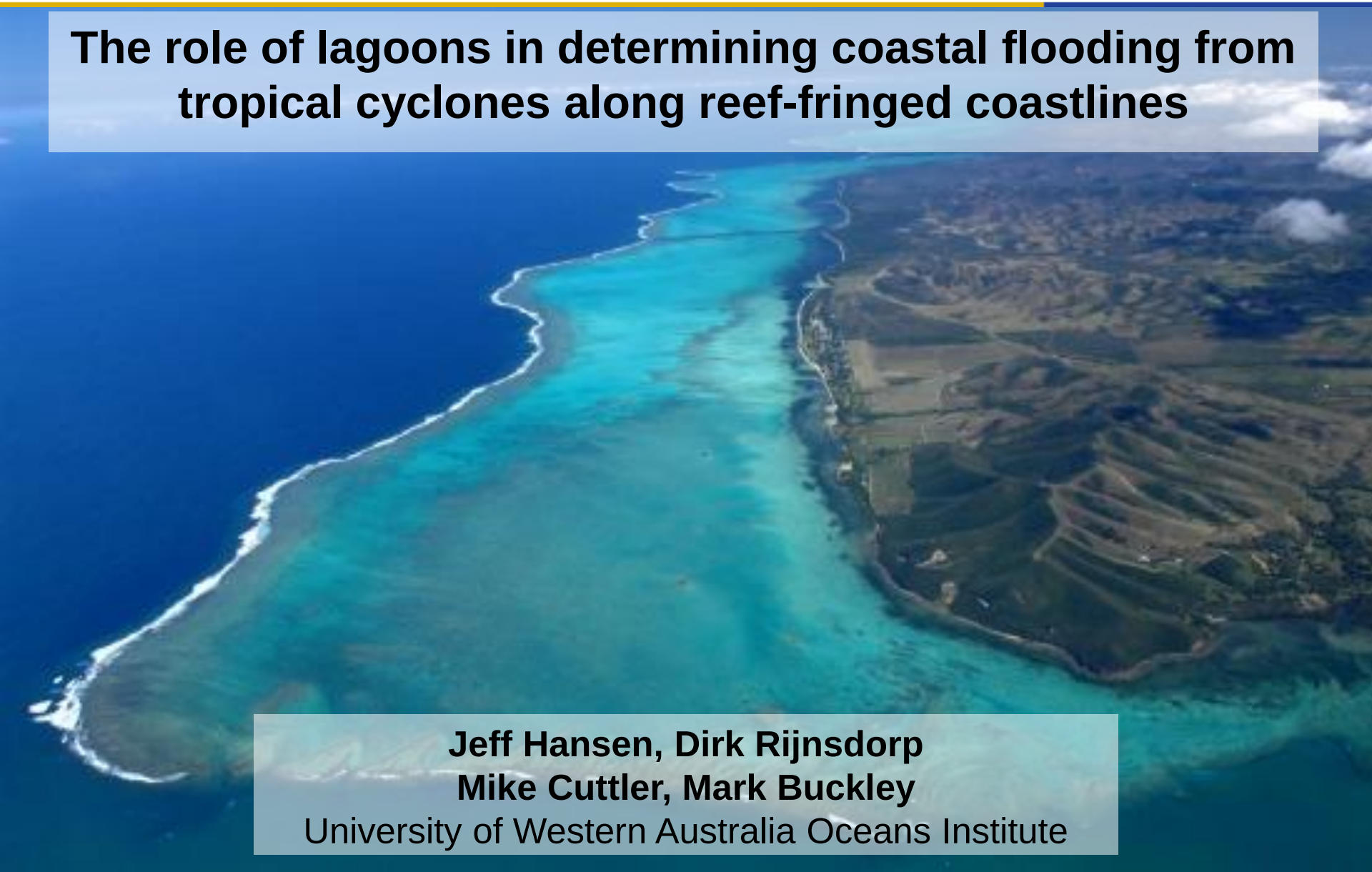
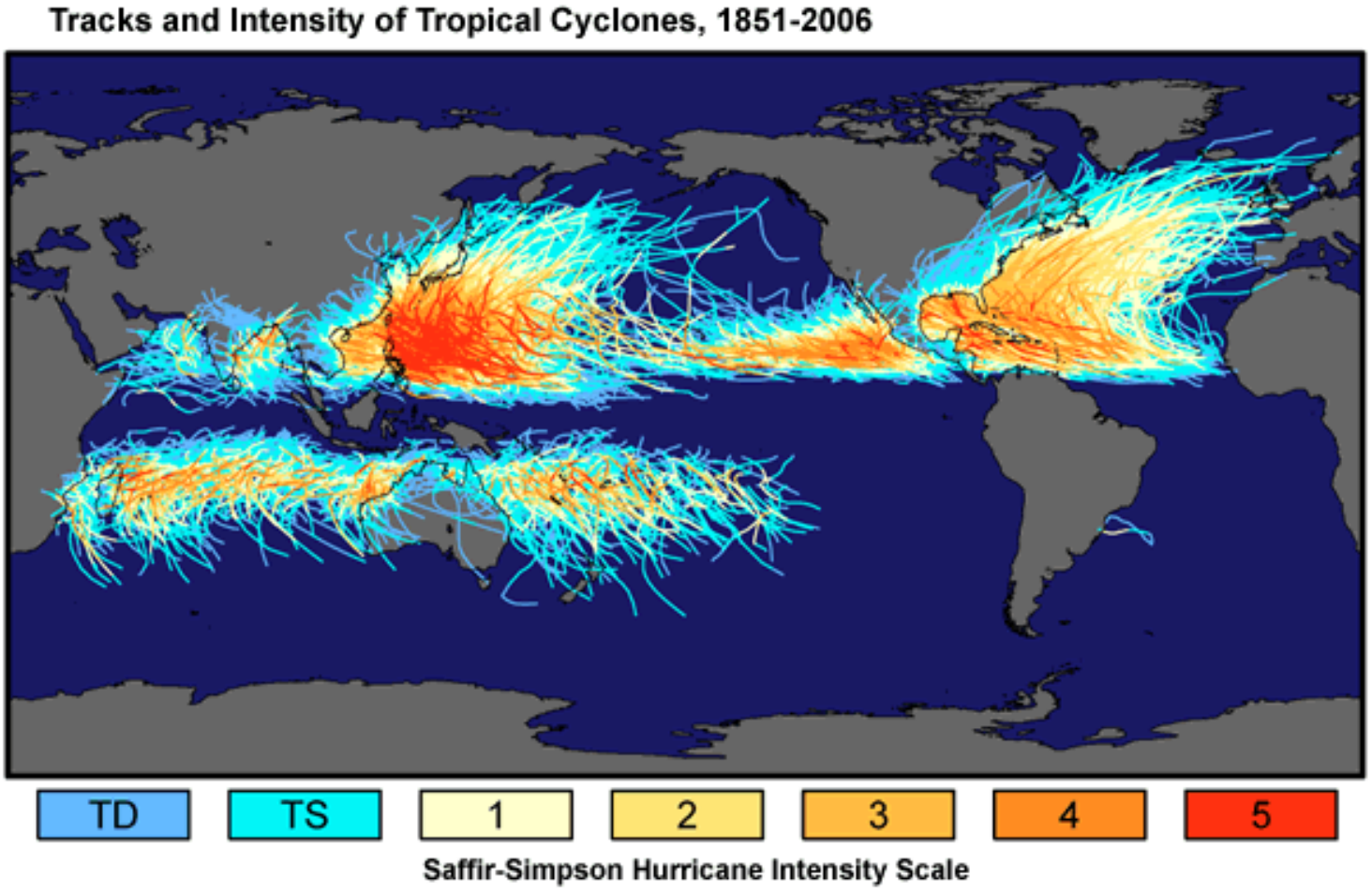
The role of lagoons in determining coastal flooding from tropical cyclones along reef-fringed coastlines



Jeff Hansen, Dirk Rijnsdorp
Mike Cuttler, Mark Buckley
University of Western Australia Oceans Institute

Global distribution of tropical cyclones

Tropical cyclones impact low latitude coastlines globally and effect many coastal communities.



Global distribution of coral reefs

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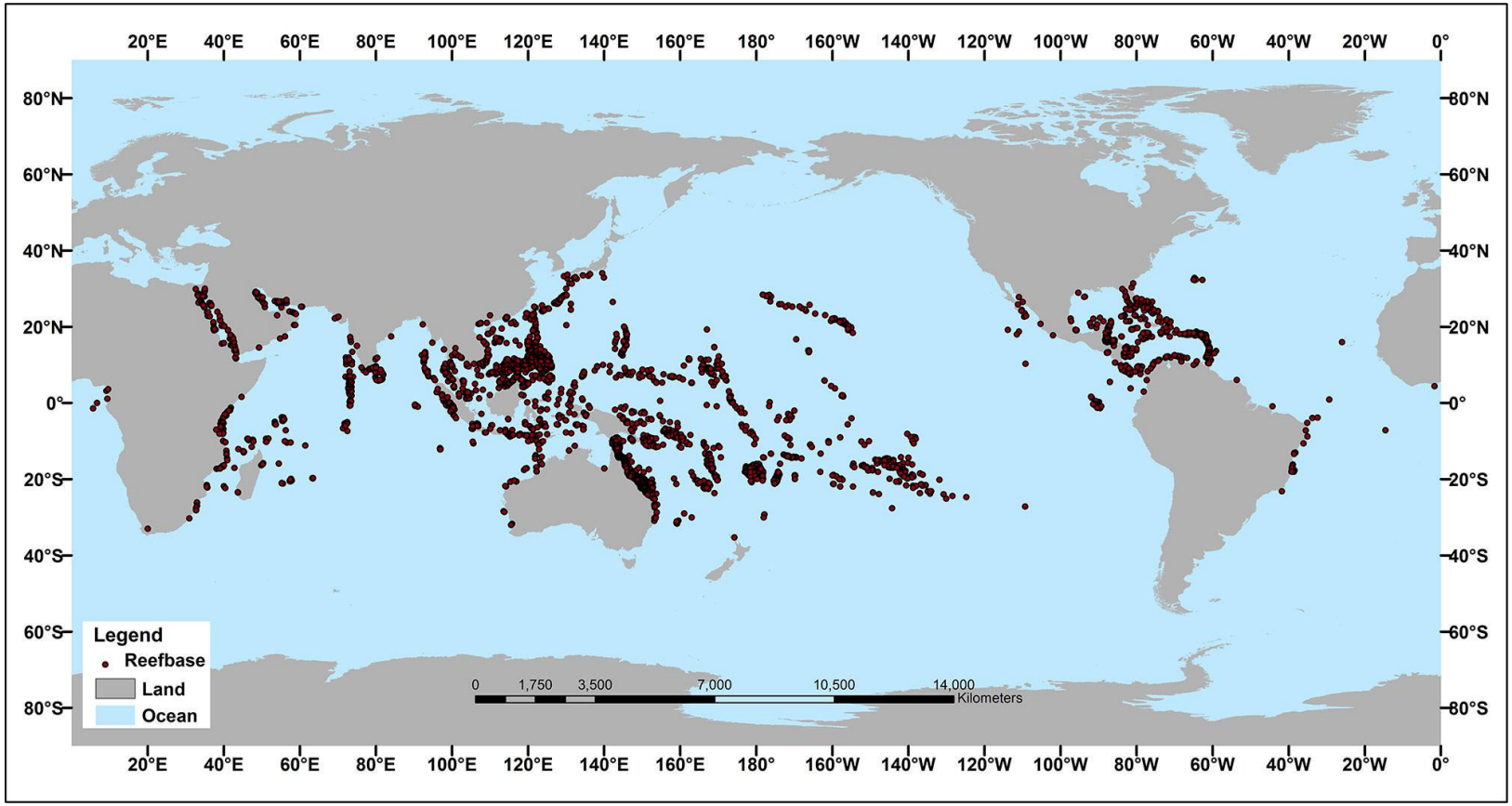
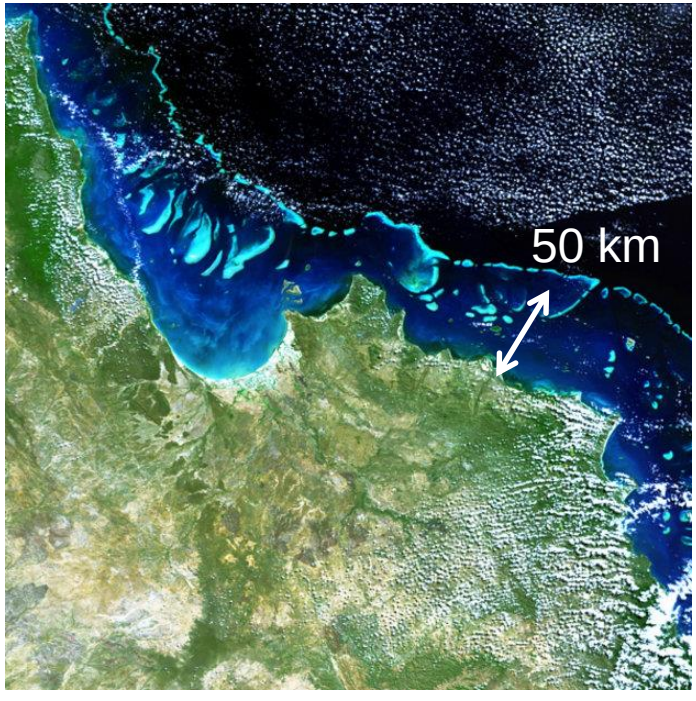
Many of the areas impacted by tropical cyclones also feature coral reefs (e.g. Hurricanes Dorian, Irma, Jose, Maria, Typhoon Haiyan).

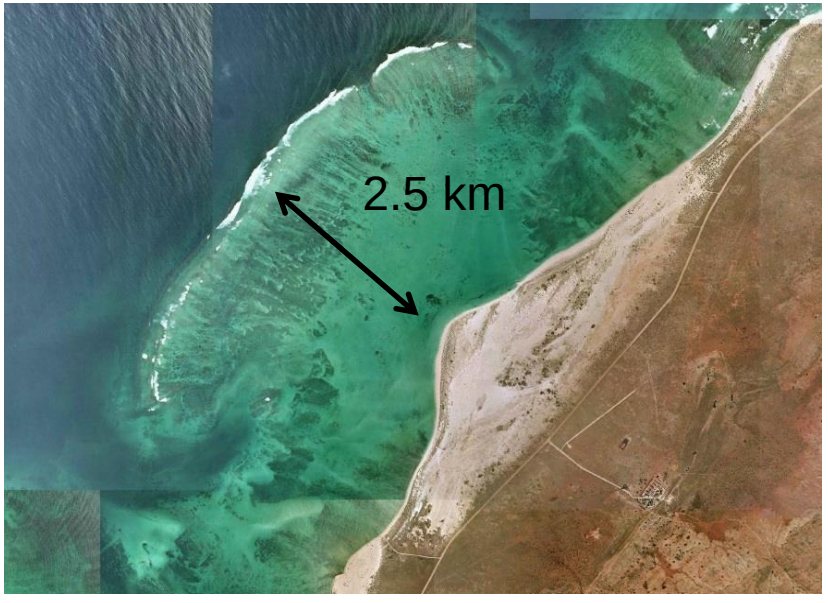


NOAA

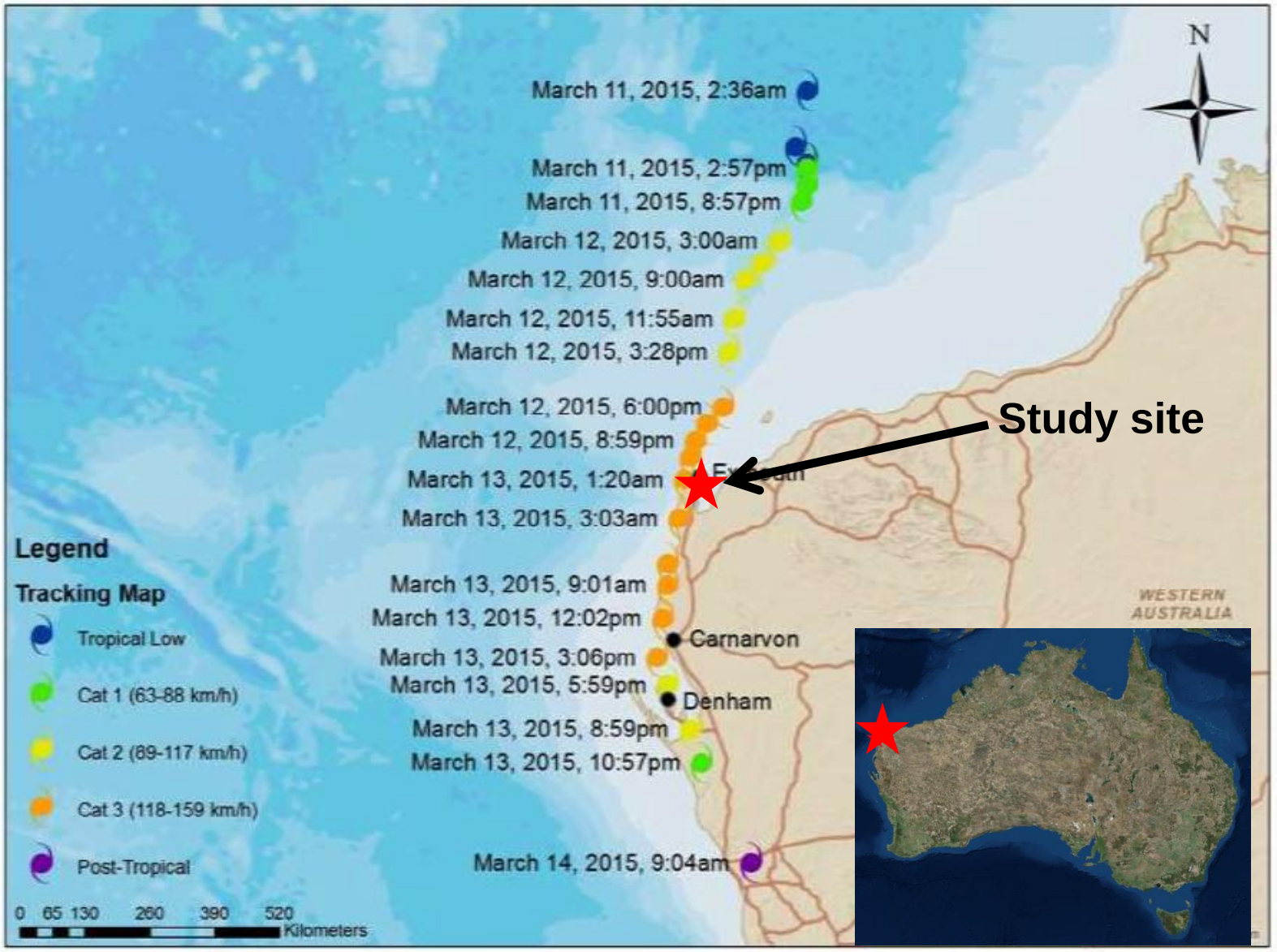
Reefs morphology varies considerably

- Reefs range from being shore attached to 10s of km from shore.
- Do lagoons offer additional coastal protection?



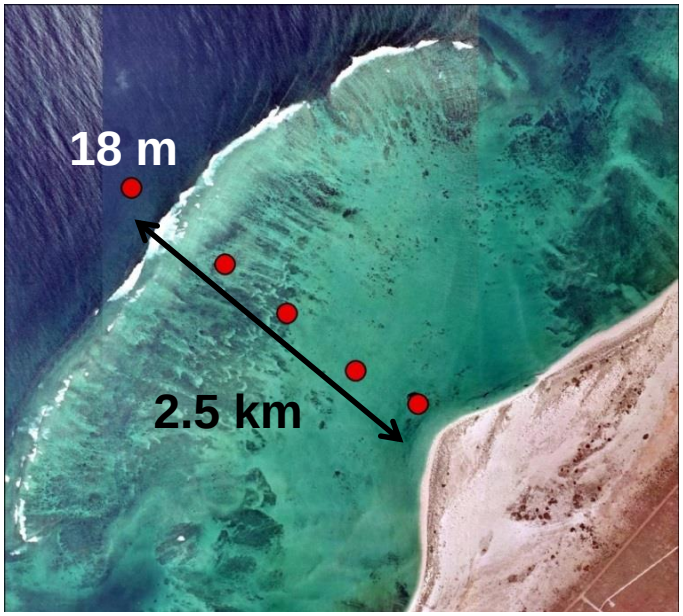


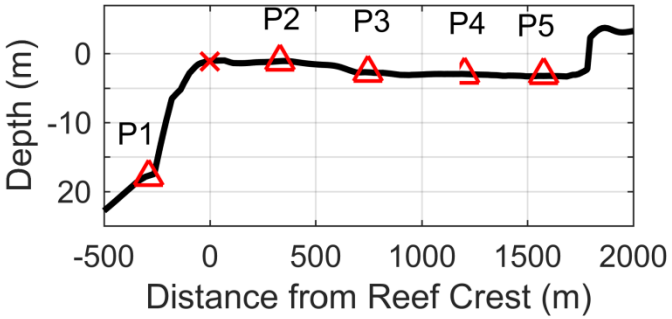
Motivation: Tropical Cyclone Olwyn (March 2015)

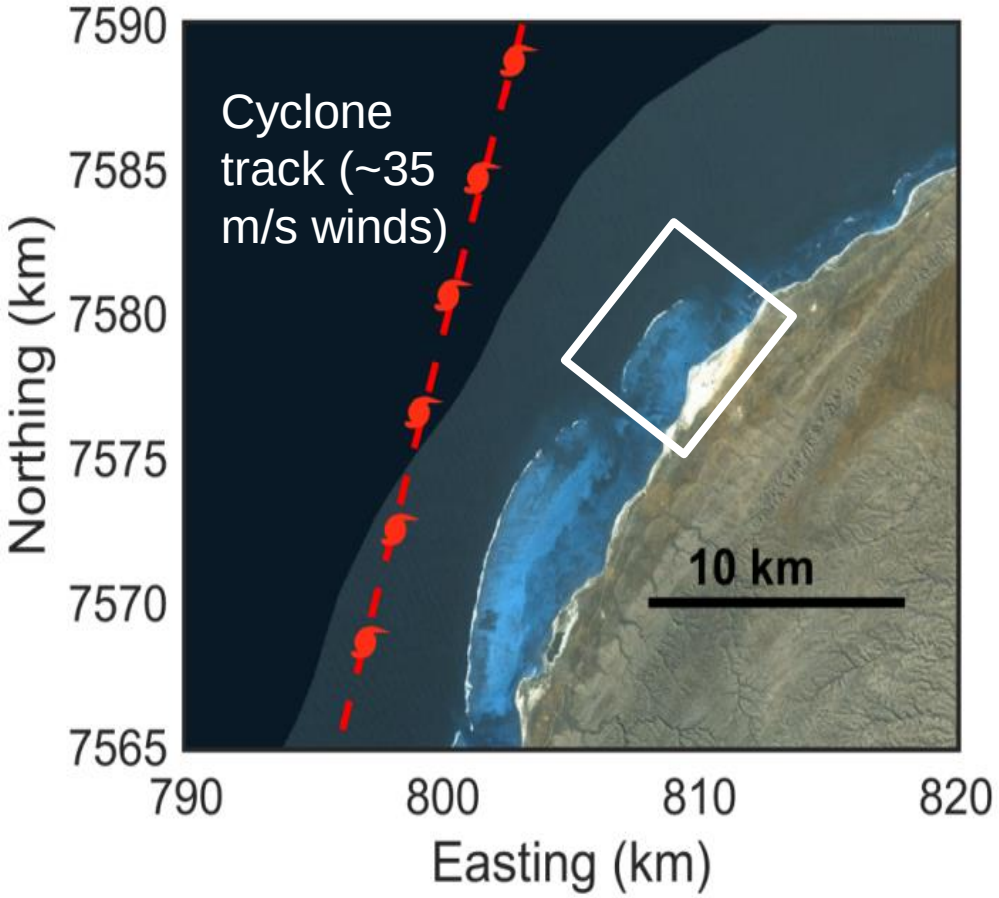


Tropical Cyclone Olwyn observations

Cross-shore array of 5 pressure sensors/wave gauges deployed several months before Cyclone Olwyn.





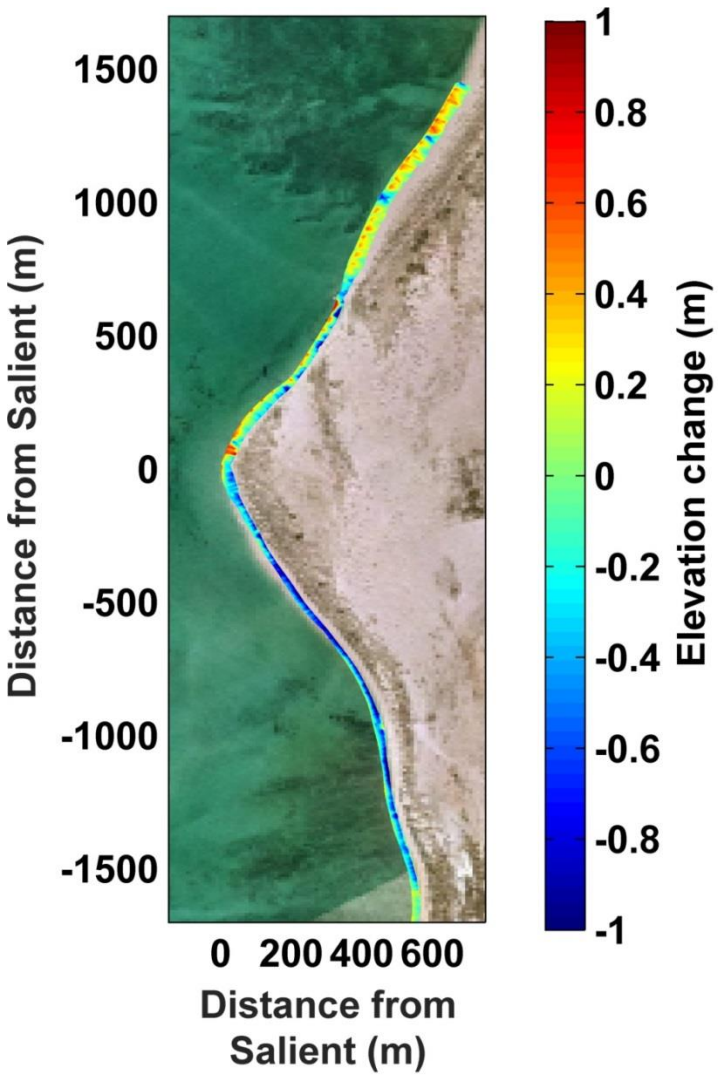


Cuttler et al., L&O Letters (2018)

What we were expecting

US Park Service

What we observed- very minimal beach change

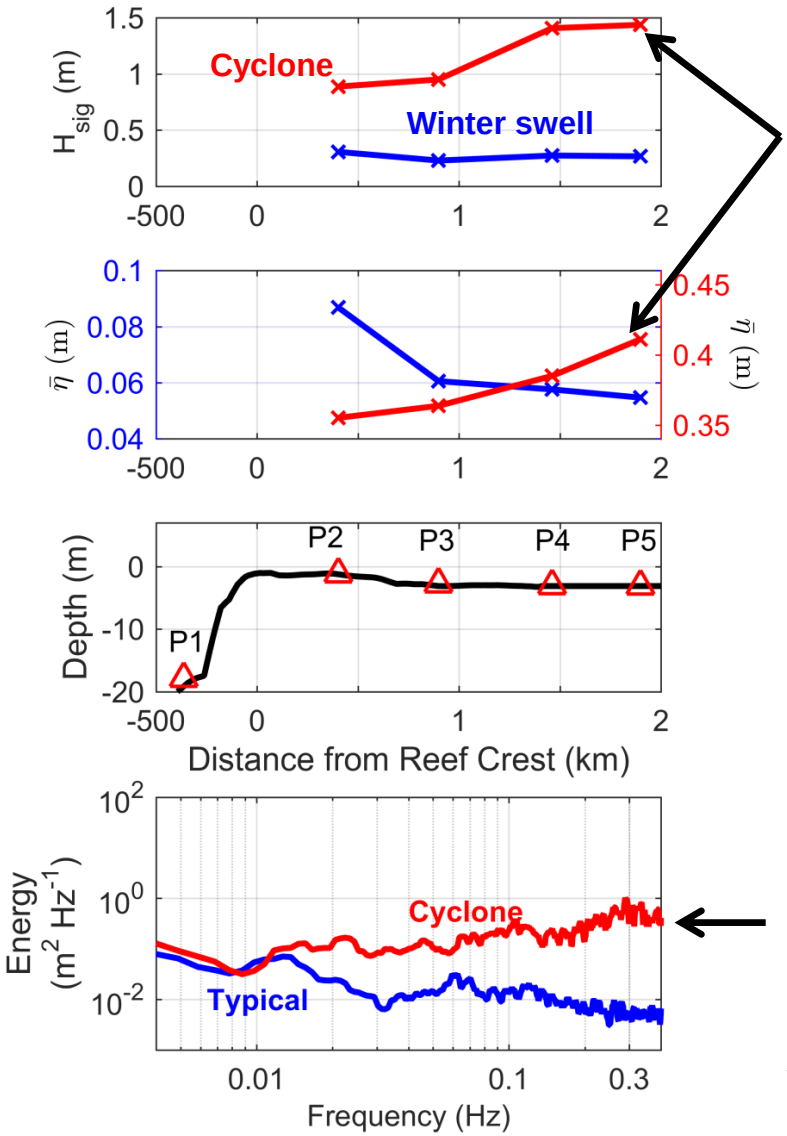


Averaged along the beach, only 3 m^3/m of erosion.

Cuttler et al., L&O Letters (2018)

Why did the beach change so little?

- The fringing reef dissipated the ~6 m offshore waves.
- The lagoon is sufficiently wide (~2.5 km) such that the beach is mostly protected from the offshore wave conditions.
- Observed beach erosion mostly due to wind wave growth within the lagoon, not offshore waves.



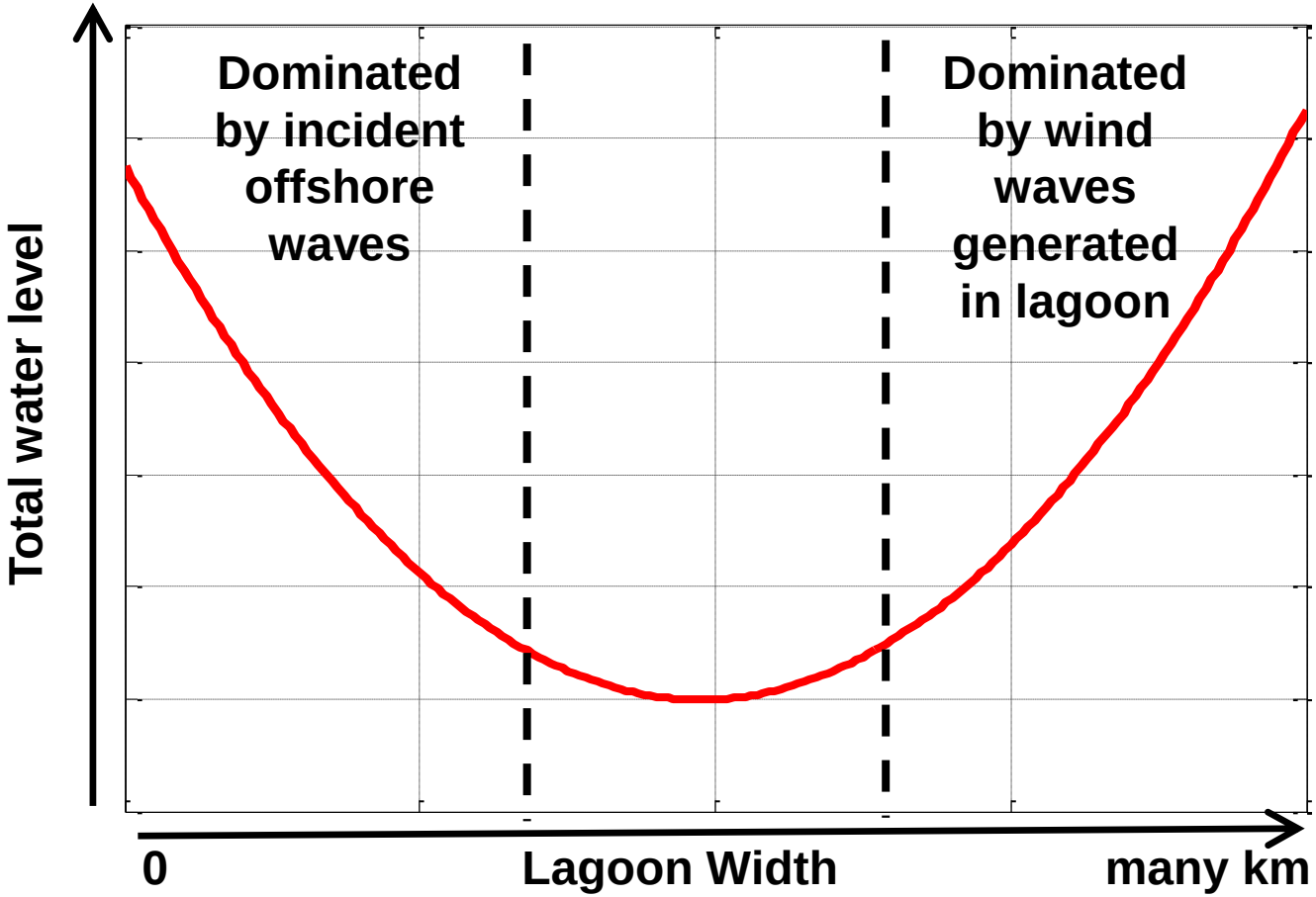
During the cyclone both wave height and setup increased towards the shoreline

Spectra at most inshore site dominated by high-frequency wind waves

Cuttler et al., L&O Letters (2018-in press)

Is there a relationship between lagoon width and cyclone impacts?

Our results suggest that the available fetch within a lagoon onshore of a fringing/barrier reef may be a determining factor in the observed coastal impact from cyclones. Here “coastal impact” is defined as the total water level at the shoreline.



Observations: Needham et al. (2015)

AGU PUBLICATIONS

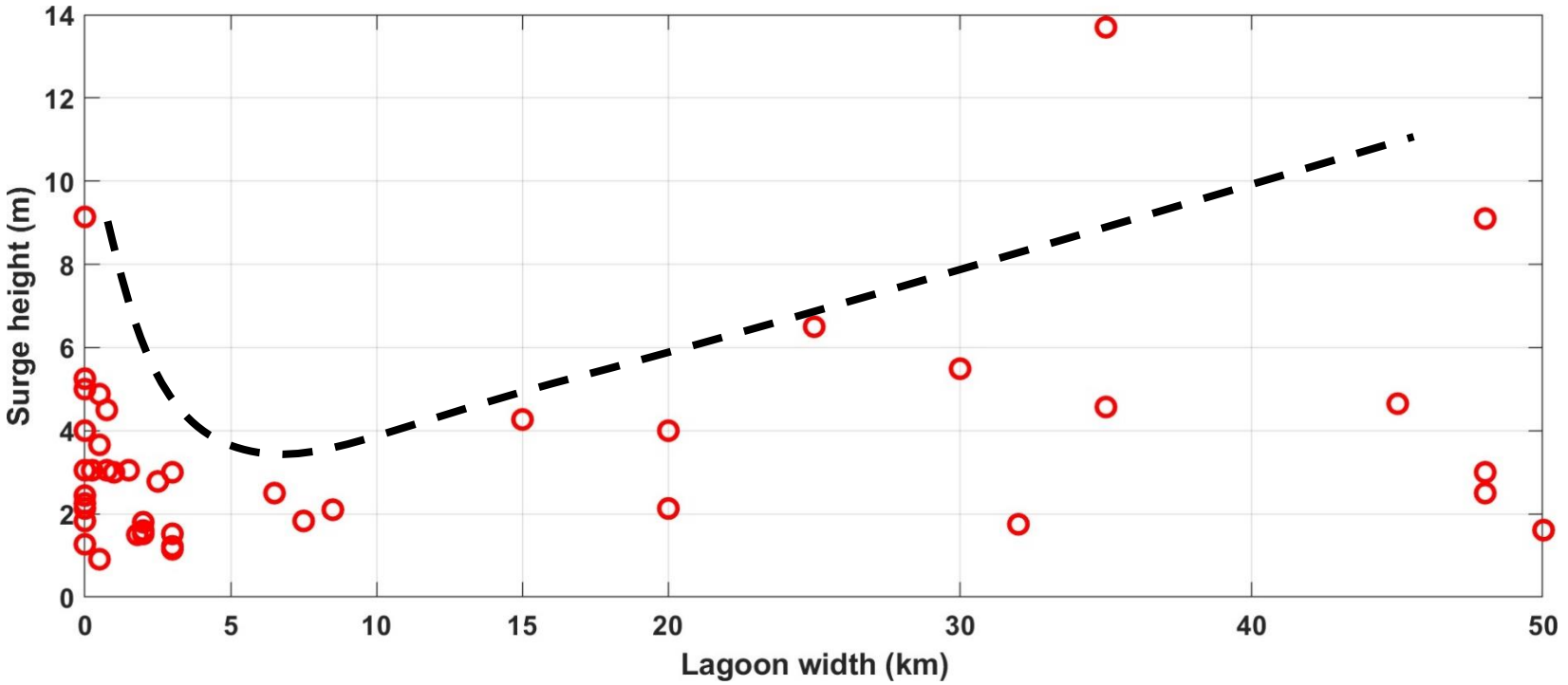
Reviews of Geophysics

REVIEW ARTICLE
10.1002/2014RG000477

Key Points:
- Identify global storm surge data sources
- Identify global storm surge observations
- Identify global storm surge impacts

A review of tropical cyclone-generated storm surges: Global data sources, observations, and impacts

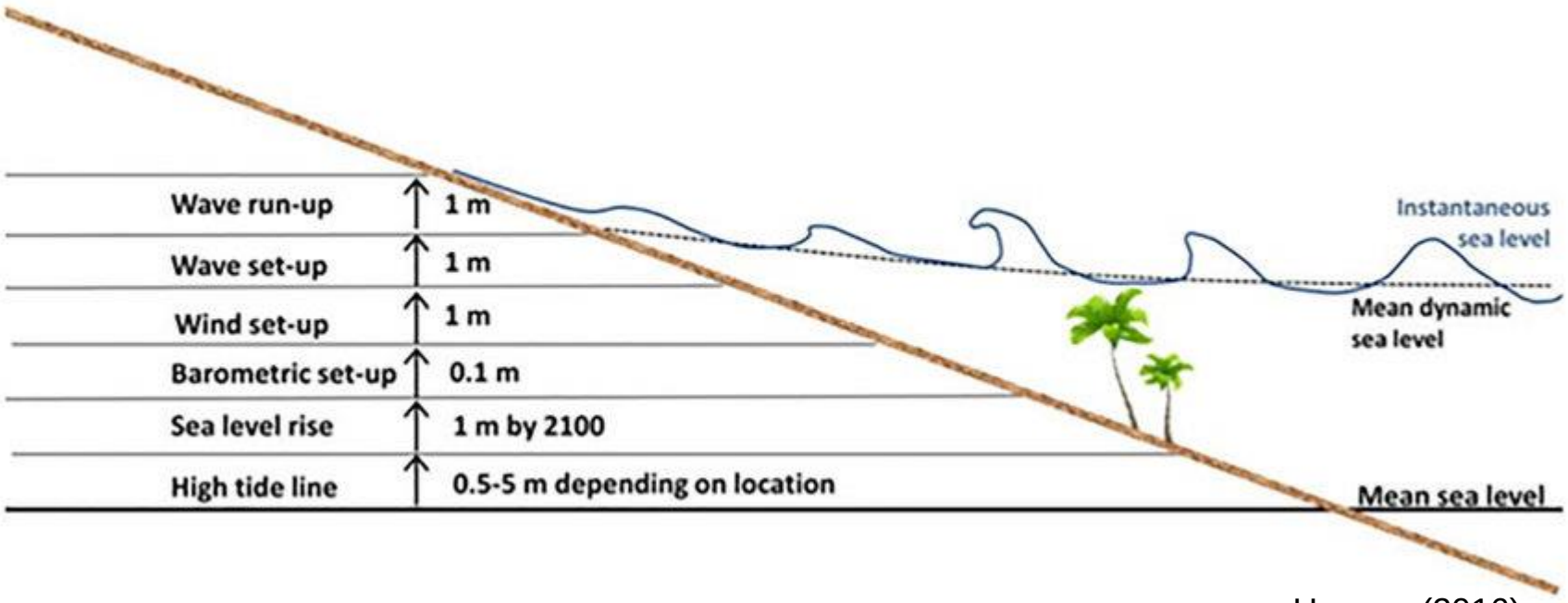
Hal F. Needham[1], Barry D. Keim[2], and David Sathiaraj[3]



Methodology

Use idealized numerical simulations to predict total water level (TWL) across a range of lagoon widths.

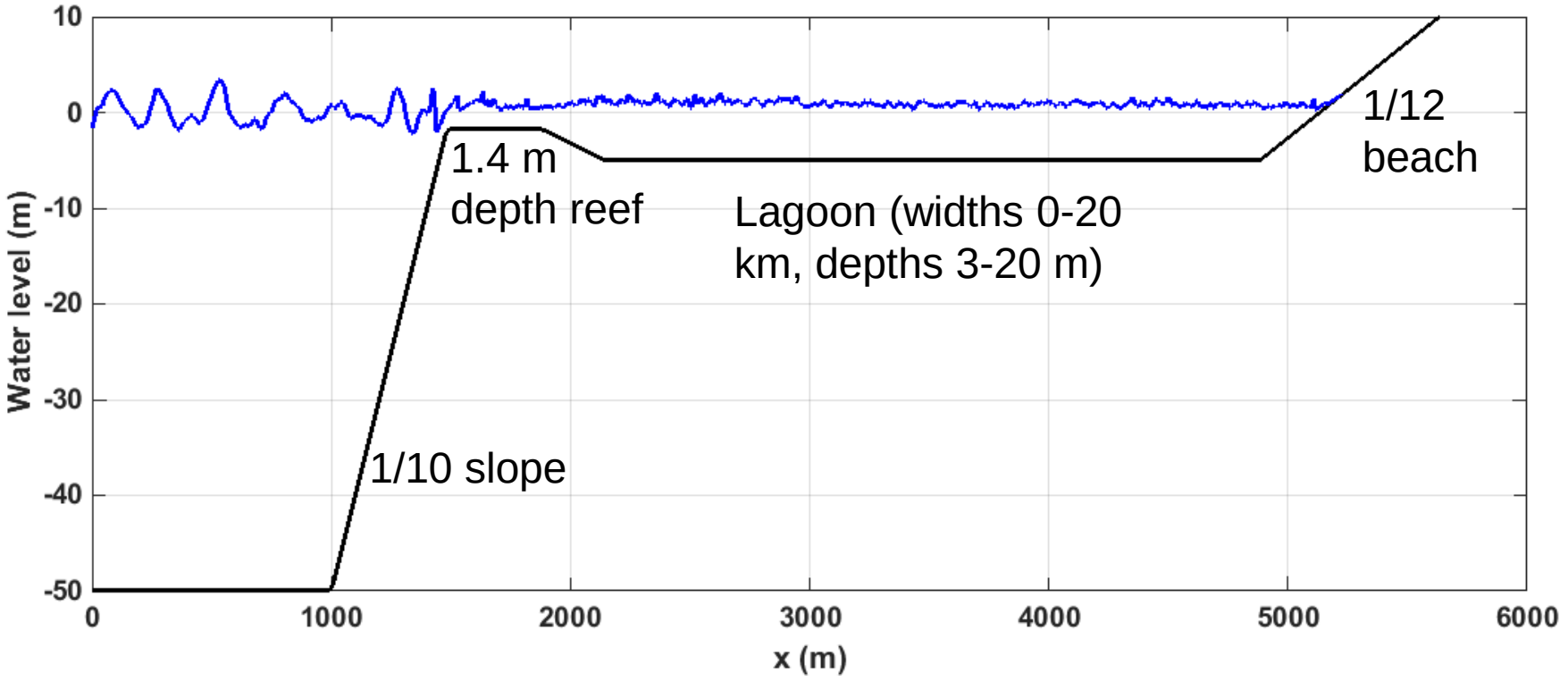
- We combine phase-resolved (to get runup) and phase-averaged (to get wind growth) model simulations.
- Focus on role of wind growth in the lagoon- most existing research has on shore attached reefs (Pearson et al [2017]) or neglected wind growth.



Hansen (2016)

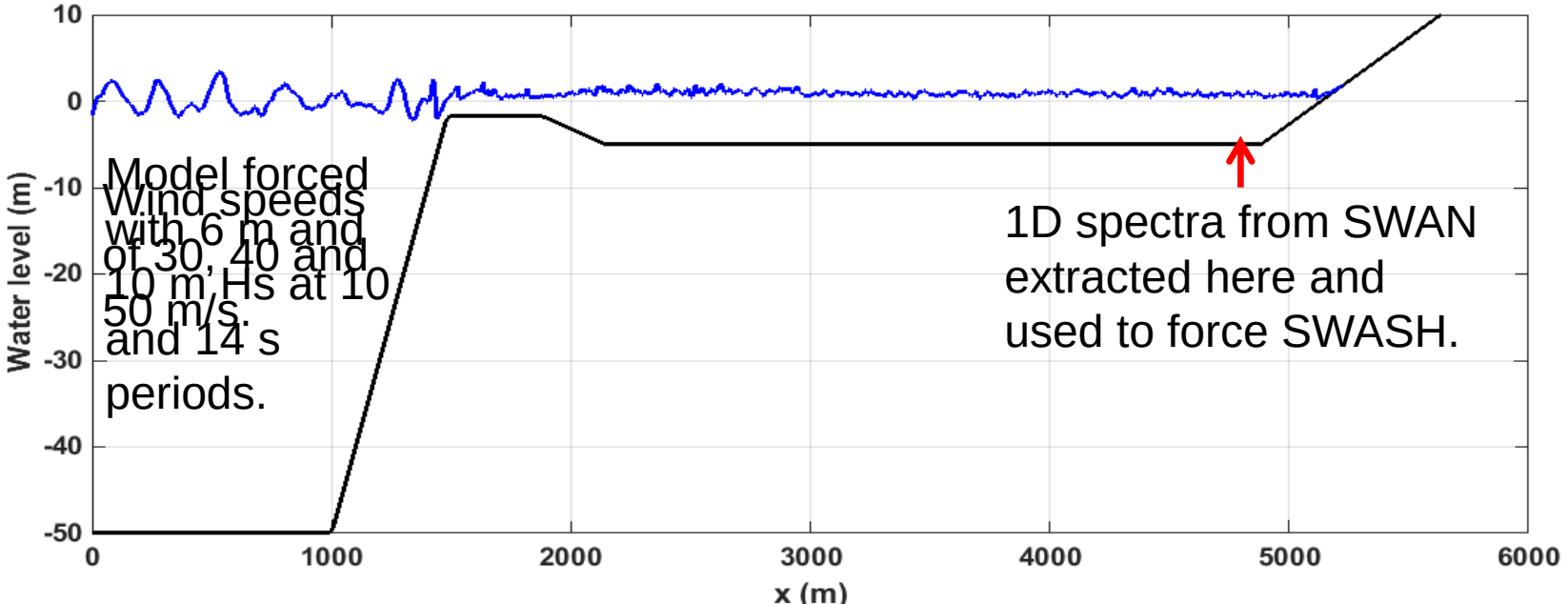
Methodology

Idealized numerical simulations of reef profiles ranging from shore attached (e.g. many Pacific islands) to barrier reefs with wide lagoons (Great Barrier Reef) to determine how lagoons impact TWL at the coast.



SWAN and SWASH models combined to predict TWL

1. SWASH (3D non-hydrostatic, 3 layers, 1 km alongshore domain) run over entire profile to predict TWL in absence of wind growth.
2. SWAN (phase-averaged) run over entire profile (1D) to predict wind growth of waves in the lagoon.
3. SWASH re-run (in 3D) using 1-D spectra from SWAN at offshore end of beach.
4. Wind setup modeled using hydrostatic SWASH simulations.



Total water level calculation

Total water level (TWL) calculated assuming linear superposition:

$$TWL = R_{sig} + \eta$$

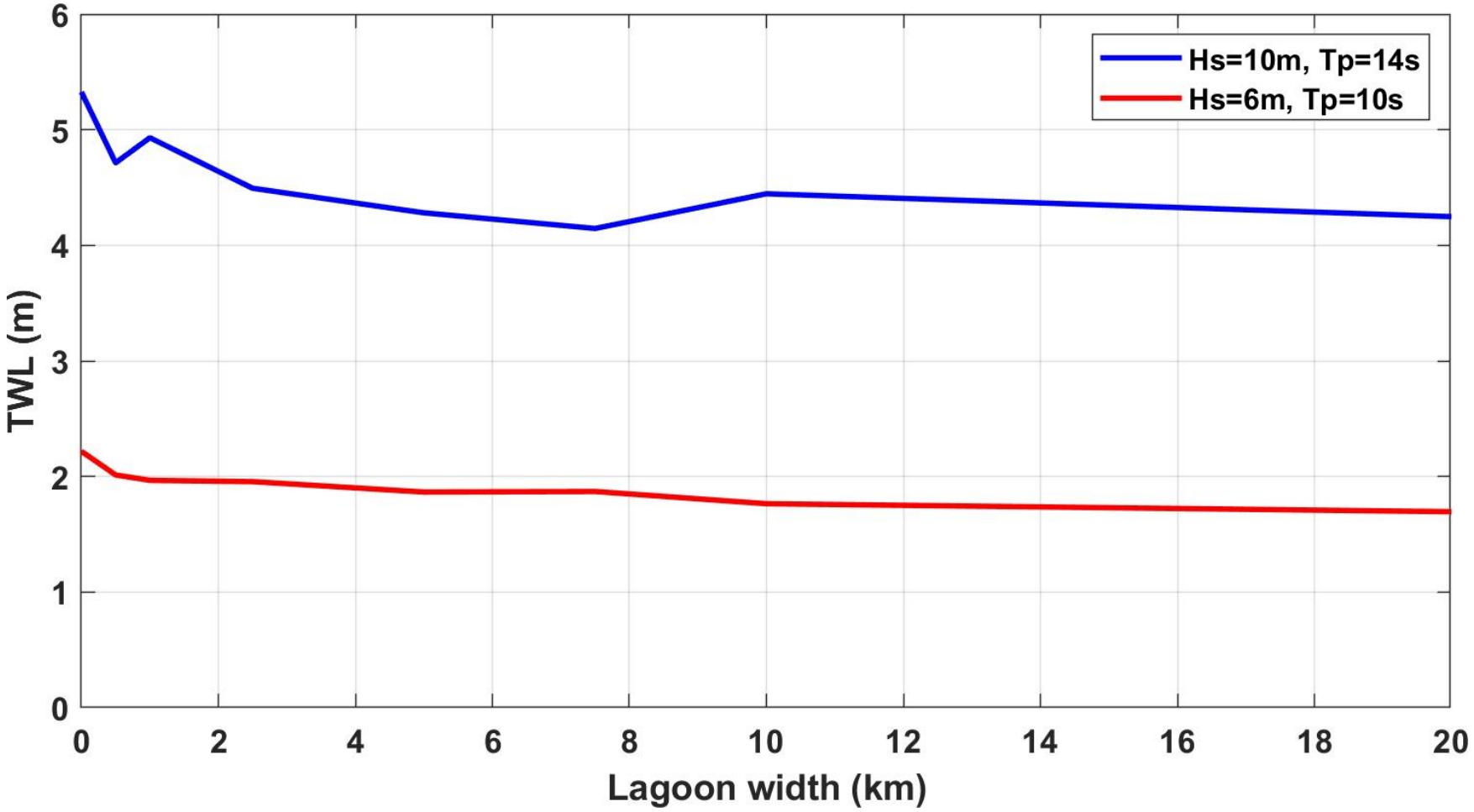
$$R_{sig} = \sqrt{R_{s1}^2 + R_{s2}^2}$$

$$\eta = \eta_{s1} + \eta_{s2} + \eta_{wind}$$

s1=SWASH over full profile
s2=SWASH forced by SWAN wind growth

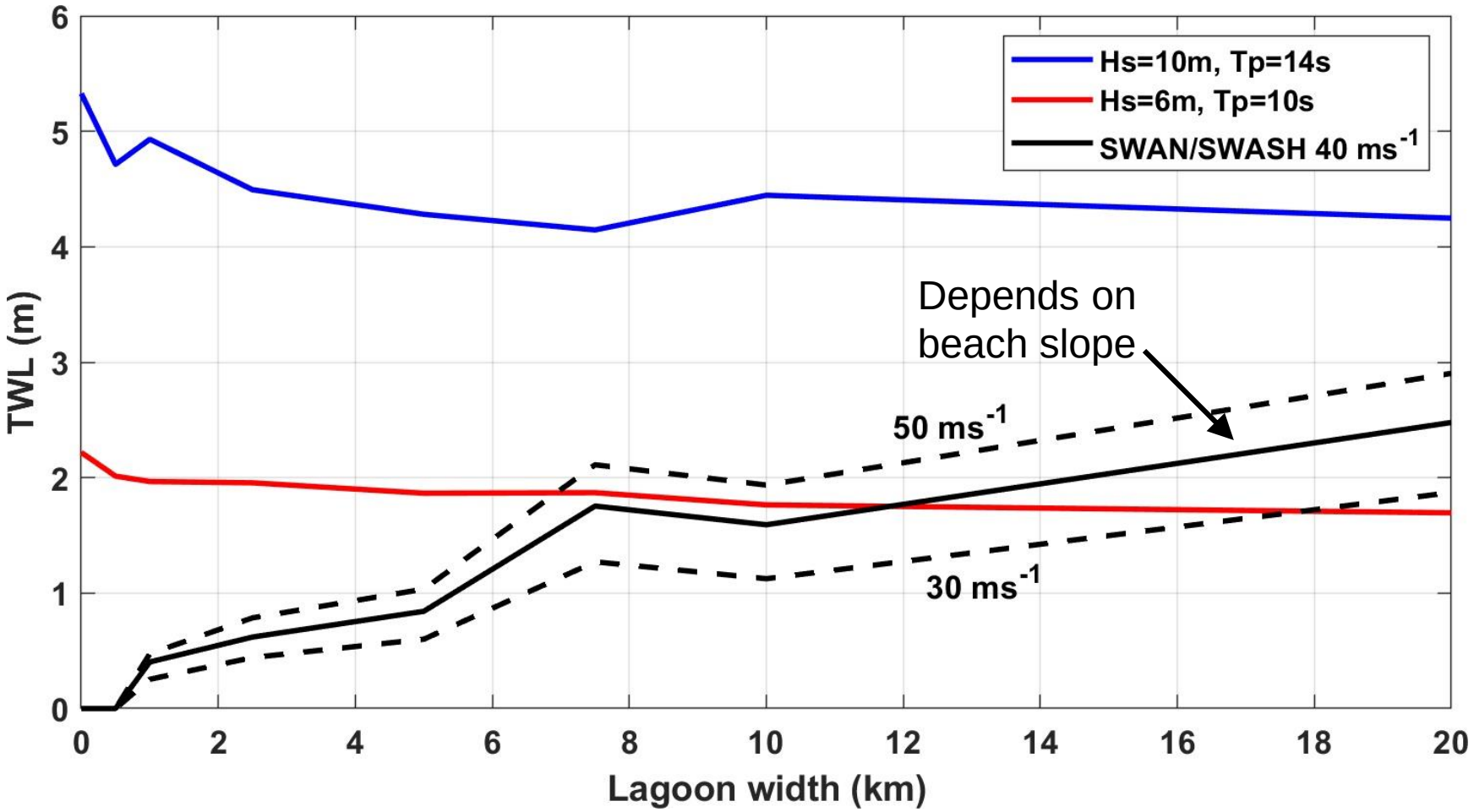
Results

SWASH only simulations (no wind growth).



Results

Including wind growth from SWAN.



Results

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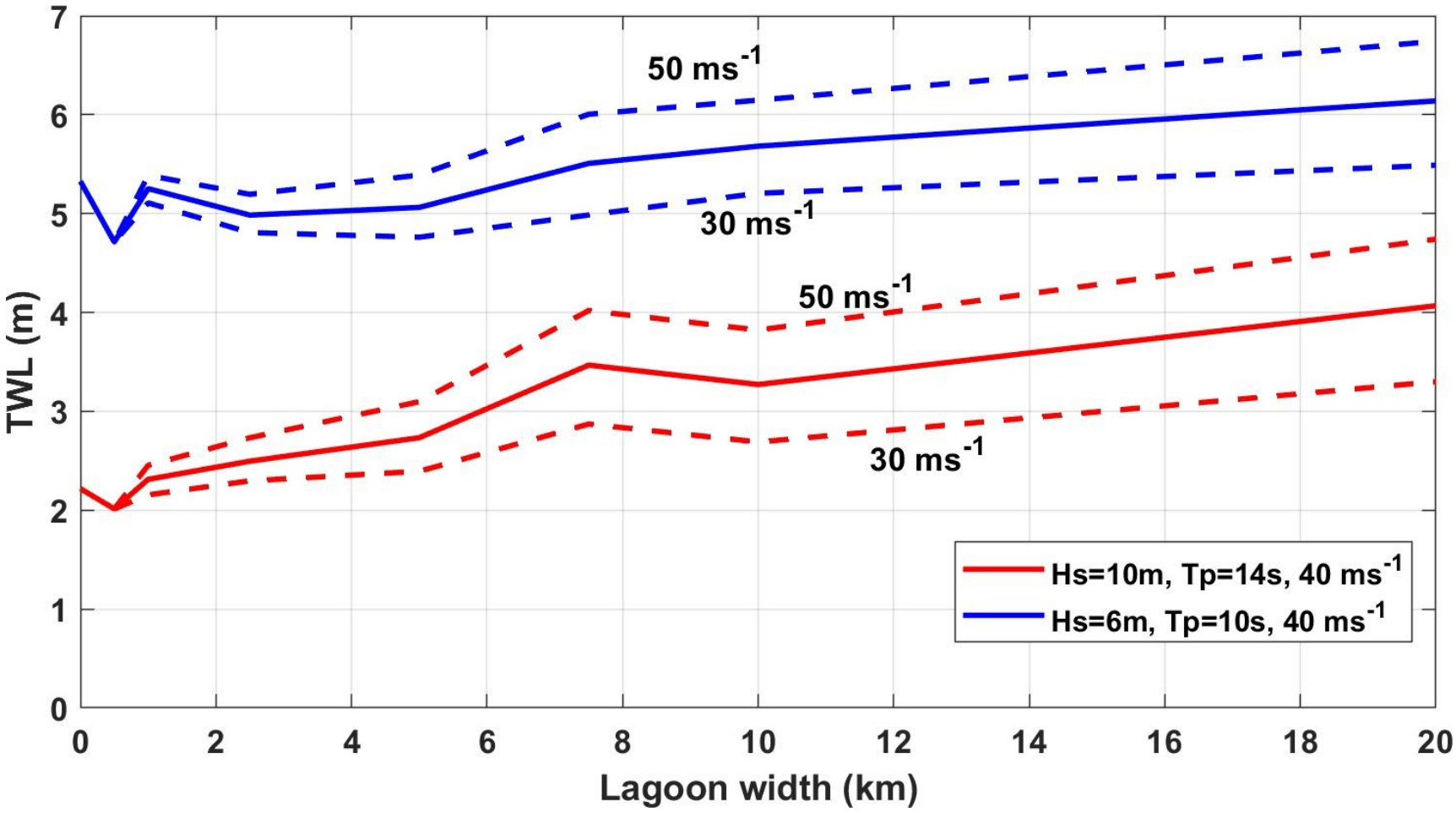
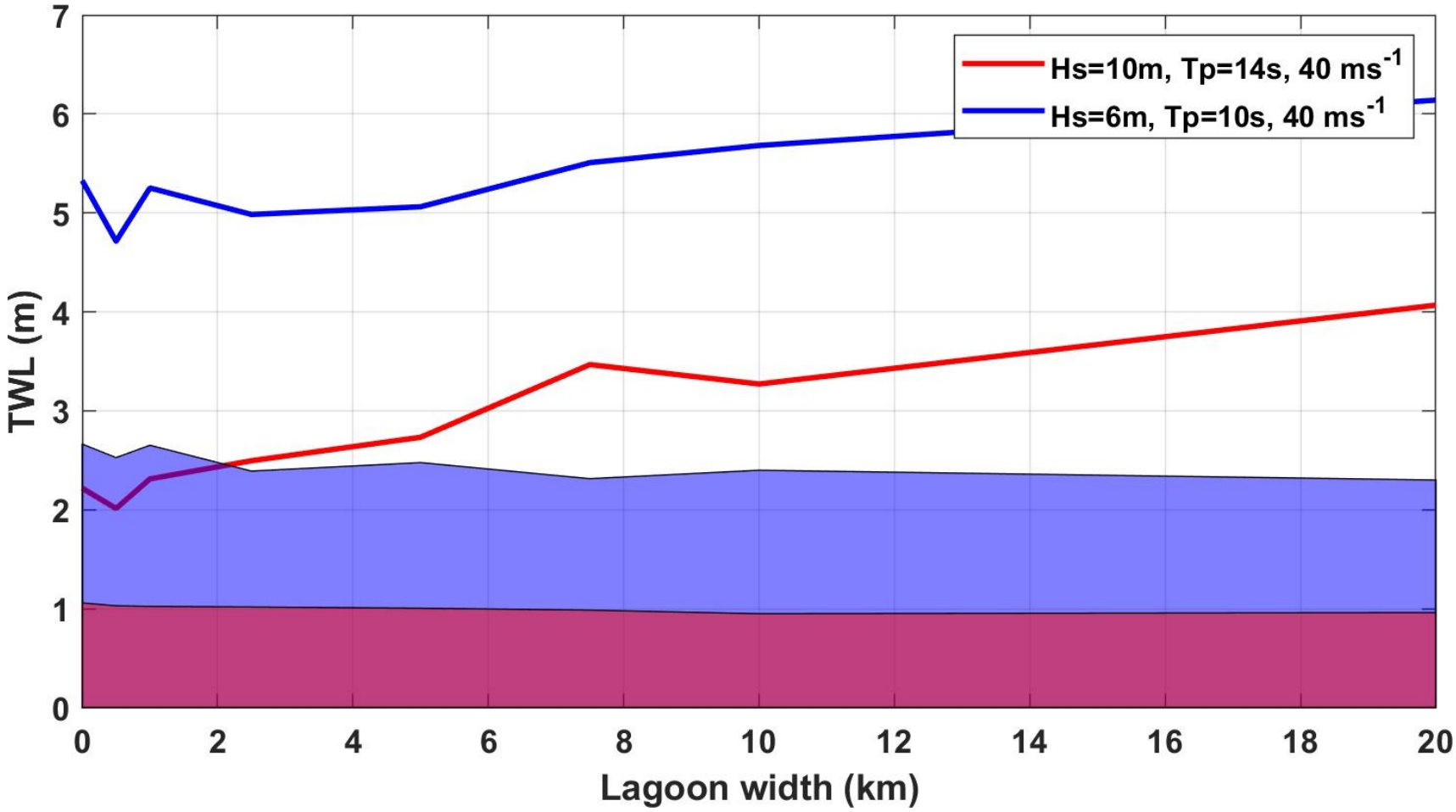
TWL with all components



Results

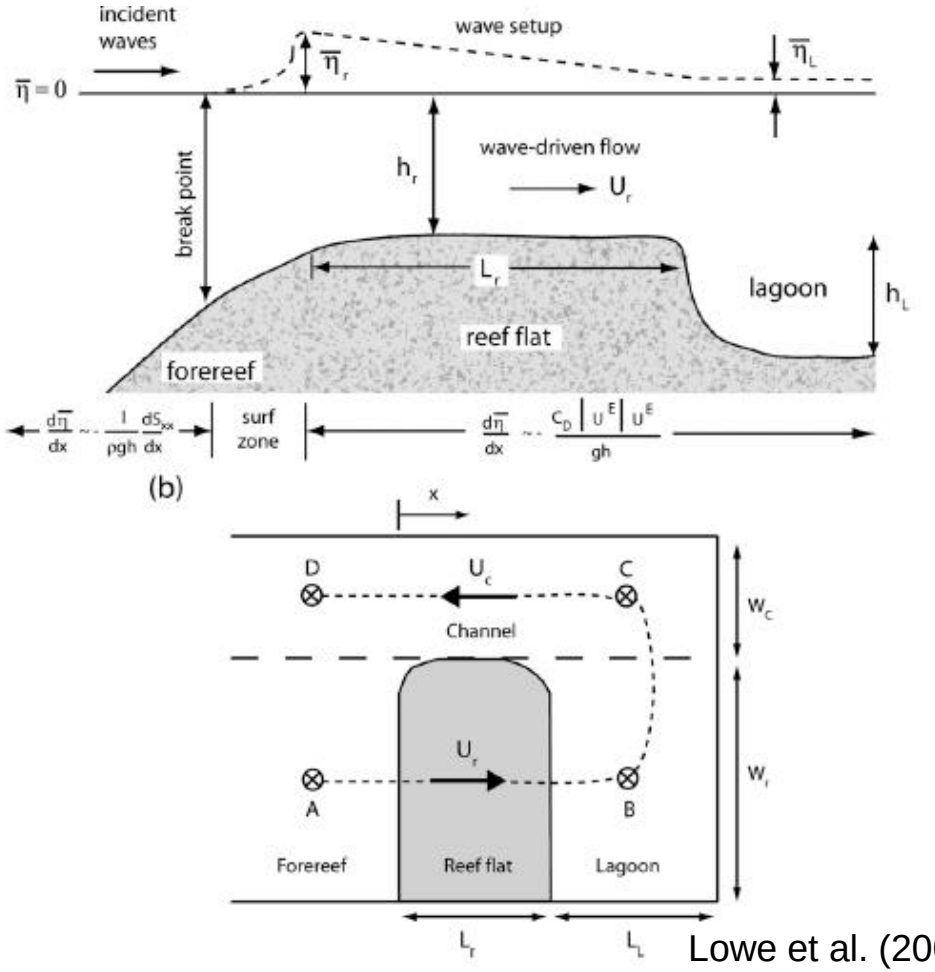
TWL with all components

- ~50% of TWL due to setup from offshore waves in lagoon.
- Assumes no lateral channels- worst case scenario



Effect of channels on setup

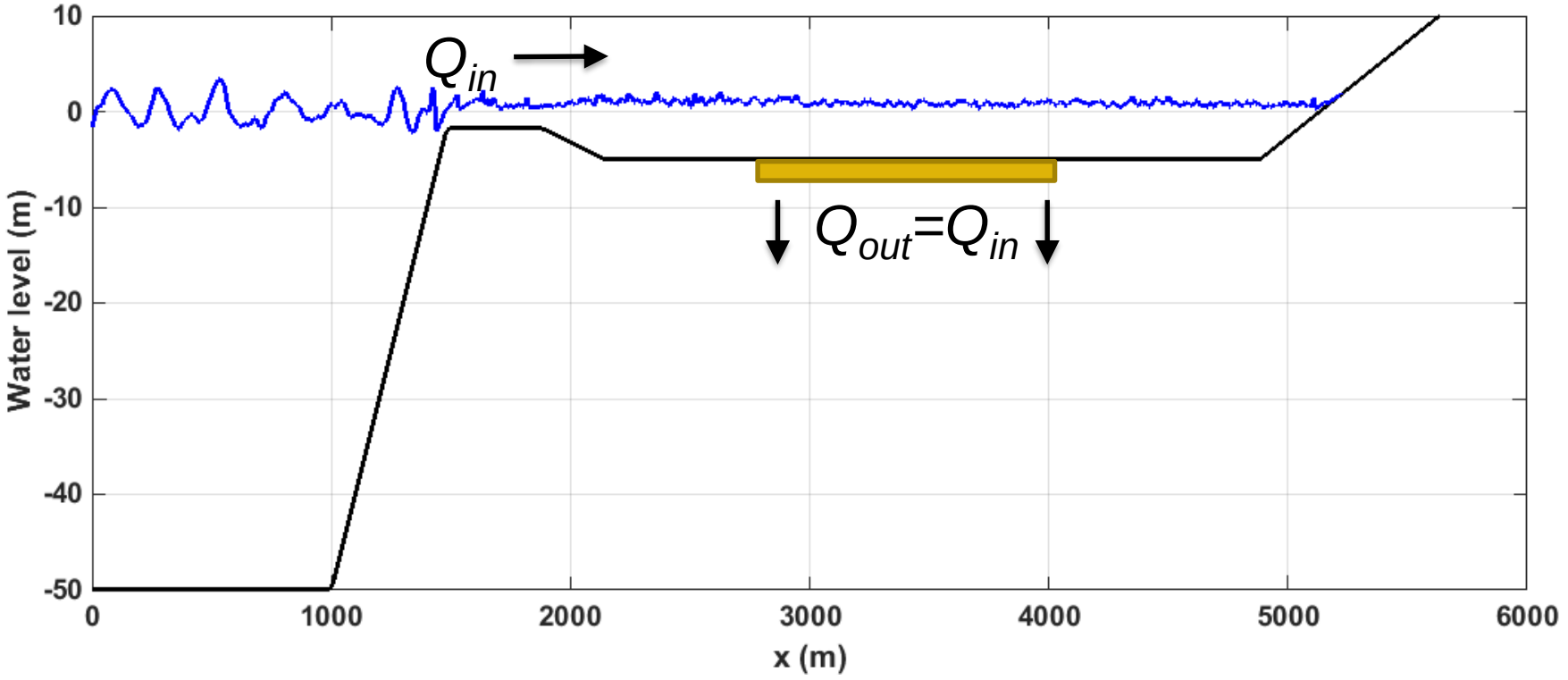
Reefs that include lagoons typically have channels that result in the wave driven setup profile “tapering” toward the shore



Lowe et al. (2009)

Methodology

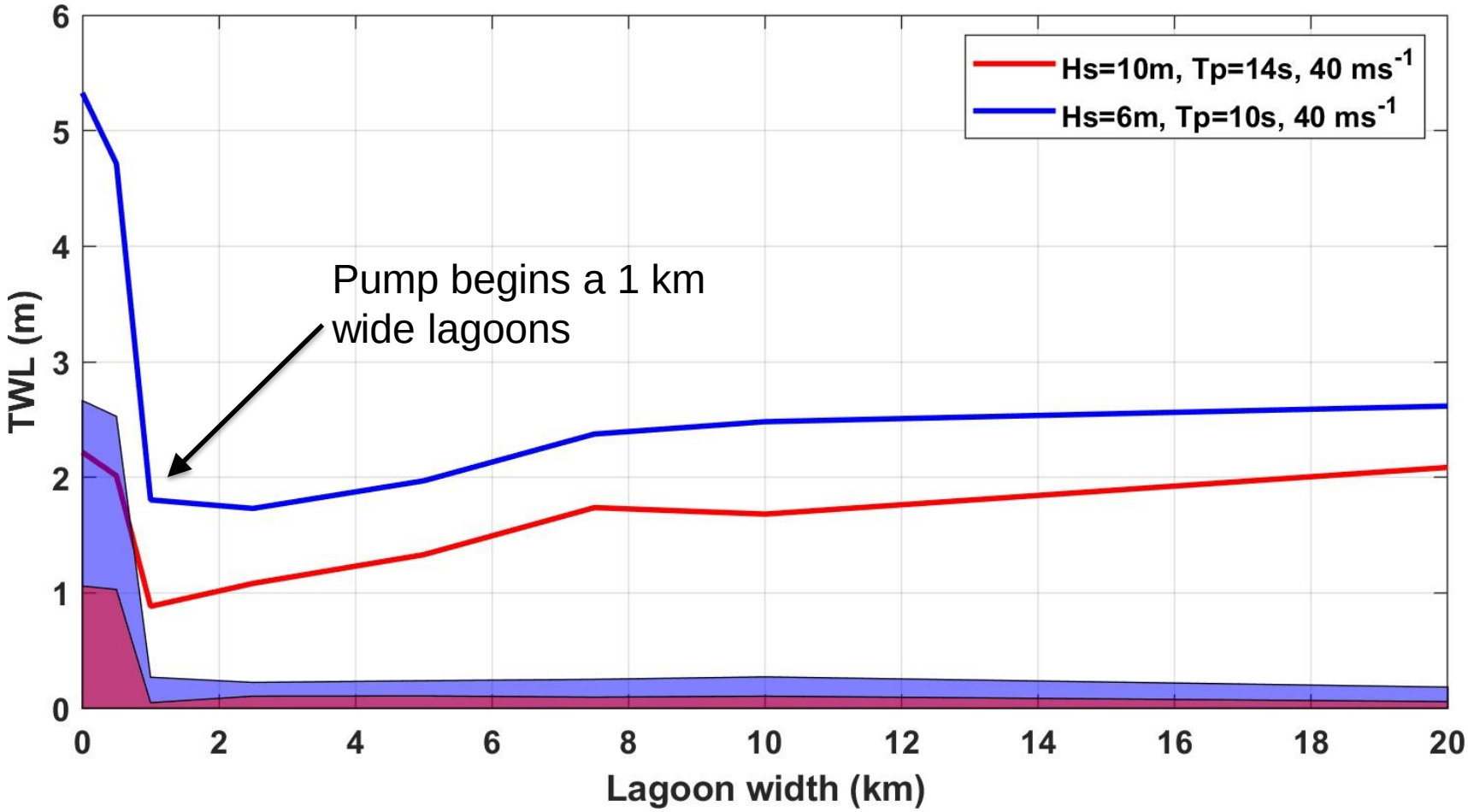
To account for lateral channels we place a “pump” in the lagoon that removes the onshore mass flux across the reef.



Results

TWL with all components including pump.

- Assumes complete outflow of onshore mass flux- best case scenario



Summary and conclusions

- Lagoons do have an impact on the coastal protection offered by reefs - but this strongly depends on the lagoon width and presence of channels.
- Wind growth is important during extreme storms, but is not included in existing models that can predict the IG motions that dominate runup.