Highly resolved turbulence budgets over a desert playa

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Motivation

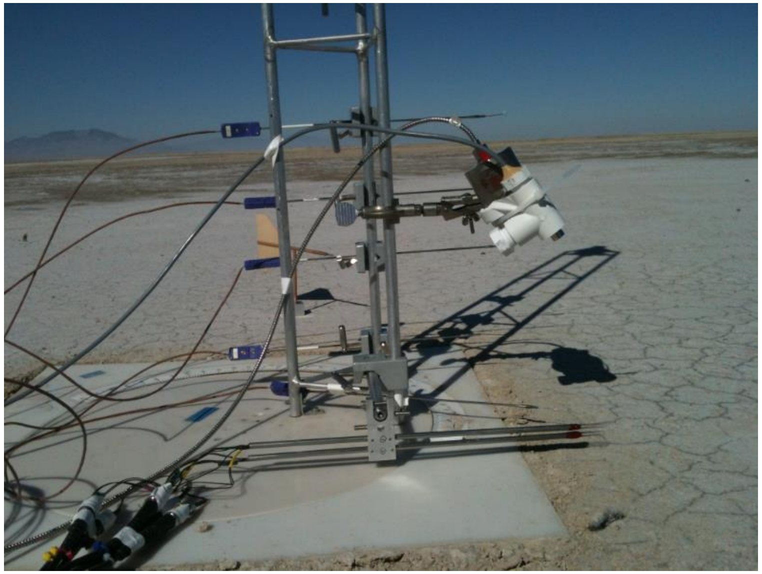
- Measurements of shear production, buoyancy production, turbulent transport and the dissipation rate of TKE terms in the budget of turbulent kinetic energy and the terms in the scalar (Temperature) variance budget were made during the MATERHORN experimental campaign at the SLTEST site of the US army’s Dugway Proving Grounds in the Utah’s west desert.

- The velocity and temperature fluctuations were obtained with two co-located x-wire and cold wires that are very close to the playa surface (~ 2cm to 50cm).

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 at the site



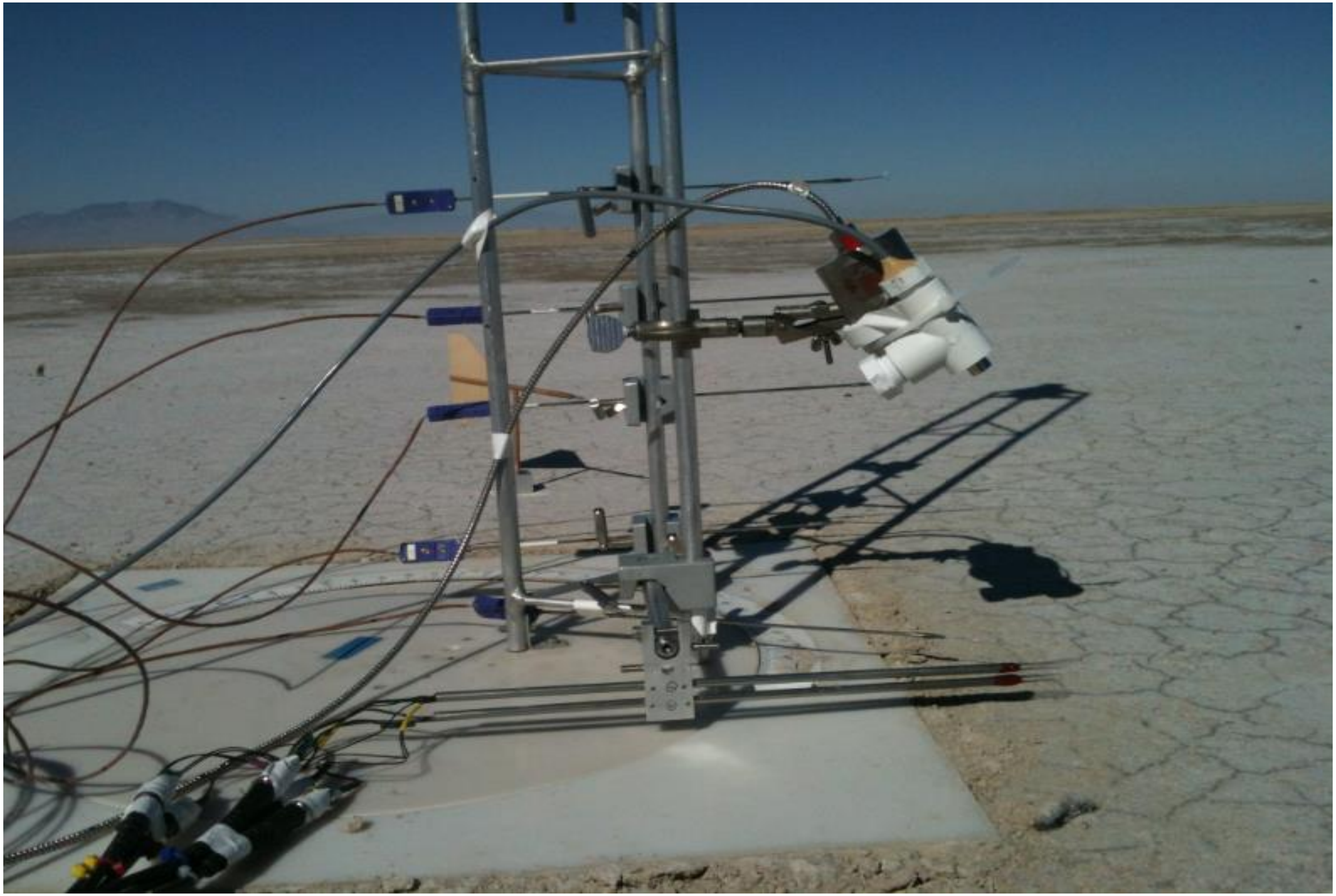
Known for :

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

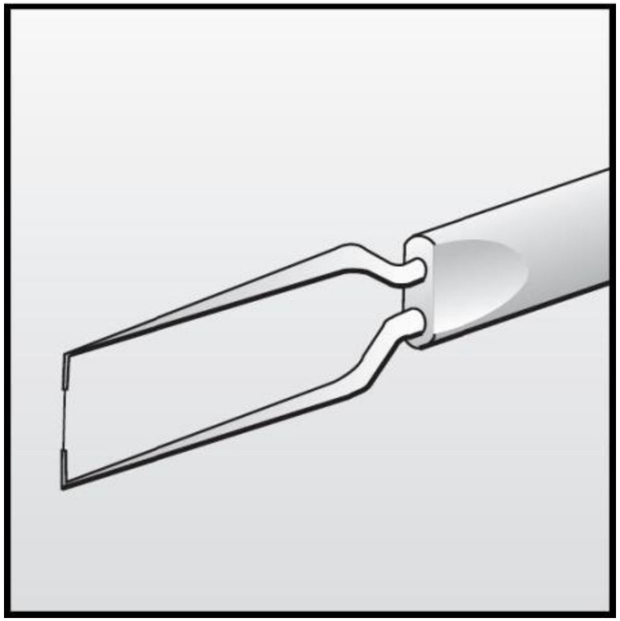
Issues :

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

Experimental Setup

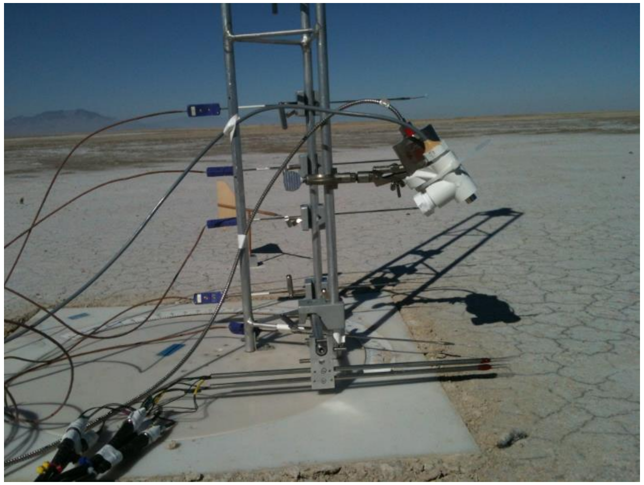


Hot-Wire Anemometer



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

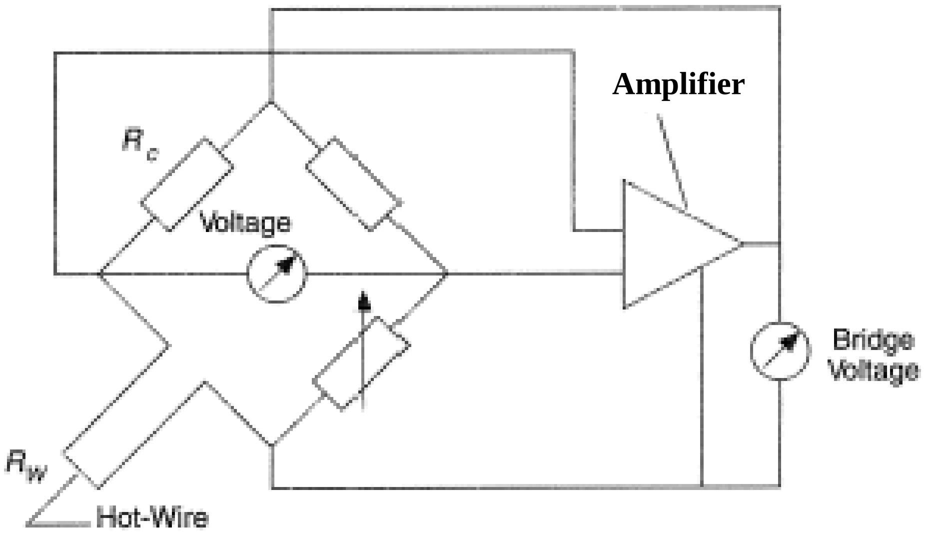
Anemometer operation modes

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

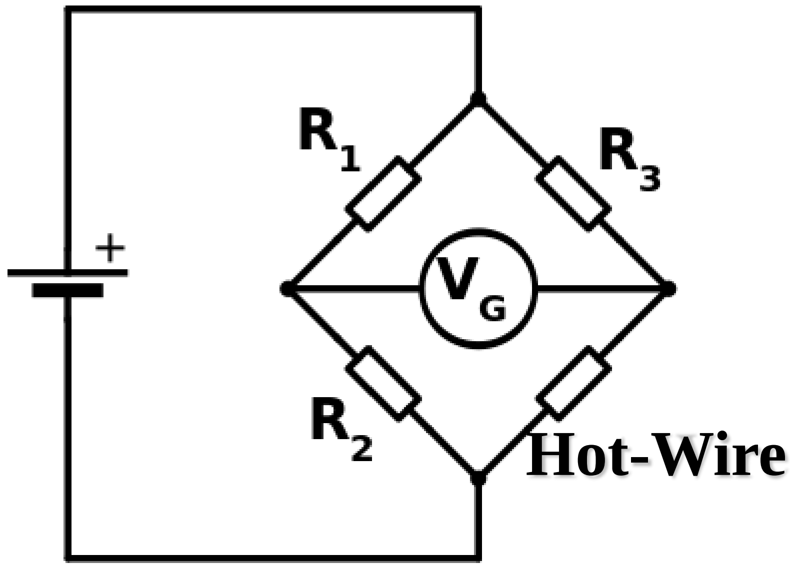
Constant current CCA (temperature) :

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



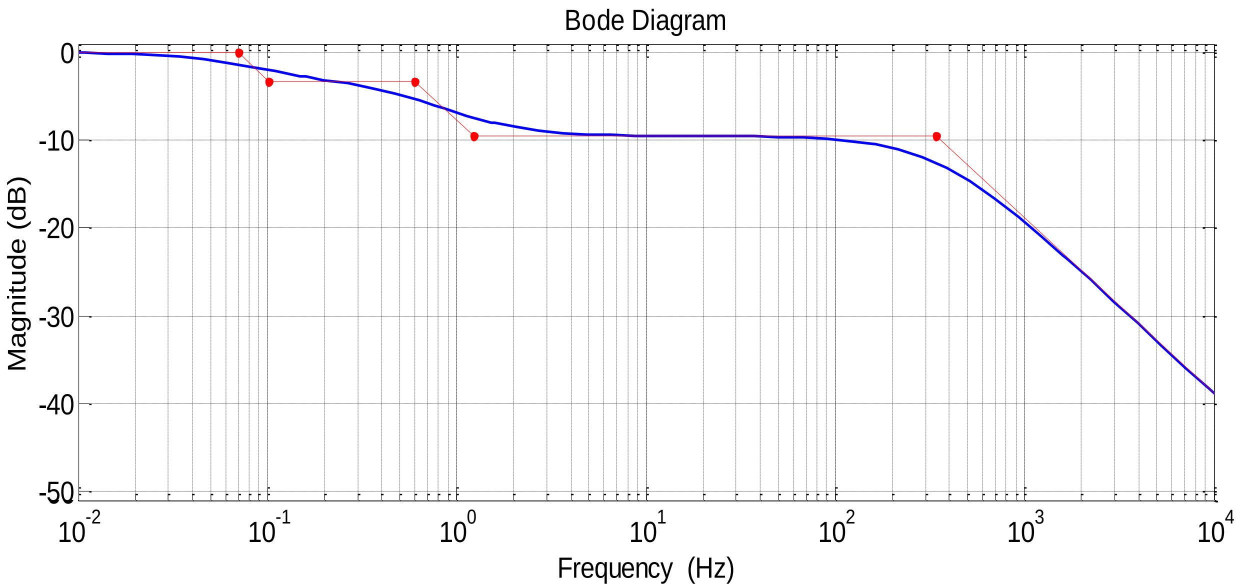
Temperature measurement (CCA)

- Serves as a constant current source with zero offset, R1=R3>>R2
- I_x~0.2 mA, V_x=20 mV



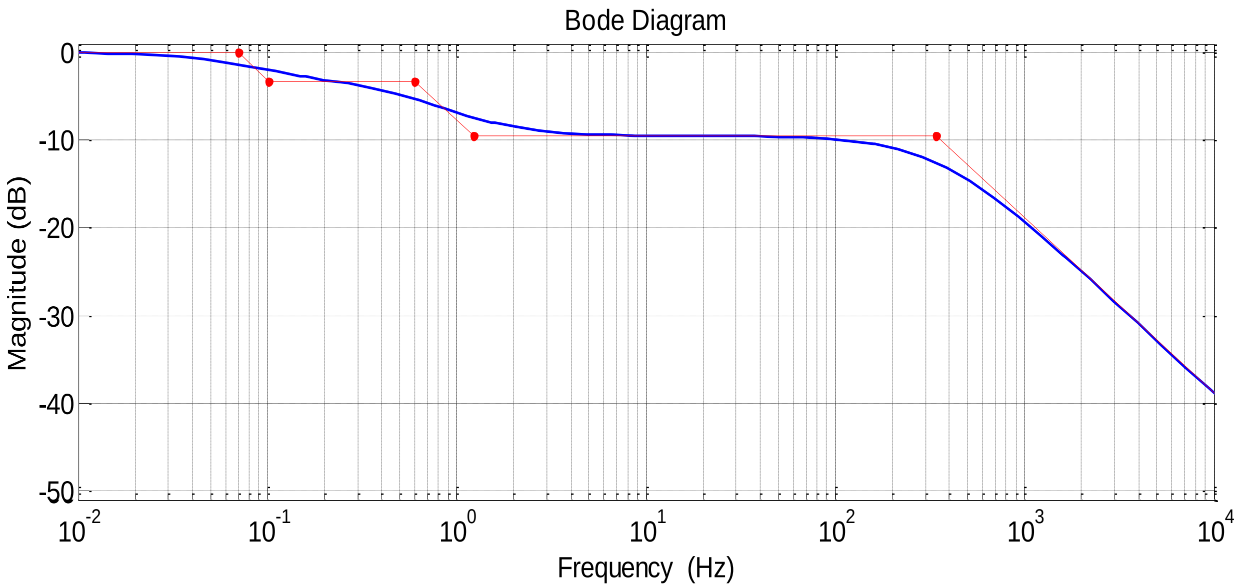
Dynamic calibration and modeling of a cold wire for temperature measurements

This plot shows the Bode diagram for the frequency response of a Cold wire system (measuring temperature fluctuations).



Dynamic calibration and modeling of a cold wire for temperature measurements

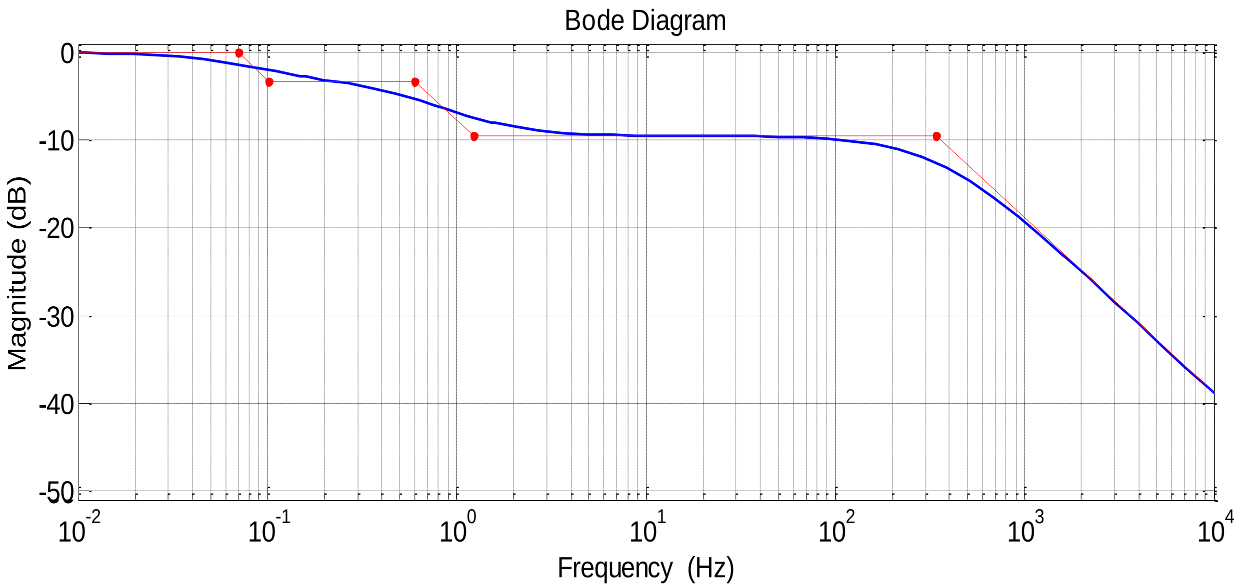
The blue line indicates the actual signal



Dynamic calibration and modeling of a cold wire for temperature measurements

The blue line indicates the FFT of the actual temperature time series.

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

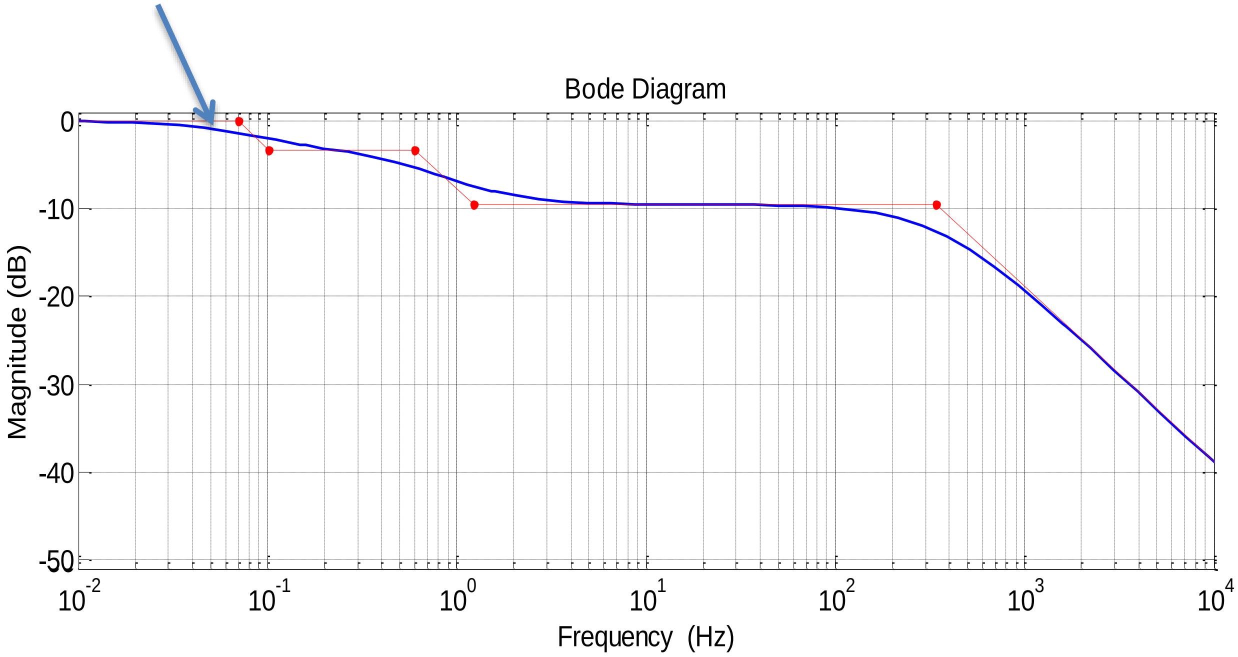


Dynamic calibration and modeling of a cold wire for temperature measurements

The blue line indicates the actual signal

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

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

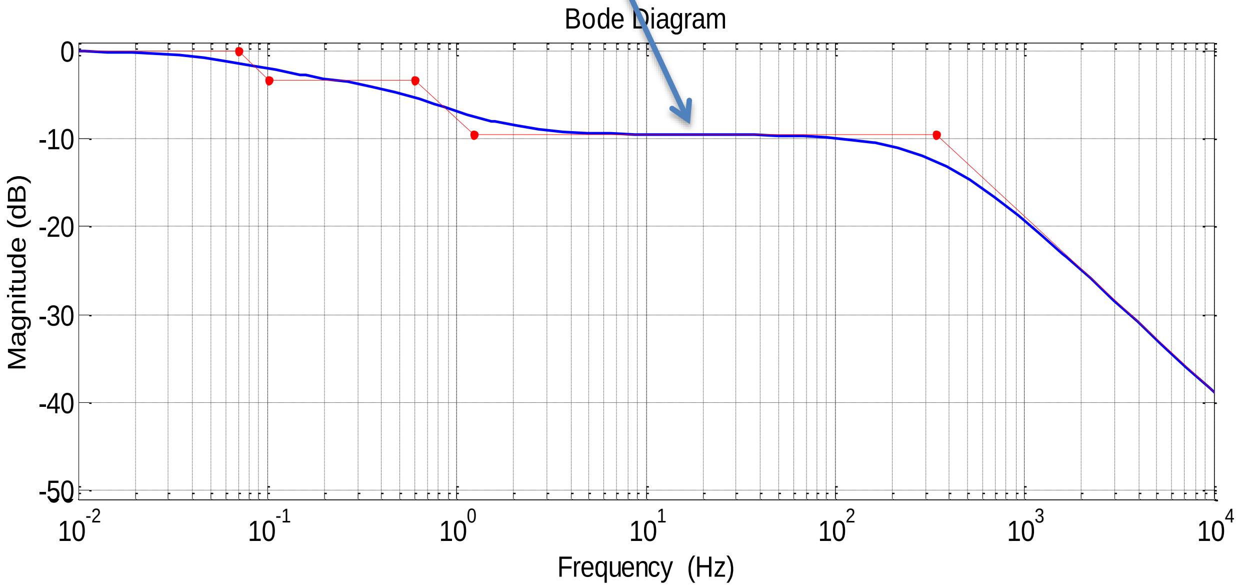


Dynamic calibration and modeling of a cold wire for temperature measurements

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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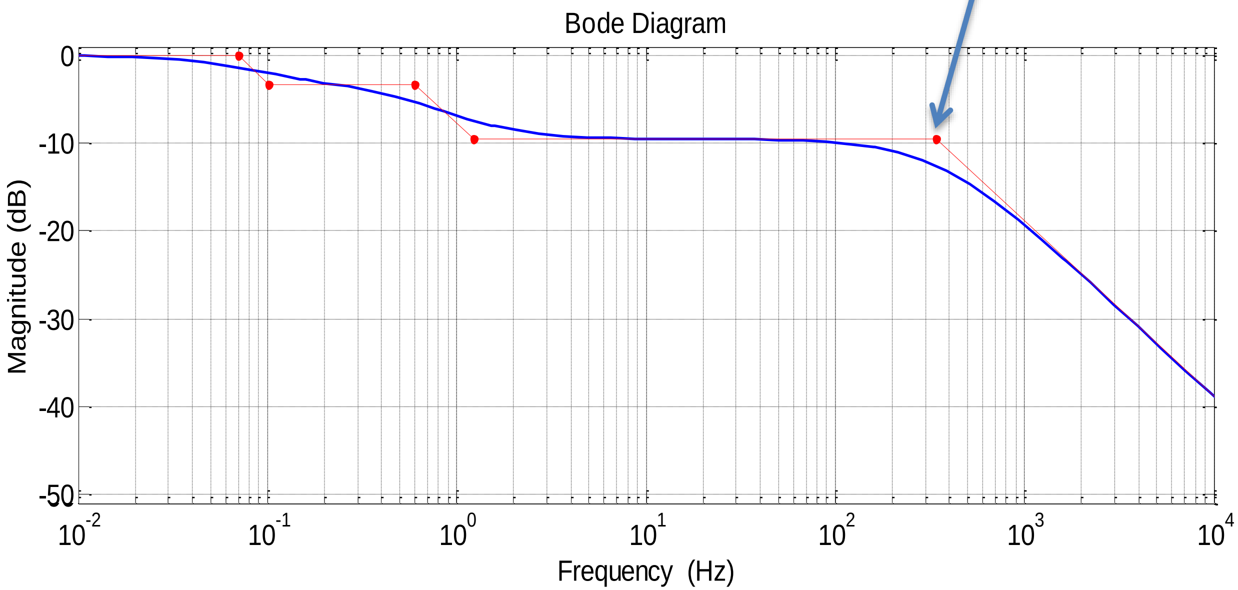
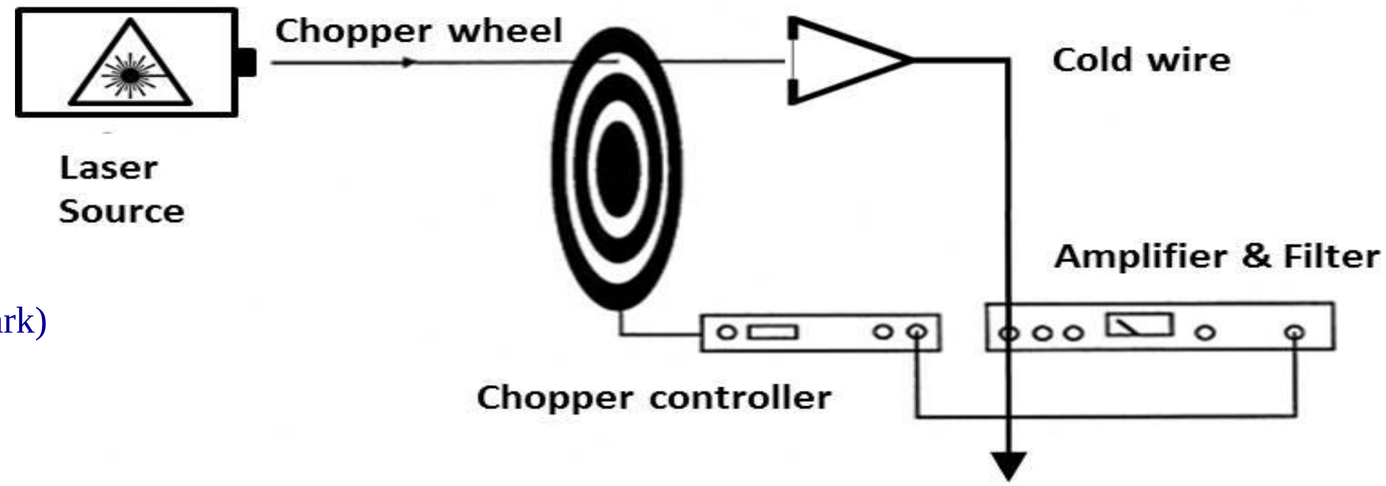
Roll – off frequency



Dynamic calibration set up

- Laser as heat source
- Optical chopper to vary the frequency



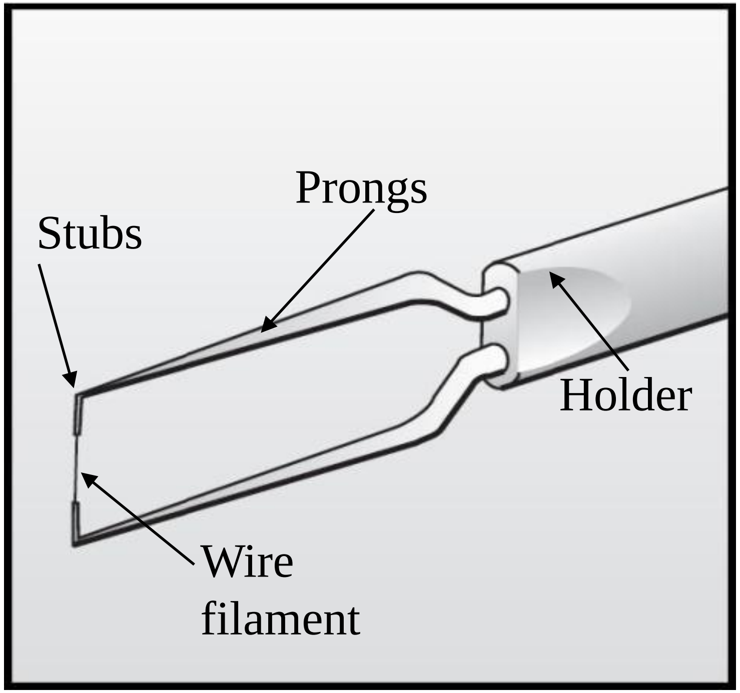
(Gilad and Hultmark)

Modeling the cold wire

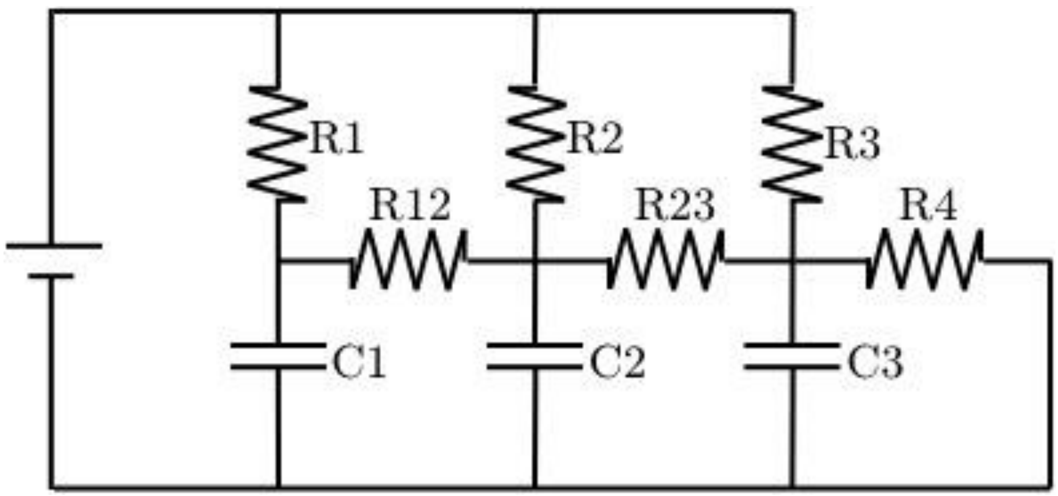
Considerations in constructing the model

(Gilad *et. al.* 2013**):**

- Three elements: wire filament, stubs, prongs
- Heat transfer to each element through laser source
- End conduction between adjacent elements
- Holder acts as a heat sink



Cold wire model (Gilad *et. al.* 2013)



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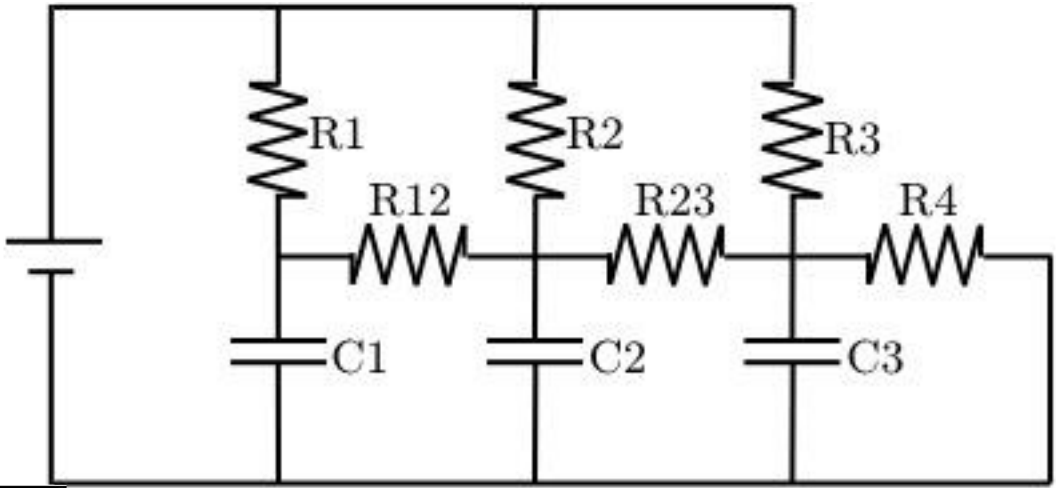
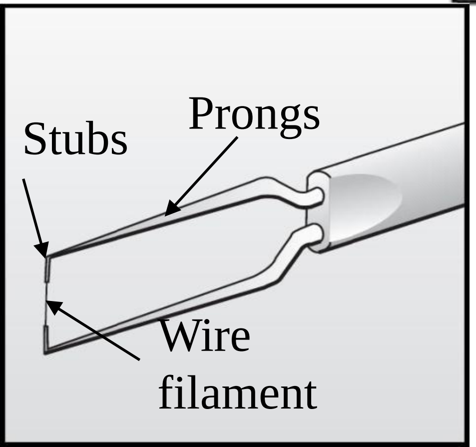
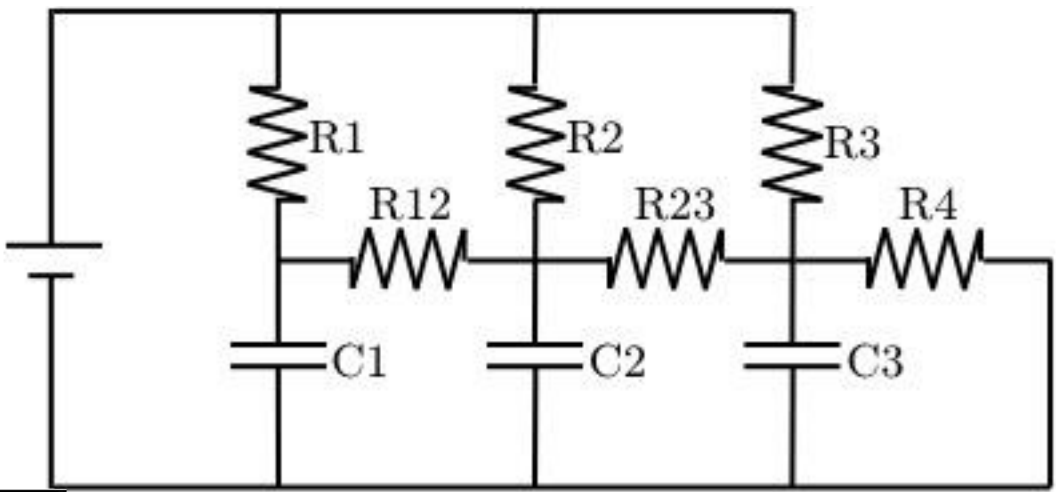
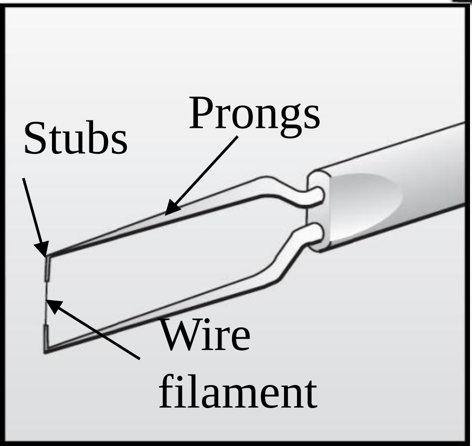




Cold wire model (Gilad *et. al.* 2013)



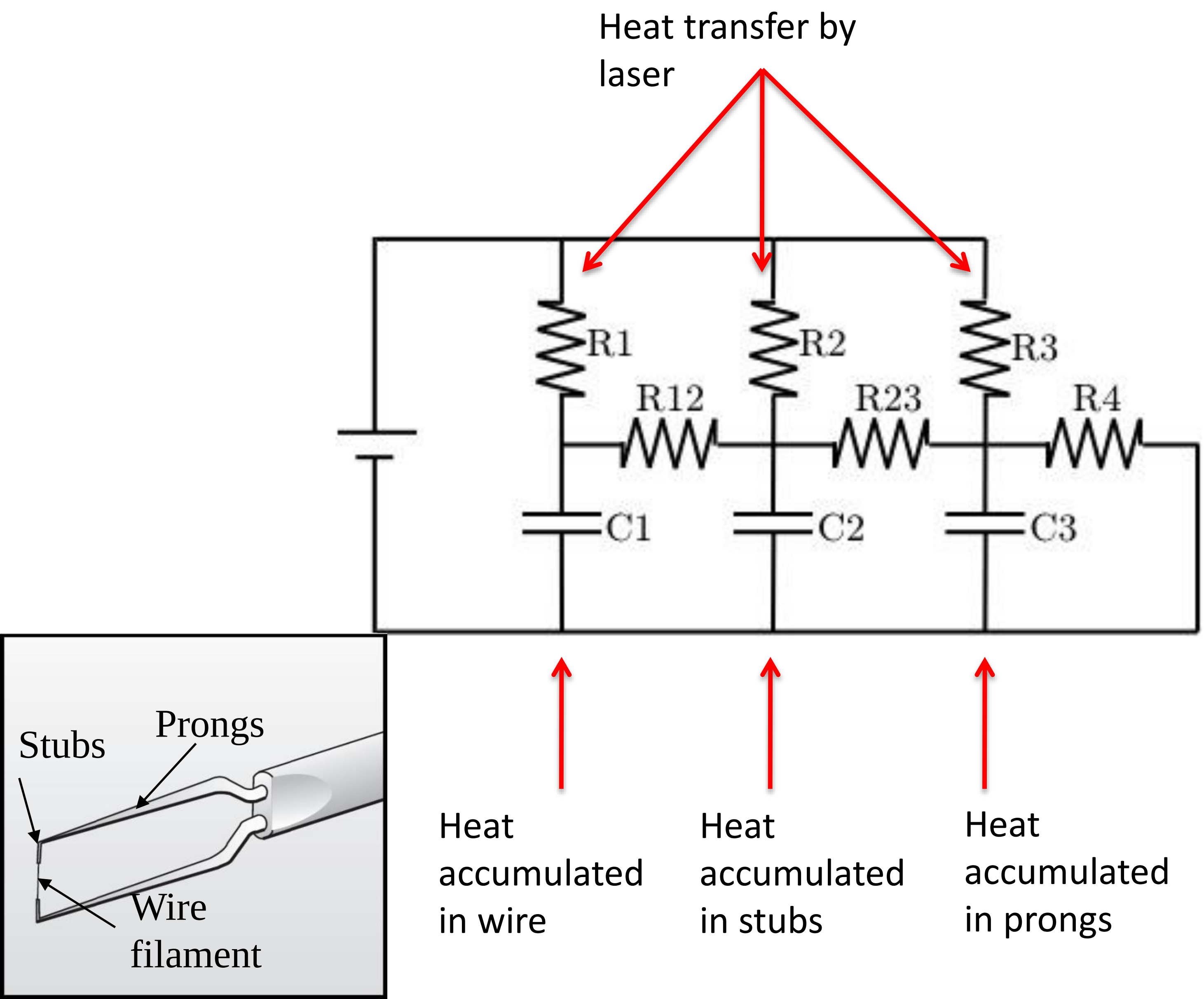


Heat accumulated in wire

Heat accumulated in stubs

Heat accumulated in prongs

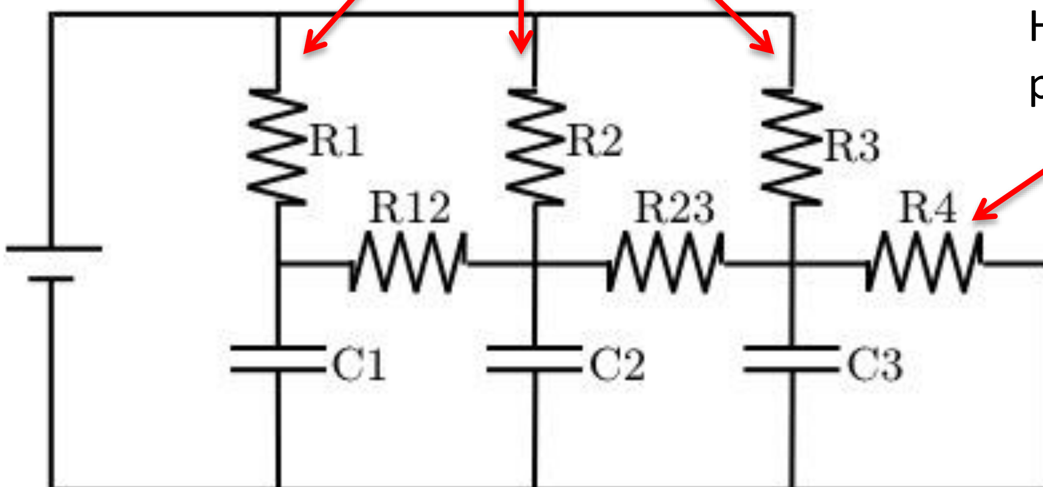
Cold wire model (Gilad *et. al.* 2013)

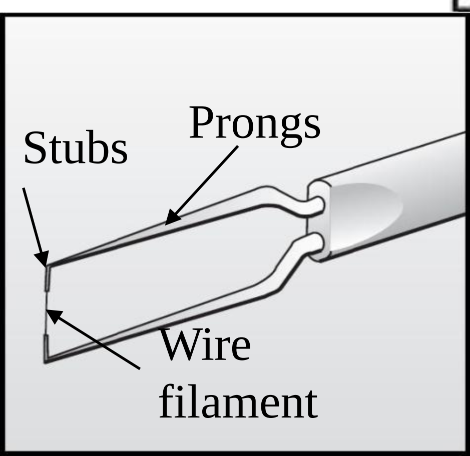


Cold wire model (Gilad *et. al.* 2013)

Heat transfer by laser

Heat conducted from prongs to holder





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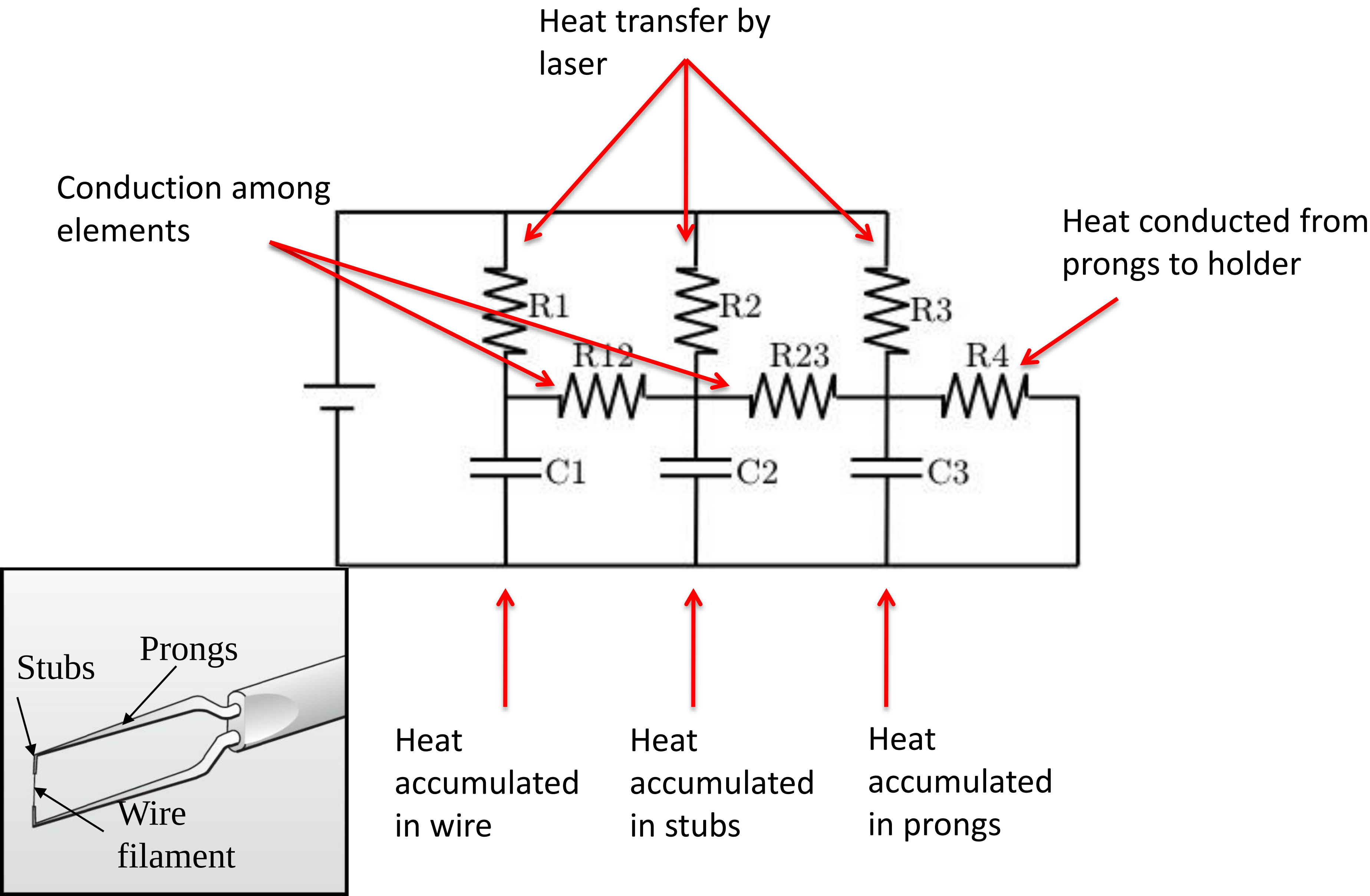
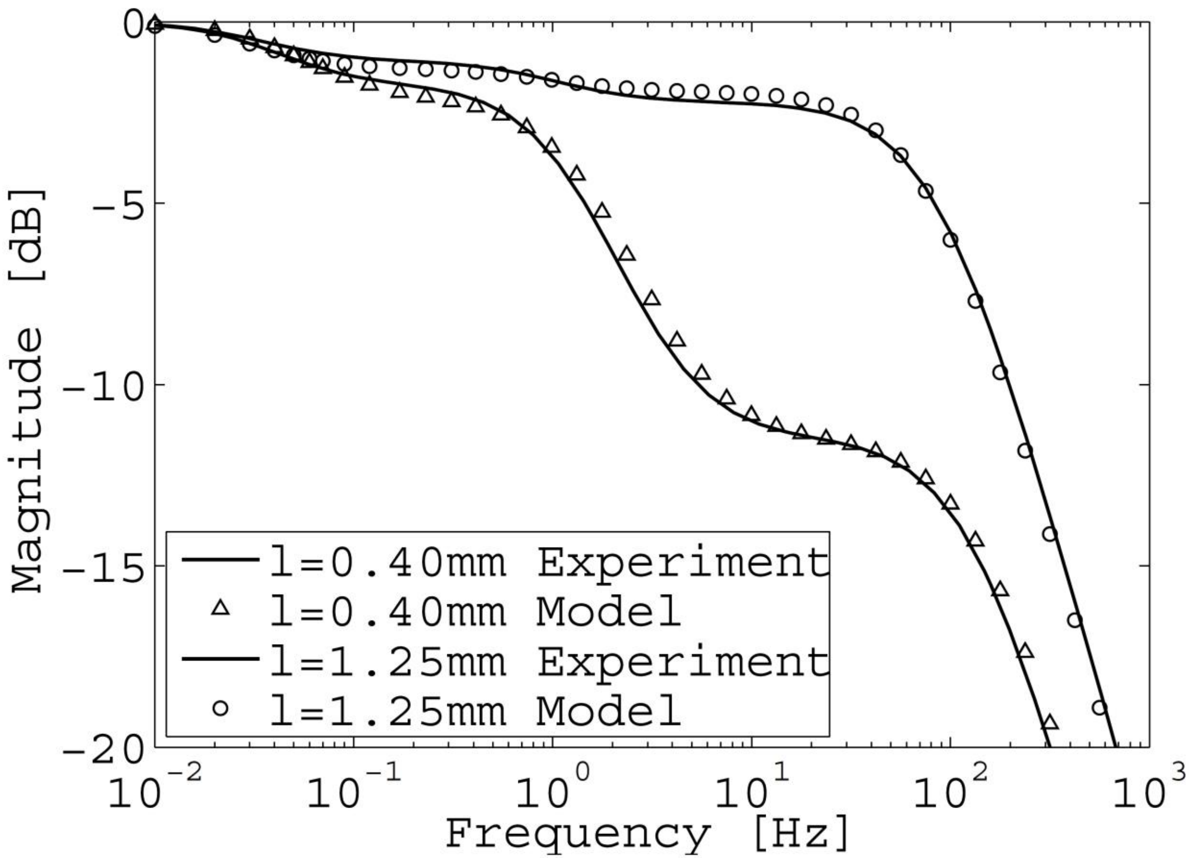


Results and the model

Wire filament length:

- Less attenuation for longer wire
- Lower roll-off frequency for longer wire

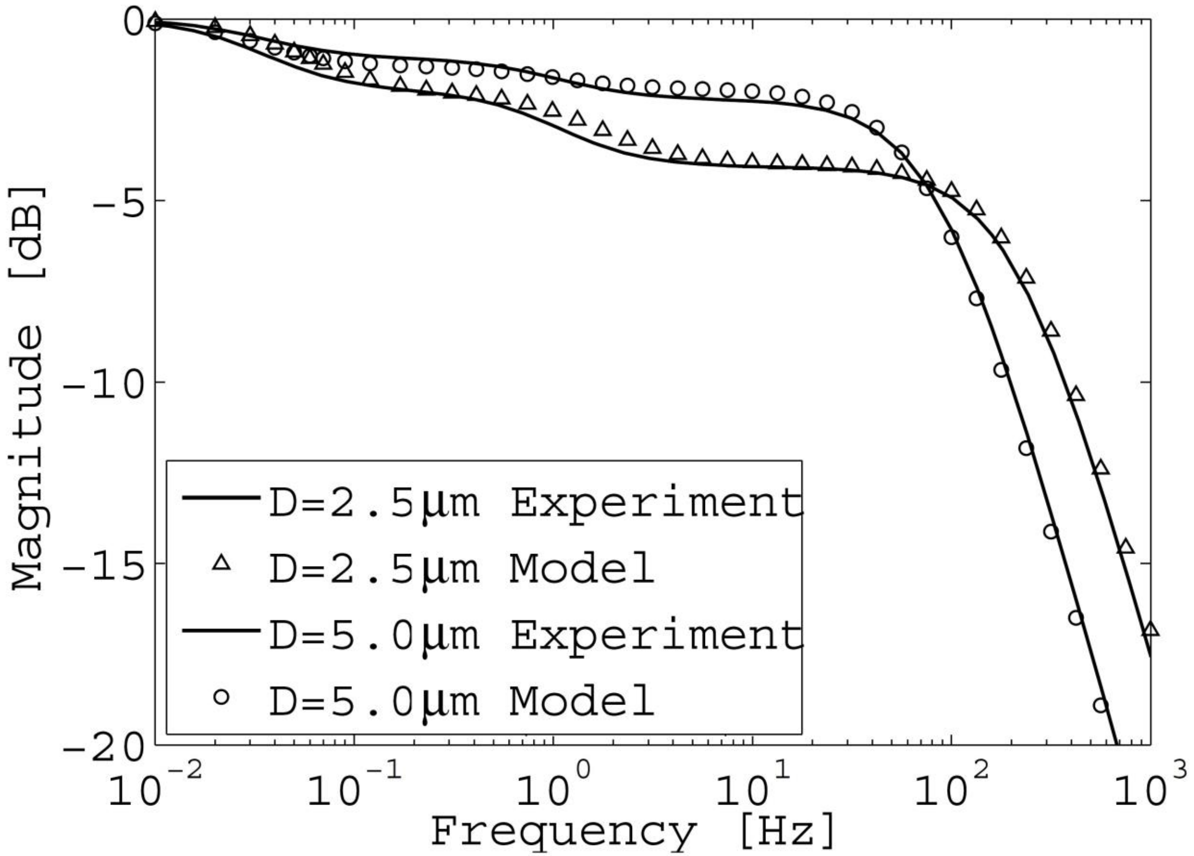


(Gilad *et. al*. 2013)

Results and the model

Wire filament diameter:

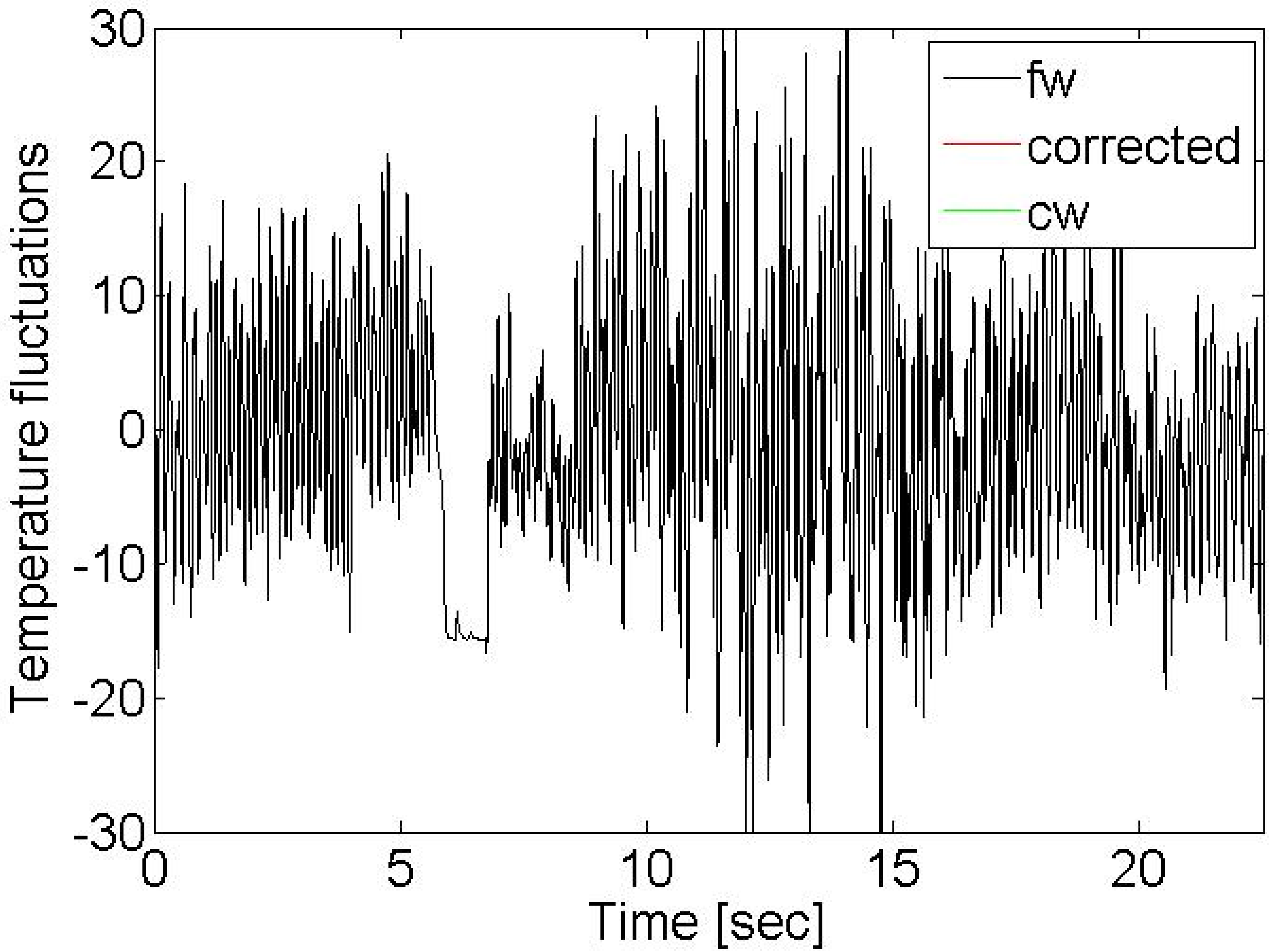
- Lower roll-off frequency for thicker wire



(Gilad *et. al.* 2013)

Experimental validation

- Oscillating jet of hot air
- Comparison of fine wire with cold wire



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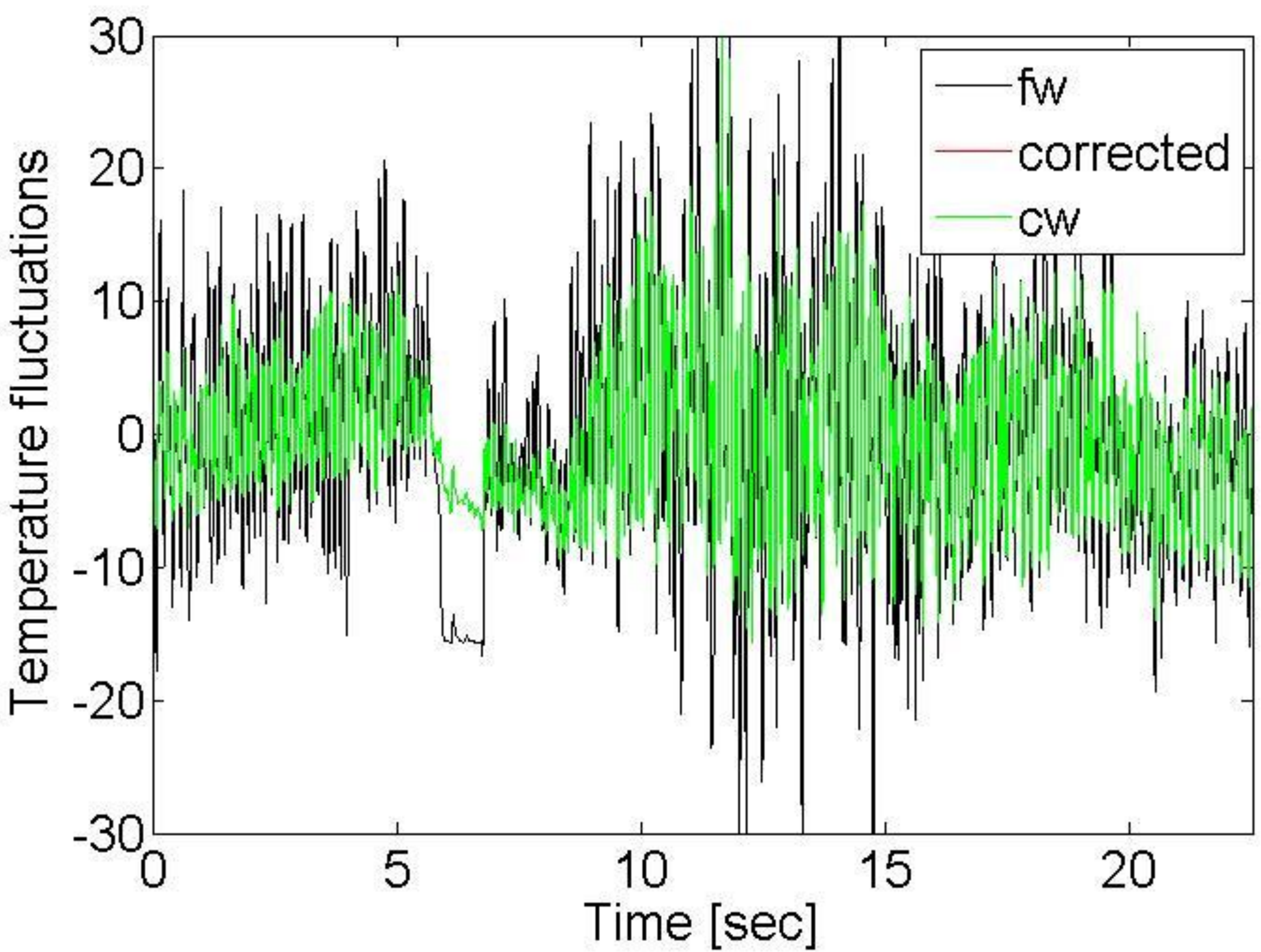

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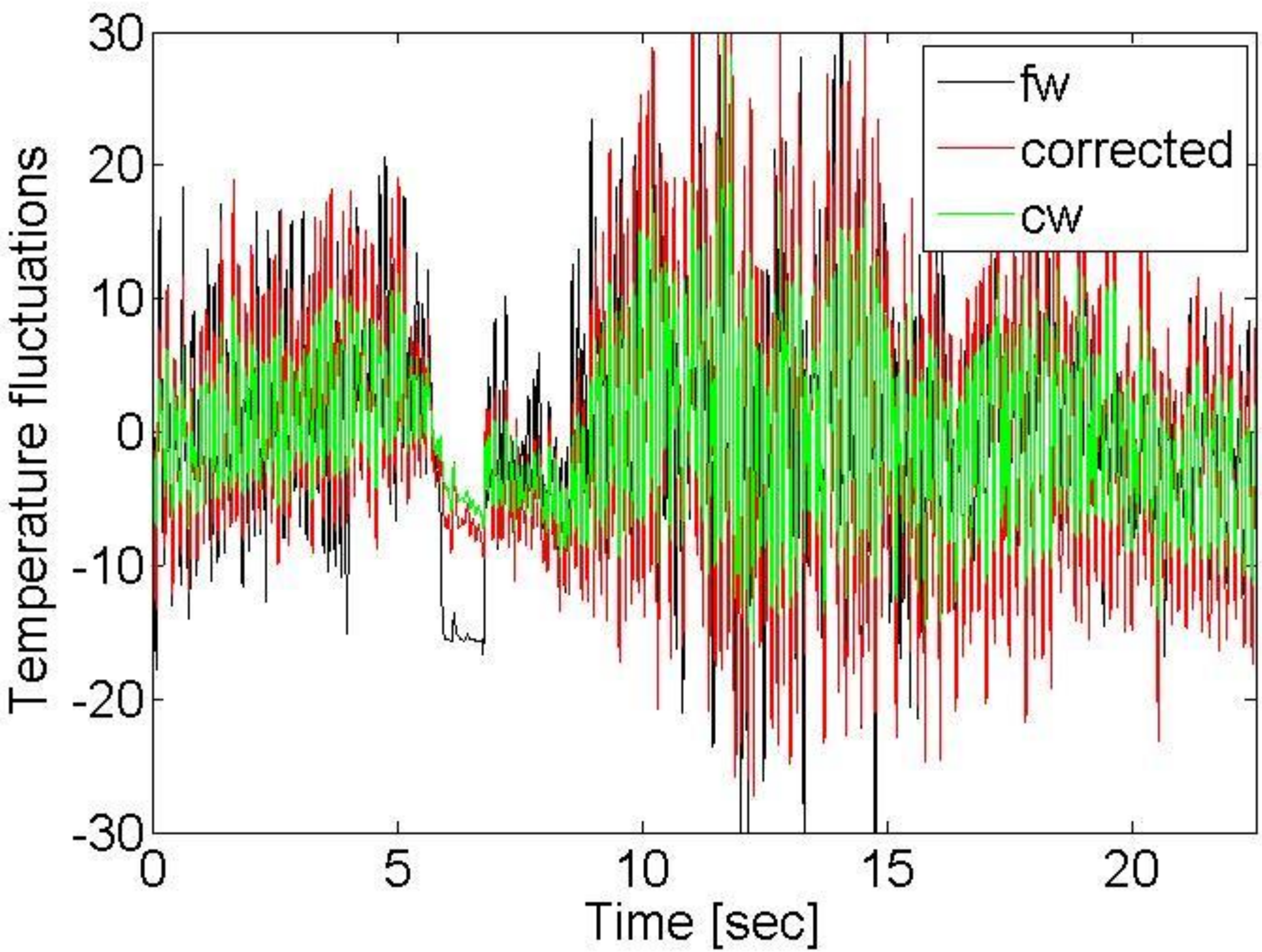
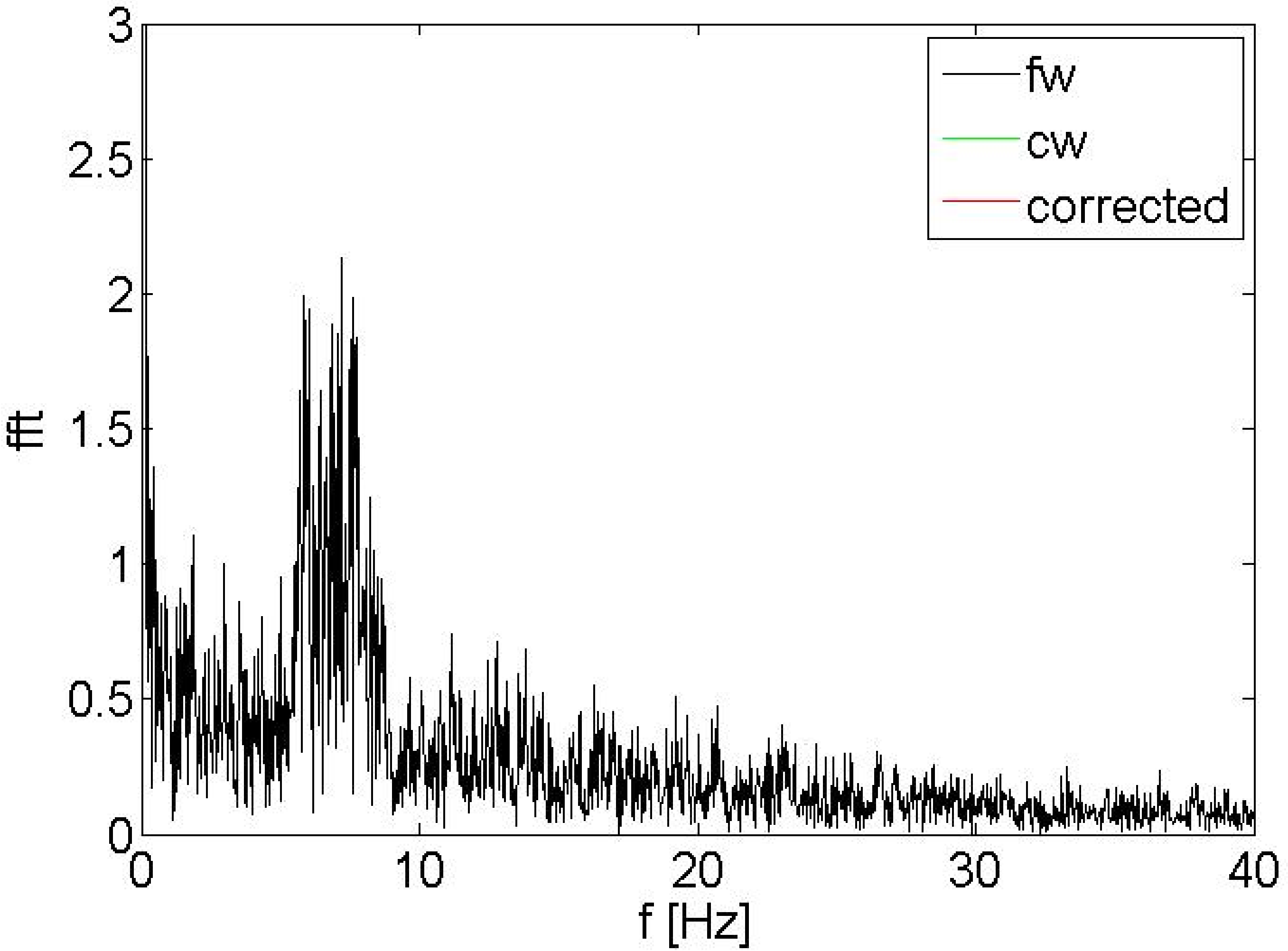


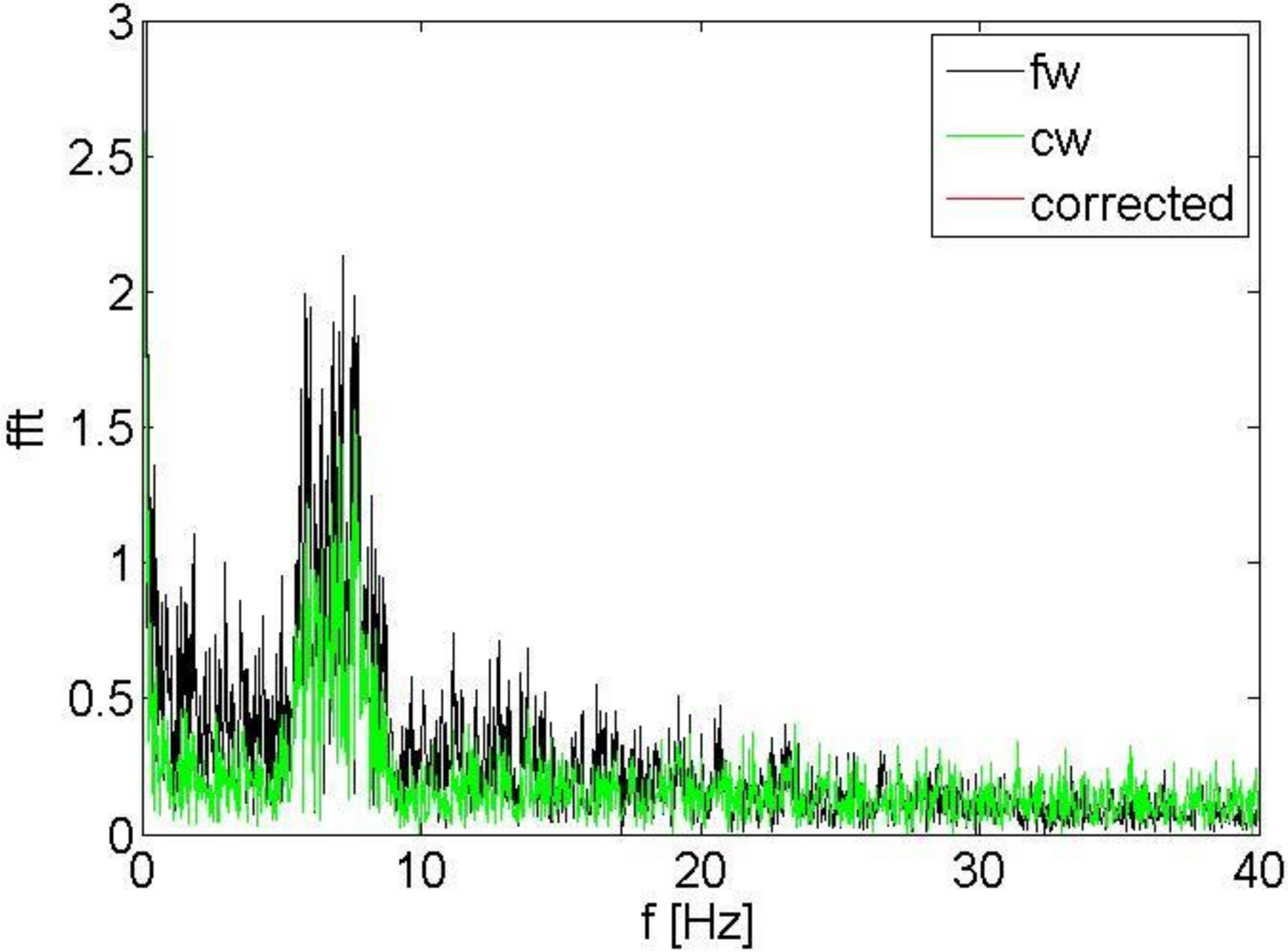
Experimental validation

- Normalized intensity-1



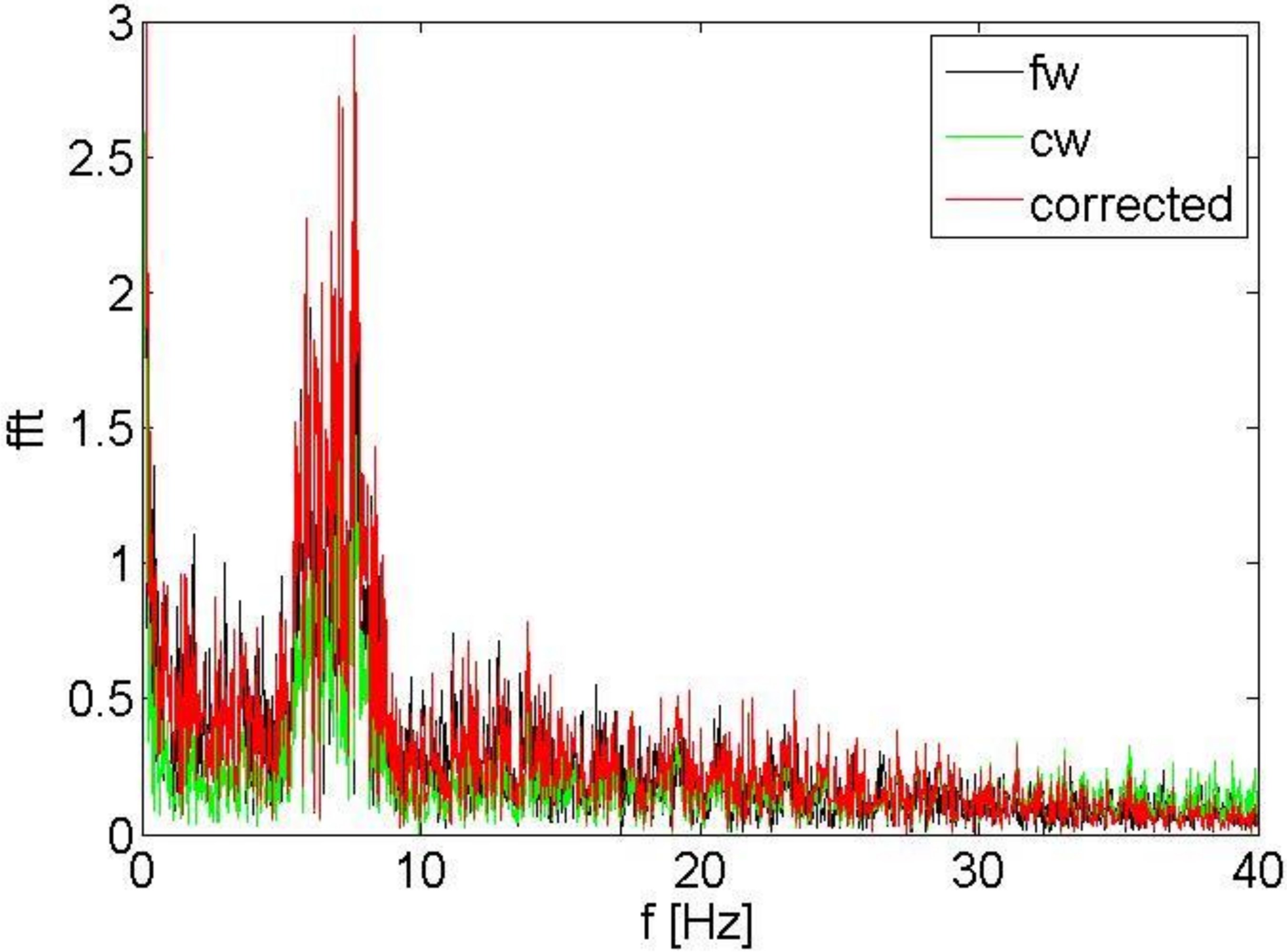
Experimental validation

- Normalized intensity-0.554



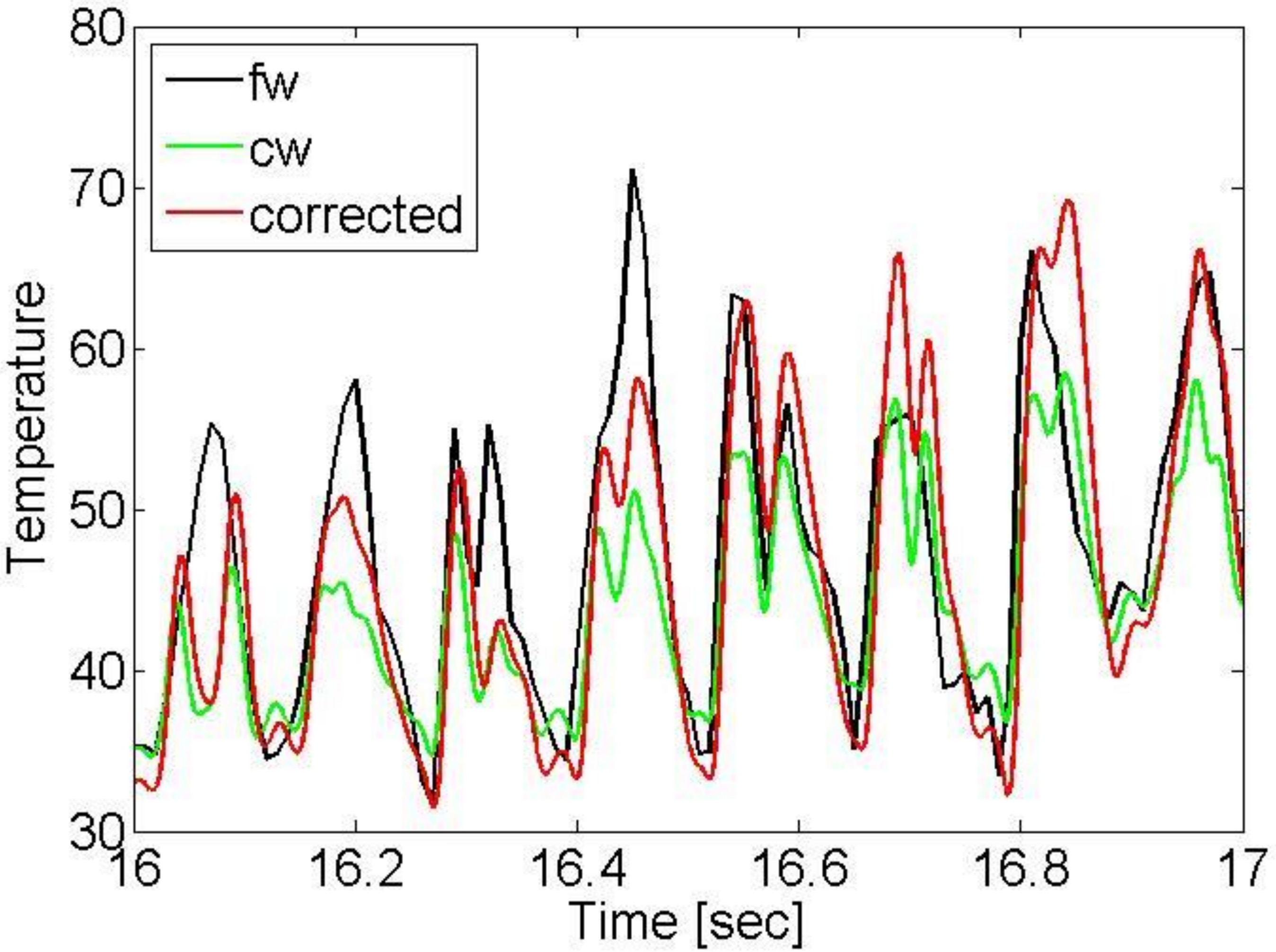
Experimental validation

- Normalized intensity-1.088



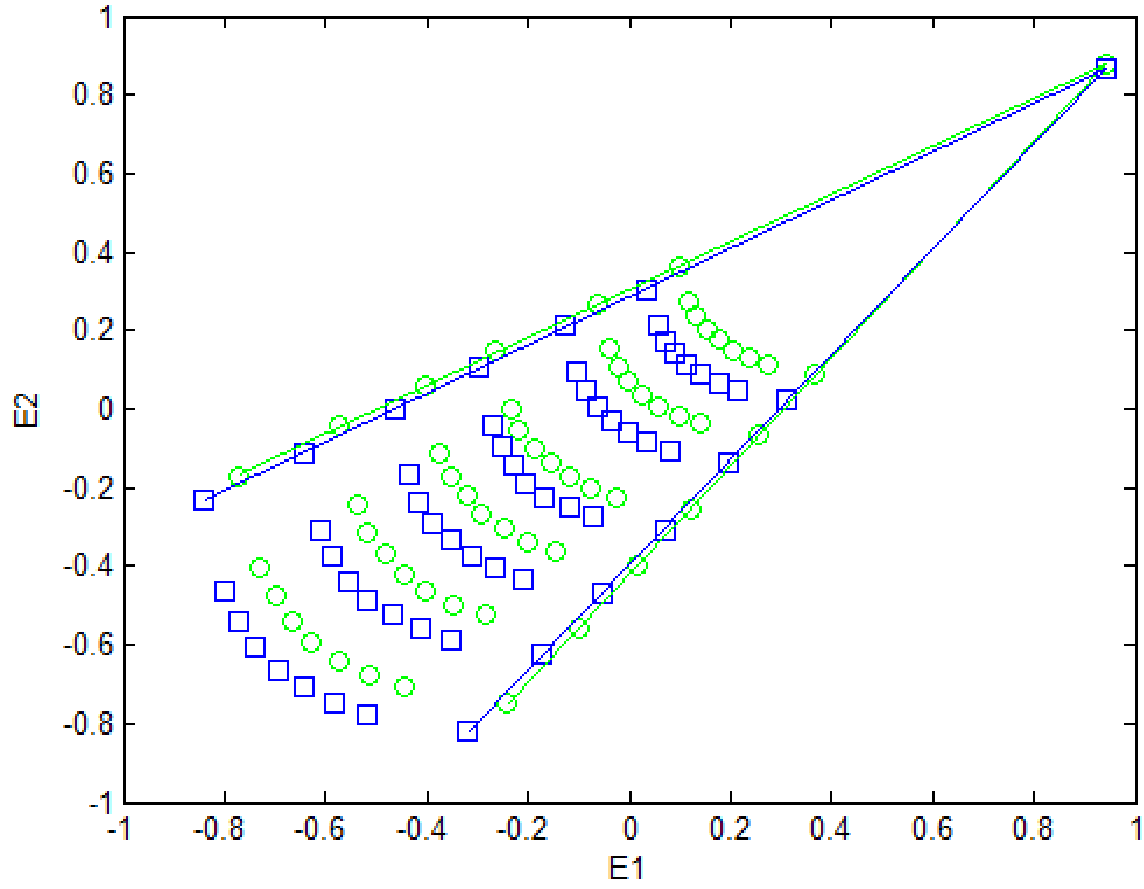
Experimental validation

- Closer look



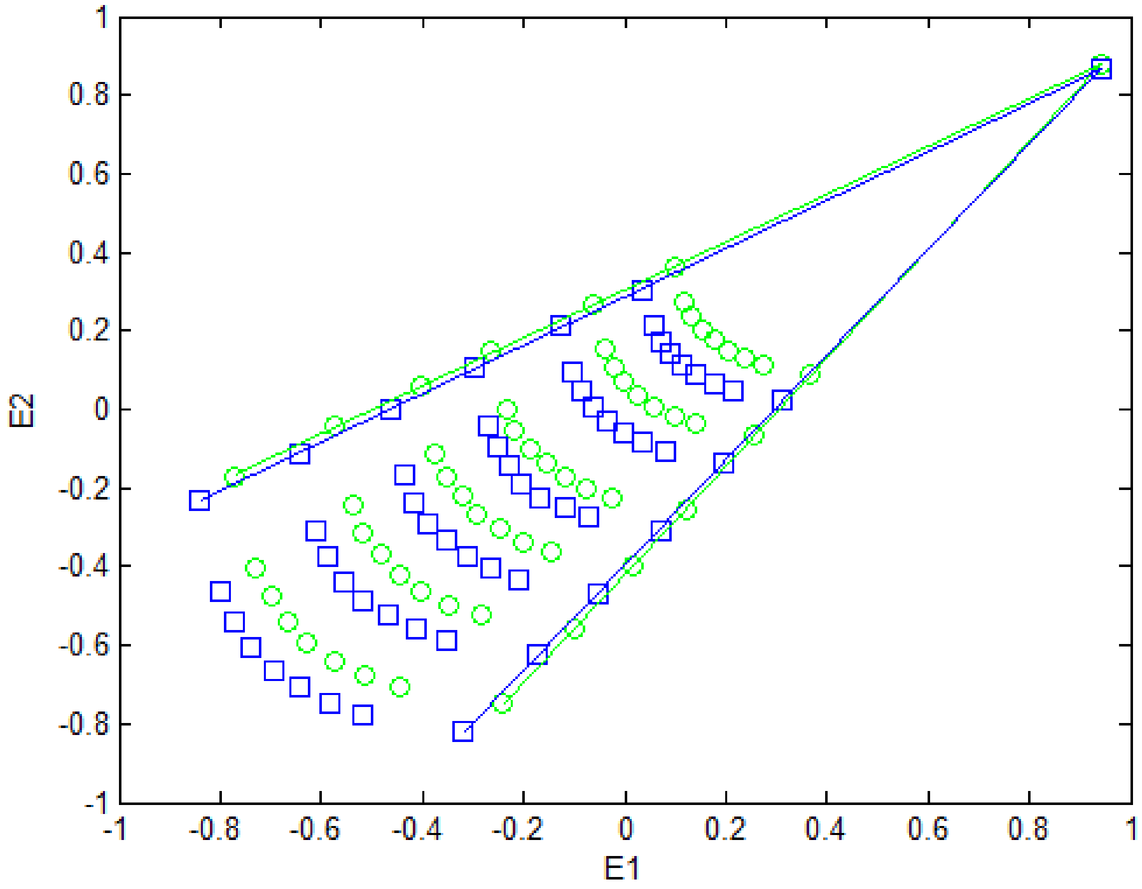
X –wire Calibration

- X-wire calibration is done for a range of velocities for a range of angles.



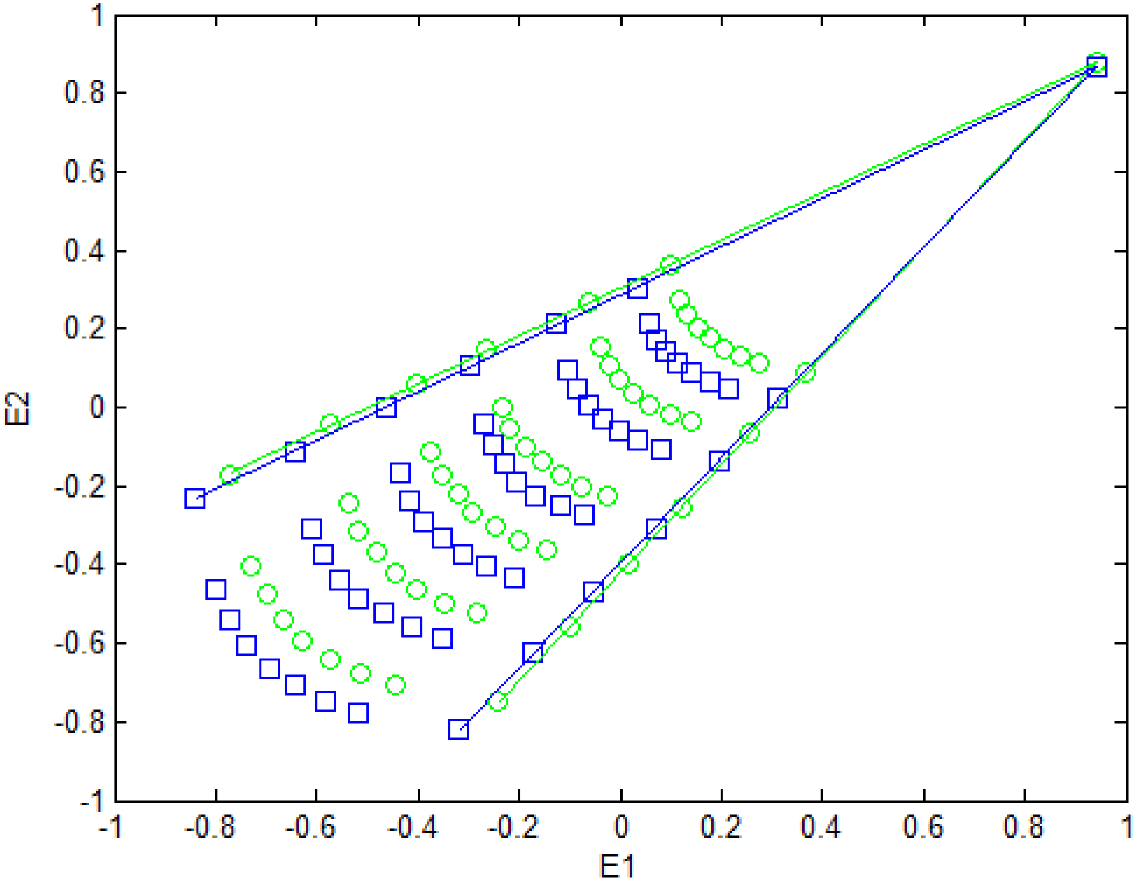
X –wire Calibration

- Blue Square – Post Calibration



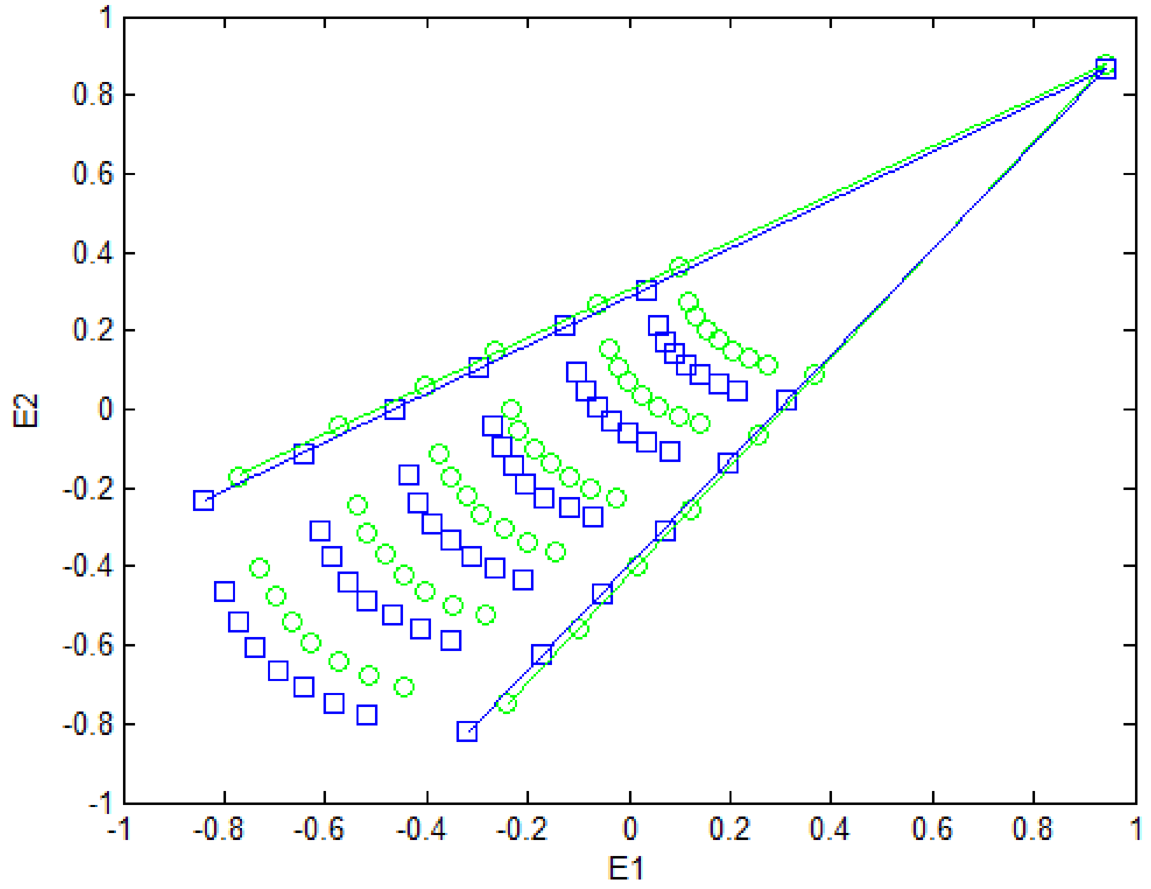
X –wire Calibration

- Blue Square – Post Calibration
- Green Circle – Pre Calibration



X –wire Calibration and Temperature Compensation

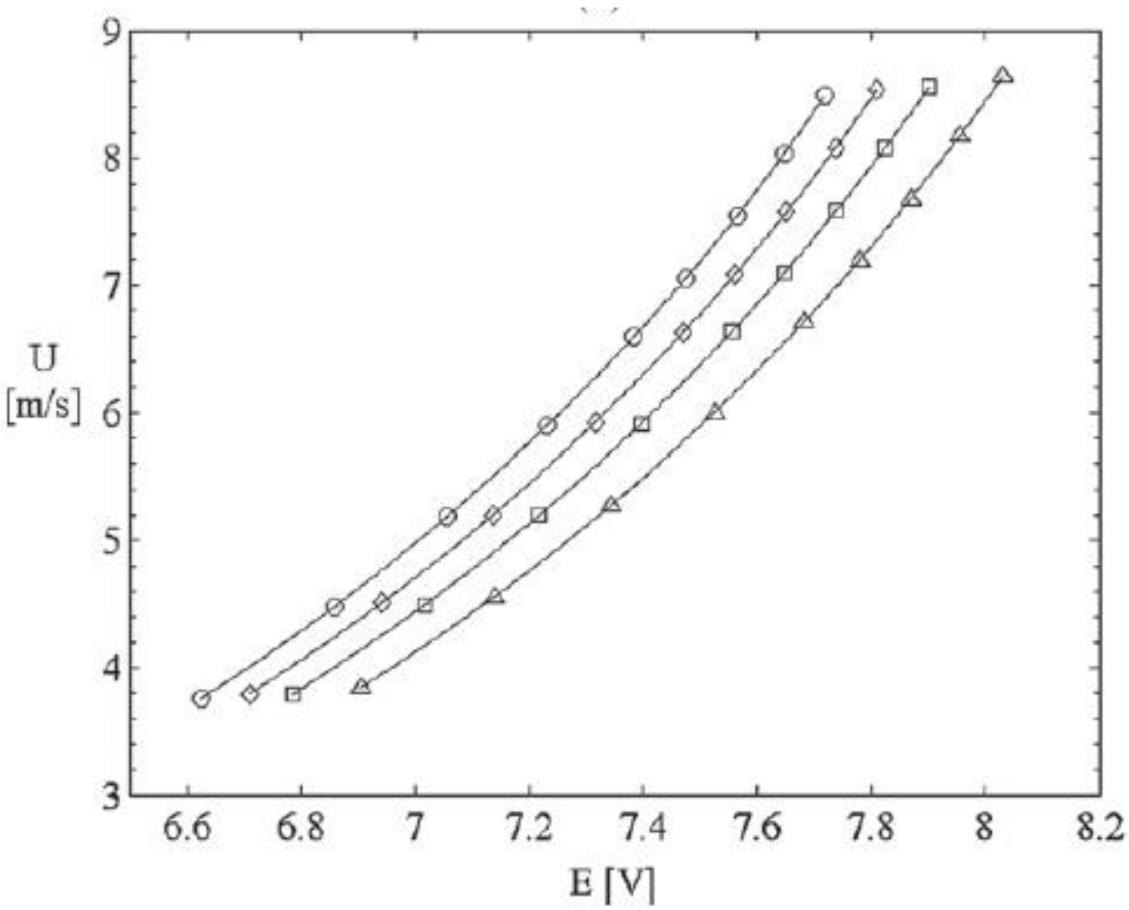
- Blue Square – Post Calibration
- Green Circle – Pre Calibration
- E1 & E2 – X – wire voltages



X –wire Calibration and Temperature Compensation

- Calibration curves for CTA operation at different temperatures for the same wire .

[Hultmark and Smits (2010)]



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.

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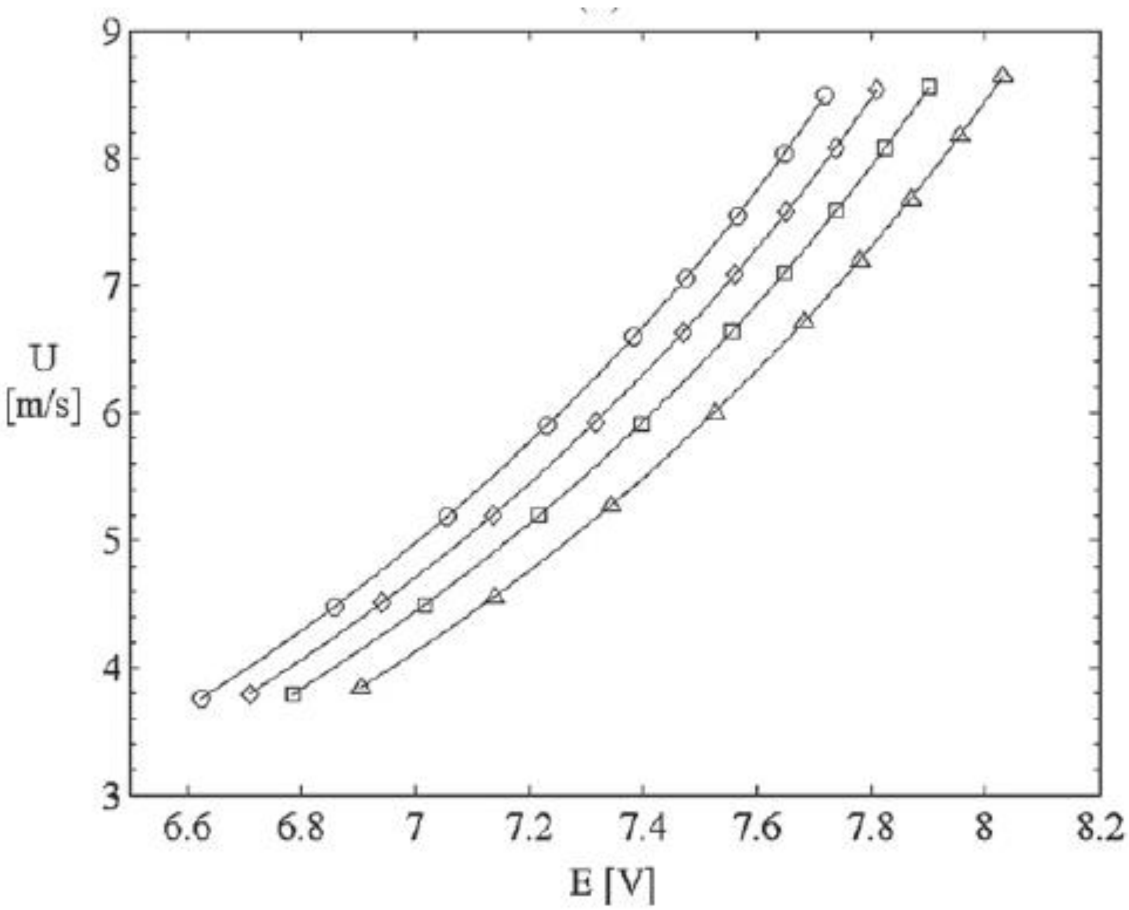
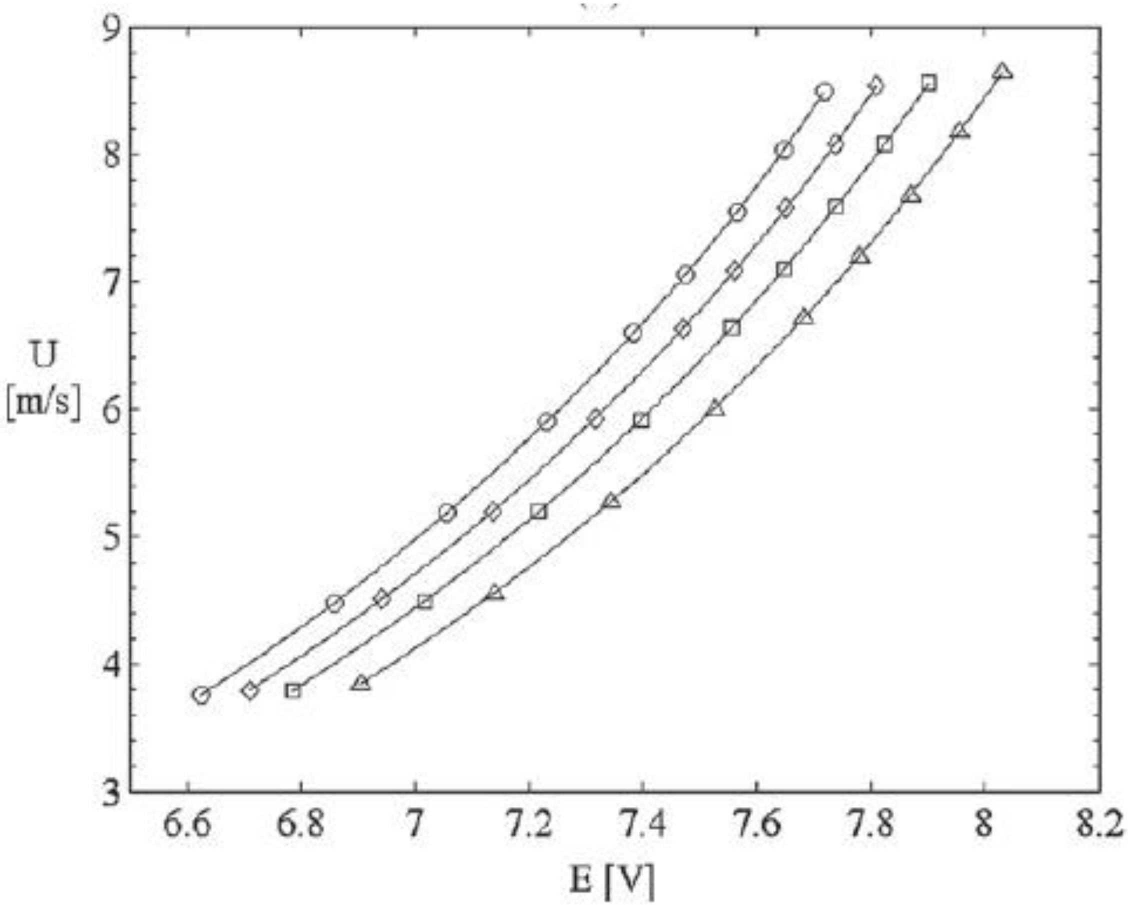


X –wire Calibration and Temperature Compensation

- 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

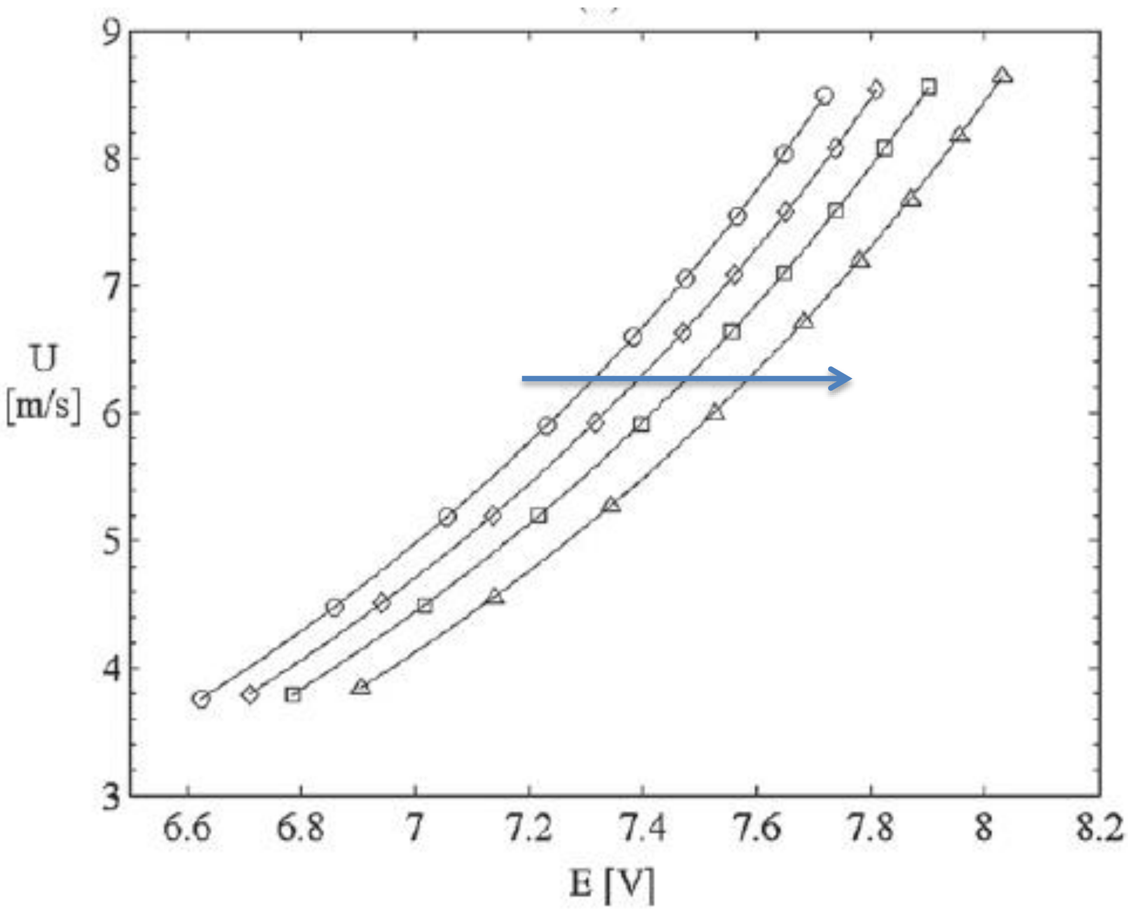
[Hultmark and Smits (2010)]



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.

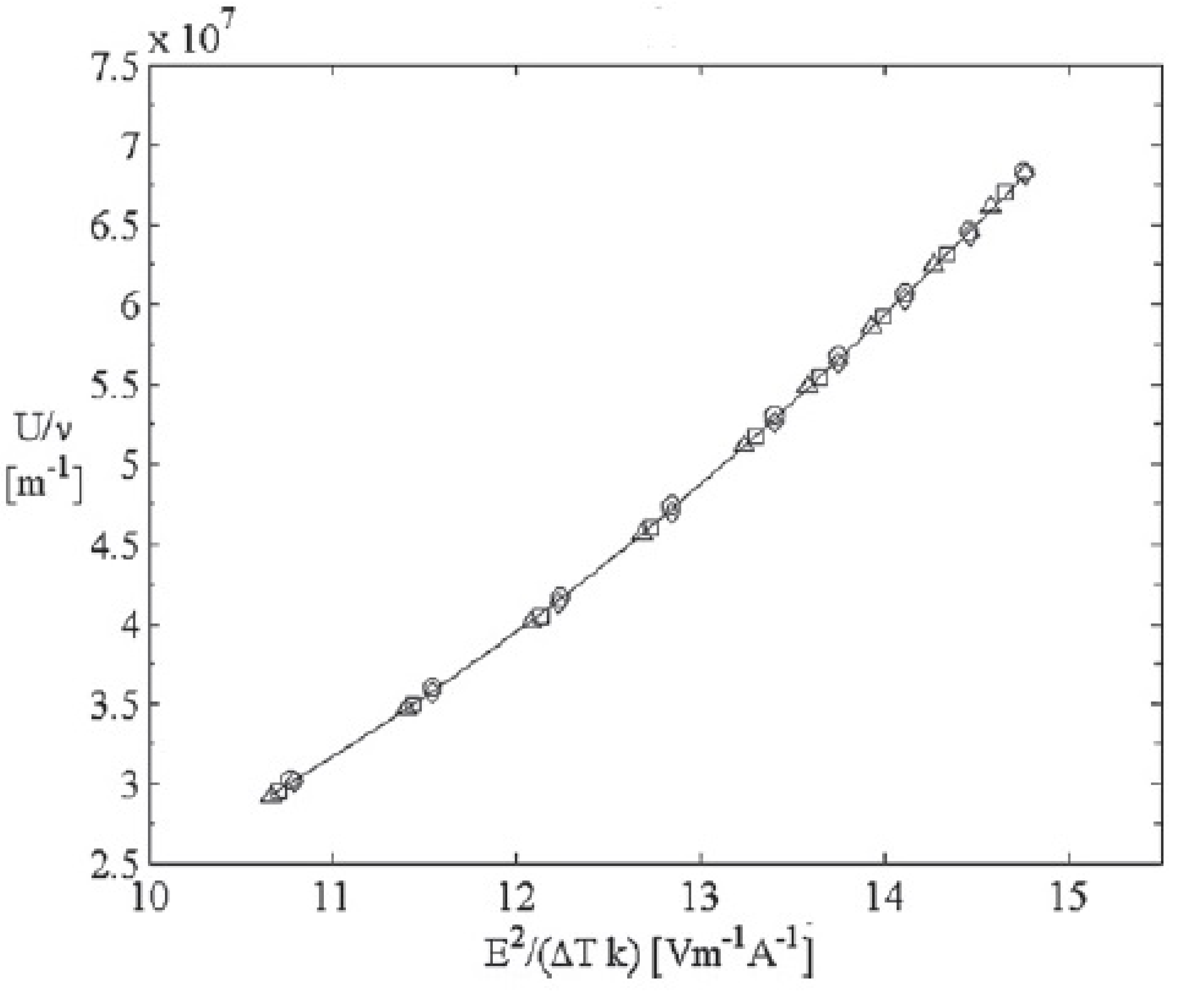
[Hultmark and Smits (2010)]



X –wire Calibration and Temperature Compensation

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

[Hultmark and Smits (2010)]



Preliminary results

Turbulence Energy Budget terms

- The hot wire calibration drift is taken care of.

Turbulence Energy Budget terms

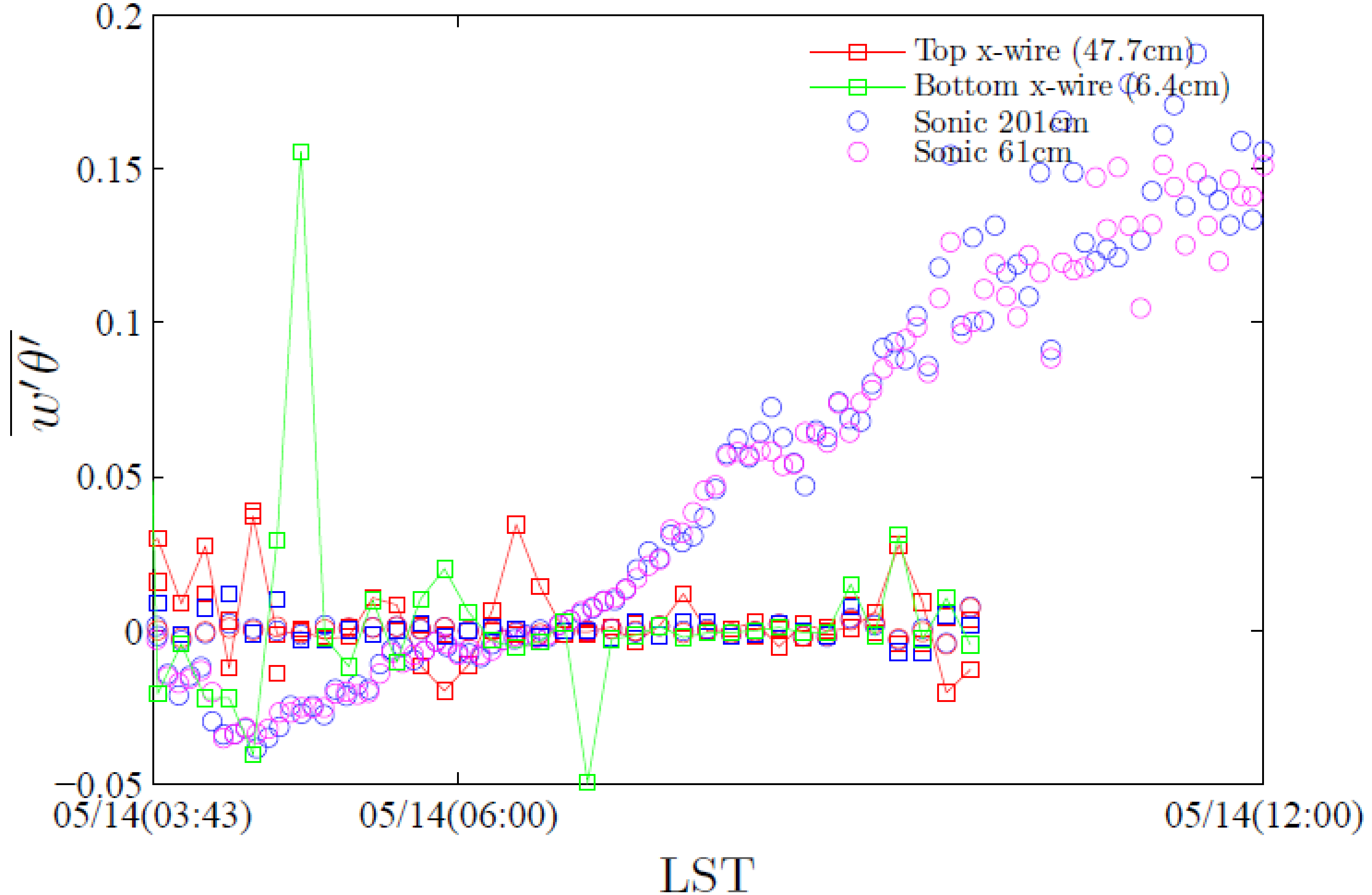
- The hot wire drift is taken care of.
- And the cold wire attenuation is also taken care of.

Turbulence Energy Budget terms

- The hot wire drift is taken care of.
- And the cold wire attenuation is also taken care of.

- Now we can calculate the terms like Sensible heat flux, Momentum flux, TKE dissipation and turbulent transport of TKE as well the temperature variance budget terms from the Hot and Cold wires.

Sensible heat flux comparison of Sonic and X-wire data sets (Spring 2013 – IOP 5)



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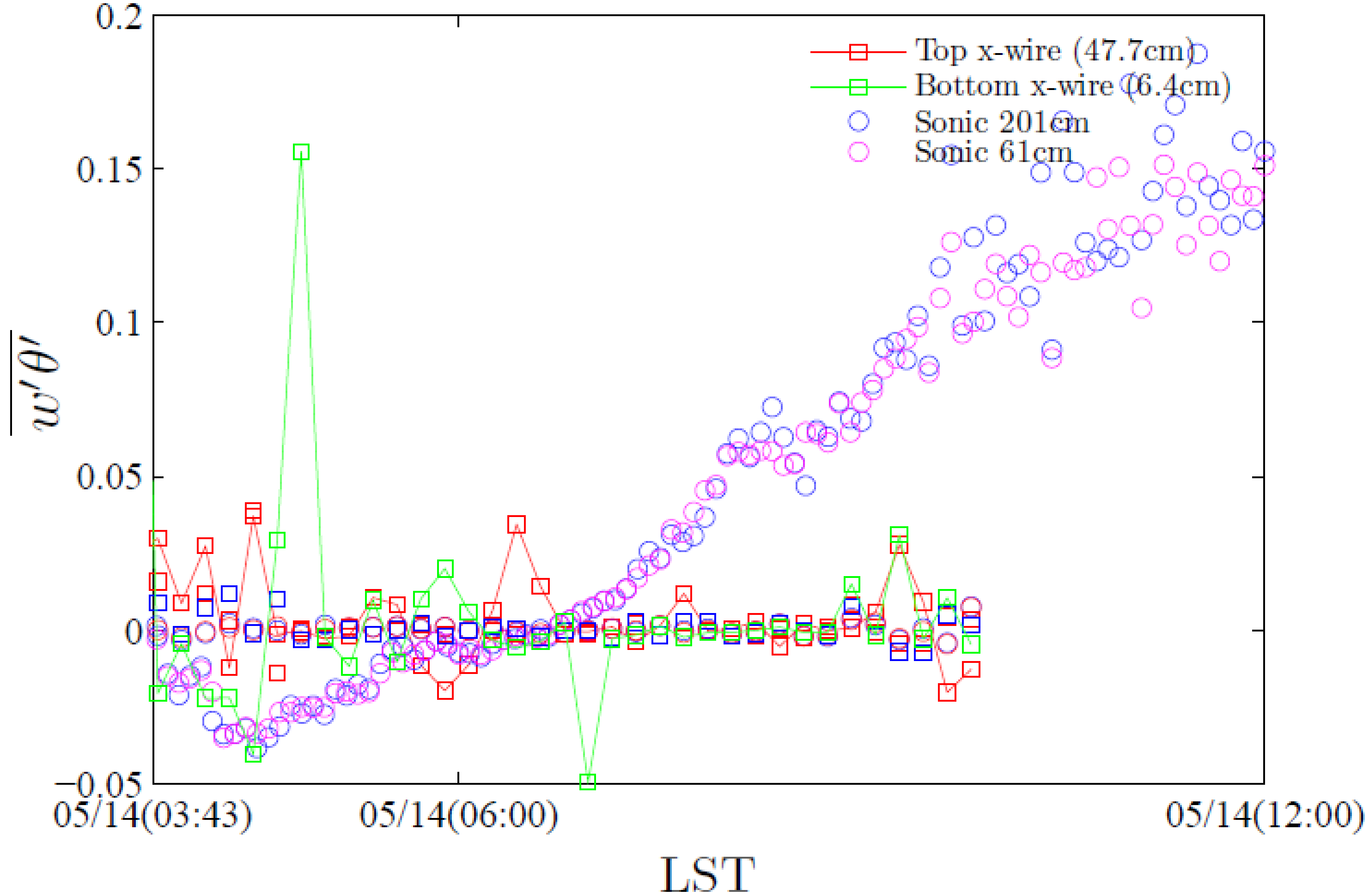
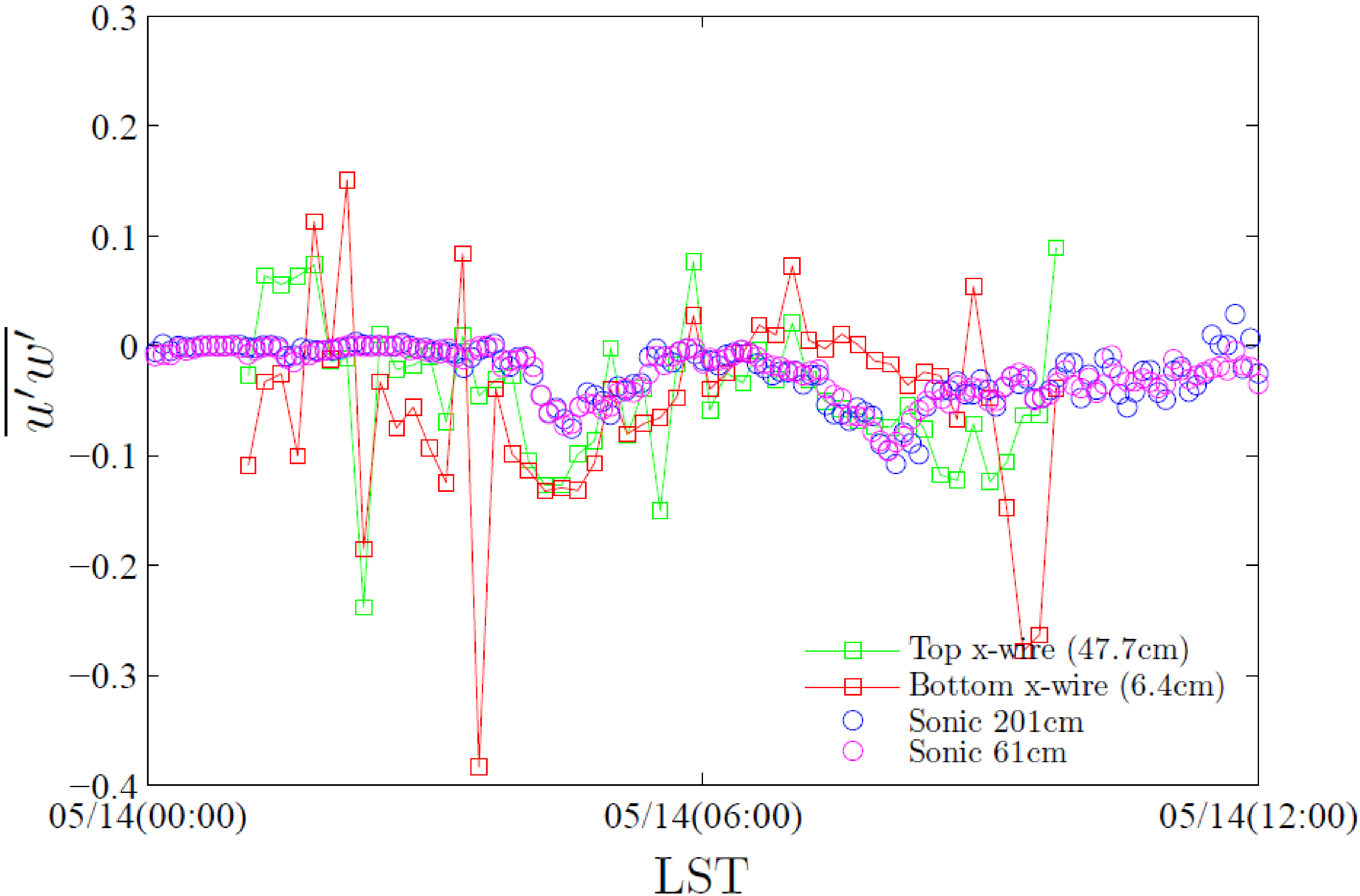
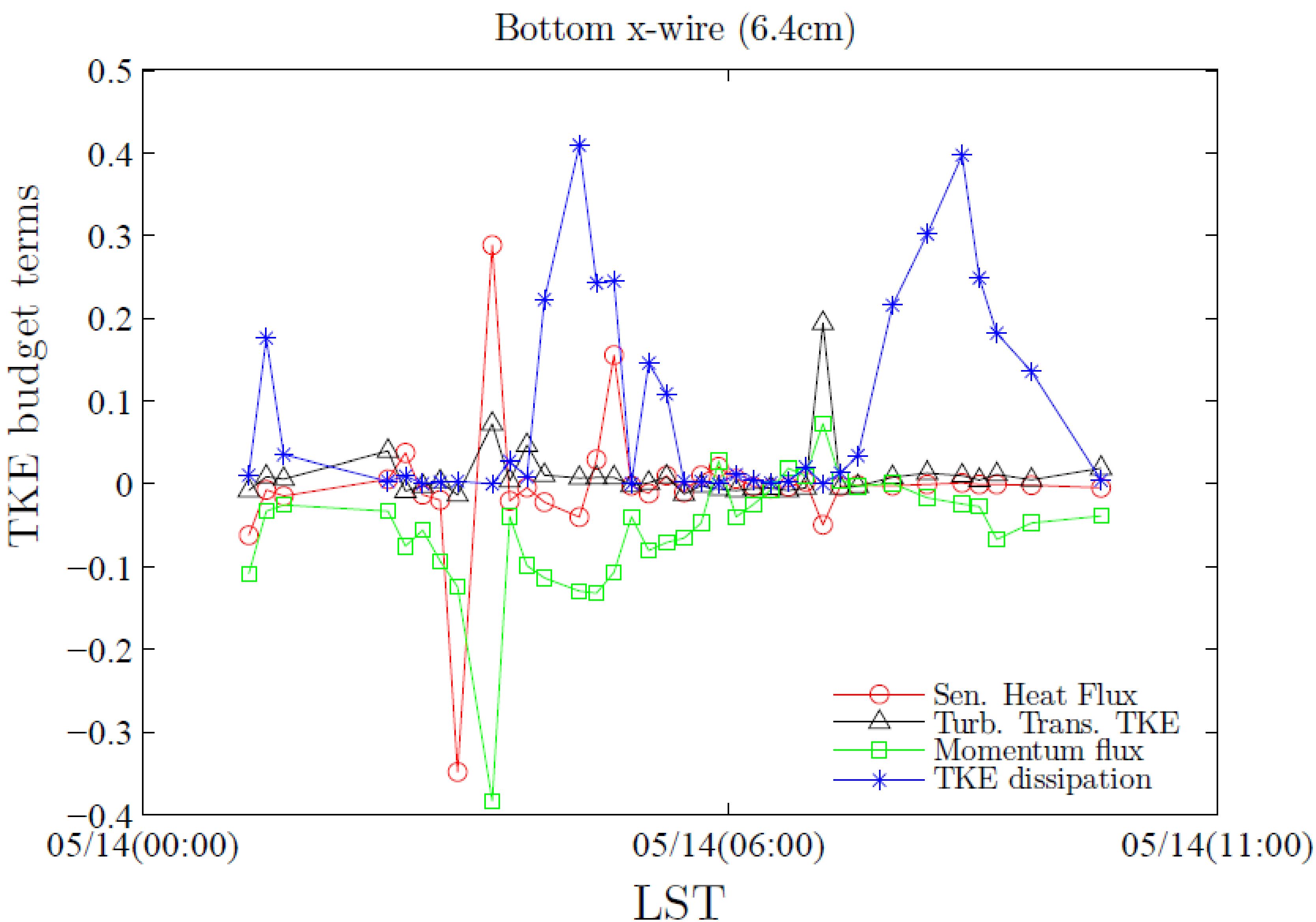


Momentum flux comparison for Sonic and X-wire data sets (Spring 2013 – IOP 5)



TKE Budget (correlation) terms



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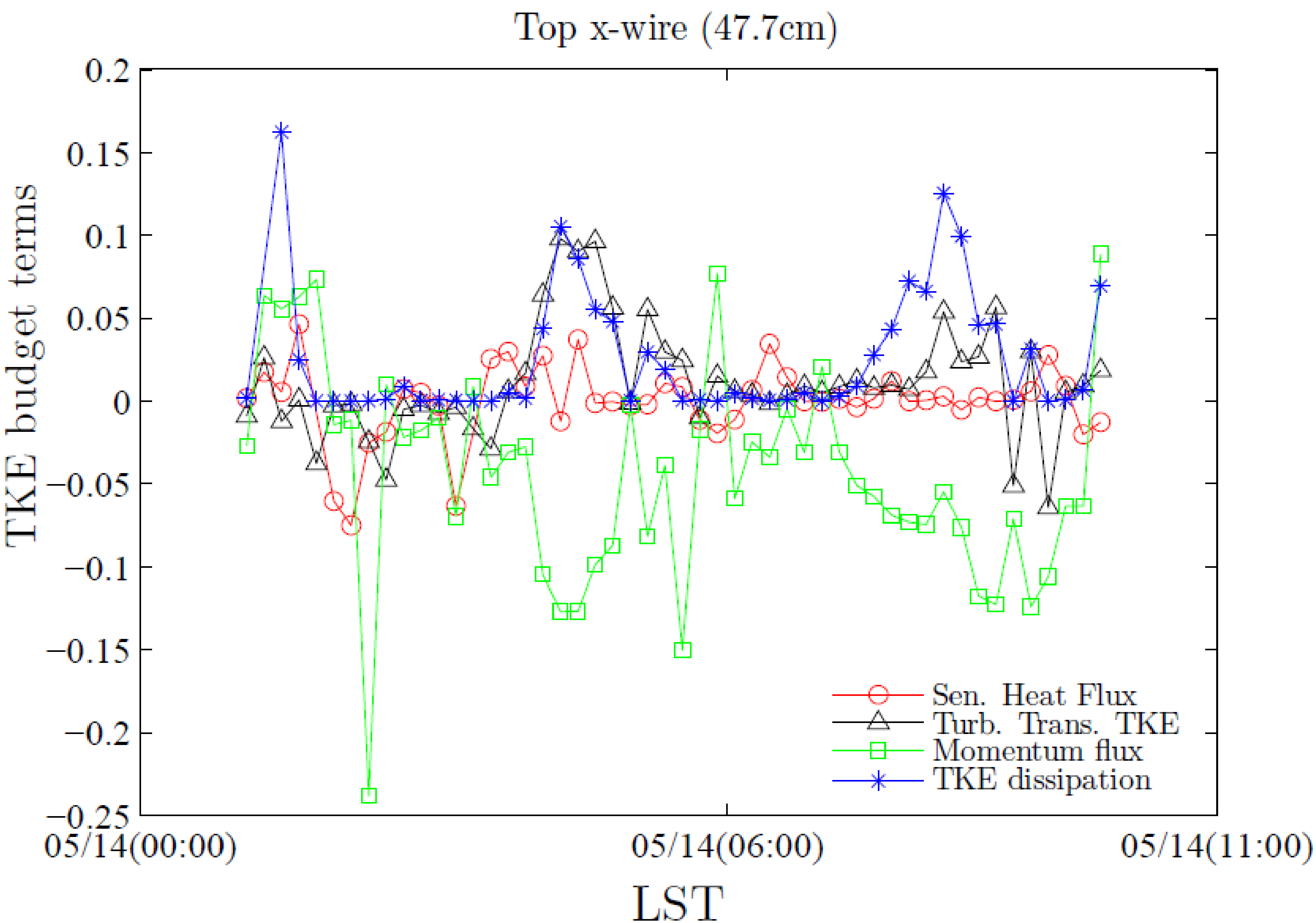
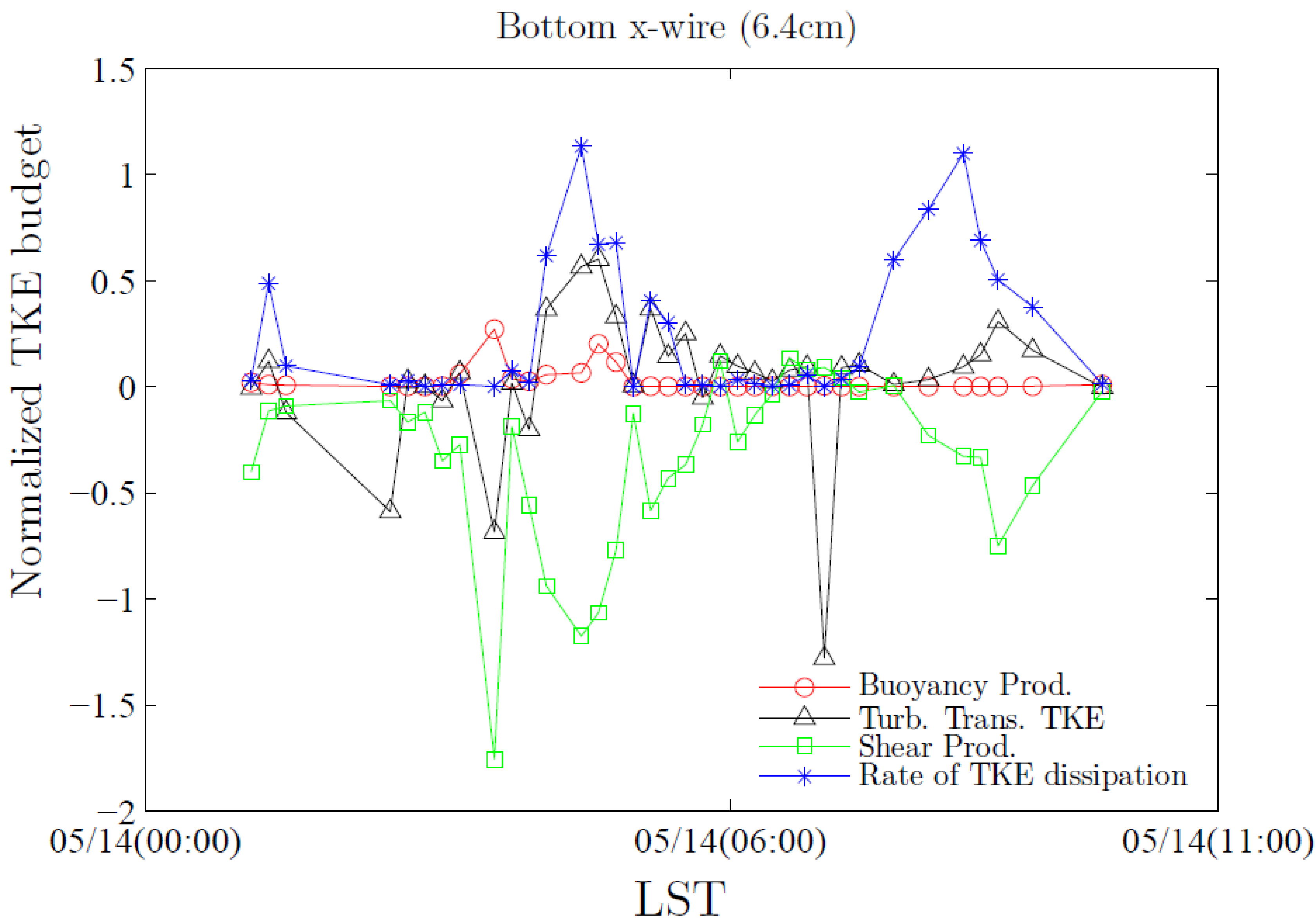
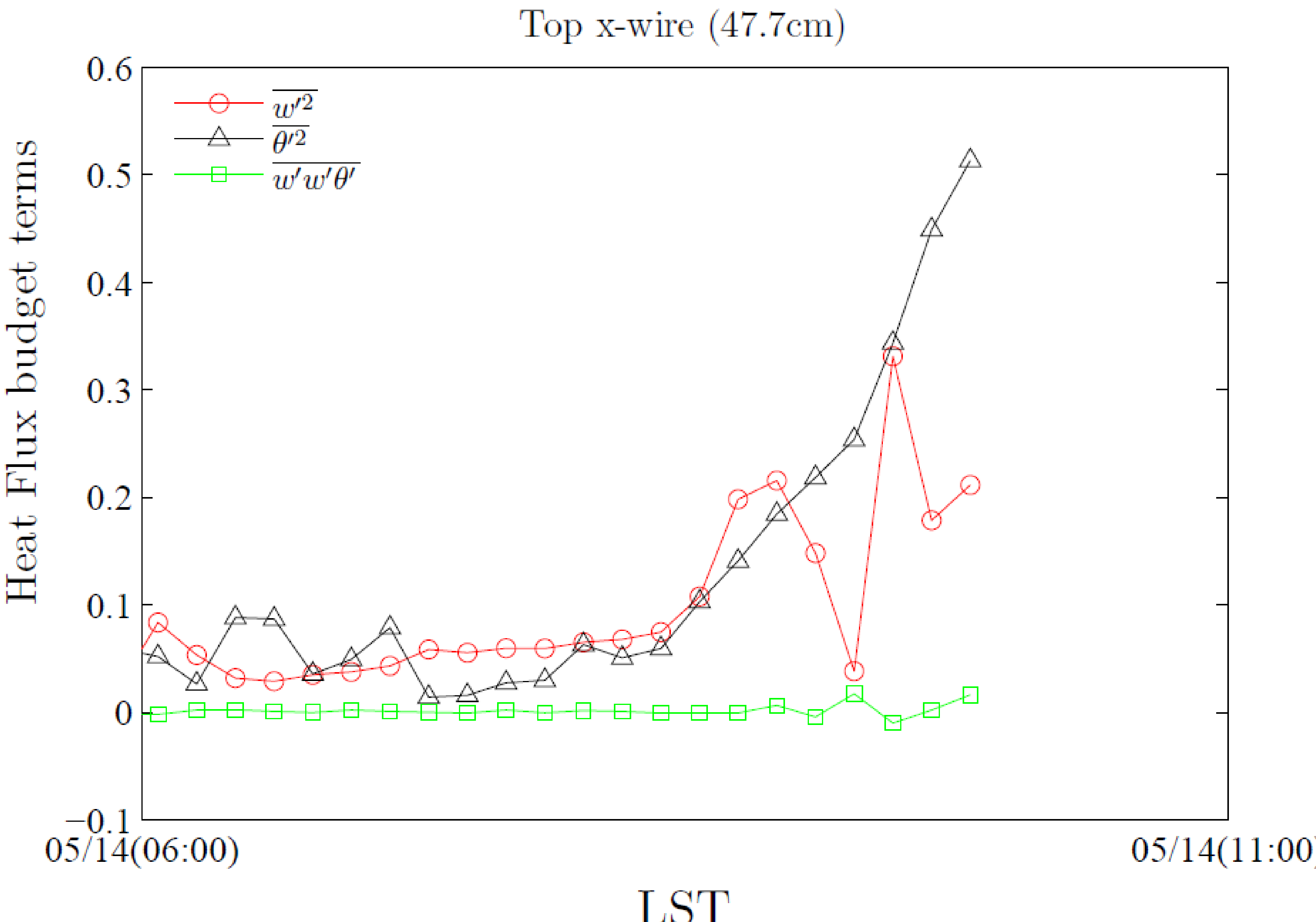


Normalized TKE budget terms



Heat flux budget (correlation) terms



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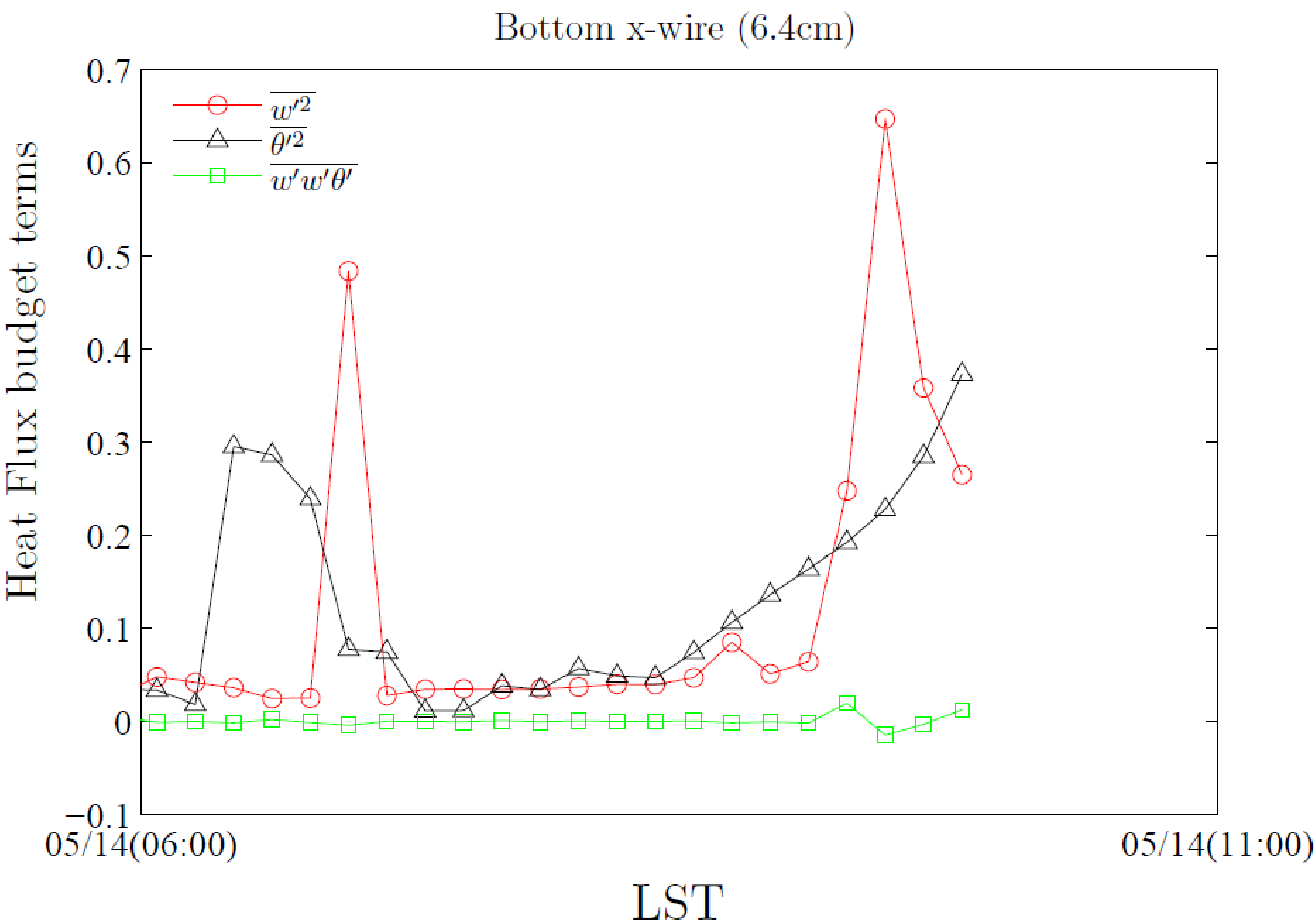
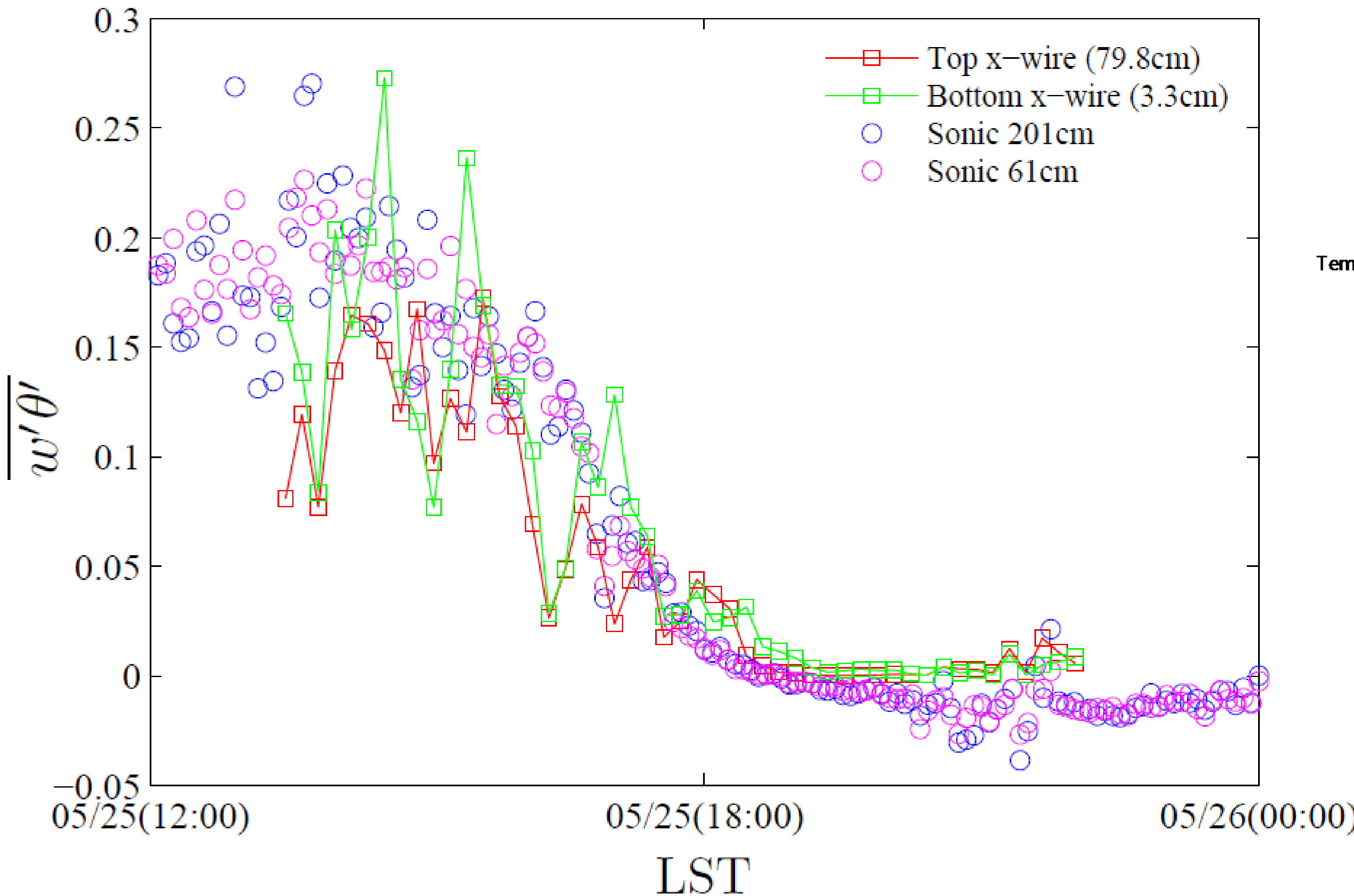
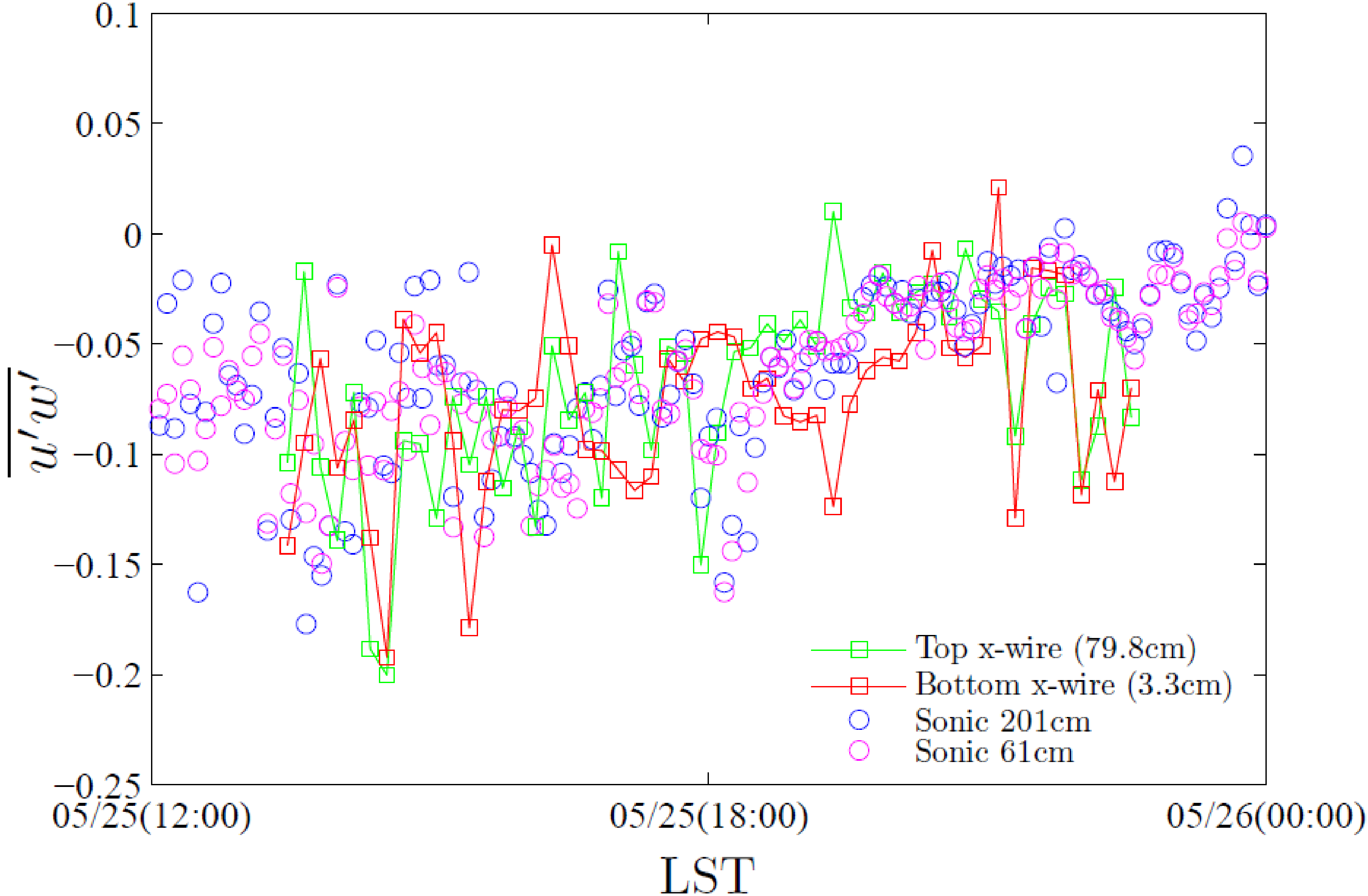


Sensible heat flux comparison for Sonic and X-wire data sets (Spring 2013 – IOP 9)

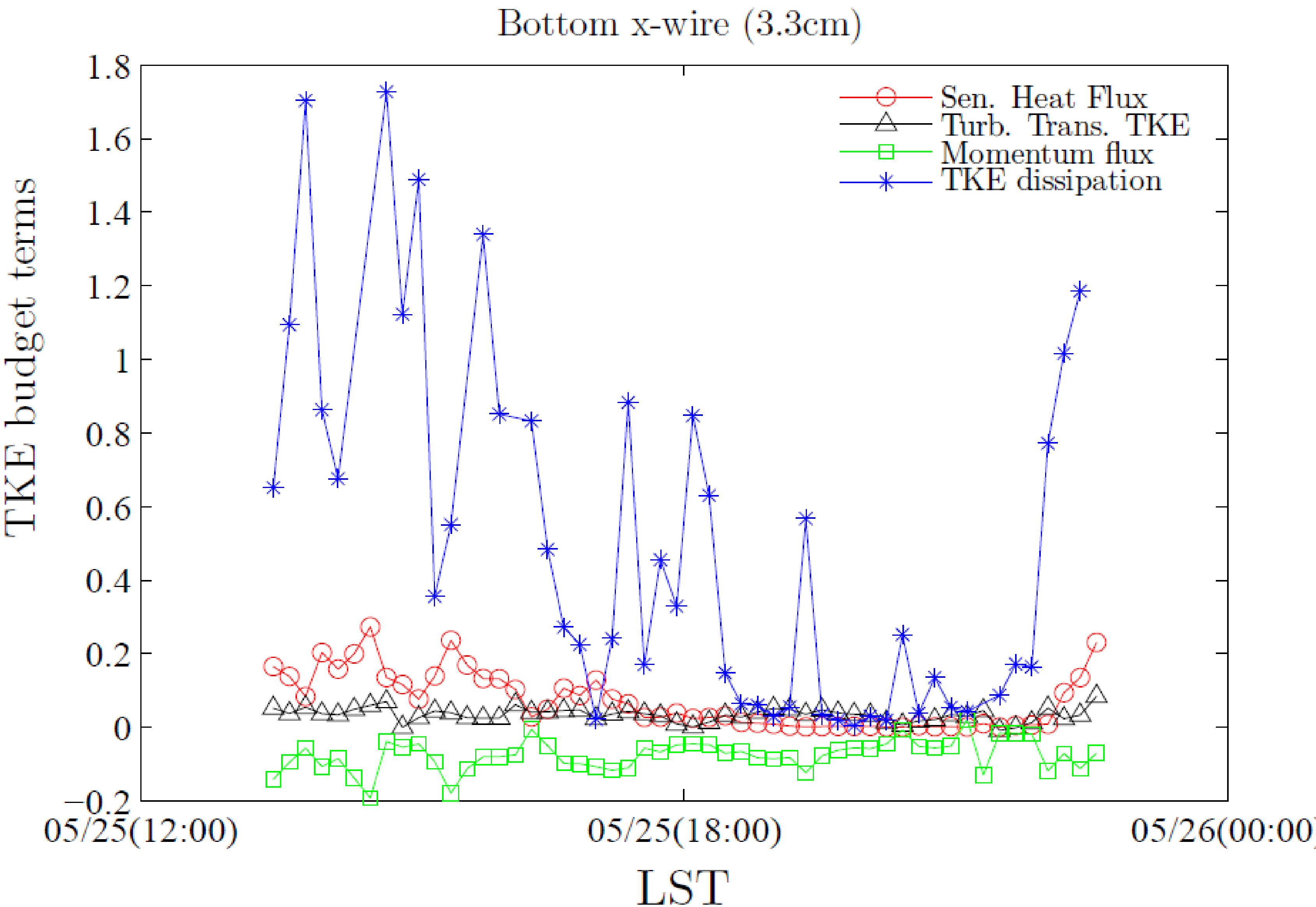


Temp_variance

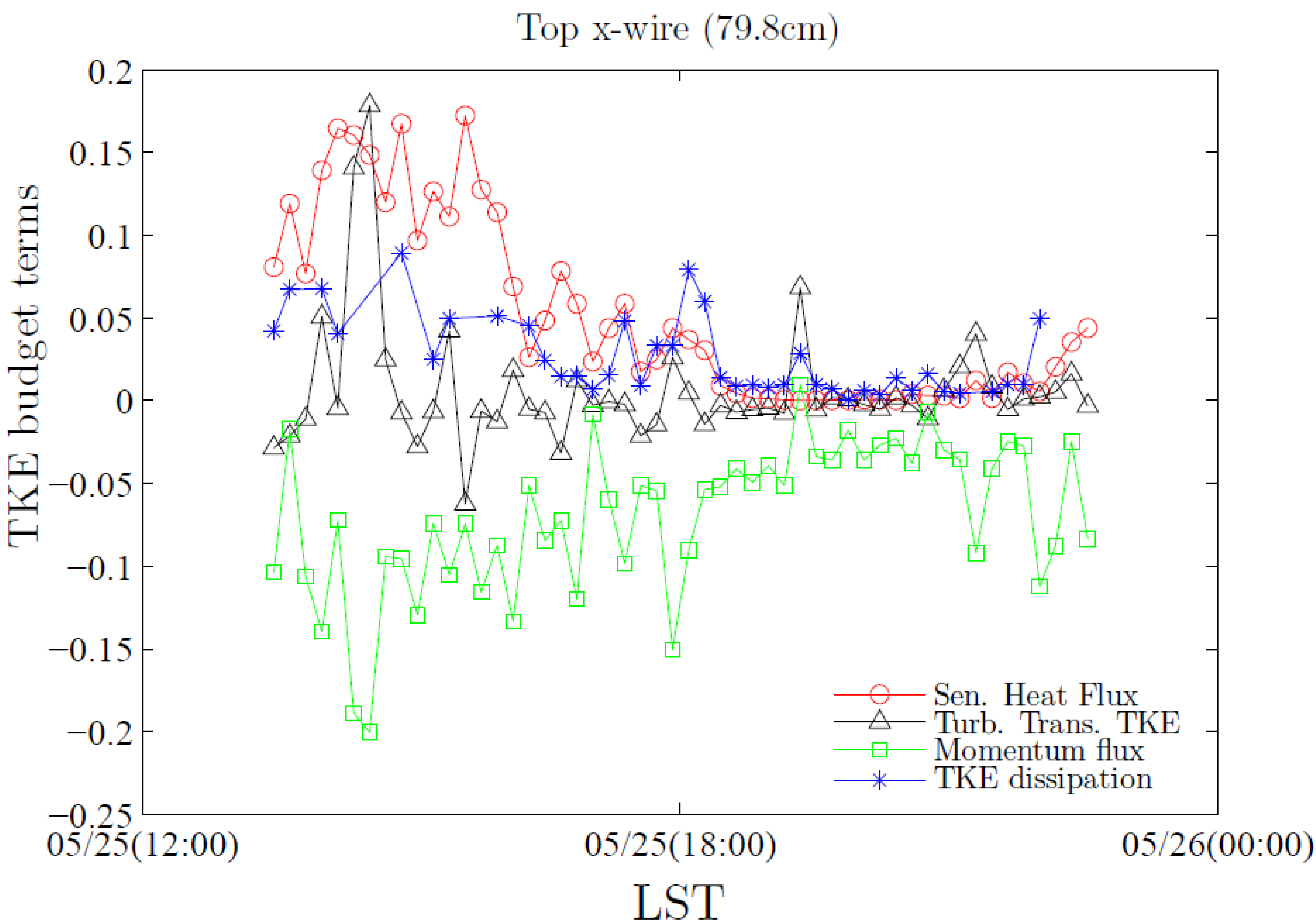
Momentum flux comparison for Sonic and X-wire data sets (Spring 2013 – IOP 9)



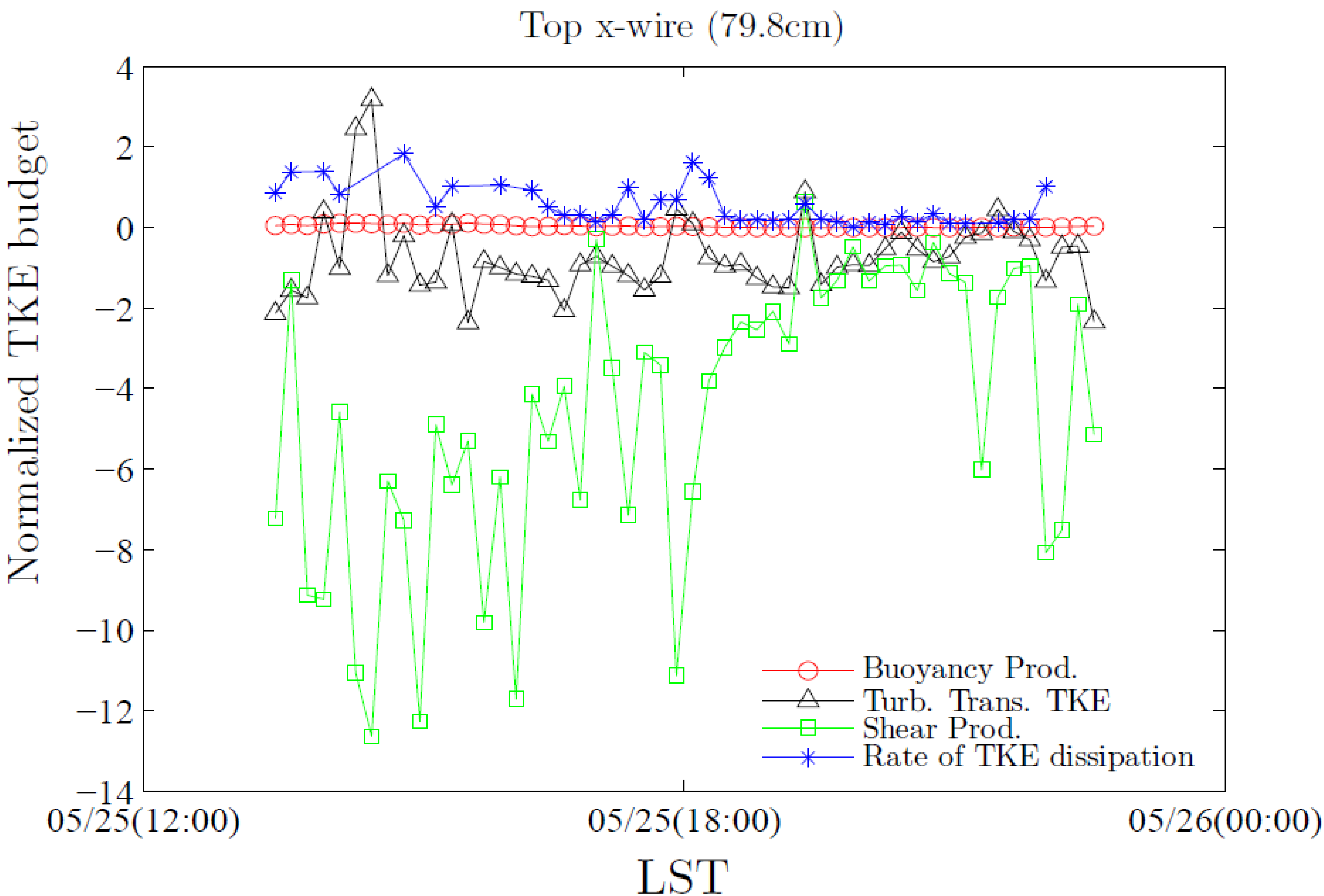
TKE Budget (correlation) terms



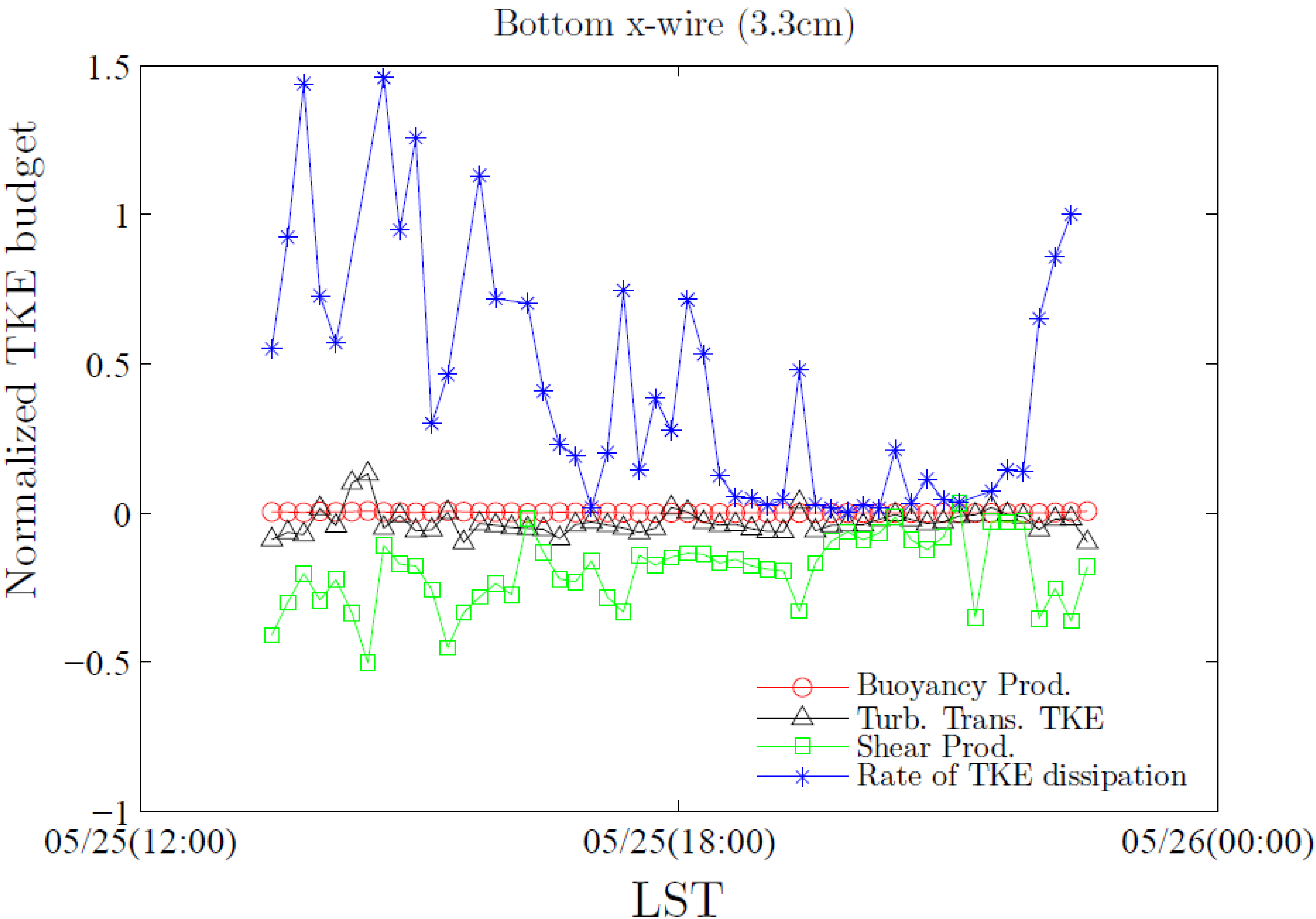
TKE Budget (correlation) terms



Normalized TKE budget terms



Normalized TKE budget terms



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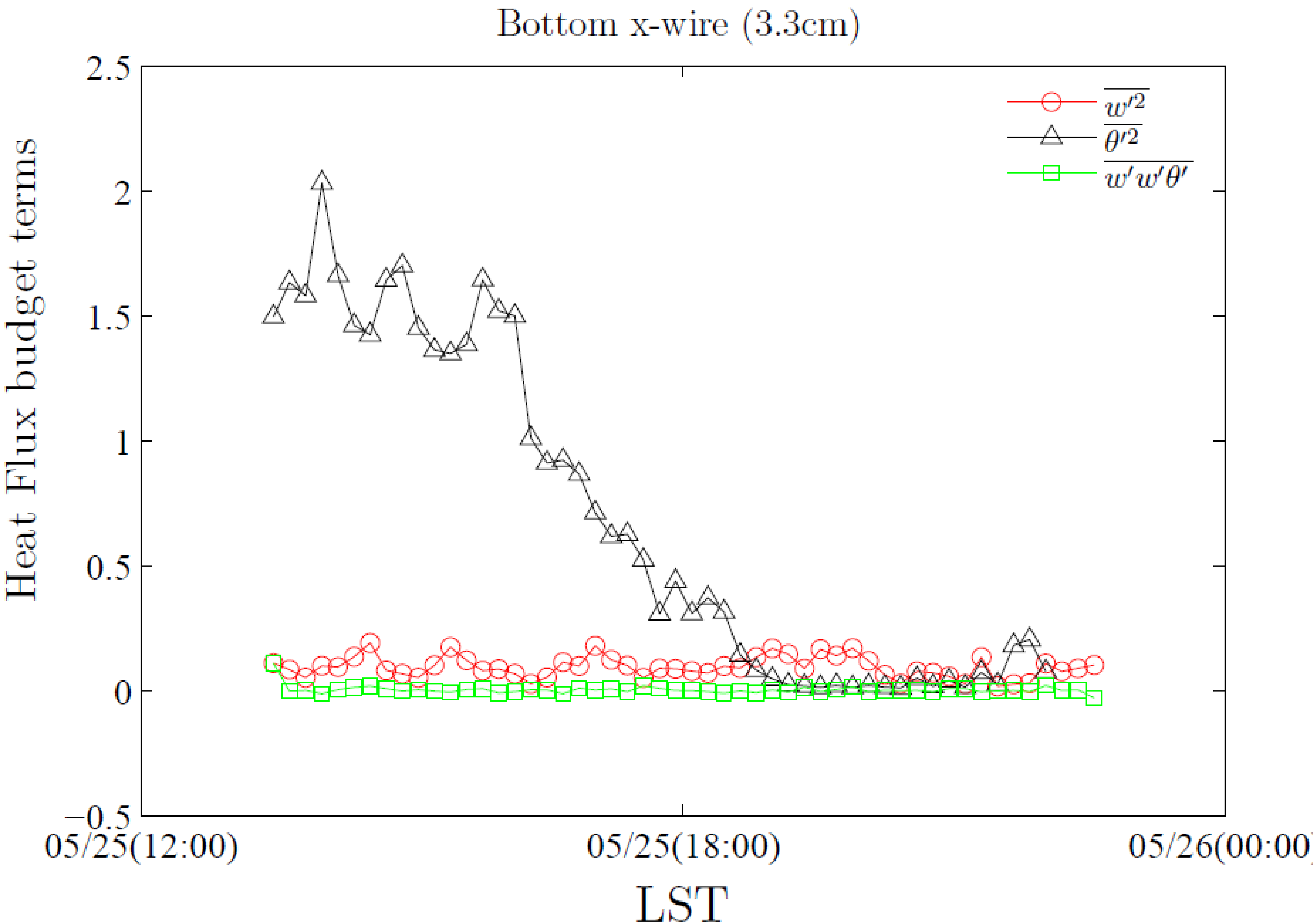
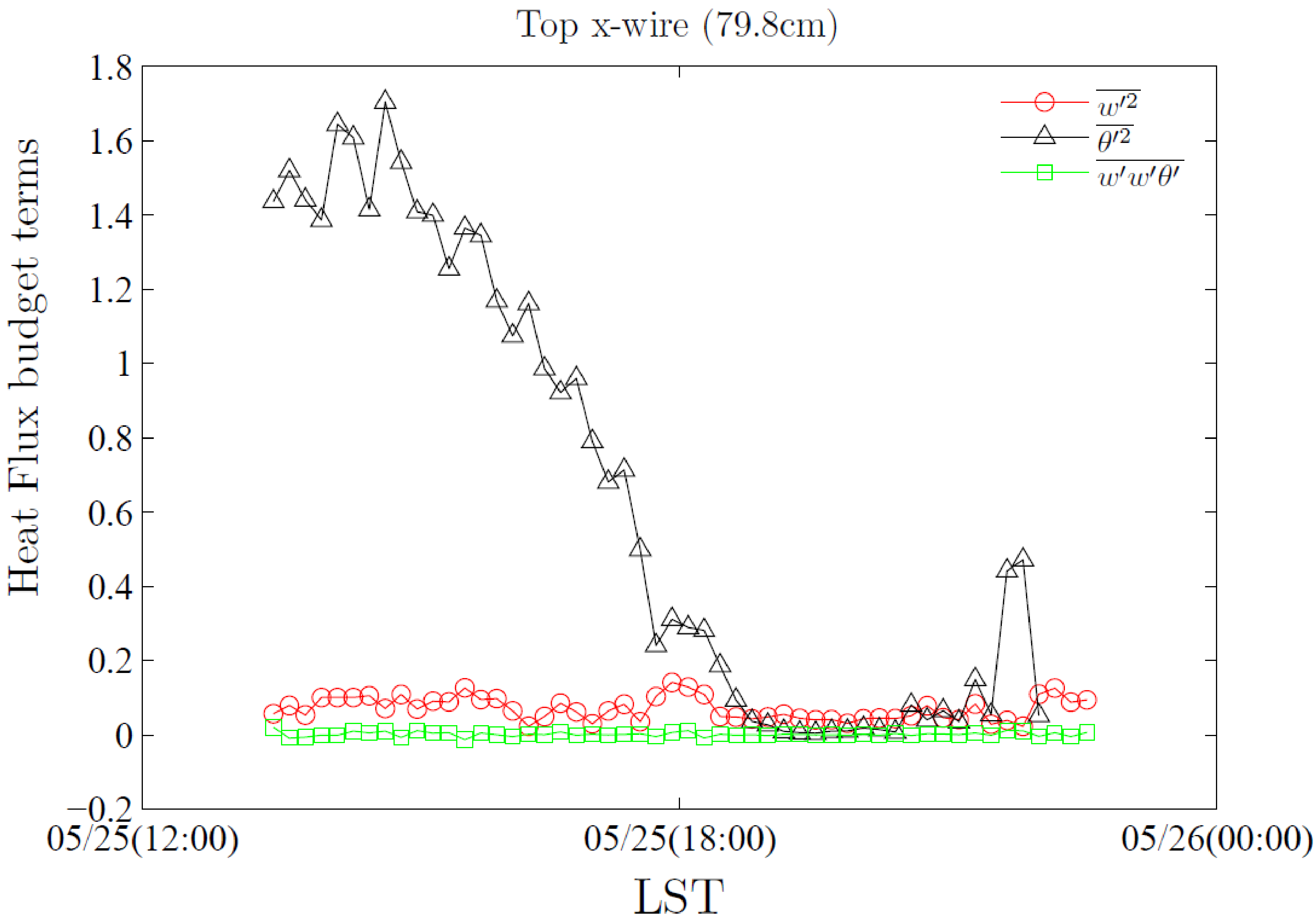
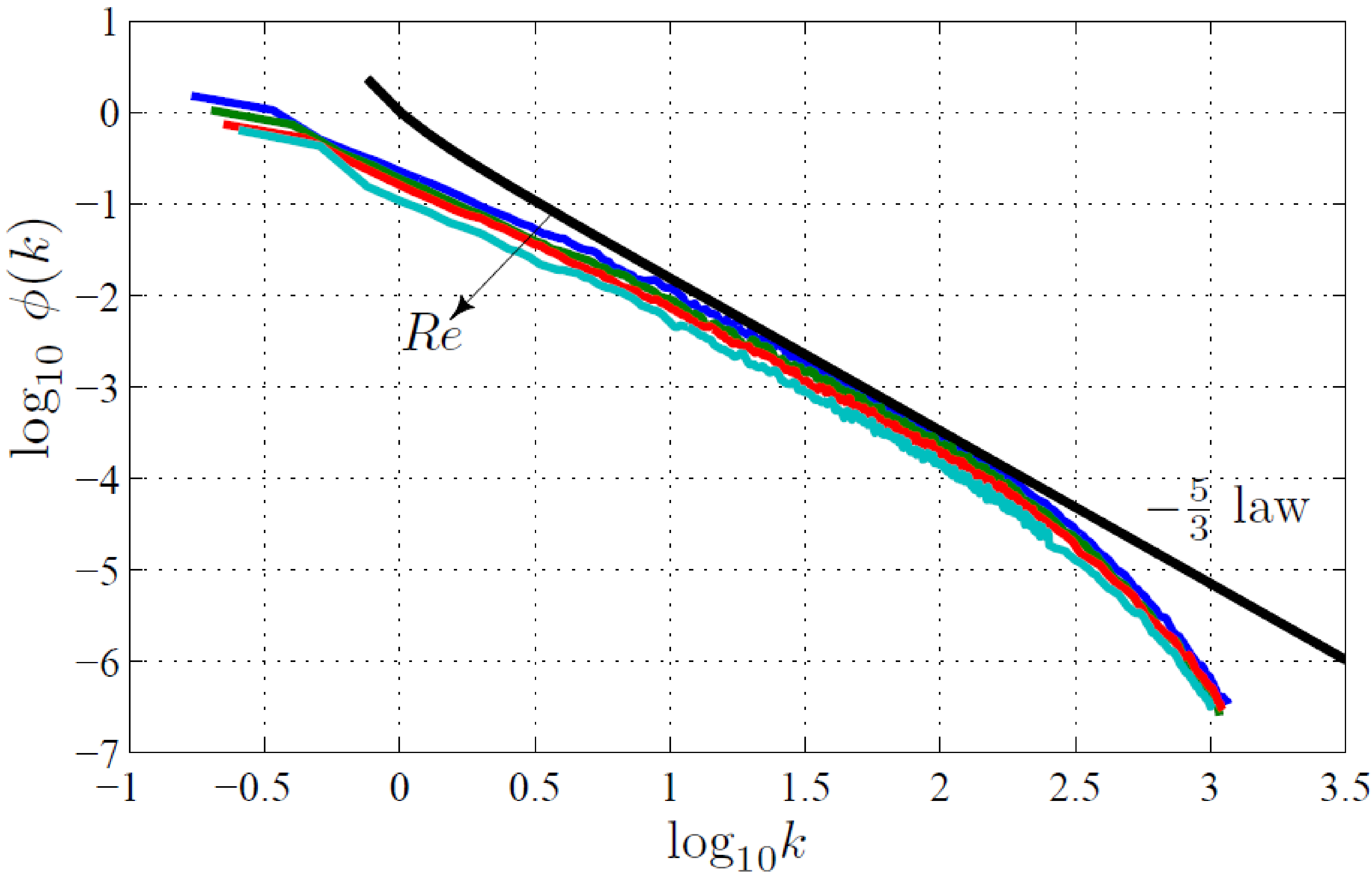


Heat flux budget (correlation) terms



Streamwise energy spectra (u-spectra)



Summary & Conclusion

- Based on these two IOPs, very close to the surface, the contribution of buoyancy term is very minimal to the TKE energy budget followed by the turbulent transport of TKE term.
- Very close to the surface, the dissipation rate of TKE is dominating the other terms of the TKE budget where the shear production term is dominant away from the surface.
- The techniques and the issues associated with measuring the velocity and temperature fluctuations were addressed.
- An extensive quality control mechanism should be administered in order to obtain high fidelity data set.
- Its still a work in progress.