SYMPOSIUM OP'24

18-22 Nov 2024 | Paris, France

Ocean Predict

In partnership with unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Development and initial performance evaluation of the KIAPS weakly-coupled atmosphere-ocean-sea ice data assimilation system

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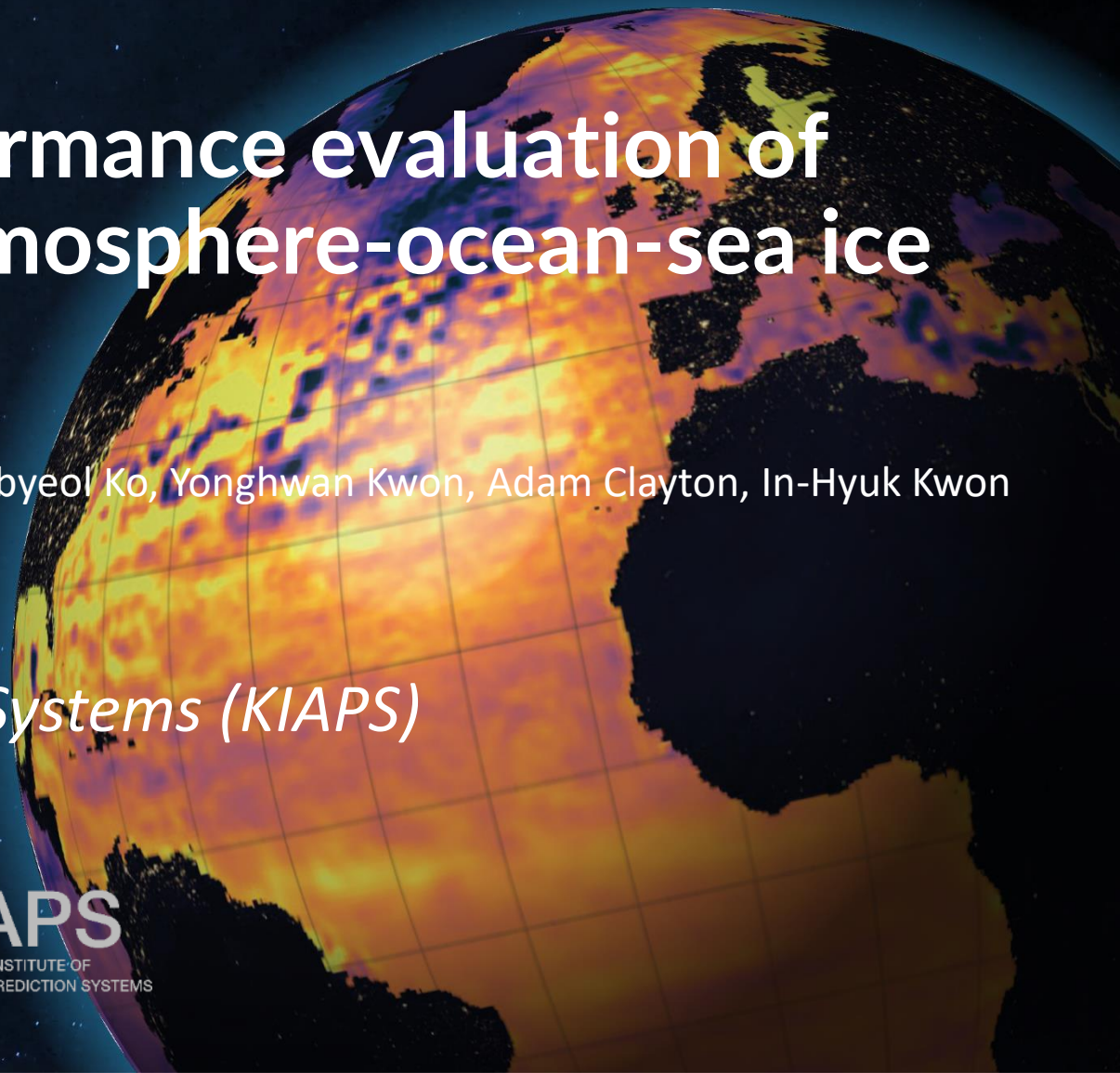

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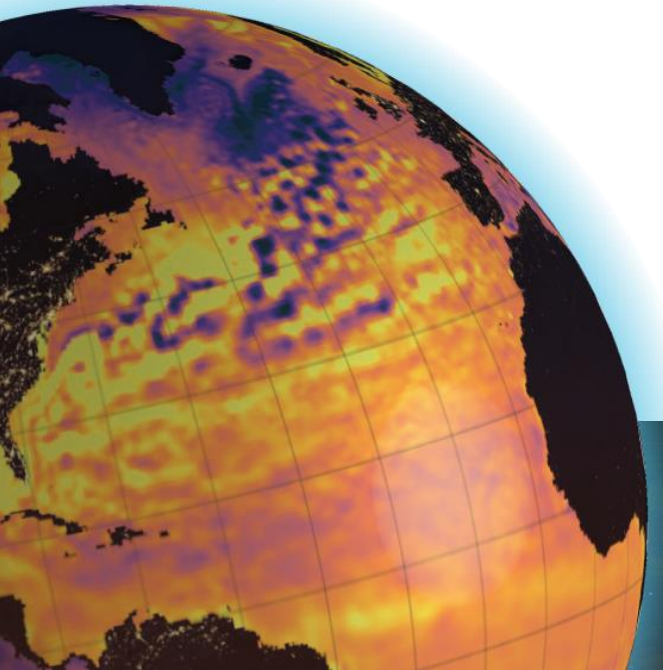
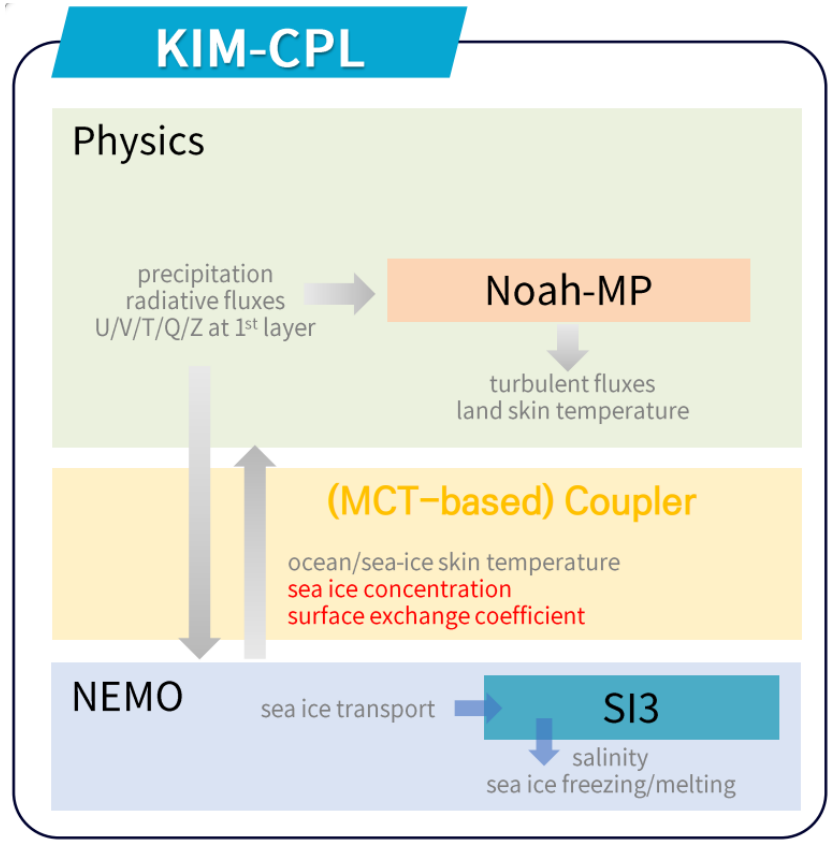


1. KIM Coupled Model

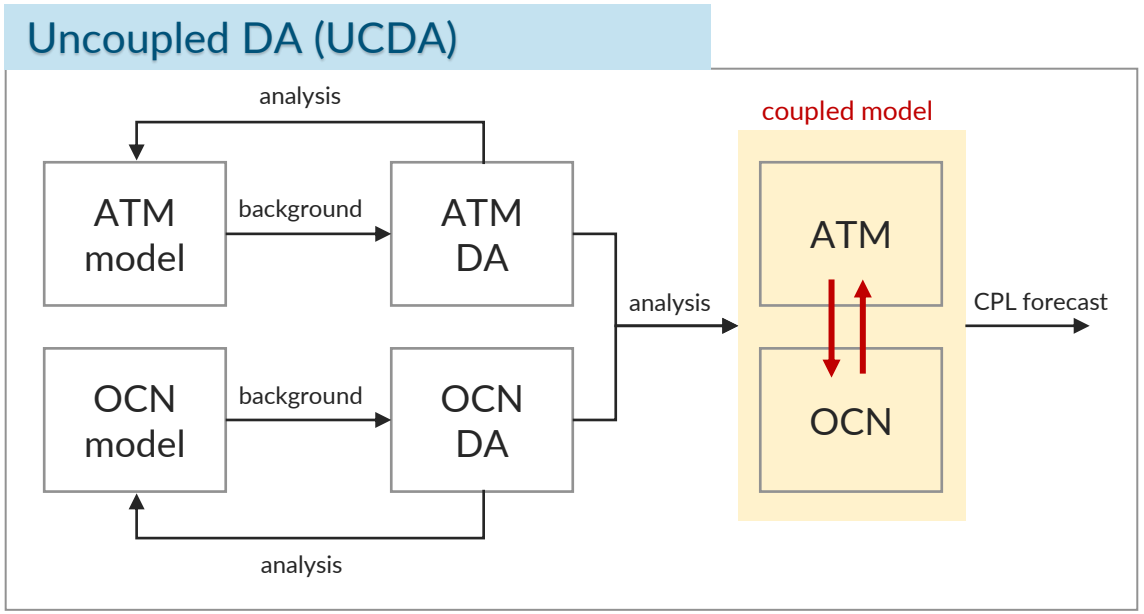
- KIAPS developed the **Korean Integrated Model (KIM)** for a global atmospheric NWP system, which is **operational** at the Korea Meteorological Administration (KMA).
- KIAPS is currently developing a **coupled atmosphere-land-ocean-sea ice model** for extended-range forecasts.
- In the KIM system, the atmosphere (KIM v4.0), ocean (NEMO v4.0), and sea ice (SI^3) components are coupled using the MCT coupler, with coupling every hour.
- Therefore, we need to **provide ocean and sea ice initial conditions to this KIM coupled model**.

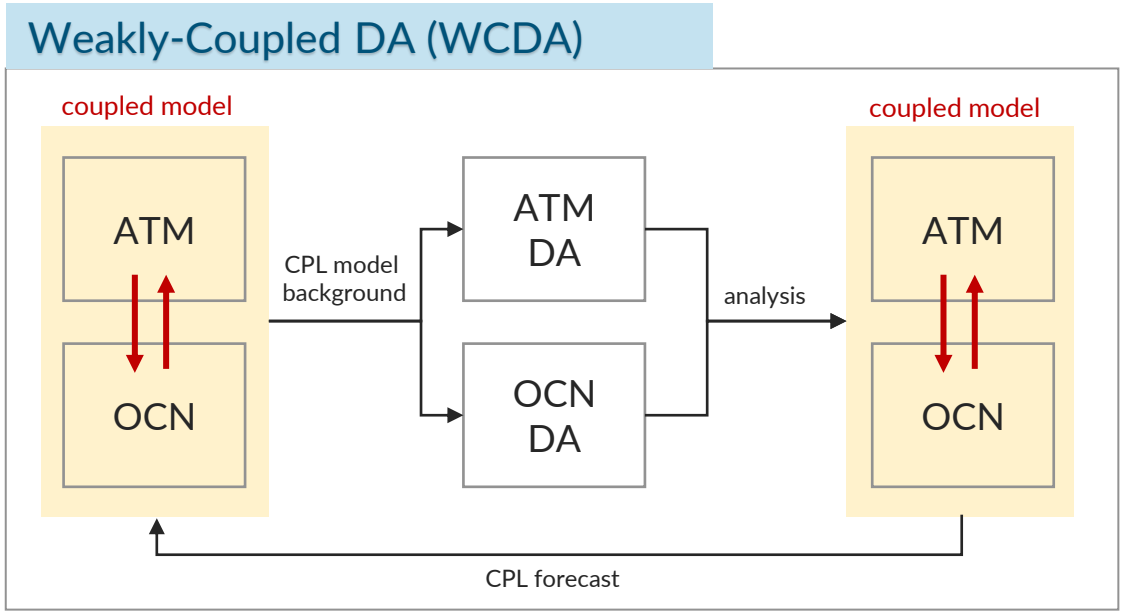


Koo et al. (2022)

2. Uncoupled and Weakly-Coupled DA

- In **uncoupled data assimilation (UCDA)**, the background fields for each DA system come from separate atmospheric and ocean models, providing uncoupled initial conditions to the coupled model.
- In **weakly-coupled data assimilation (WCDA)**, the background fields for each DA system come from the coupled model, providing coupled initial conditions to the coupled model.



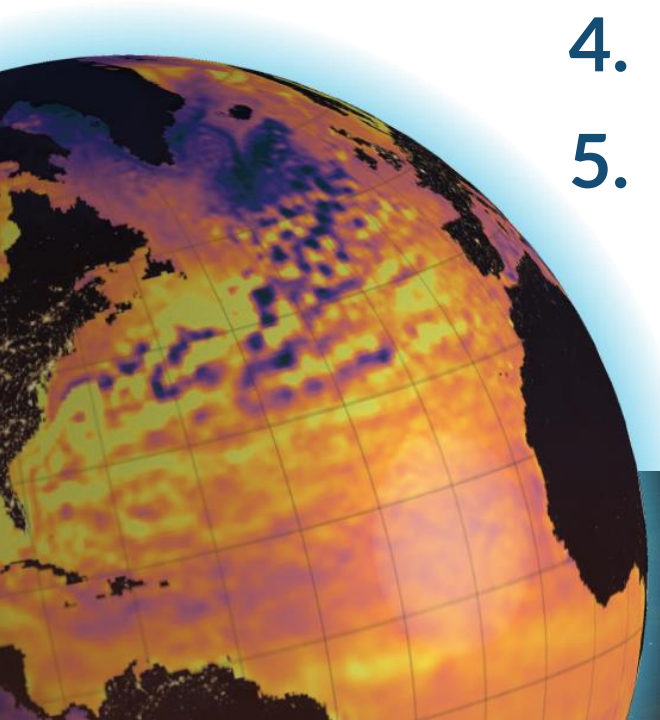


3. Research Objectives

- When atmospheric and ocean initial conditions are produced by independent DA systems (i.e., UCDA), inconsistencies at the ocean surface can lead to imbalances in the coupled model (Lea et al., 2015).
- A coupled DA approach is known to reduce this initialization shock (Mulholland et al., 2015).
- We have been developing **a weakly-coupled atmosphere-ocean-sea ice DA system to provide more balanced initial conditions to the KIM coupled model**.
- This study aims to examine whether **WCDA provides improvements compared to using separate initial conditions for the atmosphere, ocean, and sea-ice**.

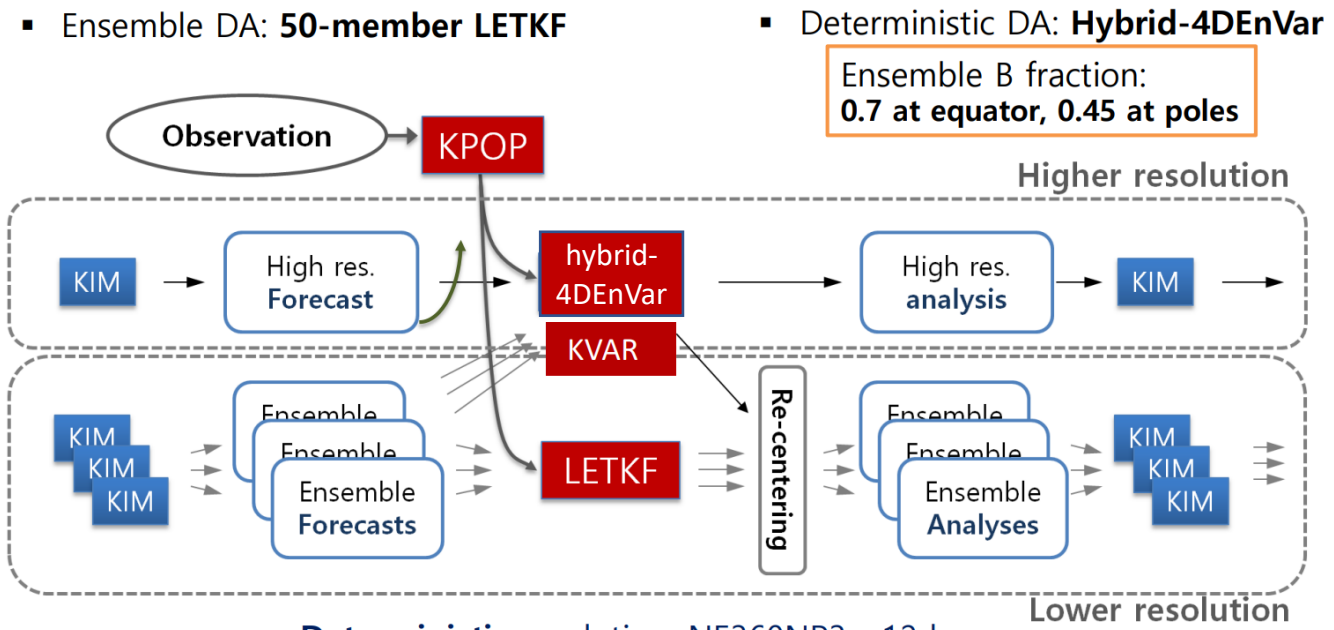
II. Weakly-Coupled DA System

1. Atmospheric DA System
2. Ocean DA System
3. Components
4. Weakly-Coupled DA System
5. Uncoupled DA System



1. Atmospheric DA System

- KVAR : KIM Hybrid-4DEnVar
- Static background-error covariance generated by the NMC method
- Ensemble covariance (initial ensemble from LETKF)
- Incremental analysis update (IAU)
- In this study, we use the **3DVar-FGAT** method.

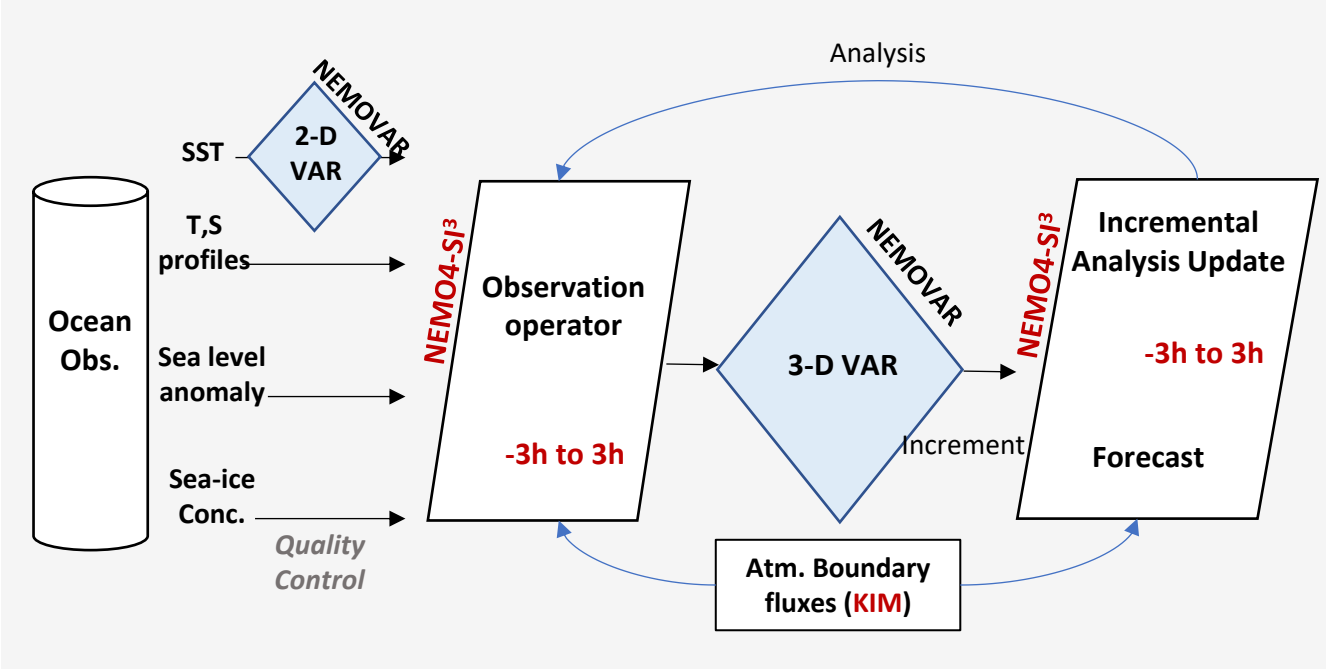


Deterministic resolution: NE360NP3 ~12 km
Ensemble resolution: NE144NP3 ~32 km
Analysis resolution: NE144NP3 ~32 km

Operational Atmospheric DA system

2. Ocean DA System

- For ocean DA, we adopted GODAPS (Global Ocean Data Assimilation and Prediction System), which includes **NEMOVAR** (NEMO Ocean Variational Analysis).
- Here are the major changes:
  1) Surface forcing model: **from KMA-UM to KIM**
  2) DA cycle and window: **from 24-hr to 6-hr** to be consistent with the atmospheric DA system
  3) Upgrade of the NEMO version and sea ice model as used in the KIM coupled model: **from NEMO-CICE to NEMO4-SI³**



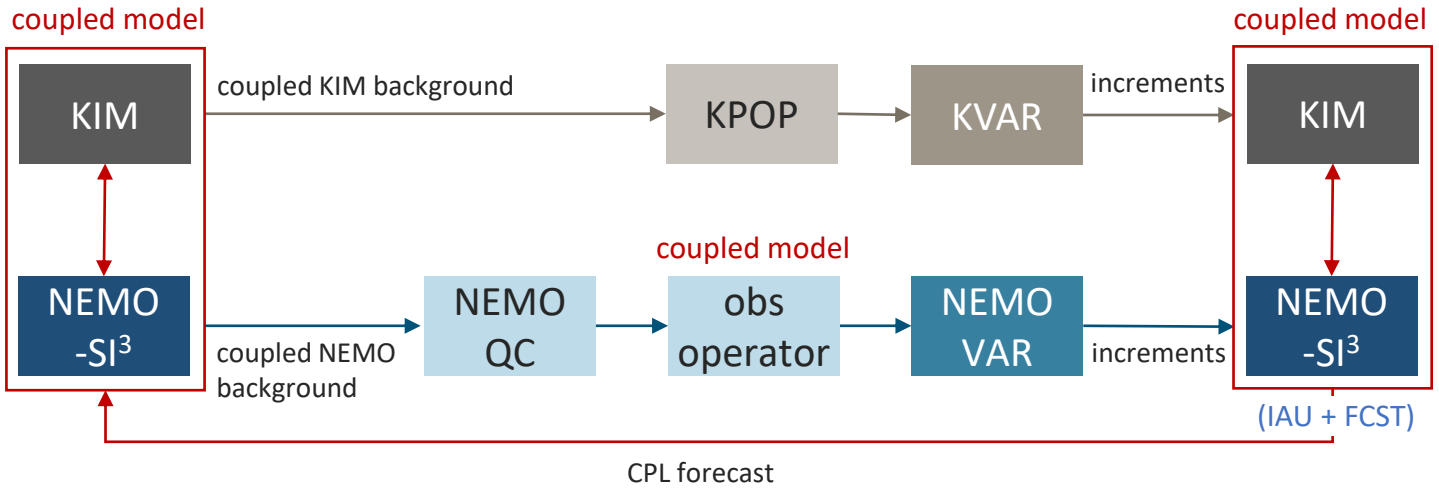
3. Components

- The atmospheric model is **KIM v4.0**, the ocean model is **NEMO v4.0**, and the sea ice model is **SI³**, with a spatial resolution of about 25 km.
- The DA is performed using the **3DVar-FGAT** method and initialized using **IAU**.

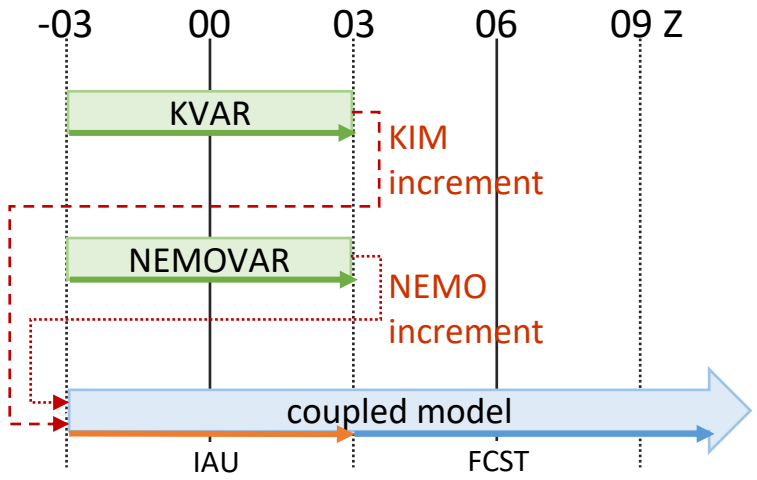
Component	Model		DA	Observations	Initialization
Atmosphere	KIM v4.0	NE180NP3L91 (~25 km)	KVAR (3DVar-FGAT)	sonde, surface, aircraft, AMSU-A, MHS, ATMS, IASI, CrIS, AMI, HIMAWARI, MSG, GPS-RO, AMV, ASCAT ...	IAU
Ocean	NEMO v4.0	eORCA025L75 (~25 km)	NEMOVAR (3DVar-FGAT)	In situ SST, T/S profiles, AVHRR, AMSR2, VIIRS, AltiKa, SRAL, Poseidon-3B, SIRAL	IAU
Sea Ice	SI³	eORCA025 with 1-snow and 2-ice layers (~25 km)		SSMIS	

4. Weakly-Coupled DA (WCDA) system

- In WCDA, the background fields for each DA system come **from the coupled model**.
- The coupled model is also used as an observation operator for NEMOVAR.
- **The NEMO IAU was matched with KIM**. That is, the analysis increments of KVAR and NEMOVAR are provided to the coupled model, and IAU and forecasts are performed as KIM and NEMO are coupled.



Workflow for WCDA system

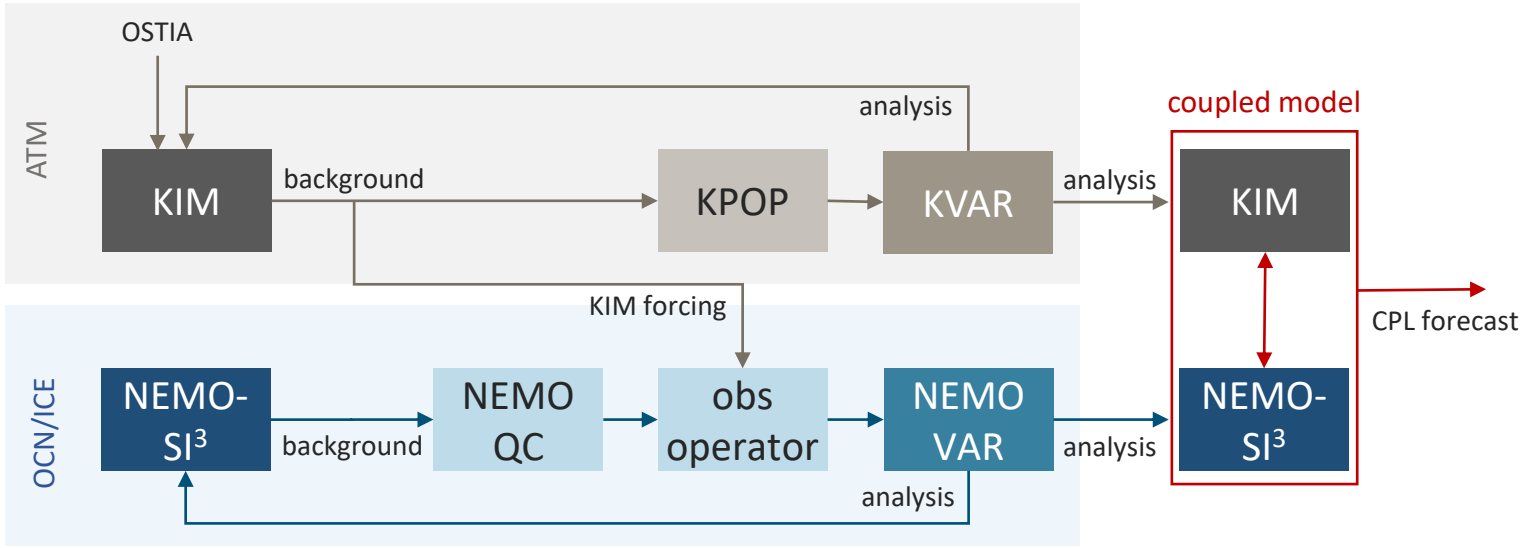


Cycles for WCDA system

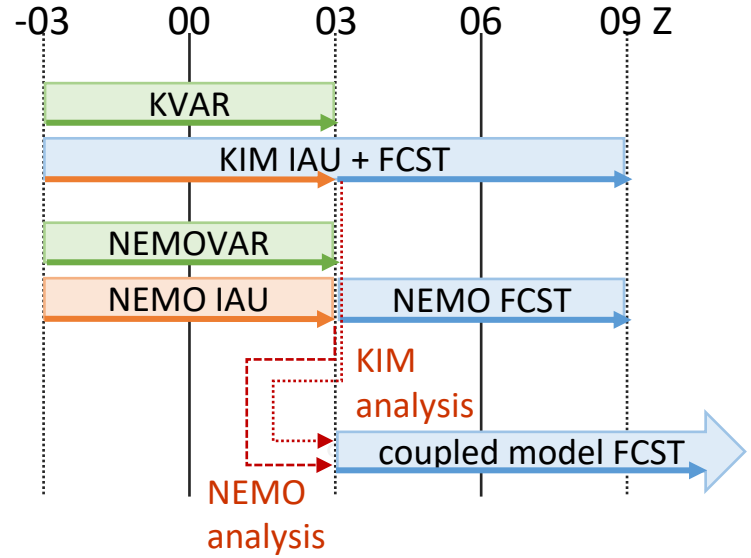
KIM : Atmospheric Model
KVAR : Atmospheric DA system
NEMO : Ocean Model
NEMOVAR : Ocean DA system
IAU : Incremental Analysis Update
FCST : Forecast

5. Uncoupled DA (UCDA) System

- The **KIM-only model forecast** is used as the background field for KVAR, and the **NEMO-only model forecast** is used as the background field for NEMOVAR.
- From -3 to 3 hours, IAU is performed, and the atmospheric and ocean analysis fields are provided as initial fields to subsequent the coupled model forecast.



Workflow for UCDA system



Cycles for UCDA system

III. Results

1. Experiments
2. Initial imbalance
3. Ocean assessment
4. Atmosphere assessment

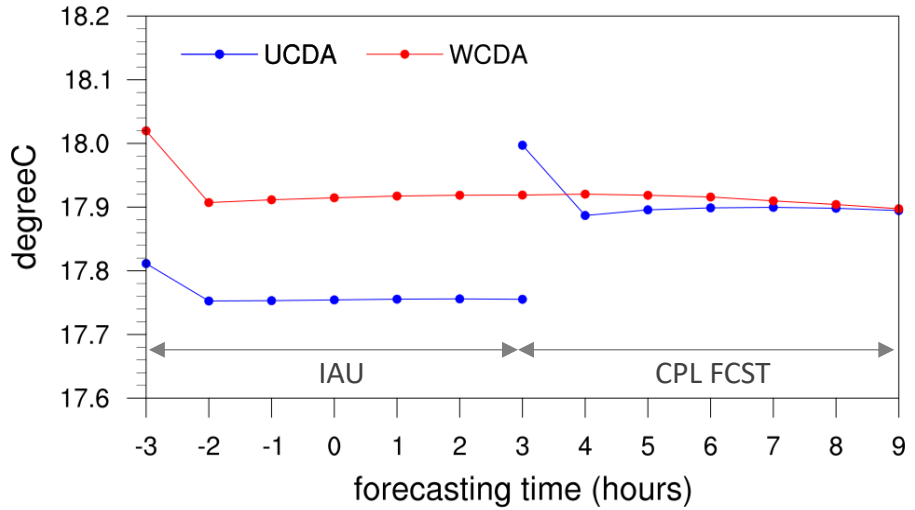
1. Experiments

- We conducted experiments to **assess the benefit of WCDA**.

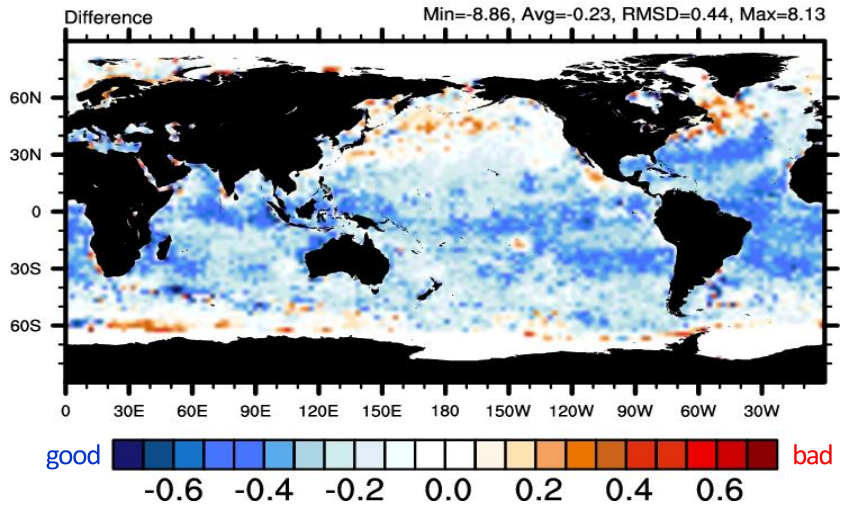
	UCDA (Control)	WCDA (Experiment)
DA	Atmosphere-only DA with OSTIA SST/Sea ice	Atmosphere-ocean coupled DA
	Ocean-only DA with KIM forcing	
FCST	Coupled forecasts with initial conditions from uncoupled DA	Coupled forecasts with initial conditions from coupled DA
DA windows	-03 ~ 03h (6 hours)	
IAU	-03 ~ 03h (6 hours)	
Periods	20220616T12Z ~ 20220731T18Z (5-day forecast at every 00 UTC)	
initial for cycle	ATM/Land ERA5, OCN/ICE NEMOv3.6 restart	

2. Initial imbalance

- In WCDA, SST comes from the coupled NEMO, while in UCDA, it comes from OSTIA during IAU. Therefore, **in UCDA, SST is not continuous** in both IAU and the coupled forecast.
- WCDA shows a smaller **initial temperature difference between the atmosphere and ocean**.
- WCDA seems to give more **balanced initial conditions** for the coupled model.



SST timeseries for the atmospheric analysis and forecast

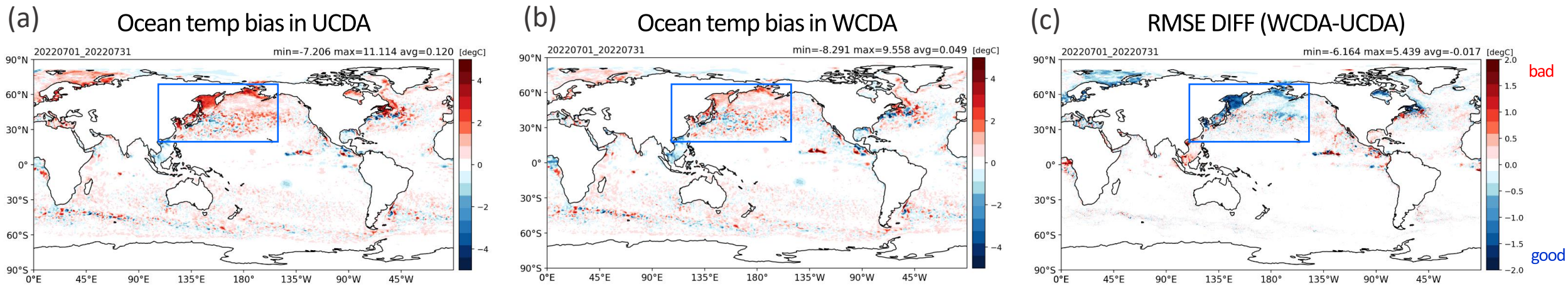


RMSD difference (WCDA-UCDA)

※ RMSD calculated from KIM 1000 hPa T and NEMO SST

3. Ocean assessment (Analysis)

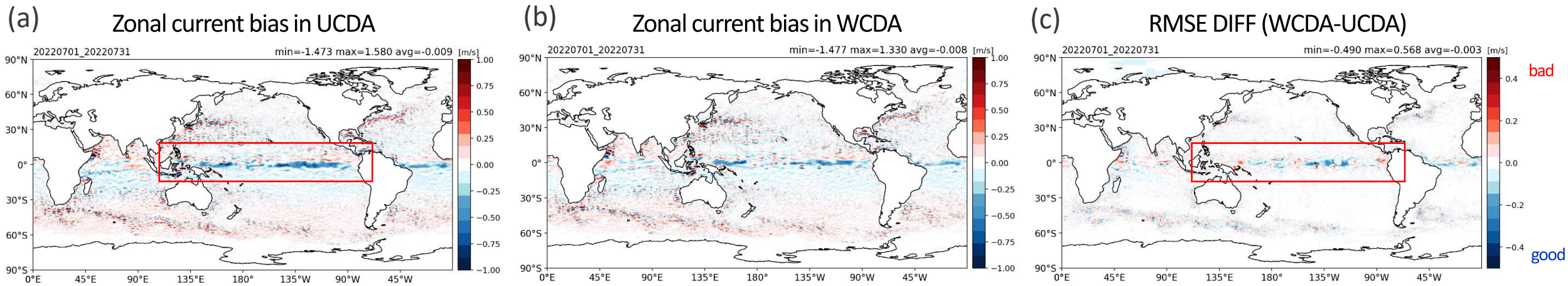
- For the ocean analysis, the SST bias of UCDA and WCDA are nearly identical.
- However, 25-m ocean temperature in UCDA shows a **larger warm bias in the East Sea and the Sea of Okhotsk** compared to ORAS5, while **WCDA shows much smaller bias** in these regions, resulting in a **smaller RMSE**.



25-m ocean temperature bias between ocean analysis and ORAS5

3. Ocean assessment (Analysis)

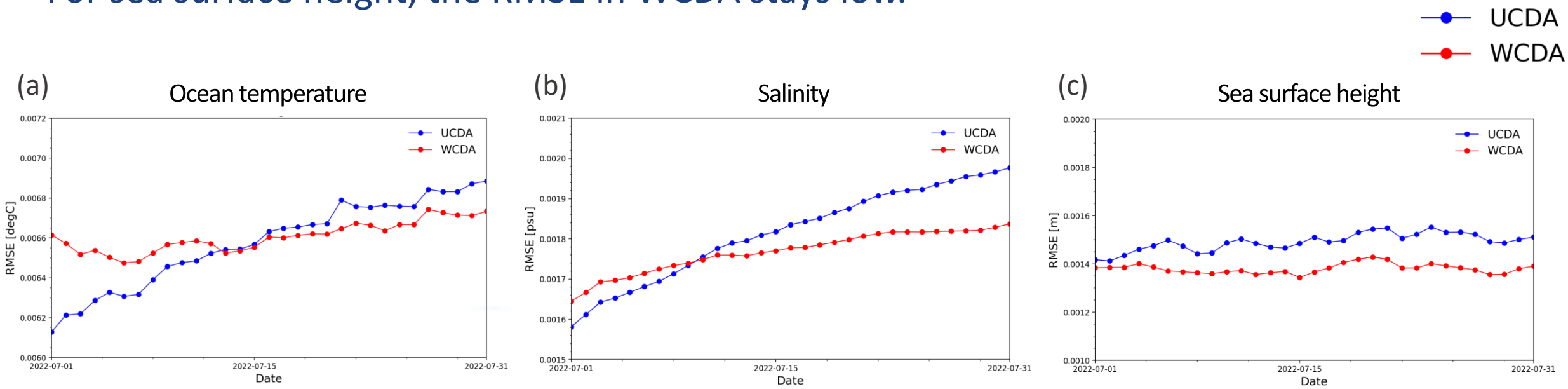
- In the surface zonal current, UCDA shows a **negative bias at the equator**.
- **In WCDA**, this negative bias is reduced, resulting in a **smaller RMSE**.



surface zonal current bias between ocean analysis and ORAS5

3. Ocean assessment (Analysis)

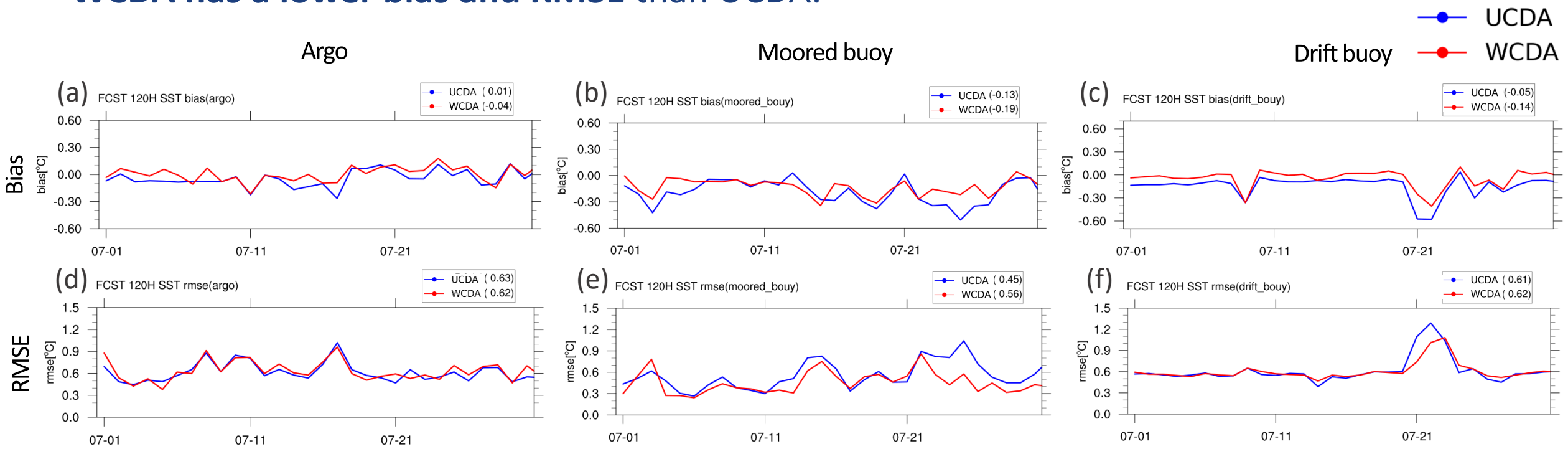
- The analysis RMSE in **WCDA gets smaller** over time for temperature and salinity.
- For sea surface height, the RMSE in WCDA stays low.



Timeseries of global vertical mean RMSE for the ocean analysis compared to ORAS5

3. Ocean assessment (5-day forecast)

- We compared the SST from 5-day ocean forecasts with in situ data.
- **WCDA has a lower bias and RMSE** than UCDA.

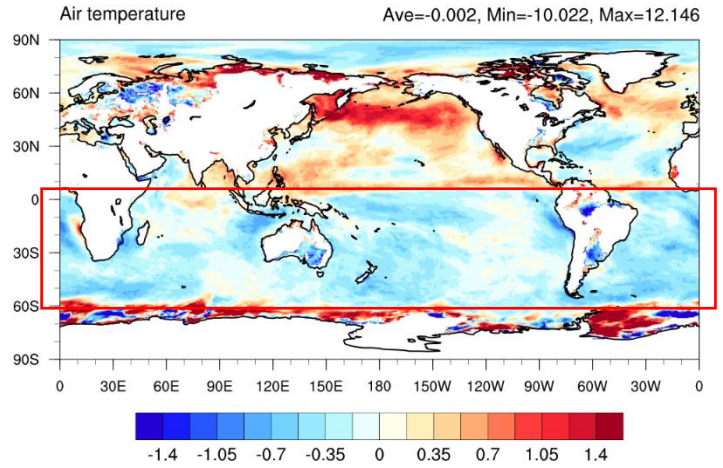


Bias and RMSE of global mean SST 5-day forecast compared to in situ data

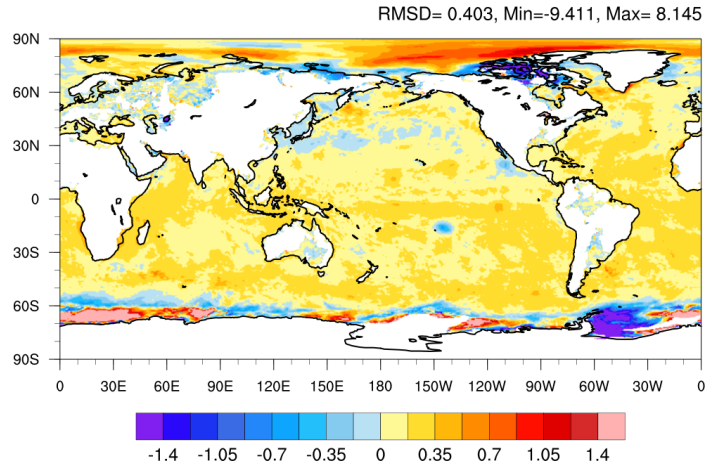
4. Atmosphere assessment (Analysis)

- Compared to IFS, air temperature analysis in UCDA has a **cold bias in the Southern Hemisphere** and a **warm bias in the North Pacific**.
- **WCDA** shows generally higher temperature than UCDA, resulting in a **lower RMSE in the Southern Hemisphere** .

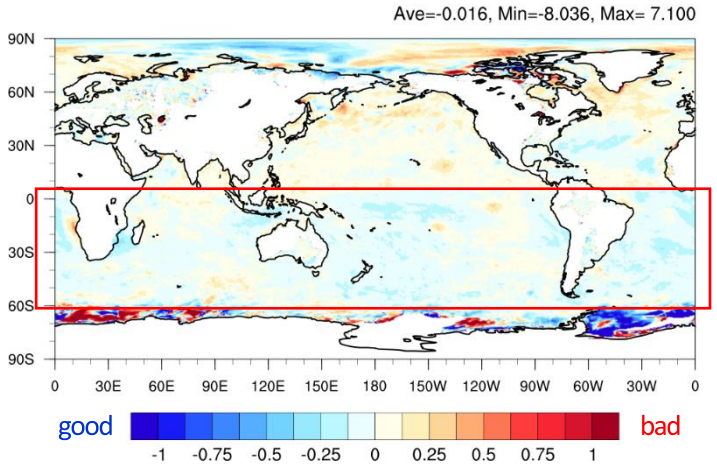
(a) Air temp bias in UCDA



(b) Air temp DIFF (WCDA-UCDA)



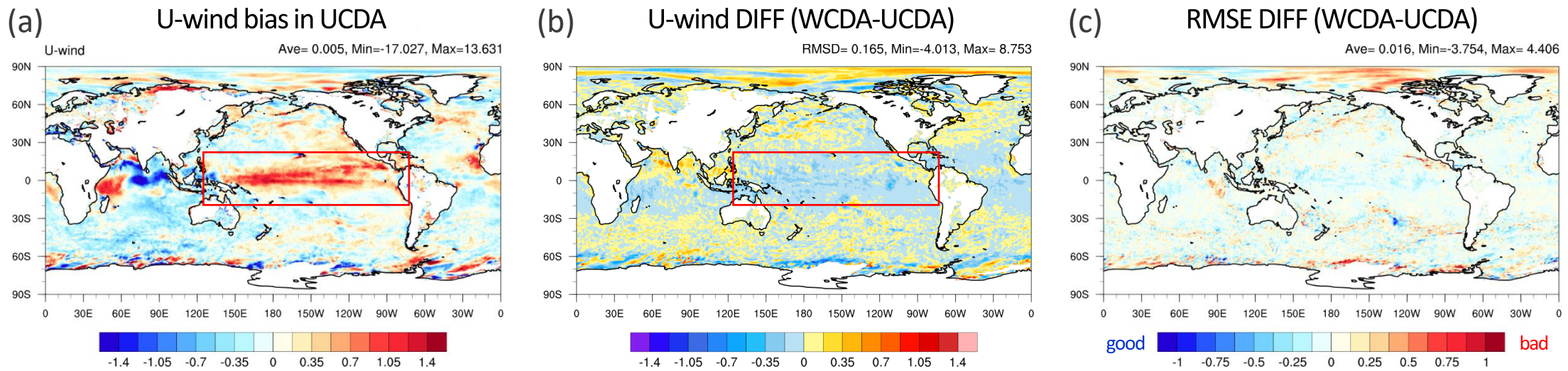
(c) RMSE DIFF (WCDA-UCDA)



Analysis difference of 1000 hPa air temperature between KIM and IFS.

4. Atmosphere assessment (Analysis)

- The eastward wind in UCDA shows a **positive bias over the tropical Pacific**.
- While **WCDA** reduces this positive bias, resulting in a **lower RMSE**.

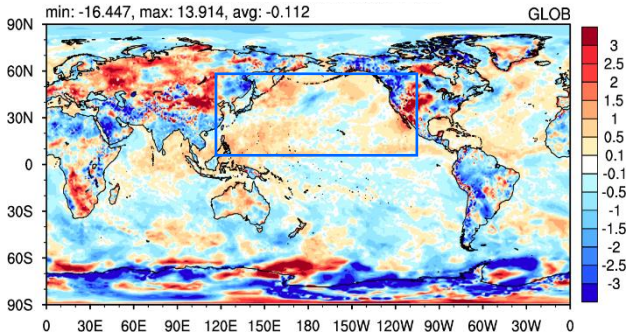


Analysis difference of 1000 hPa eastward wind between KIM and IFS.

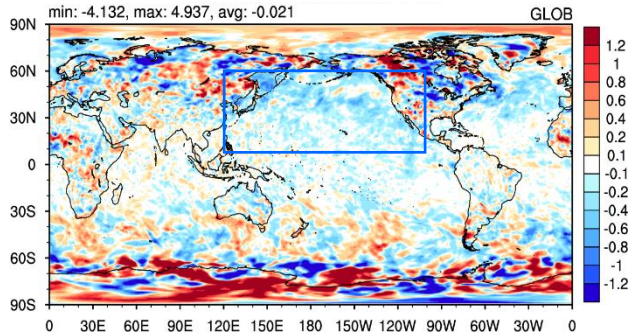
4. Atmosphere assessment (5-day forecast)

- 2-m air temperature forecast in UCDA also shows **a warm bias in the North Pacific**.
- **WCDA** predicts lower 2-m temperature in this region than UCDA, which helps **reduce RMSE**.
- It also reduces the positive bias in 2-m specific humidity, resulting in a lower RMSE.

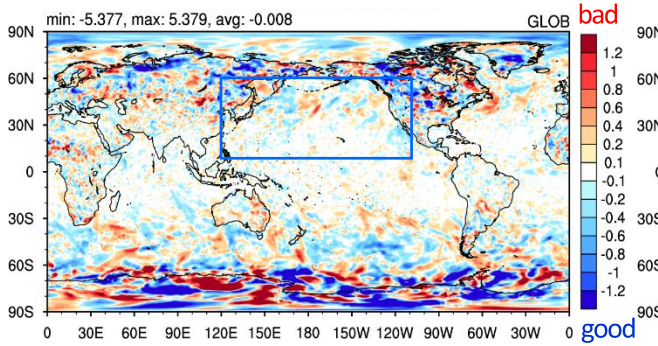
(a) 2m air temp bias in UCDA



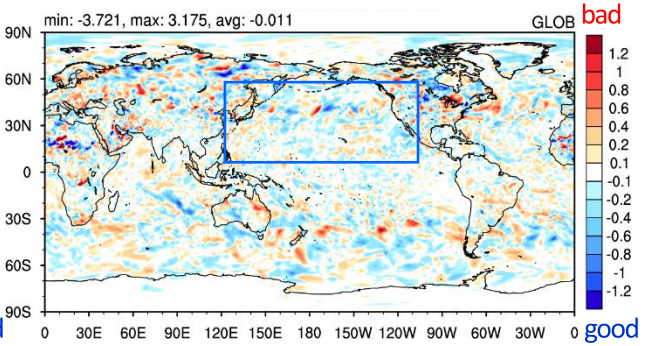
(b) 2m air temp DIFF (WCDA-UCDA)



(c) 2m air temp RMSE DIFF (WCDA-UCDA)

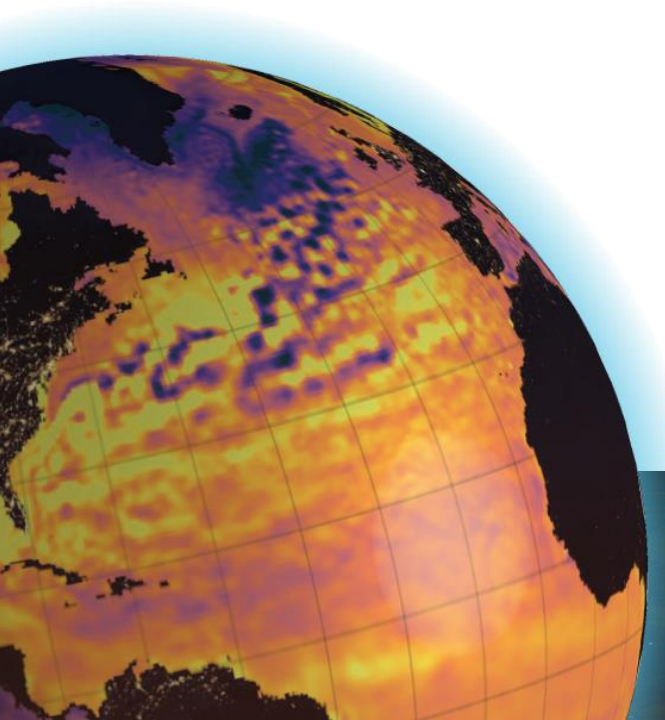


(d) 2m humidity RMSE DIFF (WCDA-UCDA)



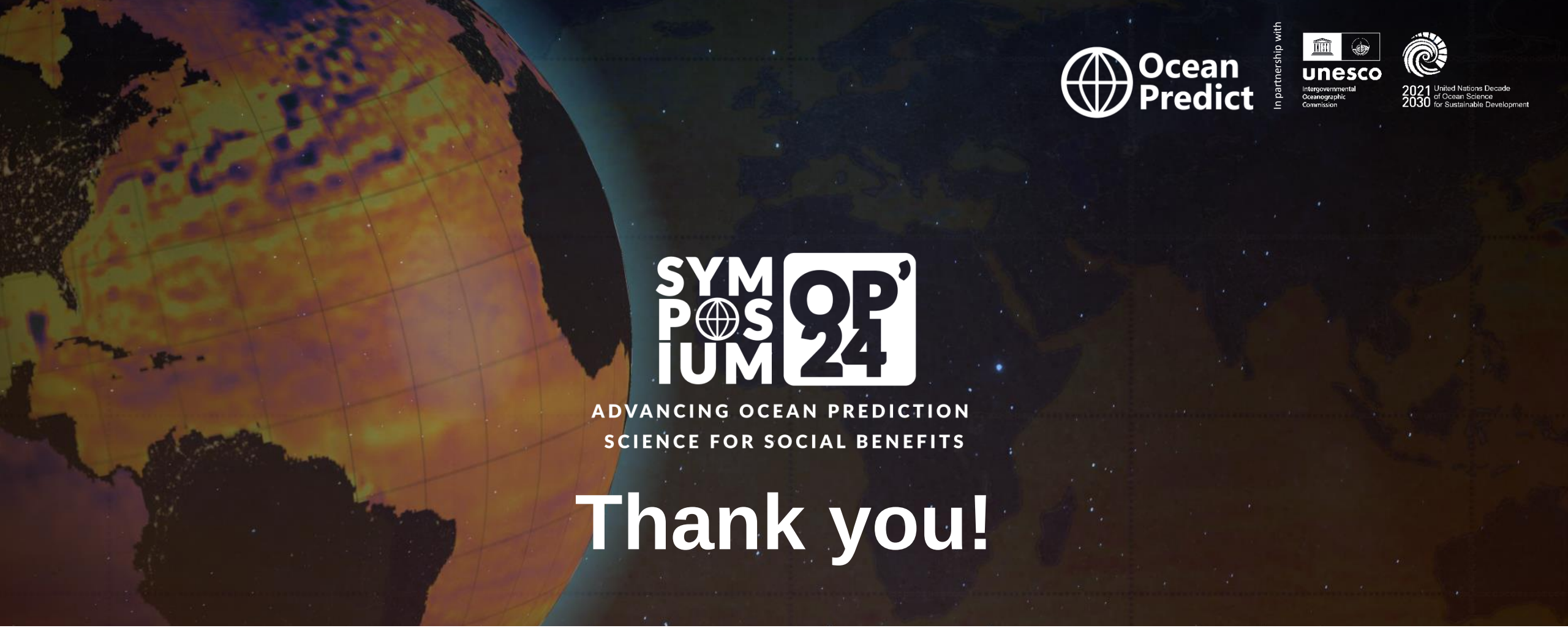
5-day forecast difference compared to IFS

IV. Summary & Plan



Summary & Plan

- In this study, we confirmed the possibility that **WCDA can provide more balanced initial conditions** to the coupled model compared to UCDA. It appears that WCDA has a positive impact on prediction performance as well.
- Through this study, we were able to confirm that **in WCDA, the ocean and air temperature, winds, and currents influence each other**. So we plan to study more deeply the impact of WCDA on the interaction between the atmosphere and ocean.
- We are continuing our experiments. So we will analyze results over a longer period and examine cases related to typhoons.
- In the future, we should consider **tuning the error covariances** and **optimizing KVAR and NEMOVAR** for the coupled model. These efforts are expected to lead to performance improvements.



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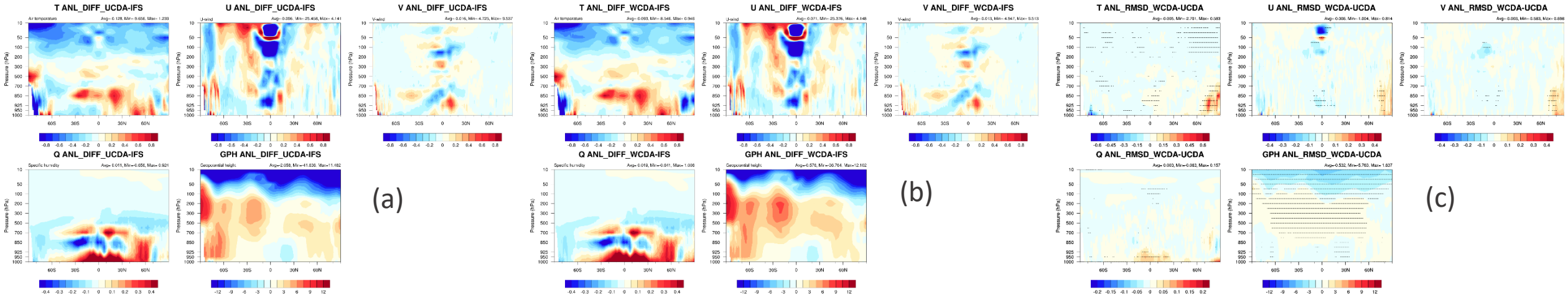
Atmosphere assessment (Analysis)

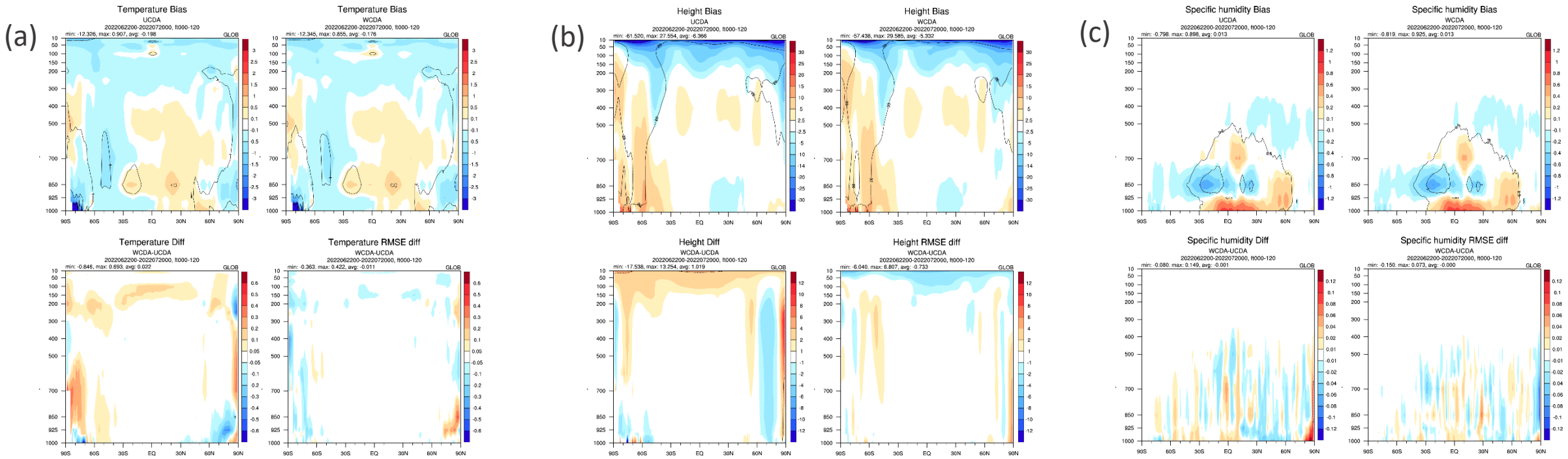
- WCDA shows a general decrease in the temperature bias compared to UCDA as lower atmospheric temperatures rise, but the bias increases in the lower Arctic region.
- WCDA shows an increase in water vapor in the lower atmosphere of the tropical region, resulting in a larger RMSE than UCDA. The GPH RMSE decreases in the lower and upper atmosphere but increases in the middle atmosphere.



Analysis difference in T, U, V, Q, and GPH between the KIM and IFS analysis. (a) UCDA, (b) WCDA, (c) WCDA-UCDA

Atmosphere assessment (Forecast)

- In WCDA, the temperature RMSE increases in the lower atmosphere over the Arctic region but decreases around Antarctica.



Zonal mean of forecast difference compared to IFS. (a) temperature, (b) height, (c) specific humidity