Evaluation of turbulence budget terms using highly resolved hot and cold wire measurements over a desert playa

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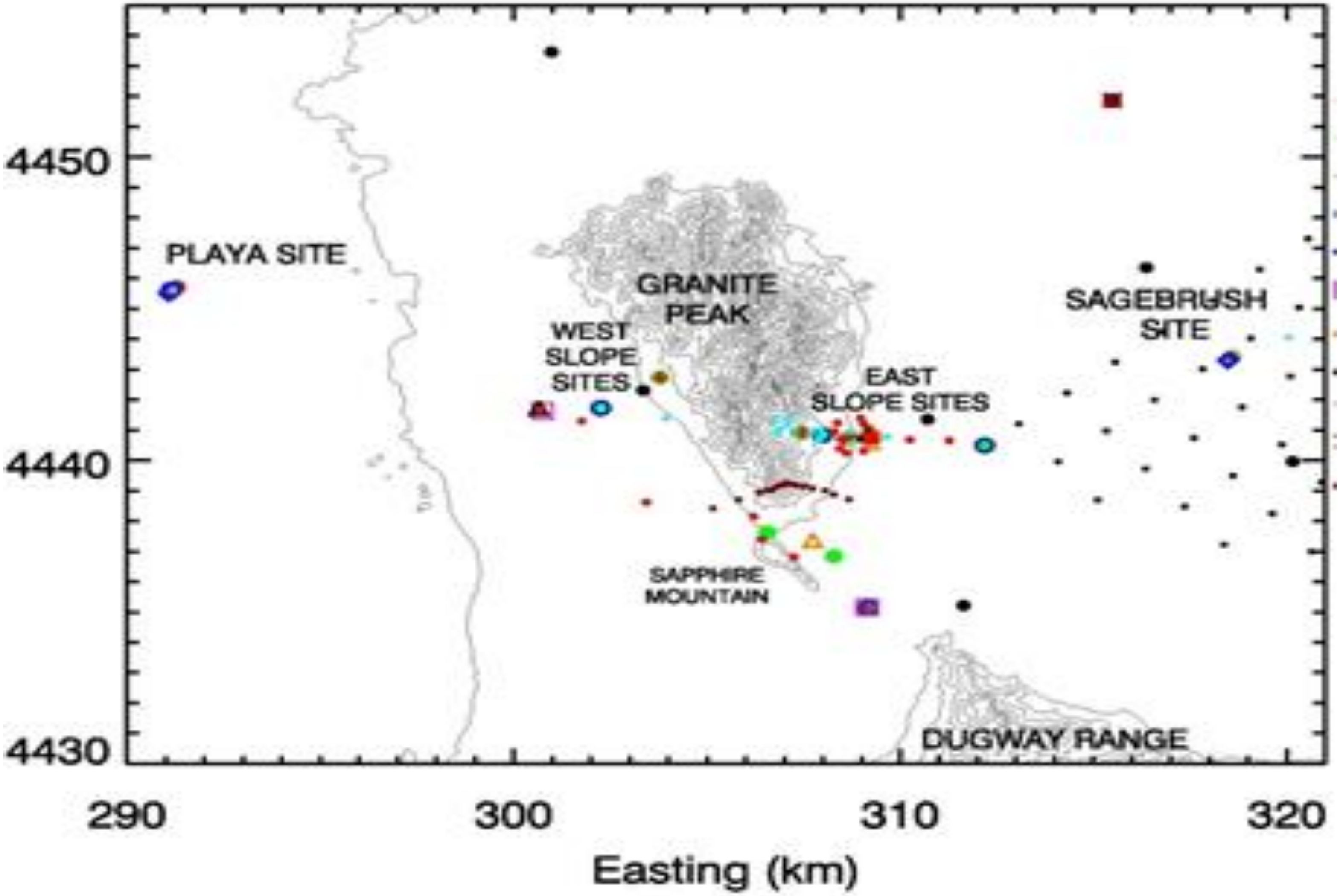
Outline

- Introduction
- Goal
- Hot & Cold wire anemometry
- Experimental set up
- Experimental results
- Conclusions
- Acknowledgement

Introduction



Properties of Playa

- Slightly higher albedo ~ 0.35 than sage and slope sites
- Dry Lake Bed
- Large, uninterrupted fetch
- Very smooth, $Z_0 \approx 1\,mm$
- Very little elevation change

Goal

- *Understanding of fine scale surface-layer processes such as distorted turbulent eddies, coherent structures and dissipation mechanisms to improve the surface flux parameterizations*

- Measure the shear production, buoyancy production, turbulent transport and the dissipation rate of TKE terms in the TKE budget.
- Large scale weather predictions are done by LES where the flow physics has been parameterized.
- Here we try to understand the physics by directly measuring the fine scale surface-layer processes to enable good parameterization.

MATERHORN - Spring 2013

IOP Summary Table (TB - tethered balloon, RS - radiosounding, NP - North Playa, SB - Sage Brush, CP - Callao Point C, ES - East Slope, SWG - Southwest of Granite Peak; NWG - North West Granite)

IOP Number	Dates and Time of Experiment in Mountain Daylight Time (UTC - 6)	TB	RS	Type	Flights	Last Precip
IOP 1	1400 MDT May 1 - 1400 MDT May 2	Playa, SB	Playa, SB	Moderate/ Quiescent	None	April 20
IOP 2	1400 MDT May 4 - 1400 MDT May 5	Playa, SB, ES	Playa, SB	Moderate	None	
IOP 3	0500 MDT May 7 - 1700 MDT May 7	None	SWG	Moderate	None	May 6
IOP 4	1400 MDT May 11 - 1400 MDT May 12	Playa, SB, ES	Playa, SB	Quiescent	None	May 7*
IOP 5	1200 MDT May 13 - 1200 MDT May 14	None	NWG, Playa	Moderate/ Transitional	None	
IOP 6	1200 MDT May 16 - 1200 MDT May 17	Playa, SB	Playa, NWG, Delta	Moderate/ Transitional GBCZ	None	
IOP 7	1715 MDT May 20 to 1400 MDT 21 May	Playa, SB	Playa, NWG, SB	Sandwhich Quiescent	None	May 18, 19
IOP 8	1400 MDT May 22 to 1400 MDT May 23	Playa, SB	Playa, NWG, Delta	Moderate	None	
IOP 9	1000 MDT May 25 to 1000 MDT May 26		Playa, SB	Moderate	None	
IOP 10	1400 MDT May 30 to 1000 MDT May 31	Playa, SB	Playa, SB	Moderate	None	May 28

*Note that the precipitation on May 7 was just local convection not sustained or range wide

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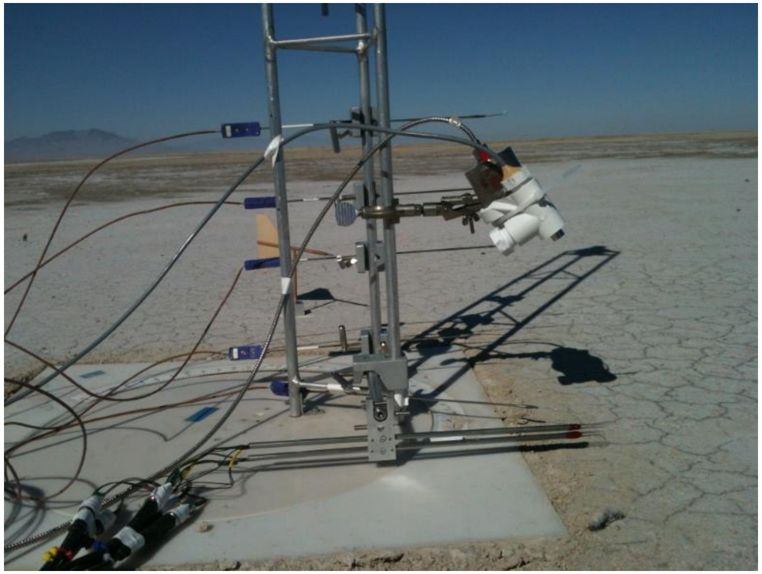
IOP- 9 Conditions

- Clear sky and strong South Westerly winds for most of the IOP.
- The velocity was 6 m/s at about 1 m from the surface.
- Ideal for Hot-wire measurements.
- Shear dominated, convectively driven Boundary Layer.

Experimental Setup

Important Components :

- Two sets of X-wires and cold wires (Co-located)
- An array of five fine wires at different heights
- Hot and Cold wire calibrations were done on-site



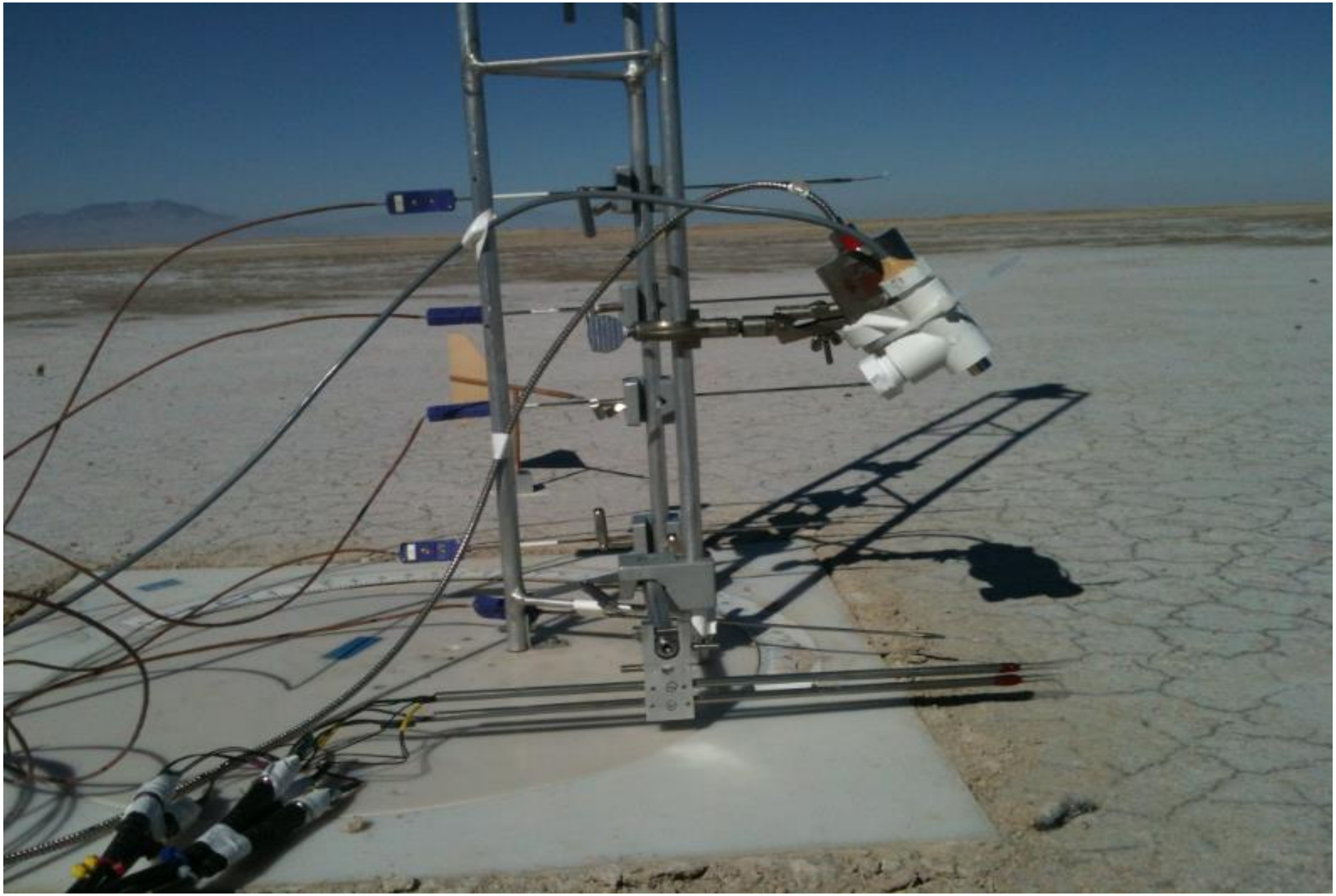
Known for :

- Measuring high frequency fluctuations (for both velocity and temperature.)

Issues :

- Calibration needs to be done for every few hours
- Response of the system is sensitive to atmospheric temperature changes (drifting).

Experimental Setup



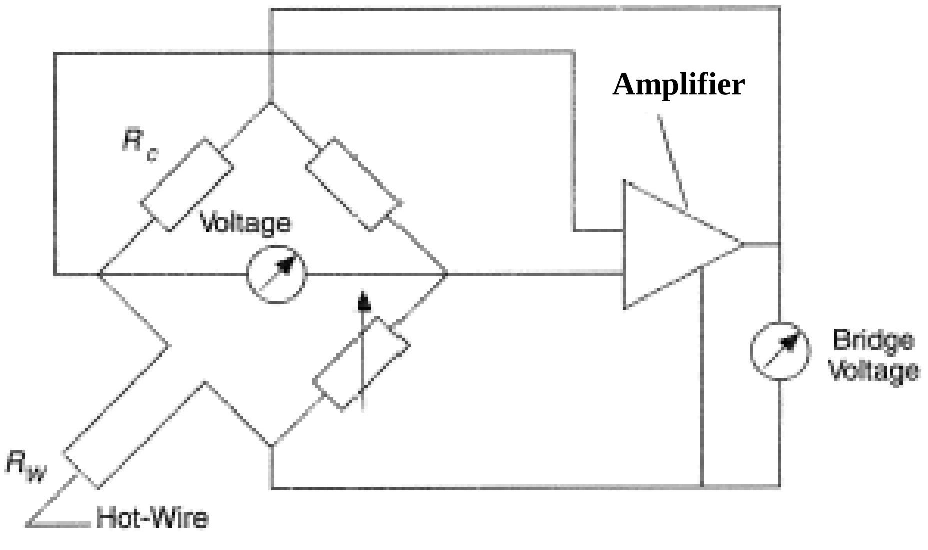
Anemometer operation modes

Constant temperature CTA (velocity) :

- Voltage difference across the bridge is amplified and used to balance the bridge through a feedback loop.
- Wire resistance and temperature are nearly constant

Constant current CCA (temperature) :

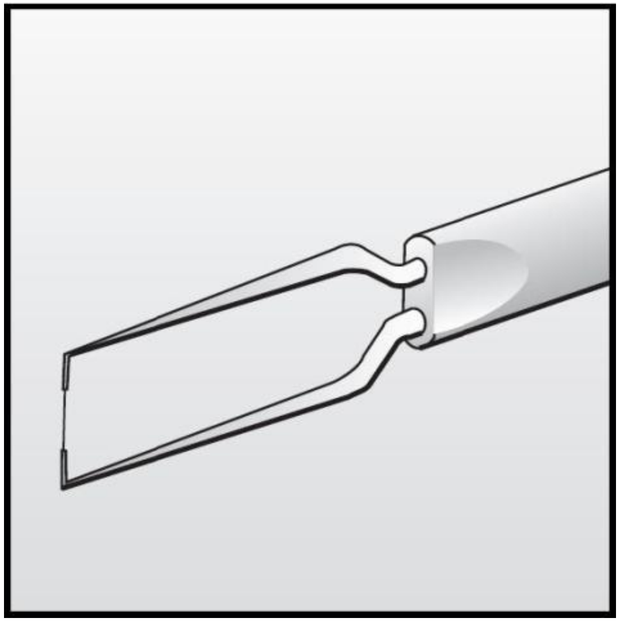
- Low constant current is fed to the wire
- The voltage drop over the wire is measured and amplified



Hot-Wire Anemometer

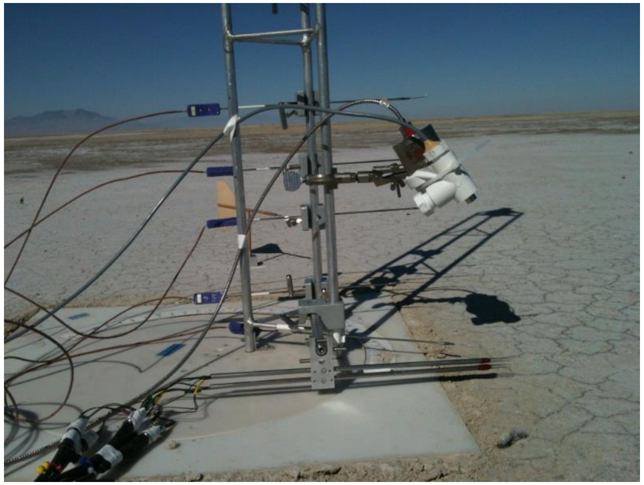
Principle of operation :

- Electrical current passes through a thin wire (5 micron)
- Wire resistance changes with temperature
- Variation in resistance is monitored
- Can measure velocity or temperature



Velocity measurement :

- The wire is heated by electrical current and cooled down by forced convection

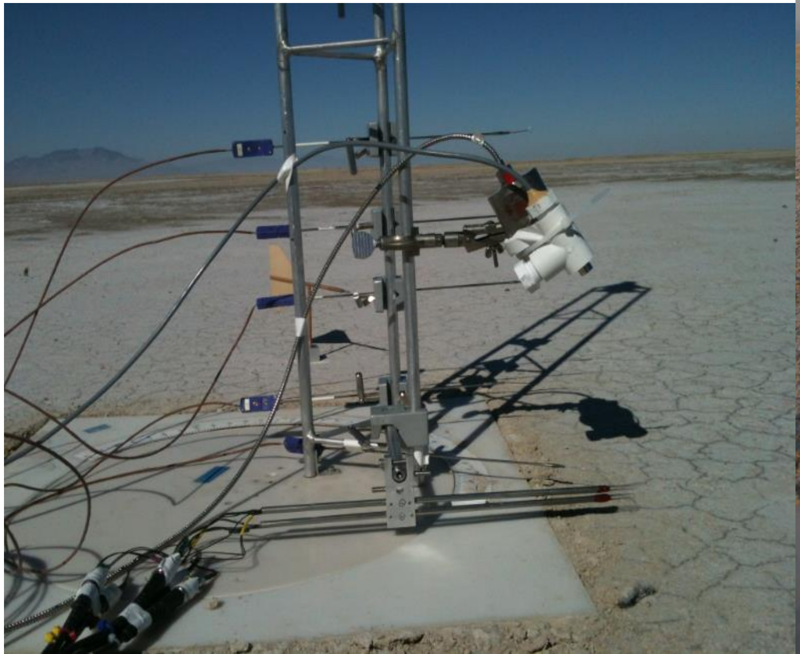


Temperature measurement :

- The wire is kept at temperature close to the ambient temperature
- Resistance is sensitive to temperature changes

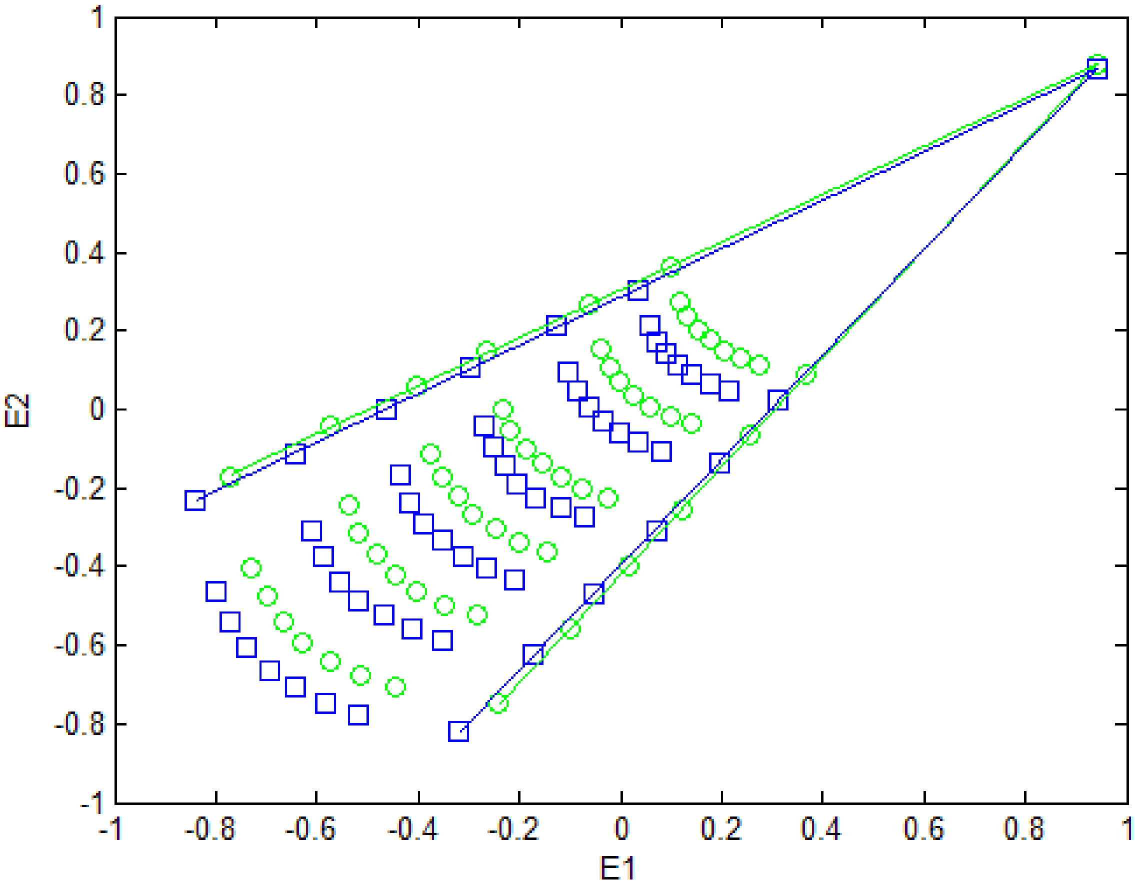
Wind direction adjustments for X-wires

- Measurements were made in bursts of 10 mins.
- A Wind vane is used to track the direction of the mean wind.
- The hot-wire tower was adjusted such that the hot and cold wire probes facing the mean wind.
- If the tower was adjusted within the 10 mins sampling window then that particular point would be flagged and removed eventually.



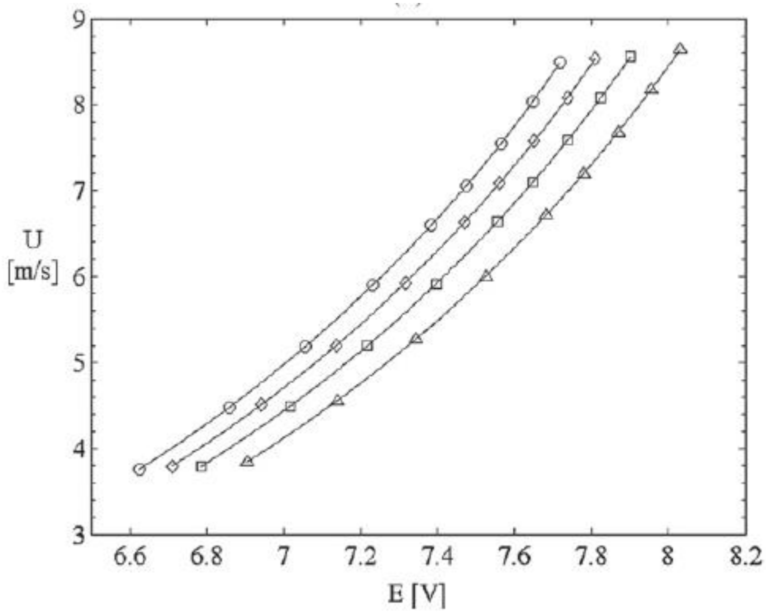

X –wire Calibration and Temperature Compensation

- Blue Square – Post Calibration
- Green Circle – Pre Calibration
- E1 & E2 – X – wire voltages



X –wire Calibration and Temperature Compensation

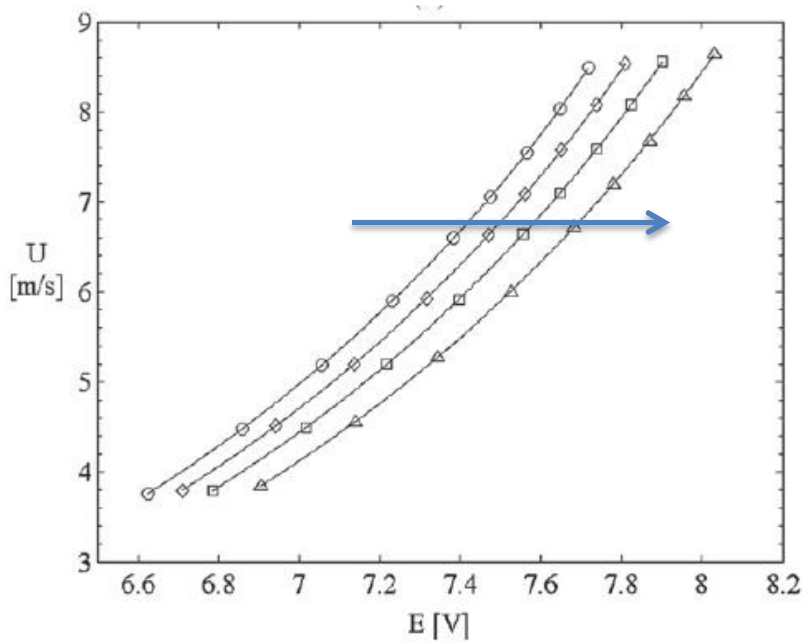
- Calibration curves for CTA operation at different temperatures for the same wire .
- ○, 48 °C; ◇, 45 °C; □, 39 °C; △, 33 °C.
- E – wire voltage & U - velocity

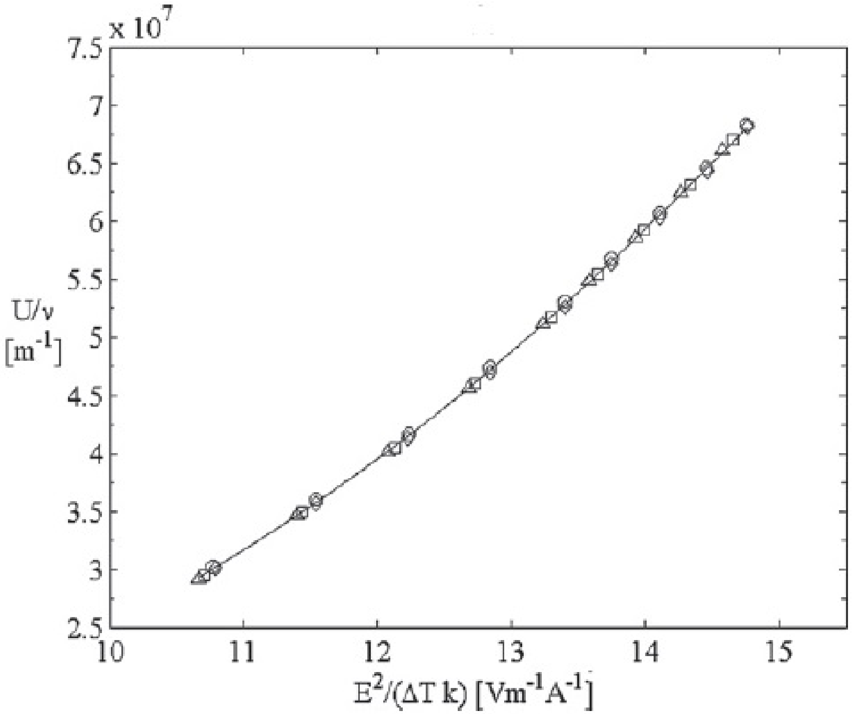


[Hultmark and Smits (2010)]

X –wire Calibration and Temperature Compensation

- Substantial drift in the voltage for the same velocity range when the temperature changes from 48 to 33 degree Celsius.



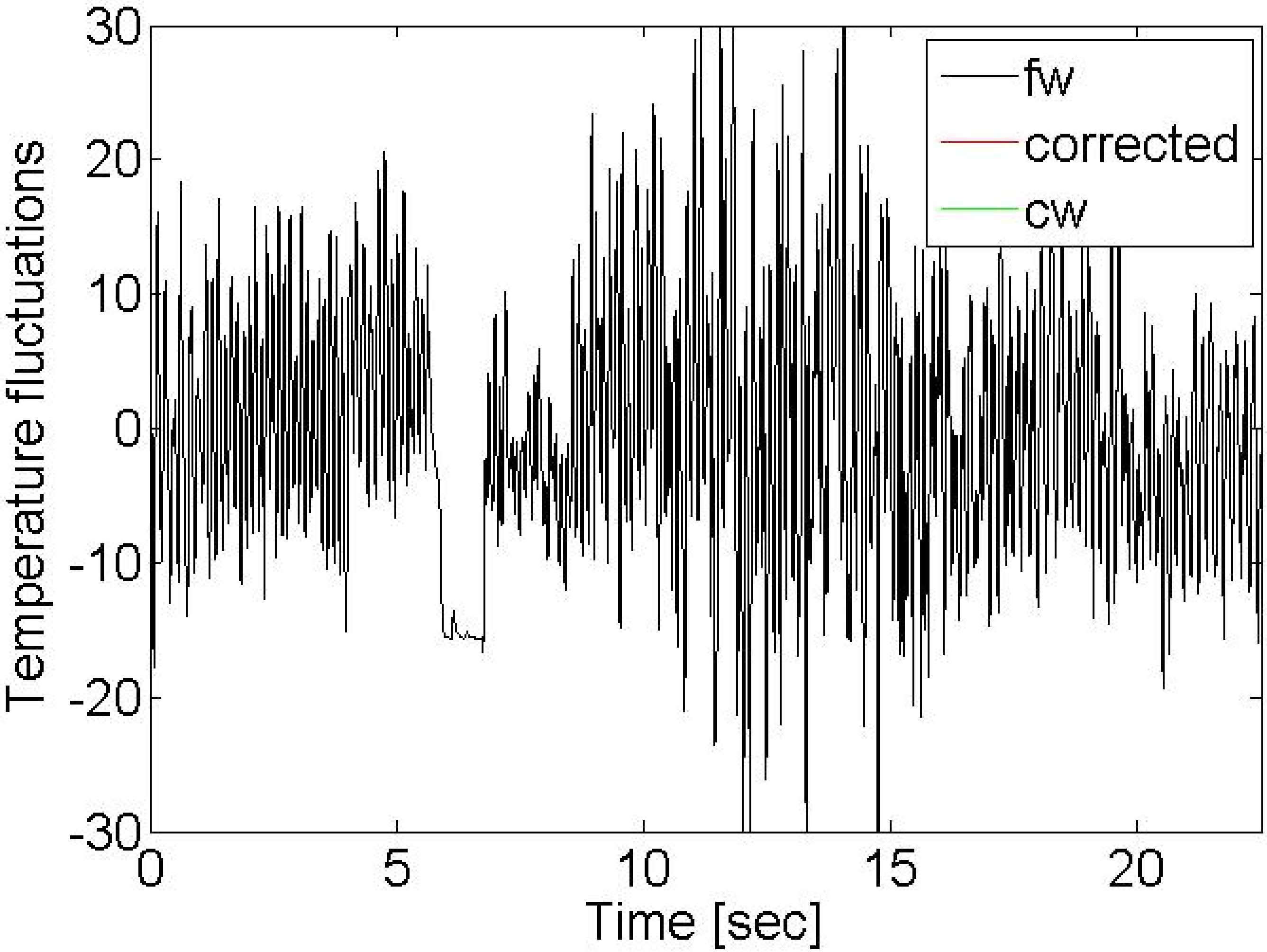


- Replotted calibration curves using the similarity variables of Hultmark and Smits (2010).

[Hultmark and Smits (2010)]

Cold wire attenuation

- Comparison of fine wire with cold wire



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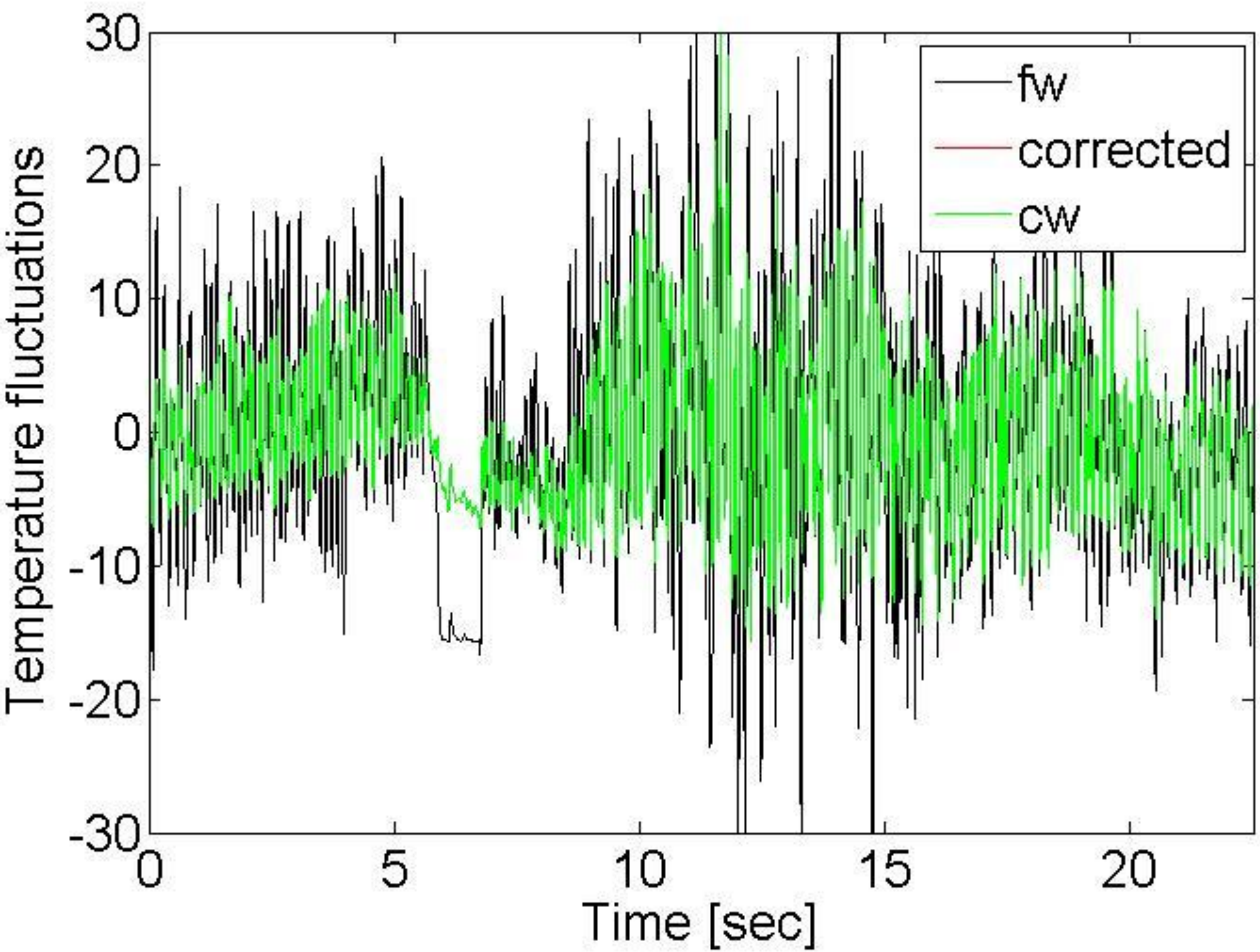
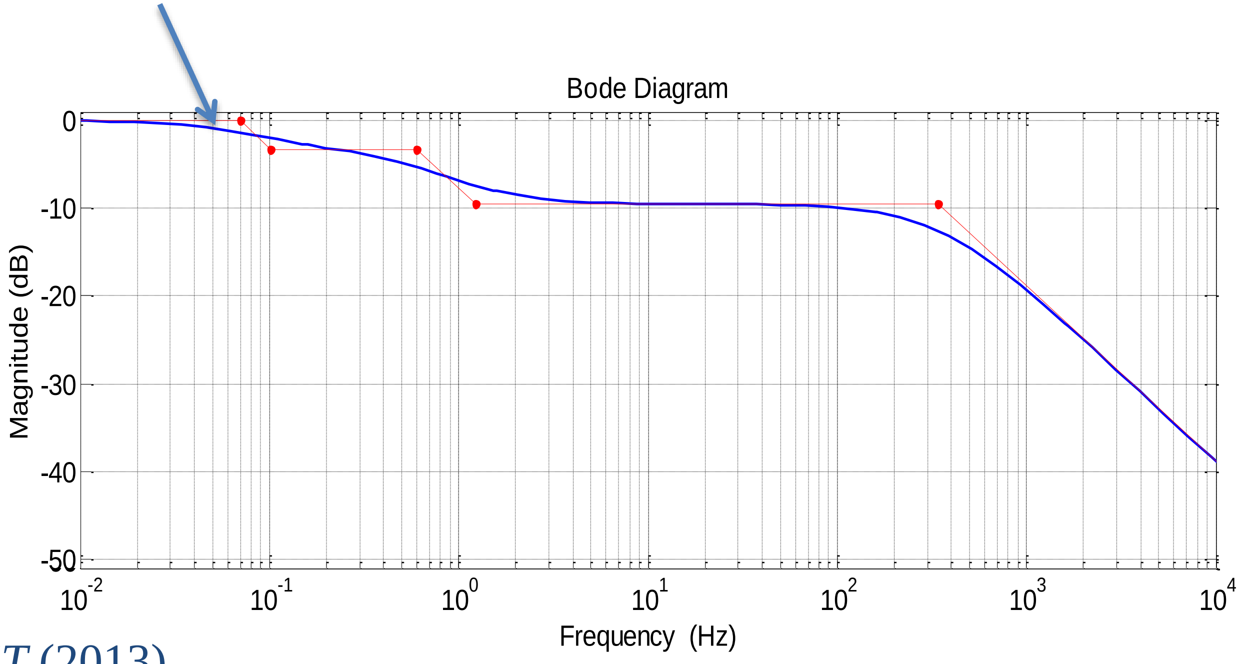


Dynamic calibration of cold wire for temperature measurements

The blue line indicates the FFT of the temperature time-series signal.

The red line indicates the amount of attenuation for different frequency ranges.

almost no attenuation from 1/100 Hz to 1/10 Hz



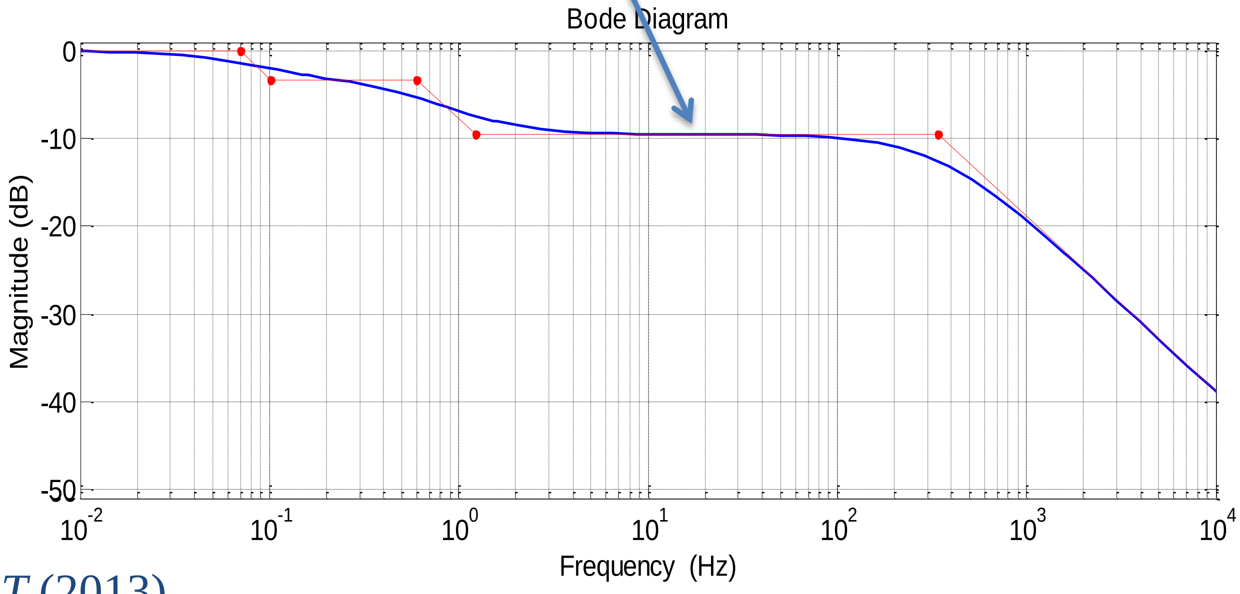
Arwatz *et al. MST* (2013)

Dynamic calibration of cold wire for temperature measurements

The blue line indicates the actual signal

The red line indicates the amount of attenuation for different frequency ranges.

10 dB attenuation from 1Hz to 200Hz



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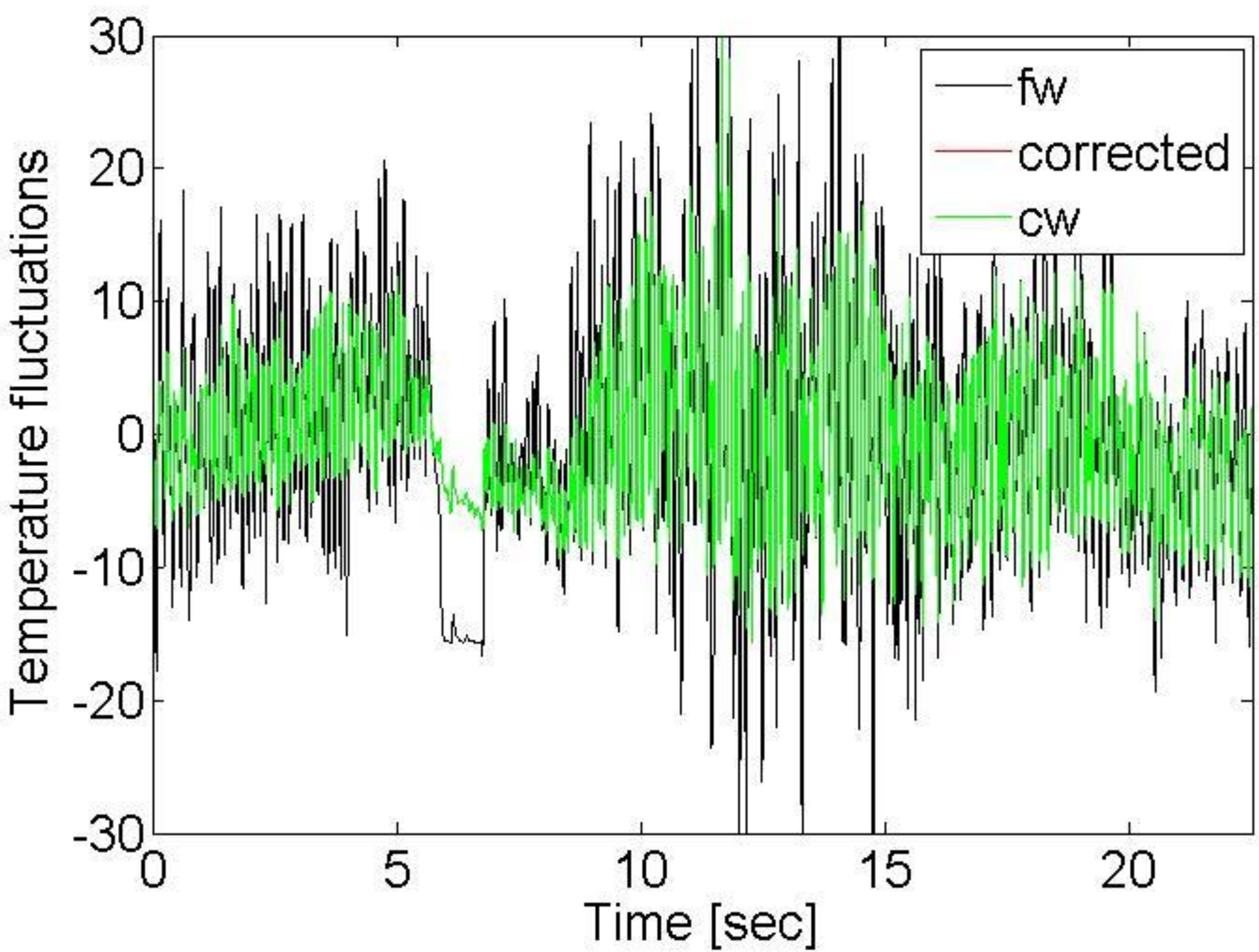
Correcting for cold wire attenuation

- Comparison of fine wire with cold wire



Correcting for cold wire attenuation

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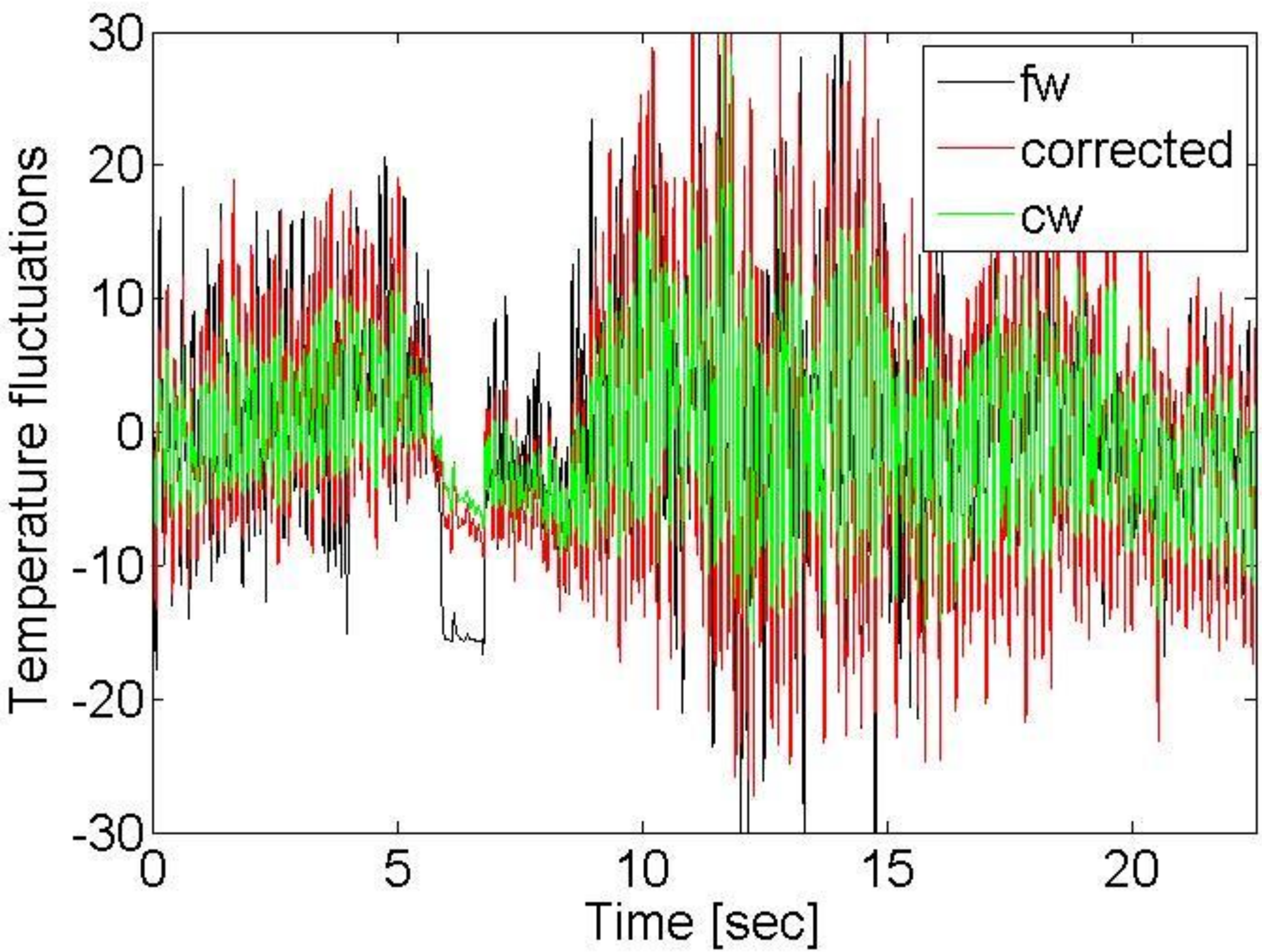

Experimental Results

Turbulence Kinetic Energy Budget (TKE) equation

$$\frac{\partial \bar{e}}{\partial t} + \bar{U}\frac{\partial \bar{e}}{\partial z} = \frac{g}{\bar{\bar{\theta}}}(\overline{w'\theta'}) - \overline{u'w'}\left(\frac{\partial \bar{U}}{\partial z}\right) - \frac{\partial(\overline{w'e})}{\partial z} - \frac{1}{\rho}\frac{\partial(\overline{w'p'})}{\partial z} - \varepsilon$$

I II III IV V VI VII

- I - Storage term
- II - Advection of TKE
- III - Buoyant production
- IV - Shear production
- V - Turbulent transport of TKE

VI - Pres. Corr. Term

VII - Dissipation of TKE

Turbulence Kinetic Energy Budget (TKE) equation

- Assuming horizontal homogeneity and neglecting subsidence.

$$\frac{\partial \bar{e}}{\partial t} + \bar{U}\frac{\partial \bar{e}}{\partial z} = \frac{g}{\bar{\theta}}(\overline{w'\theta'}) \quad -\overline{u'w'}\left(\frac{\partial \bar{U}}{\partial z}\right) - \frac{\partial(\overline{w'e})}{\partial z} \quad - \frac{1}{\rho}\frac{\partial(\overline{w'p'})}{\partial z} \quad - \varepsilon$$

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Turbulence Kinetic Energy Budget (TKE) equation

- Assuming horizontal homogeneity and neglecting subsidence.
- Did not measure pressure fluctuation term.

$$\frac{\partial \bar{e}}{\partial t} + \bar{U}\frac{\partial \bar{e}}{\partial z} = \frac{g}{\bar{\theta}}(\overline{w'\theta'}) - \overline{u'w'}\left(\frac{\partial \bar{U}}{\partial z}\right) - \frac{\partial(\overline{w'e})}{\partial z} - \frac{1}{\rho}\frac{\partial(\overline{w'p'})}{\partial z} - \varepsilon$$

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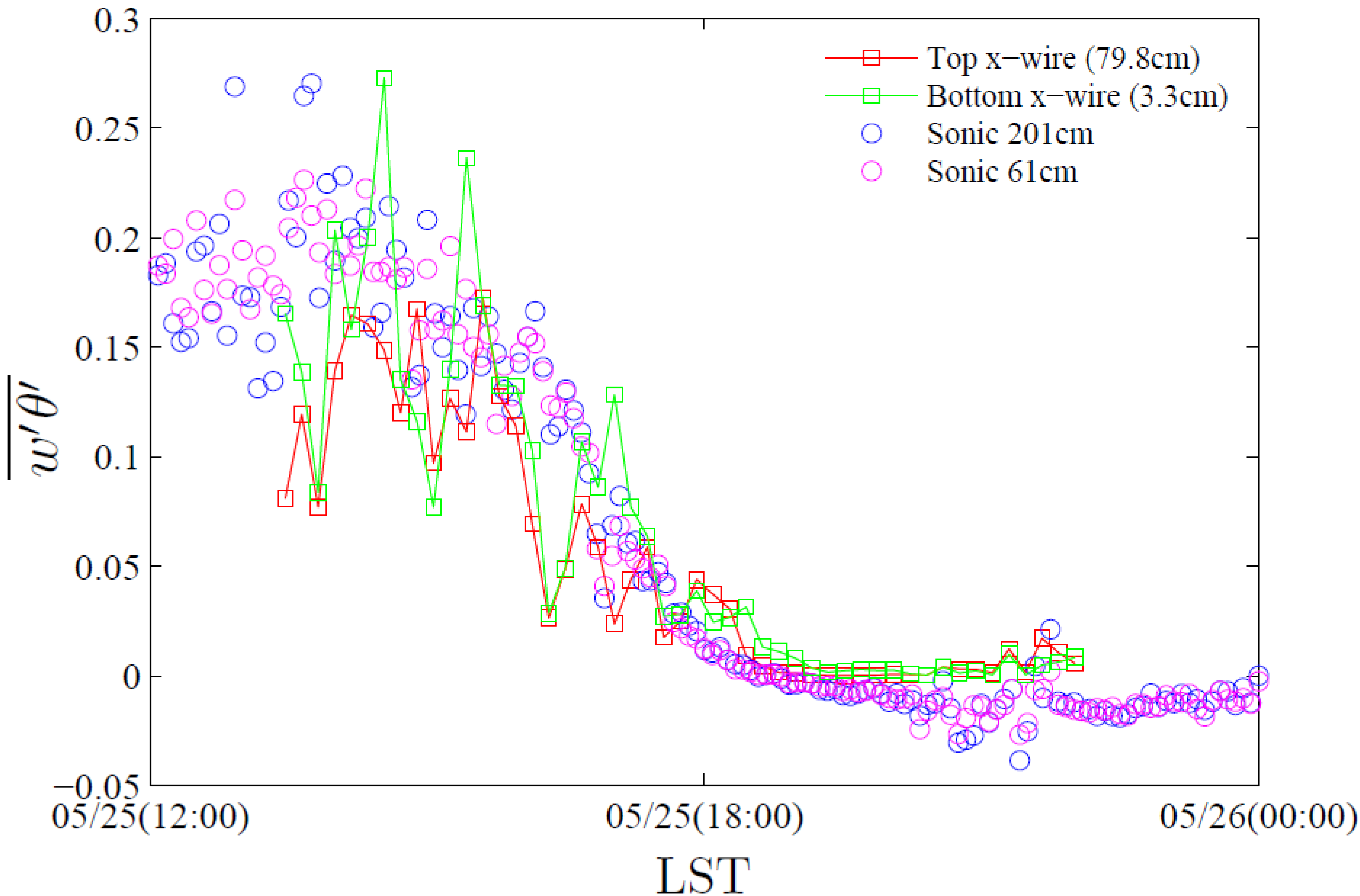
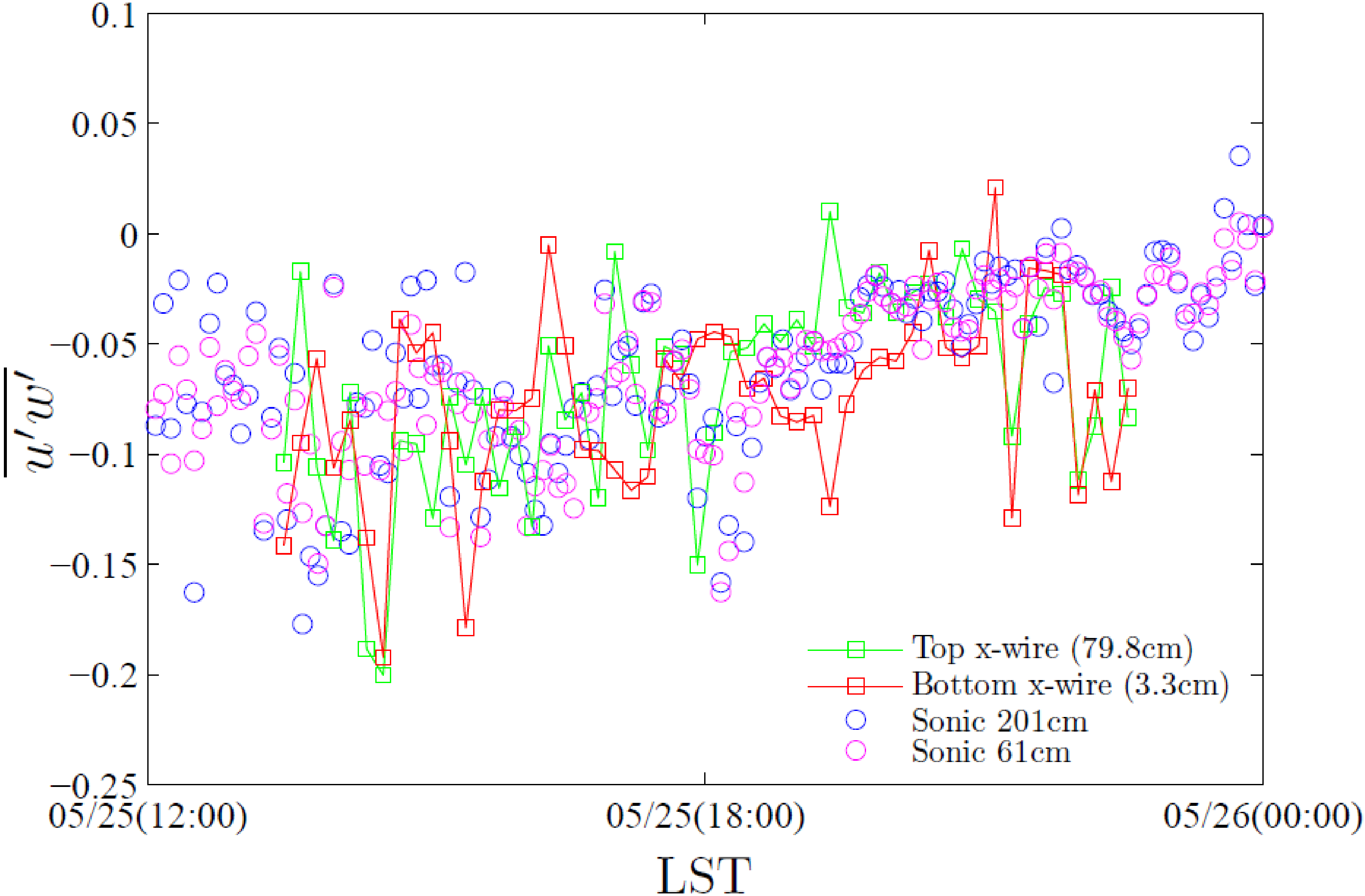
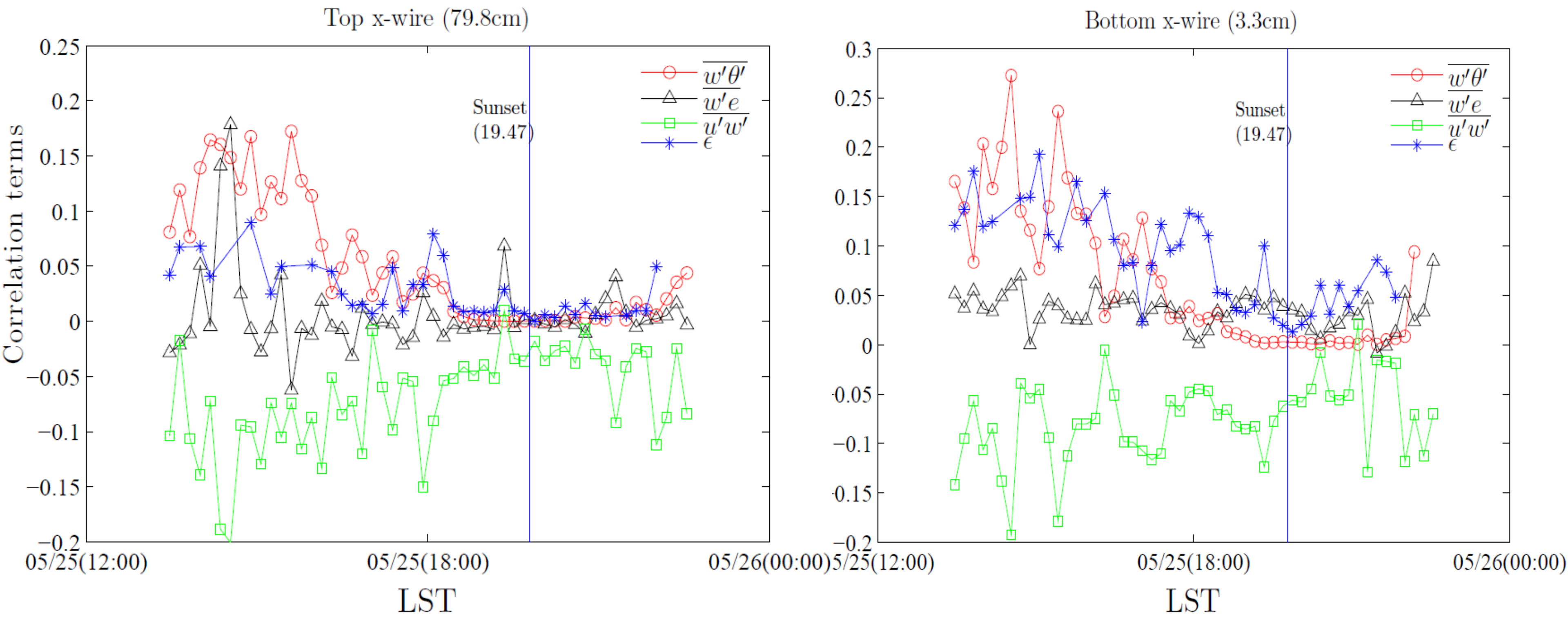
Sensible heat flux comparison for Sonic and X-wire data sets (Spring 2013 – IOP 9)



Momentum flux comparison for Sonic and X-wire data sets (Spring 2013 – IOP 9)



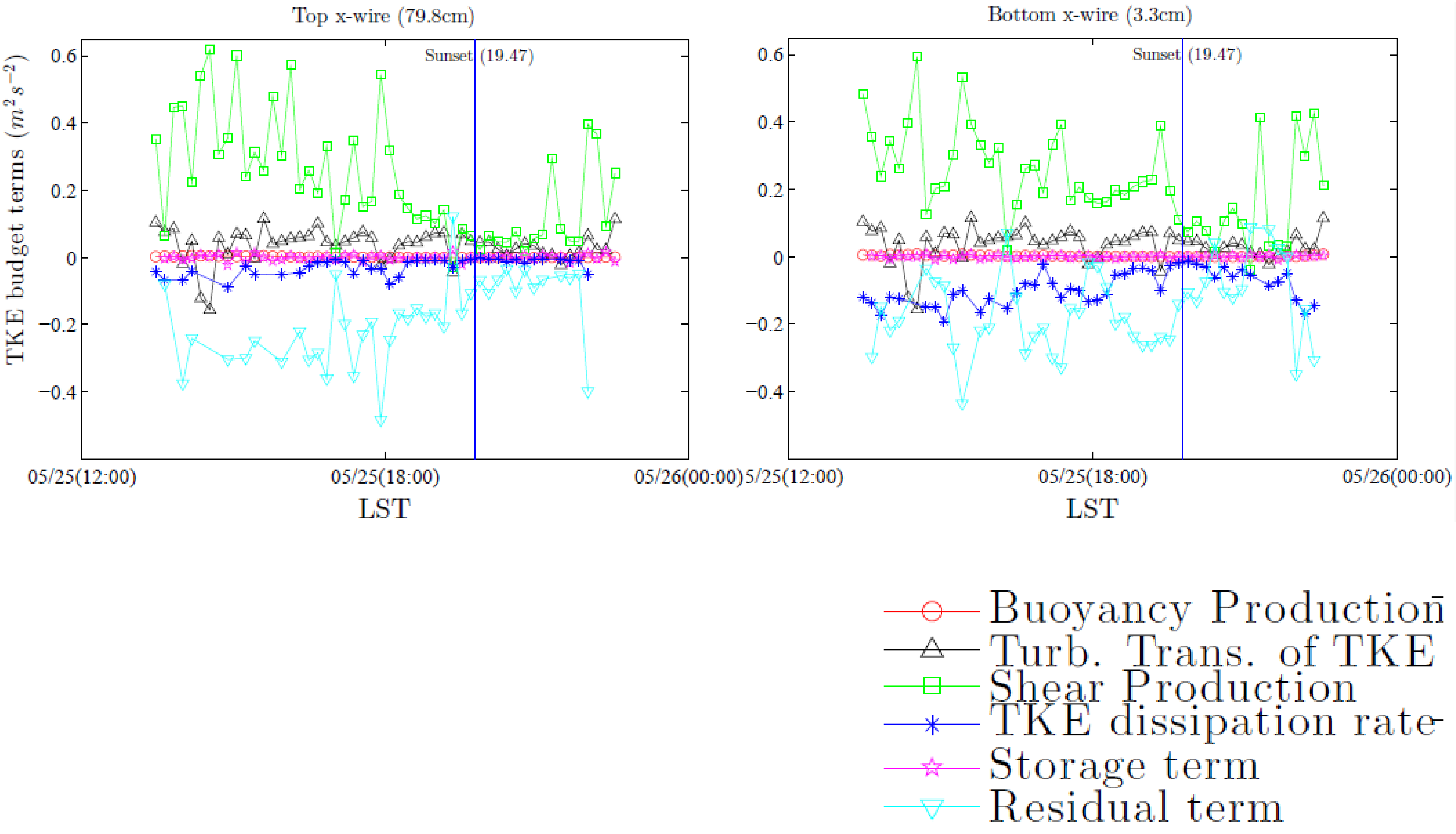
TKE Budget (correlation) terms



(Spring 2013 – IOP 9)

Non-normalized TKE budget terms

(Spring 2013 – IOP 9)



Non-normalized TKE budget terms

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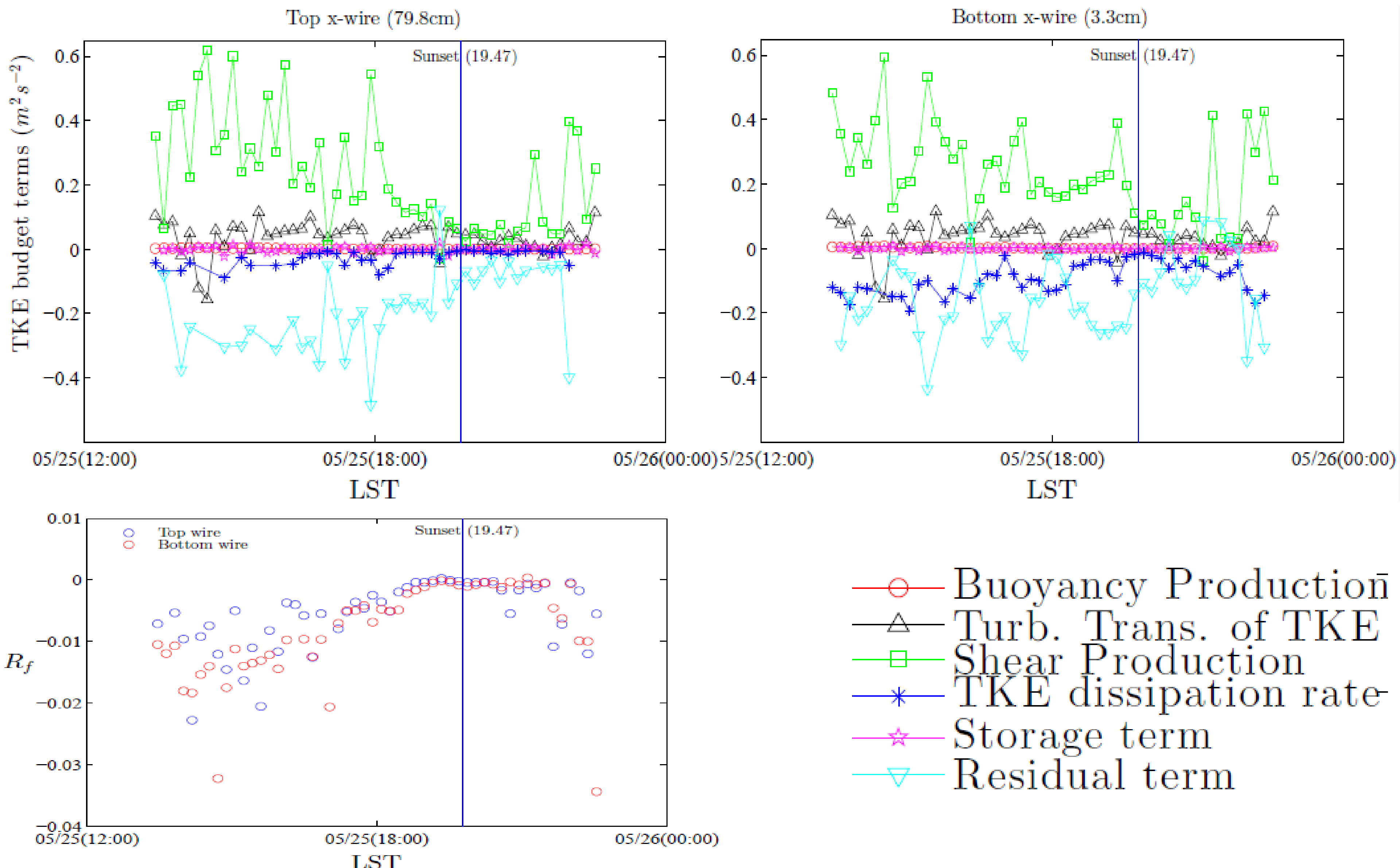

Energy spectra

- Six 10 mins windows were chosen from the X wire closest (3.3cm) to the playa from 2pm – 4pm LST on May, 25 – 2013 (IOP 9).

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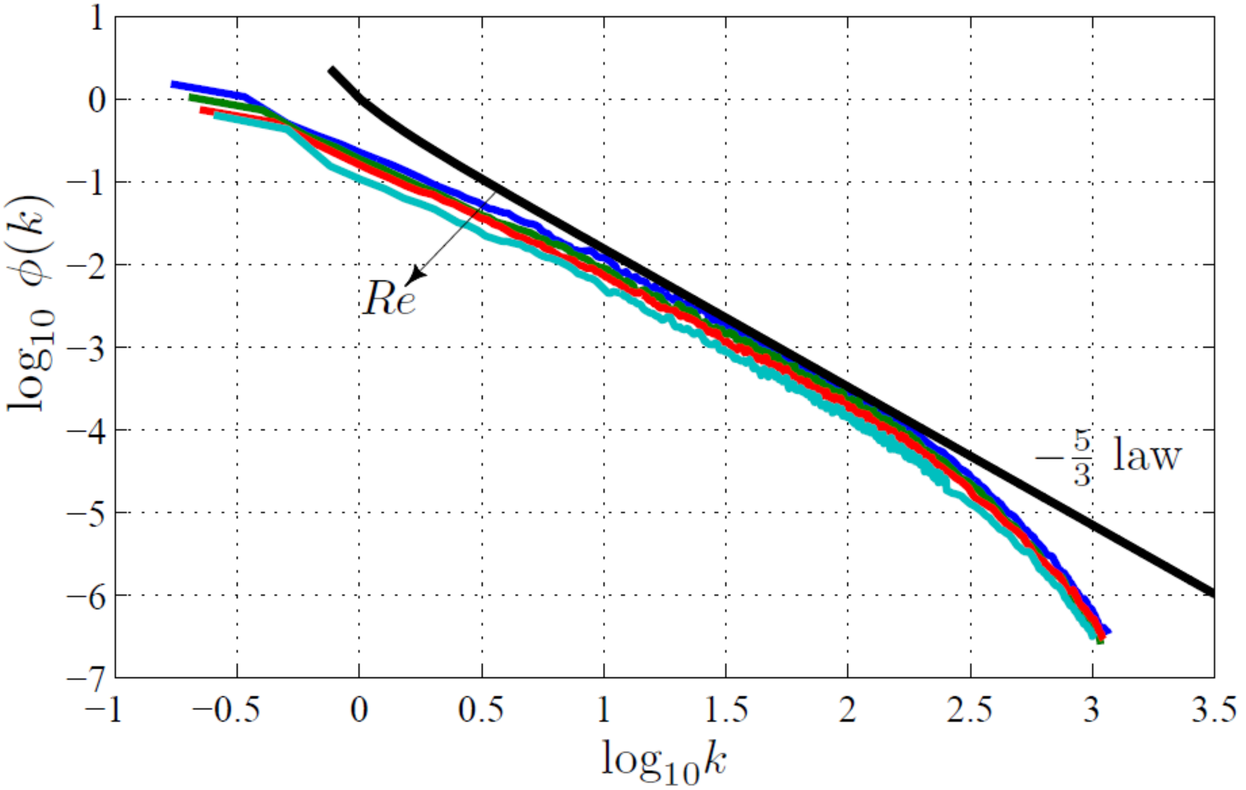

- The spectra profiles look self-similar.

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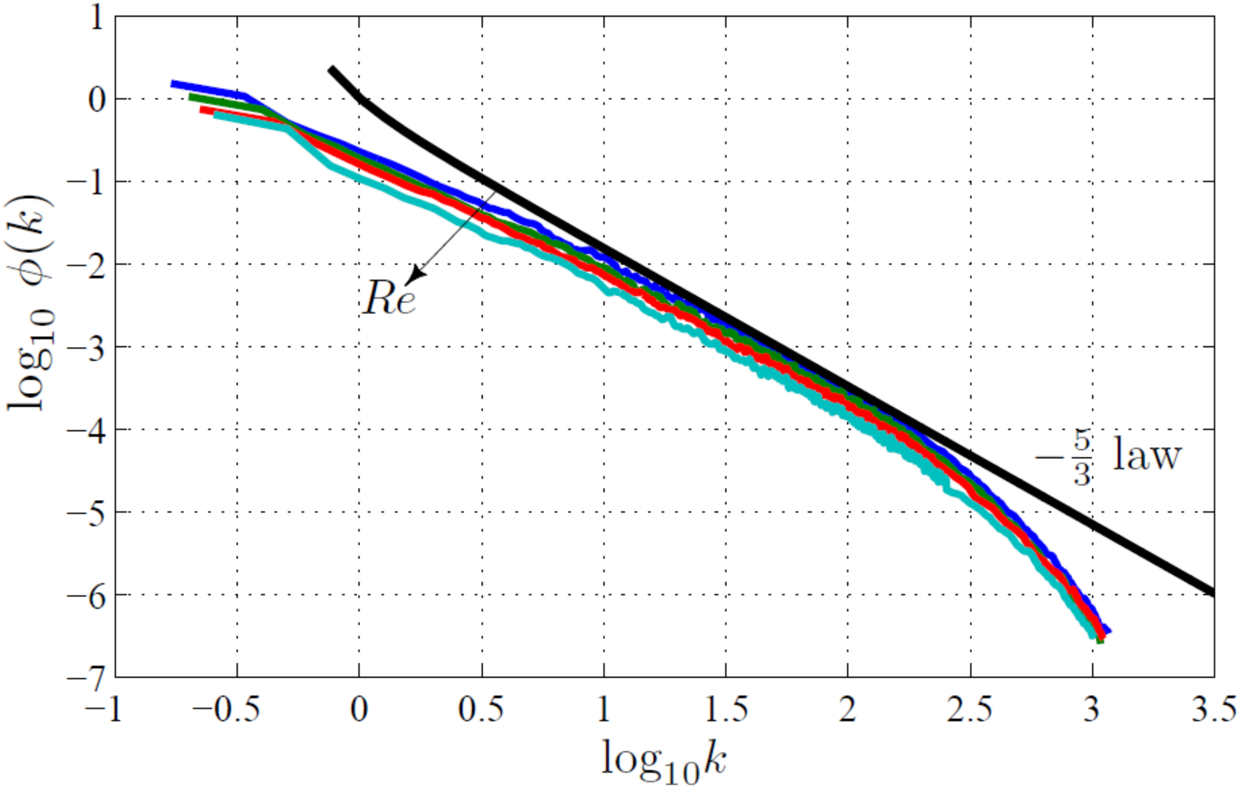

- -5/3 slope is evident in the dissipation region.

Conclusions

- The techniques and the issues associated with measuring velocity and temperature fluctuations were addressed.
- As expected the local rate of change of turbulence energy (Term I) is small compared to other terms.
- The dissipation rate (Term VII) was estimated from the inertial sub-range of the velocity spectrum.
- The turbulent transport (Term V) appears as a gain indicating the energy will be transported within the layer and dissipated locally.
- Small magnitudes of Turbulent transport and Buoyancy production terms indicate a trend towards balance between shear production and dissipation
- The large residual appears to reflect the importance of the unmeasured Pressure transport term.
- Energy spectra is self-similar and exhibits -5/3 slope in the dissipation region.

Acknowledgement

This research was funded by Office of Naval Research Award # N00014-11-1-0709, Mountain Terrain Atmospheric Modeling and Observations (MATERHORN) Program.