Observations and Modeling of Wave-driven Extreme Water Levels on Reef-Fringed Coastlines

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Australia’s diverse coastline: both coral and rocky (temperate) reefs

- Knowledge foundation of nearshore processes has been historically based on open coast sandy beaches
- Up to ~80% of the world’s coastline is coral or rocky reef (Emery and Kuhn 1982); ~30-50% of Australia’s coast is coral or rocky reef (Short 2009)
Fringing coral reefs

• Form along the shoreline of continents and relatively new tropical islands
• Also, as younger reefs along continents
• Ningaloo Reef, WA is Australia’s largest fringing reef (~300 km long)
Components of coastal flooding

Barometric pressure gradients
Onshore wind stress

Storm surge
- relatively slowly varying (hours)
- models available

Waves
Wave setup

Wave runup

Barometric pressure
Wind stress
runup
wave setup
still water level
Challenges to predicting wave runup along reef coasts

- Extensive literature on predicting runup on sandy beaches
- Numerical and empirical models (e.g. Stockdon et al. 2006)

Wave breaking on steep slopes (~1:20 to 1:1)
Reef morphology
Large bottom roughness

Properties are very different from beaches…
UWA Fringing Reef Experiment
(alongshore uniform fringing reef)

- 55-m long flume (Deltares)
- 1:36 geometry scaling
- 14 m long reef flat (500 m in prototype)
- 1:5 fore reef slope
- 1:12 beach slope
- Smooth and rough bed
- 16 wave and water level cases
- 18 wave gauges + 6 velocimeters
- Runup gauge
Numerical modelling

- NLSW + non-hydrostatic terms (phase resolving)
- Based on the 3D Euler/RANS equations
- Used 20 vertical layers
  - Eliminates need for wave breaking criteria
- Canopy model for bottom roughness
  - Model force exerted on water column by individual roughness elements
- Smooth and rough bed
  - 1.5 cm (54 cm in prototype) concrete cubes
  - ~6,000 cubes

\[ f_w = 0.16 \text{ from canopy flow theory (Lowe et. al, JGR, 2007)} \]
Sea-swell

Infragravity

Very low frequency
- natural mode 0 and 1

Wave setup

Elevation
Sea-swell

Infragravity

Very low frequency
- natural mode 0 and 1

Wave setup

Elevation
Runup on reefs vs plane beaches

\[ R_{20\%} \text{ vs } H_{\text{rms,0}} \]
SWASH simulation

Conditions
$H_{rms} = 1.7 \text{ m}$
$T_p = 16 \text{ s}$
$Dir = 18^\circ$
$D_{spr} = 20^\circ$
$h_r = \sim 1 \text{ m}$

Grid
5 m x 5 m
1 layer
Manning’s $n = 0.035$

Elevation contours
[-2 : 2 : 4]

Depth-averaged velocity
Wave setup

Reef crest (max) setup

Lagoon ($x = 1800$ m) setup
Reefs as coastal protection?

It depends…

- Reef geometry
  - Along-shore uniform vs open channels
  - Reef flat length
- Reef roughness
- What are you comparing to?

Current and future research

- More modeling (reef geometry and roughness)
- More field datasets, including runup measurements
Questions?

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Reefs as coastal protection?

Does a reef fronting a coastline always reduce storm damage?

Relevant to both coral and rocky reef coastlines…
Effect of channels in fringing reefs

Along-shore uniform

No net mass flux
Bottom stress directed seaward

Open channels

Shoreward net mass flux
Bottom stress directed shoreward