# Coupled Data Assimilation in Navy ESPC

NRL Ocean Dynamics and Prediction[1]: Charlie N. Barron, Clark D. Rowley, Tamara L. Townsend, Mozheng Wei, Max Yaremchuk, and Jan M. Dastugue
NRL Atmospheric Dynamics and Prediction[2]: Sergey Frolov, Craig H. Bishop, and Benjamin C. Ruston
Vencore[2]: Peter L. Spence, Ole Martin Smedstad
[1]Naval Research Laboratory, Code 7320, Stennis Space Center, MS [2]Naval Research Laboratory, Code 7530, Monterey, CA [3]Vencore, Stennis Space Center, MS

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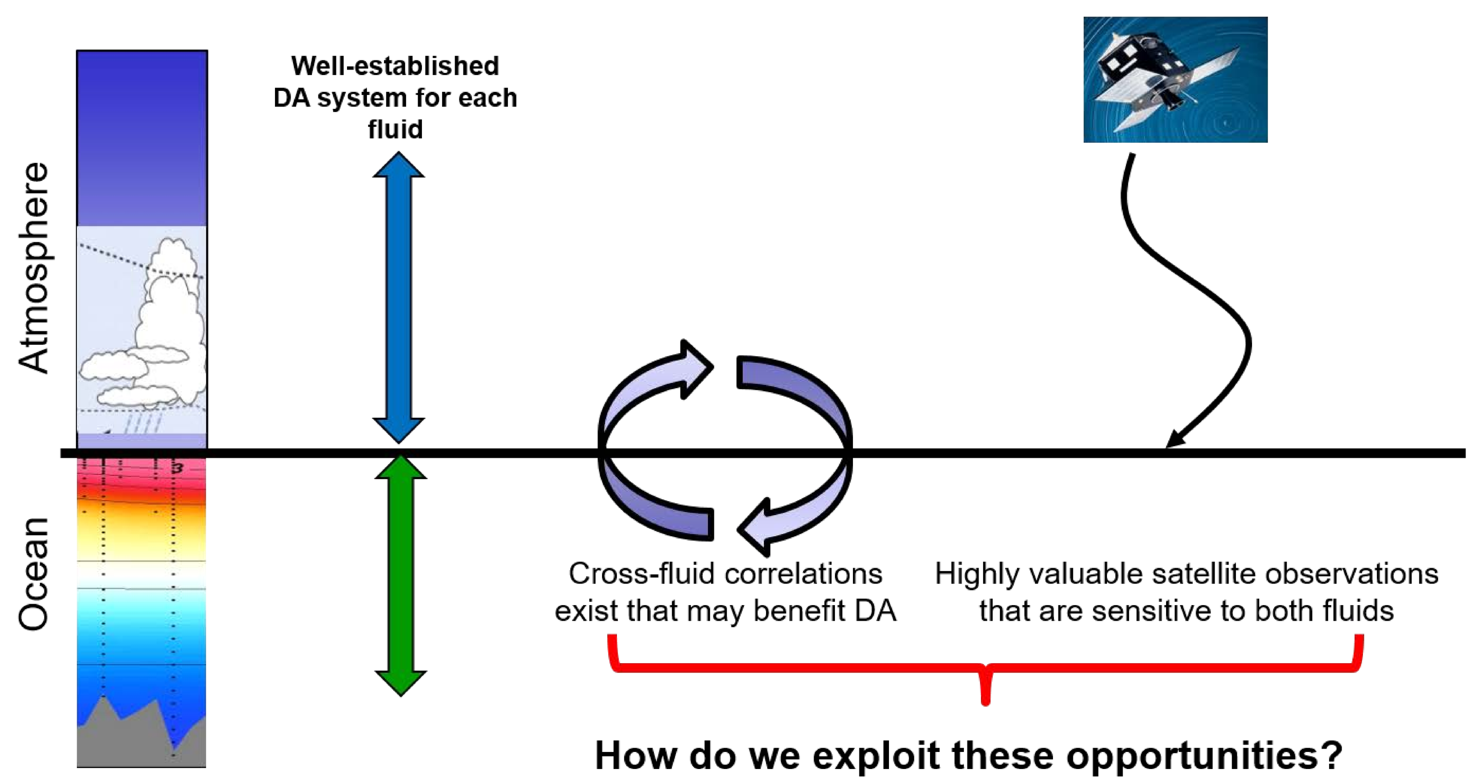
## Abstract

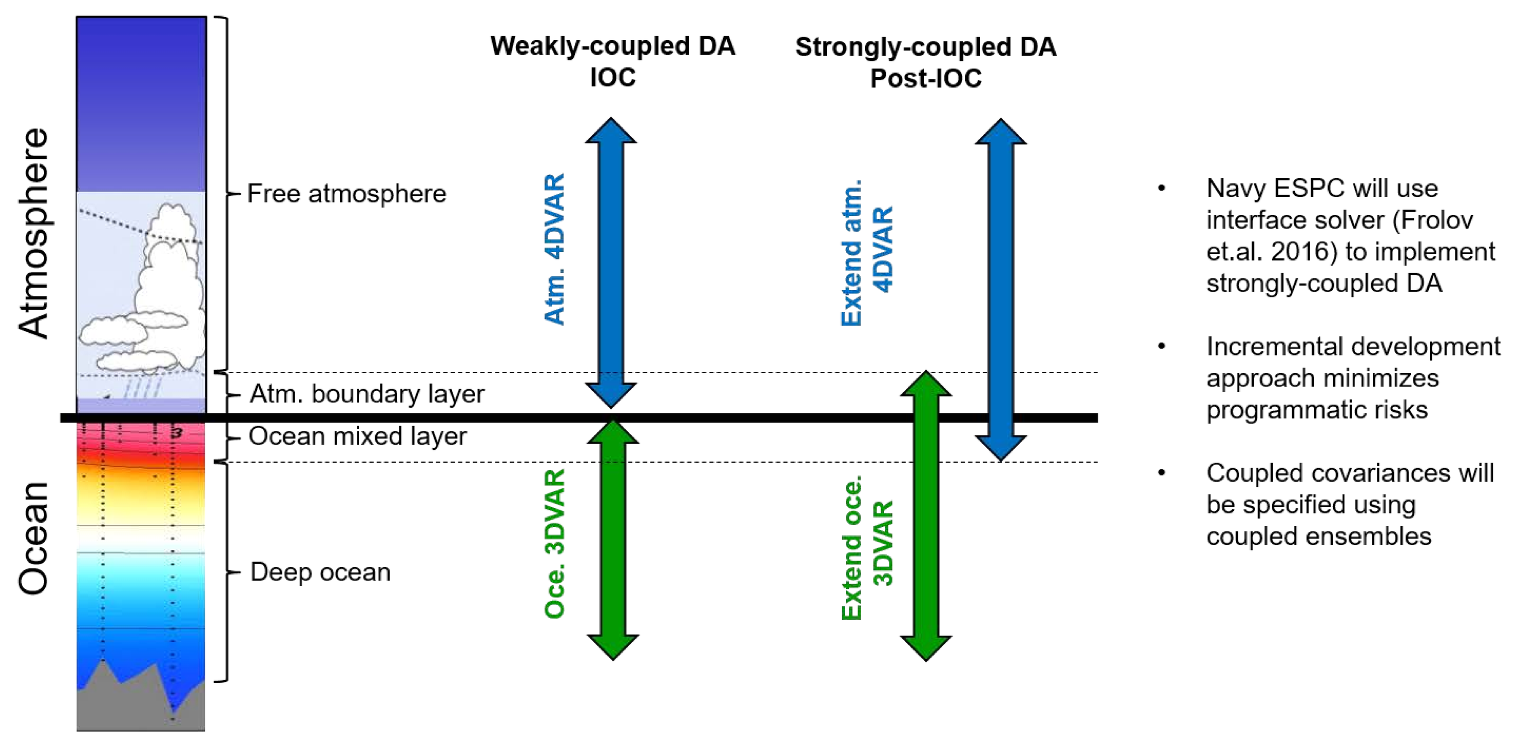
Data assimilation under global coupled Earth System Prediction Capability (ESPC) presents significantly greater challenges than data assimilation in forecast models of a single earth system like the ocean and atmosphere. In forecasts of a single component, data assimilation has broad flexibility in adjusting boundary conditions to reduce forecast errors; coupled ESPC requires consistent simultaneous adjustment of multiple components within the earth system: air, ocean, ice, and others. Data assimilation uses error covariances to express how to consistently adjust model conditions in response to differences between forecasts and observations; in coupled ESPC, these covariances must extend from air to ice to ocean such that changes within one fluid are appropriately balanced with corresponding adjustments in the other components. We show several algorithmic solutions that allow us to resolve these challenges. Specifically, we introduce the interface solver method that augments existing stand-alone systems for ocean and atmosphere by allowing them to be influenced by relevant measurements from the coupled fluid. Plans are outlined for implementing coupled data assimilation within ESPC for the Navy's global coupled model. Preliminary results show the impact of assimilating SST-sensitive radiances in the atmospheric model and first results of hybrid DA in 1/12 degree model of the global ocean.

## The coupled DA opportunity




**How do we exploit these opportunities?**

## Architecture of the ESPC coupled DA

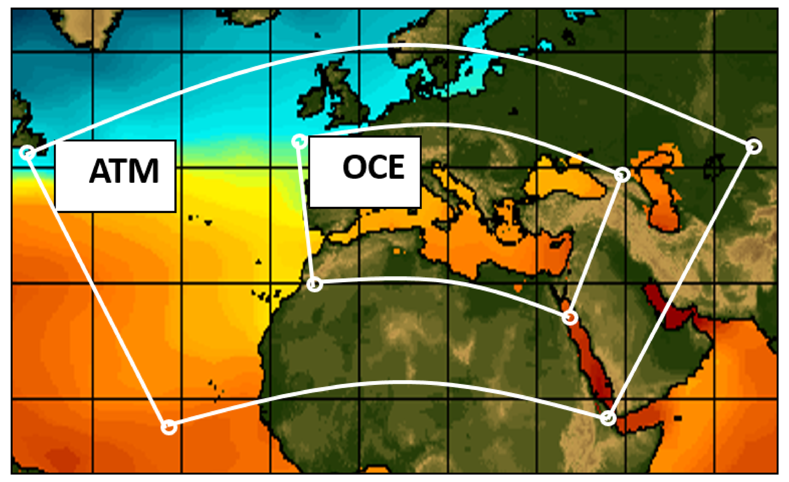



- Navy ESPC will use interface solver (Frolov et.al. 2016) to implement strongly-coupled DA
- Incremental development approach minimizes programmatic risks
- Coupled covariances will be specified using coupled ensembles

## Milestones

1) **Implement hybrid covariance in existing solvers**
   - **ATM: NAVDAS-AR-Hybrid in operations since fall 2016**
   - **OCE: NCODA-Hybrid in development**
2) **Implement hybrid coupled state variables**
   - **ATM: SST, ice concentrations velocities and temperatures, ..**
   - **OCE: scatterometer winds, radiative flux retrievals, ice**
3) **Coupled covariance**
   - **Use perturbed observation method**
   - **Leverage work on global coupled ensembles**
4) **Test benefits of the coupled DA**
   - **ATM: initial testing is underway**
   - **OCE: yet to be done**

## Does interface solver work?



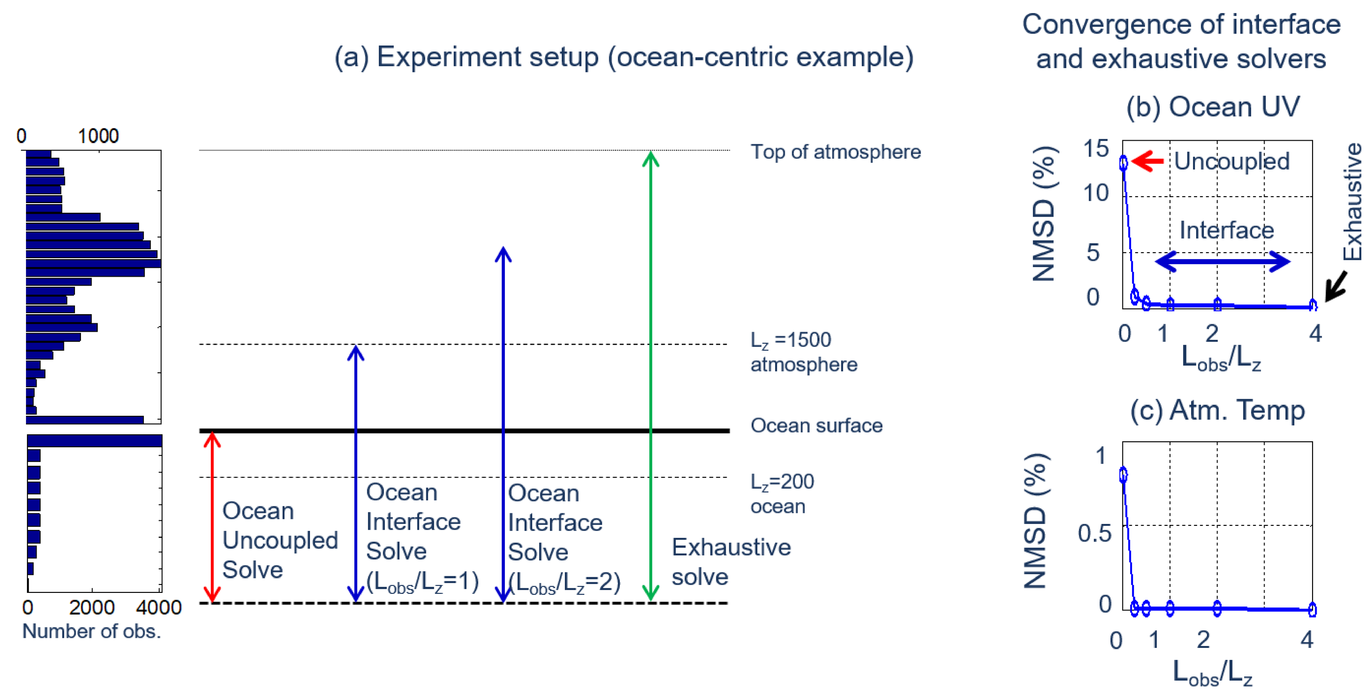

**Forward model:**
- Coupled, nested COAMPS/NCOM
- Atm. resolution 42 km
- Oce. resolution 12 km
- Coupling every 6 min.

**Ensemble system:**
- 20 members
- Driven by global atm. ensemble
- Augmented by ET cycling

**Observations:**
- Twin experiment based on real obs. locations

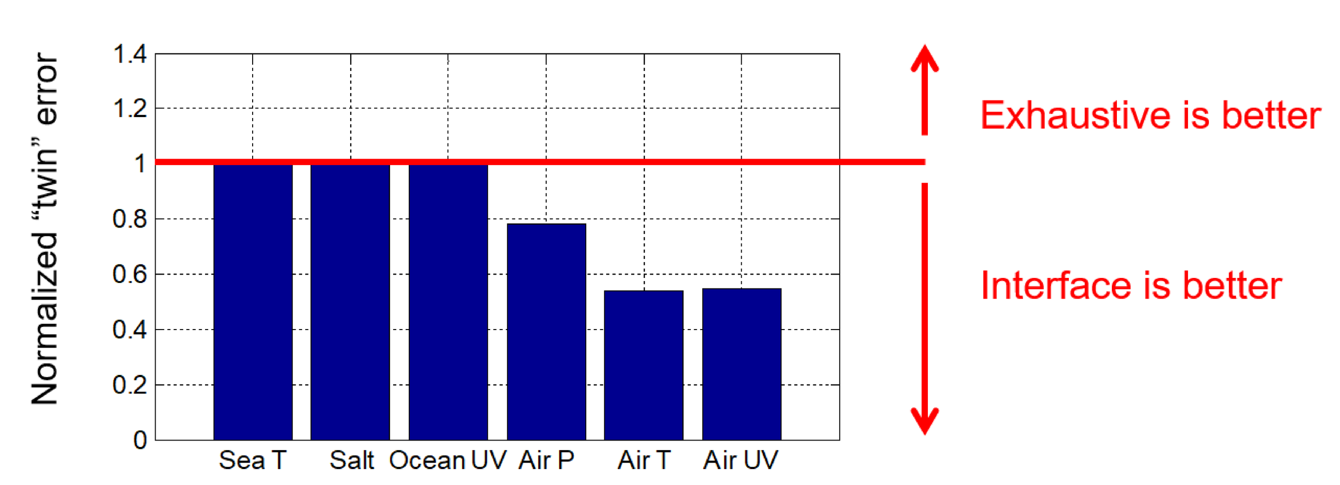
**DA system:**
- Hybrid-3DVAR

## Does interface solver work?




**Interface solver converges quickly to exhaustive solution**

## Interface solver can outperform 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

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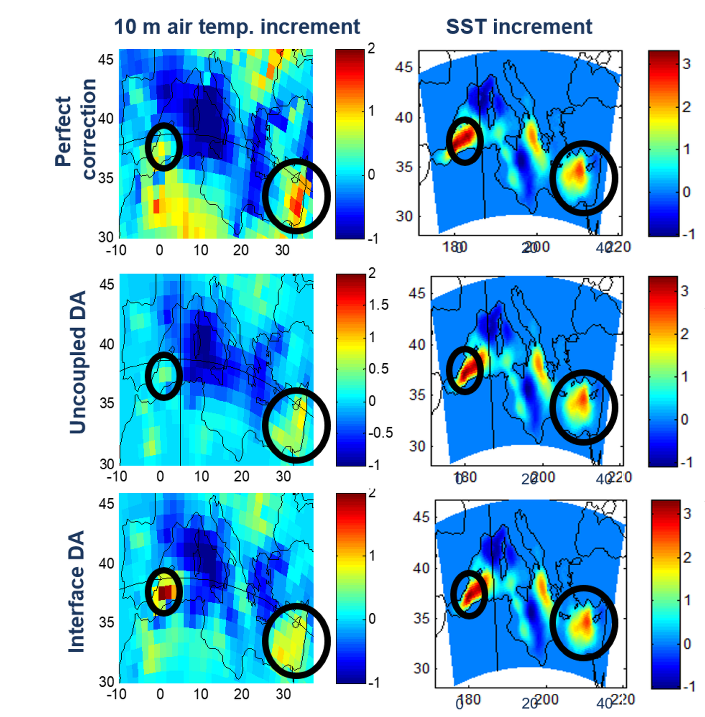
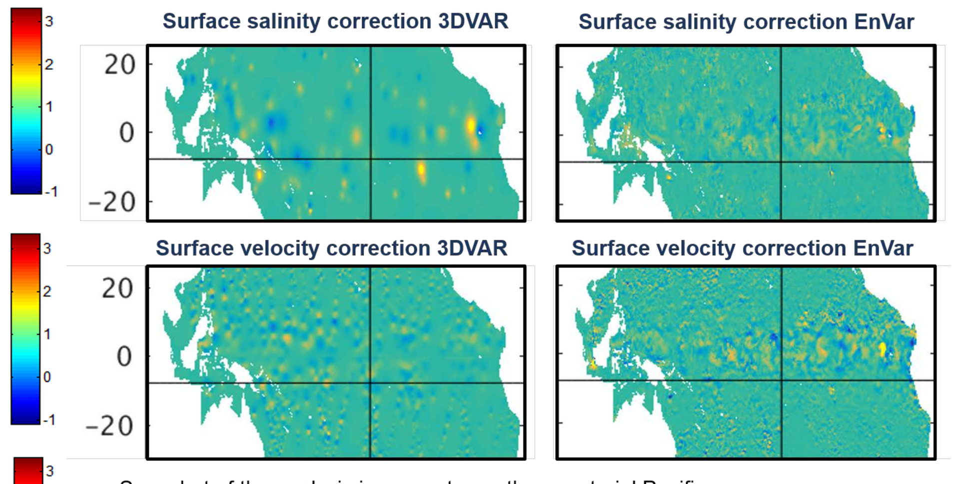
## Results

**Example of coupling between ocean and atmosphere**



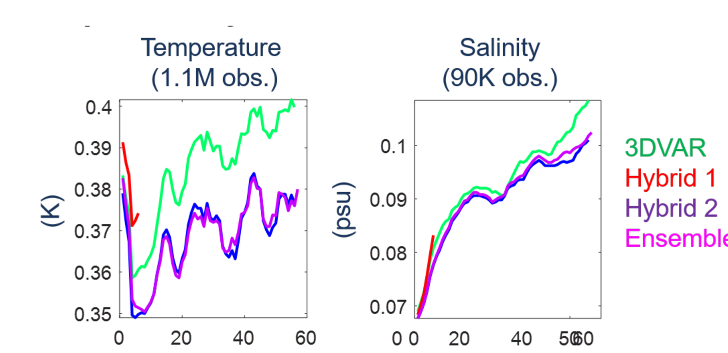

Results:
- SST increments are similar between all three experiments
- Positive impact of SST increments on the low atmosphere is clear along the coast of Israel and Portugal

Comparisons of static and ensemble increments




- Snapshot of the analysis increment over the equatorial Pacific
- EnVar solver with 20 perturbed-obs. members
- Ensemble (and hybrid, not shown) show more realistic-looking corrections to the salinity and velocity fields than the when using static covariances in standard 3DVAR

**Impact of hybrid covariance on ocean DA**




Using hybrid covariances ocean DA in the Pacific reduces RMS 24-hour forecast errors relative to in situ temperature and salinity observations

**Impact of interface coupling on atmosphere DA**

| Sensor | Channels | % Bias Reduction in the first guess |
|---|---|---|
| IASI | water vapor | 42.0 |
| CRIS | water vapor | 1.3 |
| CRIS | surface | 24.3 |
| CRIS | troposphere | 22.2 |
| MHS | water vapor | 19.3 |
| ATMS | water vapor | 4.7 |
| GEOCSR | all | 2.2 |

Coupled DA reduces 6-hour forecast bias across a wide range of remote sensors sensitive to the lower atmosphere

## Conclusions


Need to find right balance in coupled DA
(e.g. outer loop coupling, interface solver)

Working hypothesis:
- The forecast skill will degrade if we implement strongly-coupled DA right now (due to poor knowledge of the coupled error covariance).
- Over the next 10 years, implementing approximations to the strongly-coupled DA will allow refining the coupled error covariance and, at the same time, controlling the strength of the coupling.

## Planned activities in the next year

Specific work plans:
- Completing work on SST-sensitive channels
- Tuning the performance of the ocean Hybrid-EnVAR
- Implementing impact of ice velocities and temperatures on the atmosphere
- Implementing impact of scatterometer winds, surface temperature, and humidity retrievals on the ocean