EXTRATROPICAL CYCLONE MODELLING

Author: Ioana Dima-West – Willis Towers Watson (WTW)

INTRODUCTION

Figure 1: Extratropical cyclone approaching Europe - 26 January, 2013 (Source: UK Met Office)

The wind-related risk in Europe is dominated by that associated with extra-tropical cyclones (ETCs). These types of atmospheric disturbances draw their energy from the interaction between warm (and moist) and cold (and dry) air masses: the larger the temperature differences between these air masses the more powerful the storm. The extratropical cyclones affecting Europe form in mid-northern latitudes (~30°-70°N), and most of the time originate in the North Atlantic Basin.

The mid-latitude atmospheric westerly background flow carries the Atlantic-based systems towards Europe where the storms can cause significant damage. These storms can occur at any time during the year, but the most significant and damaging ones take place during the winter months (typically considered October to March), when the temperature contrasts between air masses are greatest – consequently the ETCs are also referred to as 'winter-storms'.

The ETCs have very large spatial extents (on the order of about 2000 km on average - *Figure 1*), a life cycle on the order of about a week and are significantly more complex than tropical cyclones, in both their horizontal and vertical structure. The storms are characterized by high-wind frontal zones (cold and warm fronts), and the flow within the storm is counter-clockwise (in the Northern Hemisphere) around the storm's low-pressure centre; in the vertical, the extratropical cyclones strengthen with height and display a tilt backwards, into the colder air. The mid-tropospheric cloudiness that accompanies the winter storm most frequently displays a characteristic comma-shape (*Figure 1*).

Because of these particular complexities, the modelling of the ETC hazard has historically evolved from a more simplistic/parametric representation, which works well for tropical cyclones but not well for extratropical cyclones, into a more numerical-model based representation, using general circulation models and/or mesoscale numerical weather prediction models. The parametric and numerical types of modelling will be described in more detail in a subsequent section.

The European countries have been affected by a large number of powerful storms over time. *Table 1* shows a list of the most powerful named storms,

Table 1: List of large named storms that have produced significant loss in Europe

Index	Storm	Year
1	Daria	1990
2	Lothar	1999
3	Kyrill	2007
4	Great Storm	1987
5	Vivian	1990
6	Klaus	2009
7	Martin	1999
8	Xynthia	2010
9	Anatol	1999
10	Erwin	2005
11	Herta	1990
12	Emma	2008
13	Wiebke	1990
14	Gero	2005
15	Uli	2012
16	Dagmar	2011
17	Xylia	1998
18	Oratia	2000
19	Jeanette	2002
20	Fanny	1998
21	Yuma	1997
22	Lore	1994

largely organized by the amount of damage they have produced across Europe.

Losses associated with these storms can differ significantly from one catastrophe model to the other, which underlines the importance of the cat-model user to try and gain a deeper understanding of the inner-workings of the model, the key assumptions considered and the methodological steps that go into simulating historical or stochastic storms.

The European windstorms rank *second* after US Hurricanes in terms of global natural catastrophe insurance loss.

Climatology and Trends

Extratropical storms affecting the European continent are not distributed uniform across all countries, with the UK and the Nordic countries receiving the larger number of storms on average per year, while the southern countries and the regions located further inland receiving considerable less number of storms. This is exemplified in *Figure 2* which shows the tracks of the top 200 most intense storms that have travelled over North Atlantic and Europe.

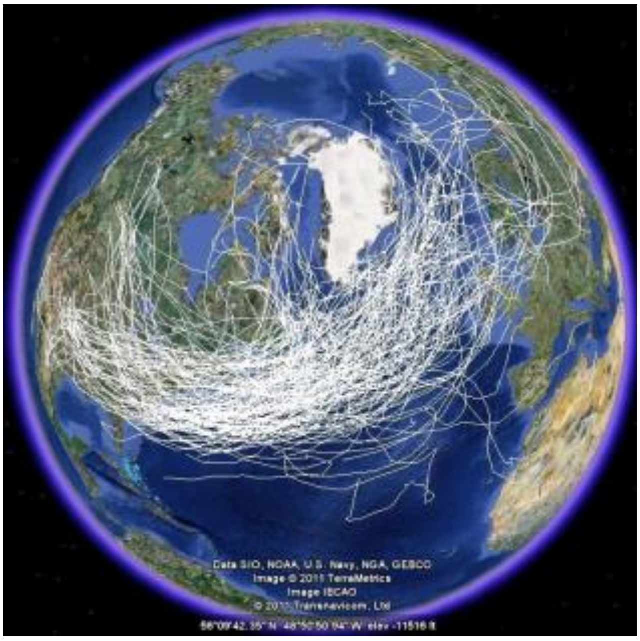


Figure 2: Tracks of the 200 most intense winter storms in the North Atlantic basin and Europe (Source: http://www.met.reading.ac.uk/~storms/method/)

The European windstorms are most common in the winter months with January leading as the top month of winter storms. The seasonal average for European storms is between 4 and 5 windstorms per year.

Studies of past changes in the frequency and intensity of extratropical storms have low confidence and are therefore inconclusive. This is particularly true for extreme wind speeds analyses before the middle of the 20th century.

When considering the future windstorm risk in European countries, the global circulation models tend to predict a slight reduction in the number of extratropical cyclones in Europe, and a possible poleward shift of the mean storm tracks in the Northern Hemisphere for medium to long term future climate change (IPCC, 2012). Such a northward shift could bring a larger/reduced number of storms over different regions in Europe, changing the risk landscape in particular areas.

ETC Risk and Catastrophe Models

Catastrophe Modelling has become the norm in the insurance/reinsurance industry and it is considered a must-have for any reputable company in the field. There are currently three main cat-models used for evaluating the ETC-related risk in Europe: AIR Worldwide (AIR), Risk management Solutions (RMS) and CoreLogic-EQECAT (RQE). The models display a different coverage over Europe (between 15 and 24 countries), in addition to employing distinct methodologies for estimating respective risk and losses.

But what is a cat-model and how does it work? In simple terms, a cat-model represents a risk-evaluating-tool meant to extrapolate the very limited historical experience by means of various statistical or numerical methods to many more (tens of thousands or more) virtual years of storms. Once created, the large and comprehensive set of synthetic/stochastic storms allows for a proper probabilistic evaluation of risk. Insurance/Reinsurance companies generally use cat-models to guide them in their internal capital management as well as for purchasing reinsurance to cover their risks.

The general structure of a cat-model is presented in *Figure 3* where three main components are highlighted:

(1) HAZARD - includes the *stochastic catalogue of events* and the *wind calculation* for any given storm in the event set

(2) VULNERABILITY - assigns specific vulnerability curves based on the exposure information included in the portfolio; the corresponding damage is computed in accordance with the modelled hazard at location

(3) FINANCIAL MODULE - considers specific policy conditions like *deductibles* or *limits* for each portfolio, in order to compute final loss numbers for the user.

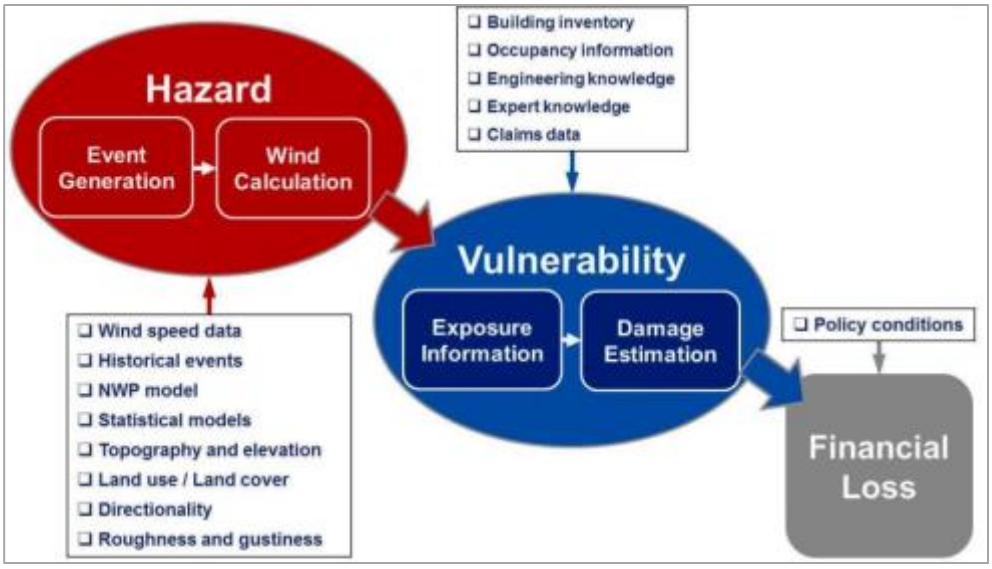


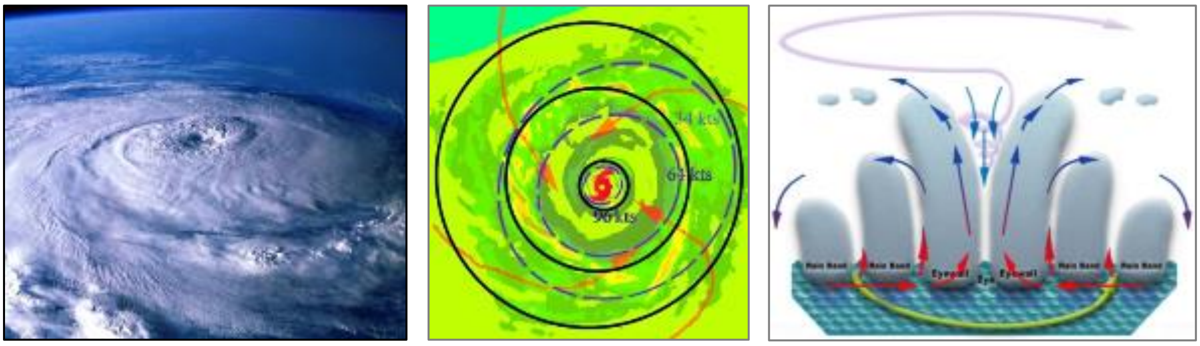
Figure 3: General structure of a cat-model: main modules and required inputs

HAZARD

Parametric vs Numeric

As briefly mentioned in the Introduction, there are largely two different ways of computing the hazard in a cat-model: *Parametric* or *Numeric*. To better explain what the two methodologies really entail, we take the examples of modelling tropical and extratropical cyclones. *Figure 4* loosely illustrates the general horizontal and vertical structures of a tropical and extratropical wind storms, respectively.

Tropical Cyclone


Satellite view — *Horizontal structure* — *Vertical cross-section*

Extratropical Cyclone

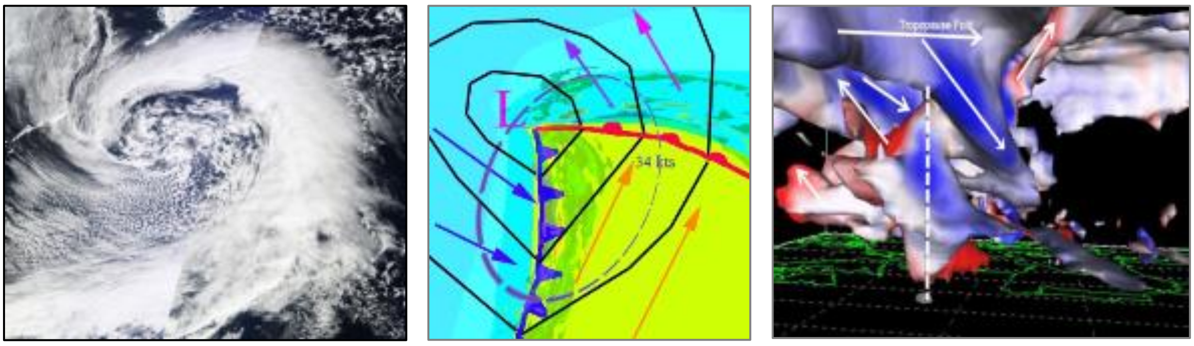

Satellite view — *Horizontal structure* — *Vertical cross-section*

Figure 4: Tropical vs extratropical cyclone structures

As can easily be observed, the tropical cyclones have a fairly organized structure and can be well described by quasi-symmetric circles in the horizontal and by symmetric convection columns in the vertical; the wind circulates around a well-defined low pressure center also known as the eye of the storm.

On the other hand, the extratropical cyclones have a much more complex structure, with sharp temperature gradients driving the warm and cold fronts across the horizontal surface, and with a vertical structure much more irregular and chaotic compared to that of the tropical cyclones. The winter storms usually display an asymmetric comma cloud pattern, though usually not around a well-defined eye, as it is the case with the tropical cyclone.

Due to their more simplistic structure, the circulation of the wind around a tropical cyclone can be represented using a simple set of equations and characteristic parameters, a representation called '**parametric**'. On the other hand, there is no simple set of equations that can describe the much more chaotic nature of the extratropical cyclones. In this case, only a numerical model, which is specifically built for the purpose of representing such atmospheric systems, can be used to correctly capture the wind footprint associated with this peril. A numerical model represents a set of many thousands of dynamical and hydrodynamical equations describing step-by-step the structure and evolution of the atmosphere – such models are expensive to develop and to run. The representation of the ETCs using numerical models is called '**numeric**'.

All cat-models covering the extratropical cyclone risk in Europe make use, to a larger or smaller extent, of a numerical model.

Stochastic catalogue of events

There are as many ways of developing a *stochastic catalogue of wind storms* as there are model vendors covering this peril. Moreover, scientists outside the cat-modelling world have also started to get involved in this interesting problem - Figure 5 features an European stochastic event set (through a sum of footprints per year) recently developed by scientists across various research centers.

As highlighted in the previous section, a correct representation of extratropical cyclones must involve, to a certain degree, the use of a numerical model. As such, a numerical model can be either run to produce the entire set of stochastic storms, or can be used to reproduce a limited number of storms which are then perturbed to create an additional number of derived storms using various statistical methodologies.

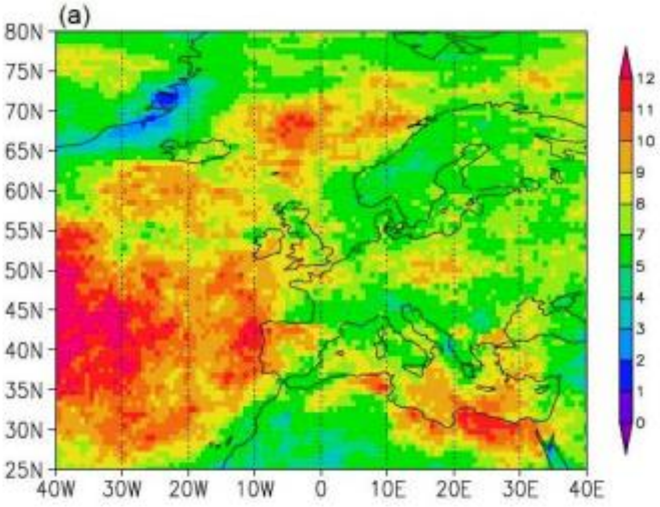


Figure 5: Accumulated yearly number of detected storms based on ERA-Interim Reanalysis Data (Source: R. Osinski et al., 2015, http://www.nat-hazards-earth-syst-sci.net/16/255/2016/)

To produce a full set of extratropical cyclones, a general circulation model (a numerical model operating on a global scale) can be used to generate realistic wind storms. Such numerical models are known to have biases in reproducing the position and intensity of the storms. These biases have to be accounted for and corrected in the catalogue of events, by performing a careful comparison with the historical record. Even more importantly, the resolution of these global models is too low to meet the needs of a catastrophe model, so the wind footprints generated by a general circulation model need to be further 'brought down' to a much higher resolution (see next section).

Another way of creating a catalogue is by first using a numerical model to reproduce a set of historical storms and then perturbing these to create additional stochastic footprints. The perturbations applied need to take into account the intensity of the event, its size and shape as well as the location of the storm track. Model vendors use either statistically-based or empirically-based methodologies to carry out the perturbation step. Attention must be paid to this procedure, in order to make sure the virtual storms created through such perturbations remain realistic and correlations are maintained between different storm parameters.

Wind-Footprint calculation / Downscaling

All numerically produced footprints need to be re-generated or 'brought down' to a higher resolution surface level, a process generally described as 'downscaling'. This step can involve one, two or three of the processes described below:

Numerical Downscaling

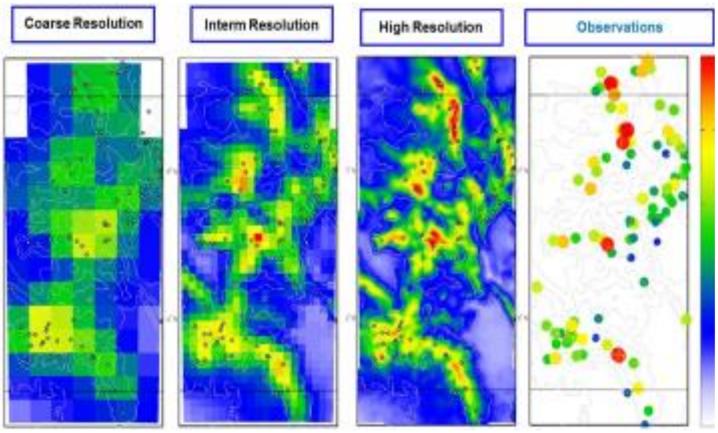


Figure 6: Numerical downscaling of a footprint using a set of higher resolution numerical models
(Source: https://www.ral.ucar.edu/projects/conus-downscaling)

A higher resolution regional numerical model can be used to ingest the initial coarser resolution storms to ultimately output surface level winds of a much improved fidelity (*Figure 6*). Depending on the initial methodology used to generate storms (via a general circulation model or through perturbations from a fix set of storms) this step may be *necessary* in improving the original footprint representation, yet most certainly *not enough* - winds generated through this step need further processing using one or both of the additional downscaling methods introduced below.

Bias Correction or Statistical Downscaling

Without exception, the output of any numerical model has to be corrected for biases. This step is accomplished through a careful analysis of the statistical relationship between the modeled-winds as produced by the numerical model, and the observed-winds as obtained from historical records. Also known as '*quantile-quantile matching*', this methodology ensures the modelled winds offer a good statistical representation of the winds observed on the ground, across all quantiles (a quantile represents a fraction of points below a given threshold; e.g. the 0.25 quantile represents the point where 25% of the total data falls below the point and 75% of the data falls above the point). An example of quantile-quantile matching is presented in *Figure 7*. Quantiles are useful measures because they are less susceptible than means to long-tailed distributions and outliers. The statistical downscaling is a very effective methodology of correcting model output and is very often used in cat-modelling.

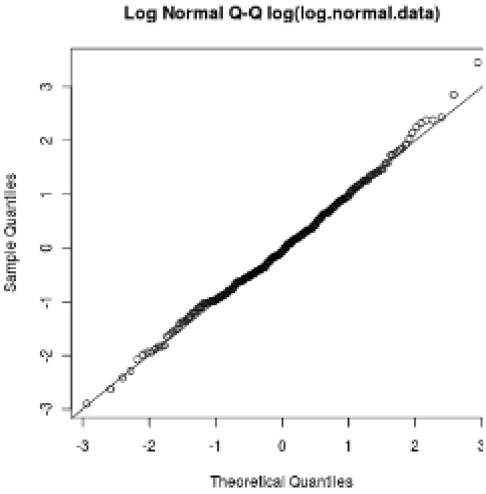


Figure 7: Example of a quantile-quantile matching exercise
(Source: http://aberdave.blogspot.co.uk/2011/06/q-q-plots-to-examine-sql-execution-time.html)

Physical Downscaling

A correct representation of surface winds needs explicit accountability of surface effects. These include considerations of *elevation* (winds are higher at higher altitudes), *topography* (winds are increased on the windward slopes of mountains and hills), *roughness/friction* (winds are decreased due to flowing over different types of terrain) and *gustiness* (winds are increased due to increased turbulence close to surface).

The *directional effects* of surface friction on the wind value at a location are also very important to consider, an issue which in cat-modelling language is known as ‘*directionality*’. Basically, the land over which the wind has travelled before reaching the location of interest must be considered in determining the appropriate roughness value (wind travelling over a smooth surface from one direction will have a higher value at its destination compared to winds that have travelled over rough terrain from a different direction before reaching the same destination).

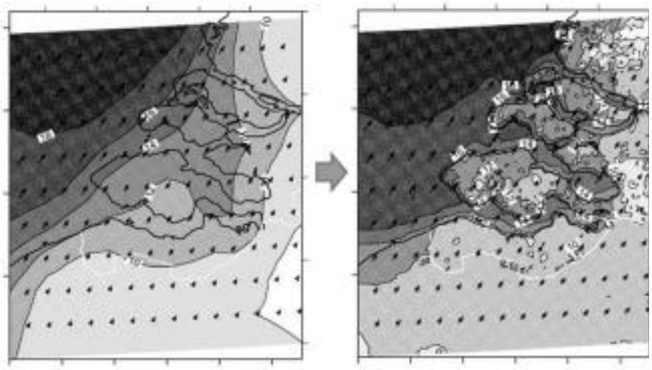


Figure 8: An exemplification of physical downscaling
Source: http://www.knmi.nl/kennis-en-datacentrum/publicatie/local-wind-speed-estimation-by-physical-downscaling-of-weather-model-forecasts

These terrain effects are determined based on specific datasets, available for different coverages and different resolutions, e.g. Land Use Land Cover data (LULC / CORINE), Topography and Elevation data (Digital Elevation Model – DEM). Along with the methodology adopted for computing terrain effects, the choice of the underlying data set can also result in different wind values at the same location.

Figure 8 shows an example of *physical downscaling* and highlights the importance of this process in improving the wind representation at the surface.

Hazard extrapolation to extreme values

One of the important roles that a wind cat-model needs to fulfil is the extrapolation of the limited observed historical record to hazard and loss values that have not yet been observed, yet values that are possible to occur in extreme cases. Most certainly, such extreme winds have very high damage potential and it is important that these are *correctly* accounted for from a windstorm-risk perspective.

There are various ways of carrying out this hazard extrapolation. The *Extreme Value Theory* is a branch of statistics dealing with such extreme deviations from the median of probability distributions. Within this branch a well-known technique used in cat-modelling is that of fitting a *Generalized Pareto Distribution* (GPD) to the available observed wind data - this GPD methodology has been particularly developed to model the *tail* of a distribution. An example of a GPD extrapolation is shown in

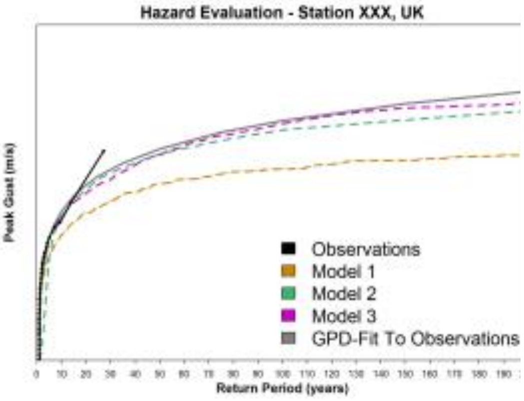


Figure 9: Vendor-model hazard OEPs (colors), wind-observations empirical OEP (black) and theoretical GPD fit to wind-observations (grey)
Source: http://blog.willis.com/2015/12/quantifying-european-windstorm-models-comparing-the-hazard-models/

Figure 9 where the solid-grey curve represents a GPD extrapolation of the limited observed wind record shown in black.

Another way of creating extreme wind values or *extreme storms* is through perturbations of existing storm-footprints, based on the shape, intensity and size of historical storms. Those perturbations can also be carried out in several different ways, either through a more rigorous statistical methodology or in a more empirical manner.

Ultimately, independent of the method used for extrapolating the hazard to high return periods, close attention must be paid to the structure of the stochastic storms generated in the end, as to make sure these storms still make sense from a physical and dynamical point of view.

As it is the case, the very different methodologies considered for this step result in similarly diverging views of risk in cat-models for specific parts of Europe, particularly those regions where wind observations are sparser. Since winds at these extreme levels cannot be validated, one can only discuss the methodologies used and form an opinion on whether these are appropriate and robust.

Hazard Uncertainties

The uncertainties related to the hazard calculations are often disregarded or minimized, while these can be quite large and, equally, can have an important impact on the final loss numbers. Below are a few examples of such uncertainties imbedded in the wind computations.

Representation of terrain effects

- The choice of the surface data (LULC, DEM Topography/Elevation), used to represent the terrain effects can make a difference in the final value of the wind at a respective location (*Figure 10*). The *vintage* of the data, its *resolution*, the vendor and specific *methodology* used to produce the data, all can result in different representations of the terrain effects.

- Another source of uncertainty lies within the range of possible friction and gust values (also known as site coefficients) that can be attributed to various components of the surface data. In other words, different friction and gust values are equally valid for a single surface feature. This in fact represents a useful model-calibration knob often used by model vendors, but at the same time a source of important uncertainties in the wind calculation.

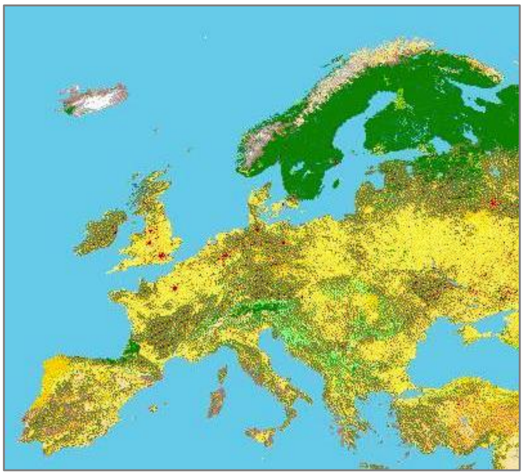


Figure 10: Land Use Land Cover over Europe (Source: http://edc2.usgs.gov/glcc/eurasia_img.php)

- The computation of those surface effects, as well as their associated directionality, also depends on the resolution at which winds are represented in the model: for example, the frictional effect computed at a grid level is going to be different than that calculated at a postcode or a cresta level. The transition between such different resolutions is achieved in various ways in cat-models and therefore it represents another source of hazard uncertainty specifically related to surface effects.

Choice of numerical model used to generate winds and storm tracks

As mentioned, the representation of the winds associated with extratropical storms involves, to a smaller or a larger extent, the use of a numerical model. Cat-models make use of either a General Circulation Model (GCM) or an Earth System Model (ESM), or a regional numerical model like WRF or MM5, or a combination of those. All numerical models vary in their coverage, numerical schemes, resolution and parametrizations; hence there is no surprise that the output they produce can also vary significantly from one model to the next. Invariably, all numerical models also display various biases in the storm intensity, extent and tracks that they produce, which need to be corrected when used within a cat-model.

Underlying observed station data

The development of the stochastic catalog of storm tracks and footprints relies on a Europe-wide historically observed data set (an example of such data is shown in *Figure 11*). This underlying data consists of station wind observations from various meteorological sources. While some common ground exists between cat-models, all vendors ultimately use a different observational data set.

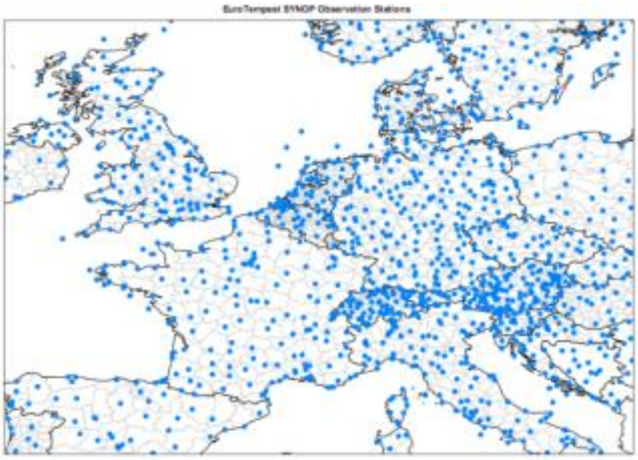


Figure 11: Example of wind station observations across Europe (Source: EuroTempest)

While often the station wind observations are considered to be “the truth”, this data is also plagued by inevitable uncertainties, either due to the instrumentation used and associated measurement errors, or to the manner and timing of reporting of the data, or both.

In addition, there are also significant differences in the post-processing of the data before it is being used in the cat-model. This post-processing step involves *cleaning* of the data (e.g. for erroneous reportings), *adjustments* of the data (e.g. for height) or *interpolation* of the data to various model-specific grids. And in particular cases, some vendors also apply particular *bias corrections* to the observed data that they consider justifiable, but that are not necessarily adopted by the other vendors, leading to additional differences between models, as well as increased uncertainty. Perhaps the largest uncertainties and model-differences are most apparent in regions where the underlying observed wind data is sparser (e.g. the Nordic region).

Windstorm Frequency

Aside from offering a correct representation of the intensity or severity of the stochastic events, the cat-model is expected to also offer a correct representation of the frequency (or return period) of those events. In this case the length of the historical record considered becomes important. All available cat-models consider different *ranges* of historical data in their development, therefore also the frequency associated with their stochastic or historical events will inadvertently vary, sometimes significantly, which leads to another source of considerable uncertainty in the model.

Hazard Validation

Any model is as good as its validation. Proof of hazard validation as carried out by the model-vendors is included in individual model documentations. The extent of this material, the diversity of the analyses carried out and ultimately the level to which the modelled-winds match the observed-winds are all a demonstration of a good hazard validation. While sometimes overlooked by model-users, the hazard validation is an essential component of the building of a model and the only way to gain trust in the model.

In recent years, some of the model-vendors have started to open up their black boxes and allowed the model to become more transparent. The newly granted access to the hazard of the model is extremely valuable as it allows users to carry out own validation against in-house observational data.

The validation of the hazard is an essential part in checking that the model is built on solid foundation and making sure no known or avoidable biases are transitioned forward into the next module of the Vulnerability.

VULNERABILITY

The Vulnerability Module is the middle step between Hazard and Loss and the part that is most highly guarded by model-vendors, as all vulnerability functions defined within are highly proprietary. The module takes as an input the wind computed in the Hazard Module along with the company ‘exposure’, and for each location of interest computes the damage associated with that wind value.

The wind speeds in extratropical cyclones are relatively low compared to those recorded in tropical cyclones, rising mostly to those equivalent to a category 1 or 2 storm on the Saffir-Simpson Hurricane Wind Scale. However, the extratropical cyclones have much larger horizontal sizes and they extend considerably further inland, leading to very large damage-footprints. The moderate wind speeds associated with these storms generally produce non-structural damage to buildings, hence relatively minor losses are recorded at individual locations, but since many location are affected these claims can add up to large insurance losses.

Exposure

The value of all properties in a company portfolio and the characteristics of those properties (e.g. construction, occupancy, building height, year built, roof type etc) define what is known as *Exposure*. This represents an essential input to the Vulnerability Module and the quality and level of detail of this file can make a significant difference in what the model provides as output.

Therefore great care must be given to preparing the portfolio exposure data, including correct information on location as well as on property descriptors, all considered to the highest degree of detail that is possible.

Vulnerability Functions

In simple terms, a vulnerability function represents the (non-linear) relationship between hazard and damage. Damage is usually expressed as the ratio between the loss observed by the property and the absolute value of the property (also known as Total Sum Insured or TSI) - this is also known as 'damage ratio'.

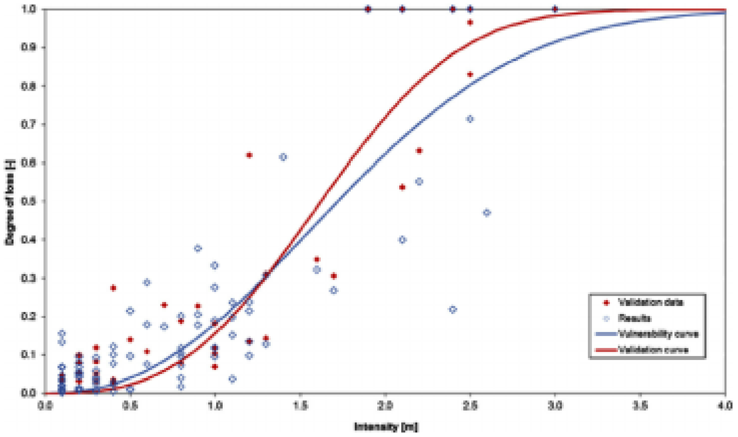


Figure 12: An example of a vulnerability curve (blue) and its validation curve (red)
(Source: https://www.researchgate.net/profile/M_Papathoma-Koehle/publication/267634629/figure/fig2/Fig-2-The-vulnerability-function-blue-curve-and-the-validation-function-red-curve.png)

The traditional and most robust way of building a vulnerability function is based on available claims data: damage claims recorded by insurance companies after windstorm events are paired with corresponding wind values at all locations affected, and a relationship is subsequently developed off of this data. Obviously, the larger the amount of claims data used for developing this relationship, the more robust the vulnerability function and the more trust one will have in the respective vulnerability module. *Figure 12* shows an example of a vulnerability function and its validation curve.

Primary Modifiers and Secondary Modifiers

There are four primary modifiers that every cat-model considers: *Construction*, *Occupancy*, *Building-Height and Year-Built*.

Construction is one of the fundamental parameters characterizing the behavior of a building during a storm and its cores resistance to wind damage. Some examples of construction types are wood, masonry, light metal, light steel, reinforced concrete.

On the other hand, the *Occupancy* refers the usage of the building, either for Residential, Commercial, or Industrial purposes; the Residential occupancy is generally expected to be most vulnerable, followed by the Commercial and Industrial occupancies.

Building-Height is another important modifier, which takes into account the different vulnerabilities for short and tall buildings. It is well known that wind speed increases with the height, which means that, for a given storm, taller buildings will experience higher wind-loads than shorter buildings. However, taller buildings are typically designed for higher wind speed and follow much more stringent design code requirements than in the case of shorter buildings. If the same typology of construction is assumed for two buildings, one tall and one short, the significantly larger replacement value of tall structures would mean that for similar levels of wind damage to both structures, the damage ratio would be much smaller in the tall building than that in the short one. Overall, the vulnerability is expected to decrease with increasing building height.

The *Year-Built* modifier in a cat-model aims to capture the evolution in construction practices that result in vulnerability reductions within the building stock. These reductions come from the update and implementation of building design codes, as well as the usage of better construction materials and practices in recent times. Consequently, newer buildings are expected to have lower vulnerability than older buildings, and these considerations are implemented within cat-models.

Secondary Modifiers, which describe the more specific characteristics of a building (e.g. roof type, cladding, chimney, building foundation connection, wall type) are sometimes considered in cat-models. This kind of detailed information is more readily available in US than in Europe, hence the US cat-models all include secondary modifiers, while in Europe only one vendor explicitly includes those in their model. These modifiers can enhance or reduce the vulnerability of the building.

UNKNOWN Treatment

Often time various characteristics of portfolio properties are not known or not provided, in which case the exposure file lists them as '*Unknown*'. Cat-models need to be able to deal, in an objective manner, with such a shortcoming of the input data.

Generally, the *Unknown* vulnerability functions are constructed based on the typical mix of buildings-type around the location of interest. Preferably, the mix of buildings would be determined by the contributing-percentage of each building-type in the region.

Storm DURATION

Although storm-duration can play an important role in the final value of the damage observed in a building, this aspect is not *generally* captured in cat-models, for either tropical or extratropical cyclones. Design wind loads can be exceeded during a storm at which point the weak links within the structural system of the building can become overwhelmed. If this process continues, as it is the case for slow moving storms of reasonable intensity, the loads get transferred to the next point of vulnerability. The longer the duration of the damaging winds, the longer the strain on the building and the greater the damage to the building.

The proper way to compute duration effects on a building is to develop the complete time-profile of the winds speeds for each location affected – such a consideration can be quite computationally intensive and can increase the run-time of the cat-model. A more simplistic approach is to approximate storm-duration through a factor and apply that factor during the loss calculation.

Vulnerability regions

Due to regional differences in vulnerability for buildings with similar properties (vulnerability of a similar masonry building in UK versus France), cat-models often times consider specific vulnerability regions. The differences in those regional vulnerabilities arise from

- differences in construction practices due to various wind hazard across regions; these variations are captured in the design wind speed maps used to define local building codes

- differences in claims and exposure valuation across different regions and countries

The notion of a 'vulnerability region' is quite fluid: some cat-models consider a country to define a vulnerability region, others follow more strictly the contouring of the design wind speed across Europe, while others also differentiate between regions with various exposure loads (e.g. urban vs rural) to add more color to their definitions of vulnerability regions.

Vulnerability Uncertainties

The vulnerability component of a cat-model is an important source of uncertainties. These uncertainties stem from the very nature of the damage functions and how are these built, as well as the inherent volatility in the response of similar buildings to given windspeed.

Availability of claims data

The claims data, as provided by insurance companies or collected from post-disaster surveys, are a crucial part in the development of vulnerability functions - they provide the required information on the damage produced by hazard at all affected locations. It is well known that this data is not always reliable, and that it has a high variability (often times the data plots as a minimally-shaped cloud of points). The vulnerability functions are then defined through a statistical fit / regression onto this data. The higher the variability in the claims-data, the higher the uncertainty associated with the vulnerability function. Obviously, the more claims-data used in the development of a damage-function, the more trustful the regressional-fit.

Extension to high winds and high damage ratios

Another source of uncertainty comes from extrapolating the damage functions to higher winds and higher damage, a region of the curve where no wind-observations are available. This is a place where model vendors use empirical or statistical methods complemented with engineering expertise and theoretical studies, to extend the curve based on all data available at smaller winds speeds. Choosing the right method for carrying out this step is of great significance as this directly controls the high return period losses.

Secondary uncertainty

Studies have revealed an inherent variability in the damage associated with a given wind speed. The so-called *secondary uncertainty* defines the unpredictability in damage and wind calculations at a location. The uncertainty in the hazard is attributed to un-modelled local phenomena and/or terrain effect factors and was discussed in the HAZARD section. The uncertainty in the damage is due to the variable response of buildings of similar characteristics (construction, occupancy, etc) to windspeeds of a given value. This variable response can be explained only partially by the variability in construction materials, workmanship etc. To account for this observed inherent variability in the damage cat-models include a probability distribution around every mean damage ratio computed by the vulnerability function for a given wind speed at location. This means that for every wind speed, there exist a full set of possible loss outcomes. The probability distribution around each mean-damage-ratio varies from model to model, and some debate exists with respect to which type of distribution is most appropriate in this instance. Some models also include additional empirically-derived probabilities of 0% and 100% damage levels.

Vulnerability Validation

A validation of vulnerability functions is intrinsically related to a validation of losses. This relates mainly to the *absolute* values of mean-damage-ratios provided by a damage function. Equally important is the validation of *relativities* between damage functions for different primary modifier classes, and even relativities between vulnerability functions for different regions or countries.

A holistic validation of vulnerability functions must involve engineering research and analysis, findings from published papers in the field and results from experimental work. In the end, the vulnerability functions included in the model must follow certain engineering principles and logic, to make sure they make sense both in terms of shape and amplitude.

In addition, a proper validation must involve a comparison of the damage function against detailed claims data. Most certainly, the data used for validation must be different than the data used for development and calibration of a vulnerability function.

CLOSING THOUGHTS

Certain aspects of the European regulatory environment with respect to cat-modelling are much less stringent than those existent in the US. A well-established compliance entity in US known as “The Florida Commission”, closely monitors all hurricane catastrophe models used for rating in Florida. High-level specialists in the field of Meteorology, Statistics, Wind Engineering, Software Development, IT/Coding, as well as Actuary, form the body of this commission. These specialists query, in great detail, all aspects of the all cat-models to make sure they are correct and un-biased. A cat-model that doesn’t pass the Florida Commission Standards is no allowed to write business in Florida - of course, the model can still be used elsewhere in the US, but not having passed the Florida Commission means the model cannot be trusted.

One of the main principles of the Florida Commission is that all three modules of a cat-model, *Hazard*, *Vulnerability* and *Financial Module*, have to be sound, robust and stand on their own. In other words the three modules have to be validated independently. It is not allowed for one module to be calibrated as to compensate for biases in another module.

Something equivalent to this does not yet exist in Europe. Here catastrophe models are not checked for individual validation of each module, rather they just need to make sense in terms of final output, the loss.

- THE END -

Appendix 1: Aspects not covered in this document

-- PLA or Demand Surge
-- Clustering
-- Inland Flooding
-- Storm Surge
-- Alternative Event Sets or Climate Views
-- Glossary: GU, GR, NET, Premium, Deductible, Limits, OEP, AEP
-- Financial Module: policy conditions
-- Loss validation: very important – any cat-model is as good as the accuracy of losses it produces