

## Future Coastal Waves along Southeast Australia Using Regional Climate Models

**Dr. Aditya Deshmukh**, A/Prof Mitchell Harley, Prof. Jason Evans,  
and Prof. Ian Turner



Water  
Research  
Laboratory  
School of Civil and  
Environmental Engineering



Department of Climate Change,  
Energy, the Environment  
and Water



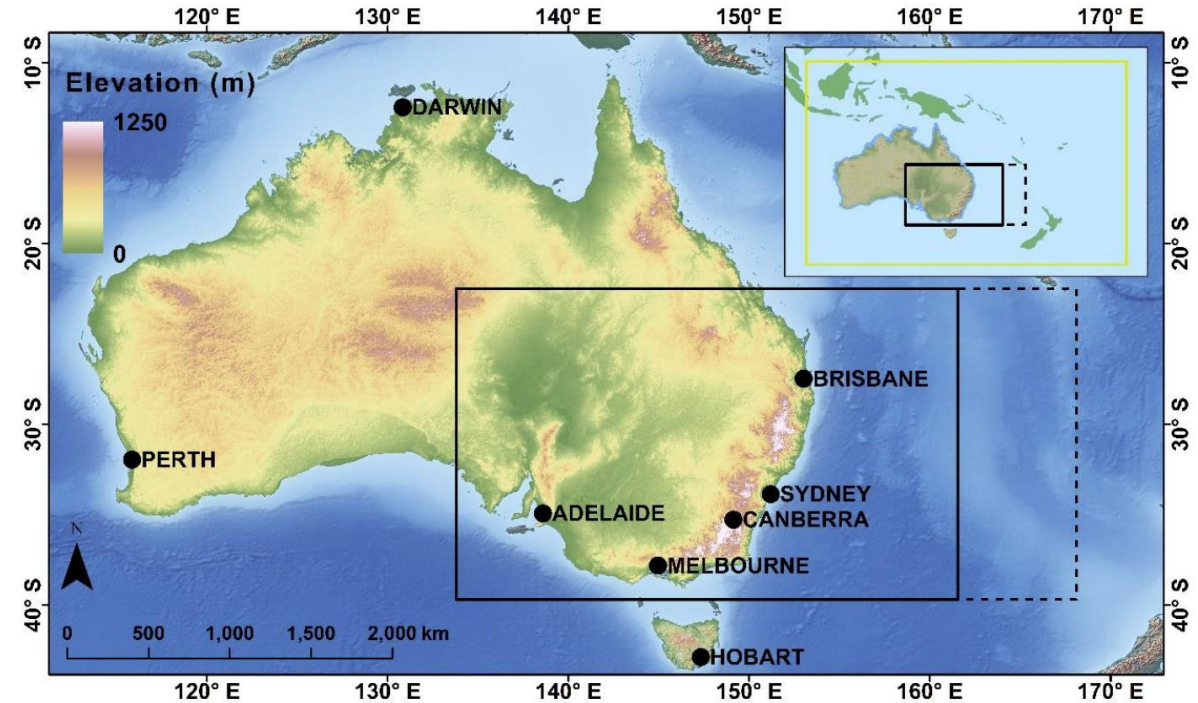
# Introduction

- Coastlines are influenced **by waves** and tides/water level
- SE Australia's coastline is **wave dominated**
- Coastal **waves projections** are crucial to safeguard coasts
- Anthropogenic climate change effects complicate projections



# Introduction

- **GCM/RCMs** are the main tool to understand past, present and future climate
- Wave models forced with GCM/RCM winds can project waves
- GCM based wave projections **not suitable for regional and local level studies**
- New South Wales (NSW)/Australian Capital Territory (ACT) Regional Climate Modelling (NARClIM) is a regional climate downscaling project
- NARClIM RCM provides an opportunity to derive regional scale wave projections

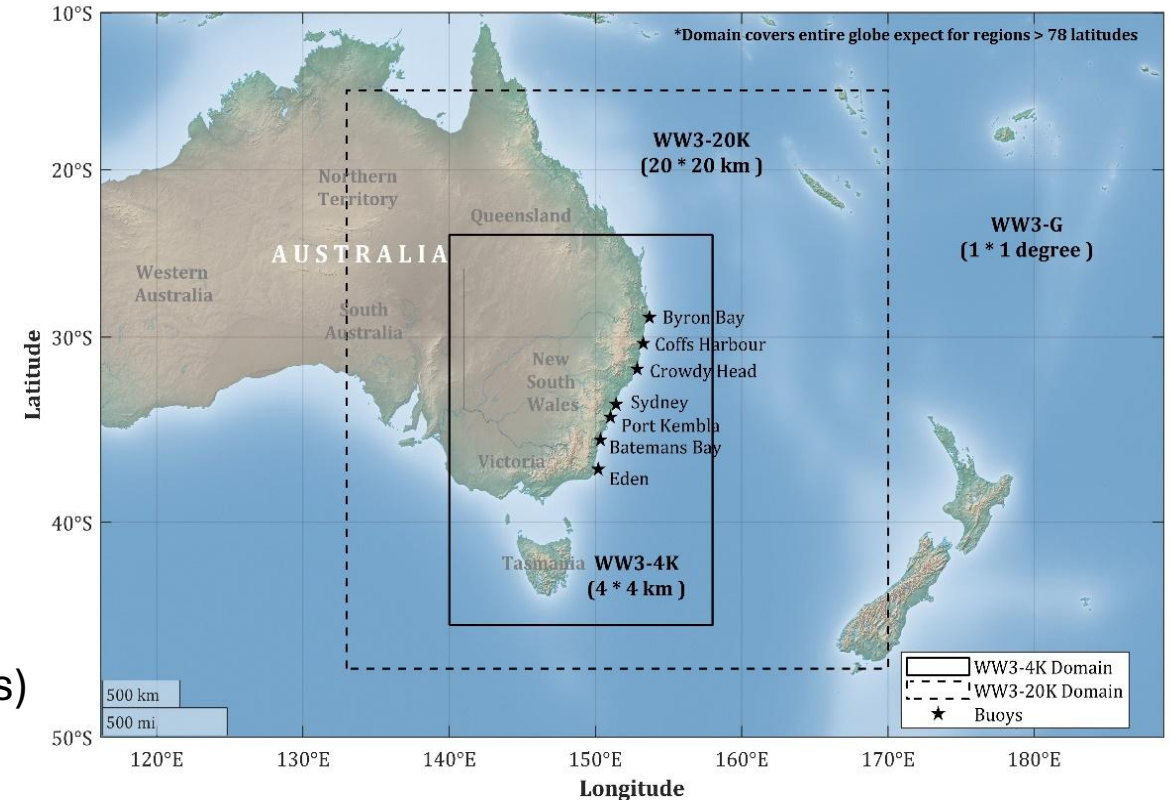


*Domain extents of NARClIM1.5 (dashed line) and NARClIM2.0 (solid line) wind model*



# Objective and Overview of Methodology

- Derived **coastal wave projections** (at seven buoy locations) using six-member **NARcliM1.5** RCM (completed) and 10-member **NARcliM2.0** RCM (ongoing)
- Improved representation through suitable bias correction technique
- Examined three aspects of the wave climate:
  - (1) **modal** conditions (50<sup>th</sup> percentile)
  - (2) **high** wave conditions (>95<sup>th</sup> percentile Hs)
  - (3) **severe** wave conditions (>99<sup>th</sup> percentile of Hs)
- The analysis is focused on bulk wave parameters Hs, Tp and Dp using time slices and continuous evolution to investigate interannual variability



*Domain extent used for NARcliM2.0 wave model simulations.*

# Coastal Wave Simulations

## **NARClIM 1.5**

**Driving GCMs:** 3 - CMIP5 based

**WRF Downscaling Configuration:** R1, R2

**Spatiotemporal Resolution:** 10 km, 1 hr

**Future Pathways:** RCP8.5, RCP4.5

**Wave Simulation Period:** 1981-2005

(historical), 2006-2100 (future)

## **NARClIM 2.0**

**Driving GCMs:** 5 - CMIP6 based

**WRF Downscaling Configuration:** R3, R5

**Spatiotemporal Resolution:** 4 km, 1 hr

**Future Pathways:** SSP1-2.6, SSP3-7.0

**Wave Simulation Period:** 1990-2014

(historical), 2015-2100 (future)

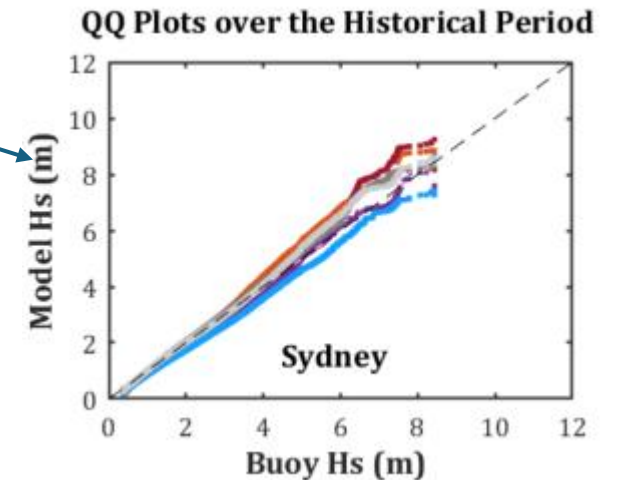
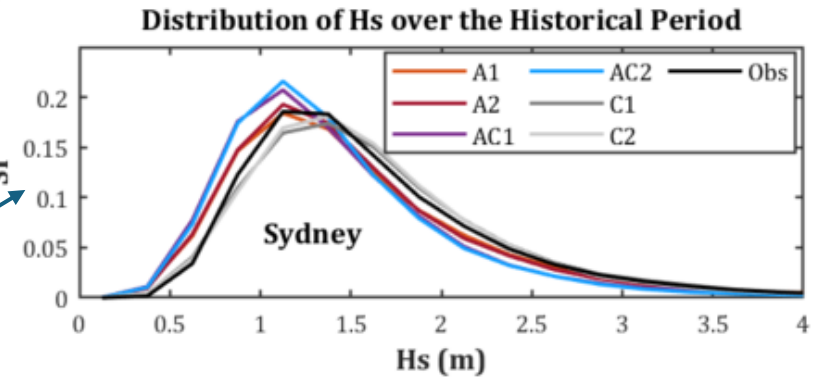
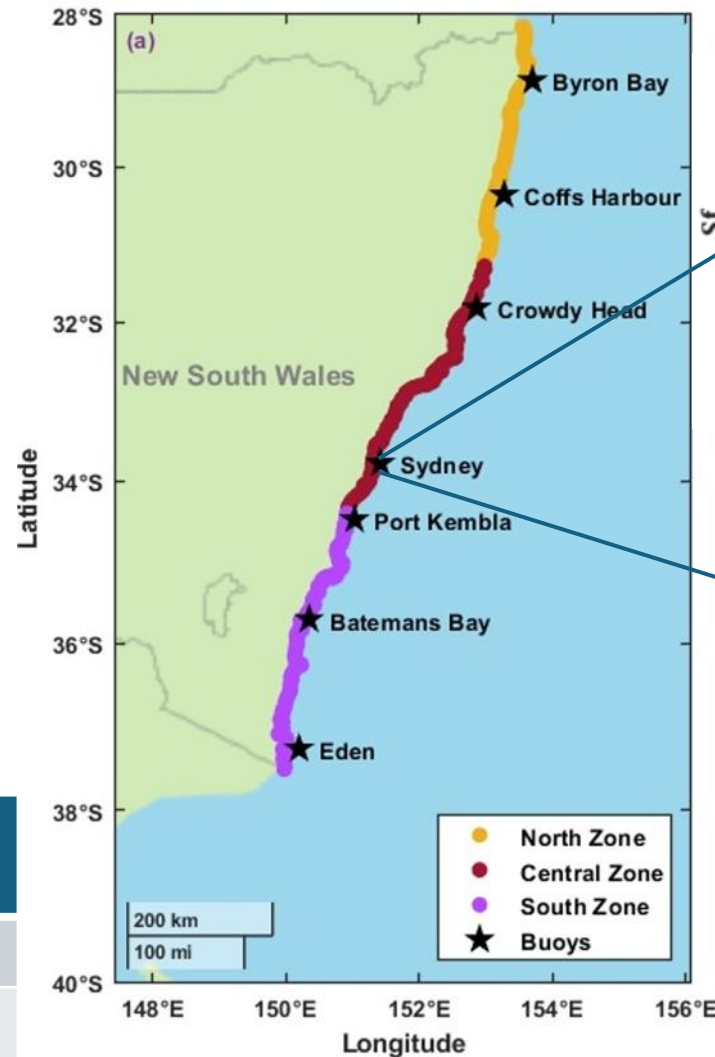
# Validation

- Bulk wave parameters were evaluated against observations from seven buoys
- Entire probability distribution** is compared to understand performance against different regimes (modal and extremes)

$$PDF - Score = \int \min(PDF_{RCM}, PDF_{Buoy})$$

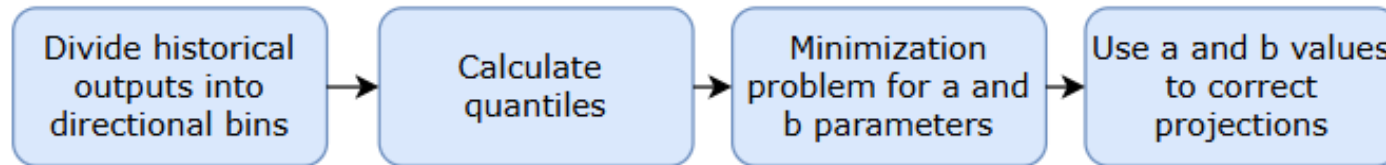
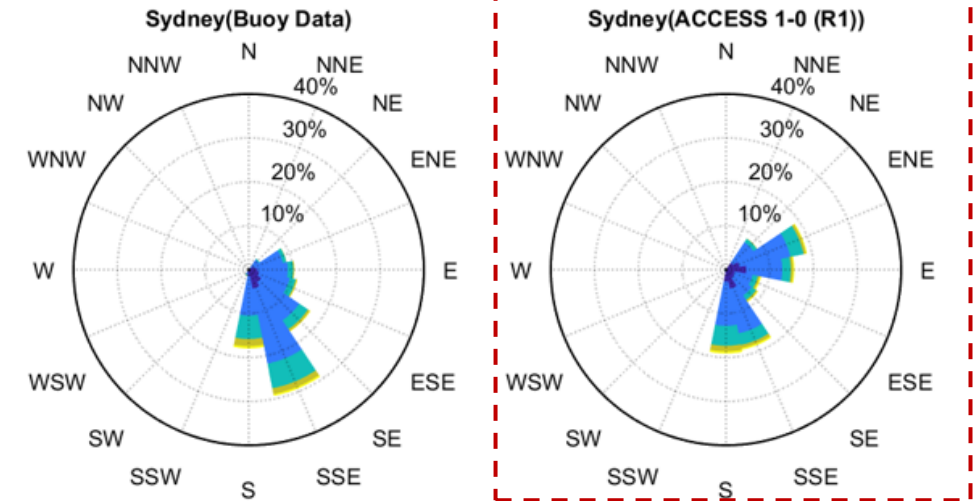
## Evaluation of six-member NARClIM1.5 RCM wave climate with observation

|                          | Hs          | Tp          |
|--------------------------|-------------|-------------|
| PDF-Score: (range 0 to1) | 0.74 - 0.98 | 0.68 - 0.81 |



# Implementation of Bias Correction Technique

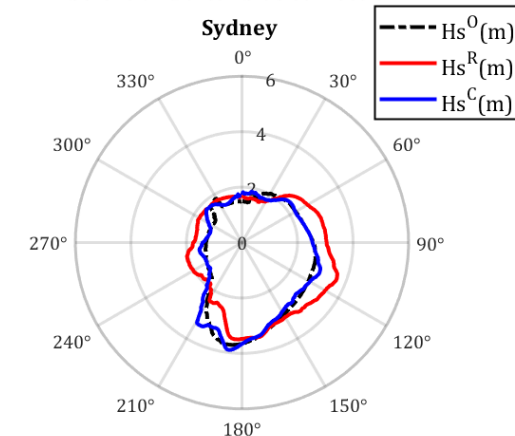
- Model output shows biases with **underestimation of southerly waves** and **overestimation of easterly waves**
- Implemented **Directionally Adjusted empirical Quantile Mapping (DAGQM)** bias correction



$$H_S^C = a^R(D_p)(H_S^R)^{b^R(D_p)} \quad (1)$$

- Bias-correction increases PDF-Score of both Hs and Tp by 25%

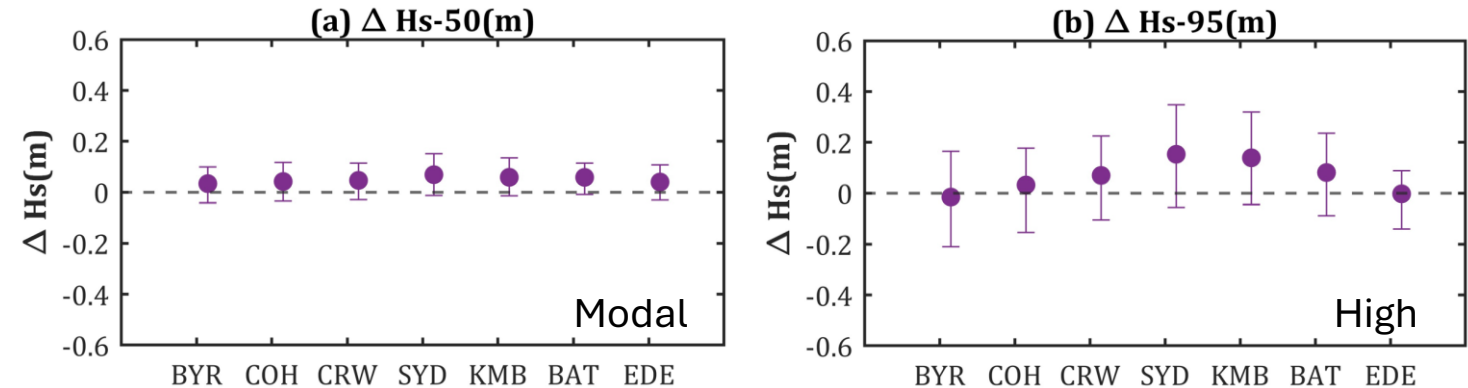
Comparison of 95<sup>th</sup> percentile Hs from A1 before and after bias correction



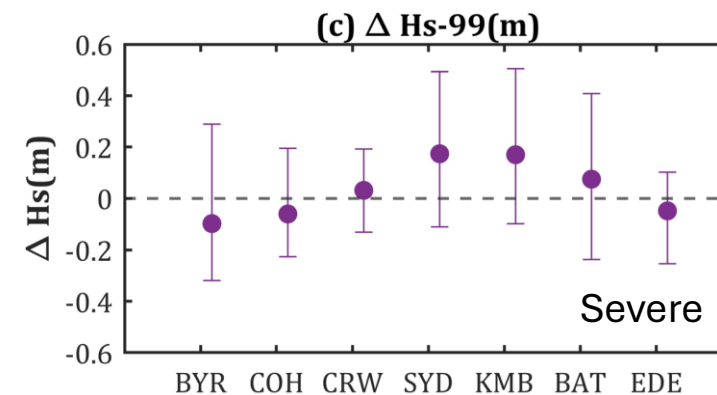
# Future Changes (NARClIM1.5) in Significant Wave Height (2075-2099) vs (1981-2005)

- Future changes depend on driving GCM
- The central region (Sydney and Port Kembla) shows relatively consistent increases in Hs for high wave conditions
- Similar trends but with reduced magnitudes for RCP4.5

Future change in Hs for RCP8.5 (2075-2099) vs (1981-2005)



| Wave condition        | Future Changes in Hs (RCP8.5) |
|-----------------------|-------------------------------|
| Modal waves (Hs-50)   | ~-0.05 to +0.15 m             |
| High waves (>Hs-95)   | -0.2 to ~+0.4 m               |
| Severe waves (>Hs-99) | -0.3 to +0.55 m               |

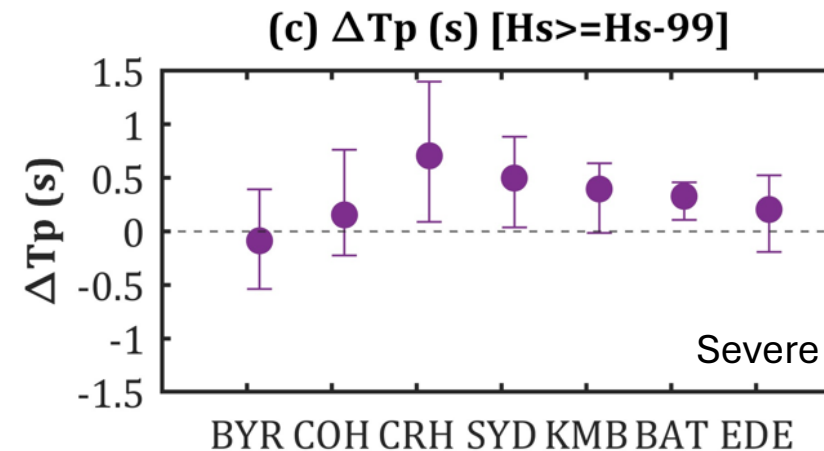
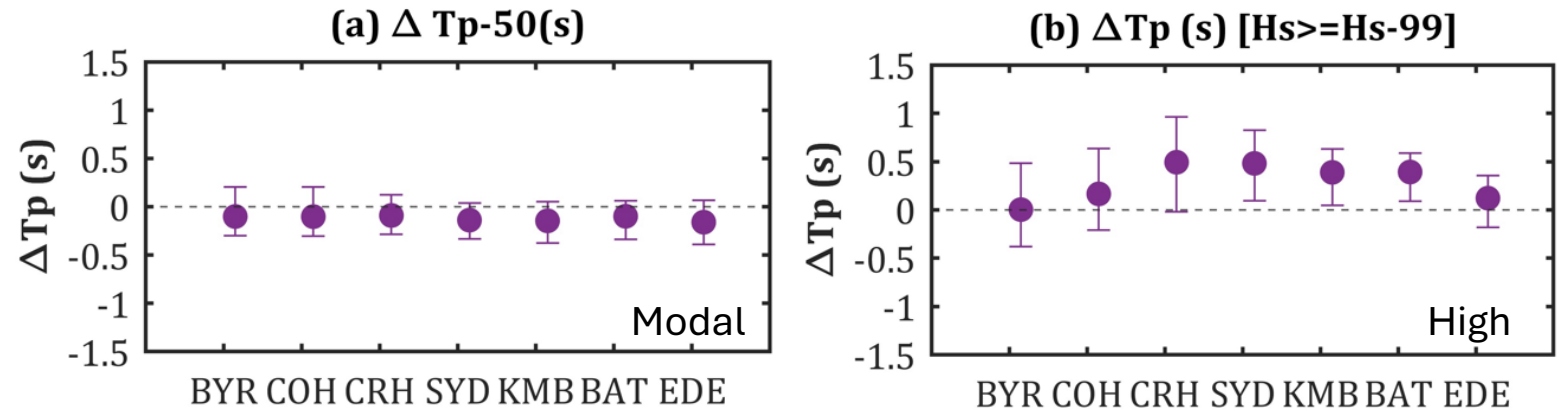




# Future Changes in Peak Wave Period (2075-2099) vs (1981-2005)

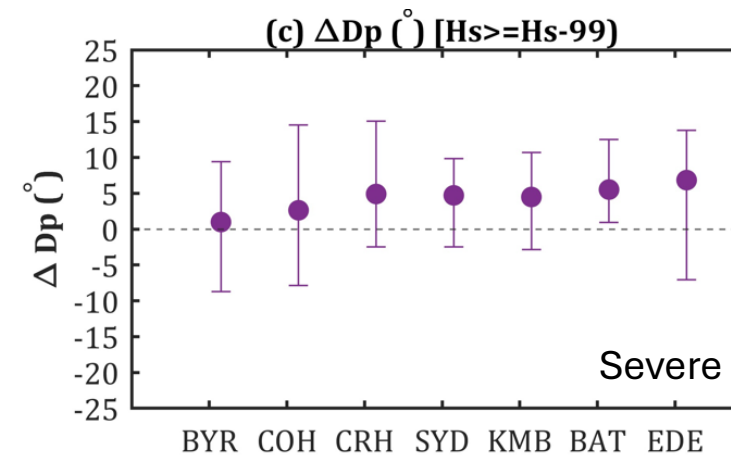
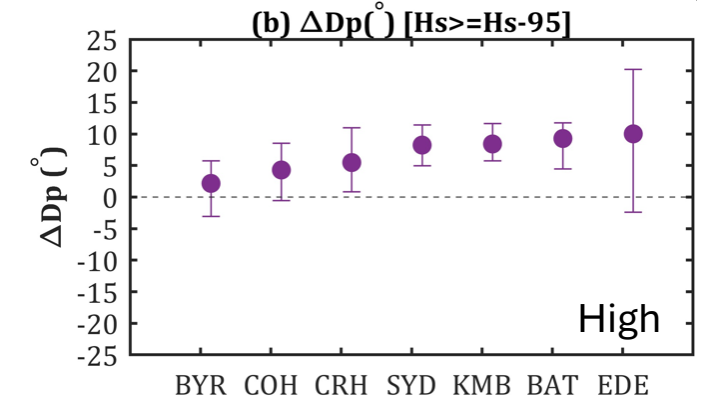
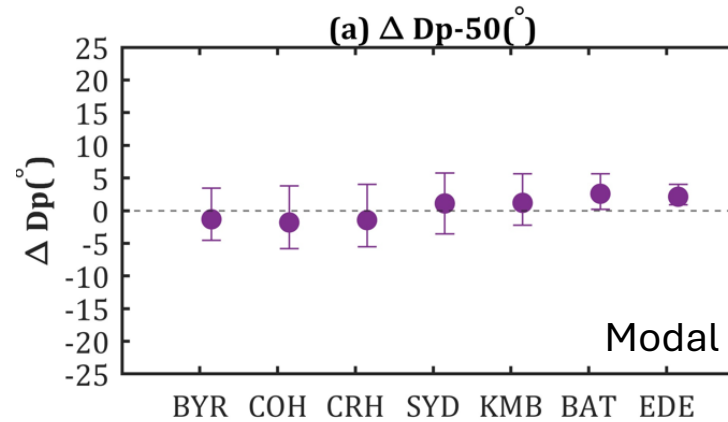
- Future changes depend on driving GCM
- The central region show consistent increases in  $T_p$  of  $\sim 0.5$  seconds
- Similar trends but with reduced magnitudes for RCP4.5

| Wave condition             | Future Changes in $T_p$ (RCP8.5) |
|----------------------------|----------------------------------|
| Modal waves (Hs-50)        | -0.3 to 0.25 s                   |
| High waves ( $>H_s-95$ )   | $\sim -0.4$ to $+1$ s            |
| Severe waves ( $>H_s-99$ ) | $-0.5$ to $\sim +1.5$ s          |



# Future Changes in Peak Wave Direction (2075-2099) vs (1981-2005)

- Consensus on more southerly waves during high and severe conditions with minimal changes in modal waves
- Southerly direction shift more prominent ( $\sim 10$  degrees) towards southern NSW
- Similar trends but with reduced magnitudes for RCP4.5



| Wave condition        | Future Changes in Dp (RCP8.5)                   |
|-----------------------|---|
| Modal waves (Hs-50)   | -6° to 6°                                       |
| High waves (>Hs-95)   | $\sim -3^{\circ}$ to $10^{\circ}$ (except Eden) |
| Severe waves (>Hs-99) | $\sim -9^{\circ}$ to $15^{\circ}$               |

# Summary of NARClIM1.5 RCM Coastal Wave Projections

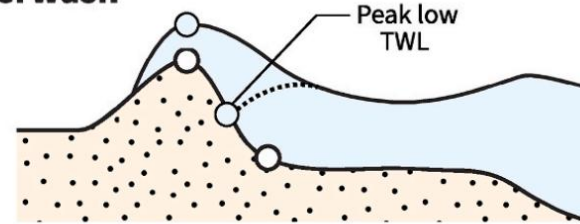
- Modal waves show minimal changes in bulk parameters Hs, Tp and Dp
- High waves (95<sup>th</sup> percentile) projected to slightly increase, particularly around Sydney
- High waves also projected to be more southerly, particularly towards southern NSW
- Results sensitive to driving GCMs
- RCP4.5 show reduced changes
- Further investigation with latest NARClIM2.0 based ensemble is required to improve confidence

| RCP8.5          |                  |                                |                 |
|-----------------|------------------|--------------------------------|-----------------|
| Wave conditions | Modal            | High                           | Severe          |
| Hs              | ~-0.5 to +0.15 m | -0.2 to ~+0.4 m                | -0.3 to +0.55 m |
| Tp              | -0.3 to 0.25 s   | ~0.4 to +1 s                   | -0.5 to ~+1.5 s |
| Dp              | -6 ° to 6 °      | ~-3 ° to 10 °<br>(except Eden) | ~-9 ° to 15 °   |

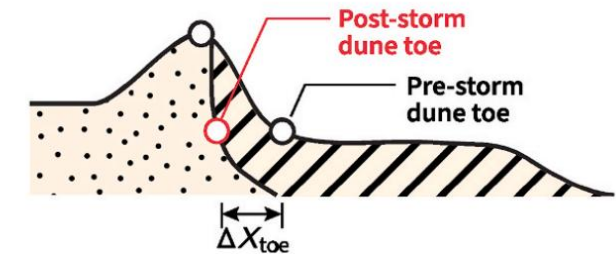
# Implications for coastal impacts

- $H_s$  and  $T_p$  increases can result in increased wave runup and overtopping of coastal structures during high wave conditions
- More southerly waves can lead to clockwise realignments of embayed beaches and potential erosion at southern extremities
- More southerly storms likely to reduce short-term erosion risk due to headland wave attenuation on this coastline
- Local studies essential for more detailed insights

**Overwash**

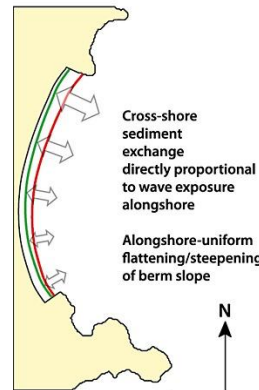


**Dune face erosion**



**(1) Wave exposure alongshore**

← 55% of variability →

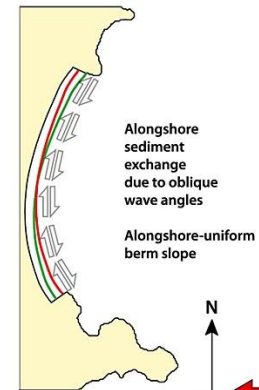


OFFSHORE  
WAVE CLIMATE



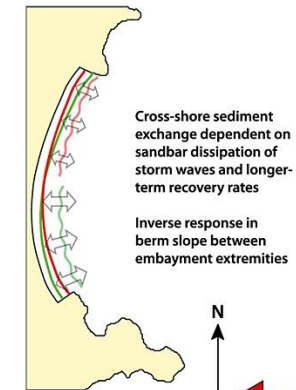
**(2) Reversing alongshore currents**

← 22% of variability →



Storm/non-  
storm  
cycles

**(3) Sandbar influences**



Longer-term  
(> 30 days)  
wave shifts

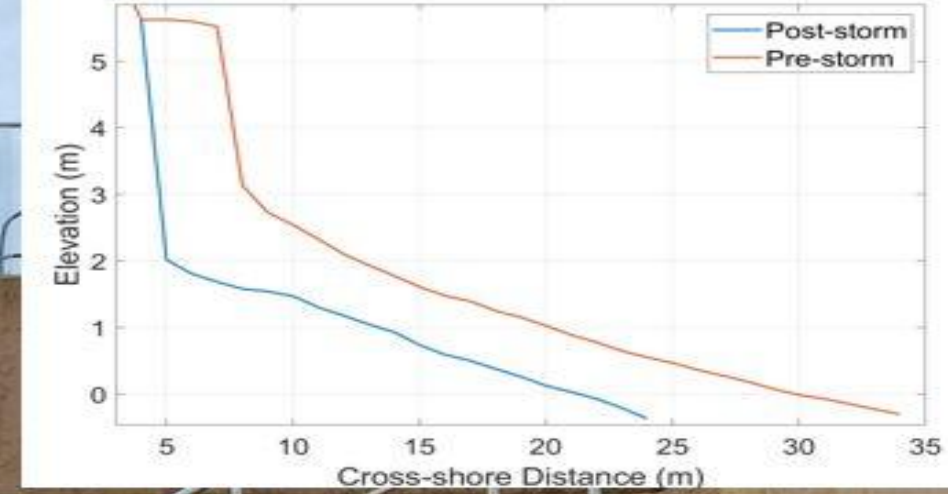
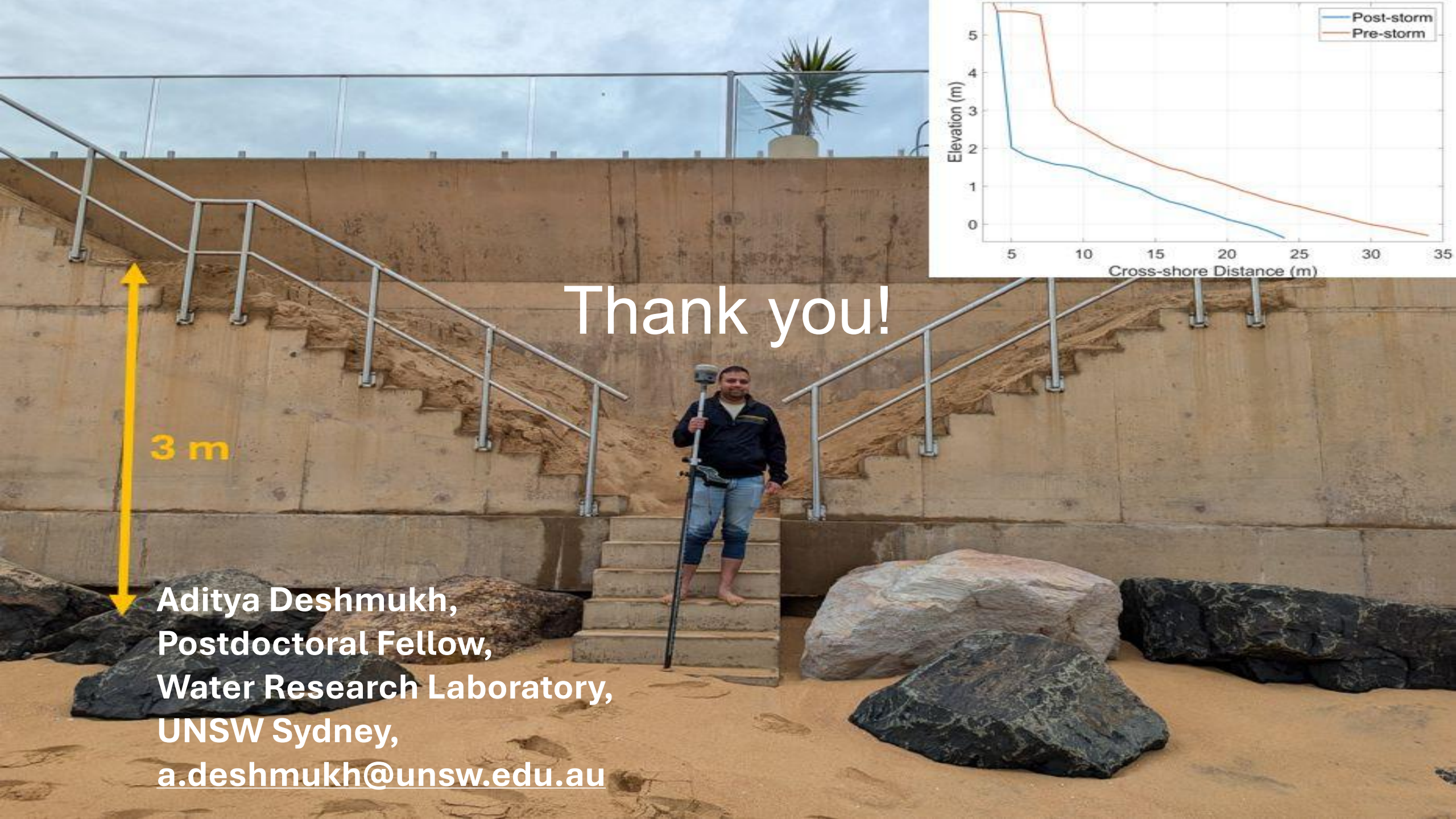
Storm and  
longer-term  
wave shifts



# NARClIM2.0 RCM Coastal Wave Projections

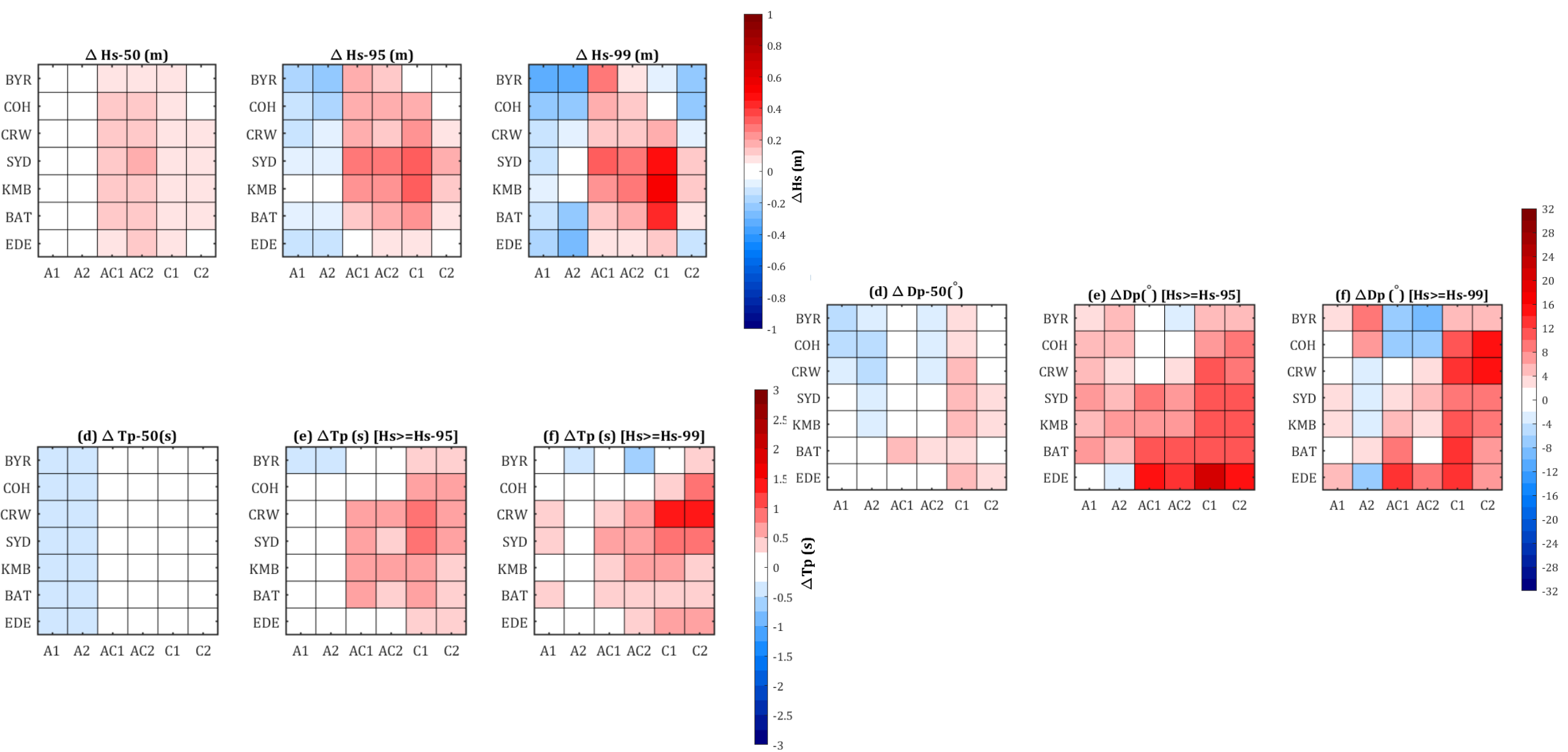


- **Version:** NARClIM2.0
- **Driving GCMs:** 5 CMIP6-based
- **WRF Downscaling configuration:** R3 and R5
- **Future Pathway:** SSP 1-2.6, SSP3-7.0
- **Spatiotemporal Resolution:** 4 km, 1 hr
- **Simulation Period:** 1990-2014 (historical), 2015-2100 (Future)



Thank you!

Aditya Deshmukh,  
Postdoctoral Fellow,  
Water Research Laboratory,  
UNSW Sydney,  
[a.deshmukh@unsw.edu.au](mailto:a.deshmukh@unsw.edu.au)



| Wave Simulation Name | NARClIM Version | CMIP  | Driving GCM   | RCM | Historical Period | Future Periods | CMIP Future Pathway  | Spatial, Temporal Resolution |
|----------------------|-----------------|-------|---------------|-----|-------------------|----------------|----------------------|------------------------------|
| A1                   | NARClIM1.5      | CMIP5 | ACCESS 1-0    | R1  | 1981-2005         | 2006-2100      | RCP8.5<br>RCP4.5     | 10 km, 1 hour                |
| A2                   |                 |       | ACCESS 1-0    | R2  |                   |                |                      |                              |
| AC1                  |                 |       | ACCESS 1-3    | R1  |                   |                |                      |                              |
| AC2                  |                 |       | ACCESS 1-3    | R2  |                   |                |                      |                              |
| C1                   |                 |       | CanESM2       | R1  |                   |                |                      |                              |
| C2                   |                 |       | CanESM2       | R2  |                   |                |                      |                              |
| AE1                  | NARClIM2.0      | CMIP6 | ACCESS-ESM1-5 | R3  | 1990-2014         | 2015-2100      | SSP1-2.6<br>SSP3-7.0 | 4 km, 1 hour                 |
| AE2                  |                 |       | ACCESS-ESM1-5 | R5  |                   |                |                      |                              |
| EC1                  |                 |       | EC-Earth3-Veg | R3  |                   |                |                      |                              |
| EC2                  |                 |       | EC-Earth3-Veg | R5  |                   |                |                      |                              |
| NM1                  |                 |       | NorESM2-MM    | R3  |                   |                |                      |                              |
| NM2                  |                 |       | NorESM2-MM    | R5  |                   |                |                      |                              |
| MP1                  |                 |       | MPI-ESM1-2-HR | R3  |                   |                |                      |                              |
| MP2                  |                 |       | MPI-ESM1-2-HR | R5  |                   |                |                      |                              |
| UK1                  |                 |       | UK-ESM1-0-LL  | R3  |                   |                |                      |                              |
| UK2                  |                 |       | UK-ESM1-0-LL  | R5  |                   |                |                      |                              |