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Improved Performance of Operational Wave Models at Australian Coast

Aihong Zhong[1], Neal Moodie[2], Stefan Zieger[3] & Ying Zhao[3]

[1]Bureau National Operations Centre (BNOC)
[2]Weather Forecasting Branch
[3]Research & Development

Bureau of Meteorology, Australia

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Outline

- Introduction
- AUSWAVE configurations & recent upgrades
- Model performance and verification
- Wave Optimal Consensus Forecasting (OCF)
- Summary

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Introduction

- The Bureau is the primary provider of marine forecasts for the Australian region
- Marine forecasts heavily rely on numerical model guidance.
- Wave model guidance is used daily by forecasters to produce forecasts and warnings for the general public. Direct model output is used to produce graphics for the external web
- This guidance is also used by the Bureau's commercial weather services to produce tailored forecasts for commercial ports and offshore industry.
- The diverse range of wave conditions present in the Australian high seas forecasts zones as well as along the Australian coastline create a challenging forecasting environment, requiring models on a range of scales.

National services

Products and Services

Graphical products:

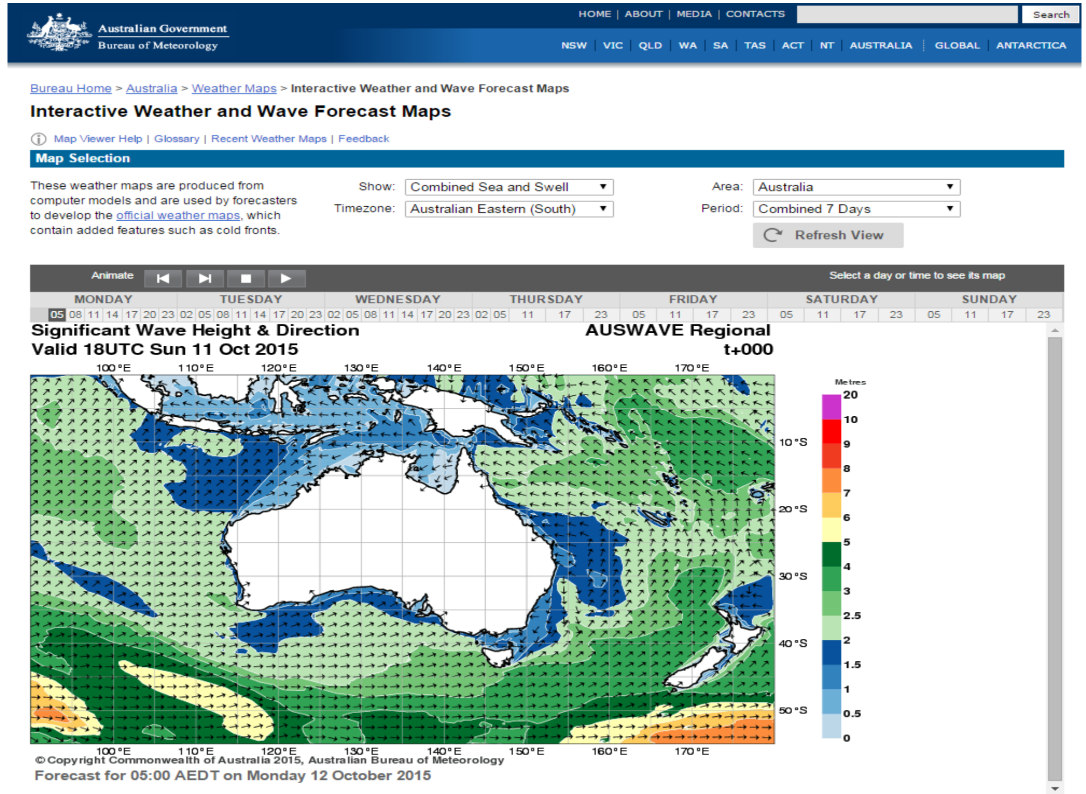
Online webpage

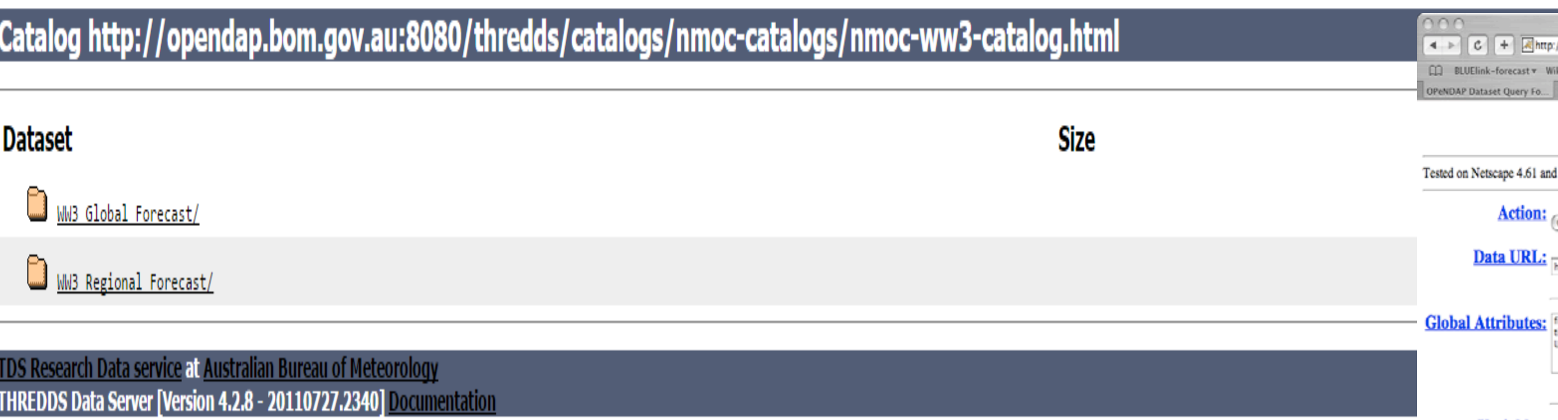
www.bom.gov.au/australia/charts/viewer/index.shtml

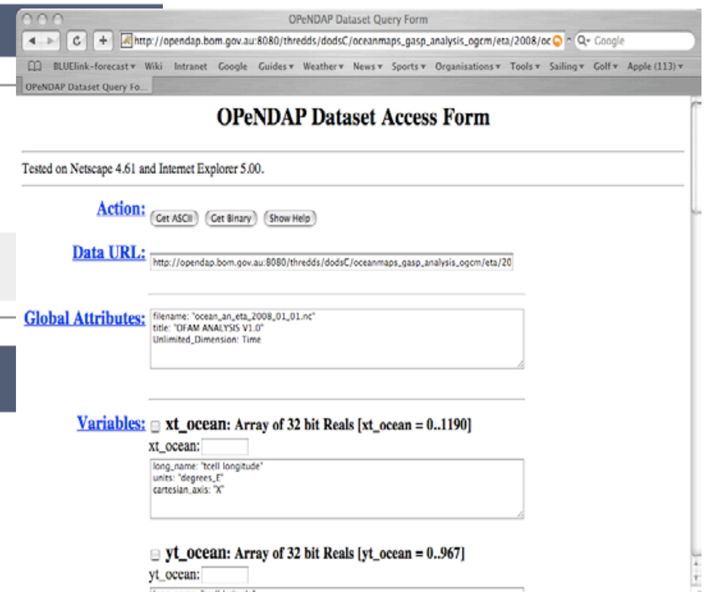
Data products:

Registered user data products

OPeNDAP server







High Seas Forecasts and Warnings

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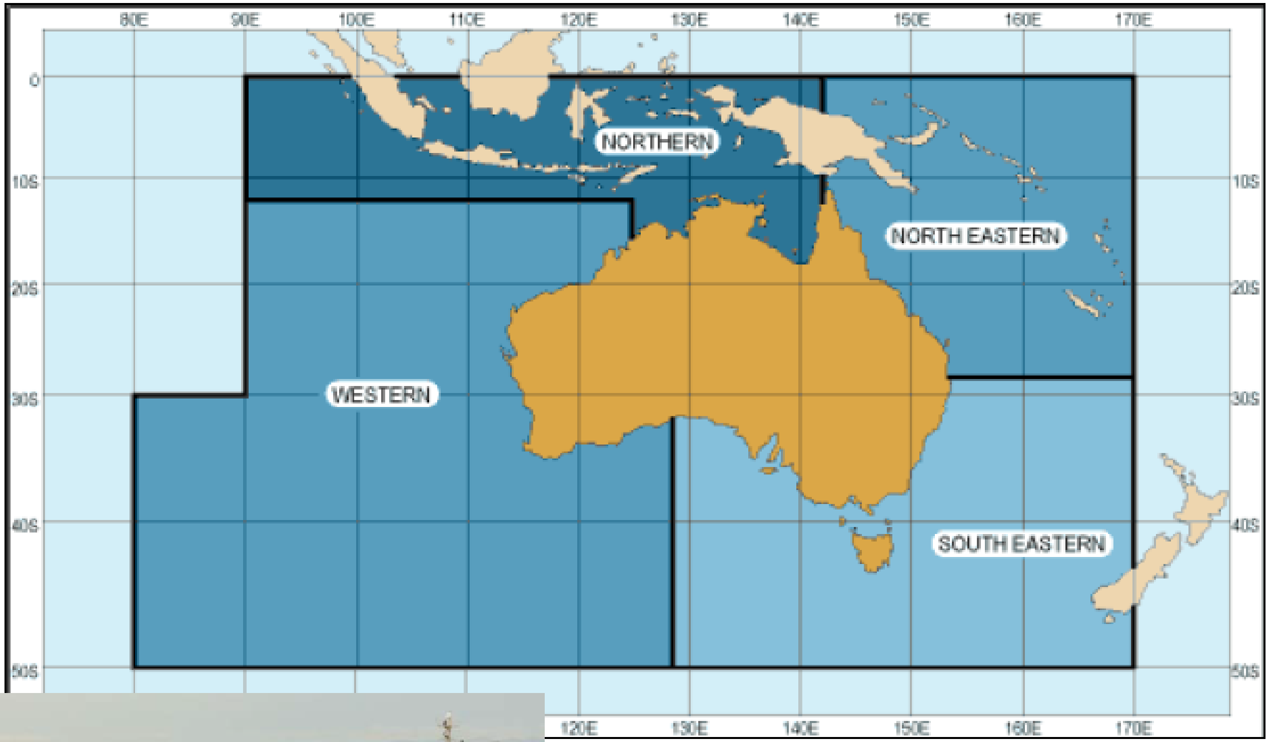
- Australia is responsible for 16 million square kilometres of ocean
- Approximately $200 billion worth of cargo is moved around our ports annually
- Ocean Wind Warnings
  - gale,
  - storm force,
  - hurricane force
  - Tropical Cyclones



Ocean areas for high seas forecasts

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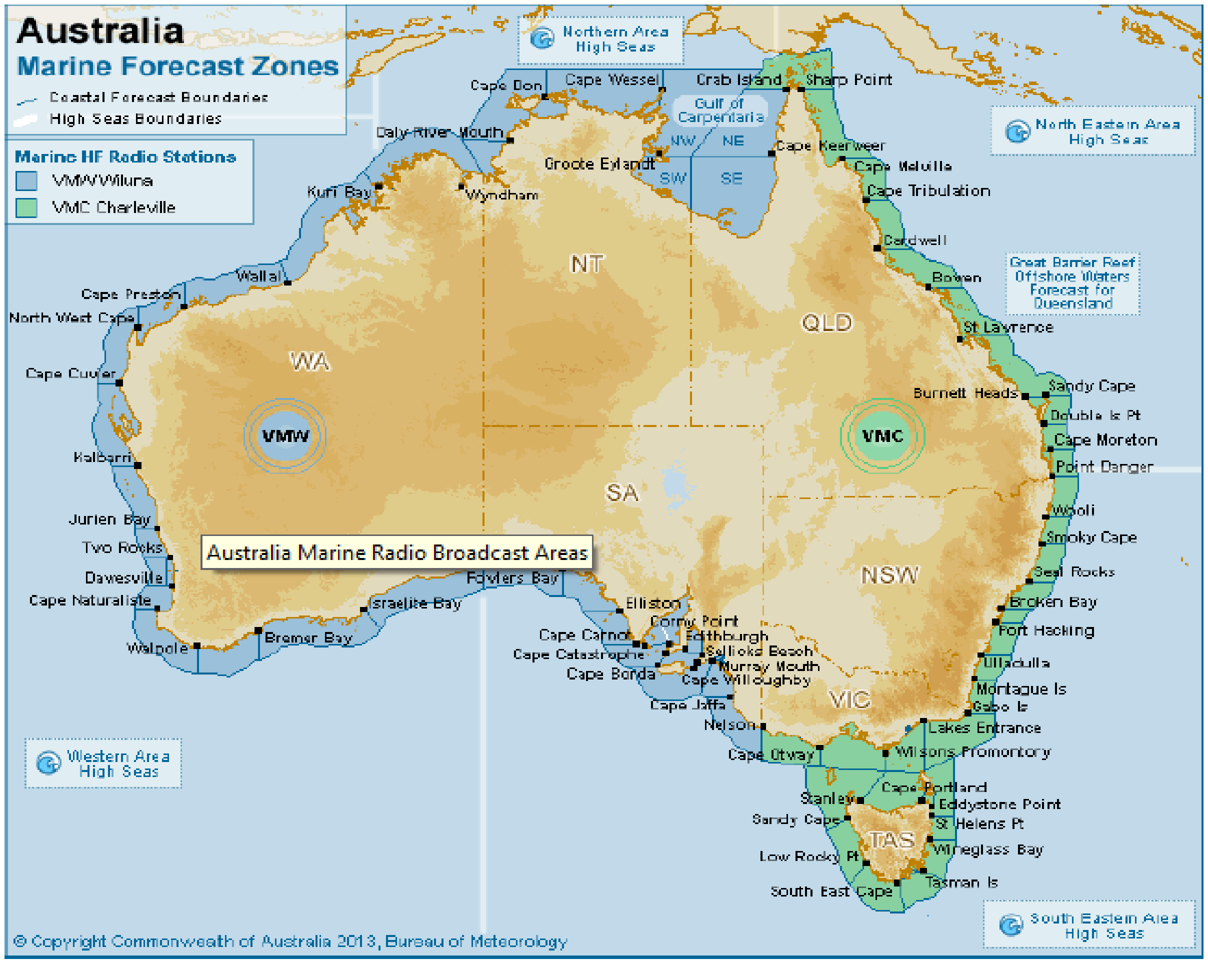
Coastal Water Forecast and Warnings

Within 60 Nautical Miles offshore

- 78 marine zones
- > 35000 km of coastline
- Warnings issued for same zones
  - strong wind,
  - gale,
  - storm force or
  - hurricane force winds



Operational Wave Models

- Bureau National Operations Centre started running a version of WAM wave model in June 1994

- Following the implementation of the Australian Community Climate and Earth-System Simulator (ACCESS) Numerical Weather Prediction systems, WAM model was replaced by AUSWAVE in 2010. AUSWAVE was based on the version of 3.14 WaveWatchIII

- In 2012-2013 AUSWAVE was upgraded following the change of global ACCESS system from APS0 ("Australian Parallel Suite") to APS1

- In 2015 the second wave model upgrade occurred due to the change of ACCESS APS1 to APS2:
  - ✓ global model resolution increased from 0.4 deg to 0.25 deg;
  - ✓ wave model code in version 4.18
  - ✓ source term changed from ECMWF WAM parameterisation ST3 (Bidlot 2012) to ST4 described by Ardhuin et al 2010 and Leckler et al 2013

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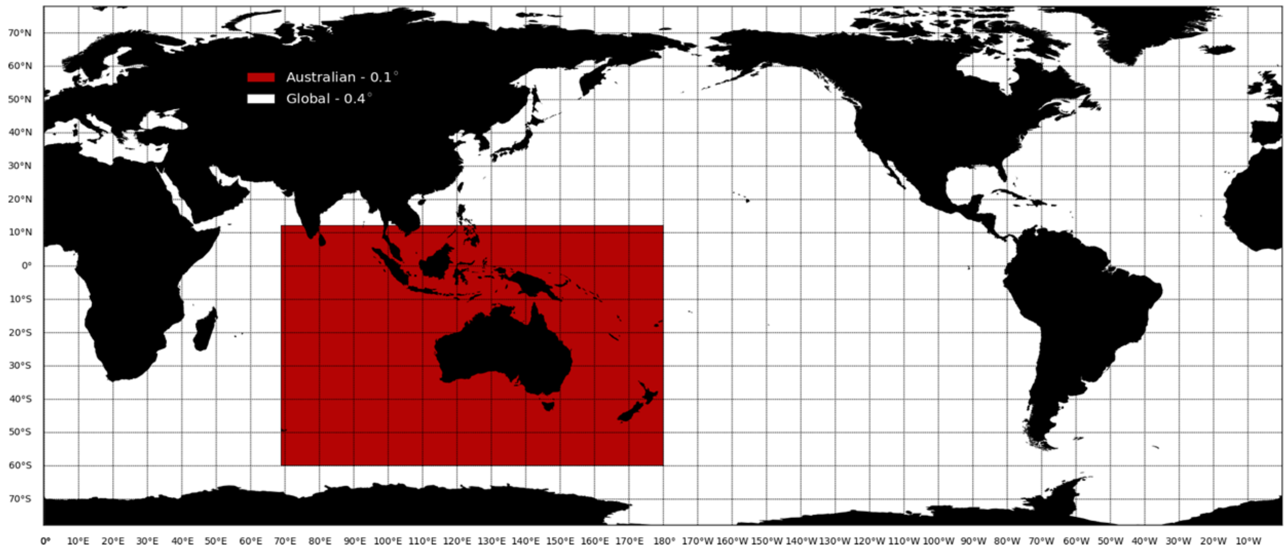
Model Configurations



Wave spectra were discretized
•24 directional bins: every 15º
•25 frequency bins 0.0418 Hz to 0.4114 Hz or from 24 to 2.5 seconds

AUSWAVE	Domain	Forcings	Resolution	Domain (lat xLon)	Forc Period (hours)
APS0-G	Global	ACCESS-G0	1.0º	78ºS-78ºN 0-359ºE	+168
APS1-G	Global	ACCESS-G1	0.4º		
APS2-G	Global	ACCESS-G2	0.25º		
APS0-R	Regional	ACCESS-R0	0.5º	60ºS-12ºN 69-180ºE	+72
APS1 (or 2)-R	Regional	ACCESS-R1(or 2)	0.1º		

First upgrade: Evaluation of Marine Surface Winds

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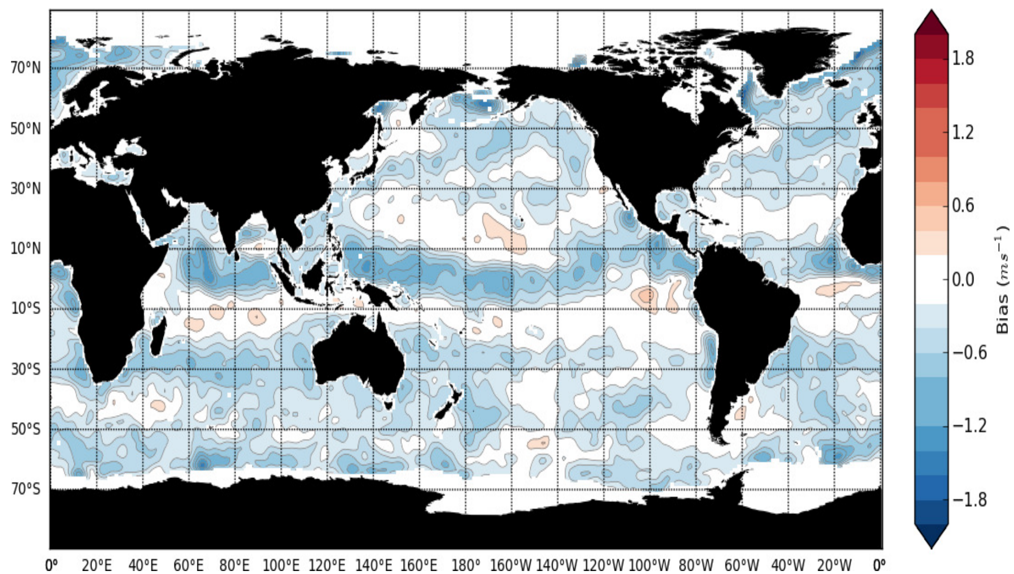
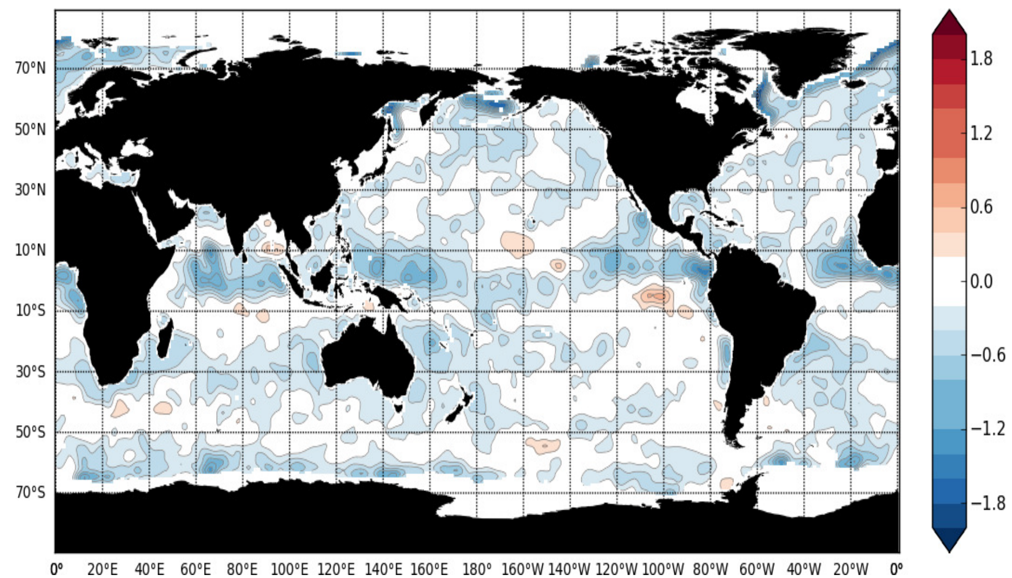
Mean Bias: APS0 ACCESS-G



Mean Bias: APS1 ACCESS-G



- **Mean bias of wind speed from APS0 (top) and APS1 ACCESS-G compared with ASCAT data for May 2012. Data are binned into 1º x 1º**
- **Global bias is improved significantly by 30% & low around Australian Coast and ITCZ in APS1 ACCESS-G**

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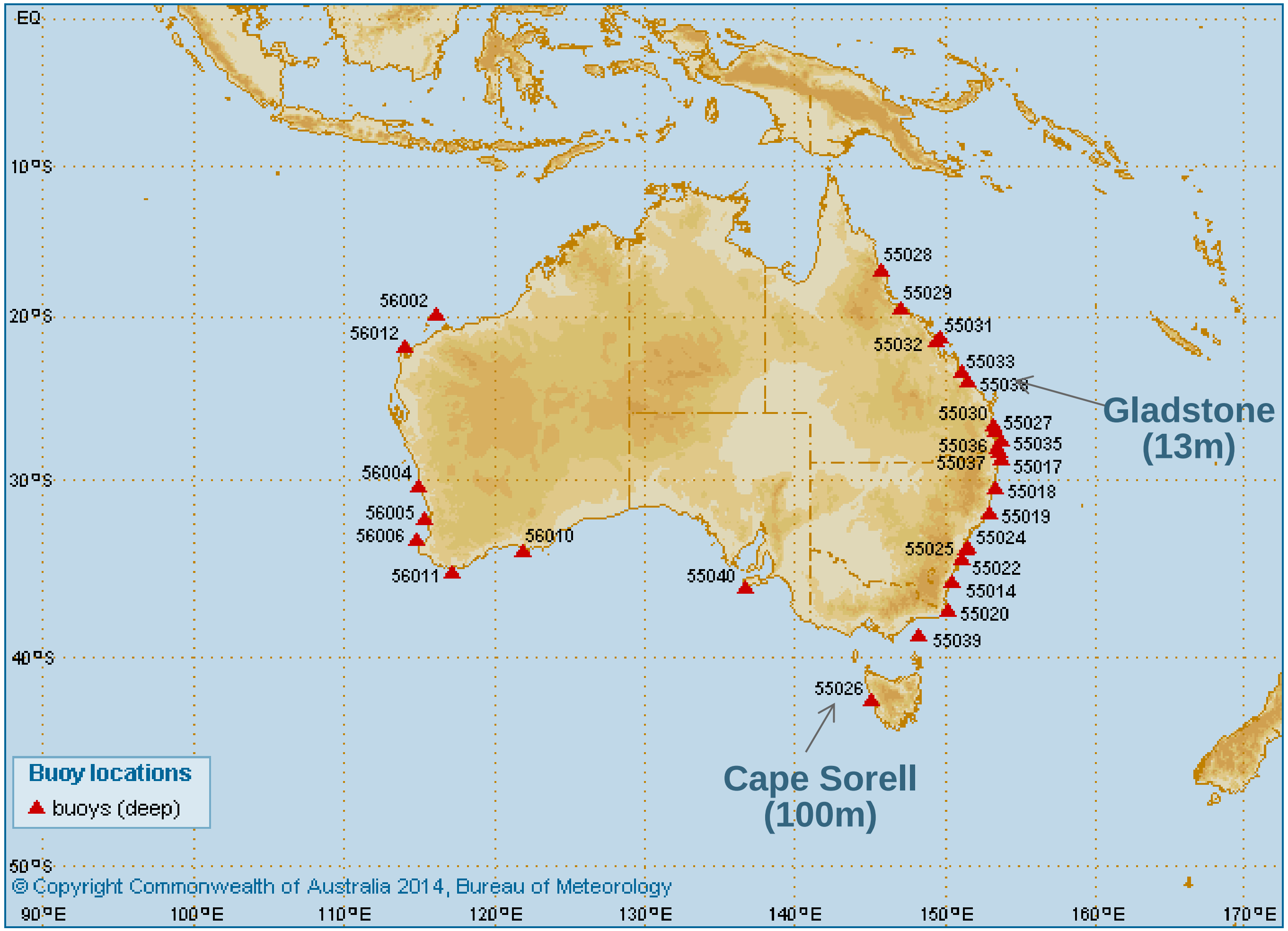
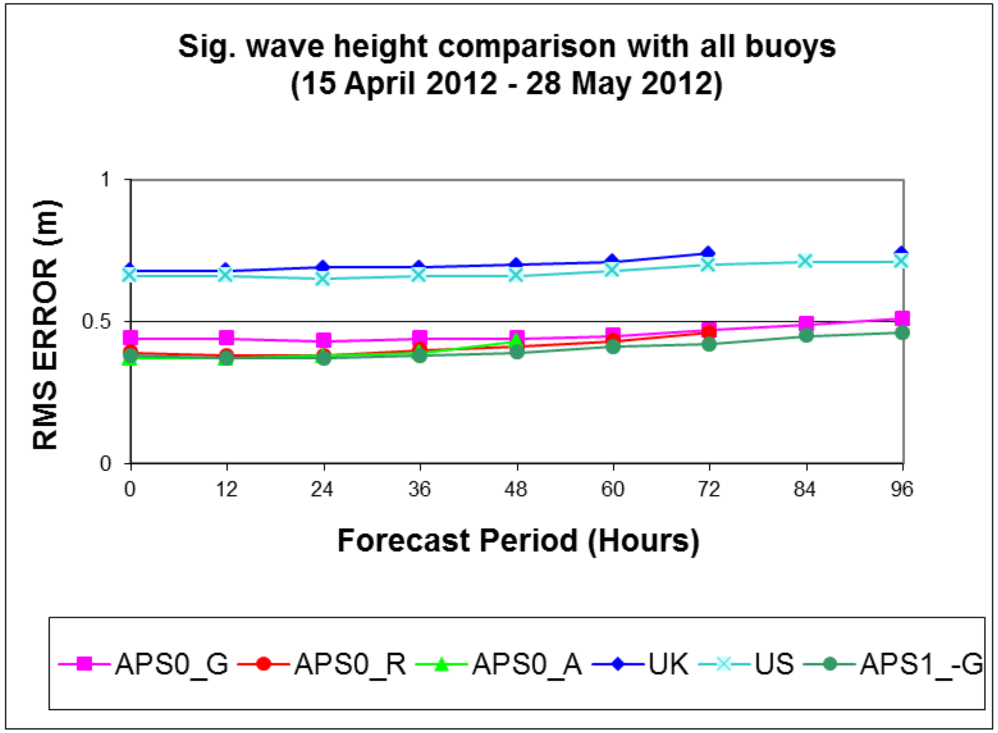
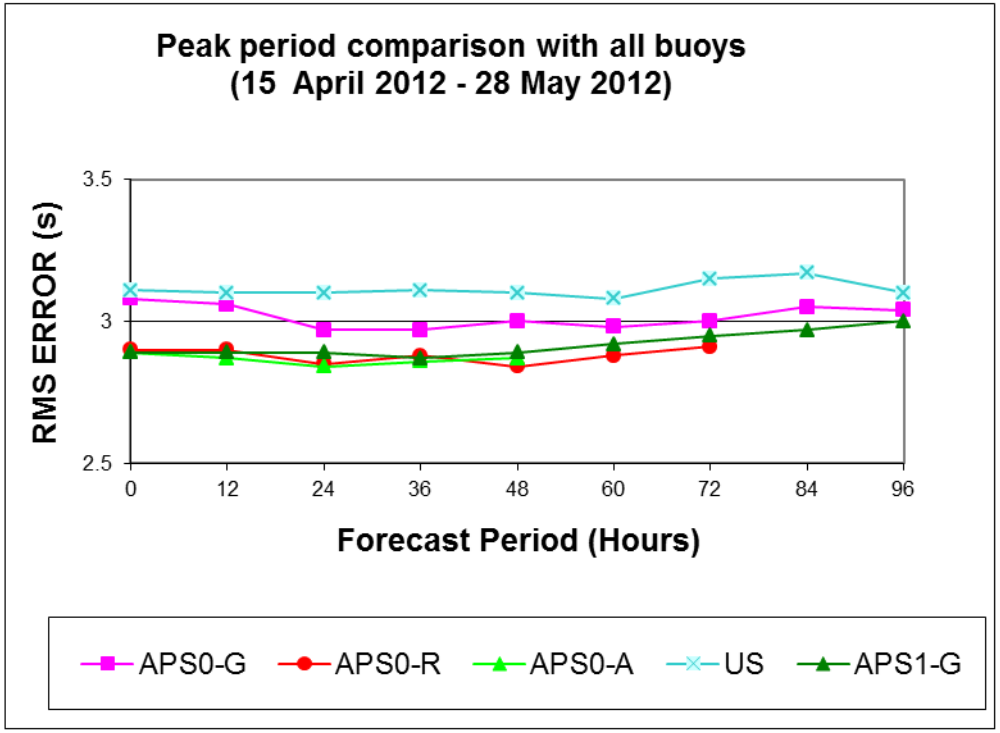
In-Situ Australian Waverider Buoys



Wave Model Performance vs In-situ Aus Buoys





- **25 buoys sites around the Australian Coast**
- **Among the six models, the APS1 global wave model exhibits the smallest RMS errors in SWH: reduction of RMS error of 16% compared to APS0 AUSWAVE-G.**
- **RMS error of Peak Period is reduced by 6% in the APS1 global wave model.**

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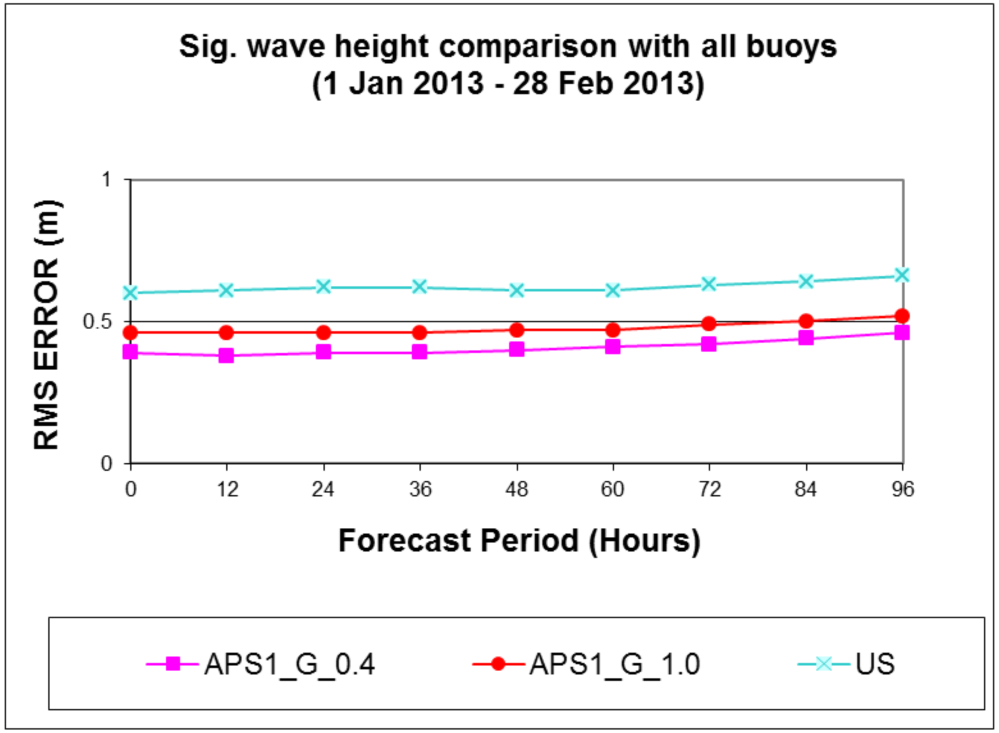
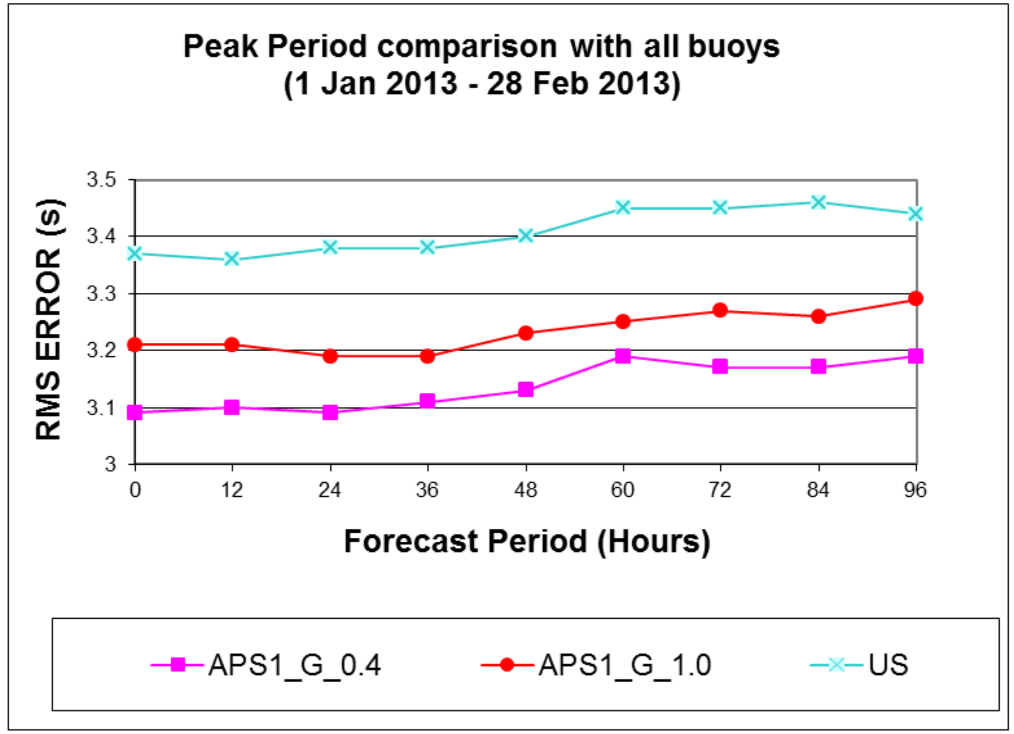
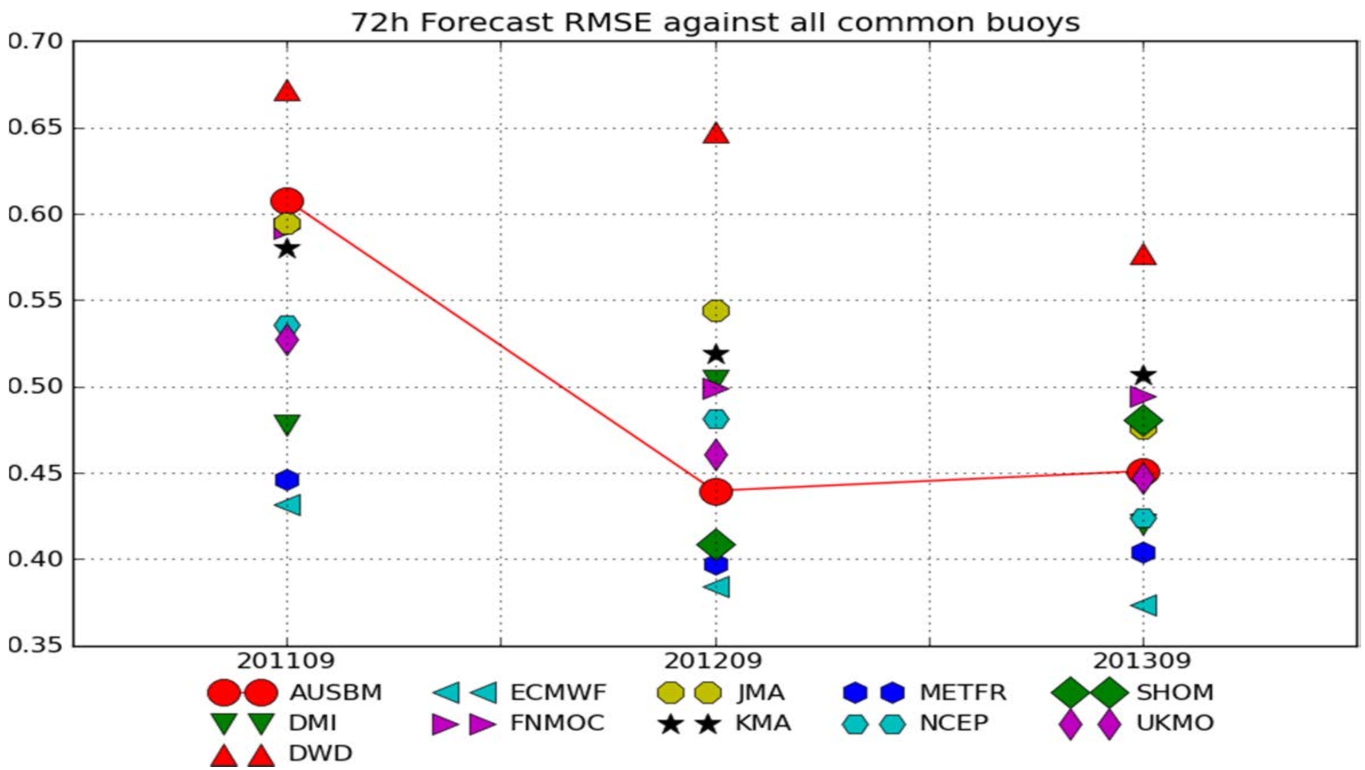
Increase of Wave Model Resolution





- **Same APS1 ACCESS-G provides wind forcing for the global wave model**
- **Wave model resolution was increased from 110km (APS1-G_1.0) to 44km (APS1_G_0.4)**
- **The improvement in the new wave model performance is mainly due to the increase in the wave model resolution than the change in the wind forcing**

Inter-comparison of Operational Wave Forecasts



- Comparison of the Bureau's RMSE against international systems at all common buoy locations around the world from the JCOMM inter-comparison.
- Post APS1 upgrade Sep 2012, the Bureau's +72h Hs forecast was improved significantly and ranks 4th in the world in terms of RMSE.

Recent NWP upgrade: Evaluation of Wind Forcings (July 2015)

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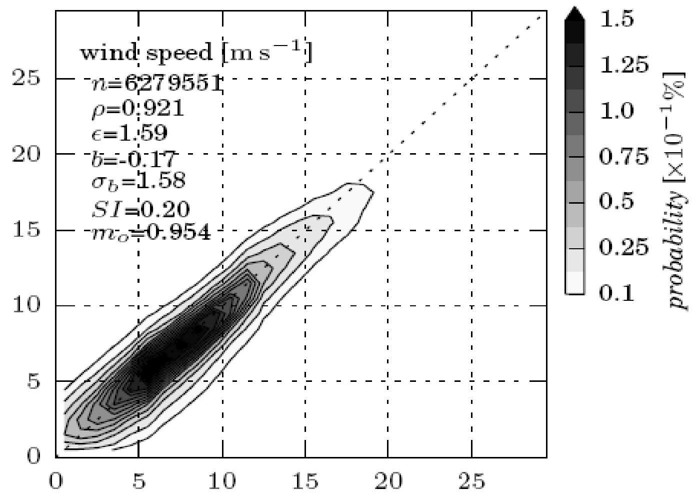
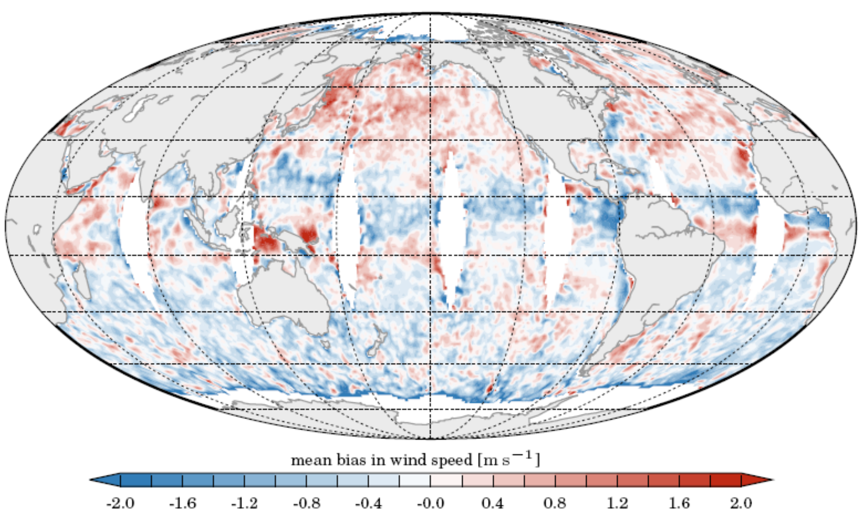
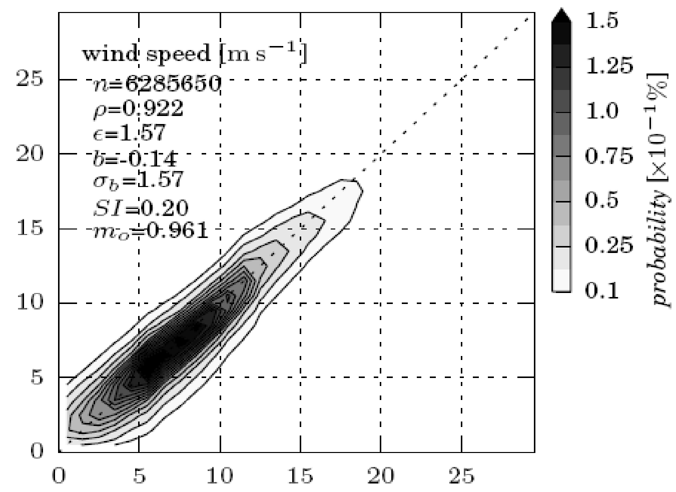
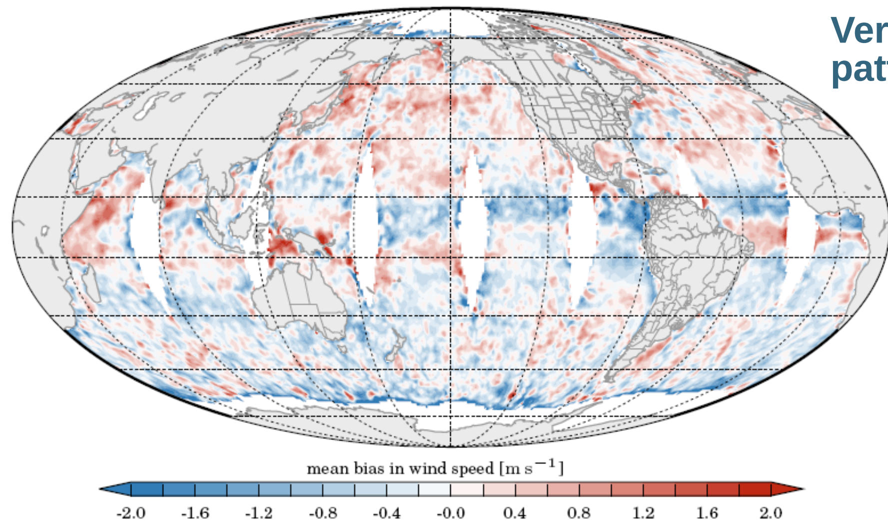
APS1





APS2





Very similar bias pattern

Wave Model Verification vs Satellite Data

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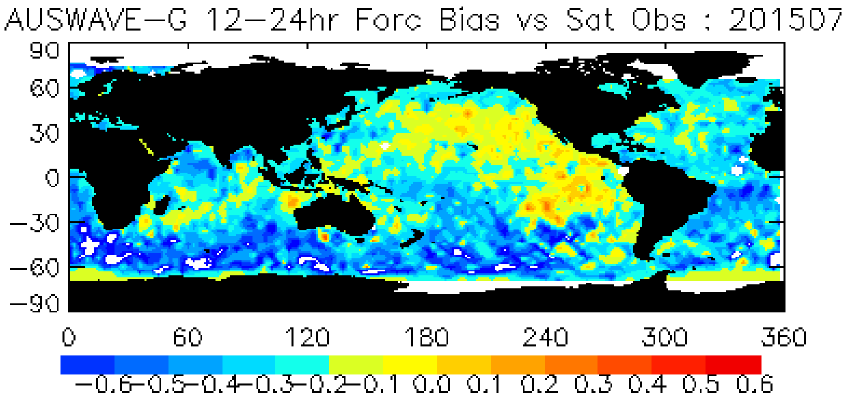
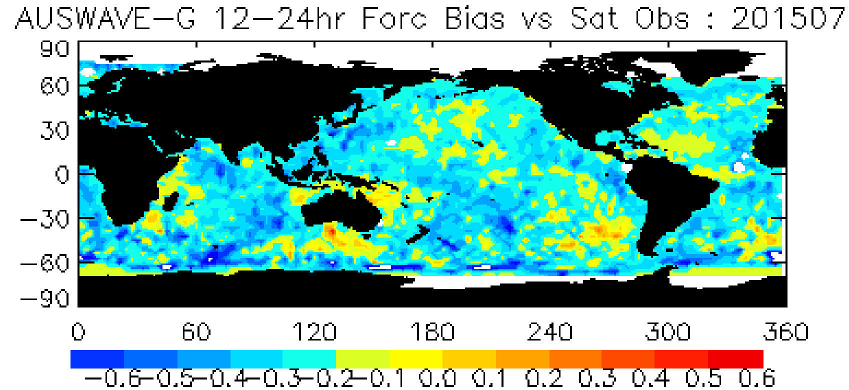
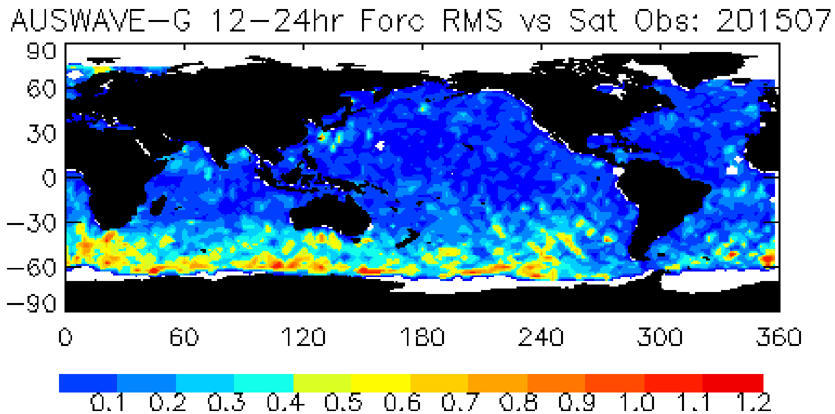
APS1-G | **APS2-G**

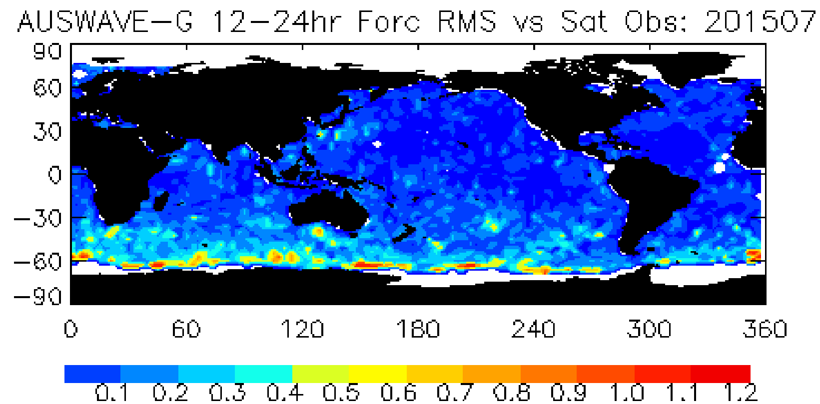
BIAS





RMS





- Satellite altimeters provide accurate observations of waves with excellent spatial coverage over the open ocean
- Wave model accuracy depends on the accuracy of the surface winds. Negative bias of marine winds in ACCESS over the globe contributes to negative bias in wave forecasts.
- Overall large model bias and RMS especially over Southern Ocean were significantly reduced in APS2-G.

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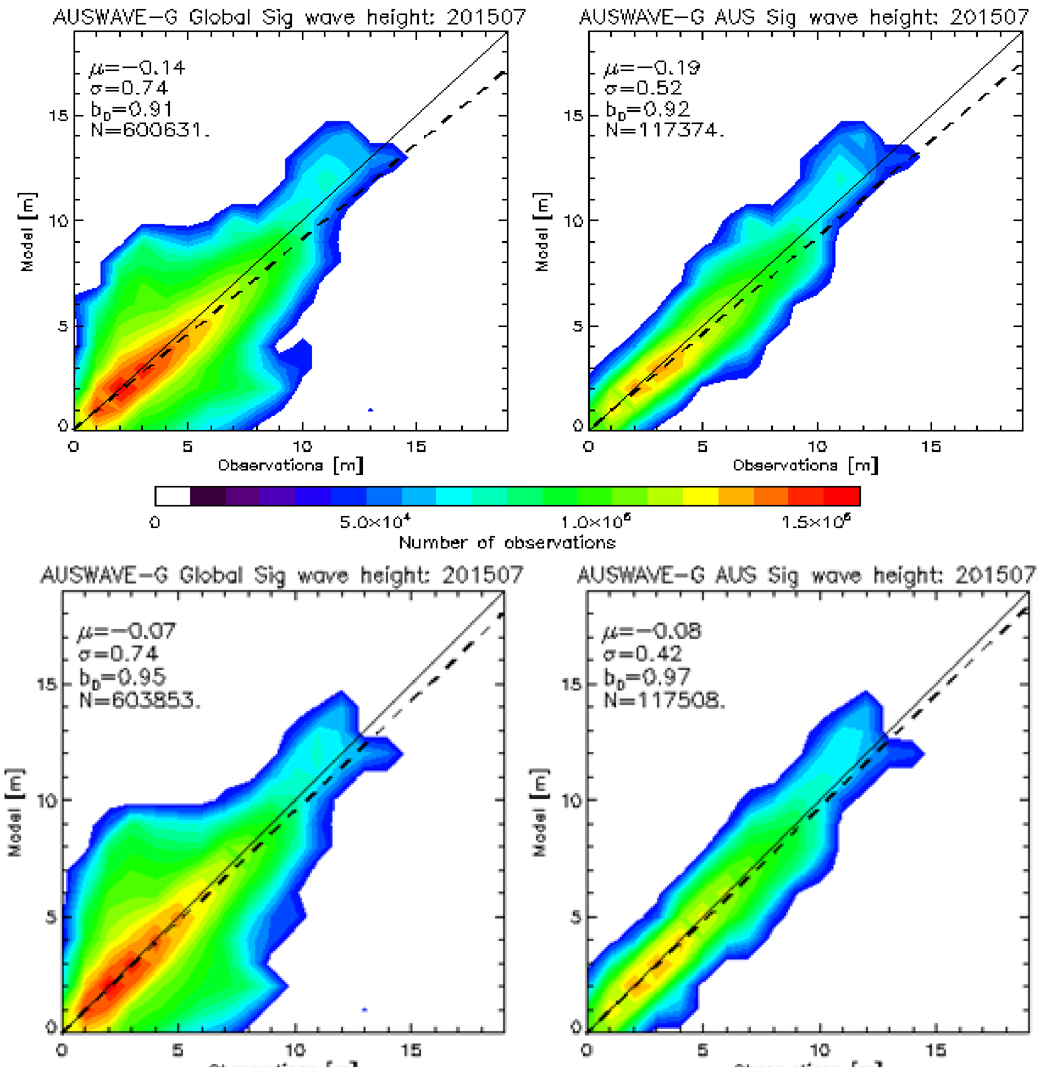
Scatter plot of Sig Wave Height

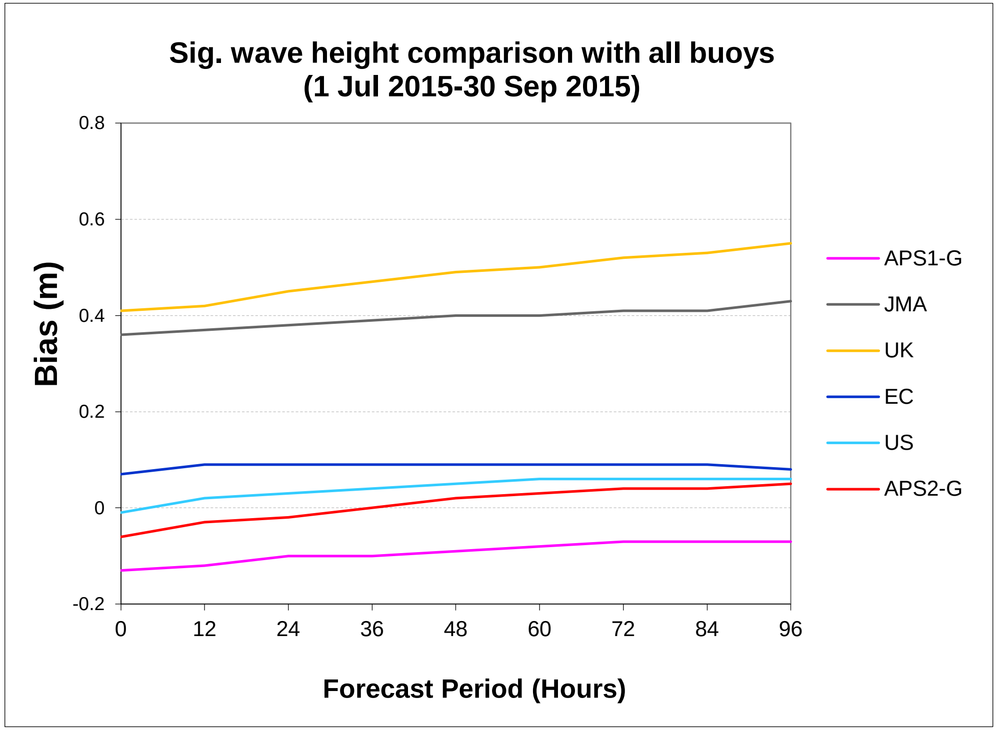
APS1-G

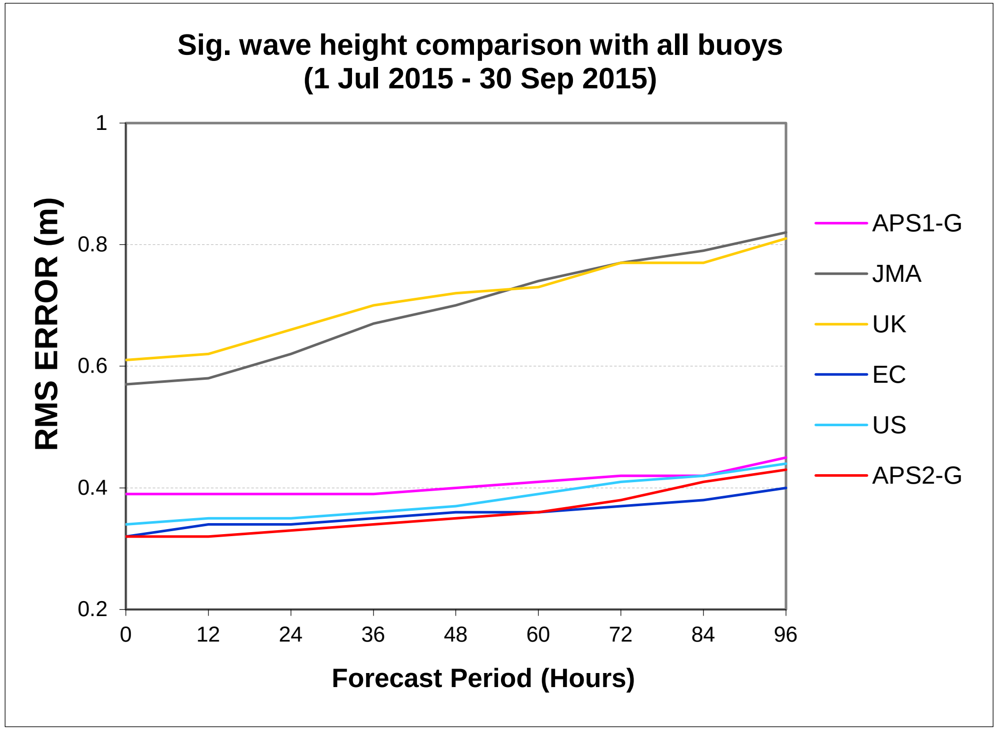
APS2-G



- The root mean square error is around 0.74m for both models and the bias is slightly reduced in the new version of wave model
- New version of wave model produces the best line fit through the observations globally or over Australian region and significant reduction of RMS over Australian region.

Model verification vs In-Situ Australian buoys





- APS2 ACCESS-G provides wind forcing for the global wave model
- Wave model resolution was increased from 0.4 deg (APS1-G) to 0.25 deg (APS2_G) & new physics
- The improvement in the new wave model performance is mainly due to improved physical parameterization of source term rather than simple increase of model resolution. Also see comparison and validation of physical wave parameterizations in spectral wave models by Stopa et al. 2015

Optimal Consensus Forecast Approach – Why?

- Averaging forecasts from more than one model results in more accurate predictions than from the individual models.
- On average, the error in the combined forecast is smaller than that of forecasts from each component model
- Greatest benefit from independent models
- It also reduces the amount of information the forecaster needs to combine in his or her head

The adopted methodology for Sites OCF

- **Sources of forecasts**:
  - Use DMO from all available models: Bilinearly interpolate gridded DMO to observation site locations
- **Bias-correct each model individually for each observation site** using a fixed 30-day window
  - we require at least 15 observations in past 30 days.
  - The Bias is calculated using the Best Easy Systematic estimator (BES) for forecast errors from the previous 30 days:
    - BES = $(q_{0.25} + 2\, q_{0.5} + q_{0.75})/4$
    - $q_{0.25}$ and $q_{0.75}$ are the lower and upper quartiles and $q_{0.5}$ is the median

for the sample of all forecast errors from the previous 30 days; BES is computed for each model and forecast lead time

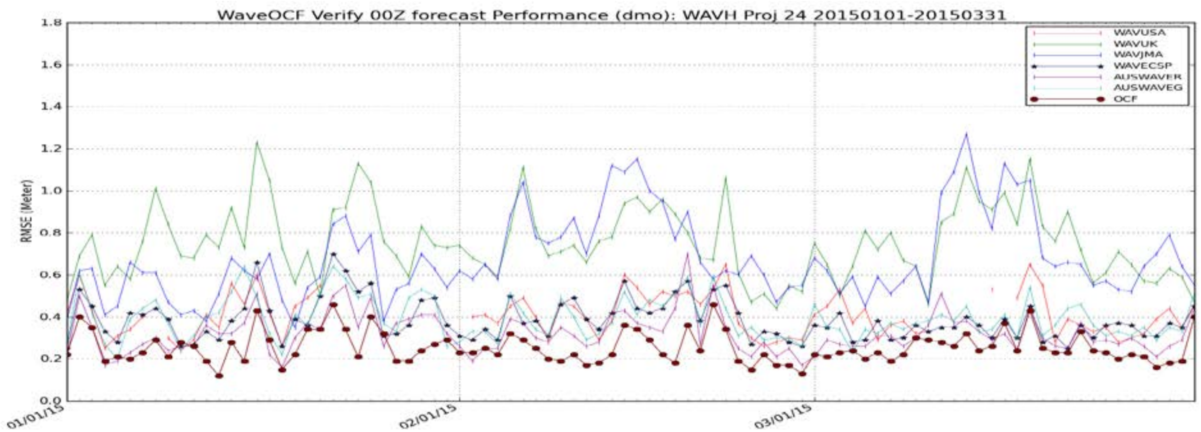
- Take **weighted average** of forecasts: weight each component using the inverse of the mean absolute error (MAE)
  - MAE is calculated from the previous 30 days of forecasts

$$w_i = \frac{\frac{1}{MAE_i}}{\sum_{j=1}^{N} \frac{1}{MAE_j}} \qquad OCF = \sum_{i=1}^{N} w_i f_i$$

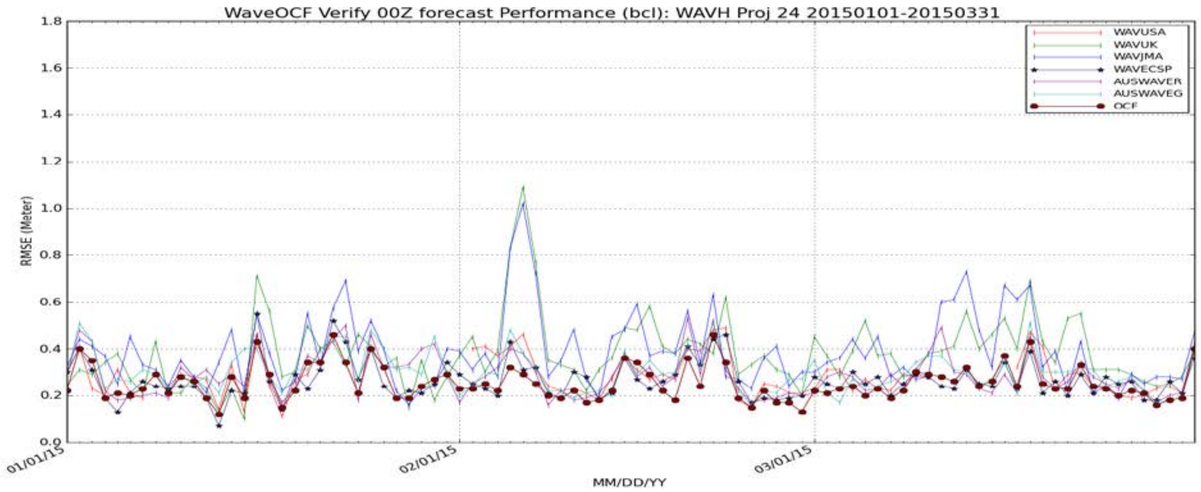
Wave Optimal Consensus Forecast (OCF)

- Combine forecasts from six wave models to produce forecasts of significant wave height, peak wave period, wind direction and wind speed up to 5 days ahead at 30 selected sites.

Mean absolute error of SWH from direct model outputs



Mean absolute error of SWH from model outputs after bias correction



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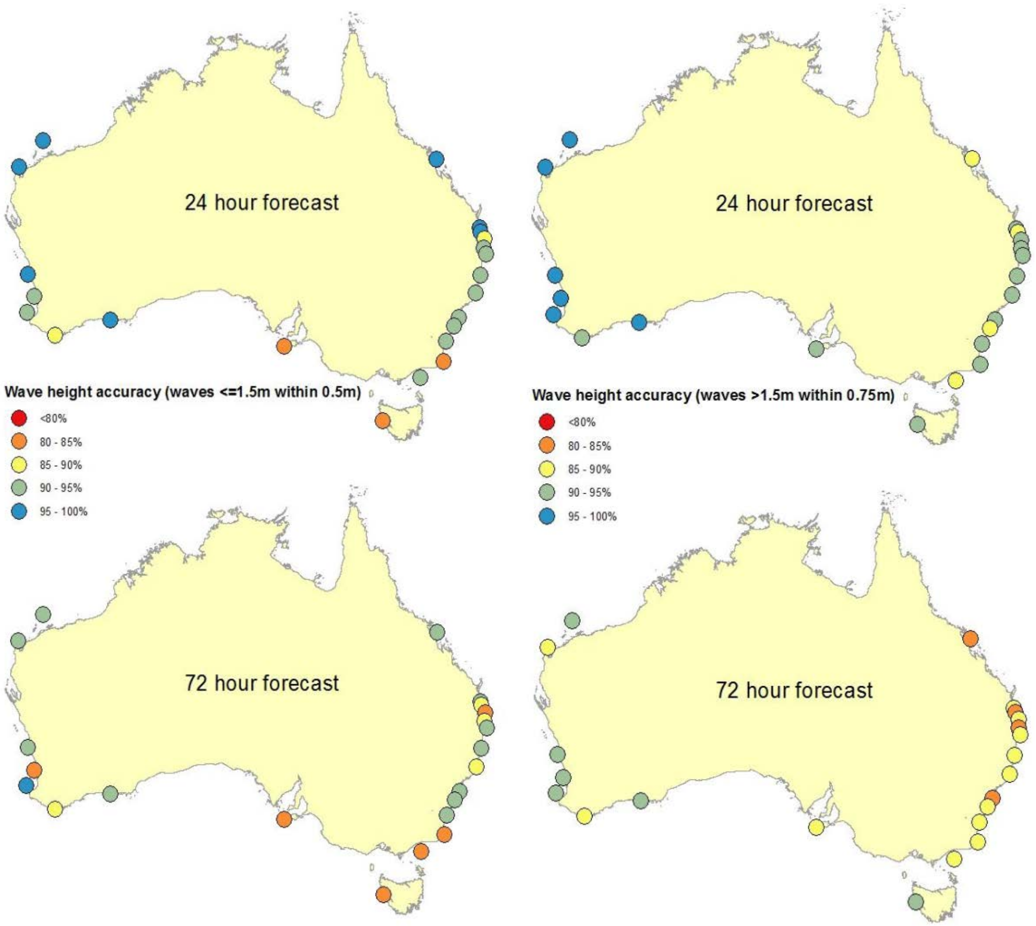
Wave OCF verification (2012-2013)



Forecast challenges exist primarily along the East Coast likely due to complex wave generating systems such as East Coast Lows

Overall wave height forecast reliability and wave period reliability for periods of >=12 seconds

	Wave height (all obs)		Wave period (>=12sec)	
	OCF	Auswave-R	OCF	Auswave-R
+24hrs	94%	92%	90%	87%
+72hrs	89%	88%	89%	86%

- **3% improvement from the AUSWAVE-R model to the OCF at both +24 and +72 hrs.**

Reliability statistics for observed waves >= 3m forecast within 0.75m. Period of study indicated in parentheses

	Wave height (forecast within 0.75m for obs > 3m)	
	OCF (24 months)	Auswave-R (24 months)
+24hrs	87% (n=1673)	79% (n=1676)
+72hrs	78% (n=1673)	68% (n=1676)

- **For large waves over 3m, 8-10% more reliable than AUSWAVE-R at both +24 & +72 hrs**

Summary

- The global AUSWAVE wave model (AUSWAVE-G) are comparable to all the global wave models around the world

- The improvement of wave model performance largely comes from the improved physical parameterisation of source term than simple increase of model resolution.

- Wave OCF combines forecasts from several models, removes the model's biases and produces more accurate wave predictions around the Australian coast than from any individual models.

- Wave OCF forecast challenges exist primarily along the East Coast

- Work in progress on developing gridded wave OCF using multi-model ensembles of wave forecasts