

## MODELLING FOR EXTREME CLIMATE EVENTS IN THE PACIFIC

*"The average global citizen wants to know about today's weather but they also want to know how their world will change in terms of more or less rainfall, warmer or cooler conditions" — Prof Peter Lemke, Chairman of the World Climate Research Programme's science advisory group, March, 2002.*

Storm surges and associated coastal flooding are among the most potentially devastating consequences of tropical cyclones.

Identification of risk-prone areas in the Pacific and the capacity to simulate storm surges using computer models is necessary to understand the impact of, and prepare for, the effects of storm surge.

Modelling allows scientists to explore beyond the limits of their knowledge.

As a major new component of the South Pacific Sea Level and Climate Monitoring Project, Australian scientists at CSIRO Atmospheric Research, working in partnership with Global Environmental Modelling Systems (GEMS) are developing a state-of-the-art storm surge inundation modelling system for use in four locations in the Pacific.

### USING COMPUTER MODELS

Computer models are a feature of most facets of daily life, providing a guide as to how we manage our lives tomorrow and well into the future—from short-term forecasts of weather to population growth and the projected service and infrastructure needs of a community.

To use information acquired before today to project an outcome for tomorrow requires extremely powerful computers which model or simulate a situation. The computer or numerical 'model' is a set of mathematical equations, stating the laws of physics (or other related characteristics) that are resolved on a high-speed computer.

In the 1920's, an Englishman, Lewis Fry Richardson, wrote—*"Perhaps some day in the dim future it will be possible to advance the computations faster than the weather advances and at a cost less than the saving to mankind due to the information gained. But that is a dream."*

Decades before the creation of computers, Richardson used a mathematical approach to developing a weather forecast. That approach underpins modern-day weather forecasts and climate assessments.

Computing power is creating virtual oceans and therefore new horizons in climate and marine science.

### APPLICATIONS

Globally, one hundred million people live within about one metre of present day sea-level. Changes in sea-level will be felt through:

- Increases in intensity and frequency of storm surges
- Increased erosion
- Loss of important wetlands and mangroves
- Impact on coastal ecosystems ie. coral reefs
- Impact on human settlements

Scientists are interested in "forecasts" which extrapolate the ocean state for locations and variables distant from measuring instruments.

For emergency management, it might be the prediction of storm surge height and local flooding while for coastal management, it might be the evaluation of probabilities of certain sea level heights being exceeded in any particular year.

### MAKING A COMPUTER MODEL?

Making a computer model requires some background understanding of the object or process that is to be modelled. Often it means simplifying what would otherwise be complex. Evaluate what the important features of the system are—the main components and how they interrelate, the influencing factors or variables (input variables) and the outcome or results.

- Construct a mathematical model. Typically this will be a set of equations that describes real world behaviour.
- Obtain the necessary data. For example, to construct models capable of simulating patterns of extreme sea level due to storm surges and tides, accurate topographic and bathymetric data has been sourced from counterpart agencies such as South Pacific Applied Geoscience Commission (SOPAC). Tidal data obtained by National Tidal Facility Australia is used to validate the model performance in simulating tides.

Establishing probabilities of storm surges requires data on historical cyclone occurrence and this was obtained from the New Zealand Meteorological Service.

- Use the model to get results. This process is called simulation. Computer simulation involves feeding values into the model to see how it behaves under specified conditions. Simulation is dynamic in that it exercises the static description of the model under a number of different conditions.

### MODELLING IS A USEFUL AND VALUABLE EXERCISE. WHY?

It draws attention to how the 'system' works. The very act of making or understanding a model allows communities to appreciate what is involved in the 'system' being modelled.

Because models are necessary simplifications, scientists cannot be sure that they have included all the important factors involved. Running a simulation through a model and comparing the results with what they might expect to happen can tell them whether their model fairly describes or represents what it is that they are modelling. If the model is reasonable then it will give them outcomes, and allow them to ask "what if" questions leading to predictions.

Models continue to develop and be refined, based on their own simulations and new data acquired through monitoring and observations.

### FEEDING THE MODEL

The quality and accuracy of a model's forecast is directly related to the quality of the data on which it is fed.

Global ocean observing networks are now being fostered and developed by organisations such as the International Oceanographic Commission and the World Climate Research Programme.

Acquiring the data is a very expensive process and in some cases is reliant on agreements between

scientists, research organisations, commercial operations and governments. Most national research agencies are also reliant on the co-operation of commercial shippers to obtain information along key shipping routes.

In ocean, coastal and climate science, that data has many sources:

- Satellites providing sea surface height, temperature and winds data
- Research vessel instrumentation providing the most detailed picture of ocean conditions from the surface to the sea floor
- Expendable, moored, drifting and robotic cycling instruments
- Tide gauges
- Hydrographic and topographic surveys
- Meteorological services

### APPLICATIONS FOR PACIFIC NATIONS

For four Pacific locations—Fiji, Vanuatu, Tuvalu and Samoa—the storm surge modelling system has three main components:

- A tidal prediction component
- A risk analysis component
- A storm surge modelling system

#### Tide prediction

This component will enable the user to predict and display tides within the Exclusive Economic Zone of the four Pacific locations in the South Pacific.

The aim is to quickly and easily generate tidal information during a specified time period when extreme events are most likely to occur.

#### Risk analysis

For each of the four selected locations, a statistical model of cyclone behaviour has been developed based on observed cyclone behaviour over the available historical record. Historical cyclone data has been made available by the New Zealand Meteorological Service.

This model is used to randomly generate many hundreds of cyclones for which the storm surges are modelled and analysed, generating information on probabilities of storm surges of given heights occurring in a particular year under varying climate change conditions to assist authorities in planning and management applications.

#### The Storm Surge Modelling System

The system comprises a cyclone wind model, a tide model, the storm surge inundation model,

bathymetric and topographic data on two model grids for each location and various display options.

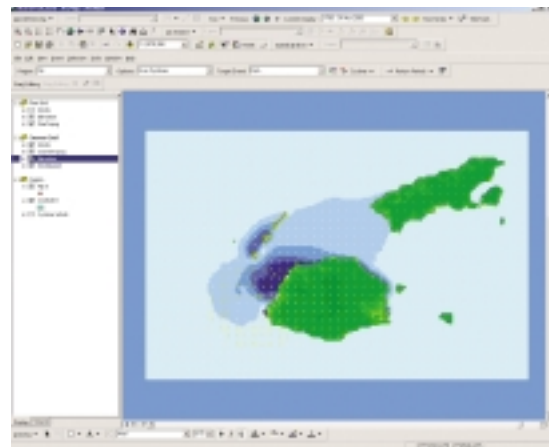
The storm surge model used in this study simulates currents and sea surface elevations on continental shelves. The model solves a set of mathematical equations over a grid comprised of equally spaced points in an east-west and north-south direction over the region of interest. The solutions give ocean current speed and direction and water depths at each model grid-point and a time-frame of the simulated surge occurring.

Of the two model grids used for each location, the outer grid spans a large area at a relatively low resolution, but which is very economical to run. The more detailed higher resolution grid over a smaller area provides detailed storm surge simulations including overland flooding if it occurs.

Setting up the model grids requires incorporating the high-resolution topographic and bathymetric data into a format in which the coastlines are accurately represented.

The model is then tested in tides-only mode to check that it can reproduce tidal variations at the location of the tide gauge. Where sufficient information on historical storm surge events exists, the cyclonic conditions are recreated and the model is tested.

The storm surge model is driven by wind stresses and atmospheric pressure gradients acting on the ocean surface, and tidal heights on its outer boundaries.



(Above) An example of the spatial pattern of storm surge and tropical cyclone winds for a cyclone that has travelled southwards to the point marked by the red dot as simulated by StormTrak. (Credit: CSIRO)

(Below) StormTrak also contains a tide prediction model to allow tide forecasts to be carried out for various locations within the EEZ of each of the four selected countries. (Credit: CSIRO)

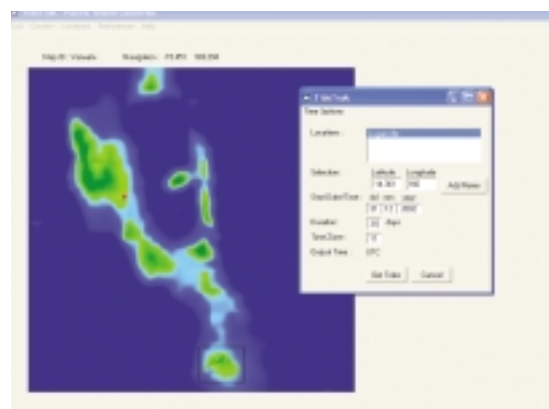
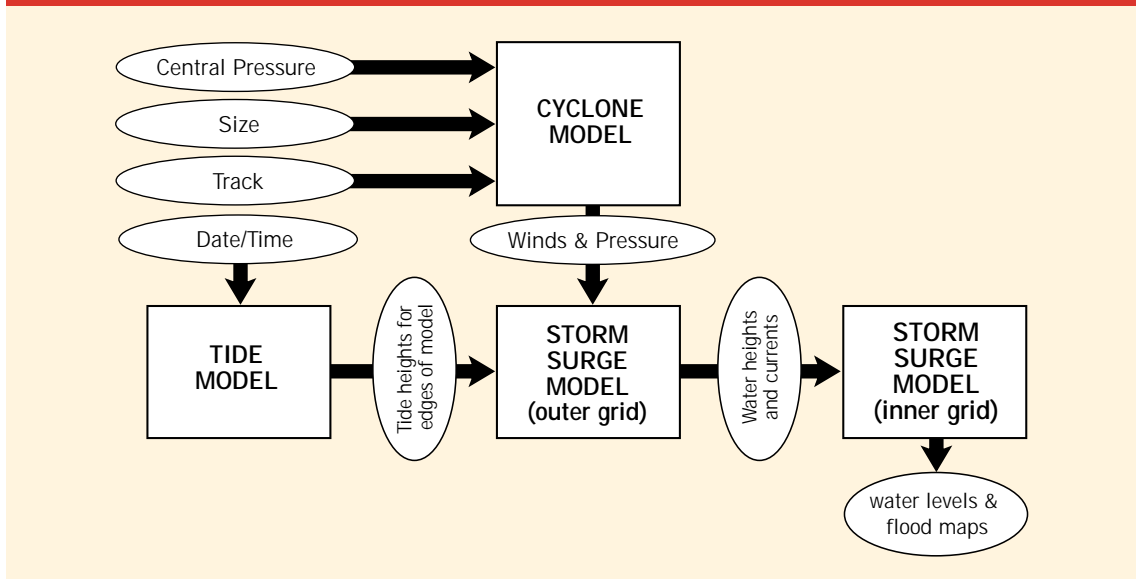


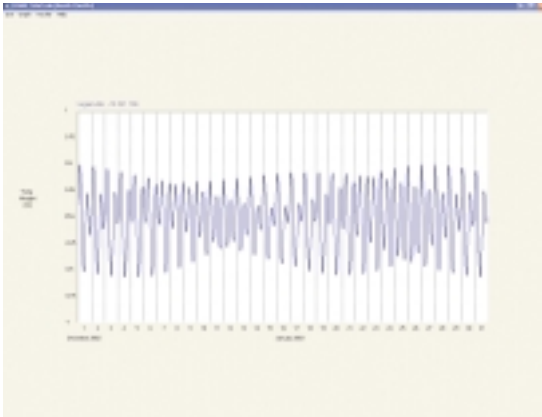
FIGURE 1



Example of the inputs, models and outputs of the StormTrak cyclone wind and storm surge modeling component.

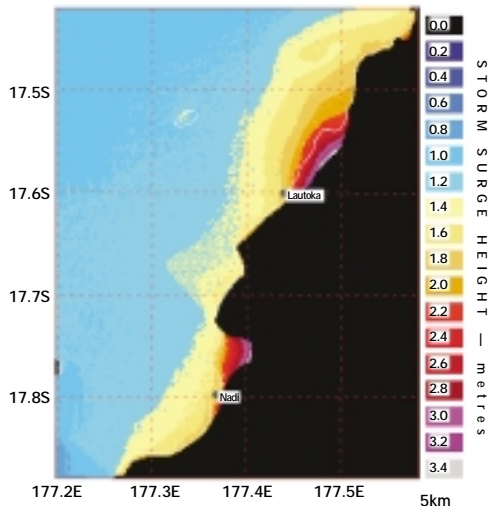
## APPLICATIONS

The model can be used as a forecasting tool. Based on a predicted cyclone track and associated uncertainty, a series of surge-only simulations can be run to determine the worst-case scenario.



TideTrak output for December, 2002 and January 2003 providing greater accuracy for near-shore regions. (Credit: CSIRO)

### Fiji-1 in 1000 year stormtide levels



Example of the spatial maps of sea level for a given return period. Note that overland inundation has occurred to the north of Nadi and Lautoka.

These can be added to a worst-case tide by running the tidal prediction program for a period that spans the cyclone's likely arrival times.

The system can be used as a management tool to explore alternative flood scenarios. For example, how would the extent of inland flooding have differed if the surge had coincided with a stronger than normal spring tide?

Or, if global sea levels increased by half a metre, what would be the extent of flooding of the one-in-100 year storm surge?

## SUMMARY

The process of developing and testing models is, like the program of ocean observations, an essential part of oceanography but the fluid environment is continually presenting new challenges to scientists.

To unravel the complexity of physical and chemical processes taking place in the oceans and coastal waterways of the South Pacific—and to do so efficiently and accurately—scientists require powerful computers to construct predictive models.

Research has generated tremendous advances in the understanding of how scientists can harness knowledge of ocean behaviour and its interaction with the atmosphere and then transfer that knowledge to a climate prediction system.

In the medium and long-term, the combination of continued ocean monitoring and observations, detailed information acquisition and computer modelling will help shape scientific understanding of climate change affecting the nations of the Pacific region.

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