

# Ocean Data Assimilation

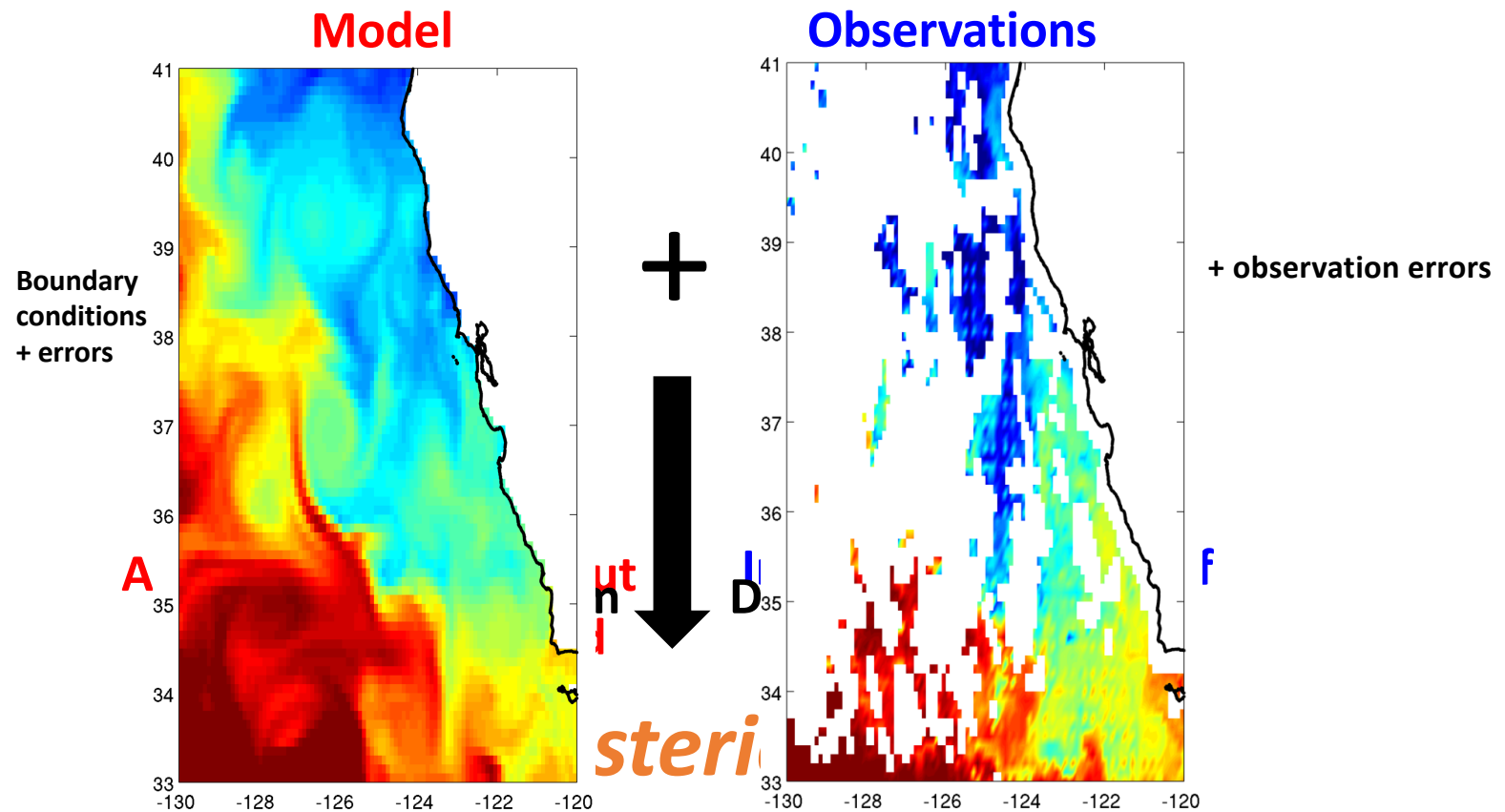
**Stefano Ciavatta (Plymouth Marine Lab)**  
**&**  
**Andy Moore (UC Santa Cruz)**

Background: The abstract of Bayes' paper in Trans Phil. Roy. Soc. (1763)

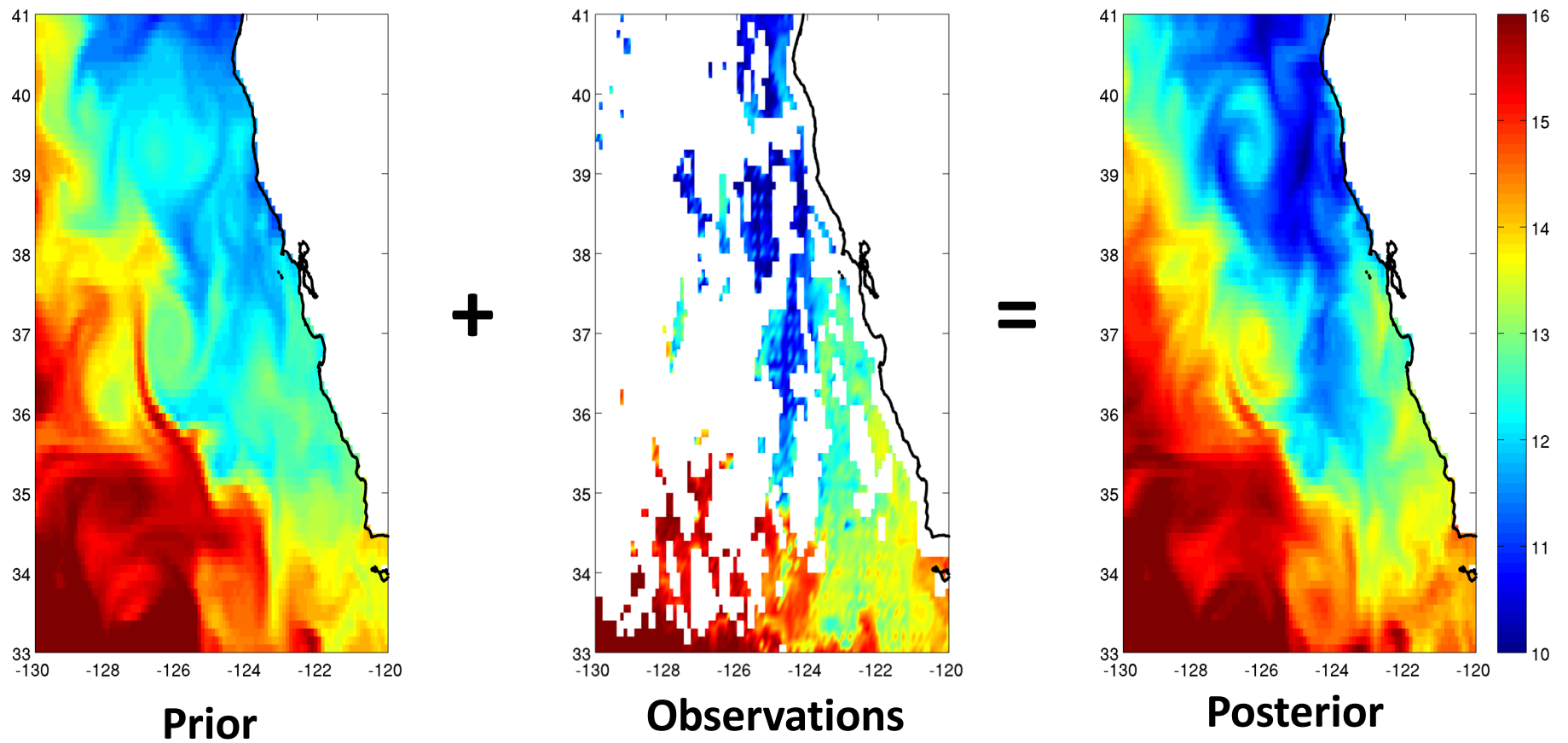
# Outline

- Earliest ocean DA efforts inspired by MODE/POLYMODE and TOGA
- Data assimilation – some essential ingredients
- Approaches and current status
- Challenges
- Expert forums and promoting community dialog
- A look to the future...

# Data Assimilation



## California 4D-Var SST Analysis, Jan. 2010

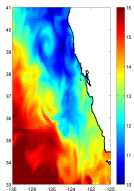




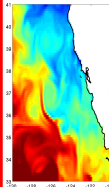
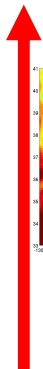
# Essential Ingredients of an Analysis

Most likely, unbiased estimate for ocean state,  $\mathbf{x}$ , assuming Gaussian-distributed errors:

$$\mathbf{x}^a = \mathbf{x}^b + \mathbf{B}\mathbf{H}^T \left( \mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R} \right)^{-1} \left( \mathbf{y}^o - H(\mathbf{x}^b) \right)$$



Analysis  
or  
Posterior



Background  
or  
Prior



Prior  
error  
covariance



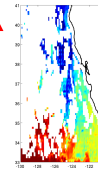
Ocean  
Dynamics



Ocean  
Dynamics



Observation  
error  
covariance

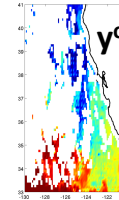
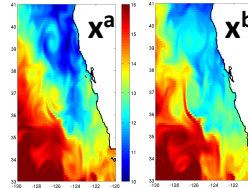


Observations



Prior  
estimate of  
observations

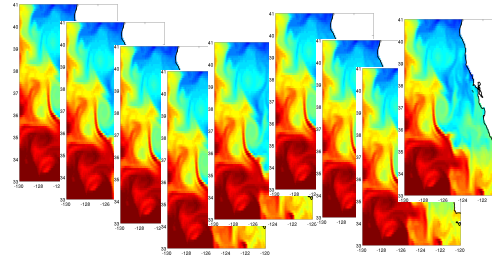
# Approaches & Current Status



Two main flavors of DA these days:

- **Variational (3D-Var, 4D-Var):**
  - space-time dynamic interpolation ( $H, H^T$ )
  - heavily parameterized error covariances ( $B$ )
  - long windows for climate studies (eg ECCO)
- **Ensemble Kalman Filters:**
  - forecast model ensemble
  - flow-dependent error covariances (“errors of the day”)  
(e.g.  $B \approx \overline{(x - \bar{x})(x - \bar{x})^T}$ )

$$\mathbf{x}^a = \mathbf{x}^b + \mathbf{B}\mathbf{H}^T \left( \mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R} \right)^{-1} \left( \mathbf{y}^o - H(\mathbf{x}^b) \right)$$



Successful marriage of the two – hybrid DA

- combines covariance models and ensemble-derived covariances
- often using variational approach

Other non-Gaussian ensemble DA methods also gaining favor:

- particle filters

Applications:

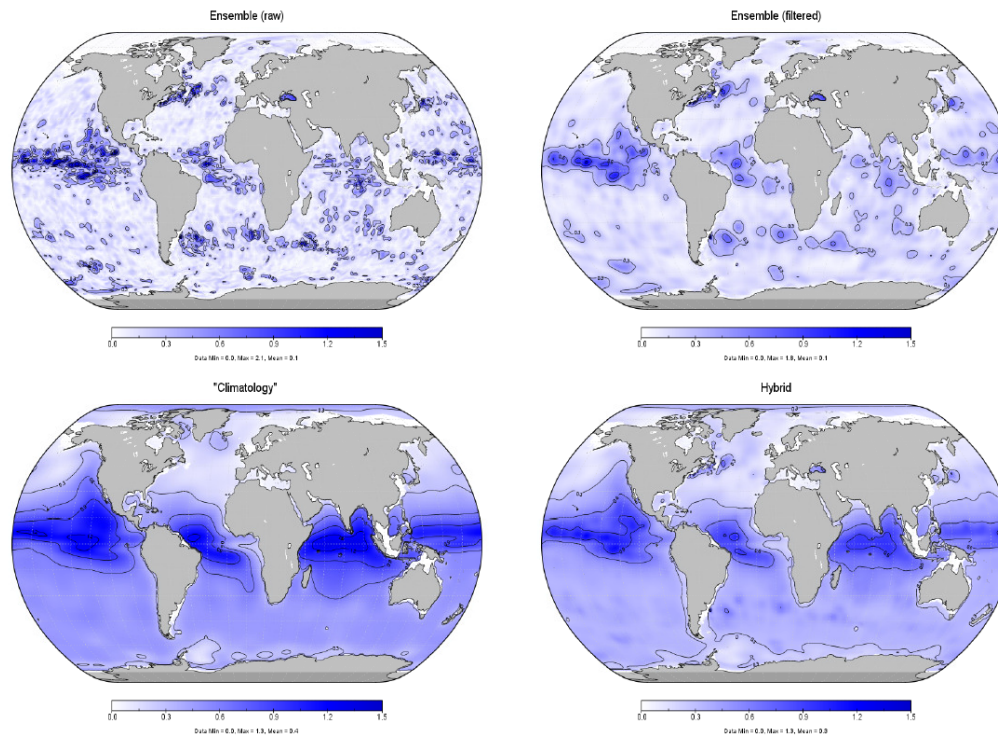
- Global DA
- Regional DA
- Coupled DA (O-A, O-I, O-BGC, etc)

**Covariances are Critical!**

## **B: Hybrid variational-ensemble DA in NEMOVAR**

5-member ensemble (4 perturbed + 1 unperturbed) from 31/05/2015.  
Background temperature error standard deviations at 100 m.

The marriage of a  
covariance model and  
ensemble-derived  
covariances



Courtesy of  
Anthony Weaver  
CERFACS

# Challenges

General:

$$\mathbf{x}^a = \mathbf{x}^b + \mathbf{B}\mathbf{H}^T \left( \mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R} \right)^{-1} \left( \mathbf{y}^o - H(\mathbf{x}^b) \right)$$

- Quantifying errors (prior, model, observation & posterior)
- Covariance models
- Ensemble sampling errors (localization and inflation)
- **Model & observation bias (which violate basic DA assumptions)**
- Correlated observations errors (e.g. remote sensing data)
- Non-Gaussian variables (tracers, sea-ice,...)

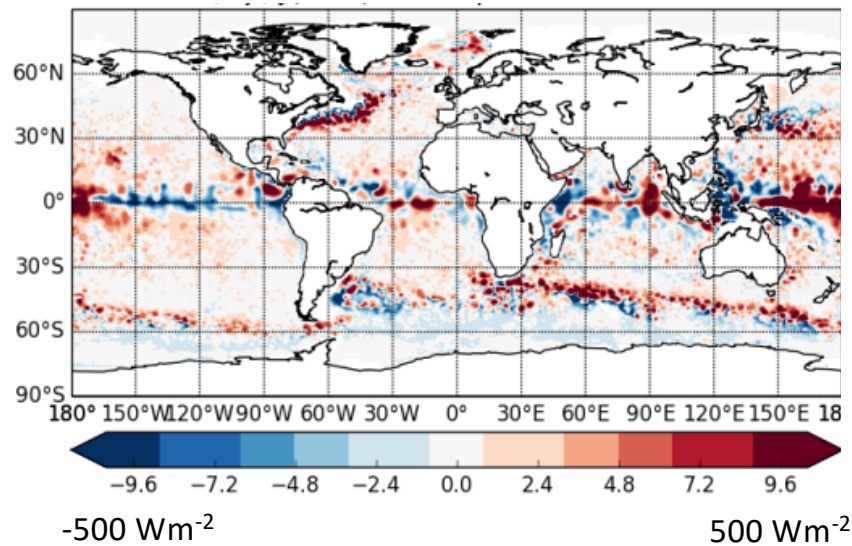
Regional DA specific:

- Coastal altimetry (MDT, land contamination, appropriate corrections)
- HF radial observations (observation errors, data thinning)
- Others...

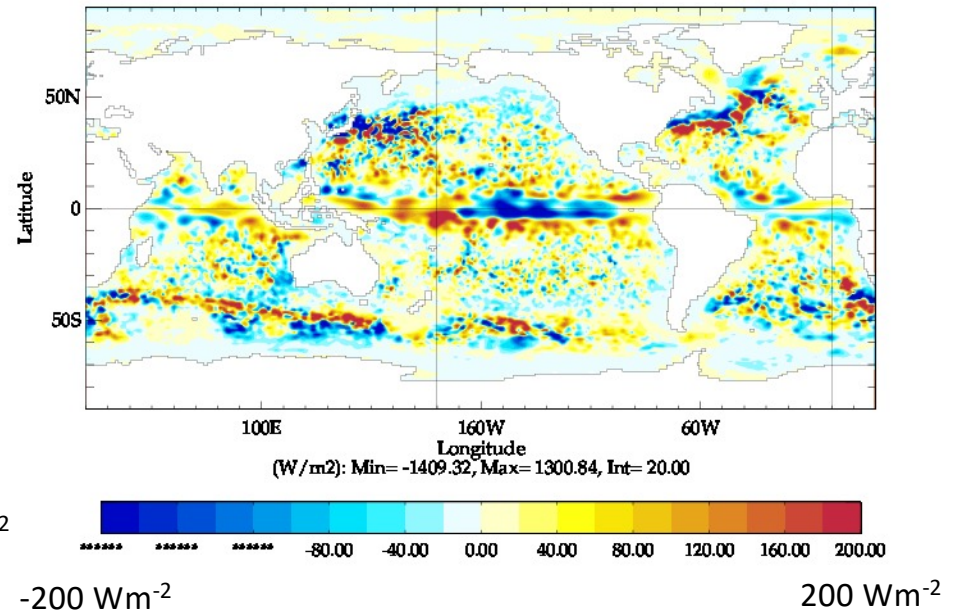
# Bias

$$\mathbf{x}^a = \mathbf{x}^b + \mathbf{B}\mathbf{H}^T \left( \mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R} \right)^{-1} \left( \mathbf{y}^o - H(\mathbf{x}^b) \right)$$

Met Office GloSea5 (1/4 deg)



ECMWF ORAP5 (1/4 deg)



Inter-comparison of average vertically integrated T increments:  
NEMO, ¼ deg, 3D-Var-FGAT

Courtesy of Matt Martin, Met Office

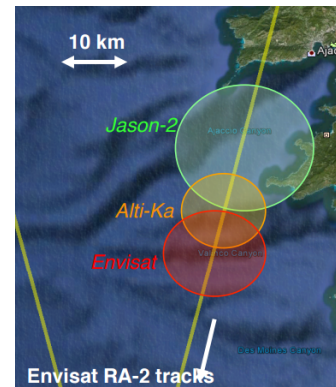
# Challenges

## General:

- Quantifying errors (prior, model, observation & posterior)
- Covariance models
- Ensemble sampling errors (localization and inflation)
- Model & observation bias (which violate basic DA assumptions)
- Correlated observations errors (e.g. remote sensing data)
- Non-Gaussian variables (tracers, sea-ice,...)

## Regional DA specific:

- Coastal altimetry (MDT, land contamination, appropriate corrections)
- HF radial observations (observation errors, data thinning)
- Forcing, boundary conditions, tides,...

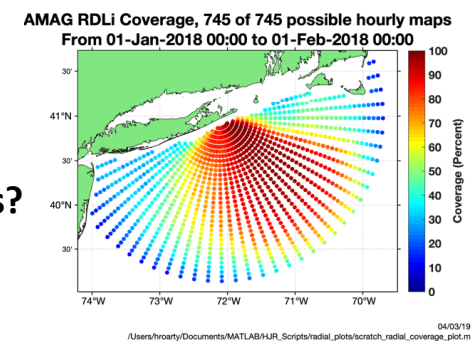


## Coastal altimetry:

- Contamination of signal from land
- MDT poorly known
- Standard corrections may not be appropriate

## HF radar obs:

- Observation errors?
- Data thinning?

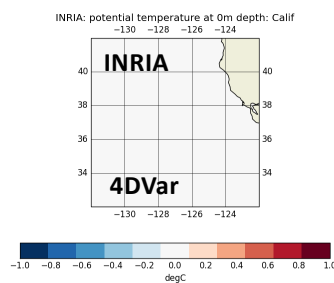
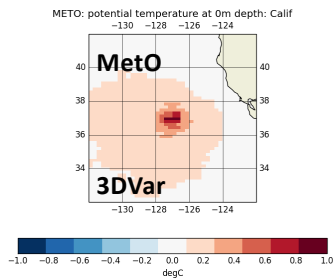
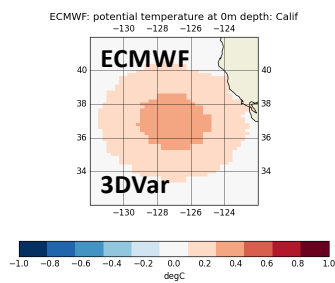
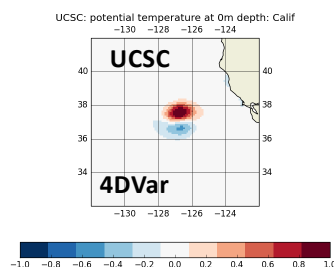
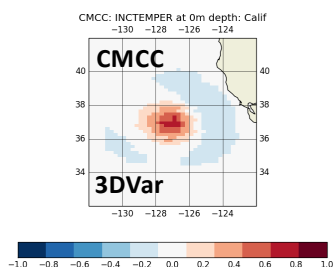


# GOV Expert Forums - Promoting Dialogue

DA features heavily in *all* GOV Task Teams:

- DA forum- Data Assimilation-Task Team
- Observing system assessment – Observing System Evaluation-Task Team\*
- Biogeochemical DA – Marine Ecosystem Analysis and Prediction-Task Team\*
- DA evaluation metrics – Intercomparison and Validation-Task Team
- Coupled DA – Coupled Prediction-TT
- Global-to-regional downscaling and applications of DA – Coastal and Shelf Seas-Task Team

Coordinated activities:



Single T/S profile DA experiments:  
SST increments

Courtesy of Matt Martin, Met Office

## Some thoughts about the future

- Hybrid DA
- Coupled DA
- Planning for future observing platforms (e.g. SWOT, SKIM)
- DA of the sub-mesoscale
- Capitalize on available community resources:  
DART, OOPS, JEDI, PDAF, EnKF-C,...

DART: Data Assimilation Research testbed

OOPS: Object-Oriented Prediction Systems

JEDI: Joint Effort for Data assimilation Integration (JEDI)

PDAF: Parallel Data Assimilation Framework (PDAF)

EnKF-C: Ensemble Kálmán Filter in C