



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

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)

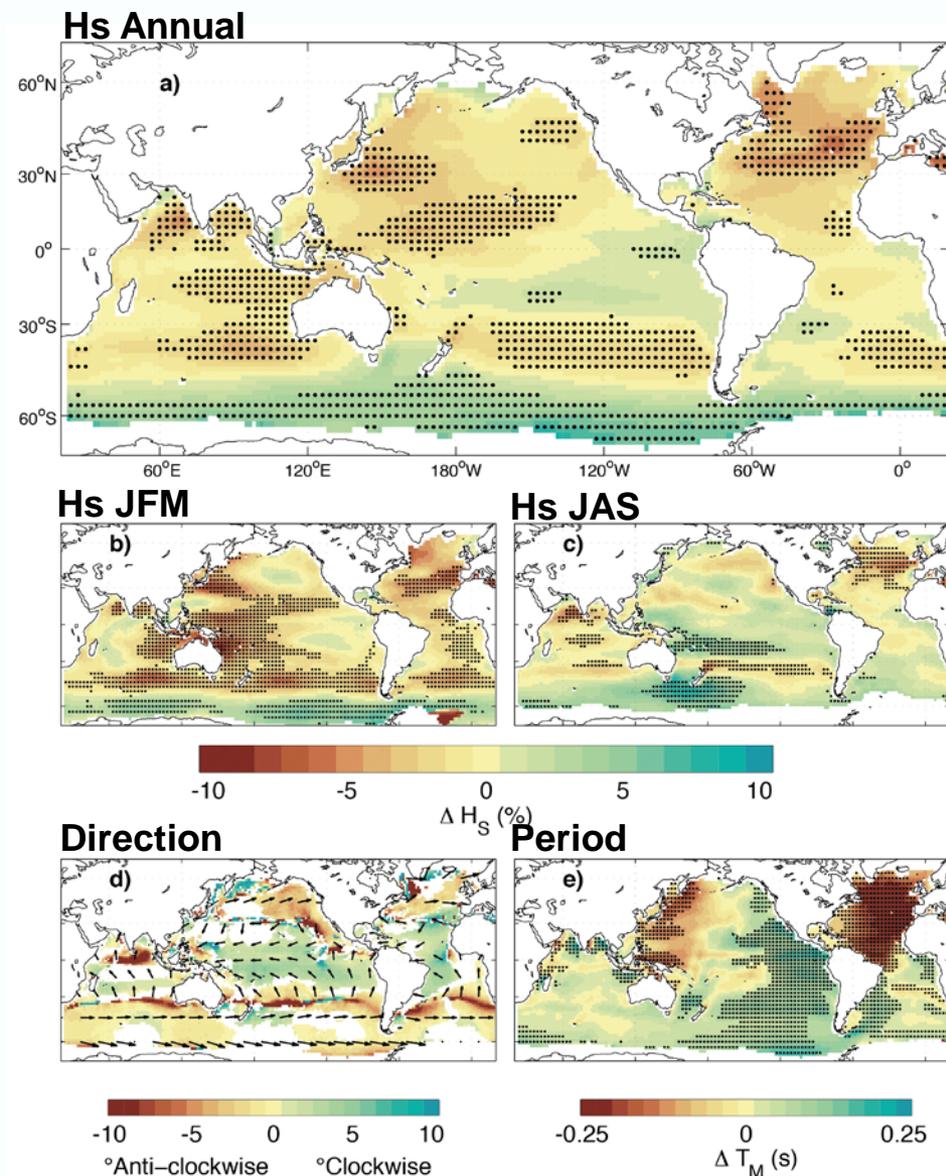
COWCLiP goals

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

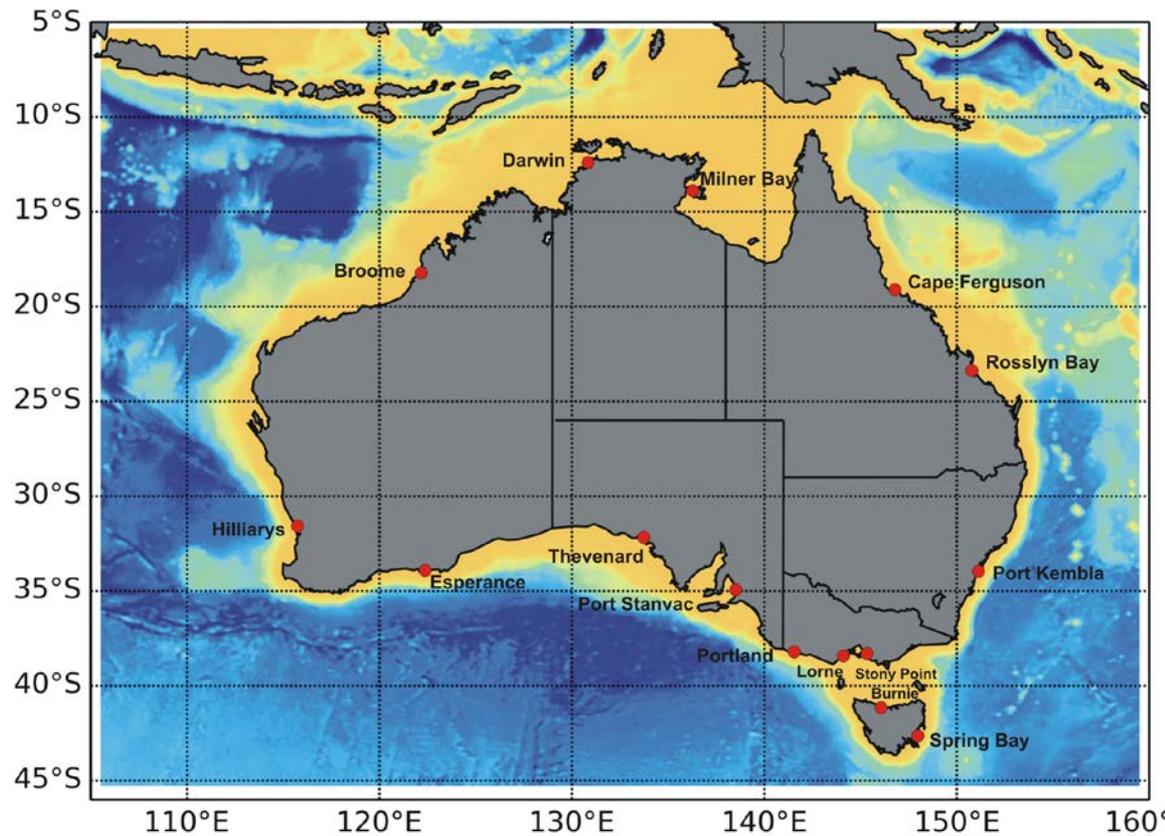
So what about a Coordinated Ocean Storm Surge Climate Project (COSSCLIP)?

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)



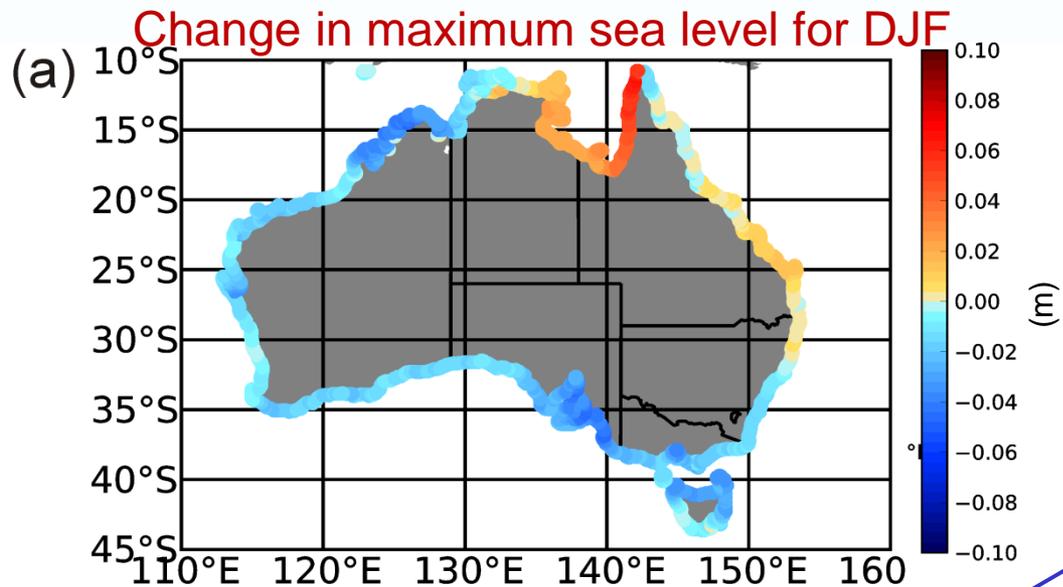
Experiments I-III enable us to investigate tide-surge interaction

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

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

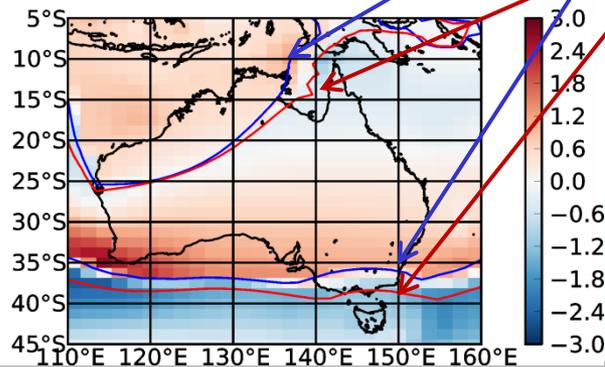
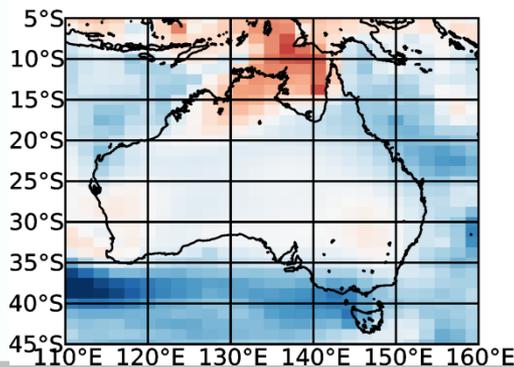
Run	Atmospheric Forcing	Years
I	ACCESS1.0	1980-1999, 2080-2099
II	HadGEM-ES	1980-1999, 2080-2099
III	INMCM4	1980-1999, 2080-2099
IV	CNRMCM5	1980-1999, 2080-2099

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?

(b) Change in wind variability (c) Change in wind speed



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 Kleermaeker¹ and L. Buckman¹
¹ Deltares, Delft, Netherlands; martin.verlaan@deltares.nl ² TU Delft

~ 5 km resolution on the continental shelf

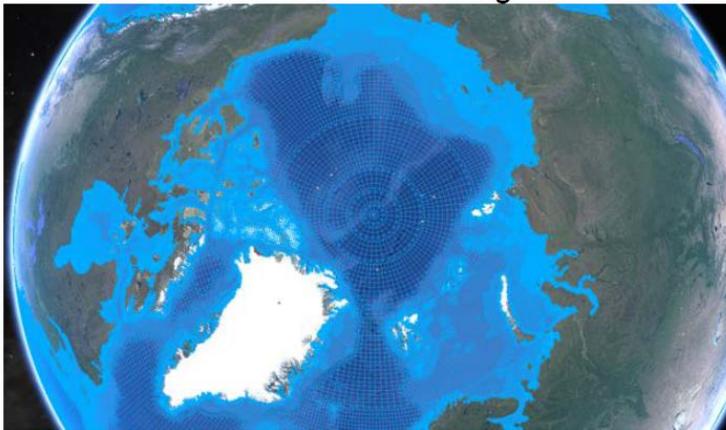


Figure 1 Thinning of the D3D-FM grid at high latitudes; the number of cells are halved at higher latitudes to maintain a similar resolution at all latitudes.

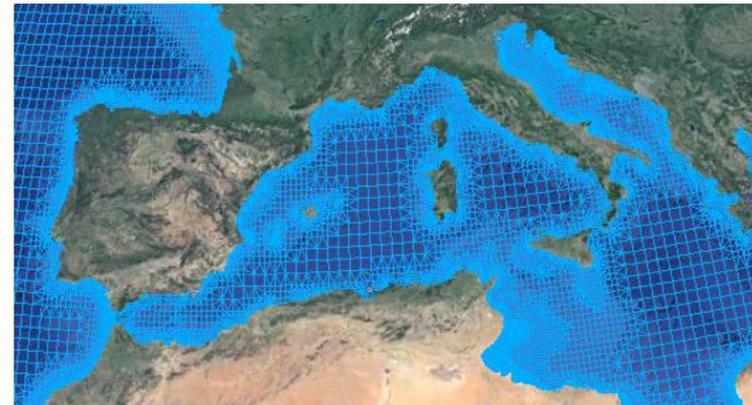


Figure 2 Refinement of the D3D-FM grid in shallow areas of the Mediterranean; the resolution is based on the Courant number; this improves the result in the areas of interest and areas with high dissipation

Recent Model Developments support global scale storm surge modelling



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Continental Shelf Research

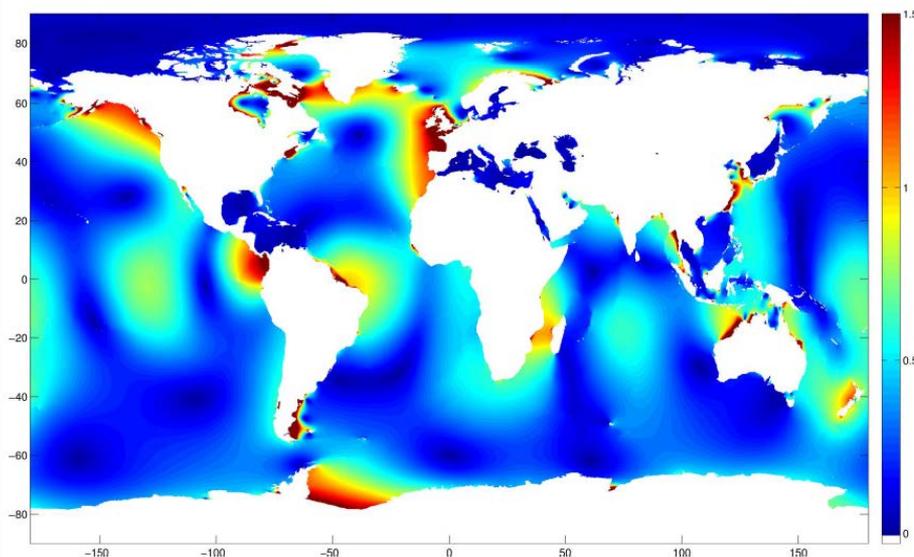
journal homepage: www.elsevier.com/locate/csr



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)

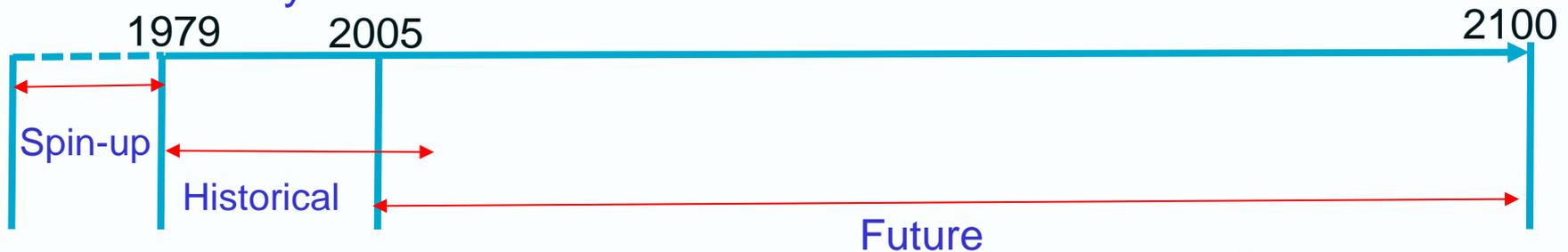
~14 x 14km at its coarsest equatorial resolution

Near-global Eddy-resolving Ocean Model – OFAM3

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

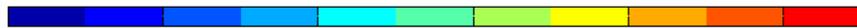
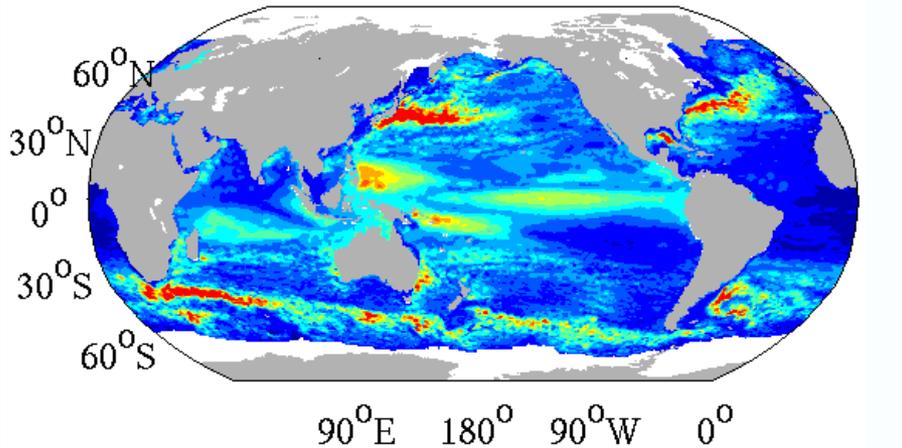
- Ocean Forecasting Australia Model – version 3 (OFAM3)
- Based on GFDL MOM4p1
- Near-global domain, 75°S – 75°N, 0.1°x0.1° resolution
- 51 vertical layers, 5 m resolution down to 40 m, then 10 m resolution down to 200 m.
- JRA-55 provides current-day mean state (F_{mean}) + (repeating) high-frequency variability (F_{HF})
- long-term climate change component (ΔF_{mean}) from 17 climate model(s), i.e.
$$F = F_{\text{mean}} + F_{\text{HF}} + \Delta F_{\text{mean}}$$

Total years of model simulation: ~140 Years



Standard deviation of annual sea level (m)

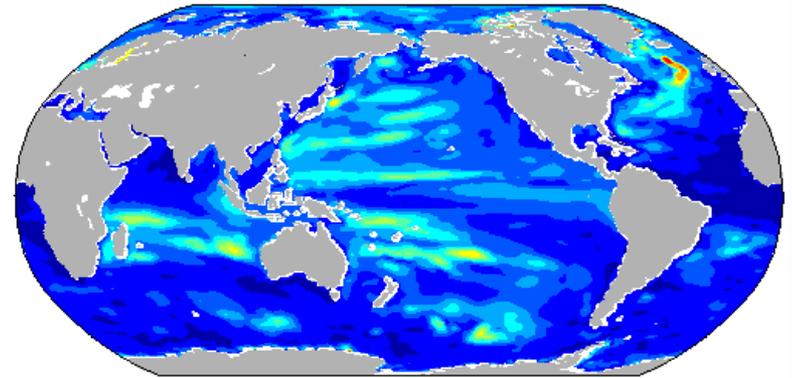
Altimeter



0.02 0.04 0.06 0.08 0.1

(AVISO 0.25°x0.25°)

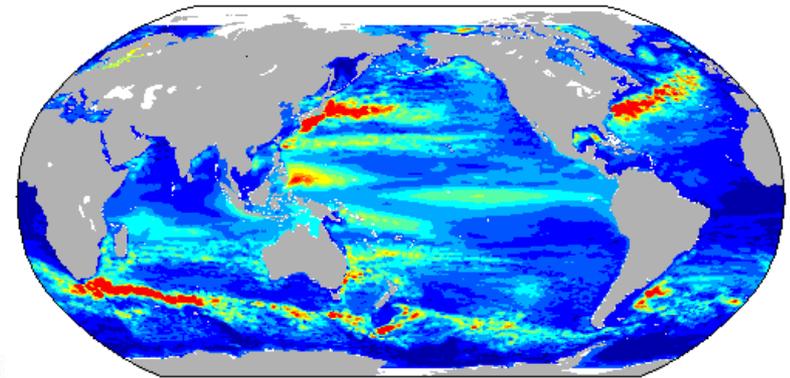
ACCESS1-0



90°E 180° 90°W 0°

1°x1°

OFAM3

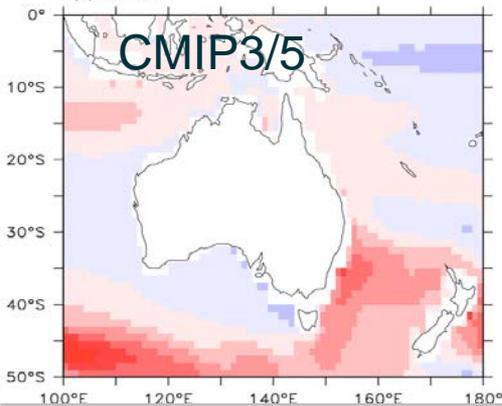


90°E 180° 90°W 0°

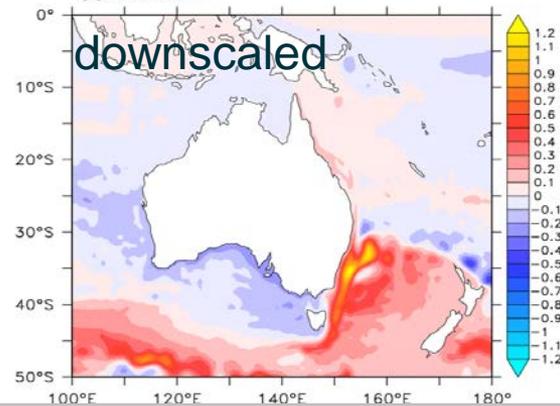
0.1°x0.1°

Dynamic sea level change for Australia

(a) CMIP3&5



(b) Downscaled



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)

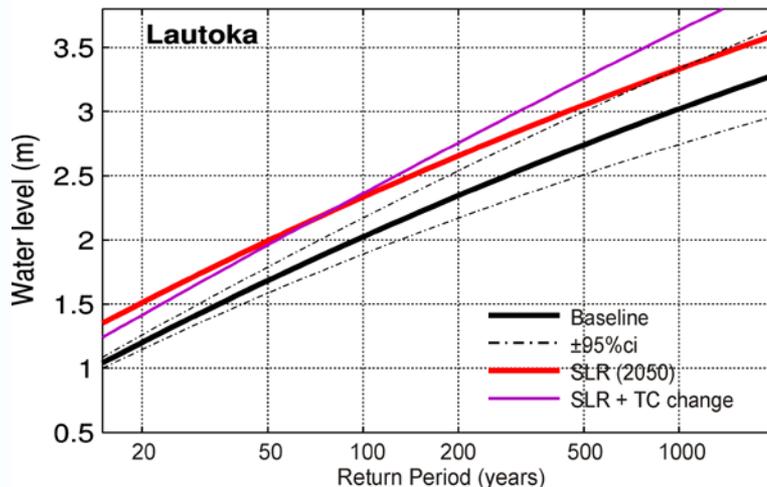
4. Verlaans (GLOSSIS, 2015)

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

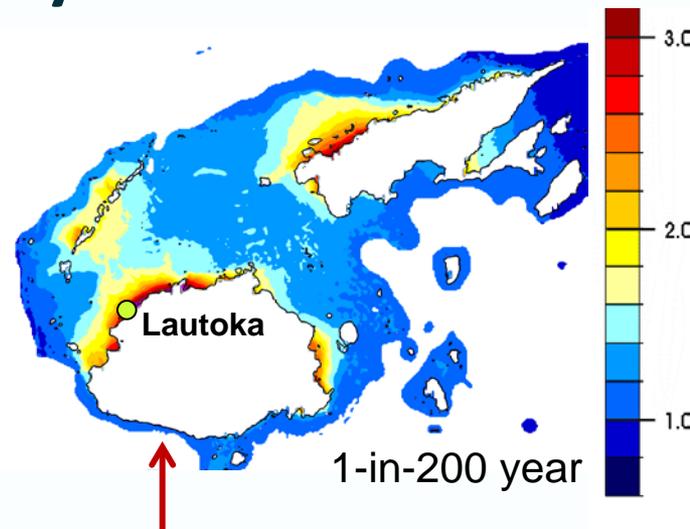
Storm tides evaluated from stochastic cyclones

Fiji:

Storm tides are largest on northwest coastlines of the Fiji Islands



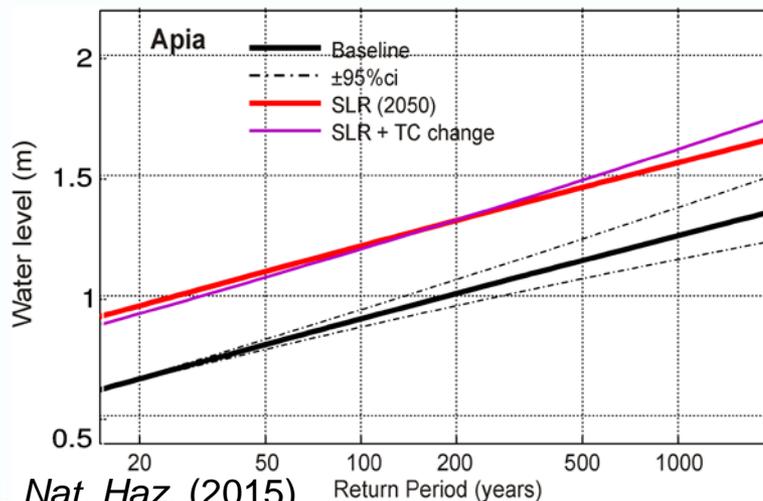
Source: McInnes et al, *Glob. Planet. Change.* (2014)



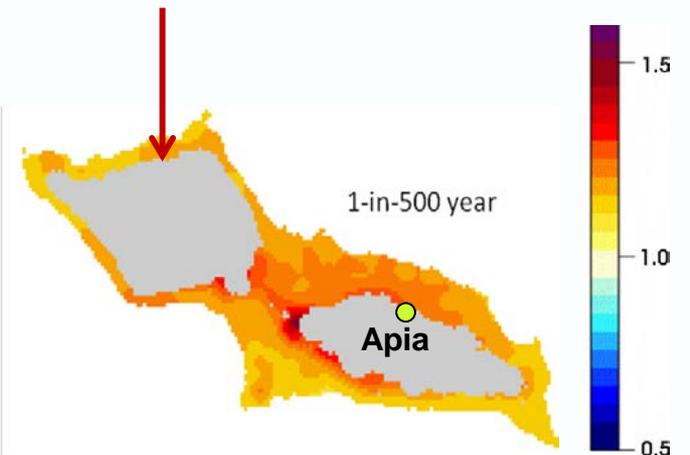
But waves are important, -particularly along narrow, steep-shelved islands!

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



Example: Wave flooding in small island nations

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

DREF operation final report
 International Federation of Red Cross and Red Crescent Societies

Papua New Guinea: Floods
 DREF operation n° MDRPG003
 GLIDE n° FL-2008-00243-PNG
 Final Report
 2 September 2009

January 23, 2009
 www2.hickam.af.mil

Wake Island recovers from 'rogue wave' hit

15 AW, Det 1



After a month since a large wave hit Wake Island, operations have recovered to normal.

On Dec. 7, 2007, at approximately 0430, Wake Island was hit by a rogue wave with an estimated height of 30 foot prior to the wave's force was estimated at the downtown where a majority of the island support and personnel are located.

The event resulted in sub-damage to several vehicles with the dining facility. Damages and

Wake Island was stuck by a powerful wave last month. Over the last several weeks, recovery efforts led by 15 AW personnel have rapidly returned the island to normal operations.

Courtesy photos

tion to the history of Wake Island having serviced thousands of aircrews.

The on-island leadership of the 15 AW, Det 1 Commander, Maj Bradley Waters, and the entire Wake Island community were key elements to the rapid response ensuring the safety of all island personnel.

"We truly have an amazing team on Wake Island. During the first few hours after the rogue wave, we had crews launching aircraft, emergency responders securing the flooded areas, civil engineers restoring power and other vital systems, services personnel relocating residents and the dining facility and crews beginning clean-up operations. In all of this, we never

Hickam Air Station (USD 165,000 or EUR 120,360) was created from the International Federation's Disaster Relief Emergency Fund (DREF) on 15 December 2008 to support Papua New Guinea Red Cross Society in delivering assistance to approximately 15,450 beneficiaries, and to replenish disaster preparedness stocks.

Abnormally high sea levels resulted in severe floods in Papua New Guinea in December 2008. The Papua New Guinea Red Cross (PNGRC), with the International Federation and the



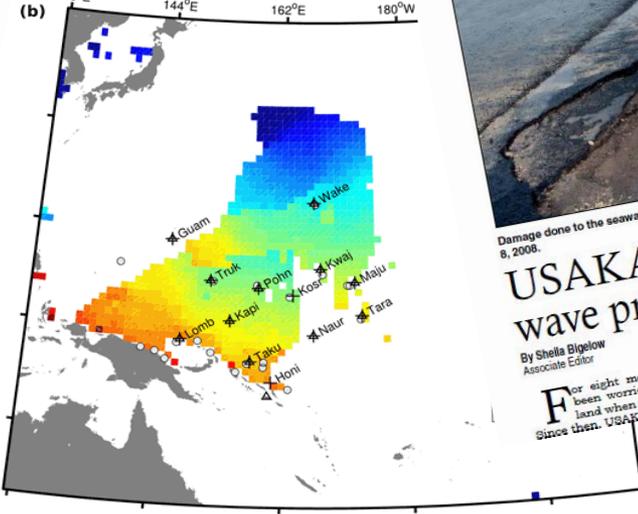
Damage done to the seawall near the northeast end of the runway during the wave surge that hit Roi-Namur on December 8, 2008.

USAKA seeks funding for shoreline, wave protection on Roi-Namur island

By Shella Bigelow
Associate Editor

For eight months, Roi-Namur residents have been worried about damages done to the island when a major wave surge hit their shores. Since then, USAKA has implemented temporary dam-

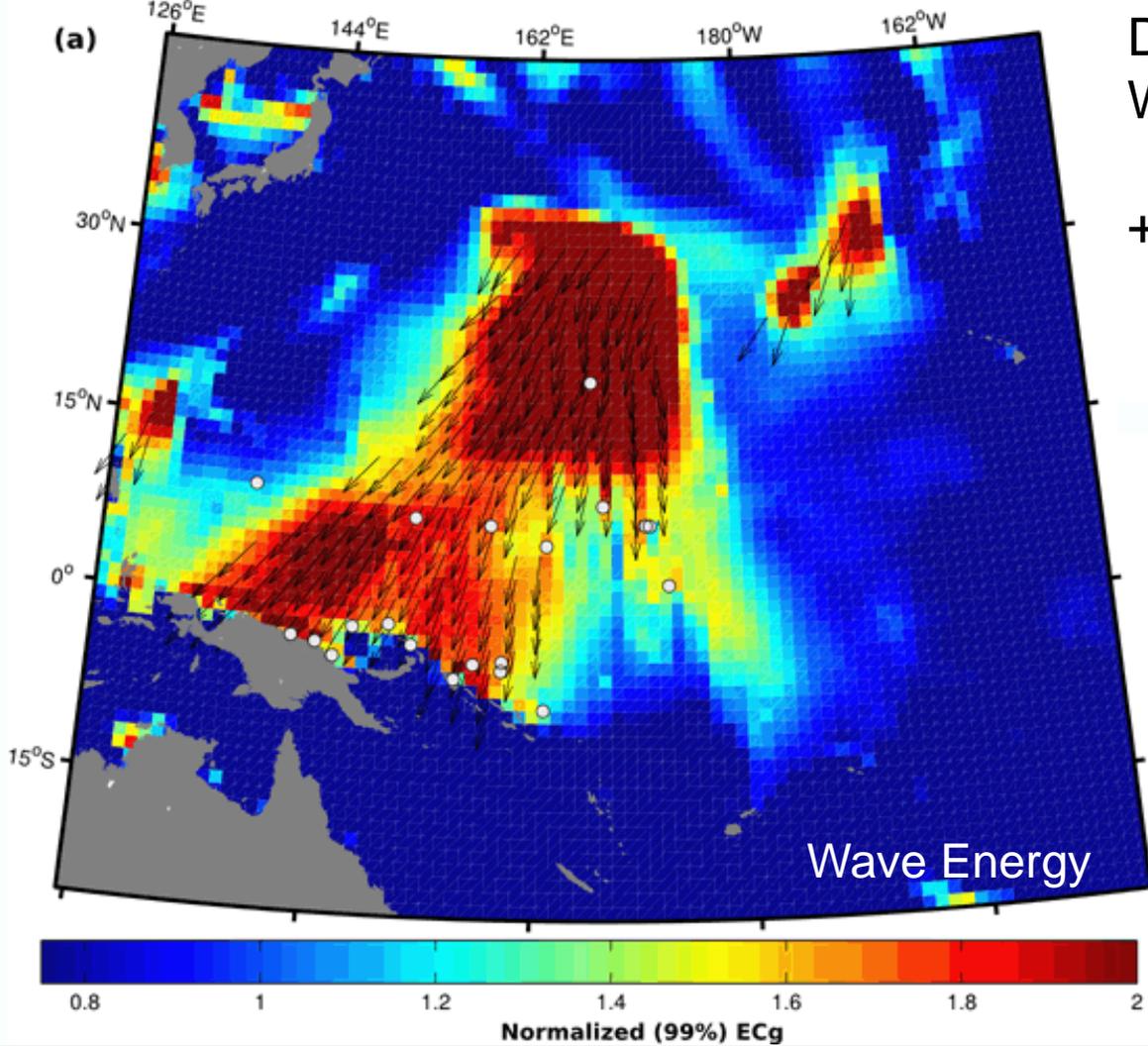
severely depreciated by the waves. Saltwater was forced under the seawall and blew out the top concrete causing major damage to the seawall and debris was thrown onto the runway. Runway damage was categorized as critical. Other crucial locations affected include the Speedball Area, Telemetry dome facility 8223 and the lens wells. The lens wells are of major



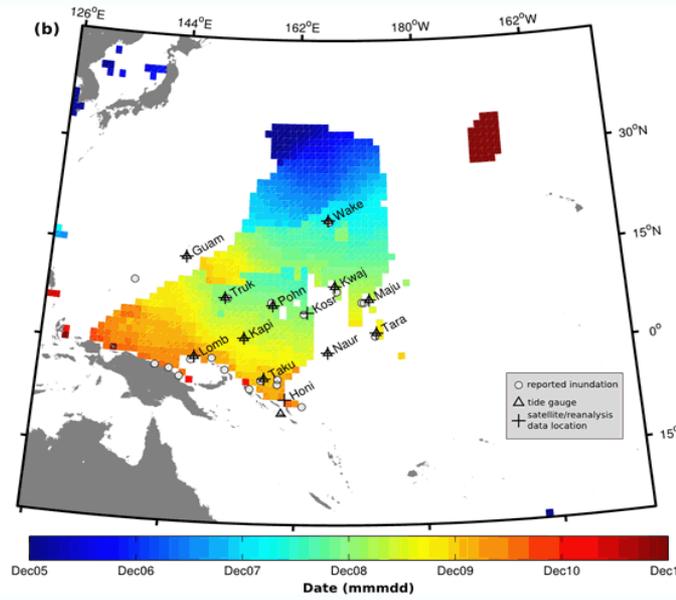
A documentary crew making 'There once was an island' captured the impact of these waves on Taku'u Atoll



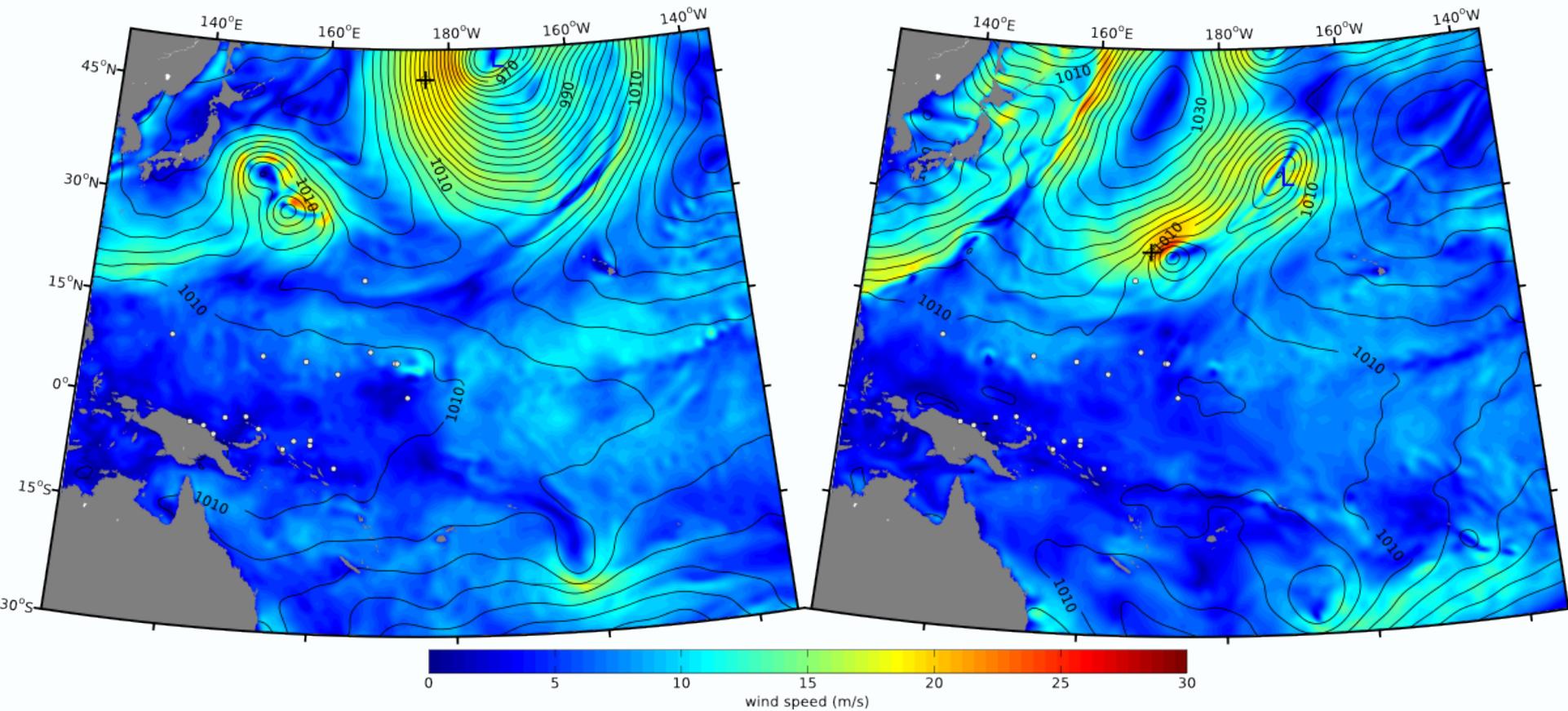
The cause was swell waves from a north Pacific storm ~4000 km away



December 2008
Wave energy about twice 99th percentile levels
+ positive regional sea level anomaly = widespread inundation



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



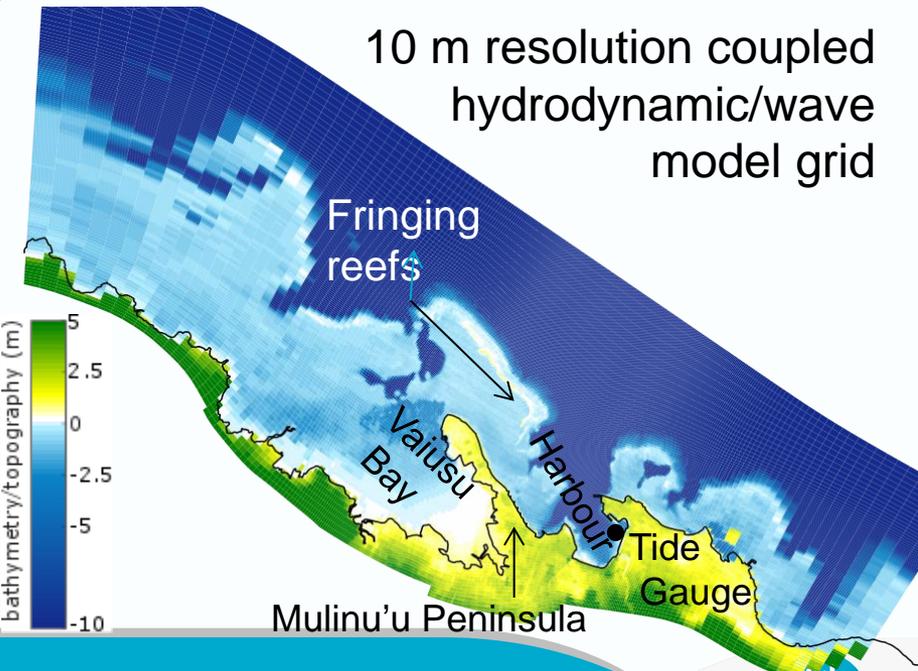
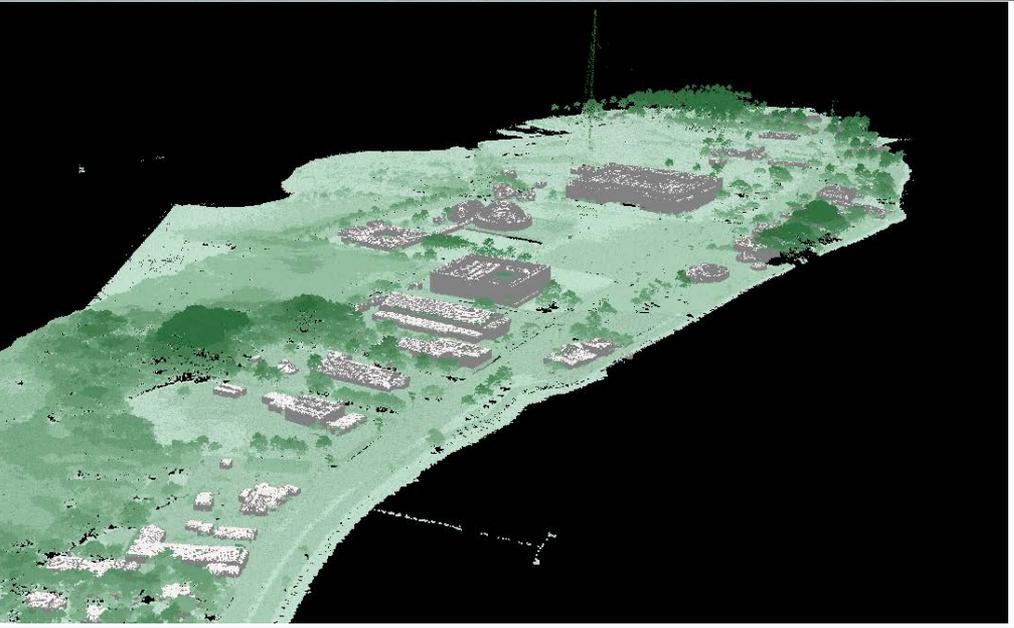
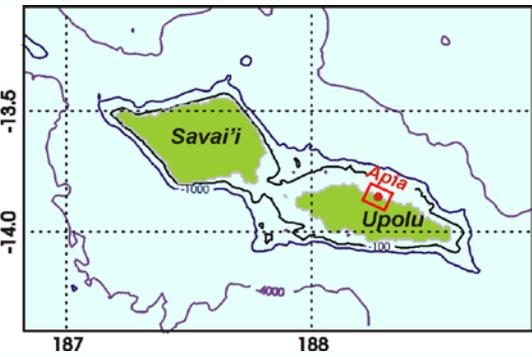
1800 3 December 2008

1800 6 December 2008

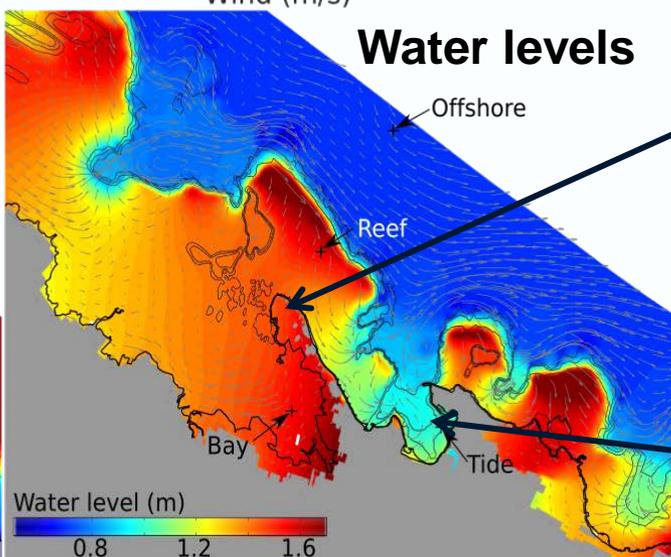
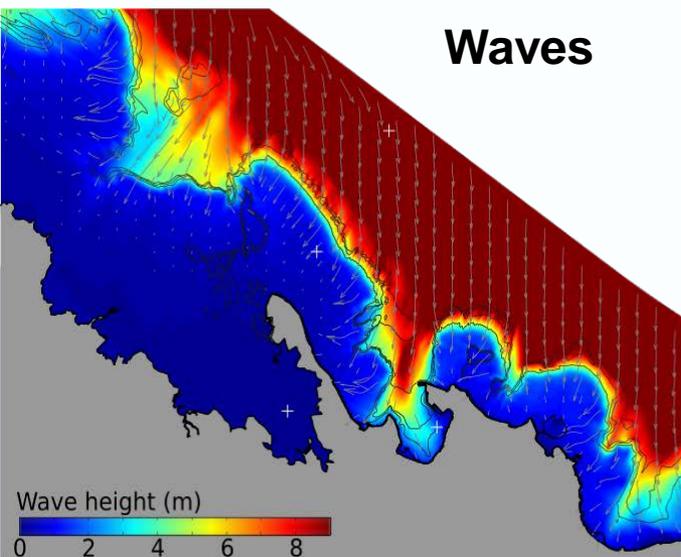
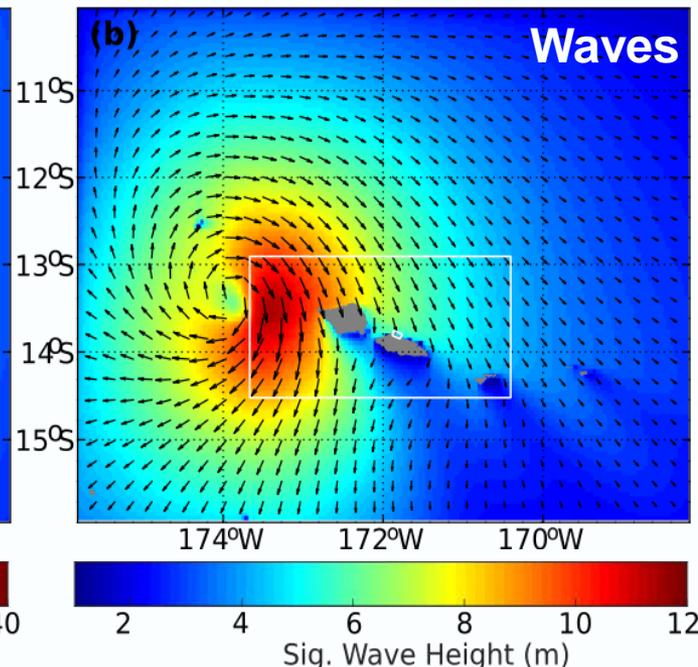
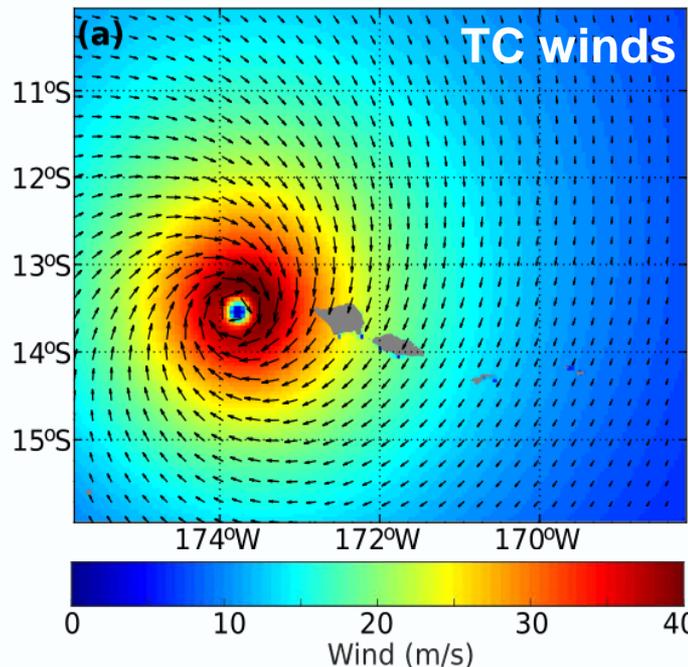
Source: Hoeke et al, 2013: Widespread inundation of Pacific islands triggered by distant-source wind-waves. Global Planetary Change 108: 128–138



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



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



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