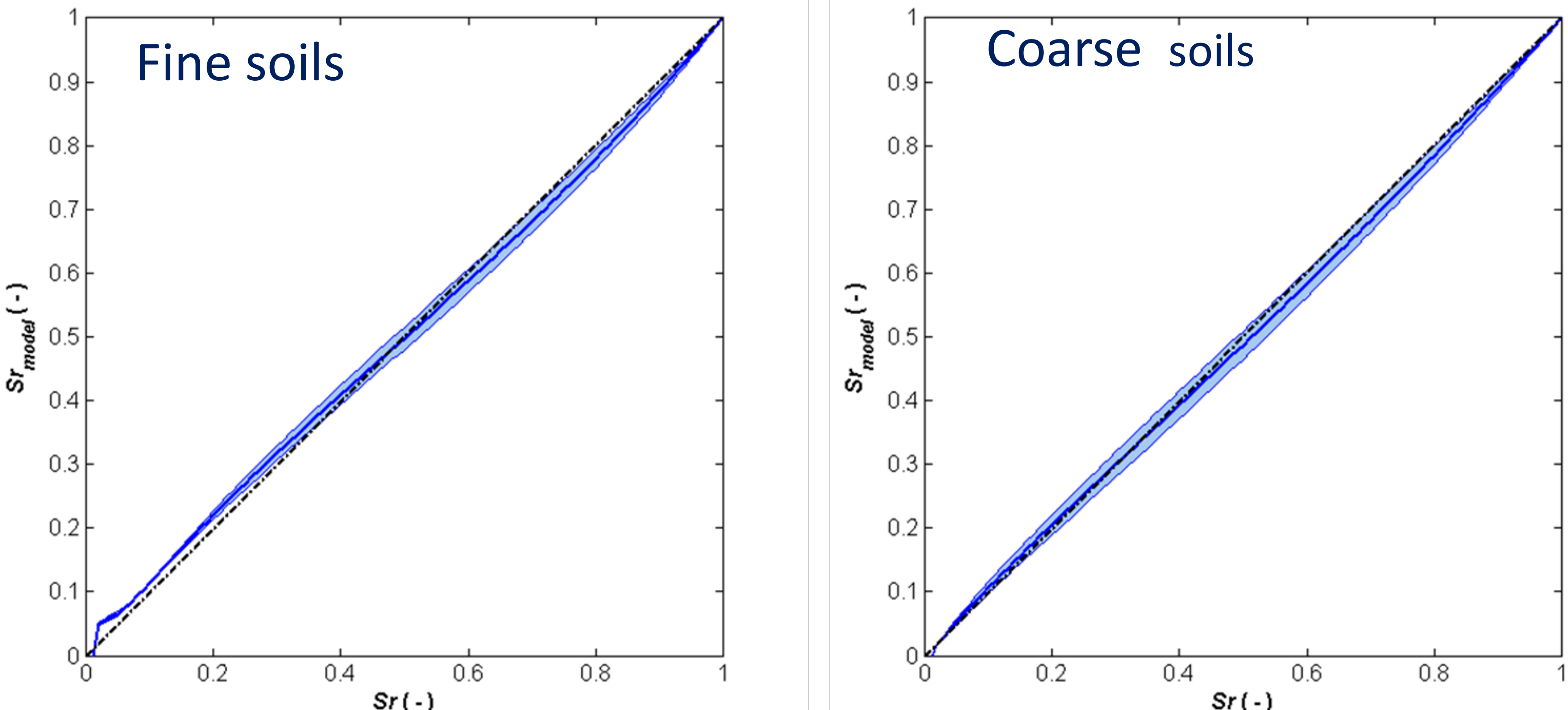
$$Ke = \frac{Tcum_{sat}^{b}}{Tcum^{b}}\left[\frac{Tcum_{dry}^{b} - Tcum^{b}}{Tcum_{dry}^{b} - Tcum_{sat}^{b}}\right]$$

- Degree of saturation (*Sr*) can be computed from published models relating *Ke* to *Sr*. e.g. Lu et al. (2007):

$$Ke = \exp\left\{\propto\left[1 - S_r^{(\propto-1.33)}\right]\right\}$$

α = 0.96 for coarse soils, α = 0.27 for fine soils

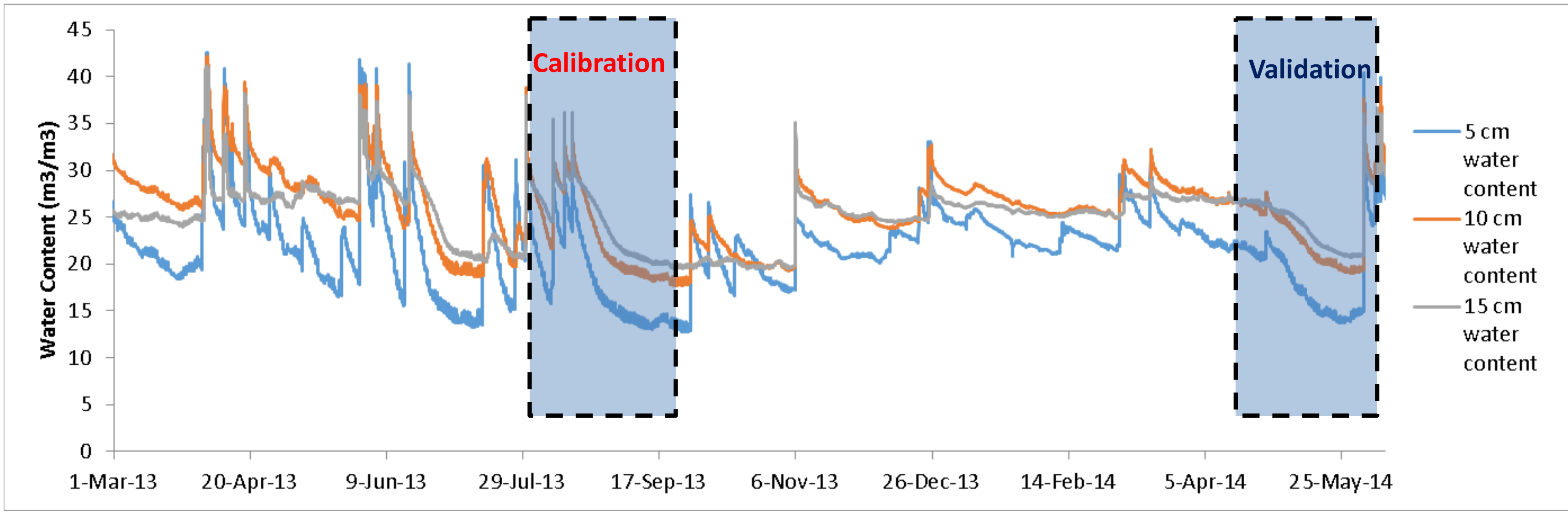
Numerical Simulation



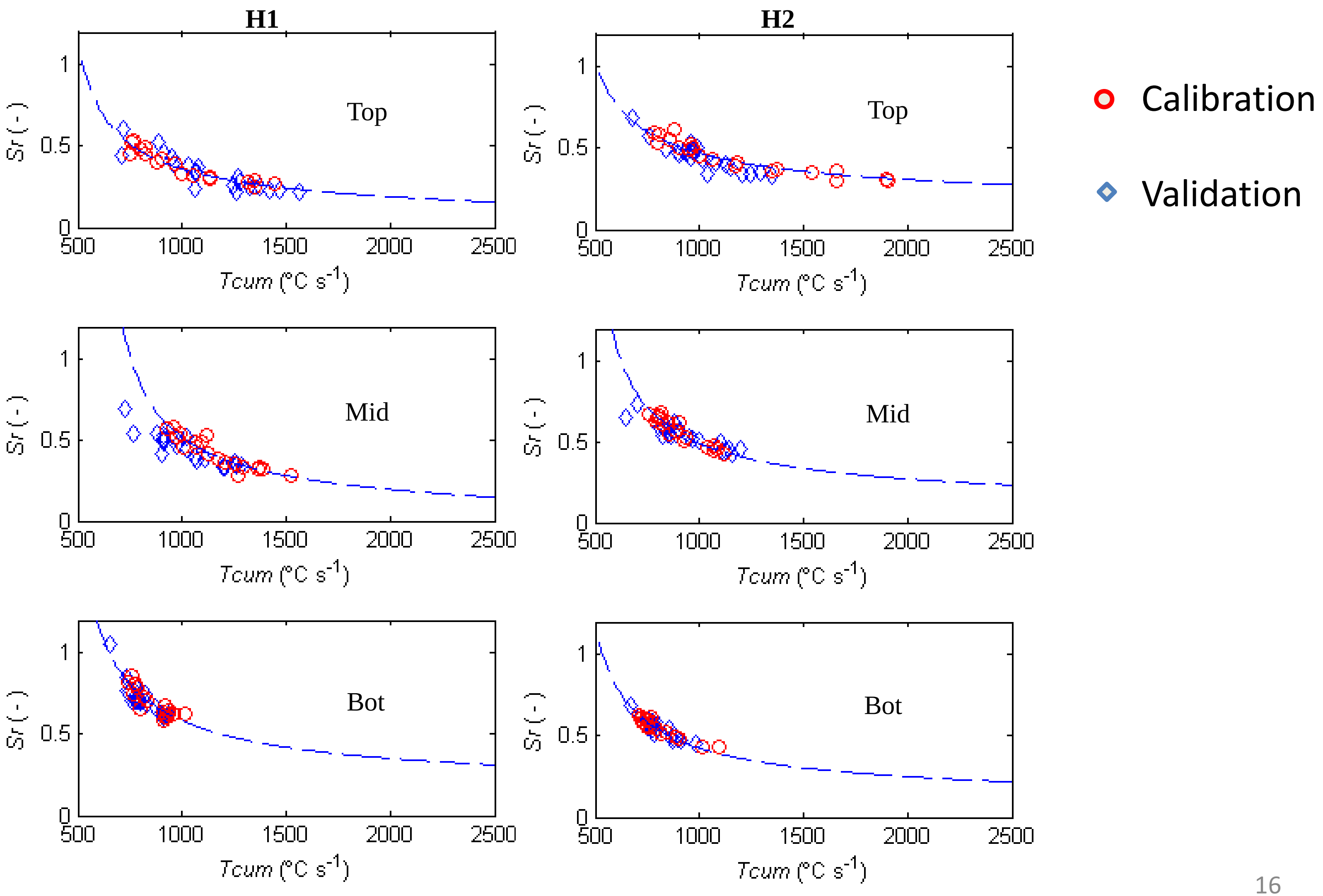
Synthetic (Sr) vs modeled (Sr_{model}) degree of saturation (blue line). The shaded areas represent 1 standard deviation in Sr_{model}

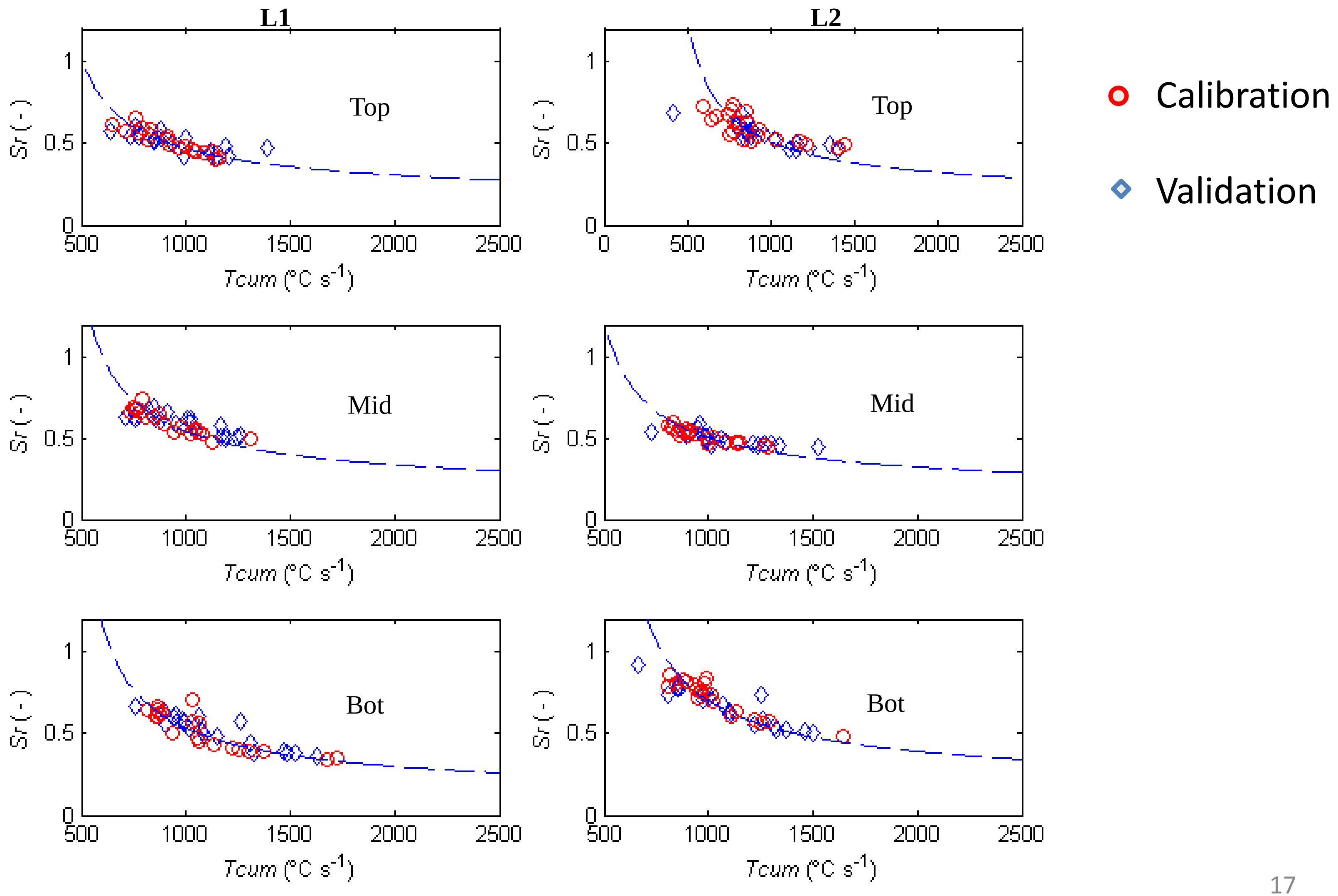
CV=1.5 %

Field Validation



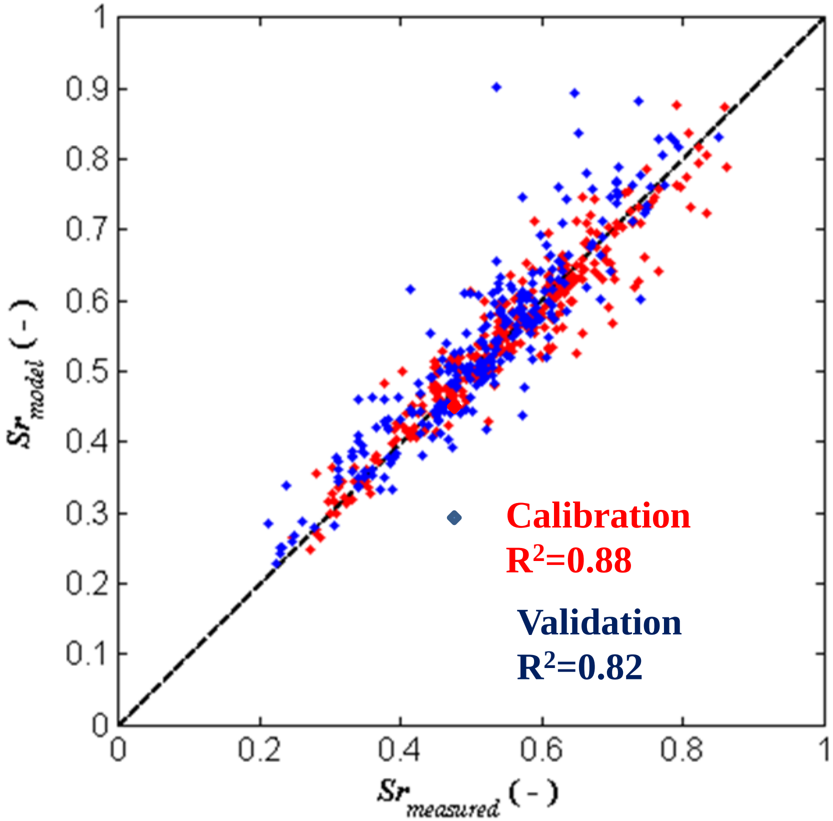
Field Validation





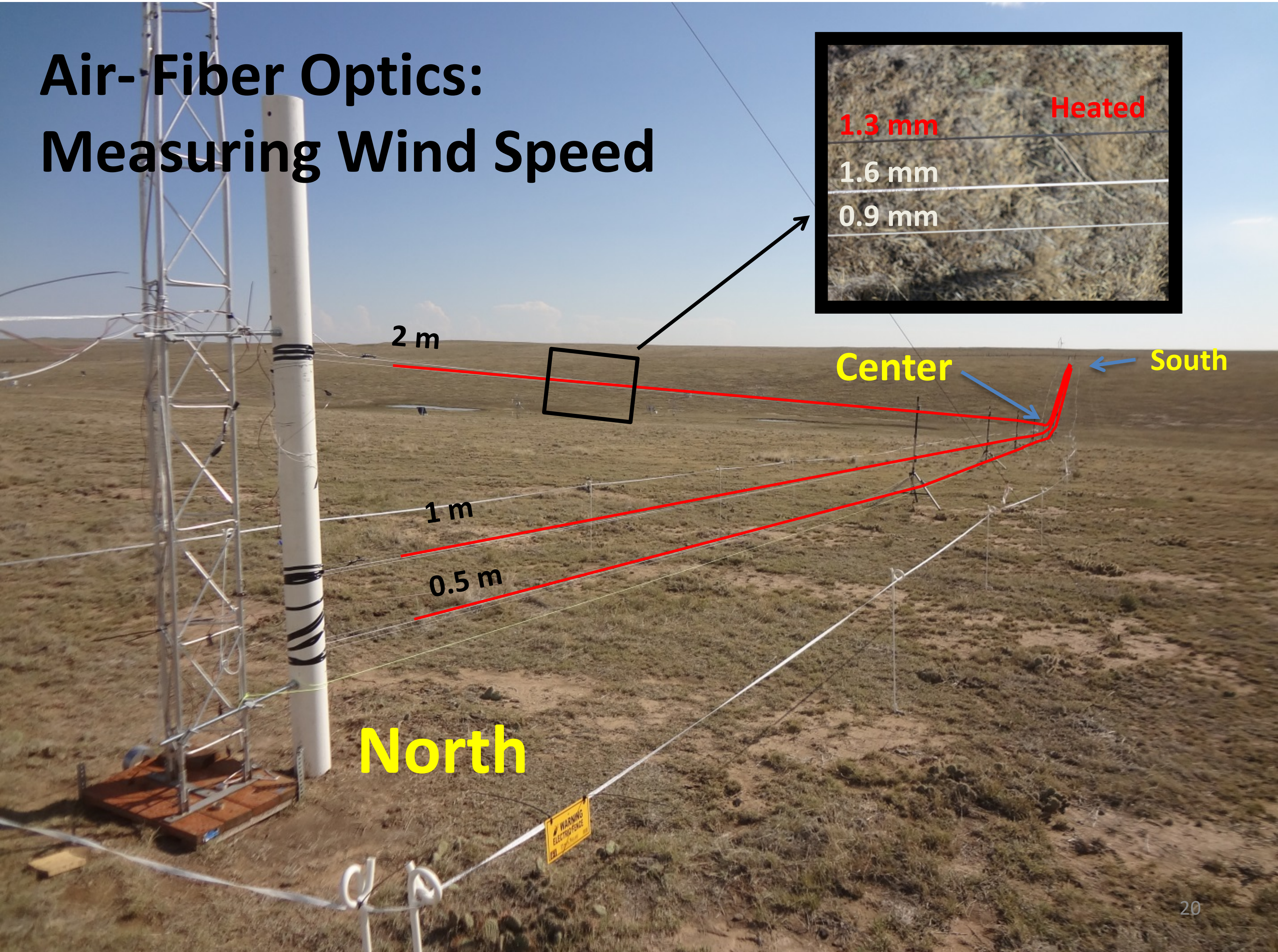
L1
L2
Top
Mid
Bot
Sr (-)
Tcum (°C s-1)
Calibration
Validation

New Model Performance



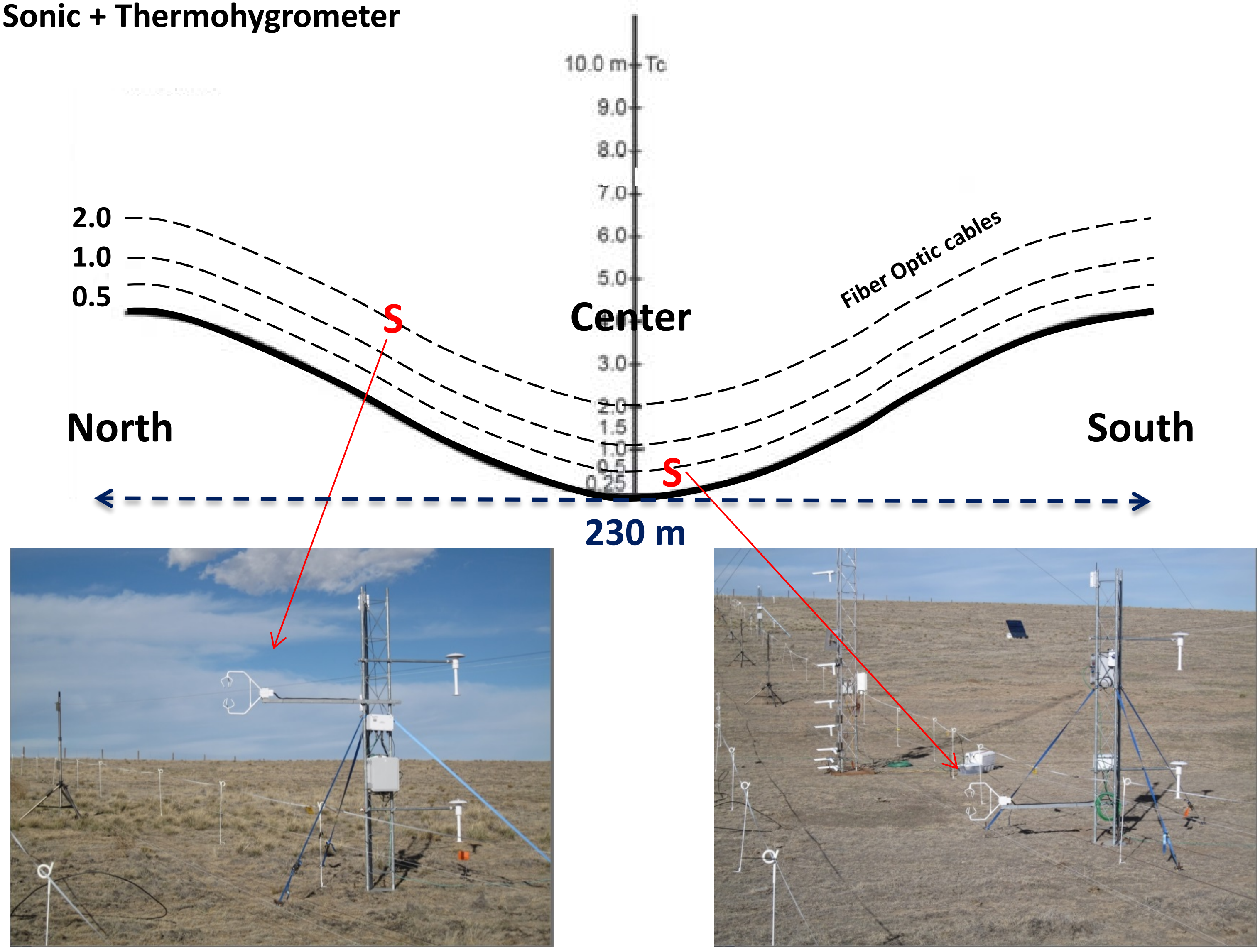
Soil Fiber Optics
Take Home Message

- Soil moisture can be measured every 0.125 m along buried cable >10 km length
- Distributed calibration model applicable for wide range of soils
- T_{cum} at saturation and at dry conditions
- Future work: combine passive and active measurements

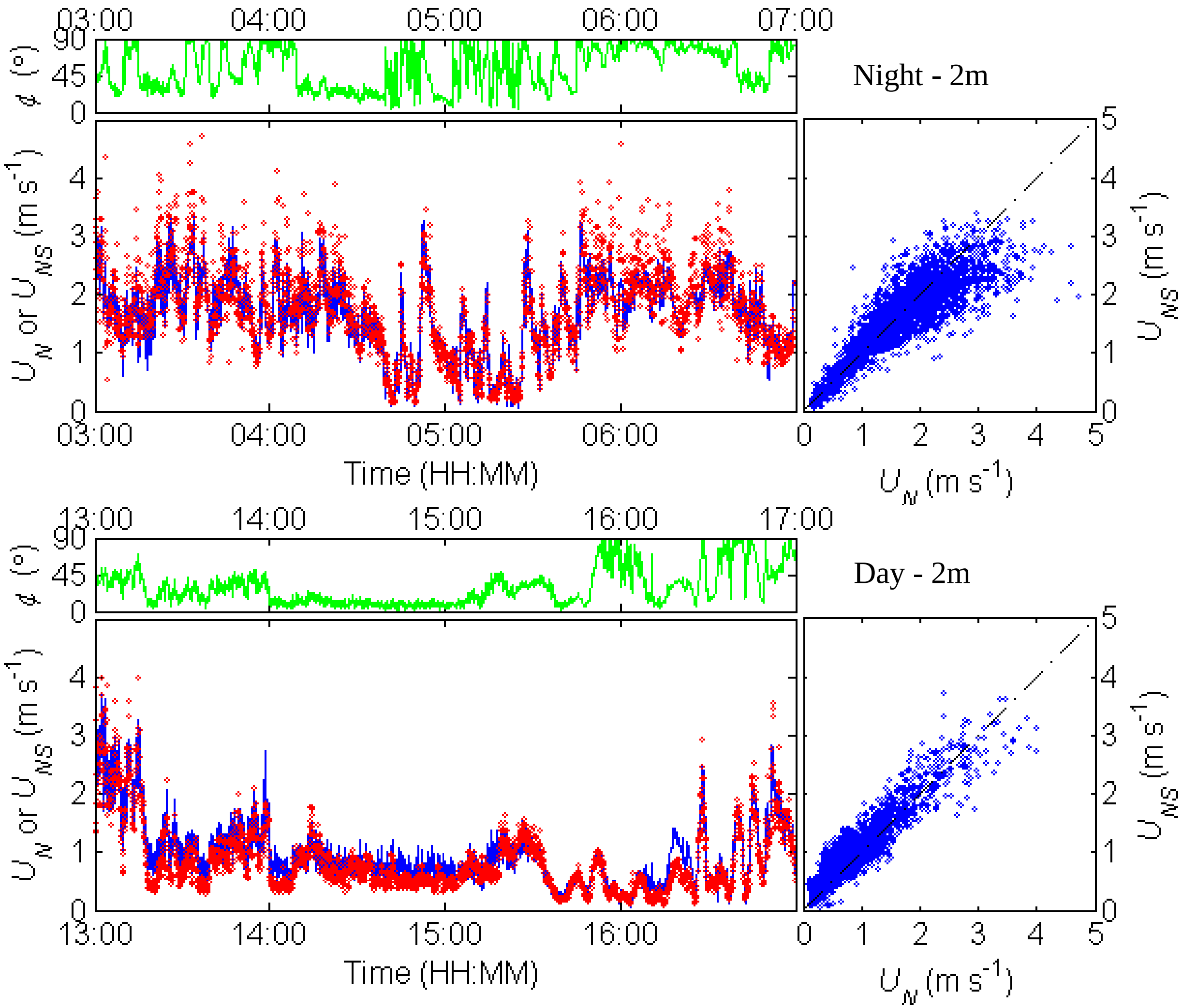

Air- Fiber Optics:
Measuring Wind Speed
Heated
1.3 mm
1.6 mm
0.9 mm
2 m
Center
South
1 m
0.5 m
North

Tc = Thermocouple
S = Sonic + Thermohygrometer

OSU Transect

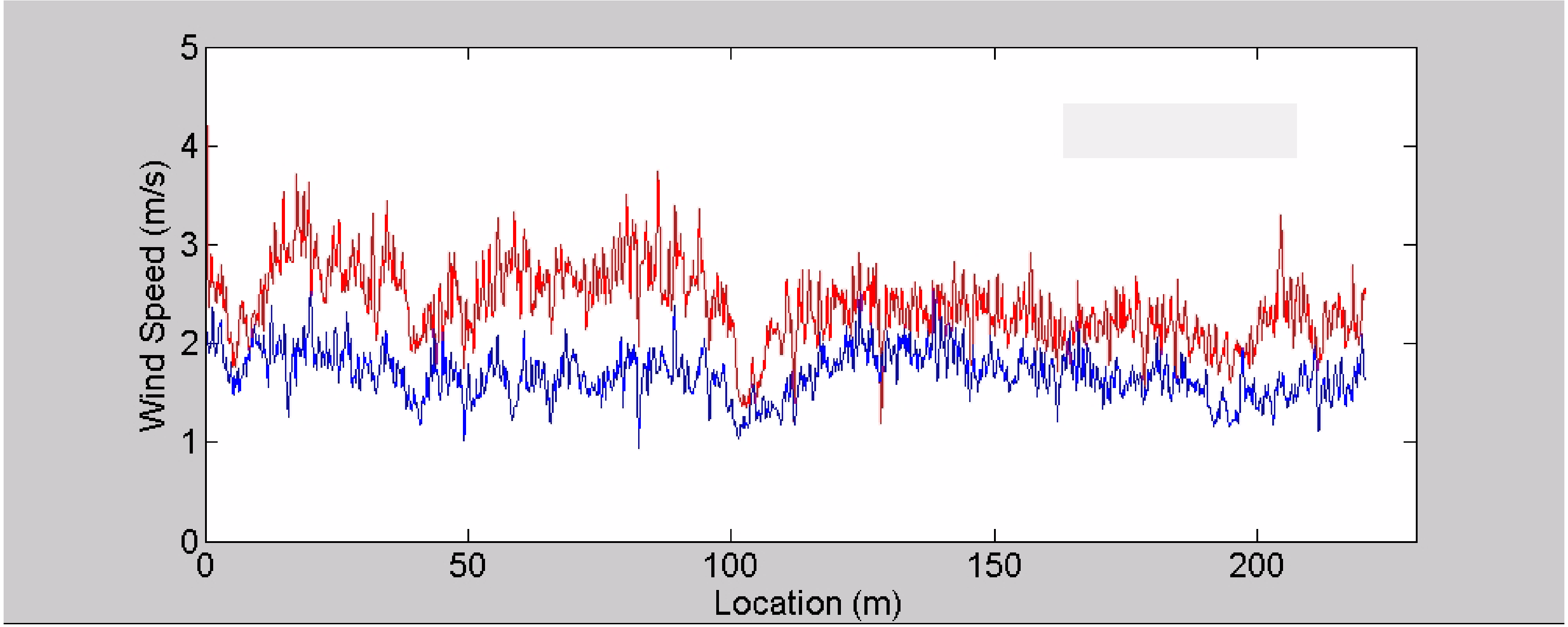


Sonic vs. DTS



R^2 = 0.80

R^2 = 0.83


Wind Speed (m/s)
0
1
2
3
4
5
0
50
100
150
200
Location (m)

Humidity

DTS → Sling Psychrometer

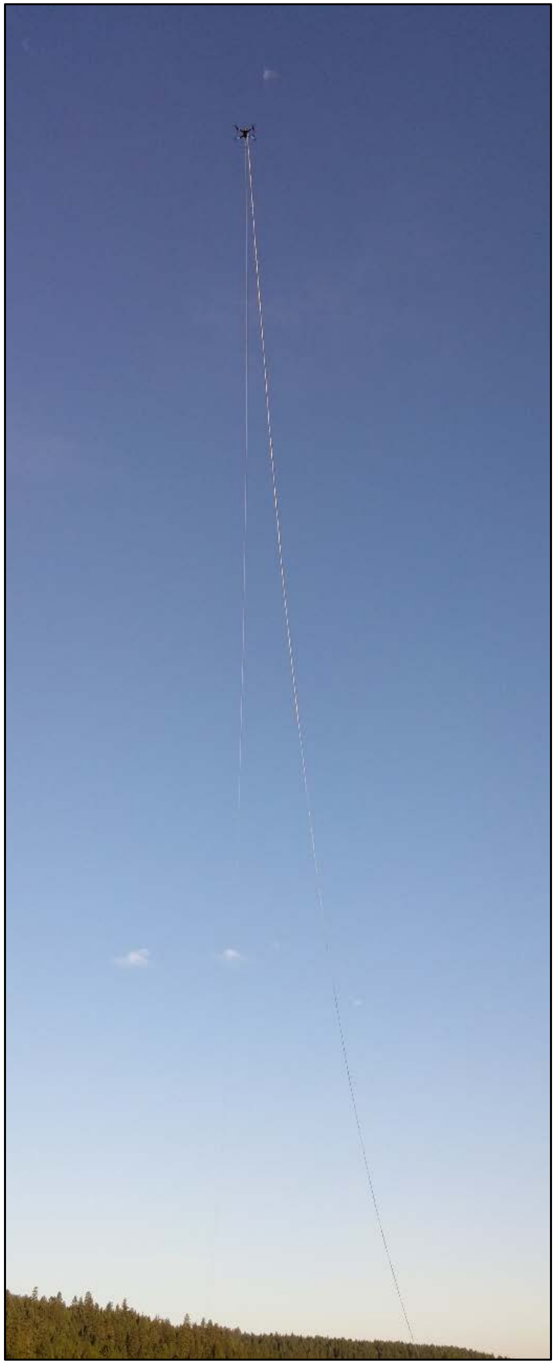
$\cong$

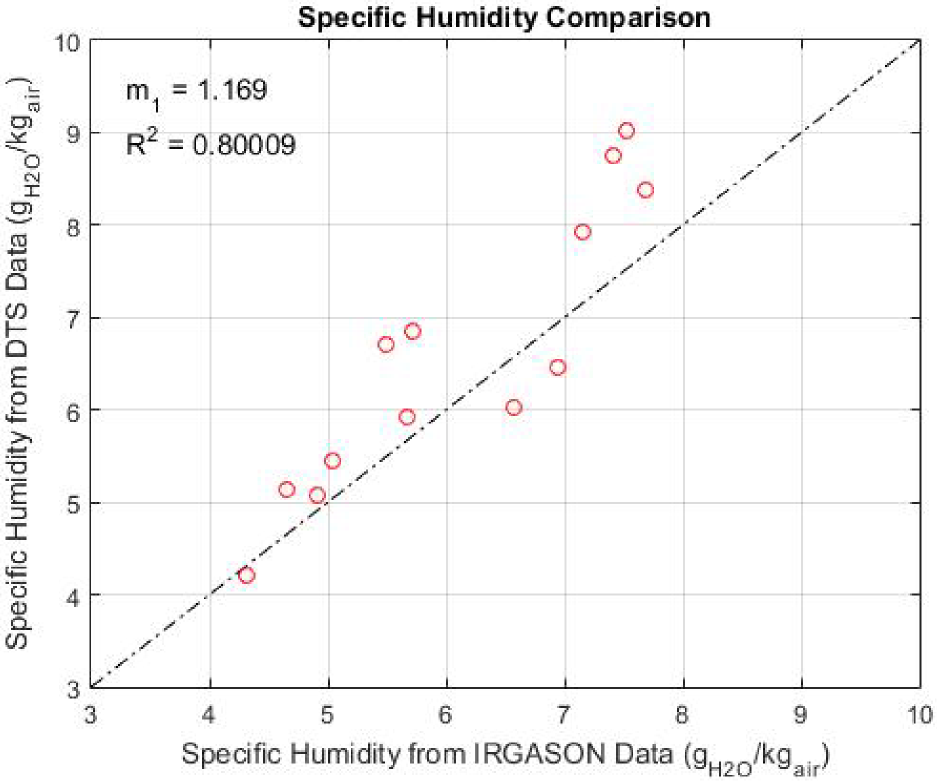
$$e_a = e_s - \gamma(T_a - T_w)$$

$$e_s = 0.61 e^{\frac{17.3 T_{w,d}}{T_w + 237}}$$

$$\gamma \equiv \frac{c_a P}{0.622\, L_e}$$

Vertical Profiling of Temperature and Humidity using DTS and UAV





Air-Fiber Optics
Take home message

- Wind speed can be measured at high temporal and spatial resolutions **(every Second, every 12 cm)**
- It is sensitive to wind direction. Great!
- Humidity can be measured at high spatial and temporal resolution , if corrected by wind speed measurements
- Measuring ET is our end coal. We are very close!

Acknowledgements

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