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Analysis of the decoupling between surface heat flux and temperature gradient during afternoon transition

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Afternoon and Evening Transition

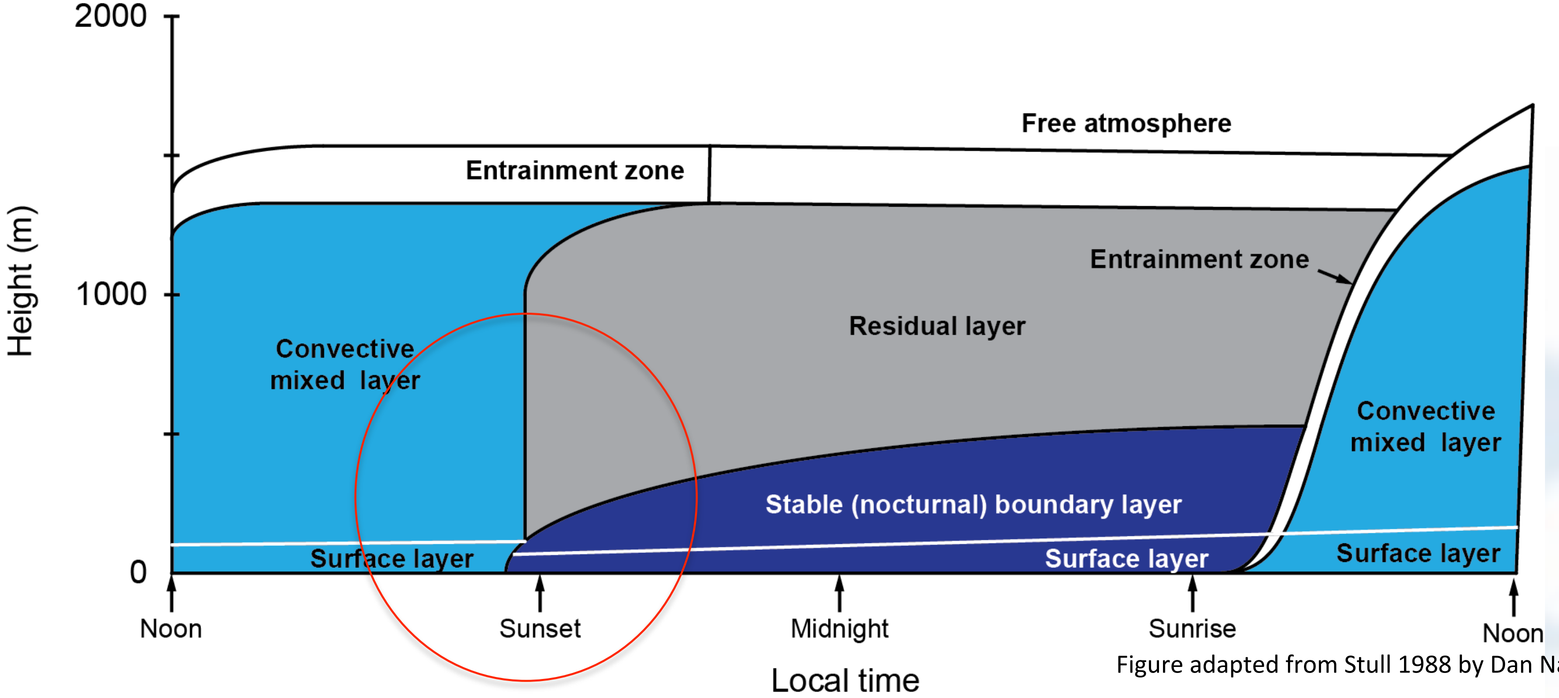
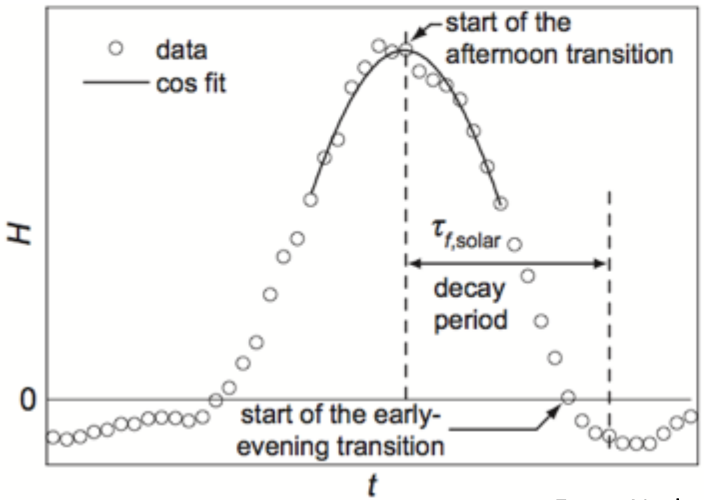
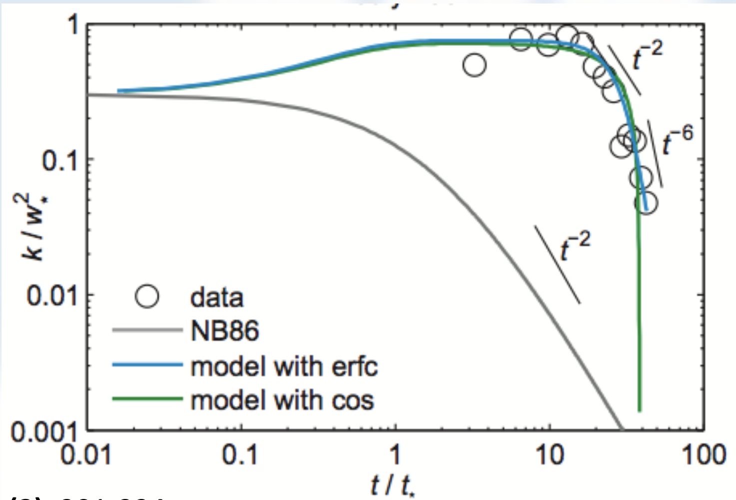


Figure adapted from Stull 1988 by Dan Nadeau





From Nadeau et al. 2011, BLM, **26 (2)**, 301-324

Motivation

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? What are the physics that govern the delay?
3) Can these shortcomings be explained with a simple counter gradient formulation?
4) Do turbulent viscosity and thermal diffusivity play an important role during afternoon transition at the surface layer?

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BLLAST - Boundary Layer Late Afternoon and Sunset Transition Experiment

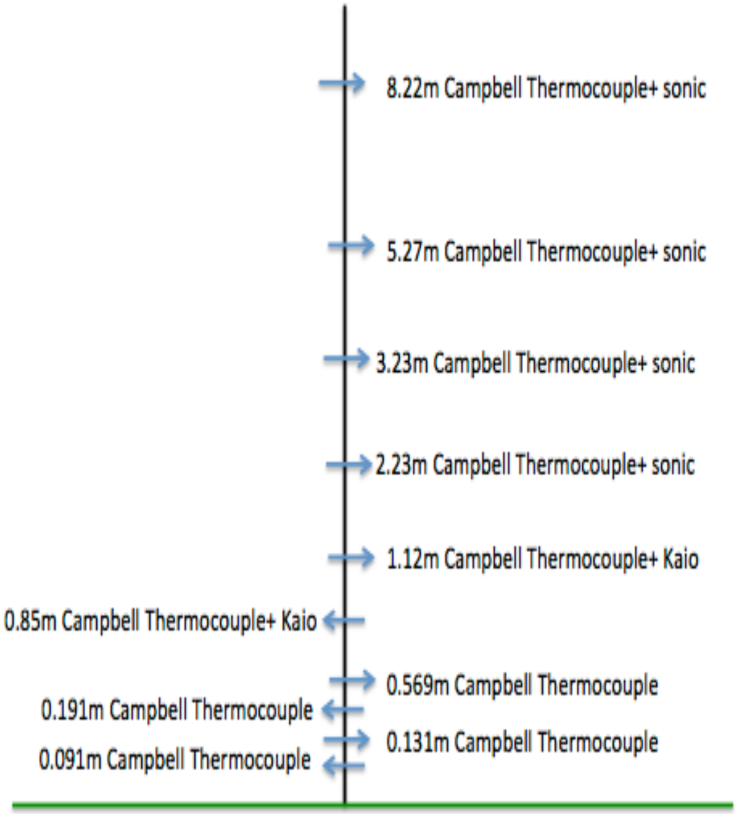
- Lannemezan, France 14 June – 8 July 2011
- Lead Scientist - M. Lothon, Laboratoire d'Aérologie, CNRS, FRANCE

Objectives of the BLLAST Campaign

- To understand the importance of surface heterogeneity during the Late Afternoon Transition (LAT).
- To study the vertical structure and evolution of the boundary layer itself during LAT.

Skin Flower Tower – Site 1

- 3D Sonics at 6 Levels
- FW TCs at 9 levels



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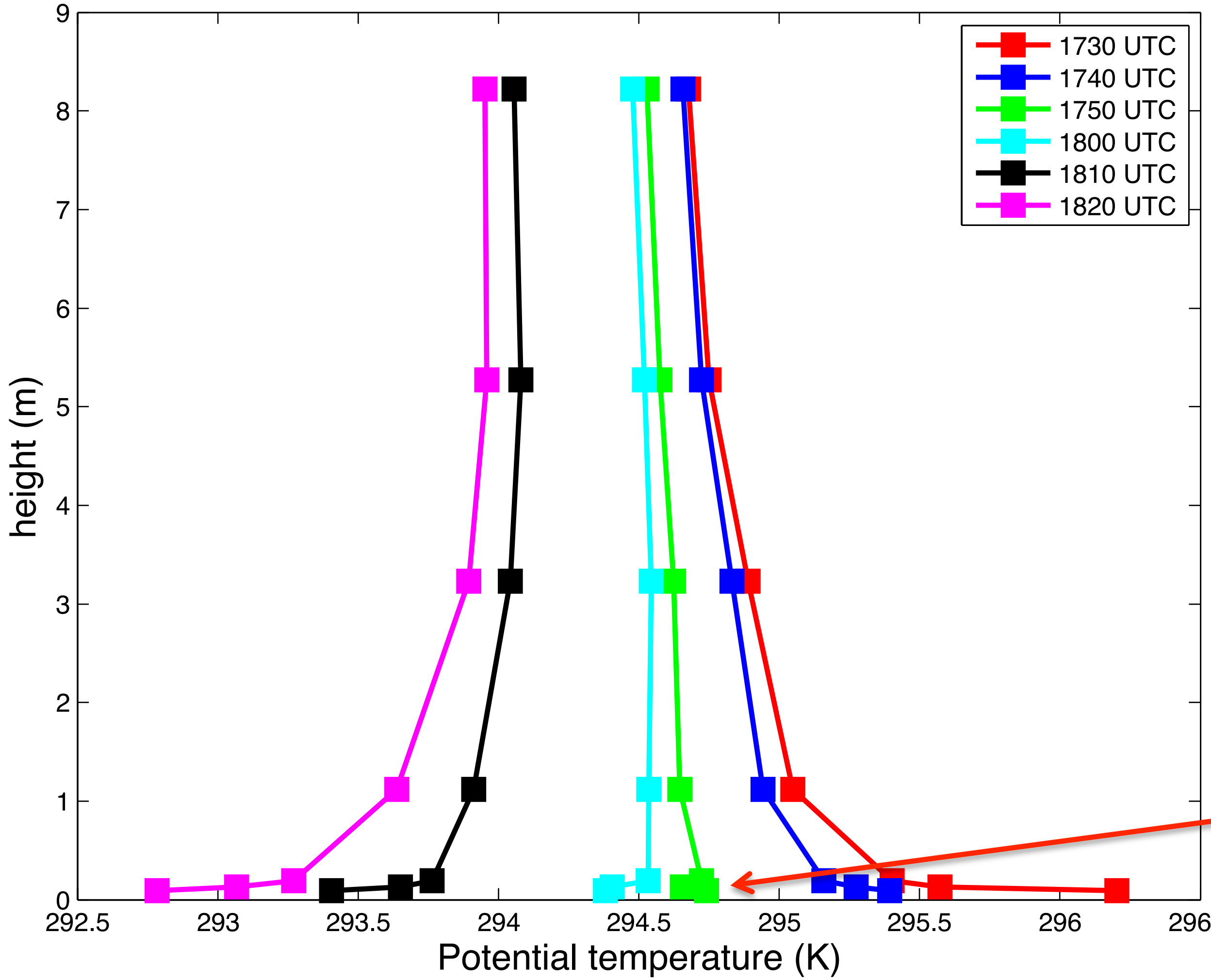
Temperature Profile Observations



1-Jun-2011

Possible presence of Lifted Temperature Minimum (Future Work)

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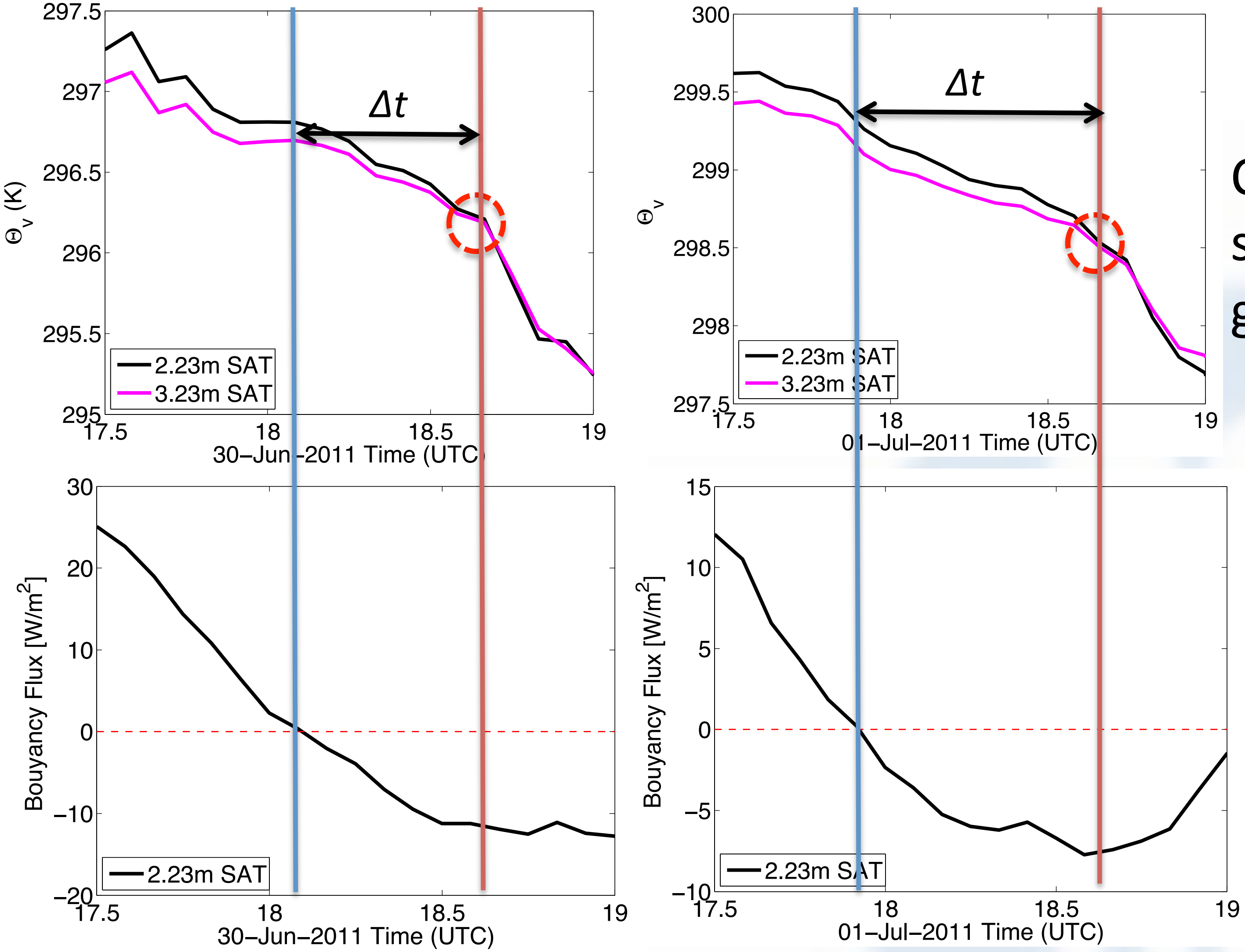
Methodology



Change of the sign of the θ_v gradient

Change of sign of the buoyancy flux

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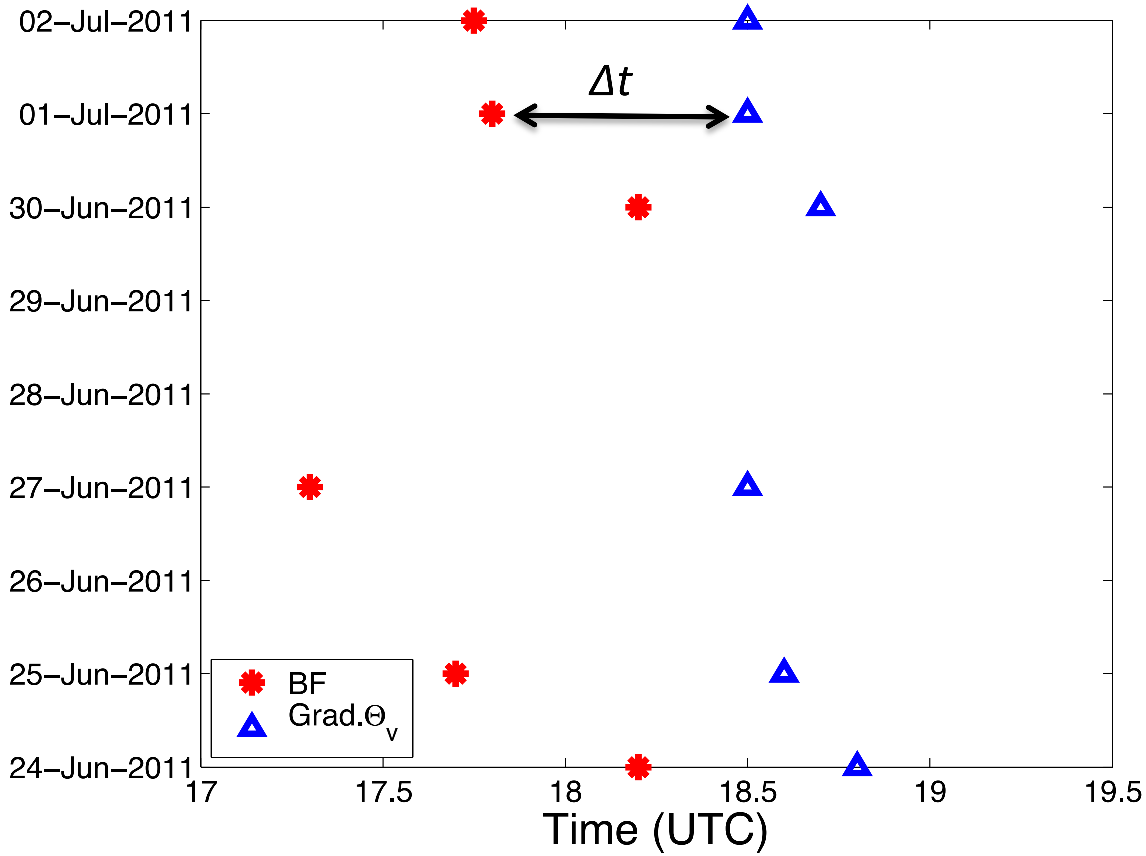
Results



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

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

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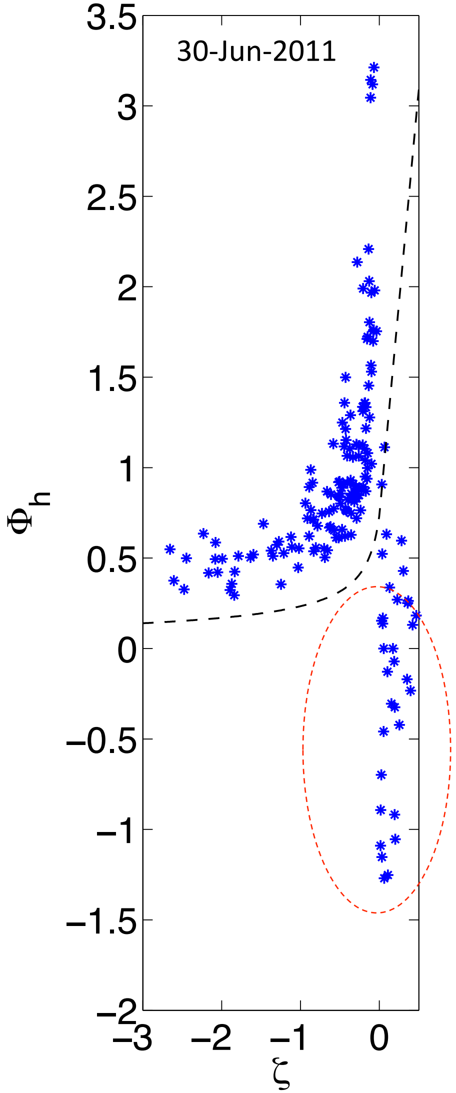
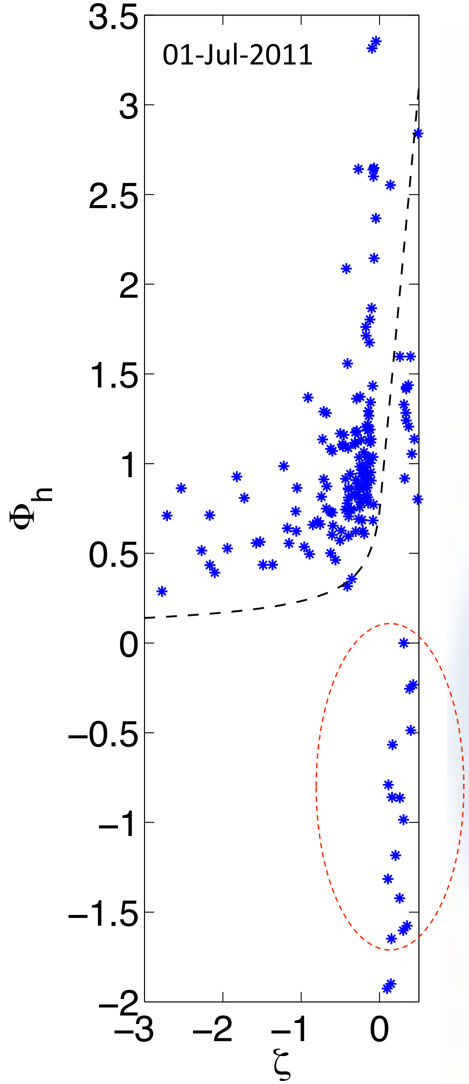
Results

MOST Temperature Gradients





Presence of Counter Gradient Fluxes

$$\phi_h = \frac{kz}{\theta_*^{SL}} \frac{\partial \theta}{\partial z} = \frac{kzu_*}{-\left(\overline{\omega'\theta_v'}\right)_s} \frac{\partial \theta}{\partial z}$$

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

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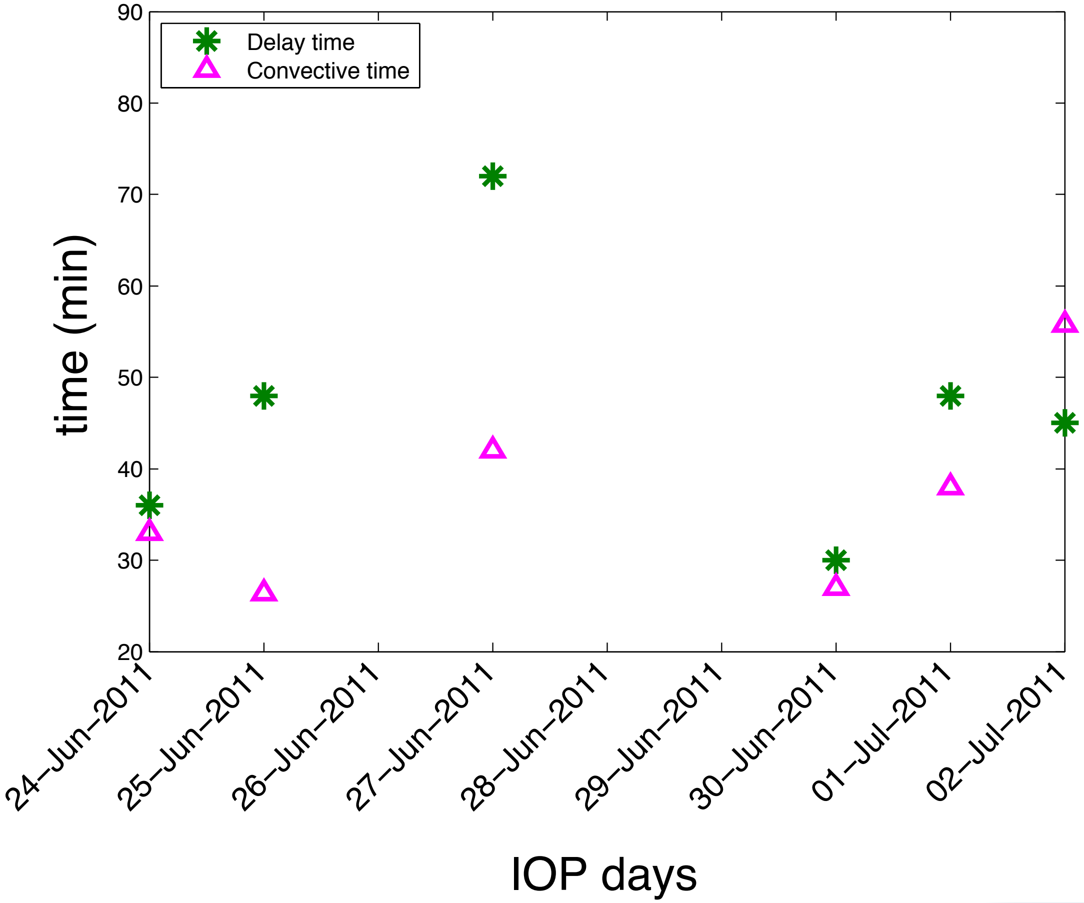
Results

Convective time

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



Does delay time appear for the last eddy movement?

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?

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Results

Obukhov Length

<u>Convective days</u>

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

<u>Weakly convective days</u>

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

↓

Why??

↓

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

z=2.23 m

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

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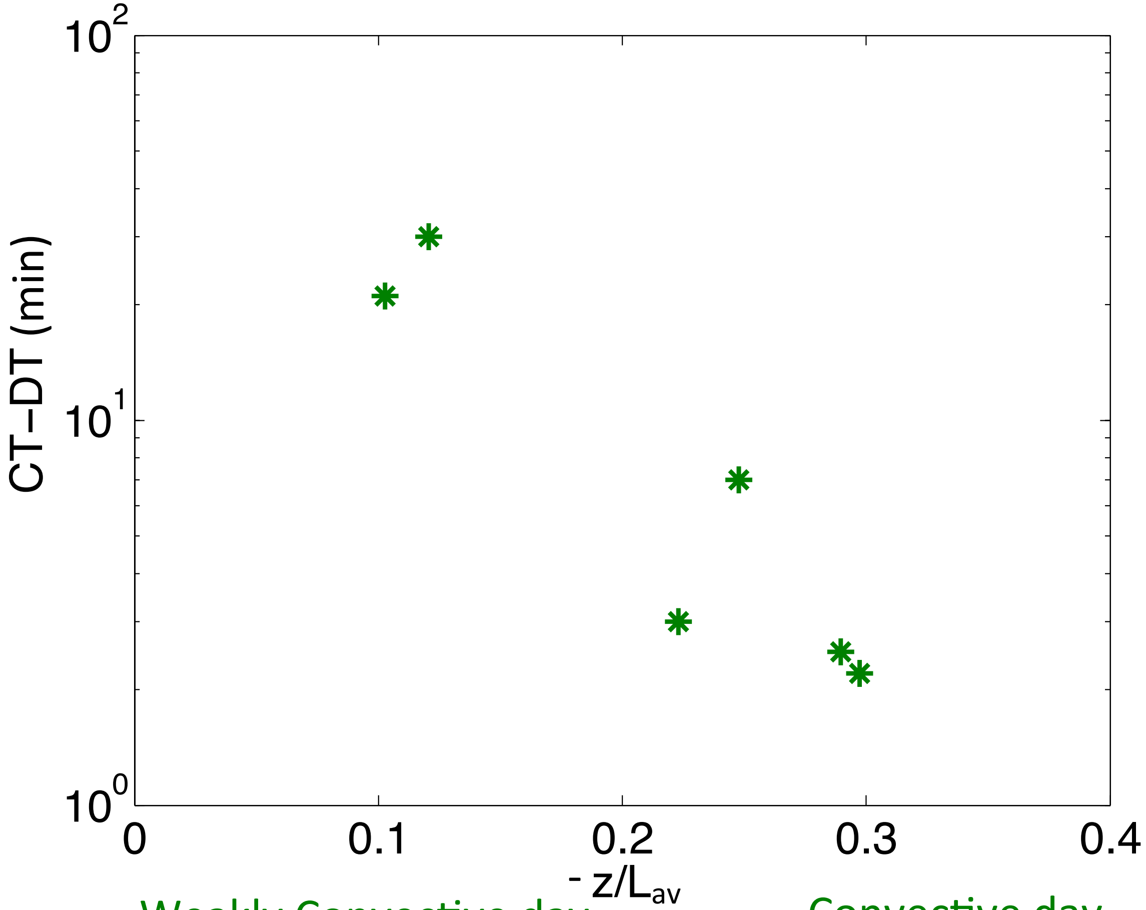
Results

Obukhov Length

Exponential relation between DT-CT and $-z/L$



Weakly Convective day

Convective day

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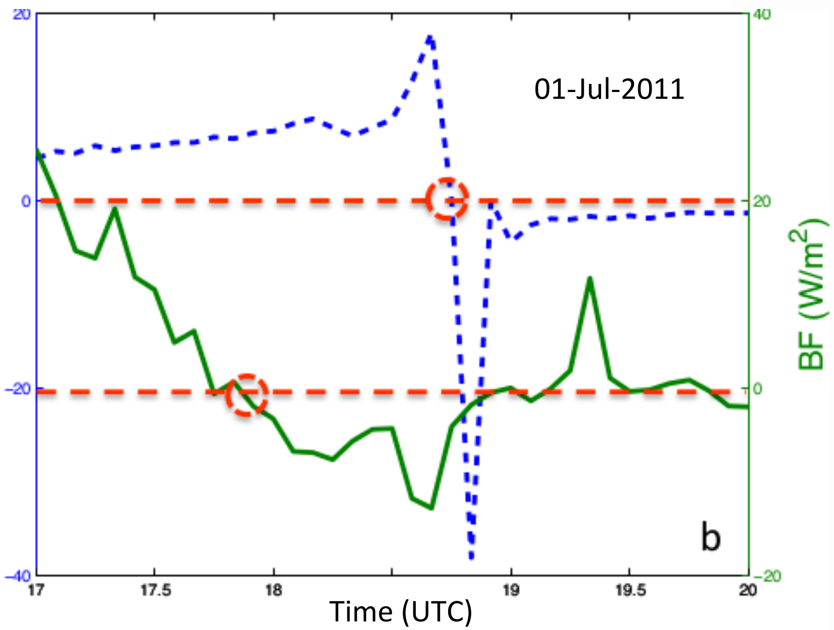
Results

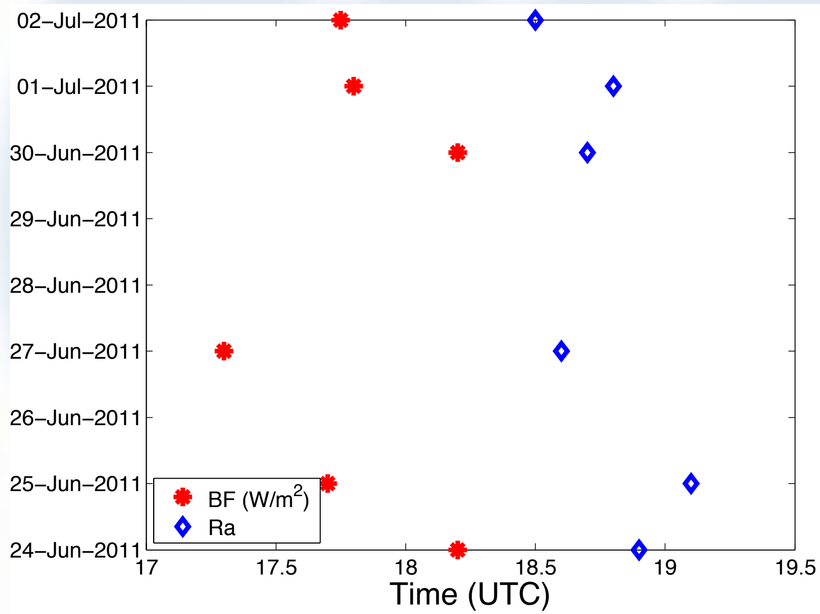
Turbulent Rayleigh number physical approximation

Ra → compares the destabilizing forces (buoyancy forces) with the stabilizing forces (viscosity and thermal diffusivity).

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

In all IOP buoyancy flux ceases before Ra is negative → a physical approximation → during this period viscosity and thermal diffusivity may play a role in the slow down of the cease of the convection.





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Conclusions

- There is a **<u>delay</u>** between buoyancy flux cease and the change in the vertical gradient of θ_v.
- During moderate convective days, the delay time is small and close to the last eddy movement (**<u>convective time</u>**).
- When convection is lower, larger u_*, the delay time is larger due to the increase of **<u>horizontal turbulence</u>**.
- **<u>Turbulent viscosity and thermal diffusivity</u>** may help to slow down the last eddy movement increasing the convective time.

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Thank you

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