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Report no. 11/2011
Oceanography
ISSN:
Oslo, November 9, 2011

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Norwegian
Meteorological Institute
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report

Number	Subject	Date	Classification	ISSN
11/2011	Oceanography	October 31, 2011	☒ Open ☐ Restricted ☐ Confidential	

Title

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Client(s)	Client reference
met.no	Ensemble validation

Abstract

In this study the performance of both, a global and a regional Ensemble Prediction System (EPS) are analyzed and compared at oceanic locations. The global system comes from the European Centre for Medium-Range Weather Forecasts, ECMWF, which has 51 members and the limited-area from the Norwegian Meteorological Institute, METNO, with 21 members. The forecasts performance is assessed by using available buoy data over two years, 2007-2008, within the regional domain which covers northern Europe and adjacent sea areas. The variables analyzed where the wind speed at 10 meters and significant wave height. For the wind speed both, global and regional, EPS were statistically consistent with observations. Only minor differences between the two systems where found. For the significant wave height both systems have an overforcasting tendency and the global EPS performs better than the regional. This study suggests that there is no clear advantage of using the high resolution regional EPS at the buoy locations used. There is however some indications that winds are better predicted by the limited area system in enclose areas and we infer from it that wave predictions will be better there. Unfortunately no wave data, at these locations, were available.

Keywords

wind and wave ensemble forecast, ensemble Validation

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1 Introduction

Ensemble prediction systems (EPS) are currently run operationally at several centers, such as the European Center for Medium Range Weather Forecasting (ECMWF), with global coverage and the Norwegian Meteorological Institute (METNO), with a limited area coverage. In this article we validate and compare the performance of these two systems against buoys observations over two years, 2007-2008. The variables analized were significant wave height and wind speed at 10 meters. The main advantage of using limited area models is that it allows for substantially higher horizontal resolution than what is possible for the global models. In the context of wave forecasting this is expected to improve the winds, and hence the waves, particularly in the near coastal areas where orographic effects may significantly alter both the winds speed and the direction.

This paper is structured as follow. Section 2 describes the ECMWF wave EPS. Section 3 describes the METNO wave EPS. Section 4 describes the observations. Section 5 and 6 shows the results of the performance of both EPS. Finally, conclusions are presented on section 6.

2 Global Ensemble Prediction System

2.1 Coupled atmospheric and wave forcing

ECMWF has been issuing its operational global ensemble prediction system since 1992. An overview of the current operational system is given in Leutbecher and Palmer (2008). Since September 2006, the ECMWF operational EPS has been running with a variable resolution (Buizza et al. , 2007), with 51 members, one starting from unperturbed initial conditions and 50 from perturbed initial conditions defined by adding small dynamically active perturbations to the operational analysis for the day. The technique used to perturb the initial conditions is based on the leading singular vectors of the operator that describes linear perturbation dynamics over a finite time interval of 2 days. The singular vectors maximise perturbation growth over this time interval. At present, the EPS is based on the notion that forecast uncertainty is dominated by error or uncertainty in the initial conditions. Each EPS perturbation is a linear combination of singular vectors with maximum growth computed using a total energy norm, over a 48 hours period. In all model integration, the atmospheric model is coupled to the wave model WAM (Janssen et al. , 2008) and (Komen et al. , 1994). For simplicity all ensembles start from the same initial wave conditions as prescribed by the latest operational analysis. The horizontal resolution is 1.0°. The global EPS is run two times a day with a forecast length of 240 hours and the spectral resolution is 24 directional and 30 frequency bins.

3 Limited-area Ensemble Prediction System

3.1 The Atmospheric Forcing

At METNO a 21-member limited area EPS (LAMEPS) for the atmosphere was set into operational use in February 2005, (Frogner et al. , 2006) providing 60 hour forecasts on daily basis.

In addition to continental Norther Europe and the Scandinavian Peninsula the model domain covers the Nordic Seas including the adjacent North Sea and the Barents Sea, see Fig. (1). LAMEPS integrates 20 ensemble members from perturbed initial conditions in addition to the control run which uses the unperturbed analysis as the initial state. The model domain is on a rotated spherical grid with origin at 0° East and 65° North. The horizontal resolution of the LAMEPS in 2007 was 0.2°. In 2008 the resolution changed to 0.1° after 13th of February. At the lateral boundaries the LAMEPS is forced by a low-resolution ensemble prediction system based on targeted singular vectors TEPS. TEPS are constructed by combining initial and evolved singular vectors that at 48 hours are targeted to maximize the total energy in a domain containing northern Europe and adjacent sea areas. A more detailed description of LAMEPS is given by Frogner and Iversen (2002).

3.2 The wave component

The wave model is the METNO version of the ocean wave prediction model WAM cycle 4. The model was set into operation at METNO in 1998 and is currently run for a number of limited-area domains with various horizontal resolutions. The spectral resolution is 24 directional and 25 frequency bins. The wave EPS covers the same model domain as the LAMEPS, (see Fig. 1). The horizontal resolution is 0.1°. The hourly 10-metre winds form the LAMEPS are used as external forcing and all ensemble members are started from the same initial condition. The current version of the wave EPS is run without data assimilation and the initial condition is the latest 24-hour forecast. The systems is run daily and the forecast lead time is 60 hours. On the lateral boundaries all ensemble members are forced with a lower resolution forecast for the North Atlantic Ocean (large domain in Fig. 1). Ideally, a limited-area wave ensemble should be forced by a global, or a larger domain, ensemble prediction system on the boundaries. At METNO no such system is currently available and the use of one deterministic forecast as boundary condition for all members is a compromise that has to be applied until another option becomes possible. Future plans are to disseminate wave spectra from the ECMWF system for use at the boundaries. This requires huge amount of data to be routinely transferred and is not possible with the present data infrastructure. However, the reader should keep in mind the possible limitations imposed by the use of one single deterministic forecast as boundary value for all wave ensemble members.

The global EPS runs 2 times a day, at 00:00 and at 12:00 UTC while the limited-area EPS runs once a day at 18:00. For this comparison we took the observations at 12:00 from the global EPS. The main differences between the two systems are summarized in table (3.2).

4 Observations

Wind and wave observations from moored buoys, ships and platforms are routinely collected by national organizations in their offshore areas of interest. Hourly data are transferred to meteorological centres via the Global Telecommunication System and archived together. In the remainder of this paper, the word buoy is used to refer to the selected moored buoys and platforms since most of the reliable observations comes from moored buoys. A number of

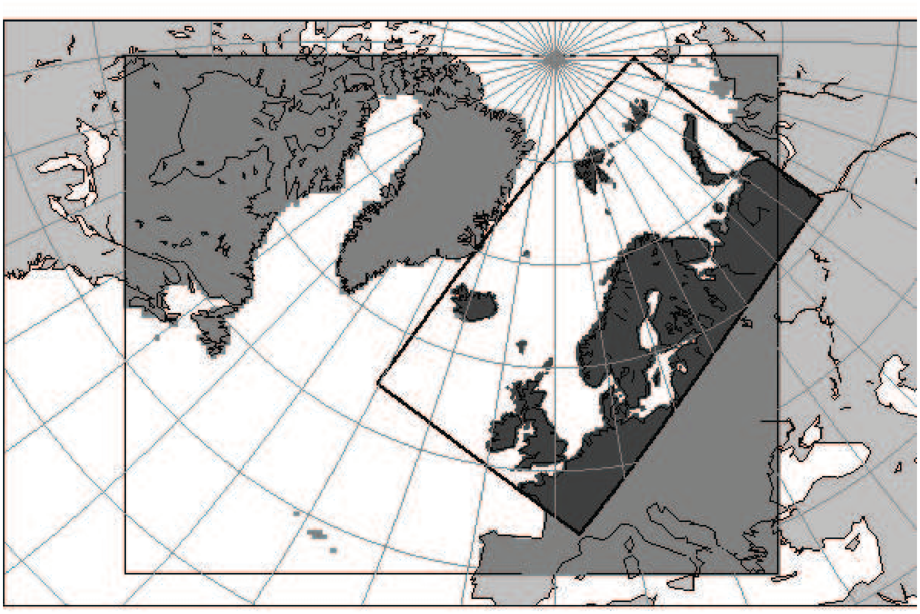

Figure 1: Model domains. The large area is the model domain of the coarse resolution wave model providing lateral boundary values for the the nested wave EPS. The small domain covering the Nordic Seas is the model domain of limited area wave EPS.

Variables	Wind speed at 10m		Significant wave height	
Institute	ECMWF	METNO	ECMWF	METNO
Model	atmsph. model coupled with WAM	LAMEPS	WAM coupled with atmsph.	WAM uncoupled
Coverage	global	limited	global	limited
Horizontal grid size	1.0°	0.2° 0.11° after Feb 2008	1.0°	0.1°
Wave Spectra resolution			24dir 30fr	24dir 25fr
Ens. members	51	21	51	21
Forecast length hr	240	60	240	60
Daily time used	12:00	18:00	12:00	18:00
No of obs.	26748	27393	23646	22359
No of stat.	65	60	51	51

Table 1: Information about the two EPS.

stations report data that are well within the regional model grid and are located in relatively deep water (depth of 100 m or more) The present investigation covers the period between 1 January 2007 to 31 December 2008.

The number of observations used are listed in table (3.2). Fig. (2) shows the data coverage within the limited-area model domain. Unfortunately not all the buoys have wave and wind observations at the same time during the period studied. For example around Island there were no wind observations and in the English channel there were no wave observations. Some stations have data only at 12:00 and not at 18:00 and vice versa.

From the buoy records, time series are reconstructed to perform a basic quality check on the data (Bidlot et al. , 2002). Temporal scales are made comparable by averaging the hourly observations in a window of 4 h centred around the verification time. Buoys exhibit a high-frequency variability on a time scale of 1 h. Not averaging the data will result in a scatter between the models and observations, which can be linked to high frequency variability, not present in the model (Janssen et al. , 1997). For a more detailed description of the data treatment, see Bidlot et al. (2002) and Saetra & Bidlot (2004).

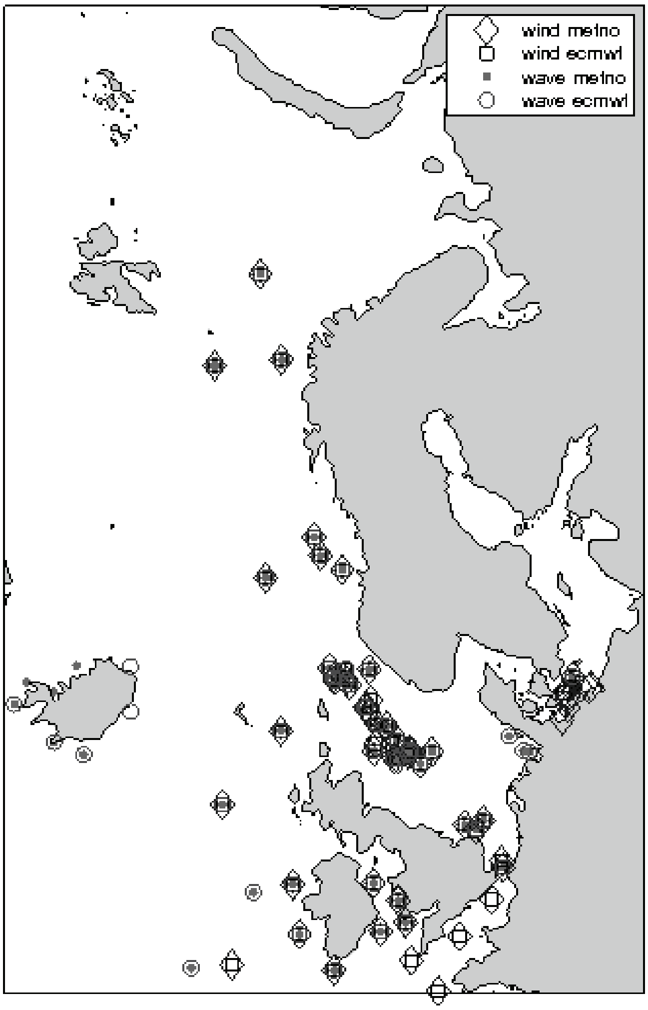

Figure 2: Positions of the buoy and platform observations used in this investigation.

5 Ensemble Statistics

Ensemble predictions are estimates of the true probability distribution for given weather and wave parameters as nature evolves. The problem when verifying ensemble forecasts is the fact the natural probability distributions are never observed. The observed weather events are one realization from these distributions. When verifying ensemble forecasts, this has to be taken into consideration. One single observation can say nothing about the quality of the model system as observations are expected to fall in the low probability part of the distribution with a certain frequency for any well tuned system. The basic assumption when using the EPS is that for a perfect system the ensemble members and the observation are random draws from the same probability distribution. If this assumption is true, it should of course be impossible to distinguish the observation from the ensemble members when using statistical methods. A number of consequences of this assumption can be outlined and used to test the EPS against observations. Another consequence of this is that the number of observation needed for proper statistical verification is far greater than when verifying deterministic forecasts.

Below, this basic hypothesis will be tested in terms of ensemble spread, the relation between spread and skill and the reliability of the foretasted probabilities. We will also test the relative economic value of the system for the use in decision support.

5.1 Ensemble Spread

The ensemble spread will be tested by using rank histograms (Hamill , 2001). The idea is that for a given forecast range, the ensemble members and the observations are pooled and sorted from the lowest to the highest value. For a perfect system the observation may occur at any rank with the same probability. If this process is repeated for a number of observations, a flat histogram over possible ranks is expected.

When using rank histograms, Saetra et al. (2004) demonstrated that observations errors can lead to a false impression of too low spread in the ensemble system. They suggested adding normal distributed noise, with the same standard deviation as the observation errors, to the ensemble prediction system before it is presented to the verification tools. A similar approach was also suggested by Anderson (1996). Janssen et al. (2003) estimated the observation errors for the buoys to be about 10% of the significant wave height.

Figures (3) and (4) show the ranks histograms with normally distributed noise added to the ensemble members at the 48 hour forecast. The standard deviation on the noise was taken to be 10% for both the significant wave height and the wind speed.

For the wind speed, Fig. (3), the limited-area system presents a slight overforacasting bias while the u-shape rank histogram of the global system indicates a lack of ensemble spread. However both are very close the perfect histogram indicated by the horizontal line. The same happens with the 24 and 60 hour forecast (not shown).

For the significant wave height, Fig. (4) both rank histograms present their maximum in the middle bins implying that the ensemble spread is too large. This feature is present in the 24 and 60 hour forecast as well (not shown). The limited-area system also present an overforcast feature since observed frequency of observations at the highest ranks is too low. The rank histogram closest to a flat distribution is the one from the limited-area system.

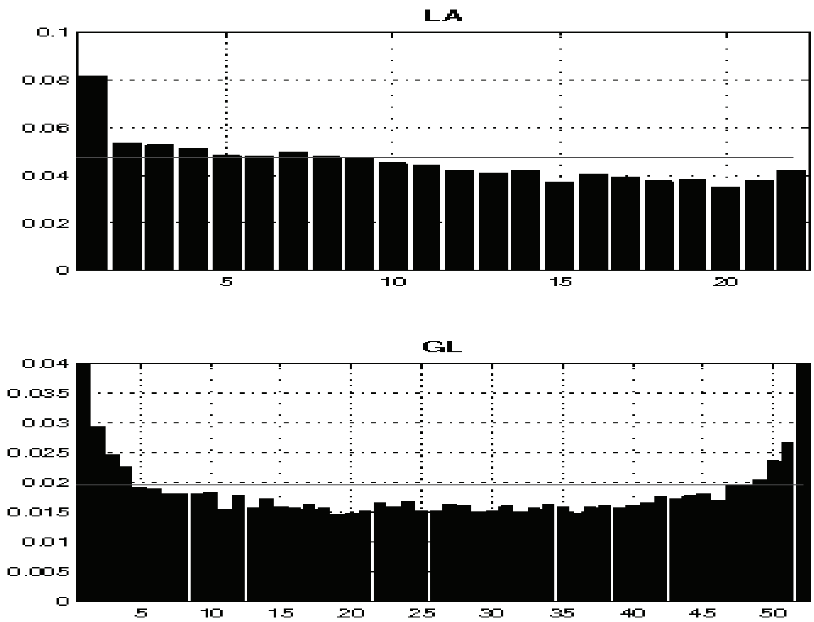

Figure 3: Rank histograms of the wind speed at 48 hours forecast for the limited area EPS, indicated with LA, and for the global EPS, indicated with GL.

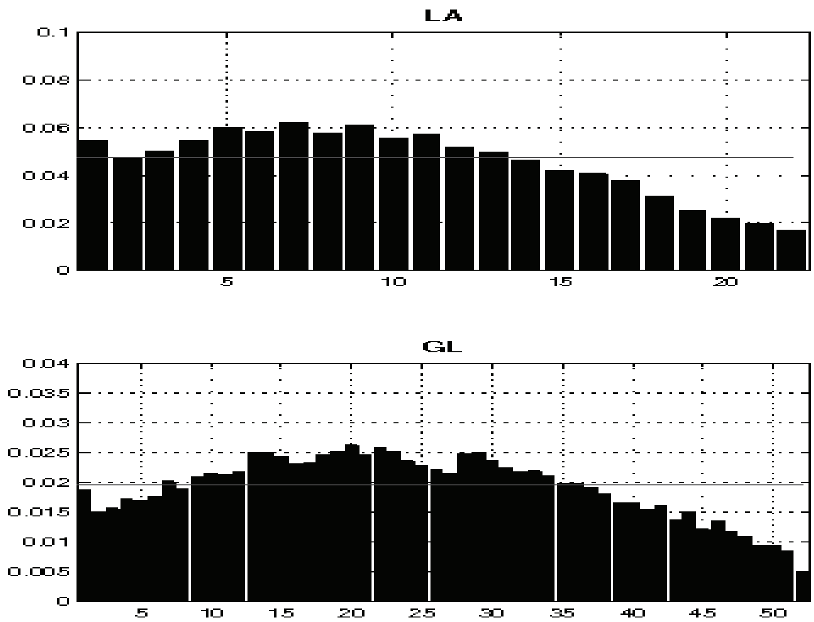

Figure 4: Rank histograms of the significant wave height at 48 hours forecast for the limited area EPS, LA, and for the global EPS, GL.

5.2 Spread-Skill Relation

The spread is defined as the standard deviation of the ensemble members about the ensemble mean. For our analysis the spread is divided into bins, of 0.15cm/s for the wind speed and 0.1m for the significant wave height.

The forecast error is defined as the absolute value of the difference between the ensemble mean and the observed value. Within each bin, the error distributions for the deterministic forecast are then calculated within each bin for the spread. The spread-skill relation is tested by plotting the 90 percentile of the forecasts errors as a function of ensemble spread. If a spread-skill relation is present, the 90 percentile will increase with increasing ensemble spread.

Fig. (5) shows the spread-skill for the 48 hour forecasts. This plot reveals a clear spread-skill relation with the 90 percentile more or less following a straight line with a slope of 1.554 for the wind speed and 1.7351 for the significant wave height.

These results strongly supports the idea that the ensemble spread can be interpreted as a measure of the expected accuracy of the deterministic forecast. The results are also in close agreement with those obtained by Saetra & Bidlot (2004) for the global wave ensemble. Only minor differences can be seen between the global and regional systems.

5.3 Reliability

The reliability diagrams, (Wilks , 2006), are shown in Figs. (6), (7), (8) and (9). For the wind speed at 48 hour forecast, Fig. (6), the results of both systems indicate good reliability especially for the case of winds higher than 15m/s. For the threshold values of 5 and 10m/s there is a small tendency for the points to lie below the diagonal, which indicates that probabilities were overforcasted over a large range of forecast probabilities. For the case of winds higher than 15m/s this tendency appears in a smaller range. In this last case the limited-area systems scores better in the lower range of forecast probabilities. For the case of winds higher than 20m/s the reliability curves present the typical noisy behavior of insufficient sample size. Similar result are found for the 60 hours forecast (not shown).

For the 24 hours forecast, Fig. (7), the two systems differ more between them and from the line of perfect reliability. The limited-area system gives better reliabilities in the lower range of forecast probabilities while the global system is closer to the perfect reliability in the middle range of forecast probabilities.

Larger differences between the global and regional EPS appear in the significant wave height. Fig. (8) shows reliability diagram for the 48 hour forecast and Fig. (9) for the 24 hour forecast. For all wave thresholds the limited-area system has a tendency to overforecast over the entire range of probabilities while the global system oscillates between the under and over forecast regions. Except for the threshold of 2m in Fig. (9), where both systems score equally, the wave global system scores better than the limited-area in the sense that the distance between its points and the perfect reliability line is shorter than for the other system. The same general features found for the 48 hour forecast are present for the 60 hours forecast (not shown).

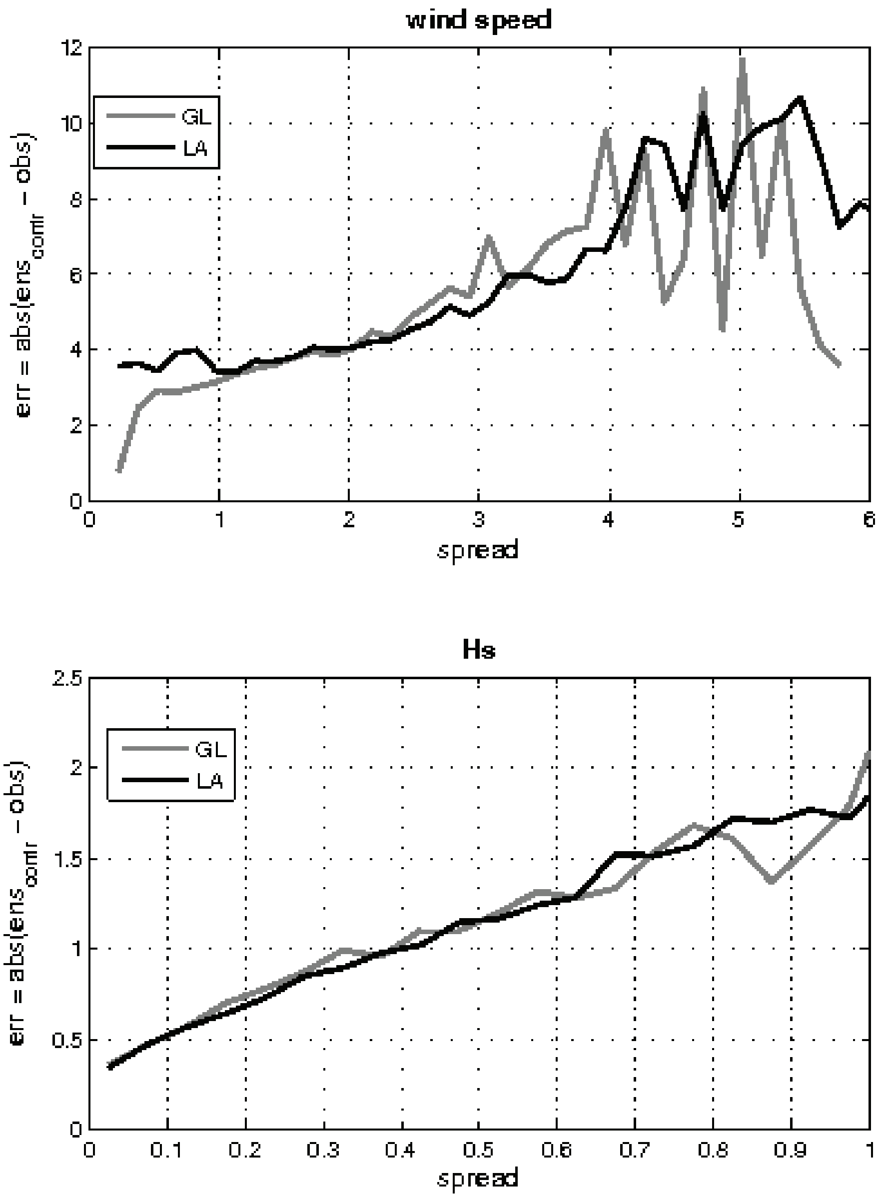

Figure 5: Spread-skill relation for the 48 hour forecasts. The solid line is the 90 percentile of the observations errors.

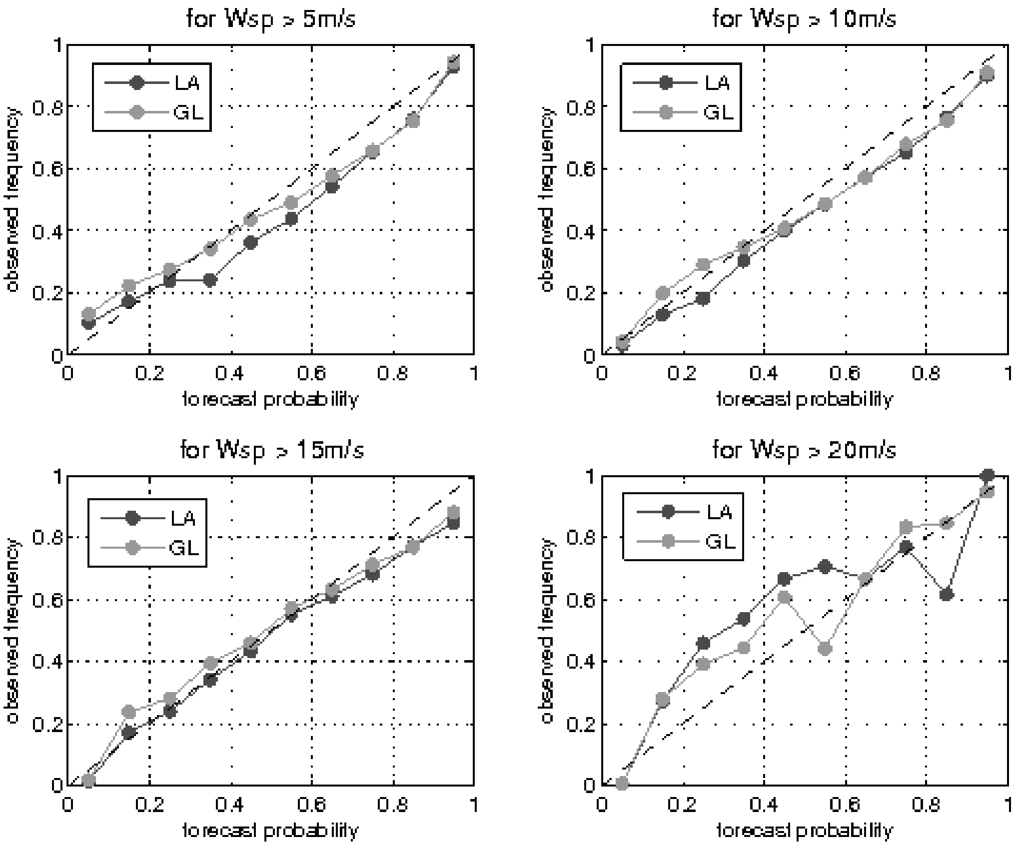

Figure 6: Reliability diagram for the wind speed at 48 hours.

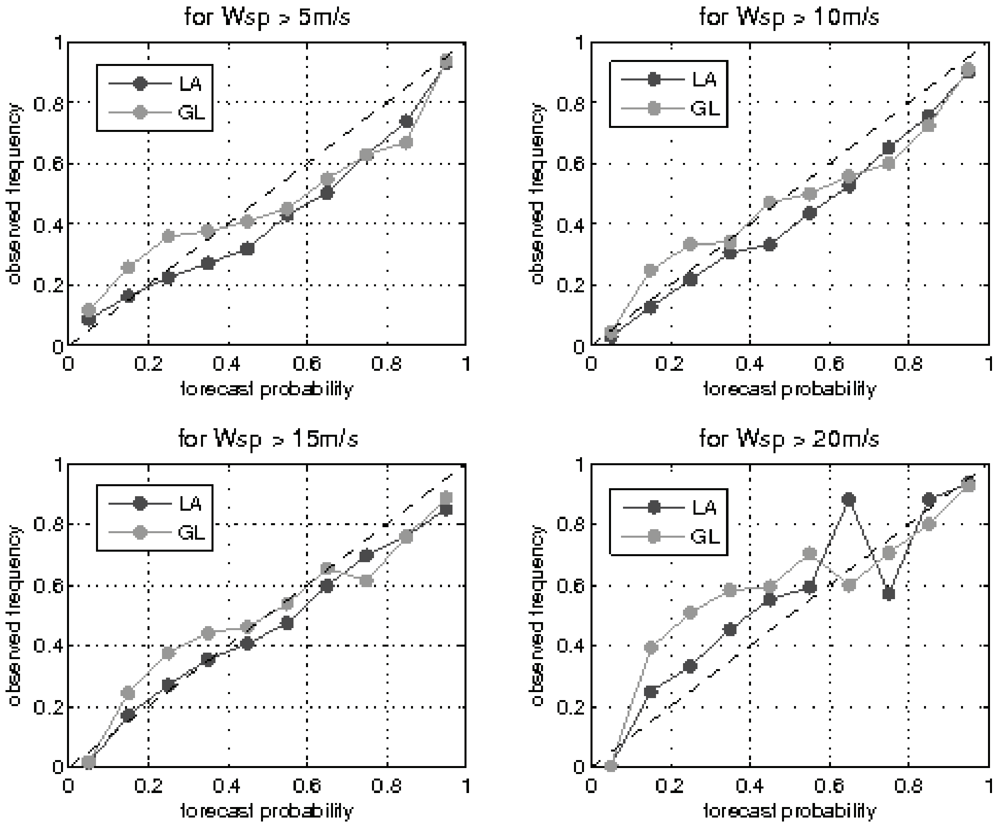

Figure 7: Reliability diagram for the wind speed at 24 hours.

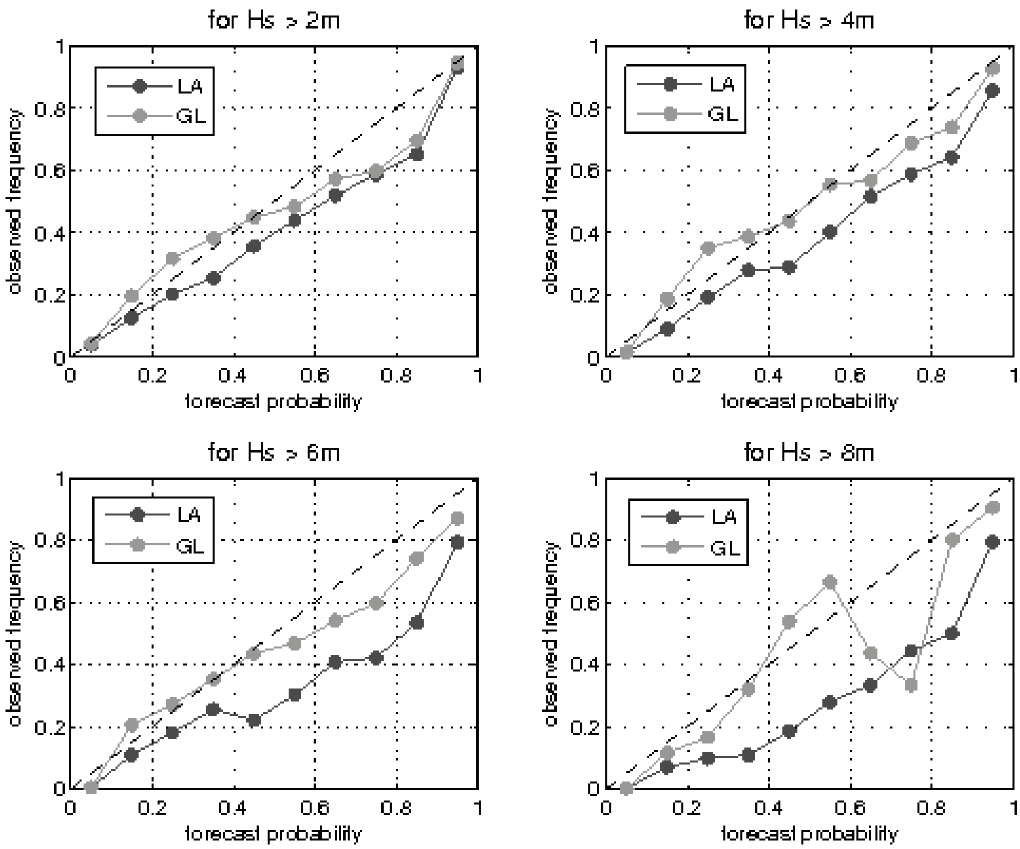

Figure 8: Reliability diagram for the significant wave height at 48 hours.

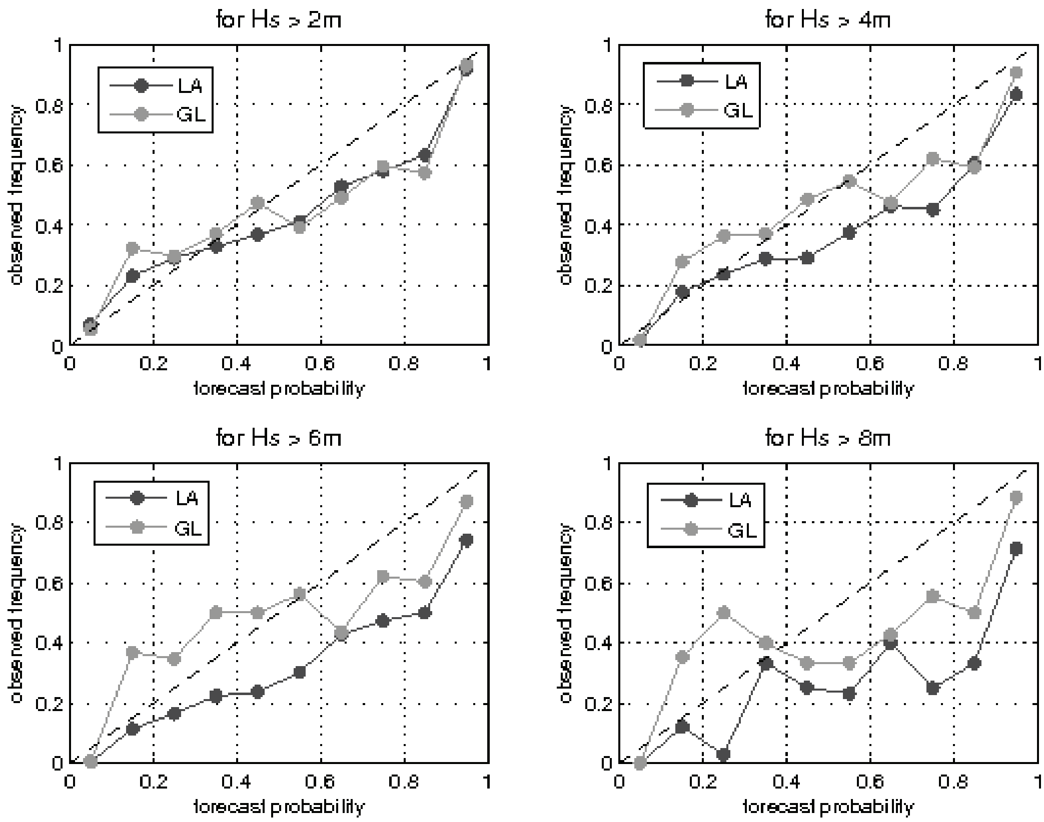

Figure 9: Reliability diagram for the significant wave height at 24 hours.

5.4 ROC areas and relative Economic Value

Relative Operating Characteristic, or ROC diagrams, are constructed by calculating the hit rate H and false alarm rate F for a discrete number of probability classes from 0 to 1. The hit rate is defined as the fraction of occurrences of the event which were correctly forecasted, while the false alarm rate is the fraction on non-occurrences for which the event was incorrectly forecasted. The ROC diagram is then constructed by plotting the hit rate against the false alarm rate. The point $(0,0)$ corresponds to never forecasting the event and the point $(1,1)$ corresponds to always forecasting the event and the point $(0,1)$ represents perfect forecast. Random forecasts with the sample climatological probabilities will have a curve along the 45° diagonal line. It is convenient to summarize a ROC diagram using a single scalar variable. The usual choice for this is the area under the ROC curve, say A. A perfect forecasting system has a ROC curve that includes the entire unit square, $A_{perf} = 1$. ROC curves for random forecasts along the diagonal line have the area $A_{rand} = 0.5$.

Here, the ROC areas have been calculated for the same threshold values as for Fig. (6) and (8) for tow different forecast hours, 48 and 60. The results are listed in table (6). The table also list the number of cases when the observed data exceeded the threshold value. The ROC area values are large. For the higher threshold classes few cases can give an artificially high ROC areas. The ROC areas from the global systems are equal or larger than those from the limited area.

The cost loss model proposed by Richardson (2000) assess the economic value of a forecast when both the monetary loss L (in, say, dollars) due to adverse weather situations and the cost C of preventing weather damage are known in monetary terms. For a given event the cost C is assumed to be less than the loss L. The idea is to consider a hypothetical decision maker who must choose to take action or do nothing. The decision is based on the forecast available. The definition of V is a skill score of expected expenses with climatology as reference. When $V > 0$ the decision maker will gain some economic benefit by using the forecast information. When $V = 0$ the system is as bad as the climatology. The maximum value of $V = 1$ is reached when the system perfectly predicts the future.

The relative economic value, V, of the ensemble, versus the cost loss ratio, C/L, for the wind speed and the significant wave height at 48 hours forecast are presented in Figs. (10) and (11). The high scores for the relative economic values demonstrated that the forecasted probabilities may have a bias and still be of value to end-users. Specific users will use specific C/L ratios. The two systems predict very similar economic values for the wind speed while for the significant wave height the global system generally scores better than the limited-area.

6 Enclose areas

So far the high resolution limited area system does not represent any improvement over the low resolution global system. However in locations surrounded by land the regional wind EPS gives benefits. For the stations around the English Channel and Denmark, shown in Figs. (12), rank histograms and reliability diagrams are calculated for the 48 hour forecast, see Fig. (13). Around 5200 observations where used during the period studied (2007-2008). The

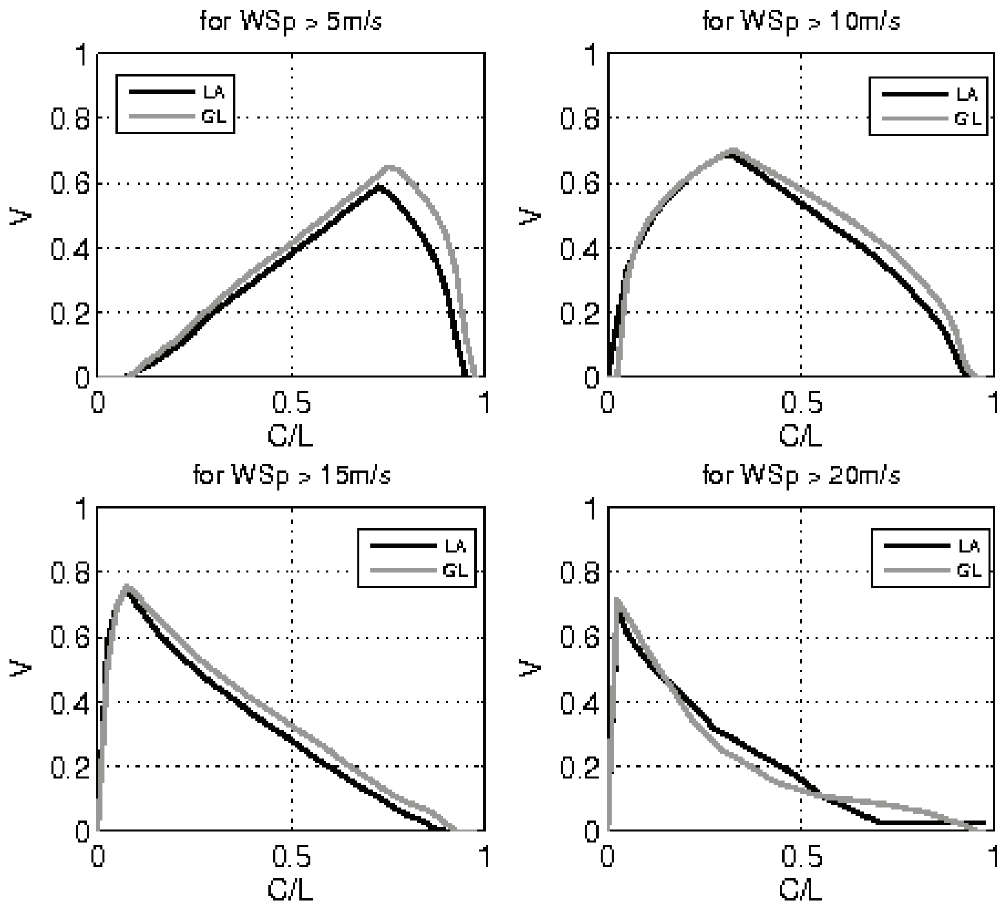

Figure 10: Relative economic value, V, versus cost loss ratio for wind speed at 48 hours forecast.

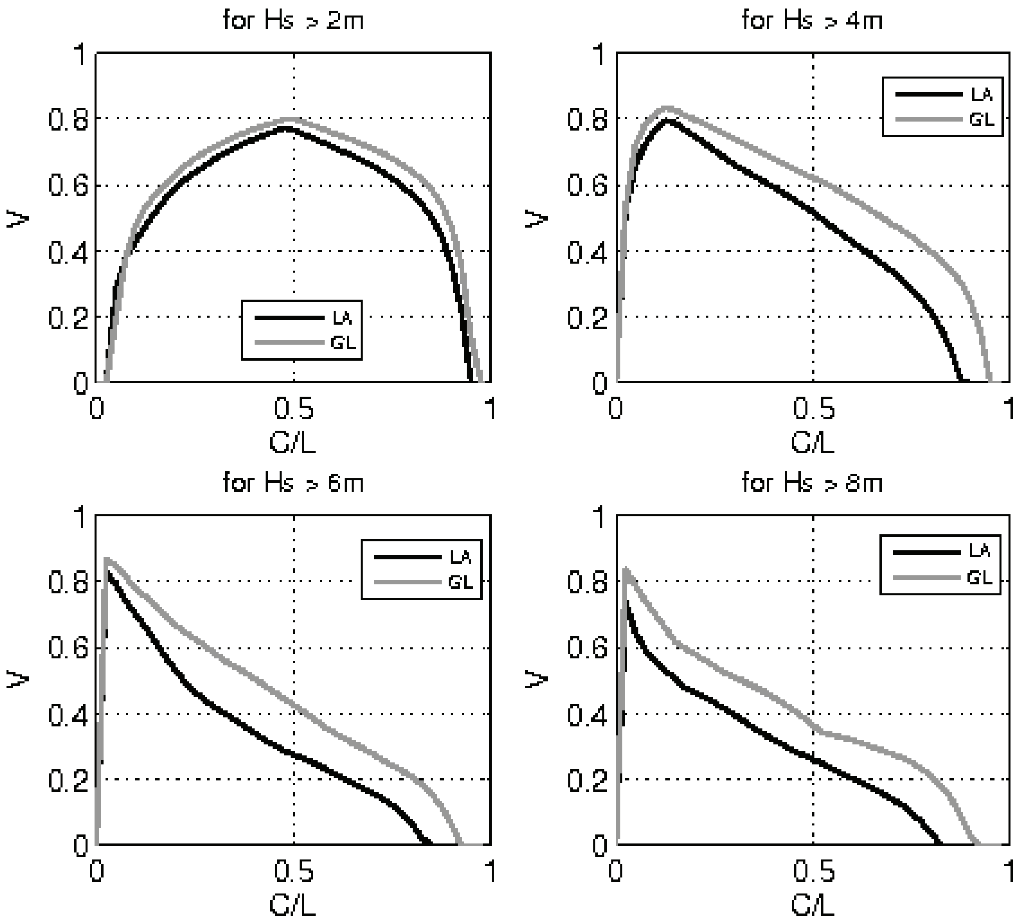

Figure 11: Relative economic value, V, versus cost loss ratio, for the significant wave height at 48 hours forecast.

48 hours				
Threshold	20m/s	15m/s	10m/s	5m/s
Area (LA)	0.87	0.92	0.92	0.85
cases	308	2045	8545	19929
Area (GL)	0.9	0.93	0.92	0.87
cases	332	2164	8661	20244
Threshold	8m	6m	4m	2m
Area (LA)	0.92	0.94	0.95	0.94
cases	111	629	2994	10737
Area (GL)	0.95	0.96	0.96	0.95
cases	124	657	3166	11532
60 hours				
Threshold	20m/s	15m/s	10m/s	5m/s
Area (LA)	0.83	0.91	0.9	0.82
cases	350	2037	8552	20118
Area (GL)	0.88	0.91	0.91	0.86
cases	332	2164	8661	20244
Threshold	8m	6m	4m	2m
Area (LA)	0.93	0.95	0.95	0.94
cases	113	636	3035	10670
Area (GL)	0.93	0.96	0.96	0.93
cases	124	657	3164	11446

Table 2: Areas under ROC-curve for two different forecast hours.

spread of the limited area system presents an overforcasting bias while the global system an underforcasting. The reliability diagrams indicate that the probabilities are underforecasted by the global system while the limited area presents a good reliability. The spread of the wind ensemble and the reliability are better predicted by the limited area than by the global system. In these stations the limited area system resolves better the neighboring land topography than the global giving better results. Unfortunately we cannot make any statement about the waves because there is not wave data at these locations.

7 Conclusions

A comparison of the performance between global and regional, wind and wave EPS is done at the locations shown in Figure (2). The global system comes from ECMWF and the limited-area from METNO. In this study, the forecast performance is assessed using available buoy data within the regional model domain over two years, 2007-2008. The variables studied where wind speed at 10m and significant wave height.

The mains features of the wind EPS are that in spite of the difference in shape of the rank histograms both are very close to the features of a perfect ensemble system. The difference

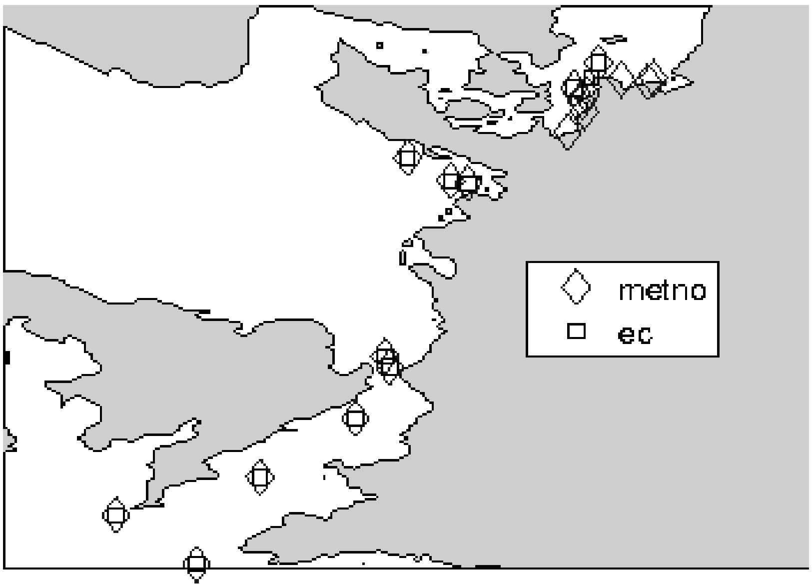

Figure 12: Enclose area observations.

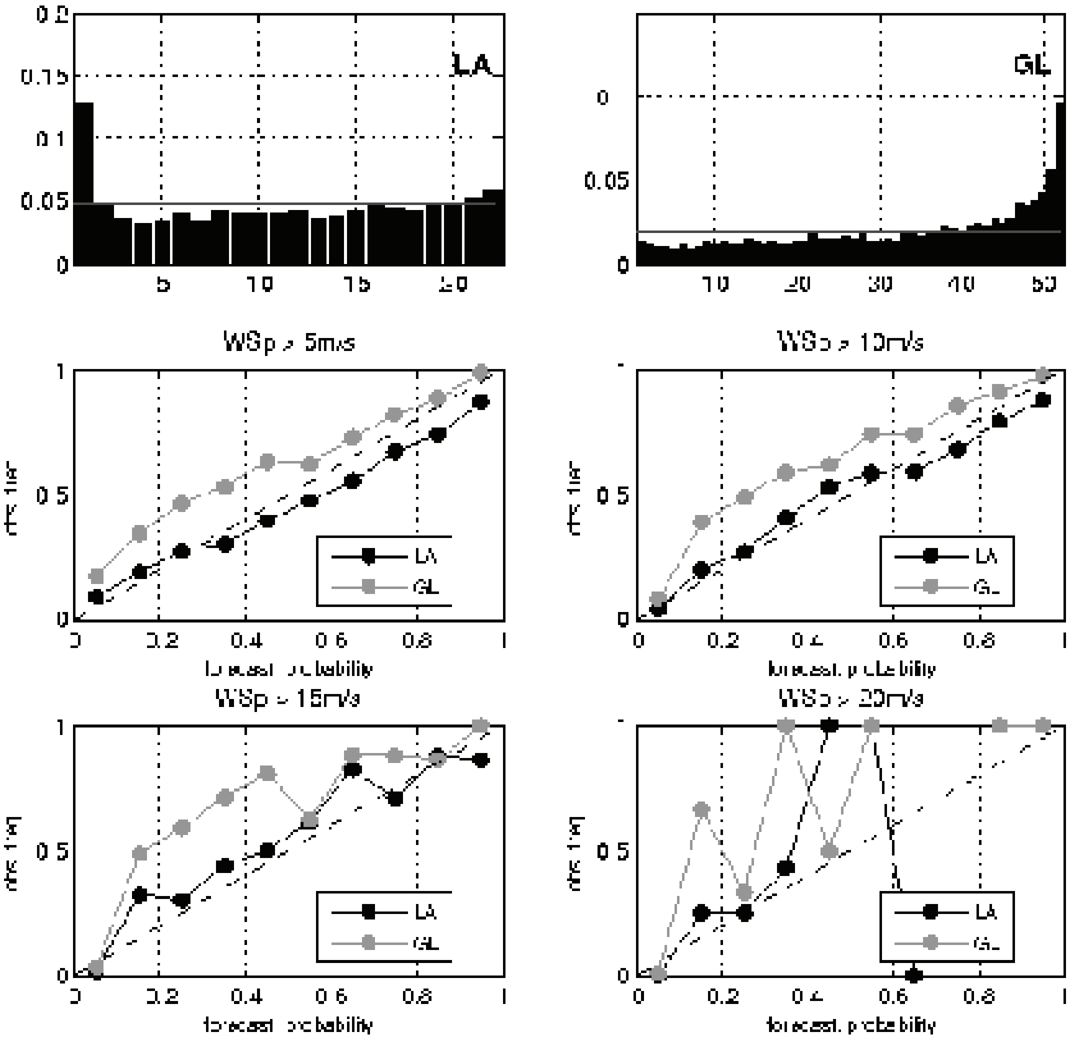

Figure 13: Rank histograms (two top plots) and reliability diagrams calculated from the observations shown in Fig. (12) for the wind speed at 48 hours

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between both systems with respect to reliabilities diagrams, spread-skill relation and relative economic values is very small. Just for stations in enclosed areas the regional wind EPS performs clearly better than the global.

The main features of the wave EPS are that both systems have an ensemble spread too large. The regional has an stronger overforcasting tendency than the global. Both systems present a very similar spread-skill relation. The global system presents a better reliability and relative economic values than the regional. The wave global EPS performs better than the regional. No conclusions about enclosed areas can be done because of lack of data.

Thus this study suggests that there is not apparent benefit of using this particular set-up of limited area EPS at these buoy locations.

Since the winds of both systems are very similar the difference between the wave EPS might be due to the coupling of the wave model which is absent at the limited area system.

References

Anderson, J. L., A Method for Producing and Evaluating Probabilistic Forecasts from Ensemble Model Integrations, 1996, J. Climate, 9, 1518-1530.

Bidlot, J.-R., D. J. Holmes, P. A. Wittmann, R. L. Lalbeharry, & H. S. Chen, Intercomparison of the performance of operational ocean wave forecasting systems with buoy data, 2002, Wea. Forecasting, 17, 287-310.

Buizza, R., Potential Forecast Skill of Ensemble Prediction and Spread and Skill Distribution of the ECMWF Ensemble Prediction System, 1997, Mon. Wea. Rev, 125, 99-119.

Buizza, R., Miller, M. and Palmer, T. N., 1999: Stochastic representation of model uncertainties in the ECMWF ensemble prediction system. Q. J. R. Meteorol. Soc., 125, 2887-2908.

Buizza, R., Bidlot, J.-R., Wedi, N., Fuentes, M., Hamrud, M., Holt, G. and Vitart, F., 2007: The new ECMWF variable resolution ensemble prediction system). Q. J. R. Meteorol. Soc., 133, 681-695.

Farina, L., On ensemble prediction of ocean waves, 2002, Tellus, 54A, 148-158.

Farina, L., A. M. Antônio, & J. P. Bonatti, Approximation of ensemble members in ocean wave prediction, 2005, Tellus, 57A, 204-216.

Frogner, I-L., & T. Iversen, High-resolution limited-area ensemble predictions based on low-resolution targeted singular vectors, 2002, Q. J. R. Meteorol. Soc., 128, 1321-1341.

Frogner, I-L., H. Haakenstad & T. Iversen, Limited-area ensemble predictions at the Norwegian Meteorological Institute, 2006, Q. J. R. Meteorol. Soc., 132, 2785-2808.

Hamill, T. M., Interpretation of Rank Histograms for Verifying Ensemble Forecasts, 2001, Mon. Wea. Rev, 129, 550-560.

Komen, G., J. L. Cavaleri, M. Donelan, K. Hasselman, S. Hasselman, & P. A. E. M. Janssen, Eds., 1994, Dynamics and Modelling of Ocean Waves, Cambridge University Press, 533 pp.

Janssen, P., B. Hansen, & J.-R. Bidlot, Verification of the ECMWF forecasting system against buoy and altimeter data, 1997, Wea. Forecasting, 12, 763-784.

Janssen, P., J. D. Doyle, J.-R. Bidlot, B. Hansen, L. Isaksen & P. Viterbo, Impact and feedback of ocean waves on the atmosphere, 2002, Atmosphere-Ocean Interaction, N. Perrie, Ed., Advances in Fluid Mechanics, Vol. I, WIT Press, 155-197.

Janssen, P., S. Abdalla, & H. Hersbach, Error estimation of buoy, satellite, and model wave height data, 2003, ECMWF Research Dept. Tech Memo. 402. 17 pp.

Janssen, P. A. E. M., 2008: Progress in ocean wave forecasting. J. Comp. Phys., 227, 3572-3594.

Leutbecher, M and Palmer, T. N., 2008: Ensemble Forecasting. J. Comp. Phys., 227, 3515-3539.

Lorenz, E. N., Deterministic nonperiodic flow, 1963, J. Atmos. Sci., 20, 130-141.

Palmer, T. N., Buizza, R., Doblas-Reyes, F., Jung, T., Leutbecher, M., Shutts, G. J., Steinheimer, M. and Weisheimer, A., 2009: Stochastic Parameterization and Model Uncertainty. ECMWF Tech. Memo., 598, ECMWF, Reading, United Kingdom, 41pp.

Richarson, D. S., Skill and relative economic value of the ECMWF ensemble prediction system, 2000, Q. J. R. Meteorol. Soc., 126, 649-667.

Roulston, M. R., & L. A. Smith, Combining dynamical and statistical ensembles, 2003, Tellus, 55A, 16-30.

Saetra, Ø., H. Hersbach, J.-R. Bidlot, & D. S. Richardson, Effects of Observation Errors on the Statistics for Ensemble Spread and Reliability 2004, Mon. Wea. Rev, 132, 1487-1501.

Saetra, Ø., & Bidlot J-R. Potential Benefit of Sig Probabilistic Forecasts for Waves and Marine Winds Based on the ECMWF Ensemble Prediction System, 2004, Wea. Forecasting, 19, 673-689.

Wilks, D. S., Statistical Methods in the Atmospheric Sciences: Secon Edition, Academic Press, 627 pp.