Severe wind gust thresholds for Meteoalarm derived from uniform return periods in ECA&D

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1 ABSTRACT

This study presents guidelines for wind gust warning thresholds in Meteoalarm, the severe weather warning website for Europe (meteoalarm.eu). To that end we calculated the return value of the annual maximum wind gust associated with various return periods using validated wind gust data from the European Climate Assessment and Dataset (ECA&D, eca.knmi.nl). Return periods indicate how extreme an event is under local climate conditions and can be used as a measure of the possible danger of the event and its impact on society. Furthermore, warning thresholds based on return periods that are the same for the whole of Europe do not change abruptly at country borders the way the current thresholds do, which solves the problem of unrealistic differences in frequency and levels of warning between neighbouring countries. This makes for a more uniform pan-European warning system.

The chosen return periods reflect current Meteoalarm warning levels. Codes orange and red are based on the average return periods for median sized countries in the current guideline: respectively 2 and 5 years. These return periods are realistic and also represent the extensive experience of the participating National Hydrological and Meteorological Services with the damage caused by earlier extreme events. For some large and many smaller countries however, the return periods become unrealistic when they are adjusted for the size of the country as prescribed by the current guideline. Although the average return period for code yellow warnings in a median sized country is 8 times a year, we linked warning level yellow to a return period of 1 year for pragmatic reasons.

Analysis of return values shows that regional warning thresholds are required for wind gust warnings and that stations should be grouped into 3 "climate regions": coastal, inland and mountainous regions. Whether warning thresholds should depend on the season, can be established with data and tools provided in ECA&D and statistics can be used to account for population density differences. We based the choice of the new warning thresholds for wind gusts on the median of the return values.

At the time of the study ECA&D contained gust data from 8 of the 10 countries providing wind measurements. Mainly due to the standard completeness requirements and the fact that some countries provided too few stations, representative medians of the return values of annual maximum gust could be calculated for 5 countries. New thresholds for Norway, Ireland, the Netherlands, Germany and Spain are given, where the need to distinguish between coastal, inland and mountainous regions is demonstrated. The thresholds put forward in this study differ significantly from current Meteoalarm threshold for coastal and mountainous regions, for code orange and red alarm levels.

2 INTRODUCTION

There is a growing demand for accurate severe weather warnings. Worldwide the number of so-called "great natural catastrophes" (events with thousands of casualties, hundreds of thousands made homeless and substantial economic losses) has gradually increased over the past 60 years (Munich Re, 2009). Of the weather related catastrophes (as opposed to geophysical events such as earthquakes, volcanic eruptions and tsunamis) 7% are caused by extratropical storms and in 2009 alone, such storms caused losses equivalent to 81 billion US Dollars (of which about $48 billion insured). On the European scale, Meteoalarm is the initiative to answer the demand for severe weather warnings.

Meteoalarm is an initiative by EUMETNET, the public European Weather Services Network within the World Meteorological Organisation (WMO), to present all weather warnings for Europe on one web-site: meteoalarm.eu. In one overview it presents the status of all weather warnings in Europe with up-to-date reports in about 650 areas of the 30 participating countries. Warnings for up to 10 weather parameters are provided by the National Weather Service of each country, for up to 24-48 hours ahead. On the website colour codes are used to indicate the severity of the warnings. Although there are guidelines for the frequency of issuing these colour codes, they are not always followed because they translate into unrealistic warning thresholds for small and large countries. As a result, there are problems with unrealistic differences in the frequency and levels of warnings between neighbouring countries.

The aim of this study is to help establish a pan-European Meteoalarm guideline for the frequency of issuing wind gust warnings and new thresholds for these warnings. In order to get a uniform warning system the new Meteoalarm guideline is based on return periods that are the same for all countries. Because of differences in local climate conditions, uniform return periods provide return values and therefore warning thresholds that will be different for each country.

A return period is not only a measure of the likelihood of an event, but also a measure of how extreme an event is compared to the local climate conditions and as such the associated return value is a very useful indication of the possible danger of the event and its impact on society. Therefore we expect this guideline to lead not only to a more uniform warning system, but also to better warnings of the possible danger of the weather-related event and its impact on society.

2. DATA

This study uses the framework of the European Assessment and Dataset Project (ECA&D, eca.knmi.nl,, Klok and Klein Tank, 2008). ECA&D currently receives data from 63 countries throughout Europe and the Mediterranean, contains data for more than 3600 stations and serves as a data portal and climate monitoring tool for the climate research community.

For this study validated daily wind data (daily average wind speed, wind direction and daily maximum gust) were added to the ECA&D dataset. So far 10 countries provide these data: Norway, Germany, Luxembourg, Spain, Estonia, The Netherlands, Ireland, Hungary, Slovenia and Slovakia. New stations and countries are being added regularly to the ECA&D database.

Metadata are included where available. Metadata are essential for verifying homogeneity tests. For wind measurements in particular, metadata are especially important because gradual changes in the surface roughness of the surroundings can introduce a non-climatic trend in the data.

The data in ECA&D are checked for coding errors, like non-existent dates, negative speeds, gusts and directions, directions greater than 360 degrees and speeds that are higher than the gusts. Erroneous outliers are also flagged as suspect: gusts that exceed 76 m/s or average wind speeds of more than 46 m/s. Furthermore, the wind data are considered suspect if, for a number of successive non-calm days, the values remain the same.

The outlier criteria for gusts are based on extremes found in the literature. McClatchey (1996) reports on the highest official Scottish gust, which was 77 m/s at Cairngorm summit on 20-3-1986. Lamb and Frydendahl (1991) report on two higher but unofficial gusts of 79 and 84 m/s from the islands Unst and Jan Mayen respectively, far north of the Scottish mainland. Ceppi et al. (2008) show gusts of 74 m/s from two mountains (above 2400 m) in Switzerland. The upper limit which WMO advises for wind gust measurements is 75 m/s (WMO 1996), but bearing in mind the Cairngorm record, the upper limit for daily maximum wind gusts was set a little higher.

In order to base the outlier limit for average wind speed (*fg*) on that for the maximum gust (*fx*), *fg/fx* was calculated for 28 years of measurements from Jan Mayen (one of the windiest stations in Europe) and this turned out to be 0.6 with a standard deviation of 0.06 for the 84 days with *fg* $\geq$ 17.2 m/s (8 Beaufort or higher). Stations in other locations are unlikely to have a higher value of *fg/fx* because the surface roughness at Jan Mayen should be low because it is surrounded by the sea. Sixty percent of the 76 m/s gust outlier criterion was therefore used for the daily average wind speed upper limit of 46 m/s.

The repetitive test flags data as suspect when there are more than 4 successive days with the same gust or more than 5 successive days with the same speed or direction, excluding calm periods. Here the definition of calm used depends upon the element being considered: for direction (*dd*), *dd* = 0 was used (which is the WMO meteorological code for calm), for gust, *f*x < 4 m/s and for speed, *fg* < 2 m/s (Tsai et al., 2004).

The two indices used in this study were calculated using blended series. Information on the blending procedure can be found on eca.knmi.nl.

3. METHOD

In relating the return periods to the Meteoalarm warning levels for severe weather, we used that the thresholds currently used by the individual countries are a reflection of the damage experienced in the past. The return periods that we suggest should produce warning thresholds that reflect this local knowledge. The current guideline is problematic for some large and many smaller countries, because Meteoalarm decided that larger countries should use shorter return periods for the warning thresholds than smaller countries (Stepek et al, 2010).

For a median sized country yellow and red warnings are issued respectively more than 8-9 times a year and less than once in 3-4 years. Consequently, the proposed return periods for the new guidelines are as follows: 1 year for yellow, 2 years for orange and 5 years for red. Although the average return period for code yellow warnings in a median sized country is 8 times a year , we linked warning level yellow to a return period of 1 year which is currently the lowest available return period in ECA&D. So, the return values we calculate should be seen as an upper limit for new yellow warning thresholds.

Return values are calculated for time series of the annual maximum gust, only if the series covers a period of at least 10 years and there is data for 80% of the years in that period. A Gumbel distribution is fitted to the annual maxima and an Anderson-Darling test (Stephens, 1986) with a 5% significance level is used to determine the quality of the fit. Gumbel is preferred over the alternative GEV method which may give a better fit, but which generates return values that are much more unstable (Hogg and Swail, 2002). The Weibull distribution, which is often used as a fit for wind speed measurements, does not work well for extremes (Perrin, 2006). No adequate Gumbel fit could be found for 4 Dutch stations (Den Helder, De Bilt, Texelhorst and Houtribdijk) and 2 German stations (Muenchen and Dresden) so they are excluded from the analysis.

The return values were sorted into three "climate regions" (coast, inland and mountain) because the analyses indicated that they have different wind climates. The difference between coastal and inland areas is made clear in figure 1. Here, the 1 year and 10 year return values for the period 1991-2009 are set out against the distance between the station and the coastline where the open sea begins. Going to a longer return period does not affect the general relationship between return value and distance. Figure 1 shows that the gusts decrease rapidly with distance as the greater surface roughness of the land slows the wind down. From about 50 km from the coast, the influence of the sea is no longer felt and such stations can clearly be defined as inland. The distance used to define coastal stations should concentrate on the area very close to the shore where the very highest gusts are experienced because the aim here is to discover warning thresholds for coastal areas. Bearing this in mind, the defining distance was set at 12 km, with stations between 12 km and 50 km from the coast being defined as intermediate between coastal and inland.

The definition of coastline used, was that all points on this coastline are the centre of a circle of radius 20 km, with no land within the semicircle on the sea side. The flat side of this semicircle must touch land and be oriented in such a way that no other such semicircle would have it's centre closer to land. In this way the wind on the sea side of this coastline is undisturbed by the slowing effect of land because the wind in most circumstances recovers it's strength 20 km downwind from land (Barthelmie and Pryor, 2004). This definition of coastline was used instead of simply the distance to the nearest coast so that stations at the inland edge of long estuaries with an inland wind climate would not be incorrectly sorted into the group of coastal stations.

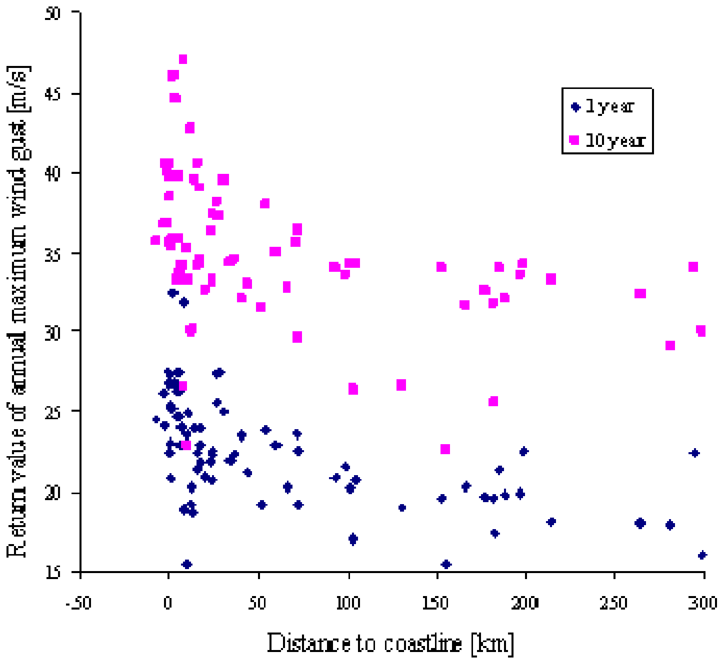

Figure 1. One and ten year return values of annual maximum wind gust [m/s] for the period 1991-2009 against distance between station and the coastline where the open sea begins

Figure 2 shows all the 1 year return values, with the exception of Alicante, plotted as a function of station height. For mountain stations (heights > 800 m) the 1 year return value increases with elevation. This increase in the wind above 800 m may be due to the presence of higher winds above the planetary boundary layer (PBL). Liu (2010) showed that for land stations the daily average of the PBL height is about 600 meters. The difference in height can be explained by daytime heating of the land surface. This causes both a deeper PBL and higher wind speeds (and extreme gusts) than at night. So the daily average PBL height is lower than the daytime average (possibly 800 m), which is more appropriate when considering extreme gusts. Coastal stations (distance to open sea ≤ 12 km) show a relatively large spread in gust values. All of these stations have a station height of less than 50 m, with the exception of one station in Spain: San Sebastian Igueldo which is a coastal station on a 252 m high cliff. For inland stations (distance to open sea

> 50 km) the spread in return values is smaller. Finally there are the intermediate stations (12 km < distance to open sea ≤ 50 km) which are not analysed.

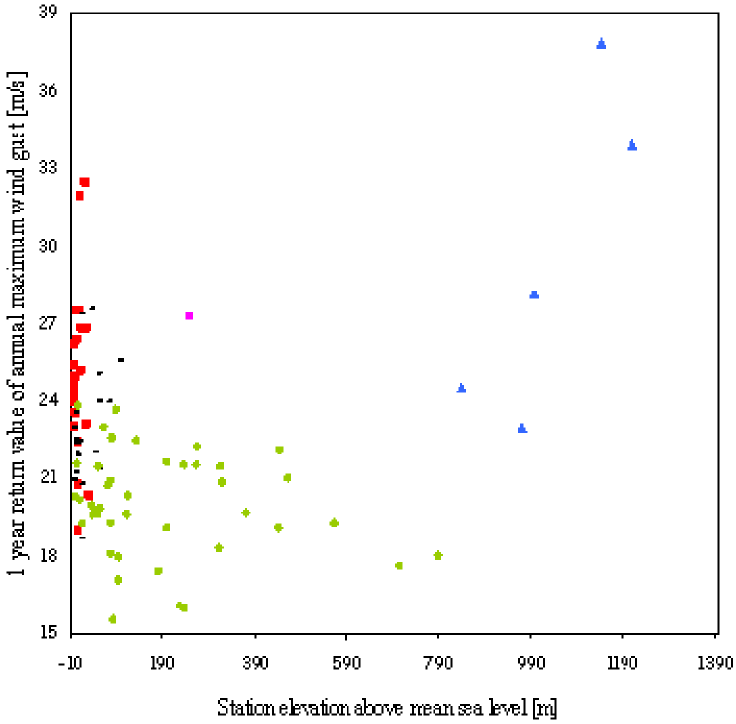

Figure 2. 1 year return values for the period 1991-2009 as a function of station height: triangles are mountain stations, dots inland stations, squares coastal stations and hyphens intermediate stations (excluded from further analysis)

4. RESULTS

The median of the return values for each "climate region" of each country is presented in table 1 (in brackets the number of stations on which the median is based). Table 1 shows, as expected, that the wind climate is more extreme in coastal and mountainous areas than in inland areas.

Table 2 shows that in nearly all the areas where enough data is available for analysis, the return period is more than 8 days per year (which is the current guideline for a median sized country). Furthermore, the threshold currently used for the yellow warning is, for all but one of the areas, indeed lower than the median of the 1 year return values (table 1). For inland areas the difference between the thresholds currently used and the 1 year return values is small, but in coastal and mountainous areas yellow warnings are most probably issued far more often than the new guidelines suggest they should.

The proposed new orange warning thresholds based on the median of the 2 year return values of the annual maximum gusts are summarized in table 1. For coastal and mountainous areas in Germany the difference is large. Current thresholds are respectively 6 and 14 m/s too low, so it is most likely that the warnings are issued more often than once in 2 years. In the mountains warnings are probably issued more than once a year, because the current threshold (28.6 m/s) is lower than the 1 year return value of 34 m/s (table 1). The new and current thresholds also differ greatly for the Irish coast and warnings are probably issued more often than once a year there too. Once again, none of the current thresholds are significantly higher than the new ones.

Table 1 shows the red warning thresholds based on the 5 year return values of the annual maximum gusts. The current threshold is much higher (by 8 m/s) for Spanish coastal and German inland areas. With the current thresholds, red warnings will not be issued once in 5 years in these areas, but a lot less often: only about once every 50 years (table 1) at half of the stations. For Irish coastal and German mountain stations the current threshold is 8-9 m/s lower than the newly proposed one. With the current thresholds, red warnings will be issued more often than once every two years, but not more than once a year (table 1). This probably means that too many red warnings are issued for these coastal and mountainous areas. Norway does not issue warnings for severe gusts, but plans to in the near future. For the Norwegian coast, with the exception of the southeastern part, the planned red warning threshold does not differ significantly from the threshold based on 5 year return values. This is also the case for the German coast and inland Ireland. The Netherlands has chosen to upgrade an orange warning to a red one when the impact of the event on society is greater. There are no objective thresholds for red warnings other than the ones used for orange warnings.

1 year return values & current thresholds for yellow warnings					
	Norway	Netherlands	Spain	Germany	Ireland
Coast	23 (4) -	25 (10) 20.8	20 (3) 19.4	27 (3) 18	32 (3) 19.5
Inland	19 (3) -	20 (3) 20.8	*18* (2)	20 (28) 18	23 (6) 19.5
Mountain	*23* (1)	-	-	34 (5) 18	-
2 year return values & current thresholds for orange warnings					
Coast	32 (4) -	30 (10) 32.7	26 (3) 24.5	35 (3) 28.6	40 (3) 30
Inland	23 (3) -	27 (3) 27.3	24 (2)	27 (28) 28.6	30 (6) 30
Mountain	*30* (1)	-	-	43 (5) 28.6	-
5 year return values & current thresholds for red warnings					
Coast	36 (4) 43,37 SE	33 (10) 33	28 (3) 36.1	40 (3) 38.8	44 (3) 36.1
Inland	25 (3) -	30 (3) 28	*27* (2)	31 (28) 38.8	33 (6) 36.1
Mountain	*33* (1)	-	-	48 (5) 38.8	-
10 year return values					
Coast	38 (4)	35 (10)	30 (3)	42 (3)	46 (3)
Inland	27 (3)	32 (3)	*29* (2)	33 (28)	35 (6)
Mountain	*36* (1)	-	-	51 (5)	-
50 year return values					
Coast	44 (4)	40 (10)	34 (3)	45 (3)	51 (3)
Inland	30 (3)	36 (3)	*34* (2)	38 (28)	40 (6)
Mountain	*41* (1)	-	-	58 (5)	-

Table 1. First number in each column is the median of the return values of the annual maximum gusts for 1991-2009 (m/s). If the number of stations on which the median is based (between brackets) is < 3 then the median values (in italic) are not representative for the climate region. Italic values can therefore not be used for comparison with current thresholds. Available current thresholds (m/s) are added to the right of the number between brackets.

	Netherlands	Germany	Ireland
Coast	45 days a year (7)	-	93 days a year (5)
Inland	-	14 days a year (20)	44 days a year (6)
Mountain	-	62 days a year (3)	-

Table 2. Median of the average number of days in a year where the maximum gust exceeds19.4 m/s (the median of the current yellow warning thresholds) for period 1971-2000 and between brackets the number of stations that the median is based on

5. DISCUSSION

Although most of the countries along the west coast of Europe are represented, the scarcity of data over much of Europe remains a problem for forming a pan-European assessment of gust warnings. The lack of uniformity in how each country calculates daily values is another problem which interferes with such efforts.

Homogeneity tests are required for reliable calculations of climatic trends. One needs to exclude “breaks” and artificial trends in order to make sure that the trend one discovers in the data is indeed due to climate change and not to relocation of stations, changes in the station surroundings or changes in measuring equipment or methods. Several methods are explored to test for inhomogeneities in the wind data, including the Petrović Redistribution index (RDI, Petrović, 2004), which uses wind direction, and the standard ECA&D homogeneity tests (Wijngaard et al, 2003) using the annual average of the wind gust factor. The latter is the aggregate of daily maximum wind gust *fx* divided by the daily average wind speed *fg*, where *fg* is not zero. However, these tests were not implemented for this study because of the experimental character of the RDI and the fact that the completeness requirements were not met for many years in the case of the wind gust factor. It would be interesting to investigate homogeneity tests based on comparing the measurement series to a reference series such as the geostrophic wind.

The Netherlands have recently increased the orange warning winter threshold for coastal areas from 27.7 to 33.3 m/s based on an earlier analysis of return values (Wever, 2009). The present analysis also shows that for The Netherlands the once in 2 year gusts are on average 5-7 m/s higher in the winter half year than in the summer half year, but not only for coastal areas. It would be worthwhile investigating if a similar seasonal difference can be found for other countries and whether the difference can be explained assuming that convection is the main cause of gustiness in the summer half year and synoptic scale weather systems in the winter half year.

Whether or not a warning is issued does not only depend on the likelihood and the possible danger of the extreme event, but also on how densely populated the affected area is and whether or not almost everyone is safe indoors, e.g. at night. In our method we do not account for the latter, but differences in population density can be taken into account by choosing different statistical methods to summarise the return values. In The Netherlands the orange and red warnings are only issued if a large enough area is likely to be affected. This minimum area affected (MAA) is 50 km² which is a bit less than 10% of the total land area. Obviously, the MAA's will vary per country and in some cases per region. Generally, the appropriate statistic for a warning area that is the same size as the MAA, is the minimum of the return values in that area (in the return period there is one station in the area where the extreme event exceeds the threshold). If the warning area is twice the size of the MAA, the median is more appropriate and in an area four times the MAA the upper quartile is the correct choice. In conclusion, the statistical method used to summarise the return values can and should be matched to the relative size of the warning area compared to the MAA considered appropriate by the issuing NMHS. The method used in this study allows for the inclusion of these country-specific requirements.

6. CONCLUSIONS

Current Meteoalarm guidelines are based on subjectively chosen return period ranges (more than 30 times a year for code yellow, 1-30 times a year for code orange and less than once a year for code red warnings) that are normalised to a standard country size of 300.000 km². Table 2 shows that these general guidelines translate into country specific guidelines that are very unrealistic for many countries. Consequently, not all countries choose their national thresholds to meet these guidelines and unrealistic differences in frequency and level of warnings between neighbouring countries are observed.

In order to make the warning system more uniform throughout Europe, new guideline return periods are proposed that are the same for all Meteoalarm countries and based on an objective and reproducable methodology: less than 1 year for code yellow, a 2 year return period for orange and 5 years for red. The return values that are based on these uniform return periods, are different for each individual country. They indicate how extreme the event is compared to the local climate and are a powerful means to indicate the possible danger of an event and its impact on society.

The results of this study indicate that warnings for hazardous wind gusts should be regionalised for coastal, inland and mountainous areas. Generally speaking, the current thresholds of the Meteoalarm countries are reasonably well chosen for the inland areas but new thresholds are required for coastal and mountainous areas.

In the ECA&D dataset there are other measurements of the weather, such as daily maximum and minimum temperature, daily snow depth and daily precipitation amount, that can be used to improve and homogenize the Meteoalarm guidelines for hazardous weather parameters other than the wind gusts considered here.

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