Impacts of climate change on tropical cyclone hazard: current understanding and future directions

W.C. Arthur, J.D. Griffin, and R.P. Cechet
Risk and Impact Analysis Group, Geoscience Australia

Introduction

There has been much debate on the influence climate change may have on global tropical cyclone activity (Webster et al. 2005, Landsea 2005, Emanuel 2005, Knutson et al. 2001), but the impacts on human settlements is even less clear. Regional differences in projected changes are also apparent, further clouding the issue of identifying changes in hazard and risk. As part of a contribution to the Garnaut Climate Change Review (Garnaut 2008), Geoscience Australia examined the changes in a number of indices of tropical cyclone activity as diagnosed from Intergovernmental Panel on Climate Change 4th Assessment Report (IPCC AR4) simulations. These results can be used to infer likely changes in tropical cyclone hazard.

General circulation models (GCMs) are normally too coarse to accurately resolve peak winds associated with tropical cyclones (Walsh and Ryan 2000). Tropical cyclone-like vortices may be present in the finer resolution models, but these are a poor facsimile of observed tropical cyclones and thus are unsatisfactory predictors of changing tropical cyclone characteristics (Camargo et al. 2007). To gain some understanding of the potential changes in tropical cyclone behaviour under different future climate regimes, we use GCM outputs to examine environmental indices that have been linked to the intensity and frequency of tropical cyclones.

Methodology

The analysis used maximum potential intensity (MPI) to examine changes in intensity, and genesis potential index (GPI) to examine changes in frequency. MPI is a thermodynamic estimate of the theoretical peak intensity attainable by a tropical cyclone and is dependent only on thermodynamic attributes of the environment. In this paper, we use the MPI as defined by Bister and Emanuel (1998). The GPI incorporates the MPI and dynamical factors (e.g. vertical wind shear and low level vorticity) to estimate the likelihood of tropical cyclone genesis (Emanuel and Nolan 2004).

Both MPI and GPI were calculated from a suite of IPCC AR4 GCM simulations for which sufficient data were available. Monthly mean data were used to calculate the indices, and then from these monthly mean values, long-term annual mean maximum values were determined for 20-year time slices. MPI and GPI values were determined for Climate of the 20th Century (C20C) simulations, SRES B1, A1B and A2 scenarios at 2050, 2070 and 2090. Data were interpolated to a uniform 2° x 2° grid over the Australian region to allow the suite of input models to be combined. We calculated percentage changes in each index for the ensemble mean of all available models, and percentage change *per degree global warming* (PDGW).

Changes to vertical wind shear, sea surface temperatures and upper tropospheric temperatures were also calculated, but the results of this analysis are not presented here.

Results

The most striking result is the consistency in the increase in MPI (PDGW) across all scenarios, presented in Figure 1. All three scenarios show a spatially consistent trend in the MPI, with a 3% increase over tropical latitudes. There is an increase of up to 7% PDGW over the Tasman Sea, hypothesised to be related to warming of the East Australia Current. This may have some impact on the intensity of explosively developing east coast lows along the NSW coastline.

With this consistent change PDGW, the largest increases in MPI are associated with those scenarios that will lead to the largest increase in global mean surface temperature, namely the A2 scenario (4°C warming by 2090). The mean increase in MPI by 2090 over the Australian region is 4.5%, 7% and 8.5% for the B1, A1B and A2 scenarios respectively. The relationship between global mean temperature and MPI change can be exploited to estimate MPI changes for scenarios not included in this analysis (Table 1).

Changes in GPI are less uniform, but are dominated by changes in MPI (Figure 2). The magnitude of the changes is more than double that of the MPI changes, with most tropical regions indicating increases of greater than 6% PDGW. Similar changes are found for other scenarios (not presented).

Together, changes in MPI and GPI suggest that tropical cyclone hazard will increase. However, the environmental indicators used here treat intensity and frequency separately; to quantify changes in hazard, intensity and frequency estimates need to be examined concurrently. A stochastic modelling approach is being adopted to address this problem.

Current and Future directions

For our stochastic approach we have obtained synthetic tropical cyclone tracks representing approximately 50 years of activity under three different climate scenarios from WindRiskTech (Emanuel et al. 2006). These synthetic events are used as an input dataset to Geoscience Australia's Tropical Cyclone Risk Model. A preliminary analysis indicates that an increase in tropical cyclone frequency in the Australian region is likely. There is little clear trend in the peak intensity of tropical cyclones, but there is a poleward (southward) shift in the latitude of the peak intensity.

The WindRiskTech datasets were analysed for landfall probability and proximity to major communities. The probability of landfall may increase along the east coast, but due to the sensitivity to ENSO, the trend remains unclear (GCMs are notoriously poor at representing ENSO). Analysis of events that pass within 200 km of Port Hedland, Darwin and Cairns indicate a trend towards increased frequency of intense tropical cyclones, but the low number of events in the available event sets limits our confidence in the analysis.

Discussion and Conclusions

The environmental analysis suggests that more intense tropical cyclones are possible, with modest increases in MPI likely. The magnitude of the increase appears to be closely linked to increases in global mean surface temperature. Changes in GPI suggest an increase in tropical cyclone frequency. Preliminary work using a stochastic approach broadly agrees with these results, although intensity trends are less clear. The finding of increasing intensity with global warming is consistent with the literature, however a suggested increase in frequency is at odds with previous modelling studies for the Australian region (Abbs et al. 2006; Leslie et al. 2007; Walsh and Ryan 2000).

Our results suggest tropical cyclone hazard will increase with global warming. However, there remains a significant amount of work to be completed before we have a clear picture of the changes in tropical cyclone hazard. Our work program will continue to use the latest research on the meteorology of tropical cyclones and climate change to inform our hazard and risk assessments.

Acknowledgements

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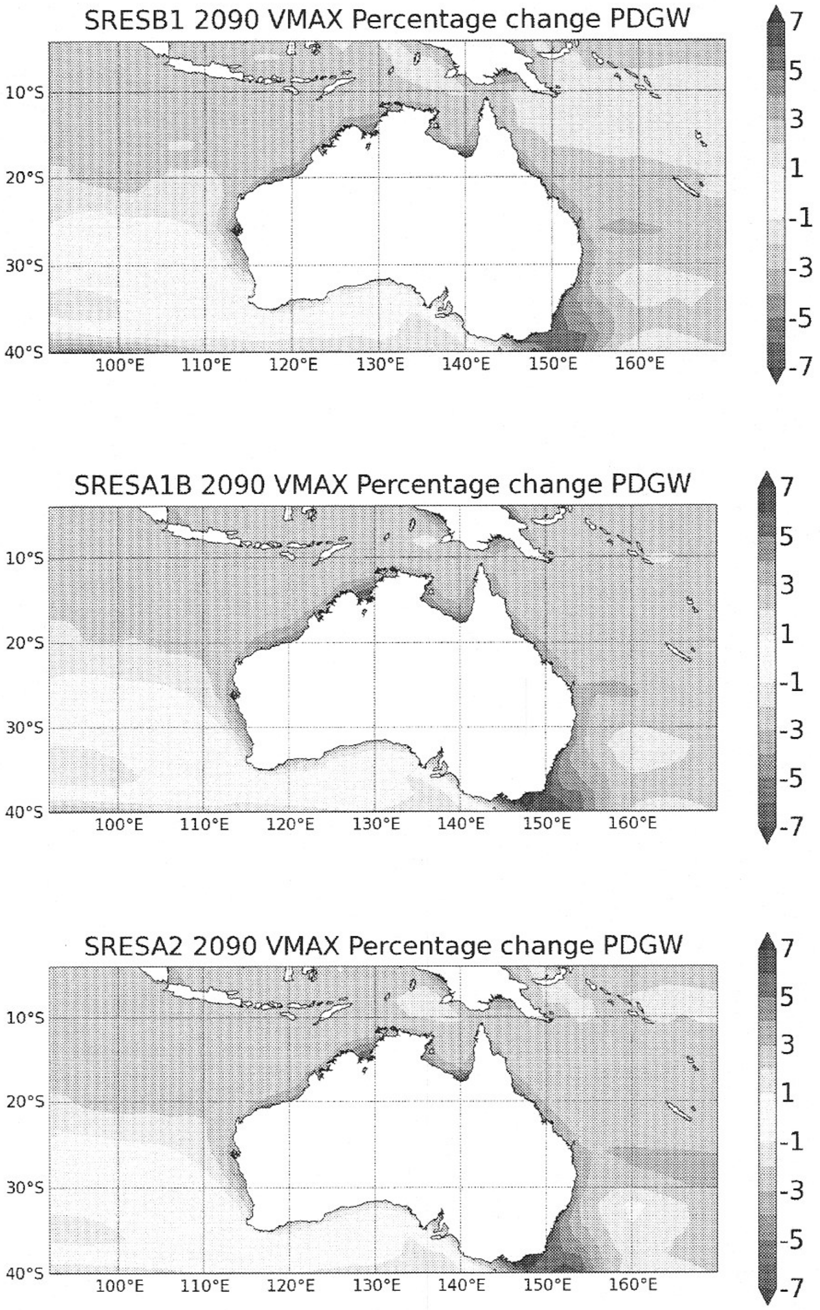

Figure 1: Ensemble mean percentage change in MPI PDGW by 2090 for SRES scenarios B1 (top); A1B (middle); and A2 (bottom). All scenarios show a 2-3% increase in MPI in Australia's tropical regions PDGW. In subtropical regions MPI changes are more spatially variable; however the pattern of spatial variation is consistent between the scenarios.

Table 1: Estimates of percentage change in MPI by 2090 based on a linear relationship between global mean temperature and MPI. Global temperature change estimates were obtained from IPCC AR4 (2007). Likely estimates are bound by the 10th and 90th percentiles. Lowest likely MPI estimate are calculated using a 2% increase in MPI PDGW and taking the lowest temperature change estimate; highest likely MPI estimates use a 3% increase PDGW and the highest temperature change estimate.

Scenario	**Temperature change (°C at 2090 from 1990)**		**MPI change (% change in V_{max} in Australian tropical regions at 2090 from 1990)**	
	Best estimate	**Range of likely estimates**	**Best estimate**	**Range of likely estimates**
B1	1.8	1.1 – 2.9	4.5	2.2-8.7
A1T	2.4	1.4 – 3.8	6	2.8-11.4
B2	2.4	1.4 – 3.8	6	2.8-11.4
A1B	2.8	1.7 – 4.4	7	3.4-13.2
A2	3.4	2.0 – 5.4	8.5	4-16.2
A1FI	4.0	2.4 – 6.4	10	4.8-19.2

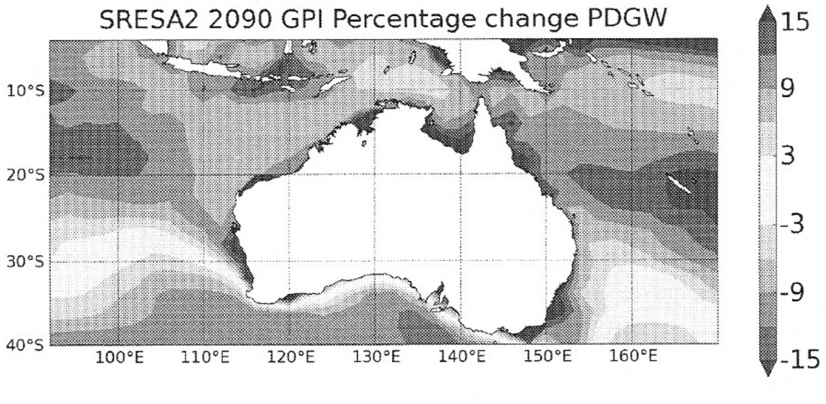

Figure 2: Ensemble mean percentage change in GPI PDGW by 2090 for SRESA2. GPI increases 6-12% PDGW in most of the genesis regions (equatorward of 15°S). GPI changes are more spatially variable than for MPI. SRESA1B and B1 (not shown) show similar GPI changes PDGW; however inter-scenario differences are greater than for MPI.