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Tropical Cyclones and Climate Change Projections

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Abstract

Accounting for wind extremes is essential for wind engineering design. Tropical cyclones are one of the main types of weather events causing widespread extreme winds. It is estimated that globally they result in 10,000 deaths per year and damages of $26 billion US dollars (Mendelsohn et al. [14]). Accurate forecasting of tropical cyclones is challenging due to the lack of reliable data for all regions and time scales necessary. Tropical cyclones (TCs) form over the tropical oceans with sufficiently warm sea surface temperature and some initial cyclonic circulation. As most TCs form and spend most of their life over oceans, there is only limited surface observational data available for assessment. Currently, satellites are the primary tools for determining the location and strength of TCs. However, TC intensity is related to surface wind strength, which satellites cannot determine accurately. As a result of the different observation practices of organisations that study TCs (such as period of sustained winds) and the relative low frequency of occurrence of these events, current trends in number and intensity of TCs are hard to determine.

Capturing changes in TCs with anthropogenic warming is another challenging problem, and limitations in techniques available make clear determination of changes or trends by mid-century or the end of the century difficult. However, most methods for projections indicate an overall decrease in TC frequency, but with a potential increase in the more intense TCs in the future. From a wind engineering perspective, this may require changes to requirements for construction of structures with a long lifespan to deal with the possibility of stronger winds in the more intense storms.

Introduction

Tropical Cyclones (TCs) are one of the most notable weather phenomena that cause wind extremes. While only occurring in limited regions near the equator of the globe, their size, frequency and tracks cause many extreme weather conditions around the world. TCs typically cover an area on the order of 100s of kilometres, can last for several days and travel for several thousand kilometres so their effects are felt in urban areas with dense populations and well-developed infrastructure.

Forecasting of tropical cyclones has improved significantly over the last several decades due to better observations, mostly via satellite, which have been able to provide better initial conditions necessary for numerical weather predictions of current TC path and intensity. However, significant uncertainties exist in the projected changes in tropical cyclones related to climate change. Changes to TCs projected for mid-century and end of the century can have significant impact on the design of structures that might be affected by TCs

In this paper, a summary of the state of knowledge related to forecasting tropical cyclones and their projected changes in the future will be presented. First, a summary of what a tropical cyclone is and the conditions necessary for it to form is presented. This is followed by discussion of issues related to observing the characteristics of TCs and assessment of any trends. Our current understanding of future changes in TCs is then presented. This is followed by some guidelines on the generation, use and presentation of climate projection information.

What are Tropical Cyclones?

The typical structure of a tropical cyclone is presented in Figure 1. Tropical cyclones are typically low latitude strong wind systems driven by the release of latent heat of condensation. They are characterised by strong surface winds (used to classify the strength of the TC) and heavy rainfall, with an ‘eye’ at the centre with light winds and little rain.

While there are differing names and criteria for classifying the intensity of TCs around the world, the Saffir-Simpson scale is defined as the maximum sustained wind speed of:

CATEGORY 1: 33-42 m/s.
CATEGORY 2: 43-49 m/s.
CATEGORY 3: 50-58 m/s.
CATEGORY 4: 58-70 m/s.
CATEGORY 5: > 70 m/s.

The conditions that typically are needed to form tropical cyclones are 1) warm sea surface temperatures, typically above 27 °C, needed to provide a good source of moisture; 2) low vertical stability of the atmosphere above; 3) low-level cyclonic circulation away from the equator; 4) sufficient atmospheric moisture especially in the mid-levels in order to allow enough condensation and latent heat release to provide the energy to maintain and build the system and counter the effects of friction; 5) some sort of outflow at upper tropospheric levels in order to allow the system to deepen and 6) low vertical windshear so that the convection is vertical. Although these conditions provide the larger scale ingredients necessary for TCs to form and develop, there is still a need for an initial disturbance to initiate the development, such as an enhanced region of convection.

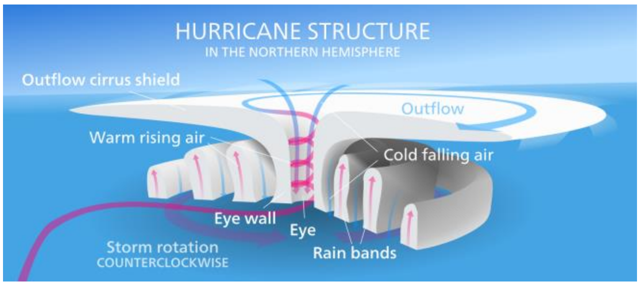

Figure 1: Schematic of a tropical cyclone in the Northern Hemisphere. Note that storm rotation is counterclockwise in the Northern Hemisphere, but clockwise in the Southern Hemisphere. https://upload.wikimedia.org/wikipedia/commons/4/4f/Hurricane-en.svg.

Observations and historical trends of Tropical Cyclone frequency and intensity

As indicated previously, the key ingredients for tropical cyclone formation are warm sea surface temperatures, a moist unstable atmosphere, weak vertical wind shear and outflow in upper levels. As a result, TCs typically form near the equator. They do not form on the equator as they need to have a cyclonic circulation due to the Coriolis effect of the earth's rotation. Once formed, they can travel many thousands of kilometres to regions well outside the tropics (Figure 2). The average annual number of TCs (winds greater than 17 m/s) for each basin are: western North Pacific, 26,; eastern North Pacific, 17; South Indian ocean, 17; North Atlantic, 12; Australia/South Pacific region, 10; and the North Indian Ocean, 5. As TCs move outside the region of formation, they either die when they move over land (which cuts off the source of energy from surface moisture fluxes) or move into environments not conducive for TCs (such as those with colder sea surface temperatures, stronger vertical wind shear or drier air), with some TCs then transitioning into mid-latitude extratropical cyclones.

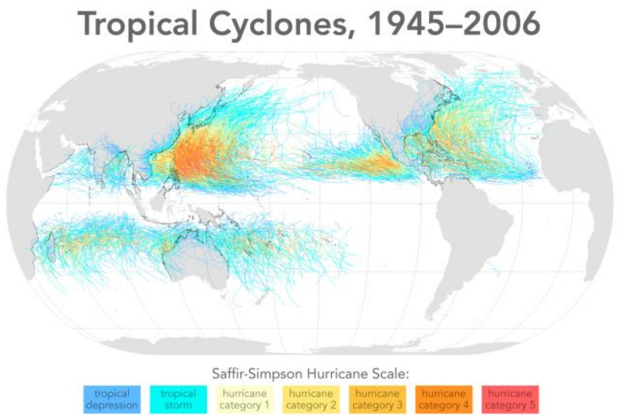

Figure 2: Distribution of tropical cyclones from 1945-2006. https://upload.wikimedia.org/wikipedia/commons/6/6f/Tropical_cyclones_1945_2006_wikicolor.png.

While the distribution and intensity of TCs are generally well understood, there remain significant uncertainties, especially in regard to trends over the last several decades.

In a recent study, Knapp & Kruk [13], compared the maximum observed sustained winds for TCs from the different reporting agencies with data from the International Best Track Archive for Climate Stewardship (IBTrACS) global tropical cyclone dataset. The maximum sustained winds were normalized by correcting for known changes in operational procedures. While the normalization helped, it was concluded that more details of operational procedures are needed for a more realistic reanalysis of tropical cyclone intensities.

In another study, Kossin et al. [12] noted that formal analysis of the historical global IBTrACKS records of tropical cyclones is encumbered by temporal heterogeneities in the data caused by changes in detection and assessments, such as by the introduction of satellite observations since 1979. This is particularly problematic when attempting to detect trends in tropical cyclone metrics that may be attributable to anthropogenic warming. By creating a new homogenized record of tropical cyclone intensity, they suggest that globally tropical cyclones have become more intense at a rate of about 11 m s^{-1} per decade during the 28-year period 1982–2009, but the statistical significance of this trend is marginal. The trends per basin (see Figure 3) indicate mainly increases in the North Atlantic and South Pacific basins.

In a comprehensive analysis, Knutsen et al. [10] discuss previous studies where the characteristics of tropical cyclones have changed, often with conflicting results. Large amplitude interannual fluctuations in the frequency and intensity of tropical cyclones greatly complicate both the detection of long-term trends and their possible attribution to rising levels of atmospheric greenhouse gases. Trend detection is further impeded by substantial limitations in the availability and quality of global historical records of tropical cyclones. Therefore, it remains uncertain whether past changes in tropical cyclone activity have exceeded the variability expected from natural causes.

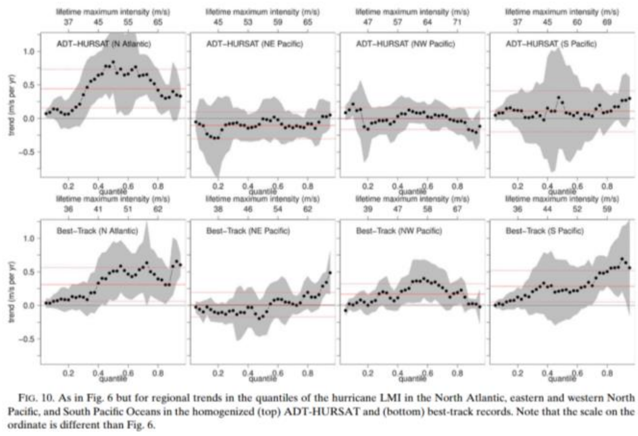

Figure 3: Regional trends in the quantiles of tropical cyclone lifetime maximum intensity index in different basins using a homogenised dataset (top) and the IBTrACS dataset. (from Kossin et al. [12])

A possible trade-off between intensity and frequency was found by Kang & Elsner [10] who noted an average annual increase in global tropical cyclone intensity (increases in wind speed of 1.3 m s^{-1}) over the past 30 years of ocean warming, occurring at the expense of a reduction by 6 in the number of tropical cyclones worldwide.

Webster et al. [20] examined the changes in tropical cyclone number, duration, and intensity over the past 35 years, the period when satellite data has been available. Their main finding was although the number of cyclones decreased throughout the planet excluding the north Atlantic Ocean, there was a great increase in the number and proportion of very strong cyclones.

Schiermeier [17] found that the strongest tropical cyclones are getting stronger, particularly over the North Atlantic and Indian oceans. Wind speeds for the strongest tropical storms increased from an average of 225 km/h in 1981 to 251 km/h in 2006, while the ocean temperature, averaged globally over all the regions where tropical cyclones form, increased from 28.2 °C to 28.5 °C during this period.

The summary in the latest Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (AR5, IPCC [9]), along with changes in TC assessment from previous reports, indicates that globally, there is low confidence in attribution of changes in tropical cyclone activity to human influence. This is due to insufficient observational evidence, lack of physical understanding of the links between anthropogenic drivers of climate and tropical cyclone activity, and the low level of agreement between studies as to the relative importance of internal variability, and anthropogenic and natural forcings. In the North Atlantic region there is medium confidence that a reduction in aerosol forcing over the North Atlantic has contributed at least in part to the observed increase in tropical cyclone activity there since the 1970s. There remains substantial disagreement on the relative importance of internal variability, greenhouse gas forcing and aerosols for this observed trend. (see Table 1)

Table 1: Global-scale assessment of recent observed changes, human contribution to the changes and projected further changes for the early (2016–2035) and late (2081–2100) 21st century. Bold indicates where the IPCC AR5 (black) provides a revised global-scale assessment compared to the Special Report on Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation (blue) or previous fourth assessment (red). Projections for the early 21st century were not provided in previous assessment reports. Projections in the AR5 are relative to the reference period of 1986–2005, and use the new RCP emission scenarios. Adapted from IPCC [9].

Phenomenon and direction of trend	**Assessment that changes occurred (typically since 1950 unless otherwise indicated)**	**Assessment of a human contribution to observed changes**	**Likelihood of future changes**	
			Early 21st century	**Late 21st century**
Increases in intense tropical cyclone activity	***Low confidence*** in long term (centennial) changes Virtually certain in North Atlantic since 1970	***Low confidence***	***Low confidence***	***More likely than not*** in the Western North Pacific and North Atlantic
	Low confidence Likely in some regions, since 1970	Low confidence More likely than not		More likely than not in some basins Likely

Holland & Bruyere [8] found no anthropogenic signal in annual global tropical cyclone or hurricane frequencies using another index. The proportion of stronger Category 4 and 5 hurricanes has increased at a rate of ~25–30 % per °C of global warming after accounting for analysis and observing system changes, balanced by a similar decrease in Category 1 and 2 hurricane proportions for all ocean basins. The analysis also suggests that following an initial climate increase in intense hurricane proportions a saturation level will be reached beyond which any further global warming will have little effect.

Tropical Cyclones and Climate Change

To assess the possible changes in tropical cyclones in the future, there are several different techniques that have been used. Global climate models are limited in the simulation of TCs due to the balancing the high resolution necessary to accurately simulate TCs (typical climate models have horizontal resolution of 100-200 km, while resolutions of on the order of kilometres are needed to adequately capture TCs) with the need to run simulations for many years using many ensemble members, which is computationally expensive. However, many studies use alternative methods such as assessing tropical cyclone-like vortices in global models or calculating TC genesis indices based on the large-scale environment to capture TCs in climate projections. Other methods to achieve the higher resolution necessary for TC studies are the use of regional climate models, downscaling and statistical–dynamical techniques. A recent assessment of these different approaches can be found in Camargo & Wing [3].

Gray [7] developed the first genesis index as a function of several environmental parameters: low level (950 hPa) vorticity, vertical wind shear (between 950 and 200 hPa), the Coriolis parameter, ocean thermal energy (the temperature excess above 26 °C integrated from the ocean surface down to 60 m depth), moist static stability (the vertical gradient of the equivalent potential temperature between the surface and 500hPa), and average relative humidity (between 500 and 700 hPa). However, this index is not appropriate to explore TC activity in climate change scenarios, as it uses a fixed ocean temperature threshold, which would always indicate an increase in TCs in the future with warming.

One modified version of a genesis potential index (GPI), in which the potential intensity replaces SST, is:

$$\mathrm{GPI} = \left|10^5\eta\right|^{3/2}\left(\frac{H}{50}\right)^3\left(\frac{V_{\mathrm{pot}}}{70}\right)^3\left(1+0.1\,V_{\mathrm{shear}}\right)^{-2}$$

where η is the absolute vorticity at 850 hPa, H is the relative humidity at 600 hPa, Vpot is the potential intensity, and Vshear is the magnitude of the vertical wind shear between 850 and 200 hPa. Walsh et al. [19] found that coarser-resolution models simulate the GPI better than they simulate formation of tropical cyclones directly.

Tory et al. [18] used a modified technique to ascertain the regions for likely TC formation. They suggest that the RH at 700 hPa can explain the high detection rates in the eastern South Pacific and South Atlantic basins where the RH is large compared with observations, and zero detections in some very active real-world basins where the model RH is low compared with observations

Emanuel [5] indicates that global warming is likely to increase the intensity but decrease the frequency of hurricane and cyclone activity. Emanuel [6] stated that potential hurricane destructiveness, a measure combining hurricane strength, duration, and frequency, "is highly correlated with tropical sea surface temperature, reflecting well-documented climate signals, including multidecadal oscillations in the North Atlantic and North Pacific, and global warming". Emanuel also predicted "a substantial increase in hurricane-related losses in the twenty-first century".

Future projections based on theory and high-resolution dynamical models (Knutson [11]) consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2–11% by 2100. Existing modelling studies also consistently project decreases in the globally averaged frequency of tropical cyclones, by 6–34%. Higher resolution modelling studies typically project substantial increases in the frequency of the most intense cyclones, and increases of the order of 20% in the precipitation rate within 100 km of the storm centre. For all cyclone parameters, projected changes for individual basins show large variations between different modelling studies.

In the latest IPCC report [9] (see Table 1), there is low confidence in long-term (centennial) changes in tropical cyclone activity, after accounting for past changes in observing capabilities. However, over the satellite era, projected increases in the frequency and intensity of the strongest storms in the North Atlantic are robust (very high confidence). However, the cause of this increase is debated. Some high-resolution atmospheric models have realistically simulated tracks and counts of tropical cyclones and models generally can capture the general characteristics of storm tracks with evidence of improvement since the previous assessment. Storm track biases in the North Atlantic have improved slightly, but models still produce a storm track that is too zonal and underestimate cyclone intensity.

While projections indicate that it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged, concurrent with a likely increase in both global mean tropical cyclone maximum wind speed and rainfall rates, there is lower confidence in region-specific projections of frequency and intensity. However, due to improvements in model resolution and downscaling techniques, it is more likely than not that the frequency of the most intense storms will increase substantially in some basins under projected 21st century warming (see Figure 4).

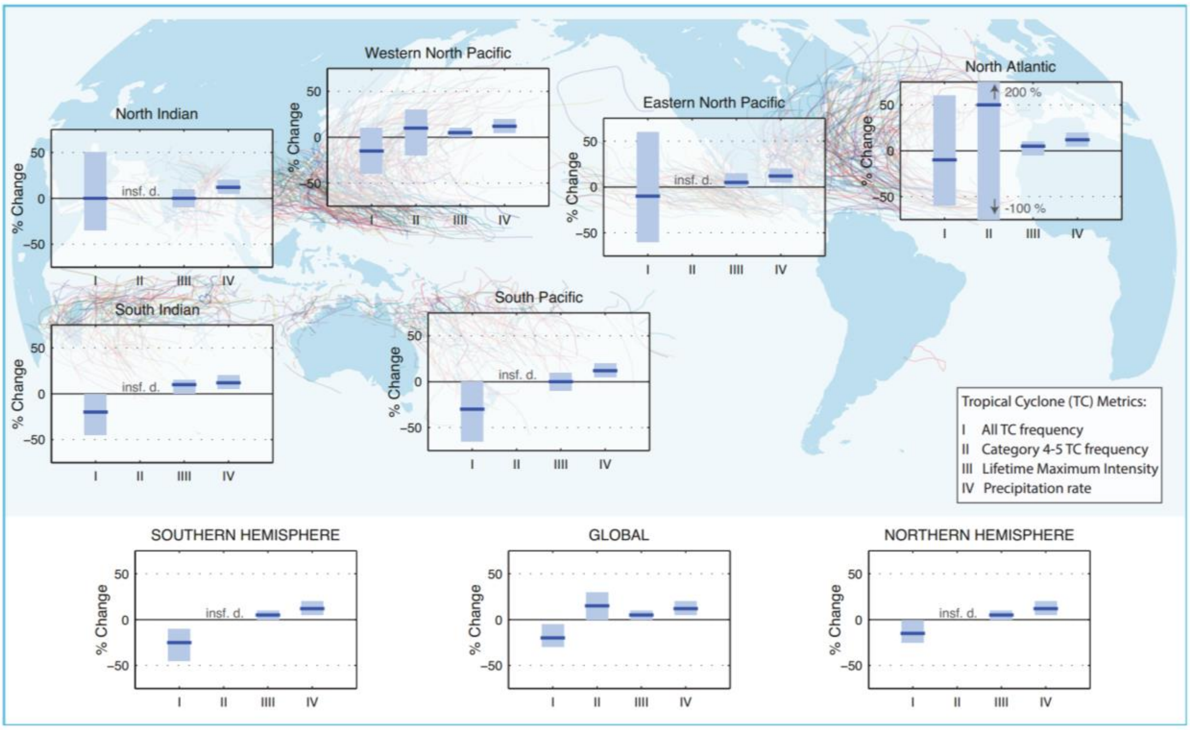

Figure 4: General consensus assessment of the numerical experiments projecting future TC characteristics. All values represent expected percent change in the average over the period 2081–2100 relative to 2000–2019, under a mid-range emission scenario, based on expert judgement after subjective normalization of the model projections. Four metrics were considered: the percent change in (I) the total annual frequency of tropical storms, (II) the annual frequency of Category 4 and 5 storms, (III) the mean Lifetime Maximum Intensity (LMI; the maximum intensity achieved during a storm's lifetime) and (IV) the precipitation rate within 200 km of storm centre at the time of LMI. For each metric plotted, the solid blue line is the best guess of the expected percent change, and the coloured bar provides the 67% (likely) confidence interval for this value (note that this interval ranges across –100% to +200% for the annual frequency of Category 4 and 5 storms in the North Atlantic). Where a metric is not plotted, there are insufficient data (denoted 'insf. d.') available to complete an assessment. A randomly drawn (and coloured) selection of historical storm tracks are underlain to identify regions of tropical cyclone activity. Adapted from IPCC [9].

In a recent analysis of TC behaviour (Murakami et al. [15]) using an ensemble of high-resolution (20km) global model simulations, the projected frequency of TC occurrence shows a consistent decrease in the western part of the western North Pacific (WNP) and in the South Pacific Ocean (SPO), while it shows a marked increase in the central Pacific. A future increase in the frequency of intense TCs globally is also projected (see Figure 5).

In the Australian region, the recently completed Australian Climate Change Science Programme study (ACCSP [1]) refined the TC projections based on an ensemble of recent global climate models, which were selected based on their performance under several criteria (including new TC formation thresholds). Through comparing the occurrence of TCs in outputs of these models from a high-level emissions pathway (RCP 8.5) with those in the model's baseline period, our refined Australian region ensemble projections show (see Figure 6):

- Lower TC numbers overall.
- Regional differences in projected change, with large decreases in TC frequency in the western basin (west of 135°E), robust to the choice of TC detection scheme used, as well as less clarity in TC frequency change in the eastern basin, where results vary between methods from increases to little change in TC frequency.
- Changes in TC formation and track consistent with modelled changes in large-scale atmospheric and oceanic variables.
- A small southward shift in genesis and decay of TCs, particularly in the western basin.
- Little change in the proportion and spatial distribution of TCs making landfall.

In a recent project for the Philippines, (DFID [4]), an ensemble of global models was downscaled, producing simulations over the Philippines that were analysed for projected changes in TCs. Each model simulation shows different changes in future tropical cyclone activity, meaning that there is a range of possible future outcomes (Table 2). Three simulations project fewer tropical cyclones in the Philippines region by the mid-21st century than in the current climate, while two simulations show no change. Two of the five simulations show a small but clear increase in the intensity of tropical cyclones, while the other three simulations show no clear trend. The key findings from all five simulations are:

- The total number of tropical cyclones in the Philippines region is likely to remain the same or decrease by the mid-21st century
- Results show some evidence of an increase in the intensity of tropical cyclones in the Philippines region by the mid-21st century
- There will continue to be high year-to-year variability in the number and intensity of tropical cyclones.

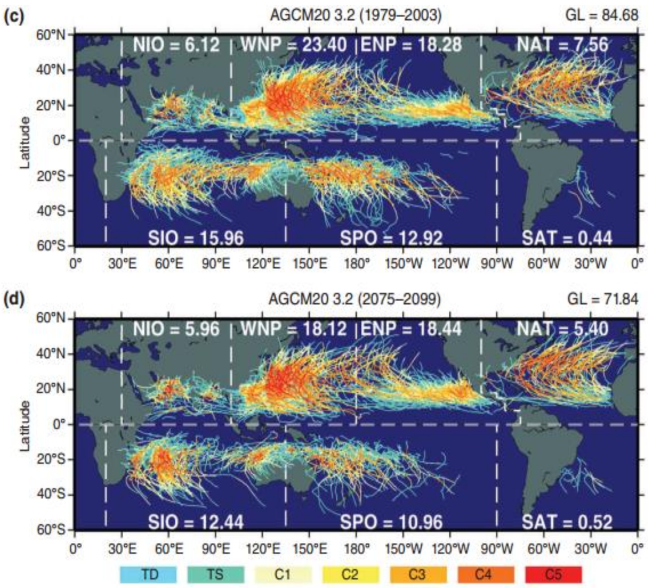

Figure 5: Global distribution of TC tracks during all seasons from 1979 to 2003 for (c) the PD (present day) simulation using AGCM20_3.2 (MRI AGCM version 3.2), and (d) the global warming projection using AGCM20_3.2. The numbers for each basin show the annual mean number of TCs. TC tracks are coloured according to the intensities of the TCs as categorized by the Saffir–Simpson hurricane wind scale [e.g., tropical depression (TD), tropical storms (TSs), and Categories C1–C5]. (Adapted from Murakami et al. [15])

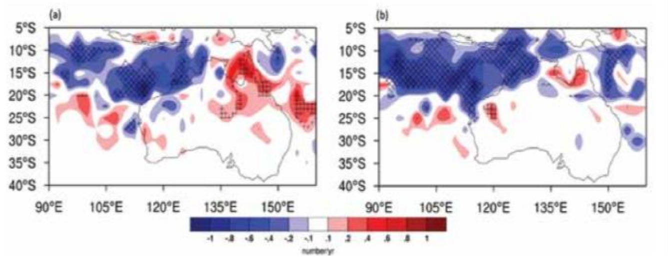

Figure 6: Ensemble mean change in tropical cyclone frequency between 2070-2100 under the RCP8.5 scenario and 1970-2000 under the historical scenario from detections using (a) the CSIRO Direct Detection scheme and (b) OWZ method. Stippling indicates where most models agree on the sign of the change (3/4 models in this case). (from ACCSP [1], see report for details)

Table 2: Projected changes to tropical cyclones affecting the Philippines by the mid-21st century, assuming large increases in greenhouse gas concentrations. Black arrows indicate clear changes, grey arrows indicate possible changes, and a dash indicates no change. (From DFID [4])

	Climate Model Simulations				
	1	2	3	4	5
Change in tropical cyclone frequency	↓	↓	—	—	↓
Change in tropical cyclone intensity	—	↑	↑ (grey)	↑	↑ (grey)

Guidelines for Using Climate Projections

The above results indicate a range of possible futures and risks associated with changes to TCs. As with all climate projections, there are various uncertainties in what will happen in the future. The following guidelines present ten steps to help you better understand and access the climate data you need to assess the potential impact of climate change on TCs and in particular on wind intensity. However, it is important to note that this process is not always linear. A more complete description of these steps, and some examples and sources of more information can be found here: http://www.rccap.org/guidance-and-case-studies/developing-climate-information/.

Initially, define your requirements

In order to define your requirements, you need to identify your users and/or other stakeholders, define the project objectives, specify project inclusions and exclusions. Then you can establish the project context and establish an appropriate approach or methodology.

Collect and assess observed climate information

Once you have established your needs, you need to source the appropriate observational data to understand the current climate for the region of interest. Does the data have metadata? Are there gaps in the observed data? Do you need to fill the missing data? What are the terms of use of the data?

Select range of Representative Concentration Pathways

One of the largest uncertainties, and source of the range of possible futures, is related to what humans and governments will do with emissions of greenhouse gases. A range of possible scenarios have been generated and used for climate projections. These are based upon reasonable assumptions of economic growth, resource utilisation and innovation. Since we do not know actual future emission levels, a range of scenarios should be considered. Two examples of projected global warming associated with the higher and lower emissions scenarios are shown in Figure 7.

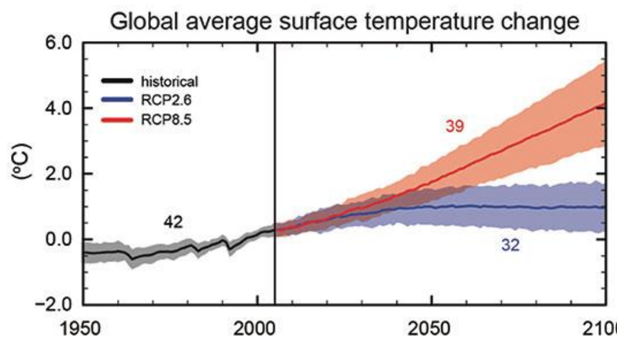

Figure 7: CMIP5 multi-model simulated time series from 1950 to 2100 for change in global annual surface air temperature relative to 1986-2005. Shown is the time series of projections (bold lines) and uncertainty (shading) for RCP2.6, a low emission scenario (blue) and RCP8.5, a higher emission scenario (red). Black (grey shading) is the modelled historical evolution of temperature using historical constructed forcings. The numbers of CMIP models used to calculate the multi-model mean is indicated (i.e. 42, 32, and 39 for the historical, RCP2.6, and RCP8.5, respectively).(Adapted from IPCC [9]).

Find all relevant sources of climate projection data

The next step is to explore and access as large a range of model data as possible. You need to understand the type of model data you obtained and how the data was generated. It is recommended that you conduct an initial check of the reliability of the climate model data. You also should check the terms of use and intellectual property (IP) rights of the information you are using.

Evaluate climate model data

Checking the reliability of the model data for your region helps to establish confidence ratings in climate projections. This is based on the premise that the closer the model simulation is to the observed climate, the closer the enhanced greenhouse response of the simulation will be to the real-world response.

Select climate projections

Once you have completed your initial assessment of the climate information, you need to decide on which projections capture the range of possible futures and which you will have time to analyse and use within the constraints of the project.

Choose all necessary variables to analyse from one model; do not select different variables from different models as this may lead to physical implausibility. You need to select a range of models that capture the spread of all plausible scenarios for your area of interest. Try to select an ensemble (group of models) suitable for your purpose. Include information on the likelihood of the outcome the percent of models indicating a particular direction and/or magnitude of projection). In your selection process, one should also consider model results that capture the current climate better.

Construct climate change projections

There are several methods to construct the required climate projections. It is important to ensure a physically consistent and supportable method. Depending upon your needs, either use climate change fields of the relevant variables or use long-term trends of the variables into the future. It is important to choose a time period long enough to avoid misrepresenting climate variability as a climate change signal. It is recommended that at least 30 years be used for both historical and future periods in order to determine a more robust signal. Using trends avoids this issue as long as the trend is computed over a long enough period (more than 50 years).

Analyse climate projections

It is expected that typically this is where most time on a given case is spent. One needs to evaluate the magnitude of the change values relative to the natural variability; is the climate change signal greater than natural variability? One way to asses this is to compute appropriate statistical measures of significance of the projected changes. In order to build confidence in the changes, it is advised that one should evaluate the large-scale drivers of the change to better understand the changes. This will help explain the projected changes and possibly build confidence in the projections. As indicated before, one needs to consider all variables comprehensively and in a physically consistent manner. One way to assess the projections is to compare the projected trends against observed trends, assuming that the climate change signal is already evident in the current climate. Any addition relevant information should be gathered as well (other studies, other methods of analysis, etc.)

Correct possible biases

As no model is perfect, there may be resulting biases in the climate projections. There are many methods to correct these biases, though care must be made to ensure the climate change signal is not altered by these methods. Two common techniques used are the delta method and the quantile-quantile bias-correction method. The delta method of Santer [16] adds the climate change signal (the `delta') to an observed dataset. The quantile-quantile method of Bennett [2] adjusts the distribution of the variables to match the observed distribution, and the same adjustment is used to correct the future variables. All bias correction methods require high-quality observational data.

Communicate your information

The final and one of the most important steps is the communication of your results to the end-user or users. There are guidelines for scenario consistency and reporting. It is important to appropriately cite your sources of information and techniques. Using standard notation is recommended for clarity and for comparing with other results. You must describe your methods and provide the data in the appropriate format for the next user. Finally, you need to present your results, ensuring the range of climate futures and the uncertainties impacting your area of interest are conveyed.

Conclusions

This paper summarises the current information about tropical cyclones (TCs) and their potential changes in future frequency and intensity that may be relevant to wind engineering projects. Several issues related to the observation and assessment of any trends remain. While the observed distribution of TCs is well known, there is still some uncertainty about their historical trends. In addition, due to the relatively low frequency and large interannual variability in numbers and intensity, it is difficult to determine if there is any statistically significant trend in TC numbers.

Assessing TCs in climate projections has additional complications, as the main tools to assess climate change are global climate models, which typically at this time still do not have high enough resolution to truly capture TCs. Studies analyse TC-like vortices in models or large-scale variables (combined to form potential TC genesis indices) which are required for TC formation, or employ high resolution global atmospheric modelling and dynamical downscaling with regional models in order to assess potential changes in TCs due to global warming. Each method has its strengths and weaknesses.

Overall, most studies indicate that the number of tropical cyclones will decrease into the future, but that the more intense ones may become more frequent (see, for example. IPCC [9]). This implies the potential for more extreme winds when the cyclones make landfall. There currently is large uncertainty about any changes in TC tracks, though some studies suggest they may move further poleward.

Finally, some guidelines were presented to help assist you in using climate projection information. These guidelines are available with more complete explanation online, including some examples of applications. The main goal of these guidelines is to ensure appropriate use of climate information and communication of the results, with a range of projections used to capture the full range of possible futures associated with potential changes in emission levels, technology and government regulations.

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