

Improving Swell Predictions Using Data Assimilation

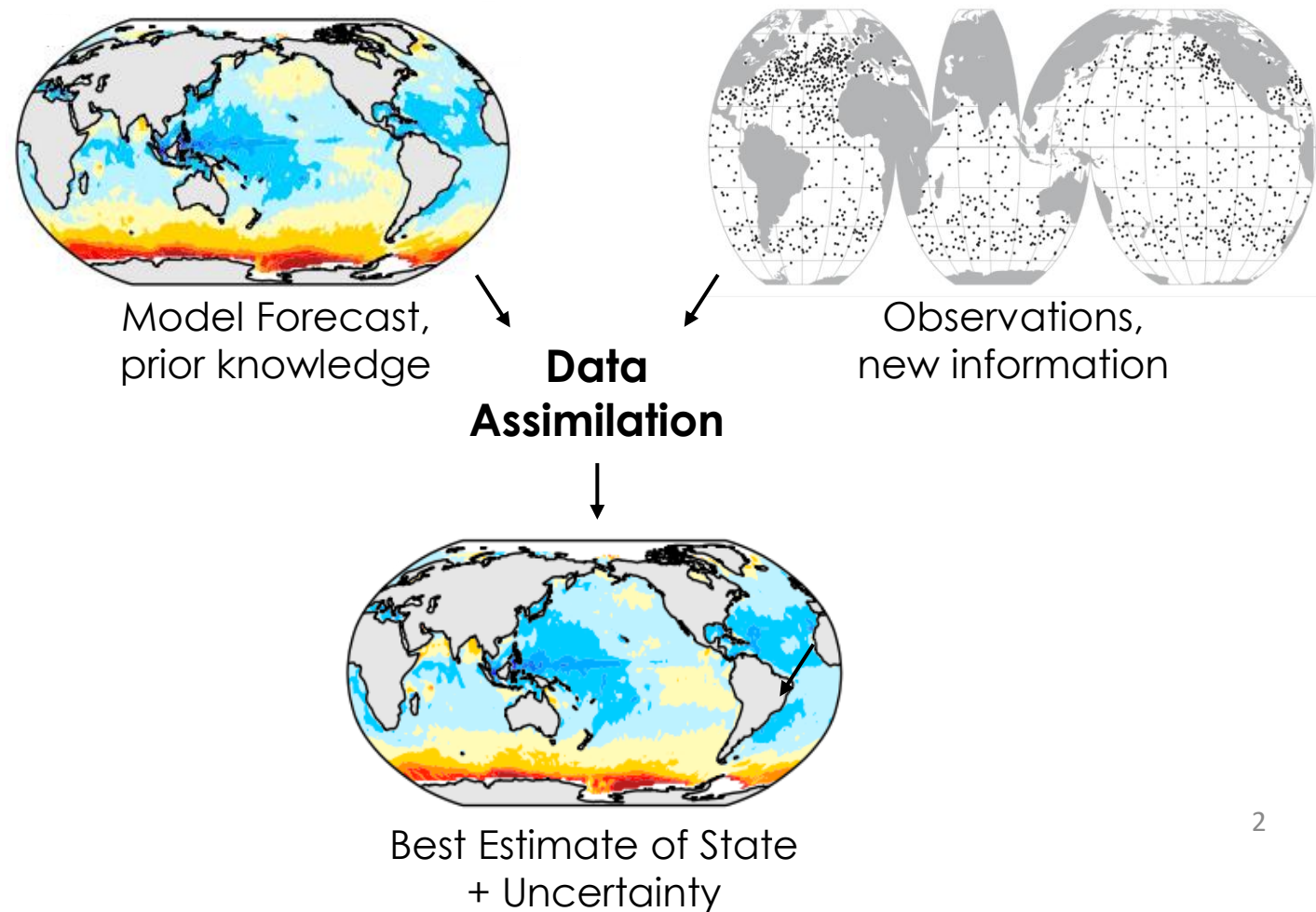
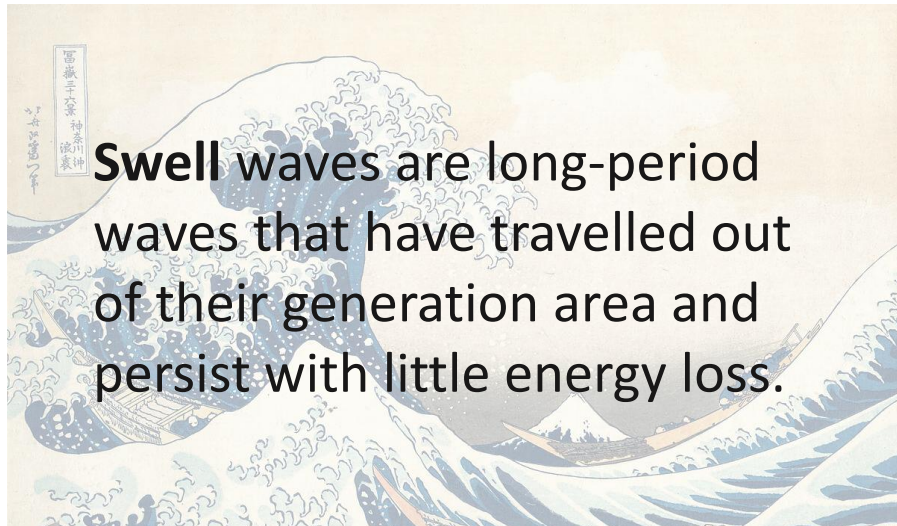
September 2025

Research Objectives

 **TIDE**: developing new science and technology through Digital Engineering to optimise offshore energy infrastructure management — making it both cheaper and more reliable.

Wave Focus:

Improving operational wave forecasts through **data assimilation (DA)**, emphasizing **swell** prediction.



Wave Model



Australian Government
Bureau of Meteorology



A multiple-resolution global wave model

Stefan Zieger and Diana J. M. Greenslade

May 2021

WaveWatch-III wave model



Wind:
ACCESS-G3



Current:
OceanMAPS



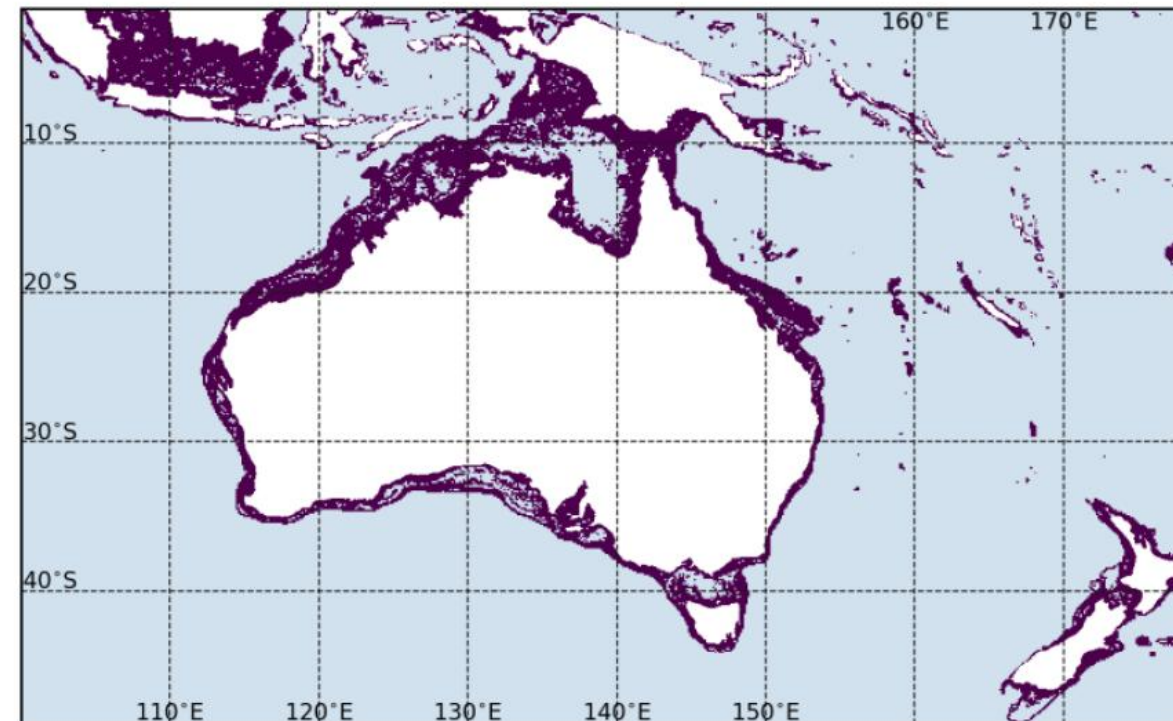
Spectral resolution:

30 direction bins

28 frequency bins (0.0412Hz - 0.5401Hz)

Spatial resolution:

~12km global with ~6km sub-grid



Challenge of DA in Wave Modelling

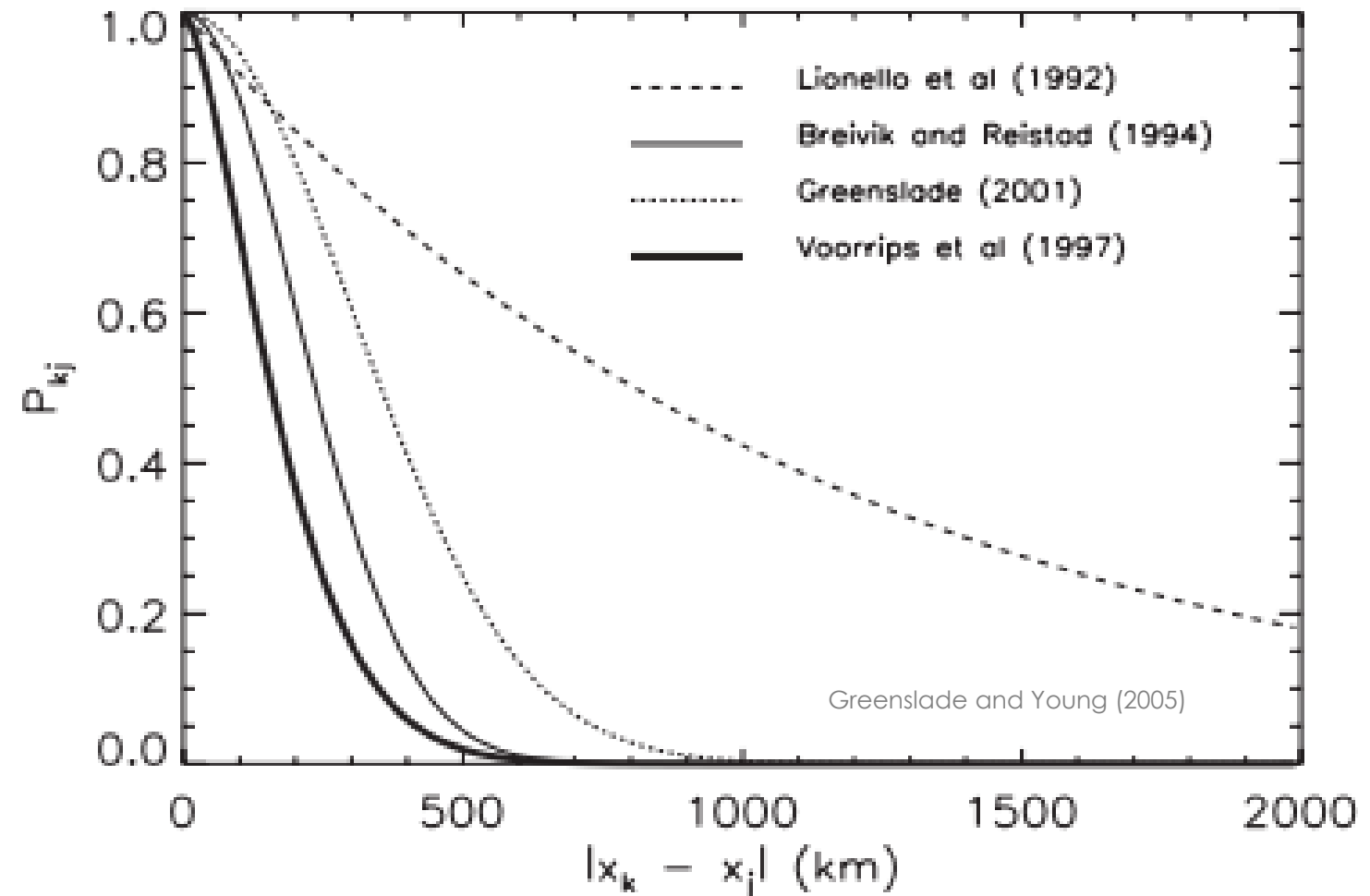
Data assimilation requires error covariance specification.

In wave modelling:

Many definitions exist in the literature (often with little explanation). True error structures remain poorly understood.

Using highly complex DA schemes may not be justified yet.

$$P_{kj} = \left(1 + \frac{|x_k - x_j|}{L}\right)^a \exp\left[-c\left(\frac{|x_k - x_j|}{L}\right)^b\right]$$

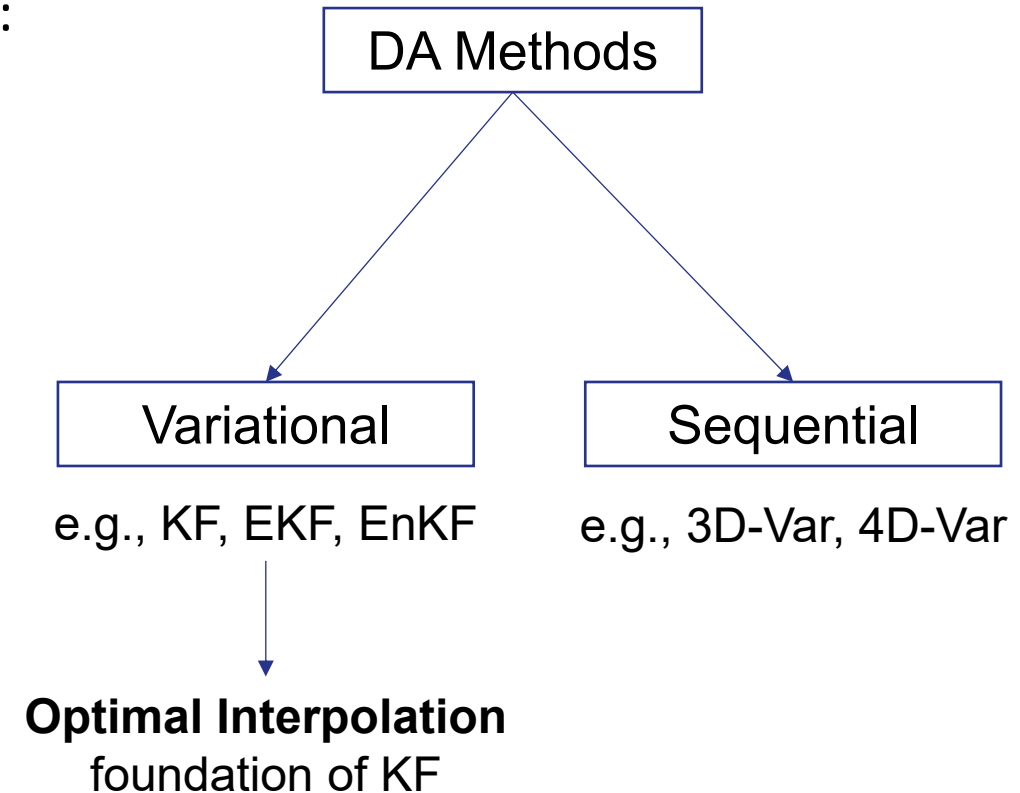


A Simple Approach

We use a simple, pragmatic **Optimal Interpolation** scheme:

- Avoid costly matrix inversions,
- Directly compute correction weights. Each observation location paired with model grid points.
- ✓ Result: fast updates, computationally efficient and operationally feasible.

This is implemented in WaveWatch-III as a modular switch file (DA1), offering two background error covariance options (Voorrips 1997; Greenslade & Young 2005), and is openly available on GitHub.



Long-term Forecast Experiments

Setup:

Period: Feb – Dec 2024

Frequency: 2 forecasts/day (initialized every 12h)

Lead time: 7 days → short & medium-range skill

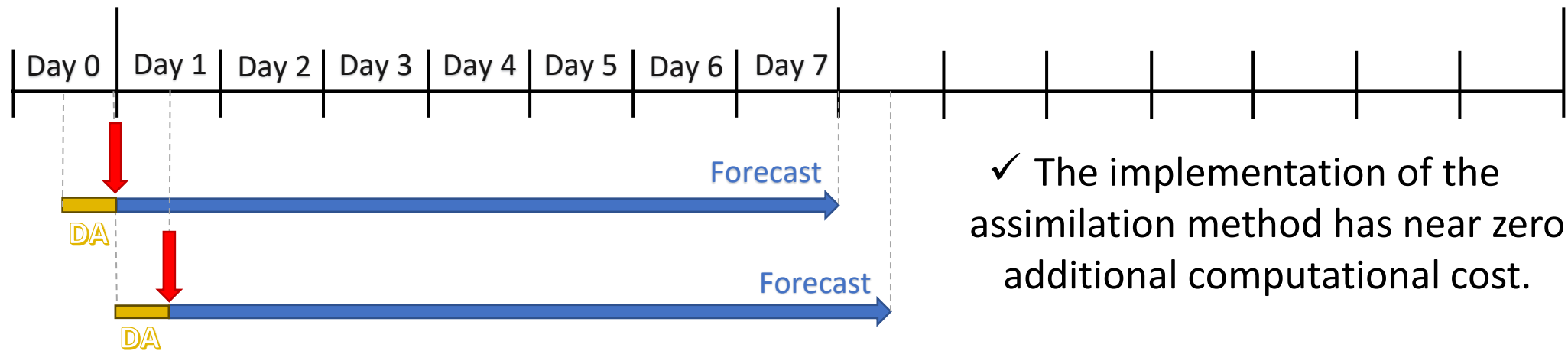
Assimilation:

Observation: Altimeter Hs (hourly assimilation)

Processing: 10-s bins (~50–70 km)

QC: ≥ 5 valid obs & $\sigma_{Hs}/Hs \leq 20\%$

Data Assimilation Setup

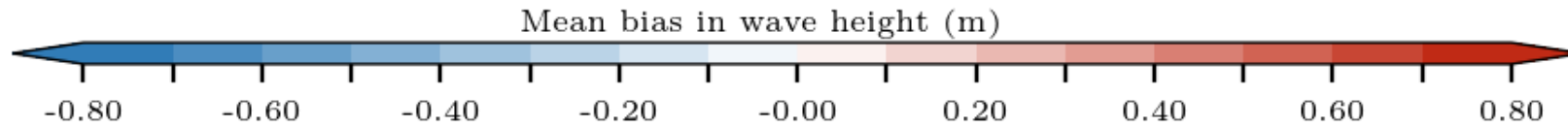
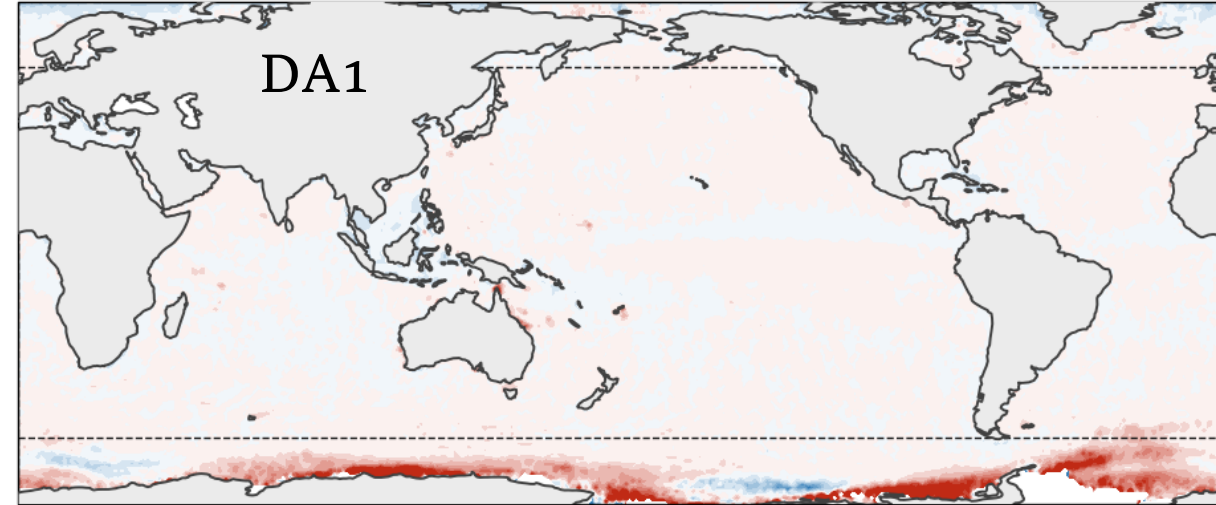
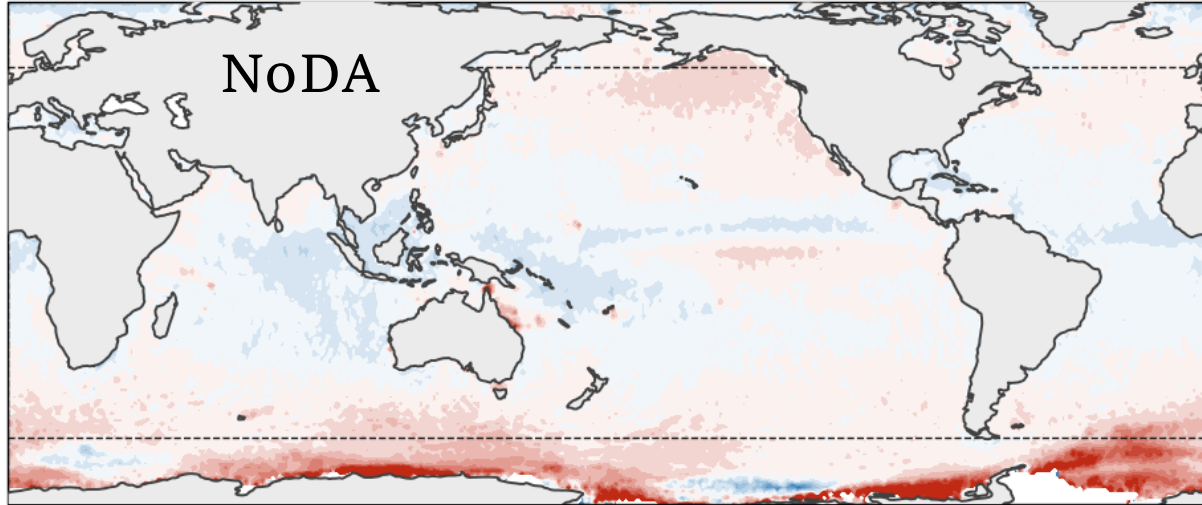
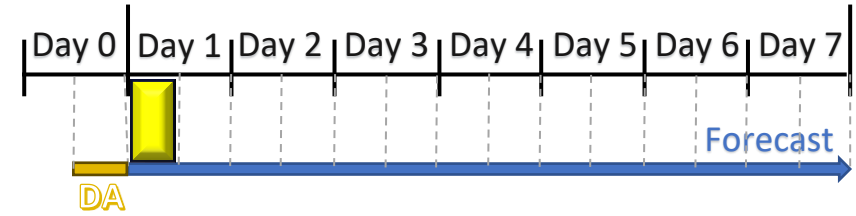


✓ The implementation of the assimilation method has near zero additional computational cost.

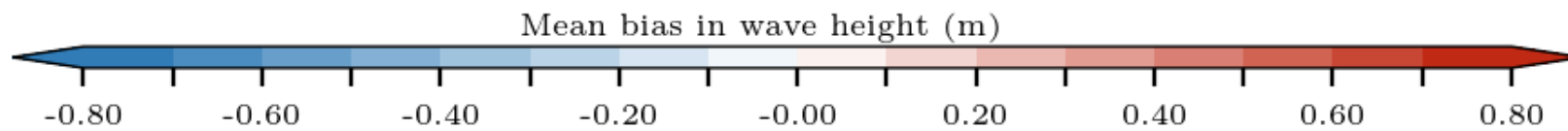
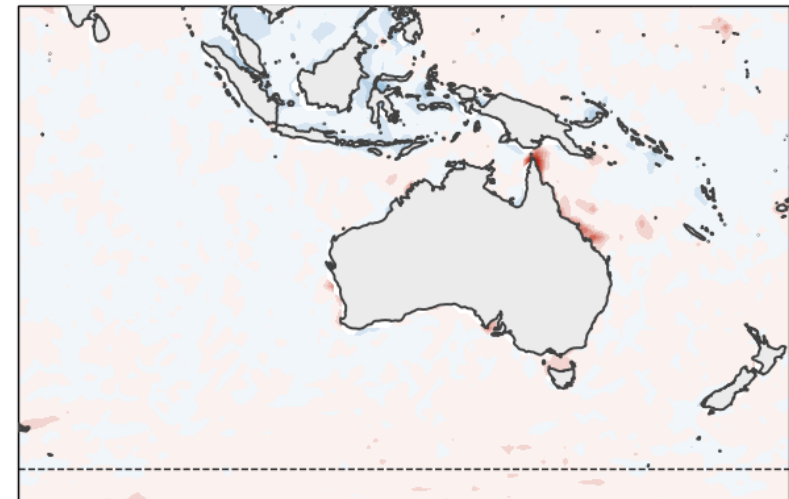
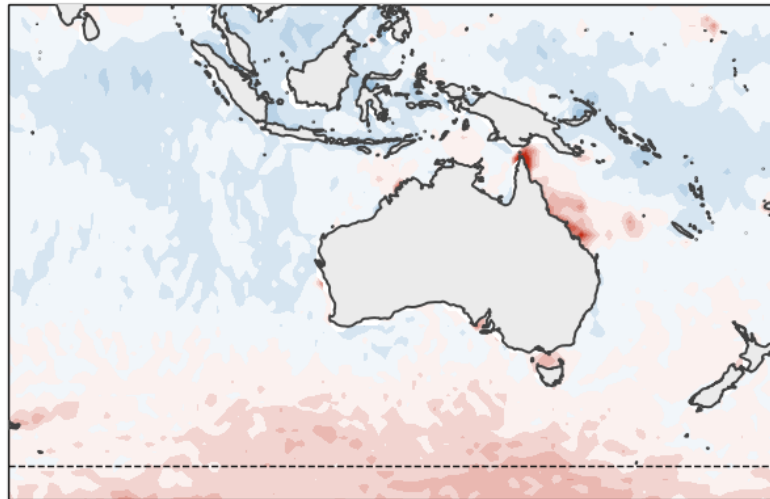
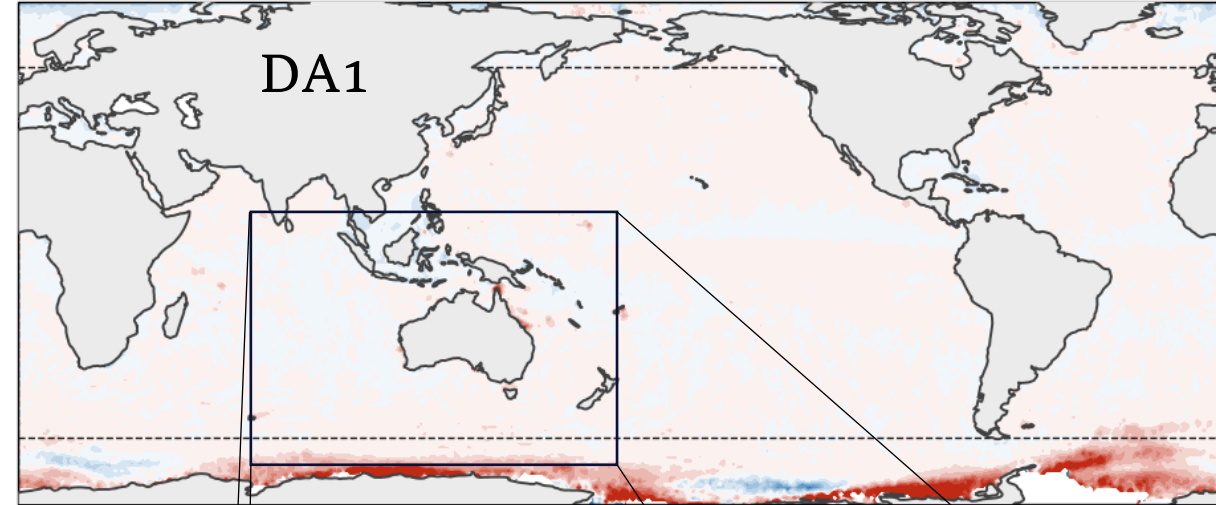
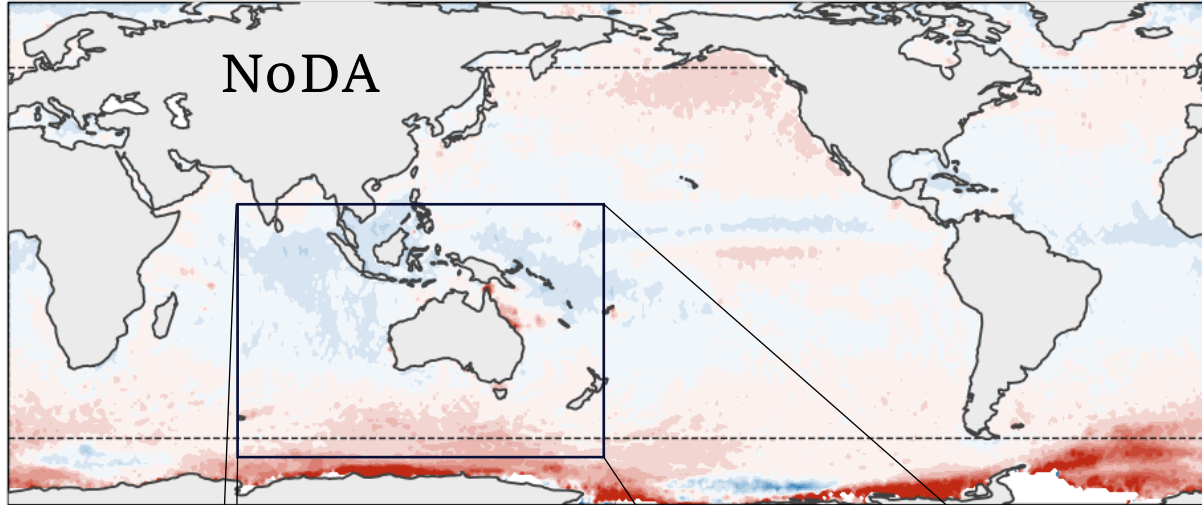
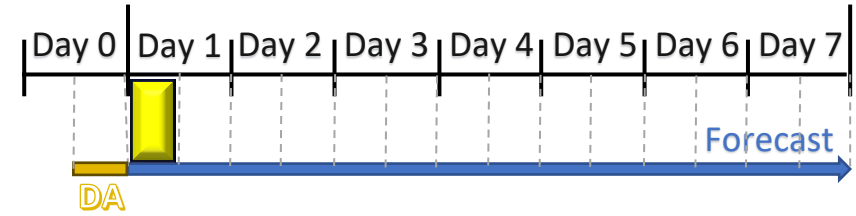
Global Model Evaluation

Forecasts are compared with independent altimeter data. Assimilation stops at initialization, so only non-assimilated observations are used → ensuring an unbiased measure of true forecast skill.

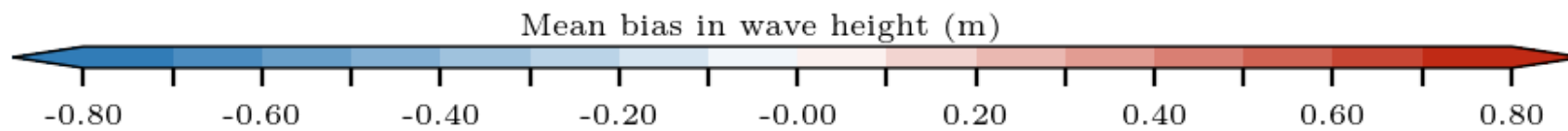
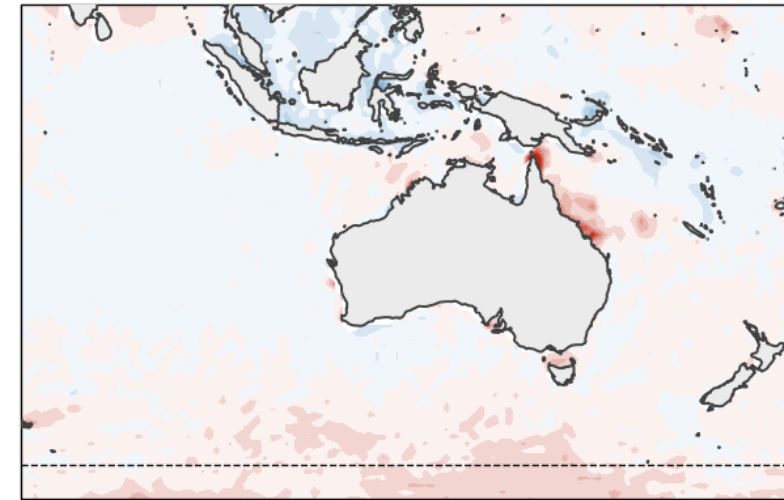
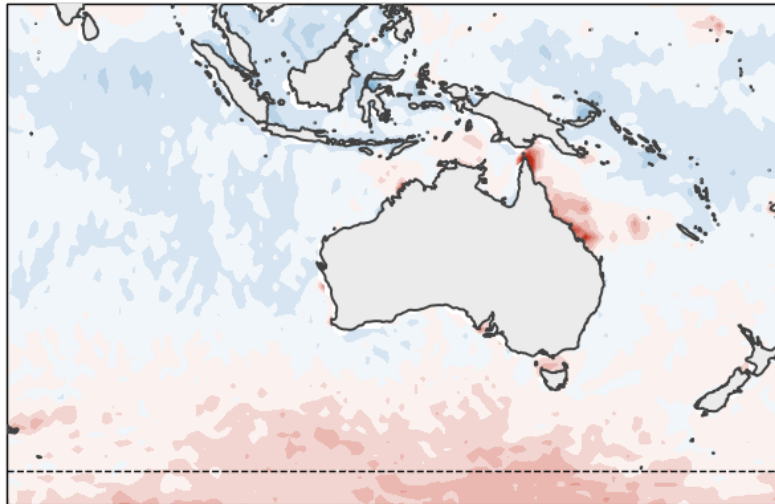
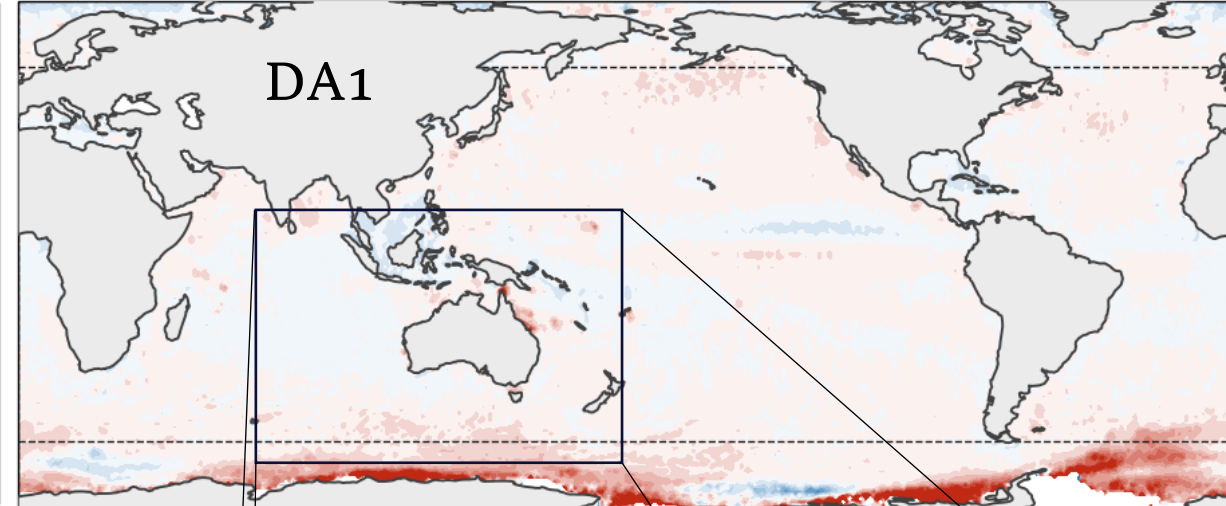
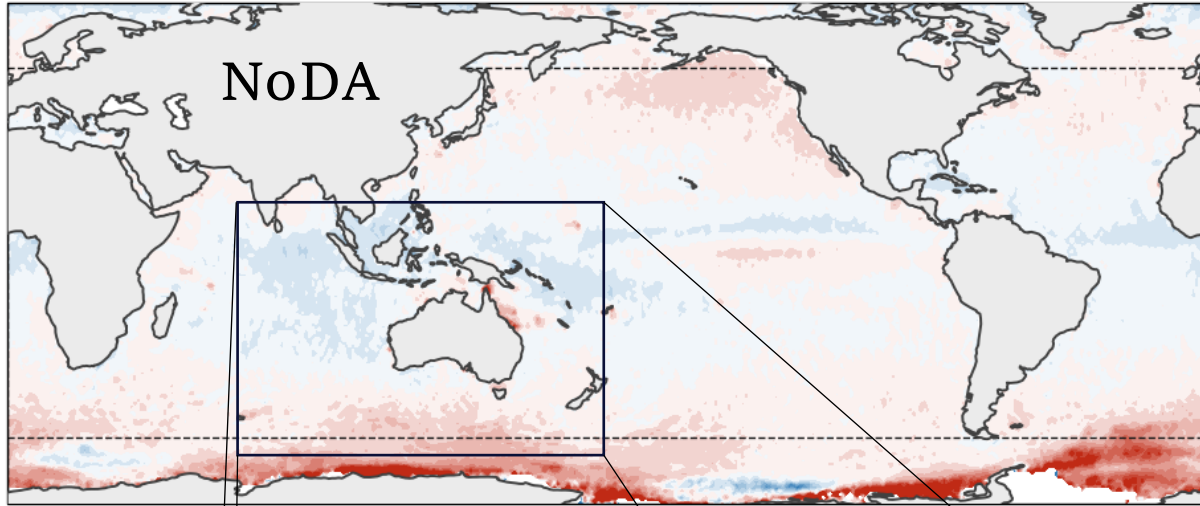
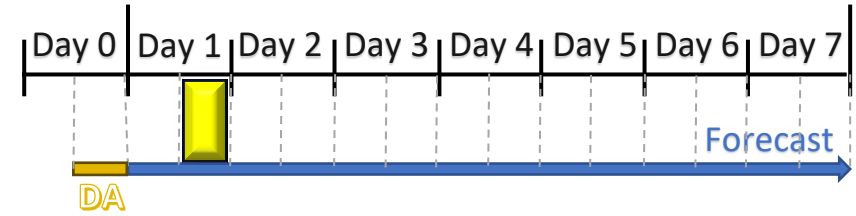
Global Model Evaluation, 0-12 h Forecast



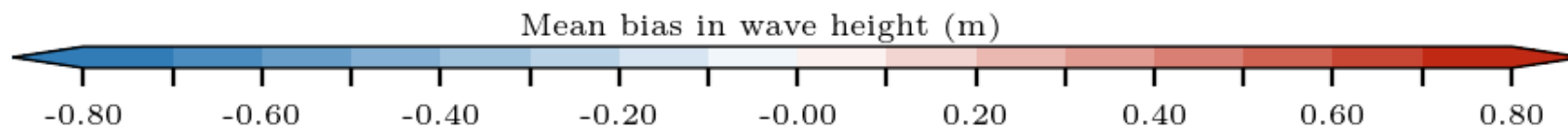
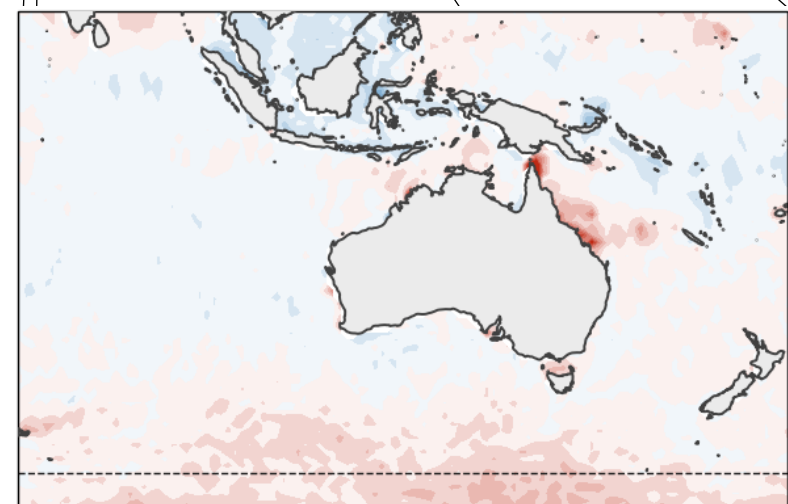
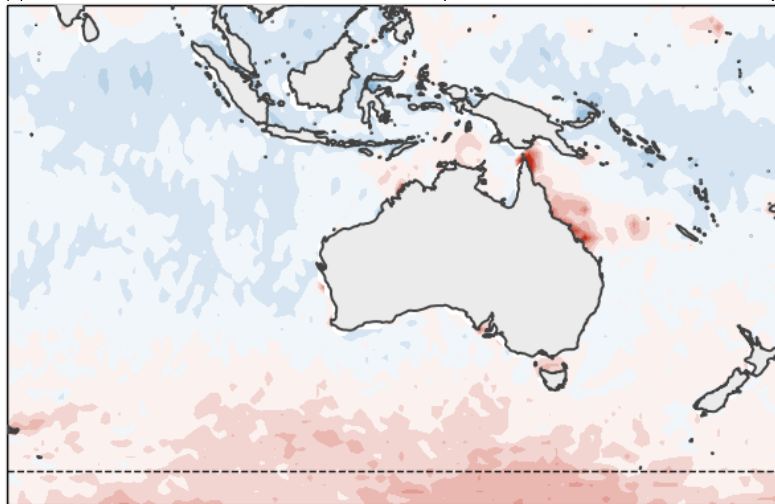
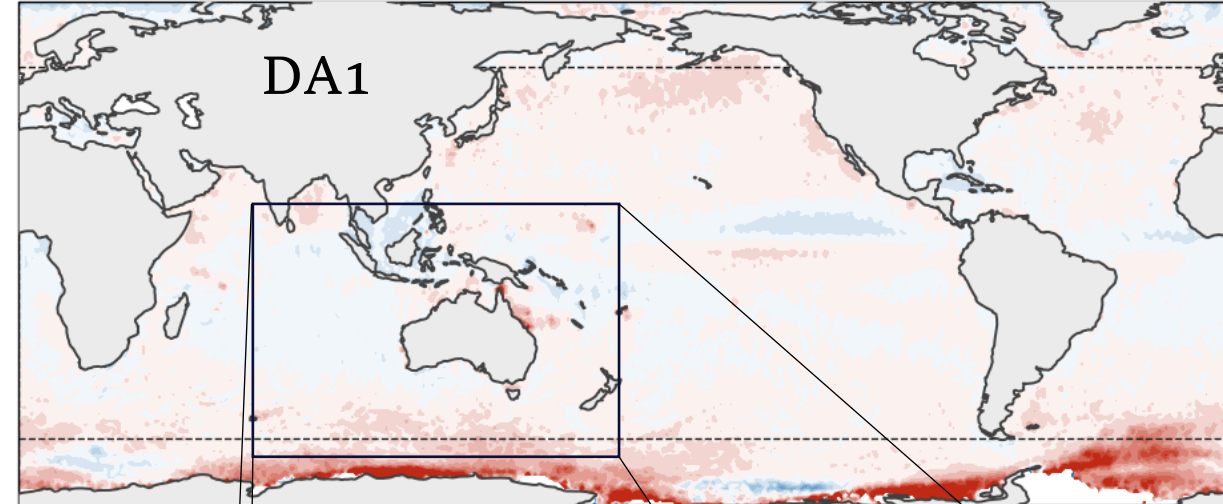
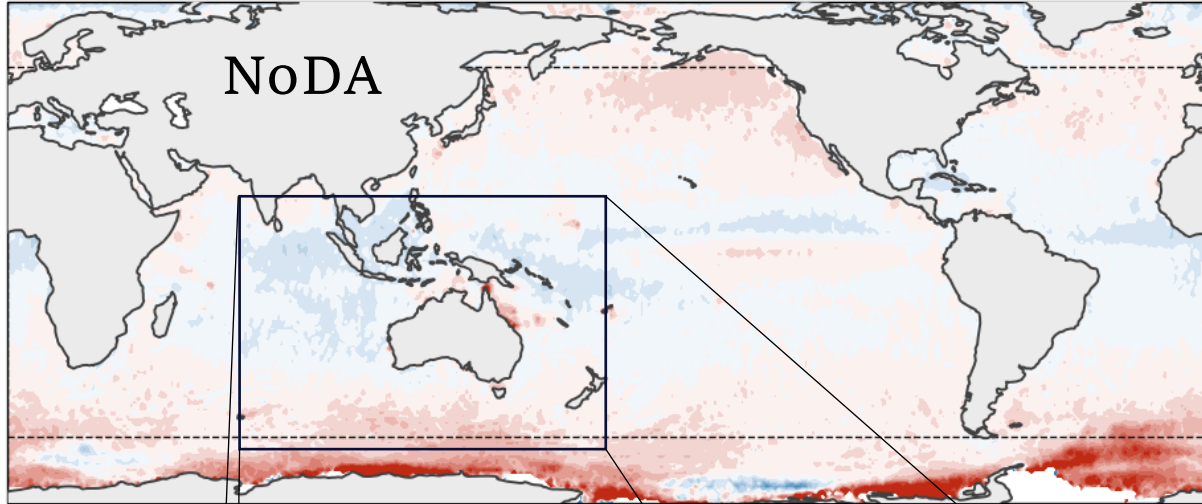
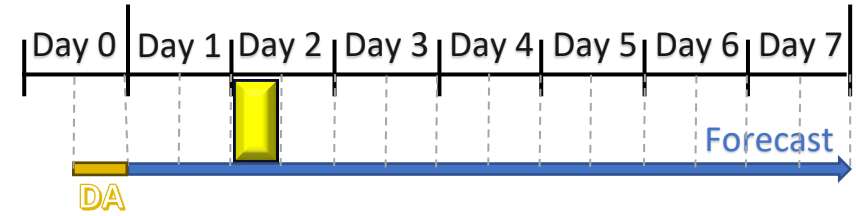
Global Model Evaluation, 0-12 h Forecast



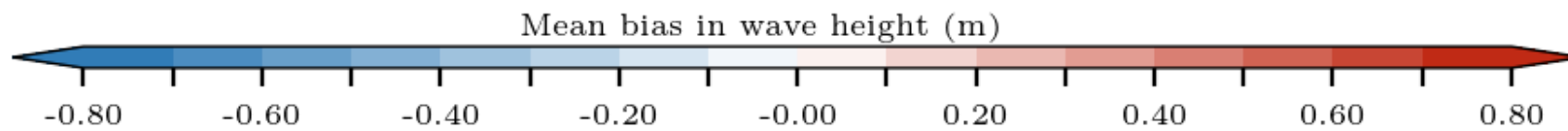
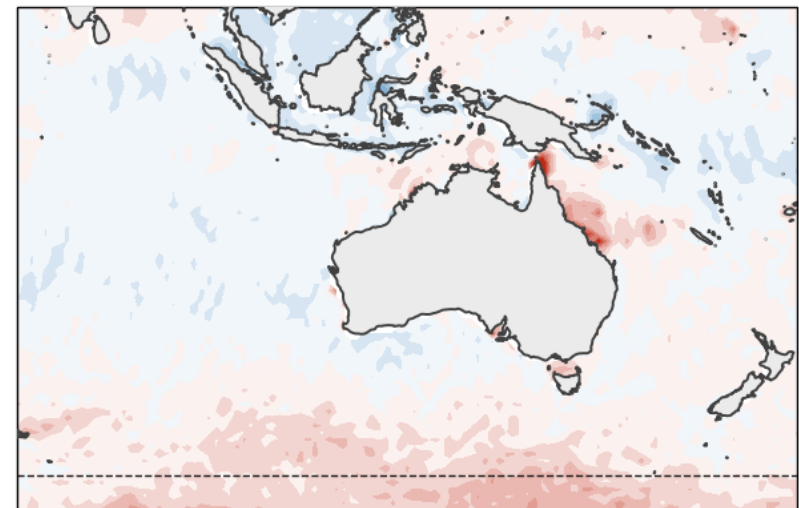
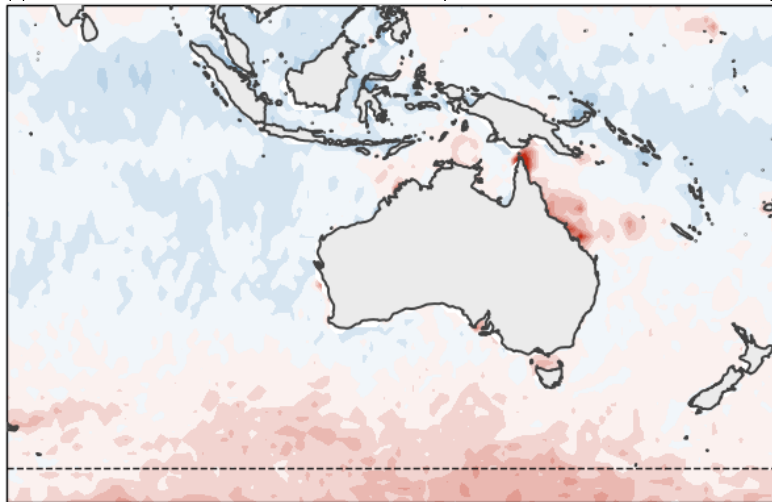
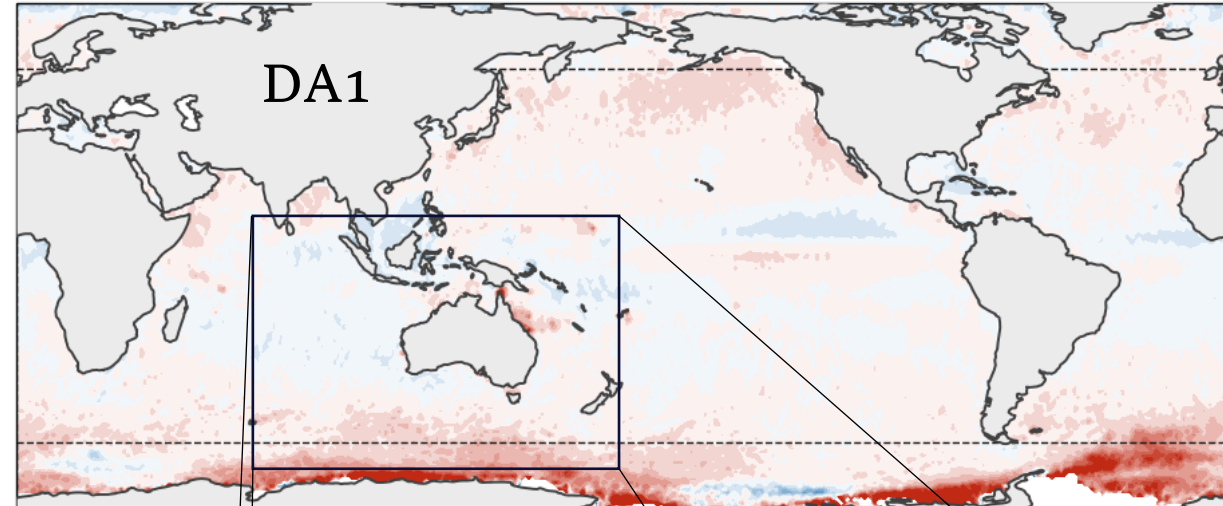
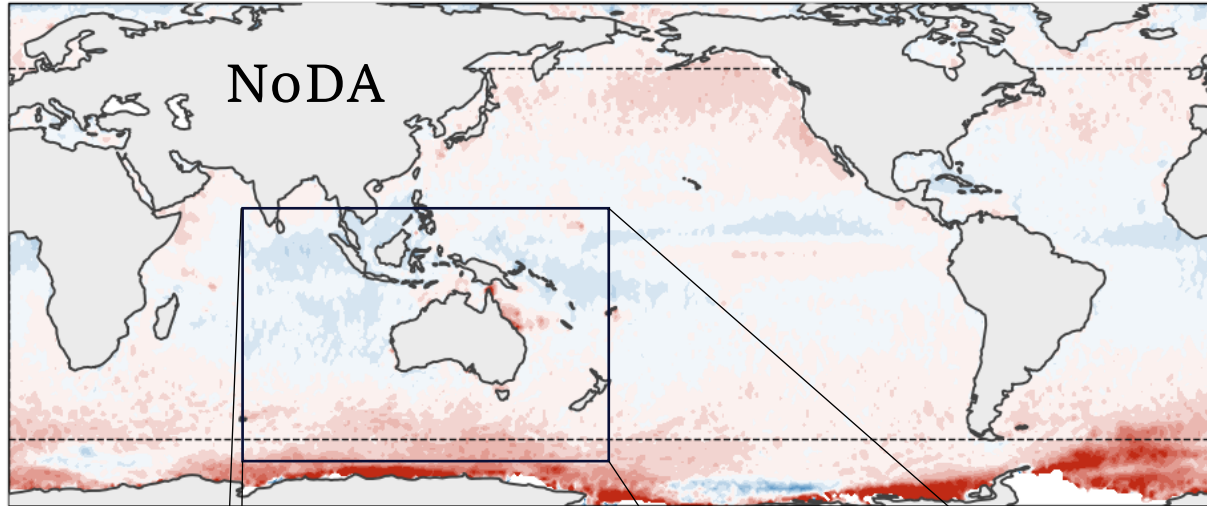
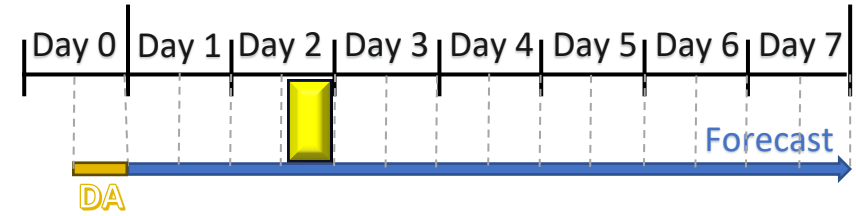
Global Model Evaluation, 12-24 h Forecast



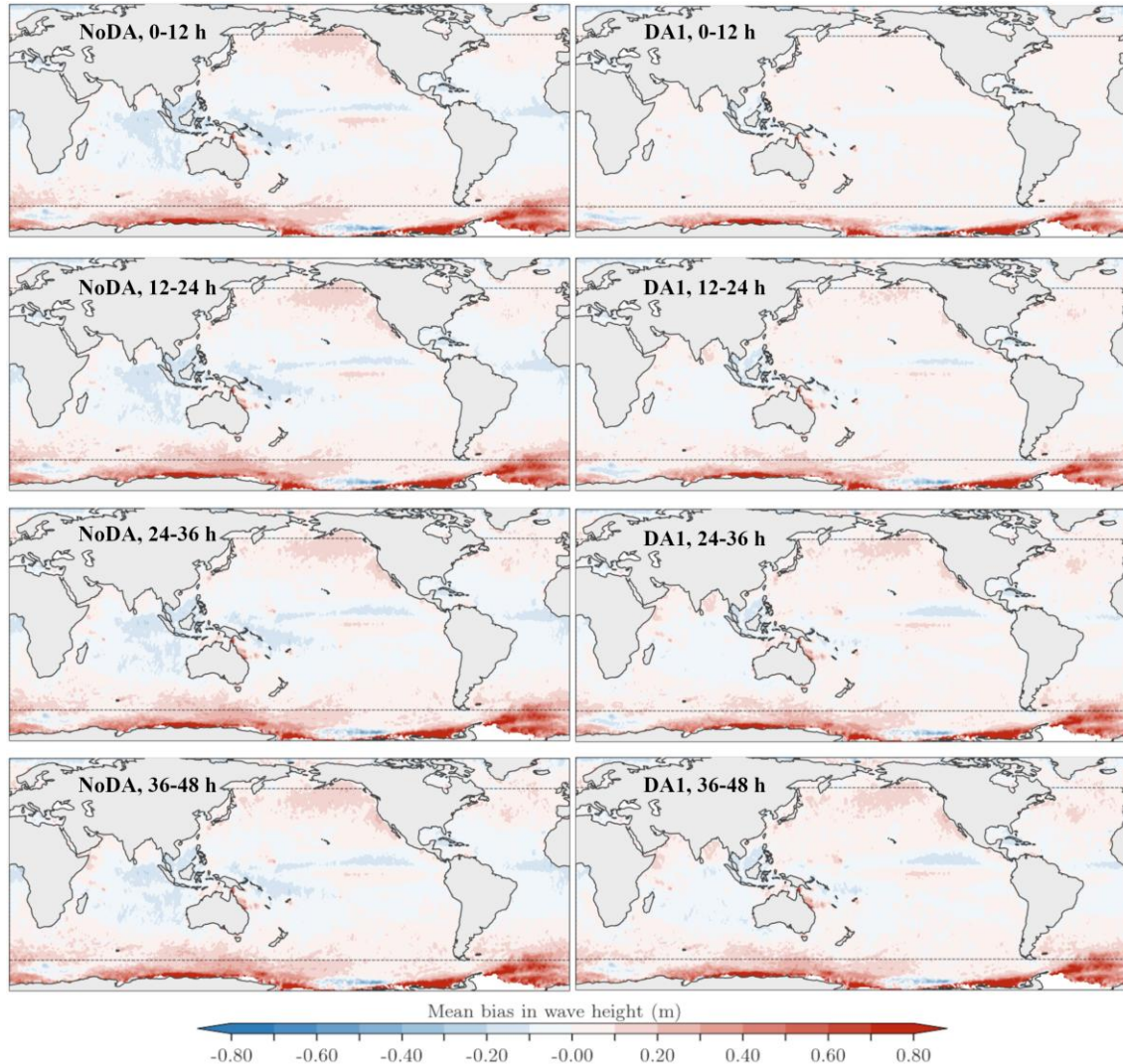
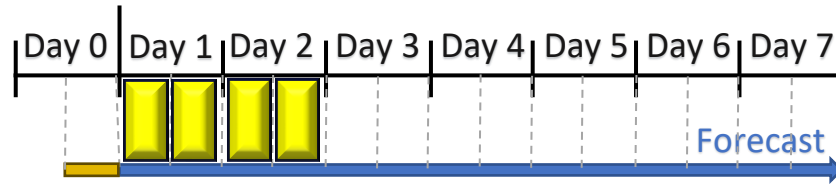
Global Model Evaluation, 24-36 h Forecast



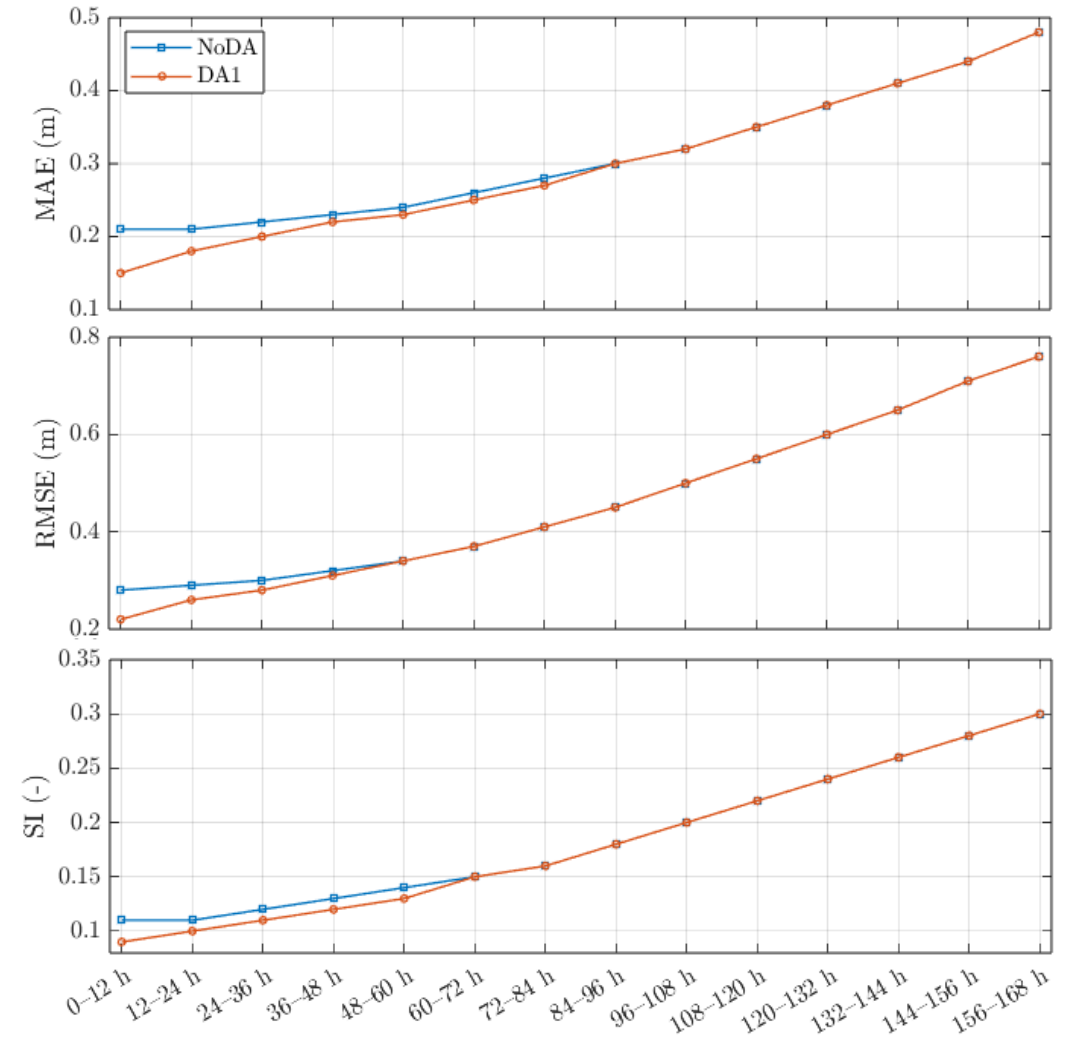
Global Model Evaluation, 36-48 h Forecast



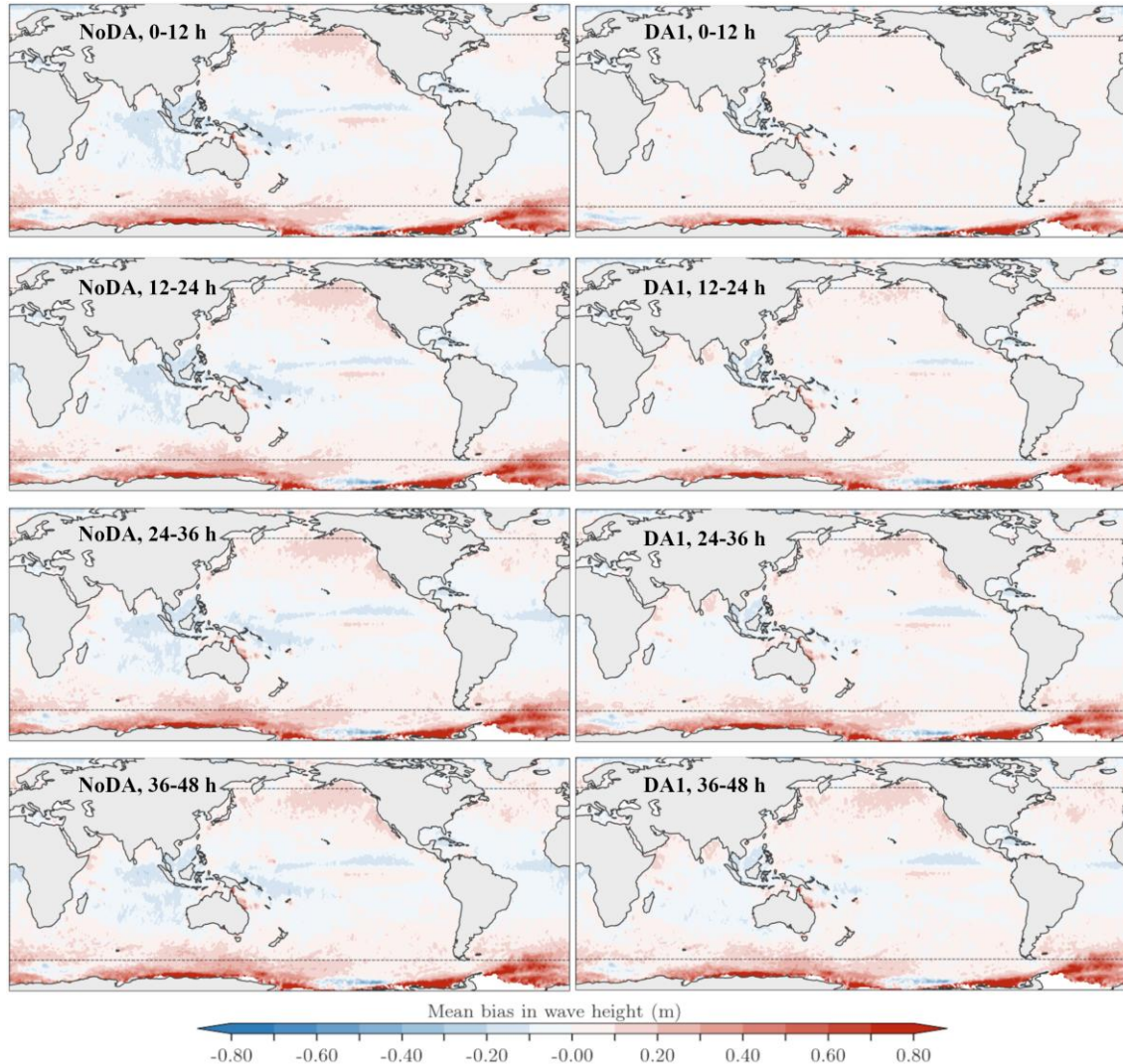
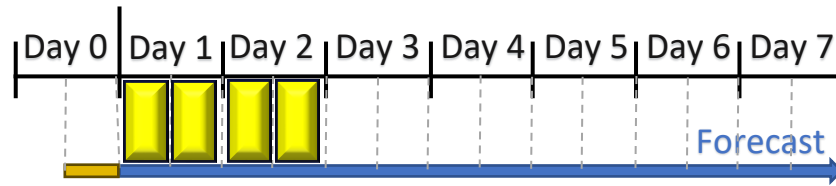
Error Statistics with Lead Time



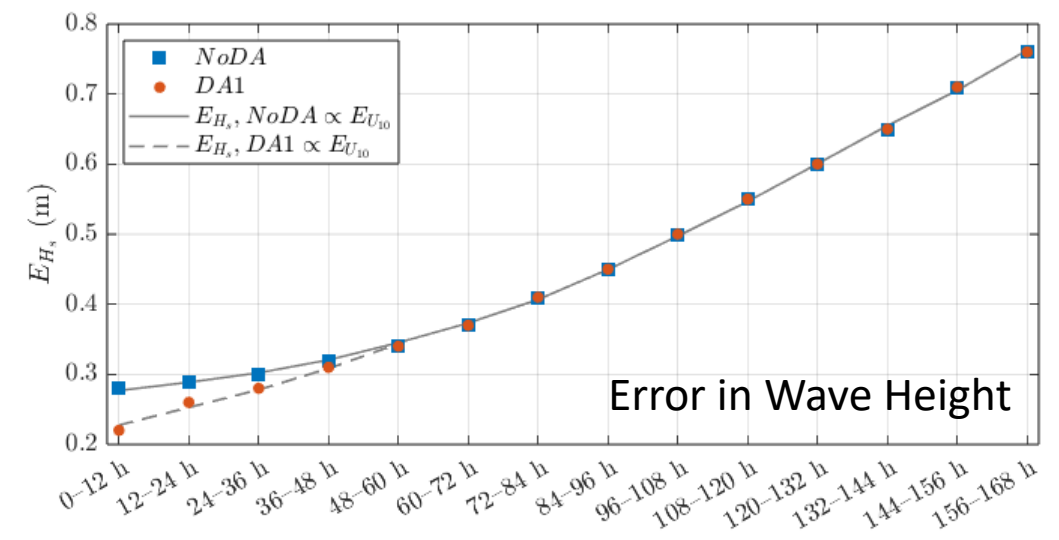
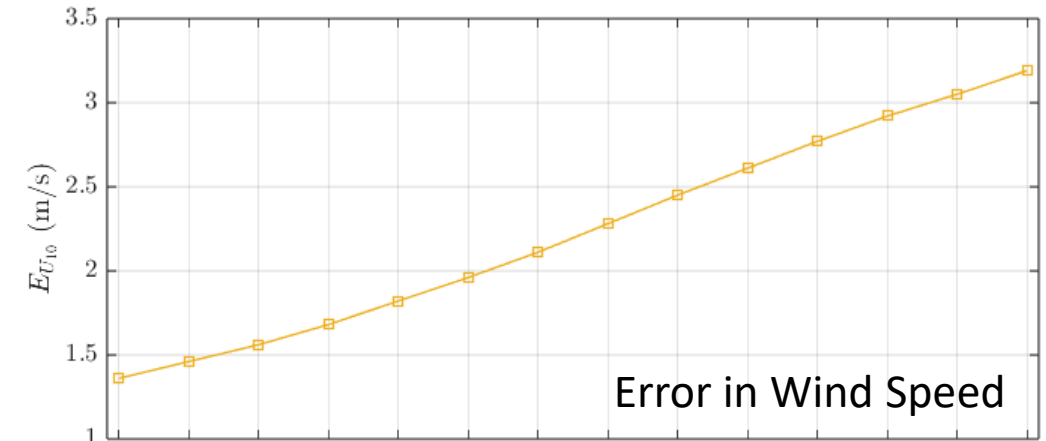
- High latitudes show the largest errors, we restrict our analysis to 55°S to 55°N.



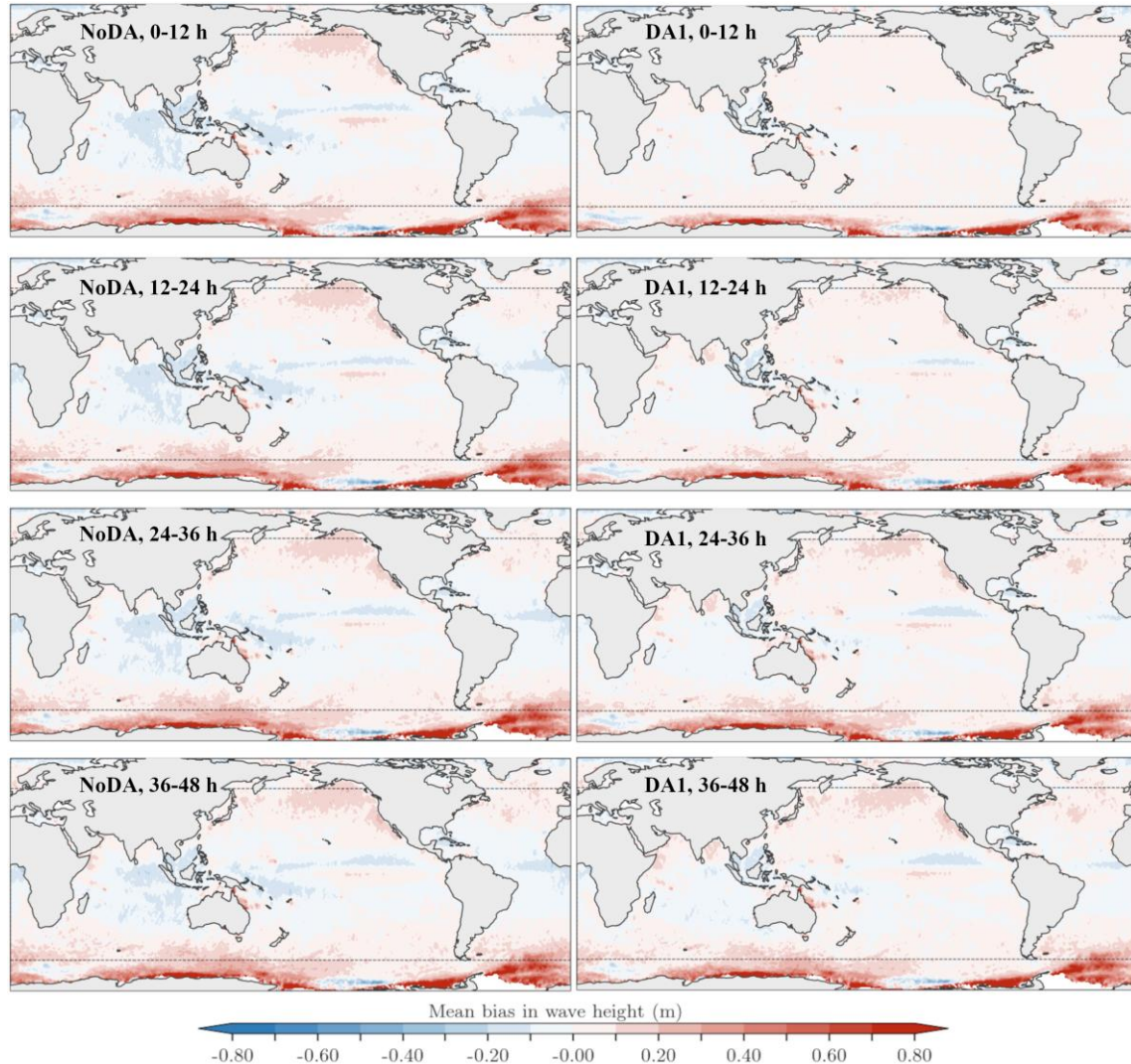
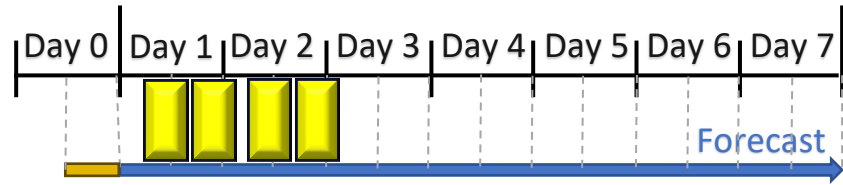
Limits of DA in Wave Models



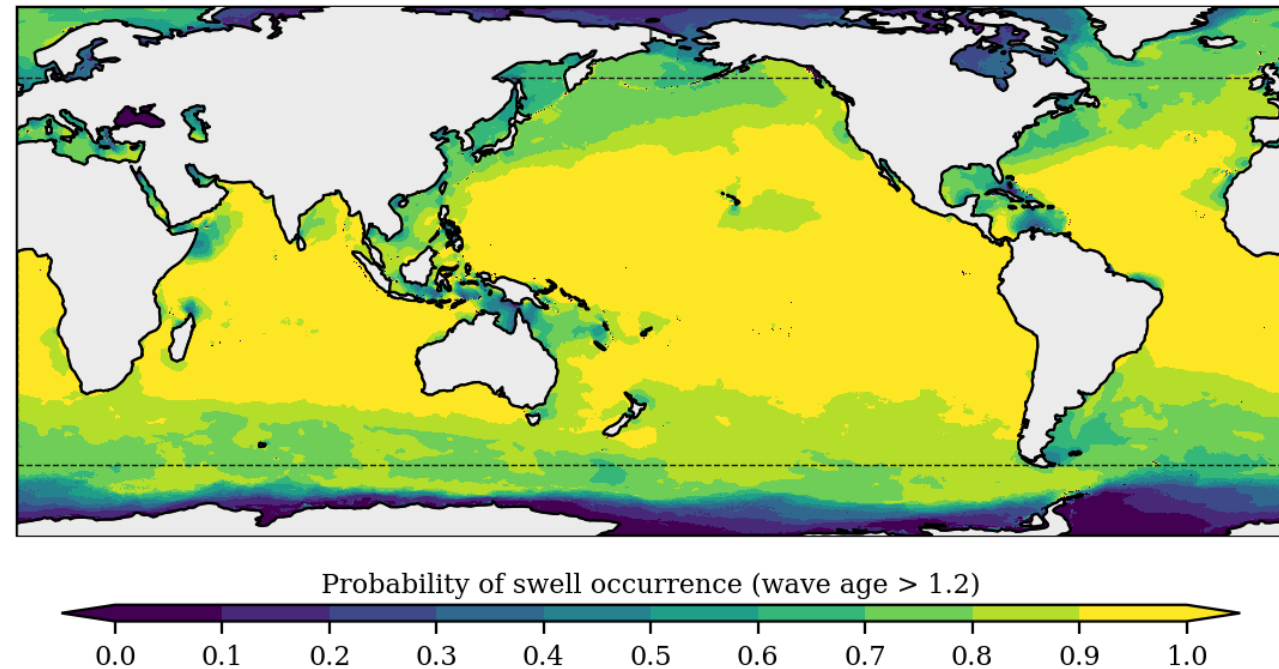
- Wave model errors are ultimately limited by wind errors. **DA cannot eliminate the impact of wind-forcing errors.**



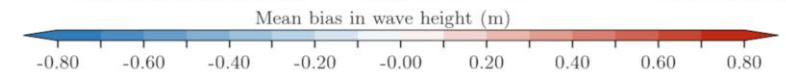
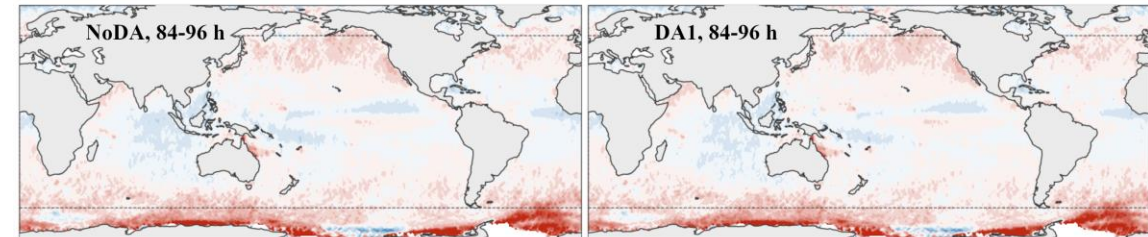
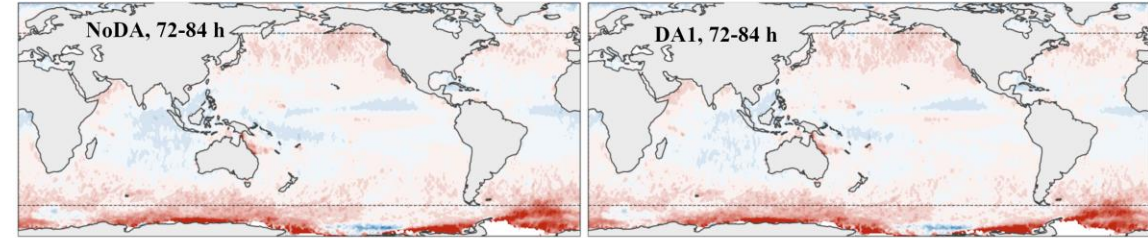
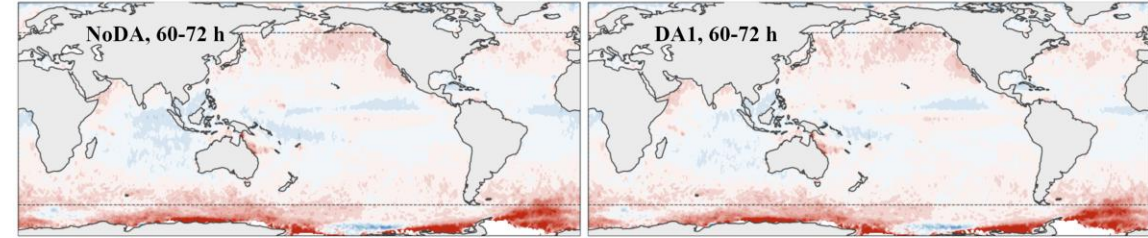
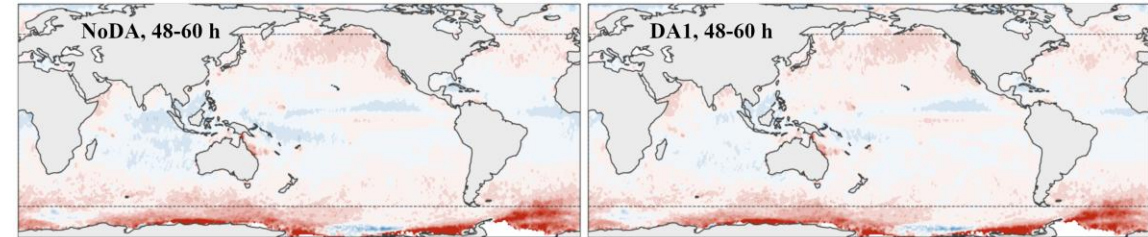
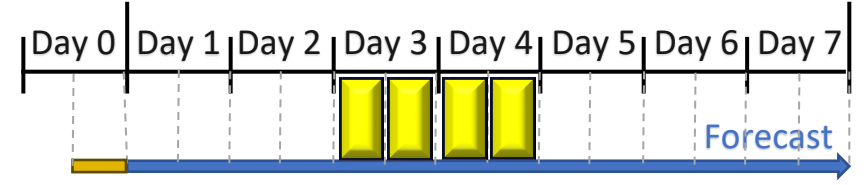
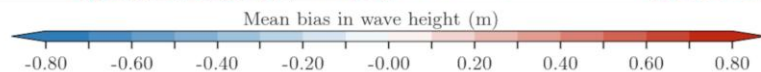
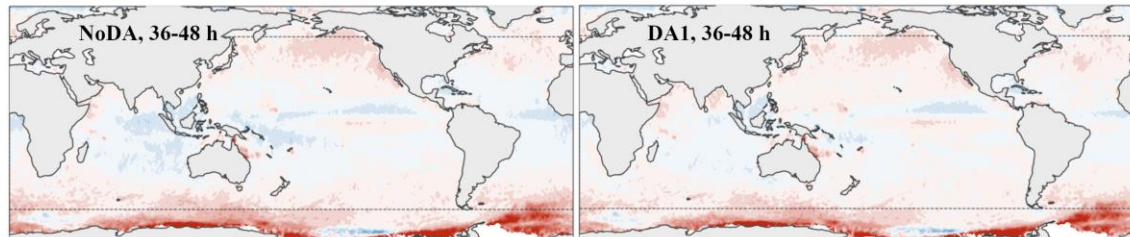
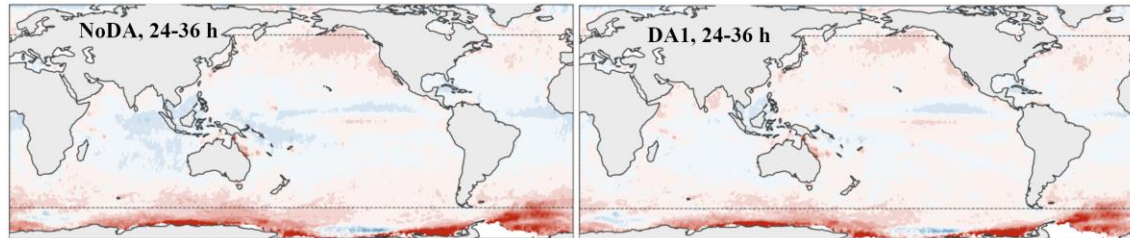
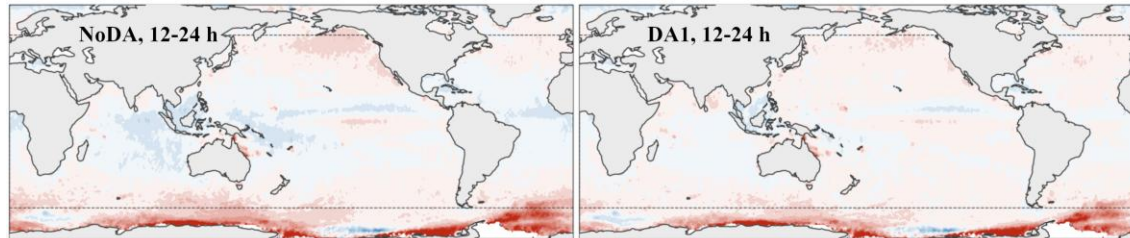
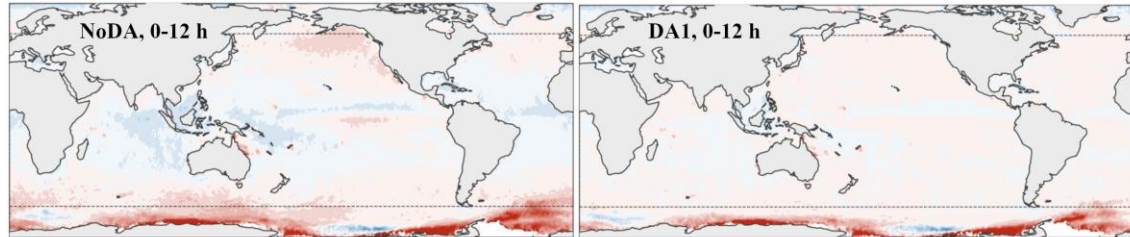
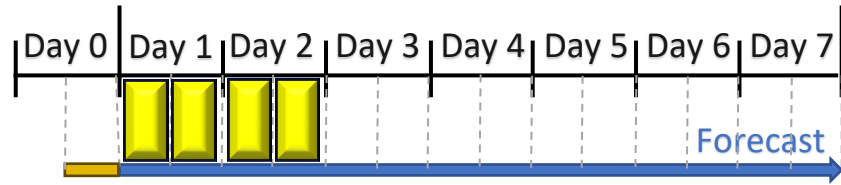
Persistent Improvements in Swell Dominated Regions



- Low to mid latitudes are where the model improvements are most persistent, particularly in **swell-dominated regions** identified by the **wave age criterion** ($cp/U_{10} > 1.2$).



Global Model Evaluation, 0-4 Day Forecast





Summary & Conclusions

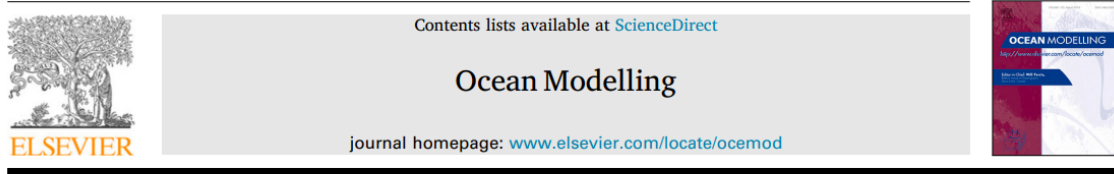
- A simple data assimilation module (**DA1**) has been developed and implemented in WaveWatch-III as a modular switch file.
- The scheme based on Optimal interpolation (OI) was designed with operational applications in mind: it requires virtually no additional computational cost.
- **OI is well-suited for swell**: swells travel long distances with little energy loss and behave like an initial value problem (long memory, weak short-term forcing), making OI a practical and justifiable choice.
- Long-term forecast experiments demonstrate clear improvements in wave forecasts, with the largest gains in **wind-sea dominated regions**, and improvements that persist longer in **swell-dominated regions**.

The background is a deep blue gradient. A series of glowing blue particle trails, resembling a nebula or a data visualization, sweep across the middle of the frame. These trails are composed of many small, bright blue dots of varying intensity, some appearing as sharp points of light while others are more diffuse. The trails curve and flow horizontally, creating a sense of dynamic movement.

BEYOND THE NUMBERS

How does it compare with literature?

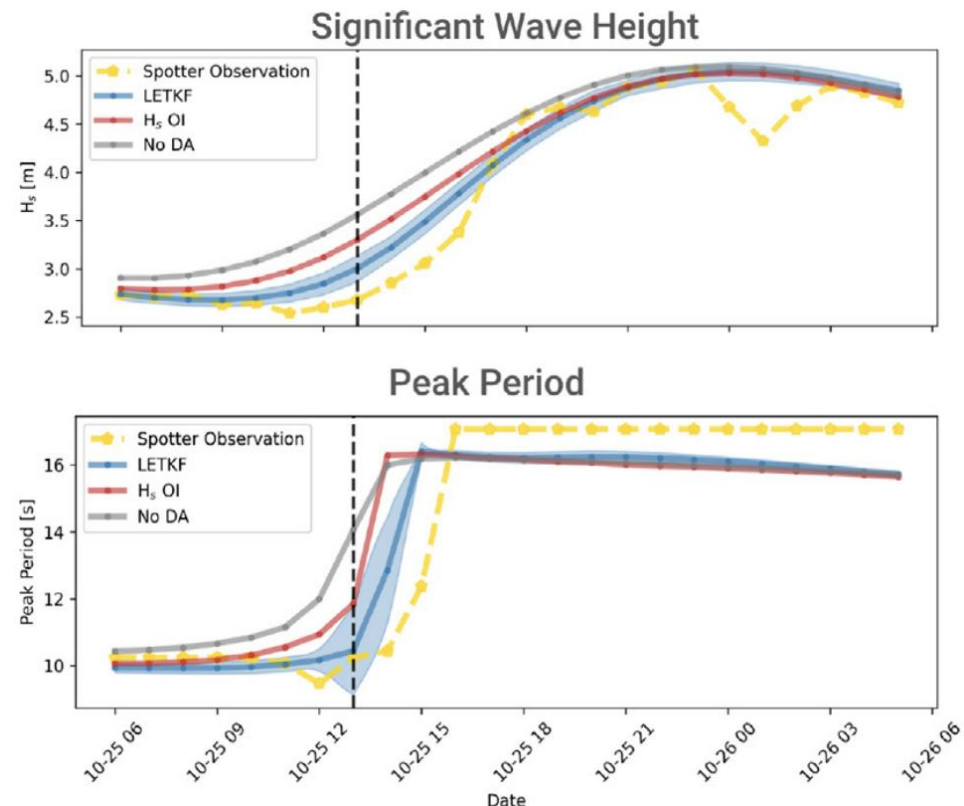
Ocean Modelling 183 (2023) 102200



Ensemble-based data assimilation of significant wave height from Sofar Spotters and satellite altimeters with a global operational wave model

Isabel A. Houghton^{*}, Stephen G. Penny, Christie Hegermiller, Moriah Cesaretti, Camille Teicheira, Pieter B. Smit

^{*}Sofar Ocean, Pier 28, San Francisco, 94105, CA, USA



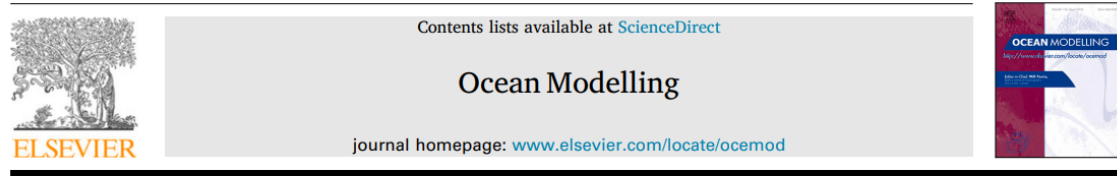
Station 2 – 3 has been studied. Note the differences in:

- Wave model
- Input forcing
- DA scheme
- Input DA data
- Start time of the forecast
- And more....



How does it compare with literature?

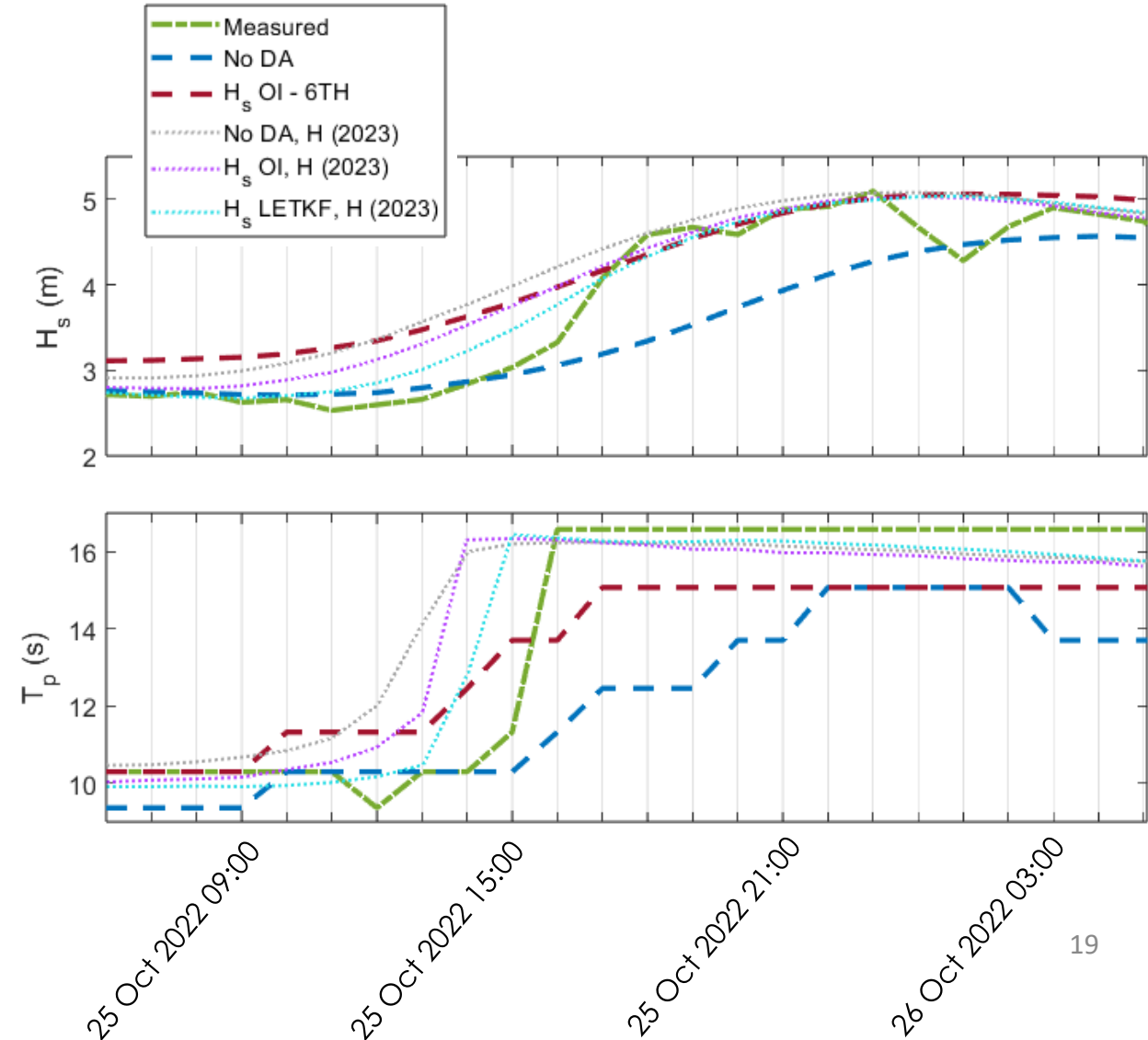
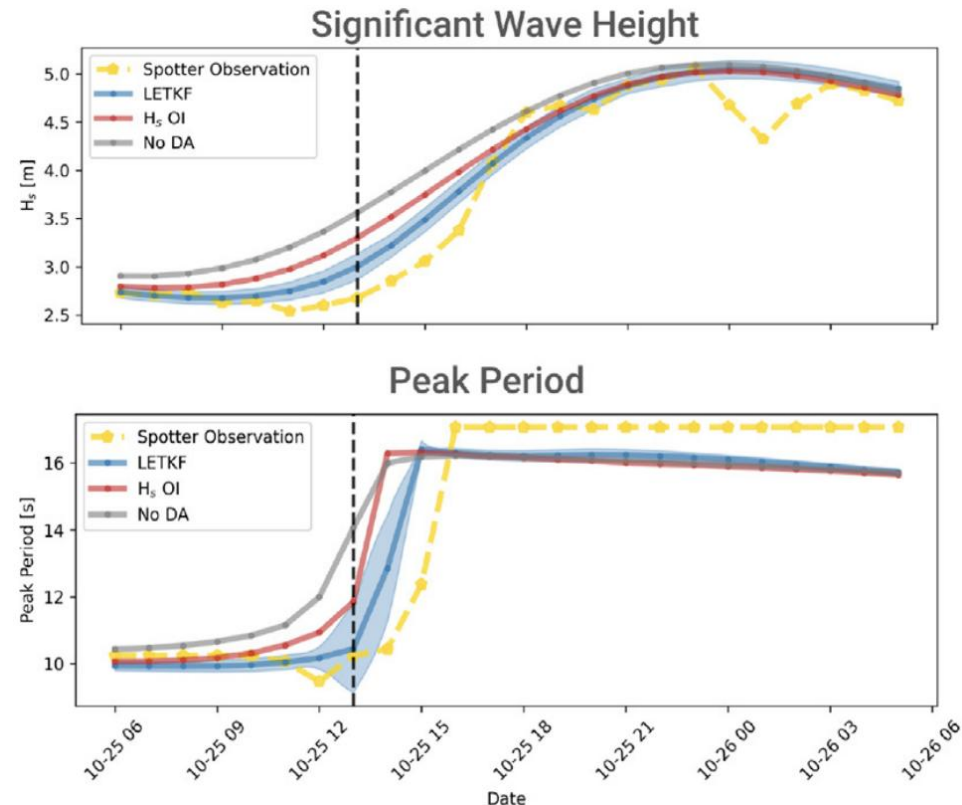
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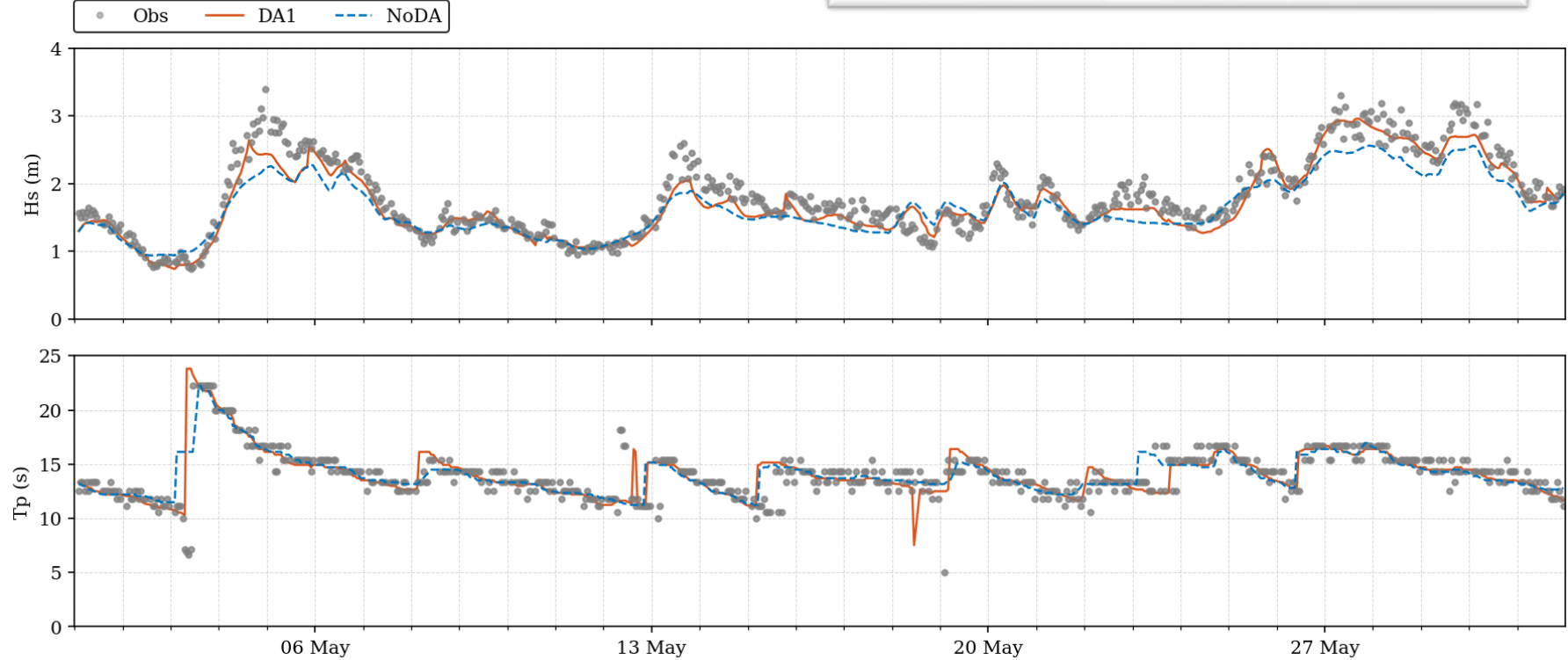
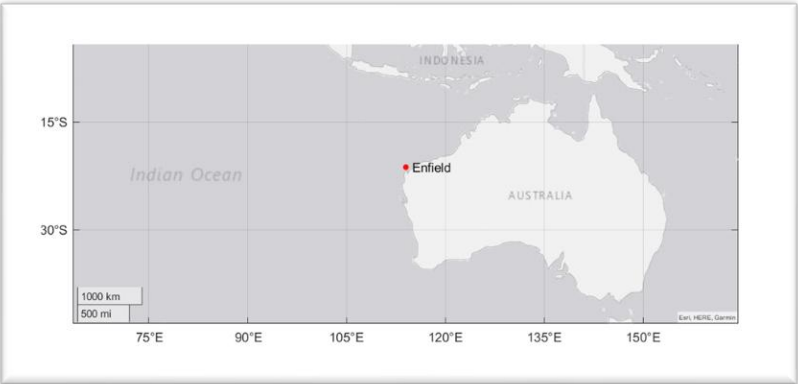
Sofar Ocean, Pier 28, San Francisco, 94105, CA, USA



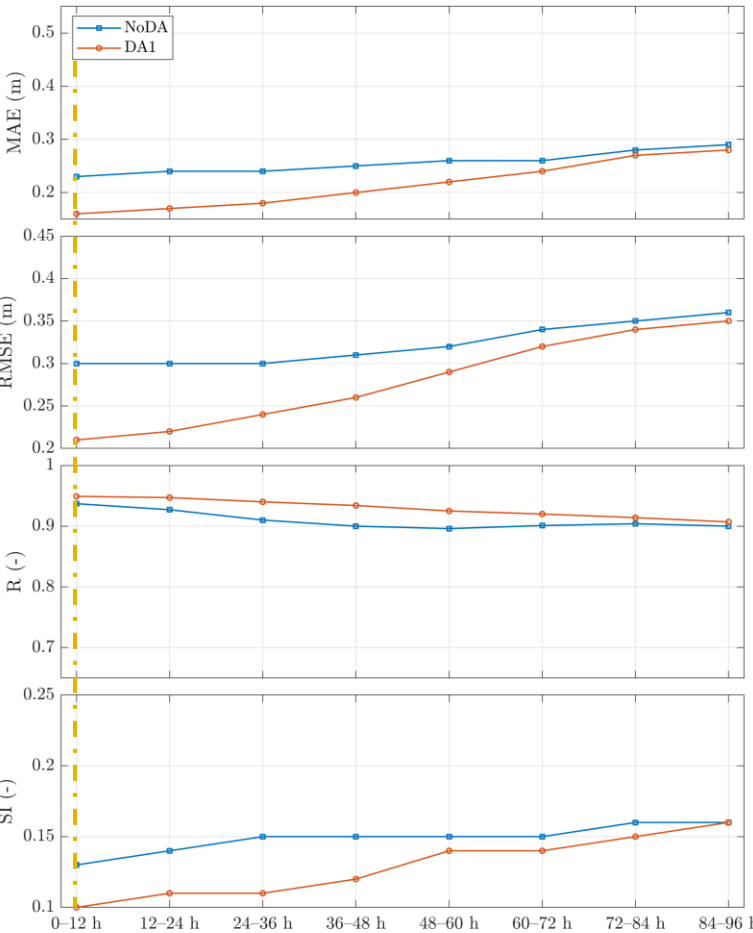
Site-Based Model Evaluation



Enfield 0-12 h Forecast



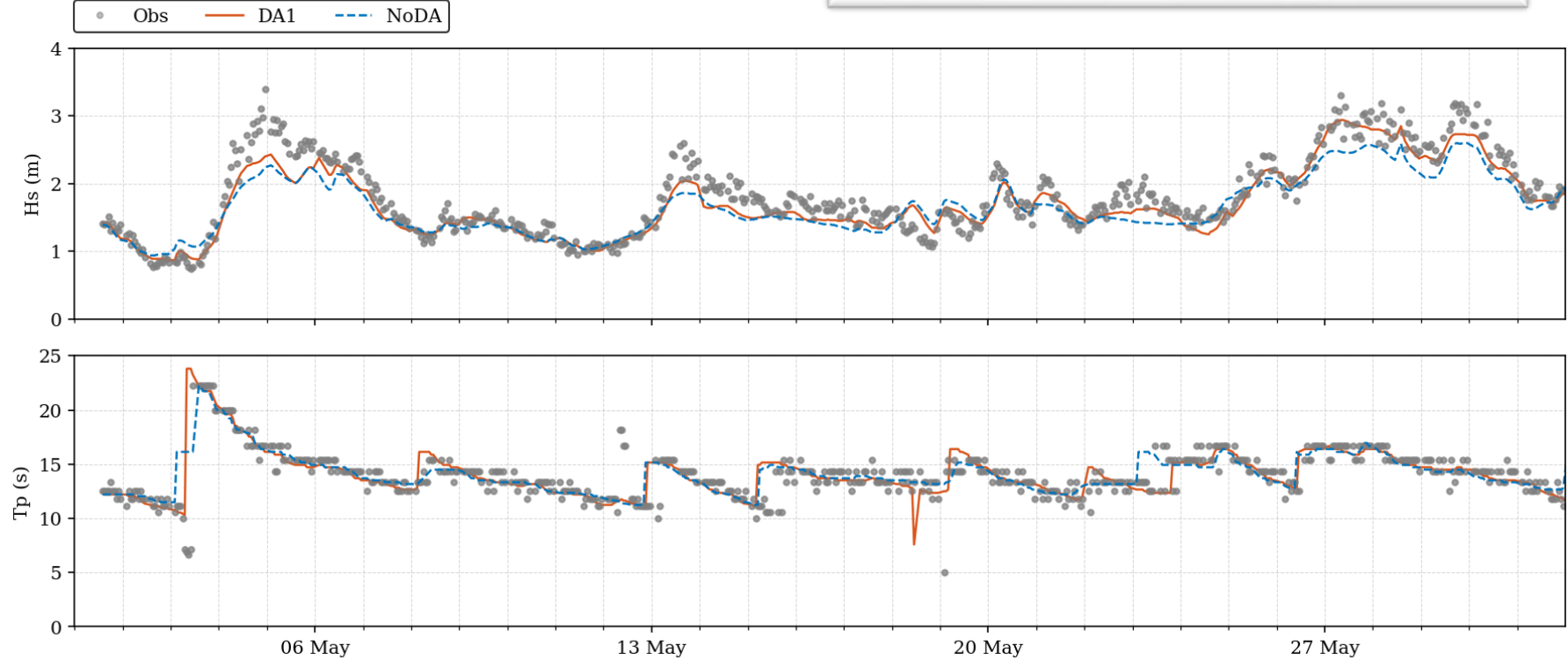
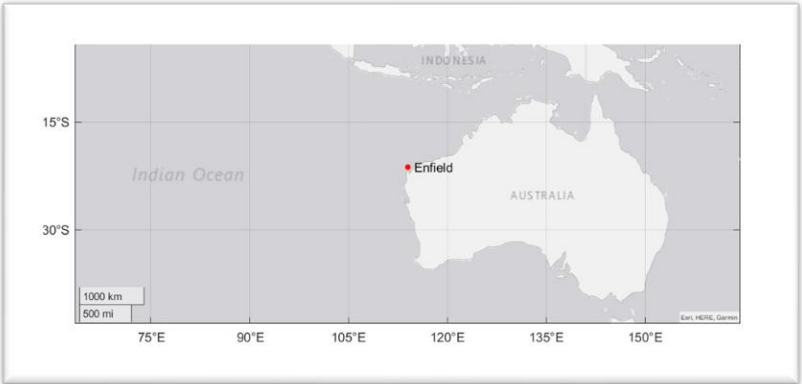
Hs Error Statistics in May 2024



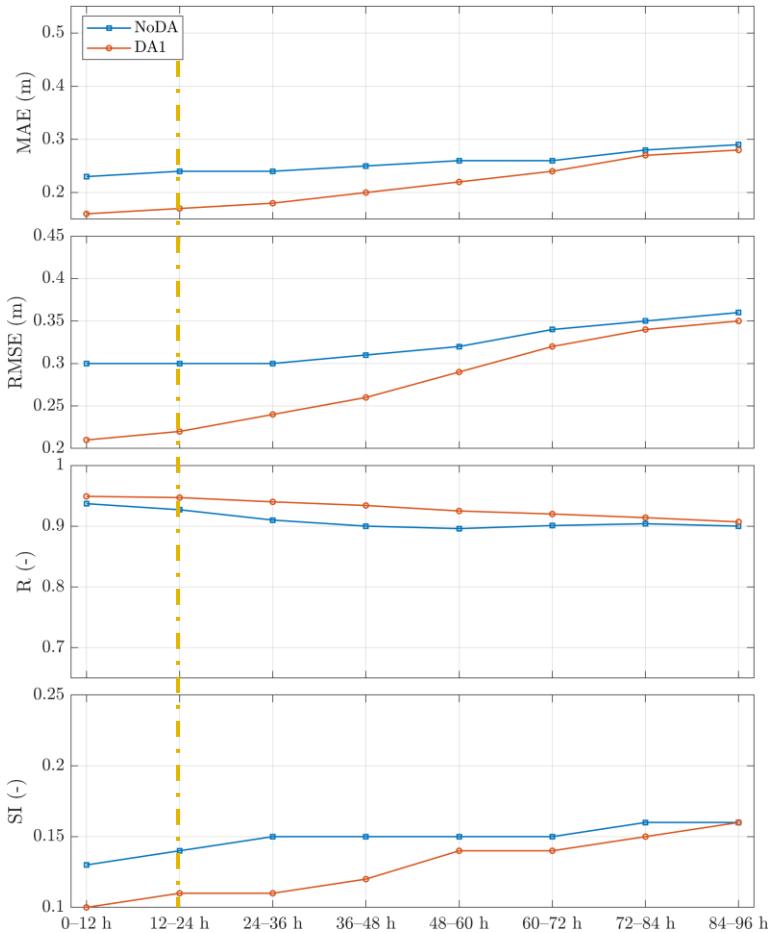
Site-Based Model Evaluation



Enfield 12-24 h Forecast

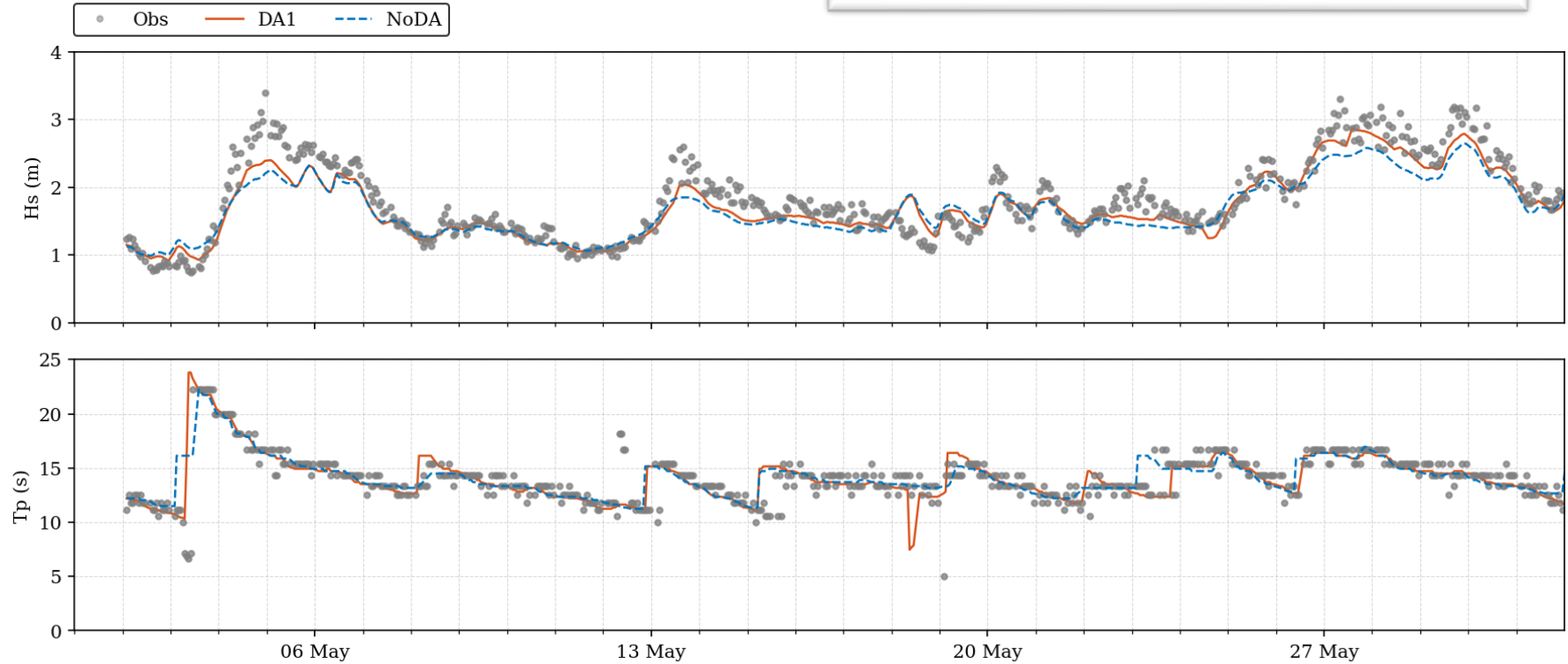
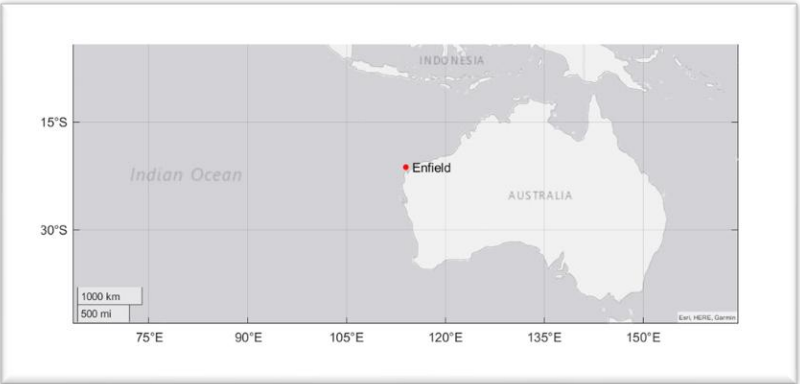


Hs Error Statistics in May 2024

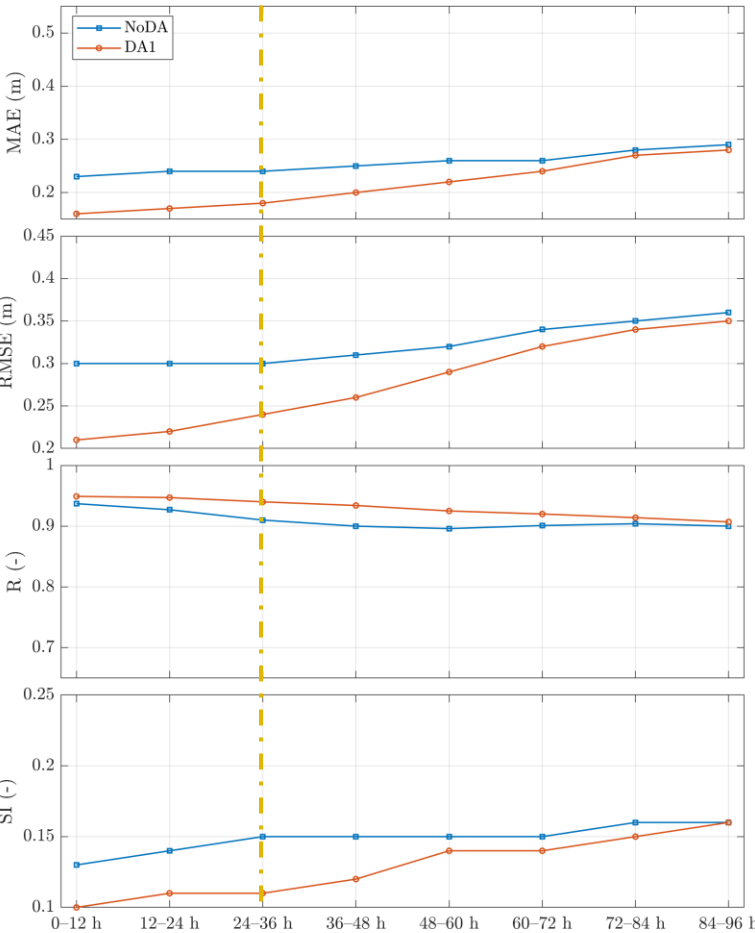


Site-Based Model Evaluation

Enfield 24-36 h Forecast



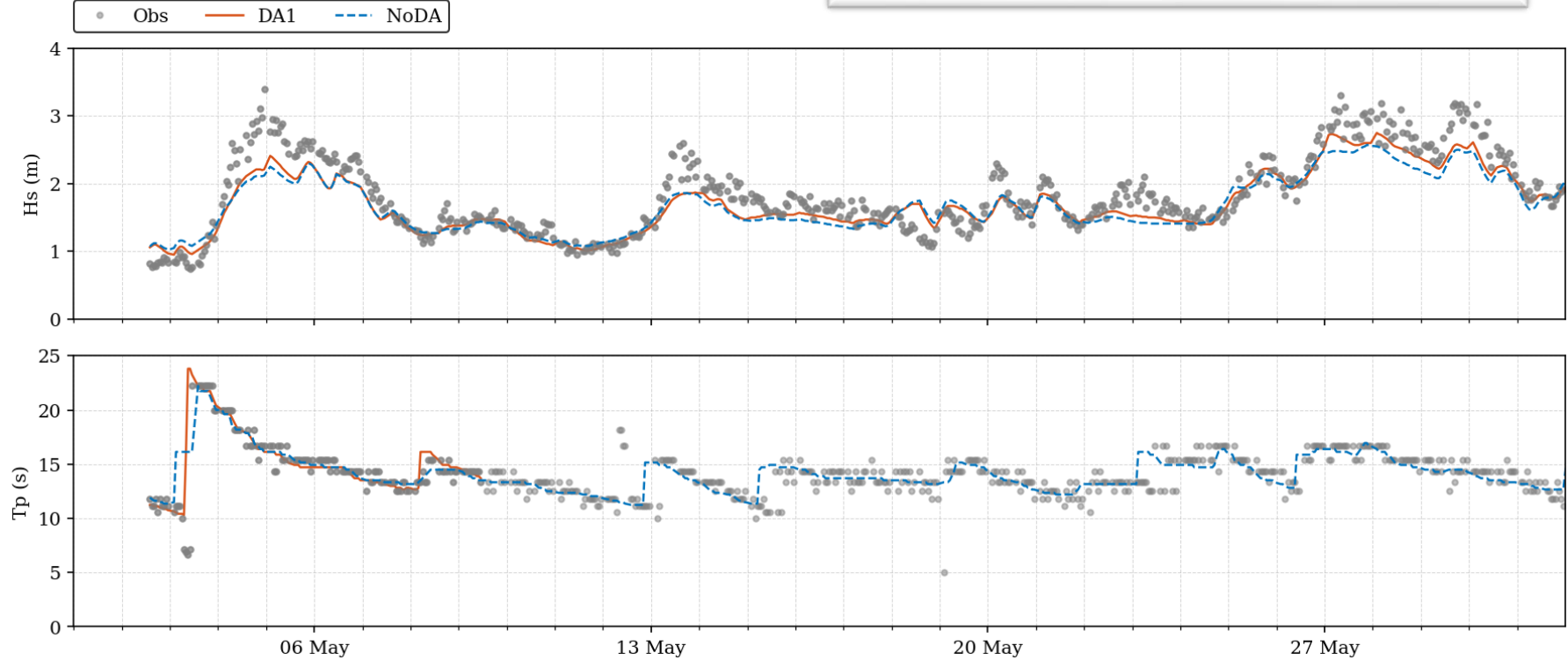
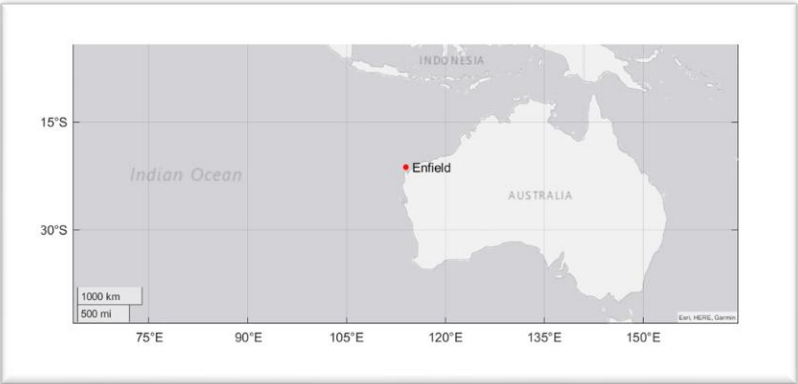
Hs Error Statistics in May 2024



Site-Based Model Evaluation



Enfield 36-48 h Forecast



Hs Error Statistics in May 2024

