Evolution of the turbulence during the afternoon transition of the convective boundary layer

Clara Darbieu[1], Fabienne Lohou[1], Marie Lothon[1], Jordi Vila-Guerau de Arellano[2], Fleur Couvreux[3], Pierre Durand[1], David Pino[4,5], Edward Patton[6], Erik Nilsson[1,7], Estel Blay-Carreras[4], and Beniamino Gioli[8]

(1) Laboratoire d'Aérologie, University of Toulouse – CNRS, France
(2) Wageningen University, Meteorological Air Quality group, The Netherlands
(3) CNRM-GAME (Météo-France and CNRS), Toulouse, France
(4) Universitat Politècnica de Catalunya, Spain, (5) Institute for Space Studies in Catalunya
(6) National Center for Atmospheric Research, USA
(7) Uppsala University, Uppsala, Sweden
(8) Institute of Biometeorology-National Research Council (IBIMET-CNR), Florance, Italy

Workshop Barcelona, February 2nd, 2015

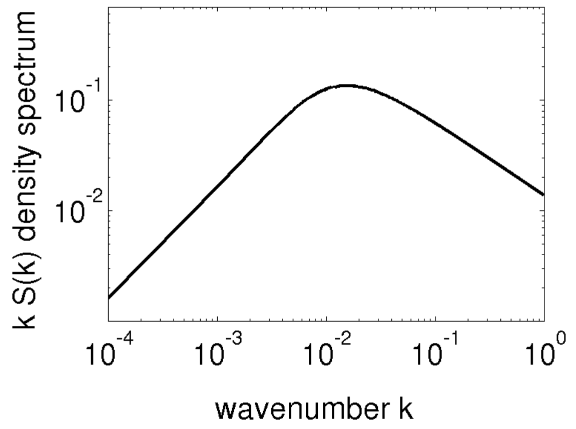
Structure of the presentation

1. **Summary of Darbieu et al. 2014**
   - Research strategy
   - Data set
   - Methodology
   - Summary of the results
2. **Confirmation/Invalidation of the assumptions**
   - Role of wind shear
   - Impact of entrainement & demixing process
   - Role of anisotropy
   - Coherent structures

Motivation and research strategy

- How do the turbulence characteristics vary in time and height?
- How does an idealized LES ?

Back to the
w spectra



Observations
& LES

BLLAST Campaign
&
NCAR LES code

Data used

BLLAST Campaign provides:

➢Turbulence observations along the afternoon

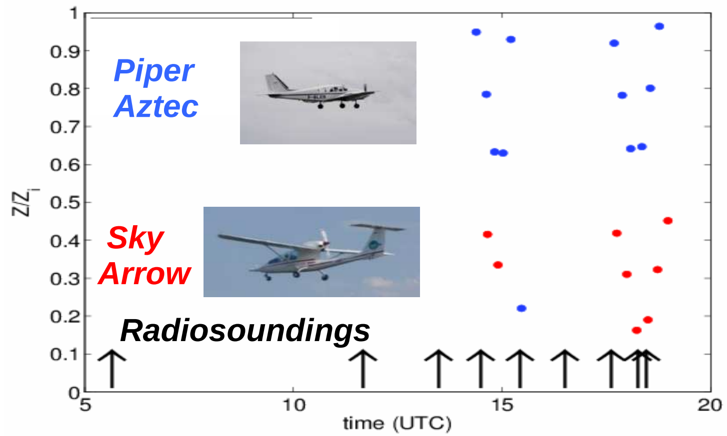
➢Conditions for an ideal case simulation

Large eddy simulation of an ideal case provides:

➢Complete vertical and temporal evolution of turbulence

➢An access to physical processes too complex to be observed

Vertical and temporal data coverage on 20 June 2011



+Surface energy balance stations

NCAR LES code

(Moeng, 1984, 1986 / Sullivan et al., 1996 / Patton et al., 2005)

•Case: 20 June 2011 of BLLAST campaign

•Domain: 10 km x 10 km x 3 km Resolution: $\Delta x = \Delta y = 40$ m and $\Delta z = 12$ m

•Prescribed initial profiles and surface flux based on most representative surface

•'Simple' wind profile

•Prescribed total advection (AROME)

→Similar thermal structure obtained

→1.5 times less TKE in LES

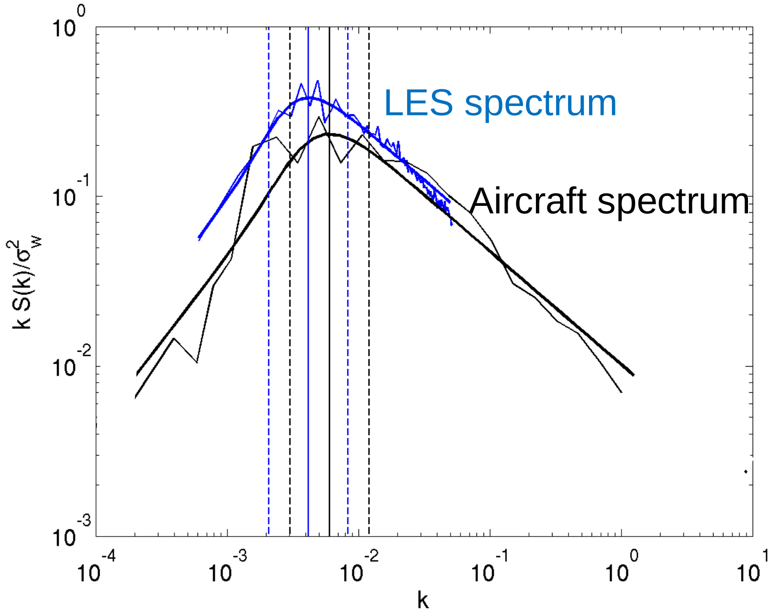
→Lower zi (850 m VS 1100 m)

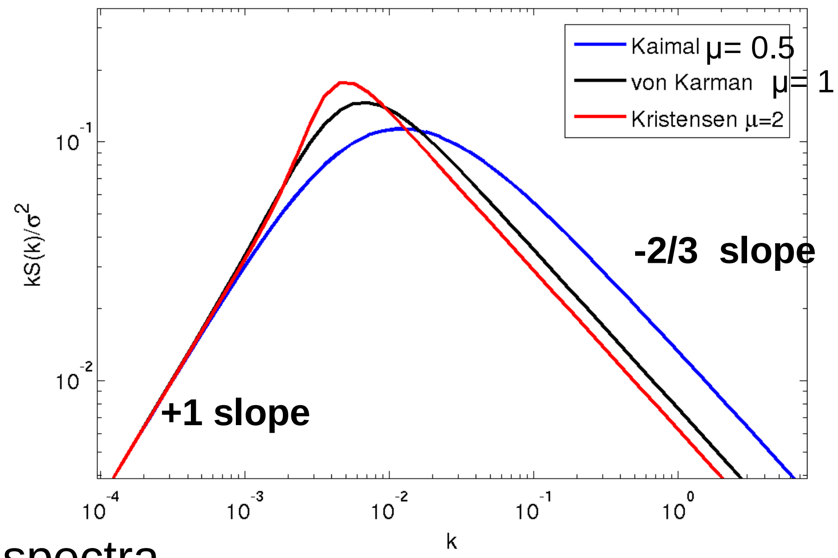
Methodology: Spectral analytical model

Kristensen et al. 1989 : A generalized kinematic spectral model *for anisotropic horizontally homogeneous turbulence*

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

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





➢ μ and l_w fit to simulated & observed spectra

Results of Darbieu et al. 2014

- LES ability to reproduce the turbulence evolution

Results of Darbieu et al. 2014

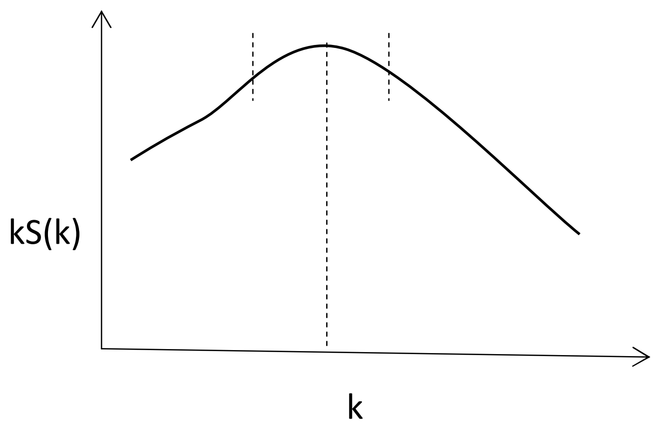
- The AT can be divided into two phases: the « Early Afternoon » and the « Late Afternoon »

Results of Darbieu et al. 2014

Altitude

Early Afternoon

- TKE decays with a slow rate
- No significant change in the turbulence characteristics
- It's a long quasi-stationnary period



0 (BF_{max}) 0.75 τ_f 1 τ_f (BF=0)

Results of Darbieu et al. 2014

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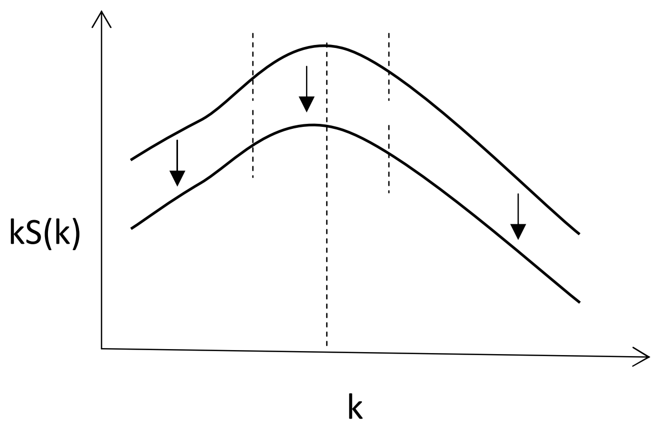

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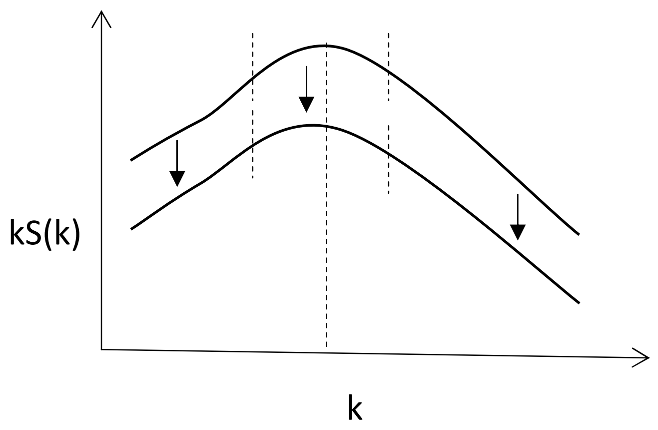
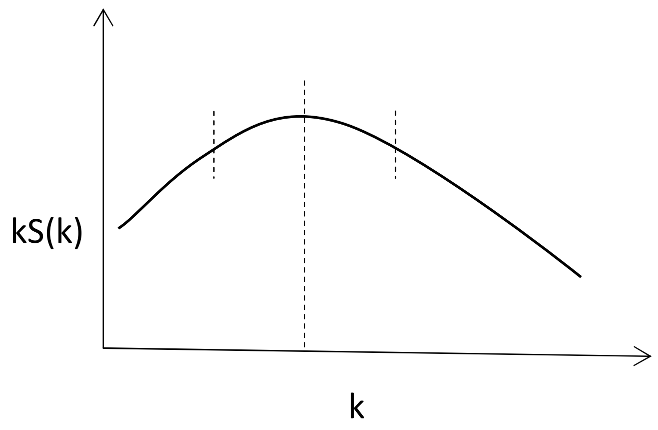
Late Afternoon

- Larger TKE decay
- Change of the spectra shape





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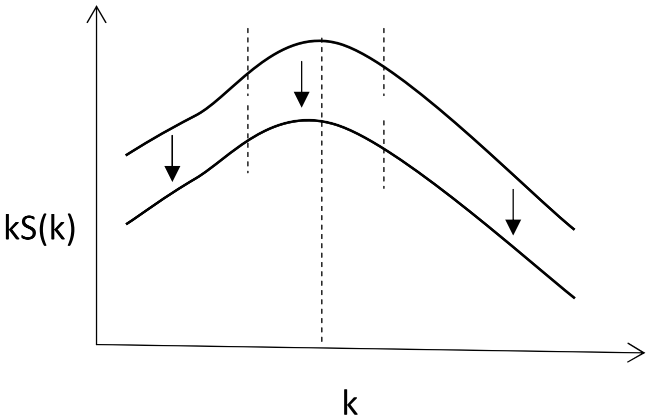
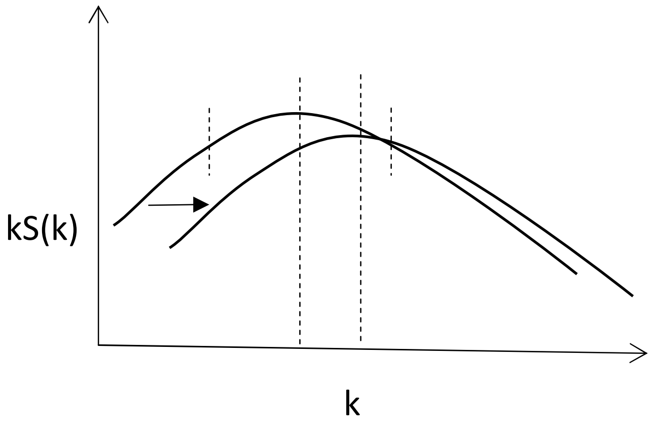


Late Afternoon

- Larger TKE decay
- Change of the spectra shape
  - At surface: Kaimal spectrum, decrease of the integral lengthscales



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Results of Darbieu et al. 2014

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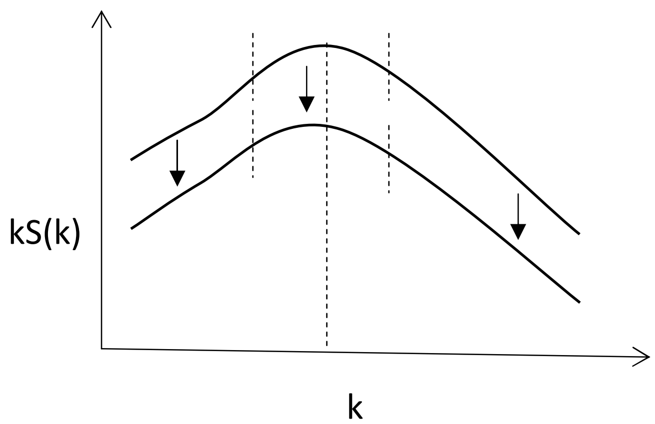
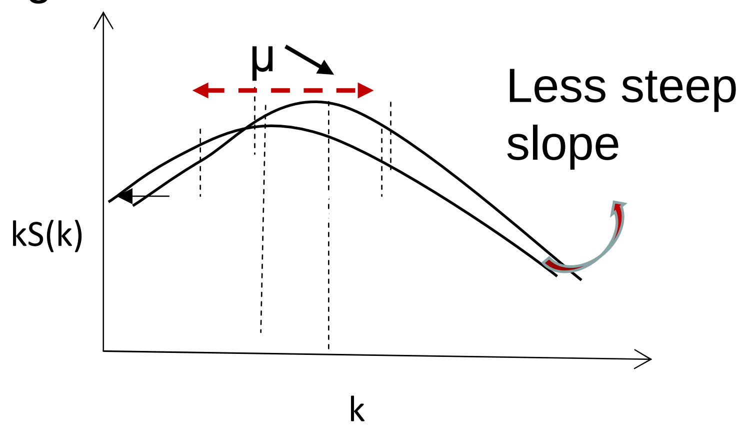


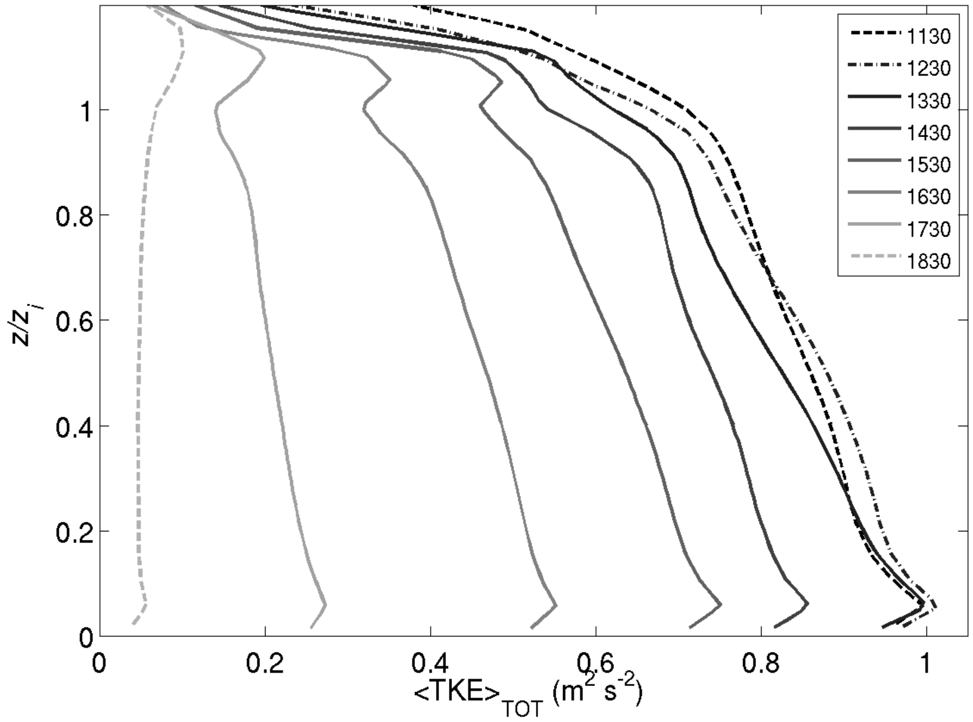
Late Afternoon

- Larger TKE decay
- Change of the spectra shape
  - At surface: Kaimal spectrum, decrease of the integral lengthscales
  - Above surface: flattening of the spectra, increase of the integral lengthscales



0   0.75 τ_f 1 τ_f

Results of Darbieu et al. 2014



- ➢ The changes occur first in the upper region of the PBL.
- ➢ The higher within the PBL, the stronger the spectra shape changes.

Results of Darbieu et al. 2014

Altitude

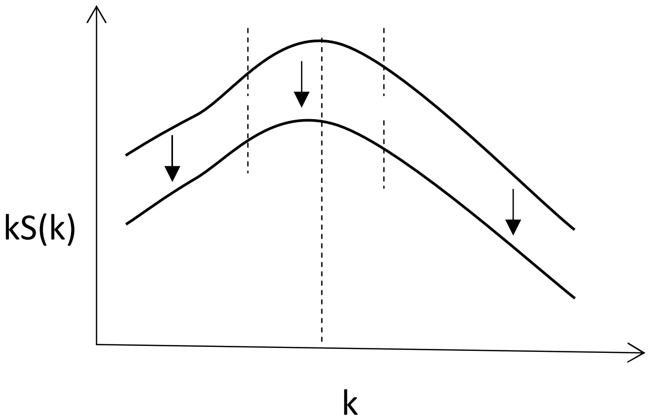
Early Afternoon

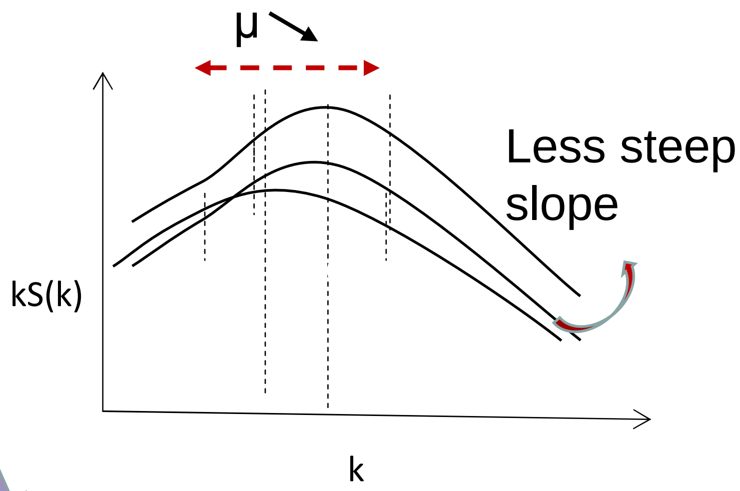
Late Afternoon

- TKE decays with a slow rate
- No significant change in the turbulence characteristics

- Larger TKE decay
- Change of the spectra shape

- The changes occur first in the upper region of the PBL.
- The higher within the PBL, the stronger the spectra shape changes.

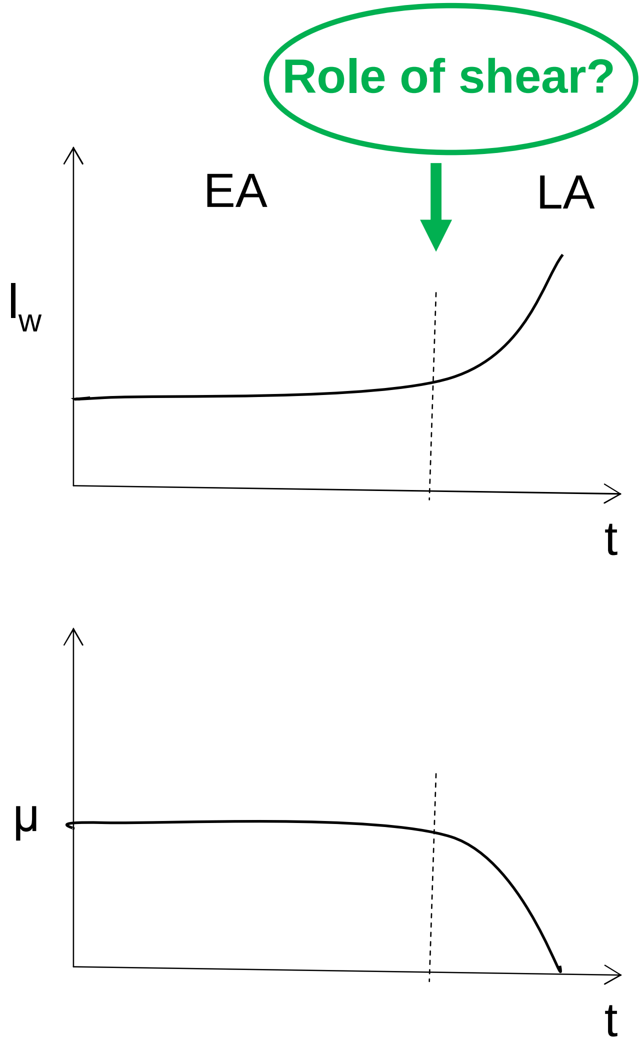


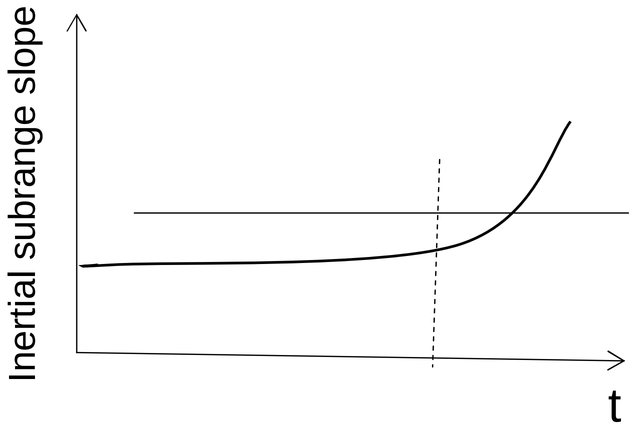


0   0.75 τ_f 1 τ_f

Hypothesis to explain the results

H1: How does wind shear impact on the proceedings of the two phases?

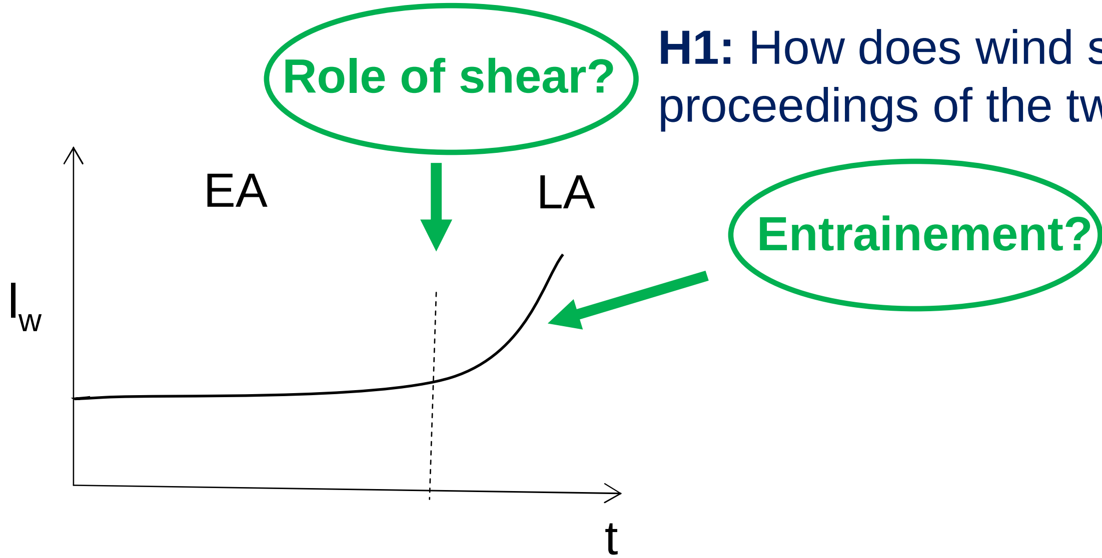


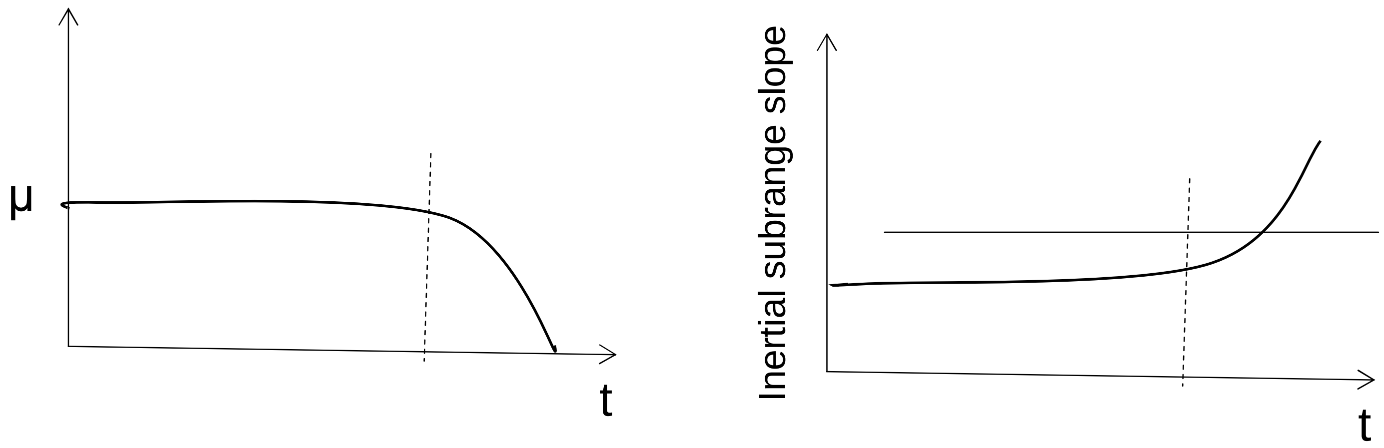


Hypothesis to explain the results

H1: How does wind shear impact on the proceedings of the two phases?

H2: The entrainement and the demixing process could explain the increase of the integral lengthscales during the LA



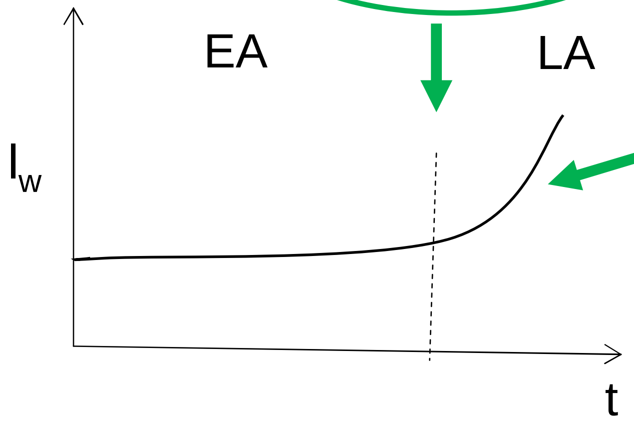


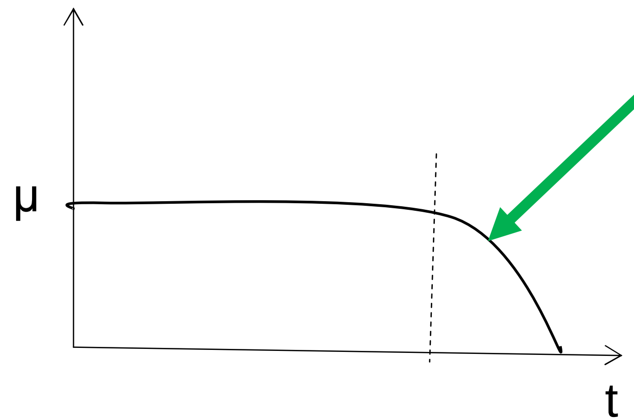
Hypothesis to explain the results

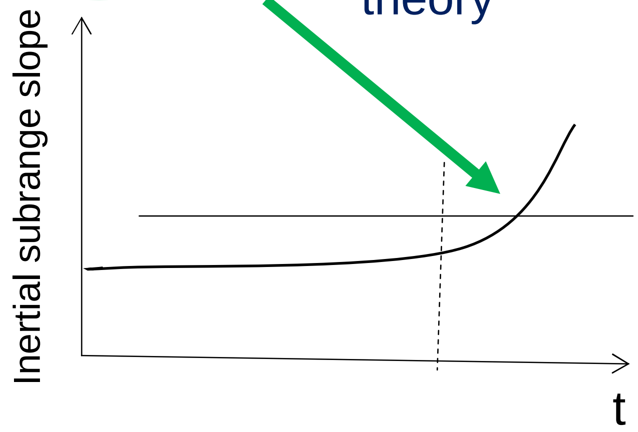
H1: How does wind shear impact on the proceedings of the two phases?

H2: The entrainement and the demixing process could explain the increase of the integral lengthscales during the LA

H3: Anisotropy could modify the spectral characteristics from what is predicted by the theory







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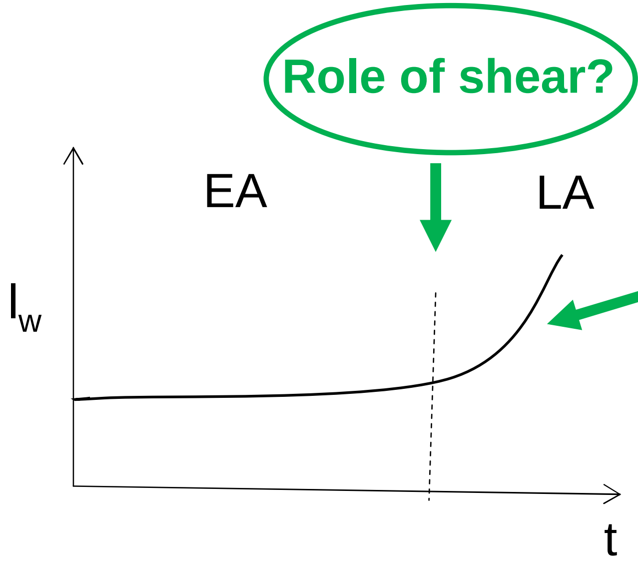

H2: The entrainement and the demixing process could explain the increase of the integral lengthscales during the LA

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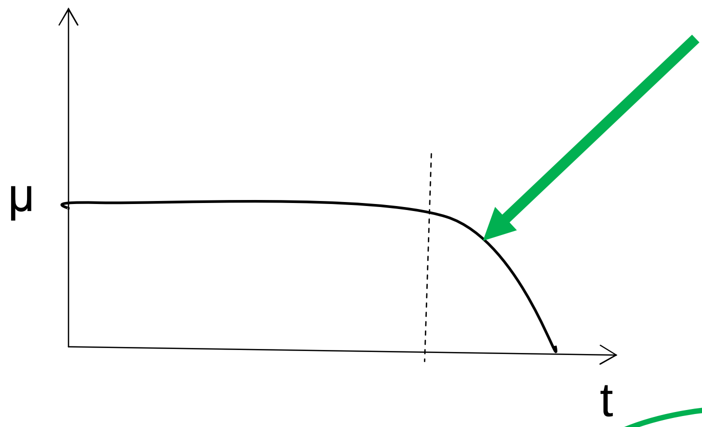
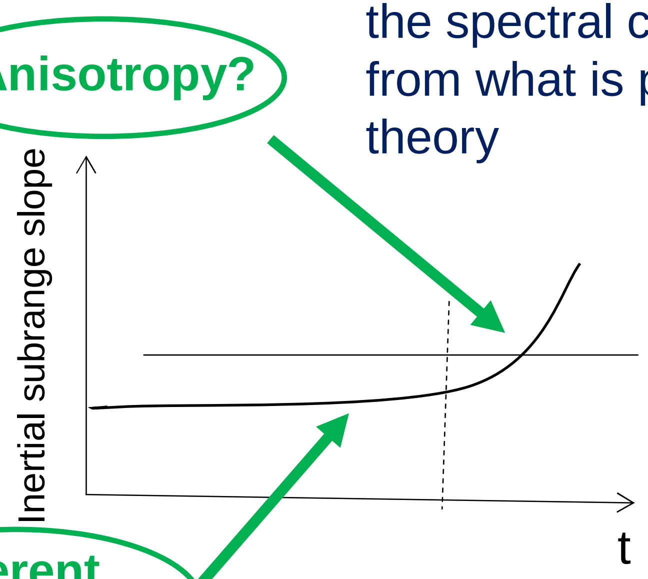
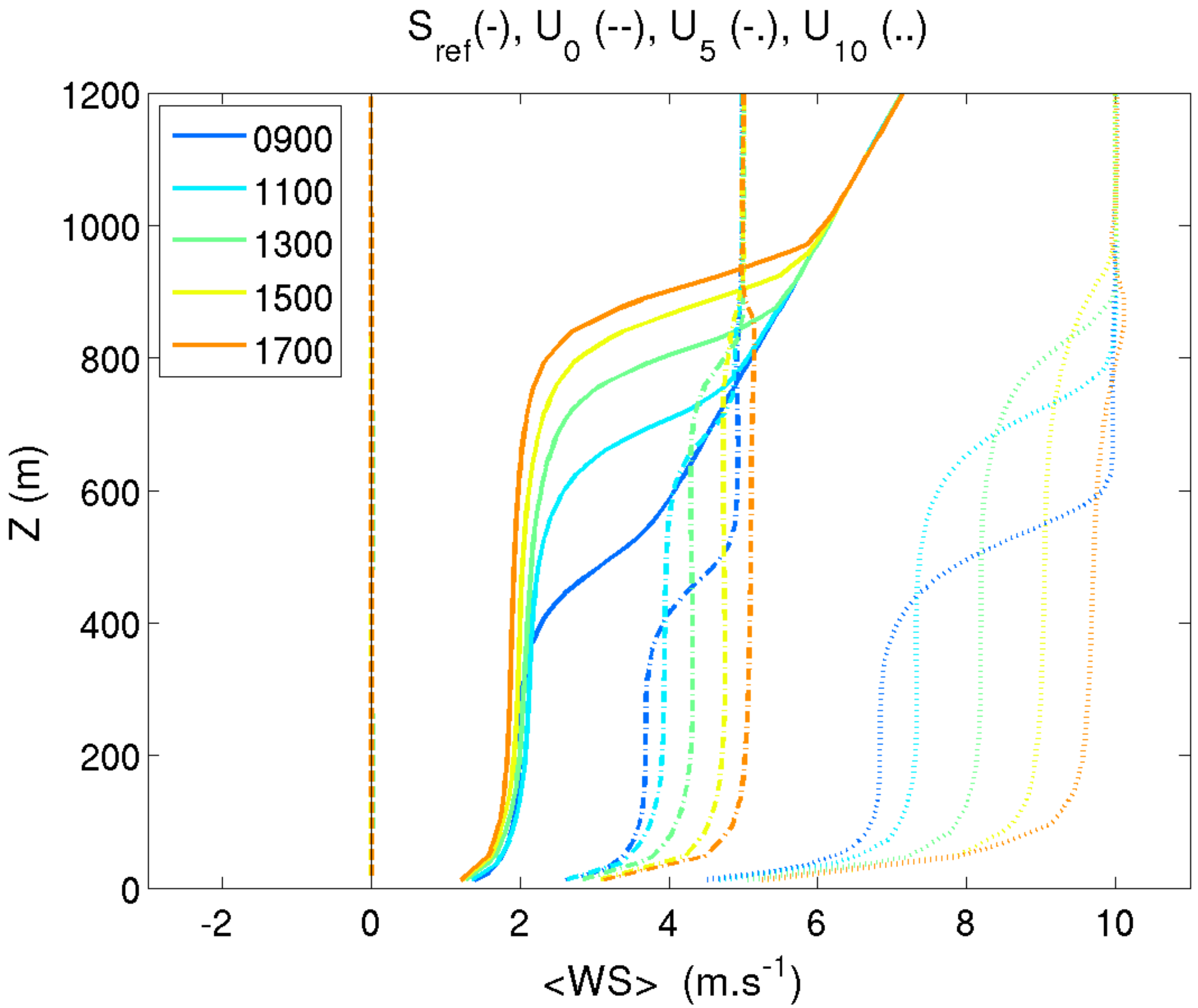




H4: Coherent structures are suspected to modify the spectra

H1: How does wind shear impact on the proceedings of the two phases?

- New set of simulations



H1: How does wind shear impact on the proceedings of the two phases?

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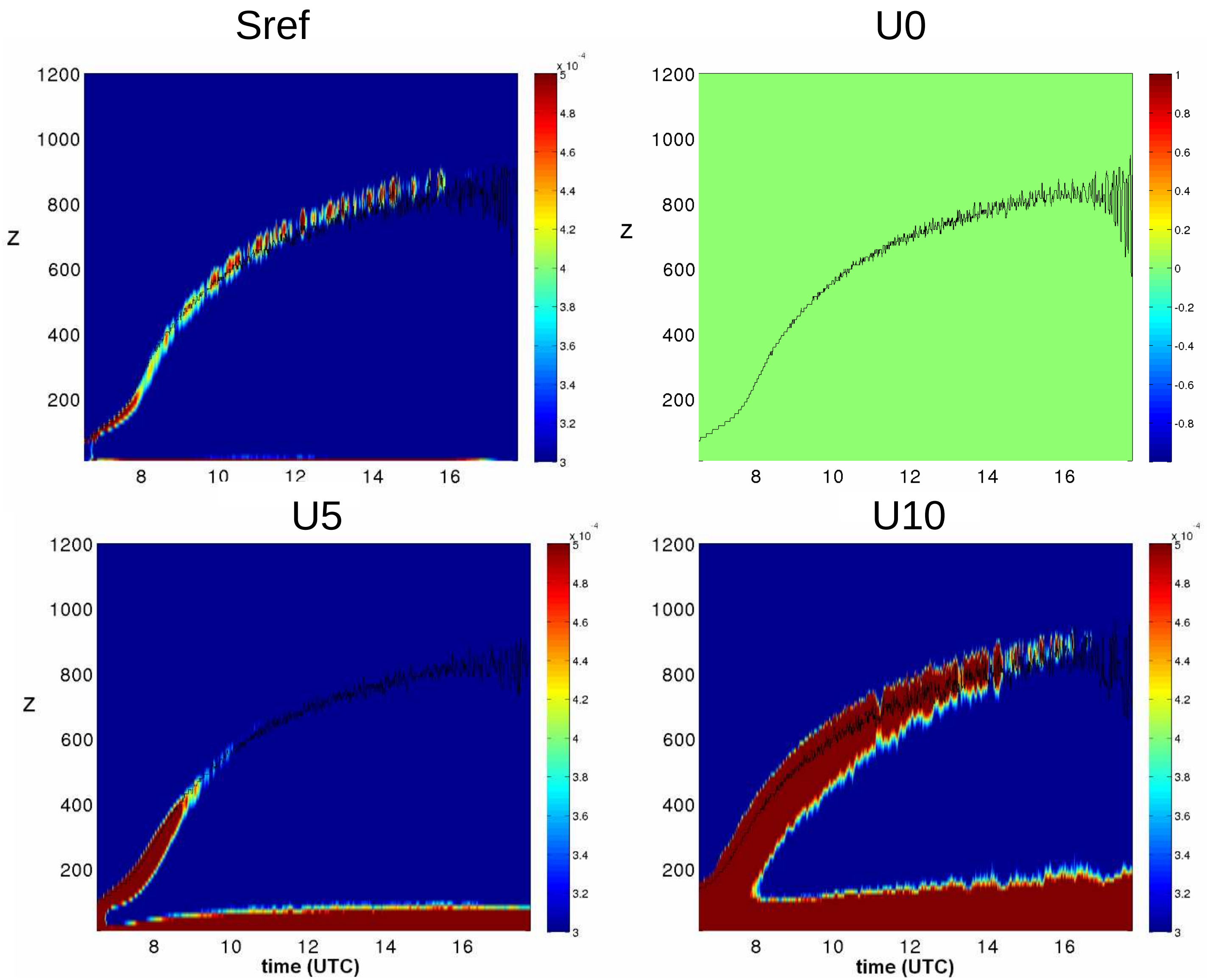
Dynamical production term



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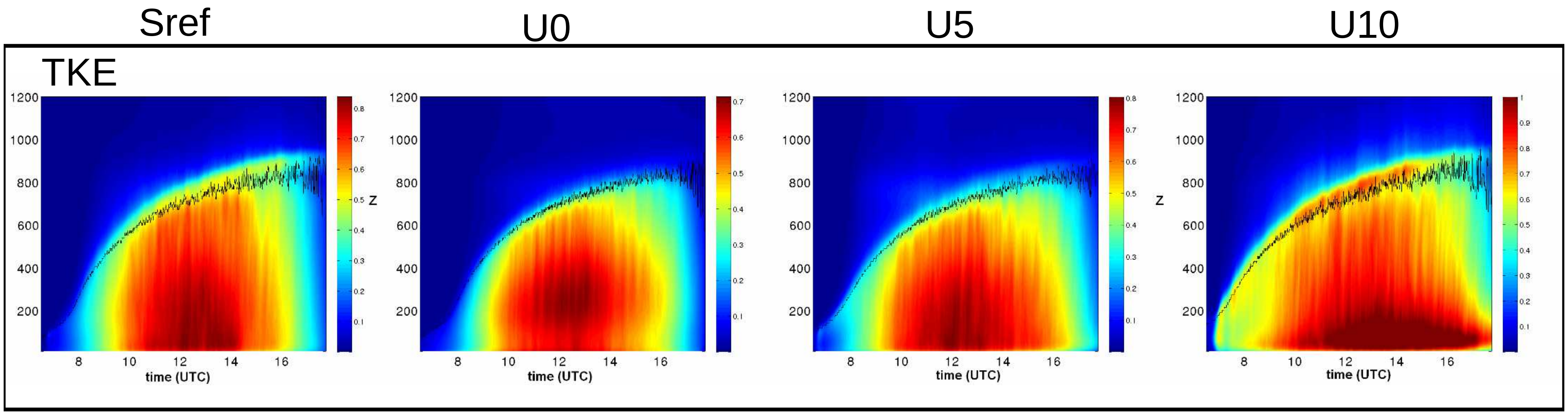

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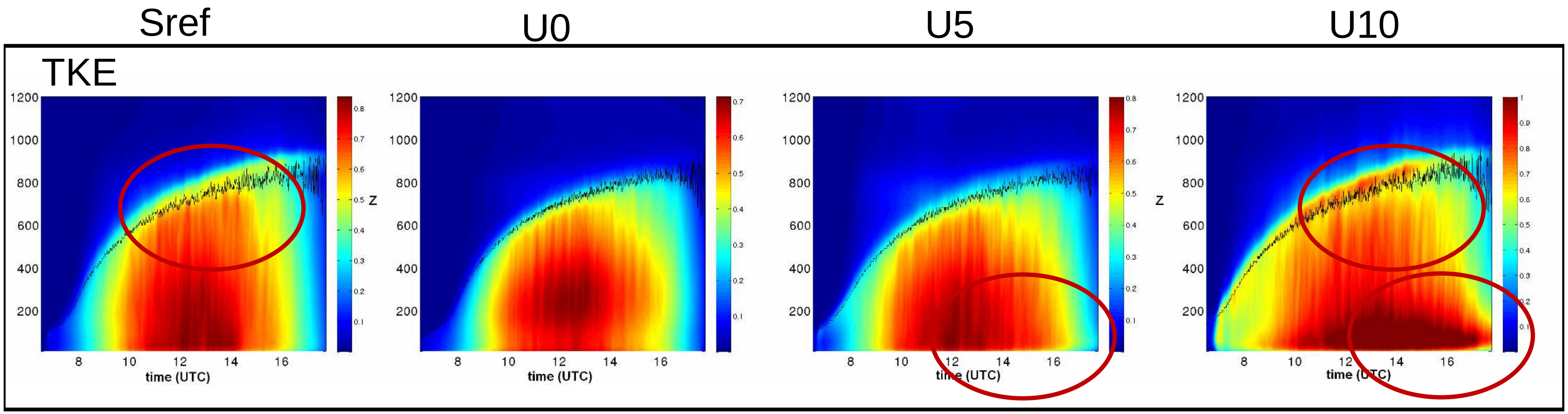
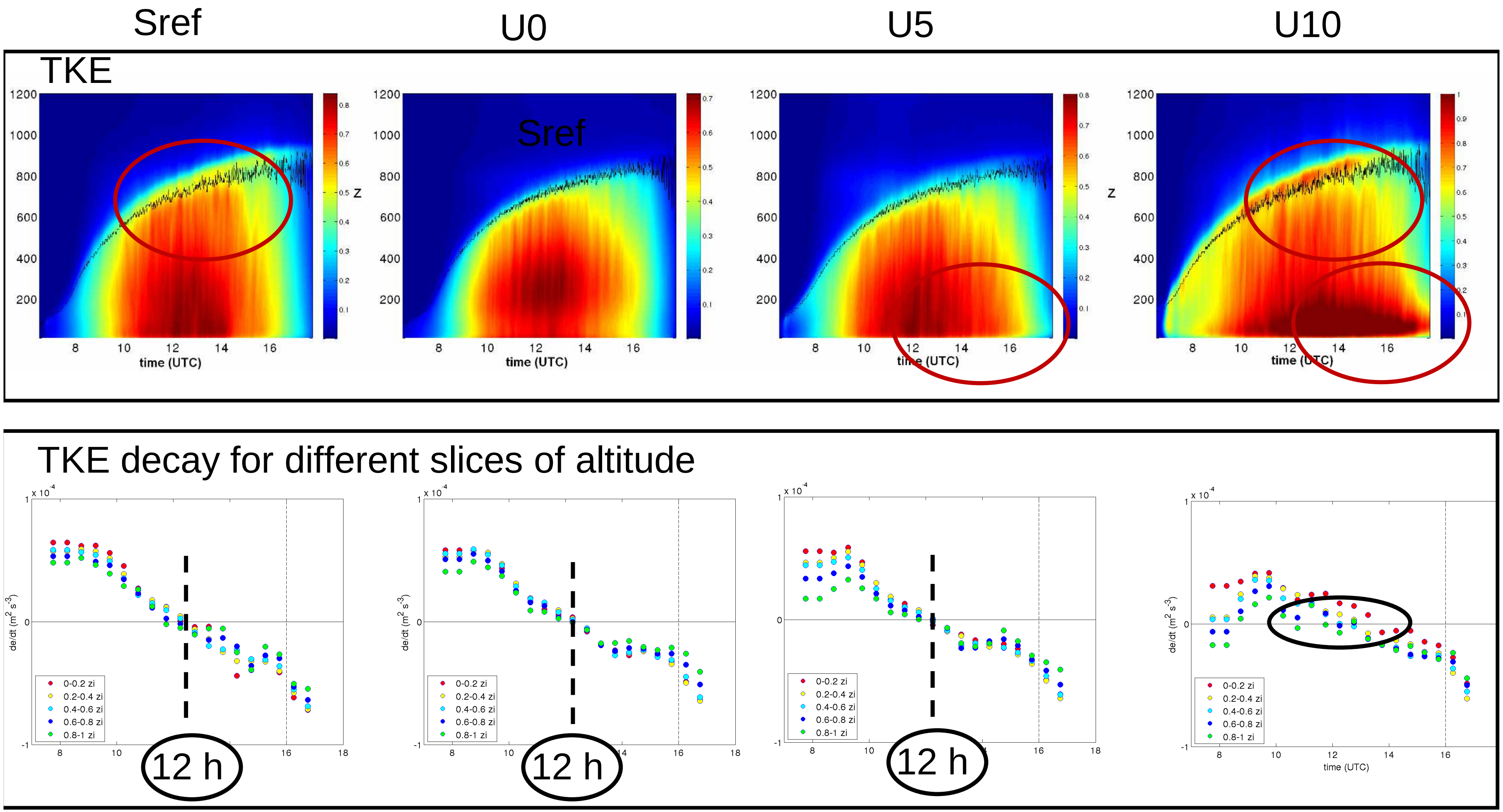


- **TKE maintained in case of wind shear**

H1: How does wind shear impact on the proceedings of the two phases?



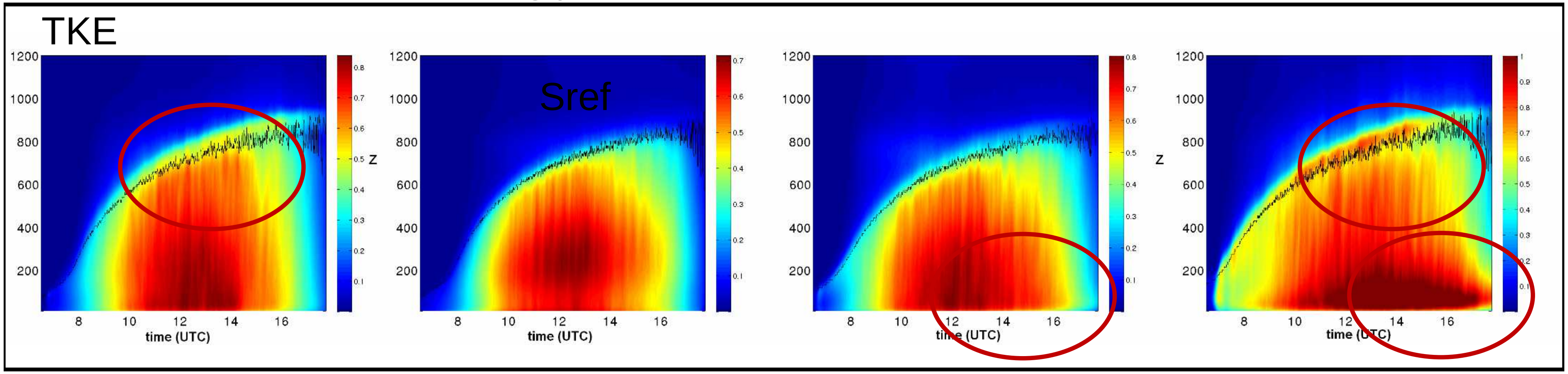
➢ **Wind shear delays the decay of TKE and maintains the TKE**

H1: How does wind shear impact on the proceedings of the two phases?

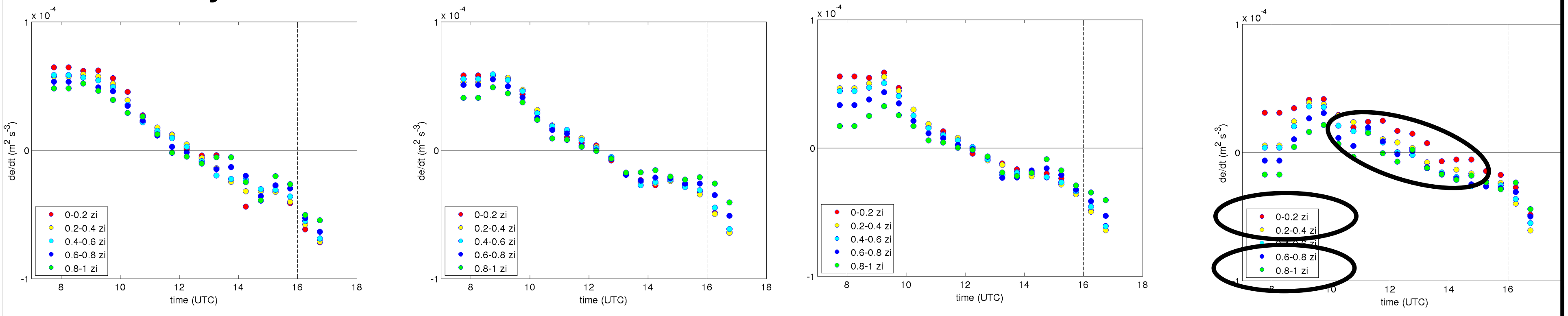
Boundary Layer Late Afternoon and Sunset Turbulence

Sref U0 U5 U10

TKE



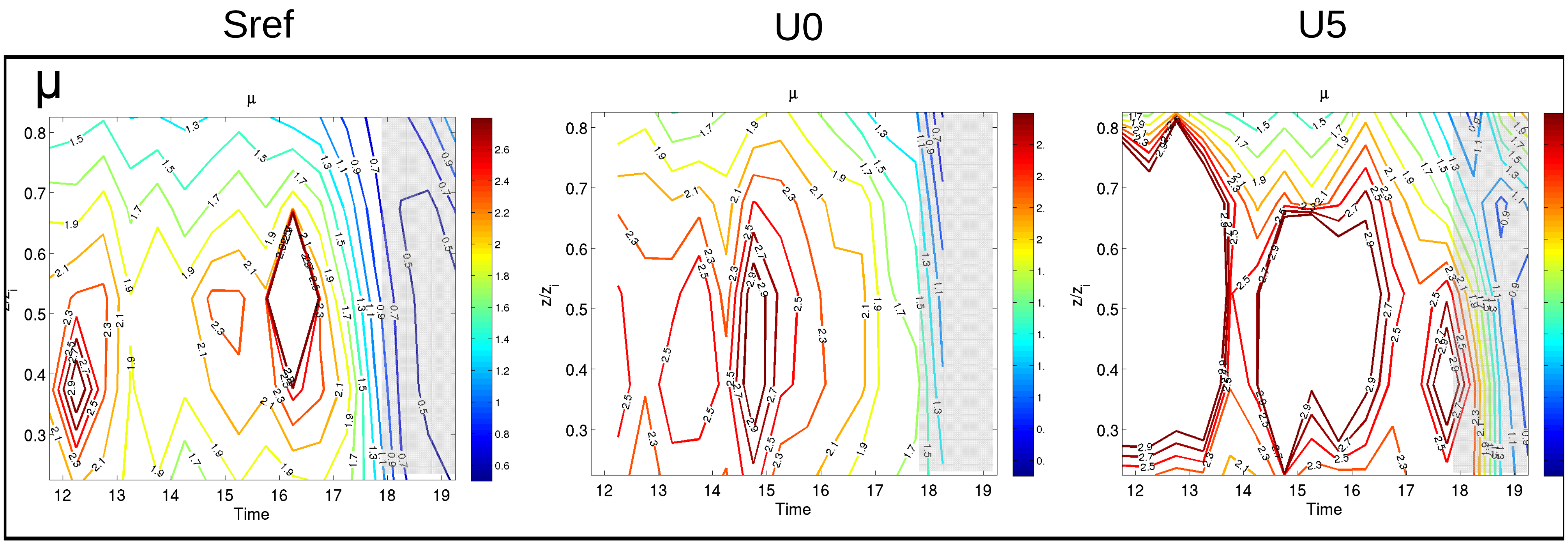
TKE decay for different slices of altitude



- **Wind shear delays the decay of TKE and maintains the TKE**
- **Smaller TKE decay in the zones of mechanical production**

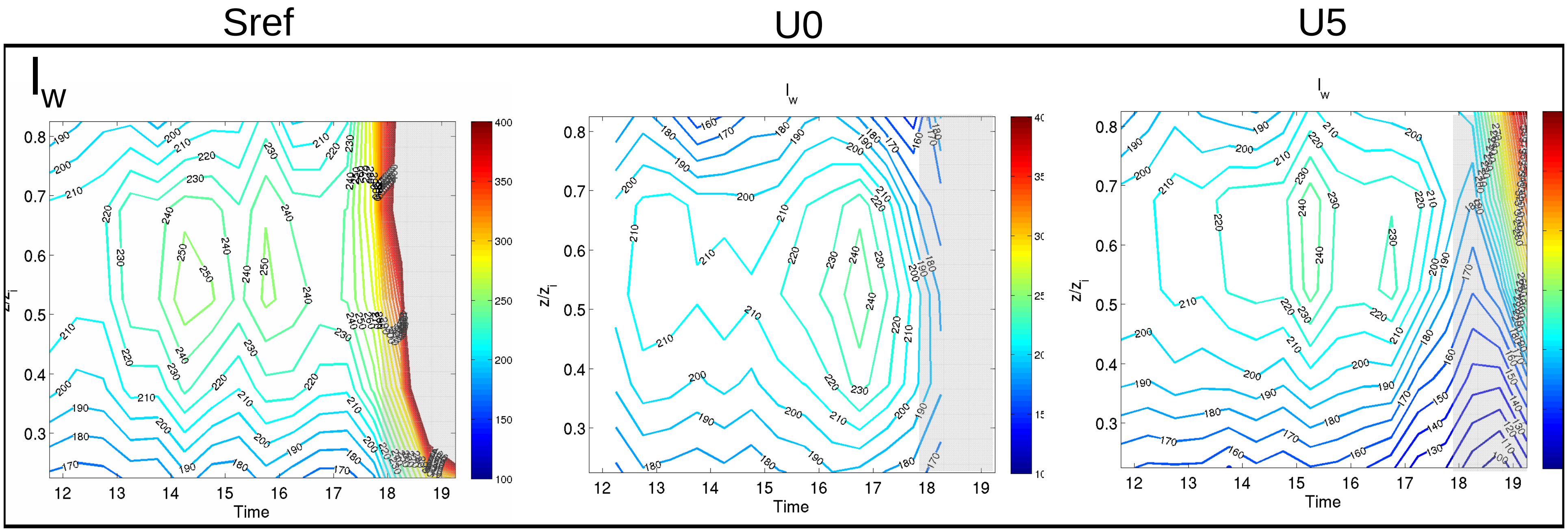
H1: How does wind shear impact on the proceedings of the two phases?

- Sref: μ maintained until 1700 UTC
- U0: μ decreases everywhere from 1500 UTC
- U5: μ decreases earlier at the top of the PBL (no wind shear)



H1: How does wind shear impact on the proceedings of the two phases?

- Sref: increase of l_w at the top of the PBL
- U0: l_w constant
- U5: l_w constant at the top of the PBL, decreases in the lower layers



H1: How does wind shear impact on the proceedings of the two phases?

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- Sref: increase of l_w at the top of the PBL
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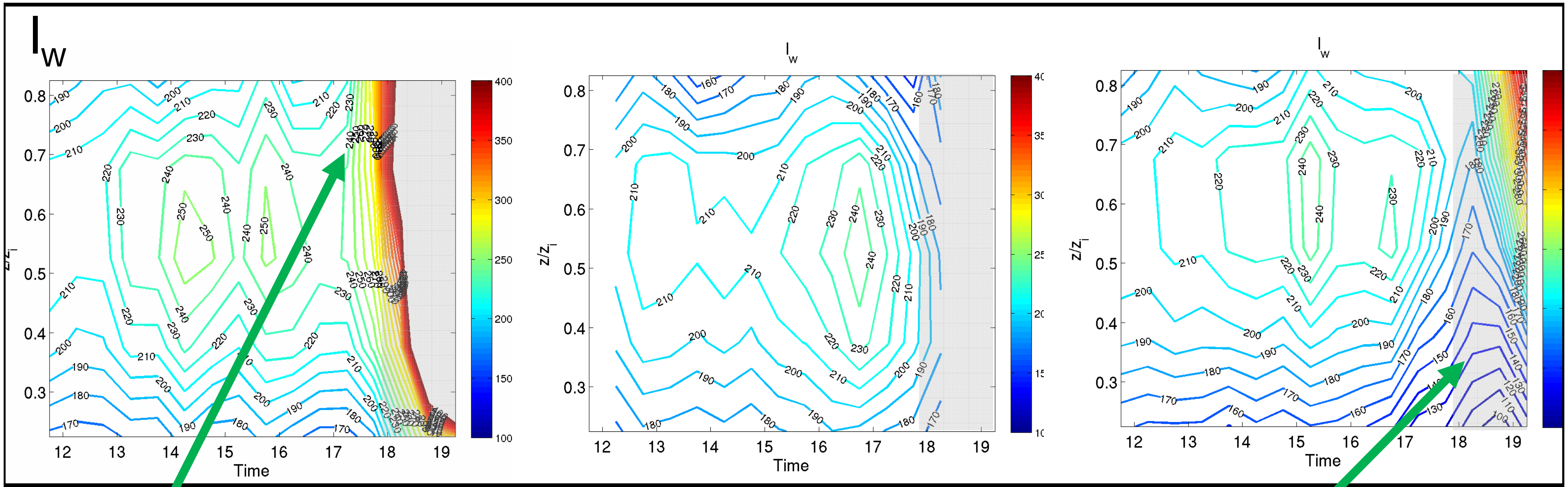
Sref U0 U5

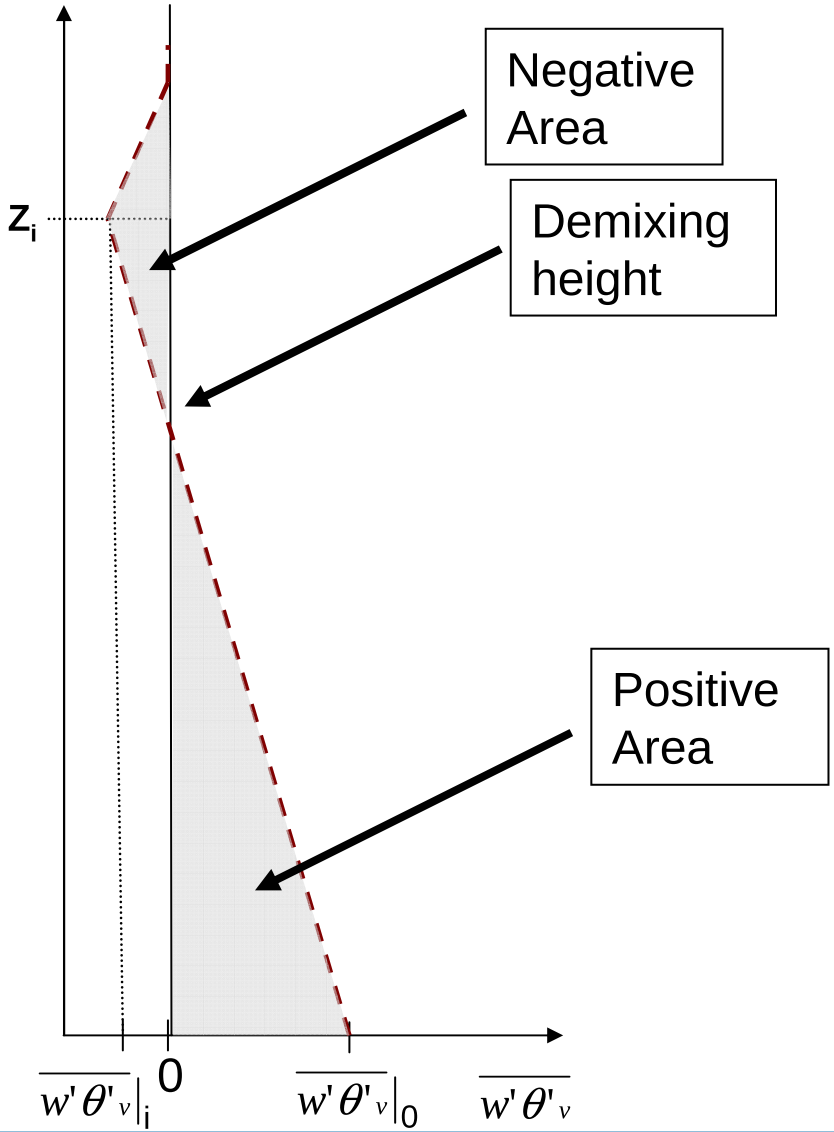


Wind shear at the top of the PBL seems to increase the entrainement process

Wind shear at surface creates turbulent eddies and reduce the influence of entrainement

H2: Does an increase of the entrainement process induce an increase of lengthscales ?

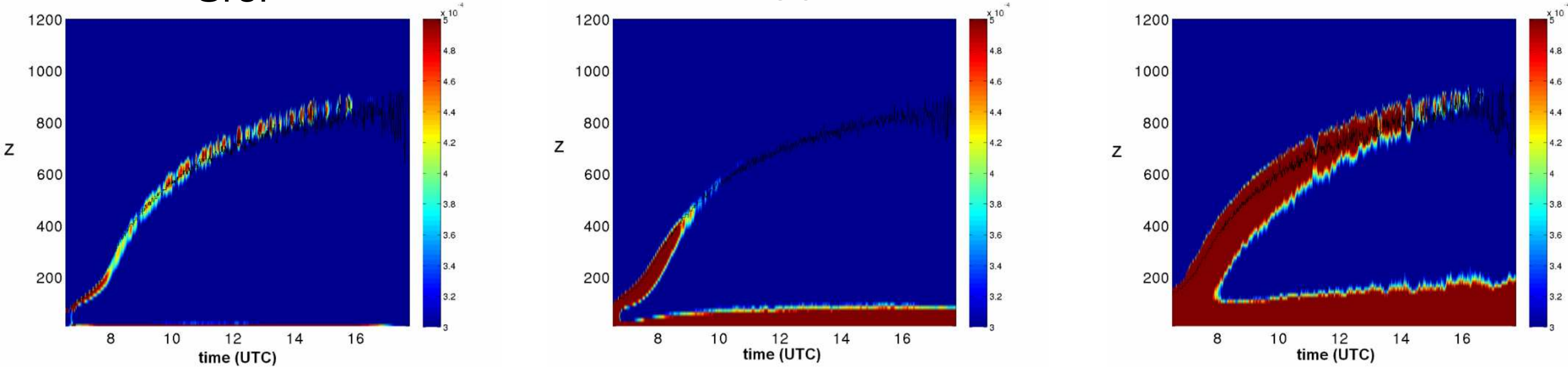
$$B = \frac{\overline{w'\theta'_v}|_i}{\overline{w'\theta'_v}|_0}$$

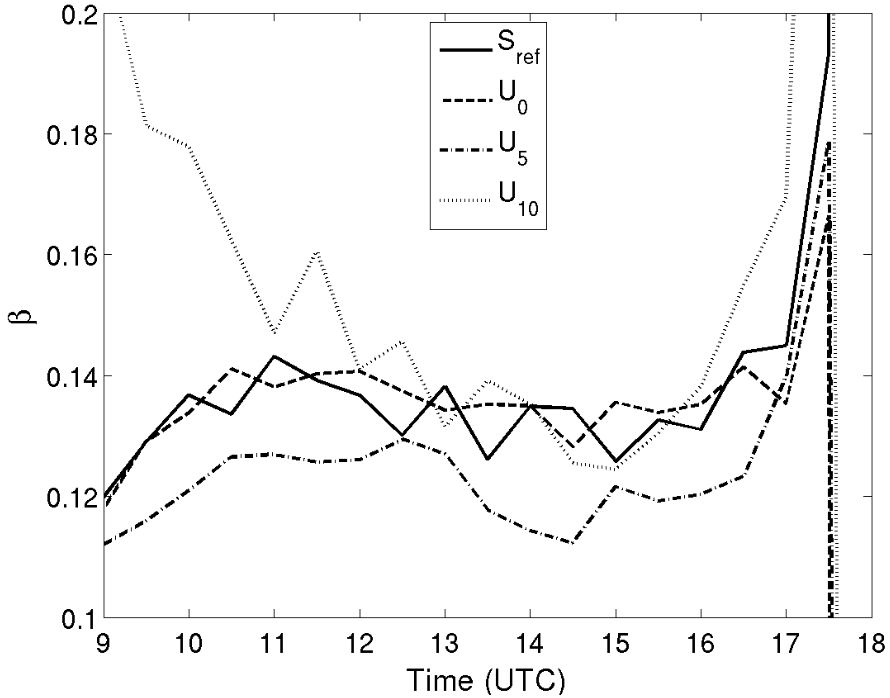


H2: Does an increase of the entrainement process induce an increase of lengthscales ?

Boundary Layer Late Afternoon and Sunset Turbulence

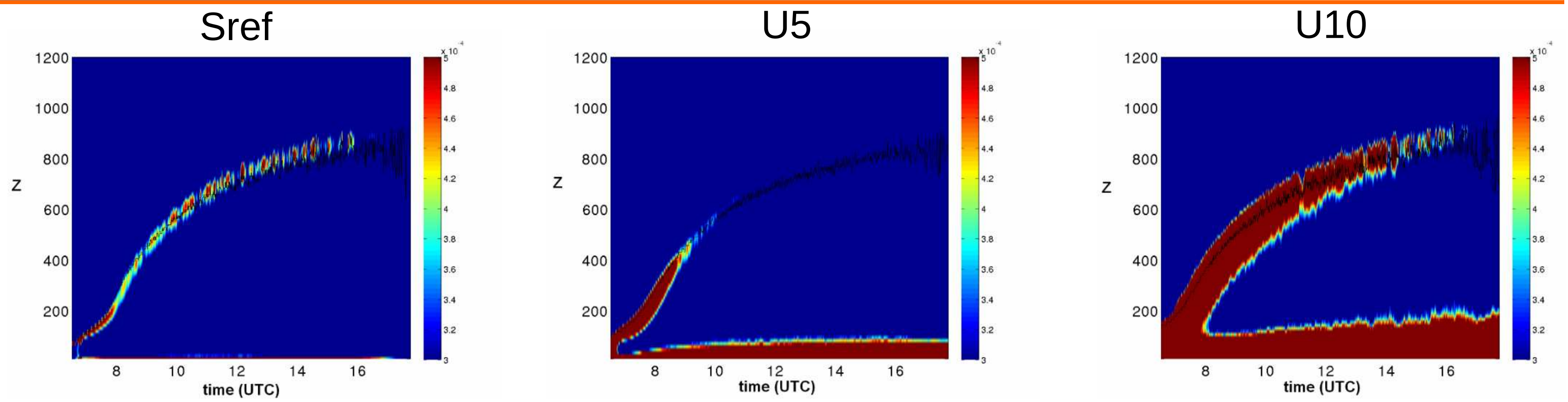
Sref U5 U10



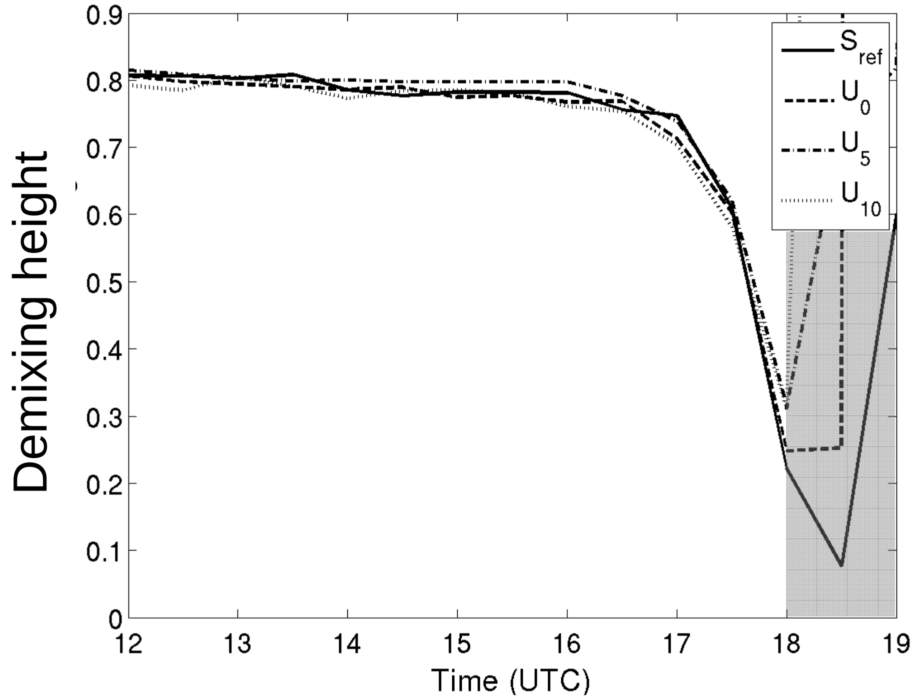


- Beta very similar (0.14)
- U10 a bit larger in the morning
- U5 a bit smaller

H2: Does an increase of the entrainement process induce an increase of lengthscales ?

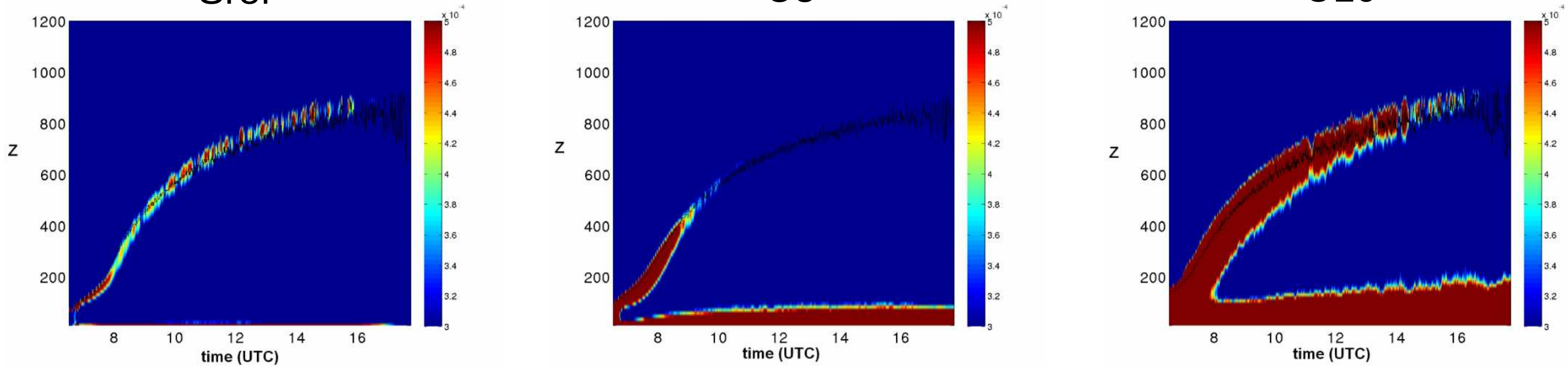


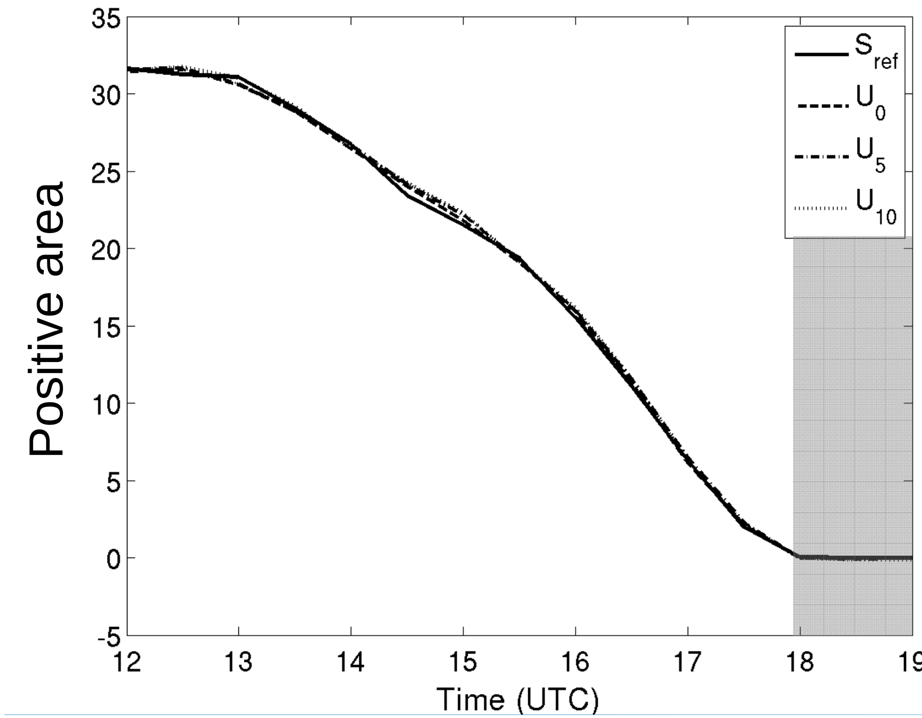
➢ The height at which the buoyancy flux is cancelling is very similar

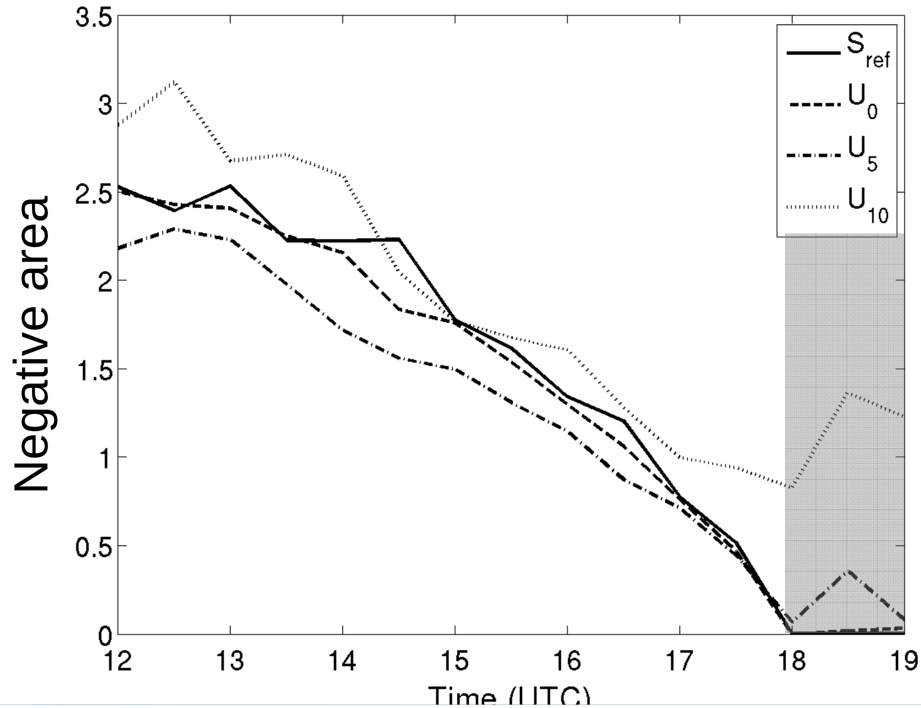


H2: Does an increase of the entrainement process induce an increase of lengthscales ?

Sref U5 U10

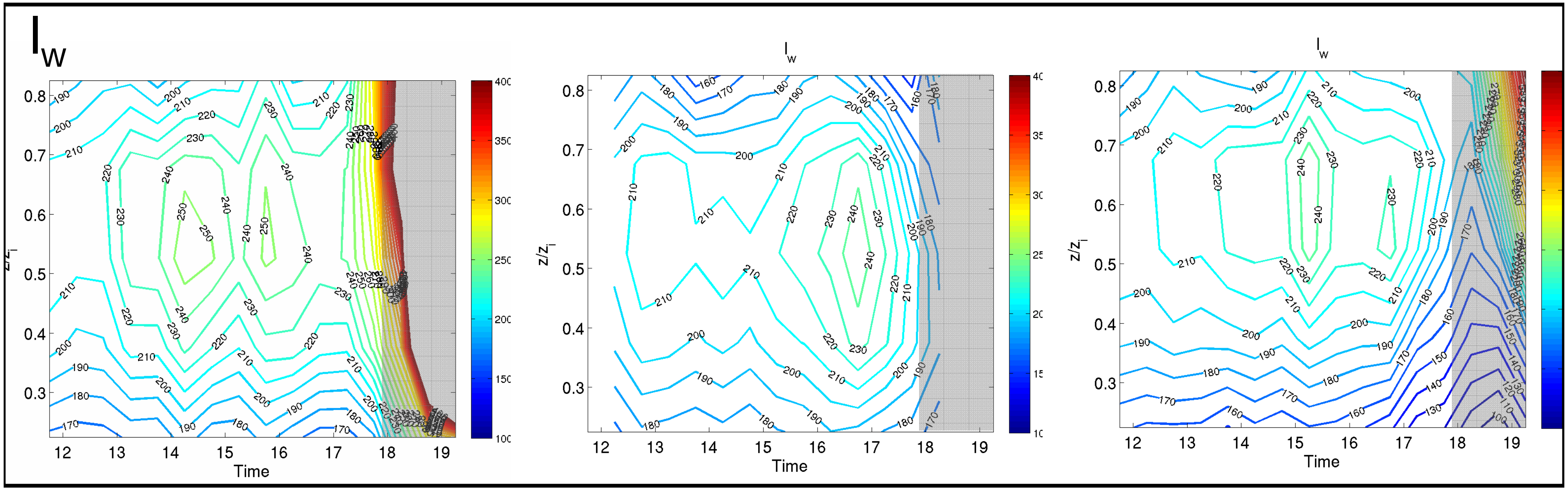






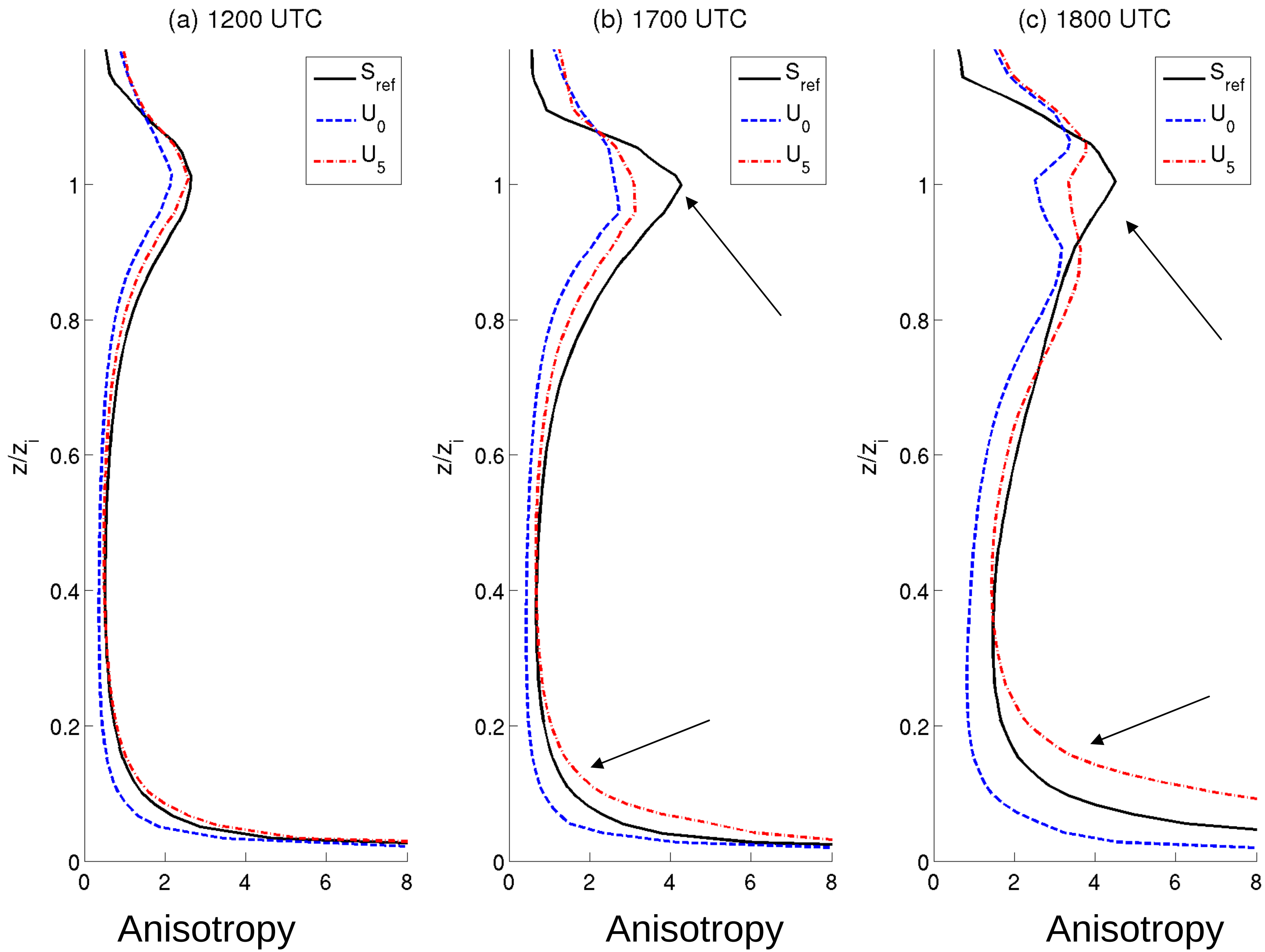
H2: Does an increase of the entrainement process induce an an increase of lengthscales ?

Sref U0 U5



- Sref: According to l_w, the increase seems to propagate towards surface.
- The entrainement process might not be highlithed by studying buoyancy only.

H3: Could anisotropy modify the spectral characteristics?

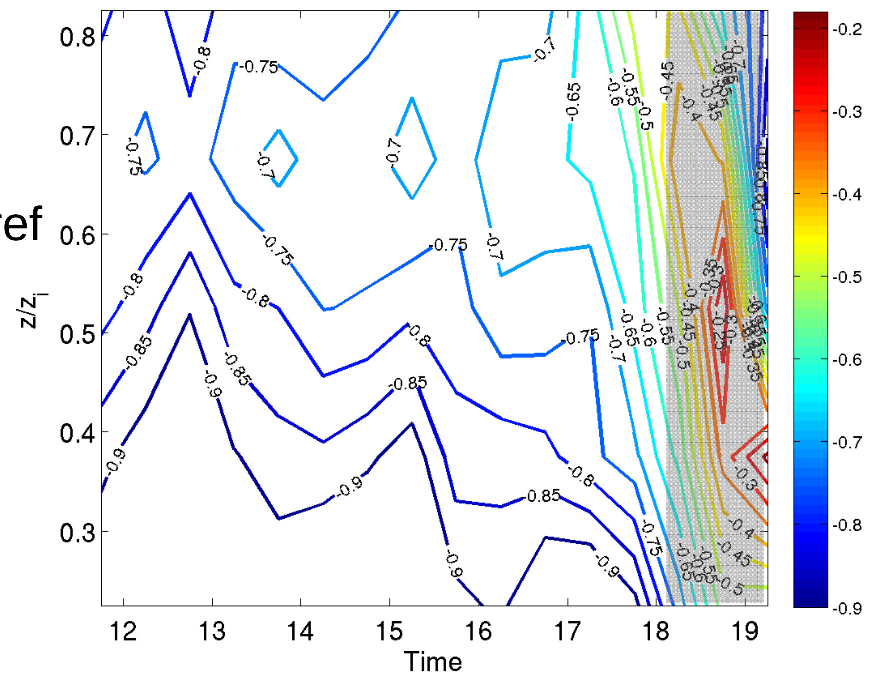


H3: Could anisotropy modify the spectral characteristics?

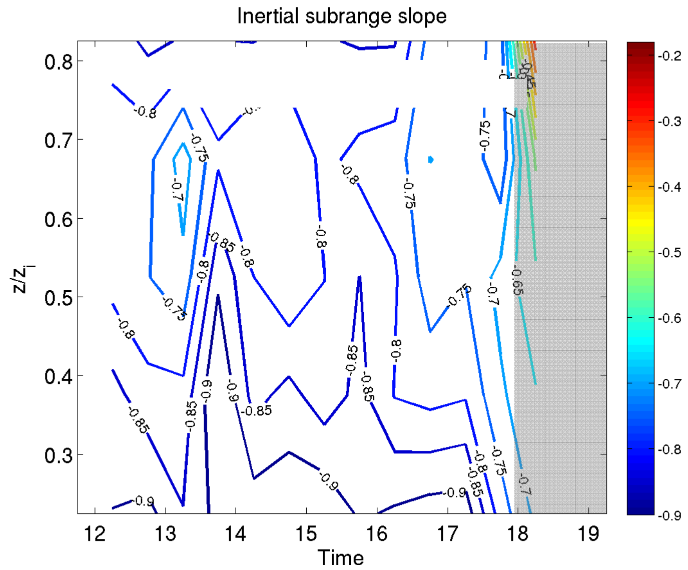
Boundary Layer Late Afternoon and Sunset Turbulence

Inertial subrange slope

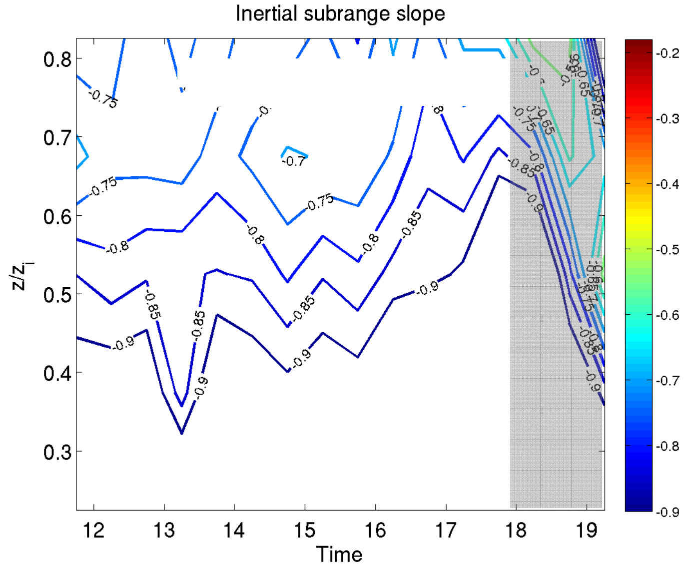
Sref



U0



U5



H3: Could anisotropy modify the spectral characteristics?

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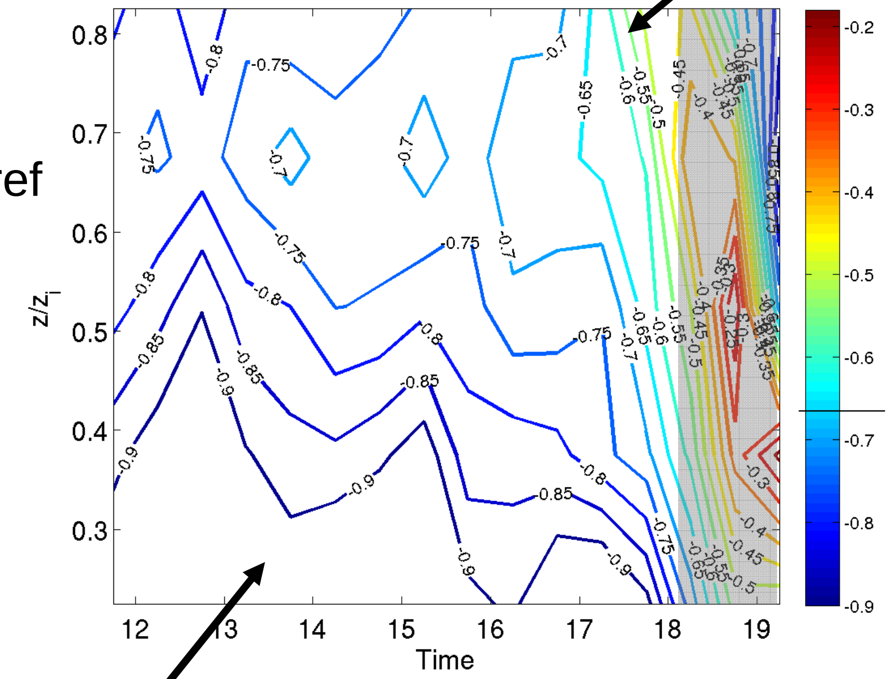
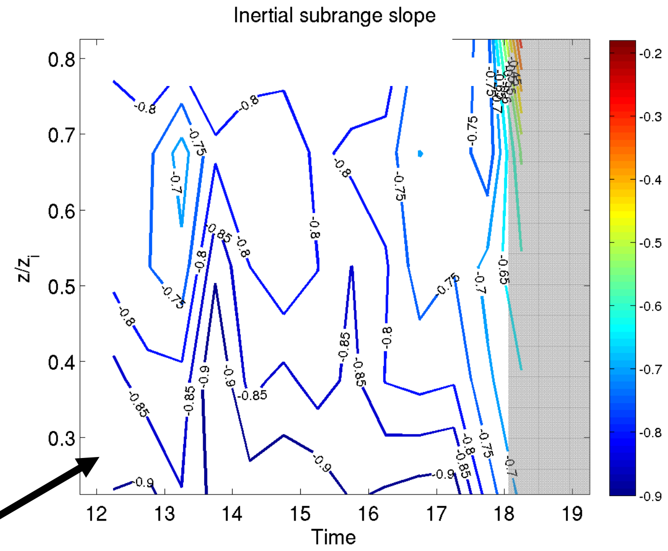
Inertial subrange slope

Sref

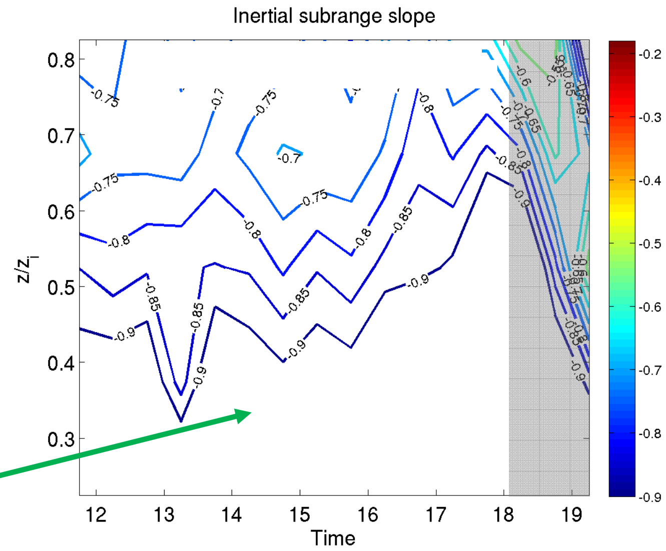


-2/3

U0



U5

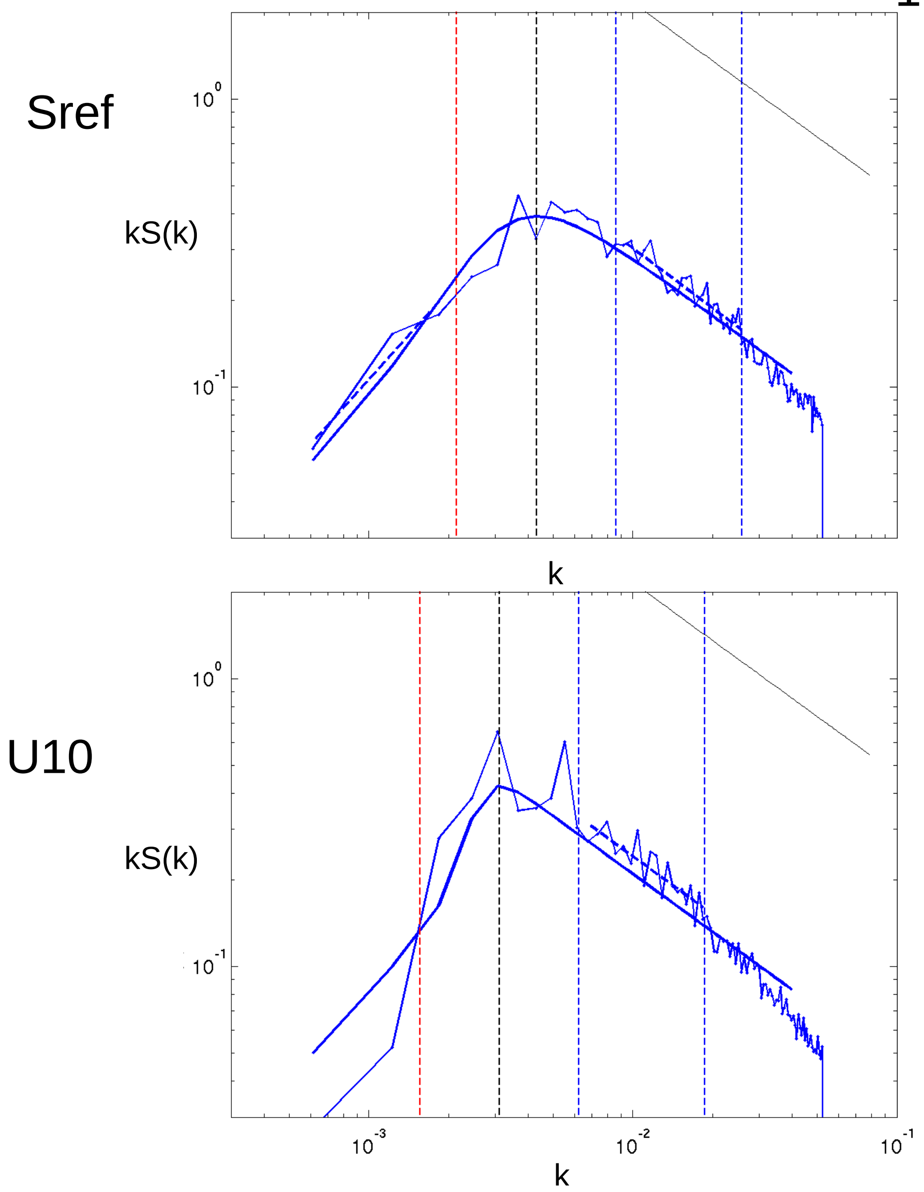


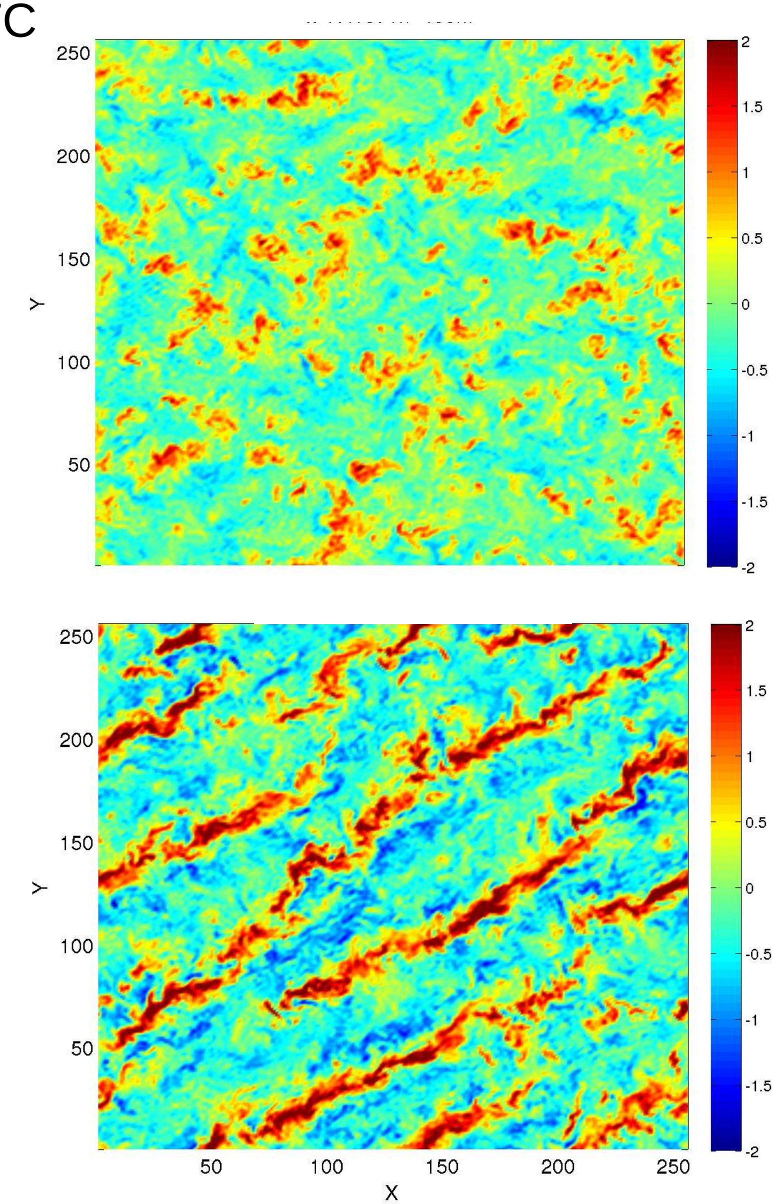
- Anisotropy flattens the inertial subrange slope

Coherent structures?

H4: Are the coherent structures at the origin of the steeper spectral slopes?

1715 UTC

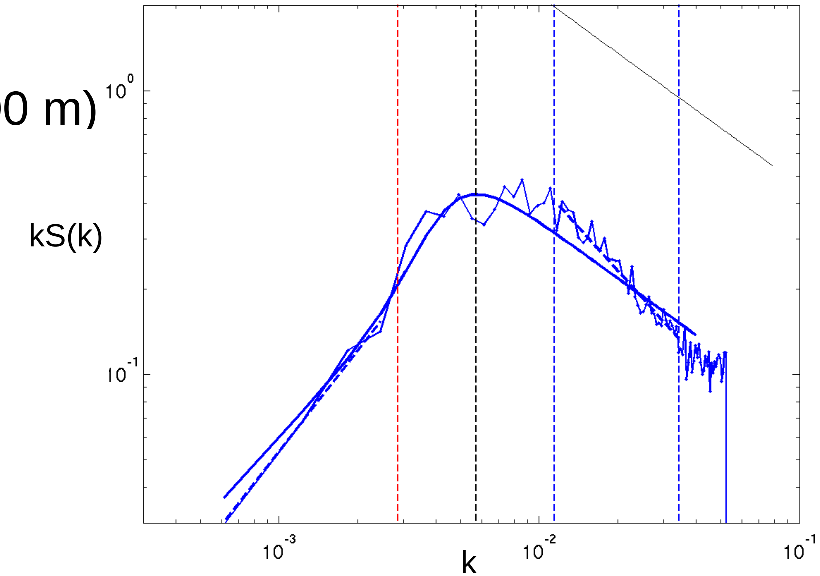




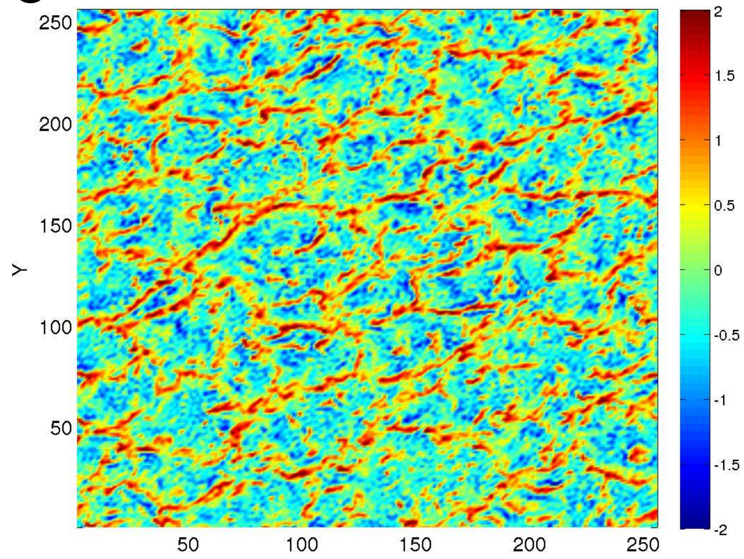
H4: Are the coherent structures at the origin of the steeper spectral slopes?

U5

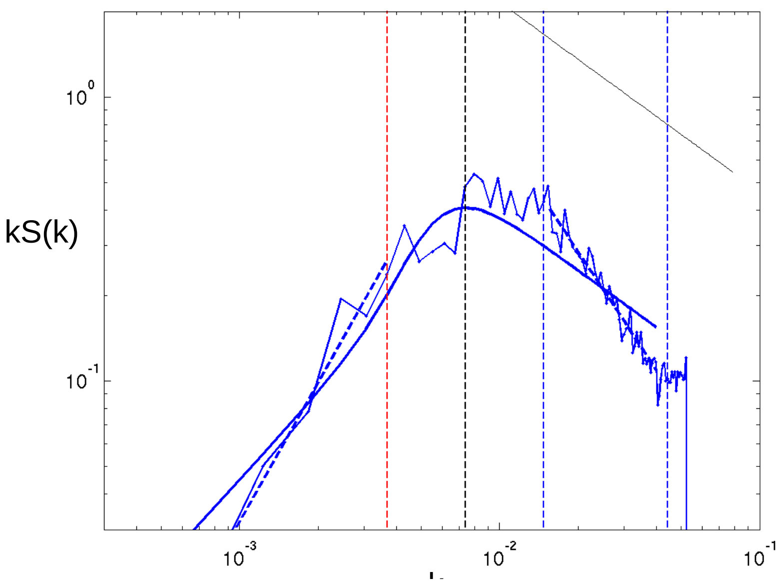
(100 m)

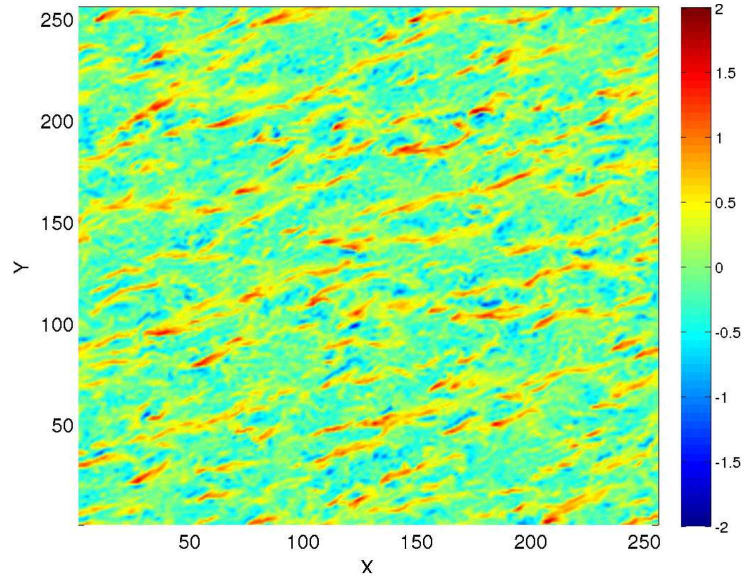


1200 UTC

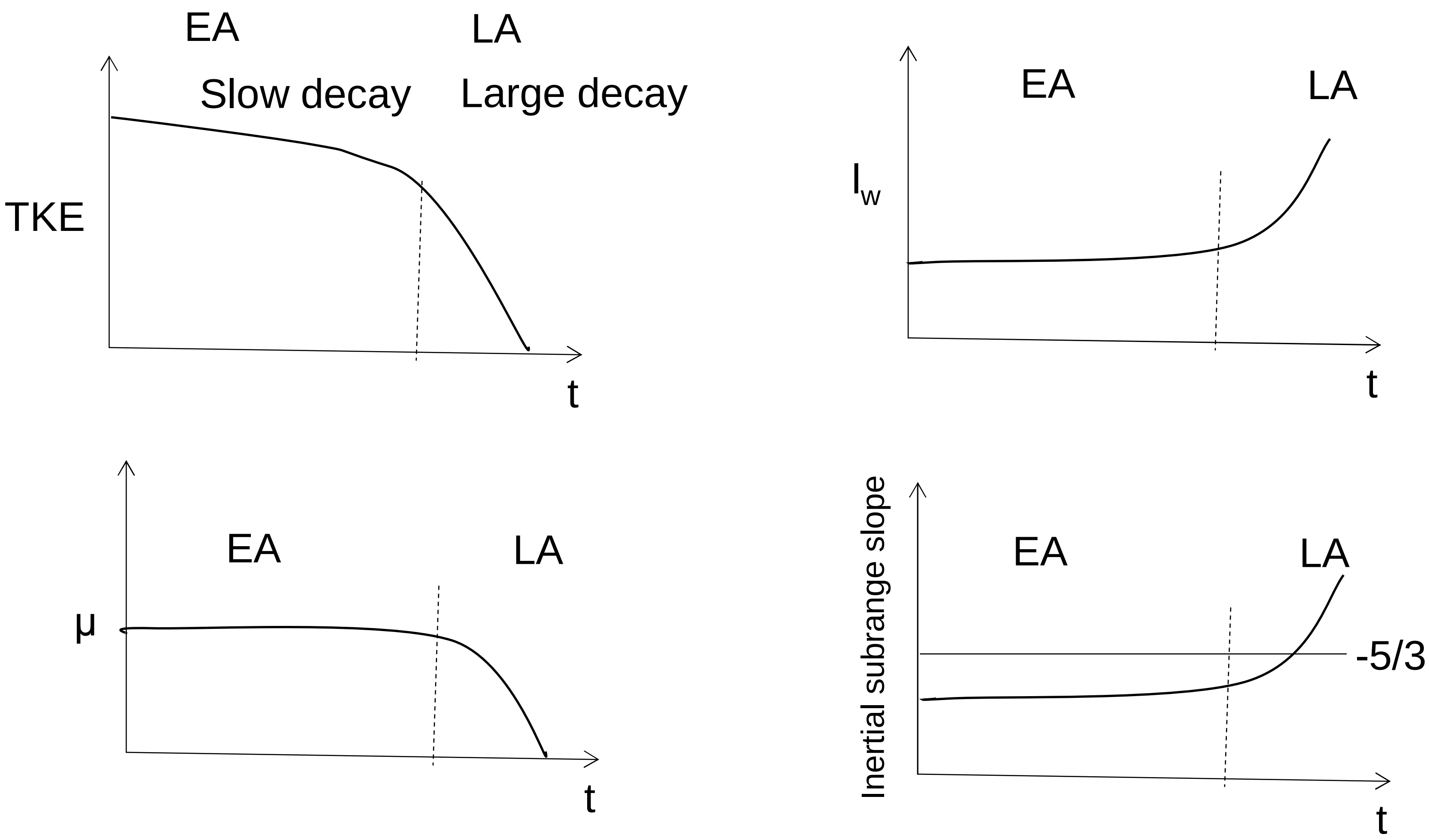


1715 UTC





Conclusions and perspectives

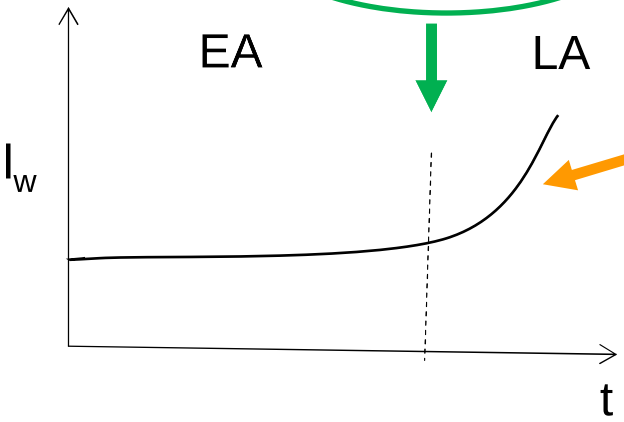


Conclusions and perspectives

Boundary Layer Late Afternoon and Sunset Turbulence

Role of shear

✓ Shear delays the turbulence decay and the LA

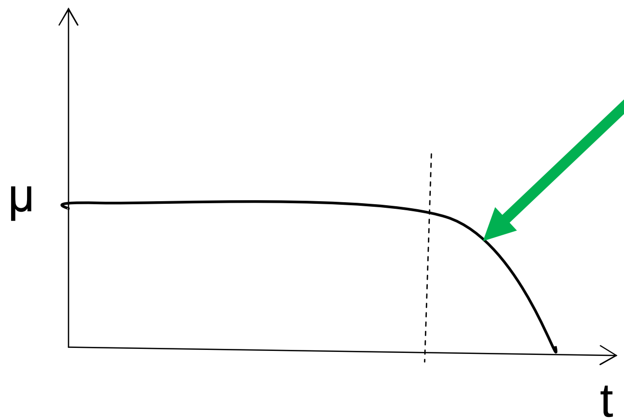


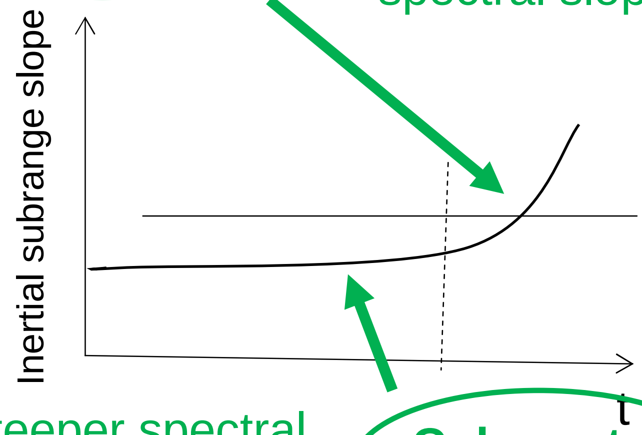
Entrainement

✓ Entrainement might explain the increase of the lengthscales but has to be more analyzed (with other tracers?)

Anisotropy

✓ Anisotropy flattens the inertial spectral slope



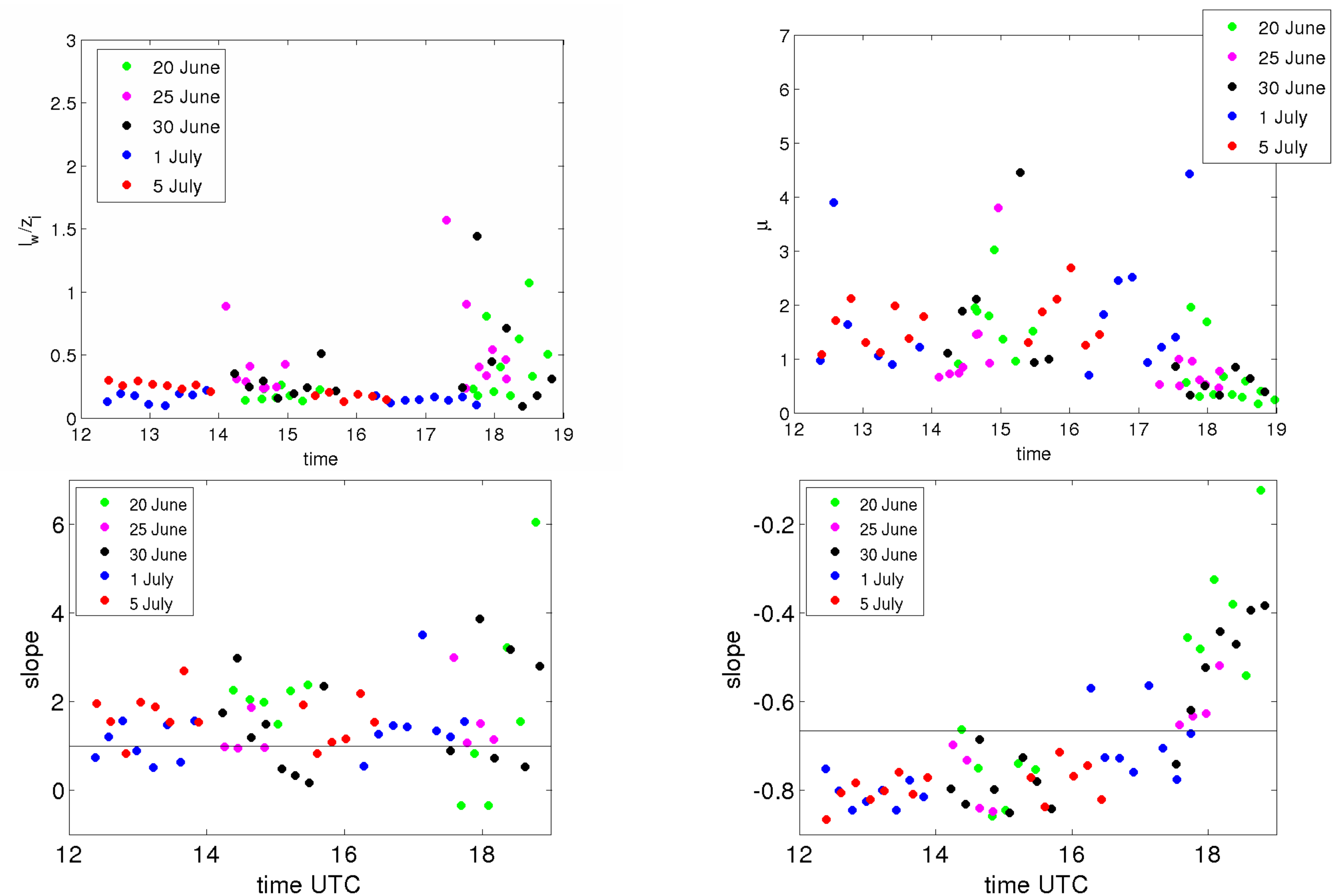


✓ Coherent structures explain the steeper spectral slopes during the midday convective conditions

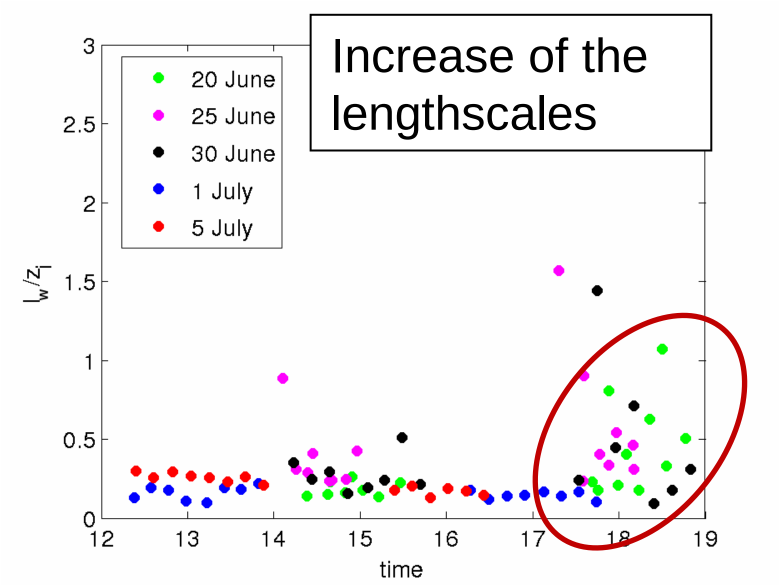
Coherent structures

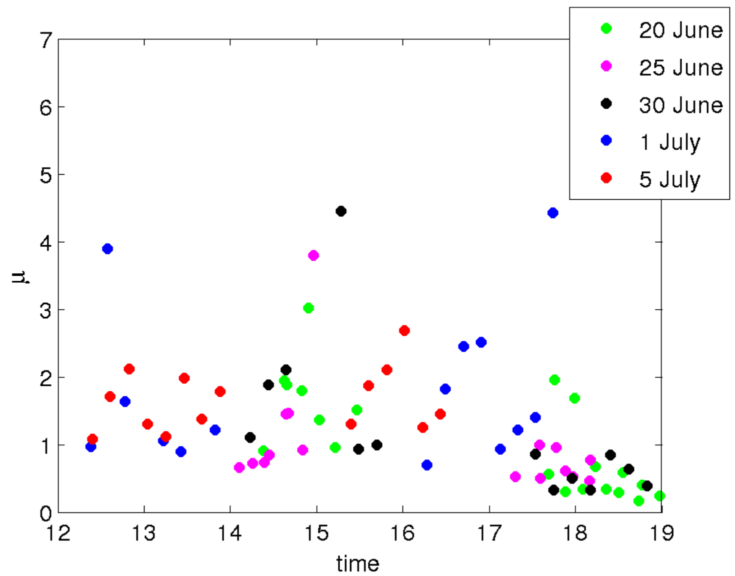
Thank you for your attention

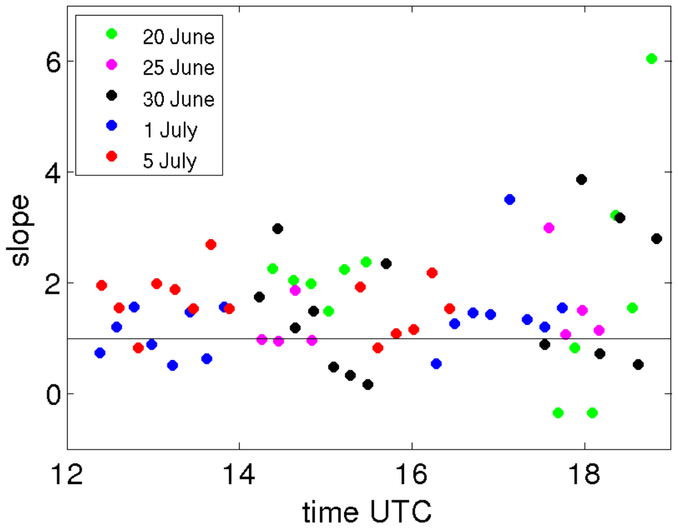
Do we find the same turbulence evolution on other days? Analysis on 4 other flights

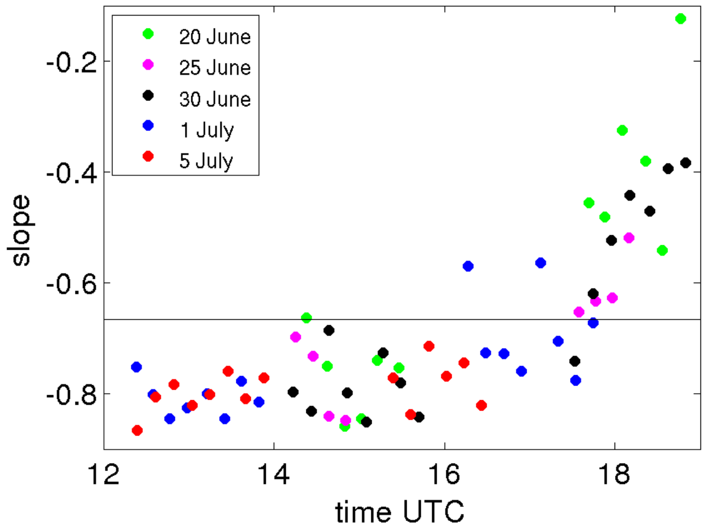


Do we find the same turbulence evolution on other days? Analysis on 4 other flights









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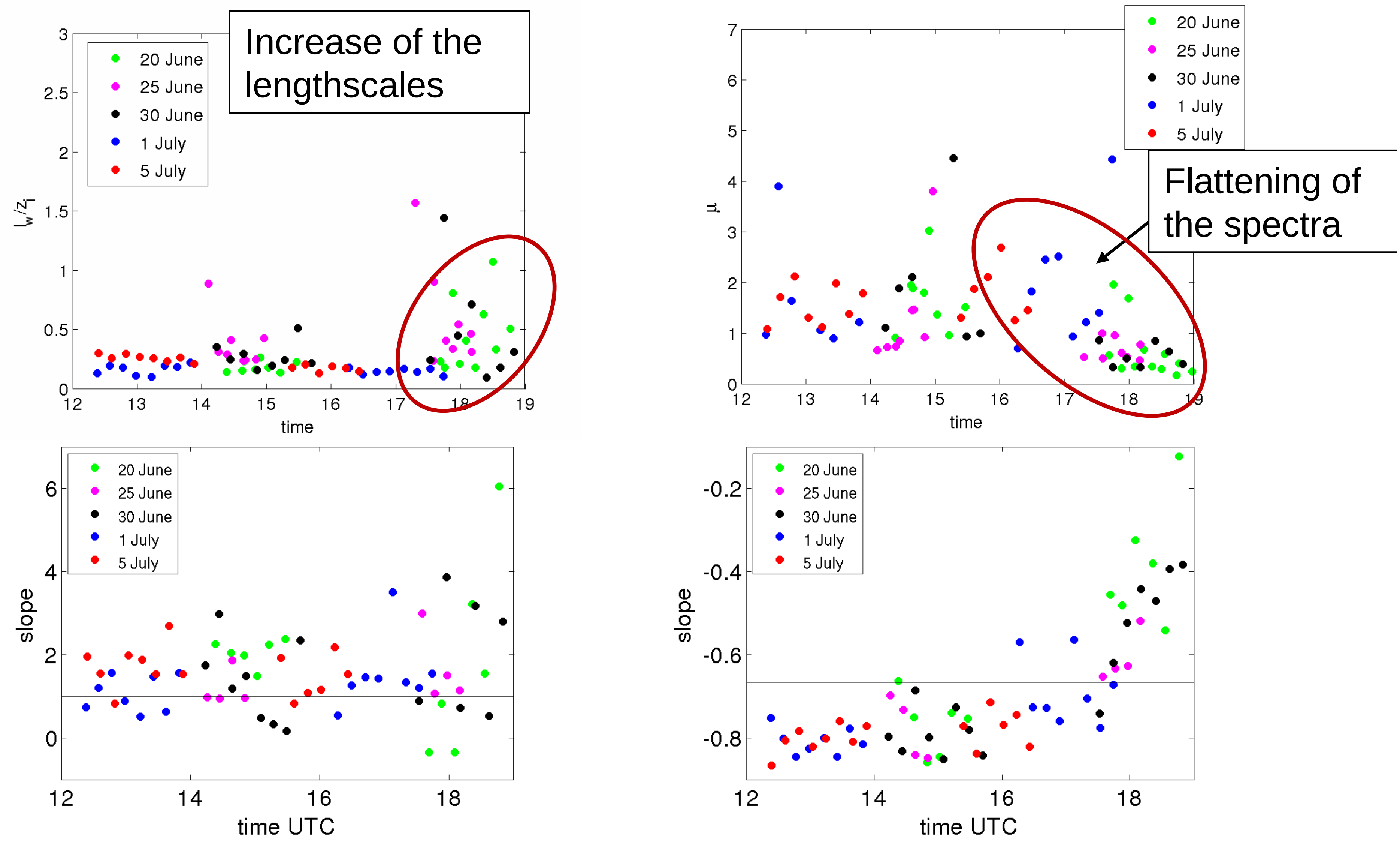
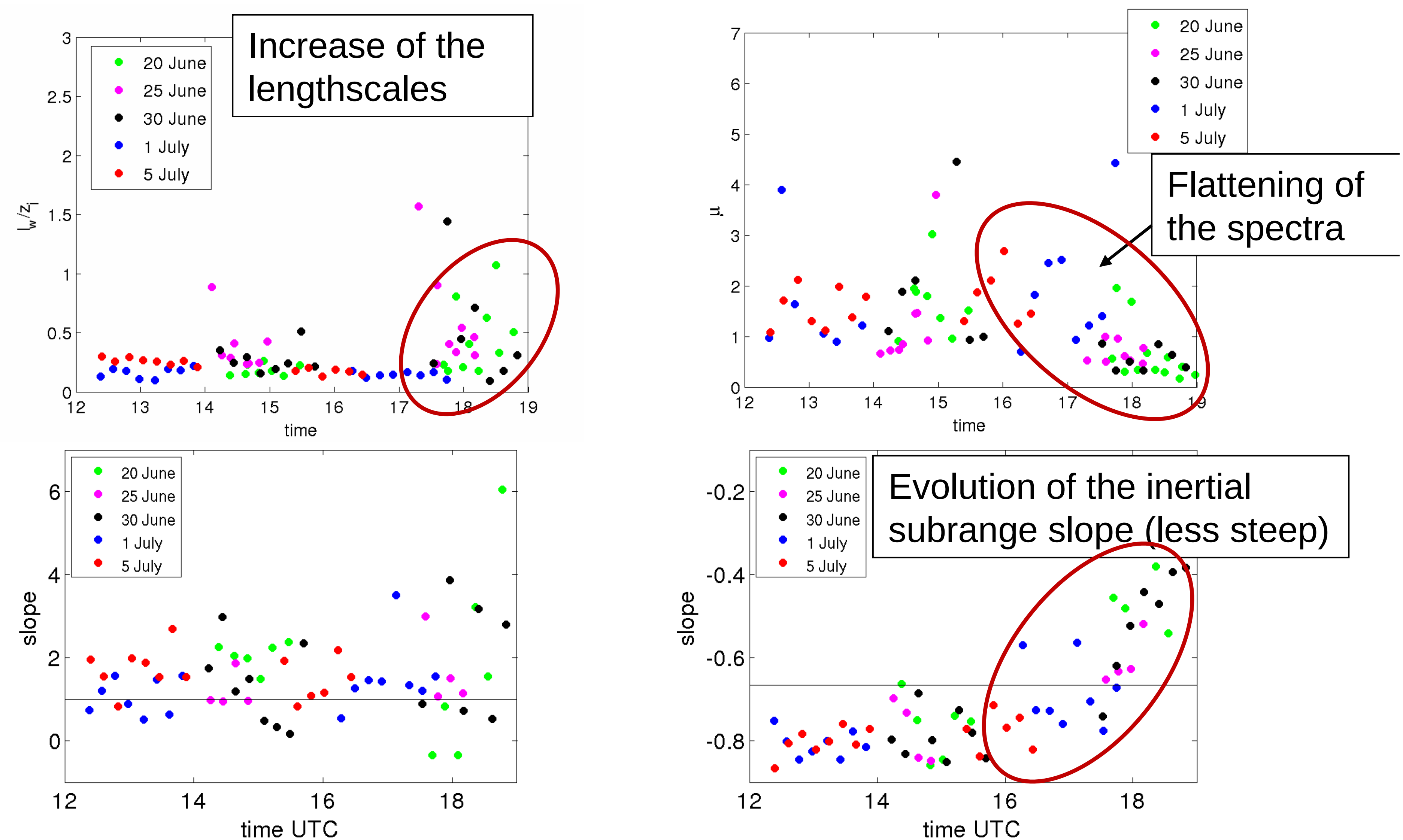


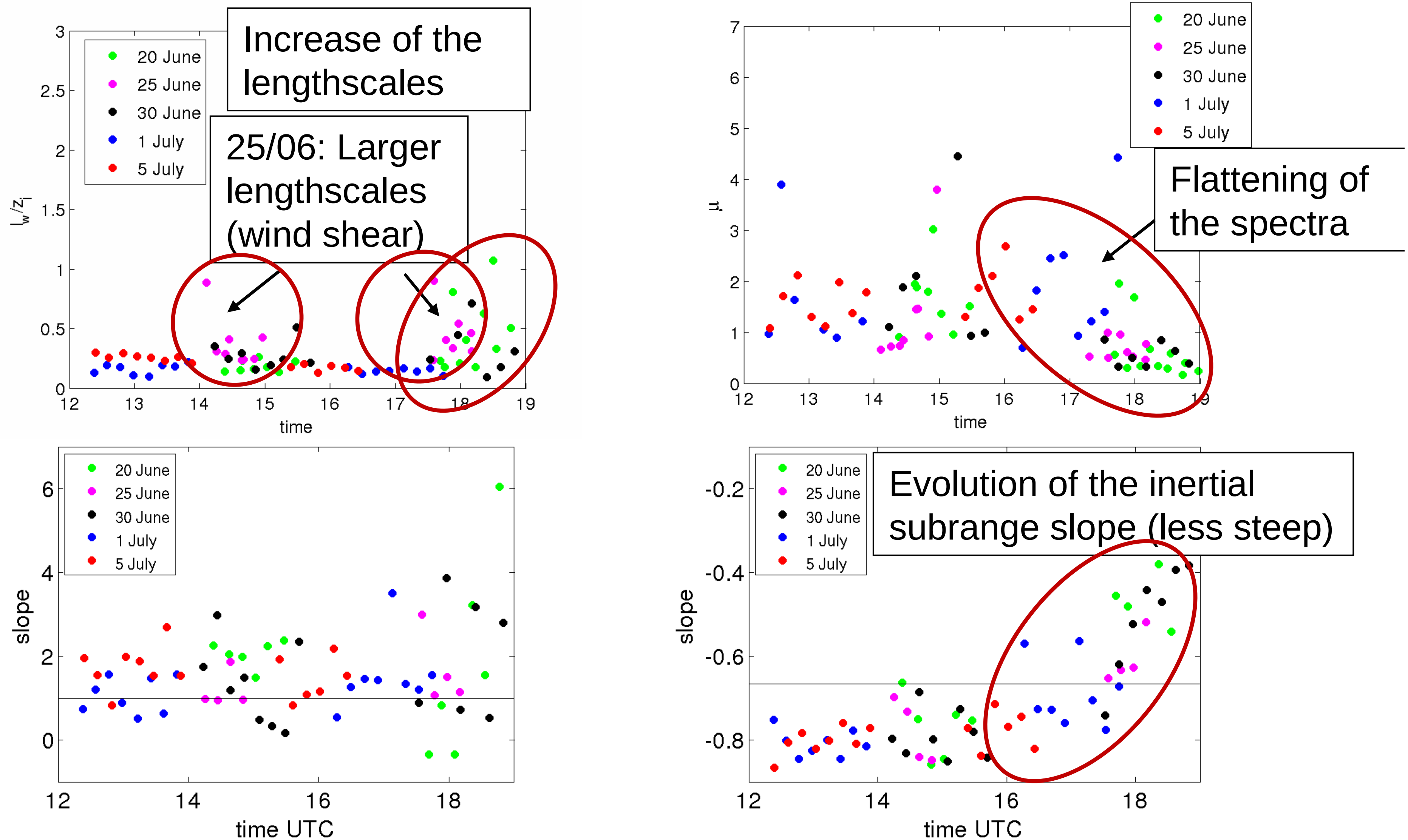
Do we find the same turbulence evolution on other days? Analysis on 4 other flights

Boundary Layer Late Afternoon and Sunset Turbulence



Do we find the same turbulence evolution on other days? Analysis on 4 other flights

Boundary Layer Late Afternoon and Sunset Turbulence

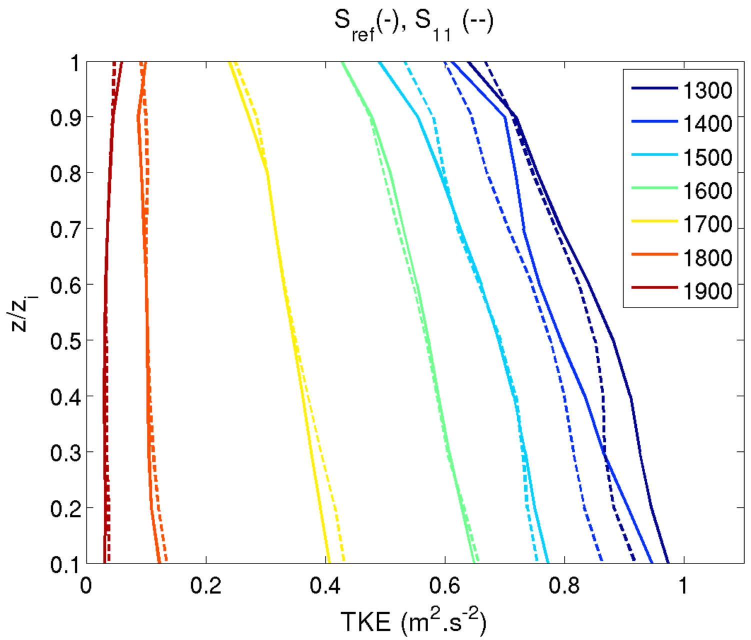


Are the results sensible to the time initialisation?

- New simulation initialized at 1100 UTC

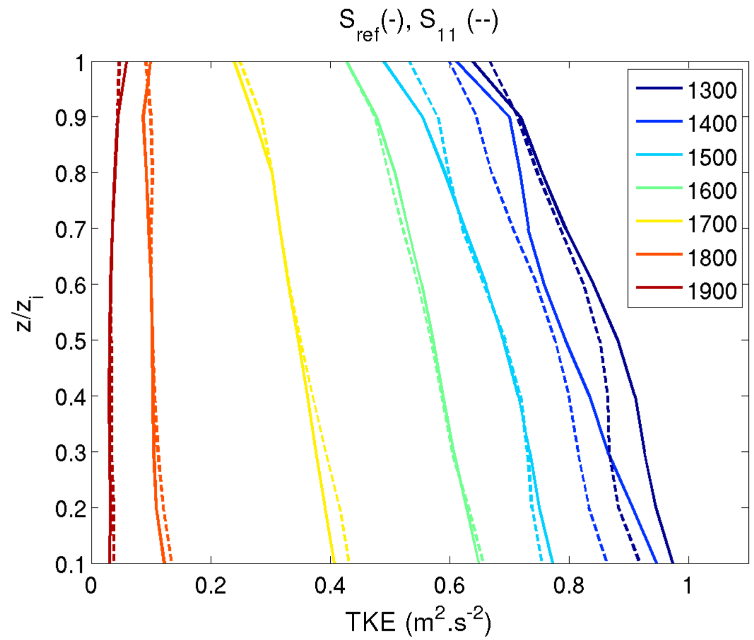
- Same mean structure (Temperature, humidity, wind)
- Same z_i
- Differences observed in the **turbulent structure**

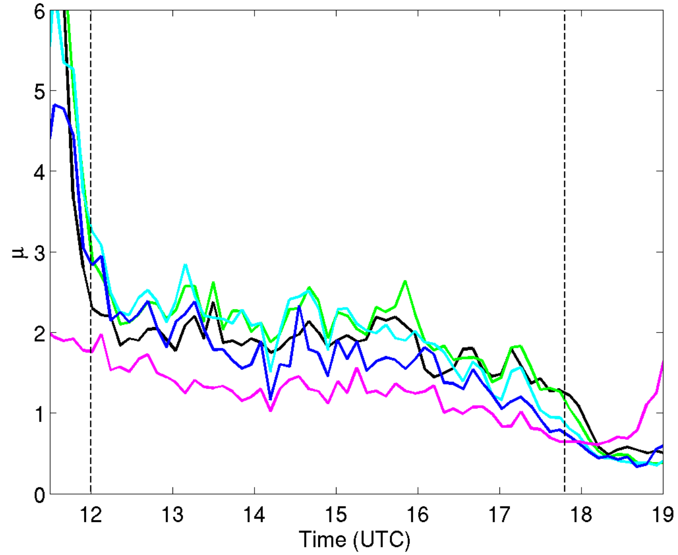
Are the results sensible to the time initialisation?



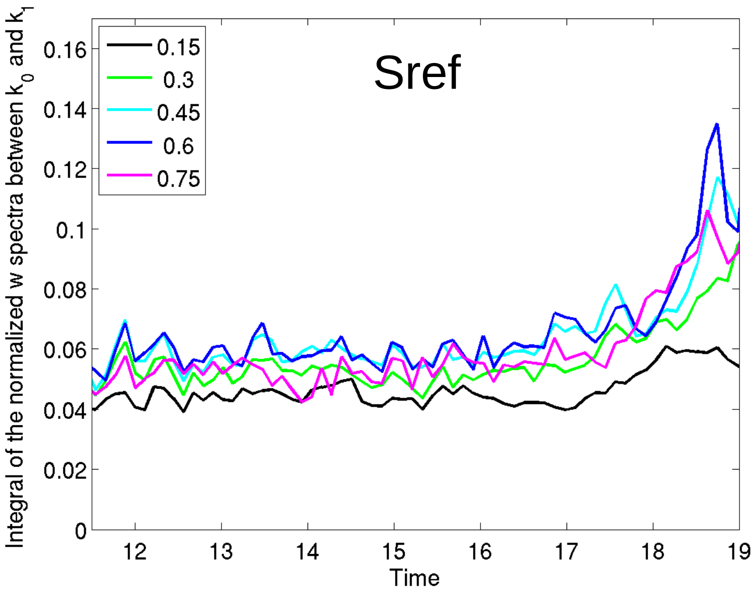
- TKE starts to decrease everywhere at the same time

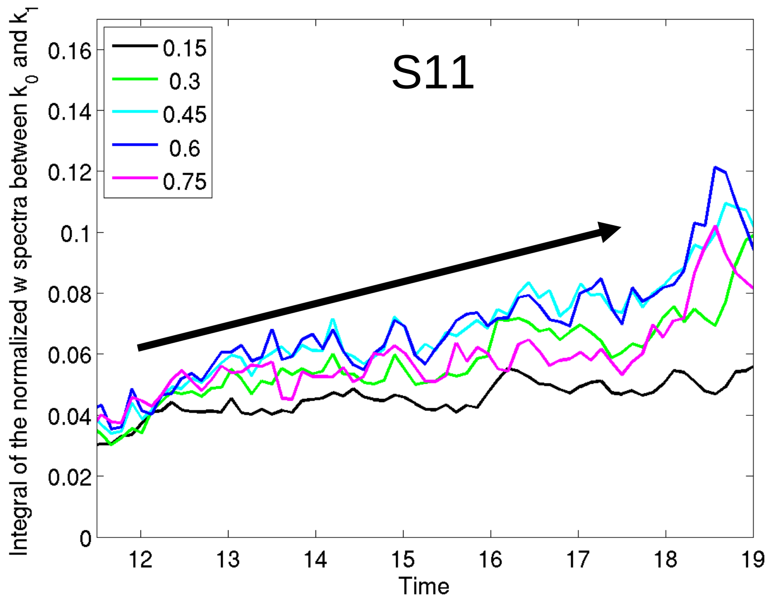
Are the results sensible to the time initialisation?



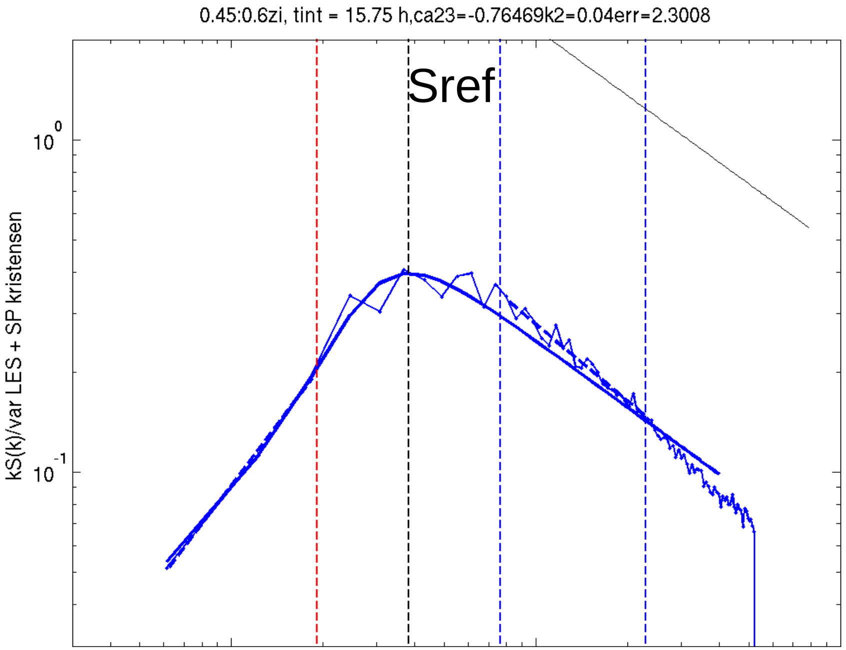


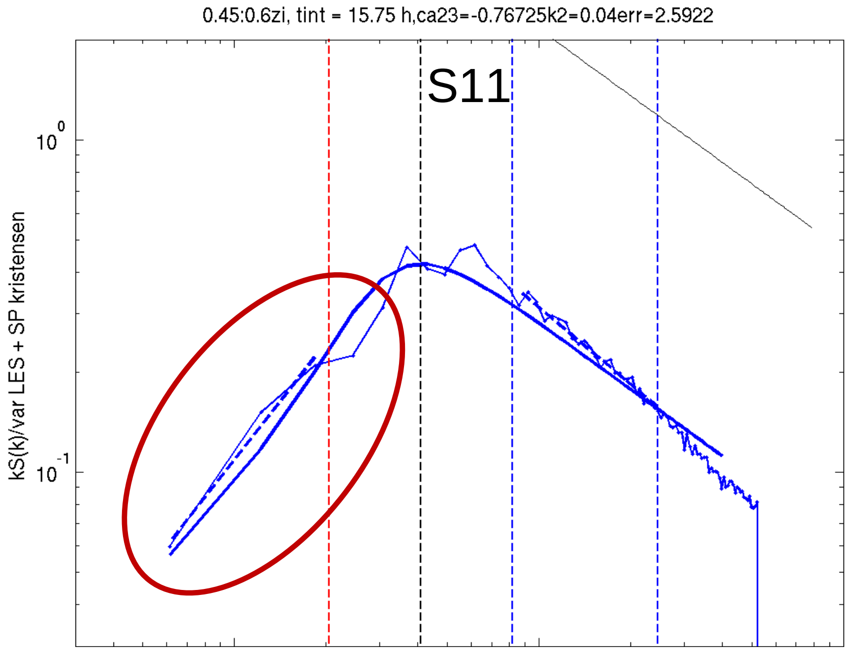
- TKE starts to decrease everywhere at the same time
- The spectral changes happen earlier than in Darbieu et al. 2014





- ➢ Evolution of the contribution of the low wavenumber range





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LES does not have enough time to create the larger turbulent structures