Afternoon transition turbulence decay revisited by Doppler Lidar

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

Laboratoire de Météorologie Dynamique
LIDAR-Atmosphere, Biosphere & Climate team (ABC)
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 laser (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

AMS 20BLT, Boston, 8-13 July 2012
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.

\[ t_* = \frac{z_i}{w_*} \]

→ 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.
\(TKE_w\) 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

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

Buoyancy Production (B)  Shear Production (S)  TKE Transport (Te)  Pressure transport  Loss due to viscous dissipation (-\(\varepsilon\))*

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?

* \(\varepsilon\) 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

During that period, all the terms are of the same magnitude. Buoyancy remains the same at 396 m, same rate of energy dissipation. Transport of TKE do play a role in TKE decrease.
Effect of TKE transport

B-\(\varepsilon\)+Te+S is not enough to balance the TKE budget in the mid-CBL

Effect of wind shear

At 122 m the TKE budget is globally balanced and \(\frac{de}{dt} < 0\)

\(\rightarrow\) 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)
Neglecting shear, transport of TKE above the surface layer

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

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

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

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

Gravity waves

June 23, WISCOM

July 02, BLLAST

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 $l_w$ and Brunt-Vaisala frequency

In-situ=solid line
lidar= dotted line

$\text{Large } l_w \text{ remains at 396 m}$

$l_w \text{ decreases close to the surface 30 m - 122 m}$

$\text{Main turbulent forcing frequency (Carruters and Hunt, 1986)}$

$f = \sqrt{\frac{w^2}{l_w V}}$

$\rightarrow \text{Oscillations associated to large } l_w \text{ can remain at 396 m}$