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Assessing the validity of Monin-Obukhov Similarity Theory (MOST) over mountainous desert terrain

Derek Jensen[1], Eric Pardyjak[1]

[1]Mechanical Engineering, University of Utah, Salt Lake City, United States

Motivation

- MOST is used extensively to organize micrometeorological information as well as predict information where direct measurements are not possible. (Arya, 1988)
- Although the assumptions of MOST are quite limiting it has been shown to hold in conditions weakly deviating from the ideal. (de Franceschi et al. 2009)
- We would like to compare MOST's performance over three very different sites as well as explore possible turbulent parameterizations for transitional stability periods. Reword!! And get more slope pictures 222

Monin-Obukhov Similarity Theory

1. Assume:
   1. Horizontal Homogeneity & Quasi-Stationarity
   2. Inertial Sublayer ($dFlux/dz$=0)
   3. Coriolis force is negligible
   4. Molecular Diffusion << Turbulent Transport
   5. u_* fully accounts for surface roughness, BL height and geostrophic winds.
2. Hypothesis: Mean and Turbulent Flow Characteristics a function of only four independent variables: $z, u_*, \overline{w_0'T_0'}, g/T_0$
3. Apply Bucking ham Pi: $Flow = \phi\left(\frac{z}{L}\right) = \phi(\zeta)$

- $Obukhov\ Length, L = -u_*^3 / \left[\kappa\left(\frac{g}{T_0}\right)\left(\frac{H_0}{\rho c_p}\right)\right] \frac{Shear}{Buoyant}\ Production$

Arya, 1988

Three Extended Flux Sites

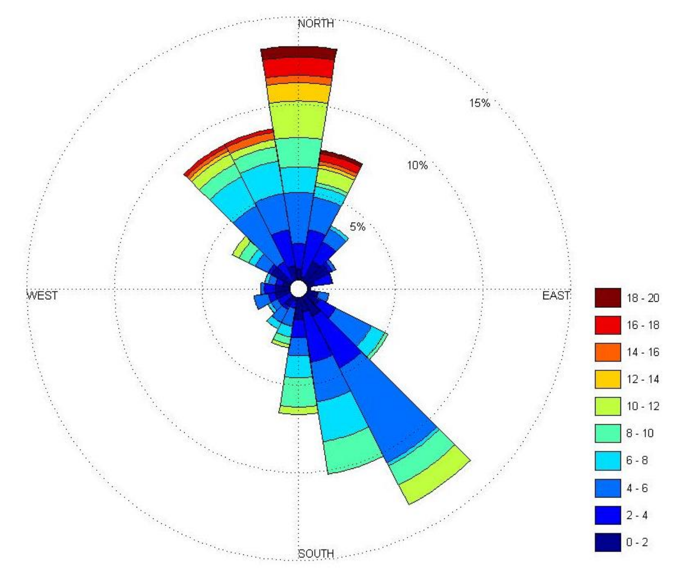
- Net Solar Radiation
- Net Longwave Radiation
- Multi-depth soil moisture and temperature
- Surface Temperature
- Pressure
- Multi-height sonic anemometry (20 Hz)
- Multi-height finewire thermocouples (20 Hz)
- Near Surface FW arrays
- Fast Response H_2O
- Fast Response CO_2 (Sage and Playa only!)
- Multi-height T/RH
- Sage only: 2 IRGAs
- Playa only: Tethered Balloon, Radiosondes, Hot Wire Anemometry, Thermal Camera, Microphones

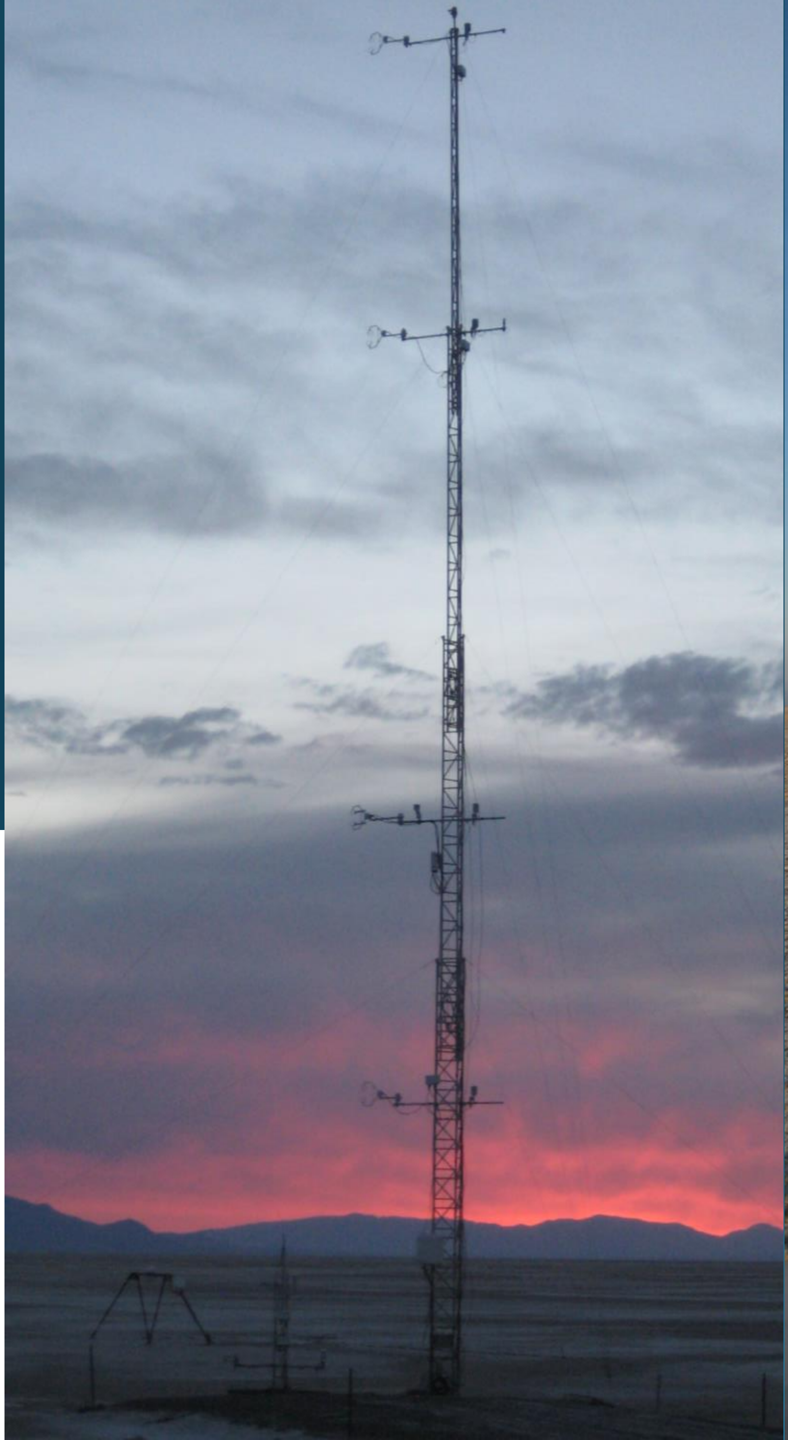
Playa

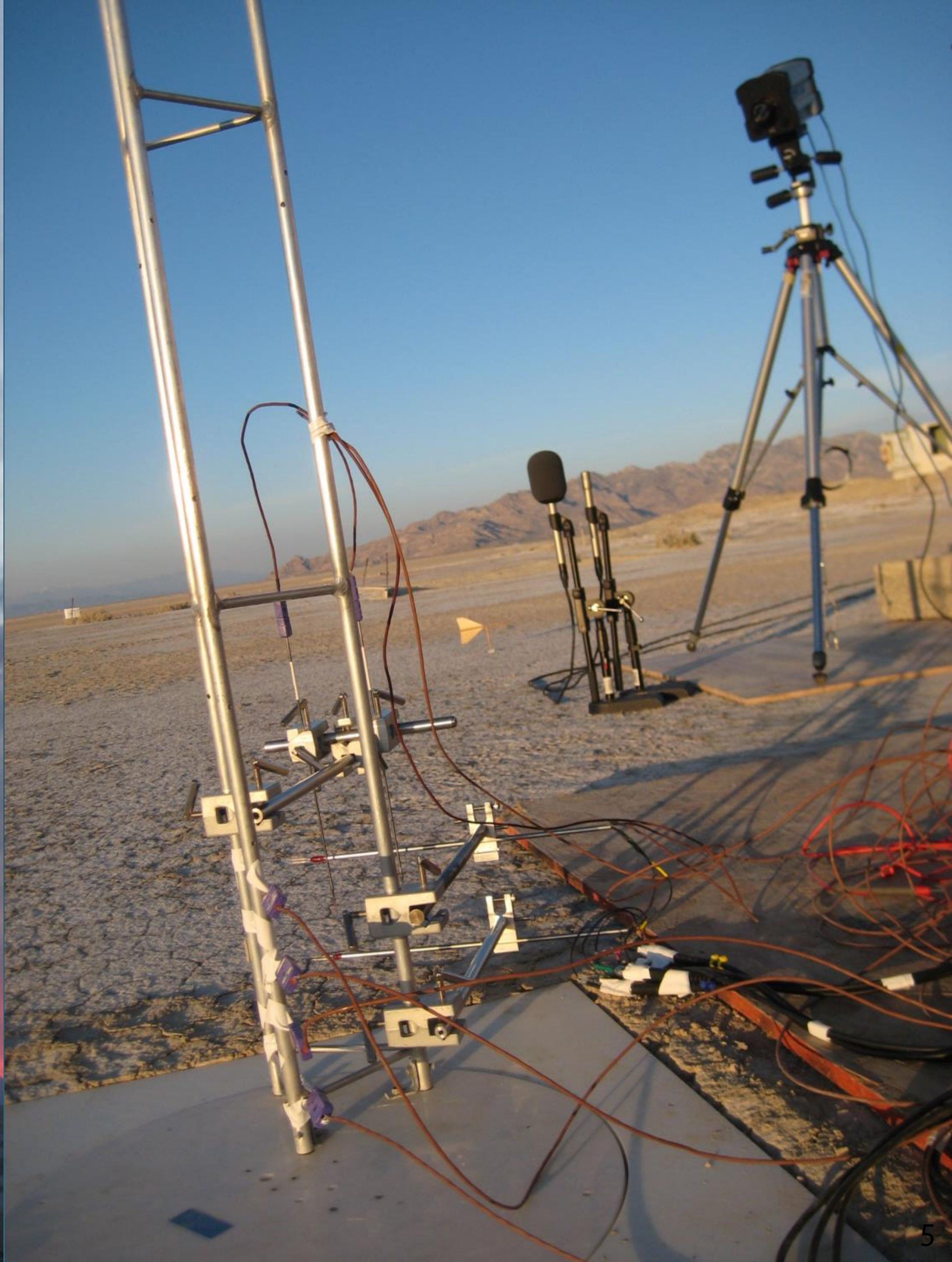
Heights: 28, 20, 10*, 5, 2, 0.5 m

*H_2O and CO_2 IRGA

- High Albedo
- Dry Lake Bed (High Soil Moisture)
- Very smooth, $Z_0 \approx 1\ mm$
- Very little elevation change
- Large, uninterrupted fetch
- Characterized by bi-directional thermally driven wind



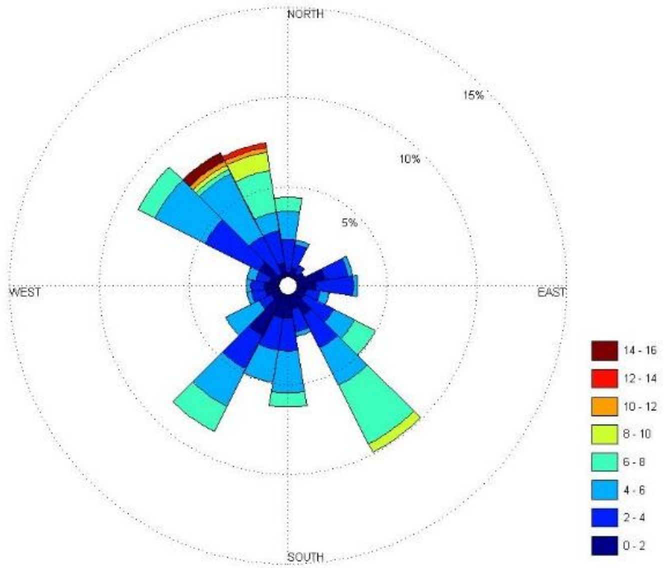




Sage

Heights: 20, 10*, 7.5**, 5, 2, 0.5 m
*H_2O and CO_2 IRGA
** 2nd IRGA for 10 days in fall

- Lower Albedo
- Very Dry
- Desert step (sparse vegetation ~ 1m tall)
- Playa Breeze Present
- Large fetch with some interaction from nearby mountains

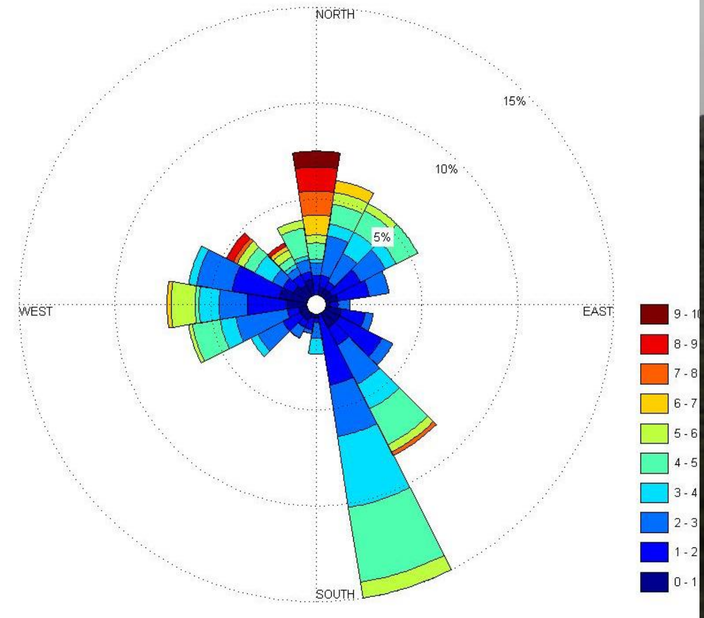


Slope

Heights: 20, 10, 5, 2*, 0.5 m

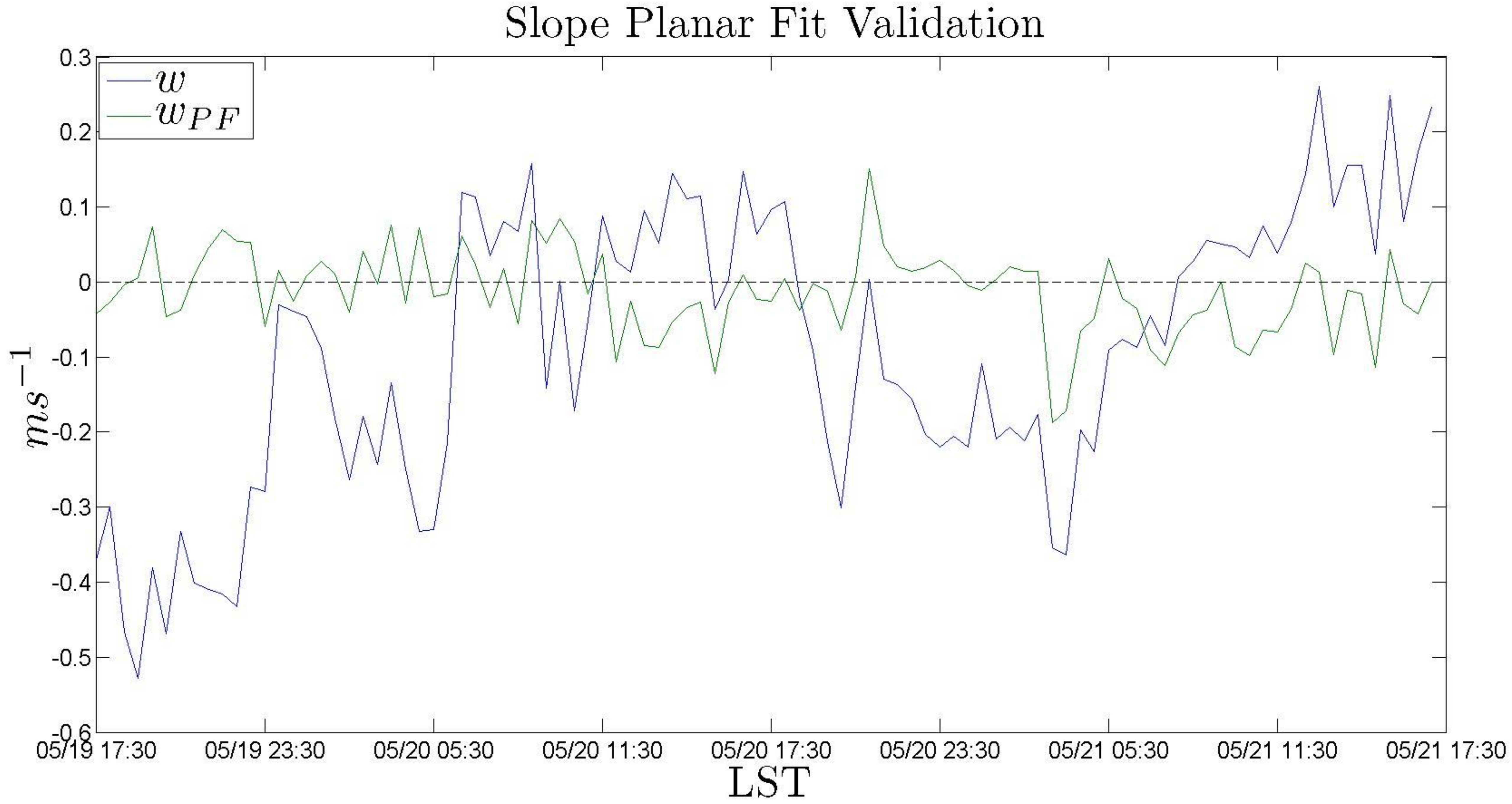
*H_2O (Only) IRGA

- Lowest Albedo
- Very Dry
- 5-7° slope
- Desert step (sparse vegetation ~ 0.5m tall)
- Upslope/downslope flow with valley interaction

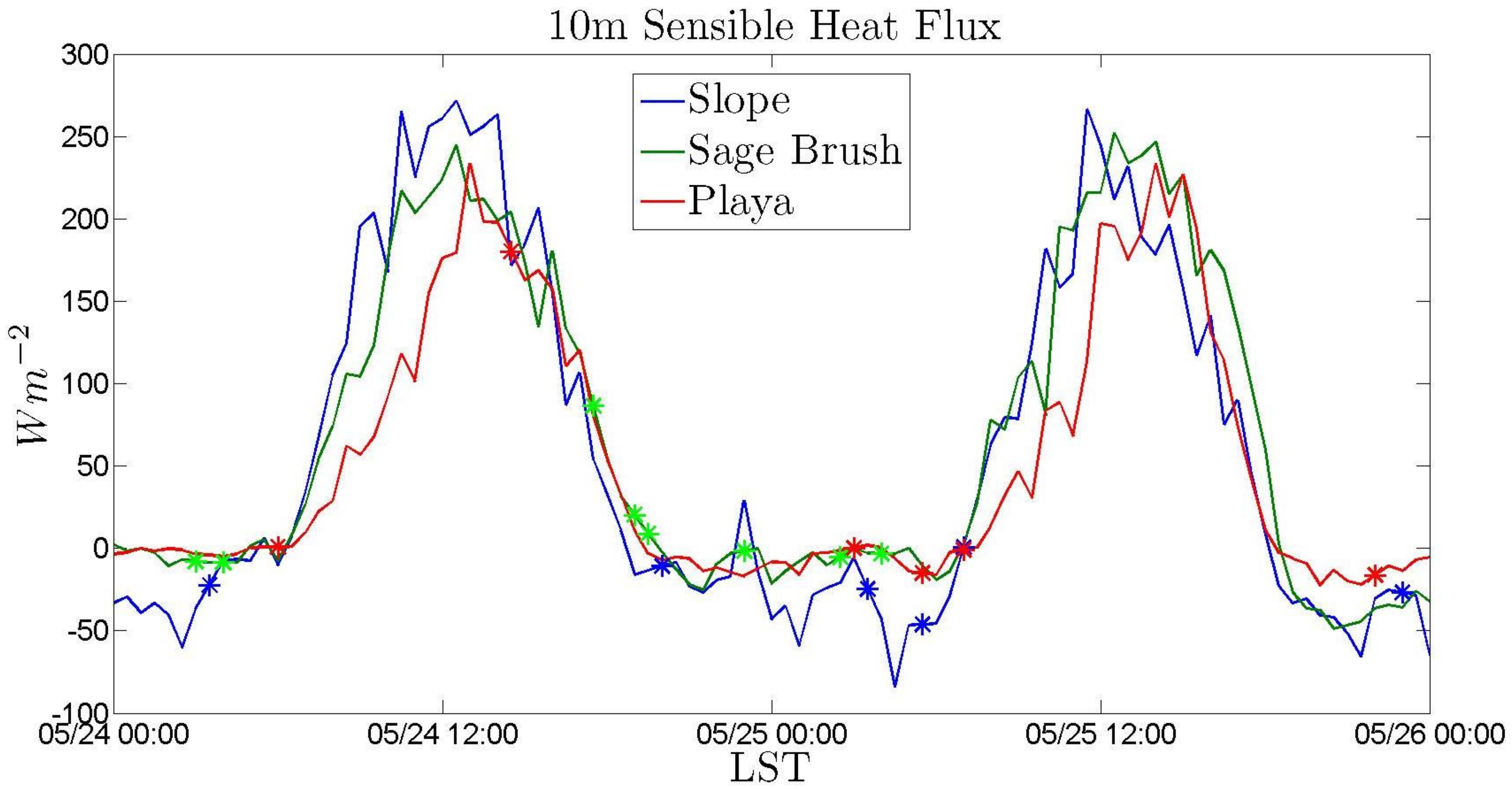


Data Processing

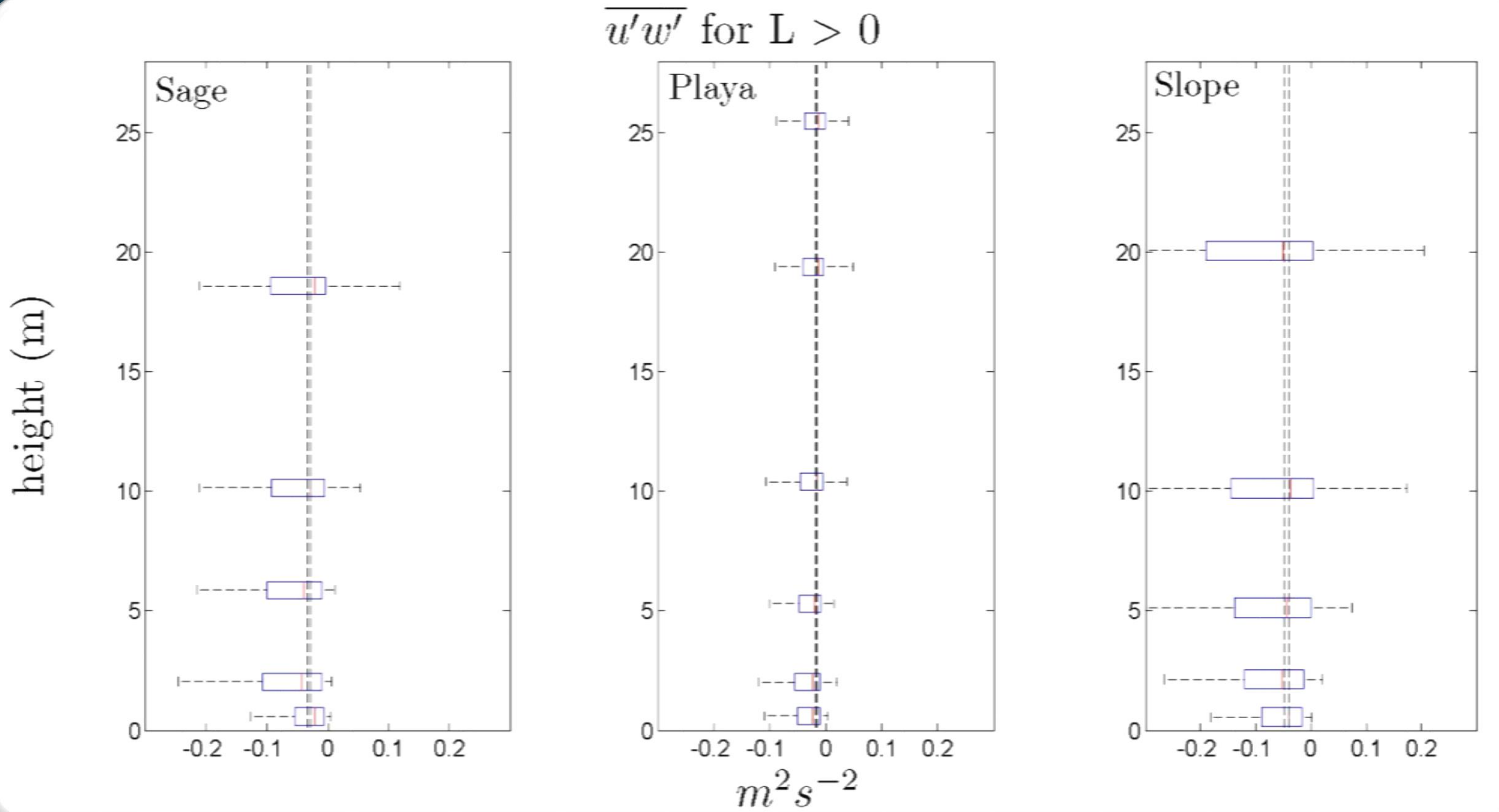
- Data Flagging True if
  - More than 0.02% of data for an averaging period is a NaN
  - 0.02% of data for an averaging period falls more than 5 standard deviations from the mean
  - Mean wind flow comes from within +/- 15 degrees of tower center
- Pertubations found from linear detrending with 30 minute averages
- 10 Day, 2 sector Planar Fit (Wilczak, 2000)
- Density(WPL) Corrections for H_2O and CO_2 Fluxes (Webb et al., 1980)
- Additionally, O_2 corrections applied for slope H_2O flux (Aubinet, 2012)

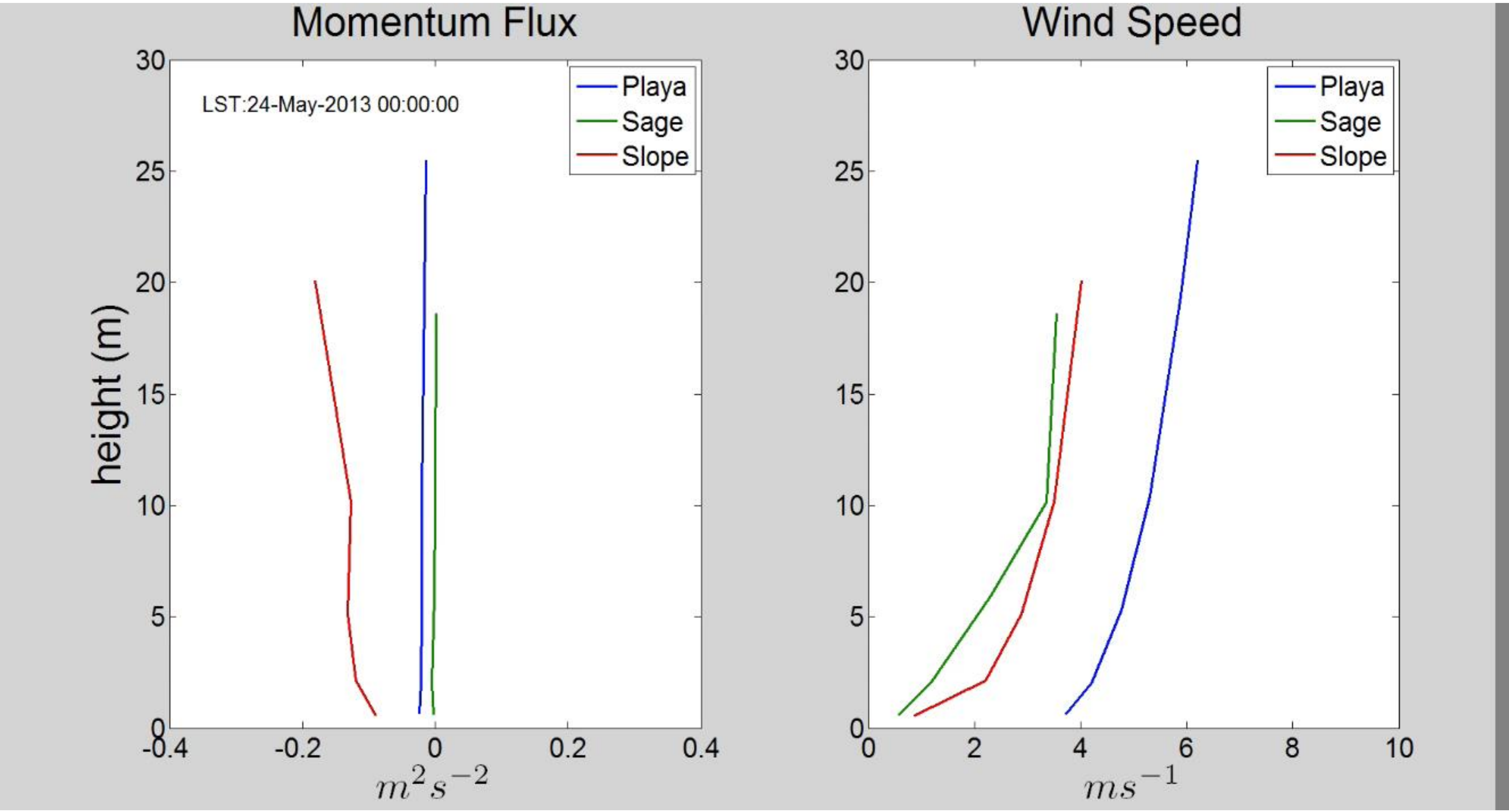


Slope Planar Fit Validation
w
w_{PF}
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
ms^{-1}
05/19 17:30
05/19 23:30
05/20 05:30
05/20 11:30
05/20 17:30
05/20 23:30
05/21 05:30
05/21 11:30
05/21 17:30
LST

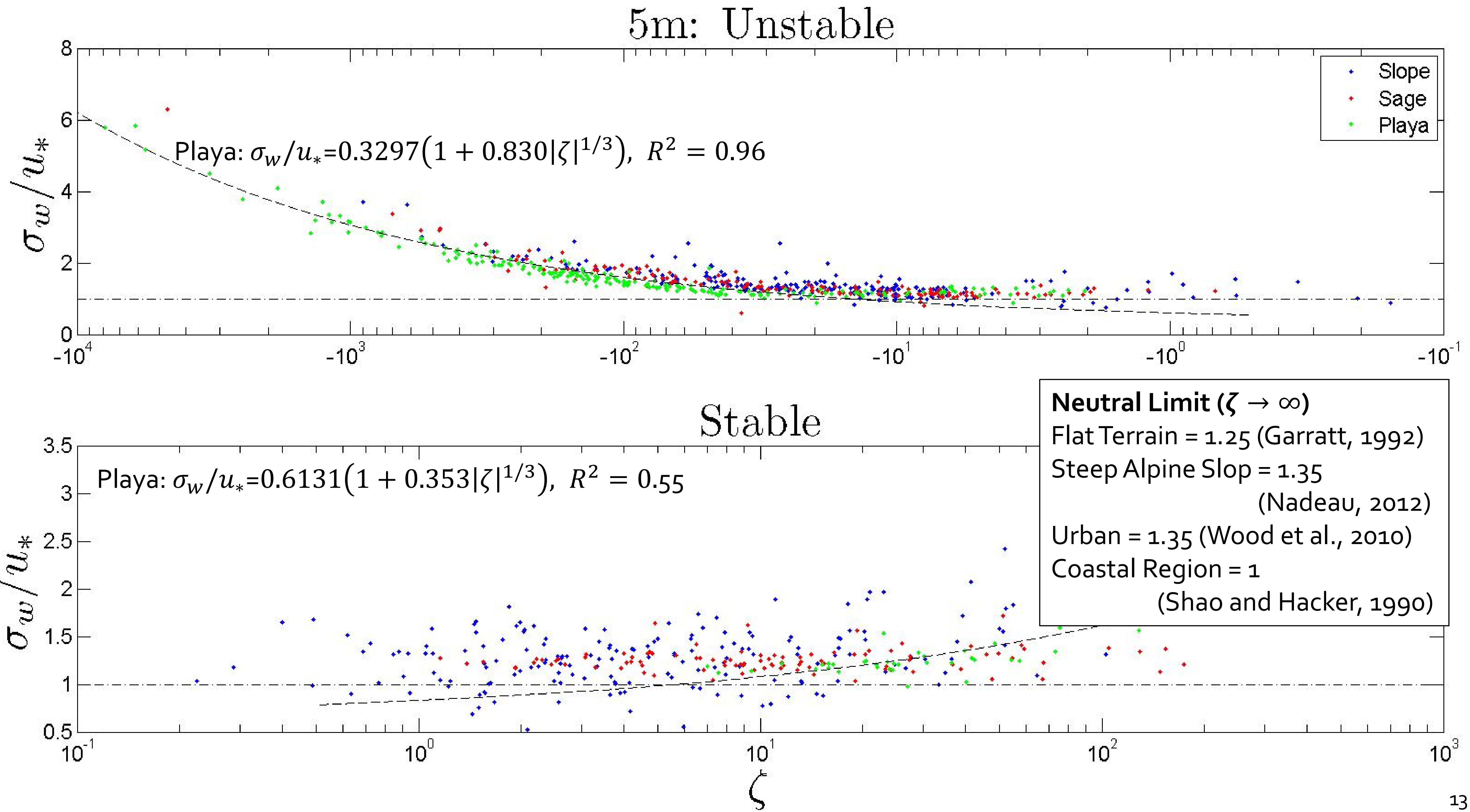

10m Sensible Heat Flux
Slope
Sage Brush
Playa
Wm^{-2}
300
250
200
150
100
50
0
-50
-100
05/24 00:00
05/24 12:00
05/25 00:00
05/25 12:00
05/26 00:00
LST

Constant Flux Layer?





Momentum Flux
LST:24-May-2013 00:00:00
Playa
Sage
Slope
height (m)
30
25
20
15
10
5
0
-0.4
-0.2
0
0.2
0.4
m^2s^{-2}
Wind Speed
Playa
Sage
Slope
30
25
20
15
10
5
0
0
2
4
6
8
10
ms^{-1}



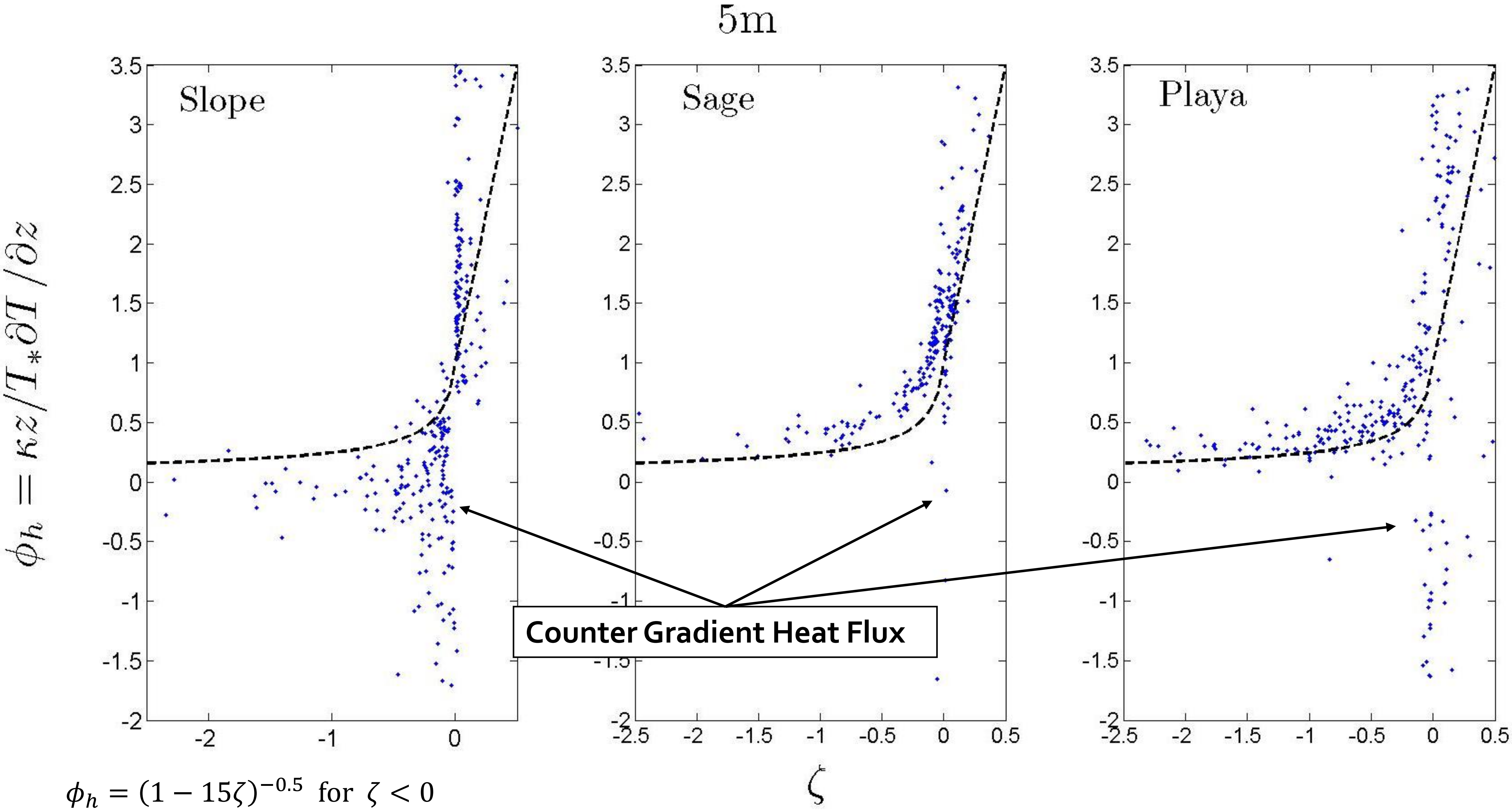
Neutral Limit ($\zeta \to \infty$)

Flat Terrain = 1.25 (Garratt, 1992)

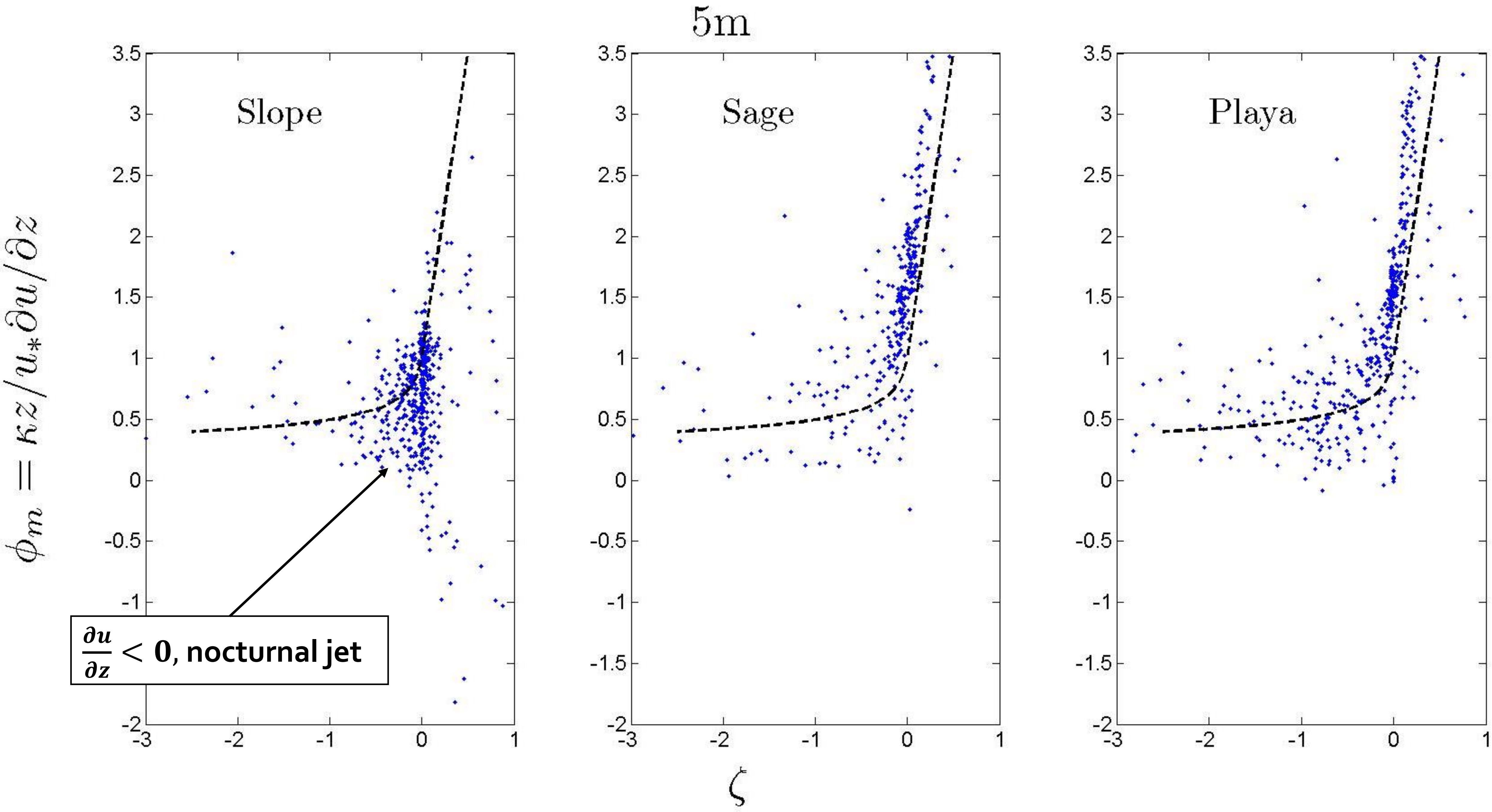
Steep Alpine Slop = 1.35 (Nadeau, 2012)

Urban = 1.35 (Wood et al., 2010)

Coastal Region = 1 (Shao and Hacker, 1990)



$$\phi_h = (1 - 15\zeta)^{-0.5} \text{ for } \zeta < 0$$
$$\phi_h = 1 + 5\zeta \quad \text{for } \zeta \geq 0$$ (Arya, 1988)


5m
Slope
Sage
Playa
$\phi_m = \kappa z/u_* \partial u/\partial z$
ζ
$\frac{\partial u}{\partial z} < 0$, nocturnal jet
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-3
-2
-1
0
1

Conclusions

- The playa sensible heat flux lags behind the other sites and has a smaller magnitude due to higher soil moisture.
- The Slope site has larger negative heat fluxes at night due to katabatic flow
- Although the mean statistics (box plots) seem to indicate somewhat constant flux layers at all sites, the profile video shows this is not the case.
- σ_w/u_* scales quite well with ζ at all sites under unstable conditions and appears to reflect the literature in the neutral asymptotic limit
- The universal functions agree reasonably well at all sites under unstable conditions. Under stable conditions counter-gradient heat transfer occurs at all sites and negative ϕ_m values occur at slope due to the katabatic flow

Future Work

- Quantify Self Correlation
- Evaluate Stationarity and intermittency under Stable Conditions
- Evaluate Homogeneity at the Slope Site
- Look at spectra and cospectra. How do they compare with MOST
- Examine alternative formulations