Employing Catastrophe Loss Modelling to Price and Manage European Flood Risk

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To create new mechanisms to transfer risk requires a technical foundation comprising two key components: ***risk pricing*** *- the ability to quantify the 'expected (average annualised) loss' for the risk, and* **portfolio risk analysis:** *the means to determine the loss exceedence probability by which to manage concentrations of risk, whether by diversification or risk transfer. While risk pricing can be accomplished using simple models to determine the occurrence of extremes at a single site, only Catastrophe Loss Modelling provides a methodology which combines risk pricing and the portfolio risk quantification. The programme of catastrophe flood risk modelling currently underway for Europe by Risk Management Solutions (RMS) is described, including the 1998 release of the first linked windstorm - storm-surge catastrophe loss model. The programme is now concentrating on developing river flood catastrophe loss models for Europe and the Caribbean region.*

Catastrophe Loss Modelling

'Catastrophe Loss Modelling' (event-specific stochastic modelling of highly-correlated multi-location loss) was developed in the late 1980s, initially for problems associated with earthquake insurance and reinsurance. These techniques were successfully expanded to cover hurricane loss modelling in the early 1990s, and extra-tropical cyclone windstorms in the mid 1990s.

Catastrophe loss modelling involves the generation of a population of stochastic events, each comprising a complete and realistic representation of the 'hazard field' (ie spatial extent and strength of earthquake vibration, wind-gusting, flood-depths etc) of a physical catastrophe. This stochastic population has to comprise adequate regional coverage, rich parameter diversity and a sufficient number of extreme events (most readily achieved by employing stratified sampling to create larger numbers of events of reduced probability in the extreme tails of distributions). The hazard field of each synthetic event has to respect the inherent complexity of earthquake fault-rupture or hurricane circulation as well as the modifying potential of the terrain, on the propagation and amplification of seismic vibration or localised modifications of windspeeds. Based on empirically calibrated vulnerability relationships between hazard effects and damage (typically expressed as a % of value), each synthetic event is applied to one, or a portfolio of, location(s) of properties to determine event loss.

Populations of different numbers of stochastic events are convergence tested to arrive at an event set of adequate size to provide a reliable answer to the specific problem in question, whether: expected loss at one location; extreme losses to portfolios, or the correlation of loss between locations at increasing spatial separation. From the losses for each member of the stochastic population two fundamental perspectives on risk become available: the expected (or average annualised) loss is the sum of each event loss multiplied by its respective probability, and the Exceedence Probability (or EP) relationship displays the probability of suffering a loss in excess of any value within a selected time-interval. The EP curve provides the fundamental perspective on which all reinsurance transaction structures can be evaluated both for their expected loss and their impact on the residual risk after reinsurance. It is important for many applications in insurance and reinsurance portfolio management to preserve the underlying events in the model so that new analysis results (the set of stochastic event losses) can simply be added to those already obtained for the portfolio. This also preserves the full intrinsic complexity of the inter-relationships among losses at different locations (which become lost within a simplified correlation matrix).

As the correlation of loss within the same event is of central importance to Catastrophe Loss modelling it is important to recognise, and where appropriate include, all those agents of damage that result from the originating event. For an earthquake this could include not only damage directly linked to ground vibration but also that consequent on the liquefaction of the underlying soil; landslides released by the vibrations; a tsunami triggered either directly by the earthquake or by an underwater landslide and fires initiated as a result of damage to buildings and lifelines. For windstorms these agents of damage can include the direct results of high winds, as well as flooding associated both with intense rainfall and storm surge. In steep terrain, intense rainfall will create landslides. A tropical cyclone (eg hurricane) may last in excess of ten days, affecting a whole series of locations along its path, in particular when moving across an archipelago of islands or making multiple landfalls. In all these circumstances the event loss may need to include all the different agents of damage affecting many separate regions. In some circumstances, such as fire-following earthquake or surge-flood following a windstorm the outcome may be critically determined by the interaction with the variable and unrelated speed of the wind or height of the tide at the time of the event and this independent interaction needs to be incorporated into the model.

Catastrophe loss modelling requires interdisciplinary teams of scientists, engineers and statisticians. As many of the users of this kind of information are not engineers, models need to be delivered in the form of desk-top business-management software applications. RMS is the largest company specialising in catastrophe loss modelling with around 450 staff engaged in all those activities required to develop and support the use of software models.

Of all the causes of natural catastrophe loss, flood is the peril that offers the greatest potential for intervention (through building flood defences/levees). Through being more locationally determined than either windstorm or earthquake flood is also less likely to be covered by conventional insurance, as there are inherent problems in achieving adequate risk sharing among stakeholders who have very different susceptibilities to the risk. The variation in the availability of private flood insurance from country to country is to some extent hydrologically determined: the reason that the UK insurance industry has offered (since 1961) generalised flood coverage for all property insurance policies is because Britain is an island comprising many short rivers, thereby distributing the risk.

Flood Catastrophe loss modelling

Floods are well suited to the catastrophe modelling methodology as they comprise events that are highly correlated along the same (or neighbouring) section(s) of a river system (or coast for surge events). River and flash floods are determined by precipitation events that display strong spatial and temporal controls from meteorology, topography and catchment run-off characteristics. However the main challenge in flood catastrophe modelling concerns the impact of human activity; for unlike the situation in an earthquake or windstorm where the vibration or gusting impacts directly on a property, a flood is mediated by human changes to a river channel and in the construction of artificial embankments or levees. These changes can mean that a historical record of flood heights requires re-interpretation to be used in determining the probabilities of flood-heights today. The fragility of flood defences and the procedures in place for water storage as part of upstream flood management will all need to be taken into consideration in modelling flood outcomes It is also necessary to have suitable high-resolution geocoding information on the locations of properties to set against the fine-scale topographic determinants of flood propagation.

RMS is currently embarked on a 3 year programme to develop high-resolution Flood Catastrophe Models for Europe, concentrating initially on those countries in which there is an actual or potential market for flood risk insurance. The methodologies already developed in this programme, for both river flood and storm surge flooding have general application in building similar flood risk models for other regions worldwide. In each case the starting point is to determine the physical controls on the originating events. For river and flash floods these include the specific meteorological conditions that determine the shape, magnitude and duration of major precipitation events as well as the antecedent conditions, that could include ground saturation and lying snow. The first model to be released (in 1998) in this European Flood development programme was for East Coast UK Storm Surge Flood. As the largest storm surges are a product of major windstorms, that are commonly damaging in their own right, it was important that this model allowed a user to link their losses between the flood and the wind damage across the whole of Western Europe, as a surge flood in the UK may be associated with a storm that gives extensive wind damage in the Netherlands and Germany. (The stochastic model for European windstorm comprising 17,500 windstorm events was released by RMS during 1997.)

East Coast UK Storm-surge flood model

Storm surge floods have affected the low-lying coast of Eastern England throughout history. The impact of these floods became greater as embankments were built along the coasts, and as settlements developed in the coastal zones behind them. In the absence of improvements in the defences, flood risk rises year on year, as the south-east corner of Britain continues to sink (at around 1-2mm/yr) as a response to the postglacial recovery, while global sea-levels have risen (1mm/yr) through the 20th Century, most likely as a response to global warming.

The RMS East Coast UK storm surge model covers the impact of coastal flooding along 800 km of coastline from Hornsea in East Yorkshire to Margate in Kent, a region that includes the greatest potential concentration of storm surge flood exposure.

The last catastrophic storm surge to impact this region occurred on 31 January 1953. Since September of that year, hourly sea-level height-data have been monitored at 25 tide-gauge stations by the Storm Tide Warning Service (STWS). Based on these observations a complete data set of all significant East Coast UK surges since 1953 has been developed. Still water data from tide gauges have been separated into constituent tide and surge components and for each surge event a series of surge parameters have been recorded including: 1) the peak surge residual (maximum difference between observed water level and predicted tidal level); 2) surge at high water (surge component of the observed high water); 3) deviation between the time of actual and predicted high water (storm surges often bring the timing of high water forward), and 4) event duration.

The peak surge residual may occur at any point during the tidal cycle. However the interaction between surge and tide means the surge tends to be damped when it occurs close to the high tide but becomes amplified when a surge occurs on a rising tide. This non-linear interaction between tide and surge has to be incorporated when considering how to combine a specific windstorm-induced surge with a particular tide.

Surge Generating Windstorms

Storm surges are primarily driven by wind. The most extensive and powerful winds in the North Sea are associated with extra-tropical cyclone (ETC) windstorms and the largest surges accompany the storms with the strongest and most persistent winds over the sea.

After studying all significant surges over the past 45 years, RMS researchers found that the ETC windstorms that generate East coast UK surges could be classified into three types:

- ***Type 1, Northern North Sea:*** Large intense storms moving east across the northern North Sea, in which the following northerly winds sweep down the East coast UK. A major surge of this type was associated with the Capella storm of Jan 1st/2nd 1976, which also generated a major surge in the south-east North Sea, causing significant flooding and damage around Hamburg.
- ***Type 2, SE tracking***: Intense storms moving to the South East across the eastern North Sea, typically bring their highest winds across the western North Sea, pushing water along the coast of Eastern England down towards the Netherlands. A catastrophic surge of this type was associated with the January 31st 1953 storm which caused approximately 1800 fatalities in the Netherlands and Eastern England.
- ***Type 3, Southern North Sea:*** When an ETC storm moves slowly across the southern North Sea, it may become compressed by an anticyclone over Norway

developing tightened isobars to the north of the low pressure centre. These can create strong onshore north-easterly winds. A surge of this type was associated with the January 12th 1978 storm, that caused localised flooding in northern Norfolk.

Local variations in the strength of the winds along the coast, can create local variations in the height of the surge residual. For all significant surges of the past 46 years, the causative windfield has been reconstructed from the original 6 hourly synoptic pressure maps, so that for each event the windfield can be linked with the surge. To achieve the same linkage for the stochastic storms in the RMS European Windstorm model the windfield of all stochastic windstorms for each of the three storm has been sampled over a series of fourteen locations across the western North Sea. The linkage between windstorm and surge has also been tested against surge forecasting models and the exceedance probabilities of surge height are found to be consistent with the record of extremes from the historical tide-gauge record, and from a number of recent studies of the return periods of extreme water-levels down the UK East Coast.

Daily tidal maxima vary between neap and spring levels over a period of a quarter of a synodic month (7.36 days). As the same windstorm may arrive at a wide range of possible tidal states, leading to great differences in the elevation and extent of the resultant surge, the stochastic windstorms have been split into two or three potential surge event outcomes according to this surge-tide interaction. Stratified sampling has been used to ensure that the population of stochastic surges is concentrated in the more important extreme tail of water-heights. For each windstorm, tide and surge are combined for each of the 69 reference ports along the East Coast to define local extreme water levels for each stochastic event in the model.

Sea Defence Failure

Extreme water levels pose a threat to defence integrity once the water levels rises above the elevation of the landward side of the defence. Event duration is therefore defined as the time for which the water remains above this level and is a function of the modelled interaction between surge and tide. Extreme waves, produced in association with the surges, have been incorporated into the assessment of defence failure probabilities

Sea defence data have been obtained from the 1996 Environment Agency Sea Defence Survey, and include information on the height, location, construction type/material and condition of the 917 defences which protect insured property along the East coast UK. Each defence has been allocated to the closest reference port, for which the extreme surge height has been defined for each stochastic surge event.

There are two possible modes of defence failure (overtopping and/or breaching). The type of defence (material, construction type, condition and foreshore type), defence height and length, and the duration of the high water event, are all factored into the breach probability. For any extreme water height the ‘defence fragility model’ outputs the probability that each sea-defence will be breached. The dependence on event duration and defence length is based on the principles of reliability theory, whilst other parameters of the model are based on calibration against data from the sea defence survey, and historical events such as the 1953 flood.

For any extreme water level - defence combination there are four possible outcomes: (1) no flooding, (2) breaching without overtopping, (3) breaching with overtopping and (4) overtopping with no breaching. If breached then a defence is assumed to erode rapidly to an elevation close to the landward elevation and laterally to an extent defined by the defence type. For either mode of failure the model computes the dimensions of flow through/over the defence (velocity from a spillway equation, depth and width) and hence the flux of water entering the coastal floodplain zone.

For a given high water event (surge plus tide), there are a wide range of possible breach scenarios. Each defence may or may not be breached according to the probability output from the sea defence fragility model. The sampling of breach scenarios from all the possibilities has been performed in a statistically rigorous manner, to ensure an adequate geographical spread of breach events, and an appropriate combination of impacts along different stretches of the coast from a single event. Two flood events (i.e. combinations of coastal breaching scenarios) are selected for each high water event, but stratified sampling of breaching has been undertaken using groups of similar high water events to achieve an appropriate diversity of possible flood outcomes.

The distance that the flood travels (transgression) from a point of defence failure or overtopping is a function of the flux entering the coastal zone and the duration for which water passes through, or over, the defence. The flood is propagated in the model according to this water flux, as well as the topography and roughness over which the flood has to travel to determine the maximum extent of the flooding. The flood is time-stepped to find its maximum extent and inland depth: something which is of great importance for storm surge floods, that, as a result of the underlying tide, are of relatively short (2-4 hour) duration of extreme water-heights.

All flow routing, flood depth and flood loss calculations have been performed at postcode unit level (approximately 15 houses) using a 50m DEM.

586 stochastic windstorms in the 17,500 RMS European stochastic Windstorm model generate storm surges which impact the East coast of the UK. Each surge is divided into a maximum of 3 tide scenarios and then further divided into 2 breach scenarios (maximum of 6 surge events per windstorm) allowing the user to explore the range of possible surge losses which could accompany the originating windstorm loss.

Vulnerability

The loss functions are based on RMS's extensive analysis of flood loss data, including observations relating to storm-surge floods (including that of Towyn, 1990). Vulnerabilities have been developed for about 30 different building and occupancy types. Much use has also been made of the relativities of loss determined from RMS's own property by property detailed analysis of losses in the Midland Floods in Easter 1998. Loss functions are based on typical examples of each property type, and contents inventory. Building height is very important in determining the % damage, and contents damage tends to pass through a series of thresholds as water-levels reach an additional floor height. Impact of basements is important in affecting the losses at the lowest flood depths, and the proportion of basements is itself a function of the age of the property. Damages at different water levels relative to the overall height of the building flood levels were expressed as a percentage of the total sum insured (MDR).

The magnitude of the loss in a specific unit is not only dependent upon the depth and duration of flooding but also the velocity of water. High velocity flood water can cause significant structural damage in the near coastal zone close to breached or seriously overtopped sea defences. A velocity damage modifier for depths in excess of 1.5 m, declining exponentially with distance from the source of flood water, was derived based on US (FEMA) data on surge damage and applied to units with centroids up to 1500 m from the source of flood water.

Losses from Associated Living Expenses and Business Interruption, that are particularly significant following floods, were also developed.

RMS’s own UK postcode unit building exposure data is based on national property type and occupancy class surveys, regional variation in rebuilding cost data, insurance policy data and reported insurance penetration.

Models make Markets

The technical foundation for flood insurance demands the dual components of risk pricing **-** the ability to quantify the ‘expected (average annualised) loss’ for the risk, and portfolio risk analysis: the means to determine the loss exceedence probability by which to manage concentrations of risk, whether by diversification or risk transfer. Solving the scientific challenges of Catastrophe Loss Models for Flood opens the way to explore how flood risk can be quantified and transferred in regions where insurance coverage is currently unavailable. The RMS East Coast storm surge model illustrates how it is possible to develop models to manage aggregations of risk, not only from a single flood but from the windstorms that may correlate with them. The RMS Catastrophe Loss European River Flood models, to be released in 2000, allow the exploration of aggregate loss from floods that could be within a single catchment, or as is more common, across several different river systems in the same event.

River and storm surge flood models are also under development for regions affected by hurricanes, including the Caribbean and Central American areas. In mountainous areas, the priority is not just risk pricing but saving lives. Models provide the means to quantify the probabilities of regional events more extreme than anything seen in recent history. In countries like Mexico or Jamaica, such models can help plan infrastructure, development and risk transfer against the possibility of extreme rainfalls from slow-moving hurricanes, before having to experience a disaster comparable to 1998 Hurricane Mitch.