Is interface solver a way forward for complex coupled systems?

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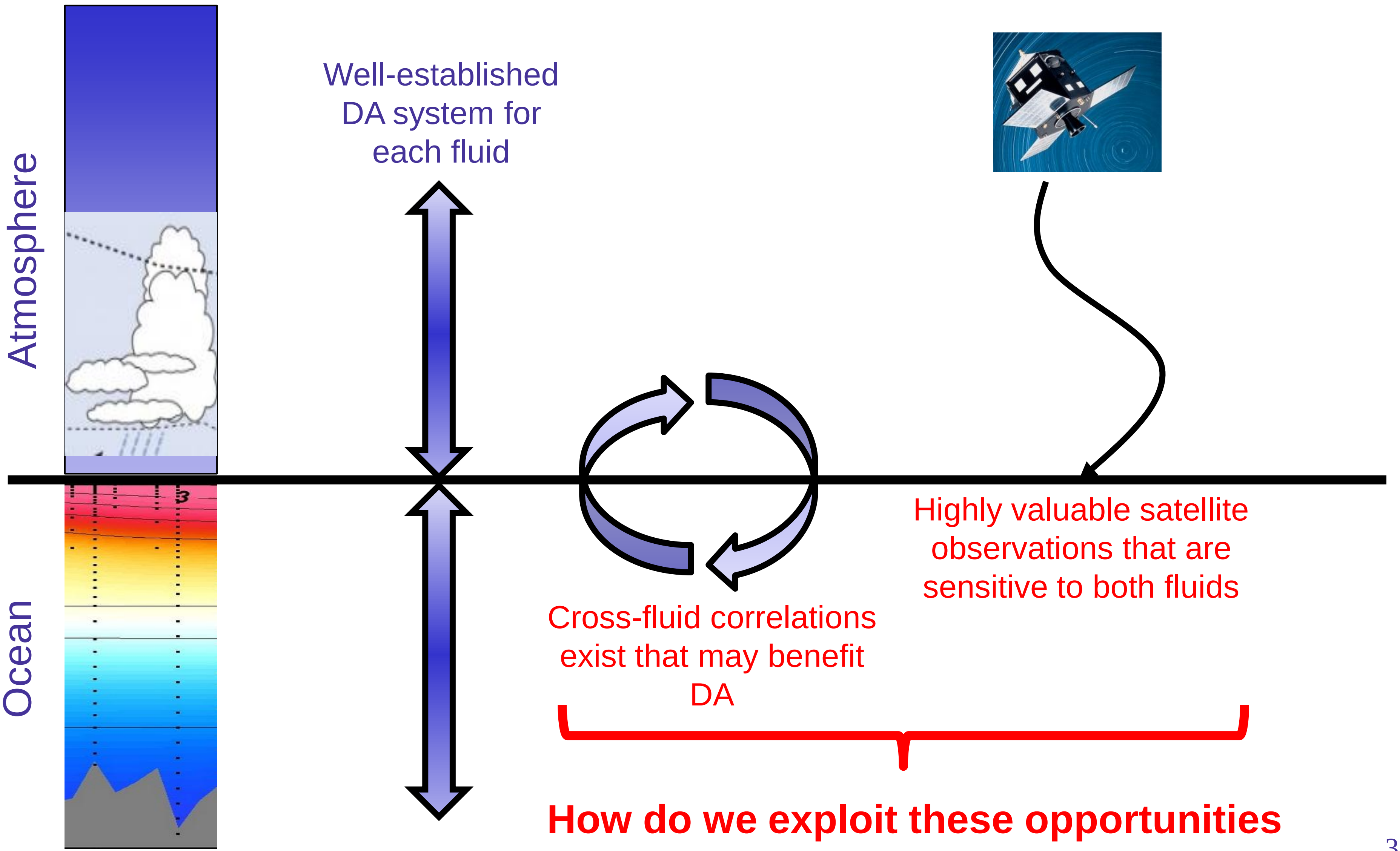
With help from:
Craig Bishop; Clark Rowley; Charlie Barron; Ben Ruston; Doug Allan
and many others at NRL

Coupled DA workshop, France, 2016

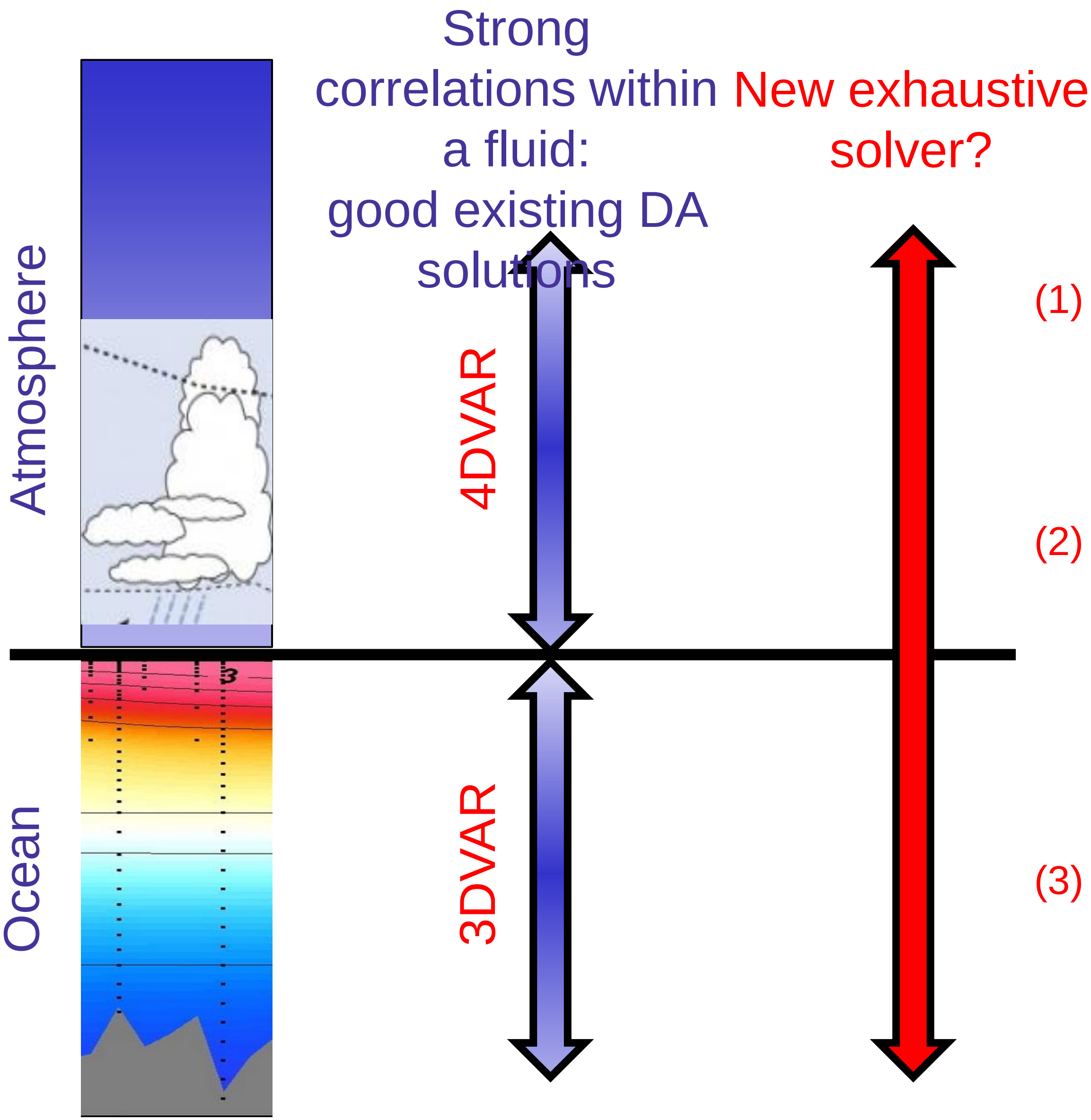
Managing complexity is a key challenge for CDA

- **Interface solver** (this talk) allows to contain scientific and organizational complexity
- **LETLM** (talk later today) allows to contain software development and maintenance costs.
- **Standardized software libraries and tools** (something we should be talking about) is what makes execution of these complex suits possible.

The coupled DA opportunity



Challenge of the coupled DA



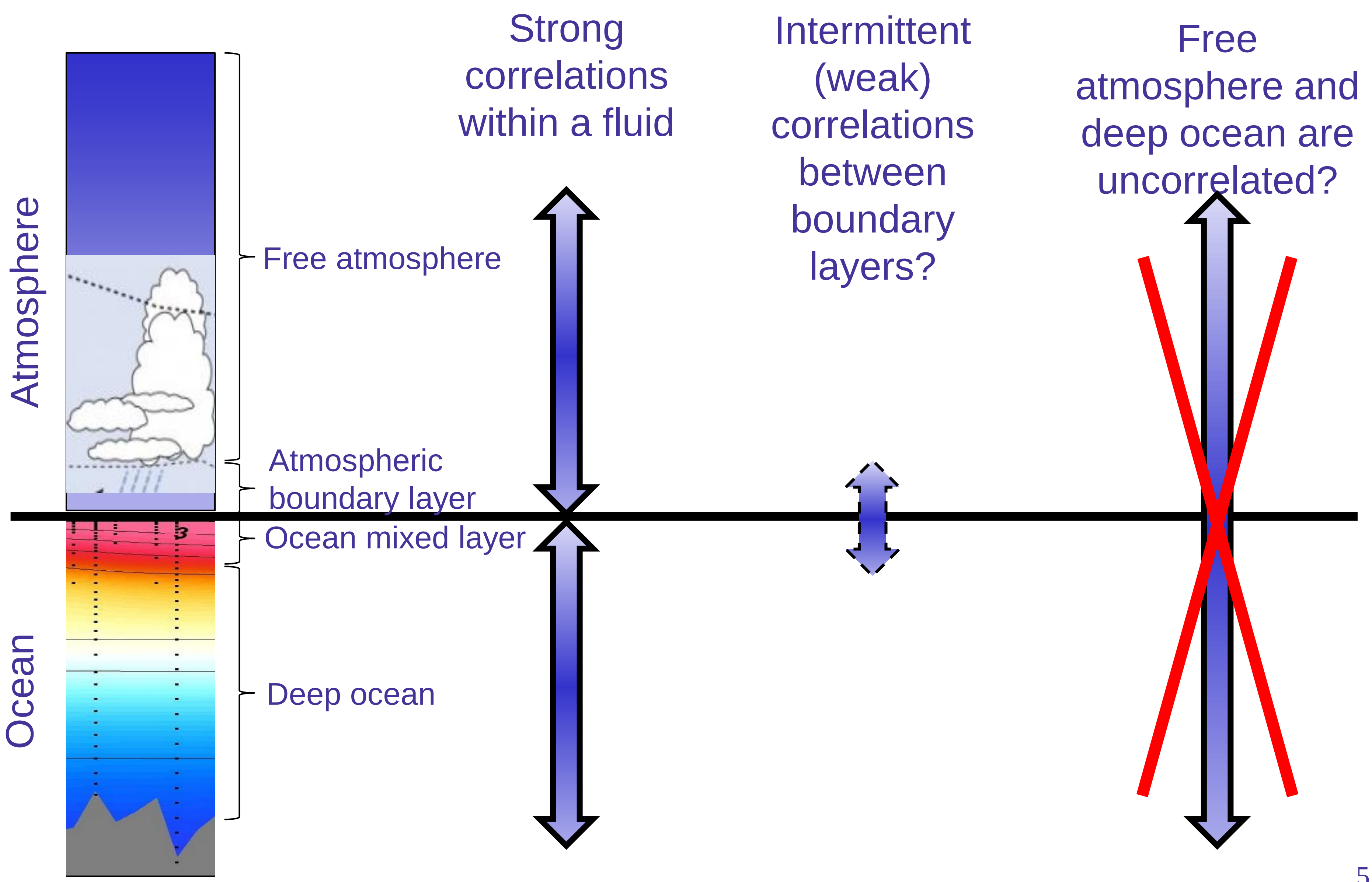
Difficult

(1) Programmatic challenge: In an operational center, complete replacement of existing system is very risky and expensive.

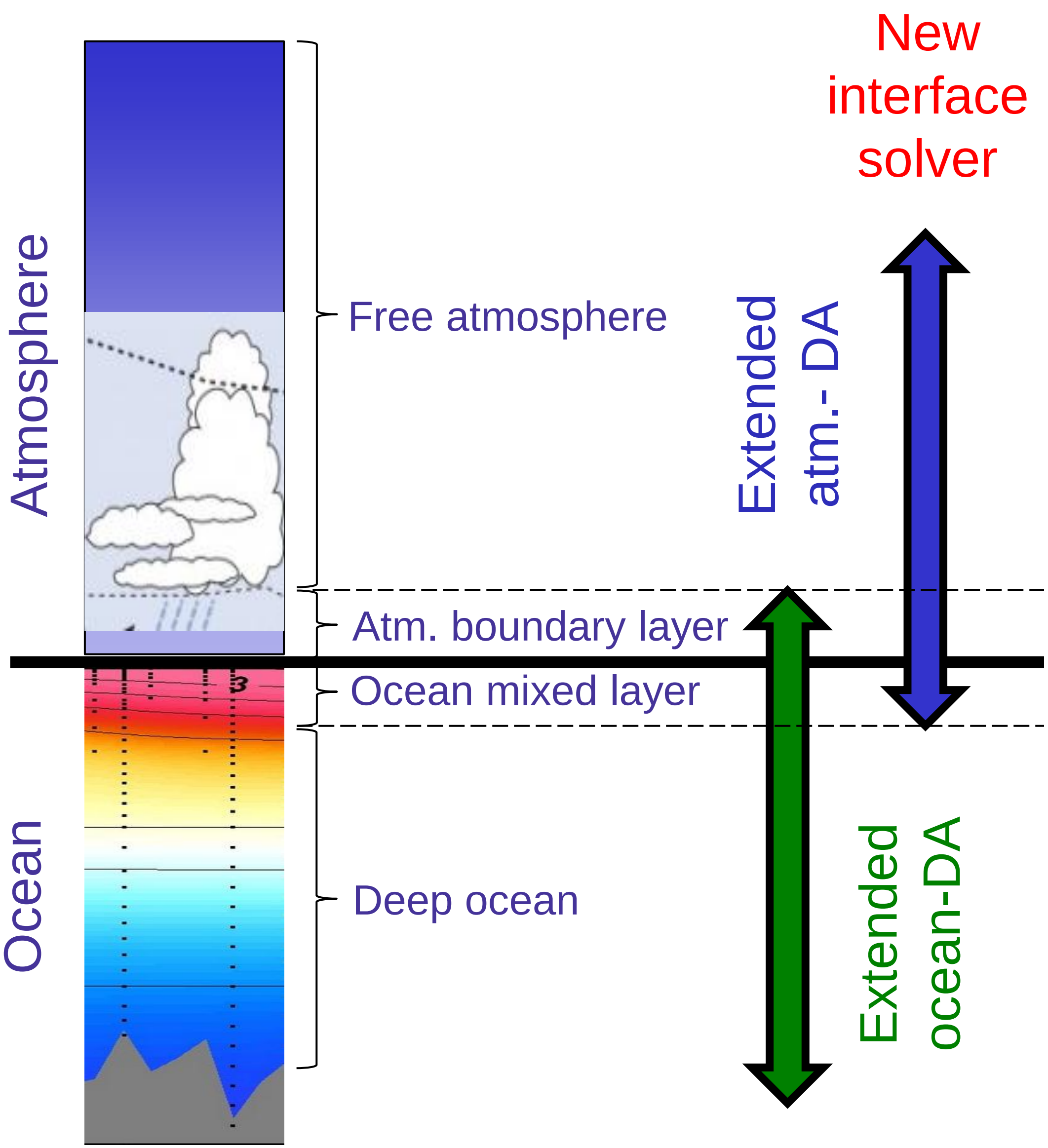
(2) Community challenge: DA in each mediums are still evolving rapidly and it is essential that each community retains freedom to experiment with different DA methods

(3) Algorithmic challenge: Coupled DA presents serious questions for either ensemble and variational frameworks.

Interface solver: Does it have to be so difficult?



Does it have to be so difficult?
New idea: Interface solver



Tractable

Interface solver implementation:

(1) Specifies "missing" coupled covariances using ensemble covariances

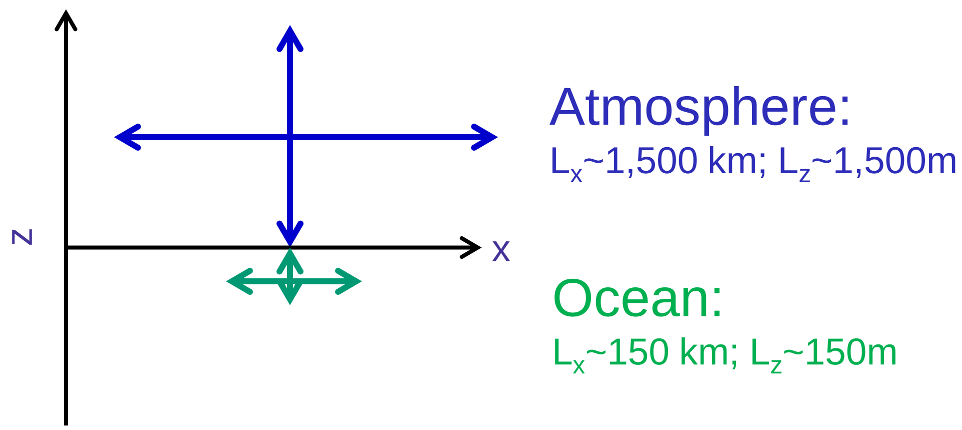
(2) Requires very **little** modification to existing software and scripts

(3) Can use different DA schemes (e.g. 4DVAR in atm. and 3DVAR in ocean)

Outline

- Motivation
- **Localization for coupled ensemble covariance**
- Results in a mesoscale system
- Progress to-date on the global Navy model.

Localization of coupled ensemble covariances



Challenge:

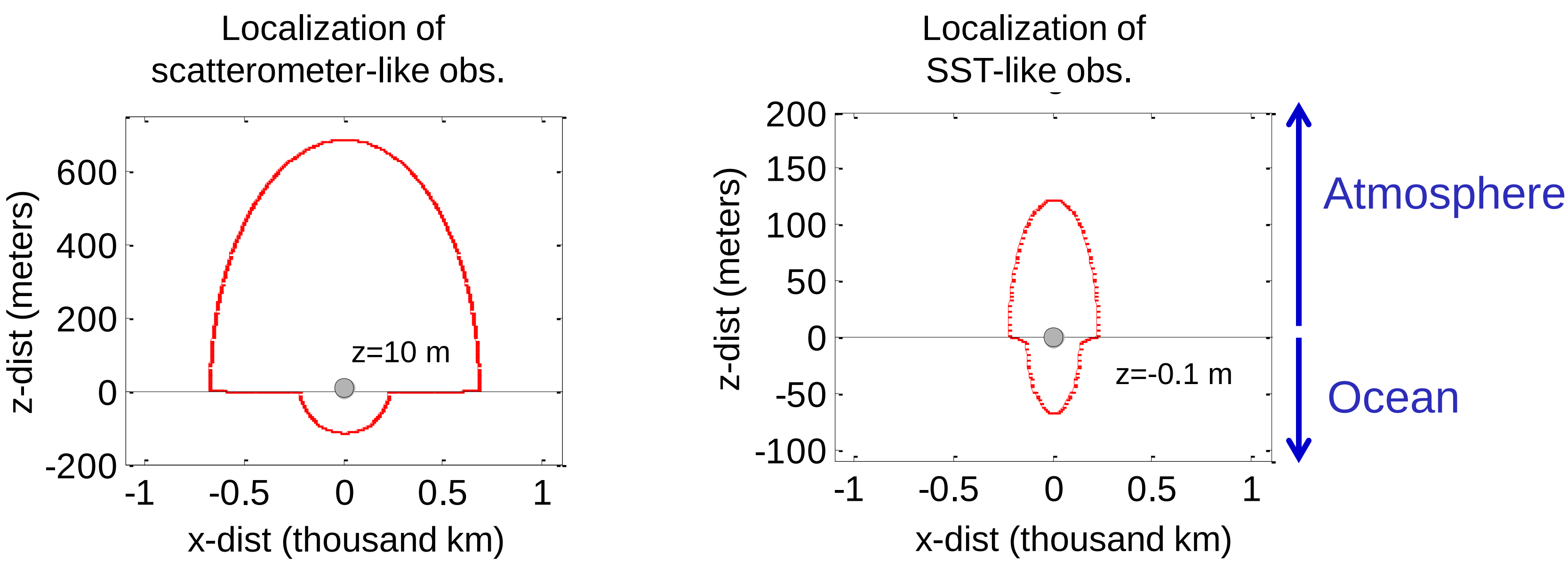
- Correlation scales wary wildly between ocean and atmosphere

Solution:

- Modify the Gaspari-Cohn distance function

$$dist(obs_{atm} - obs_{oce}) = \sqrt{\left(\frac{x_A - x_O}{0.5\cdot(L_{x|A} + L_{x|O})}\right)^2 + \left(\frac{y_A - y_O}{0.5\cdot(L_{y|A} + L_{y|O})}\right)^2 + \ldots + \left(\frac{z_A}{L_{z|A}} - \frac{z_O}{L_{z|O}}\right)^2 + \left(\frac{t_A - t_O}{0.5\cdot(L_{t|A} + L_{t|O})}\right)^2}$$

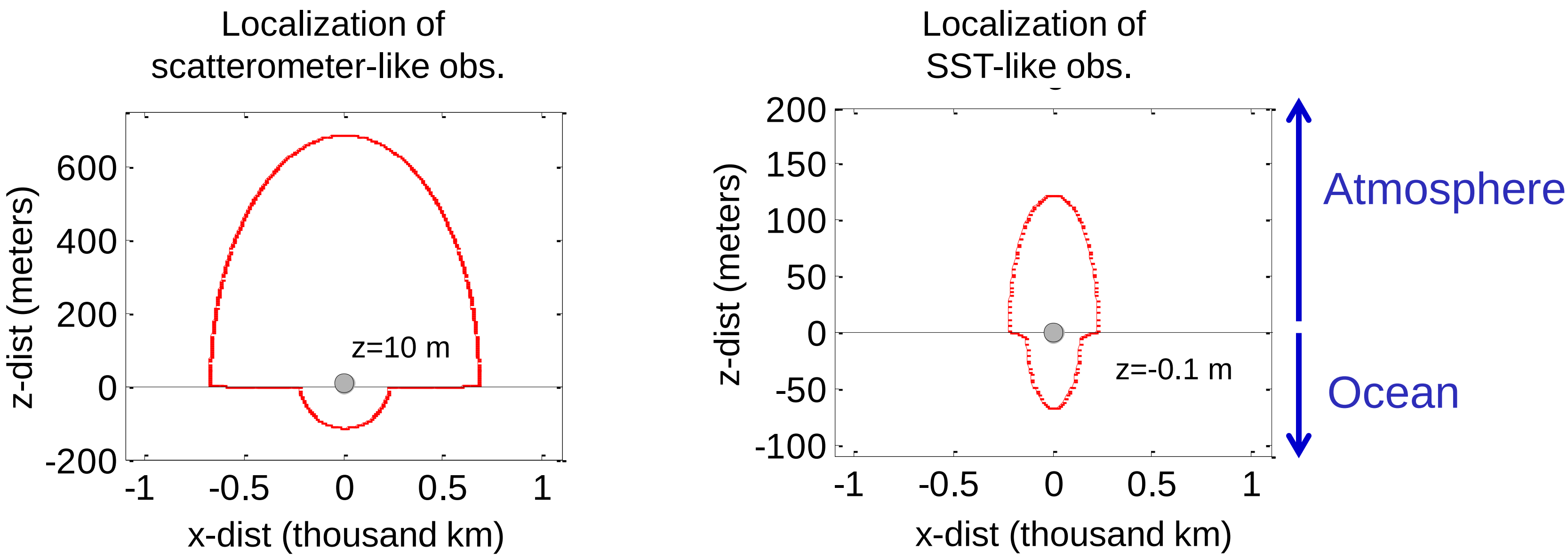
Coupled localization

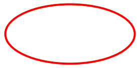


– value of localization function equal to 0.5

$$dist(obs_{atm} - obs_{oce}) = \sqrt{\left(\frac{x_A - x_O}{0.5\cdot(L_{x|A} + L_{x|O})}\right)^2 + \left(\frac{y_A - y_O}{0.5\cdot(L_{y|A} + L_{y|O})}\right)^2 + \ldots + \left(\frac{z_A}{L_{z|A}} - \frac{z_O}{L_{z|O}}\right)^2 + \left(\frac{t_A - t_O}{0.5\cdot(L_{t|A} + L_{t|O})}\right)^2}$$

Coupled localization



 – value of localization function equal to 0.5

Summary of results:

- Twin experiments (next slides) show that it is beneficial to use different localization scales in the ocean and atmospheric
- However, when the ocean atmospheric scales differ considerably, the proposed function is no longer positive definite
- To maintain PD of the localization, it might be necessary to localize the square root of the ensemble covariance

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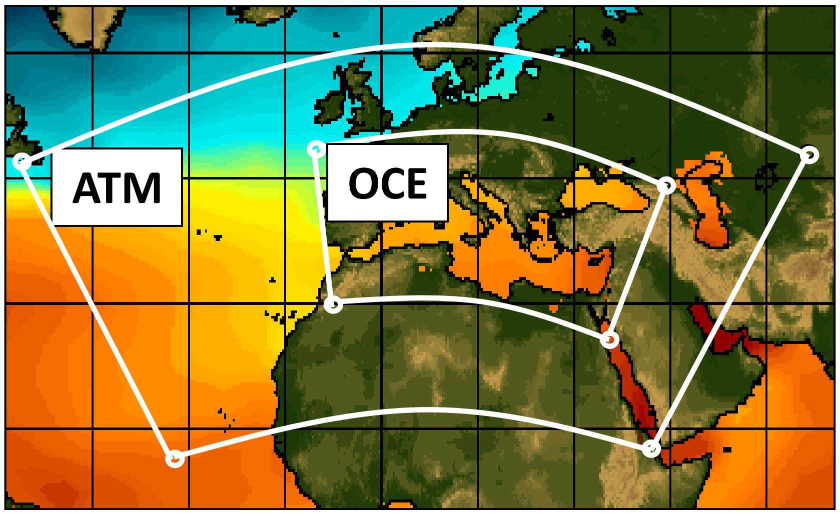
Can interface solver give the same result as exhaustive solver?



Forward model:

- Coupled, nested COAMPS/NCOM
- Atm. resolution 42 km
- Oce. resolution 12 km
- Coupling every 6 min.

Ensemble system:

- 20 members
- Driven by global atm. ensemble,
- Augmented by ET cycling

Observations:

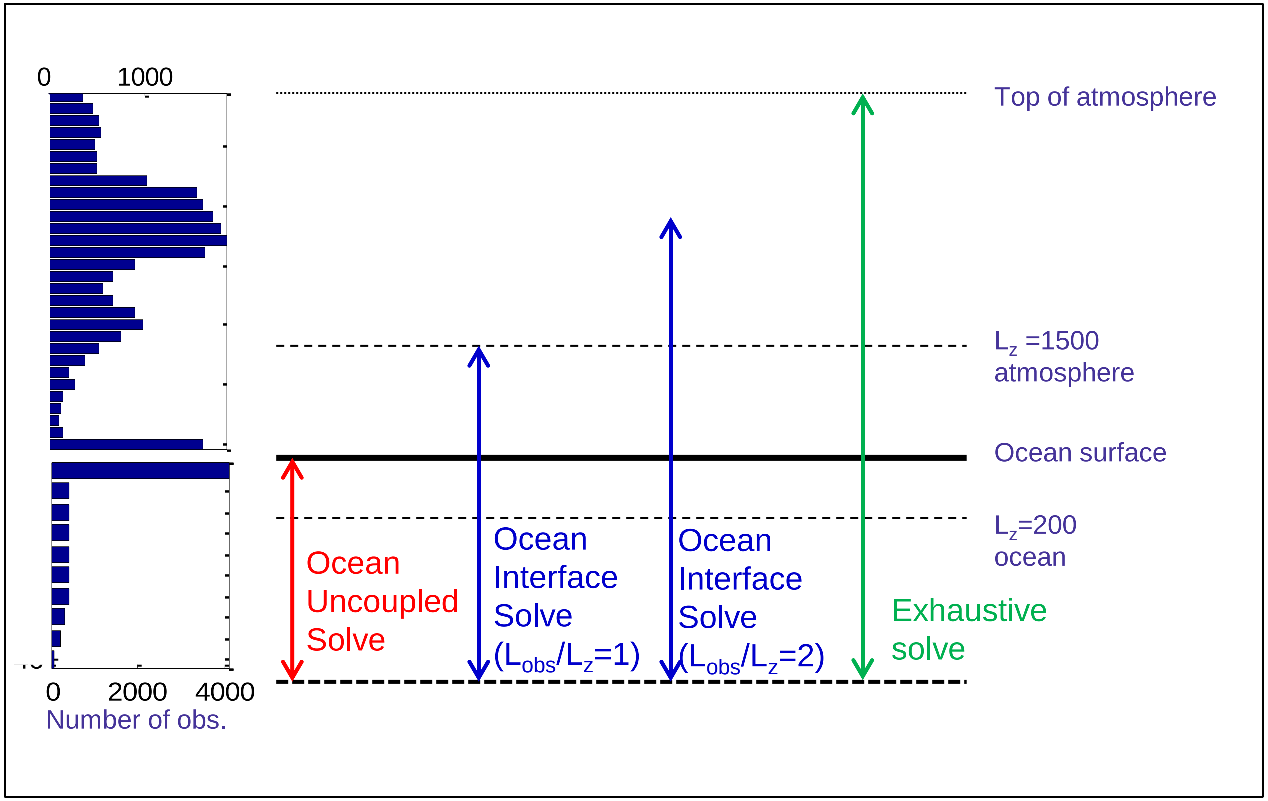
- Twin experiment based on real obs. locations

DA system:

- Hybrid-3DVAR

Can interface solver give the same result as exhaustive solver?

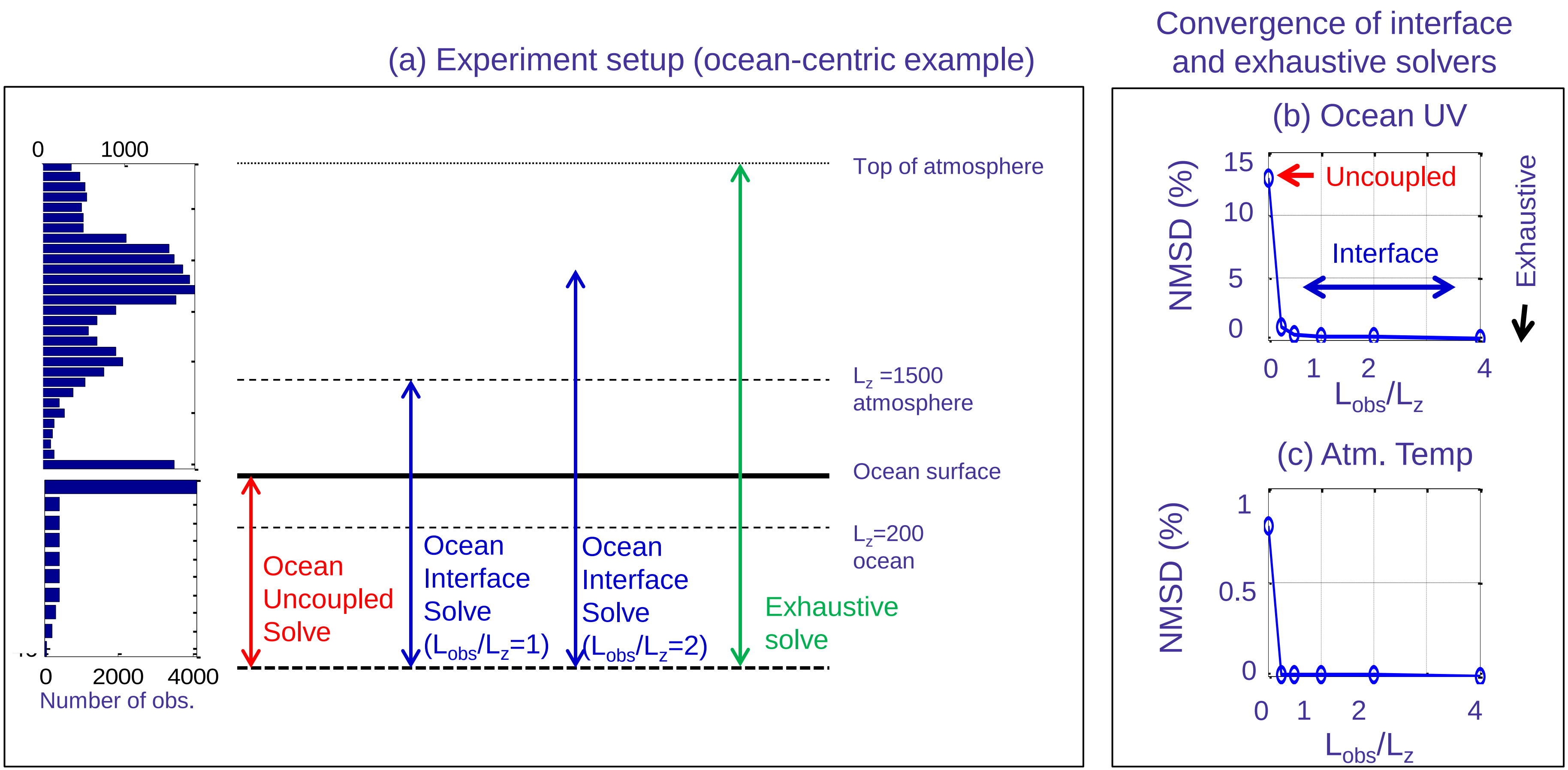
(a) Experiment setup (ocean-centric example)



Objective:

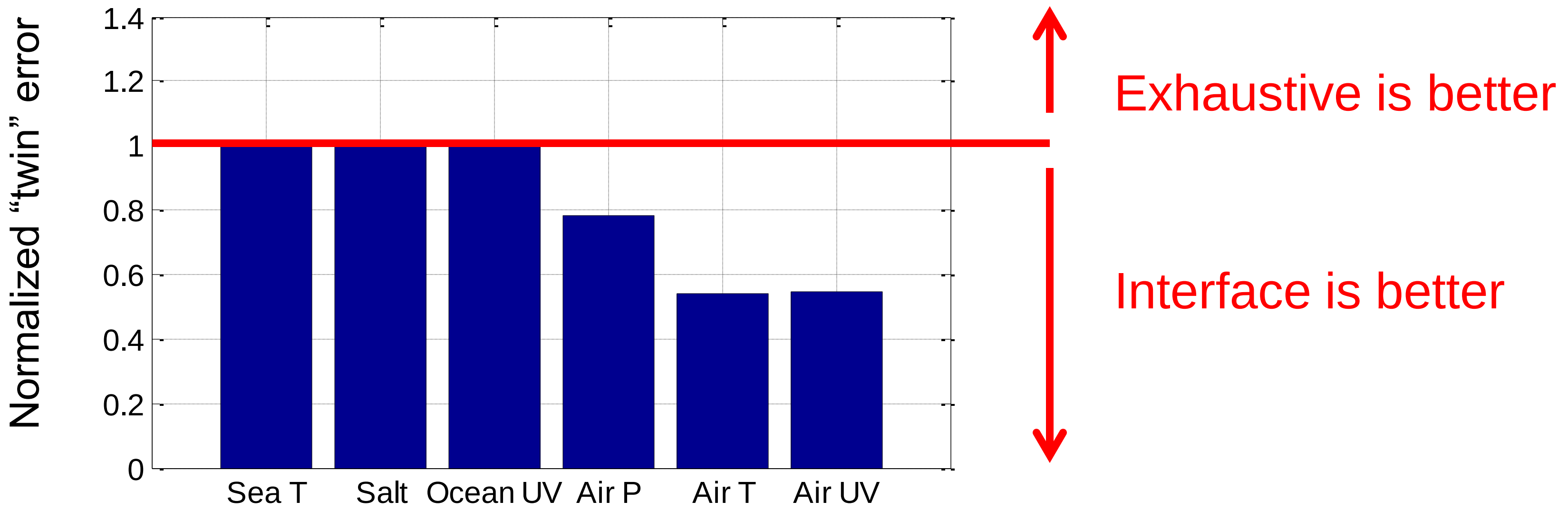
- Determine how fast does interface solver converges to exhaustive solution?

Can interface solver give same result as exhaustive solver?



Interface solver converges quickly to exhaustive solution

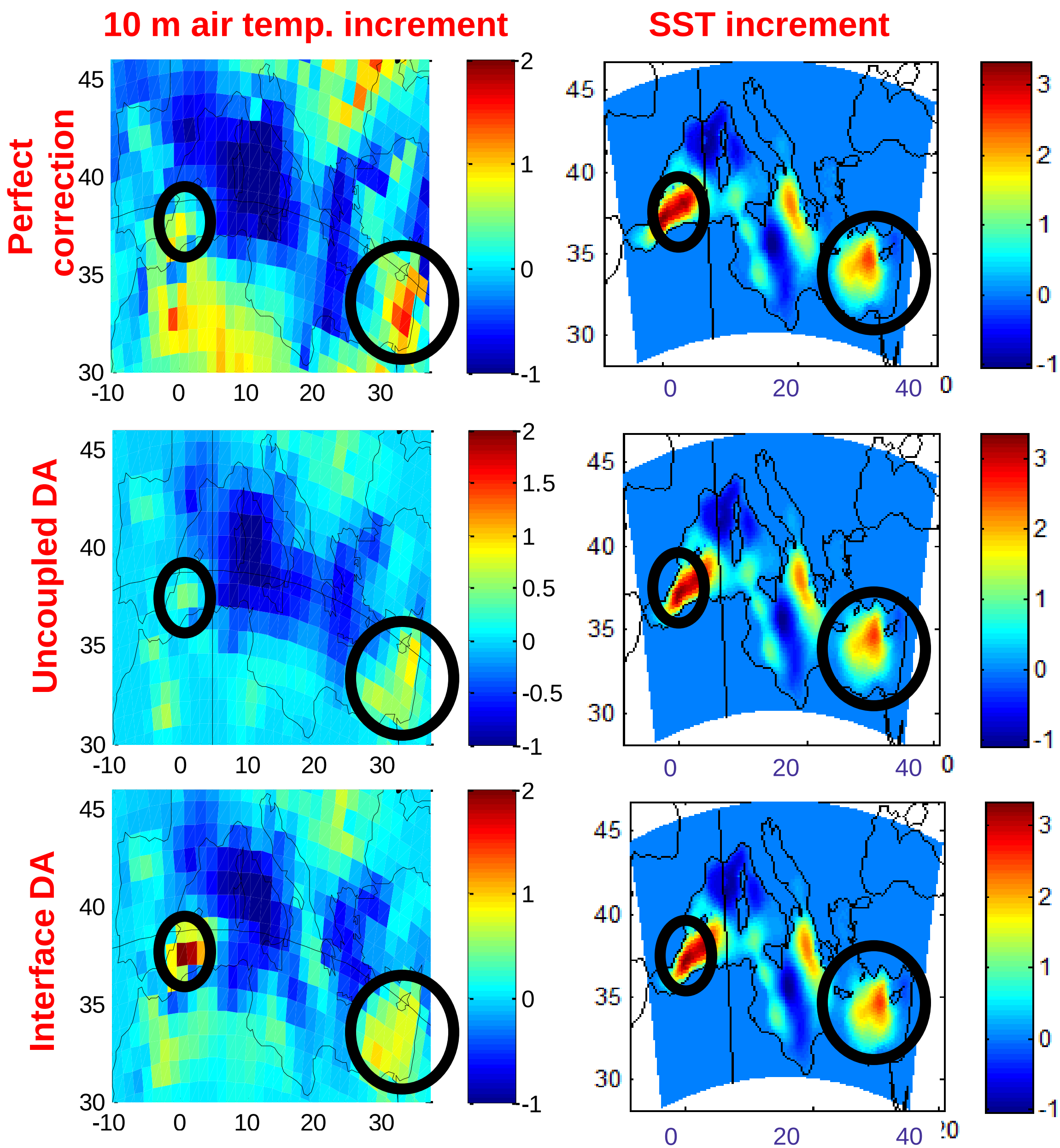
In fact interface solver can outperform the exhaustive solver



Solver configuration	Optimal ocean scales	Optimal atmospheric scales
Exhaustive	L =300 km	L = 500 km
Ocean + atm. bnd. layer	L = 300 km	L = 400 km
Atmosphere + ocean. bnd. layer	L = 500 km	L = 900 km

Interface configuration

Example of coupling between SST and atm. temperature



Results:

- SST increments are similar between all three experiments
- Positive impact of SST increments on the low atmosphere is clear along the coast of Israel and Portugal

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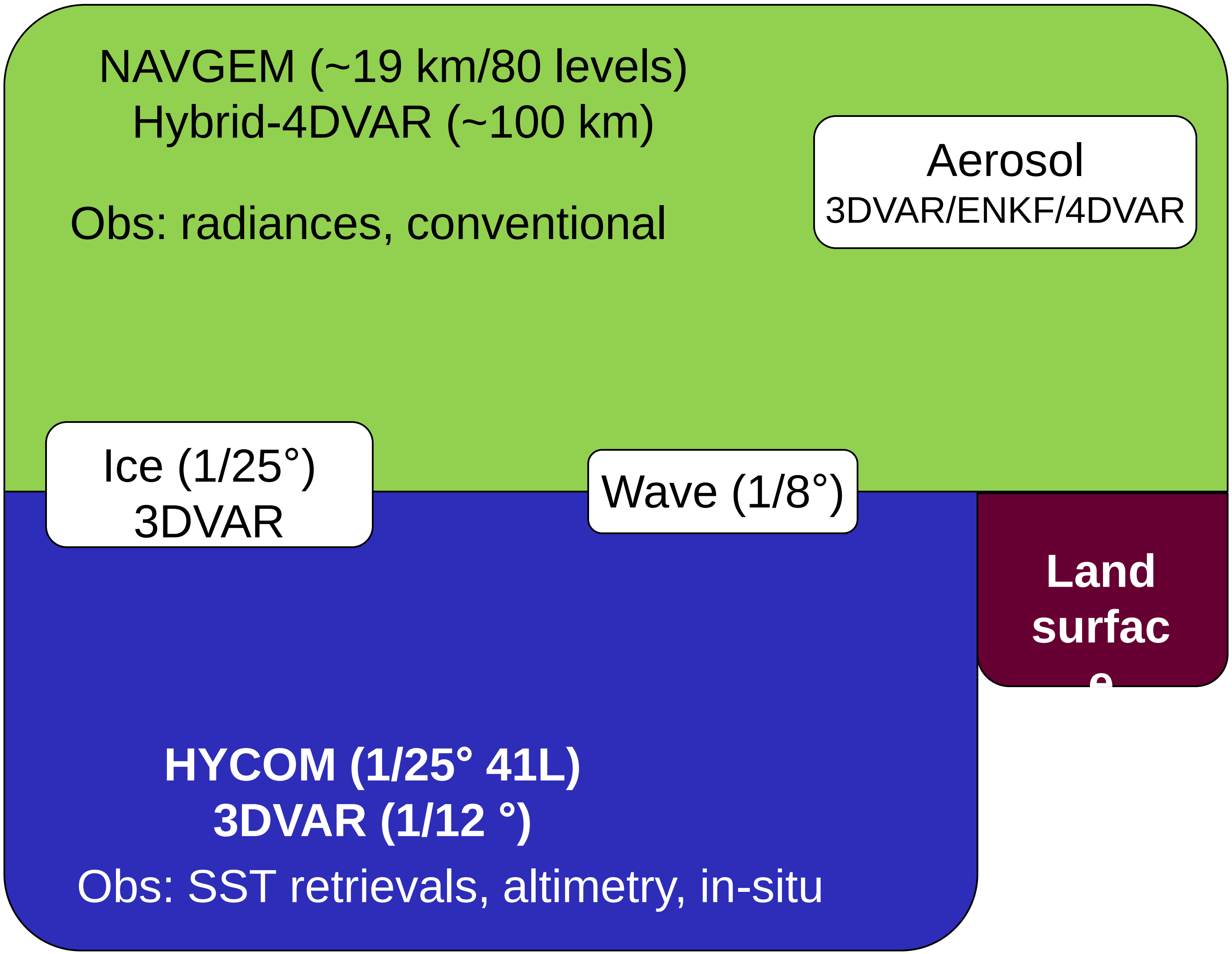
  - **System design**
  - **Impact of SST-sensitive channels**
  - **Towards a global ocean EnVar solver**
  - **Opportunities in ice-covered regions**

Existing coupled system



Existing coupled system

NAVGEM (~19 km/80 levels)
Hybrid-4DVAR (~100 km)

Obs: radiances, conventional

Aerosol
3DVAR/ENKF/4DVAR

Ice (1/25°)
3DVAR

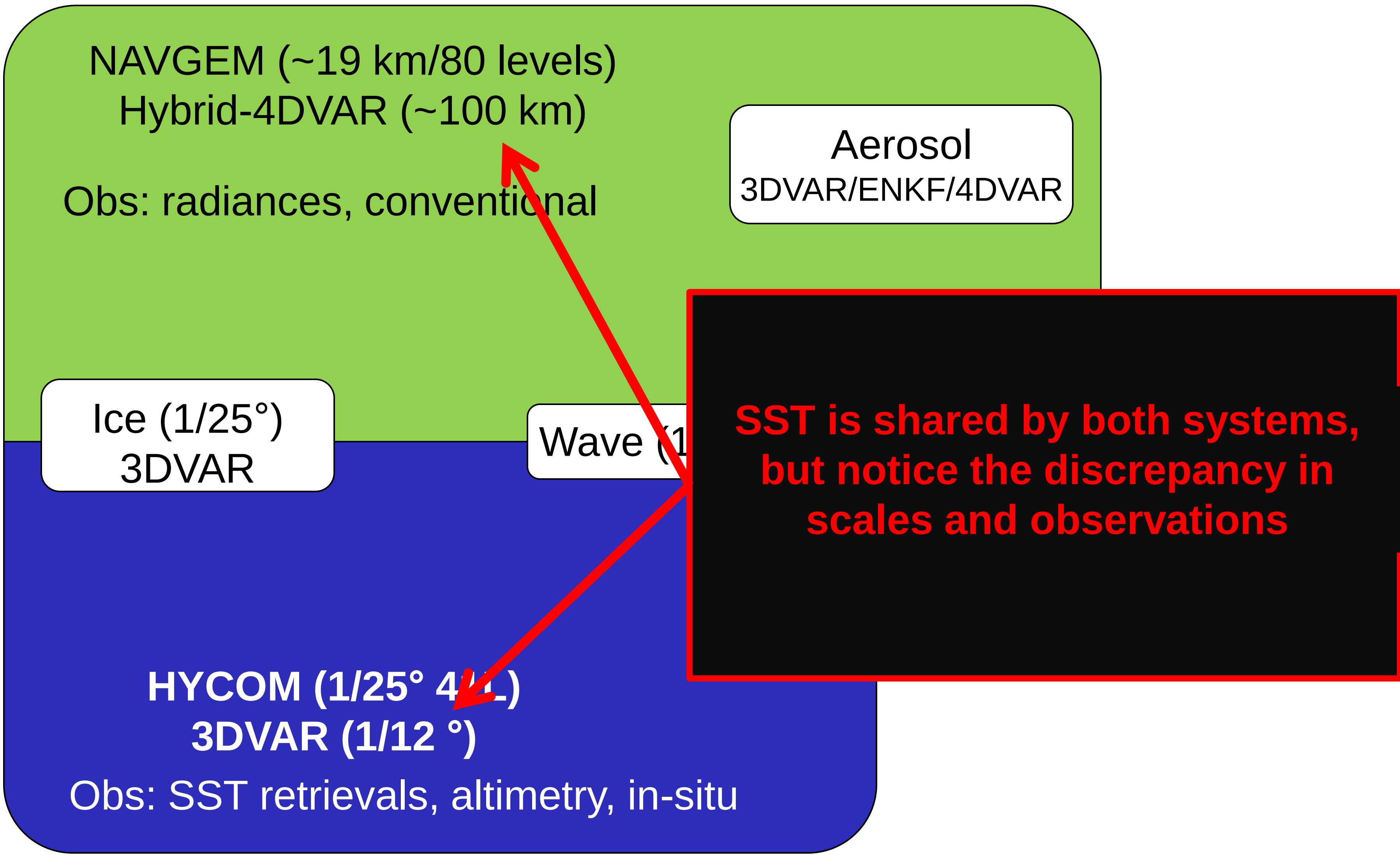
Wave (1

Very different dynamics, scales, maturity, communities, concerns, and resolutions, suggesting that interface solver might be a good fit.

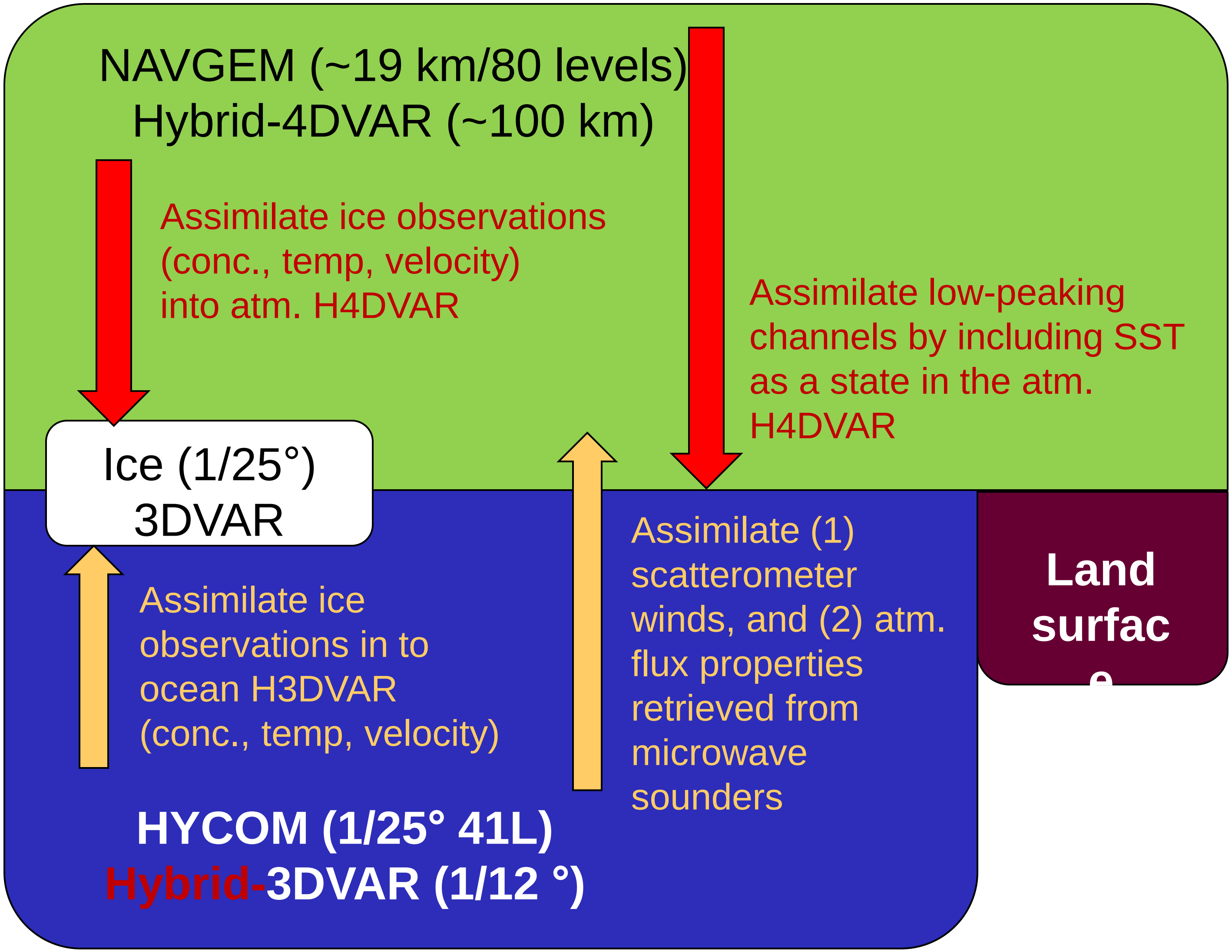
HYCOM (1/25° 41L)
3DVAR (1/12 °)

Obs: SST retrievals, altimetry, in-situ

SST chalenge



Plans for the coupled system (2020- 2022)



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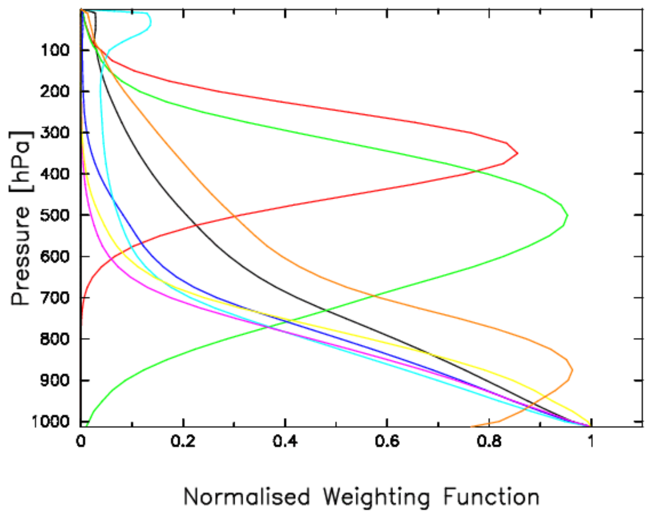
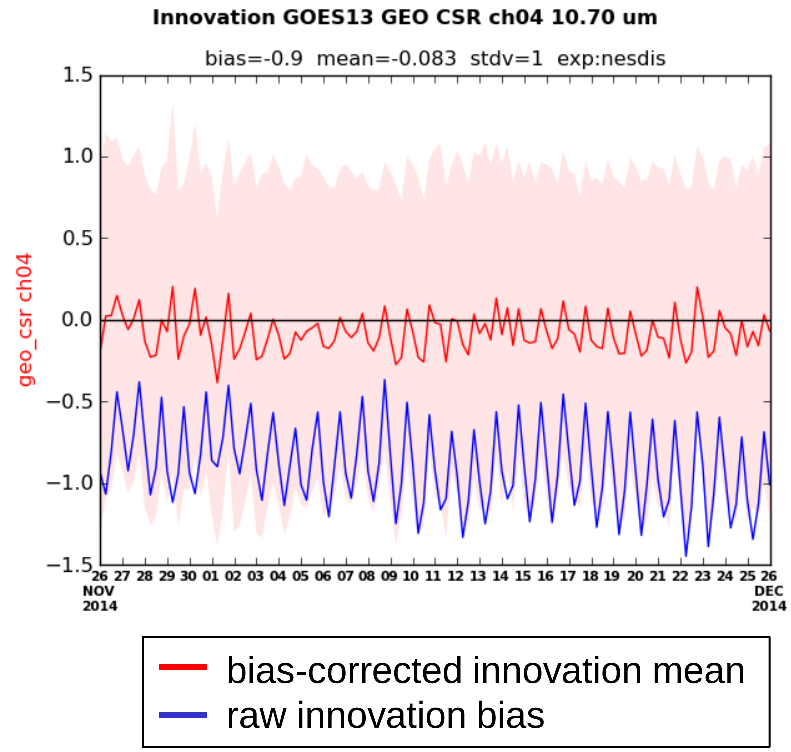
Need for NAVDAS-AR-SST

Weighting functions for GEO CSR (standard atm.)





- Satellite radiances with sensitivity to the ocean surface are currently ignored by atm. H4DVAR
- When assimilated, innovation show strong diurnal signal due to un-modeled SST variability

NAVDAS-AR-SST: implementation details

$$x^{coupled} = [x^{atm}; x^{sst}]$$

Coupled state with SST

$$y^{radiance} = \mathbf{H}^{crtm-jacobian} x^{coupled} = \begin{bmatrix} \mathbf{J}^{atm} \\ \mathbf{J}^{sst} \end{bmatrix} \begin{bmatrix} x^{atm} \\ x^{sst} \end{bmatrix}$$

Observations are coupled using CRTM Jacobian

$$\mathbf{P}^{coupled} = \begin{bmatrix} \mathbf{P}^{AA} & \mathbf{P}^{AO} \\ \mathbf{P}^{OA} & \mathbf{P}^{OO} \end{bmatrix} \approx \begin{bmatrix} \mathbf{P}^{AA} & 0 \\ 0 & \sigma^2 \mathbf{I} \end{bmatrix}$$

$$\mathbf{M}^{coupled} = \begin{bmatrix} \mathbf{M}^{AA} & \mathbf{M}^{AO} \\ \mathbf{M}^{OA} & \mathbf{M}^{OO} \end{bmatrix} \approx \begin{bmatrix} \mathbf{M}^{AA} & 0 \\ 0 & \mathbf{I} \end{bmatrix}$$

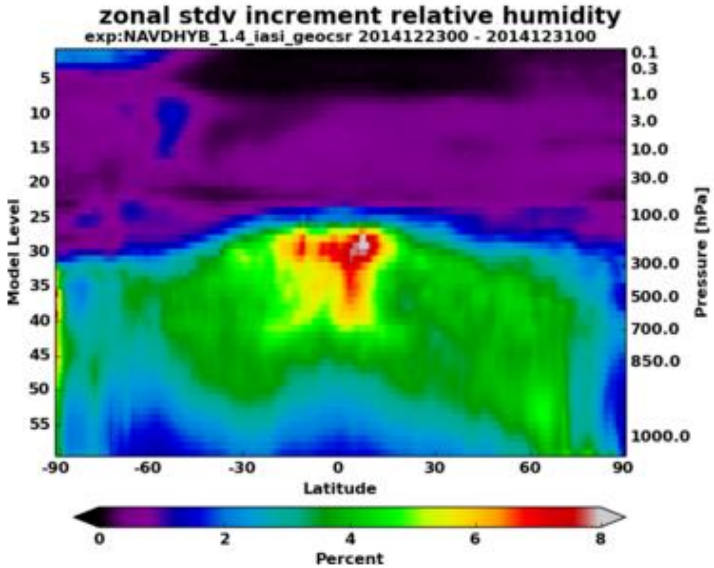
Simple approximations are used for coupled covariance and TLM.

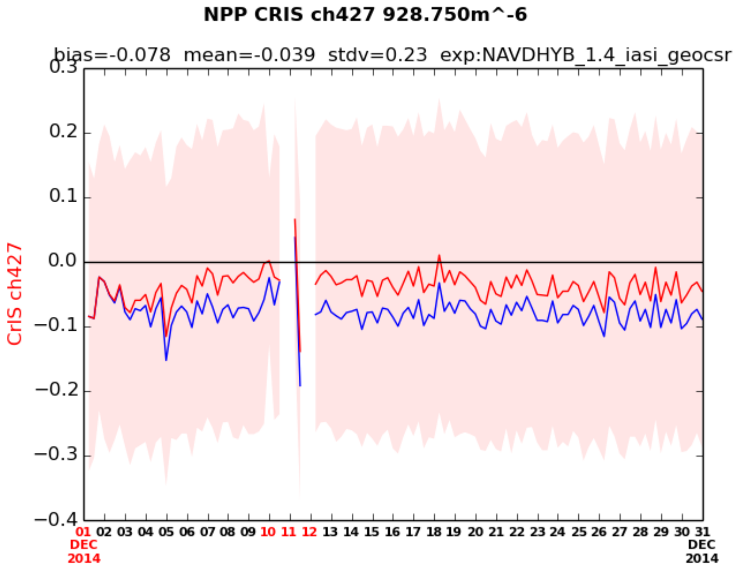
- Currently SST is implemented as a "sink" variable
  - $\mathbf{M}^{AO} = \mathbf{M}^{OA} = 0$; $\mathbf{M}^{OO} = \mathbf{I}$ and $\mathbf{P}^{AO} = \mathbf{P}^{OA} = 0$; $\mathbf{P}^{OO} = \sigma^2 \mathbf{I}$
- **In future, we plan to use coupled ensembles to approximate coupled covariances and TLMs**

In collaboration with: C. Bishop, B. Ruston, D. Kuhl, N. Barton

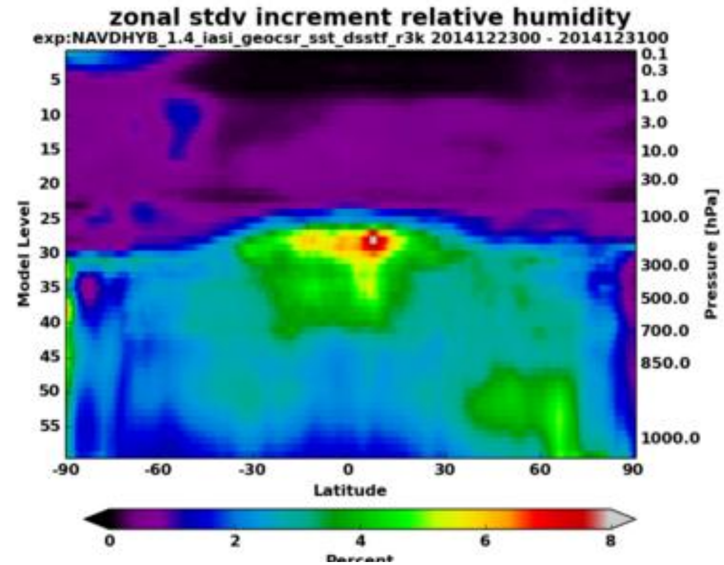
Results

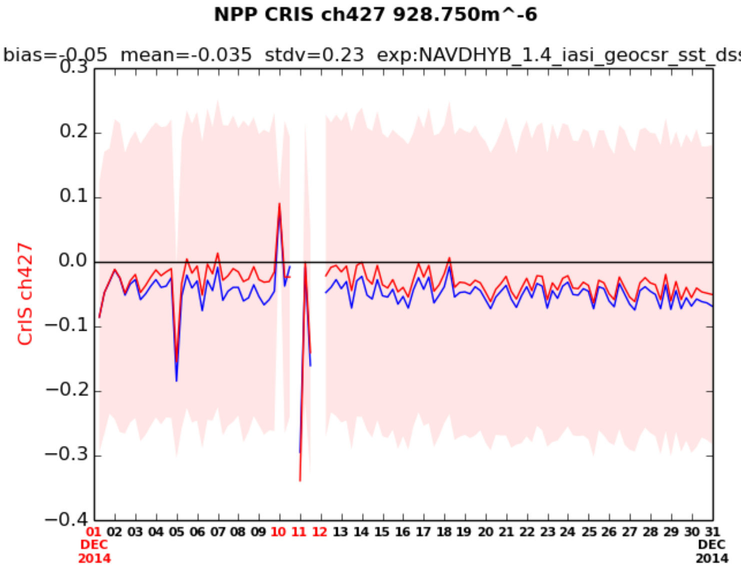
Uncoupled DA





Coupled DA





innovations; bias corrected innovation mean; innovation bias

Innovation statistics

Valid. channels \ Run name	Reference	New channels	Diurnal SST	SST state variable
Old channels	0.50	0.48	0.48	0.48
New channels	NA	0.49	0.46	0.47
Water vapor channels	1.23	1.16	1.15	1.15
Tropospheric channels	0.45	0.46	0.45	0.45

- Inclusion of low peaking channels is beneficial to non-assimilated water-vapor channels
- Inclusion of the diurnal SST model and SST state variable helps to tie-down the errors further

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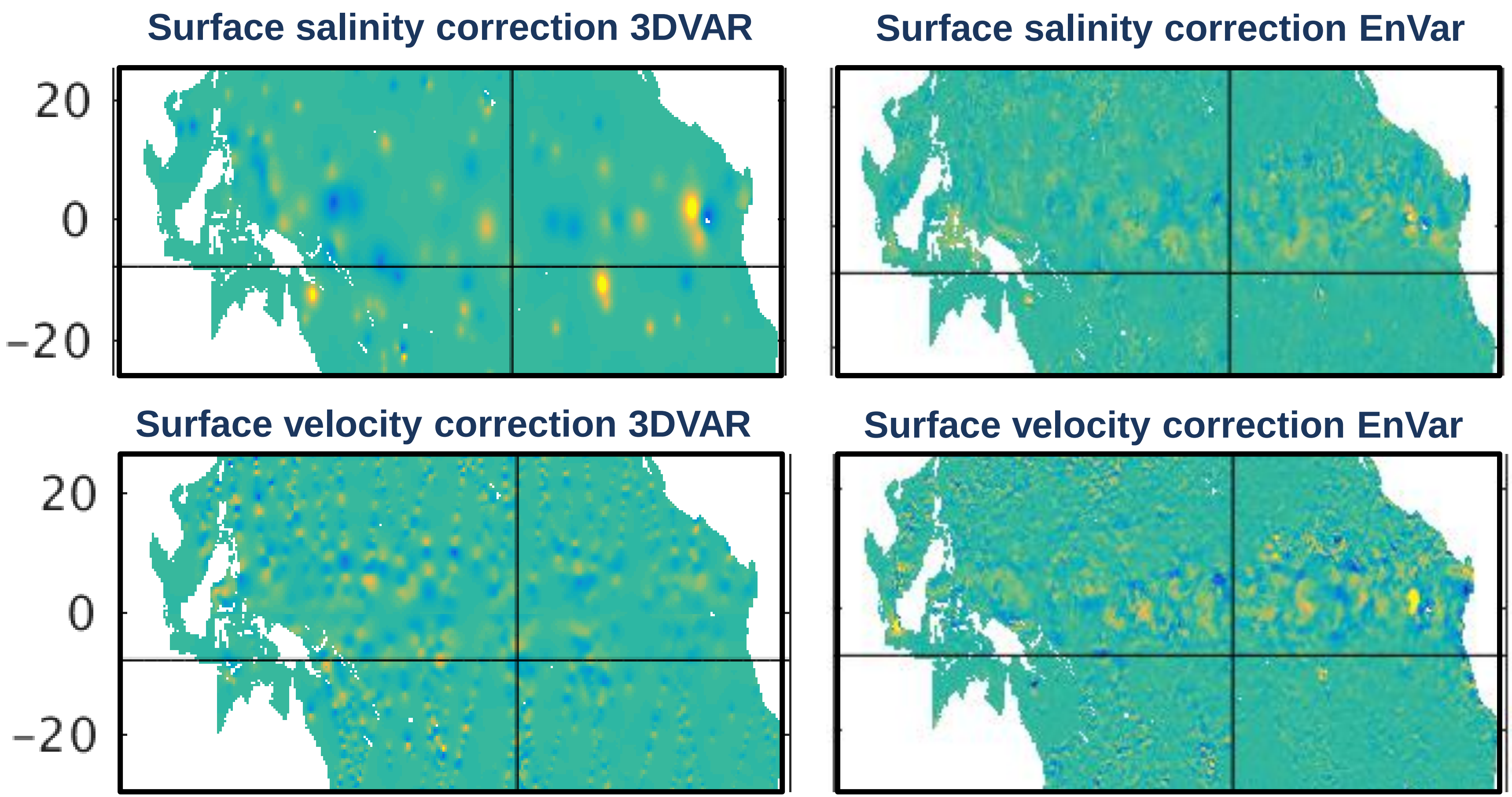
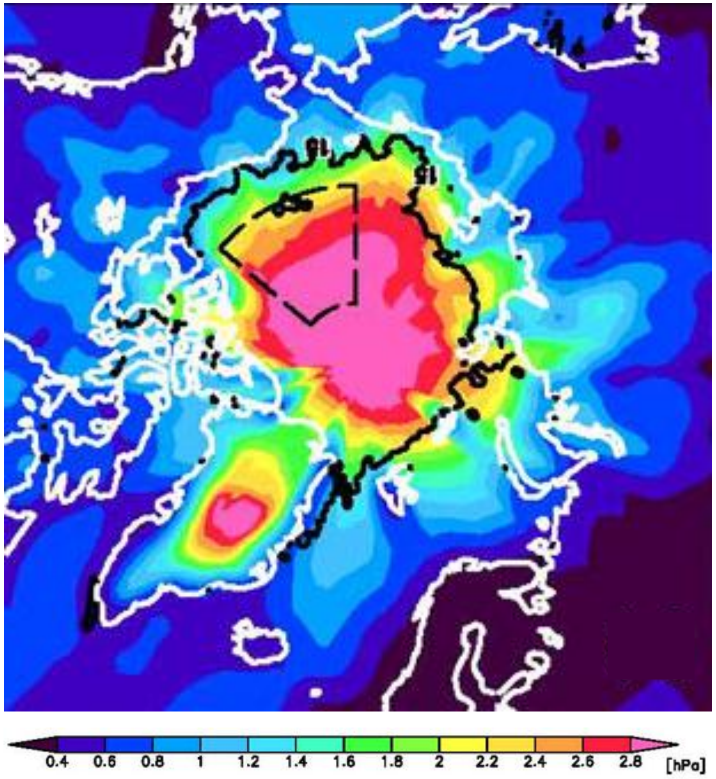
Towards global ocean EnVar (very preliminary results)



- Snapshot of the analysis increment over equatorial Pacific
- EnVar solver with 20 perturbed-obs. members
- Ensemble (and hybrid) show more realistic-looking corrections to the salinity and velocity fields
- Further testing is needed to characterize error statistics

Importance of ice observations (proposal submitted)

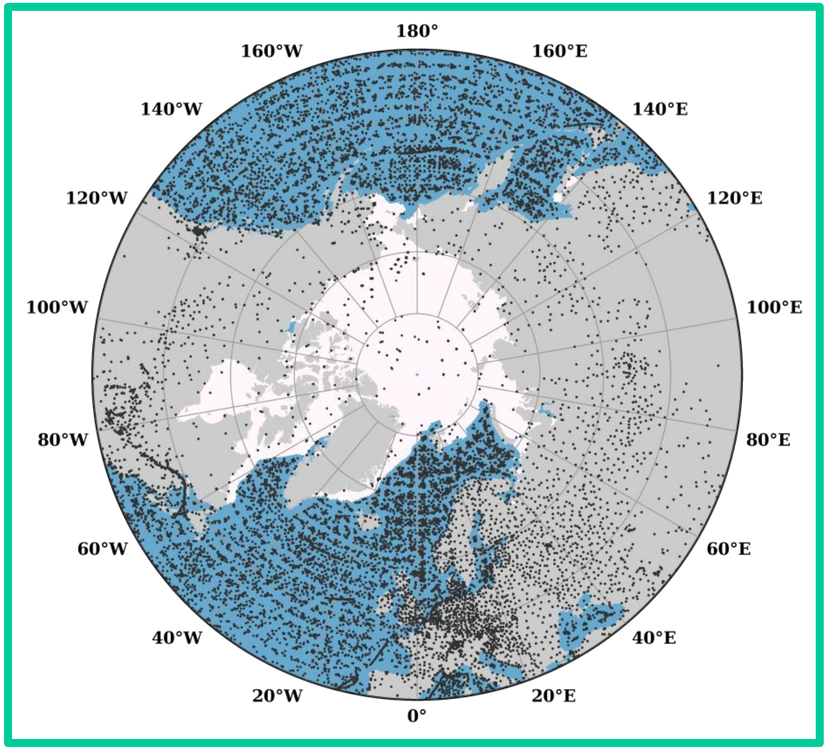
Spread of Surface Pressure From 40 Similar Forecasts



Low ← Uncertainty in Forecast → **High**

Inoue et al. (2009) *GRL*

observations in-use by current coupled system



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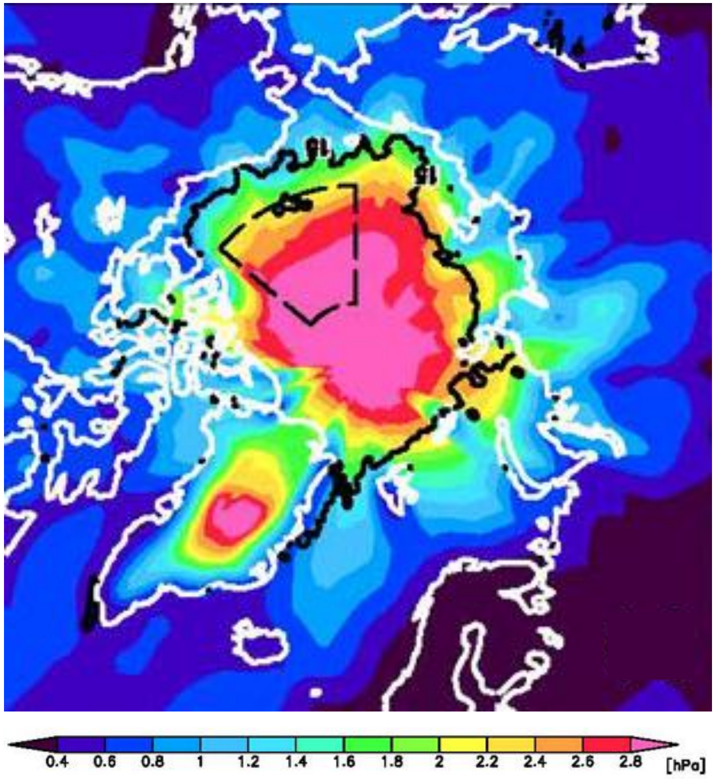

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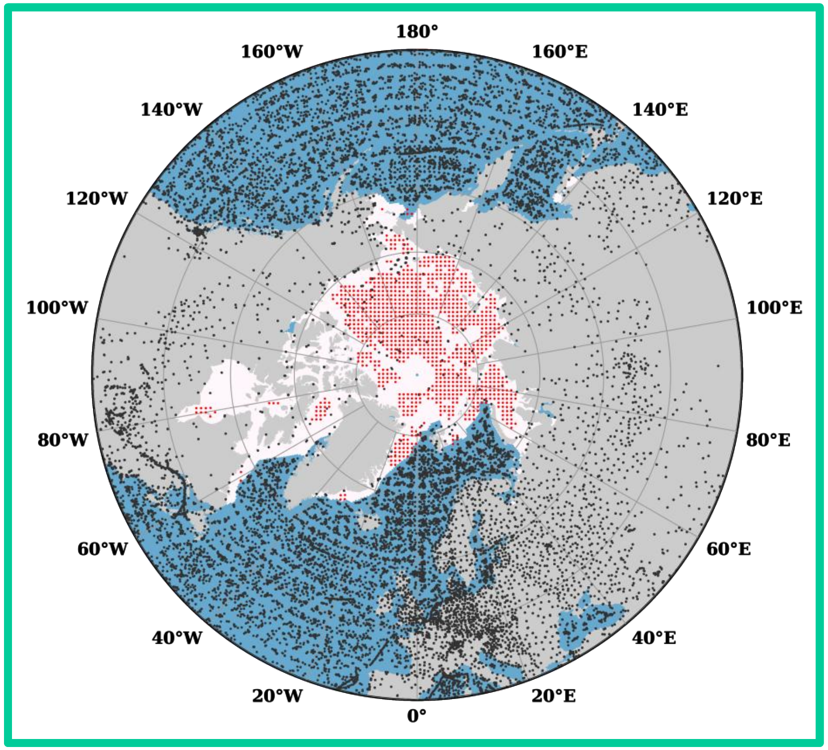
In red are ice motion vectors



Summary

<u>Interface solver</u>:

- A mathematically-principled way to contain the scientific, computational, and organizational costs of coupled systems
- Very encouraging results in the mesoscale system
- Some preliminary results in the global system

End