# Vertical and temporal evolution of turbulence spectra in the late afternoon transition

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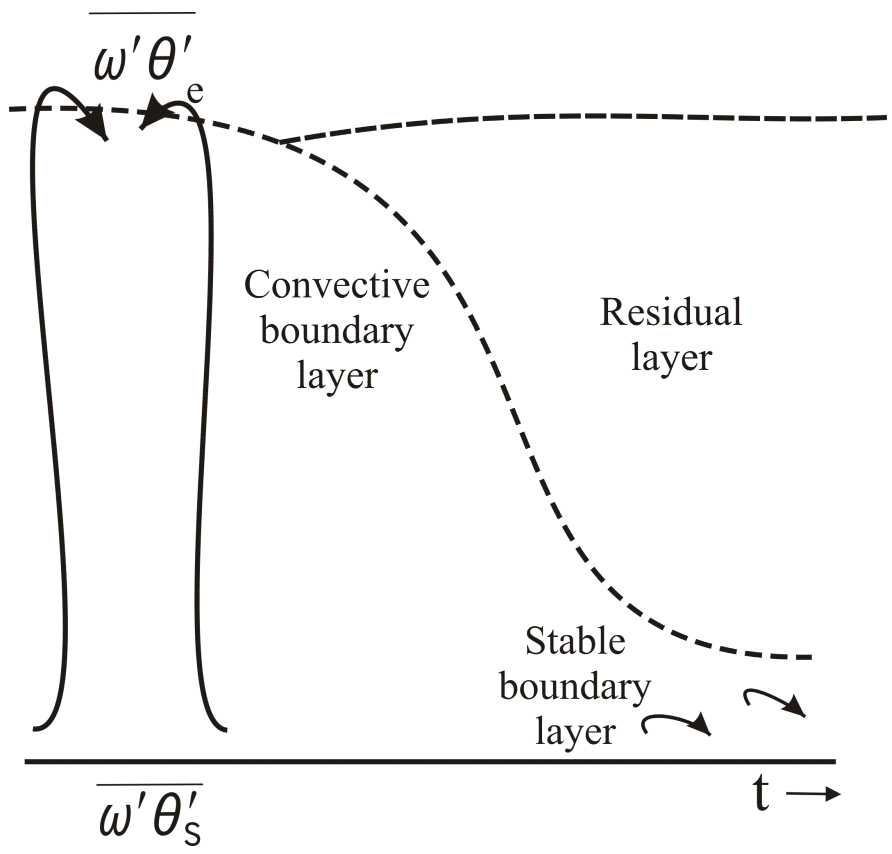
and BLLASTers

# Research strategy

Improve our understanding of the vertical structure of the BL during the afternoon transition




**Is there a decoupling between surface and higher levels during LAT?**

- **Spectral analysis** at different heights (aircraft, surface measurements, LES)

→ Evolution of the characteristic length scales of w

→ Evolution of the shape of the turbulence spectra

# Spectral analysis: previous studies

Until now :

**Shape of the spectra**

-Many models for convective conditions :

Kaimal et al. (1976) (validated in surface: Kansas, Minnesota experiments), von Kàrmàn (1948)

- Analytical spectra models not always adapted within the entire CBL (Lothon et al. (2009))

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BLLAST
Boundary Layer Late Afternoon and Sunset Turbulence

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→ Kristensen et al. analytical model (shape parameter)

-Few studies on its temporal evolution

## Kristensen et al. (1989) general kinematic spectral model

**Hypothesis** : Anisotropic horizontally homogeneous vertical velocity field

$$\frac{S(k)}{\sigma_w^2} = \frac{l_w}{2\pi} \frac{1 + \frac{8}{3}\left(\frac{l_w k}{a(\mu)}\right)^{2\mu}}{\left(1 + \left(\frac{l_w k}{a(\mu)}\right)^{2\mu}\right)^{\frac{5}{6\mu}+1}}$$

$$a(\mu) = \pi \frac{\mu\Gamma\left(\frac{5}{6\mu}\right)}{\Gamma\left(\frac{1}{2\mu}\right)\Gamma\left(\frac{1}{3\mu}\right)}$$

$$\lambda_w = \left\{\frac{5}{3}\sqrt{\mu^2 + \frac{6}{5}\mu + 1} - \left(\frac{5}{3}\mu + 1\right)\right\}^{1/(2\mu)} \frac{2\pi}{a(\mu)} l_w.$$

**Two characteristics :**

$l_w$ (integral scale)

μ (shape)

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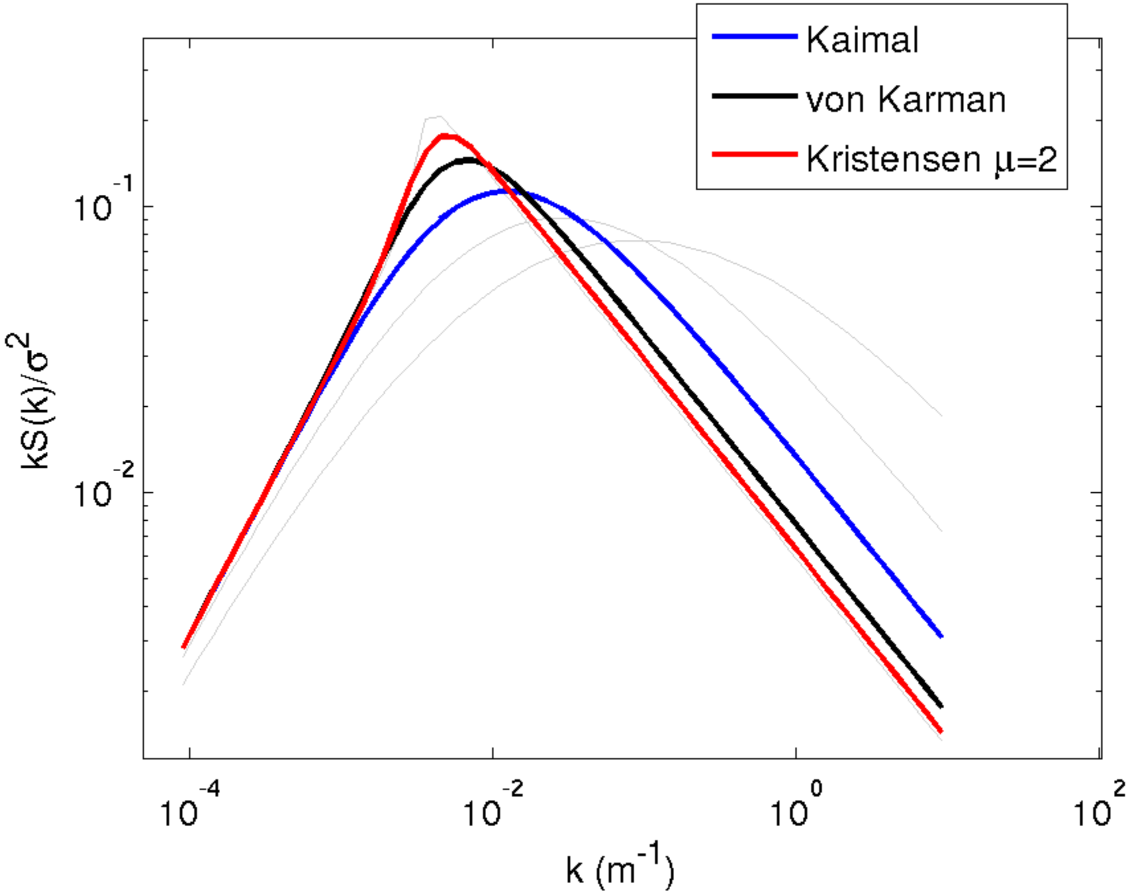

# Spectral analysis: previous studies

Until now :

**Lengthscales**

-Many ways to define those scales

→ **wavelength of the energy spectrum peak** (energy production) :

*Nieuwstadt and Brost (1986)*

*Grant (1997)*

→**integral scale** (energy-containing eddies): *Sorbjan (1996)*

→ **weighted integral of the spectrum** : *Pino et al. (2006)*

→ etc...

- Lack of agreement in the evolution of those scales during LAT

# Spectral analysis: previous studies

Until now :

**Lengthscales**

-Many ways to define those scales

→ **wavelength of the energy spectrum peak** (energy production) :

*Nieuwstadt and Brost (1986)* → *constant*

*Grant (1997)* → *decrease*

→**integral scale** (energy-containing eddies): *Sorbjan (1996)* → *increase*

→ **weighted integral of the spectrum** : *Pino et al. (2006)* → *increase, except for w (constant)*

→ etc...

- Lack of agreement in the evolution of those scales during LAT

**During LAT:**

# Spectral analysis: previous studies

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**Lengthscales**

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→ etc...

- Lack of agreement in the evolution of those scales during LAT

## What is our contribution?

- **Spectral analysis during the LAT (BLLAST + LES) using Kristensen et al. analytical spectra model**

1/ Evolution of the characteristic length scales of w (2 methods) during the LAT

2/ Evolution of the shape of the turbulence spectra

# Working assumptions and methods

1) Case study : 20 June 2011

2) Use of an **analytical spectra model** for convective BL as a reference (Kristensen et al.,1989)

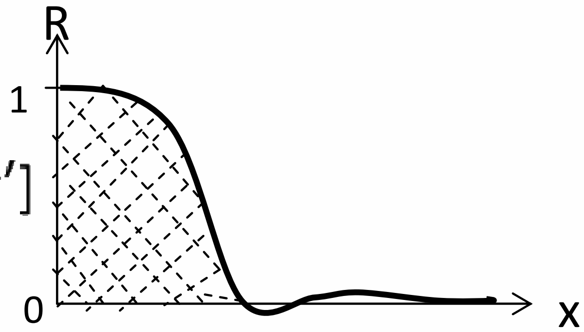
- Calculation of the turbulence spectra (with LES and BLLAST data) every 30min : compromise between sufficient number of eddies and stationnary conditions
- Search of ($\mu$,$l_w$) which gives the best fit

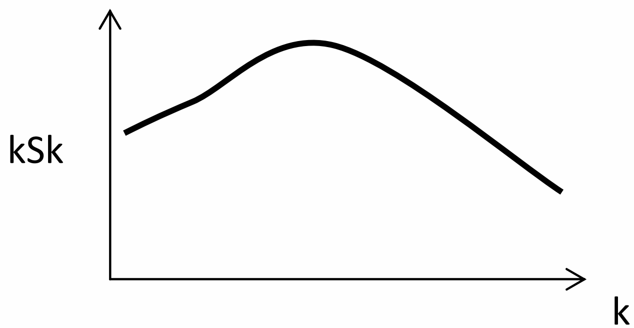
3) **Calculation of the integral length scales** from 2 methods :

(1) with the autocorrelation function

(2) from the analytical spectra model (lw)

$$lw = \max[\int_0^r R(r')dr']$$



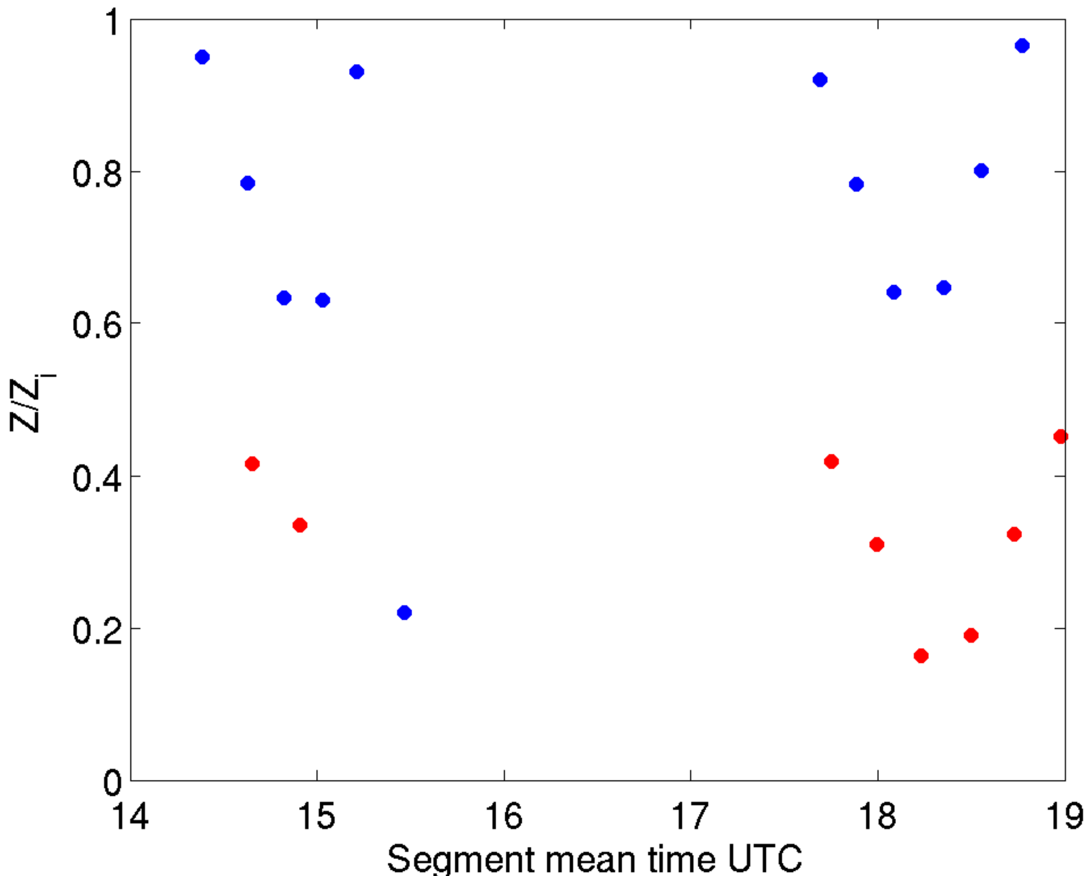
# Data used to calculate the spectra

- BLLAST data : Various surfaces, 60m mast, aircrafts
- LES

## Piper Aztec and Sky Arrow on 20 June

2 flights for each in the afternoon

*Three // legs, 6 heights, 3 latitudes*

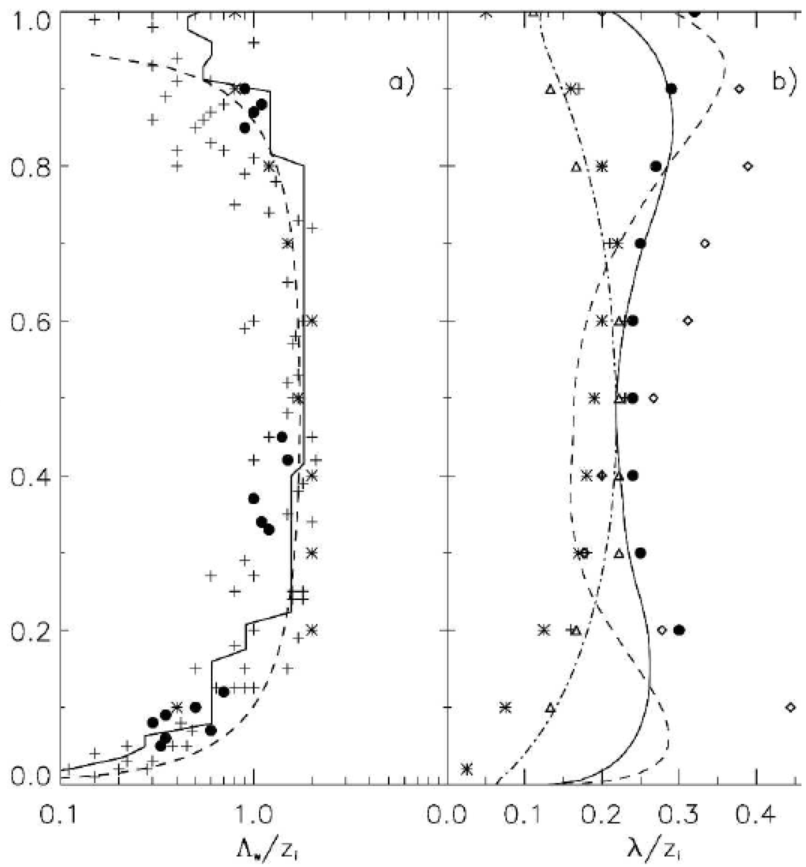


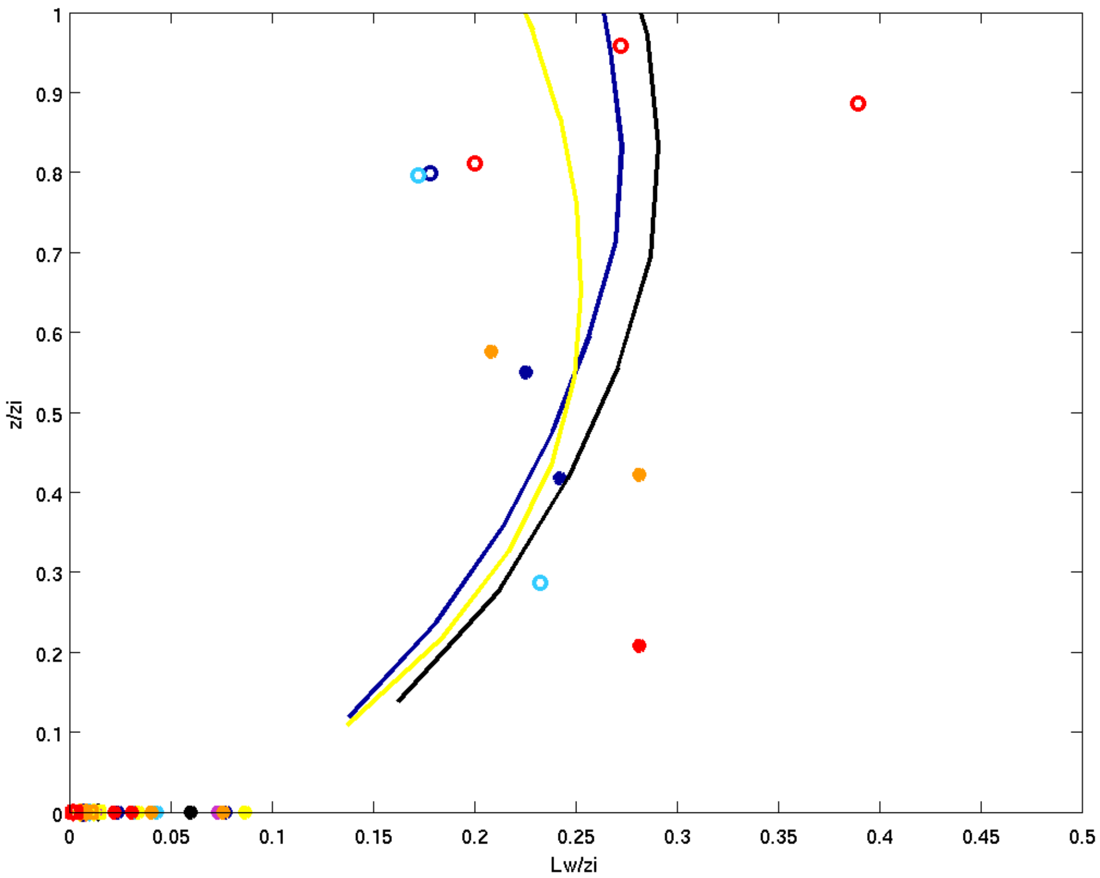

- Aircrafts: dense observations of the turbulence decay within the ML
- Measurements over various surfaces

# Validation of results found in litterature for vertical profiles of lengthscales at 12h

Dosio et al. (2005)

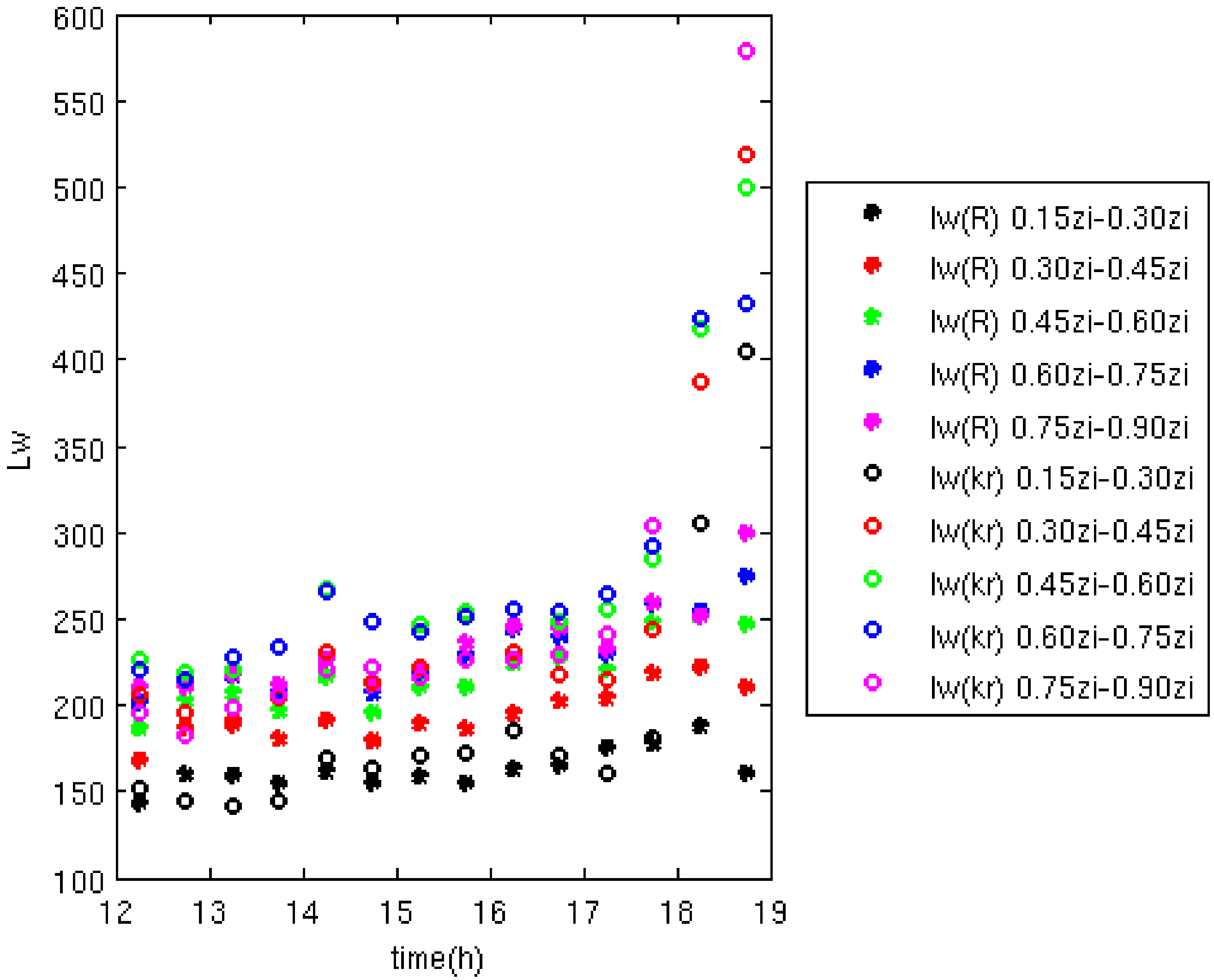
Vertical profiles of w lengthscales from BLLAST data (points), and LES (continuous lines) evolving with time (color changing from black to red)




➔ At 12h, same lengthscales than Dosio et al : lw ~ 0.25 zi

# Temporal evolution of w integral length scales from the 2 methods at different heights. **With LES**




*From autocorrelation function*

*From analytical spectra model*

- 2 consistent methods
- Increase with altitude
- Both increase in the afternoon, and after 17pm with a different amplitude

# Temporal evolution of $l_w$ from the fit with aircrafts and LES

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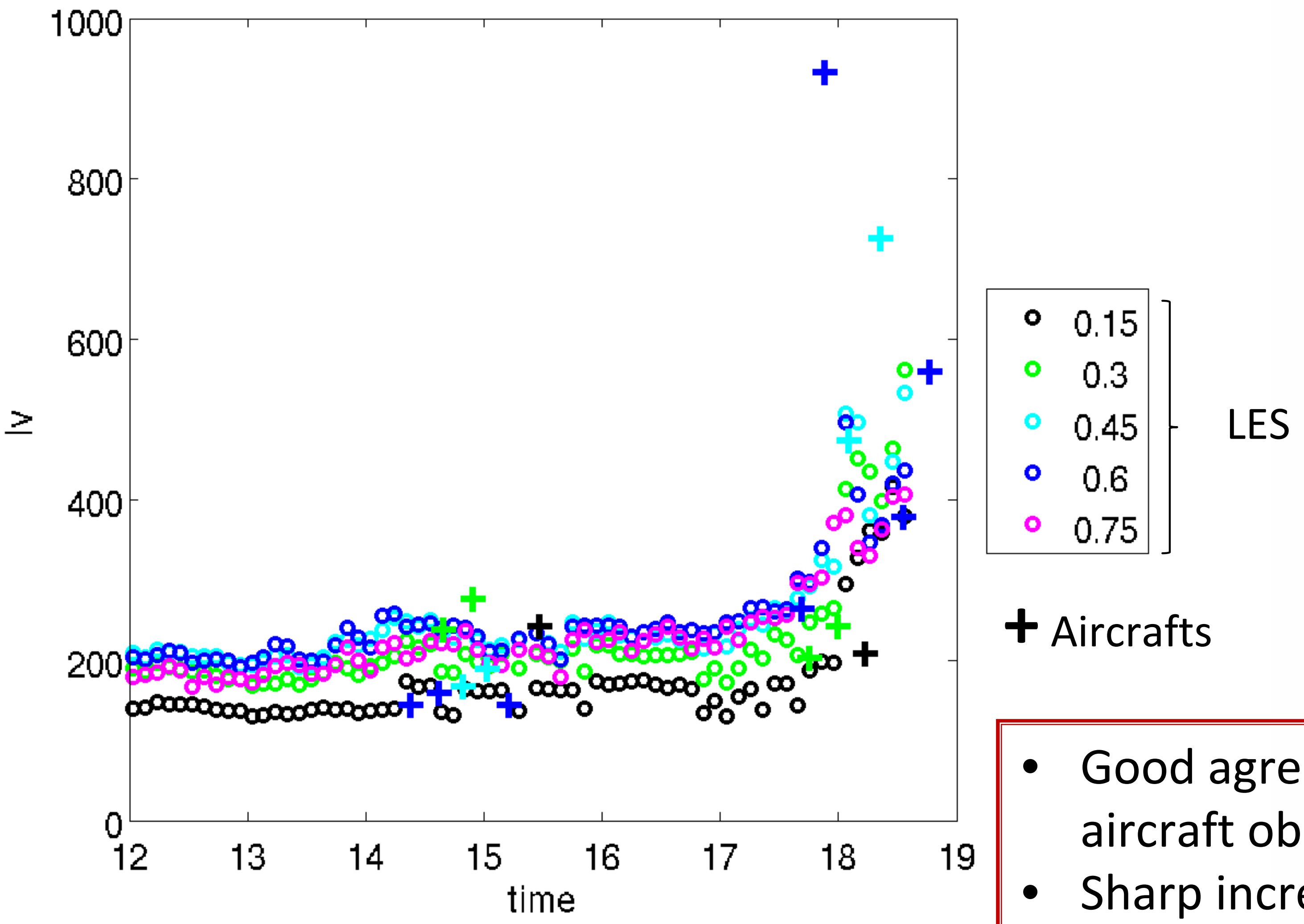
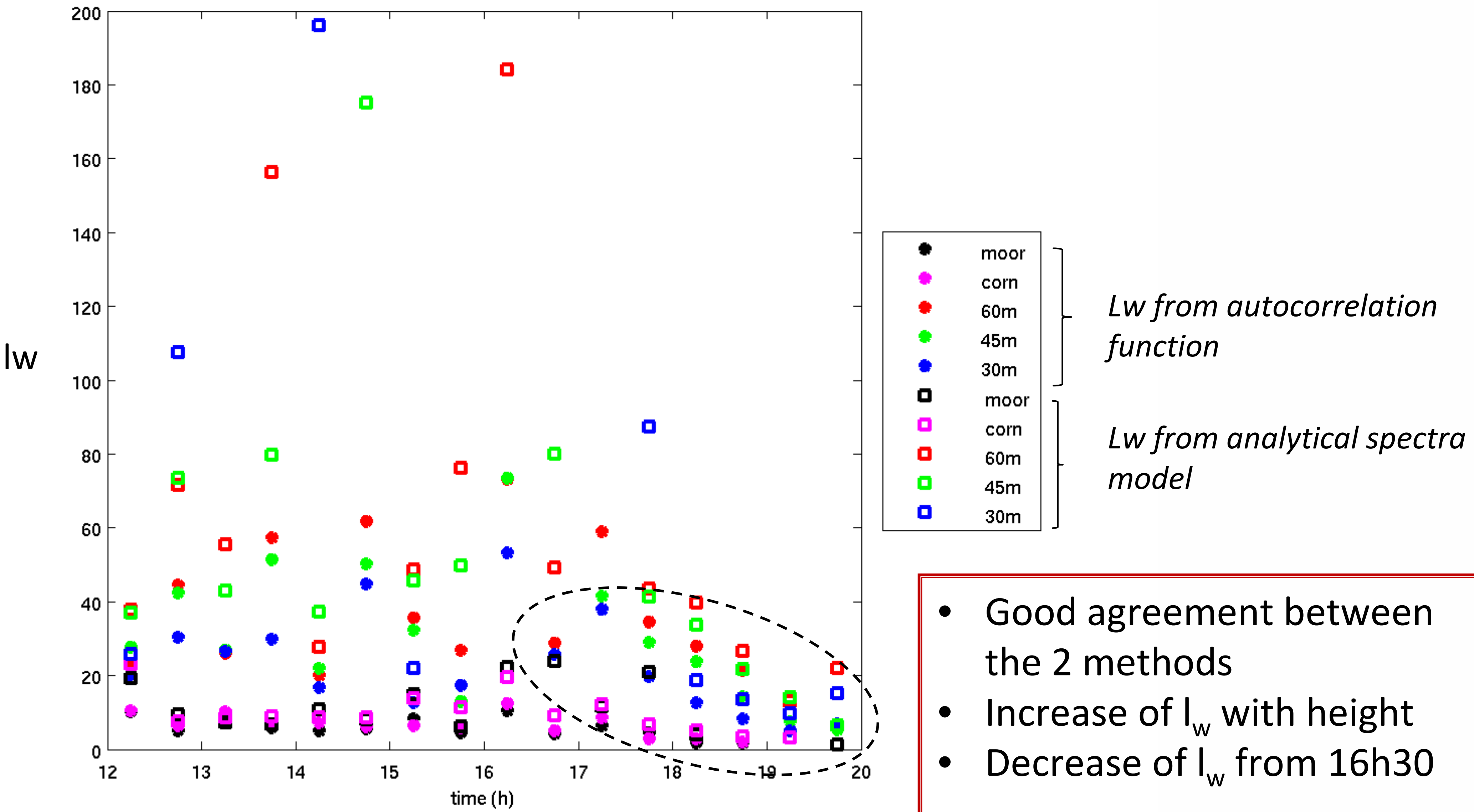
## Evolution of the $l_w$(z/zi, t)




- Good agreement between aircraft observations and LES
- Sharp increase of $l_w$ from 17h

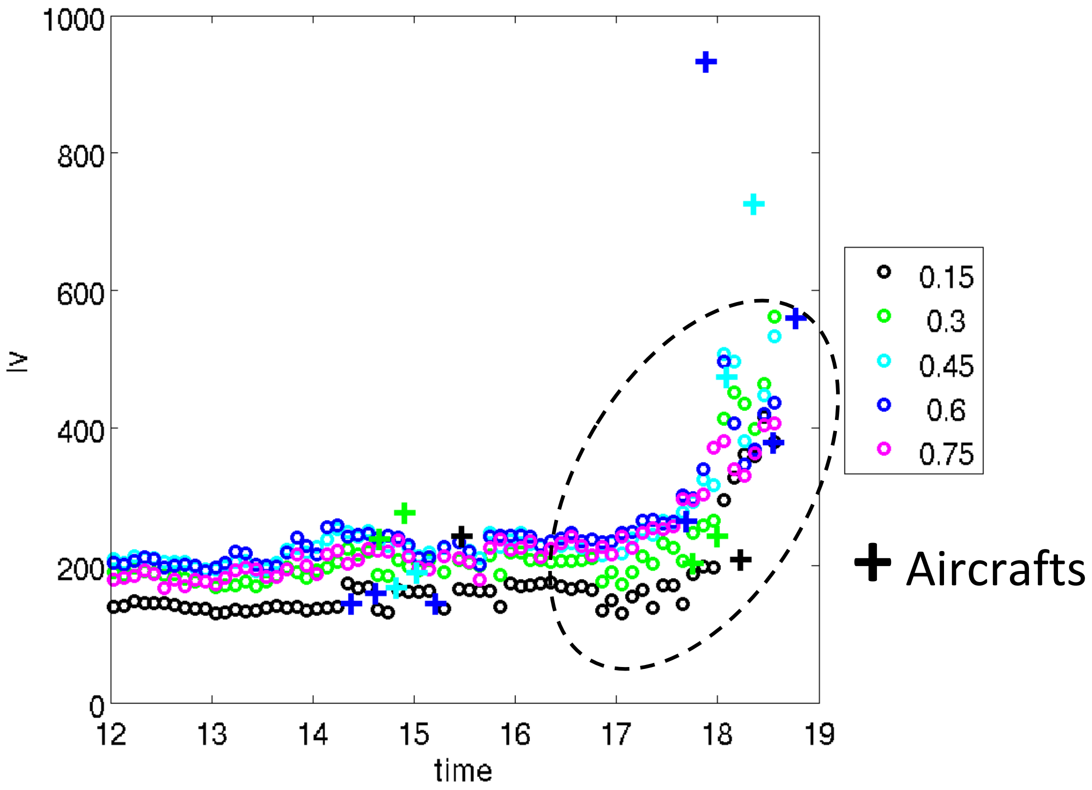
# Temporal evolution of w integral length scales from the 2 methods. Surface and 60m mast

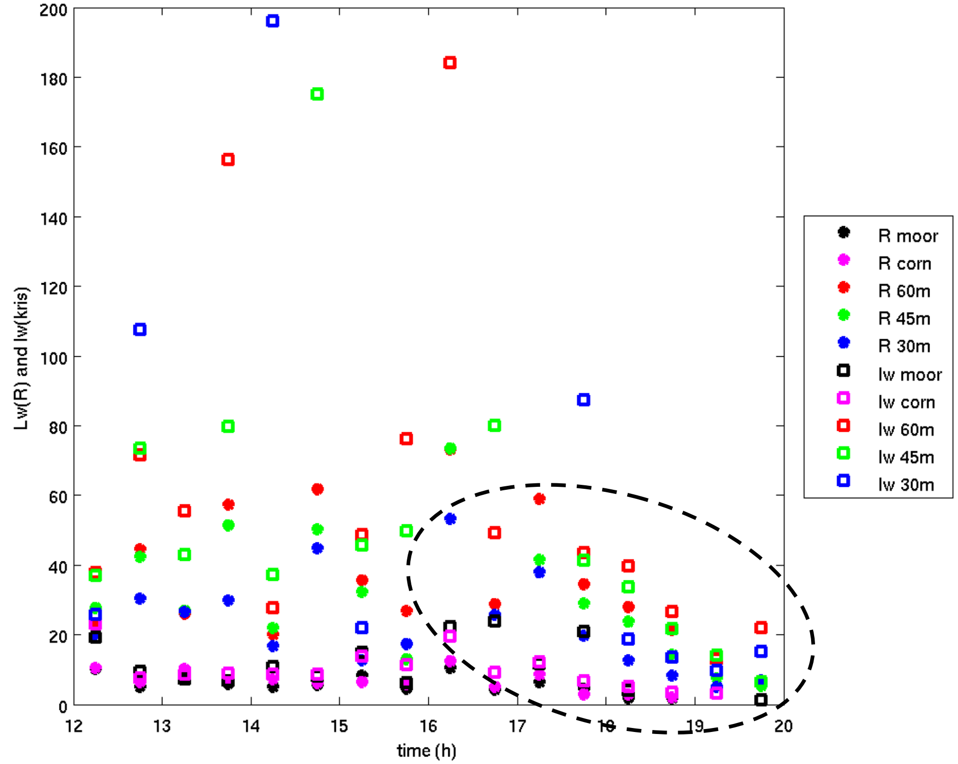
BLLAST
Boundary Layer Late Afternoon and Sunset Turbulence




- Good agreement between the 2 methods
- Increase of $l_w$ with height
- Decrease of $l_w$ from 16h30

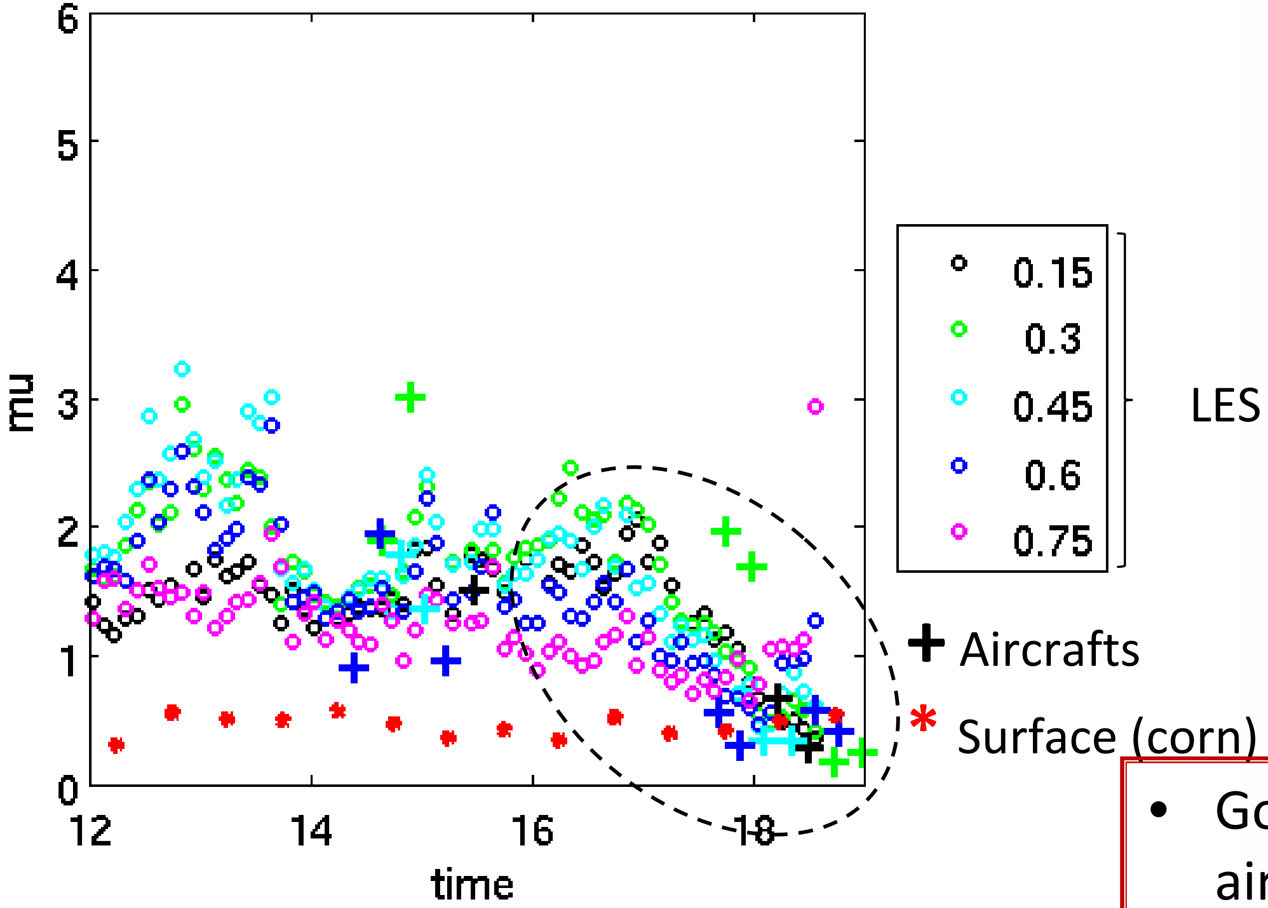
# Decoupling between surface layer and the layer above

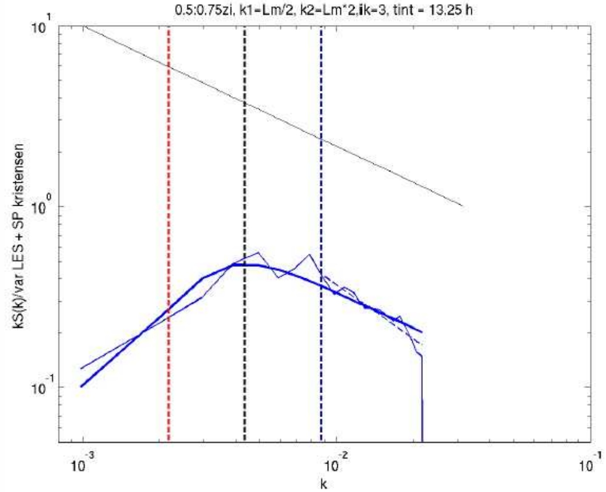



- LES could fill the gap between surface and aircraft measurements
- How low can we estimate $l_w$ with LES according the resolution ?

# Evolution of μ (z/zi, t)

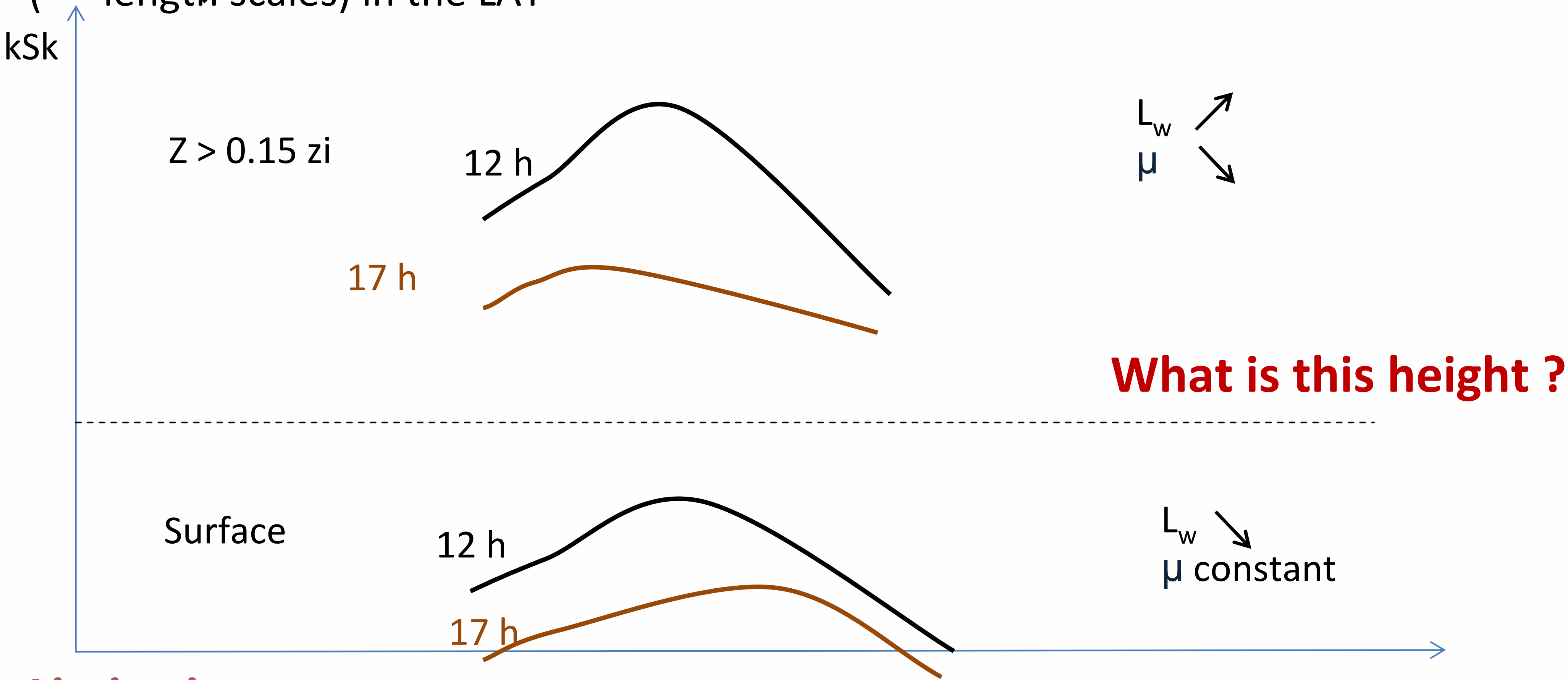



- Good agreement between aircrafts and LES
- From 16h30, the spectra flatten above 0.15zi
- At surface, μ remains constant (Kaimal !)

## Conclusions:

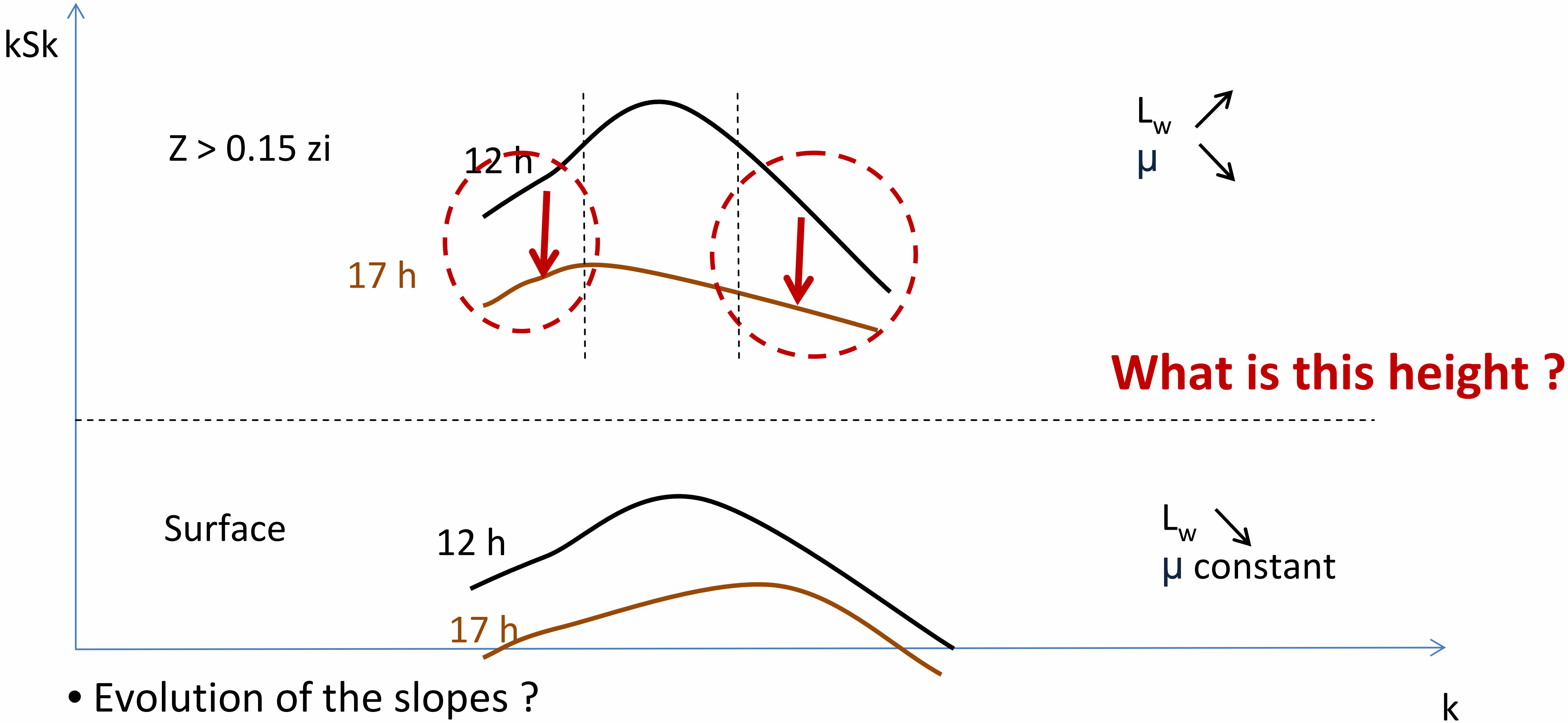
- Decoupling between the surface layer (↘ length scales) and the overlying layer (↗ length scales) in the LAT




## Limitations:

- Hypothesis : homogeneous isotropic turbulence
- Zi estimation

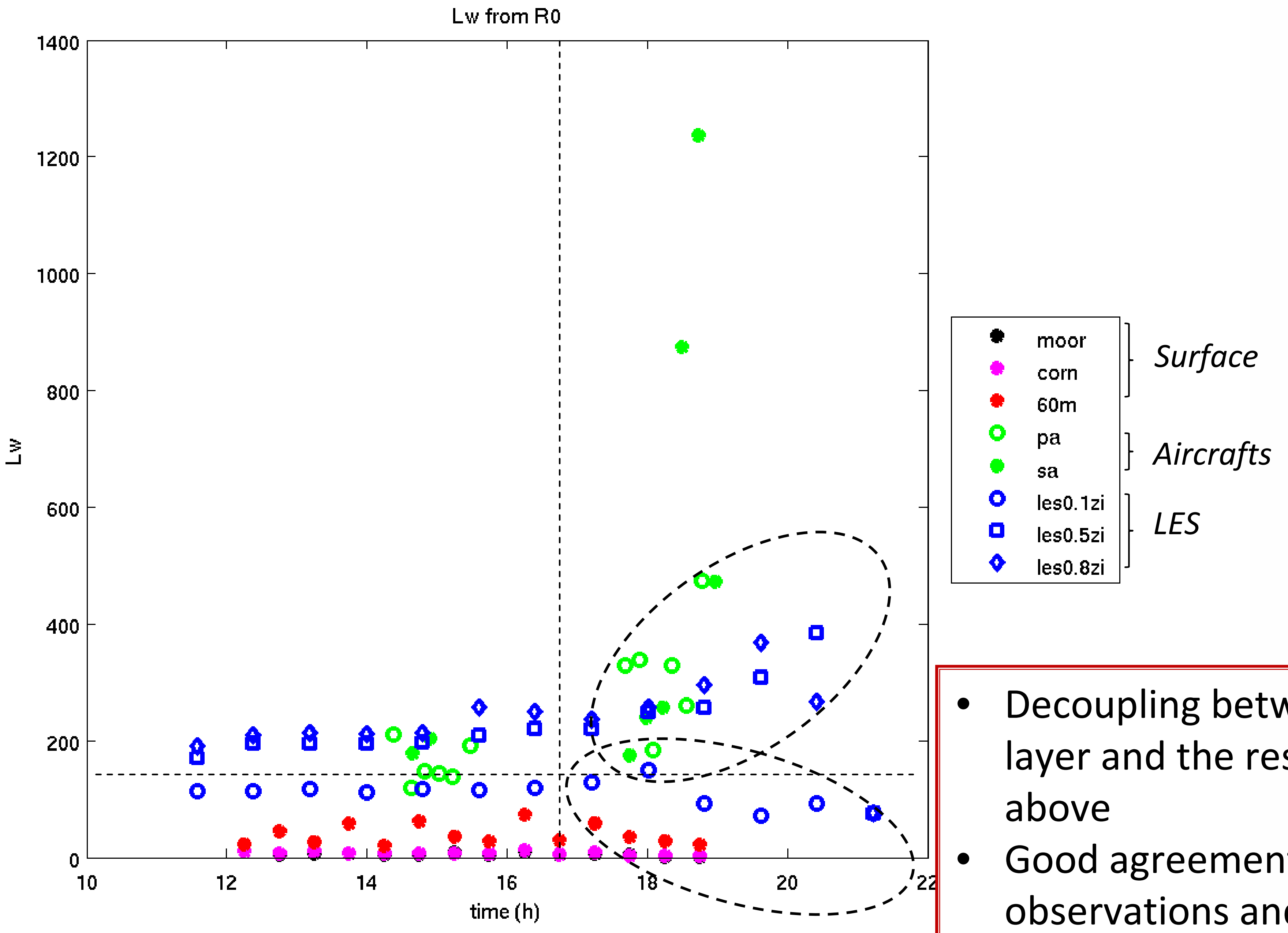
## Perspectives:




- Evolution of the slopes ?
- Evolution of the contribution of the different frequency domains ?
- Extend the study to other variables (T, u, v)

Thank you for your attention !

# Temporal evolution of w integral length scales at different levels, from observations (surface, 60m, aircrafts) and LES



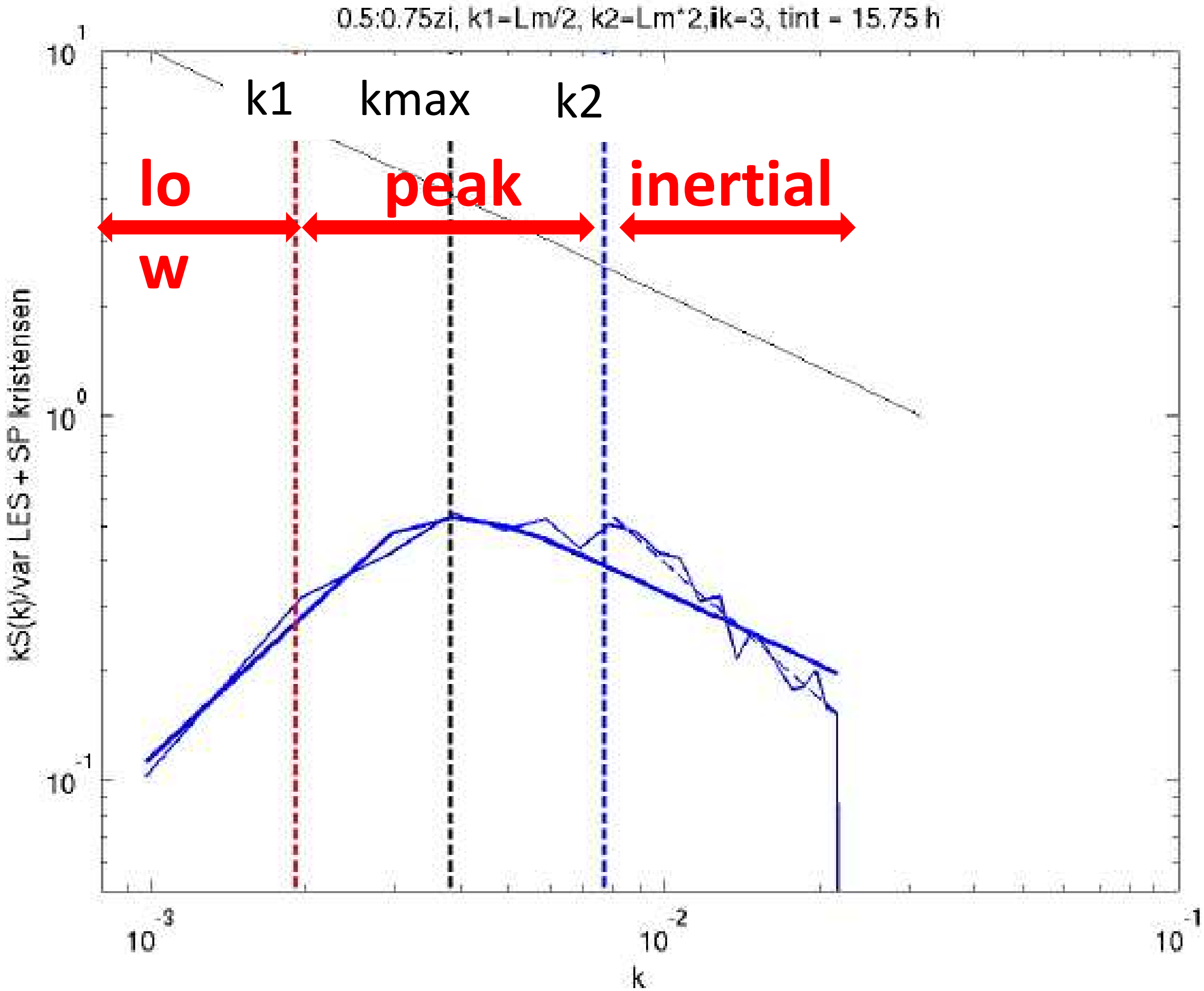

- Decoupling between surface layer and the residual layer above
- Good agreement between all observations and LES

# Spectral analysis

## Three domains defined

*Limits are μ-depending in case of observations, fixed when applied to shorter LES-range.*

1. The low wavenumber range
2. Around the peak of the maximum of the spectra
3. The inertial subrange




OBS

$k1 = 5/\mu\ k_{max}$

$k2 = \mu/5\ k_{max}$

LES:

$k1 = ½\ k_{max}$

$k2 = 2\ k_{max}$

# Contribution (%) of the 3 frequency domains

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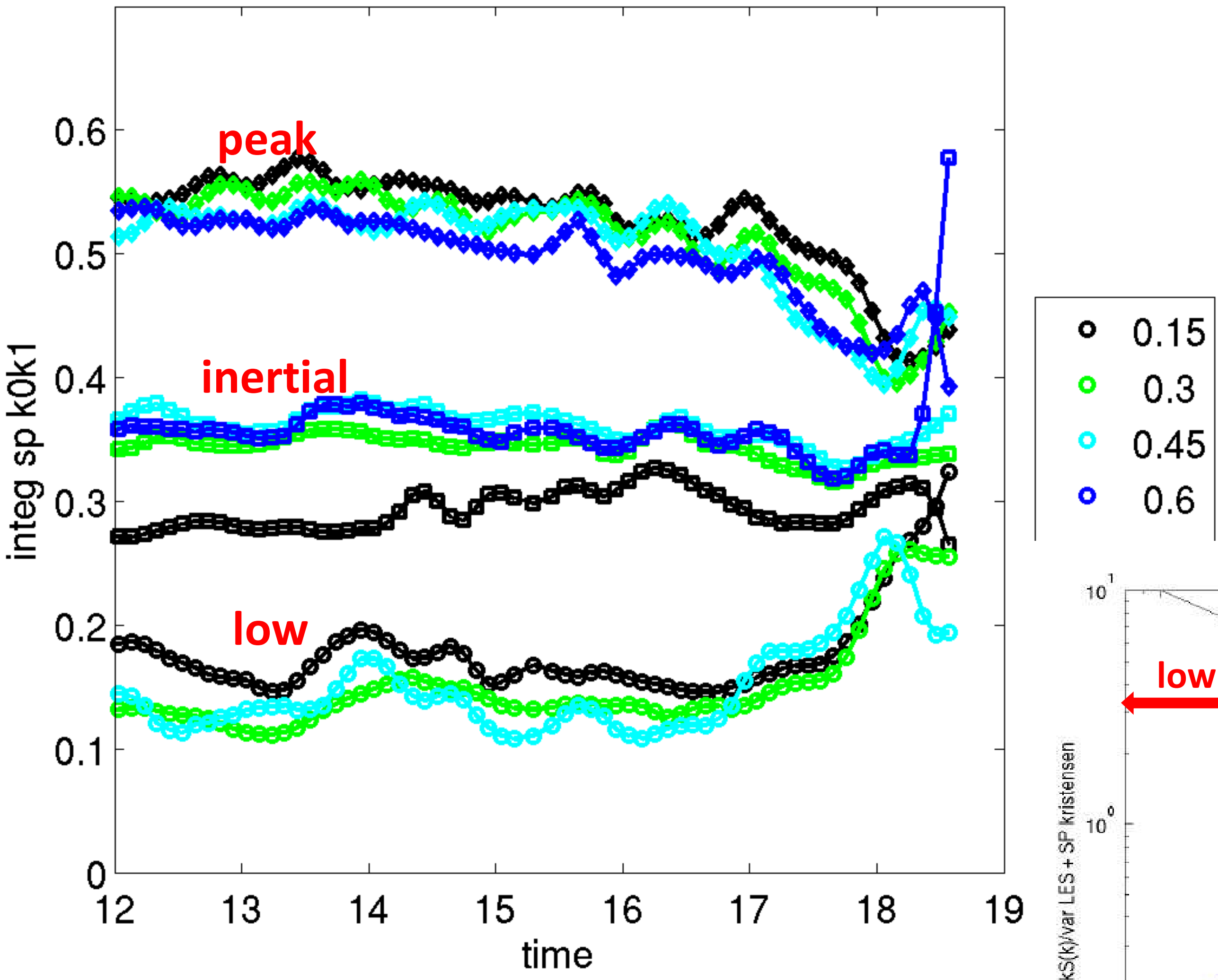
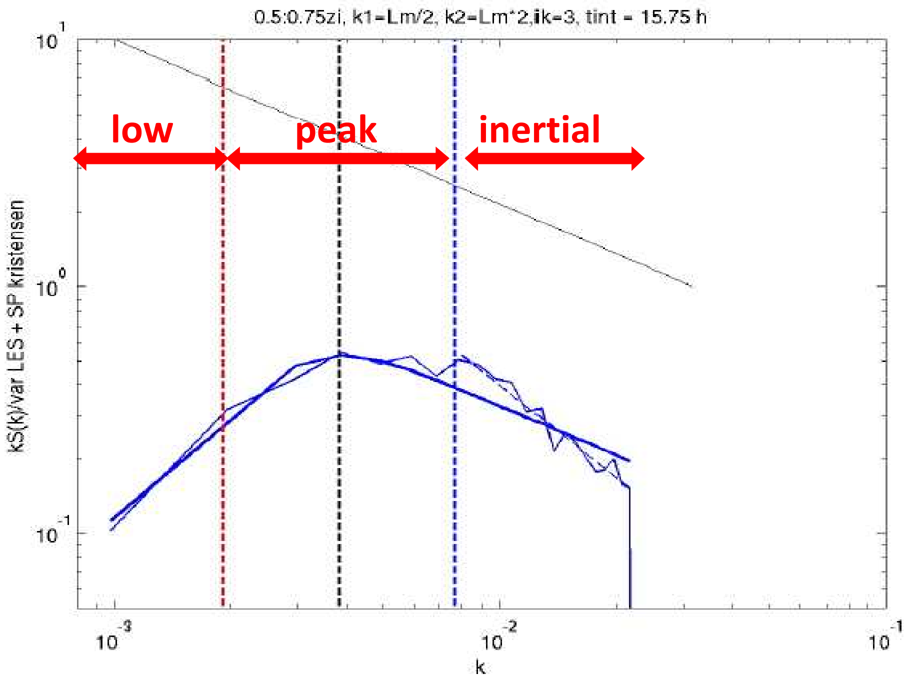
evolution of the integral of the spectra in the 3 domains (o d s)



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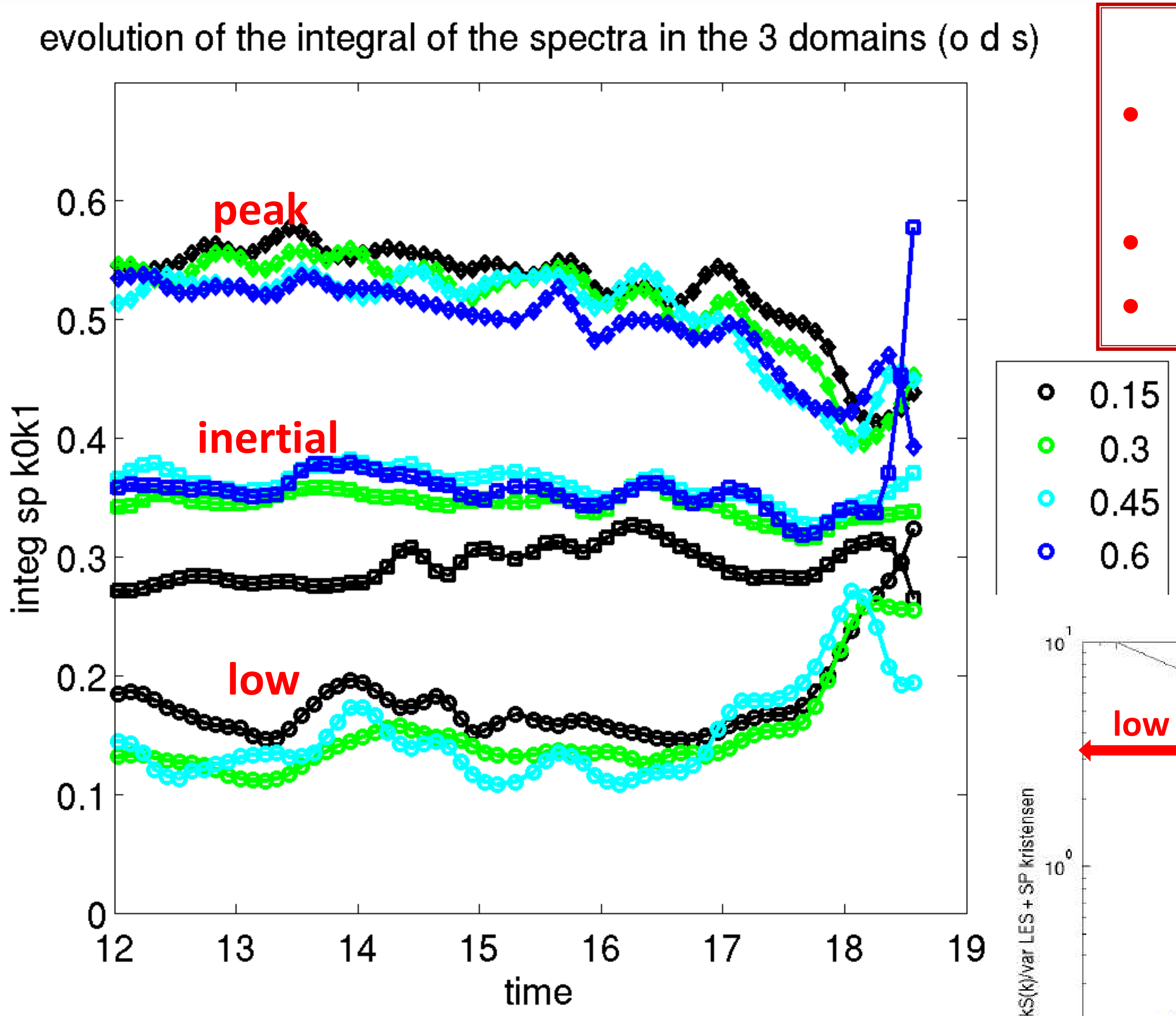
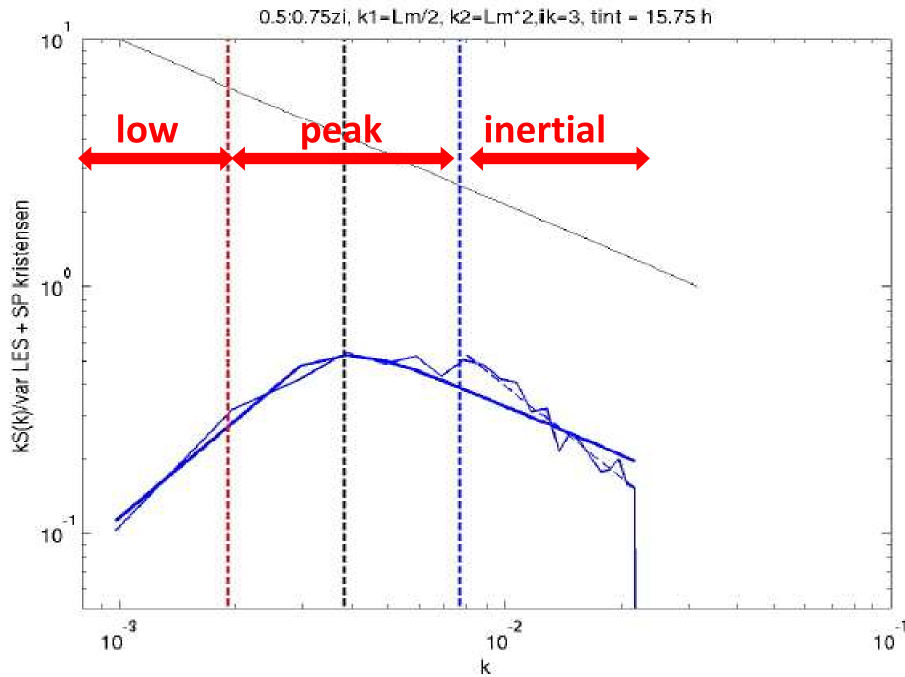



**Contributions (%)**

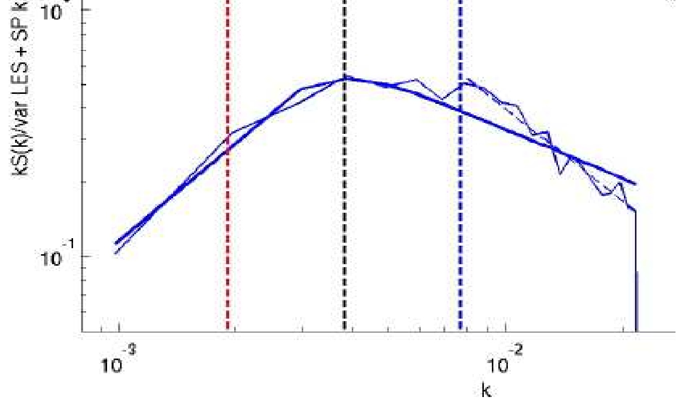
- **peak** : decreases from 16h30
- **low** : increases from 16h30
- **Inertial** : stays constant



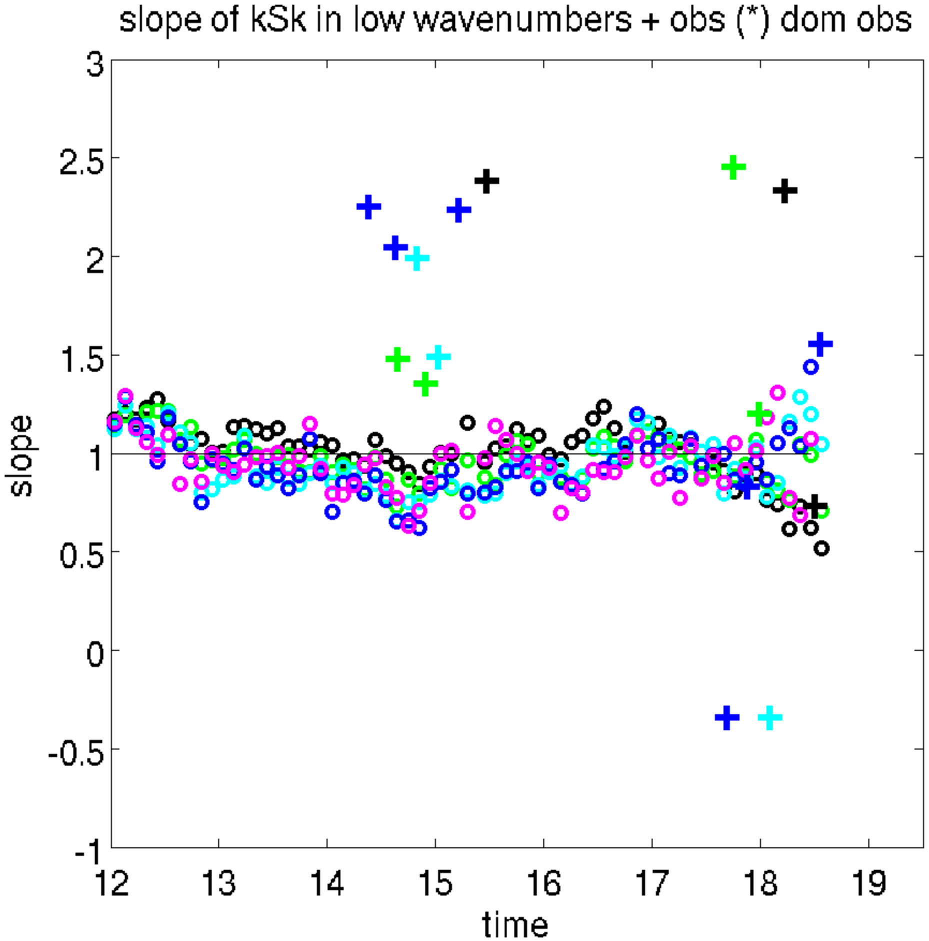
## II] How do the turbulent spectra evolve during the LAT?

- Results

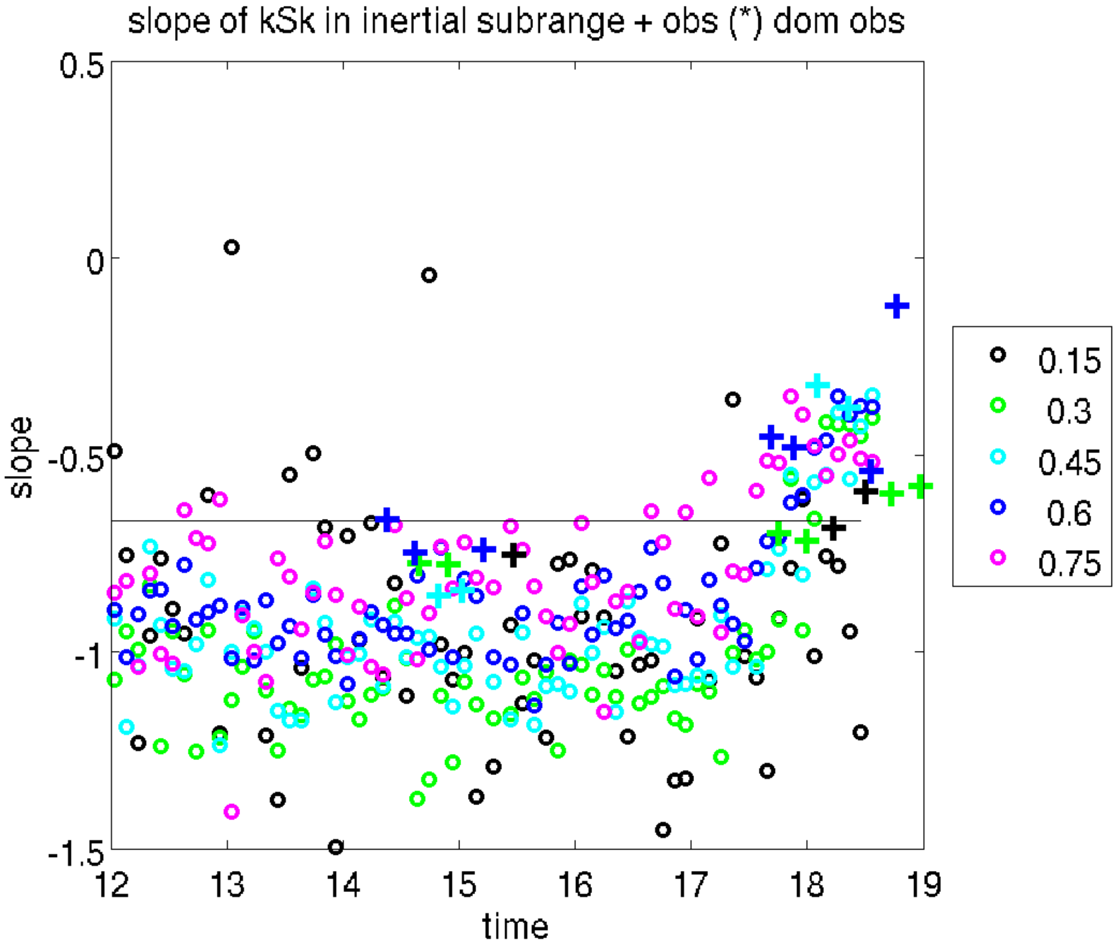
*LES for 20 June(o) + Obs of the 2 planes(+)*




### Evolution of the slopes in low wave numbers




### Evolution of the slopes in the inertial subrange



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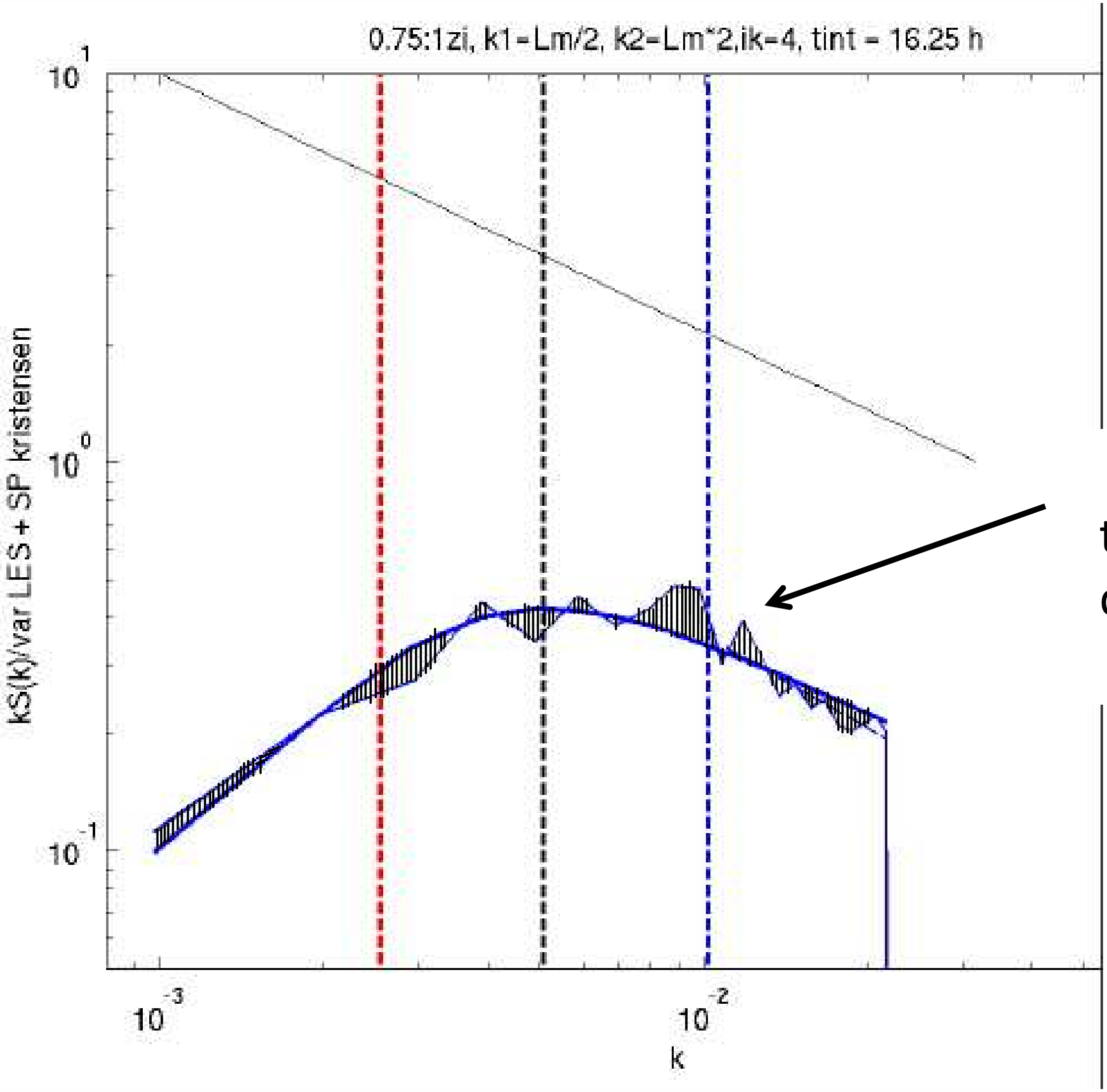
# Departure from the analytical model




Integral over k of the difference between the fit and the LES spectra in the three domains

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Boundary Layer Late Afternoon and Sunset Turbulence

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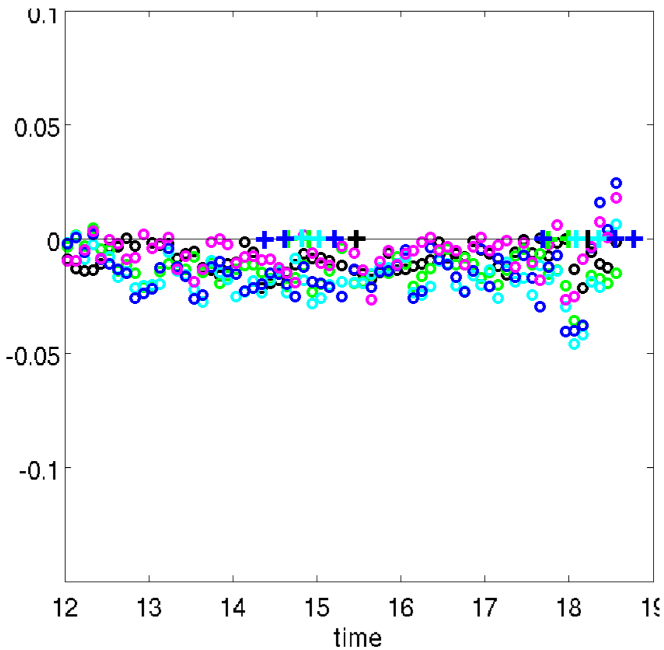
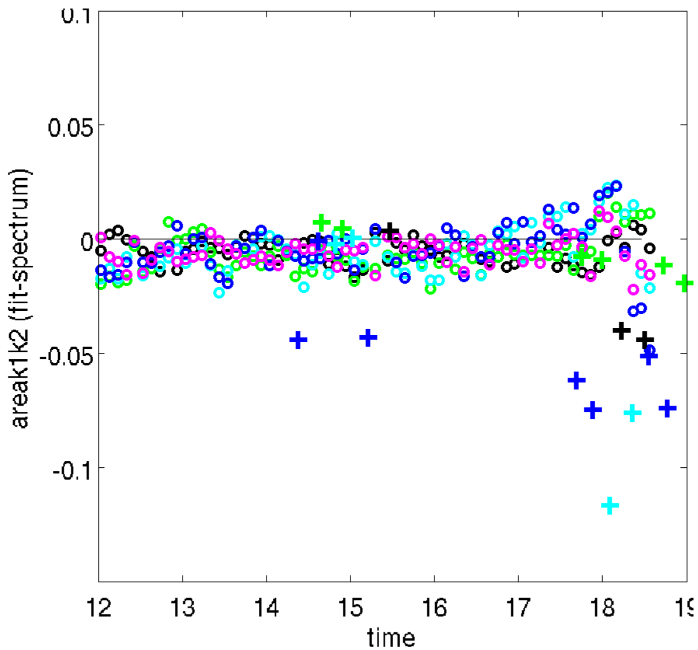
- Integral over k of the difference between the fit and the LES spectra in the three domains

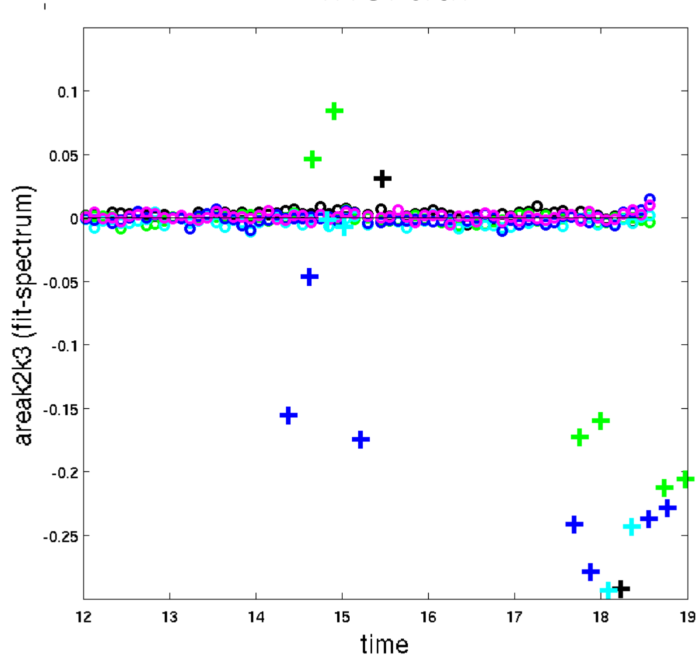
low




peak




inertial




- Integral over k of the squared difference between the fit and the LES spectra
- Integral over k of the difference between log(fit) and log(LES) spectra
- Integral over k of the squared difference between log(fit) and log(LES) spectra

Ongoing work …