Design wind speeds from reanalysis: are we ready?

Francesco Ricciardelli [a], Andac Akbaba [b], Simone Sperati [c], Matteo Lacavalla [d]

[a] *University of Campania "Luigi Vanvitelli", Aversa, Italy, friccia@unicampania.it*
[b] *University of Campania "Luigi Vanvitelli", Aversa, Italy, andac.akbaba@unicampania.it*
[c] *Ricerca sul Sistema Energetico (RSE) SpA, Milano, Italy,simone.sperati@rse-web.it*
[d] *Ricerca sul Sistema Energetico (RSE) SpA, Milano, Italy,matteo.lacavalla@rse-web.it*

SUMMARY
The assessment of return wind speeds for structural design purposes has traditionally been carried out using historical records from field measurements. Only recently has the use of data from reanalysis products been considered a viable alternative. Although reanalysis wind speeds have been shown to perform well in representing wind climate in wind energy studies, their ability to reproduce storm maxima, both deterministically and in terms of their statistical and spectral properties, remains uncertain. This paper presents a comparison of data taken from two reanalysis products with wind LiDAR measurements and airport data. Comparison is carried out both in terms of time series and through extreme value analysis.

Keywords: Wind speed measurements, LiDARS, Climate reanalysis, Extreme value analysis, Design wind speeds.

1. INTRODUCTION

First step in assessing of wind actions on civil engineering works is the selection of appropriate design wind speed values, and to this aim wind hazard maps are developed for use in wind loading codes. Current practice in developing wind hazard maps relies on the collection, filtering, correction and statistical processing of anemometric data from meteorological stations. Many shortcomings are associated with the use of measured wind speeds, among which are (*a*) the low spatial density of meteorological stations, (*b*) the heterogeneity and often poor quality of records, (*c*) the need for standardization of measurements, and (*d*) the need for additional meteorological data to separate wind events of a different nature in case of mixed climates. As a result, existing extreme wind maps often exhibit limited reliability, leading to potential bias and significant uncertainty in reported values. This directly affects the assessment of wind actions on structures, particularly when it comes to the calibration of partial safety factors.

In recent years, increasingly refined wind-speed datasets have become available from global climate reanalyses, often combined with regional downscaling and data assimilation techniques. These datasets now offer spatial resolutions of up to 1 km, hourly temporal resolution, and records spanning several decades. Numerical Weather Prediction (NWP) outputs thus represent an attractive alternative to field measurements, and if their reliability can be demonstrated, they could potentially replace measurements in both mean and extreme wind climate studies. The appeal of such datasets is evident, and the aim of this paper is therefore to contribute to the ongoing discussion on whether NWP-based products can supplement or even replace measured wind data in the development of extreme wind maps.

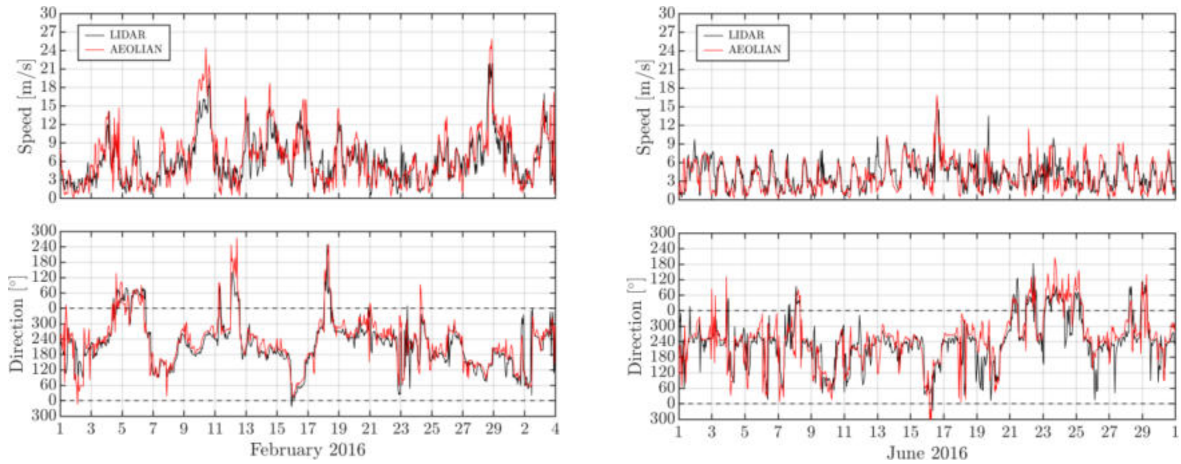

Figure 1. Monthly comparison of AEOLIAN reanalysis wind speeds and directions with the LiDAR measurements at 180 m from the ground.

2. DATA COMPARISON

Figure 1 shows a comparison of the wind speeds and directions obtained from the AEOLIAN dataset (Sperati et al. 2024) and those measured by a LiDAR at 180 m of height at a site in the city of Aversa (40° 58' 0.29" N, 14° 12' 0.32" E, altitude 47 m), in southern Italy. Comparison at an height of 180 m allows to minimise the influence of the ground. The winter month of February 2016 was characterised by a number of storms of major or minor intensity, whose patterns appear to be globally reproduced by reanalysis, both in terms of intensity and direction. However, reanalysis tends to overestimate the largest speed occurring during storms. A different pattern is that observed in the summer month of June 2016, associated with land/sea breezes. During the first half month, highest wind speeds occur around midday, and are associated with see breezes coming from approximately 240°N; in such situations, the measured and calculated directions are in rather good agreement. This is not necessarily the case at night, when the wind speed can be very low, and directions tend to be more random. During the second half of the month, the day/night breeze pattern is less regular, and the agreement between reanalysis data and measurements is worse.

As the purpose of this research is to assess the ability of reanalysis in reproducing storm maxima with the purpose of EV analysis, Figure 2 analyses the high winds occurred between October 19 and 25, 2015. In this case to the AEOLIAN reanalysis dataset also the MERIDA HRES (Viterbo et al. 2024) dataset has been added. A first storm passage is observed on October 20-21, giving largest speeds of about 15 m/s for all three datasets, all occurring during the night of October 20 and the following morning. However, while measurements and AEOLIAN indicate that the storm started to decay in the afternoon of October 20, MERIDA HRES shows a recovery of wind speeds, with values in excess of 17 m/s between 5 and 10 p.m., and reducing below 5 m/s only at 5 a.m., i.e. five hours after the other two datasets. Even stronger differences are found in the coming hours. In the afternoon of October 22, the development of a storm is observed from reanalysis data, with largest speeds of 22.4 m/s (MERIDA HRES) and of 16.6 m/s (AEOLIAN) around 4 a.m. of October 23. During these hours, measurements stay below 5 m/s, to increase to 14.0 m/s only in the afternoon of October 23, when a similar wind speed is given by MERIDA HRES, but AEOLIAN indicate values below 6 m/s. Finally, a wind speed of 17.7 m/s is given by MERIDA HRES at 2 a.m. of October 24, when both the measurements and AEOLIAN stay below 5 m/s. As to directions, while quite consistent with each other during the October 20-21 event, they are in

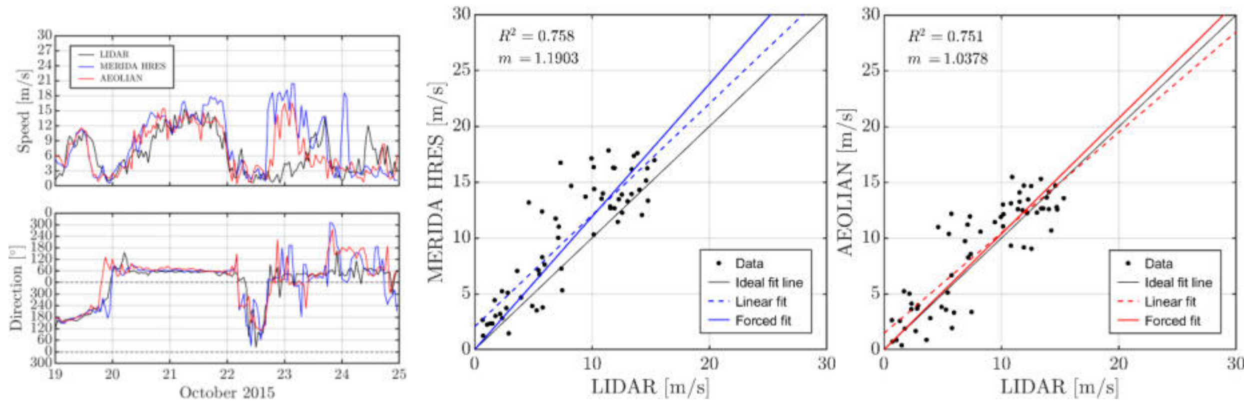

Figure 2. Comparison of MERIDA HRES and AEOLIAN reanalysis wind speeds and directions with LiDAR measurements at 180 m from the ground for the storms of October 19-24, 2015. Time histories of wind speed and directions and correlation plots for the time window going from midnight on October 20 to noon on October 22.

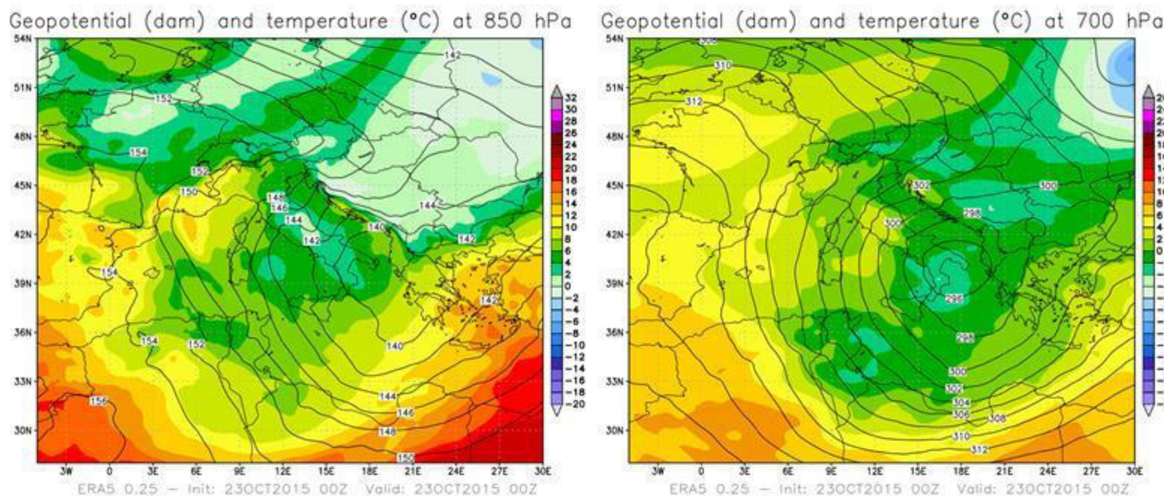

Figure 3. ERA5 geopotential height and temperature at 850 hPa (a) and 700 hPa (b) for the storm of 23 October 2015 at 00 UTC.

disagreement after that, and up to October 25. The correlation plots in Figure 2 refer to the time window from midnight on October 20 and noon on October 22. R^2 indexes of 0.758 for MERIDA HRES and of 0.751 for AEOLIAN are calculated. The regressed lines do not go through the origin, and when forced, slopes of 1.190 and of 1.038 are calculated for MERIDA HRES and AEOLIAN, respectively, showing an average overestimate of 19% and 4%, respectively.

Further insight of the situation of October 23, 2015 is given with Figure 3, where the synoptic pattern reconstructed by ERA5 for the event appears dominated by a deep low-pressure over the central-eastern Mediterranean. This atmospheric circulation is associated with cold advection at 850 and 700 hPa, as well as a closed or nearly closed mid-level low pressure over the Balkans-Greece region. This configuration determinates a significant geopotential gradient over southern Italy and promotes strong synoptic flow across the central and southern Apennines. In this synoptic weather pattern, interaction between the large-scale circulation and complex orography may intensify wind through orographic acceleration, channelling, and local downslope effects. With focus on the Campania region, it is possible to notice that the orographic shielding effect expected by the Taburno-Camposauro massif is not perfectly reproduced by the models.

3. DESIGN WIND SPEEDS

The measured and reanalysis data at 10 m of height for the Napoli Capodichino International Airport site were used to evaluate the wind speed associated with a return period of 50 years, v_{50}, using XIMIS. The 200 largest storm maxima from each dataset in the period 2000 to 2019 were selected, and the results are given in Table 1. A value of 20.9 m/s is calculated from measurements, as opposed to values of 22.8 m/s and 21.1 m/s calculated from MERIDA HRES and AEOLIAN. These correspond to wind speed ratios of 1.088 and 1.008, and to velocity pressure ratios of 1.184 and 1.016, respectively, and turn out into an overestimate of wind loads of 18% and 1.6%, respectively. A similar exercise was done using the data from the VHR-REA IT product (Raffa et al. 2021), and a value of v_{50} was found of 13.8 m/s, corresponding to a wind speed ratio of 0.630, to a wind pressure ratio of 0.436, and an underestimate of wind loads of 56%.

Table 1 - Results from the application of XIMIS to the Napoli Capodichino datasets over the period 2000-2019.

Dataset	v_{50} [m/s]	Ratio of speeds	Ratio of pressures	Variation of loads
Measurements	20.9	-	-	-
MERIDA HRES	22.8	1.088	1.187	+18%
AEOLIAN	21.1	1.008	1.016	+1.6%
VHR-REA IT	13.1	0.660	0.436	-56%

4. CONCLUSIONS AND PERSPECTIVES

In spite of the enormous progress occurred in the last decades in the field of NWP, the authors believe that available data and tools are not yet ready to make reanalysis products supersede measurements in the evaluation of design wind speeds. Not only the effects of grid resolution, which seem to be the main focus for many authors, but also the ability to properly reproduce the effects of orography, terrain roughness and see-land discontinuities need to be further investigated, together with the ability of reanalysis at resolving wind speed fluctuations within the lower mesoscale. On the other hand, the indeterminacy of design wind speeds must be understood in the broader context of structural reliability, by comparing the sources of error associated with measured values with those associated with numerical models. Quantification of such errors would allow establishing a target reliability for NWPs to be comparable with that of measurements. To the author's best knowledge, such approach has not been explored.

REFERENCES

Raffa M., Reder A., Marras G.F., Mancini M., Scipione G., Santini M., Mercogliano P. 2021. VHR-REA_IT dataset: Very high resolution dynamical downscaling of ERA5 reanalysis over Italy by COSMO-CLM. Data 6(8), 88.

Sperati S., Alessandrini S., D'Amico F., Cheng W., Rozoff C.M., Bonanno R., Lacavalla M., Aiello M., Airoldi D., Amaranto A., Decimi G., Vergata M.A. (2024). A new Wind Atlas to support the expansion of the Italian wind power fleet. Wind Energy, 27(3), 298-316, https://doi.org/10.1002/we.2890.

Viterbo F., Sperati S., Vitali B., D'Amico F., Cavalleri F., Bonanno R., Lacavalla M. 2024. MERIDA HRES: A new high-resolution reanalysis dataset for Italy. Meteorol. Appl., 31, e70011, 1-26. https://doi.org/10.1002/met.70011.