Towards a Coordinated Ocean Storm Surge Climate Project

2nd JCOMM Storm Surge Symposium and 14th Workshop on Wave Hindcasting and Forecasting
Key West, 8-13 November 2015

Kathleen McInnes and Mark Hemer

CSIRO

IPCC 5th Assessment Report Summary

It is *very likely that there will be a significant increase in the occurrence of future sea level extremes by* 2050 and 2100. This increase will primarily be the result of an increase in mean sea level (*high confidence)* (IPCC WG1, Ch 13)

There is *low confidence in region-specific projections of storminess* and associated storm surges.

Low confidence because:

1. Few studies
2. Limited regions studied
3. *Low confidence* in projections of storms

It is likely (medium confidence) that annual mean significant wave heights will increase in the Southern Ocean as a result of enhanced wind speeds.

The Coordinated Ocean Wave Climate Project (COWCLiP)

COWCLiP goals

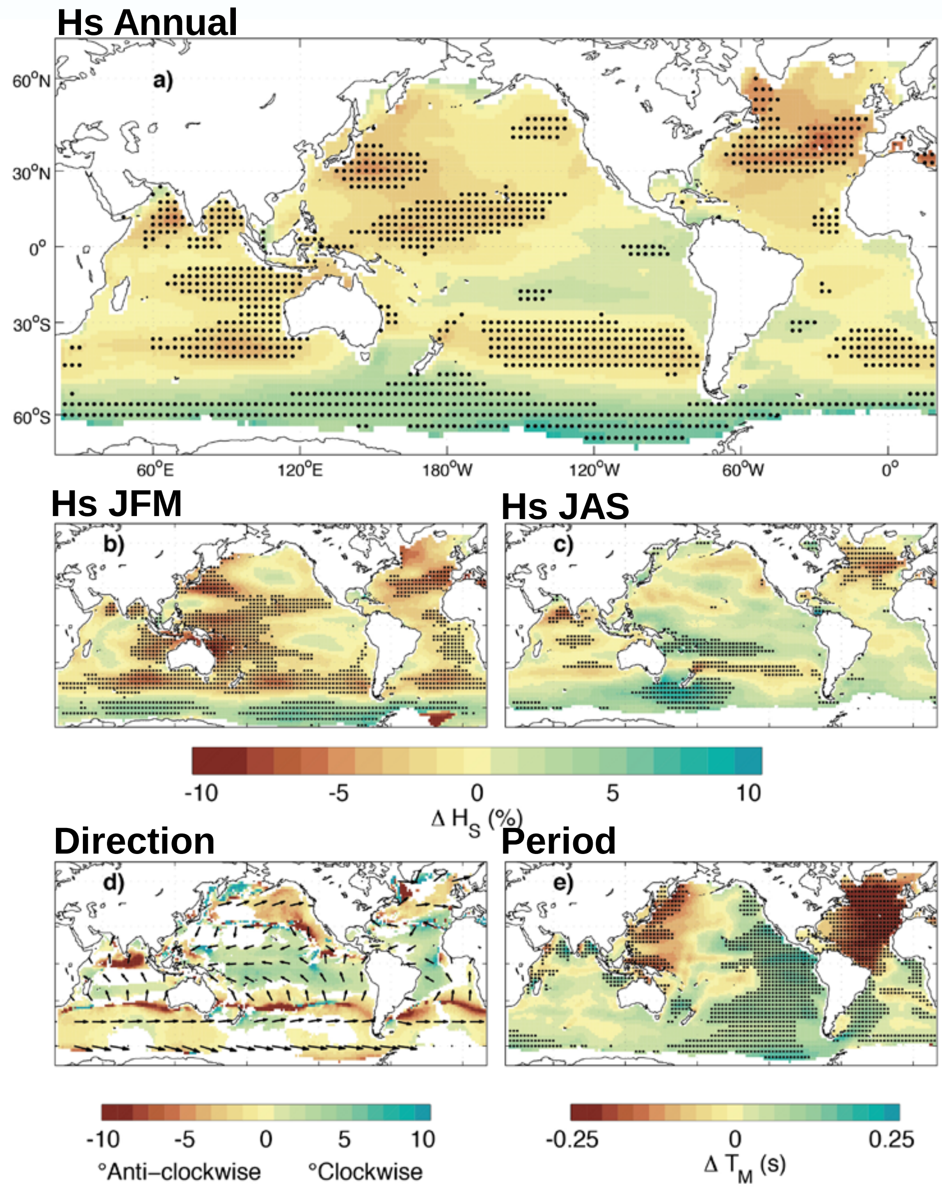
1. Establish a collaborative working group to focus on global wave climate, historical and future variability and change
2. Resolve priority questions to aid climate impacts community
3. Document wave climate projections methods being applied, and summarise existing wave climate projection studies
4. Define a working protocol for wave climate projections:
   a. Agreed standard inter-comparison experiments to obtain adequate coverage of sampling space, to establish variance associated with several layers of uncertainty
   b. Minimum set of analyses/validation requires to foster inter-comparisons (projections and coupled models independently)
5. Develop a technical framework to support the working group
   a. Project data server, QC, standard variables, etc

21st Century Global Wave Projections

Phase 1 (CMIP-3) inter-comparison provided first community projection of global wave climate change (~2075-2100 compared with ~1980-2009).

Phase 2 (CMIP-5) experiment is designed to better understand uncertainty in projected wave conditions.

.



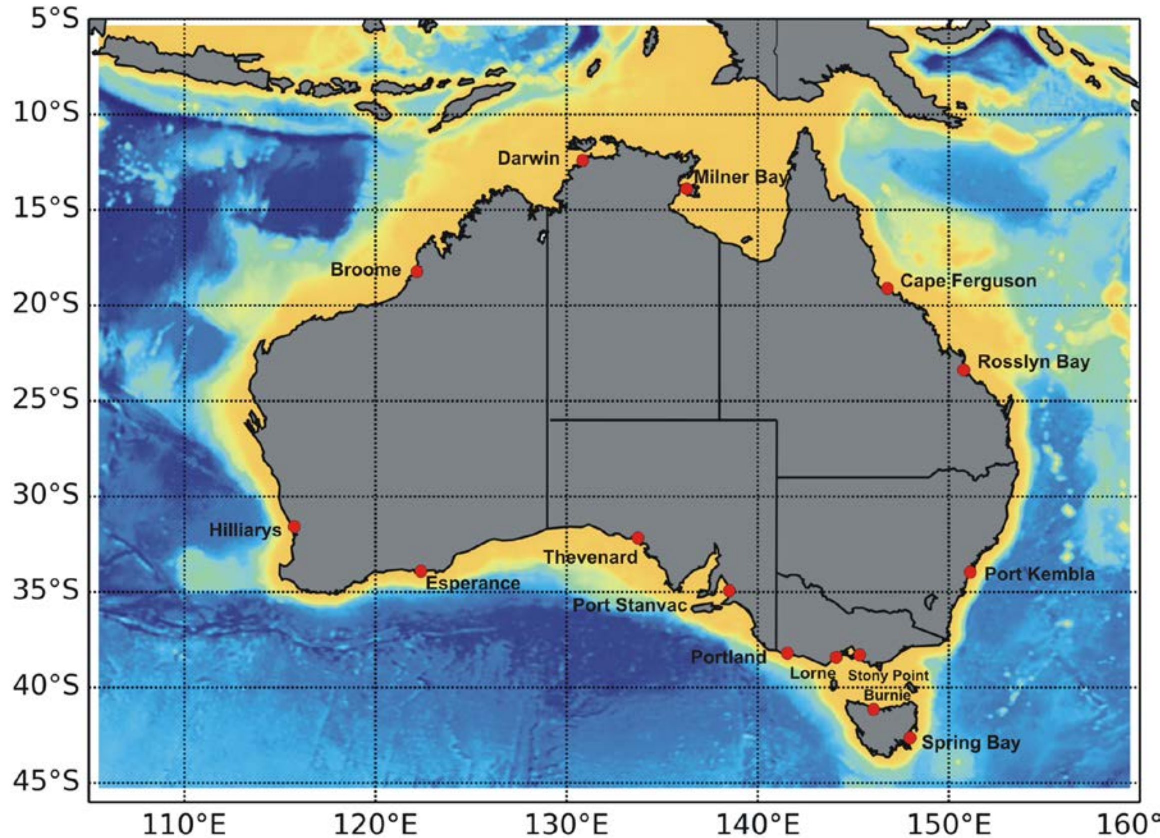
Church et al. (2013) IPCC WGI AR5. Figure 13-26

So what about a Coordinated Ocean Storm Surge Climate Project (COSSCLIP)?

Storm surges are a coastal problem and manifest on the continental shelf.

Ocean Model

- ROMS (Shchepetkin et al., 2006)
- Barotropic model setup, 5km grid
- (865x1025)
- GEBCO bathymetry (1min)
- Tidal forcing using TPXO7.2, 8 tidal constituents: M2, S2, N2, K2, K1, O1, P1, Q1
- CFSR wind and pressure forcing (hourly, 0.33 degree)



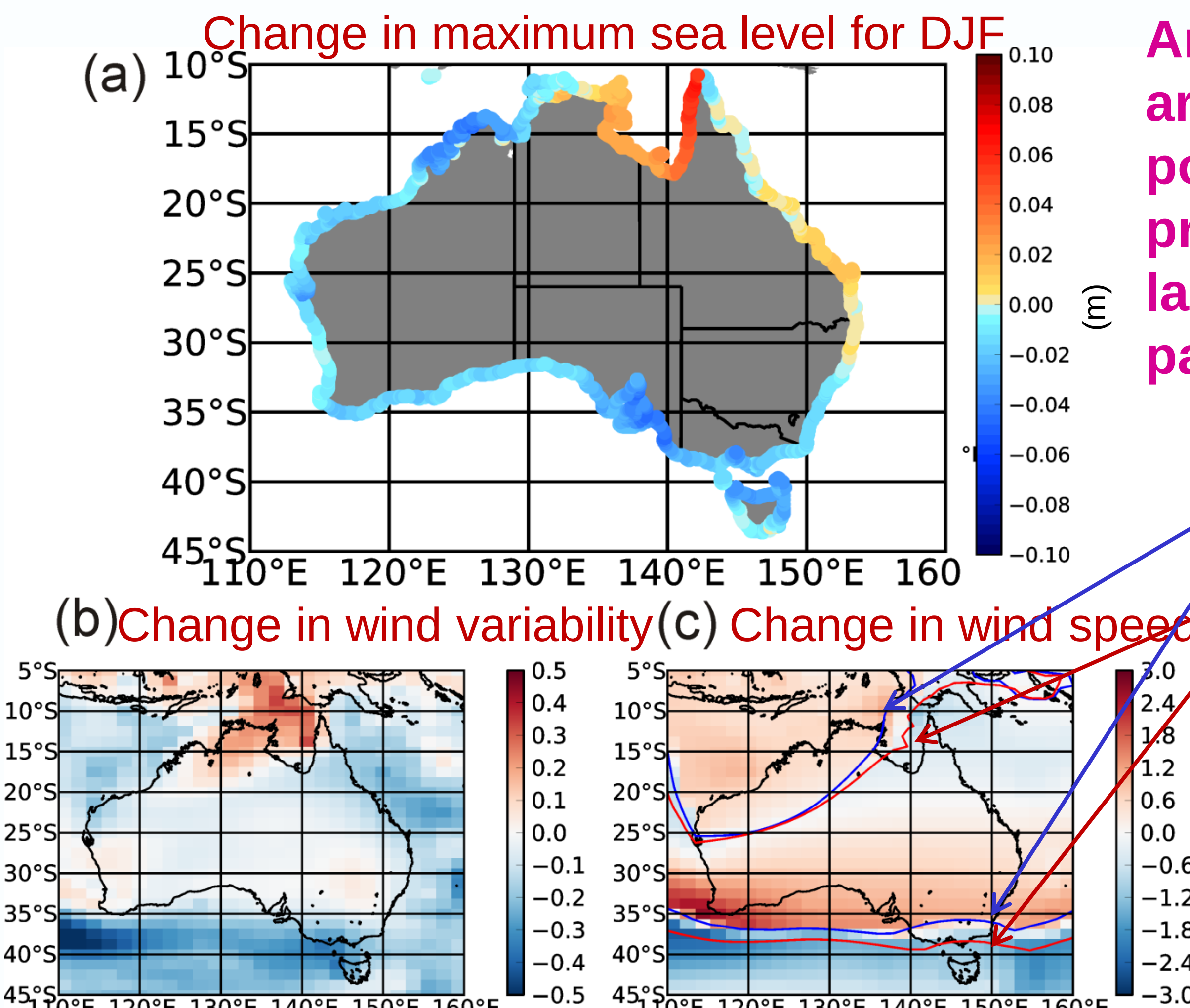
Experiments I-III enable us to investigate tide-surge interaction

Run	Forcing	Years
I	CFSR	1981-2012
II	CFSR+TIDES	1981-2012
III	TIDES	1981-2012
IV	RESIDUALS (as II-III)	1981-2012

Climate change experiments using CMIP5 model data (RCP8.5)

Run	Atmospheric Forcing	Years
I	ACCESS1.0	1980-1999, 2080-2099
II	HadGEM-ES	1980-1999,2080-2099
III	INMCM4	1980-1999,2080-2099
IV	CNRMCM5	1980-1999,2080-2099

Hydrodynamic simulations under future climate conditions highlight potential hotspots for future change



Are there other locations around the globe that are potentially sensitive to projected changes in large scale weather patterns?

Zonal wind zero contour (1980-1999)

Zonal wind zero contour (2080-2099)

In southern Australia, southward movement of STR may change dominant littoral transport from westerly to easterly in DJF

Recent model developments supporting global scale storm surge modelling

Australasian Coasts & Ports Conference 2015
15 - 18 September 2015, Auckland, New Zealand

Verlaan. M et al.
Global Storm Surge Forecasting and Information System

GLOSSIS: Global Storm Surge Forecasting and Information System

M. Verlaan[1,2], S. De Kleermaeker[1] and L. Buckman[1]
[1] Deltares, Delft, Netherlands; martin.verlaan@deltares.nl [2] TU Delft

~ 5 km resolution on the continental shelf

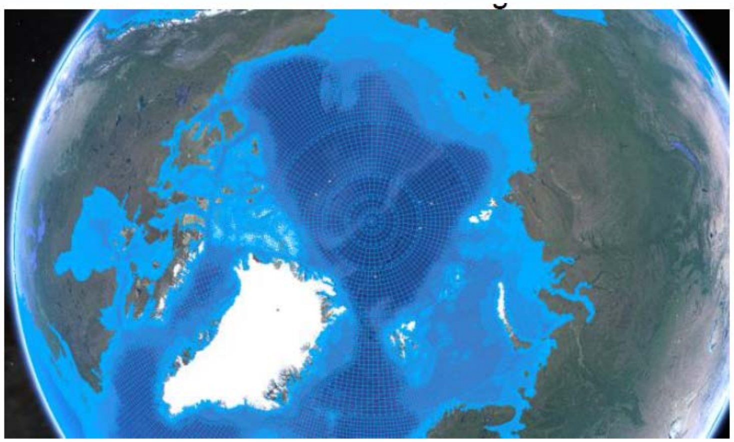


Figure 1 Thinning of the D3D-FM grid at high latitudes; the number of cells are halved at higher latitudes to maintain a similar resolution at all lattitudes.

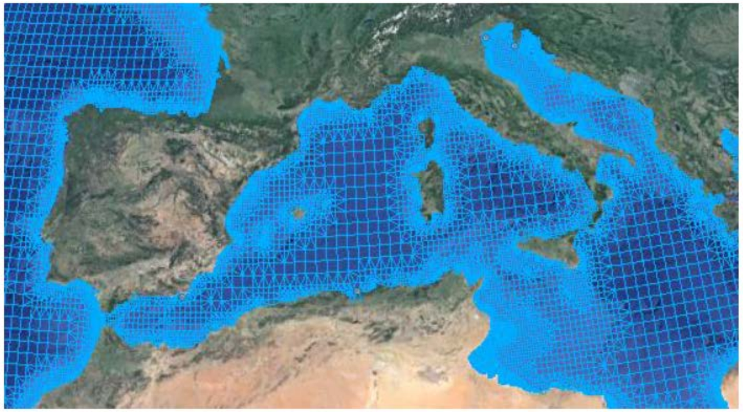


Figure 2 Refinement of the D3D-FM grid in shallow areas of the Mediterranean; the resolution is based on the Courant number; this improves the result in the areas of interest and areas with high dissipation

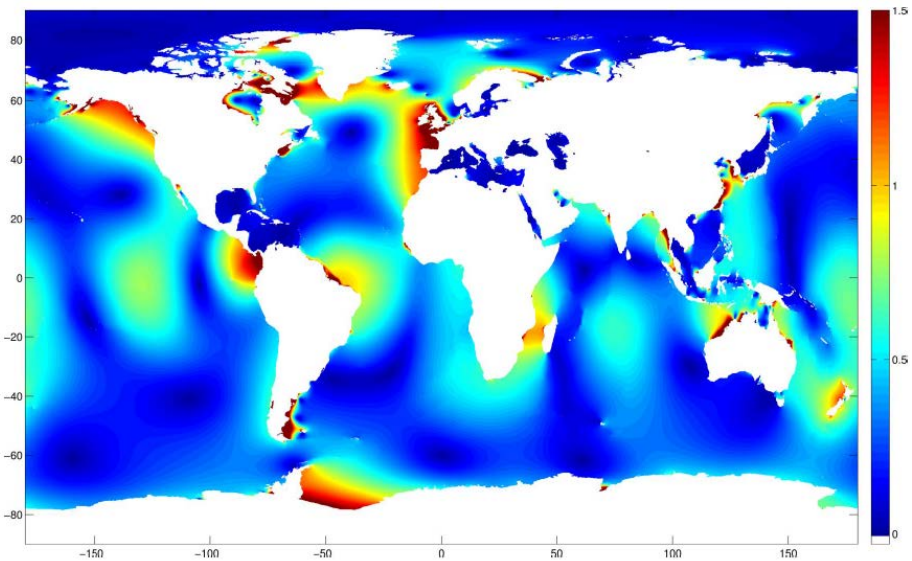
Recent Model Developments support global scale storm surge modelling

Contents lists available at SciVerse ScienceDirect
Continental Shelf Research
journal homepage: www.elsevier.com/locate/csr

Research papers

The impact of future sea-level rise on the European Shelf tides

M.D. Pickering [a,*], N.C. Wells [a], K.J. Horsburgh [b], J.A.M. Green [c]



Source: Pickering (2014)

Tidal model of Egbert et al (2004)

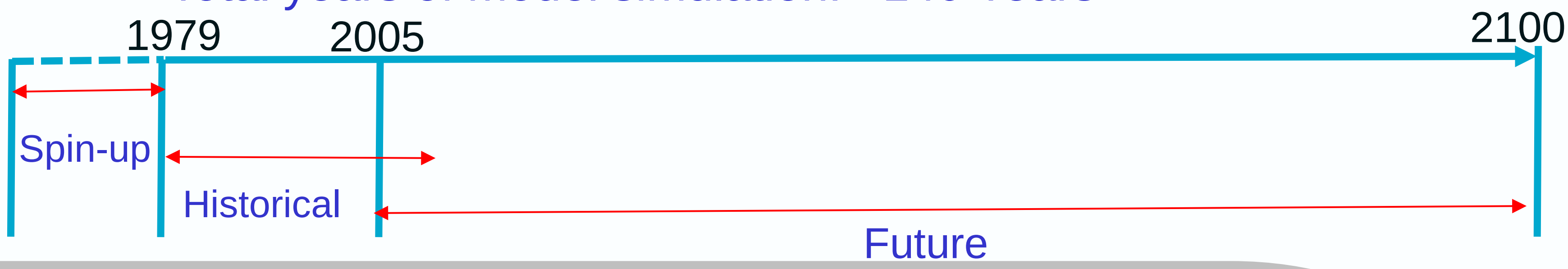
~14 x 14km at its coarsest equatorial resolution

Near-global Eddy-resolving Ocean Model – OFAM3

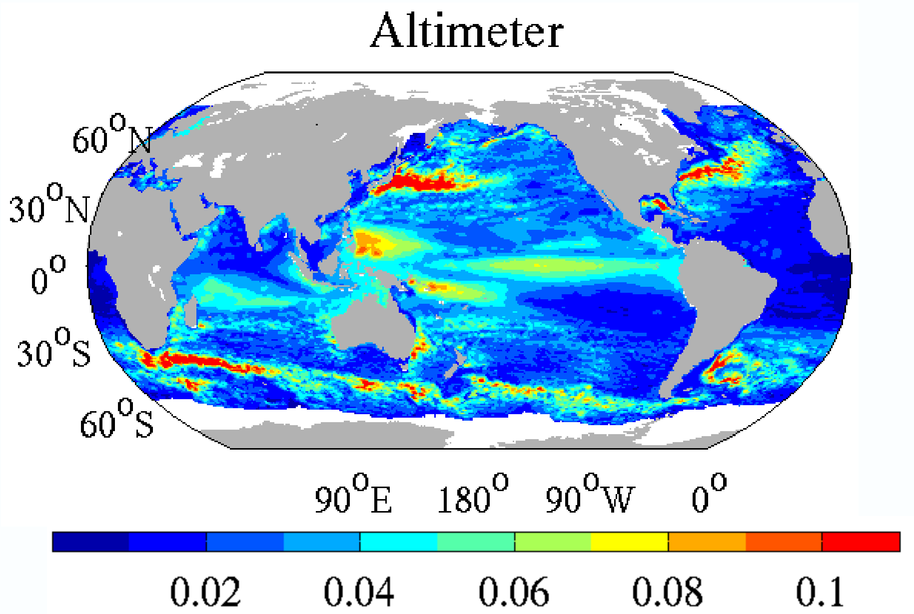
(developed for high res. sea level rise simulations by Xuebin Zhang)

- Ocean Forecasting Australia Model – version 3 (OFAM3)
- Based on GFDL MOM4p1
- Near-global domain, 75ºS – 75ºN, 0.1ºx0.1º resolution
- 51 vertical layers, 5 m resolution down to 40 m, then 10 m resolution down to 200 m.
- JRA-55 provides current-day mean state (F_{mean}) + (repeating) high-frequency variability (F_{HF})
- long-term climate change component (ΔF_{mean}) from 17 climate model(s), i.e. $F = F_{mean} + F_{HF} + \Delta F_{mean}$

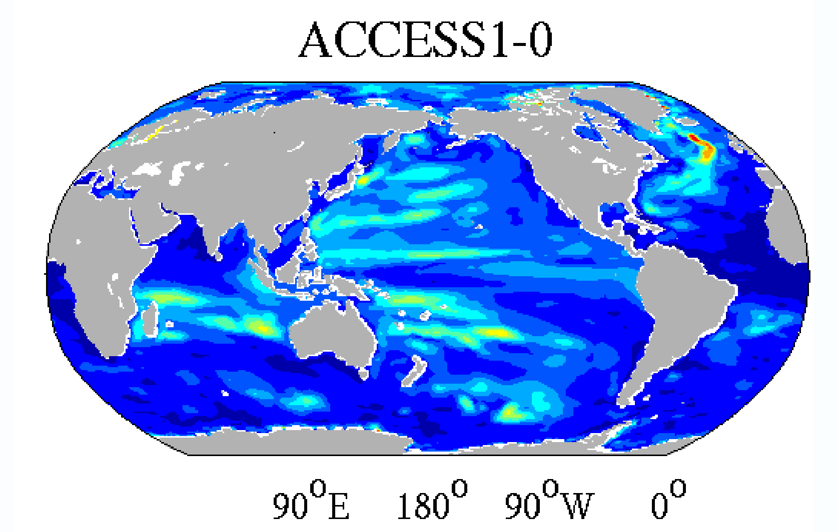
Total years of model simulation: ~140 Years



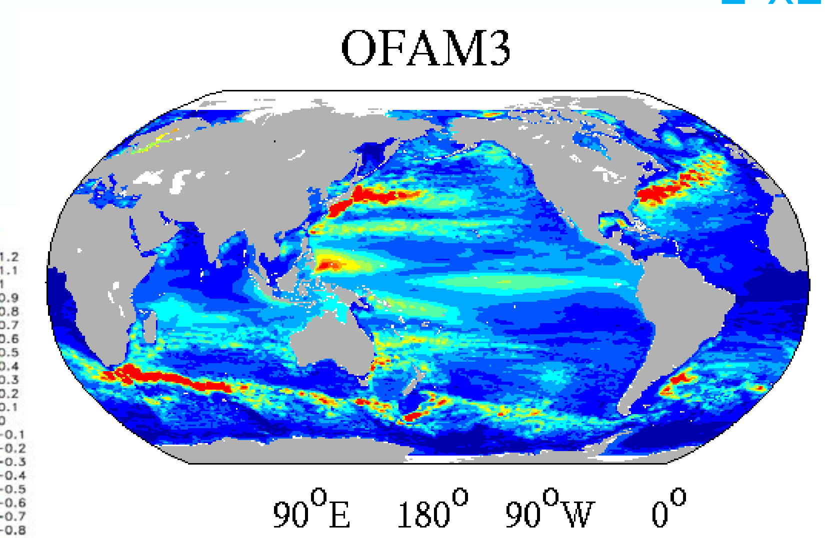
Standard deviation of annual sea level (m)



(AVISO 0.25°x0.25°)

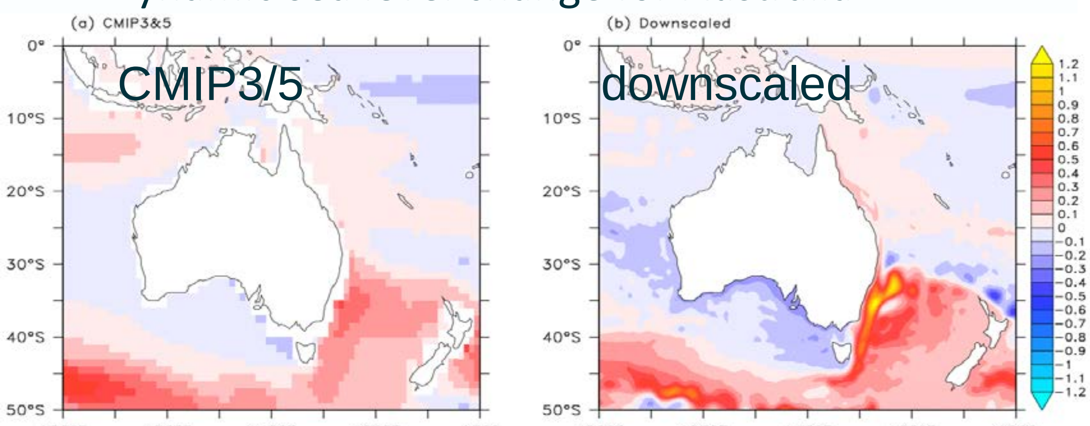


1°x1°



0.1°x0.1°

Dynamic sea level change for Australia



Representing changes to tropical cyclones in hydrodynamic downscaling studies

1. Mousavi et al., (2011)

   Used relationship between SST and TC intensity to relate GCM changes in SST to storm surge change (Corpus Christie, Texas)

2. Lin et al. (2012)

   Stochastic cyclone approach to scale up the number of cyclones in GCMs (New York)

3. McInnes et al., (2014, 2015)

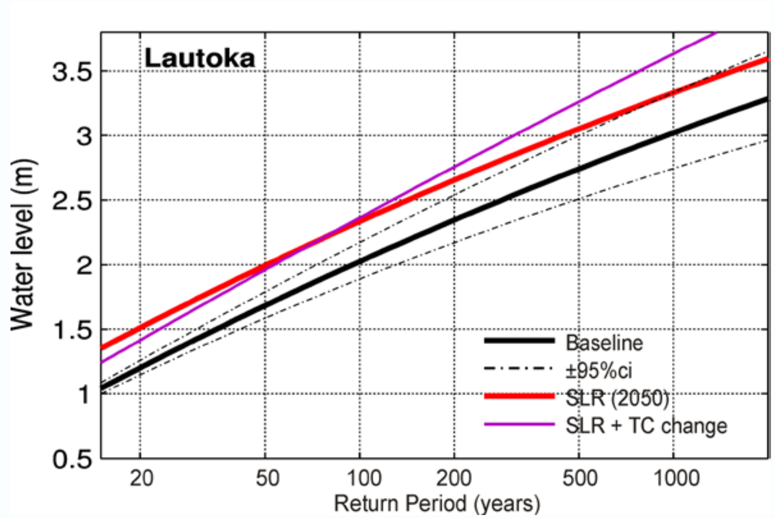
   Perturb present day extreme value parameters describing cyclone intensity and frequency to represent future conditions in stochastic cyclone modelling (Fiji and Samoa)

4. Verlaans (GLOSSIS, 2015)

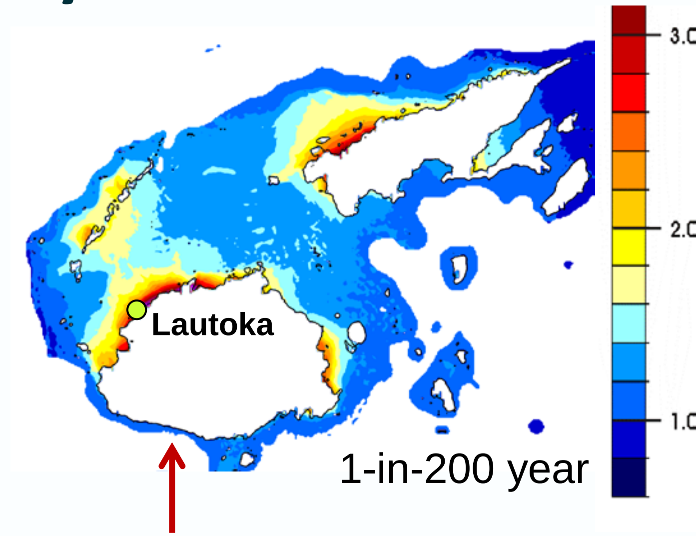
   Wind Enhancement Scheme enables perturbation of unstructured grid to accommodate a Holland cyclone vortex

Storm tides evaluated from stochastic cyclones

Fiji:
Storm tides are largest on northwest coastlines of the Fiji Islands

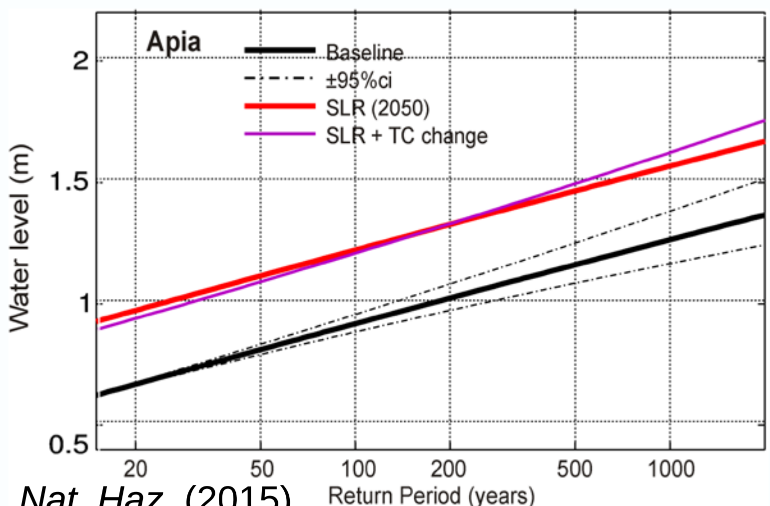


Source: McInnes et al, *Glob. Planet. Change.* (2014)

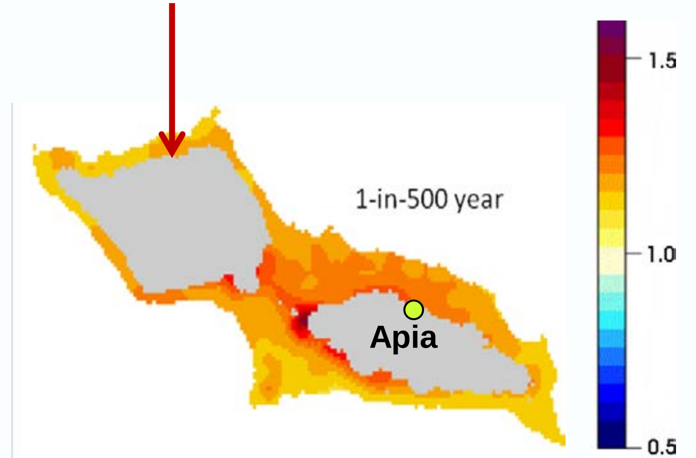


But waves are important, -particularly along narrow, steep-shelved islands!

Samoa:
Storm tides are more uniform around the coastlines of the Samoan Islands



Source: McInnes et al, *Nat. Haz.* (2015)



Coastal Impacts from Waves

Wave swell from the southern ocean hits south coast of Viti-Levu in Fiji


Coast swamped

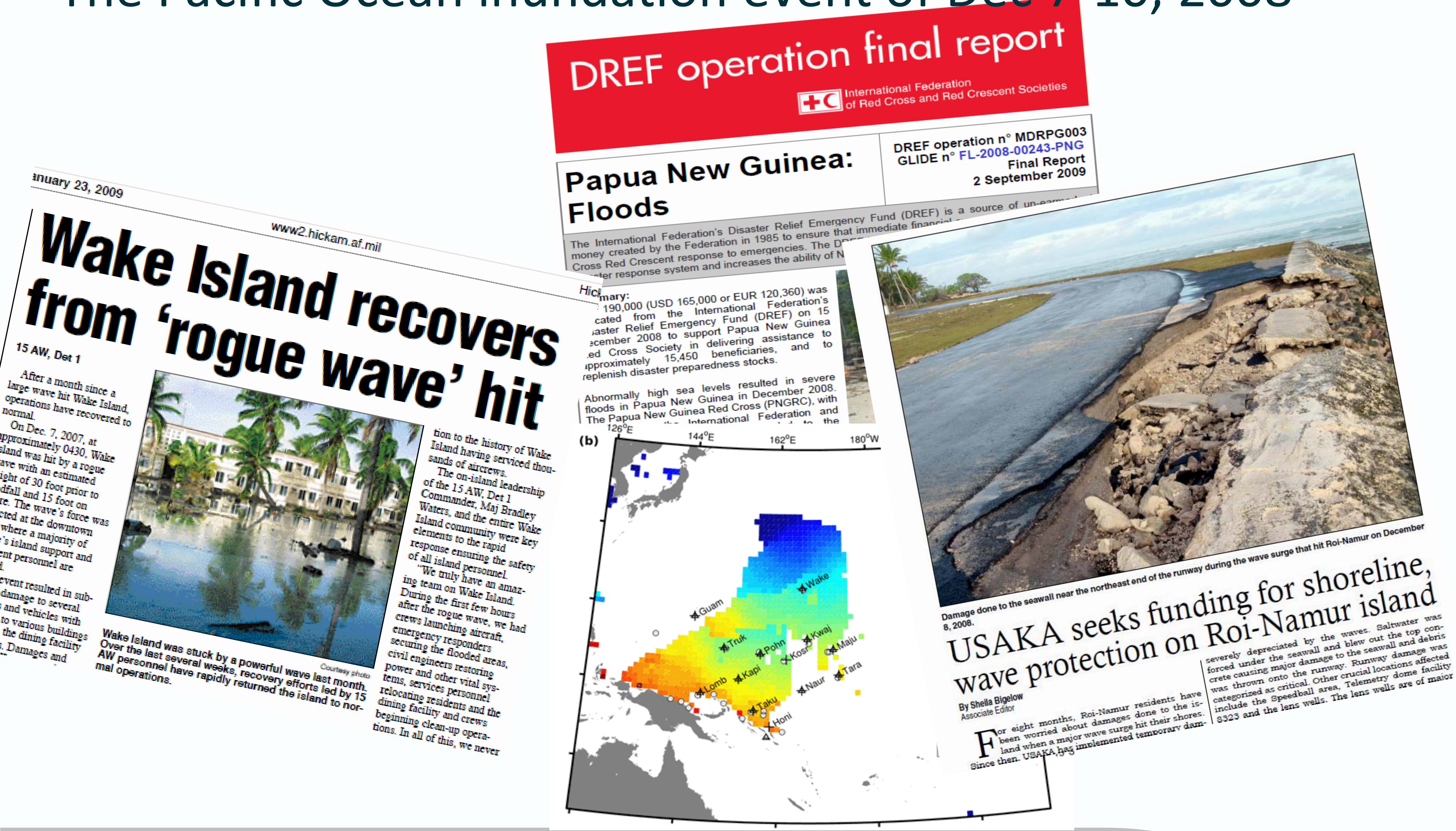
TIDAL SURGE Giant waves flood hotel rooms

Fiji Times,May 21, 2011

Photos courtesy of Jens Kruger – SPC SOPAC

Example: Wave flooding in small island nations

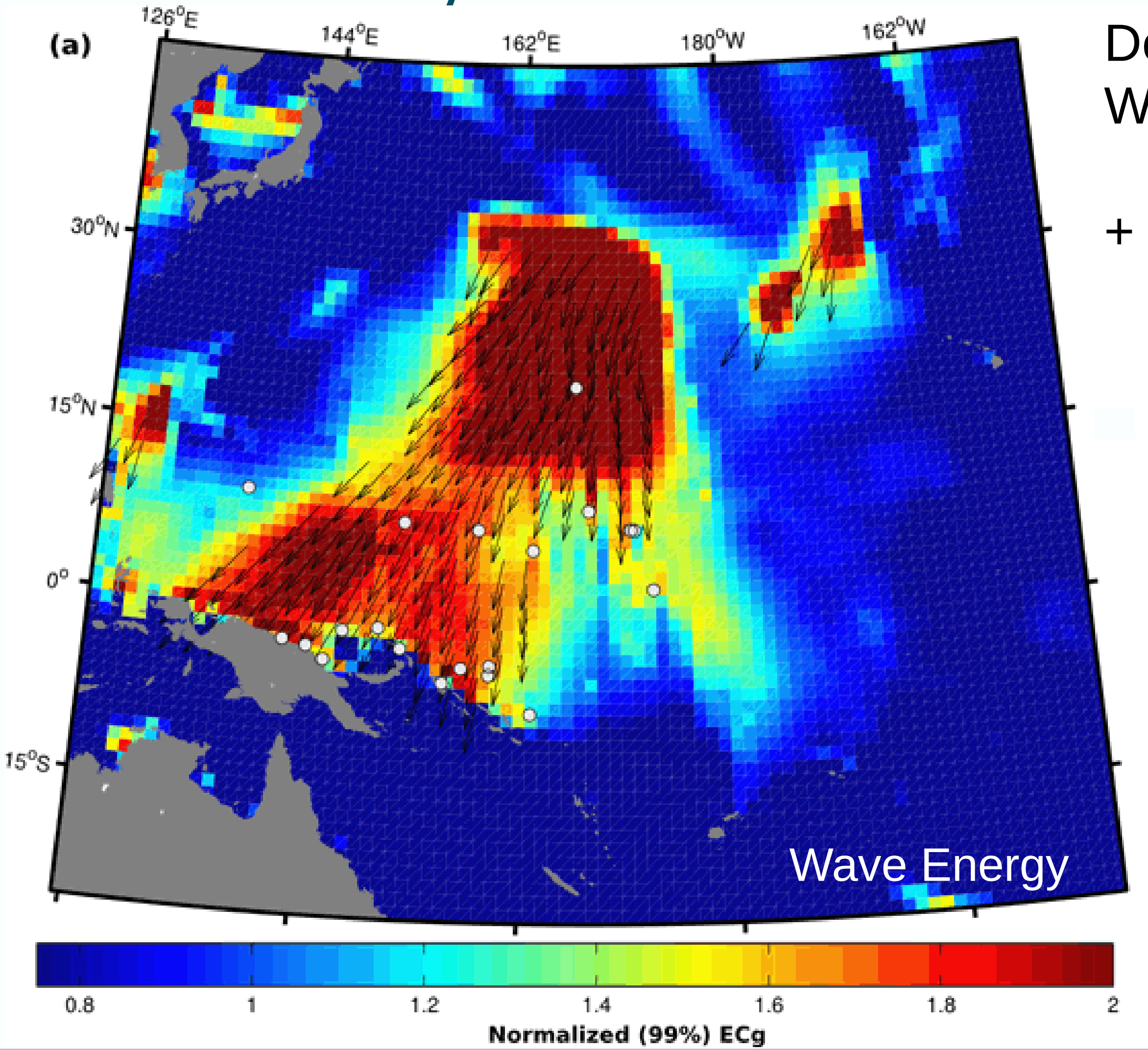
The Pacific Ocean inundation event of Dec 7-10, 2008



Source: Hoeke et al, 2013: Widespread inundation of Pacific islands triggered by distant-source wind-waves. Global Planetary Change 108: 128–138

A documentary crew making ‘There once was an island’ captured the impact of these waves on Taku’u Atoll

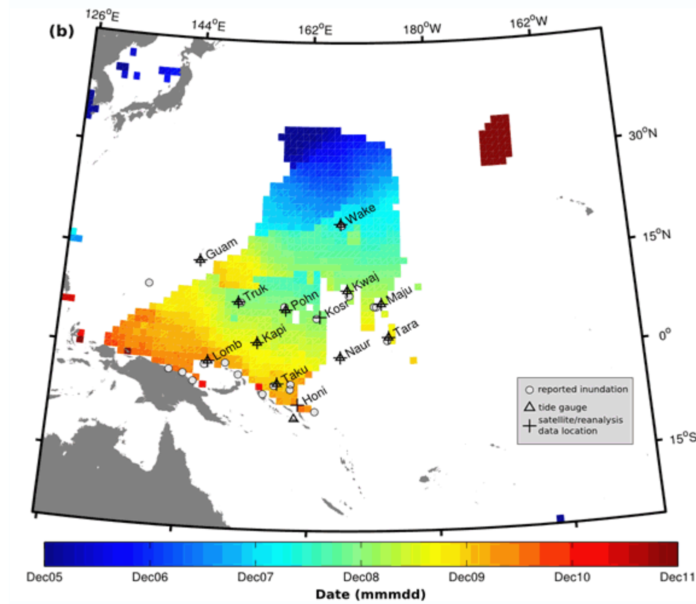
The cause was swell waves from a north Pacific storm ~4000 km away



December 2008

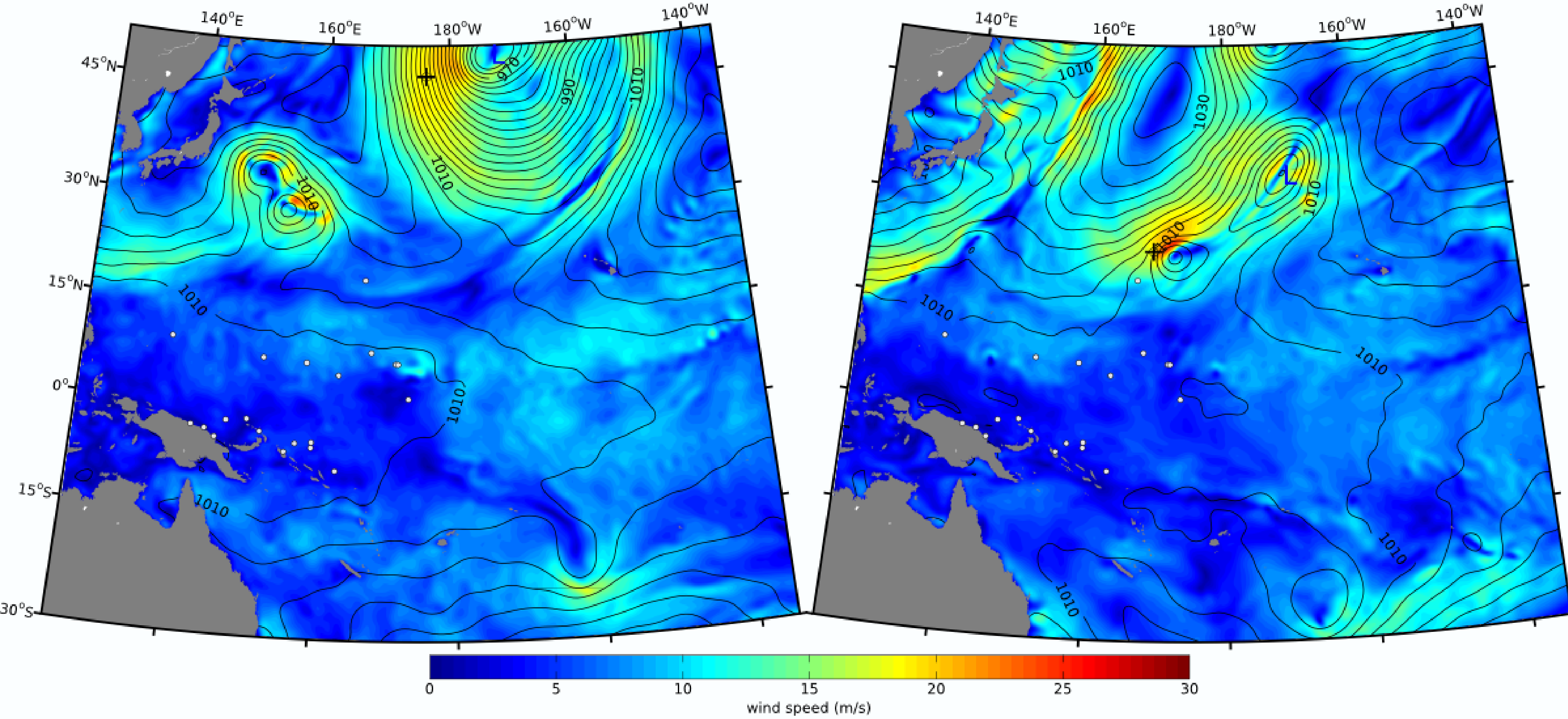
Wave energy about twice 99th percentile levels

+ positive regional sea level anomaly = widespread inundation



Source: Hoeke et al, 2013: Widespread inundation of Pacific islands triggered by distant-source wind-waves. Global Planetary Change 108: 128–138

The cause was swell waves from a north Pacific storm ~4000 km away



1800 3 December 2008

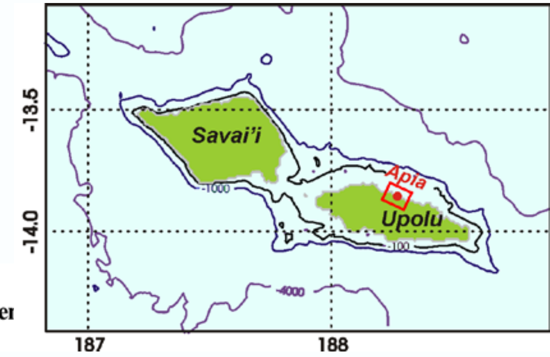
1800 6 December 2008

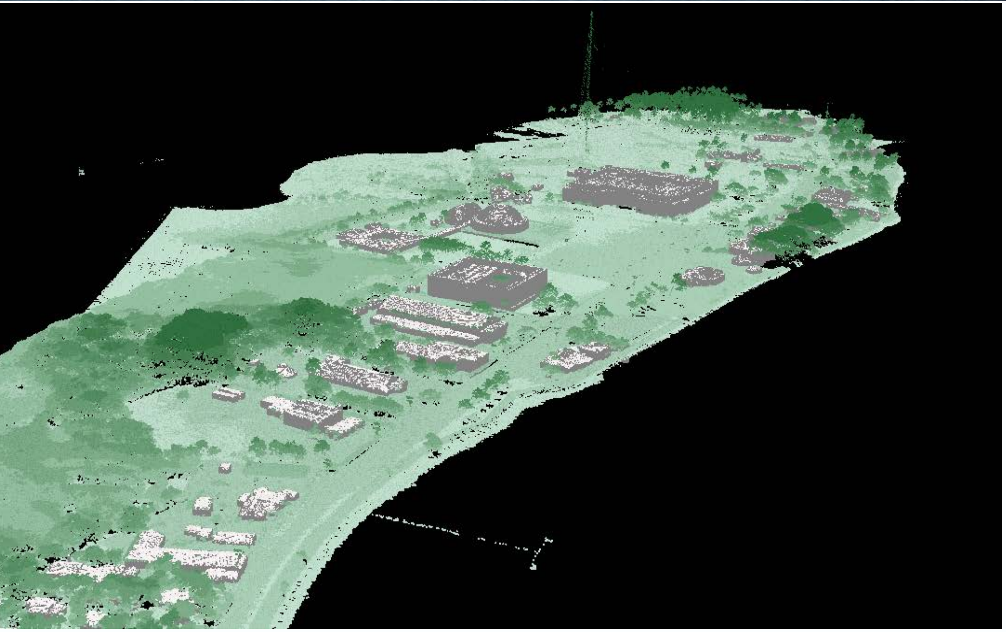
Source: Hoeke et al, 2013: Widespread inundation of Pacific islands triggered by distant-source wind-waves. Global Planetary Change 108: 128–138

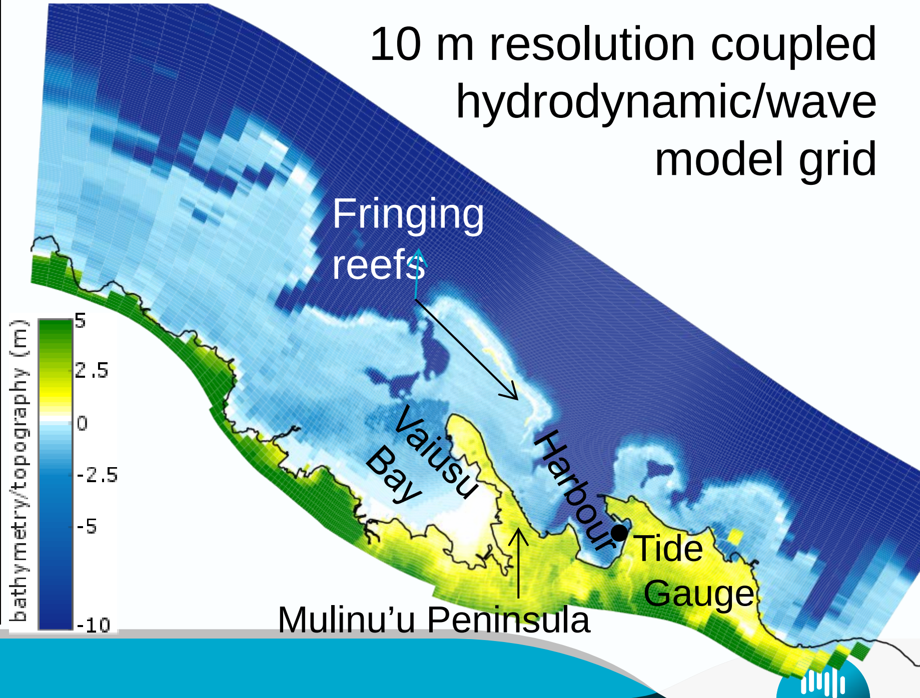
Contributions to Extreme Sea Levels at a Tropical High Island: A Stochastic Cyclone Simulation Study for Apia, Samoa

Australian Aid

Australian Government

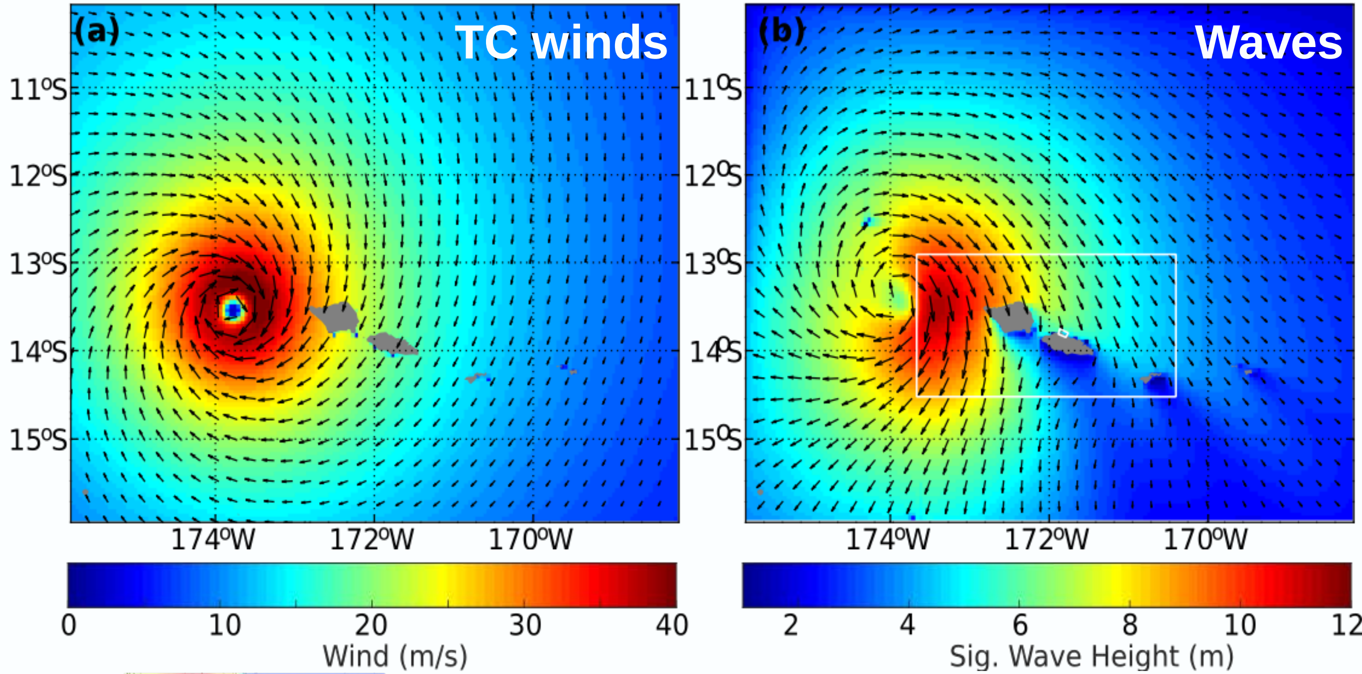


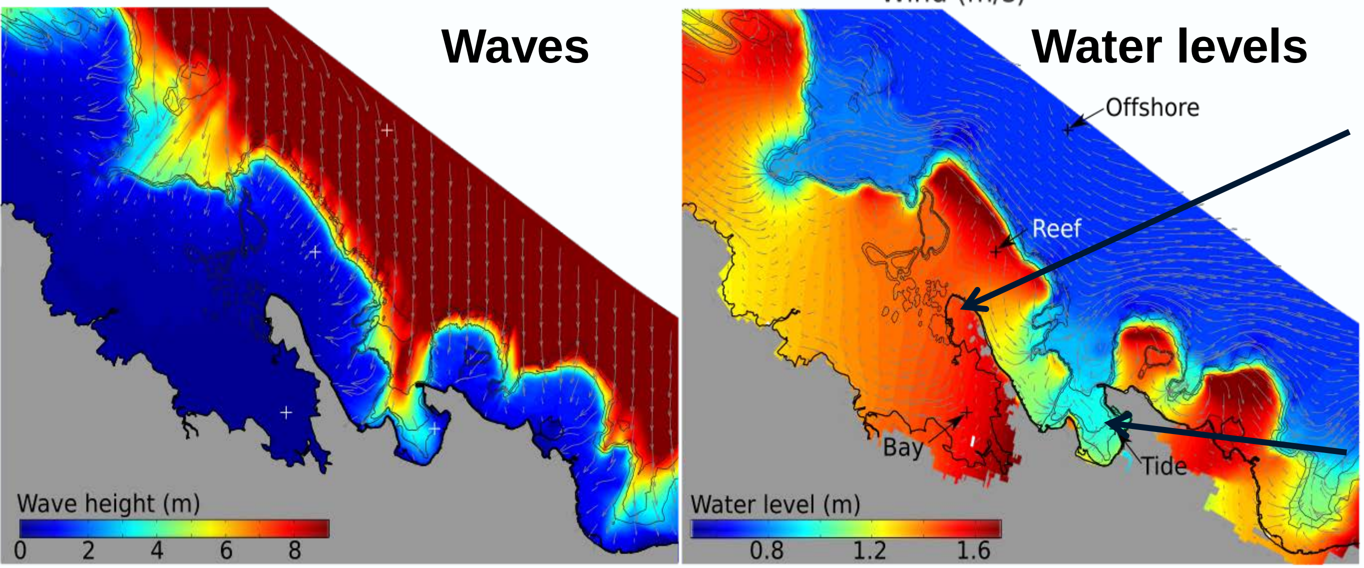




Source: Hoeke et al, 2015: JMSE special issue

Example for TC Ofa





Water levels inshore of reef up to 1 m higher than tide gauge location

Water levels at tide gauge Similar to the 'stormtide only' i.e. waves don't increase sea levels through setup

Summary

1. The lack of consistent global storm surge/storm tide **analyses** and **projections** hinders coastal adaptation efforts in many places (lack of data or incomplete data)
2. Numerical and computational barriers have reduced significantly in recent years – indicating that global modelling efforts are now feasible
3. Many challenges remain (e.g. representing small scale weather systems, quantifying uncertainty, resolving small islands, incorporating wave effects) – but a global community of researchers could collectively focus on solutions to these problems
4. Benefits include highlighting hotspot areas for future change where higher resolution studies should be prioritised
5. Together with COWCLiP, the two efforts provide consistent data (hydrodynamic and wave projections) relevant for assessing coastal extremes and physical coastal impacts such as erosion and inundation

Thank you

For more information
kathleen.mcinnes@csiro.au

http://www.cmar.csiro.au/sealevel/