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METEOROLOGY

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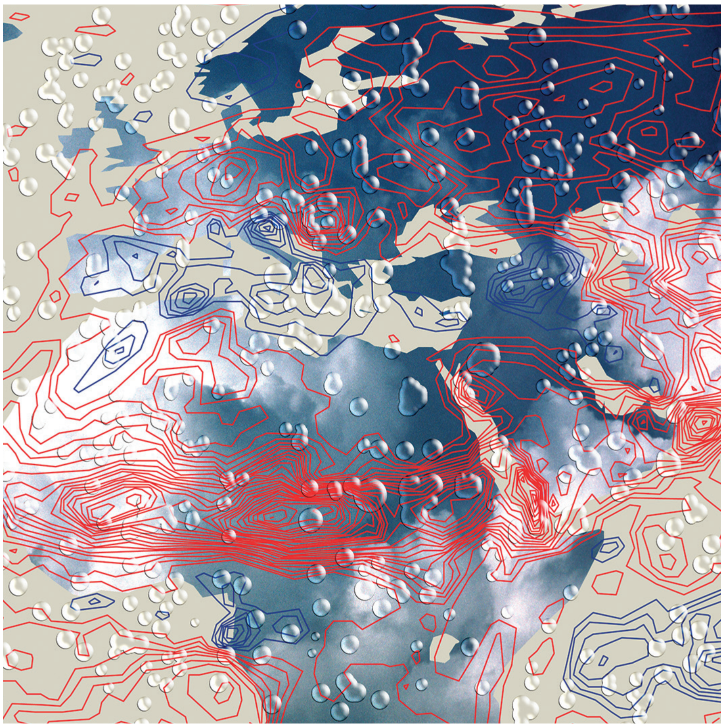

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Hindcasts of historic storms with the DWD models GME, LMQ and LMK using ERA-40 reanalyses

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Understanding the circumstances in which coastal floods occur is very important as preparations can then be made to reduce the impact of these events. The main forcing for the coastal floods is the surface wind.

To analyze historic floods NLWKN (Forschungsstelle Küste des Niedersächsischen Landesbetriebs für Wasserwirtschaft, Küsten- und Naturschutz, www.nlwkn.de), the Coastal Research Station of Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency, contracted Deutscher Wetterdienst (German Weather Service, DWD) to provide high-resolution winds for the Ems river estuary in northwestern Germany. NLWKN chose 22 storms from the famous Hamburg Storm in February 1962 to a storm in October 2002. Most of these storms occurred in winter, and only one in summer (19 August 1990). Table 1 lists the dates chosen for the hindcasts and the strongest winds observed at the east Friesian island Norderney off the coast of Lower Saxony.

To perform these hindcasts it was necessary to have a modelling capability with adequate resolution. This was provided by the three linked models GME, LMQ and LMK of DWD. In addition access was required to high-quality analyses from the last forty years. The ERA-40 reanalyses prepared at ECMWF were used for this purpose.

The results show that the combination of the three DWD models starting from the ERA-40 reanalyses provide information of the kind required by NLWKN.

Models and set-up

DWD produced wind fields during these storms using its model chain GME, LMQ and LMK starting from ERA-40 reanalysis data. LMQ and LMK are versions of the Lokal-Modell (LM). Details about these models are given in Box A and there is a short summary of their characteristics in Table 2.

A series of 18 hour forecasts starting from 00 and 12 UTC analysis data was used to obtain high-resolution hourly wind fields along the German North Sea coast with a grid spacing as small as 2.8 km. To allow for an adaptation of the models to the initial fields only forecasts from 6 to 18 hours are provided to NLWKN. The 6 and 18 hour forecasts for the same verification time are averaged.

The ERA-40 reanalyses were produced with ECMWF's Integrated Forecasting System (IFS) using a spherical harmonics representation TL159 and a reduced Gaussian grid corresponding approximately to a mesh size of 125 km (*Uppala et al.,* 2005). Strong cyclones cannot be well resolved with such a resolution. Therefore, it is scaled down in three steps: first, to the GME model with 40 km resolution, then to LMQ with 7 km mesh size, and finally to LMK with 2.8 km mesh size.

The nesting of LMK in LMQ and of LMQ in GME is shown in Figure 1. For this plot the GME orography was interpolated to the LMQ rotated geographical grid using the nearest neighbour as interpolation method. NLWKN is interested in wind fields in an area around the Ems river estuary at the North Sea coast along the Dutch-German border. The LMK domain cuts through the North Sea and crosses the Alps. It is not optimal for this application. However, the simulations served also as test bed for LMK which was put in daily pre-operational suite in summer 2006.

As there is no data assimilation for the models we allow 6 hours of adaptation to the interpolated initial conditions before the forecasts are used. During these hours the deepening of the central pressure in cyclones of the high- resolution model compared to that for the lower-resolution driving model can take place.

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Start and end dates of the run	Maximum wind (ms^{-1})	Time of maximum wind
15 February to 18 February 1962	–	No data
22 February to 24 February 1967	26.7	18 UTC on 23 February 1967
2 January to 4 January 1976	33.4	06 UTC on 3 January 1976
19 January to 22 January 1976	25.7	00 UTC on 21 January 1976
29 December to 31 December 1977	23.1	19 UTC on 30 December 1977
22 November to 26 November	23.6	07 UTC on 24 November 1981
3 December to 5 December 1988	14.9	05 UTC on 5 December 1988
12 February to 15 February 1989	22.6	07 UTC on 14 February 1989
24 January to 27 January 1990	20.5	00 UTC on 26 January 1990
19 August to 21 August 1990	23.1	04 UTC on 21 August 1990
18 December to 21 December 1991	14.9	10 UTC on 18 December 1991
21 January to 23 January 1993	17.5	00 UTC on 23 January 1993
8 December to 10 December 1993	19.0	19 UTC on 9 December 1993
18 December to 20 December 1993	20.1	22 UTC on 19 December 1993
25 January to 29 January 1994	24.2	07 UTC on 28 January 1994
12 March to 14 March 1994	21.1	20 UTC on 13 March 1994
31 December to 2 January 1994	19.5	11 UTC on 1 January 1995
7 January to 11 January 1995	25.2	04 UTC on 10 January 1995
29 October to 30 October 1996	22.1	11 UTC on 29 October 1996
3 February to 6 February 1999	23.0	06 UTC on 5 February 1999
2 December to 5 December 1999	25.0	18 UTC on 3 December 1999
25 October to 29 October 2002	26.0	20 UTC on 27 October 2002

Tabel 1 List of the analysed storms and the maximum observed 10 m wind at the island Norderney.

Characteristic	GME	LMQ	LMK	ERA
Mesh size (km)	40	7	2.8	125
Domain (km^2)	Global	2324×2324	1176×1288	Global
Grid points	$10\times192^2+2$ $= 368642$	333×333 $= 110889$	421×461 $= 194081$	
Levels	40	40	50	60
Top height (km)	~31	23.6	22.0	~65
Top pressure (hPa)	10	~20	~39	0.1
Time step (s)	133.3	40.0	30.0	
Time stepping	LF	LF	RK	

Table 2 Characteristics of the models and domains (LF = Leap Frog, RK = Runge-Kutta).

Global model GME

A

The global model GME is a hydrostatic weather prediction model (*Majewski et al.,* 2002). It operates on the icosahedral-hexagonal grid. The model has a mesh size of approximately 40 km and 40 layers up to 10 hPa.

For operational runs at DWD an intermittent data assimilation based on optimum interpolation is used to determine the initial state of the model. For these hindcasts the initial state was interpolated from the ECMWF ERA-40 reanalysis to the GME grid. A digital filter initialization over 1 hour with a cut-off period of 3 hours was performed prior to the forecast to reduce noise from the interpolation of the ERA-40 analysis.

LMQ and LMK versions of Lokal-Modell

The Lokal-Modell (*Steppeler et al.,* 2003) is a non-hydrostatic limited-area atmospheric prediction model operating on the meso-beta and meso-gamma scale. It uses a regular C-grid in rotated geographical coordinates. It is applied here in two different setups.

The first setup is called LMQ. In this case the mesh size is 7 km (0.0625°). A leap-frog scheme with a time step of 40 s is used for time integration. Deep and shallow convection are parametrized using a mass flux approach. The model domain consists of 333x333 grid points. The initial state for LMQ is interpolated from the GME initial state. LMQ is nested within GME with an hourly update of lateral boundary values.

Within LMQ the high-resolution version LMK is nested. Its mesh size is only 2.8 km (0.025°). Hence, it is assumed that deep convection can be explicitly resolved by the model. Only shallow convection is parametrized through moisture convergence in the planetary boundary layer. For time stepping a Runge-Kutta scheme of third order with time step 30 s is used. Initial values are interpolated from LMQ. Lateral boundary values, taken from LMQ, are updated hourly.

Both, LMQ and LMK have the same rotated geographical coordinates with the north pole at 40°N, 170°W.

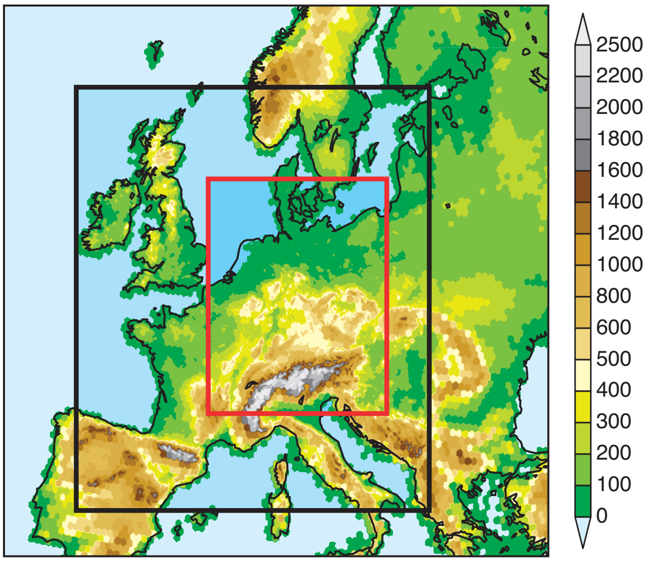


Figure 1 Model orography and nesting of LMQ in GME (black box) and LMK in LMQ (red box).

Results for some storms

We present results for three arbitrarily chosen storms. The storms selected are one from the 1970s, the only summer storm and the very strong storm in December 1999 (which is remembered by one of the authors for the broken trees and news about the destructions in Denmark).

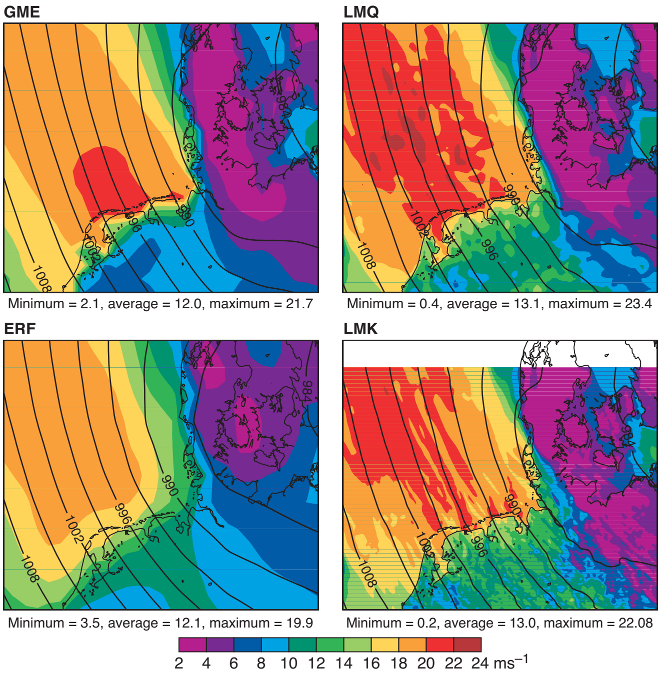
For the plotted maps the GME data was interpolated from the original hexagonal grid to the rotated coordinates of LM with a mesh width of 0.25°. The ERA-40 forecast data had been interpolated to a regular grid of 0.5° using ECMWF's MARS software. For the maps it was interpolated from this regular grid to the LM coordinates with a mesh width of 0.25°. As the reduced Gaussian grid has a coarser mesh width this interpolation should not reduce the winds significantly.

Storm on 30 December 1977

On 30 December 1977 a cyclone passed from the north Atlantic across southern Norway and Sweden to the Baltic Sea. In the lee of the Norwegian mountains a secondary low developed over Denmark. The strongest winds occurred west of this low over the North Sea - see Figure 2. The highest winds are predicted by LMQ. LMK shows more details such as the realistic streaks of high winds over the North Sea.

Time series for the island Helgoland in the German Bight are compared with observations in Figure 3. The breaks in the curves come from missing observations or from the jump from an 18 hour forecast of one run to the 6 hour forecast of the following run. The second pressure minimum at 18 UTC on 30 December 1977 is overestimated by GME, LMQ and LMK, and there is a phase shift of the maximum wind. However, the strength of the maximum wind of approximately 20 ms^{-1} is well predicted by all three models. The reanalysis cannot capture it. Wind direction is very similar for all models.

LMK is the only model to simulate strong fluctuations of the wind speed between 4 and 11 UTC on 30 December 1977 similar to the observations. This can be an indication that the wind streaks seen in Figure 2 are realistic.



GME: Minimum = 2.1, average = 12.0, maximum = 21.7

LMQ: Minimum = 0.4, average = 13.1, maximum = 23.4

ERF: Minimum = 3.5, average = 12.1, maximum = 19.9

LMK: Minimum = 0.2, average = 13.0, maximum = 22.08

Figure 2 Mean wind speed at 10 m in ms^{-1} at 21 UTC on 30 December 1977 simulated by GME, LMQ, LMK, and the ERA-40 forecast (ERF) initialised at 12 UTC on 30 December 1977. The mean sea level pressure in hPa is shown by isobars. The LMK domain does not cover the whole area shown in the maps.

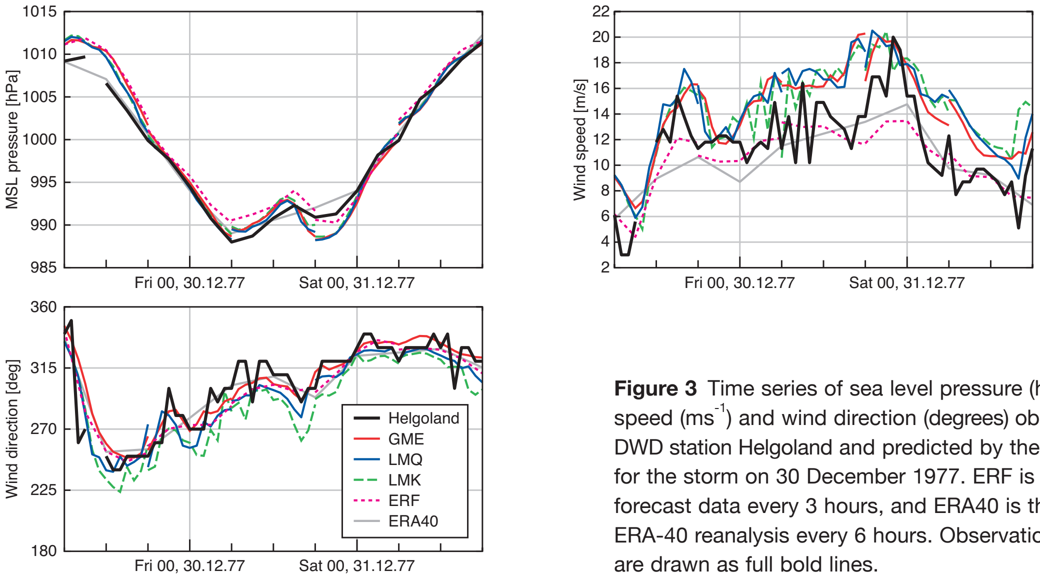


Figure 3 Time series of sea level pressure (hPa), wind speed (ms^{-1}) and wind direction (degrees) observed at DWD station Helgoland and predicted by the models for the storm on 30 December 1977. ERF is ERA-40 forecast data every 3 hours, and ERA40 is the ERA-40 reanalysis every 6 hours. Observations are drawn as full bold lines.

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Storm on 20 August 1990

The summer storm moved from Scotland to Denmark. For almost one day it stayed over the North Sea hardly advancing. During this period the wind direction was westerly at Norderney while the wind speed increased from 10 ms^{-1} to 20 ms^{-1} as shown in Figure 4. There was a band of strong winds along the cold front. However, the strongest winds followed in the cold sector. Observations at Helgoland and on the east Friesian island Norderney directly off the coast of Lower Saxony showed a very pronounced jump in wind direction from south to west in the morning of 20 August 1990. LMQ and LMK show this jump very well though one to two hours too late. Wind speed increased almost continuously behind the front until the following night. The magnitude and direction is similar for all DWD models, but LMQ and LMK show lower surface pressure which is closer to observations.

Figure 5 shows the wind speed and pressure at 03 UTC on 21 August 1990 at the Ems estuary. LMK is the only model where the east Friesian islands are resolved at least partly by the grid. The reduced wind speed on and downstream of the resolved islands is clearly visible. Also the acceleration of the wind from northwest to southeast in the Jadebusen Bay, on the east side of the section shown, can only be modelled by LMK.

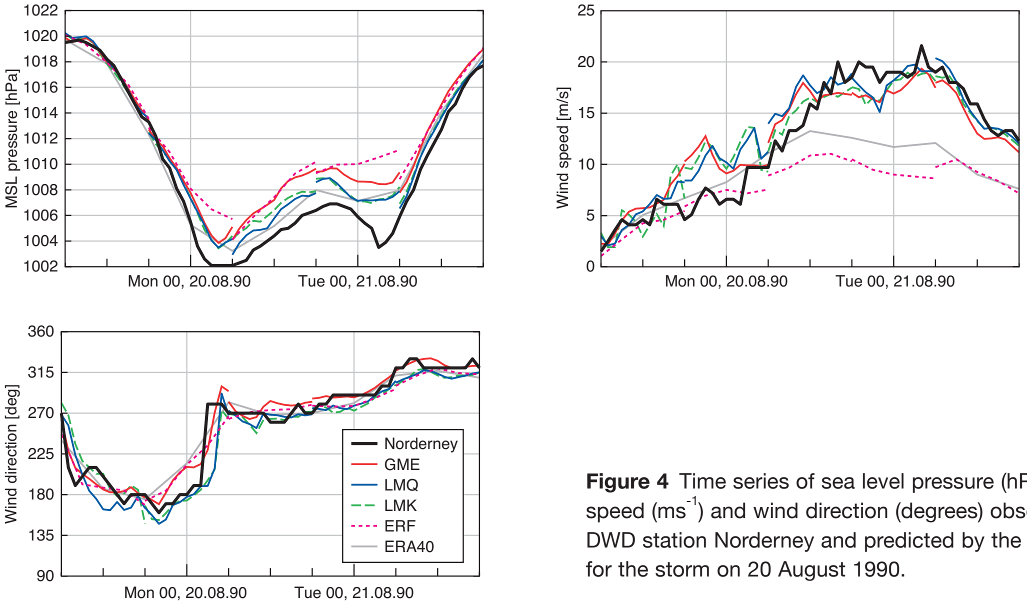
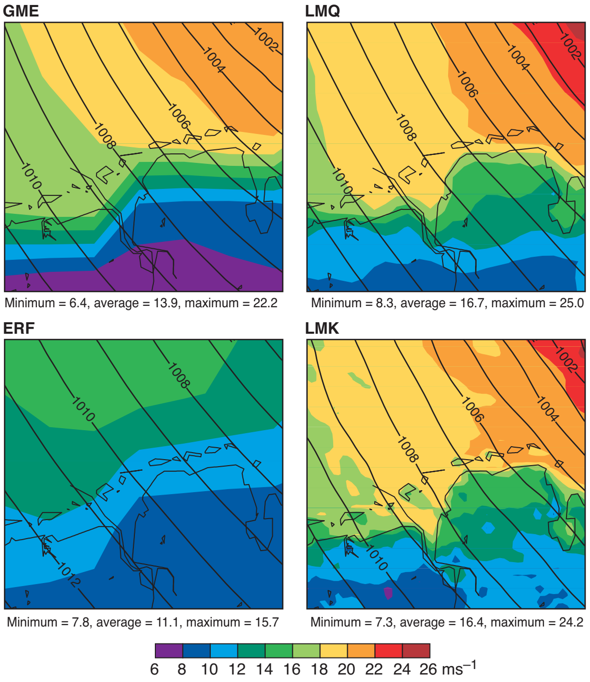


Figure 4 Time series of sea level pressure (hPa), wind speed (ms^{-1}) and wind direction (degrees) observed at DWD station Norderney and predicted by the models for the storm on 20 August 1990.



GME: Minimum = 6.4, average = 13.9, maximum = 22.2

LMQ: Minimum = 8.3, average = 16.7, maximum = 25.0

ERF: Minimum = 7.8, average = 11.1, maximum = 15.7

LMK: Minimum = 7.3, average = 16.4, maximum = 24.2

Figure 5 Mean wind speed at 10 m in ms^{-1} at 03 UTC on 21 August 1990 simulated by GME, LMQ, LMK, and the ERA-40 forecast (ERF) initialised at 12 UTC on 20 August 1990. The mean sea level pressure in hPa is shown by isobars. The Ems estuary is in the centre of the domain, the Jadebusen Bay is near the eastern boundary.

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Storm on 3 December 1999

Similar to the storm in August 1990, the storm on 3 December 1999 crossed the North Sea from Scotland to Denmark. However, it was very fast and traversed the North Sea in less than 12 hours. Sea level pressure dropped to 952 hPa. This was the strongest observed storm in Denmark (*Rosenørn,* 2000).

The small cyclone cannot be captured well with the ERA-40 resolution. This storm has been investigated using ECMWF's Ensemble Prediction System (EPS). *Buizza & Hollingsworth* (2001) showed that a high-resolution EPS (T255) predicted this storm much better than the then operational EPS (T159) which has the same resolution as the ERA-40 reanalysis.

Figure 6 shows the time series of pressure and wind at Helgoland. The minimum pressure occurred at 15 UTC on 3 December. The mean wind speed at 10 m at that time is given in Figure 7. The higher the resolution of the model the lower the minimum pressure of the storm centre. The strongest winds occur in the cold sector south and southwest of the centre. The models GME, LMQ and LMK predict approximately the same maximum speeds. The ERA-40 reanalysis and forecast give much weaker 10 m winds because the pressure gradient is weaker. In addition, the sea surface roughness, z_0, is greater – over 5 cm compared to approximately 2 mm for the DWD models. LMK is the model which best captures the short backing of the wind at 23 UTC on 2 December and 18 UTC on 4 December.

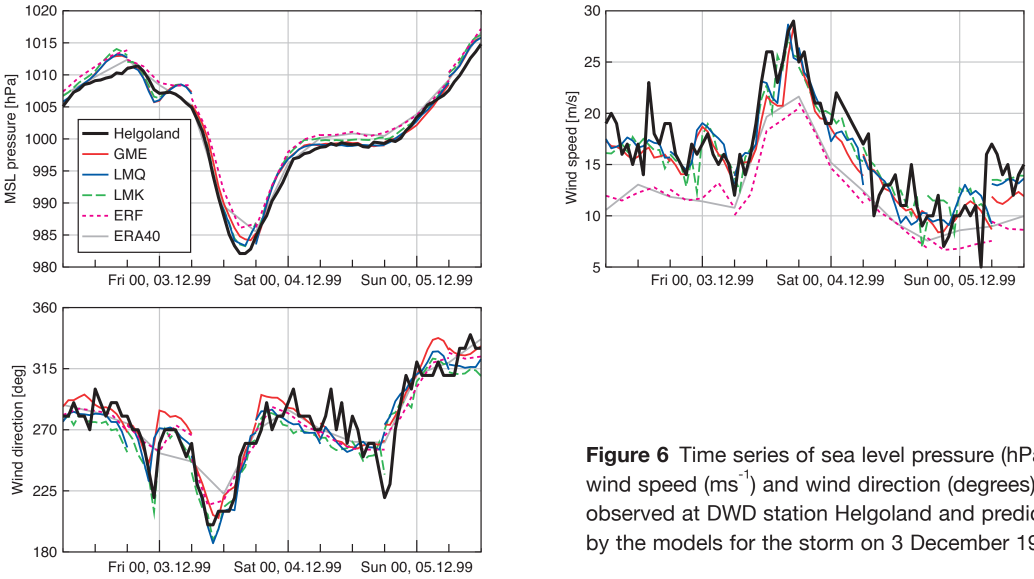
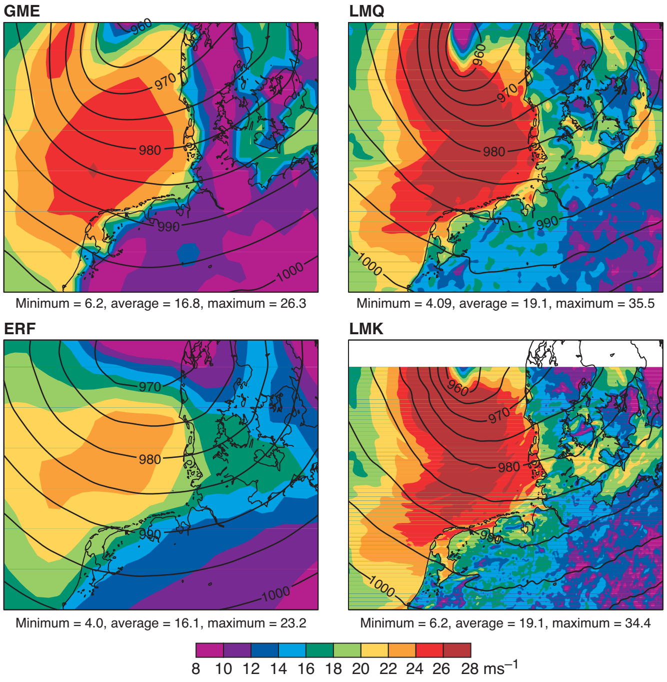


Figure 6 Time series of sea level pressure (hPa), wind speed (ms^{-1}) and wind direction (degrees) observed at DWD station Helgoland and predicted by the models for the storm on 3 December 1999.



Minimum = 6.2, average = 16.8, maximum = 26.3

Minimum = 4.09, average = 19.1, maximum = 35.5

Minimum = 4.0, average = 16.1, maximum = 23.2

Minimum = 6.2, average = 19.1, maximum = 34.4

Figure 7 Mean wind speed at 10 m in ms^{-1} at 15 UTC on 3 December 1999 simulated by GME, LMQ, LMK, and the ERA-40 forecast (ERF) initialised at 00 UTC on 3 December 1999. The mean sea level pressure in hPa is shown by isobars.

Value of high-resolution hindcasts

The short comparison with observations shows satisfactory results. The high-resolution model LMK simulates much more detail (e.g. rain bands and gust streaks) than the other models. Also, it is the only one to resolve at least some of the Friesian islands off the coast of Germany and the Netherlands. Further verification will be done by NLWKN which will use the wind fields for coastal protection studies.

This study shows that a combination of the DWD models GME, LMQ and LMK, and the ERA-40 reanalyses provides the capability to produce high-resolution hindcasts that can be used to investigate extreme weather events from the past. Such hindcasts may be of value to many organisations that need to carry out studies to help reduce the impact of extreme weather.

We would like to acknowledge the contributions made to this study by Nils Kaiser and Katharina Klein from the University of Bonn, and Kai Sven Radtke from the University of Leipzig who performed the calculations and the first analysis.

Further reading

Buizza, R. & **A. Hollingsworth,** 2001: Severe weather prediction using the ECMWF EPS: The European storms of December 1999. *ECMWF Newsletter No. 89,* 2–12.

Majewski, D., D. Liermann, P. Prohl, B. Ritter, M. Buchhold, T. Hanisch, G. Paul & **W. Wergen,** 2002: The operational global icosahedral-hexagonal gridpoint model GME: Description and high-resolution tests. *Mon. Wea. Rev.,* **130,** 319–338.

Rosenørn, S., 2000: De kraftigste storme i det tyvende århundrede i Danmark. *Vejret,* **82,** 15–18.

Steppeler, J., G. Doms, U. Schättler, H.W. Bitzer, A. Gassmann, U. Damrath & **G. Gregoric,** 2003: Meso-gamma scale forecasts using the nonhydrostatic model LM. Meteorol. *Atmos. Phys.,* **82,** 75–96.

Uppala, S.M., P. Kallberg, A. Simmons, U. Andrae, V. da Costa Bechtold, M. Fiorino, J. Gibson, J. Haseler, A. Hernandez, G. Kelly, X. Li, K. Onogi, S. Saarinen, N. Sokka, R. Allan, E. Andersson, K. Arpe, M. Balmaseda, A. Beljaars, L. van de Berg, J. Bidlot, N. Bormann, S. Caires, F. Chevallier, A. Dethof, M. Dragosavac, M. Fisher,M. Fuentes, S. Hagemann, E. Holm, B. Hoskins, L. Isaksen, P. Janssen, R. Jenne, A. McNally, J.-F. Mahfouf, J.-J. Morcrette, N. Rayner, R. Saunders, P. Simon, A. Sterl, K. Trenberth, A. Untch, D. Vasiljevic, P. Viterbo & **J. Woollen,** 2005: The ERA-40 re-analysis. *Q. J. R. Meteorol. Soc.,* **131,** 2961–3012.

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