PROJECT 2.4: PHYSICAL-STATISTICAL MODELLING OF EXTREME EVENTS

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Key research findings and highlights

Milestone 2.4.1 *Selection of high-quality weather recording stations*

The selection of high-quality stations is now complete and has been reported on.

Milestone 2.4.2 *Availability of modelled data that could be integrated with observed records to in-fill gaps*

We have shown that output from a regional climate model adds information to the spatial modelling of extreme rainfall, making it potentially useful in regions for which data is sparse, for example, in the regions in NWWA where data from rainfall stations is sparse. A final report has been submitted and will be published on the IOCI website.

Milestone 2.4.3 *Predictor selection methodologies and their application*

We have been using our method of fast variable selection to identify potential drivers of extreme rainfall at individual stations in NWWA. Many of the variables, such as sea-level pressures and components of wind, are consistent with other studies. In the next step, we will be using some of these variables in the spatio-temporal model used in 2.4.2.

Milestone 2.4.4 *New statistical model for extreme temperature (and rainfall) events*

Using our statistical model for hot spells, we have found that hot spells in SWWA are related to the Southwest Australian Circulation (SWAC) index. A manuscript describing our results is currently being prepared.

Milestone 2.4.5 *Key atmospheric predictors for extreme heat (and rainfall) events*

We have found a new mechanism that describes the variability and increasing trend of summer rainfall over Northwest Western Australian. The mechanism is described in a manuscript submitted to the *Journal of Climate*.

Milestone 2.4.6 *Report on the potential forecast skill on seasonal time scales*

Report on seasonal forecast skill under preparation for internal review. Application of the predictors identified is reported against Milestones 2.4.4 and 2.4.5. We have tried lagged predictors such as the the Southwest Australian Circulation (SWAC) index and the Southern Annular Mode (SAM) and will be reporting on others.

Milestone 2.4.7 *Report documenting the likely changes in the frequency, intensity and region of occurrence of tropical cyclone-like vortices (TCLV) affecting WA*

This milestone uses the outputs from regional climate models to identify likely changes in the frequency and region of occurrence of TCLVs affecting WA. A report documenting these changes has been submitted. The development of projections of changes in intensity requires the high-resolution downscaling of TCLVs to resolve the TC structures (e.g. the eye wall) in which the extreme winds and high rainfall occur. Downscaling of TCLVs from one regional climate simulation is complete and preliminary results are described below. An interim report detailing these results is provided separately.

Milestone 2.4.8 *Dissemination of climate change scenarios for intensity-frequency-duration characteristics and extreme heat events*

We are currently collating relevant GCM and RCM projections of temperature in preparation for applying the models developed in 2.4.4.

Milestone 2.4.9 *Report documenting likely change in extreme rainfall events*

Extreme rainfall events in NWWA are due to a number of synoptic systems, one of which is tropical cyclones (TC). In this milestone, we will downscale non-TC extreme rainfall events for the current and future climates to provide high resolution projections of changes in extreme rainfall intensity. Changes in TC-related rainfall will be provided through analysis of downscaled simulations from Milestone 2.4.7.

Milestone 2.4.10 *Provision of projections and modelled output (e.g. changes to ARIs, temporal rainfall patterns) in a format suitable for use by stakeholders*

We will provide the outputs from Milestones 2.4.7 and 2.4.9 to stakeholders in the form of maps and graphs and made available on a web site.

Milestone Reports

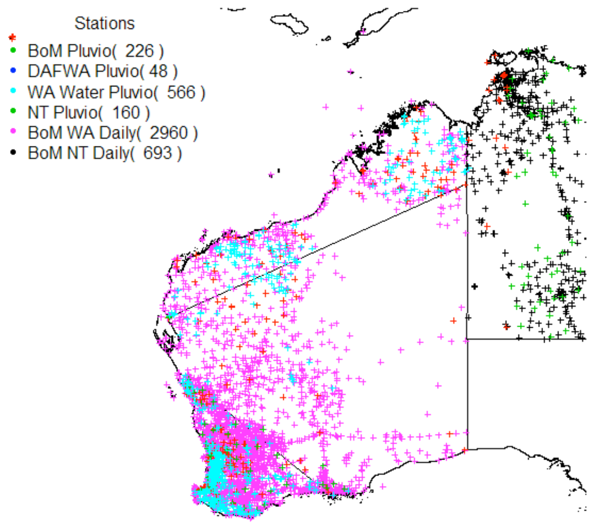
Milestone 2.4.1 *Selection of high-quality weather recording stations* **Completed**

The high quality data sets described by the Bureau of Meteorology are spatially sparse in NWWA. We have therefore used raw rainfall data sets (see figure below), and will carefully scrutinise them to ensure that we can select the top *r* rainfall values for a season within a year. Note that the model we use does not require continuous runs of data over seasons, so we can be less stringent in our requirements. This can, to some extent, alleviate the need to use modelled data for infilling (note the sparsity of data in the Great Sandy Desert).

We use not only daily rainfall records but also data from pluvio graphs (essentially continuous measurements of rainfall). BoM data has been supplemented with data from DAFWA and Dept of Water.

Data from the NT (both daily and pluvio), close to the WA border, has also been acquired.

The selection of these stations is now complete.



Potential rainfall stations in NWWA and SWWA

Milestone 2.4.2 *Availability of modelled data that could be integrated with observed records to in-fill gaps*

In areas of NWWA where there are no rainfall stations, we require surrogate variables that might be related to extreme rainfall. Currently, we use geographical information such as latitude/longitude or eastings/northings; distance from the coast; and topographic information. We also briefly considered using a satellite-based measure of green vegetation cover (normalized difference vegetation index, or NDVI), but found that it had little predictive utility.

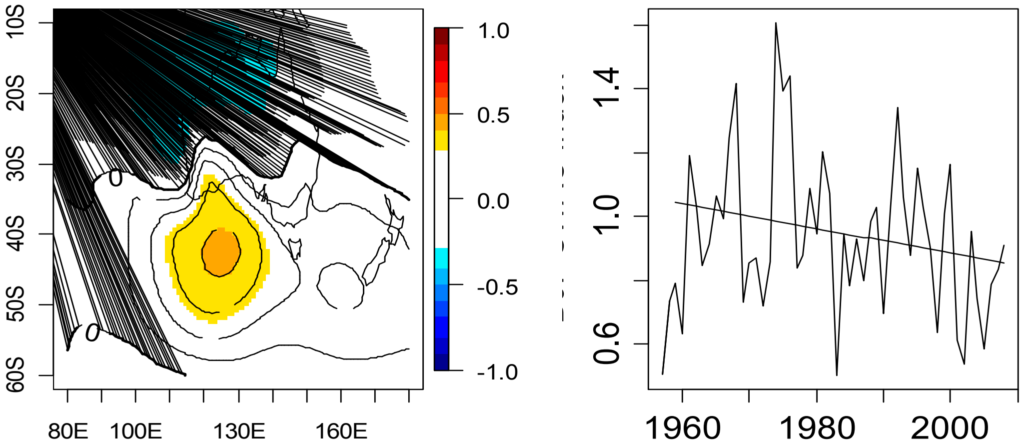
Recently, however, we have explored using output derived from regional climate models (RCMs). Although these models do not generally replicate all the characteristics of extreme rainfall particularly well, they may nevertheless supply additional information that can be incorporated into the existing spatio-temporal model that we are developing for NWWA. As a first step, we have shown that the parameters of the generalized extreme value distribution derived from existing data are related to the same parameters derived from regional climate model output. Consequently, we believe that output from RCMs can play a useful role in adding information when we have regions of sparse data. The next step will be to incorporate this information into the existing spatio-temporal model. We will also investigate RCMs that produce output at a finer resolution, which may be even more informative.

Milestone 2.4.3 *Predictor selection methodologies and their application*

We have continued to develop our methodology for selecting variables that are potentially related to extremes in the Kimberley and Pilbara regions of NWWA. The methodology allows us to select variables from gridded data, e.g., reanalysis data or output from GCMs and RCMs. Using reanalysis data, we have found that the variables that are selected on a station-by-station basis include components of wind, dew-point temperature depression and sea level pressure. Often, though not always, variables are selected in spatially contiguous blocks. The selected variables will be incorporated in the spatio-temporal model being used in 2.4.2 to determine whether a climate change signal in these variables will propagate through the model and produce, for example, different return-level/return-period curves for future climates.

Milestone 2.4.4 *New statistical model for extreme temperature (and rainfall) events*

We have used our statistical model of hot spells to model heat waves over Southwest Western Australia (SWWA) by using station and grid point maximum temperature data over the region. Trends in the frequency, duration, and intensity of hot spells are fitted as well. In order to quantify the influence of climate drivers such as the Southern Annual Mode, the Southwest Australian Circulation (SWAC), and atmospheric blocking, indices of these climate drivers are also fitted as covariates to assess their relationship to frequency, duration, and intensity of hot spells. One of the key findings thus far is that hot spells in SWWA appear be related to the weakening SWAC index. The outcome of this work will provide an indication of future hot spells once the climate drivers are more accurately predicted/projected. Detailed results are documented in a paper under preparation.



(Left) Correlation between SWAC and sea level pressure during days with Perth maximum temperature greater than 39°C in 1957–2009. (Right) Averaged SWAC index on days with maximum temperature greater than 39°C.

Milestone 2.4.5 *Key atmospheric predictors for extreme heat (and rainfall) events*

We have found a new mechanism on the variability and increasing trend of summer rainfall over Northwest Western Australian. With the atmospheric ascent instigated by the warming of sea surface temperature (SST) over the tropical Atlantic, a Rossby wave train is propagating southeastward from off the west coast of subtropical South America to mid-latitudes of the South Atlantic Ocean. This then travels eastward, embedded in the westerly jet waveguide over the South Atlantic and South Indian Oceans. The eastward-propagated Rossby wave induces an anticyclonic anomaly in the upper troposphere over Australia, which is at the exit of the westerly jet waveguide. This leads to an in-situ upper-tropospheric divergence, ascending motion and a lower-tropospheric convergence, and is associated with an increase in rainfall in NWWA. Thus, the increasing trend in atmospheric upward motion induced by the warming of SST in the tropical Atlantic may partially explain the observed rainfall trend in NWWA. Results have been documented in a paper submitted to the *Journal of Climate*.

Milestone 2.4.6 *Report on the potential forecast skill on seasonal time scales*

On schedule for completion by June 30. Predictors identified, e.g., SWAC index, have been used in Milestones 2.4.4 and 2.4.5. We have tried lagged predictors such as the the Southwest Australian Circulation (SWAC) index and the Southern Annular Mode (SAM) and will be reporting on others.

Milestone 2.4.7 *Report documenting the likely changes in the frequency, intensity and region of occurrence of tropical cyclone-like vortices (TCLV) affecting WA.*

We have analysed the outputs from 11 climate change simulations conducted using CSIRO's Conformal Cubic Atmospheric Model (CCAM). An analysis of outputs from CCAM downscaled to 65 km grid spacing with NCEP reanalyses shows that the model is able to simulate the spatial characteristics of tropical cyclone (TC) occurrence in the Australian region and that the configuration used for these simulations is able to differentiate between El Niño and La Niña events. However, the modeled frequencies are less than observed with, on average, approximately 60% of the observed number of TCs simulated by CCAM. The underestimate in TC occurrence is partly due to the relatively coarse grid spacing used in the CCAM simulations.

Climate change projections using this modelling system show a strong tendency for a decrease in TC numbers in the West Australian region, especially in the region of current preferred occurrence. On average, for the period 2051-2090 relative to 1971-2000, the simulations show an approximately 50% decrease in occurrence for the NWWA region, a small decrease (0.6 days) in the duration of a given TC and a southward movement of 100 km in the genesis and decay regions.

Further downscaling of individual TCLVs is required to provide projections of changes in the intensity of TCs and requires the use of specialized atmospheric models. In particular, the models used must be non-hydrostatic so that they can be run at the fine spatial scale (5km or better) required to resolve TC structures such as the eye wall; they must also represent cloud processes that are important for the intensification of TCs. The model used is the non-hydrostatic Regional Atmospheric Modelling System (RAMS). TCLVs from one of the CCAM simulations used to provide projections of changes in TC occurrence have been downscaled to a grid spacing of 5 km for the climates of the late 20th Century (1960-2000) and late 21st Century (2050-2090). One hundred and twenty TCLVs were downscaled for each climate time slice. The analysis of these outputs is ongoing but our results show a tendency towards larger, more intense TCs. This is illustrated in Figures 1 and 2 which show changes in the storm maximum wind speed, the storm maximum integrated kinetic energy (both measures of intensity); the radius of maximum winds and the radius to gales (both measures of size).

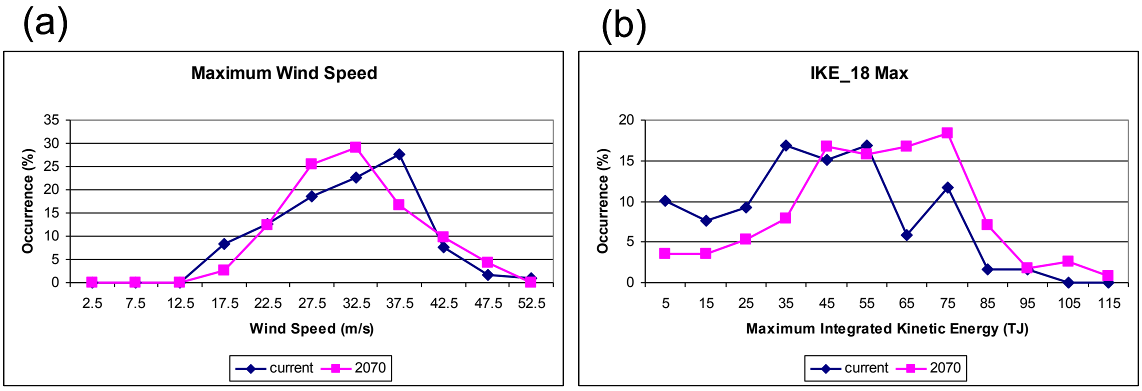


Figure 1 Probability density functions of (a) storm maximum winds speed and (b) integrated kinetic energy for the current and 2070 time slices.

The storm maximum wind speed (Figure 1a) is the maximum wind speed that is simulated throughout the lifetime of the TC and is based on a single value in both space and time. This measure of storm intensity shows an increase in the proportion of storms with a maximum wind speed greater than 40 ms^{-1}. According to Powell & Reinhold (2007) the integrated kinetic energy (IKE) is a better measure of the destructive potential of a TC, particularly that due to waves and storm surge. The IKE is calculated by integrating (summing) the kinetic energy produced over that part of the TC in which the wind speeds are greater than 18 ms^{-1} for each time. Thus the IKE contains information related to both strong winds and TC size. Figure 1b shows a tendency for an increase in IKE. A quantitative description of IKE values is provided in the accompanying Interim Technical Report

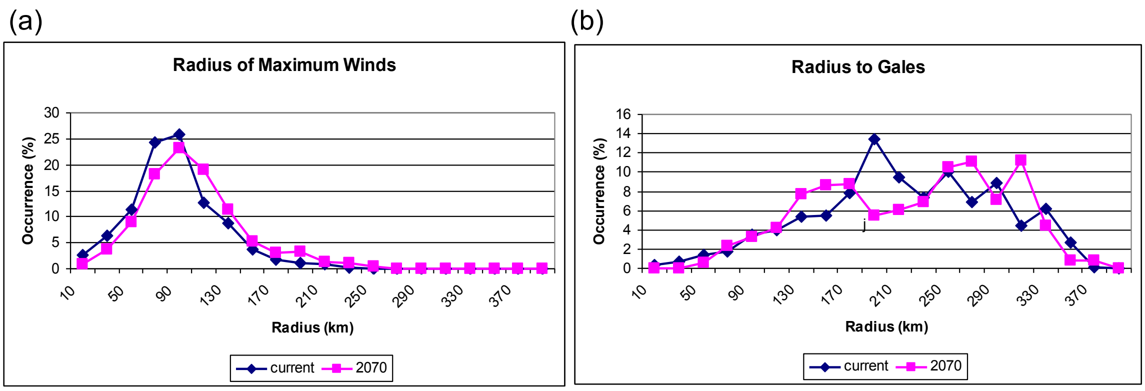


Figure 2 Probability density functions of (a) the radius of maximum winds and (b) radius to gales (18 ms^{-1}) for current and 2070 time slices.

As mentioned above, IKE contains information related to both TC size and strong wind speed. The radius of maximum winds is the distance between the centre of a cyclone and its band of strongest winds. The highest rainfall rates also occur in this region. Figure 2a shows an increase in the radius of maximum winds of late 21st Century TCs. One method of determining a tropical cyclone's size is to measure the radius of gale force winds. Figure 2b shows a tendency towards larger storms in the future. Other measures of size are also being considered.

Milestone 2.4.8 *Dissemination of climate change scenarios for intensity-frequency-duration characteristics and extreme heat events*

We are currently collating GCM and RCM projections under different future climate change scenarios. We will apply new statistical models for hot spells and heat waves developed in Project 2.4.4 to the projections in order to estimate intensity-frequency-duration characteristics and extreme heat events. Results will be delivered by the end of December 2011.

Milestone 2.4.9 *Report documenting likely change in extreme rainfall events*

The analysis of extreme rainfall from our TC simulations is ongoing. An analysis of the rainfall from the 65 km CCAM TCLVs shows an average 17% increase for rainfall within 300 km of the TC centre

Non-TC extreme rainfall events for the current and future climates have been identified and downscaling of these will commence before the end of June. Projections of changes in extreme rainfall based on these simulations will be available with a grid spacing of 5 km.

Milestone 2.4.10 *Provision of projections and modelled output (e.g. changes to ARIs, temporal rainfall patterns) in a format suitable for use by stakeholders*

Extreme value statistics will be applied to the modelled outputs from Milestone 2.4.9 to provide projected changes in Average Recurrence Intervals for extreme rainfall in the NWWA. Results will be available at the end of the project. Results will be provided in the format of maps and graphs and made available on a web site.

List of publications accepted and submitted.

Lin, Z., and Y. Li, 2011: Remote influence of the tropical Atlantic on the variability and trend in North West Australia summer rainfall. *Journal of Climate* (Submitted). Manuscript ID: EP11510

Rex Lau and Y. Li, 2011: A Markov model of the hot spell activities. *Monthly Weather Review* (In preparation).

M. M. P. B. Fuentes and D. Abbs, 2010: Effects of projected changes in tropical cyclone frequency on sea turtles. *Marine Ecology Progress Series*, **412**, 283–292, doi: 10.3354/meps08678

Abbs, D., 2010: The Impact of Climate Change on the Climatology of Tropical Cyclones in the Australian Region. Technical Report. 16 pp

List of IOCI-related presentations at national or national and international conferences, symposia and workshops.

Li Y., and R. Katz, 2011: Statistical modelling hot spells in southwest Western Australia. Proc. Joint Conference of the New Zealand Meteorology Society and the Australian Meteorological and Oceanographic Society, 100. Wellington, New Zealand, 9-11 Feb, 2011.

Rafter, A. and D. Abbs, High resolution dynamical downscaling of model-based tropical cyclones. Proc. Joint Conference of the New Zealand Meteorology Society and the Australian Meteorological and Oceanographic Society, 100. Wellington, New Zealand, 9-11 Feb, 2011.

Abbs, D: Tropical cyclones – methods to analyse changes In frequency and intensity for the Australia-Pacific region. Greenhouse 2011, Cairns. 4-8 April, 2011.

Rafter, A and D. Abbs: Tropical Cyclones - Methods To Analyse Changes In Frequency And Intensity For The Australia-Pacific Region. IUGG 2011, Melbourne. 28 June-7 July 2011.

S. L. Lavender , M. Chattopadhyay and D. J Abbs, Contribution of tropical cyclones to rainfall and extreme rainfall: Observations and GCMs. 3rd International Summit on Hurricanes and Climate Change. Rhodes, Greece. 27 June-1 July, 2011.

D. J. Abbs, S. L. Lavender, K.J.E. Walsh and A. S. Rafter: Dynamically downscaled simulations of Australian region tropical cyclones – a multi-model approach for the Australian region. 3rd International Summit on Hurricanes and Climate Change. Rhodes, Greece. 27 June-1 July, 2011.