
Bluelink capabilities are world-leading in prediction of the upper ocean in priority areas including the Indo-Pacific-Southern Ocean domain. Bluelink forecast systems deliver fit-for-purpose atmospheric, wave and ocean forecasts to the Department of Defence at regional, shelf and littoral-scales, including user-initiated forecasts.

Bluelink Ocean Forecasting

Strategic Plan 2025

NAVY

ROYAL AUSTRALIAN NAVY

Bluelink Strategic Plan 2025

NAVY VALUES

HONOUR HONESTY COURAGE INTEGRITY LOYALTY

Bluelink

Ocean Forecasting

Australian Government

Department of Defence

Australian Government

Bureau of Meteorology

CSIRO

Strategic Plan 2025 Document Structure

1. Goal
2. Vision
3. Objectives
4. Scope
5. About the Partnership
6. Ocean Modelling
7. Bluelink Infrastructure
8. Bluelink Partnership Delivery Pathways
9. Governance Structure and Bluelink Documents
10. Communication and Stakeholder Engagement
11. Risk Management

Annexes

A. Bluelink Collaborating Partners
B. Bluelink Portfolio Roadmap
C. Bluelink Management Committee Terms of Reference
D. Bluelink Operations and Development Committee Terms of Reference
E. Bluelink MSA-OSOFS KPIs

Goal

Develop and maintain world-leading global, regional, and littoral ocean forecast systems to support Defence applications and maintain a national ocean forecasting capability for Australia.

Vision

Bluelink capabilities are world-leading in prediction of the upper ocean in priority areas including the Indo-Pacific-Southern Ocean domain. Bluelink forecast systems deliver fit-for-purpose atmospheric, wave and ocean forecasts to the Department of Defence at global, regional, shelf and littoral-scales, including user-initiated forecasts.

Objectives

1. Sustainment of world-leading global and high-resolution ocean-atmosphere-wave forecasts.

2. Enhance ocean forecasting capabilities through a portfolio of research and development activities.

3. Collaborate as strong partners in the ocean forecasting enterprise, to generate synergies from partner efforts and provide leadership for the benefit of Australia.

Annex A Bluelink Collaborating Partners

Besides the three Bluelink partners, there are crucial collaborating partners which are **IMOS**, **DSTG**, **NCI**, and the **University sector**. BoM and CSIRO's extensive experience in the development and sustainment of ocean forecasting services is complimented by each of the Collaborating Partners, who deliver critical support to Bluelink partners.

Australia's National Science Agency

Bluelink regional-scale ocean modelling – basic test: barotropic tides

David Griffin (+many CSIRO colleagues) | 16 October 2019

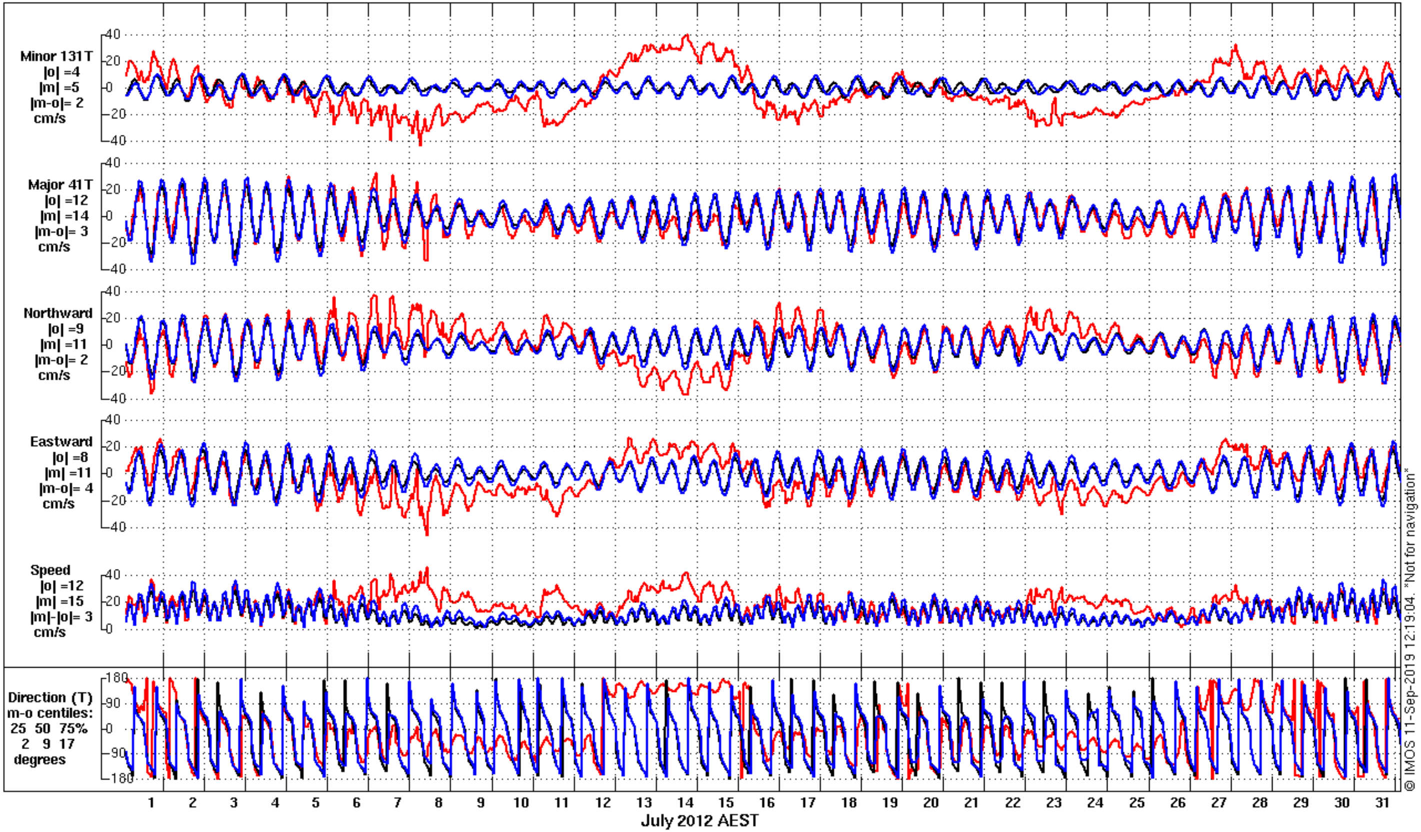
Advice is useless unless you know how credible it is

- This is why IMOS (and other) *in situ* ocean observations are important to Bluelink, even if those obs are not used by the model
- ROAM = Relocatable Ocean Atmosphere Model
- Nested within OceanMAPS, adds tides. Hourly output.
- But how credible is it? Would you make an operational decision, with lives or $M at stake, based on it?

The most predictable thing about the ocean is the tide.

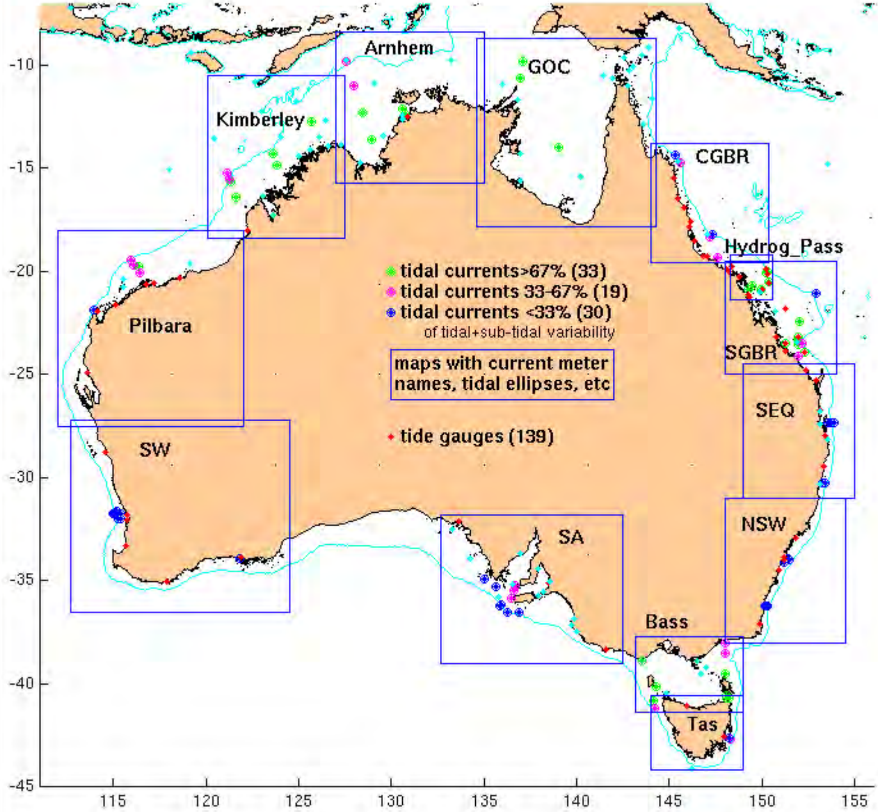
- And in many places, it is most of the variance
- So why is there not an official tidal current prediction, but only predictions of tidal sea level?
- Because the credibility of tidal current predictions is either too low, unknown, or both.
- *OceanCurrent* now has a tides section, presenting OTPS predictions and comparison with 82 IMOS and other current meters.
- Let’s start with Palm Passage, near Townsville.

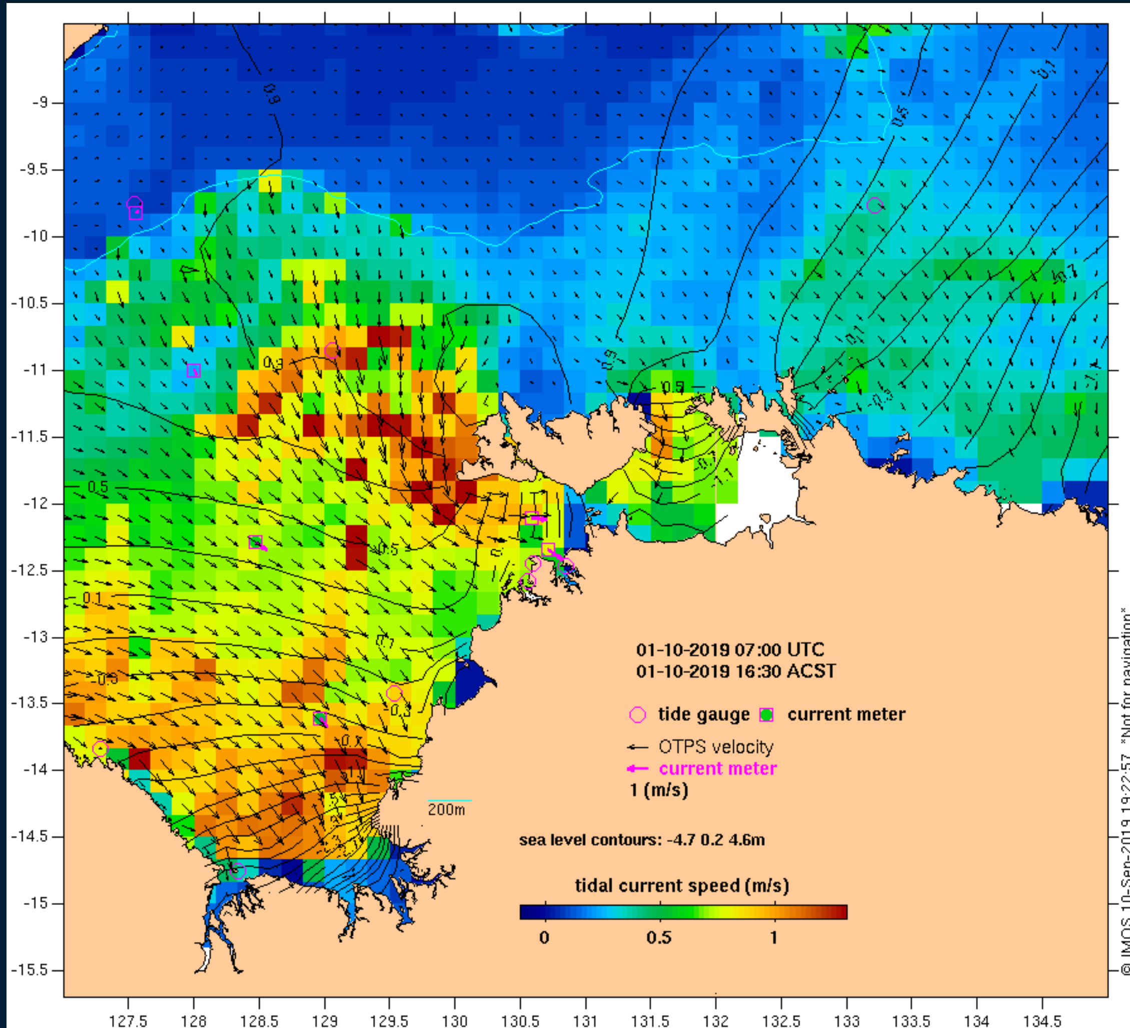
Predicted depth-average tidal velocity (black from obs, blue from model) at GBRPPS 18.3S 147.2E. Observations (tidal+non-tidal) in red.
Water is 72m deep, 57m in model . Rms model vector error |m-o| = 3 cm/s. Observed sub-tidal velocity is 16cm/s rms + 5cm/s -156T mean



IMOS Integrated Marine Observing System

OceanCurrent - Tidal currents and sea level - Announcement





01-10-2019 07:00 UTC
01-10-2019 16:30 ACST
tide gauge
current meter
OTPS velocity
current meter
1 (m/s)
200m
sea level contours: -4.7 0.2 4.6m
tidal current speed (m/s)
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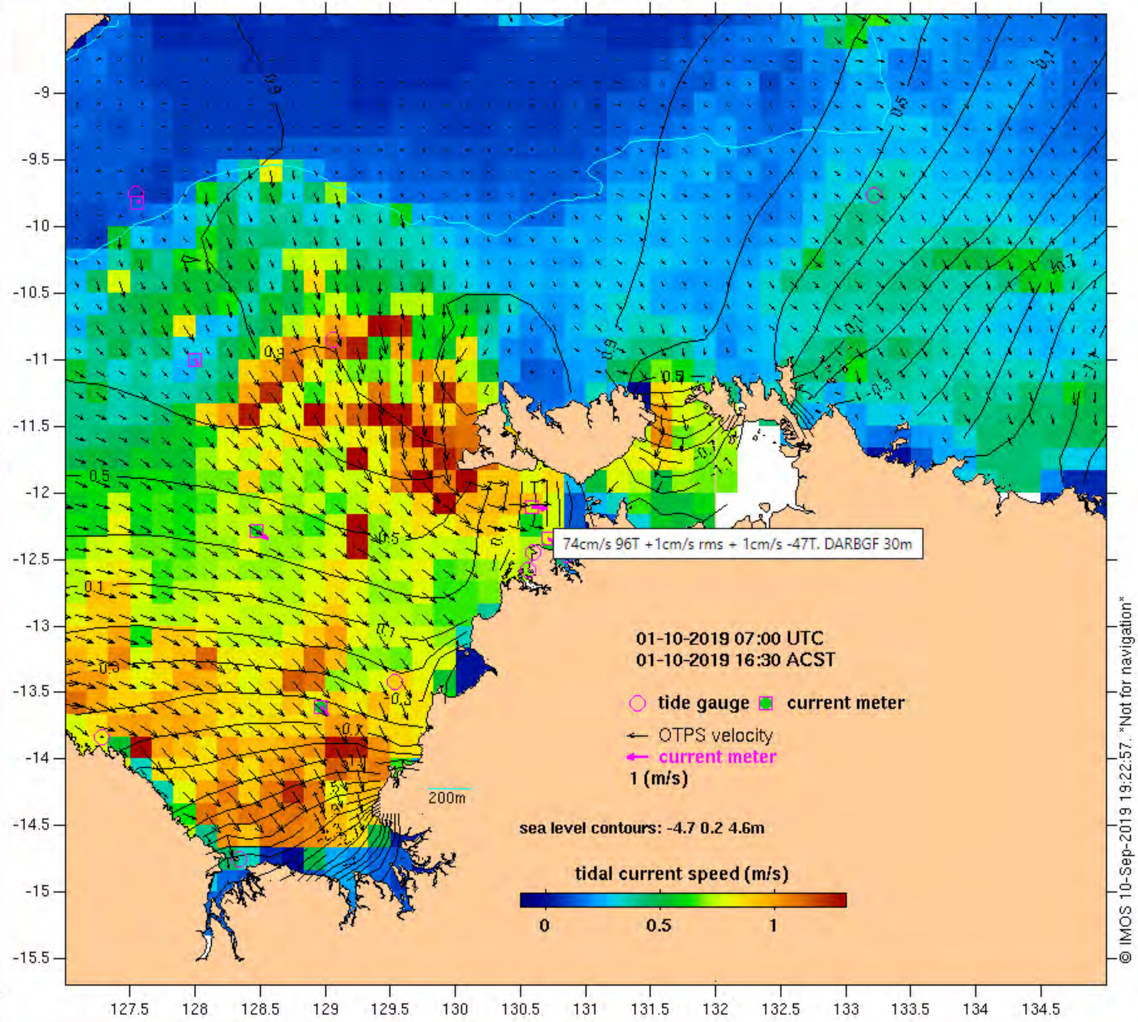
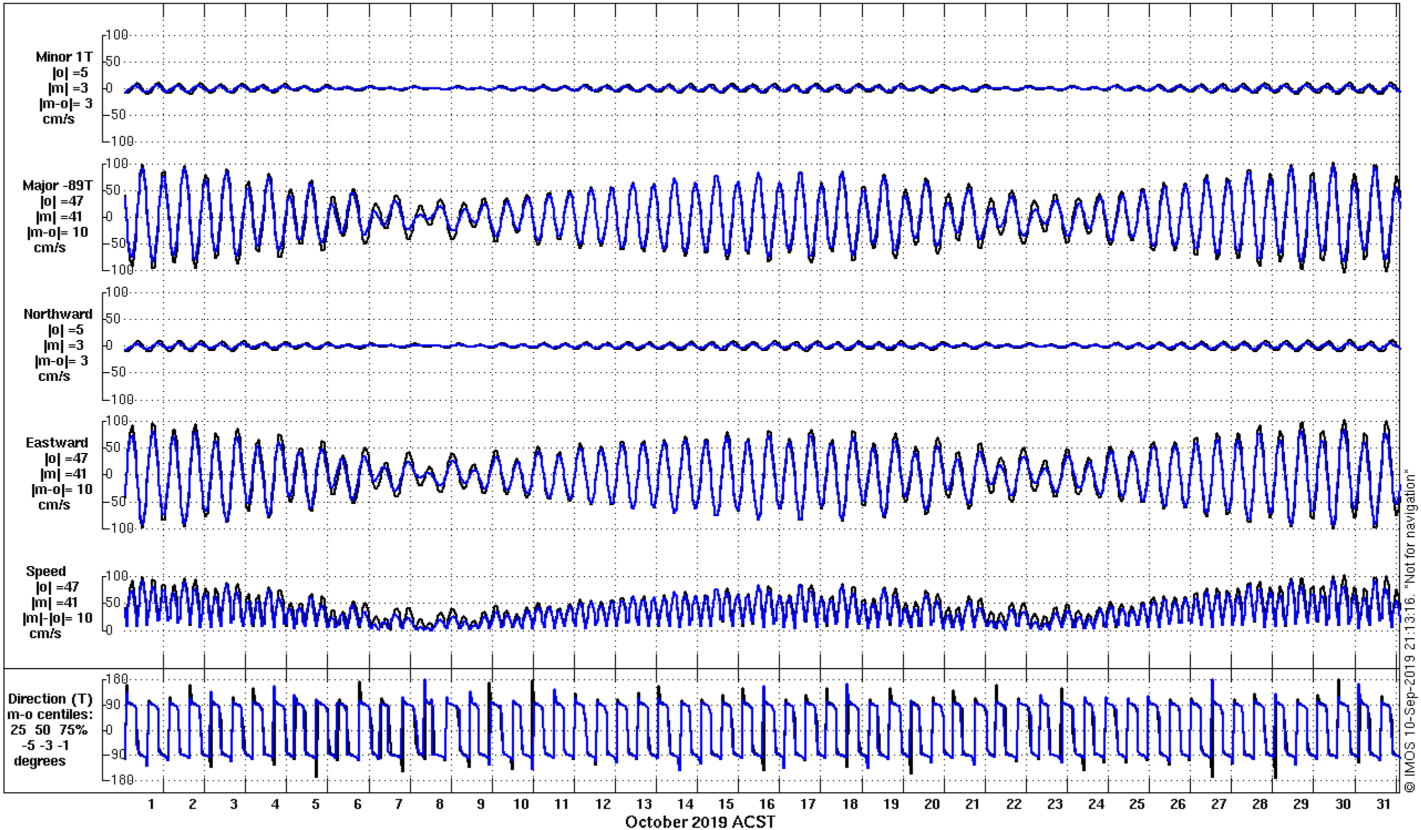
© IMOS 10-Sep-2019 19:22:57. "Not for navigation"

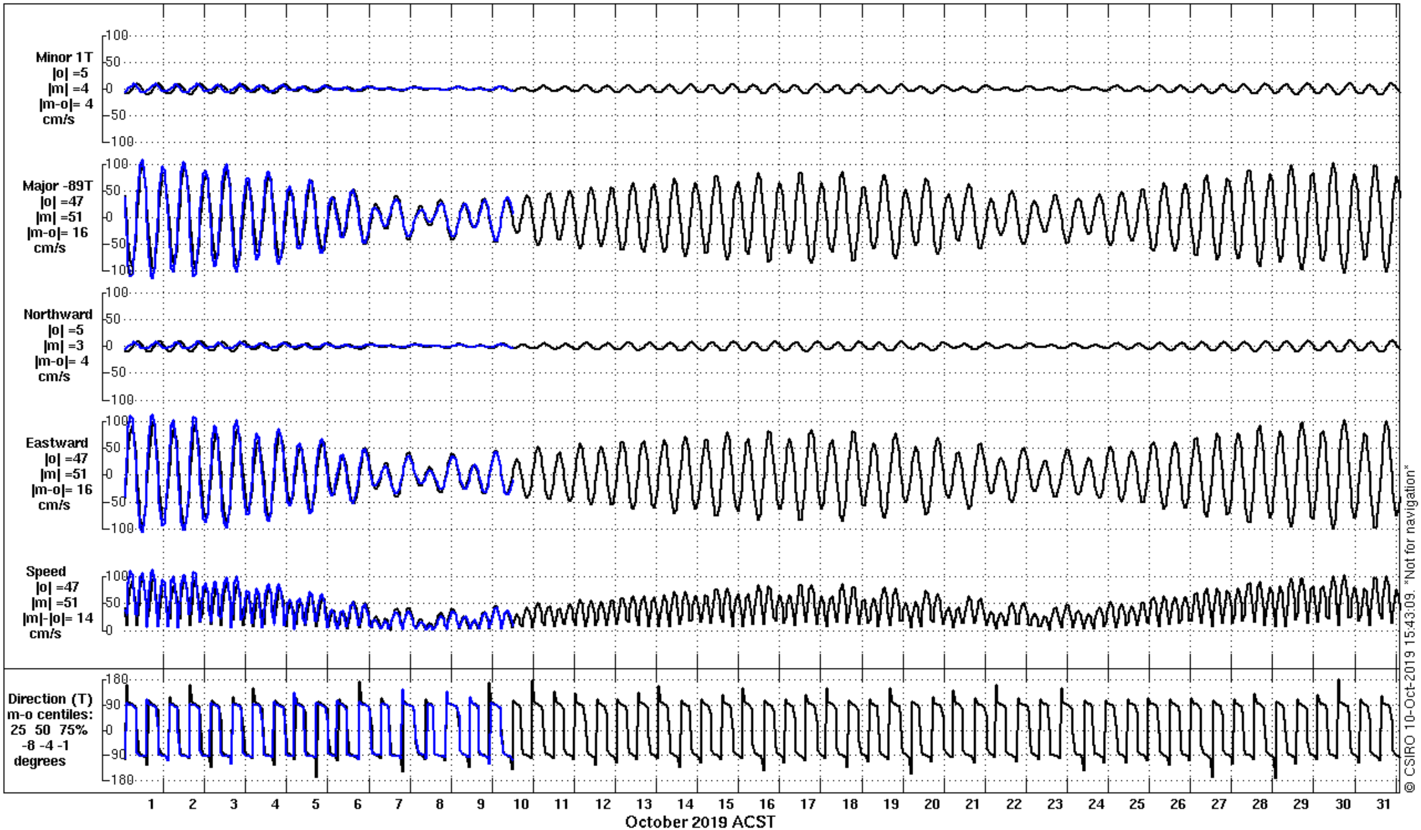
[OceanCurrent] [tides] [SPD/SL] [PREV] [NEXT] [DATE INDEX] [Conditions of use]

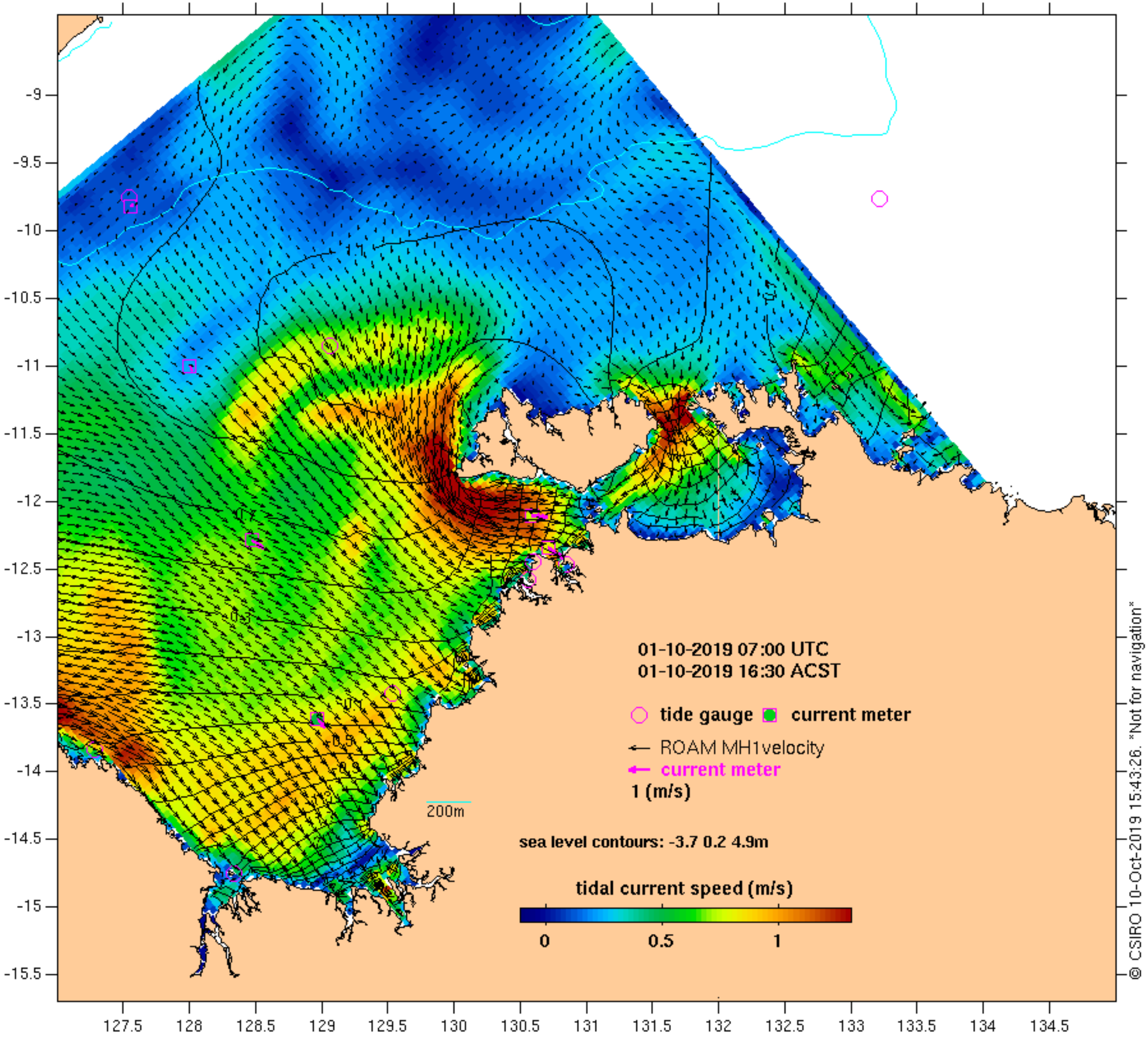


Predicted depth-average tidal velocity (black from obs, blue from model) at DARBGF 12.1S 130.6E.
Water is 30m deep, 24m in model. . Observed sub-tidal velocity is 1cm/s rms + 1cm/s -47T mean



Predicted depth-average tidal velocity (black from obs, blue from ROAM MH1) at DARBGF 12.1S 130.6E.
Water:30m. Model: 30 28m at 4 2km. Rms model vector error |m-o| = 15 cm/s (13cm/s with 24h lag). Obs sub-tidal velocity is 1cm/s rms + 1cm/s -47T mean





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current meter
ROAM MH1velocity
current meter
1 (m/s)
200m
sea level contours: -3.7 0.2 4.9m
tidal current speed (m/s)
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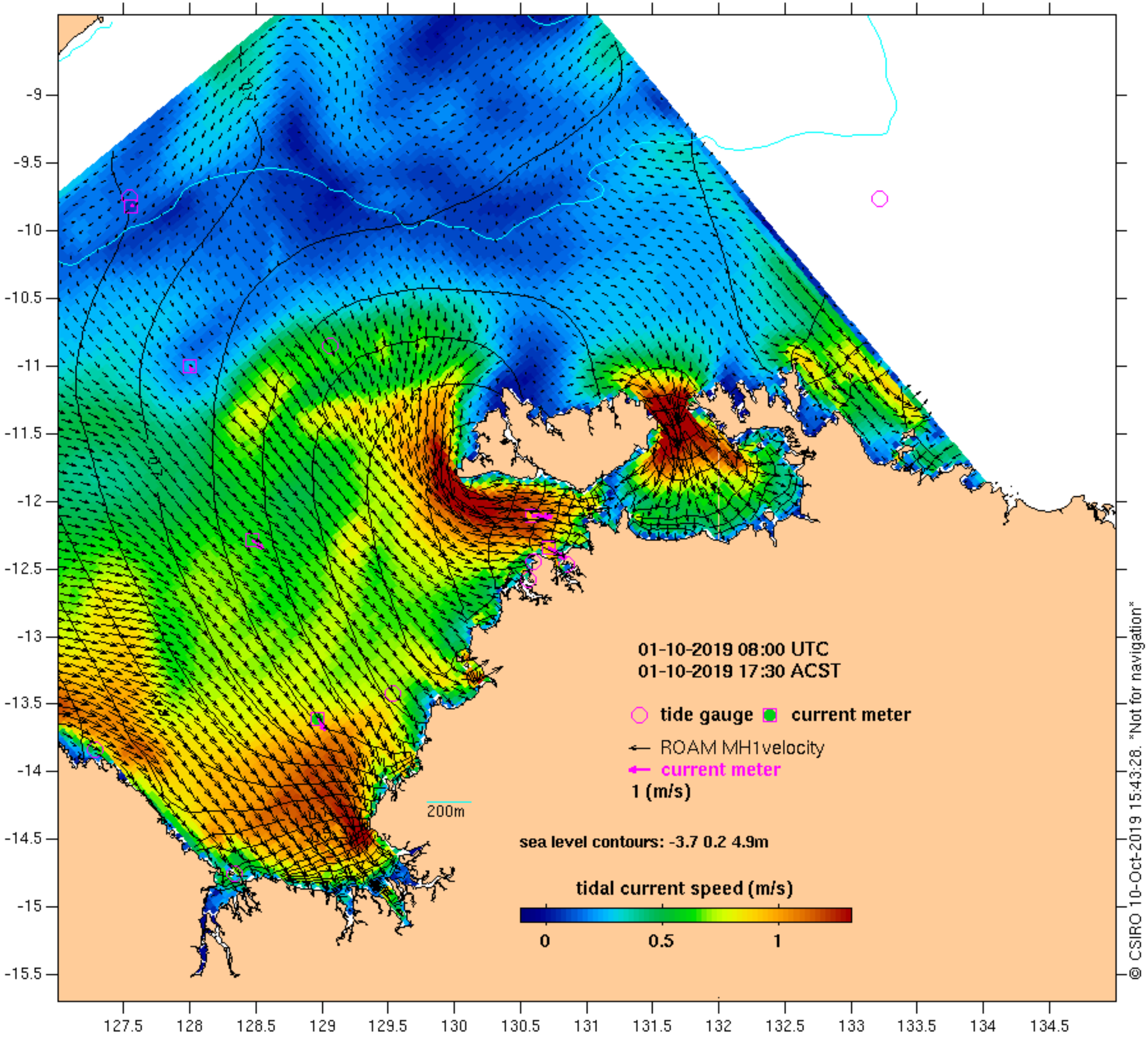

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01-10-2019 08:00 UTC
01-10-2019 17:30 ACST
tide gauge
current meter
ROAM MH1velocity
current meter
1 (m/s)
200m
sea level contours: -3.7 0.2 4.9m
tidal current speed (m/s)
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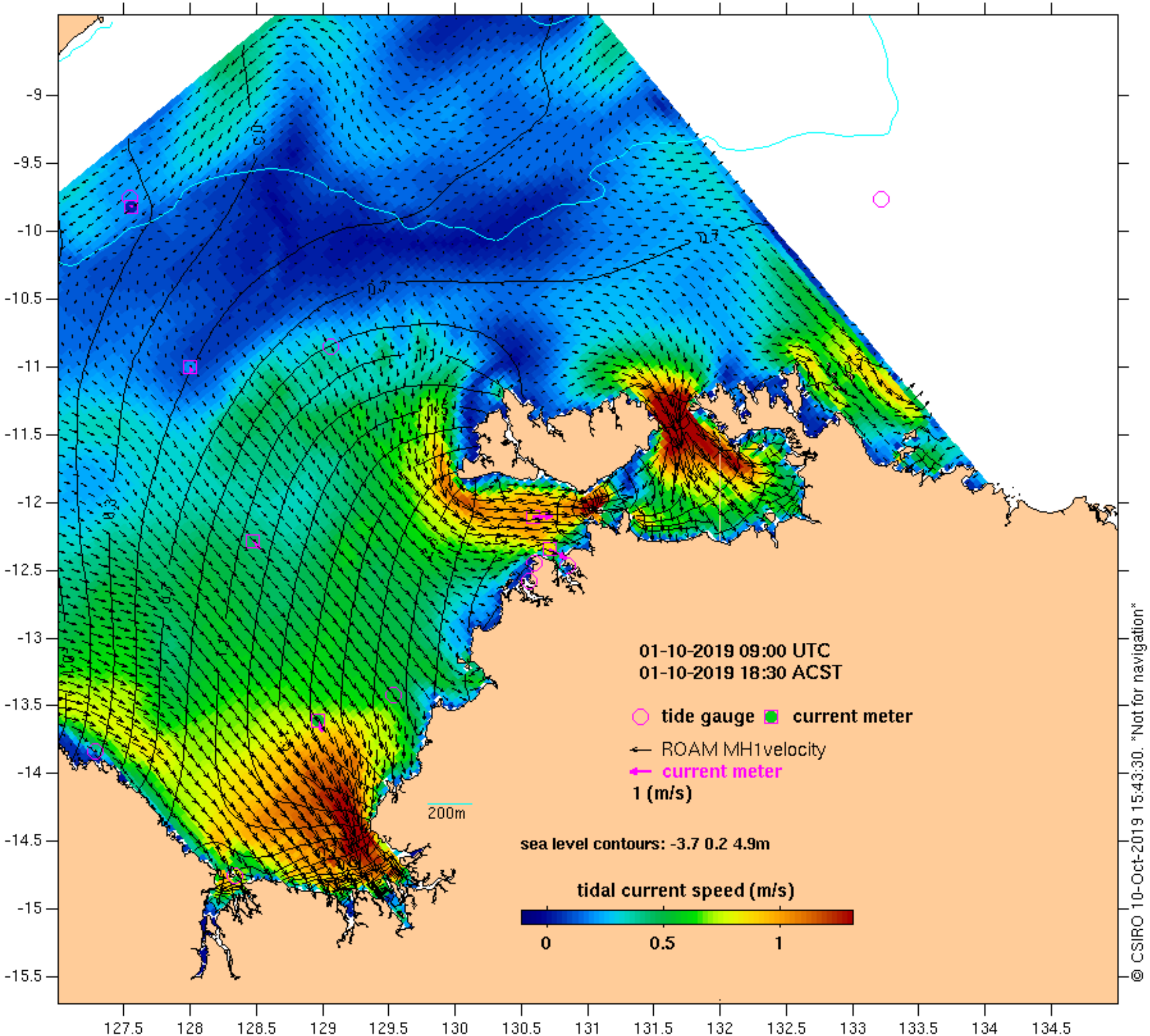

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current meter
ROAM MH1velocity
current meter
1 (m/s)
200m
sea level contours: -3.7 0.2 4.9m
tidal current speed (m/s)
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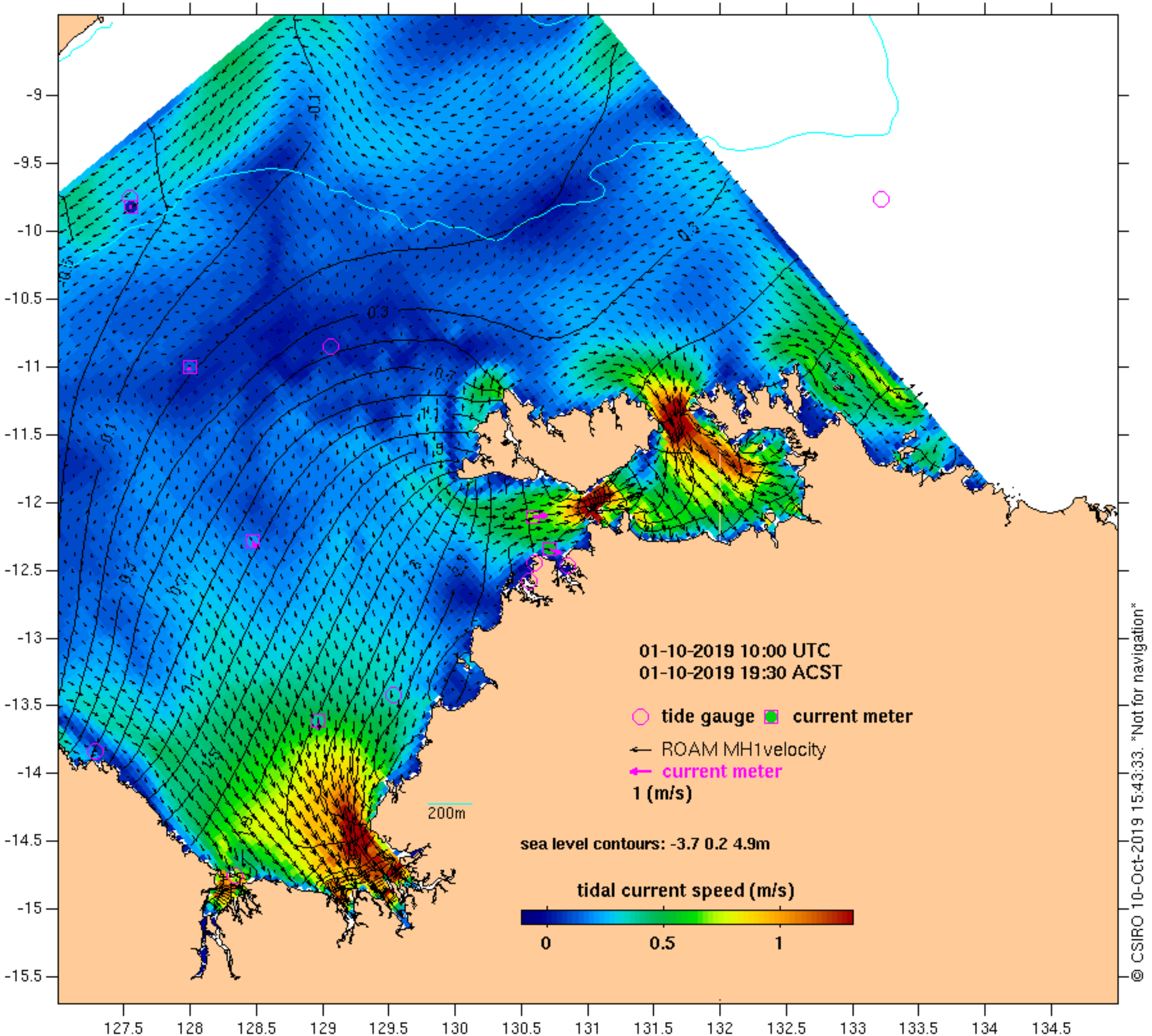

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01-10-2019 19:30 ACST
tide gauge
current meter
ROAM MH1velocity
current meter
1 (m/s)
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sea level contours: -3.7 0.2 4.9m
tidal current speed (m/s)
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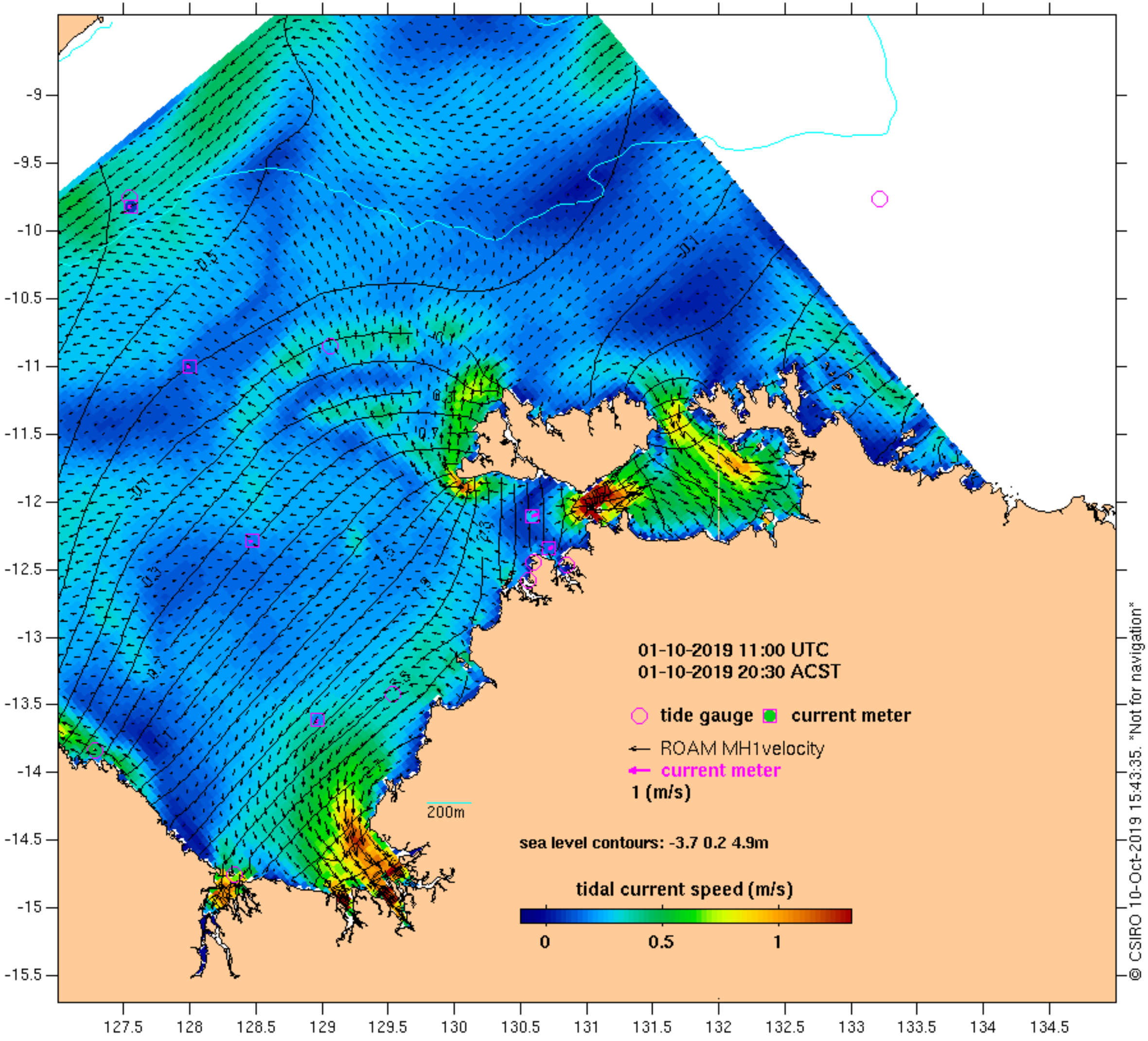
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01-10-2019 20:30 ACST
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current meter
ROAM MH1velocity
current meter
1 (m/s)
200m
sea level contours: -3.7 0.2 4.9m
tidal current speed (m/s)
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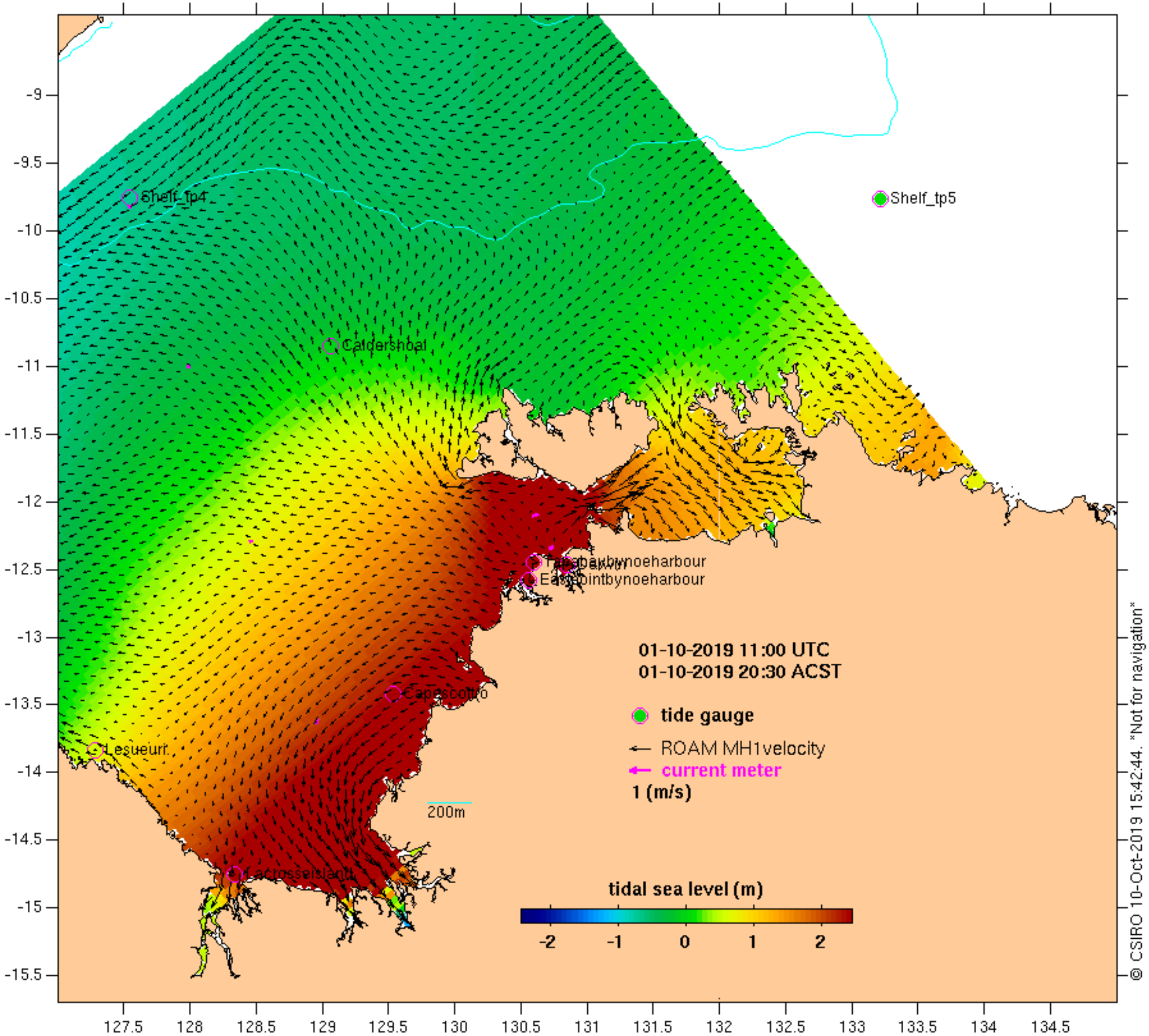

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tide gauge
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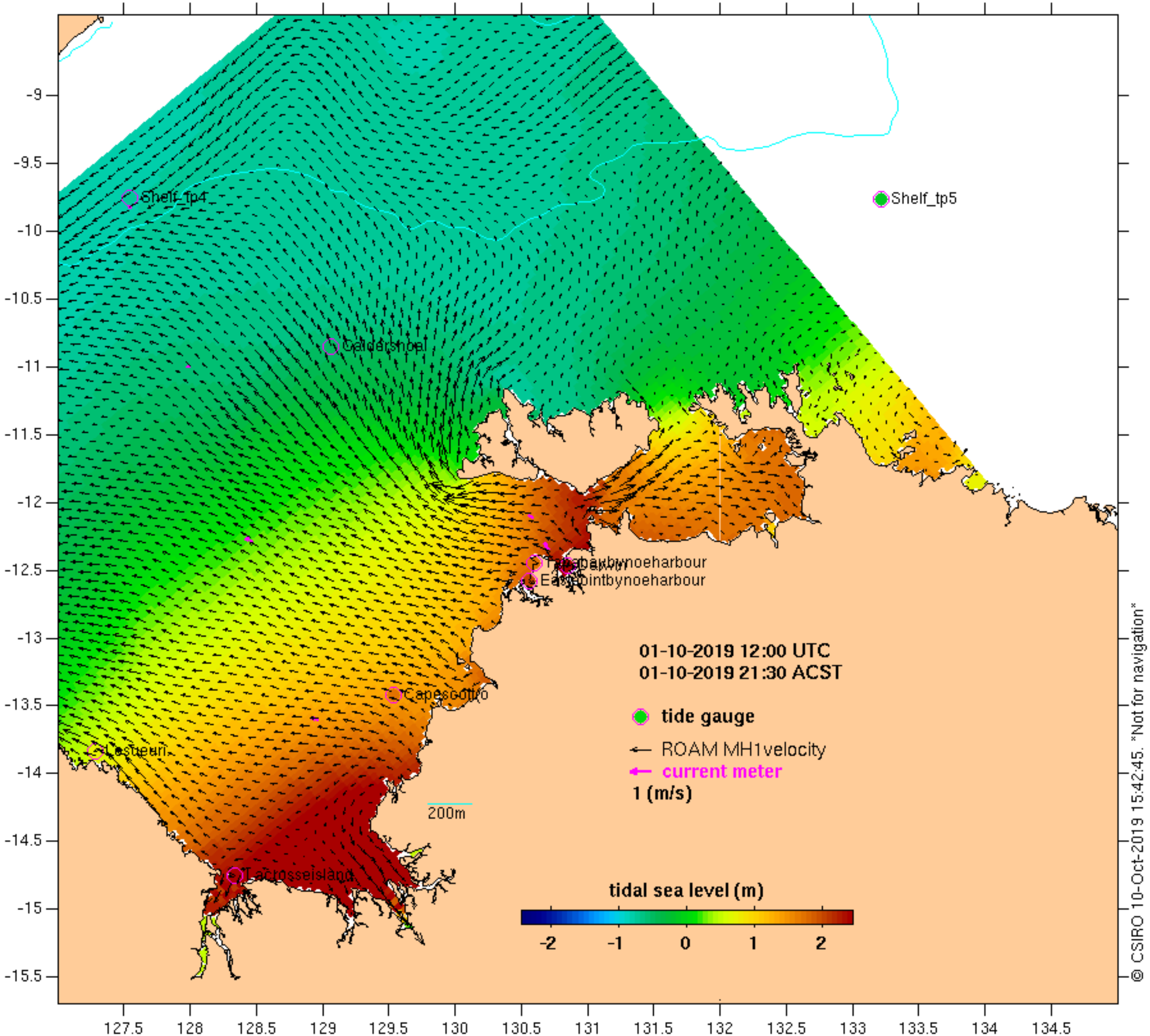

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Fatpointbynoeharbour
Darwin
Eastpointbynoeharbour
Capescott
Lesueur
Lacrosseisland
01-10-2019 12:00 UTC
01-10-2019 21:30 ACST
tide gauge
ROAM MH1velocity
current meter
1 (m/s)
200m
tidal sea level (m)
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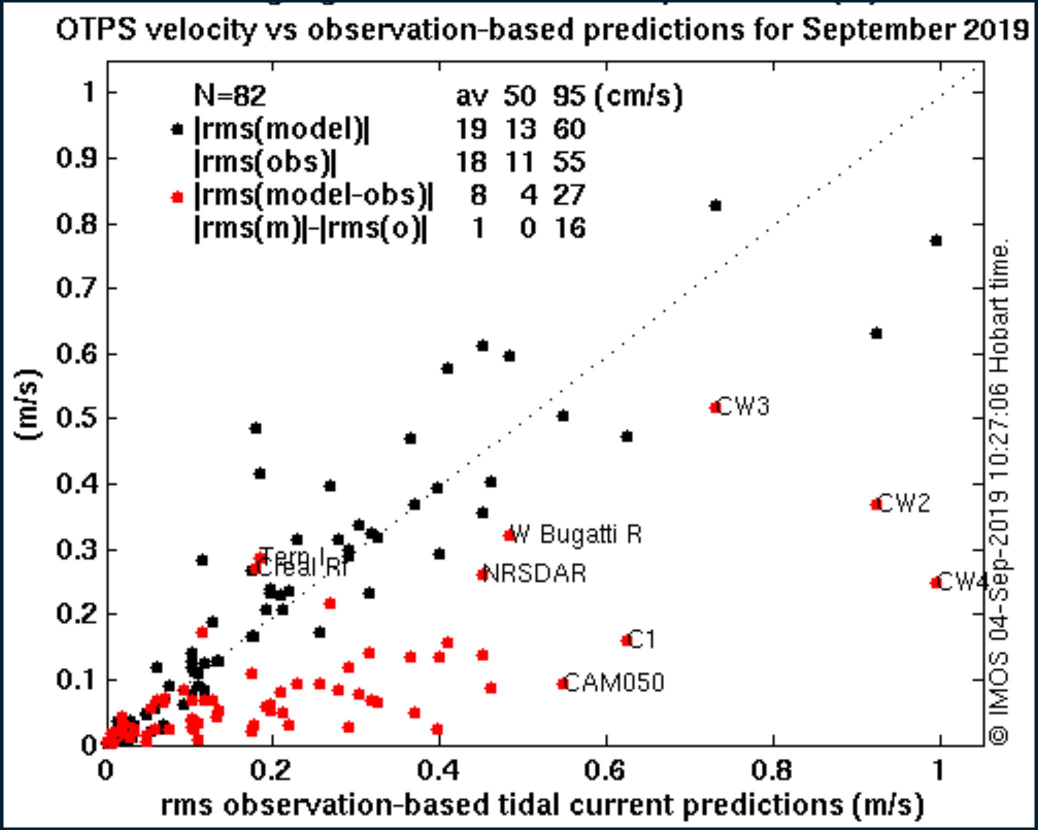

OTPS velocity vs observation-based predictions for September 2019
N=82 av 50 95 (cm/s)
|rms(model)| 19 13 60
|rms(obs)| 18 11 55
|rms(model-obs)| 8 4 27
|rms(m)|-|rms(o)| 1 0 16
(m/s)
rms observation-based tidal current predictions (m/s)
CW3
CW2
CW4
W Bugatti R
NRSDAR
C1
CAM050
© IMOS 04-Sep-2019 10:27:06 Hobart time.

Conclusions

- For those regions where tides are dominant, useful predictions of currents can be made as far ahead as you like.
- (not shown, but trust me) The next most predictable thing is the response to wind, e.g. flooding in Adelaide. This is also predictable. But so are the energetic inertial oscillations.
- The challenges: internal tides (NW especially, but elsewhere too) and eddies/boundary currents.

Thank you

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David Griffin

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David.Griffin@csiro.au

Bluelink

Ocean Forecasting

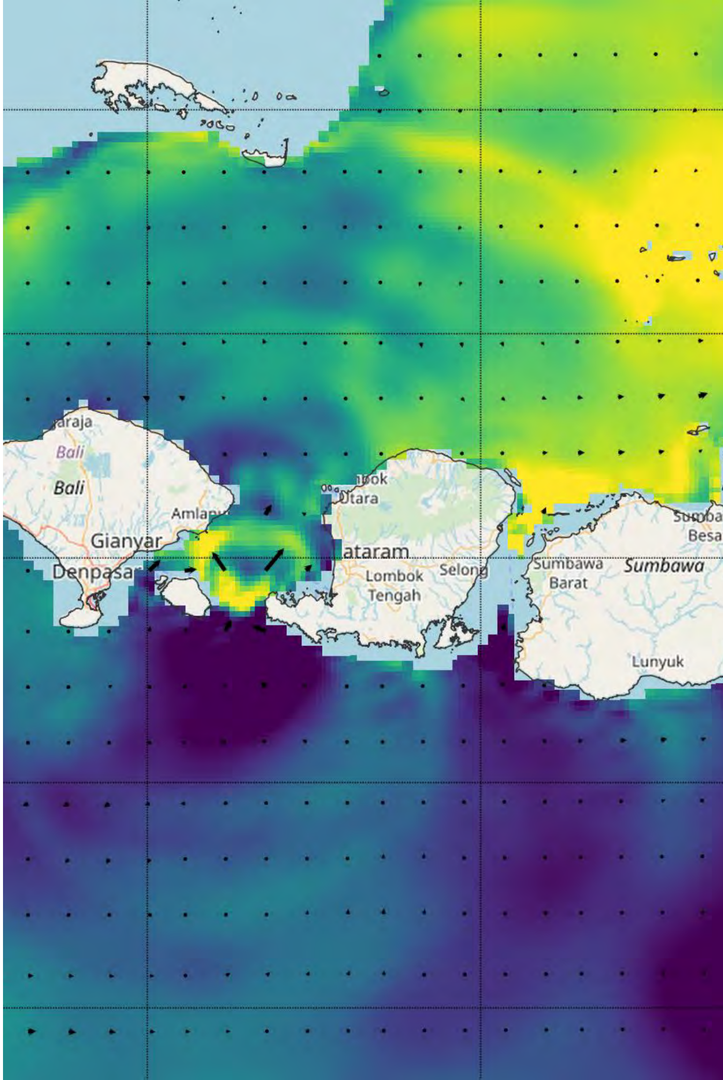
At

Regional & Littoral Scales

Edward King | 16/10/2019

For:

- Emlyn Jones & Uwe Rosebrock, and
- Ron Hoeke, Paul Branson & Stephanie Contardo

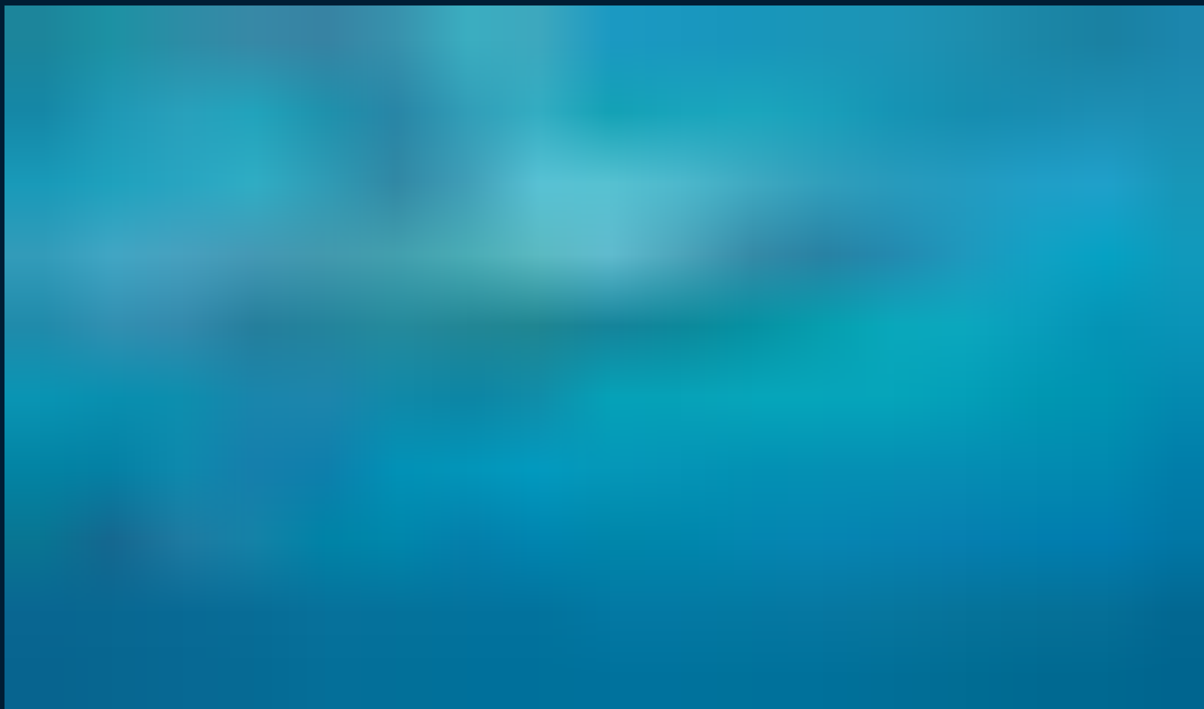


How much information do you need to manage risk?

Imagine you are diving and this is the only piece of information you have to decide if it is safe.

How much information do you need to manage risk?

What about now?



How much information do you need to manage risk?

What about now?

How much information do you need to manage risk?

… or now?

WHY?

- In coastal regions and complex shallow bathymetry global models lack spatio-temporal resolution and key processes.

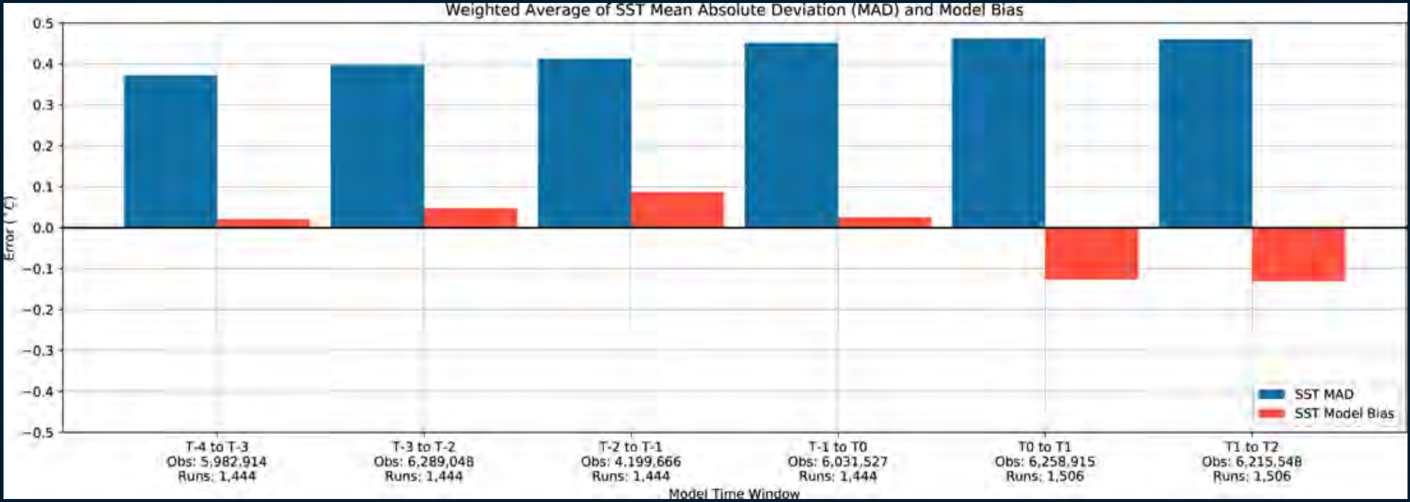
HOW?

- Within Bluelink, a user driven workflow allows non-experts to setup and run high resolution ocean, wave and atmospheric models. This set of tools is the Relocatable Ocean Atmosphere Model (ROAM), based on the Bluelink Modelling Framework (BMF).

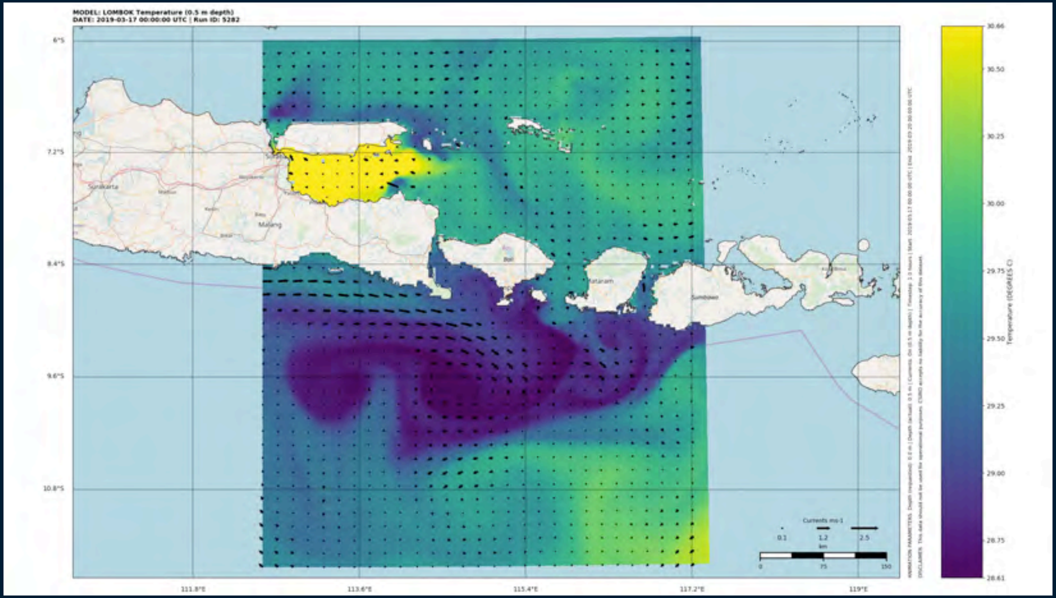
SO WHAT?

- Safe maritime operations require timely and accurate predictions of the current and future state.
    - Decision makers need to have confidence in the model predictions, therefore the models require thorough assessment to determine if they are fit for purpose.
    - As an example, the ROAM-Ocean system has been assessed against IMOS obs (Next slide) in many diverse domains (e.g. ITF region), and has data assimilation capabilities.

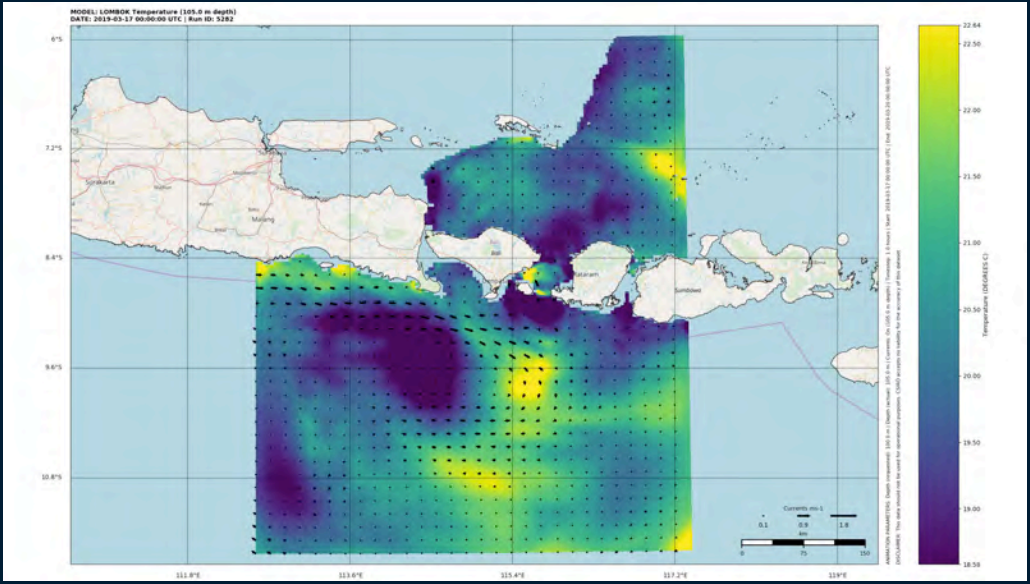
ROAM-Ocean: SST forecast error growth



ROAM-Ocean: Indonesian throughflow
1. T at Surface

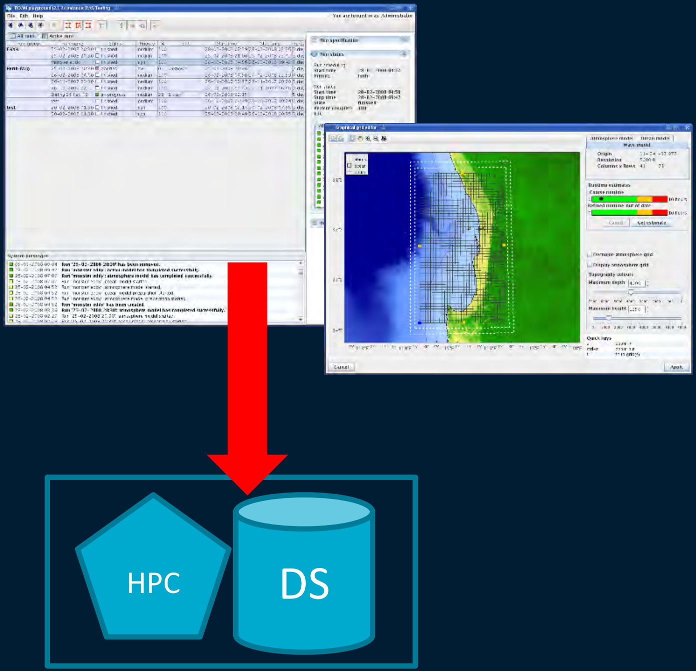


ROAM-Ocean: Indonesian throughflow
2. T at 100m



Bluelink Modelling Framework 1

- *2003 - ‘What if we could allow a non-expert user to reliably run small-scale ocean and atmosphere models’*
- *Originally conceived as desktop client for remote (and dedicated) HPC*

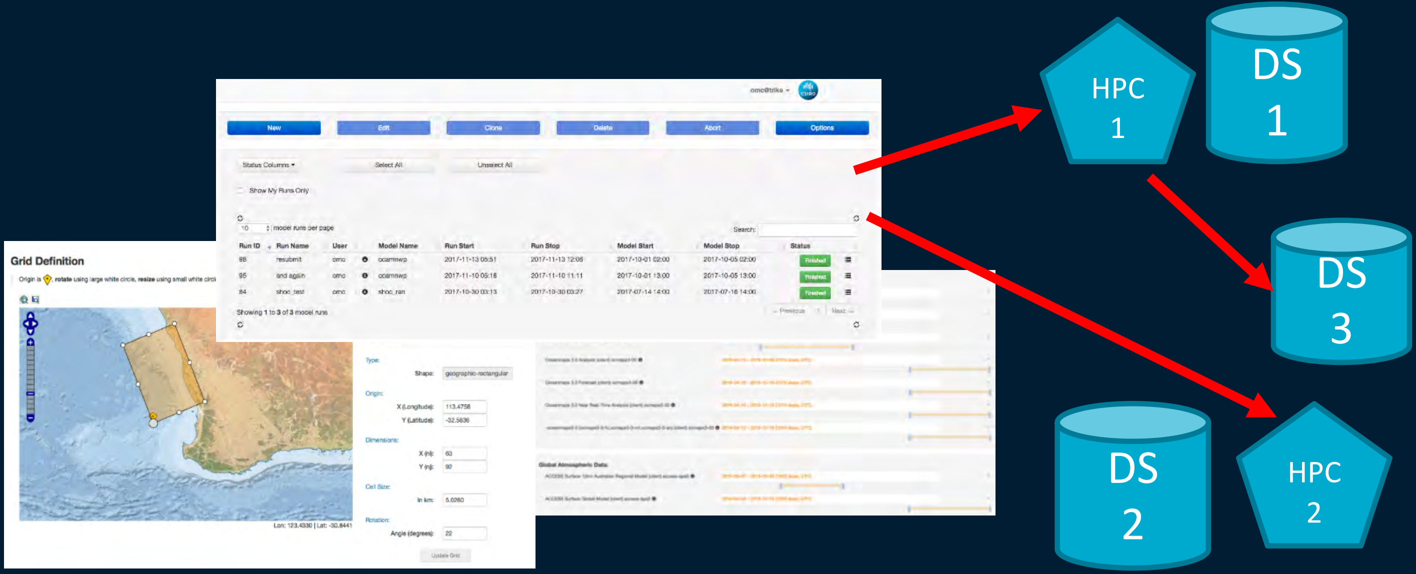


Supports:

- SHOC (Sparse Hydro Ocean Code), CSIRO
- COMPAS (Coastal Ocean Marine Prediction Across Scales , unstructured grids), CSIRO
- CCAM (Cubic Conformal Atmospheric Model), CSIRO
- SWAN wave mode, Deltares
- XBEACH littoral zone model, Deltares
- & several others (now obsolete)

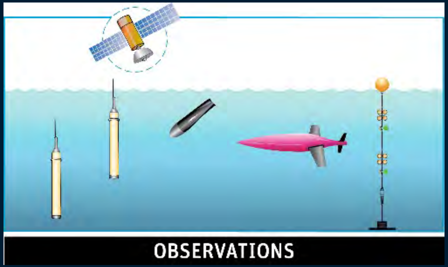
Bluelink Modelling Framework 2

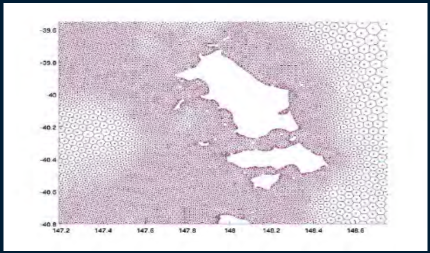
- *2016 - a web-based client including extended data selection and custom parameterisations*
- *Enables a more modular, distributed back-end for HPC and data management*
- *More resilient, robust, flexible and extensible*



BMF Strategic Development

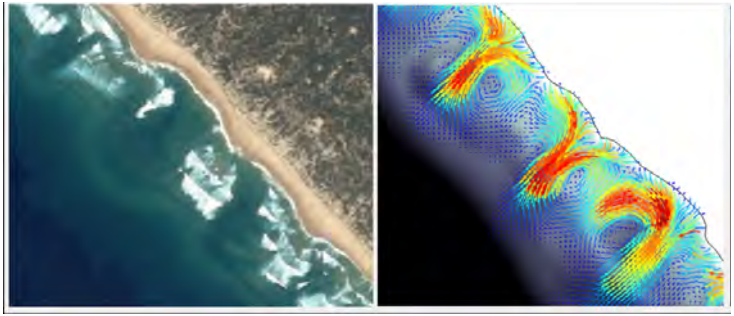
- Will be user-driven by client and scientific needs
- Data flows
  - Tighter and more seamless coupling between component models
  - New data streams for assimilation (Himawari-8 and SWOT)
- Underlying models
  - Taking advantage of new modelling technologies (e.g. unstructured grids – COMPAS and SWAN)
  - Compute architecture changes
- Ongoing deployment of field-based modelling capability
  - You don't always have access to HPC infrastructure when in the field, but still need to make informed decisions.
- Data assimilation and automated model assessments
  - Ongoing refinement of the DA methods to take advantage of observing system upgrades and new observational products.
  - Real-time and automated assessment of model skill to alert decision makers if/when degraded performance is apparent.





Bluelink Littoral: High-resolution wave and littoral dynamics prediction:

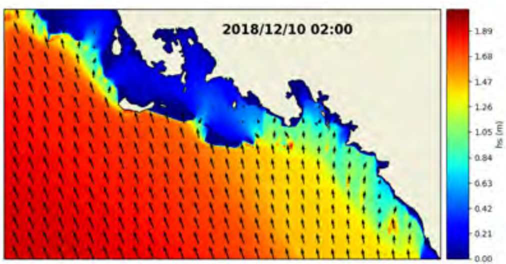
support for RAN and related research activities.



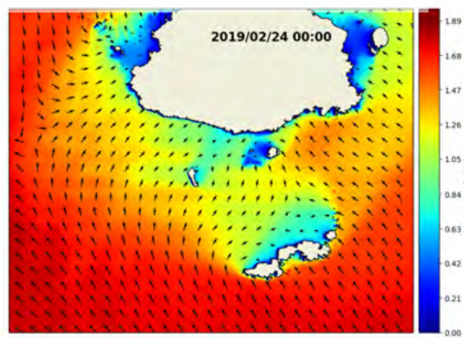
Example simulated rip-current dynamics, Gunnamatta Beach, Victoria

*On demand/quasi-operational (mostly on NCI and/or CSIRO HPC)

Support for the 2019 Asia-Pacific Economic Cooperation(APEC) Summit: Port Moresby

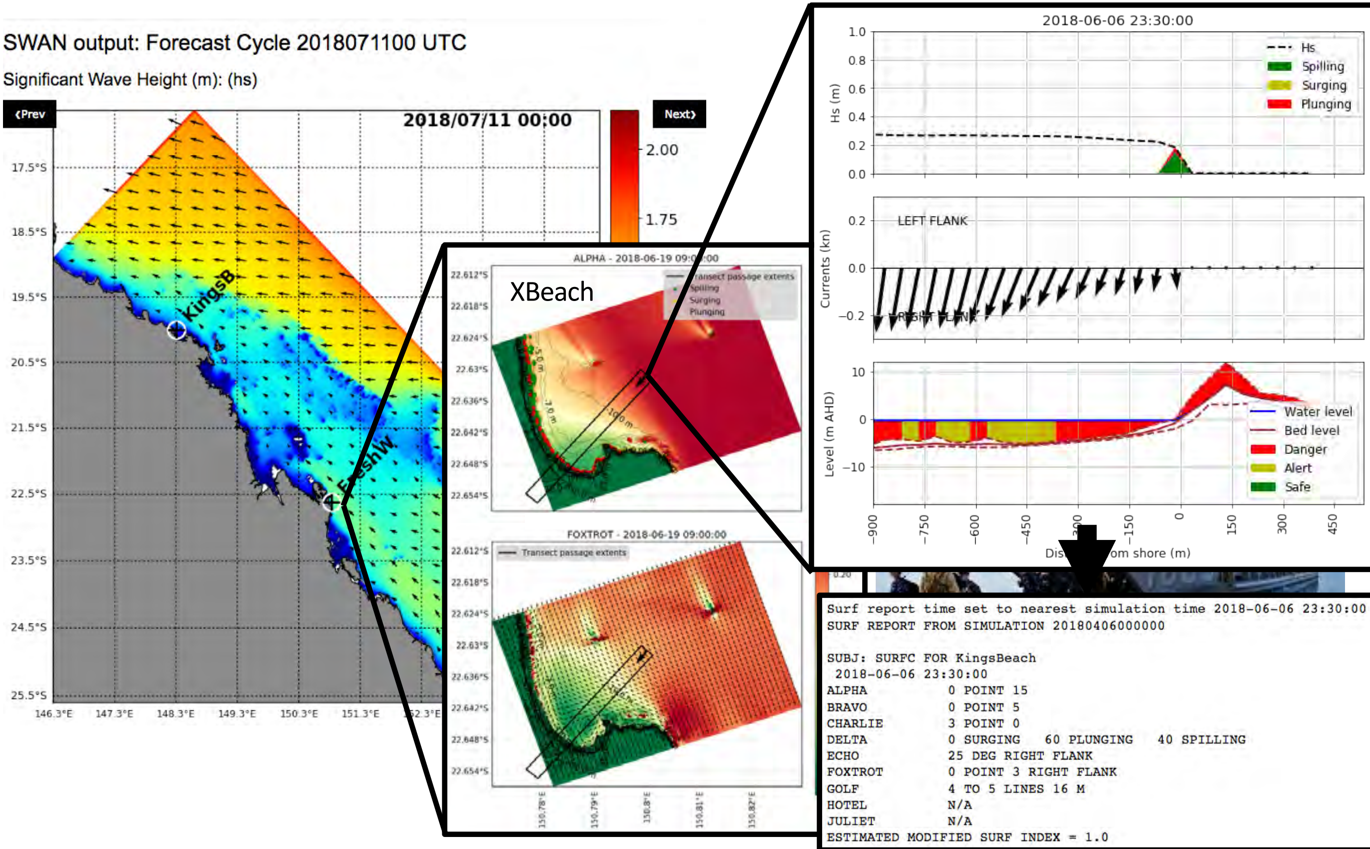


Research into forecast skill with reconstructed wave spectra On-going southern Fiji



Bluelink Littoral: Development of tactical decision making tools:

Sea-Series Exercises 2018



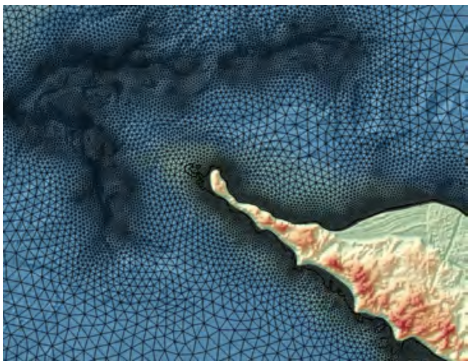
ROAM - Littoral Zone

Bluelink Littoral: Future work: incorporation of:

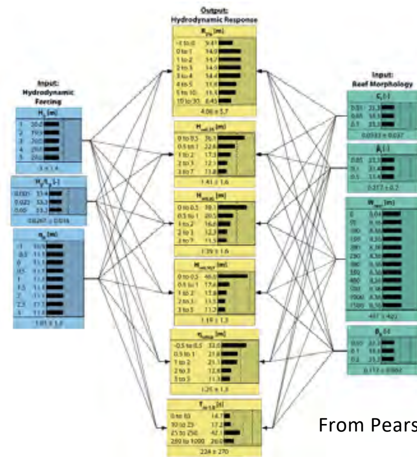
New sensing platforms*



Unstructured mesh-modelling*



Machine-learning/meta-modelling*



From Pearson, et al. 2017

***In collaboration with academic and commercial partners**

Thank you

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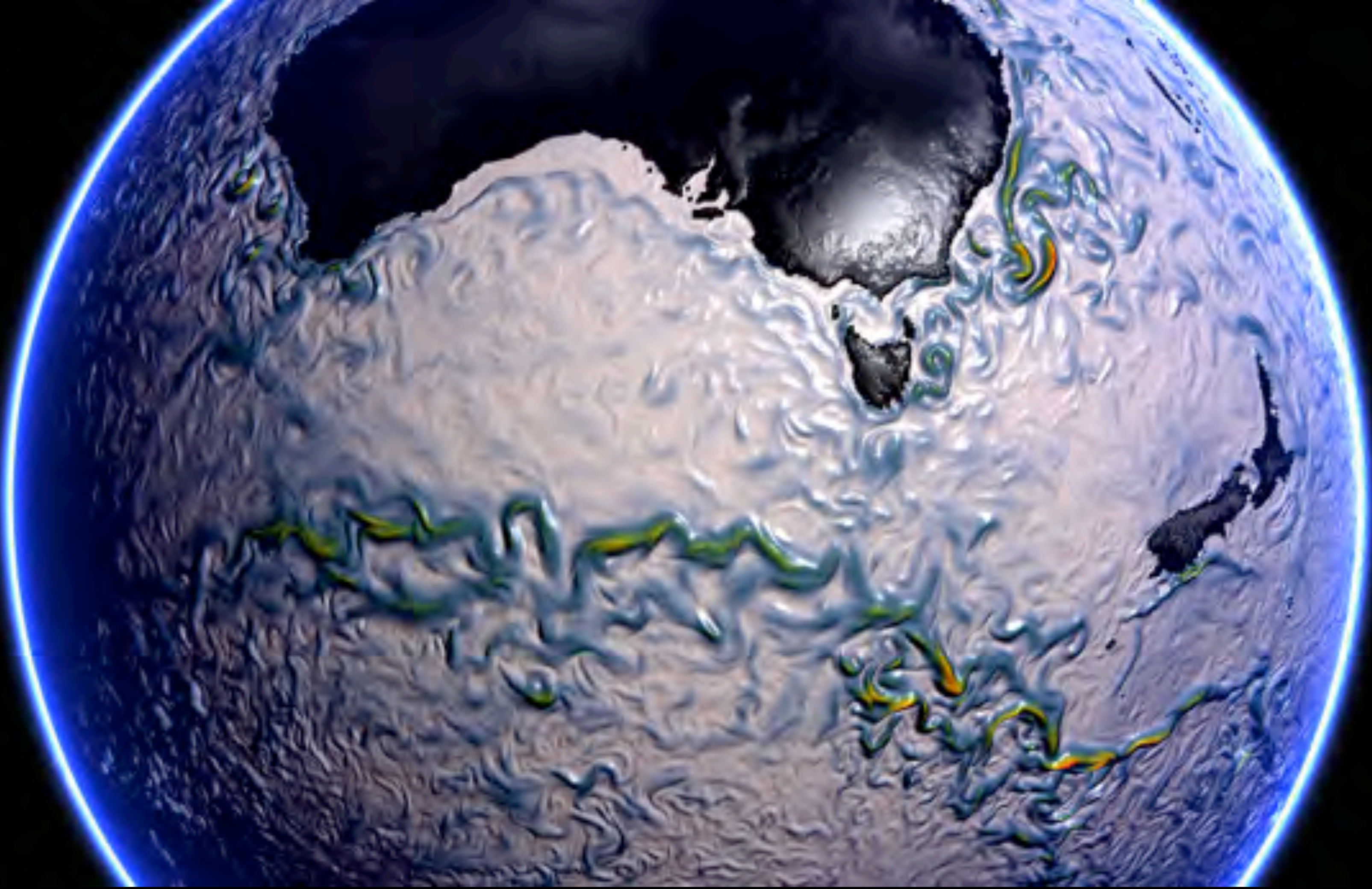
Regional Forecasting: Emlyn.Jones@csiro.au

Littoral Forecasting: Ron.Hoeke@csiro.au

Bluelink
Ocean Forecasting

CSIRO NAVY Australian Government Bureau of Meteorology



Operational ocean forecasting @ BoM

operational since 2007

Brassington, Entel, Zhong, Sakov, Divakaran, Beggs, Huang, Sweeney, Velic, Freeman, Beckett

Bluelink Ocean Forecasting

Australian Government Bureau of Meteorology

CSIRO

NAVY

Australian National University

IMOS

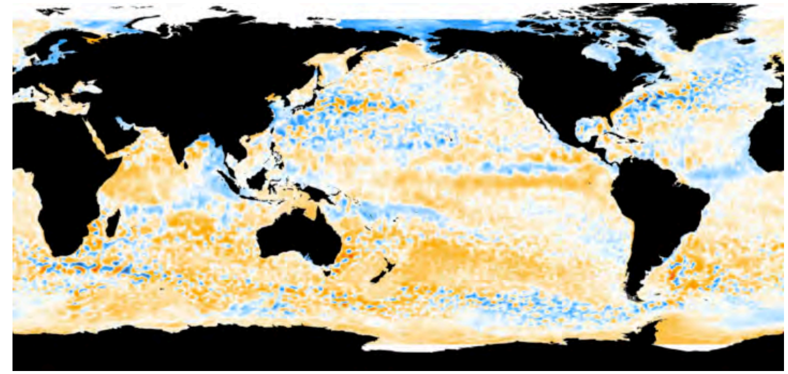
Overview

Global ocean forecasting system status

see talk Sweeney AMOS-2019

see poster Brassington OceanPredict’19

see talk Divakaran, Bluelink science workshop

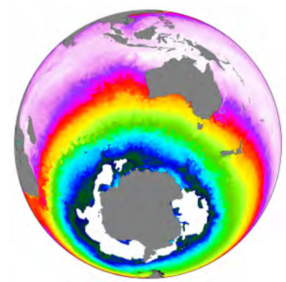


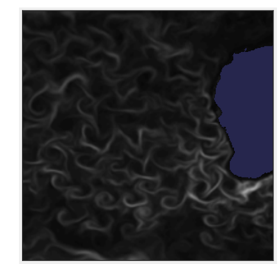
Next generation global ocean forecasting

see talk Sakov, Bluelink science workshop

see talk Kiss, AMOS-2019

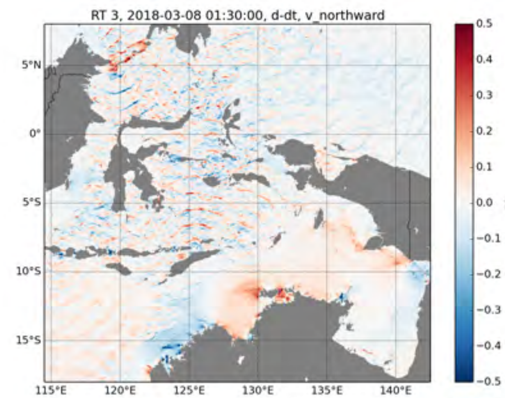
see talk Brassington, OceanPredict’19

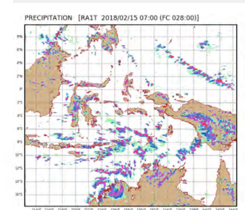


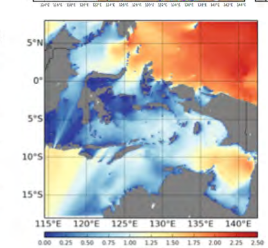


Next generation regional ocean forecasting

see talk Brassington AMOS-2019







Ocean Model Analysis and Prediction System
OceanMAPS version 3.2

Ocean Model
MOM 5
z* vertical coordinate
Smith and Sandwell, v11.1
$3599 \times 1499 \times 51$

0-360, 75S-75N ($0.1° \times 0.1°$)
0-15 m (Δz = 5 m)
15-90 m (Δz~5 to 10 m)
90-200m (Δz=10 m)
Minimum column depth – 15 m

GOTM, K-eps mixed layer scheme
No tides
No sea-ice

Data Assimilation
ENKF-C (Sakov, 2014)
Ensemble optimal interpolation
State vector (eta, T, S, u, v)
144-member ensemble
Restart initialisation

Observations
Satellite altimetry (Jason3, Sentinel3A, Cryosat2, AltiKa)
Satellite SST (Metop-A, Metop-B, VIIRS, AVHRR, AMSR2)
In situ profiles Argo, CTD, XBT

Forcing
ACCESS-G APS2 (fluxes)
Climatological river discharge

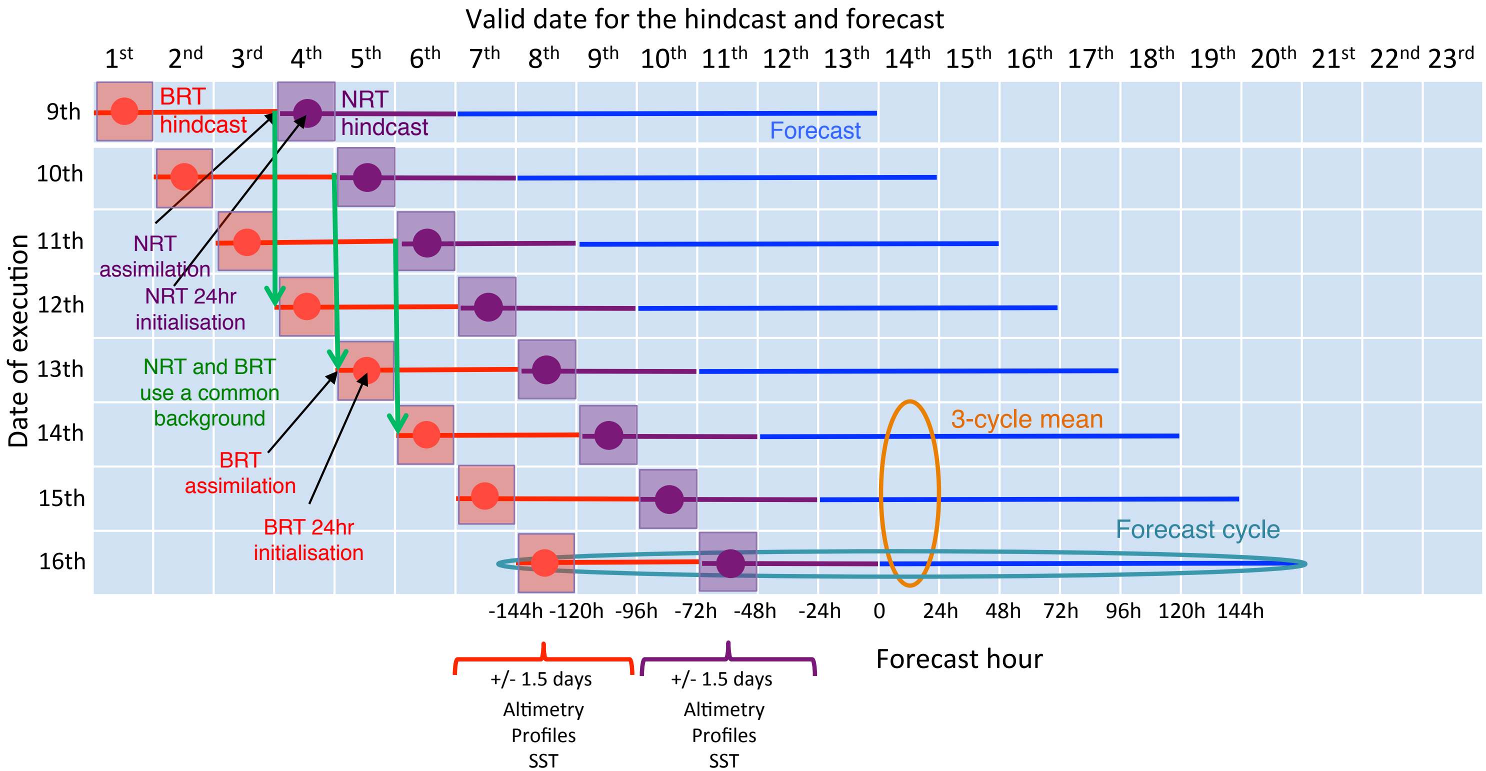
Bluelink Ocean Forecasting

Australian Government
Bureau of Meteorology

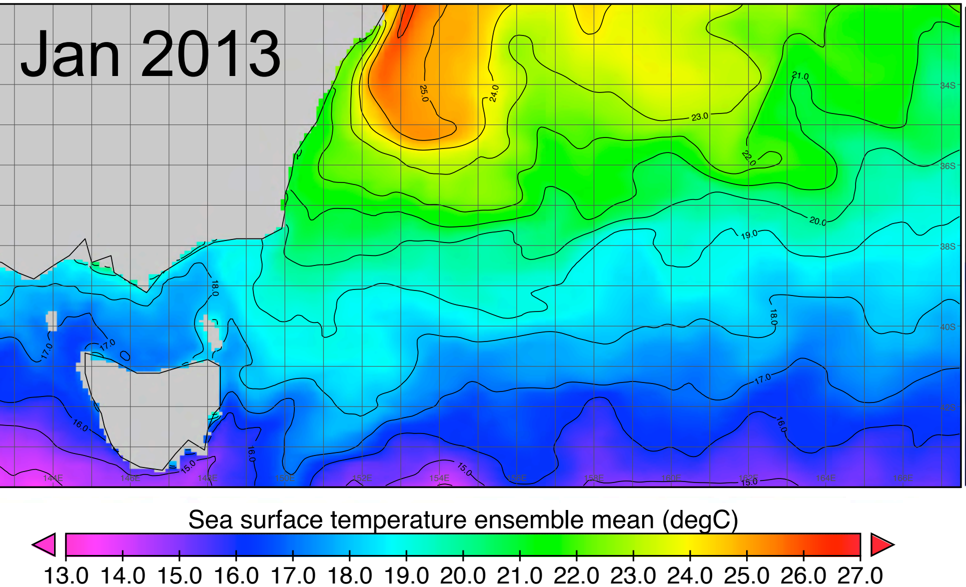
CSIRO

NAVY

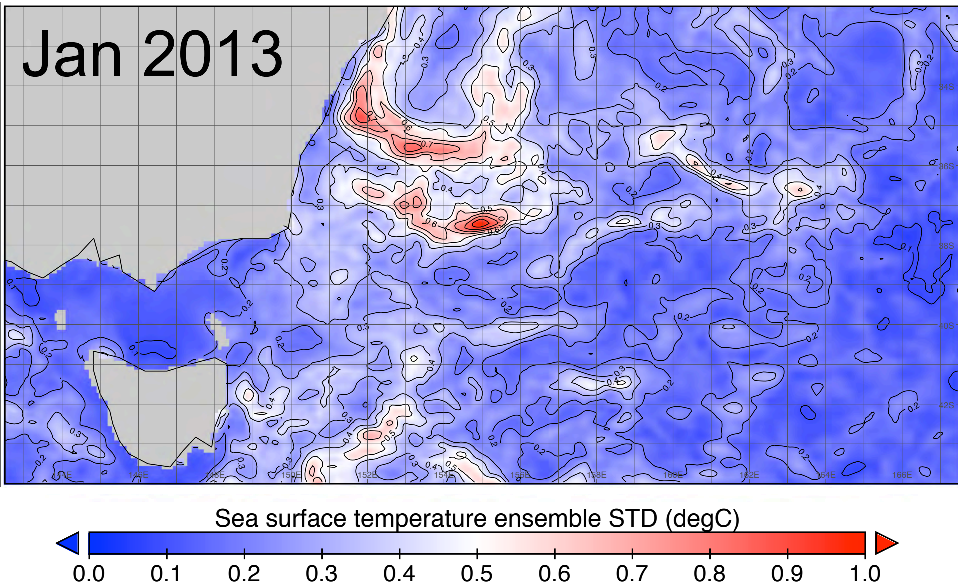
Thanks also to GFDL, the global ocean observing system, IMOS and JCOMM



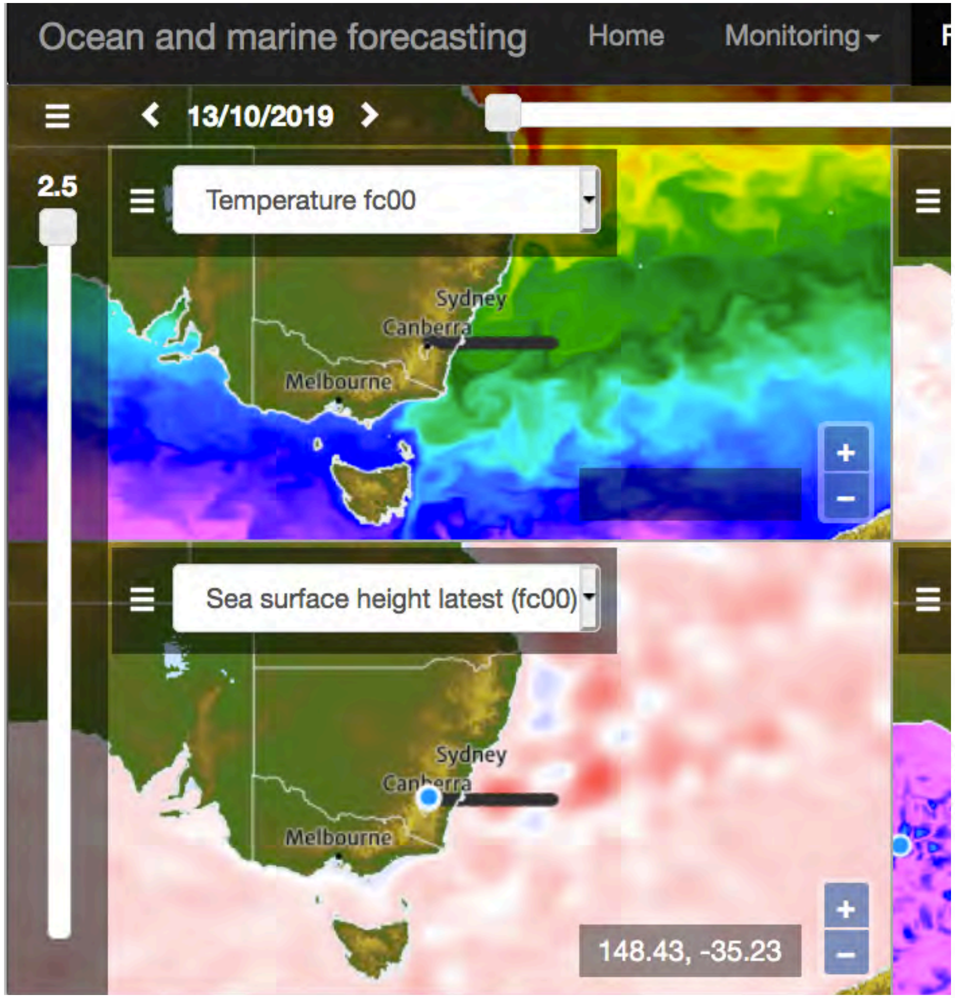
SST monthly average ensemble mean

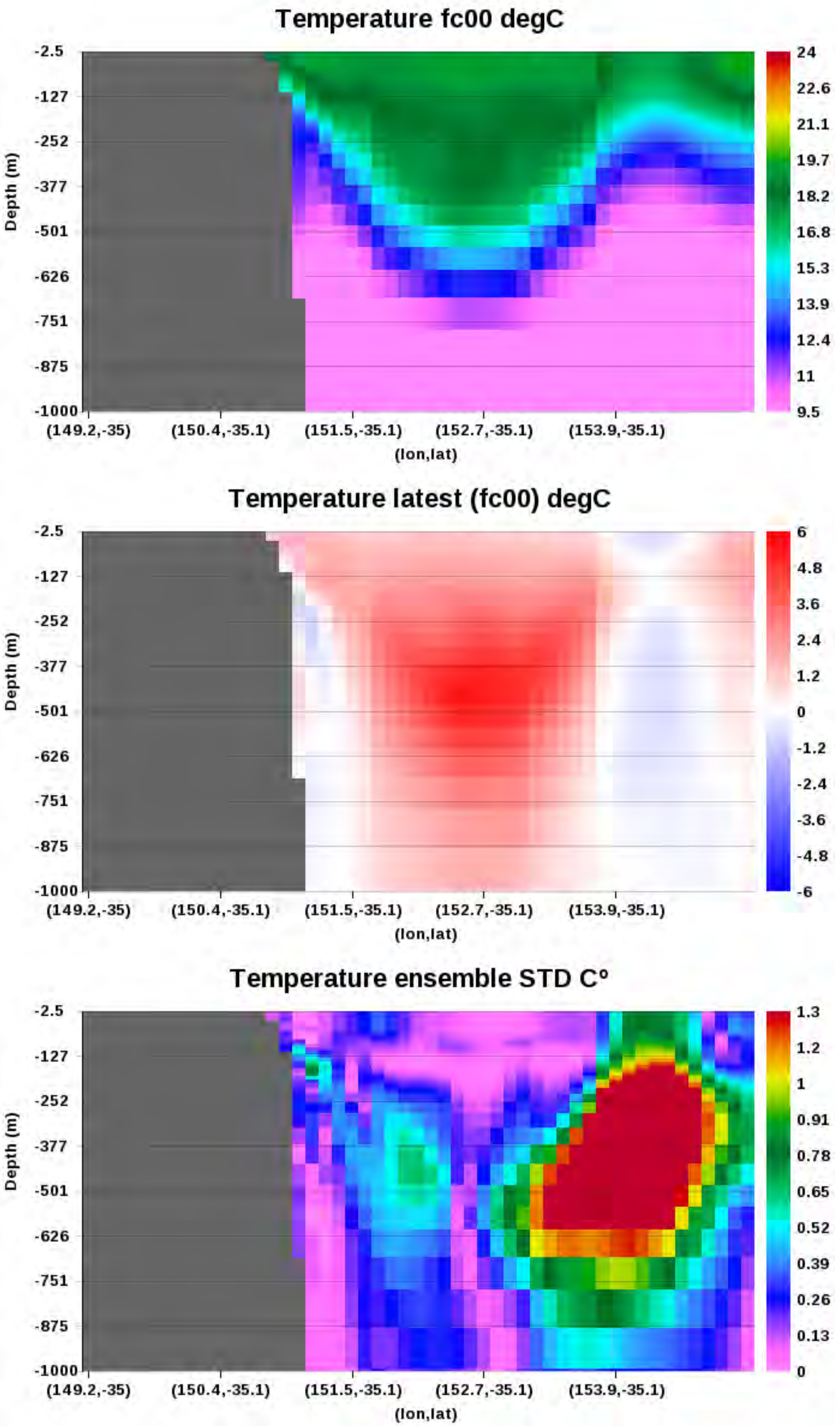


SST monthly average ensemble STD



Web-services





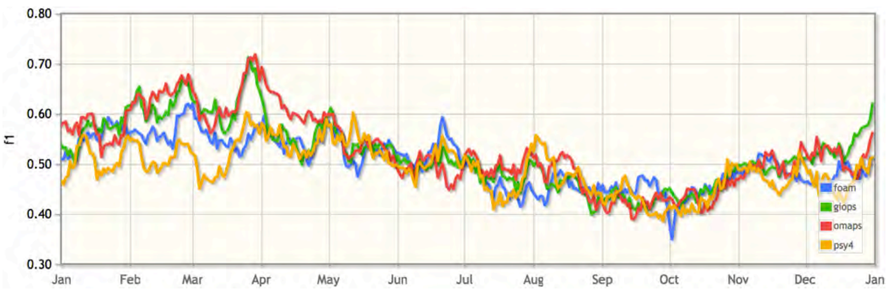
Intercomparison – Argo (2018)

Day 1 forecast

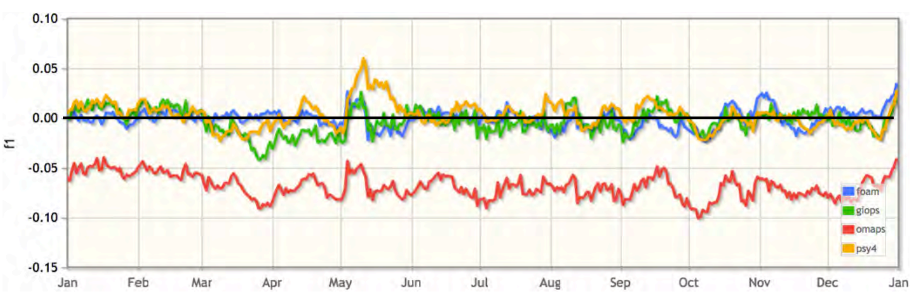
Mean Absolute Difference

Mean Difference

Temperature



Salinity



Australia UK France Canada

Australian region

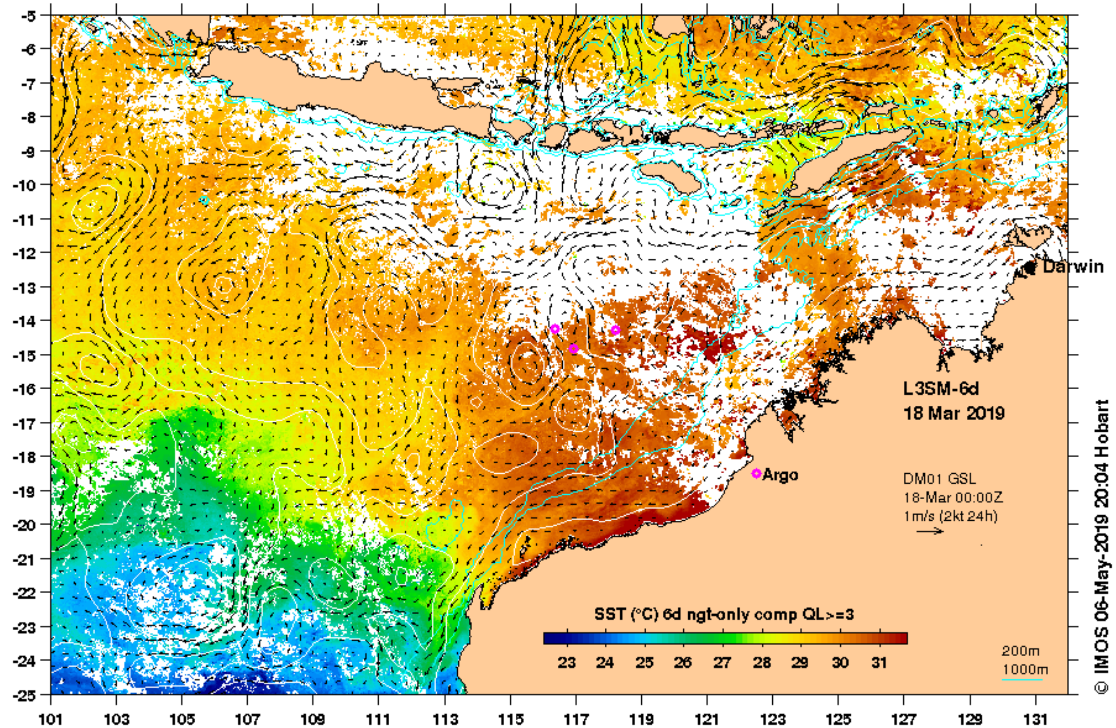
Global baseline performance

Temperature comparable MD/MAD

Salinity outlier in MD

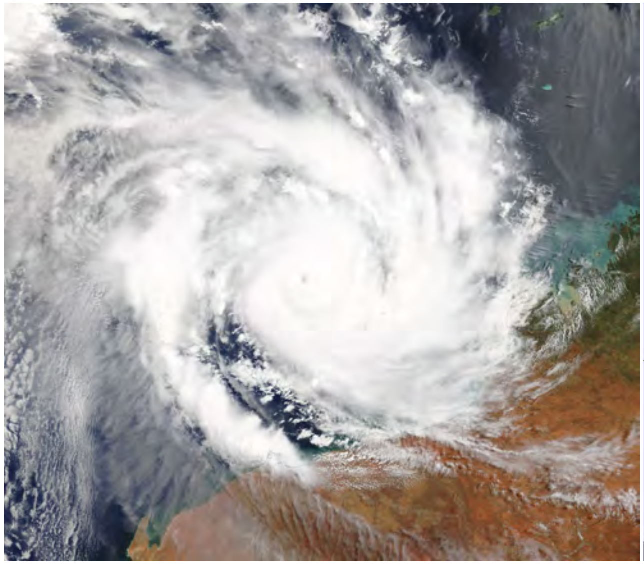
CASE STUDY 3

TC
cold-core
eddy



- Hot water everywhere 18th March 2019

- Along comes TC Veronica …



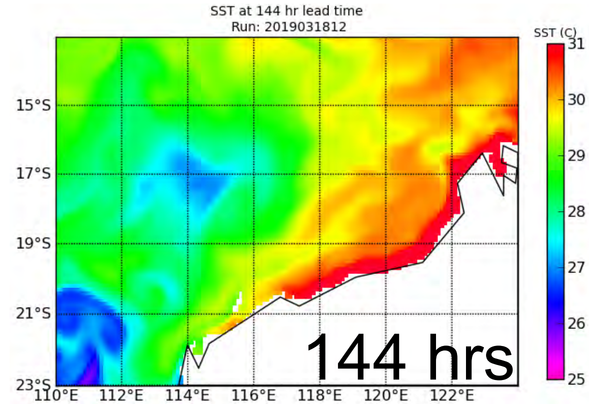
EarthData NASA

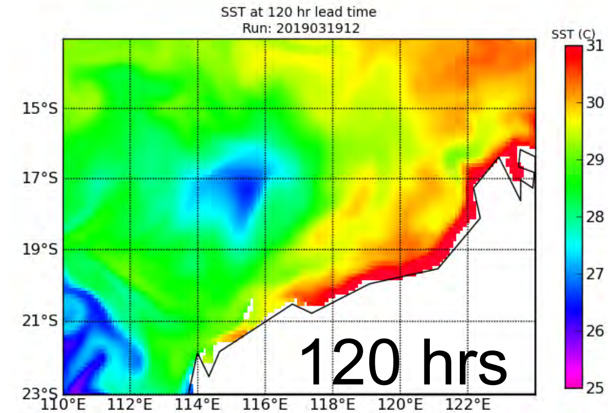
see Sweeney, AMOS 2019 talk

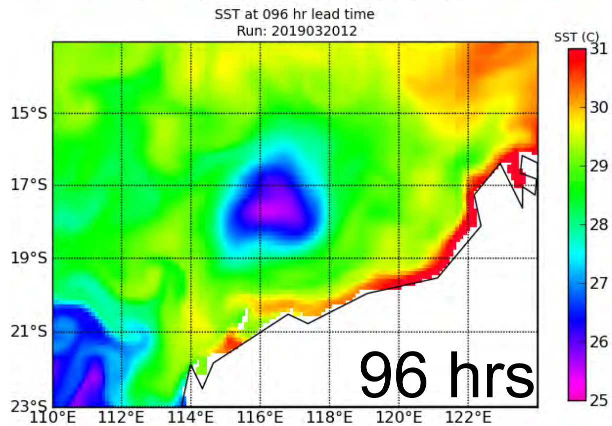
Was it forecasted?

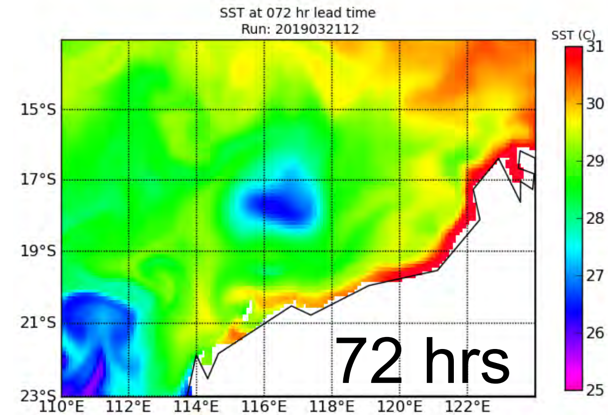
TC
cold-core
eddy

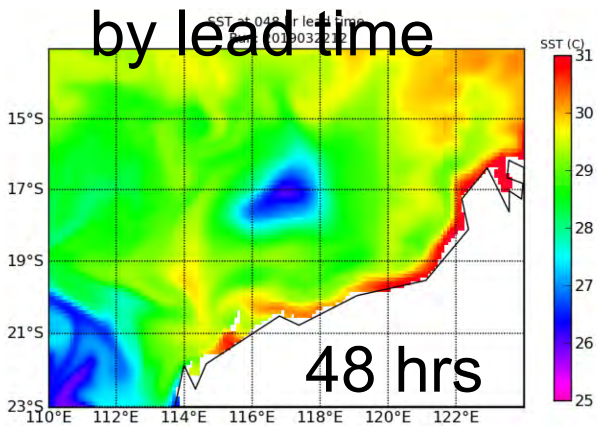
Forecasts for 24^{th} March 2019 by lead time

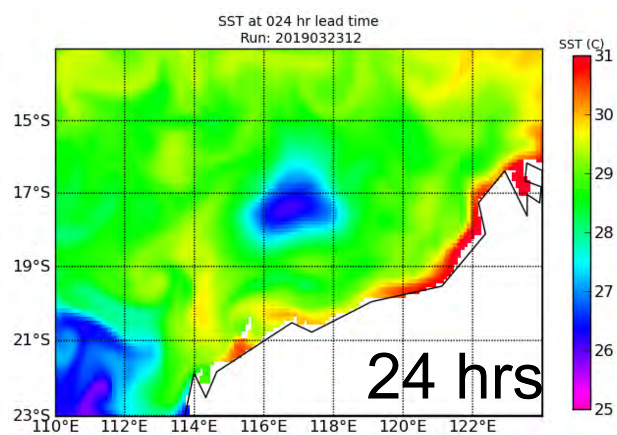


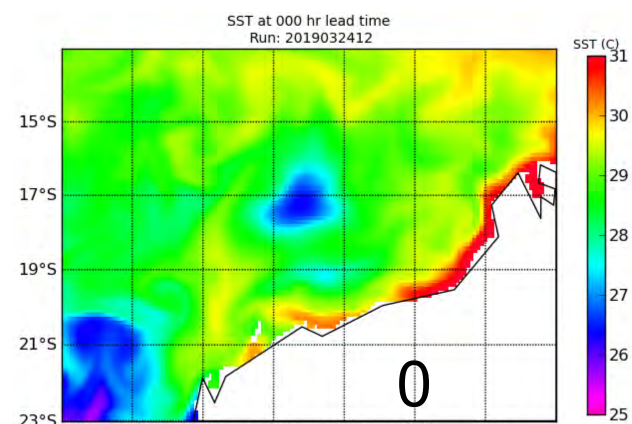








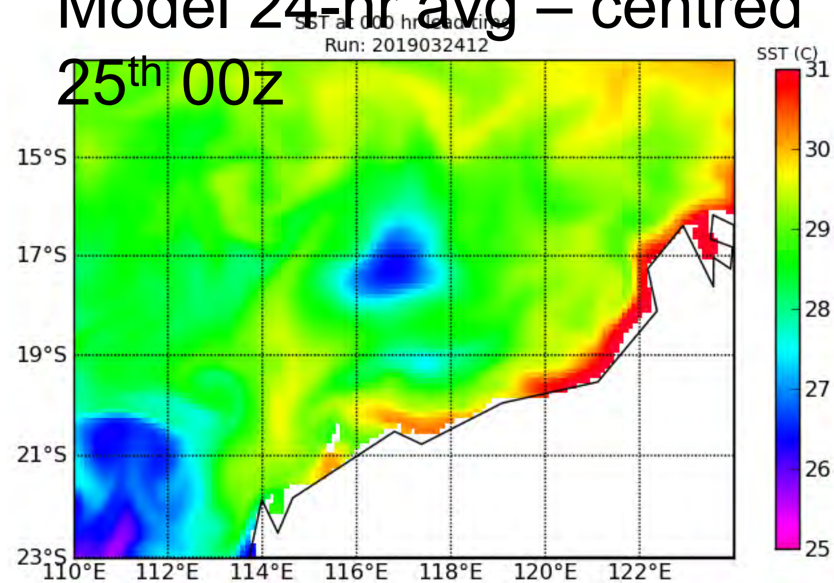




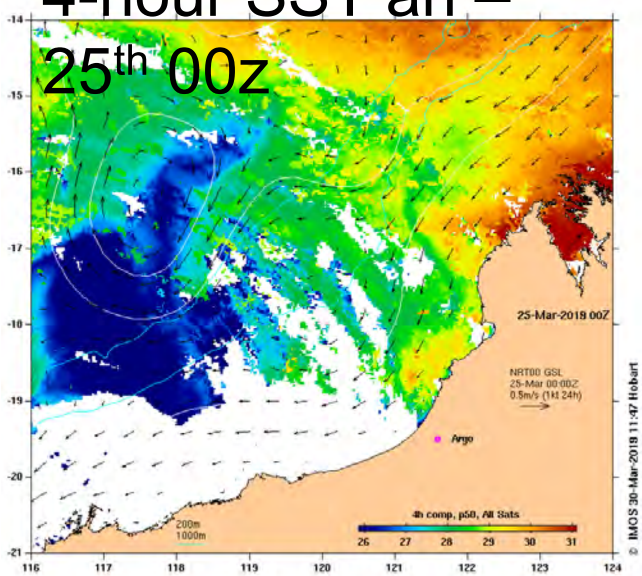
The cloud cleared on the 24th …

TC
cold-core
eddy

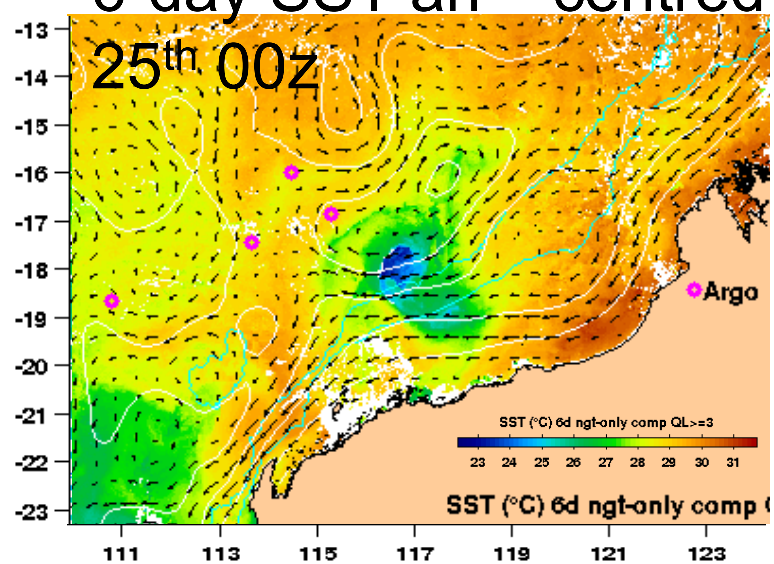
Model 24-hr avg – centred 25th 00z



4-hour SST an – 25th 00z



6-day SST an – centred 25th 00z

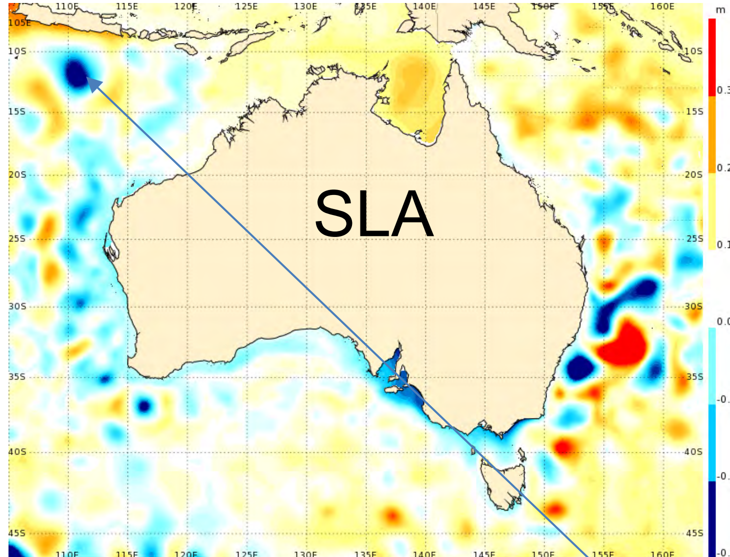


IMOS Ocean Current

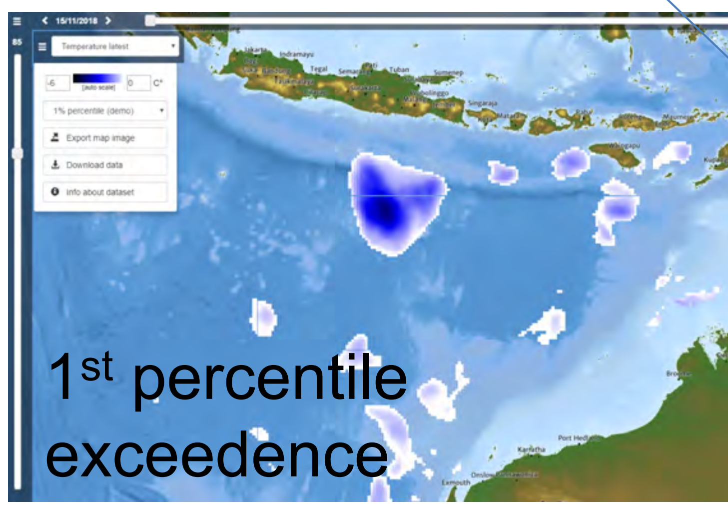
CASE STUDY 4

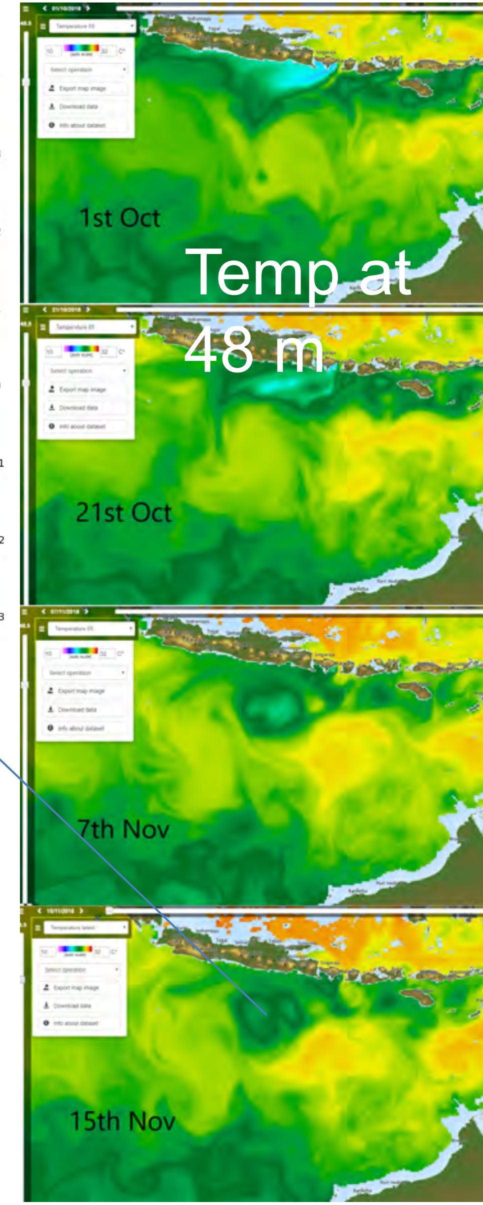
Unusual cold-core eddy

- Extreme cold eddy south of Java
- Temps over 6 deg cooler than 1^{st} percentile



Sea Level Anomaly (m): 24hr Average centred on **Mon 19 Nov 2018** 00UTC
Model Base Time: Sun 18 Nov 2018 12UTC
(c) Copyright Australian Bureau of Meteorology | **OceanMAPS**

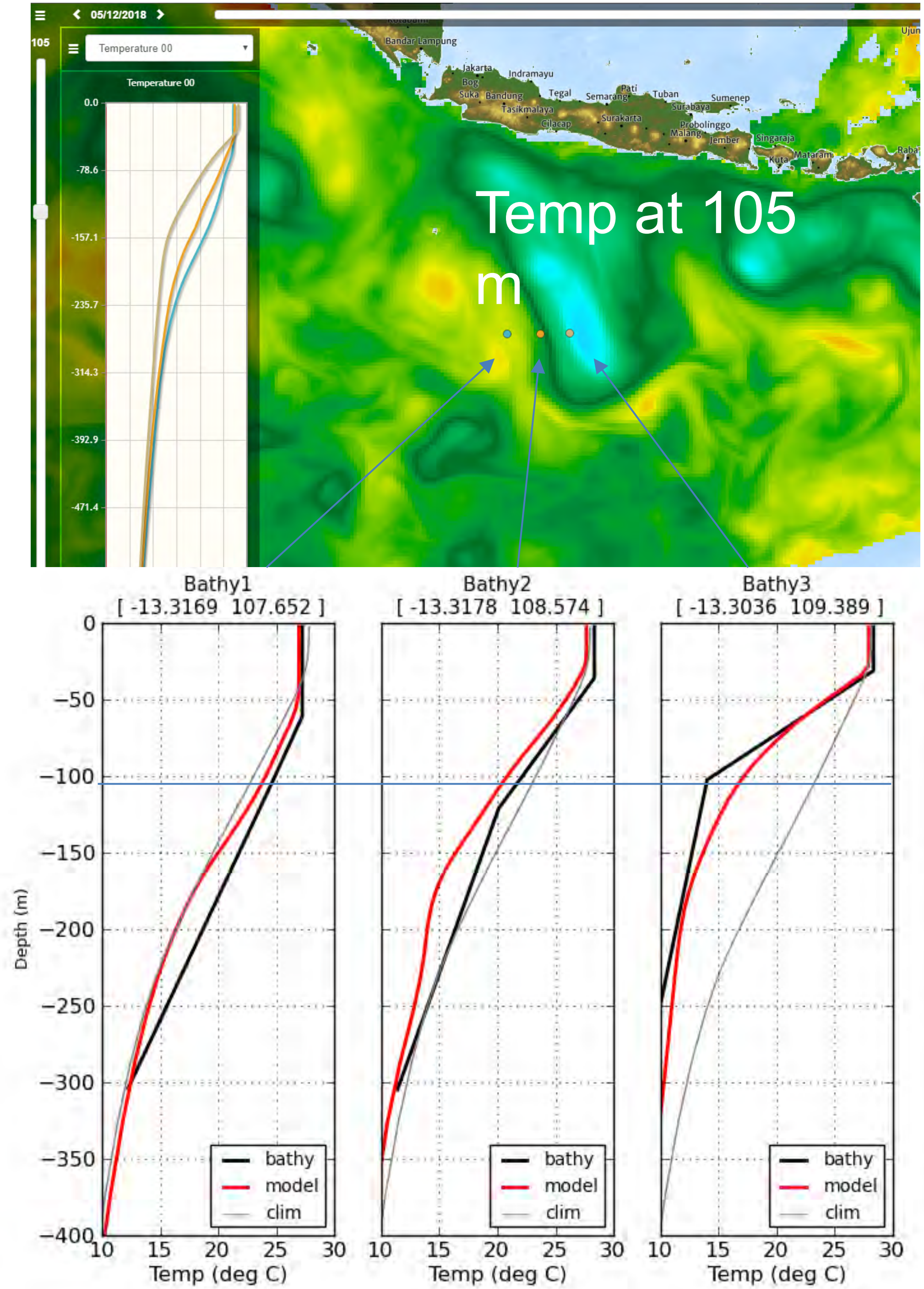




Comparison with XBTs

Unusual cold-core eddy

RAN dropped XBTs
5^{th} Dec 2018



Ocean Model Analysis and Prediction System
OceanMAPS version 3.3 – TARGET 2018

Ocean Model
MOM 5.1
z* vertical coordinate
Smith and Sandwell, v11.1
3599 × 1499 × 50

0-360, 75S-75N (0.1° × 0.1°)
0-15 m (Δz = 5 m)
15-90 m (Δz~5 to 10 m)
90-200m (Δz=10 m)
Minimum column depth – 15 m

GOTM, K-eps
No tides
No sea-ice

Data Assimilation
ENKF-C (Sakov, 2014)
Ensemble optimal interpolation
State vector (eta, T, S, u, v)
144-member ensemble
Restart initialisation

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Satellite altimetry (Jason3, Sentinel3A, Cryosat2, AltiKa)
Satellite SST (Metop-A, Metop-B, VIIRS, AVHRR, AMSR2)
In situ profiles Argo, CTD, XBT

Forcing
ACCESS-G APS3 (bulk-formulae)
Climatological river discharge

Bluelink
Ocean Forecasting

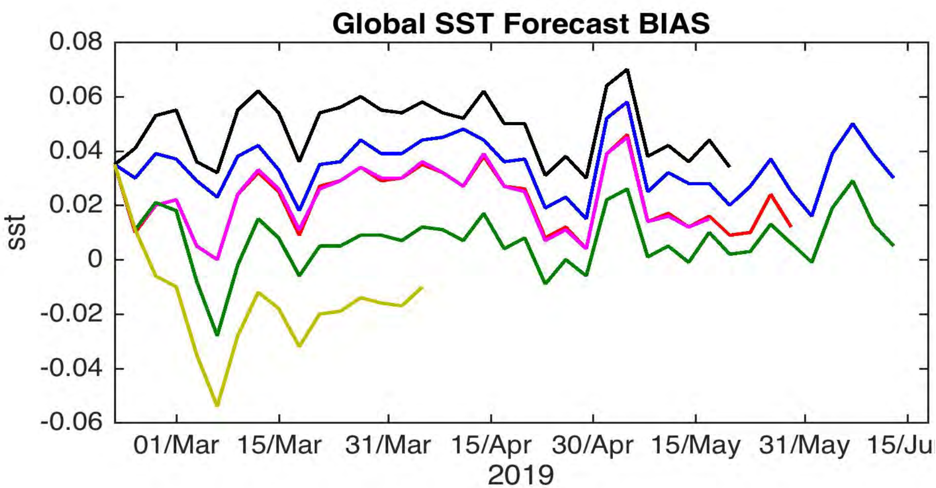
Australian Government
Bureau of Meteorology

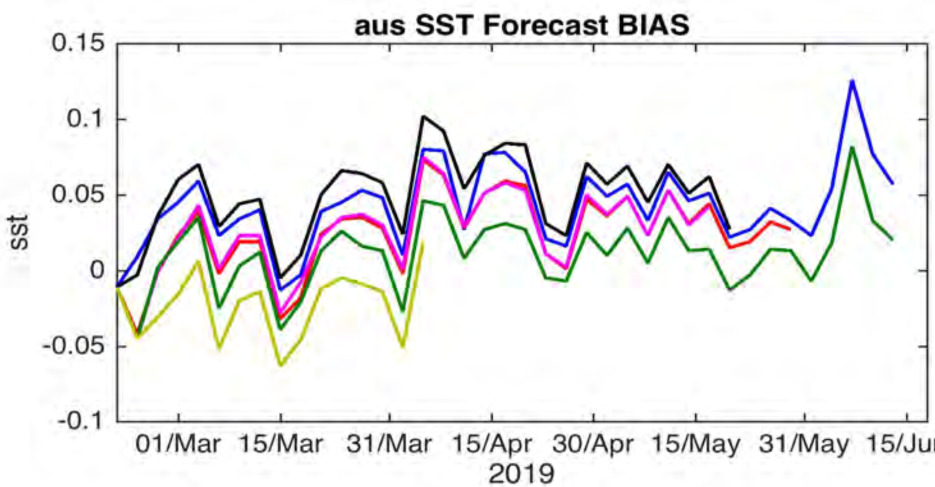
CSIRO

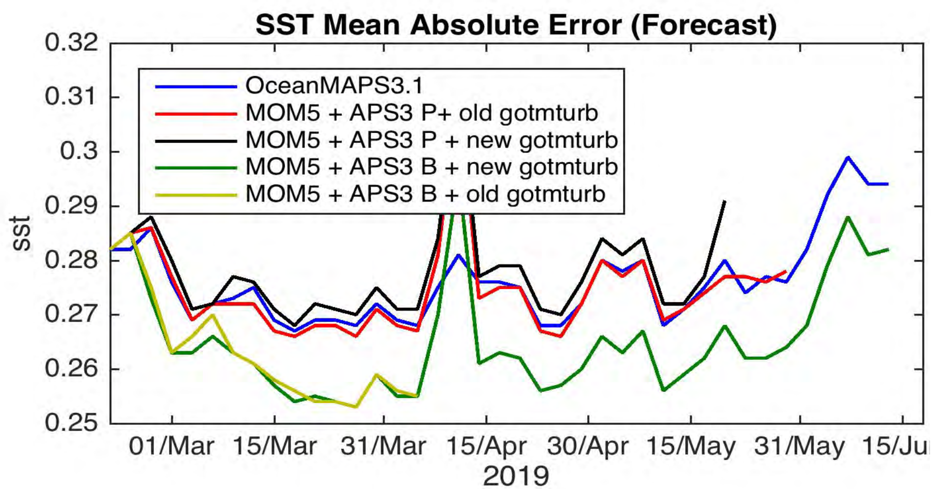
NAVY

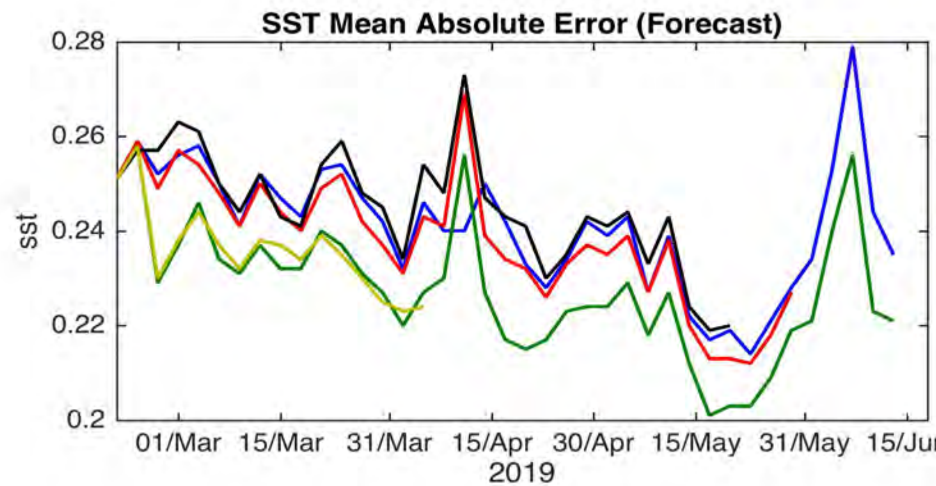
Thanks also to GFDL, the global ocean observing system, IMOS and JCOMM

SST Data Assimilation stats









OceanMAPS3.1
MOM5 + APS3 P+ old gotmturb
MOM5 + APS3 P + new gotmturb
MOM5 + APS3 B + new gotmturb
MOM5 + APS3 B + old gotmturb

see Divakaran

OceanMAPS v3.x

Skilful
First glimpse at forecast uncertainty
Outperforming BRAN
Internationally competitive
Robust and up to date
Capable of capturing synoptic anomalous conditions

Highly recommended for downscaling

Next generation OceanMAPS version 4

2019/20

- **ACCESS-OM2-01** (see Kiss, AMOS-2019)
- **EnKF** (see Sakov, BL workshop)
- ACCESS-G (1hrly) / GE perturbations
- Systematic errors (multi-scale DA) (see Matt Chamberlain)

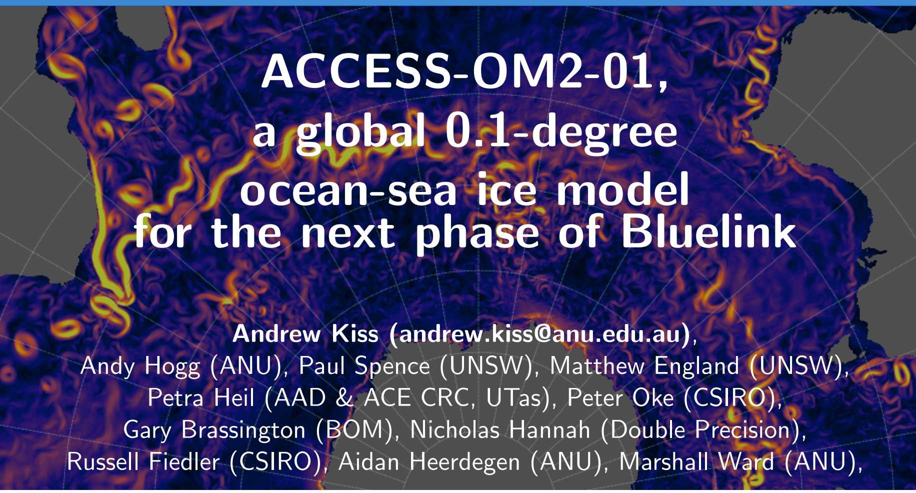
2020/21

- Ensemble forecasting / probabilistic forecasts
- Semi-coupled ACCESS-OceanMAPS
- AUSWOT (see Shane Keating)

2021/22

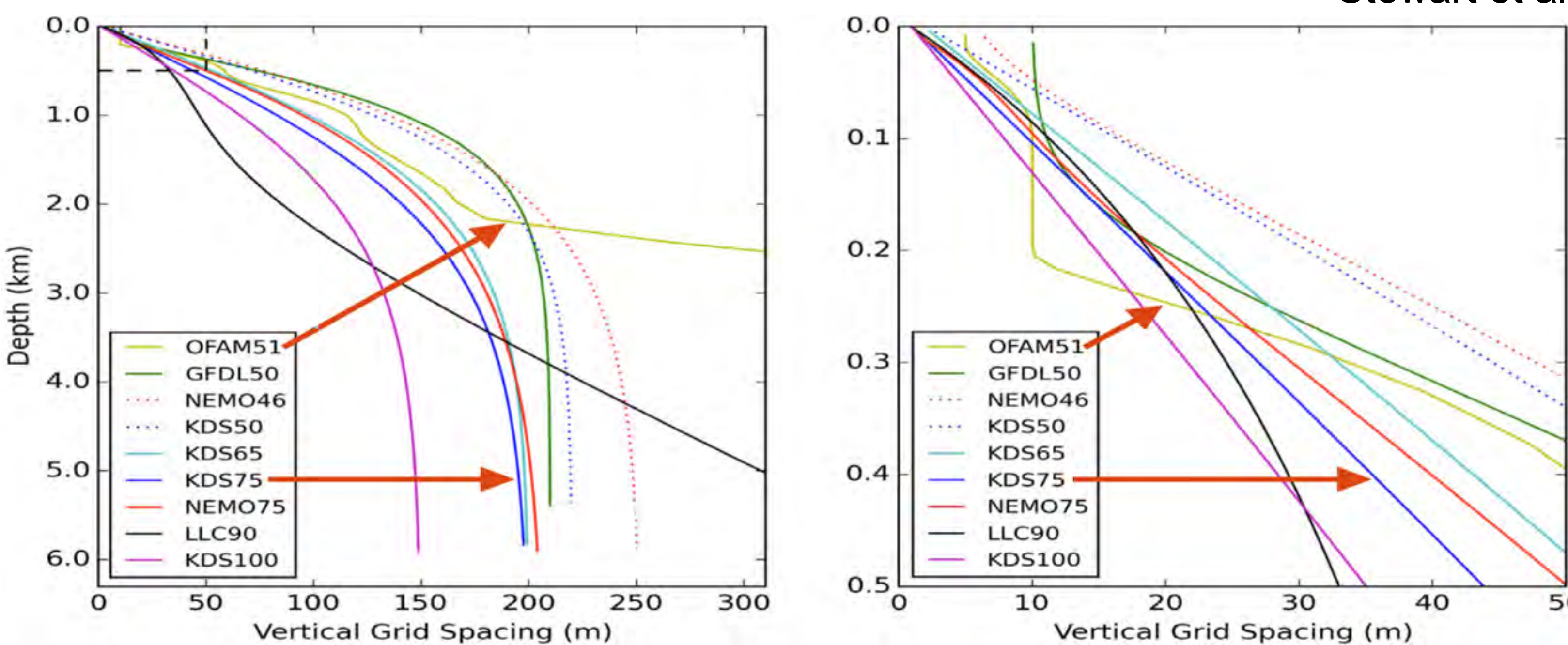
- Coupled ocean-wave-sea-ice (see Alex Babanin)

Next generation OceanMAPS v4.0 (model)

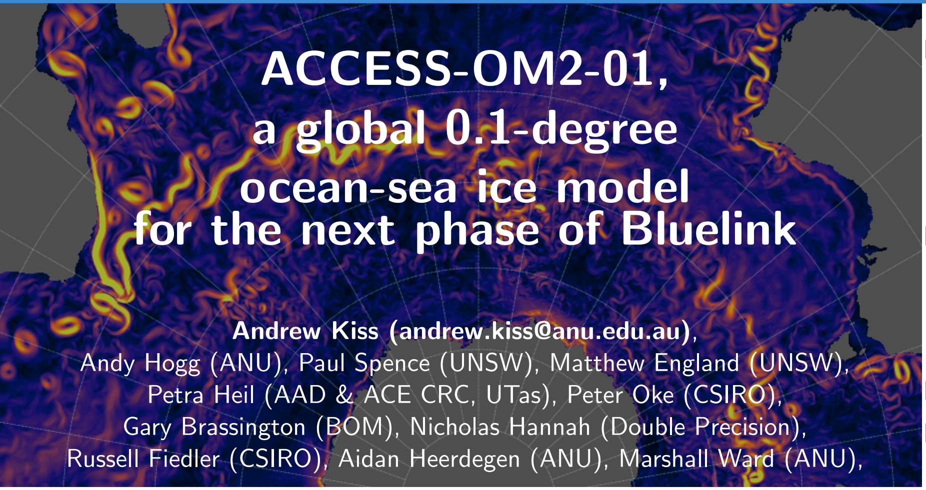


- **Ocean model**: Modular Ocean Model (MOM) 5.1
  - global (90°N – 81°S); tripolar in Arctic; Mercator for 65°N – 65°S
  - **three resolutions:** 1°, 0.25°, 0.1° horizontal resolution
  - z^* vertical coordinate, 50 or 75 levels
  - **Initial condition and salt restoring:** World Ocean Atlas 2013v2
- **Sea-ice model**: CICE 5.1
  - classic EVP dynamics (for now)
  - ridging scheme with 5 thickness categories
  - mushy ice thermodynamics at 0.1° (for now), 4 ice layers + 1 snow
- **Prescribed atmospheric forcing**: JRA55-do
- **Coupler**: OASIS3-MCT

Stewart et al., (2017)



Next generation OceanMAPS v4.0 (model)



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  - mushy ice thermodynamics at 0.1° (for now), 4 ice layers + 1 snow
- **Prescribed atmospheric forcing**: JRA55-do
- **Coupler**: OASIS3-MCT

Expected benefits

Defence: Afternoon effect, Mixed layer, Thermocline

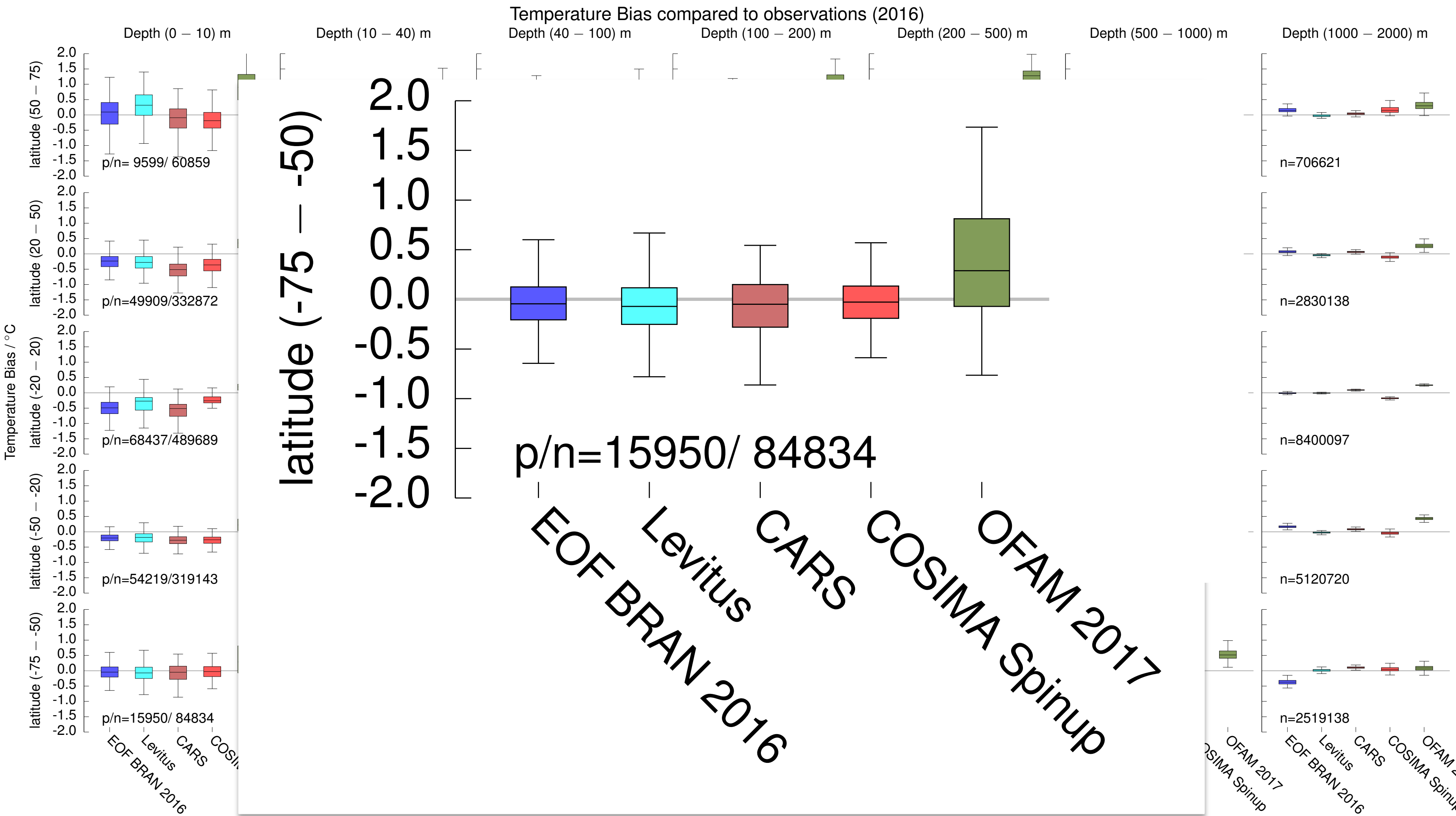
Maritime Safety: 1.1m (top cell), hrly, Mixed layer currents, Sea-ice concentration etc.

Coastal operations: Improved surge/upwelling, CTW's

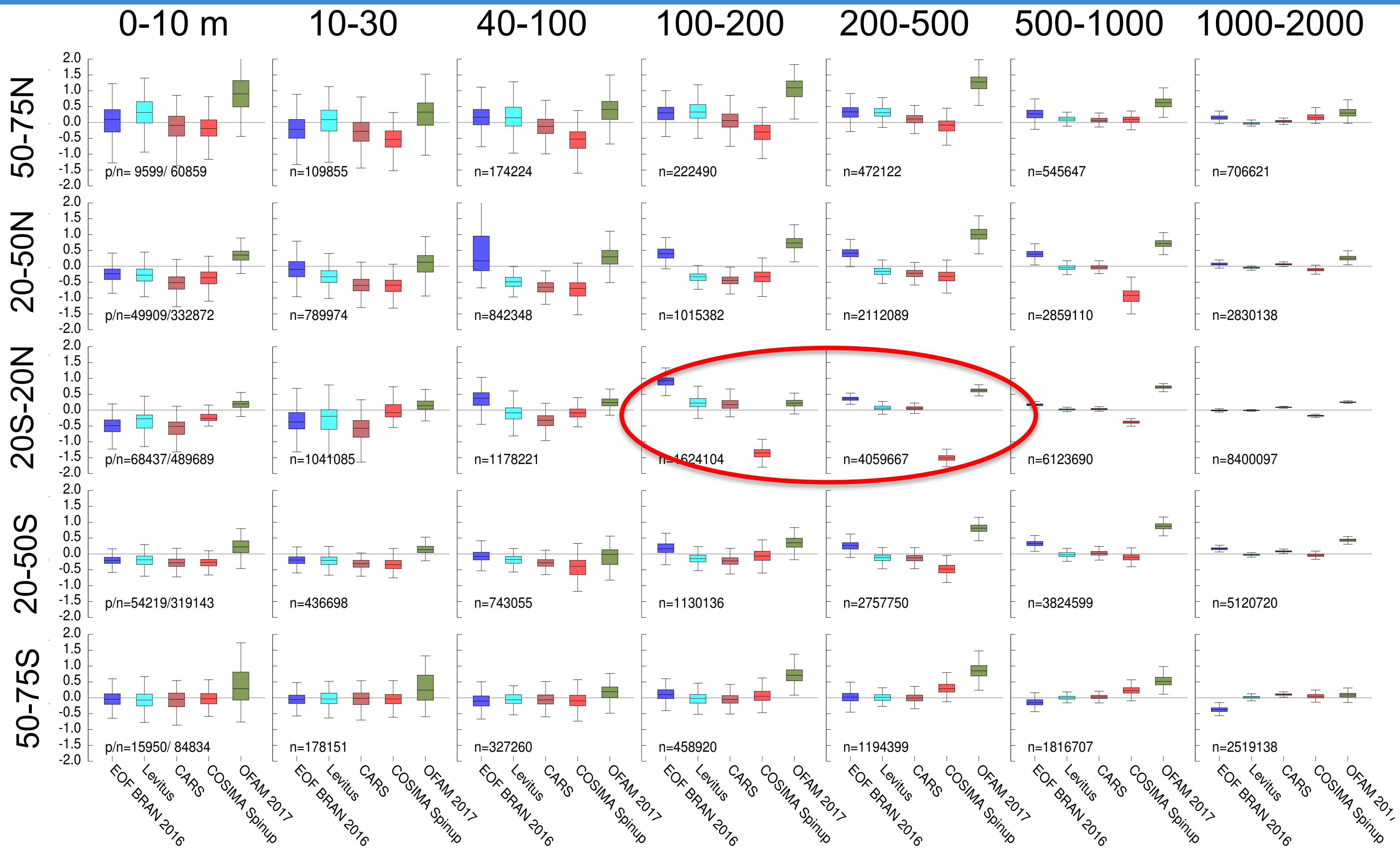
Weather forecasting: Full global SST and sea-ice concentration forecasts

Downscaling: Reduced systematic biases

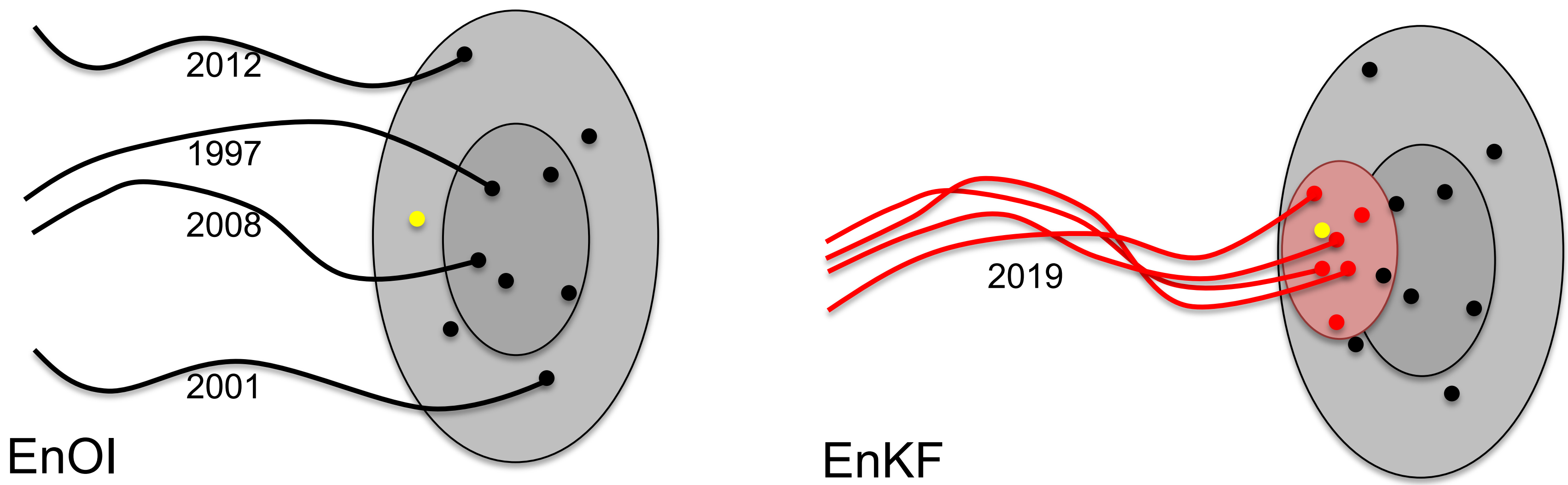
Temperature MD (Argo, 2016)



Temperature MD (Argo, 2016)



Why move from EnOI to EnKF ?



Benefits

EnKF more dynamically balanced / reduced smoothing

Better samples unlikely/extreme events

mesoscale eddies,
boundary current meanders
TC mixing
Upwelling
…

Ensemble (probabilistic) forecasting

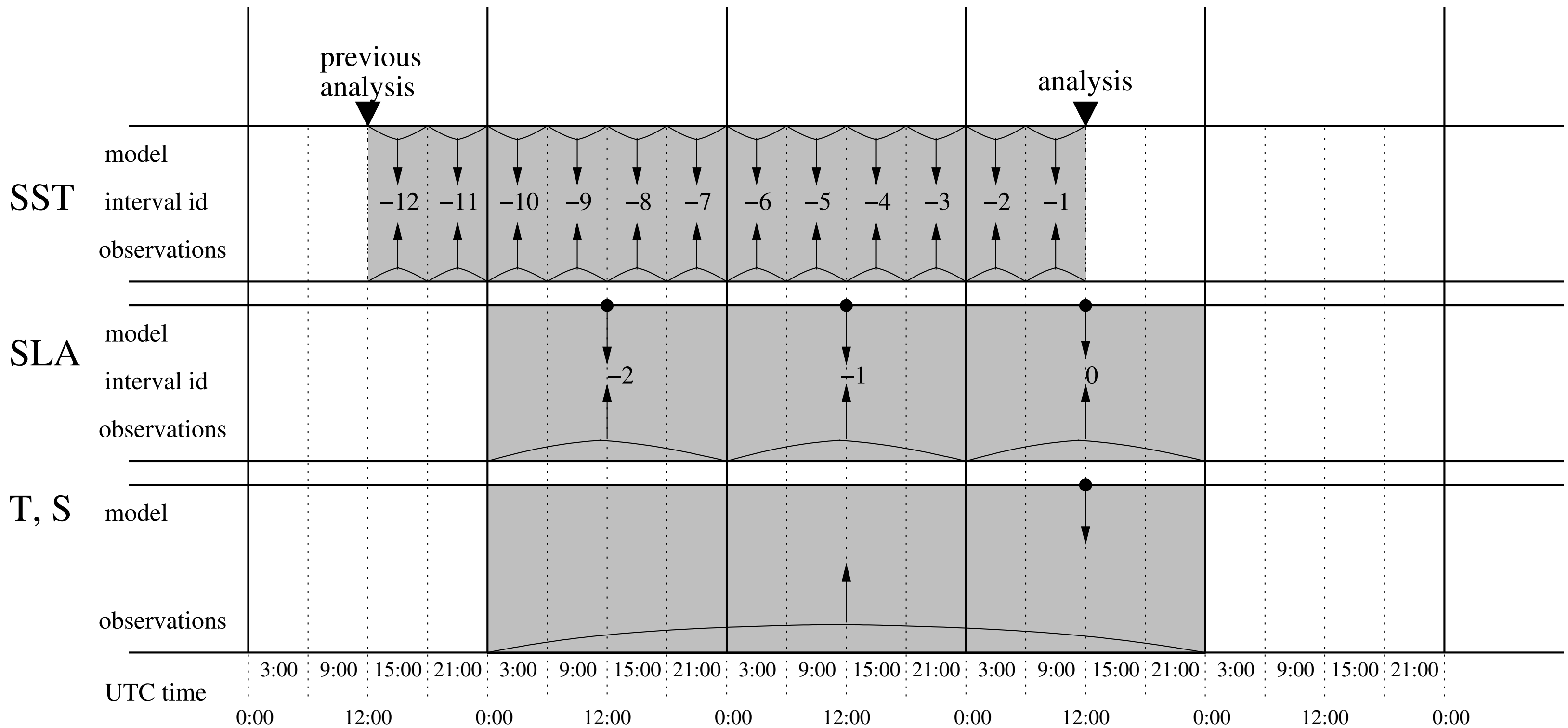
Why not move from EnOI to EnKF ?

OFAM3 + EnKF-C

- 96-member ensemble
- RADS altimetry, NAVO, VIIRS, profiles
- 3 day cycle
- Localisation: 150 km SLA and SST
  - 450 km T and S
- 3% capped inflation
- SST bias correction

Resources:

- CPU: ~9 kSU / cycle
- Footprint: 4-7 TB
- Full restart: 2.8 TB
- (compressible to 310GB)



EnKF + OFAM3

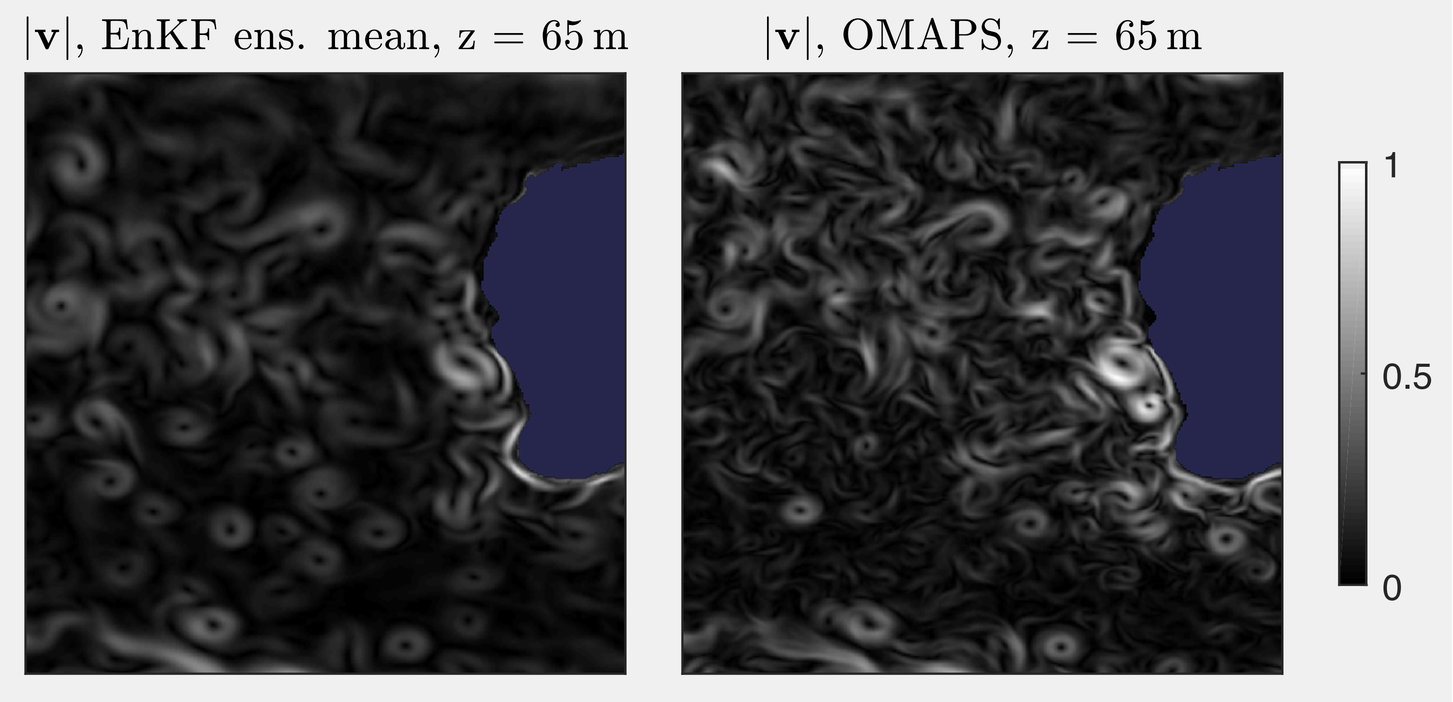
Region: Global

	SLA	SST	T	S
EnKF	0.044	0.264	0.426	0.079
OMAPS	0.052	0.283	0.503	0.112
	15%	7%	15%	29%

Region: Australia

	SLA	SST	T	S
EnKF	0.042	0.255	0.408	0.076
OMAPS	0.047	0.248	0.487	0.105
	11%	-2%	16%	28%

Performance summary for 01/01/2018 – 30/06/2018
(MAD of forecast innovation)

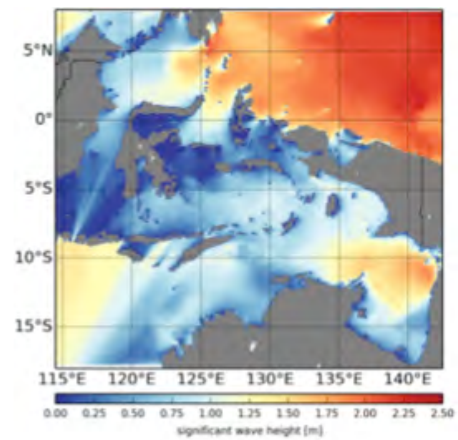


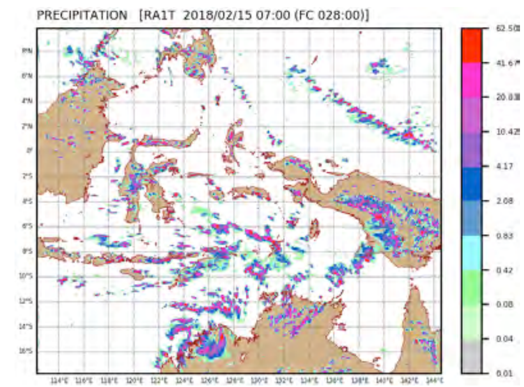
Maritime Continent Model

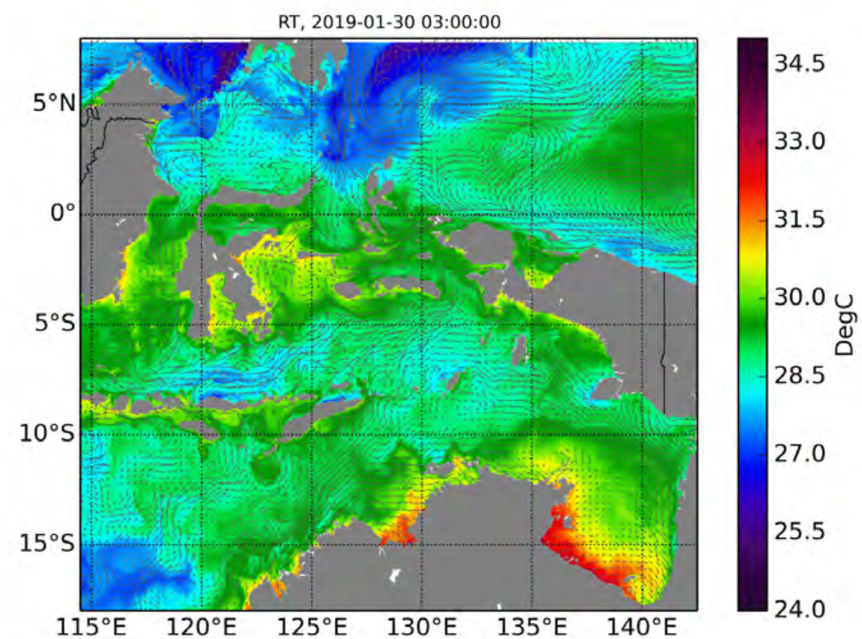
Brassington, Dietachmayer, Colberg, Zeiger, Sakov, Aijaz, Bende-Mihl, Sun and Roff

Design

- Atmosphere, Ocean & Wave
    - UM (ACCESS-C), ROMS, WWIII
- Ocean data assimilation (EnOI)
- Large fixed priority regions O(30 x 30)
    - Operate Bureau infrastructure
    - Secure to third party
    - Better resolve internal tide climate
- High resolution ~1/50° x 1/50°
    - Added value
    - Comparable cost to global model
    - HPC application
- Pre-configured and optimised
- Multi-year hindcasts/reanalyses
- Routine operation
    - Secure to third party
- e.g., MCM 112.4E-142.4E, 19.1S-7.7N



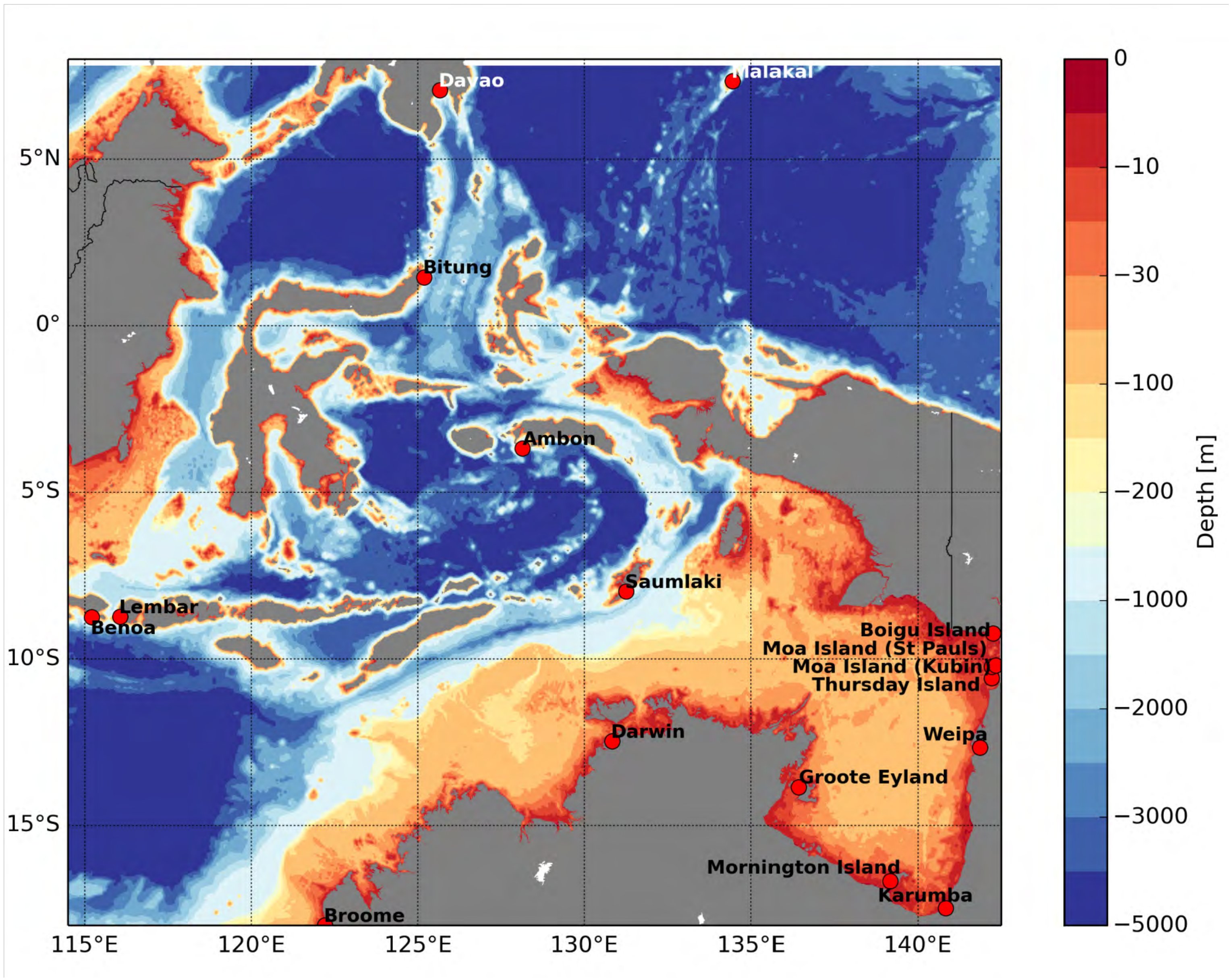




see talk AMOS-2019

MCM configuration - summary

Atmosphere	Ocean	Wave
Unified Model v10.6	ROMS	WAVEWATCH III implicit
80 terrain-following levels Top of model 38.5 km	30 sigma-levels SRTM30+ bathymetry	Variable grid (525,836)
Full Euler (non-hydro) Semi-implicit/ Semi-Lagrangian Explicit convection Options: RA1-T (physics - tropics) RA1-M (physics – mid-lat)	Hydrostatic Mellor-Yamada AKIMA advection Forcing (options) ACCESS-R (RT1) ACCESS-MCM (RT2)	29 freq bins (0.035-0.5047) Directional inc 10d (36) SRTM30+ bathymetry Forcing (options) ACCESS-R ACCESS-MCM
Boundary conditions APS2 ACCESS-R	Boundary conditions OceanMAPS TPXO7.2 Dai and Trenberth, rivers	Boundary conditions AUSWAVE-R
Initial conditions Downscaling ACCESS-R	Initial conditions Downscaling OceanMAPS	



Available tide gauges that have been compared with modelled sea levels

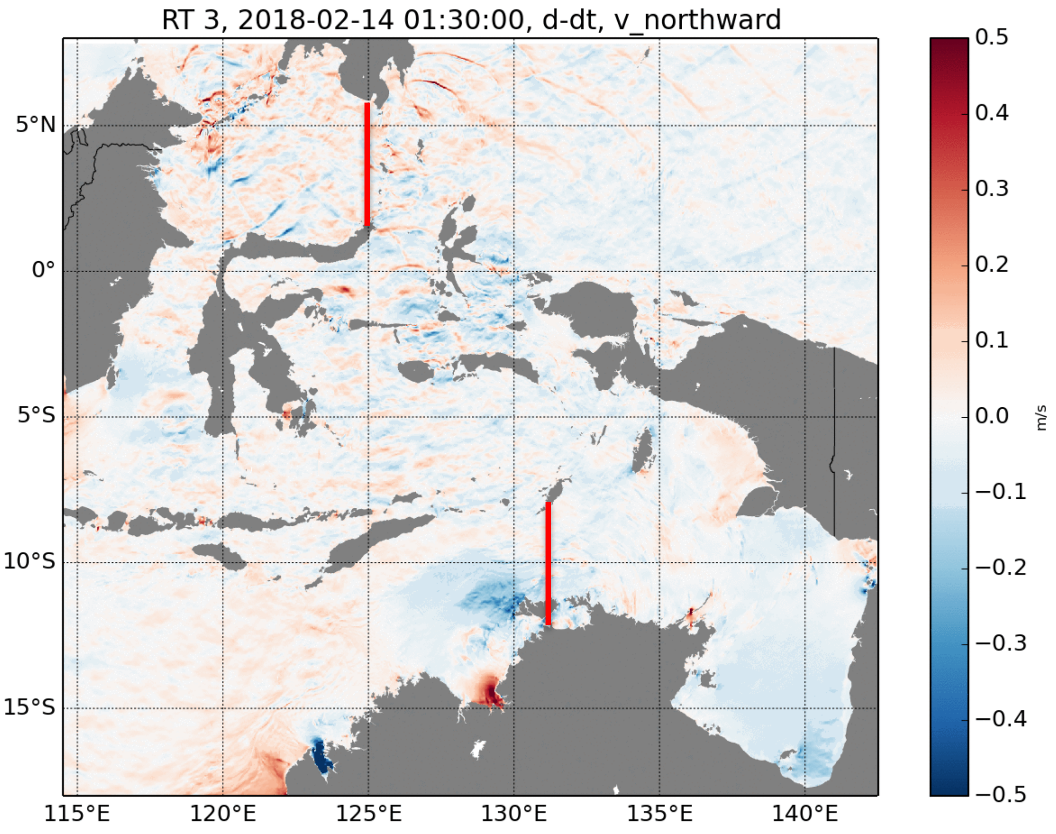
Name	Coordinates	Time Avail	Source	RMSE [m]	MAD [m]	Rmax (Lag)	HAT [m]
Davao (Philippines)	125.669, 7.07	Jan-Feb 2018	Uni H.	0.15, 0.17	0.13, 0.13	0.96 (1), 0.95 (1)	1.08
Lembar (Indonesia)	116.069, -8.736	Jan-Feb 2018	Uni H.	0.10, 0.11	0.08, 0.08	0.97 (0), 0.96 (0)	0.93
Benoa (Indonesia)	115.209, -8.755	Jan-Feb 2018	Uni H.	0.26, 0.26	0.22 0.22	0.99 (1) 0.99 (1)	1.35
Ambon (Indonesia)	128.15, -3.687	Jan-Feb 2018	Uni H.	0.19, 0.20	0.16, 0.16	0.94 (0), 0.94 (0)	1.08
Saumlaki (Indonesia)	131.26, -7.982	Jan-Feb 2018	Uni H.	0.23, 0.23	0.2, 0.2	0.93 (1), 0.94 (1)	1.27
Bitung (Indonesia)	125.193, 1.44	Jan-Feb 2018	Uni H.	0.17, 0.16	0.14 0.14	0.96 (1), 0.96 (1)	0.87
Malakal (Palau)	134.463, 7.33	Jan-Mar 2018	Uni H.	0.12, 0.13	0.09, 0.10	0.97 (0), 0.96 (0)	1.05
Broome	122.218, -18.00	Jan-Mar 2018	BoM	NA	NA	NA	NA
Darwin	130.845, -12.471	Jan-Mar 2018	BoM	0.43, 0.46	0.34,0.35	0.97 (0), 0.97 (25)	3.65
Groote Eyland	136.4158, -13.86	Jan-Mar 2018	BoM	0.17, 0.19	0.14, 0.14	0.9 (1), 0.86 (1)	0.67
Weipa Tide	141.8622, -12.67	Jan-Mar 2018	BoM	0.22, 0.24	0.18, 0.19	0.95 (0), 0.93 (0)	1.12
Thursday Island	142.216, -10.583	9 Feb-Mar 2018	BoM	0.41, 0.41	0.34, 0.34	0.83 (23), 0.82 (23)	1.61
Moa Island (Kubin)	142.214, -10.236	9 Feb-Mar 2018	BoM	0.25, 0.26	0.20, 0.20	0.90 (0), 0.90 (0)	1.55
Boigu Island	142.253, -9.2436	9 Feb-Mar 2018	BoM	0.27, 0.27	0.21, 0.21	0.94 (0), 0.94 (0)	1.82
Moa Island (ST Pauls)	142.334, -10.195	17 Feb-Mar 2018	BoM	0.31, 0.31	0.25, 0.25	0.91 (0), 0.90 (0)	1.64
Karumba Tide	140.834, -17.488	Jan-Mar 2018	BoM	0.36, 0.37	0.29, 0.30	0.96 (1), 0.95 (1)	1.67
Mornington Island	139.17, -16.667	Jan-Mar 2018	BoM	0.25, 0.27	0.21, 0.21	0.97 (1), 0.94 (1)	1.09
Mean				0.24, 0.25	0.20, 0.20	0.94, 0.93	

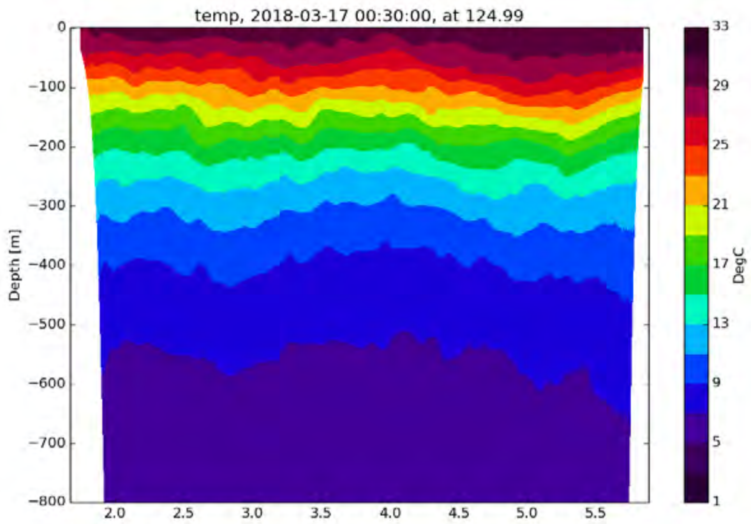
10-20%

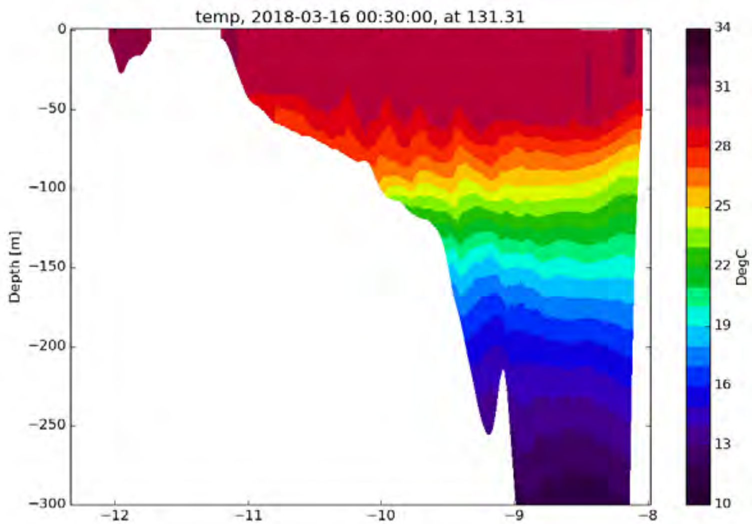
20-25%

Table 8: Available tide gauges. Root Mean Square Error (RMSE), Mean Absolute Difference (MAD), Maximum Correlation (R_{max}) and highest astronomical tide (HAT) are shown for RT1 and RT2.

Internal tides - surface expression and transects







MCM phase I outcomes

Ocean component

- 1/50 degree adequate
- significant added value (resolving internal tides)
- ACCESS-MCM forcing performed better than ACCESS-R
- Optimising DA
- 3 year reanalysis

Wave component

- Unstructured mesh, modest statistical improvement
- Improvements due to resolving straits/islands
- ACCESS-MCM improved for extremes (not shown)

Atmospheric component

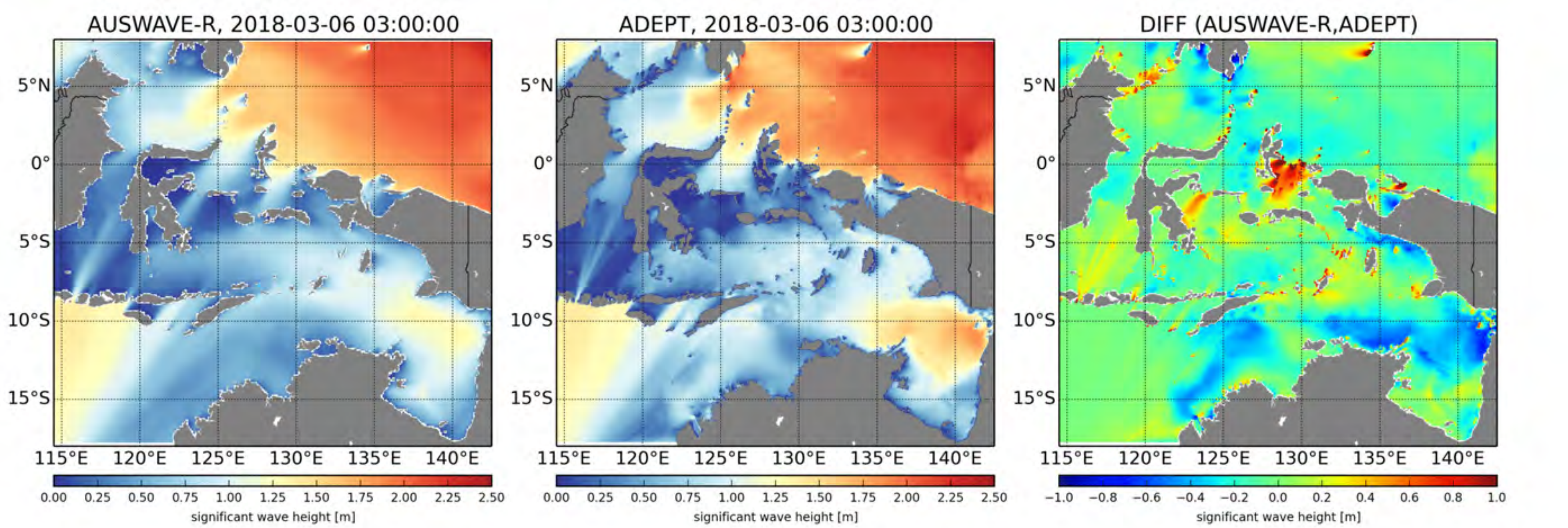
- Stability over New Guinea for extreme systems (TC's)
- Optimising ACCESS-MCM (convection/boundaries)

Recommended for operationalisation

Many areas for further improvement

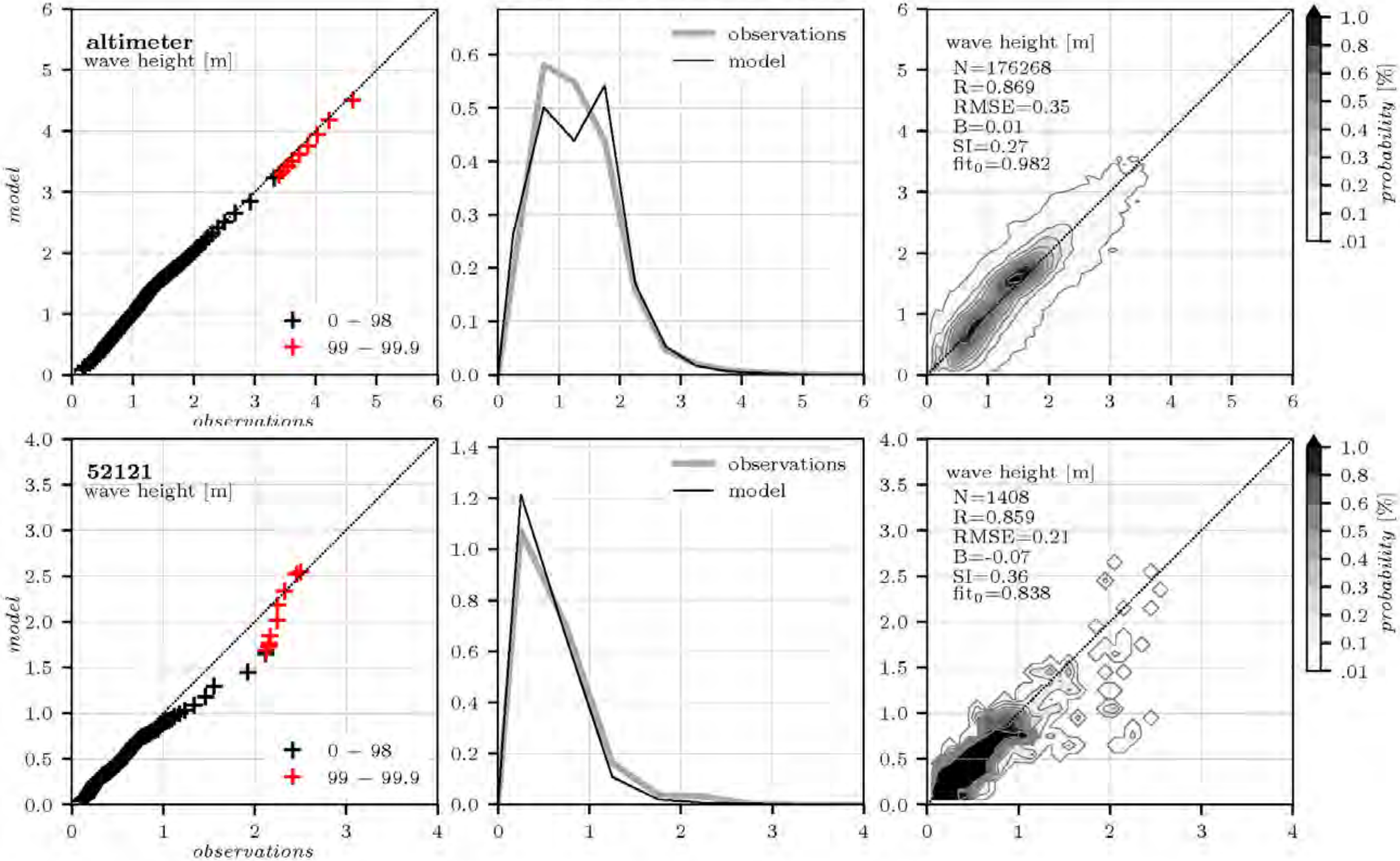
Partnering (national and international), BMKG, CDU, UWA?, NSF

MCM Wave



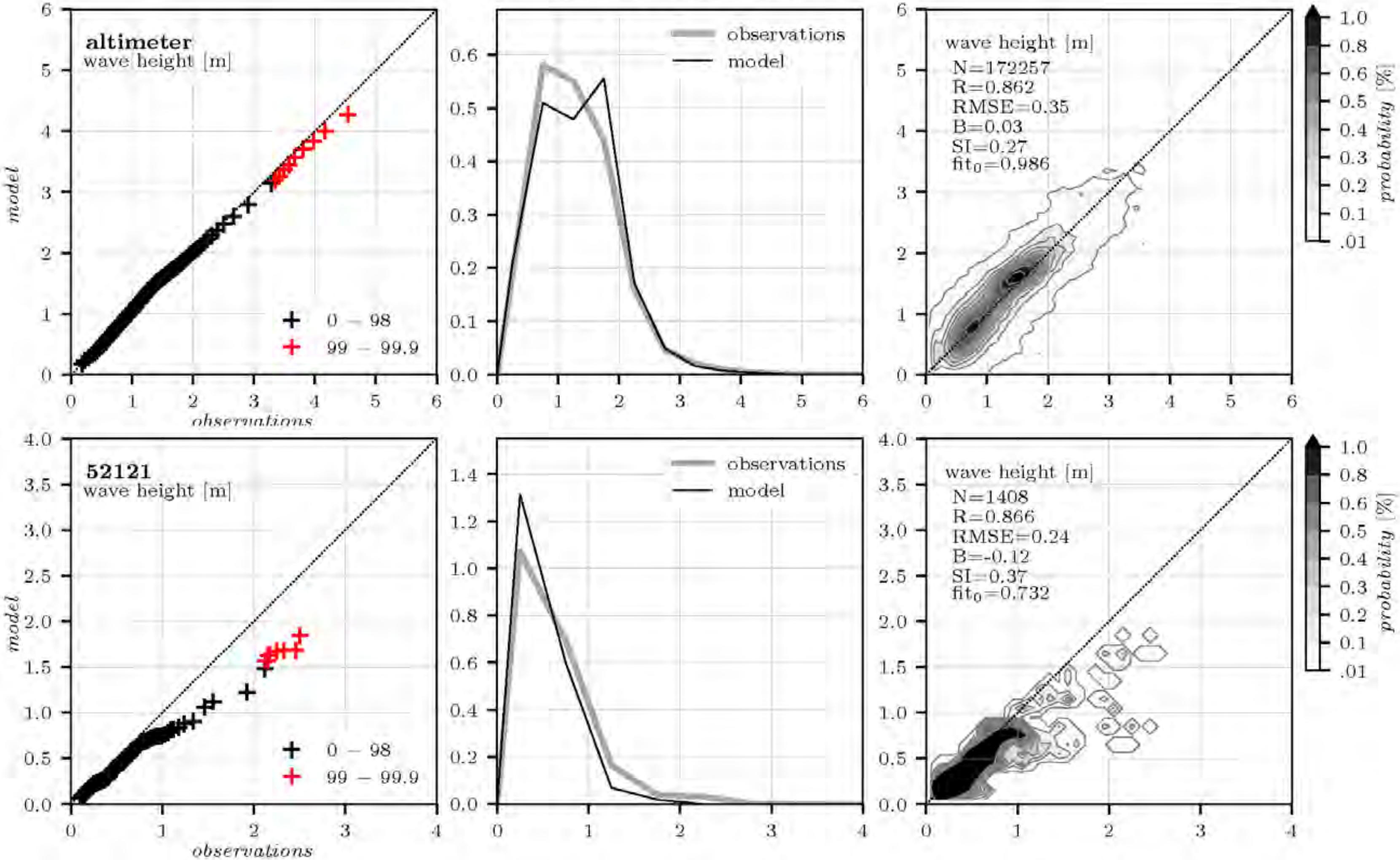
Comparison of regional and MCM wave prediction
Better resolved island groups and straits
Improved representation of fine scale winds

MCM Wave +48 hrs



Comparison of modelled 25-48 h forecasts of Hs for the MCM model. Plots shown from left to right: QQ-plots, probability plots and scatter plots.

AusWAVE Wave +48 hrs



Comparison of modelled 25-48 h forecasts of Hs for the AUSWAVE-R model. Plots shown from left to right: QQ-plots, probability plots and scatter plots.

Multiscale Data Assimilation in Bluelink Reanalysis (BRAN)

Matt Chamberlain
CSIRO, Ocean and Atmosphere, Hobart,

and Bluelink Global Modelling Team.
Peter Oke, Gary Brassington, Paul Sandery, Russ Fiedler, Prasanth Divakaran

Forum for Operational Oceanography

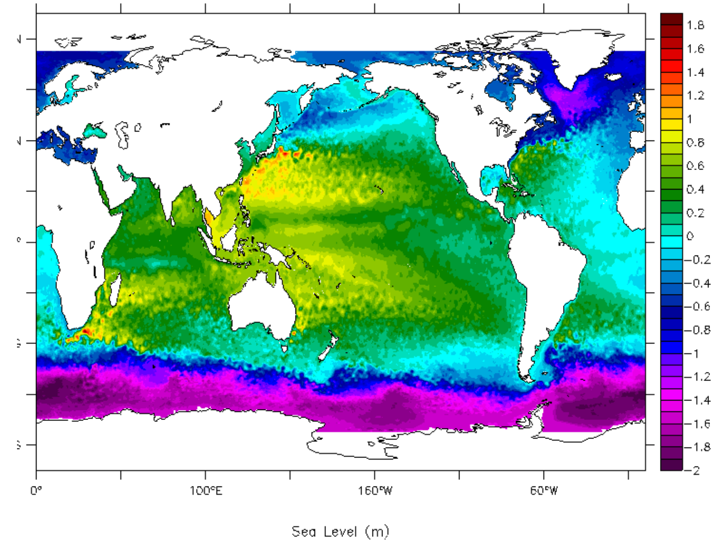
Oct. 2019.

Multiscale DA Overview

- BRAN runs simulate the state of the global ocean at 0.1-degree resolution over the past decades.
- There is significant improvement in the fit of the simulated ocean to observations using 2-stage, multiscale data assimilation process.
- Calculating corrections at coarse resolution is effective at reducing biases in the subsurface.
- Mean absolute errors in subsurface temperature are reduced by up to 33% and 13% for analysis and forecast (3-day) fields respectively.

Introduction

- Bluelink Project, a partnership since 2001 between CSIRO, BoM, and RAN; supporting development of operational ocean forecasting services for Australia.
- OFAM3 platform, near-global 0.1 deg resolution ocean model (Oke et al., GMD, 2013).
- Bluelink Reanalysis (BRAN) experiments, simulate the mesoscale ocean state over the past decades, assimilating SST, sea level, and subsurface T+S profiles; e.g. Oke et al. Ocean Modelling 2018.
  (~ OceanMAPS from BoM.)



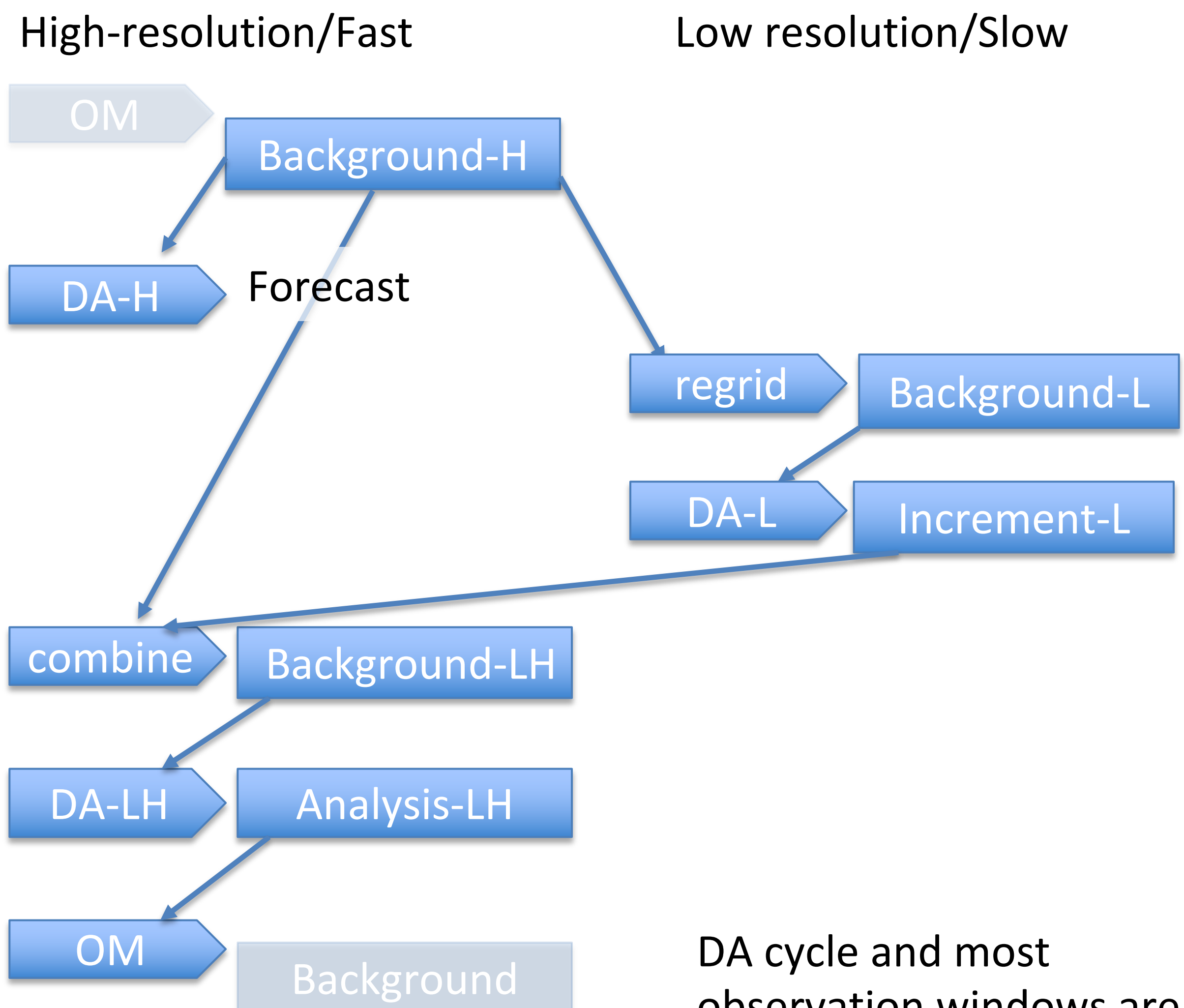
- Output from OFAM spinups and reanalyses publicly available on NCI data catalogue.
  https://geonetwork.nci.org.au and search OFAM/BRAN.

- OBJECTIVE: Noted that large features (> mesoscale) in thermocline not being corrected for efficiently in current data assimilation system.
  Want to make better use of subsurface observations (ARGO).

Multiscale DA schematic

Cycle sequence

1. Background from previous ocean model cycle.
2. DA calculation of forecast statistics (DA-H)
3. Average background onto coarse grid.
4. DA calculation at low resolution (DA-L) for coarse increment.
5. Interpolate increment and add to original background.
6. DA calculation at high resolution (DA-LH) for analysis and new initial condition.
7. Run ocean model forward 3 days; generate initial background for next cycle.



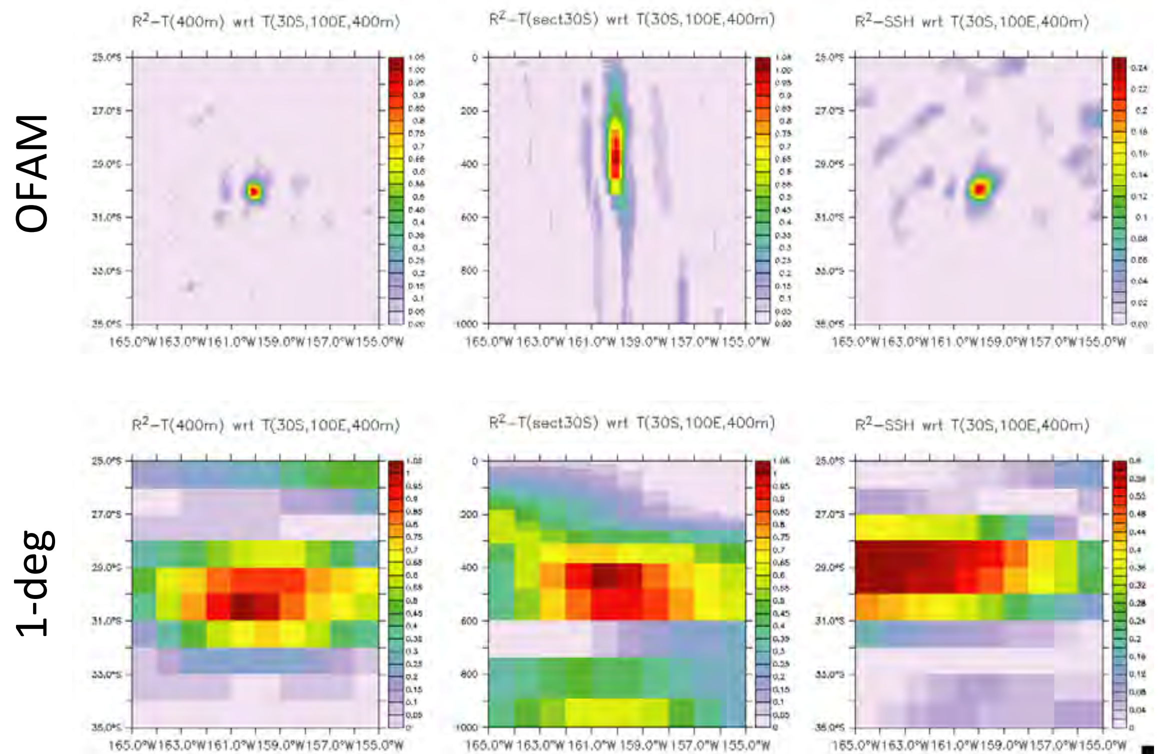
DA cycle and most observation windows are 3 days.

BRAN Multiscale DA - ensemble correlation

BRAN data assimilation uses Ensemble Optimal Interpolation (EnOI). An ensemble of anomalies from a previous model run is used to apply corrections to the model state, in space and across different ocean variables.

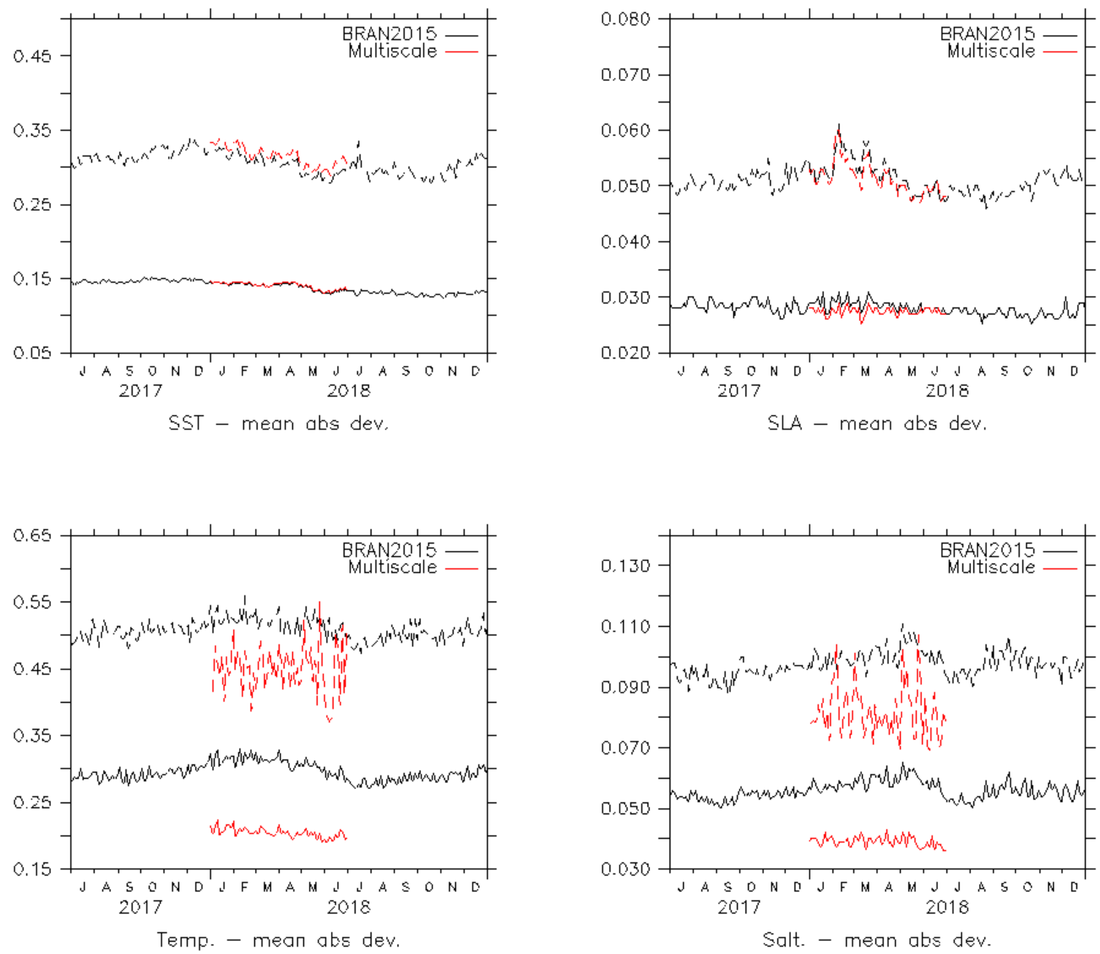
Shown here are examples of covariance from each ensemble set

- OFAM ensemble “3-day minus 3-month average”; captures eddies and mesoscale variability.
- ACCESS 1-deg ensemble of monthly climatological anomalies from 40-years of ocean-ice model with historical forcing (JRA-55); captures broad 100+ km scale variability.



Global Mean Absolute Deviations - forecast and analysis

- Multiscale statistics shown for Jan-Jun 2018.
- Little change in surface fields which are well observed.
- Substantial improvement in subsurface.



al Mean Absolute Deviations - forecast and an

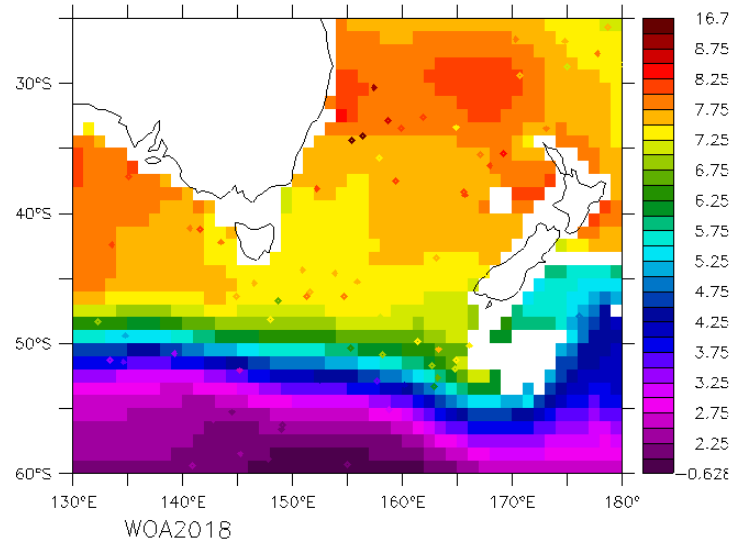
	BRAN2015		Multiscale			
	Analysis	Forecast	Analysis		Forecast	
SST (C)	0.139	0.304	0.141	+1.0%	0.315	+3.6%
Sea height (cm)	2.85	5.22	2.74	-4.0%	5.13	-1.9%
Subsurface temperature (C)	0.308	0.519	0.204	-33.8%	0.449	-13.5%
Subsurface salinity (psu)	0.0586	0.1003	0.039	-33.4%	0.0817	-18.5%

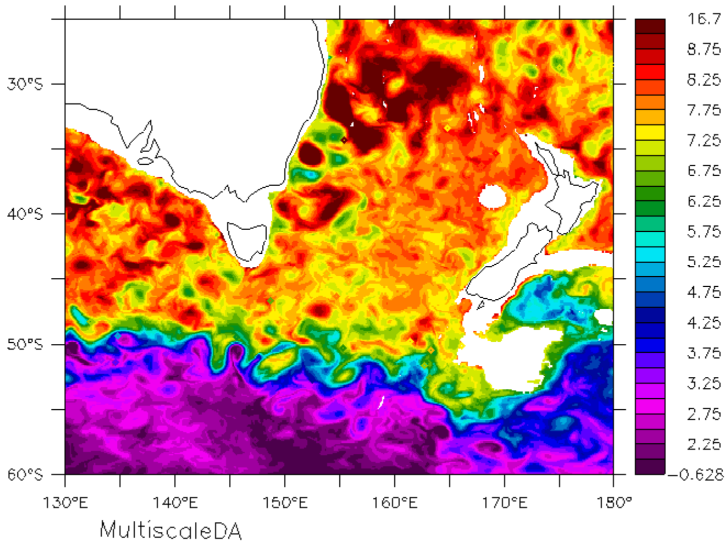
- Statistics averaged over Jan-Jun 2018.
- Little change in surface fields, which are well observed. Slight degradation of SST, improvement in sea level corresponding to a better ocean interior.
- Substantial improvement in statistics from subsurface.

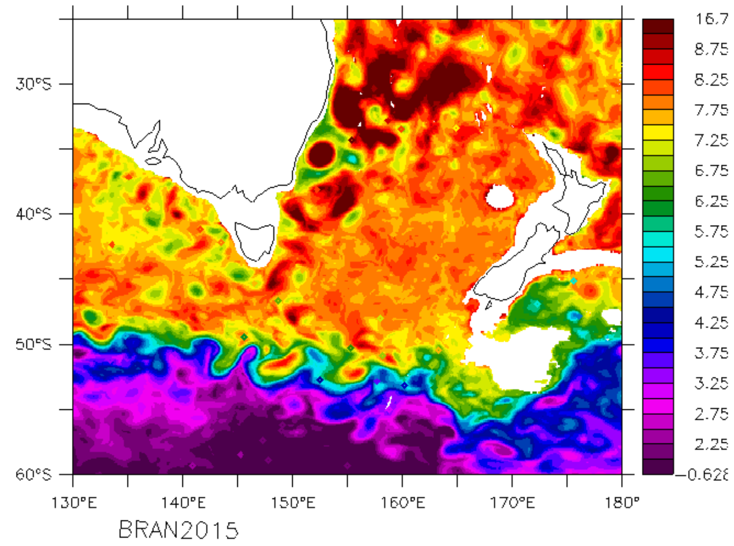
Improvements to ocean state

Eg. 1-Dec-2017, temperatures at 680 m, compared with subsurface observations assimilated 2-Dec.

- Tasman Sea cooler
- Australia Bight warmer
- EAC separation eddies same (both warmer cf WOA)
- Bounty Trough (NZ) cooler







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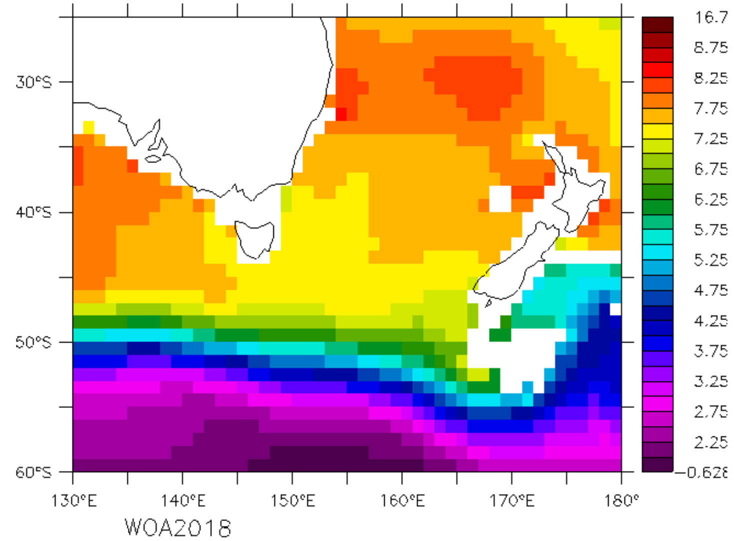
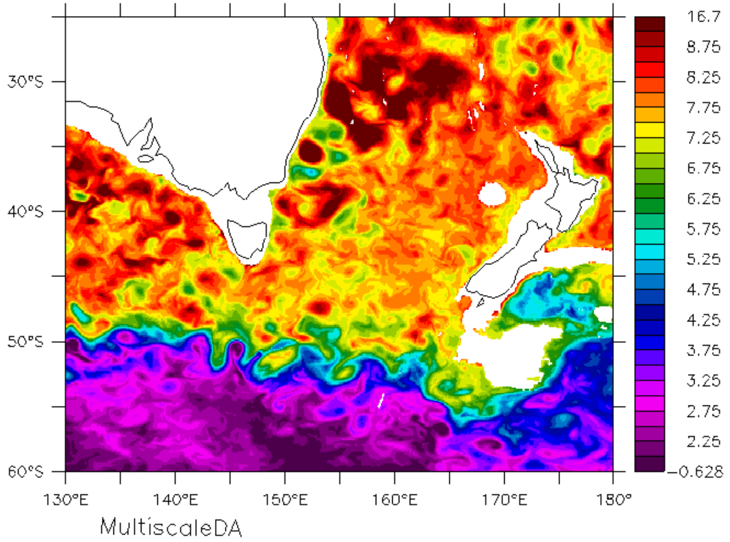
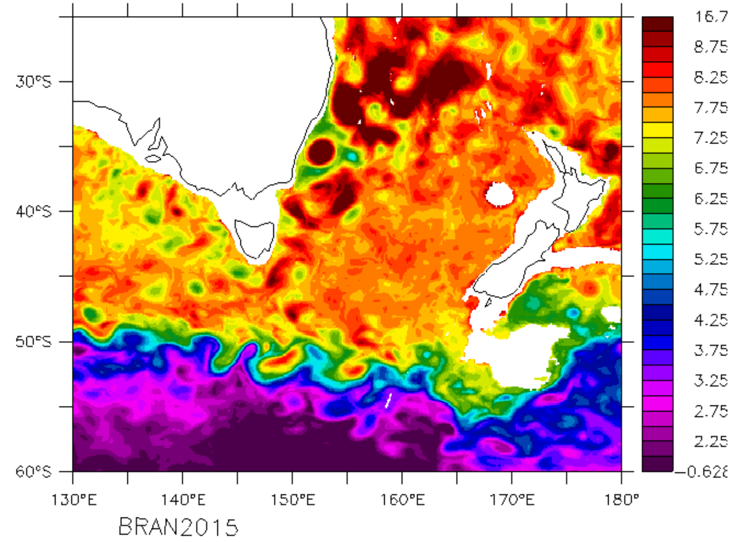


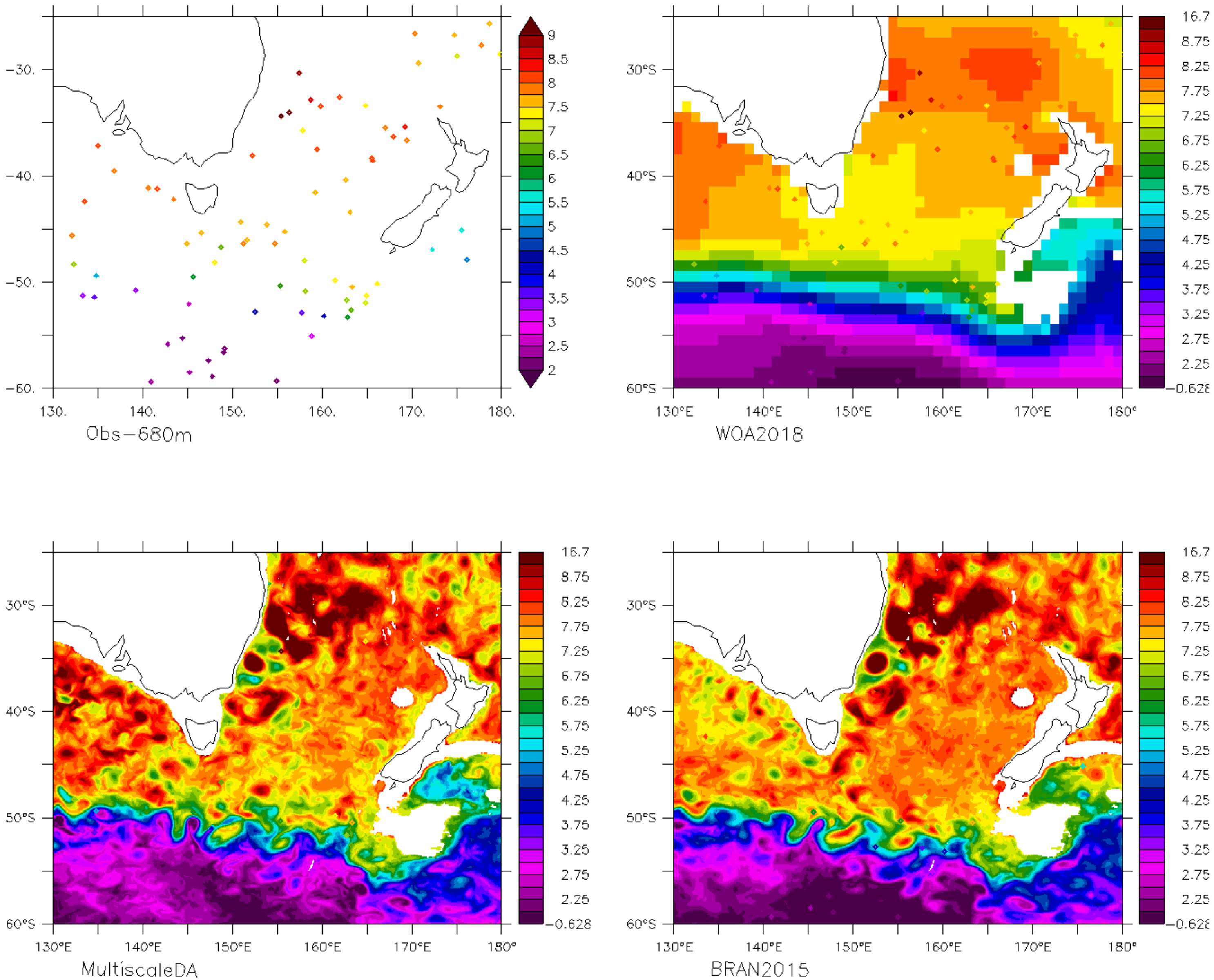




Improvements to ocean state

Eg. 1-De

- Tasr
- Aust
- EAC
  (bot
- Bou



Discussion

- Improvements found in ocean state at depth; surface fields (SST, SLA) are already well observed/constrained.

- Ideally, DA system would only have to correct for dynamics. In reality, it also corrects for model biases.

- Broader footprints of correlation in the coarse ensemble make the multiscale system more efficient at correcting for these biases.

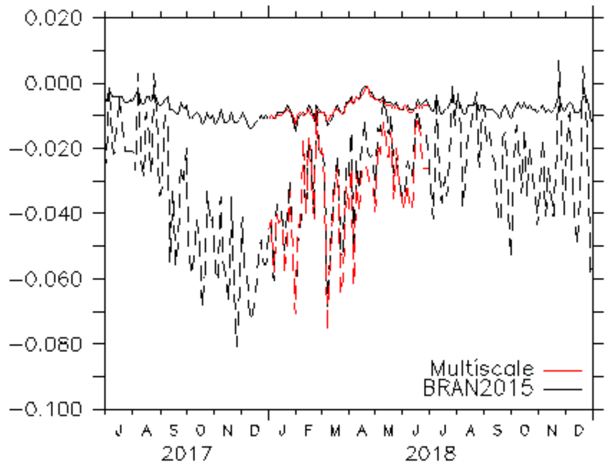
- DA system is robust and able to use ensembles from different model platforms. It is advantageous to run a coarse model for longer control experiments and 'cleaner' climatological anomalies.

Summary

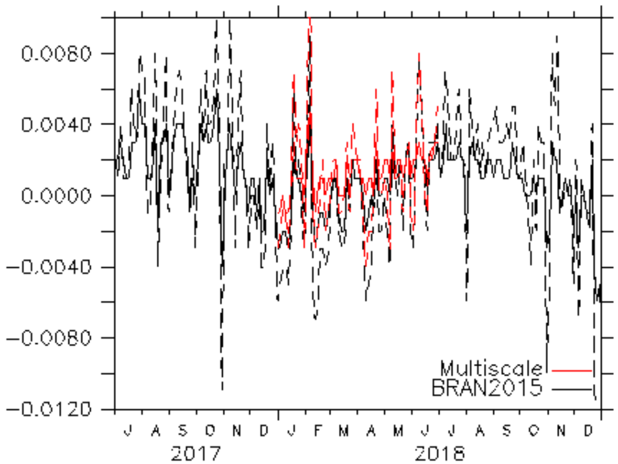
- There is significant improvement in BRAN simulations using 2-stage/multiscale data assimilation process.
- Calculating corrections at coarse resolution is effective at reducing biases in the subsurface where observations are sparse.
- Mean absolute errors in subsurface temperature are reduced by up to 33% and 13% for analysis and forecast (3-day) fields respectively.
  Improvements are comparable to 100-member EnKF systems for a fraction of the computational cost.
- Apply to future BRAN/OceanMAPS runs.

- Done!

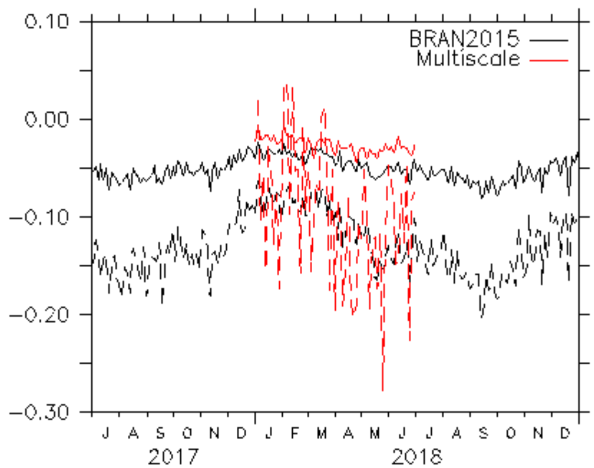
sep19c - global biases



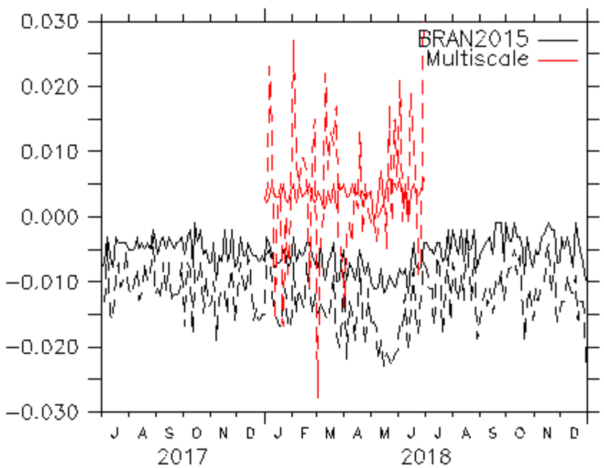
SST – mean abs dev.



SLA – mean abs dev.



Temp. – mean abs dev.



Salt. – mean abs dev.

Global Mean Absolute Biases - forecast and analysis

	BRAN2015		Multi scale	
	Analysis	Forecast	Analysis	Forecast
SST (C)	-0.007	-0.03	0.141	0.315
Sea height (cm)	0.03	-0.05	2.74	5.13
Subsurface temperature (C)	-0.043	-0.107	0.204	0.449
Subsurface salinity (psu)	-0.0074	-0.0149	0.039	0.0817

Standard BRAN process

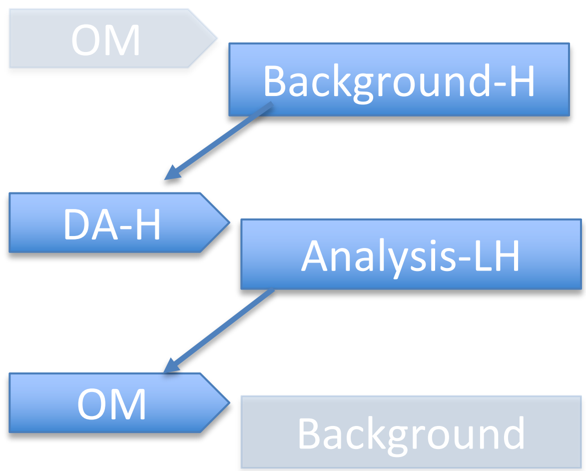
Cycle sequence

1. Background from previous ocean model cycle.

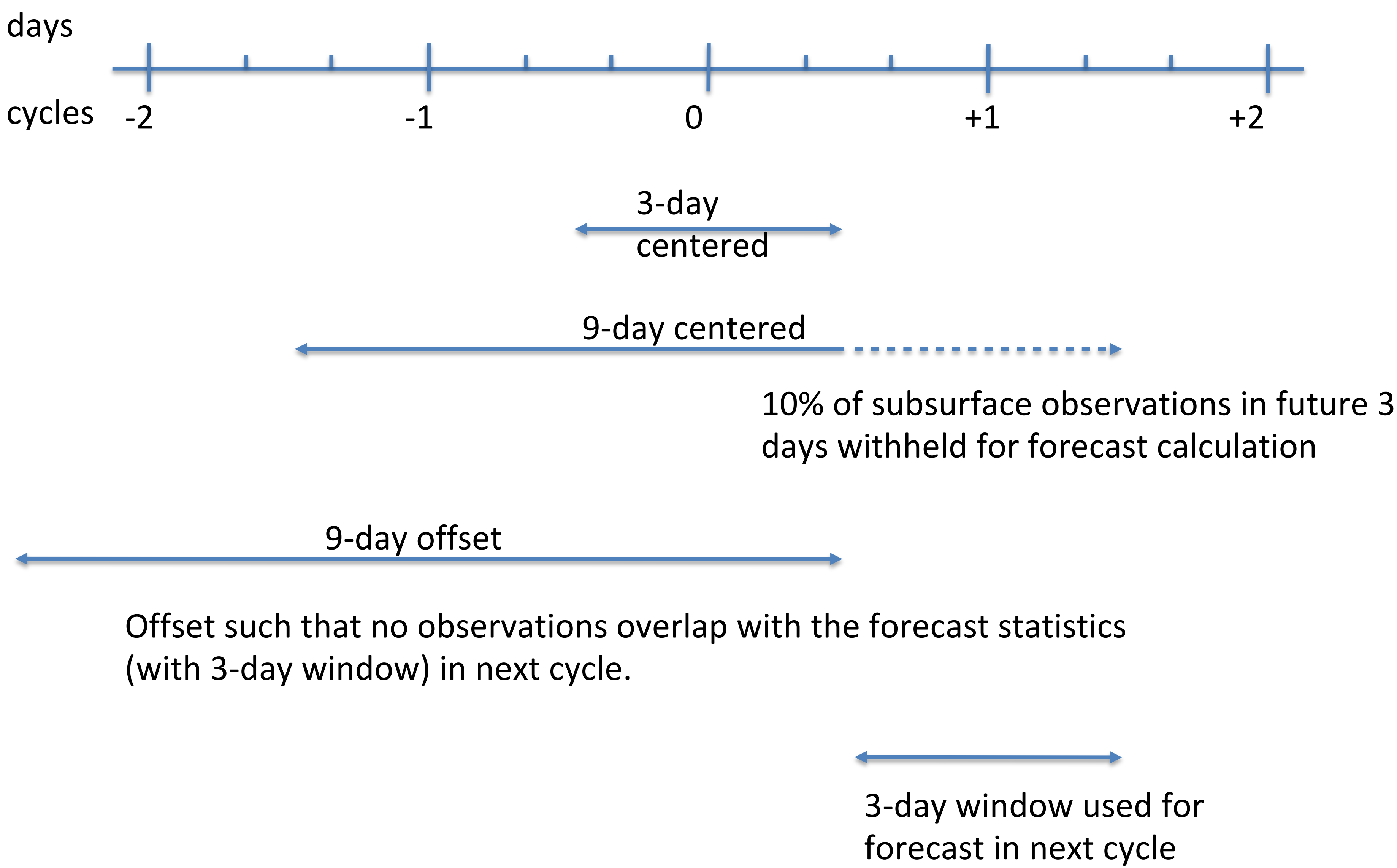
2. DA calculation of forecast and analysis (DA-H) and obtain new initial condition.

7. Run ocean model, generate initial background for next cycle.

High-resolution/Fast



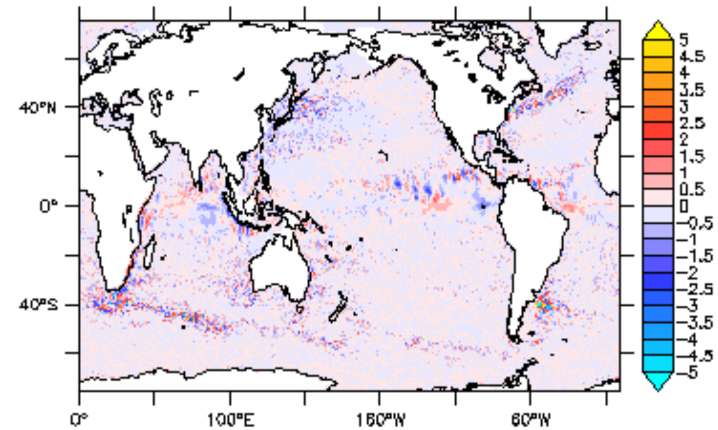
DA Cycles and Observation Windows Schematic



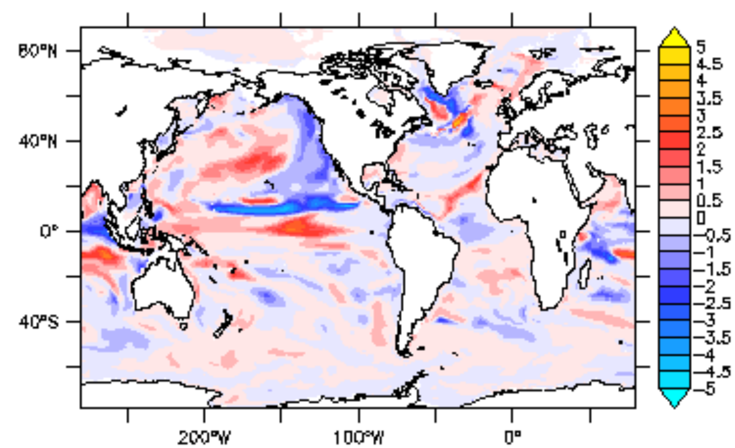
BRAN Multiscale DA - Ensembles

- BRAN ensemble “3-day minus 3-month average”; captures eddies and mesoscale variability.

- ACCESS 1-deg ensemble of 480 monthly anomalies (wrt. climatology of detrended time series) from 40-years of ocean-ice model with historical forcing (JRA-55); captures broad 1000-km scale variability.



OFAM temp ens. member– 100m



ACCESS 1–deg temp ens. member– 100m