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TRENDS IN STORMINESS OVER THE NETHERLANDS, 1962–2002

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ABSTRACT

Trends in the annual number of independent wind events over the Netherlands are studied for the period 1962–2002. The events are selected out of 13 hourly 10 m wind speed records that are part of a high quality dataset of near-surface wind observations at Dutch meteorological stations. Comparisons are made with trends in independent wind events selected from geostrophic wind speed records and reanalysis data.

The results for moderate wind events (that occur on average 10 times per year) and strong wind events (that occur on average twice a year) indicate a decrease in storminess over the Netherlands between 5 and 10%/decade. This result is inconsistent with National Centers for Environmental Prediction–National Center for Atmospheric Research or European Centre for Medium-Range Weather Forecasts reanalysis data, which suggest increased storminess during the same 41 year period.

Possible explanations are given for the discrepancy between the trends in storminess based on station data and the trends in storminess based on reanalysis data. Evaluation of trends in geostrophic wind, both from station data and reanalysis data, and evaluation of trends in vector-averaged (upscaled) 10 m wind over the Netherlands point towards inhomogeneities in the reanalysis data as the main cause of the discrepancy. We conclude that it is likely that the decrease in storminess observed in Dutch station records of near-surface wind in the past four decades is closer to reality than the increase suggested by the reanalysis data. Copyright © 2005 Royal Meteorological Society.

KEY WORDS: extratropical storms; wind climate; trend analysis

1. INTRODUCTION

Despite the obvious importance of storminess for safety and economy, little is quantitatively known of climate changes that have occurred in storminess. The main reason for this lack of information is that the quality of the observational records of near-surface wind is generally too poor for assessing changes in the wind climate. Near-surface wind observations are very sensitive to changes in instrumentation, changes in exact measuring location or measuring height and changes in local obstacles in the direct surroundings of the measurement site. These factors readily generate inhomogeneities in series of wind observations that are sufficiently large to obscure trend signals. Only a few studies have reported systematic changes in storminess on the basis of station observations. A notable example for Europe is Schiesser *et al.* (1997), who reported a significant negative trend in the number of winter storms in Switzerland north of the Alps between 1864 and 1994. Furthermore, Pirazzoli and Tomasin (2003) reported a decrease in wind activity for the central Mediterranean and Adriatic region between 1951 and 1970 and an increase from 1970 onwards. Analyses based on wind gusts indicate no sustained trends over the UK over the 20th century up to 1990 (Hammond, 1990) and in Dublin (Ireland) up to 2000 (Sweeney, 2000).

A number of studies have bypassed the problem of inhomogeneities in series of station observations by considering geostrophic wind speed calculated from surface air pressure as a proxy for near-surface wind.

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Alexandersson *et al.* (1998) analysed the period 1881–1995 and found a decrease in the frequency of storms (95th and 99th percentiles) in northwestern Europe between the late 19th century and around 1960, followed by an increase to values that correspond with the pre-1900 level. From this, they concluded that the storm frequencies at the end of their analysis period are not unique. An update with years up to 1998 (Alexandersson *et al.*, 2000) showed that the increasing trend in recent decades stopped after 1995. Schmidt and von Storch (1993) did not find any trend in the 50th, 90th and 99th percentiles of the annual distribution of geostrophic wind speed for the period 1876–1990 in the German Bight area. For the shorter period of 1961–90, Mietus (1995) found a weak increase in annual mean geostrophic wind speed for the northern part of the North Atlantic, but did not provide information on extremes. On the basis of these and other studies, the WASA Group (1998) concluded that the wind climate along the European coast has not become more severe in the past 100 years or so (1881–1995). They found increasing strong geostrophic wind speeds from around 1965 onward, but do not label them as alarming when compared with conditions earlier in the 20th century and at the end of the 19th century.

Pressure tendencies are another proxy that is used for near-surface wind in storminess analysis. Kaas *et al.* (1996: figures 5 and 6) found variations in cyclonic activity on the decadal time scale but no significant overall trends for the northern North Atlantic region in the second half of the 20th century. Schmith *et al.* (1998) found a small increase since about 1970 in the northeast Atlantic winter storminess for the period 1875–1995. Alexander *et al.* (2005) found a positive trend in the number of severe storm events in the south and west of the UK but no trend over Iceland for the period mid-1950s to 2001. Bärring and von Storch (2004: figure 1) analysed storminess indices for two Swedish station records covering the period of about 1800 to 2002; from 1960 onwards, the trends are slightly positive.

Other investigators based their trend studies on reanalysis wind data of the National Centers for Environmental Prediction and the National Center for Atmospheric Research (NCEP–NCAR; Kalnay *et al.*, 1996; Kistler *et al.*, 2001) and the European Centre for Medium-Range Weather Forecasts (ECMWF; ERA-40; Simmons and Gibson, 2000), implicitly assuming that these data are of higher quality than station wind data. Most studies make use of NCEP–NCAR data: Yan *et al.* (2002) analysed trends in daily maximum near-surface wind speed in northwestern Europe for the period 1958–98. They found an increase over the ocean

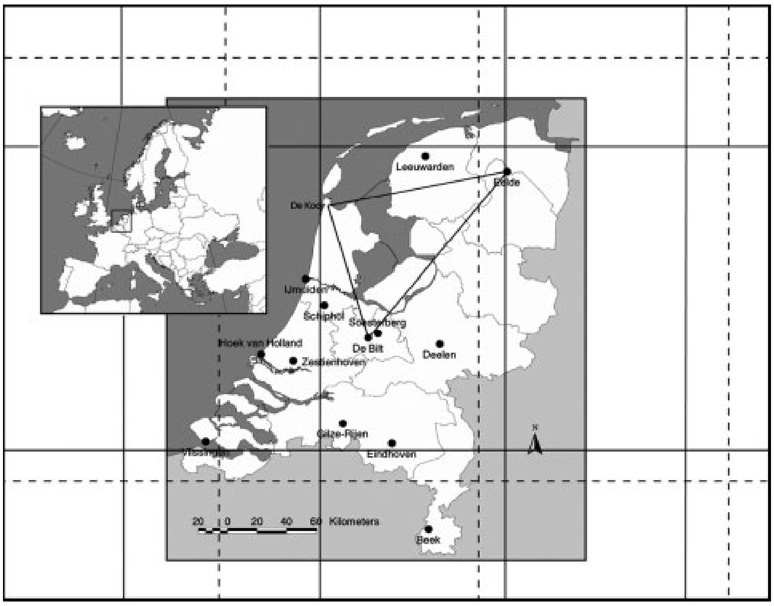


Figure 1. The 13 stations used in the present study with 10 m wind speed records (indicated by dots), the three stations used in the calculation of geostrophic wind speed (indicated by a triangle), and the grid boxes for the reanalysis data (indicated by solid rectangles for NCEP–NCAR and dashed rectangles for ECMWF)

in winter but a decrease over continental Europe in summer. Trigo *et al.* (2000) found that the intensity of Mediterranean cyclones decreased in the period 1958–96 while the overall frequency of these cyclones did not change. Pryor and Barthelmie (2003) found increased 850 hPa wind speeds over the Baltic region for the period 1953–99, especially in the upper quartile of the wind speed distribution of instantaneous values. Keevallik (2003) investigated changes in the mean wind speed at 500 and 850 hPa over Estonia in late winter and spring during the period 1955–95. She found increases only in March, whereas no changes were found during the rest of the period. Sterl and Caires (2005) composed a Web-based wave atlas based on ECMWF reanalysis data (www.knmi.nl/waveatlas). The 1958–2001 trend maps in the atlas indicate significant (at the 5% level) increases in the 90th and 99th percentiles of 10 m wind speed over the North Sea area (bordering the Netherlands) for February and September, and no trends for the other months.

The overview above illustrates that a great amount of evidence for changing storminess over northwestern Europe is based on indirect data and reanalysis data rather than on station wind data. This motivated us to perform a trend study on the basis of actual observations of near-surface wind. Trends in storminess are investigated over the Netherlands based on hourly records of 10 m wind speed observations at 13 meteorological stations. The annual numbers of independent wind events that last for several hours and occur at more than half of the stations are considered (i.e. countrywide events). Event severities are determined by the observed hourly peak wind speeds, since these peak intensities cause most of the damage. Trends are calculated for a range of event severities, focusing on moderate wind events that occur on average 10 times per year up to strong wind events that occur on average twice a year. Moderate events correspond with wind speeds that gradually change from about 15–16 m/s (7 Bft) along the coast to wind speeds of 12–13 m/s (6 Bft) inland. Strong wind events correspond with about 19–20 m/s (8 Bft) along the coast and 16–17 m/s (7 Bft) inland. For comparison, trends are also calculated for the upper quantiles of the distribution of all hourly values. Our study is possible because of the recent development of a high quality dataset of near-surface wind observations at Dutch meteorological stations. The availability of sufficient and complete station records restricts the study period to 1962–2002.

Comparisons are made with trends in wind events in geostrophic wind speed records calculated out of surface air pressure observations and with trends in wind events in series of 10 m wind and geostrophic wind derived from reanalysis data of the NCEP–NCAR and ECMWF. In contrast with 10 m wind, geostrophic wind speed is not representative for the wind speed near the surface, but gives an indication of the wind speed just above the planetary boundary layer. The evaluation of geostrophic wind allows for comparisons between station and reanalysis wind data, which may help to detect causes of discrepancies in 10 m wind trends. To rule out possible scale effects in wind trends derived from station point data on the one hand and the reanalysis grid box data on the other hand, events in vector-averaged (upscaled) station winds over the Netherlands are also considered.

In Section 2 the wind speed data are described in more detail, and in Section 3 the methods are outlined for selecting independent wind events and calculating the trends. Section 4 presents the results, which are discussed in Section 5.

2. DATA

A high quality dataset comprising 53 long station records of near-surface wind in the Netherlands was recently developed within the framework of the HYDRA (hydraulic conditions) project (see www.knmi.nl/samenw/hydra). The records have hourly resolution and were corrected for observational changes (Verkaik, 2000). Adjustments were made for differences over time in instruments, measuring heights and local roughness. The corrected observations correspond with 10 m wind over short grassland (flat terrain). Compared with the underlying raw series, the records are relatively free from homogeneity breaks. This makes them suitable for trend analysis. From the dataset, 13 stations have been selected for the present study (Figure 1). They span an area of about $150 \times 250\ \text{km}^2$ and have uninterrupted records for the time period 1962–2002.

NCEP-NCAR reanalysis data (Kalnay *et al.*, 1996; Kistler *et al.*, 2001) and ECWMF reanalysis data (Simmons and Gibson, 2000) for wind speed at 10 m (and 850 hPa) are used for the grid box representative for the Netherlands (Figure 1). The dimensions of the grid box are 1.875° × 1.905° (about 128 × 212 km^2) for NCEP–NCAR and 2.5° × 2.5° (about 170 × 278 km^2) for ECMWF. The time resolution of the reanalysis data is 6 h with instantaneous values at 6, 12, 18 and 24 UTC. The NCEP–NCAR reanalysis data cover 1962–2002 and the ECMWF reanalysis data cover 1962–2001.

Hourly geostrophic wind speeds for the period 1962–2002 are calculated from hourly surface air pressure observations at three stations in the Netherlands at a mutual distance of about 120 km (station geostrophic wind; Figure 1), following the so-called triangle method (Schmidt and von Storch, 1993). For the reanalysis data, geostrophic wind speeds are calculated from air pressure values by applying the triangle method to adjacent grid boxes (reanalysis geostrophic wind; Figure 1).

3. METHODS

3.1. Selection of independent wind events

For each station, independent events that are free from autocorrelation are selected from hourly records of near-surface wind speed at the 13 meteorological stations. The algorithm labels an hour and its corresponding wind speed value as an event if the wind speed during the middle hour of a moving window of 97 h equals the maximum wind speed of the whole window. The window of 97 h implies that consecutive events are separated by at least 48 h. This value of 48 can be regarded as the minimum inter-event arrival time and determines the degree of independence between events. A value of 48 hours is often used in extreme value analysis of wind speed, because it guarantees that subsequent events are sufficiently independent (Palutikof *et al.*, 1999). Smaller values would mean that a higher number of events are selected, whereas larger values would reduce the number of events selected. We verify the choice of 48 h for the minimum inter-event arrival time and show that values of 24 or 96 h do not change the conclusions of our study.

Next, the selected independent events are ranked by their wind speed values. Events that occur on average 30, 10 and 2 times per year are called weak, moderate and strong wind events respectively. They correspond with the top 1230, 410 and 82 events in the 41-year record. Figure 2 shows an example of the application of the selection algorithm. In this example, three independent events are selected out of a 10 day hourly wind speed record from station Schiphol. In the overall ranking for this station, the three events selected take positions 280 (moderate), 1 (strong) and 74 (strong).

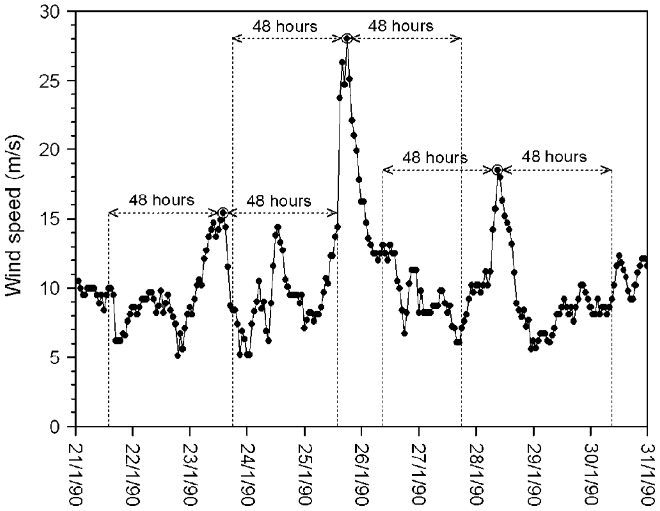


Figure 2. Example of the selection of independent events in a 10 day (21–30 January 1990) hourly wind speed record of station Schiphol. The dots indicate hourly mean wind speed values. A window of 97 h is applied, which implies a minimum inter-event arrival time of 48 h. The criterion leads to the selection of three events in this example. These three events are marked as circled dots

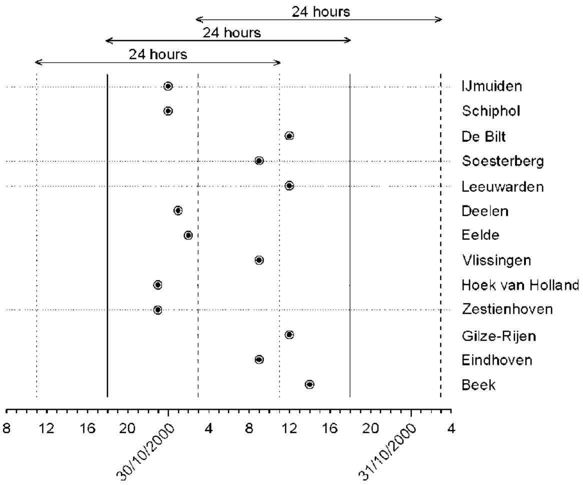


Figure 3. Example of the selection of a countrywide event (for 29–31 October 2000). The dots represent independent events that have been selected from the individual station records (station names on the right). Three windows are given, for which the condition of at least seven occurrences of a station event within a period of 24 h is met. The window with the dotted lines includes nine station events, the window with the solid lines includes 13 station events, and the window with the dashed lines includes seven station events. On the basis of the averaged logarithms of return periods as a measure of severity, only the countrywide event that includes all 13 station events is retained

The label 'countrywide event' is assigned to those events that occur at least for 7 of the 13 stations. To account for the time that a typical storm travels over the country, the station events selected are grouped into single countrywide events if the time difference between the individual station events is less than 24 h. To guarantee independence between subsequent countrywide events, a minimum inter-event arrival time of 48 h is also prescribed. This procedure is illustrated in Figure 3. Each of the three (partly overlapping) events in the figure meets the condition of at least seven stations with an event occurrence within 24 h, but only the middle one is retained because of the independence criterion. Rather than averaging the hourly wind speed values to obtain the intensity of the countrywide event, the logarithms of the return periods of the (at least seven) individual station events are averaged. The return periods are empirically determined with the help of the plotting position formula of Gringorten (1963):

$$T_{\mathrm{p}}(u_m) = \frac{Y}{N\left(1 - \dfrac{m - 0.44}{N + 0.12}\right)} \tag{1}$$

where N represents the total number of selected wind speed events, Y is the number of years (41) and u_m the ranked wind speed event from the smallest (u_1) to the highest (u_N). For example, the event at station Schiphol on 28 January 1990 (see Figure 2) with a maximum hourly wind speed value of 18.5 m/s ($N = 3041$, $m = 2968$) is labelled with a return period of 0.56 years. The logarithm of the return period is introduced because of the skewed property of this quantity. Our measure of severity accounts for the gradient that exists in absolute wind speed levels over the Netherlands, with high values along the coast and lower values inland. As for the individual station events, the selected countrywide events are ranked by severity. By means of visual inspection of weather maps, it was verified that in most cases the combination of 7 out of 13 stations and a value of 24 h for the maximum time difference between individual station events leads to retaining those events that originate from single synoptic situations only.

The same selection algorithm is used to derive series of independent wind events from the station geostrophic wind and the reanalysis wind (10 m, 850 hPa and geostrophic). These series are also ranked by their wind speed values. As the reanalysis data have four daily values rather than 24 daily values, independent wind events are selected from six times less data than the (hourly) station data.

Finally, independent wind events are selected from a series of vector-averaged station wind speeds representative for a grid box of the size of the Netherlands (150×250 km^2). This upscaling of station data to areal averages allows for a direct comparison with the area-averaged results that are obtained from the geostrophic and reanalysis data. The series of vector-averaged wind speeds is calculated using the 13 station records. To prevent regional differences in the wind climate dominating the temporal variation in the average wind speed, every hourly station value is first scaled by the annual mean wind speed at that station, after which the u component (wind speed times cosine of wind direction) and v component (wind speed times sine of wind direction) are calculated and subsequently averaged over all stations ($\overline{u}$ and $\overline{v}$). The wind speed that corresponds with the mean values of u and v is given by $\sqrt{(\overline{u})^2 + (\overline{v})^2}$. Independent events are selected from the resulting series of vector averages by the selection algorithm with a minimum inter-event arrival time of 48 hours and $\sqrt{(\overline{u})^2 + (\overline{v})^2}$ as the measure of severity of the event.

3.2. *Calculation of trends*

All series of independent events are subjected to trend analysis for the period 1962–2002 by applying linear regression on annual counts of the number of events. This is done for event severities ranging from on average about 76 times per year (i.e. all events) to on average 30 times per year (i.e. weak events) and 10 times per year (i.e. moderate events) up to an average of twice a year (i.e. strong events). For all event severities, the coefficients of the slope and the corresponding 95% confidence intervals are calculated.

By definition, the trend coefficients for the lowest severity level are nearly zero for all series, since a maximum of about 76 events is selected in each year as a result of the inter-event arrival time of 48 h. The trend coefficients for the highest severity level face another restriction. The fundamental relation between trend detectability in event count records, time series length and event extremity as provided in Klein Tank and Können (2003: equation (3)) limits the possibilities for trend detection. For this reason, only trends are presented in the 41-year series for events that occur on average at least twice a year. Considering trends in more extreme wind events is impossible given the short time series. The decreasing trend detectability for more rare events also implies that the 95% confidence intervals of the trends for relatively high severity levels are wider than those for lower severity levels, a feature that is clearly apparent in our graphs.

4. RESULTS

4.1. *Station near-surface wind*

Figure 4 shows the annual number of weak, moderate and strong wind events for the coastal station Hoek van Holland and the inland station Gilze-Rijen, as well as the corresponding trend lines.

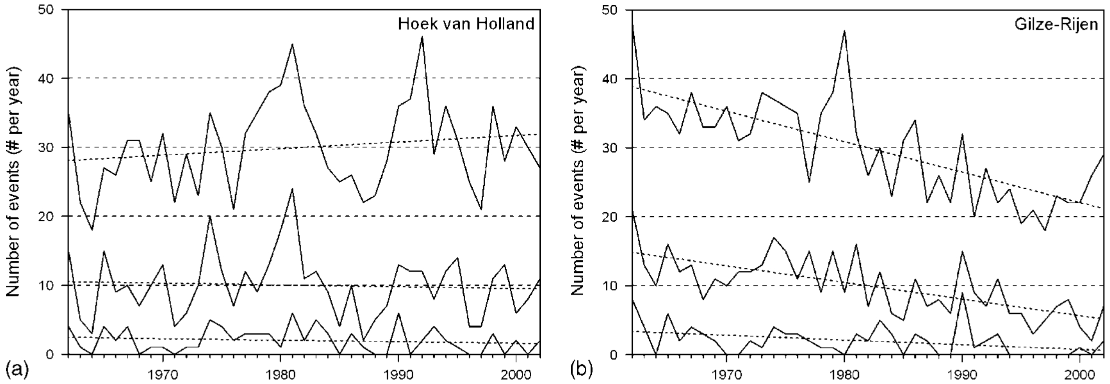
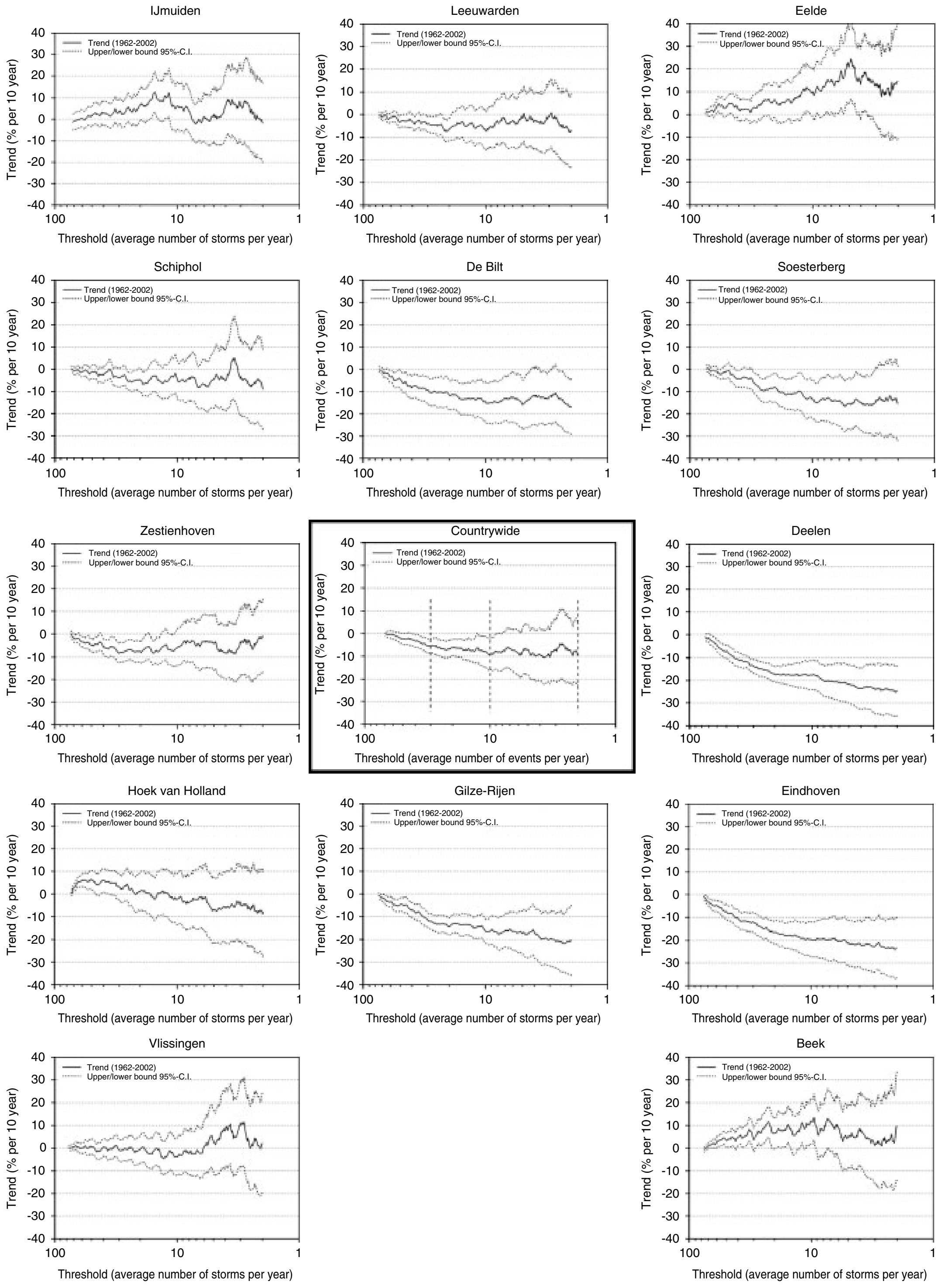


Figure 4. Annual number of wind events for three severity levels for stations (a) Hoek van Holland and (b) Gilze-Rijen. The upper line indicates weak events (which occur on average 30 times per year), the middle line indicates moderate events (on average 10 times per year) and the bottom line indicates strong events (on average twice a year). The regression trends are given by dotted lines



IJmuiden

Leeuwarden

Eelde

Schiphol

De Bilt

Soesterberg

Zestienhoven

Countrywide

Deelen

Hoek van Holland

Gilze-Rijen

Eindhoven

Vlissingen

Beek

Figure 5. Trends (%/decade) in the annual number of storm events as a function of severity level for the 13 stations in the Netherlands. The panels are arranged according to the geographical location of the stations. Solid lines are the coefficients of the slope; dotted lines are the corresponding 95% confidence intervals. The middle panel (labelled countrywide) gives the trends for the annual number of independent countrywide events. The dashed vertical lines in that panel correspond with the three severity levels distinguished in the text (on average 30 (weak events), 10 (moderate events) and 2 times per year (strong events))

The figure illustrates that the number of events varies strongly from year to year and that the trends are different for different stations and severity levels. The trends for station Hoek van Holland vary from positive for weak and moderate wind events to slightly negative for strong wind events (although not significant at the 5% level). The trends for station Gilze-Rijen are negative for each severity level.

A summary of the trends at all 13 stations and all severity levels is given in Figure 5, in which the stations are roughly arranged according to their geographical location in the Netherlands, with coastal stations to the left and inland stations to the right. The middle panel shows the results of the trend analysis for the countrywide events. Apart from the trend coefficients (%/decade), the corresponding 95% confidence intervals are also presented.

The middle panel of Figure 5 shows that the trends found for the countrywide events are negative over the whole range of event severities. Progressively larger decreases are found for higher severity levels. For weak events, the decrease is ∼5%/decade and for moderate and strong wind events the decrease is between 5 and 10%/decade. Figure 6(a) and (b) shows that the trends for events with inter-event arrival times of 24 or 96 h instead of 48 h are in good agreement with those for 48 h. Consistent results are also found for the trends calculated straightforwardly for the upper quantiles of the distribution of all hourly values. To illustrate this, Figure 6(c) shows the results for station Soesterberg.

Figure 7 presents the geographical pattern of the trends for weak, moderate and strong wind events. The figure shows a tendency for stronger negative trends at inland stations compared with coastal stations (see also Figure 5). Station Beek (in the far south) and station Eelde (in the northeast) form marked exceptions to this pattern, showing positive trends for each severity level.

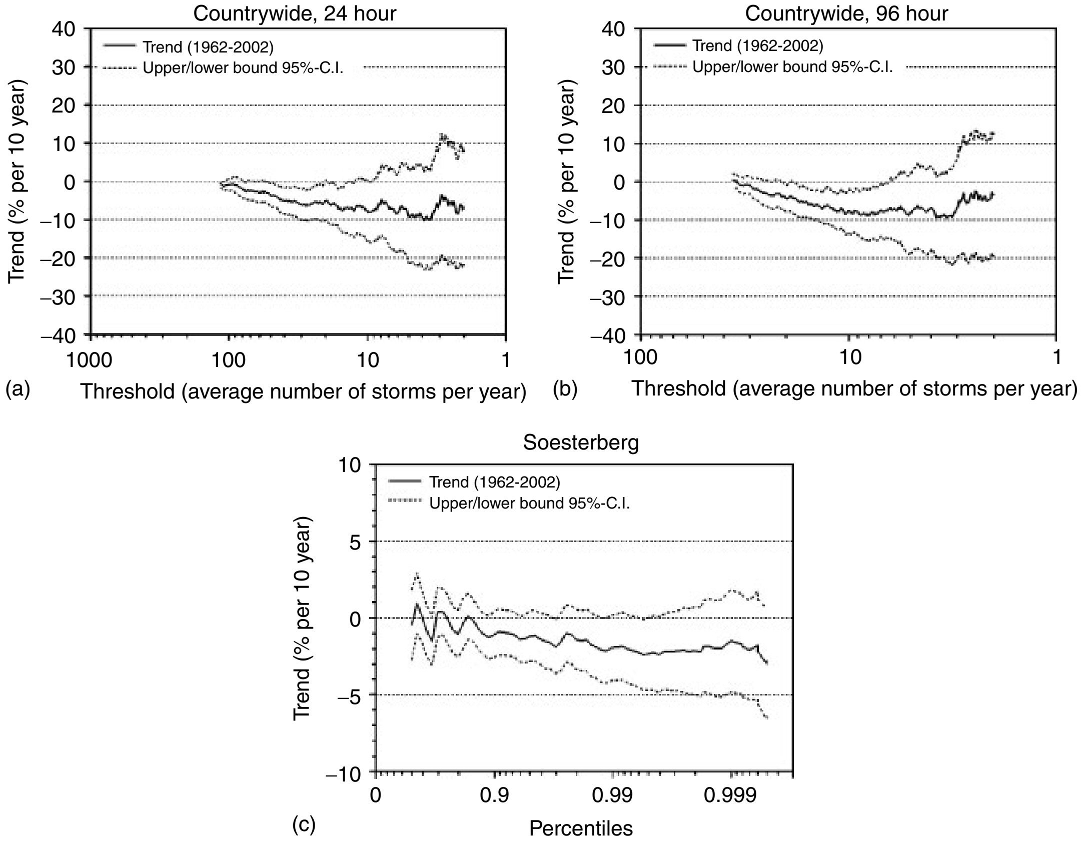


Figure 6. As Figure 5 countrywide events (middle panel), but instead of a minimum inter-event arrival time of 48 h, now values of (a) 24 h and (b) 96 h are chosen in the event selection procedure. (c) Trends in the quantiles of the distribution of all hourly wind speed values for station Soesterberg

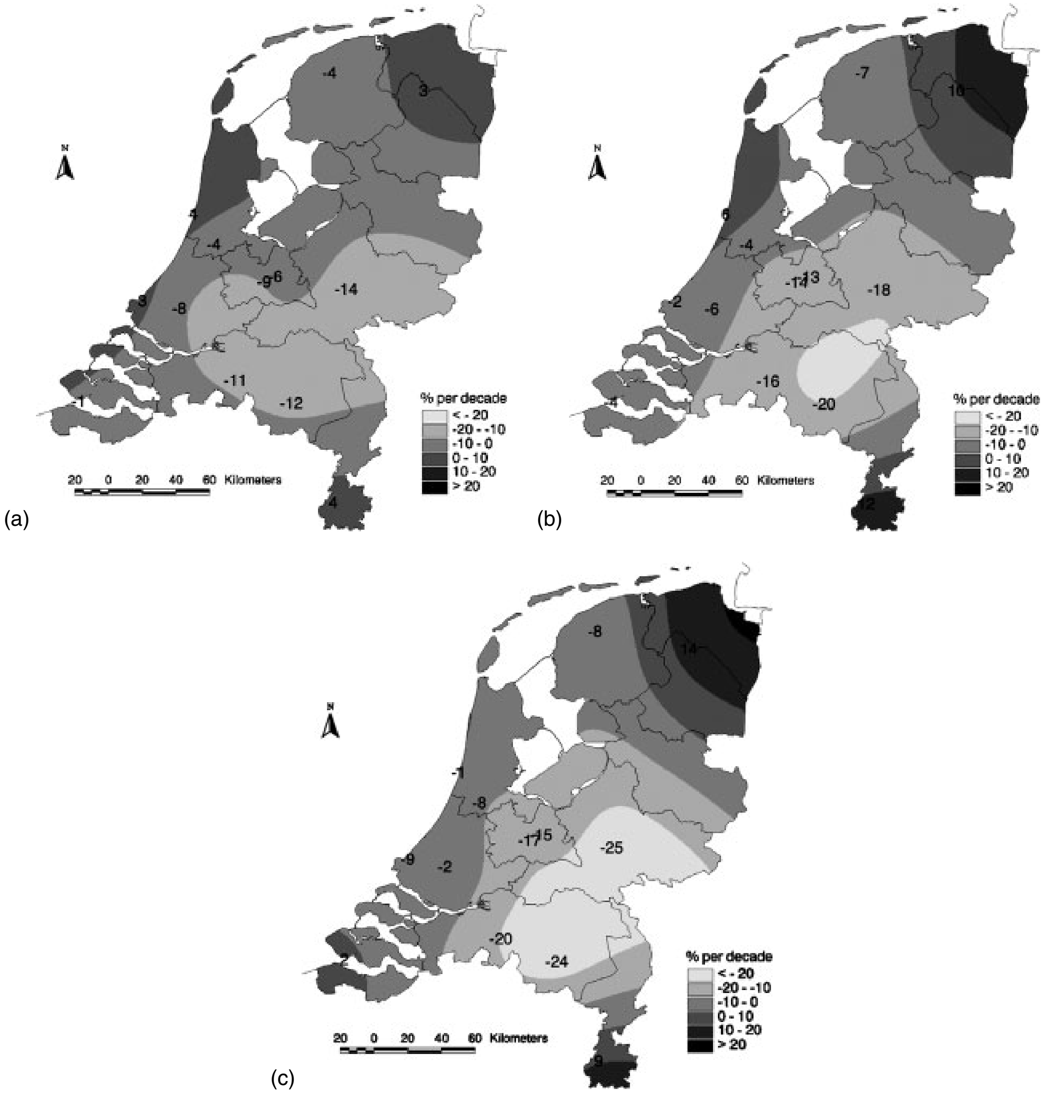


Figure 7. Trends (%/decade) in the annual number of wind events for three levels of severity (on average (a) 30, (b) 10 and (c) 2 times per year). The shading results from statistical interpolation of the station values using a minimum curvature spline method (Franke, 1982)

4.2. Geostrophic, vector-averaged and reanalysis wind

Figure 8 compares the trends in the countrywide 10 m wind (repeated from the middle panel of Figure 5) with the trends for wind events in station geostrophic wind and 10 m vector-averaged wind over the Dutch stations. Figures 9 and 10 show the trends in the 10 m, 850 hPa and geostrophic wind in the NCEP–NCAR and ECMWF reanalysis data for the grid box of the Netherlands. Trends in adjacent grid boxes are similar (not shown). The trends for the countrywide and vector-averaged 10 m wind (Figure 8) are mutually consistent. They have trend values between 5 and 10%/decade for moderate and strong wind events. However, the trends for 10 m station wind in Figure 8 differ greatly from the strongly positive trends for the NCEP–NCAR (Figure 9) and ECMWF (Figure 10) reanalysis 10 m wind, with values up to +20%/decade for moderate wind events and even higher values for strong wind events. The trends for reanalysis geostrophic wind are also positive, both in the NCEP–NCAR (Figure 9) and ECWMF (Figure 10) data. Station geostrophic wind shows no trend (Figure 8).

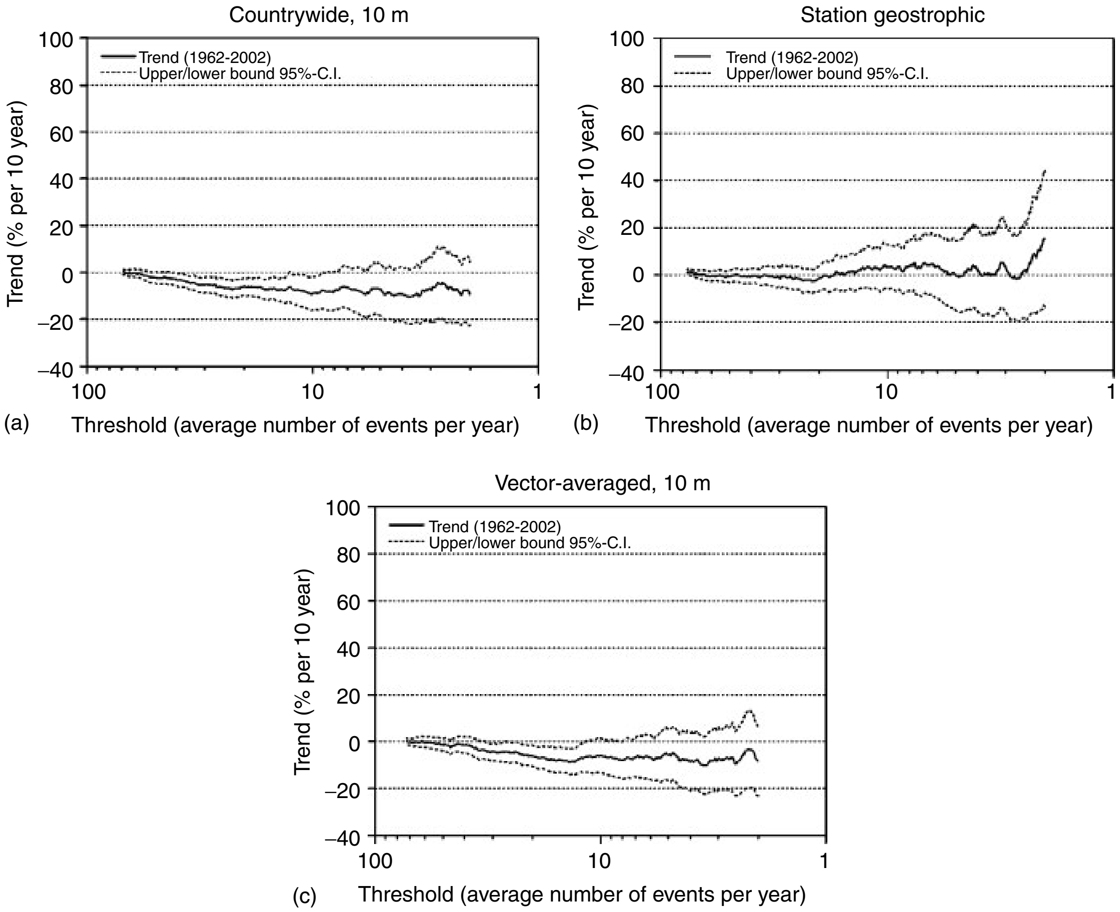


Figure 8. As Figure 5 countrywide events ((a) repeated with different vertical axis), but now also for (b) station geostrophic wind and (c) vector-averaged (upscaled) events

5. DISCUSSION

Our trend analysis of counts of independent wind events, which are derived from a high quality dataset of near-surface wind speed records, indicates a decrease in storm activity over the Netherlands in the period 1962–2002. Decreases between 5 and 10%/decade are observed for events that occur 10 times per year on average (wind speed 6–7 Bft), which we call moderate wind events. Decreases of the same magnitude are observed for events that occur twice a year on average (wind speed 7–8 Bft), which we call strong wind events. The trends identified only represent the linear change over the past 40-year period. We did not investigate whether these trends are part of longer term changes or whether decadal fluctuations are present as well.

For reasons of trend detectability constraints, no trends were calculated for events that are more severe than those that occur on average twice a year. Our results are at best indicative for the trends in the storms over the Netherlands that cause high impacts. These storms are included in the analysis, but only as a subset of the larger group of strong wind events.

The trend results are robust for the choices made with respect to the selection of wind events. A study of independent events is preferred over a straightforward calculation of upper quantiles in the annual distribution of all hourly wind speed values. This is because in many problems the peak wind of an event is the most relevant parameter. We have briefly shown that the trends in the moderate and strong wind events defined in this paper are in good agreement with the trends for the upper quantiles.

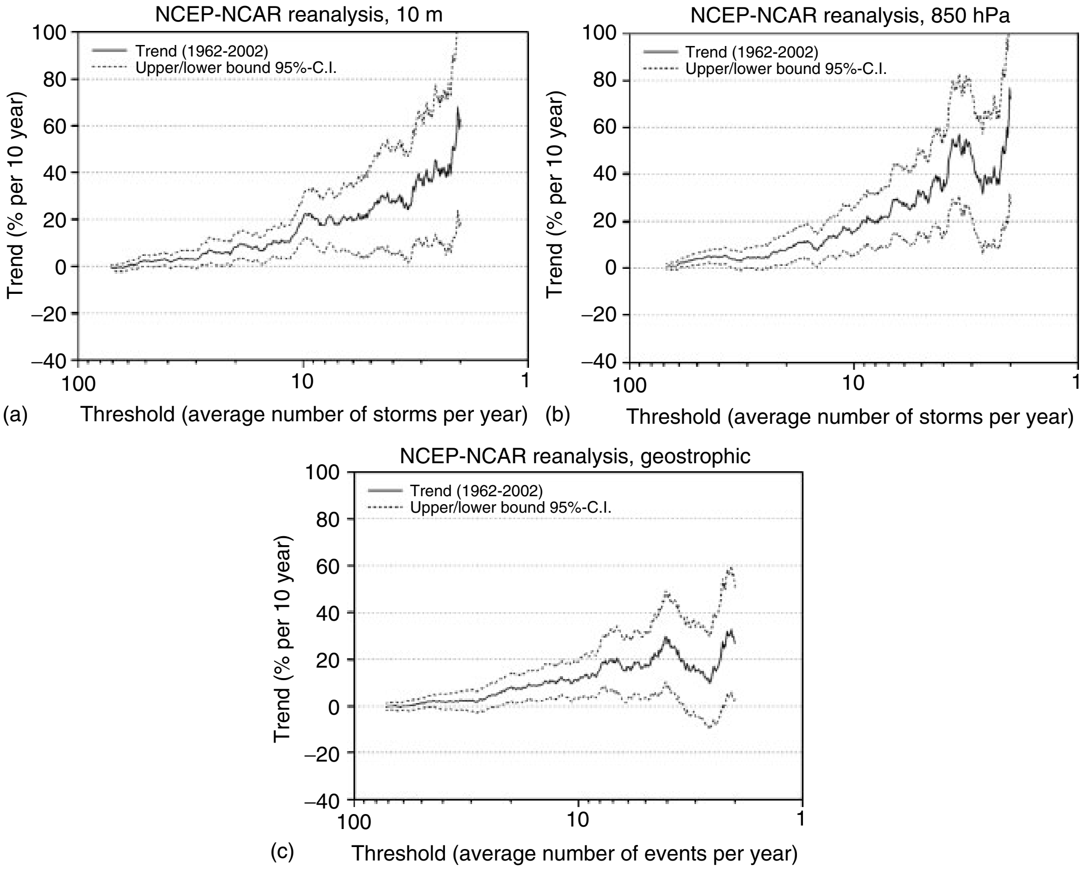


Figure 9. As Figure 5, but now for NCEP–NCAR reanalysis data: (a) 10 m wind; (b) 850 hPa wind; (c) geostrophic wind

The negative trends in storminess derived from near-surface wind at Dutch stations differ from the results for reanalysis data that show marked positive trends. The discrepancy remains when station data are upscaled to wind data (vector-averaged wind speeds are calculated from the station data) representative for the 150 × 250 km^2 reanalysis grid box covering the Netherlands. The fact that the discrepancy remains effectively rules out scale effects as a cause for the discrepancy. Adjacent reanalysis grid cells show the same discrepancy with the upscaled observations.

Possible causes for the discrepancy are homogeneity breaks. It is not obvious beforehand whether they occur predominately in the station data or in the reanalysis data. However, considering the geostrophic winds can provide a clue. The trends in the reanalysis geostrophic wind (being qualitatively consistent with those in the reanalysis 10 m wind) differ from the trends in the station geostrophic wind. This strongly suggests that inhomogeneities in the reanalysis data rather than in the observational data are the main cause for the discrepancy, because station geostrophic wind is based on station surface air pressure series that are relatively free of homogeneity breaks. The fact that our result of no trends in station geostrophic wind is in line with the findings of Alexandersson *et al.* (2000), in particular for the triangle Vestervig–Nordby–Lund, which is the one nearest to the Netherlands, strengthens this belief. Future research along the lines of Sterl (2004) should give more insight into the likelihood of the conclusion that the reanalysis data are to blame.

Nevertheless, it cannot be ruled out that the negative trends in the observed 10 m winds bear some artefacts of inhomogeneities, e.g. caused by trends in surface roughness. Although local surface roughness changes (together with other observational changes, like differences in measuring height and instrumental changes) have been effectively accounted for in the correction procedure of station data using a gustiness analysis, no corrections have been made for changes in meso-scale (∼50 km resolution) surface roughness. As in many

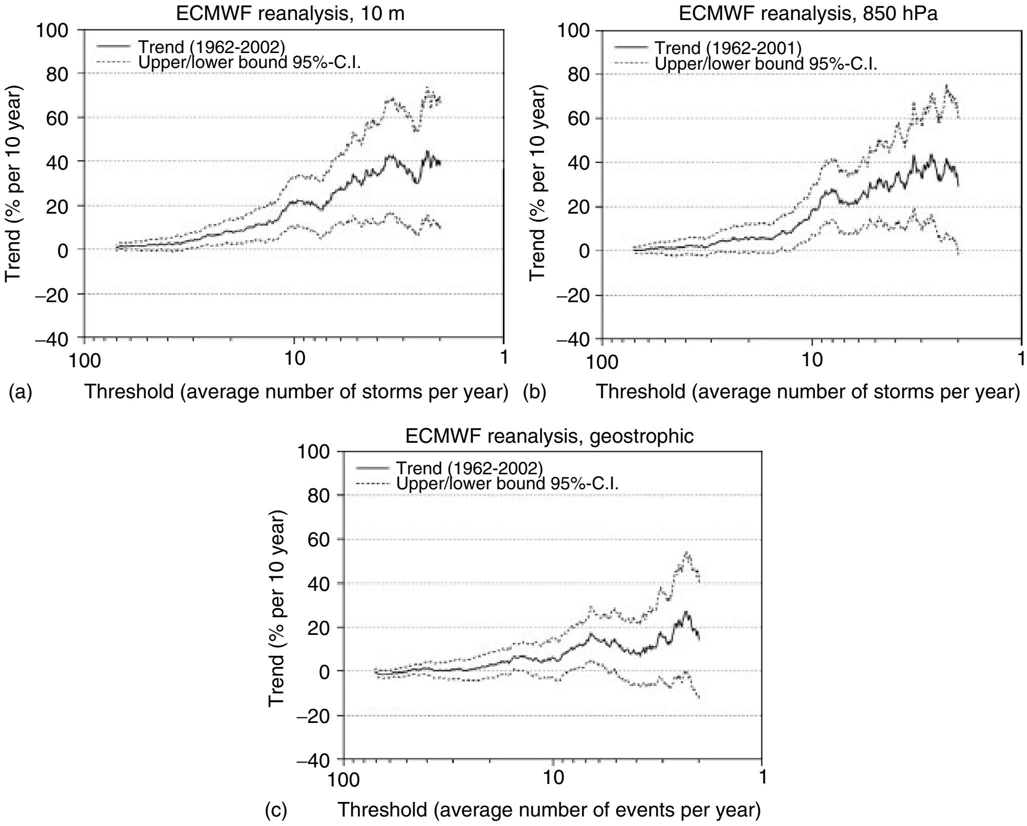


Figure 10. As Figure 5, but now for ECMWF reanalysis data: (a) 10 m wind; (b) 850 hPa wind; (c) geostrophic wind

other densely populated areas, meso-scale surface roughness over the Netherlands has increased between 1962 and 2002 due to the increase in the percentage of built-up area. However, the effect is too small to explain the observed decrease in storminess of between 5 and 10%/decade, as it can be shown that this decrease would imply an increase in surface roughness that at present would correspond with a covering of the whole territory of the Netherlands with skyscrapers, which is clearly not the case. Furthermore, it should be noted that, for the coastal stations (like Hoek van Holland) changes in meso-scale surface roughness have hardly any effect on storminess, because the vast majority of gales have westerly wind directions, and thus a fetch over the open water of the North Sea.

A further possibility exists that the negative trends in the observed 10 m winds are exaggerated because of inhomogeneities in the station data other than caused by surface roughness changes. This is also suggested by the fact that the station geostrophic wind does not show any significant trend. But this behaviour is consistent with the reanalysis data, which also indicate that the trends in geostrophic wind are weaker than the trends in 10 m or 850 hPa wind. Therefore, we conclude that the observed negative trends are possibly too high, but at the same time it is unlikely that the real trend is positive.

Further investigation of the precise reason for the discrepancy between the trends based on station near-surface wind and reanalysis wind is necessary. This should include a seasonal breakdown of the trends in order to see whether the trends are similar in each season of the year. In western Europe, the typical storm season is from October to March, and thus the winter atmospheric circulation determines the number of wind events in a year. The winter atmospheric circulation itself is governed by the North Atlantic oscillation (NAO), but correlations between the NAO index and the annual number of wind events over the Netherlands are <0.4 and mostly not significant ($\alpha = 0.05$). Apparently, even in situations of strong westerlies (high NAO index), the exact position of the jet stream and accompanying storm systems determines the number of wind events over the Netherlands in a more subtle way. For this reason, it is recommended to compare the trends at Dutch stations with those at stations in neighbouring countries over the same period. Unfortunately, data availability may be the limiting factor that hampers such an analysis.

Despite all the uncertainties, the conclusion of the present study is that storminess over the Netherlands decreased in the past decades. This conclusion awaits confirmation from other observational datasets, in particular from neighbouring countries in western Europe.

6. CONCLUSIONS

Based on station data, we conclude that the 10 m storminess over the Netherlands in the period 1962–2002 decreased by a value of between 5 and 10%/decade. Reanalysis data are inconsistent with this result, indicating increases of about 20%/decade or more.

The discrepancy cannot be explained by scale differences between the station point data and the reanalysis area-averages. Inhomogeneity in the reanalysis data is identified as the main cause of the discrepancy.

Although the negative trend in observed storminess is considered to be real, an overestimation cannot be excluded.

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REFERENCES

Alexander L, Tett S, Jonsson T. 2005. Recent observed changes in severe storms over the United Kingdom and Iceland. *Geophysical Research Letters* submitted for publication.

Alexandersson H, Schmith T, Iden K, Tuomenvirta H. 1998. Long-term variations of the storm climate over NW Europe. *The Global Atmosphere and Ocean System* **6**: 97–120.

Alexandersson H, Tuomenvirta H, Schmith T, Iden K. 2000. Trends of storms in NW Europe from an updated pressure data set. *Climate Research* **14**: 71–73.

Bärring L, von Storch H. 2004. Scandinavian storminess since about 1800. *Geophysical Research Letters* **31**: L20202. DOI: 10.1029/2004GL020441.

Franke R. 1982. Smooth interpolation of scattered data by local thin plate splines. *Computers and Mathematics with Applications* **8**: 237–281.

Gringorten II. 1963. A plotting rule for extreme probability paper. *Journal of Geophysical Research* **68**: 813–814.

Hammond JM. 1990. Storm in a teacup or winds of change? *Weather* **45**: 443–448.

Kaas E, Li T-S, Schmith T. 1996. Statistical hindcast of wind climatology in the North Atlantic and northwestern European region. *Climate Research* **7**: 97–110.

Kalnay E, Kanamitsu M, Kistler R, Collins W, Deaven D, Gandin L, Iredell M, Saha S, White G, Woollen J, Zhu Y, Chelliah M, Ebisuzaki W, Higgins W, Janowiak J, Mo KC, Ropelewski C, Wang J, Leetmaa A, Reynolds R, Jenne R, Joseph D. 1996. The NCEP/NCAR 40-year reanalysis project. *Bulletin of the American Meteorological Society* **77**: 437–471.

Keevallik S. 2003. Changes in spring weather conditions and atmospheric circulation in Estonia (1955–95). *International Journal of Climatology* **23**: 263–270.

Kistler R, Kalnay E, Collins W, Saha S, White G, Woollen J, Chelliah M, Ebisuzaki W, Kanamitsu M, Kousky V, van den Dool H, Jenne R, Fiorino M. 2001. The NCEP–NCAR 50 year reanalysis: montly mean CD-ROM and documentation. *Bulletin of the American Meteorological Society* **82**: 247–267.

Klein Tank AMG, Können GP. 2003. Trends in indices of daily temperature and precipitation extremes in Europe, 1946–1999. *Journal of Climate* **16**: 3665–3680.

Mietus M. 1995. Vector of geostrophic wind over the North Atlantic region as an index of local atmospheric sub-circulation. In *Proceedings of the Sixth International Meeting on Statistical Climatology*, Galway: Ireland; 227–230.

Palutikof JP, Brabson BB, Lister DH, Adcock ST. 1999. A review of methods to calculate extreme wind speeds. *Meteorological Applications* **6**: 119–132.

Pirazzoli PA, Tomasin A. 2003. Recent near-surface wind changes in the central Mediterranean and Adriatic areas. *International Journal of Climatology* **23**: 963–973.

Pryor SC, Barthelmie RJ. 2003. Long-term trends in near-surface flow over the Baltic. *International Journal of Climatology* **23**: 271–289.

Schiesser HH, Pfister C, Bader J. 1997. Winter storms in Switzerland north of the Alps 1864/1865–1993/1994. *Theoretical and Applied Climatology* **58**: 1–19.

Schmidt H, von Storch H. 1993. German Bight storms analysed. *Nature* **365**: 791.

Schmith T, Kaas E, Li T-S. 1998. Northeast Atlantic winter storminess 1875–1995 re-analysed. *Climate Dynamics* **14**: 529–536.

Simmons AJ, Gibson JK (eds). 2000. *The ECMWF project plan*. ECMWF Project Report Series, vol. 1, ECMWF, Reading: UK.

Sterl A. 2004. On the (in-)homogeneity of reanalysis products. *Journal of Climate* **17**: 3866–3873.

Sterl A, Caires S. 2005. Climatology, variability and extrema of ocean waves: the Web-based KNMI/ERA-40 wave atlas. *International Journal of Climatology* **25**: 963–977. DOI: 10.1002/joc.1175

Sweeney J. 2000. A three-century storm climatology for Dublin 1715–2000. *Irish Geography* **33**(1): 1–14.

Trigo IF, Davies TD, Bigg GR. 2000. Decline in Mediterranean rainfall caused by weakening of Mediterranean cyclones. *Geophysical Research Letters* **27**: 2913–2916.

Verkaik JW. 2000. Evaluation of two gustiness models for exposure correction calculations. *Journal of Applied Meteorology* **39**: 1613–1626.

WASA Group. 1998. Changing waves and storms in the northeast Atlantic? *Bulletin of the American Meteorological Society* **79**: 741–760.

Yan Z, Bate S, Chandler RE, Isham V, Wheater H. 2002. An analysis of daily maximum wind speed in northwestern Europe using generalized linear models. *Journal of Climate* **15**: 2073–2088.