THE UNIVERSITY OF WESTERN AUSTRALIA

Australia is different: an oceanic wave climate for offshore wind

Jana Orszaghova, Paul H. Taylor, Hugh Wolgamot, Guy McCauley, Adi Kurniawan

Australian Research Council BLUE ECONOMY COOPERATIVE RESEARCH CENTRE

Challenger waves meeting, Imperial College, 23rd June 2026

Contents - mostly physical oceanography / geophysics aimed at Offshore Wind Turbines

- Wind resource

- Wave environment
- Persistence and seasonality
- Extremes

} comparisons to North Atlantic / North Sea

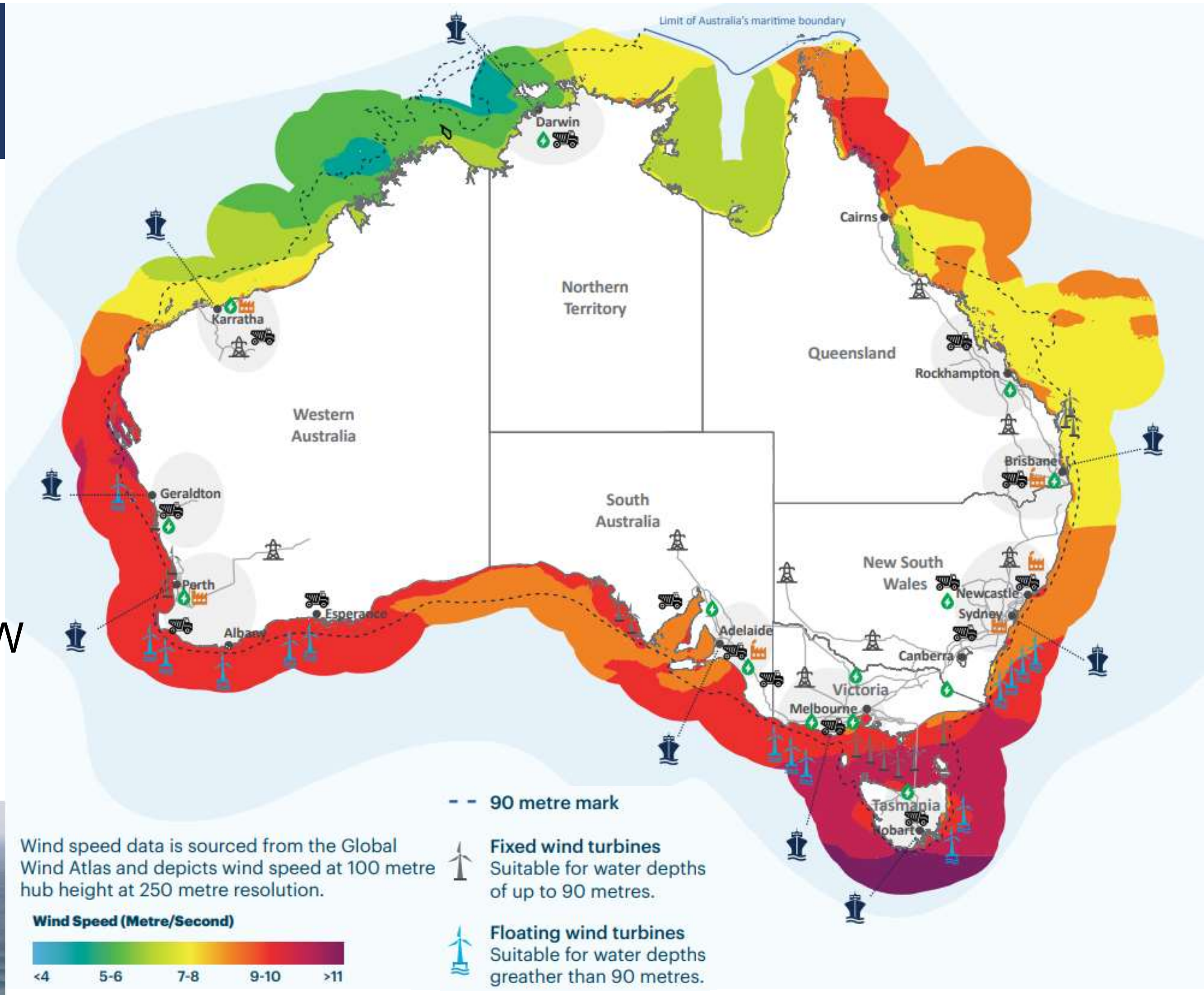
- Fixed OWT wave loading
- Implications for design

- Are Australian conditions unique?

World-class wind resource

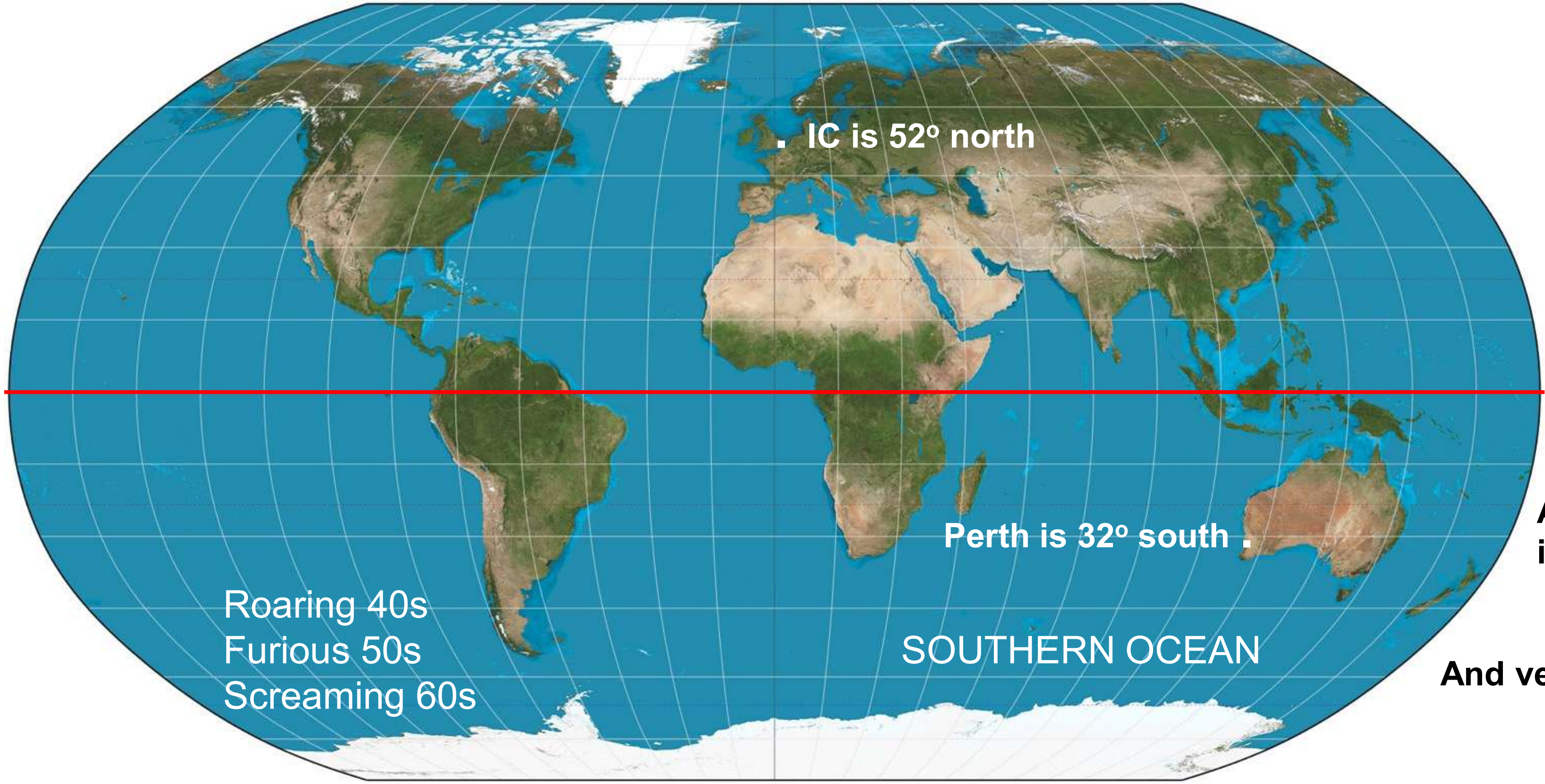
- High wind speeds along SW, S and SE coasts
- High capacity factors
- Better than on-shore

→ continuous swell waves from SSW-SW



Source: Offshore Infrastructure Regulator
https://www.oir.gov.au/sites/default/files/Offshore%20Wind%20Energy%20Brochure.pdf

Where is Australia ?



Australia
is NOT very far south!

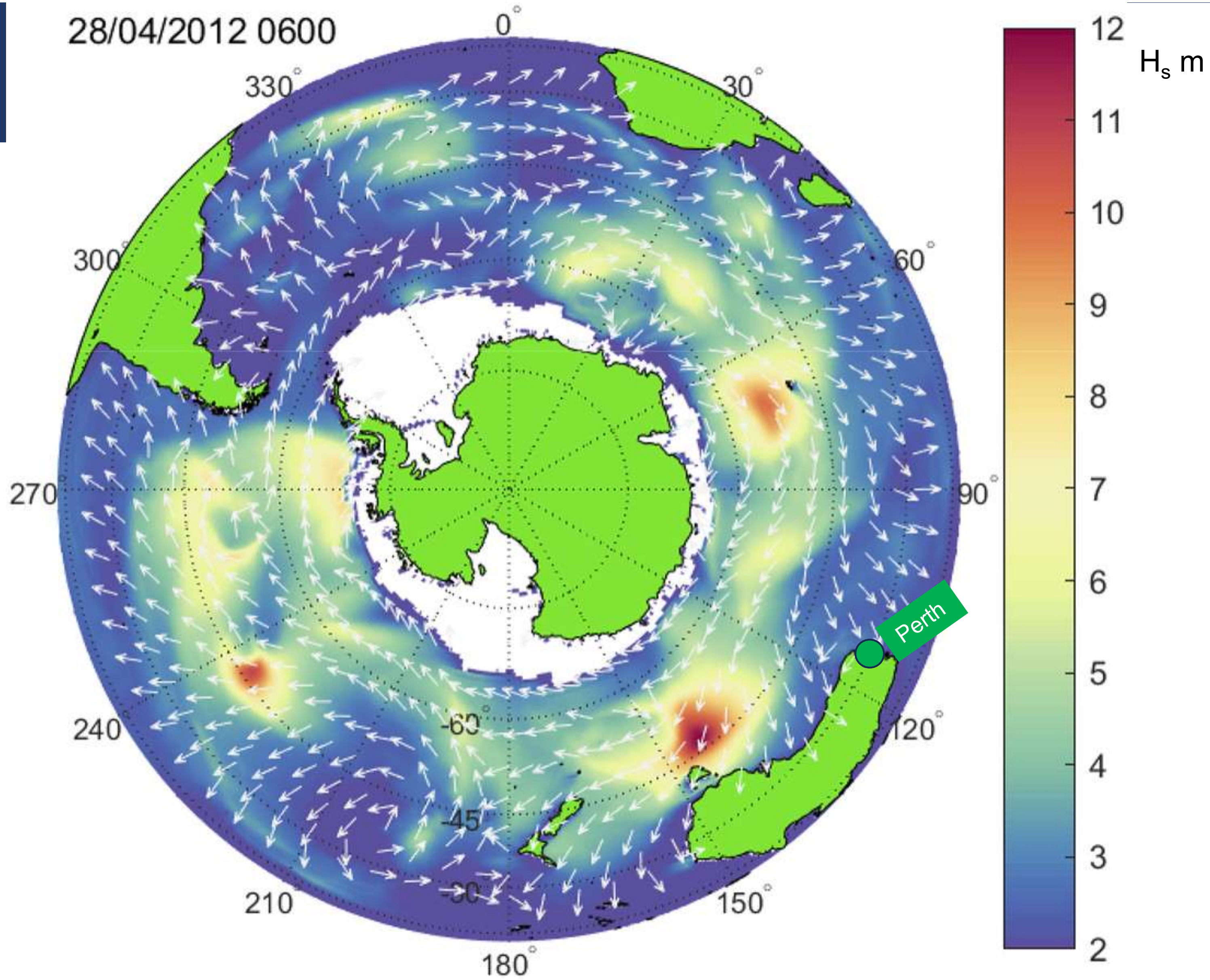
And very large gap to Antarctica

https://en.wikipedia.org/wiki/File:Robinson_projection_SW.jpg

Antarctica and the Southern Ocean

WAVES

circulate around Antarctica, swell leaks northwards to Australia



Source: Young et al. 2020, Journal of Physical Oceanography, https://doi.org/10.1175/JPO-D-20-0031.1

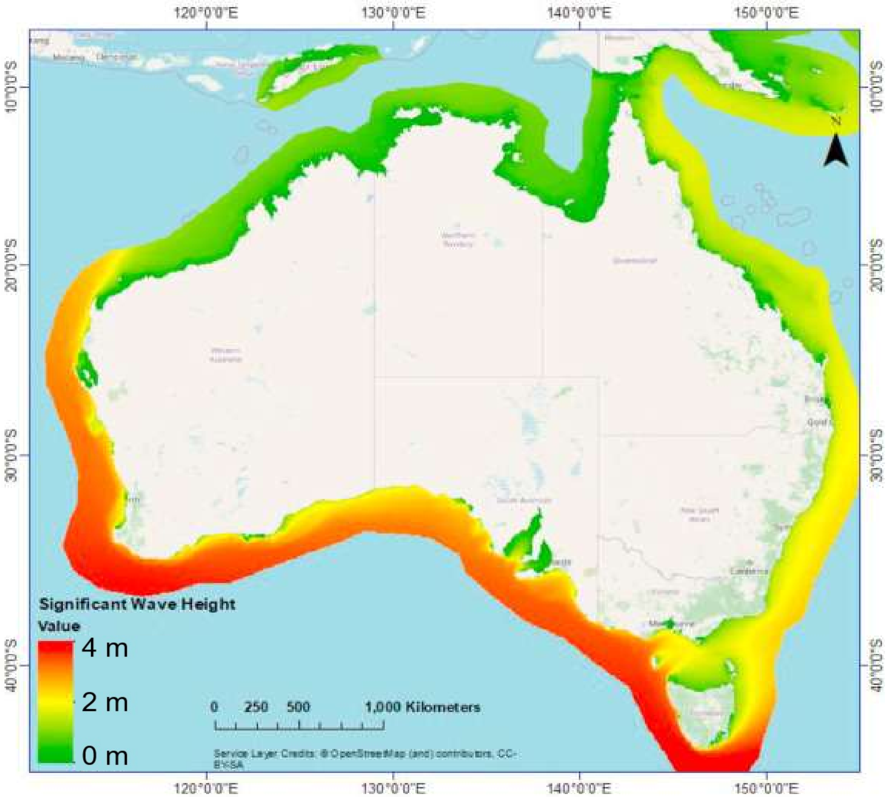
Australian wave climate – variation of (Hs, Te …) over long times (>1year)

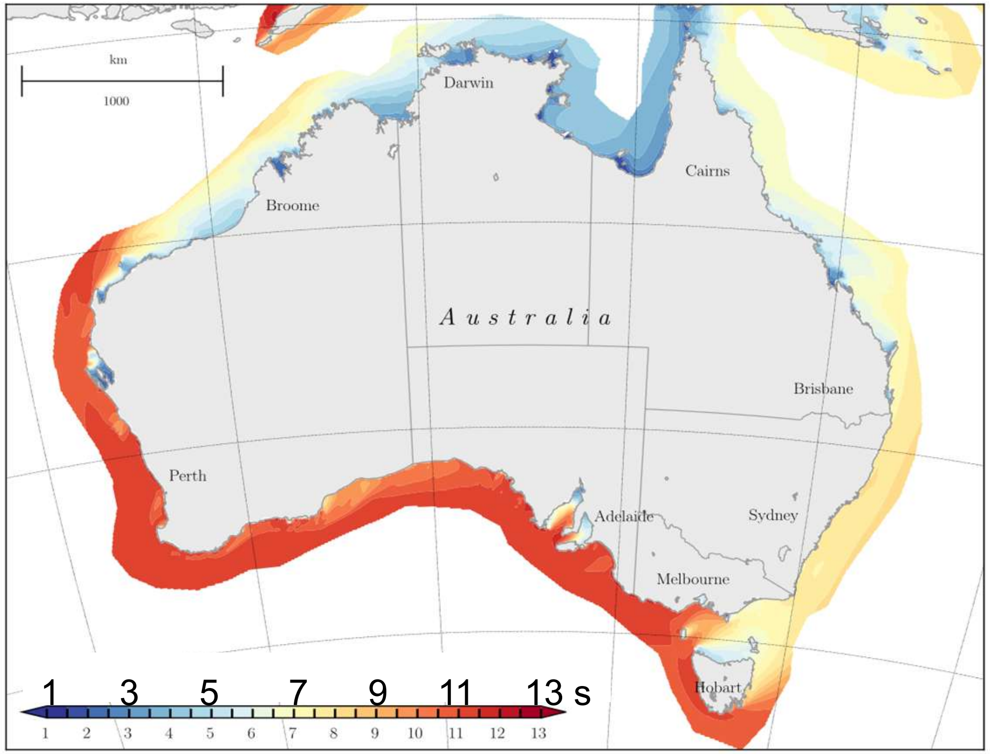
Significant wave height H_s

annual mean ~ **4 m**

Wave energy period T_e

annual mean ~ **11 s**





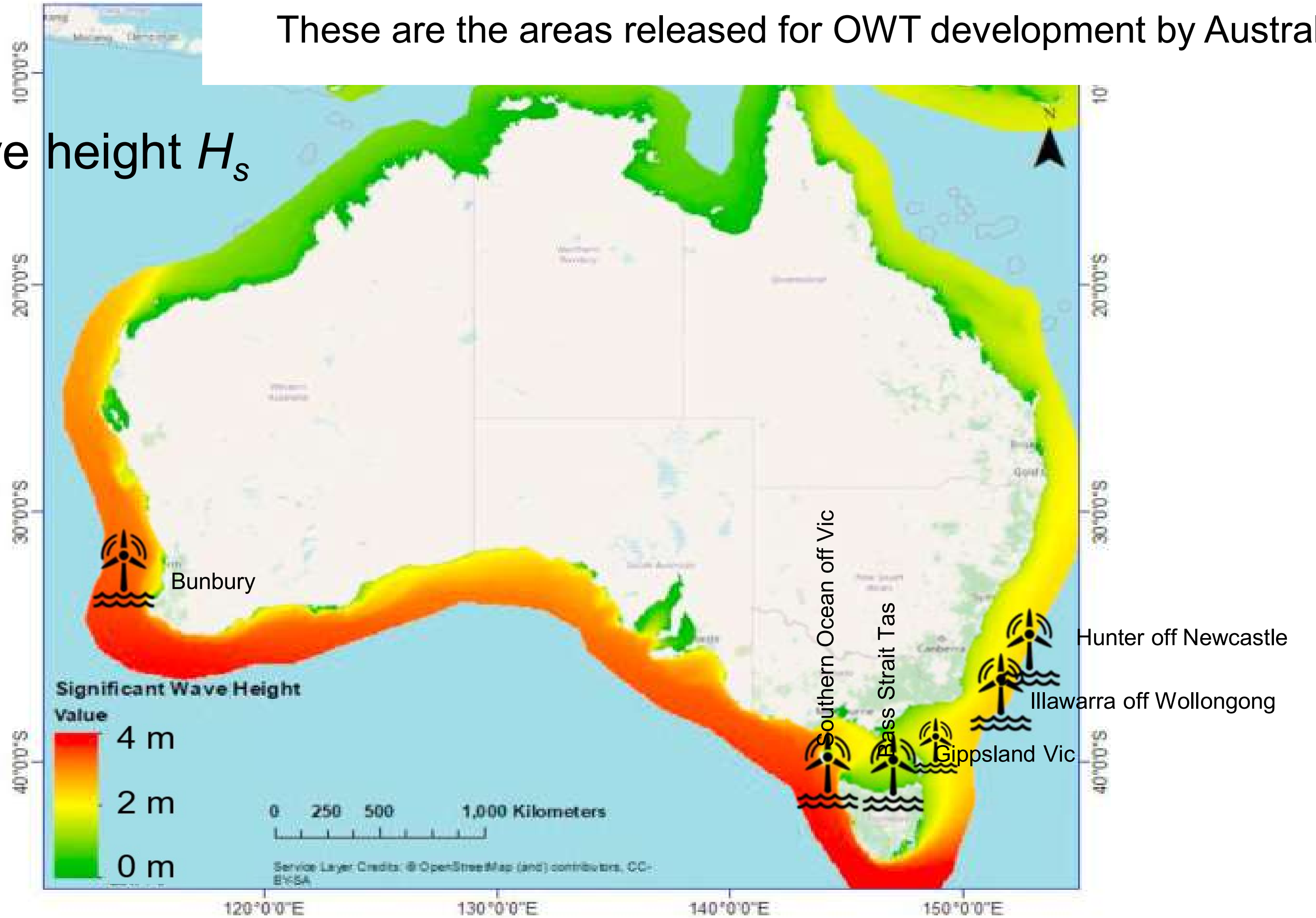
Source: Marsh et al. 2021, Renewable Energy, https://doi.org/10.1016/j.renene.2021.04.093 and Hemer et al. 2017, Renewable Energy, https://doi.org/10.1016/j.renene.2016.08.039

Australian waves

All 6 offshore wind zones influenced by the Southern Ocean

These are the areas released for OWT development by Australian federal gov.

Significant wave height H_s
(annual mean)



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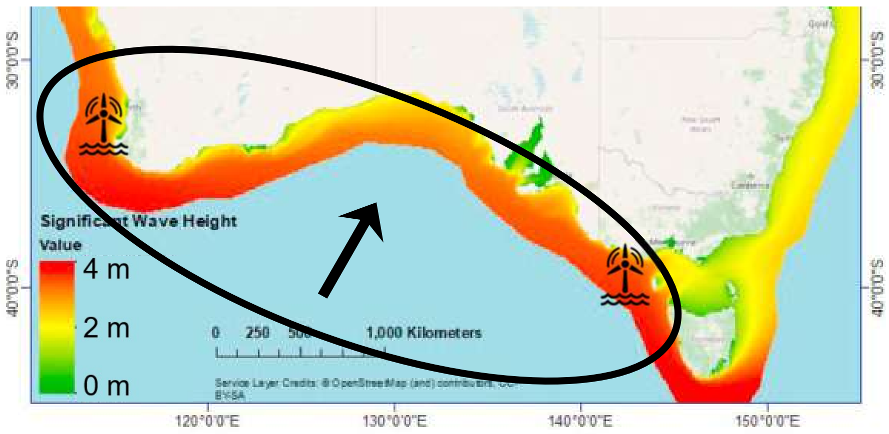
Australian waves

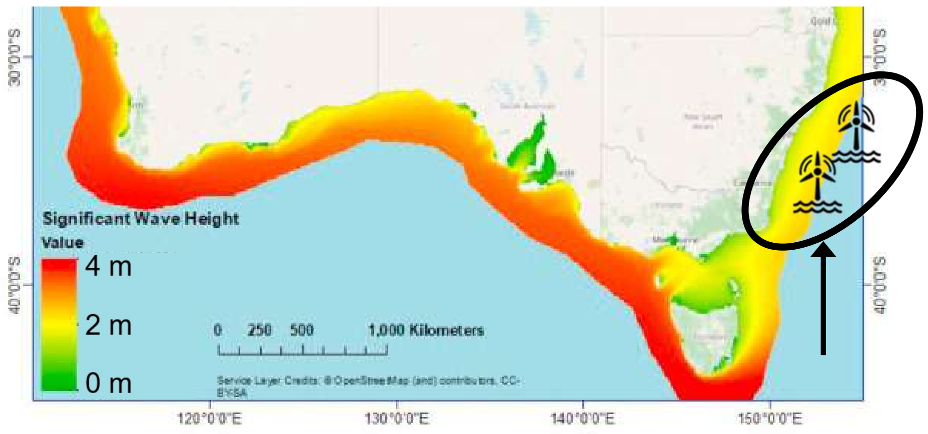
Significant wave height H_s
(annual mean)

Wave energy period T_e
(annual mean)

All 6 offshore wind zones influenced by the Southern Ocean.

3 broad 'oceanographic' zones
- S and SW
- SE, sheltered from swell from Southern Ocean





Source: Marsh et al. 2021, Renewable Energy, https://doi.org/10.1016/j.renene.2021.04.093 and Hemer et al. 2017, Renewable Energy, https://doi.org/10.1016/j.renene.2016.08.039

Australian waves

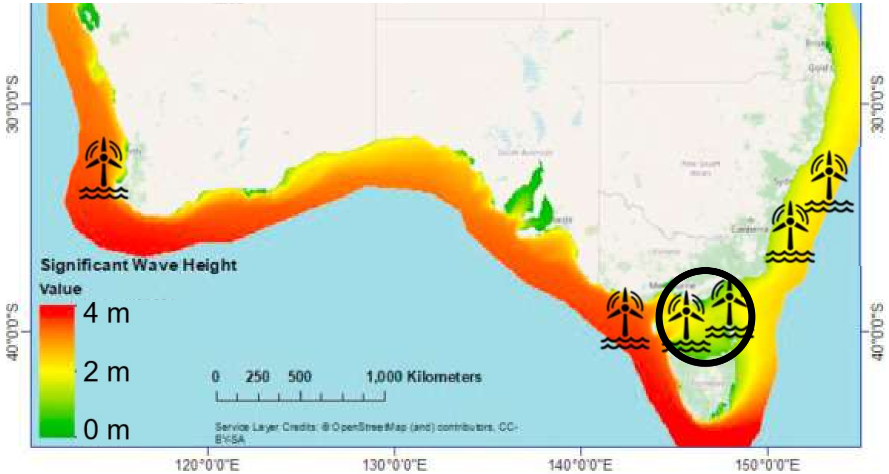
Significant wave height H_s
(annual mean)

Wave energy period T_e
(annual mean)

All 6 offshore wind zones influenced by the Southern Ocean.

3 broad ‘oceanographic’ zones
- S and SW
- SE

- Bass Strait + Gippsland
  more complicated sheltering by Tasmania
  currents &local winds in Bass Strait



Source: Marsh et al. 2021, Renewable Energy, https://doi.org/10.1016/j.renene.2021.04.093 and Hemer et al. 2017, Renewable Energy, https://doi.org/10.1016/j.renene.2016.08.039

Why waves matter for OWTs

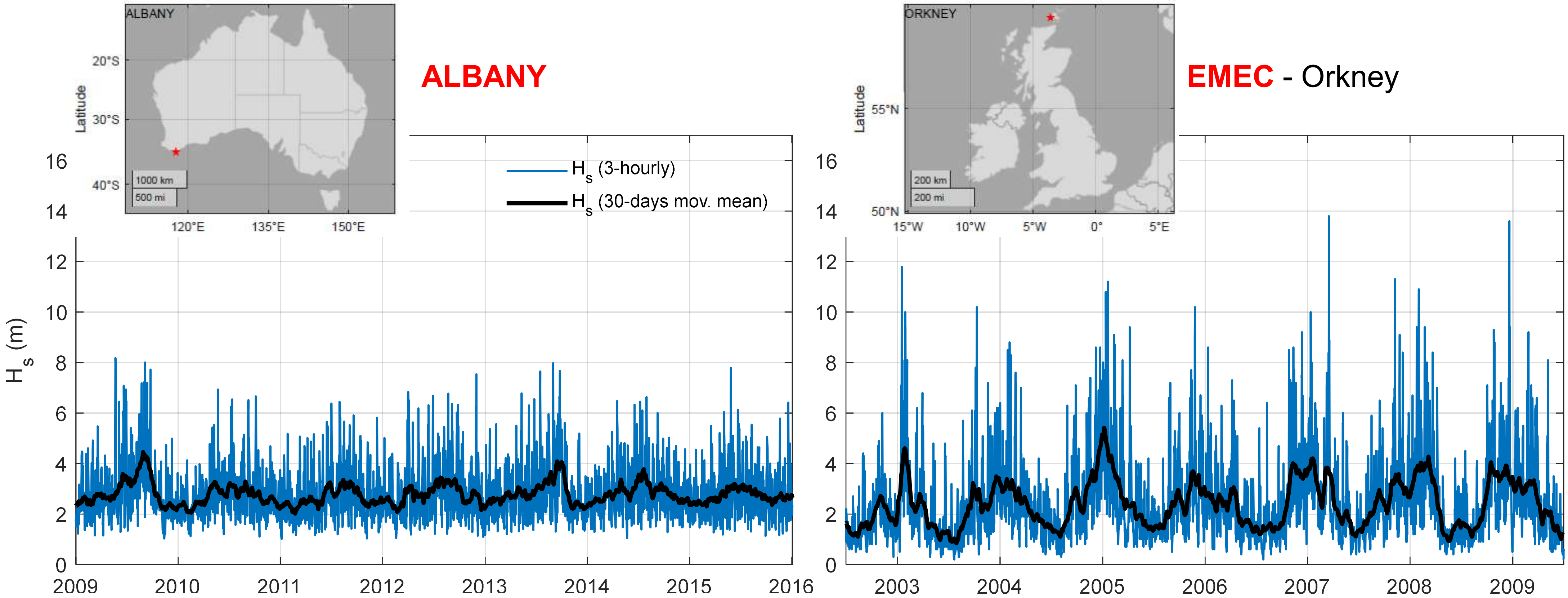
- OWT substructure
  - **support** for tower & rotor
  - **resists** forces (metocean and rotor / aero)

- We design against
  - **rare extreme** waves → ultimate loads
  - **many smaller** waves → fatigue loads

- In addition to **design**, waves also matter for
  - **installation**
  - **maintenance**

Wave heights – peaks, persistence and seasonality - over 7 years

- Waves are **omni-present** and **persistent** along Australian coast (below 30° S)



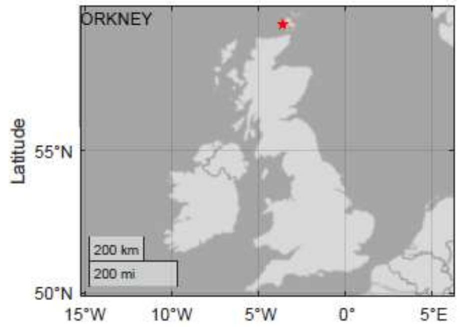
Source: Santo et al. 2020, Renewable Energy, https://doi.org/10.1016/j.renene.2019.06.146

Wave heights – persistence and probability of occurrence

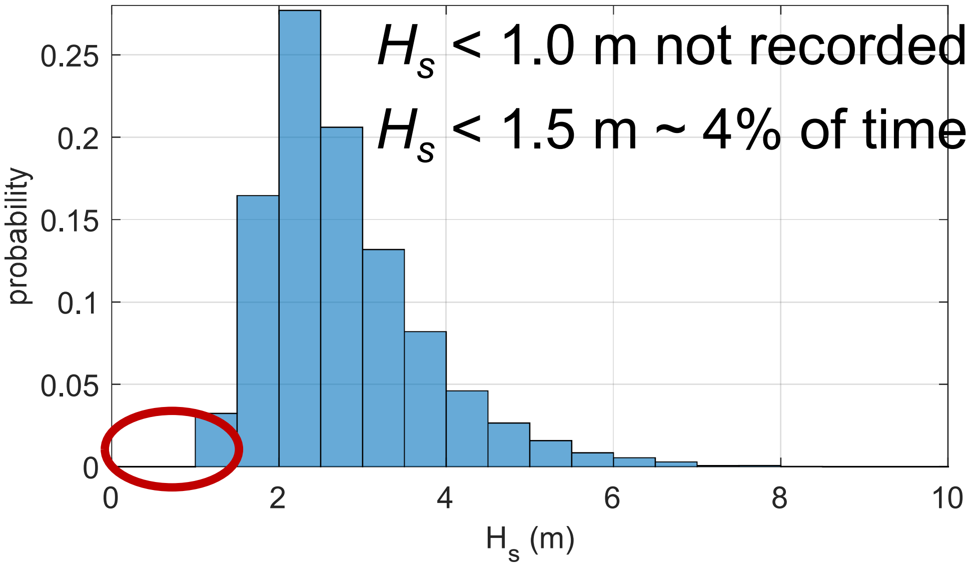
- Waves are **omni-present** and **persistent** along Australian coast (below 30° S)

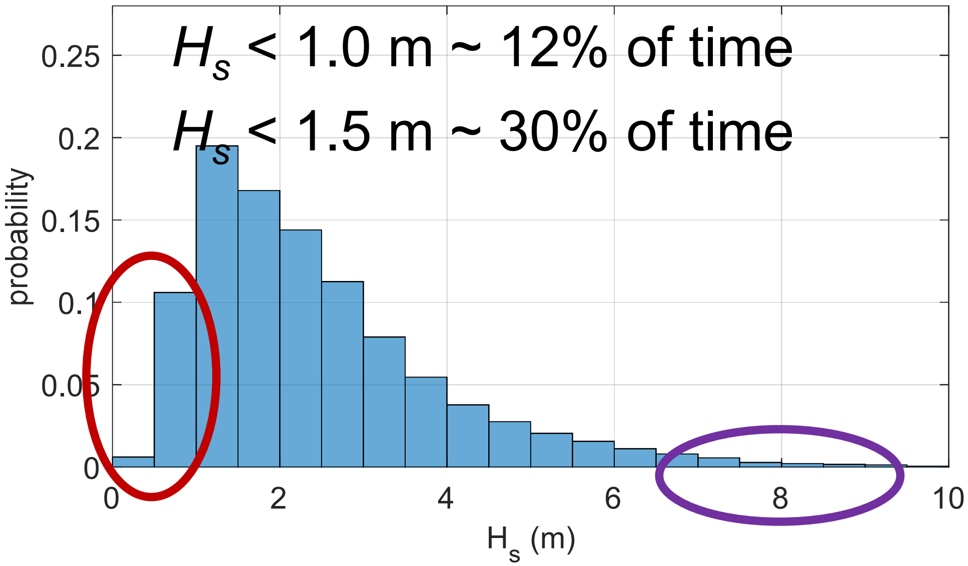
Source: Santo et al. 2020, Renewable Energy, https://doi.org/10.1016/j.renene.2019.06.146

ALBANY

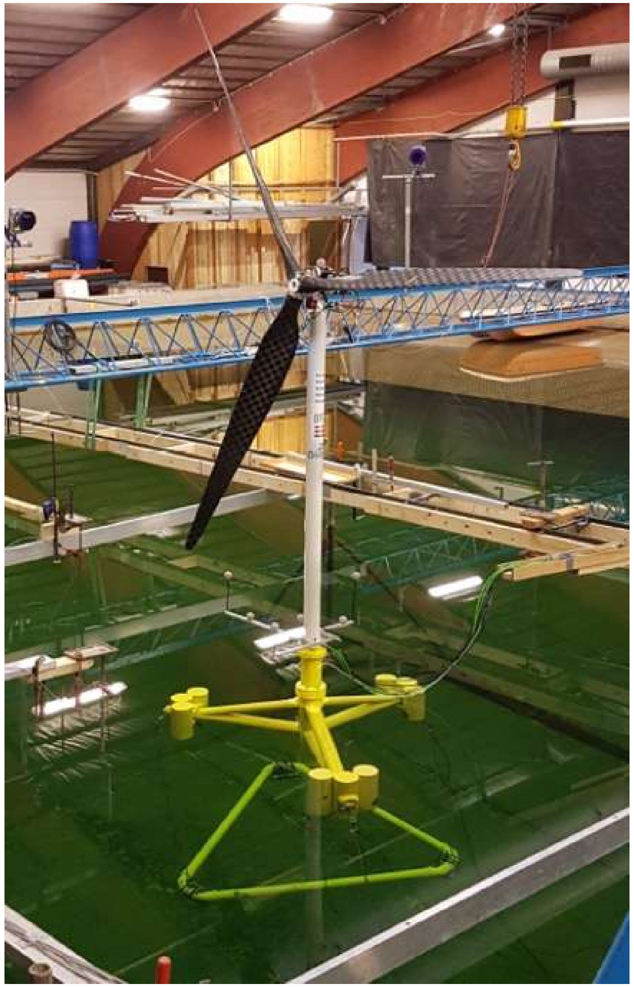


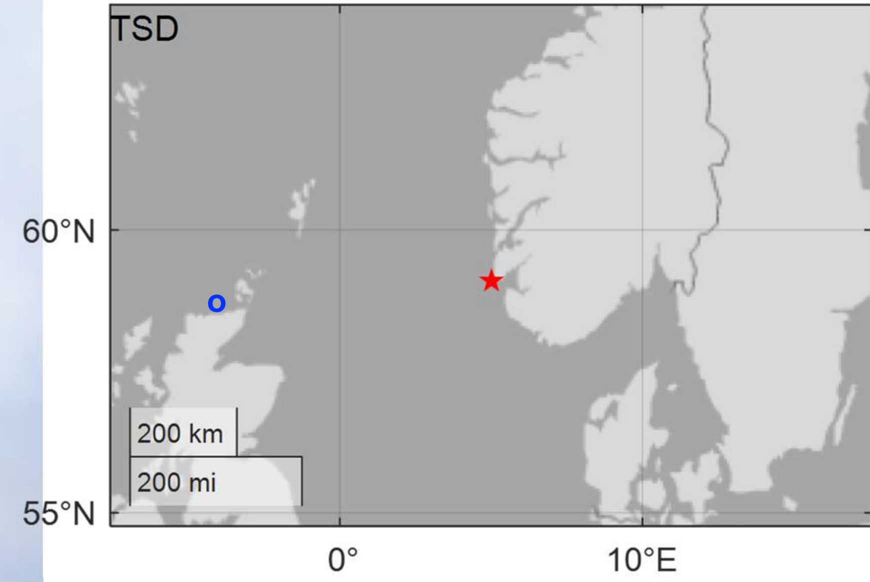
EMEC - Orkney





Waves at TetraSpar Demonstrator off west coast of Norway





EMEC slightly worse than location of

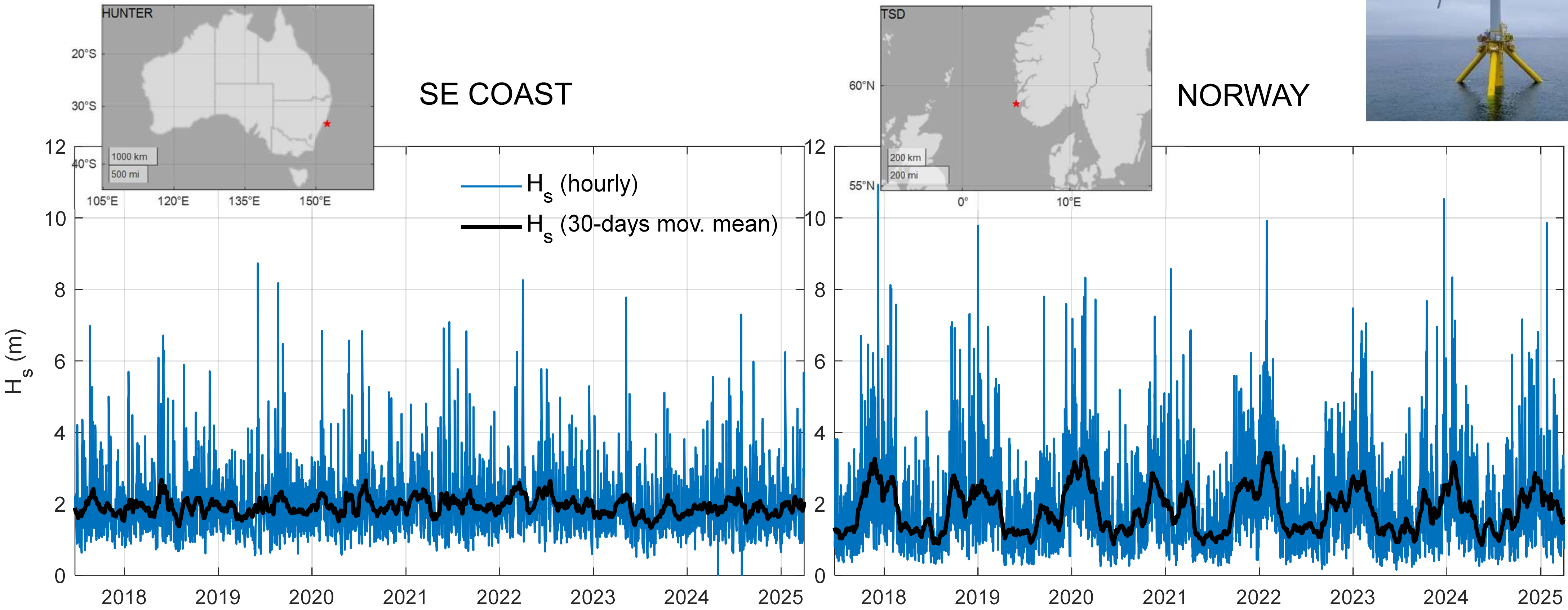
7 FOWTs to be installed at the
100 MW Pentland Floating Offshore Wind Farm
north of Dounreay, Scotland

– price of electricity set Jan ‘26

Source: McCauley et al. 2024, Ocean Engineering, https://doi.org/10.1016/j.oceaneng.2024.117627,
Orszaghova et al. 2021, Journal of Fluid Mechanics, https://doi.org/10.1017/jfm.2021.874

Wave heights - persistence

- Waves are **omni-present** and **persistent** along Australian coast (below 30° S)



Source: McCauley et al. 2024, Ocean Engineering, https://doi.org/10.1016/j.oceaneng.2024.117627, Durrant et al. 2019, CSIRO, http://hdl.handle.net/102.100.100/137152?index=1, Behrens et al 2013, MET Norway

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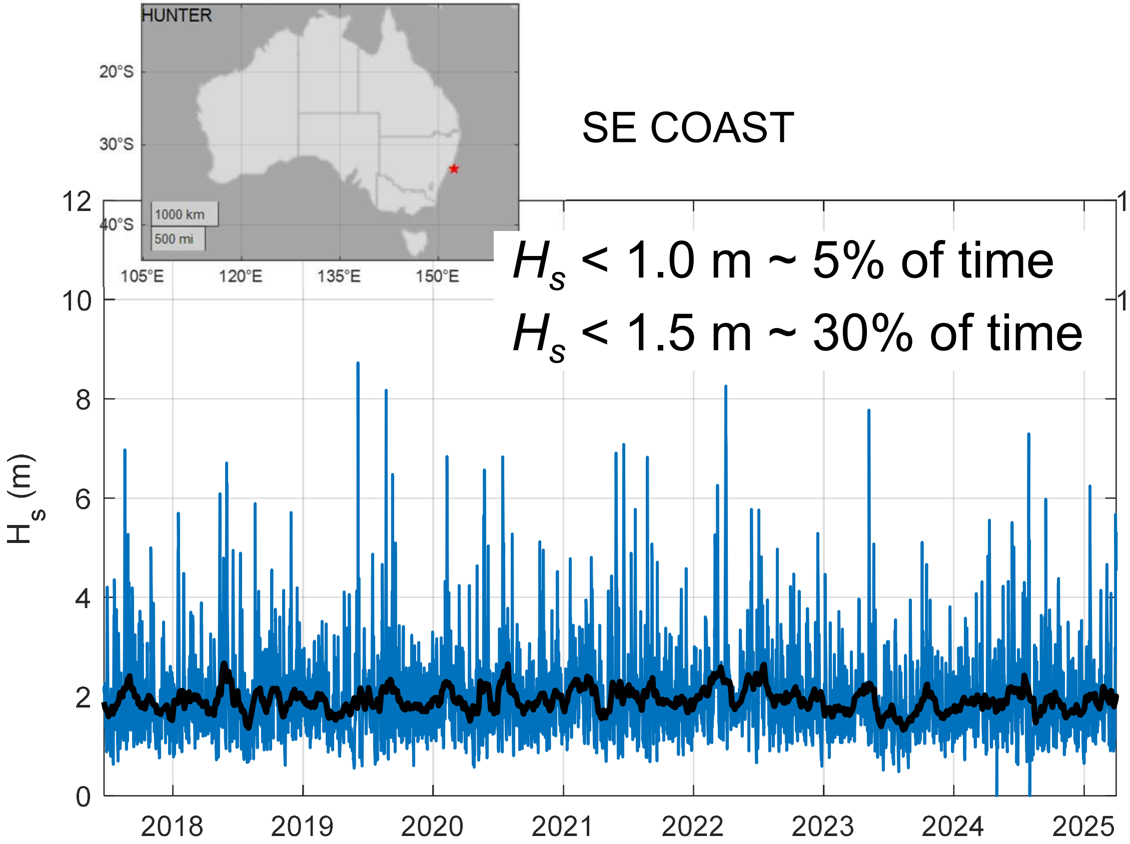
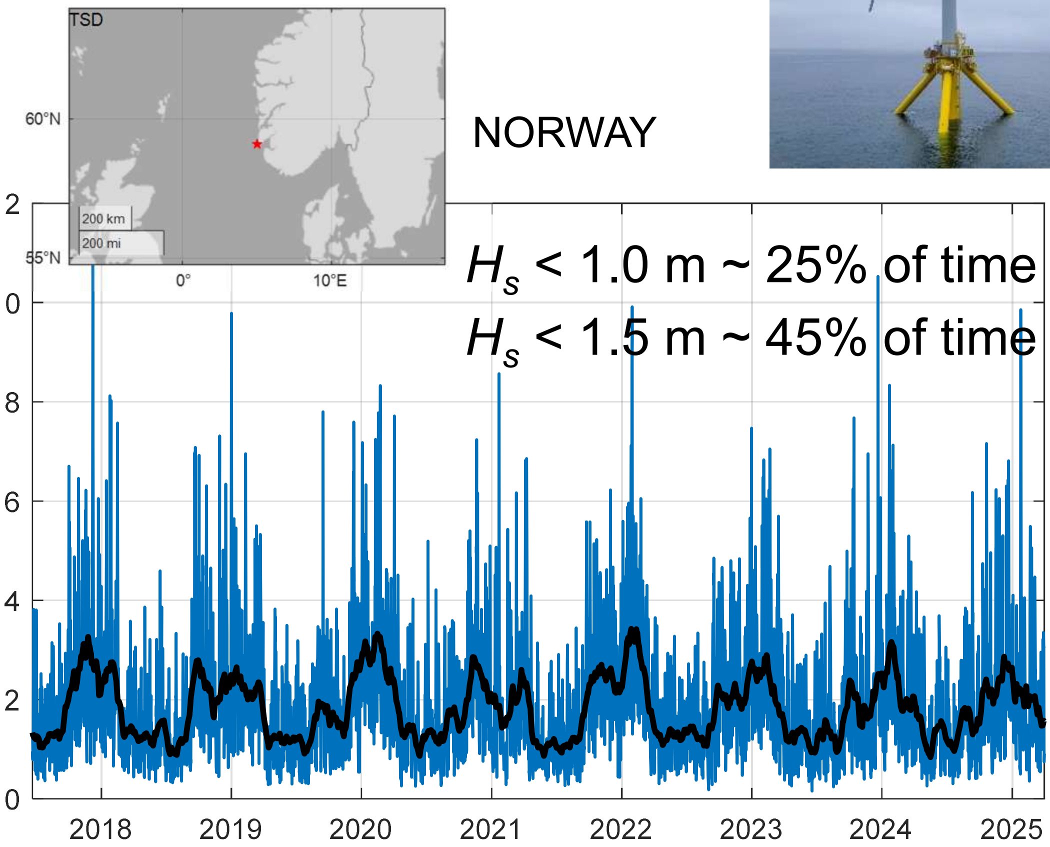
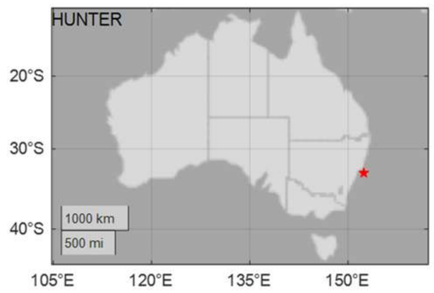




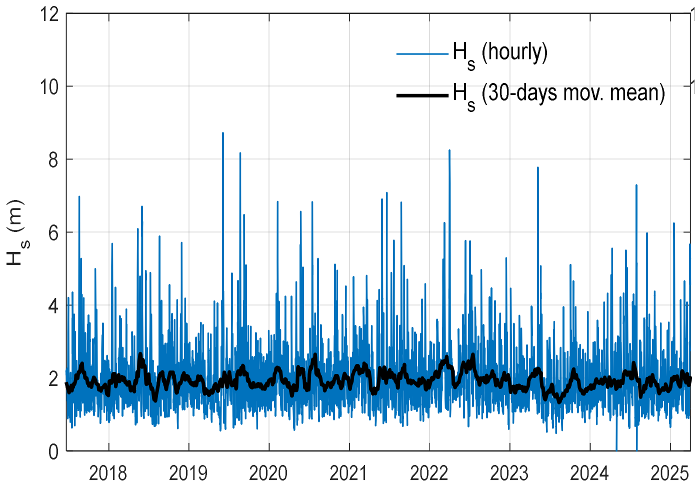
Source: McCauley et al. 2024, Ocean Engineering, https://doi.org/10.1016/j.oceaneng.2024.117627, Durrant et al. 2019, CSIRO, http://hdl.handle.net/102.100.100/137152?index=1, Behrens et al 2013, MET Norway

Wave heights – mean time between and duration of lulls

- Waves are **omni-present** and **persistent** along Australian coast (below 30° S)

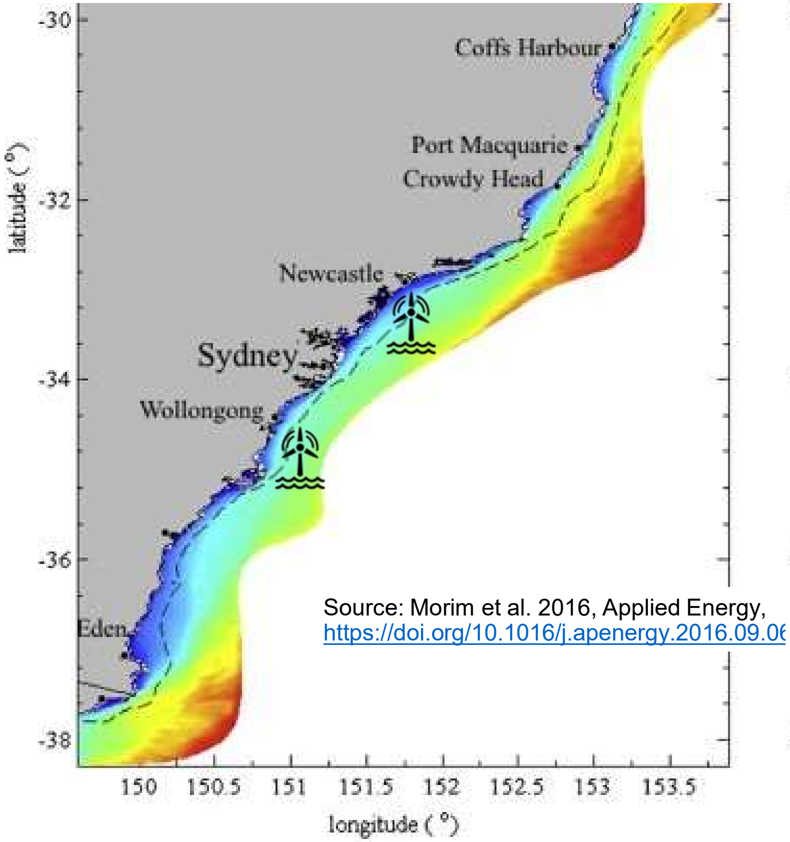


SE COAST



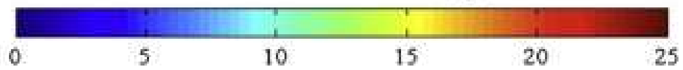
H_s < 1.0 m ~ 5% of time

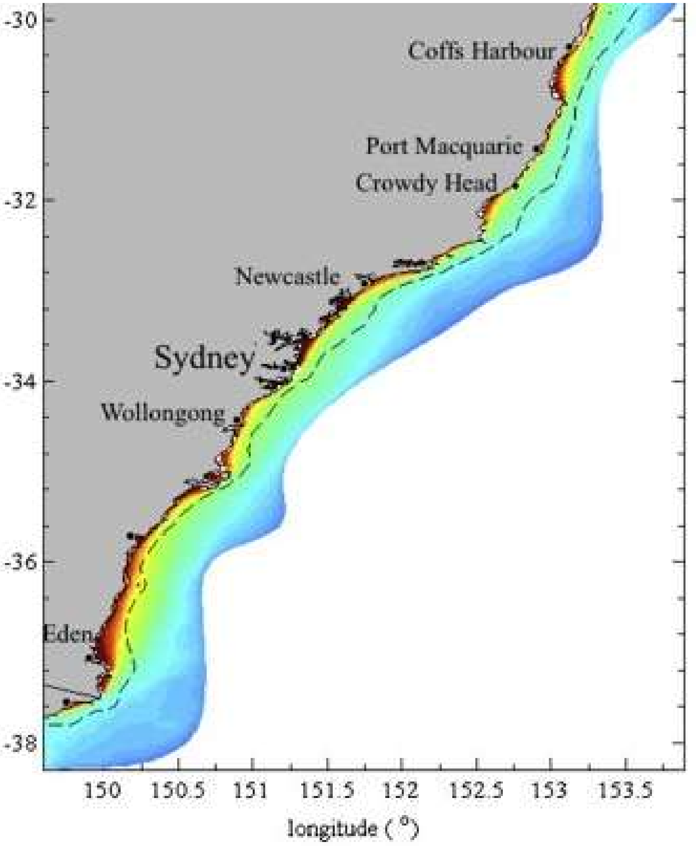
H_s < 1.5 m ~ 30% of time



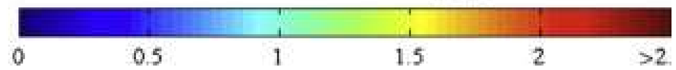
Source: Morim et al. 2016, Applied Energy, https://doi.org/10.1016/j.apenergy.2016.09.06

Mean time between H_s < 1 m (in days)





Mean duration of H_s < 1 m (in days)

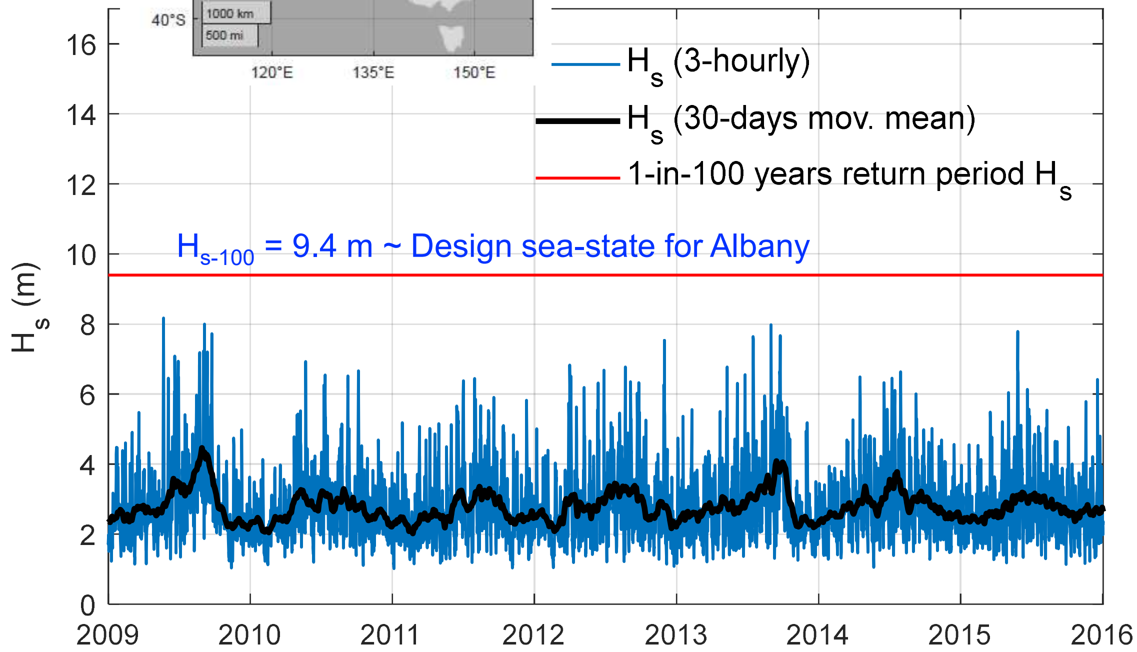


Wave heights – extreme conditions (identical POT extrapolation)

- **Extreme waves are lower** in Aus. waters (below 30° S) compared to open N. Atlantic

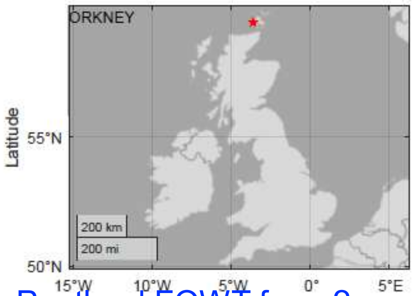
ALBANY

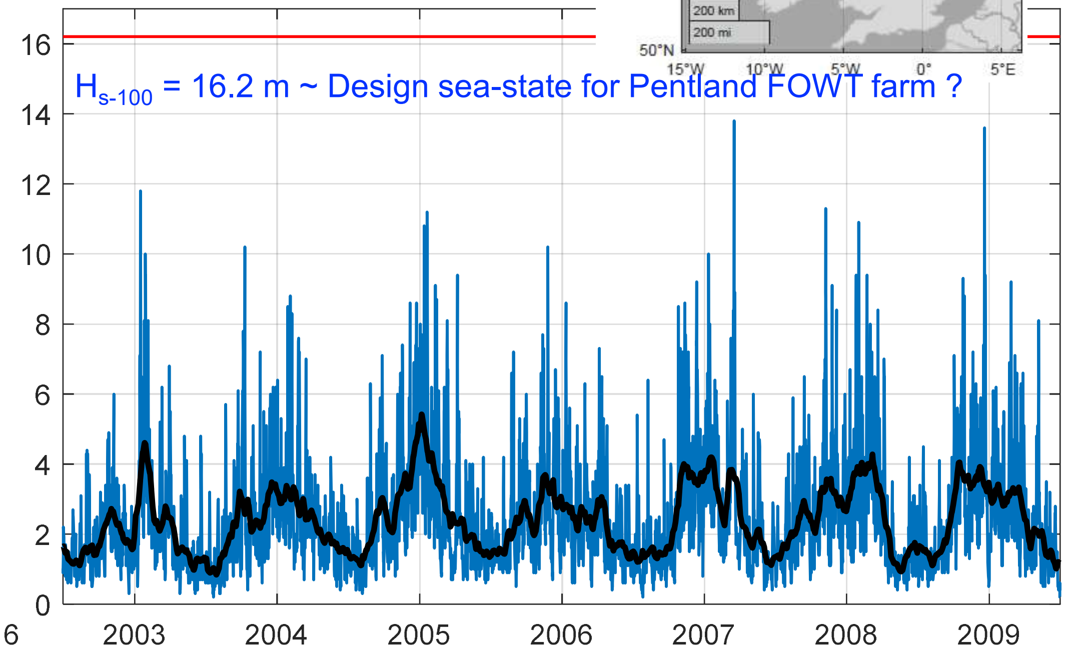
$$\frac{100\text{-yr } H_s}{\text{mean } H_s} \sim 3.3$$



ORKNEY

$$\frac{100\text{-yr } H_s}{\text{mean } H_s} \sim 7$$





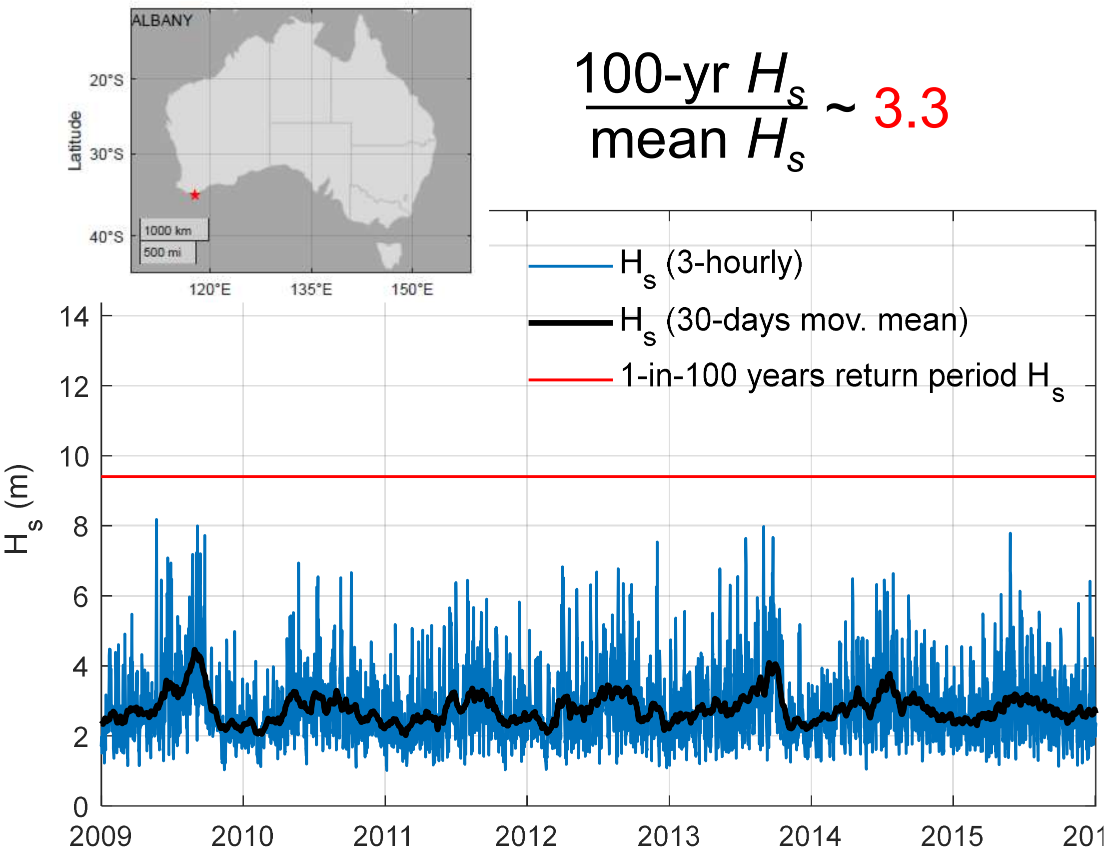
Source: Santo et al. 2020, Renewable Energy, https://doi.org/10.1016/j.renene.2019.06.146

Wave heights – extreme conditions

- **Extreme waves are lower** in Aus. waters (below 30° S) compared to North Sea

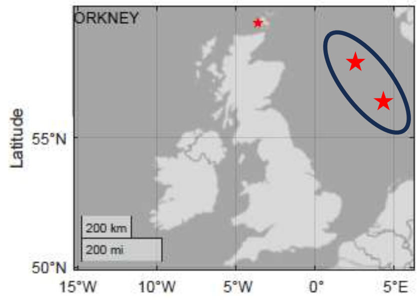
ALBANY

$$\frac{\text{100-yr } H_s}{\text{mean } H_s} \sim 3.3$$



Northern / Central NORTH SEA

$$\frac{\text{100-yr } H_s}{\text{mean } H_s} \sim 6 - 7$$



Around Tasmania
and in Bass Strait

$$\frac{\text{100-yr } H_s}{\text{mean } H_s} \sim 3.5 - 5$$

Sources:

Santo et al. 2020, Renewable Energy, https://doi.org/10.1016/j.renene.2019.06.146

Santo et al. 2016, Proc. Royal Society A, https://doi.org/10.1098/rspa.2016.0376

Wave heights (in S, SW, SE Aus. and Bass Strait)

- Waves are **omni-present** and **persistent** around southern half of Australia

  reduced installation & maintenance opportunities due to **limited weather windows**

  potential for more fatigue damage due to **near-continuous loading**

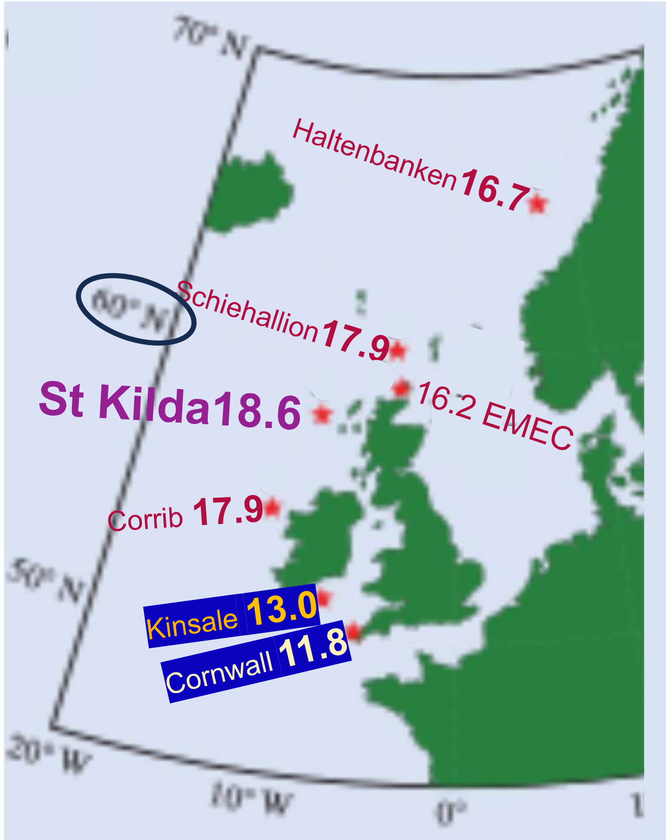
- Extreme wave conditions are **less severe**

  Fatigue, rather than overload, may dominate design

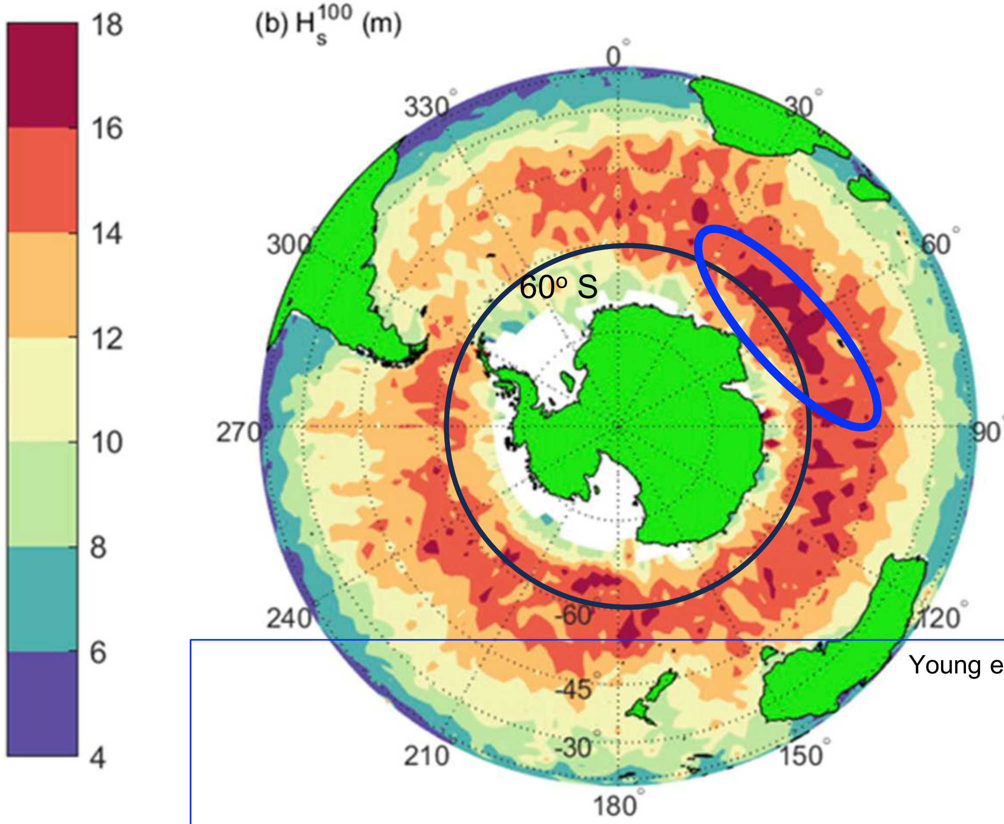
An aside: Extreme open ocean waves in northern and southern hemispheres

100-year H_s in open North Atlantic and Southern Ocean similar ~ 18 m

Both in ***severity*** and ***latitude***



Santo H, Taylor PH, Gibson R PRS-A (2016)

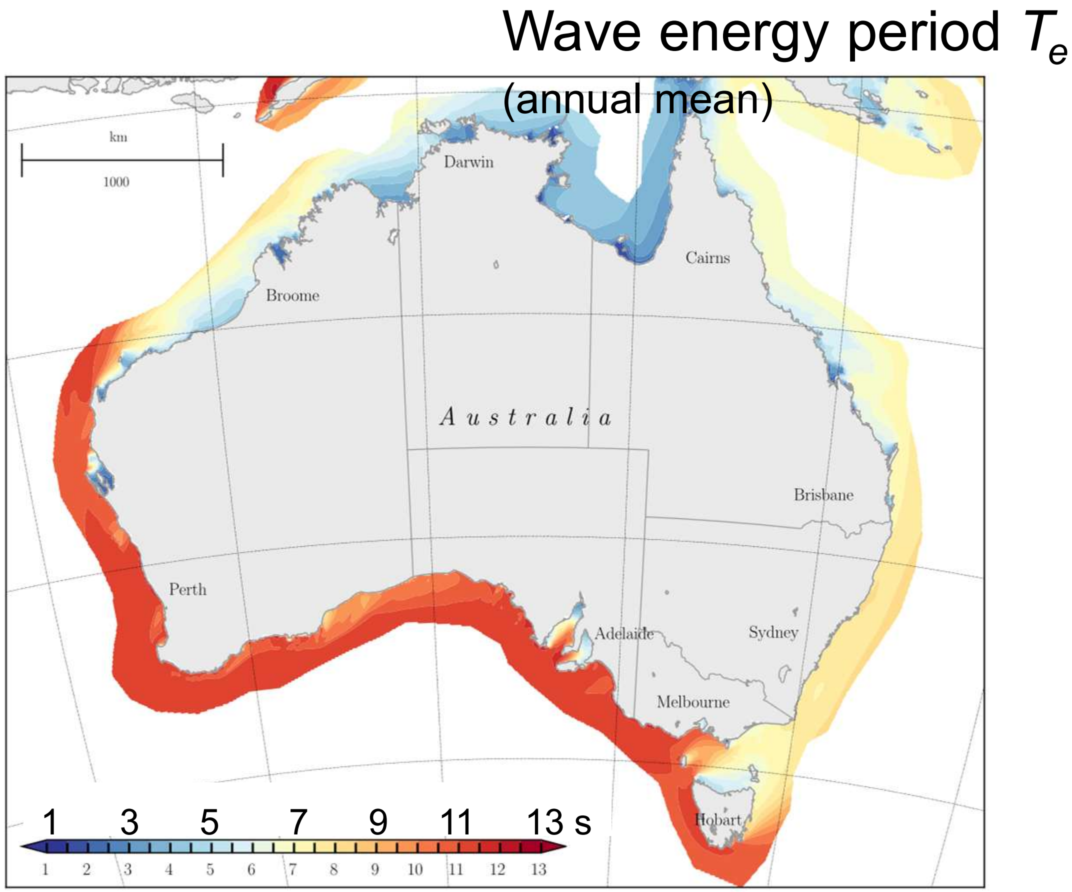


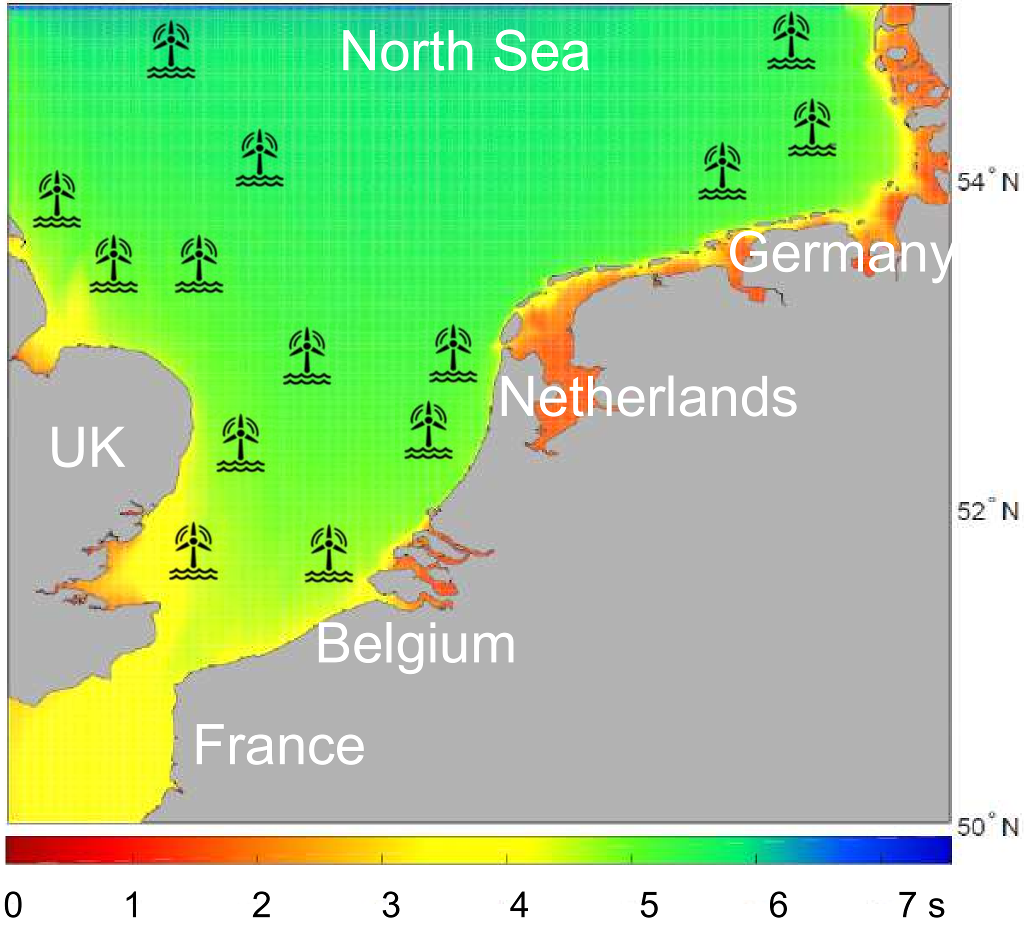
Young et al. JPO (2020)

Notice the reduction east of S. America, and the southward trend of $H_{s\text{-}100}$ from there

Wave periods

- **Waves periods are longer** in Aus. waters (below 30° S) compared to N. Sea/N. Atlantic





Source: Hemer et al. 2017, Renewable Energy, https://doi.org/10.1016/j.renene.2016.08.039

Source: Lavidas and Polinder 2019, Atmosphere, https://doi.org/10.3390/atmos10090551

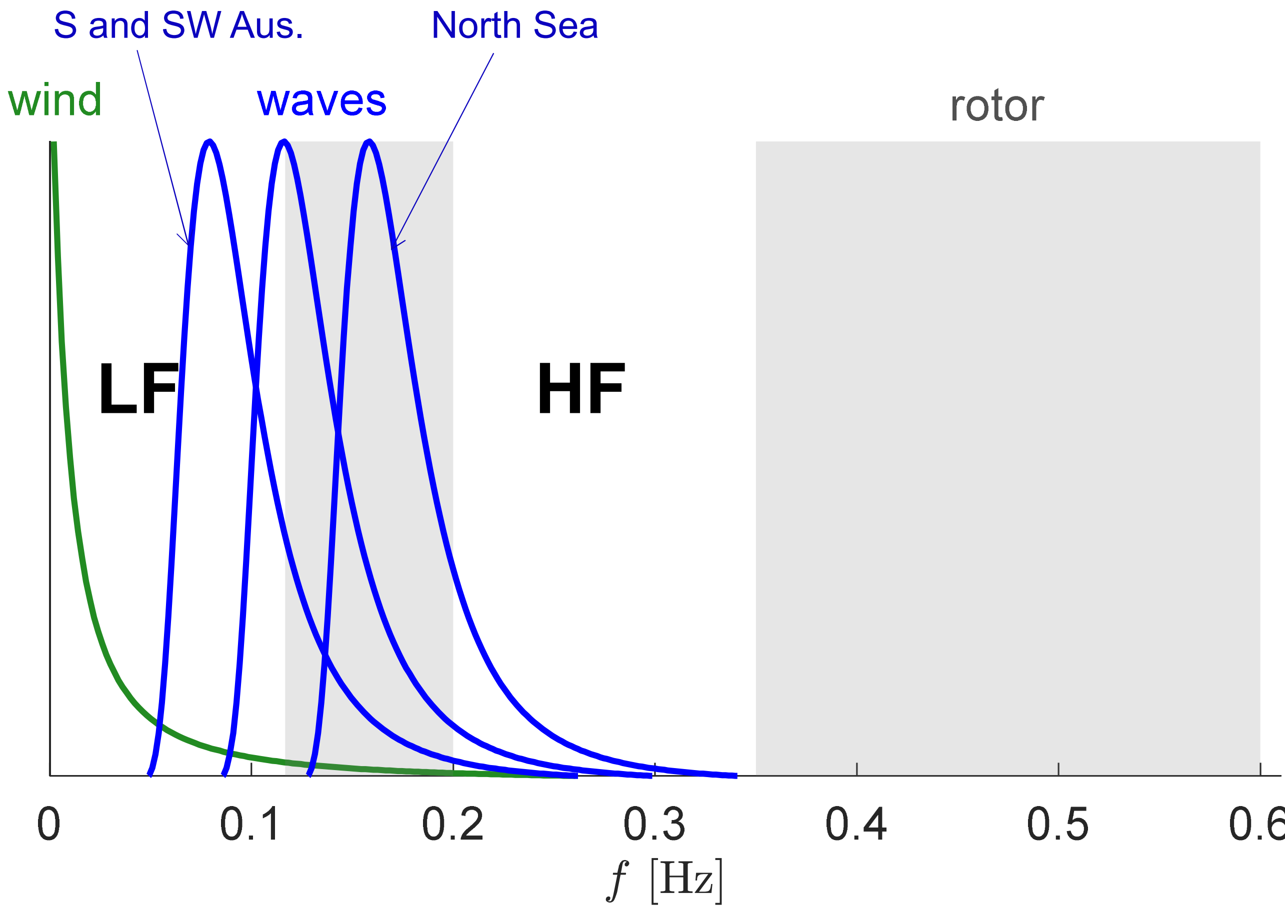
Wave periods – why they matter

- Waves, wind and rotor provide **oscillatory excitation**

- Design aim: **resonance avoidance**

  LF for floater motions (soft-moored)

  HF for tower bending (in general)



Wave periods – why they matter

- Waves, wind and rotor provide **oscillatory excitation**

- Design aim: **resonance avoidance**

  LF for floater motions (soft-moored)

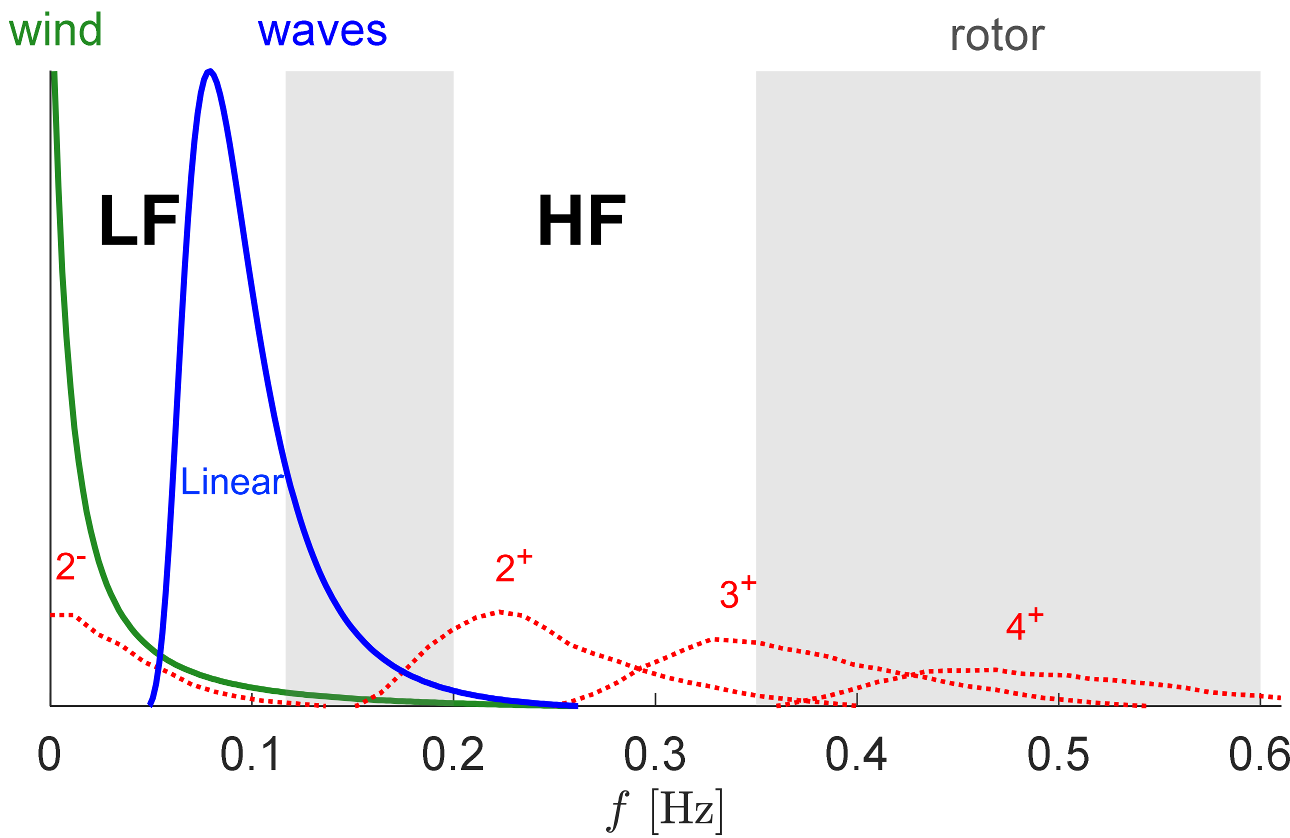
  HF for tower bending (in general)

- In longer waves,

  effectively shallower water

  amplified **wave and force nonlinearity**

  - acts at both **low** & **high** frequencies



Nonlinear excitation is incomplete / missing in present industry models

Wave forces

UWA Coastal and Offshore Research Laboratory

Wave forces on offshore wind monopile

depend on wave height, wave period and water depth

also on column diameter

In long waves, loading is entirely dominated by

Morison inertia and nonlinear potential flow extensions

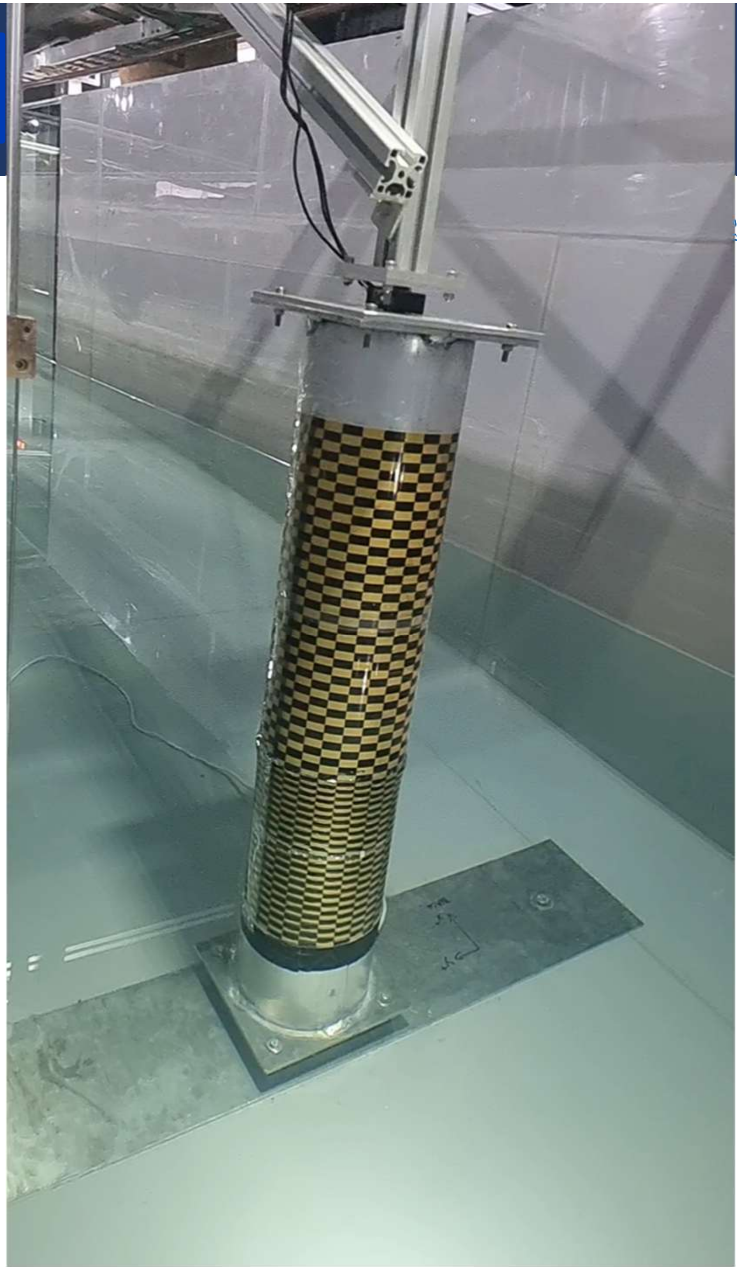
Morison drag is small

Demonstrated in flume tests at UWA :

although the local flow structure around the column is complex,

the total force is relatively simple $F \sim \frac{\partial \eta}{\partial t}$,

with strong harmonics in undisturbed free-surface motion η(t)



Monopile loads in focussed NewWave groups – wave flume **experiments**

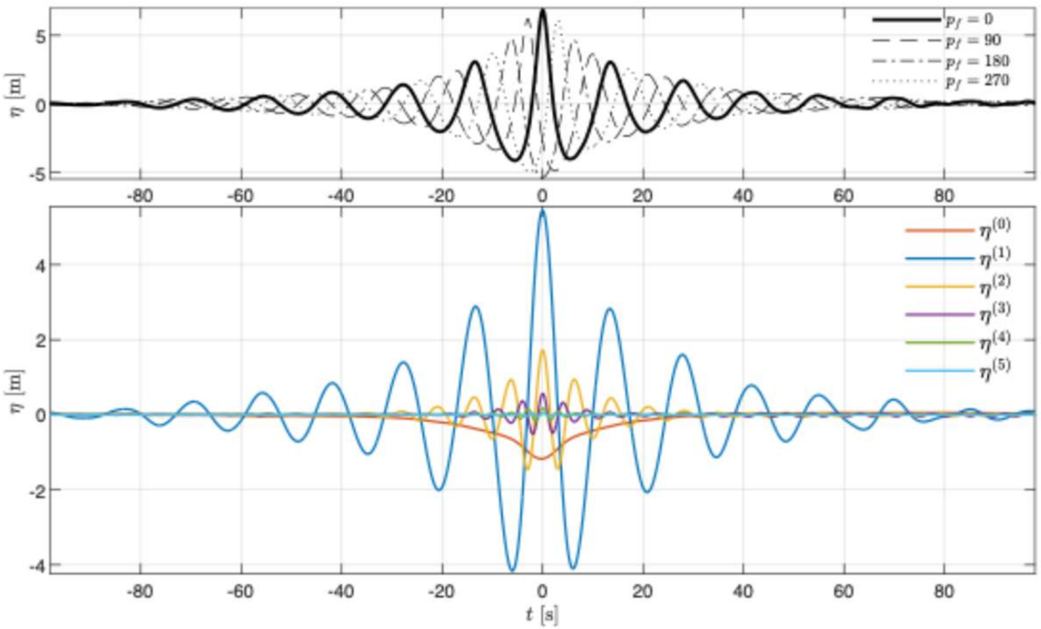


FIGURE 3: TIMESERIES OF THE UNDISTURBED (IN THE ABSENCE OF THE MONOPILE) FREE SURFACE. TOP PLOT: TOTAL FREE SURFACE IN THE FOUR PHASE-MANIPULATED TESTS. BOTTOM PLOT: SEPARATED WAVE HARMONICS.

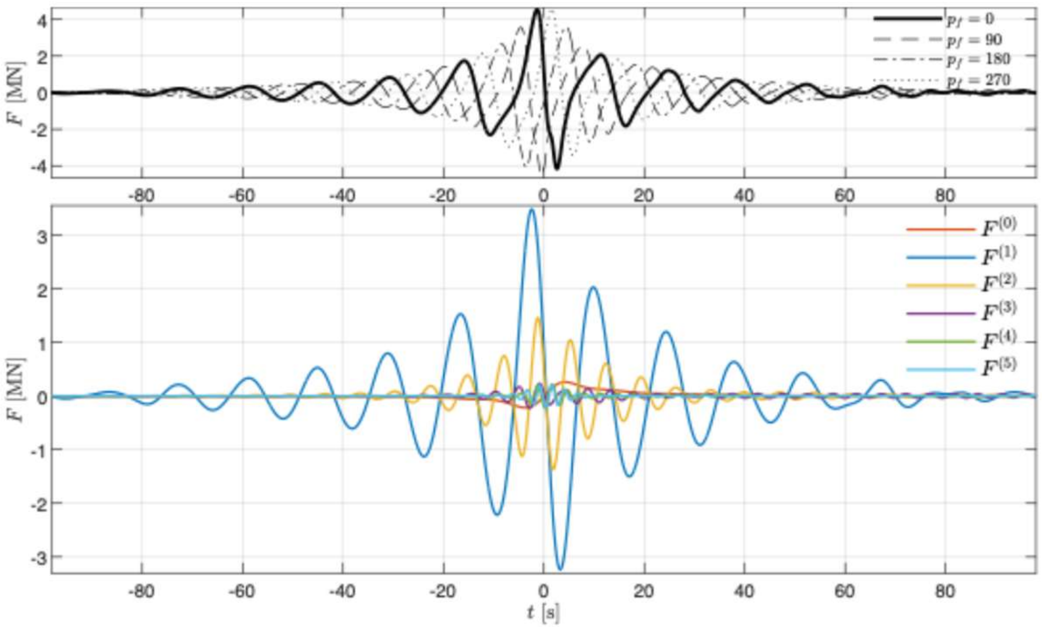


FIGURE 4: TIMESERIES OF THE HORIZONTAL FORCE. TOP PLOT: TOTAL FORCE IN THE FOUR PHASE-MANIPULATED TESTS. BOTTOM PLOT: SEPARATED FORCE HARMONICS.

WAVE
- almost perfect 4-phase decomposition

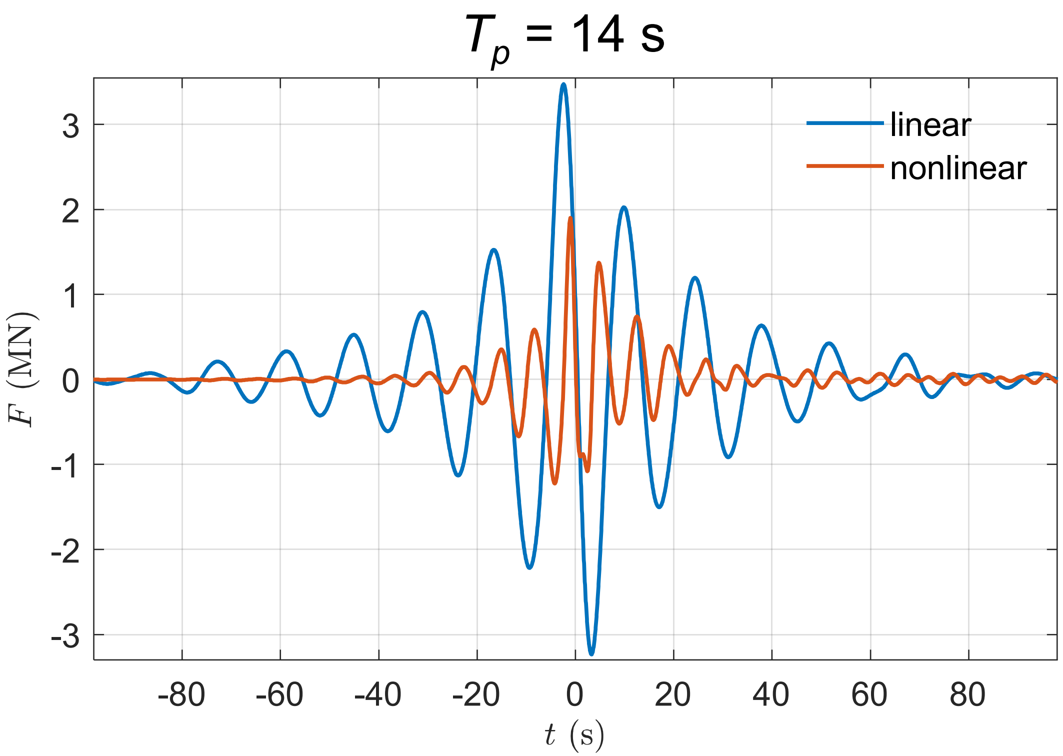
FORCE
- all harmonics zero-cross for NewWave crest input

Source: Orszaghova et al. 2025, OMAE, https://doi.org/10.1115/OMAE2025-156732

Wave periods

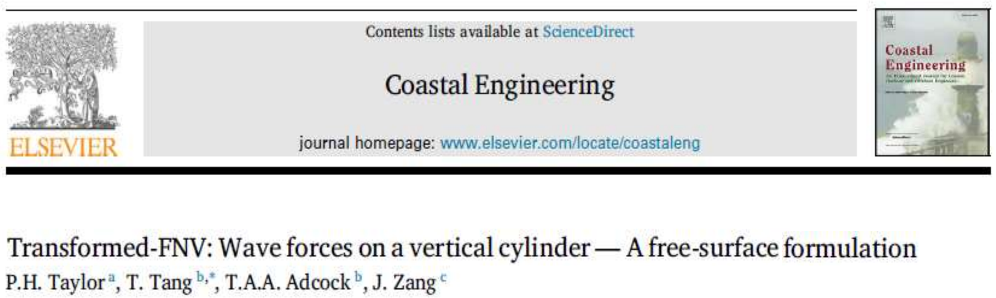
Source: Orszaghova et al. 2025, OMAE, https://doi.org/10.1115/OMAE2025-156732

- Wave forces on offshore wind monopile



Nonlinear wave loads in long waves

- significant proportion of total → **overload**
- broad frequency range → struct **resonance**
- Industry needs ***improved engineering models***



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

ELSEVIER

Transformed-FNV: Wave forces on a vertical cylinder — A free-surface formulation

P.H. Taylor[a], T. Tang[b,*], T.A.A. Adcock[b], J. Zang[c]

Source: Taylor et al. 2024, Coastal Engineering, https://doi.org/10.1016/j.coastaleng.2024.104454

In summary

- Australian **oceanic wave climate** represents a **new loading regime**
  - (much) longer wave periods
    - year-round persistence and less seasonality
  - (much) lower extremes

- Practical experience from OWTs in the North Sea may not be useful:
  - local wind seas versus long period swell

- Fatigue ***more*** important, extremes ***less***

- Need for **innovation** and **opportunities for R&D**
  - for FIXED and FLOATING offshore wind turbines for **Australia**

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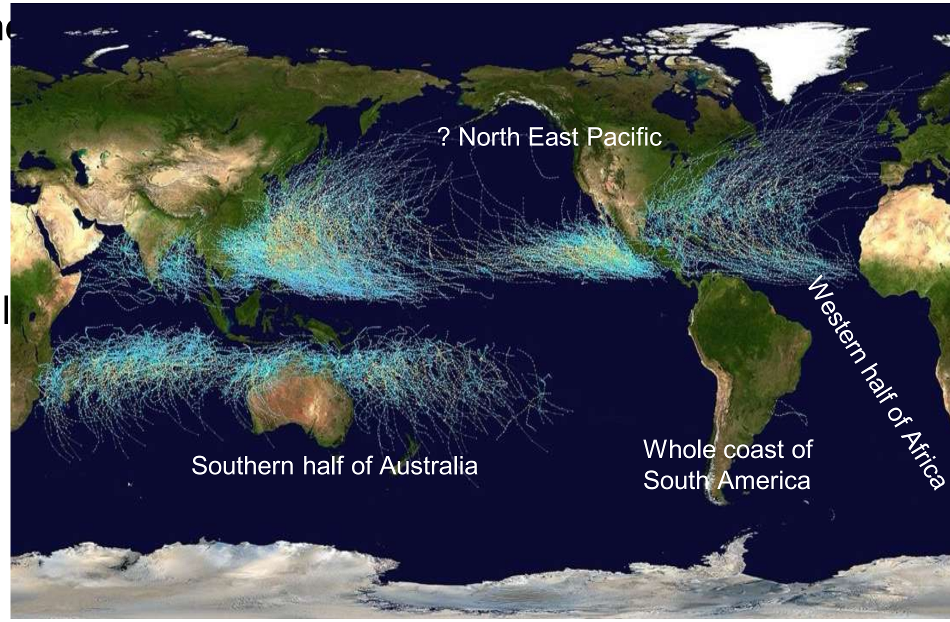
    local wind seas versus long period swell

- Fatigue ***more*** important, extremes ***less***

- Need for **innovation** and **opportunities for R&D**

    for FIXED and FLOATING offshore wind turbines for **Australia** and **ELSEWHERE :**



open ocean, away from tropics, *away from tropical storm tracks*

South America, southern Africa, NE Pacific ?

For further information: paul.taylor@uwa.edu.au jana.orszaghova@uwa.edu.au