# MesoNH simulation sensitivty to numerical choices

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# CONTEXT

- Earth System Models (ESM) and Numerical Weather Prediction (NWP) systems often have large biases in their representation of surface fluxes.
- This is due to the representation of the heterogeneous surface and the degree of interaction between the atmospheric flow and surface processes.
- Flow over heterogeneous surfaces is complex – varying vegetation, humidity, temperature, human interference (all seasonal) etc.
- Near-surface turbulent flow is influenced strongly by the surface state. Here heterogeneity is not just mechanical (surface roughness) but also thermal (humidity and temperature patches etc.)

# OBJECTIVES

Simulating one case from the BLLAST field experiment using a coupled MESONH-SURFEX model with a realistic surface.

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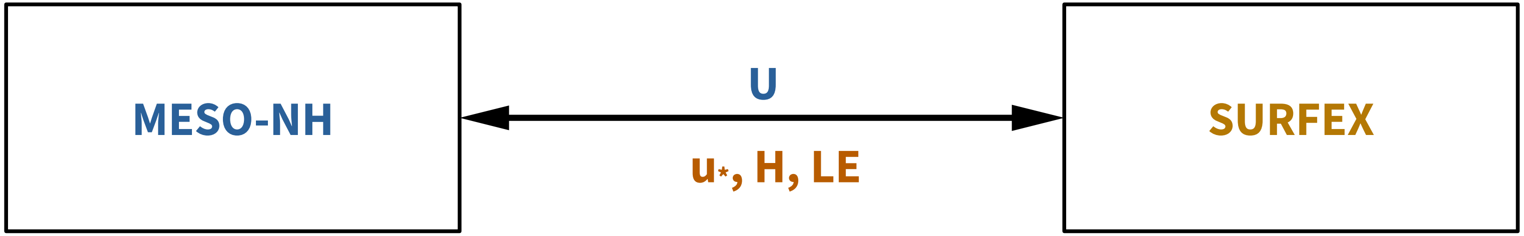
- **LES simulations of REFERENCE CASES for 4 homogeneous surfaces – prairie, wheat, maize, and forest.**

  In the process we hope to,

  - Understand the influence of surface heterogeneity on near-surface turbulent exchanges and boundary layer flow.
  - Document the influence of thermal (humidity /temperature patches ) and mechanical (z0 differences) on the boundary layer flow.
  - Explore the best (simplest) possible way to represent surface heterogeneity.
  - Document modeling issues and complexities.

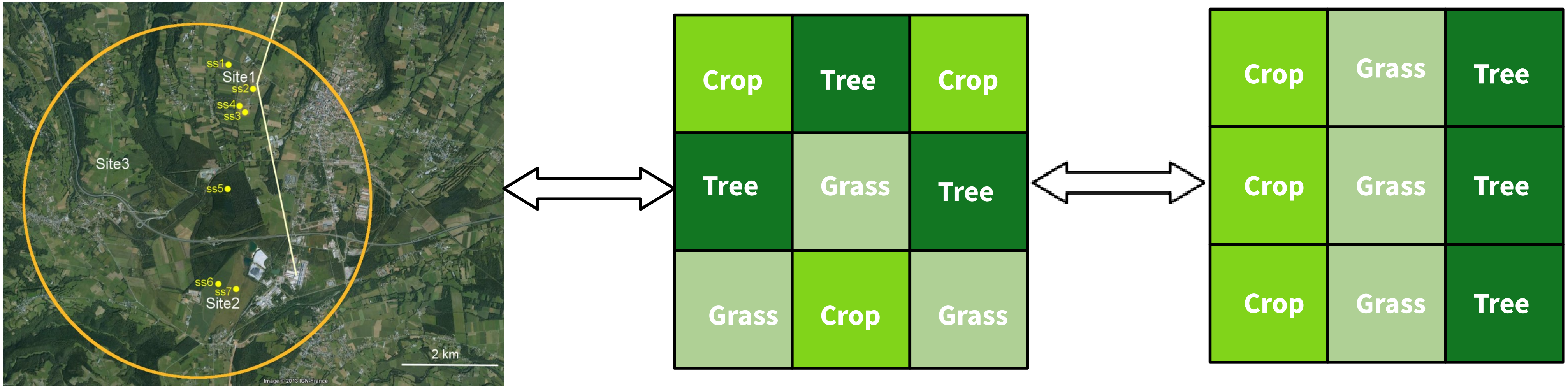
# THE NUMERICAL MODEL

- MesoNH – SURFEX coupled model.
- MesoNH : Meso-scale non hydro-static atmospheric model capable of simulating the main turbulent eddies of the atmospheric flow. Model can be used in LES or bulk mode.
- SURFEX : Surface model that provides surface information such as mechanical roughness ($z_0$), friction velocity ($u_*$), surface humidity, surface temperature, sensible and latent heat fluxes etc. to MesoNH.



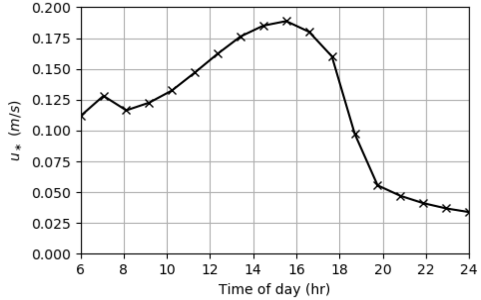

- SURFEX can be used using realistic maps, or in an idealized / semi-idealized format.

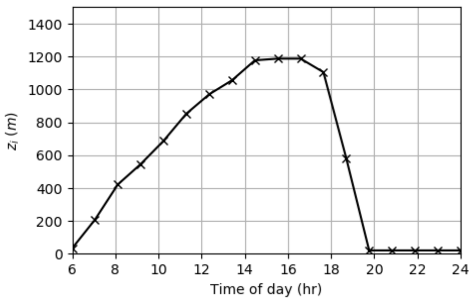
# KEY QUESTION: How to represent surface heterogeneity ?

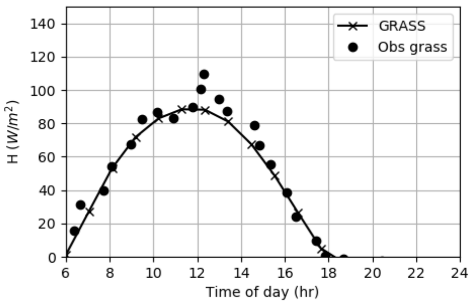


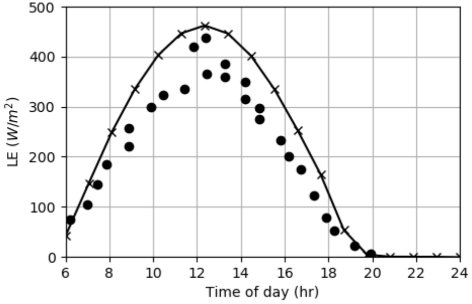

- Is there an alternative, easier way to represent surface heterogeneity? Can we simplify the problem?
- Does the arrangement of surface heterogeneity (same percentage) have the same effect on the turbulent flow and boundary layer development?
- Which heterogeneity is more important – mechanical or thermal? And to what extent?

# FIRST SIMULATION : PRESCRIBED to DIURNAL fluxes

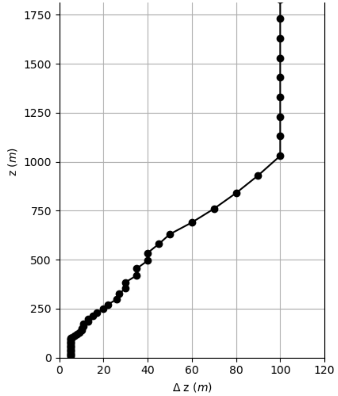


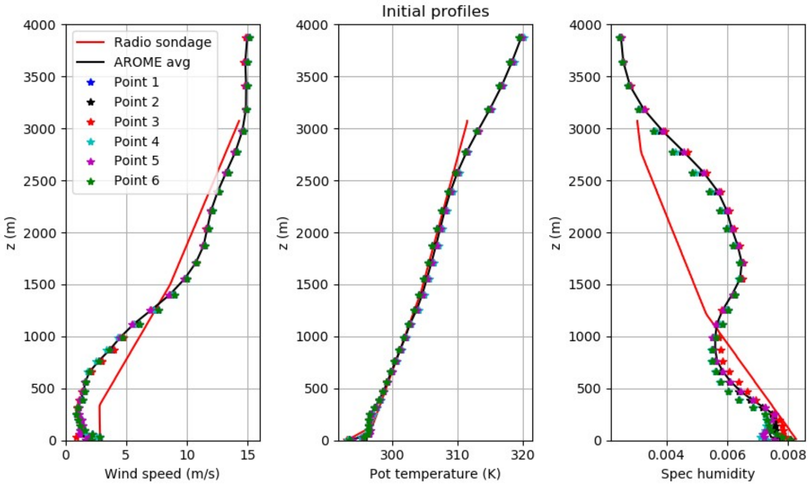



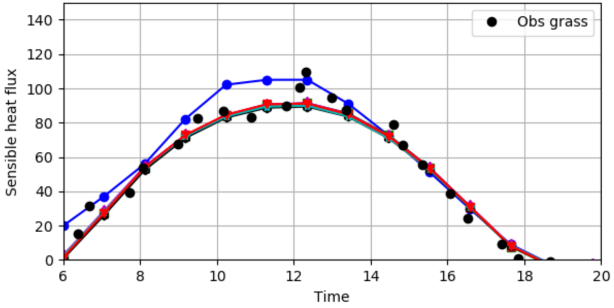



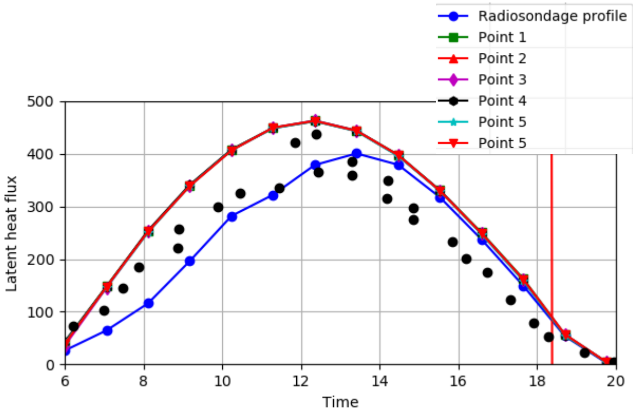

- **1D domain**, with a stretched vertical grid.
- Time step 4s, period 18h.
- Starting from the simulations of Darbieu et al. (2015) with prescribed surface fluxes we obtain the BLLAST diurnal observations for prairie (grass).
- Prescribed fluxes imply shortcutting the atmosphere/surface interaction to reproduce the observed surface fluxes and BL flow.
- Can we reproduce the same, without prescribing surface fluxes?



# CHOICE OF INITIAL PROFILES :



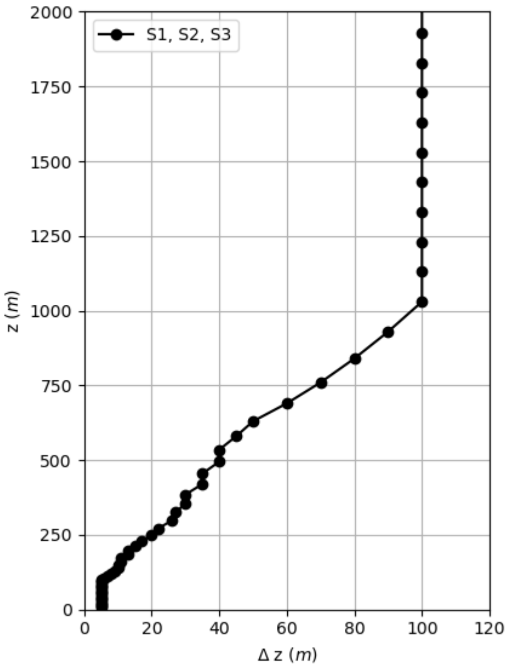




- Similar 1D domain with a stretched vertical grid.
- No significant differences in the simulated surface flux profiles between AROME and RADIO SOUNDING initial profile choices. Simulated values are close to those observed during the BLLAST experiment.
- No significant change in BL development and turbulent flow (results not shown).
- Hereafter, **we chose** the RADIO SOUNDING profile corresponding to the BLLAST experimental site for all future simulations.

# NUMERICAL UNCERTAINITIES

- **Numerical choices can influence the outcome of simulations, and therefore lead to misleading artifacts.**
- **These choices include:**
  - Domain size.
  - Horizontal and vertical grid resolution
  - Time step and simulation duration.
  - Boundary conditions.
  - Surface conditions.

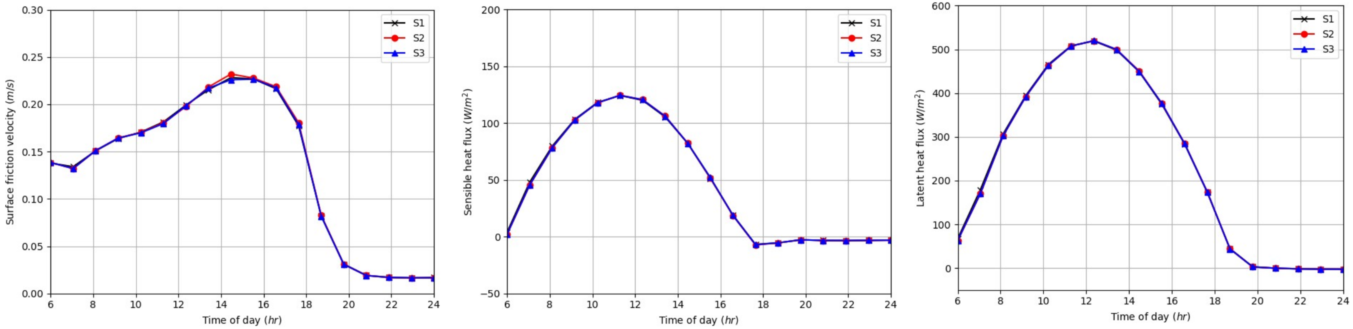
# DOMAIN SIZE?

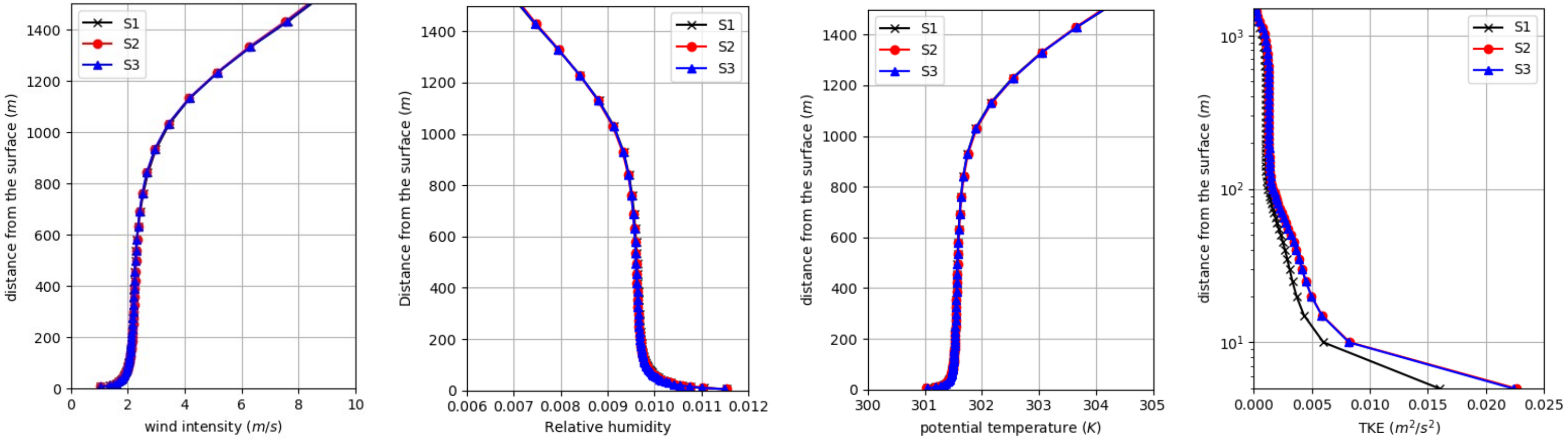



- Three domain sizes: 5X5, 10X10 and 25X25km horizontal layout and 4km depth (vertical).
- Same vertical and horizontal grid across simulations.
- Time step: 3s.
- Simulation duration: 18hrs.
- Lateral BC: cyclic (infinite fetch).
- Vertical BC: absorption layer at 3500m.
- Surface: 90% grass cover of LAI=2.5.

# DOMAIN SIZE?

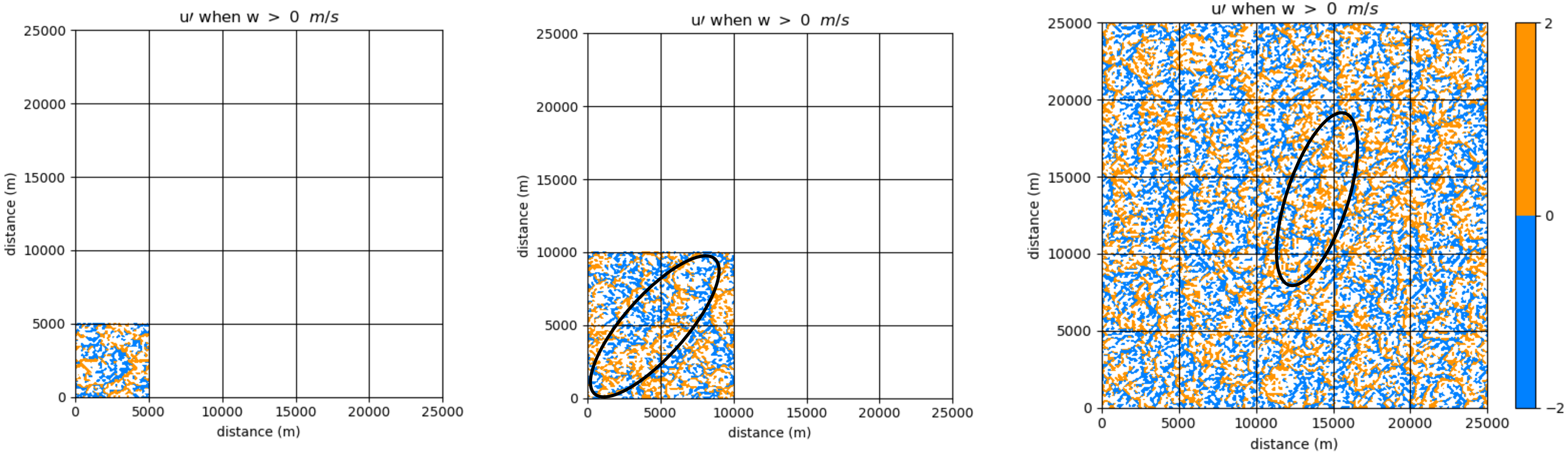
- No effect on the mean surface fluxes – u*, H, LE.
- No effect on the space time (11h-17h) averaged vertical wind, rel humidity and pot temp profiles.
- Smaller domain (S1) underestimates the TKE near the surface.



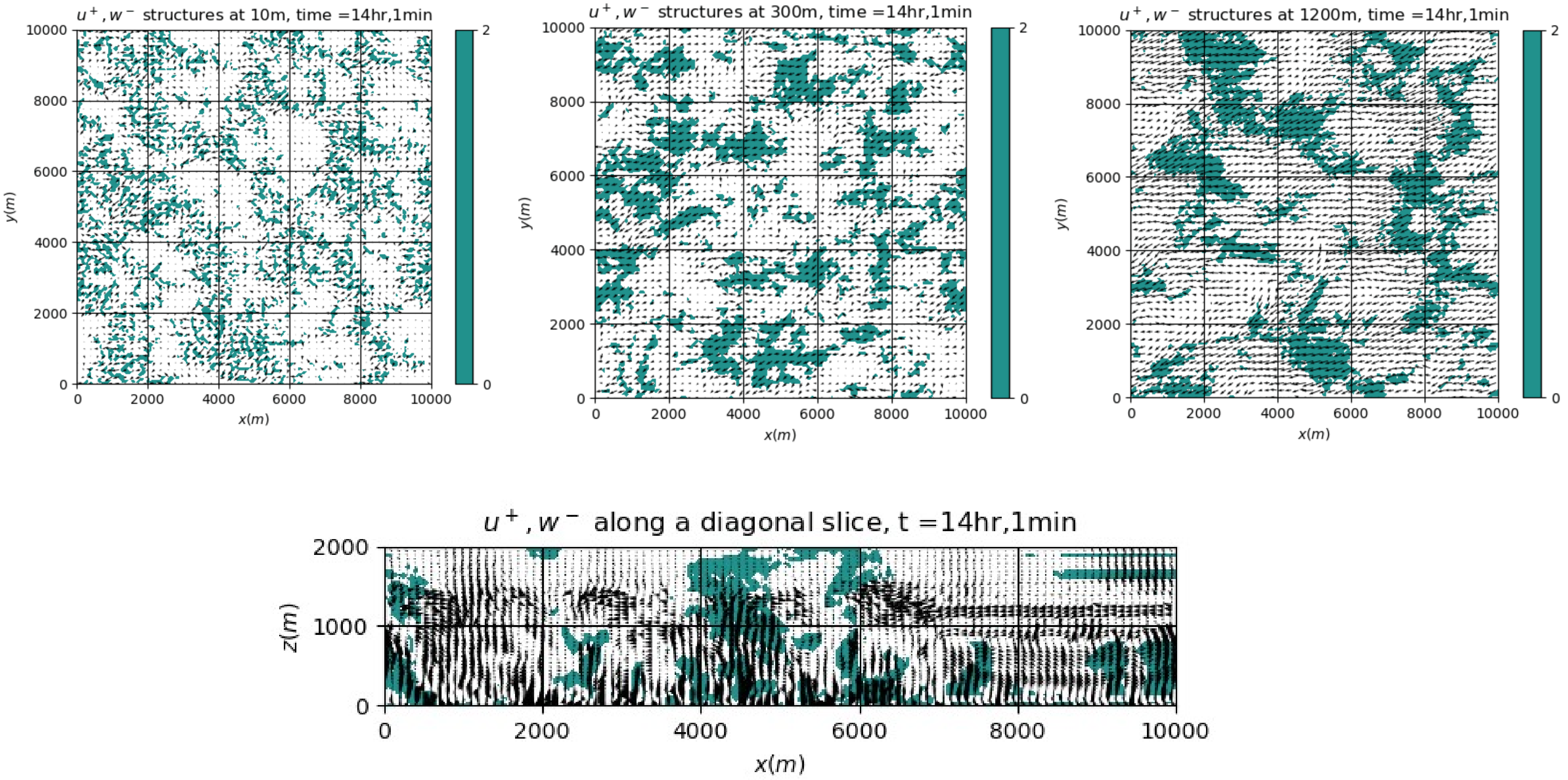
# DOMAIN SIZE?

- The size of turbulent structures do not change with domain size.
- The largest, elongated structures near the surface seem larger than the smallest domain S1 (5X5km).
- S1 seems not sufficient enough to fully simulate the turbulent structures.
- S2 (10X10km) domain appears to be sufficiently large for the turbulent structures to form fully.

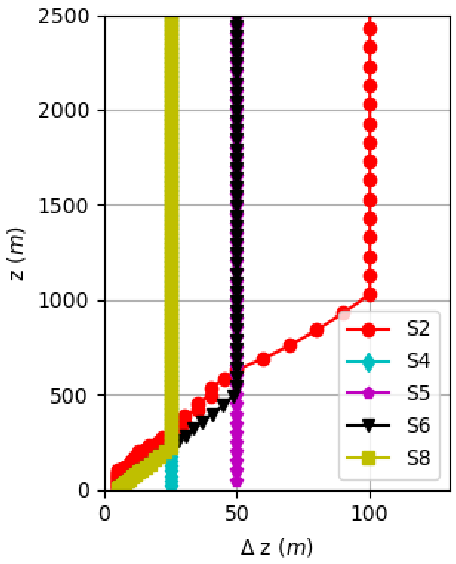



**Snap shot at 14h**

# DOMAINE SIZE?



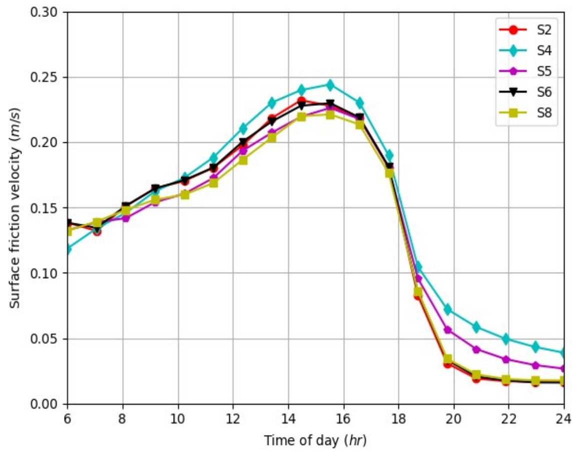
# THE CHOICE OF VERTICAL GRID RESOLUTION

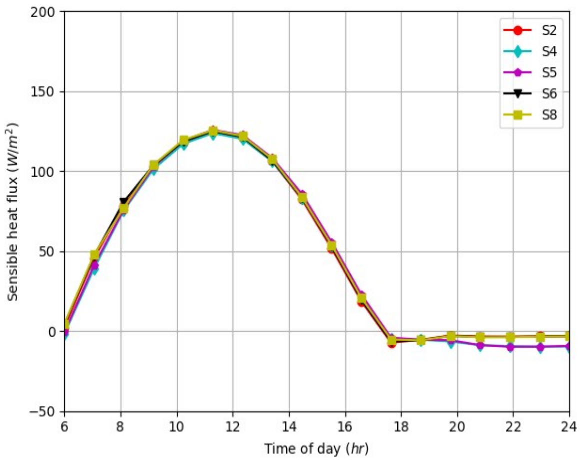


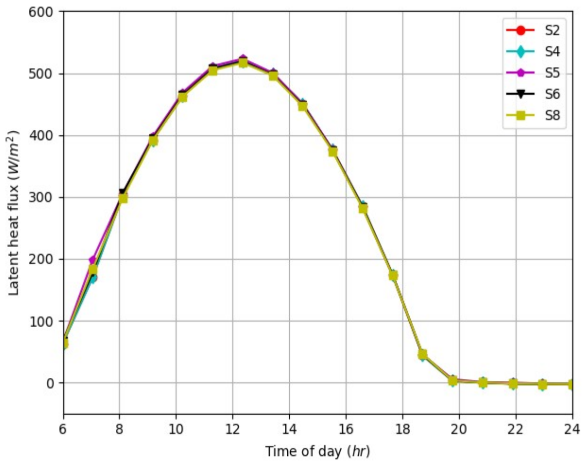

| Case | No levels | z_end | dz(min)/ dz (max) |
|---|---|---|---|
| S2 | 72 | 4000 | 10 / 100 |
| S4 | 65 | 4000 | 50 / 50 |
| S5 | 130 | 4000 | 25 / 25 |
| S6 | 81 | 4000 | 5 / 50 |
| S8 | 139 | 4000 | 5 / 25 |

- Same 10X10km domain across cases.
- Same time step of 3s.
- Simulation duration: 18hrs.
- Lateral BC: cyclic.
- Vertical BC: absorption layer at 3500m.
- S4: constant dz of 25m.
- S5: constant dz of 50m.
- S6: dz1=5m, stretched until dz=25m, and constant thereafter.
- S8: dz1=5m, stretched until dz=50m, and constant thereafter.

# THE CHOICE OF VERTICAL GRID RESOLUTION



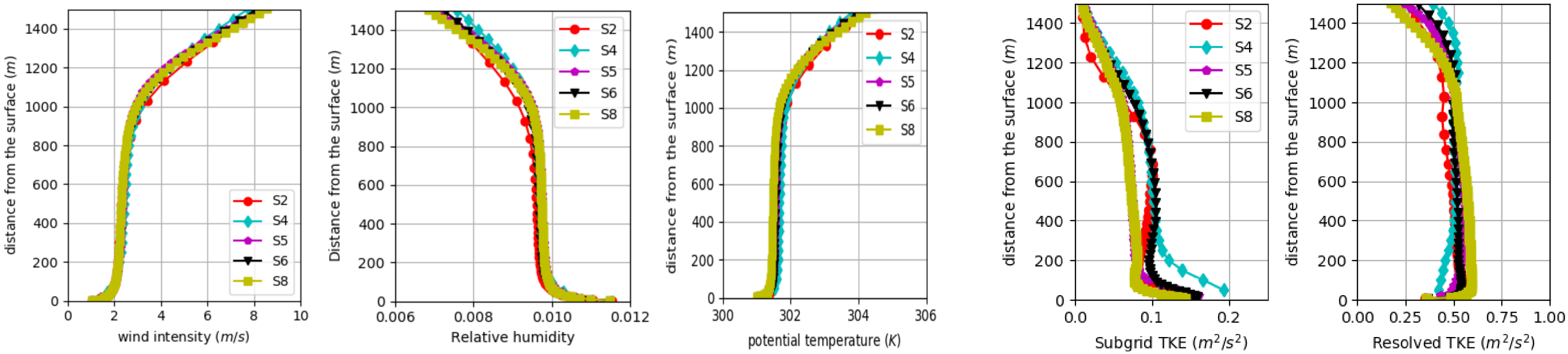




- No influence of vertical grid resolution on the surface heat fluxes (sensible and latent).
- Coarser near-surface grid tends to over estimate the friction velocity, most probably because its incapacity to explicitly resolve the most important turbulent structures. Hence a larger subgrid contribution (greater impact of parameterisations and empirical constants).

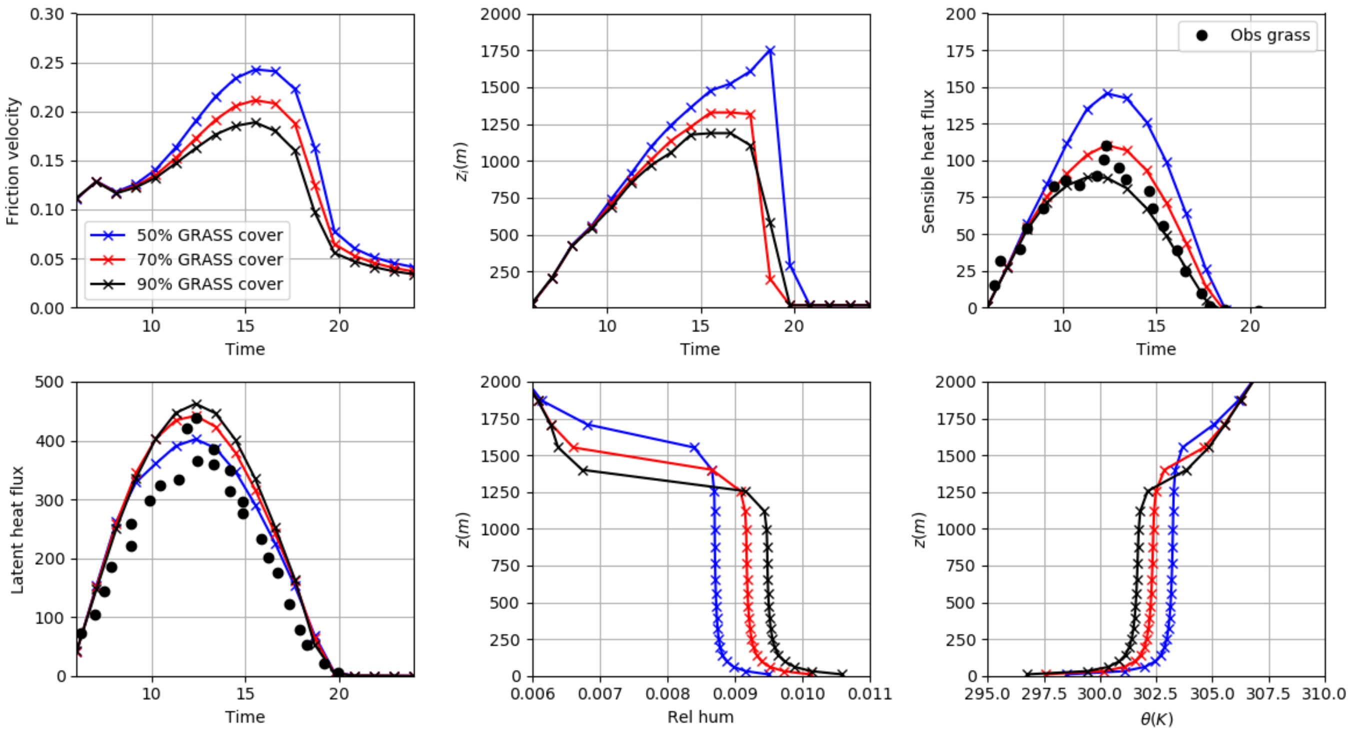
# THE CHOICE OF VERTICAL GRID RESOLUTION

**Average between 12h & 16h**




- No remarkable impact of vertical grid resolution on the mean wind, rel humidity, and potential temperature profiles.
- Coarse near-surface grid over estimates the subgrid TKE and cannot resolve the most important structures (thus a lower resolved TKE).
- A finer grid, as seen in S8, better resolves the turbulence: greater contribution of resolved TKE. But costs more!

# SURFACE CHOICES ?

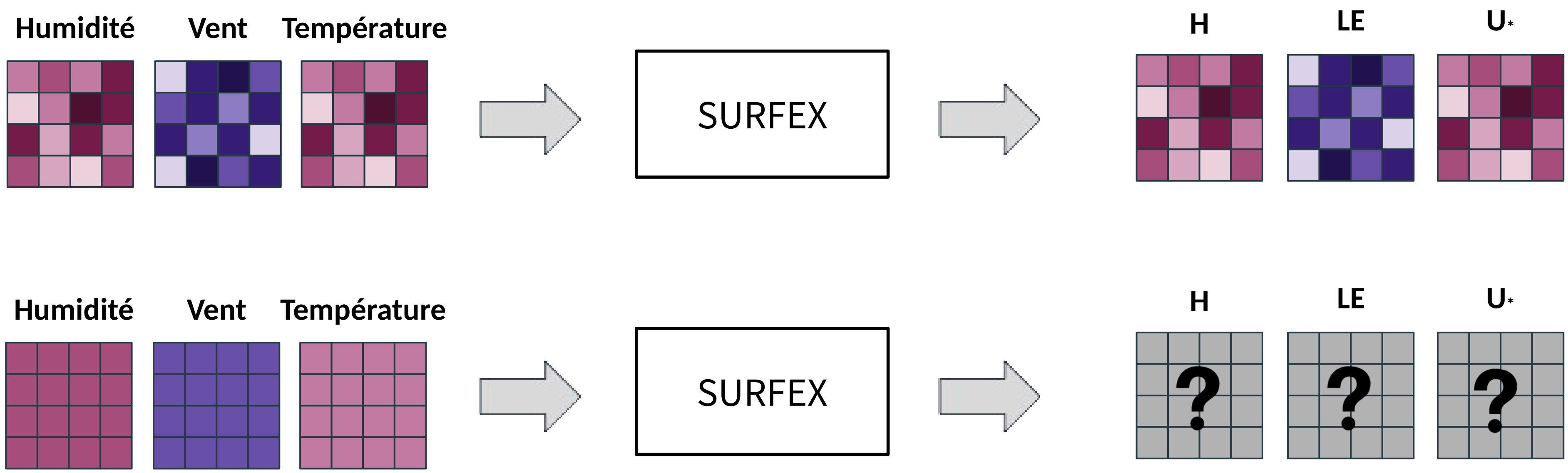



- Surface characteristics strongly influences both the near-surface turbulent flow and the BL growth.
- A more heterogeneous surface (50% cover), is rougher, and therefore leads to a greater $u_*$ and a deeper BL.
- A larger vegetation cover, leads to lower H due to lesser bare surface and a greater LE on account of more prominent evapo-transpiration.
- This is also seen in the lower rel humidity and greater potential temperature for lower vegetation cover.

# SUMMARY: SIMULATION CHOICES

- INITIAL PROFILES: Average AROME from 6 different points.
- TEMPERATURE FORCING: function of chosen date (solar radiation) and geographical location.
- DOMAIN SIZE: 10x10km for idealized cases.
- GRID RESOLUTION: 50x50m horizontal. z1=5m, stretched at 10% to z=50m and constant thereafter upto 4000m.
- TIME STEP: 3s.
- LATERAL BOUNDARY CONDITION: cyclic.
- VERTICAL BOUNDARY CONDITION: absorption layer at 3500m.
- SURFACE FLUXES: a function of temperature forcing and choice (type) of surface but not grid dimension or domain size.

# SENSITIVITY TO WIND AND TEMPERATURE FLUCTUATIONS

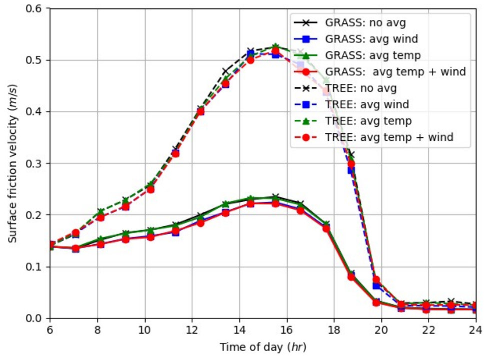


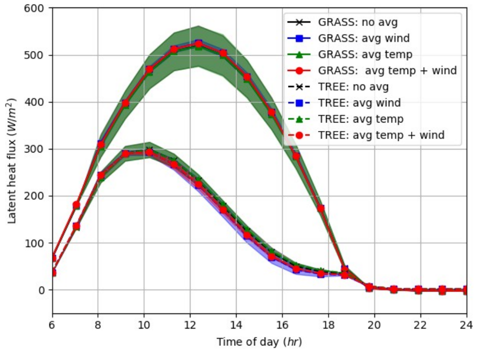
# SENSITIVITY TO WIND AND TEMPERATURE FLUCTUATIONS

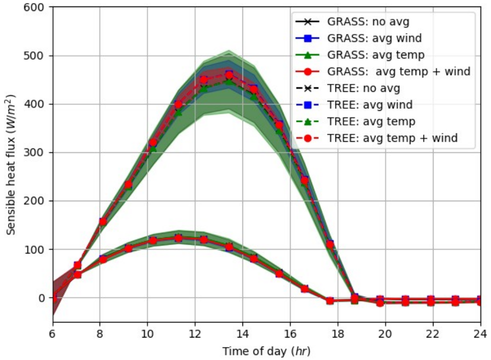
| PARAMETER | GRASS CASE | TREE CASE |
|---|---|---|
| Surface cover | 90 % | 90 % |
| SWI (surface) | 0.05 | 0.05 |
| SWI (root) | 0.30 | 0.30 |
| SWI (deep soil) | 0.70 | 0.70 |
| Root depth | 1m | 4m |
| Surface Temperature | 286.5 K | 285.0 K |
| Deep soil temperature | 293.5 K | 293.5 K |
| Vegetation height | 10cm | 10m |

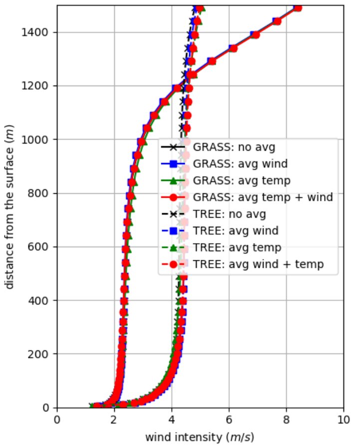
- 4 cases for each surface cover :
  - CASE1 : Unmodified simulation.
  - CASE2 : Averaged wind intensity at the 1st grid cell, before estimation of surface fluxes in SURFEX.
  - CASE3: Averaged temperature at the 1st grid cell, before estimation of surface fluxes in SURFEX.
  - CASE4: Averaged wind and temperature.

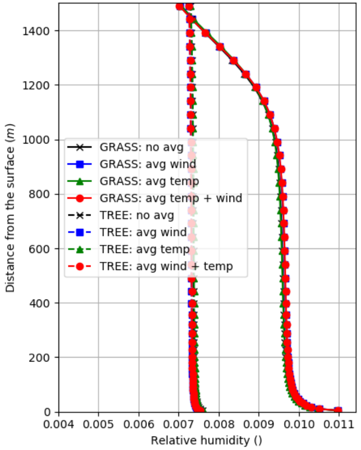
# SENSITIVITY TO WIND AND TEMPERATURE FLUCTUATIONS

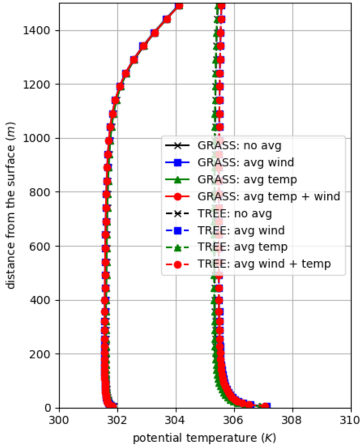


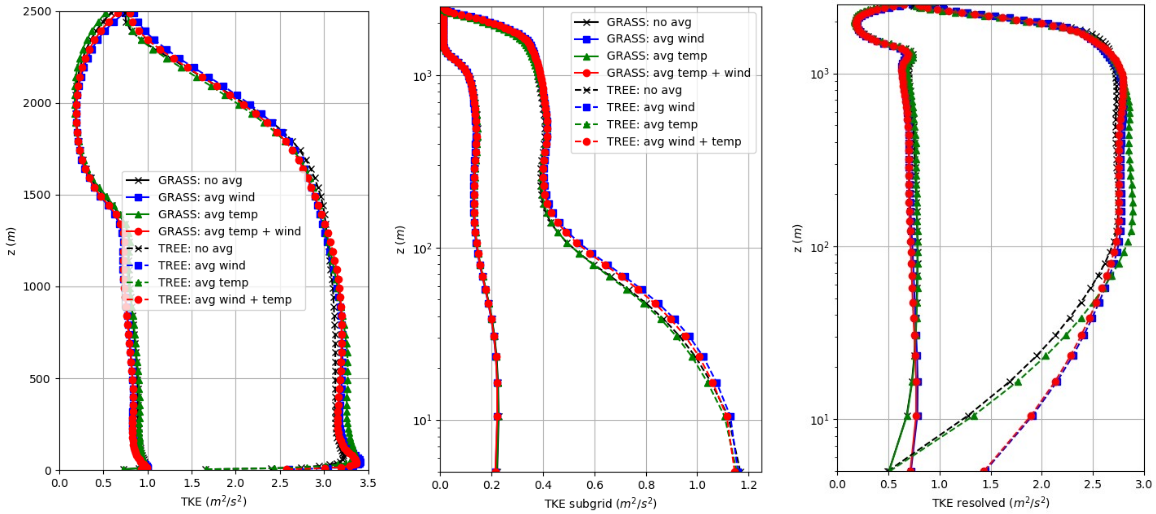



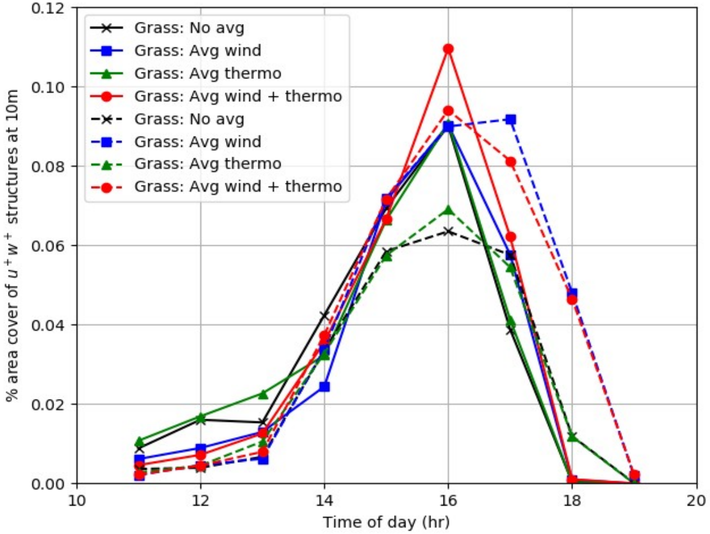

- Wind fluctuations impact LE fluxes more strongly than H. This impact is greater for TREE than GRASS surface cover.
- Wind speed fluctuations have a more stronger impact on the friction velocity than temperature ones.
- No difference in the vertical profiles of wind intensity, rel humidity and potential temperature.

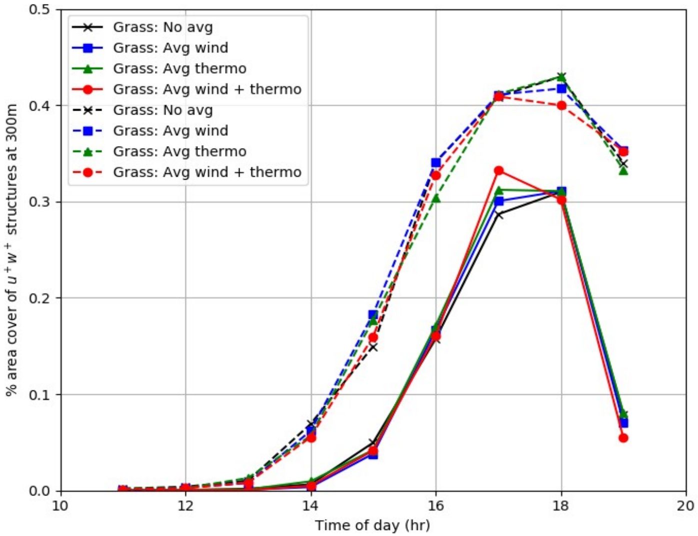
# SENSITIVITY TO WIND AND TEMPERATURE FLUCTUATIONS




- Wind / temperature averaging at the surface influences TKE distribution in the BL, even at distances of 100m.
- Subgrid TKE is purely a function of the grid resolution.
- Overall, the effect of wind fluctuations on the TKE is twice as more important over forests as over grass. This is part is due to the higher mechanical turbulence resulting from a greater surface roughness.

# SENSITIVITY TO WIND AND TEMPERATURE FLUCTUATIONS




- Effect of wind is more pronounced on the near-surface turbulence, and this is strongly linked to the surface roughness.
- At 300m, the effect of surface fluxes appears to even out (disappear)?

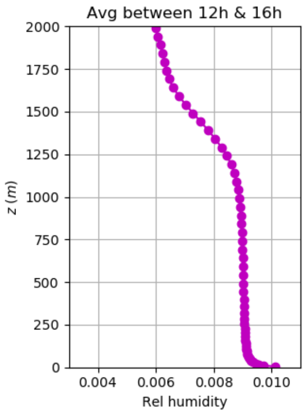
**TAKE AWAY: Surface wind influences strongly the turbulent transport and BL flow, and this effect is modulated by the surface roughness.**

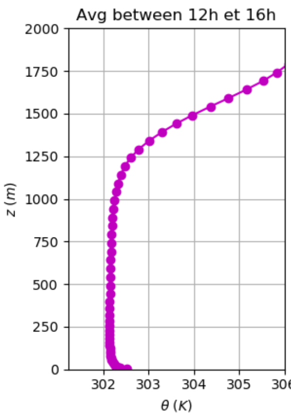
# SUMMARY

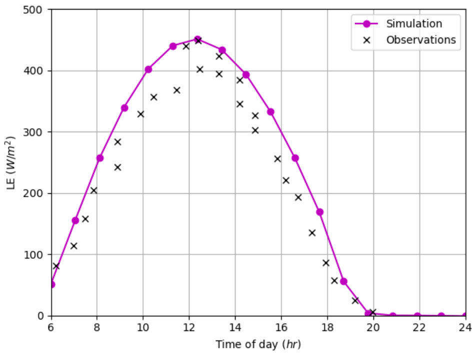
- Our analyses helped choose the right domain size, grid resolution, and time step for future simulations.
- We confirmed the previously suspected fact that the wind is a stronger motor of the near-surface turbulence and boundary layer flow.
- Surface fluxes and their sensitivity affects not just the flow close to the surface, but also at distances as far as 100m. However, father into the boundary layer, the flow is less influenced by the surface and more by the large-scale tendencies.
- Surface heterogeneity (mechanical) can influence surface fluxes and the depth of the BL.
- The simulated flow is extremely sensitive to the choice of surface features.

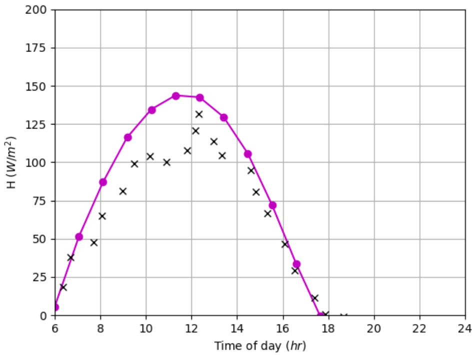
# REFERENCE CASE : PRAIRIE

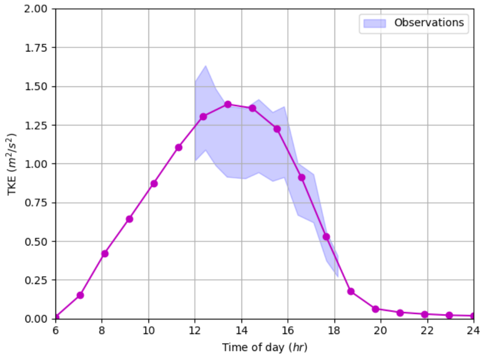
- **Domain :** 10x10km, with a 50x50m horizontal grid, and time step 3s.
- **Vertical grid :** z1=5m, stretched at 10 % until 50m and constant thereafter.
- **Veg cover:** 90%
- **Veg LAI:** 2.5
- **Surface temperature:** 285.5K
- **Surface SWI:** 0.05
- **Day of year:** 20/06/2011.
- **Lateral BC:** cyclic (infinite fetch)
- **Vertical BC:** absorption layer at 3500m

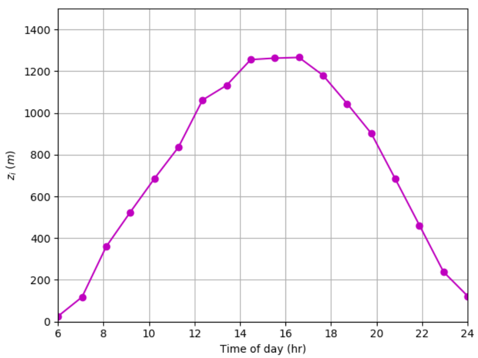


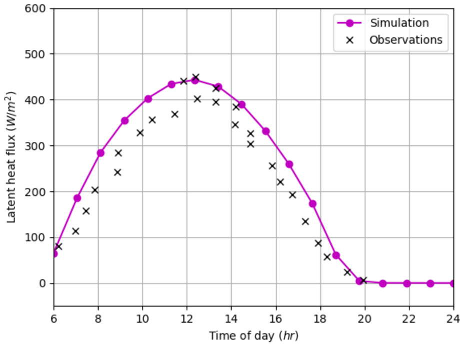



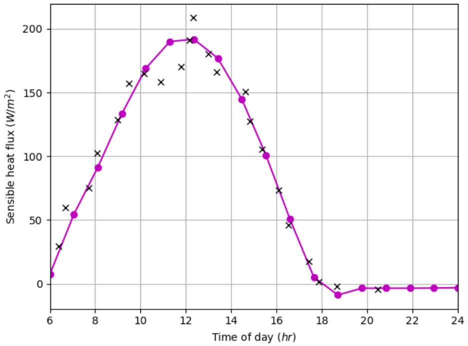



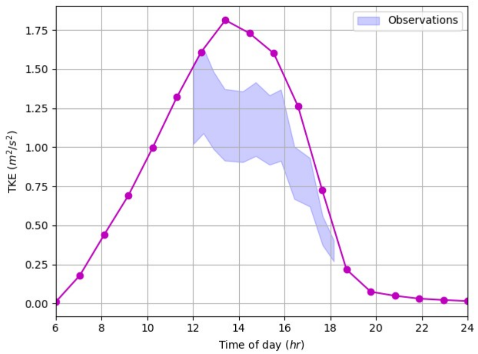



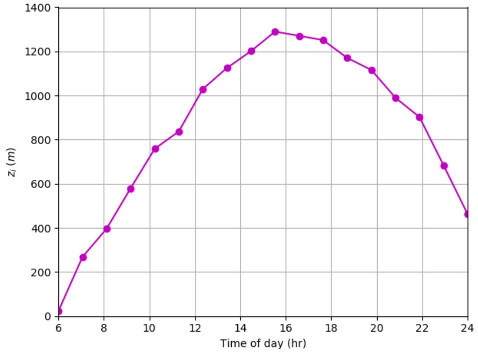



# REFERENCE CASE : WHEAT

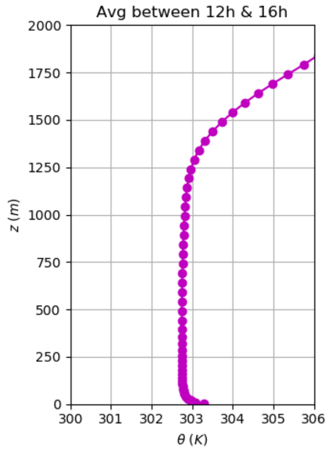


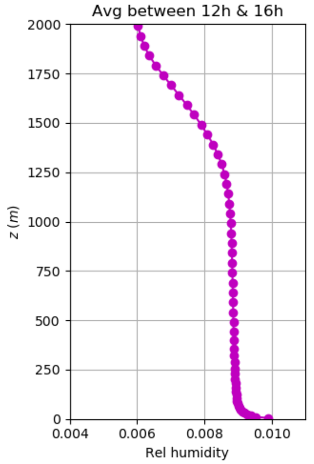



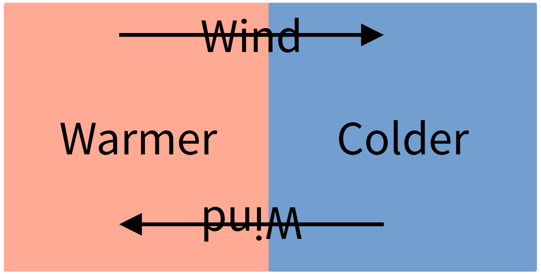




- **Domain :** 10x10km, with a 50x50m horizontal grid, and time step 3s.
- **Vertical grid :** z1=5m, stretched at 10 % until 50m and constant thereafter.
- **Veg cover:** 70%
- **Veg LAI:** 3.5
- **Surface temperature:** 287.0K
- **Surface SWI:** 0.05
- **Day of year:** 20/06/2011.
- **Lateral BC:** cyclic (infinite fetch)
- **Vertical BC:** absorption layer at 3500m



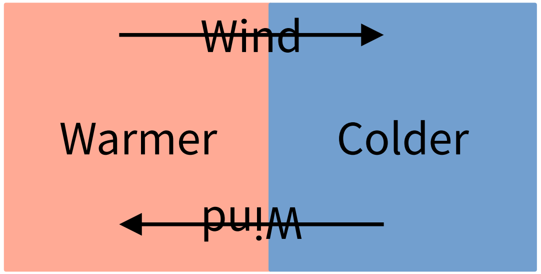



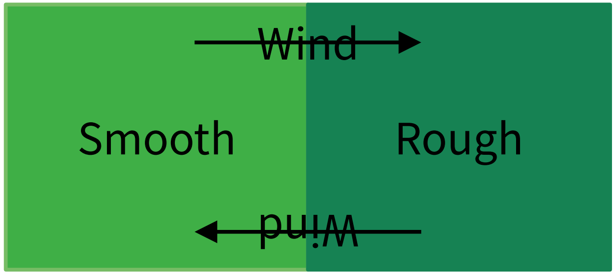
# WHAT NEXT ?




- What impact do surface heat patches have on the BL developement and turbulent flow ?
- Does the wind direction have a significant effect?

# WHAT NEXT ?



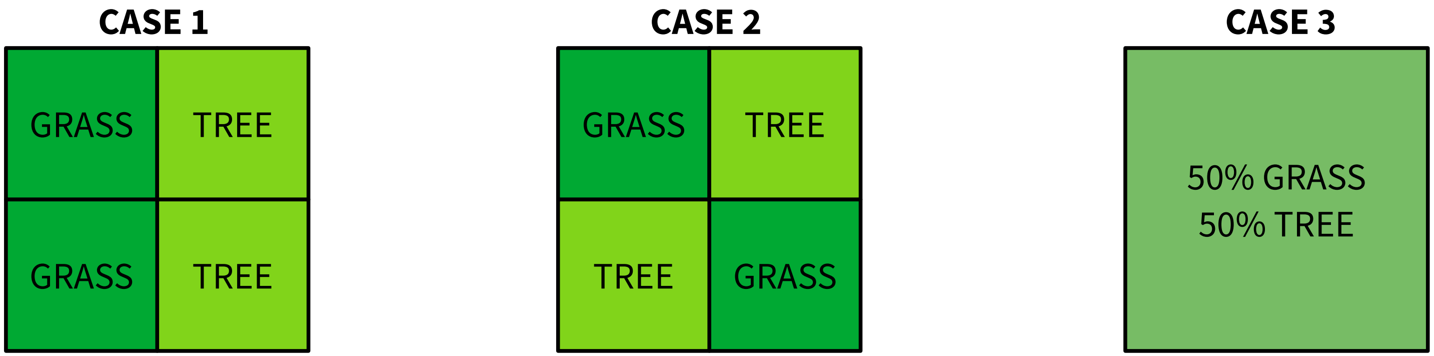




- What impact do surface heat patches have on the BL developement and turbulent flow ?
- Does the wind direction have a significant effect?

- Similarly, what impact does z0 change have on the wind flow and BL development.
- To what extent is this a function of the wind direction?

To what extent do humidity patches play a role on the turbulent flow ?

# AND THEN ?




- To what extent can we simplify the representation of surface heterogeneity?
- Are the 3 surface representations similar?
- Does surface influence ( based on surface choice) disappear at some scale? If yes, at what scales?
- How best can we quantify heterogeneity?

**Simulating one case from the BLLAST field experiment using a coupled MESONH-SURFEX model with a realistic surface.**


Merci!