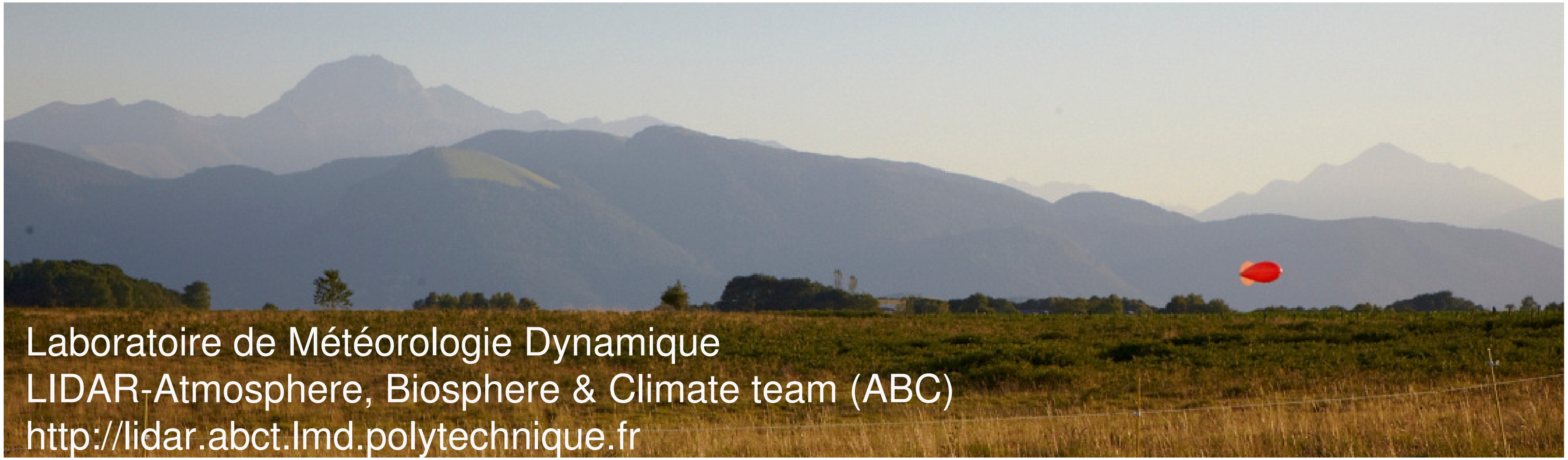
Afternoon transition turbulence decay revisited by Doppler Lidar

Fabien GIBERT, Arnaud DUMAS, Ludovic THOBOIS, Yannick BEZOMBES, Grady KOCH, Alain DABAS and Marie LOTHON



AMS 20BLT, Boston, 8-13 July 2012

Overview

Case study from observations of Doppler Lidar and in-situ sensors
Clear air conditions

Main points:

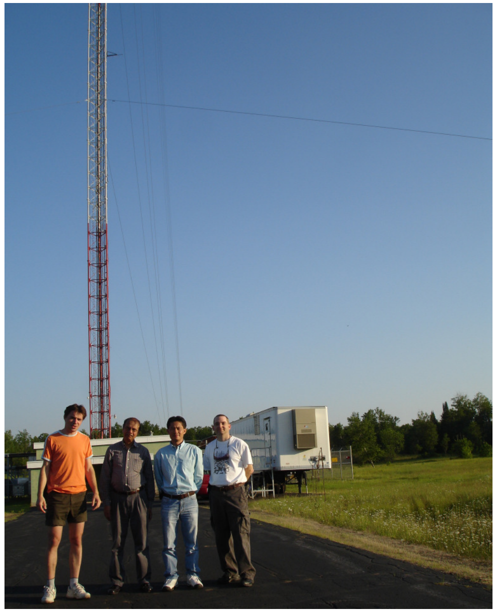
-TKE decrease during the afternoon transition (vertical view)
-TKE budget at different height using in-situ sensors / Lidar
Which term prevails at what height?
- Evolution of w' Integral scales – How it is linked to the TKE budget?

Method:

Statistics in the temporal domain using lidar and in-situ measurements (Eulerian point of view)

- Horizontal homogeneity (no heterogeneity from advection)
- Taylor « frozen turbulence » hypothesis
- 1h gate: compromise between sufficient number of eddies and stationary conditions

Experimental sites and instrumentation



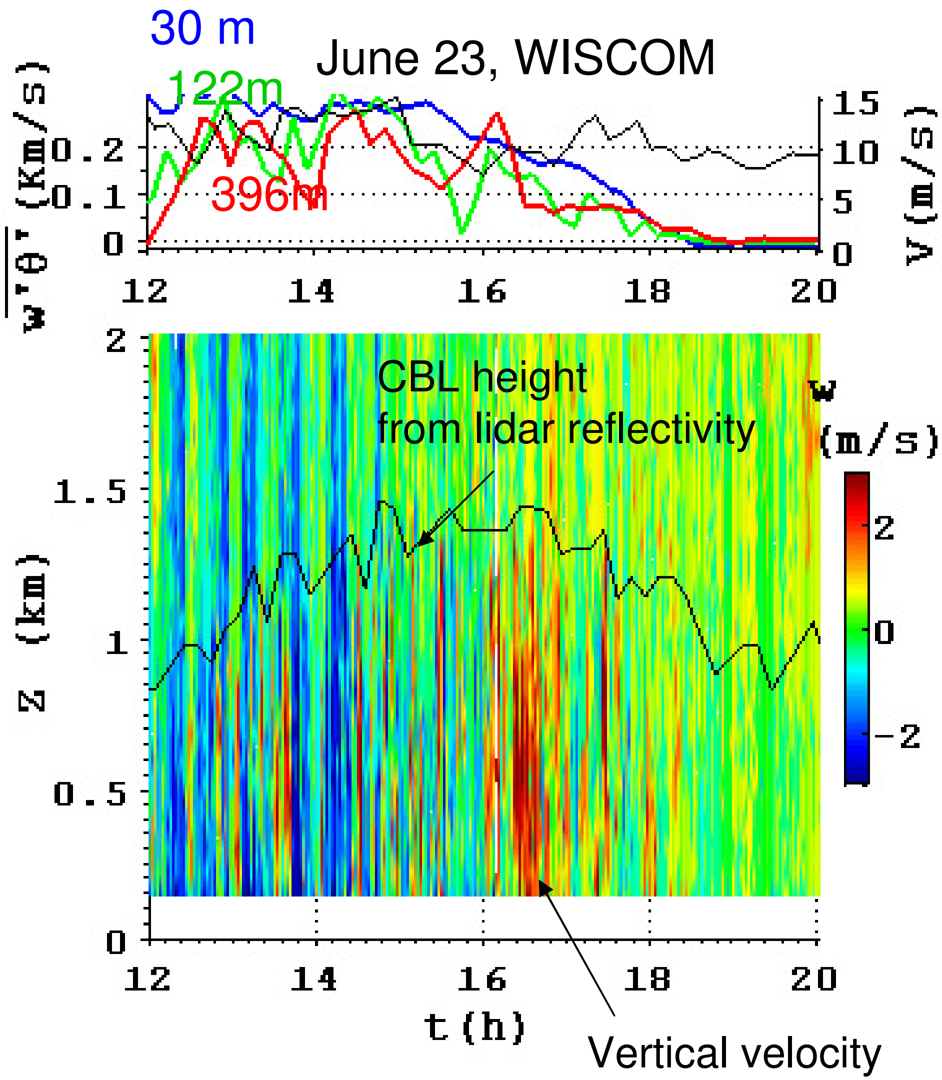
WISCOM
Wisconsin, Park Falls, USA, June 2007
Doppler Lidar: (NASA Langley)
2 µm pulsed lase (80 mJ/ 2.5 Hz)
Range & Time resolution: 75 m / 40 s

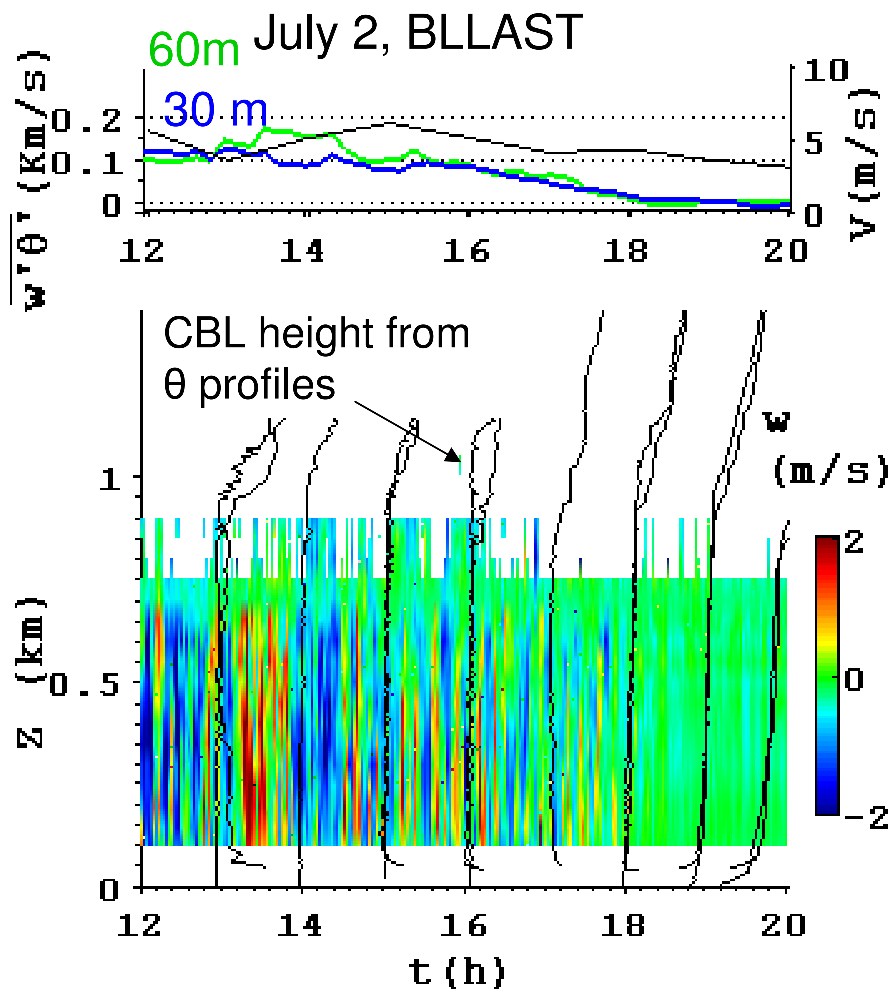
Sonic anemometers **30, 122, 396 m**

BLLAST
Lannemezan, FRANCE, June-July 2011
Doppler Lidar: WindCube 200 (Leosphere)
1.5 µm pulsed fiber laser (100 µJ/ 20kHz)
Range & Time resolution: 50 m / 5 s

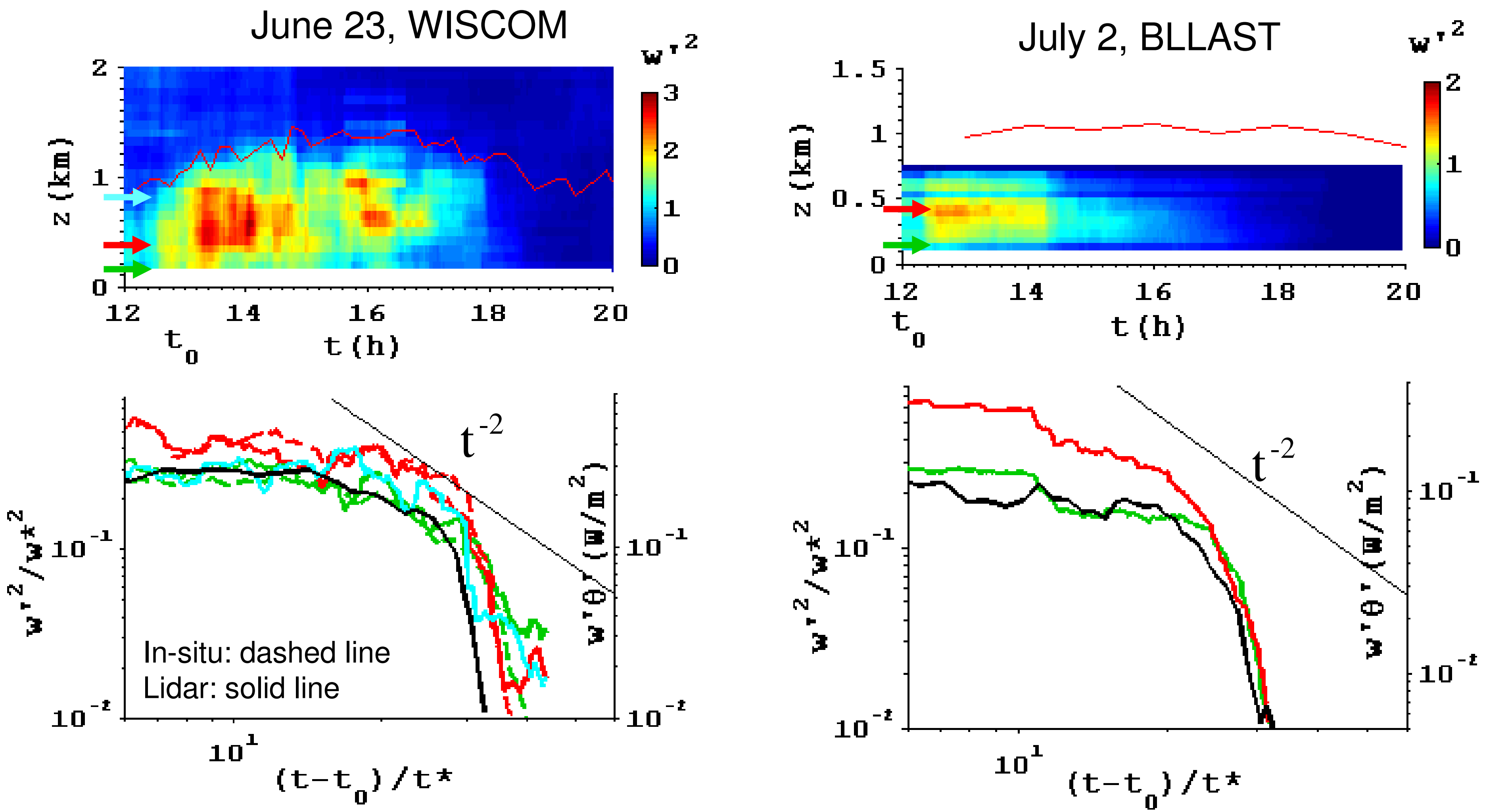
Sonic anemometers **30, 60 m**

2 cases study





$TKE_w(=0.5w'^2)$ afternoon decay

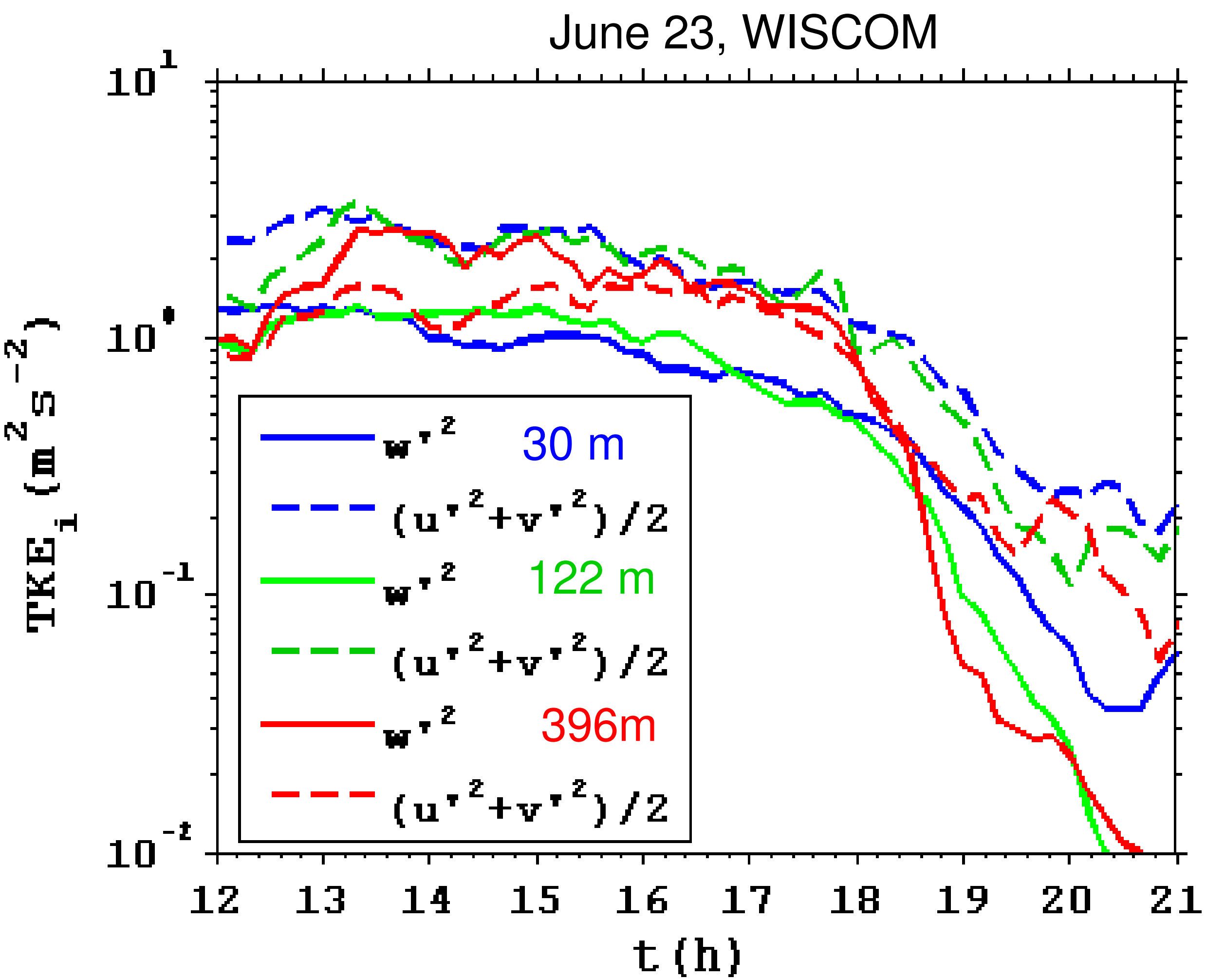


→The decrease is faster and earlier at higher altitude

→The decrease of TKE_w seems to follow the decreasing law of surface heat flux rather than any power law

$$t_* = z_i / w_*$$

TKE_w contribution in TKE decay



→At 30 and 122 m the main source of TKE is from horizontal components

→At 396 m:
TKE is equally shared between the 3 components
Same rate of decrease during the main part of the afternoon transition (until 18:30)

TKE budget

$$\bar{e} = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)$$

TKE budget equation assuming horizontal homogeneity

$$\frac{\partial \bar{e}}{\partial t} = \frac{g}{\overline{\theta_v}}\overline{w'\theta_v'} - \left(\overline{u'w'}\frac{\partial U}{\partial z} + \overline{v'w'}\frac{\partial V}{\partial z}\right) - \frac{\partial \overline{w'e}}{\partial z} - \frac{1}{\bar{\rho}}\frac{\partial \overline{w'p'}}{\partial z} - \varepsilon$$

Buoyancy Production (B)

Shear Production (S)

TKE Transport (Te)

Pressure transport

Loss due to viscous dissipation (-ε)*

Nieuswstadt and Brost (1986), Fernando et al. (2003), Nadeau et al. (2011) analyzed the TKE decay neglecting shear, transport of TKE and pressure terms. What about observations?

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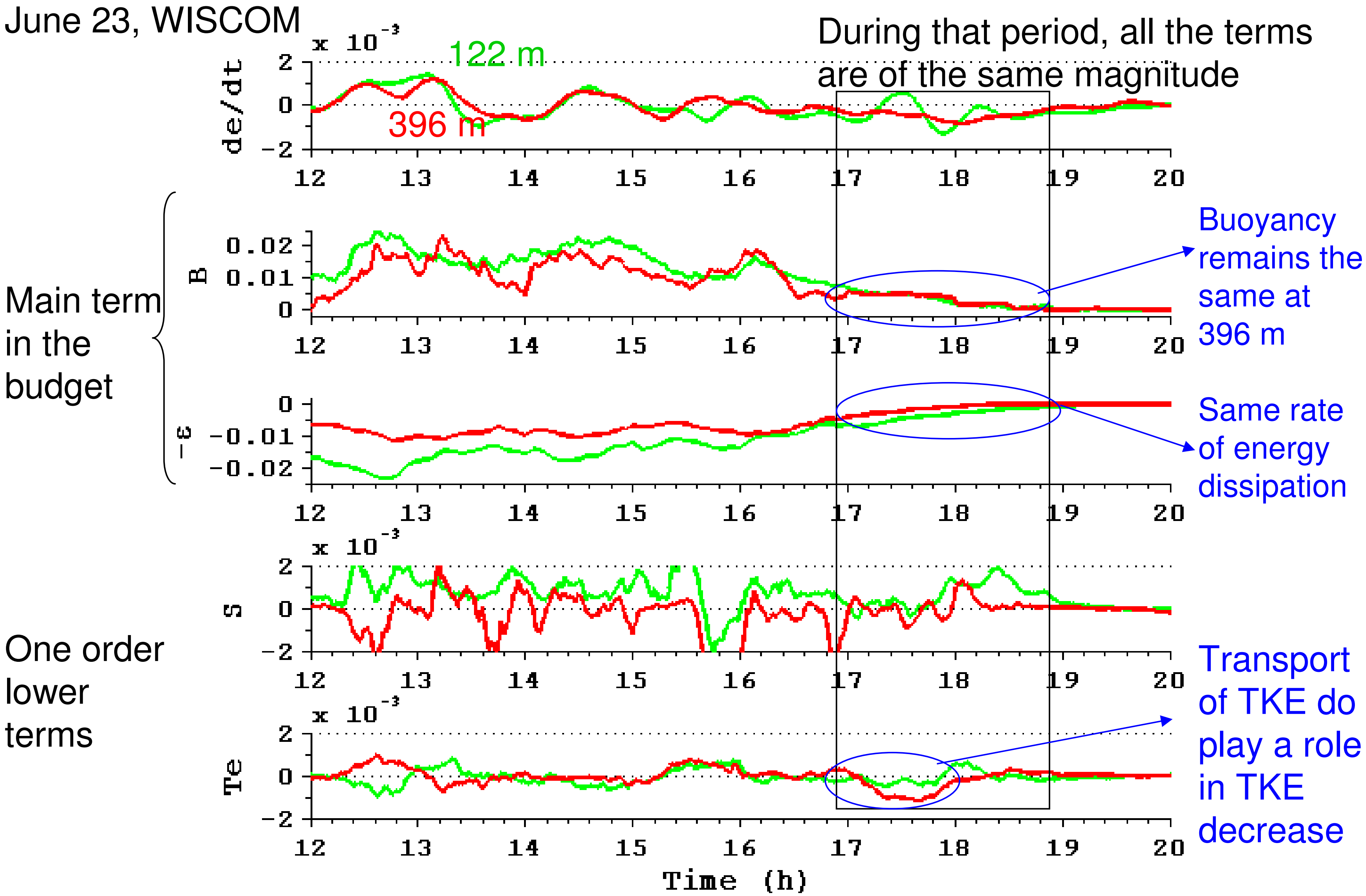
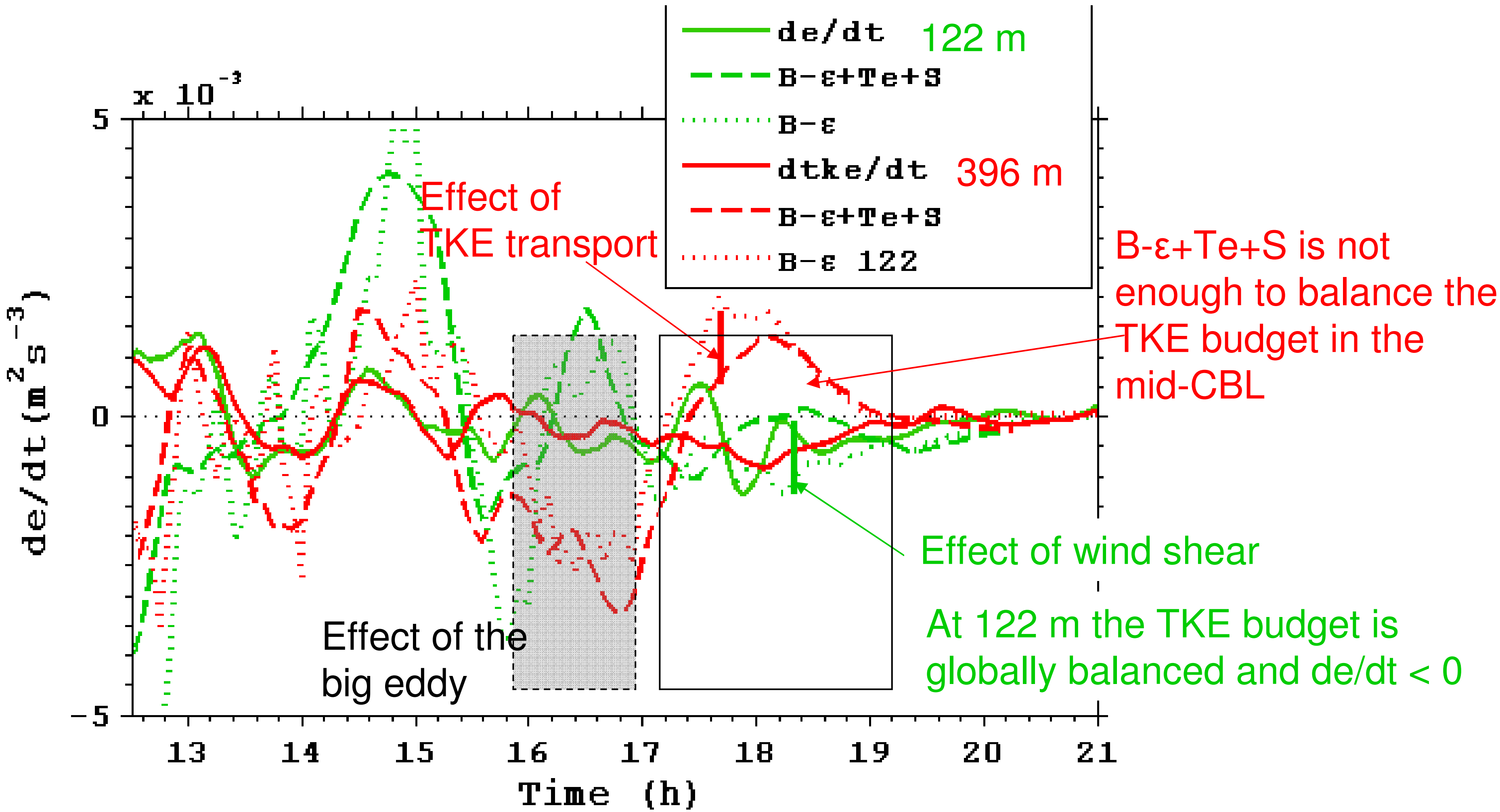
* ε is calculated using Kolmogorov law in the inertial subrange: $E(k) \sim \varepsilon^{2/3}k^{-5/3}$ where k is the wavenumber and E(k) the spectral density of TKE

The different terms in TKE budget

June 23, WISCOM



TKE budget- the missing term



→ Pressure transport and buoyancy seem to be the key players to balance TKE above the surface layer (confirms LES results in Pino et al. 2006)

Buoyancy – Pressure transport oscillation

Neglecting shear, transport of TKE above the surface layer

$$\frac{\partial \overline{e}}{\partial t} = \left(\frac{g}{\overline{\overline{\theta}}_v} \overline{w'\theta_v'} \right)_{>\varepsilon} - \frac{1}{\overline{\overline{\rho}}} \frac{\partial \overline{w'p'}}{\partial z}$$

In Boussinesq approximation, we can find the following wave equation:

$$\frac{\partial^2}{\partial t^2}\left(\nabla^2 w'\right) + N^2 \nabla_H^2 w' = 0$$

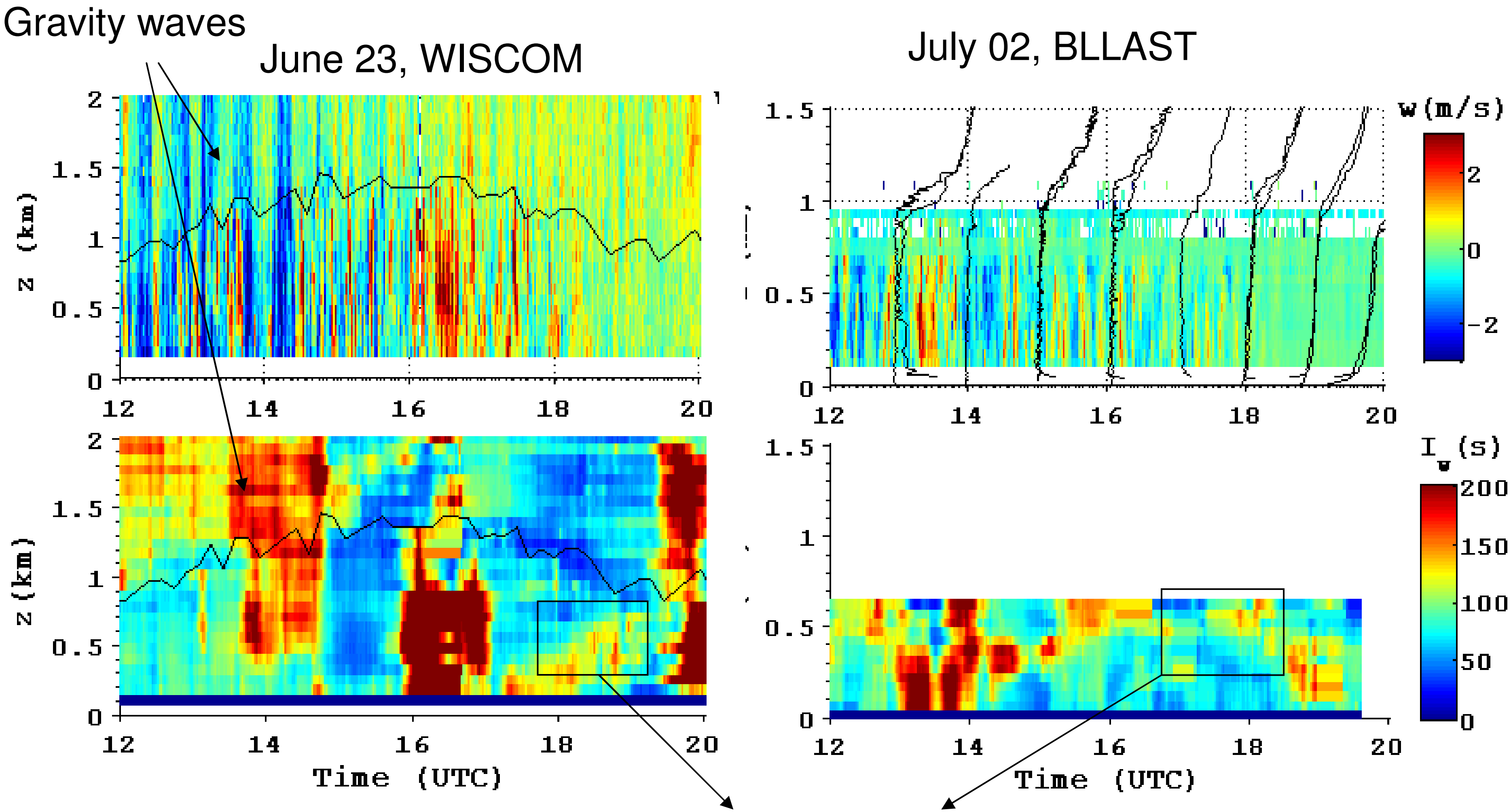
Brunt-Vaisala pulsation

Dispersion relation $f^2 k^2 - f_N^2 k_\perp^2 = 0$

Condition for wave propagation: $f < f_N$

Although we don't have clear evidence of wave phenomenon...
In the case of pressure transport – buoyancy oscillations, the atmosphere is expected to act as a low pass filter for convective forcing frequency

Integral scale estimates $I_w = \max\left(\int ACR(w)\right)$



Large integral scales remain during the transition in the mid-CBL while they disappear close to the surface

Conclusion

-w'^{2} decay seems to follow the decrease of surface heat flux for several days (~ 7) during BLLAST and WISCOM experiments.

-Doppler lidar measurements show that w'^{2} decreases earlier and faster at higher altitude

- In the middle of the CBL, the evolution and contribution of each component of TKE seem to be similar during the transition (not the case close to the surface layer)

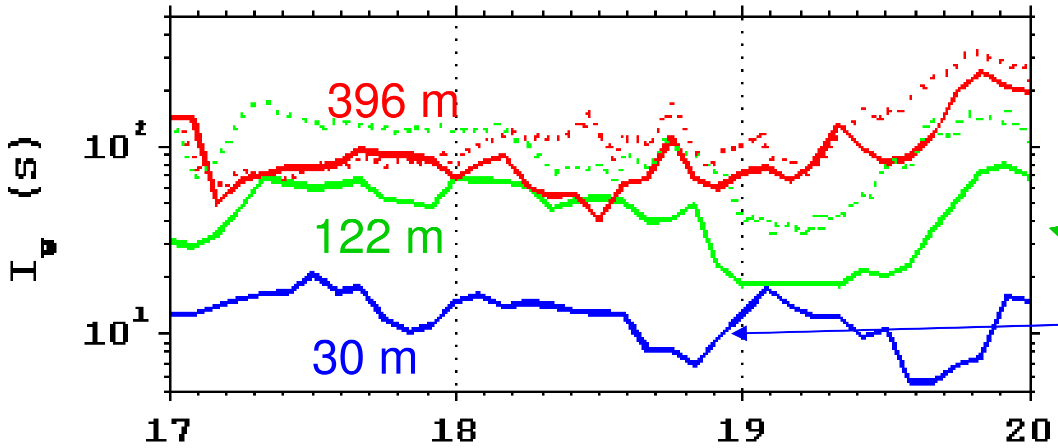
-TKE budget seems to show a major role of the pressure term to balance buoyancy positive anomalie (relative to dissipation) in the mid CBL.

-Shear and TKE transport do play a role but there are not sufficient to balance the TKE budget.

-Integral scales are maintained in the mid-CBL while there become smaller close to the surface. Possible explanation can be that the atmosphere acts as a low pass filter for convective forcing frequency during the transition.

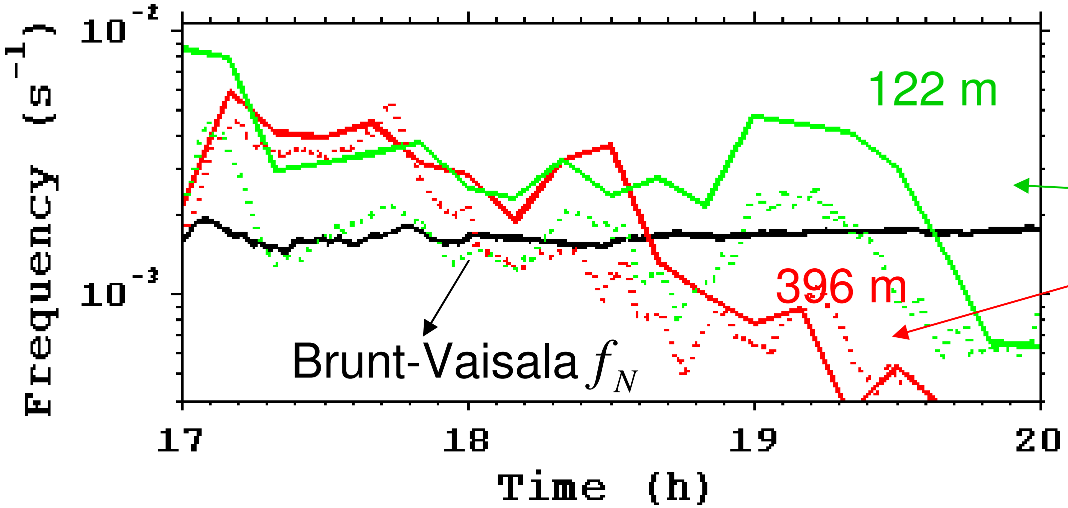
Lenght scale I_w and Brunt-Vaisala frequency

In-situ=solid line
lidar= dotted line



Large I_w remains at 396 m

I_w decreases close to the surface 30 m – 122 m



Main turbulent forcing frequency *(Carruters and Hunt, 1986)*

$$f = \sqrt{\overline{w'^2}} / (I_w . V)$$

→Oscillations associated to large I_w can remain at 396 m