Long term simulation of atmospheric flow with Code_Saturne and comparison with SIRTA measurements

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Objective

The objective of this work is to simulate the long term micro-scale atmospheric flow characteristics over SIRTA using a dynamical downscaling with a CFD model nested in a meso-scale model.

Methodology

The meso-scale WRF model has been run over the region surrounding SIRTA for the whole year 2011. Three embedded domains have been used with a horizontal resolution of 3 km in the smaller domain and 39 stretched vertical levels. The hourly wind, temperature, and turbulence profiles corresponding to the grid point closest to SIRTA are imposed as inlet boundary conditions of the CFD code *Code_Saturne* (developed at EDF-R&D and CEREA), which allows to take into account the small scale heterogeneities of the site (buildings, forests). Rather than simulating all the atmospheric states at hourly frequency with *Code_Saturne*, clustering methods are used to reduce the number of atmospheric states (8760 states for 1 year) to a low number of representative clusters [1]. This reduces the computational time cost. Two methods of clustering have been used: one supervised and one non-supervised.

SIRTA data set

For comparison with the SIRTA measurements, 3 sonic anemometers have been used: one from Zone 1 at 10 m (denoted z1_10m), and two from zone 4 at 10m and 30m (denoted z4_10m and z4_30m) (figure 1). The measured flow variables used here are the wind velocity components and the turbulent kinetic energy.

Clustering Methods

The input parameters used for the clustering are: (i) the wind velocity components *(u, v)* at 50 m and the Richardson number *Ri* (between 6 m and 50 m) for the non-controlled clustering, and (ii) the wind speed and direction and the Richardson number for the controlled clustering (at same heights). For the non-controlled clustering the algorithm Kmeans based on the Euclidian distance in the parameters space *(u, v, Ri)* is used, and the optimal number of clusters defined using the Kullback-Leibler divergence *(KL)* is found to be around 200. To keep the number of clusters in the controlled clustering as close as possible to that of the non-controlled clustering, 36 wind direction sectors, four classes of wind speed, and four classes of the atmospheric stability are used. Only one wind speed is considered for the neutral class (similarity hypothesis). The resulting number of the non-empty clusters is 202. In the figure 2 are shown the clusters distribution for both methods. To assess the clustering performance two parameters are used: Kullback-Leibler divergence (KL) and Mean Absolute Error (MAE).

$$KL = \sum_{k=0}^{N} P(k) \log \frac{P(k)}{Q(k)} \qquad MAE = \frac{1}{N} \sum_{k=0}^{N} |P(k) - Q(k)|.$$

where P and Q are the distributions before and after clustering respectively

Fig. 1: SIRTA site configuration

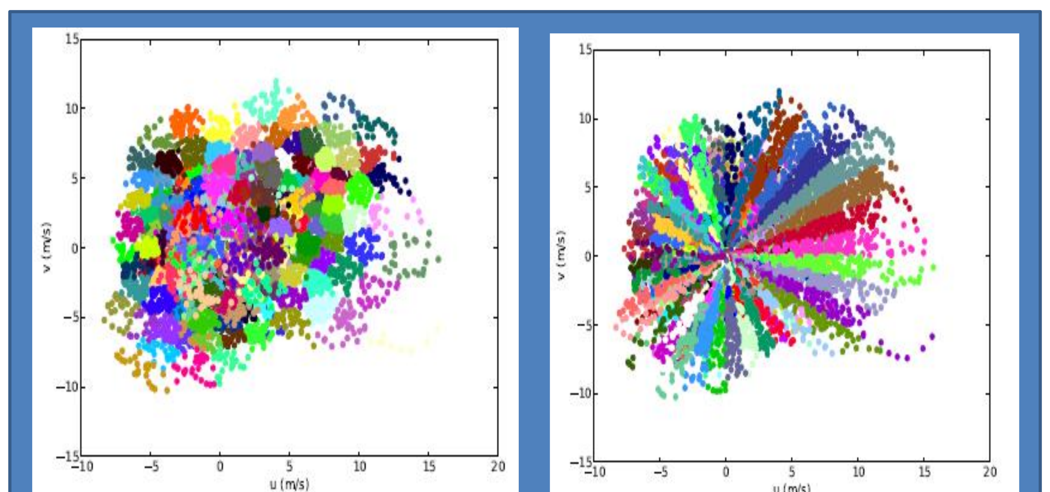


Fig. 2: Clusters distribution in *(u, v)* space obtained with the non-controlled (left) and controlled (right) clustering methods

Code_Saturne Simulations

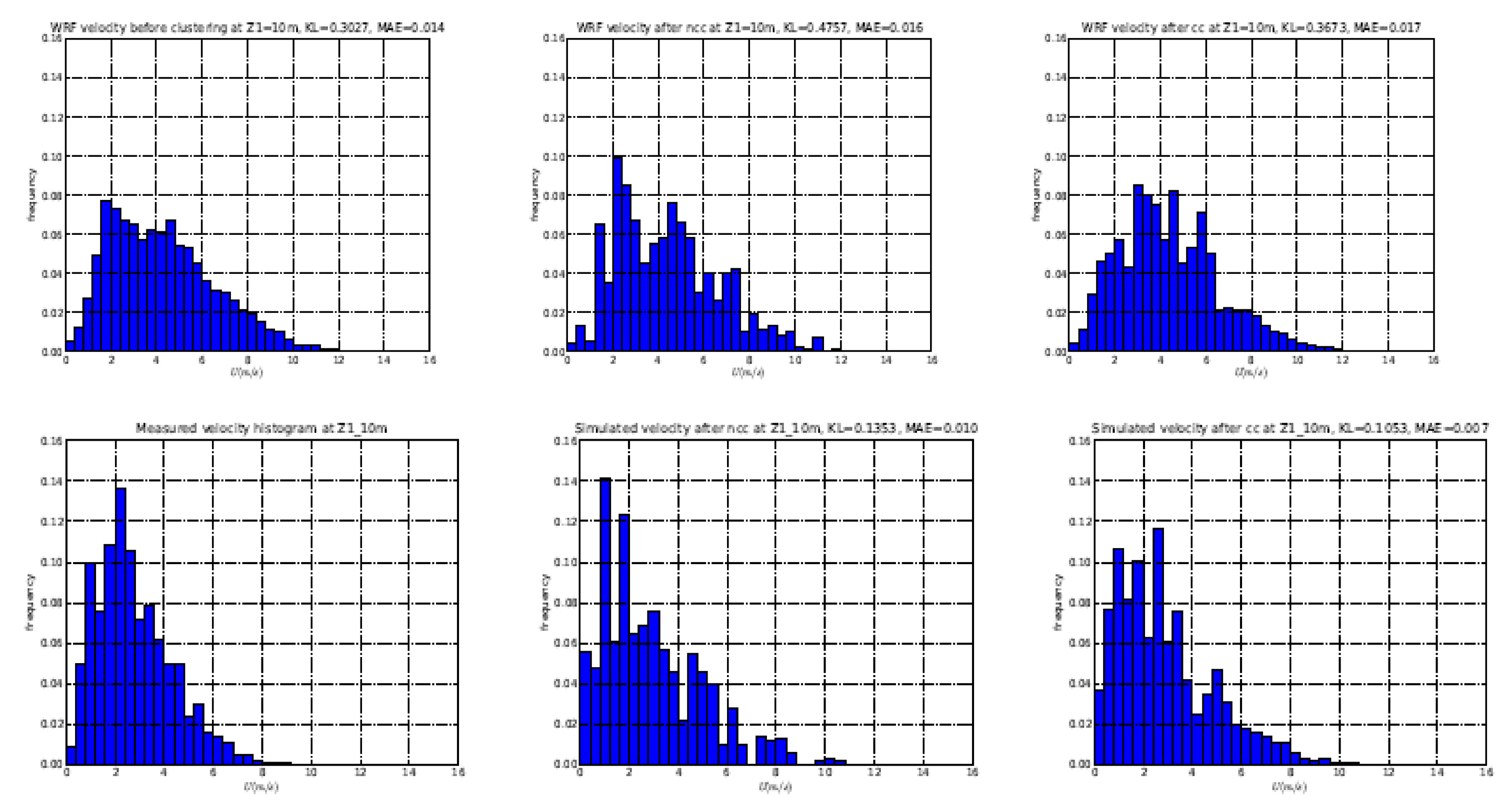
For both the controlled and non-controlled clustering, the representative states of the clusters are simulated using *Code_Saturne*. The atmospheric module is used taking into account the thermal stratification of the atmosphere. The simulation domain size is taken to 2.2 km and 1.8 km in the WE and SN directions. The domain is discretized with a high enough resolution (5 m) to account for the ground heterogeneity. The buildings are represented explicitly as obstacles while the forests are modelled as porous media using the drag force approach [2].

Conclusion

- *Code_Saturne* has been used to simulate the long term atmospheric flow over SIRTA using nesting in WRF and clustering
- This downscaling methodology leads to wind and turbulence distributions in good agreement with SIRTA measurements
- The two clustering methods (controlled and non-controlled ones) lead to similar results

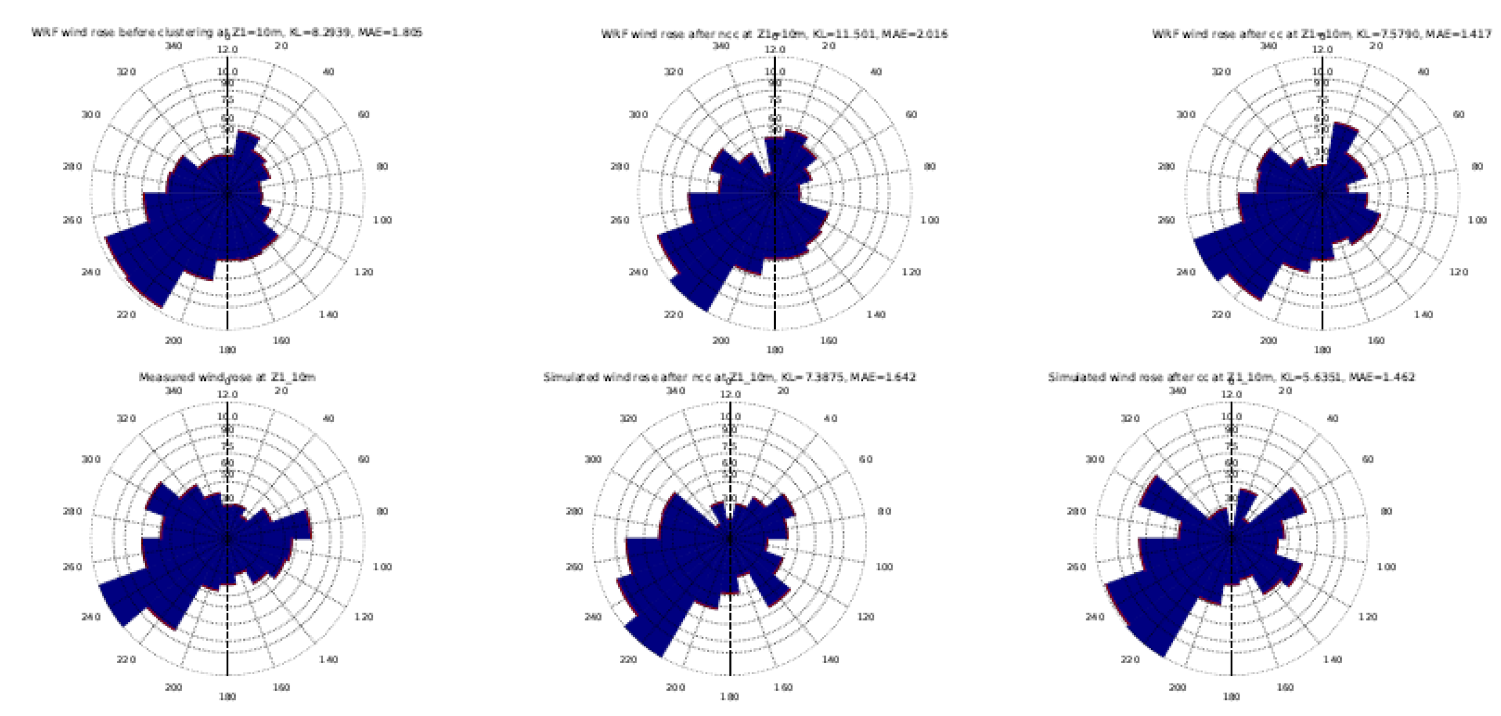
Results

WRF and *Code_Saturne* velocity distribution before and after clustering (Z1_10m)



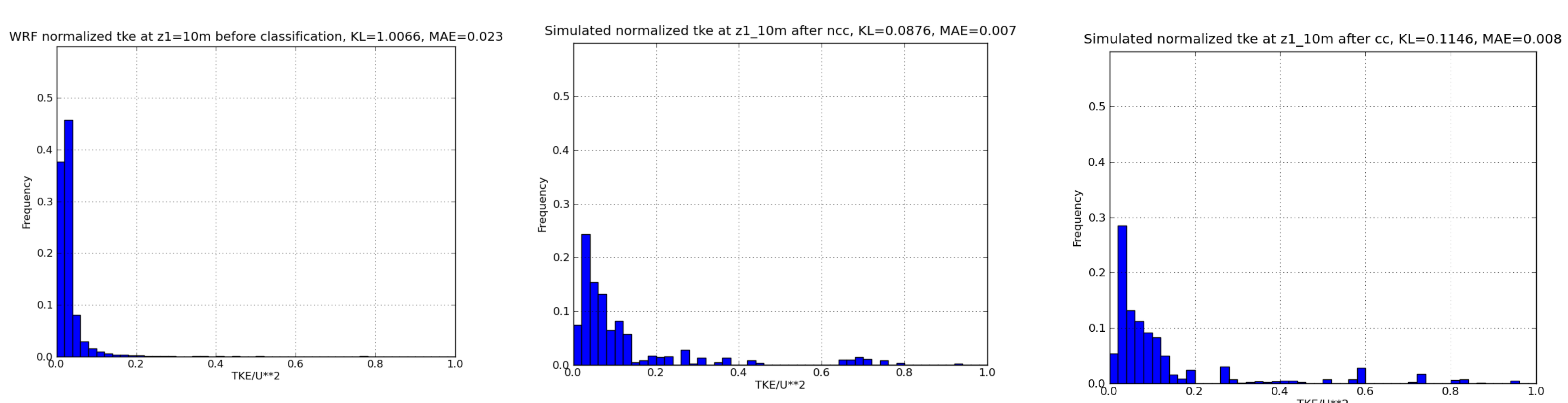
- Code_Saturne wind speed histograms are closer to the measured ones than the WRF ones
- The wind speed histograms obtained with Code_Saturne are shifted to lower values because of the effect of the forests and buildings.

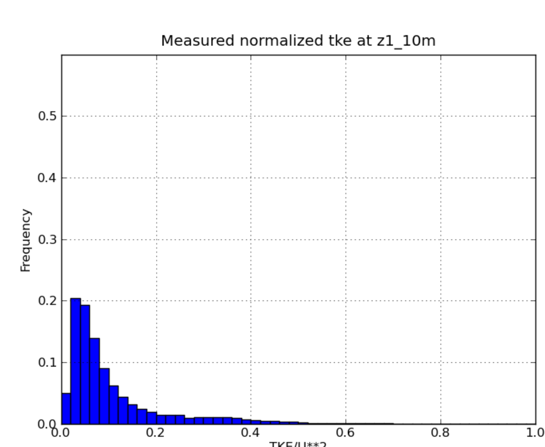
WRF and *Code_Saturne* wind roses before and after clustering (Z1_10m)



- Both before and after clustering:
  - (i) The WRF wind rose at the location of the sonic anemometer and the simulated ones with *Code_Saturne* capture well the dominant wind directions (220°-240°)
  - (ii) The WRF wind roses before and after clustering present a secondary dominant direction at θ=20°, while the measured one has a secondary peak at θ=80°: the winds from the north east direction turned towards east because of the forest effect. Code_Saturne reproduces partly this rotation
- The simulated wind roses with *Code_Saturne* are closer to the measured ones than the WRF ones, as indicated by the lower values of the MAE and KL.

WRF and *Code_Saturne* distributions of normalized turbulent kinetic energy before and after clustering (Z1_10m)

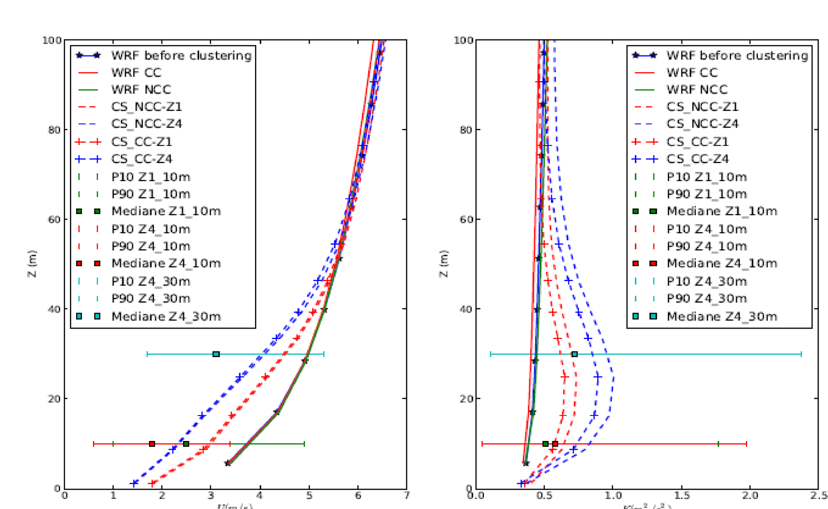




- The distribution of normalized TKE obtained with WRF is dominated by low values.
- The distribution obtained with Code_Saturne is wider and extends to much higher values, in accordance with the measured distribution.
- This increase of the normalized TKE values is mainly due to the forest effect for wind direction ranging from north-west to north-east.

Annual average vertical profiles of the wind speed

(CS: *code_saturne*, CC and NCC: controlled and non-controlled clustering, P10 and P90 are the percentiles 10 and 90)



- The *Code_Saturne* vertical profiles are closer to the measures than the WRF ones;
- Near the ground, the Code_Saturne vertical profiles of the wind speed are shifted to lower values because of the effect of forests and buildings.
- The turbulent kinetic energy near the ground increases due to the forests top that promotes turbulence.

Annual average of the flow variables

(First value: annual mean, Second value: median)

Points	z1_10m	z4_10m	z4_30m
U (CC Saturne)	2.87/2.50	2.43/2.04	3.98/3.68
U (NCC Saturne)	2.89/2.42	2.43/1.99	3.98/3.63
U (WRF)	4.30/4.02	4.30/4.02	4.91/4.56
U (CC WRF)	4.37/4.14	4.37/4.14	4.97/4.14
U (NCC WRF)	4.37/4.20	4.37/4.20	4.93/4.54
U (Measure)	2.76/2.50	1.94/1.80	3.35/3.10
k/U^2 (CC Saturne)	0.138/0.066	0.144/0.141	0.157/0.135
k/U^2 (NCC Saturne)	0.128/0.067	0.147/0.142	0.162/0.045
k/U^2 (WRF)	0.05/0.022	0.05/0.022	0.057/0.023
k/U^2 (CC WRF)	0.03/0.021	0.03/0.021	0.035/0.022
k/U^2 (NCC WRF)	0.035/0.022	0.035/0.022	0.04/0.022
k/U^2 (Measure)	0.06/0.066	0.17/0.17	0.216/0.07

- The values of the normalized turbulent kinetic energy k/U^2 from *Code_Saturne* are closer to the measures than the WRF ones before and after clustering: *Code_Saturne* models well the local effects;
- The mean U and k/U^2 obtained with *Code_Saturne* both after controlled and non-controlled clustering are close to the measures.

Bibliography

[1] Jain, A., Murty, M., Flynn, P., 1999. Data clustering: A review. ACM Computing Surveys 31, 265–323.

[2] Zaidi, H., Dupont, E., Milliez, M., Musson-Genon, L., Carrisimo, B., 2013. Numerical simulations of the microscale heterogeneities of turbulence observed on a complex site. Boundary-Layer Meteorol 147.