SynObs2026 (2026/08/24) Mutsu

Validation of ocean state estimation by satellite altimeters targeting meso-scale eddies south of Japan

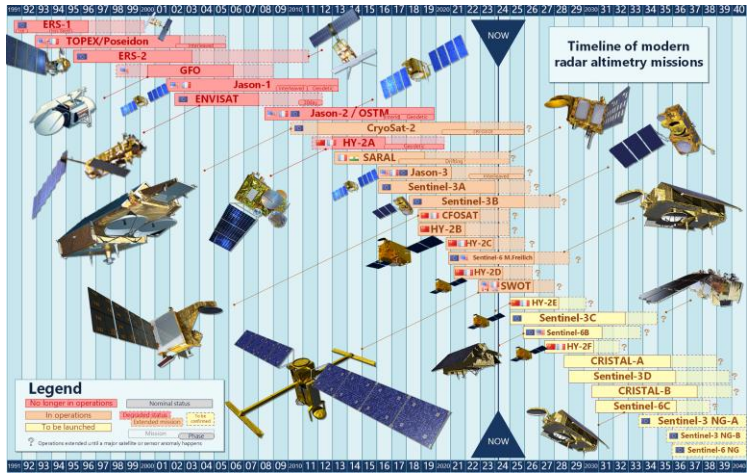
Miyazawa, Miyama, Chang, Hayashida, Kido, Guo, Nagano (JAMSTEC)

★Unprecedented wide-swath altimeter SWOT has been working successfully and demonstrating the capability of capturing fine-scale oceanic phenomena. Here we are focusing on **the impacts on operational data assimilation into an OGCM**.

★To validate surface ocean current estimation, we **conducted massive surface drifter observation** south of Japan. We demonstrate **the state estimation skill dependence on variants of the satellite observation network** to clarify actual roles of the new type wide-swath altimeter.

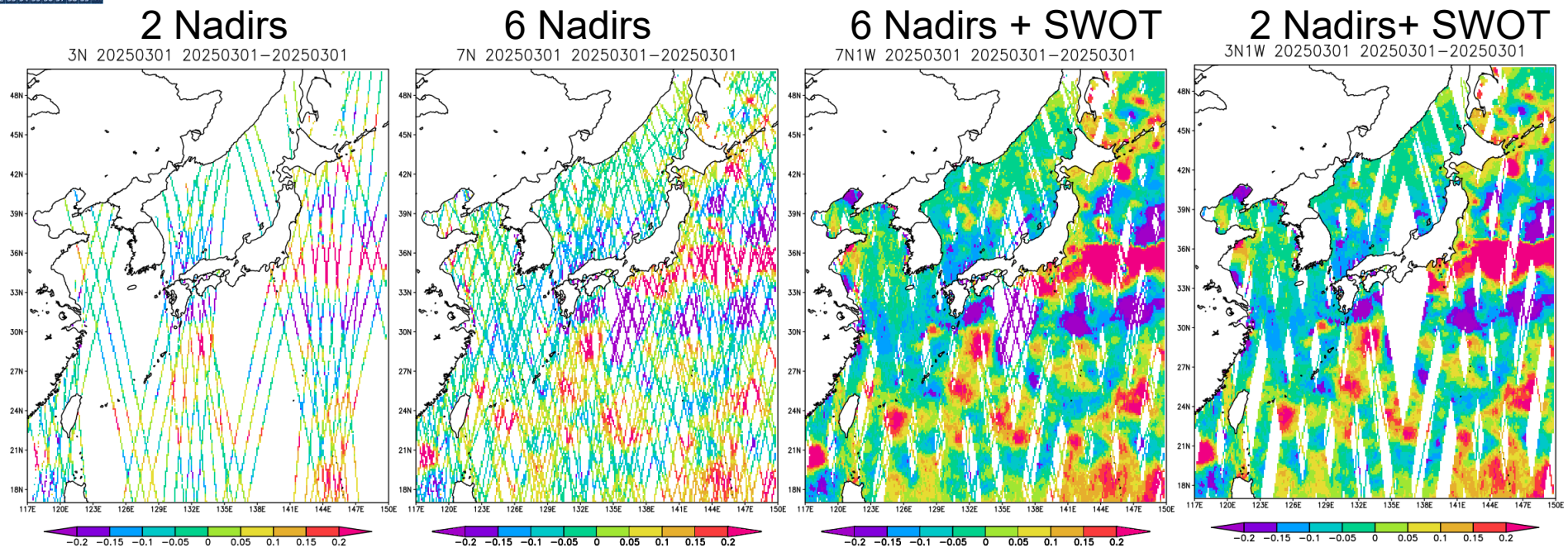
★Combining massive particle tracking simulations using model velocities smoothed by different horizontal scales with massive drifter observations allows us to evaluate **Constrained horizontal Scale Minimum (CSM)** represented by data assimilation products.

Evolution of satellite altimeter network



★Past over 30 years, the altimetry network has been enhanced by increasing number of satellite operations.
★We examined the sensitivity of various altimeter combination, keeping in mind the history of satellite altimetry observations.

(Ballarota et al. 2025 Ocean Sci.)



like 30-years ago | present time | present time | a few yeas later?

Increasing data amount →

?

Observation System Experiments

Before going to demonstration of the SWOT fine-scale assimilation, we have examined operational effects of SWOT in a framework of an eddying (not eddy-resolving) regime.

Period: 2025/02/22-2025/03/17

Model: 1/12° Northwetern Pacific JCOPE3 (Varlamov and Miyazawa 2022)

7 DA cases

DA parameters
3DVAR 100km / 4-day
3DVAR 70km / 4-day
3DVAR 50km / 4-day
3DVAR 30km / 4-day
3DVAR 50km / 2-day
3DVAR 30km / 2-day
4DEnVAR (a4dvar)

X

4 Observation systems

Altimeter networks
2 Nadirs (like 30-year ago and a few years later)
6 Nadirs (present time)
6 Nadirs + 1 Wide-swath (present time)
2 Nadirs + 1 Wide-swath (Possibly a few years later)

→ 28 cases

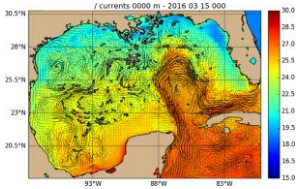
Validation:

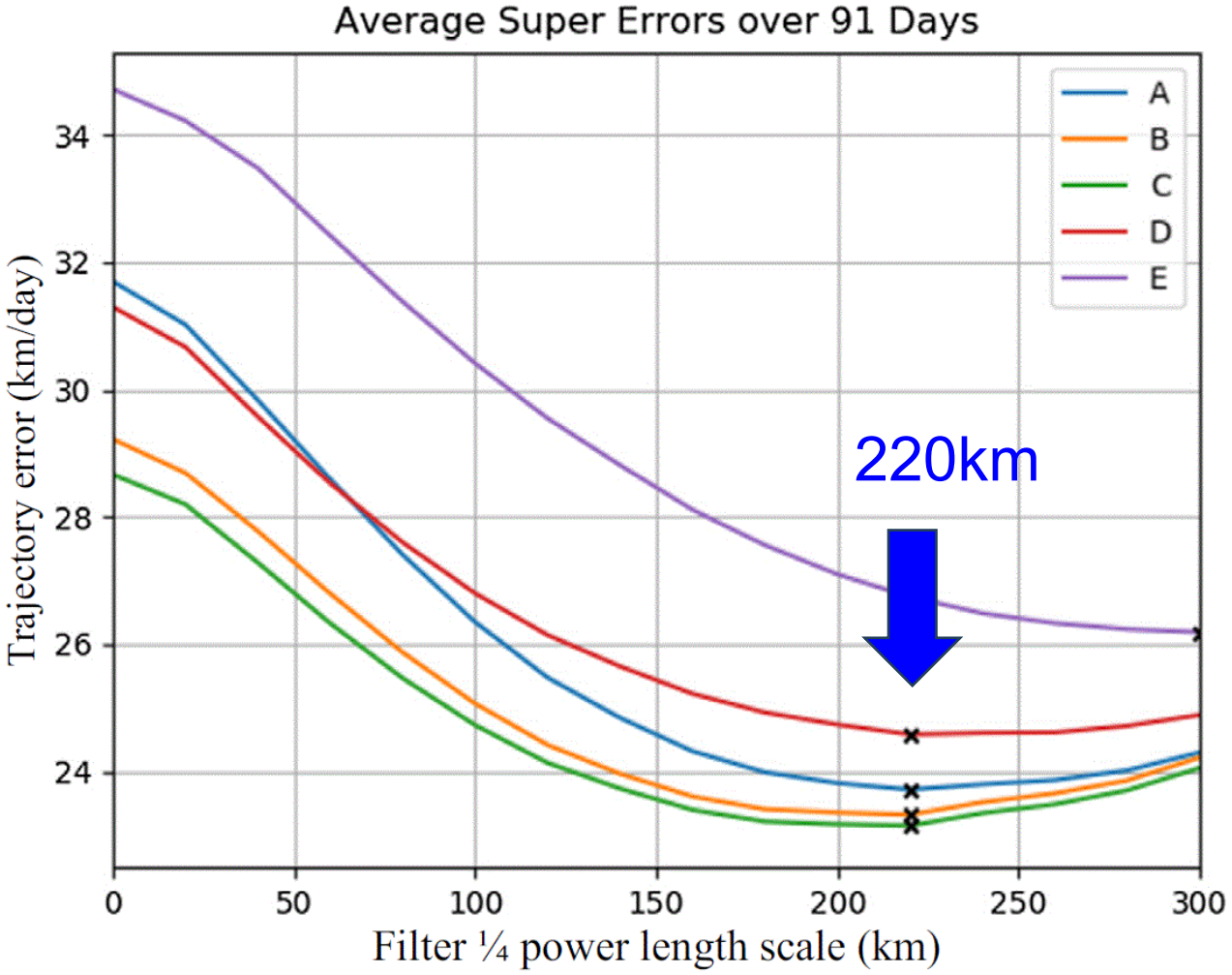
Direct comparison of drifter and particle simulation tracks with successive 2-day periods

→ Calculate RMSD of drifter trajectories (‘trajectory difference’)

Constrained Scale Minimum (CSM)

Gulf of Mexico (2016)





(Jacobs et al. 2021 Advances in Space Research)

CSM is estimated as s for minimum of Trajectory RMSD:

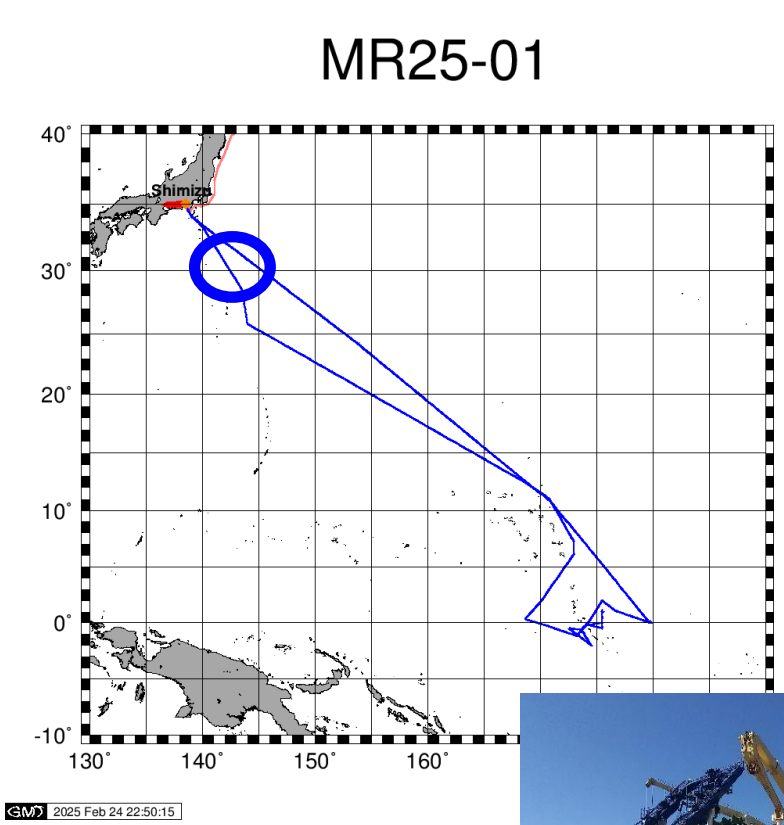
$$\frac{1}{M}\sum_{m}^{M}\sqrt{\frac{1}{N}\sum_{n}^{N}\left(O_{mn}-M(s)_{mn}\right)^{2}}$$

-O_{mn} : Position of a drifter m for period n
-$M(s)_{mn}$: Position of a particle starting from initial location of drifter m in period n
-s: Horizontal scale used for smoothing model velocities

Smaller CSM means better capturing the meso-scale eddies.

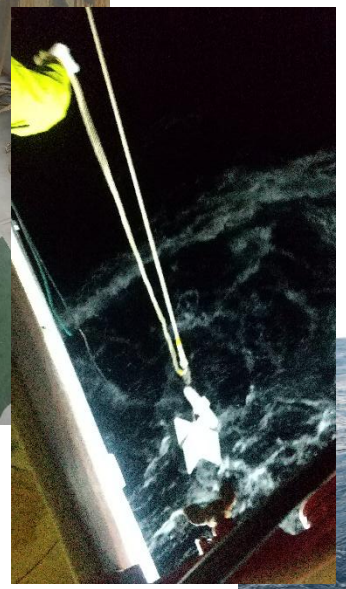
We have done a massive observation experiment and simulations south of Japan.

Deployment of 115 CARTHE drifters

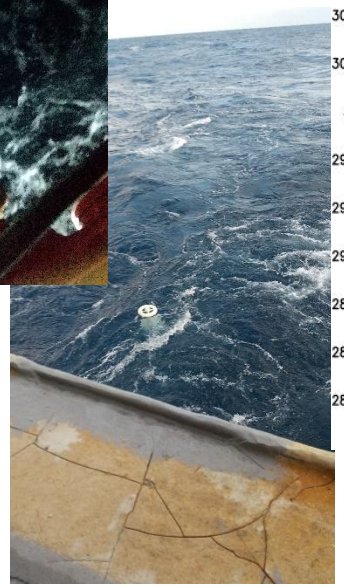




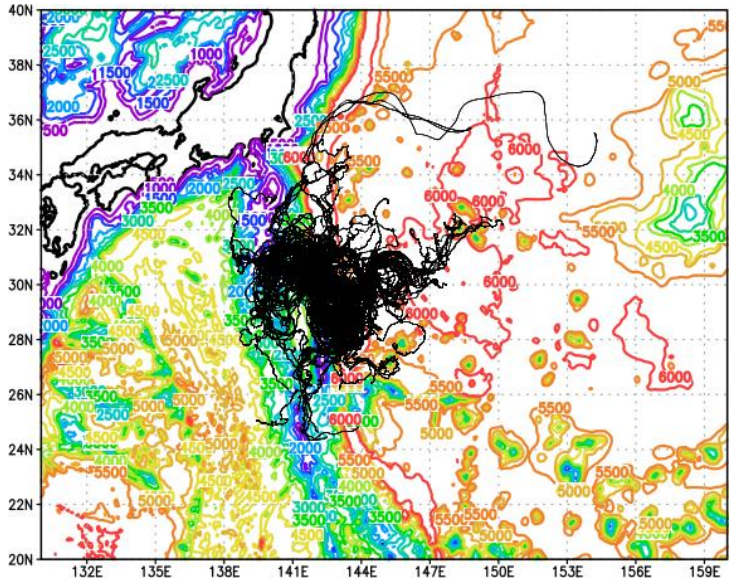


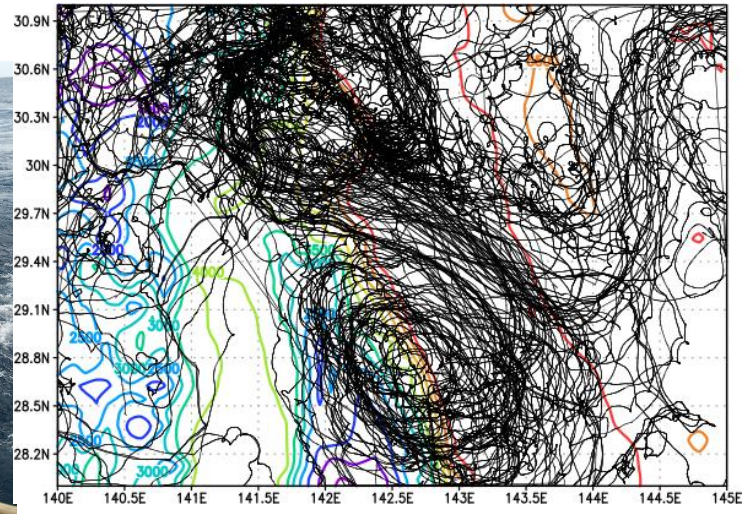






2025/2/22～
2025/4/12
115 drifters





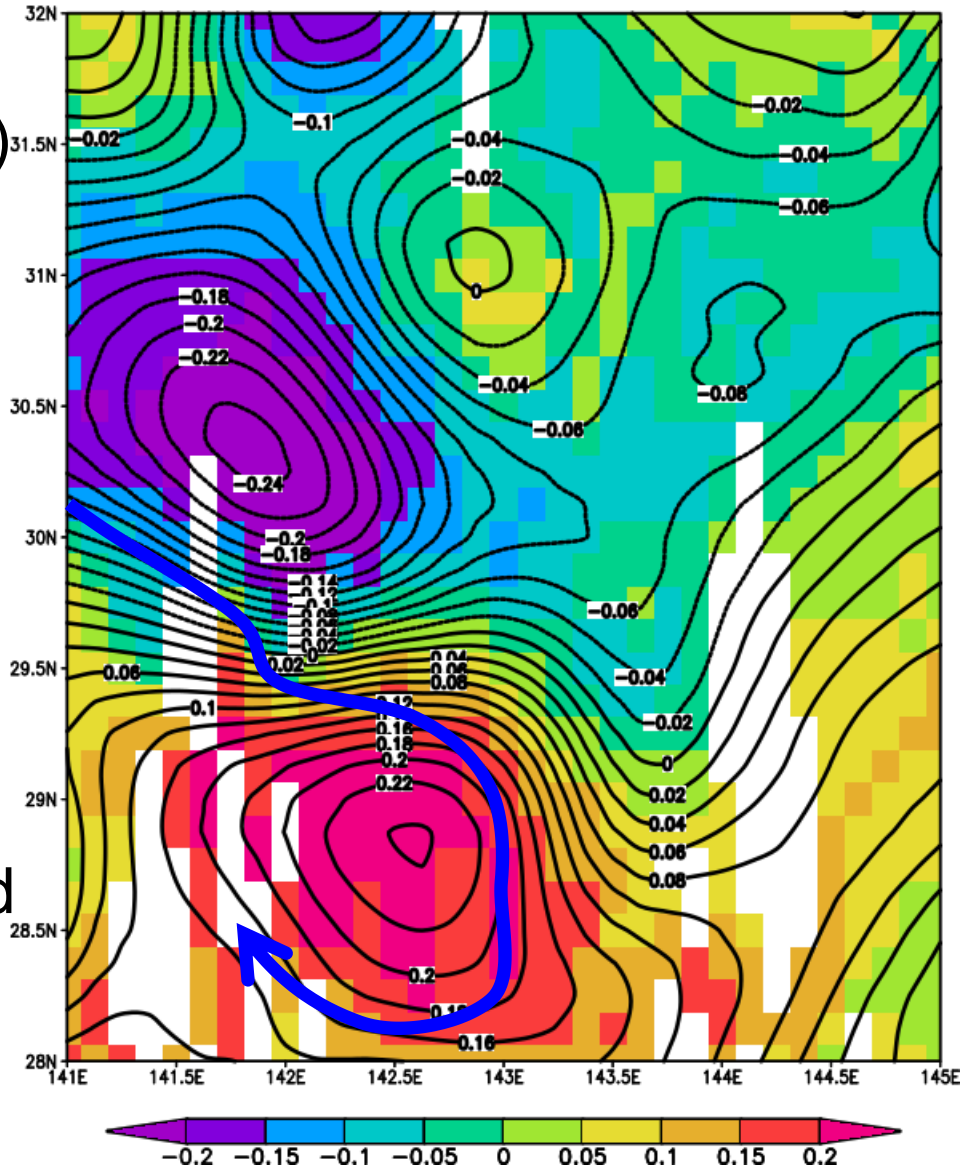
JAMSTEC R/V Mirai みらい
MR25-01 cruise
2025/01/11-2025/02/24

Model estimation and observed tracks

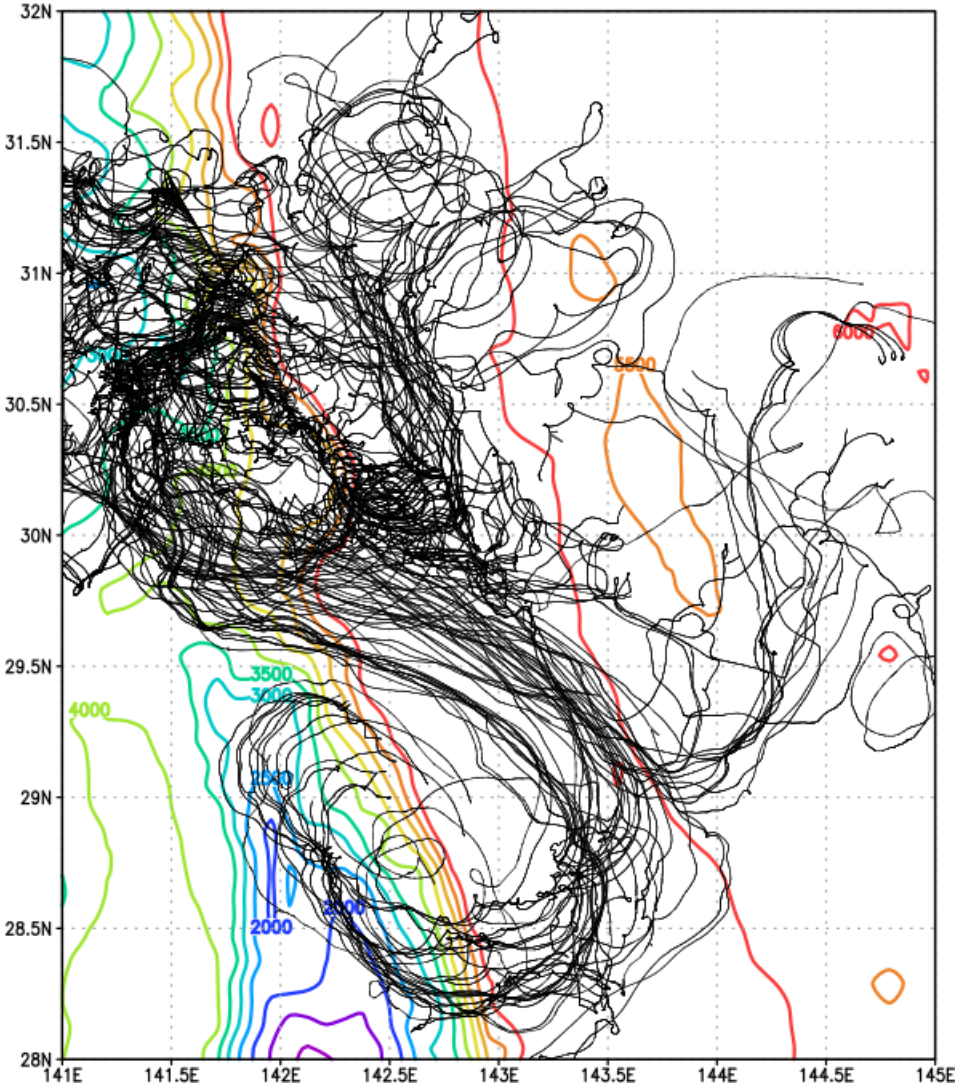
Contours:
4dEnVAR(a4dvar)
Color shades:
6Nadirs+SWOT

4DEnVAR(a4dvar) seems to reproduce eddies as observed by drifters

Sea surface height anomaly
a4s 20250305 20250301–20250309

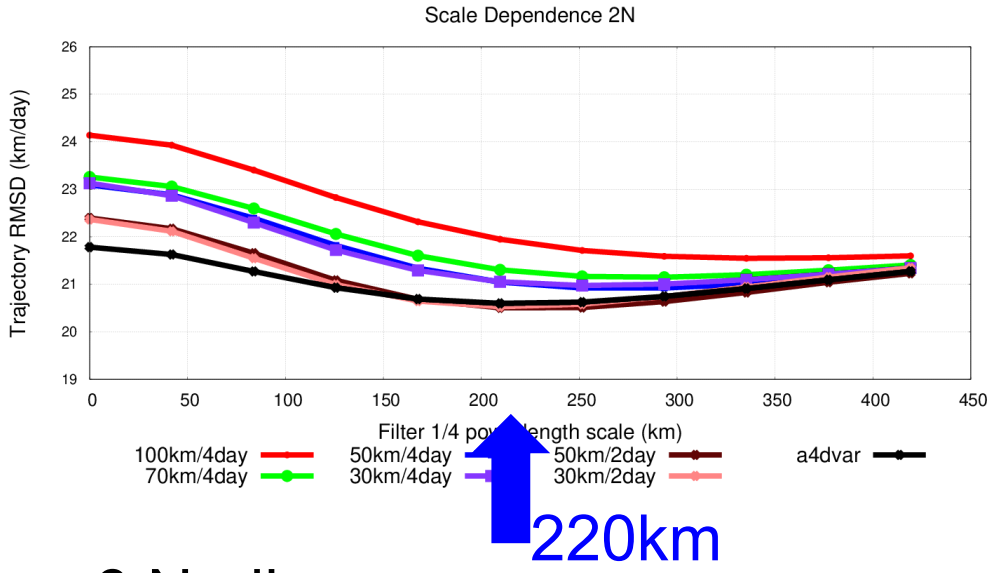


Drifter trajectories
20250223–20250317

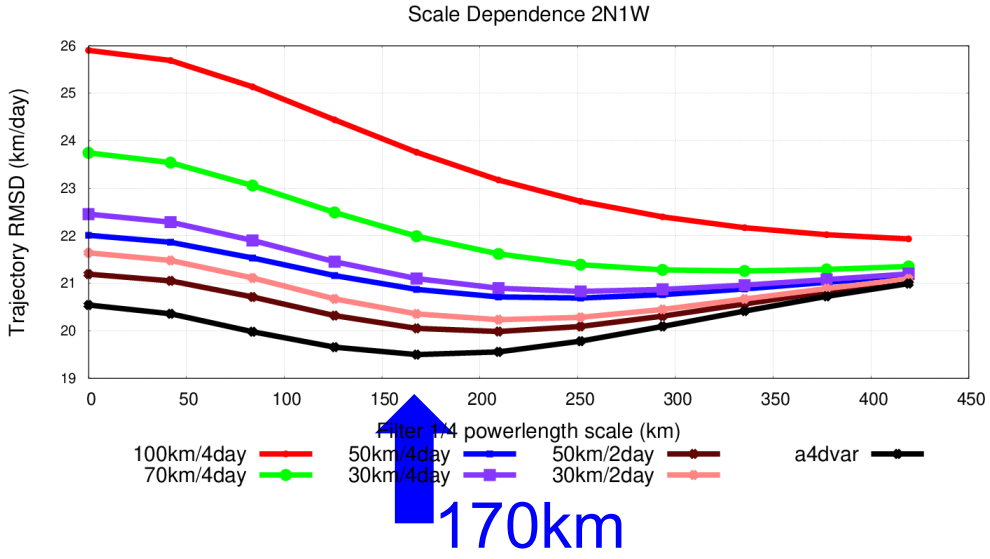


Constrained Scale Minimums (CSMs)

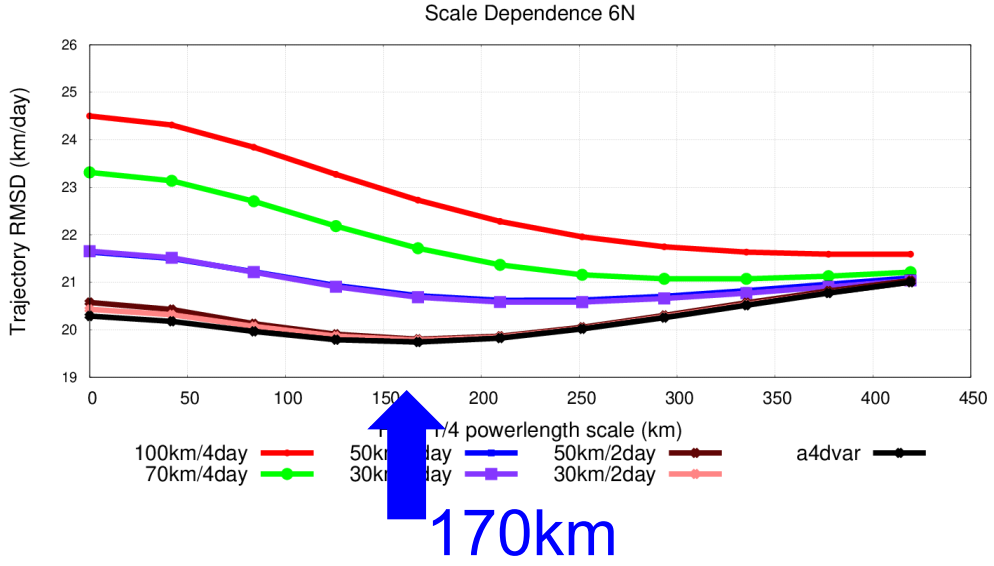
2 Nadirs



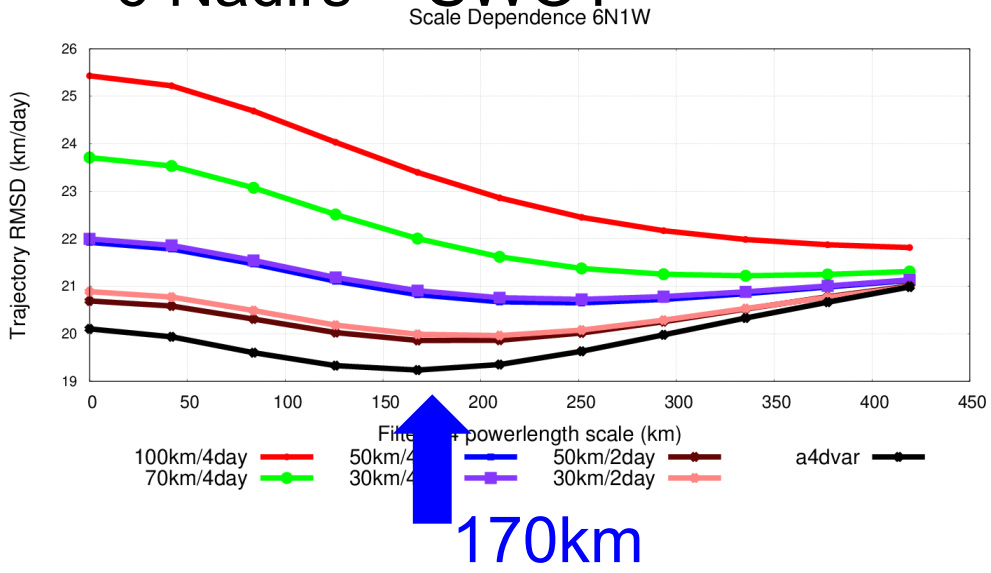
2Nadirs + SWOT



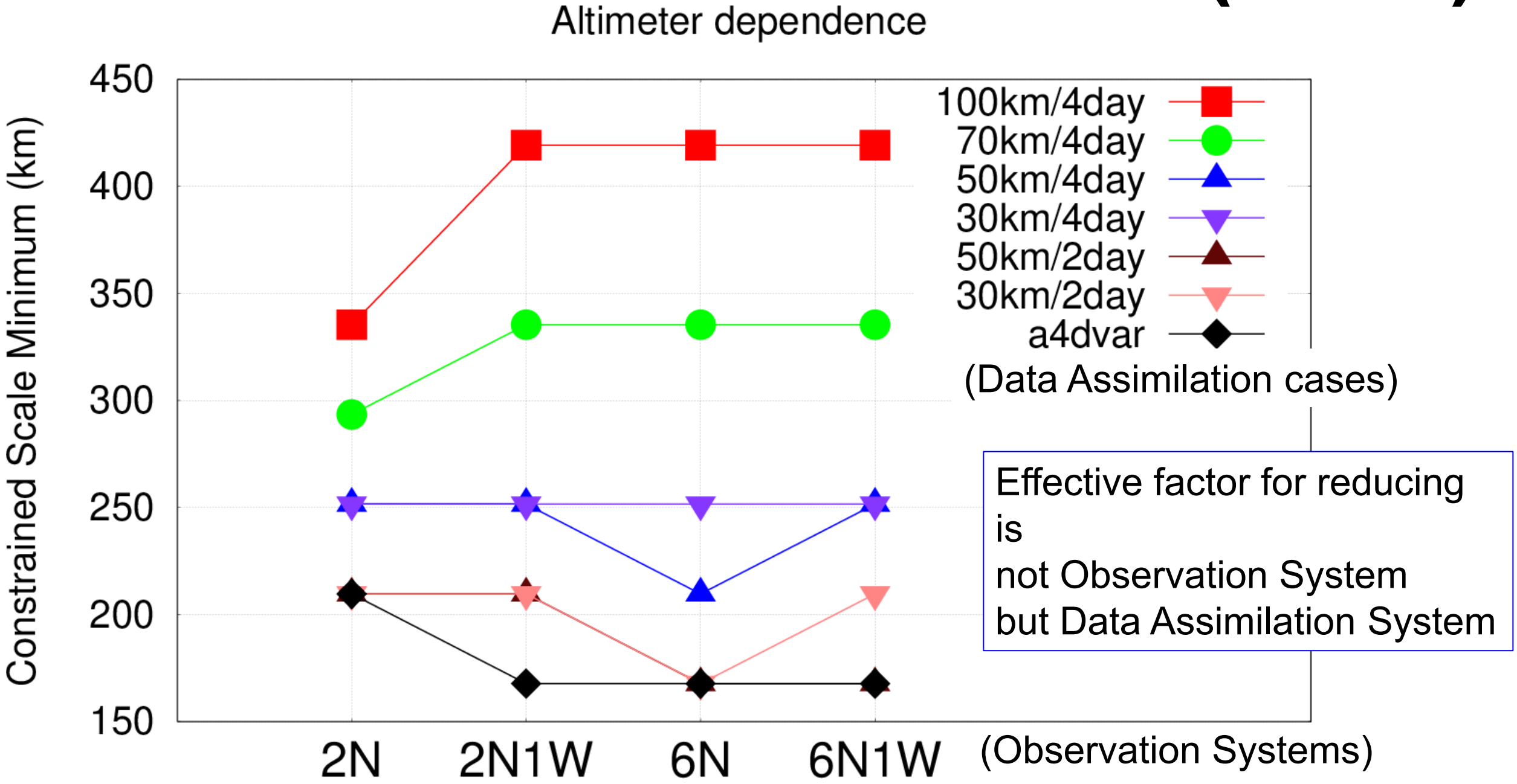
6 Nadirs



6 Nadirs + SWOT

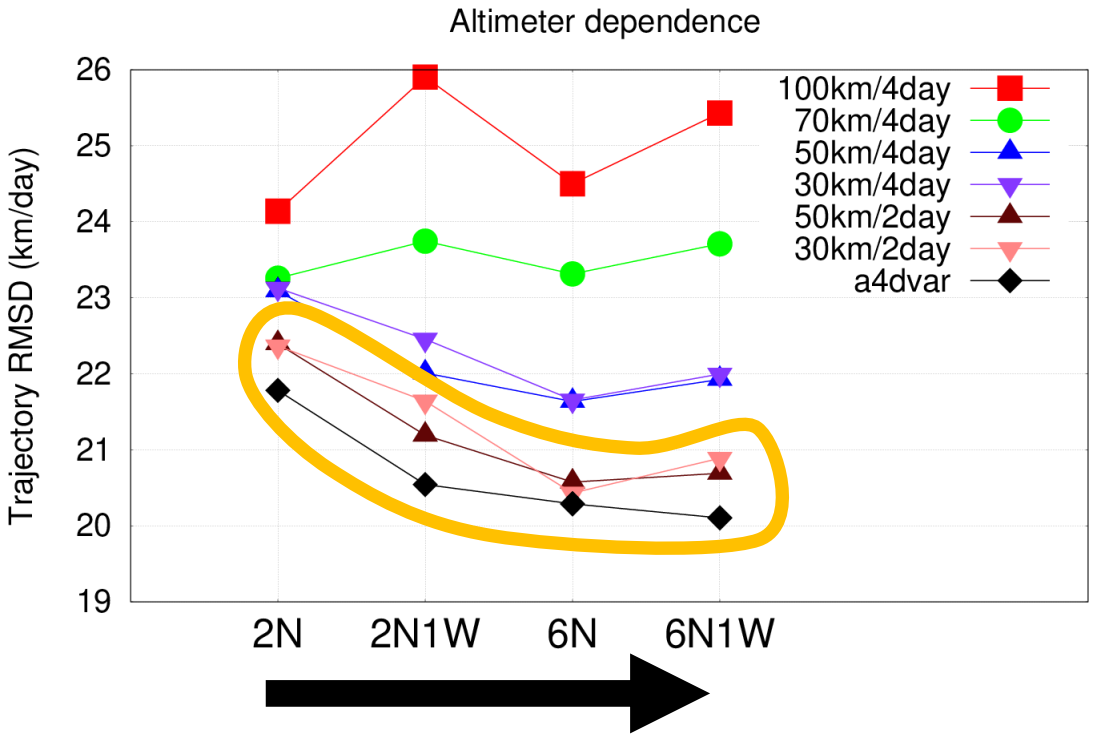


Constrained Scale Minimums (CSMs)



Lesson from Observation System Experiments 1: Need skillful DA systems

Trajectory RMSD based on non-smoothed velocities



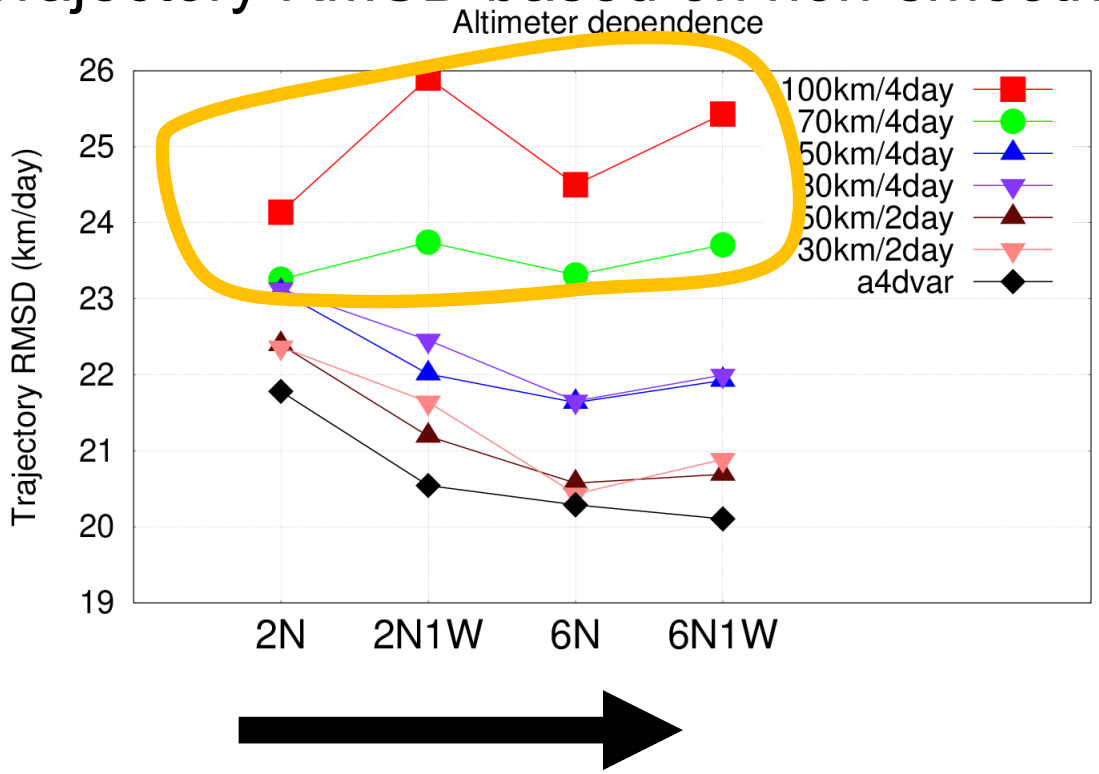
Increasing assimilation data

Only the advanced 4DEnVAR (a4dvar) system demonstrates a commensurate skill improvement as the volume of observational data increases, strongly suggesting the need for continued development of data assimilation technology

The ‘simple’ (stationally) 3DVAR might be not able to assimilate the dynamical information of time-varying mesoscale eddies represented by the SWOT data, but 4DEnVAR well does it.

Lesson from Observation System Experiments 2: Avoid bad parameters

Trajectory RMSD based on non-smoothed velocities

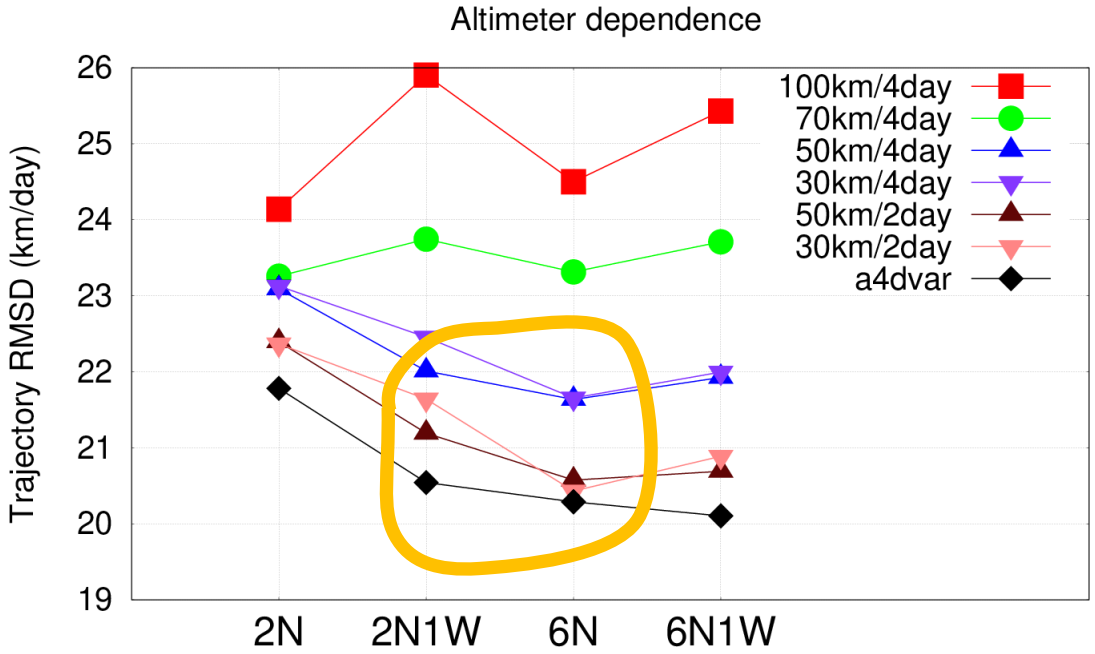


Increasing assimilation data

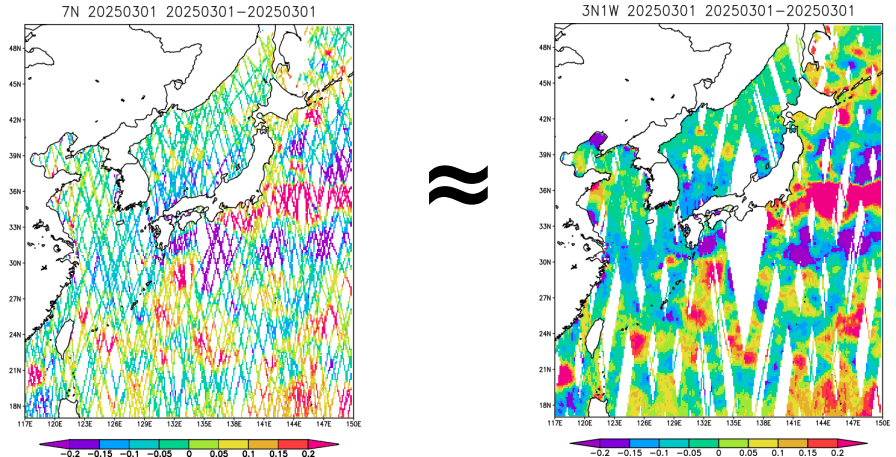
The 3DVAR with larger horizontal scales (70km, 100km) results in unfavorable decline of the skills even with increasing observation data amount by adding more and more altimeter data.

We need to carefully tune the data assimilation systems to utilize available data as many as possible.

Lesson from Observation System Experiments 3: 3~4 Nadirs = 1 Wide-swath



6Nadirs ≈ 2Nadirs+1Wide-swath



The skills achieved by assimilation of 6 nadirs are roughly comparable with those by 2 nadirs and 1 wide-swath altimeters,

indicating 1 wide-swath altimeters works as 3~4 nadir altimeters.

The present favorable situation of 6 available nadir altimeters is not sustainable in the future.

More 1 wide-swath altimeter would be a simple solution for strengthening the altimeter measurement network.

Summary

We conducted observation system experiments (OSEs) to clarify roles of satellite altimeters in reproducing surface ocean currents south of Japan using ocean data assimilation systems.

・Massive surface drifter deployments allowed us to evaluate the skills reproducing the drifter movements by conducting massive particle tracking simulations according to the observed drifter locations.

・Skills achieved by 4 types of the satellite altimeter network are compared among each other. A) 2Nadirs (situation in 20-years ago), B) 6Nadirs (present), C) 6Nadirs+1Wide-swath (present time), D) 2Nadirs+1Wide-swath (possibly a few years later).

・Critical messages are

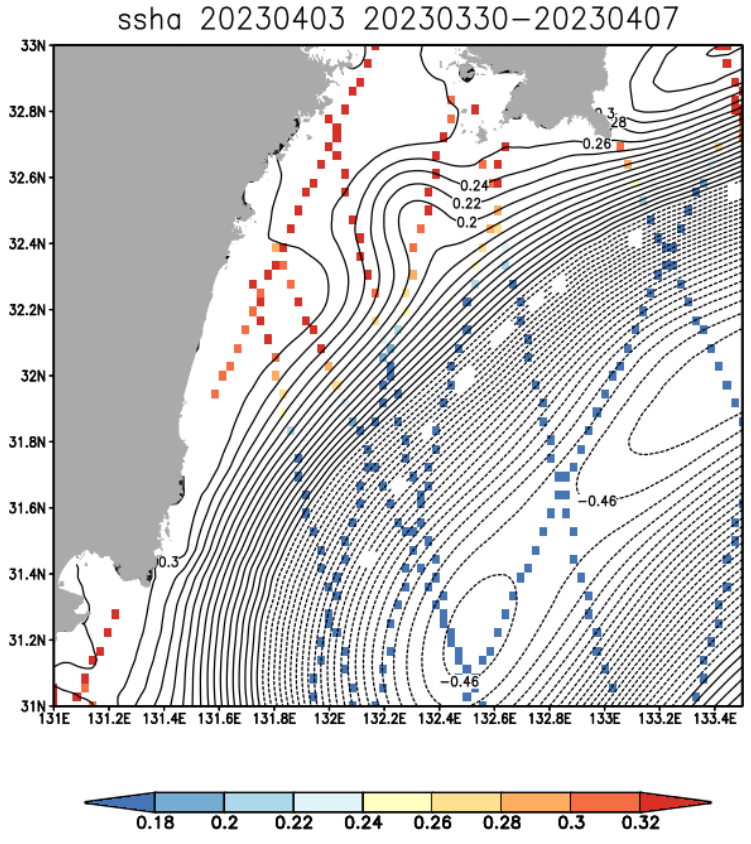
1) Constrained horizontal scales of meso-scale eddies are critically governed by Data Assimilation Systems (Parameters) rather than Observation Systems,
2) Data Assimilation Systems should be successively improved to well assimilate more and more new types data,
3) Wide-swath type altimeter has a potential to replace 3-4 nadir satellites by one satellite.

Potential of SWOT data

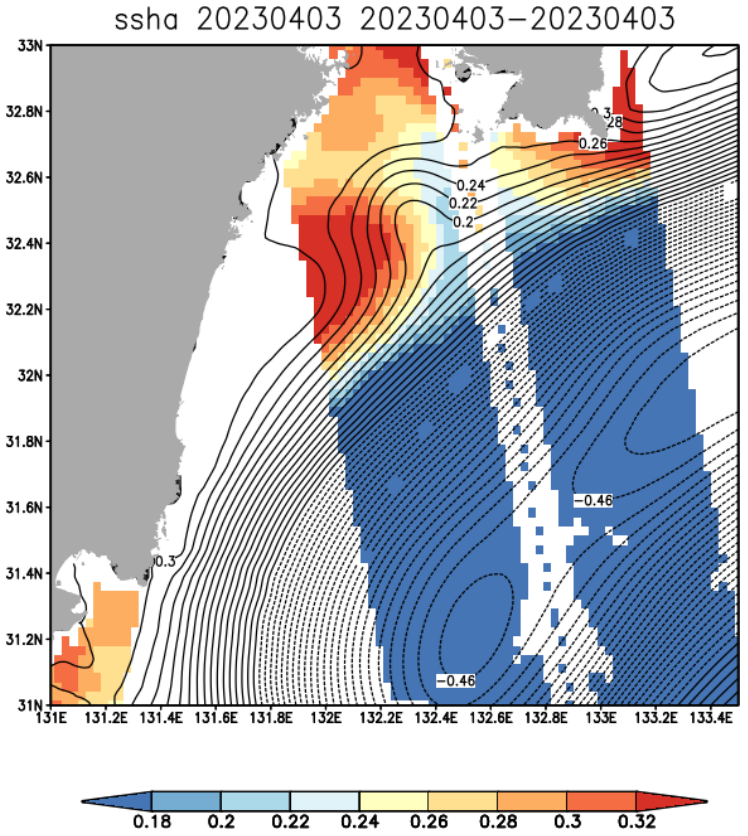
Minimum resolution: 250m

We must investigate potentials of the SWOT data for capturing smaller scale phenomena

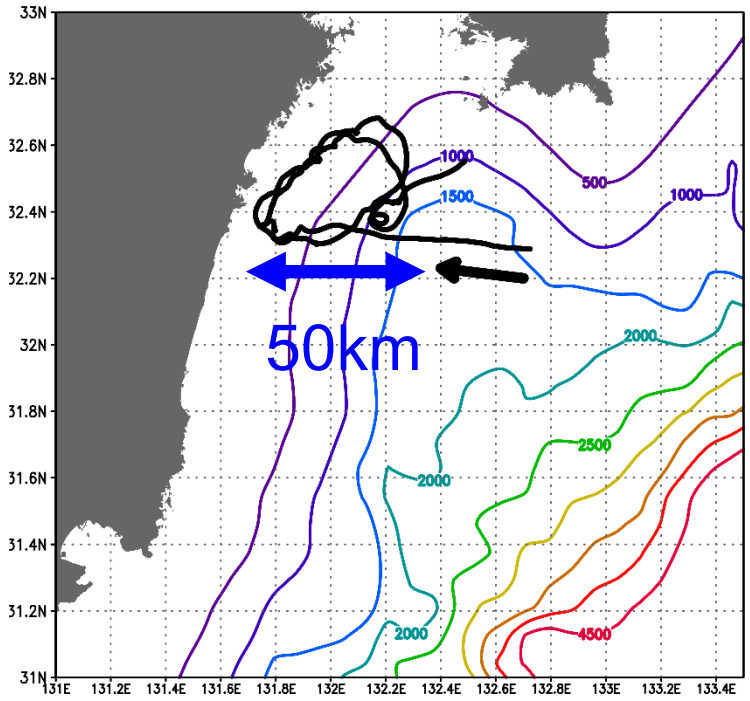
6 Nadirs

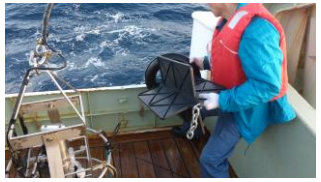


1 Wide-swath(SWOT)



Drifter trajectory



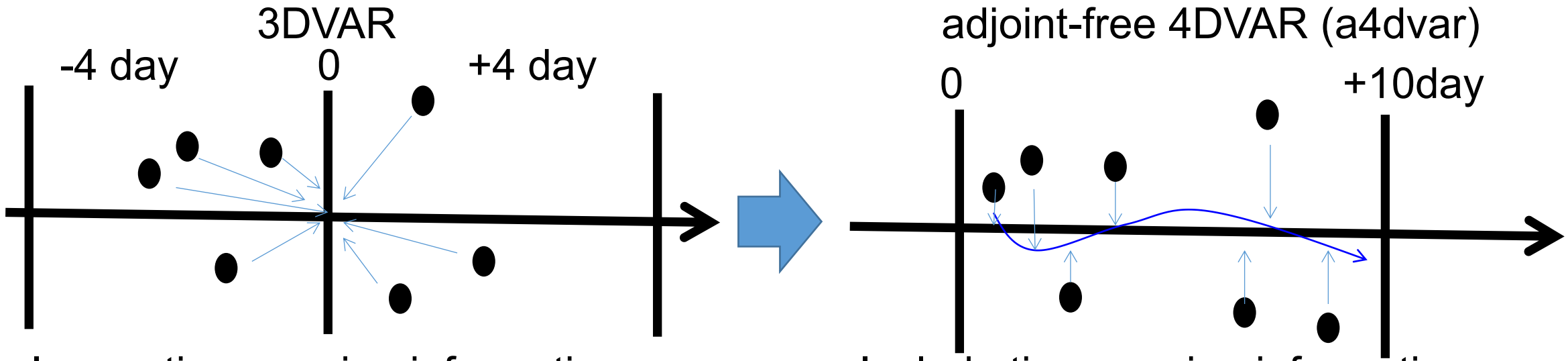


Shade: Satellite altimetry Sea Surface Height Anomaly (SSHA)

Black contours: JCOPE-T DA (3km) model SSHA

Evolution of Data Assimilation Systems

★Transition from **3DVAR to 4DVAR** framework past over 10 years



Ignore time-varying information
(Miyazawa et al. 2017 Ocean Dyn.)

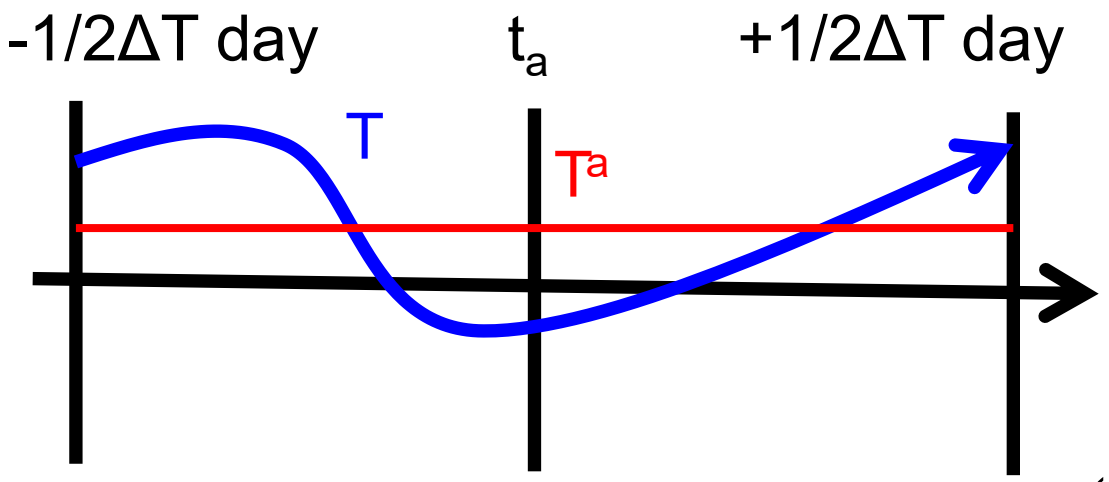
Include time-varying information
(Miyazawa et al. 2024 Ocean Dyn.)

A critical parameter:
Horizontal scale constant in error covariance should be empirically prescribed

Horizontal scale of error covariance is dynamically/automatically adjusted

Another parameter in 3DVAR

ΔT: Incremental Analysis Updated (IAU) period



3DVAR provides temperature/salinity at the analysis date: t_a

For initialization of velocities or other prognostic variables, temperature (T) and salinity (S) are relaxed to the analysis T^a/S^a

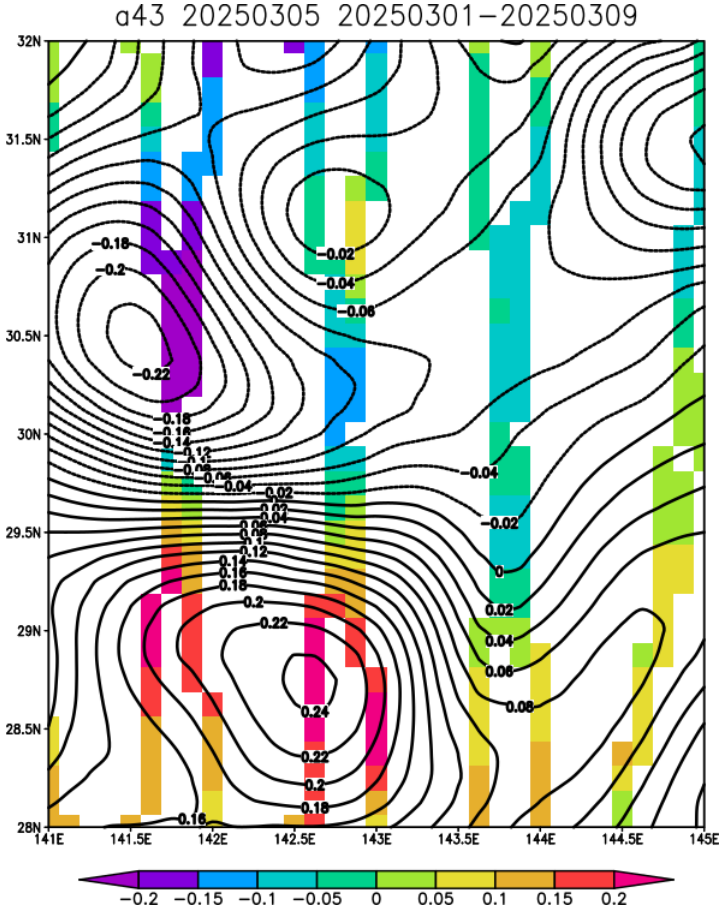
$$T(S)^{t+1} = T(S)^{t} + \frac{\left(T^{t_a}(S)^{t_a} - T^{a}(S)^{a}\right)}{\Delta T}$$

Shorter ΔT means stronger constraint to the analysis T/S but possibly breaks the dynamical balance

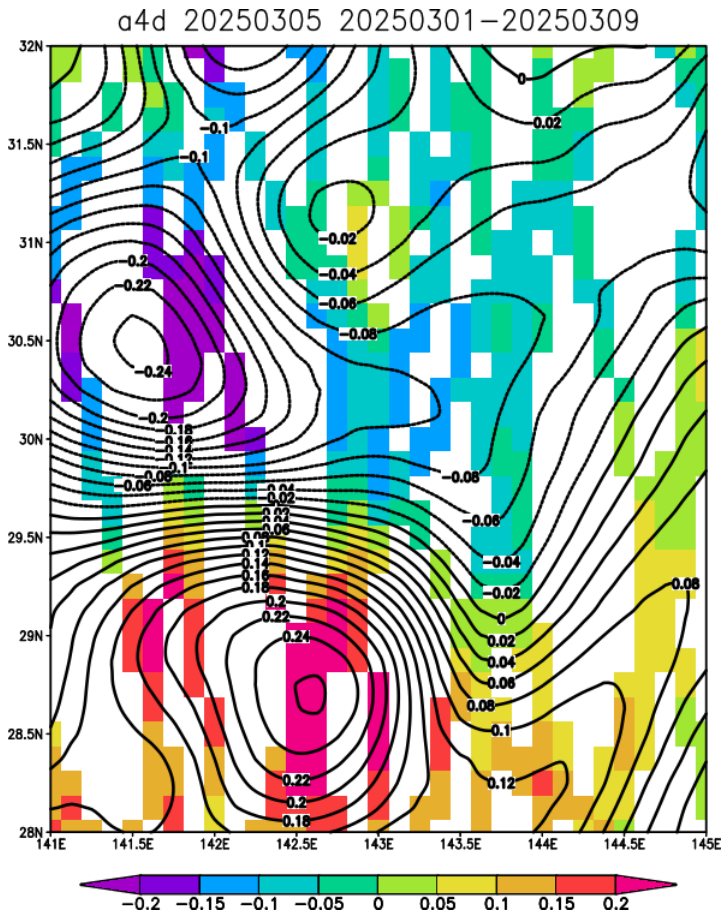
ΔT: 4-day or 2-day?

Reasonable skill improvements with increasing observation data by a4dvar

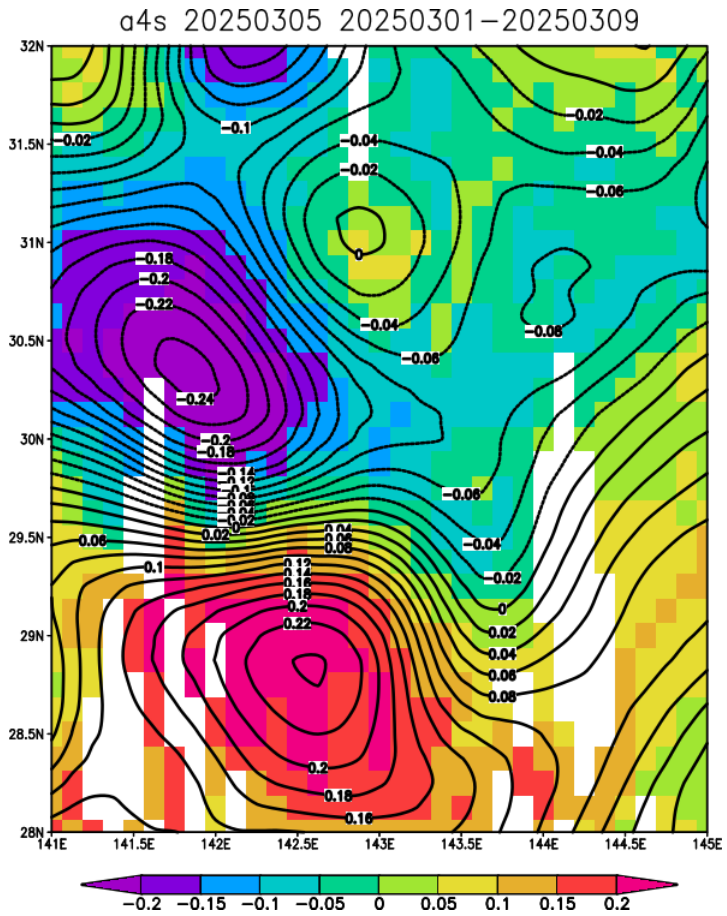
2 Nadirs



6 Nadirs



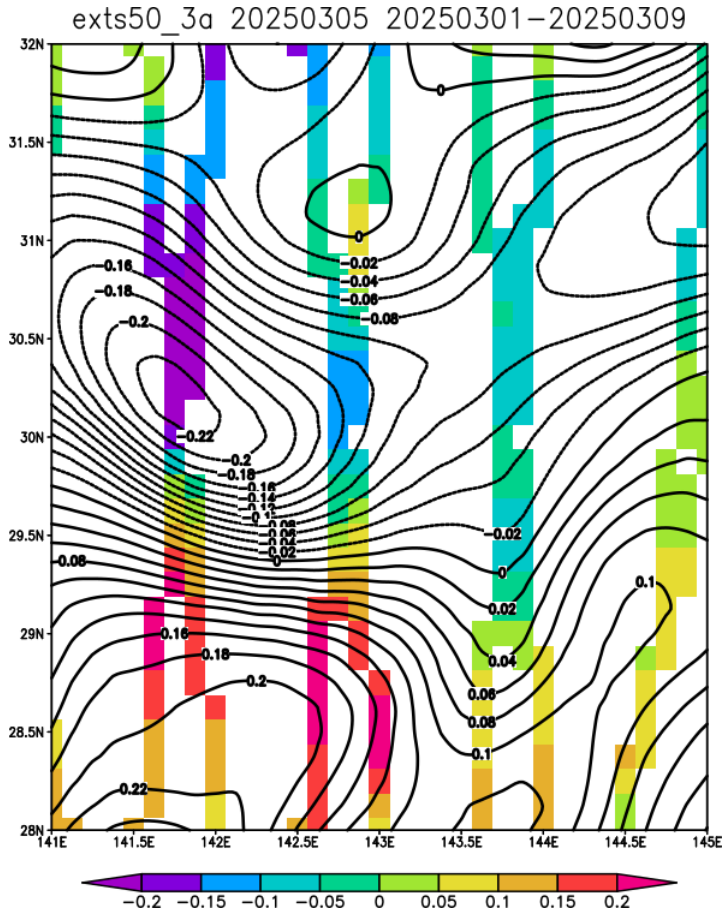
6 Nadirs + SWOT



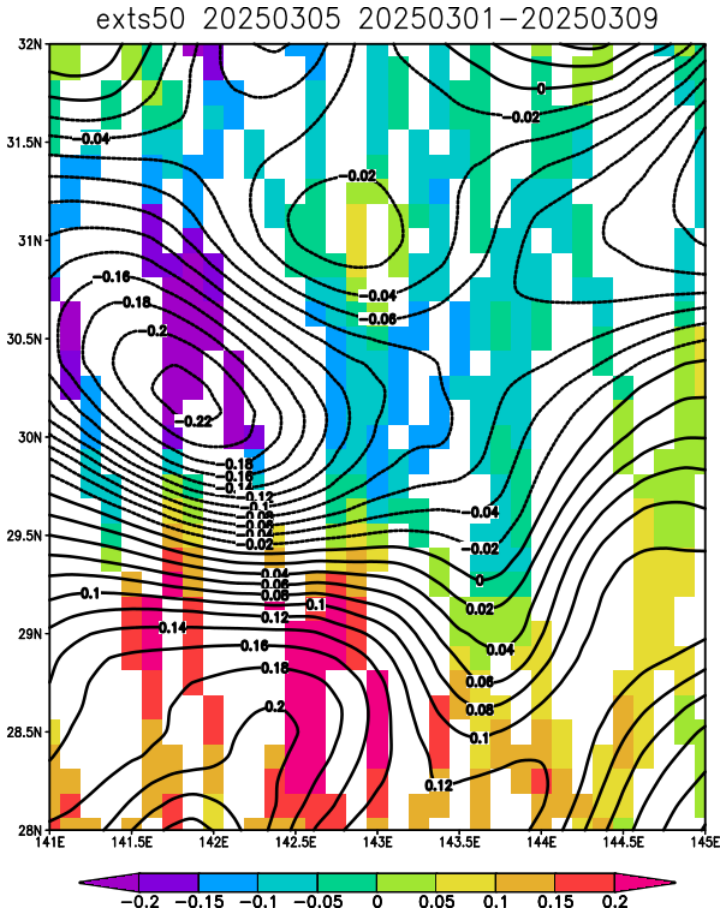
Fine scale eddy structures seem to be reproduced by increasing assimilation data.

Moderated skill improvements with increasing observation data by 3DVAR

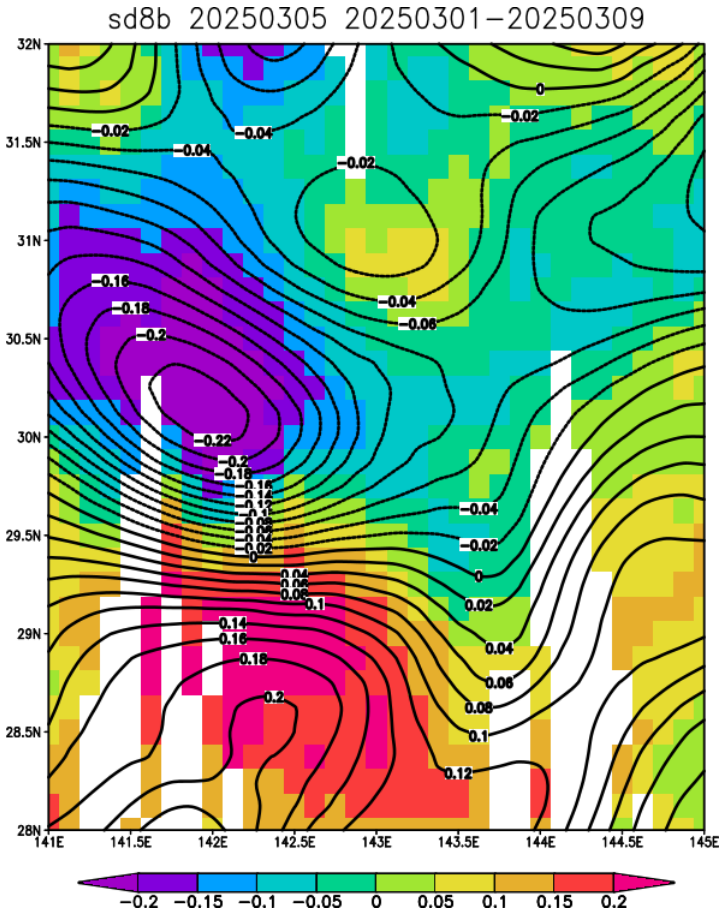
2 Nadirs



6 Nadirs

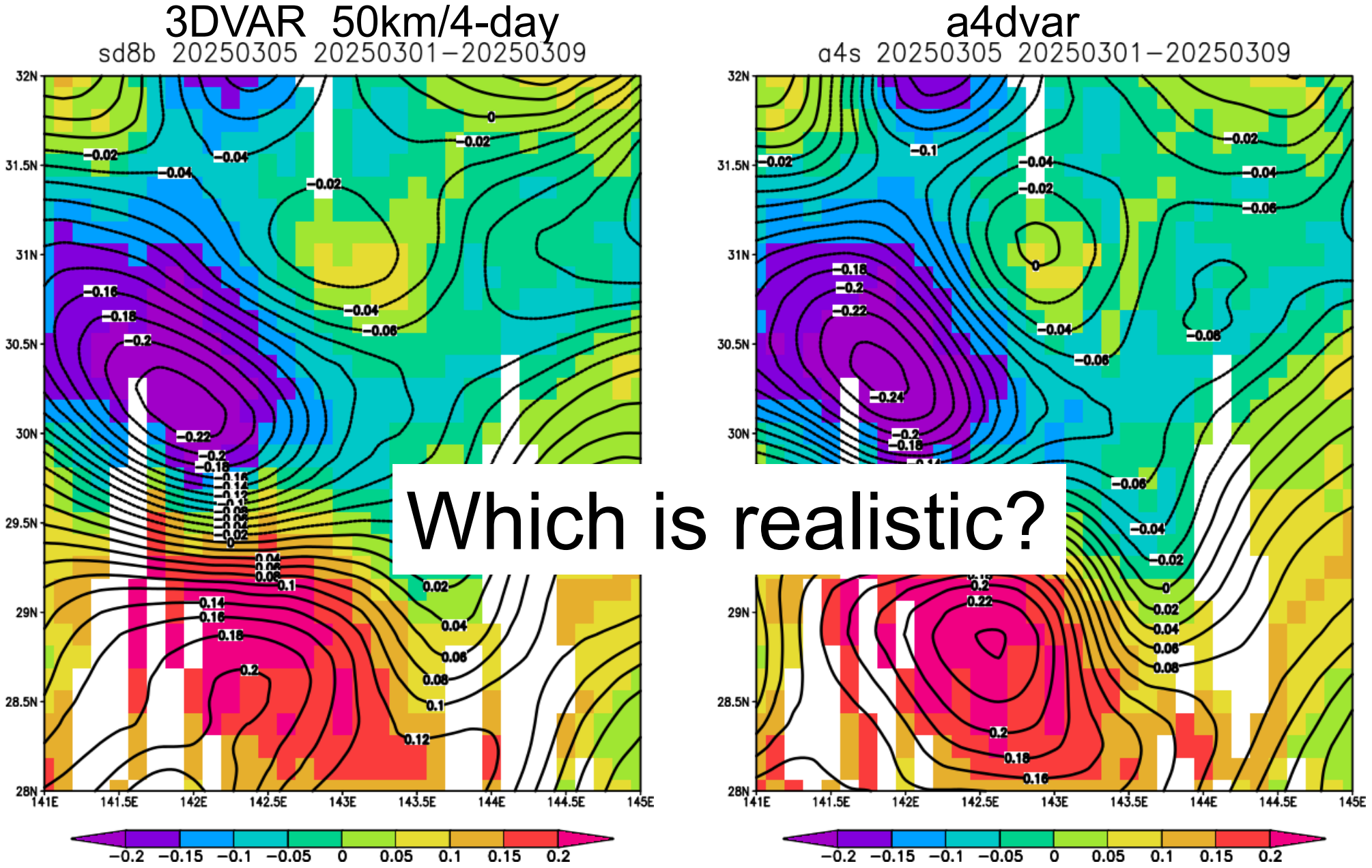


6 Nadirs + SWOT



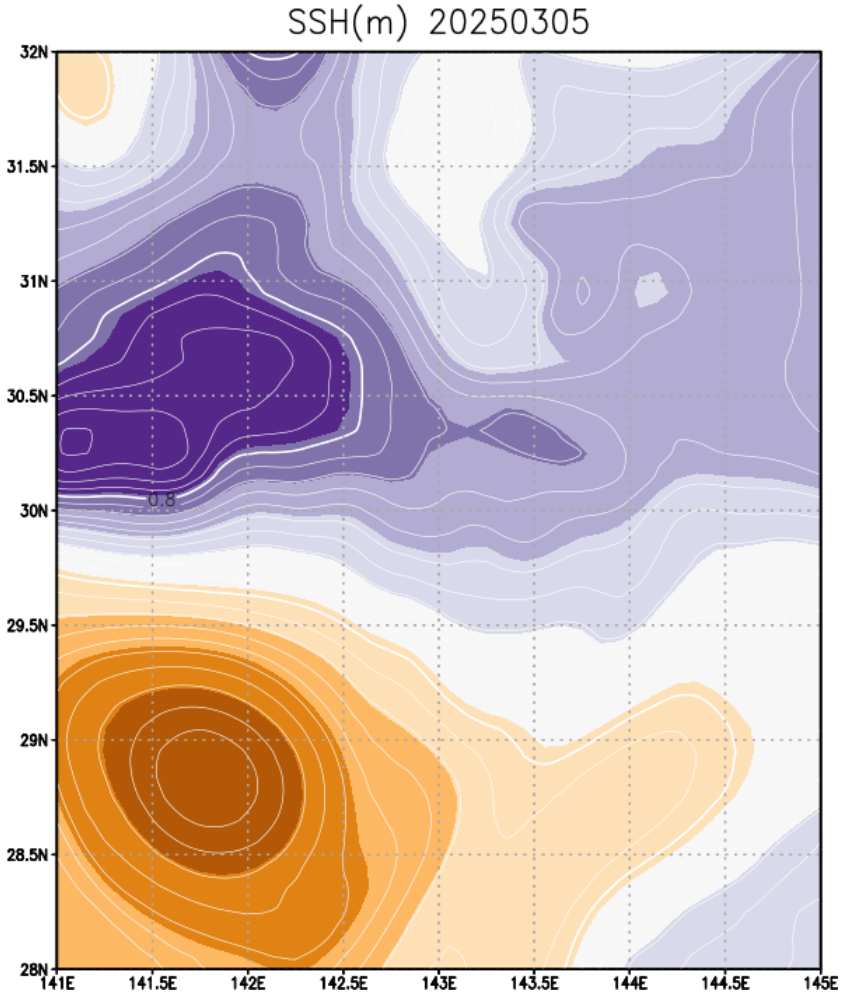
Representation of eddy structures seem to be gradually changed by increasing data.

Same data – different DA systems

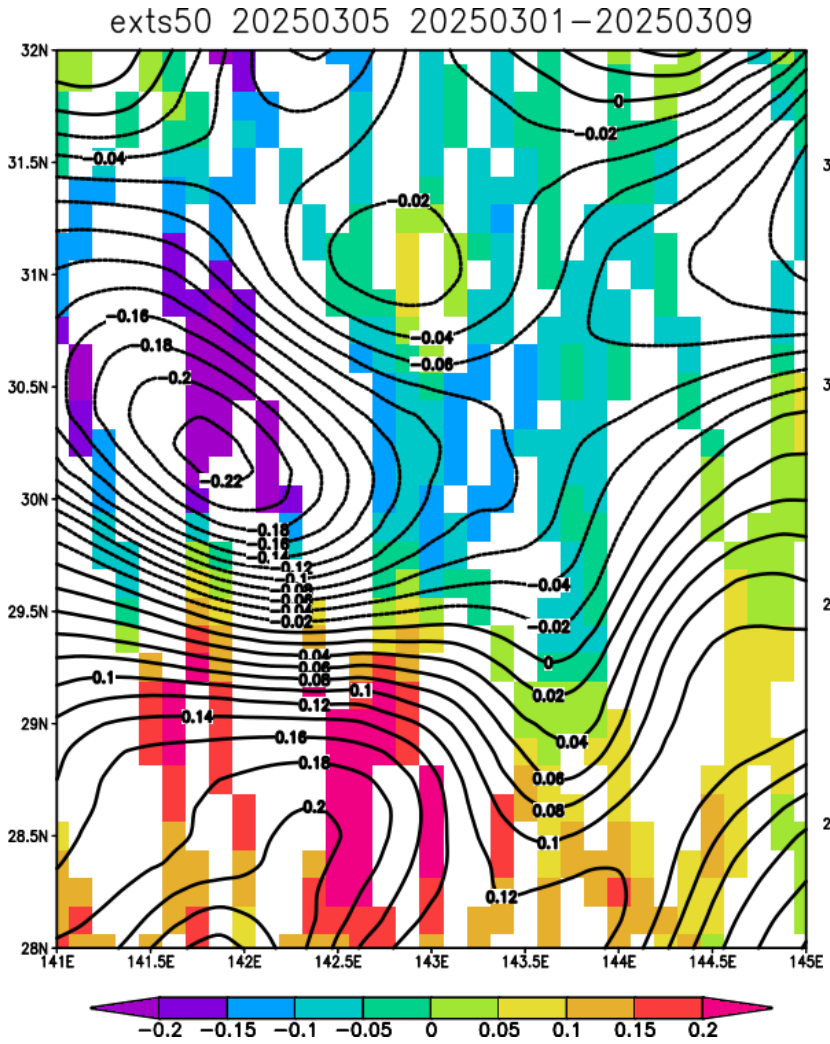


GLORYS12

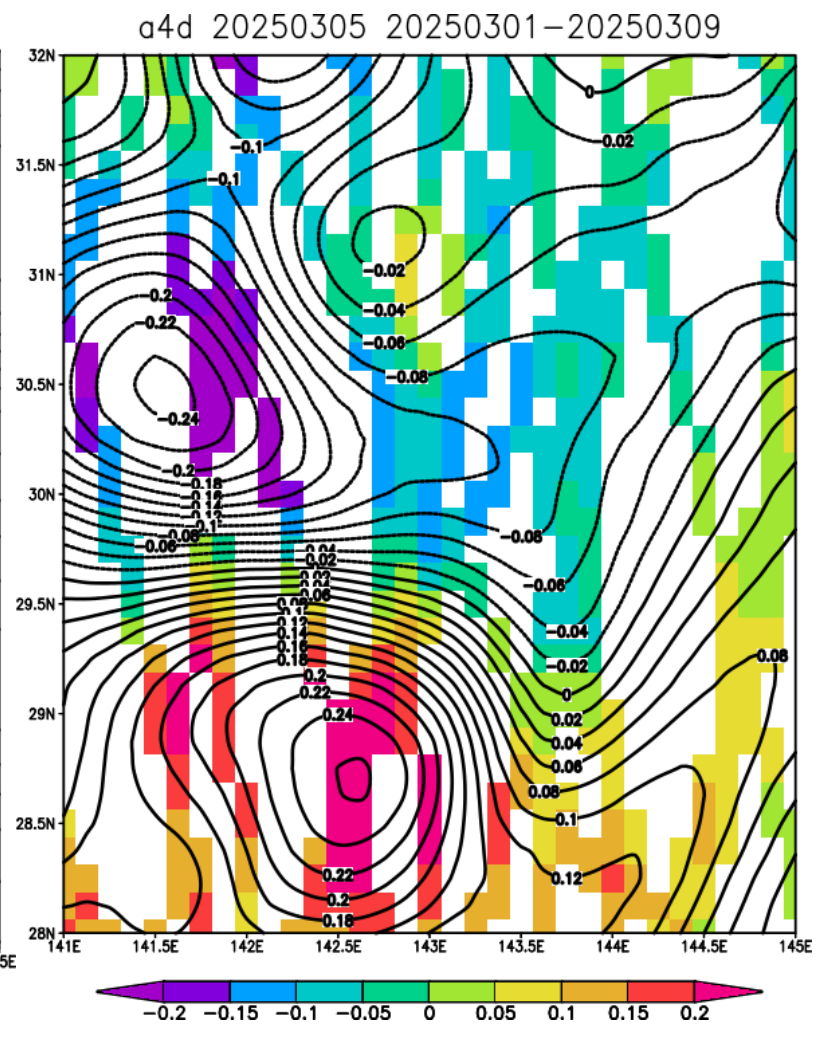
GLORYS12 (EOI)



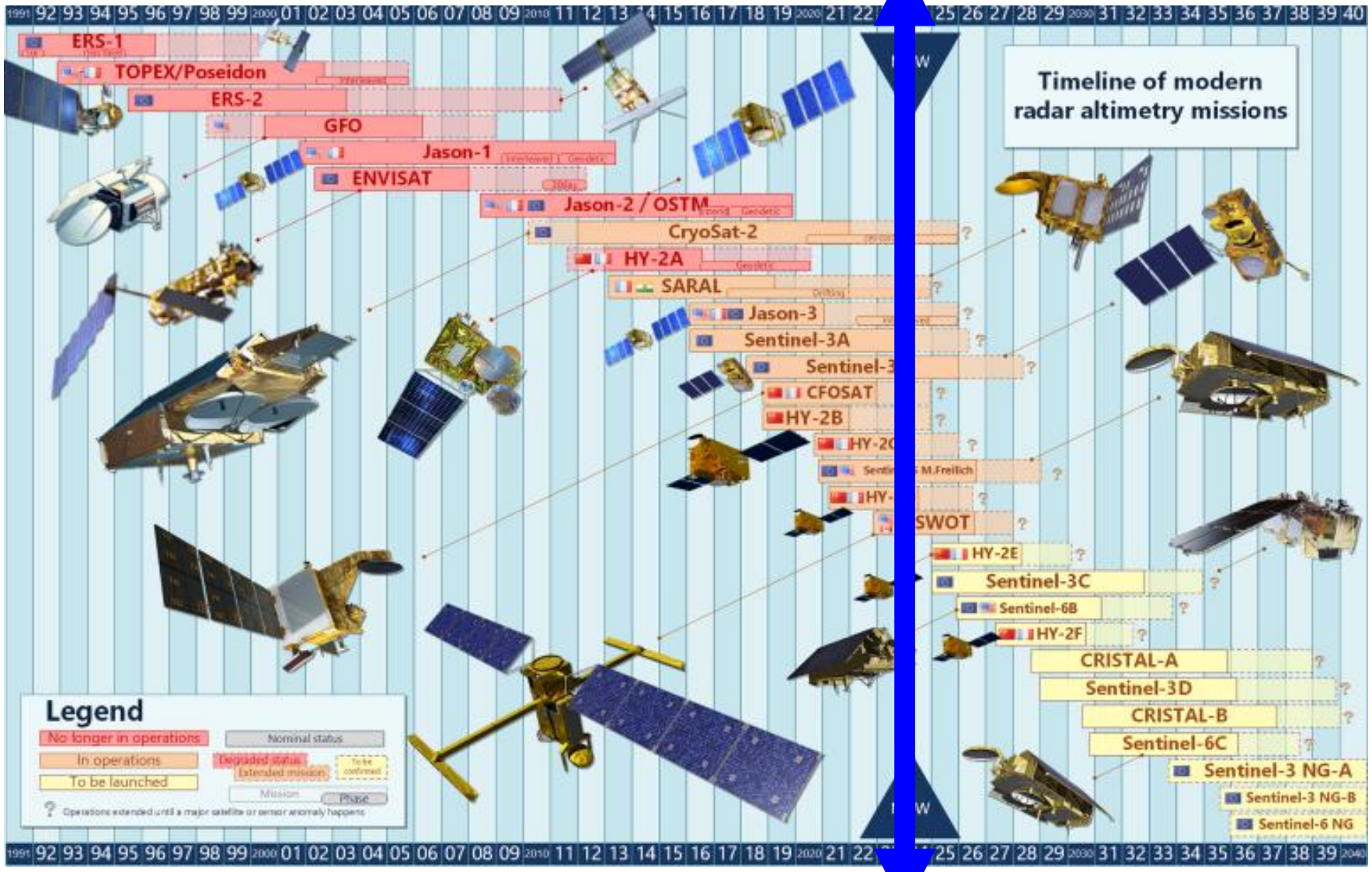
3DVAR(50km)



4DEnVAR



Future view of altimeter constellations



(Ballarota et al. 2025 Ocean Sci.)

A timeline of planned altimeter missions predicts a poor constellation period within coming a few years.

Addition of 1 wide-swath altimeter is surely effective for maintaining the current level of the altimeter measurements.