Evaluation of Spectral Wave Models Physics as Applied to a 100-Year Southern Hemisphere Extra-Tropical Cyclone Sea State

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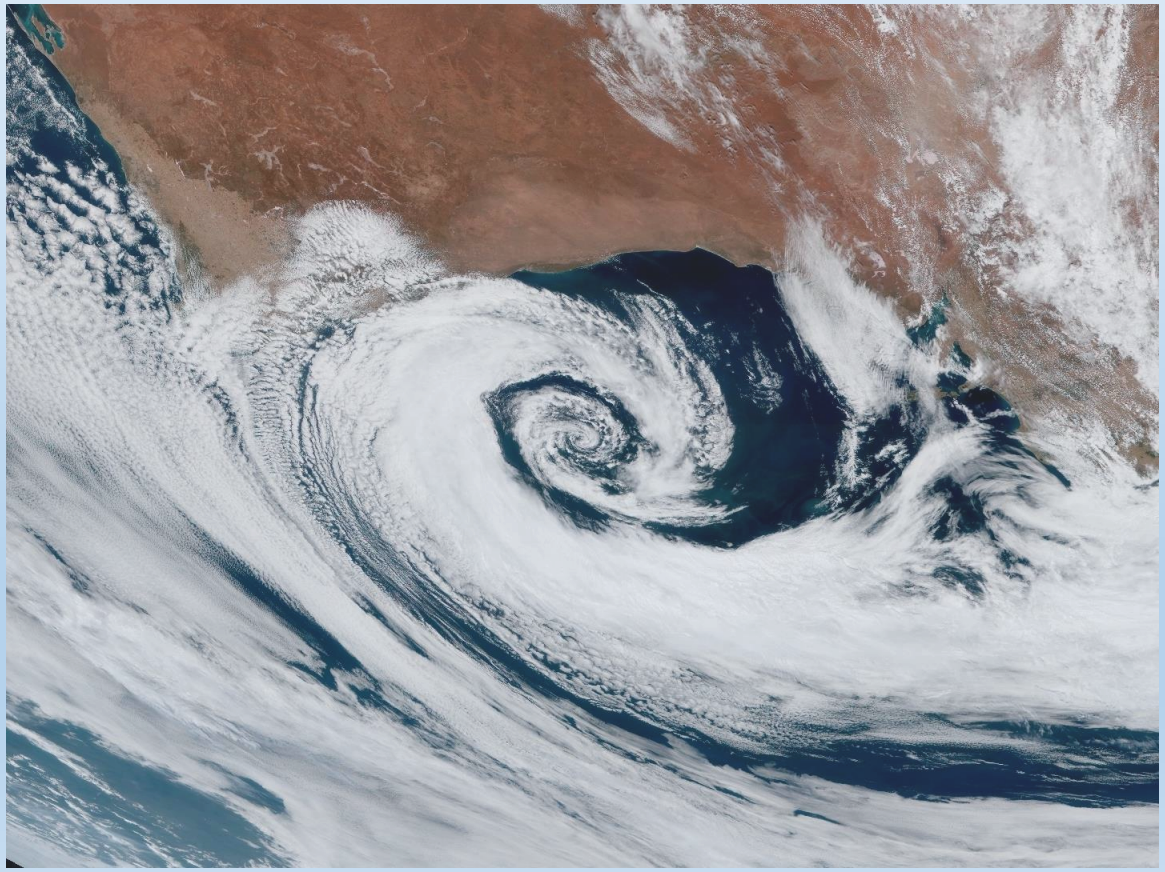
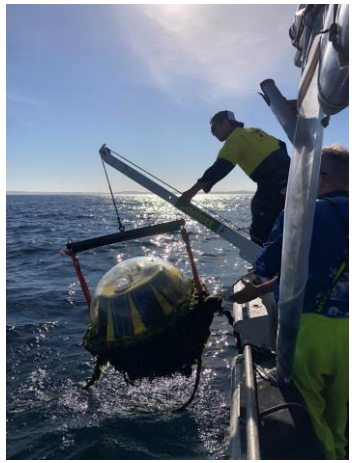


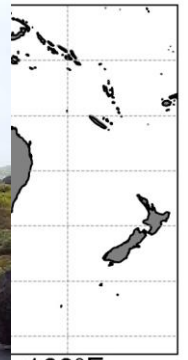
April 2021 storm

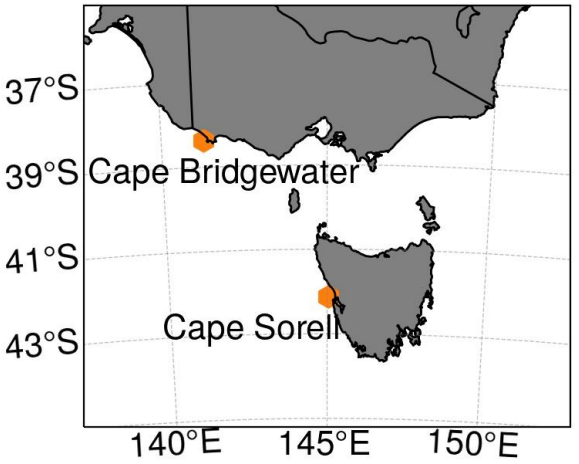


Cape Bridgewater Triaxys buoy removal

Jan. 2022

Port Fairy, April 2021 (*ABC News*)



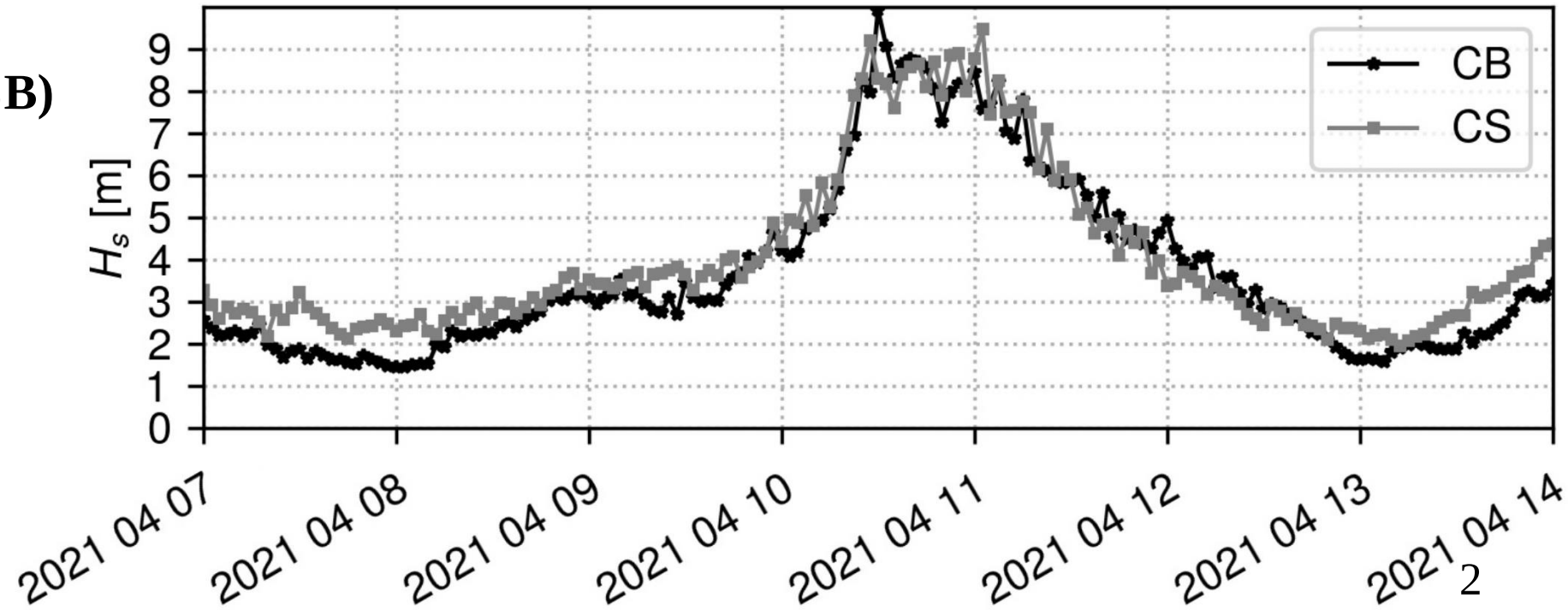


Cape Bridgewater (CB)

$H_{s,max}$ = 9.9 m

Cape Sorell (CS)

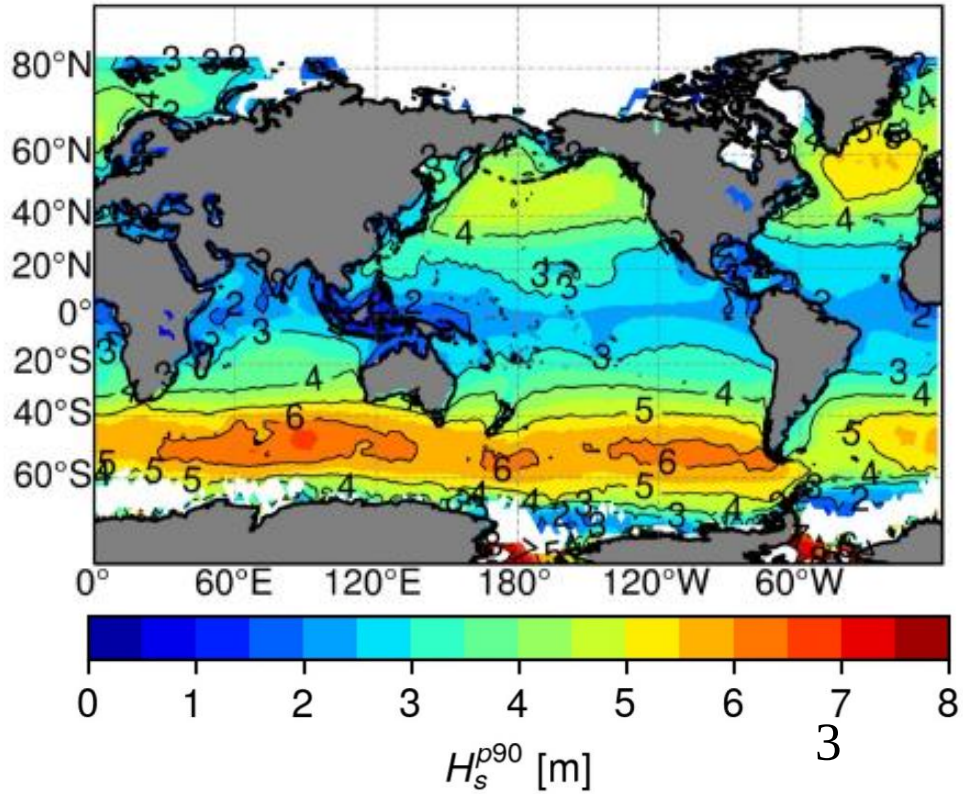
$H_{s,max}$ = 9.47m



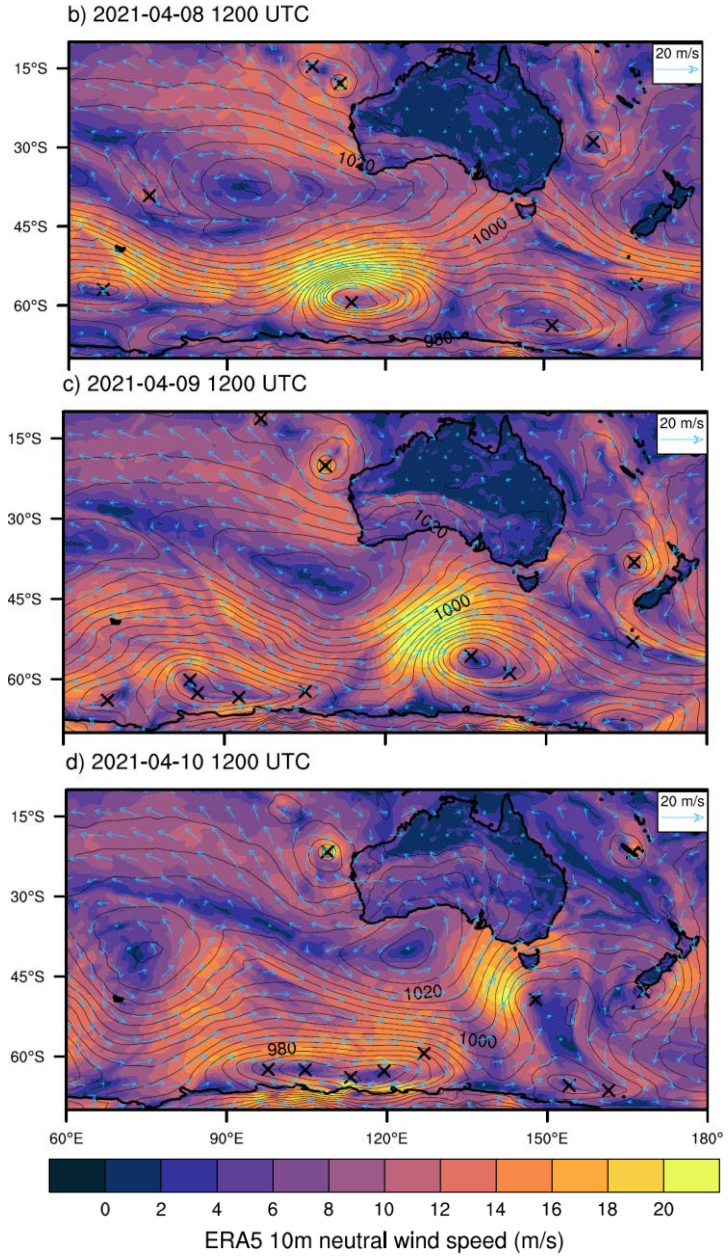
ETCs and metocean extremes

- **ETCs** are synoptic low-pressure system that dominate Earth's weather
- **ETCs** generate **large swells** that propagate far and affect global coastlines.
- ETCs are **frequent** and **large** events that dominate global metocean extreme climate statistics

As we are using global **hindcast**, **ensemble forecast**, or **reanalysis datasets** to estimate **1-in-N-year return periods**, for coastal engineering project design, we need to understand how well these models represent the ETC-generated wind-wave fields.



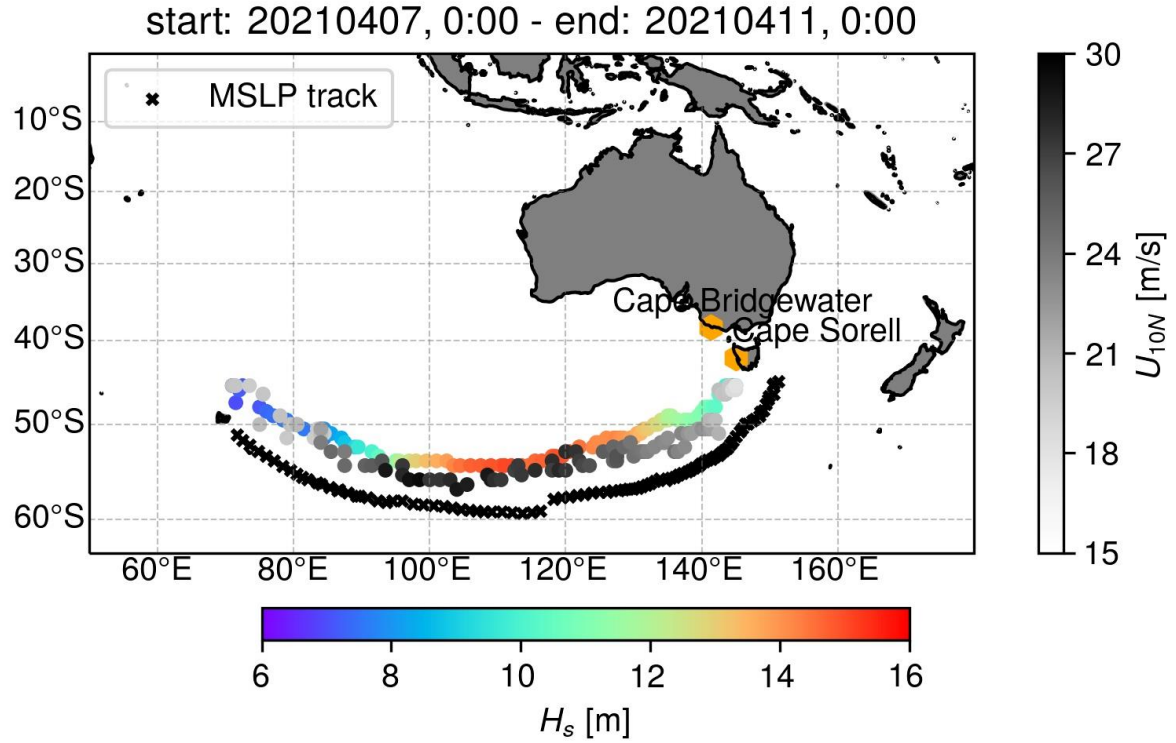
April 2021 storm



(Murray and Simmonds, 1991)

Minimum MSLP storm tracking technique

ERA5 Storm track – MSLP, U_{10}^{max}, H_s^{max}



JGR Oceans

RESEARCH ARTICLE

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Evaluation of Spectral Wave Models Physics as Applied to a 100-Year Southern Hemisphere Extra-Tropical Cyclone Sea State

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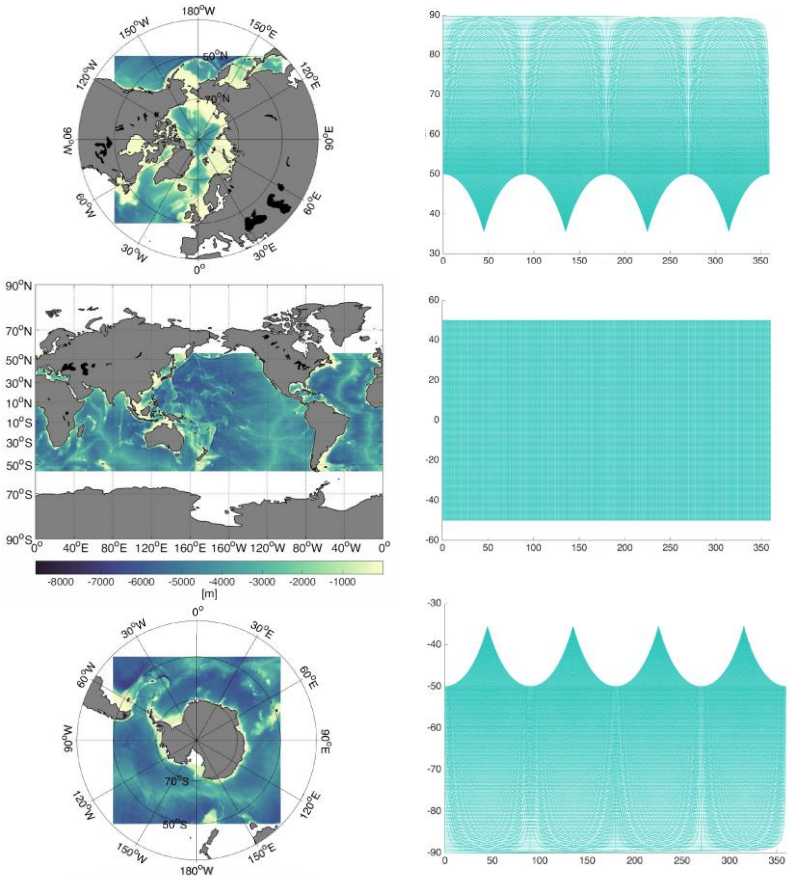
Model set up

WAVEWATCH III® (WW3) v6.07 forced with ERA5 **daily sea-ice** and **hourly wind** (Liu et al., 2021; Meucci et al., 2023)

Grid

Irregular
Regular
Irregular grid

(Rogers et al., 2018)



Curv. grid
34 Km res.
@ 70˚N

Regular 0.5˚
rect. grid ~
55Km res.

Curv. grid
34 Km res.
@ 70˚S

Sea-ice

- <25% open ocean
- 25% < SI < 75% ln decay
- >75% land

(Tolman et al., 2003)

Physics

- **ST4** or **ST6** parametrization
- **DIA** scheme non-linear int.
- **No currents**

Outputs

1-hourly outputs re-gridded over a global 0.5˚ reg. grid

Spectral res.:

- 50 freq. (0.03/0.035 - 0.96 Hz)
- 36 dir. ($\Delta\theta = 10^{\circ}$)

(Meucci et al., 2023)

Model simulations

Model settings

c: wind stress calibration
f: minimum frequency test
r: spatial resolution test

Test ID	
ST6-c1f1r1	Minimum frequency resolution test • f_{min} = 0.03 Hz or • f_{min} = 0.035 Hz
ST6-c1f2r1	
ST6-c1f1r1	ST6 wind stress calibration: • CDFAC1.0 (Zieger et al., 2015) • CDFAC1.08 (Liu et al., 2021)
ST6-c2f1r1	
ST6-c1f1r1	Source terms physics: • ST6 • ST4
ST4-f1r1	
ST6-c1f1r1	Global horizontal resolution: • 0.5° • 0.25°
ST6-c1f1r2	

WW3 with ERA5 wind and sea-ice forcing (WW3/ERA5):

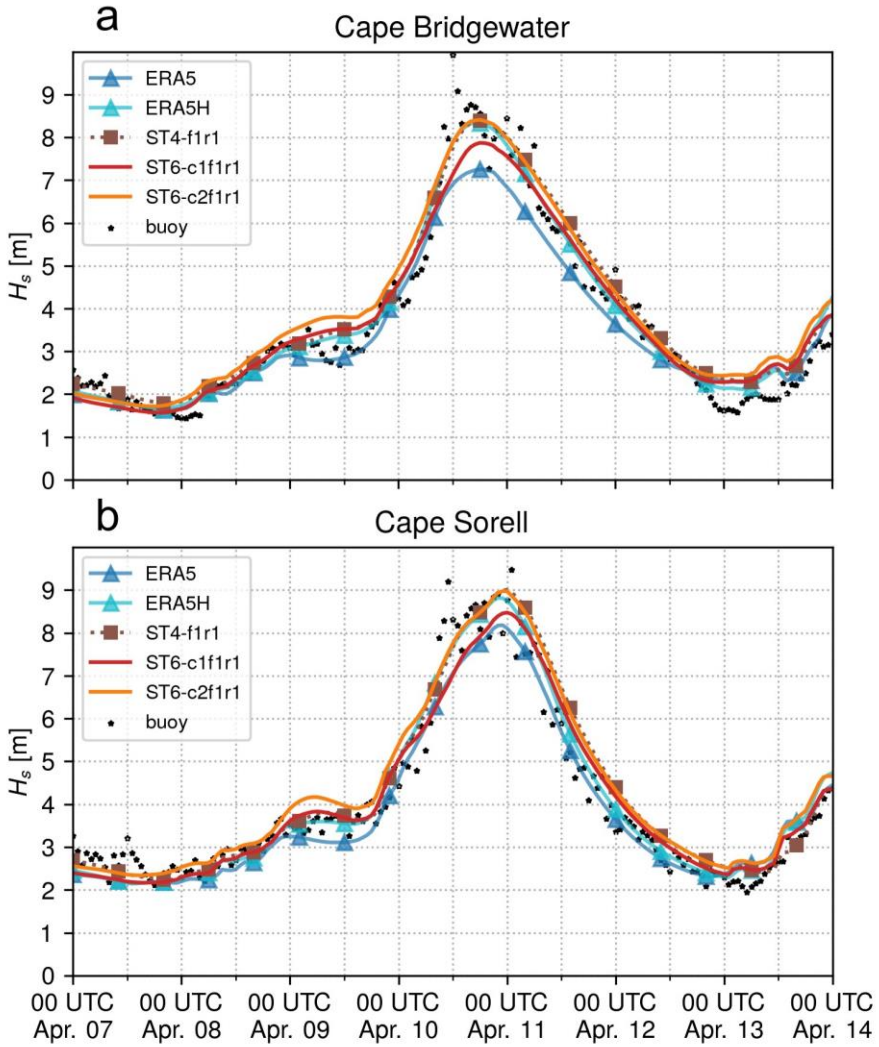
(Liu et al., 2021; Meucci et al., 2023)

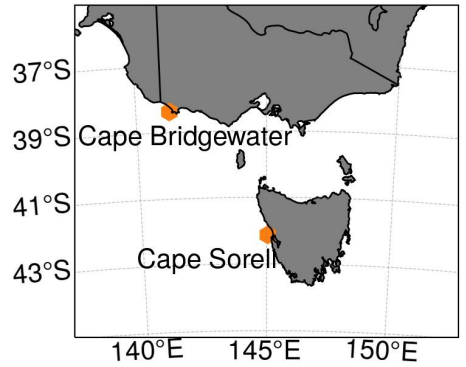
External datasets for comparison:

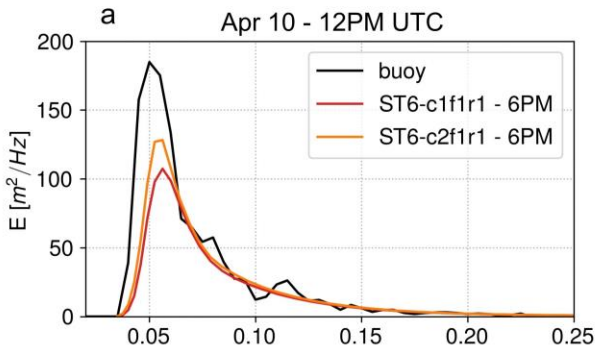
Global models:
- ERA5 – ECMWF reanalysis
- ERA5H – ECMWF wave hindcast with updated physics

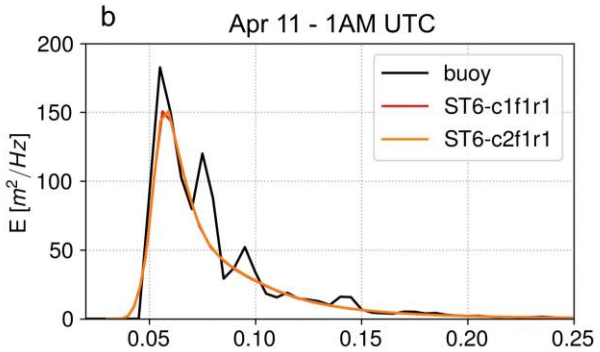
Observations:
- In-situ Tryaxis and Waverider buoys
- Multi-mission scatterometers and altimeter measurements
- CFOSAT directional spectra

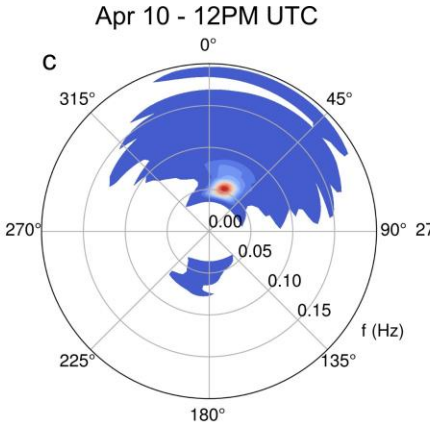
Cape Bridgewater (CB) and Cape Sorell (CS) time series

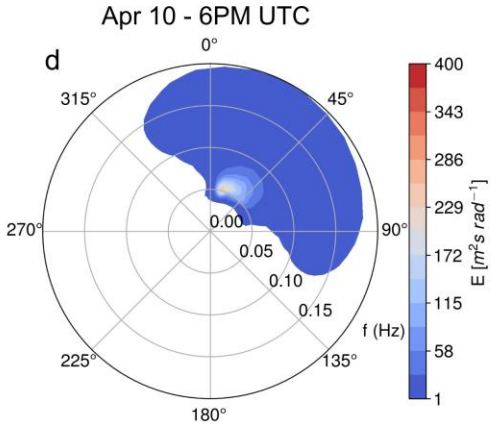


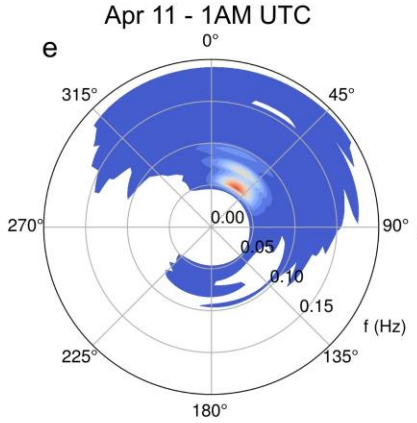


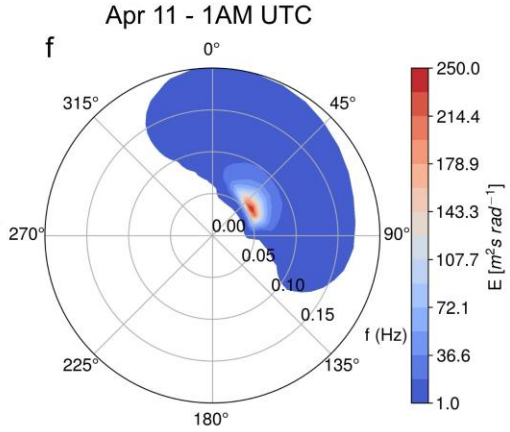






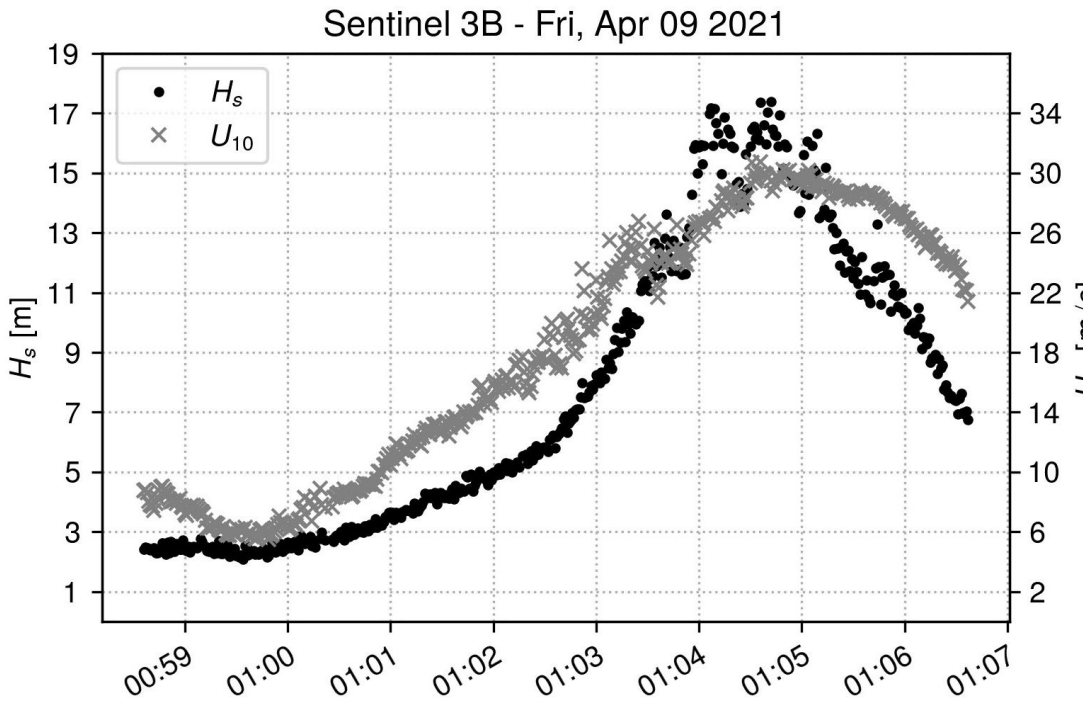


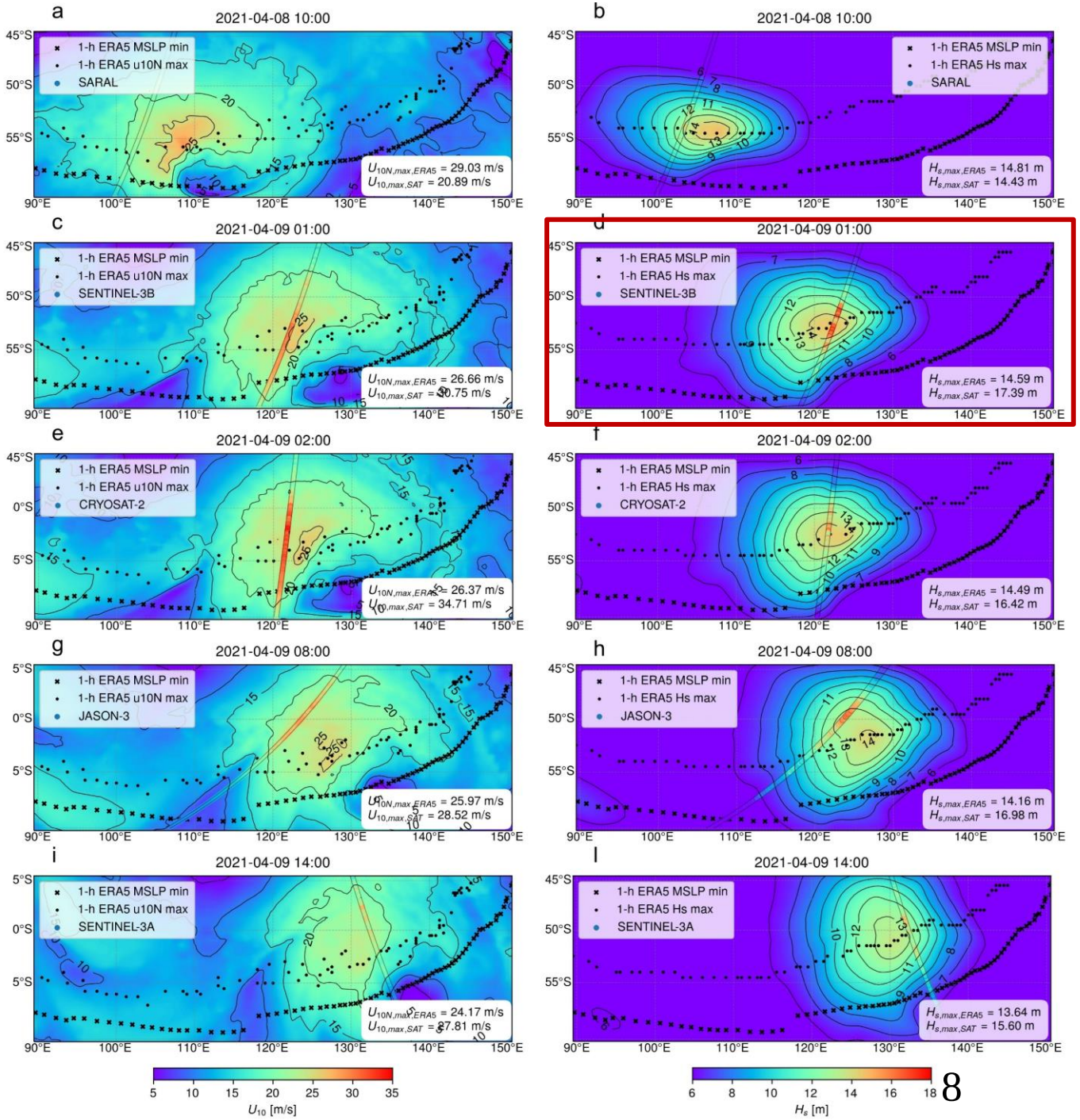




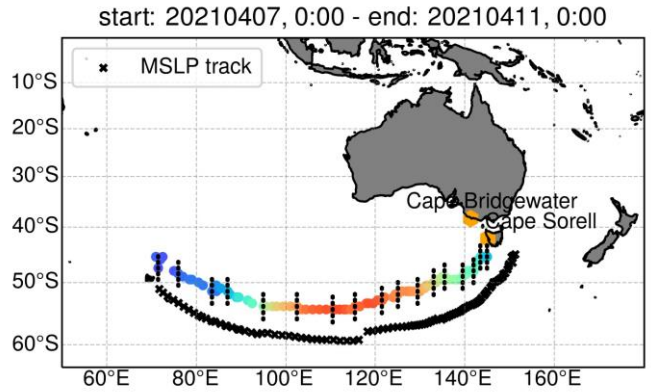
Altimeter wind speed and wave height

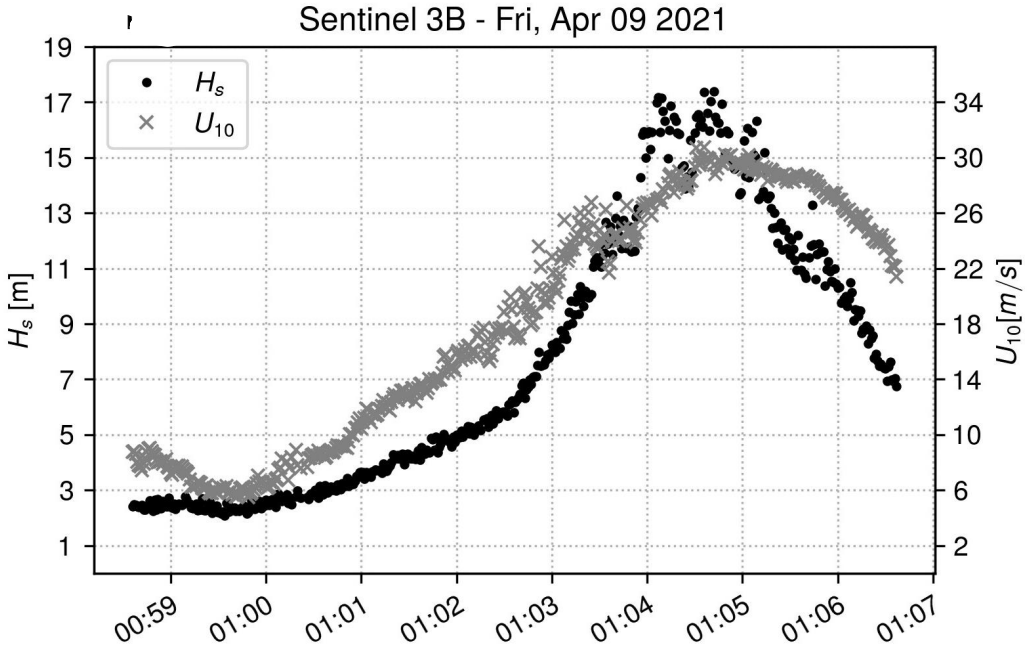
	Hs [m]
Sentinel-3B	17.39
ERA5	14.59

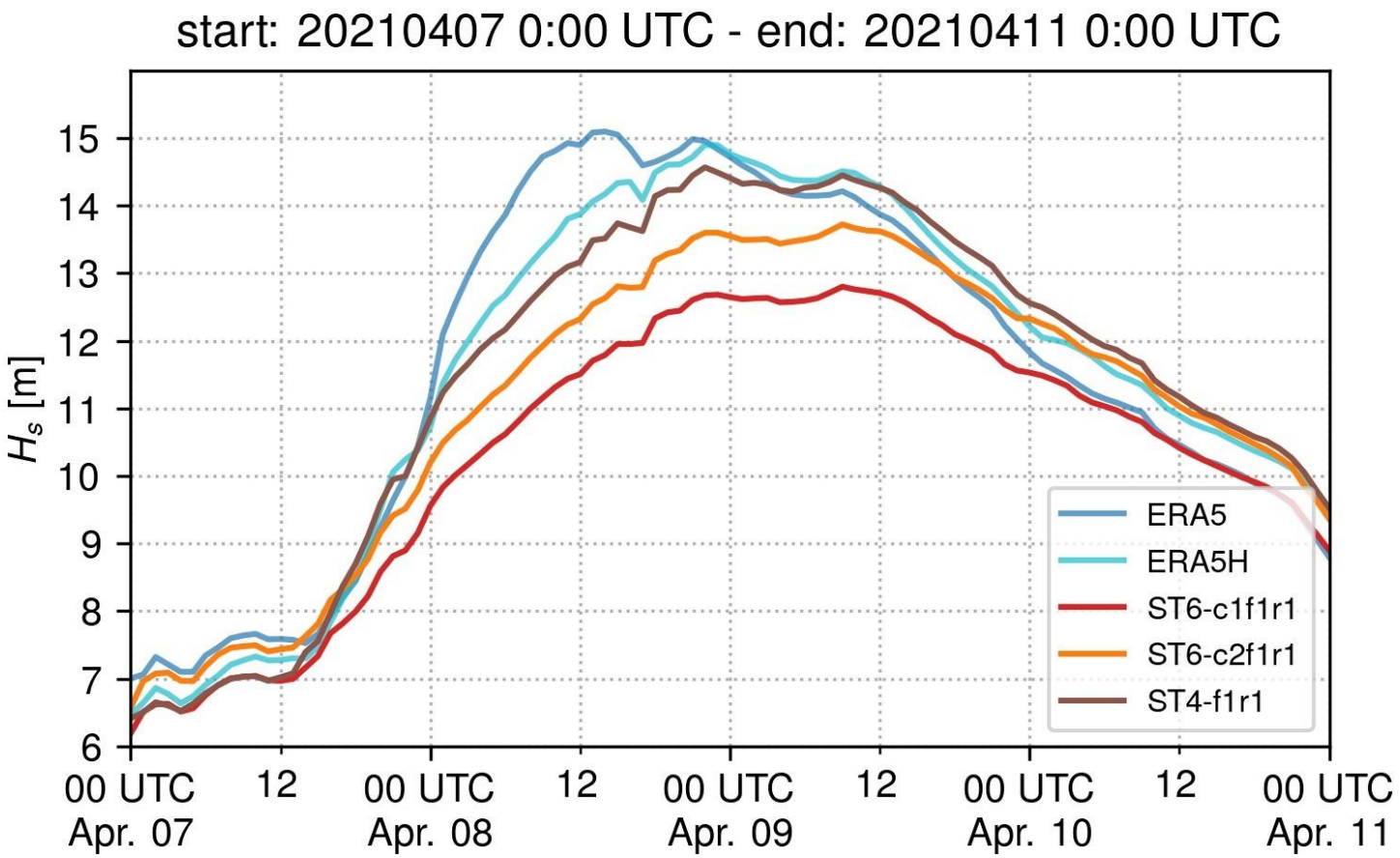




Along track maximum Hs

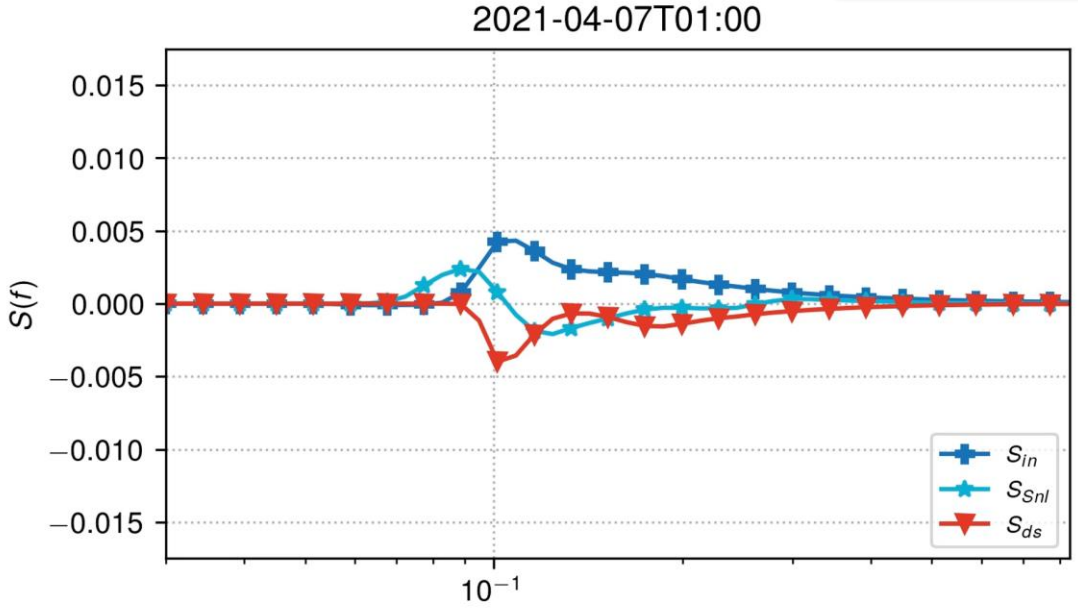


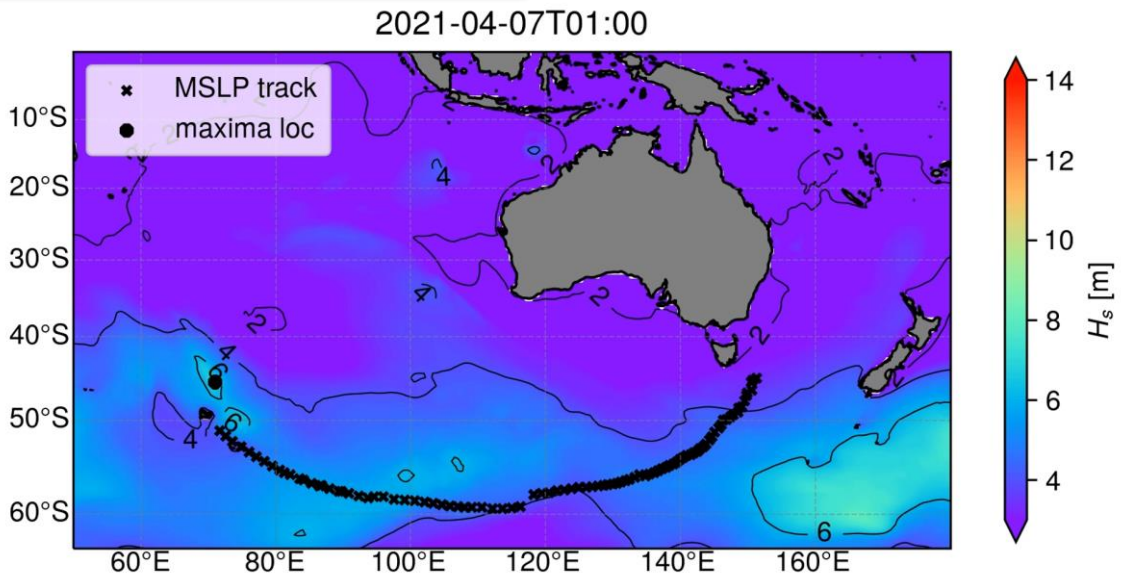


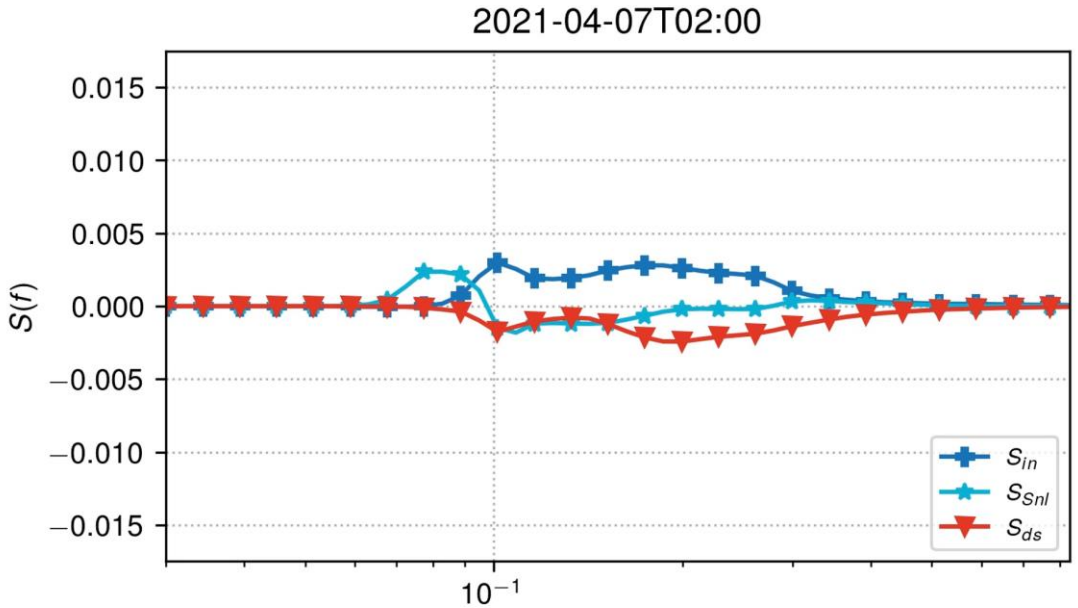


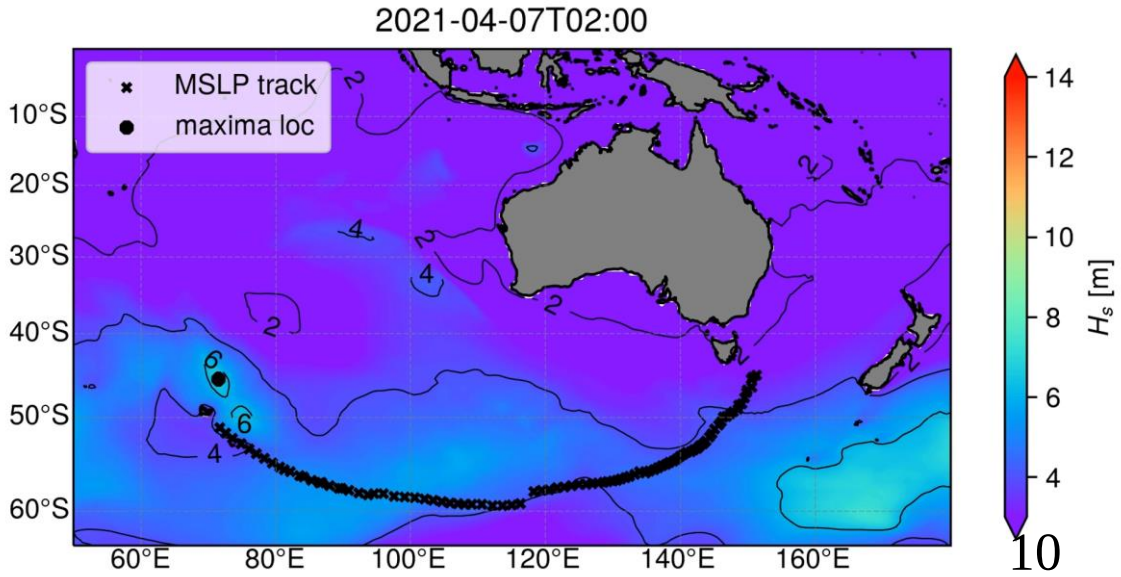
Source terms

$$S_{tot} = S_{ln} + S_{in} + S_{ds}$$









Source terms

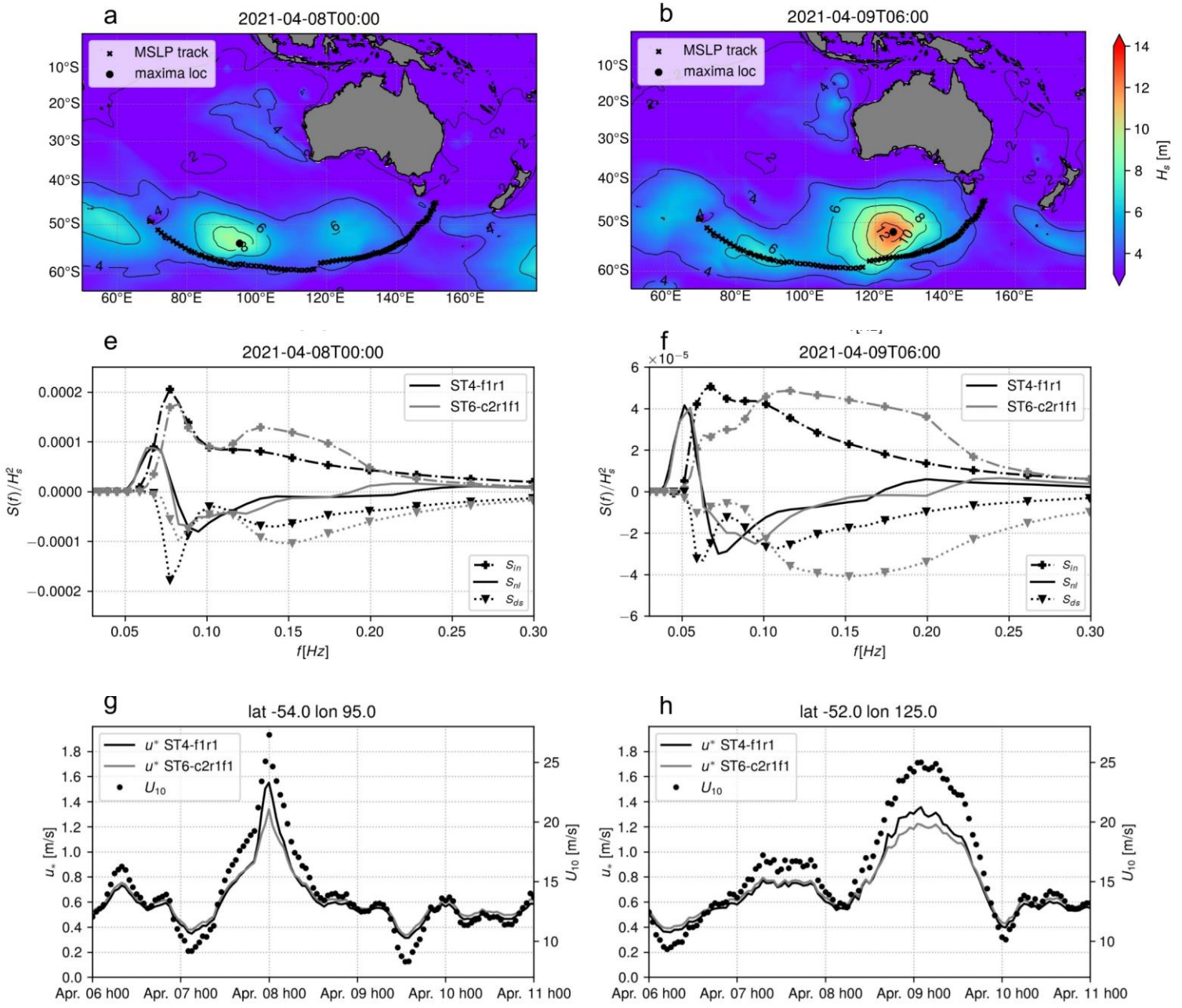
H_s^2 scaling and wind stress

- Difference between ST4 and ST6 wind input magnitude as well as active frequency range
- The wind input (normal stress) is capped through wind stress empirical formulae

$$\tau_{\text{norm}} \leq \tau_{\text{tot}} - \tau_v$$

$$\tau_{\text{norm}} = \rho_w g \int_{f_1}^{10\,\text{Hz}} \frac{S_{\text{in}}(f)}{C} df$$

$$\vec{\tau} = \rho_a C_d U_{10}^2 = \rho_a u_\star^2$$

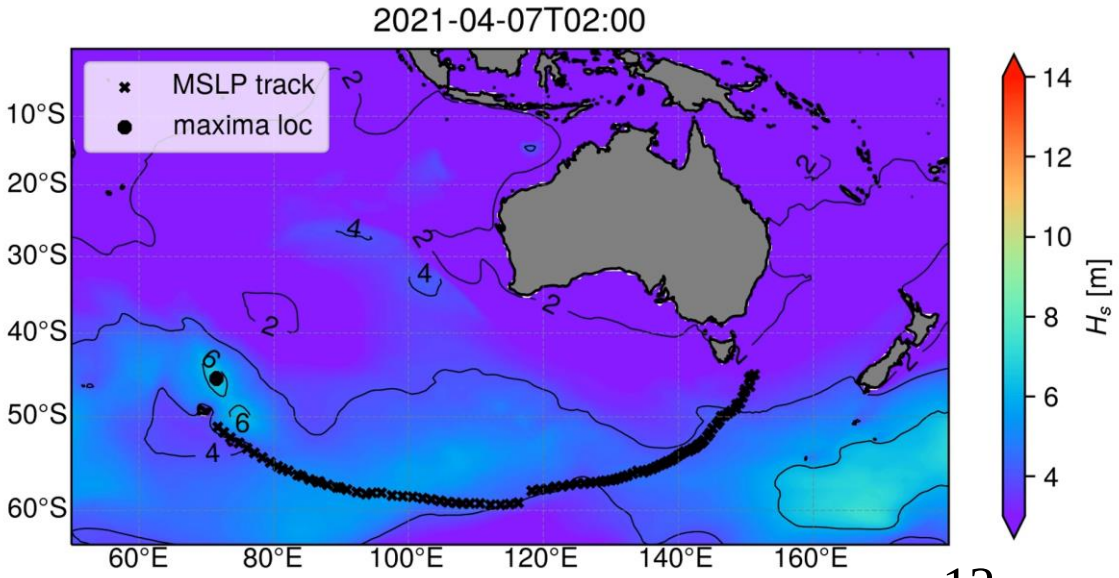


Conclusions

It's the wind you fools! … Yes, BUT

- The picture is a bit more complicated for ETC waves!
- **Bulk adjustment** to wind fields (CDFAC) is useful but **only for systematic biases** in the wind field,
- Wind stress physical constraint should be **revisited** for wind speed between 20 to 30 m/s,
- For ETCs, the inaccuracies found in the wave model generation region far offshore may as well be the cause of the **model biases** in **swell magnitude** and **swell arrival times** at the coastlines.

Any reanalysis, forecast, or hindcast datasets should *be treated with care* when performing **Extreme Value Analysis** to estimate **one-in-N-year return period** for engineering design purposes.



The coupled approach

An ERA6 prototype based on wind speed corrections and the *Janssen and Bidlot* (2022) new results on the wind input term and the background roughness length