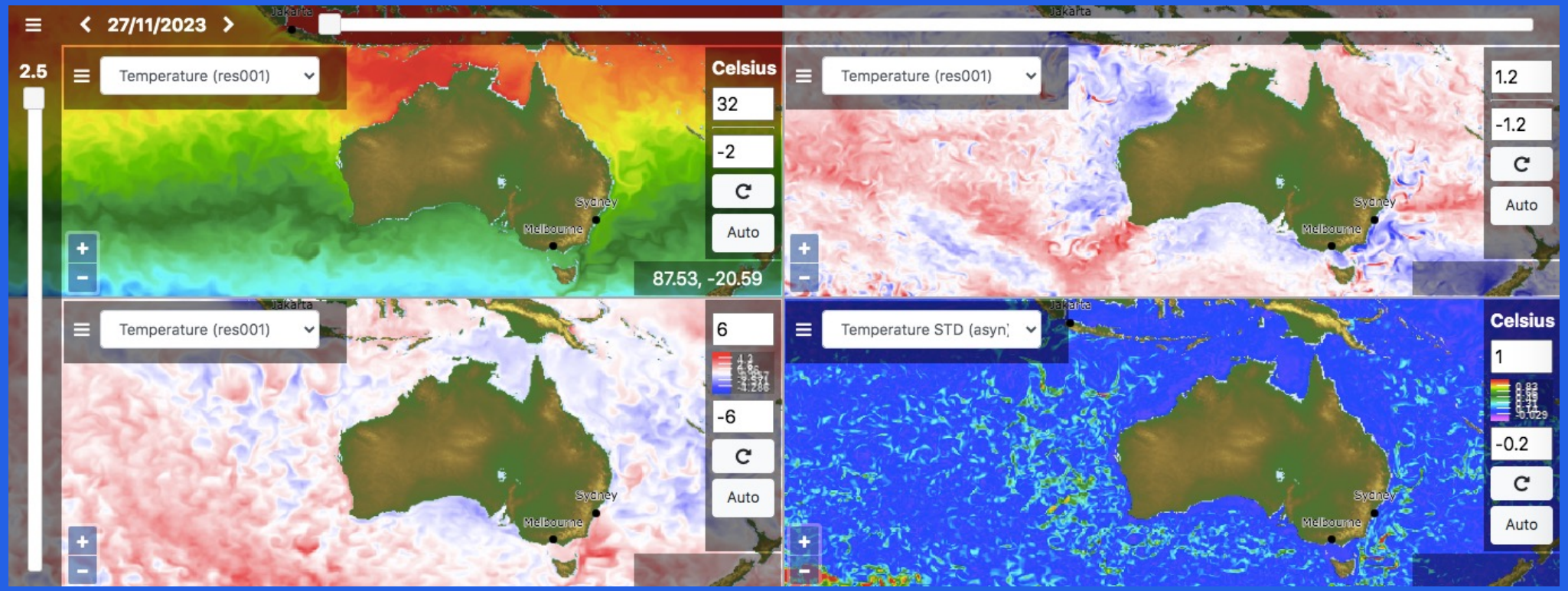
The Bureau of Meteorology

Advances in Bureau's ocean forecasting services



Brassington, Sakov, Divakaran, Allen, Aijaz, Velic, Chamberlain, Oke, Fiedler, Huang, Sanders, Yonghong, Zhong, Entel, Khan, Colberg, Bladwell, Zhou, Sweeney-van Kinderen, Kiss, Hogg, Heil, Roughan, Keating

Bluelink Ocean Forecasting

CSIRO

NAVY

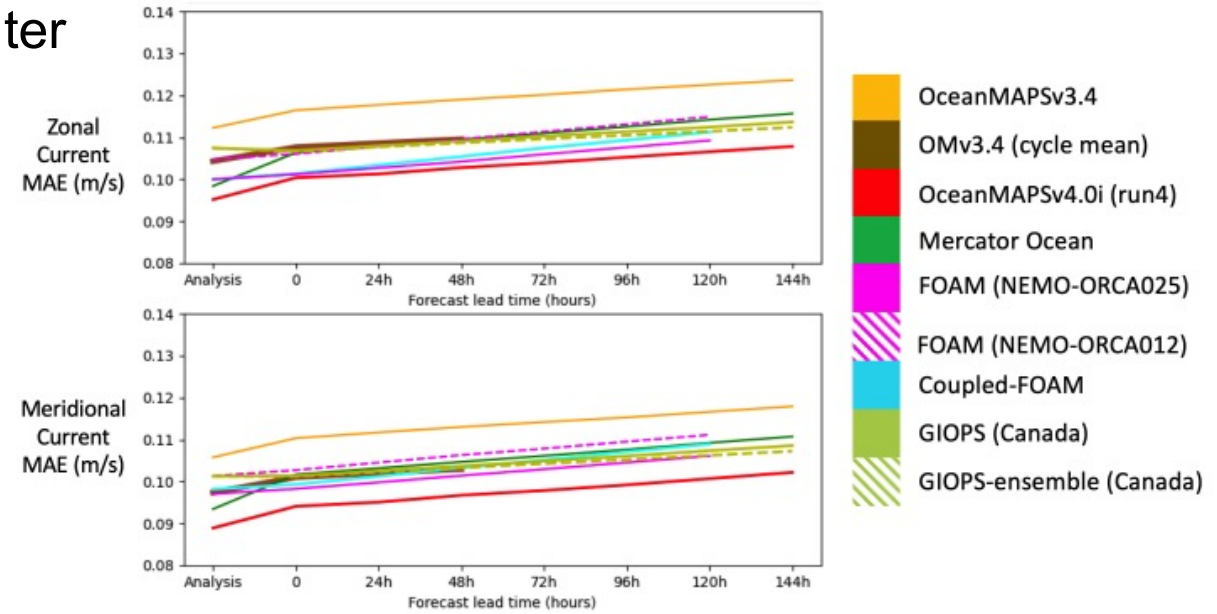
Australian National University

IMOS

Quick recap

OceanMAPS – introduction of Ensemble Kalman Filter

- Major transformation
- Encourage national uptake/exploitation
- Encourage community engagement

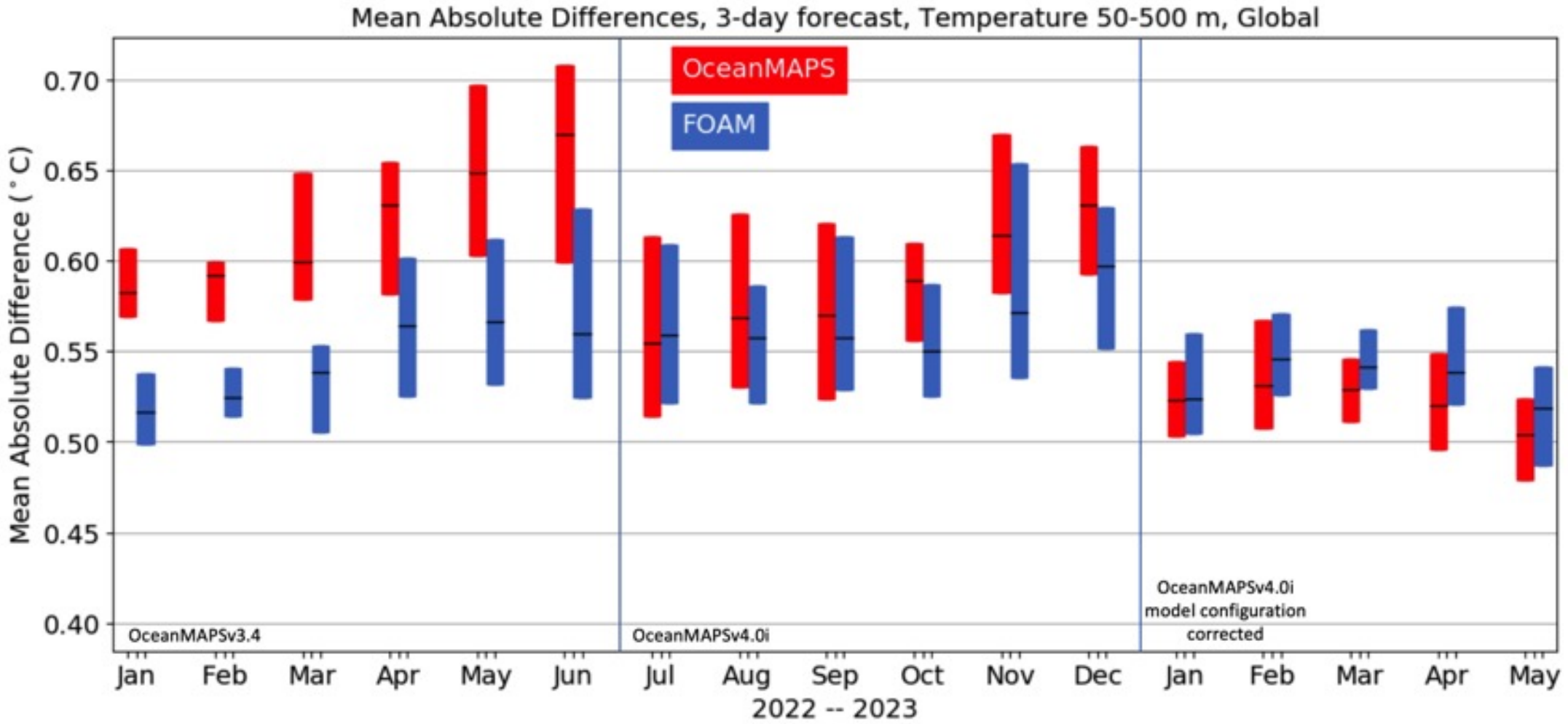


Brassington, G. B., et al., 2023. OceanMAPSv4.0i: a global eddy resolving EnKF ocean forecasting system, In *OCEANS 2023, Hampton Roads* (pp. 8). IEEE

Known next steps (last year)

- 10 year reanalysis
- Extended range prediction
- Probabilistic ocean forecasting
- **EnKF optimisation - 1-day cycling**
- Full global ocean-sea-ice forecasting
- Active investigations
  - Coupled NEWP
  - SWOT

Operational system providing sustained performance
Model configuration effecting temperature was implemented



Paul’s quote: “3 models all agree and the buoy went in the opposite direction”

Natural response would be to lose confidence in the models

Our model is the best performing system for ocean currents

Can this scenario be explained even if we agreed the forecast models were GOOD?

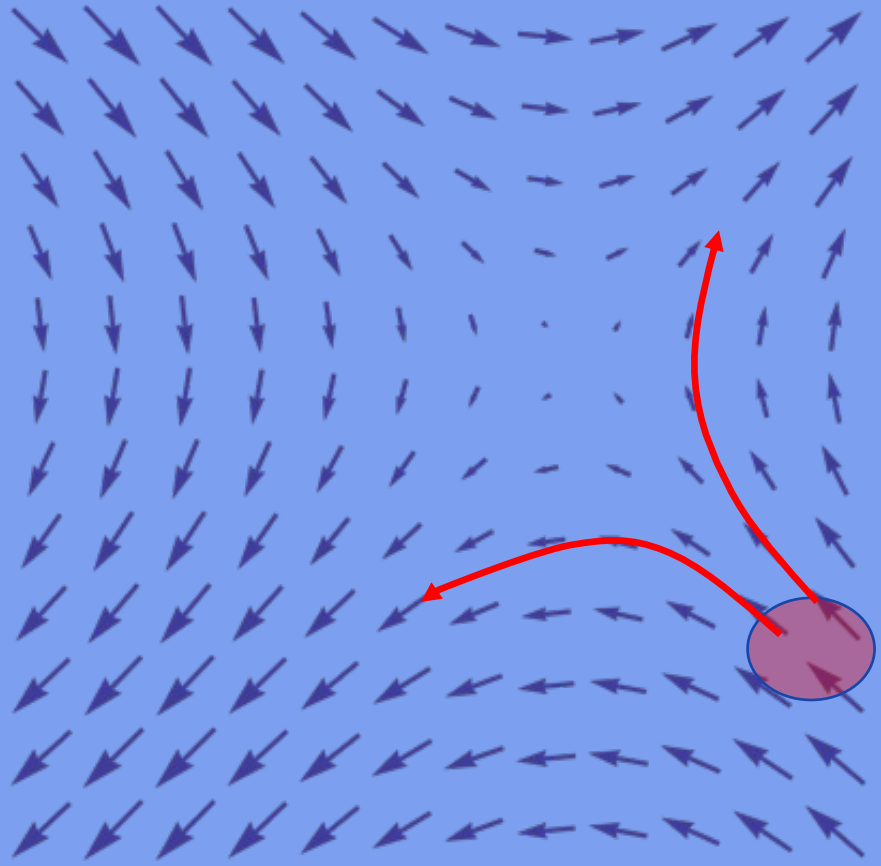
Paul's quote: "3 models all agree and the buoy went in the opposite direction"

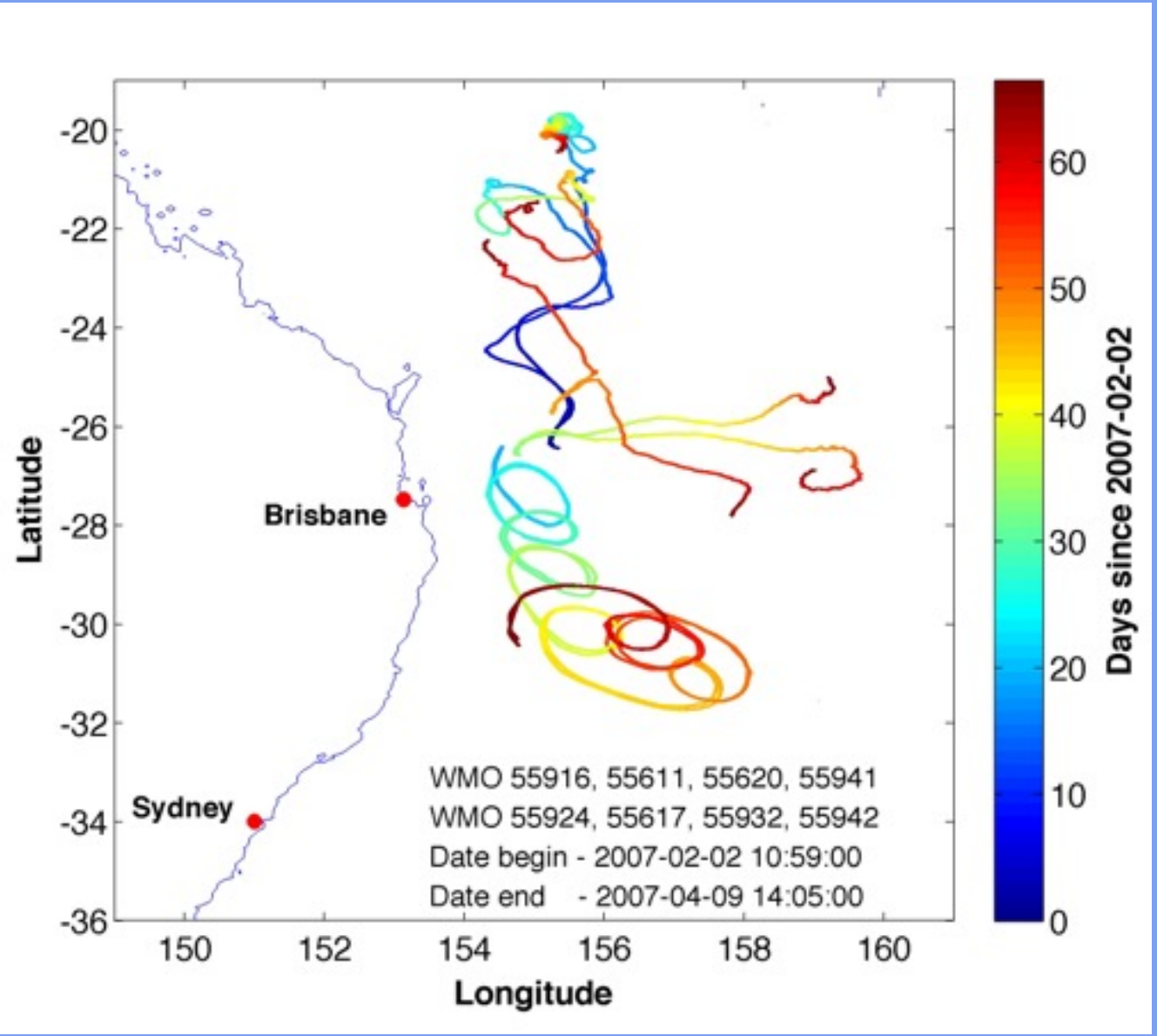
Natural response would be to lose confidence in the models

Our model is the best performing system for ocean currents

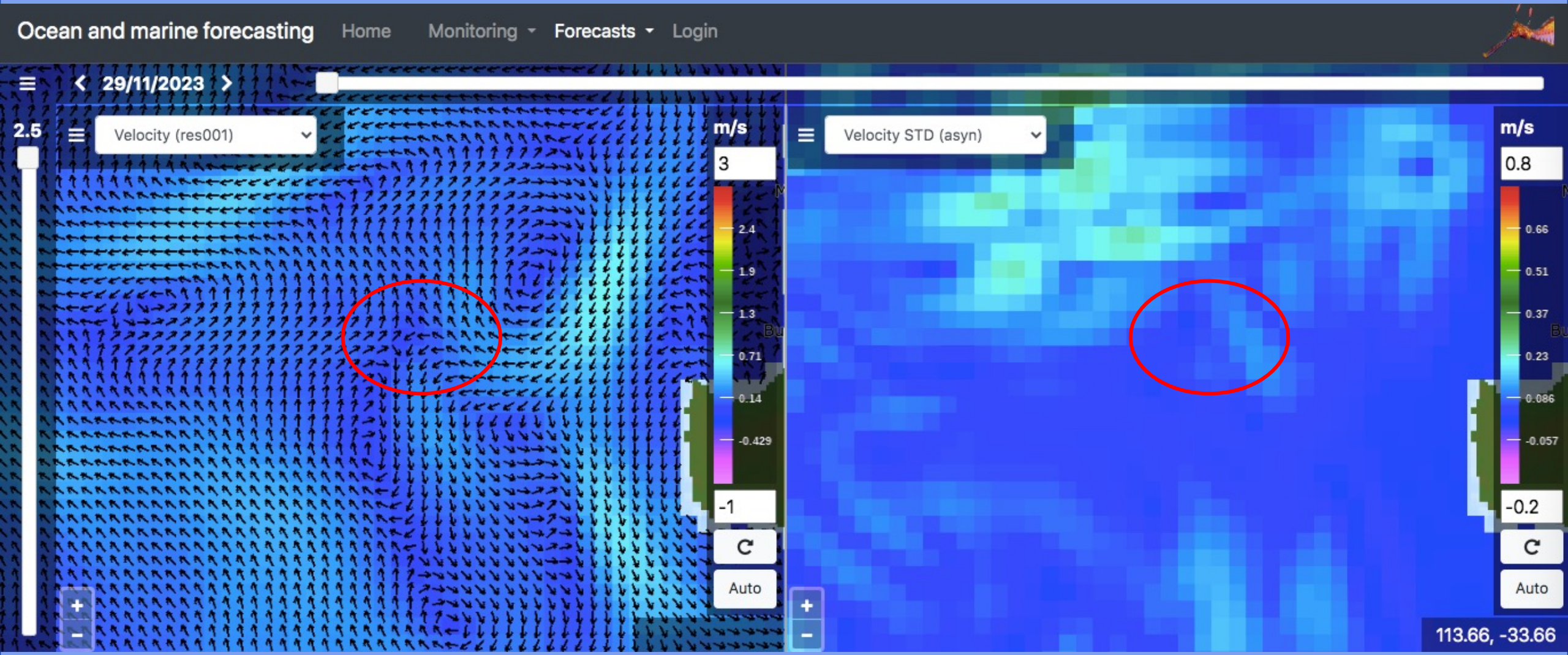
Can this scenario be explained even if we agreed the forecast models were GOOD?

A **saddle point** close to the SAR event





In the presence of a saddle point, buoy data will also diverge rapidly



Saddle point off WA today

Low uncertainty

GOOD model behavior

Modelled saddle points **exist**

“Accurate” currents and position

Accuracy will decline **“slowly”** with time

Do we need better resolution?

1/10 degree – macro saddle points

<1/10 degree – micro saddle points

Sensitivity to search area?

Suggested SAR decision tree

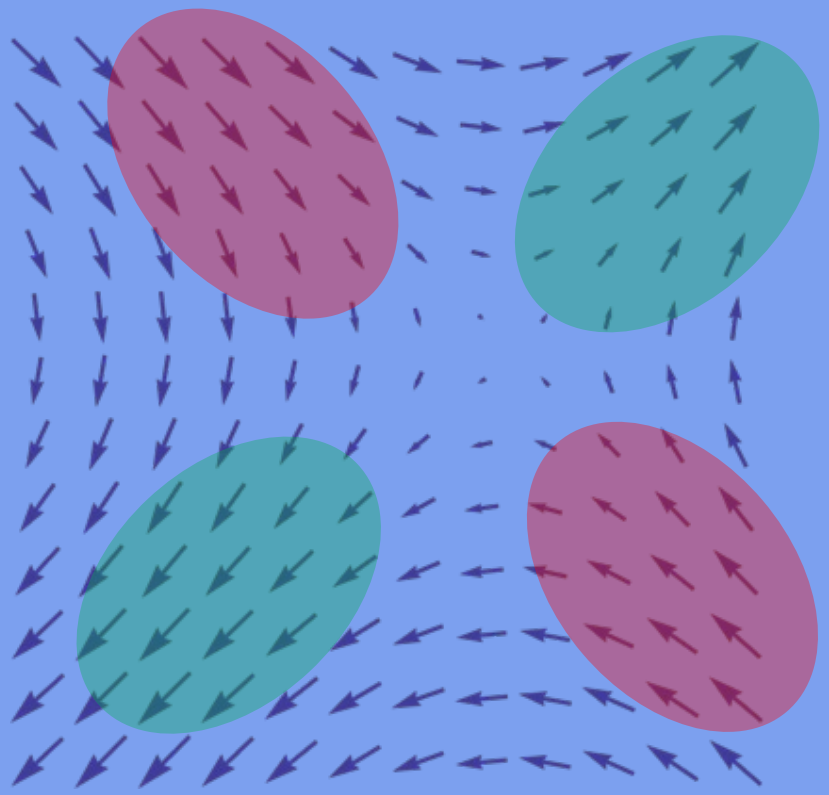
Identify any saddle points

Deploy multiple buoys to verify position

Define the unstable regions

Estimate period to divergence point

Double the search area



OceanMAPS version 4.1i

TARGET 2024

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 (1-day cycle)
48 dynamic members
144 low-mode members
FGAT, Restart initialisation

Atmospheric forcing
ACCESS-G4 (APS4)
Bulk formulae

Observations
In situ profiles (GTS, GDAC)
Satellite altimetry (RADS, J3, SARAL, Sentinel-3A, Cryosat-2)
Satellite SST (AMSR2, NAVOCEANO, NPP-VIIRS, NOAA20-VIIRS)

Forecasts
EnKF (-2 day analysis) + 3 day hindcast
Daily 7 day forecasts
48-member ensemble forecasts

New features

Data assimilation
EnKF-C
Hybrid-EnKF (1-day cycle)

Atmospheric forcing
ACCESS-G4 (APS4)

Forecasts
Target 48-member ensemble forecasts

Impact

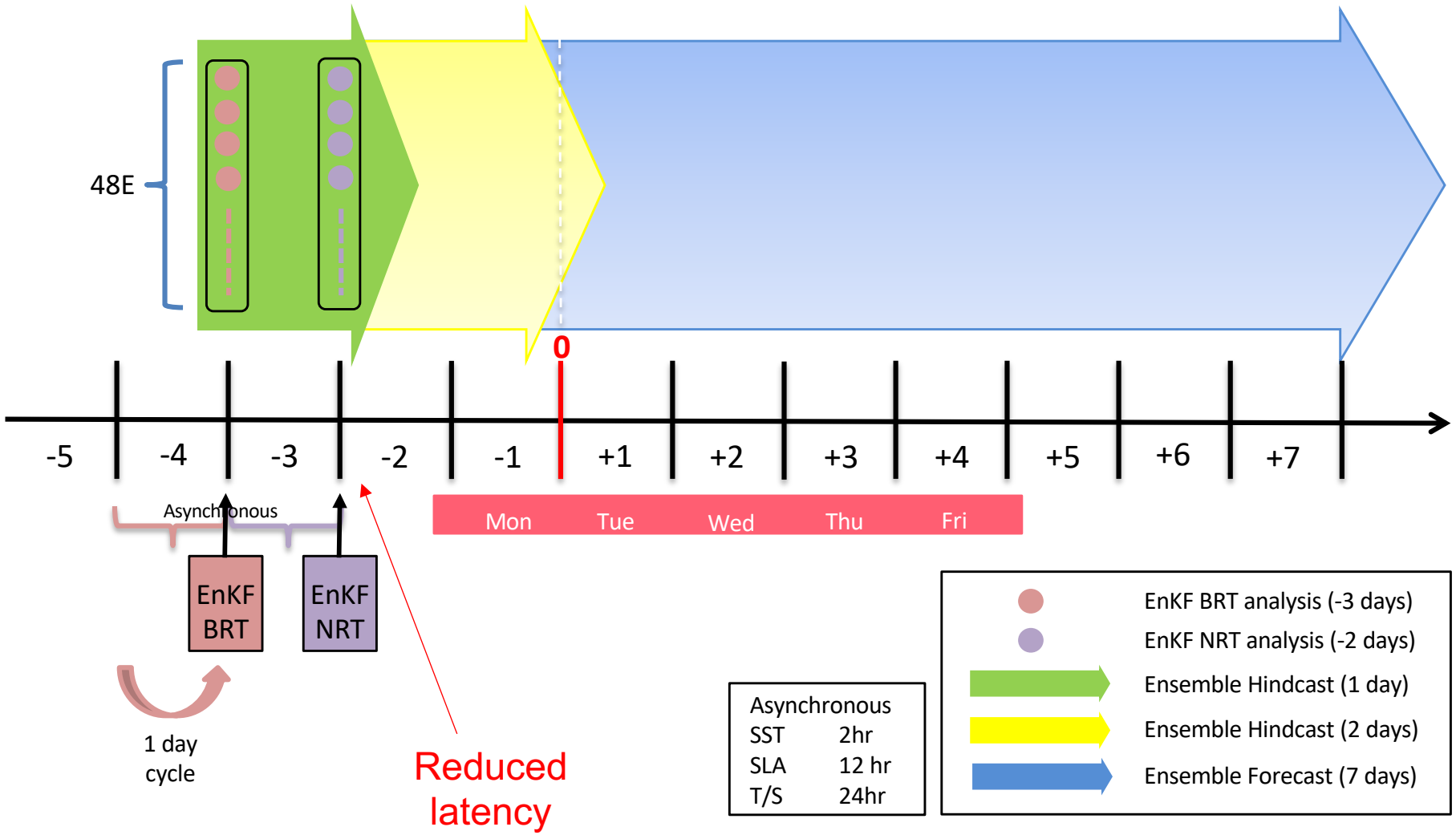
Performance
- Forecast skill
- Beats persistence
- Best performing international system
- Probabilistic forecasts

V4.1i + NRT	Global	Australia
SSHA	5%	11%
SST	**14%**	**13%**
TEMP	9%	4%
SALT	7%	8%
CURRENT	7%	NOT MEASURED*[1]

Bluelink Ocean Forecasting

References
Sakov, P. and Oke, P.R., 2008. A deterministic formulation of the ensemble Kalman filter: an alternative to ensemble square root filters. *Tellus A: Dynamic Meteorology and Oceanography*, *60*(2), pp.361-371.
Sakov, P., Evensen, G. and Bertino, L., 2010. Asynchronous data assimilation with the EnKF. *Tellus A: Dynamic Meteorology and Oceanography*, *62*(1), pp.24-29.
Sakov, P., 2014. EnKF-C user guide. *arXiv preprint arXiv:1410.1233*.
Brassington, G. B., et al., 2023. OceanMAPSv4.0i: a global eddy resolving EnKF ocean forecasting system, In *OCEANS 2023, Hampton Roads* (pp. 8). IEEE

Forecast schedule – v4.1i



Ensembe size TBD
48 members available

Costs and priority
Justification required
Is the uncertainty GOOD?
Do we know how to use it?
Would it be used?

Uncertainty estimates 12 or 16 is likely enough

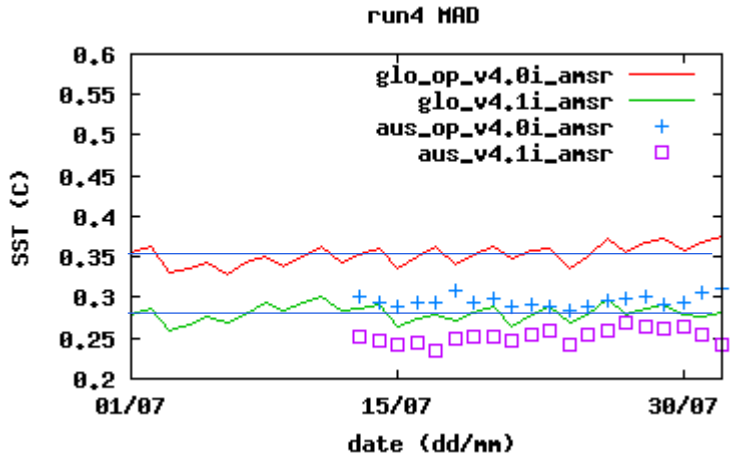
Probabilistic = 24+ threshold exceedance
Bi-modal behavour
Medium-range forecasts

Considering a demonstrator

Is there enough interest in the room to evaluate, downscale, define products, assess impact?

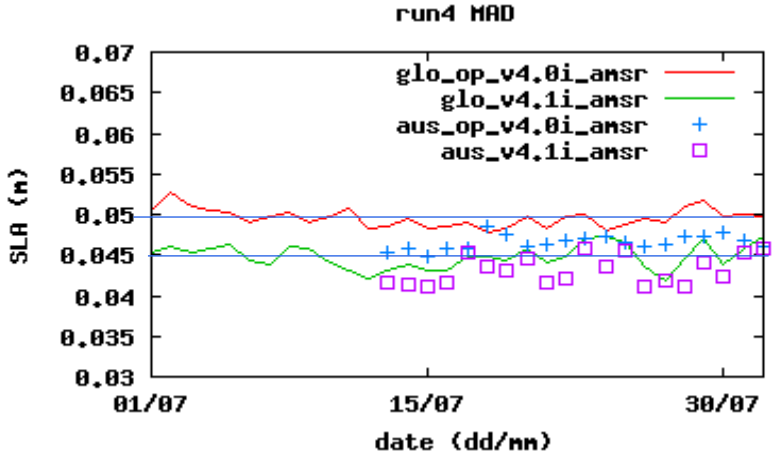
OceanMAPSv4.1i – pre-operational trial

SEA SURFACE TEMPERATURE



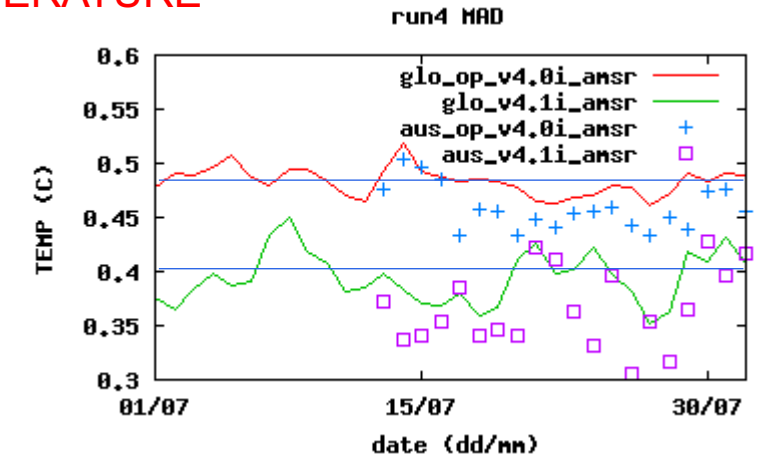
0.07/0.35
~ 20%

SEA LEVEL ANOMALY



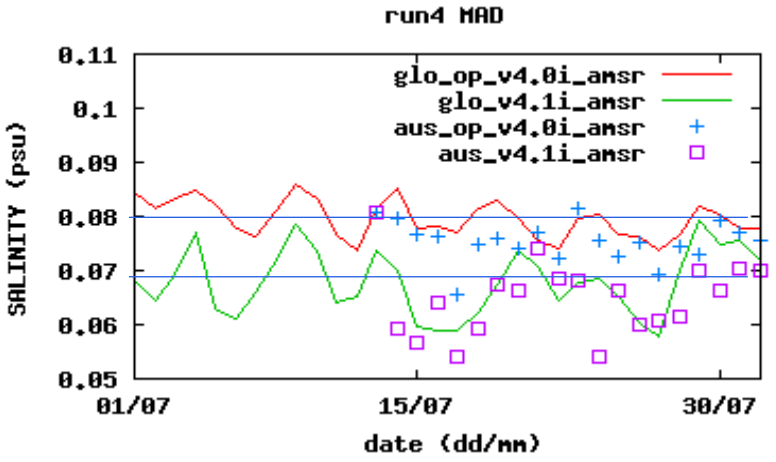
0.005/0.05
~ 10%

TEMPERATURE



0.08/0.48
~ 17%

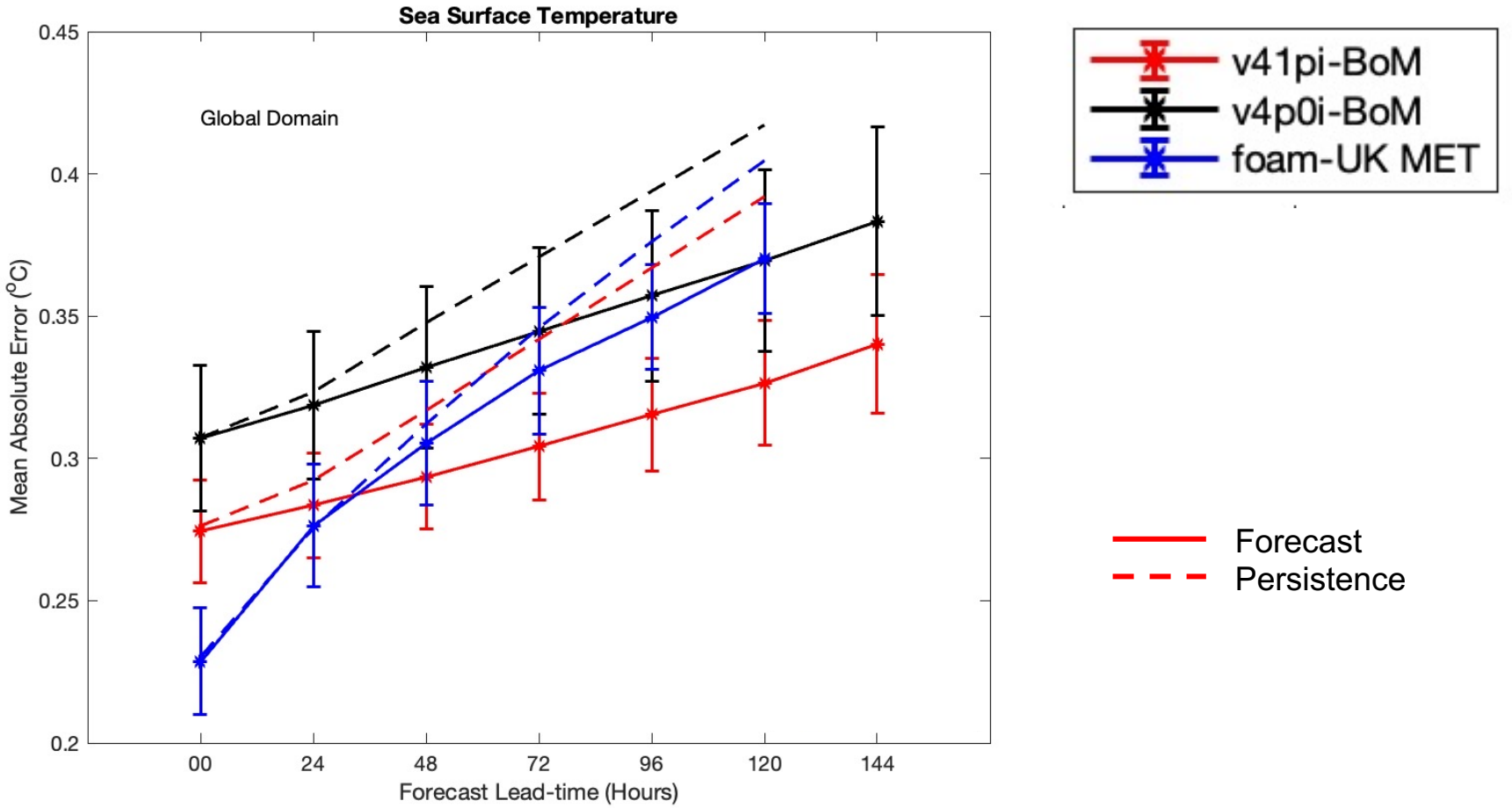
SALINITY



0.01/0.08
~ 12.5%

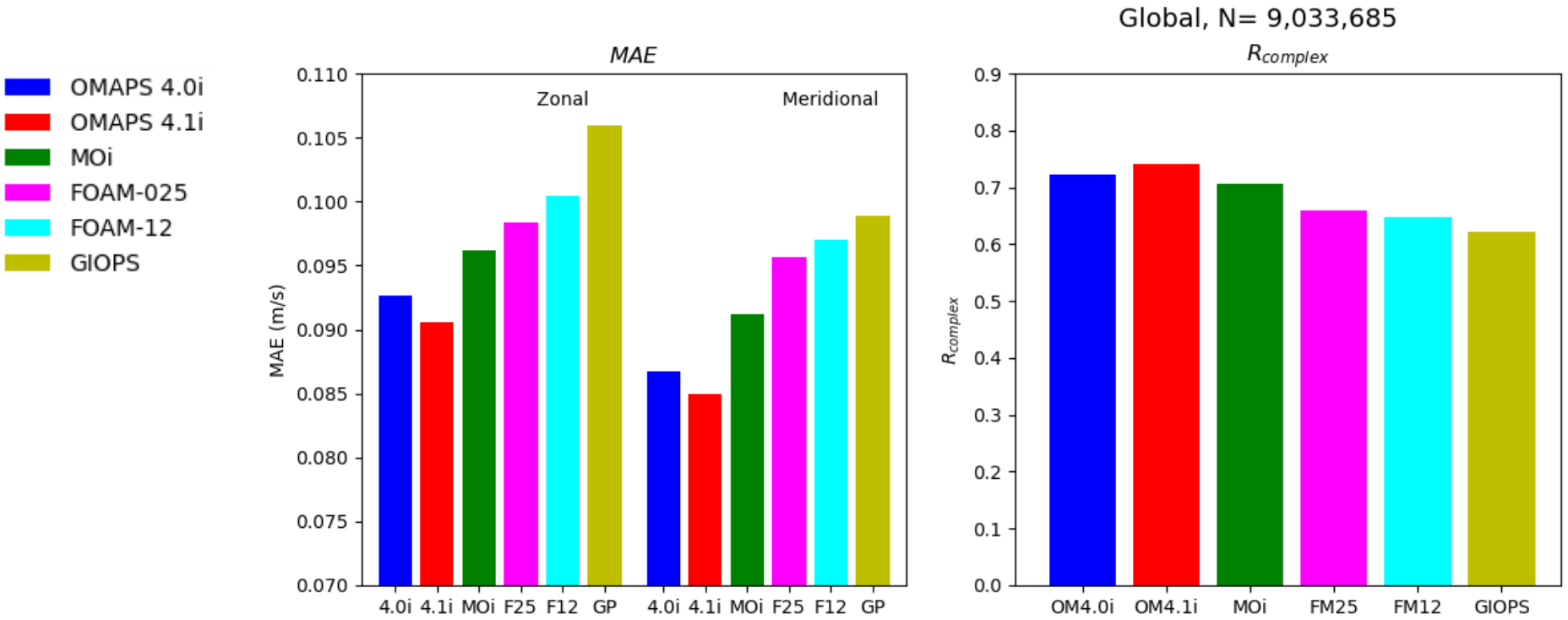
72 hr day forecast

OceanMAPSv4.1i – comparisons



Promising performance for uncoupled or coupled weather prediction

OceanMAPSv4.1i – comparisons



$R_{complex}$ – complex correlation

Aijaz, S., Brassington, G.B., Divakaran, P., Régnier, C., Drévillon, M., Maksymczuk, J. and Peterson, K.A., 2023. Verification and intercomparison of global ocean Eulerian near-surface currents. *Ocean Modelling*, *186*, p.102241.

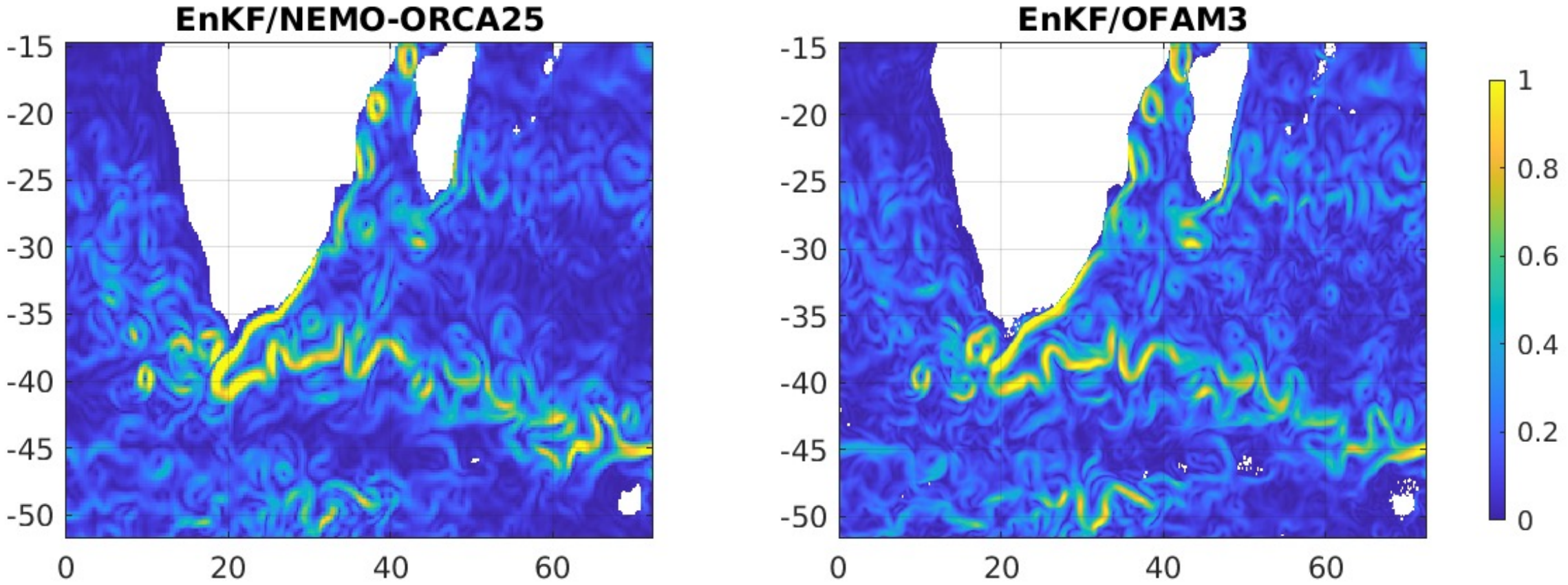
Known next steps

- OceanMAPSv4.1i – TARGET APRIL 2024
  - Hindcast experiments: ACCESS G4/GE4
- OceanMAPSv4.2 – TARGET 2025
  - Hindcast experiments: Atmospheric recasting, Sea-ice increment distribution
- Coupled NWP GC5 - TARGET 2025
  - Optimise NEMO ORCA025 – MDT, Dynamical balance of increments

Other areas of focus

- Probabilistic/extended range ocean forecasts
  - **Concept - weekly-one month ensemble forecasts**
- ARC DP/MNF: UNSW/Bureau: Tasman Sea dynamics/forecasts/predictability
- **ARC linkage: UNSW/AMSA/Bureau: Ocean currents and SWOT**
- 10 year EnKF reanalysis evaluation

|V| in Agalhas at 115m on 20201231

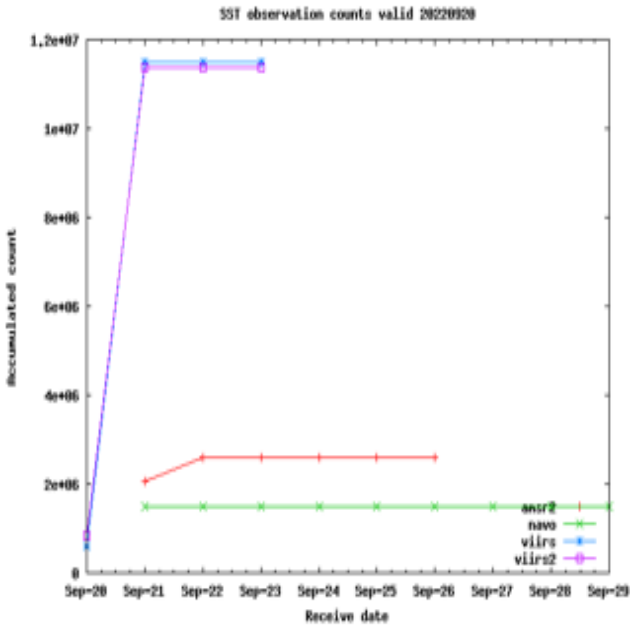


Surprising analysis for WBC's => Need to compare forecast errors
Accurate distribution of heat content/temperature gradients for NWP

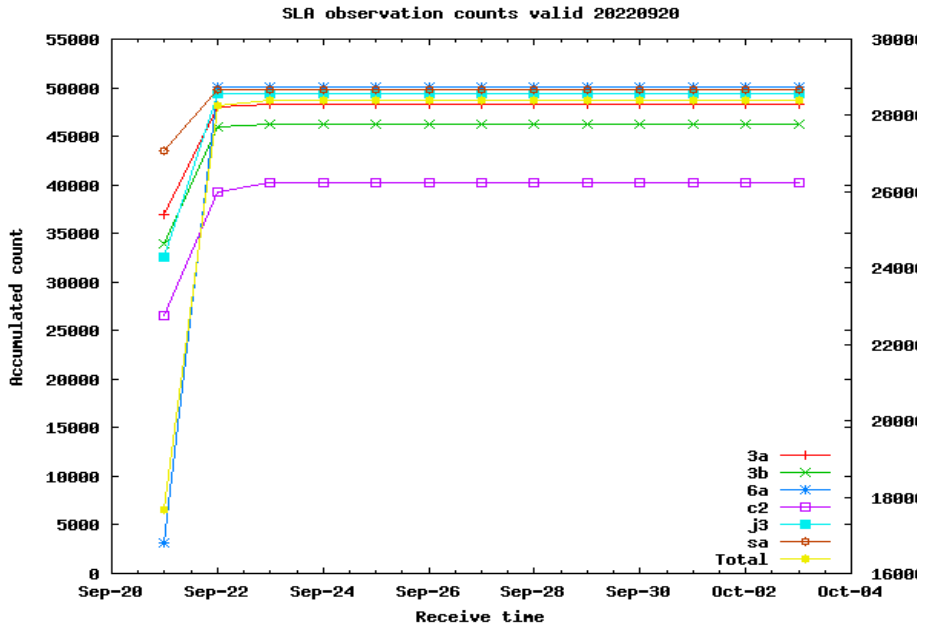
The Bureau of Meteorology

Thank you

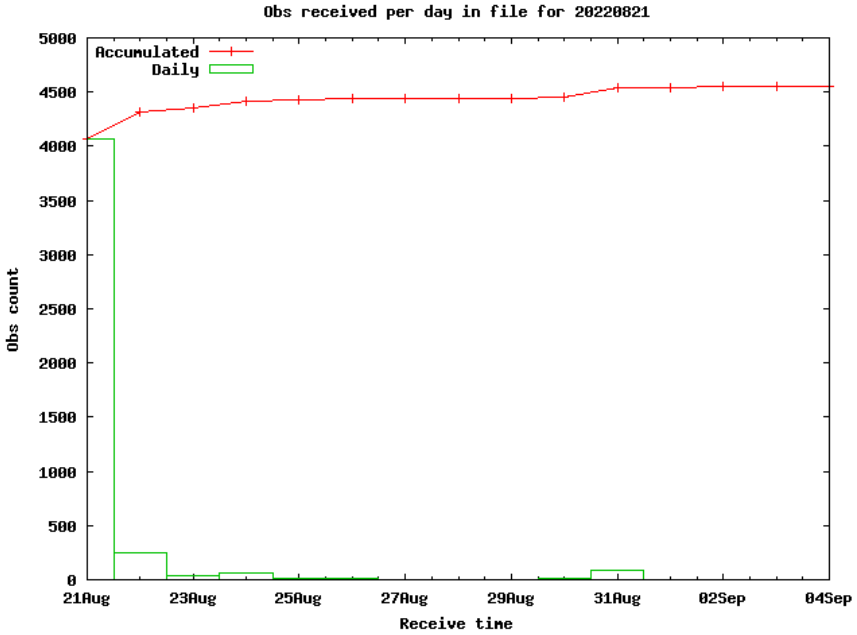
Realtime observation latency



-1 day -2 day -3 day



-1 day -2 day -3 day



-1 day -2 day -3 day

Satellite SST	Low latency/Good coverage	-3 days – persistent analysis cycle
Satellite altimetry	Medium latency/Medium coverage	-2 days – intermediate analysis to introduce available obs
Profiles	Medium latency/Sparse coverage	-1 days – imbalanced obs not tested

OceanMAPS version 4.2

TARGET 2025

System

Model
ACCESS-OM2-01 (MOM5-CICE5)
80S-90N, 0-360
0.1° x 0.1°, 75 z*-levels (1.1m top cell)

Data assimilation
EnKF-C
Hybrid-EnKF (1-day cycle)
48 dynamic members
144 low-mode members
FGAT, Restart initialisation

Atmospheric forcing
ACCESS-GE4 or GC5/GE5
Bulk formulae

Observations
In situ profiles (GTS, GDAC)
Satellite altimetry (RADS, J3, SARAL, Sentinel-3A, Cryosat-2)
Satellite SST (AMSR2, NAVOCEANO, NPP-VIIRS, NOAA20-VIIRS)
SIC (AMSR2 L2p, SSMI/S)

Forecasts
EnKF (-2 day analysis) + 3 day hindcast
Daily 7 day forecasts
48 ensemble forecasts

New features

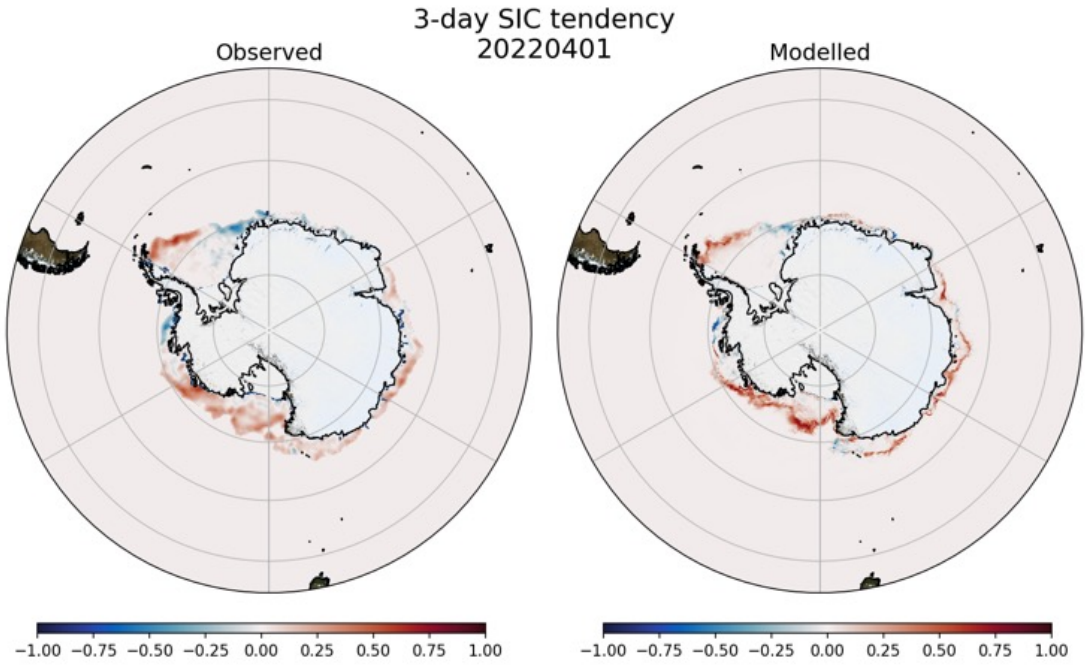
Model
ACCESS-OM2-01 (MOM5-CICE5)
80S-90N, 0-360
0.1° x 0.1°, 75 z*-levels (1.1m top cell)
~x5 cost

Atmospheric forcing
ACCESS-GE4 or GC5/GE5

Observations
SIC (AMSR2 L2p, SSMI/S)

Impact

Performance
- Underprediction sea-ice melt
- Sea-ice skill for growth phase
- MIZ forecast tendency
- Interior sea-ice underspread



Development priorities
Atmospheric recasting (forecast boundary conditions)
Sea-ice ensemble spread (atmospheric ensemble)
Wave energy => MIZ breaking (Insolation/Albedo)

Bluelink Ocean Forecasting

References
Sakov, P. and Oke, P.R., 2008. A deterministic formulation of the ensemble Kalman filter: an alternative to ensemble square root filters. *Tellus A: Dynamic Meteorology and Oceanography*, *60*(2), pp.361-371.
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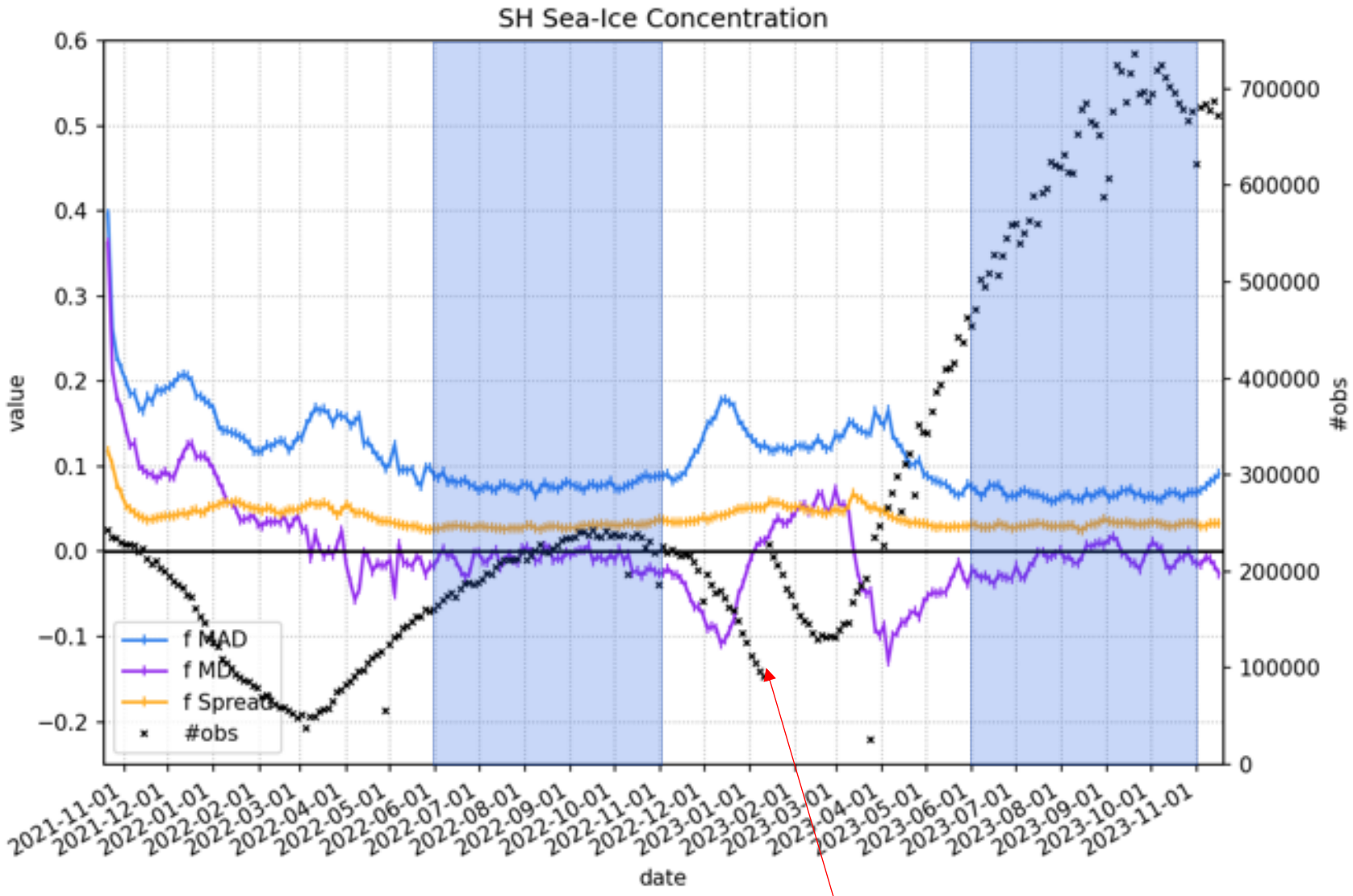
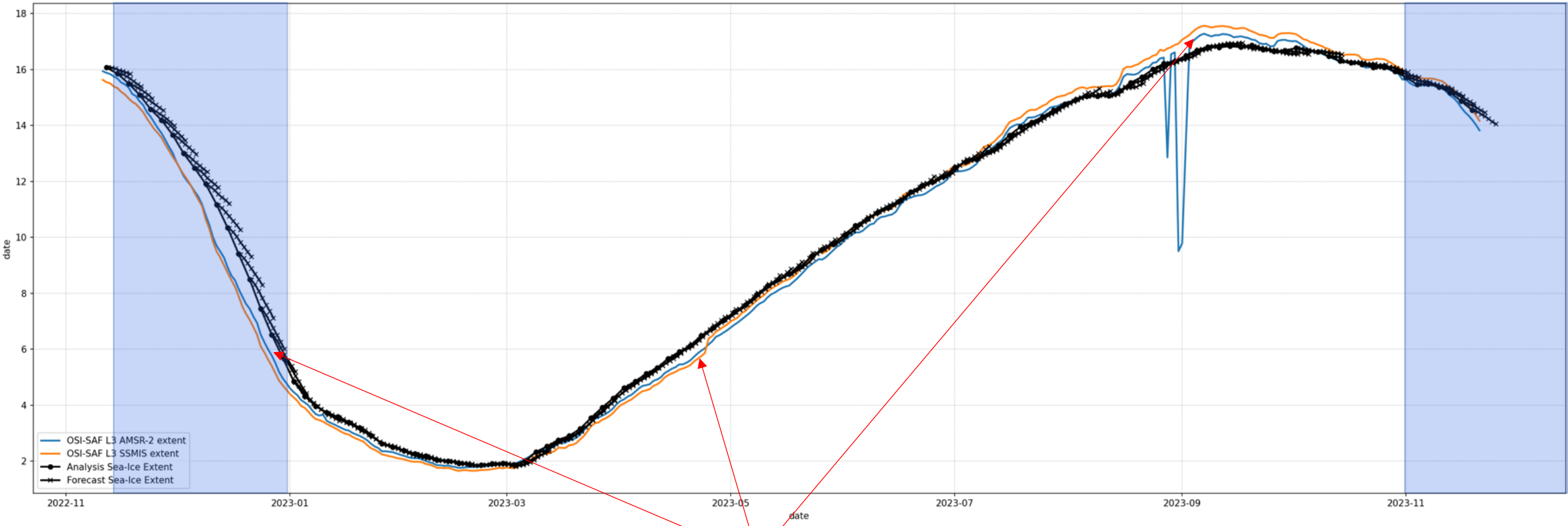


During growth phase
Consistent with introducing sea-ice into the thinnest category
Atmospheric boundary conditions compatable

Addition
SSM/I



Overprediction errors

Systematic errors

During melt phase
Atmospheric boundary conditions incompatible

Coupled NWP - NEMO developments

TARGET 2025

1/4-degree hybrid Ensemble Kalman Filter based forecasting system using NEMO

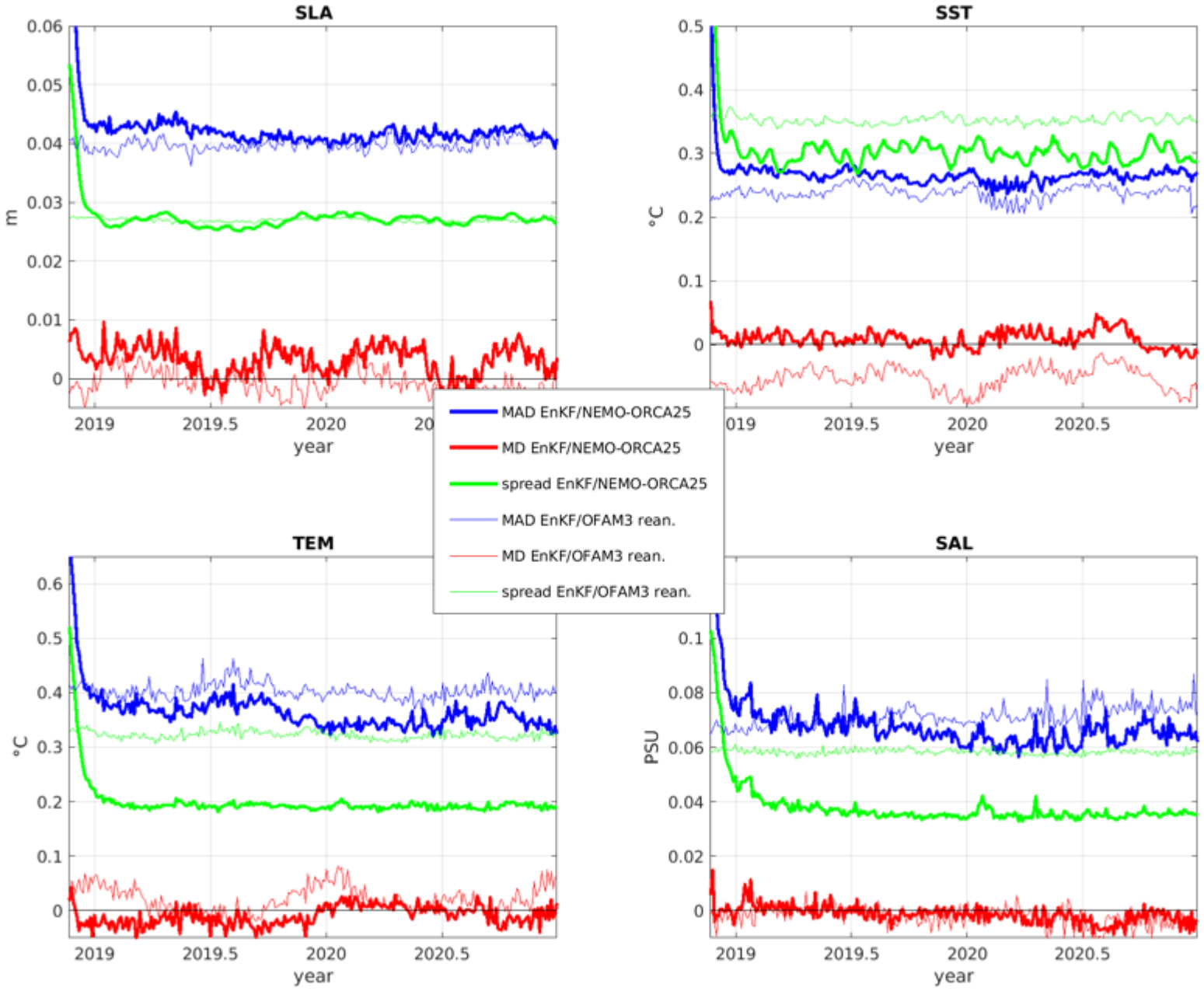
- Configure the GOSI9 eORCA025 (NEMO/SI3 UK Met Office) model on NCI and set up ERA5 forcing.
- Set up the hybrid EnKF static ensemble from a 10 year hindcast of the 1/4 degree model from 2011 with 3-day cycles.
- Currently analysing the hindcast and investigating SSH anomalies.
- Work is continuing on optimisation of the GOSI9 eORCA12 model (1/12th degree) on NCI for a high-resolution forecasting system.

A comparison of the GOSI9 and ACCESS-OM2 025 configuration:

	GOSI9 eORCA025	ACCESS-OM2 025
Ocean Model	NEMO4.0.4	MOM5.1
Ice Model	**SI3**	**CICE5**
Coupler	None	OASIS3
Horizontal grid	Tripolar C-grid (1442, 1207)	Tripolar B-grid (1440,1080)
Vertical coordinate	z* partial step (75 levels)	z* partial step (50 levels)
Free surface	Nonlinear (biharmonic smoother)	Nonlinear (Laplacian smoother)
Vertical mixing	**Turbulent kinetic energy**	**KPP**
Atmospheric forcing	CORE2/ERA5	JRA55-do/ERA5
PME normalisation	Not used	**Used**
Salinity restoring	Not used	**10 day time scale (33 default)**
Initial T and S	Monthly climatology from **EN4 reanalysis**	**World Ocean Atlas 2013**

Development priorities

- Unbiased multi-year ERA5 integration, generate static ensemble
- Controlled experiment comparison with ACCESS-OM2-025



Global domain

Forecast innovation (3 day cycle)

OFAM3+EnKF reanalysis since 2010
NEMO-ORCA025+EnKF since Nov 2018

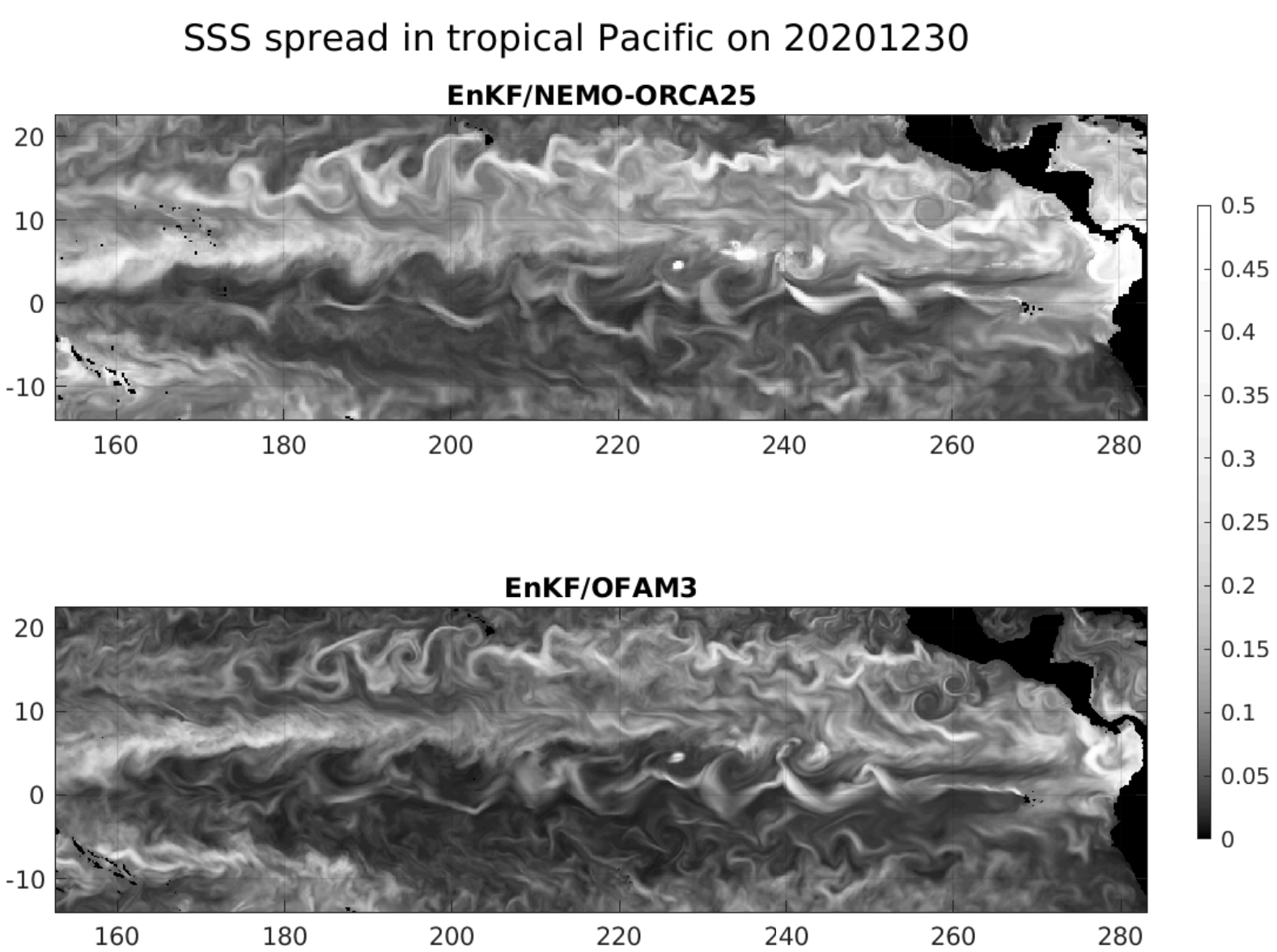
MD - Mean difference
MAD - Mean absolute difference
Spread - Mean ensemble STD

Systematically reduced spread (except SLA)

Reduction in biases (except SLA)

MAD temperature approaching 0.3deg
MAD salinity approaching 0.06 PSU

Advantage of resolution/variability



Overall higher spread as expected
Encouraging similarities in the distribution