Impact of Atmospheric and Model Physics Perturbations On a High-Resolution Ensemble Data Assimilation System of the Red Sea

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Objective

- ✓ To demonstrate the importance of accounting various sources of uncertainty in ocean data assimilation systems.

- ✓ To provide improved high-resolution ocean reanalysis for the Red Sea (RS), which in turn help to improve ocean forecasts of the basin on a range of time scales.

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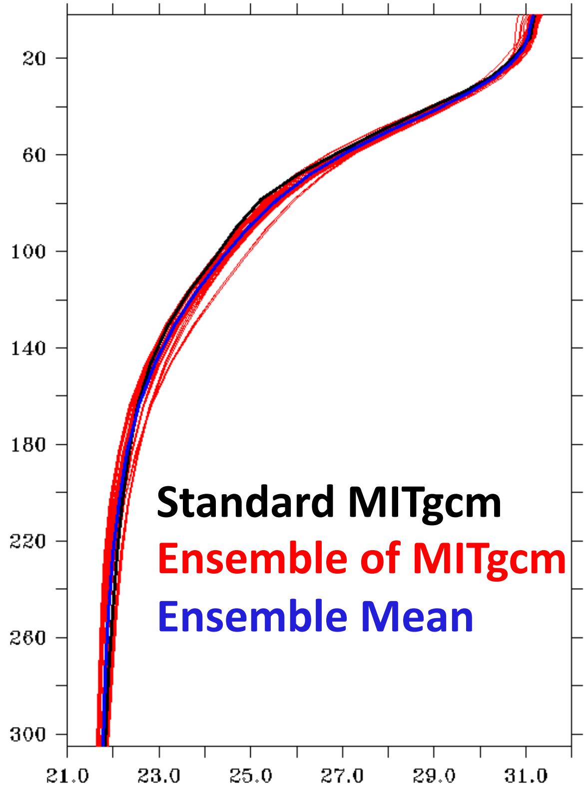
Quick look at the basic concept(s) related to the present study

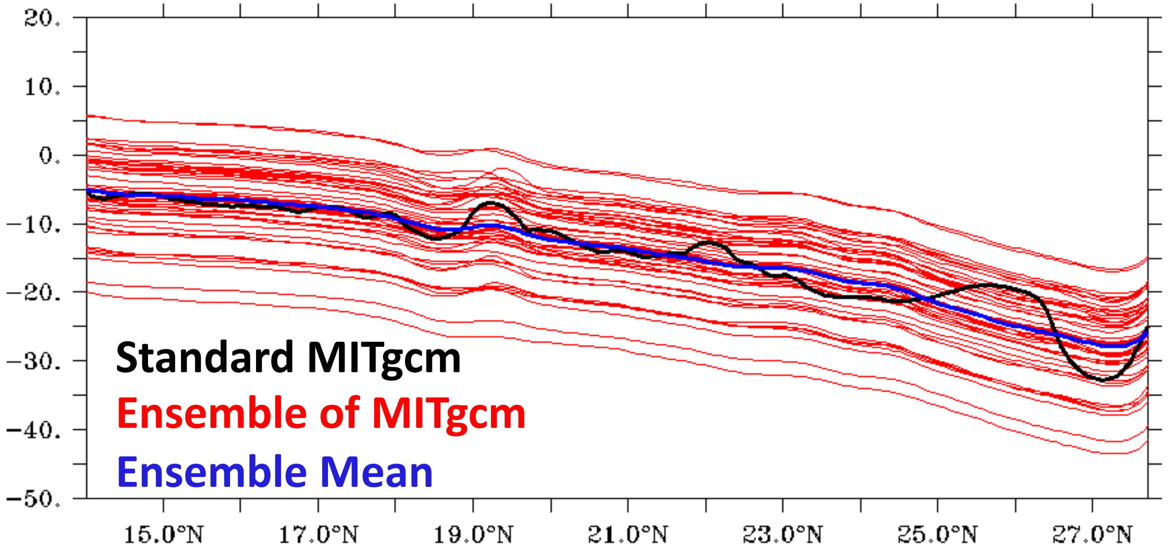
What are the Sources of **forecast errors** in Ocean models?

- Uncertainties/errors in
  - Ocean initial conditions
  - Atmospheric forcing
  - Model Physics
  - Open Ocean boundary conditions (more relevant for the regional models)
  - Bathymetry (more relevant near coast)

Temperature profile at an arbitrary location in the RS



Sea Surface Height (cm) at an arbitrary location in the RS



This information of uncertainty is an important input for ocean data assimilation

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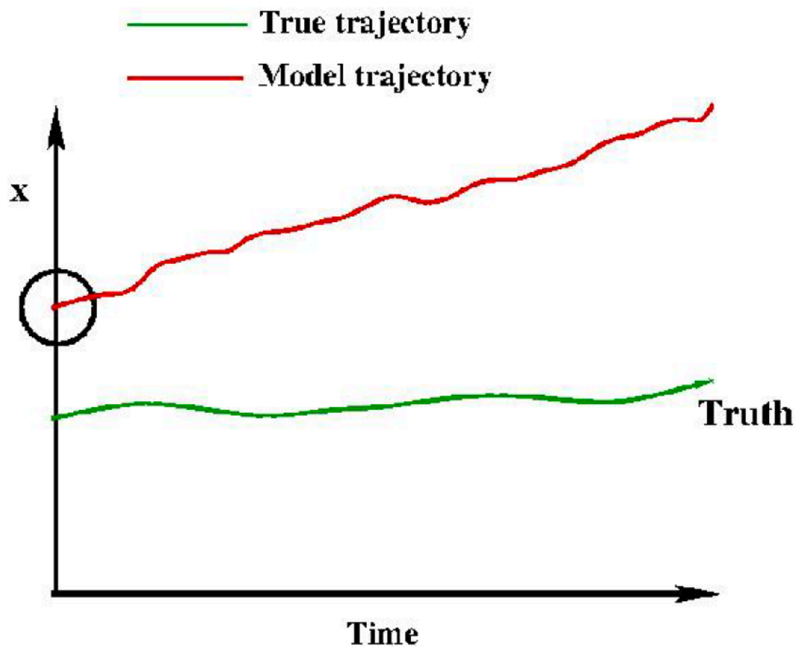
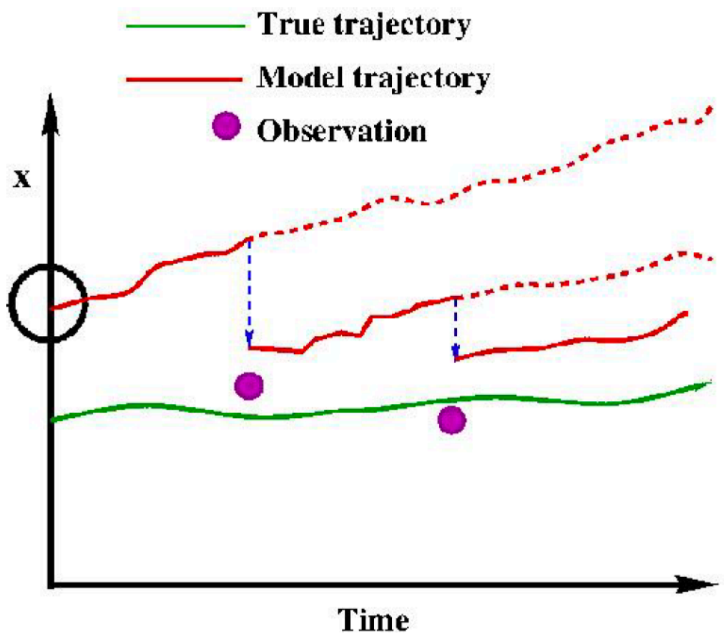
Data Assimilation: What does it do?



No Assimilation



Assimilation

Truth

Data Assimilation corrects the model trajectory based on sparse observations

$$X^a = X^b + BH^T[HBH^T + R]^{-1}[Y - HX^b]$$

X^a ----→ Analysis

X^b ----→ Forecast

Y ----→ Observations

H ----→ Transformation/Interpolation operator

B ----→ Forecast error covariance

R ----→ Observations error covariance

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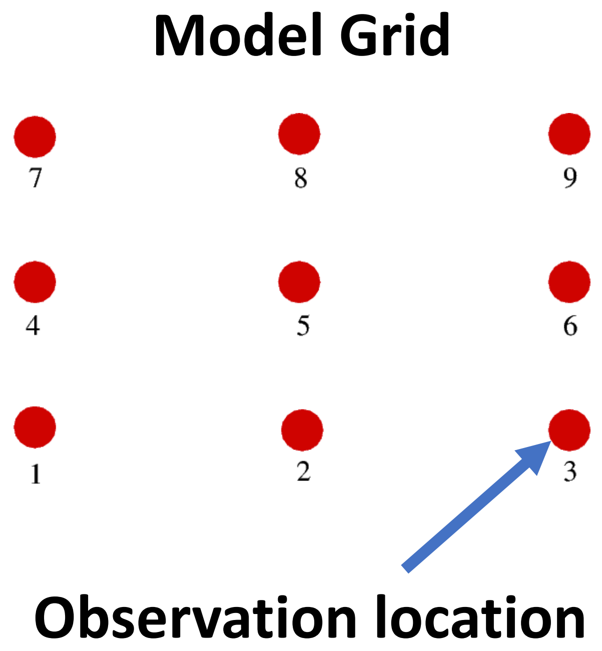
What is the Role of Forecast Error Covariance (**B**)?

$$X^a = X^b + BH^T[HBH^T + R]^{-1}[Y - HX^b]$$



$$X^b = \begin{bmatrix} x_1^b \\ x_2^b \\ x_3^b \\ \vdots \\ . \\ x_9^b \end{bmatrix}$$

$$Y = [y_o]$$

$$H = [0 \quad 0 \quad 1 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]$$

B=

$$\begin{bmatrix} B_{11} & B_{12} & . & . & B_{19} \\ B_{21} & B_{22} & : & : & B_{29} \\ B_{31} & B_{32} & B_{33} & . & . \\ . & . & . & . & . \\ . & . & . & . & B_{99} \end{bmatrix}$$

$$R = [\sigma_o^2]$$

$$\begin{bmatrix} x_1^a \\ x_2^a \\ x_3^a \\ \vdots \\ . \\ x_9^a \end{bmatrix} = \begin{bmatrix} x_1^b \\ x_2^b \\ x_3^b \\ \vdots \\ . \\ x_9^b \end{bmatrix} + \begin{bmatrix} B_{13} \\ B_{23} \\ B_{33} \\ \vdots \\ . \\ B_{93} \end{bmatrix} \frac{(y_o - x_3^b)}{(B_{33} + \sigma_o^2)}$$

B propagates observations information from one grid/location/variable to another

Brief description about the assimilation system and Experiments conducted

Configuration of Red Sea Data Assimilation System

- Model: 4km-MITgcm
- Assimilation: DART with Ensemble Adjustment Kalman Filter (EAKF)
- Ensemble members: 50
- Localization: ~300 km in the horizontal; No vertical localization
- Inflation: 1.1 (10%)
- Observations assimilated:
  - Satellite Level-4 Reynolds SST. Observation error used is between **0.1 to 0.6 degC**
  - Satellite Level-3 altimeter SLA (merged). Observation error used is **4cm**.
  - In situ T & S profiles from EN4 dataset (fully QC'd). Observation error used for T & S profiles is **0.5 degC and 0.2 psu** respectively
- Initial conditions : 1st Jan, 2011
  - Free model: WRF5km evolved simulation
  - MITDART: 50 ensembles prepared based on hind casts re-centered on 1st Jan, 2011
- Forcing
  - Free model: Ensemble (50) mean of ECMWF 0.5 x 0.5 perturbed forcing
  - MITDART: ECMWF 0.5 x 0.5 perturbed forcing (50 members)
- OBCS: Daily averaged ocean state from 25km-resolution GLORYS ocean reanalysis
- Length of Experiments: 1 year starting from 1st Jan, 2011

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Configuration of Experiments

Experiment	Initial condition	Atm. Forcing	Physics	Assimilation
Fexp	Single. 1st Jan, 2011	Ensemble mean	STANDARD	No
Iexp	50-member ensemble based on hindcasts recentered for 1st Jan, 2011.	Ensemble mean	STANDARD	Yes
IAexp	50-member ensemble based on hindcasts recentered for 1st Jan, 2011.	50-member ensemble	STANDARD	Yes
IAPexp	50-member ensemble based on hindcasts recentered for 1st Jan, 2011.	50-member ensemble	RANDOM across members (multi-model monthly OBCS were used)	Yes

Iexp → Uncertainties accounted only from Initial conditons
IAexp → Uncertainties accounted from Initial conditions and atmospheric forcing
IAPexp → Uncertainties accounted from Initial conditions, atmospheric forcing, and model physics

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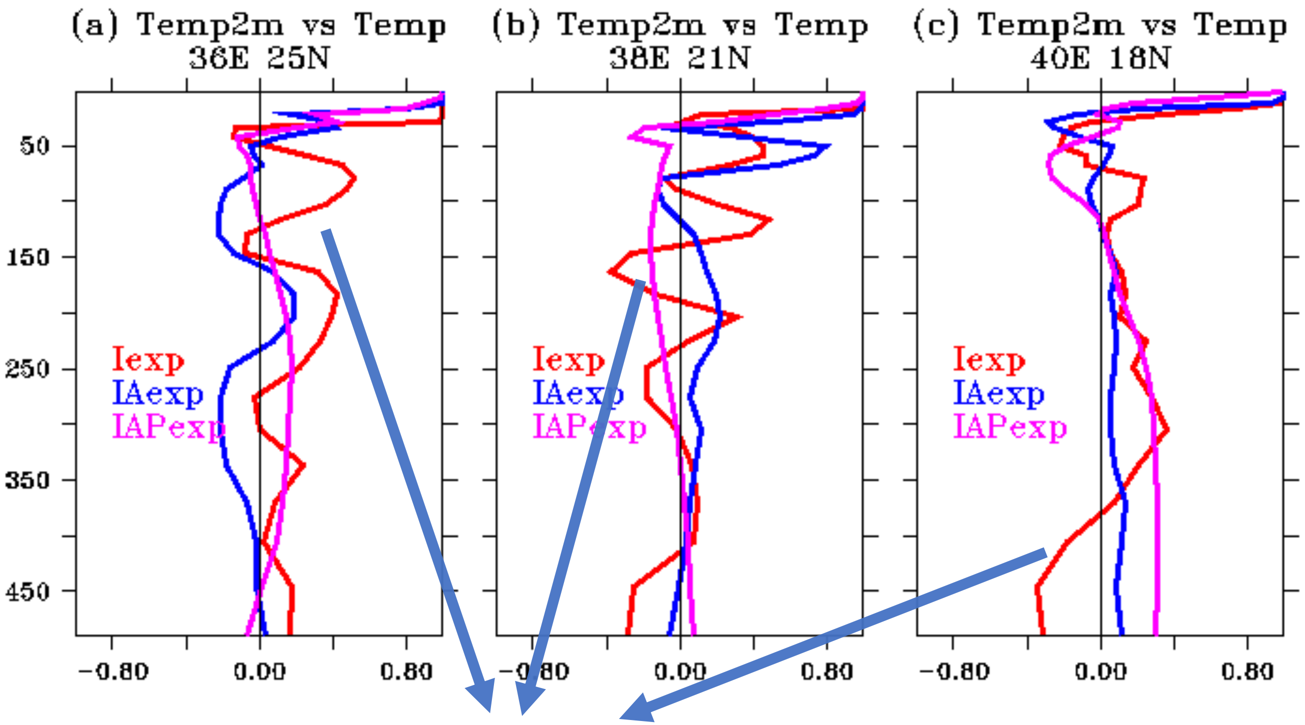
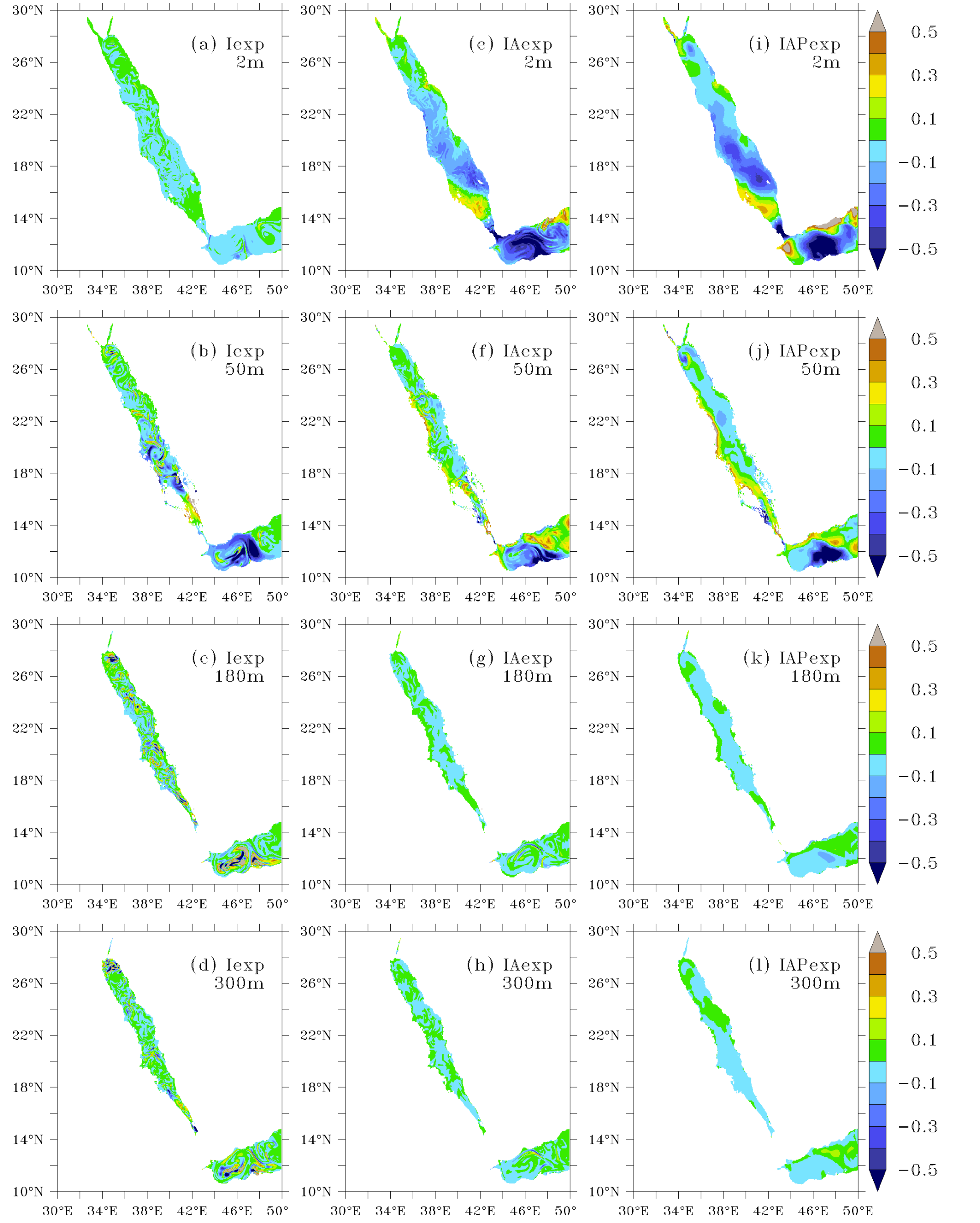
Results highlighting the improvements in *IAPexp* compared to other experiments

Analysis corrections on 1st October, 2011

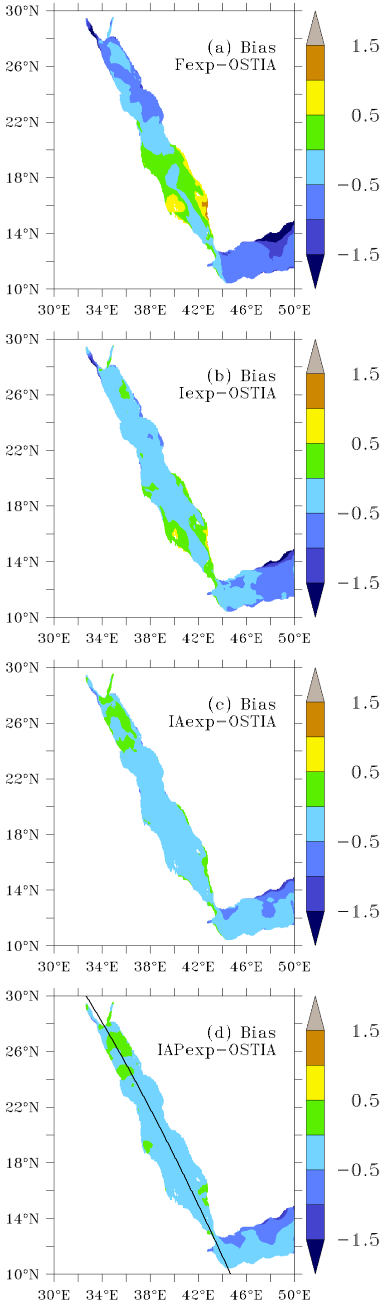
Anomaly correlations within Ensemble on 1st October, 2011



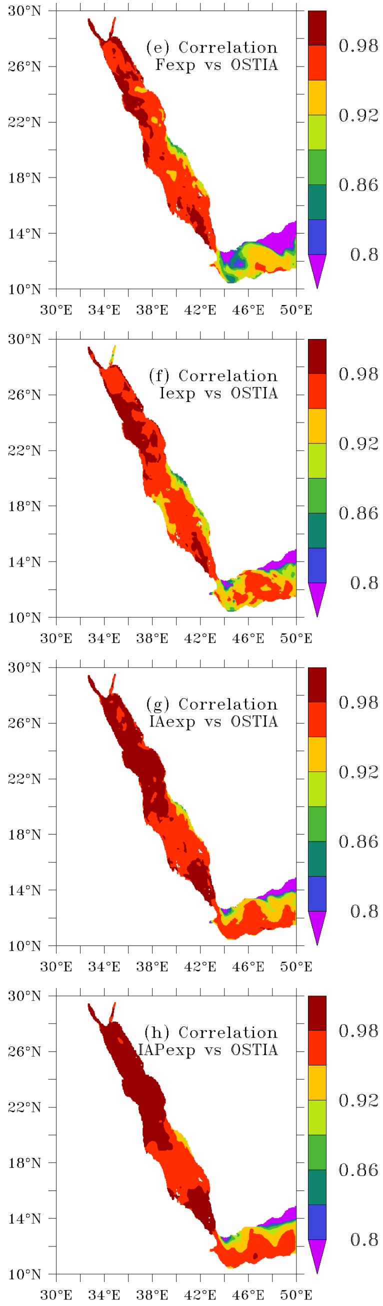
Too Noisy correlations in *Iexp* become more organized in *IAPexp*.



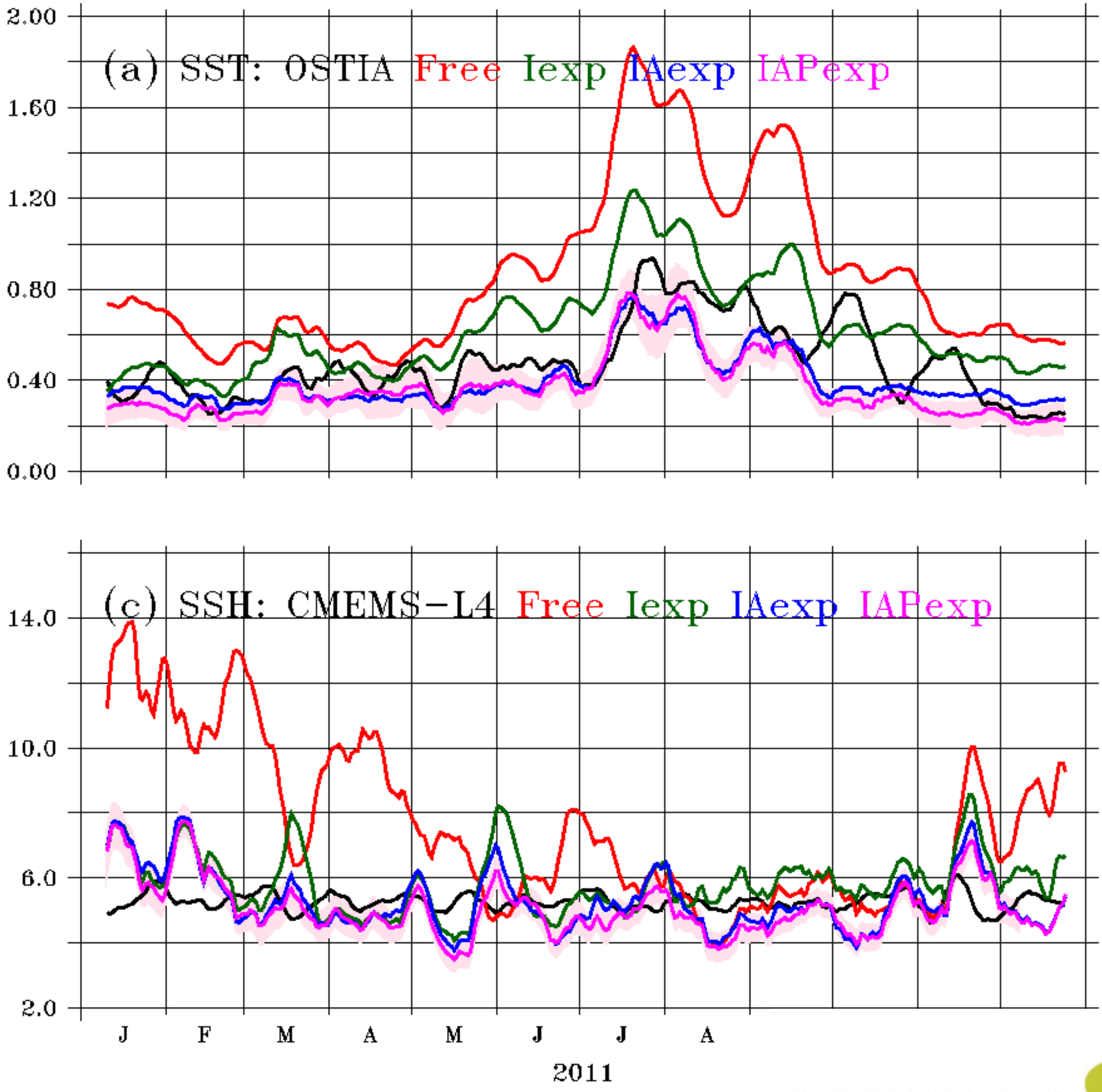
SST bias



SST Correlation



Root Mean Square Differences



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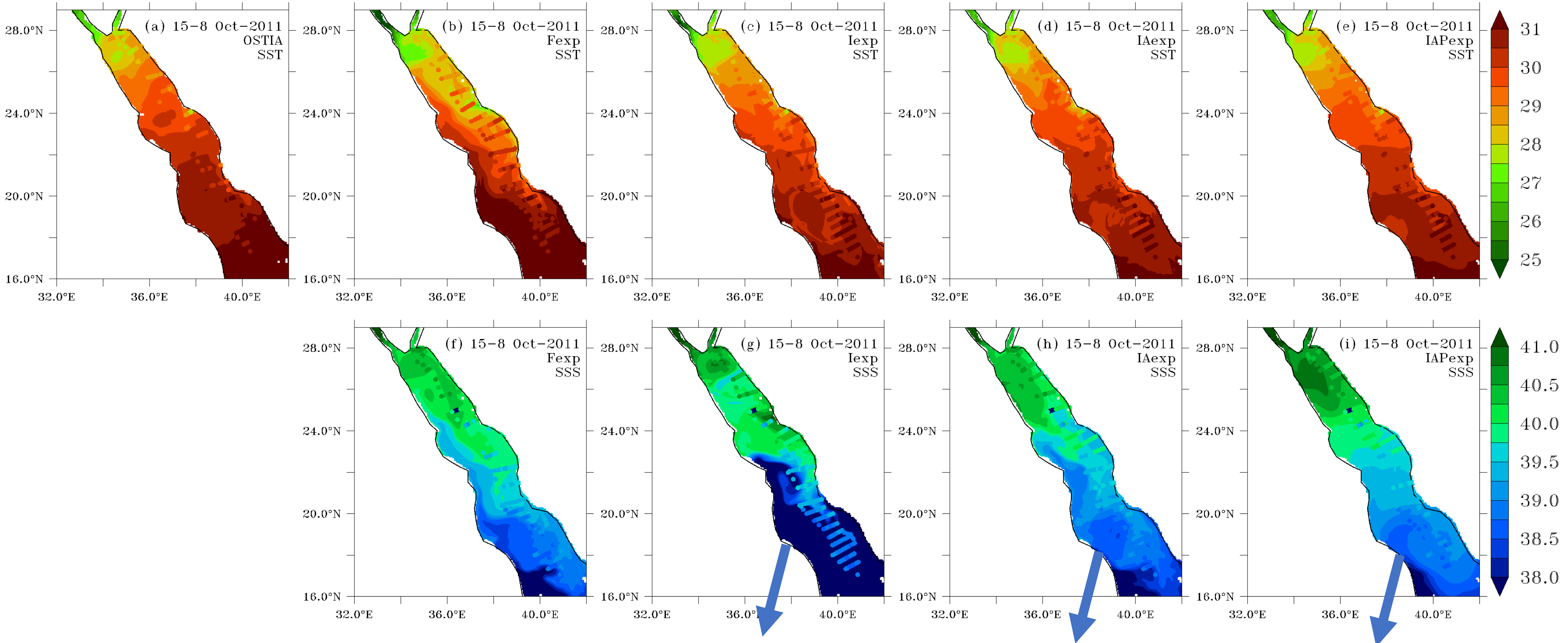
Comparisons with in-situ SST and SSS observations during WHOI/KAUST cruise

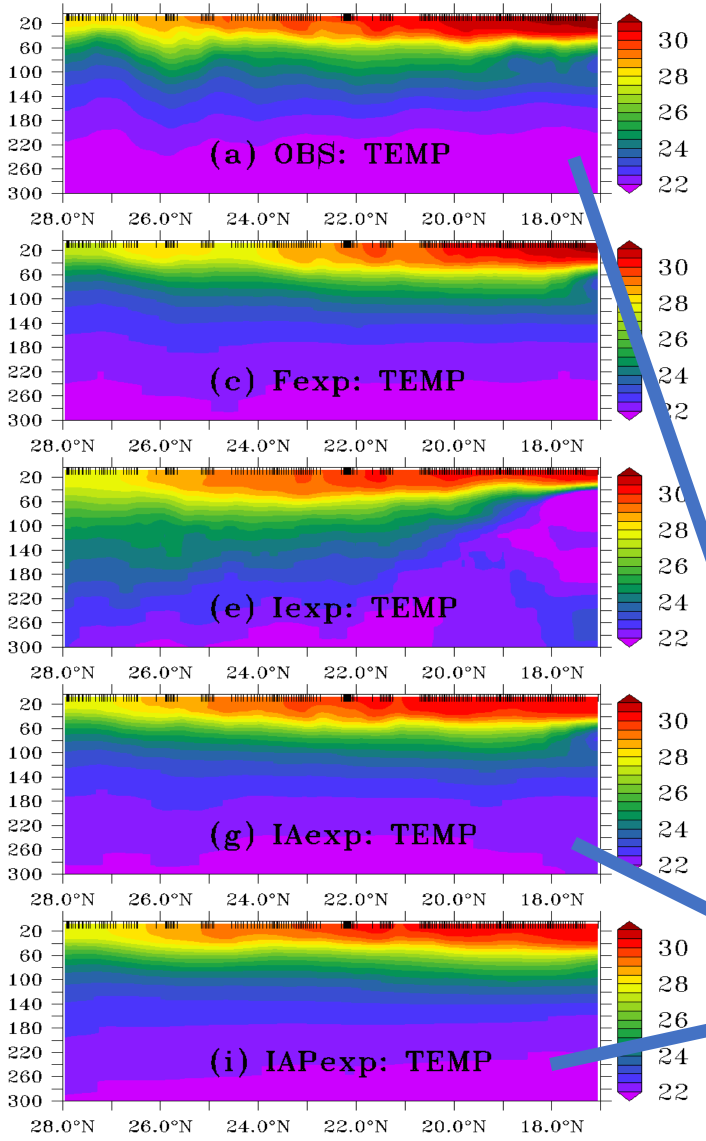


Noisy and too anomalous

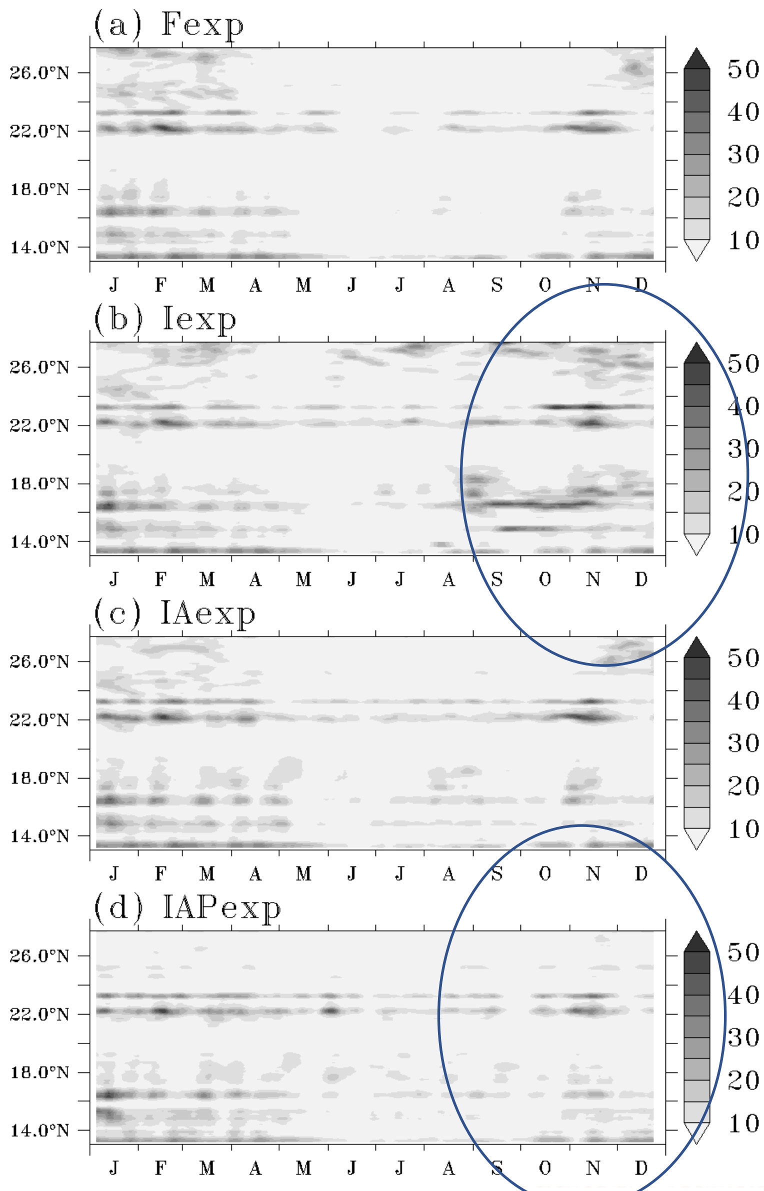
Slightly Noisy

Less Noisy and more organized

Subsurface Temperature comparisons during WHOI/KAUST cruise

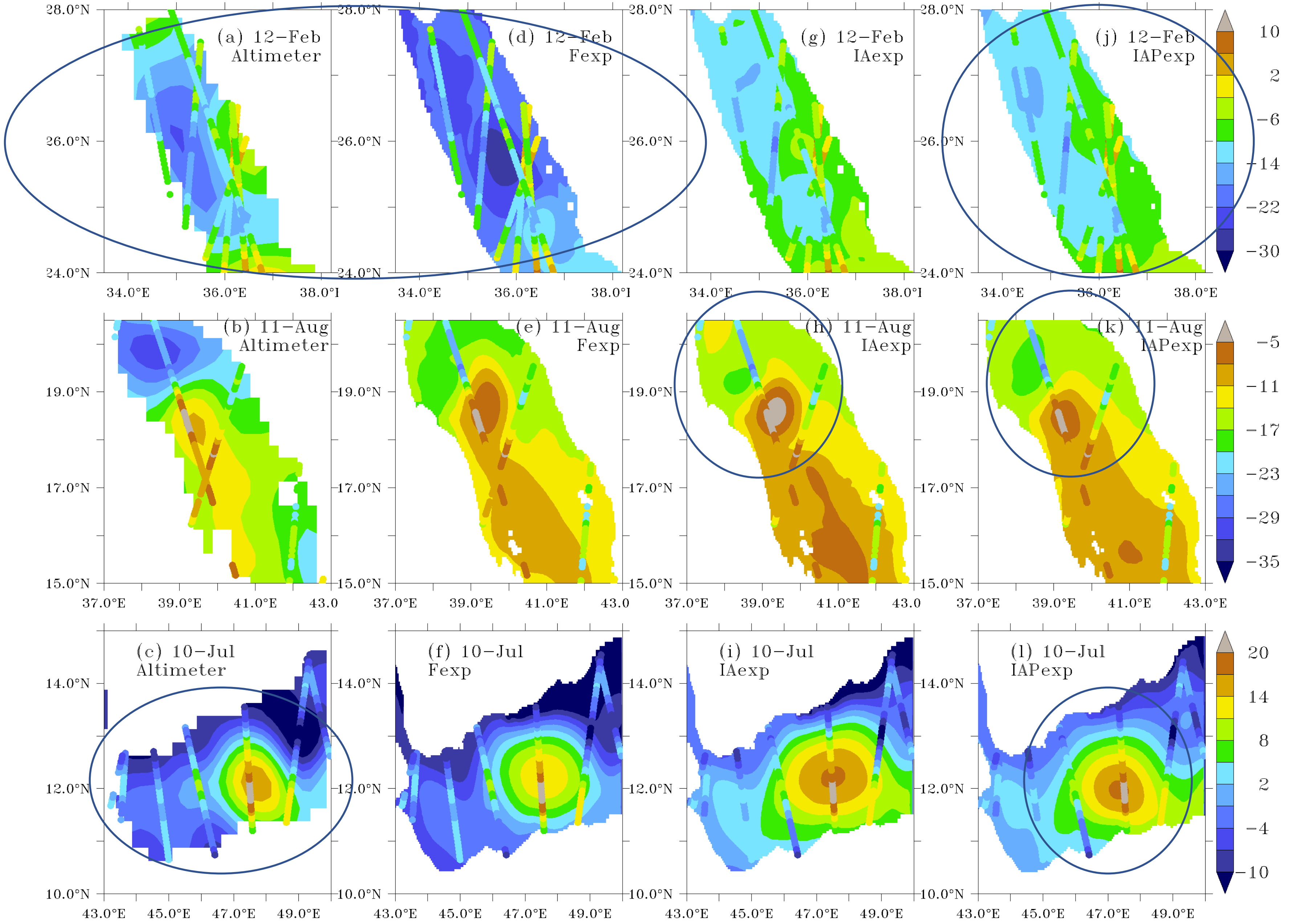


Maximum Vertical Velocity in the ocean column along RS axis



Improved biases in the deep layers with *IAPexp*

SSH Comparisons with along-track observations



IAPexp is better than interpolated level-4 product of AVISO.

Also, It represents the basin scale eddies better than any other experiment.

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Conclusions

- ✓The old “perturbing initial conditions alone” strategy yields minimal SST improvements and creates large imbalances within the ocean state.

- ✓Admitting additional source of uncertainty, atmospheric forcing, yields substantial improvements.

- ✓Admitting the uncertainties in model physics, atmospheric forcing, and initial conditions not only yield substantial improvements but obtains more dynamically balanced solutions. It improves basin scale eddy features too.

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