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KNMI

Statistical guidance for the North Sea

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Contents

1. Introduction

Since 1991 a statistical forecast for the oil platform K13 (see Fig. 1) has been available to the forecasters of the Maritime Meteorological Service (MMD) of the Royal Netherlands Meteorological Institute (KNMI). This so-called K13 guidance provides wind and wave forecasts up to five days ahead. It is based on statistical interpretation of model output from the European Centre for Medium-Range Weather Forecasts (ECMWF) as well as from the UK Meteorological Office (UKMO).

The shipping and off-shore industry, commercial clients of the MMD, need detailed forecasts of the wind and the sea state for various locations in the North Sea. Also for safety reasons detailed weather forecasts are indispensable in this area. To meet the requirements of the customer there is a clear need to extend the K13 guidance to other locations.

This paper describes an extension of the K13 guidance which will be referred to as the 'nautical guidance' in the remainder of the paper. It provides forecasts of wind direction, wind speed and maximum wind speed (at 10 m), significant wave height and significant wave period at four locations in the North Sea. These locations -- AUK, EURO, K13 and W4 -- are shown in Fig. 1. Forecasts are made for 12 and 00 UTC for day 1 until 5 (based on +36 until +144 atmospheric model output). An example is shown in Fig. 2. The guidance is issued once a day and is available to the MMD early in the morning. Unlike the K13 guidance the nautical guidance only uses ECMWF model output.

The data used are summarised in section 2. In addition, the reason for not using UKMO products is explained. In section 3 the final predictor selection is discussed. In section 4 verification results for the winter of 95/96 are given. Also, for the shorter forecast ranges a comparison is made with the HIgh Resolution Limited Area Model (HIRLAM) wind speed forecasts as well as with wave height forecasts produced by the Dutch limited area wave model (NEDWAM). Finally, a few concluding remarks and plans for the future are presented in section 5.

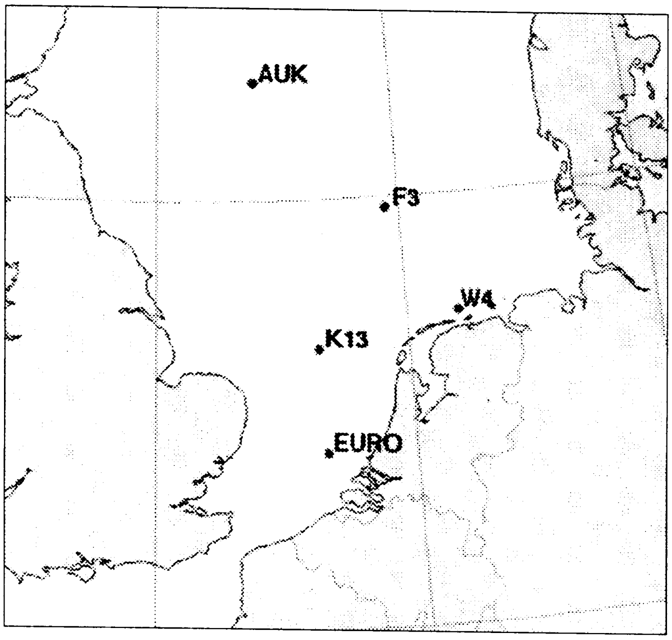

Fig. 1. Nautical guidance locations as well as oil platform F3.

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GUIDANCE POSITION AUK  E/F BLOCKS

ISSUED (YYMMDDHH):97070103

DDHH               :  0212  0300  0312  0400  0412  0500  0512  0600  0612
WIND DIRECTION     :    SE    SE     S     S    SW     W     W    NW    NW
SPEED (KTS)        :    15    13    11     7     9     9    11    13    15
MAX SPEED (KTS)    :    18    17    14     8    11    11    14    17    19
WAVE HEIGHT(0.1M)  :    17    20    19    16    14    15    14    16    18
PERIOD (S)         :     7     7     7     7     7     7     7     7     7


GUIDANCE POSITION EURO  P BLOCKS

ISSUED (YYMMDDHH):97070103

DDHH               :  0212  0300  0312  0400  0412  0500  0512  0600  0612
WIND DIRECTION     :     S    SW    SW     S     S     E     N     W    NW
SPEED (KTS)        :    13    11    12    11     9     9    11    12    14
MAX SPEED (KTS)    :    16    14    14    14    11    11    13    14    17
WAVE HEIGHT(0.1M)  :     9    10     9     7     7     7     6     7     9
PERIOD (S)         :     4     5     5     4     4     4     5     5     5


GUIDANCE POSITION K13   K BLOCKS

ISSUED (YYMMDDHH):97070103

DDHH               :  0212  0300  0312  0400  0412  0500  0512  0600  0612
WIND DIRECTION     :     S     S     S     S     S    SE    NW     W    NW
SPEED (KTS)        :    12     9    12    11     9     9    10    14    14
MAX SPEED (KTS)    :    15    12    14    14    11    12    12    17    18
WAVE HEIGHT(0.1M)  :    11     9     8    10     9     9     8     8     9
PERIOD (S)         :     5     5     5     5     5     6     5     6     6


GUIDANCE POSITION W4    M BLOCKS

ISSUED (YYMMDDHH):97070103

DDHH               :  0212  0300  0312  0400  0412  0500  0512  0600  0612
WIND DIRECTION     :     S    SE     W     W     W    NW    NW    NW    NW
SPEED (KTS)        :    12    14     8    10     7    11    11    14    14
MAX SPEED (KTS)    :    15    18    10    13     9    14    14    17    18
WAVE HEIGHT(0.1M)  :     5     5     7     7     4     8     6     8     9
PERIOD (S)         :     5     5     5     6     6     6     6     6     6
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Fig. 2. Example of the nautical guidance issued 1 July 1997.

2. Model derivation

2.1. Data

The nautical guidance is based on the Model Output Statistics (MOS) approach. The equations of the statistical model have been derived with a multiple linear regression method. For details about MOS the reader is referred to Lemcke and Kruizinga (1988) and Kok et al. (1997). MOS equations have been developed for wind speed, significant wave height and wave period. No use has been made of MOS for wind direction and maximum.

The observations for EURO and K13, necessary to develop and verify the model, have been extracted from the database of the climatological department of KNMI. For AUK as well as W4 the data originate from the KNMI Moerav database. At the position W4 only wave data are available. Therefore the wind observations of Huibertsgat (15 km east of W4) have been used. Because the 10 m wind data are inhomogenous a few corrections were necessary; the correction factors used are given in Table 1 (see also Benschop, 1996).

Two sets of model data have been used: ECMWF data on a 1.5° x 1.5° grid and UKMO data (only used for the experiment described in section 2.2) on a grid of 1.25° x 1.25°. The ECMWF and UKMO data for a certain location result from linear interpolation of the four nearest grid points. The data set used for developing the statistical model covers the 'winter months' (October-March) between October 1992 and November 1995 (EURO, K13) or between October 1993 and November 1994 (AUK, W4). For the wind speed only cases with observations above 5 knots have been used. By only using the winter months and applying a threshold of 5 knots less weight is put on the prediction of quiet weather situations.

station	before 1/1/94	1/1/94 -31/3/95
AUK	1,07	1,07
EURO	0,89	1,03
K13	0,81	1,04
W4	1,00	1,00

Table 1. Correction factors for the wind observations

2.2. Justification for using ECMWF predictors only

In developing the K13 guidance, UKMO as well as ECMWF data were used. Only predictors were considered with valid times the same as that of the predictand. It turned out that the best results could be obtained by combining predictors from both models (personal communication, S. Kruizinga). However, a disadvantage of an operational guidance depending on the availability of model output from two different weather centres is the vulnerability to errors in the data flow. Therefore an experiment has been performed to compare a statistical model based on ECMWF predictors only with a statistical model based on predictors from both ECMWF and UKMO. In the model based entirely on ECMWF, not only wind speeds from a particular forecast time have been used as a predictor but also the wind speeds of the previous and following forecast time (12 hours earlier and later, respectively). In the remainder of the paper these will be referred to as 'lagged' wind speeds. It turned out that for all forecast times the results were the same or slightly better (not shown) by using time-lagged wind speeds instead of UKMO predictors from one forecast time only. For example, for the +48 forecast the UKMO predictors could be replaced by the ECMWF 10 meter wind forecast for +60 without loss of skill. These results suggest that phase and/or amplitude errors in the atmospheric model can be partly corrected for by using weighted averages of wind speeds over different forecast times.

We believe that the results of this experiment justify the use of only ECMWF predictors in developing the statistical relations for all predictands of the nautical guidance.

2.3. Potential predictors

The relevance of a large number of potential predictors, derived from the ECMWF model, has been examined. Observations have not been considered as predictors, because the inclusion of observations is not very beneficial for larger lead times.

The predictors included in the statistical analysis are:

- wind speed at 1000, 850 and 500 hPa.
- wind speed at 10 meter (ff10) as well as time-lagged 10 m wind speeds (ff10p for previous forecast time, 12 hours before and ff10n for next forecast time, 12 hours after). In addition, zonal and meridional 10 m wind components (u and v) for the same lead times.
- vorticity and temperature at 1000, 850 and 500 hPa.
- the sine and cosine of the wind direction at 10m.
- cross terms to incorporate explicitly the varying effect of the wind speed with wind direction: the wind speed at 10 m times the (co)sine of the wind direction, and the wind speed times the u/v component of the 10 m wind. These terms are introduced at 10 m only.
- parameters expressing atmospheric stability, such as the

difference between the temperatures at 1000 and 850 hPa, and between 850 and 500 hPa.
- large scale predictors derived from the circulation pattern at 500 hPa: so-called scores, representing the degree of zonality, meridionality and cyclonicity of the flow over western Europe (sc1, sc2 and sc3) as used for the P27-classification (Kruizinga, 1979). The scores are available for 00 UTC only. For 12 UTC the scores of 12 hours earlier as well as 12 hours later are used.

For significant wave height additional potential predictors are:
- wind speed squared (ff^2), because of the theoretical non-linear relation between wind speed and wind sea (Groen and Dorrestein, 1976).
- the guidance wind speed as computed with MOS (ffmos) as well as the MOS wind speed for previous times (-12 or -24 hr) .

ECMWF Wave Model (WAM) data have not been considered because its grid was too coarse to use in the North Sea (the WAM resolution has been changed in December 1996).

Finally, for significant wave period also:
- wave height computed with MOS (hsmos), and hsmos for previous times (-12 or -24 hr).

3. Statistical model

In this section the final predictor selection is discussed. The choice has been determined on the basis of statistical criteria (significance and stability of the predictors) as well as physical considerations. In addition, consistency in space and time has been taken into account. Spatial consistency means that for a particular synoptical situation the correlation of the forecasts between different locations is realistic. Temporal consistency is desirable because consecutive forecast times should form a consistent time series representing the atmospheric development. An elaborate discussion of these topics is given by van Vliet and Kok (1995) and Glahn et al. (1991).

3.1. Wind speed

A list of all selected predictors is given in Table A1. The 10 m model wind is always selected. For larger forecast times the lagged 10 m winds, ff10p and ff10n, become more important. By introducing lagged winds some smoothing may occur, but errors due to phase errors of the atmospheric model can be reduced.

With larger forecast times large scale predictors, such as the P27 scores, become more important. For the +72 and onwards P27 scores are included in almost all cases. Most frequently selected are sc1 and sc3. These scores are included in such a way that westerly flow and cyclonicity contribute positively.

3.2. Wind direction and maximum wind speed

The maximum wind speed in the nautical guidance is defined as the maximum of the 10 minute mean wind speed measured once every hour in the 12 hour period prior to the valid time. No statistical equations for wind direction and maximum wind speed have been developed. For wind direction simply Direct Model Output (DMO) is used. The maximum wind speed is taken to be 125% of the guidance forecast of the 10 m wind. This percentage is derived from the forecasting practice.

3.3. Significant wave height

The selected predictors for the significant wave height are presented in Table A2. From theoretical principles it follows that for a sea in equilibrium wave height is proportional to the square of the wind speed (Groen and Dorrestein, 1976). The wind speeds selected are therefore always squared. They are not only obtained from the particular forecast time but often also the lagged wind speeds for 12 or 24 hours earlier are used. By doing this a poor man's approximation of swell can be obtained. Also the u and v components of the 10 m wind play a role indicating that the wave height is dependent on wind direction. This can be explained by differences in fetch and water depth.

P27 scores are also frequently selected. For AUK and K13 the cyclonicity of the flow (sc3) appears to be the dominant large scale predictor, whereas for EURO and W4 the 'meridional score' sc2 is the most important one.

3.4. Significant wave period

The selected predictors for the wave period forecasts are shown in Table A3. The wave height guidance forecast is always used as a predictor, and again values from different forecast times are included (the forecast time of interest and 12 or 24 hours earlier). For the wave period a direction dependency exists which is related to differences in fetch and water depth as mentioned for wave height in the previous section. As seen before, P27 scores become more important at larger forecast times.

● ● ● ● 6 Statistical model

4. Verification

The data set used for verification is an independent set of observations, covering the period from December 1995 through March 1996. The number of cases (N) is about 120. Wind speed at 10 m, significant wave height and period are verified. The bias and standard deviation of the error of these forecasts are shown.

4.1. Wind speed

An overview of the verification results for wind speed for MOS as well as ECMWF is presented in Fig. 3. With respect to the bias MOS and ECMWF give similar values for AUK and K13. For AUK MOS gives a small underestimation and for K13 a small overestimation. For EURO and W4 MOS gives in general an overestimation but in all cases less than 2 knots. It proves significantly better than DMO, which underestimates the wind speed between 2 and 4 knots. The standard deviation (of the error) is similar for both models. Only for the largest forecast times MOS performs generally better. Note that especially for W4 the standard deviation is clearly higher for the forecast times verifying at 00 UTC (i.e. +36, +60, +84, +108 and +132) than for the intermediate forecast times. This might be related to the fact that for 00 UTC the standard deviation of the observations is 8.4, whereas for 12 UTC it is 7.1 kts.

In Fig. 4 verification results are shown for observed wind speed ≥ 22 knots (≥ 6 Beaufort). There are only 20-30 cases, so the results can only be seen as a first indication. The bias is always negative and larger compared to the whole set of wind speeds, which is inherent in forecasting extremes. The standard deviation for most stations and forecast times is slightly better in the statistical model than in the ECMWF model.

The improvements accomplished by using MOS instead of DMO are most significant for EURO and W4. For the stations AUK and K13, which are less influenced by coastal effects, the improvement is less clear.

In the *APL in progress* report (Koek, 1996) a verification for HIRLAM is shown for the winter period of 1996 (December, January and February). The +24 and +36 hr HIRLAM forecasts can be compared with the +36 and +48 hr of the statistical model, because they are available to the forecaster at about the same time. For both EURO and K13 (the stations mentioned in the APL report), no clear differences are found between HIRLAM and the statistical model in terms of bias and standard deviation.

4.2. Significant wave height

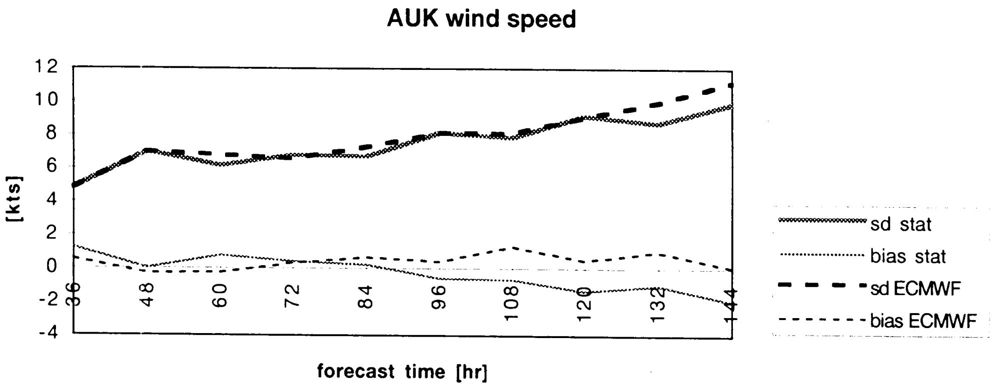
The results for significant wave height of the statistical model are shown in Fig. 5. Wave heights at EURO and W4 tend to be slightly overestimated. For the larger forecast times an underestimation can be seen for AUK and W4. At K13 the bias is about zero. For EURO the standard deviation increases slightly with larger forecast times, whereas for the other stations a bit more differentiation can be seen between the standard deviations of the consecutive forecast times. The highest standard deviations are found for AUK. This is probably related to the fact that at this location the waves are relatively high and swell can be quite significant (whereas the nautical guidance is not particularly suitable for swell forecasts, see section 4.3.).

For the +36 and +48 the MOS results for EURO and K13 can be compared with the +24 and +36 results of NEDWAM obtained from *APL in progress* (Koek, 1996). In case of K13 the bias is less overestimated in the statistical model than in NEDWAM. For EURO the opposite is true. The standard deviation is more or less the same in both models.

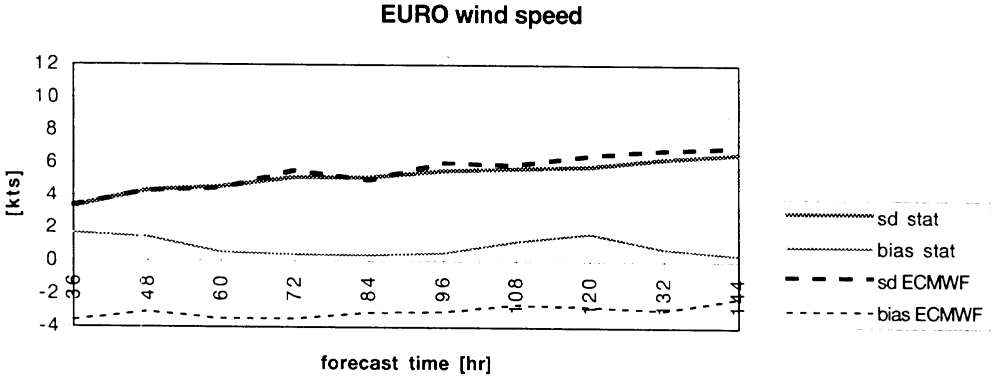
The bias and standard deviation for cases with (observed) wave height above 2.5 m are depicted in Fig. 6. There are between 5 and 50 cases that meet the criterion, depending on the location of the station. As was to be expected, the waves > 2.5 m are systematically underestimated. This underestimation increases with forecast time. The standard deviation for these higher waves is not distinctly different from the standard deviation for the whole set of wave heights. Swell is indirectly incorporated by using wind speeds of previous forecast times. Especially for AUK, where swell can be high, it may be necessary to model swell and wind sea separately.

4.3. Significant wave period

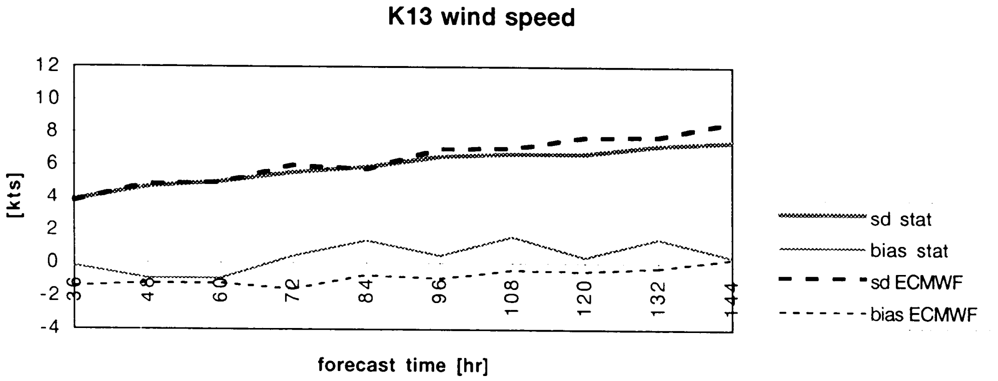
Fig. 7 presents the verification results for the wave period. The bias is small for all stations. Usually standard deviation increases with larger lead times, but for all stations we looked at, the standard deviation was not changing significantly with forecast time. It turns out that the standard deviation of the errors of the MOS forecasts are only slightly less than those of the observations (not shown). Apparently, predicting wave period in the way we have done does not produce satisfactory results and therefore a different approach should be considered. Making a distinction between wind sea and swell, as mentioned for wave height, could prove to give better results.



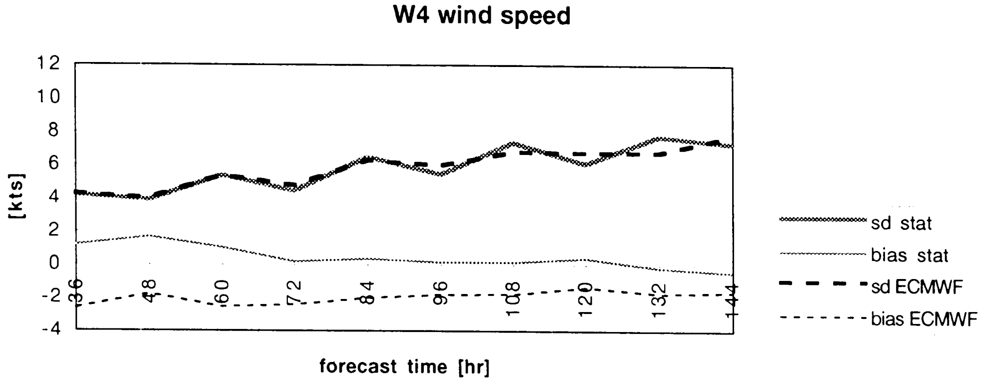
AUK wind speed



EURO wind speed



K13 wind speed



W4 wind speed

Fig. 3 Bias and standard deviation of the wind speed for both the statistical model and ECMWF.

Period:
December 1995 - March 1996.
Number of cases (N) = 100-200.

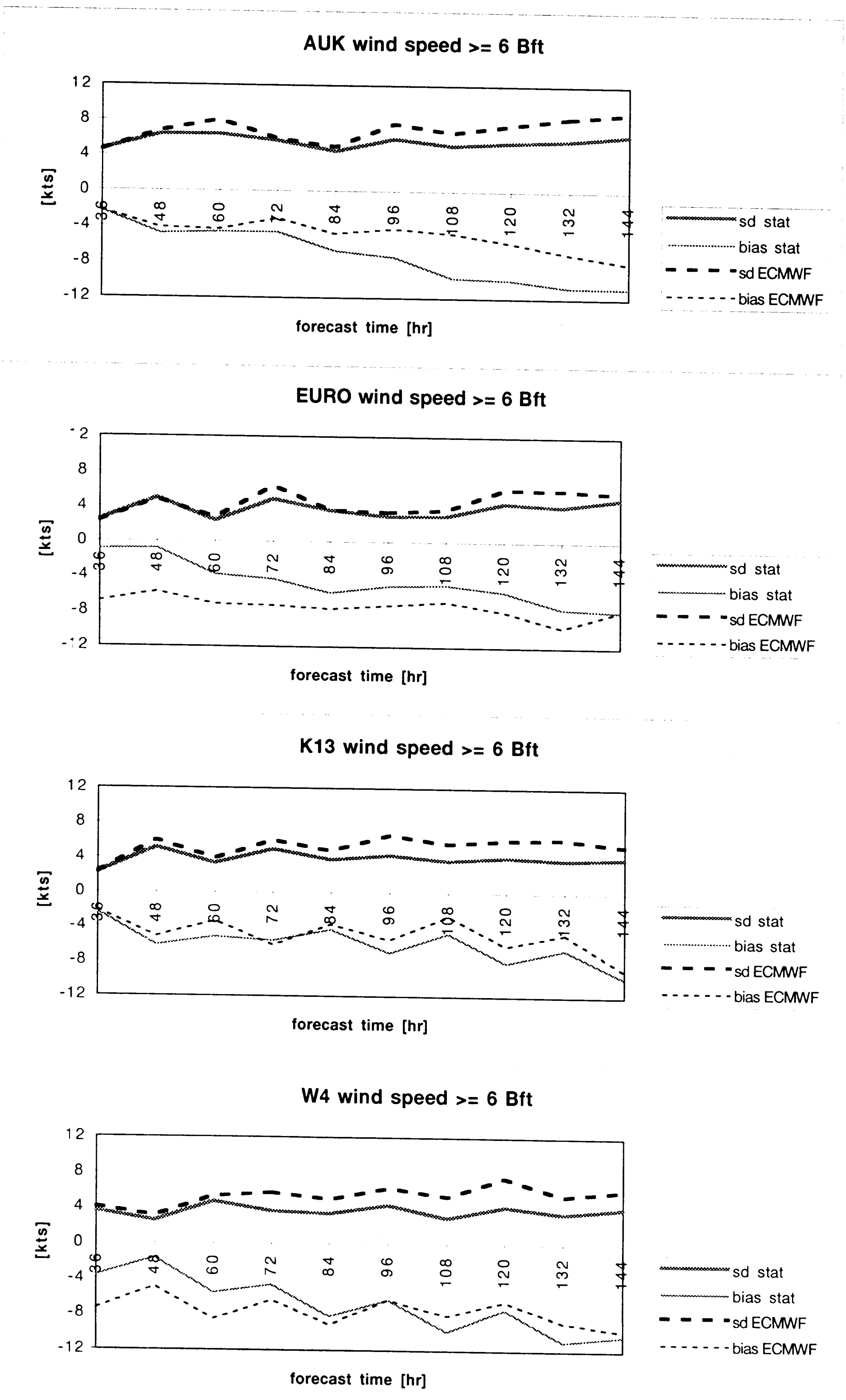


Fig. 4. Bias and standard deviation for cases with observed wind speed of 6 Beaufort and higher, for both the statistical model and ECMWF.

Period:
December 1995 - March 1996.
N = 20-30.

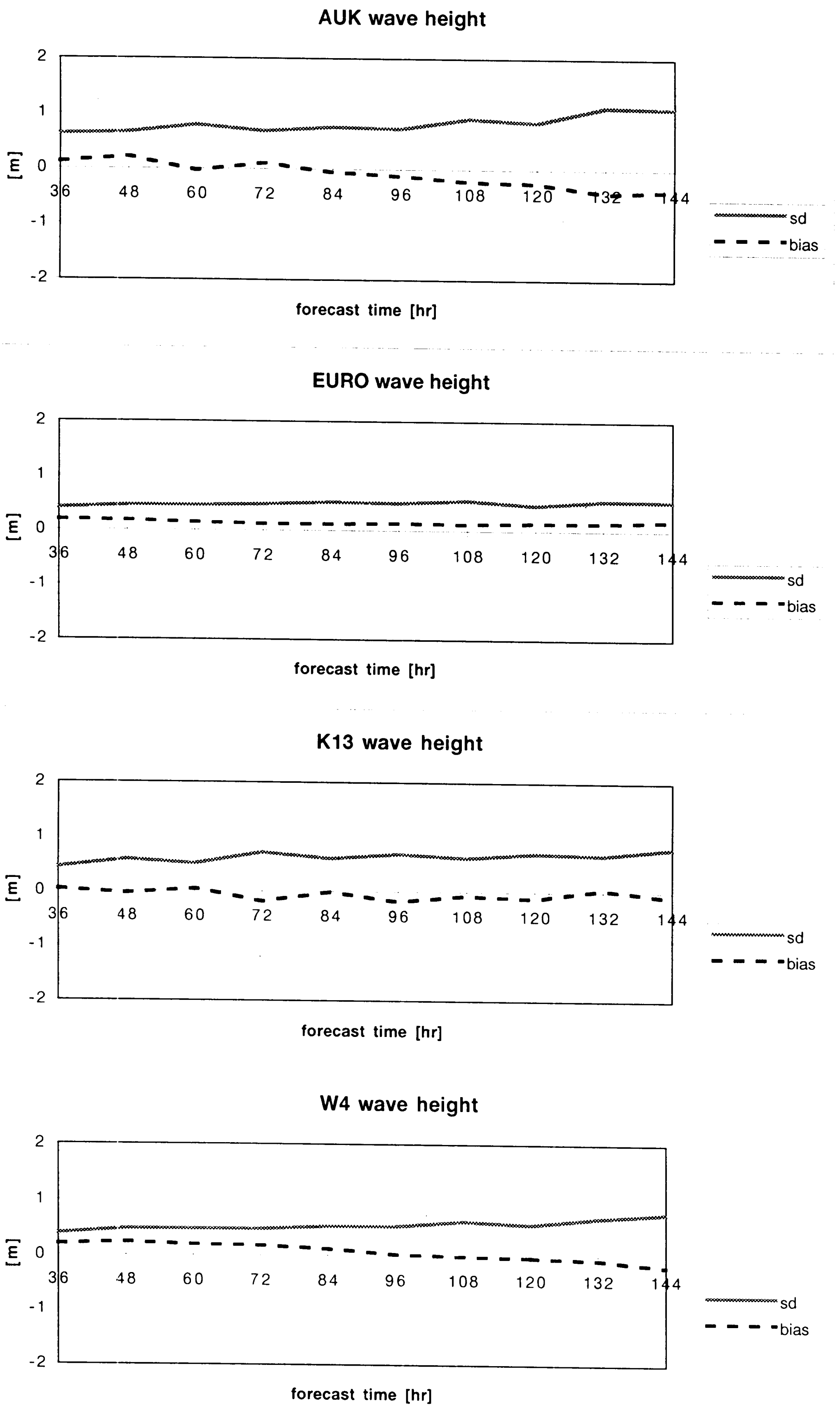


Fig. 5. Bias and standard deviation of the wave height for the statistical model.

Period:
December 1995 - March 1996.
N=100-120.

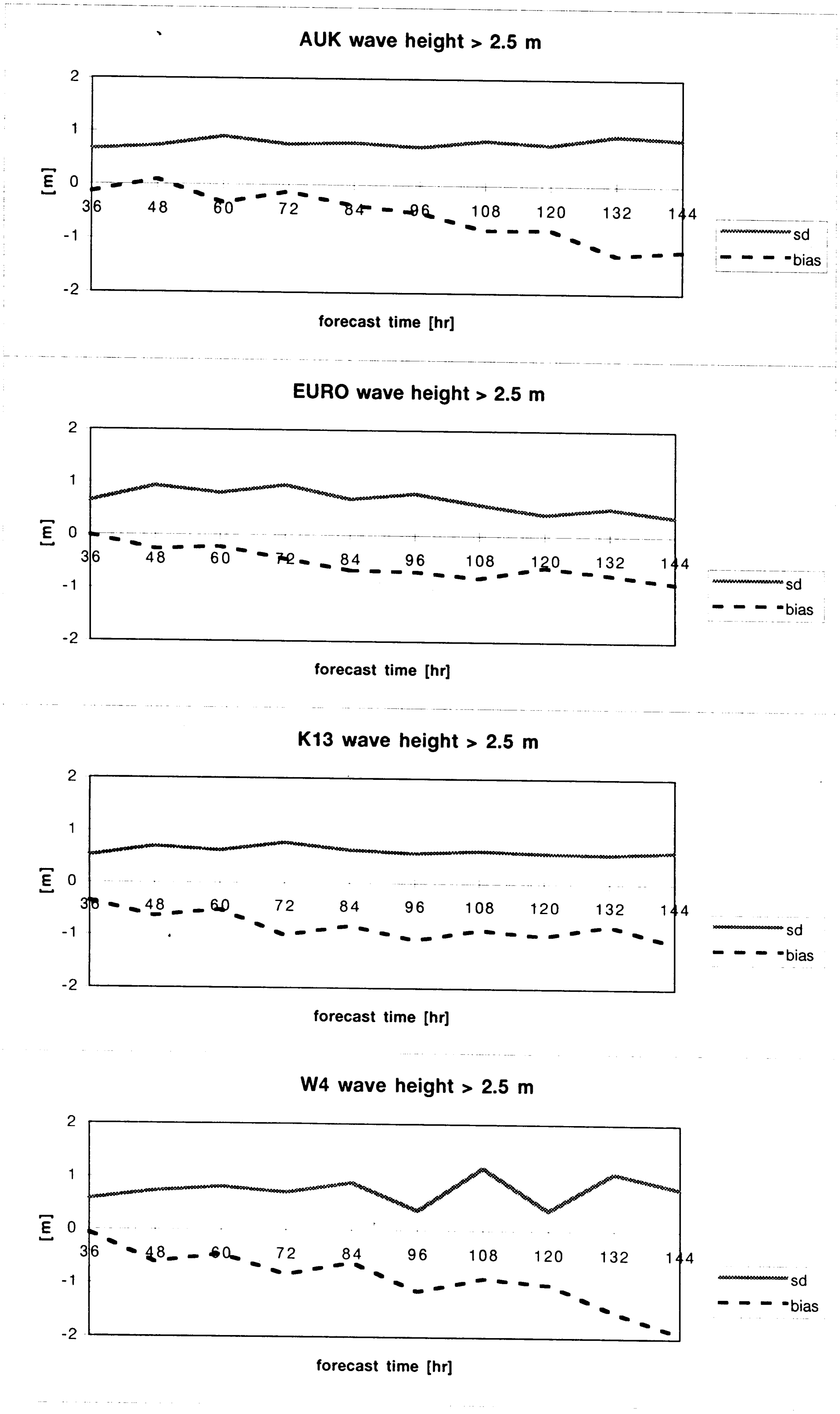


Fig. 6. Bias and standard deviation of the wave height above 2.5m for the statistical model.

Period:
December 1995 - March 1996.
N=50 (AUK), N=8 (EURO),
N=22 (K13), N= 5(W4).

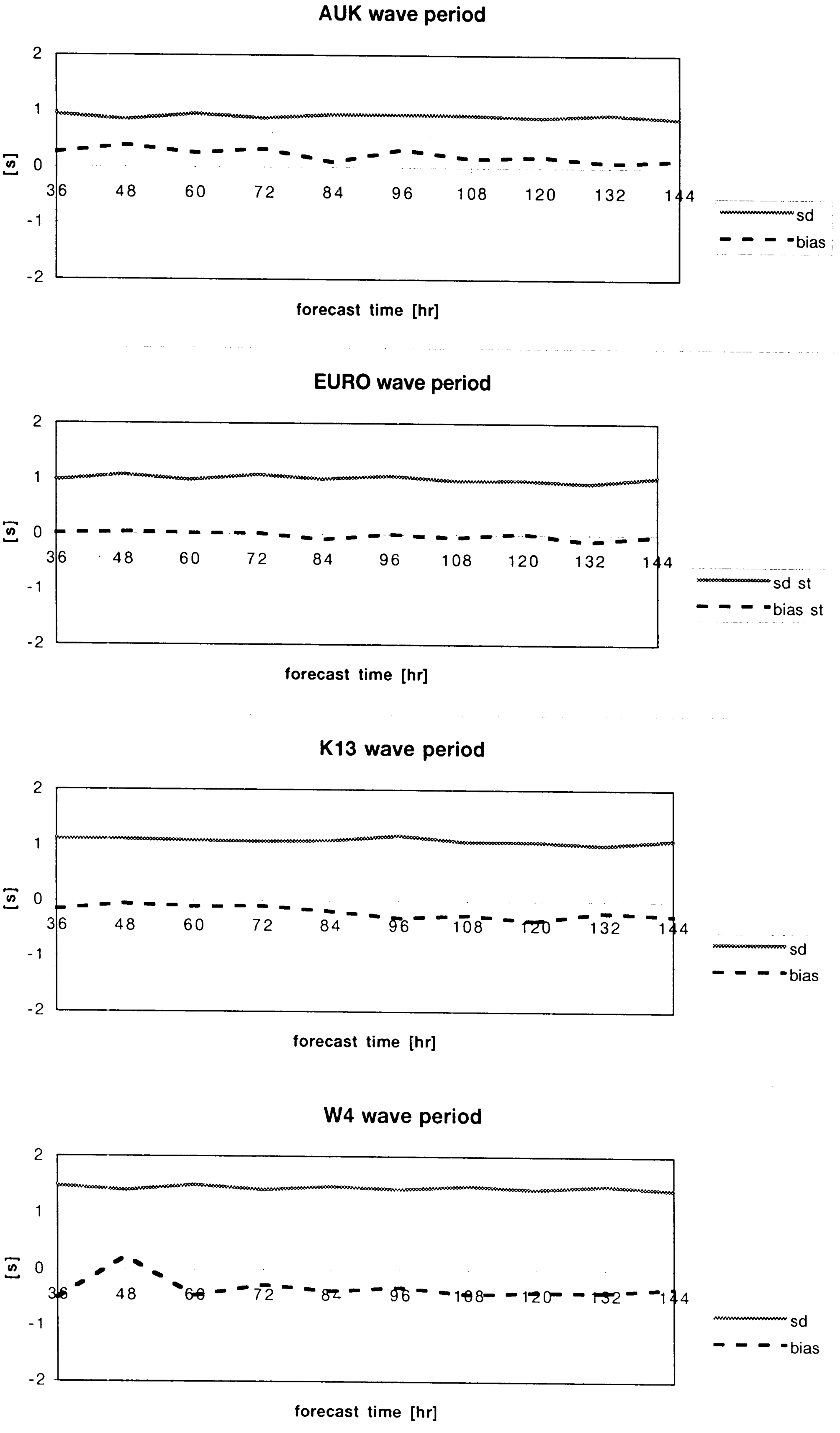


Fig. 7. Bias and standard deviation of the wave period for the statistical model.

Period:
December 1995 - March 1996.
N=100-200.

5. Concluding remarks

The nautical guidance presented in this report has been developed to give MMD forecasters an additional prediction tool for the one to five day forecasts for the North Sea. The performance of the MOS model compared to (ECMWF) DMO has been discussed in detail in section 4. For wind speed and wave height the MOS guidance generally improves the quality of the forecasts.
For the short term a comparison between wind forecasts from HIRLAM and the statistical guidance based on output of the ECMWF model run of 12 hours earlier showed more or less the same results. Therefore it is possible that a guidance based (also) on HIRLAM output can improve the results for the short term even further.

A similar argument holds for the wave height guidance. This is also based on statistical interpretation of output of the atmospheric model only. No information from a physical wave model (e.g. WAM) is used as yet. It might be conceivable therefore, that after sufficiently increasing its resolution, WAM could have a positive impact.

The results for wave period are disappointing. Presumably, an approach different from the one pursued here is needed. By using the wave spectrum of observations it is possible to make a distinction between wind sea and swell with respect to height and period and thus to model wind sea and swell separately.

In the near future the nautical guidance will be extended with a forecast for location F3 (Fig. 1). However, no wave data are available here so the MOS technique is not directly applicable; a different approach will be needed for forecasting significant wave height and period. For example, observations from nearby stations can be used to derive forecast equations for F3. Finally, a probability (MOS) forecast for extreme weather events would be a useful addition to the nautical guidance.

Acknowledgements

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Appendices

	+36	+48	+60	+72	+84	+96	+108	+120	+132	+144
AUK	ff10 ff10n	ff10 ff10n	ff10 ff10p ff10n	ff10 ff10p ff10n	ff10 ff10p ff10n sc1[84]	ff10 ff10p sc1[84]	ff10 ff10p ff10n sc1[108] sc3[108]	ff10p ff10n sc1[108] sc3[108]	ff10p ff10n sc1[132] sc3[132]	ff10 sc1[132] sc3[132]
EURO	ff10	ff10	ff10 sc1[60]	ff10 ff10p ff10n sc1[84]	ff10 ff10p sc1[84]	ff10 ff10p ff10n sc1[108]	ff10 ff10p ff10n sc1[108]	ff10 ff10p ff10n v10	ff10 ff10p sc1[132]	ff10p ff10n sc1[132]
K13	ff10 ff10n sc1[36]	ff10 ff10n sc1[36]	ff10 ff10n sc1[60]	ff10 ff10n sc1[60]	ff10 ff10n sc1[84]	ff10 ff10p sc1[84]	ff10 ff10p sc1[108]	ff10 ff10p sc1[108]	ff10 ff10p sc1[132]	ff10p ff10n sc1[132]
W4	ff10 vo1000	ff10 ff10n	ff10 ff10n	ff10 ff10p ff10n sc1[60]	ff10 sc1[84] sc3[84]	ff10 ff10p ff10n sc1[84]	ff10 sc1[108]	ff10 ff10p sc1[132]	ff10 ff10p sc1[132]	ff10p sc1[132]

Table A1. Selected predictors for the wind speed in AUK, EURO, K13 and W4, for forecast times 36, 48.....144.
ff10: 10 m wind speed. suffixes p and n: 12 hours before and after the verifying forecast time. vo1000: vorticity at 1000 hPa.
sc.[forecast time]: scores of indicated forecast time, 1=zonal 2=meridional, 3=(anti)cyclonic.
For more detailed information the reader is referred to section 2.3.

	+36	+48	+60	+72	+84	+96	+108	+120	+132	+144
AUK	ff^{2}10 ff^{2}10p u10 v10	ff^{2}10 ff^{2}10p u10 v10	ff^{2}mos ff^{2}10p u10 v10 sc3[60]	ff^{2}mos ff^{2}mos[48] u10 v10 sc3[60]	ff^{2}mos ff^{2}mos[60] u10 v10 sc3[84]	ff^{2}mos ff^{2}mos[72] v10 sc3[84]	ff^{2}mos ff^{2}mos[84] sc3[108]	ff^{2}mos ff^{2}mos[96] sc3[108]	ff^{2}mos ff^{2}mos[108] sc3[132]	ff^{2}mos ff^{2}mos[120] sc3[132]
EURO	ff^{2}10p ff^{2}mos v10 u10p	ff^{2}10p ff^{2}mos v10 u10p	ff^{2}mos v10 ff^{2}mos[36] u10p	ff^{2}mos v10 ff^{2}mos[48] u10p	ff^{2}mos v10 ff^{2}mos[60]	ff^{2}mos v10 ff^{2}mos[72]	ff^{2}mos v10 ff^{2}mos[84]	ff^{2}mos v10 ff^{2}mos[96] sc2[108]	ff^{2}mos v10 ff^{2}mos[108] sc2[132]	ff^{2}mos ff^{2}mos[120] sc2[132] sc3[132]
K13	ff^{2}10 ff^{2}10p v10	ff^{2}10 ff^{2}10p v10	ff^{2}10 ff^{2}10p v10	ff^{2}mos ff^{2}10p v10	ff^{2}mos ff^{2}10p v10 sc3[84]	ff^{2}mos ff^{2}10p v10 sc3[84]	ff^{2}mos ff^{2}10p v10 sc3[108]	ff^{2}mos ff^{2}10p v10 sc1[108]	ff^{2}mos ff^{2}mos[108] sc3[132] sc2[132] u10p	ff^{2}mos ff^{2}mos[120] sc3[132] sc2[132] u10p
W4	ff^{2}10p ff^{2}mos v10 sc2[36]	ff^{2}10p ff^{2}mos v10 sc2[36]	ff^{2}10p ff^{2}mos v10 sc2[60]	ff^{2}mos[48] ff^{2}mos v10 sc2[60]	ff^{2}mos[60] ff^{2}mos v10 sc2[84]	ff^{2}mos[72] ff^{2}mos v10 sc2[84]	ff^{2}mos[84] ff^{2}mos v10 sc2[108]	ff^{2}mos[96] ff^{2}mos v10 sc2[108]	ff^{2}mos[108] ff^{2}mos sc2[132]	ff^{2}mos sc2[132]

Table A2. Selected predictors for the significant wave height in AUK, EURO, K13 and W4, for the forecast periods 36, 48.....144.
ffmos: 10 m wind computed with MOS. ffmos[forecast time]: 10 m wind (MOS) for the indicated forecast time. ff^2..: square of stated 10 m wind.
u10 en v10: u en v components of 10 m wind. For explanation of the other terms: see table A1.

	+36	+48	+60	+72	+84	+96	+108	+120	+132	+144
AUK	hsmos ffmos v10p	hsmos hsmos[36] ffmos v10p	hsmos hsmos[36] ffmos v10p	hsmos[48] sc2[60] sc3[60]	hsmos[60] sc2[84] sc3[84]	hsmos[72] sc2[84] sc3[108]	hsmos[84] sc2[108] sc3[108]	hsmos[96] sc2[108] sc3[108]	hsmos[108] sc2[132] sc3[132]	hsmos[120] sc2[132] sc3[132]
EURO	hsmos v10p $v^2$10p	hsmos v10p $v^2$10p hsmos[36]	hsmos v10p $v^2$10p hsmos[36]	hsmos v10p $v^2$10p	hsmos v10p $v^2$10p	hsmos v10p $v^2$10p	hsmos v10p $v^2$10p sc3[108]	hsmos v10p sc3[132]	hsmos sc2[132]	hsmos sc2[132]
K13	hsmos v10p $v^2$10p	hsmos v10p $v^2$10p	hsmos v10p hsmos[36]	hsmos v10p hsmos[48]	hsmos v10p hsmos[60]	hsmos v10p hsmos[72]	hsmos[84] sc2[108] sc3[108]	hsmos[96] sc2[108] sc3[132]	hsmos[108] sc2[132] sc3[132]	hsmos[120] sc2[132] sc3[132]
W4	hsmos v10p u10p	hsmos v10p u10p	hsmos[36] v10p u10p	hsmos[48] v10p u10p	hsmos[60] v10p u10p	hsmos[72] v10p u10p	hsmos[84] v10p u10p	hsmos[96] v10p u10p	hsmos[108] v10p u10p	hsmos[120] v10p u10p

Table A3. Selected predictors for the significant wave period in AUK, EURO, K13 and W4, for the forecast times 36, 48.....144.
hsmos: wave height computed with MOS. hsmos[forecast time]: hsmos for the indicated forecast time. $v^2$10p: square of v10p.
For explanation of other terms see table A1 and A2.