DTU

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DTU Wind Energy

HPCWE Workshop 2020

Latest developments in mesoscale to microscale model chain for wind resource assessment: The importance of HPC

Motivation

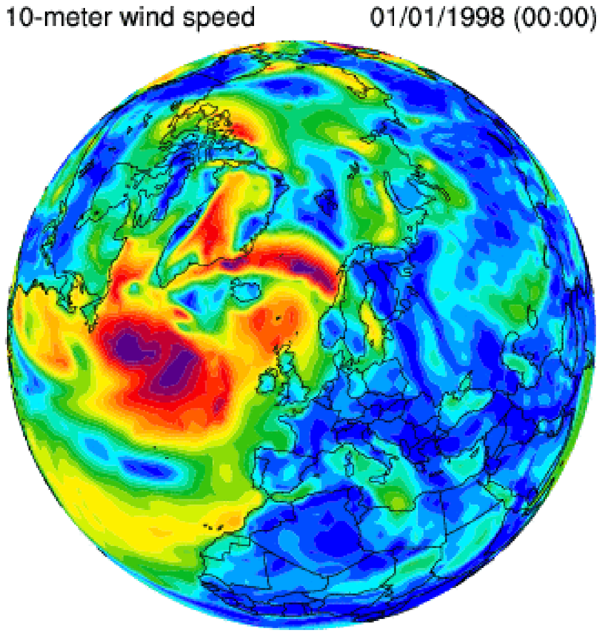
- Accurate wind resource assessment matters
  - What does a 1% error mean on resource assessment?
    – Cost of Energy ~75 USD per MWh (IEA, 2020)
    – 100 MW with 35% Capacity Factor wind farm
      » 1% error AEP approximately $230000 per year
    – 50 GW installation per year globally
      » $100 million per year

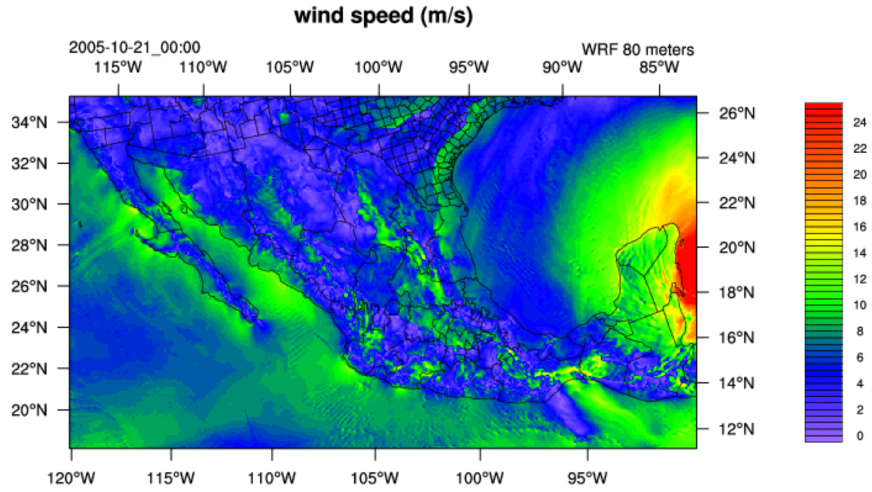
    – Positive bias can lead to performance below expectation
    – Negative bias can lead to unrealized projects
    – Random error can lead to too great an uncertainty (low P90) and high capital costs

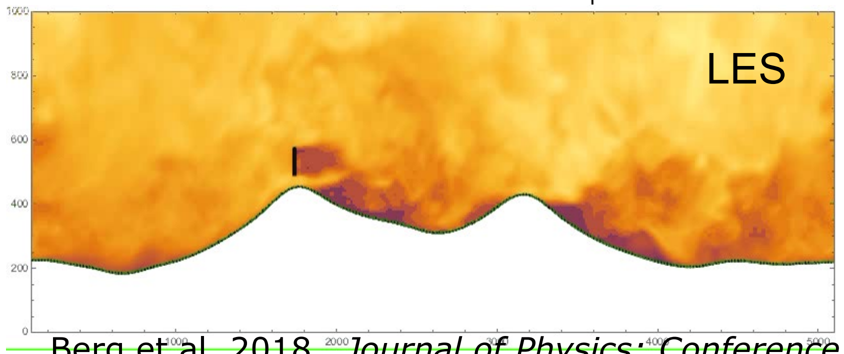
IEA, 2020: Impact on levelised cost of electricity for newly commissioned renewable power capacity in Europe by level of financing costs, 2015-2020, IEA, Paris https://www.iea.org/data-and-statistics/charts/impact-on-levelised-cost-of-electricity-for-newly-commissioned-renewable-power-capacity-in-europe-by-level-of-financing-costs-2015-2020

Model chain

DTU Wind Energy
Sophia Cluster
512 compute nodes, 2 x AMD 7351 CPU (2 x 16 cores) 16 384 cores
300 TFLOPS







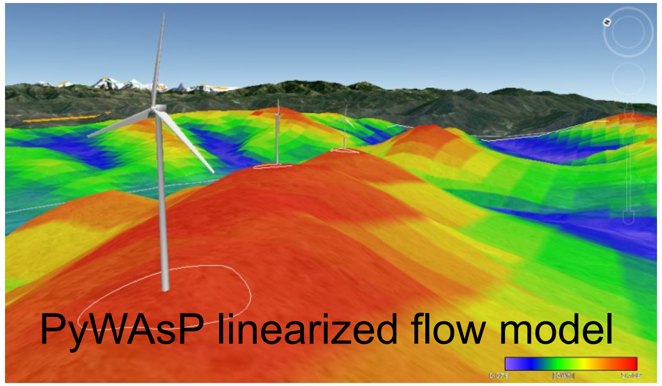
Berg et al, 2018, *Journal of Physics: Conference Series*, https://doi.org/10.1088/1742-6596/1037/7/072015

Global

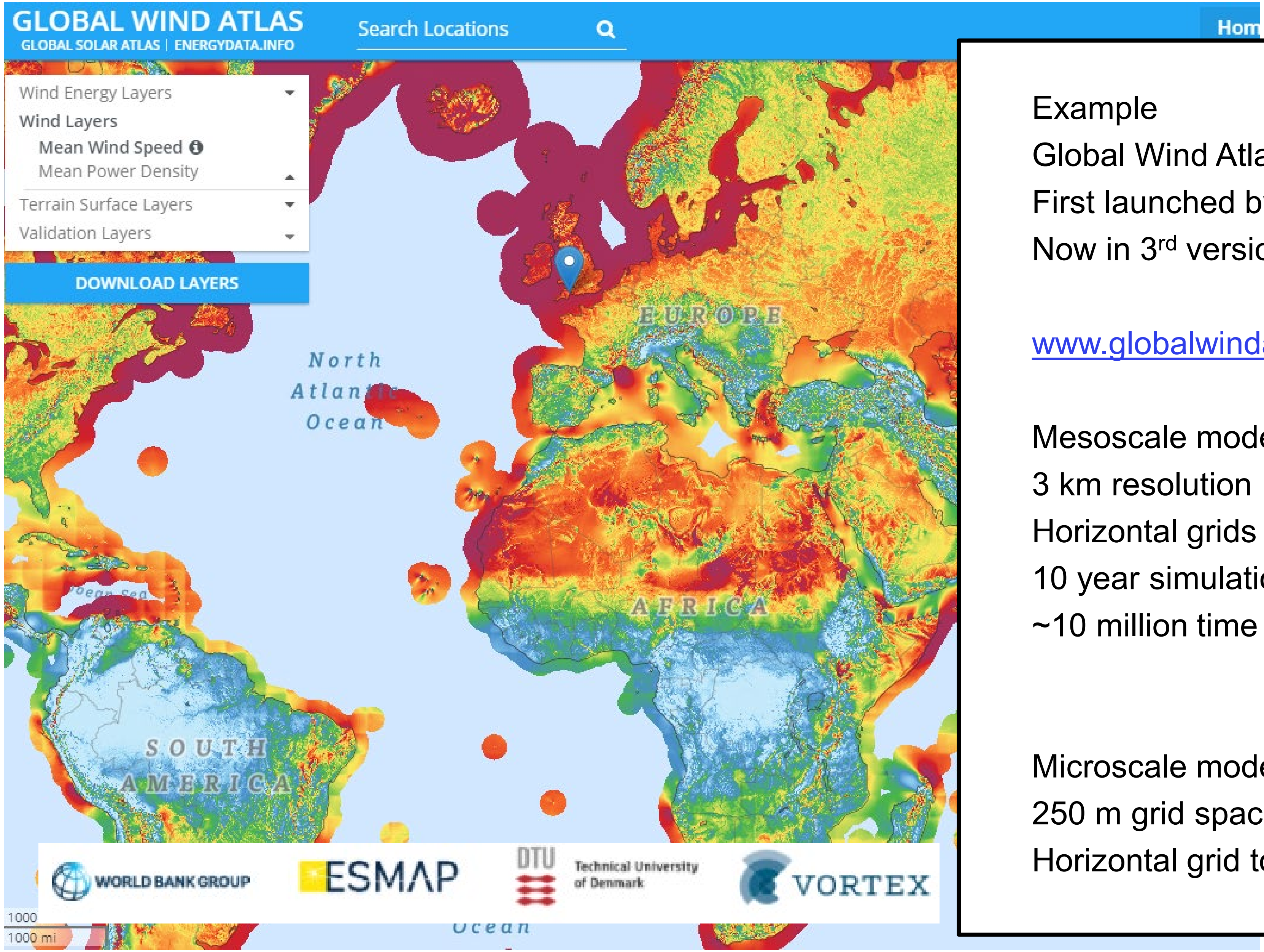
Regional

Downscaling

Site



ECMWF
Cray XC40 system
8499 TFLOP
nearly 1% Exoscale



Example

Global Wind Atlas

First launched by DTU in 2015

Now in 3rd version

www.globalwindatlas.info

Mesoscale modelling WRF simulations:

3 km resolution

Horizontal grids total ~10 million points

10 year simulation

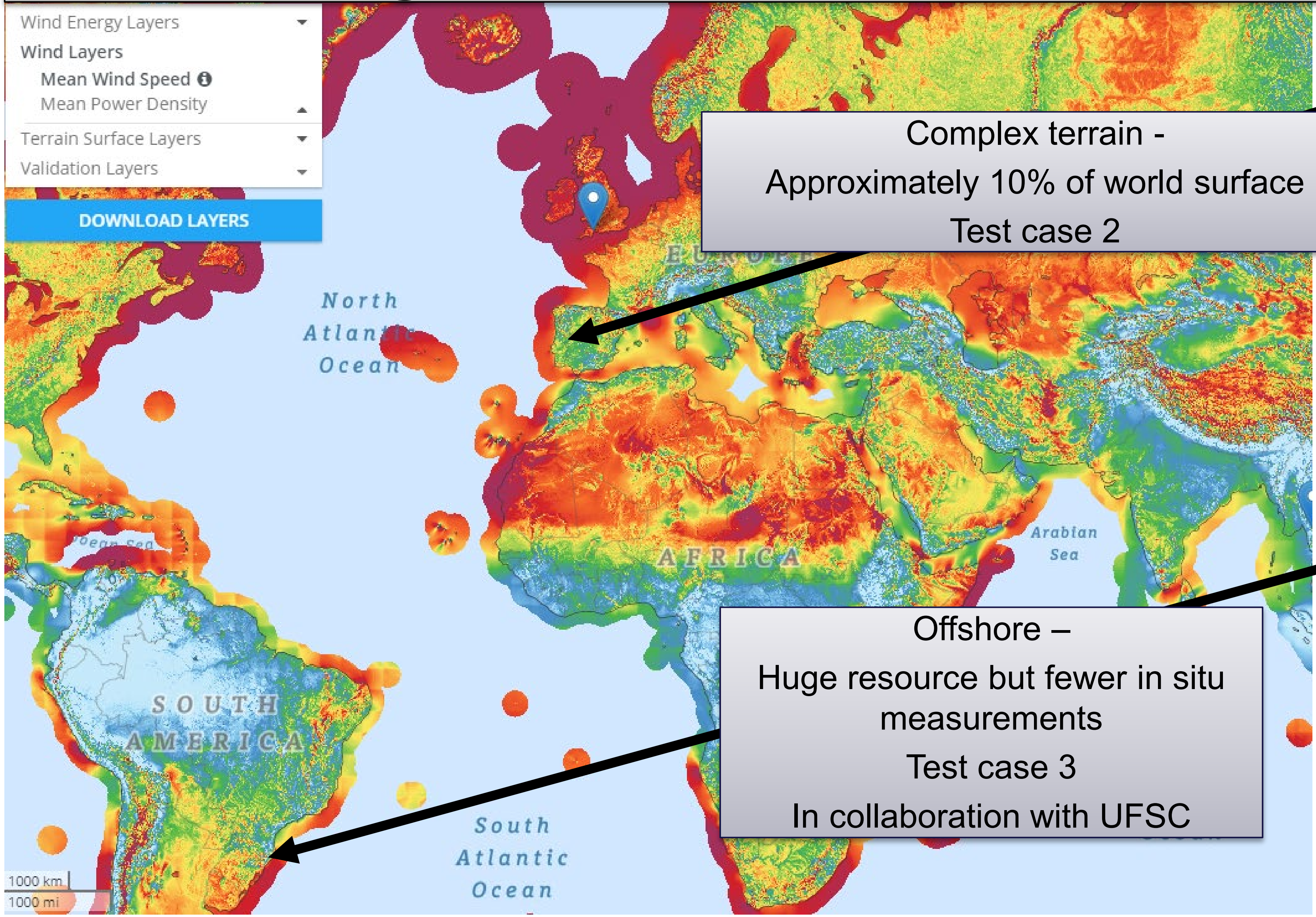
~10 million time steps

Microscale modelling WAsP modelling:

250 m grid spacing

Horizontal grid total ~1.5 billion points

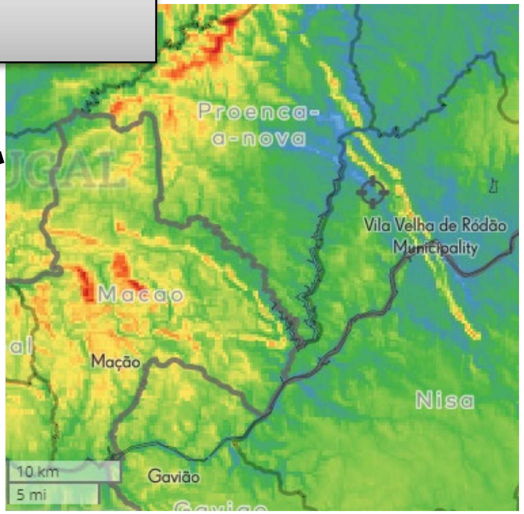
Challenge of uncertainties



Complex terrain -

Approximately 10% of world surface

Test case 2

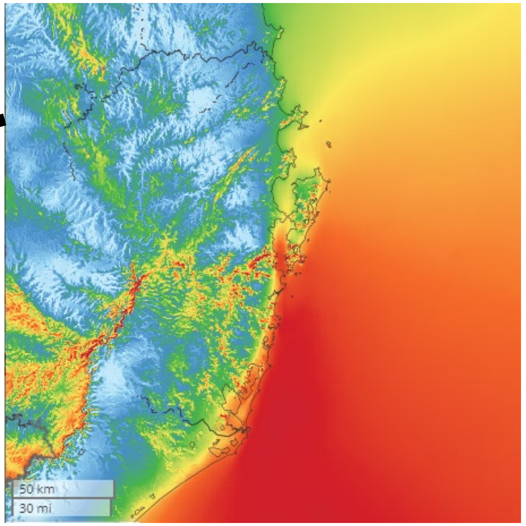


Offshore –

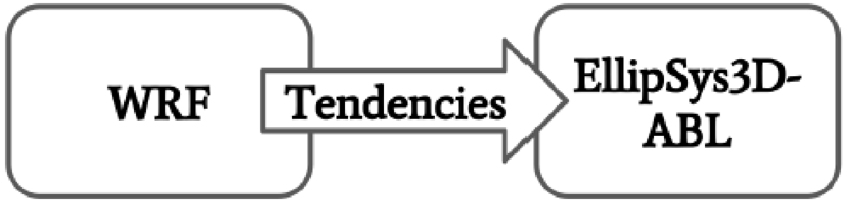
Huge resource but fewer in situ measurements

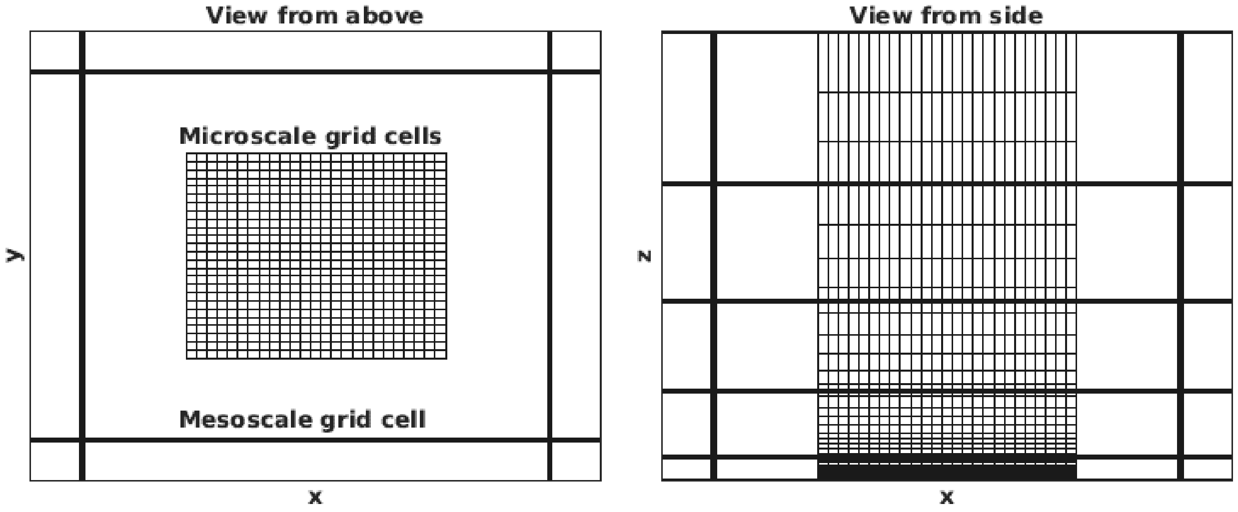
Test case 3

In collaboration with UFSC



Model chain: Advancements in Mesoscale to Microscale linkage





- Follows Sanz-Rodrigo et al. (2017)
- Body-forces
- Time- and height-dependent
- ψ from Businger et al. (1971)
- Mesoscale z_0 used in microscale model

$$F_U = \dot{U}_{\mathrm{ADV}} + \dot{U}_{\mathrm{PGF}}$$

$$F_\Theta = \dot{\Theta}_{\mathrm{ADV}}$$

$$\Theta_{z_0} = \Theta_2 - \frac{\Theta_*}{\kappa}\left[\ln\left(\frac{2 - z_0}{z_0}\right) + \psi\left(\frac{2 - z_0}{L}\right)\right]$$

Tendencies from WRF are updated every 10 minutes

.

What is new in 2020 through the HPCWE project?

Part 1

- A new way of averaging of physics tendencies from WRF

Part 2

- A new way of applying the tendency fields from WRF in Ellipsys3D

For both parts:

– What it means for physics modelling...

– What it means for HPC aspects…

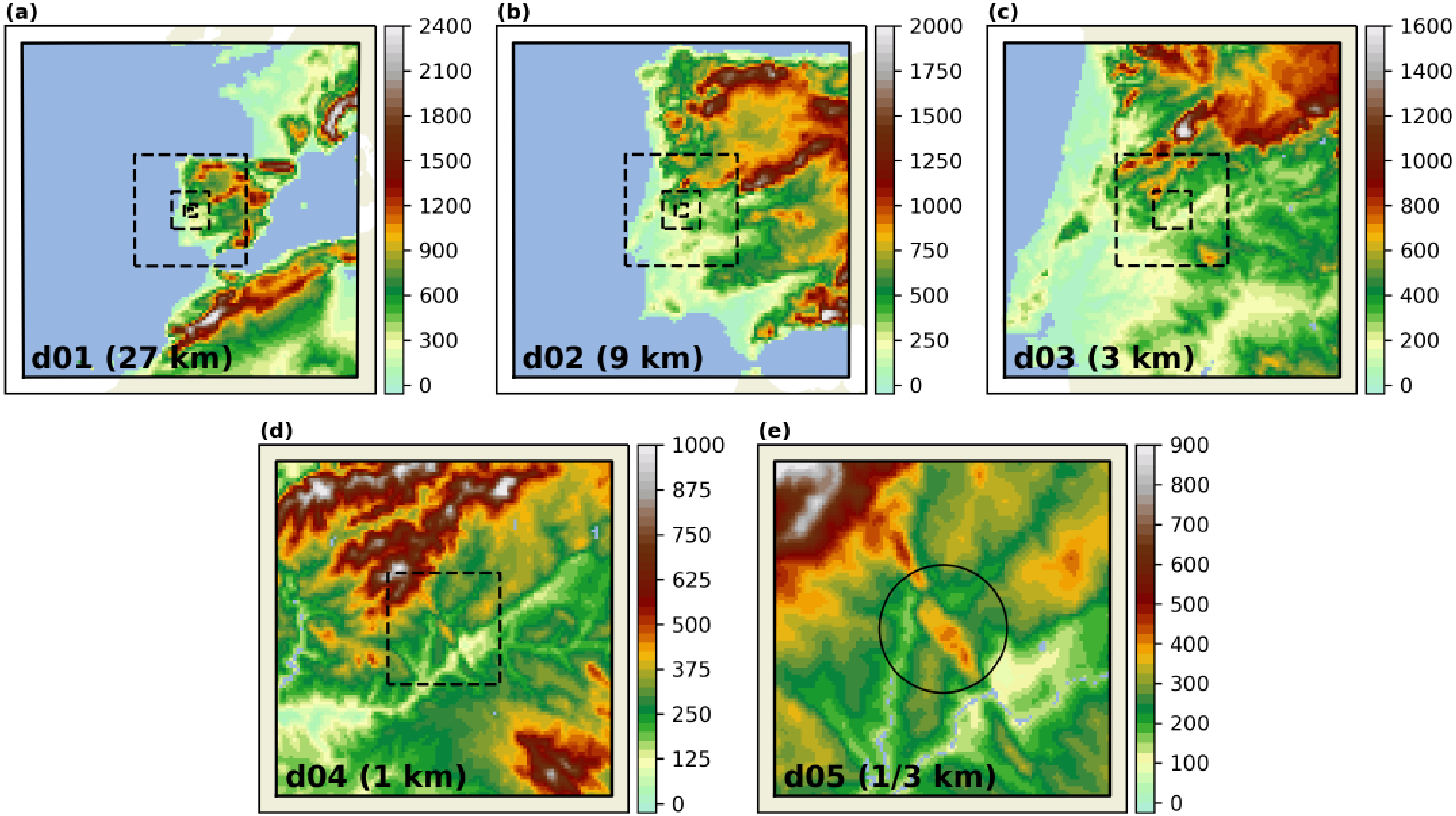
Part 1- Inline averaging of physics tendencies

- Pre-HPCWE
  - tendency averaging was done as post-processing
  - every 5 sec (same as the model time-step) tendencies written out by WRF

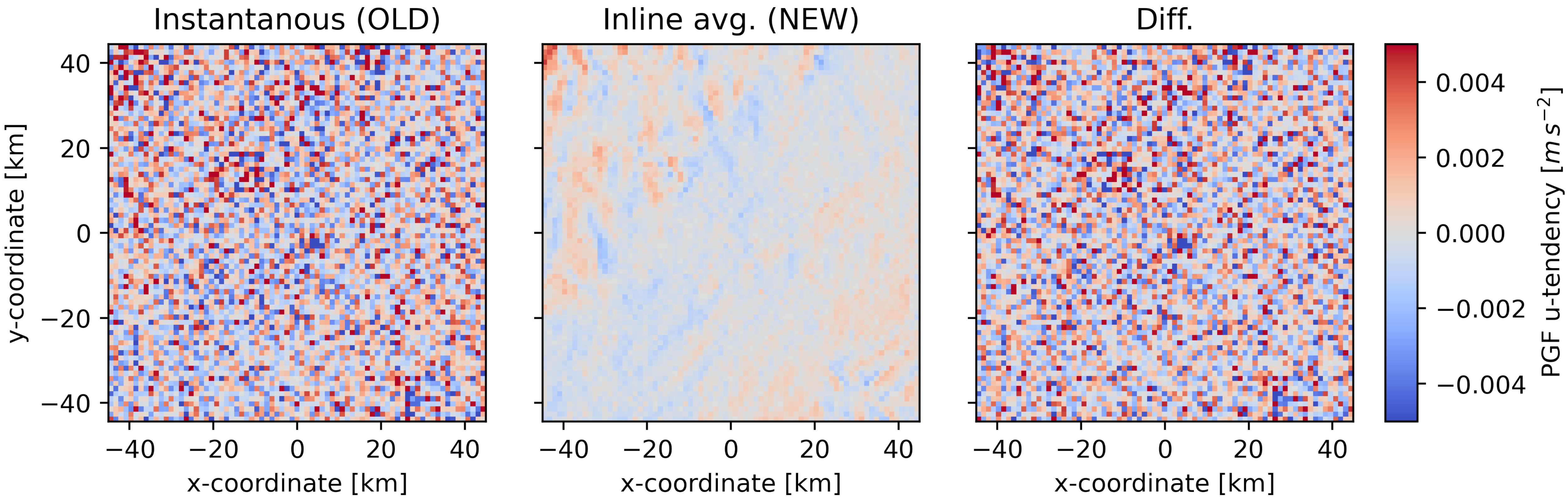
- In HPCWE the method of Chen et al (2020) has been implemented
  - tendency averaging performed during execution (“inline” averaging)
  - improves pressure-gradient tendency term, which contains high-frequency signals

Chen, T.C., Yau, M.K. and Kirshbaum, D.J., 2020. Towards the closure of momentum budget analyses in the WRF (v3. 8.1) model. *Geoscientific Model Development*, *13*(3).

Model set-up, WRF, Perdigao site



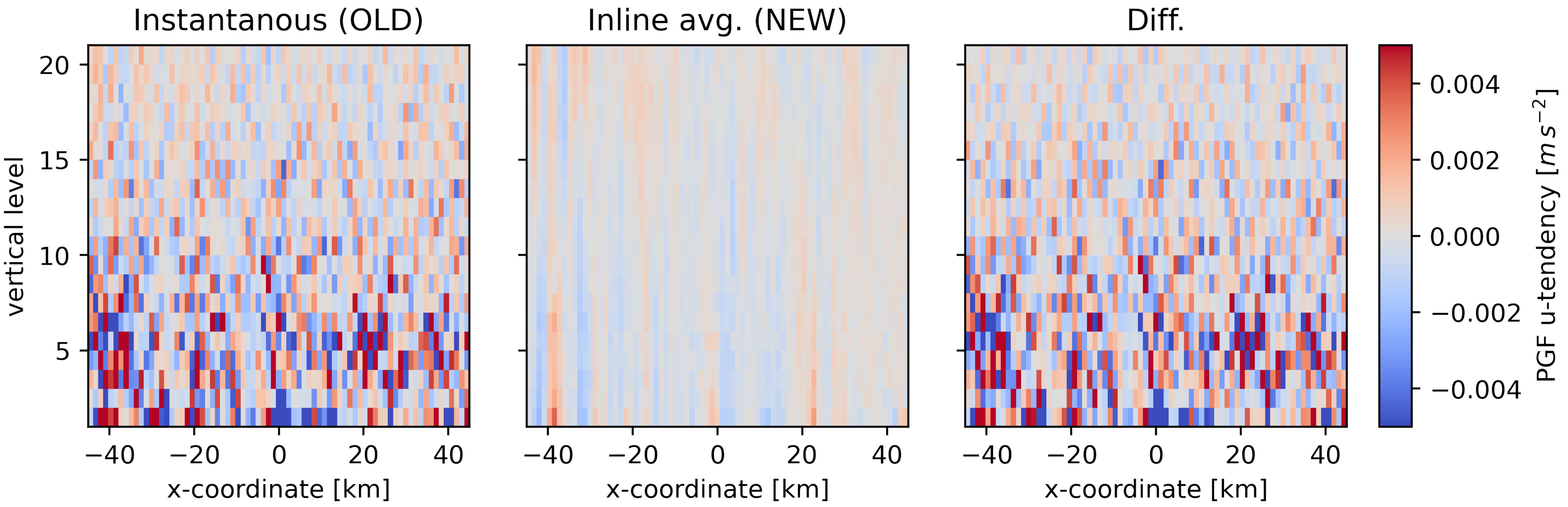
Comparison: horizontal slice at 100 m a.g.l.



2017-04-07 16:40:00 UTC of the pressure gradient u-velocity tendency term.

At approx. 100 m above the surface a Perdigao

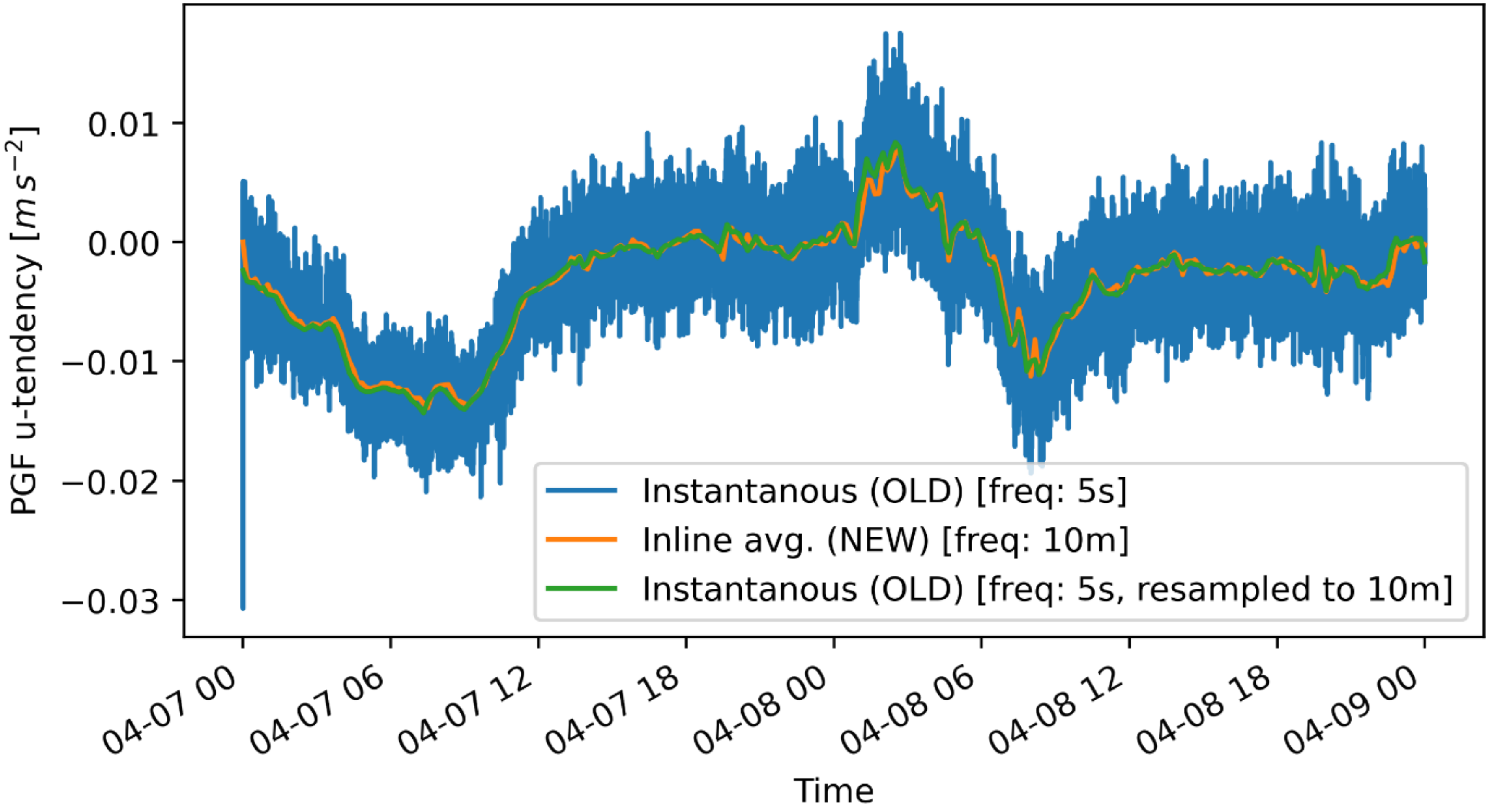
Comparison: vertical slice, from 0 at ~1000 m a.g.l.



2017-04-07 16:40:00 UTC of the pressure gradient u-velocity tendency term.

A west-east vertical through Perdigao. It is the lower ABL (up to approx 1000 m).

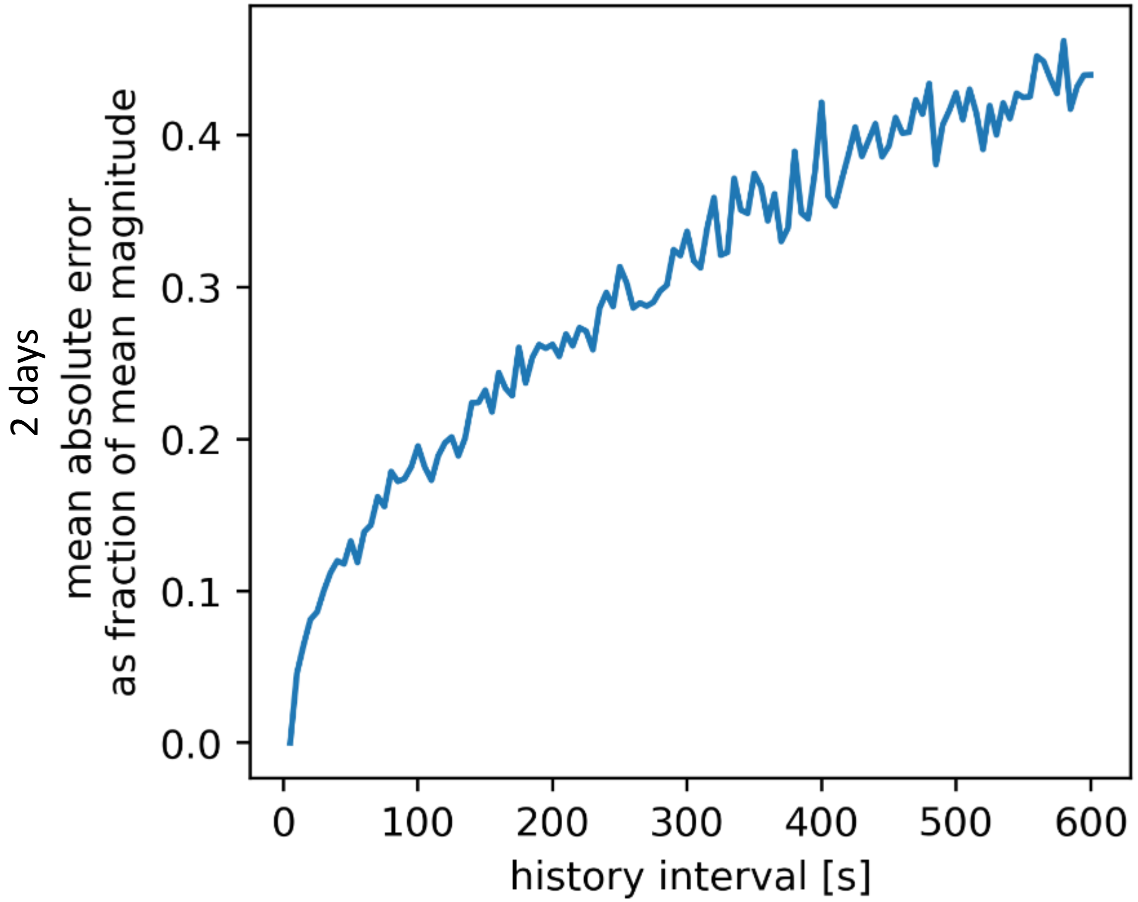
Comparison: time-series (2 days)



Time-series of the pressure-gradient u-tendency term for the two methods

at 100 m above the surface at Perdigao.

Post-processing method sensitivity to write interval



Post-processing averaging can give large deviations from the true mean at 2 days if write out is not frequent enough

Writing out every 2 min gives a mean absolute error that is about 20% on the

Part 1: Summary

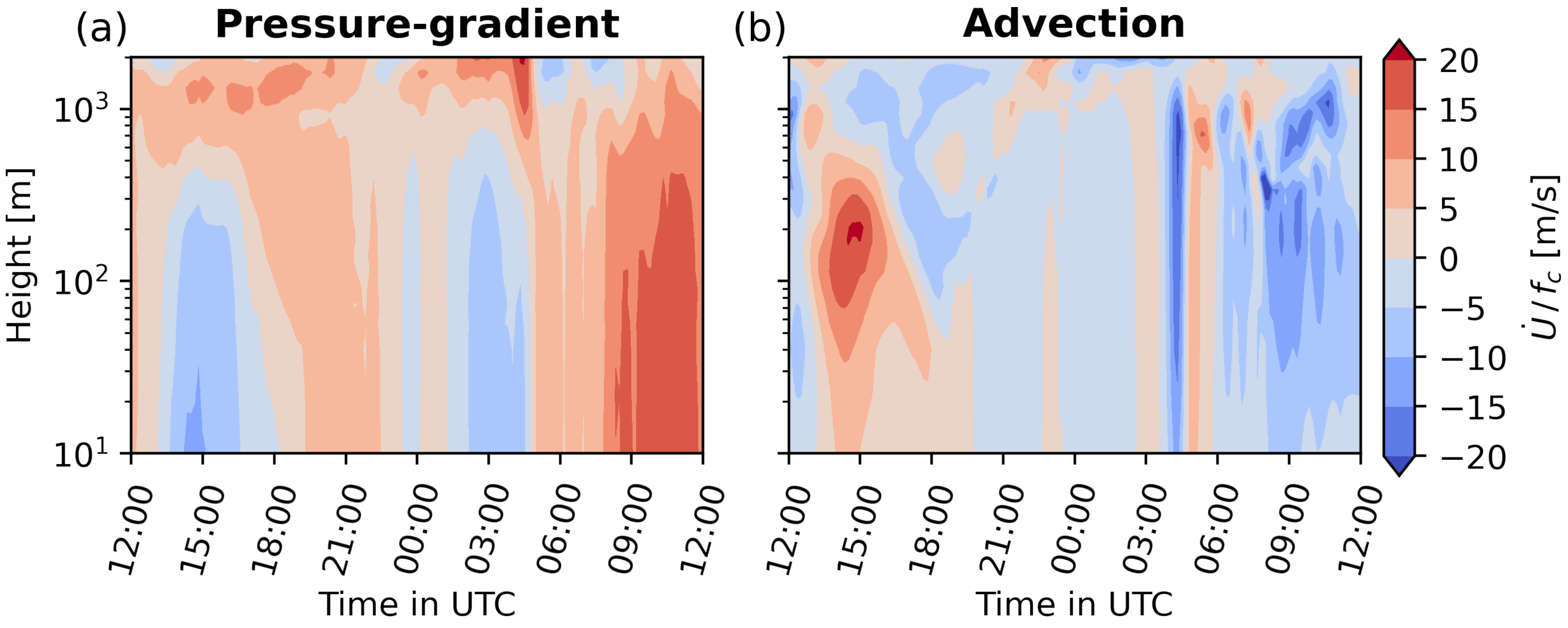
- Tests from a two-day simulation with the old and the new method for Perdigao (on 1 node - 32 cores)
  - Pre-HPCWE: 256 minutes and produced 3.2 TB of data
  - HPCWE: 73 minutes and 109 GB of data

- So the new method
  - Uses 1/4 the time
  - Uses 1/30 the amount of data

- Freed up resources has several implication, including:
  - increase mesoscale modelling resolution
  - increase simulation period
  - set-up mesoscale multi-model ensemble runs

Part 2: New 3-D tendency fields from WRF

- Pre-HPCWE
  - tendency information from WRF to Ellipsys3D was 1-D horizontally averaged
  - Single "column" of tendencies for entire Elliipsys3D domain
  - Evolves in time



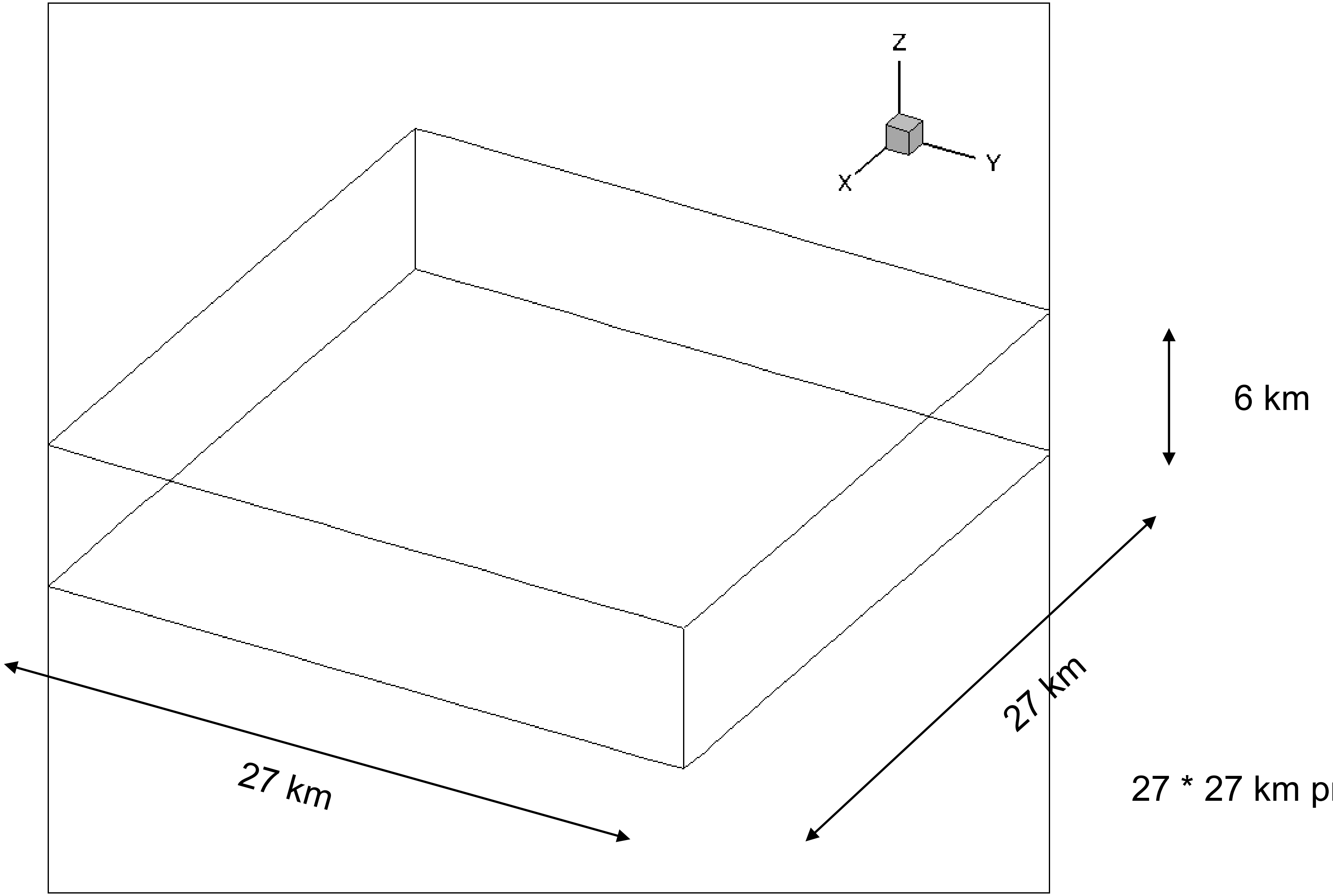
Reminder from slide 7:

$$F_U = \dot{U}_{\text{ADV}} + \dot{U}_{\text{PGF}}$$

Part 2

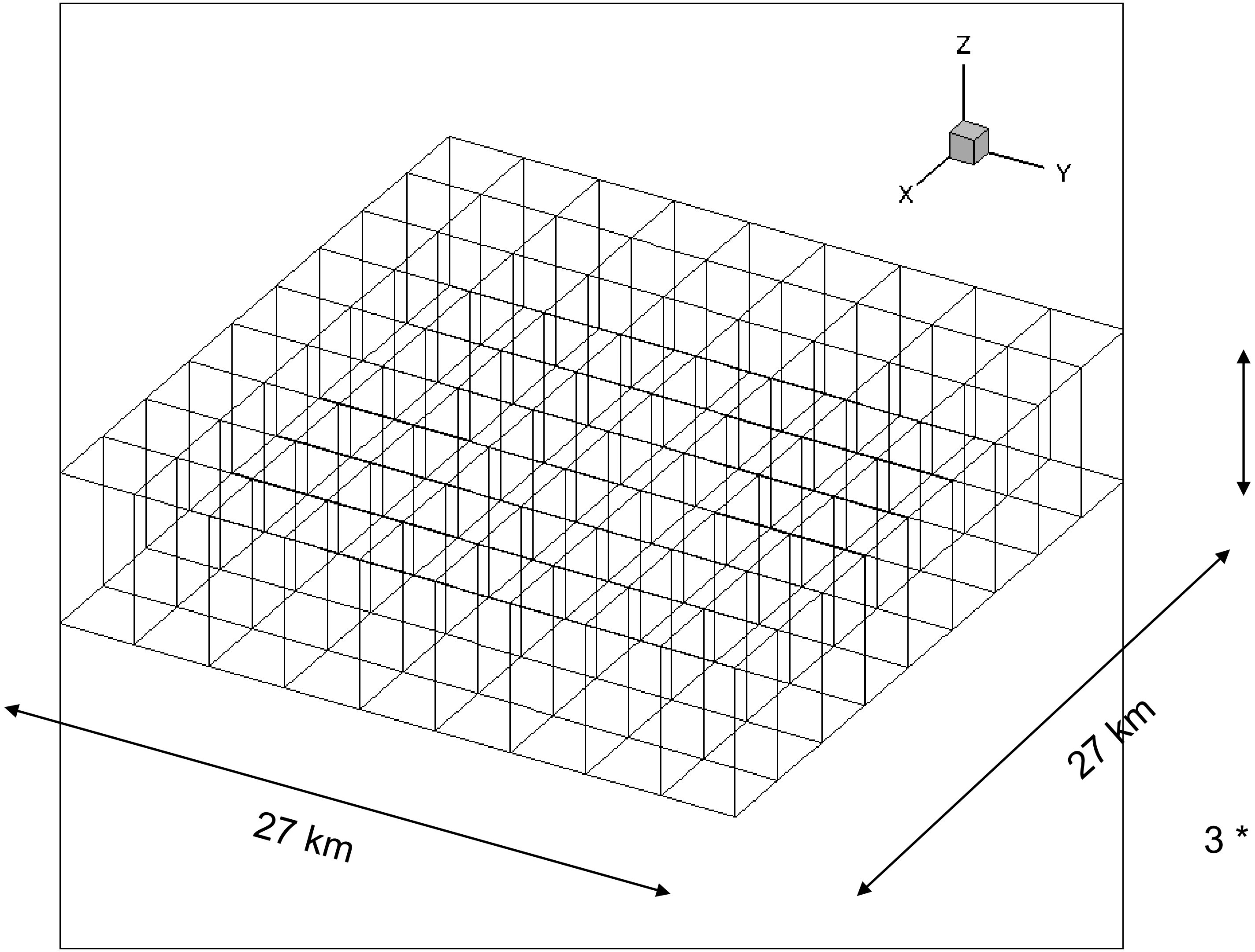
- In HPCWE
  - tendency information from WRF to Ellipsys3D is 3-D
  - Many “columns” of tendencies for covering Elliipsys3D domain appropriately
  - Evolve in time

Mesoscale tendencies from 1 vertical profile



27 * 27 km profile

Mesoscale tendencies from 81 (= 9 * 9) vertical profiles



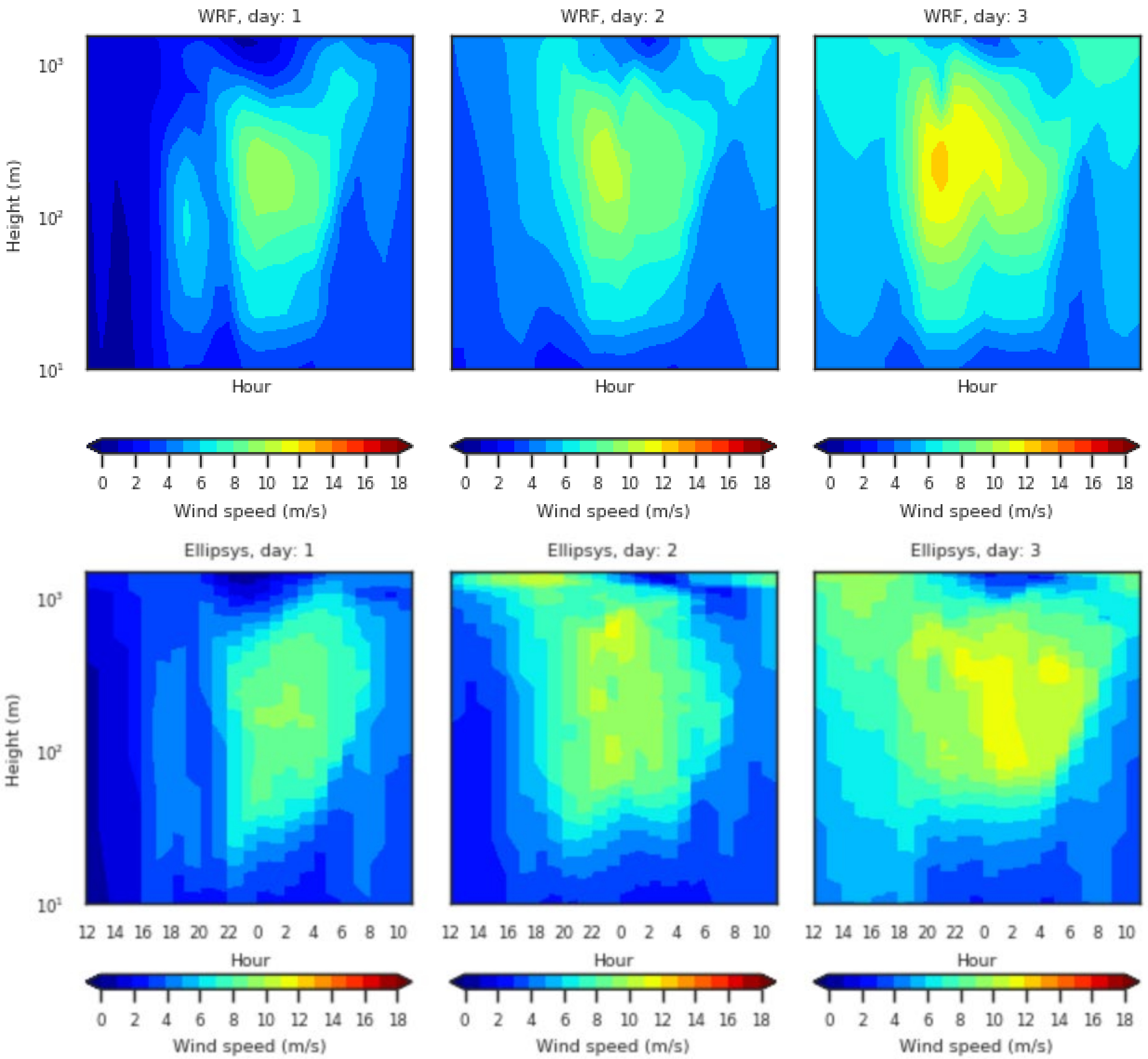
3 * 3 km profiles

3D microscale solver with mesoscale tendencies from 1 profiles

Mesoscale tendencies from

3 km WRF grid

1 profile



WRF
wind speed

Ellipsys3D
wind speed

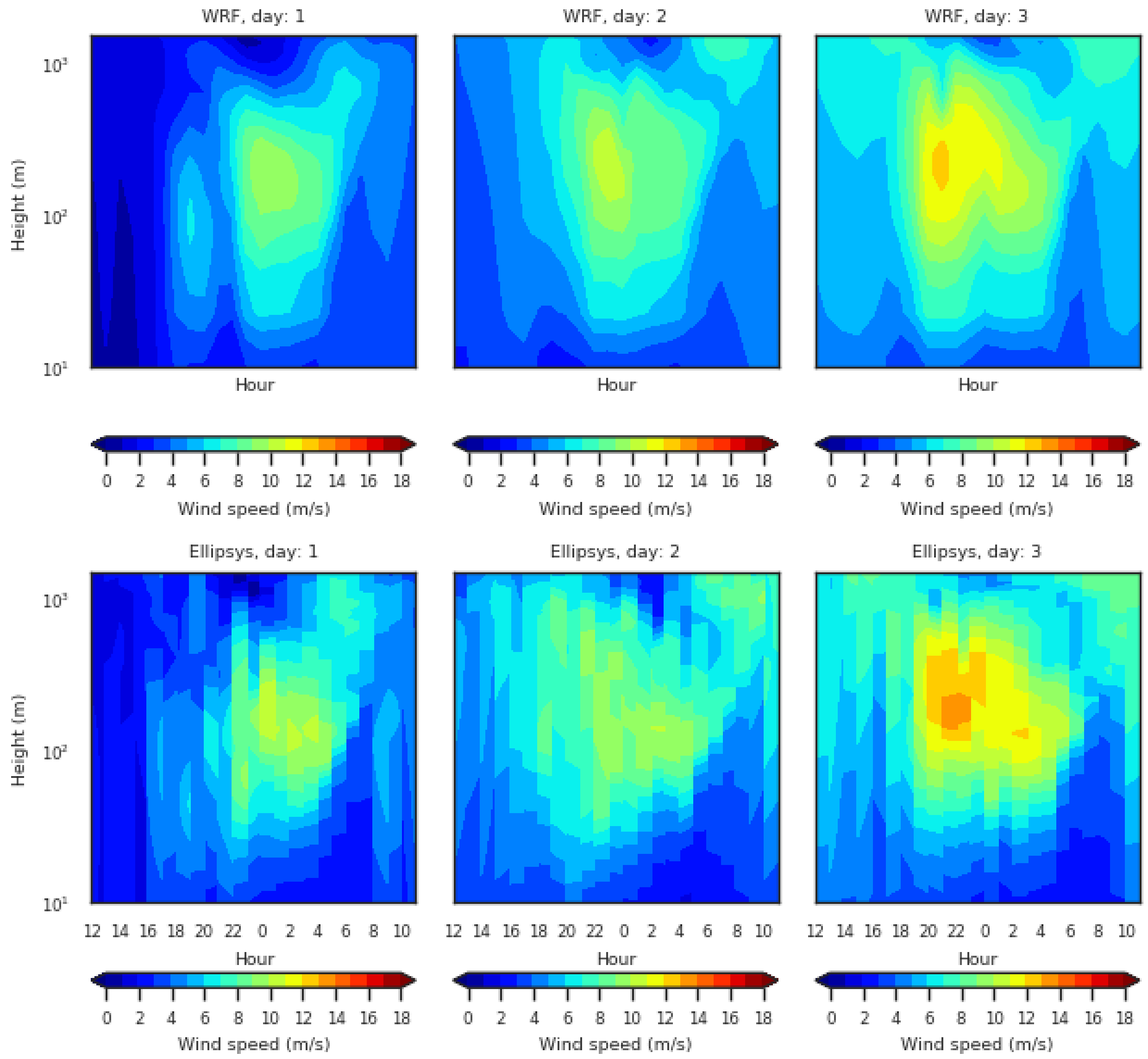
Cabauw, case

3D microscale solver with mesoscale tendencies from 81 profiles

Mesoscale tendencies from

3 km WRF grid

9 x 9 = 81 profiles

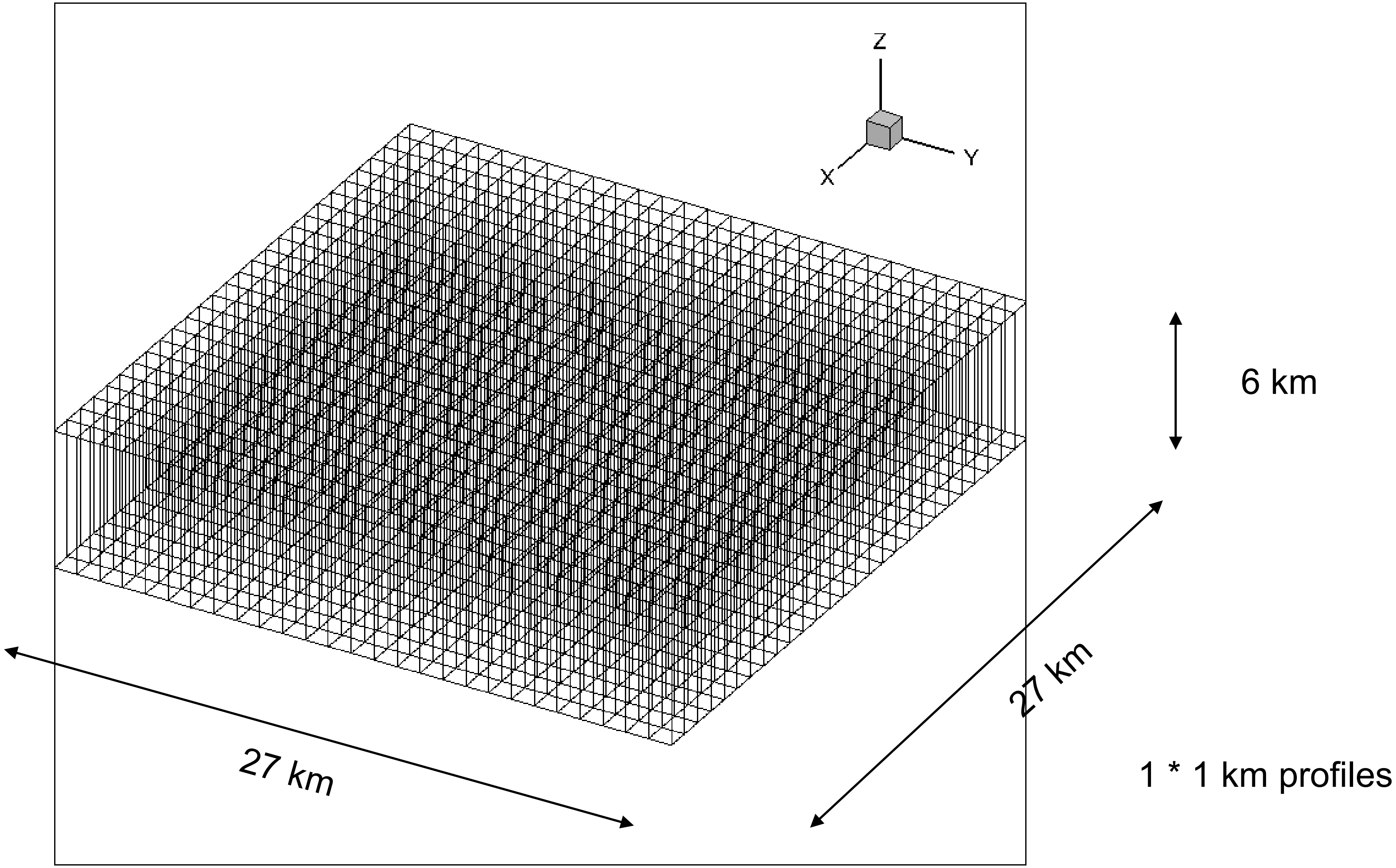


WRF
wind speed

Ellipsys3D
wind speed

Cabauw, case

Mesoscale tendencies from 729 (= 27 * 27) vertical profiles

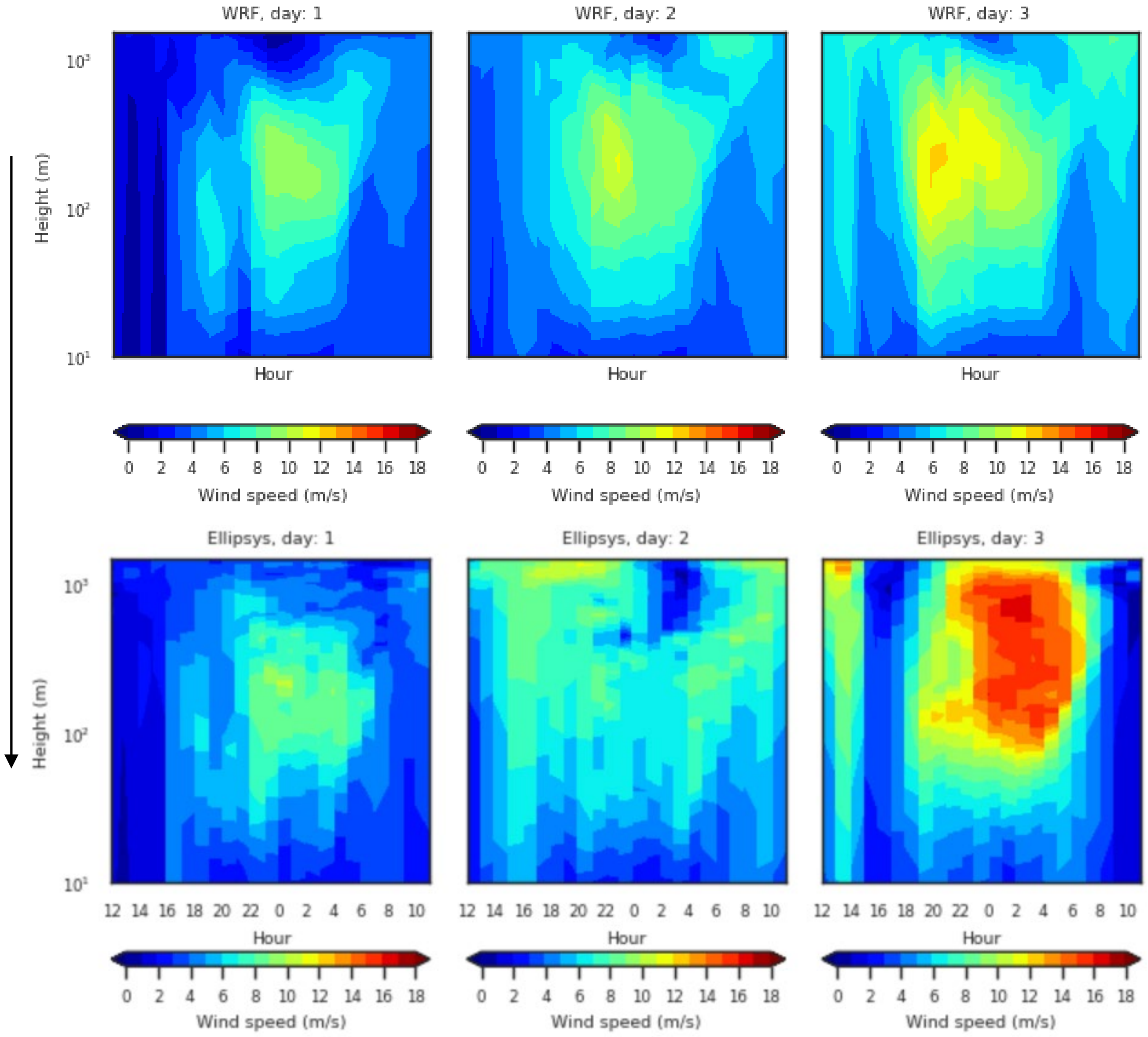


3D microscale solver with mesoscale tendencies from 1 profile1

Mesoscale tendencies from

1 km WRF grid

1 profile



WRF
wind speed

Ellipsys3D
wind speed

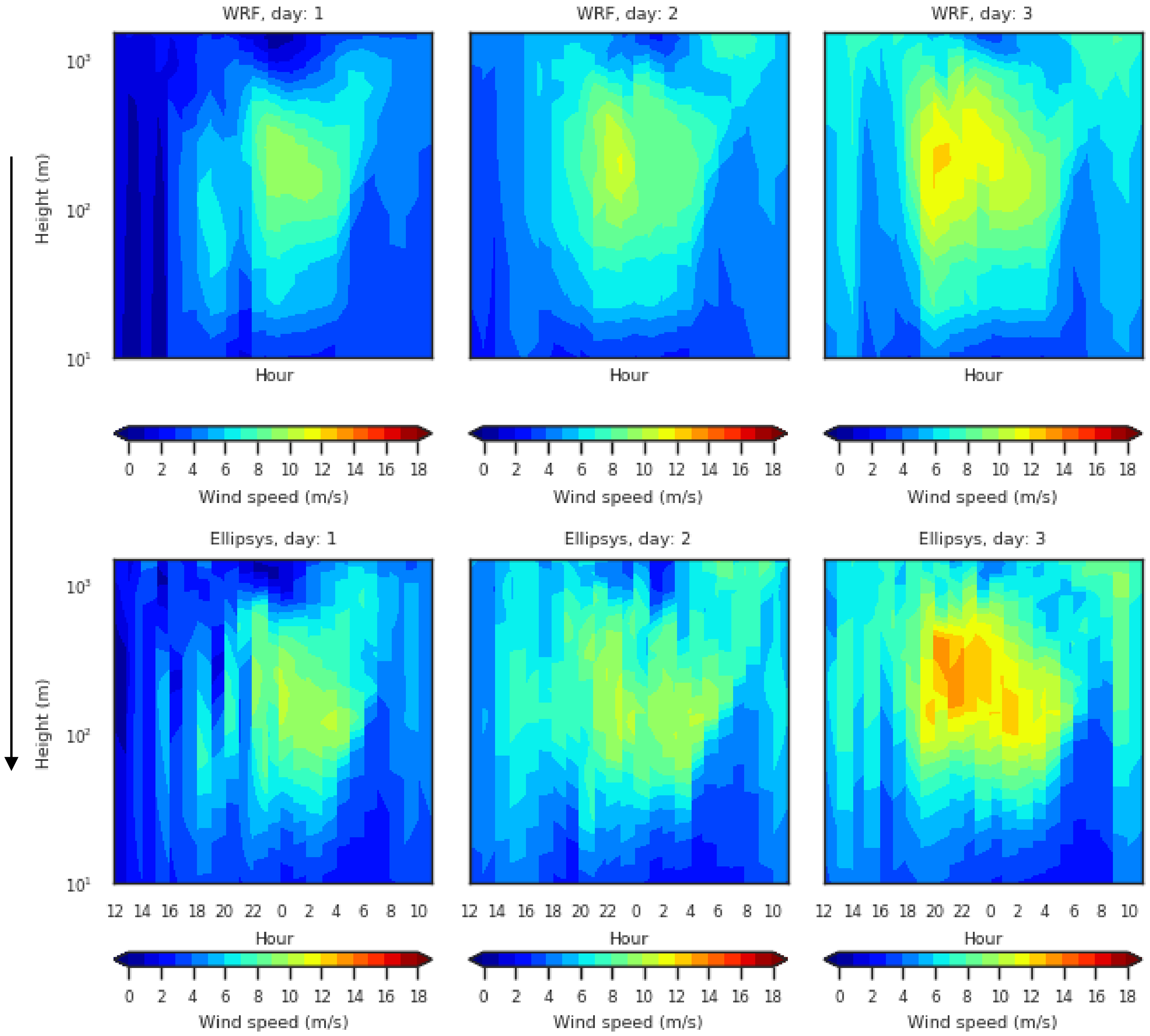
Cabauw, case

3D microscale solver with mesoscale tendencies from 729 profiles

Mesoscale tendencies from

1 km WRF grid

27 x 27 = 729 profiles

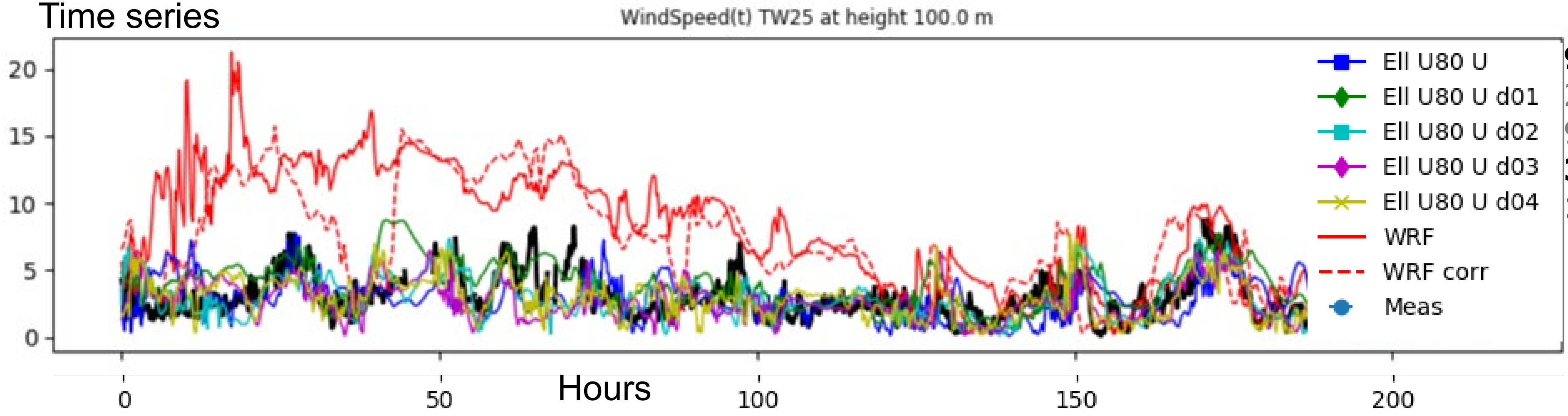


WRF wind speed

Ellipsys3D wind speed

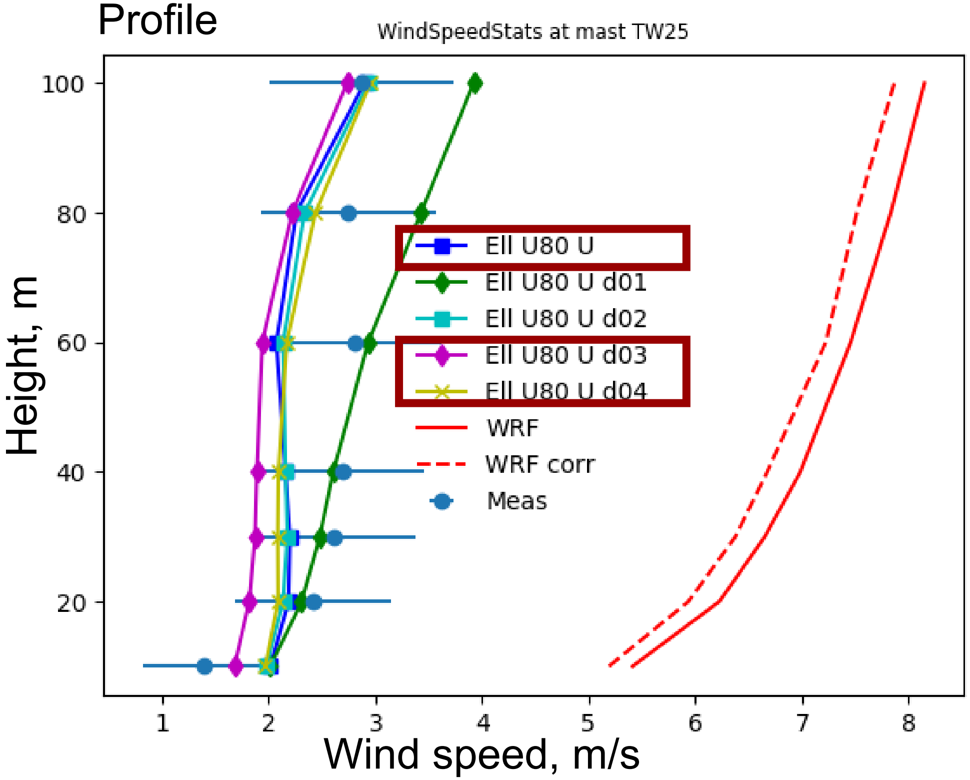
Cabauw, case

Time series

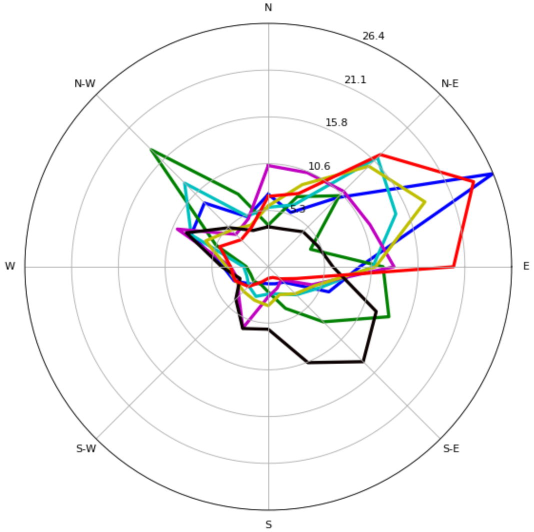


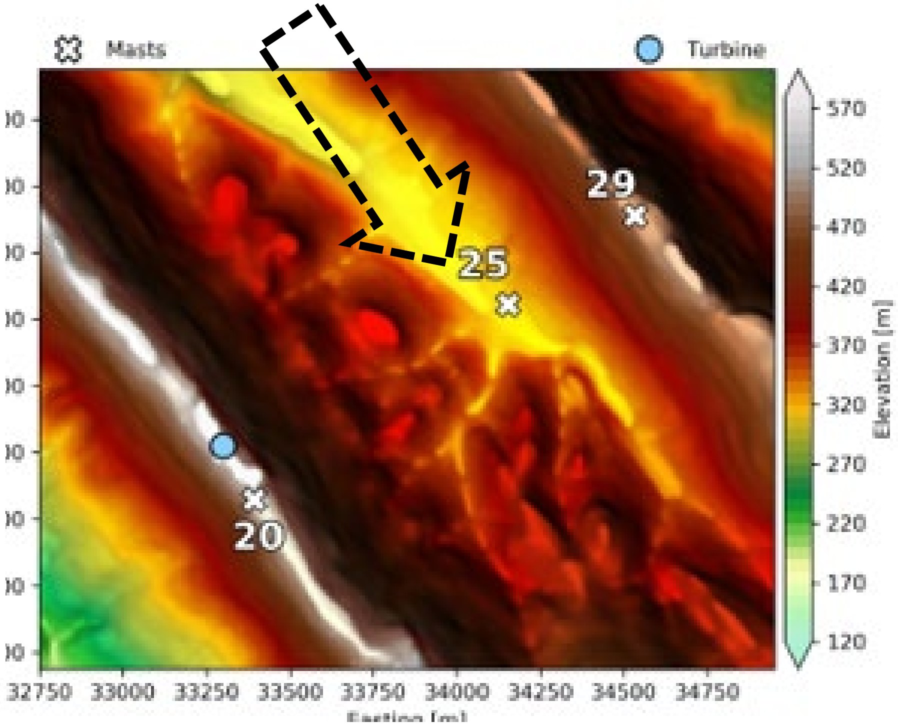
9km ->27 km
27 km -> 27 km
9 km -> 9 km
3 km -> 3 km
1 km -> 1 km

Profile



Wind rose





Perdigao, case

Part 2: Summary

- Proof of concept of using 3D mesoscale tendencies from 27, 9, 3, and 1 km domains has been implemented and executed for 3 sites, including Perdigao.
- Choosing the best configuration with validation cases is still underway.
- Implementation of method for integrating mesoscale forcing of various complexity (scalars to 4D fields), into the generic data read stream already of EllipSys3D code is performed.
- I/O operations in Ellipsys3D when using time varying 3D mesoscale tendencies have been identified as something that could be improved to reduce I/O bottleneck.

THE END

Thanks for your attention

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