Dealing with extreme storm surges in The Netherlands

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1. Introduction

A considerable part of The Netherlands lies beneath mean sea level, see Figure 1, including the most densely populated economical and political centres near the coast with cities like Amsterdam, Rotterdam and Den Haag (The Hague). However, since the storm surge disaster of 1953, no serious flooding has occurred, and the threat of high water levels either at the coast or from the rivers is not perceived as very serious.

The coastal defences are designed to be able to withstand a storm surge that occurs once every 10,000 years. Where the natural barriers, dunes, are not sufficient, they have been augmented by dikes. In the Nieuwe Waterweg at Hoek van Holland and the Oosterschelde, movable storm surge barriers have been built, which allow in- and outflow of seawater and traffic to and from the Rotterdam harbour under normal circumstances. But in case of a sufficiently high storm surge, they will be closed and protect the population, land and infrastructure behind.

Fig. 1. The Netherlands: land below sea level (blue) and storm surge barriers

Forecasts for storm surges are issued by Rijkswaterstaat (RWS) and are a joined responsibility with the Netherlands' Royal Meteorological Institute (KNMI). Under normal circumstances the forecasts are issued by RWS's Hydro-Meteo Centres, but when high water levels are expected, the Netherlands' Water Management Centre (WMCN) takes over and coordinates the actions to be taken by local authorities. The former Storm Surge Warning Service (SVSD) has recently become part of WMCN.

Optimal operation of the storm surge barriers and guidance for local authorities require accurate storm surge forecasts as far as 2 days ahead. Preparation for (potentially) dangerous storm surge events, on the other hand, can greatly benefit from forecasts up to 10 days ahead. There, forecasters and also scientists have an even more important task to help decision makers with the interpretation of this kind of information and integration into their considerations.

This paper will outline forecasting procedures and practices in day-to-day and also extreme situations, and introduce the forecasting tools which are available. The focus will be on the medium-range decision making process in the case of high storm surges.

2. Storm surge management

The impact of a storm surge is determined by the combination of the astronomical tide and the meteorological effect. Therefore, the total sea level is the defining parameter for the classification of a storm surge event. An overview of significant levels for actions to be taken is given in Table 1.

When the probability of reaching at least the Warning level within 8 days in any of the coastal regions is more than 25%, KNMI contacts WMCN. This triggers an escalation ladder for coordination of the

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TABLE 1. Significant levels for storm surge forecasts

Level	Action	Exceedance [year^{-1}]	ID
Information	KNMI informs WMCN	10	IP
Pre-warning	WMCN issues limited warnings	5	VP
Warning	WMCN office opened, issues warnings	2	WP
Regional Alarm	WMCN advises local authorities, LCO active	0.2	RAP
National Alarm	DG-RWS leading	$5 \cdot 10^{-2} - 10^{-2}$	LAP
Critical	NCC leading	$5 \cdot 10^{-3} - 10^{-3}$	KRIT
Design		$5 \cdot 10^{-4} - 10^{-4}$	MHW

WMCN	Netherlands' Water Management Centre
LCO	National Flooding Committee
DG-RWS	Director General of Rijkswaterstaat
NCC	National Crisis Centre

actions to be taken to deal with the possible consequences of the high water. When the forecasts for the coming 48 hours exceed the Warning level, WMCN advises local authorities on measurements like watching of dikes and closing of openings in flood walls. From a probability of 20% of exceeding the Regional Alarm level the National Committee on Inundation Threat (LCO) will evaluate the situation and advise on additional measures and possible evacuations. In case the forecasts exceed the National Alarm or Critical levels with more than 20%, this is taken to the higher levels of the Director General of Rijkswaterstaat and the National Crisis Centre, where cabinet ministers will take part in decision making if necessary.

3. Numerical storm surge forecasts

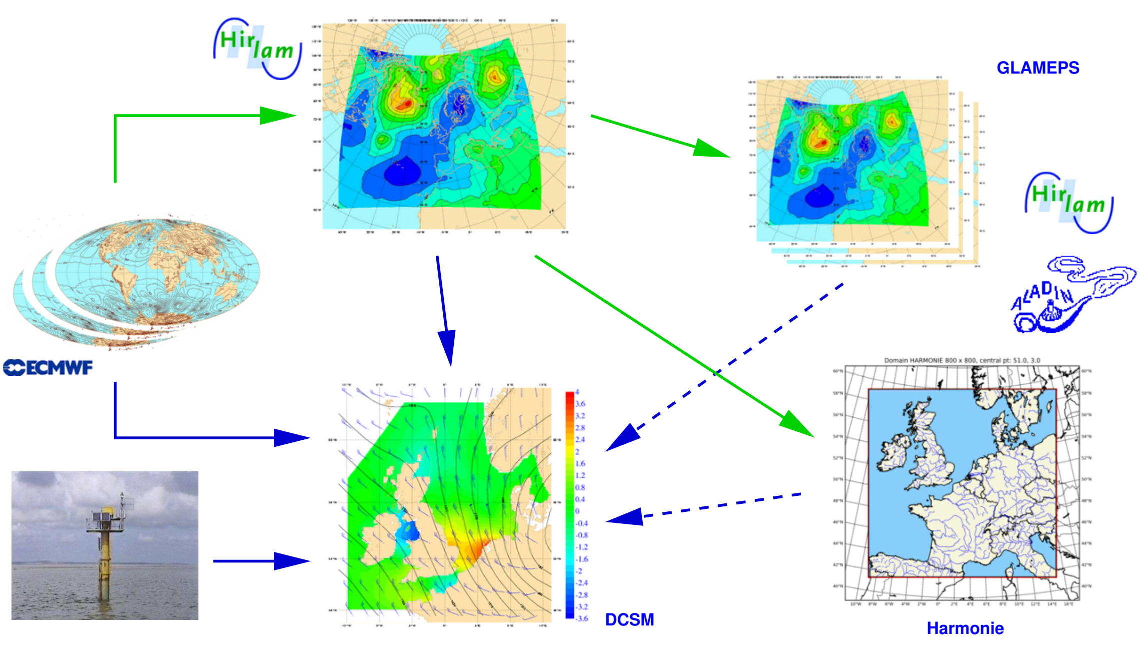

FIG. 2. Storm surge model DCSM and its meteorological inputs

The storm surge model currently in general use for The Netherlands is the WAQUA/DCSMv5 model (Gerritsen et al. 1995). This depth averaged model solves the shallow water equations over the NW European Continental shelf with a grid of $\frac{1}{8}^\circ \times \frac{1}{12}^\circ$ ($\sim$ 8 km).
The model is used for short-range forecasts, i.e. less than 48 hours ahead, with input from the Hirlam atmospheric model, which runs operationally at KNMI. In this mode, the model assimilates observed water levels, which help improve the forecasts for the first 12 – 15 hours.
For medium-range forecasts from 2 – 10 days ahead, input from the ECMWF atmospheric ensemble

is used and the ensuing water level ensemble is used to generate calibrated probability forecasts for key locations at the coast of The Netherlands (de Vries 2009).

Developments

Recently, a new storm surge model has been developed, WAQUA/DCSMv6, which has a resolution 5 times finer than the current operational model, and also covers a considerably larger area. This model is expected to become the operational model for short-range forecasts in the course of 2014. Nested in this model are several models which cover smaller areas in even higher detail.
For the medium-range ensembles, the current model will remain in use. It is much cheaper computationally, and the improved accuracy and detail of the new model is not useful due to the increasing uncertainty in the meteorological forecasts for the medium range.
On the meteorological side, there is on the one hand the availability of the short-range ensemble GLAMEPS. This has not been applied to drive storm surge forecasts in The Netherlands yet, but seems to be an attractive tool to quantify uncertainty for the first 48 hours.
The other development is the high resolution non-hydrostatic atmospheric model Harmonie, which will succeed Hirlam in future. Together with the new high resolution storm surge models, much more detailed forecasts for the coast should be possible.

4. Accuracy of storm surge forecasts

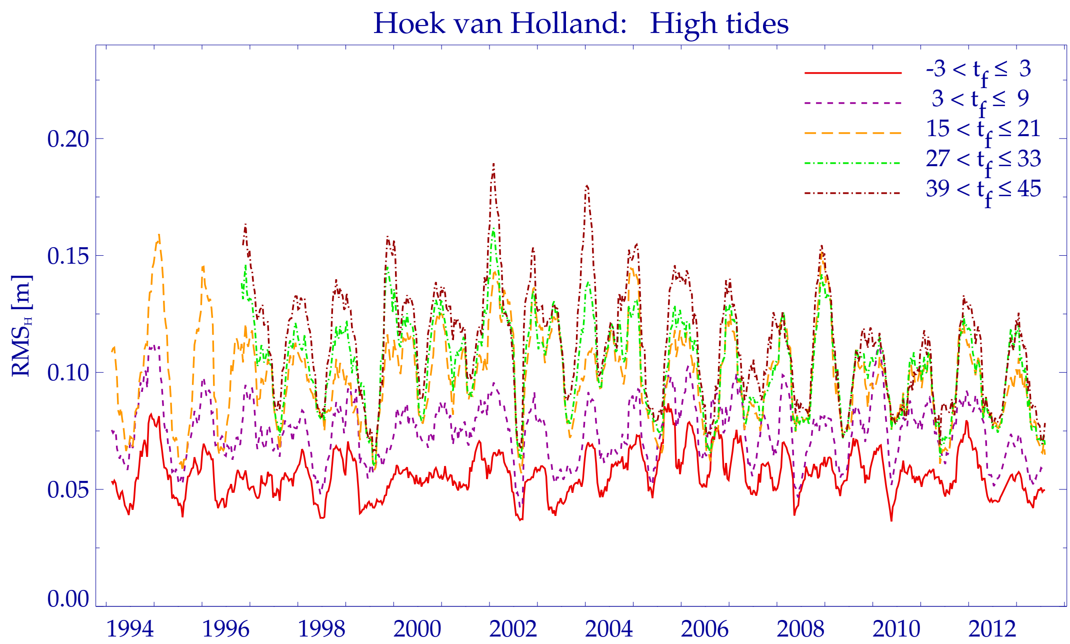

FIG. 3. Three-monthly running RMS error for different forecast ranges t_f for high-tide forecasts for Hoek van Holland

For the users of storm surge forecasts it is very important to have information on their accuracy. Therefore, verification data on the forecasts are made available on a regular basis, e.g. Figure 3 for the RMS error in Hoek van Holland for short-range forecasts.
However, these verification figures are not very informative on extreme cases. Extremes are by definition rare, and therefore hardly play a role in statistical analysis of model results. Experience learns that the average model behaviour can not be extrapolated to extreme forecasts. Moreover, the fact that in extreme cases any model error is likely to make the forecast less extreme should cause a systematic underestimation of extreme surges, even if the model is on average unbiased. For short-range decision making a skilled forecaster can improve the model forecast, based on observations and experience.
For the performance of medium-range forecasts figures like Figure 4 give valuable information. These figures count cumulatively the forecasts that exceed a certain probability for reaching a chosen level, arranged by whether the level was reached or not, the latter being a potentially false alarm. Figure 4

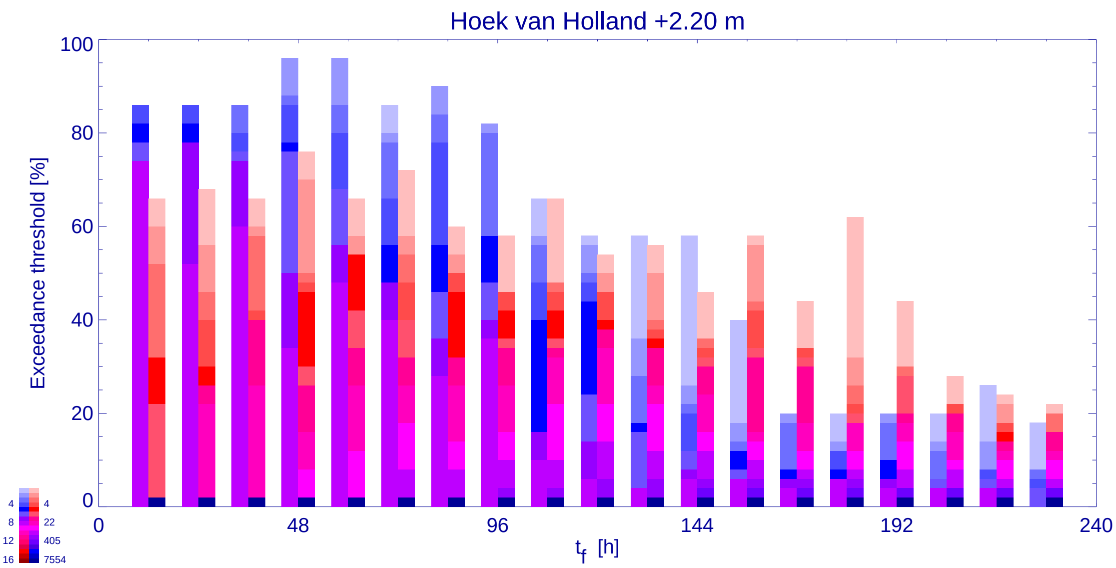

FIG. 4. Number of forecast exceedances from 2007 – 2012 of the Warning level in Hoek van Holland as a function of the forecast range. Left bars count the number of forecasts where the observation indeed was at least as high as the Warning level; the right bars where it did not.

shows this for the Warning level in Hoek van Holland based upon all forecasts from 6 years. For 4 – 5 days ahead the figure shows that all cases where the Warning level has been exceeded can be captured with not too many false alarms. The figure also shows that after 4 days the maximum probabilities decrease and the false alarms start to dominate.
Similar figures for levels higher than the Warning level are not very informative, because these levels occur only rarely and are also rarely forecast.

5. From forecast to decision

As a rule, decision makers are not very experienced in assessing the value of meteorological or storm surge forecasts. Moreover, the use and interpretation of probability forecasts requires an extra leap in thinking. Traditionally, the forecaster would combine all available information with his own experience and give just one value for others to act upon. But, certainly in the medium-range term, probabilities are the best way to make optimal use of the available forecast information.
The bottom line for the use of probability forecasts is that, in principle, when the cost of action C, the avoidable loss L, and the probability P that the event will occur are known, action should always and only be taken when $C < P \times L$. However, to quantify cost and especially avoidable loss is very often not easy, and other considerations will have to be taken into account.
All this makes intensive communication between forecasters and decision makers during an approaching storm surge event critical. Also, in anticipation, decision makers should be educated in the interpretation of forecasts in general and of probability forecasts in particular. When ensembles and probability forecasts were first developed, scientists guided the meteorologists in their use. As a result, they have nowadays become an essential tool in the forecasting offices. The same is not yet so for those who use the forecasts, and KNMI therefore regularly organises courses to make users familiar with the idea and use of probability forecasts. During an event this will help them to value the meaning of the forecasts and also facilitate the communication with meteorologists on this matter.

6. Extreme water level exercise

Preparedness

To check the preparedness for extreme situations, Rijkswaterstaat organised in 2012 an exercise to simulate the threat of large-scale flooding due to a coincidence of an extreme NW storm on the North Sea and high discharge of the river Rhine after a period of substantial rainfall. This exercise was designed to train and evaluate the cooperation between different organisations on the national and also the local level, including forecasters and decision makers.
An earlier exercise in 2008 had already revealed the difference in ability to deal with a calamity and a

threat: a calamity means that action has to be taken anyhow; a threat means that actions have to be considered. In the latter case, taking measures in an early stage might be very effective, or even the only option, e.g. preparing for an evacuation of a densely populated area like Rotterdam city. But at the moment these decisions have to be taken, there is no certainty yet that the calamity will actually occur and the action might be in vain. In fact, if the probability is reliable, it will tell how often the action is unnecessary, but not whether this is such a case. All this poses big dilemmas for decision makers.

Meteorological and storm surge forecasts

In the exercise the first clear sign of extreme water levels was to come 6 days ahead (D-6). The focus of the meteorological and storm surge forecasts was on D-6 – D-4, when there is still only a threat, and time remains for discussion on actions to be taken.
An important prerequisite for the exercise was that it had to take place at all: the forecast at D-6 should trigger all organisations without doubt. The resulting requirements for probabilities for the water level in Hoek van Holland are given in Figure 5. That this is indeed an extreme scenario can be seen by comparison with Figure 4, which gives exceedances for (only) the Warning level, green in Figure 5. The maximum value ever forecast in 6 years for D-4 (96h ahead) is approximately 80% and this drops to 60% beyond D-5. But for the exercise more than 90% is required up to 132h ahead.
These high probabilities and the similarly high probabilities for higher levels make it questionable that the scenario is realistic.

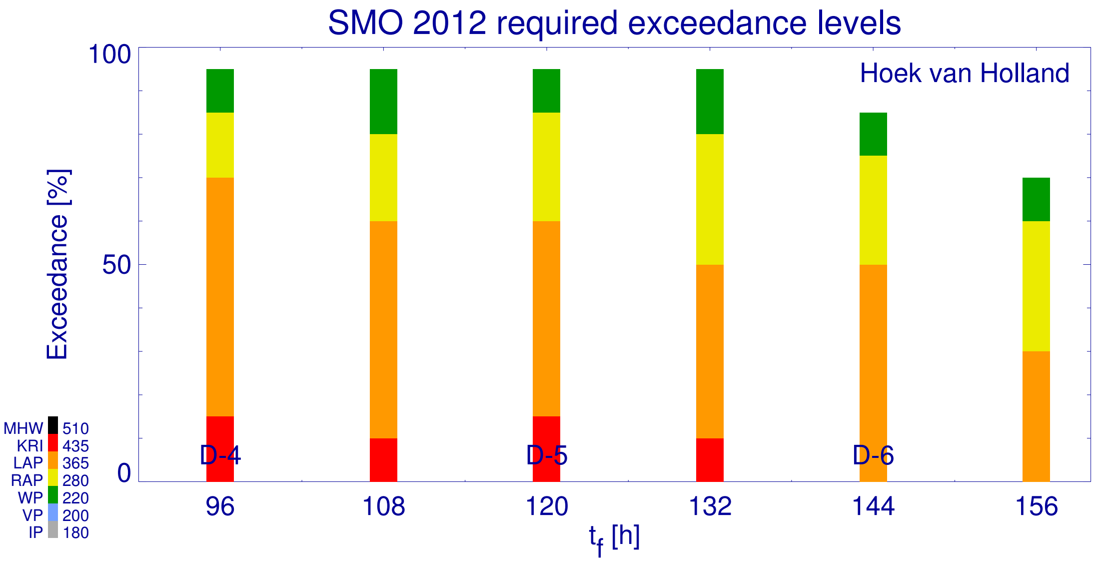

FIG. 5. Training requirements: exceedance probabilities from successive forecasts of significant levels (see Table 1) for the highest high tide.

Tests with the meteorology for the most severe storm (November 2007) combined with the highest spring tide in recent years show that when wind speeds around the peak of the storm are increased with 25% (approximately 1 Beaufort), the probabilities in Hoek van Holland become sufficiently high, but in Vlissingen they become unrealistically high, and in other coastal regions they remain still too low.
In the end, to satisfy the requirement, the low probabilities were simply raised to the demanded values. But this also meant that there was no consistent meteorological explanation anymore for the occurring surges.

Evaluation

Also afterwards KNMI stressed that the forecasts had been unrealistic. Nevertheless, it was concluded that the exercise had fulfilled its goal, which was to bring all organisations together and test procedures and communication. To this end, it was regarded more important to get everyone involved than to have a realistic situation. Of course, several possible improvements in the organisation and communication were identified. One of them was that there had been too much discussion on forecast details on a too-high level.

7. Role of the media

In case of a threat of a possibly calamitous event, (social) media will be an important means of communication with the public. One aspect of managing a threat nowadays is to manage the media. If you bring them in too soon, they might overreact and create too much turbulence, particularly when the threat lessens later. But if you wait too long, they might have picked it up themselves already and given it their own interpretation.

An interesting example of this was earlier this year when WMCN was contacted by some local authorities with the question why they had not heard from them yet: there had been messages on (social) media which announced a storm with high water levels and they had started procedures already to deal with that. WMCN, however, had been convinced that the water levels would not be that high and therefore no action was needed, and this proved to be the proper decision afterwards.

8. Conclusions

To deal with the threat and consequences of situations with extreme high water, meteorological and storm surge forecasts can be very valuable. Good communication between forecasters and decision makers is very important to make optimal decisions and minimise potential damage, based upon the available forecast information.

Especially for the medium range, probability forecasts are increasingly important to quantify existing uncertainty. This requires preparation and training of those who will use the forecasts.

An exercise to test the preparedness for storm surges revealed that there is still friction between what forecast models can provide and decision makers would like to have to base their actions on.

To manage the media just before and during a severe storm surge event, it is advisable to develop a strategy beforehand.

References

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