Understanding the Behavior of Fluxes and Variance in the Surface Layer During Evening Transition

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(Many others)

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Summary – Current BLLAST related Efforts

1. Conducted the MATERHORN (Mountain Terrain Atmospheric Modeling and Observations) field campaign – overlapping goals with BLLAST
2. Estel Blay-Carreras – visiting student to the University of Utah from May 2012 – November 2013.
3. Steep Slope Evening Transition Progress- Daniel Nadeau
    1. Nadeau, D.F., Pardyjak, E.R., Higgins, and H., Parlange, M.B., Similarity scaling over a steep alpine slope, Boundary-Layer Meteor, 147(3), 401-419, 2013.
    2. Nadeau, D.F., Pardyjak, E.R., Higgins, C.W., Huwald, H., Parlange, M.B., Flow during the evening transition over steep Alpine slopes. Q. J. R. Meteorol. Soc., 139(672), 607-624, 2013.
    3. Nadeau, D.F., E. R. Pardyjak, C. W. Higgins, H. J. S. Fernando, and M. B. Parlange, A simple model for the afternoon and early-evening decay of turbulence over different land surfaces, Boundary-Layer Meteor., 26 (2), 301-324, 2011.

Summary – Current BLLAST related Efforts

4. BLM Paper on surface temperature fluctuations with Anirban Garai, Jan Kleissl et al.
5. Daniel Alexander and Chaoxun Hang
    1. Investigating the decay of potential temperature variance
    2. Understanding the effect of larger scale synoptic forcing on TKE decay rates
6. Proposal submitted to NSF in July 2013 – requested funding to include student help to process BLLAST data

MOST Dimensionless Gradients

Turbulent Diffusivity of a

$$K_a = -\frac{\overline{w'a'}}{\partial\overline{a}/\partial z}$$

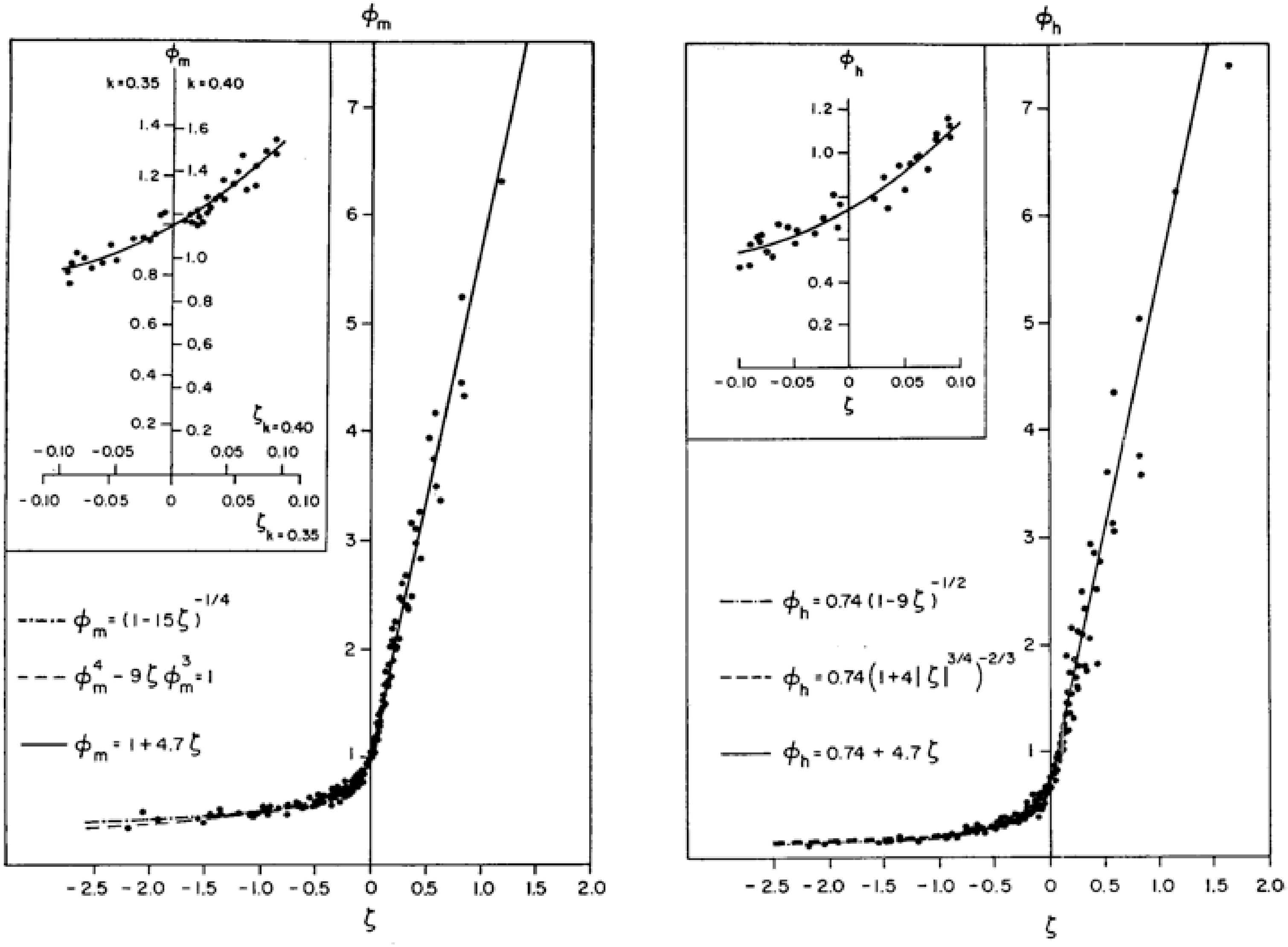
Turbulent Diffusivity in the context of MOST

$$K_a = \frac{ku_*z}{\phi_a(z/L)}$$

Dimensionless Gradient of a

$$\phi_a(z/L) = \frac{\partial\overline{a}}{\partial z}\frac{kz}{a_*}$$

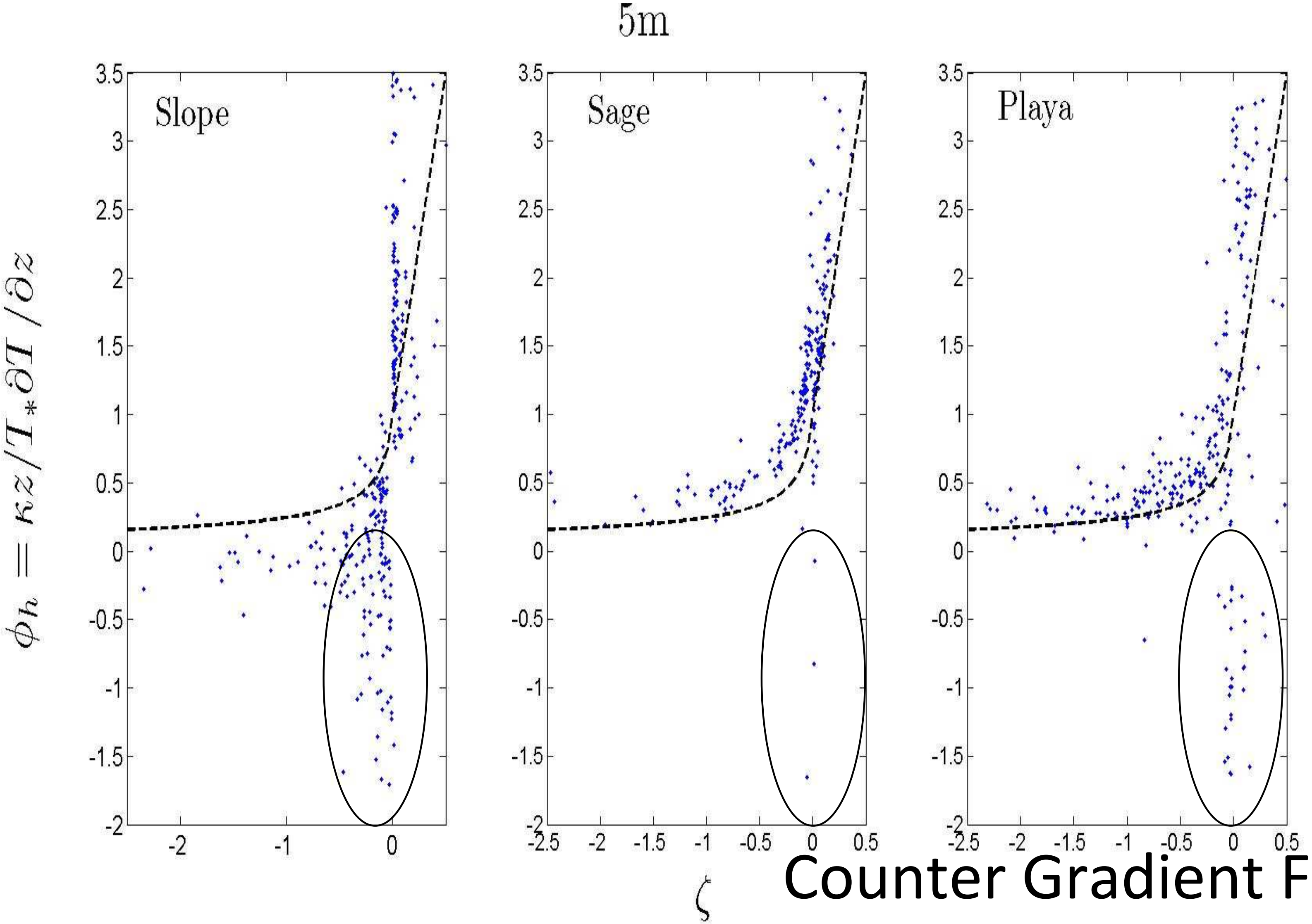
MOST Dimensionless Gradients



From Businger et al. 1971

MOST Dimensionless Gradients

Temperature Gradients from MATERHORN



Counter Gradient Fluxes

Scientific Questions

1) Does the buoyancy flux cease at the same time the local gradient of the virtual potential temperature becomes positive as predicted by flux gradient theory?
2) If a delay exists, can it be parameterized using simple theory?
3) What physics govern the failure of flux gradient theory?
4) Can these shortcomings be overcome with a simple counter gradient formulation?

Experiment Details – Skin Flow Tower – Site 1

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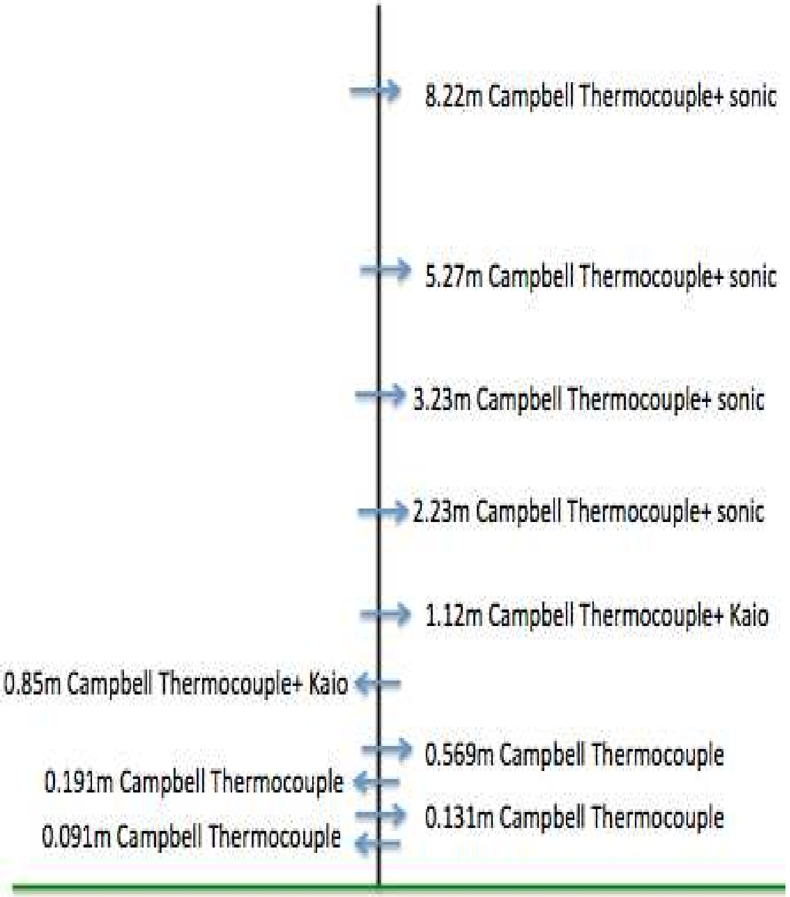
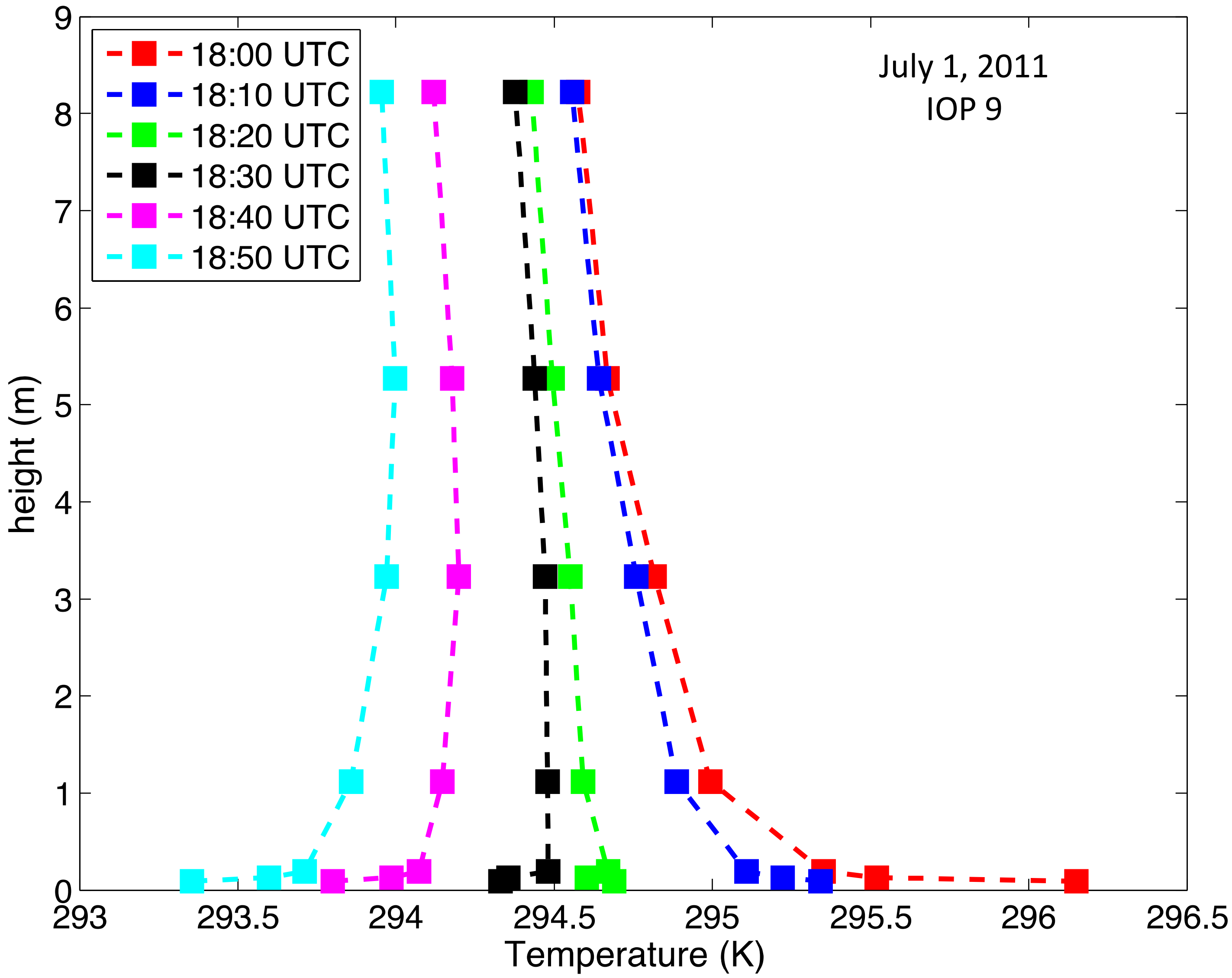
1) 3D Campbell Sonics at 6 Levels (20 Hz)
2) FW TCs at 9 levels

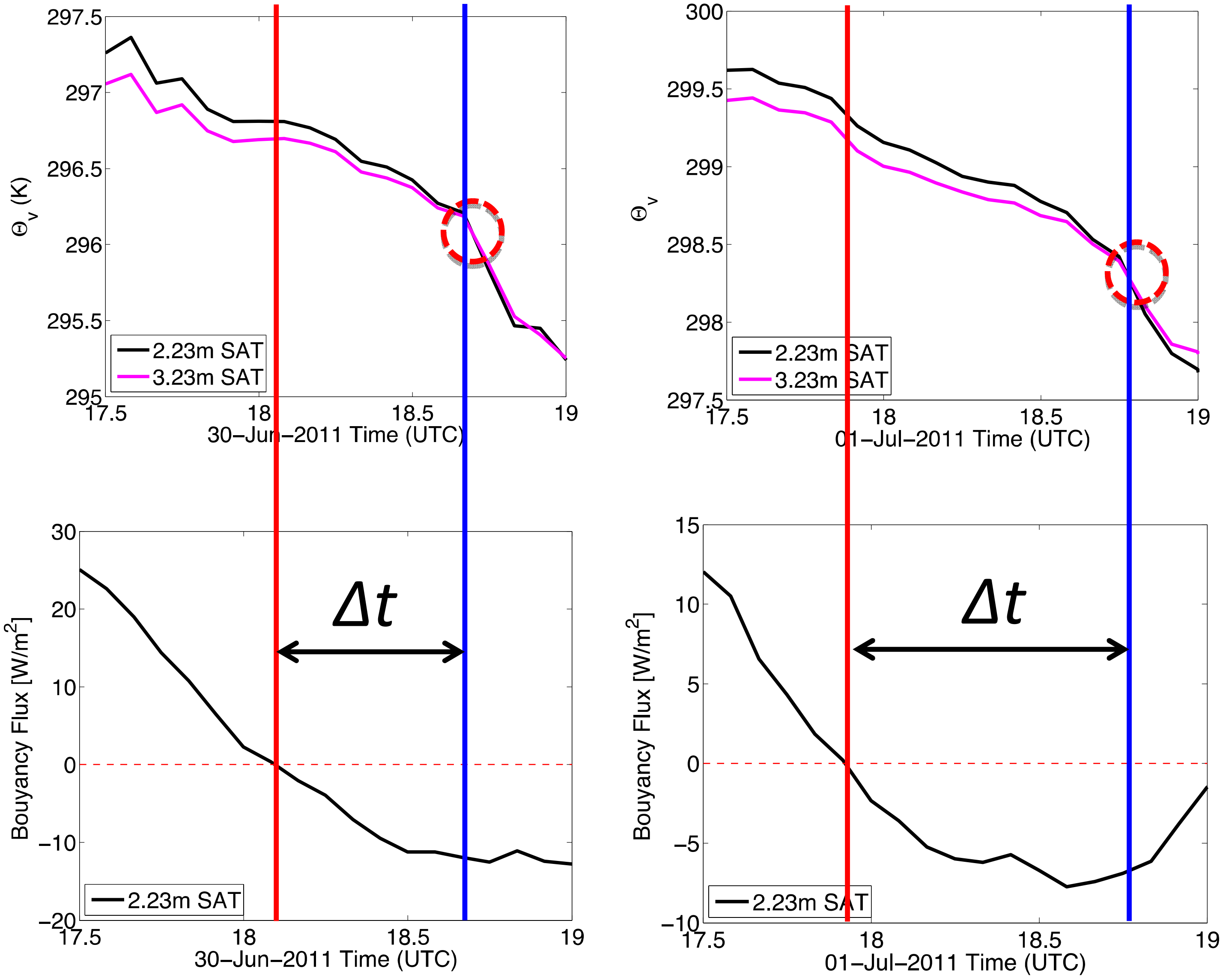


Temperature Profiles During Decay



July 1, 2011
IOP 9

Illustration of the Delay Between Buoyancy Flux and Potential Temperature Gradient Sign Changes



Change of the sign of the θ_v gradient

Change of sign of the buoyancy flux

Summary of Flux Gradient Delay

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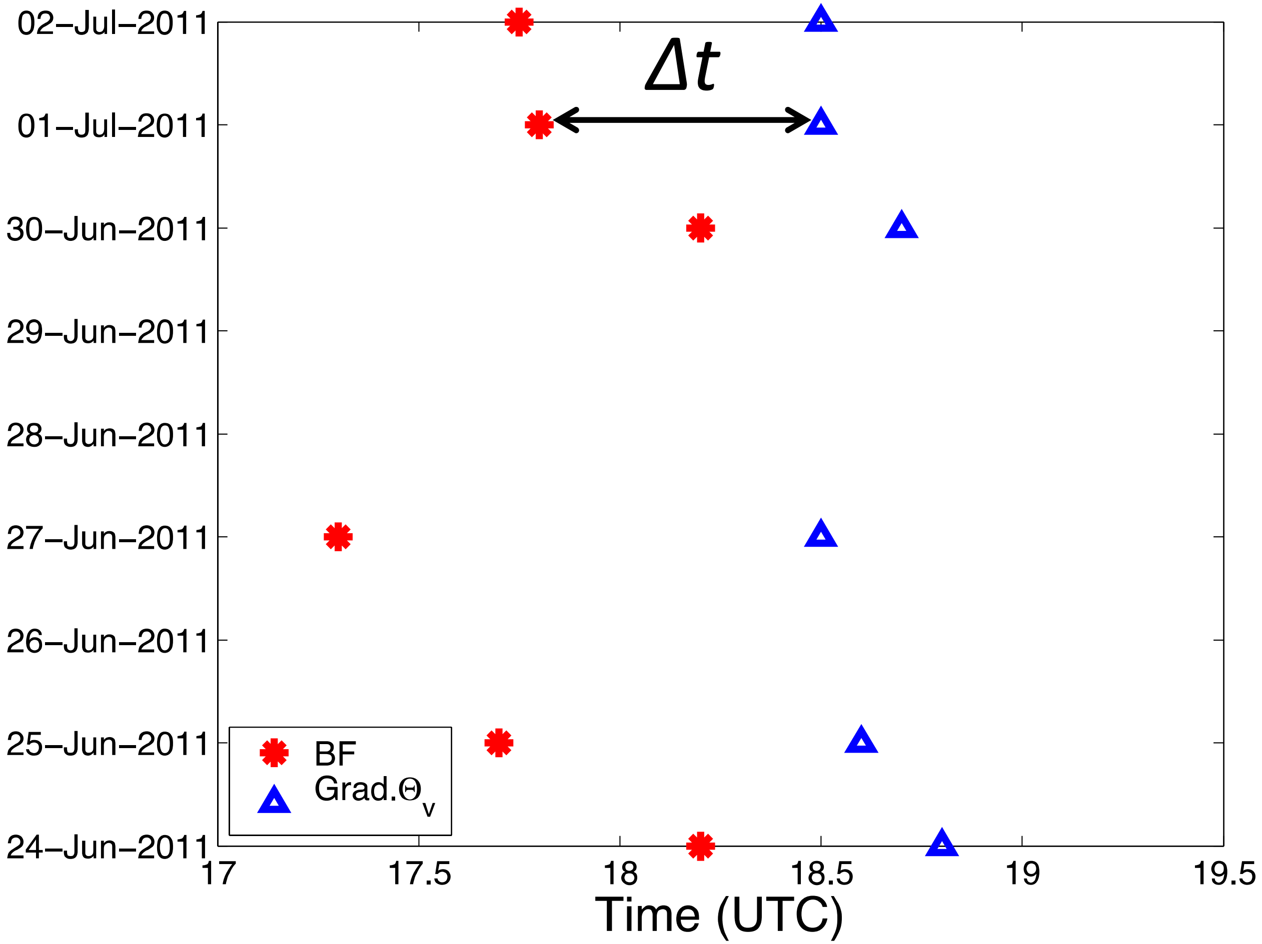
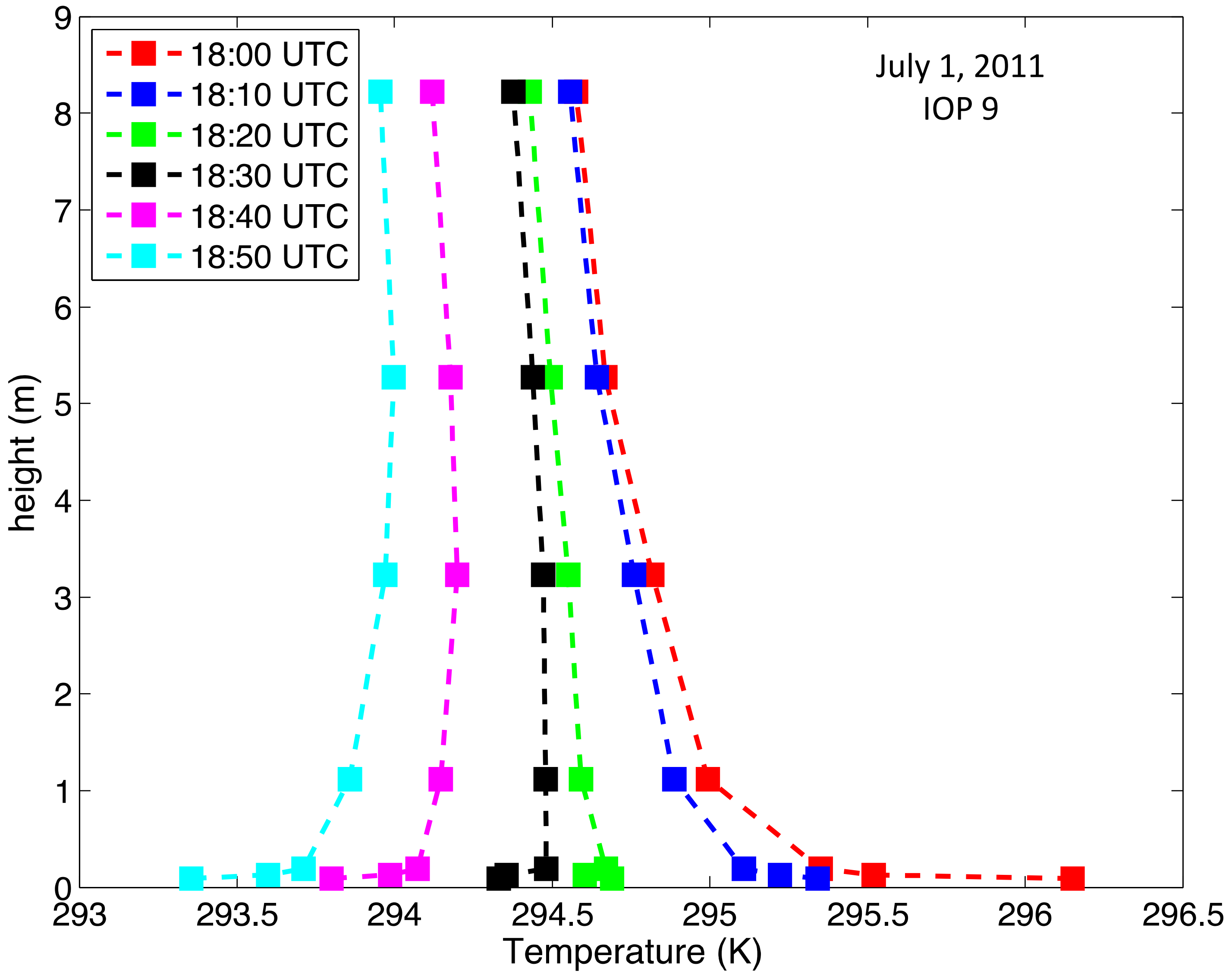


$$t\left(\overline{w'\theta'_v}\Big|_s \approx 0\right) \ vs \ t\left(\partial\theta_v / \partial z \approx 0\right)$$

There is a delay time in all the IOP analyzed (30-70 min)

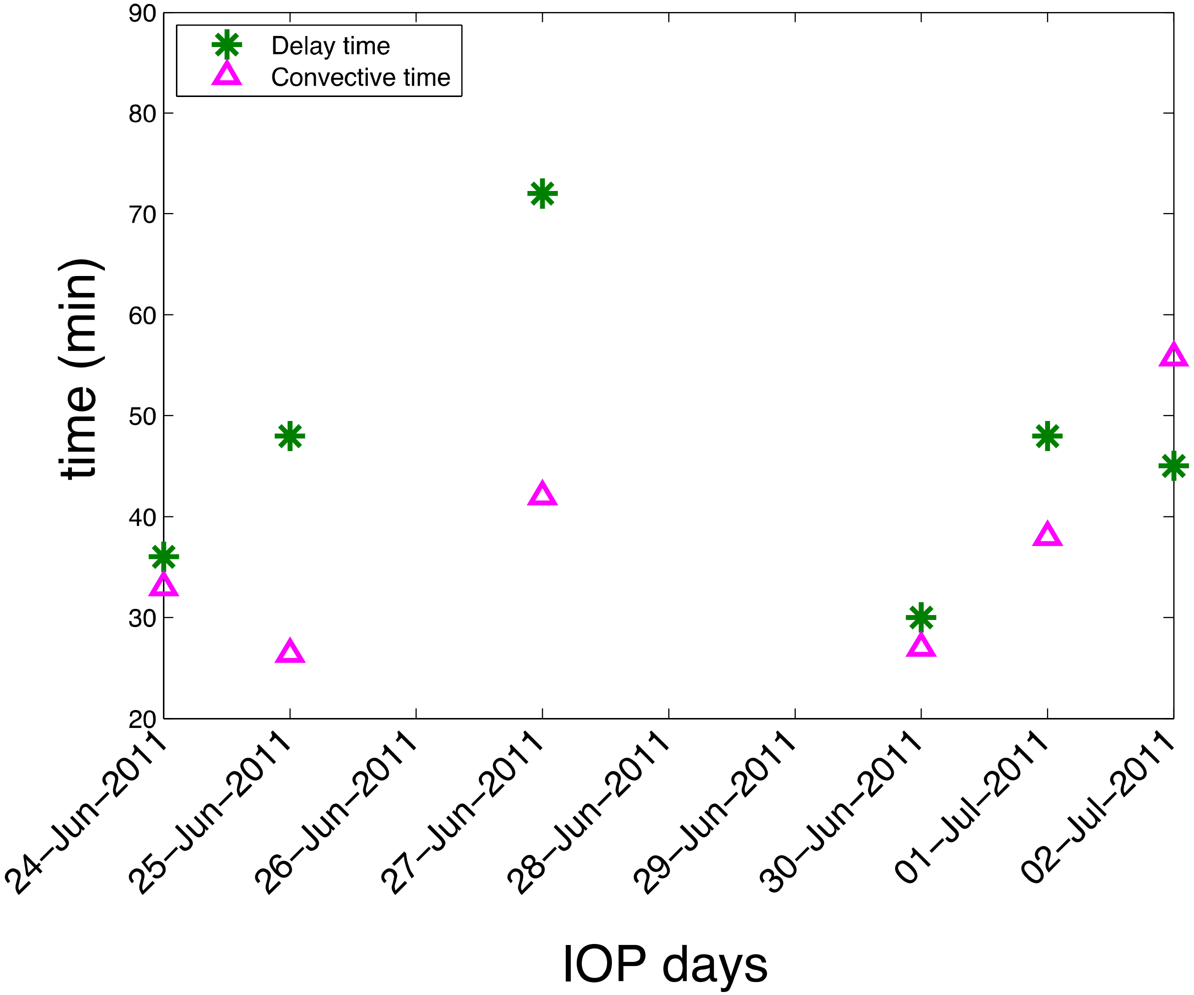
Phenomenological Description



July 1, 2011
IOP 9

Understanding the Flux Gradient Delay

$$Delay\ time\ (DT) = t\left(\partial\theta_v/\partial z \approx 0\right) - t\left(\left.\overline{w'\theta'_v}\right|_s \approx 0\right)$$



Does delay time appear for the last eddy movements?

Convective time :

$$w_* = \left[\frac{g z_i}{\overline{\theta_v}}\left(\overline{w'\theta_v'}\right)_s\right]^{1/3}$$

$$t_* = \frac{z_i}{w_*}$$

Why some days DT is similar to the convective time?

Understanding the Flux Gradient Delay

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Convective days

24/06 & 30/06: IOPs with **large -*z/L*** averaged between 12 UTC-16:45UTC have **small** DT-CT.

Weakly convective days

25/06 & 27/06 → IOP with **small –*z/L*** averaged between 12UTC-16:45UTC have **large** DT-CT.

↓

Why??

↓

$$-\frac{z}{L}=\frac{kzg\left(\overline{w'\theta_v'}\right)_s}{\overline{\theta_v}u_*^3}$$

z=2.23 m

Weakly convective IOPs have larger u_* → more shear induced turbulence → larger delay time

Understanding the Flux Gradient Delay

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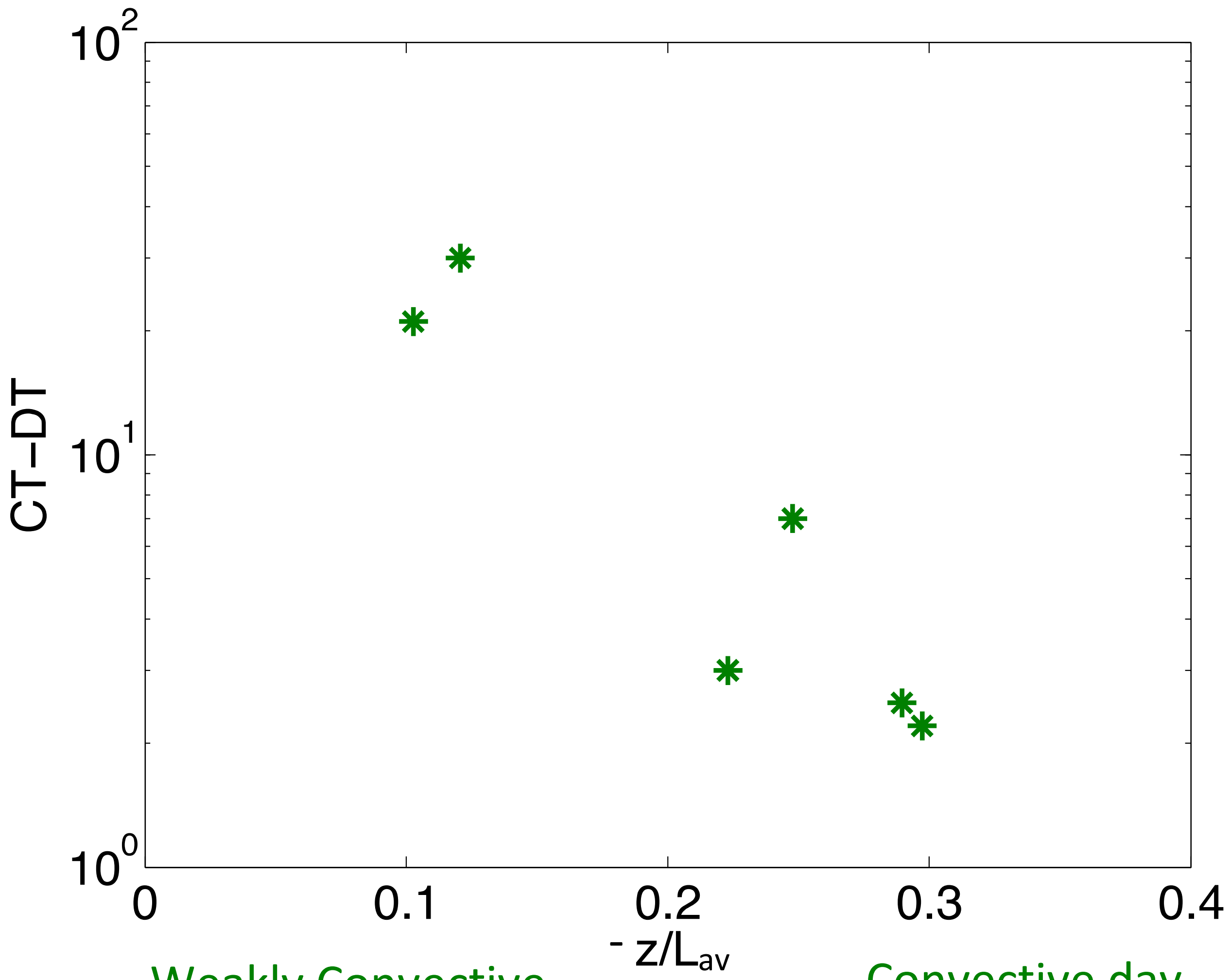
Exponential relation between DT-CT and –*z*/*L*



Weakly Convective day

Convective day

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1) There is a **delay** between the local halt in buoyancy flux & the change in the sign of the vertical gradient of θ_v.
2) During moderately convective days, the delay time is small and close to the **convective time scale**.
3) When convection is weaker, larger u_*, the delay time is larger due to the increase of **shear induced turbulence**.
4) **Turbulent viscosity and thermal diffusivity** may help to slow down the last eddy movement increasing the convective time.

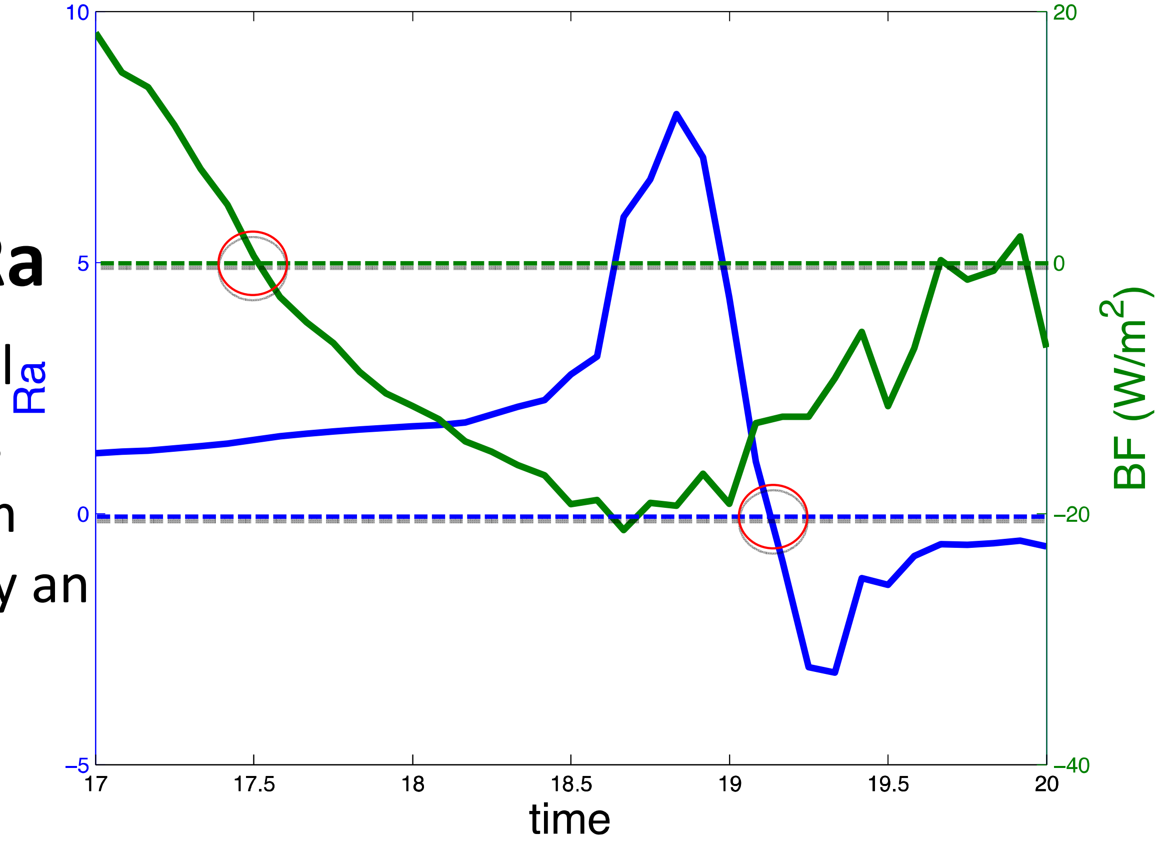
Future Work

Turbulent Rayleigh number physical approximation

Ra → compares the destabilizing forces (buoyancy forces) with the stabilizing forces (viscosity and thermal diffusivity) – Consider defining a "turbulent Rayleigh number"

Bénard problem → turbulent viscosity and turbulent thermal diffusivity difficult convection movements.

All IOPs - buoyancy flux ceases before Ra is negative → a physical interpretation → during this period turbulent momentum and thermal diffusivities play an important role



Understanding the of Temperature Variance in the Surface Layer

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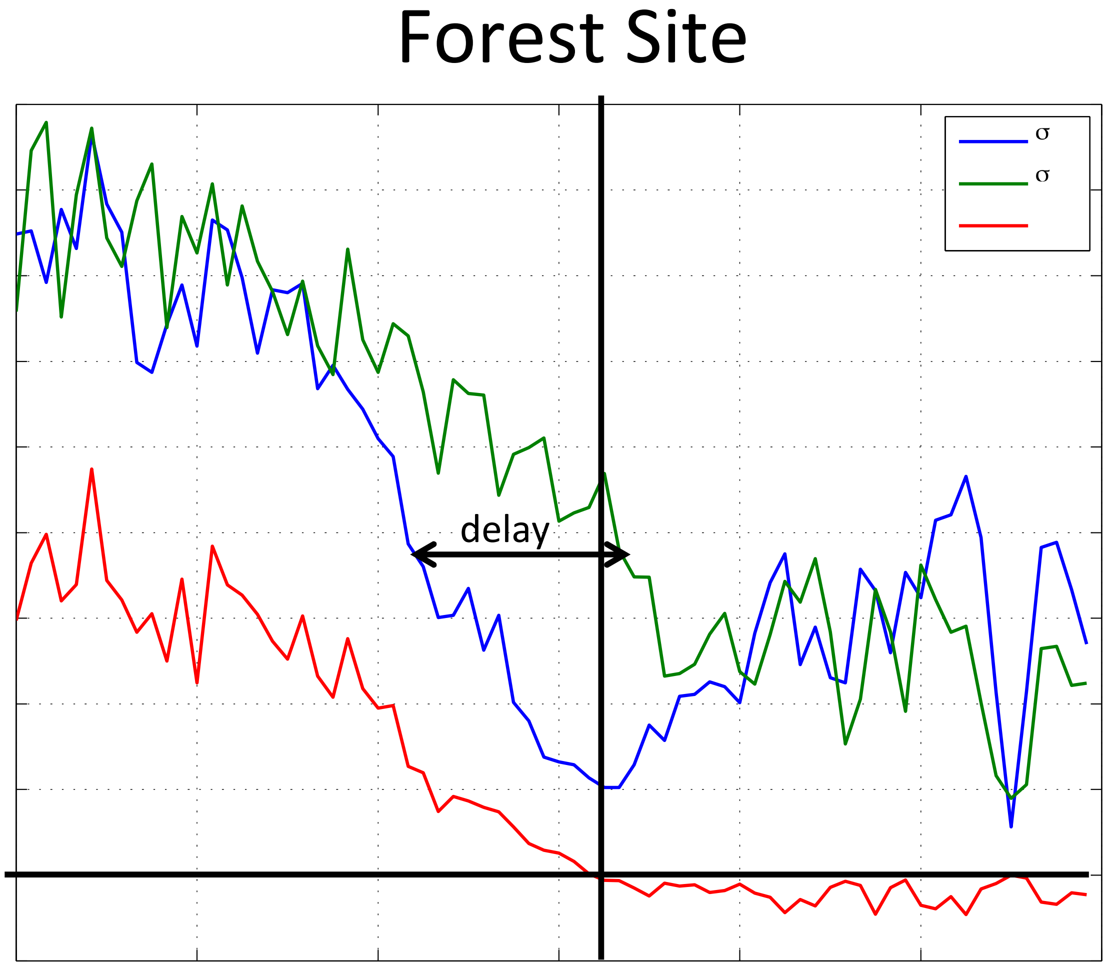
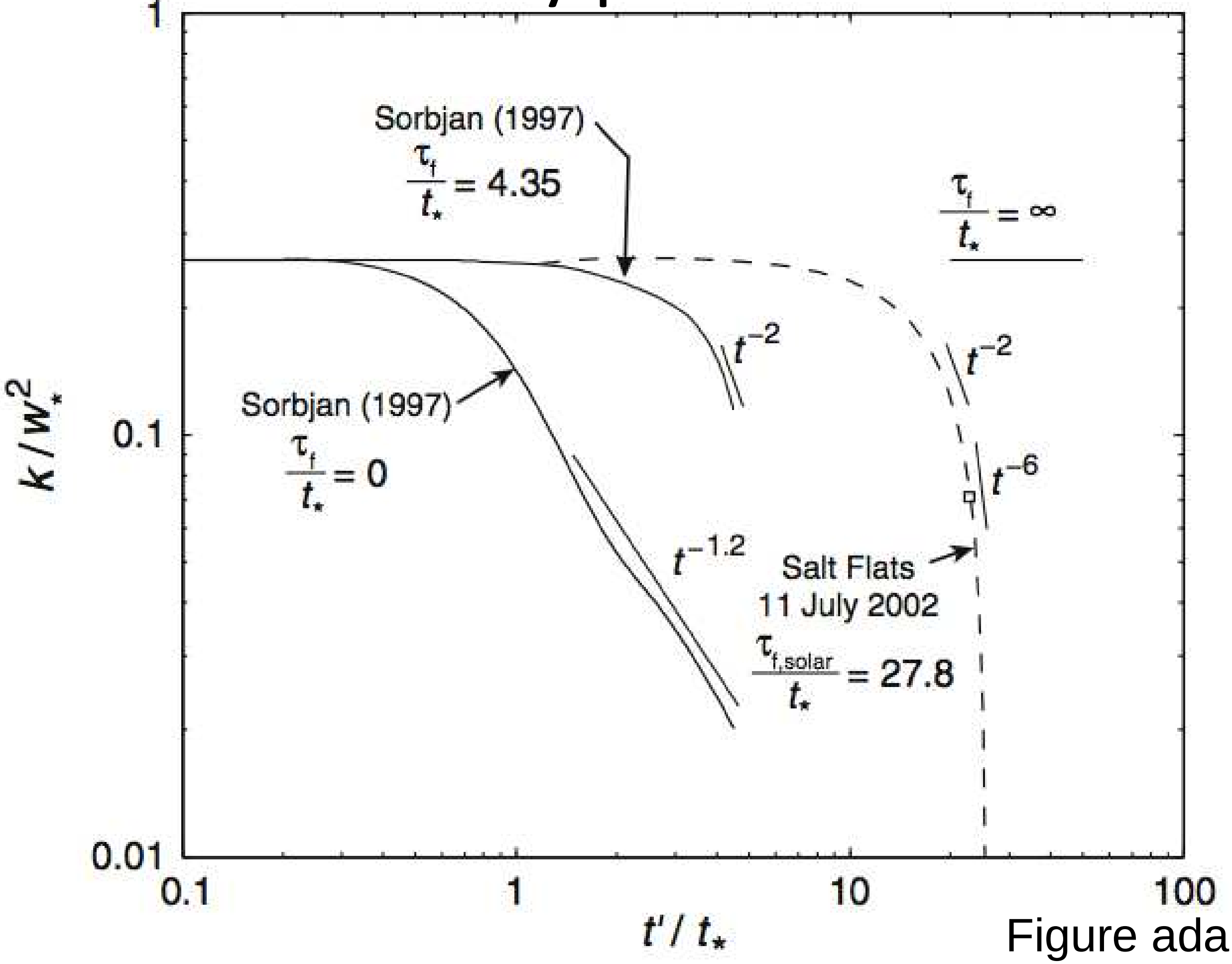


30 m IOP 3

1. What is the governing balance?
2. What are the decay regimes?
3. Can the delay be parameterized?

Understanding the of Temperature Variance

TKE decay power laws



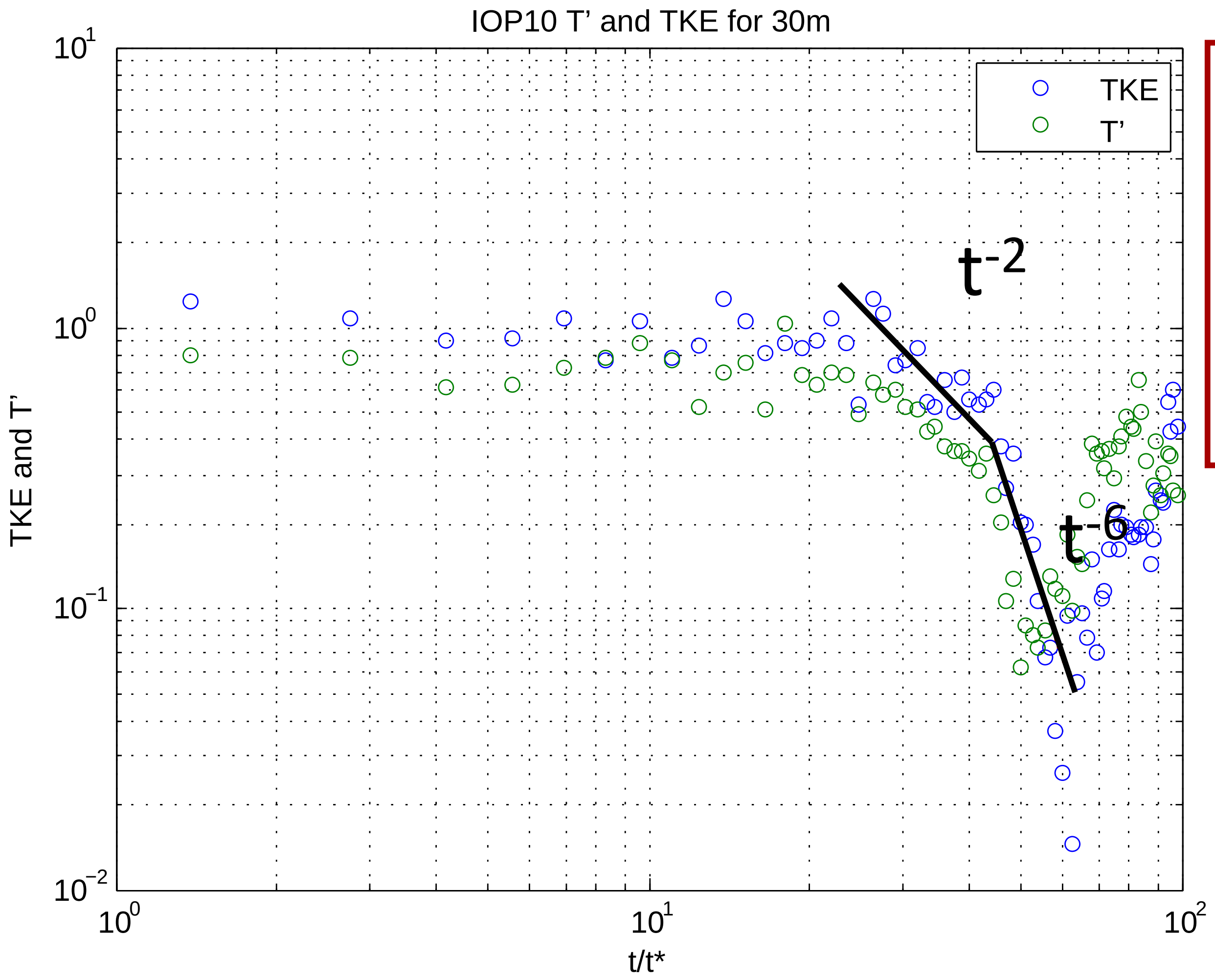
Simple Model

$$\frac{\partial \overline{k}}{\partial t} = \frac{g}{\theta_v}(\overline{w'\theta_v'}) - \varepsilon.$$

Figure adapted from Sorbjan
by Dan Nadeau

Potential Temperature Variance and TKE Decay

Forest Site

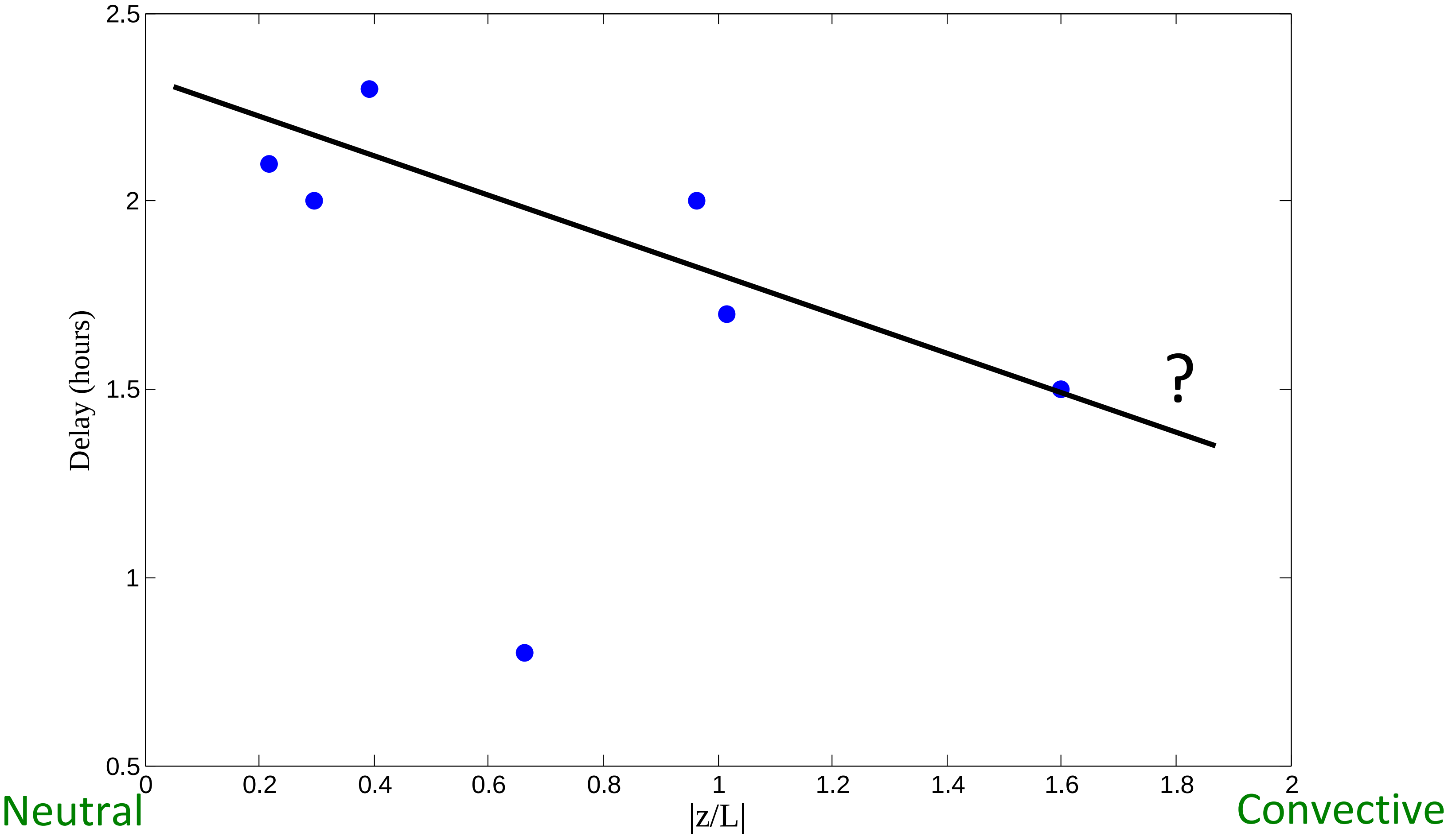


Forest Eddy Covariance Tower

Measurement Height: 30m
Forest Height: ~21 m
Ground Covering: Forest
Instruments used: CSAT3

Delay Between Decay of Potential Temperature Variance and TKE

Forest Site



(z-d)/L at the start of the decay period

Potential Temperature Variance Budget

$$\underbrace{\frac{\partial \overline{\theta'^2}}{\partial t}}_{\text{term I}} + \underbrace{u_j \frac{\partial \overline{\theta'^2}}{\partial x_j}}_{\text{term II}} = -\underbrace{2\overline{\theta' u_j'}\frac{\partial \overline{\theta}}{\partial x_j}}_{\text{term III}} - \underbrace{\frac{\partial \overline{u_j'\theta'^2}}{\partial x_j}}_{\text{term IV}} - \underbrace{2\epsilon_\theta}_{\text{term V}} - \underbrace{\epsilon_R}_{\text{term VI}} - \underbrace{\mu\phi_v}_{\text{term III}}$$

Storage

Advection by Mean Wind

Production

Turbulent Transport

Molecular Dissipation

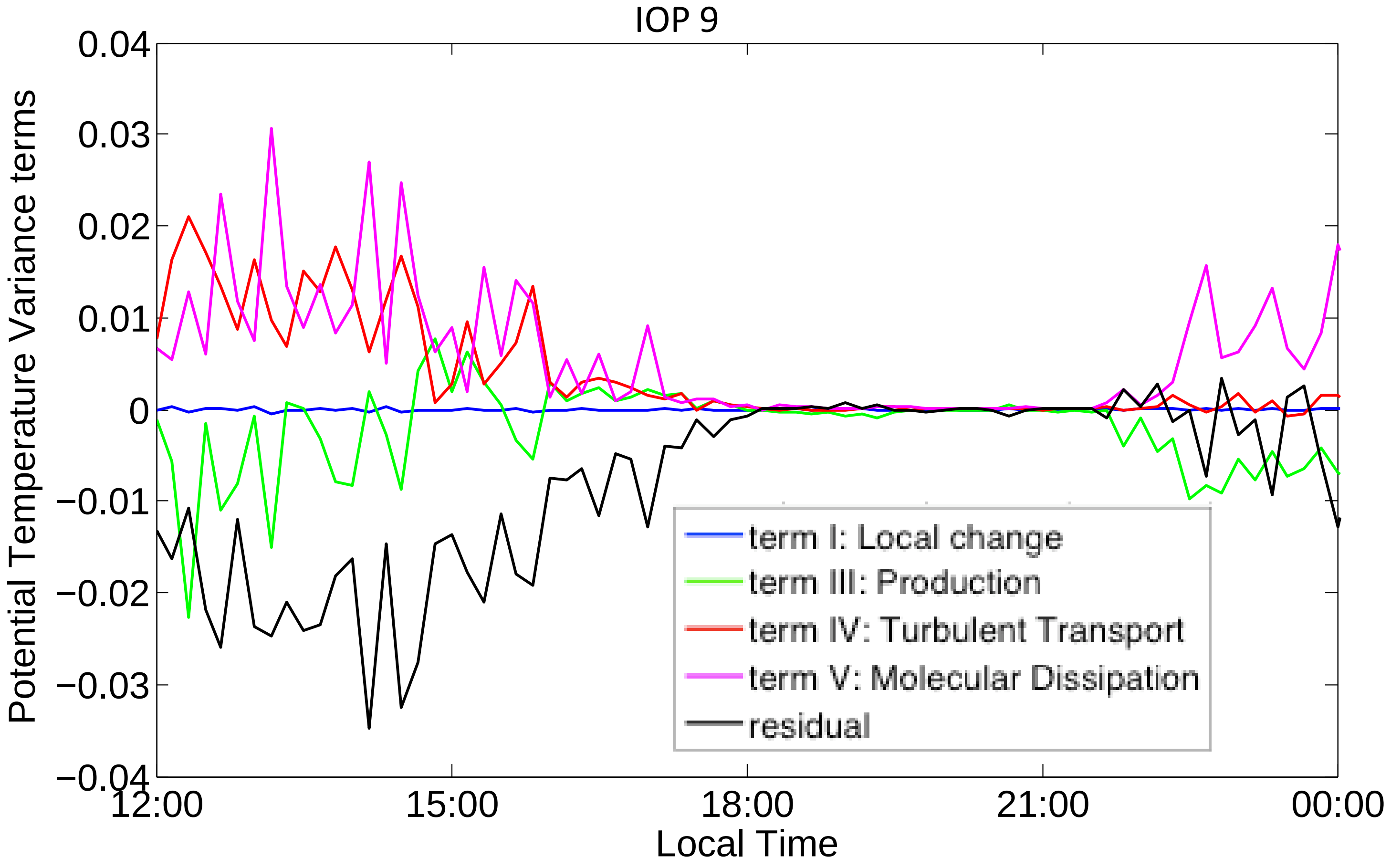
Radiation Destruction

Viscous Dissipation

Assuming horizontal homogeneity, no subsidence, and neglecting molecular diffusion:

$$\underbrace{\frac{\partial \overline{\theta'^2}}{\partial t}}_{\text{term I}} = -\underbrace{2\overline{\theta' w'}\frac{\partial \overline{\theta}}{\partial z}}_{\text{term III}} - \underbrace{\frac{\partial \overline{w'\theta'^2}}{\partial z}}_{\text{term IV}} - \underbrace{2\epsilon_\theta}_{\text{term V}} - \underbrace{\epsilon_R}_{\text{term VI}}$$

Potential Temperature Variance Budget



Forest Site

$$\underbrace{\frac{\partial \overline{\theta'^2}}{\partial t}}_{\text{term I}} = -\underbrace{2\overline{\theta' w'}\frac{\partial \overline{\theta}}{\partial z}}_{\text{term III}} - \underbrace{\frac{\partial \overline{w'\theta'^2}}{\partial z}}_{\text{term IV}} - \underbrace{2\epsilon_\theta}_{\text{term V}} - \underbrace{\epsilon_R}_{\text{term VI}}$$

Current MATERHORN work

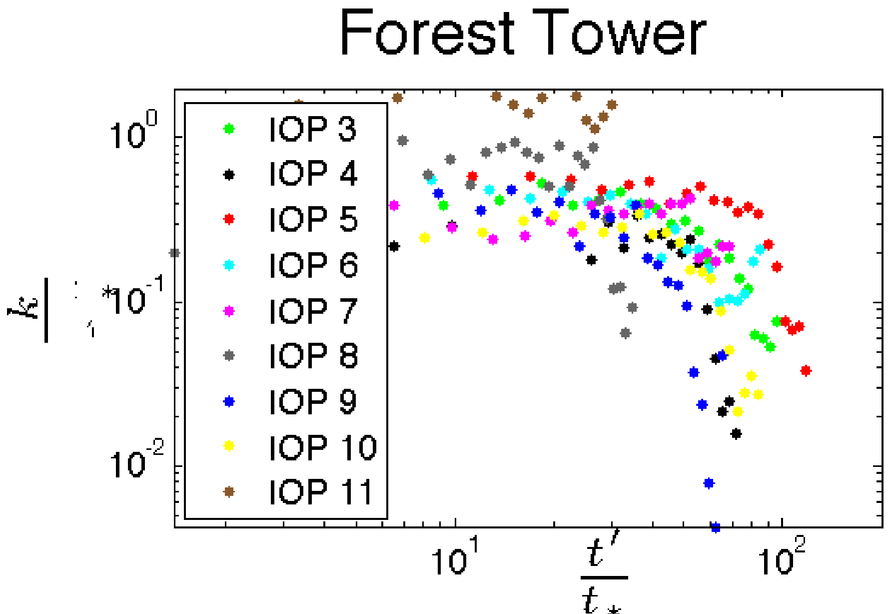
Summary

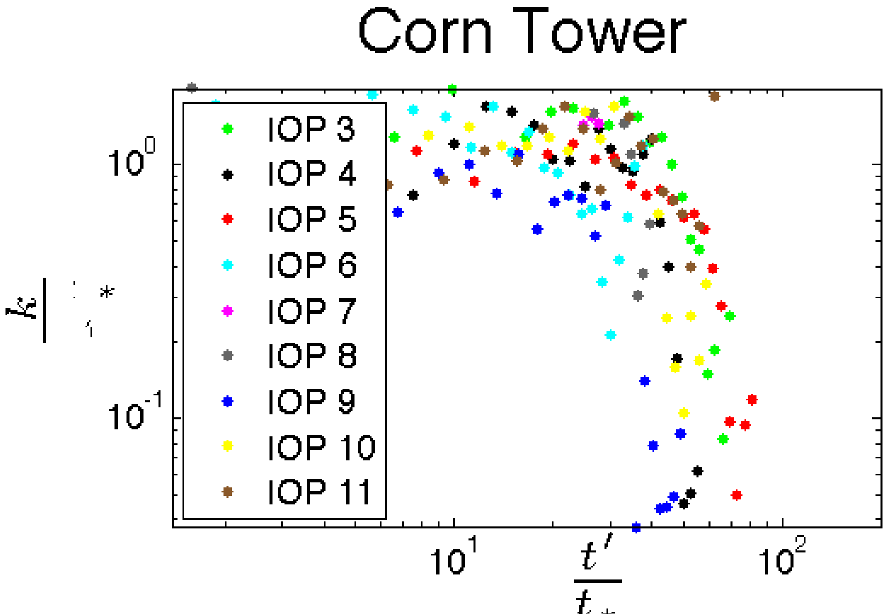
1)There appears to be two decay regimes for the decay of potential temperature variance fluctuations as with TKE

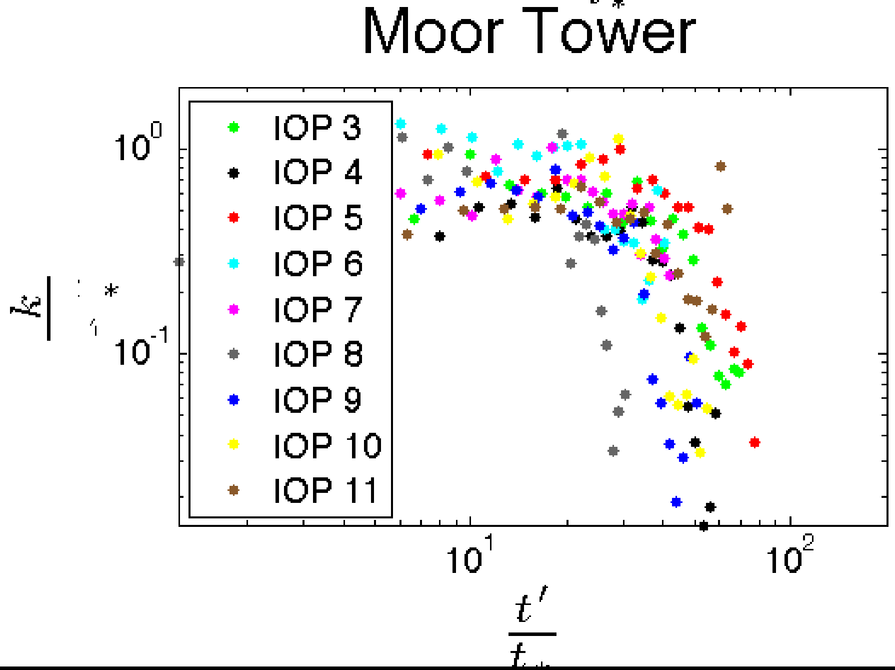
2)There is a delay in the TKE with respect to the variance

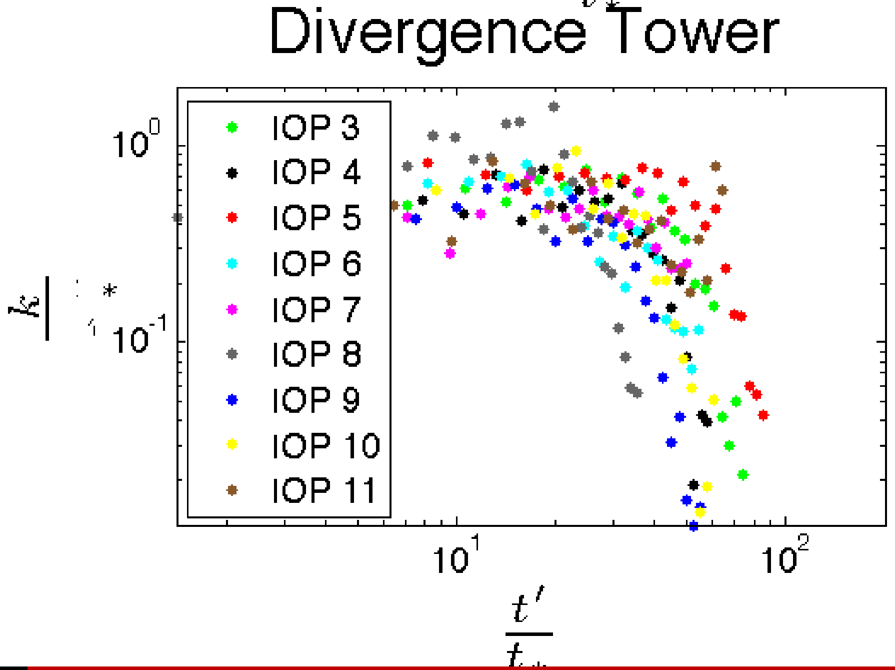
3)Need to further investigate the temperature variance budget to better understand the origins of the residual and to be able to model the decay

Additional Work – TKE Decay









Additional Work -

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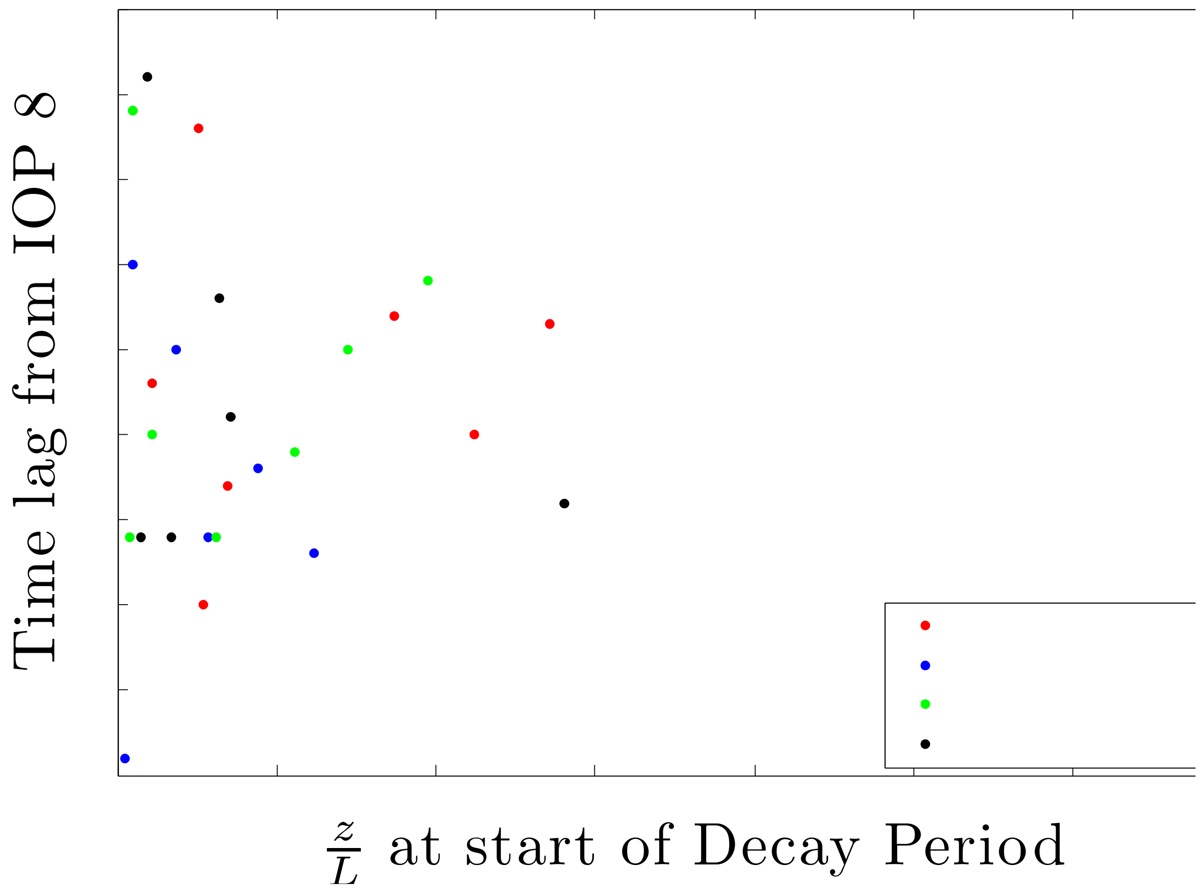

Additional Work -

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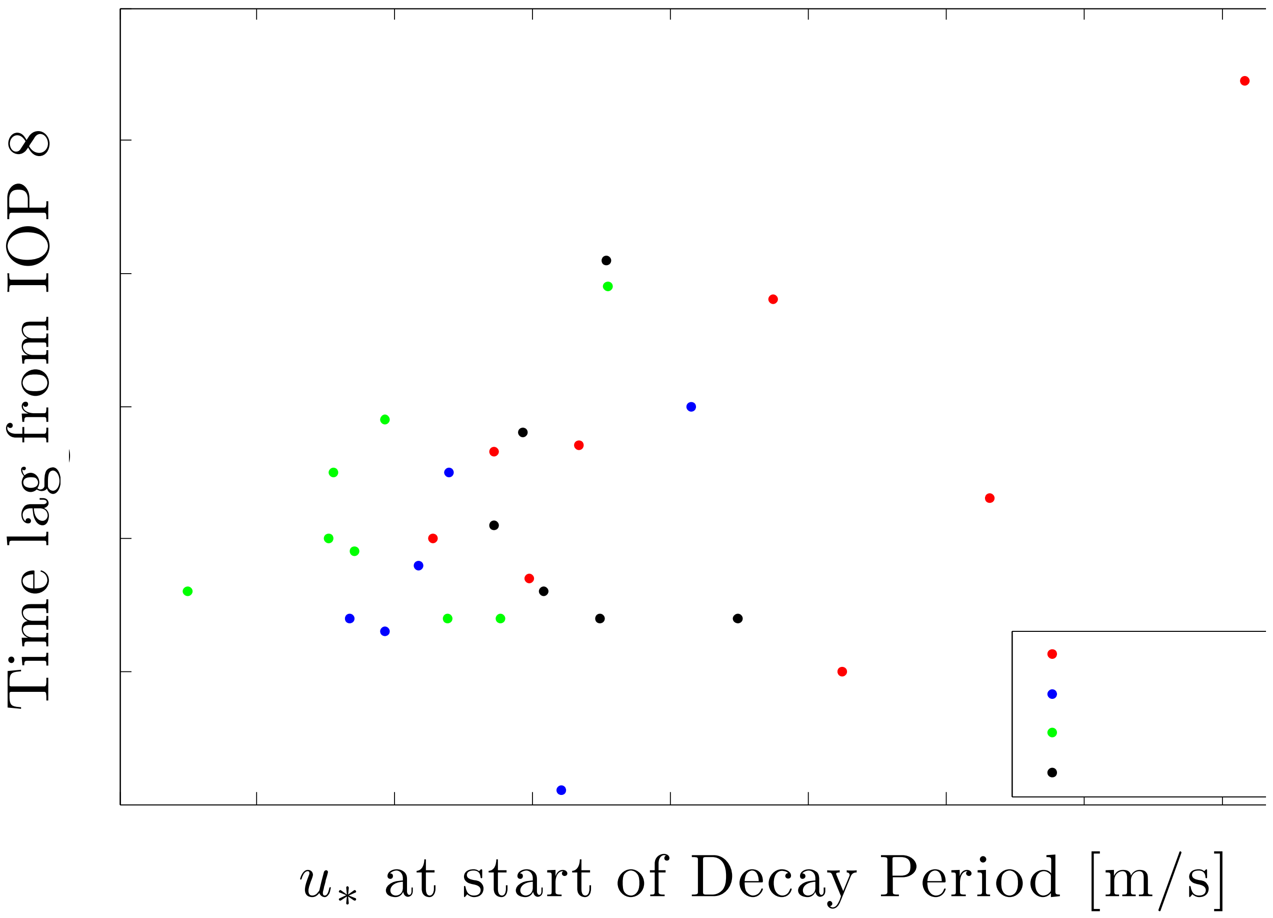
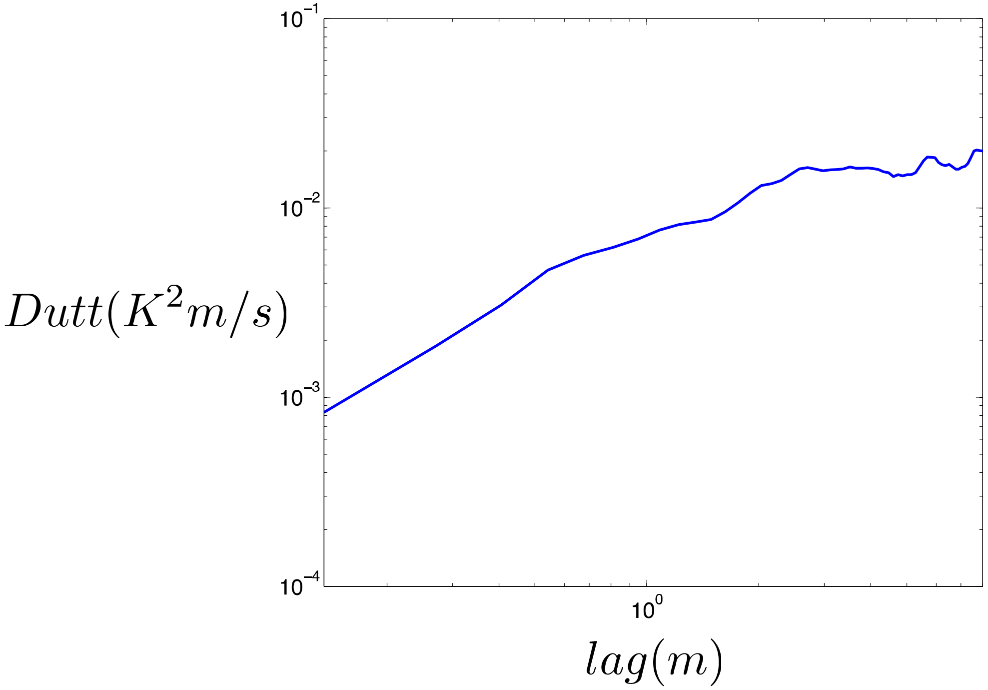


Calculating Molecular Dissipation using the Third Order Longitudinal Structure Function



$$-\frac{4}{3}r\left\langle \epsilon_\theta \right\rangle = \left\langle (u(x+r)-u(x))(\theta(x+r)-\theta(x))^2 \right\rangle$$

IOPs

- IOP 1 – 15 June 2011
- IOP 2 – 19 June 2011
- IOP 3 – 20 June 2011
- IOP 4 – 24 June 2011
- IOP 5 – 25 June 2011
- IOP 6 – 26 June 2011
- IOP 7 – 27 June 2011
- IOP 8 – 30 June 2011
- IOP 9 – 01 July 2011
- IOP 10 – 02 July 2011
- IOP 11 – 05 July 2011