Impact of Hydrography and Geostrophic Current Observing Systems on Circulation Modeling in the Northwestern Pacific and Marginal Seas

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    3. Regional and global observing systems
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    1. Vertical structure of temperature and salinity
    2. Sea surface height
    3. Surface currents
4. **Discussion**
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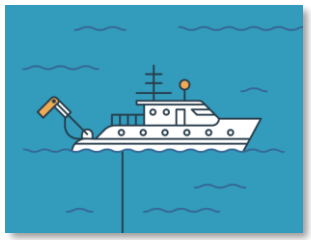
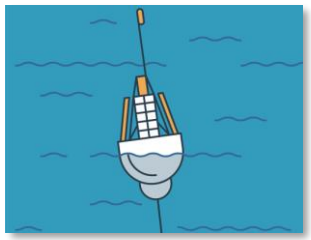
1. Introduction

Observations

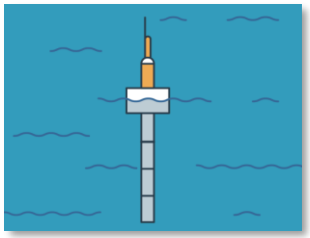


Research Vessels
(**KHOA, NIFS**)



Moored buoys
(KHOA)

Satellite sensors
(SST, **SSH**)



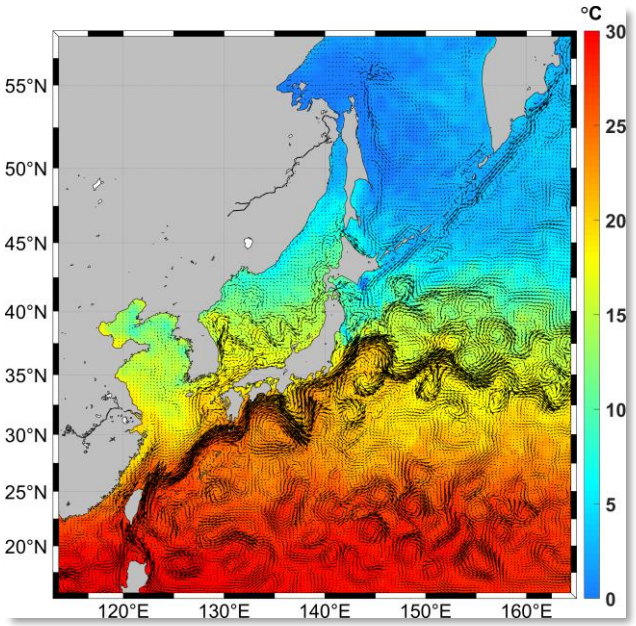
Argo profiling
floats (GTSPP)

+

Data assimilation

Optimal ocean state

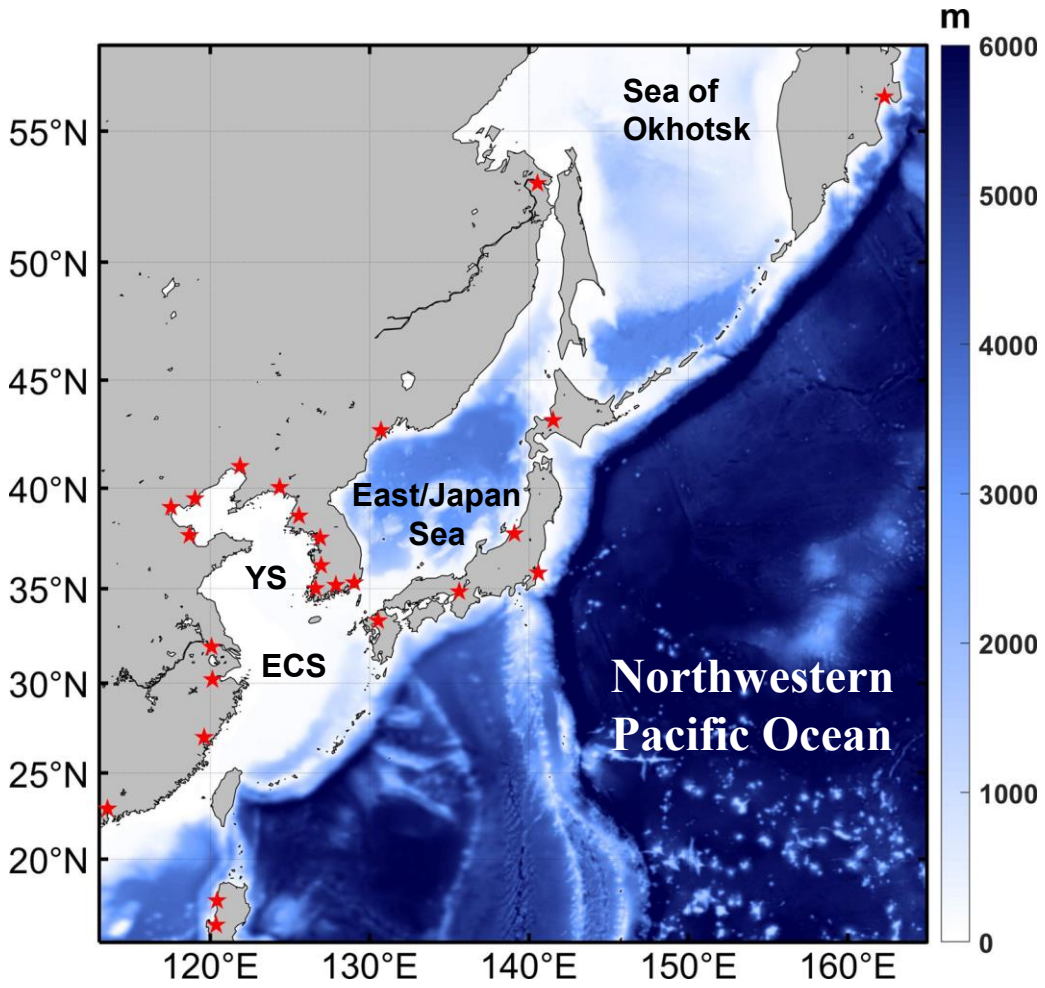
Numerical model



Objective of this study is to evaluate the impact of data assimilation from regional and global ocean observing systems on a regional ocean circulation modeling.

Figure credit: https://marine.copernicus.eu/

2.1. Modeling domain



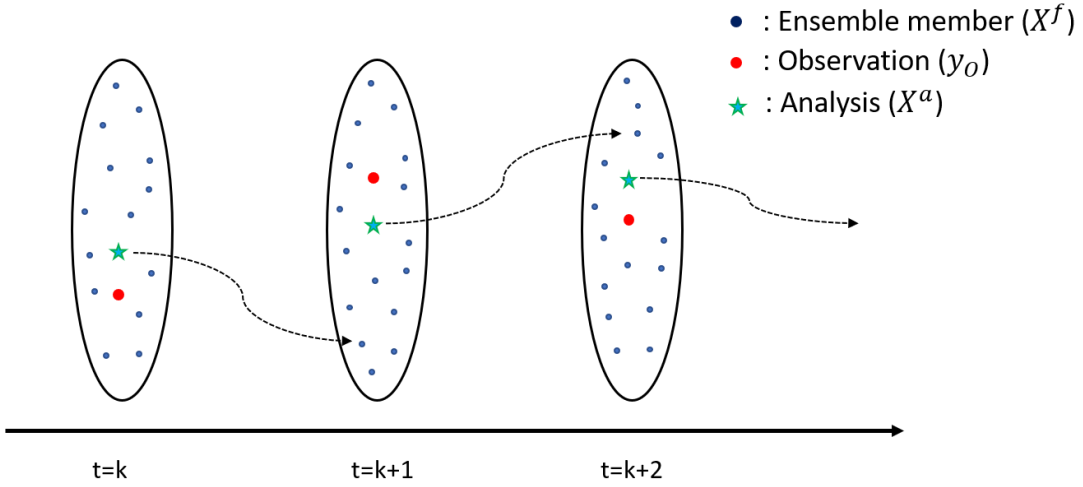
Regional Ocean Modeling System (ROMS)	
Domain	113.03~164.97°E, 15.02~57.98°N
Horizontal resolution	**1/24°**
Vertical resolution	30 sigma layers
Initial condition	HYCOM
Boundary condition	HYCOM daily mean (Sea surface elevation, Temperature, Salinity, U· V velocity)
Forcing	ECMWF ERA5 3 hourly (U· V wind component, Net solar radiation, Total precipitation, Relative humidity, Air pressure, Air temperature)
River discharge	25 stations
Tide	8 major constituents from TPXO9 ($M_2, S_2, K_1, O_1, N_2, K_2, P_1, Q_1$)
Vertical mixing scheme	K-profile parameterization (Large et al., 1994)
Viscosity	60 m/s^2

Model domain includes the **East China Sea (ECS), Yellow Sea (YS), East/Japan Sea (EJS), Sea of Okhotsk**, and the **northwestern Pacific**. Blue shading represents bottom topography (m).
Red diamonds indicate the locations of 25 river discharge stations.

2.2. Data assimilation method

$$X^a = X^f + K(y_o - HX^f)$$

X^a : Analysis state vector
X^f : Forecast state vector
K : Kalman gain matrix
y_o : Observation state vector
H : Observation operator



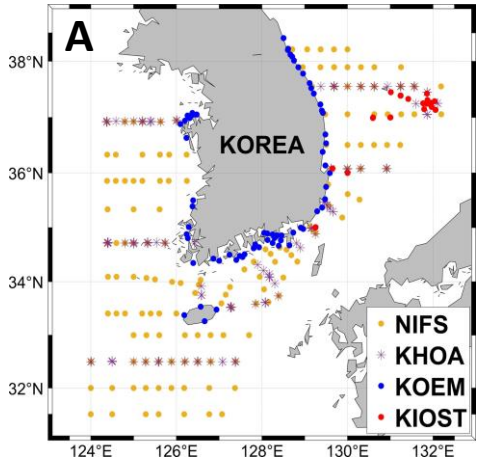
Schematic diagram of Ensemble Optimal Interpolation (EnOI).

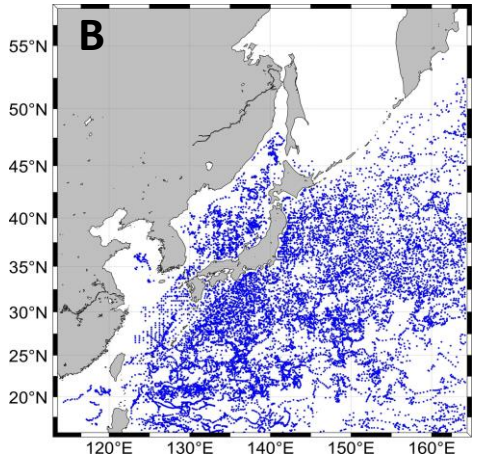
Ensemble Optimal Interpolation (EnOI)		
Period		**2019.01.01 - 2020.12.31**
Hindcast		1994.01.01-2022.12.31
Assimilation window		1 day
Number of ensemble member		**30**
Decorrelation length scale	Horizontal	50km
	Vertical	100m

Summary of Ensemble Optimal Interpolation (EnOI) configurations

2.3. Ocean Observing Systems

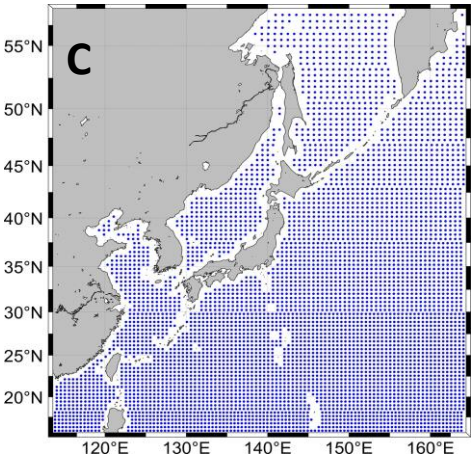
Regional Observing Systems
T/S profiles

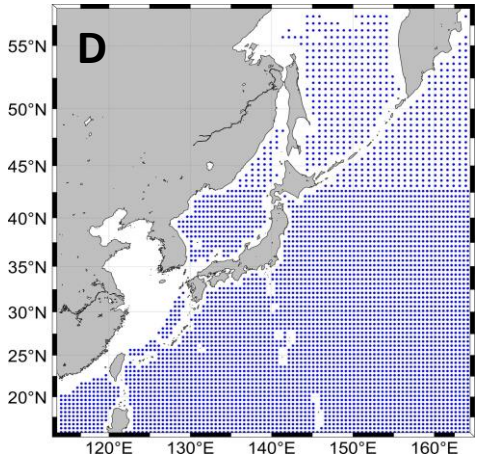




GTSPP, WOD
T/S profiles

OSTIA
SST





Surface geostrophic current (SGC) derived from gridded SSH data

(A) T/S profiles from the Korean **National Institute of Fisheries Science (NIFS)**, the **Korea Hydrographic and Oceanographic Agency (KHOA)**, the **Korea Marine Environment Management Corporation (KOEM)**, and **the Korea Institute of Ocean Science & Technology (KIOST)**.
(B) T/S profiles from Global Temperature and Salinity Profile Programme (**GTSPP**) and World Ocean Database 2018 (**WOD18**),
(C) **Sea Surface Temperature** from Operational and Sea Ice Analysis (**OSTIA**),
(D) **Surface geostrophic currents** derived from gridded SSH dataset from Copernicus Marine Environment Monitoring Service (CMEMS)

2.4. Observing System Experiment design

Observing System Experiment. The circle in each cell represents the assimilation of the corresponding observational dataset in each experiment.

	T/S profiles							SGC	SST
Experiment	NIFS	KHOA	KOEM	KIOST	GTSPP	WOD	WOA	CMEMS	OSTIA
Free run	-	-	-	-	-	-	-	-	-
CTRL	o	o	o	o	o	o	o	o	o
NO NIFS	-	o	o	o	o	o	o	o	o
NO KHOA	o	-	o	o	o	o	o	o	o
NO SGC	o	o	o	o	o	o	o	-	o

Free run: No observational data were assimilated

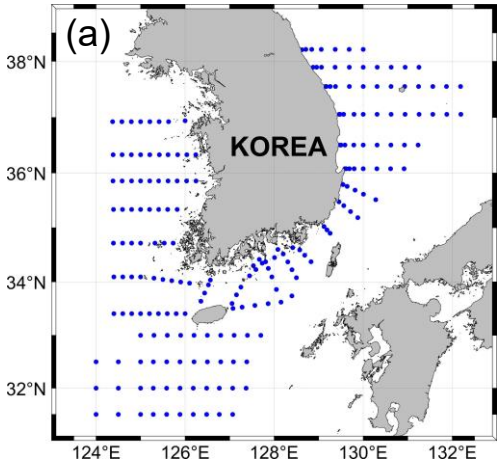
CTRL: Control model which assimilates **all observation datasets**
NO NIFS: Data from the National Institute of Fisheries and Science of Korea are not included in the assimilation process
NO KHOA: Data from the Korea Hydrographic and Oceanographic Agency are not included in the assimilation process
NO SGC: surface geostrophic current estimated from gridded sea level data are not included in the assimilation process

2.4. Observing System Experiment design

Observing System Experiment. The circle in each cell represents the assimilation of the corresponding observational dataset in each experiment.

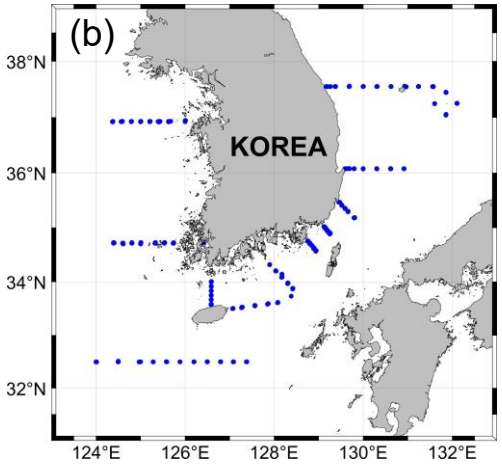
	T/S profiles							SGC	SST
Experiment	NIFS	KHOA	KOEM	KIOST	GTSPP	WOD	WOA	CMEMS	OSTIA
Free run	-	-	-	-	-	-	-	-	-
CTRL	o	o	o	o	o	o	o	o	o
NO NIFS	-	o	o	o	o	o	o	o	o
NO KHOA	o	-	o	o	o	o	o	o	o
NO SGC	o	o	o	o	o	o	o	-	o

NIFS



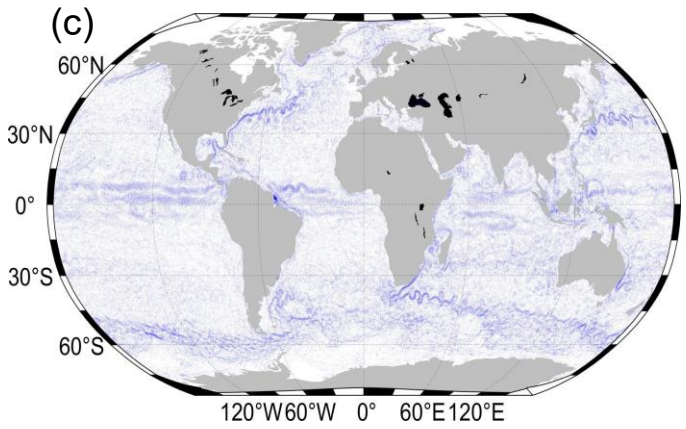
T/S profiles (2,4,6,8,10,12)

KHOA



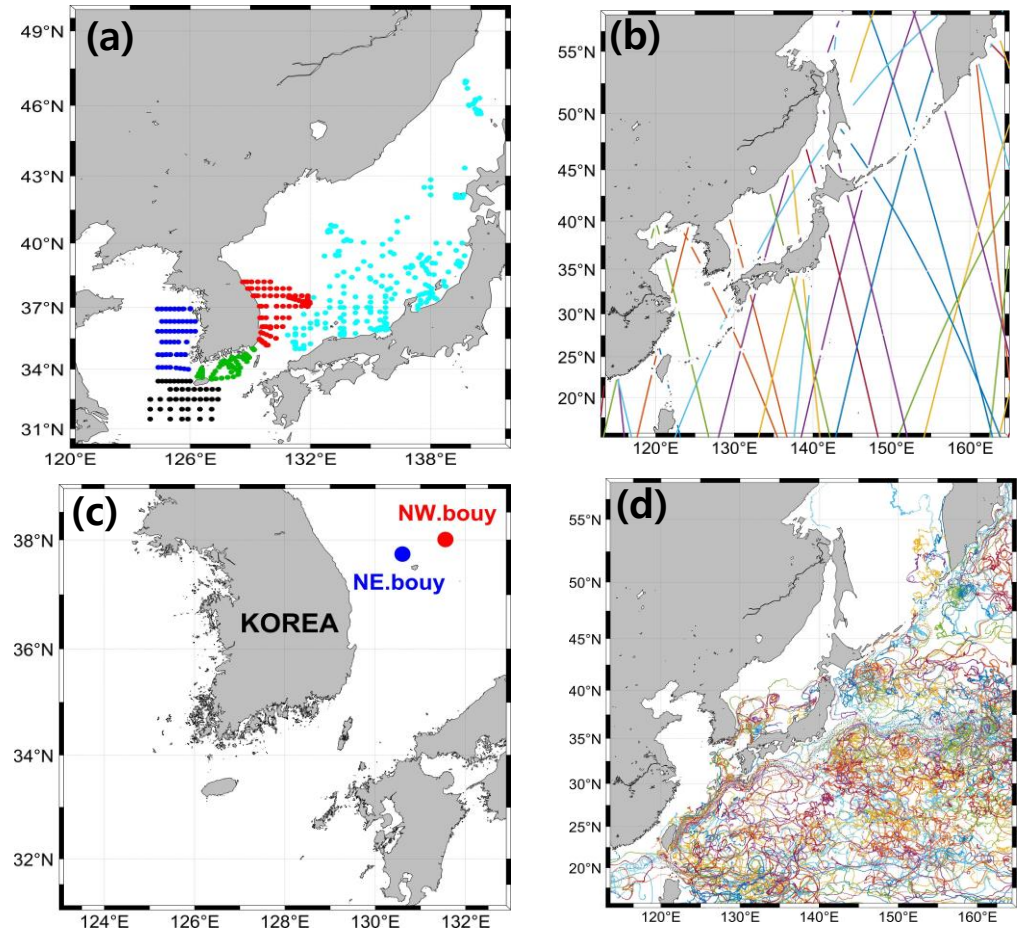
T/S profiles (3,5,7,9,11)

SGC



surface geostrophic current

2.5. Evaluation dataset and statistical metrics

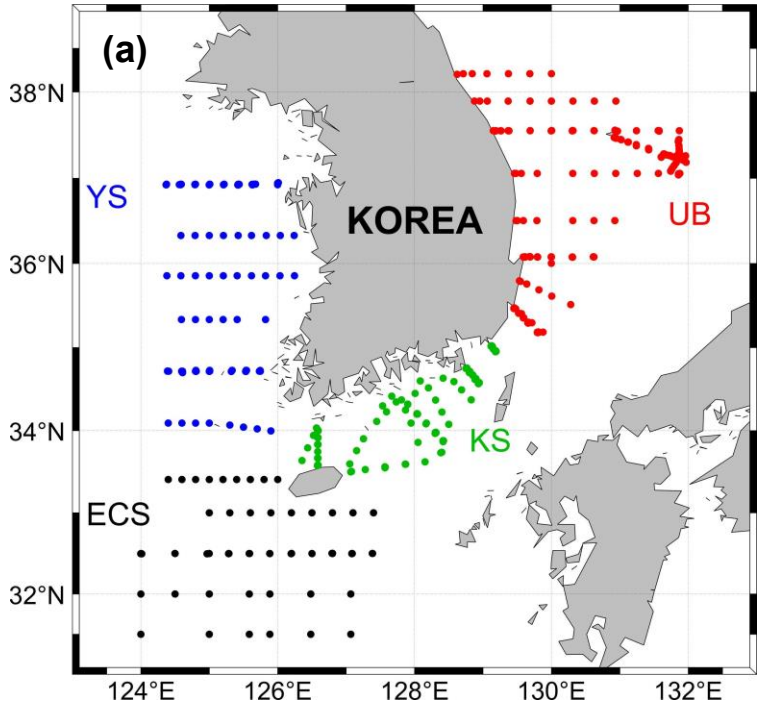


Spatial distribution of **independent observation data** used for validation. (a) independent **temperature and salinity profiles**. (b) along-track sea level anomaly (**SLA**) from CMEMS on 1 January 2019. (c) KHOA **buoys** located in the Northeast (NE.bouy) and Northwest (NW.bouy) of Ulleungdo, respectively. (d) all the **surface drifters**.

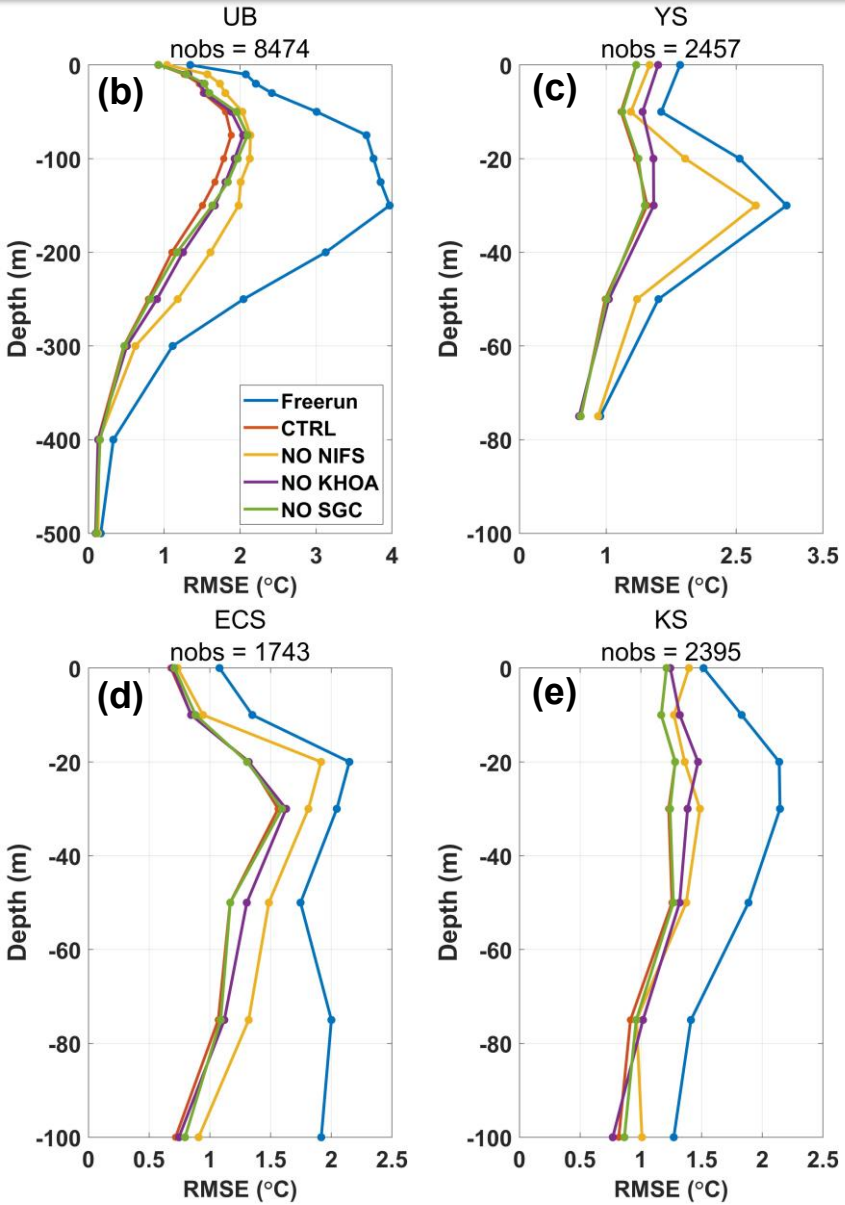
Metric	Equation
Root Mean Square Error (RMSE)	$\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - y_i)^2}$
Correlation coefficient (r)	$\frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}$

Summary of statistical metrics used within the study. x_i and y_i are the values of the ith modelled and observed variables, respectively. n represents the number of observations available for validation.

3.1. Vertical profiles of RMSEs in temperature

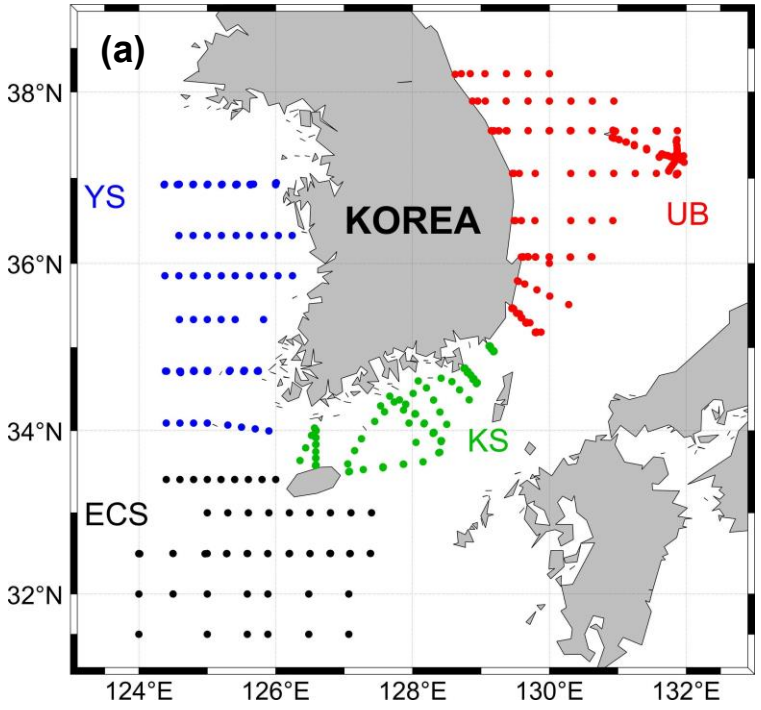


Spatial distribution of **independent temperature profiles** located UB (Ulleung Basin), YS (Yellow Sea), KS (Korea strait) and ECS (East China Sea) respectively.

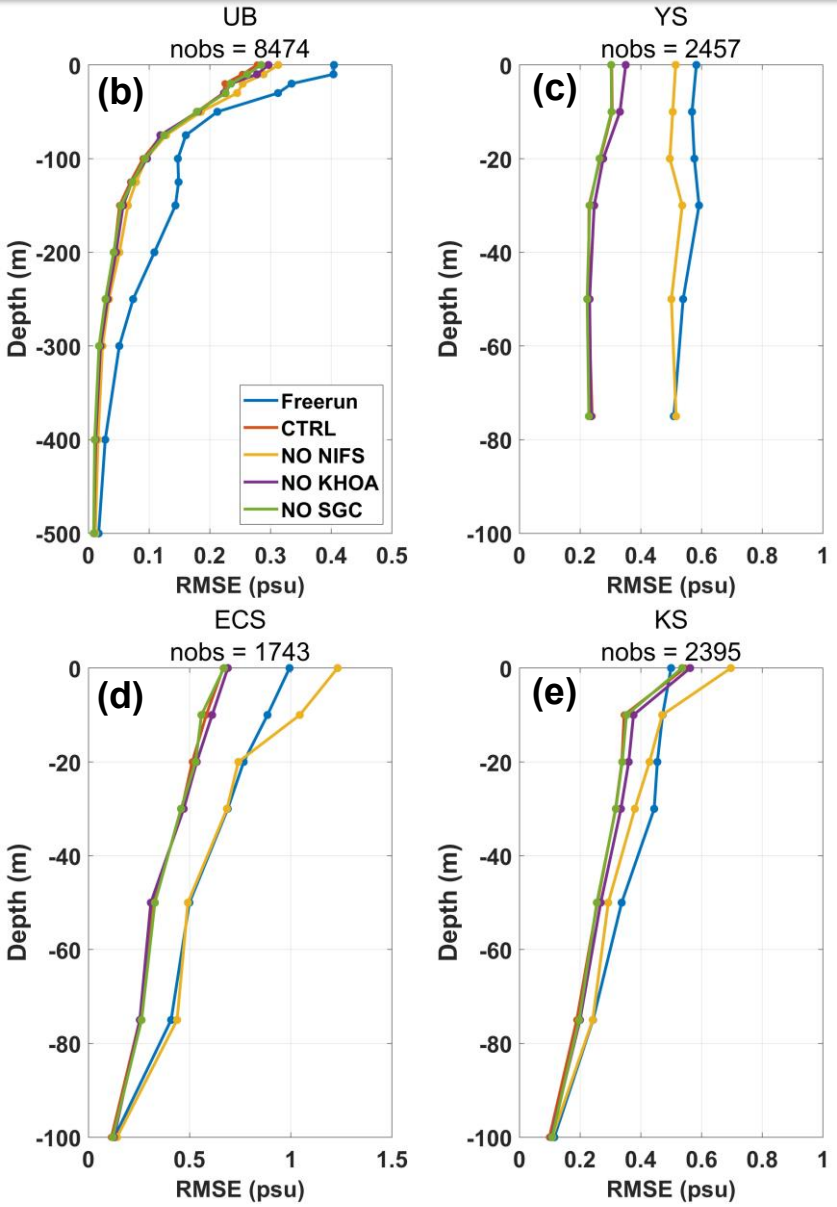


Vertical profiles of the RMSEs in temperature in UB, YS, ECS, and KS.

3.1. Vertical profiles of RMSEs in salinity

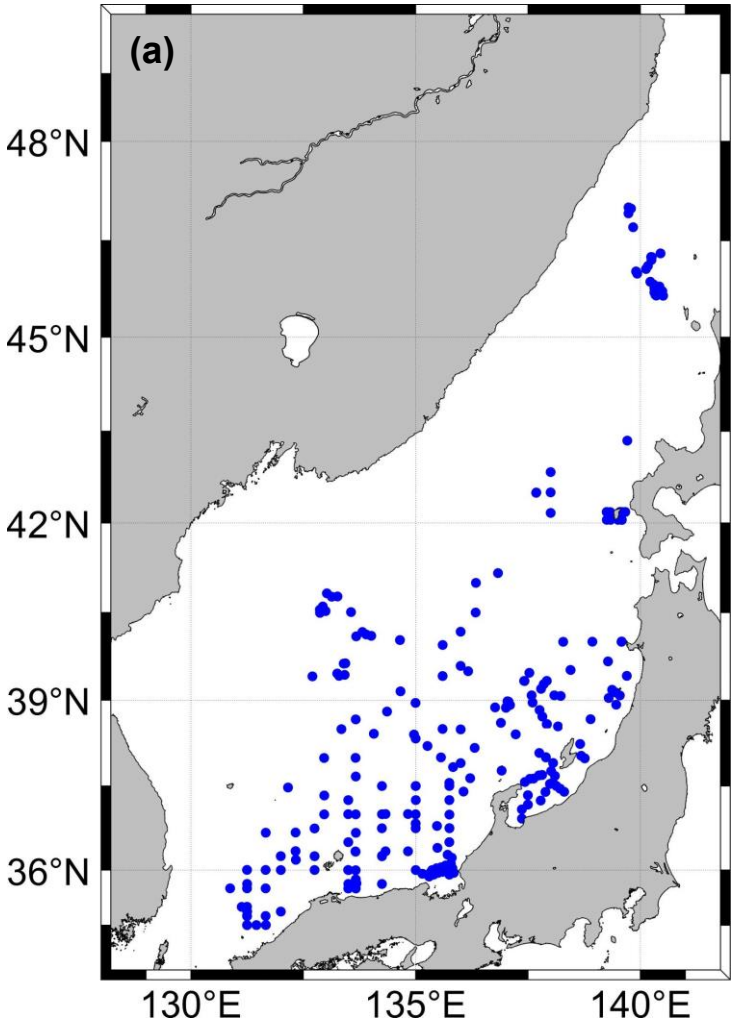


(a) Spatial distribution of **independent salinity profiles** located UB (Ulleung Basin), YS (Yellow Sea), KS (Korea strait) and ECS (East China Sea) respectively.

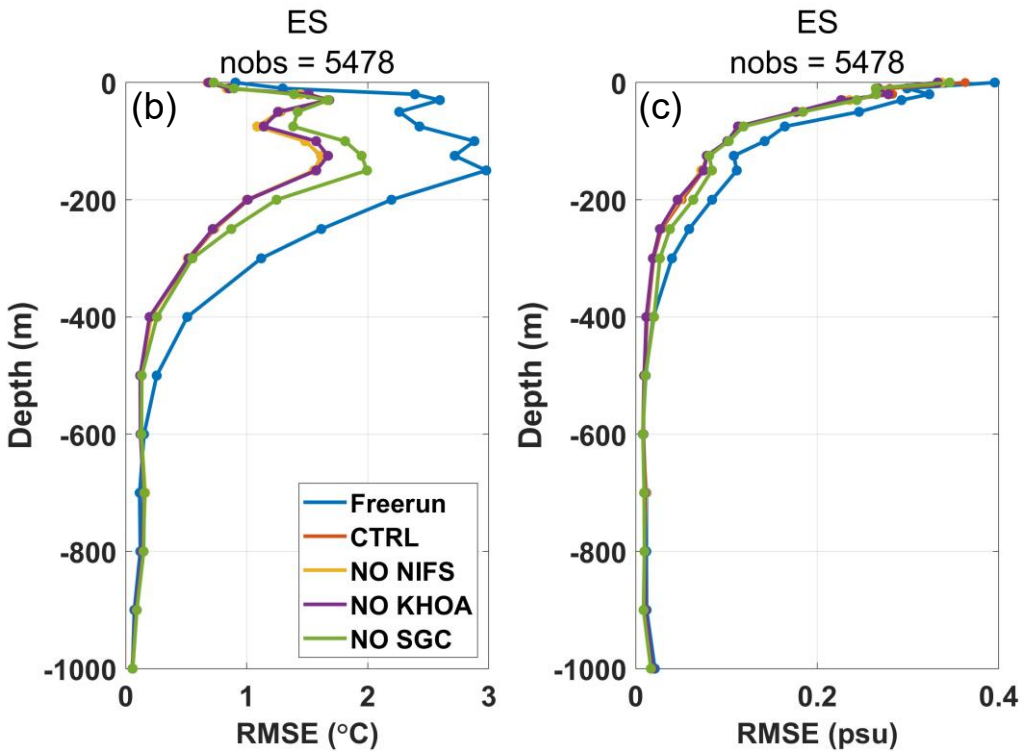


Vertical profiles of the RMSEs in salinity in UB, YS, ECS, and KS.

3.1. Vertical profiles of RMSEs in the East/Japan Sea (ES)

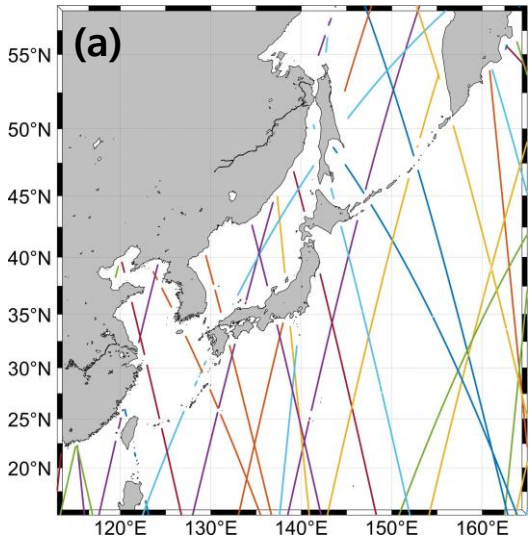


(a) Spatial distribution of **independent temperature and salinity profiles** used for located East/Japan Sea (ES).



Vertical profiles of the RMSEs in (b) temperature and (c) salinity in the ES.

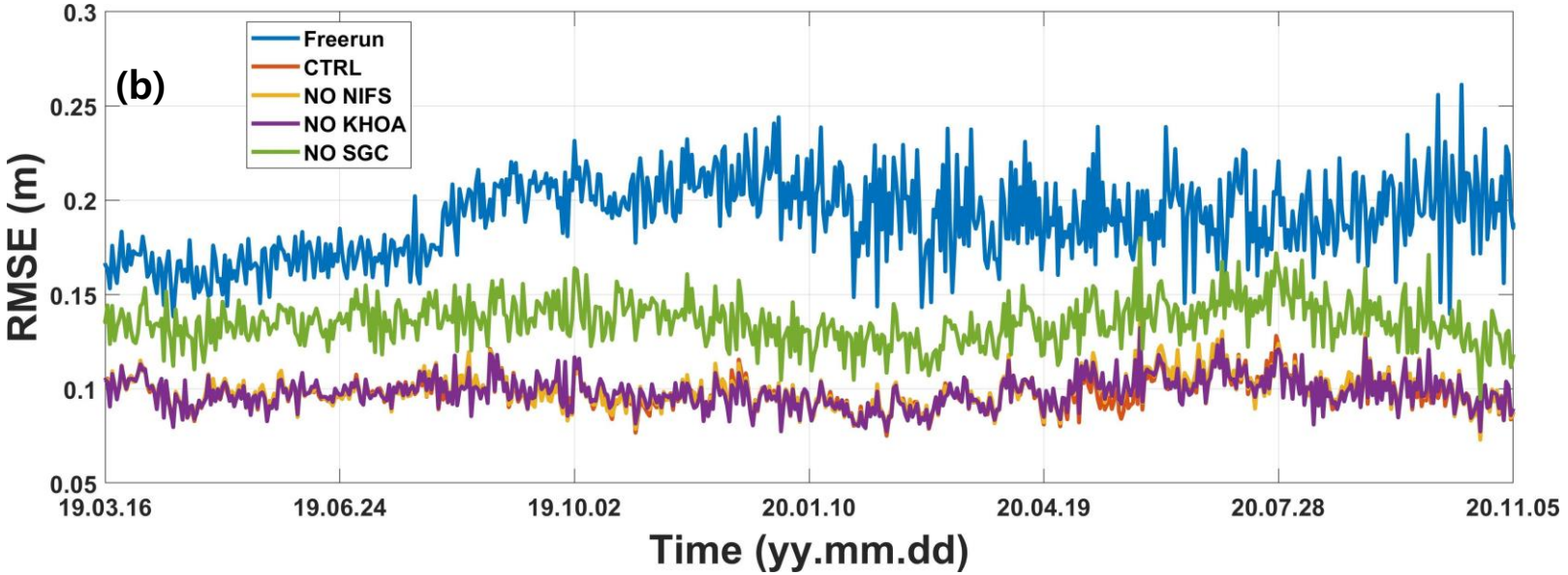
3.2. Along-track SLA RMSE (time series)



(a) Spatial distribution of along-tracks SLA on January 1, 2019.

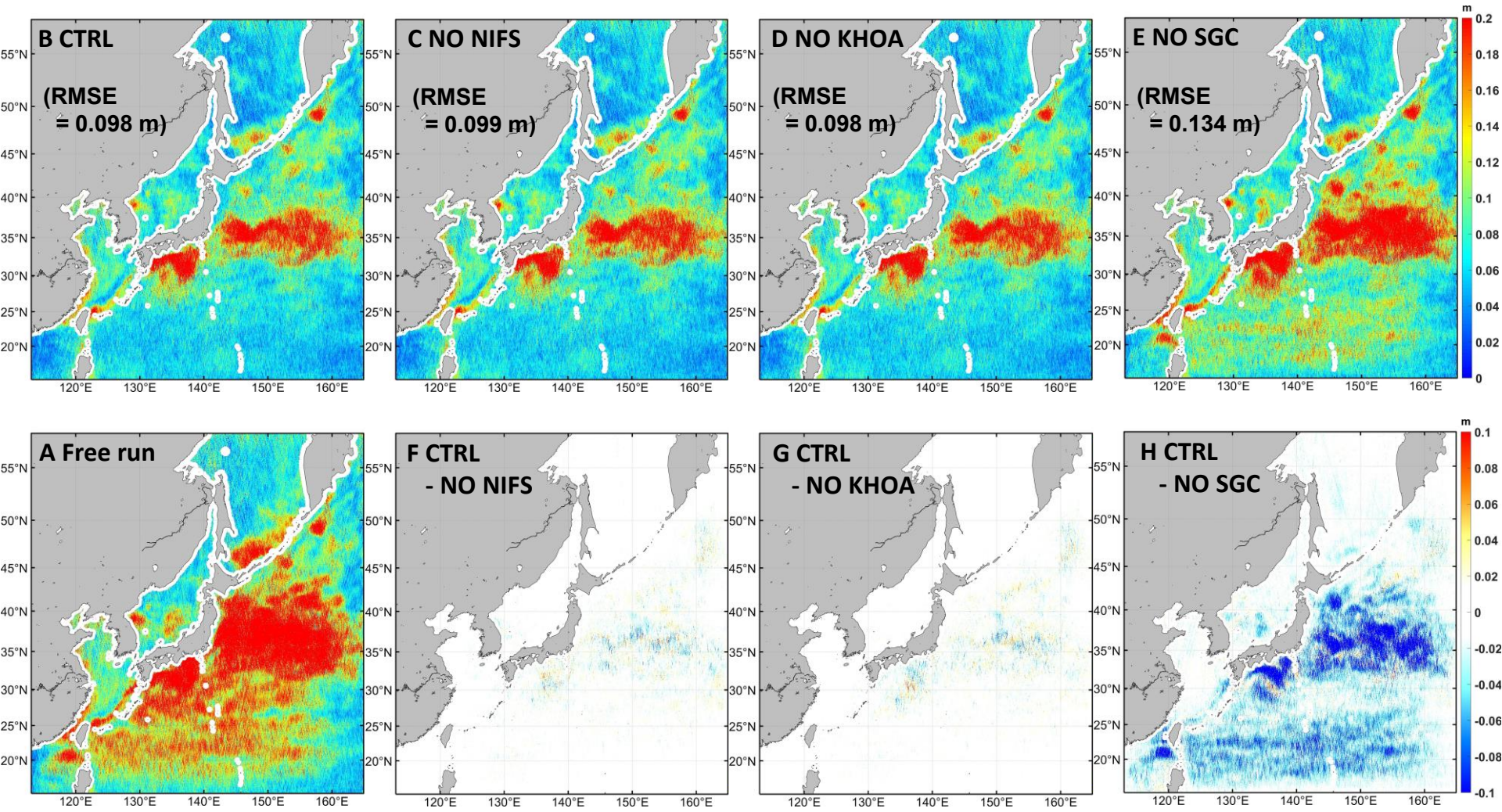
Experiment	RMSE (m)
Free run	0.1870
CTRL	**0.0977**
NO NIFS	**0.0987**
NO KHOA	**0.0980**
NO SGC	**0.1341**

Average of RMSEs in the five simulations.



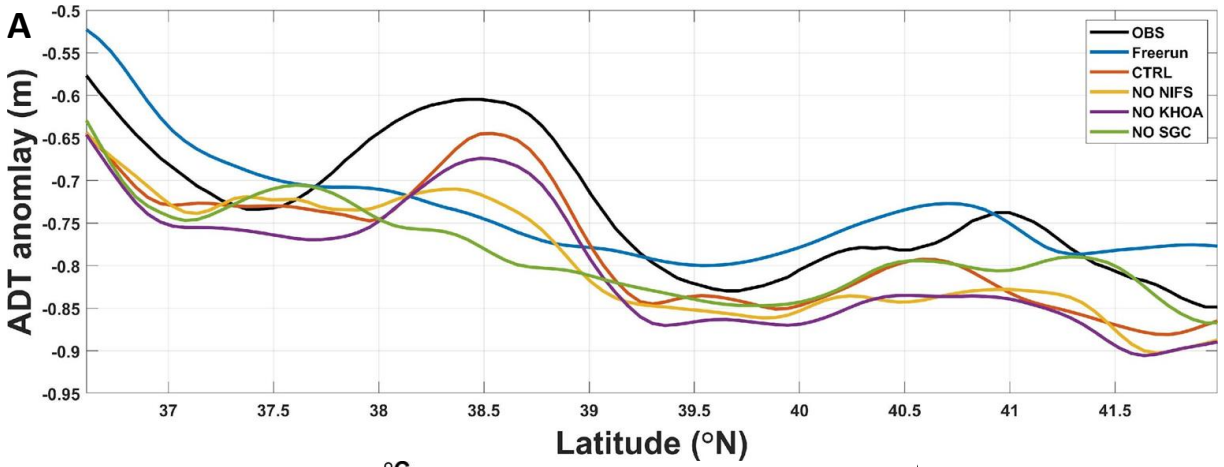
(b) Time evolution of the RMSE in **Sea Level Anomaly** (SLA) between observations and the five simulations.

3.2. Along-track SLA RMSE (spatial distribution)

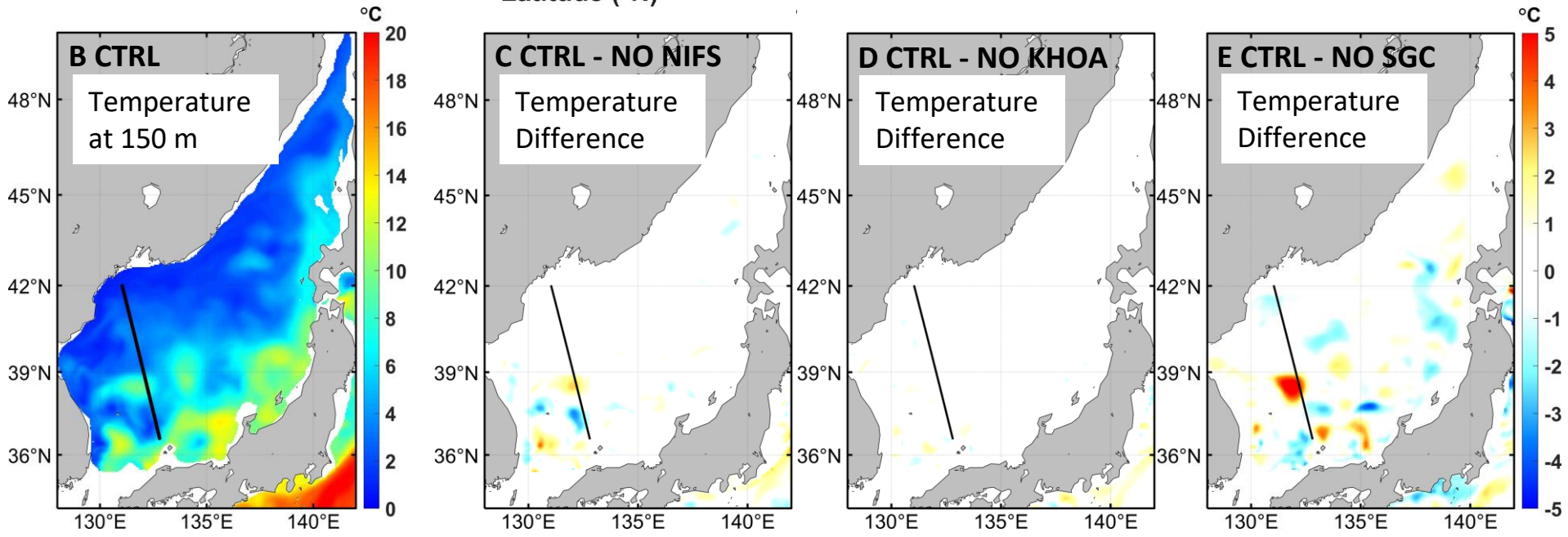


Spatial distribution of RMSE for SLA and difference field. (A–E) RMSE for the SLA from each experiment compared with CMEMS L3 along-track data from satellite altimeters. (F-H) Difference field between (b) CTRL and (f) NO NIFS, (g) NO KHOA, and (h) NO SGC.

3.2. Along-track SLA RMSE (spatial distribution in the ES)

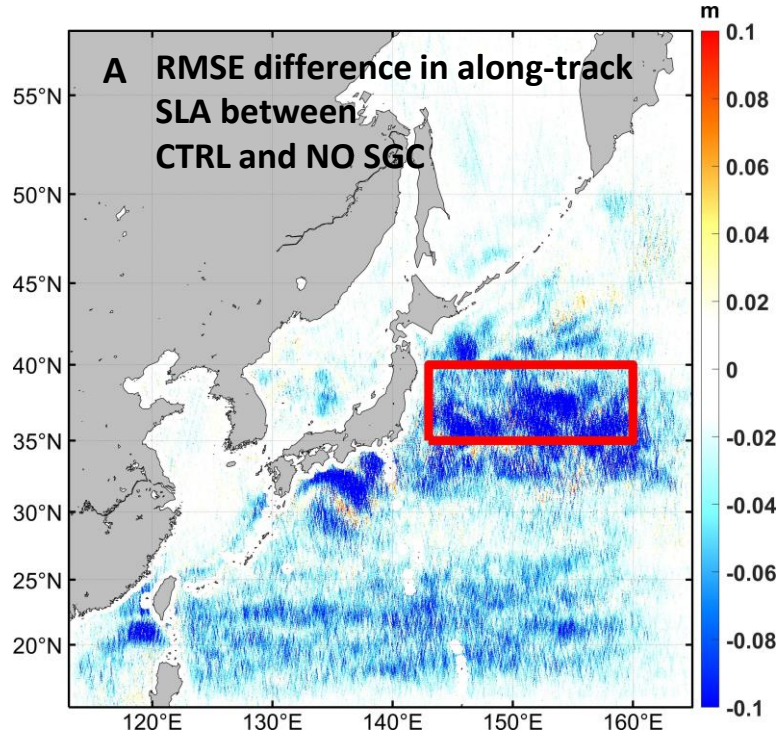


Sea level along
a **Sentinel-3A** ground-track
on August 28, 2020.

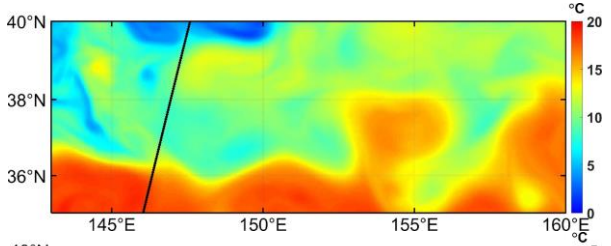


(A) SLA from Sentinel-3A observation and the five experiments on August 28, 2020. (B–E) Spatial distribution of temperature and temperature difference field in the East/Japan Sea. The **ground-track of Sentinel-3A** is indicated by black line.

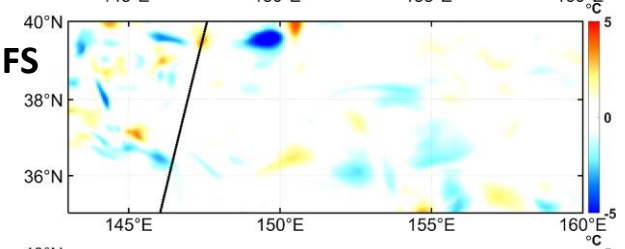
3.2. Along-track SLA RMSE (spatial distribution in the Kuroshio Extension



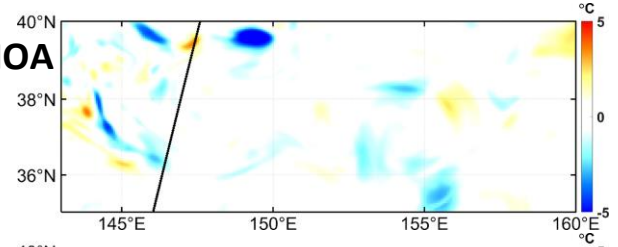
(B) CTRL Temperature at 200 m on October 20, 2019



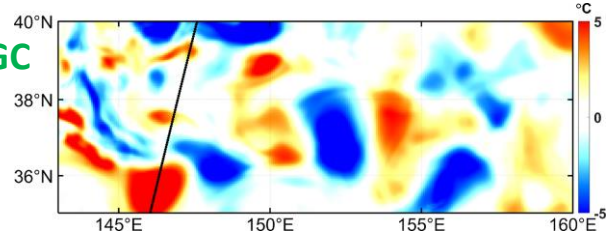
(C) CTRL - NO NIFS



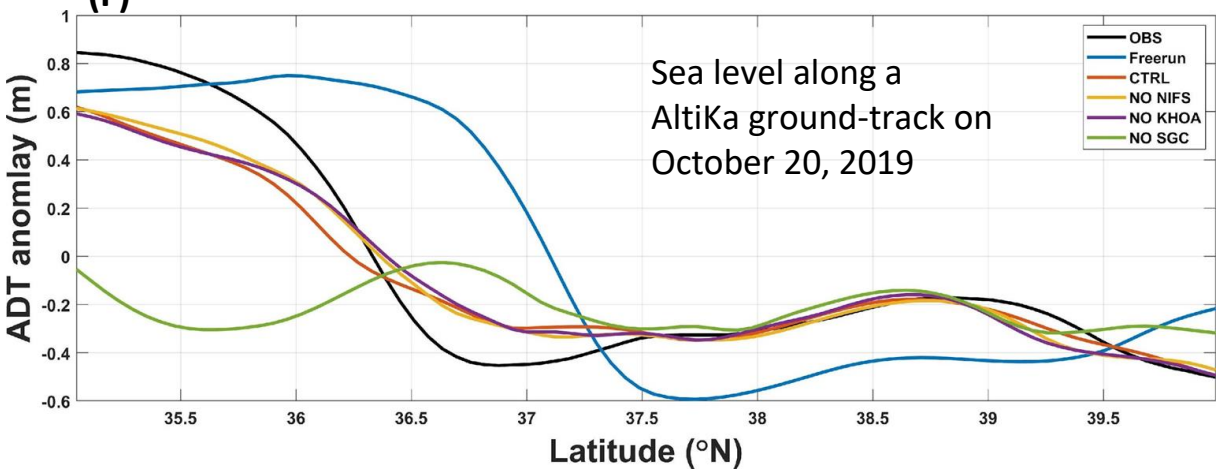
(D) CTRL - NO KHOA



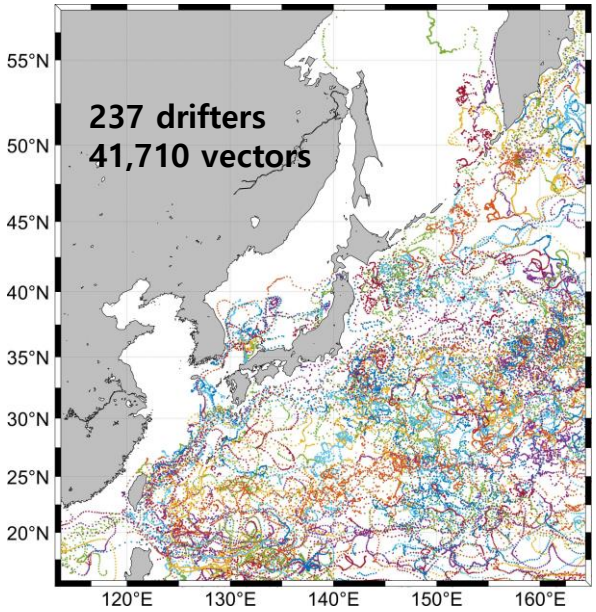
(E) CTRL - NO SGC



(F)



3.3. Surface currents from surface drifters



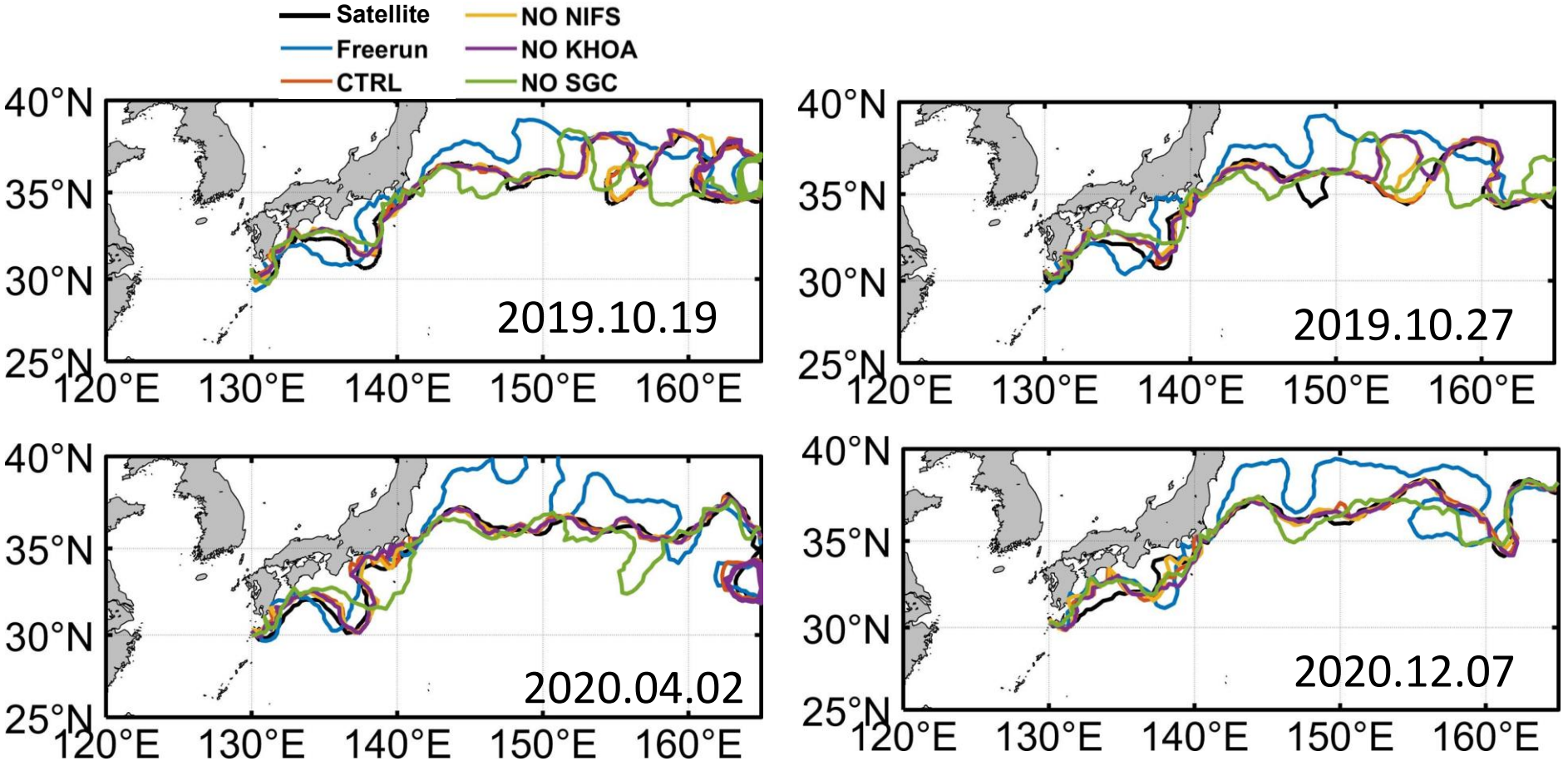
Experiment		Free run	CTRL	NO NIFS	NO KHOA	NO SGC
RMSE (m/s)	U	0.284	**0.179**	0.180	0.180	**0.244**
	V	0.248	**0.158**	0.159	0.158	**0.221**
mean		0.266	0.169	0.170	0.169	0.233
r	U	0.271	**0.705**	0.700	0.702	**0.428**
	V	0.257	**0.670**	0.668	0.673	**0.353**
mean		0.264	0.688	0.684	0.688	0.391

Correlation coefficient (r) and **RMSE in surface currents** from **surface drifters** and the five experiments in the Northwestern Pacific. U and V indicate eastward and northward velocities, respectively.

3.4. Kuroshio path

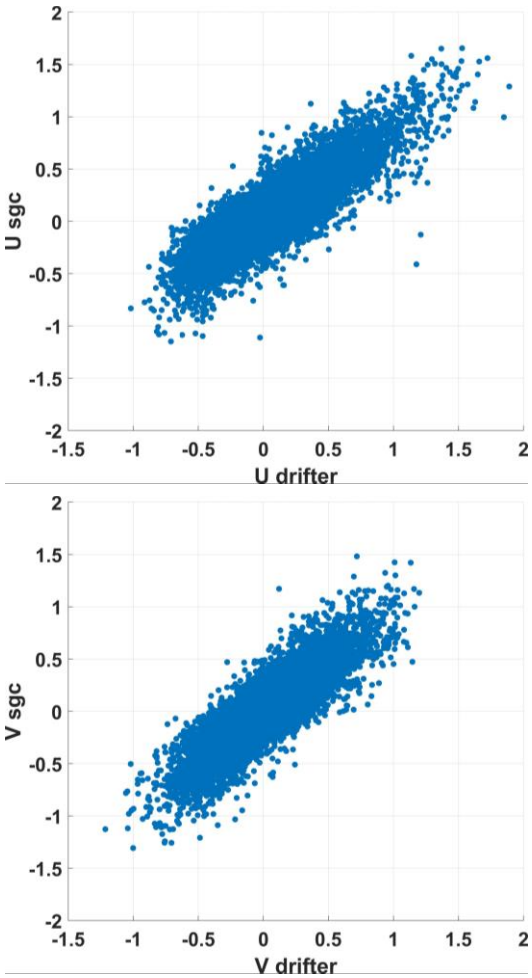
	Free run	CTRL	NO NIFS	NO KHOA	NO SGC
RMSE (km)	140	**90**	89	89	96

RMSE in the latitudes of the main current path in the Kuroshio-Kuroshio Extension regions.



Detected **Kuroshio main path** estimated using maximum current speeds

4. Discussion on observation error in SGC



Scatter plots of **velocities** from surface drifters and SGC estimated based on gridded sea surface height data. U and V denote u and v component, respectively.

	RMSE (m/s)	Correlation
u	0.13	0.84
v	0.12	0.83
mean	0.13	0.84

RMSE and correlation coefficients between **Lagrangian surface currents** from surface drifters and **surface geostrophic current** (SGC) estimated from the satellite observation of sea surface height in the northwestern Pacific.

5. Summary and Conclusions

In this study, observing system experiments (**OSE**s) were conducted by assimilating both **regional** hydrography observation data and **global** surface geostrophic current data using the EnOI method to a northwestern Pacific Ocean circulation model.

(1) Regional observing systems, such as NIFS and KHOA temperature and salinity profile observation, enhance the accuracy of temperature, salinity, and surface currents of **local and near field regions** within the numerical ocean prediction system.

(2) Global observing systems, such as surface geostrophic current data derived from the gridded sea surface height measurement, further improve the accuracy of temperature, salinity, **major current meandering paths, and mesoscale eddy locations** in the numerical ocean prediction system.

(3) The estimation of observation errors in surface geostrophic currents requires further investigation.

Thak you for your attention.

Any questions or comments?