European Climate Assessment & Dataset

ECA&D

Analysis of wind gust thresholds in Meteoalarm

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Abstract:

The main aim of this work is to propose new wind gust related thresholds for Meteoalarm which are based on local climate. At the moment each participating country individually decides what threshold to use for the different levels of warning (colour codes yellow, orange and red). There is a Meteoalarm guideline for the frequency of issuing warnings, but it gives very unrealistic guidelines for many countries and not all countries choose their thresholds accordingly. Unrealistic differences in the frequency and severity of the warnings between neighbouring countries are the result of this. Thresholds based on return values will make the warning system more uniform and will give a better idea of how extreme the weather related event is compared to local climate. We expect these new thresholds to give a more realistic warning of the possible danger of the weather-related event and its impact on society.

We calculated return values for annual maximum gusts with the wind data available in the European Climate Assessment & Dataset (ECA&D). So far, only 6 countries provide wind gust information and there is significant data reduction, mainly due to the completeness requirements. We suggested new thresholds for wind gust warnings based on 1 year return values for code yellow, 2 year return values for code orange and 5 year return values for code red. Stations were grouped into coastal stations, inland stations and mountain stations and we were able to calculate new thresholds for Norway (coast), The Netherlands (coast), Spain (coast), Germany (inland) and Germany (mountain). For coastal areas, the thresholds currently used by Norway are far too low (for all warning levels) so warnings are probably issued too often. The same is true for mountainous areas in Germany. For inland areas the thresholds currently used by Germany are fairly good, but code red warnings are not issued often enough. In The Netherlands, the recently implemented winter thresholds for the orange coastal warnings are a bit too high compared to the thresholds we calculated and these warnings are issued slightly less often than they should be. The current yellow and summer orange warnings for the Dutch coast are issued slightly too often. Furthermore, the maximum gusts in the winter half year are about 6 m/s higher than in the summer half year, and not only on the coast.

Because of climate change, thresholds based on return values may slowly change in time. It may also be useful to consider the seasonal dependence of return values.

Content:

1. Meteoalarm guidelines

In Meteoalarm there are 10 awareness types for dangerous weather-related events. For each awareness type the current Meteoalarm guideline is to issue lowest level warnings (yellow) more than 30 times a year, orange warnings 1-30 times a year and highest level warnings (red) less than once a year. These return periods are initially the same for all countries but are then normalised to a standard country size of 300.000 km^2. The reason for applying this size weighting to the return period is that intuitively you would expect large countries to issue warnings more often than small countries because the chance that dangerous weather will hit large countries is greater. However, this normalisation for country size results in very unrealistic guidelines for many countries (appendix 1) and this implies that the above reasoning which seems intuitively right is in fact fundamentally flawed.

The intuitive reasoning that bigger countries should issue more warnings than smaller ones is true if one assumes that the warning thresholds and the climate are the same for all countries but that is obviously not true. For example: Germany is about 3 times bigger than Iceland, but despite this you would expect Iceland to warn more often for high winds because the Icelandic climate is windier. On the other hand, if Germany uses a low threshold, then it may issue just as many or even more warnings than Iceland.

Thresholds should not be the same for all countries because what is extreme for the one country, might be very normal for the other and how extreme the event is compared to the local climate will, to a large extent, determine the possible danger or social impact of the event (and therefore the level of the warning). Thresholds based on return values do reflect the local climate and they also take into account the size of the country because they are based on measurements made throughout the whole country.

The aim of this report is to present new Meteoalarm return period guidelines which are similar to the current guidelines for most of the member countries but then with warning thresholds which are based on the corresponding return values calculated using measurements of the local climate of each country.

2. Return values in ECA&D

Return values are a good measure of how extreme the event is in comparison with local climate. A return value of 2 years for example refers to an event that happens on average once in 2 years. There is a standard tool available in the European Climate & Assessment Dataset (ECA&D) to calculate thresholds that match with return values of 2, 5, 10 and 20 years (eca.knmi.nl). Fig 1 shows that for the Netherlands the 2 year return value for the annual maximum gust is 30-34 m/s on the coast and 26-30 m/s inland. This means that on average most stations in the Netherlands should expect an annual maximum gust between 26 and 34 m/s once every 2 years. The 1 year return value of the annual maximum gust in a given period is the same as the maximum gust that on average occurs once a year in that period and that is equal to the average of all the annual maximum gusts in the period.

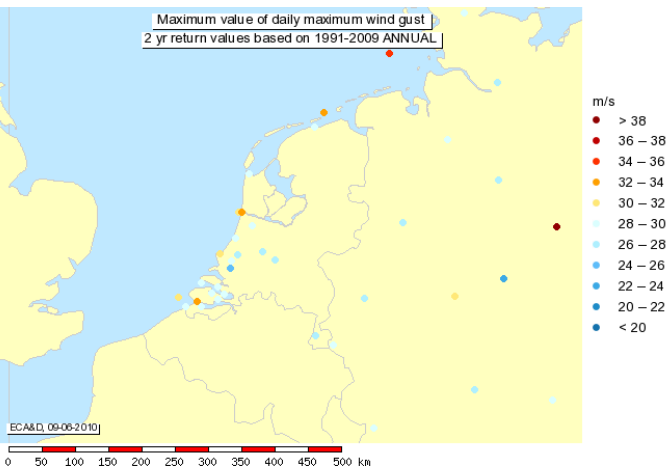

Fig 1: 2 year return values of the annual maximum gust [m/s] based on 1991-2009 period: values between 26 and 34 m/s

3. Availability of data

Appendix 2 gives an overview of the daily wind data (average winds speed, maximum wind gust and wind direction) currently available in ECA&D (June 2010). New wind data are expected soon from Ireland. Wind gust data are available from The Netherlands, Germany, Norway, Luxembourg, Estonia and Spain (fig 2).

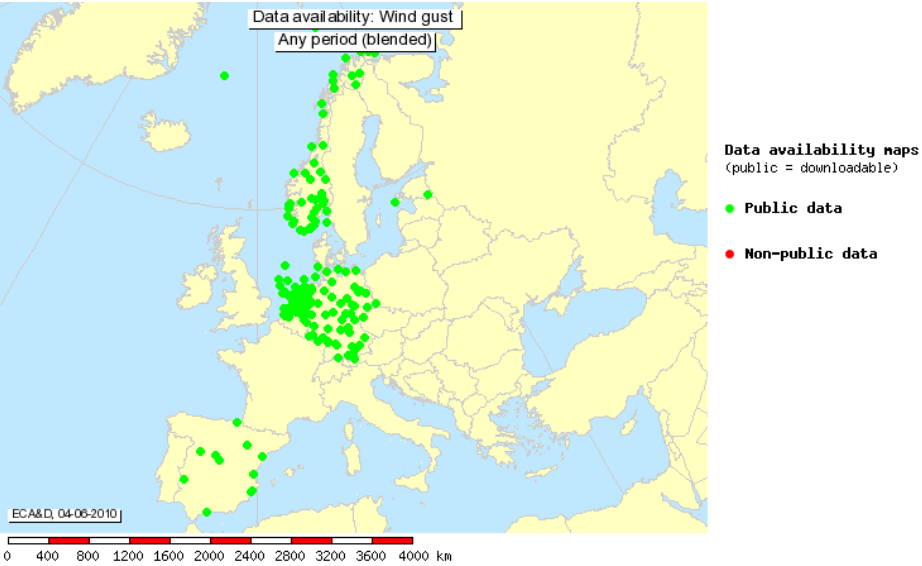

Fig 2: Map of all the stations with wind gust data in June 2010 (new stations are being added regularly)

Before these data can be used, they have to be checked (quality control and homogeneity tests) and only data that meet stringent completeness requirements will be used to calculate indices (such as the annual maximum gust). Additional completeness requirements and testing are necessary to decide whether return values can be calculated based on these indices (appendix 3). Because of the incompleteness of many wind gust series, we calculated return values with data that were not tested for homogeneity. Because only data that have passed homogeneity tests can be reliably used for calculating trends, we cannot tell if these return values (based on the most recent 19 years) are likely to change in the future. This is however the best we can do without more and better data. Even without the homogeneity tests, data reduction is significant (table 1):

Country	**Total number of stations with gust data**	**Number with the index annual maximum gust**	**Number of stations with return values**
Netherlands	60	27	23
Norway	53	13	13
Germany	52	39	37
Luxembourg	1	0	0
Spain	11	7	7
Estonia	2	2	2

Table 1: Data reduction due to completeness & Gumbel fit requirements (appendix 3)

4. Results

All available 1 year return values for the period 1991-2009 are plotted as a function of station height in fig 3. Based on this plot we distinguish between:

- Coastal stations (in red) which have a relatively large spread in values. All of these stations have a station height of less than 50 m (appendix 4), with the exception of two stations in Spain (pink): San Sebastian Igueldo which is a coastal station on a 252 m high cliff and Alicante at 82 m. Why Alicante has such a low 1 year return value, or in other words a low long-term average of the annual maximum gust (15 m/s) despite the fact that it is higher than the other coastal stations is not clear. Station Alicante el Altet, just south of Alicante, has on average annual maximum gusts of 20 m/s which is more in line with what we find for other coastal stations.
- Inland stations (green) where the spread is significantly smaller. As the light blue stations Salamanca Aeropuerto in Spain (790 m high) and Kempten in Germany (705 m high) show relatively low return values (26 and 24 m/s), we decided to group them in the inland stations category as well.
- Mountain stations (in dark blue, heights > 800 m) where the 1 year return value increases with elevation.

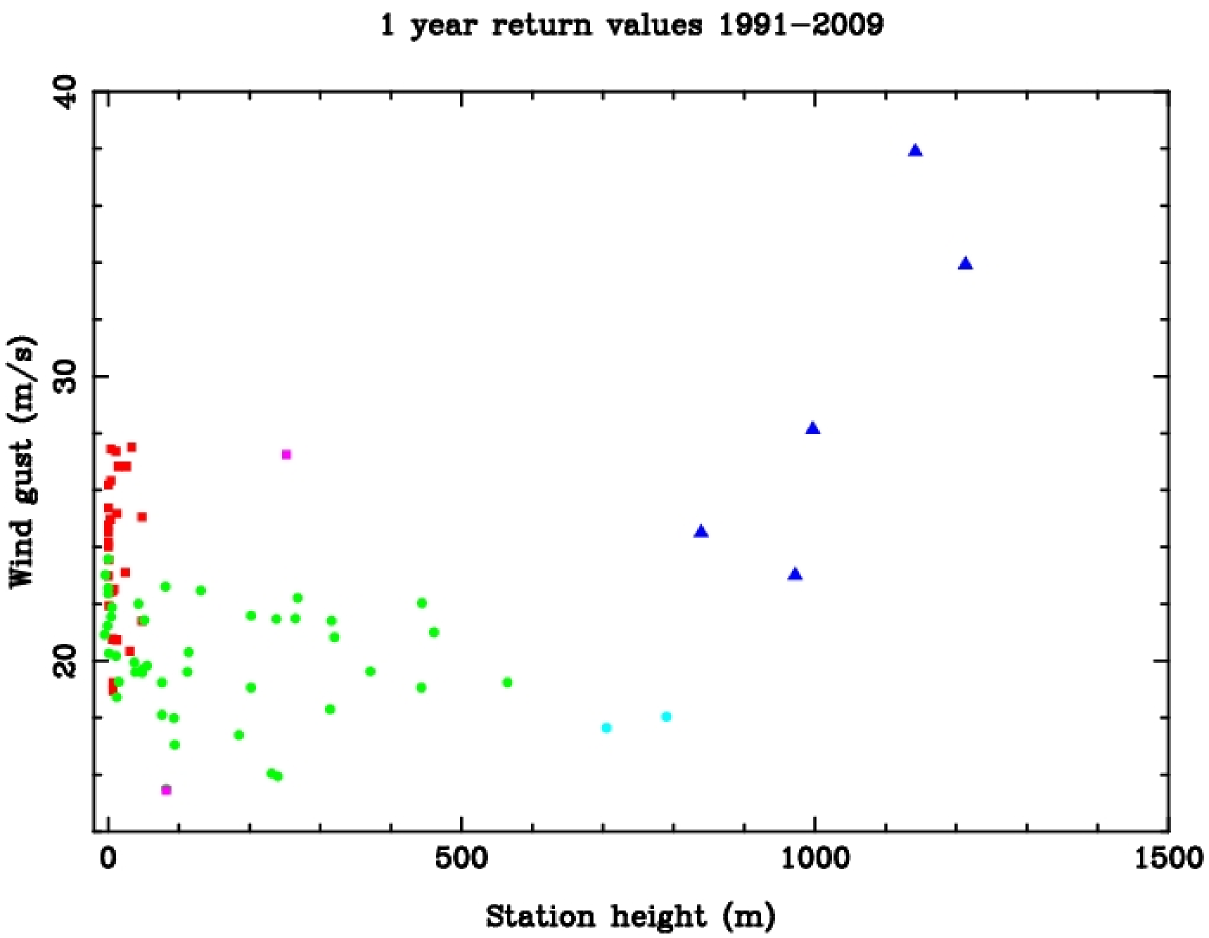

Fig 3: 1 year return values for period 1991-2009 as a function of station height: blue triangles are mountain stations, green dots inland stations (but Salamanca Aeropuerto, Spain at 790 m and Kempten, Germany at 705 m are light blue), red squares coastal stations (but Spanish stations San Sebastian at 252 m and Alicante at 82 m are pink). Fokstugu, Norway at 2574 m is not included in the plot.

The median return values for coastal, inland and mountainous areas are summarized (per country) in table 2a (50 year return value), 2b (10 year return value), 2c (5 year return value), 2d (2 year return value) and 2e (1 year return value) and the number of stations on which the median is based is shown in brackets.

	Norway	Estonia	Netherlands	Spain	Germany
Coast	41 m/s (8)	41 m/s (1)	40 m/s (13)	34 m/s (5)	44 m/s (3)
Inland	32 m/s (4)	25 m/s (1)	38 m/s (10)	34 m/s (2)	38 m/s (29)
Mountain (> 800 m)	41 m/s (1)	-	-	-	58 m/s (5)

Table 2a: 50 year return values

	Norway	Estonia	Netherlands	Spain	Germany
Coast	37 m/s (8)	35 m/s (1)	36 m/s (13)	30 m/s (5)	40 m/s (3)
Inland	28 m/s (4)	23 m/s (1)	33 m/s (10)	29 m/s (2)	33 m/s (29)
Mountain (> 800 m)	36 m/s (1)	-	-	-	51 m/s (5)

Table 2b: 10 year return values

	Norway	Estonia	Netherlands	Spain	Germany
Coast	35 m/s (8)	33 m/s (1)	34 m/s (13)	28 m/s (5)	38 m/s (3)
Inland	27 m/s (4)	21 m/s (1)	31 m/s (10)	27 m/s (2)	31 m/s (29)
Mountain (> 800 m)	33 m/s (1)	-	-	-	48 m/s (5)

Table 2c: 5 year return values

	Norway	Estonia	Netherlands	Spain	Germany
Coast	32 m/s (8)	29 m/s (1)	30 m/s (13)	26 m/s (5)	34 m/s (3)
Inland	24 m/s (4)	19 m/s (1)	28 m/s (10)	24 m/s (2)	27 m/s (29)
Mountain (> 800 m)	30 m/s (1)	-	-	-	43 m/s (5)

Table 2d: 2 year return values

	Norway	Estonia	Netherlands	Spain	Germany
Coast	23 m/s (8)	21 m/s (1)	24 m/s (13)	20 m/s (5)	27 m/s (3)
Inland	19 m/s (4)	16 m/s (1)	22 m/s (10)	18 m/s (2)	20 m/s (29)
Mountain (> 800 m)	23 m/s (1)	-	-	-	34 m/s (5)

Table 2e: 1 year return values

Table 2: Red indicates that the median values are representative for the topographical area and can be used, green indicates that there were not enough stations (< 3 stations) and blue that the stations were not sufficiently evenly distributed (e.g. most of the inland stations were close to the coast). The number of stations on which the median is based is shown in brackets.

We based our decision (whether a median value is representative for a specific topographical area) on the number of stations in the area and on how evenly these stations are distributed over the area. In the Netherlands for example, coverage for the coast is very good (13 stations), but the inland stations are not evenly distributed: most of them are nearly coastal sites and only 2 of the 10 stations are in the east of the country (fig 4).

Fig 4 also shows that two of the three coastal stations in Germany are actually off-shore stations and therefore not very representative for the German coast. There are however enough evenly distributed inland stations (29) and mountain stations (5) in Germany. These 5 are the inland German stations with return values above 30 m/s.

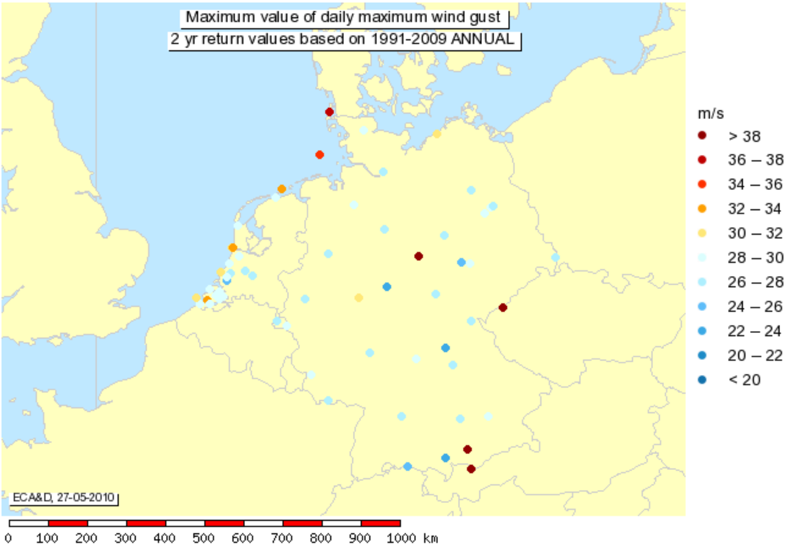

Fig 4: 2 year return values of annual maximum wind gust [m/s] based on 1991-2009 period

Fig 5 shows that coastal coverage in Spain (5 stations) and Norway (8 stations, looks like less but some are so close together that you only see one dot) is reasonable, but not as good as in the Netherlands. The spatial distribution of the 4 inland stations in Norway is poor (2 near Oslo and 2 so close to coastal stations that you only see one station).

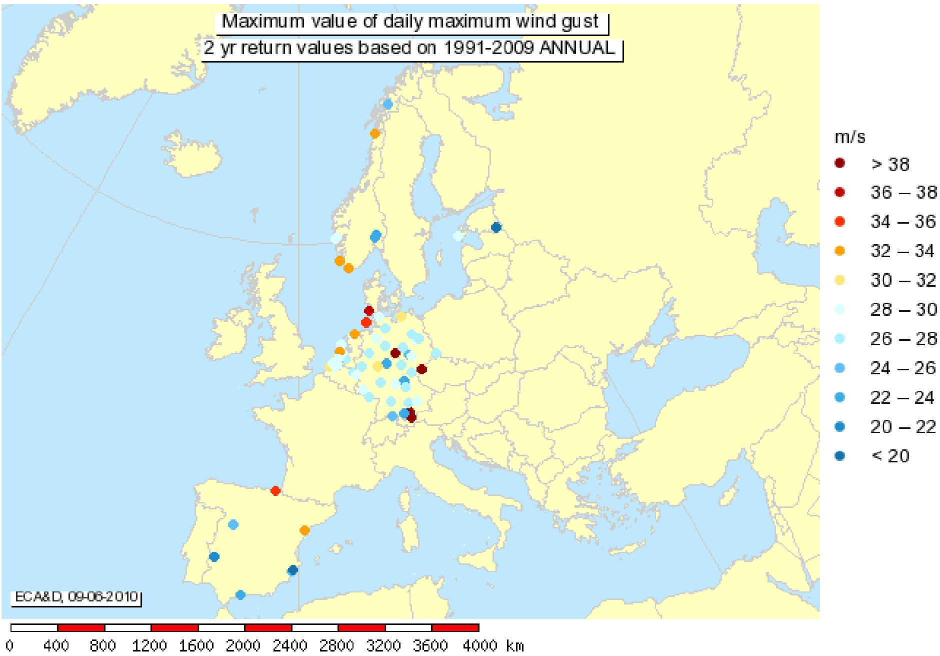

Fig 5: 2 year return values of annual maximum wind gust [m/s] based on 1991-2009 period

The median return values we calculated can be used as warning thresholds. In that case the corresponding extreme event will exceed the threshold for about half of the stations. However, in larger countries current operational practice is probably based on warnings for smaller areas.

4.1 New code yellow thresholds for annual maximum wind gust

According to Meteoalarm guidelines, a median sized country should issue code yellow warnings for wind gusts more than 8 times a year. Using the most recent climatological dataset (1971-2000) we calculated for each station the average number of days in a year where the maximum gust ≥ 19.4 m/s (which is the median of the current code yellow thresholds):

	Netherlands	Spain	Germany
Coast	45 days a year (9)	19 days a year (3)	-
Inland	-	-	14 days a year (21)
Mountain	-	-	62 days a year (3)

Table 3: Median of the average number of days in a year where the maximum gust exceeds the median of the code yellow warning thresholds (19.4 m/s) for period 1971-2000 (and number of stations that the median is based on)

From table 3 we can draw the conclusion that in all of the above cases the median of the thresholds currently used for code yellow meets the Meteoalarm guideline for median sized countries (that they should issue code yellow warnings more than 8 times a year). However for the Dutch coast and the German mountains the warnings would be issued far more often than 8 times a year and a higher threshold would seem more appropriate. The number of stations we could use for our calculations is limited by the strict missing data criteria and the fact that wind gust measurements only become widely available in the course of the 1970's. That is why Norway does not appear in the table and for the other countries the number of useful stations is less than in the period 1991-2009.

According to Meteoalarm guidelines, most countries (with the exception of Malta and Luxembourg) should issue code yellow warnings more than once a year (appendix 1). Which return period should be linked to code yellow warnings is up to the Meteoalarm Expert Team, but as a first estimate we looked at 1 year return values (see Table 4).

	Norway	Netherlands	Spain	Germany
Coast	23 m/s (13,8 m/s)	24 m/s (20.8 m/s)	20 m/s (19.4 m/s)	-
Inland	-	-	-	20 m/s (18 m/s)
Mountain (> 800 m)	-	-	-	34 m/s (18 m/s)

Table 4: Median of annual maximum gust based on 1 year return values for 1991-2009 in red, current thresholds for code yellow (appendix 5) in green, empty boxes if there are no data, not enough stations (< 3) or if stations are not sufficiently evenly distributed

- If the aim is to issue a code yellow warning more than once a year, the threshold currently used by Norway is far too low for coastal areas (by at least 9 m/s). This means that code yellow warnings are issued far more often than once a year. The current threshold may adhere to the Meteoalarm guideline of more than 38 times a year but we cannot conclude that based on our calculations. During the 2009 Meteoalarm Expert Meeting, a presentation by Ludo van der Auwera did show that Norwegian thresholds for wind gust warnings are low compared to those of other Meteoalarm countries (appendix 5).[1]
- For Spanish coastal areas there is a good match between the threshold based on 1 year return values and the threshold currently used for the whole country. Furthermore, the current threshold should be (and is) a bit lower than the return value one because the warnings should de issued not once a year but more than once a year. The current threshold is exactly equal to the median of all the current code yellow thresholds (70 km/h ~19.4 m/s), but unfortunately that does

[1] At the more recent Meteoalarm Expert Meeting of 29.6.10 the view was aired that the Norwegian wind gust thresholds in appendix 5 are actually for average wind speed because they coincide with levels from the Beaufort Scale.

not mean that the current threshold is necessarily adequate for the rest of the country. The current threshold is probably too high for inland areas, where we expect lower return values than on the coast.

- The current threshold for inland Germany is only about 2 m/s lower than the one based on ECA&D return values. However, for mountainous areas in Germany the current threshold is a colossal 16 m/s lower, which implies that warnings are currently issued far more often than once a year.
- For Dutch coastal stations the current threshold is about 4 m/s lower than the one based on ECA&D return values, suggesting that also The Netherlands currently issue these warnings more often than once a year.

4.2 New code orange thresholds for annual maximum wind gust

According to current Meteoalarm guidelines France (with 643.427 km² the biggest of the Meteoalarm countries) should issue a code orange warning between 2 and 65 times a year and Malta (with 316 km² the smallest of the Meteoalarm countries) at most once in 33 years. For the median of the sizes of the countries these values are between 8-9 times a year and once in 3-4 years. Which return period should be linked to code orange warnings is up to the Meteoalarm Expert Team, but as a first estimate we looked at 2 year return values because this is appropriate for a median sized country according to the current guidelines (table 5):

	Norway	**Netherlands**	**Spain**	**Germany**
Coast	32 m/s (20,8 m/s)	30 m/s (27,7 m/s and 33.3 m/s for coast in winter)	26 m/s (25 m/s)	-
Inland	-	-	-	27 m/s (29,2 m/s)
Mountain (> 800 m)	-	-	-	43 m/s (29,2 m/s)

Table 5: Median of annual maximum gust based on 2 year return values for 1991-2009 in red, current thresholds (appendix 5) for code orange in green, empty boxes if there are no data, not enough stations (< 3) or if stations are not sufficiently evenly distributed

- If the aim is to issue a code orange warning once every 2 years, the threshold currently used by Norway is far too low for coastal areas (by about 11 m/s). Warnings are issued far too often. With the current threshold (20.8 m/s) we should see code orange warnings on the Norwegian coast more than once a year because the current threshold is lower than the 1 year return value (23 m/s in table 4). See footnote 1 in section 4.1.
- For Spanish coastal areas the threshold based on 2 year return values matches very well with the threshold currently used for the whole country. The threshold is also equal to the median of all code orange thresholds currently used by Meteoalarm countries (90 km/h ~ 25 m/s). The current threshold is probably too high for inland areas, where we expect lower return values than on the coast.
- For German inland stations the current threshold is about 2 m/s higher than the one based on ECA&D return values. For mountainous areas in Germany the difference is a lot bigger (about 14 m/s lower). We should see code orange warnings too often there (more than once a year), because the current threshold (29.2 m/s) is lower than the 1 year return value (34 m/s in table 4).
- The Netherlands have recently increased the threshold in winter for coastal areas from 27.7 to 33.3 m/s based on an earlier analysis of return values by Wever (2009). Wever proved that return values for the winter period are the same as annual return values (appendix 6). That is why we can directly compare this new threshold for the winter period with the one based on ECA&D return values for the whole year and conclude that it is 3 m/s higher. As far as the 2 year return values for the individual stations are concerned, there are no significant differences between the ones Wever calculated and the ECA&D ones (despite small differences in the method of calculating

them). Wever did not choose a threshold based on the median of the return values, but looked at the two coastal stations with the highest return values. It is hardly surprising that his threshold is higher than ours. So the 3 m/s difference is mostly due to the different methods of translating the return values into warning thresholds and not due to the return values themselves which represent the local climate. If one was to ignore the above argument, one might be inclined to conclude that (compared to our threshold) there are too few warnings issued in the winter, but the 3 m/s difference is barely statistically significant. We do however find a strong seasonal influence: in the summer half year most stations in The Netherlands should expect a maximum daily gust between 20 and 30 m/s on average once every 2 years (fig 6), in the winter between 25 and 35 m/s (fig 7). Once in 2 year gusts are on average 5-7 m/s higher in winter than in summer and not only in coastal areas.

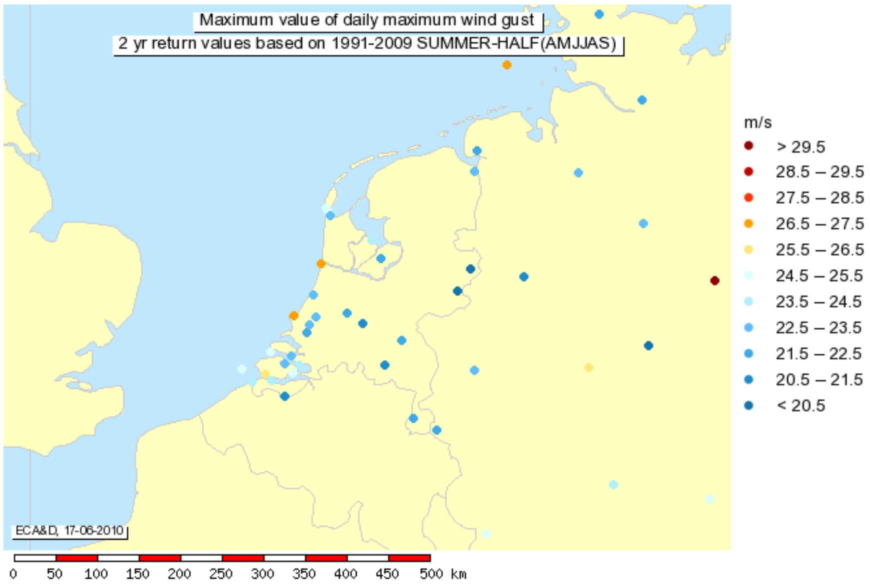

Fig 6: 2 year return values of summer half year maximum wind gust [m/s] based on 1991-2009 period (values between 20 and 30 m/s)

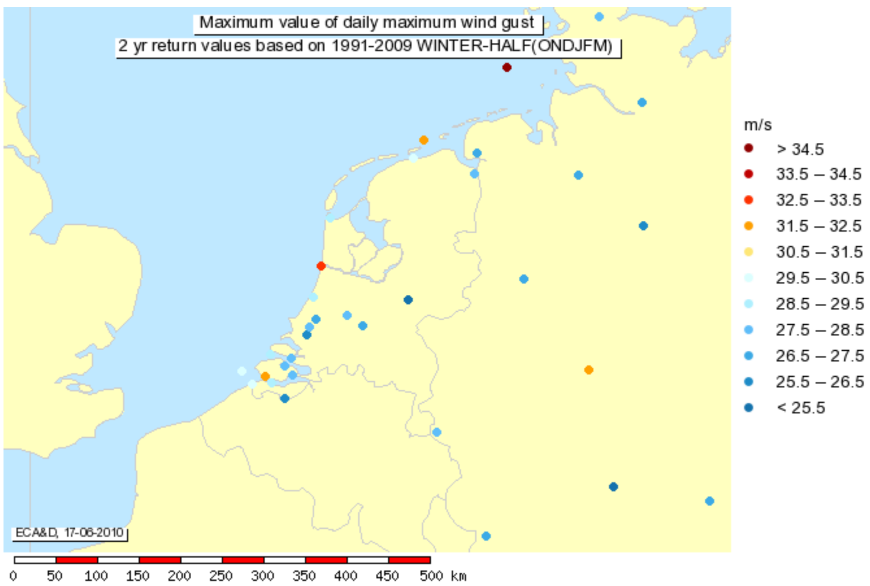

Fig 7: 2 year return values of winter half year maximum wind gust [m/s] based on 1991-2009 period (values between 25 and 35 m/s)

4.3 New code red thresholds for annual maximum wind gust

The result of country size weighting of the code red guideline (as is done in the current Meteoalarm guideline) is that France has to issue a code red warning less than 2 times a year, Malta less than once in 950 years (appendix 1). A medium sized country such as Ireland (70273 km²) has to issue a code red warning less often than once every 4 years. Which return period should be linked to these warnings is up to the Meteoalarm Expert Team, but as a first estimate we looked at 5 year return values:

	Norway	**Netherlands**	**Spain**	**Germany**
Coast	35 m/s (25 m/s)	34 m/s (-)	28 m/s (36.1 m/s)	-
Inland	-	-	-	31 m/s (38.8 m/s)
Mountain (> 800 m)	-	-	-	48 m/s (38.8 m/s)

Table 6: Median of annual maximum gust based on 5 year return values for 1991-2009 in red, current thresholds (appendix 5) for code red in green, empty boxes if there are no data, not enough stations (< 3) or if stations are not sufficiently evenly distributed

Conclusions:

- Thresholds currently used by Norway are significantly lower (by 10 m/s) than thresholds based on 5 year return values. With the current threshold (25 m/s), we should see code red warnings on the Norwegian coast more often than once every two years, but not more than once a year (table 4 and 5). See footnote 1 in section 4.1.
- For Spanish coastal areas the threshold currently used for the whole country is significantly higher than the threshold based on 5 year return values (by 8 m/s). This implies that code red warnings are not issued often enough. Table 7 shows that wind gusts equal to the current threshold (36.1 m/s) happen less than once every 50 years at half of the Spanish stations.
- For German inland stations the current threshold is about 8 m/s higher than the newly proposed one (appendix 5: Van der Auwera also found that the current code red threshold is high compared to other Meteoalarm countries) and for mountainous areas about 9 m/s lower. With the current threshold (38.8 m/s), we should see code red warnings for half of the inland German stations about once in 50 years (table 7) and for mountainous areas in Germany more often than once every two years, but not more than once a year (table 4 and 5). This means that too few code red warnings are issued for inland areas while too many are issued for mountainous areas.
- The Netherlands has chosen to upgrade a code orange warning to a code red one when the impact of the event on society is greater. There are no actual thresholds for code red warnings other than the ones used for code orange.

	Norway	**Netherlands**	**Spain**	**Germany**
Coast	41 m/s (25 m/s)	40 m/s (27,7 m/s and 33.3 m/s for coast in winter)	34 m/s (36.1 m/s)	-
Inland	-	-	-	38 m/s (38.8 m/s)
Mountain (> 800 m)	-	-	-	58 m/s (38.8 m/s)

Table 7: Median of annual maximum gust based on 50 year return values for 1991-2009 in red, current thresholds (appendix 5) in green, empty boxes if there are no data, not enough stations (< 3) or if stations are not sufficiently evenly distributed

Appendix 1: Return periods matching official Meteoalarm guidelines per country

Country name	Country Size [km2]	Country size weighted Meteoalarm criterium (once a year)	Country size weighted Meteoalarm criterium (30 times a year)
Austria	83858	once in 3-4 years	8-9 times a year
Belgium	30528	once in 9-10 years	3-4 times a year
Cyprus	9251	once in 32-33 years	about once a year
Czech rep	78866	once in 3-4 years	7-8 times a year
Denmark	43094	once in 6-7 years	4-5 times a year
Estonia	45100	once in 6-7 years	4-5 times a year
Finland	338145	1-2 times a year	33-34 times a year
France	643427	about 2 times a year	64-65 times a year
Germany	357022	1-2 times a year	35-36 times a year
Greece	131957	once in 2-3 years	13-14 times a year
Hungary	93032	once in 3-4 years	9-10 times a year
Iceland	103000	once in 2-3 years	10-11 times a year
Ireland	70273	once in 4-5 years	7-8 times a year
Italy	301318	about once a year	30-31 times a year
Latvia	64600	once in 4-5 years	6-7 times a year
Lithuania	65300	once in 4-5 years	6-7 times a year
Luxembourg	2586	once in 116-117 years	about once in 4 years
Malta	316	once in 949-950 years	about once in 33 years
Netherlands	41528	once in 7-8 years	4-5 times a year
Norway	385155	1-2 times a year	38-39 times a year
Poland	312685	about once a year	31-32 times a year
Portugal	91982	once in 3-4 years	9-10 times a year
Romania	238391	about once a year	23-24 times a year
Serbia	77474	once in 3-4 years	7-8 times a year
Slovakia	49033	once in 6-7 years	4-5 times a year
Slovenia	20256	once in 14-15 years	2-3 times a year
Spain	505992	about 2 times a year	50-51 times a year
Sweden	449964	1-2 times a year	44-45 times a year
Swiss	41284	once in 7-8 years	4-5 times a year
UK	242900	about once a year	24-25 times a year
Median	81362	once in 3-4 years	8-9 times a year

In green the biggest and the smallest Meteoalarm countries France and Malta.

Appendix 2 Wind in ECA&D dataset

The ECA&D project was initiated in 1998 and is co-ordinated by KNMI. From the ECA&D website (http://eca.knmi.nl/) long time series of daily data can be downloaded and used for climate research. ECA&D receives data from 62 countries throughout Europe and the Mediterranean. So far we have 7 countries that provide us with wind data (we expect data from Ireland soon). Background information on how the database is set up can be found in the Algorithm Theoretical Basis Document (ATBD) on the ECA&D website.

Country	Average windspeed [m/s]	Max Gust [m/s]	Direction [degrees]	Number of stations with gusts	Number with index annual maximum gust	Number of stations with return values
Netherlands	24 x 10 min average speed	3 sec gust	Vect avg of dir 06, 12 and 18 UTC (*a)	60 (*b)	27 (*c)	23 (*d)
Norway	Average speed 06, 12 & 18 UTC	10 sec gust	Dir at 12 UTC	53	13 (*e)	13
Germany (> 31-03-01)	24 x 10 min average speed	3 sec gust	Speed weighted; not used	52	39 (*f)	37 (*g)
Germany (< 01-04-01)	Average speed 06:30, 13:30 & 20:30 UTC	3 sec gust	Speed weighted; not used			
Luxembourg	-	2 sec gust	Dir at max gust time; not used	1	0 (*h)	0
Spain	4 x 10 min average speed			11	7 (*i)	7
Estonia	Mean of 8 x 10 min average speeds at 21 UTC previous day and 0, 3, 6, 9, 12, 15, 18 UTC today	Max 18-18 UTC	-	2	2	2
Slovenia	Mean of 3 x 10 min average speeds at 7, 14 and 21 CET	-	-	0	0	0

(*a) We decided to calculate a "normal" average, not a speed-weighted average (stronger winds contribute more to the wind direction average than lighter winds) because we are interested in the real distribution of the wind direction (trends in prevailing wind direction for example).
(*b) 33 were already in ECA&D, but without wind data; the number is excl. the following 12 stations that we plan to add to the database because they provide us with more than 10 years of gust data: Auk (203), F3-Fb-1 (239), Terschelling (250), Auk-Alpha (253), Meetpost Noordwijk (254), Soesterberg (265), Stavoren (267), Houtrib (268), Zierikzee (325), Auk (551), Meetpost Noordwijk (554) and Herwijnen (604).
(*c) Dutch stations (33) that did not pass the "completeness reguirement" described in appendix 3 (ECA&D sta_id between brackets): D15-FA-1 (3167), K14-FA-1C (3168), A12-CPP (3169), F16-A (3170), L9-FF-1 (3171), AWG-1 (3172), J6-A (3174), Hoorn-A (3175), Wijdenes (3178), K13 (3179), Oosterschelde (3184), Lichteiland Goeree (3188), Europlatform (3189), Vlieland (601), Berkhout (451), Hoorn Terschelling (594), Stavoren (596), Lelystad (597), Leeuwarden (603), Marknesse (411), Deelen (2563), Heino (453), Hoogeveen (2565), Eelde (164), Hupsel (454), Nieuw Beerta (500), Twenthe (2569), Westdorpe (2571), Gilze-Rijen (599), Eindhoven (2566), Volkel (442), Ell (600) and Arcen (464).
(*d) Dutch stations (4) that did not pass the "Gumbel-fit requirement" as described in appendix 3: De Bilt (162), Den Helder (160), Houtribdijk (3180) and Texelhors_MM (3177).

(*e) Norwegian stations (40) that did not pass the "completeness reguirement" as described in appendix 3 (ECA&D sta_id between brackets): Gulsvik II (2627, Lyngor Fyr (1042), Torungen Fyr (331), Nesbyen-Todokk (953), Kongsberg Brannstasjon (2576), Tromso (328), Skrova Fyr (1056), Fruholmen Fyr (1059), Karasjok (190), Karasjok-Markannjarga (942), Sihccajavri (1058), Suolovuopmi-Lulit (955), Vardoe (195), Svalbard Airport (186), Jan Mayen (189), Roros Airport (2579), Lindesnes Fyr (1044), Oksoey Fyr (264), Utsira Fyr (194), Ona II (329), Tafjord (1051), Tveitsund (1043), Slettnes Fyr (2216), Rygge (2589), Sarpsborg (2590), Tryvasshogda (2600), Drevsjo (2603), Kise Pa Hedmark (2605), Ostre Toten – Apelsvoll (2620), Bjoernoeya (179), Gvarv – Nes (2640), Fet I Eidfjord (2677), Slatteroy Fyr (2685), Sunndalsora III (2711), Trondheim – Voll (2720), Namsskogan (2726), Nordoyan Fyr (2727), Torsvag Fyr (2750), Makkaur Fyr (2754) and Sveagruva (2756).

(*f) German stations (13) that did not pass the "completeness reguirement" as described in appendix 3 (ECA&D sta_id between brackets): Westermarkelsdorf/Fehmarn (471), Greifswald (473), Emden-Flugplatz (474), Lindenberg (324), Nurburg-Barweiler (485), Meiningen (486), Karlsruhe (51), Rheinstetten (2762), Straubing (493), Jena Sternwarte (49), Kaiserslautern (50), Stuttgart-Schnarrenberg (3506) and UFS TW Ems (4670.

(*g) German stations (2) that did not pass the "Gumbel-fit requirement" as described in appendix 3: Muenchen (52) and Dresden-Klotzsche (483).

(*h) Luxembourg stations (1) that did not pass the "completeness reguirement as described in appendix 3 (ECA&D sta_id between brackets): Luxembourg Airport (203).

(*i) Spanish stations (4) that did not pass the "completeness reguirement" as described in appendix 3 (ECA&D sta_id between brackets): Madrid-Retiro (230), Navacerrada (232), Valencia (237) and Zaragoza Aeropuerto (238).

Appendix 3: ECA&D tests and completeness requirements

Quality Control:

Requirements:

- Max gust should be ≥ 0 m/s and ≤ 76 m/s
- Max gust should be ≥ average wind speed
- The number of days with the same maximum gust should not be more than 4 (unless the weather is calm, i.e. max wind gust < 4 m/s)

With the blending procedure missing data can be "filled in" with data from nearby ECA or SYNOP stations (ECA stations get priority) that are at most 25 km away and 50 m higher or lower. The blending procedure is also used to extend data sets (if there is less than 10 years difference between the year of the last date of the data set and the current date).

Homogeneity tests:

Homogeneity tests are required if you want to reliably calculate return values or say something about climate change (trends). You need to exclude "breaks" (caused by relocation of stations or changes in surroundings, but also by changes in measuring equipment or methods) in order to make sure that the trend you see is a real one caused by climate change and not by changes in where and how you did your measurements. If you measure higher wind gusts due to relocation, this will have an impact on return values.

Different homogeneity tests have been developed to detect "breaks" in data-sets and the standard tests in ECA&D are Standard Normal Homogeneity Test, Buishand, Pettitt and Von Neumann. These tests were run on the annual average of the daily wind gust factor (maximum wind gust divided by daily average wind speed) because this parameter gives a good indication of the surface roughness at the station. Homogeneity tests are done for periods starting in 1901, 1946, 1961, 1976 or 1979 and ending last year and 2 years earlier. In the period considered the wind gust factor should be available for 80% of the time. Most experts are not very optimistic about successfully correcting wind data sets with breaks in them.

Completeness requirements:

For a particular year, indices (such as the annual maximum gust) will only be calculated if there is sufficient data (at least 362 days per year with valid daily data). Only sufficiently long series (at least 10 years) are stored in the database and can be used for calculating return values.

Gumbel fit requirements:

It is only possible to calculate a return value for a certain period if there is an index for 80% of the years in that period. In order to get a return value, an Extreme Value Distribution (Gumbel in this case) is fitted to the index (annual maximum gust) and an Anderson-Darling test with a 5% significance level is used to determine whether this fit is good enough. Gumbel is the best fit for wind data (the alternative GEV method gives a better fit, but the return values generated by the fit are much more unstable). 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).

Appendix 4 Station Info

The stations and data used in this research are described in the tables below and grouped according to topographical area and country. The stop date in most cases does not mean that the station is no longer operational but simply that after that date we did not use the measurements.

Coastal stations:

Name (ECA&D sta_id)	Country	Lat/lon	Elevation (m)	Data start date	Data stop date
Hopen (187)	Norway	+76:30:00, +25:04:00	6	1987-10-01	2010-05-31
Bergen Florida (265)	Norway	+60:23:00, +05:20:00	12	1982-01-01	2010-05-31
Bodoe VI (266)	Norway	+67:16:02, +14:21:32	11	1982-01-01	2010-05-31
Lista Fyr (1045)	Norway	+58:06:36, +06:34:06	14	1982-01-01	2009-11-17
Sola (1046)	Norway	+58:53:03, +05:38:13	7	1982-01-01	2010-05-31
Bergen/Flesland (2230)	Norway	+60:17:21, +05:13:35	48	1982-01-01	2010-05-31
Obrestad Fyr (2669)	Norway	+58:39:33, +05:33:19	24	2002-05-01	2010-05-31
Bodoe - Vagones (2733)	Norway	+67:17:00, +14:28:00	33	2005-10-02	2006-01-30
Vilsandi (269)	Estonia	+58:22:59, +21:48:55	6	1970-01-01	2009-12-31
De Kooy (161)	Netherlands	+52:55:00, +04:47:00	0	1972-08-01	2010-05-31
Vlissingen (166)	Netherlands	+51:26:31, +03:35:45	8	1971-01-01	2010-05-31
Lauwersoog (413)	Netherlands	+53:24:33, +06:11:46	3	1991-03-18	2010-05-31
Wilhelminadorp (567)	Netherlands	+51:31:49, +03:53:39	1	1989-11-05	2010-05-31
Hoek van Holland (602)	Netherlands	+51:59:13, +04:05:31	12	1981-01-01	2010-05-31
Valkenburg (2570)	Netherlands	+52:09:54, +04:25:09	0	1971-01-01	2010-05-31
IJmond (3173)	Netherlands	+52:28:00, +04:31:00	0	2001-02-01	2010-05-31
IJmuiden(3176)	Netherlands	+52:27:48, +04:34:31	0	1981-01-01	2010-05-31
Huibertgat (3181)	Netherlands	+53:34:28, +06:23:59	0	1981-01-01	2010-05-31
Cadzand (3182)	Netherlands	+51:22:51, +03:22:51	1	1972-01-01	2010-05-31
Hoofdplaat (3183)	Netherlands	+51:22:42, +03:40:22	1	1997-02-01	2010-05-31
Vlakte van de Raan (3185)	Netherlands	+51:30:17, +03:14:32	0	1997-02-01	2010-05-31
Schaar (3187)	Netherlands	+51:39:22, +03:41:40	0	1983-01-01	2010-05-31
Malaga Aeropuerto (231)	Spain	+36:40:00, -04:29:17	7	1942-05-01	2009-12-31
San Sebastian – Igueldo (234)	Spain	+43:18:27, -02:02:22	252	1939-04-01	2009-12-31
Tortosa - Observatorio del Ebro (236)	Spain	+40:49:14, +00:29:29	48	1942-01-01	2009-12-31
Alicante El Altet (309)	Spain	+38:17:09, -00:33:20	31	1967-01-01	2009-12-31
Alicante (412)	Spain	+38:22:00, -00:29:40	82	1938-09-02	2009-12-31
Helgoland (468)	Germany	+54:10:35, +07:53:35	4	1971-01-01	2010-04-30
List/Sylt (469)	Germany	+55:00:45, +08:24:45	26	1971-01-01	2010-04-30
Rostock-Warnemunde (472)	Germany	+54:10:54, +12:04:56	4	1967-01-01	2010-04-30

Inland stations (< 800 m):

Name (ECA&D sta_id)	Country	Lat, Lon	Elevation (m)	Data start date	Data stop date
Oslo Blindern (193)	Norway	+59:56:34, +10:43:15	94	1982-01-01	2010-05-31
Gardermoen (1048)	Norway	+60:12:23, +11:04:49	202	1982-01-01	2010-05-31
Bardufoss (1057)	Norway	+69:03:32, +18:32:25	76	1982-01-01	2010-05-31
Kjevik (2656)	Norway	+58:12:01, +08:04:06	12	1982-01-01	2009-11-17
Voru (268)	Estonia	+57:50:46, +27:01:10	82	1970-01-01	2009-12-31
Maastricht (168)	Netherlands	+50:54:57, +05:46:37	114	1971-01-01	2010-05-31
Cabauw (438)	Netherlands	+51:58:18, +04:55:08	-1	1986-04-23	2010-05-31
Herwijnen (478)	Netherlands	+51:51:30, +05:08:43	1	1989-10-31	2010-05-31
Schiphol (593)	Netherlands	+52:18:05, +04:46:27	-4	1971-01-01	2010-05-31
Rotterdam (598)	Netherlands	+51:57:25, +04:26:14	-5	1971-01-01	2010-05-31
Woensdrecht (604)	Netherlands	+51:48:50, +04:16:14	15	1996-01-01	2010-05-31
Hansweert (3186)	Netherlands	+51:26:48, +03:59:52	0	1997-02-01	2010-05-31
Stavenisse (3190)	Netherlands	+51:35:47, +04:00:22	0	1997-10-01	2010-05-31
Tholen (3191)	Netherlands	+51:30:25, +04:07:04	0	1981-04-16	2010-05-31
Rotterdam Geulhaven (3192)	Netherlands	+51:53:34, +04:18:46	5	1991-11-01	2010-05-31
Badajoz Talavera (229)	Spain	+38:53:00, -06:49:45	185	1955-01-01	2009-12-31
Salamanca Aeropuerto (233)	Spain	+40:56:44, -05:29:46	790	1961-01-01	2009-12-31
Bamberg (40)	Germany	+49:52:31, +10:55:19	240	1971-07-17	2010-04-30
Berlin-Dahlem (41)	Germany	+52:27:50, +13:18:06	51	1971-01-01	2010-04-30
Bremen (42)	Germany	+53:02:47, +08:47:58	4	1971-01-01	2010-04-30
Frankfurt (44)	Germany	+50:02:47, +08:35:55	112	1971-01-01	2010-04-30
Halle (45)	Germany	+51:30:53, +11:57:02	93	1971-02-13	2010-04-30
Hamburg Fuhlsbuettel (47)	Germany	+53:38:06, +09:59:24	11	1971-01-01	2010-04-30
Potsdam (54)	Germany	+52:23:01, +13:03:50	81	1991-01-01	2010-04-30
Aachen (356)	Germany	+50:47:02, +06:05:42	202	1971-01-01	2010-04-30
Schleswig (470)	Germany	+54:31:44, +09:32:58	43	1971-01-01	2010-04-30
Neuruppin (475)	Germany	+52:54:19, +12:48:31	38	1967-01-01	2010-04-30
Hannover (476)	Germany	+52:27:57, +09:40:47	55	1971-01-01	2010-04-30
Magdeburg (477)	Germany	+52:06:12, +11:35:04	76	1967-01-01	2010-04-30
Dusseldorf (479)	Germany	+51:17:50, +06:46:12	37	1971-01-01	2010-04-30
Kassel (480)	Germany	+51:17:52, +09:26:37	231	1971-01-01	2010-04-30
Leipzig-Schkeuditz (482)	Germany	+51:26:10, +12:14:29	131	1972-05-01	2010-04-30
Gorlitz (484)	Germany	+51:09:48, +14:57:11	238	1967-01-01	2010-04-30
Erfurt-Bindersleben (487)	Germany	+50:59:05, +10:57:47	316	1967-01-01	2010-04-30
Wurzburg (489)	Germany	+49:46:17, +09:57:32	268	1971-01-01	2010-04-30
Hof (490)	Germany	+50:18:48, +11:52:39	565	1971-01-01	2010-04-30
Saarbrucken/ Ensheim (491)		+49:12:51, +07:06:30	320	1971-01-01	2010-04-30
Nurnberg (492)	Germany	+49:30:16, +11:03:25	314	1971-01-01	2010-04-30
Augsburg (494)	Germany	+48:25:35, +10:56:35	416	1971-01-01	2010-04-30
Konstanz (495)	Germany	+47:40:41, +09:11:28	443	1972-11-01	2010-04-30
Kempten (496)	Germany	+47:43:28, +10:20:11	705	1971-01-01	2010-04-30
Muenster/Osnabrueck (Airport) (2758)	Germany	+52:08:07, +07:42:00	48	1989-10-01	2010-04-30
Berlin-Tempelhof (2759)	Germany	+52:28:07, +13:24:14	48	1971-01-01	2010-04-30

More inland stations (< 800 m):

Name (ECA&D sta_id)	Country	Lat/lon	Elevation (m)	Data start date	Data stop date
Trier-Petrisberg (2760)	Germany	+49:44:57, +06:39:33	265	1971-01-01	2010-04-30
Stuttgart/Echter-dingen (2763)	Germany	+48:41:21, +09:13:31	371	1971-01-01	2010-04-30
Muenchen-Flughafen (2764)	Germany	+48:21:30, +11:48:33	444	1992-05-17	2010-04-30

Mountain stations (> 800 m):

Name (ECA&D sta_id)	Country	Lat/lon	Elevation (m)	Data start date	Data stop date
Fokstugu (2574)	Norway	+62:06:52, +09:17:14	972	1990-07-10	2010-05-31
Hohenpeissenberg (48)	Germany	+47:48:07, +11:00:43	997	1971-01-01	2010-04-30
Zugspitze (58)	Germany	+47:25:20, +10:59:12	2964	1971-01-01	2010-04-30
Fichtelberg (488)	Germany	+50:25:46, +12:57:19	1213	1967-01-01	2010-04-30
Kahler Asten (WST) (812)	Germany	+51:10:54, +08:29:24	839	1971-01-01	2010-04-30
Brocken (2006)	Germany	+51:48:00, +10:37:12	1142	1967-01-01	2010-04-30

Appendix 5 Current thresholds for wind gusts in Meteoalarm

Van der Auwera summarised the thresholds currently used in Meteoalarm for wind gusts (in km/h) in a presentation to the Meteoalarm Expert Meeting in June 2009 (see footnote 1 in section 4.1):

WINDGUST km/h			
Austria	60	90	120
Belgium	80	100	130
Swiss	90	1'0	130
Cyprus	95	1'5	125
Czech R	70	90	110
Germany	65	105	140
Denmark		90	115
Spain	70	90	130
Finland	70	90	110
France	80	100	130
Greece	80	1'0	130
Hungary	60	90	110
Ireland	70	1'0	130
Iceland		140	210
Italy	50	60	100
Luxemb	65	90	110
Malta			
Netherl	75	100	
Norway	50	75	90
Poland	70	90	125
Portugal	70	90	130
Romania	60	95	125
Sweden	75	90	100
Slovenia	50	70	100
Slovakia			
UK	110	130	160
Latvia	70	90	120
Estonia	55	90	120
Lithuania	55	90	120
Serbia	50	60	85

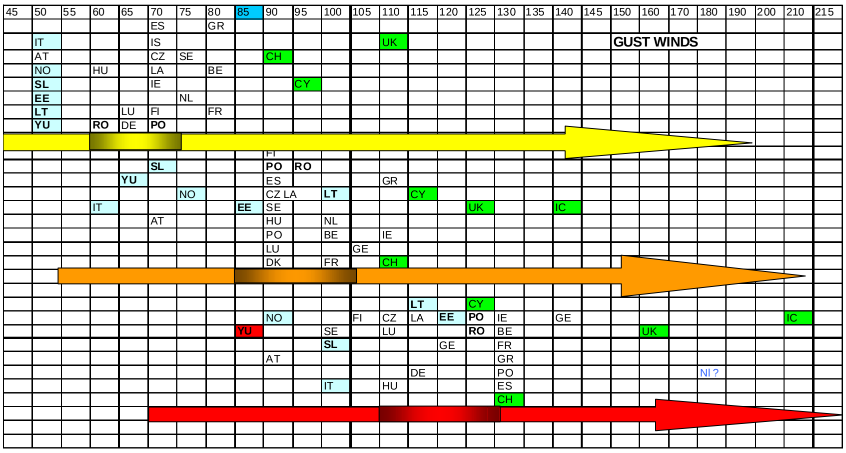

Fig A: Wind gust thresholds currently used in Meteoalarm

The wind gust criterium for code orange warnings in The Netherlands has recently changed to 100 km/u, but in winter along the coast to 120 km/u.

Appendix 6 Analysis of wind gust climatology in the Netherlands by Wever (2009)

The Netherlands have recently increased the threshold for the code orange warning in winter for coastal areas from 27.7 to 33.3 m/s based on an earlier analysis of return values by Wever (2009). Wever proved that return values for the winter period are the same as annual return values, at least for The Netherlands (fig C) and in doing so we can conclude that this threshold is about 3 m/s higher than the one based on ECA&D return values (33 m/s instead of the median of the ECA&D return values of all Dutch coastal stations of 30 m/s).

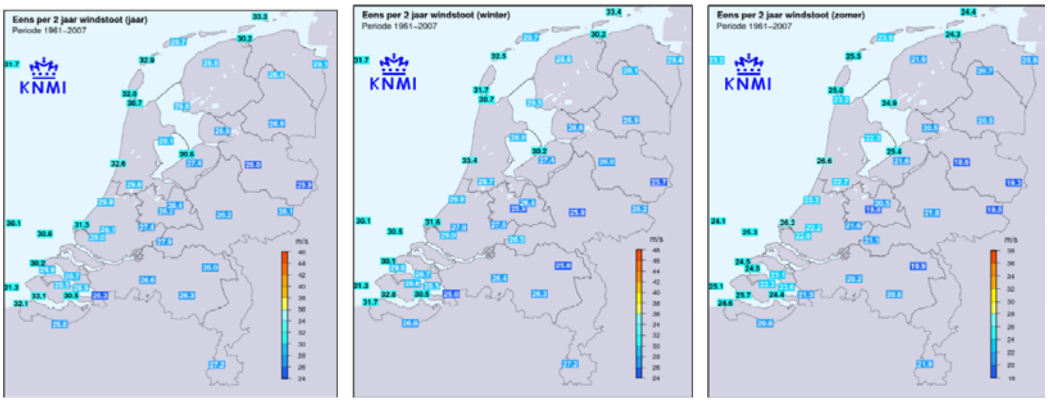

Fig B: 2 year return values of annual and seasonal maximum gust for 1961-2007, Wever (2009)

Wever uses values for the daily maximum wind gust FXX from the REH-table (which is a table in the Dutch climatological database KIS with aggregated values), just like ECA&D does. FXX is only available if all 24 hours show a maximum wind gust, otherwise no value for FXX is stored in the REH-table.

ECA&D analysis compared to Wever:

- The ECA&D return values are calculated for 1991-2009 (most recent 19 years) instead of 1961-2007. Consequently, we might expect ECA&D return values to be more accurate, because reliably calculating return values using the Gumbel-fit as is done here, requires a stable climate for the period considered and the risk of a trend is greater in 45 than in 19 years. Then again, a fit based on more data will be more accurate if the climate is stable.
- Wever requires that the number of days per year with valid maximum wind gust should be at least 82% (at least 300 days for the whole year and 150 for summer/winter). The ECA&D completeness requirement is more stringent (at least 362 days per year with valid data).
- Only series of 10 years and longer are used to calculate return values by Wever, which is the same as in ECA&D, but in ECA&D there is an additional requirement that 80% of the years in the period under consideration (in this case 1991-2009) should have sufficient daily maximum wind gust data.
- Wever uses a station subset from KIS that is slightly different from the one used for the analysis in ECA&D. For Wever's analysis all Dutch stations have been used with the exception of Terschelling Brandaris and Arcen. The number of coastal stations used in both analyses is comparable (ECA&D 13, Wever 15).
- In both analyses an Extreme Value Distribution (Gumbel in this case) is fitted to the annual maximum wind gusts (blue dotted line in fig D) and the Maximum Likelihood Method is used to determine the characteristics of the fit (μ and σ) per station. Wever uses the Bootstrap Method to determine the 95% confidence level of the measurements ("between" the green lines in fig D): if a return value is outside the 95% confidence intervals (green lines), there is still a 5% chance that the fit is correct. In general, return values can be calculated more accurately if there are more measurements (green lines will usually be closer together). Except for Cadzand, all the ECA&D return values (table A) are within the confidence interval (green lines) of Wever. Therefore there is no indication that the 3 m/s difference between the threshold based on ECA&D and the one based on Wever return values, is caused by the way the return values were calculated.

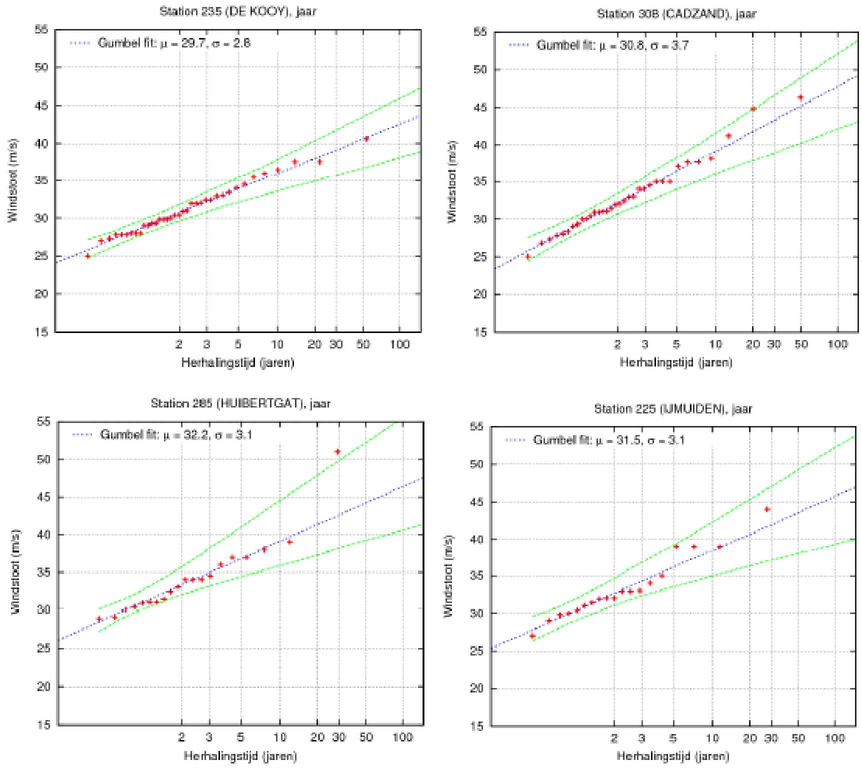

Fig C: Return values for annual maximum gusts for 1961-2007 (Wever 2009)

- Wever did not choose a threshold based on the median of the return values, but looked at the two coastal stations with the highest return values. It is hardly surprising that his threshold is higher than ours.
- If we calculate the median of Wever's return values for the 11 common stations (table A) and compare that to the median of the ECA&D return values for those stations, the difference is 1.8 m/s (Wever 31.5 m/s, ECA&D 29.7 m/s). So even if the stations are the same and the return values of those stations are not significantly different, the median of the return values can vary by 1.8 m/s. For The Netherlands we can therefore assume that differences between the current Meteoalarm thresholds and those based on ECA&D 2 year return values are only significant, if they are more than 2 m/s.

Coastal stations ECA&D analysis	Coastal stations Wever (2009)	Common stations	2 year return value ECA&D	2 year return value Wever	WMO number	ECA&D sta_id
Cadzand	Cadzand	Cadzand	29.97	32.1	06308	3182
De Kooy	De Kooy	De Kooy	29.60	30.7	06235	161
Hoek van Holland	Hoek van Holland	Hoek van Holland	31.06	31.5	06330	602
Hoofdplaat					06311	3183
Huibertgat	Huibertgat	Huibertgat	33.14	33.3	06285	3181
IJmond					06209	3173
IJmuiden	IJmuiden	IJmuiden	32.60	32.6	06225	3176
Lauwersoog	Lauwersoog	Lauwersoog	29.54	30.2	06277	413
Schaar	Schaar	Schaar	29.46	29.9	06316	3187
Valkenburg	Valkenburg	Valkenburg	28.89	29.9	06210	2570
Vlakte van de Raan	Vlakte van de Raan	Vlakte van de Raan	30.67	31.3	06313	3185
Vlissingen	Vlissingen	Vlissingen	32.45	33.1	06310	166
Wilhelminadorp	Wilhelminadorp	Wilhelminadorp	28.30	28.5	06323	567
	Oosterschelde			30.2	06312	-
	Terschelling Hoorn			29.7	06251	-
	Texelhors			32	06229	-
	Vlieland			32.8	06242	-

Table A: Common coastal ECA&D and Wever stations used to calculate 2 year return values of annual maximum gusts

References

Wever, N (2009). "Windstotenklimatologie Nederland". KNMI Technisch Rapport TR-306, 11 juni 2009.