Forecasting coastal overtopping: What's the worst that can happen?

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Abstract

Much is known about what is possible around the coast; Astronomical Tides follow fairly predictable rules, Physics limits the effects of weather on top of that. In recent years we have invested significantly in better forecasting for coastal extremes, attempting to determine whether the apparently random conjunction of tide and weather will overtop our sea walls and beaches, and if it does what the hazard or inundation extent, depth, speed and impact will be. Internationally, these factors may not be the sole drivers for flood risk management, but by recognising short and long term limits of these variables we can better describe the coastal risk and a "reasonable" worst case of possible impact.

We are able to forecast coastal storm possibilities out to 5 days and as flooding approaches we are able to narrow the range of that forecast, which may or may not exclude the worst extremes. How do we use that as a heads-up to prepare for the possibilities without scaring people? By sharing extreme possibilities with responders who understand the low probability, but who may have to mobilise, we can prepare for that worst case. This process may escalate with the proximity of the event and the likely scenarios narrowing towards that expected. Conversely, as the worse events become less likely, we can scale down the response needed

The biggest variable around our coast is the tide. As it is driven by the pull of the moon and sun predominately, it can be predicted indefinitely ahead, with reasonable accuracy. Around 6 times a year, these work together to generate threatening sea levels. Second to the tide, storm surge is a major contributor, adding up to 3m onto the water level. On top of the sea level, wind driven wave action may give overtopping of defences well above that combined height. We will look at the way these factors combine and we forecast their impact.

As we know from flooding history, these events where the factors combine to their worst effect are rare. The way they add together varies around our coast and more so around the world; that same history means that exposed locations will have been affected by similar events in the past and the risks should be well known. We have defended much of the coast where people and property are at risk, so we are dealing with the remaining vulnerability. We can't build an unsurmountable wall round our coast and we wouldn't want to, so we defend against events proportionately and prepare to respond to extreme events.

Our defences are affected by wave action in a storm. Beaches are a major part of our defence as waves will break before they get close, but that wave action tends to mobilise sand or shingle and move it offshore. Hard defences may be damaged by heavily plunging waves or be undermined by overtopping waves. Either of these will affect the way the event is managed and need repairs planning if possible. These and the extreme events need a plan to deal with the failure of that defence.

Major Incident Plans are maintained for events where serious or widespread overtopping or defence failure occurs. In some areas, demountable defences may be applicable, others may require evacuation. Knowing the worst that can happen is vital to planning this response. The uncertainty in our forecast at 5 days out means we shouldn't mobilise at that point, acting according to our best-most likely- forecast, be prepared for the reasonable worst case and monitor for any unprecedented escalation to give as much warning as possible.

1 Introduction.

There is a growing appetite for a better understanding of the coastal hazards caused by extreme coastal conditions. Coastal flooding is a significant risk for the UK, sitting only behind pandemic flu on the National Risk Register (NRR) of Civil Emergencies (Cabinet Office. 2017) Recent significant coastal flood events such as Dec 2013 storm surge and the Jan / Feb 2014 storms have highlighted that we can and do provide a world class response to coastal flooding. We inform, prepare and protect people and property from extreme coastal conditions. But we can do better. Climate change and our dynamic coastline mean we cannot stand still and should continue to invest in new science and technology, smarter data, models, tools, approaches and focus on stronger partnerships across Government bodies.

From the perspective of the Environment Agency Modelling and Forecasting team, this is a snapshot of where we're at. We will outline our role in helping England become more resilient to coastal extremes through our coastal flood forecasting service. We will describe how we work with Met Office inputs and the embedded FFC (Flood Forecasting Centre) and how we use our 'local' models to forecast coastal overtopping and the impact those forecast conditions could have on communities and infrastructure. We will focus on the challenges of understanding the uncertainty in that forecast and communicating the range of possible impacts to responders and those at risk.

2. Our approach to forecasting the impacts of coastal overtopping in England

Our coastal flood models describe our coastal risk landscape and our coastal flood forecasts highlight the communities, properties or infrastructure we believe could be impacted and the response actions (close a road, put in place a temporary gate/barrier or evacuate a community) we need to take to manage and reduce the impact of coastal flooding.

The Environment Agency's 'Think Big, Act Early, Be Visible 'approach is critical to the success of managing coastal flood incidents well.To support this approach we use long range forecast information to inform 'planning' decisions, using a 'Reasonable Worst Case' and 'Best Estimate' scenarios, driven by Met Office surge and wave ensembles forecasts. This allows us to describe and plan for a range of possible impacts. As we move along the timeline towards 2 to 0 days before and we start to take flood response actions (such as closing gates or sending flood warnings direct to communities) we try to fine tune our forecasts…..

Long range forecasts are great for planning response, but the uncertainty increases rapidly with range. Longer range forecasts give us some heads up of increased possibility, but generally we look out 5 days for a complete detailed picture and it is important for us to pass the best interpretation of that information to those at risk and responders.

To get a better understanding of our coastal flood risk to communities, we have been able to make increasingly detailed models describing the storm sea, defences and the area at risk behind, but there is still a lot of uncertainty. Our 5 day weather forecast from the Met Office recognizes this by giving us a 24 member ensemble forecast for Residual Surge (the component of total water level minus the normal or astronomical tide)(Fig 2) which mostly defines the envelope of likely surge conditions. Wind speed and direction will have the same treatment. The Environment Agency translates this into local flood risk information using models to predict how that level of water and the waves on it will impinge on defences, then affect the lives and properties at risk.

The crucial output of this process is the rate and volume of water overtopping the defences and directly, the impact of that volume.

Currently, the Agency uses a Reasonable Worst Case scenario to describe the upper limit of the surge, but uses the best forecast values for wind and hence waves to add to this

Our current flood forecasts relate to communities or infrastructure as that is the impact that concerns us. Each Flood Warning Area being alerted or warned according to thresholds crossed within the forecasting system

Added to this is the need to forward plan our response days ahead when people and plant needs to be in place, not on holiday or elsewhere. As the event approaches, there is also the desire to de-escalate in response to a reduced worst case.

In modelling and mapping the impact of storm events, planning to respond to events is the last link in the chain. Having people on the ground in response is often a binary event. Mobilising teams for standby unreasonably will lead to problems of willingness and budget, even with the best communication of the causes.

2 What adds up to a coastal flood event and how predictable are they?

Astronomical Tides

In a field where accuracy is difficult, prediction of astronomical tides is complex but very predictable. The planetary drivers are well accounted for; though the effects of local bathymetry affect the detail, they can mostly be considered reliable.

The nature of large bodies of water moving around the planet means that the tidal range are variable around our coast. In the North West and Bristol Channel events are mostly limited to spring high Tides. Fig1 shows how this varies and is less of an issue elsewhere.

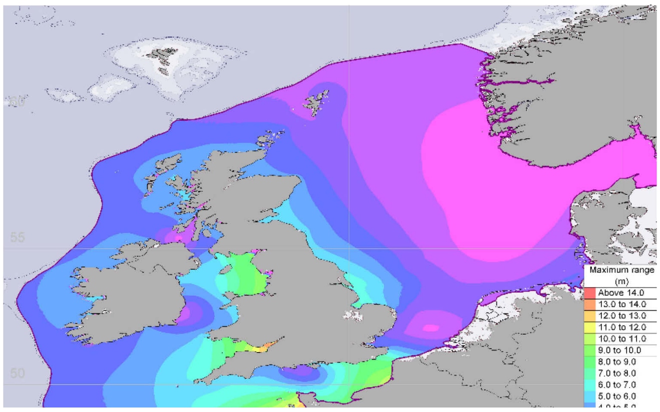

Figure 1: Astronomical Tidal range around Britain. © Copyright 1983 - 2015 Innovation & Research Focus

Storm Surge

The two components of Tidal Surge, onshore wind and atmospheric pressure uplift have a complex relationship, but usually considered together. (Fig 2) The Met office CS3X surge model gives us a 5 day forecast of an ensemble of equally valid scenarios translated into "still water level" (Met Office. 2018) which is measured locally by tide gauges as a check. Although this affects the tide level with the astronomical, they are not linked in their timing. Where there is a small tide range, the surge can be the dominant flood risk, though spring tides would be needed for the worst impacts. Surge is difficult to forecast forward and in detail and when we ask "what is the worst case?" it is important to exclude extremes that are we don't think are at all likely. The Reasonable Worst Case recognizes this, but uncertainty in the modelling based on this has to be also allowed for, especially locally.

Generating the Reasonable Worst Case scenario; RWC Figs 2 and 3 show the problems with longer term forecasting where storms are involved. The possible 1.8m skew surge turned out to be 0.3m with almost no impact.

So 5 days prior to a storm event, we are unable to quantify accurately the possible surge except for a likely limit of 1.5m, based on evidence, depending on storm path and intensity.

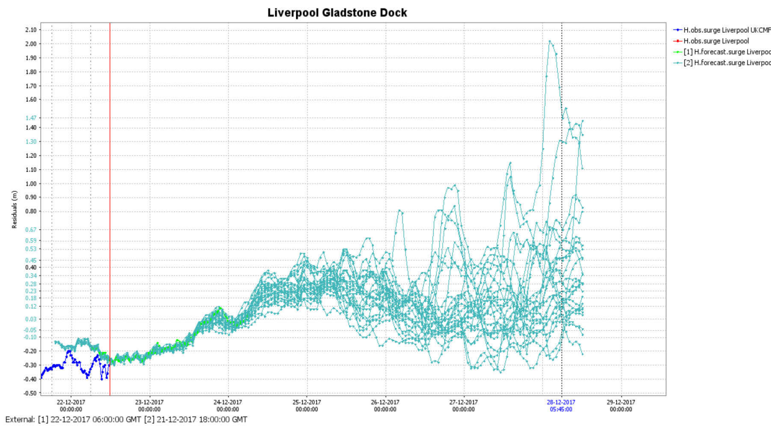

Figure 2: 5 day outlook for 28th Dec17

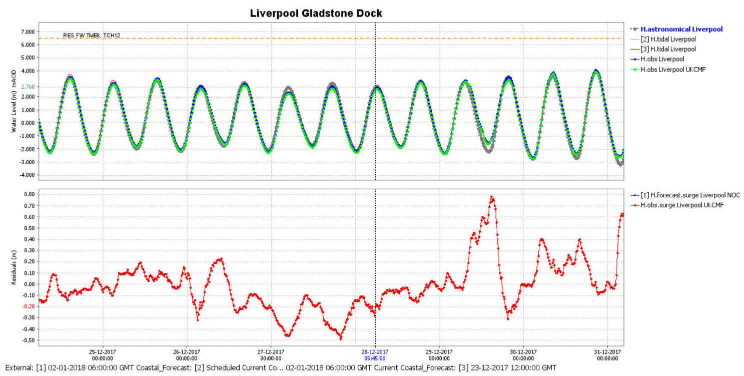

Figure 3: Actual surge on the 28th Dec

Our forecast of astronomical tide is much more reliable and by adding a maximum surge figure to that, we can identify windows when tidal events are possible, given the storm coincidence.

So we can allow for the worst case on a relatively small number of occasions when we should be prepared. If there is no storm or major astro imminent, that readiness can be relaxed. Within 5 days we can usually say if a serious event cannot occur; a storm can only move at a certain speed. Conversely, a storm may be on track to be possible, with more or less certainty for time and strength. Both of these will become clearer nearer to the time, so the "envelope" of possibilities decreases

Wind and Wave

Related to surge, the wind direction also generates waves which may add to the flood risk. On exposed coasts this can also cause overtopping of defences and flooding even on reduced high tides. Where there is a long stretch of open sea or fetch, swell waves are much more powerful and erode sand and shingle beaches and can damage vulnerable defences. The wide variety of these events are hard to predict, but we do have wave buoys offshore that give short term warning and our modelling does allow prediction of the possibility of such an event.

The way waves impact the defences is highly complex. Much theoretical and empirical work has been done in the UK and there are some stretches of simple hard defences that have been well modeled. Many coastal communities have a mix of aged defences that create a chaotic response only predictable in general terms based on previous events. Most defences need a combination of surge and wind events to overtop. By calibration to known storm events, the range of the forecast can be reduced to a manageable error band corresponding to the surge forecast accuracy. Figure 3 shows how our modelling may fail to predict overtopping where it is driven by onshore wind; this location has now been calibrated using the same evidence

Figure 3: New Brighton Dec 2013

3 So what is the worst that can happen?

None of these effects exclude the others, so we have to be prepared for all striking together at their worst, though having all together is highly unlikely

Spring Tides: (2.Met Office. 2018.) at the full or new moon are highly predictable and of these 24 or so in the year, generally less than half are concerning and they can be scheduled on the calendar. There are many factors that influence their magnitude but the major moon and sun effects are the biggest, so follow the lunar cycle. Given the extra level induced by storms, even the worst astronomical tide struggles to have any impact without some Storm Surge

Storm Surges. Although these are produced by global weather patterns that are difficult to predict in detail, we can measure their progress far enough to be ready for an event. They can be seen as a large raised body of water travelling over the sea, Lifted by low atmospheric pressure and driven by prevailing wind, their inertia gives them more short range predictability. Except for tide locking fluvial events inland, spring tides are needed with that surge to cause flooding

There is difficulty in exactly defining and forecasting the severity and impact of a surge until very near the event, so if people and plant need mobilising, that has to be in time. Where this includes evacuation, this can be a major decision with great consequences.

Whereas the biggest surge experienced in the Irish Sea is around 2.5m, the biggest experienced at high water has been around 1.2m. Because the deeper water brings the tide in faster, this shows up as an increased surge, which can excite responders. Modelling and history allows us to include this in our forecasts. In the build up to an event the Reasonable Worst Case has to be planned for

Big Swell Waves; where there is exposure to the powerful ocean waves, this can be foreseen as a possibility but difficult to estimate precisely. The full force of the wave requires some tidal lift or will break in shallower water further out. A weather pattern that generates these conditions can also be giving a storm surge which makes them tend to occur together. These waves are also damaging and erode sand and shingle defences quickly at elevated tides, but that in itself is unpredictable except as a possibility.

All of these conditions have been recorded and given a probability statistically, to we can say how likely a certain combination of events is. Some combinations are impossible and some are exceedingly unlikely. This combined or multivariate risk culminates in events that have not occurred, or possibly occurred hundreds of years ago. We use records of the major events such as occurred in 2013 as a yardstick to give a perspective on forecast events. When we see the different factors coming together, we prepare our response accordingly. We are learning to ramp up as the probability rises and deadlines for action approach. It is more difficult to de-escalate before the event as there is usually a small risk remaining.

When can we Stand Down?

The Factors mentioned and the response needed add up to a series of preparatory events that would be exhausting to repeat fortnightly. The incoming information and forecasts allow us to avoid more than a watching brief most of the time, Either or both of the storm and tide criteria cause us to escalate, then as our forecasts get less extreme in their worst case, we can stand down to some extent, accordingly.

We already have a standing down procedure. Every storm that comes our way, every spring tide, every swell wave pattern, is raising flags in our monitoring systems. Teams are being alerted that may be needed. As the possibility rises, there are decision points that have to be planned for.

On the East coast we have the possibility of storm surges that can flood large areas, so each storm is analysed for its possible path and intensity. In the very worst case event evacuation would be called for with all the consequences. It may need to start before the risk is sure, so that decision would be based on the best information possible, so that process would have been considered strategically well ahead. Generally, we can see when there is no longer a possibility of a major event and the timely escalation is not needed.

Where the tide range is greater, the surge is a more equal contributor as they combine to reach flood levels with wave action adding to the risk of overtopping defences. This can be forecast to the most part and we can define limits to the event we are forecasting, more so as it approaches

Approaching an event, the only known variable is the astronomical tide. We don't try to forecast our ensembles far out as they would include a huge range of events. Currently we forecast out to 5 days on the coast. Where there is a storm coming in, we can limit our response at that point depending on our reasonable worst case.

We have the Reasonable Worst Case scenario to help us describe the extent we need to prepare for the worst and also to limit it. It is not completely inclusive, especially in a changing climate, so we have to be alert to circumstances where it is exceeded. It is not what we expect to happen, our Best Forecast is that which we expect to happen

Closer to the peak of an event we can get warning of unexpected variation in the weather patterns and escalate to suit. Diverting emergency response from one location to another may be needed and can be allowed for when we can understand the real time situation. With this in mind, we need to hold the state of preparedness beyond what might seem needed.

Flood Alerts and Warnings.

The Environment Agency aims to put tidal Flood Warnings out for areas at risk at least 9 hours ahead of flooding with the tide cycle, this avoids confusing one with the next high tide. Aiming to improve on that we have scaling up processes nationally via the NFFDM, National Flood Forecasting Duty Manager, allowing a nationally planned response though our partners, escalating and de-escalating according to that Reasonable Worst Case

Climate Change:

We only forecast for current events, so we don't need to consider the effects of climate change.But climate change factors are still important, the potential increased energy in the atmosphere means that we have to allow for the possibility of unprecedented storms, or increased storminess (reference Ivan Haigh)

4 Conclusion

We have described how the combination of high water levels (caused by high tides and surges) together with waves can lead to coastal flood impacts such as risk to life, damage to property, infrastructure and the environment by overtopping, inundation and wave action.

We have looked at the extremes that can occur at the coast and how close to a possible event we can exclude extreme possibilities. We have the Astronomical calendar that gives us a predictable rhythm and weather systems that can be seen approaching and so forecast. The ability to predict storm paths and intensity is our major difficulty in being able to prepare the suitable response with confidence, so at each milestone, each point of no return, we have to make decisions. We can escalate or de-escalate as we get better data, as the envelope reduces, but we have to be prepared for that extra unreasonable weather.

4 References

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