The Bureau of Meteorology

National Report Australia

OPST-8, November 2023

Gary Brassington
Bureau of Meteorology

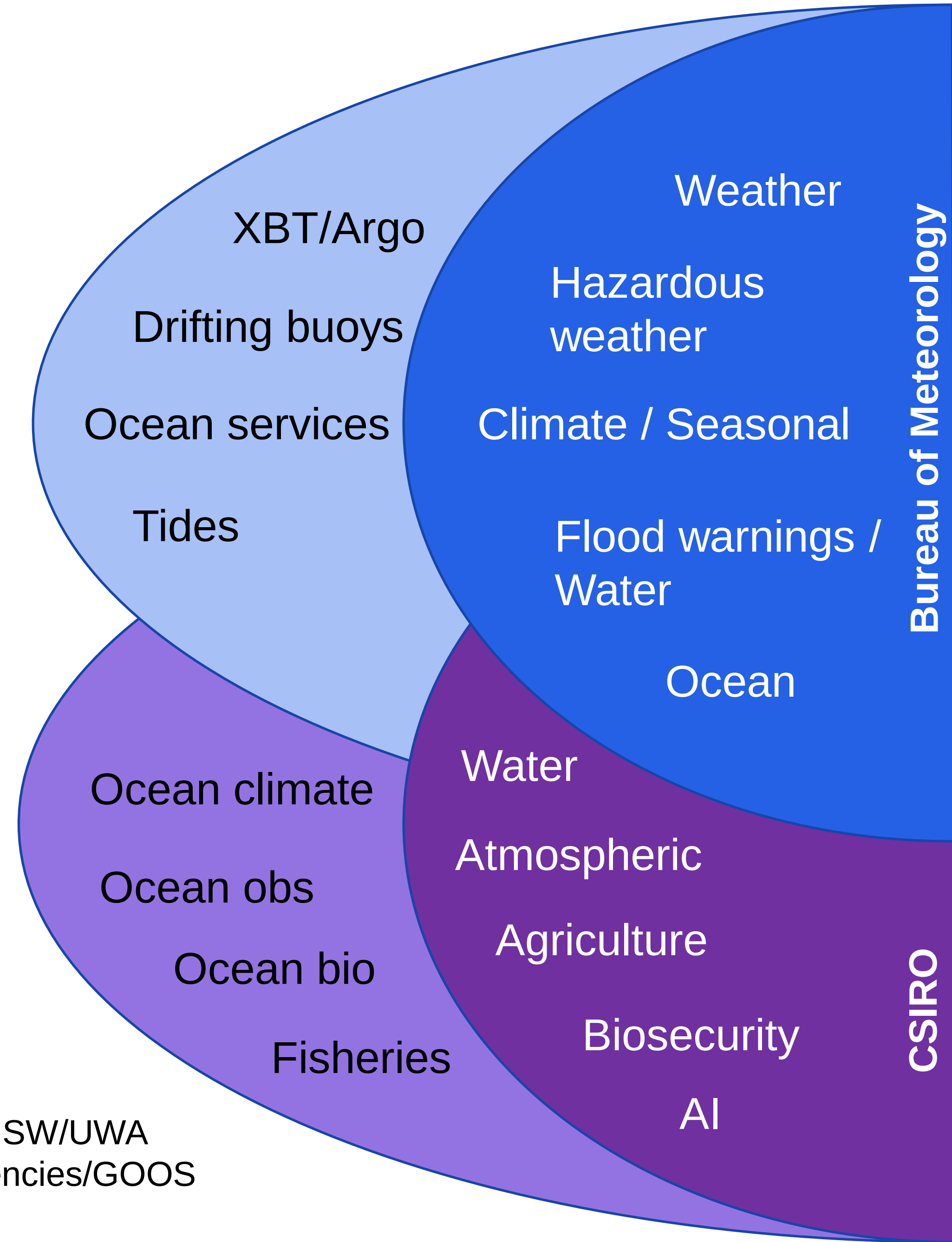
Scope

Bureau of Meteorology

- Global/Regional
- OceanMAPS, ADEPT
    - Eddy-resolving => Internal-tides
    - large scale HPC/fixed domain
- MOM5 / ROMS / NEMO
- EnKF-C, EnKF/EnOI
- Ensemble forecasting
- Coupled forecasting
- Reanalysis – EnKORe, ADEPT
    - Model climatologies
- Acoustic verification

CSIRO

- Shelf/Coastal/Littoral/Surf/BGC
- BRAN/BRAN-bio
- ROAM
- SHOC/CoMPAS
- ROAM-surf/Bio-ROAM
- Acoustics



Bluelink partners – Bureau/CSIRO/Defence
National partners – IMOS/COSIMA-2/ANU/UNSW/UWA
International partners – UKMO/GFDL/Sat-agencies/GOOS

Report - in one page

Operational system – OceanMAPSv4.0i

- EnKF data assimilation
- Hybrid EnKF (48-dynamic / 144-stationary)
- Good performance gains and comparisons
- Brassington, Sakov, Divakaran, Aijaz, Sweeney-Van Kinderen, Huang and Allen, 2023, June. OceanMAPS v4. 0i: a global eddy resolving EnKF ocean forecasting system. In *OCEANS 2023-Limerick* (pp. 1-8). IEEE.

OceanMAPSv4.1i (PRE-OP) (mid-2024)

- Optimized EnKF more gains for all variables
- Greatest gains for SST

OceanMAPSv4.2 (TRIAL) (2025) **–** coupled ocean-sea-ice and assimilation of SIC
OceanMAPSv5 (Research) – NEMO ORCA12 + EnKF

BRAN2020

- routine updating
- Some developments on multi-scale EnOI
- Extension to include BGC variables

EnKORe

- 12 year reanalysis

Coupled NWP – GC5 UM + NEMO ORCA025

- Development ORCA025 + EnKF

OTHER QUESTIONS

Plans for digital twins and AI/ML

- No current plans for digital twins within Bluelink
- AI/ML – a lot of interest developing across the Bureau and CSIRO
    - Some small projects scoping the capability

Relationship and communalities with NWP groups

- Coupled NWP is active with the UM partnership
- Key challenges for merger of capabilities
    - Eddy-resolving or better models
    - Ensemble-based data assimilation vs 4DVar or hybrid-4DVar

Awareness of OP-DCC interactions (e.g. Atlas), best practice approaches, etc

- Some interest to contribute, discussion on region-33, resource limited

Operational system

OceanMAPSv4.0i*

*Ocean Model, Analysis and Prediction System (OceanMAPS)
v4.0 - Version 4.0
i – interim system (New DA / Persist model)

OceanMAPS version 4.0i

System

Model
OFAM3 (MOM5)
75S-75N, 0-360
0.1° x 0.1°, 51 z*-levels (5m top cell)

Data assimilation
EnKF-C
Hybrid-EnKF
48 dynamic members
144 low-mode members
3-day analysis cycle (-3 day BRT)
FGAT, Restart initialisation

Atmospheric forcing
ACCESS-G3 (APS3)
Bulk formulae

Observations
In situ profiles (GTS, GDAC)
Satellite altimetry (RADS, JASON3, SARAL, Sentinel-3A/3B, Cryosat-2)
Satellite SST (AMSR2, NAVOCEANO, NPP-VIIRS, NOAA20-VIIRS)

Forecasts
EnKF (-3 day analysis) + 3 day hindcast
Daily 7 day forecasts
Average restart forecast
3 synchronous ensemble forecasts
7 lagged ensemble forecasts

New features

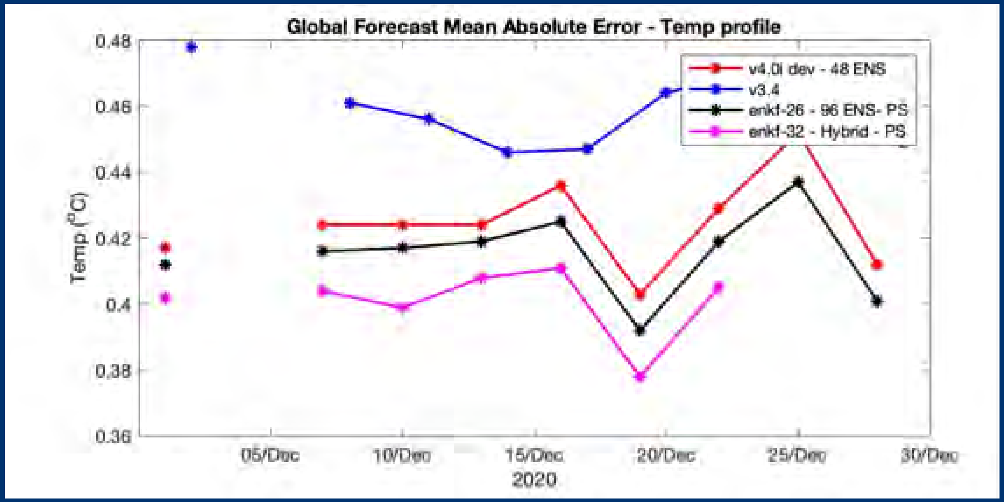
Hybrid EnKF
48-dynamic ensemble members
144-stationary model anomalies
- Anomaly (month– annual mean)

~7 kSU / day

OPERATIONAL – OCT 2022

Impact

Performance
- Reduction in increment variance
- Improved dynamical balance of increments
- Beats persistence
- Reduction in abyssal noise
- Separation of eddies
- Sustaining low signal to noise eddies



References

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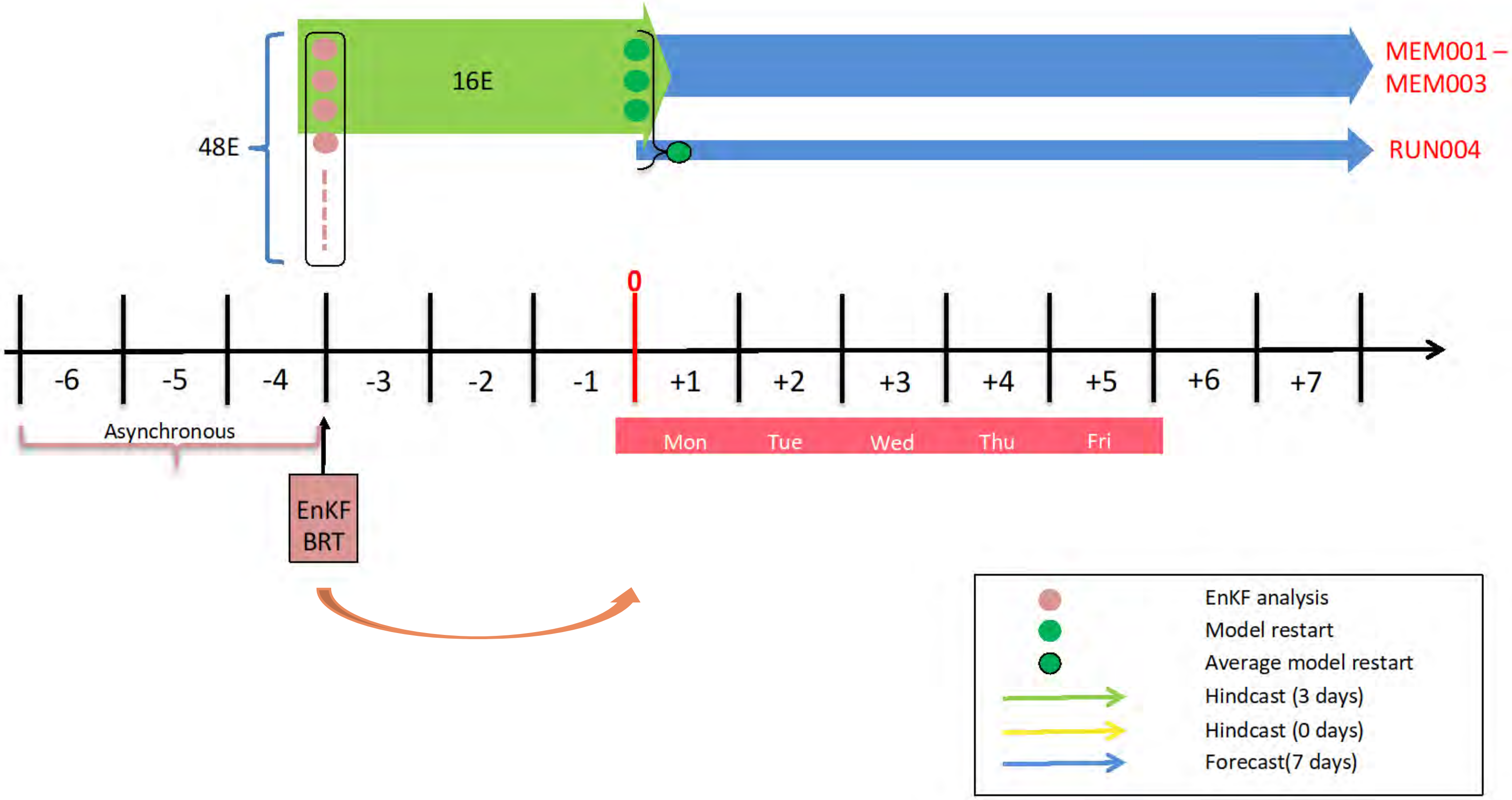
Sakov, 2014.. *arXiv preprint arXiv:1410.1233*.

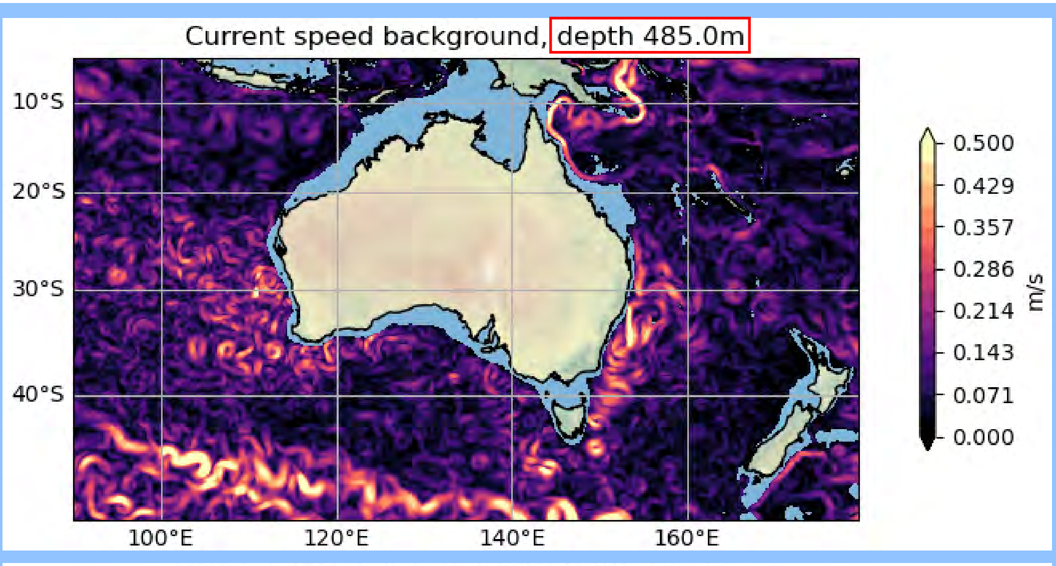
Bluelink
Ocean Forecasting

OPERATIONAL SCHEDULE



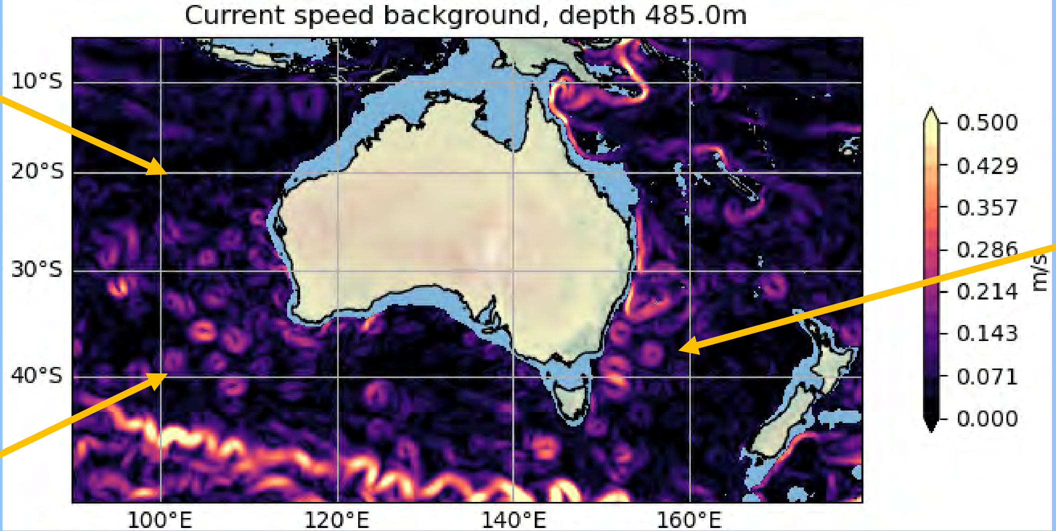
EnKF vs EnOI

OceanMAPSv3.4



Realistic passive regions

OceanMAPSv4.0i



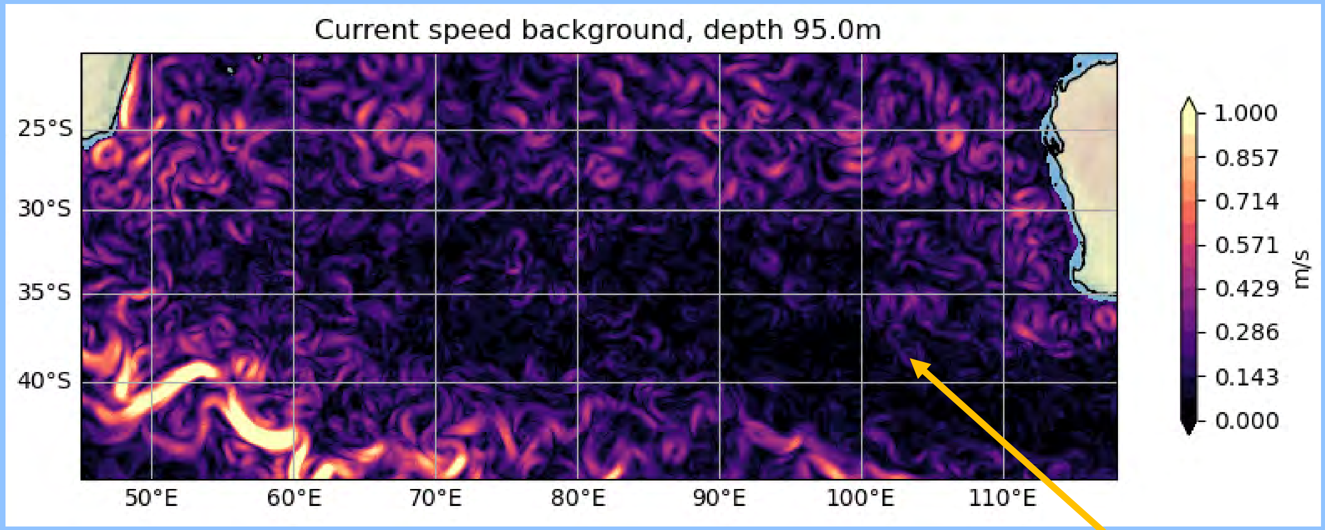
Clear separation of eddies

Clearly defined eddies that are observed

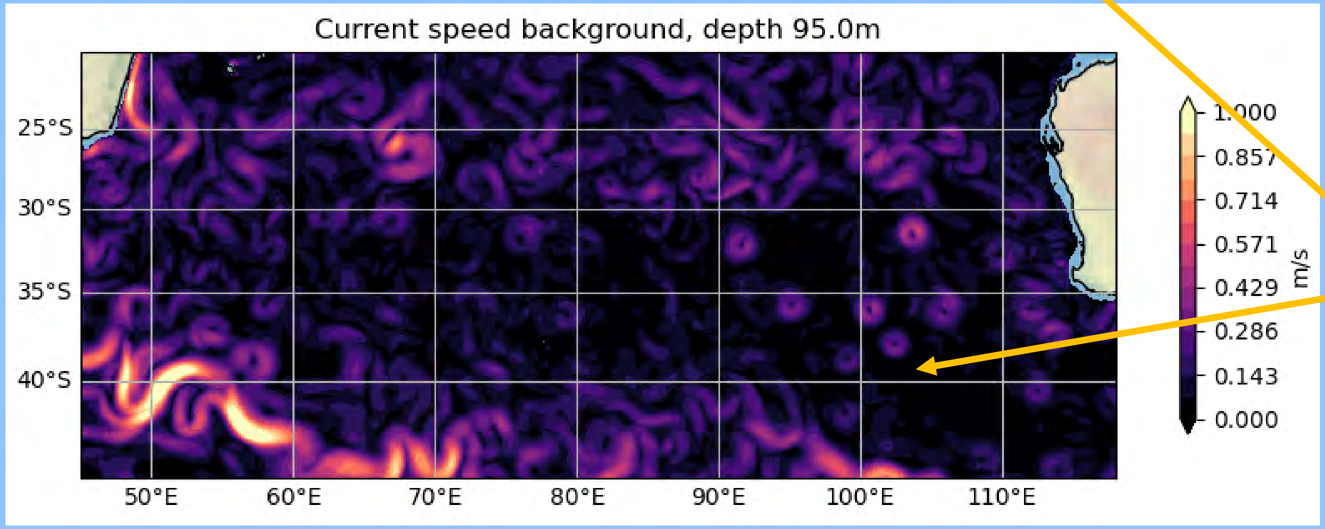
EnKF vs EnOI

Indian ocean

EnOI



EnKF



EnKF retains eddies

EnKF vs EnOI

CORRELATION COEFFICIENTS - (eta,TEMP), (eta, SALT) in the presence/absence of eddies

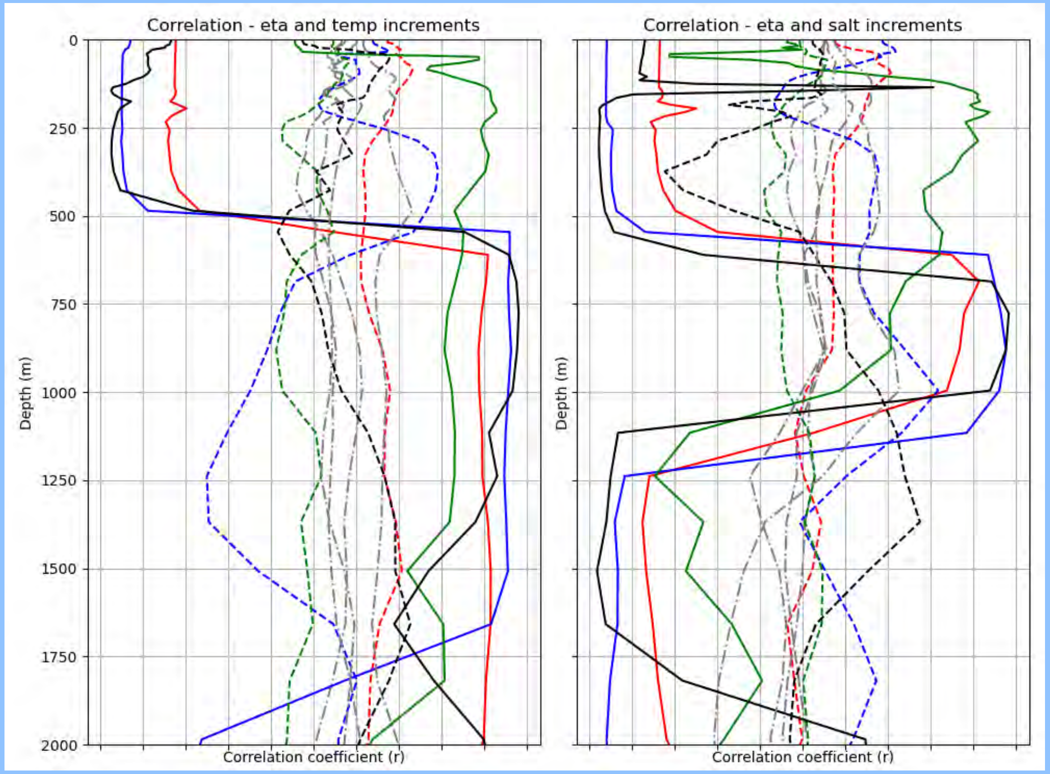
Four eddies (cold-core) from SE Indian Ocean eddy graveyard.

Identified through SLA signature in EnKF ensmean.

Solid lines are correlations for EnKF ensemble increments when eddy is present

Dashed lines are correlations for EnKF ensemble increments at same location on a different day (no eddy)

Grey lines are correlations for EnOI stationary ensemble members at the same location.



EnKF vs EnOI

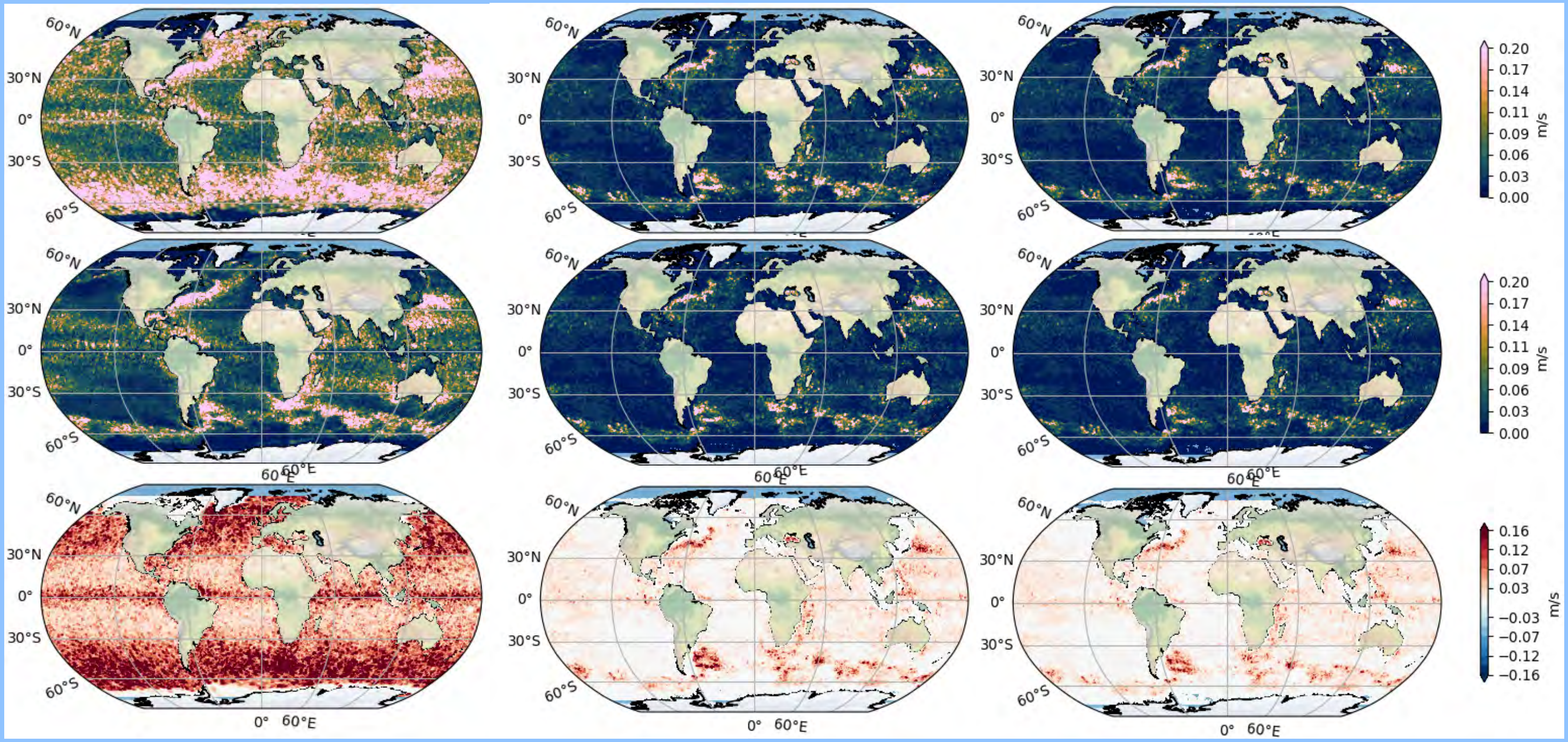
current increments

	V3.4 EnOI	EnKF MBR 001	EnKF ensmean

Actual $|\mathbf{u}_{inc}|$

Available geostrophic $|\boldsymbol{u}^{a}_{inc}|$

Difference $\Delta\mathbf{u}_{inc}$



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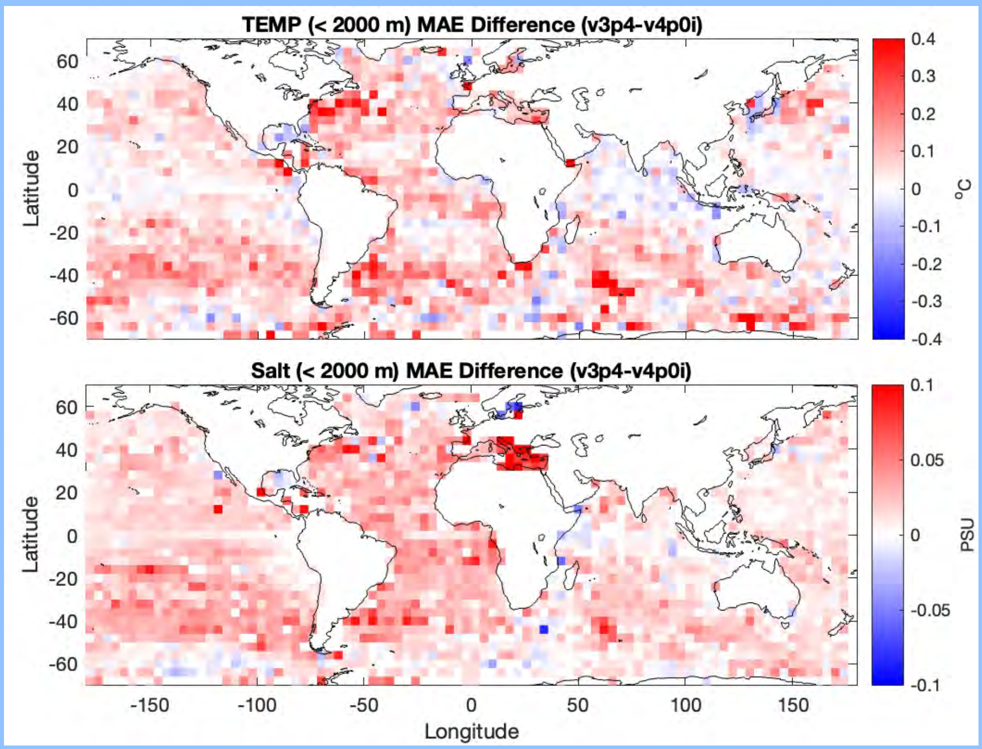
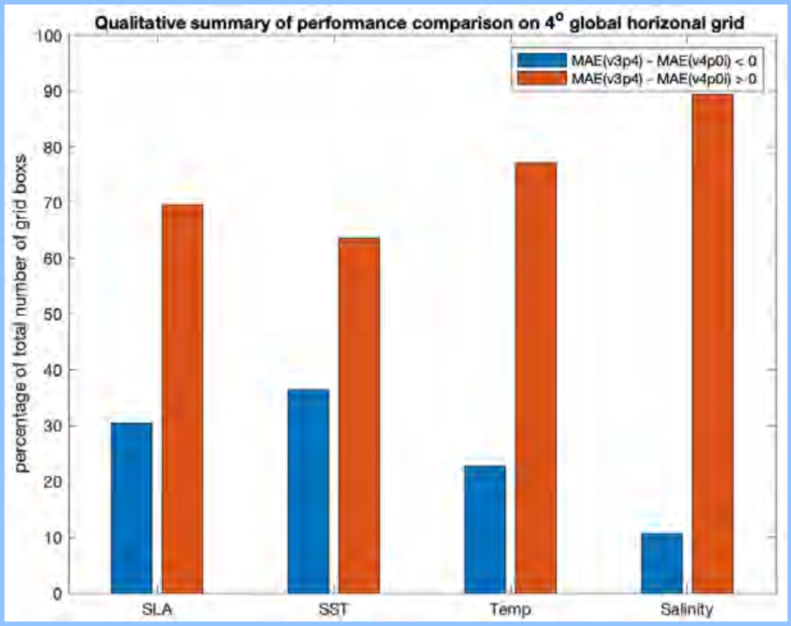
2021 04 29

EnKF vs EnOI

T/S



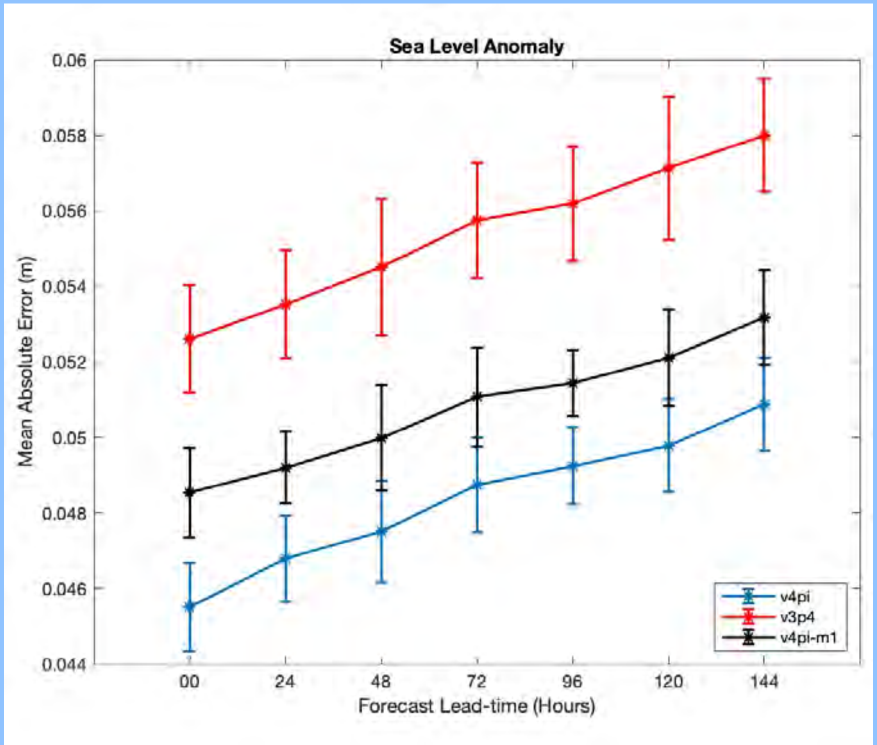
The difference in Mean Absolute Difference (MAD) of OceanMAPSv3.4 minus OceanMAPSv4.0i each compared with a common set of vertical in situ Argo profiles of temperature over the upper 2000m for the hindcast period Jul 2021to Jun 2022. The MAD statistics are applied each 4 x 4 degree bin.

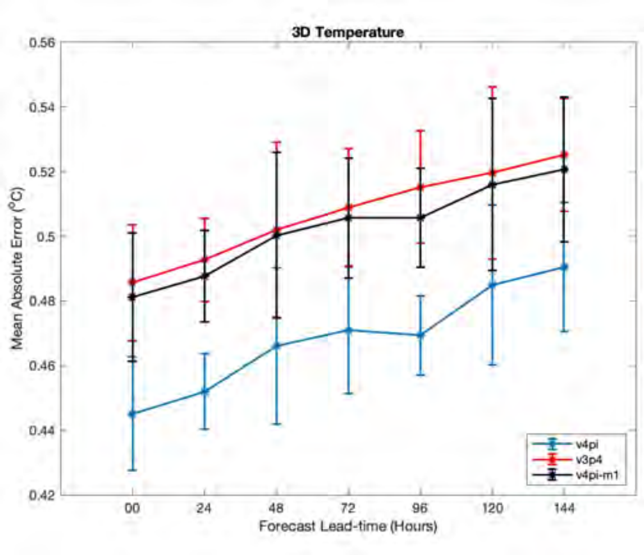


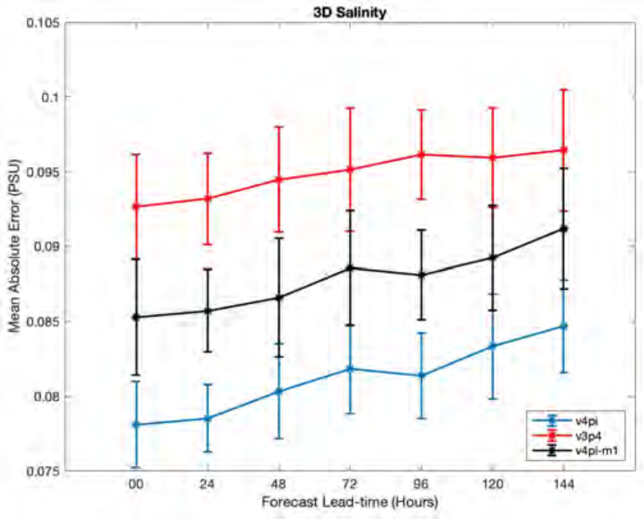
Percentage of negative(blue) and positive(red) bins of MAE difference (v3.4 – v4.0i)

Brassington, Sakov, Divakaran, Aijaz, Sweeney-Van Kinderen, Huang and Allen, 2023, June. In *OCEANS 2023-Limerick* (pp. 1-8). IEEE.

EnKF performance

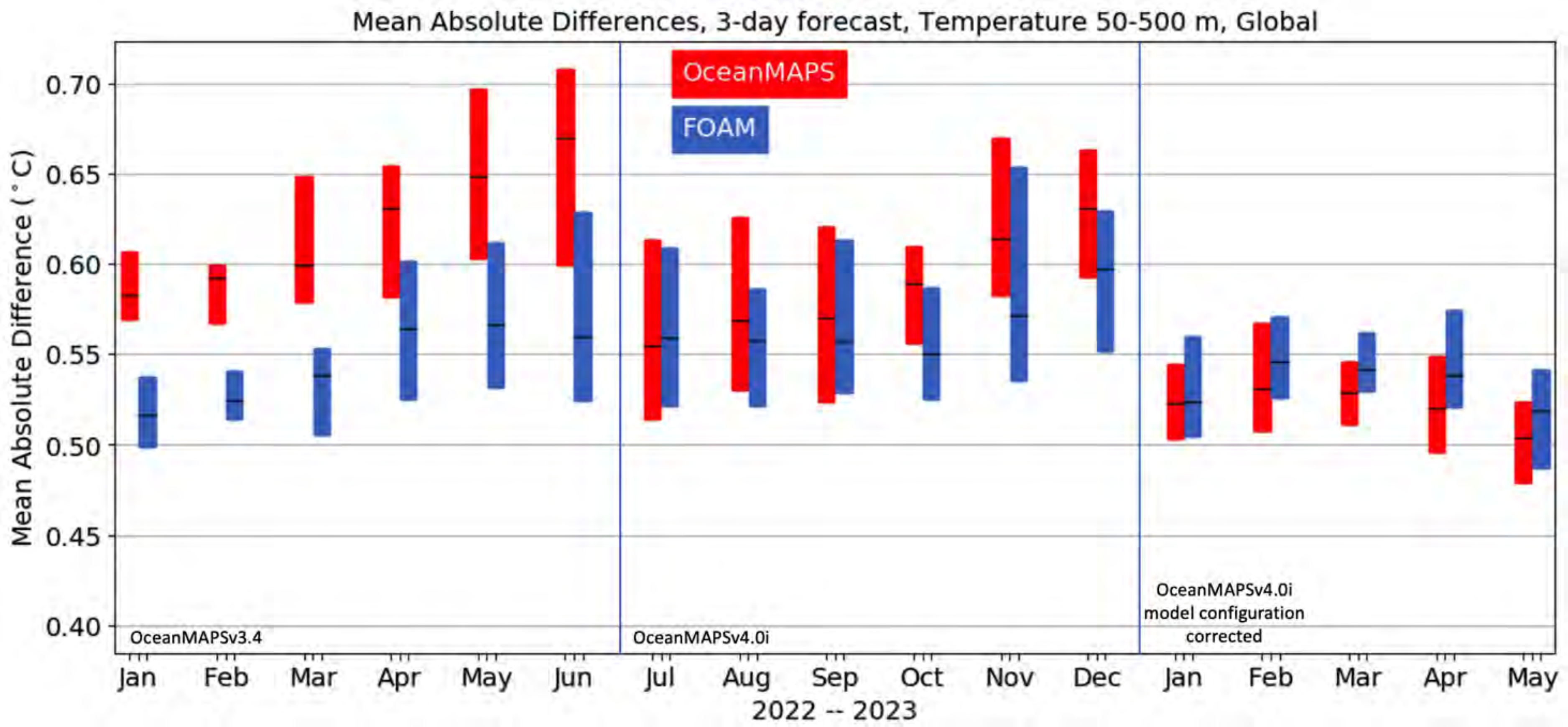






EnKF comparison

Temp

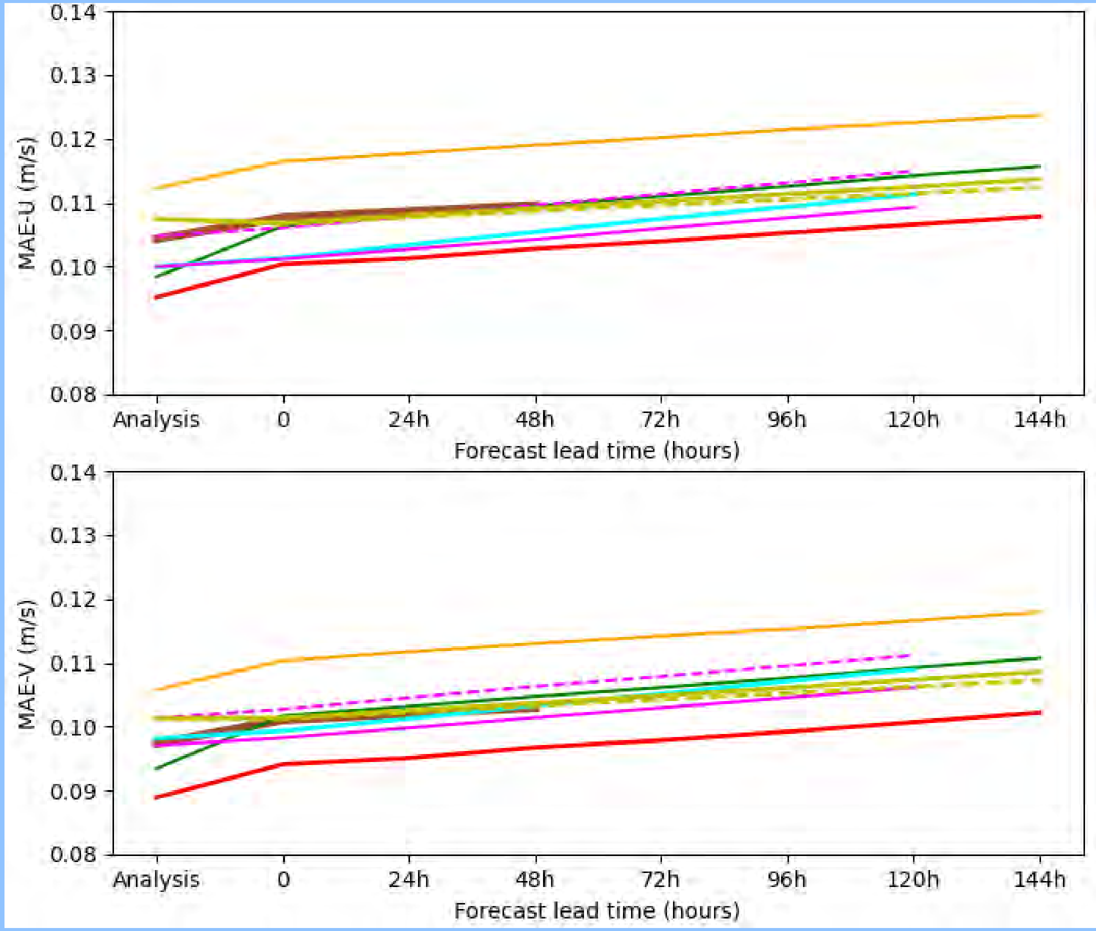


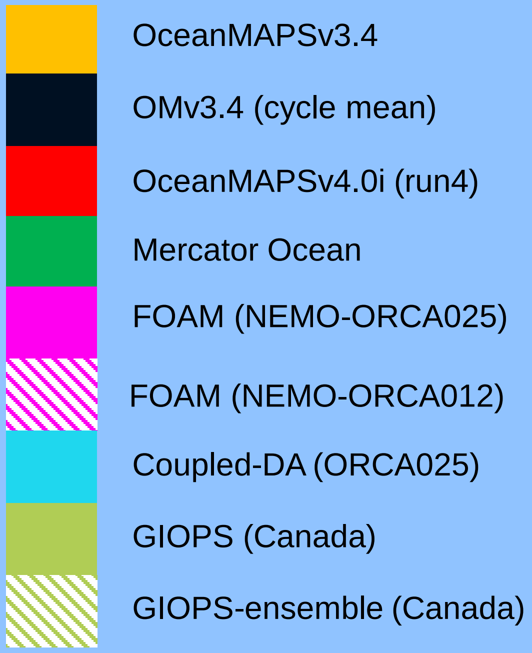
EnKF comparison

Currents

Zonal Current MAE (ms-1)

Meridional Current MAE (ms-1)





Period
20 May 2021 - 16 May 2022
OMAPS, ENS-OMAPS, Moi, GDPS, GEPS
6 Jan 2021 – 16 May 2022
OMAPSv4.0i
20 May 2021 - 28 Feb 2022
FOAM, FOAM12, and CPLDA

Aijaz, Brassington, Divakaran, Régnier, Drévillon, Maksymczuk and Peterson, 2023. *Ocean Modelling*, *186*, p.102241.

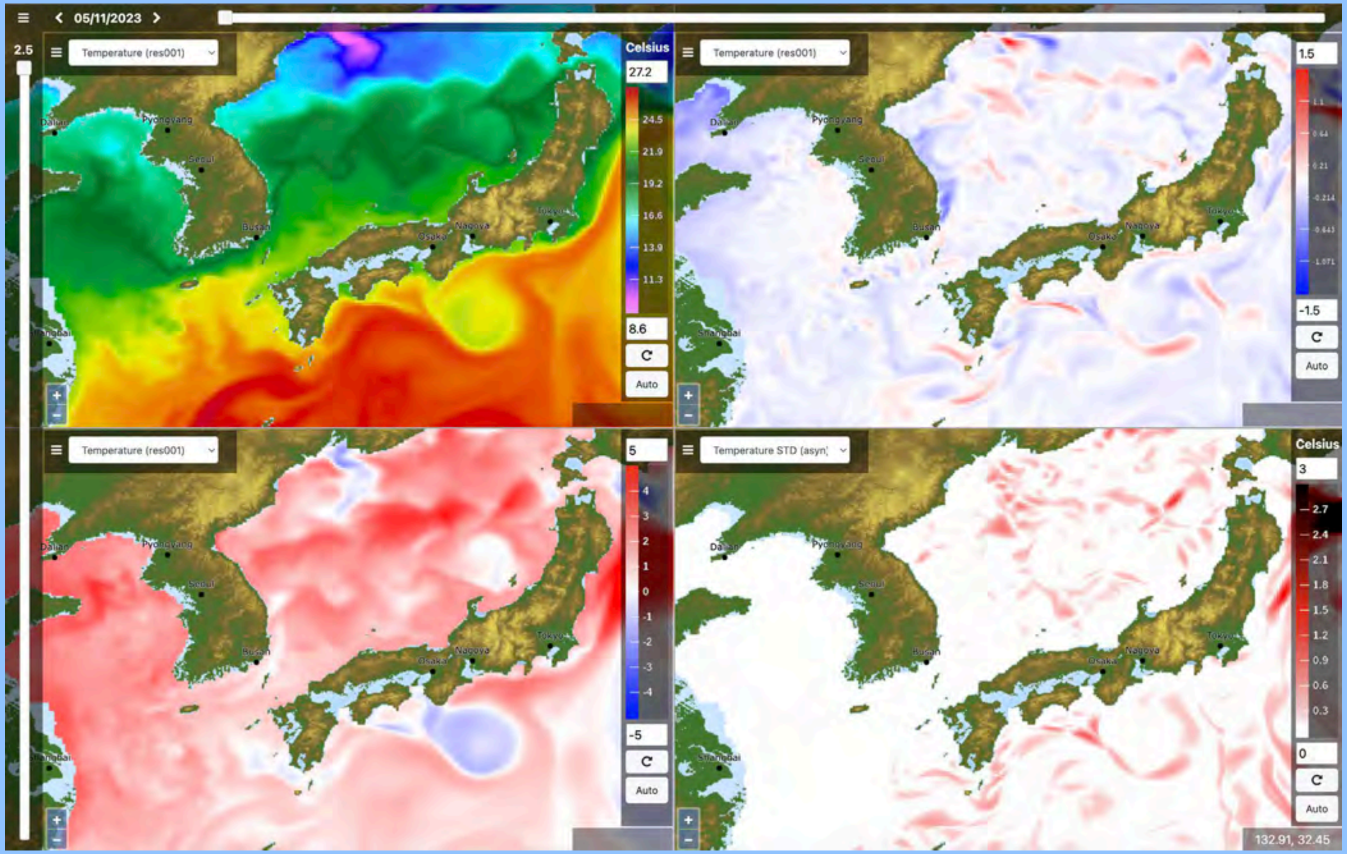
Forecast/hindcast products

7 day forecasts - average restart, member 1, 2 other members

Synchronous(3-mem)/Asynchronous(7-mem) ensemble std. dev.

48-member ensemble average/std. dev. hindcast

Tendency



Seasonal anomaly

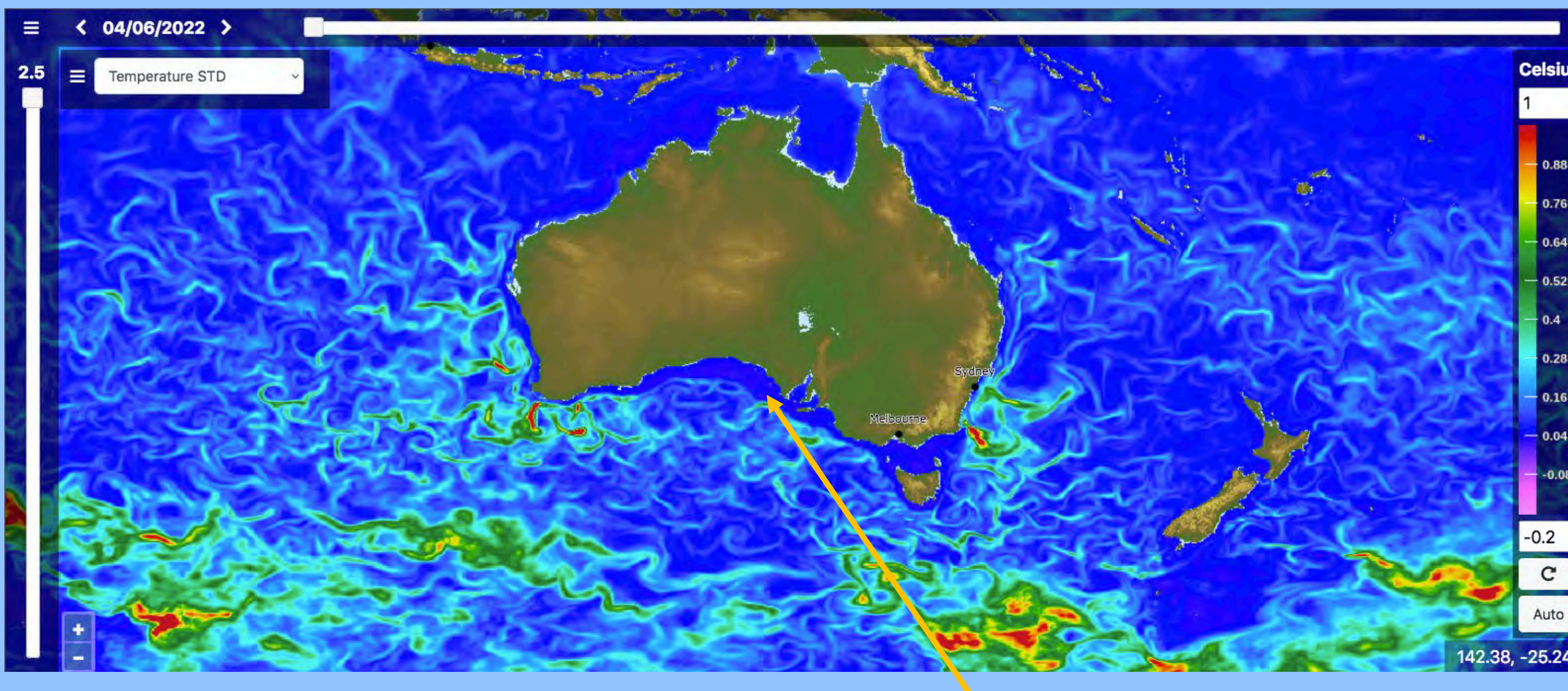
Asynchronous Std. Dev.

Forecast/hindcast products

7 day forecasts - average restart, member 1, 2 other members

Synchronous(3-mem)/Asynchronous(7-mem) ensemble std. dev.

48-member ensemble ensemble average/std. dev. hindcast



Underestimated

Known upgrades

OceanMAPSv4.1i (mid-2024)

OceanMAPSv4.2   (2025)

OceanMAPS version 4.1i

System

Model
OFAM3 (MOM5)
75S-75N, 0-360
0.1° x 0.1°, 51 z*-levels (5m top cell)

Data assimilation
EnKF-C / Hybrid-EnKF
48 dynamic members
144 low-mode members
1-day analysis cycle (-3 and -2 day BRT)
FGAT, Restart initialisation

Atmospheric forcing
ACCESS-G4 (APS4)
Bulk formulae

Observations
In situ profiles (GTS, GDAC)
Satellite altimetry (RADS, JASON3, SARAL, Sentinel-3A/3B, Cryosat-2)
Satellite SST (AMSR2, NAVOCEANO, NPP-VIIRS, NOAA20-VIIRS)

Forecasts
EnKF (-3 day analysis) + 3 day hindcast
Daily 7 day forecasts
Average restart forecast
3 synchronous ensemble forecasts
7 lagged ensemble forecasts

New features

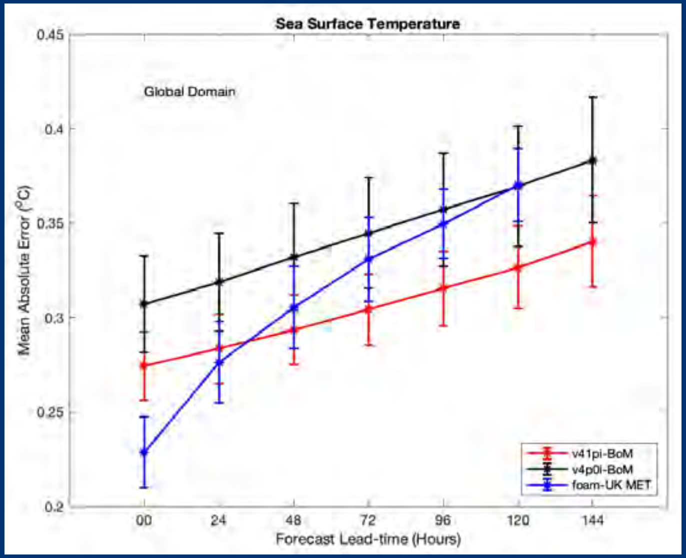
1-day analysis cycle
-3 and -2 day analyses
G4 fluxes
Ready for full ensemble forecasting

STATUS - PRE-OPERATIONAL TRIAL
TARGET - mid-2024

Impact

Performance

- Improved forecast skill for all prognostic variables
- Significant performance gains for SST



References

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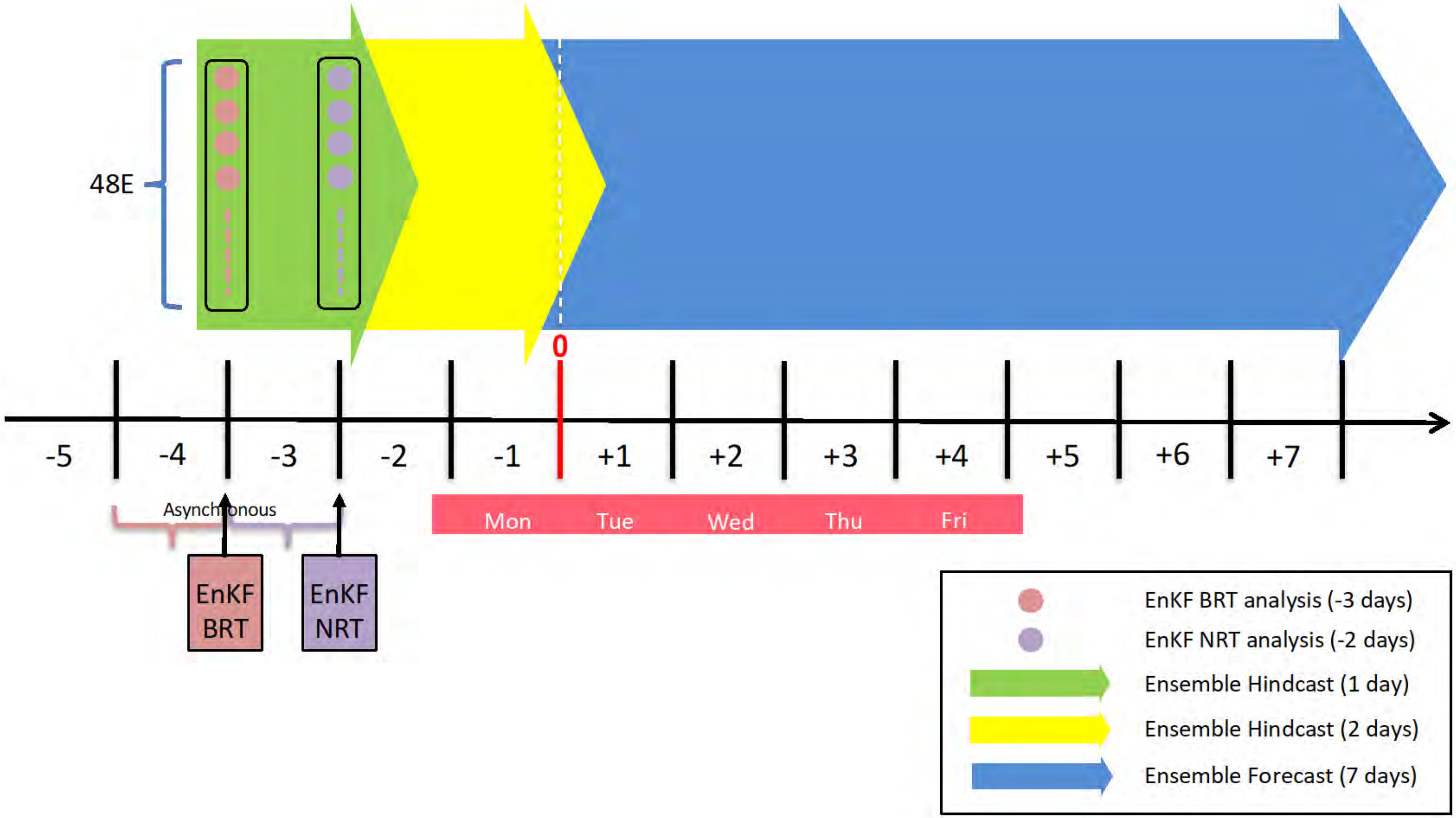
Sakov, 2014.. *arXiv preprint arXiv:1410.1233*.

Bluelink
Ocean Forecasting

TRIAL SCHEDULE

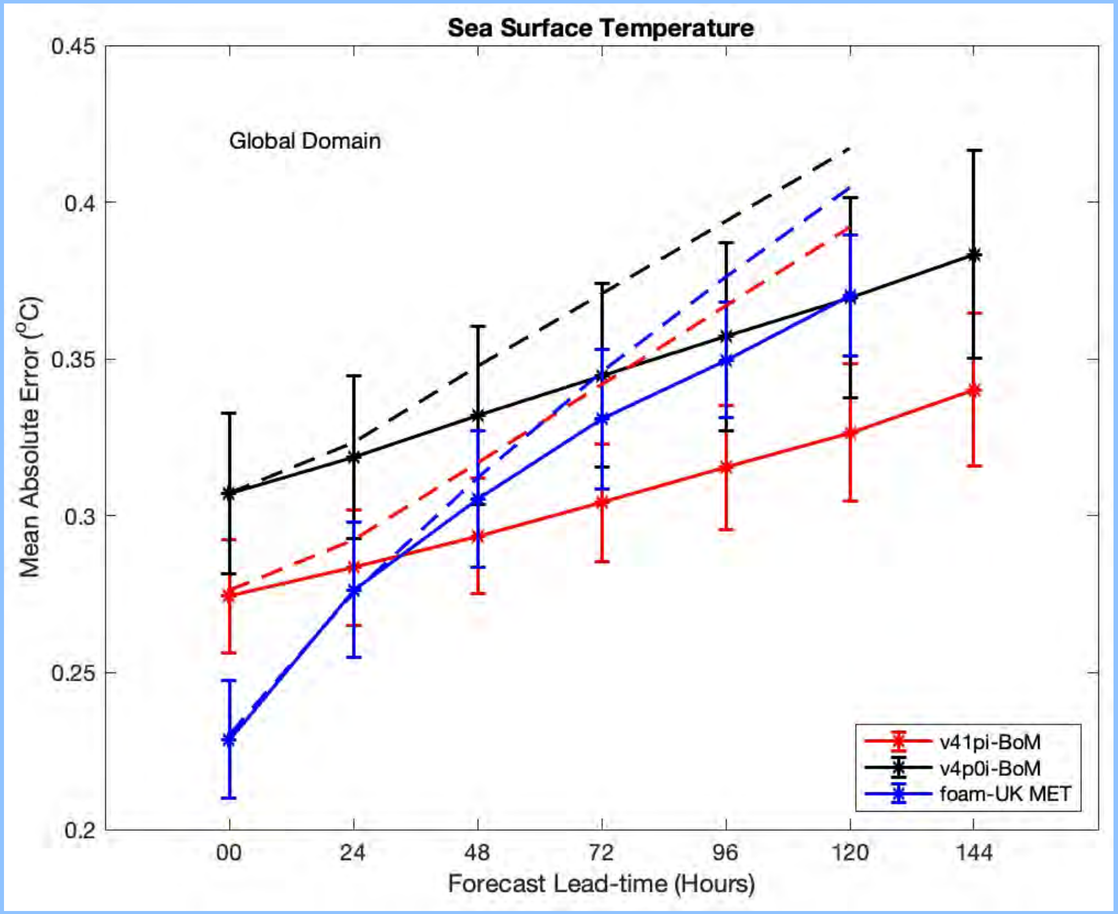
DAILY
CYCLE



Foundation for ensemble-based probabilistic forecasting
Optimisation required on the ensemble atmospheric forcing

How do we compare?

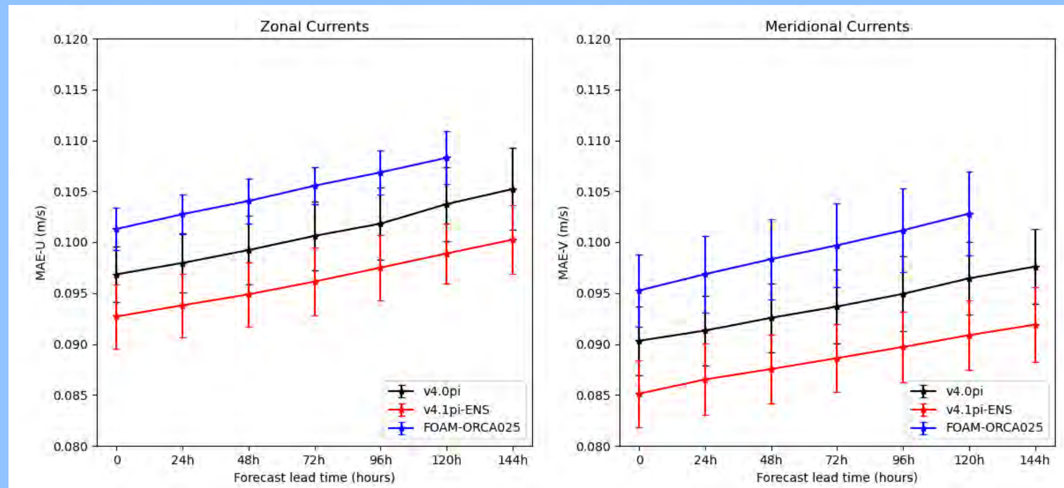
SST



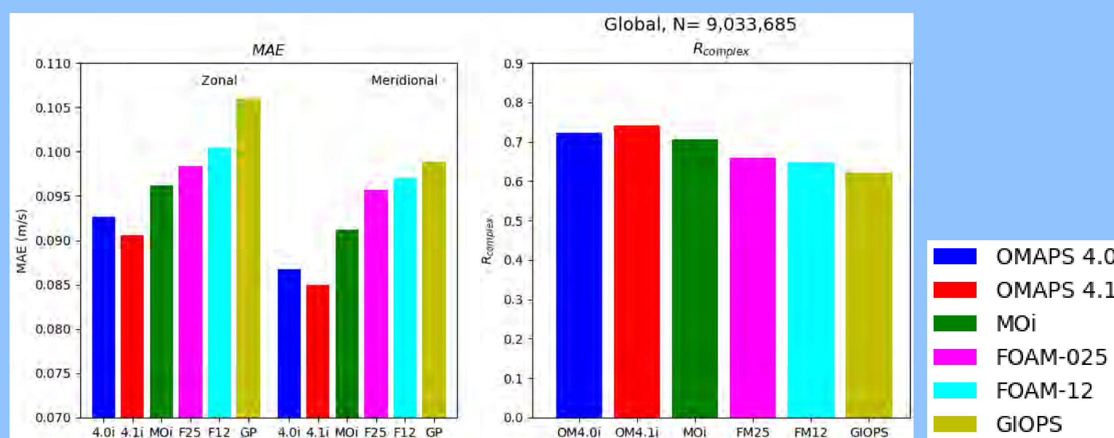
Comparison of global sea surface temperature forecasts against in situ drifting buoy observations for Jan 2023. The mean and standard deviation of the daily Mean Absolute Error (MAE) is shown versus forecast lead time. The three systems include the ensemble mean of the proposed OceanMAPSv4.1i (red), the average restart forecast of the operational OceanMAPSv4.0i (black) and the operational UKMO FOAM ORCA025 system (blue).

How do we compare ?

currents



Comparison of global ocean currents (15m) forecasts against drifting buoy observations for Jan 2023. The mean and std. dev. of the daily Mean Absolute Error (MAE) is shown versus forecast lead time. OceanMAPSv4.1i (red), the average restart forecast of OceanMAPSv4.0i (black) and UKMO FOAM ORCA025 (blue). The Lagrangian trajectories are 24 hr av. filtered and corrected for Stokes Drift.



$R_{complex}$ – complex correlation

OceanMAPS version 4.2

System

Model
ACCESS-OM2-01 (MOM5/CICE5)
85S-90N, 0-360
0.1° x 0.1°, 75 z*-levels (1.1m top cell)
5 thickness categories

Data assimilation
EnKF-C / Hybrid-EnKF
48 dynamic members
144 low-mode members
3-day analysis cycle (-3 day BRT)
FGAT, Restart initialisation

Atmospheric forcing
ACCESS-G4/GE4 (APS4)
Bulk formulae

Observations
In situ profiles (GTS, GDAC)
Satellite altimetry (RADS, JASON3, SARAL, Sentinel-3A/3B, Cryosat-2)
Satellite SST (AMSR2, NAVOCEANO, NPP-VIIRS, NOAA20-VIIRS)
Satellite SIC (AMSR2, SSMI/S)

Forecasts
EnKF (-3 day analysis) + 3 day hindcast
Daily 7 day forecasts
Average restart forecast
3 synchronous ensemble forecasts
7 lagged ensemble forecasts

New features

Model
Coupled ocean-sea-ice
Full global ocean
75 vertical levels
1.1m top cell

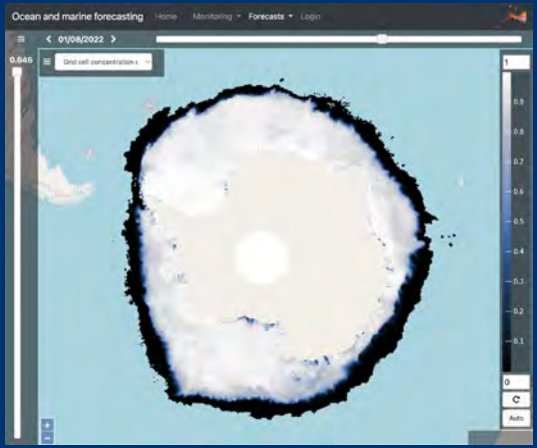
Data assimilation
SIC (AMSR2, SSMI/S)

Atmospheric forcing
ACCESS-GC5/GCE5

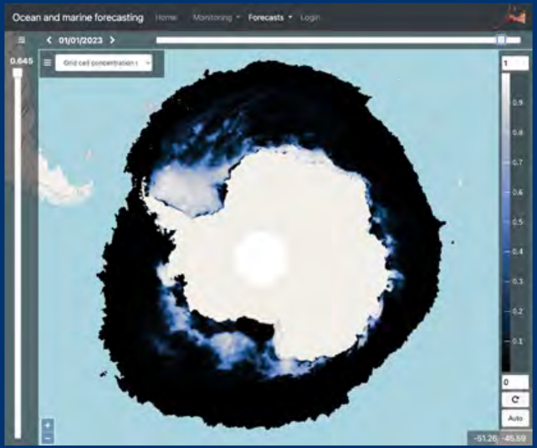
STATUS - RESEARCH DEMONSTRATOR

Impact

Performance
- First sea-ice forecasts at Bureau
- Sea-ice skill for growth phase
- Underprediction sea-ice melt
- Realistic MIZ forecast tendency
- Interior sea-ice underspread



1st Aug 2022



1st Jan 2023

References

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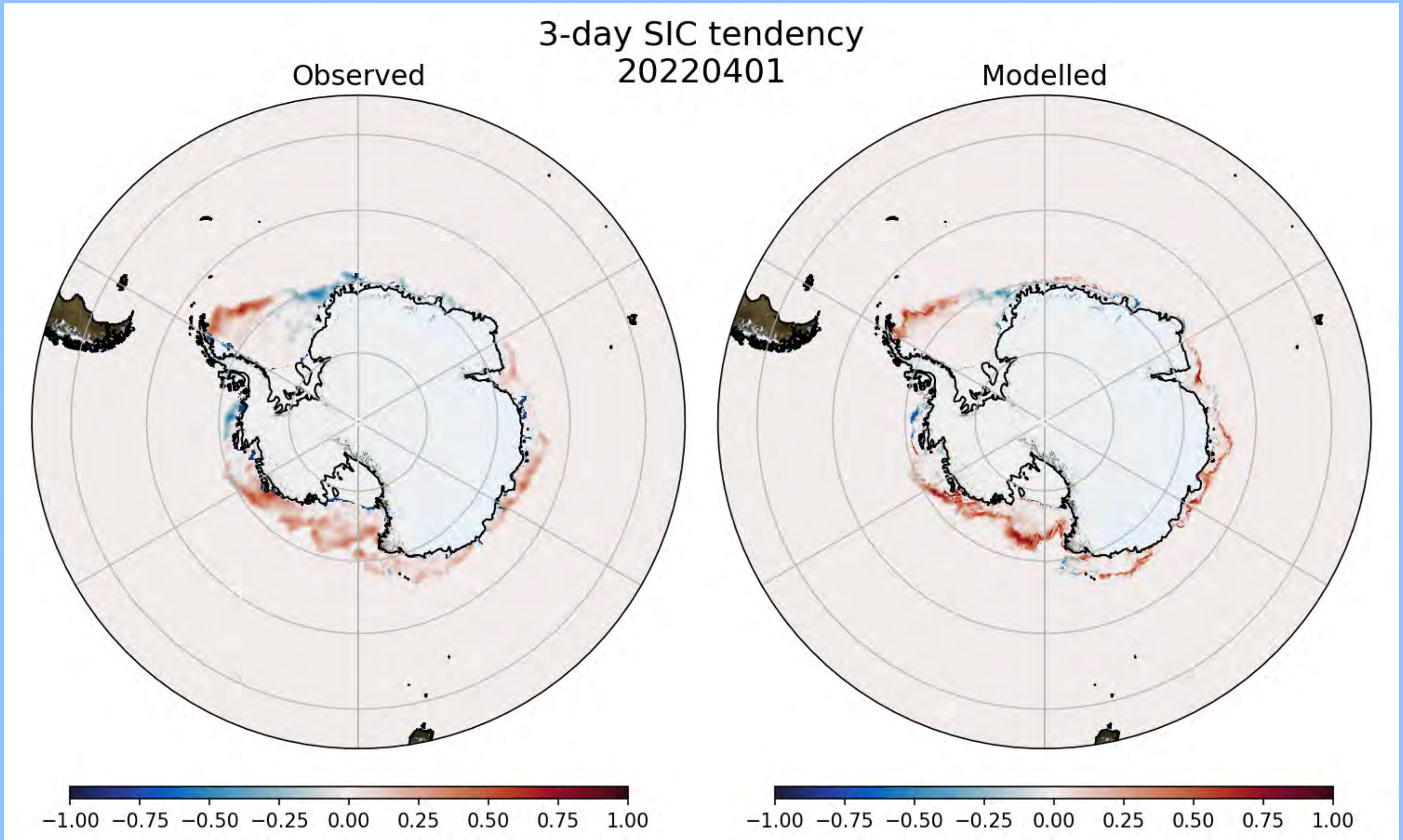
Bluelink
Ocean Forecasting

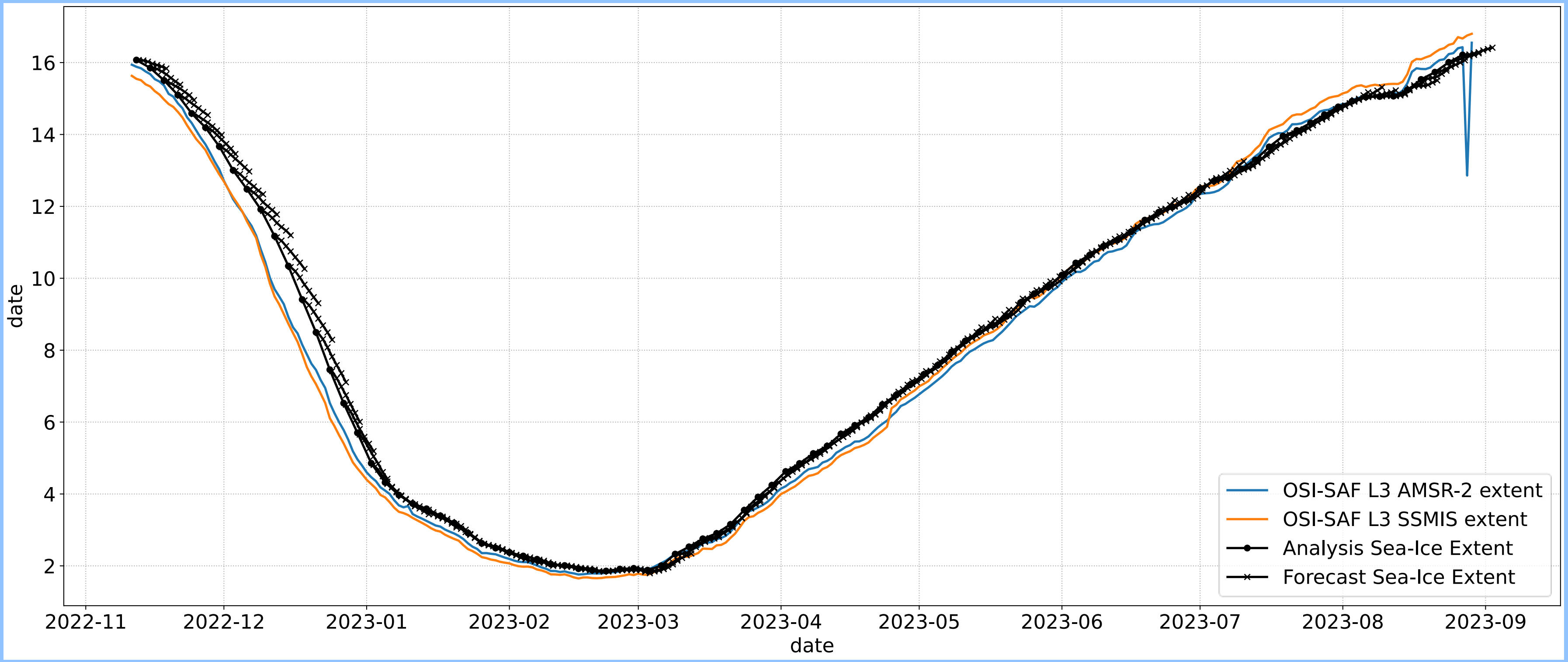
Performance

SIC



Performance

SIC



Analysis and forecast Antarctic sea-ice extent since 12 Nov 2022

Other developments

ACCESS-GE

- Optimise EnKF
- Ensemble forecasting

NEMO

- NEMO ORCA025 + EnKF => Coupled NWP
  - Encouraging performance
- NEMO ORCA12 (computational optimisation)

Coupled NWP

- GC5 UM + NEMO ORCA025
- Decision EnKF vs NEMOVAR

Other activities

Machine learning/AI

Series of activities being explored across portfolio
Couple of projects funded
Scope for many areas but no specific successes at this stage

Digital twins

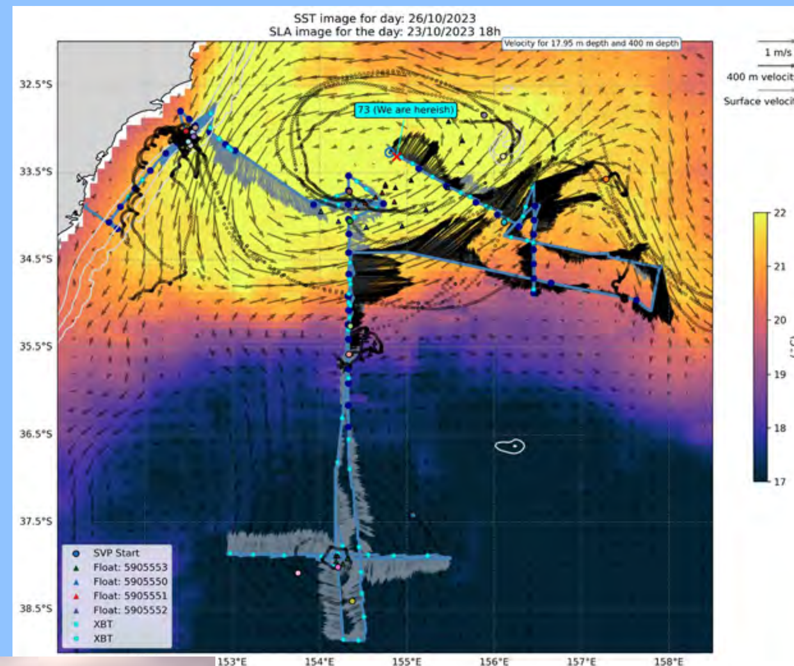
No specific activities being explored within Bluelink
Some scenario work has been undertaken in other coastal projects

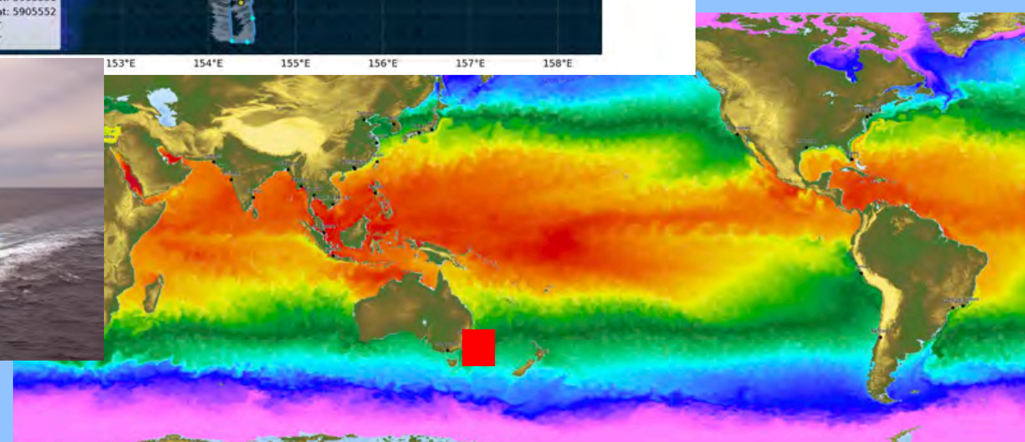
MNF Cruise

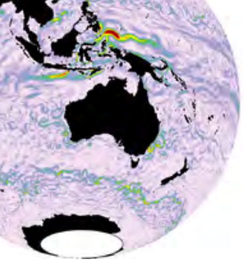
Tasman Sea
9th Oct – 2nd Nov 2023

Eddy depth structure
Eddy evolution
SWOT assimilation

Data collection
Argo
CTD casts
Drifting buoys
Sea-saw
ADCP



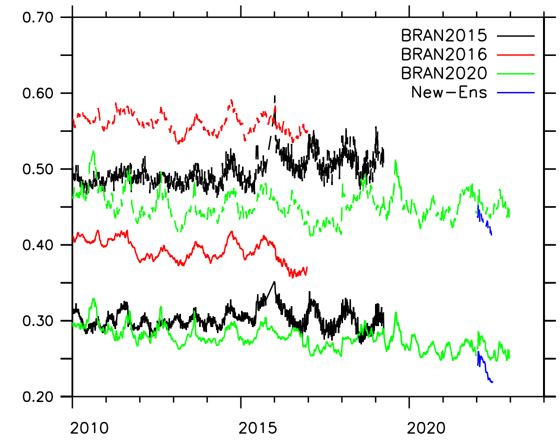




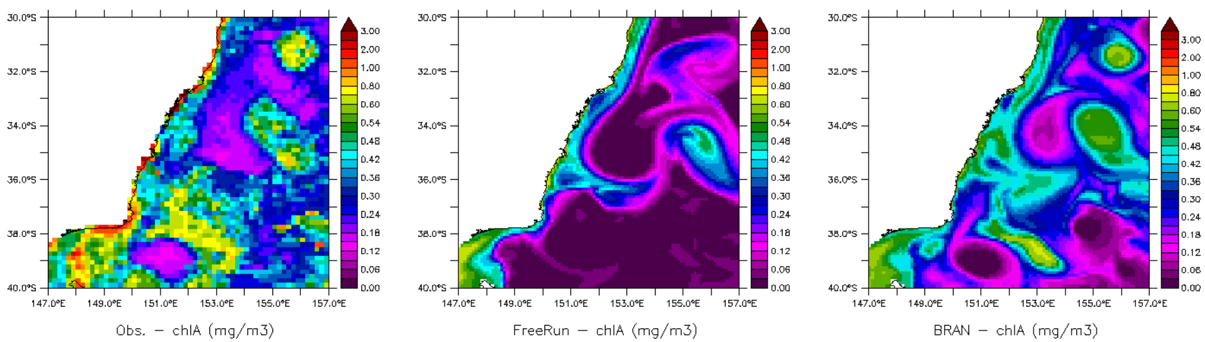
Updates to the Bluelink ReANalysis
BRAN2020 and beyond

- BRAN is a near-global ocean reanalysis at 0.1 deg. resolution; SST, sea level and insitu data are assimilated every 3 days with an Ensemble Optimal Interpolation DA system.
  The 2020 version of BRAN has output from 1993 to almost real-time that is publicly available:
  NCI Data Catalogue – https://doi.org/10.25914/6009627c7af03
  Data Description – ESSD, https://doi.org/10.5194/essd-13-5663-2021

- Average magnitudes of observation-model insitu temperature differences of recent versions of BRAN are shown (**upper right**) for both before and after analysis; differences from BRAN2020 (green) are smaller than previous versions (red and black). The next BRAN version (post-JRA55) will use new ensembles that further reduce these differences (blue).

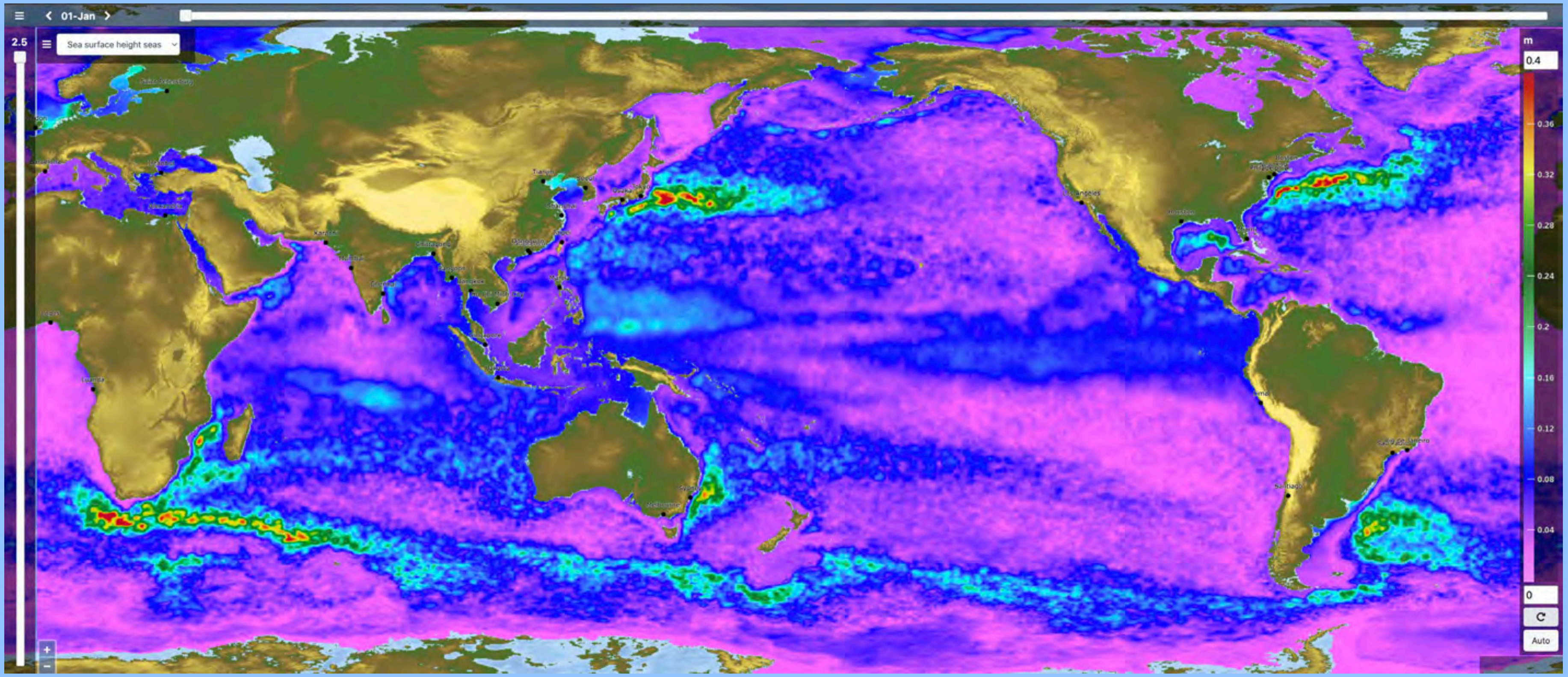


- Preliminary tests of BGC in BRAN show a good correlation of mesoscale features between simulated and observed chlorophyll relative to free-running tests (**lower right**), even without assimilating BGC data. BGC will be included in the next BRAN. Methods are being tested to reduce the magnitude of BGC artifacts at low latitudes associated with assimilation of physical data.



Observed and simulated surface chlorophyll – Tasman Sea

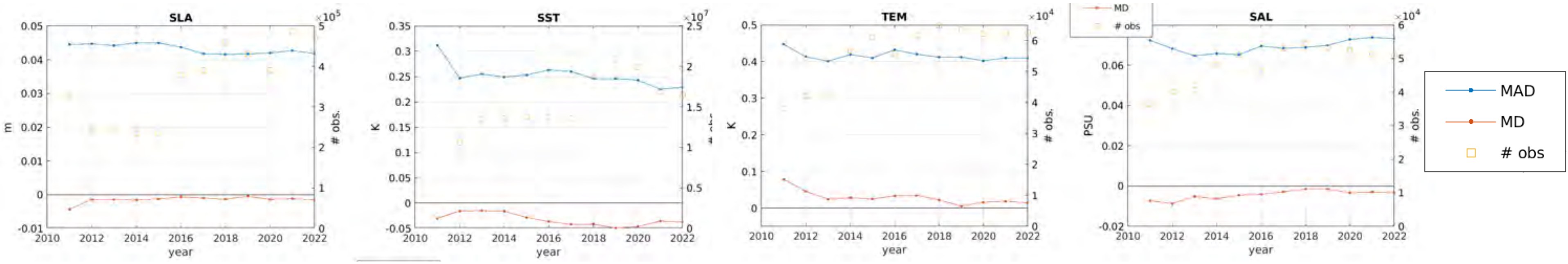
Model climatology

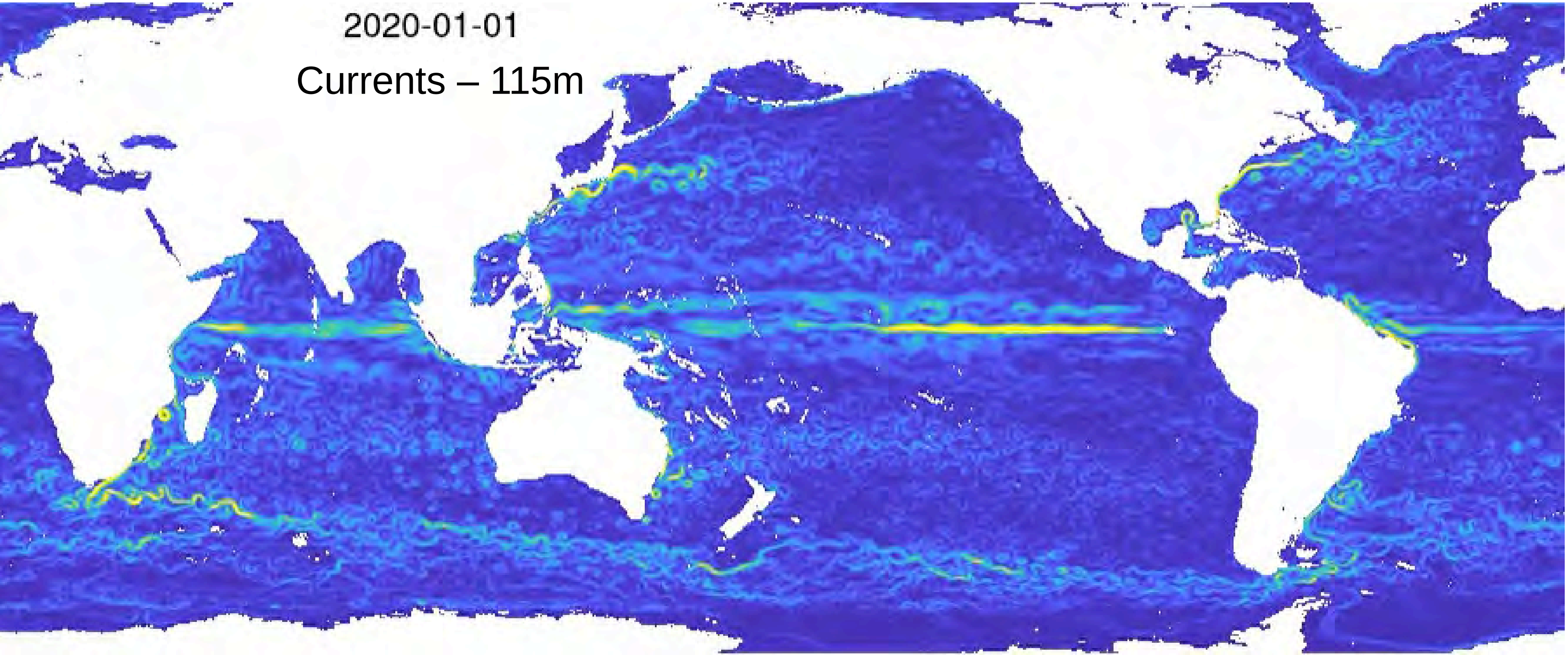


9-EOF MODE CLIMATOLOGY
SEA SURFACE HEIGHT SEASONAL ANOMALY STANDARD DEVIATION

Ensemble Kalman filter Ocean Reanalysis (EnKORe)

OFAM3(MOM5) + Hybrid EnKF (3-day cycle)
2010-2022





Report - in one page

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- EnKF data assimilation
- Hybrid EnKF (48-dynamic / 144-stationary)
- Good performance gains and comparisons
- Brassington, Sakov, Divakaran, Aijaz, Sweeney-Van Kinderen, Huang and Allen, 2023, June. OceanMAPS v4. 0i: a global eddy resolving EnKF ocean forecasting system. In *OCEANS 2023-Limerick* (pp. 1-8). IEEE.

OceanMAPSv4.1i (PRE-OP) (mid-2024)

- Optimized EnKF more gains for all variables
- Greatest gains for SST

OceanMAPSv4.2 (TRIAL) (2025) **–** coupled ocean-sea-ice and assimilation of SIC
OceanMAPSv5 (Research) **–** NEMO ORCA12 + EnKF

BRAN2020

- routine updating
- Extension to include BGC variables

EnKORe

- 12 year reanalysis

Coupled NWP – GC5 UM + NEMO ORCA025

- Development ORCA025 + EnKF

The Bureau of Meteorology

Thank you

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