A user oriented verification methodology for wind forecast

Maria Stefania Tesini

ARPAE, HydroMeteoClimateService of Emilia-Romagna region, Bologna, Italy

1 Introduction

The 10-m wind is a weather parameter characterized by strong dependence on orographic and topographic details and high temporal variability. Therefore the verification of wind forecast requires a methodology taking into account these features.
On top, any verification method should be tailored for the specific purpose defined by the user of that forecast, being the developer of the model, the forecaster in the operational room or the stakeholder for a practical application.
One of the main uses of wind forecast at Arpae-SIMC is to issue warnings when wind speed exceeds some threshold. For example, strong easterly winds can determine the possible occurrence of sea storms over the Italian coast of the Adriatic Sea (see figure 1), but also less intense winds can cause problems to the tourist's activity on the beach.

Figure 1: Wind observations in the north Adriatic Sea coast

Verification should therefore address several user-related aspects, in particular it should quantify:

- the ability of the model to predict wind speed above (or below) critical thresholds, including false alarms or misses,
- the forecast skill in terms of wind direction,
- the dependence of forecast error on wind direction
- the interplay between wind-speed and wind-direction inaccuracies

In addition, another very important aspect to consider is the communication of the results to the end user, which should be as clear and concise as possible.

doi:10.5676/dwd_pub/nwv/cosmo-nl_19_08

2 The Performance-Rose

In order to meet the needs of our end-user we have studied a methodology of verification that seeks to take into account wind speed and direction at the same time, but that it is also effective in communicating results. For this purpose we developed a novel summary-plot of the scores derived from the contingency table, denominated "Performance Rose". In a wind-rose plot, the observed and forecast wind frequency is represented subdivided into the usual 8 sectors. In additions to this, each spoke is broken down into color-coded bands that show information about errors in wind speed and direction. Moreover usual scores such as the Probability of Detection, the Threat Score and the Success Ratio are plotted for each sectors (i.e. for each direction) as symbols on the appropriate scale (from 0 to 1 for all of them) in the radial axes.
First of all, for each station 10m-wind observations (hourly or 3/6-hourly) and corresponding data predicted by model are categorized in octants for wind direction (N, NE, E, SE, S, SW, W, NW) and in classes for wind speed, according to table 1.

LIGHT	ws $<$ 10 Knots	ws $<$ 5.1 m/s
LIGHT-MODERATE	10 $\leq$ ws $<$ 20 Knots	5.1 $\leq$ ws $<$ 10.3 m/s
MODERATE	20 $\leq$ ws $<$ 30 Knots	10.3 $\leq$ ws $<$ 15.4 m/s
STRONG	ws $\geq$ 30 Knots	ws $\geq$ 15.4 m/s

Table 1: Wind speed classes

For each specific wind speed class (e.g. "Light-Moderate") a "Performance-Rose" diagram is produced, as showed in figure 2.

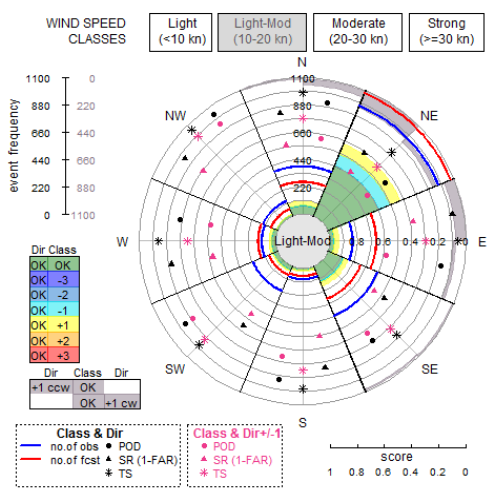

Figure 2: The Performance-Rose diagram

Like in a usual wind rose, the frequency of winds of the specific wind class blowing from particular directions over a specified period is represented:

- **Blue line** is the observed frequency of the specific speed-class
- **Red line** is the forecast frequency of the specific speed-class

The number of events can be read on the radial scale (frequency axis), increasing outwards from the center.

Using sectors of different colours we described how model predicts the reference speed class in each direction, ***being the direction correct***. For example:

Green means speed class is correctly forecast

Cyan means speed is underestimated of 1 class (e.g. the forecast is “Moderate” but the observation is “Strong”)

Yellow means speed is overestimated of 1 class (e.g. the forecast is “Moderate” but the observation is “Light-Moderate”)

The number of events of each sector can be deduced using the radial scale of the frequency axis.
In addition, the gray half-sectors represent the number of forecast in each direction that are "nearly" correct in direction, ***being the intensity correct***:

Half sector on the left means forecast is shifted of 1 octant clock-wise (e.g. if the fcst is NE, the obs in N)

Half sector on the right means forecast is shifted counterclock-wise (e.g. if the fcst is NE, obs is E)

In this particular case, the number of events can be deduced using the reverse radial scale of the frequency axis (starting from the outermost circle).

A quantitative assessment of the goodness of the forecasts is made using some scores evaluated form the elements in a contingency table (see figure 3) that shows the frequency of "yes" and "no" forecasts and occurrences:

$$POD = \frac{hits}{hits + misses} \quad \text{(Probability of Detection)}$$

$$TS = \frac{hits}{hits + misses + false\,alarms} \quad \text{(Threat Score)}$$

$$SR = (1 - FAR) = \frac{hits}{hits + false\,alarms} \quad \text{(Success Ratio)}$$

$$FAR = \frac{false\,alarms}{hits + false\,alarms} \quad \text{(False Alarm Ratio)}$$

$$BIAS = \frac{hits + false\,alarms}{hits + misses} \quad \text{(Bias Score)}$$

Event forecast	Event observed		
	YES	NO	Marginal Totals
YES	Hit	False Alarm	Fcs yes
NO	Miss	Correct non-event	Fcs no
Marginal Totals	Obs yes	Obs no	Sum total

Figure 3: Contingency table for dichotomous (yes/no) forecasts

For our purposes, we have defined two types of "yes"/"no" events and for each of them a specific contingency table has been constructed:

1. **"Class & Direction"**: the "yes" event is defined by speed class and direction correctly forecast at the same time, while other entries of the contingency table are defined as in the table in figure 4

“Class & Dir “	OBS in DIR & CLASS	OBS not in DIR or not in CLASS
FCS in DIR & CLASS	Hit	False Alarm
FCS not in DIR or not in CLASS	Miss	Correct non-event

Figure 4: Contingency table for event defined as "speed class and direction correctly forecast at the same time"

2. **Class & Direction $\pm$1:** the "yes" event is defined by speed class correctly forecast, but direction is considered correct even if differs by one octant. According to the table in figure 5 we defined only "false alarm" and "miss" events, since correct negatives have been removed from consideration.

   This definition of "extended direction", even if not completely proper, is meant to address the user’s request to know whether the source of error depends on either wind speed or wind direction, if compared with scores based on the exact correspondence of direction and speed.

"Class & Dir ±1"	OBS in DIR ±1 & CLASS	OBS in DIR & CLASS	OBS not in DIR ±1 or not in CLASS
FCS in DIR & CLASS	Hit	Hit	False Alarm
FCS not in DIR ±1 or not in CLASS		Miss	

Figure 5: Contingency table for event defined as "speed class correctly forecast, but direction is correct even if differs by one octant"

In the Performance Rose, the scores related to the two event definitions are plotted as symbols of different colors (black for the event "Class & Direction" and magenta for event "Class & Dir ±1").
Their value can be read on the radial scale (score axis) and, as in a archery target, the perfect score 1 is represented in the innermost ring.
The Frequency Bias is not explicitly calculated but it can be deduced for the "Class & Direction" event by the relative position of observed frequency line (in blue) and forecast frequency line (in red):

- Red line outer means overestimation of the number of events
- Blue line outer means underestimation of the number of events

3 Examples of application of the Performance-Rose diagrams

The Performance-Rose is designed primarily to help forecasters understand the behaviour of models, particularly on some coastal stations, where for geographical reasons it is essential to identify errors in the forecast of wind intensity as a function of direction.
For example, in figure 6 are plotted the Performance-Rose diagrams for the verification of 10m wind predicted by COSMO-I7 00 UTC run for the station "Chioggia" located in the north Adriatic sea near Venice.
The statistics refer to 1 year (JAN-DEC 2016) of hourly data from 1 to 24 hours of forecast (DAY 1) and corresponding observations. Looking to the plots, following the possible interests of forecasters as final users, some considerations can be done:

When the wind is predicted in the "Light" class the errors on direction are significant as suggested by the dimension of the gray sectors and the better scores for the "Class & Dir ±1" event with respect to "Class & Dir". The errors in direction decrease as the wind is predicted in higher classes (very small differences in the scores for "Moderate" or "Strong" winds).

Underestimation of the intensity ,with correct direction predicted, is more evident for "Light" and "Light-moderate" classes (see cyan sectors). In case of "Moderate" winds predicted the number of cases of underestimation is very small, while the number of overestimated events is significant (see yellow sectors).
This information is important for the forecasters as they can be confident about the low risk of missing critical events.

Unfortunately the performance-rose relative to "Strong" wind shows that the scores relative to this type of event are very low. In addition to cases of overestimations, the most frequent error is the complete missing of the event (predicted in lower wind classes with very different direction and therefore not visible in the Performance-Rose diagram).

If instead we consider the case in which models developers are the end user of our verification, it can be interesting to compare if some errors in the wind forecast of a particular model are also found in other models, considering the same station and period. For this purpose, in the framework of WG5 Common plots activities during the year 2018 the production and analysis of Performance-Rose diagrams for several models was started.

Data of 10m wind forecast from COSMO-5M (Arpae-Italy), COSMO-PL (IMGW), COSMO-GR4 (HNMS), ICON-EU (DWD),COSMO-DE/D2 (DWD) were used to produce Performance-Rose diagrams for four different periods (JJA2017,SON2017,DJF2017-18,MAM2018) on a set of selected stations belonging to Common Area 1 (see figure 7).

Since the goal of the Performance-Rose diagram is to provide the end user with effective feedback on the model's forecasts, trying to answer the question of a specific user, it was decided to compare the various models by identifying some targeted issues, depending on the characteristics of the wind field on individual station.

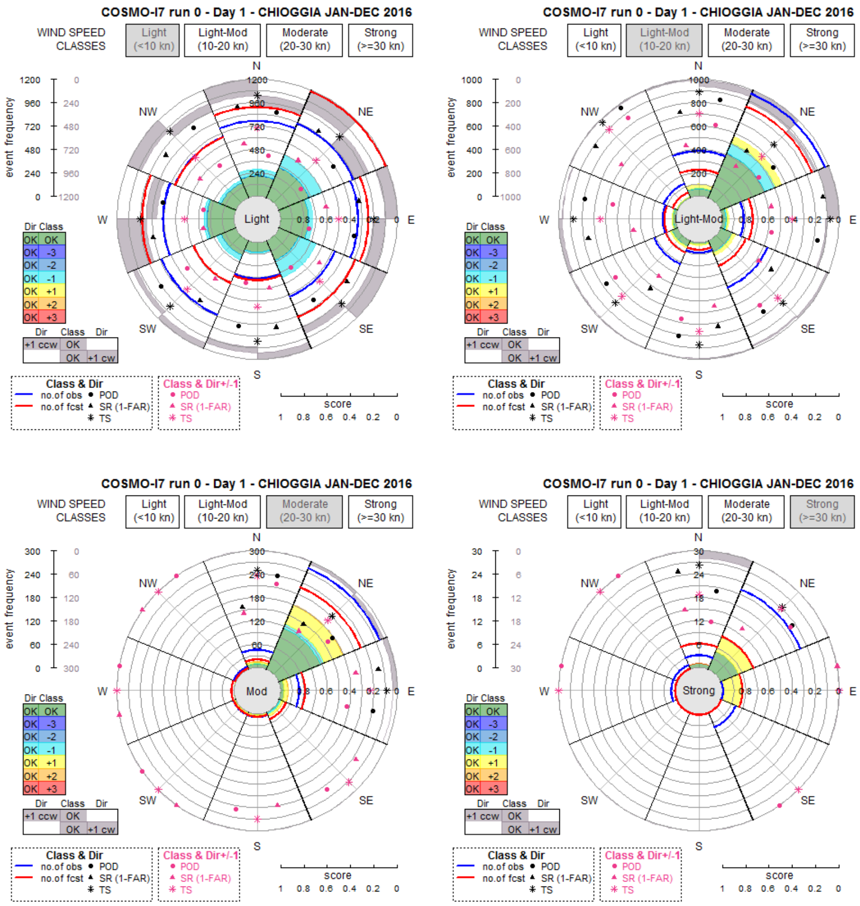

Figure 6: Performance-Roses for the verification of 10-m wind hourly data predicted by COSMO-I7 00 UTC run for the station "Chioggia" in the period January-December 2016. Each single plot refers to a specific speed class: "Light" (top-left), "Light-Moderate" (top-right), "Moderate" (bottom-left), "Strong" (bottom-righ).

Selected stations:

	code	name	height
1	16105	VENEZIA TESSERA	6
2	16088	BRESCIA/GHEDI	97
3	11816	BRATISLAVA-LETISKO	134
4	11012	KREMSMUENSTER	390
5	12830	VESZPREM/SZENTKIRALYSZABADJA	281
6	11659	PRIBYSLAV	536
7	11683	SVRATOUCH	740
8	11766	CERVENA U LIBAVE	753

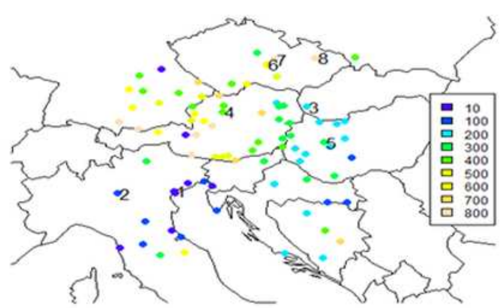

Figure 7: Selected stations in Common Area 1. The colors of the symbols represent the height of the stations in meter a.s.l.

For example, wind verification of both COSMO-5M and COSMO-I2 (2.8 Km resolution) performed in Emilia-Romagna region (Italy) pointed out a a general underestimation of the forecast intensity in mountain stations. To see if this behaviour was also common to other models, the station "Svratouch", located at 740 meter a.s.l., was chosen and Performace-Roses representing the performance of the first 24 hours of forecast of the four different models during the period June 2017 - May 2018 were produced.
In figure 8 the Peformance-Roses of COSMO-5M for the four different wind-speed class are represented, while in figures 9-11 only the two lower wind-speed classes of COSMO-PL , COSMO-GR and ICON-EU are plotted, since there are no forecast in the "Moderate" and "Strong" classes.

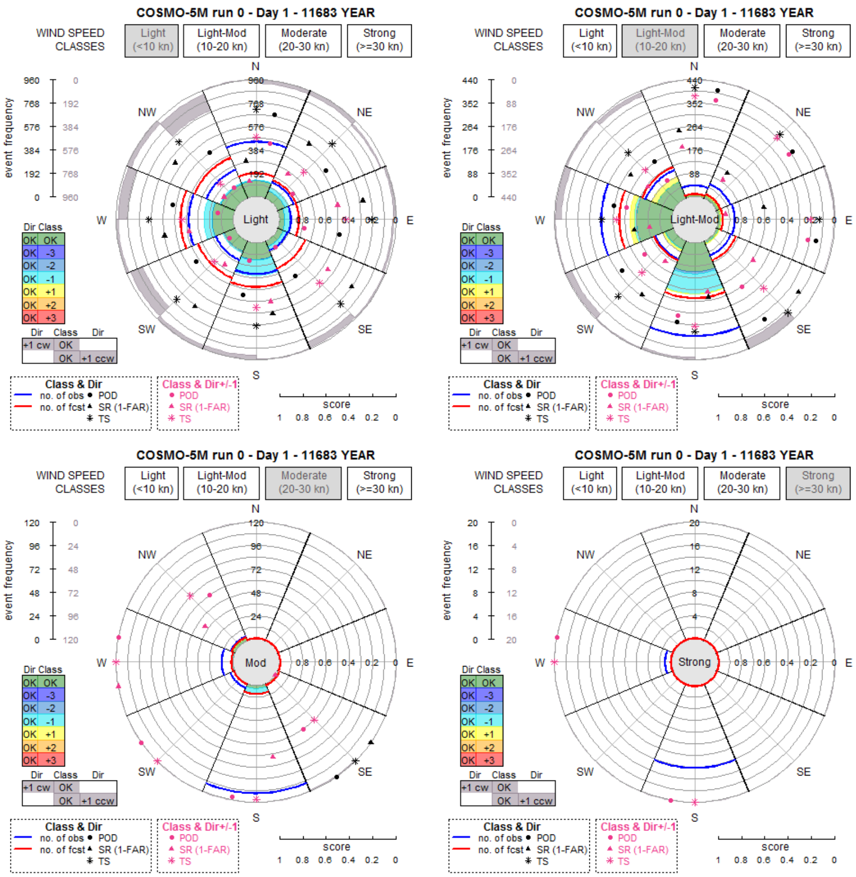

Figure 8: Performance-Roses for the verification of 10-m wind hourly data predicted by COSMO-5M 00 UTC run for the station "Svratouch" in the period June 2017-May 2018. Each single plot refers to a specific speed class: "Light" (top-left), "Light-Moderate" (top-right), "Moderate" (bottom-left), "Strong" (bottom-righ).

With reference to figures 8-11 some considerations can be done: In general, cyan sectors indicate that the forecast is correct only in direction while the intensity is underestimated , i.e. the observed wind intensity is one speed-class higher.

The COSMO models considered exhibit this type of behaviour in the two lover speed-class and particularly in the direction "South" for the "Light-Moderate" class, indicating that the corresponding wind observations were in the "Moderate" class. In fact, if you look to the plot referring to the "Moderate" class of COSMO-5M (see figure 8) the number of observations (blue line) is higher than the number of the forecast (red line). For other models forecast events are zero (not shown). ICON-EU graphs show less cyan sectors, i.e. less underestimation, but also less green sectors and therefore less correct forecasts in both intensity and direction. The presence of grey sectors indicates that the intensities have been correctly predicted while it is the direction that is missed, as for example can be seen from the underestimation of the number of events in the "South" direction that seems partly compensated by the occurrences in the "South-East" direction (grey sector).

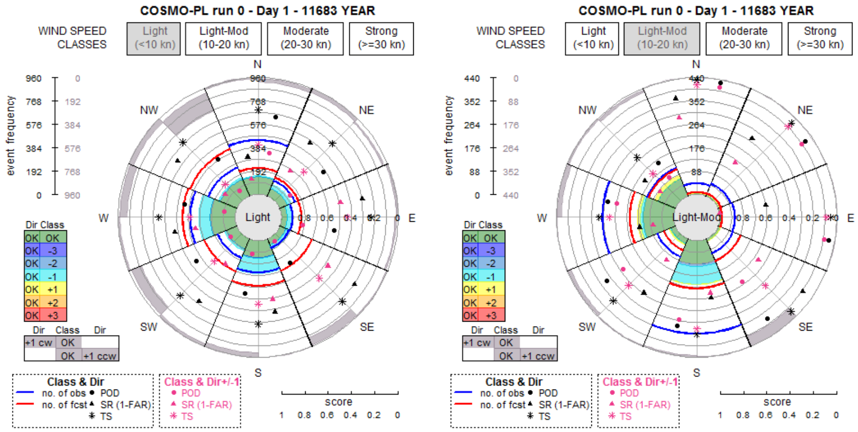

Figure 9: Performance-Roses for the verification of 10-m wind hourly data predicted by COSMO-PL 00 UTC run for the station "Svratouch" in the period June 2017-May 2018. Each single plot refers to a specific speed class: "Light" (top-left), "Light-Moderate" (top-right).

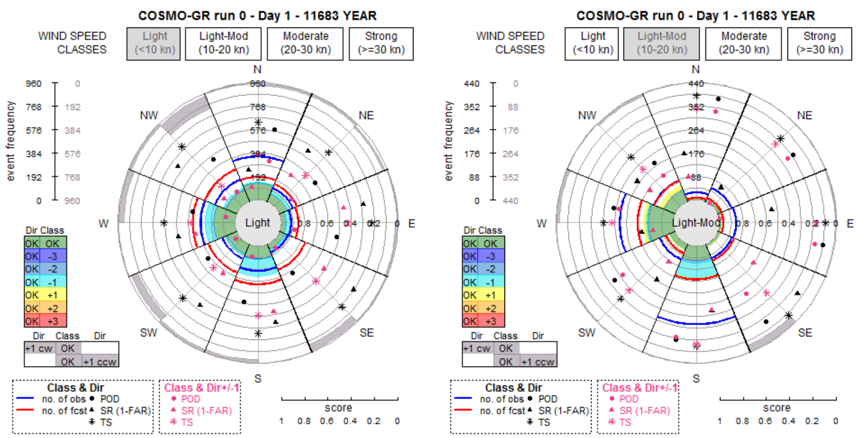

Figure 10: Performance-Roses for the verification of 10-m wind hourly data predicted by COSMO-GR 00 UTC run for the station "Svratouch" in the period June 2017-May 2018. Each single plot refers to a specific speed class: "Light" (top-left), "Light-Moderate" (top-right).

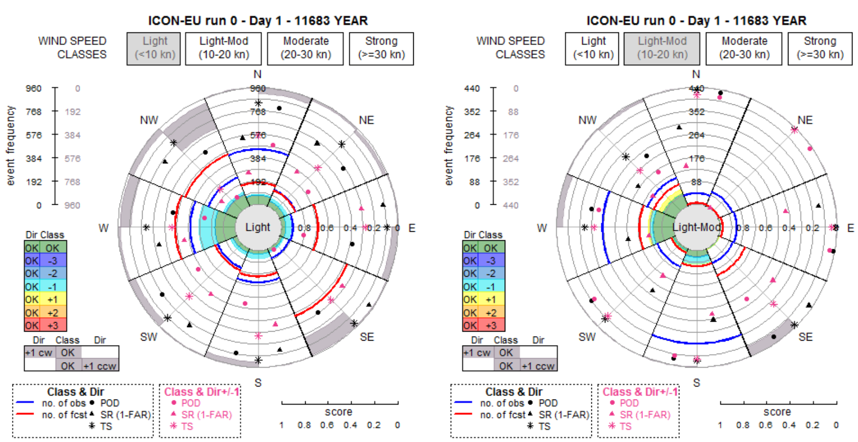

Figure 11: Performance-Roses for the verification of 10-m wind hourly data predicted by ICON-EU 00 UTC run for the station "Svratouch" in the period June 2017-May 2018. Each single plot refers to a specific speed class: "Light" (top-left), "Light-Moderate" (top-right).

5 Conclusion

One of the most tricky aspects of verification is to provide end-users with an effective feedback on model forecast, both in terms of contents and communication. The idea of the "Performance Rose" diagram addresses precisely this issue, trying to answer the questions of a specific users.
Since a lot of information is summarized in the Performance-Rose diagram, it is necessary to focus from time to time on specific aspects, depending on the user's needs.