Ocean Predict

SYMPOSIUM OP'24

In partnership with unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Evaluation of Vertical Coordinate Systems in a Regional MOM6 for Northwest Pacific

Young Ho Kim[1], Inseong Chang[1], Young-Gyu Park[2], Gyundo Pak[2], Hyunkeun Jin[2], Robert Hallberg[3], Andrew C.Ross[3]

[1]Division of Earth Environmental System Science, Pukyong National University,

[2]Ocean Circulation & Climate Research Department, Korea Insititute of Ocean Sciences and Technology

[3]NOAA OAR Geophysical Fluid Dynamics Laboratory

PUKYUNG NATIONAL UNIVERSITY 부경대학교

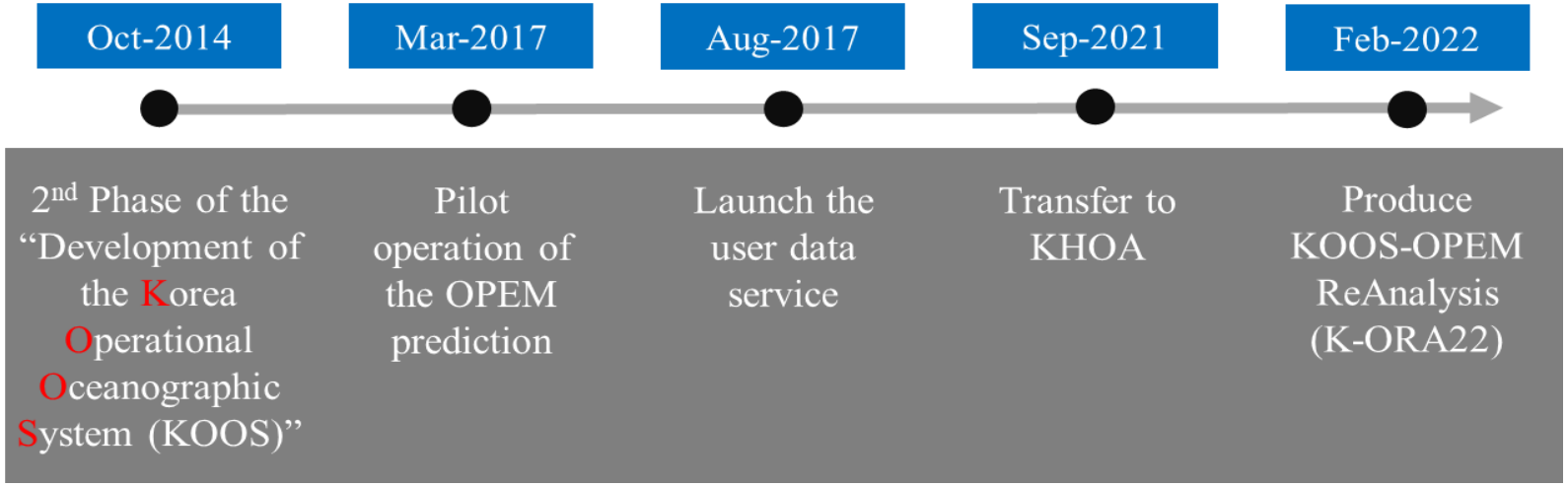
KIOST KOREA INSTITUTE OF OCEAN SCIENCE & TECHNOLOGY

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE

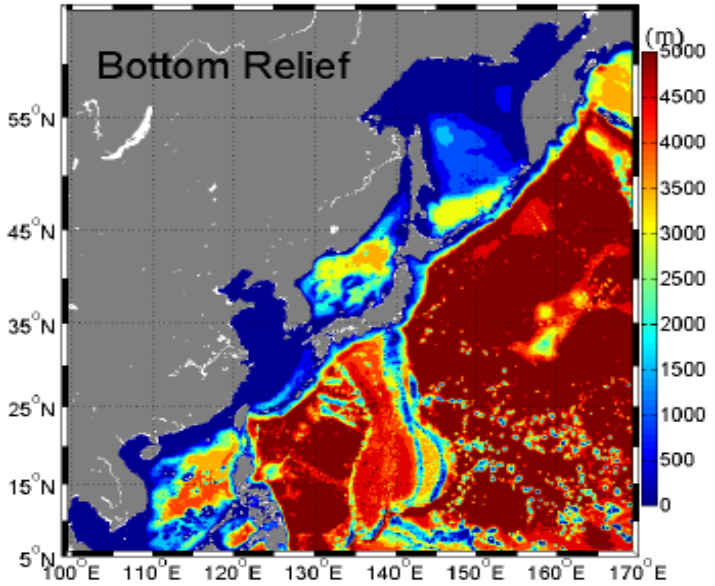
Ocean Predict

1. Introduction
2. Model Configurations
3. Comparison of Vertical Coordinate Systems
4. Sensitivity Tests on Hybrid Vertical Coordinate Configurations
5. Summary & Future Plan

Introduction - KOOS-OPEM (Northwest Pacific Regional Prediction System)



Major history of OPEM



- **Model domain and Bottom Relief**

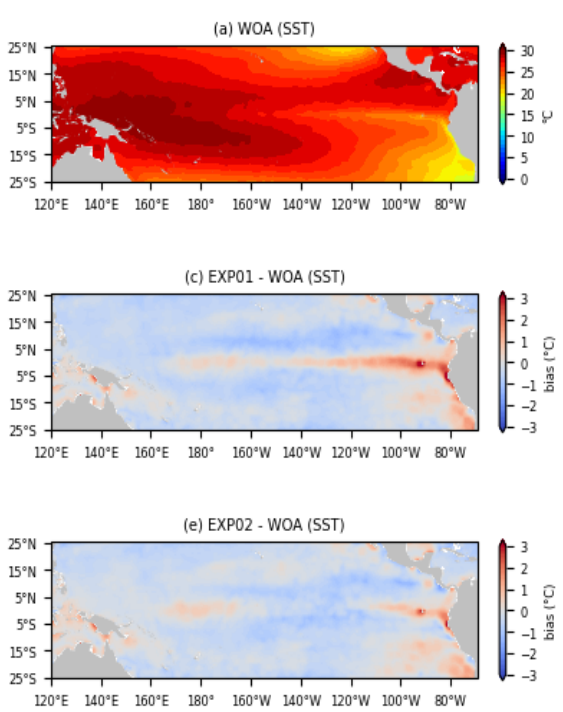
- Based model : GFDL-MOM5
- Resolution : 1/24 ˚x 1/24 ˚ (Arakawa B-grid) & 51 layers (Z* coordinate)
- Data assimilation system: Ensemble Optimal Interpolation (Kim et al., 2015)

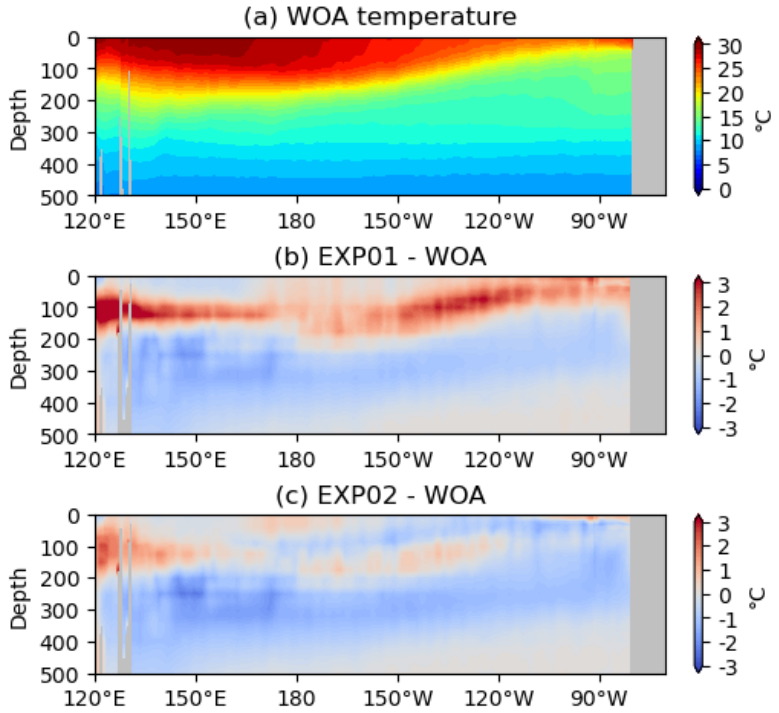
Recent research

✓ Evaluating observing system (satellite and regional *in situ* profile) on ocean prediction system in Northwest Pacific (Chang et al., 2023)
✓ Producing regional reanalysis data for Northwest Pacific (Chang et al., 2024)
✓ Establishing 10-days operational ocean prediction system (Jin et al., *in Press*)

Introduction– applying Modular Ocean Model Version 6 (MOM6)

- **Horizontal Grid**: Based on the C-grid structure.
- **Vertical Coordinate**: Uses ALE (Arbitrary Lagrangian Eulerian) remapping to support z*, isopycnal, terrain-following, or hybrid coordinates.
- **Stability**: Vertical ALE eliminates CFL constraints, ensuring stability even in thin or vanishing layers.
- **Physical Closures**: Scale-aware mesoscale eddy parameterizations.
  - ✓ Langmuir mixing in boundary layers.
  - ✓ Mixing from breaking gravity waves.
  - ✓ Neutral diffusion without spurious extrema





EXP01 : KPP (Large et al., 1994)
EXP02 : ePBL (Reichl and Hallberg, 2018)

(Park et al., 2024)

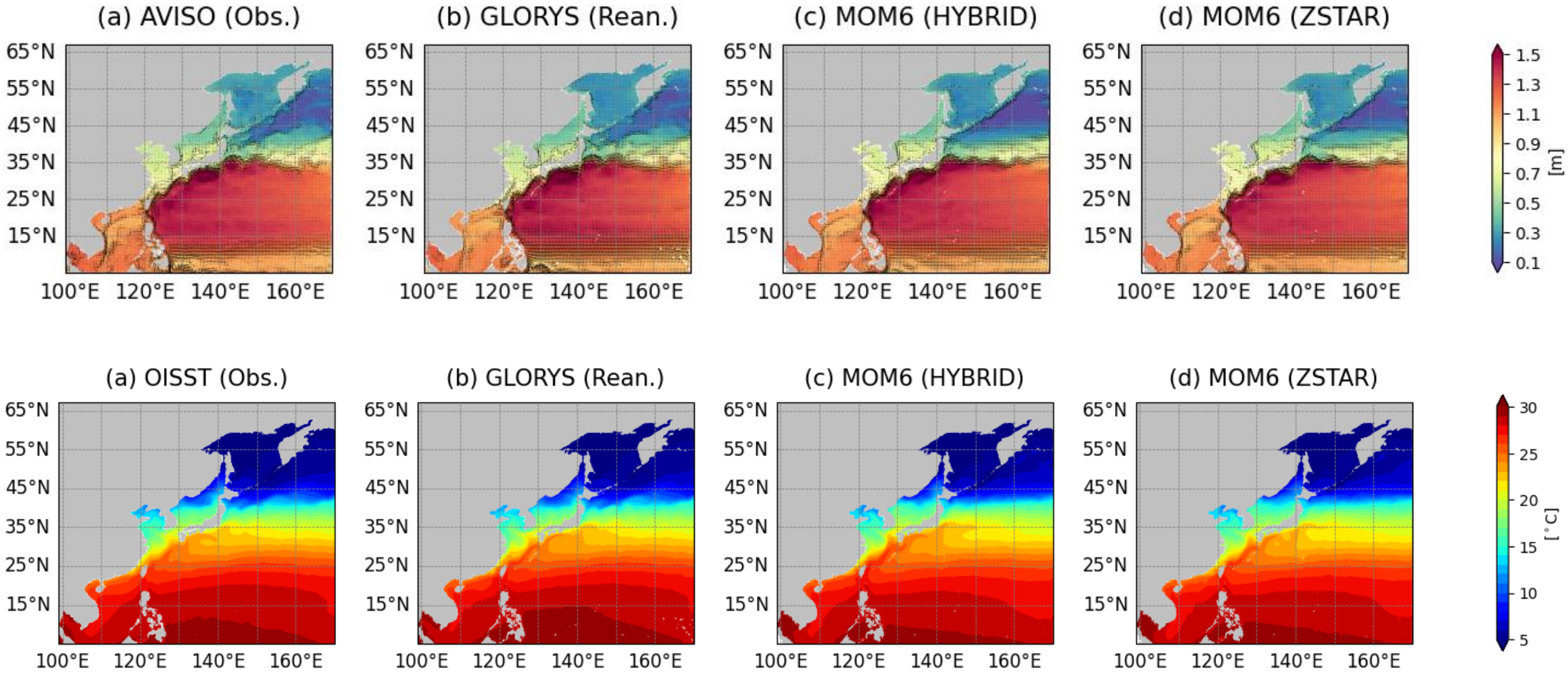
Model Configurations

- System title : MOM6 KOOS-OPEM (Ocean Predictability Experiment for Marine environment) version 2
- Based model : GFDL-MOM6
- Domain : 5-63˚N, 99-170 ˚E (Northwestern Pacific)
- Resolution : 1/24 ˚x 1/24 ˚ (Arakawa C-grid) & 61 layers (Hybrid coordinate system : Z* coordinate + Isopycnal)
- Vertical mixing parameterization : Energetically-constrained Planetary Boundary Layer (ePBL)
- Horizontal viscosity : Biharmonic Smagorinsky viscosity

Table 1. Summary of key changes

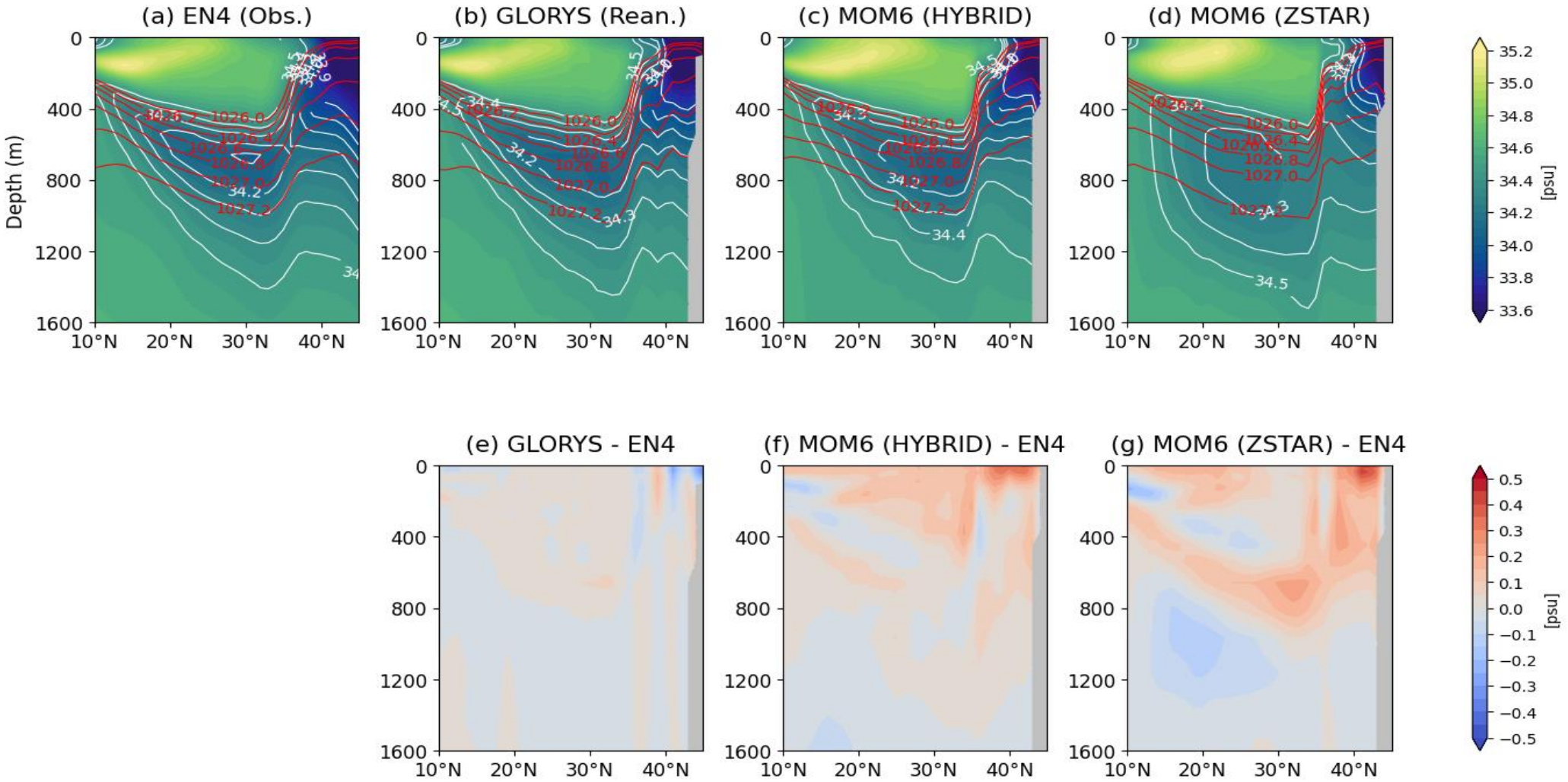
	KOOS-OPEM version1	**KOOS-OPEM version2**
Base model	MOM5	MOM6
Horizontal Resolution	1/24˚ x 1/24˚ (B-grid)	1/24˚ x 1/24˚ (C-grid)
Vertical coordinate	Z* coordinate	Hybrid coordinate (Z* + isopycnal)
Vertical levels	51	61
Ocean boundary layer mixing parameterization	KPP	ePBL
Tidal forcing	X	O

Comparison of V. Coordinate Sys. – SSH with current vectors and SST



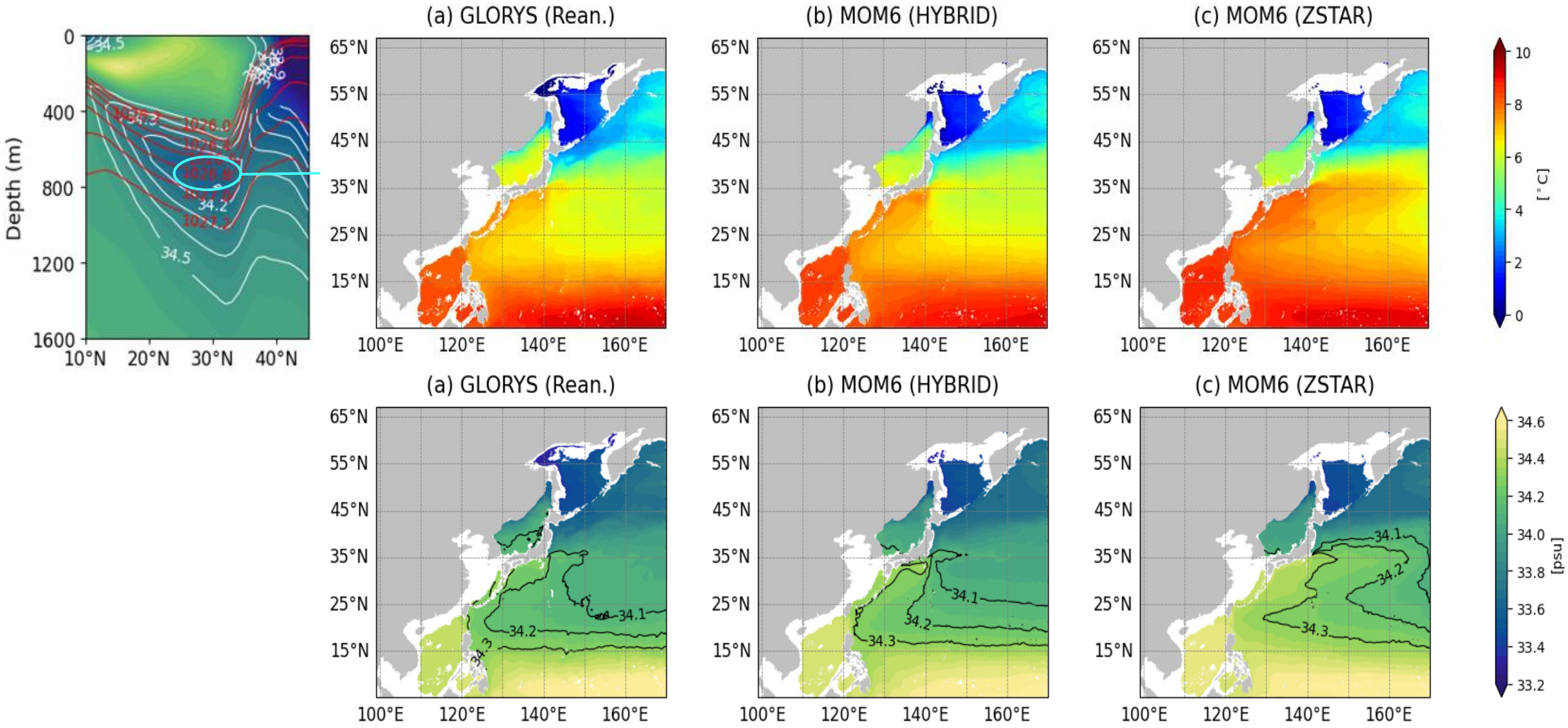
- The Kuroshio separation points in both models closely align with the observation and reanalysis data even though data assimilation is not performed.
- Both models exhibit a notable low SST bias in the Northwest Pacific, while displaying a warm bias of approximately 2˚C in the Kuroshio-Kuroshio extension and the East/Japan Sea.
- The warm biases of the two models in the East/Japan sea seem to be attributed to the overshoot of the East Korean Warm Current.

Comparison of V. Coordinate Sys. – Meridional salinity section (148˚E)



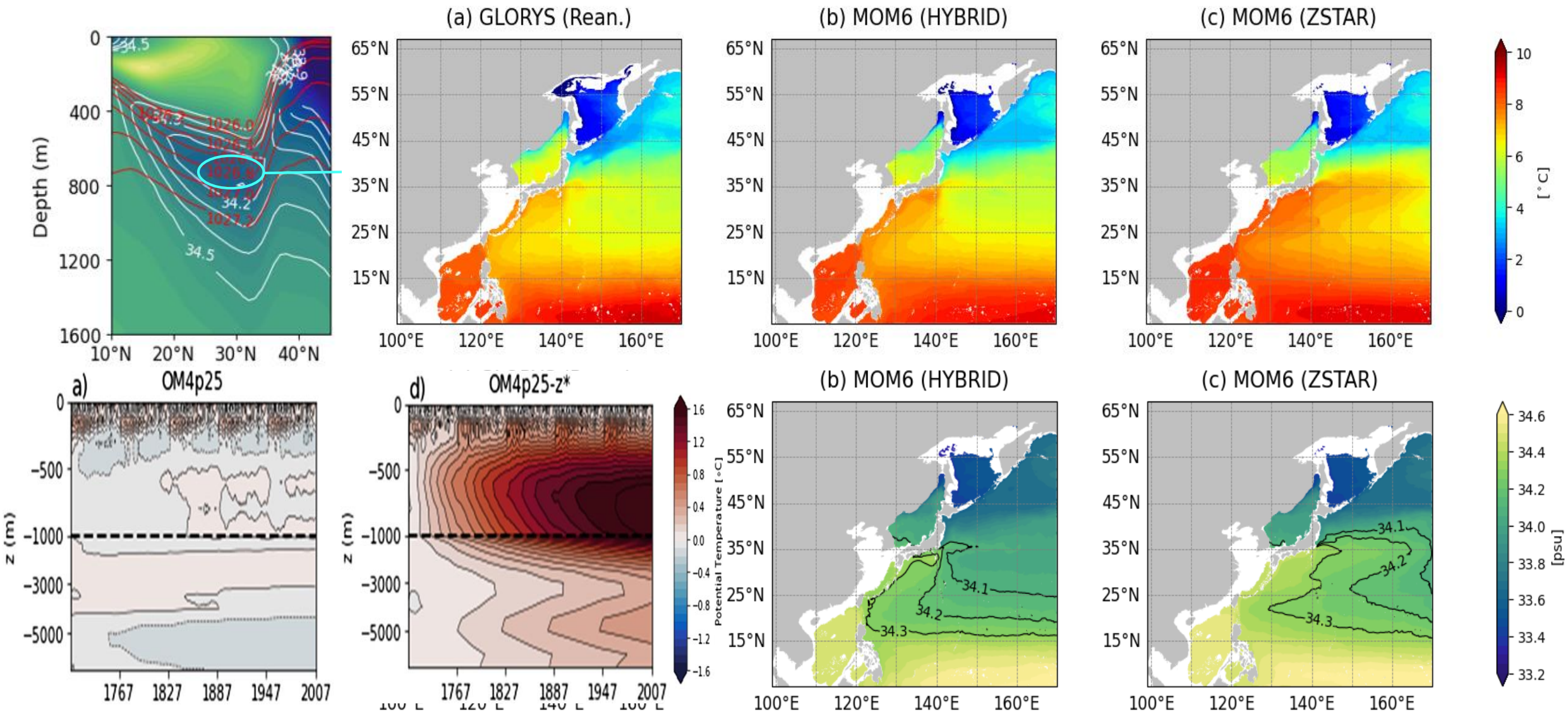
- The Z* coordinate model exhibits a warm bias in high latitudes where cold and fresh water intrudes into the intermediate layer, the hybrid coordinate model shows an improvement in mitigating this warm bias.
- The hybrid coordinate model effectively simulates the thickness of the isopycnal layers associated with NPIW similar to observational and reanalysis data.
- The Z* coordinate model tends to simulate the thickness of these isopycnal layers as excessively thick.

Comparison of V. Coordinate Sys. – temperature at depth of isopycnal (26.8 σ_θ)



- The Z* coordinate model shows a significant warm bias and positive salinity bias at 26.8 σ_θ isopycnal depths due to spurious diapycnal mixing, while the hybrid coordinate model closely matches GLORYS salinity distributions, even without data assimilation, and mitigates the warm bias.

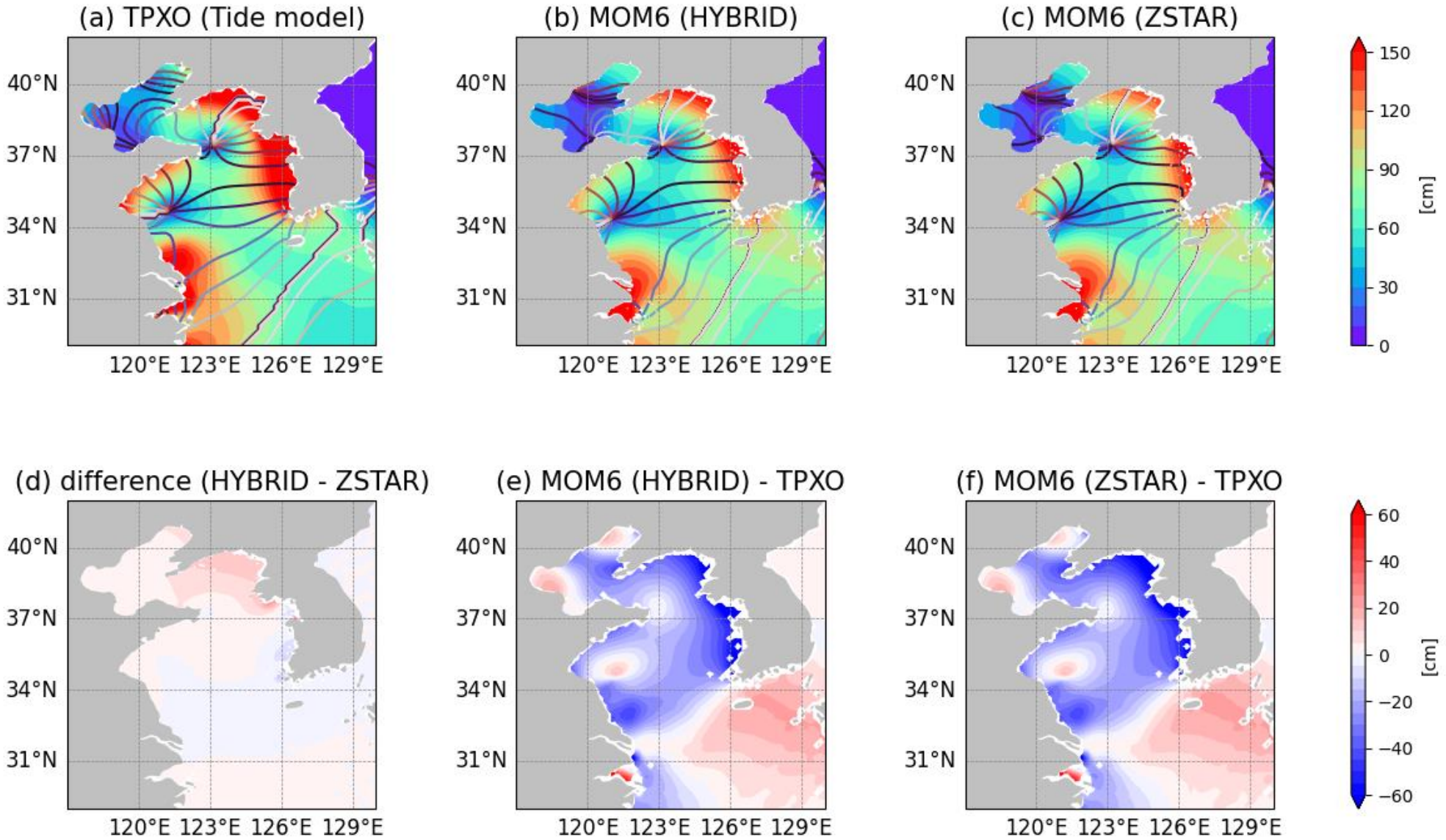
Comparison of V. Coordinate Sys. – temperature at depth of isopycnal (1026.8)



Adcroft et al. (2019)

- **This spurious diapycnal mixing found in the traditional Eulerian geopotential coordinate models is considered to be the primary cause of model drift.**

Comparison of V. Coordinate Sys. – Tidal amplitude and phase for M2



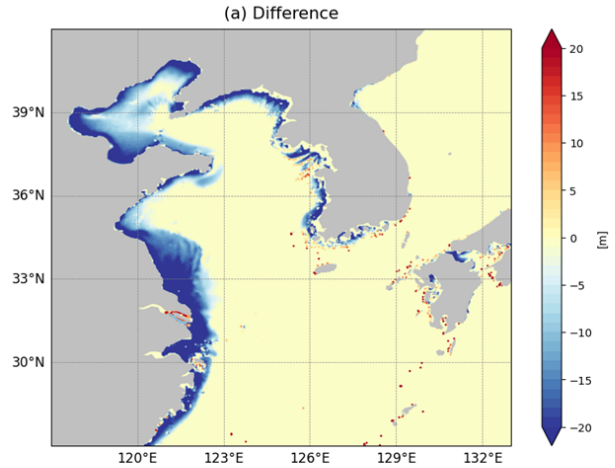
- Both models show a tidal phase similar to tide model, but underestimate tidal amplitude.
- The hybrid coordinate model shows an improvement in mitigating biases for tidal amplitude in Yellow Sea.

Sensitivity Tests on Hybrid Vertical Coordinate Configurations

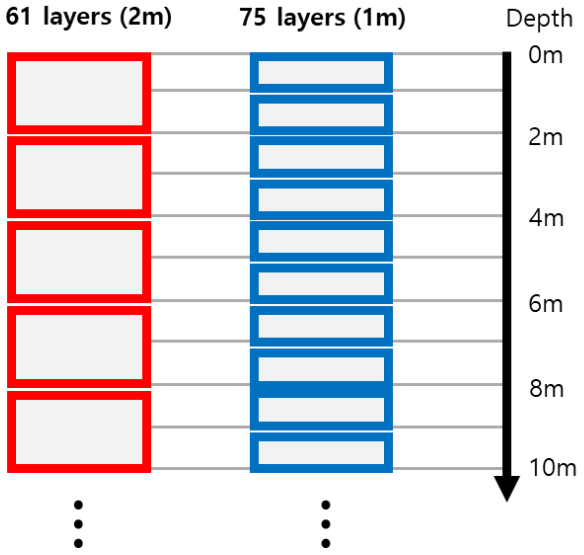
- This model exhibited certain limitations, including a warm bias in western boundary currents, an overshoot of the East Korean Warm Current, and an underestimation of tidal amplitude in the Yellow Sea.

- To address these limitations, we conducted additional sensitivity experiments for minimum depth and vertical resolution.

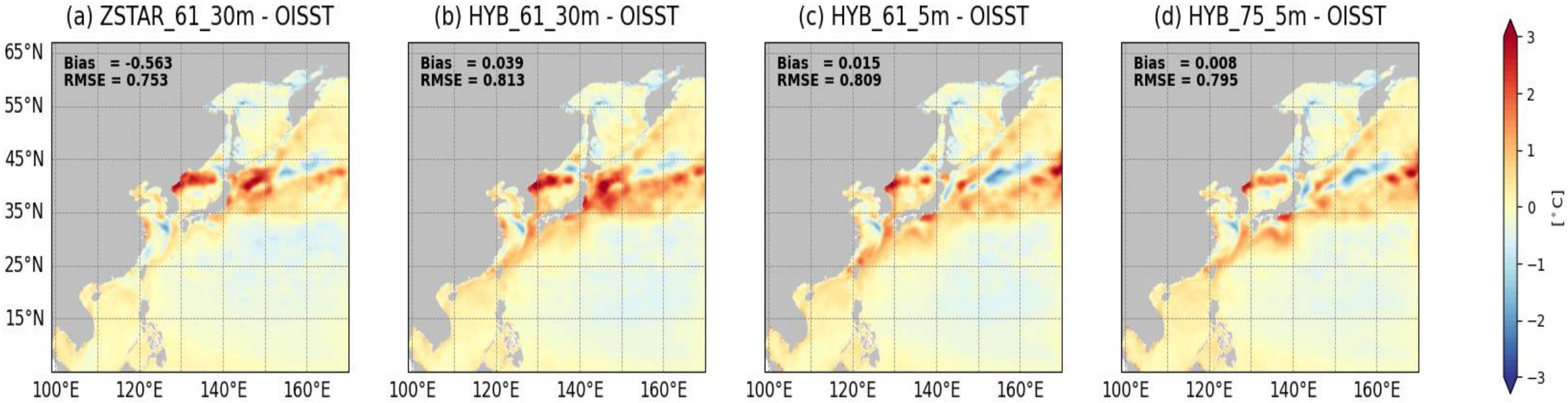
Experiment	Vertical coordinate	Vertical resolution	Minimum depth
ZSTAR_61_30m	Zstar	61 layers (2m)	30m
HYB_61_30m	Hybrid	61 layers (2m)	30m
HYB_61_5m	Hybrid	61 layers (2m)	5m
HYB_75_5m	Hybrid	75 layers (1m)	5m



- **Min(5m) – Min(30m)**

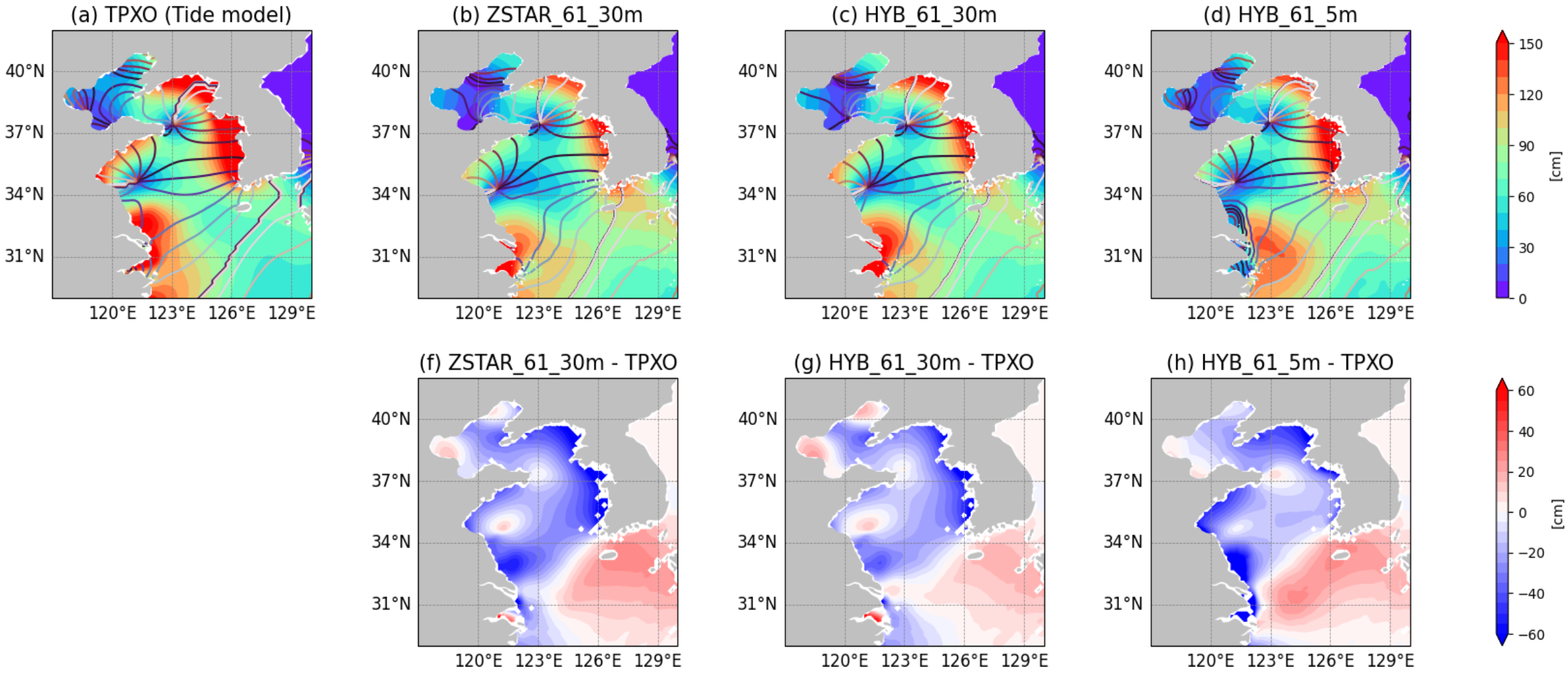


Sensitivity test on Hybrid V. - SST bias



- Reducing the minimum depth and increasing vertical resolution mitigated warm biases in the East Sea Warm Current and Kuroshio Current.
- However, reducing the minimum depth intensified cold biases in high-latitude regions.
- Higher vertical resolution improved the vertical structure of temperature and salinity.

Sensitivity test on Hybrid V. – Tidal amplitude

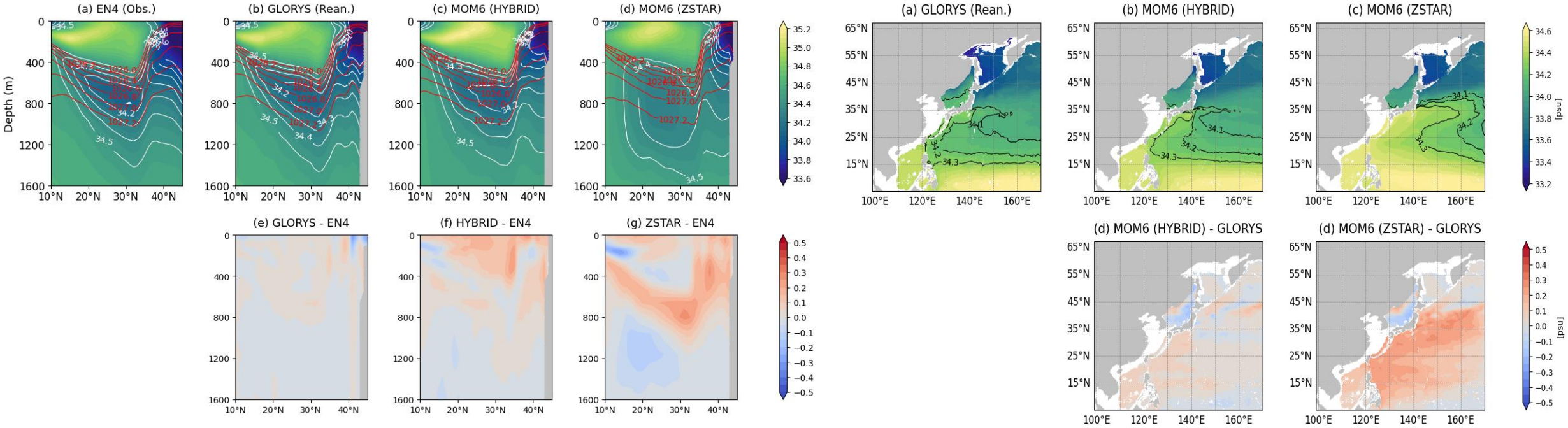


- Adjusting the minimum depth improved tidal amplitude in the Yellow Sea and significantly enhanced tidal phase accuracy in the Bohai Sea.

Summary

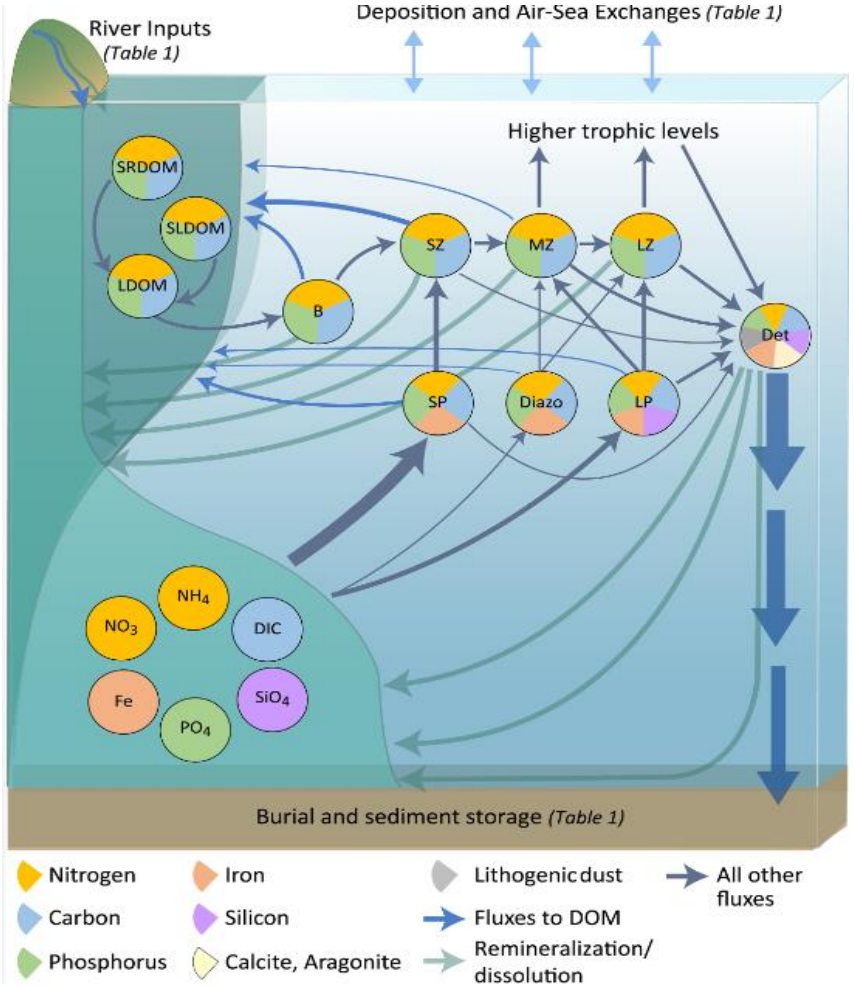
- We have developed a next-generation regional ocean model for the Northwest Pacific using GFDL-MOM6. Sensitivity experiments were conducted to evaluate the strengths and weaknesses of the Z* and hybrid coordinate models.

- Key findings include:
  - ✓ **Kuroshio Separation:** Both models accurately reproduce the Kuroshio separation points, consistent with observations and reanalysis data, despite the absence of data assimilation.
  - ✓ **Hybrid Coordinate Performance**: The hybrid coordinate configuration better represents the thickness of isopycnal layers associated with North Pacific Intermediate Water.
  - ✓ **Tidal Simulation**: Both models replicate tidal phases well but underestimate tidal amplitude.
  - ✓ **More Improvements**: Additional experiments reduced warm biases in the western boundary current and enhanced tidal reproducibility.

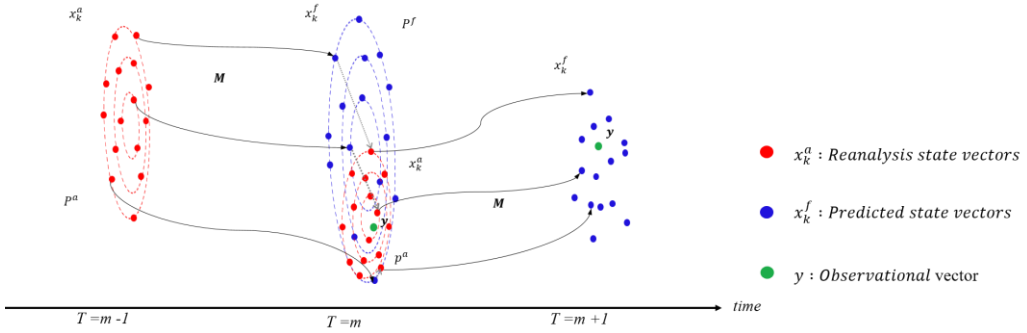


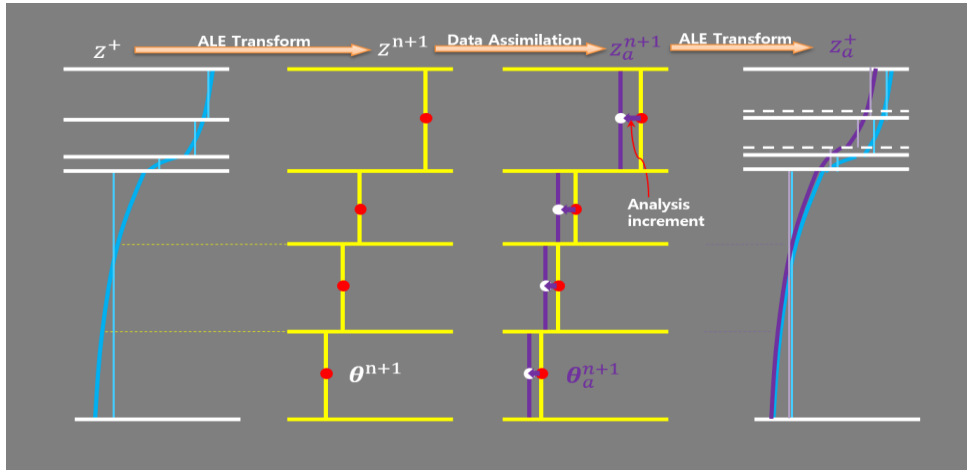
Future Plan – BGC & Data Assimilation

- **COBALT version 3**



- **Ensemble based assimilation for the hybrid vertical coordinate system**

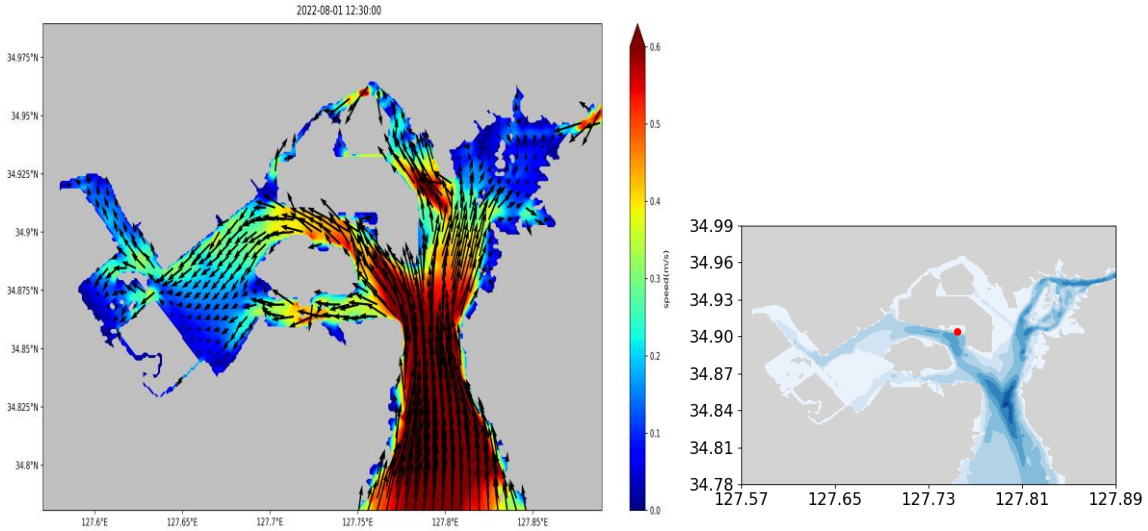




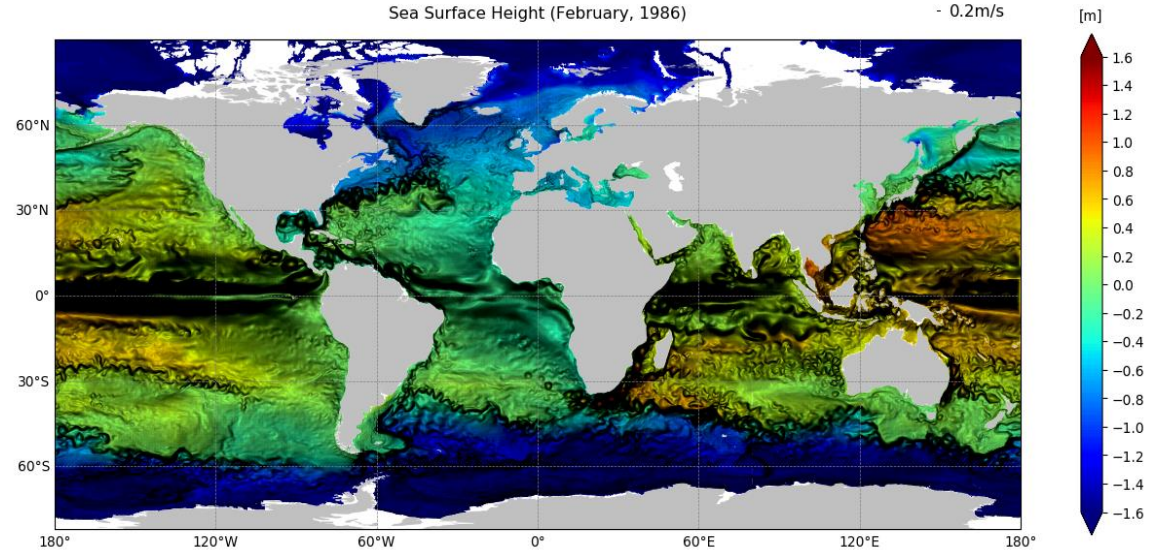
Future Plan – Global to Coastal

- **Coastal Ocean Configuration**

Base model : GFDL-MOM6
Domain : 127.57-127.89°E, 34.78-34.99°N
Hor. Resolution: 100m



- **Global Ocean Configuration**



Ocean Predict

SYMPOSIUM OP'24

In partnership with unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Thank you!

Presenter : Young Ho Kim (yhokim@pknu.ac.kr)

PUKYUNG NATIONAL UNIVERSITY 부경대학교

KIOST KOREA INSTITUTE OF OCEAN SCIENCE & TECHNOLOGY

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE