Towards Probabilistic Operational Wave Modelling at the Bureau of Meteorology

Stefan Zieger – Research Program

3rd International Workshop on Waves, Storm Surges, and Coastal Hazards, Notre Dame, IN 46556 USA

Outline

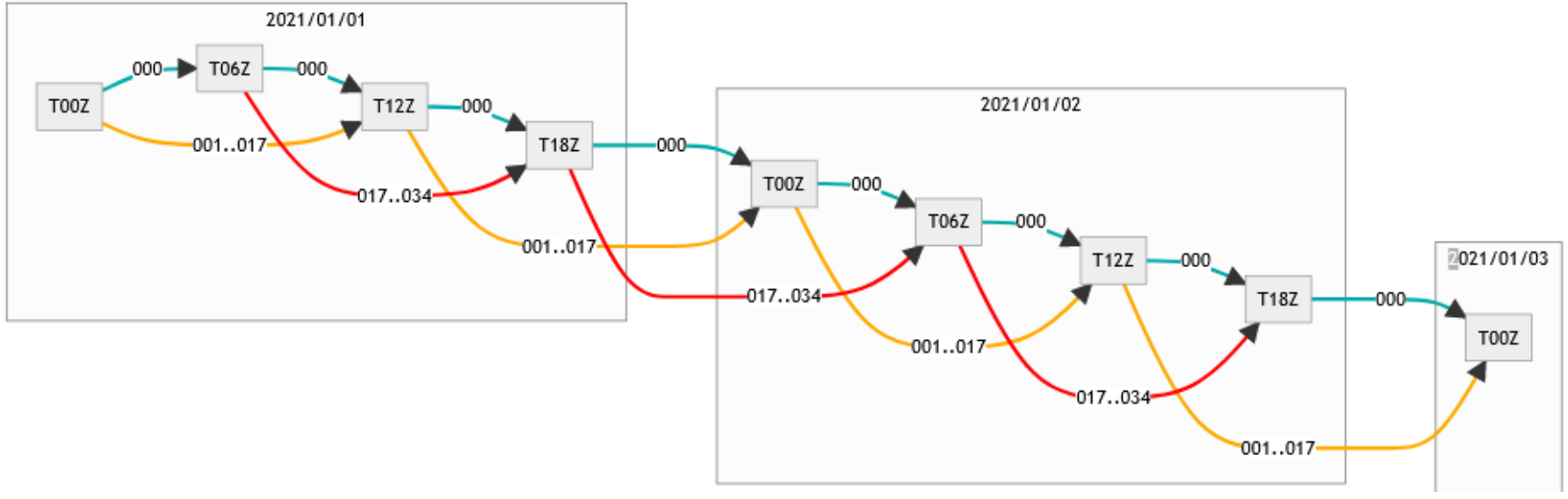
- Background
  - Numerical weather prediction ensemble
  - Wave model configuration
- Ensemble verification
  - Bias
  - Spaghetti plots
  - Spread-skill diagrams
  - Reliability diagrams
- Next steps
  - Probability of exceedance
- Summary

Background

Ensemble model

Numerical weather prediction

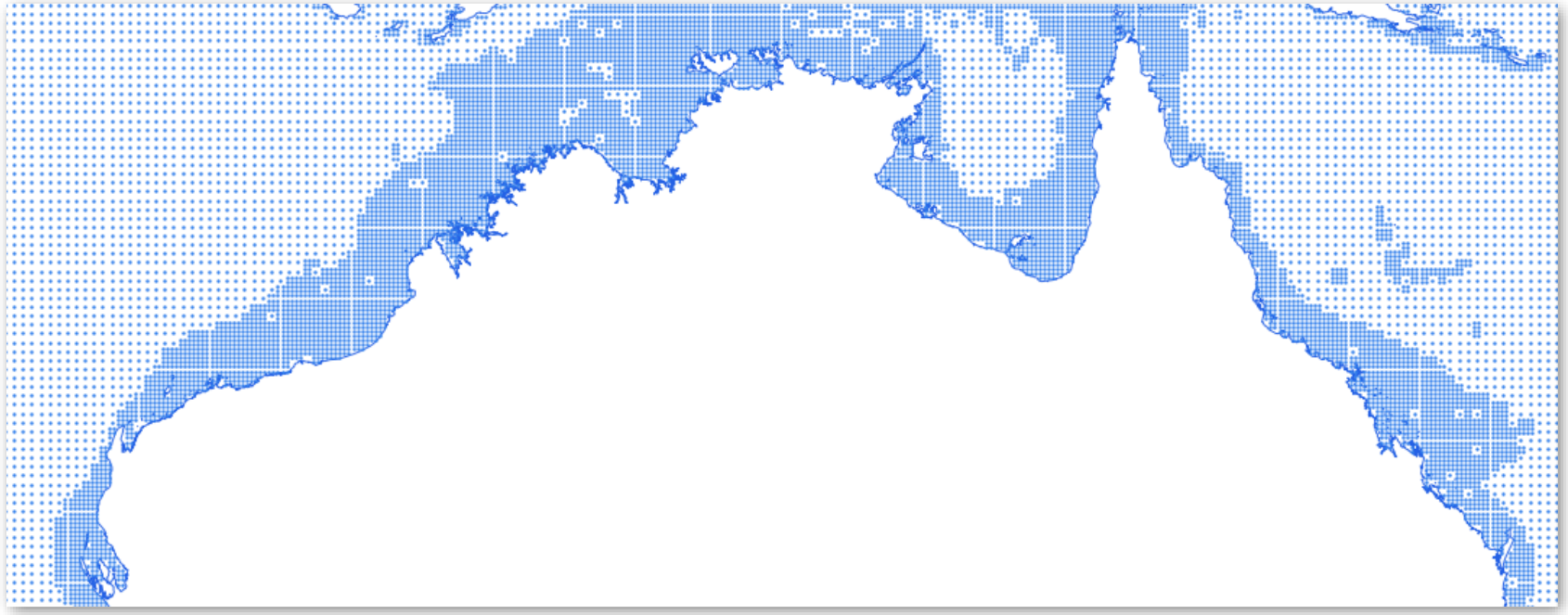
- Numerical weather prediction ensemble (ACCESS-GE)
- Fourth-generation (APS4) with a spatial resolution of 0.30° (north-south) and 0.45° (east-west)
- 36 time-lagged ensemble members
- Forecast range is +10 days
- Unified Model (UM) with ENDGame Dynamical Core (Wood et al 2014)
- Hybrid 4DVAR with variational bias correction for satellite observations and extended Kalman Filter for land-based observations.



Ensemble model

Wave model configuration

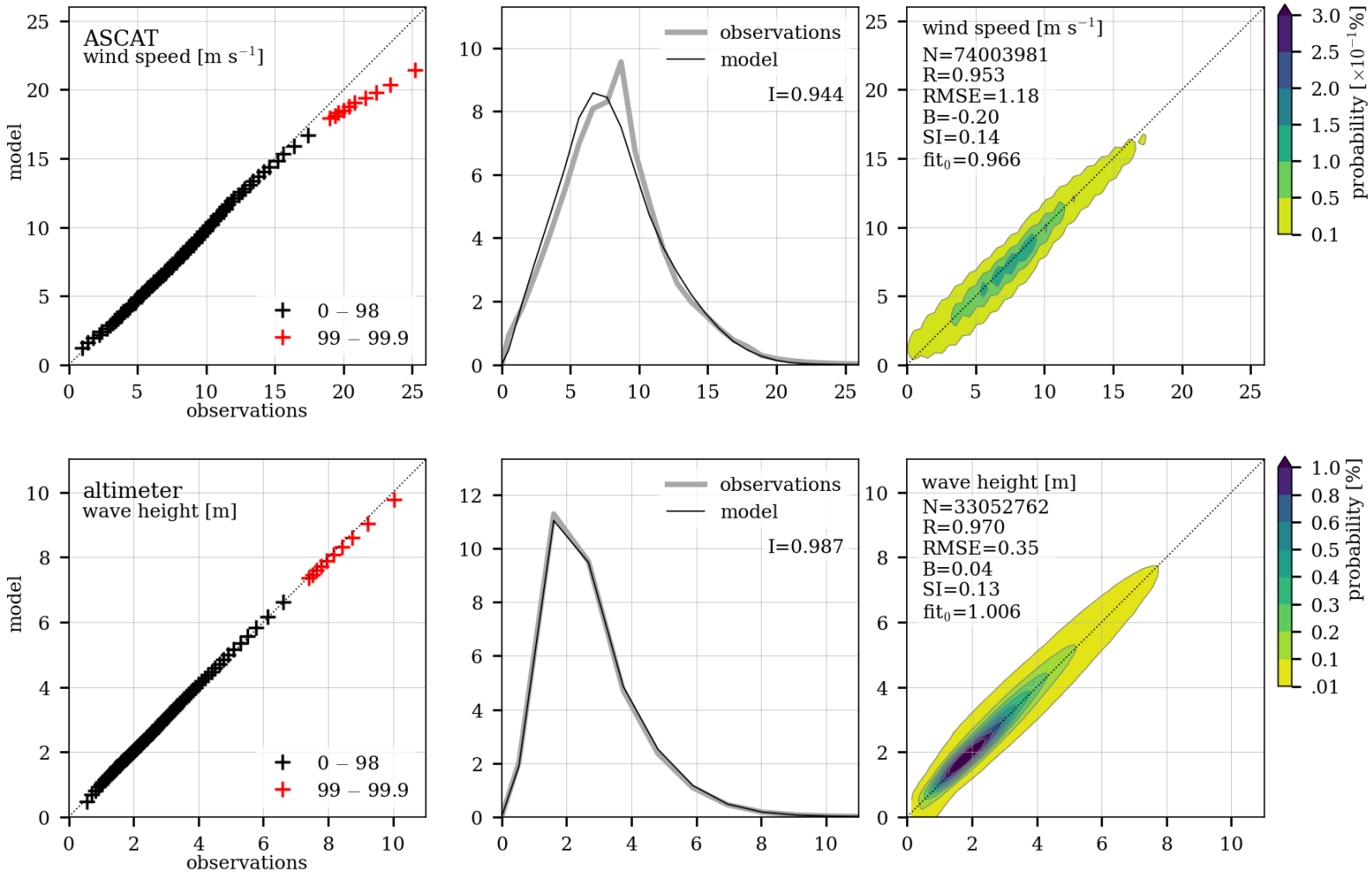
- Based on global deterministic model AUSWAVE-G (APS3) (Zieger & Greensalde 2021)
- SMC grid with two-tier resolutions 1/4° and 1/8° (around islands and less than 300m water depth)
- ST6 physics (Zieger et la 2015; Liu et al 2019)
- Wave model output is remapped to 1/4° x 1/4°
- Forcing fields: surface wind speed (3-hourly) and sea ice concentration (daily)
- 4 base times (~1h per run @96CPUs)
- 5,000 CPU hours (storage 200GB) per day



Ensemble model

Wave model calibration

- Model verification for Feb-Aug 2021
- Marine surface winds verification
- $H_s \propto \beta g^{-1} U_{10}^2 \rightarrow \mathrm{e_{Hs}} = 2\beta \bar{U} g^{-1} \mathrm{e_U}$
- $\mathrm{e}_{Hs} = \frac{2 \cdot 0.22 \cdot 7.3}{9.81} 1.18 = 0.39\mathrm{m}$
- Swell dissipation (4% negative input a_0 and constant swell dissipation coefficient b_1)
- FLX4 wave boundary layer flux scheme
- Bulk bias correction trialled
  $W = W + (W - w_1) \cdot w_2$ for $W \geq w_1$
- Excellent performance for significant wave height up to 10m

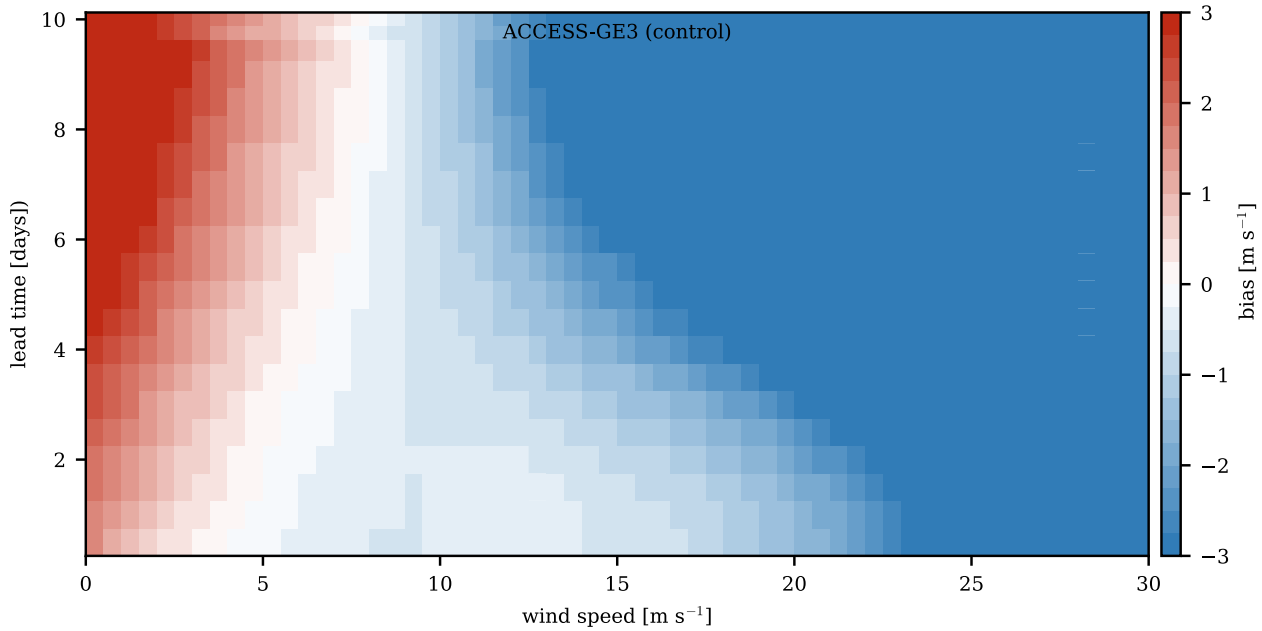


Ensemble verification

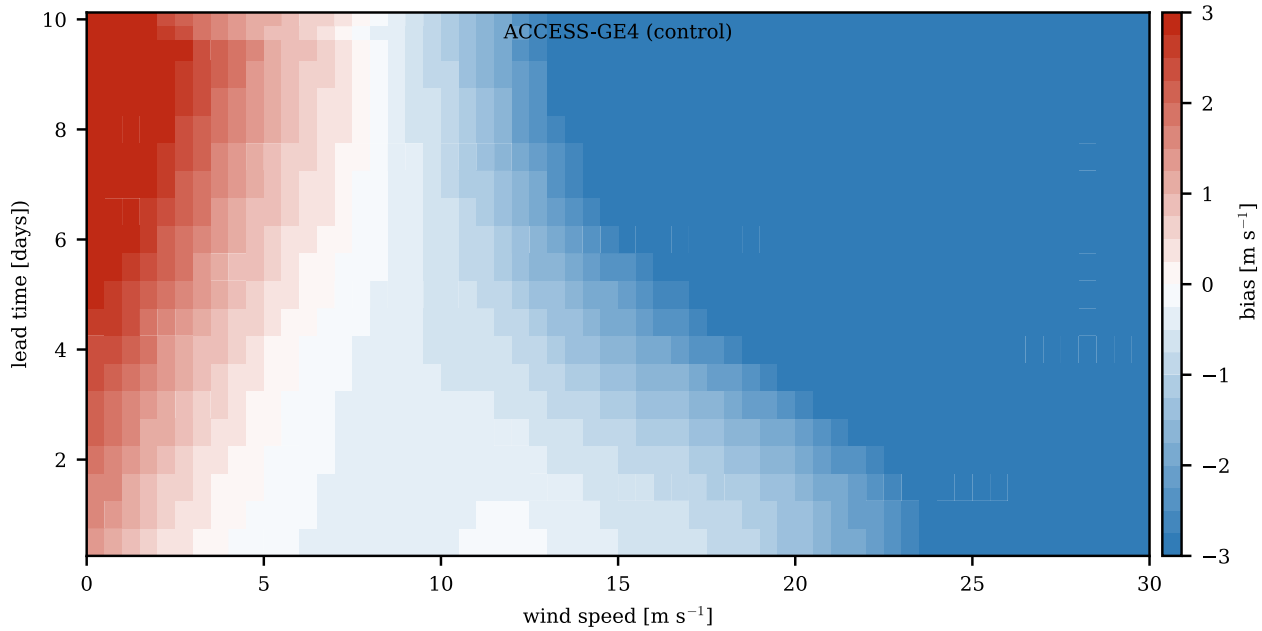
Ensemble verification

Wind speed bias (Feb - Apr 2021)

APS3 (without data assimilation)



APS4 (with data assimilation)

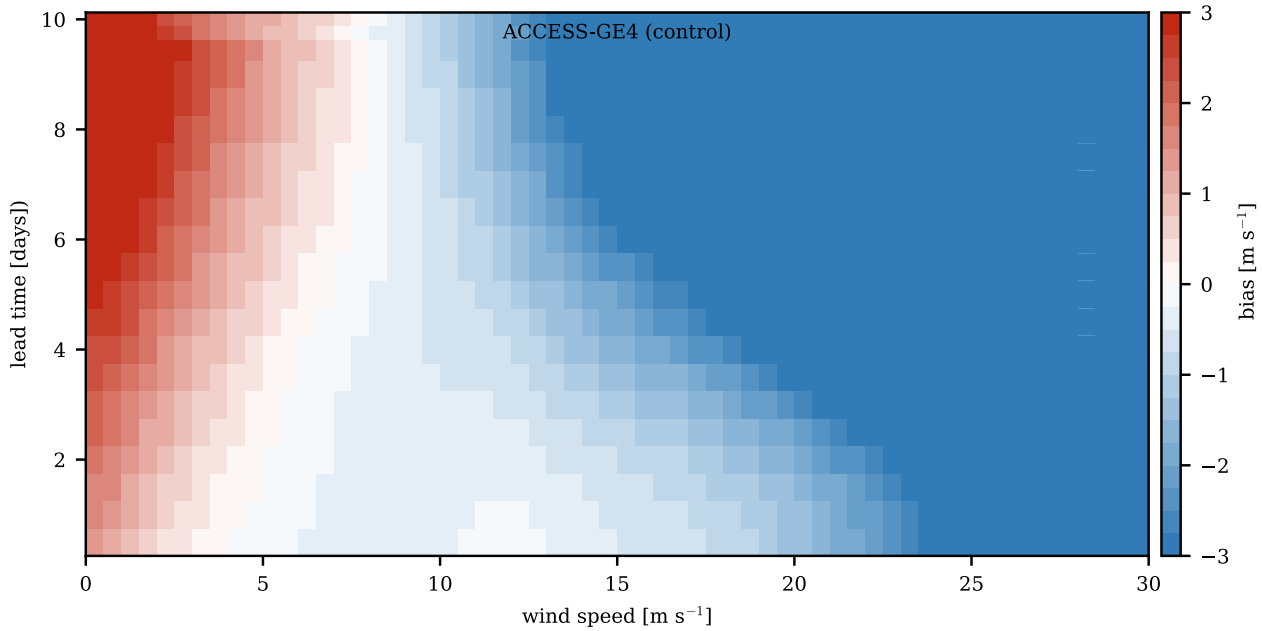


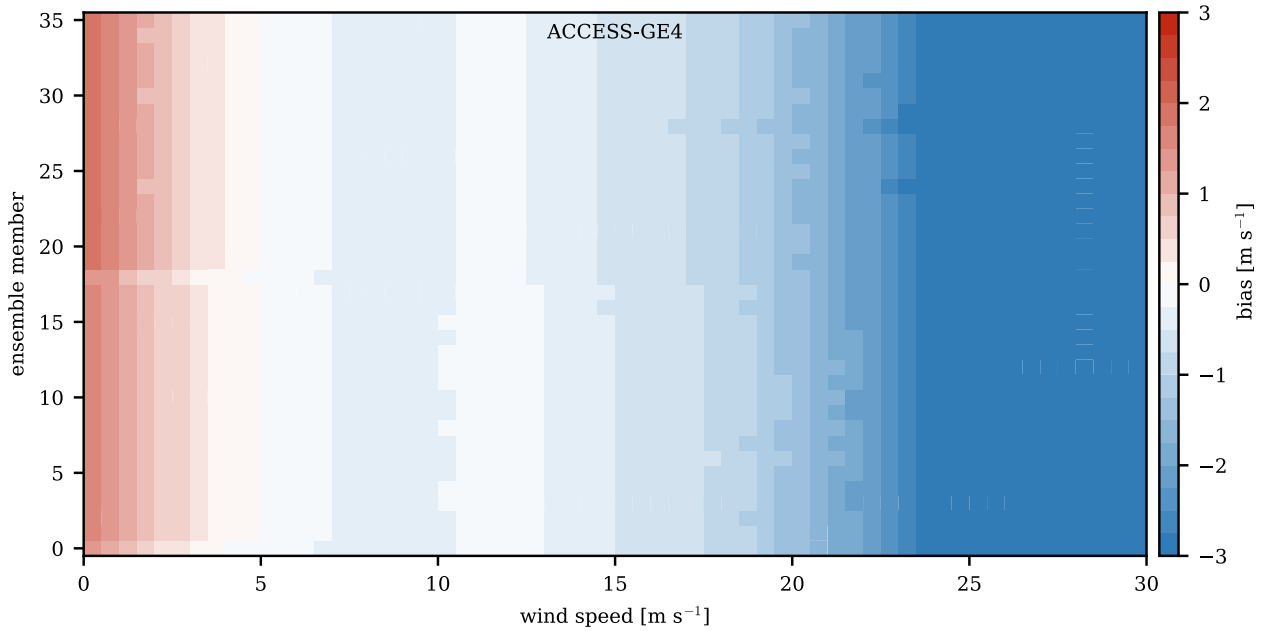
Ensemble verification

Wind speed bias (Feb - Apr 2021)

APS4

+12h forecasts

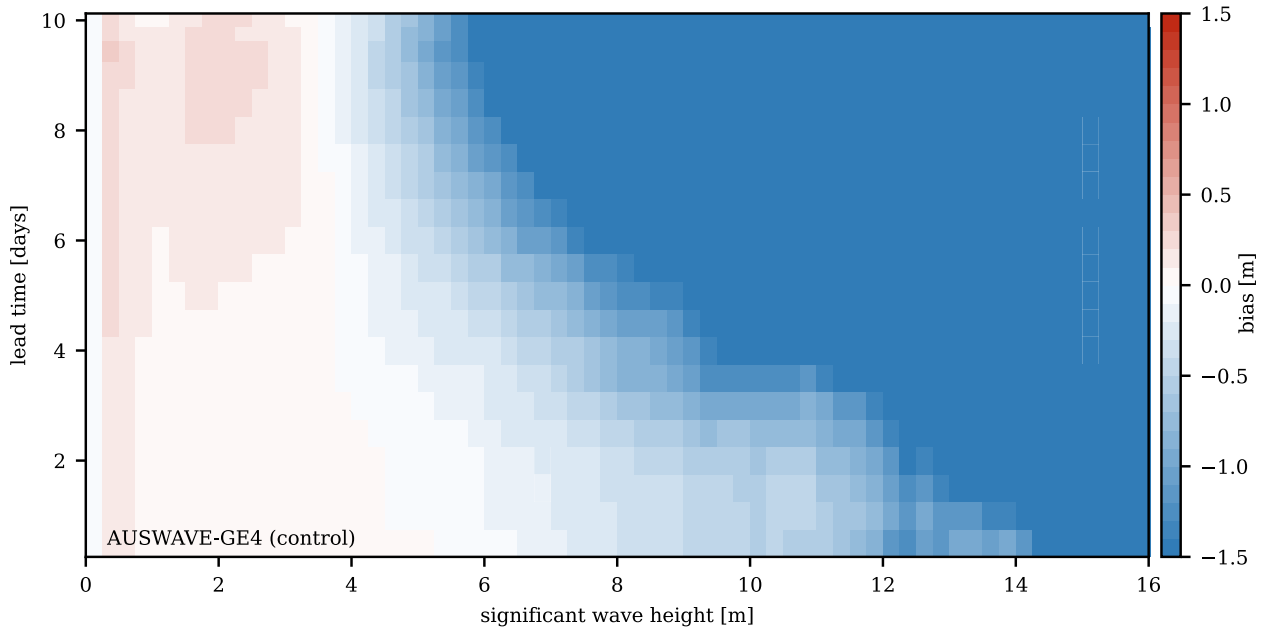




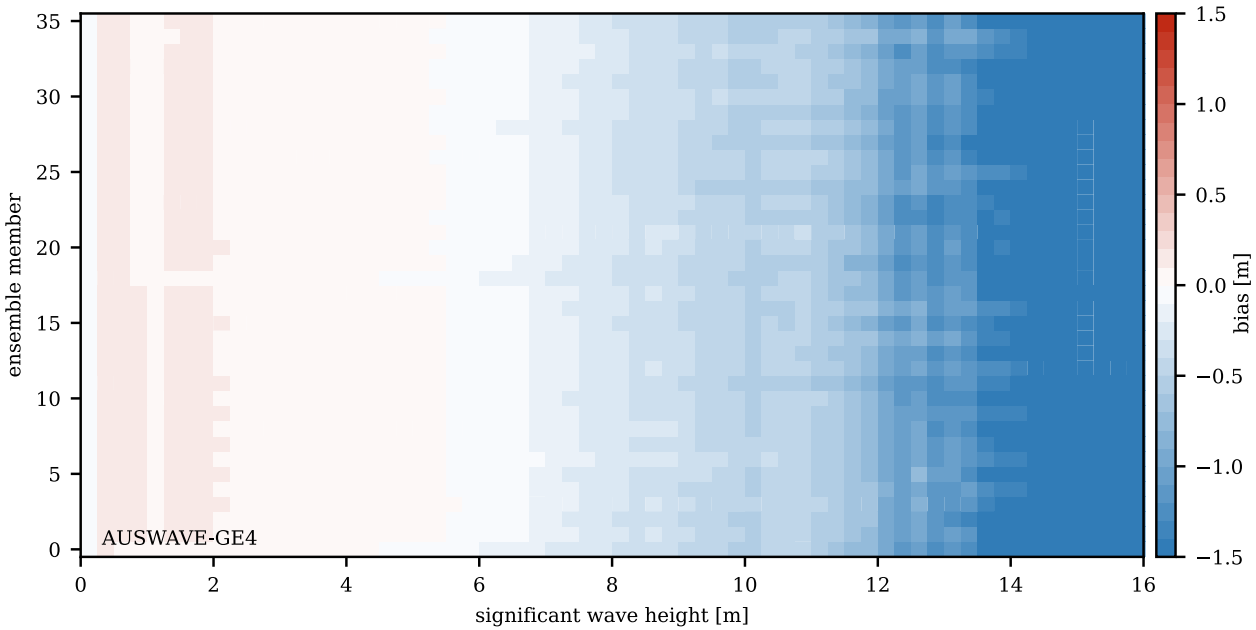
Ensemble verification

Wave height bias (Feb - Apr 2021)

APS4



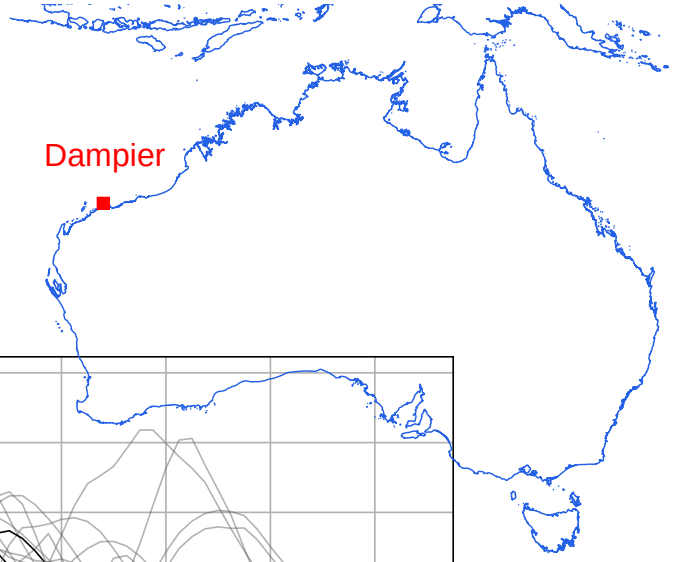
+12h forecasts

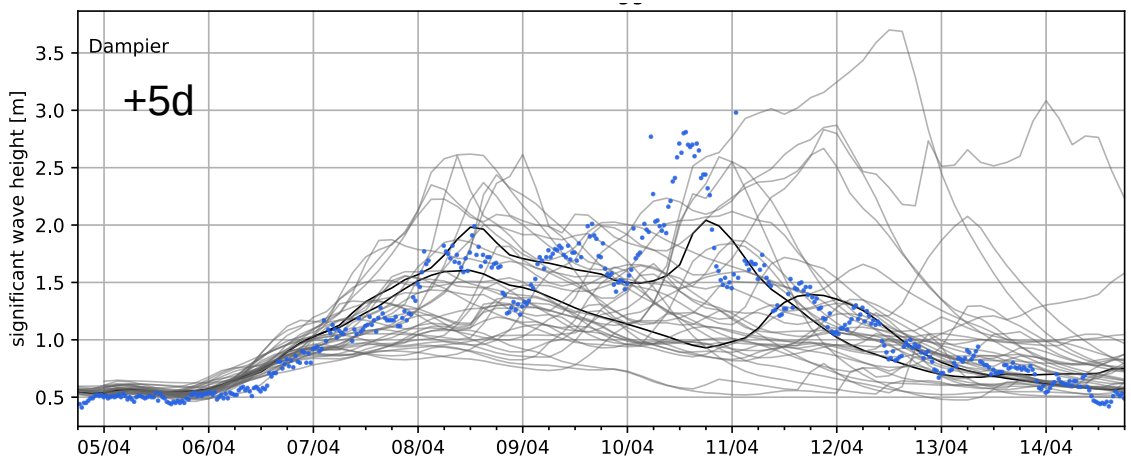


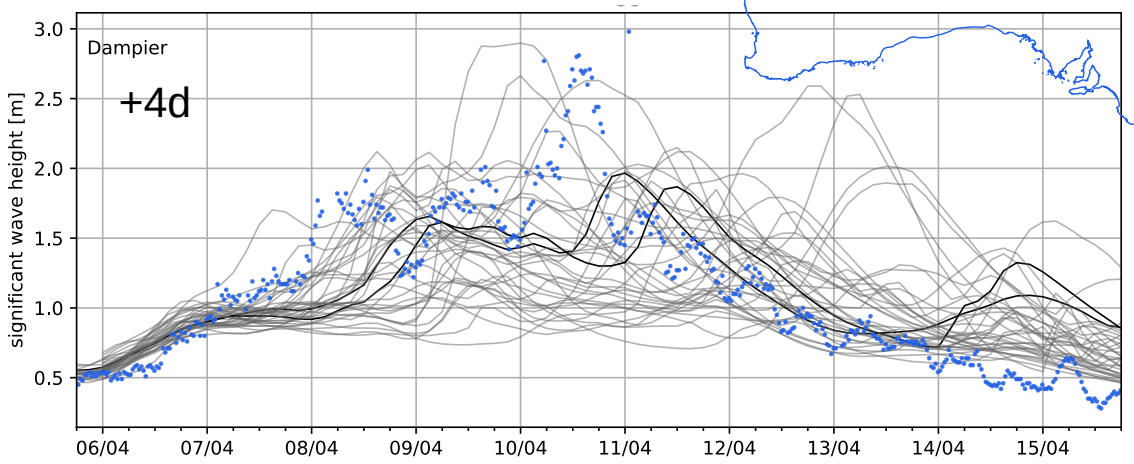
Ensemble verification

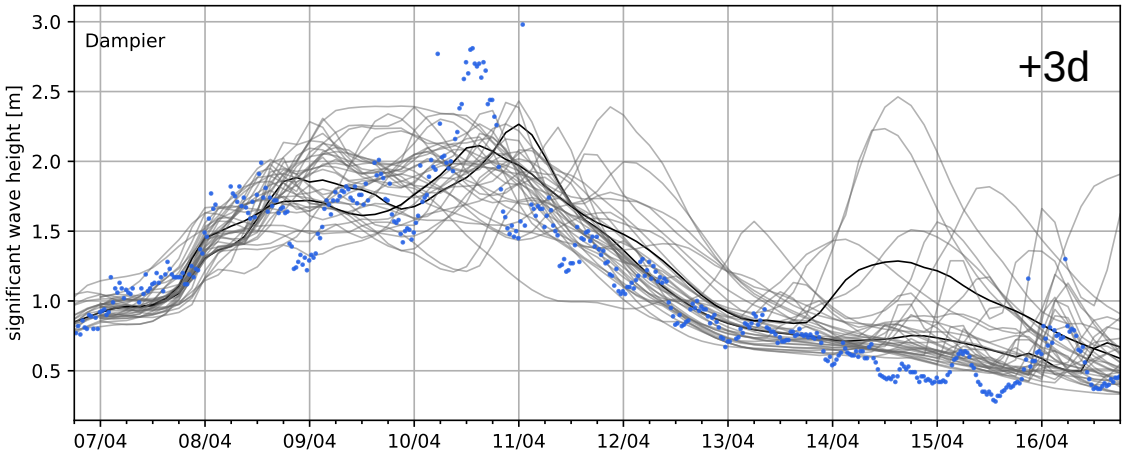
Dampier

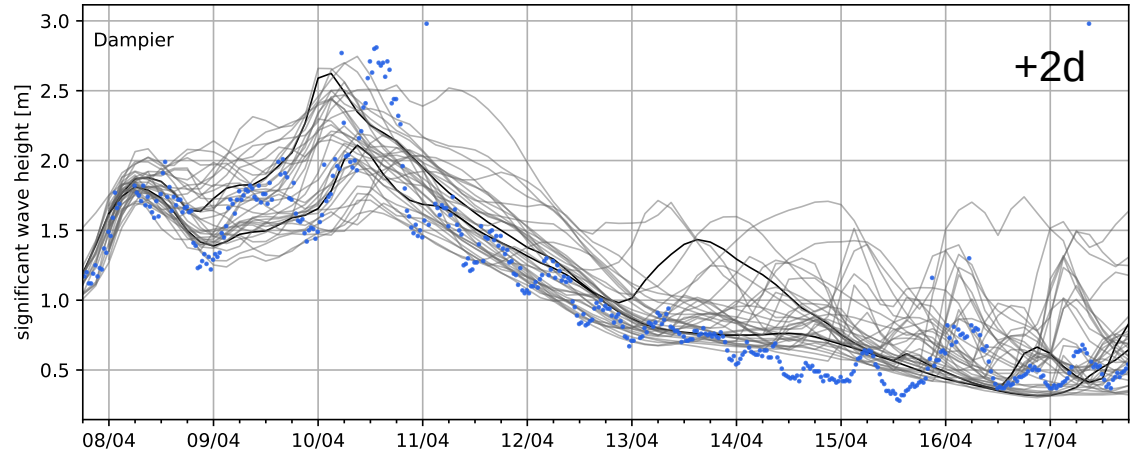
116.52°E 20.48°S







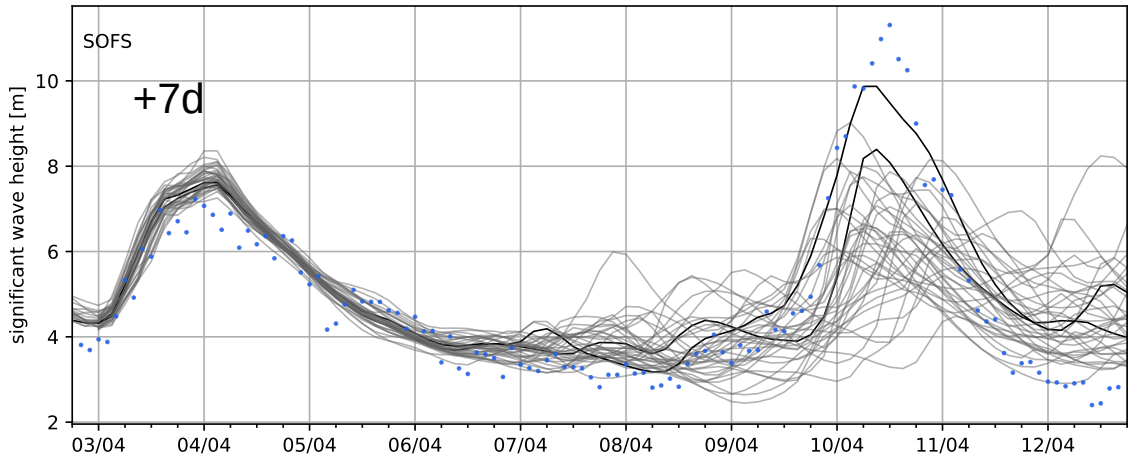


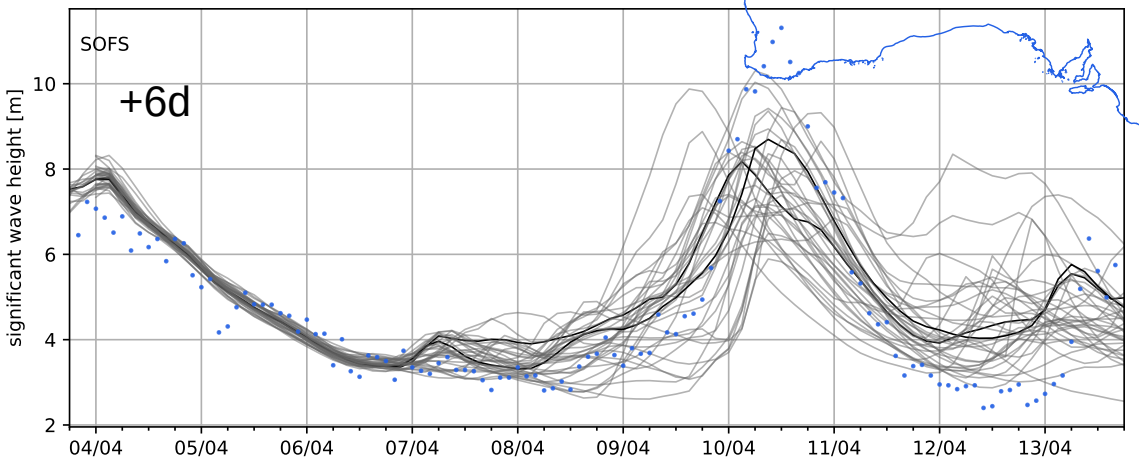


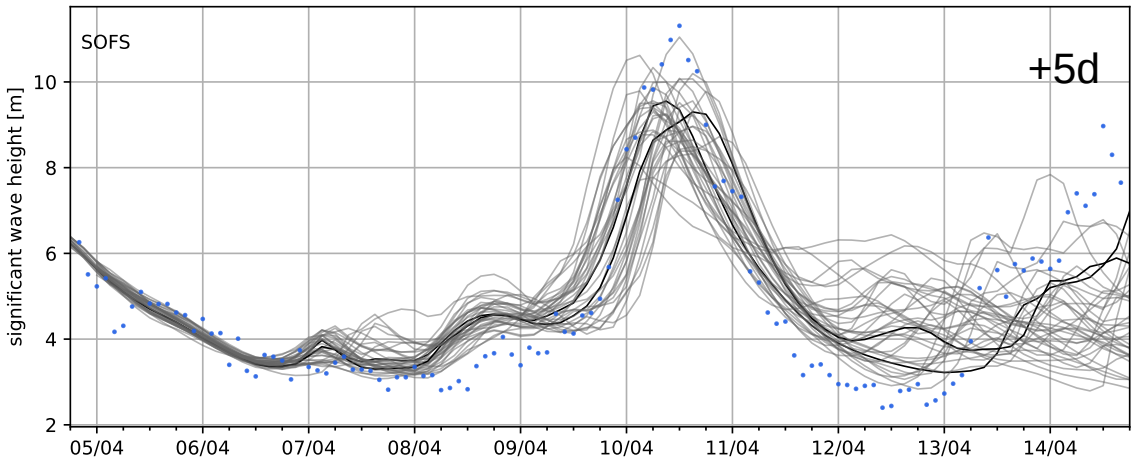
Ensemble verification

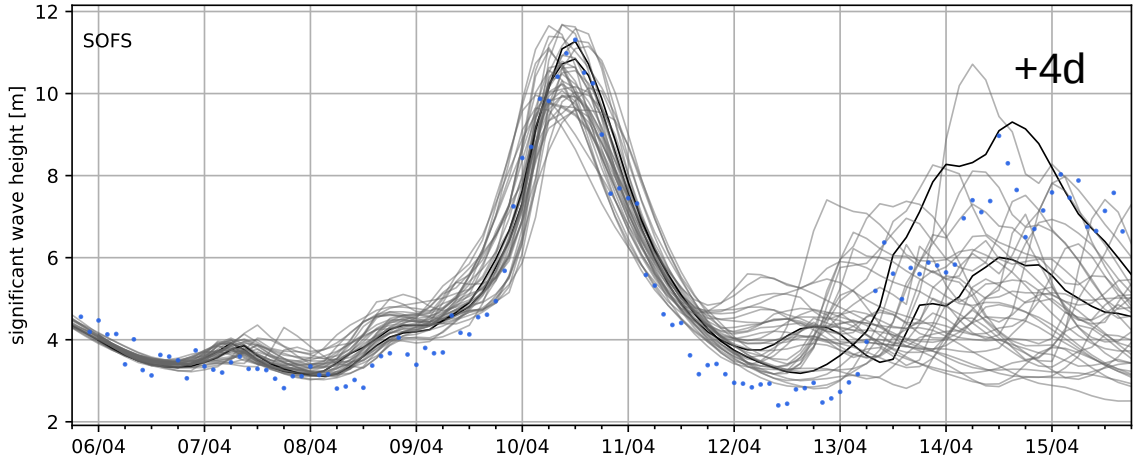
Southern Ocean Flux station 141.87E 46.73S

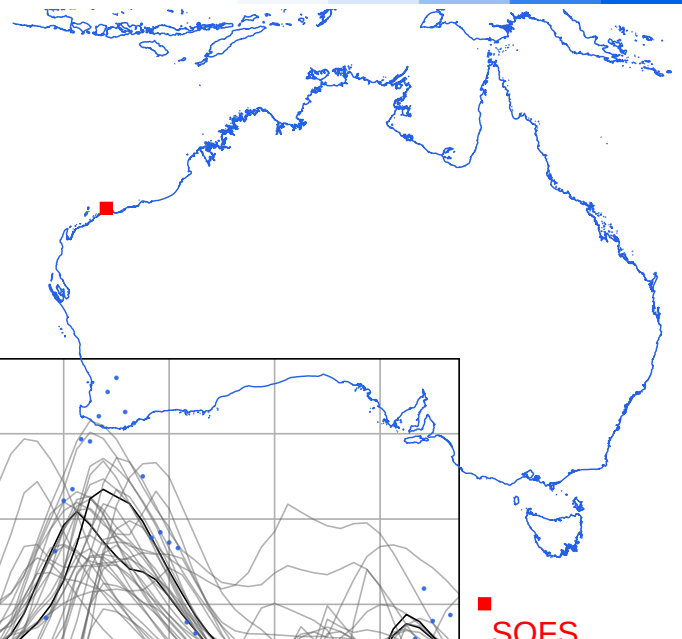
141.87°E 46.73°S











Ensemble verification

Spread-skill diagram

- Measure of the quality of the ensemble system.
- Underlying hypothesis is exchangeability between a random variable represented by the ensemble member and the observation.
- In a perfect ensemble, any member could be exchanged with the verifying observation at any forecast time, so that one could not distinguish ensemble forecast from observation, without increasing the error estimate and changing the joint distribution of the ensemble members.
- Skill (root-mean-square error) is equivalent to the sum of squared bias and variance of the biases.

Continuous Ranked Probability Score

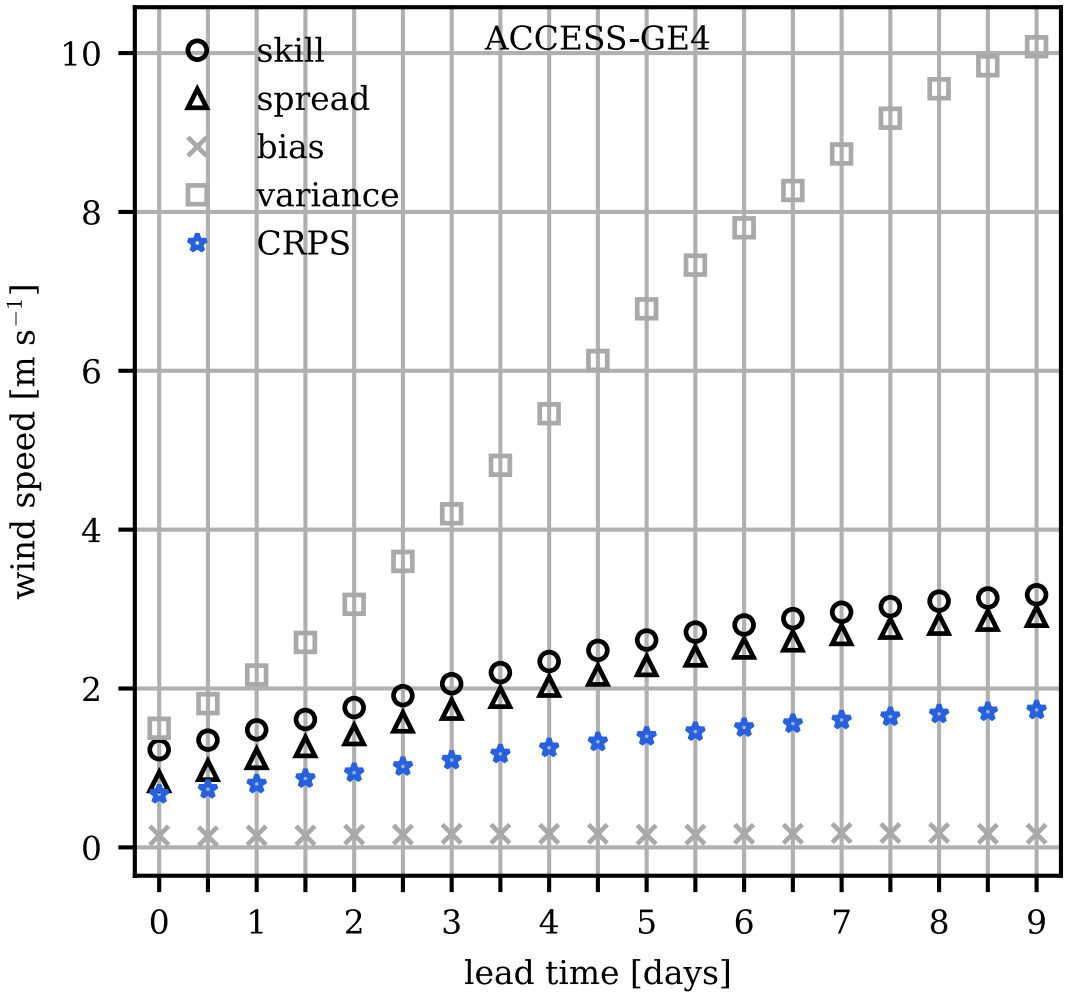
- The continuous ranked probability score (CRPS) is a scoring rule that is popular for assessing the quality of ensemble forecasts. It is a quadratic measure of the difference between the forecast cumulative distribution function (CDF) and the empirical CDF of the observation.

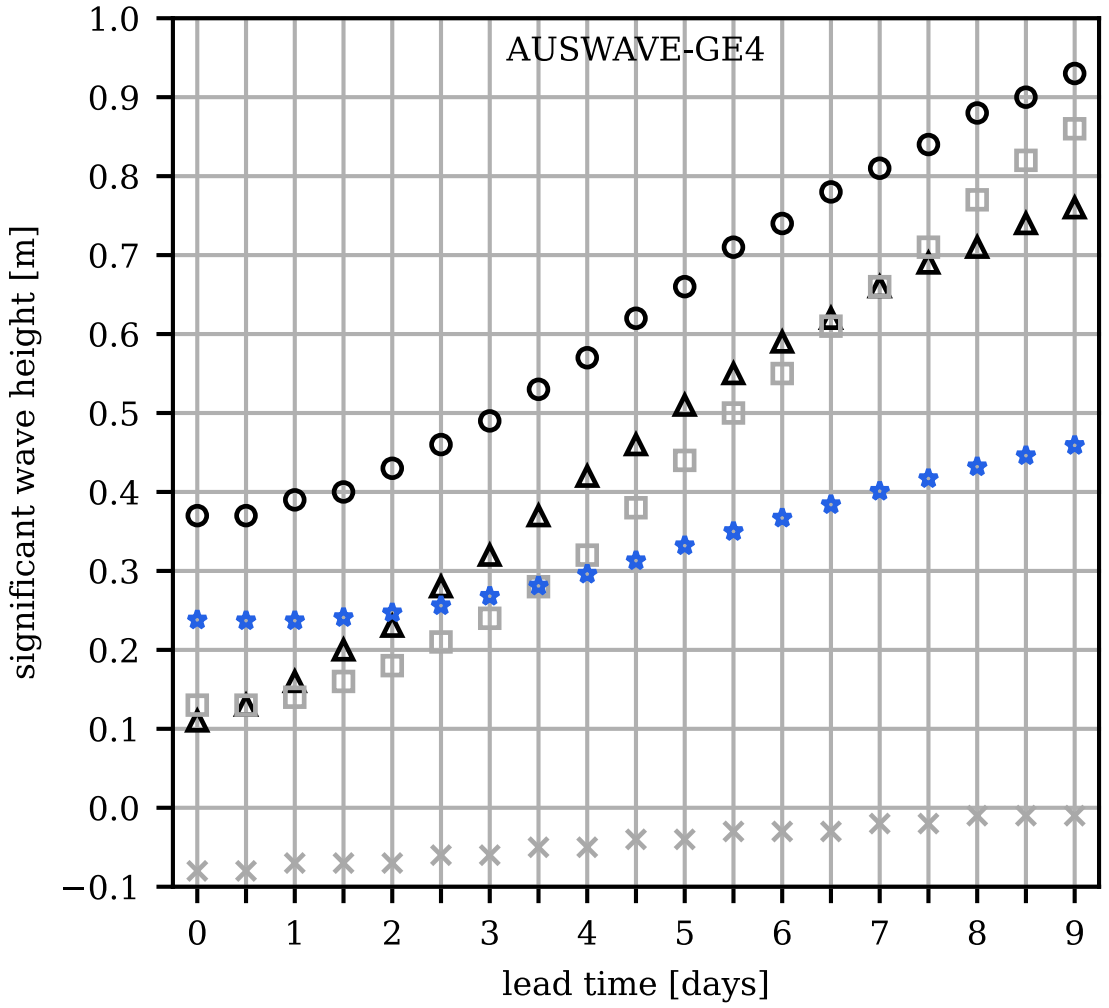
Reliability diagram

- Reliability diagrams measure the quality of probabilistic forecasts and assesses the difference between predicted probabilities and the observed frequency.

Ensemble verification

Spread-skill diagrams for Feb-April 2021



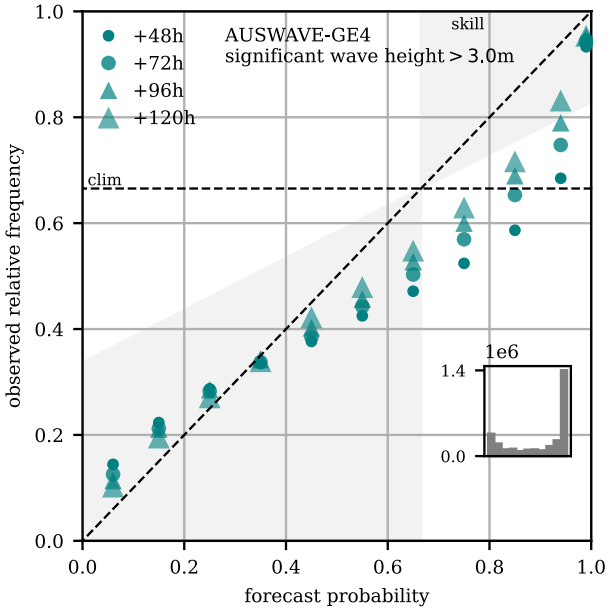


Ensemble verification

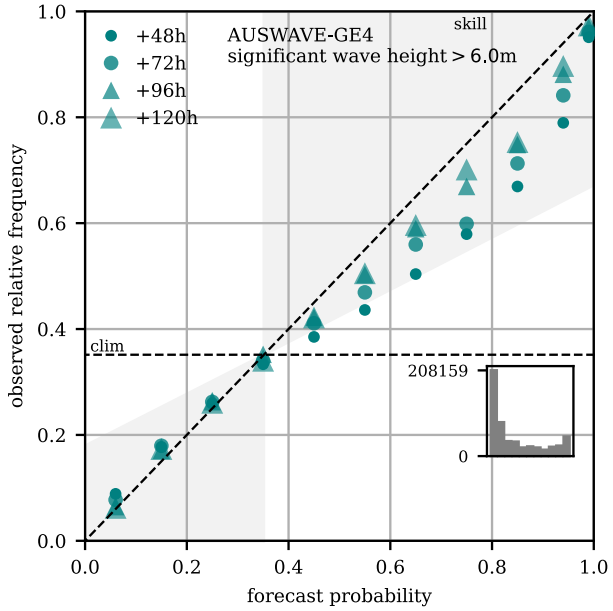
Reliability diagrams for Feb-April 2021

- Global altimeter observations (Young & Ribal 2022)
- +2 to +5 day forecast range

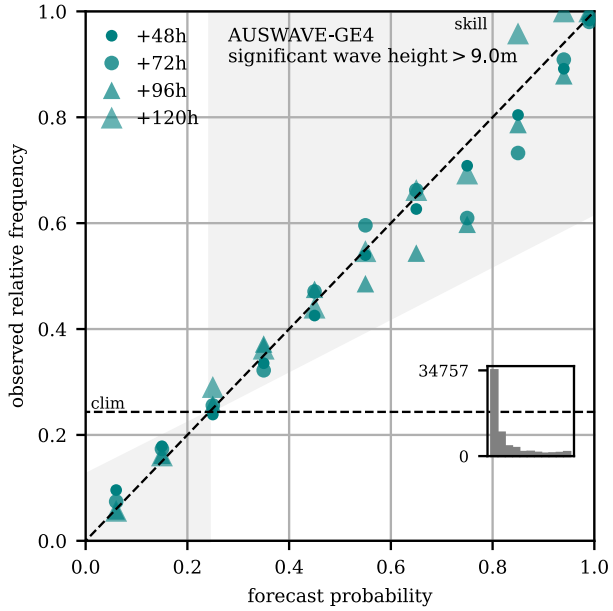
>3m



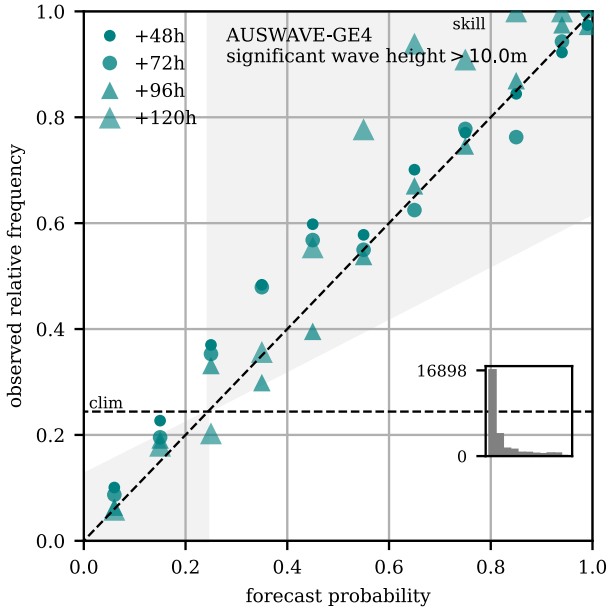
>6m



>9m



>10m

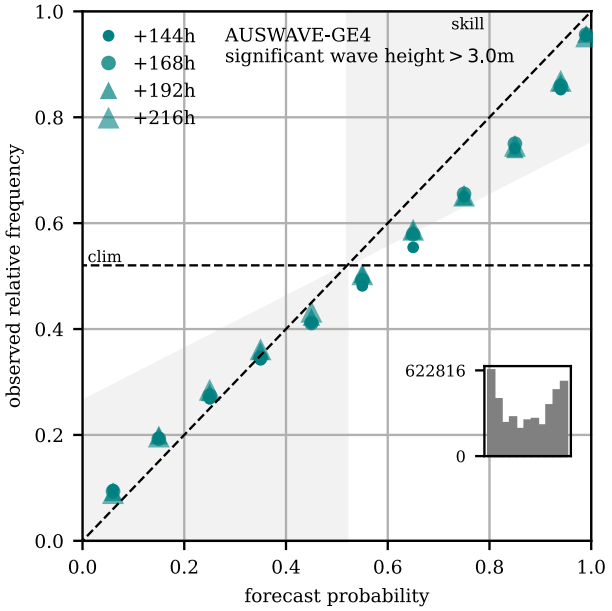


Ensemble verification

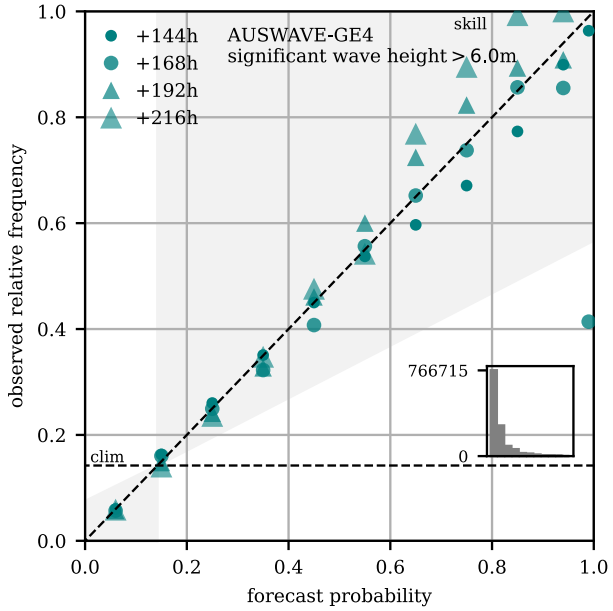
Reliability diagrams for Feb-April 2021

- Global altimeter observations (Young & Ribal 2022)
- +6 to +9 day forecast range

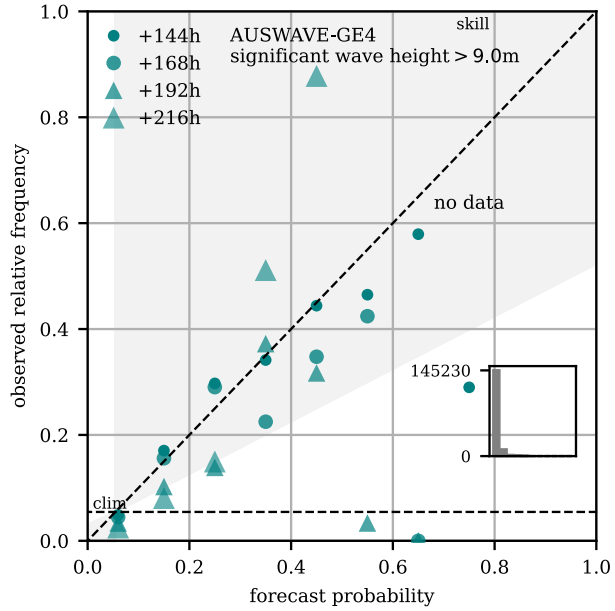
>3m



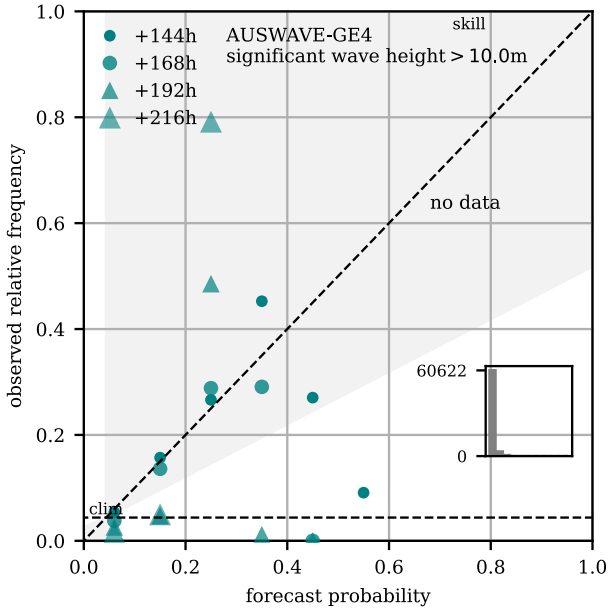
>6m



>9m



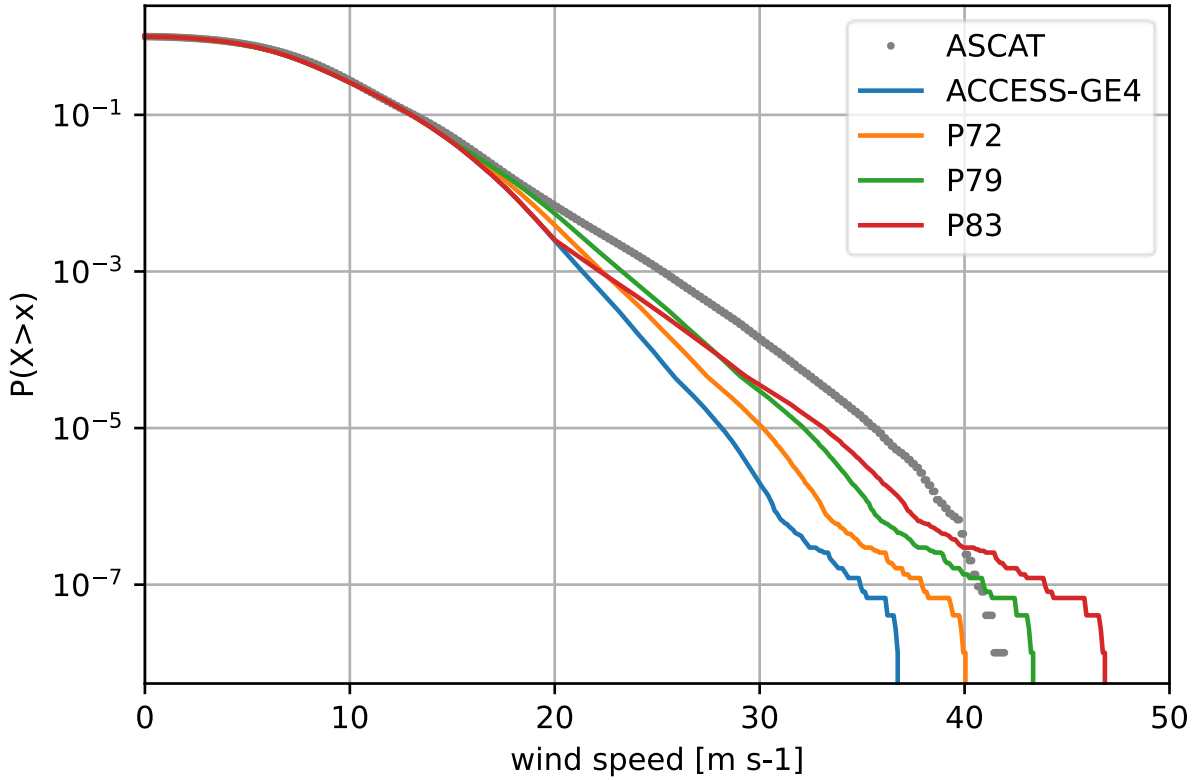
>10m

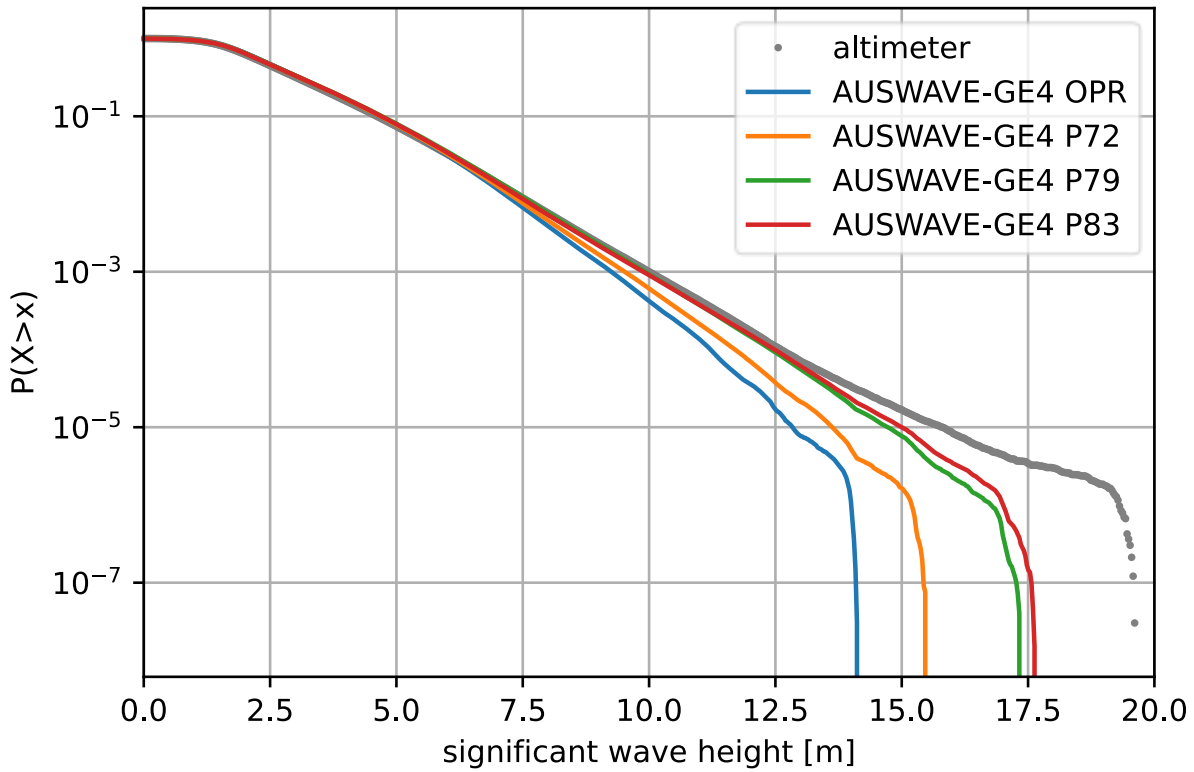


Next Steps

Next steps

Probability of exceedance





Next steps

- Complete ensemble forecasts for 2021
- Extended buoy verification
- Continue trial with P83 configuration?

Summary

- Bias correction works seamless across wave model configurations.
- Good skill up to +3 days forecast range but not enough spread.
- Wave ensemble has some skill in the +3 to +7 day forecast range.
- Beyond +7 days little to no skill.
- Bias in significant wave height increase with forecast range (model error).
- Excellent performance for significant wave height up to 10m.
- Negative bias in significant wave height for waves greater than 10 m.

Questions?

stefan.zieger@bom.gov.au