WRF

THE MICROSCALE AWAKENS

LES

VORTEX

Alex Montornès
Pau Casso
Gil Lizcano
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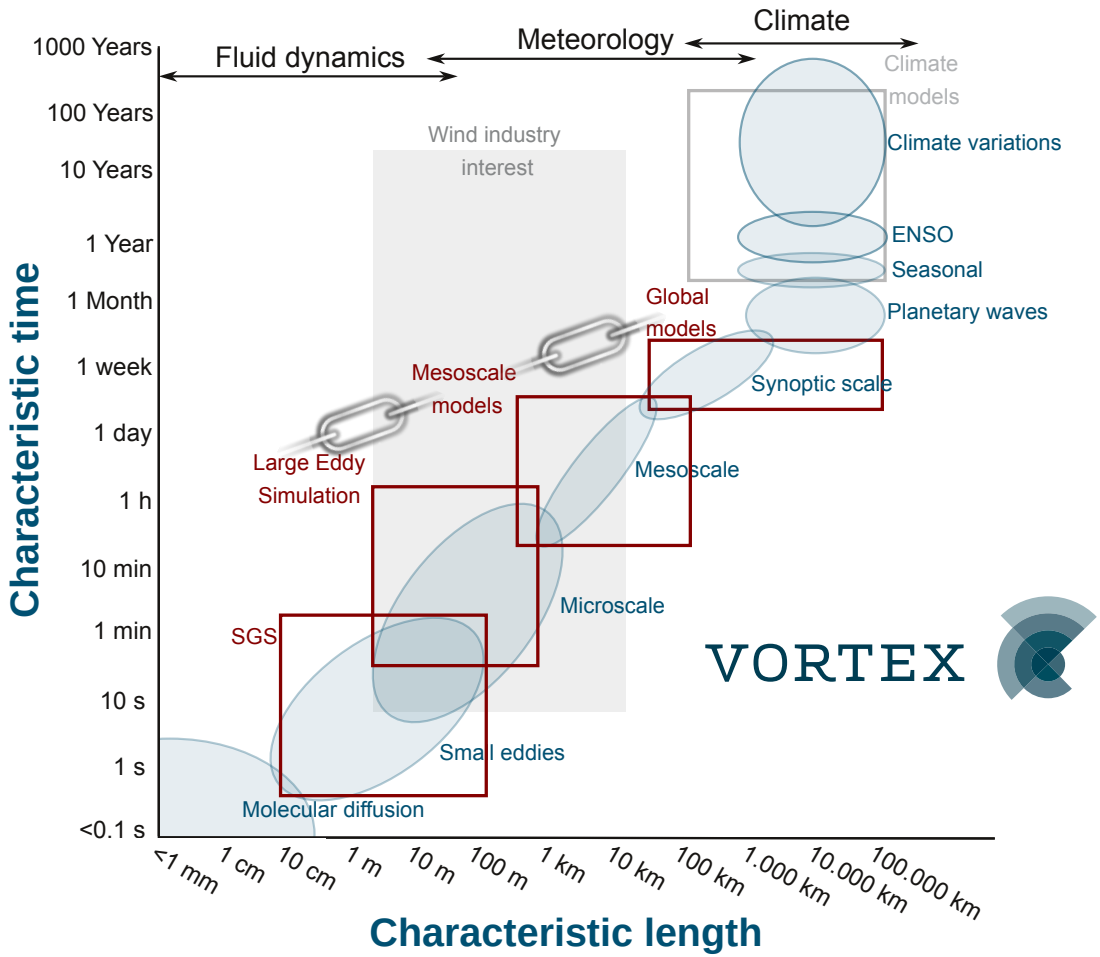
Episode I: WRF-LES in the real world: Towards a seamless modeling chain for wind industry applications



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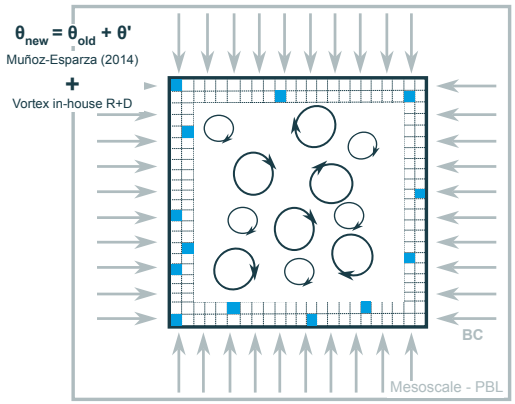


Reanalysis

Vortex
WRF-LES
Mesoscale PBL
Microscale LES

4 Hz output

Postprocessing
10' averages
3'' gust
10' standard deviation
20-150 meters above ground

1-year time-series (10')
110 m grid-size
Region 2.5x2.5 km

Wind speed, Wind direction, Temperature, Pressure, Richardson Number, PBL Fluxes, Veer, Inflow angle, ...

Episode I: WRF-LES in the real world: Towards a seamless modeling chain for wind industry applications

Episode II: WRF-LES in 250+ real sites: Learnings and Challenges

38 sites - wind industry heights

Jan, 1 to Feb, 29 2016 (2 months)

Mean values

	WRF 3 km (CFSR)	ERA-5 31 km	WRF 3 km (ERA-5)
R^2	0.594	0.659	0.661
RMSE (ms^{-1})	2.6	3.0	2.5

R^2 = **-9.9%** R^2 = **+0.3%**

RMSE = **+13.3%** RMSE = **+16.7%** → Grid resolution!

Episode II: WRF-LES in 250+ real sites: Learnings and Challenges

Does this mean the end of the mesocale models for operational forecasting and applications like wind resource assessment?

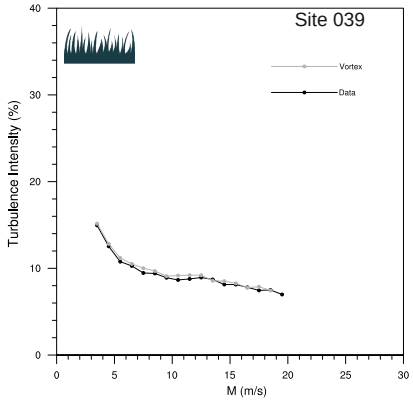
Episode II: WRF-LES in 250+ real sites: Learnings and Challenges

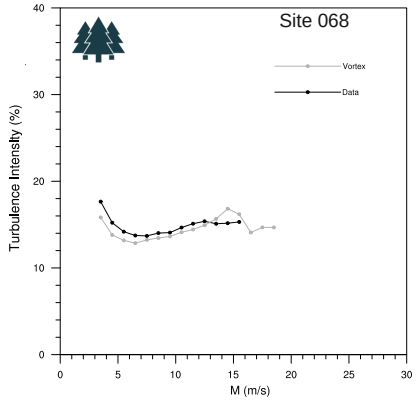
3.1% Off-shore **41.7%** Flat terrain **25.0%** Complex terrain **30.2%** Forest

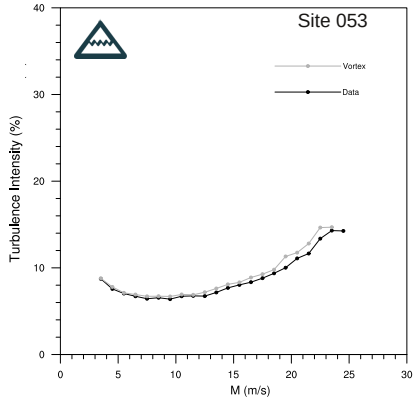
Anemometers: **18.1%** 20-50 m **68.1%** 50-100 m **13.8%** 100-150 m

1-year validation
Wind speed validated at 96 sites at different mest-mast heights
Turbulence validated at 56 sites at different mest-mast heights

		Bias (%)	RMSE (ms-1)	R^2
All (100%)	10-min		2.6	0.605
	Hourly	2.4	2.5	0.637
	Daily		1.7	0.807
Off-shore (3.2%)	10-min		1.9	0.837
	Hourly	0.4	1.8	0.855
	Daily		1.1	0.937
Flat (40.9%)	10-min		2.5	0.593
	Hourly	-3.4	2.4	0.625
	Daily		1.6	0.811
Complex (30.1%)	10-min		2.9	0.590
	Hourly	7.1	2.8	0.623
	Daily		1.9	0.790
Complex Forest (25.8%)	10-min		2.6	0.610
	Hourly	6.5	2.5	0.646
	Daily		1.7	0.805



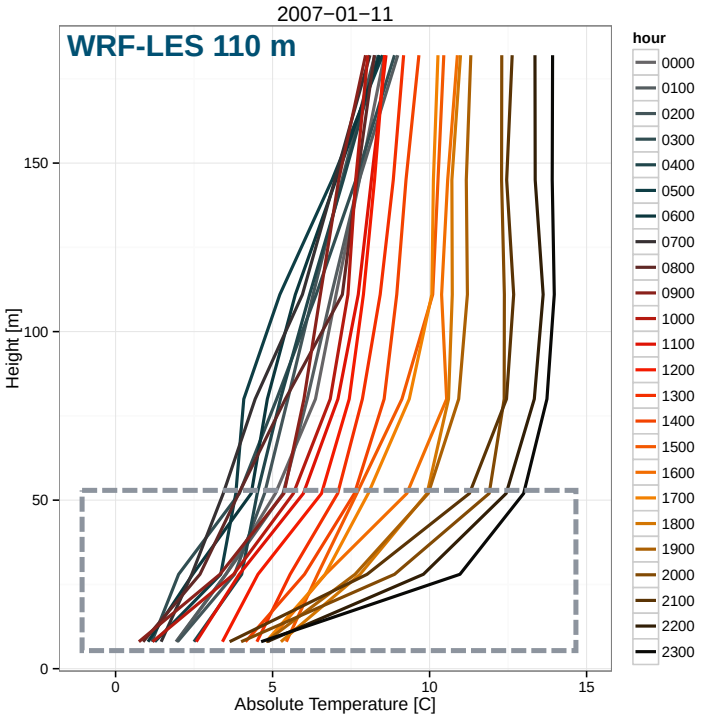


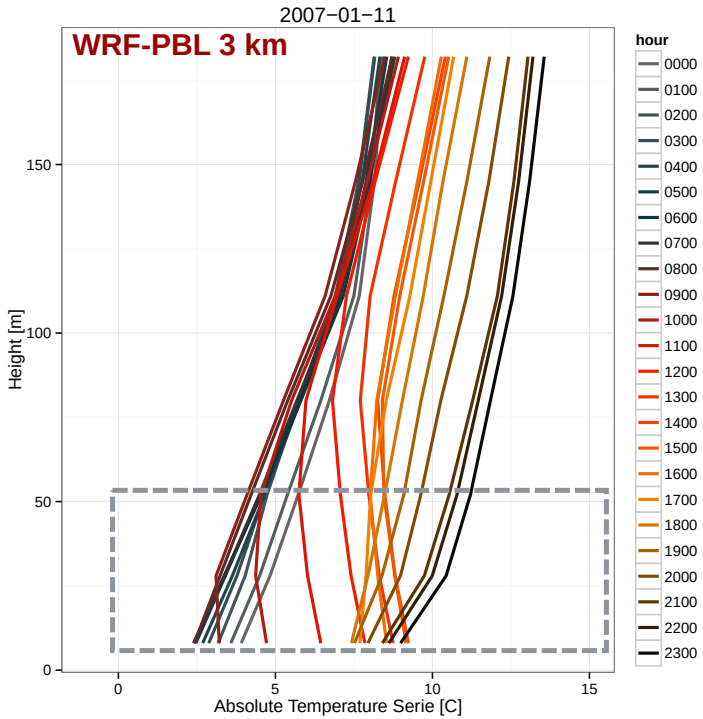


And now.... Challenges!

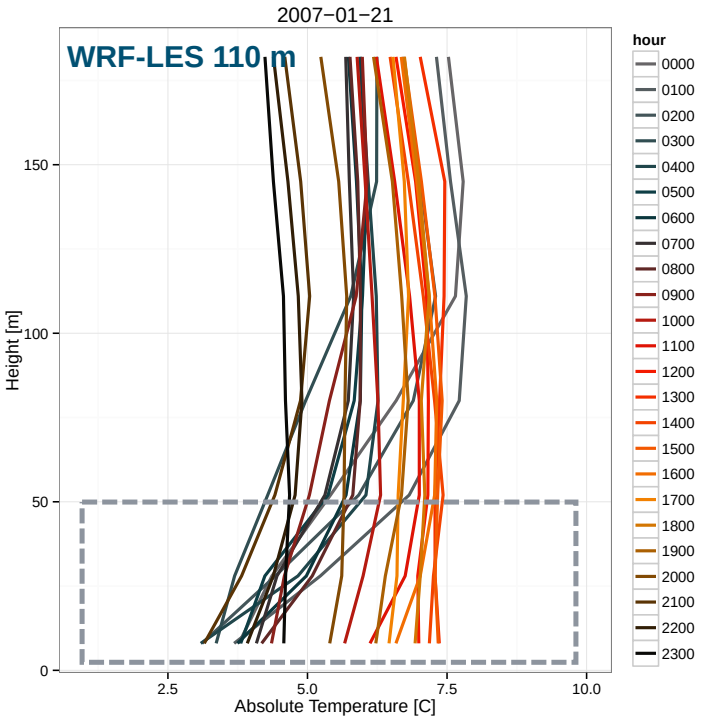
- Terra-Incognita
- Surface cooling
- Storage problem

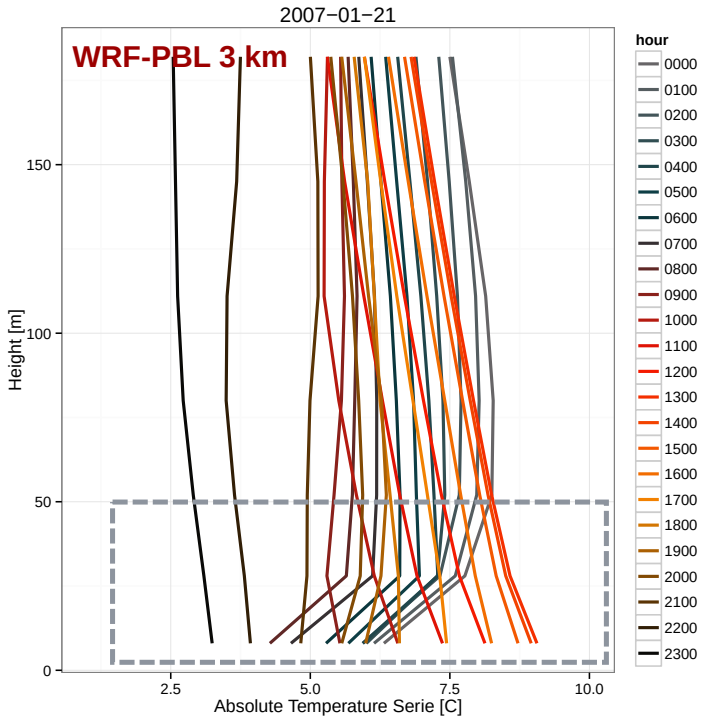
Surface cooling problem





Surface cooling problem





Subgrid Scheme: TKE 1.5

- From Moeng et al. (2006)

$$\frac{1}{2}K_M D_{ij}^2 - K_H \frac{g}{\theta}\frac{\partial \theta}{\partial z} = \epsilon = c_\epsilon \frac{e^{3/2}}{l} \tag{1}$$

- where

$$\text{Strain rate: } D_{ij} = \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \tag{2}$$

$$\text{SGS eddy viscosity: } K_M^{SGS} = c_k l \sqrt{e} \tag{3}$$

$$\text{SGS eddy diffusivity: } K_H^{SGS} = \left(1 + \frac{2l}{\Delta s}\right) K_M^{SGS} \tag{4}$$

Subgrid Scheme: TKE 1.5

- ... and

$$\text{Filtered length scale: } \Delta s = (\Delta x \Delta y \Delta z)^{1/3} \tag{5}$$

$$\text{SGS length scale: } l = \min\left(0.76 e^{1/2} \left(\frac{\partial \theta}{\partial z}\right)^{1/2}, \Delta s\right) \tag{6}$$

- c_k is proposed by Moeng and Wyngaard (1988)

Subgrid Scheme: TKE 1.5 — module_diffusion_em.F

- In non-isotropic case (i.e. $\Delta x, \Delta y > \Delta z$)
- Unstable case:

$$l_h = \sqrt{\Delta x \Delta y} \tag{7}$$

$$l_v = \min\left(\Delta z, 0.76 e^{1/2} \left(\frac{\partial \theta}{\partial z}\right)^{1/2}\right) \tag{8}$$

- Stable/Neutral case:

$$l_h = \sqrt{\Delta x \Delta y} \tag{9}$$

$$l_v = \Delta z \tag{10}$$

Subgrid Scheme: TKE 1.5 — module_diffusion_em.F

$$10^{-6} l_h^2 \leq K_{M,h}^{SGS} = c_k l_h \sqrt{e} \leq M l_h^2 / dt \tag{11}$$

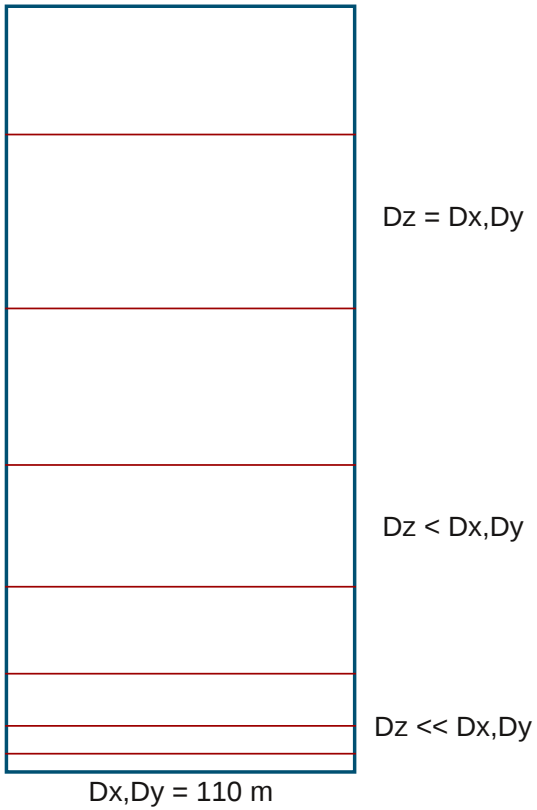
$$10^{-6} l_v \leq K_{M,v}^{SGS} = c_k l_v \sqrt{e} \leq M l_v^2 / dt \tag{12}$$

- M is a non-dimensional upper limit for diffusion coefficient (Registry, 0.1)
- And...

$$K_{H,h}^{SGS} = \frac{1}{P_r} K_{M,h}^{SGS} \tag{13}$$

$$K_{H,v}^{SGS} = \left(1 + \frac{2 l_v}{\Delta z}\right) K_{M,h}^{SGS} \tag{14}$$

Subgrid Scheme: TKE 1.5 — module_diffusion_em.F



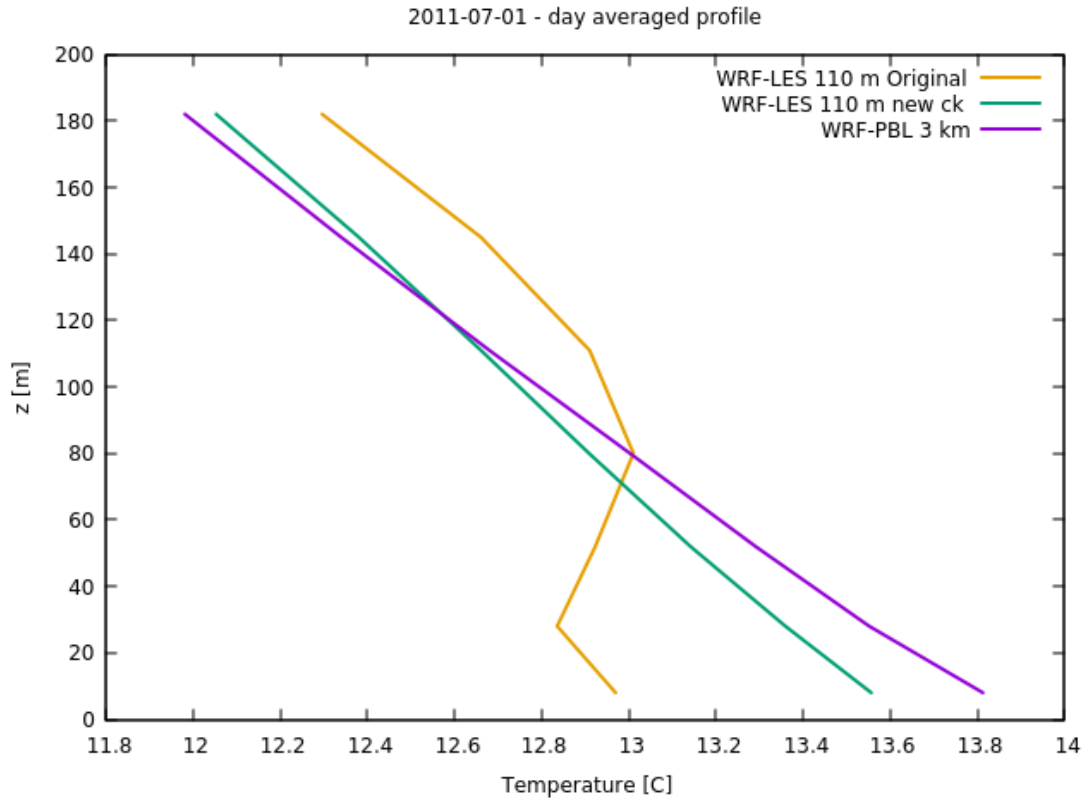
- At the lower levels of the model and under stable regimes $l_x = \sqrt{\Delta x \Delta y} = 10^2$ and $l_v = \Delta z = 1 - 10$.

$$\frac{K_{M,h}}{K_{M,v}} = \frac{l_h}{l_v} = 10 \tag{15}$$

$$\frac{K_{H,h}}{K_{H,v}} = \frac{3}{P_r}\frac{K_{M,h}}{K_{M,v}} = \frac{30}{P_r} \tag{16}$$

We propose...

- New c_k for the vertical diffusion at the first levels of the model in order to take into account the deformation of the grid-cells (high non-isotropy).



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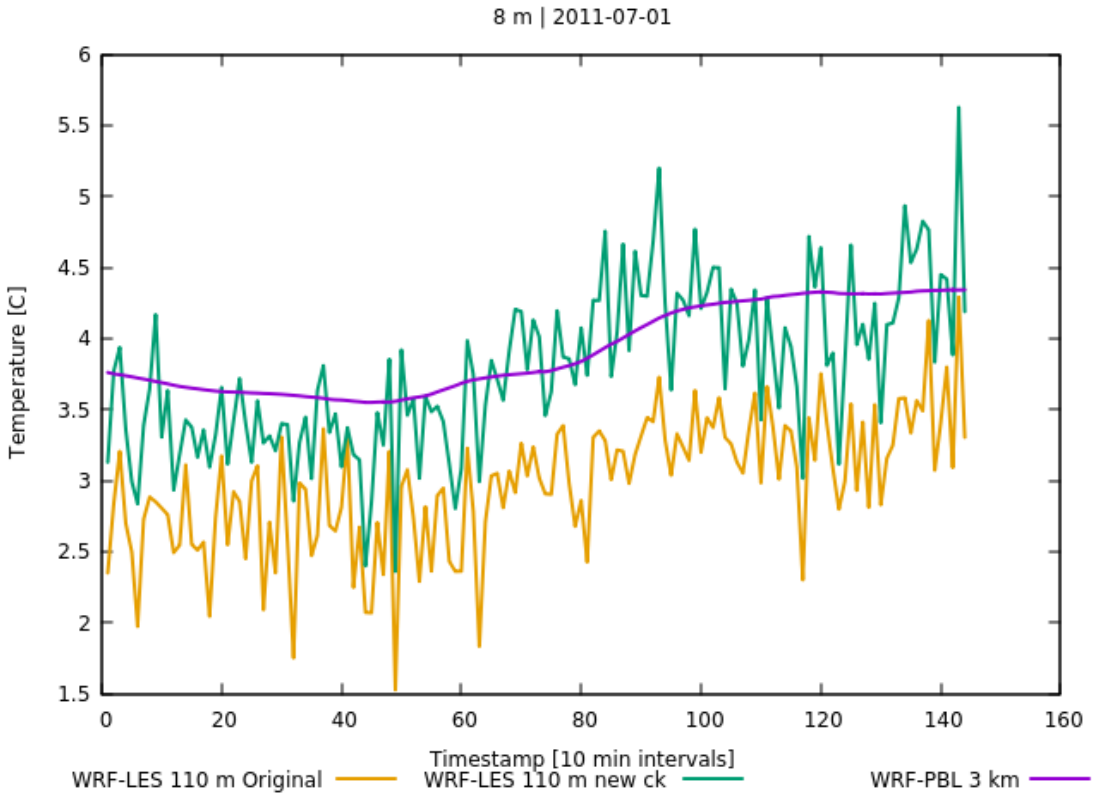

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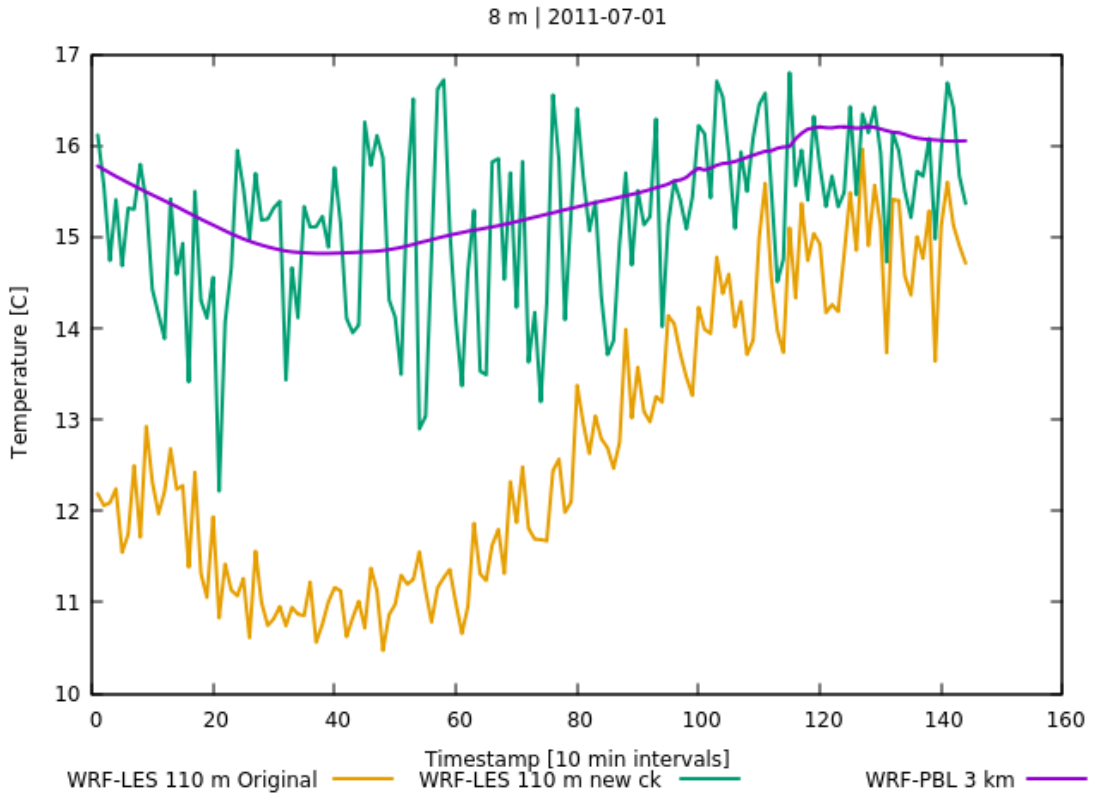

However, more work is needed...

- New c_k for the vertical viscosity at the first levels of the model for reducing the increment of the noise.
- A full validation.

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And now.... Challenges!

- Terra-Incognita
- Surface cooling
- Storage problem

WRF-LES storage...

1 site

Output at 4 Hz

1 day + 12 h spin-up

15 vertical levels (0-180 m)

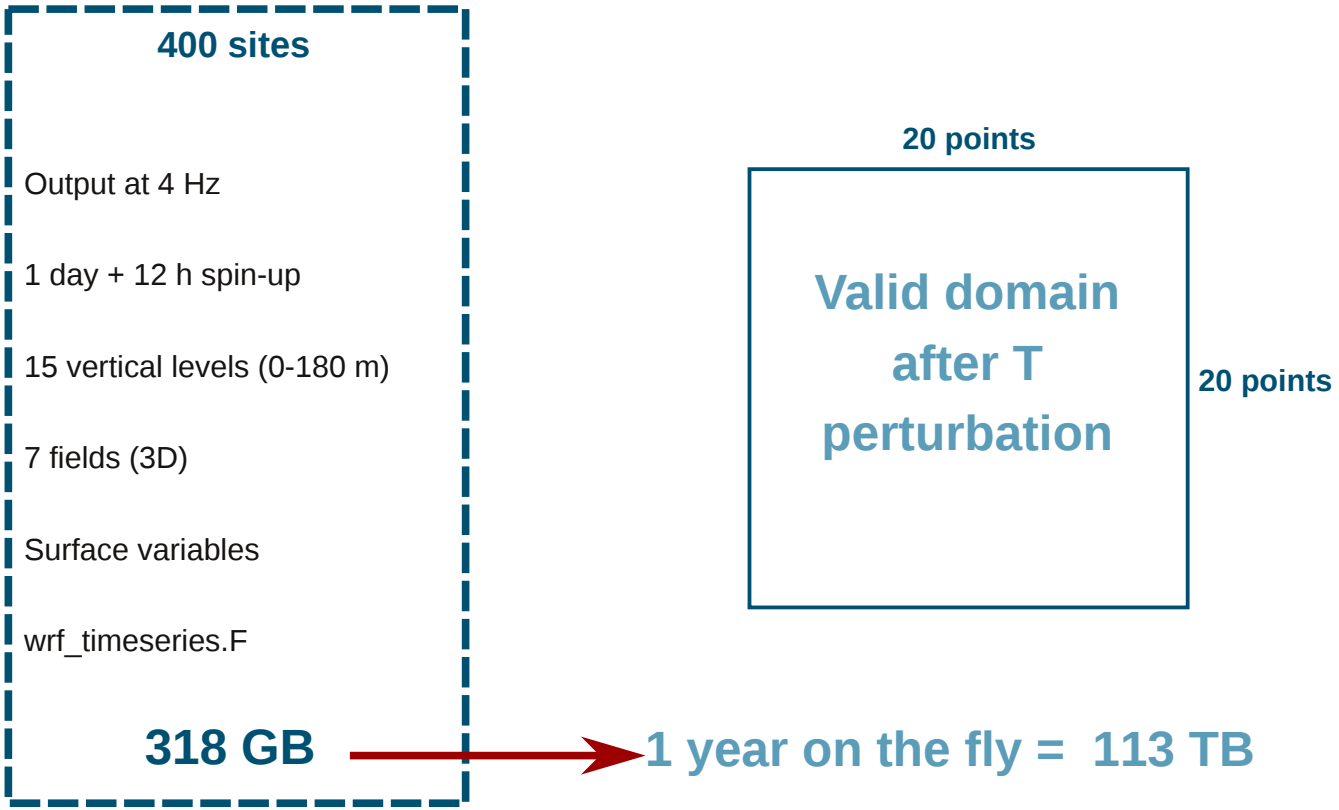
7 fields (3D)

Surface variables

wrf_timeseries.F

815 MB

WRF-LES storage...



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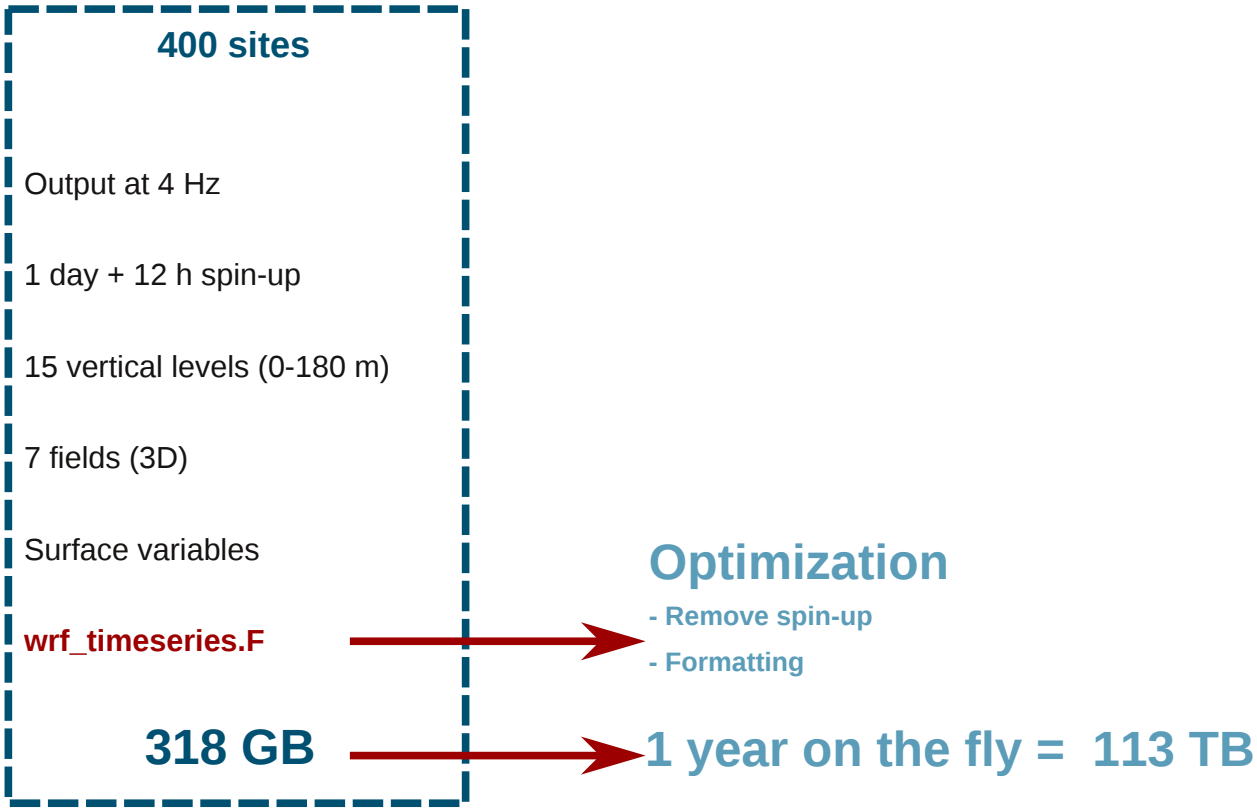

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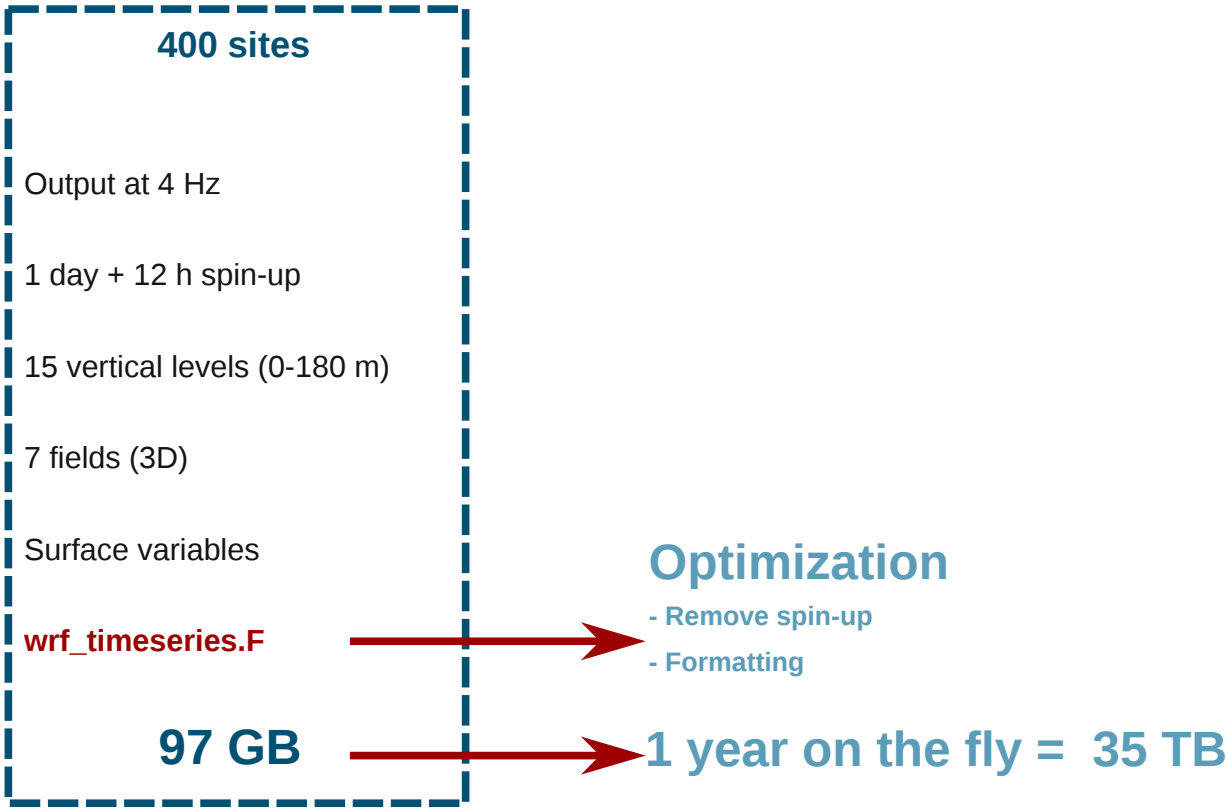


WRF-LES storage...

400 sites

Output at 4 Hz

1 day + 12 h spin-up

15 vertical levels (0-180 m)

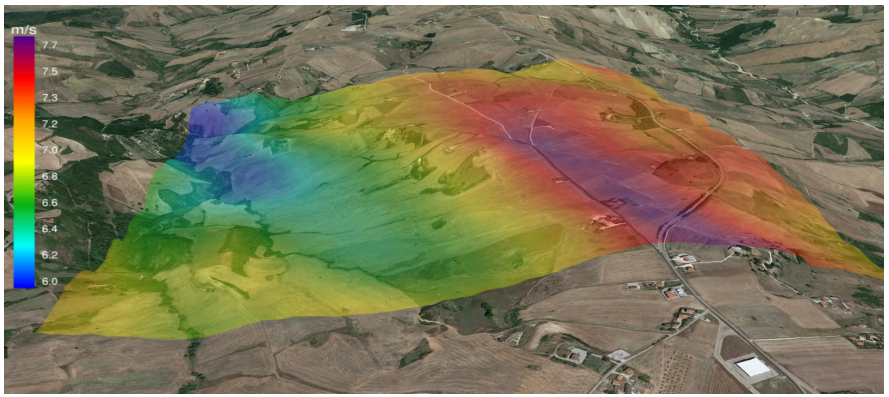
7 fields (3D)

Surface variables

wrf_timeseries.F

97 GB

1-y mean wind speed



Optimization

- Remove spin-up
- Formatting

1 year on the fly = 35 TB

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