Assessing Wind Gust Diagnosing Methods over Complex Terrain in the Basque Country

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1. Introduction

Accurate forecasting of wind gusts is essential for anticipating severe weather events, given their significant impact on infrastructure, transportation, and public safety (Gaztelumendi et al 2021).

The Basque Country is located in the Iberian Peninsula, in a region of complex topography (Fig. 1), which significantly affects the distribution and intensity of wind gusts. From October to April, severe wind gusts of up to 120–140 km/h may occur, mainly under southerly flow, causing substantial disruption across the territory (e.g. Egaña et al 2009, 2021, Gaztelumendi el al, 2009, 2010.)

Wind gusts are strongly influenced by atmospheric boundary-layer processes, particularly turbulence and vertical momentum transport, which remain challenging to represent in numerical weather prediction models. Since wind exposure varies considerably from one location to another, and following Euskalmet's current severe weather protocol (GV 2025), meteorological stations within the region are classified into two main categories (Gaztelumendi et al 2018): **exposed stations**, located along the coast and at elevated sites where the strongest wind gusts are typically recorded, and **non-exposed stations**, which include urban and valley locations characterized by lower wind exposure.

The main objective of this work is to evaluate and compare predictions from two wind gust diagnostic methods against observations from exposed and non-exposed stations within the Euskalmet Network.

By analyzing how these methods perform under different boundary-layer regimes and surface characteristics, this study aims to support future improvements in operational wind forecasting at the Basque Meteorology Agency (Euskalmet).

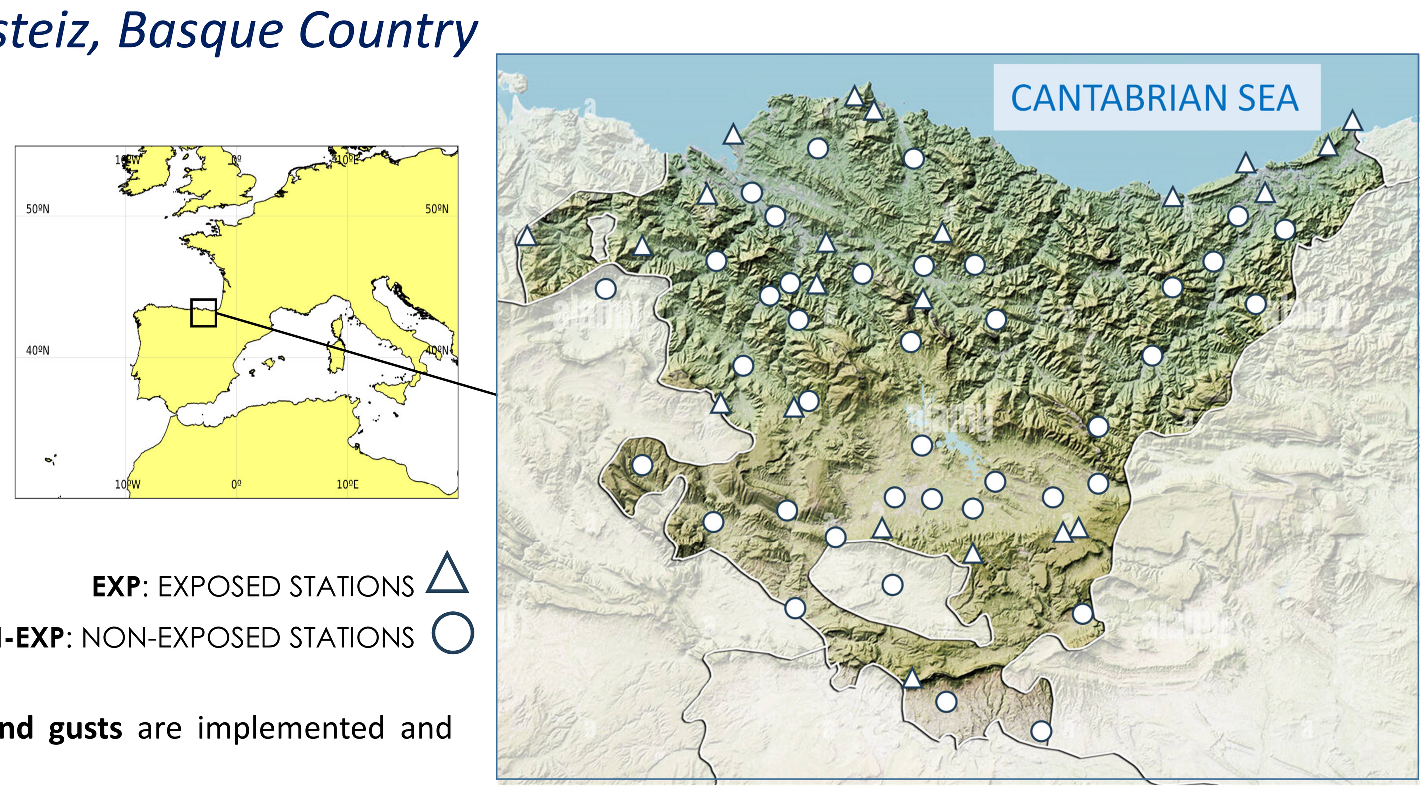


Figure 1. Location of the Basque Country and distribution of weather stations in exposed and non-exposed areas

2. Methodology and Data

The validation framework spans a **two-year study period from 01/03/2024 to 28/02/2026**, focusing on severe wind events that had a notable impact on the Basque Country. **Observational data** are gathered from the representative stations of the Basque Automatic Weather Station (AWS) network managed by Euskalmet. **Model data** are derived from a high-resolution numerical modeling framework using the operational Weather Research and Forecasting (**WRF**) model configuration employed operationally (Euskalmet 2025). The modeling setup includes a state-of-the-art Mellor-Yamada-Nanjundiah-Niino (**MYNN**) turbulence closure scheme and a surface-layer formulation that accounts for thermal roughness as a function of vegetation height, ensuring a coherent representation of boundary-layer processes and surface–atmosphere interactions. Forecast verification is performed using **D-1 lead-time (24–48 hours) from the 00 UTC model run** (see Table 1).

Within this consistent modeling framework, **two distinct methods for diagnosing wind gusts** are implemented and compared:

IFS-based scheme: This method computes gusts using turbulent velocity scales derived from surface stress and atmospheric stability.

NOAA-based scheme (UPP method): This approach estimates maximum gust potential through vertical momentum transport from the top of the planetary boundary layer.

Table 1. Summary of the WRF model configuration and physical parameterizations

WRF configuration and physics	Value
Model Version	WRF-ARW 4.2.2
Central Point	43.085 ºN, 2.58 ºW
Horizontal resolution (km)	3 nested domains (9; 3; 1)
Vertical resolution	45 eta levels (dzbot = 30 m)
Radiation schemes	RRTMG (SW & LW)
Surface Physics	Noah LSM (mosaic option ON)
PBL & surface-layer scheme	MYNN 2.5

IFS-BASED SCHEME

$$U_{gust} = U_{10} + C_e u_* [f(^{z_i}/_L)] + 0.6D(\max(0, U_{MLA} - U_{MLB})),$$

$$\text{where } f(^{z_i}/_L) = \begin{cases} (1 - 0.5\, ^{z_i}/_{12L})^{1/3} & if\ L < 0 \\ 1 & if\ L \geq 0 \end{cases}$$

.

U_{10} is the10-m mean wind speed, C_e (=7.2 in cycle cy47r3), u_* the friction velocity, z_i the PBL height, and L the Obukhov length. The red term is activated through the Boolean variable D when the deep-convection scheme is active. Since deep convection is largely resolved explicitly in our 1-km model configuration, this term is neglected

NOAA-BASED SCHEME (UPP method)

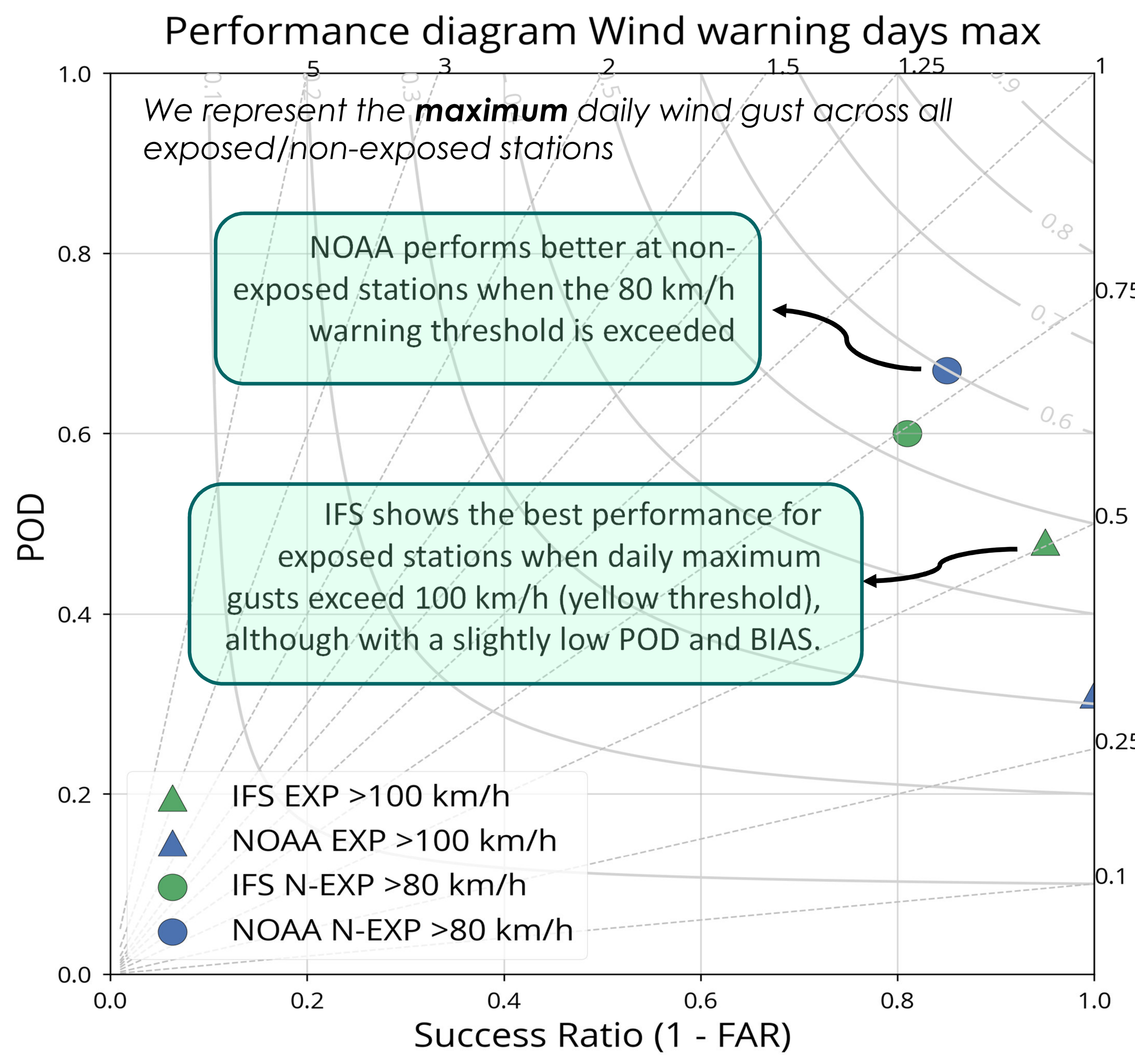
$$U_{gust} = U_{10} + (U_{PBL} - U_{10})\left(1 - \frac{h_{PBL}}{2000}\right),$$

U_{PBL} is the wind speed at the top of the PBL and h_{PBL} is the PBL height in m (≤ 1000 m).

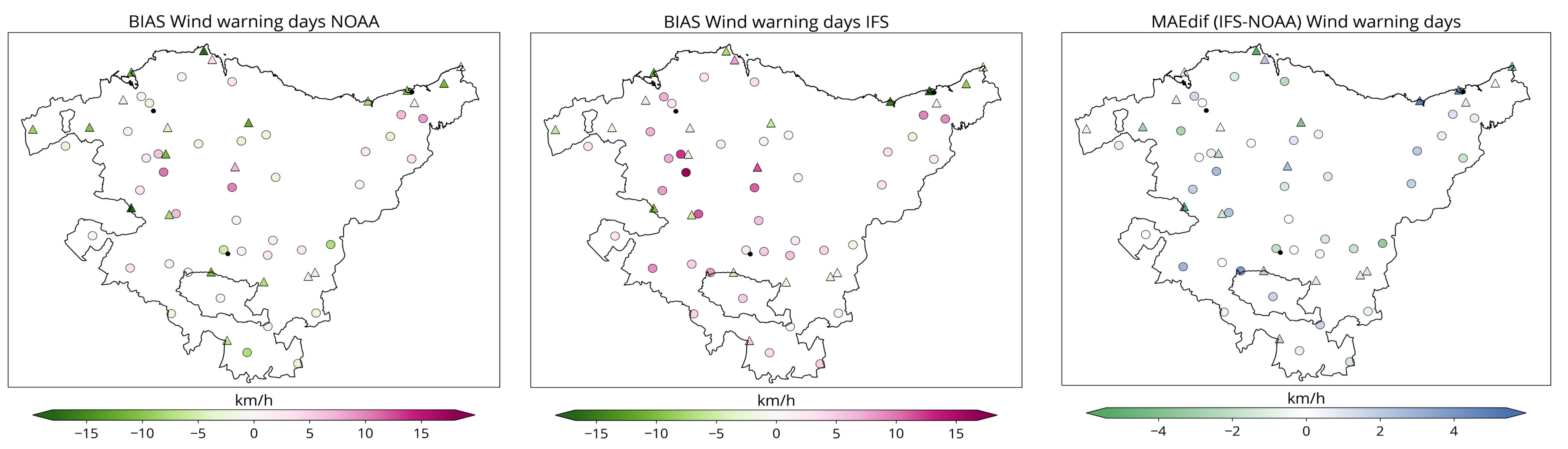
This method estimates wind gusts considering the maximum momentum that can potentially be transferred from the PBL-top to the surface; it is interpreted as the wind-gust potential.

3. Results and discussion

1. Overall performance when wind warning thresholds are exceeded



2. How do the methods perform spatially?



Daily max wind **gusts** are **underestimated** at most **exposed stations**. Small bias in non-exposed stations, slightly larger in some Cantabrian valleys.

Daily max wind **gusts** are **slightly overestimated** at most **non- exposed stations**. At exposed stations slight underestimation, greater along the coast.

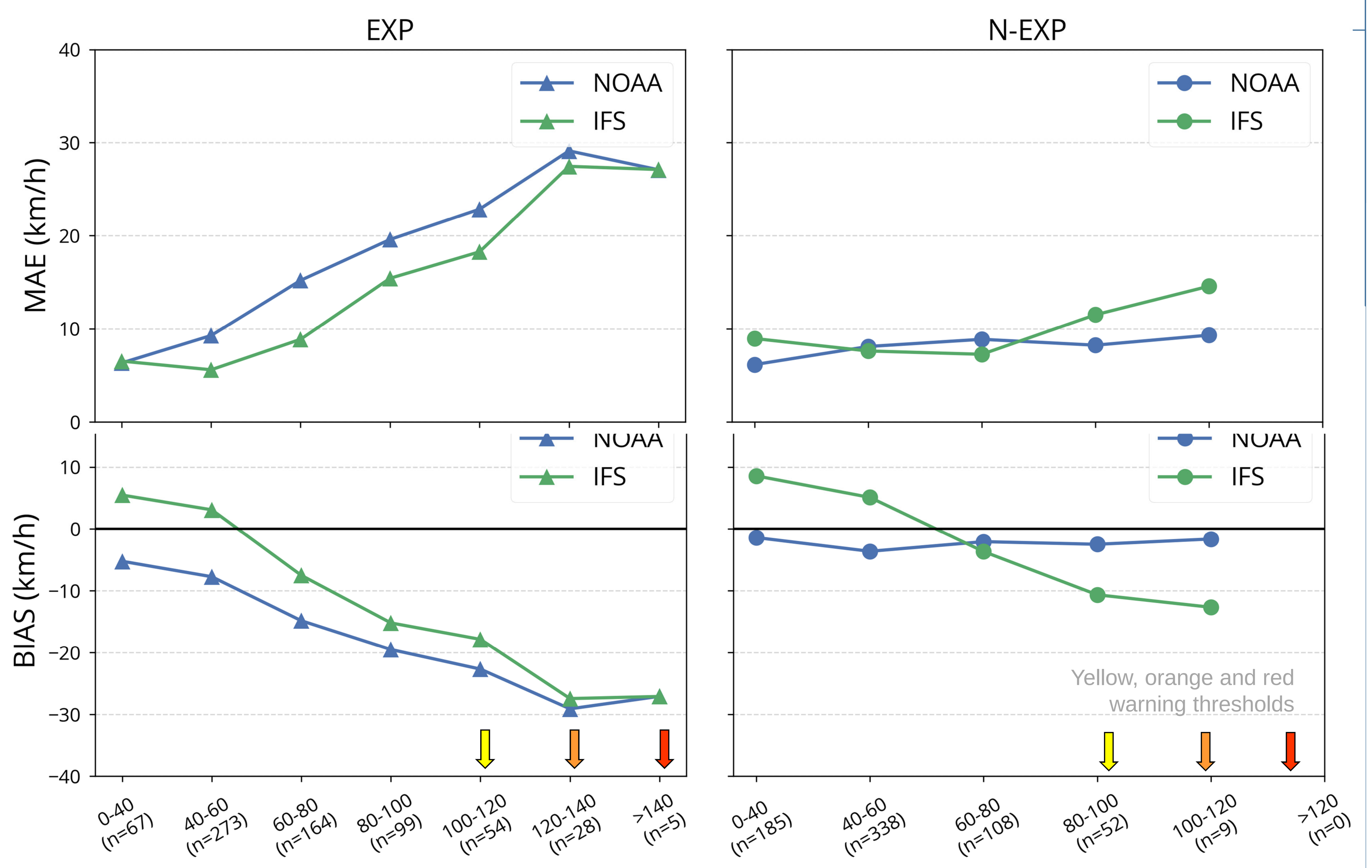
Marked differences between nearby stations. IFS performs slightly better at exposed stations, whereas NOAA performs better at non-exposed stations.

3. How do the methods perform across different wind-gust ranges?

***We represent the 95^th^ percentile** of daily maximum wind gusts across all exposed/non-exposed stations, representing the strongest range of gusts.*

At EXPOSED STATIONS errors increase for the strongest gusts owing to a growing negative bias. IFS shows lower bias than NOAA, except for the highest and lowest gust ranges.

At NON-EXPOSED STATIONS NOAA performs better for the yellow and orange warning thresholds, exhibiting a near-zero mean bias, whereas IFS shows a negative bias of around 10-15 km/h.



4. Conclusions

- ✓ Station exposure is a key factor controlling the performance of wind-gust diagnostic methods.
- ✓ The NOAA diagnostic method performs best at urban and valley stations, reproducing the strongest observed gusts with an overall near-zero mean biasMomentum transfer from the PBL top provides a robust estimate of gust potential across a wide range of wind conditions.
- ✓ The IFS diagnostic method performs best at exposed stations and for sub-warning wind gusts, likely due to the inclusion of surface stress and atmospheric stability effects in the gust formulation.
- ✓ Area-based wind maxima may improve the representation .
- ✓ of severe wind events and deserve further evaluation.

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