

Reconstruction of offshore wind and turbulence profiles using data-driven methods

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Problem statement

Importance of characterizing wind and turbulence profiles at offshore sites

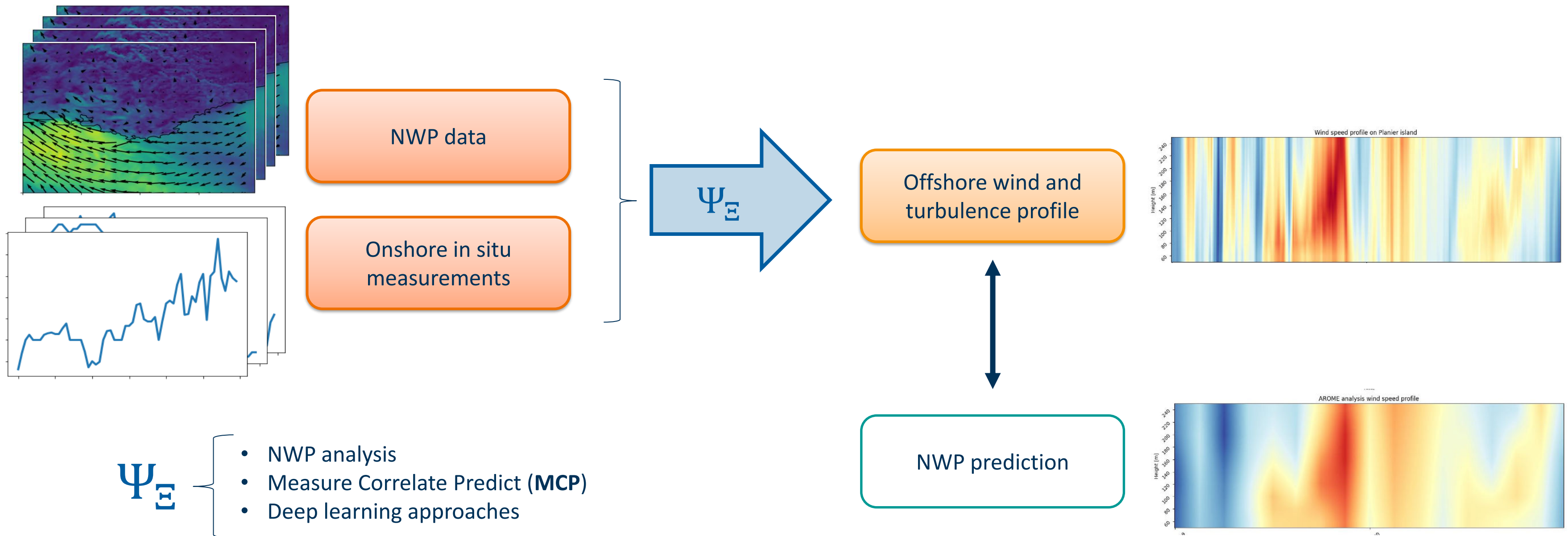
- Power production estimates and fatigue assessment
- Site-specific coastal micro-meteorology
- Very expensive Lidar campaigns especially for deep water sites
- Opportunity to leverage coastal measurement for offshore profiles reconstruction

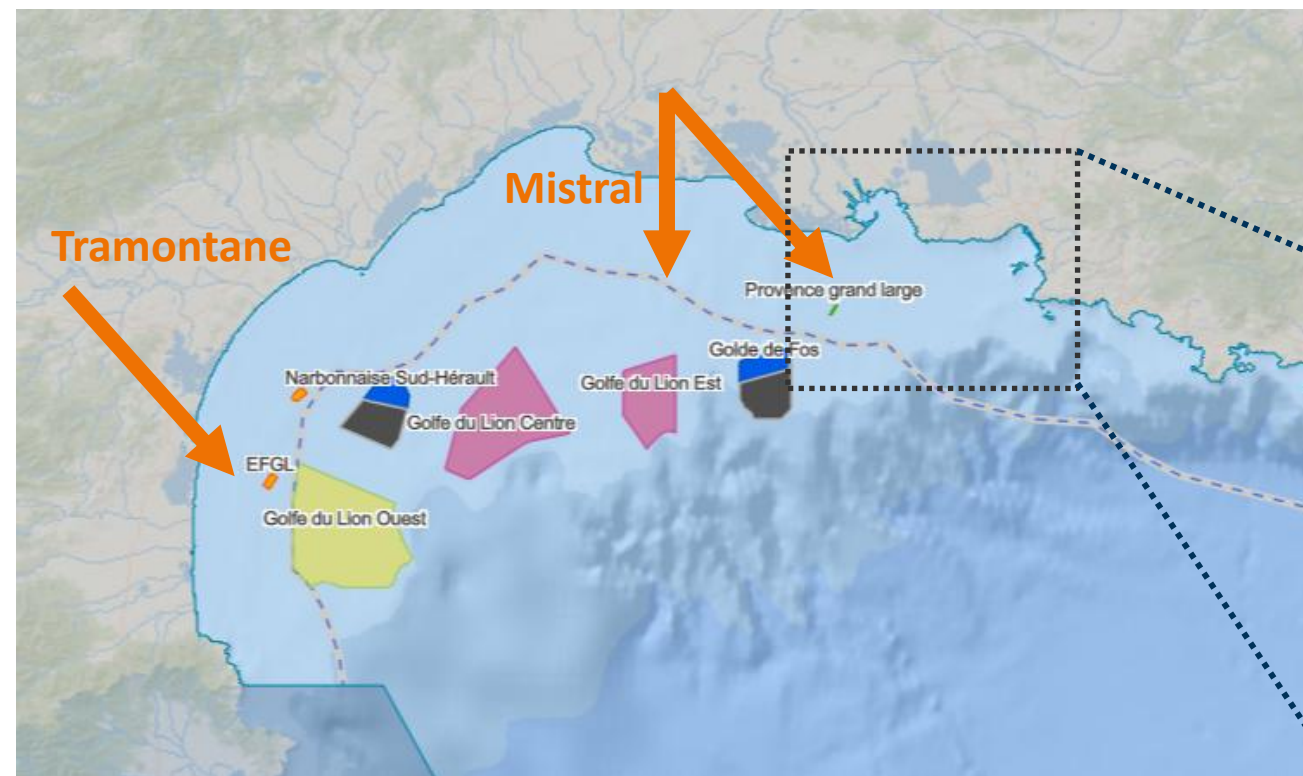
Need for advanced models for profiles reconstruction

- Measure-Correlate-Predict methods rarely applied to full profile and turbulence
- Deep learning models as an opportunity for advanced MCP
- Turbulence parameterization in LES and NWP can be insufficient

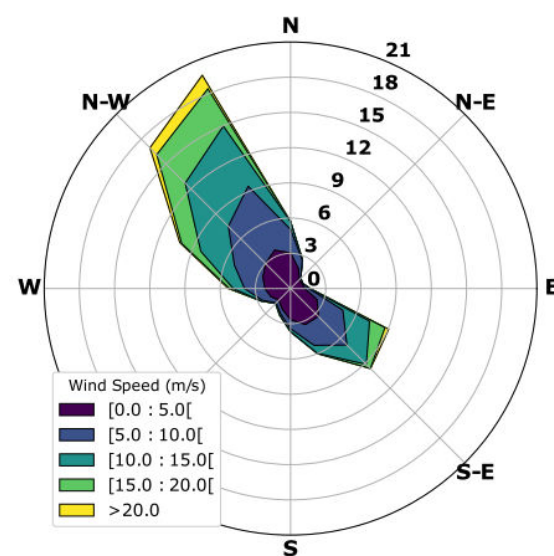
Can we deploy **advanced deep learning-based strategies** to **jointly improve wind and turbulence profiles** predictions at sea using **onshore measurements** ?

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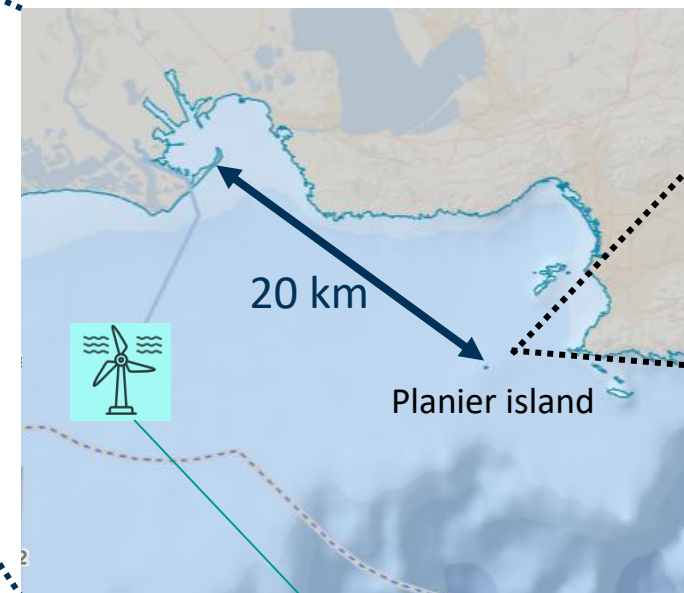




Map of the study area influenced by strong regional winds



Wind rose at the Planier island

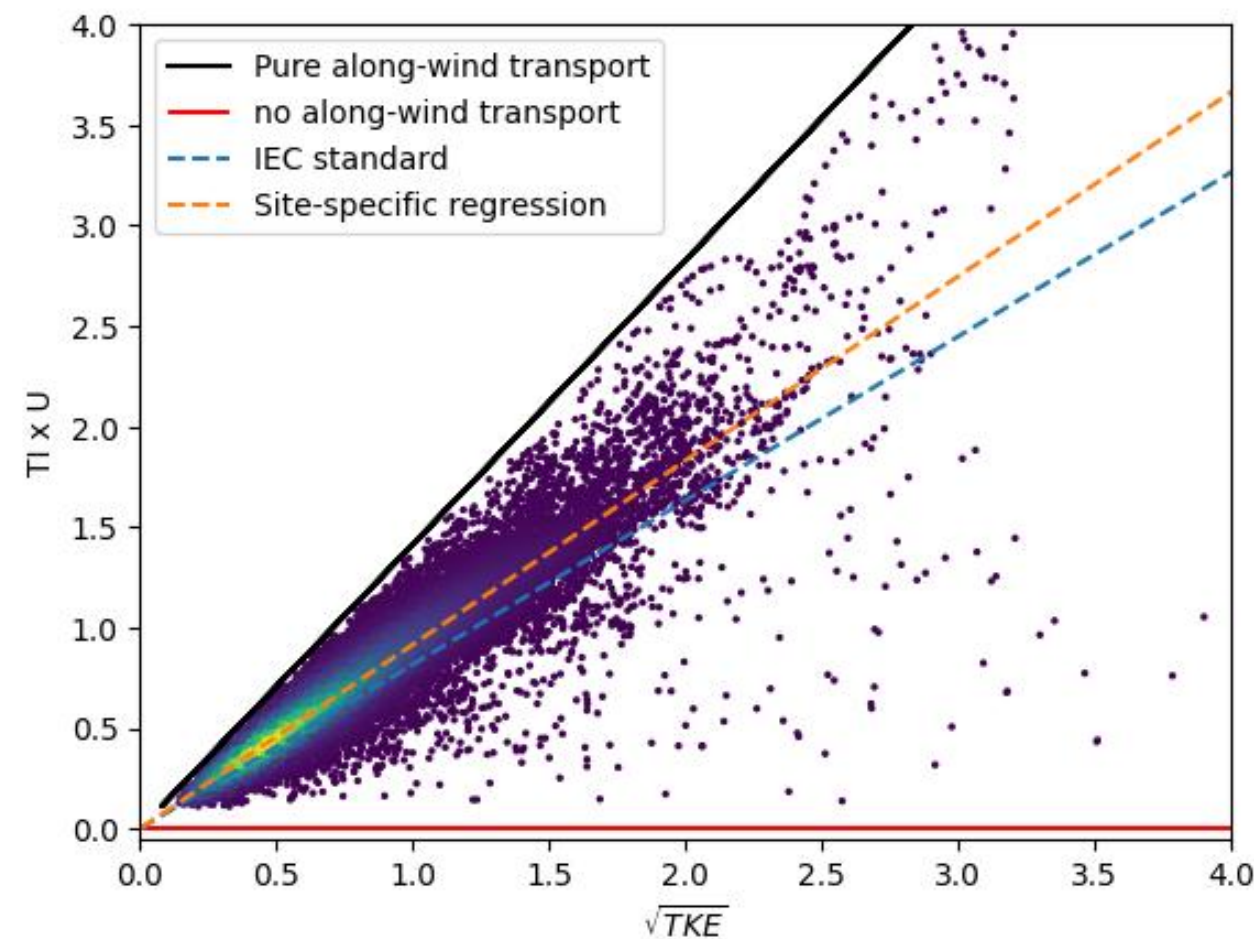


Operating pilot farm Provence
Grand Large 3 x 8,4 MW



Planier island measurement station – Taken from (Thiébaud et al. 2024)

- Site **representative of offshore wind development** areas in the Gulf of Lion
- **Bi-modal wind** distribution, dominant **offshore blowing winds**
- **4-year long** time series
- 1Hz, **3D** wind measurements from 60m to 220m a.s.l.
 - Reconstructed **3D turbulence** (standard method)



$$TKE = \frac{1}{2} (\overline{u'^2} + \overline{v'^2} + \overline{w'^2}) \rightarrow \text{output from NWP and LES}$$

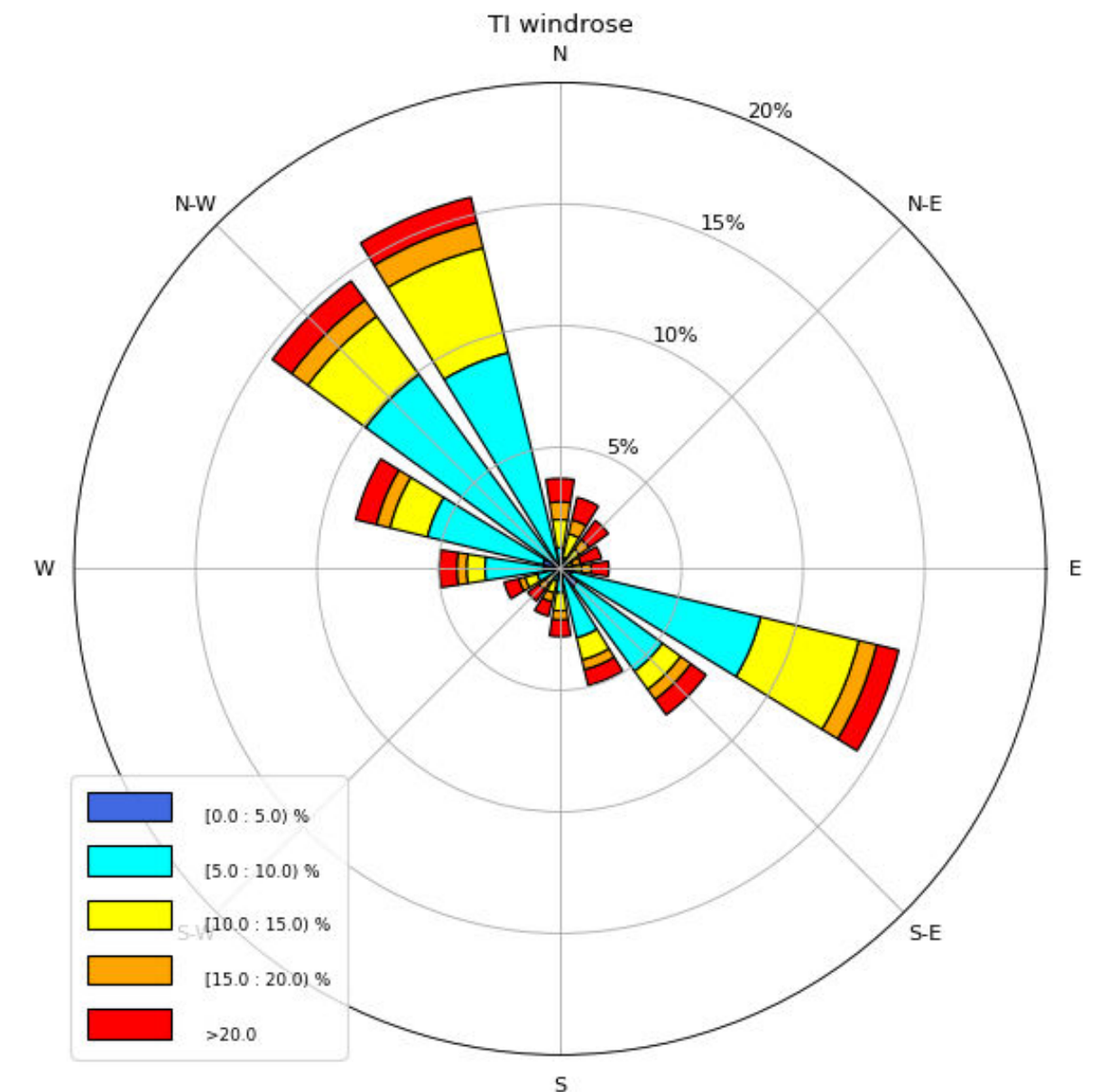
$$TI = \frac{\sigma_u}{U} \rightarrow \text{Main parameter used for wind turbine control}$$

$$TI = \frac{\sqrt{\frac{2}{3} TKE}}{U} \rightarrow \text{IEC standards (isotropy)}$$

$$\text{Relationship from data: } TI \sim \frac{0,9\sqrt{TKE}}{U}$$

- **Anisotropic** turbulent flow
- Different wind regimes imply different TI/TKE relationship

- Importance of **offshore turbulence measurements** to characterize **TI-TKE relationship**
- Very **different wind regimes** in terms of TI/TKE relationship
- Need for a **dedicated TI MCP strategy**



Raw NWP profiles at closest grid point

- IEC TKE/TI conversion
- Situation without offshore profile measurements

$\Psi_{raw\ NWP}$

Corrected NWP profiles with OLS

- Benchmark regression

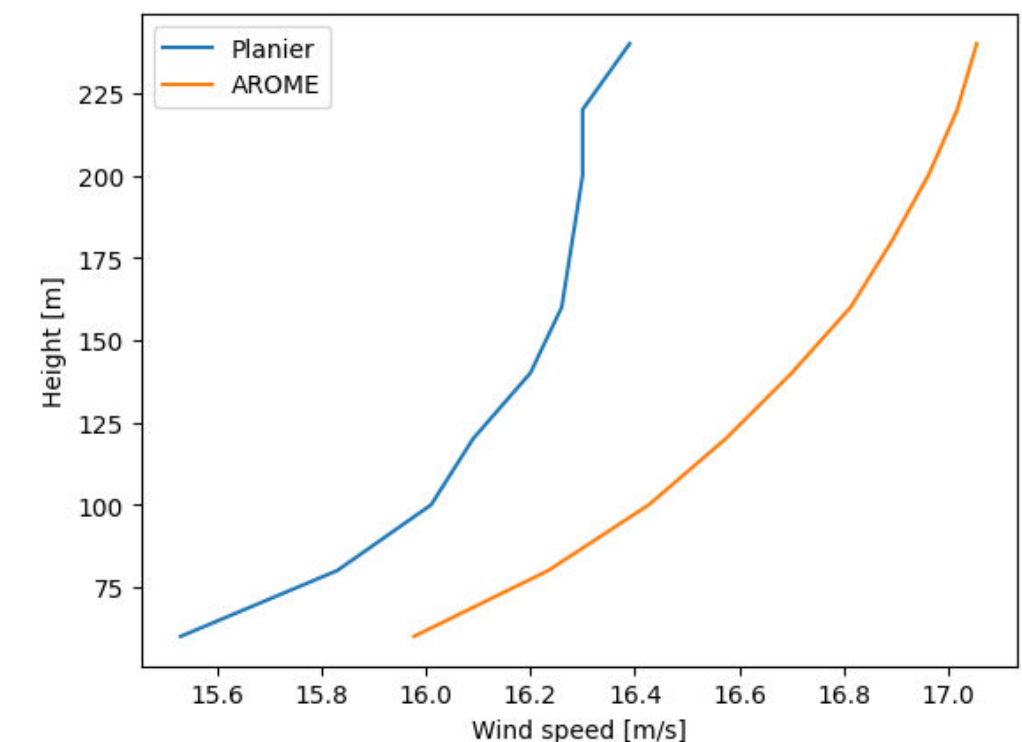
$\Psi_{OLS\ NWP}$

Empirical feature selection :

- Wind speed and direction profiles at target
- SST-land temperature difference
- Bulk Richardson number
- Wind at closest coastal station
- Advanced MCP benchmark

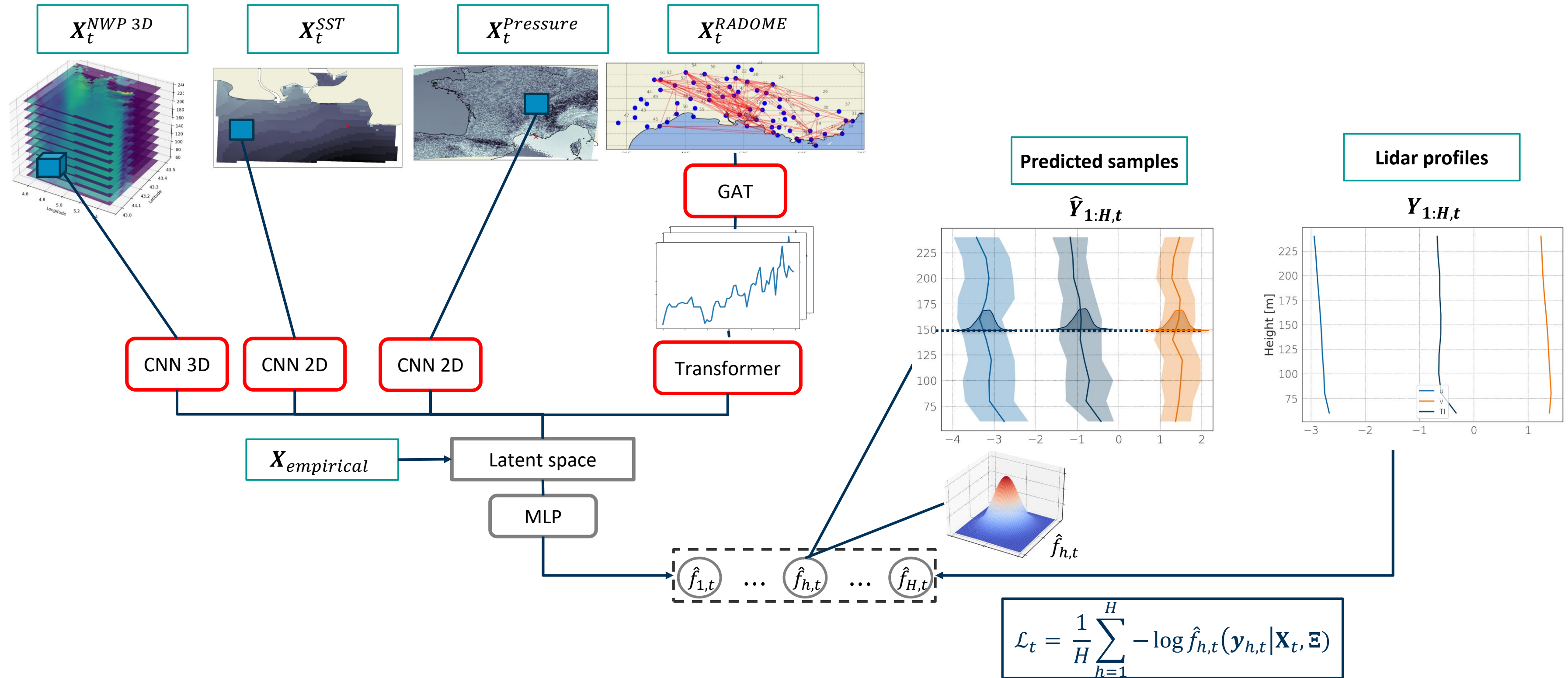
$\Psi_{empirical}$

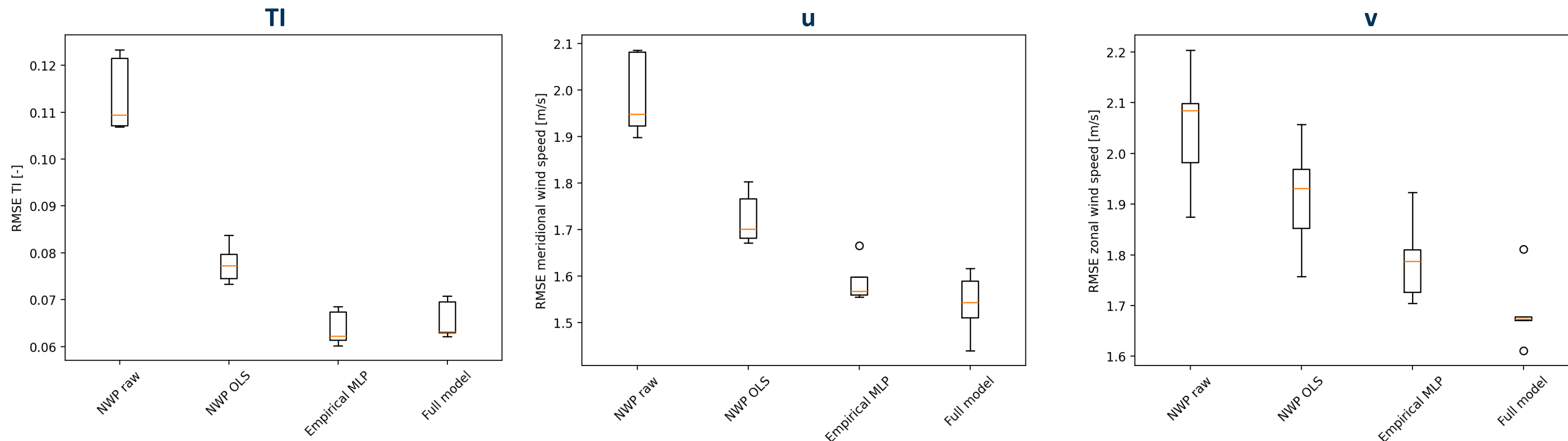
Raw profile (u, v, TI)



$$\mathcal{L} = \frac{1}{T_{test}} \sum (\hat{y}_{test} - y_{test})^2$$

A deep learning approach for offshore profile prediction





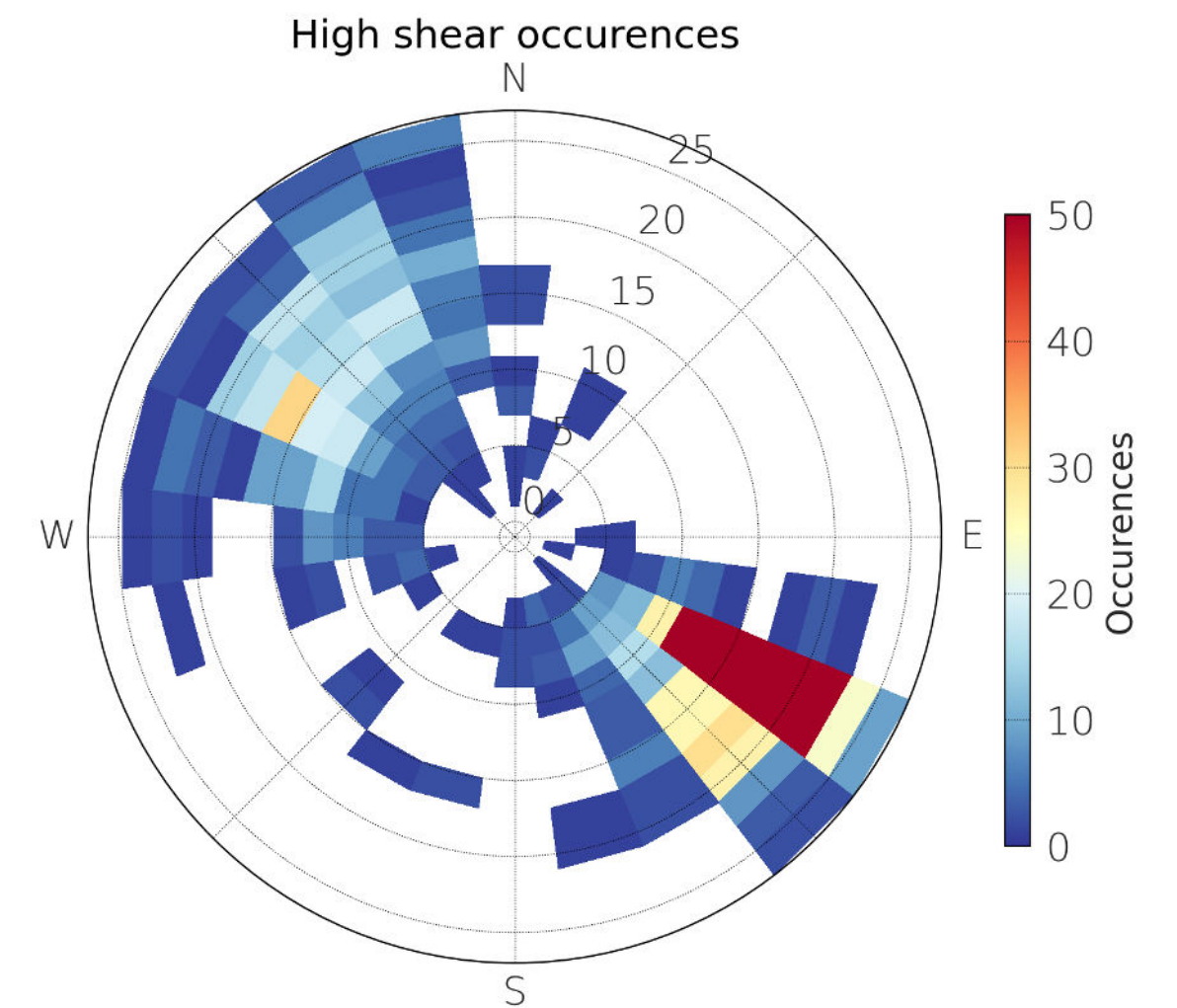
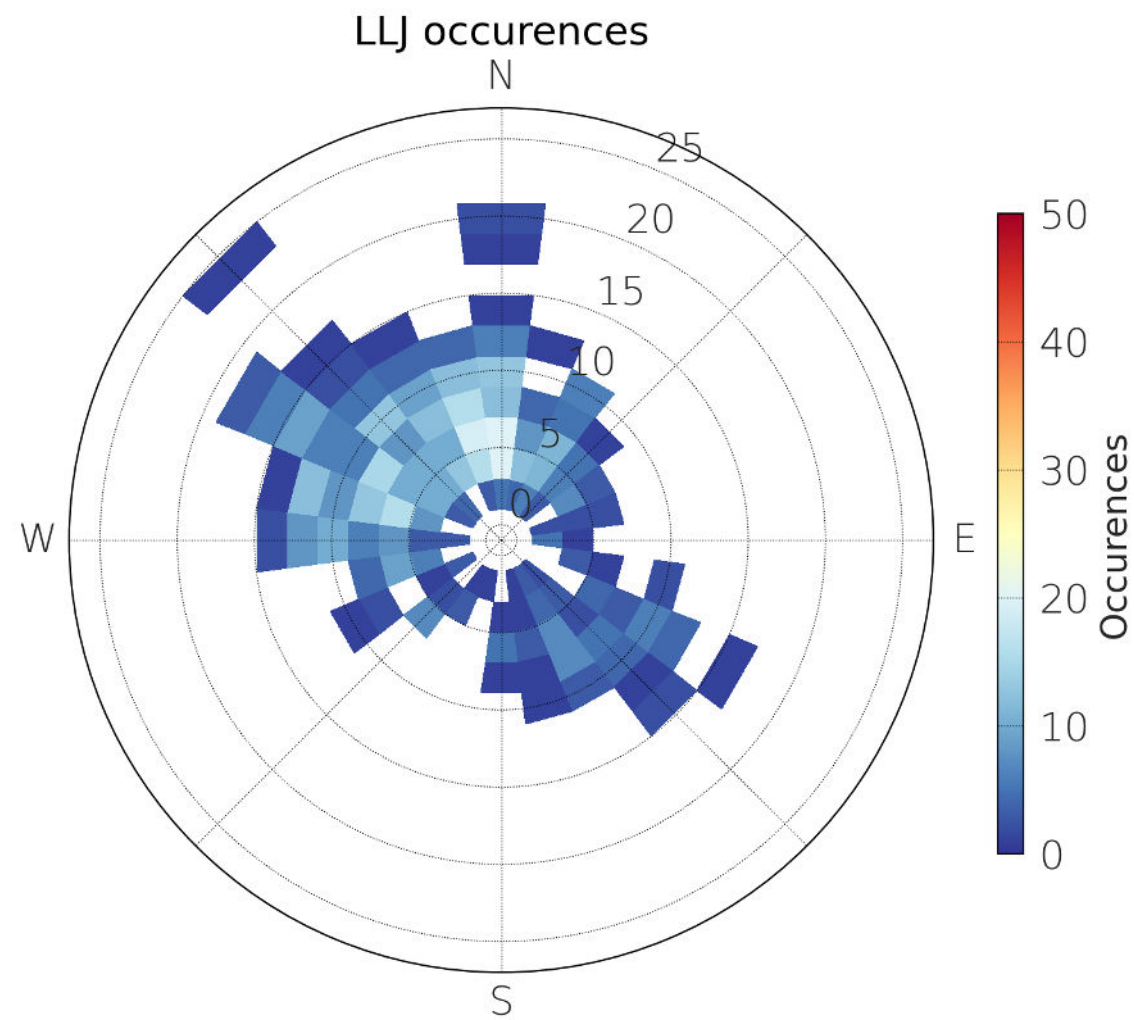
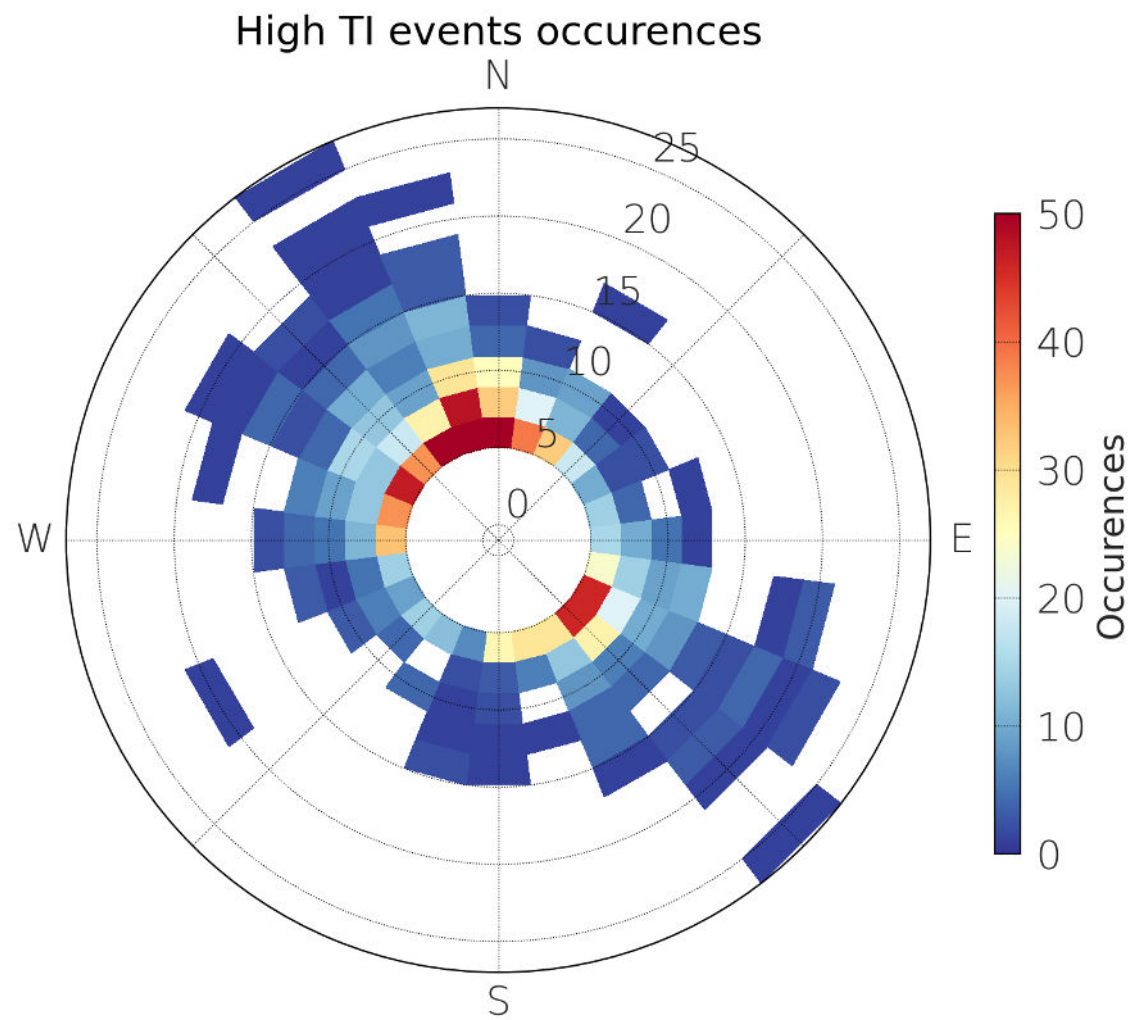
- **Consistent forecast improvement** using deep learning
- **MCP for TI prediction is essential** since TI is not directly predicted by NWP
- Little added information for TI with full input → need for additional coastal measurements
- Simple Multi-Layer Perceptron on reduced set of features is a very competitive MCP benchmark

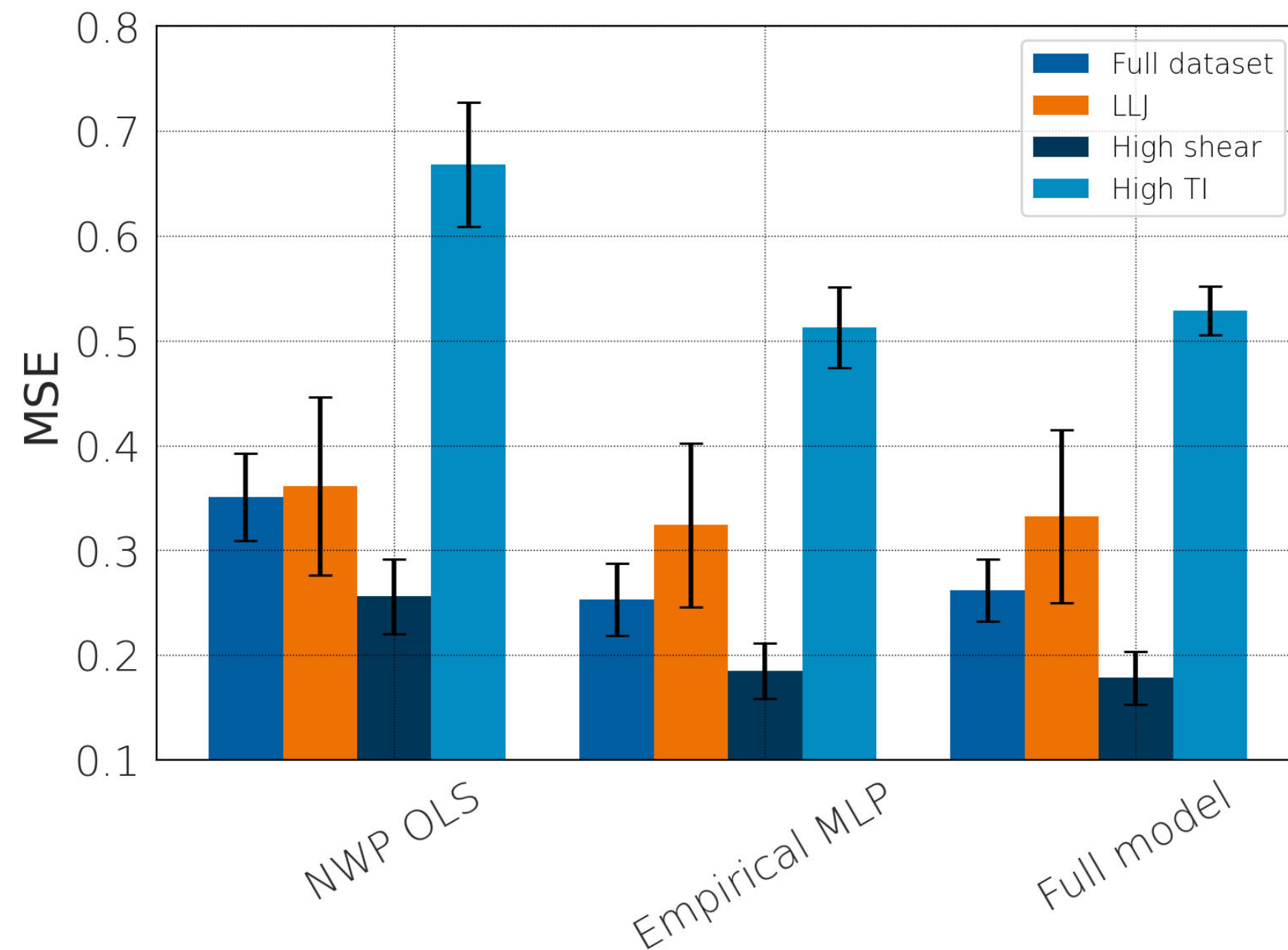
Model	RMSE u [m/s]	RMSE v [m/s]	RMSE TI [-]
$\Psi_{raw\ NWP}$	2,05 +/- 0,11	1,99 +/- 0,08	11,4 +/- 0,7
$\Psi_{NWP\ OLS}$	1,91 +/- 0,10	1,72 +/- 0,05	7,8 +/- 0,4
$\Psi_{empirical}$	1,79 +/- 0,08	1,59 +/- 0,04	6,4 +/- 0,3
Ψ_{full}	1,70 +/- 0,10	1,53 +/- 0,06	6,7 +/- 0,4

Specific profile events

Identify **specific events** related to profile shape and score models on:

- **Low-level jets (LLJ)**
- **High TI** (TI > 16%)
- **High shear** (Shear exponent > 0,035)





- Very **high MSE** on **high TI** situations
- Low error and **good improvement** for **high shear** situations
- **Low improvement** in **LLJ** situations

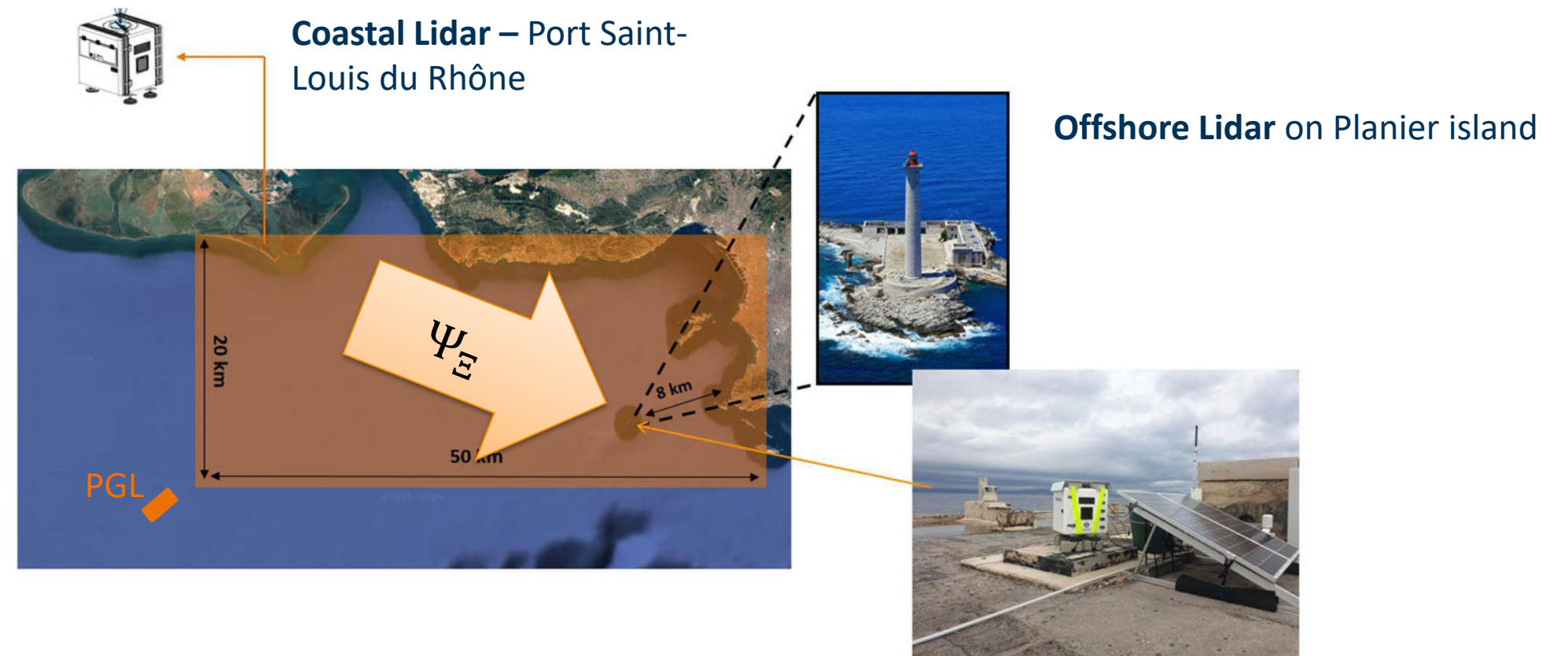
- **High TI relative errors** drive the performances
- **Deep learning** profiles are **smoothed**
 - Low improvement for LLJ
- Very different errors profiles for specific wind profiles situations
 - Design new **specific binary predictors** for profile events ?

Further research on the coastal transition

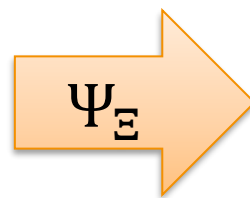
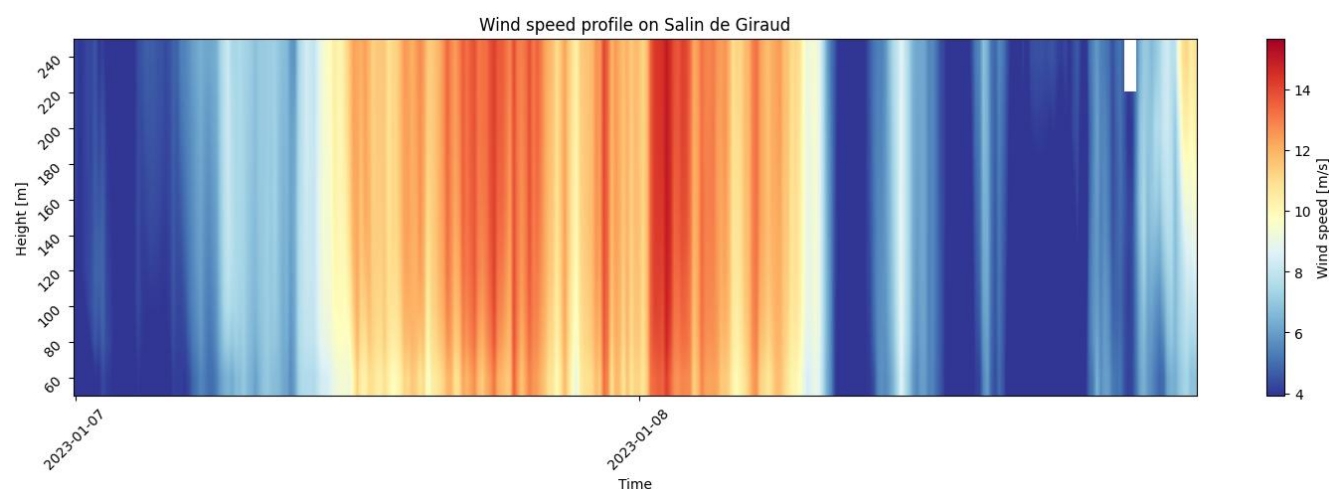
- **Characterization of coastal transition for turbulent** wind profiles
- Add **coastal profile measurements** as input for offshore prediction
- **Comparison to LES** with onshore and offshore calibration

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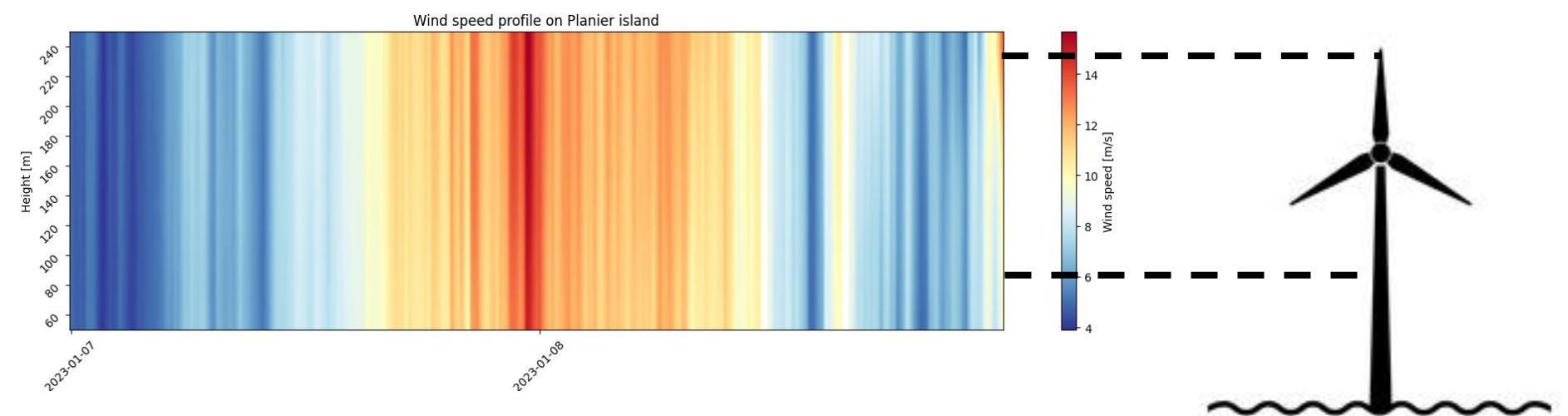
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Coastal profile

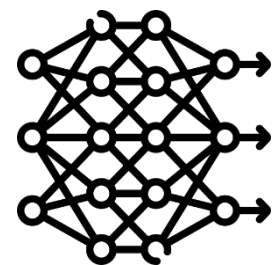


Marine profile on production site



Advanced data-driven MCP

- **Production forecasting**
- **Wake characterization**
- **Fatigue**
- **Extreme events**

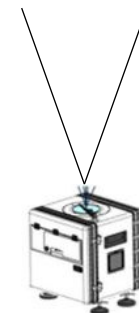
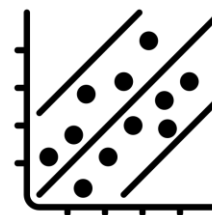


Advanced MCP with deep learning

Large data input pre-processing

Uncertainty prediction

Saptio-temporal feature extraction from onshore measurements

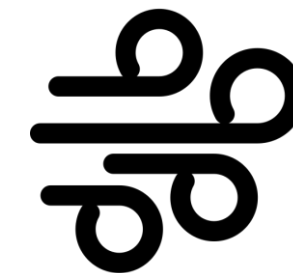


MCP for offshore profiles

Importance of using offshore profile measurements as target

Integrate onshore measurements as explanatory variables

Simple MCP are useful, data matters most



Turbulence profile reconstruction

Large errors on TI profiles from NWP and LES

TI should be included in a dedicated MCP strategies

Need for collocated onshore and offshore TI measurements

Thank you for your attention

