Wave-driven Flood-forecasting on Reef-lined Coasts
Early warning system

Many low lying coasts and islands with coral reefs are experiencing wave-driven flood events that currently strike with little to no warning. These events are a result of a combination of sea surface elevation and wave height, and can cause severe flooding even on windless, sunny days. Increasing the resilience of coastal communities while decreasing the risk to life, are critical for these people to maintain their way of life, and to continue to live in these locations.

2008 Flooding event in the Marshall Islands

Flooding in the Maldives

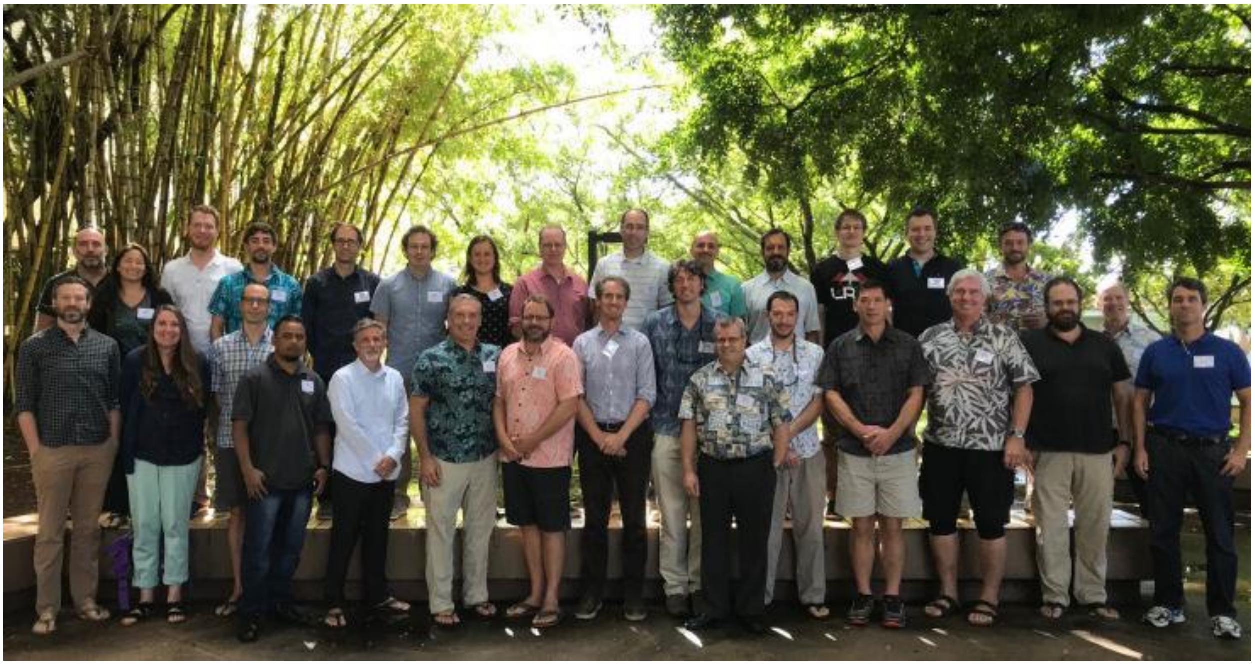
Flooding in Kirbati

There is a very real need along the world's coral reef-lined coasts for a tool that is able to predict the timing and severity of wave-driven flooding events. Without this tool, coastal communities are vulnerable to:

- loss of life from drowning
- loss of, and damage to property and infrastructure
- decreasing viability of communities via loss of, and damage to crops, fishing (via decreased water quality and wave damaged reefs), and freshwater resources
- reduction of livable land due to increased erosion and salt intrusion

Background

On 5-7 February 2018 in Honolulu, Hawaii, scientists from the US National Oceanic and Atmospheric Administration (NOAA), the US Geological Survey (USGS), Deltares (Netherlands), ReefSense Pty Ltd (Australia) and the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO), with funding from NOAA (via ReefSense) and USGS (via Deltares) organised an international workshop titled Understanding Flooding on Reef-lined Islands Coasts (UFORIC). A group of 30 experts, representing 15 agencies and research institutes from around the globe, attended to discuss key issues related to the vulnerability of island states to wave-driven flooding due to climate change and sea level rise.



Participants of the UFORIC Workshop, Honolulu 5-7 February, 2018

During the workshop a number of quite sophisticated efforts to develop wave-driven flood forecasts were identified. These models are very costly to implement and do not lend themselves to being easily implemented more broadly. Some of these models have been implemented on a small number of locations, e.g. one in the Marshall Islands covering the eastern end of Majuro, one in Fiji and a number of models that have been implemented around the Hawaiian Islands. There are other models either planned or under development. All of these models are very site specific and only provide forecasts for a small strip of coastline.

Along with a short Workshop Report, published in EOS, a journal article titled Steps to Develop Early Warning Systems and Future Scenarios of Storm Wave-Driven Flooding Along Coral Reef-Lined Coasts summarised workshop discussions and was published in Frontiers in Marine Science.

Following the workshop, it was clear that the science and knowledge already existed to develop a simplified, less computationally expensive, Early Warning System (EWS) for forecasting wave-driven flood events along coral reef-lined coasts that is capable of being implemented worldwide.

NOAA STAR, the USGS Pacific Coastal and Marine Science Centre, Deltares and ReefSense (jointly have the tools and knowledge to develop such a simplified EWS, and have combined their capabilities to form a team to develop and deliver a simplified EWS for flood forecasting. This model is not as complex and possibly not as accurate as the sophisticated site-specific flood models mentioned above, however, it will be possible to provide global coverage for all reef-lined islands and coasts.

Challenge - Forecasting Wave-Driven Flood Events along Reef-Lined Coasts and Islands

Currently there are flood forecasting systems in wide-spread use for sandy shorelines, however these do not accurately predict wave-driven flooding on reef-lined coasts, leaving inhabitants without appropriate warnings. Flood models for reef-lined coasts have only been implemented on a small number of reef-lined coasts throughout the world because existing techniques are costly and require large amounts of computing power.

Using existing techniques a project to set up a system that generates high resolution forecasts for wave-driven flooding on all coral reef-lined coasts throughout the world would cost approximately US$1 billion.

The WaveFoRCE Solution - a Cost Effective Global System

The Wave-driven Flood-forecasting on Reef-lined Coasts Early warning system (WaveFoRCE) is a simplified early warning system, designed to be able to be implemented as an operational flood forecasting system on all coral reef-lined coasts throughout the world. WaveFoRCE's goal is to provide coastal flood forecasts 7.5 days in advance, at 3 to 6 hourly increments. Forecasts will be provided globally for all reef-lined coastlines at intervals of approximately 200 metres.

WaveFoRCE will take 5 years to deploy along every coral reef-lined coast in the world, at a cost of $10.6 million per year (total of $52.921 million). Once operational, it will cost an order of magnitude less to

maintain and can easily be maintained by one or a number of the major weather forecasting agencies such as NOAA, the Australian Bureau of Meteorology, the UK Met Office, etc.

Local Stakeholder Engagement

Stakeholder engagement is a primary focus of the WaveFoRCE project. The project will conduct ongoing user engagement, including a series of workshops, in order to ensure that the outputs and delivery mechanisms fit the needs for a variety of user groups. Workshops will focus on three main aspects:

1) Involving users in the development of the design of the forecast delivery look and feel.

2) Involving users and stakeholders in citizen science to gather flood levels when floods occur.

3) Education on how to use and interpret WaveFoRCE forecasts, and gathering feedback.

Benefits of WaveFoRCE

- *Cost-effective*: the global implementation of WaveFoRCE will cost 4% of a traditional high-resolution forecasting system
- *Computationally simple*: WaveFoRCE can be run for a region on a basic PC
- *Accuracy*: Tests show that WaveFoRCE comes within 7% accuracy of more costly high-resolution models
- *Local engagement*: the WaveFoRCE project will develop close collaborative relationships with local users and stakeholders
- *Development of new coral reef management tools*: ongoing maintenance of WaveFoRCE necessitates the need to know where coral reef bathymetry has changed significantly so that reef profiles can be updated. The WaveFoRCE project will develop new tools for the automatic detection of reef degradation via tools such as satellite-based mortality and mechanical damage tools. These tools will also be invaluable for the management of coral reefs.

GEO Blue Planet and Implementation Partners

WaveFoRCE is a project of the GEO Blue Planet Initiative. GEO Blue Planet is a global network of ocean and coastal-observers, social scientists and end-user representatives from a variety of stakeholder groups, including international and regional organizations, NGOs, national institutes, universities and government agencies.

GEO Blue Planet is the ocean and coastal arm of the Group on Earth Observations (GEO), an intergovernmental partnership of 110 national governments and over 100 Participating Organizations working together to support the international community with Earth observation data and tools. Priority areas include activities related to global policy agendas, the Sustainable Development Goals of the UN and the Sendai Framework for Disaster Risk Reduction. GEO Blue

Planet does this by promoting and supporting real-life applications of observational data and the co-development of decision support tools.

The WaveFoRCE science team include the National Oceanic and Atmospheric Administration (NOAA), the United States Geological Survey (USGS), Deltares, ReefSense Pty Ltd and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The Implementing partners include the WaveFoRCE Science Team as well as four implementing partners, one from each of the Indian and Atlantic Oceans, and two from the Pacific. Although three of the implementing partners have not been chosen yet, the Pacific Community (SPC) have agreed to be one of the Implementing Partners in the Pacific.

How will WaveFoRCE work?

WaveFoRCE will combine satellite data, hydrodynamic models and reef profiles to produce 61 flood forecasts, updated 4 times per day, for each point, at intervals of 200 meters for every coral reef-lined coast in the world. To achieve this, an operational flood model would require a sophisticated, high resolution model to be run at every point throughout the world, 244 times per day. This would require a huge super computer that would be extremely costly to run and maintain. Normally, this would spell the end of such an ambitious project as WaveFoRCE, however the scientists within the WaveFoRCE team have come up with a brilliant solution to this seemingly intractable problem. Using a computer with considerable computing power, they have pre-calculated all the answers they need by running many hundreds of thousands of combinations of wave height, sea surface elevation, and reef profiles (bathymetry) through a high resolution model called X-Beach. The outputs have then been incorporated into an intelligent spreadsheet that can then be interrogated with lightning speed. This then allows WaveFoRCE to not only provide the flood forecasts needed to achieve its desired spatial and temporal coverage, but do so using a large PC, rather than a super computer. It also allows WaveFoRCE to be used to provide regional forecasts using a modest PC.

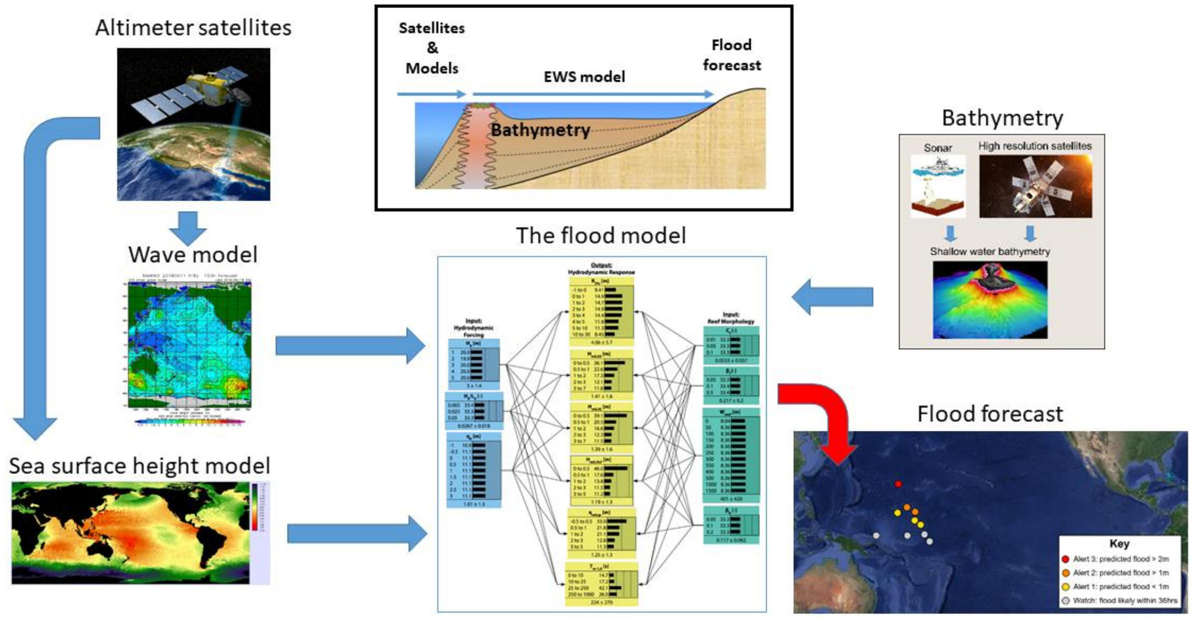
The WaveFoRCE System

WaveFoRCE will utilize satellites and models to derive forecasts of sea surface elevation and wave heights

- Sea surface elevation is a combination of:
    - tides (full cycle twice per day)
    - local sea level (which fluctuates on a daily to weekly time scale due to currents and eddies)
    - storm surge (from near-by storms or cyclones)
    - short term climate change (e.g. ENSO)
    - long term climate change (e.g. due to global warming)

- Waves can be categorized into
    - locally-derived storm waves that are generated by nearby storms or cyclones (i.e. short wavelength wind waves)
    - swell waves that are generated by distant storms (e.g. long wavelength waves from storms in the Arctic and Antarctic or cyclones somewhere else in the ocean basin).

      **Tsunamis are also a source of waves that can cause flooding, however WaveFoRCE will not produce forecasts that include tsunamis, these are covered by other forecasting systems.*



<u>Schematic of WaveFoRCE system:</u> The box at the top center shows how the system is broken into three parts. The satellites and models provide wave height and sea surface elevation forecasts (left three items in schematic); note that the bathymetry is predetermined (top right of schematic); WaveFoRCE then takes these inputs and compares them with the precalculated flood levels (lower center of the schematic); and produces a flood forecast that is then output in a fit for purpose manner (bottom right of schematic).

Learning about Historic Flood Events by Running WaveFoRCE Back Through Time:

Wave heights and sea surface elevation have been modelled and monitored for many years. WaveFoRCE will utilize these data to produce historic flood predictions. These are valuable to the project for two reasons. Historic flood predictions can assist users to interpret the outputs for the forecasts by comparing the heights of forecast floods with what they know happened during a past event if WaveFoRCE can describe the current forecast in terms of historic flood events. This is in effect calibrating the forecasts against local knowledge. The second use of historic flood predictions is to assist planners to understand the frequency of historic events and to therefore determine how often parts of their coast are expected to flood. This can be very valuable information for planning, approval of applications for new buildings, and determining how and where to modify infrastructure to make it more resilient to future flood events.

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