Hazard Specific Risk Assessment: Meteorological

1 - Tropical Cyclones

Key words: tropical cyclone, loss exceedance curve (LEC), wind speed hazard curve, storm surge run-up, mean damage ratio (MDR), climate change

With few exceptions, only limited information is available about catastrophic events that occurred in the past. Even less is known about events that will occur in the future. Given the short historical records for many of the ocean basins where tropical cyclones occur, it is safe to say that most coastal locations have not yet experienced anything close to the "worst case" tropical cyclone event. When considering the possibility of highly destructive events occurring in the future, any risk analysis should use probabilistic analytical models that allow for available historical information to be used in predicting potential catastrophic consequences. The risk evaluation of extreme events should follow a prospective focus, thus anticipating the rates of occurrences of events of different magnitudes, and the consequences that will be associated with each event. Such an evaluation must consider the uncertainties that arise when estimating the severity and frequency of these events.

When undertaking a probabilistic catastrophe risk analysis, the relevant components of risk, which include the exposed assets, their physical vulnerability, and the hazard intensities, must be represented in such a way that they can be consistently estimated through a rigorous and robust procedure, in both analytical and conceptual terms. Probabilistic risk analysis is a state-of-the-art technique that allows accounting of many of the uncertainties associated with the hazard intensities and the physical vulnerability characterization. The main result of such an analysis, the Loss Exceedance Curve (LEC), specifies the frequencies, usually expressed annually, with which events will occur that exceed specified loss values. The LEC is recognized as being the most robust technique for catastrophe risk assessment representation[1].

Disasters can be considered as implicit contingent liabilities that increase the fiscal vulnerabilities of any country. In other words, a future disaster is an uncertain hidden public debt that becomes a realized fiscal liability when the event occurs. To properly assess a country's fiscal sustainability, this "contingent debt", which represents the potential losses from future catastrophes, must be added to the current explicit debt. If the total value of current and contingent debts exceeds the discounted present value of future primary surpluses of the country, there is an unbalance in the equation of the country's fiscal sustainability. Governments should therefore recognize that future disasters need to be considered in the country's balance sheets, as they can generate important macroeconomic imbalances. This is related to the country's fiscal responsibility, which corresponds to losses to public assets as well as those affecting the low-income population dwellings. The best way of

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assessing these potential losses is by using a probabilistic framework, which allows governments to measure disaster risk in the context of fiscal sustainability. With such an approach, it is then possible to identify optimal strategies for financial protection which involve either transferring or retaining this sovereign risk.

Risk assessment requires three analytical steps, as follows:

- **Hazard assessment**: For each of the natural phenomena considered, a set of events is defined along with their respective frequencies of occurrence that is an exhaustive representation of said hazard. Each scenario contains spatial distribution parameters that will permit the construction of the probability distributions for the intensities produced by their occurrence.
- **Exposure assessment**: An inventory of the exposed assets must be constructed and this should specify the geographical location for each, and the following main parameters to classify them: a) Replacement value, and b) Building class to which the asset belongs to.
- **Vulnerability assessment**: Each building class must be associated with a vulnerability function for each type of hazard. This function characterizes the structural behavior of the asset during the occurrence of the hazard phenomena. The vulnerability functions then allow a loss probability distribution to be computed as a function of the hazard intensity for specific scenarios. These sets of curves relate the expected value of damage and standard deviation of damage with the intensities for each scenario.

Cyclones, which broadly encompass tropical cyclones, extratropical cyclones, and subtropical (or hybrid) cyclones (which share some characteristics of both tropical and extratropical cyclones), are some of the most impactful hazards in the world. Cyclones can cause large economic losses and large death tolls in both coastal and inland settlements due to the combination of very strong winds, storm surge, and heavy rainfall. Secondary effects of cyclones can include large ocean waves, inland river flooding, landslides, forest blowdowns, tornadoes, and ecological disruption. To assess the risks posed by cyclones to a given country, the hazard must be modelled adequately. In this chapter, we will discuss the general modeling framework only for tropical cyclones. A worldwide risk assessment of tropical cyclones can be found in Cardona et.al. (2014)[2].

Hazard assessment

The purpose of a probabilistic risk assessment is to characterize and quantify the losses on a set of exposed elements, given the occurrence of hazardous events. Given that there are uncertainties in the estimation, the loss should be modeled as a random variable. In general terms, one would be interested to know the following about the loss:

- The universe of all possible losses (i.e. the domain of the random variable describing the loss), and

- The probability density function of the loss, which is defined within the domain of the variable.

The objective is to establish the probability of occurrence of any future loss event. The definition of such an event should depend on what questions the stakeholders desire to answer. This means that such events are defined arbitrarily, depending on the type of decision to be made. However, the definition of these events is not of interest; we are interested to know their probability of occurrence. To calculate the probability of occurrence of any arbitrarily-defined loss event, any appropriate mathematical framework must require the definition of a set of mutually exclusive and collectively exhaustive loss events to be used as the basis of the calculation. These base loss events are then obtained and characterized by assessing the losses due to a collection of hazard scenarios, each of which results in a different loss event. Likewise, the hazard scenarios must also be mutually exclusive and collectively exhaustive. Fully probabilistic risk assessment requires that the definition of hazard scenarios and, therefore, hazard models, must return an assessment in terms of a collection of scenarios.

For assessing tropical cyclone hazard two main approaches are typically used: i) the *statistical* approach, which broadly consists of performing statistical regressions on wind or tidal data for a unique geographical location in order to define an artefact (i.e., a collection of carefully-crafted statistical relationships) to characterize future hazard conditions; and ii) the *stochastic* approach, in which a large number of cyclones are stochastically generated from a model that is based on historical records, in order to forecast, for an entire country or region, the future hazard conditions due to the passing of physically-plausible future tropical cyclones.

The stochastic simulation of tropical cyclones is a widely-accepted approach for hazard assessment. It involves the simulation of the characteristics of synthetic tropical cyclones, i.e., cyclones that are not included in the historical database, but which have statistical properties similar to those of cyclones in the historical database. The characteristics typically required are: the locations that the center of the cyclone passed over (e.g., the *track*), the maximum winds associated with the tropical cyclone (i.e., the *intensity*), the minimum central pressure, the environmental pressure, and the extent of the maximum winds about the center (the *radius of maximum winds*, or RMW). Stochastic simulation of these characteristics fits well with the abovementioned scenario-based approach that is required for probabilistic risk assessment. The stochastic generation of cyclone tracks must incorporate the historical information as a basis. Therefore, a *tropical cyclone database* is required as the starting point for any risk analysis. Practitioners should be aware of the biases and deficiencies inherent to such databases, as biased historical data can result in significant errors in the results of the hazard assessment (see Box 1).

Once a suitable historical database has been constructed, three different methods of hazard simulation can be followed: *random*, *integral* and *hybrid* simulation. The *random* simulation method constructs a large set of tropical cyclone events by perturbing the historical tracks using random-walk techniques (e.g., a bi-dimensional Wiener process). This computationally-efficient approach must be applied with care to avoid constructing tracks that are inconsistent or physically-impossible. The second method, the *integral* simulation technique (also known as *dynamical downscaling*), allows the generation of physically-based cyclone tracks based on general atmospheric and oceanic conditions by using a full-physics dynamical model to simulate the cyclone using the fields of a global reanalysis for a present or past climate, or a general circulation model in the case of a future climate projection (for a recent example, see Knutson et al. (2015)[3]. Such an approach requires more detailed data and a large amount of computational resources, not to mention an atmospheric and oceanographic backend model to provide the necessary inputs for the generation of the realistic synthetic cyclones. This type of approach is the most appropriate method for simulating cyclones in a future, changing climate (see Box 2). Finally, the *hybrid* simulation approach (sometimes referred to as *deterministic downscaling*) combines the strengths of the abovementioned ones[4]. Tracks are randomly generated and then the associated TC intensity is modeled using a reduced complexity dynamical *intensity* model to take into consideration parameters from the atmospheric-oceanic system that influence the lifecycle of a tropical cyclone. This approach requires much less computational resources than a full dynamical downscaling, yet allows for an adequate simulation of the intensity life cycle of tropical cyclones in an atmospheric-ocean state that is consistent with the future climate projected by general circulation models.

Once the full set of cyclone tracks has been defined for the hazard model (usually including both historical and simulated tracks), the effects of those cyclones must be evaluated at the local scale. As mentioned previously, these effects include: strong winds, storm surge, and heavy rainfall. To assess the site-specific effects of a tropical cyclone, three main types of models can be applied: *parametric*, *kinematic* and *dynamic*. Parametric models are useful when they can be validated by a significant amount of data, meaning that they require calibration (they are data-driven models). Unfortunately, such validation data do not exist for many countries and territories. On the other hand, kinematic and dynamic models are physics-driven, which means that they can model the physics involved in the lifecycle of tropical cyclones. Fully probabilistic risk assessment can be based on any of the mentioned approaches, keeping in mind that the use of parametric models requires that an appropriate validation study be performed; this requires very detailed (and usually very scarce) data. If kinematic or dynamic models are used, the complexity of the modeling may require very intensive computation resources to obtain the essential outputs.

Users should also be aware of the limitations of the modeling framework they are using. For instance, most of the of the parametric wind models commonly used to assess tropical cyclone wind hazard are not applicable to the more complex wind fields of extratropical cyclones. In such cases, care must be taken to exclude the extratropical phase of a cyclone's lifecycle from the historical database used as input to the tropical cyclone hazard assessment. Then, assessment of extratropical cyclone hazard will need to be conducted separately using a separate historical database of extratropical cyclone events, as well as wind models capable of representing the wind field of an extratropical cyclone.

Modelling TC effects

As summarized by Vickery et al. (2009a)[5], wind field modelling is a three-step process:

1. Given cyclone characteristics (e.g., central pressure, translation speed, and RMW), the wind speed at gradient height is calculated. Gradient height is the altitude at which wind speed is generally unaffected by surface conditions (e.g., friction-induced mixing processes). It is usually assumed that the gradient height wind speed characterizes a representative mean wind speed of the vortex.
2. From the wind speed at gradient height, a surface speed is calculated by applying an atmospheric boundary layer (BL) model.
3. Finally, the mean surface speed (typically for 10 m height above the surface) is modified by site-specific conditions, such as topographic amplification and surface roughness, and converted to the desired gust period using the appropriate gust factor (for more on appropriate conversions between wind gusts, see Harper et al. 2010[6]). For wind loading thresholds for structures, the 3-second gust is typically used.

Enormous advances have taken place in wind field modelling since the early 1970s when the first studies took place. There are several proposals in the literature to account for each one of the steps presented above. A detailed description of wind field modelling can be found in Vickery et al. (2009). **Error! Reference source not found.** shows the integrated results of a wind hazard assessment for the Bahamas, in terms of the wind hazard curve for Nassau, and as a uniform hazard map of 25-year return period for the country.

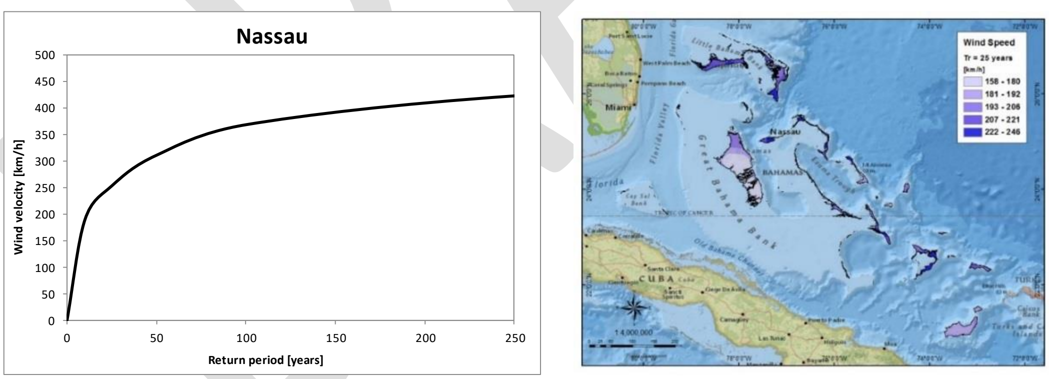

FIGURE 1 - Wind speed hazard curve for the city of Nassau (left) and wind speed hazard map for a 25-year return period for the Bahamas (right)

Storm surge is widely recognized to be one of the most destructive effects related to tropical cyclones. When assessing storm surge, the objective is to determine the sea water run-up height at the shoreline and the resulting inundation depth over land. The total run-up height should be modeled as composed by three parts: the wind-forced run-up, the barometric run-up, and the run-up due to wave setup. Storm surge hazard must be modeled in terms of the geographical distribution of the coastal inundation depth. Since the modeled storm surge height can depend critically

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on the cyclone parameters (intensity, translation speed of the center, incidence angle of the track to the coast), each of which possesses uncertainty, the storm surges associated with historic cyclone events can be modeled as an ensemble in which each member corresponds to a cyclone simulation perturbed according to the uncertainty in one or more of these parameters. FIGURE 2 - Left: mean storm surge run-up (meters) for Japan calculated from 100 simulations of Typhoon Tip. Right: mean storm surge run-up (meters) for Belize calculated from 100 simulations of Hurricane Hattie.

shows the mean run-up height calculated from 100 simulation of Typhoon Tip (1979), along the east coast of Japan, as well as the mean run-up height calculated from 100 simulation of Hurricane Hattie (1961), along the coast of Belize.

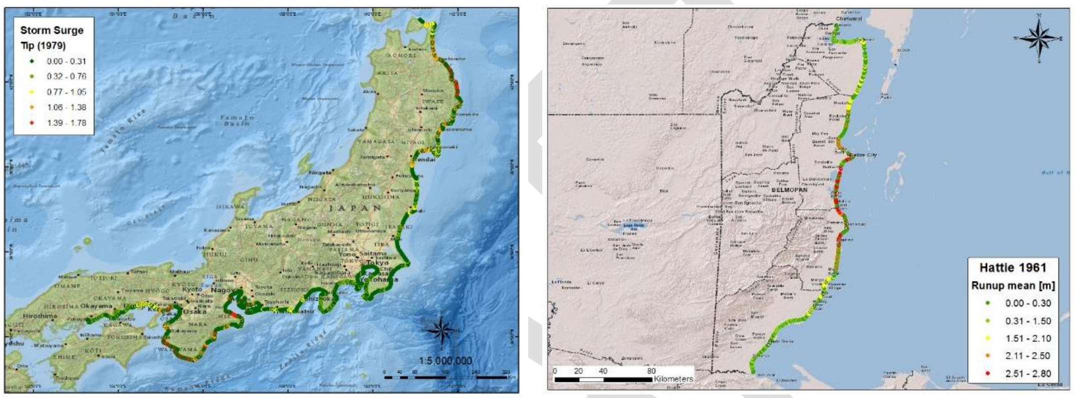

FIGURE 2 - Left: mean storm surge run-up (meters) for Japan calculated from 100 simulations of Typhoon Tip. Right: mean storm surge run-up (meters) for Belize calculated from 100 simulations of Hurricane Hattie.

Exposure

The description, characterization, and appraisal of the physical inventory of exposed elements for a probabilistic disaster risk assessment always presents serious challenges for modeling regardless of scale. In this case, a series of assumptions have been made and these naturally increase the epistemic uncertainty in the risk modeling, even in those cases in which a relative amount of detailed information is available (for example, at the urban scale in which a building-by-building inventory of structural characteristics is available). The uncertainty associated with the quality of the data is expected to be systematically reduced because the final risk outcome involves the aggregation of the losses caused for all exposed elements. During such an aggregation, the uncertainties of individual loss events aggregate into a reduced level of total uncertainty due to the law of large numbers, this. In the portfolios for insured buildings or government-owned buildings, for example, there are always doubts regarding the accuracy and reliability of certain data. Because of this, it is expected that the results from the risk assessment are approximations that provide the order of magnitude of potential losses.

In general, an exposed element is any object susceptible to suffer damage or loss because of the occurrence of a hazardous event. In addition, the exposed elements have an implicit component associated with loss liability. If, for example, the exposed elements in a risk assessment correspond to public health buildings, then the losses caused by the occurrence of hazardous phenomena will be responsibility of the corresponding public health institution. If the exposed elements, for example, are households of low socio-economic income, then the losses caused often become the fiscal responsibility of the State, given the inability of the owners of the private homes to cope with the disaster situation. It is therefore important to determine liability for losses directly in the definition of the exposed elements. For this reason, the exposed elements are grouped into portfolios.

The exposure model is the inventory of assets (buildings and infrastructure) that can be affected by the occurrence of natural hazards, i.e., is the set of exposed elements. It is an essential component in the risk analysis, and the degree of precision of the results depends on its level of resolution and detail. There are different resolution levels, and when not enough detailed information is available, or an estimation over a complete administrative area is intended (country level), it is necessary to carry out approximate estimations that represent and give account of the inventory of exposed elements. This is usually referred to as the *proxy* exposure model.

The exposure model should be based on official information about demographic, economic and social indexes at sub-national level, which, combined with statistics about the building classes' distribution, give an idea of what and where the assets are, and more importantly, of how much they cost; in summary, the main objective of the country's *proxy* exposure model is to create a suitable geographical distribution for the inventory, in such a way that it represents in general terms the location of the assets and population.

Vulnerability

For probabilistic disaster risk assessment, the vulnerability of exposed elements is assessed using mathematical functions that relate the intensity of the tropical cyclone to the direct physical impact. Such functions are called *vulnerability functions* and they must be estimated (or assigned from existing databases) for each one of the construction classes identified in the exposure database. Vulnerability functions are characterized by the variation of the statistical moments of the relative loss (also known as Mean Damage Ratio – MDR) to the hazard intensity (i.e. wind, storm surge, etc.). This enables the estimation of the loss probability function at each level of intensity.

Vulnerability functions are useful to describe the expected behaviour of the different construction classes at the national (or sub-national) level when faced to the occurrence of a tropical cyclone. The vulnerability functions should allow differentiating structural behaviour by construction class within a country. Aspects such as construction quality and the degree to which builders complied with local or regional building codes must be considered for the different classes of buildings.

FIGURE 3 -*Wind* *(left)* and Storm surge (right) vulnerability functions presents an example of wind and storm surge vulnerability functions, showing how the expected damage increases as a function of the peak wind speed and water depth for each building class.

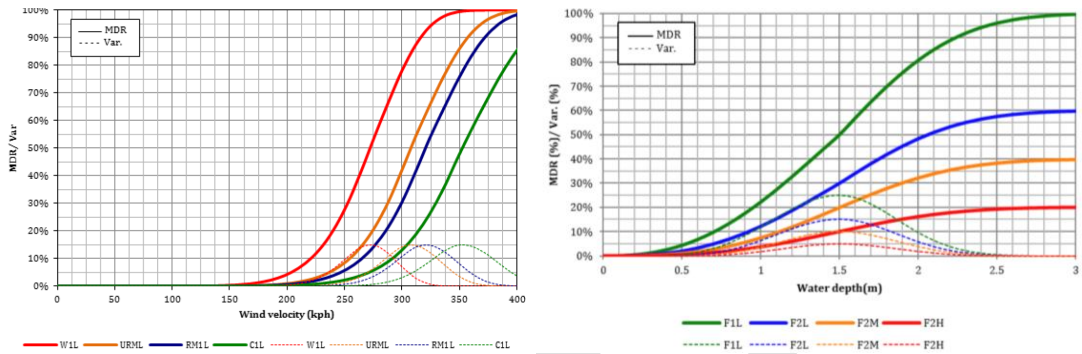

FIGURE 3 -Wind (left) and Storm surge (right) vulnerability functions

It is worth mentioning that this type of vulnerability modelling aims to capture the general vulnerability characteristics at a regional level to be compatible with the level of resolution used in the exposure database; no specific considerations should be made for any structural system. Every single kind of asset identified and included in the database must be associated with a vulnerability function for the considered hazard effects.

Loss assessment

Considering the basic objective of the probabilistic risk analysis, a specific methodology must be followed to calculate the frequencies of occurrence of specific loss levels in the exposed assets over defined periods of time given the occurrence of tropical cyclones. The risk to natural hazards is commonly described through the LEC, which contains all the information required to describe, in a probabilistic way, the process of occurrence of events (cyclones) that generate losses. The following issues should be borne in mind:

- The loss from a tropical cyclone event is an uncertain quantity whose value cannot be precisely known. Therefore, it must be seen and treated as a random variable, and methodologies should be constructed to know its probability distribution conditional to the occurrence of a certain hazard scenario.
- The loss is calculated as the sum of the losses that occur in each of the exposed assets. Each of the items in the sum is a random variable, and there is a certain level of correlation between them which should be included in the analysis.

The calculation of the LEC follows the next sequence of steps:

1. For a hazard scenario, determine the loss probability distribution in each of the exposed assets.

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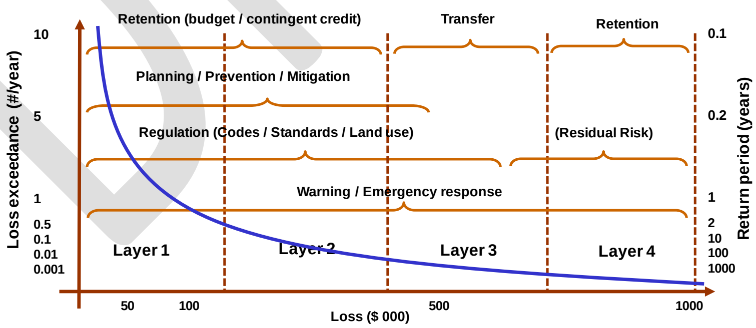
2. Based on the loss probability distribution of each asset, determine the probability distribution for the sum of these losses, considering the correlation that exists between them.
3. Once the probability distribution for the summed losses is determined for that scenario, calculate the probability that this will exceed a given value of loss.
4. The probability determined in step 3, multiplied by the annual frequency of occurrence of the hazard scenario, is the contribution of this event to loss exceedance rate.
5. The calculation is repeated for all scenarios, and in this way the LEC is constructed.

As indicated above, the LEC contains all the information required to characterize the process of occurrence of events that produce losses. However, it is sometimes not practical to use a complete curve, and therefore it is convenient to use specific estimators of risk that will allow it to be expressed by a single number. The two most commonly used specific estimators are described here described as follows:

- *Average annual loss* (AAL): this is the expected value of the annual loss. It is an important quantity, since it indicates, for example, if the process of occurrence of the damaging event is stationary from here to eternity, its accumulated cost will be the equivalent to the sum of paying the AAL annually. Therefore, in a simple insurance scheme, the AAL would be the pure premium.
- *Probable maximum loss* (PML): This is a loss that does not occur frequently and then is associated with long return periods (or, alternatively, low exceedance rates). There are no universally accepted standards to define what is meant by "not very frequently". The choice of a specific return period for a decision-making process depends on the risk aversion of who is deciding.



Error! Reference source not found. Schema of a stratified LEC or Risk Curve. (1- High probability and low/moderate losses; 2- medium probability and moderate/high losses; 3 - low probability and high losses; 4- very lose probability and very high losses)

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Conclusion

This chapter has provided an overview of probabilistic risk assessment of tropical cyclones, whose key components involve assessments of tropical cyclone hazard, the exposure of a country's assets, and the vulnerability that results. The resulting loss exceedance curves can then be used to assess a country's fiscal sustainability. While the approach described above has been comprehensive, we note that tropical cyclones can inflict other types of losses on countries due to loss of critical transportation infrastructure (e.g., roads, bridges, port facilities), communications infrastructure, and power infrastructure. Beside the replacement cost of such infrastructure, profound economic losses can occur due to supply-chain disruption, loss of human capital, and loss of livelihoods. These types of losses can result in a substantial long-term decrease to a country's Gross Domestic Product (GDP) and therefore impact a country's fiscal sustainability. To assess these types of losses, integrated economic modeling is required.

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BOX 1 - Observational uncertainty

A primary source of uncertainty arises due to incomplete and inhomogeneous historical records of the observations of tropical cyclone characteristics. Taking the North Atlantic basin as an example, prior to 1900 observations of tropical cyclones were very limited. Quantitative data were typically only gathered from ships unlucky enough to be affected by the cyclone or when cyclones approached land. Such observations were typically limited to wind speed and/or wind direction, notes on damage and/or water levels, and the occasional barometric pressure reading. Assessing the characteristics of tropical cyclones with these clues, together with observations from a sparse synoptic observing network, was a task fit for a sleuth. The advent of rawindsondes, routine aircraft observations, radar, and satellites brought much more quantitative information to bear on the problem of estimating the cyclone characteristics, however improvements to existing observations (e.g., more accurate wind speed measurements, better navigation equipment on airplanes, better radars, higher resolution satellite imagery, etc.) and the addition of new observing methods (e.g., satellite-based scatterometry for estimating surface winds, aircraft-based Stepped Frequency Microwave Radiometer for estimating surface winds) make it exceedingly difficult to compare the characteristics of cyclone events from one era to those of another. Along with changes in the observing system, operational practices for blending these disparate observational data to obtain the best possible estimate of the cyclone characteristics have changed over the years as scientific understanding evolved. One important example is the issue of how the surface wind speed is estimated from aircraft winds measured up at flight level. The development of a highly accurate GPS dropsonde in the 1990s lead to high resolution wind profiles and a seminal study that lead to an important revision in the flight level-to-surface factors used operationally at the National Hurricane Center. Because of this and other factors, the intensity of tropical cyclones from the 1940s to the 1960s are now recognized to have been overestimated by a substantial degree. Similar issues exist for aircraft measurements in the Western Pacific basin. Another important source of uncertainty arises due to the use of the Dvorak method of estimating tropical cyclone intensity from satellite imagery. While the development of the Dvorak method lead to a true revolution in operational practice, allowing tropical cyclone intensity to be estimated even in the absence of in situ measurements, differences in the application and interpretation of the Dvorak method, coupled with uncertain wind-pressure relationships, lead to widely-varying intensity estimates from agency to agency and over time. The result is that the so-called "best track" databases possess significant biases and large inhomogeneities. For the Western Pacific, there are at least several such databases, and there are stark disagreements between them for many cyclones. Blindly taking any long-term best track database, including the International Best Track Archive for Climate Stewardship (IBTrACS), and using this as input for a hazard simulation can introduce significant biases into the results of the hazard assessment. This source of uncertainty can be partially ameliorated by limiting the input data to just the historical observations from years in which the modern observing system has been in place (e.g., after 1985 for most basins). An even better solution would be to undertake a globally consistent objective reanalysis of all available observations; however, this has not yet been accomplished. Doing so will require substantial resources. Short of this ideal solution, the impact of observational uncertainty can be assessed through sensitivity experiments.

Practitioners should be aware that damage often increases exponentially with windspeed. This means that even relatively small errors in the intensity of simulated hazard events may result in significant errors in the LECs. Along the same vein, it is vital that realistic RMW values be used in the hazard assessment. Historical data on this quantity is quite lacking even in official databases. Users should be aware that the RMW values in unofficial databases may be of low quality[78].

BOX 2 - Considering climate change

Global climate change is likely to modify the trends of occurrence of extreme meteorological events, such as tropical cyclones. The Intergovernmental Panel on Climate Change (IPCC) provides a general framework associated with the effects of climate change in terms of observed and projected changes in cyclonic activity in the world:

- Observed changes: Given the changes made in the ability to observe the past, there is a low level of confidence regarding ability to observe any increase in the long term (i.e. 40 years or more) frequency of tropical cyclones.
- Projected changes: It is likely that the global frequency of tropical cyclones will decrease or remain essentially unchanged. It is likely that the average wind speed of tropical cyclones will increase, with the strongest tropical cyclones becoming more intense, although the increases may not occur in all ocean basins. It is possible that heavy precipitation associated with tropical cyclones will increase. It is almost certain that increasing sea levels will exacerbate the impacts of tropical cyclone storm surges and waves.

In this sense, we can expect an increase in the effects of cyclones (wind speed) on behalf of increased intensity (Saffir-Simpson category) of hurricanes. One of the recent efforts to study the climatological characteristics of hurricanes, particularly those in the tropical Atlantic basin, was made in the Nested Regional Climate Model project (NRCM) of the National Center for Atmospheric Research (NCAR) of the United States, in which the meteorological Weather & Research Forecasting (WRF) Model was nested in the Community Climate System Model (CCSM) to study different climatological characteristics of hurricanes in the tropical Atlantic basin region covering the tropical Atlantic, northern South America, Caribbean Sea, Gulf of Mexico, Central America and a portion of the south east USA.
These models predict future hurricane tracks which is the main input for hurricane hazard modelling. With these new sets of tracks, hurricane hazard assessment can be performed including the future changes associated with climate. Figure 5 shows the historical tracks on the left and the historical tracks plus the future tracks for the North Atlantic basin. Full hazard and risk evaluation under these conditions is presented in INGENIAR & CIMNE (2015)[9].

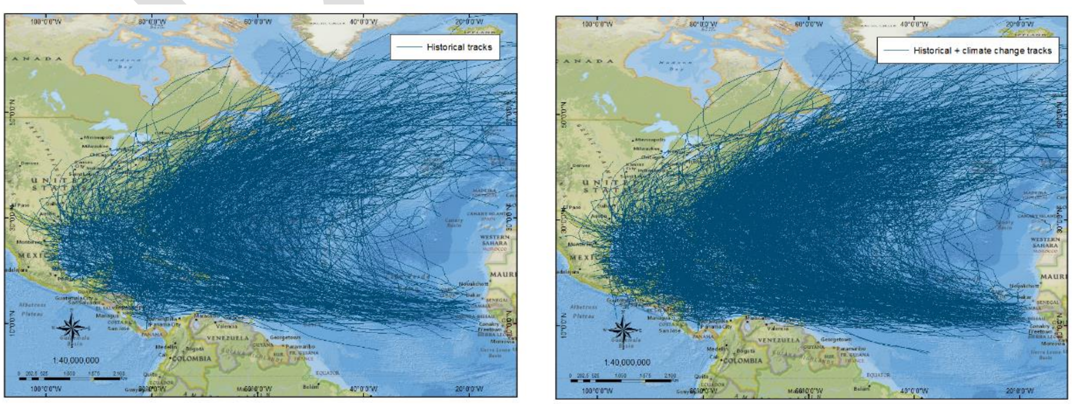

FIGURE 5 - Historical tracks (left) and historical plus future tracks (right)

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BOX 3 - Forecasting potential losses in real time: the case of Hurricane Matthew

Hurricane Matthew started on September 28 of 2016 as a tropical storm over the island of St. Lucia. On September 29, it developed into a hurricane of category 1 (Saffir-Simpson hurricane scale), with a maximum wind speed of 92.6 km/h. Matthew continued to intensity rapidly, and on October 1, it reached category 5 approximately 100 km north of the Colombian Guajira Peninsula with a maximum wind speed of 260 km/h. It impacted several countries in the Caribbean, and the southeastern states of the United States of America.

Using probabilistic hazard and risk assessment methodologies, together with real-time data on the hurricane characteristics, including track, intensity, and radius of maximum winds, it is possible to use various hazard modeling approaches to assess the footprint (or swath) of maximum wind speeds. The first such simulation, was computed using the track reported by NOAA with data from September 29 to October 4. At the time, Matthew was approaching the east coast of Cuba as a Category 4 hurricane. This maximum wind simulated in this wind swath was 300 km/h. A final wind swath was computed with the observed hurricane track reported by NOAA with data from September 29 until October 9 when it weakened and started moving out towards the Atlantic Ocean. This last simulation reached a wind speed of 322 km/h. Hazard assessments were run on the TCHM software[10].

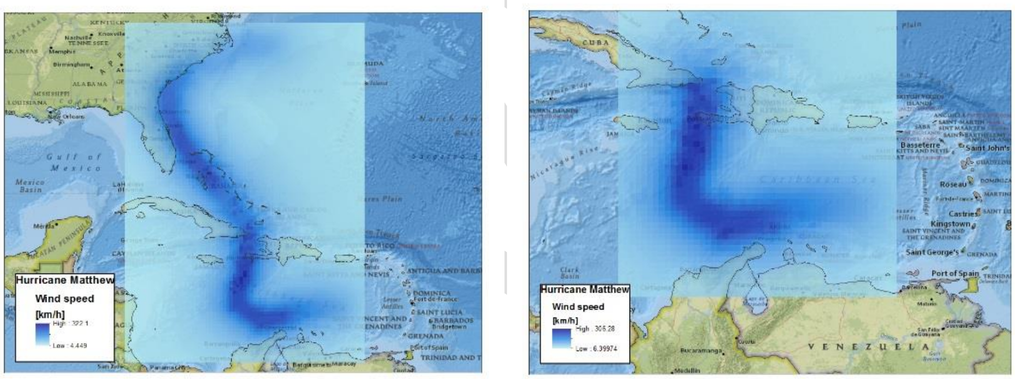

FIGURE 6 - Hazard assessments with real time data

Based on these hazard simulations, different scenarios of risk and expected losses were produced as the hurricane continued its path. The results ranged from expected losses of US$800 million for the first hazard simulation where the hurricane was approaching eastern Cuba, to US$26 billion for the final loss assessment when the hurricane turned into post tropical storm. This last model predicted the most significant losses in The Bahamas, Haiti and Cuba and the states of Florida and South Carolina in the United States of America.

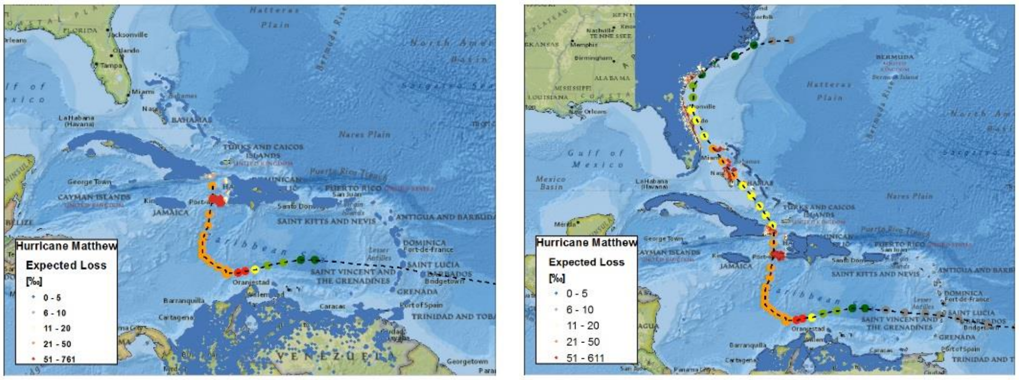

FIGURE 7 - Real-time loss assessments

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☑ Peer reviewed
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