Storm tide in the harbor of the Frisian island Terschelling

G.P. Können, Terschelling Diary 2011/01
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On 12 November 2010 we experienced a spectacular storm surge which caused the Terschelling port area to be flooded. Supported by some photos we provide this high tide ‘with a face’, that is: we lift the surge above the domain of bare numbers. But it is also indicated how rare such an event is and how much worse it can be.

During our autumn break on the Frisian island Terschelling (The Netherlands, 53° 24′N, 5° 19′ E) we were treated to a surprise: on Friday 12 November 2010 a strong WSW gale of force 9-10 Beaufort drove the sea so high that during high tide the quays around the harbor flooded. This happened despite the fact that it was neap tide (it was the day before the Moon’s First Quarter) so that the water level at high tide was supposed to be relatively low. The next day, when the gale had ceased, the high tide was back at its normal value and one could walk on the quays without getting wet.

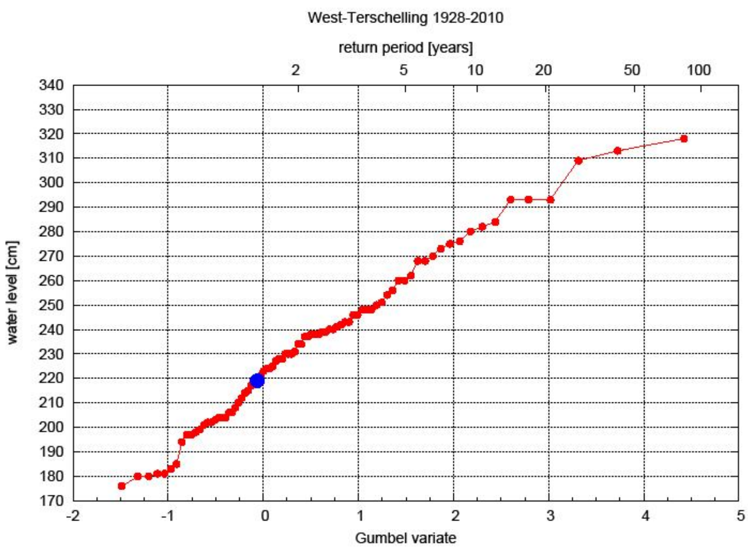
12 November 2010, 12:18 MET. The quay of the port of West-Terschelling is flooded by the surge.

13 November 2010, 11:57 MET. The gale ceased and high tide is 1½ meter lower than on the previous day.

On that Friday afternoon, the surge added considerable to the water level: instead of 64 cm above mean sea level (MSL), the high tide of the West-Terschelling harbor reached up to 219 cm above MSL – an increase of more than 1½ meter due to this storm. Not only the quay, but also most of the parking area next to the ferry terminal was flooded. Thinking of it, if it had been spring tide, this high tide could easily have been 50 cm higher. The third photo, taken on 1 March 2008 from almost the same position, shows how the quay would have looked in that case. The maximum water level then was 268 cm above MSL – hence another half meter higher than 12 November 2010.

1 March 2008, 12:30 MET. On this day a strong gale had pushed the high-tide water level 268 cm above MSL, which is a half meter higher than on 12 Nov 2010. The wall next to the footpath as well as the fence in front of the ship are almost entirely under water (photo C.H. Smit).

One may wonder how often a sea water level of 2.19 m above MSL occurs in the Terschelling harbor – or, putting it differently, how often would the parking place next to the ferry disappear under water.



High tides on a row: graph of the highest observed water levels per calendar year in West-Terschelling, 1928-2010. On this so-called Gumbel plot the 83 points nicely line up along a straight line. The blue dot is the level of 12 Nov 2010: 2.19 meter above MSL. This level occurs on average once every year; a level of 2.68 meter on average once every 5 year, so about twenty times per century (Figure credit: H.W. van den Brink).

To explore this, we have collected all annual maximum water levels and plotted them on so-called Gumbel paper [see Appendix]. The observations fit nicely a straight line. From the graph one estimates what the average interval is between two events similar to 12 November 2010[1].

The blue dot in the graph is the 2010-point: on 12 November the maximum of that year occurred. The graph tells us that one may expect the water level to match or exceed the 12-November value once a year. Rare, but certainly not extremely rare: much higher levels may occur. For instance, if the gale had been a bit stronger or if its direction had been a bit more from the north, the level could easily be one meter higher when gale and spring tide coincide. In such case the sea water would reach halfway the height of the protecting wall between the harbor and the town – hence up to the headlights of the parked cars on the 12 November photos. But to achieve this, all circumstances have to be ‘favorable’. That is why such an event is so rare: the graph tells us that a 3.15 m high tide occurs on average once every 50 years – twice in a century[2].

12 November 2010, 12:37 MET. The jetty that gives access to the lifeboats ‘Arie Visser’ and ‘Typhoon’ is flooded. One wonders what the ship rescuers would do if a violent north-westerly gale pushes the water level up by another meter.

In this context it is curious to bring up an embarrassing situation that happened 25 years ago, when the car parking place in the Terschelling port area was constructed: the newly created terrain turned out to be so low that it flooded several times per year. Quickly they had to raise the terrain by another half meter in order to bring the frequency of such a mishap back to once a year. The graph tells us that the original parking place (about 1.70 m above MSL) would be flooded more than five times per year, which is of course completely unacceptable. Remarkable that this design blunder had to happen in Terschelling, where everybody grows up with high and low tides.

*With thanks to F. Koek for comments. [NB: A Dutch version of this artikel appeared in Zenit, **39**, 14-15 (2012). It can be downloaded from the section Dutch/Klimaat of my website]*

[1] The analysis of Gumbel plots is a standard approach to empirically estimate the design heights of coastal dikes for coast protection. In principle this is done by extrapolating the fitted line till a value of the Gumbel variate (x-axis) of about 9, which is equivalent to a return period of 10.000 year (representing a probability of dike failure of 1% per century).

[2] It is a nice exercise for high school students to construct a Gumbel plot of annual extremes of some geophysical parameter, e.g. precipitation, high or low temperatures, surges, earth quakes etc. It is often amazing to see how the seemingly erratic series of the annual extremes are transformed in this representation almost always in a straight line.

APPENDIX

A magic theorem in the theory of the statistics of extreme values.

The statistics of extreme values considers frequencies of occurrence in the extreme far tail of statistical distributions – an important region, which is not easily accessible with empirical methods. A formidable obstacle in the estimation of these frequencies is the uncertainly about (mathematical) form of this far tail: satisfies the underlying distribution a Gaussian, lognormal, exponential or an other distribution? This seemingly insurmountable difficulty is bypassed by the application of an almost counter-intuitive theorem, which states that the distribution of extreme values converges to the so-called Gumbel distribution* *regardless of the form of the underlying distribution***. Thus it is justified to extrapolate an empirically obtained Gumbel distribution up to phenomena of extreme rarity, without bothering about the analytical form of the extreme tail of the distribution where that phenomenon originates from!

How can we achieve this convergence? This is done by constructing the (empirical) distribution of annual maxima, thus of the highest value that occurred in each (calendar) year. Of course, this procedure results in an enormous data thinning: of each annual series of 365 day values only one (the highest one) is used. The resulting increase in noise is the prize one has to pay to get the theorem at work.

Technically a Gumbel-analyse works as follows. Let we assume that there are 83 annual maxima available, like in case of the high-tide series of Terschelling. First, they are ordered according to the heights of the observed sea levels, after which to each value a return period is assigned – that is: the probability of occurrence in a year. For the highest value in the series, the assigned probability is 1/84, and hence an (average) return period 84 year is assumed; for the next one it is 2/84 and the return period is 42 year; for the third-highest it is 3/84 and so on; for the lowest maximum it is 83/84. With use of these 83 values a Gumbel plot is constructed, that is: a plot with on the y-axis the observed value and on the x-axis the probability, the latter being transformed with the inverse of the cumulative Gumbel distribution, thus -ln(-ln(1-probability)) (the so-called Gumbel variate). So for a point with return period 100 year (probability 0.01) the Gumbel variate is 4.6; for return period 10,000 year it is 9.2. Plotted in this representation the point-cloud organizes itself around a straight line. With aid of a ruler (or a more sophisticated technique) one obtains an estimate of water levels which belong to very large return periods. See Figure 5.

*In the cumulative representation, the mathematical form of the Gumbel distribution reads exp(-exp(-x)), where represents the (scaled) variable. In distributive form it is
exp(-x-exp(-x)).
** Strict mathematically there are two other functions to which the distribution may converge. However for most physically realistic problems the convergence is to the Gumbel distribution, or to something close to it.

Literature

General
1. http://en.wikipedia.org/wiki/Gumbel_distribution
An excellent introduction (alas in Dutch) to the extreme value statistics (to which the Gumbel distribution belongs) can be found in:
2. Buishand, T.A. en Velds, C.A. (1980) *Neerslag en Verdamping*, Deel 1 van de serie Klimaat van Nederland, KNMI/Staatsdrukkerij, Chapter 8 (blz. 104-118)
[can be downloaded from the site of the KNMI,
http://www.knmi.nl/bibliotheek/knmipubDIV/Neerslag_en_verdamping.pdf
(NB: size of the file is 16 MB)].