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Using SimCLIM for modelling the impacts of climate extremes in a changing climate: a preliminary case study of household water harvesting in Southeast Queensland

R. A. Warrick [1]
[1] *University of the Sunshine Coast, Queensland, Australia, and CLIMsystems Ltd., New Zealand*
Email: rwarrick@usc.edu.au

Abstract: The aim of this paper is to present and demonstrate features of the integrated *SimCLIM* modelling system for assessing impacts and risks of climatic extremes in a changing climate. Features of the model that can be used for risk-based analyses are first described briefly, and are then illustrated by an analysis of the risk of rainfall variability and extremes on household water tank systems.

SimCLIM is an "open-framework" software modelling system that can be customised and maintained by users for the purpose of examining the impacts and adaptations to climate variability and change, including extreme climatic events. SimCLIM contains tools for both spatial and site time-series analyses. The core features of SimCLIM that are directly relevant to risk-based climate impact assessments are its scenario generator and its extreme event analyser. In SimCLIM, the two are linked, so that estimates of the return periods for extreme events (e.g. heavy daily rainfall events) can be assessed under both current climate and under scenarios of climate change.

Time-series data perturbed by the scenario generator within SimCLIM are used to drive various impact models. In this way, the data are "processed" and the extreme events become manifested as outputs of those models. Using a water tank model "plugged-in" to SimCLIM, a preliminary case study was conducted of the effects of low rainfall conditions on household water tank systems in an area of Southeast Queensland and northern NSW centred on Brisbane. With the simplifying assumption that the storage tank is the sole source of water, the risks – expressed in terms of the number of occurrences of an empty tank and the longest period without water – were assessed under both present climate variability and future scenario of climate change for 2050 based on an ensemble of eight GCM patterns. The model was run for 30 years of daily rainfall data for 37 stations and the results were spatially interpolated to produce risk maps.

It was found that the risks vary greatly over the region, with a steep east-west risk gradient quickly transitioning from a large area of low risk to a large area of extreme risk. The simulation under a scenario of climate change, which produced drier conditions in the region by 2050, resulted in an eastward shift of the relatively narrow risk transition zone, with incursion of higher risk toward the more heavily populated coastal areas.

This preliminary study suggests that the spatial differences in the risk of tank system failure due to drought occurrences are so large that drastically different designs could be warranted over rather short distances. Simulation models that systemically assess the effects of climate variability and change could provide a basis for informing decisions regarding: (1) the advisability of tank systems for a given location as compared to other sources; (2) the system components that could be adjusted to reduce risks of failure; and (3) the degree of risk that would be acceptable to homeowners. As shown here, integrated modelling systems like SimCLIM can contribute to such assessments.

Keywords: *Climate change; climate impacts; integrated modelling; SimCLIM; water harvesting*

1. INTRODUCTION

In recent years there has been an increasing realisation that the impacts of climate change which impinge most directly on people and communities will be felt largely as changes in the *risks of extreme events*, such as floods, droughts and tropical cyclones. Arguably, the assessment and promotion of *adaptation* should therefore focus, in the first instance, on the risks of climatic extremes and changes in their frequency and intensity over time.

Throughout the world, climatic variability and extremes are commonly manifested in problems of water – either too much or too little. Australia is no exception. With future climate change, the problems could worsen considerably for Australia as well as many developed and developing countries of the world (Kundzewicz et al., 2007). In this context, integrated models and tools for climate impact and adaptation assessment are required that help bridge the gap between science and decision-making in order to lessen the risks.

The aim of this paper is to present and demonstrate features of the integrated SimCLIM system for assessing impacts and risks of climatic extremes in a changing climate. Features of the model that can be used for risk-based analyses are first described briefly, and are then illustrated by focusing on issues of impacts and adaptation in the water supply sector of Southeast Queensland, with a specific focus on household water tank systems.

2. SOME KEY FEATURES OF THE SimCLIM SYSTEM

SimCLIM is an “open-framework” software modelling system that can be customised and maintained by users for the purpose of examining the impacts and adaptations to climate variability and change, including extreme climatic events.(Warrick et al., 2005). It was developed from a “hard-wired” system originally built specifically for New Zealand, called CLIMPACTS (Warrick, 2009; Warrick et al., 2001; Kenny et al., 1999, 2000), with subsequent versions for other countries and regions (for example, the Australian version, OzCLIM; CSIRO, 2004).

The SimCLIM system combines complex arrays of data and models. It has a vertically-integrated, “top-down” structure that links global, local and sectoral models and data for the purpose of examining impacts on, for example, agriculture, health, coasts or water resources. For example, one version of SimCLIM links directly with Danish Hydraulic Institute (DHI) hydrologic models for seamless analyses (Warrick and Cox, 2007).

The “open-framework” features are a distinctive advantage of SimCLIM, as they afford users the flexibility for importing their own data customising the system for their own purposes – much like a GIS. The geographical size is a matter of user choice (from global to local), as is the spatial resolution (subject to computational demands and data availability).

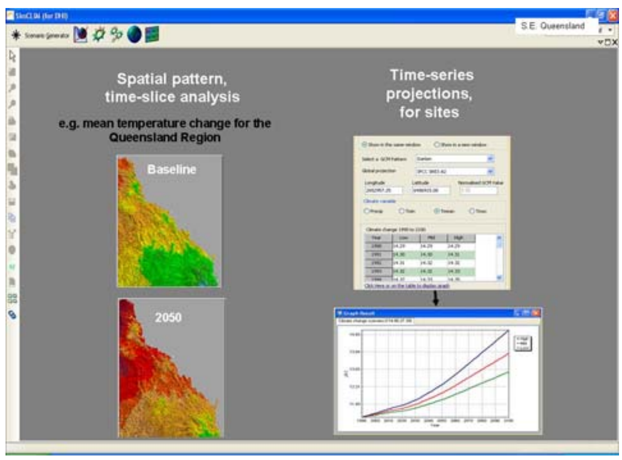

Figure 1. Spatial and site time-series projections produced by SimCLIM scenario generator

At its core, SimCLIM contains a “scenario generator” which uses a “pattern scaling” method (Santer et al., 1990; Hulme et al., 2000; Carter and La Rovere, 2001) that involves the scaling of “standardised”, spatial patterns of climate change from very complex General Circulation Models (or GCMs) by the time-dependent (e.g. year-by-year) projections of global-mean climate changes.[1]. These changes are used to perturb the present climate (whether time-series data or a spatial climatology) and thereby create climate scenarios, either spatially (time slice) or for sites (time series), as shown in **Figure 1.** The SimCLIM user interface provides the user with considerable scope for choosing amongst global projections, GCM patterns (including the most recent runs made for the IPCC AR4), model sensitivity values and future time horizons, and thus for examining the range of uncertainties involving future greenhouse gas emissions and scientific modelling.[2] There is also a sea-level scenario generator that employs similar methods (Warrick et al., 2005). The user-defined future climates or sea levels can then be used to drive impact models. A new feature of SimCLIM is the capacity to create "ensemble" patterns from user-selected combinations of GCM outputs, in which the median and lower and upper percentiles are displayed as output.

In terms of extreme events, one particularly useful SimCLIM tool is its extreme event analyser. This tool picks out the extreme values – say, extreme daily rainfall events – year by year (or season) from observed time series data. The extreme values are then plotted and a General Extreme Value (GEV) distribution is fit to the data. From this function, the return periods for user-specified extreme values (or vice versa) can be estimated, as shown in **Figure 2**.

The extreme event analyser is linked to the scenario generator so that user-specified scenarios of climate change are used to perturb the time-series data. **Figure 2** also shows the change in return period for future scenario. Currently, the scenario generator applies monthly-mean changes to scale daily values, which assumes no change in the distribution -- for example, no changes in the number of rain-days or in the intensity of extreme rainfall events).[3]

Generally, time-series data perturbed in this fashion can also be used to drive various models. In this way, the data are "processed" and the extreme events become evident as secondary outputs of those models – e.g. extremely low crop yields, damaging flood events, mortality and morbidity from heat waves, and so on. In this regard, the next section focuses on an exploratory case study of the possible effects of low rainfall extremes on household water tank systems.

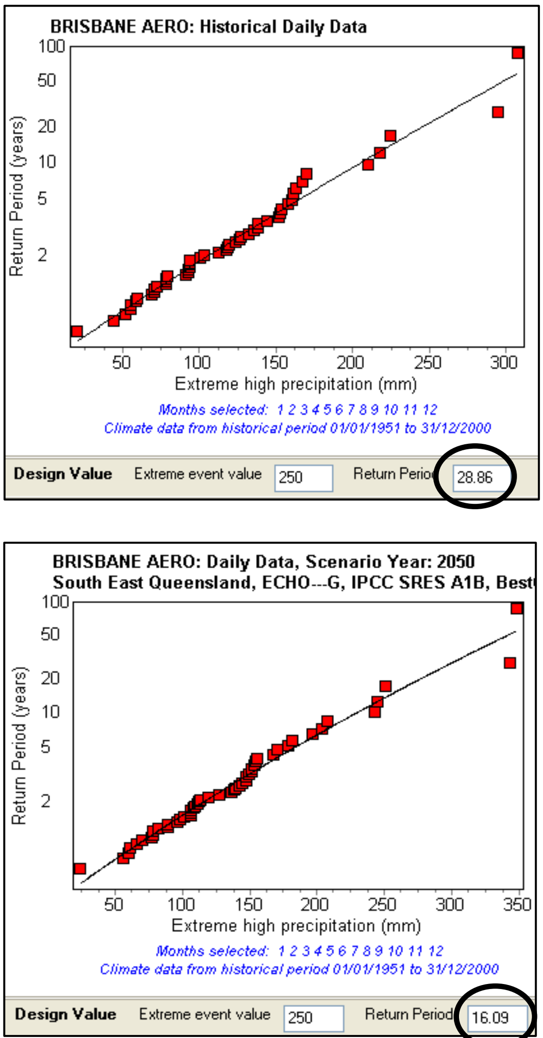

Figure 2: Example from SimCLIM extreme event analyser. Top panel: the plotted values are the annual extreme daily rainfall events from the Brisbane Aero station, 1951-2000. The bottom panel shows the extremes after being perturbed by the scenario of climate change. The circled return periods indicate that for a selected value of 250mm, the return period nearly doubles due to climate change.

3. CASE STUDY APPLICATION: THE RISKS OF LOW RAINFALL TO HOUSEHOLD WATER TANK SYSTEMS

3.1. The context and approach

Problems of water supply are widespread in Australia and have been particularly acute during the present decade with prolonged periods of low

[1] The same method is used, for example, by MAGICC-SCENGEN for global and regional scenario generation (Wigley, 2003; also see www.cgd.ucar.edu/cas/wigley/magicc/about.html).
[2] The recent AR4 GCM outputs were obtained from the CMIP3 database.
[3] New methods will soon be available in SimCLIM to simulate changes in the intensity of extremes, as is becoming evident from both observations and GCM model results for various areas of the world.

rainfall. Future climate change with the prospects of higher temperatures and decreases in rainfall could exacerbate a situation that, for many regions of Australia, is already critical. Southeast Queensland is one such region. In this region, an emerging response to the crisis has been to encourage de-centralised water-harvesting systems using roof-top runoff and storage tanks.

With the simplifying assumption that the storage tank is the sole source of water (as may be the case in many rural areas), SimCLIM is used here to conduct an exploratory assessment of the adequacy of such water-harvesting systems under both present climate variability and future climate change. Risks are assessed in terms of the frequency and duration of periods of empty tanks. The analyses are conducted on a site-by-site basis throughout Southeast Queensland, using historical records of observed daily rainfall, which, for future conditions, are perturbed by a scenario of climate change. The results of the site analyses are then interpolated spatially to provide risk maps for present and future climate conditions.

Study area and data

The study area focuses on lower Southeast Queensland and northern NSW, roughly centred on Brisbane, as shown in **Figure 3**. Also shown in Figure 3 are the locations of the total number of available stations containing daily precipitation time-series data, contained within SimCLIM as provided by the Australian Bureau of Meteorology (BoM). Of these, 37 stations were selected on the basis of: (1) covering the 30-year period 1961-1990; (2) few missing data and no long consecutive periods of missing data; and (3) evenly spaced for purposes of spatial interpolation.

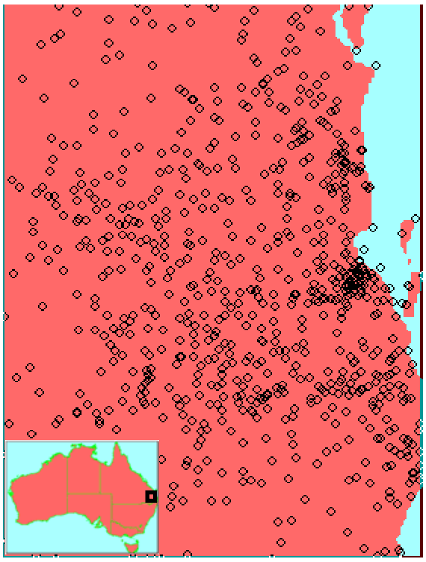

Figure 3: Study area and distribution of BoM daily rainfall stations.

3.2 Methods

One of the plug-in models to SimCLIM is a simple water tank model, which is linked to the scenario generator and is forced by daily rainfall time-series data. The interface showing the model parameters is shown in **Figure 4**. In selection of model parameters, the approach was to choose, for a wetter part of the study area (coastal areas near Brisbane), an idealised "risk-free" system design, that is: a tank size of 90,000 litres and a water catchment area (roof) of 290 m^2, in order to meet a household water demand of 550 litres per day (assumed to be constant). It was assumed that there is no water mains hook-up, grey-water use or any other source of water. It was further assumed that households could tolerate two days without water in the tank before disruption, hardship or cost is incurred (e.g. before calling out the water truck). Finally, the tank is assumed to be half-full at the start of the simulation.

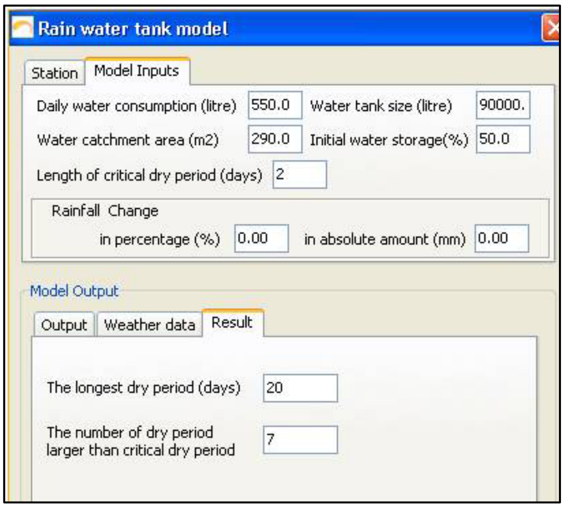

Figure 4: User interface for the SimCLIM rainwater tank model.

The model is run with daily rainfall data selected from the period 1961-1990. This 30-year period is assumed to represent "current" climate (notwithstanding the extremely dry years over the last 10 years and the fact that this region could well be entering a more permanent drier condition).

The output includes two indicators of risk: the longest period in which the tank is empty (in days); and the number of times in which the tank went dry and exceed the assumed two-day tolerance threshold during the 30-year simulation.

The model was first run for all 37 selected stations using the observed data. When missing data were encountered, it was assumed the value on the day was zero. The site values for number of times the tank went dry and the longest dry period were recorded and interpolated to the 100m grid covering the study area.

The model was then run under a scenario of precipitation change for the year 2050. The spatial pattern of change was the median value from an ensemble of eight un-weighted GCMs results, whose monthly change values (in percent) were standardized (see above), and scaled by a projection of global-mean temperature resulting from the SRES A1B emission scenario and a mid-range climate sensitivity value.[4] The output was bi-linearly interpolated to the 100m grid resolution of the study area (which corresponds to the interpolated spatial climatology developed and provided by BoM). The monthly change values were used to perturb each of the 37 observed daily rainfall time-series. The tank model was re-run for each and the performance outputs were again recorded and spatially interpolated.

3.3 Results

The results that show the risks of tank failure – that is, the frequency of the tank running out of water – are shown in **Figure 5**. The categories of risk shown were assigned rather arbitrarily as follows:

***Low or no risk*:** up to 1 failure every 5 years on average
Moderate risk: failure occurring once every 2-5 years on average.
High risk: failure occurring once every 1-2 years on average.
Extremely high risk: failure every year or more on average.

From **Figure 5 (top panel)** it can be seen that the idealized, substantial tank system that was simulated under "current" climate would adequately provide for self-sufficient household water supply for over half the study area– the eastern, wetter coastal region. However, there is a very steep gradient of risk that bisects the middle of region, such that within a short east-west distance one transitions quickly through moderate and high risk to a large area extremely high risk.

The risk as indicated by the longest period of an empty tank (in consecutive days) shows a similar spatial pattern (and so is not shown here). In the eastern areas of low risk corresponding to the top panel in Figure 5, the longest period of dry tanks is only up to about 10 days. Again, the risk gradient steepens as one moves eastward. In the area of extremely high risk, the longest period is greater than 20 days.

These spatial patterns, of course, reflect the vast contrast in average precipitation amounts between the inland hinterland and the coastal plain. Essentially, over the western, drier half of the study area the water tank system would be non-functional.

The effects of the scenario of future climate change on the spatial pattern of tank failure by the year 2050 were then examined.

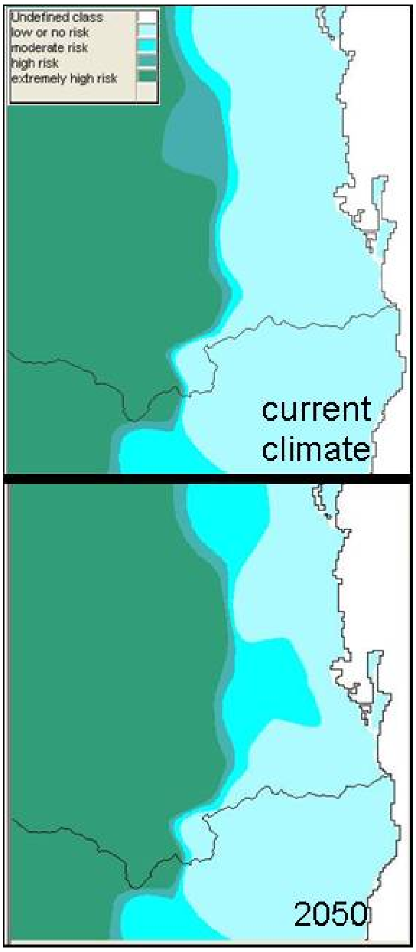

Figure 5: The patterns of risk of tank failure (occurrences of empty tank over the 30-year simulation period). Top Panel: under current climate (1961-1990 observed daily rainfall); and Bottom Panel: under scenario of climate change.

[4] The eight GCMs (and country of modeling centre) are: UKHADGEM (UK); MRI-232A (Japan); MPIECH-5 (Germany); GFDLCM21 (USA); FGOALS1G (China); ECHO-G (Germany/Korea); CCSM--30 (USA); CSIRO-30 (Australia). There are large differences between the models as regards both the direction and magnitude of precipitation change for this region.

Under the 8-model ensemble scenario, the overall regional trend is one of drier conditions. **Figure 6** shows the pattern of rainfall change (in percent) over the study area in 2050 for the drier half of the year (April-September), presumably when rainfall deficiencies would have the greatest effects on water tank performance. The precipitation changes range from about -4% in the southern part of the region, to about -15% in the north-east coastal areas.

The effects of climate change on tank failures can be seen by comparing the **top and bottom panels of Figure 5**. The eastern areas that previously experienced lowest risk of tank failure shrink substantially. The steep risk gradient and the total area of extremely high risk observed under current climate expand eastward under the scenario of climate change. Again, a similar spatial pattern of change in risk was obtained for the second risk indicator, the length of the longest period of empty tank.

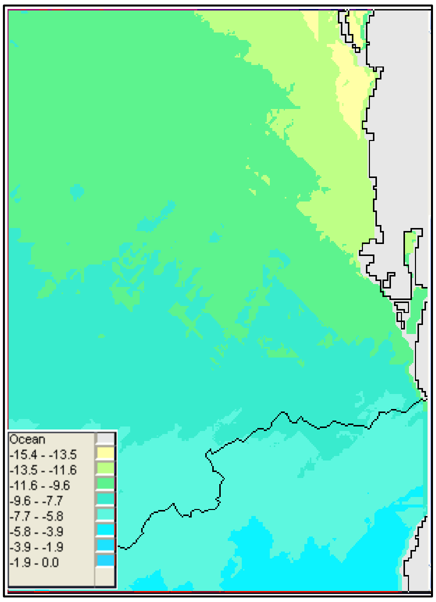

Figure 6: The percent change in April-September precipitation for the year 2050, from an eight-GCM ensemble pattern and a global-mean warming projection using the A1B emission scenario with mid-range

4. SUMMARY AND CONCLUSIONS

The purpose of this paper was primarily to demonstrate how an integrated model, SimCLIM, can be used to assess climatic extremes and their impacts in a changing climate. Focussing on household water tank systems, and assuming an idealised low risk design applicable to higher rainfall areas, SimCLIM's data bases, scenario generator and water tank model were utilised within the single modelling system to assess the spatial patterns of risk in the SEQ-NSW region centred on Brisbane.

It was found from this exploratory analysis that the risks vary greatly over the region, with a steep risk gradient quickly transitioning from a large area of low risk to a large area of extreme risk. The simulation under a scenario of climate change, which produced drier conditions in the region by 2050, resulted in an eastward shift of the relatively narrow risk transition zone, with incursion of higher risk toward the more heavily populated coastal areas.

Household water tank systems were once banned in Southeast Queensland due to health concerns. With the severe drought conditions and water supply problems over the last ten years, water tank systems are now allowed and even encouraged. A degree of water self-sufficiency in new sub-divisions is being promulgated. However, the tendency is to prescribe specifications, like tank size, with little testing of such systems through simulation under current and future climates.

The results of this preliminary analysis suggest that the spatial differences in risk of failure due to drought occurrences are so large that drastically different designs could be warranted over rather short distances. At the very least, "first-filter" assessments of the adequacy of planned tank systems under a variable and changing climate should be performed. This would provide a basis for informing decisions regarding: (1) the advisability of tank systems for a given location as compared to other sources; (2) the system components that could be adjusted to reduce risks of failure ; and (3) the degree of risk that would be acceptable to homeowners. As shown here, integrated modelling systems like SimCLIM can contribute to such assessments.

5. ACKNOWLEDGEMENTS

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