SimCLIM: Recent developments of an integrated model for multi-scale, risk-based assessments of climate change impacts and adaptation

Richard Warrick

Faculty of Science, Health and Education
University of the Sunshine Coast
E-Mail: r.warrick@waikato.ac.nz

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ABSTRACT

The SimCLIM model system simulates, both temporally and spatially, the impacts of both climate variability and change. The purpose of this paper is to describe SimCLIM and its recent developments which provide greater versatility in conducting climate impact assessments that span global, regional and local scales, and which allow issues of adaptation to climatic risks to be examined through simulation techniques. In this paper, these tools are described, along with examples of their application to issues relating to threats to rainforest areas (at a regional scale) and domestic water supply (at a local scale) in Australia.

1. INTRODUCTION

In many parts of the world, including Australia and New Zealand, climate change looms as a major threat to ecosystems and to sustainable resource management and development (Hennessy and Fitzharris, 2007). At regional scales, projected shifts in the spatial and temporal patterns of temperature and precipitation have potentially large implications for both managed and natural environments. At the local scale, many of the impacts of climate change which impinge directly on people and communities will be felt as changes in climate variability and the frequency and magnitude of extreme events, such as floods, droughts, heat waves and tropical cyclones. One problem faced by planners, policy-makers and decision-makers is how to assess the potential adverse impacts of such changes across these scales, and to evaluate adaptation options for reducing the risks.

This problem has been addressed through the development of an enhanced version of an integrated model system called *SimCLIM*. The SimCLIM system simulates, both temporally and spatially, the impacts from climate variability and scenarios of climate change. The model system has recently been expanded in ways that allow the issue of adaptation to be explored through simulation techniques. This paper first provides an overview of SimCLIM, and then gives two examples of applications in Australia, at the regional scale (focussing on ecosystems) and for a site (focussing on domestic water supply).

2. THE OPEN-FRAMEWORK SimCLIM SYSTEM

SimCLIM is an "open-framework" software system which can be customised and maintained by users for the purpose of examining the impacts and adaptations to climate variability and change (Warrick et al., 2005). It was developed from a system originally built specifically for New Zealand, called CLIMPACTS (Warrick et al., 1996, 2001; Kenny et al., 1999, 2000), with subsequent versions for other countries and regions (for example, the Australian version, OzCLIM; CSIRO, 2004).

The purpose of SimCLIM is to link and integrate complex arrays of data and models in order to simulate the impacts climatic variations and change, including extreme climatic events. As illustrated in **Figure 1**, SimCLIM has a vertically-integrated, one-way "top-down" structure that links global, local and sectoral models and data for the purpose of examining the impacts of present climate variability and future change (e.g. on agriculture, health, coasts or water resources). For example, SimCLIM has an optional seamless link with the suite of Danish Hydraulic Institute models (e.g. MIKE11) which allows hydrologic analyses to easily be performed under future scenarios of climate change (DHI, 2006). In this way, SimCLIM provides the foundation for assessing options for adapting to the changes and reducing the risks.

At its core, every SimCLIM has a "climate scenario generator" used to create scenarios of future climate and sea-level changes. For generating scenarios of future climates, SimCLIM generally employs the commonly-used method of "pattern scaling" (Santer et al., 1990; Hulme et al., 2000; Carter and La Rovere, 2001). It involves the scaling of "standardized", spatial patterns of climate change from very complex, computationally-demanding 3-D global climate models (General Circulation Models, or GCMs) with the time-dependent (e.g. year-by-year) projections of global-mean climate changes from simpler models. These changes are used to perturb the present climate (whether time-series data or a spatial climatology) and thereby create climate scenarios for a year of interest (e.g. 2050). The SimCLIM user interface provides the user with considerable scope for choosing amongst global projections, GCM patterns, model sensitivity values and future time horizons, and thus for examining the range of uncertainties involving future greenhouse gas emissions and scientific modelling.

As shown in **Figure 2**, monthly, seasonal or annual mean values for climate variables can be generated for "time-slice" comparisons or as projections (to the year 2100) for user-selected sites and scenario parameters. These values can then be used to drive impact models that require mean values in either spatial form or temporal projection.

In addition, SimCLIM accepts files of observed time-series climate station data, in hourly, daily or monthly format. SimCLIM's "data browser" allows the user to manipulate the data (e.g. to aggregate or sort). As illustrated in **Figure 3**, an "extreme event analyzer" provides the capacity for identifying extreme events from time-series data and estimating their return periods. The time-series data (and hence the extreme events) can be perturbed by the user-generated scenarios of climate change and then re-analysed (e.g. to estimate the change in return periods).

The "open-framework" features of SimCLIM are new (Warrick et al., 2005; CLIMsystems, 2005). The distinctive advantage of the open system (as opposed to the previous "hard-wired" system) is the flexibility afforded to users for importing their own data and models – much like a GIS. There are tools to allow the user to import: (1) spatially-interpolated climatologies and other spatial data (e.g. elevation surfaces); (2) site time-series data; (3) patterns of climate and sea-level changes from General Circulation Models (GCMs); (4) impact models that are driven by climate (and other) variables; and (5) shape files (e.g. boundaries, roads, streams). 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 and reliability). These "open-framework" modifications have allowed SimCLIM to transition from the realm of the specialist into a tool that can also be used by planners, consultants, policy-makers and educators.

2. CONDUCTING IMPACT AND ADAPTATION ASSESSMENTS USING SIMCLIM

How can SimCLIM be used to assess change change impacts and adaptation at regional and local scales? This section illustrates the use of SimCLIM for these purposes by focussing on two applications in the context of Southeast Queensland: possible shifts in areas climatically suitable for rainforests; and adequacy of domestic tank water supply systems. Both issues are water-related, so attention is first directed to possible future changes in precipitation in the region.

2.1 Climate changes for Queensland

For Southeast Queensland (as well as most regions of the world), changes in temperature due to increasing atmospheric concentrations of greenhouse gases as projected by General Circulation Models (GCMs) are consistently uni-directional – upwards. The uncertainties relate to the rate of warming. Warming will exacerbate problems associated with decreasing precipitation by increasing evapotranpiration and water demands. For precipitation, however, the direction of change itself varies amongst GCMs – some say wetter, others drier – by quite large margins (Suppiah et al., 2007). In light of this uncertainty, SimCLIM contains a range of GCM results so that "what if" analyses can readily be conducted.

For example, **Figure 4** shows a "severe case" scenario of regional drying, based on the Hadley Centre (UK) GCM (HadCM3) and assuming a high sensitivity of climate to changes in greenhouse gas concentrations and a high rate of future greenhouse gas emissions (SRES A1F1). In this case, by the year 2100 the region is projected to experience decreased precipitation in the range 13-22%. The next section examines the implications of such a change for rainforest boundaries.

2.2 Potential shifts in rainforest boundaries: the case of the Border Ranges World Heritage Area

Major concerns have been raised about the effects of climatic changes on Australia's tropical forests (Williams et al., 2003). Many species are well-adapted to current climatic variability. However, many are restricted to geographic and climatic ranges and are vulnerable to long-term changes in average climate and associated increases in frequency or intensity of extreme events (Hennessy and Fitzharris, 2007).

In this context, Australia's rainforests are potentially at risk. The relationship between rainforest boundaries, climate and substrate in Australia has been examined empirically (Ash, 1988). In general, observations suggest that rainforest boundaries are associated with mean annual rainfall, but moderated by the underlying substrate, as shown in **Figure 5**.

This relationship was used for the purpose of conducting a first-order assessment of the effects of rainfall change on the Border Ranges World Heritage Area, located on the higher and wetter elevations of the volcanic remnants in Southeast Queensland. From Figure 5, an average value of 1200mm of rainfall per year across substrate types was identified and assumed to represent the threshold below which the rainfall is insufficient to sustain rainforest. Within SimCLIM, the Border Ranges boundaries were overlain on the pattern of current mean-annual rainfall. As shown in the **left panel of Figure 6**, there is good correspondence between the existing 1200mm threshold and the boundaries of the Border Ranges, which provides some degree of confidence in the derived relationship between rainfall boundaries and rainfall.

The "severe case" scenario, described in Section 2.1, was then applied and the 1200mm threshold value again highlighted. As indicated in **the right panel of Figure 6**, large areas of the Border Ranges Area, particularly on the narrow, westward extensions, fall below the 1200mm threshold under climate change. These areas would presumably be unsuited to support rainforest and could potentially be subsumed by other species that are more tolerant of drier conditions. The remaining areas suitable for rainforest on the western extension of the Border Ranges become fragmented and isolated geographically. Further reductions in rainfall would presumably encompass the entire Border Ranges Area and portend its eventual disappearance.

2.3. The risks of climate variability and change to domestic water supply tank systems.

Southeast Queensland is currently undergoing one of its worst droughts on record. By mid-2007, high-level restrictions on water use were in place in a number of areas, and issues of water supply and demand top the political agenda. In a region with a rapidly growing population and economy, there is now serious consideration being given to requirements for new developments to be self-sufficient and sustainable in terms of water supply. Domestic water tanks, once banned within the region, are now back in favour.

The adequacy of domestic tank systems to supply water is largely dependent on reliable amounts and timing of rainfall in relation to tank size, water consumption and catchment area (usually the roof surface). How reliable is the current climate and what are the risks of water shortage? How might the risks change under future climate change? What adaptation measures are viable options for reducing the risks?

SimCLIM is used here to address these questions for a typical situation that might exist in the Brisbane area. One of the "plug-in" models available for SimCLIM is a "Rainwater Tank Model", which is driven by daily time-series rainfall data. As shown in **Figure 7**, the input parameter values for the model include:

- *daily water consumption* per household (assumed here to be 600 litres);
- *roof area catchment* (assume 250m^2);
- *initial water storage* (at start of simulation, assumed to be 50% full);
- *length of "critical dry period"*, that is, the number of days that can be tolerated after the tank runs dry and before the tanker is called out. The length is this period is a function of such factors as emergency water supplies and individual preferences and behaviour. (assumed here to be two days before the tanker is called out);
- *Tank size* (in litres)

The outputs include:

- *Longest dry period* (number of days in which the tank is dry);
- *Number of dry periods* (exceeding the critical threshold)

One way of performing the simulation is, in the first instance, to first determine an "acceptable level risk" in relation to the outputs, and, after setting other model input parameters, alter the tank storage to achieve the acceptable level of risk. For our simulation, it is assumed that over 30 years, running out of water about 6 times (once every five years), with a single dry period of no more than three weeks, is a risk that can be tolerated.

In order to determine required tank storage, the model is run with 30 years (1961-1990) of daily rainfall as recorded at the Brisbane Aero station. With a single 45,000 litre storage, the tank runs dry 86 times – clearly unacceptable. Doubling the storage to 90,000 litres reduces the failure rate to five times, with 22 days being the longest dry period, within the acceptable limits.

How might climate change alter the risks? In order to address these questions, the scenario of climate change described in Section 2.1 was selected, but to the year 2050, a more appropriate time horizon for future decisions regarding small-scale water supply systems. In SimCLIM, the changes in monthly rainfall are used to perturb the entire 30-year record daily rainfall values. The Rainwater Tank model was the re-run using the perturbed dataset. The results showed that the rate of failure tripled, from five to 16 failures (or about once in every two years on average) – an unacceptable level of risk.

What are the viable options for adaptation to reduce the added risks from climate change? Given that retro-fitting is often costly, there is some merit in considering measures to reduce the risks at the outset. Four options were considered:

- An additional 10,000 litre tank.
- Reduce daily water consumption by 5%
- Include the roof area for water catchment, an extra $40m^2$;
- Raise the tolerable threshold to 4 days, through better emergency preparedness

Each of the options was simulated separately and the results are shown in **Table 1**. The most obvious option, adding an extra tank, was the only moderately effective, reducing the number of failures from 16 to 11, and would probably be the most expensive. By comparison, lowering water consumption by a mere 5% dropped the number of failures to only four, and is probably a very low-cost option, although it has little effect on the longest dry period (unchanged at 22 days). Overall, the most technically effective option appears to be the inclusion of the garage roof area into the water catchment (four failures, 10 days for the longest dry period), although the costs are likely to be moderately high. The least effective (but little cost) option in reducing the risks was raising the tolerable threshold.

In general, it is important to note that the rainwater tank system itself is one way of adjusting to current climatic variability. The modifications of the system to take account the additional or *incremental risks* from climate change is *adaptation*. As demonstrated here, SimCLIM can help in assessing adjustments to natural variability as well as in identifying the incremental risks and evaluating adaptation to climate change. Final decisions are a matter of weighing and balancing a number of factors such as risk acceptance, costs, future discounting, uncertainties, and perceived efficacy of the actions, which, of course, are beyond the realm of a model such as SimCLIM.

2. CONCLUSIONS

This paper has presented an overview of the SimCLIM model system and some important new features that allow flexible, multi-scale and multi-dimensional (e.g. spatial and temporal) analyses. An application focusing on the Border Ranges World Heritage Area demonstrated the way in which scenarios of climate change can be generated and used to assess potential ecosystem threats at the regional scale. An application focusing on domestic rainwater tanks demonstrated how SimCLIM can be useful in analyzing the effects of, and adaptation to, climatic variability and change on water supply systems at a specific location.

This kind of risk-based approach to adaptation which blends natural climate variability with climate change, and which blends global and regional changes with local impacts and response, is consistent with recent efforts to find ways of merging conventional "top-down" and hazard-based "bottom-up" approaches to adaptation assessment (Warrick, 2006). The overall aim of such assessments is to promote a long-term process of "climate-proofing" development, whether in developed or developing countries (e.g. ADB, 2005). The SimCLIM model system is designed to provide a valuable tool to assist in this climate-proofing process.

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6. REFERENCES

Ash, J. 1988. The location and stability of rain forest boundaries in north-eastern Queensland. *Journal. of Biogeography* 15:619–630.

Asian Development Bank (ADB) (2005). *Climate-Proofing: A Risk-Based Approach to Adaptation*. Asian Development Bank, Philippines.

Carter, T.R. and La Rovere, E.l. (2001). Developing and Applying Scenarios, Chapter 3 in *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. The IPCC WG 2 Third Assessment Report, J.J. McCarthy et al. (eds), Cambridge University Press, Cambridge

CLIMsystems, (2005). CLIMsystems Home. http://www.climsystems.com/site/home/

CSIRO, (2004). OzCLIM Home. http://www.dar.csiro.au/publications/ozclim.html

Danish Hydraulic Institute (DHI) (2006): DHI Software - CLIMsystems (R-601). http://www.dhiwae.com/general/courses_DHICLIM_R-601.htm

Giorgi, F. and B. Hewitson (2001). Regional climate information - evaluation and projections. Chapter 10. In: IPCC (2001). *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 583-638.

Global Environment Facility (GEF), (1996). *Incremental Costs*. GEF/C.7/Inf.5. GEF, Washington DC

Henderson-Sellers, A., Zhang, H., Berz, G., Emanuel, K., Gray, W., Landsea, C., Holland, G., Lighthill, J., Shieh, S.-L., Webster, P. and K. McGuffie (1998). Tropical cyclones and global climate change: a post-IPCC assessment. *Bull. Am. Met. Soc*., 79, 19-38.

Hennessy, K. and Fitzharris, B. (2007): Australia and New Zealand. Chapter 11 in IPCC Working Group II Fourth Assessment Report (forthcoming).

Hennessy, K. and Fitzharris, B. (2007): Australia and New Zealand. Chapter 11 in IPCC Working Group II Fourth Assessment Report (forthcoming).

Hulme, M., T. Wigley, E. Barrow, S. Raper, A. Centella, S. Smith, A. Chipanshi (2000). *Using a Climate Scenario Generator for Vulnerability and Adaptation Assessments*: MAGICC and SCENGEN Version 2.4 Workbook, Climatic Research Unit, Norwich, UK, 52pp.

Japan International Cooperation Agency (JICA) (1994). *The Additional Study on Coastal Protection and Port Improvement in the Cook Islands*. Final Report for Ministry of Planning and Economic Development - The Cook Islands. Pacific Consultants International (PCI) and The Overseas Coastal Area Development Institute of Japan (OCDI).

Kenny, G.J., Warrick, R.A., Campbell, B.D., Sims, G.C., Camilleri, M., Jamieson, P.D., Mitchell, N.D., McPherson, H.G. and M.J. Salinger (2000). Investigating climate change impacts and thresholds: an application of the CLIMPACTS integrated assessment model for New Zealand agriculture, *Climatic Change* 46: 91-113.

Kenny, G.J., Ye, W., Warrick, R.A. and Flux, T. (1999). Climate variations and New Zealand agriculture: The CLIMPACTS system and issues of spatial and temporal scale. In: Oxley, L., Scrimgeour, F. and Jakeman, A. (eds.). *Proceedings of MODSIM 99 Conference*, University of Waikato, Hamilton, New Zealand, 6-9 December 1999.

Kirk, R. and Dorrell, D.E. (1992). *Analysis and Numerical Modelling of Cyclone Seastates Avarua and Nikao Areas*. Report commissioned by Government of the Cook Islands, September 1992.

Santer, B.D., T.M.L. Wigley, M.E. Schlesinger and J.F.B. Mitchell, (1990). *Developing Climate Scenarios from Equilibrium GCM Results*. Report No. 47, Max-Planck-Institut-fur-Meteorologie, Hamburg, Germany

Suppiah, R., K.J. Hennessy, P.H. Whetton, K. McInnes, I. Macadam, J. Bathols and J. Ricketts (2007): Australian Climate Change Projections Derived from Simulations Performed for the IPCC 4th Assessment Report. *Australian Meteorological Magazine*

Warrick, R.A., G.J. Kenny, G.C. Sims, N.J. Ericksen, A.K. Ahmad and M.Q. Mirza, (1996). Integrated model systems for national assessments of the effects of climate change: applications in New

Zealand and Bangladesh. *Water, Air and Soil Pollution* 92, p. 215-227.

Warrick, R.A., Kenny, G.J. and J.J. Harman (editors) (2001). *The Effects of Climate Change and Variation in New Zealand: An Assessment Using the CLIMPACTS System*. International Global Change Institute, University of Waikato, Hamilton.

Warrick, R.A., W. Ye, P. Kouwenhoven, J.E. Hay & C. Cheatham (2005). New Developments of the SimCLIM Model for Simulating Adaptation to Risks Arising from Climate Variability and Change. In Zerger, A. and Argent, R.M. (eds) *MODSIM 2005.* International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2005, pp. 170-176.

Warrick, R.A. (2006): Climate Change Impacts and Adaptation in the Pacific: Recent Breakthroughs in Concept and Practice. In Chapman, R., Boston, J. and Schwass, M. (eds) *Confronting Climate Change: Critical Issues for New Zealand*. Wellington: Victoria University Press.

Williams, S.E., E.E. Bolitho and S. Fox, 2003: Climate change in Australian tropical forests: An impending environmental catastrophe. *Proceedings of the Royal Society of London Series B - Biological Sciences*, 270, pp. 1887-1892.

FIGURES AND TABLES

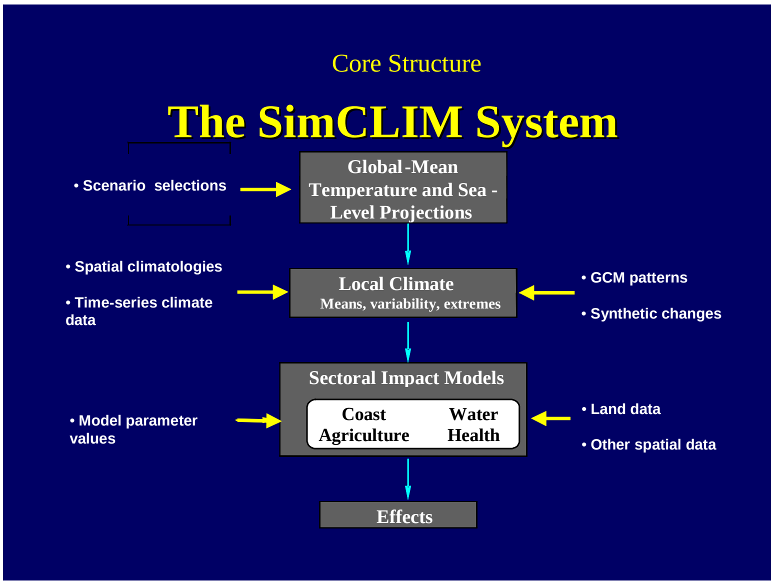

Figure 1. The major components of the SimCLIM Open-Framework System

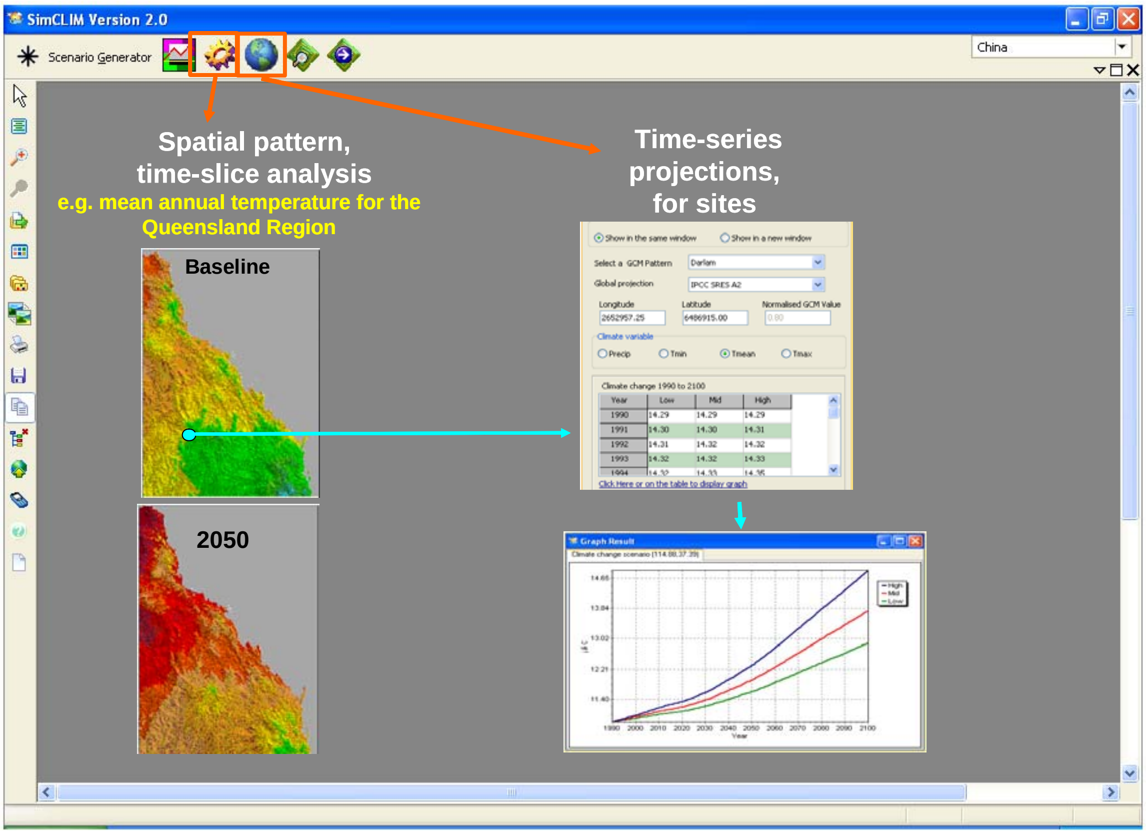

Figure 2. The scenario generator main menu in SimCLIM, with examples showing the results of functions for creating "time-slice" spatial scenarios and time-series projections of climate changes for sites.

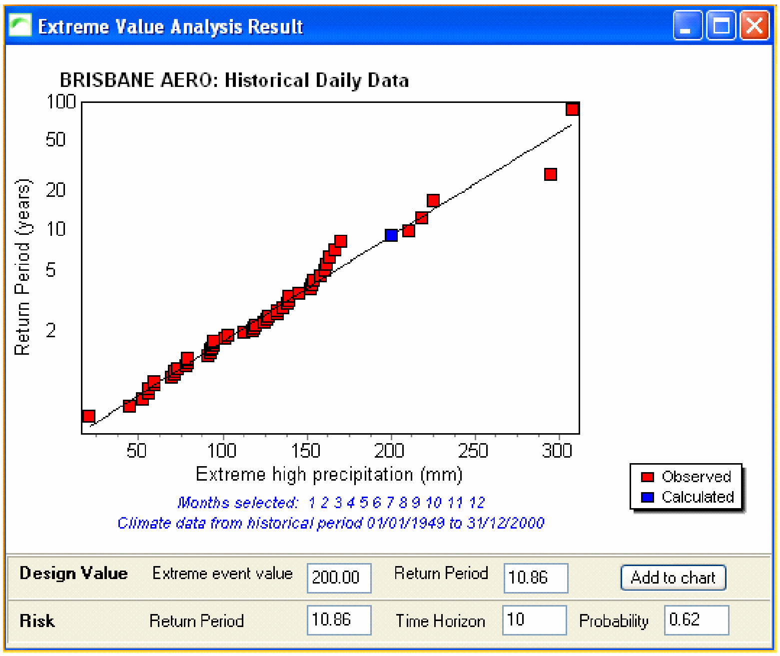

Figure 3. Output from the Extreme Event Analyer in SimCLIM. In this example, extreme daily precipitation events from 1949-2000, as recorded at Brisbane Aero station, are fit to a GEV distribution. A user-selected value of 200mm yields a return period of 10.86 years, which has 62% of occurring or being exceeded over a 10-year time horizon.

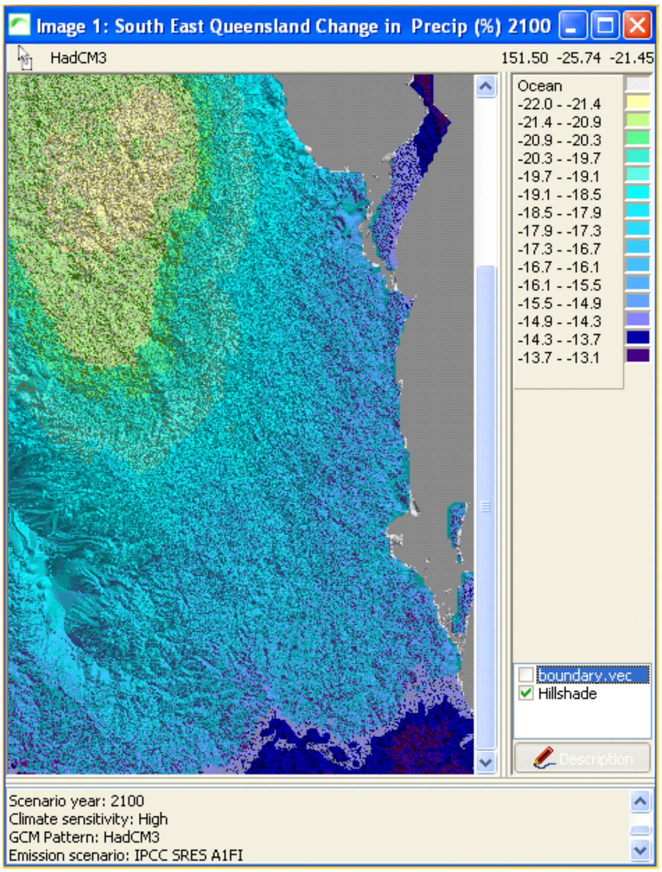

Figure 4: A "severe-case" scenario of decreasing rainfall for Southeast Queensland, as generated by SimCLIM combining the Hadley Centre GCM (HadCM3) with a high climate sensitivity value and emission scenario.

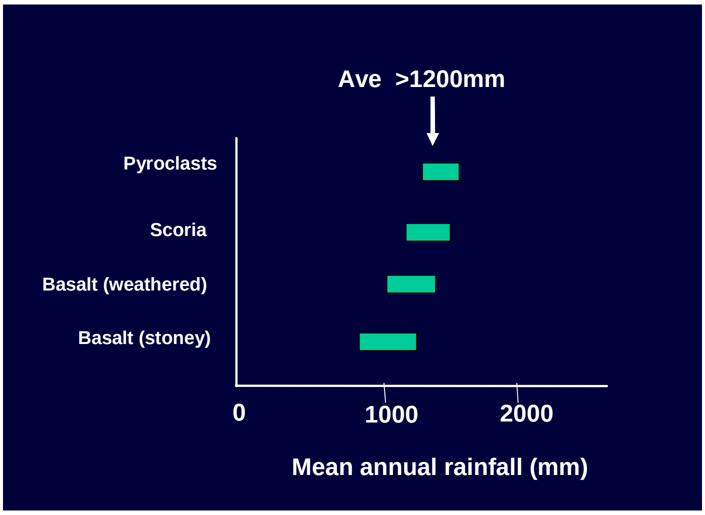

Figure 5: Location of rainforest vegetation boundaries in relation to mean annual rainfall and substrate (modified from Ash, 1988)

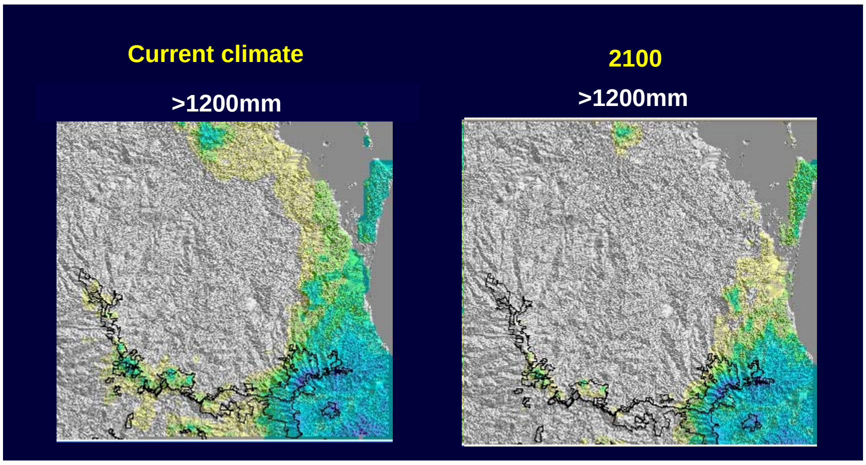

Figure 6: Boundaries of the Border Ranges World Heritage Area in relation to mean annual rainfall greater than 1200mm: Under current climate (left panel) and a "severe-case" scenario by 2100 (right panel). By 2100, the westward extension of the Area becomes fragmented and geographically isolated.

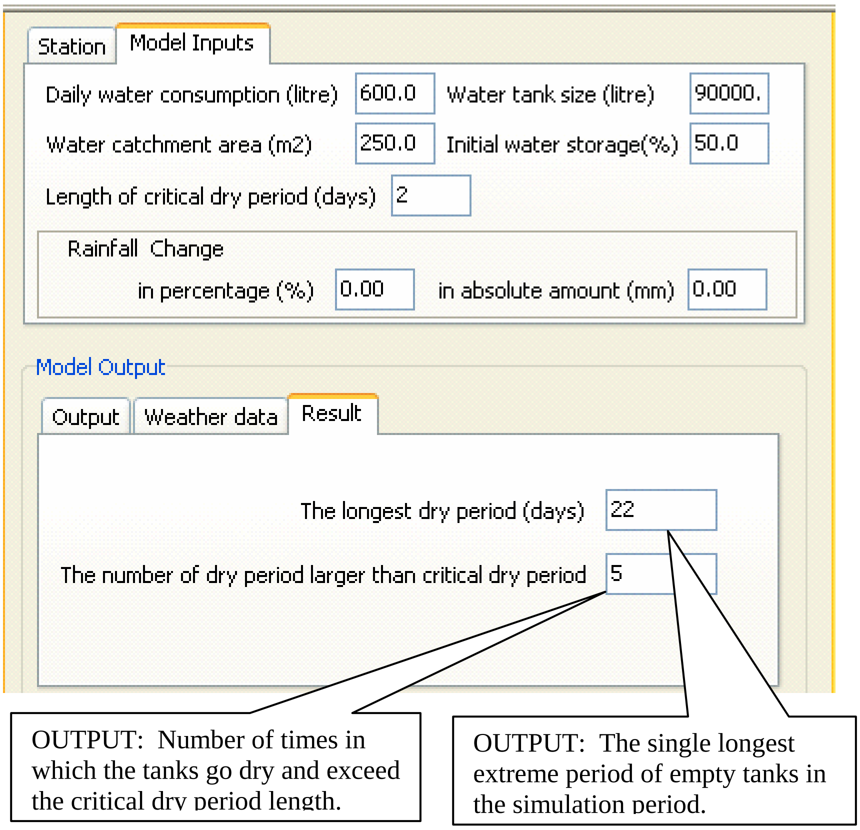

Figure 7: Input menu and output display for SimCLIM's Rainwater Tank Model.

Table 1: Assessment of adaptation options for reducing the incremental risks of rainwater tank system failure arising from climate change

Adaptation Option	No. tank failures	Longest dry period
Do nothing	16	22
Add extra 10,000 litre tank	11	22
Reduce daily consumption by 5%	4	22
Add garage roof to catchment area (40m^2)	4	10
Raise critical threshold level (extra 2 days)	13	22