ABL simulations with uncertain weather parameters and impact on WT performance and near-field noise

zEPHYR Marie Skłodowska-Curie project: Towards a more efficient exploitation of on-shore and urban wind energy resources

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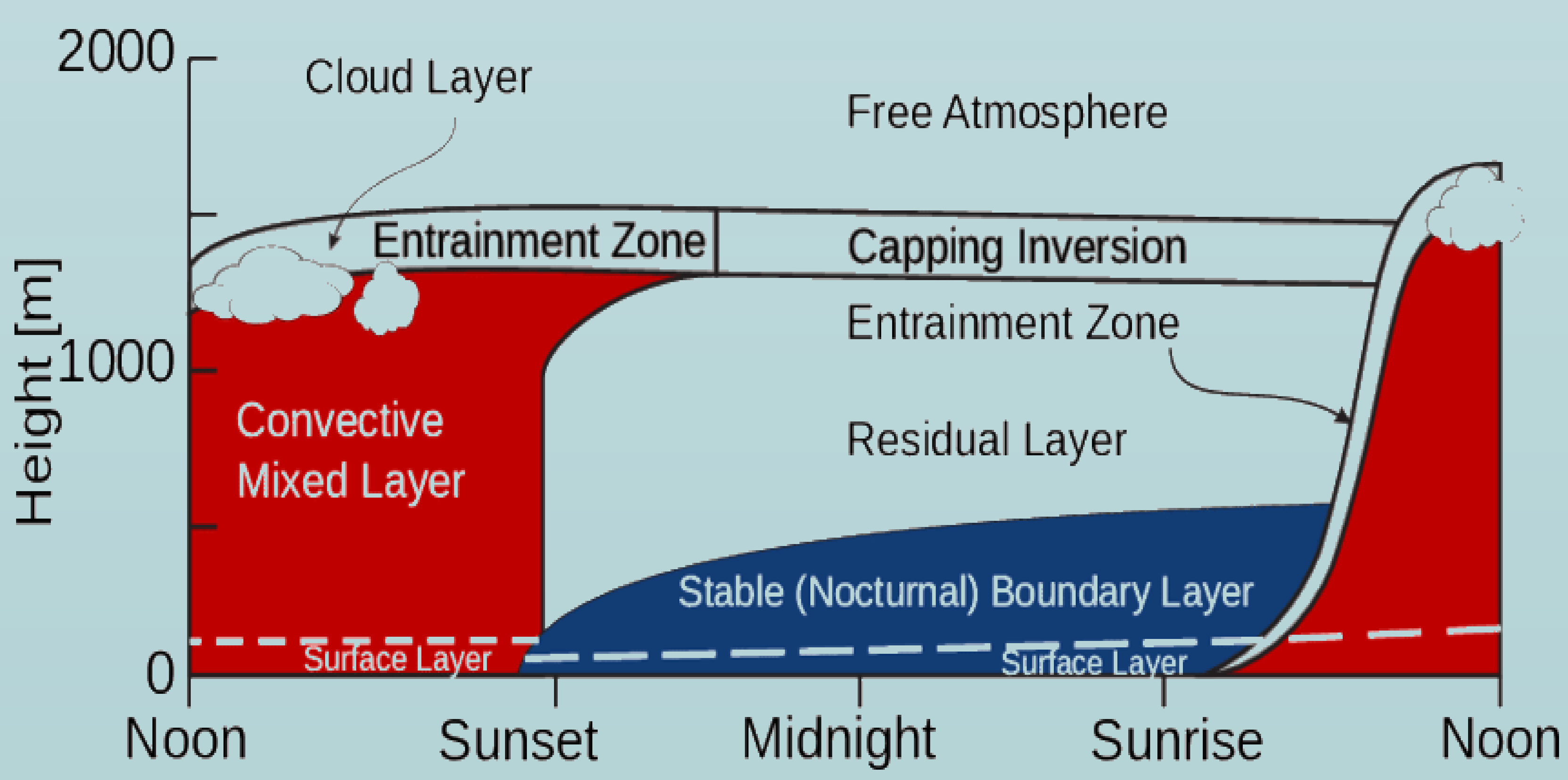
CONTEXT

The **atmospheric boundary layer (ABL)** is the lower part of the troposphere in contact with the Earth's ground. ABL consists of different layers whose structural properties change in a daily cycle.

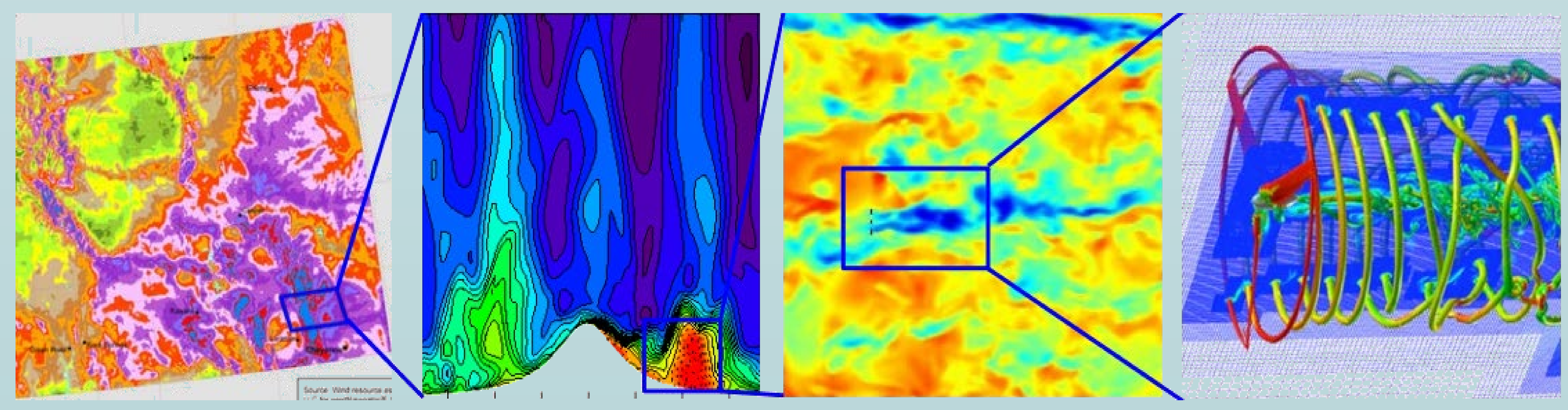
Wind turbines (WTs) operating within the ABL are affected by changes in **turbulence structure** and **dynamics** and are therefore subject to constantly changing wind flow conditions. Realistic **inflow variability** and **boundary conditions** are essential to precisely model the **aerodynamic** and **aeroacoustic** behaviors of wind turbines.



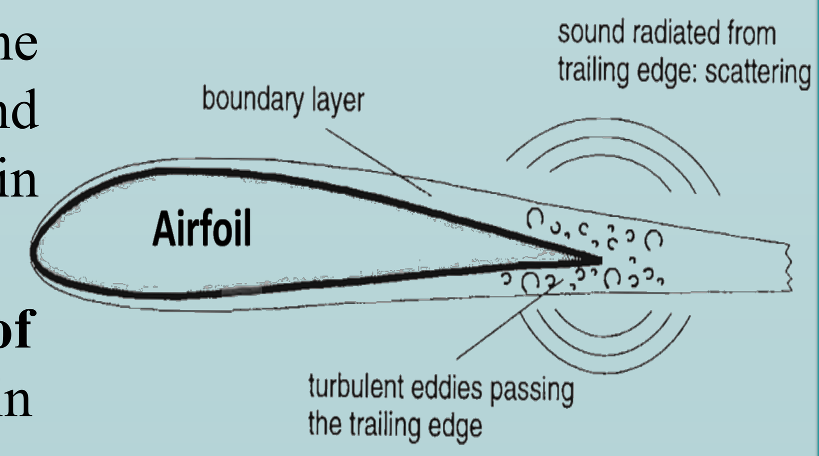
PROBLEM DEFINITION

The main problem of numerical studies regarding the **performance prediction** of wind turbines is to impose **inadequate** turbulent inflow conditions.

Using **re-analysis data set** including **atmospheric** and **land-soil variables** and **high-resolution topography** results in an accurate representation of wind turbine's aerodynamic features.



- **Trailing-edge (TE)** noise is one of the most contributing noise source in wind turbine applications and perceived in whole frequency range.
- TE noise is caused by **scattering of boundary-layer vortical structures** in acoustic waves in the vicinity of the airfoil TE.



OBJECTIVES

- Implement a **WT parameterization scheme** mimicking an active turbine yawing mechanism and perform multiscale ABL simulations in a multiphysics solver (e.g., **Weather Research and Forecasting (WRF)** model) using **Large Eddy Simulation (LES)** technique.
- Couple **WRF-LES** outputs with **semi-analytical** noise models based on **Reynolds-Averaged Navier-Stokes (RANS)** simulation inputs for short-range noise prediction.

TRAILING EDGE NOISE MODELING

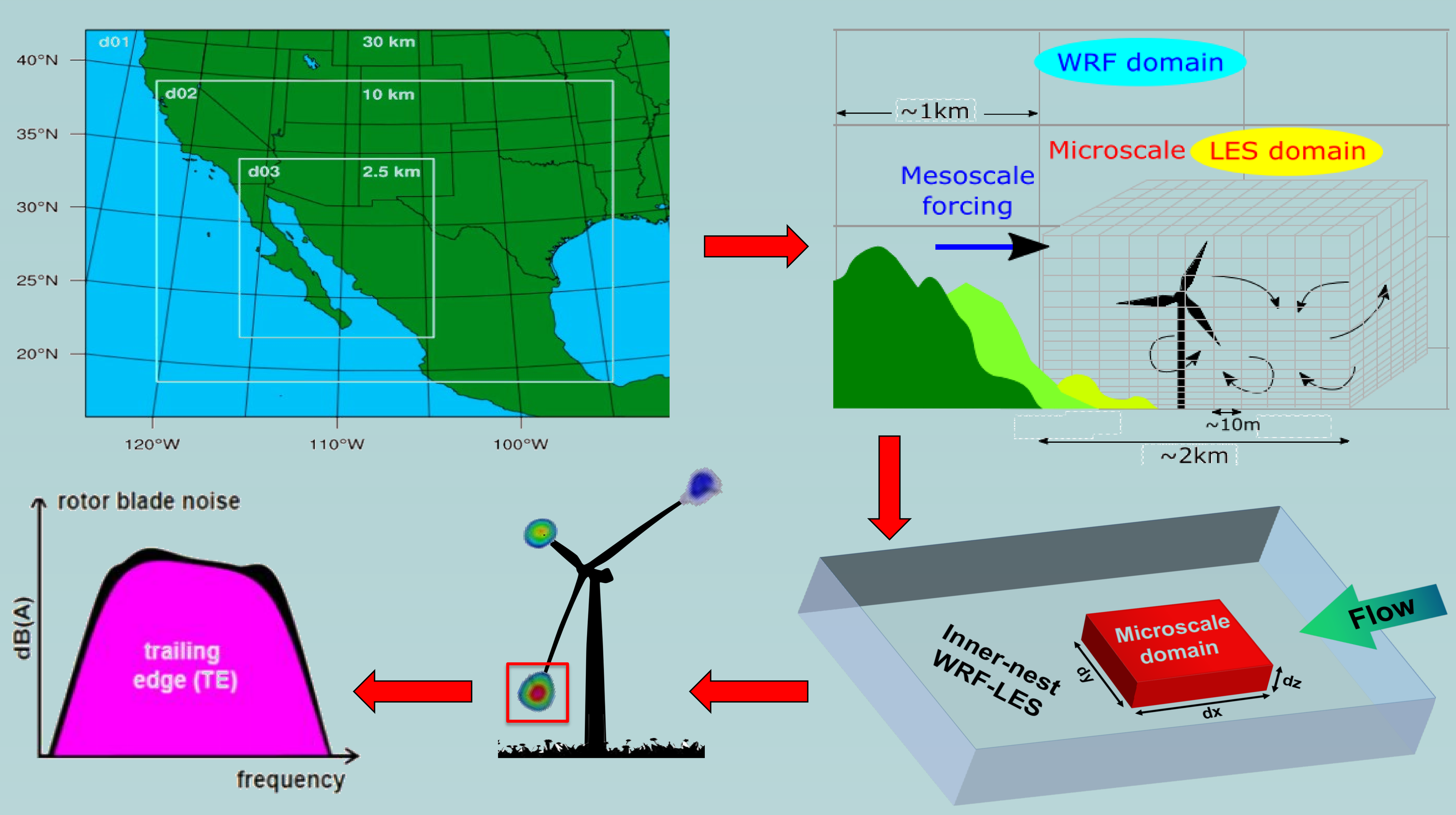
Amiet [1] theory allows predicting **TE** noise for airfoil-like profiles. Assuming a **large airfoil aspect ratio** (L/c):

$$S_{pp}(\vec{x},\omega) = d\left(\frac{kzb}{\pi\sigma_0}\right)^2 \Phi_{pp}(\omega)\,\ell_y(\omega,K_y)\left|\mathcal{L}(\vec{x},K_x,K_y)\right|^2$$

Power spectral density of the sound pressure; Observer/airfoil position; Wall pressure spectrum; Spanwise correlation length; Airfoil response function

METHODOLOGY

WRF is used to force **mesoscale** flow to the **inner-most microscale** domain to perform **LES** with **WT parameterization**. **WRF output** is later fed to a **RANS** solver for the investigation of **wind turbine noise.**

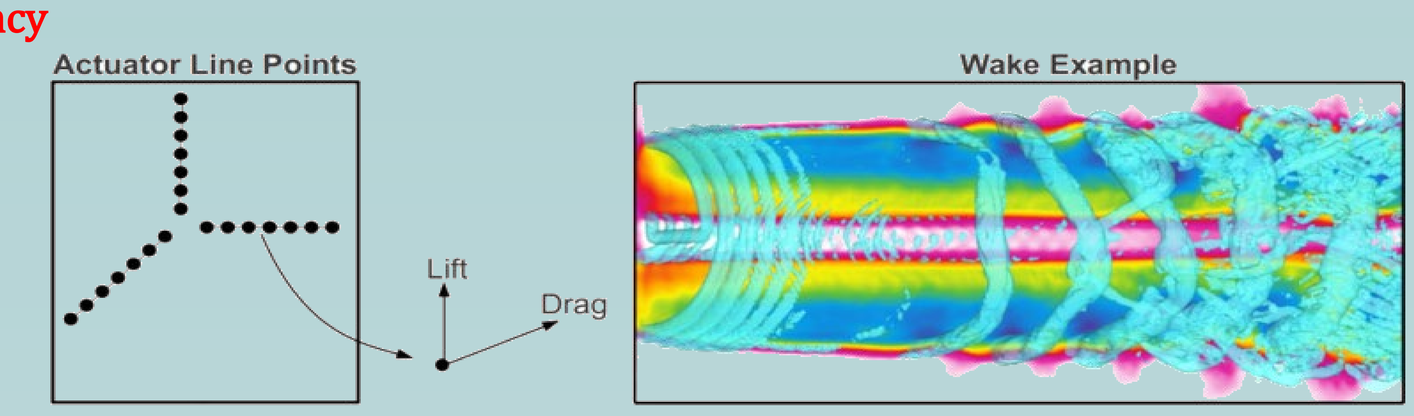


WIND TURBINE PARAMETERIZATION

- **Sørensen and Shen [2]** proposed **Actuator Line Model (ALM)** to simulate wind turbine blades by radially distributing turbine forces along blade-representing lines.
- The **ALM** uses **Blade-Element-Momentum (BEM)** theory by **Glauert [3]** and the computed forces are added to the filtered Navier-Stokes momentum equations as a **sink term** in a high-fidelity **LES** solver.

$$\frac{\partial \vec{U}_i}{\partial t} = -\frac{1}{\rho}G(r,l)\vec{F}_i \quad \text{where} \quad G(r,l) = \frac{e^{\left(-\frac{dr^2}{2\sigma_r^2}+\frac{dl^2}{2\sigma_l^2}\right)}}{2\pi\sigma_r\sigma_l}$$

Filtered momentum tendency; Gaussian smoothing term; Actuator element force



[1] R. K. Amiet, "Noise due to turbulent flow past a trailing edge," *Journal of sound and vibration* 47(3), 387-393 (1976).
[2] J. N. Sørensen and W. Z. Shen, "Numerical modeling of wind turbinewakes," *J. Fluids Eng.* 124, 393 (2002).
[3] H. Glauert, "Airplane propellers," in Aerodynamic Theory, edited by W. F. Durand (Dover, New York, 1963), pp. 169–360.

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