Development of the Four-Dimensional Variational Global Ocean Data Assimilation System for Coupled Predictions in Japan Meteorological Agency

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OceanPredict24

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MOVE/MRI.COM-G3: current operational system

	MOVE/MRI.COM-G3 (since Feb. 2022)	
	G3A (4DVAR analysis)	G3F (initialization of fcst.)
Horizontal resolution	1.0° (lon)×0.3-0.5° (lat)	0.25°
Vertical layers	60 + Bottom Boundary Layer	60
Temperature/ salinity analysis	4DVAR+IAU	Downscales G3A with IAU ("replay")
Sea ice concentration analysis	3DVAR+IAU	3DVAR+IAU
Assimilated observations	In-situ T/S MGDSST (JMA-GHRSST, L4) CMEMS SLA (L3) Sea Ice Conc. (L4)	Sea Ice Conc. (L4)
Atmospheric forcings	JRA-3Q (delayed) and Global Analysis (early)	
Assimilation window (Analysis interval)	5 days	

G3A
1 × 0.3-0.5 deg. 4DVAR analysis

↓ G3A temperature/salinity fields are dynamically downscaled

G3F
0.25 × 0.25 deg. ocean model

↓ Ocean & sea ice initial conditions

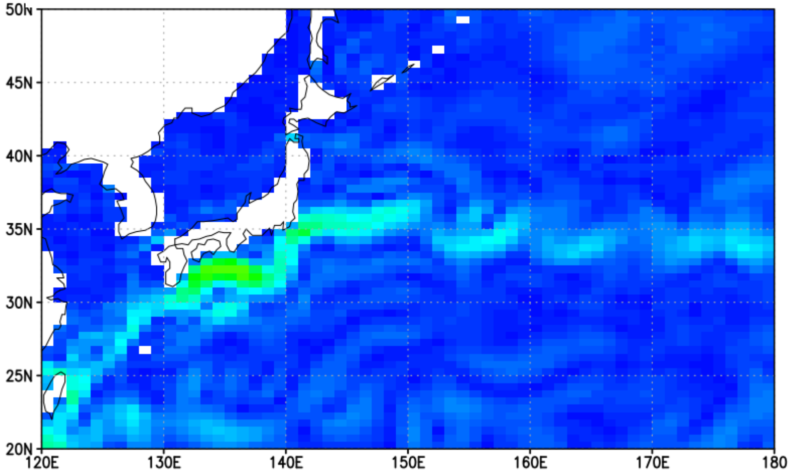
CPS3 coupled model for seasonal forecast

↓ SST as boundary condition

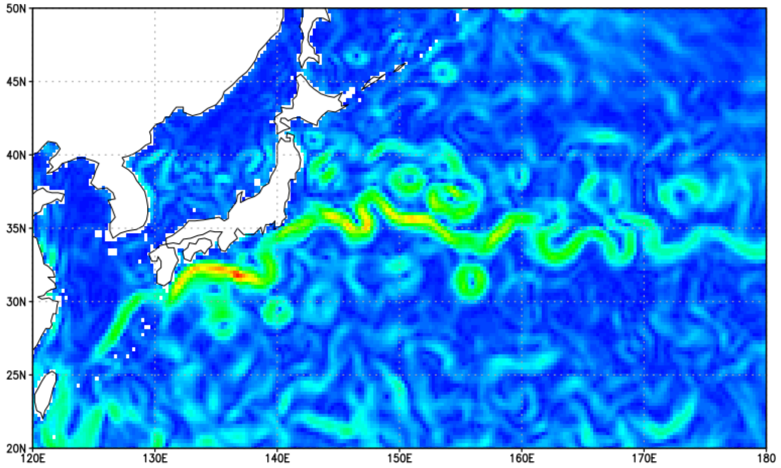
GEPS atmospheric model for extended/subseasonal forecast

Issue of G3: effective resolution (surface current on Dec 1, 2017)

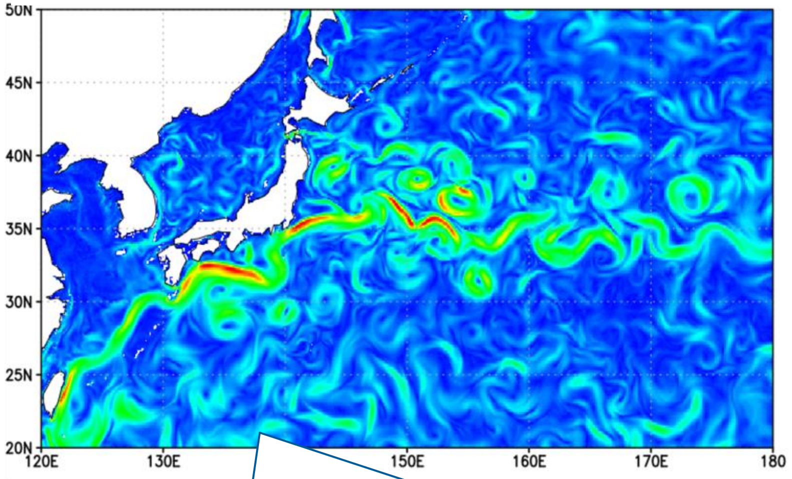
G3A (1.0°x 0.5° 4DVAR)



OSCAR (0.25° objective anl.)

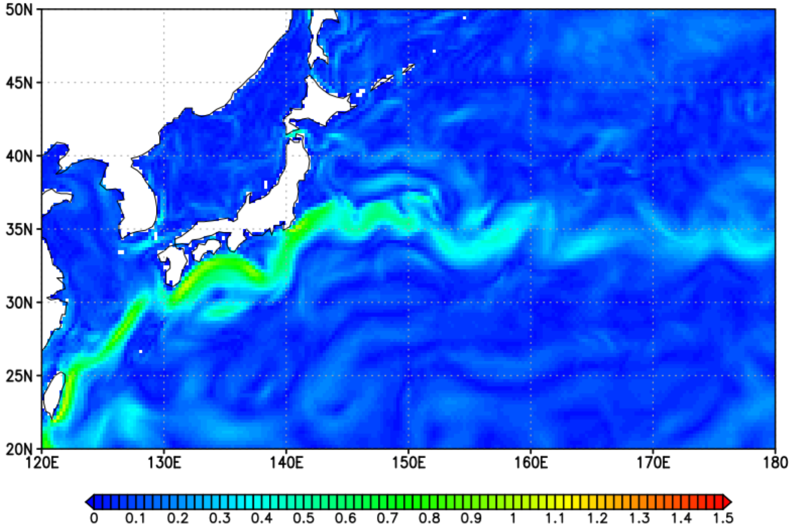


MOVE-NPR (0.1° regional 4DVAR)

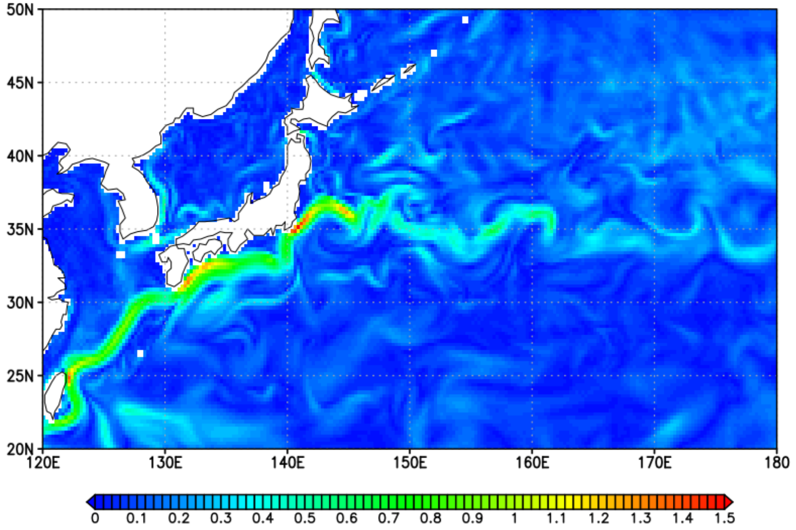


Check posters on our regional 4DVAR!
- Monday: OSE of KaRIn/SWOT
- Wednesday: 60-year reanalysis

G3F (downscaling to 0.25°)



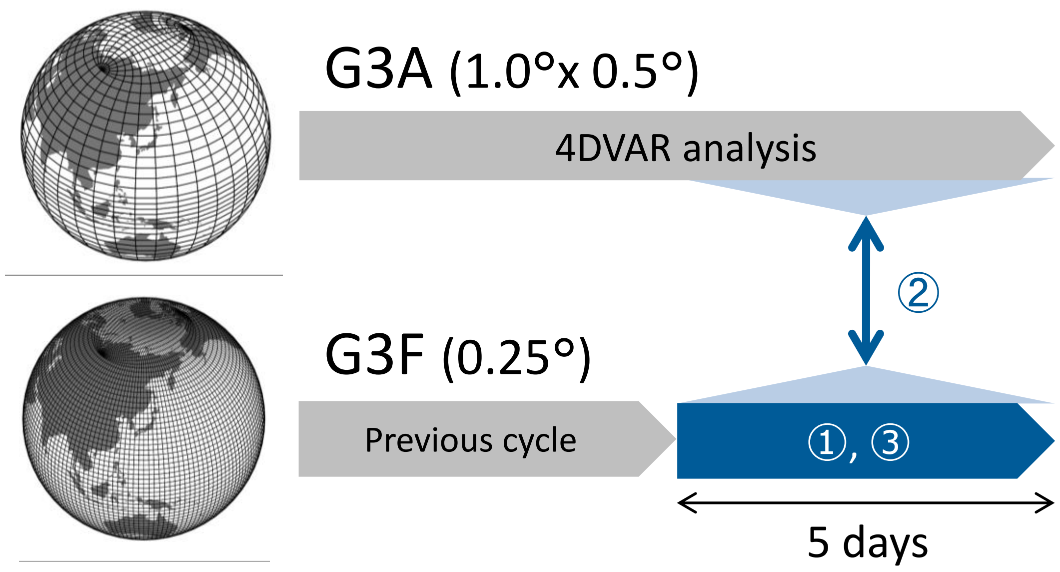
31-day forecast (0.25° model)



The midlatitude eddies in G3F are only as active as in G3A. Their activity is even lower than the model's nature (forecast).

Minor modification tested: Increment filtering in G3F downscaling

Downscaling procedure



① Run G3F model as-is

② Increment (for 5-day mean T/S) = G3A − ①

③ Run G3F model again, adding the increment

* Increment is first calculated on the G3A grid, and then interpolated to the G3F grid.

- With small-scale features represented in G3F background but not in G3A analysis, such features are dumped by the increment, resulting in over-smoothed downscaling.

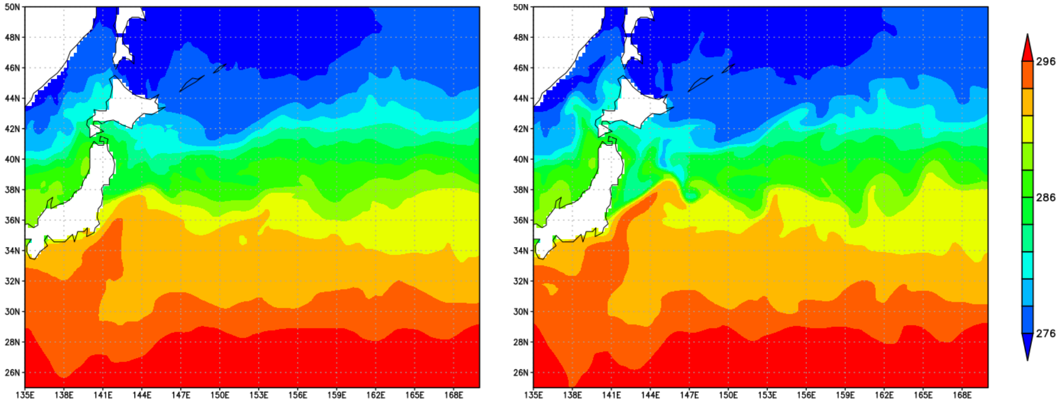
→ We test applying spatial filters on G3A analysis and G3F background when calculating an increment (②).
We expect that small-scale features in G3F background are retained and we can avoid over-smoothing.

Minor modification tested:
Increment filtering in G3F downscaling

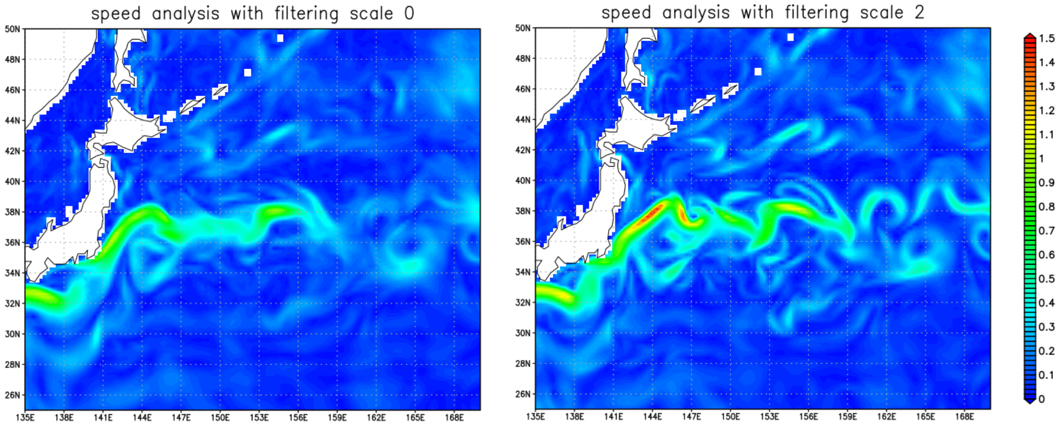
G3F, no filter

G3F with Gaussian filter
(scale = 2x G3A grid spacing)

SST
[K]

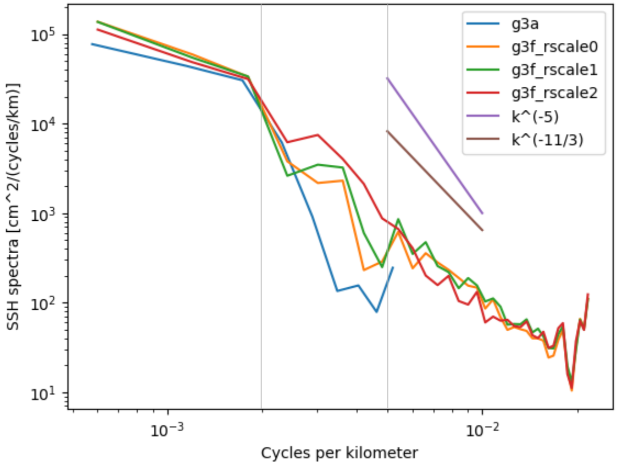


Surface
current
[m/s]



Jan 1, 2021

Wavelength 500km 200km



Zonal SSH spectra in Kuroshio Extension region averaged over 25 days

G3A (low-res 4DVAR)
G3F, no filter
G3F, 1-grid-scale filter
G3F, 2-grid-scale filter

☺ Oceanic activity increases and is closer to the nature.

☹ With more unconstrained small-scale features, analysis RMSE and ACC slightly degrade almost everywhere (when verified with independent in-situ observations, not shown).

→ Ultimately, we should constrain small-scale features by observations to overcome this trade-off.

Prospects for MOVE/MRI.COM-G4

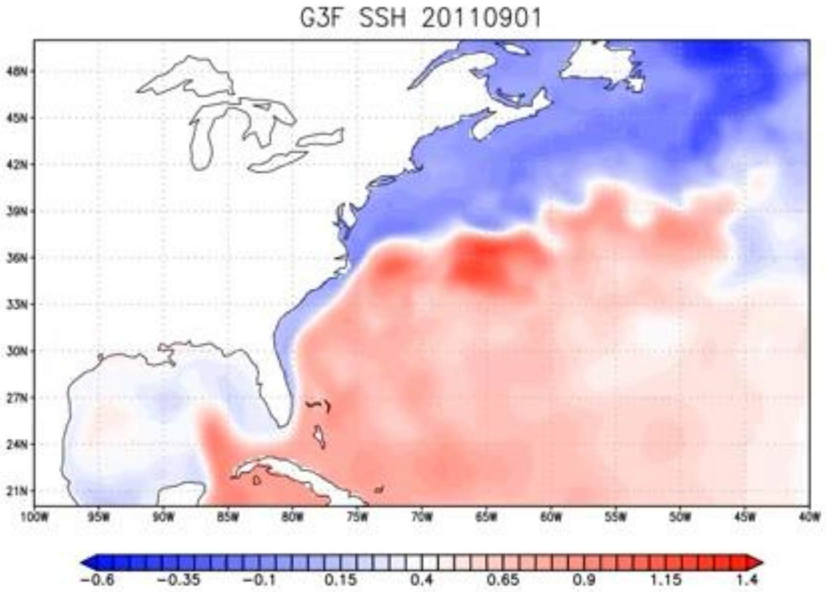
	G3	G4	Cost factor
Analysis model resolution	1.0°×0.5°	0.25°	16 (8x grid points, 2x time steps)
Operational schedule for daily initialization	5 staggered streams of 5-day cycle	Single stream 1-day cycle	1/5
4DVAR iteration	30 times	10 times	1/3

Our 4DVAR uses preliminary 3DVAR-FGAT analysis as first-guess. This ensures analysis quality even before full convergence.

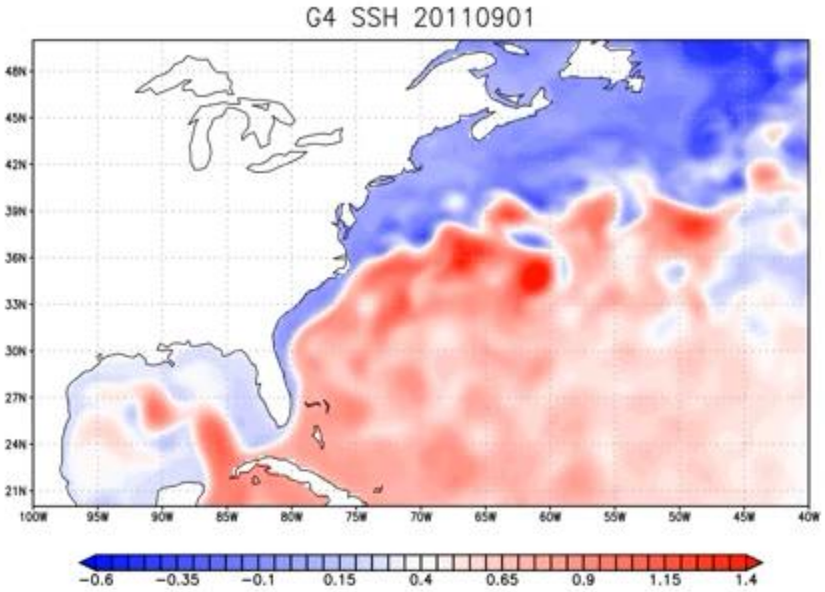
We expect enhanced analysis resolution at comparable computation cost.

Impact of analysis resolution: eddy activities

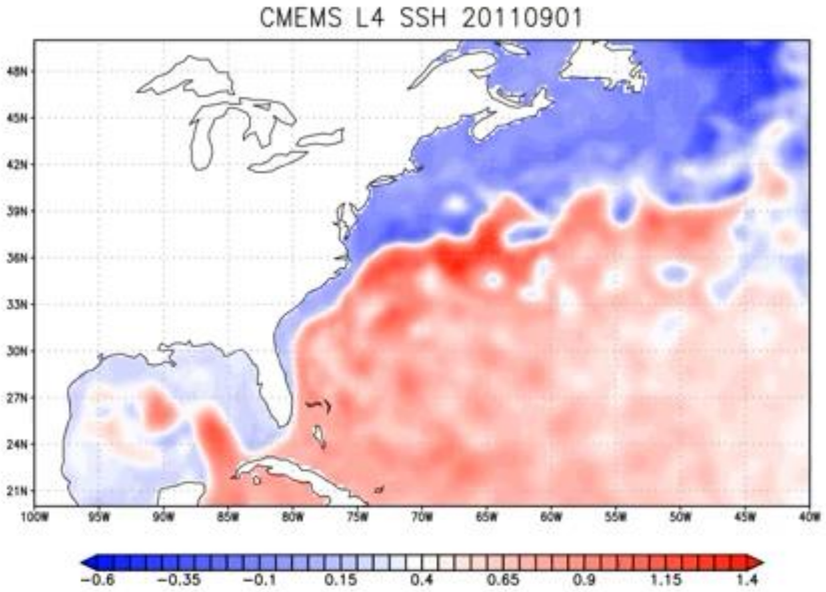
G3F SSH (0.25° downscaling)



G4 SSH (0.25° 4DVAR)



CMEMS L4 SSH (obj. anl.)



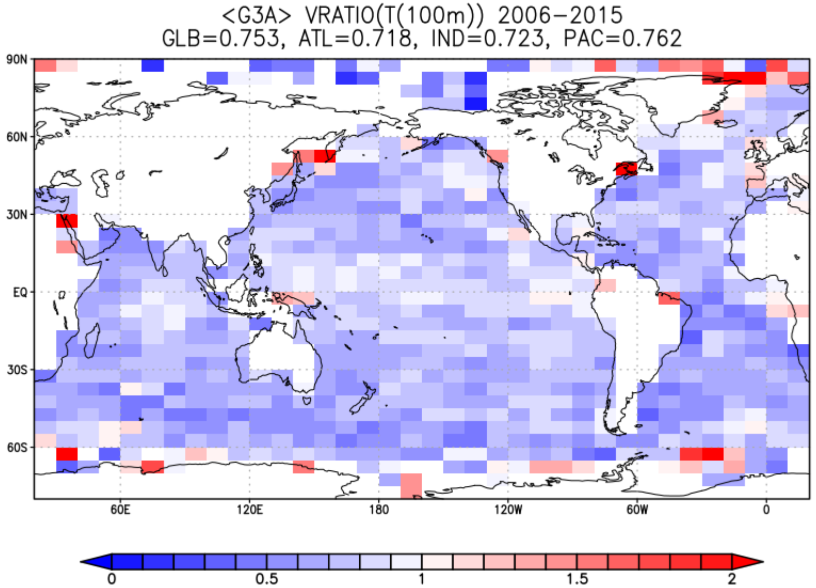
* SSH including weather noise is shown for G3F and G4 while absolute dynamic topography is shown for CMEMS.

* Bias is subtracted to account for global water mass change unrepresented in the models.

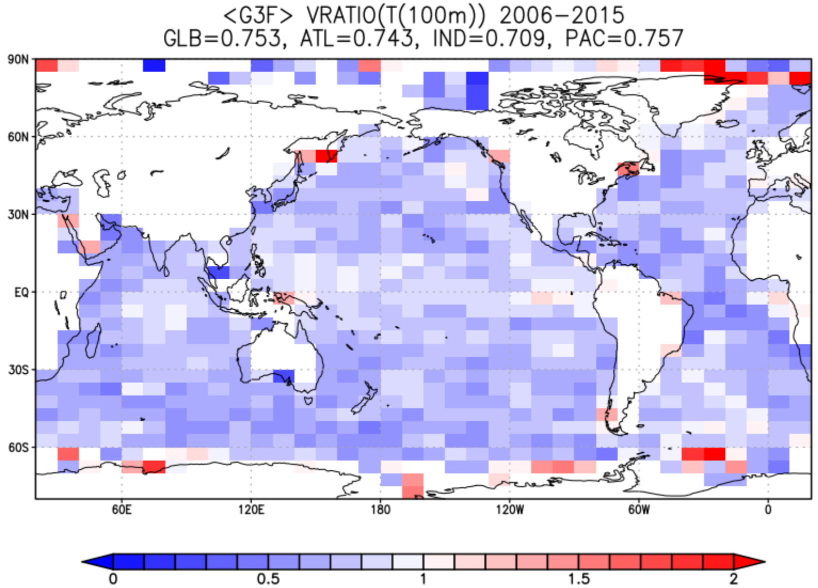
G4 reproduces meanders and eddies that are unclear in G3F. Most of such features are analyzed at true locations.

Impact of analysis resolution on variability (T at 100m)

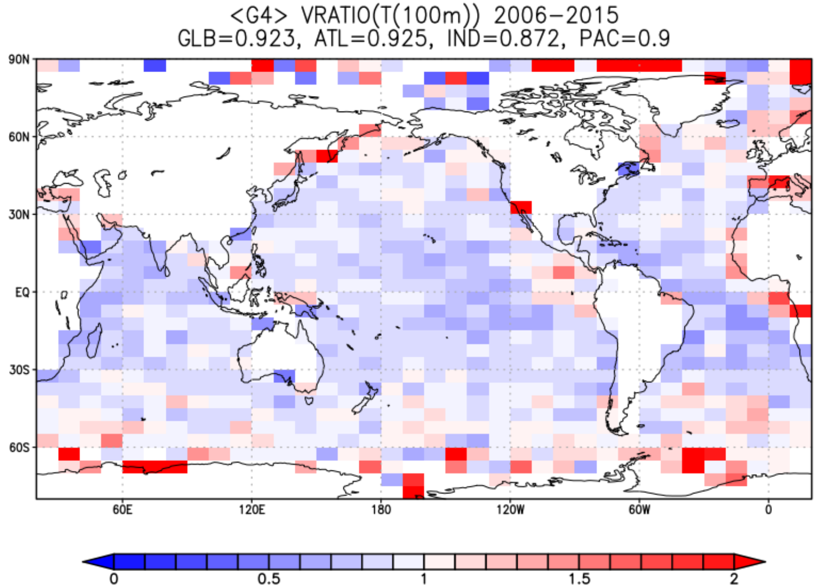
G3A (1.0° x 0.5° 4DVAR)



G3F (0.25° downscaling)



G4 (0.25° 4DVAR)



Blue: smaller variability than Argo
Red: larger variability than Argo
Thinner colors are better

Temperature variability in G3F is as small as in G3A. In G4, it is almost as large as observed.

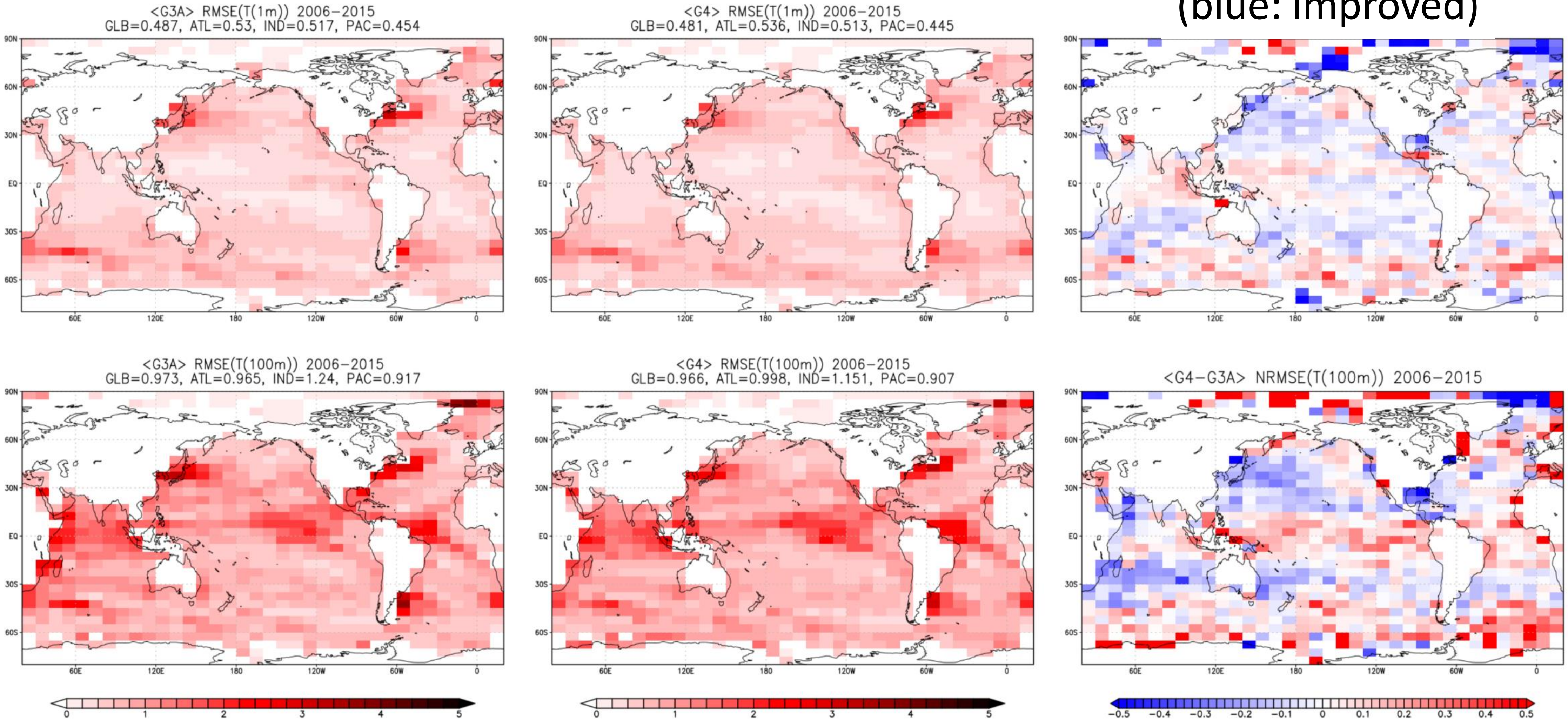
* Variance ratio = STDV(Analysis anomaly) / STDV(Observed anomaly), verified with Argo floats

RMS Errors to withheld Argo (2006-2015)

G3A (1.0° x 0.5° 4DVAR) | G4 (0.25° 4DVAR) | Normalized diff (blue: improved)

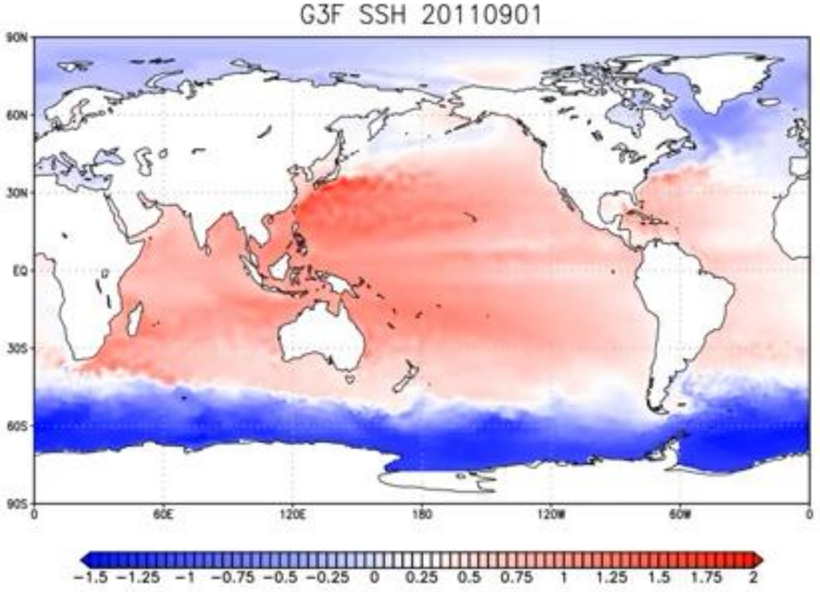
SST

T at 100m

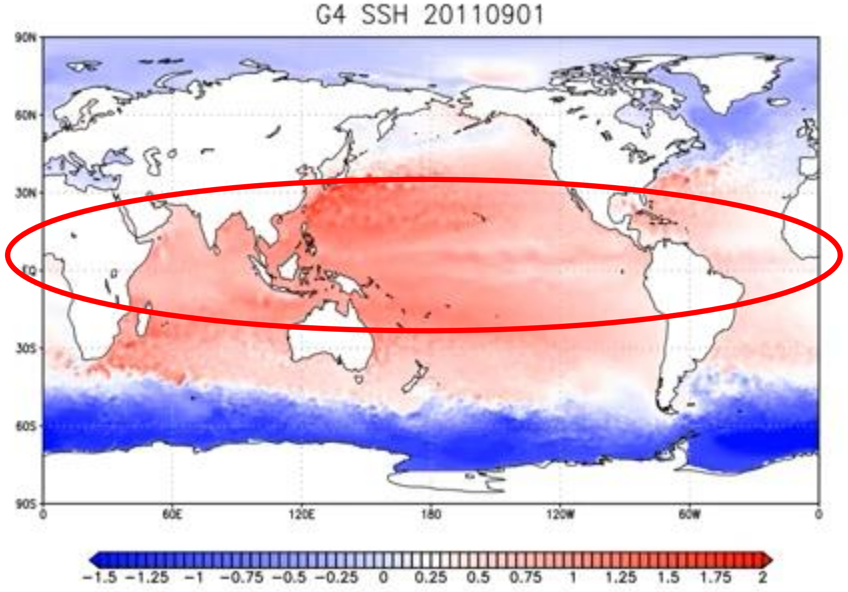


G4 issue: too much noise in the tropics

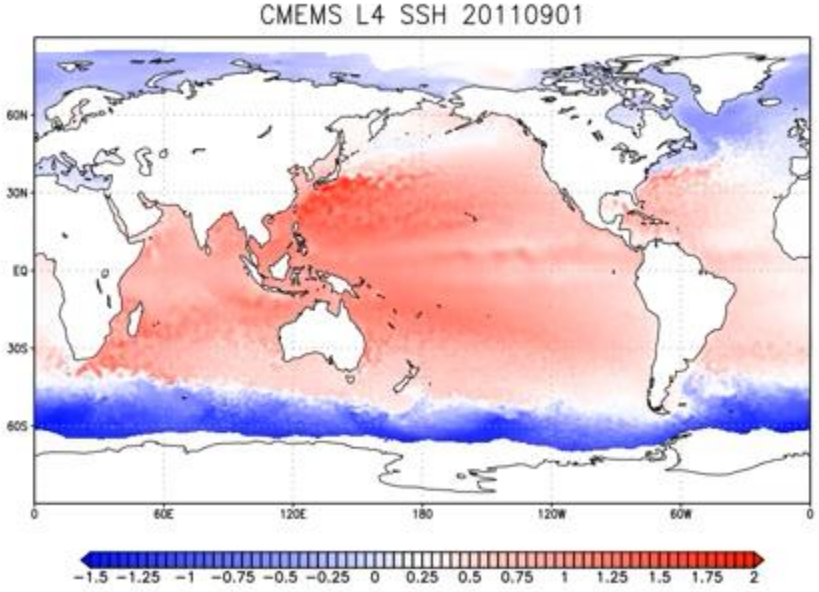
G3F SSH (0.25° downscaling)



G4 SSH (0.25° 4DVAR)

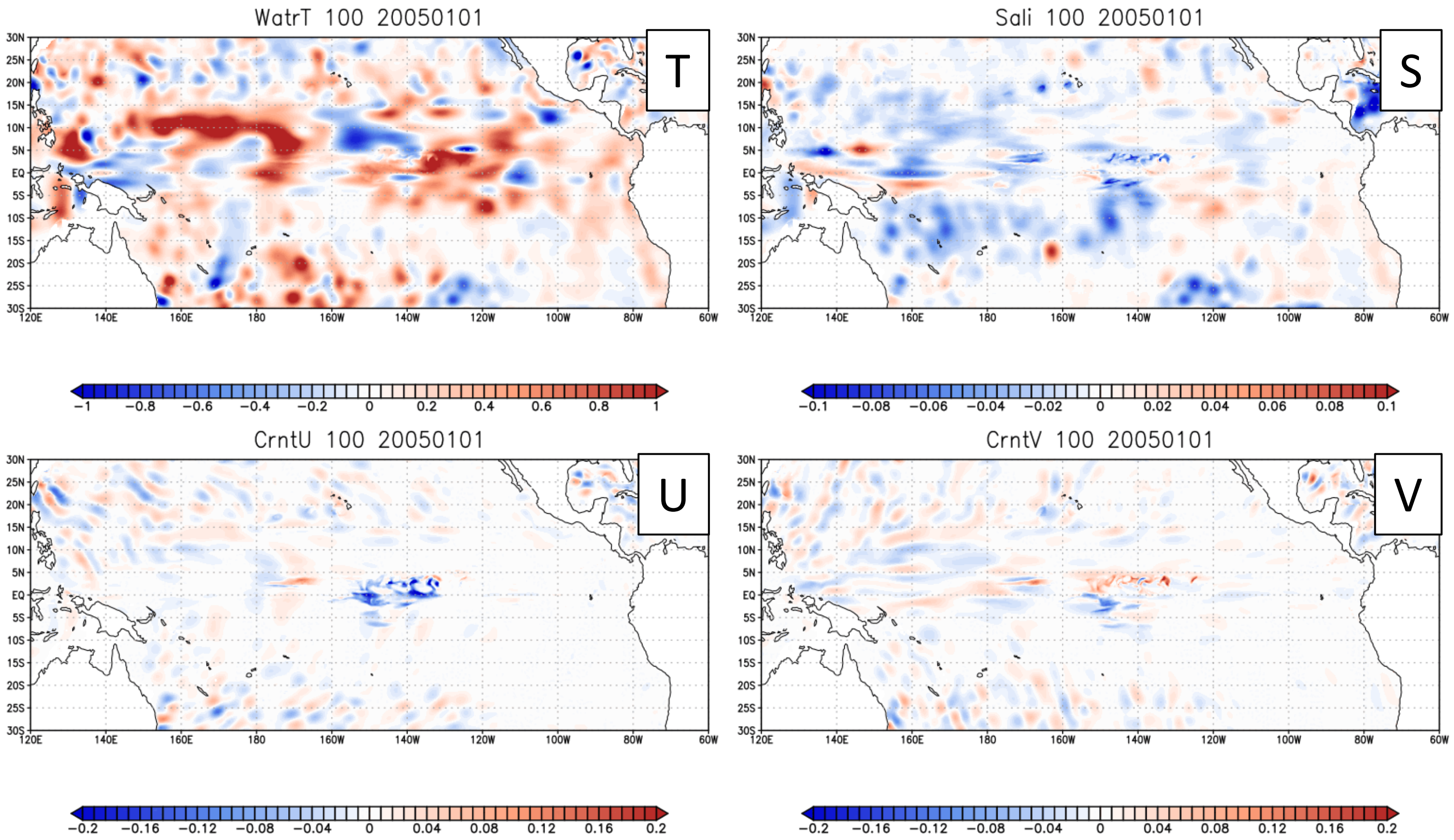


CMEMS L4 SSH (obj. anl.)



The spatial structure of SSH in G4 is much improved from G3F. However, in the tropics, high-frequency noise is seen. This noise can be attributed to the shorter 1-day IAU, and the oscillation partly explains the degraded temperature analysis through false mixing.

Perturbations caused by an increment



Here is the difference between two model runs with/without increment on the first day (1-day IAU followed by a 5-day free run), showing perturbations caused by an increment.

The model's response to the increment vastly differs by latitude:

In the extratropics, perturbations remain there as vortices.

In the tropics, most perturbations propagate as equatorial waves, resulting in noisy analyses when cycled. Extra treatment is needed.

* Daily mean values at 100m depth

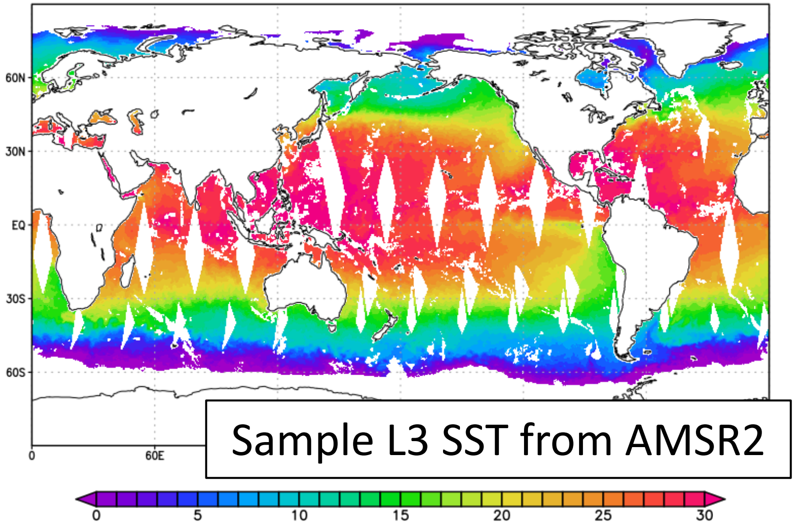
* The difference on the 1st day is multiplied by two, to account for incomplete IAU.

Another effort: direct assimilation of L3 SST

- To incorporate satellite SST observations, operational MOVE-G3 assimilates MGDSST (level 4) with in-situ T/S observations.
- However, assimilation of L4 data is suboptimal because observation coverage cannot be considered, and interpolated observations are assimilated as if they were real observations.
- In addition, near-real-time MGDSST, only using past information, is known for delayed response to rapid SST changes (Ito 2022, JSMJ).

→ We test assimilation of level-3 (collated) SST from AVHRR (NOAA-19), VIIRS (S-NPP), and AMSR2 (GCOM-W).

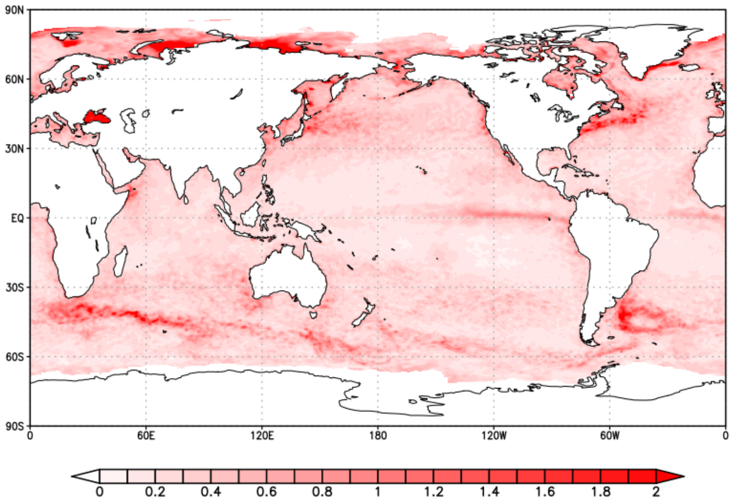
– L3 data here are the same intermediate data used for near-real-time MGDSST production. QC'ed and bias-corrected daily mean SST for each satellite is available.



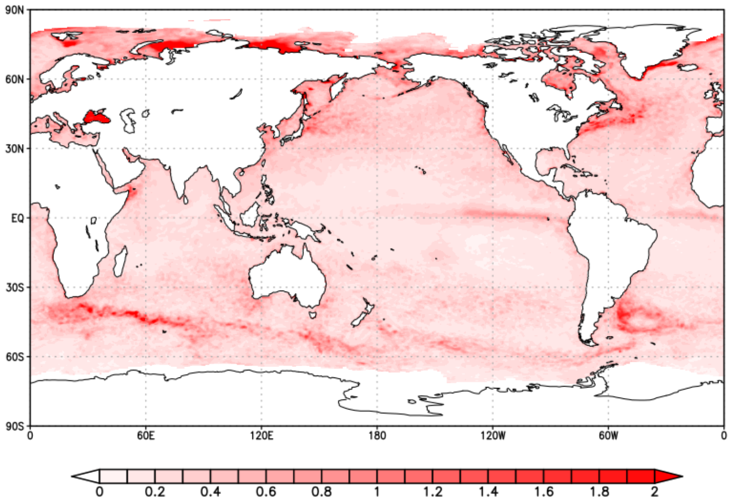
Sample L3 SST from AMSR2

Result: direct assimilation of L3 SST

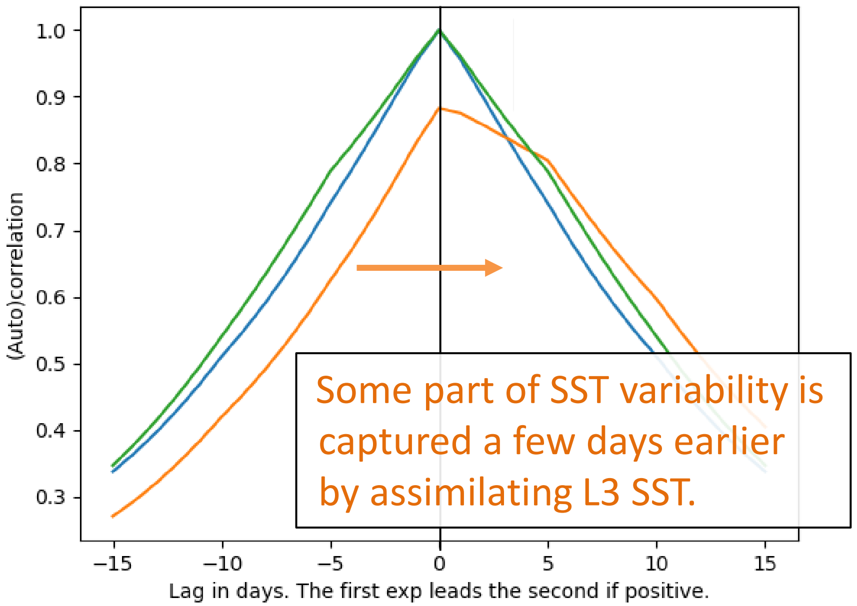
RMSD G3A SST assimilating L4



RMSD G3A SST assimilating L3

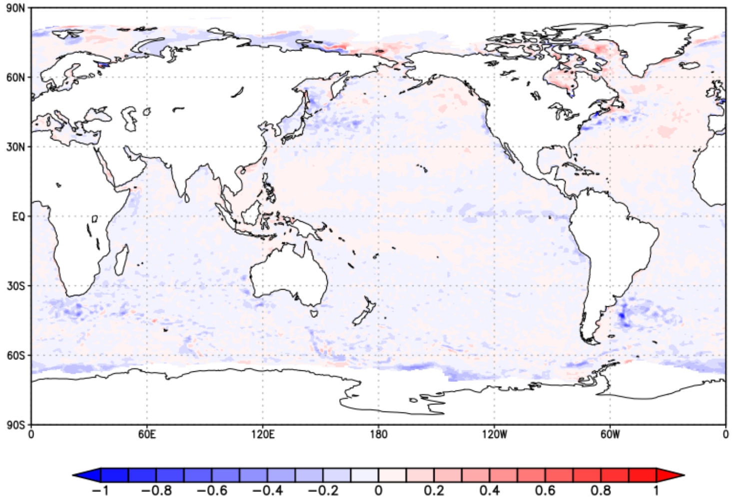


Auto- and lag- correlations of MOVE SSTs



Green: auto-correlation, assimilating L4
Blue: auto-correlation, assimilating L3
Orange: lag-correlation between experiments

RMSD diff (blue: improved with L3)



Global RMSD is reduced by ~5% by assimilating L3 instead of L4. The reduction is evident in active regions including Kuroshio, Gulf Stream, TIW, Agulhas, and Falkland.

* RMSDs here are calculated with respect to GHRSST GMPE (daily multi-product median).
* Experiment period: May 1 – Nov 6, 2022
* Operational MGDSST was updated in May 2023, and its response to rapid SST change was improved.

Summary

- JMA is operating MOVE/MRI.COM-G3, which combines global ocean 4DVAR and dynamical downscaling to a quater-degree model.
  - As a minor modification, spatial filtering of the downscaling increments is tested and confirmed to enhance effective resolution.
- JMA is now developing a new ocean analysis/reanalysis system, MOVE/MRI.COM-G4, for initializing coupled forecasts. It features 4DVAR with an eddy-permitting 0.25° model at a moderate computation cost.
- Experiments show a better representation of small-scale structures globally, and analysis error is smaller in the mid-latitudes.
- However, tropical analysis suffers from high-frequency noise that cannot be filtered with the shorter 1-day IAU. Reducing this noise is future work.
- We also test direct assimilation of level-3 SST instead of level-4, where we get reduced analysis errors and earlier response to SST changes.