Flux-gradient relationships over contrasting surfaces during the evening transition

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Background

- Flux-gradient relationships are used extensively to estimate fluxes within the atmospheric surface layer
- Monin-Obukhov Similarity Theory (**MOST**) is most common
- Data from MATERHORN are being used to evaluate flux-gradient relationships in the surface layer during the evening transition. Counter-gradient (CG) flux behavior is the principal focus.

- ***GOAL: Obtain a more complete understanding of the driving mechanisms behind near-surface, counter-gradient heat fluxes during the evening transition***

Mountain Terrain Atmospheric Modeling and Observations Program

MATERHORN

Office of Naval Research ONR Science & Technology

University of Notre Dame

DUGWAY PROVING GROUND UTAH, USA

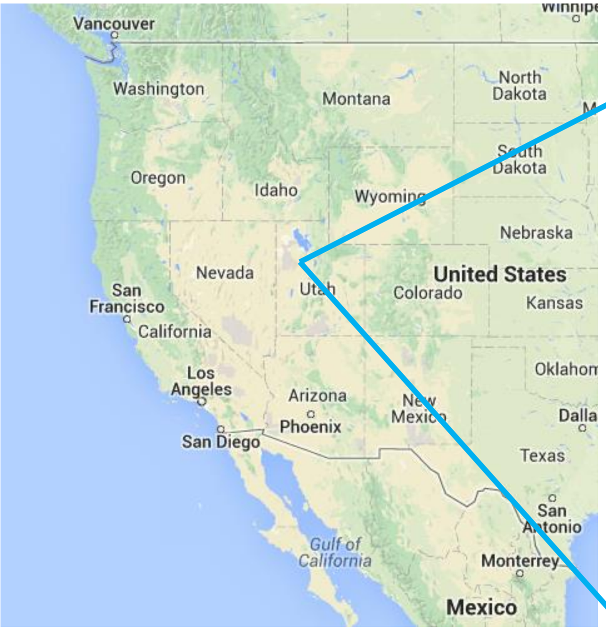
Berkeley UNIVERSITY OF CALIFORNIA

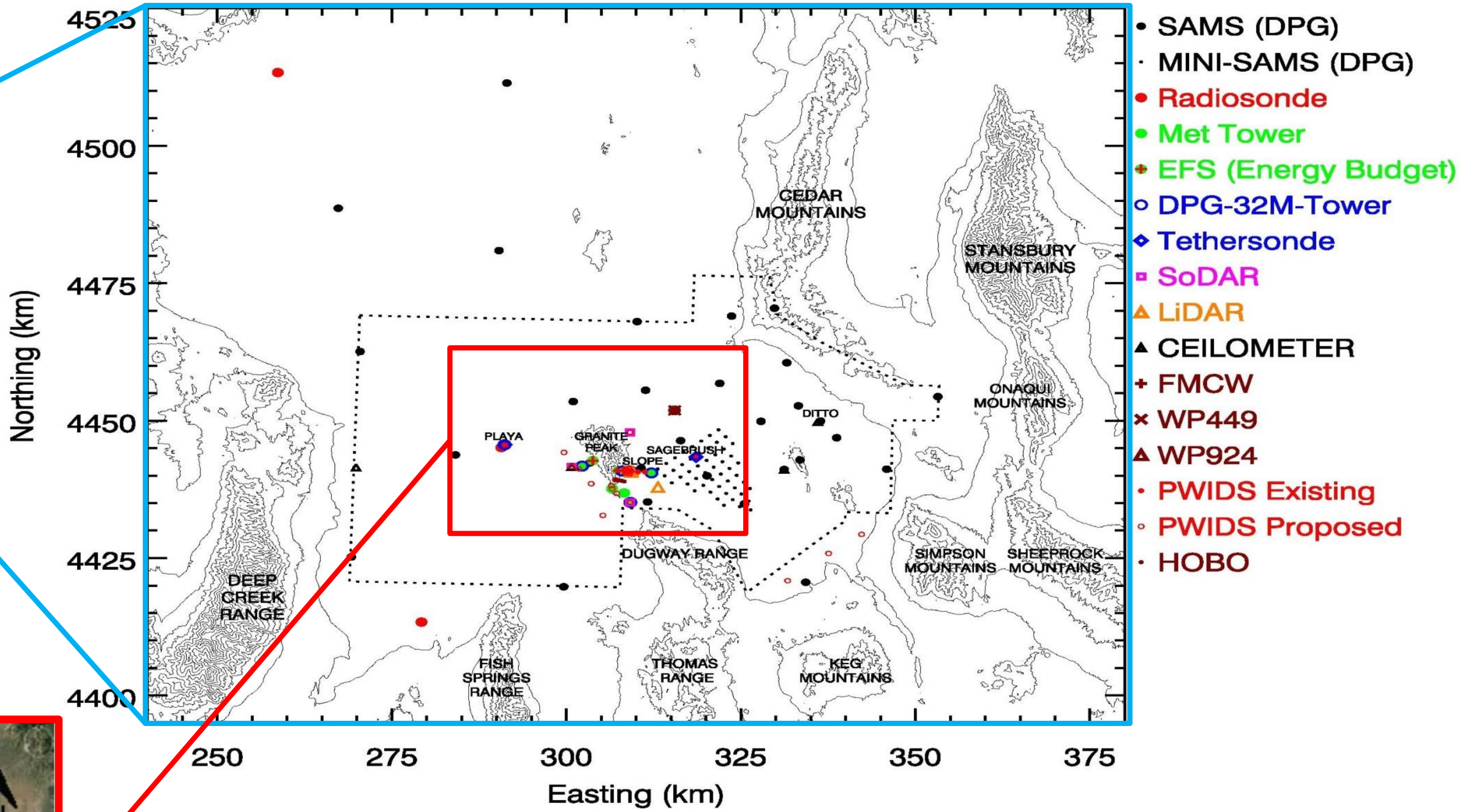
THE UNIVERSITY OF UTAH

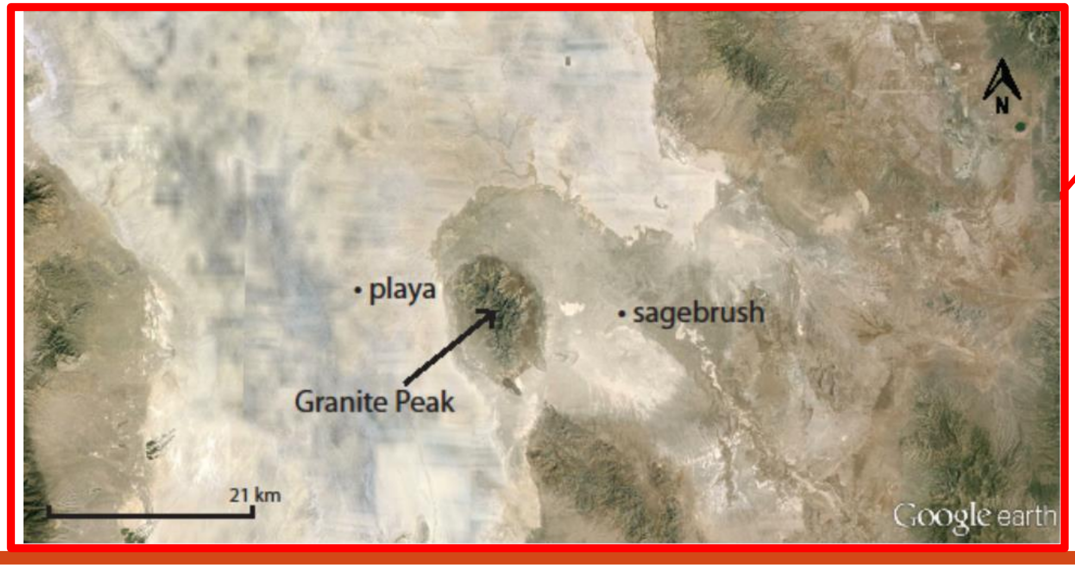
NPS PRAESTANTIA PER SCIENTIAM

UNIVERSITY of VIRGINIA

A three-year, multi-institution program designed to improve weather predictability over complex terrain







2 Field Campaigns

- Fall: 25 Sept. 2012 – 21 Oct. 2012
- Spring: 1 May 2013 – 31 May 2013

3 Sites of Interest

- Sagebrush
- Playa
- East Slope 5 (ES5)

Relevant Instrumentation

- Sonic Anemometers
- Finewire Thermocouples
- Temperature/RH
- Net Radiometers
- Soil Sensors

Playa

Heights: 0.5, 2, 5, 10, 20, 26 m

- Higher Albedo (0.32)
- **High Soil Moisture**
- $z_0 \approx 1mm$
- No vegetation

Sagebrush

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

- Lower Albedo (0.26)
- **Low Soil Moisture**
- $z_0 \approx 20\ cm$
- Desert Steppe


Playa

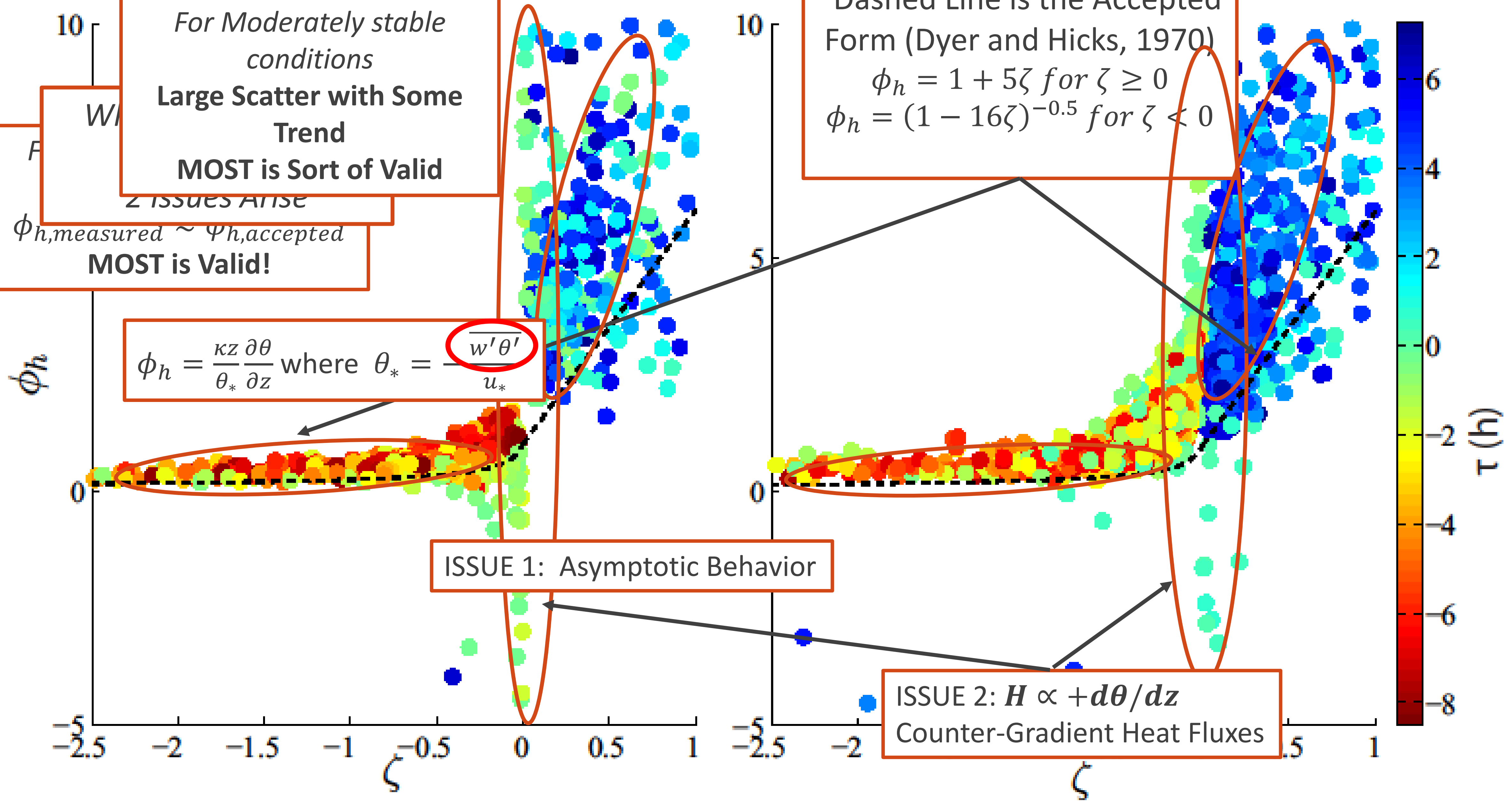

Sagebrush

Non-Dimensional Temperature Gradient, ϕ_h

- $\phi_h = \frac{\kappa z}{\theta_*}\frac{d\theta}{dz}$ where $\theta_* = -\frac{\overline{w'\theta'}}{u_*}$
- Within MOST, $\boldsymbol{\phi_h = f(\zeta)}$ where $\zeta = \frac{z}{L}$ and L is the Obukhov Length
- ϕ_h can be used to estimate temperature profiles and heat fluxes
- ϕ_h can be used to explore the validity of MOST

Transition Data Analysis

- 5 minute averaging and linear detrending
- Fine wire temperature always used
- Transition periods with high winds (> 7 m s^{-1}) and missing data neglected
- Left with 8 days at Playa, 13 at Sagebrush
- Transitional Relative Time: $\tau \equiv t - t_{Rn=0}$



F

$\phi_{h,measured} \sim \phi_{h,accepted}$

MOST is Valid!

Wh

2 Issues Arise

For Moderately stable conditions

Large Scatter with Some Trend

MOST is Sort of Valid

$$\phi_h = \frac{\kappa z}{\theta_*}\frac{\partial \theta}{\partial z} \text{ where } \theta_* = \frac{\overline{w'\theta'}}{u_*}$$

Dashed Line is the Accepted Form (Dyer and Hicks, 1970)

$$\phi_h = 1 + 5\zeta \; for \; \zeta \geq 0$$

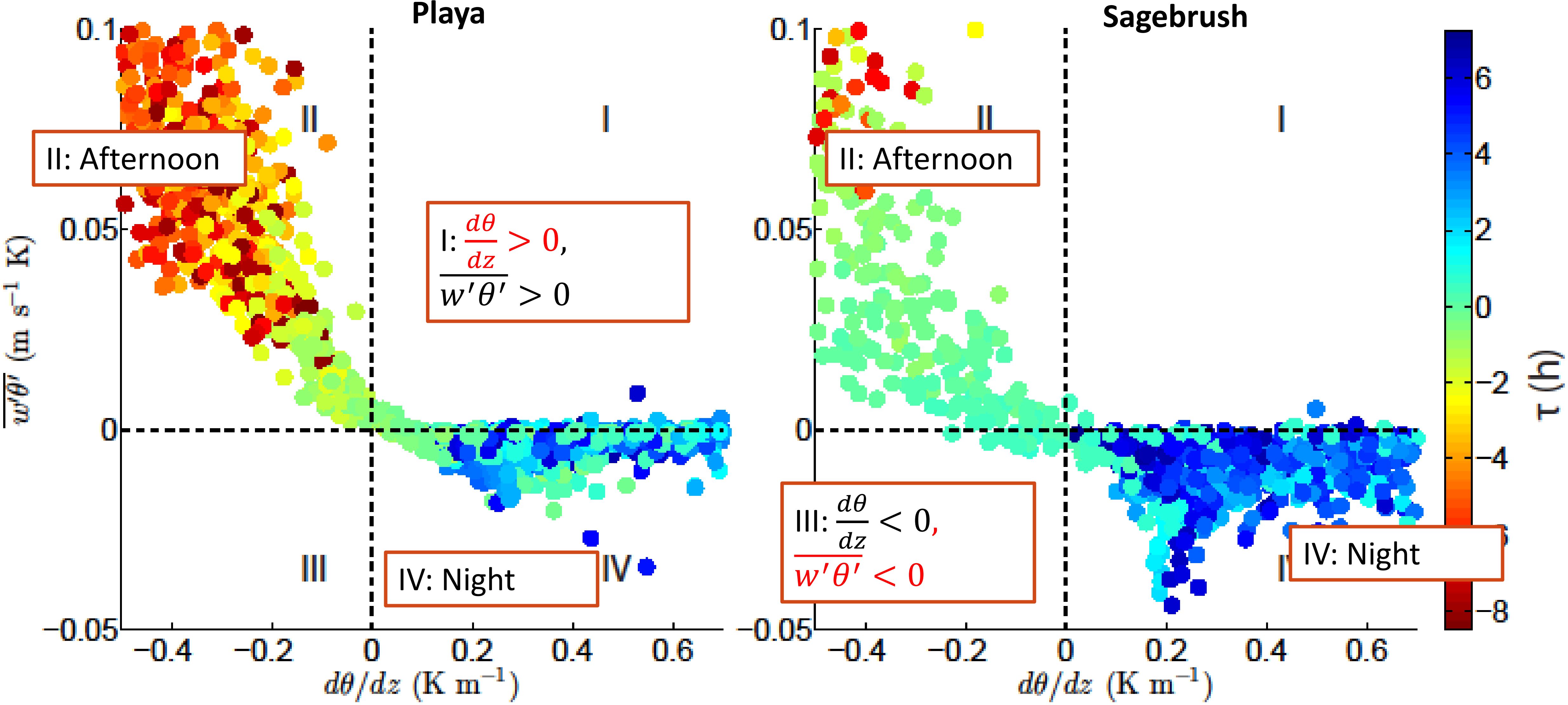
$$\phi_h = (1 - 16\zeta)^{-0.5} \; for \; \zeta < 0$$

ISSUE 1: Asymptotic Behavior

ISSUE 2: $\boldsymbol{H \propto +d\theta/dz}$

Counter-Gradient Heat Fluxes

Counter Gradient Fluxes: Quadrant Analysis



Playa

II: Afternoon

I: $\frac{d\theta}{dz} > 0$, $\overline{w'\theta'} > 0$

IV: Night

Sagebrush

II: Afternoon

III: $\frac{d\theta}{dz} < 0$, $\overline{w'\theta'} < 0$

IV: Night

Time Scales

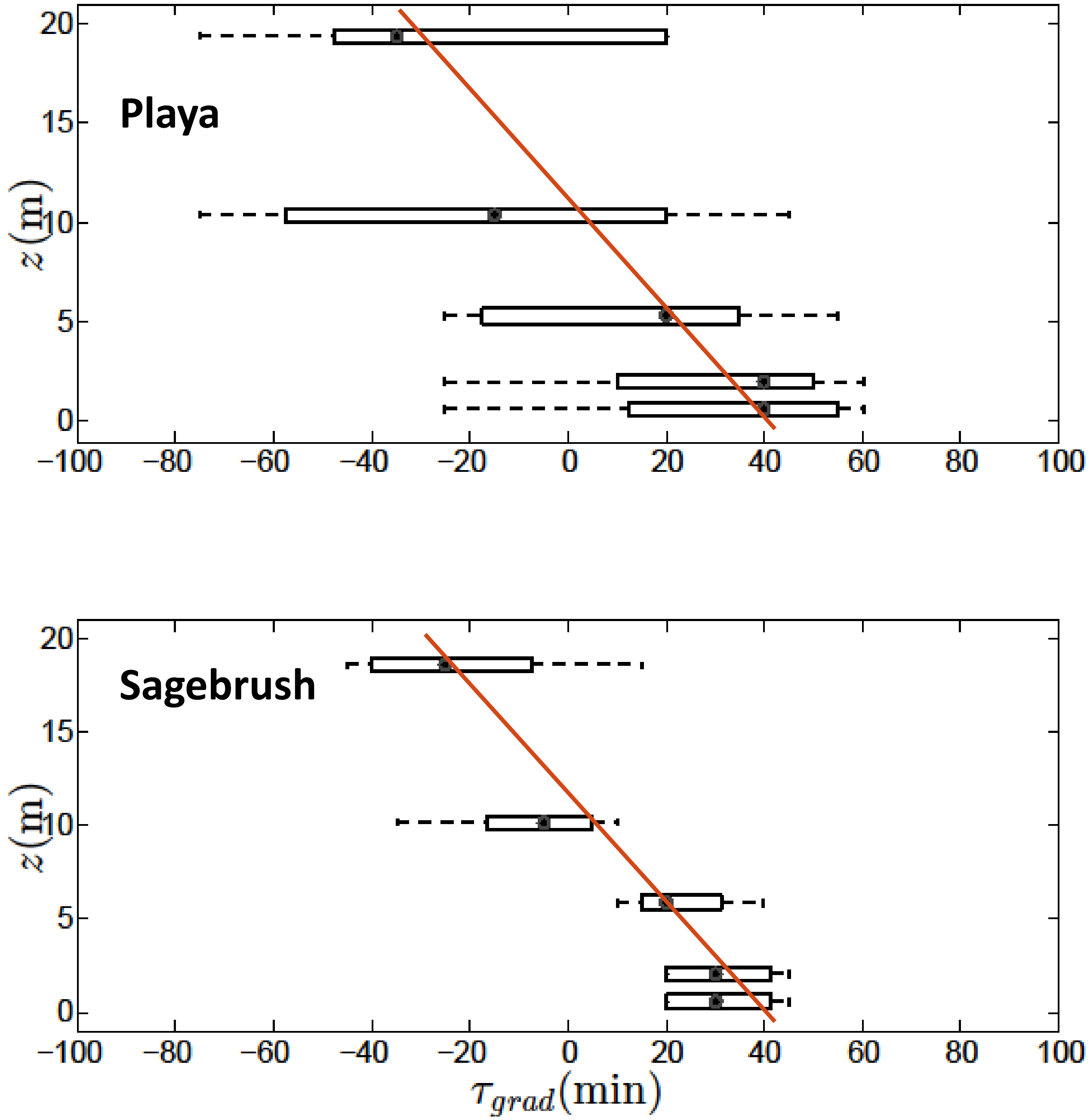
- Flux Reversal Time: $\tau_{flux} \equiv \tau_{H=0}$
- Gradient Reversal Time: $\tau_{grad} \equiv \tau_{\partial\theta/\partial z=0}$
- Lag Time: $t_{lag} = \tau_{flux} - \tau_{grad}$
  - $t_{lag} > 0$ when the **gradient reversal precedes the flux reversal**
  - $t_{lag} < 0$ when the **flux reversal precedes the gradient reversal**

Box Plots of τ_{grad}

1. Variability at Playa is large at all heights

2. Similar Trend at both sites

3. $\frac{\partial \tau_{grad}}{\partial z} \approx -4$ min m^{-1}

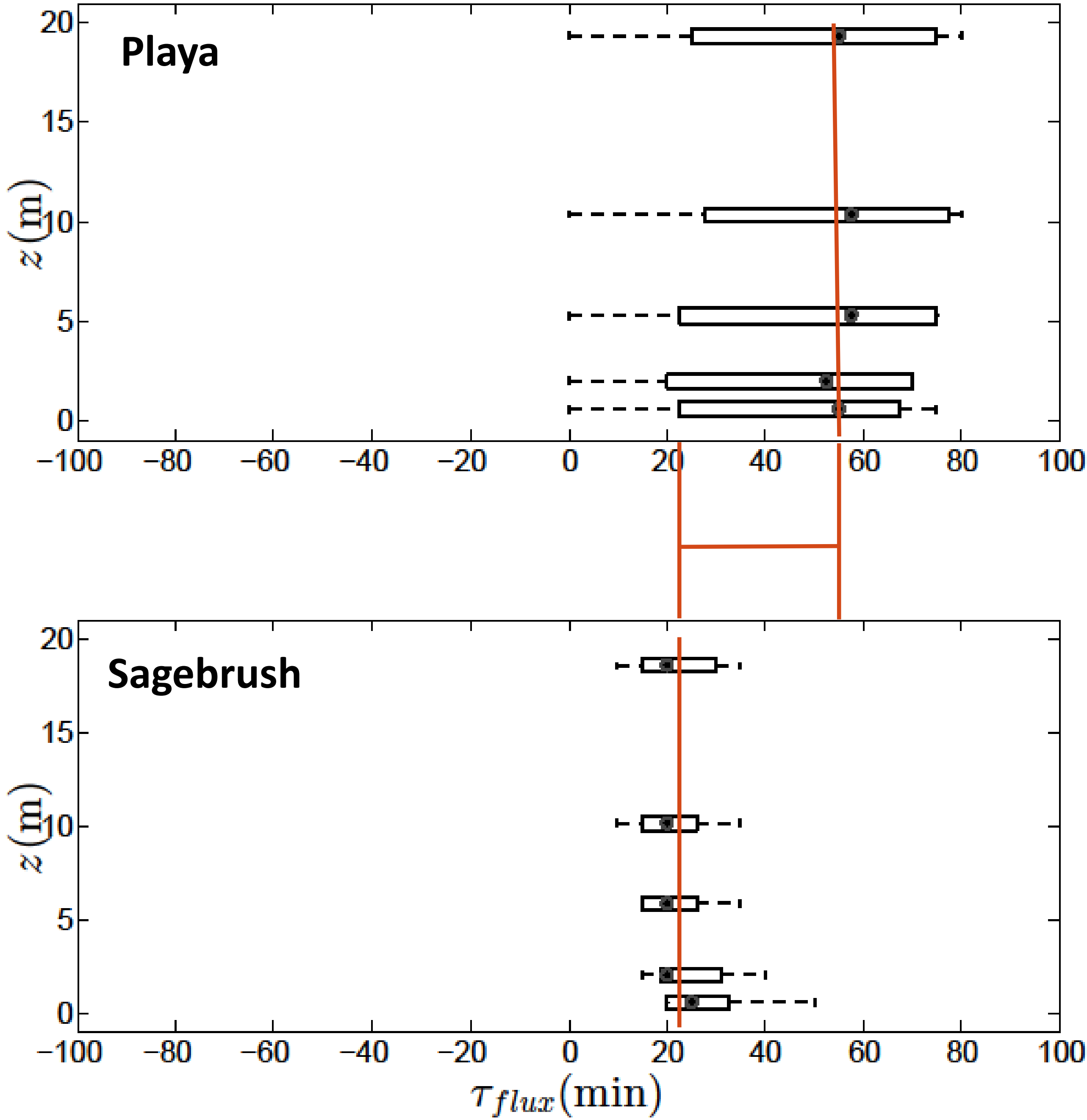


Box Plots of τ_{flux}

1. Again, Playa scatter is large

2. Occurs simultaneously at all heights

3. Median behavior of Playa lags Sagebrush by approximately 30 minutes



Box Plots of t_{lag}

1. Variability grows with height at both sites

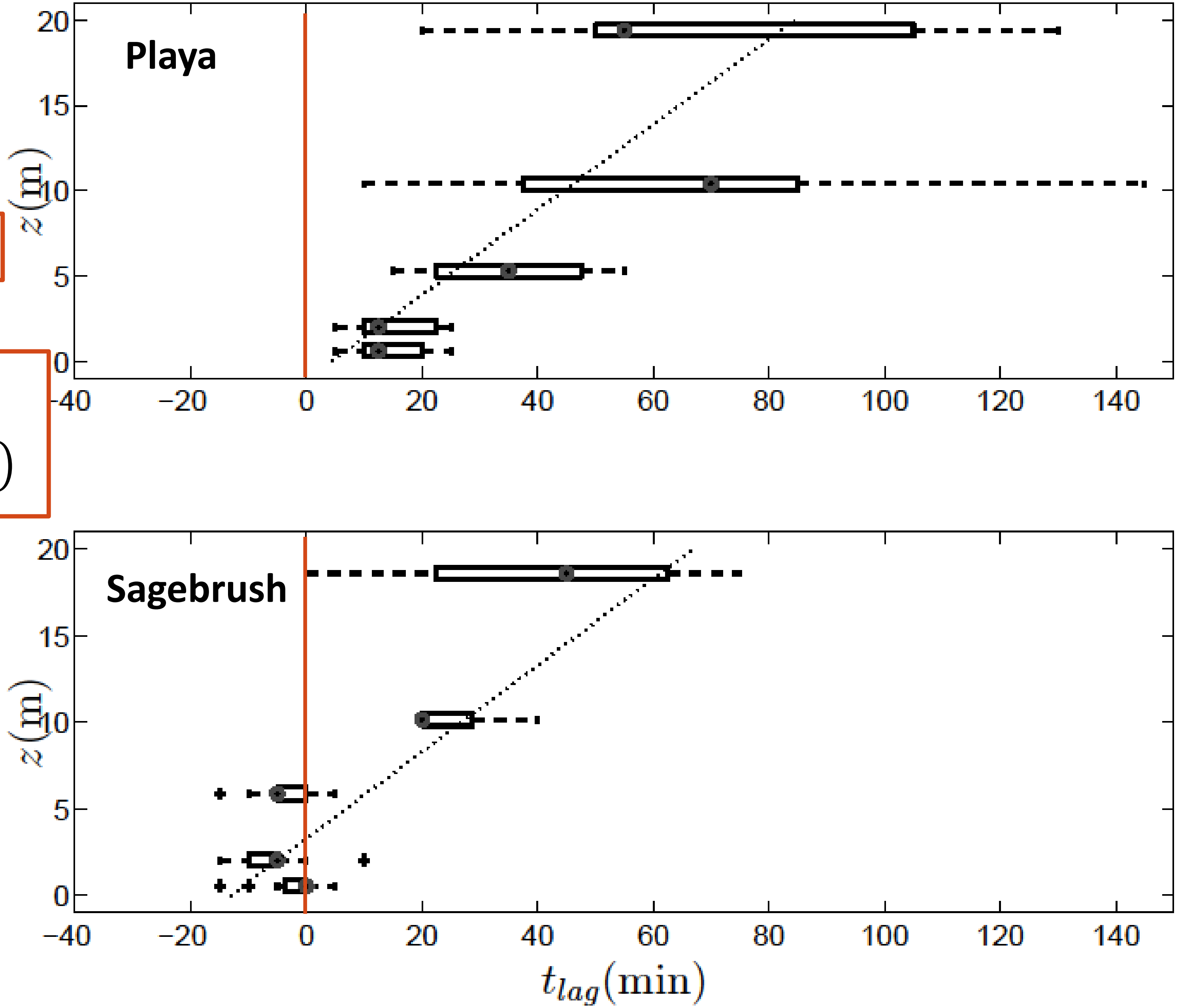
2. Dashed line computed from

$$t_{lag}(z) \approx -\frac{\partial \tau_{grad}}{\partial z}\Delta z - \left(\tau_{grad,2m} - \tau_{flux,2m}\right)$$

3. May be valid at other sites!

4. $t_{lag,Playa}(z) > 0$, i.e. gradient reversal precedes flux reversal

5. $t_{lag,Sagebrush}(z) > 0$ For $z \geq 10$ m
   $t_{lag,Sagebrush}(z) < 0$ For $z \leq 5$ m



Questions

- What is causing the **common** CG behavior at 10 m and above?
- What is causing the **opposing** CG behavior at 5 m and below?

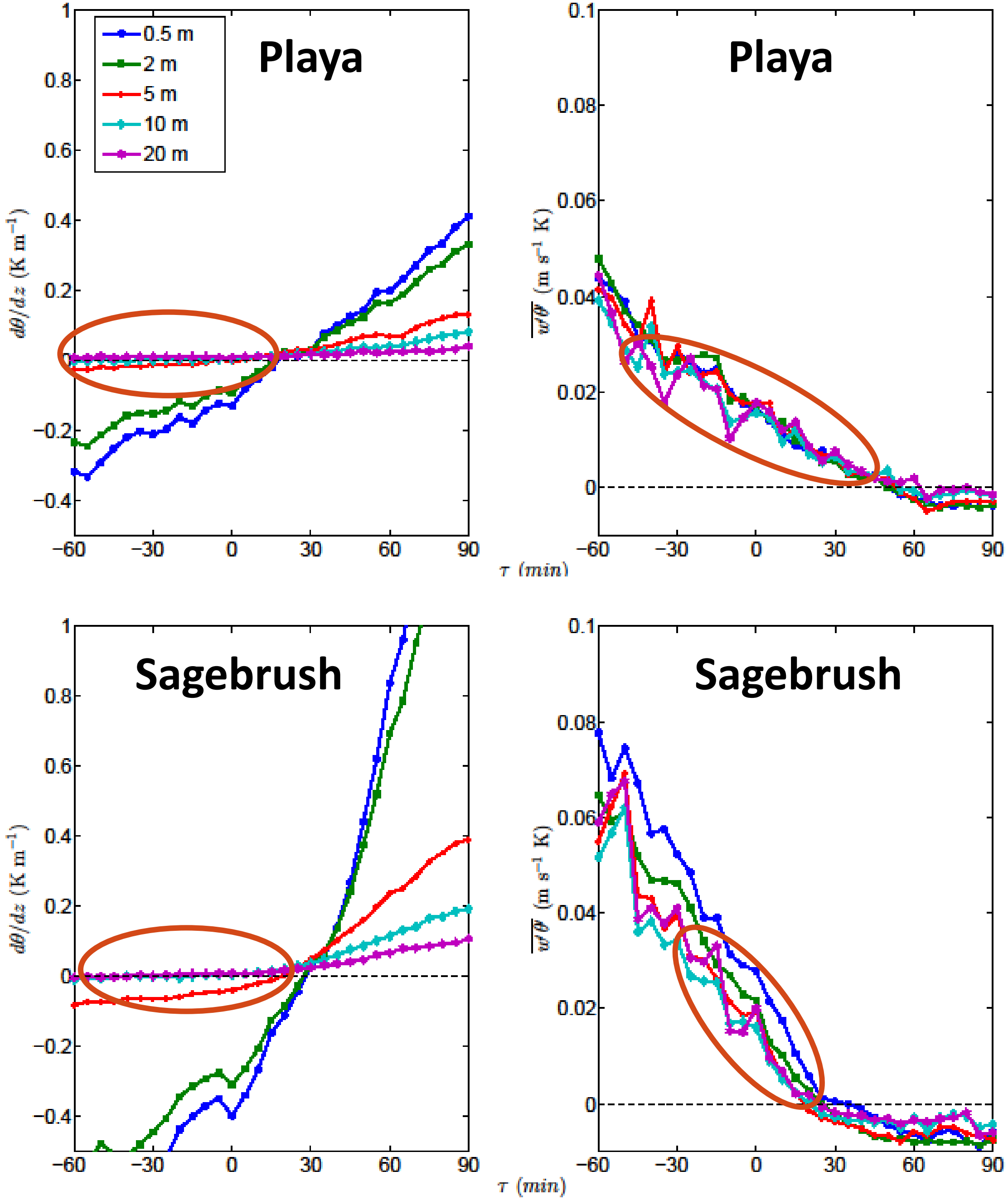
CG Behavior at ≥10 m

1. Very weak gradients aloft with stabilization occurring from the top-down

2. Strong fluxes aloft

3. Non-local effects from below allow positive fluxes to persist within weakly stable gradients

4. Why does stabilization occur from the top-down?

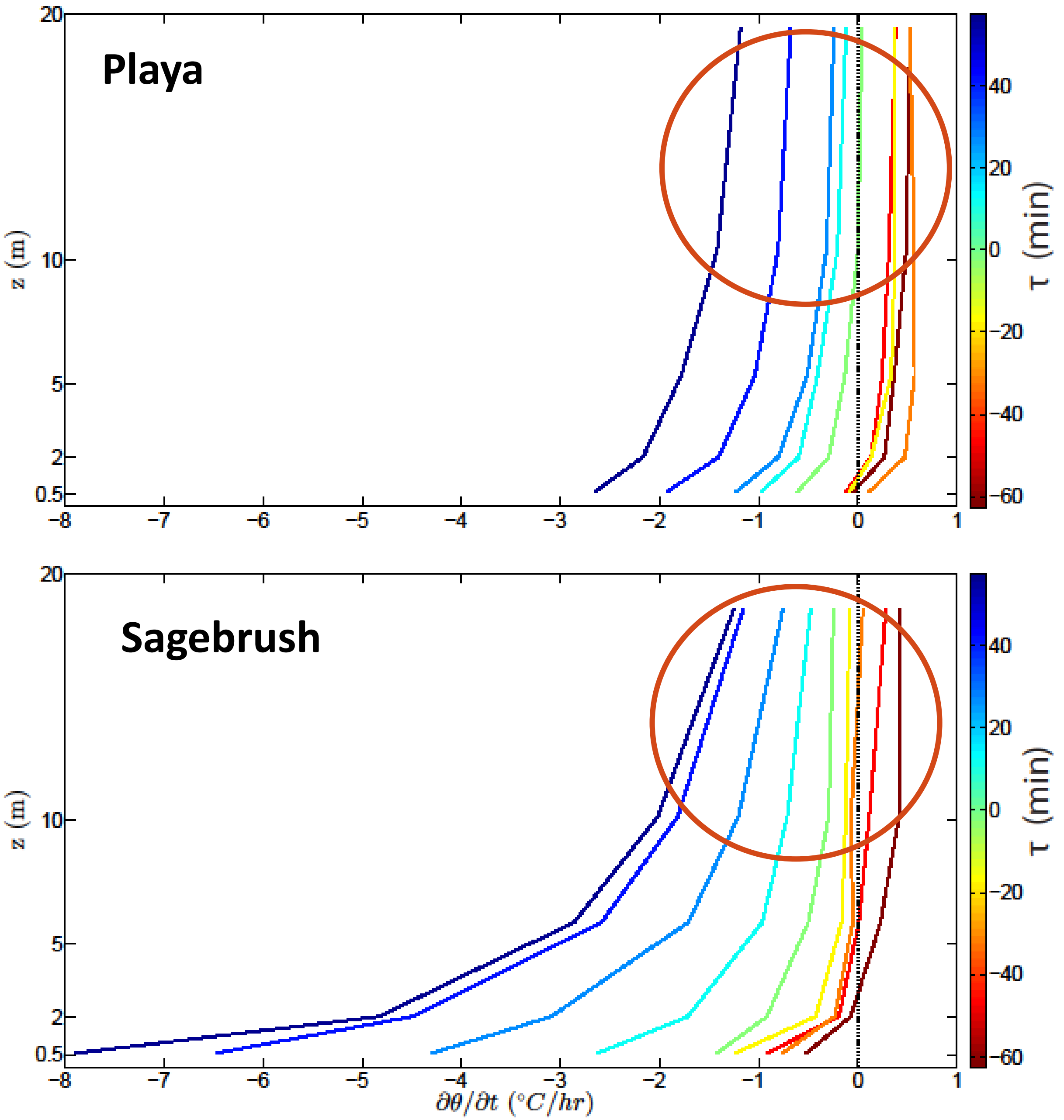


CG Behavior at ≥10 m

1. As H decreases, flux divergence creates differential cooling.

2. When $\frac{\partial^2\theta}{\partial z \partial t} > 0$ stabilization is occurring

3. Very small amount of stabilization is able to flip weak gradients aloft



CG Behavior below 5 m Hypothesis

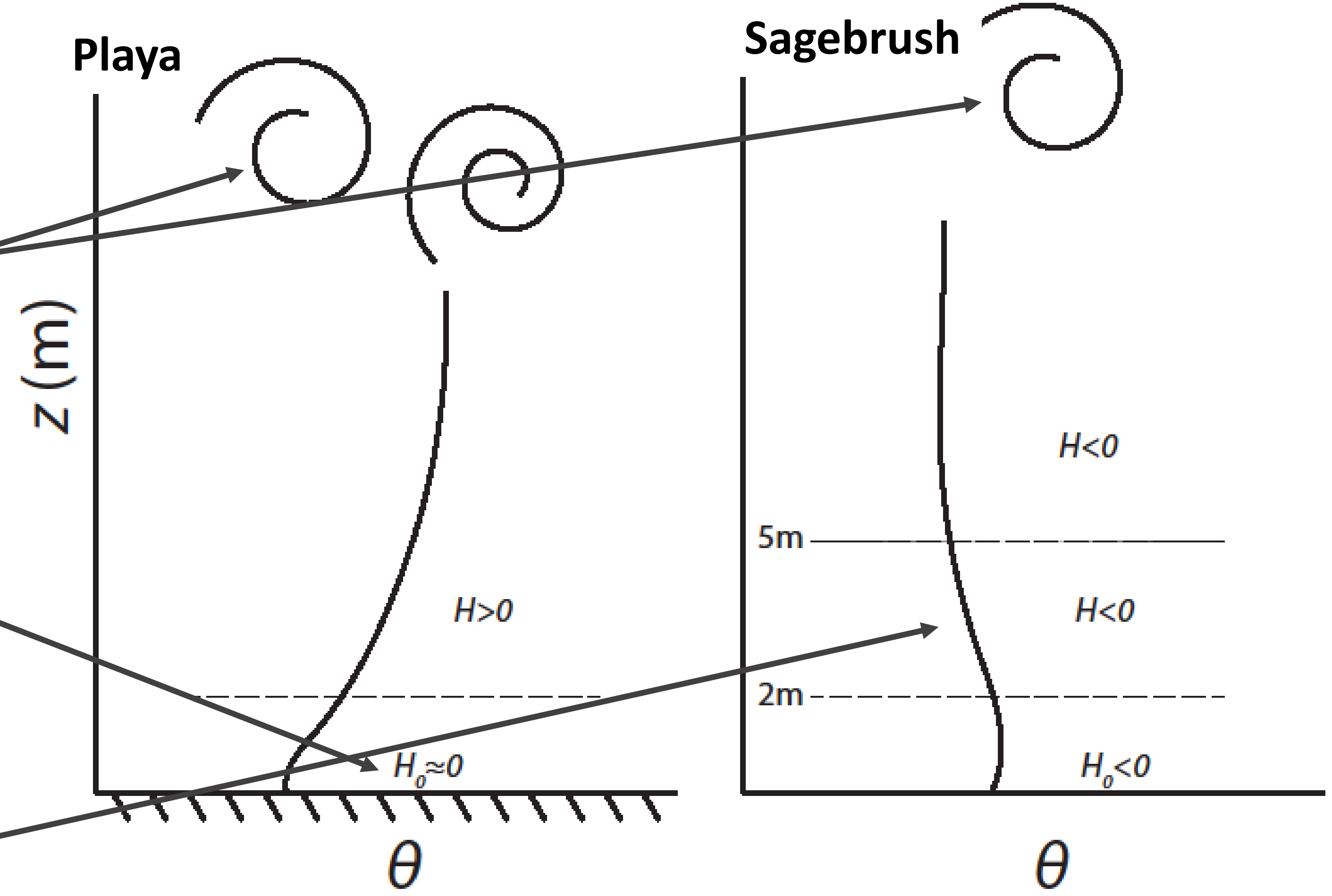
1. Eddies from atop the surface layer detach and transport cool air to the surface

$$(-w' - \theta') \rightarrow +H$$

The effect is stronger at Playa due to higher winds. Previously observed (Brunet, 2002; Sahlée et al. 2008, Smedman et al. 2007)

2. Weak surface forcing at Playa allows the non-local turbulence to drive the flux

3. A convergence zone occurs between ~ 2 and 5 m at Sagebrush where surface and non-local effects compete. Surface forcing dominates.



Conclusions

- Counter-gradient heat fluxes occur due to the flux reversal preceding the local gradient reversal and vice versa
- At Playa, CG behavior is always due to the gradient reversal preceding the flux reversal
- At Sagebrush, CG behavior is the same as Playa's above 10 m and the opposite below 5 m
- Reasons for the differing near-surface behavior will be discussed tomorrow.

Questions?
Comments?
Concerns?

H_0 Estimate

Surface Energy Budget

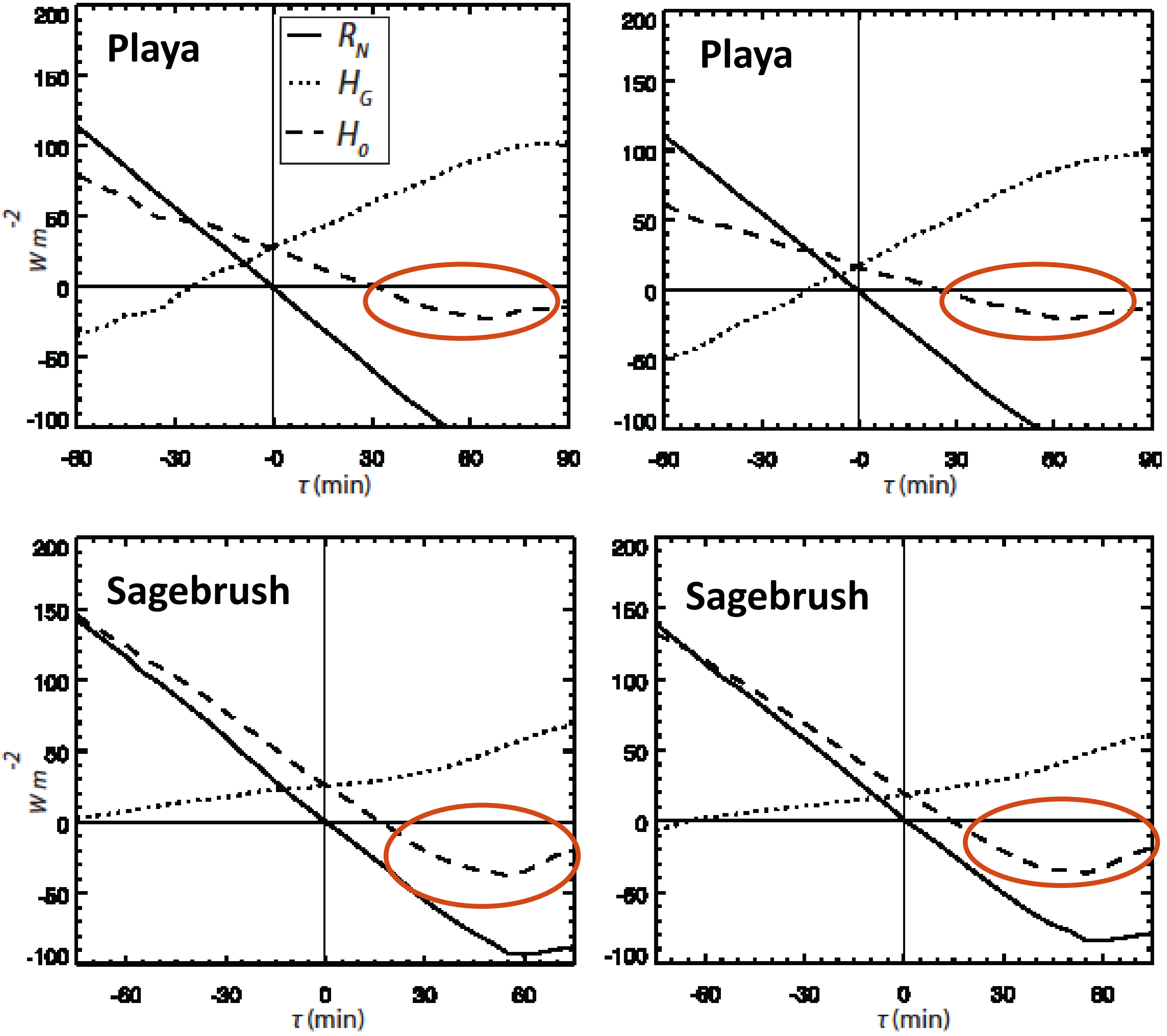
$$Rn = H + H_L + H_G + \Delta \mathrm{H_S}$$

Assume: $H_L \approx 0, \Delta H_S$ accounted for in H_G

$$H = Rn - H_G$$

2. H_{Playa} less important than $H_{Sagebrush}$

3. This lends confidence to part I of our hypothesis. What about cool air mixing downward?

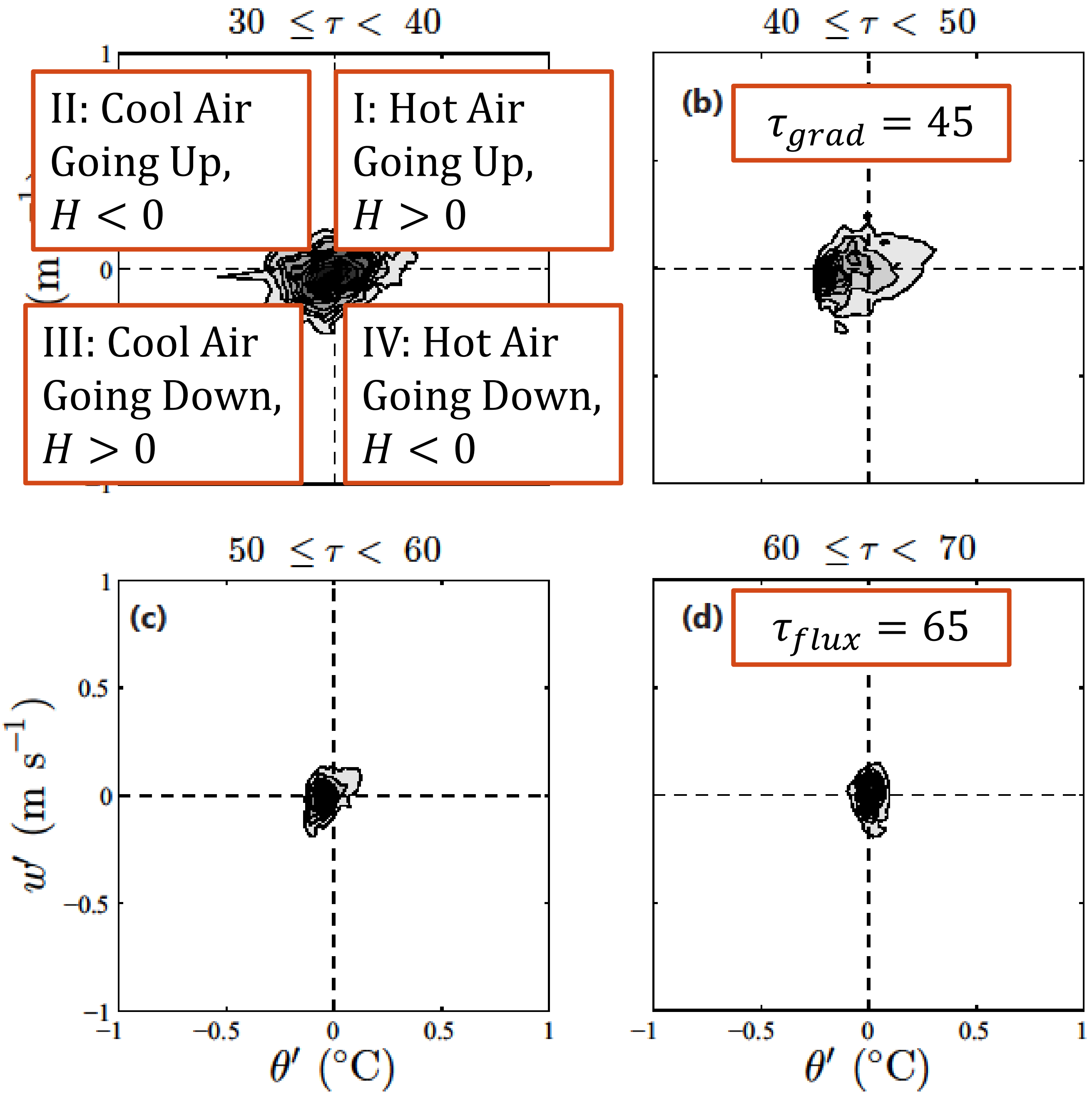


Joint Probability Distribution Function For Playa

(a) Convective conditions with $H > 0$

(b & c) Competing forces, cool air going up (surface forcing/demixing) and cool air coming down (mixing from aloft). Cool air coming down is more important → $H > 0$

(d) Surface forcing more important → $H < 0$



II: Cool Air Going Up, $H < 0$

I: Hot Air Going Up, $H > 0$

III: Cool Air Going Down, $H > 0$

IV: Hot Air Going Down, $H < 0$

$\tau_{grad} = 45$

$\tau_{flux} = 65$

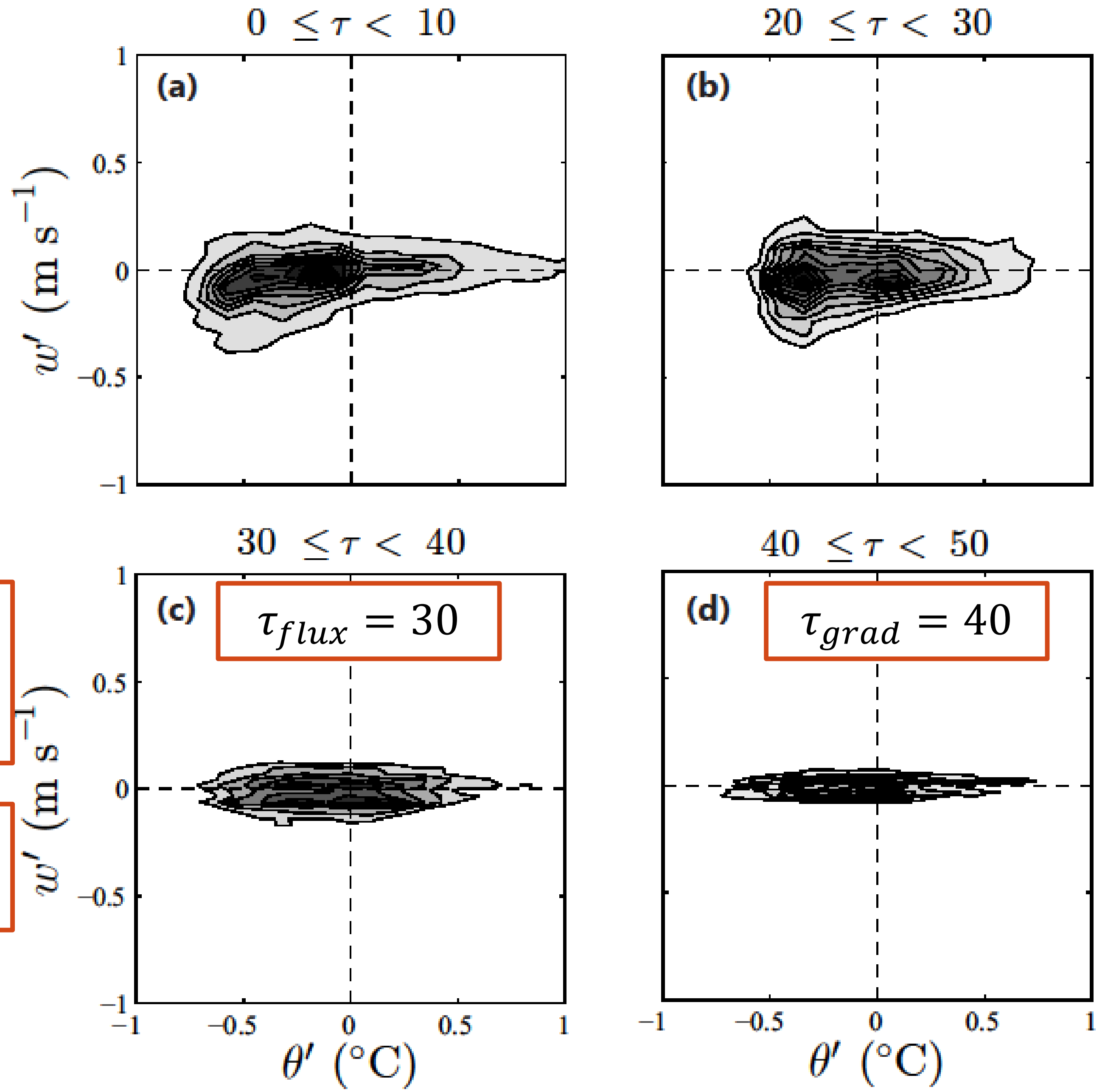
Joint Probability Distribution Function For Sagebrush

(a) Convective conditions with $H > 0$

(b) Bifurcation occurs between $H > 0$ and $H < 0$, Quadrant III wins → $H > 0$

(c) Bifurcation continues, Quadrant IV wins, → $H < 0$ w' is very small indicating viscosity, thermal diffusivity are important

(d) Vertical mixing remains small, flux is very weakly negative



$\tau_{flux} = 30$

$\tau_{grad} = 40$

Conclusions

- Counter-gradient heat fluxes occur due to the flux reversal preceding the local gradient reversal and vice versa
- At Playa, CG behavior is always due to the gradient reversal preceding the flux reversal
- At Sagebrush, CG behavior is the same as Playa's above 10 m and the opposite below 5 m
- CG behavior above 5 m due to non-local effects
- CG behavior below 5 m at Sagebrush is primarily surface driven
- CG behavior below 5 m at Playa is primarily driven from aloft
- An LES Study is needed for added clarity

Questions?

Comments?

Concerns?