

Towards strongly coupled ocean-sea ice-atmosphere data assimilation for GFS

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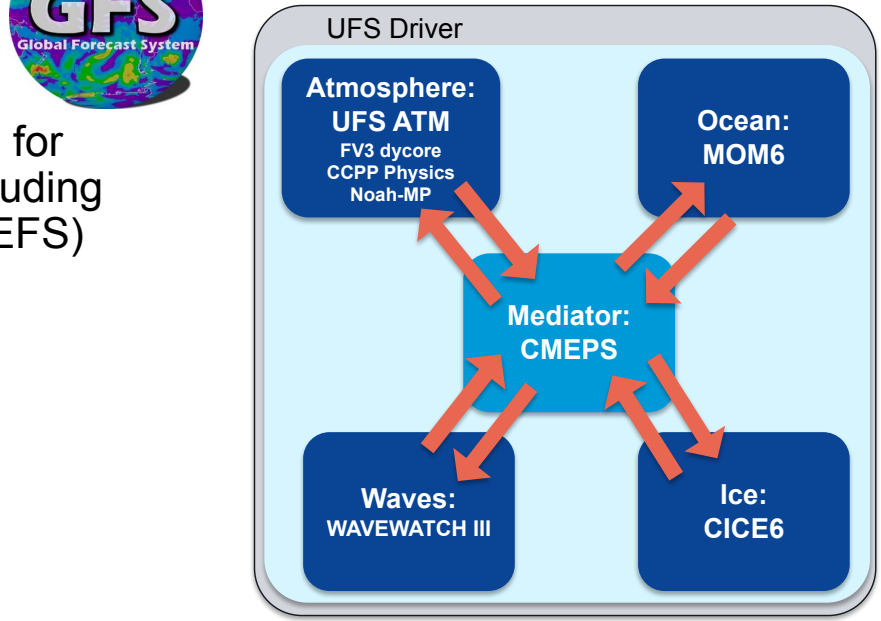
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National Oceanic and Atmospheric Administration
U.S. Department of Commerce

GFSv17: A Fully Coupled System

Global Forecasting System (GFS): NOAA's flagship global system

- Runs 4 times a day out to 16 days
- Provides initial and/or boundary conditions for multiple downstream forecast systems including the Global Ensemble Forecast System (GEFS)



GFSv17: introducing a fully coupled model

Deterministic:

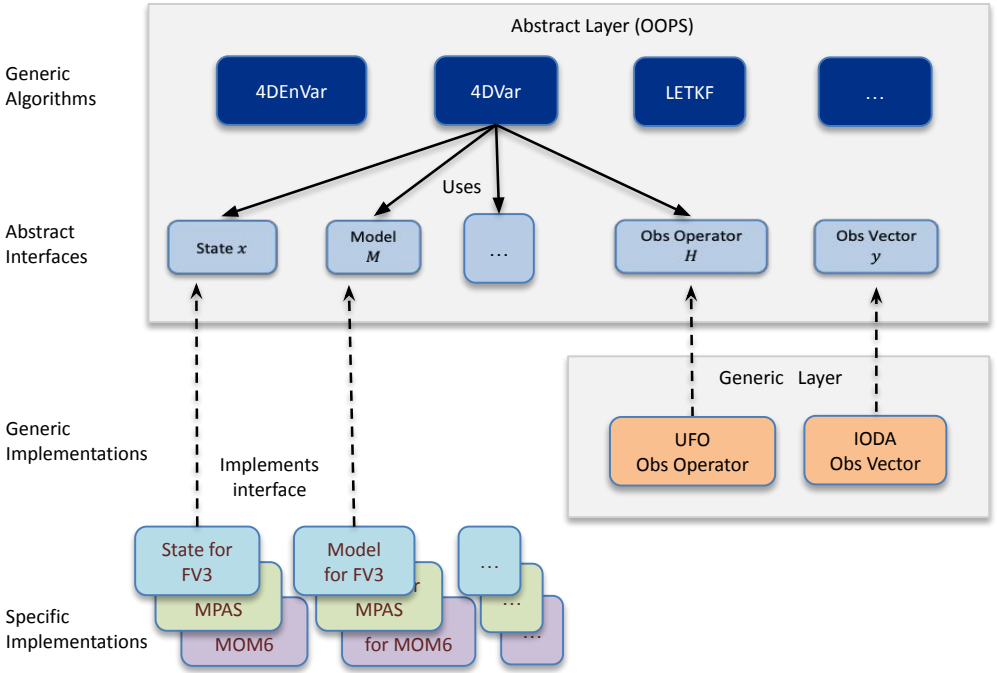
- Ocean: MOM6, 0.25 degree
- Sea Ice: CICE6, 0.25 degree
- Atmosphere: FV3, C1152 (~ 9km)

JEDI data assimilation framework

Joint Effort for Data assimilation Integration (JEDI): collaborative development of a unified DA system led by the Joint Center for Satellite Data Assimilation (JCSDA). Benefits from the close collaboration between JCSDA, NOAA, NASA, US Navy, Air Force, NCAR and UK MetOffice, as well as contributions from the community.

JEDI supports multiple algorithms, model interfaces and **coupled data assimilation** (generically for coupling model components already interfaced to JEDI).

NOAA is **transitioning GFS** (and other systems) **data assimilation to JEDI.**

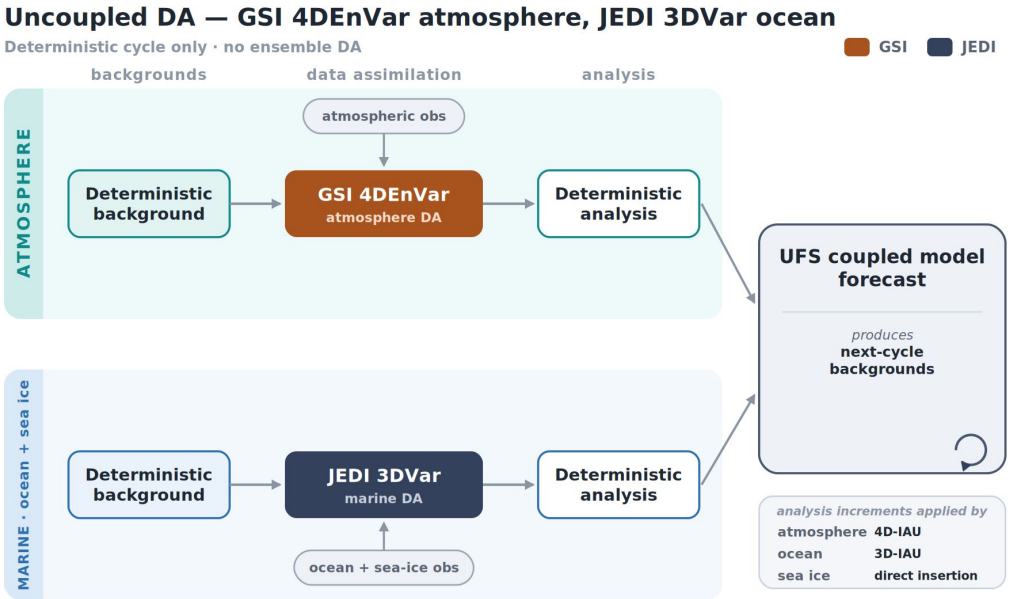


GFSv17: weakly coupled data assimilation

New marine data assimilation in GFSv17:

- JEDI-based 3DVAR-FGAT
- 6 hour DA window: following the cadence of the atmosphere for SST retrievals, drifters and sea-ice concentration
- 2 Days overlapping DA window: looking up to 2 days in the past for Argo profiles and altimeters

Work in progress on adding LETKF and upgrading 3DVar to hybrid EnVar.

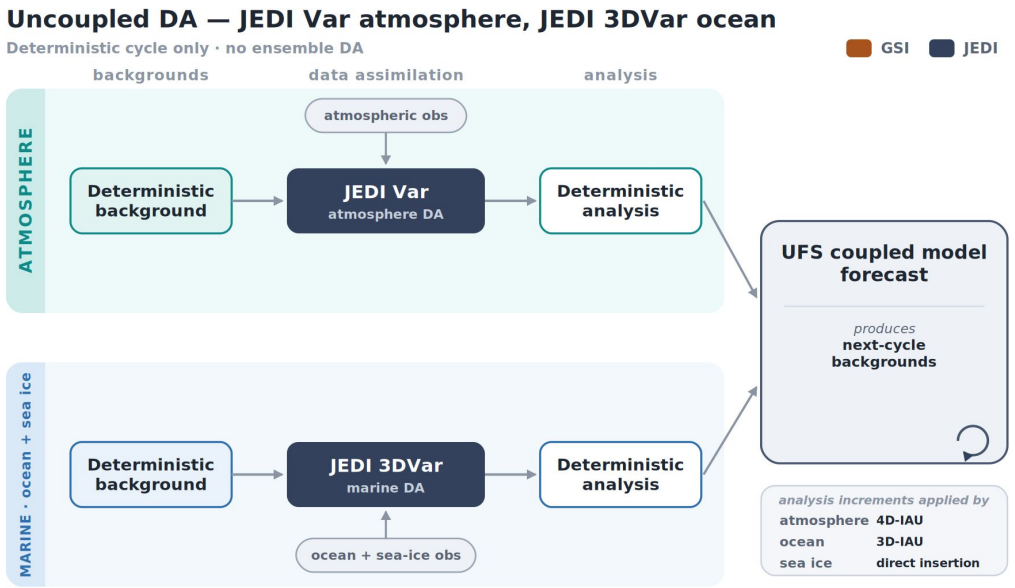


*A simplified version: ensemble DA and land DA are omitted

Atmospheric DA plans: transition to JEDI

Work in progress on **transitioning atmospheric data assimilation** from GSI **to JEDI**:

- Configurations with limited set of observations for 3DVar, hybrid 3DEnVar and hybrid 4DEnVar
- Work in progress on evaluating and adding more observation types

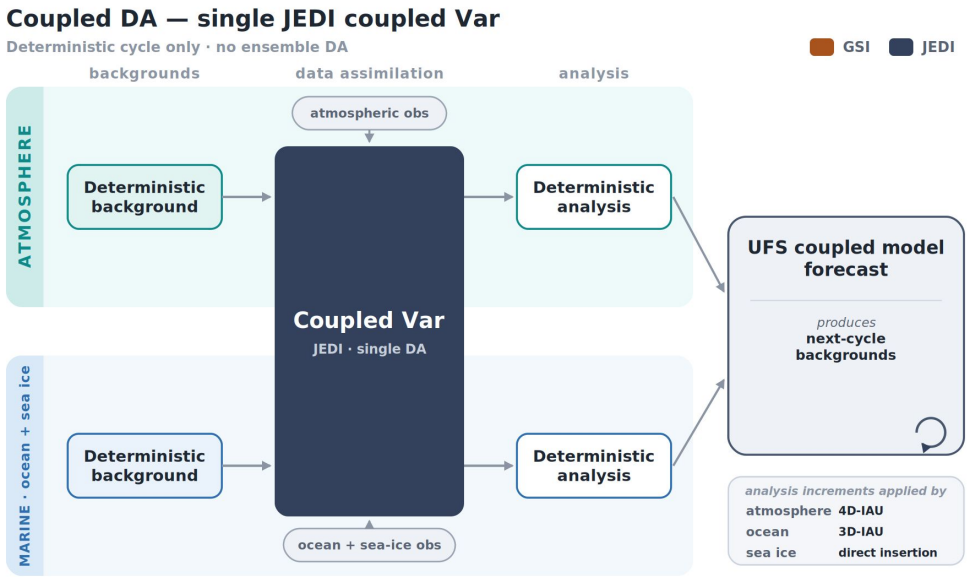


*A simplified version: ensemble DA and land DA are omitted

Coupled DA with GFS

Using JEDI framework for both atmospheric and ocean DA allows to move towards **strongly coupled data assimilation**. For Variational DA we are looking into coupling via:

- **Observation operator:** for direct radiance assimilation in the ocean.
- **Background error covariances:** coupled balance operator at the atmosphere/ocean interface.



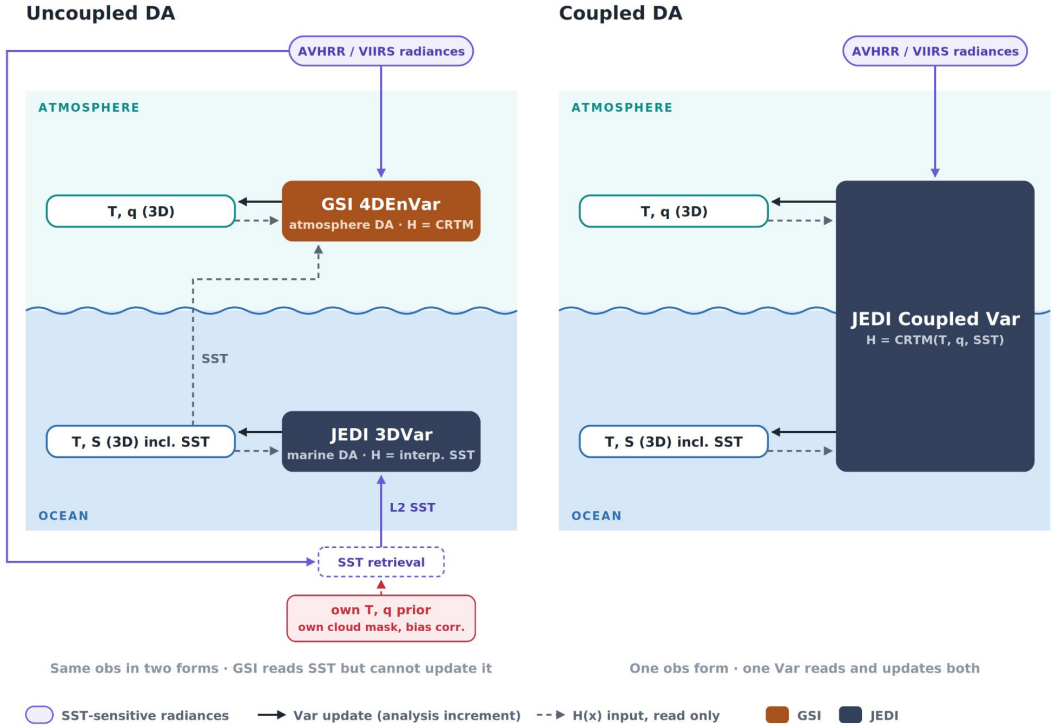
*A simplified version: ensemble DA and land DA are omitted

Coupled observation operator

Benefits of direct radiance assimilation: avoiding retrievals that use atmospheric priors that are inconsistent with GFS atmosphere may improve consistency between atmospheric and ocean updates.

Initial work on comparing AVHRR observation operator between the operational system and coupled JEDI run:

- Differences in H(x) pre-bias correction generally follow differences in SST
- Bias correction is significantly different: GFSv17 introduces better SST and AVHRR needs less bias correction than in the operations.

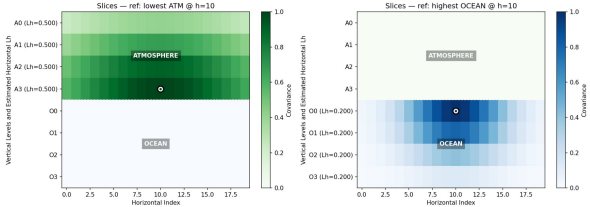


Coupled background error covariances: balance operator

Adding coupled balance operators around atmospheric and ocean background error covariances, introducing correlations at the interface between the components (similar to Garand et al, 2004 and Storto et al, 2018). Exploring using different forms of balance (lower-triangular, non-lower triangular, adding vertical balance)

Block-diagonal (uncoupled) B

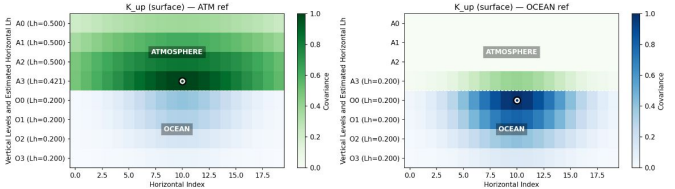
$$\mathbf{B} = \begin{pmatrix} B_a & 0 \\ 0 & B_o \end{pmatrix}$$



B with coupled balance (one way, at the surface)

$$\mathbf{B} = \mathbf{K} \begin{pmatrix} B'_a & 0 \\ 0 & B_o \end{pmatrix} \mathbf{K}^T$$

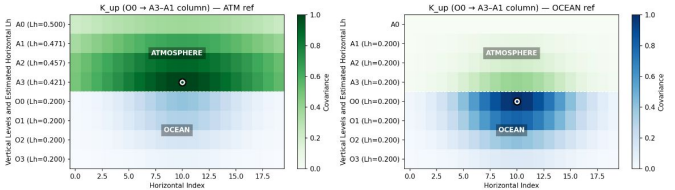
$$\mathbf{K} = \begin{pmatrix} I & K_{ao}\,\mathcal{I}_{o\to a} \\ 0 & I \end{pmatrix}$$



B with coupled balance (one way, adding vertical)

$$\mathbf{B} = \mathbf{K} \begin{pmatrix} B'_a & 0 \\ 0 & B_o \end{pmatrix} \mathbf{K}^T$$

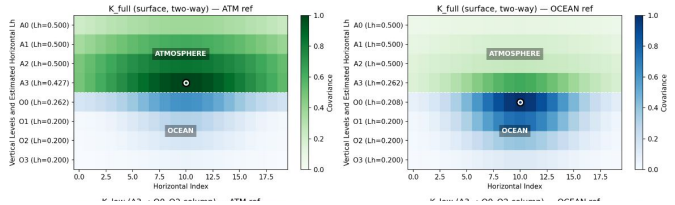
$$\mathbf{K} = \begin{pmatrix} I & K_{ao}\,\mathcal{I}_{o\to a} \\ 0 & I \end{pmatrix}$$



B with coupled balance (two ways)

$$\mathbf{B} = \mathbf{K} \begin{pmatrix} B'_a & 0 \\ 0 & B'_o \end{pmatrix} \mathbf{K}^T$$

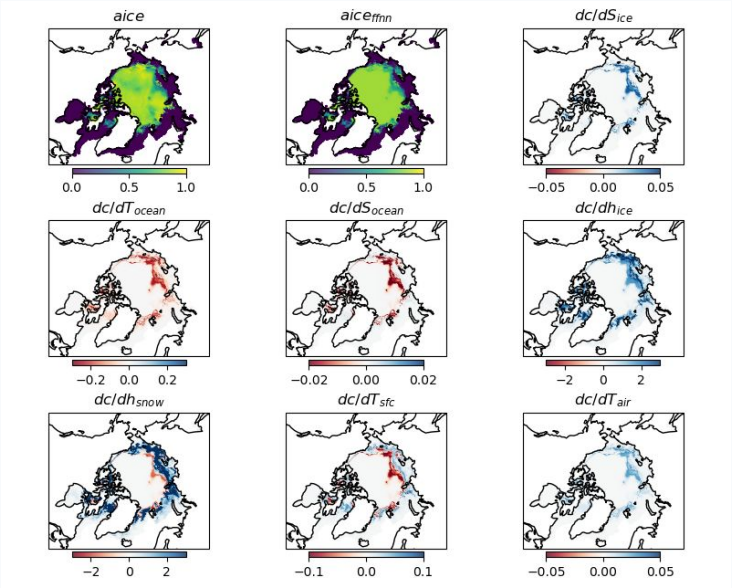
$$\mathbf{K} = \begin{pmatrix} I & K_{ao}\,\mathcal{I}_{o\to a} \\ K_{oa}\,\mathcal{I}_{a\to o} & I \end{pmatrix}$$



ML balance operator

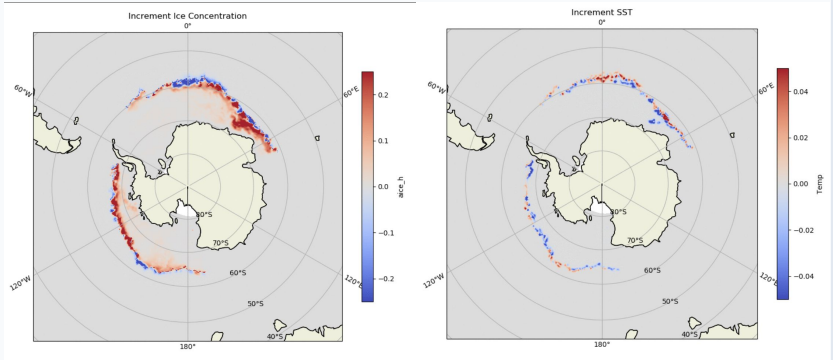
ML Balance: initial idea focussed on sea ice-ocean

Derived by linearizing a sea ice concentration emulator.



Analysis using ML balance

Assimilating only ice concentration.
Uses the Jacobian matrix to project increments onto SST.



Coupled ML balance in ocean-atmosphere: first results

Observations:

Marine: SST retrievals, ADT, argo, surface drifters, ice concentration retrievals

Atmosphere: surface pressure from stations, ships, buoys, ATMS NOAA 20

Background error covariances:

Marine: as in GFSv17, static with flow-dependent standard deviations

Atmosphere: GSI static covariances

Coupled balance: first training of ML balance (one-way, on a single date of a background), adding vertical correlation estimated from an ensemble

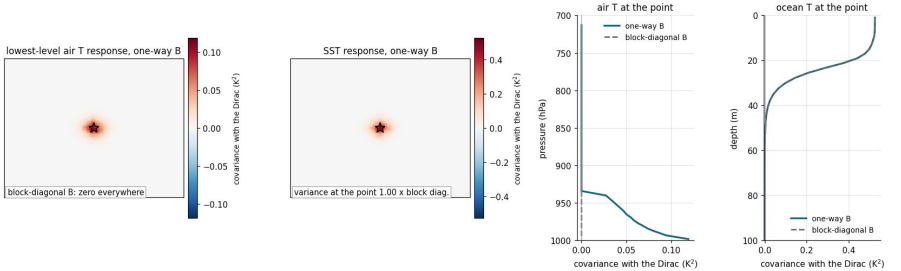
Resolution:

Marine: 0.25 degree

Atmosphere: C384 (~25 km)

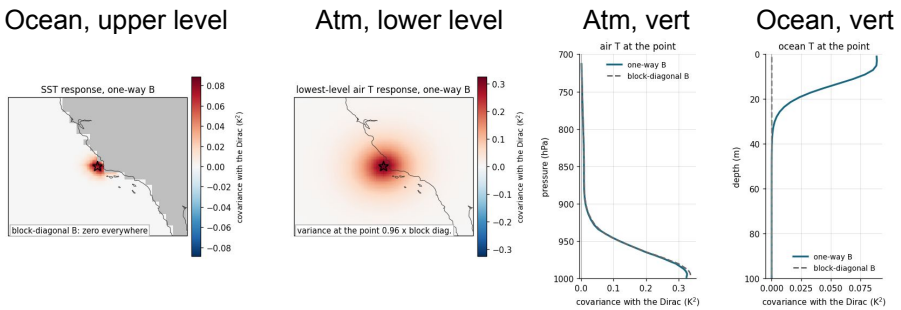
Single observation in the ocean (1st level, North Pacific)

Ocean, upper level | Atm, lower level | Atm, vert | Ocean, vert



Single observation in the atmosphere (1st level, CA coast)

Ocean, upper level | Atm, lower level | Atm, vert | Ocean, vert



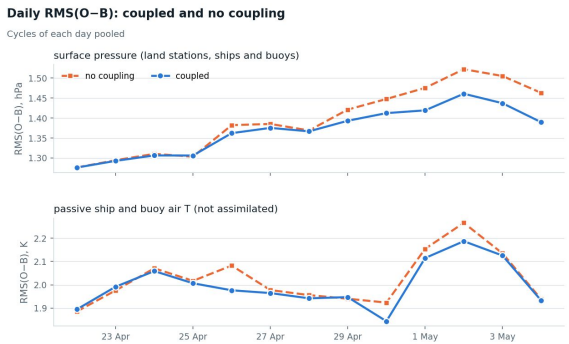
Disclaimer: very first and preliminary results, interpret with caution!

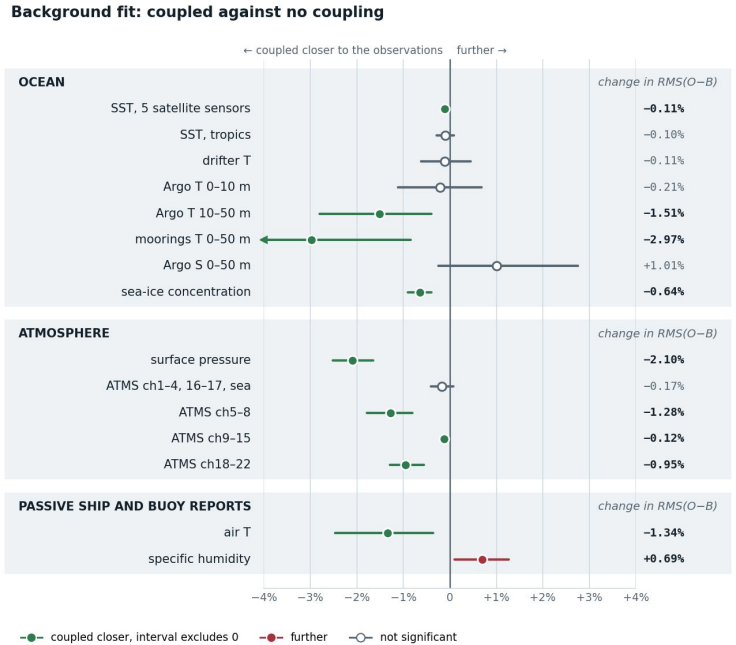
Coupled ML balance in ocean-atmosphere: first results

10 day cycling experiments, 22 April-4 May 2026

3DVar with coupled balance vs 3DVar with uncoupled covariances (both use a single Var to update atmosphere and ocean).

Small improvement in: surface pressure, passive ship and buoy temperature o-b; small degradation in passive ship and buoy specific humidity o-b.



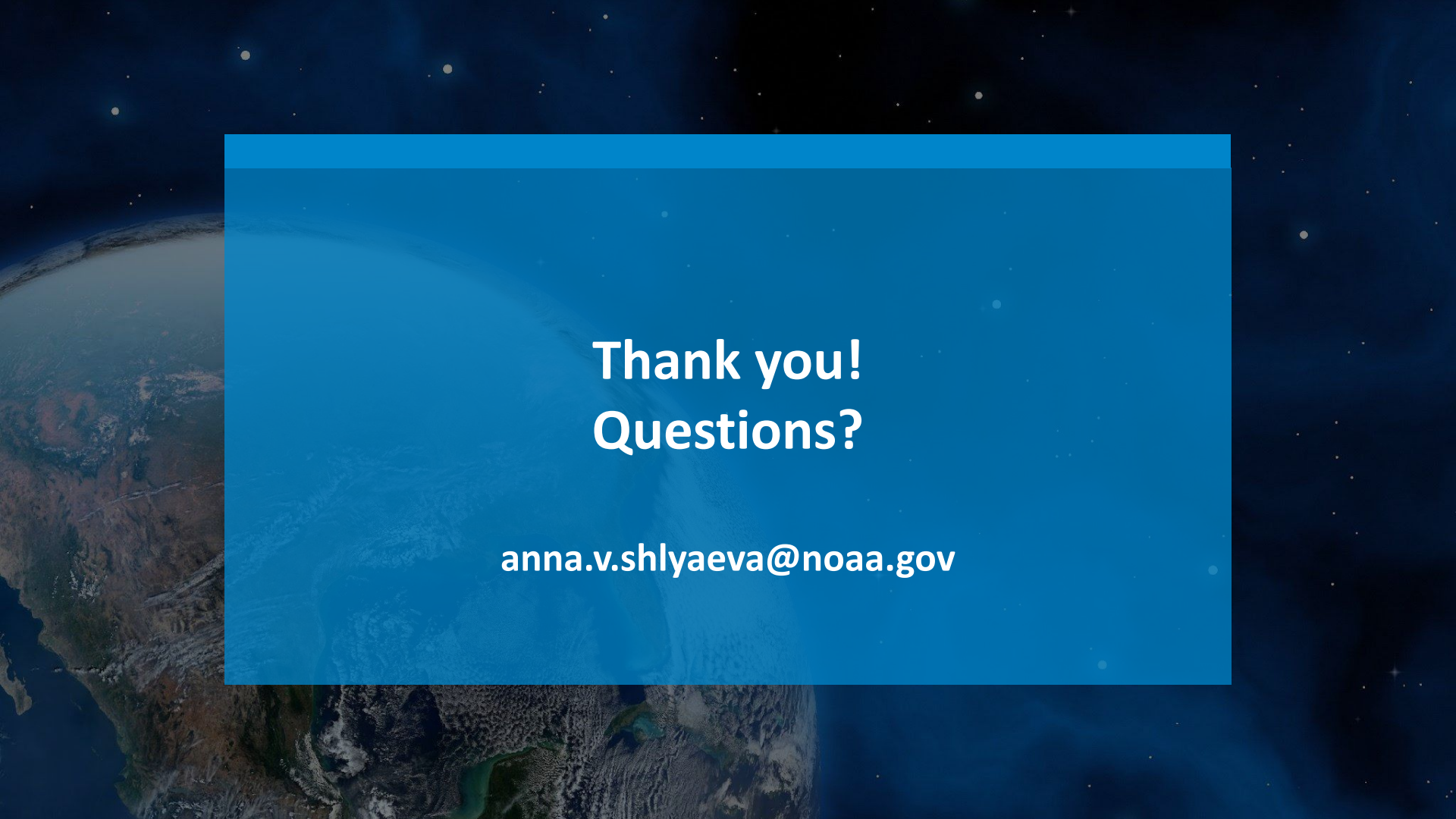


Disclaimer: very first and preliminary results, interpret with caution!

Summary and next steps

Transition to JEDI allows us to start experimenting with strongly coupled data assimilation in the context of GFS:

- Starting to work on directly assimilating AVHRR and VIIRS radiances simultaneously in atmosphere and ocean (instead of assimilating SST retrievals in the ocean)
- Experimenting with coupled covariances:
    - Coupled balance next steps: experimenting with the balance estimates (from differentiating ML emulator, or from the ensembles), experimenting with different balance structures (e.g. one-way, vertical)
    - Next steps: look into coupled ensemble covariances


Thank you!
Questions?
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