VORTEX

LES 10-minute Time Series*

* Explained in less than 10 minutes

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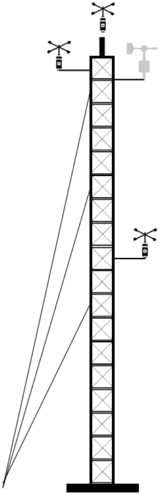
* Explained in less than 10 minutes...†

† ...if there are no questions

How can wind resource be estimated?

On-site measurements



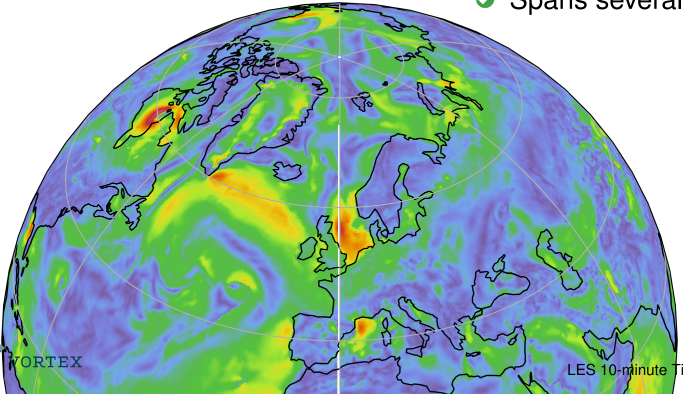
- ✓ Accurate and characterizes local effects.
- ✓ Multi-level meteorological towers and LIDARs estimate vertical profile.

- ✗ Installation and maintenance is expensive
- ✗ Require long-term datasets (10, 20 or even 30 years)

Reanalysis

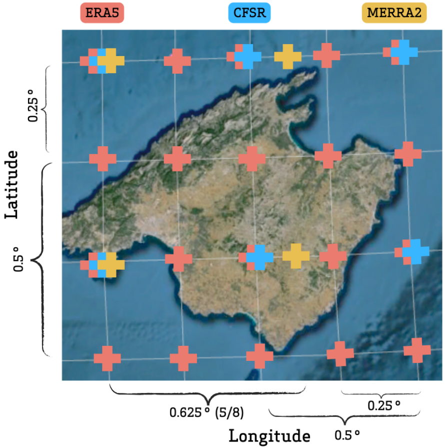
Observations (weather stations, soundings, satellite, buoys, radar) coupled with meteorological model

- ✓ Global availability
- ✓ Evenly distributed in time and space
- ✓ Spans several decades.



Reanalysis

Different datasets: ERA5 (ECMWF), MERRA2 (NASA) and CFSR (NOAA).

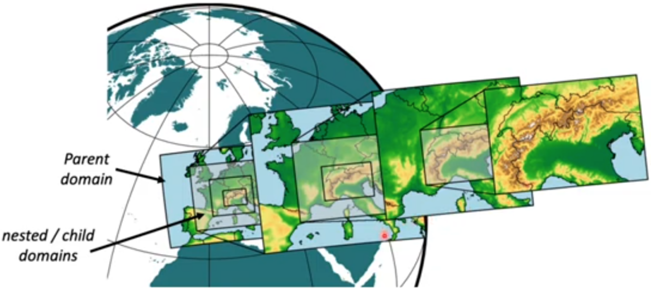


- ☒ Highest horizontal resolution is 0.25 degrees ($\sim$ 27km)
- ☒ Spatial resolution is insufficient for local effects

Mesoscale models

- ✓ Use reanalysis as initial and boundary conditions
- ✓ High resolution by using multiple nested domains

- ⊖ Turbulence + local effects not solved but parametrized.

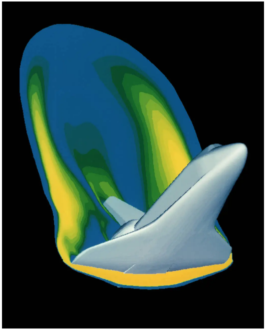


WRF model parent and nested domains **Credit** National Center for Atmospheric Research (NCAR)

Computational Fluid Dynamics

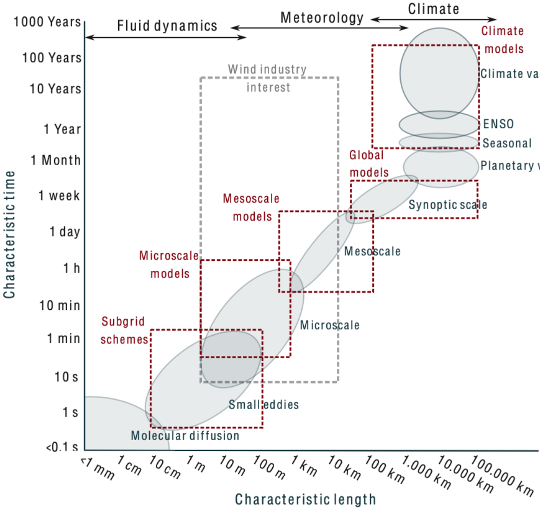
- ✓ CFD simulates very fine motion scales of a fluid
- ✓ Explicitly resolves turbulence

- ✗ High computational cost.
- ✗ Limited to small regions.



CFD simulation of air flow around the Space Shuttle during re-entry. **Credit** NASA

Meteorological scales



Credit: Alex Montornès 2018

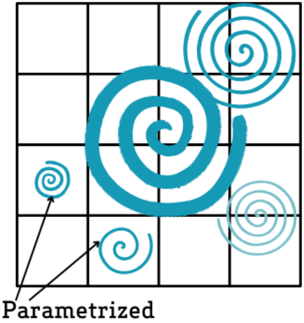
Turbulence

- It’s a small-scale and irregular air motion (variations in wind speed and direction).
    - **Mechanical**: Friction between the air and the ground, especially irregular terrain, causes eddies.
    - **Thermal**: Solar radiation heats the surface, the air above it becomes warmer and more buoyant (convection).

Thermal and mechanical turbulence. **Credit** Shutterstock

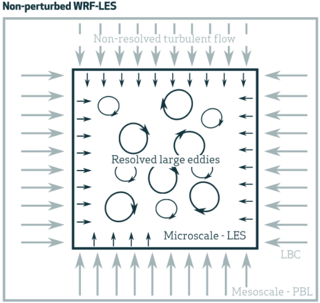
Large Eddy Simulations

- Large eddies, containing most of the turbulent energy, are explicitly solved
- Eddies smaller than the filtering threshold are modeled and their effect is calculated. (Sub-Grid Scale)
- LES reduces the computational cost by parametrizing the smallest length scales.



Methodology

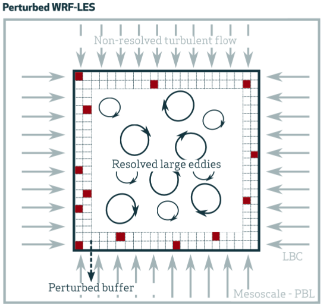
- In a mesoscale simulation, turbulence is parametrized in the PBL scheme due to the spatial and temporal resolution.
- Microscale domains start with horizontally homogeneous non-turbulent fields interpolated from the last mesoscale grid
- These initial conditions inhibit the mechanical turbulence, only thermal turbulence can be developed.



Credit Alex Montornès 2018

Methodology

- As turbulence is developed at the center of the domain, it is destroyed by the non-turbulent LBC
- Random perturbations of the potential temperature are applied to some points at the boundary of the microscale domain.
- This perturbation introduces horizontal and vertical inhomogeneities that accelerate production of mechanical turbulence.



Credit Alex Montornès 2018

Methodology

- Model output are saved at a frequency of 4 Hz (0.25 s)
- Wind, temperature, pressure, air density and moisture are aggregated into 10-min values:

$$\overline{M} = \frac{1}{2400} \sum_{0}^{2399} m_i$$

- Gusts are averaged for every 3-second interval, keeping the maximum value for the 10-min

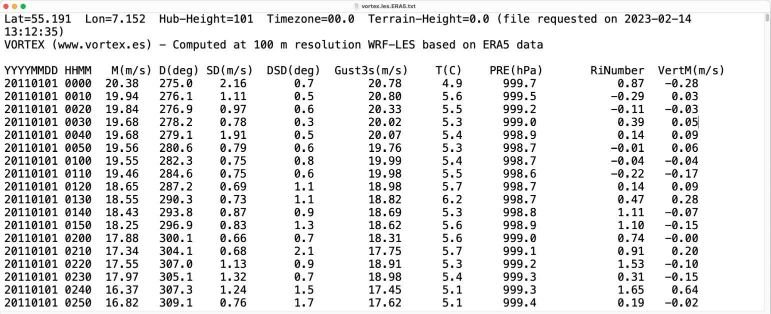
$$\text{Gust3sec} = \max\left(U_1, U_2, ..., U_{800}\right)$$

- Turbulence intensity is calculated from wind speed standard deviation

$$TI = \frac{\sigma M}{\overline{M}}$$

Vortex LES

- 10-minute time series at 100 m horizontal resolution.
- 1-full year period: selectable or long-term representative.



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Lat=55.191  Lon=7.152  Hub-Height=101  Timezone=00.0  Terrain-Height=0.0 (file requested on 2023-02-14
13:12:35)
VORTEX (www.vortex.es) - Computed at 100 m resolution WRF-LES based on ERA5 data

YYYYMMDD HHMM   M(m/s) D(deg) SD(m/s)  DSD(deg)  Gust3s(m/s)    T(C)    PRE(hPa)       RiNumber  VertM(m/s)
20110101 0000  20.38   275.0    2.16       0.7        20.78      4.9      999.7            0.87   -0.28
20110101 0010  19.94   276.1    1.11       0.5        20.80      5.6      999.5           -0.29    0.03
20110101 0020  19.84   276.9    0.97       0.6        20.33      5.5      999.2           -0.11   -0.03
20110101 0030  19.68   278.2    0.78       0.3        20.02      5.3      999.0            0.39    0.05
20110101 0040  19.68   279.1    1.91       0.5        20.07      5.4      998.9            0.14    0.09
20110101 0050  19.56   280.6    0.79       0.6        19.76      5.3      998.7           -0.01    0.06
20110101 0100  19.55   282.3    0.75       0.8        19.99      5.4      998.7           -0.04   -0.04
20110101 0110  19.46   284.6    0.75       0.6        19.98      5.5      998.6           -0.22   -0.17
20110101 0120  18.65   287.2    0.69       1.1        18.98      5.7      998.7            0.14    0.09
20110101 0130  18.55   290.3    0.73       1.1        18.82      6.2      998.7            0.47    0.28
20110101 0140  18.43   293.8    0.87       0.9        18.69      5.3      998.8            1.11   -0.07
20110101 0150  18.25   296.9    0.83       1.3        18.62      5.6      998.9            1.10   -0.15
20110101 0200  17.88   300.1    0.66       0.7        18.31      5.6      999.0            0.74   -0.00
20110101 0210  17.34   304.1    0.68       2.1        17.75      5.7      999.1            0.91    0.20
20110101 0220  17.55   307.0    1.13       0.9        18.91      5.3      999.2            1.53   -0.10
20110101 0230  17.97   305.1    1.32       0.7        18.98      5.4      999.3            0.31   -0.15
20110101 0240  16.37   307.3    1.24       1.5        17.45      5.1      999.3            1.65    0.64
20110101 0250  16.82   309.1    0.76       1.7        17.62      5.1      999.4            0.19   -0.02
```

Vortex LES

- 10-minute time series at 100 m horizontal resolution.
- 1-full year period: selectable or long-term representative.

Validation

- Wind speeds validated in 100 sites worldwide.
- Turbulence intensity validated in 50 sites.

Validation

Wind speeds	Average	Std Dev
MAE (%)	8.3	4.3
A-shape (%)	8.2	5.0
k-shape(%)	9.3	6.1
R2 10-min	0.59	0.09
R2 hourly	0.62	0.09
R2 daily	0.80	0.09

Turbulence	Average	Std Dev
MAE (%)	1.8	0.9
MAE-15 (%)	1.9	1.1

References

- Montornès, Alex and Kosovic, Branko (2016): *WRF-LES in the real world: Towards a seamless modeling chain for wind industry applications* 17th Annual WRF Users' Workshop. Boulder, Colorado. DOI:10.13140/RG.2.1.2270.1041

- Montornès, Alex (2016) *Is WRF-LES a Suitable Tool for Realistic Turbulence Analyses in Wind Resource Assessment Applications?* 22nd Symposium on Boundary Layers and Turbulence (AMS) Salt Lake City. DOI:10.13140/RG.2.1.3974.0400