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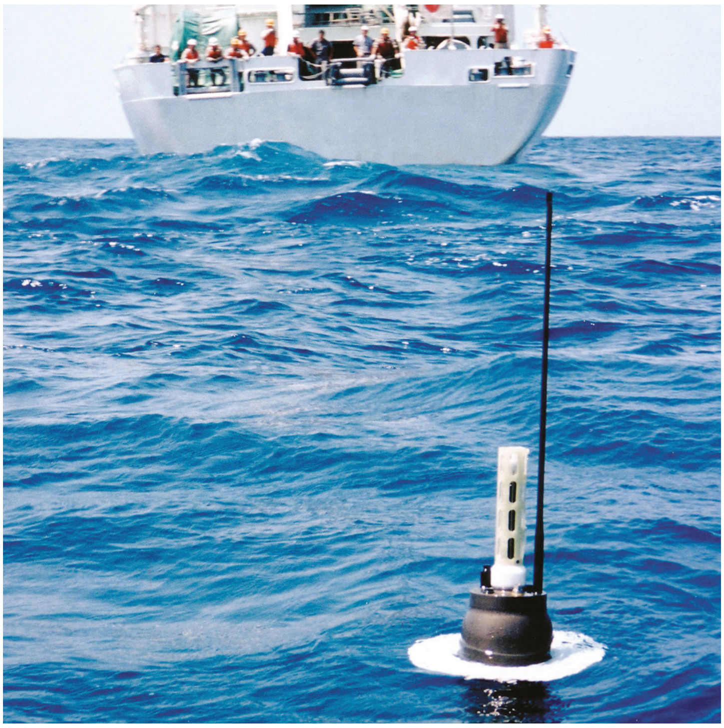

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Severe Weather Catalogue for the Netherlands and use of ERA-40

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At KNMI there is a long meteorological tradition not only in investigating, observing and forecasting the weather, but also in providing warnings of severe weather. Its founder Prof. C.H.D. Buys Ballot (in 1854) introduced, for instance, wind warnings for shipping. Soon the surge warnings for the Dutch coast followed. Over the last century warnings for fog, slippery roads, thunderstorms and other specialised warnings were introduced.

At the end of the 20th century the provision of severe weather warnings got a real boost. KNMI was given by law the authority to coordinate the warnings for major disruptive weather events, and severe weather warnings became part of its core business. In 1999 an extensive system for alarms and (early) warnings was implemented. In cases of severe, disruptive weather KNMI issues a so-called weather-alarm for the Netherlands via teletext, internet and broadcasters. For less severe weather regular warnings have been designed for special user groups (aviation, shipping, traffic etc.).

A system like this needs evaluation and verification. All events and warnings have been evaluated since 1999 not only for verification but also to increase operational knowledge. However, severe weather occurs on average about 5–10 times per year. The definition of an alarm is made bearing in mind that (a) we do not want to issue warnings too often and (b) it could be argued that extreme weather that occurs more than 10 times per year will not be considered disruptive because society will be better prepared. Clearly there was a sampling problem. Six years of weather alarm resulted in about 50-60 cases. About half of them were thunderstorms, the rest a variety of other events. We only have a very chaotic data set: there are many lists of events, damage reports, station observations, hand drawn maps, case studies and newspaper articles. Some examples of severe weather events affecting the Netherlands are given in Figure 1. All very interesting but not very useful for the evaluation of a modern warning system. But why not use the ERA-40 data produced at ECMWF?

The reanalysis project ERA-40 covers the period from September 1957 to August 2002. Three-dimensional variational techniques are applied using the T159L60 version of the Integrated Forecasting System (IFS) to produce the analyses. These involve comprehensive use of satellite data, starting in 1972, with Atmospheric Motion Vectors (AMVs) used from 1979 onwards. ERA-40 provides analyses for every six hours throughout the period, supplemented by forecasts. The products are of a reasonably high temporal and spatial resolution, with a grid-spacing close to 125 km in the horizontal and with sixty levels in the vertical.

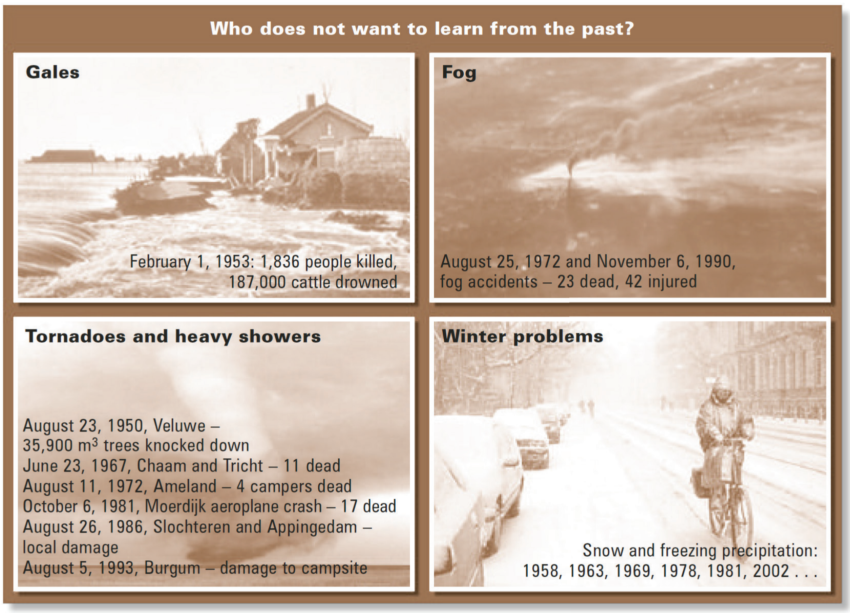

Figure 1 Examples of dates and features for the Catalogue on Severe Weather.

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ERA-40 and historic events

So far, ERA-40 has been used mainly for climatological studies (e.g. statistics and trends). But some studies have made use of "extreme" information from the archives. In 1953 a severe storm caused a devastating flood in the Netherlands and surrounding countries resulting in almost 2,000 casualties and more than 187,000 cattle deaths. The meteorological situation was reanalysed fifty years later, in 2003, with data from ECMWF, NCEP, HIRLAM and WAQUA (the Dutch wind surge model). The reanalyses gave an excellent reproduction of the synoptic situation and it was also demonstrated that a modern forecast would have given one extra day for taking precautionary measures. Something similar was shown in a study by *Jung et al.* (2003) for the Hamburg storm on 17 February 1962. This storm was well predicted by single deterministic forecasts 84 hours in advance.

This inspired us to start looking, in a more systematic way, in the ERA-40 database. We restricted ourselves to about five cases of severe weather per year, concentrating on the Netherlands, and using observations and impact reports as the search key. Our initial goal was to "collect" events in a series of reanalyses, with a five-day lead time with respect to the event. The fields retrieved are mean sea level pressure, winds at 300 and 500 hPa, wet bulb potential temperature (θ_w) at 850 hPa, potential vorticity etc.

It is recognised that the resolution (space and time) of ERA-40 is relatively coarse compared with operational high-resolution data assimilation systems. We can only hope to capture most of the large-scale dynamical conditions, even when the synoptic events occur on a smaller scale in time and space.

The synoptic reconstruction consists of a combination of ERA-40 model data and historic weather charts, surface and upper-air observations, vertical profiles (if available) and other available background material.

Content of the Catalogue

Currently we have identified 200 cases of severe weather, all relevant for the Netherlands. However, the number of cases will probably rise to more than 300 in the future as these cases are just the result of the first scan. The next step will be an objective scan of observations under weather alarm criteria. Then we will need to address issues raised by users of the Catalogue.

The Catalogue will be made available on the web. The index provides links to a database containing several severe weather events per year, indicating the dates, type of phenomenon and timescale of each severe weather event. Clicking on the date of the event leads to a short synoptic description of the case. Maps will be available for 5 days ahead of the event (sometimes up to a week), showing the origin of the event, for several appropriate parameters and levels. Several animations will be made available. And there will be a link to the observations and warnings, historic material and background (case study) articles. Initially we will concentrate on the analyses. Later, hindcasts will be added as well. An example of the index of (a subset of) the Catalogue is shown in Figure 2.

Year	Date	Charts	Phenomenon
1953	01 February 1953	28 January–04 February 1953	Extreme flooding
1958	05 January 1958	02–12 January 1958	Very rough week
1958	25 February 1958	22–26 February 1958	Snowstorm (with freezing rain)
1959	7 December 1959	03–09 December 1959	Hurricane on the Atlantic
1960	03 December 1960	29 November–05 December 1960	Storm and extreme precipitation
1962	12 February 1962	09–13 February 1962	Heavy Storm (also inland)
1967	25 June 1967	21–26 June 1967	Tornadoes Chaam and Tricht
1967	17 October 1967	13–17 October 1967	Heavy gale in autumn
1972	25 August 1972	23–25 August 1972	Traffic accident in fog
1976	27 January 1976	22–28 January 1976	Extreme cold period
1983	12 May 1983	06–13 May 1983	Ascension Day storm
1987	17 July 1987	13–18 July 1987	Tornado Oldebroek
1990	25 January 1990	19–26 January 1990	Violent storm

Figure 2 Example of a listing of a subset of the Catalogue. Note that the ERA-40 period is from September 1957 to August 2002; the extreme flooding event of February 1953 has only been analysed as a case study.

What can we learn from the Catalogue?

The catalogue can be used for several purposes apart from testing the severe weather warning system: performing case studies, training of forecasters, building a weather simulator, testing models and e-learning.

- The average forecaster will experience a severe event perhaps once every five years. Using case studies for individual training will allow forecasters to enhance their knowledge of severe weather.
- Developing a weather simulator has been suggested for some years now as training tool for forecasters, but such a simulator has not yet materialized. Creating a meteorological basis for such a simulator with the ability to realistically replay interesting weather events would be a good spin off from this project. The Catalogue offers a variety of observations, model data, background material in one database for many cases, making a simulator a very real possibility.
- The Catalogue will give suggestions for dates for model tests.
- All learning elements can be combined into an e-learning module. The educational training department of KNMI is implementing e-learning in the training of forecasters and special users. Implementation is based on the international experience that e-learning is not just scanning a book to the Web, but creating challenging, interactive lessons. The learning procedure will be a mix of an introduction to a case, followed by a challenge to understand and assess the situation, make decisions before proceeding to the next time-step, and follow the correct procedures. Finally there is a testing of knowledge. This idea has recently been implemented in a training session for maritime users and will be tested this autumn. The Catalogue contains useful information for the e-learning tool. It will provide meteorological material about the evolution of an event as well as background material such as impact-articles.

First impressions

We have started by collecting the storm cases. The first results, confirming the 1953 experiences, were very impressive. The dataset is continuous and of high quality. One of us, being an operational forecaster (GG), was surprised and impressed when comparing historic weather charts to ERA-40 reanalyses of surface pressure and θ_w. The respect goes both ways: the reanalyses look very real (a compliment to modern technology), but the quality of the old “hand” maps makes you aware of the expertise of the operational colleague’s over the past 50 years who were able to create maps with very little data. This experience strengthens the (subjective) trust in investigating model data in the reconstruction.

Some disadvantages, experienced so far, are also worth mentioning. The coarse resolution with a grid spacing of 125 km and six-hour intervals limits the detailed study of small-scale storms. A famous storm in the Netherlands (the Ascension Day storm in 1983) originated in the English Channel, developed very quickly and caused havoc in the IJsselmeer. This was captured in a broad sense, but for rapidly developing storms a shorter time step is needed. This will obviously become even more of a problem for cases where the development is mainly driven by convective processes. Nevertheless preliminary results show at least a synoptic signal associated with these smaller severe events. Furthermore we find that, due to the resolution of the surface wind fields, the ERA-40 wind are consistently underestimated with respect to the observations, sometimes up to 3 Beaufort Force. For convective events some extra parameters (e.g. CAPE) would be useful, but they are not part of the current system. The potential vorticity was an incredible asset. It is exciting to study the weather of the 1950s and 1960s through modern “PV-glasses”. Looking for instance at a development by means of a loop of potential vorticity is like searching for dry intrusion in loops of water vapour images. From recent knowledge we know that dry intrusion increases rotation or vorticity and stimulates (potential) instability.

Future plans and wishes

There is the obvious wish for higher-resolution analyses. ERA-40 is extremely useful for the general picture and for the large-scale background flow. But when it comes to studying small-scale, rapidly-developing storms more detail in space and time (at least 3-hour analysis steps) is needed. For convective systems even more detail is required in combination with indices such as CAPE.

With the 22 km HIRLAM model we will prepare reanalyses for some selected cases. This might also be taken up by a future ERA project, probably providing higher-resolution reanalyses for the Atlantic-Europe area over the entire period of ERA-40 (i.e. since 1957).

For detailed studies of events there is a need for vertical cross-sections of several parameters (e.g. to compare with the observed radiosonde soundings). This wish requires some form of model-level output, which costs a lot of resources.

Last but not least we would like to promote international cooperation for developing a web-based European Severe Weather Catalogue. Storms do not stop at our borders, and one mesoscale convective situations sometimes hits several countries.

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Example of a synoptic reconstruction: The severe storm of 12 February 1962

On 10 February 1962 a series of low pressure areas extends around an extensive area of high pressure with a maximum of 1043 hPa near the Azores. The low causing the storm two days later, is at this time situated near Newfoundland. The centre has a pressure of 1004 hPa (Figure 3) and is moving northeast near the warm side of a jet stream, deepening 14 hPa in 12 hours time whilst moving to Southern Greenland.

As time progresses the track of the low bends from an easterly to an east-southeasterly direction after passing Iceland on 11 February. One day later the pressure has dropped to 972 hPa over the Norwegian Sea and 955 hPa over Southern Sweden. The lowest surface pressure of 950 hPa occurs at around 00 UTC on 13 February 1962 over the Baltic Sea. The broad frontal system of this storm passes the Netherlands on 12 February (Figure 4): the warm front at around 00 UTC on 12 February the cold front almost 24 hours later. The model reanalysis at 12 UTC (Figure 4(b)) can be compared to the historic weather chart (Figure 5). Both the quality of the historic frontal analysis as well as the model reanalysis is shown in the thermal pattern at 850 hPa. The fronts are situated along θ_w values 7–8°C and the occluded part trough the centre of the lower values.

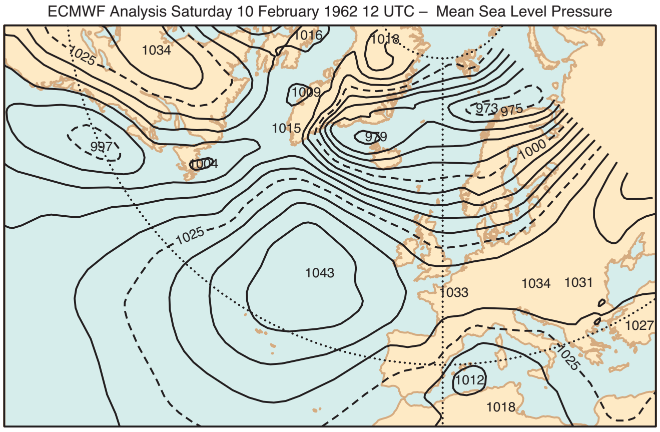

Figure 3 Surface pressure at 12 UTC on 10 February 1962 from ERA-40. Note the steering high over the Atlantic, the low pressure area passes New Foundland.

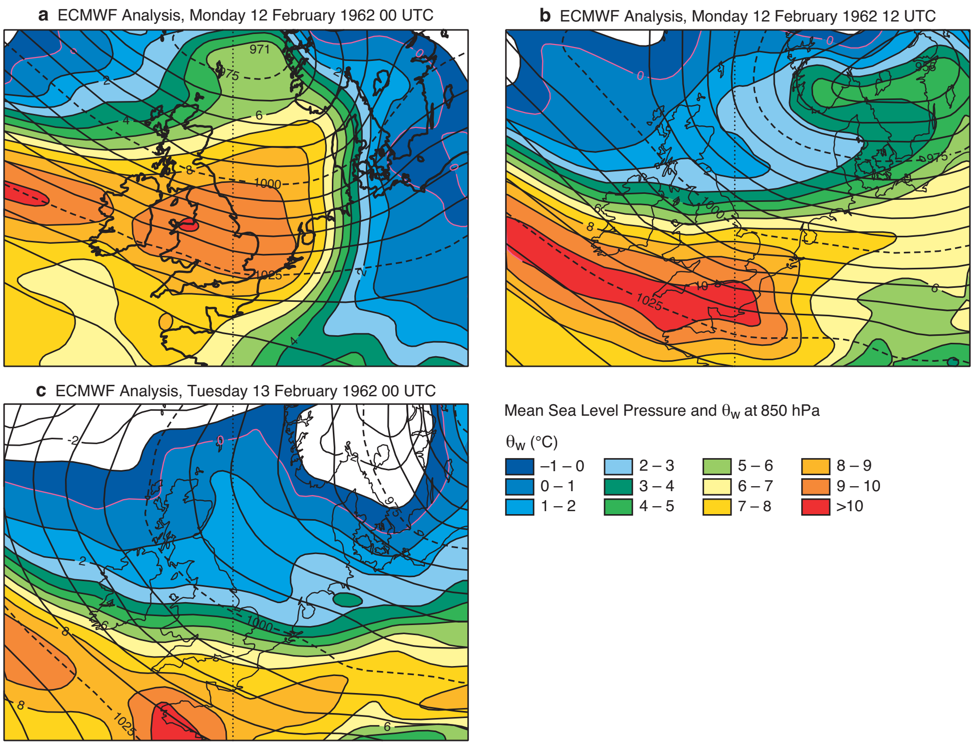

Figure 4 Surface pressure and thermal pattern (theta-w) 850 hPa from ERA-40. (a) 00 UTC on 12 February 1962: the low, still deepening, moves to Norway, with the Netherlands and England/Wales in the warm sector.
(b) 12 UTC on 12 February 1962: in the warm sector west-southwest winds at 1.5 km height increase to 35–40 ms^{-1}.
(c) 00 UTC on 13 February 1962: the storm passes the Baltic Sea with the waving cold front (situated along the 7°C isopleth of θ_w) moving southeast.

Warnings were issued for Beaufort Force 10 during a period of 24 hours, starting in the evening of 11 February. For a period of six hours a wind of Force 11 was expected along the northern coast. This did not quite materialize. The observed maximum mean hourly wind speed reached Force 9–10 (22 to 25 ms^{-1}); this occurred inland in the Netherlands, rather than at the coast, in the early of the afternoon soon after 12 UTC (13 local time). Note that in the reanalysis near-surface wind speeds reached hourly values (Figure 6) of only Force 6 to 8.

In a winter month like February with most friction over the colder land one should expect the highest wind speeds over the sea and by the coast rather than inland. One explanation for the strong surface winds inland can be found by considering the vertical structure. When the lower profile is unstable, winds aloft in the lower part of the stratosphere, say up to 1.5 km, are strong and vertical exchange of momentum contributes to surface wind speed. In this event the temperature rises in the warm sector from 4 to 10°C and at 1.5 km height wind speeds increase to about 35 ms^{-1}.

The vertical distribution of temperature, humidity and wind is important for judging stability and advection. Radiosonde soundings contain this historic information. The soundings from De Bilt (central part of the Netherlands) show a weak inversion just above 1 km (Figure 7). In the boundary layer below this inversion the profile is dry adiabatically unstable, giving maximum vertical exchange of momentum. Average hourly wind speeds reach up to 70% of the winds in the free atmosphere at 1 km height and it is likely that maximum gusts reach values close to 90%.

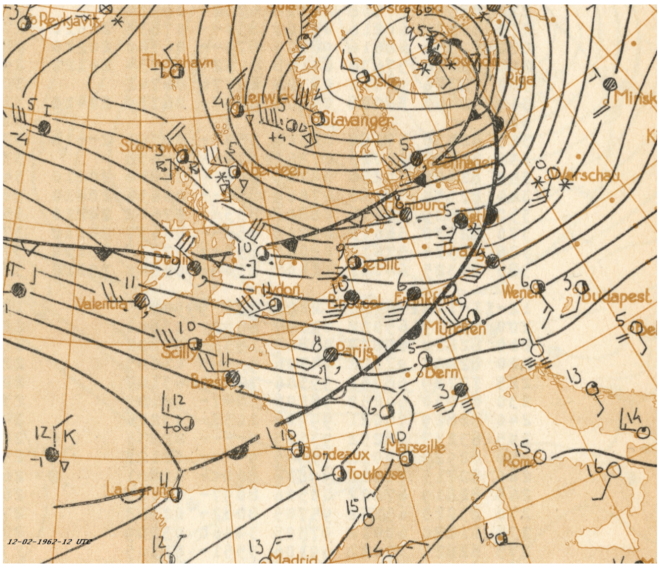

Figure 5 Handrawn surface analysis at 12 UTC on 12 February 1962.

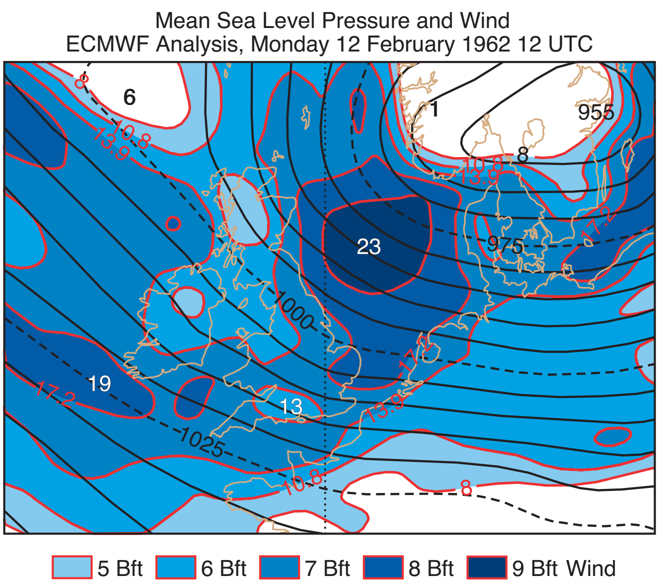

Figure 6 Surface pressure and isotachs at 12 UTC on 12 February 1962 from ERA-40. Note that the wind speed is Force 6 on land and Force 8 near coast; these values are 2 to 3 Beaufort Force too low.

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At 12 UTC, in the warm sector, with the cold front just north of the Frisian Isles, the sounding shows some decrease of humidity at 6 km to 75%, a possibly indication of dry air in the higher troposphere. Does this dry intrusion in any way influence the increase of wind speed, for instance by increasing (potential) instability ahead of the surface cold front (split-level cold front)? In the ERA-40's potential vorticity field at 12 UTC on 12 February (Figure 8) this intrusion is obvious over Southeast Scandinavia, thus giving an impulse to the low and increasing (potential) instability on the cold front. Whether this is the case over the Netherlands should be investigated in the future using cross-sections, model soundings and a high-resolution model

The study of this event ends as the cold front passes the Netherlands during the night of 12/13 February, and some waves weaken the frontal speed. After a short break in the wind speed a trough passes in the unstable northwesterly advection of semi-arctic air mass. As sea temperatures are relatively high compared to the colder advection, showers pass the Netherlands with a typical variety of precipitation types such as rain, snow and hail, and sometimes there is a thunderstorm with temperatures dropping to near 0°C.

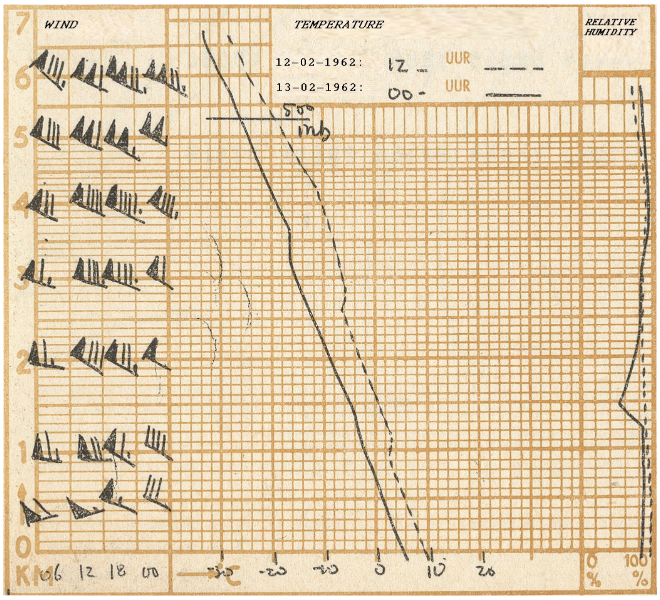

Figure 7 Soundings of temperature (centre), wind (left), relative humidity (right), at 12 UTC (dashed line) and 24 UTC (closed line) on 12 February 1962 at De Bilt. There is a weak inversion at 12 UTC at 1 km height, strong winds and high humidity. At midnight temperature and winds decrease, and the instability increases below 3.5 km. The freezing level sinks from 1.5 km to 700 metres in 12 hours.

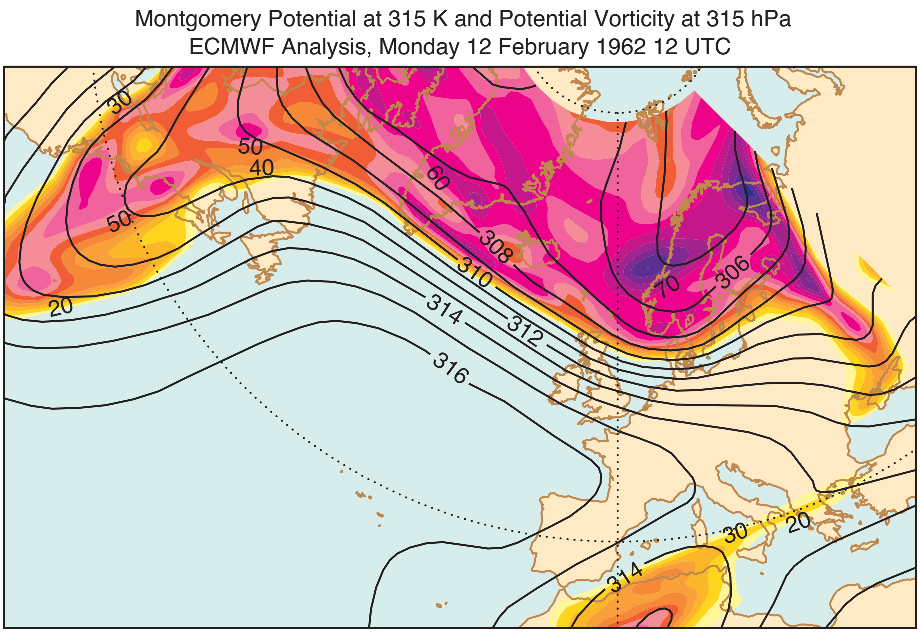

Figure 8 Potential vorticity distribution and the Montgomery Potential at the 315 K surface at 12 UTC on 12 February 1962 from ERA-40. It shows the dynamical tropopause and also how dry stratospheric air overruns the cold front near Denmark.

Further reading

Newsletter article
This article and all chart animations can be found at:
www.nvbm.nl/Newsletter/Article

Presentation at the ECMWF Forecast Products Users Meeting – June 2005
www.ecmwf.int/newsevents/meetings/forecast_products_user/Groen.ppt

General information on ERA-40
www.ecmwf.int/research/era

The ERA-40 archive
www.ecmwf.int/publications/library/ecpublications/_pdf/era40/ERA40_PRS17.pdf

ECMWF newsletter spring/autumn 2004 about ERA-40
www.ecmwf.int/publications/newsletters/pdf/101.pdf

Investigation of three major European Storms using ECMWF forecast system
(*Jung, Klinker and Uppala*)
www.ecmwf.int/publications/library/ecpublications/_pdf/era40/ERA40_PRS_10.pdf

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