New Developments of the SimCLIM Model for Simulating Adaptation to Risks Arising from Climate Variability and Change

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EXTENDED ABSTRACT

In terms of evaluating possible adaptations to climate change, one problem faced by decision-makers is how to separate the risks from present, natural climatic variations and extremes from those associated with future greenhouse-gas-induced changes in climate. In particular, this separation is necessary in order to identify the "incremental costs" of adaptation associated with climate change. As reported here, this problem has been addressed by developing an enhanced version of an integrated model system called SimCLIM.

The SimCLIM system simulates, both temporally and spatially, the impacts of both climate variability and change. The model system has recently been expanded in ways that allow the topic of "incremental costs" of adaptation to be explored through simulation, with a particular focus on coastal risks. These improvements include:

- *open-framework system*, which allows user access to import climate data and impact models for different areas and resolutions;
- *sea-level scenario generator*, which includes the capacity for including regional and local components of sea-level change;
- *land use scenario generator* that allows the user to examine the implications for vulnerability under assumptions about different pathways and controls on future growth and development;
- *capacity for transient simulations* that complements the "time-slice" approach to impact assessment and allows for time-dependent changes in climate and land use and their effects to be analysed;
- *explicit capacity for examining adaptation options*, including outputs that allow comparisons of simulations with and without climate change;
- *economic tools for evaluation* of impacts and adaptation options, specifically focussing on economic costs and benefits.

This paper describes these improvements to SimCLIM and demonstrates their application through a pilot study of coastal flood risk from tropical cyclones in a community on the island of Rarotonga, Cook Islands. Multiple simulations are conducted with and without climate change, and with and without adaptation. The results thereby give clear indications of the relative magnitude of present and future impacts of tropical cyclones and the relative costs and benefits of adaptation options for reducing the risks.

1. INTRODUCTION

In the field of climate change, one perplexing problem encountered by those concerned with assessing climate change impacts and adaptations is how to separate the risks attributable to present, natural climatic variations and extremes from those associated with future greenhouse-gas-induced changes in climate. Indeed, the inability to isolate the "incremental" impacts of climate change, and, importantly, the associated incremental costs (and benefits) of adaptations to reduce the additional future risks, has been a major constraint to providing full financial assistance for adaptation to developing countries (as, for example through the Global Environment Facility, the financial mechanism of the U.N. Climate Convention; GEF, 1996).

As reported here, this problem is addressed through simulation techniques. This was accomplished by developing an enhanced version of an integrated model system, called SimCLIM, in the context of a pilot application to an area around Avatiu, on the island of Rarotonga in the Cook Islands, an area subject to coastal flood risk from tropical cyclones (ADB, 2005). The paper first briefly describes the SimCLIM system and then discusses these new developments in the context of the Rarotonga application.

2. OVERVIEW OF THE OPEN-FRAMEWORK SimCLIM SYSTEM

SimCLIM is the generic name applied to a software modelling system developed by the International Global Change Institute (IGCI, University of Waikato, New Zealand; IGCI, 2005) for examining the impacts and adaptations to climate variability and change. It was developed from a "hard-wired" system originally built for New Zealand, called CLIMPACTS (Warrick *et al.*, 1996, 2001; Kenny *et al.*, 1999, 2000), and its subsequent derivations (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, temporally and spatially, bio-physical impacts and socio-economic effects of climatic variations, including extreme climatic events. As illustrated in Figure 1, every SimCLIM has in its core a "climate scenario generator" used to create scenarios of future climate changes. Models are attached to SimCLIM to examine the impacts of present climate variability and future change on, for example, agriculture, coasts or water resources. In this way, it provides the foundation for assessing options for adapting to the changes and reducing the risks.

The "open-framework" features of SimCLIM are new (CLIMsystems, 2005). The distinctive advantage of the open system, as opposed to the hard-wired system, is the flexibility afforded to users for importing their own data and models in order to customise the system for their own purposes – much like a GIS. As indicated in Figure 1, 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); and (4) impact models that are driven by climate (and other) variables. 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).

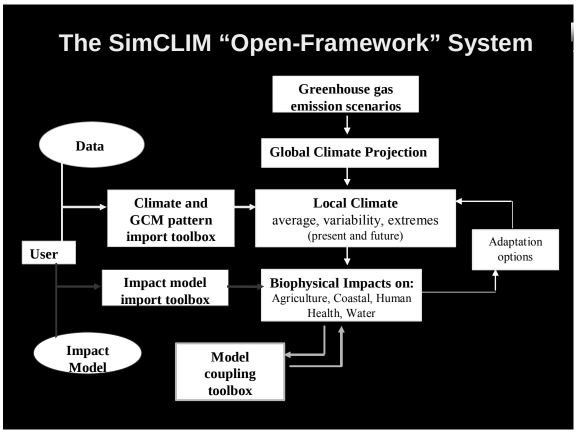


Figure 1. The major components of the SimCLIM Open-Framework System

3. CASE STUDY APPLICATION AND NEW SimCLIM DEVELOPMENTS

3.1. Pilot case study: tropical cyclone risks on Rarotonga

The island of Rarotonga has a long history of dealing with tropical cyclones. For example, the storm surge (taken here to include wave run-up as well as barometric effects and wind and wave set-up) from Cyclone Sally in 1987, estimated to be about a 1-in-13 year event, caused extensive damage to the port of Avatiu and overtopped the beach ridge along that segment of coast, causing considerable damage to residential and commercial structures and infrastructure equivalent to 66% of Cook Islands GDP (Kirk and Dorrell, 1992). Cyclone Peni losses were estimated to be over $NZ2 million, and came at a time when the Cook Islands was still recovering from Cyclone Sally. The pattern, though less damaging, was recently repeated with Cyclones Heta (2004) and Dovi (2003). Over the decades, vulnerability to such events has apparently increased, with concentrated development taking place on the exposed coastal strip, in contrast to traditional settlements which tended to be on higher ground further inland.

Climate change is threatening to exacerbate the tropical cyclone risks. Global sea-level rise will add to the storm surge height. There is also some evidence that the intensity of severe tropical cyclones could increase with global warming (Henderson-Sellers *et al*., 1998). What are the future changes in the area, population and property at risk if such extreme events worsen? How can the *incremental* impacts from future climate change be separated from those due to natural climate variability and land-use changes that add to vulnerability? What are the full and incremental benefits and costs of alternative adaptation measures, either singly or in combination, for reducing the risks?

To answer these questions, the Avatiu area was constructed within the open-framework SimCLIM at a spatial resolution of 5m and populated with elevation data and vector files of residential and commercial structures, roads, streams, and the like (Figure 2). Several new SimCLIM model developments were necessary, including: a sea-level scenario generator; land-use scenario generator; a "transient" (e.g. year-by-year) mode of simulation; functions for assessing adaptation options; and economic tools for evaluating impacts and the benefits and costs of adaptation options. These developments are described below.

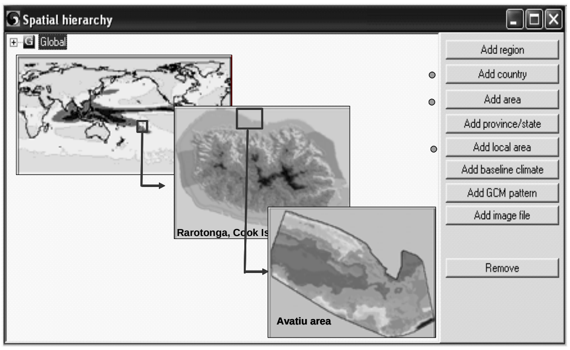


Figure 2. Multi-scale datasets in SimCLIM, from global to local

3.2. Sea-level Scenario Generator

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 for climate, changes in **sea level** also exhibit regional variations as projected by GCMs. In addition, local non-climate-change related trends (e.g. from vertical land movements) affect relative sea-level change and have to be considered. To take account of these global, regional and local components of sea-level change, the pattern-scaling method developed for SimCLIM is:

$$\Delta Z_{i,t\text{-}1990} = \left[\Delta Z_{g,\,t\text{-}1990} \times \frac{\Delta Z_{r,\,t\text{-}1990}}{\Delta Z_{2x}}\right] + Z_{nc,t\text{-}1990}$$

$\Delta Z_{i,t\text{-}1990}$ is the projected sea-level change (in cm) at location *i*, from 1990 to future year *t*.

$\Delta Z_{g,\,t\text{-}1990}$ is the change in global-mean sea level (in cm) as projected by simpler climate models for a given emission scenario and as reported, for example, in IPCC (2001).

$\Delta Z_{r,\,t\text{-}1990}$ is the *change* in regional sea level (in mm) pertaining to location *i*, as projected by a GCM.

ΔZ_{2x} is the global mean sea-level change (in mm) for an equivalent doubling of atmospheric carbon dioxide concentration (or, for transient runs of GCMs, the global mean value as averaged over the last several decades of the GCM simulation).

$Z_{nc,\,t\text{-}1990}$ is the local, non-climate-related change in sea level, usually due to vertical land movements that affect relative sea level.

As shown in Figure 3, when generating a scenario, the user chooses a GCM pattern, from which a specific location and key parameters (emission scenario, local sea level trends) are selected. Output is displayed as year-by-year changes in sea-level (relative to 1990) for low, mid and high projections which reflect scientific modelling uncertainties.

In terms of changes in **cyclone intensity**, SimCLIM also uses a simple scaling technique related to global-mean temperature change. It has variously been estimated that cyclone intensities may increase by 10-20% for a 2 to 4 degree increase in sea-surface temperature (Henderson-Sellers, 1998; Giorgi and Hewitson, 2001). On this basis, SimCLIM uses a range of 2.5% to 10% increase in cyclone intensity per degree of warming, from which the user selects a value consistent with their other assumptions.

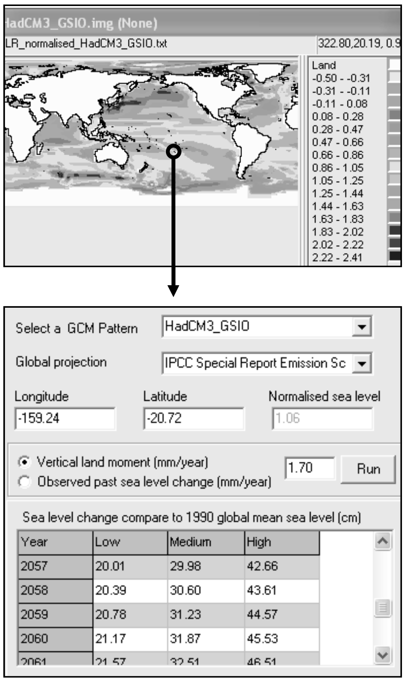


Figure 3. SimCLIM user interface for sea-level scenario generation

3.3. Land-use Scenario Generator

Future risks from tropical cyclones depend not only on the climate, but on the patterns of development in hazardous locations. In Rarotonga, the trend, especially with the emphasis on expanding the tourism sector, has been an intensification of higher-value land-use along the coastal margins most subject to storm surge. The future mix, characteristics and spatial distribution of residential and commercial structures therefore needs to be simulated as well.

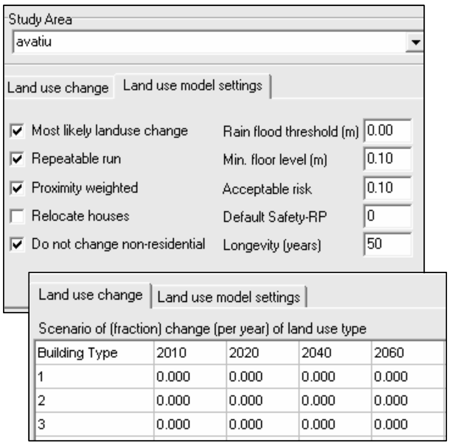


Figure 4. User interface for land-use scenario generator within SimCLIM

A stochastic land-use scenario generator was developed for this purpose. As shown in Figure 4, there are two sets of parameters which drive the changes and which can be manipulated by the user. Firstly, the user can specify the model settings or rules that determine the characteristics of buildings (for example, the lifetime of a house or commercial building type). Secondly, the user can assign weightings to the various building types in order to influence the change in the future mix of buildings (for example, by increasing the fraction of, say, commercial buildings at each time-step). With both the user-specified rules and weightings, the spatial pattern of land use is generated stochastically in the simulation on a cell-by-cell basis. In this way, at each time-step there is an array of property that is potentially subject to storm surge damage within the Avatiu area.

3.4. Adaptation Options

For the Avatiu pilot study, explicit examination of adaptation options for reducing future risks to tropical cyclones was required. Three general types of damage-reduction approaches were each represented by specific measures. For example, the category *modify damage potential* was implemented as a requirement to raise the minimum floor heights of new structures “built” in the hazard zone by the land-use scenario generator. As indicated in Figure 5, the user specifies the design risk in terms of a return period and enters the additional unit cost that is entailed in meeting the requirement. In a similar fashion the user can select *protection* (sea-wall) or *modify land-use* (avoidance of high hazard zones). These adaptation options can be run individually or in combination.

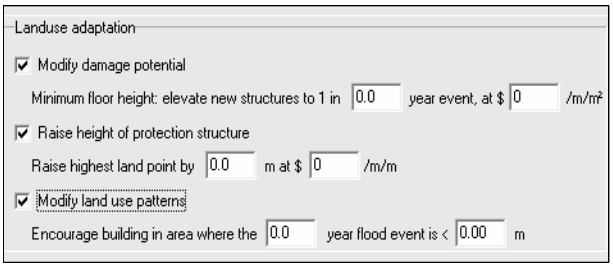


Figure 5. User-specified adaptation options within SimCLIM, as developed for the Avatiu case study area

3.5. Spatial "time-slice" and economic "transient" modes of simulation

In order to obtain a full picture of impacts and to evaluate impacts and adaptation options for the Avatiu area, two modes of simulation were required: "time-slice" (spatial) and "transient" (economic). Both modes of simulation were incorporated into SimCLIM, as shown in Figure 7.

Both modes rely on a simple reduced-form coastal flood model. The Avatiu area has benefited from a number of engineering studies which made use of complex wave models, storm surge models, and the like (e.g., JICA, 1994; Kirk and Dorrell, 1992). Policy, planning and implementation build on these studies; so does SimCLIM. Using the outputs of these studies, a chain of relationships – from wind speed, wave height to total water run-up elevation and their associated return periods – was established and related to the potential wave overtopping for a site with a given height for the beach ridge. Scenarios of future changes in tropical cyclone intensity enter into the chain by way of changing wind speed; changes in sea level enter into the chain by changing total wave run-up elevation. Flood depth and extent are calculated by determining the total run-up elevation and overtopping volume for a cyclone with a given return period. The overtopping height is determined as the difference between run-up elevation and the height of the beach ridge or protection structure. The water is distributed over the study area (downslope) with a negative exponential function, calibrated on the basis of evidence of the areal extent and depth of salt water flooding during Cyclone Sally.

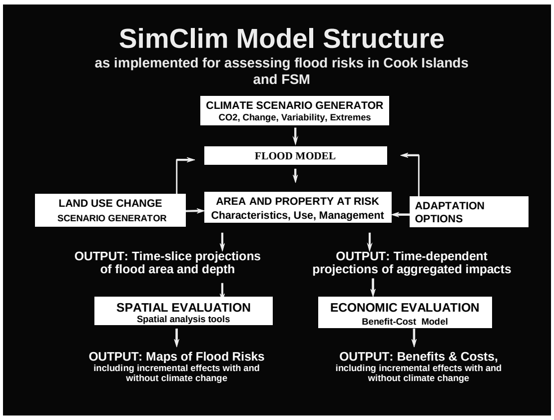


Figure 7. SimCLIM structure as developed for coastal flood risk analyses and applied in the Cook Islands case study

The capacity to create **"time-slices"** is useful for depicting physical impacts and their visualization (as well as a 2-d plan view, SimCLIM also has a 3-d fly-over visualization). This capacity was implemented for Avatiu, by linking the scenario generators with the simple coastal flood model. In using this capacity for Avatiu, scenarios of future climate and sea-level changes are specified within SimCLIM, and the coastal flood model is run for single, user-specified storm events, giving output as shown in Figure 8.

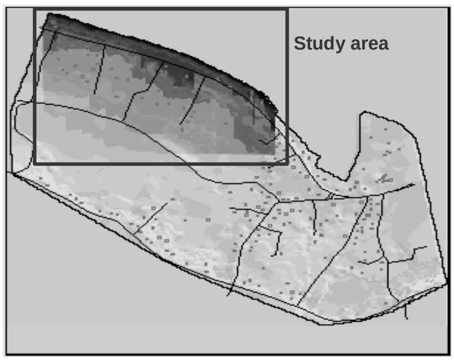


Figure 8. An example showing the areal extent and depth of the 50-year storm surge event at the year 2050 under a scenario of climate change

A complementary **"transient"** (time-dependent) mode of simulation was developed to meet the needs of economic evaluation of impacts and adaptation options. The economic evaluator, in calling on the flood model, requires simulations of floods in time-steps (e.g. yearly) and for the range of flood frequencies at each step as climate and land use change. For each building type, functions were developed that relate flood heights to dollar damages (i.e. "stage-damage" curves). For any given flood, the damages are totalled for the flooded area. At each time step, the expected damages are summed over the range of return period floods. For each simulation run over a specified time period, the damages for each future year are discounted (at a user-specified discount rate) and aggregated to give an annualised expected damage, in present dollar value. This provides a basis for comparing the benefits of adaptation options (i.e. damages prevented) with their costs (that is, “benefit-cost” analysis).

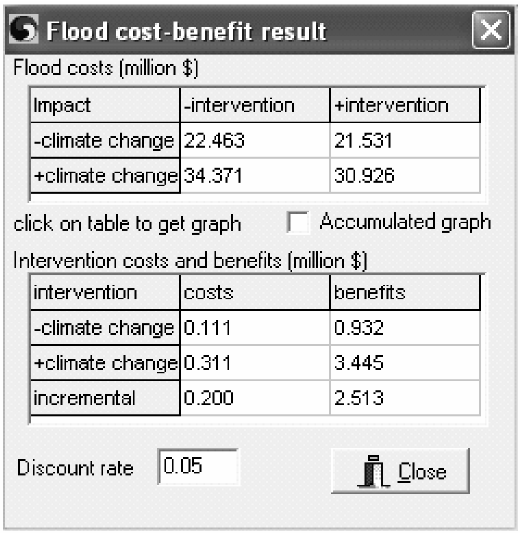
Importantly, multiple simulations with and without climate change, and with and without adaptation, also provide a basis for identifying the *incremental* benefits and costs associated specifically with climate change (as opposed to natural climate variability). The outputs are presented in non-spatial graphical and tabular format.

An example of the output for the Avatiu area is shown in Figure 9. For illustrative purpose only, this example uses a combination of user-specified parameters that produces a relatively high scenario of sea-level rise (25 cm) and change in cyclone intensity (15%) by the year 2050. The adaptation (i.e. intervention) option chosen was the raising of floor heights on new structures built (to the 1-in-25 year flood height at a nominal cost of \$100 per m/m^2).

The top panel of Figure 9 gives the simulated flood damages. It can be seen that climate change in the absence of adaptation (-intervention) increases damages considerably, by about 50% (from \$34.4m to \$22.5m). As an adaptation option (+intervention), raising floor heights is effective in reducing storm surge damages in the Avatiu study area under both current climate conditions and with climate change.

The bottom panel of Figure 9 compares the benefits (damages prevented) with the costs of adaptation (discounted at 5% and summed to present). For the Avatiu area, this simulation shows that benefits of raising floor heights exceed their costs, both under present climate variability and with future climate change – a “no regrets” option. For example, the benefit of raising floor heights in the absence of climate change is \$0.9m (i.e. \$22.4m-\$21.5m), which compares favourably to a cost of \$0.1m. With climate change, the benefits are even greater, \$3.4m, as compared to a cost of \$0.3m.

Finally, the output in the lower panel also shows the “incremental” costs and benefits of adaptation. These are the adaptation costs and benefits associated solely with climate change after subtracting the effects from natural variability. In this example, the incremental benefits of raising floor heights are \$2.5m as compared to the incremental costs of \$0.2m.



Impact	-intervention	+intervention
-climate change	22.463	21.531
+climate change	34.371	30.926

intervention	costs	benefits
-climate change	0.111	0.932
+climate change	0.311	3.445
incremental	0.200	2.513

Figure 9. Example of output of economic evaluation. The +ve and –ve signs indicate with and without, respectively.

4. SUMMARY AND CONCLUSIONS

In international negotiations regarding climate change, it has been argued strongly that the developed countries, which have been largely responsible for past emissions of greenhouse gases, have an obligation to provide financial assistance to developing countries for adaptation. While accepted in principle, such assistance has been hampered by the inability to quantify the costs of climate change impacts and adaptation apart from those occurring as the result of natural variability. This paper has demonstrated, through a case study of tropical cyclone risk in the Cook Islands, how a set of newly-developed tools within the SimCLIM Open Framework system can be used to simulate and quantify these incremental costs and to compare them to the incremental benefits of adaptation.

We suggest that the SimCLIM tools presented above represent an important breakthrough in climate change impact and adaptation assessment. The scope for their application goes well beyond resolving issues of international financial assistance. The user-friendly nature of these simulation tools suggests that they can potentially be used by a wide range of planners, policy-makers and decision-makers at local and national levels in both developed and developing countries. By integrating the effects of future climate change with current climate variability and extremes, we think that the SimCLIM tools hold promise for helping to "mainstream" climate change into actions taken routinely at the local level in dealing with floods, droughts, heat waves and other climatic risks.

5. ACKNOWLEDGEMENTS

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