SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	**Underestimate of modelled offshore blowing winds**
Computer Project Account:	SPITWM
Start Year - End Year :	2020 - 2022
Principal Investigator(s)	Luciana BERTOTTI
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Other Researchers (Name/Affiliation):	Luigi Cavaleri ISMAR-CNR Arsenale, Tesa 104 Castello 2737/F 30122 Venice, Italy

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

To assess the present situation for the possible underestimate of surface wind speed when blowing from land to sea. The plan is to analyse extended data-sets from different resolutions and sources and to understand the reasons why.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

The COVID-19 pandemic and its follow-up, with all the limitations about visiting ECMWF, has severely affected our planned activity. There is no possibility of activity at ECMWF, and in Venice too we have had for a long while severe limitations to our office. Nevertheless, also on the base of our activity at ECMWF during our last visit there, some further progress was done with respect to the previous period.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

No particular problem. Rather, the information is always timely and very clear. We much appreciate.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

1 – The area of interest
Two areas has been selected. The Mediterranean Sea, with a highly varied coastline, displaying all the possible orographic features. The English southern part of the North Sea, facing (East Anglia) a very flat coast, hence suitable to check contrary-wise the effect of orography on coastal winds.

2 – Data to be analysed
All the required data have been made available, for ECMWF concerning the operational system data (both high resolution and ensemble) plus ERA-5. Because the study is carried out in cooperation with, and the common interest of, UKMO, also their data have been made available as: Global (10 km resolution), ENS (20 km), Europe (4 km), UKV (1.5 km). All these data have been retrieved and stored as monthly files in standard format.

3 - Present results
Our first attempt was to plot the ratio model/measured wind speed versus #fetch#, i.e. the sea distance run by wind over the sea after “leaving” land. The reference measured data are scatterometer ones. While confirming the results of Cavaleri and Bertotti (2004), although with a different resolution, it was clear that a different approach and representation was required.
Thjis has been found in the representation of Figure 1. Focused in this case on the Mediterranean Sea and on the 9 km, short term forecast ECMWF results, we show here the ratio model/scatterometer wind speeds as a function of “fetch”. The blue lines represent the unstable conditions, the red ones the stable ones. The variously dotted-dashed lines (see synopsis) refer to different wind speed ranges, the continuous line to the full range of wind speeds.
It is clear that there is a substantial underestimate by the ECMWF model, the more so when in unstable conditions.

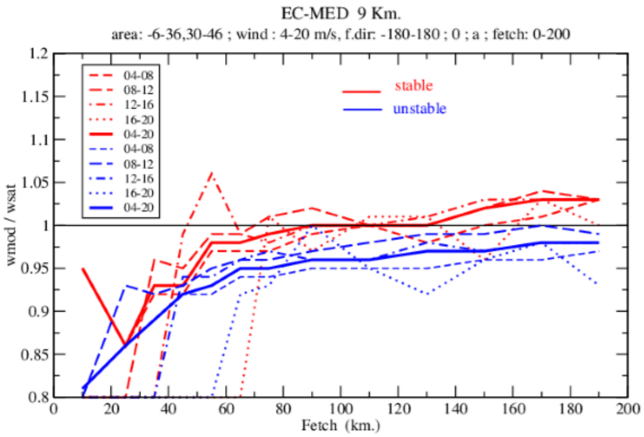

Figure 1 – Ratio model/scatterometer wind speeds as a function of “fetch”. The blue limes refer to unstable conditions, the red ones to stable ones

Much of the attention during this past year has been focused on the coastal orography. In particular, we checked how the ECMWF underestimate depends on the orography of the land the wind blows from. While in the case of East Anglia, selected for the low terrain, the wind blows from is a suitable location, its extent is in a way limited for the purpose of this research. Looking for a more ample zone we have focused our attention on the eastern part of the Mediterranean Sea, on its southern coast, where the Sahara desert reaches the coast with behind a vast extent of practically flat terrain. Here we have considered both the outgoing (from land to sea) wind cases as the incoming ones, i.e. when the wind reaches the coast blowing from the sea, hence in principle without any orographic effect. The first case is shown in Figure 2.

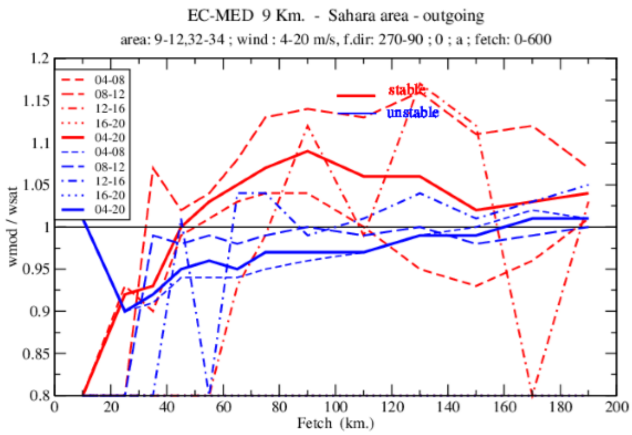

Figure 2 – As Figure 1, but for Sahara coast in the Mediterranean Sea.
There is an obvious tendency to a better fit with scatterometer data than for the general Mediterranean case. The reason is obviously the different orography of Lybia and Egypt with respect to the ones that characterises the northern coasts of the Mediterranean Sea (Pyrenees, Massif Central, Alps, Appennines, Dynaric Alps, etc). As a comparison, we show in Figure 3 the same area of incoming winds, i.e. winds blowing from the sea towards the coast.

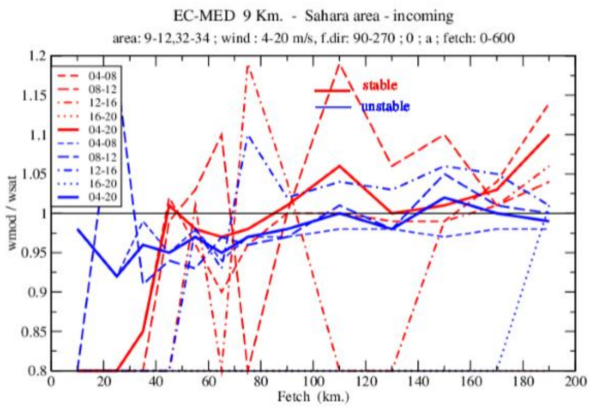

Figure 3 – As Figure 2, but for wind blowing from sea to land.

It is immediately evident that the model winds show a better fit with the scatterometer data, and again this strongly suggests a dominant effect of the local terrain in slowing down the surface wind, and its slow catch-up when on the sea.
This has shifted our attention to the specific orography. Then the question is how to characterize the local orography. Our latest discussions at ECMWF have clearly pointed out that the problem of the ECMWF wind underestimate when blowing to offshore is not only related to the passage from land to sea, but also to the characteristics of the orography the wind comes from. The question has a double face. For a long while the practical evidence along the successive increases of resolution of the ECMWF operational model showed that coastal wind quality was steadily improving with resolution. This had led to think that a better orographic description was the key to improvements. However, the various tests by Nils Wedi and his temporary Japanese visitor have clearly shown that the key to improvements is given by the increased resolution of the meteorological model. As a matter of fact, it has also turned out that an increased resolution of the orographic description leads to reduced wind speeds because of the higher drag along the mountains. Then an increase of resolution has a double effect: on one hand the coastal wind speeds are decreased because of an increased orographic drag. On the other hand the better resolution leads to a more rapid increase with fetch of the offshore blowing winds, this latter effect dominating on the first one, whence the improvement we found in the years with each increase of the ECMWF meteorological model.

All this has shifted the attention to the orography, wondering how to quantify the orography effect on the surface wind on the base of the specific orography. This has led to formulate a drag expression for a specific coastal orographic profile. This result will be going to be a key part of the final analysis and specification of the characteristics of the offshore blowing wind. We have experimented with many different profiles, checking how the various features affect the final drag value of the profile.

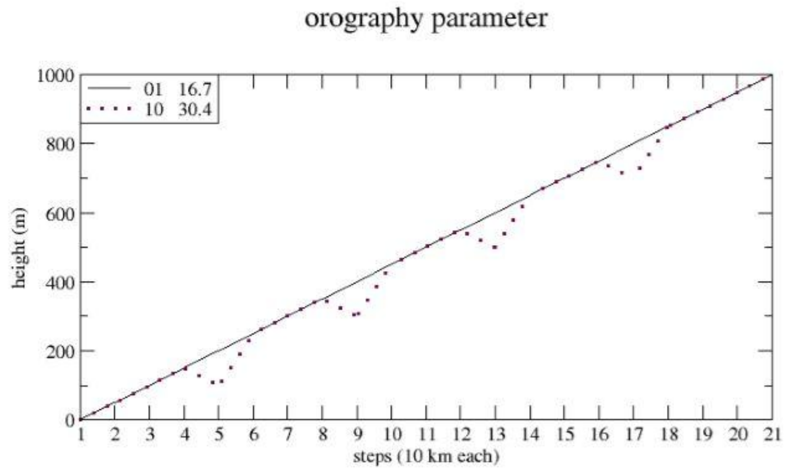

Figure 4 – A linearly sloping orographic coastal profile versus a more articulated one. In the figure there is the specification of the respective resulting drags.

A first example is given in Figure 4 where the more rugged terrain leads to doubling the resulting overall drag.

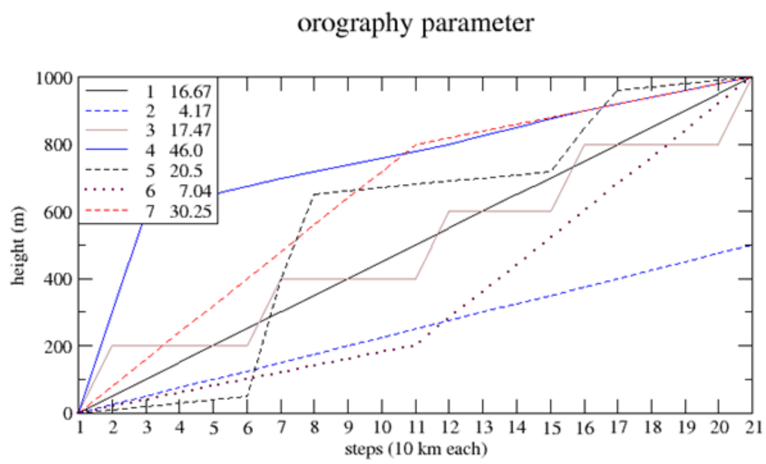

Figure 5 – As Figure 4, but with different orographic profiles

A more articulated example is in Figure 5 where, for the same height (1000 m) after 200 km inland (20 ten km steps) the different shapes of the slope leads to drag parameters with up to an order of magnitude difference.
It is therefore clear that the profile of the orography while descending towards the coast has a fundamental importance to determine the overall orographic drag, hence the characteristics of the offshore blowing wind. We are presently at the stage of characterising all the Mediterranean and southern North Sea coasts for a full evaluation of the drag, hence a new interpretation of the results we have for so long seen from the ECMWF model.

4 – The use of neutral winds
Following the results obtained during the first 18 months of the project and reported in the June 2021 report, it was pointed out that the results were not fully meaningful. The point is that in the previous

plots (see Figures 1-3), we were comparing U10 versus scatterometer wind values. However, it was pointed out that a more correct comparison would be vs neutral winds. Therefore the whole analysis was repeated with these winds. Indeed different results have been obtained.

A first result is reported in Figure 6 where we show the Uneu/Uscat between ECMWF model neutral values and corresponding scatterometer data. As a function of fetch, up to 200 km distance from the coast. We show both the resulting curves for different range of wind speed and the overall mean. Two features are macroscopically evident: the higher the wind speed, the more permanent, with fetch, is the model underestimate. This is practically absent for low wind speeds after the 100 km fetch. It persists for high wind speeds, above 16 ms-1, also beyond the 200 km fetch. On the average, the model data appear correct after 100 km due to the much higher frequency of low wind speeds.

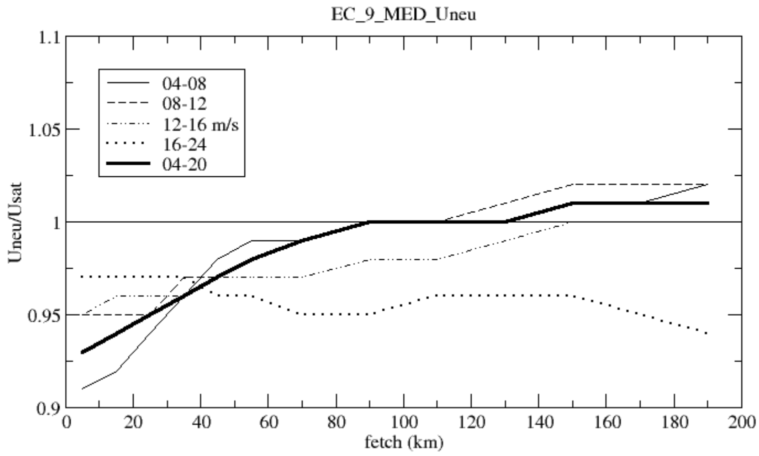

Figure 6 – Ratio between model neutral and scatterometer wind speed values as a function of fetch (km) and of the wind speed at the measurement point. The dark line is the average of all the data.

Figure 7 shows the same results for the ERA5 model. The influence of resolution is macroscopic in that model underestimate is extended well beyond the 200 km fetch. We point out that the results for ensemble (18 km resolution) are not available because at the time (Oct-Dec 2018) the ensemble neutral winds were not archived.

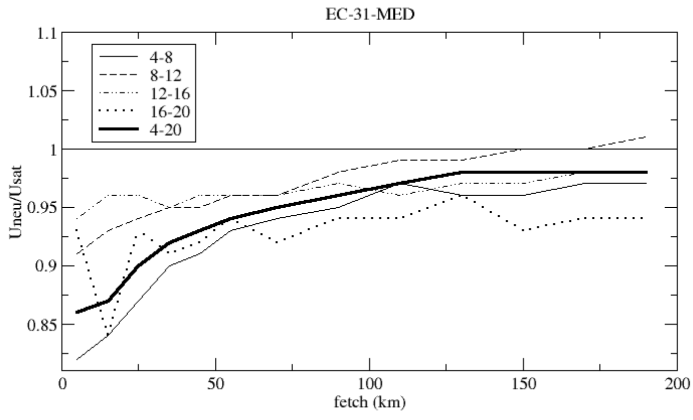

Figure 7 – As Figure 6, but for the ERA5 ECMWF results.

A feature we have repetitively found and we have also discussed with UKMO (in particular with John Edwards) is the apparent wind speed overestimate by UKMO, independently of model wind speed resolution. Focusing on stable conditions, this is shown in Figure 8, where we also see that for these conditions the ECMWF results are very close to unity for both Tco1279 and ERA5.

An interesting point has been suggested by Anton Beljaars. He pointed out that the actual fetch should not be evaluated in terms of distance (km), but as number of grid steps, hence varying with resolution. This is clearly shown in the two panels of Figure 9. The left one, showing both ECMWF and UKMO results is, as to say, the classical underestimate with respect to fetch (km). We see the expected differences according to resolution, the higher (better) resolution converging more rapidly towards unity (for ECMWF) or for the already mentioned higher asymptotic value for UKMO. In the right panel the horizontal scale is expressed as number of grid steps, obviously varying according to the specific model resolution. The convergncee of the various model resolutions towards a single curve (obviously different for ECMWF and UKMO) is evident. This stresses the relevance of the suggestion by Anton Beljaars. It also explains the reason of the progressive improvement moving to higher resolution.

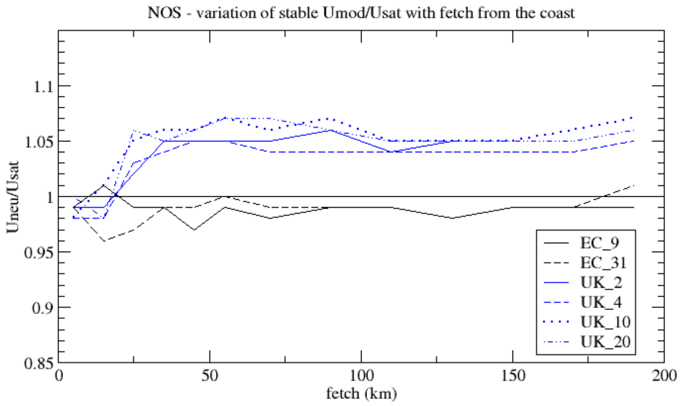

Figure 8 – ECMWF and UKMO results for wind blowing off the coast of East Anglia. All the available resolutions are shown.

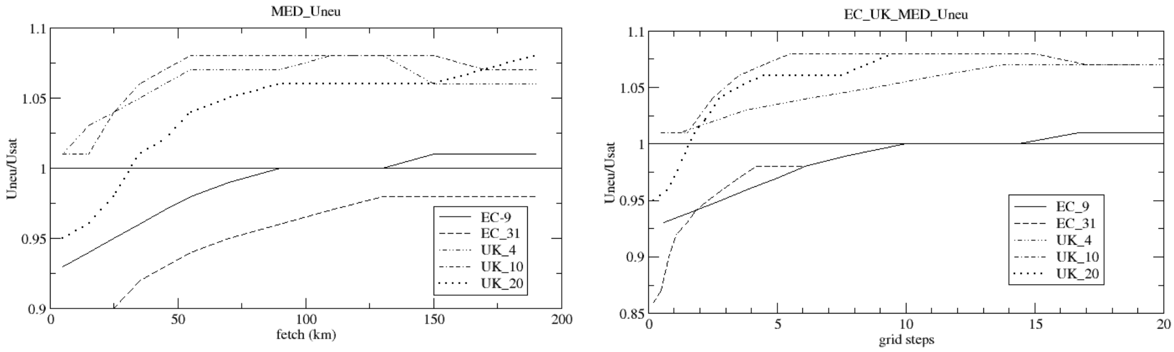

Figure 9 – Left panel: the by now classical model underestimate with respect to scatterometer data, with an asymptotic behavior with fetch. Clearly the results differ with resolution. In the right panel the horizontal dimension is scaled according to each model resolution. For each (ECMWF or UKMO) model this leads to a substantial convergence of the various curves.

5 – The relevance of orography

The relevance of orography in determining the coastal underestimate has been explored using the ECMWF Tco1279 model wind in different areas of the Mediterranean Sea. Figure 10 provides a) the overall results for the Mediterranean, b) the ones off the French coast when the Mistral wind is blowing, c) a North blowing wind off the coast of Algeria (high mountain range in the interior), d) a North blowing wind off the Libyan coast (with the flat Sahara desert in the interior). It is evident that the higher the interior orography, the higher the model wind underestimate and the longer the “recovery” time and distance while blowing to offshore.

This becomes evident when we plot the average coastal wind speeds for each resolution of both ECMWF and UKMO (IFS and UM respectively) models. Figure 11 shows how the coastal wind speeds depend substantially on the roughness of the coastal orography, here represented by the orog parameter. The higher orog, i.e. the roughness the orography, the lower in the means are the coastal wind speeds.

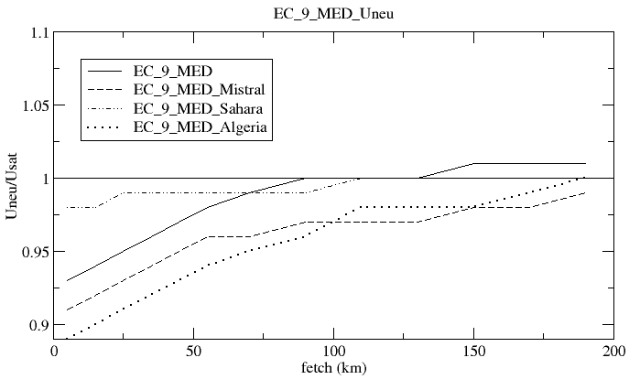

Figure 10 - Ratio between model neutral and scatterometer wind speed values as a function of fetch (km) and of the wind speed at the measurement point. Note the differences between the overall results (EC_9_MED) and the ones for areas characterized by high mountains (Mistral, Algeria) and flat terrain (Sahara) on the back coastal zone.

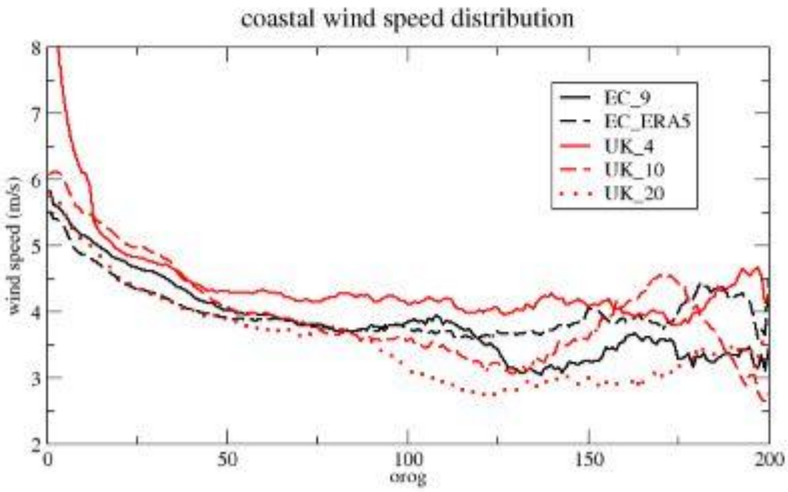

Figure 11 – Statistical distribution of the coastal wind speeds for both the IFS and UM models according to their respective resolution. The orog parameter summarizes the roughness of the last 200 km of orography before the wind reaches the coast.

6 – Computer allowance

All our experiments, being always in new conditions with continuous adjustements of the handling ECMWF software, require a strong interaction both with the local meteorologists to discuss the progressive steps of advance and User Support team. All this can be done only during our presence at ECMWF. It follows that no experiment has been done during the passed time of this project. We are waiting to see how the situation will evolve.

List of publications/reports from the project with complete references

2020 Cavaleri, L., F.Barbariol, and A.Benetazzo
"Wind-wave modeling: where we are, where to go"
J.Mar.Sci.Eng., 8, 260, 15pp, doi:10.3390/jmse8040260

2021 Sanchez-Arcilla, A., J.Staneva, L.Cavaleri, et al.
"CMEMS-based coastal analyses: conditioning, coupling and limits of applications"
Frontiers in Marine Sciences., 25pp, 8:604741, doi:10.3389/fmars.2021.604741

2021 Hoteit, I., L.Cavaleri, S.Langodan, et al.
"Towards an end-to-end analysis and prediction system for weather, climate, and marine applications in the Red Sea"
BAMS, January 2021, F99-F122, https://doi.org/10.1175/BAMD-D-19-0005.1 .

2022 Barbariol, F., P.Pezzutto, S.Davison, L.Bertotti, Cavaleri, L., A.Papa, M.Favaro, and A.Benetazzo
"Wind-wave forecasting in enclosed basins using statistically downscaled global wind forcing"
Frontiers in Marine Sciences 9:1002786. doi:10.3389/fmars.2022.1002786

2023 Langodan, S., L.Cavaleri, L.Bertotti, A.M.Qasem, S.P.Razak, A.Pomaro, and I.Hoteit
"Winds and waves in the Arabian Gulf: Physics, characteristics and long-term hindcast",
Int.J. of Clim., 1-14. https://doi.org/10.1002/joc.8043

2023 L.Cavaleri, G.Balsamo, A.Beljaars, L.Bertotti, S.Davison, J.Edward, T.Kanehama, and N.Wedi,
"ECMWF and UK Met Office offshore blowing winds: impact of horizontal resolution and coastal orography" – to be submitted

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

Special Project 2023-2025 – The role of orography and model resolution in the underestimate of model offshore blosing winds