A statistical analysis of BLLAST airplane turbulence measurements during the afternoon transition

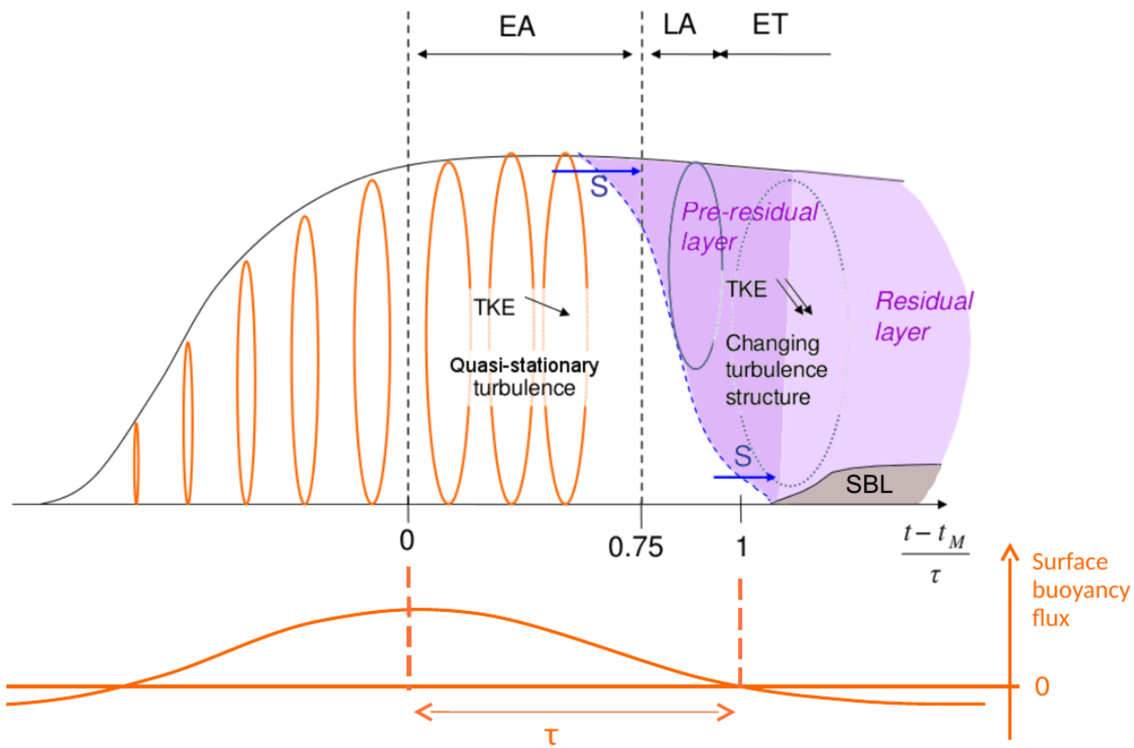
Marie Lothon, Fabienne Lohou, Pierre Durand

Laboratoire d'Aérologie, Université de Toulouse, CNRS

Starting from what we have learnt

Darbieu et al 2015, Nilsson et al 2016

- Two phases: 1. quasi-stationarity (Early Afternoon EA), 2. rapid evolution (late afternoon LA)
- A « pre-residual » layer above still unstable surface layer



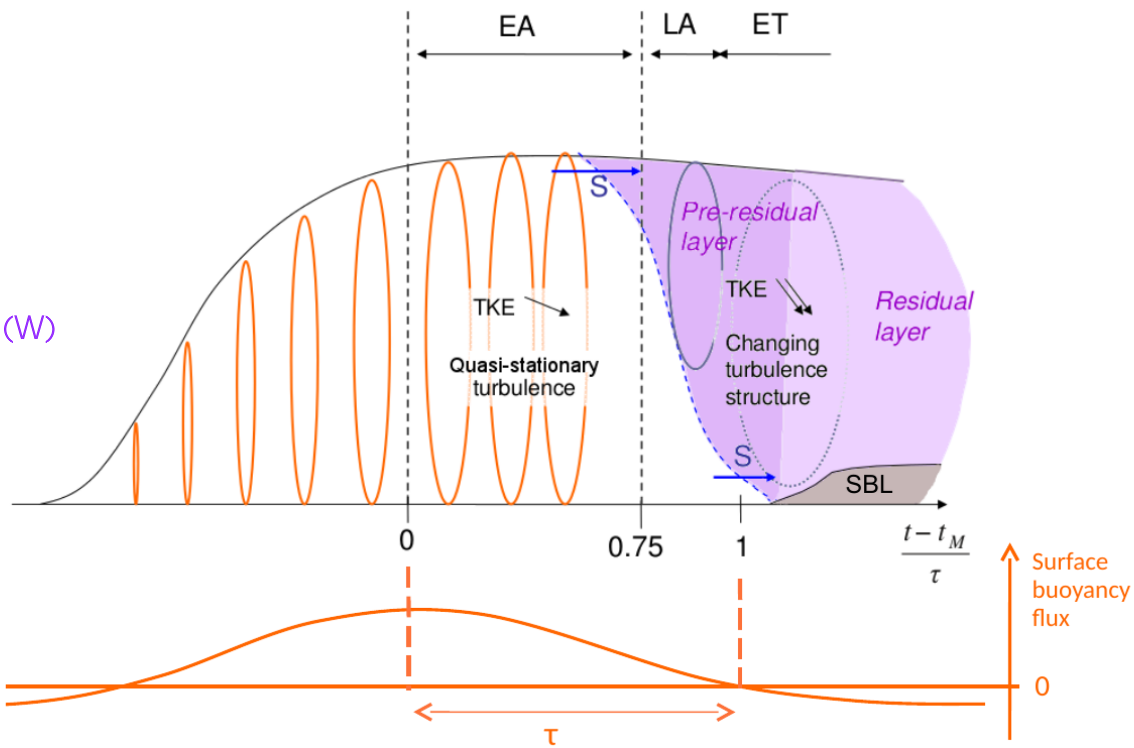
Starting from what we have learnt

Darbieu et al 2015, Nilsson et al 2016

- Two phases: 1. quasi-stationarity (Early Afternoon EA), 2. rapid evolution (late afternoon LA)
- A « pre-residual » layer above still unstable surface layer

Changes during the LA in :

- Energy decay
- Change in characteristic lengthscales (W)
- Inertial subrange spectral slopes (W)



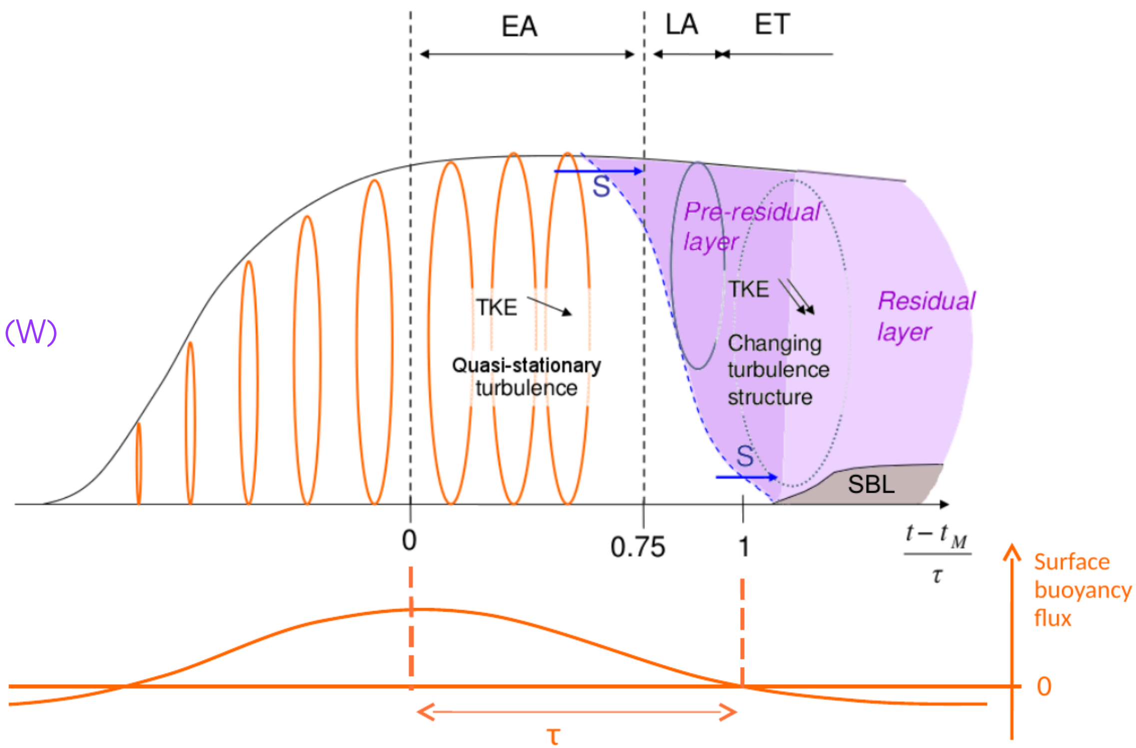
Questions

Darbieu et al 2015, Nilsson et al 2016

- Two phases: 1. quasi-stationarity (Early Afternoon EA), 2. rapid evolution (late afternoon LA)
- A « pre-residual » layer above still unstable surface layer

Changes during the LA in :

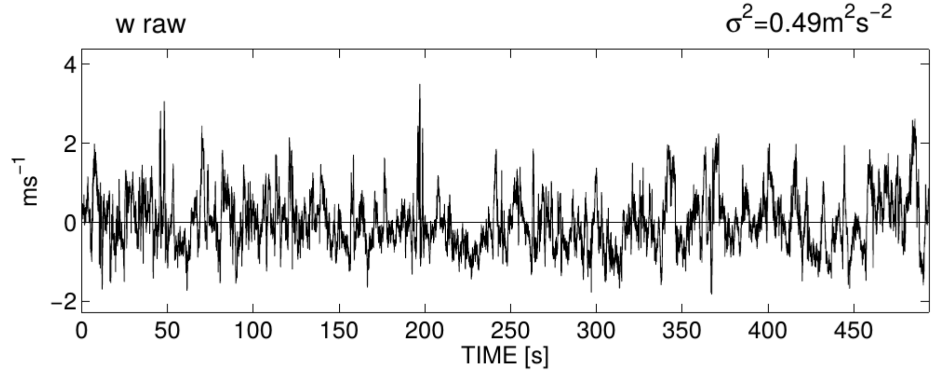
- Energy decay
- Change in characteristic lengthscales (W)
- Inertial subrange spectral slopes (W)



- Do the result extend to all flights and wind components ?
- Does the turbulence statistics in late afternoon Boundary layer (BL) differ from that found within the Free Troposphere (FT) above ?

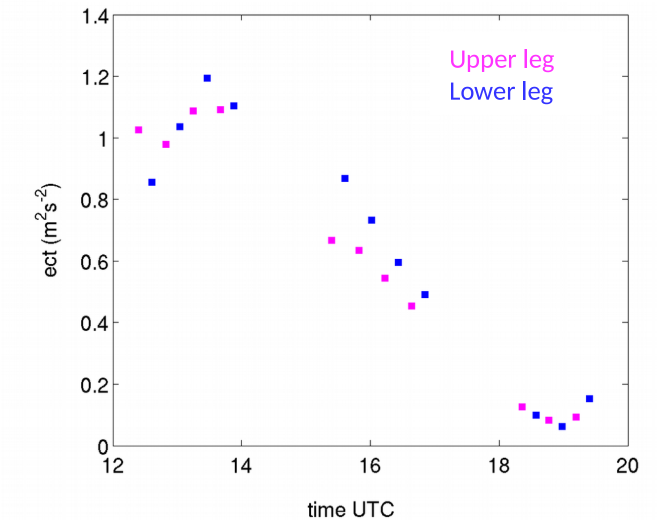
Observations used

Turbulence measurements made with the Piper Aztec aircraft



→ access to distributions, variances, skewness, energy density spectra

Turbulent kinetic energy decay
Measured with the Piper Aztec airplane
during 5 July 2018 (IOP 11)



w_* convective velocity

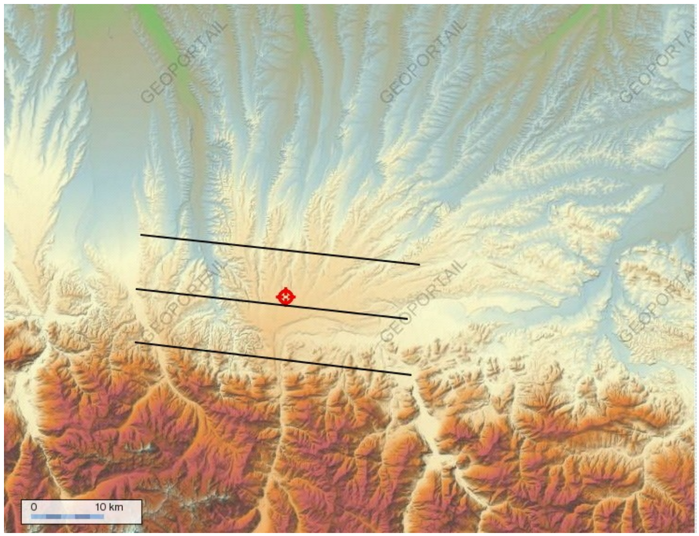
t_* convective time scale

τ forcing time scale

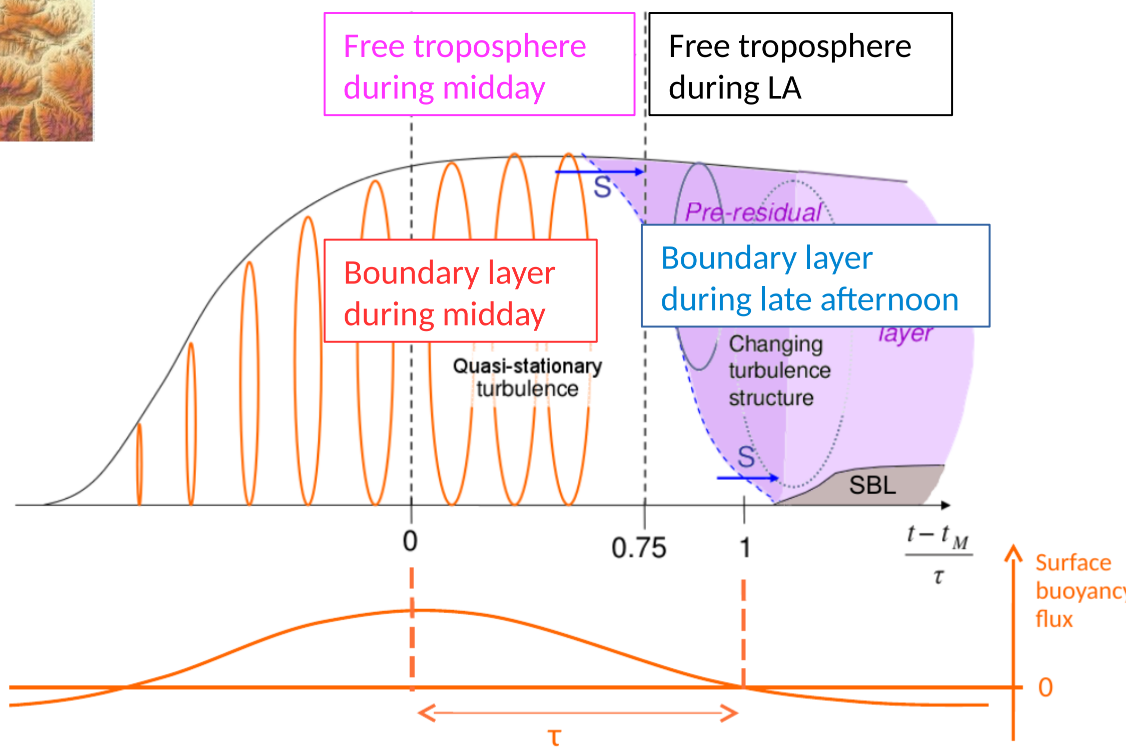
Surface station (moor) with buoyancy flux measurements

→ access to w_*, t_*, τ

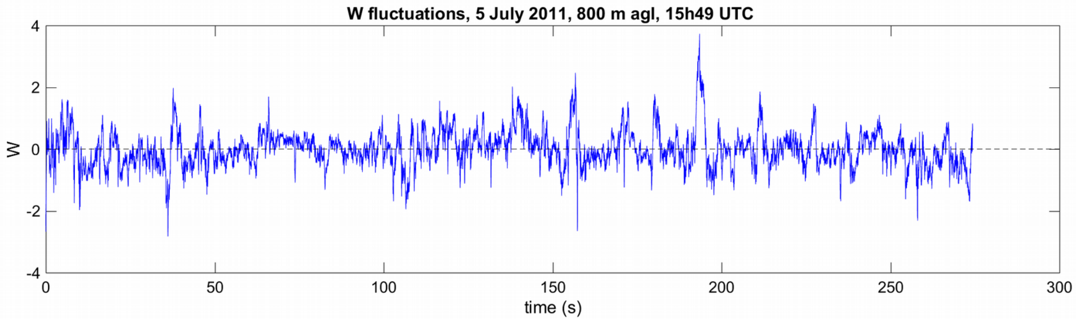
Approach and notation

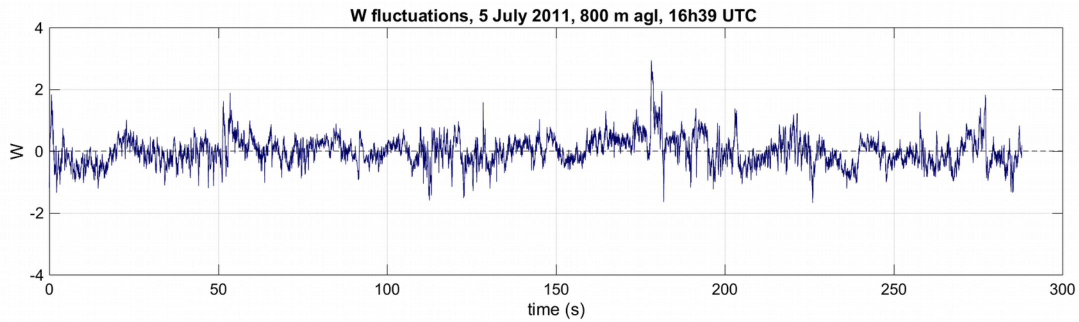


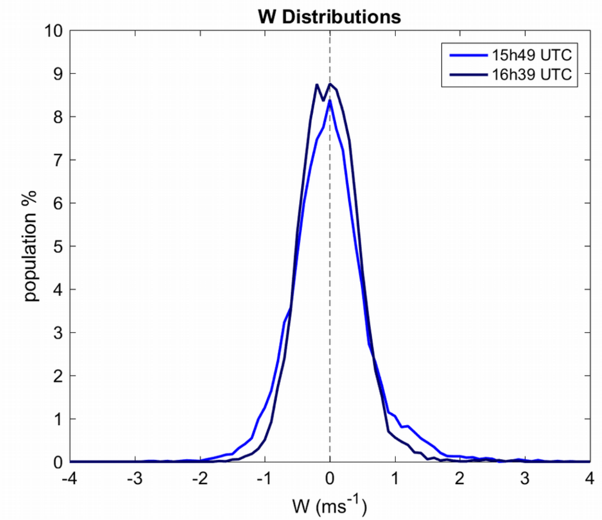
- Only East-West legs flown along the ridge and centered on the supersites are considered
- ~ 152 legs at start → ~ 90 legs remaining
- Including only 8 legs in the free troposphere !
- 10 IOPs (Piper Aztec did not fly on 24 June)

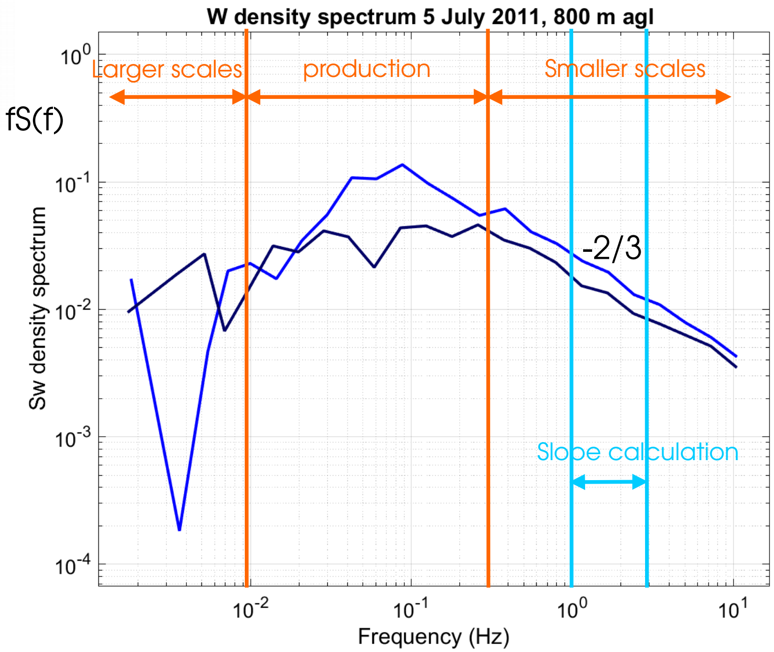


Observed series and spectra





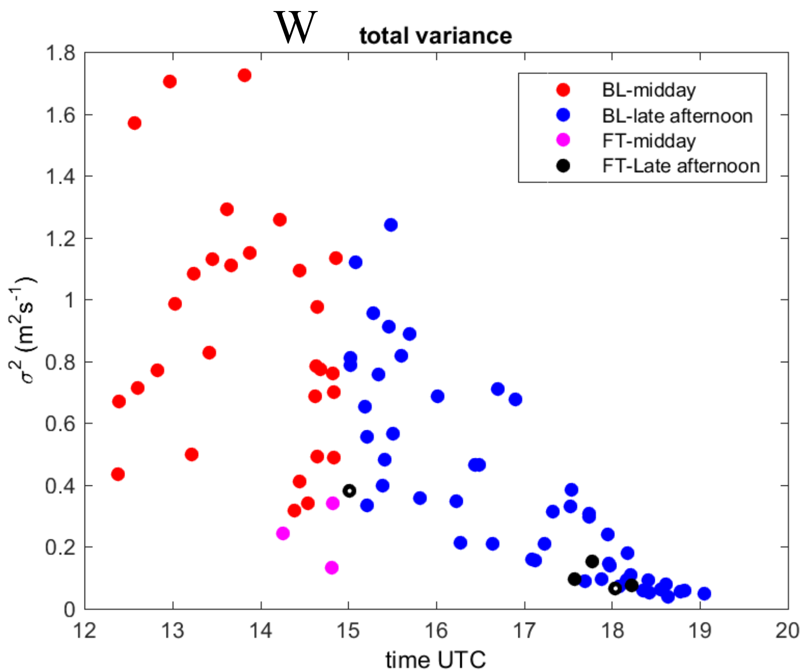


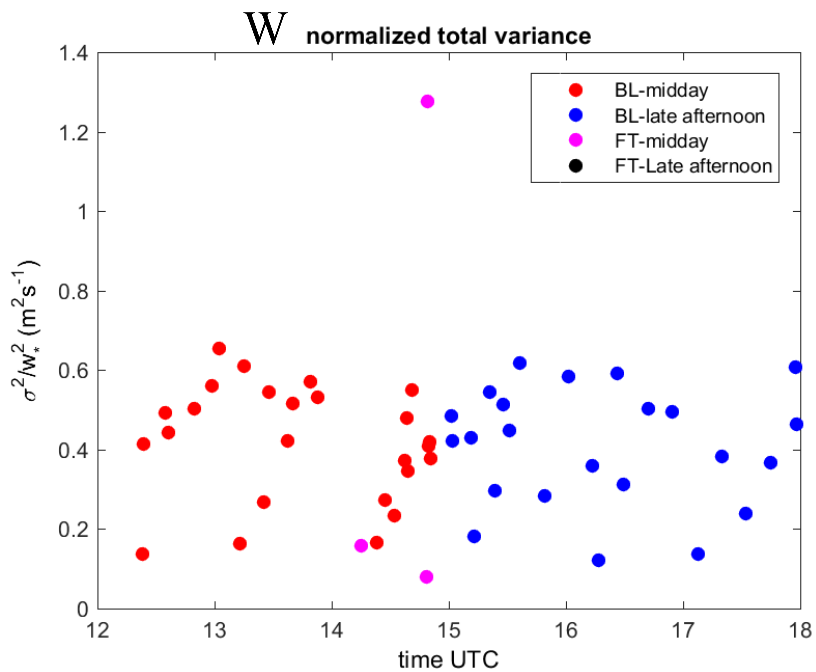


- Examples of 2 legs flown on 5 July 15h50 and 16h40, 800 m agl
- Very slight change in skewness
- Slight change in inertial slopes
- Significant change in energy spreading over the spectral range

Variance

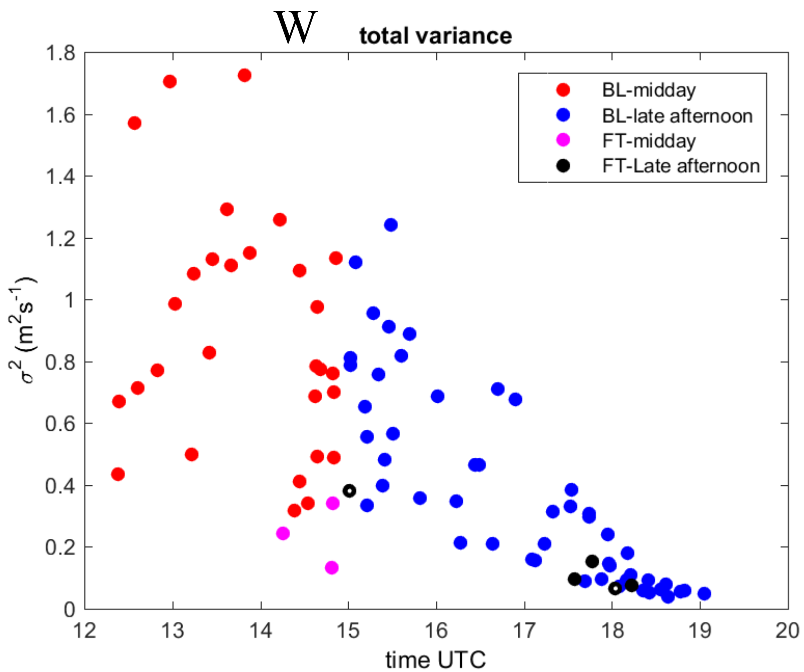
- Variance in LA and ET is close to or smaller than that found above the BL top
- Difficult to take into account the normalisation of energy and time
  (we loose important datapoints)
- Really small variances obtained at t_{norm} >1, when w_* is not defined anymore

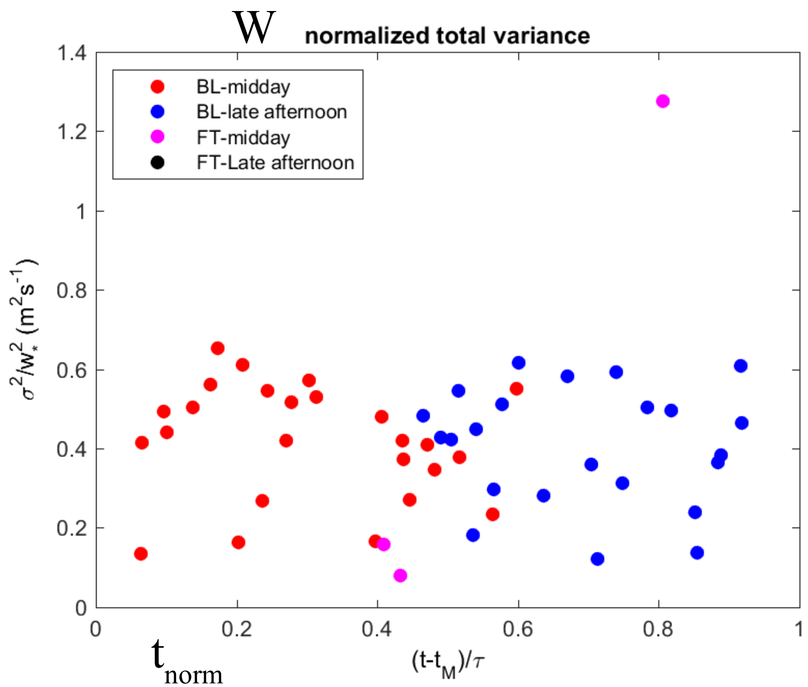




Turbulent kinetic energy

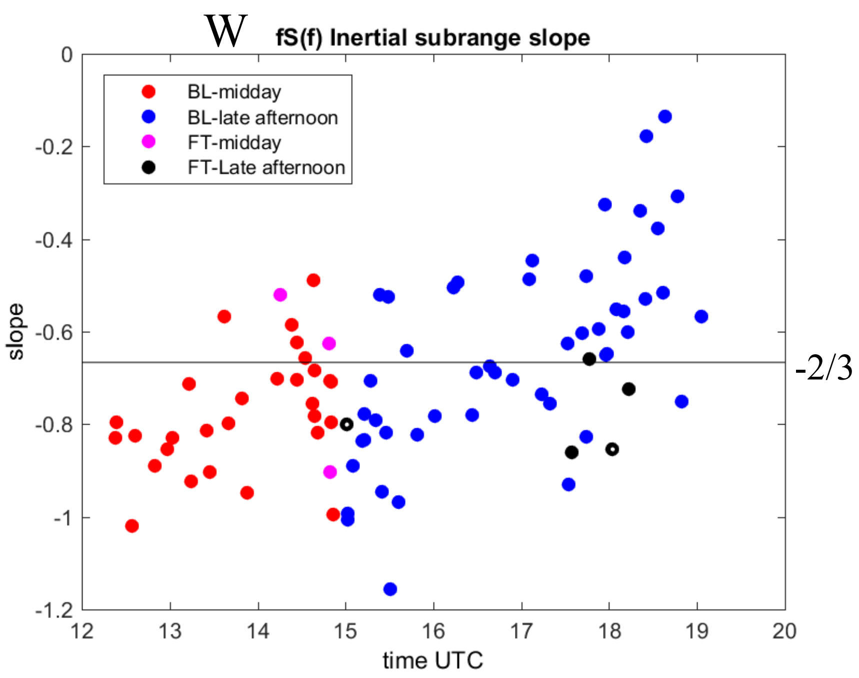
- Variance in LA and ET is close to or smaller than that found above the BL top
- Difficult to take into account the normalisation (energy and time)
  (we loose important datapoints)
- Really small variances obtained at t_{norm} >1, when w_* is not defined anymore





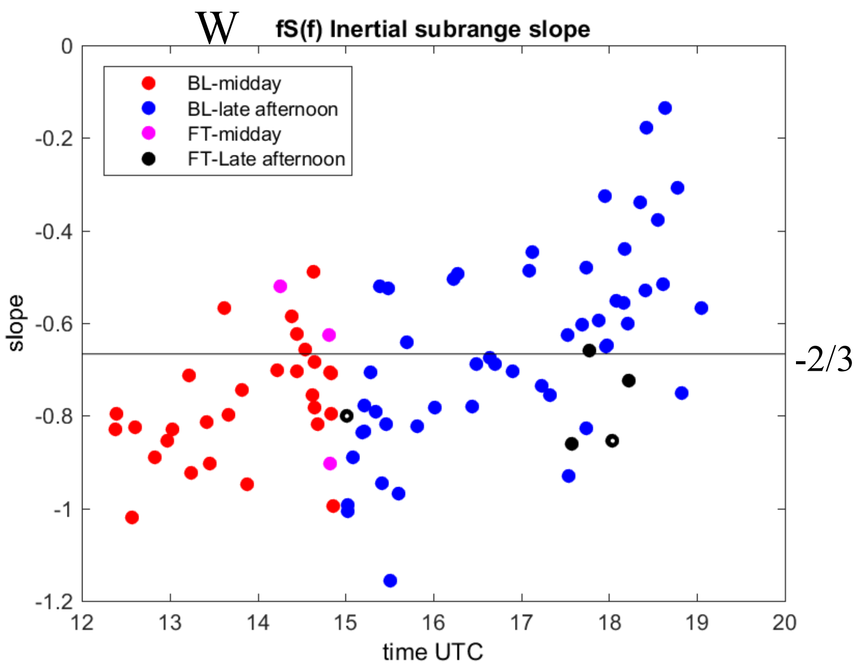
Inertial subrange spectral slopes

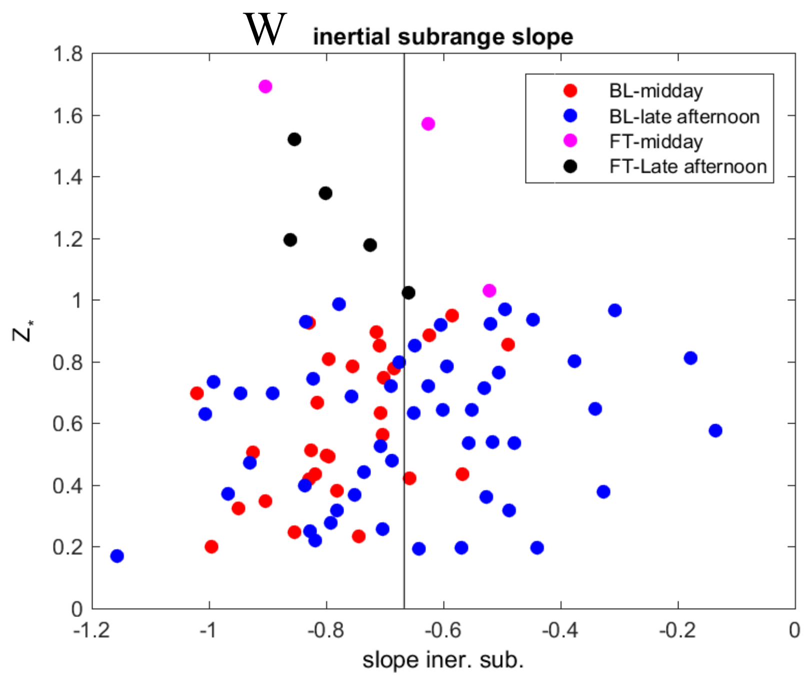
- Slopes get significantly unsteep at $t_{norm} > 0.75$ (consistently w/ Darbieu et al 2015)
- Slopes in Free Troposphere (FT) are not very different from midday BL



Inertial subrange spectral slopes

- Slopes get significantly unsteep at t > 0.75 (consistently w/ Darbieu et al 2015)
- Slopes in Free Troposphere (FT) are not very different from midday BL
- LA inertial subrange slopes changes found throughout the BL depth

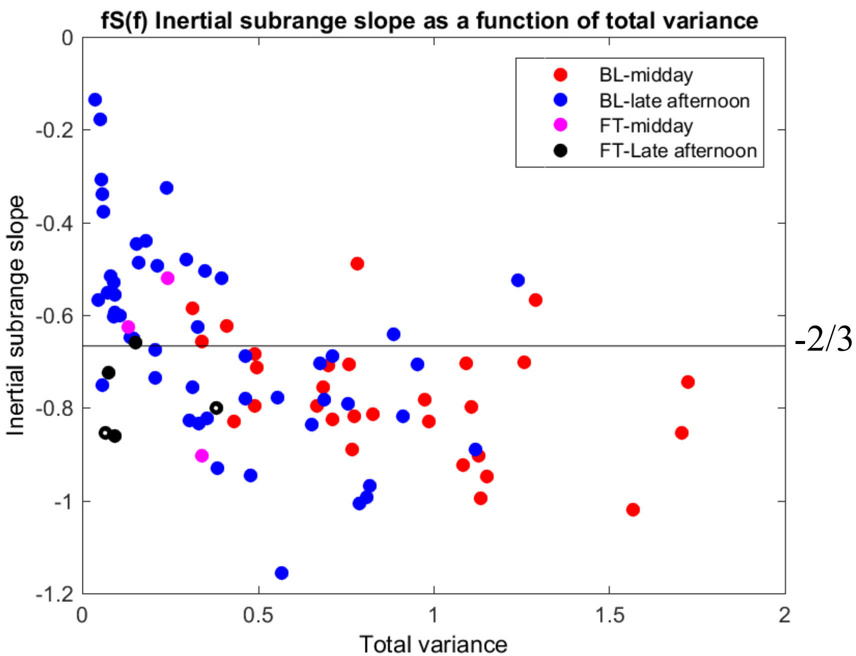


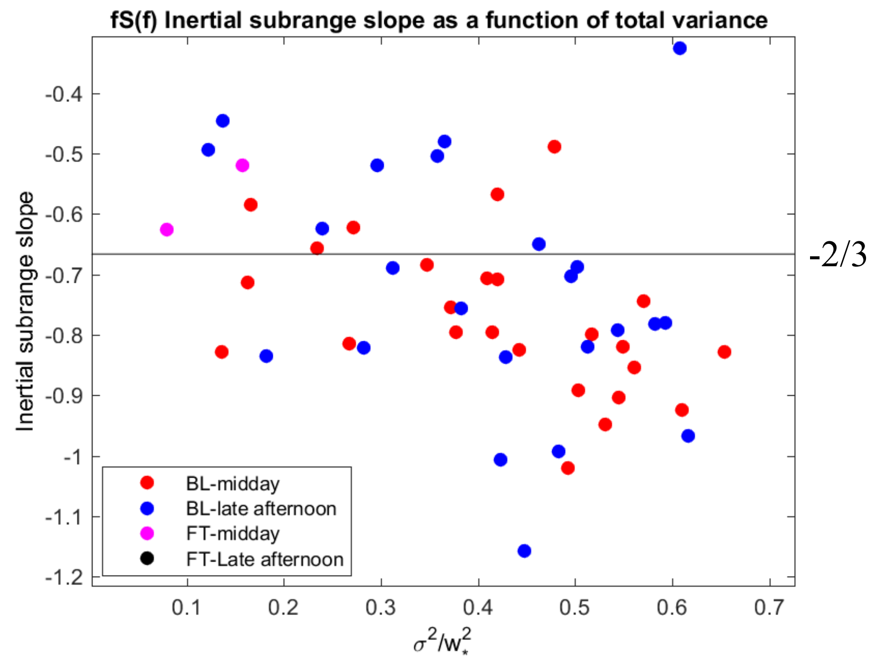


Slopes & Energy

- The least steep slopes (> -0.5) are found for smallest turbulent energy
- The steepest slopes (< -0.9) are found for larger normalized energy
- Spectra in the FT show low energy, but not flatter spectra

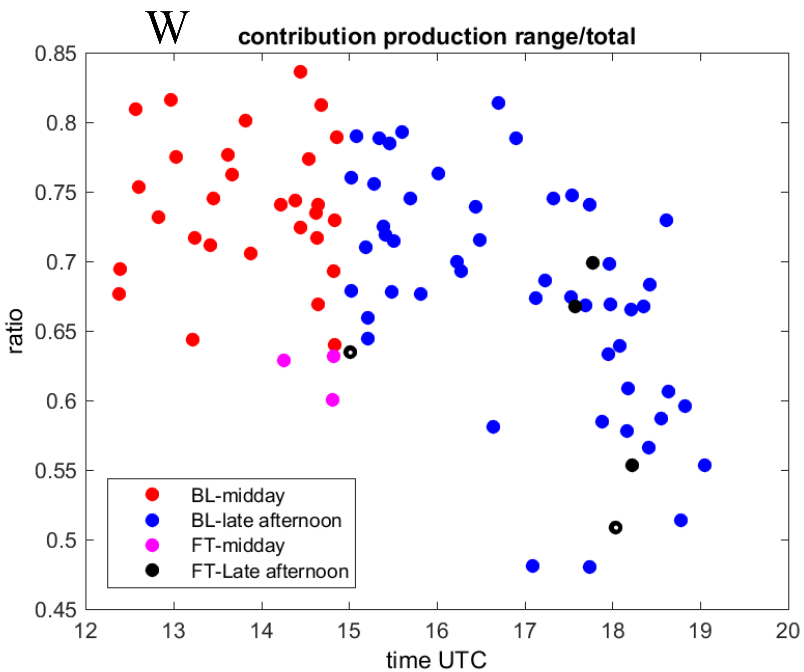
W

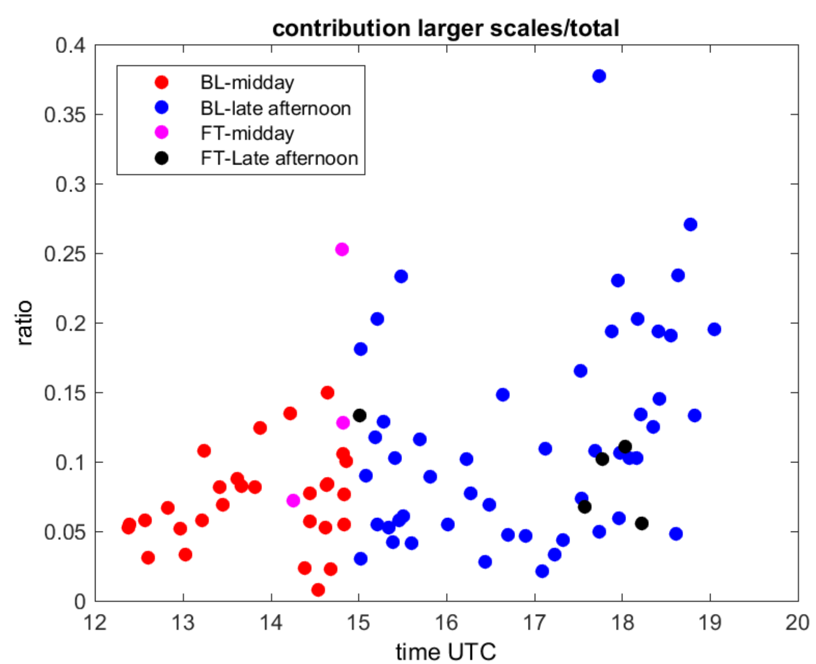




Scale contributions W

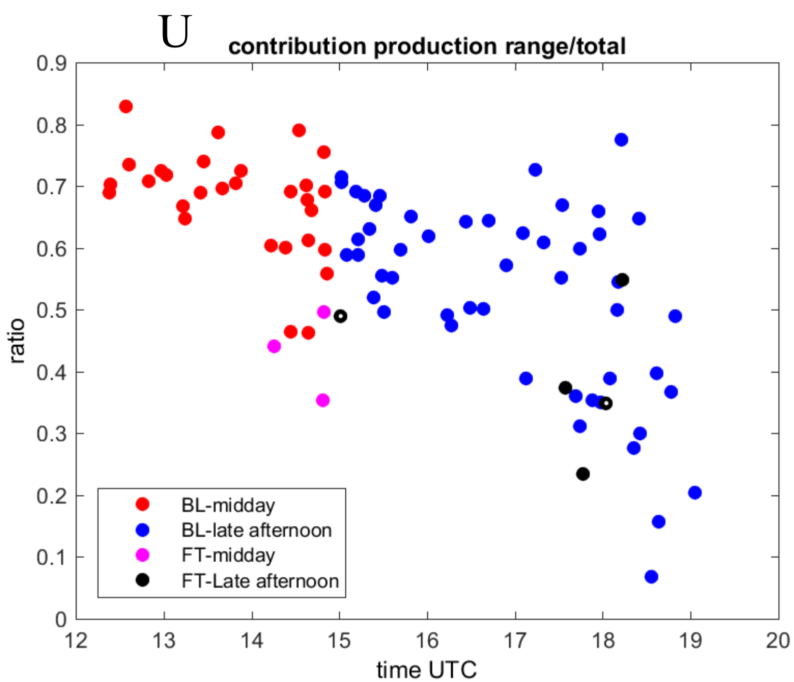
- We separate total variance in three range contributions:
  - larger scales
  - production range (= energy spectrum peak)
  - inertial subrange (= smaller scales)
- Decrease of contribution of production range and increase of contribution of largee scales during the ET (consitently with the increase of characteristic lengthscale)
- Late Afternoon BL has close behaviour to Free Troposphere for this aspect

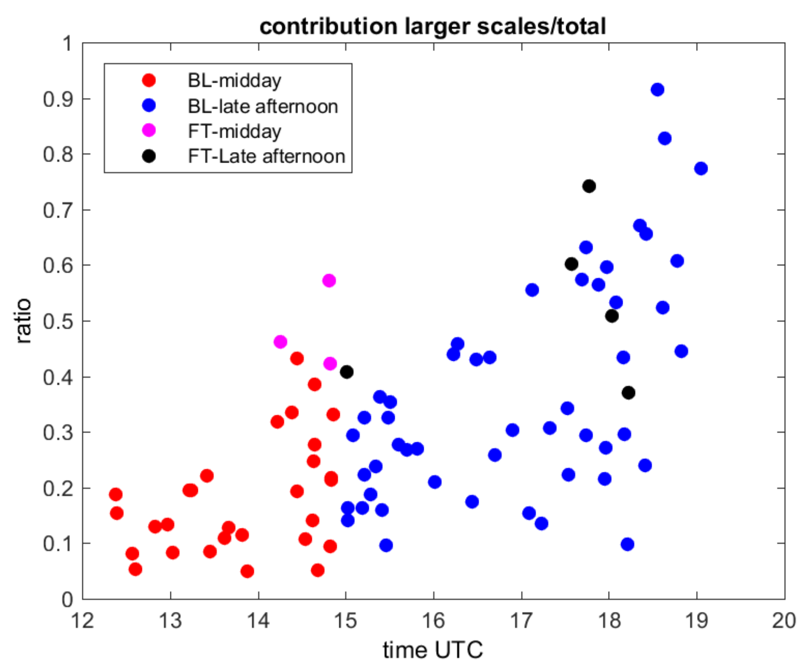




Scale contributions U

- We separate total variance in three range contributions:
  - larger scales
  - production range (= energy spectrum peak)
  - inertial subrange (= smaller scales)
- Decrease of contribution of production range and increase of contribution of largee scales during the ET → same result for U

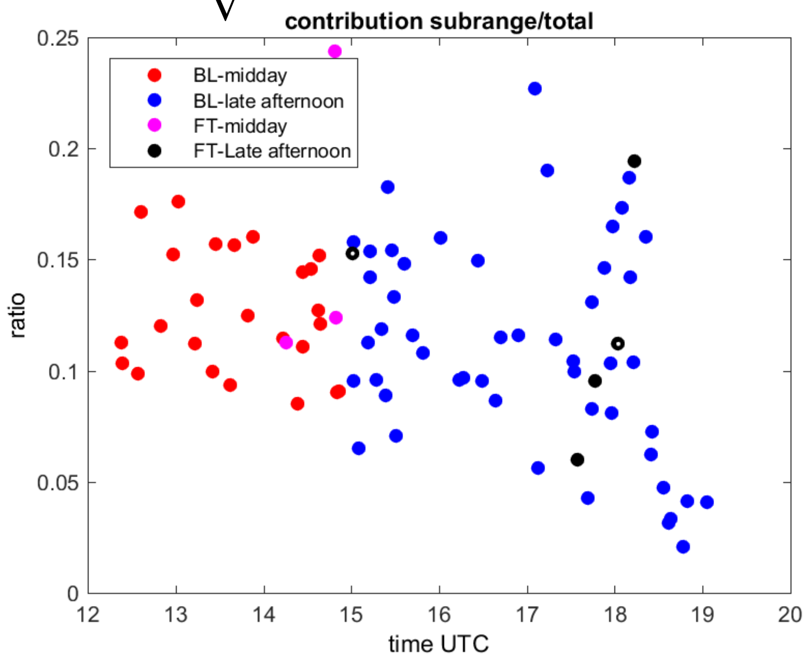


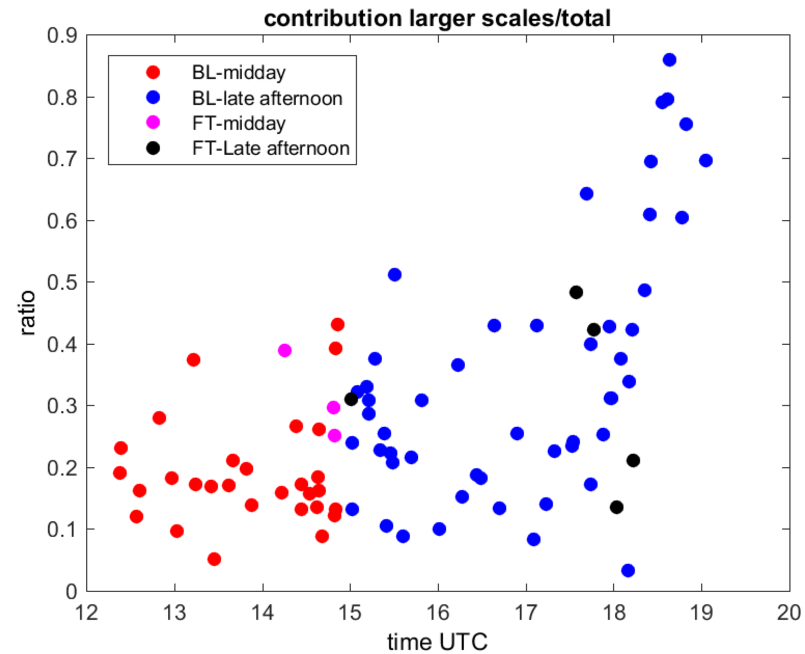


Scale contributions V

- We separate total variance in three range contributions:
  - larger scales
  - production range (= energy spectrum peak)
  - inertial subrange (= smaller scales)
- Decrease of contribution of production range and increase of contribution of largee scales during the ET → same result for U and V components

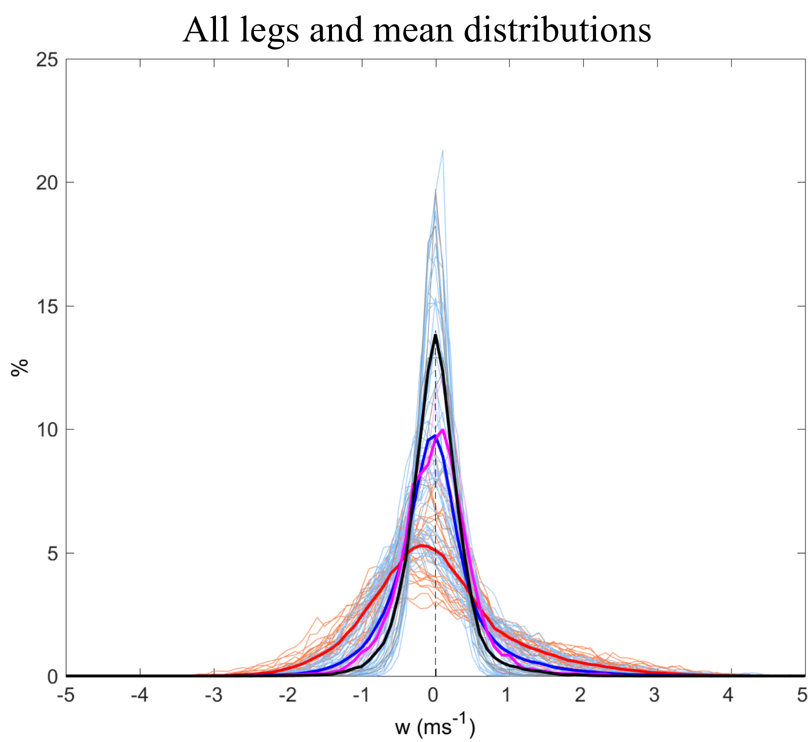
V

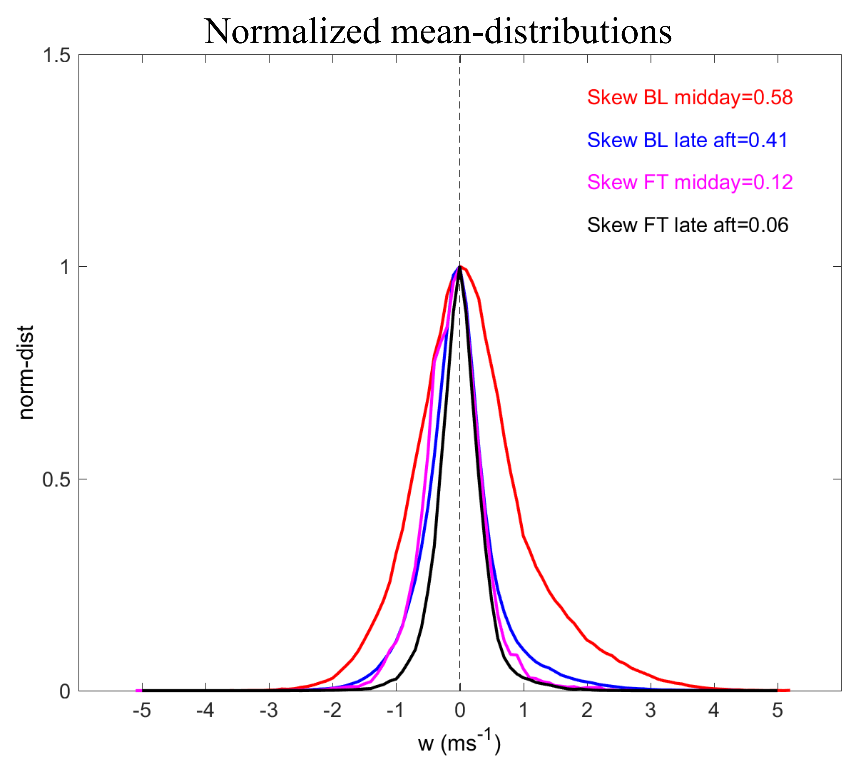




Distributions W

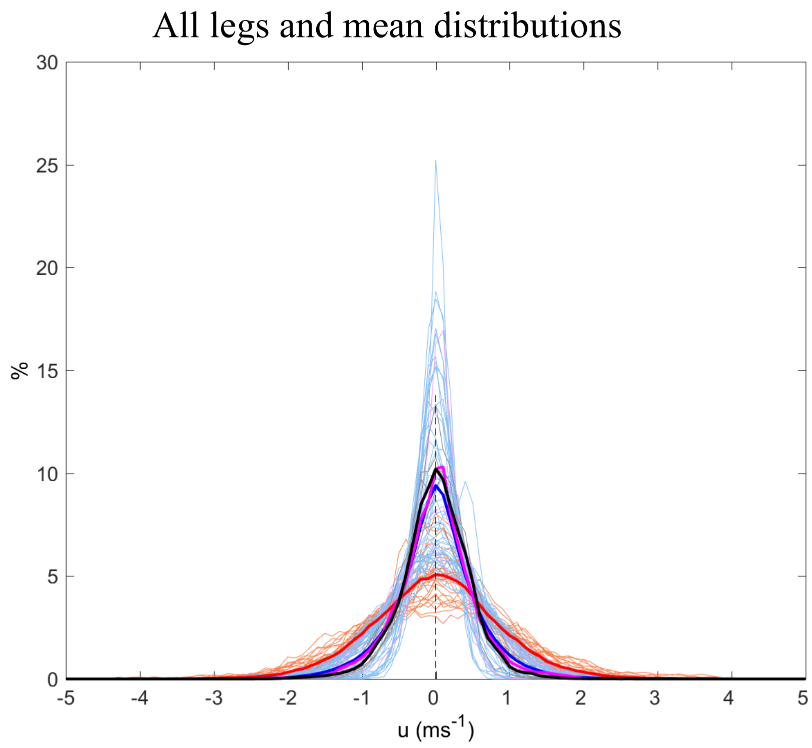
- Variance and weak-values in late afternoon BL close to free troposphere
- Non-skewed distributions within the free troposphere
- Skewed distributions within the BL, even late

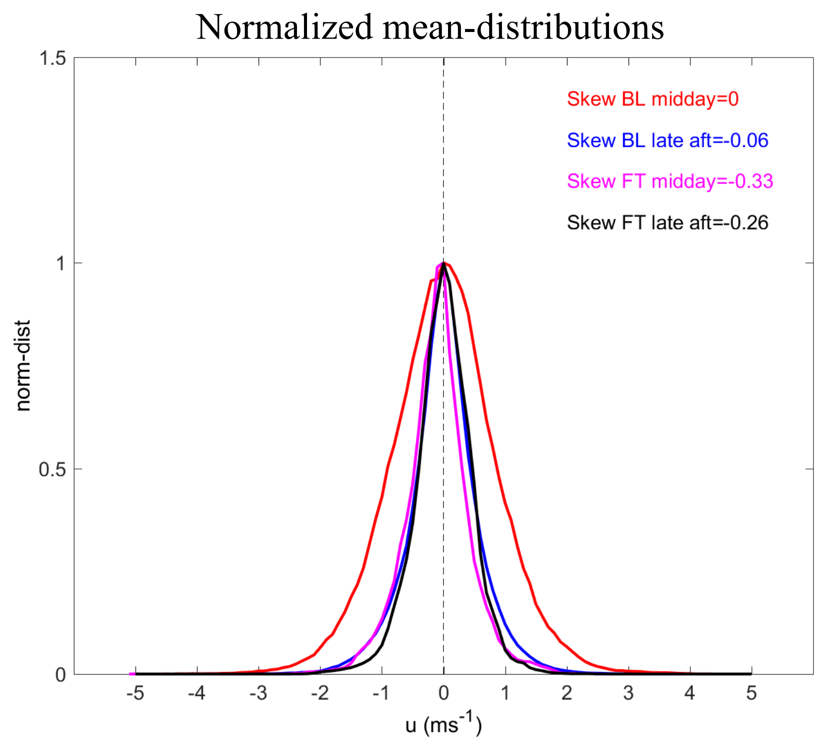




Distributions U

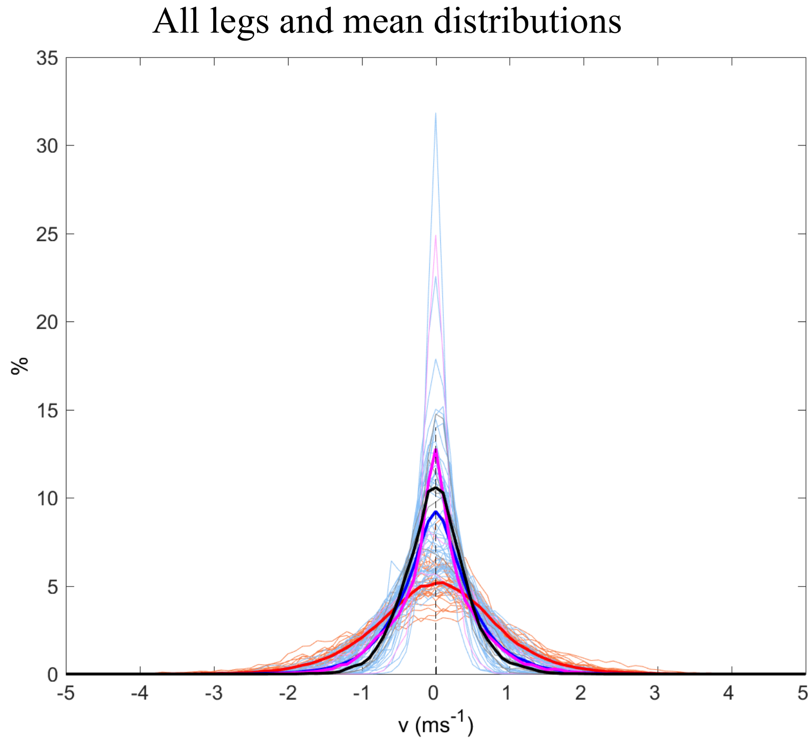
- Variance and weak-values in late afternoon BL close to free troposphere
- Skewed distributions within the Free Troposphere
- Non-skewed distributions within the BL, even late

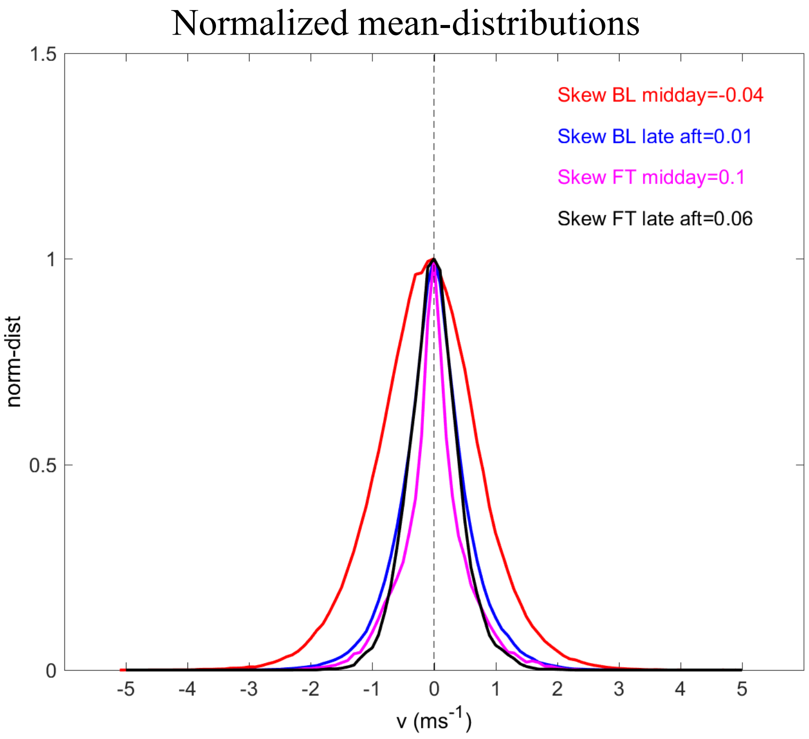




Distributions V

- Variance and weak-values in late afternoon BL close to free troposphere
- Non-skewed distributions within the BL and FT





Conclusion and limitations

- With the very small turbulence energy reached during the LA and ET, we get close to laminar conditions, that can be found within the free troposphere above.
- Turbulent energy is effectively as small within the LA BL than in the FT above
- The distribution of the U, V, W statistics though differ with the LA BL than in the more laminar free troposphere above
- The spectra also seem to show differences (inertial subrange slopes)

BUT

- We have only few legs within the free trosposphere !
- We need to consider the mean wind conditions (even if generally weak)
- We need a further look at the turbulence structure, through different points of views

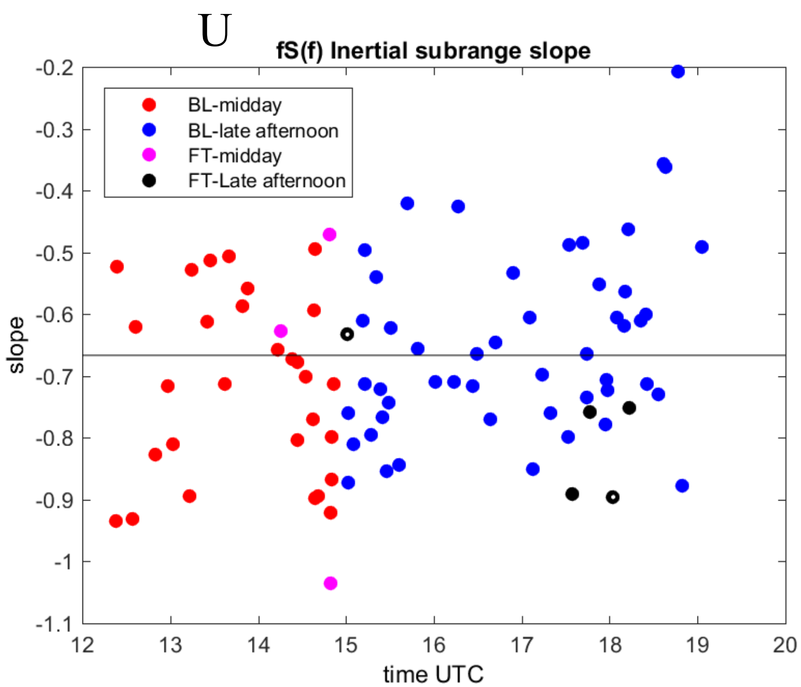
Prospectives

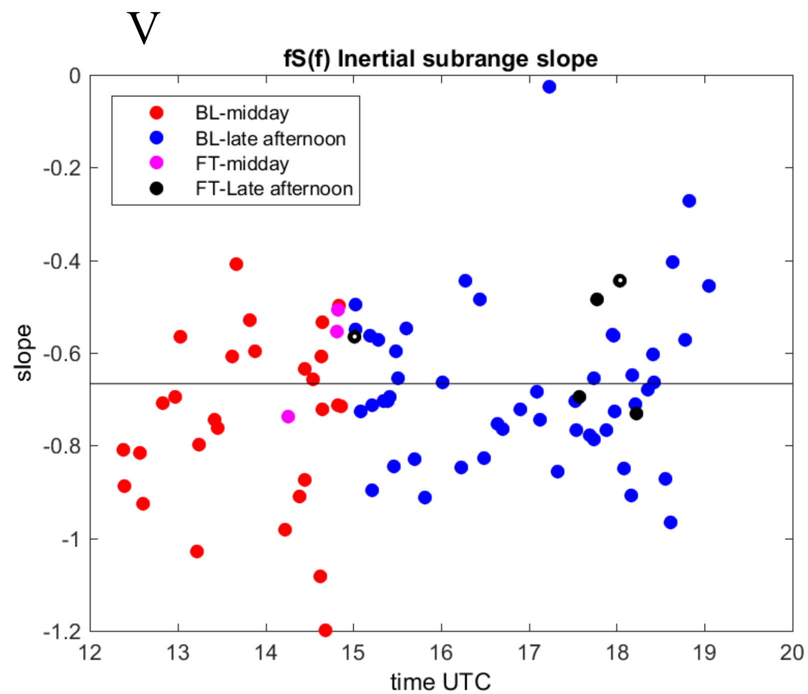
- Characterisation of turbulent structures based on both observations (aircraft PA and SA, RPAS, tethered balloon, Doppler lidar, surface stations) and Large Eddy Simulations

  Scales, co-fluctuations (quadrant analysis), bottom-up and top-down structures,…
- Analysis of the transport and associated scales with tracers emitted within the BL before, during and after the LA at different levels
- Consideration of the mean wind, shear across the BL, entrainment index, LS forcings
- Extension to morning transition
- Extension to other dataset

Inertial subrange spectral slopes

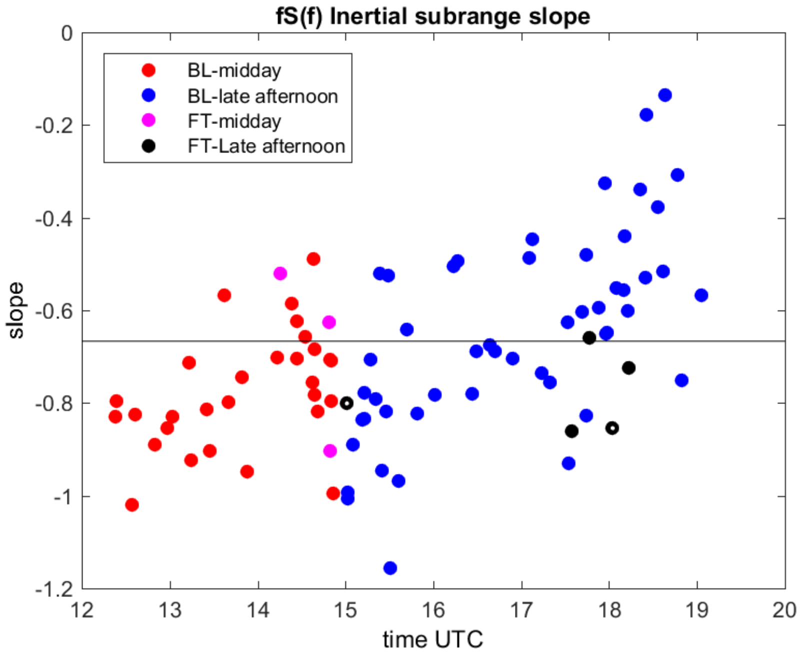
- Slopes get significantly unsteep at $t_{norm} > 0.75$ (consistently w/ Darbieu et al 2015)
- Slopes in Free Troposphere (FT) are not very different from midday BL

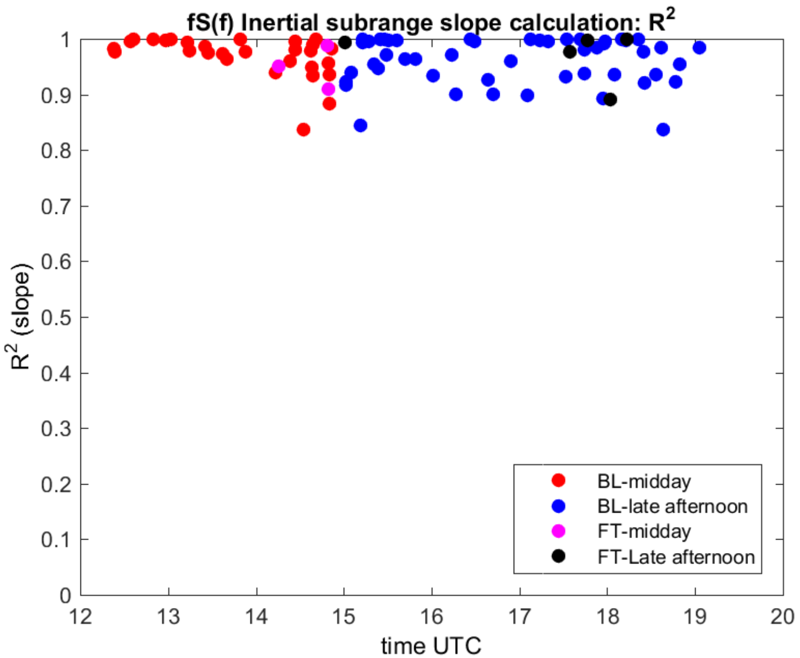




Slopes

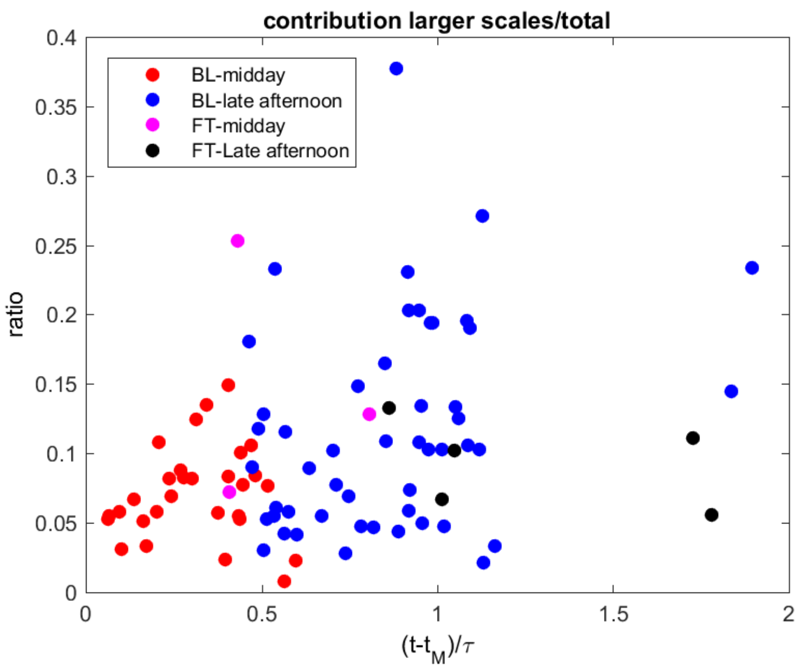
- Slopes get significantly unsteep at t > 0.75 (consistently w/ Darbieu et al 2015)
- Slopes in Free Troposphere (FT) not very different from midday BL
- LA inertial subrange slopes changes found throughout the BL depth

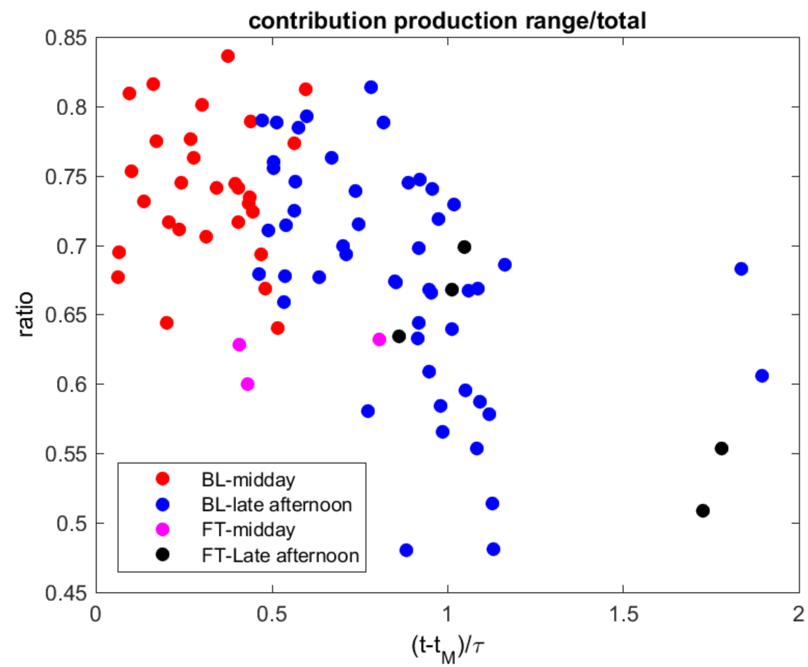




Spectra

- Variance and weak-values in late afternoon BL close to free troposphere
- Non-skewed distributions within the free troposphere
- Skewed distributions within the BL, even late





Scale contributions

- Variance and weak-values in late afternoon BL close to free troposphere
- Non-skewed distributions within the free troposphere
- Skewed distributions within the BL, even late