CARIWIG Case Study Report 8

Barbados Coastal Zone Protection

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Summary

- A PRECIS Regional Climate Model forced by two Global Climate Models (aenwh and echam5) was used to validate trends in local climate data and to project trends in wind climate via three future scenarios while 'what if' scenarios were generated by Tropical Storm Model.
- No major changes were suggested in wind speed and direction for the three scenarios generated by the echam5-driven model while small increases in wind speed and slight changes in wind direction are suggested in the aenwh-driven scenarios.
- While all three storms exhibit the same maximum and minimum wind speeds due to limits set, Katrina displayed the longest persistence of maximum wind speed regardless of category.
- The model outputs can be used by the Coastal Zone Management Unit, Department of Emergency Management, utility companies and other stakeholders to plan for future wind climate and to implement measures to protect life and property.

Aim and Objectives

The aim of the case study was to assess the utility of the Regional Climate Model and Tropical Storm Model in Integrated Coastal Zone Management (ICZM) in Barbados. Projections of wind speed are important in understanding nearshore wave climate, such that coastal climate change adaptation design takes into account the physical parameters in the coastal zone, such as waves and currents. The specific objective was to compare outputs from the Models with those outputs currently used locally in coastal protection, thereby demonstrating the value of the tools to local decision makers.

Which Tools were Used? How and why?

Ideally this case study would have used projections in sea level, storm surges and wave height/energy as well as wind speed and direction. However, coastal and offshore parameters were not available from any of the CARIWIG tools. Thus the focus was limited to wind speed and direction. The CARIWIG tool, which provides both of these parameters, is the PRECIS Regional Climate Model (RCM). Output was used from simulations forced by two different Global Climate Models (GCMs): aenwh and echam5, as well as ERA reanalysis (based on observed data for the period 1990-2003). For the GCM-based runs, a baseline period of 1981-2010 was used, and three future scenario periods were considered: the 2020s (2011-2040); 2050s (2041-2070); and, 2080s (2071-2099). PRECIS has a spatial resolution of 25 km and the A1B emissions scenario was used for all projections. Model performance was assessed using observed data from the Grantley Adams International Airport (GAIA) station. Finally, in order to

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provide decision makers with information about potential changes in risk, the projections were analysed for changes in wind speed and direction, as well as threshold exceedences.

The second CARIWIG tool used in this case study was the Tropical Storm Model (TSM). The TSM allows 'what if' scenarios to be explored by taking storms previously experienced in the Caribbean and seeing what would have happened had they tracked over Barbados. In this sensitivity study, different assumptions can be made about the storm category and its forward moving speed. The TSM outputs provide information about wind speed (and rainfall rate) along the storm track. These 'what if' scenarios provide decision makers with an indication of the potential hazard posed to their country, and facilitate the assessment of potential losses.

The findings

The observed data from the Grantley Adams airport show that the two dominant wind directions affecting Barbados during December to March (the months with strongest winds) are East-North-East (centred on 67.5 degrees) and Easterly (centred on 90 degrees) (Figure 1). Winds from each of these directions blew on 41% of days (i.e., 82% of days for the two directions) during the period 1981-2010 (Table 1). The average wind speed was 5.6 ms^{-1}, with a maximum velocity on any day of 12.1 ms^{-1}. Winds exceeded a threshold of 8 ms^{-1} on 8% of all days (and on a similar percentage, 7%, of E and ENE days).

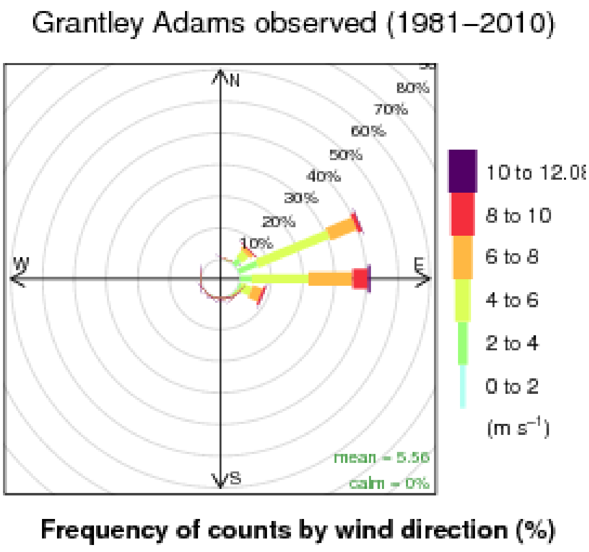


FIG.1. Frequency of wind direction and wind speeds observed at Grantley Adams International Airport for the period 1981-2010.

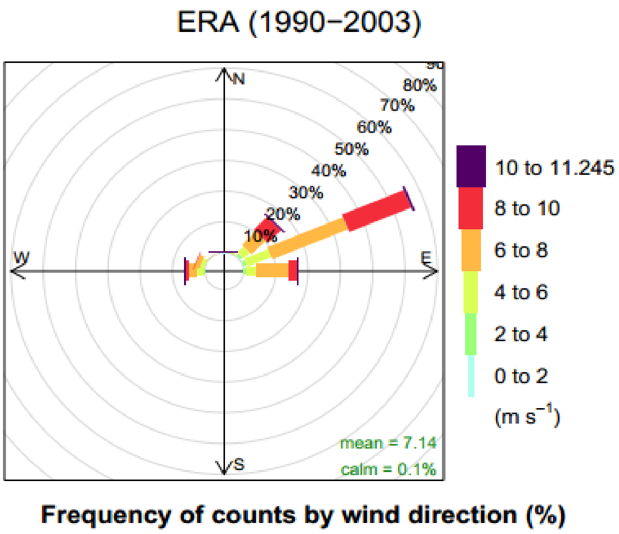


FIG. 2a. Frequency of wind direction and wind speeds generated by the *ERA*-driven PRECIS Regional Climate Model.

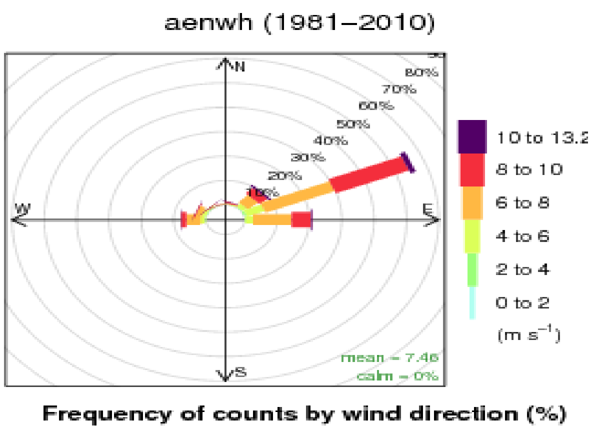
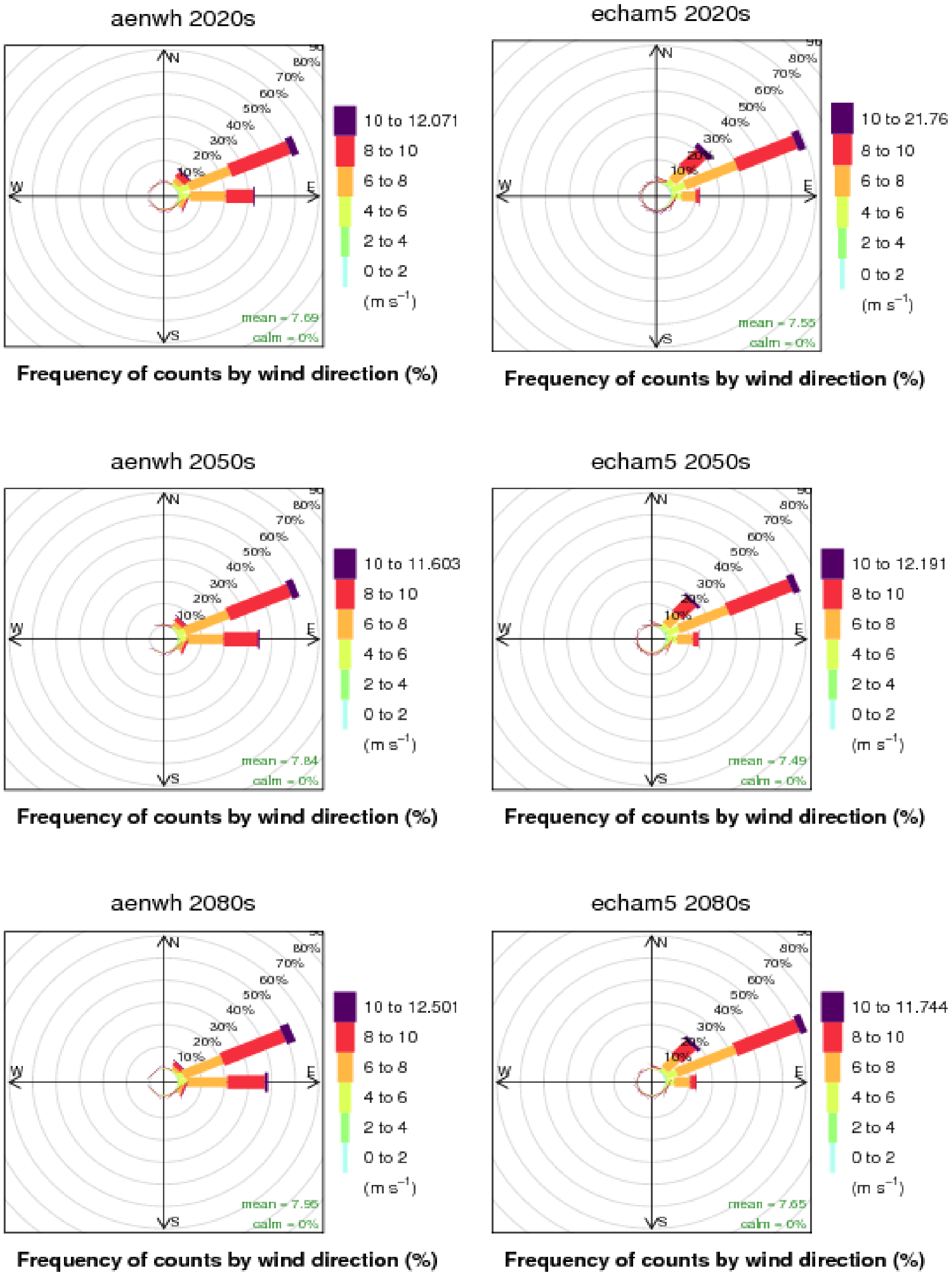


FIG. 2b. Frequency of wind direction and wind speeds generated by the *aenwh*-driven PRECIS Regional Climate Model.

FIG.3. Scenarios projected by *aenwh* and *echam5* driven PRECIS Regional Climate Model showing frequency of wind direction and speed for periods 2011-2040, 2041-2070 and 2071-2099.



Before considering future changes in wind speed and direction, it is necessary to assess how well the PRECIS RCM reproduces present-day observed conditions. The comparison made here between the observed station values from the Grantley Adams airport and the RCM values is not strictly speaking a like-for-like comparison since the latter represent area averages for a 25 km grid box (which tend to smooth out extreme values compared with station values). The comparison is made for two RCM simulations (Figures 2a and 2b). The simulation forced with ERA uses reanalysis data derived from observations – so-called perfect boundary conditions – which allow us to assess the performance of the RCM alone.

The aenwh-forced simulation (Figure 2b) uses boundary conditions from a GCM – which allows us to see whether shortcomings in the GCM further degrade model performance. Unfortunately output for the echam5-driven baseline period was not available.

Comparing Figures 1 and 2 (see also Table 1), it is evident that the RCM over-estimates mean wind speed by 1.5 ms^{-1} for the ERA-driven run and by 2 ms^{-1} for the aenwh-driven run (i.e., by 27% and 37% respectively). In addition the number of days exceeding a threshold of 8 ms^{-1} is substantially over-estimated by the RCM. The RCM also severely under-estimates the number of E-days but somewhat overestimates the number of ENE-days. The reason for the simulated days with a westerly wind direction is puzzling [this direction is not seen in the observations (Figure 1) or future projections (Figure 3)] and is being investigated by the modelling team. In general, the performance of the RCM does not seem substantially different when forced by the GCM rather than by ERA.

Because of the model biases identified above, it is necessary to consider projected changes from the model rather than the observed baseline. This makes it rather difficult to assess the echam5-forced changes as the baseline data are missing. Projected wind speed and directions for the three future periods are shown in Figure 3 and summarised in Table 1 (along with the baseline values).

Table 1: Mean and maximum wind speed, wind direction, frequency of East-North-East and Easterly winds, and days with windspeed > 8 ms^{-1} observed (at Grantley Adams International Airport) and simulated (by the PRECIS RCM forced by ERA reanalysis and the aenwh and echam5 GCMs) for baseline (1981-2010 or 1990-2003) and future (2020s, 2050s, 2080s) periods.

		Mean wind speed (ms^{-1})	Maximum wind speed (ms^{-1})	Mean wind direction (degrees)	Freq. of ENE (%)	Freq. of E (%)	Freq. of >8ms^{-1} all days (%)	Freq. of >8ms^{-1} ENE and E days (%)
Baseline Observed	1981-2010	5.6	12.1	80	41	41	8	7
Baseline PRECIS-ERA	1990-2003	7.1	11.2	64	56	17	32	24
Baseline PRECIS-aenwh	1981-2010	7.5	13.3	65	56	21	39	32
Scenario PRECIS-aenwh	2020s	7.7	12.1	75	55	33	47	42
	2050s	7.8	11.6	76	55	35	50	47
	2080s	8.0	12.5	77	53	38	53	49
Scenario PRECIS-echam5	2020s	7.6	22	66	59	12	44	31
	2050s	7.5	12	67	61	14	44	34
	2080s	7.7	12	66	64	13	45	34

In general, there are no consistent indications of major changes in mean wind speed or in wind direction across all runs. For the aenwh-forced projections, there is however suggestion of a small (about +7% for the 2080s) increase in mean wind speed and an increase in days with E-winds (+17% for the 2080s). There is also some indication of an increase in the number of days with winds > 8 ms^{-1} (+14% on all days and +17% on E/ENE days for the 2080s). There is no indication of a consistent increase in maximum wind speeds, though it should be noted that the PRECIS RCM does not explicitly parameterise wind gusts and the maximum recorded value is subject to large inherent variability (which may account for the value of 22 ms^{-1} for the echam5-forced 2020s).

For the Tropical Storm Model, three storms (Dean, Katrina and Ivan) at categories 3 and 5 with a forward moving speed of 21 knots were simulated to obtain wind speed outputs along a specified storm track (Figure 5).

At Category 3, all three storms exhibit minimum and maximum wind speeds of 34 and 64 knots (kt) (Table 2). It must be noted that the maximum wind speed obtainable from the model is 64 kt. However, in terms of persistence of the maximum speeds which is dependent on category, Hurricane Katrina displayed maximum winds which were sustained for 180 minutes along the storm track while for Dean and Ivan 50 kt was the longest sustained wind speed.

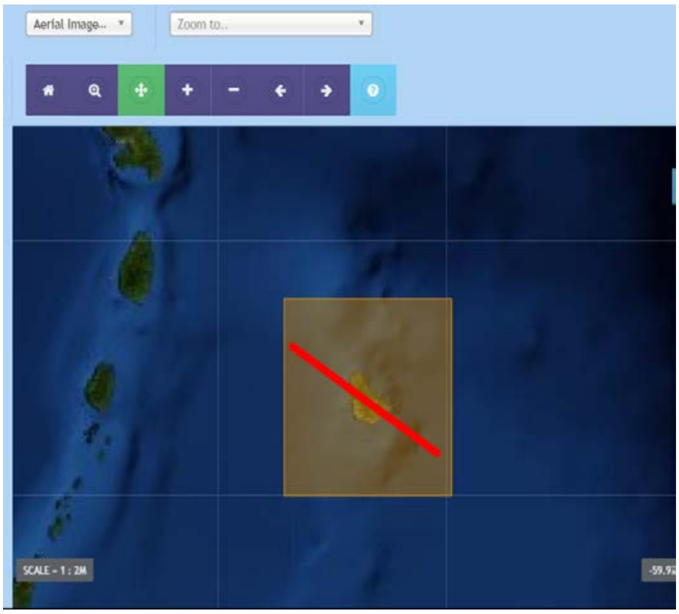


FIG. 5. Graphic of storm track over Barbados obtained from Tropical Storm Model (highlighted area referring to grid squares allocated to Barbados)

Table 2: Minimum and Maximum wind speeds, persistence of maximum wind speed and longest sustained wind speeds for selected category 3 and 5 storms at a forward moving speed of 21kmh

Category	Storm	Minimum wind speed (knots)	Maximum wind speed (knots)	Persistence (minutes)	Longest Sustained speed (knots)
3	Dean	34	64	180	50
	Katrina	34	64	360	64
	Ivan	34	64	180	50
5	Dean	34	64	310	64
	Katrina	34	64	360	64
	Ivan	34	64	240	50

At Category 5, the minimum and maximum wind speeds remain the same. However, the length of time the maximum speeds persist is increased (Table 2). Persistence of 310, 360 and 240 minutes are obtained for Dean, Katrina and Ivan respectively. There is also a shift in the longest sustained speed for Hurricane Dean, with 64 kt being sustained the longest along the storm track.

It can be inferred from the outputs that regardless of category, of the three storms Katrina will cause the most damage if the storms made landfall and this may be a result of the limit set on the maximum wind speed. Also, because persistence is dependent on category and increases with storm intensification, there may be an impact on wind speed which is unknown due to the limit on maximum wind speed.

Implications for policy and planning

If the small changes projected in wind speed throughout this study are realized, they may have more significant impacts than in other small islands where beach slope is much greater than in Barbados. Nearshore bathymetry comparisons suggest that Wave setup is dependent on wind, responding to typically insignificant changes, to produce relatively high waves. While those waves impacting the island are not locally generated, changes in wind speed may affect the energy associated with these waves when they enter local waters, potentially leading to instances of "above normal sea swells" during the December to March period. In contrast, the hurricane season in Barbados is from June to October, and though a hurricane has not made landfall in Barbados since Hurricane Allen in 1980, the island has been closely skirted by several hurricanes and tropical storms. The latest of these storms to cause significant property damage was Hurricane Tomas, which passed the southern coast of the island as a very strong Tropical Storm. A large proportion of damage caused by Tomas was the result of strong winds.

The projected increases in average wind speed and the frequency of threshold exceedance for the December to March period increase possibilities for elevated wave energy affecting the island, so that the swash zone may become a more significant factor in sediment transport along beaches during winter months. In response to these potential threats, the Coastal Zone Management Unit has devised and is implementing a Coastal Risk Assessment and Management Programme intended to increase resilience of coastal property and ecosystems to coastal hazards via enhanced management and conservation of the island's coastal zone. Through this effort, on-shore protection structures such as groynes, revetments, and seawalls have been constructed to dissipate higher than normal wave energy, thereby reducing the impacts of storm surge caused by both tropical storm and winter storm activity. Also, where the width of the buffer zone is not enough, measures such as beach nourishment, breakwaters and artificial reefs have been constructed. However, because the design life of these stabilization/protection structures is 50 years and includes projections for sea level rise, CZMU is faced with the design challenge of adapting them to impacts of increased wind speed and keeping them functional.

CZMU may also seek to use natural shoreline protection mechanisms such as reefs and mangroves as these ecosystems help to dissipate wave and wind energy. To do this, there needs to be conservation, restoration and protection of reefs while mangroves which act as natural tropical storm mitigation mechanisms should also regrown and restored to increase resilience of the coastal zone.

The Department of Emergency Management in conjunction with CZMU may use the projections of increased wind speed and the "what if" tropical storm scenarios to work towards the quantification of storm surge flooding risk, as well as drafting of an evacuation map.

Furthermore, the potential for inundation of low lying coastal infrastructure such as businesses, homes and hotels may require the Town Planning Department to revisit existing legislation, introducing changes to the Building Code in response to more events of threshold exceedance and by extension, intensified wave activity. For example, the setback of buildings from the High Water Mark may be extended further inland beyond the present limit of 100m, as the High Water Mark is expected to migrate landward with any increase in average onshore wind speed. Also, the changes to existing legislation may include a clause where coastal properties will be disallowed from rebuilding on existing footprints but might be expected to conform to new setback limits. In preparing for the potential landfall of hurricane of any category and forward moving speed, the Town Planning Department may introduce legislation requiring the new structures to be resilient to hurricane-force winds and flying debris while compelling existing properties to implement similar adaptation measures. Furthermore, new legislation may be introduced which might require new construction to include adaptation measures such as building on pillars to allow the inundation of seawater through the ground level. A policy to prevent development in vulnerable areas may be drafted and enacted, resulting in the relocation of some properties.

Entities such as the Barbados Light and Power Company Limited, Barbados Water Authority, rum distilleries, and port operations (Barbados Port Inc, Port St. Charles and Port Ferdinand) might also be threatened by projected increases in wind speed and associated wave activity. Barbados Light and Power Company Limited, a crucial utility operator on the island, has major energy generation plants located on the west and southwest coasts, which might be under threat from inland migration of the high water mark. The coastal aquifers of the Barbados Water Authority would be at risk of saltwater intrusion, reducing the quality of pumped water to residents. The impact of the projected increase in wind speed on port operations is significant as ports are constructed to withstand a particular wind speed so that vessels entering port come in a specific angle and direction based on how the pier is aligned to the wind. The fisheries sector may also be under threat from projected increased wind speed. The question at hand is – will the projected increased wind speed increase or decrease fish stocks? Currently, the island is **inundated** with *Sargassum* seaweed brought in by wind driven waves and fishermen are presently reporting declines in flying fish stocks when the levels of *Sargassum* around the island are high. Watersports operators may possibly benefit from any projected increase in wind speeds no matter how small, where activities such as sailing, surfing and wind surfing may increase in popularity.

Feedback on the tools

The Tropical Storm Model (TSM) was found to be quite user friendly and has potential applications in the fields of disaster preparedness and risk reduction. Nonetheless some assistance was required from the team who developed this tool in order to understand how to apply it in the case study. Some shortcomings in the TSM were identified. It assumes that the intensity and size of storm remains constant along the selected trajectory and makes no allowance for variations in, for example, bathymetry. The resolution is also quite coarse particularly in comparison to the size of Barbados – wind speeds are only provided for a point at the centre of each 25 km grid box.
Although PRECIS RCM output was provided for Barbados in Excel spreadsheets, considerable assistance was still required from the CARIWIG team (in particular experts at UEA) to plot and interpret the RCM wind data.

What more could be done?

As indicated in the Aims and objectives above, this case study really required information about storm surges and near-shore wind and waves. Since this information was not available from any of the CARIWIG tools, the focus was on wind speed and direction.
It is evident that the RCM has some substantial biases in simulating both wind speed and direction. The CARIWIG weather generator is able to simulate wind speed (and has been calibrated for Grantley Adams) – but future changes are not driven by RCM-derived change factors – wind only changes consistently with rainfall and other variables. And the weather generator does not provide information about wind direction. Thus future work should focus on deeper analysis of RCM-simulated winds – extending the analysis to more models and emissions scenarios to better encompass the uncertainties.

This case study has also highlighted the need for higher spatial resolution when considering small islands such as Barbados. This is an issue for both RCM simulations and the TSM.

Most importantly, this case study has highlighted a major gap in the scope of the CARIWIG tools relating to the coastal zone. While no RCMs currently simulate storm surges or waves 'online', there is clearly a need to either develop coupled models or to facilitate the input of RCM outputs to storm surge and wave models. The TSM would also provide more relevant information for stakeholders if it could simulate wind-wave interactions along the storm track, and changes in size and intensity before landfall and the influence of the coastline on the dynamic flow of storm surge.

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