JOINT CP-TT AND DA-TT MEETING

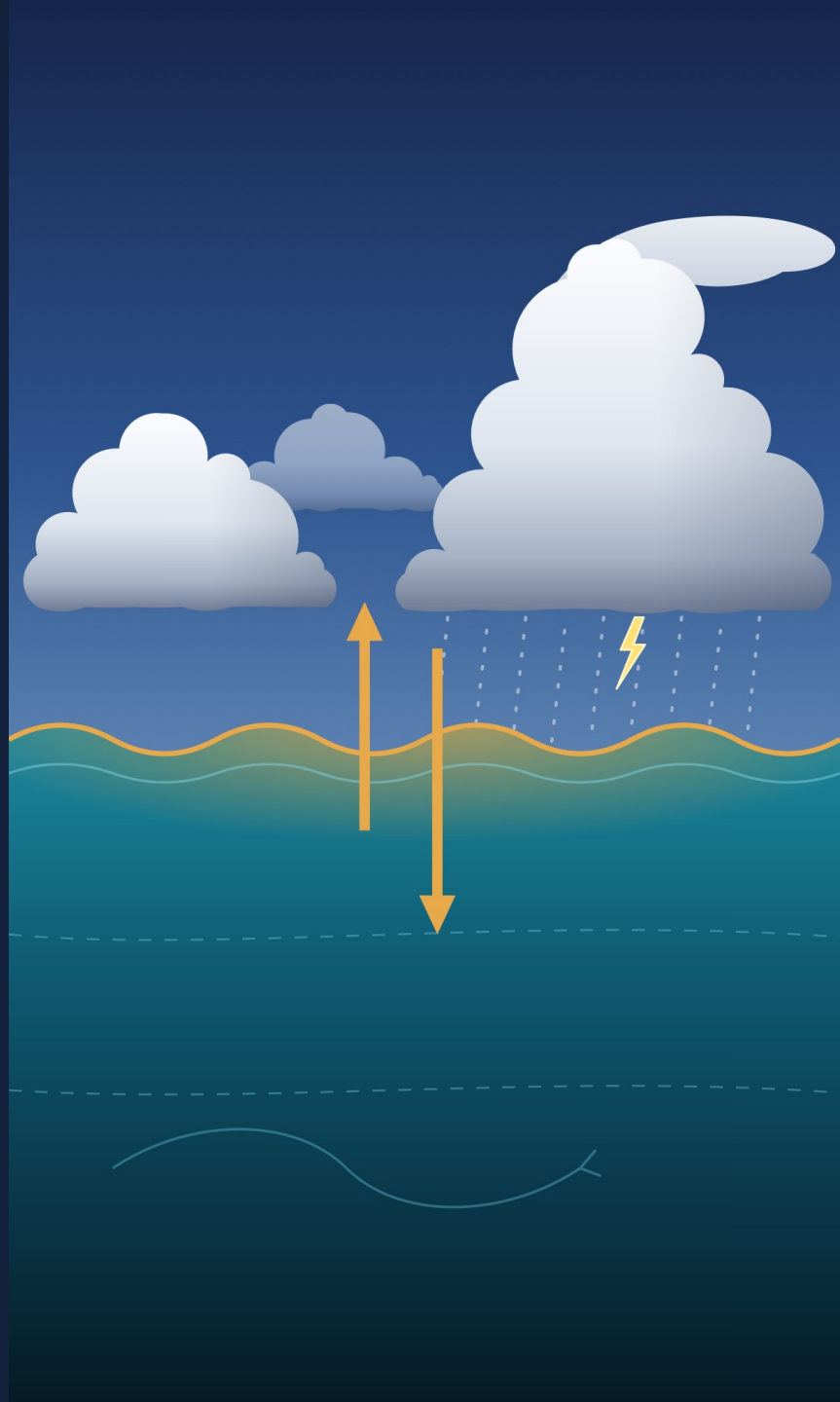
Coupled Ocean–Atmosphere Emulator

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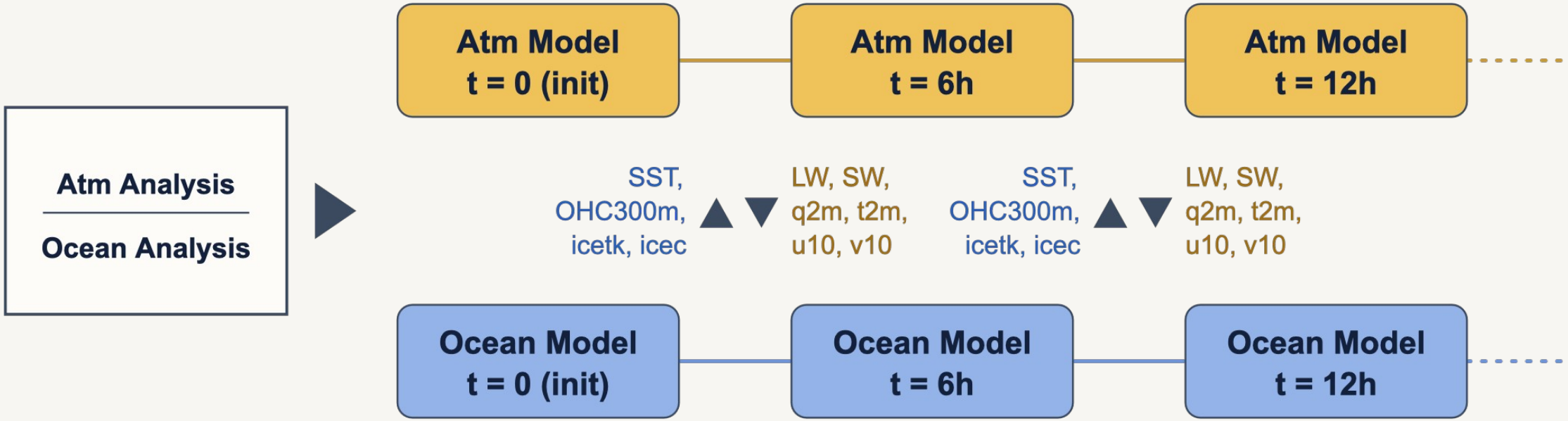


Coupling Mechanism

Coupled at the inference time using Anemoi's coupling interface

Atmosphere model 1°, 6-hour step

Ocean model 1°, 6-hour step (also have a 24 step model)



Atmospheric Emulator

Forcing

SST (Ocean), OHC300m
Ice thickness, Ice Concentration (Sea Ice)
Surface Geopotential Height
Cos Solar Zenith Angle | Cos/Sin Lat/Lon | Cos/Sin Day, Time
Land-Sea Mask

Prognostic

2D: tmp2m, spfh2m, pressfc, u10m, v10m
3D: tmp, spfh, u, v, dzdt @ 25 – 975 hPa

Diagnostic

Total Precip (6 hr), Top-of-atmosphere OLR, LW, SW
u @ 200, 850 hPa (on actual pressure levels)

Additional output for MJO diagnostics

Preprocessing / training

Regridding	Finite-volume vertical regridding using pressure thickness
Dataset	UFS-Replay
Data split	Training: 1994–2019 Testing: 2020–2021 Validation: 2022–2023
Resolution	1° spatial · 6 hour temporal
Framework	Anemoi
Model/Training Specifics	2 ICs No autoregressive training 232M trainable parameters 200,000 optimization steps Transformer processor Flash Attention Area-weighted MSE loss

Ocean Emulator

Forcing

u10m, v10m, spfh2m, tmp2m (Atmos)
Net LW/SW Radiation Fluxes into the Oceans
Cos Solar Zenith Angle | Cos/Sin Lat/Lon | Cos/Sin Day, Time
Land-Sea Mask

Prognostic

2D: SSH, Ice Concentration, Ice Thickness, Ice Temperature
3D: Temp, Salinity, U-V current velocities @ 0–500 m (7 levels)

Diagnostic

Mixed Layer Depth, Ocean Heat Content upto 300m (OHC300m)

Key ocean configuration for ocean model quality

Preprocessing / training

Regridding	Finite-volume vertical regridding using layer thickness
Dataset	UFS-Replay
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Four Coupling Setups

Analysis-based Coupling
Perfect foresight of the coupled variables.

Persisted Coupling
Persistence for all coupled variables.

Fully Coupled
Coupled variables get updated using emulator runs.

One-way Coupled
Atmosphere impacting Ocean, but Ocean not impacting Atmosphere (Ocean is persistence here).

Initial conditions (ICs): 2020-01-02 → 2023-08-29 (2020: 283, 2021: 256, 2022: 283, 2023: 192).

QC removed 28 ICs due to anomalous temperature increment in UFS-Replay on Jan 1, 2021, leaving 986 ICs per case.

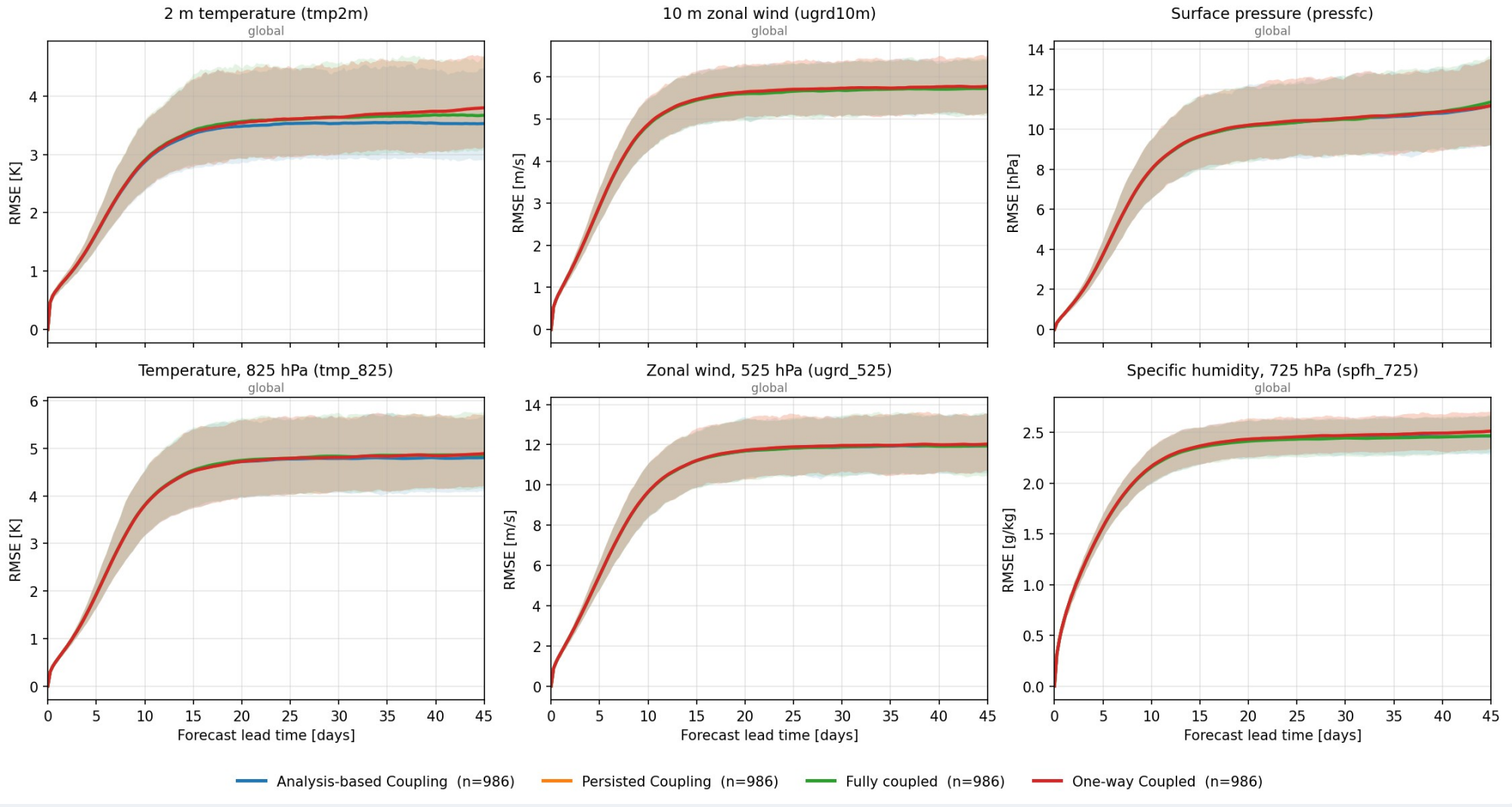
Forecasts: 45 days at 6-hourly time step

Reference Truth: UFS-Replay, testing (2020–21) and validation (2022–23).

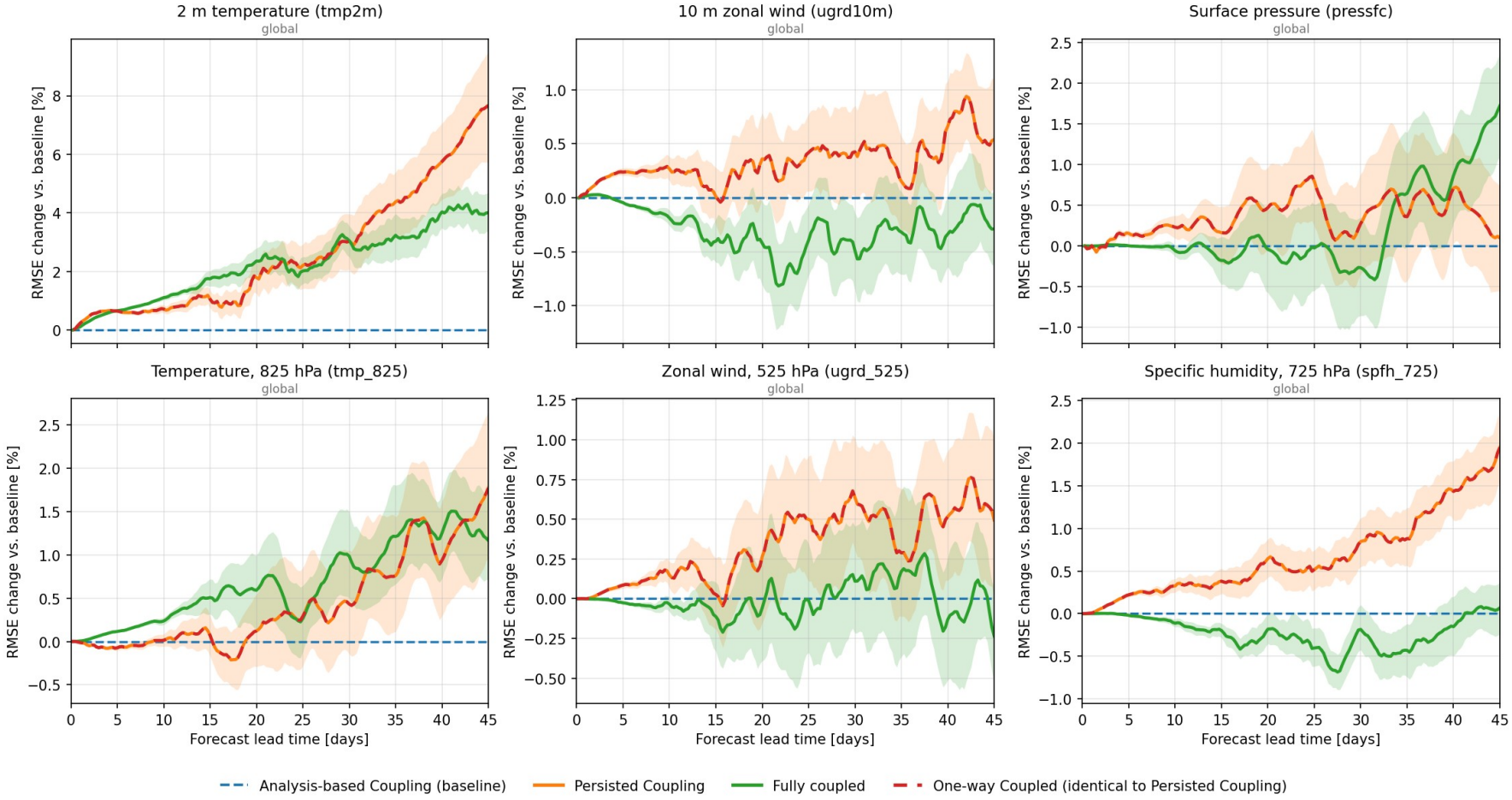
Metric: cos(lat)-weighted RMSE. Ocean fields over ocean cells only; sea ice over |lat| > 60°.

Note: For the atmosphere, **Persisted Coupling** and **One-way Coupled** are the same, because it sees persistence ocean in both cases.

RMSE-Atm: The errors look similar in all setups



Relative RMSE-Atm: A dynamic ocean impacts T2m the most

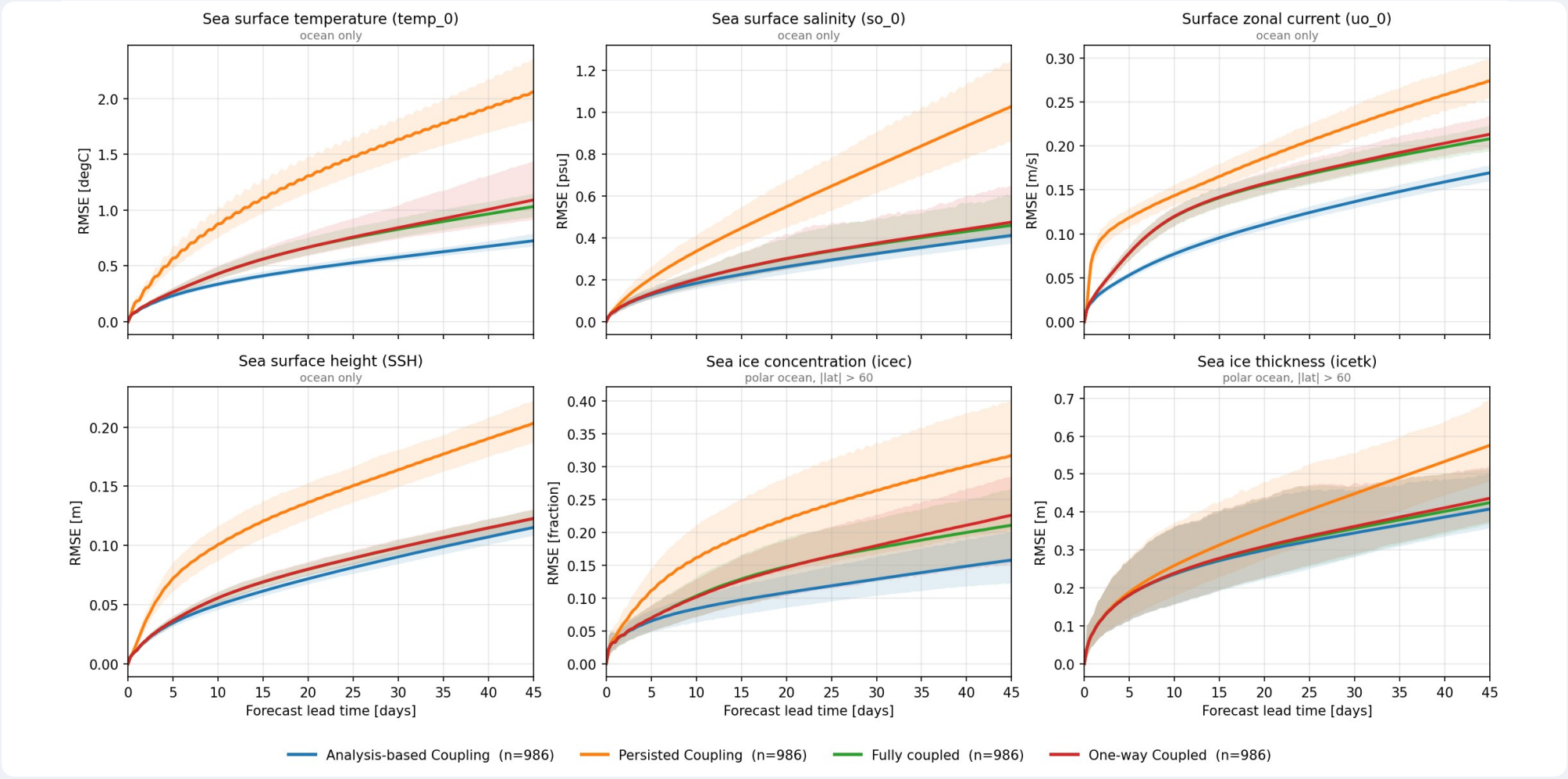


2 m temperature: Persisted and One-way +7.5% by day 45; Fully coupled +4%.

725 hPa humidity: Persisted and One-way up to +2%; Fully coupled slightly *better* than baseline over days 10–35.

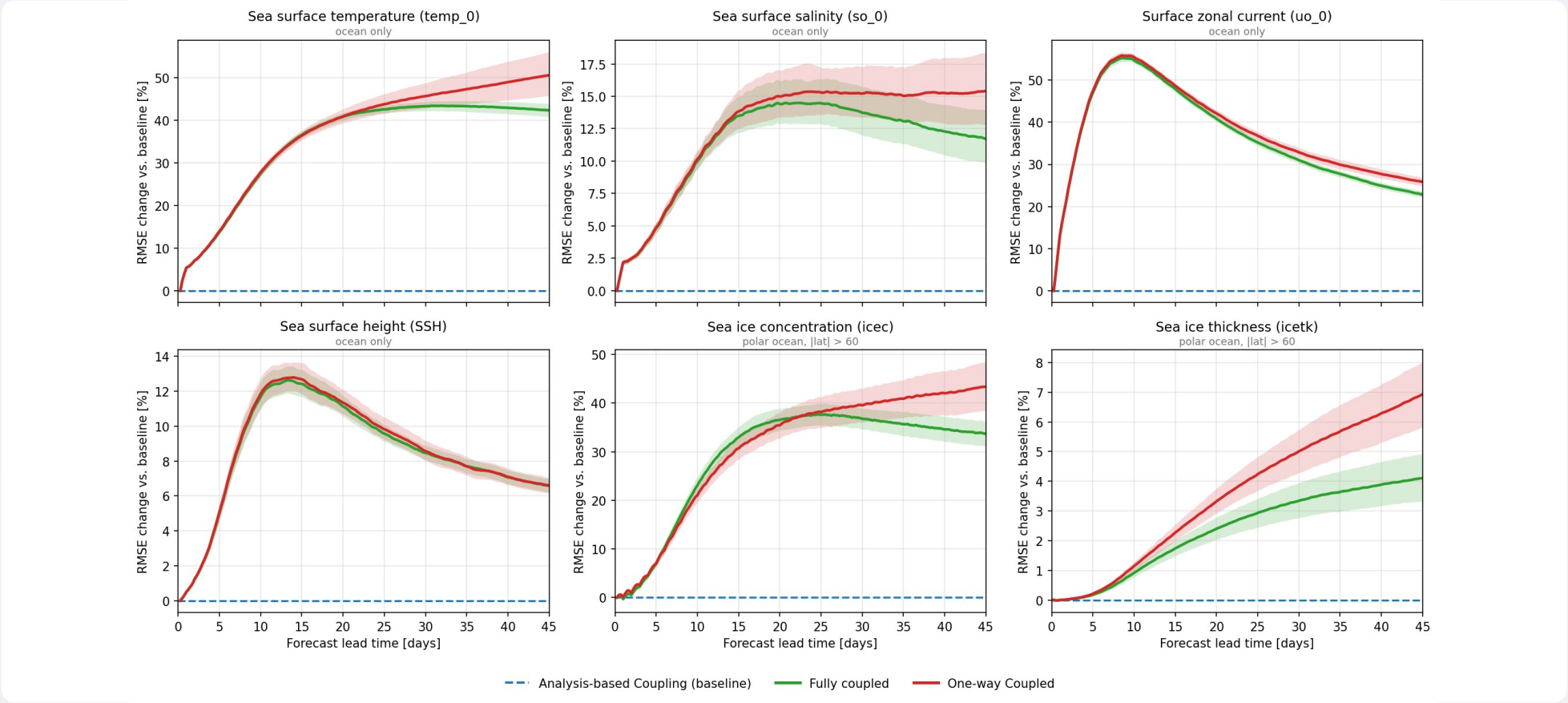
Winds, surface pressure: within ±1% mostly not significant.

RMSE-Ocn: Persisting the coupled Atm fields degrades every ocean variable



Note: These RMSEs are computed over ocean cells only (sea ice over the polar ocean, |lat| > 60°).

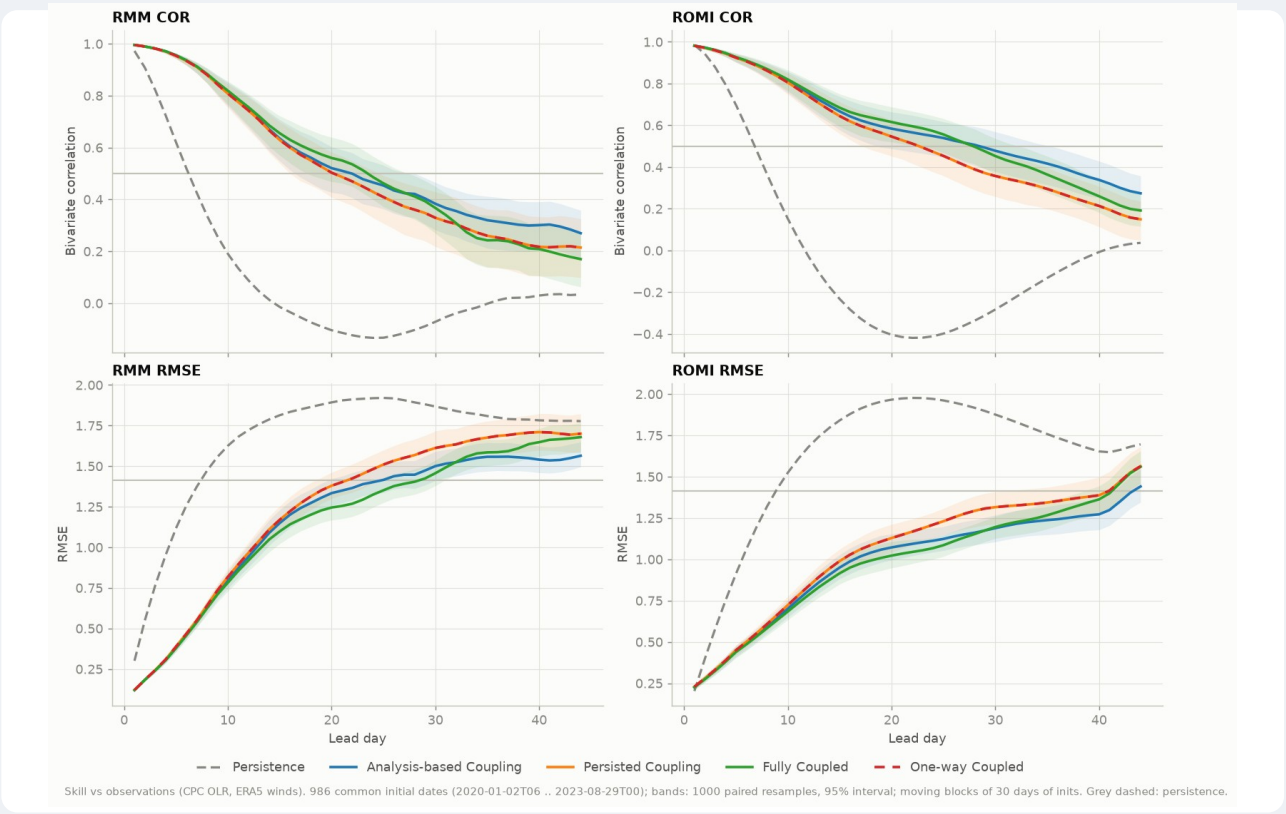
Relative RMSE-Ocn: Two-way coupling mostly pulls ahead after about three weeks



Both free-running setups trail the baseline.
Until ~day 20, Fully coupled ≈ One-way.

After 3 weeks, Fully coupled is better:
SST: +42% vs +50%, icec: +34% vs +43%,
icetk: +4% vs +7%.

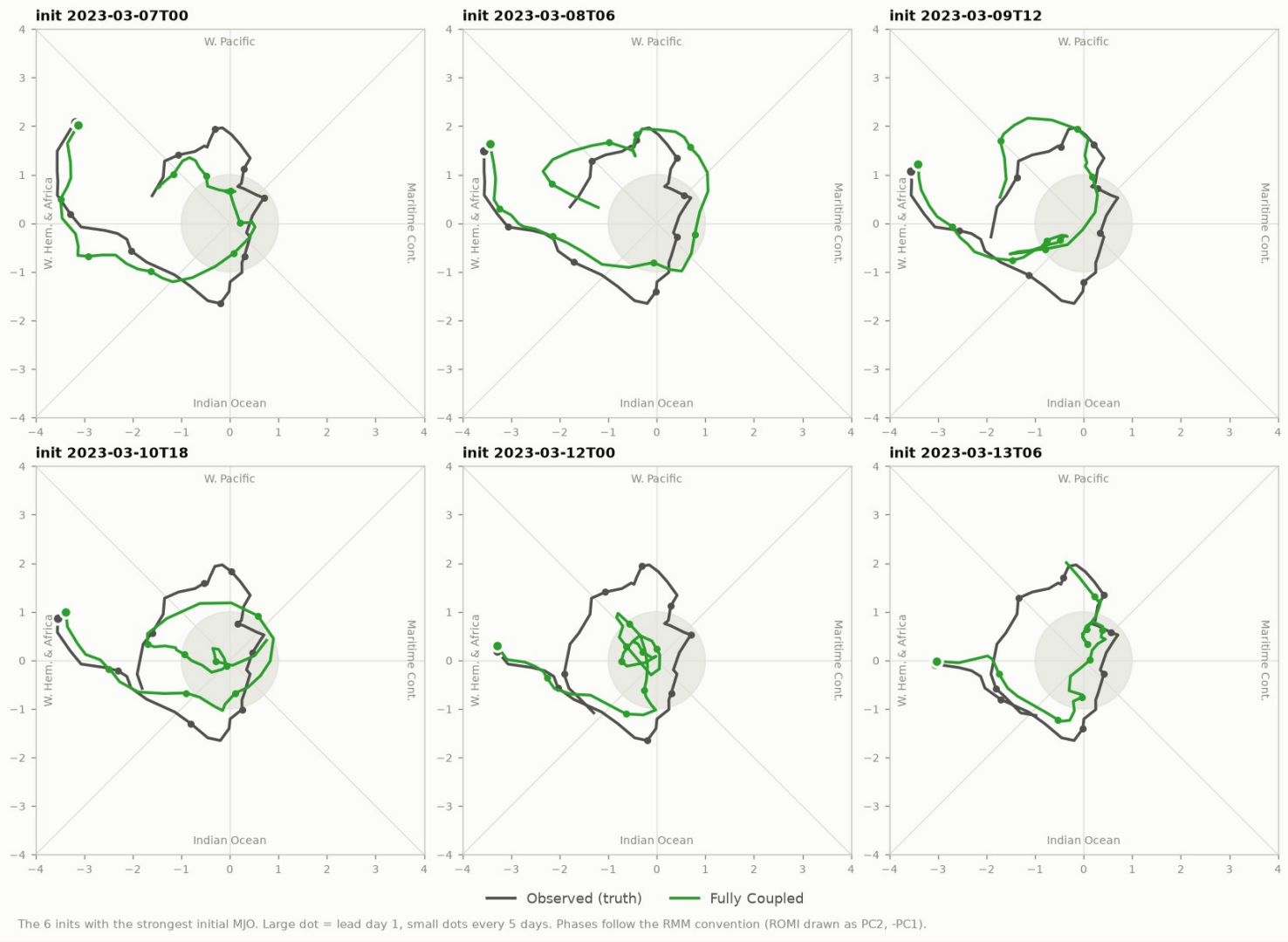
MJO Skill: RMM and ROMI Indices



Reference:
CPC OLR and ERA5 winds

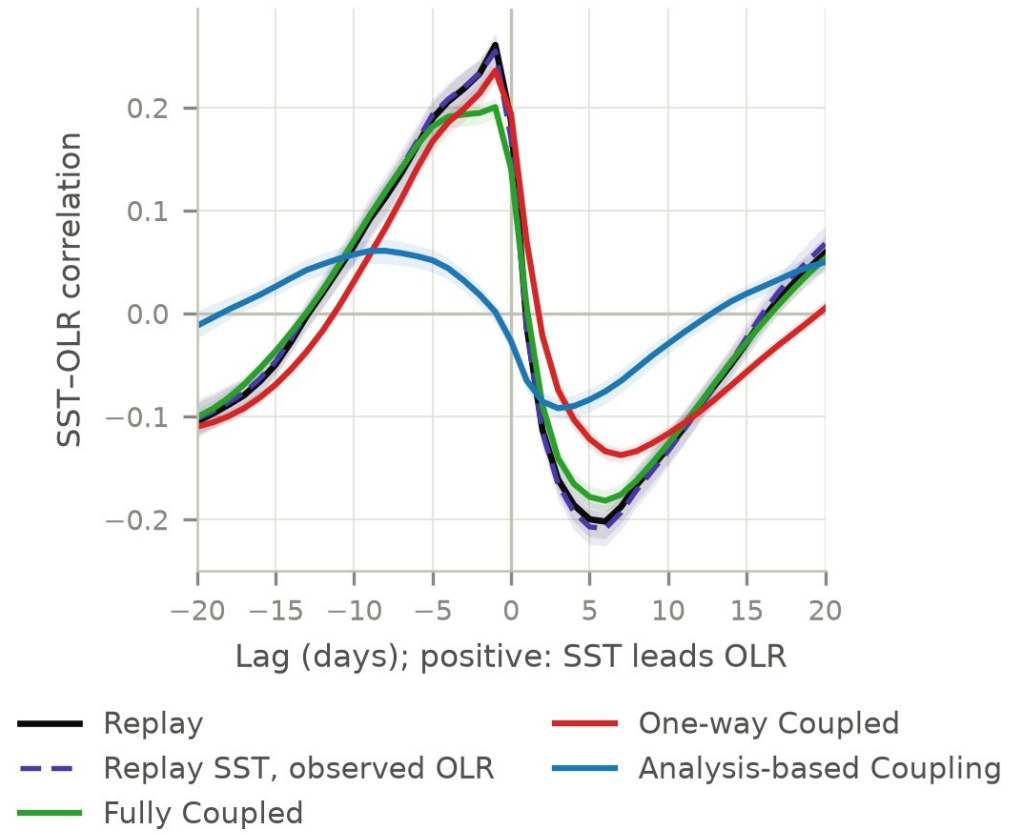
Lead day where COR crosses 0.5	RMM	ROMI	Bias-corrected RMM / ROMI
Analysis-forced	21.9 (17–28)	28.5 (19–35)	25.0 / 29.3
Two-way coupled	23.5 (18–27)	27.9 (23–32)	24.7 / 28.2
Persisted Coupling	20.2 (16–25)	22.6 (17–28)	22.7 / 23.8

Forecasts track the MJO, then drift



Grey = Observed, Blue = forecast, Large dot = lead day 1, Small dots = every 5 days, Anticlockwise = Eastward Propagation

Two-way coupling reproduces UFS-Replay's SST–Convection timing



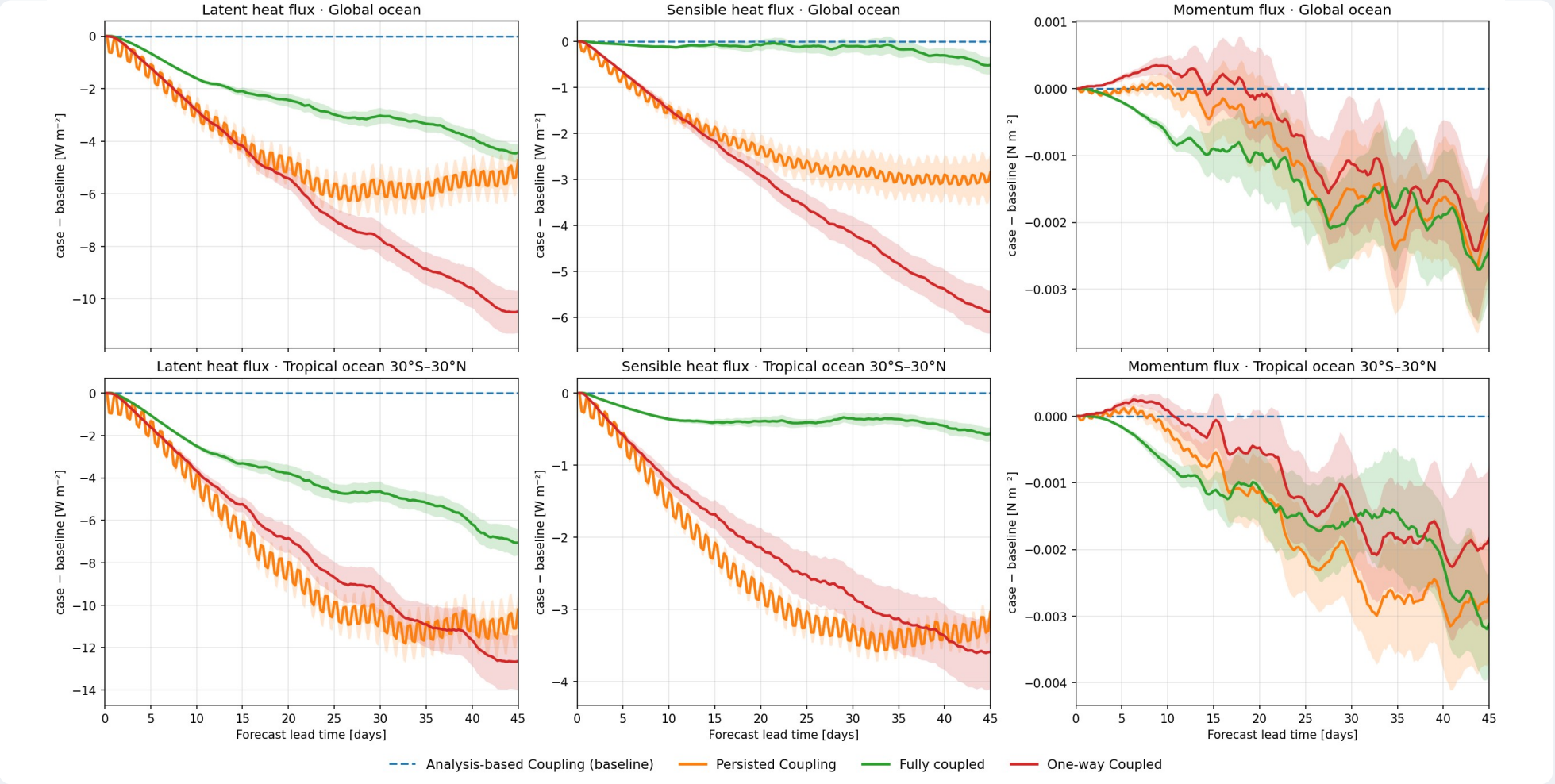
UFS-Replay and Observations: Warm SST leads convection by 5–6 days, and convection then cools the ocean.

Two-way is closest: RMS distance from the UFS-Replay curve 0.017 against 0.041 for one-way.

Analysis-forced loses it: True SST paired with an atmosphere whose MJO has drifted, as in atmosphere-only models.

Averaged over 10°S–10°N, 60°E–180°E, Detrended 44-day windows

Relative Heat Fluxes: Fully coupled stays closest to Analysis-based Coupling



Conclusions

Atmosphere

- Upper air metrics show little impact of coupling
- For near surface variables, coupling is beneficial after week 2 (gain of up to 7.5%).

Ocean and sea ice

- After ~3 weeks, two-way coupling beats one-way: SST +42% and icec +34%.

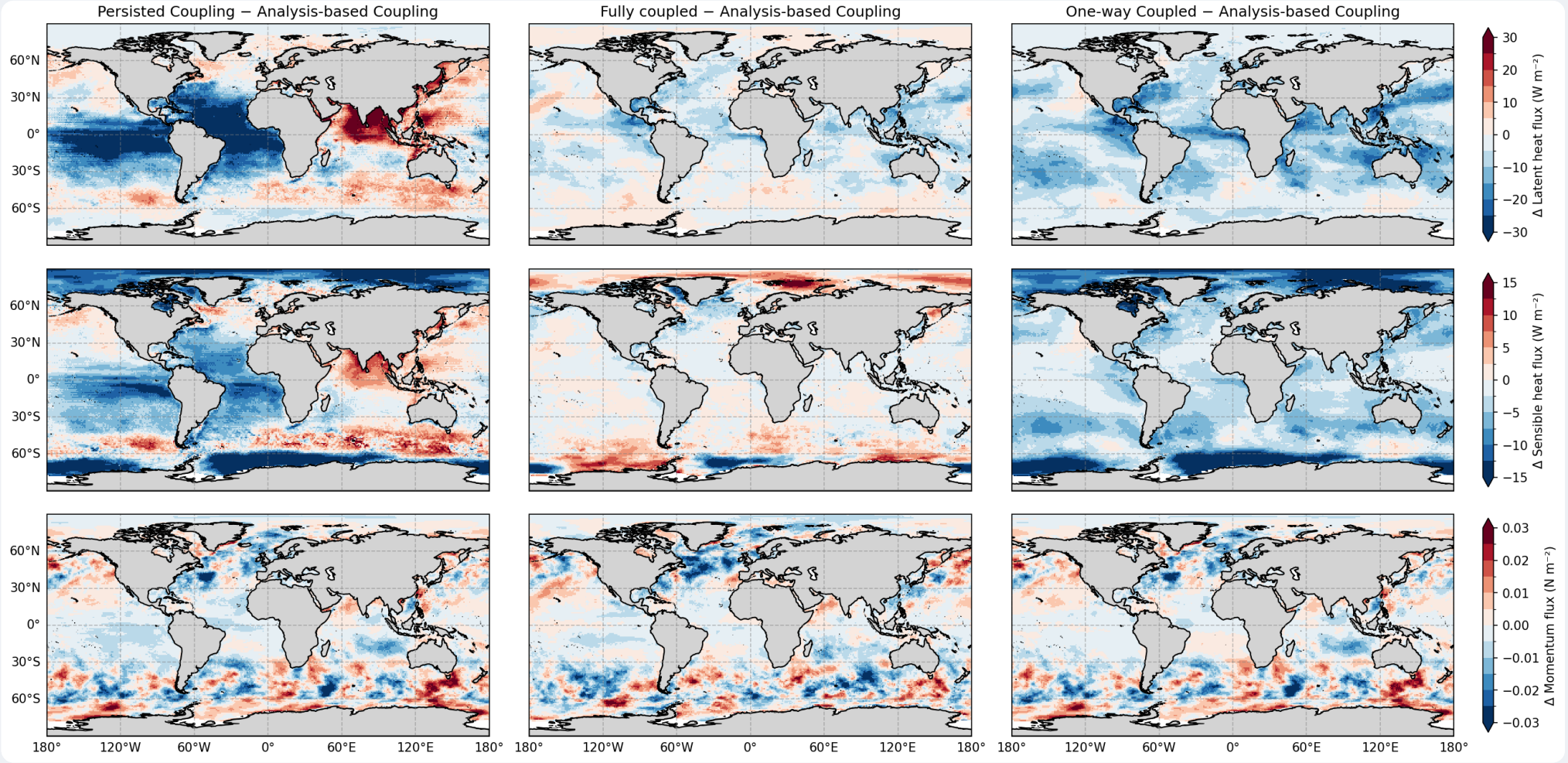
MJO

- Two-way coupling keeps useful skill (COR > 0.5) for 23.5 days (RMM) and 27.9 days (ROMI).
- This statistics is on par with Analysis-based Coupling and 3–5 days longer than Persistence Coupling.

Air–sea interaction and Fluxes

- Two-way coupling is essential to reproduce feedback between SST and deep convection timing.
- Coupling shows minimal impact on Momentum Fluxes.
- Two-way coupling improves representation of diagnosed surface fluxes.

Air-Sea Fluxes Map at Day 30



Mean over 986 inits, Red means more upward flux than baseline