Wind field from SAR over the Venice lagoon, Italy

Stefano Zecchetto[1,2] and Andrea Zanchetta[3]

[1]Istituto di Scienze Polari, Consiglio Nazionale delle Ricerche, Padova, Italy
[2]Department of Electrical Engineering, Persian Gulf University, Bushehr, Iran
[3]Department of Music, Hong Kong Baptist University, Hong Kong SAR, China

stefano.zecchetto@cnr.it andyzanchetta@gmail.com

ABSTRACT

The characteristics of the most frequent strong winds in the Venice Lagoon, northern Adriatic Sea, Italy, have been investigated through the analysis of wind fields estimated from the *Sentinel-1* SAR images by a method based on the residual network (***ResNet***), a variant of Convolutional Neural Network, at spatial resolution of *500 m by 500 m*. This methodology extracts the wind direction from SAR images, then used to compute the wind speed through the Geophysical Model Functions. The area of interest is subjected, as many coastal areas, to high spatial and temporal variability of the winds, making it a very demanding site. Results are presented in terms of statistical comparisons between in-situ, available both inside and outside the Venice lagoon, and SAR-derived winds, reporting biases of 1.3° and 2.3 m/s for wind direction and speed, and centered RMS of 16.8° and 1.9 m/s. These results are similar or better of those obtained comparing in-situ with ECMWF winds (bias 1.4° and 1.0 m/s, centered RMS of 17.8° and 2.5 m/s). The most interesting results obtained are in terms of the wind spatial variability inside the lagoon and from offshore to inshore, not obtainable in such details with in-situ and atmospheric model winds. A mean increase of the wind strength from the northern to southern lagoon of 30% and 25%, under north-eastern and south-eastern winds respectively, has been found, as well as a decrease of wind speed from offshore to inshore of 25% and 32%, in agreement with that obtained from the in-situ winds.

THE AREA 1

The *Venice Lagoon* (*Fig. 1*), located in the north-eastern part of Italy, extends for about 50 km by 10 km in the northern Adriatic Sea. It is characterized by few principal deep channels in a very shallow water surroundings. The lagoon is subjected to the main wind systems of the northern Adriatic Sea, i.e. the northeasterly ***Bora*** and the southeasterly ***Sirocco***, the former blowing roughly parallel to the lagoon major axis, the latter roughly parallel to the Adriatic Sea major axis. Winter, October 2019-April 2020, polar distributions of winds, shown in *Fig. 2*, provide a picture of the most frequent winds in this area, as well as of the differences between the distributions obtained from the forecast wind data of *ECMWF* global model *TCo1279 HRES*, with a horizontal resolution of 9 km (*left panel*) and in-situ data (*right panel*) for wind speed >6 m/s. These distributions present some difference which evidences the difficulty of having unique statistics of wind in coastal areas, where local effects as wind sheltering or breeze are very important as well as the variability of wind on both the time and space domains.

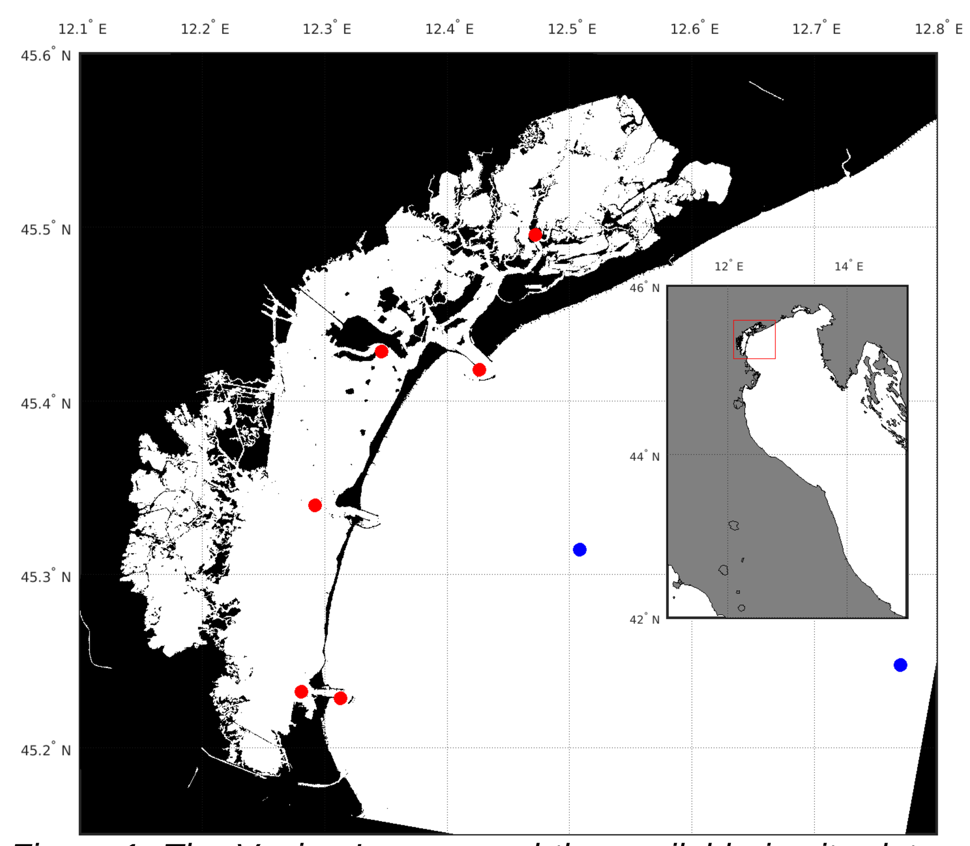

Figure 1: The Venice Lagoon and the available in-situ data locations. Blue dots are offshore buoy/platform, red dots are coastal and lagoon sites. In the inlet the red square indicates the area of interest.

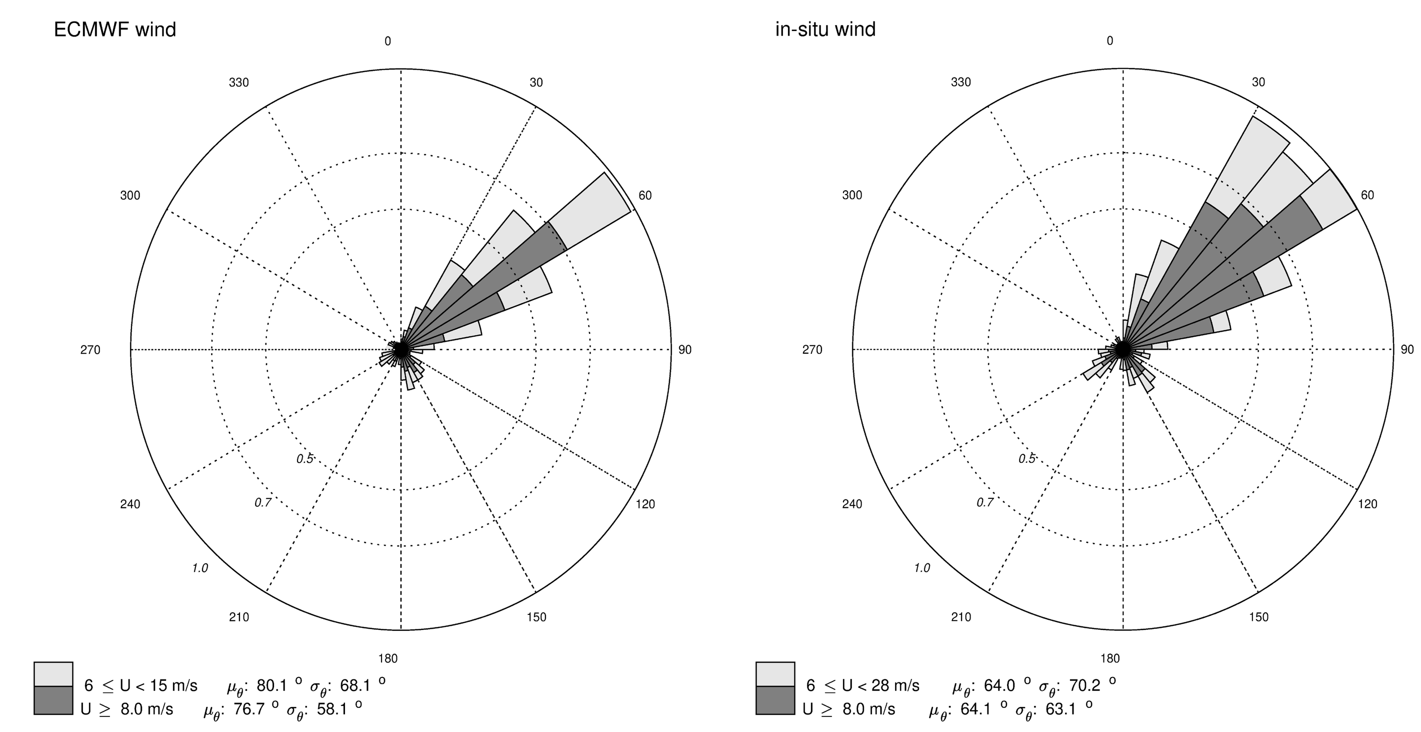

Figure 2: Winter (October 2019-April2020) polar distributions winds in the Venice lagoon, obtained from ECMWF and in-situ data.

WIND DIRECTION RETRIEVAL FROM SAR: THE DEEP RESIDUAL NETWORK (*ResNet*) METHODOLOGY 2

The determination of the wind speed from the radar backscatter values of the SAR images needs a reliable Geophysical Model Function, which requires as input the following parameters: radar incidence angle, polarization, view angle, and wind direction. The first three parameters are available from the ancillary SAR data; however, the wind direction needs to be retrieved.

The wind directions have been estimated directly from the SAR images by a novel method developed in *Zanchetta and Zecchetto, 2021*, which employs a convolutional neural network (*Goodfellow et al., 2016*) with a residual neural network structure (***ResNet***) (*He et al., 2016*). The architecture of this ***Resnet*** has been specifically designed to obtain high resolution (~1 km) aliased wind direction fields.

This methodology has shown the ability to extract the aliased wind direction exclusively from the morphological features of SAR images, without any other external information which is used only to solve the 180° ambiguity. Once obtained the wind directions, the wind speeds have been computed using the C-band CMOD5 GMF *Hersbach et al., 2007*.

COMPARISON OF ResNet vs IN-SITU WINDS 3

In *Fig. 2* the statistics obtained comparing in-situ with ***ResNet*** winds for 46 Sentinel-1 images over the area of interest (*Fig. 1*) is shown. The SAR ***ResNet*** speed speed appear underestimated with respect to the in-situ data, but this can depend on the *GMF* used. Both winds are at 10 m height and corrected for atmospheric stability. Are these comparisons satisfactory? Yes, we believe, considering the statistics of *in-situ vs ECMWF* winds shown in *Fig. 4* below, showing a worse agreement for wind speed.

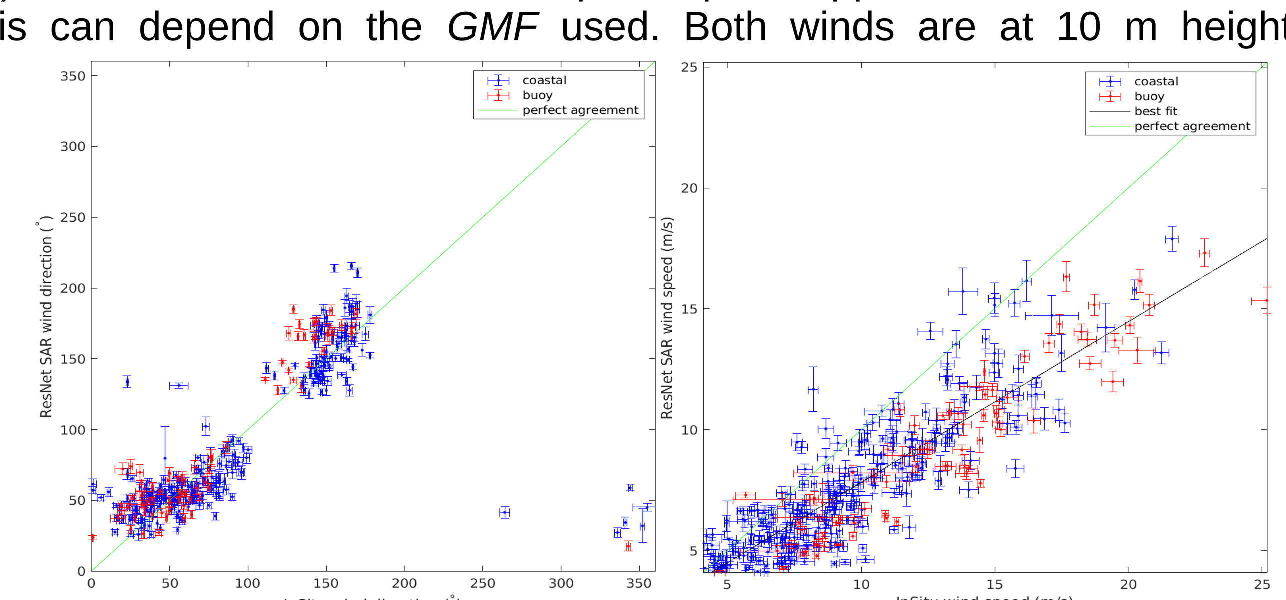

Figure 1: Comparison between ResNet and in-situ wind direction (left panel) and speed (right panel).In-situ wind speed are at 10 m of height. The SAR-derived wind speeds have been corrected for atmospheric stability.

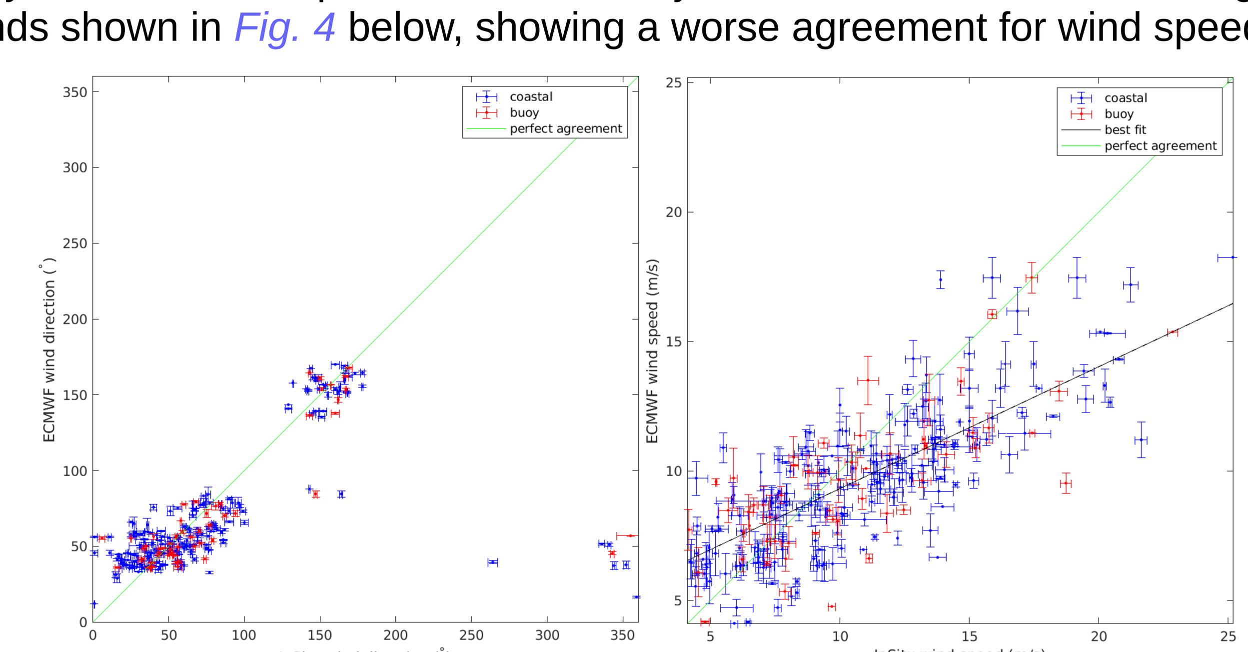

Figure 2: Comparison between ECMWF and in-situ wind direction (left panel) and speed (right panel).

EXAMPLES OF *ResNet* DERIVED WIND FIELD 4

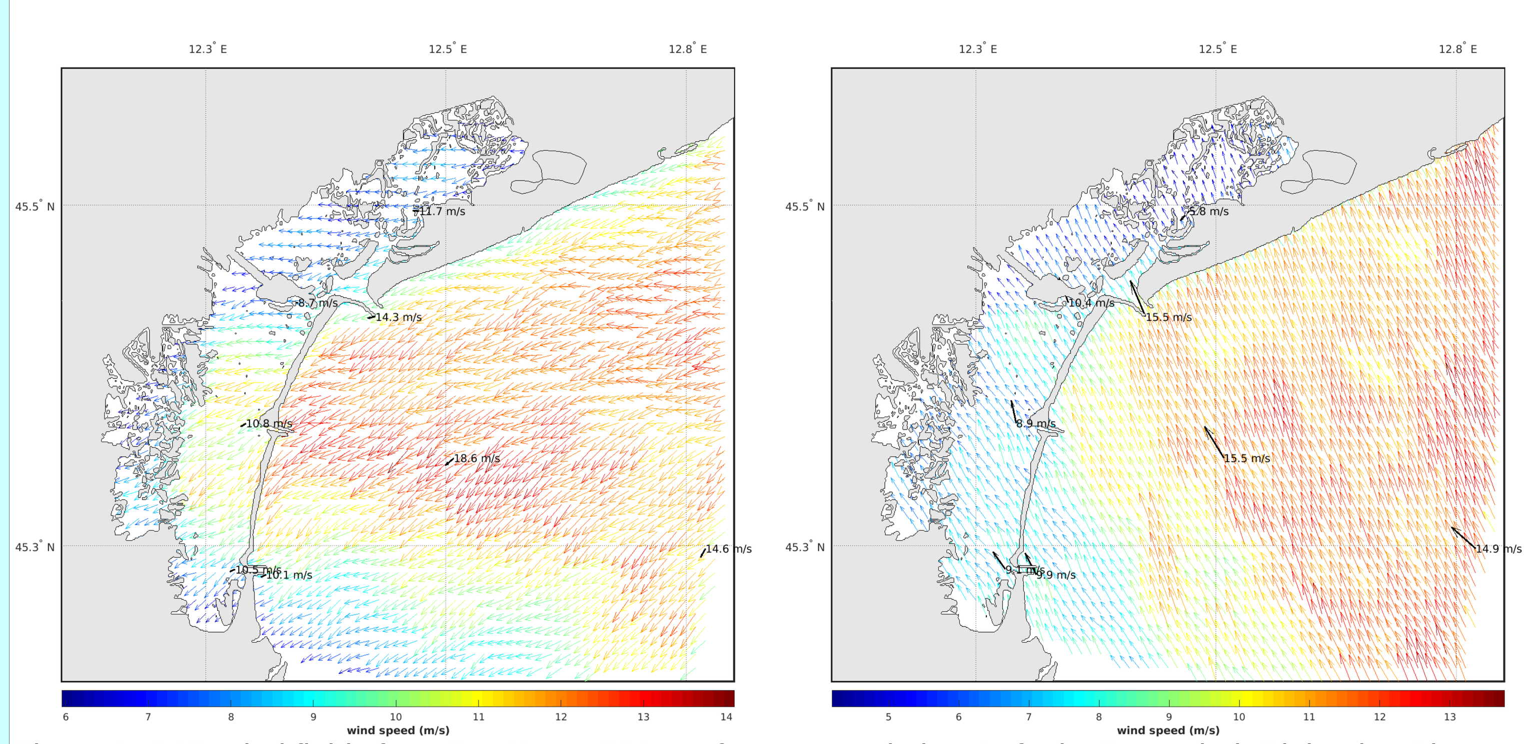

*Figure 3: SAR wind fields from **ResNet** at 500 m of space resolution. Left plot:Bora wind. Right plot: Sirocco wind. The black arrows (not in scale) are the in-situ winds.*

The results are very good, as shown in *Fig. 3* above which reports wind fields estimated by ***ResNet*** from a Sentinel-1 image at 500 m of spatial grid, a strong case of Bora (left panel) and Sirocco (right panel). ***ResNet*** is able to retrieve the wind field inside the lagoon, with an unprecedented level of detail. For comparison, *Fig. 4* reports the ***ESA OCN*** wind products considered as standard.

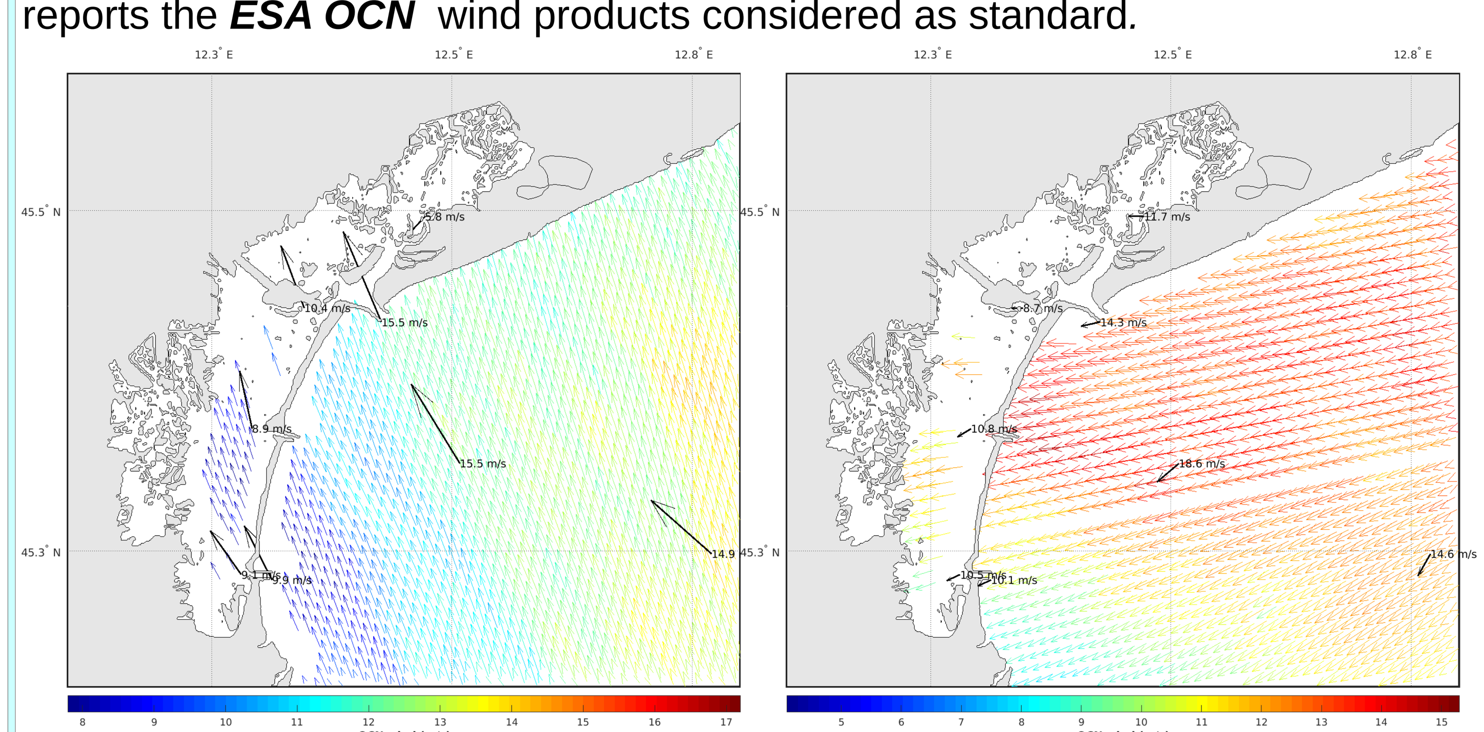

Figure 4: SAR wind fields from OCN at 1km of space resolution. Left plot: Sirocco wind. Right plot: Bora wind. The black arrows (not in scale) are the in-situ winds.

CONCLUSIONS

ResNet is able to extract the aliased wind direction exclusively from the morphological features of SAR images, *without any other external information*. The SAR-derived wind fields at *500 m* spatial resolution cover exhaustively small areas like the Venice lagoon, allowing the investigation of the wind field spatial structure. ***ResNet*** is able to retrieve the wind field even in complicated meteorological situations, such as tropical cyclones (work in progress) and in coastal seas, where also limited area regional atmospheric models have low performances. The main issue concerns the lack of wind data at true spatial resolution of ≈1 km and close to the satellite pass time (~ 0.5 h) necessary for exhaustive comparisons.

REFERENCES

Goodfellow, I., Bengio, Y. and Courville, A., Deep Learning, *MIT Press*, 2016.
He, K., Zhang, X., Ren, S., Sun, J., Deep residual learning for image recognition. In: *Proceedings of the IEEE conference on computer vision and pattern recognition*. pp. 770–778, 2016.
Hersbach, H., Stoffelen, A., de Haan, S., An improved scatterometer ocean geophysical model function: CMOD5. *Journal of Geophysical Research,* 112, 5767–5780, (doi:10.1029/2006jc003743), 2007.
Zanchetta, A. and S. Zecchetto, Wind direction retrieval from Sentinel-1 SAR images using ResNet, *Remote Sensing of Environment*, 253, doi: 10.1016/j.rse.2020.112178, February 2021.