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EnKF vs. EnOIs for data assimilation in the Red Sea and Sensitivity to Atmospheric Forcing

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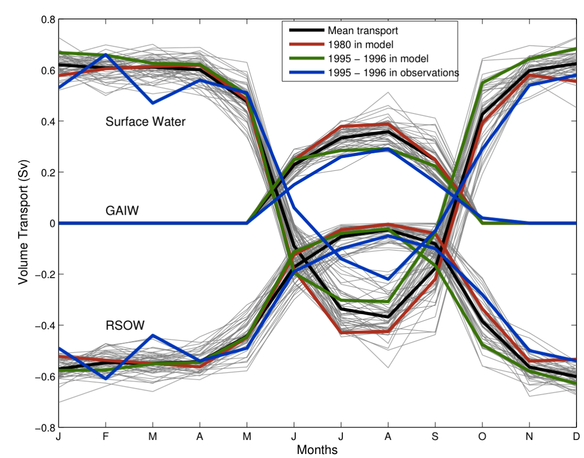
Outline

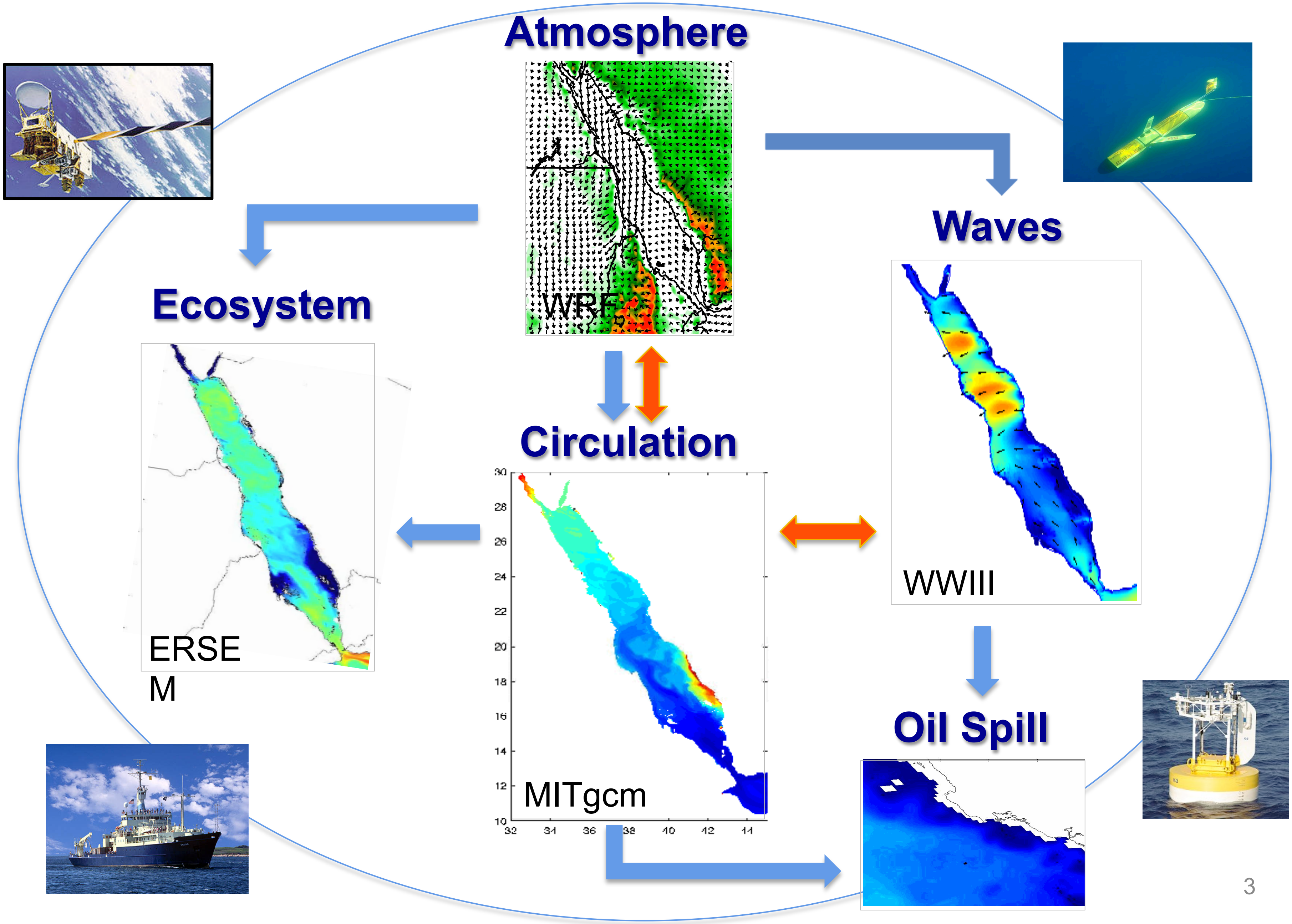
- **Introduction**
- **Model & Data**
- **EnKF & EnOI**
- **Results**
- **Future work & Acknowledgement**

Introduction – The Red Sea

- Long (2250km) and narrow (~300km) basin
- Extensive evaporation (>2m/year)
- Seasonal wind regime due to Indian Monsoon
- Significant (overturning) seasonality
- Rich in eddies



The Red Sea Assimilation and Forecasting System



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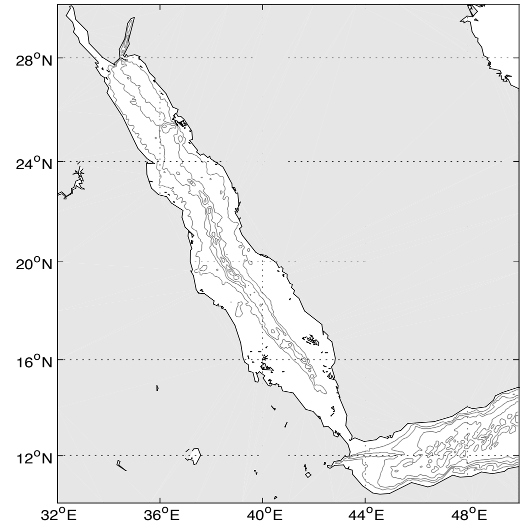
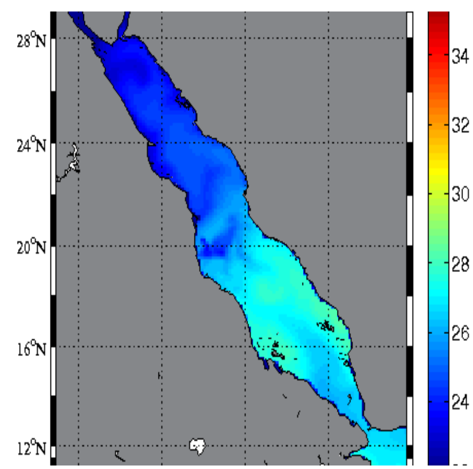
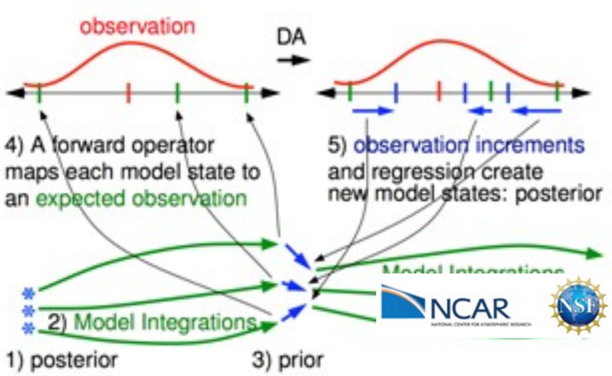
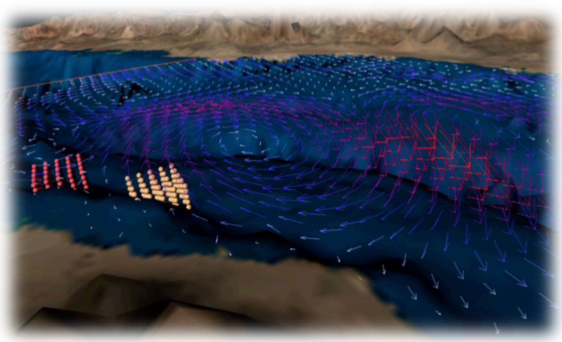
Model & DART

- MITgcm 0.04°
- 6-hourly ECMWF reanalysis 0.75°
- 6-hourly NCEP 1.75°
- ECCO2 (OBCS)
- Ensemble data assimilation
- Data Assimilation Research Testbed (DART)

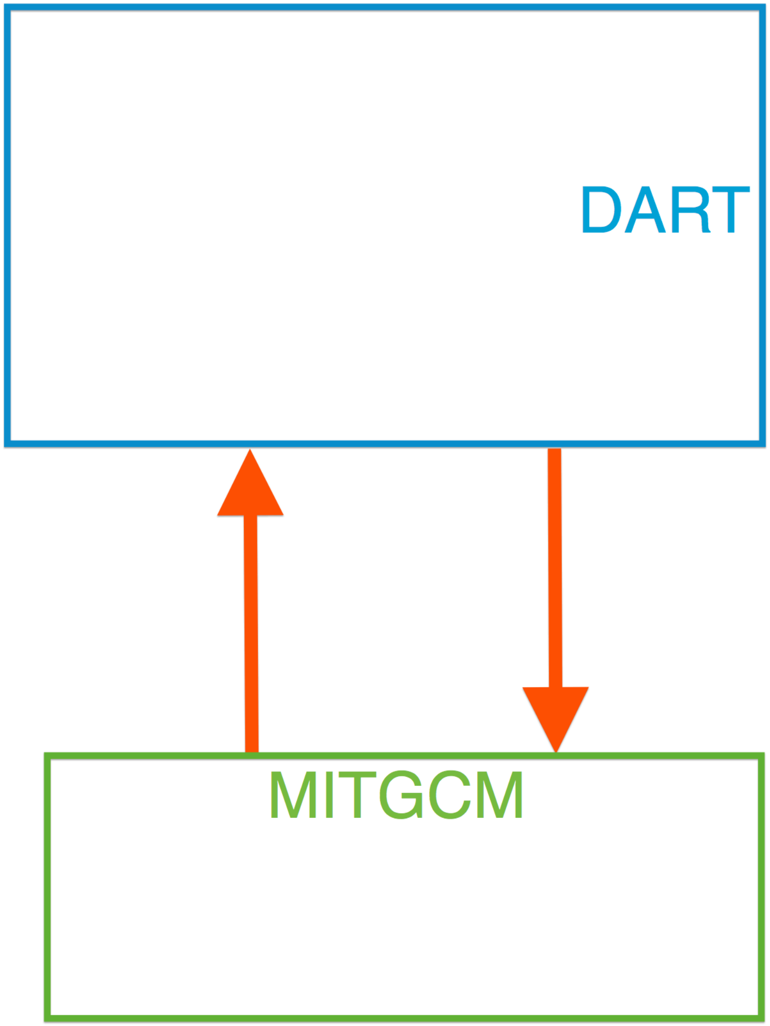




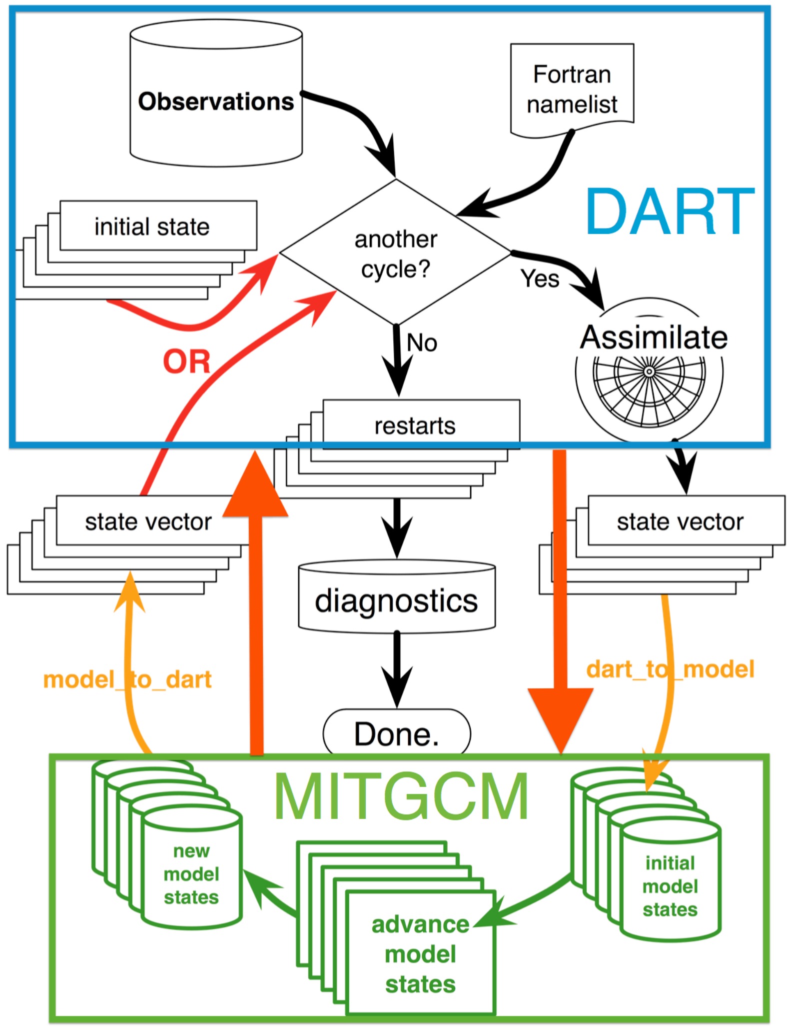




Model & DART

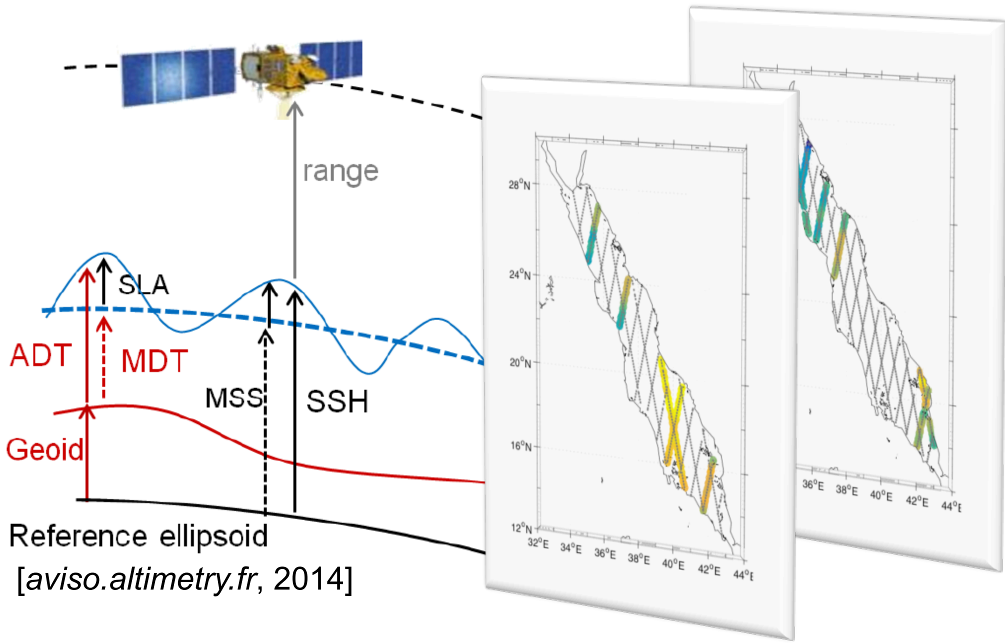


Model & DART

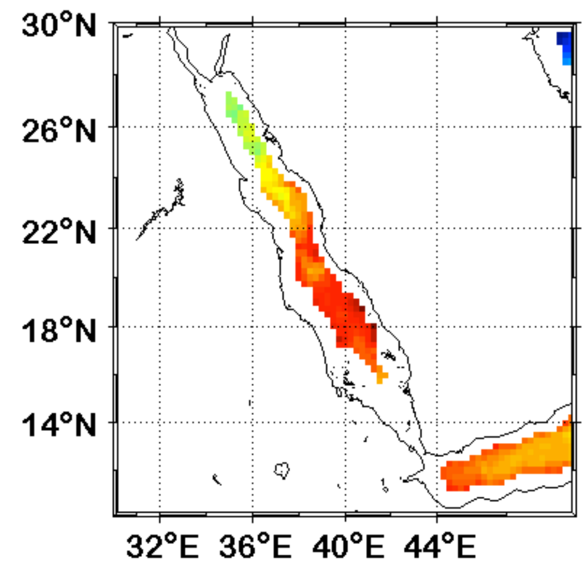


Observations
Fortran namelist
DART
initial state
another cycle?
Yes
No
Assimilate
OR
restarts
state vector
state vector
diagnostics
model_to_dart
dart_to_model
Done.
MITGCM
new model states
advance model states
initial model states

Assimilated observations – SSH & SST



[*aviso.altimetry.fr*, 2014]



- Radar Altimeter Database System (RADS)
- SLA + MSS
- Merged product from 12 satellites
- Assimilate every 3 days

- TRMM Microwave Imager (TMI)
- 1/4° × 1/4°
- Midnight data
- Assimilate every 3 days

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EnKF

EKF Forecast

$$\mathbf{x}^f(t_i) = M_{i-1}\left[\mathbf{x}^a(t_{i-1})\right]$$

$$\mathbf{P}^f(t_i) = \mathbf{L}_{i-1}\mathbf{P}^a(t_{i-1})\mathbf{L}^T{}_{i-1} + \mathbf{Q}(t_{i-1})$$

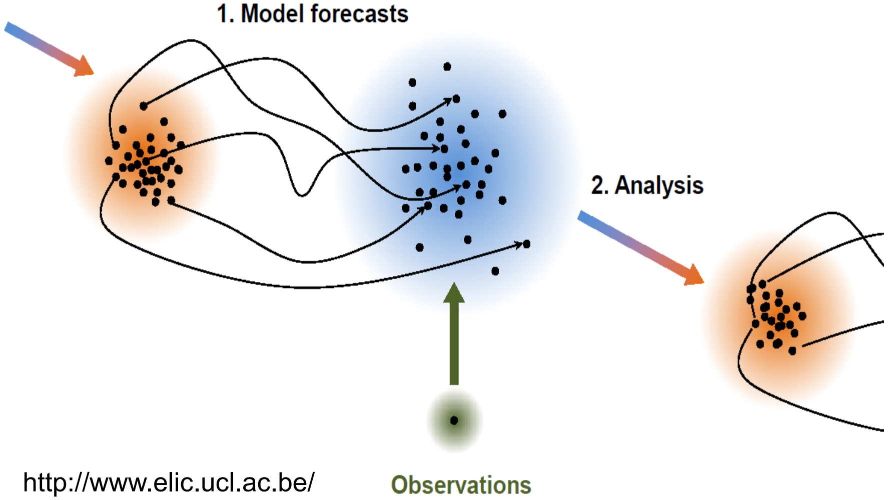
EnKF Forecast

$$\mathbf{x}_k^f(t_i) = M_{i-1}^k(\mathbf{x}_k^a(t_{i-1})) + \eta$$

$$\mathbf{P}^f \approx \frac{1}{N-1}\sum_{k=1}^{K}\left(\mathbf{x}_k^f - \overline{\mathbf{x}}^f\right)\left(\mathbf{x}_k^f - \overline{\mathbf{x}}^f\right)^T$$

- To sample the uncertainty
- To approximate the estimation error covariance P^f

Flow dependent



http://www.elic.ucl.ac.be/modx/elic

Analysis

$$\mathbf{x}^a(t_i) = \mathbf{x}^f(t_i) + \mathbf{K}_i\mathbf{d}_i$$

$$\mathbf{K}_i = \mathbf{P}^f(t_i)\mathbf{H}_i^T(\mathbf{R}_i + \mathbf{H}_i\mathbf{P}^f(t_i)\mathbf{H}^T)^{-1}$$

$$\mathbf{d}_i = \mathbf{y}_i^o - H(\mathbf{x}^f(t_i))$$

$$\mathbf{P}^f\mathbf{H}^{\mathrm{T}} = \frac{1}{N-1}\sum_k^N[\mathbf{x}_k^f - \overline{\mathbf{x}}^f][H(\mathbf{x}_k^f) - \overline{H(\mathbf{x}^f)}]^{\mathrm{T}}$$

$$\mathbf{H}\mathbf{P}^f\mathbf{H}^{\mathrm{T}} = \frac{1}{N-1}\sum_k^N[H(\mathbf{x}_k^f) - \overline{H(\mathbf{x}^f)}][H(\mathbf{x}_k^f) - \overline{H(\mathbf{x}^f)}]^{\mathrm{T}}$$

EnOI

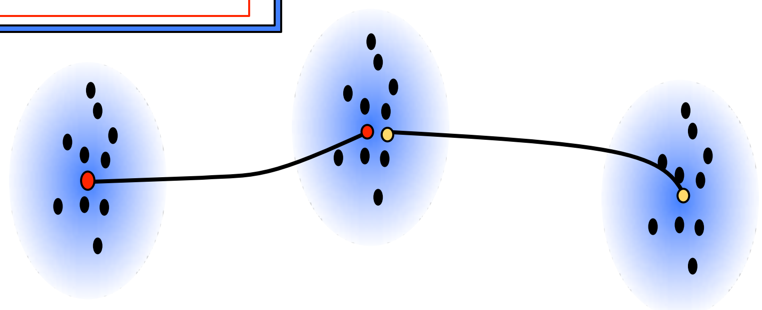
- **OI** + error covariance estimated from static **En**semble

$$\mathbf{x}^a(t_i) = \mathbf{x}^f(t_i) + \mathbf{K}_i\mathbf{d}_i \qquad \mathbf{K}_i = \mathbf{P}^f(t_i)\mathbf{H}_i^T(\mathbf{R}_i + \mathbf{H}_i\mathbf{P}^f(t_i)\mathbf{H}^T)^{-1}$$

$$\mathbf{P}^f \approx \frac{1}{N-1}\sum_{k=1}^{K}\left(\mathbf{x}_k^f - \overline{\mathbf{x}}^f\right)\left(\mathbf{x}_k^f - \overline{\mathbf{x}}^f\right)^T$$

Estimated from a static ensemble

- **Only one integration of the analysis.**

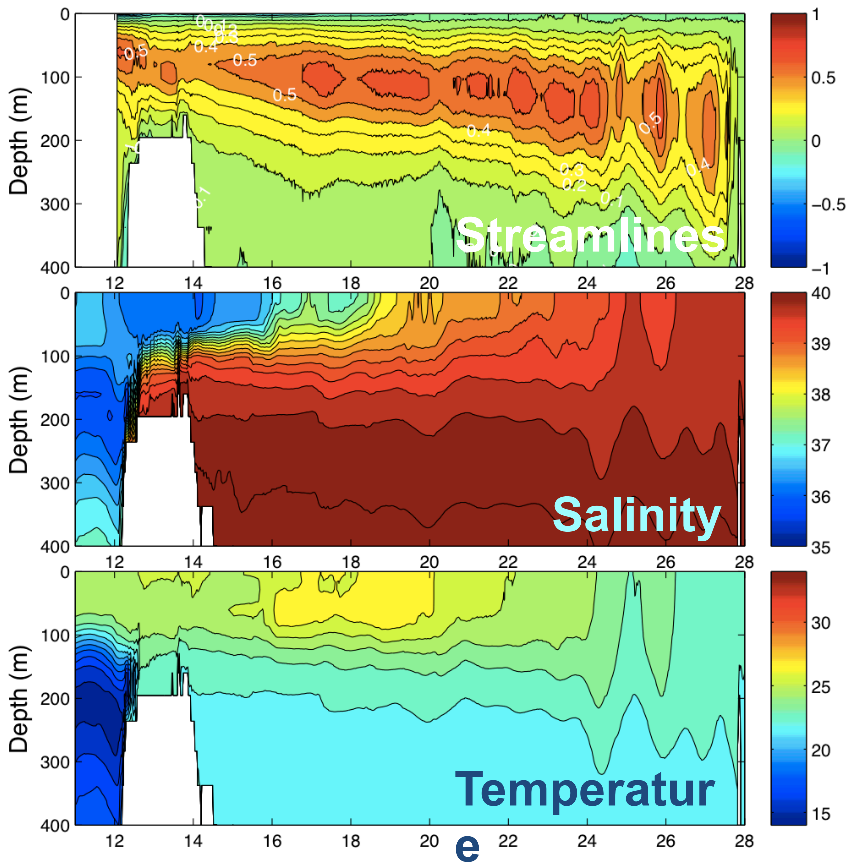


I. Inflation (1.1) is needed for EnKF, but not for EnOI.

II. In practice, for both EnKF and EnOI, assimilate the observations “locally” to mitigate for limited ensemble size and spurious correlations

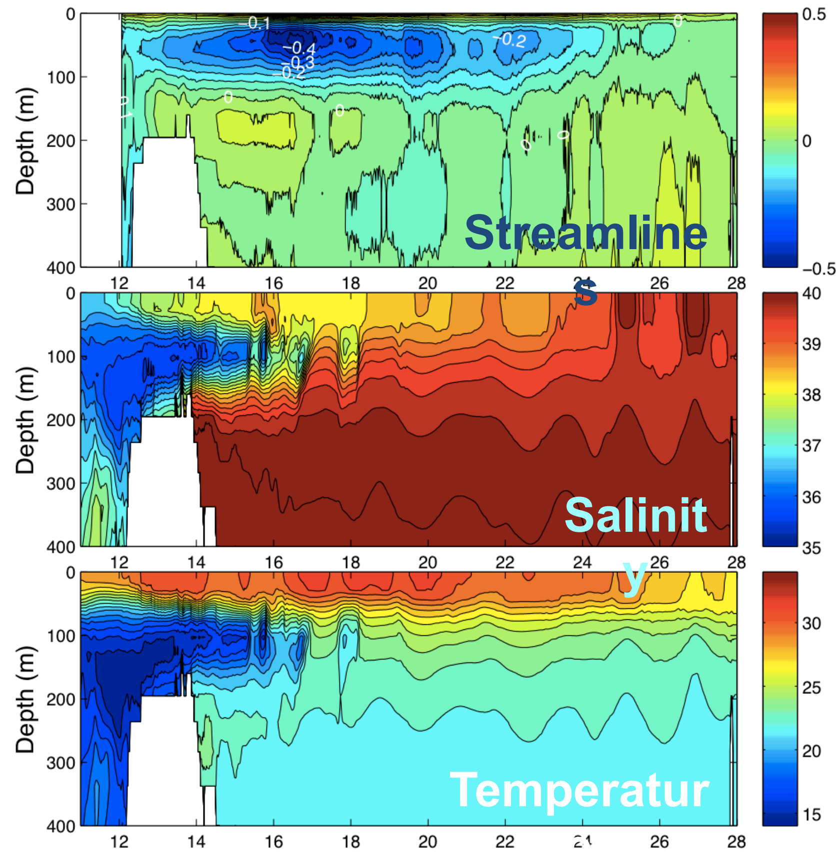
Seasonal Overturning Circulation

Winter



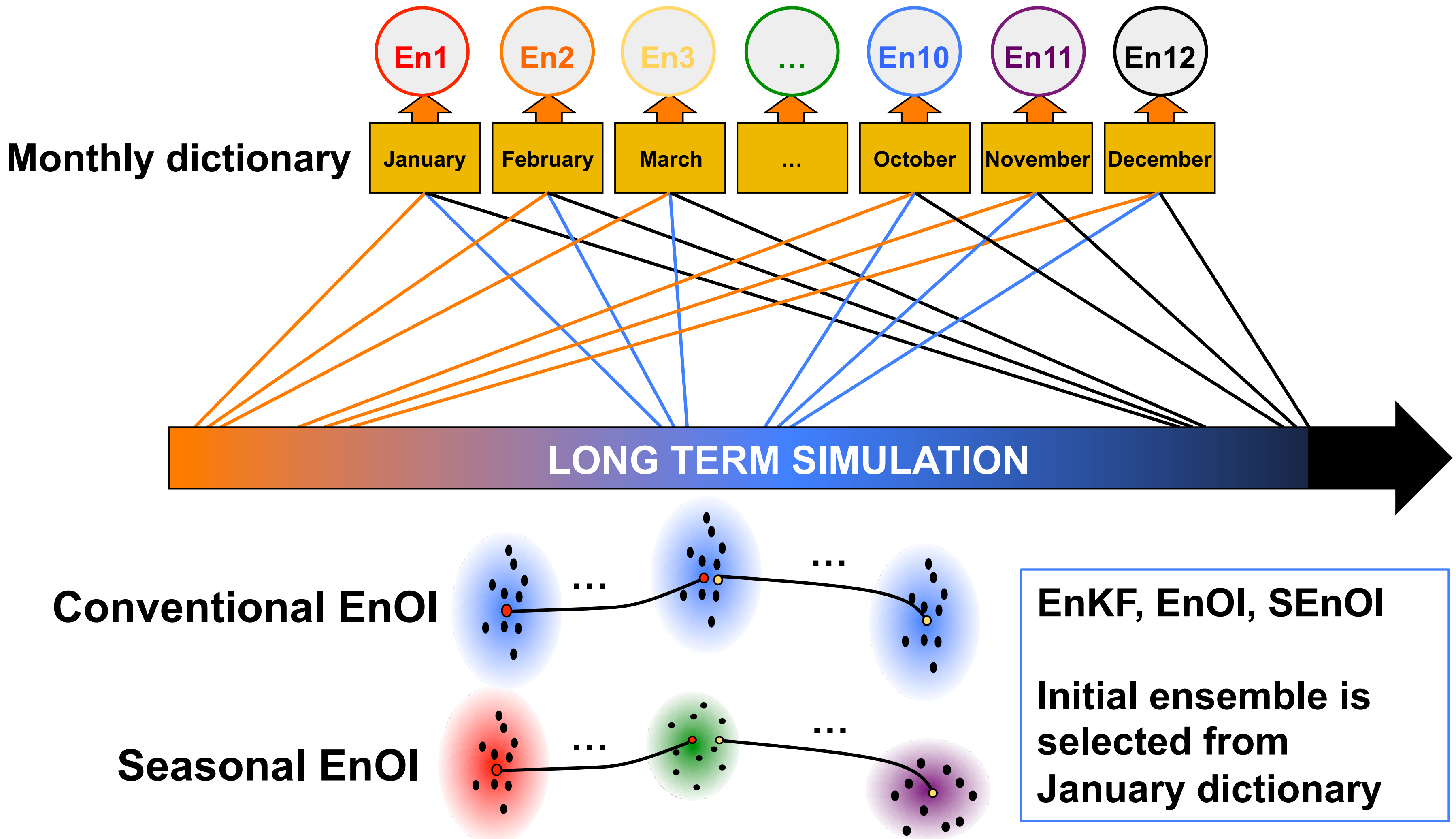
Salty and relatively cold water in the northern Red Sea drives a south-north overturning circulation

Summer



Upwelling in the GoA due to Indian monsoon and winds in the Red Sea reverses winter overturning

Seasonal EnOI



EnKF, EnOI, SEnOI

Initial ensemble is selected from January dictionary

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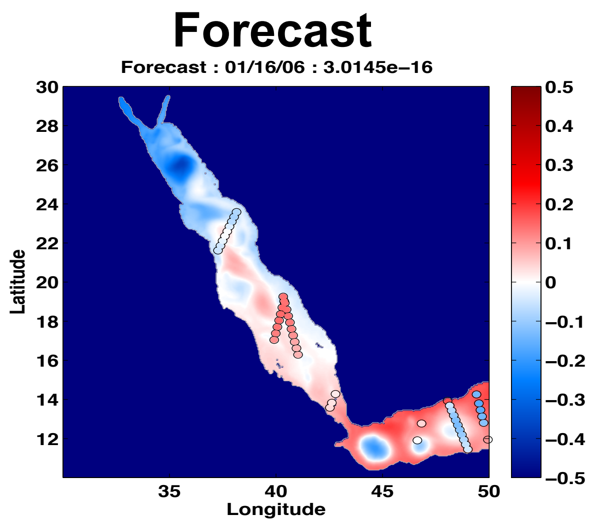
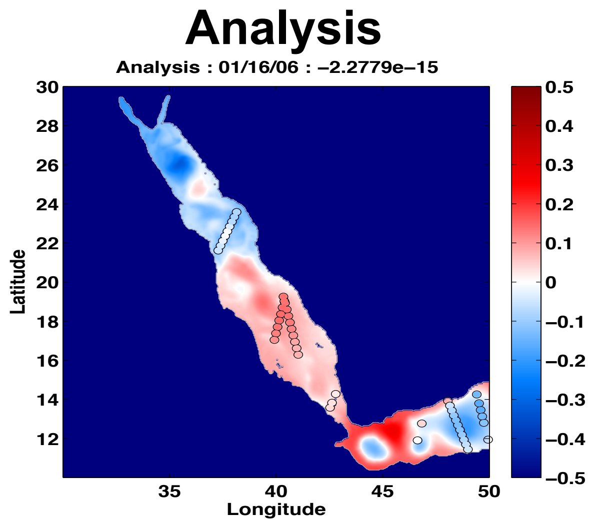
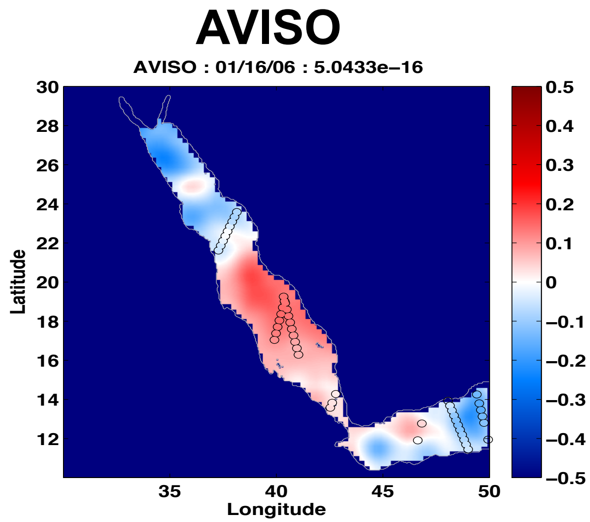
s6



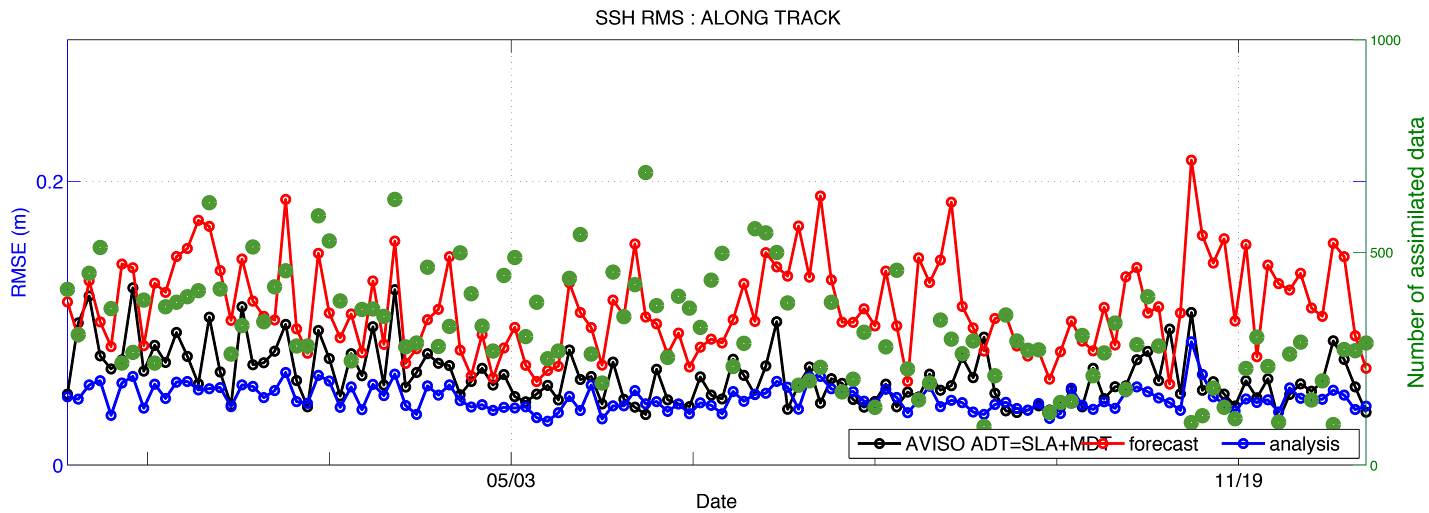
Forecast
Forecast : 01/16/06 : 3.0145e−16
Latitude
Longitude



Analysis
Analysis : 01/16/06 : −2.2779e−15
Latitude
Longitude

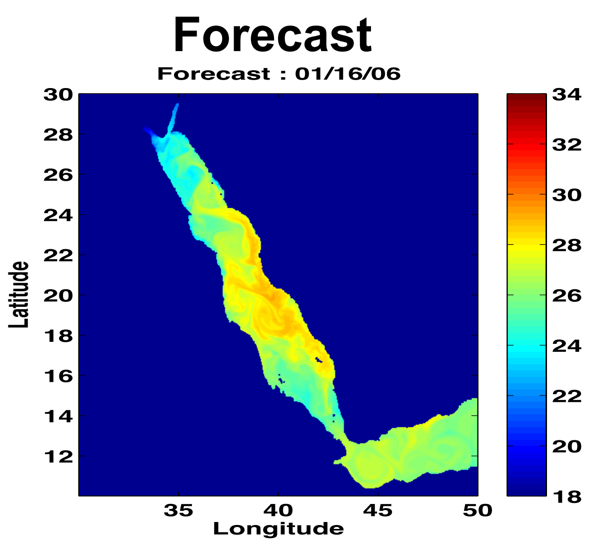


AVISO
AVISO : 01/16/06 : 5.0433e−16
Latitude
Longitude

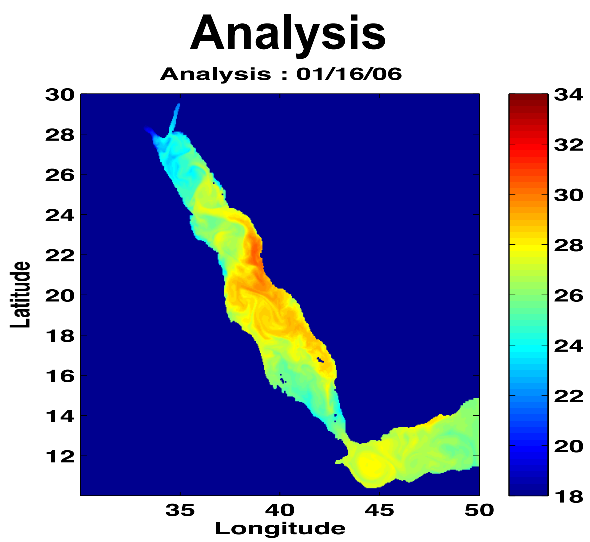


SSH RMS : ALONG TRACK
RMSE (m)
Number of assimilated data
Date
05/03
11/19
AVISO ADT=SLA+MDT
forecast
analysis

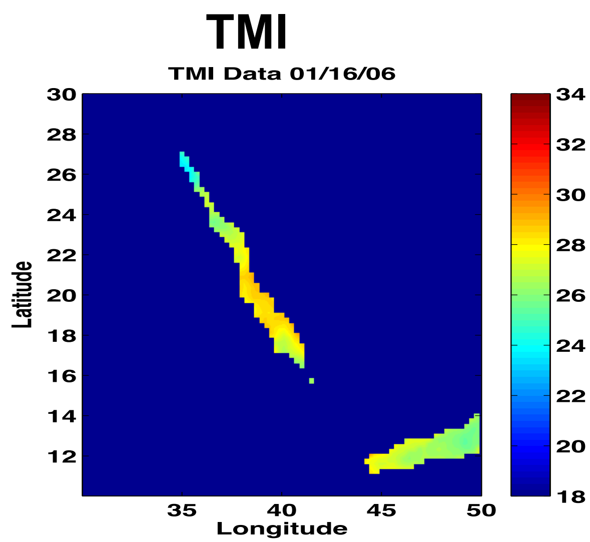
s6



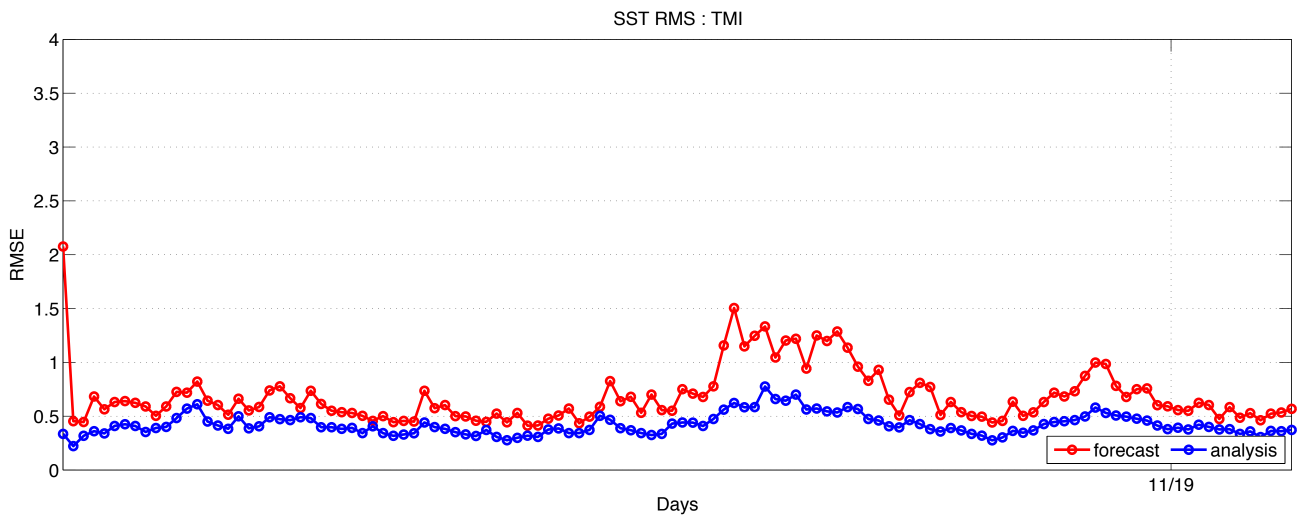
Forecast
Forecast : 01/16/06
Latitude
Longitude



Analysis
Analysis : 01/16/06
Latitude
Longitude

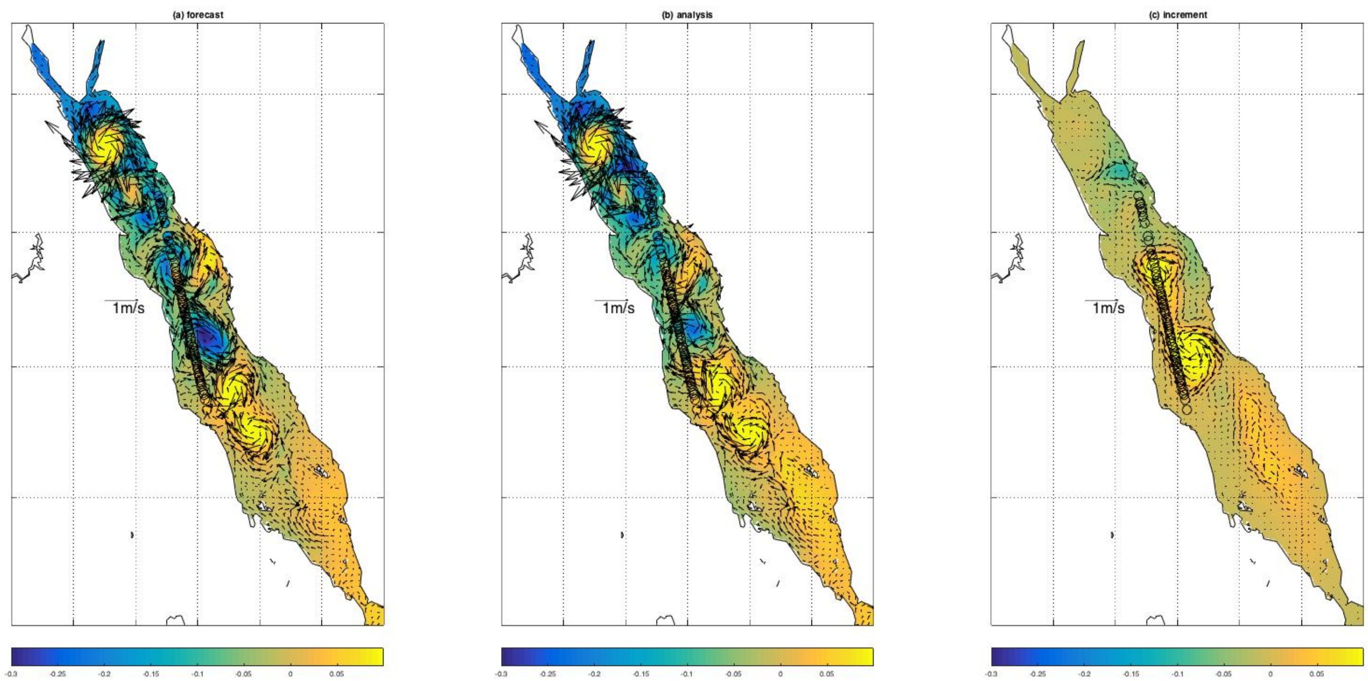


TMI
TMI Data 01/16/06
Latitude
Longitude

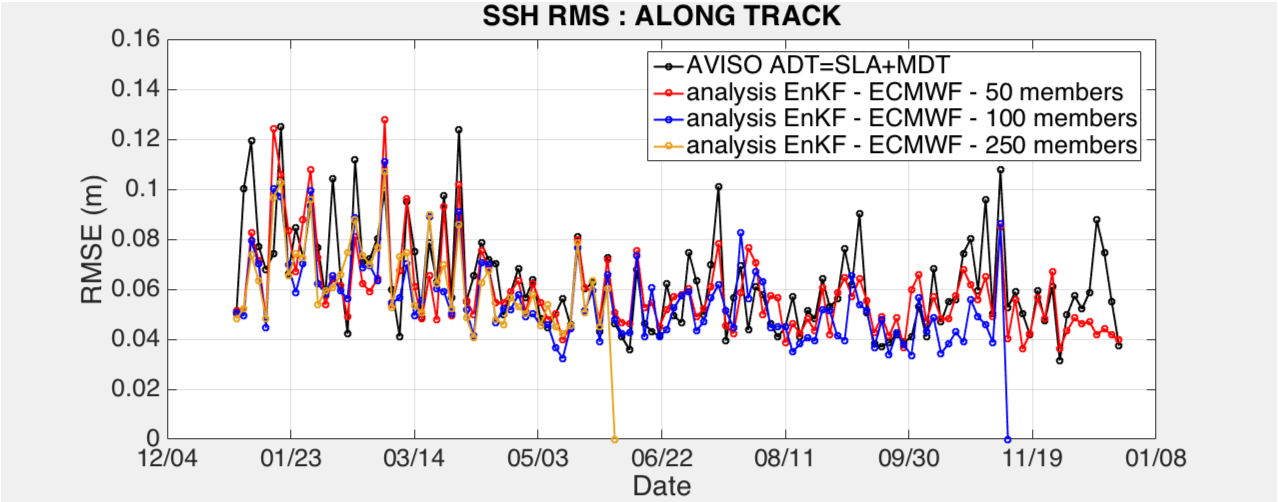


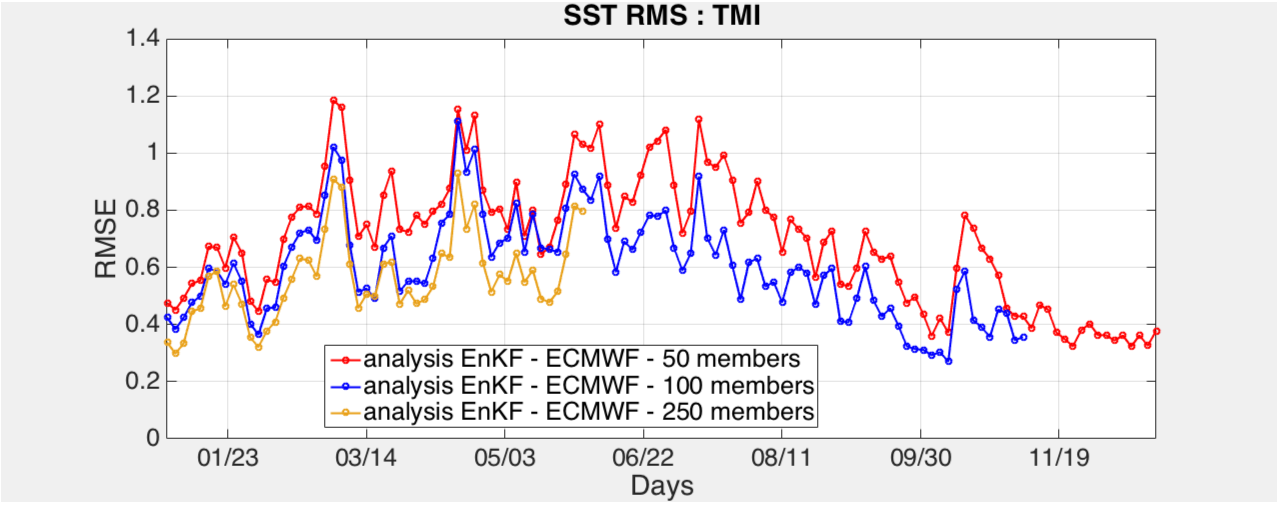
SST RMS : TMI
RMSE
Days
11/19
forecast
analysis

Correction in observed regions

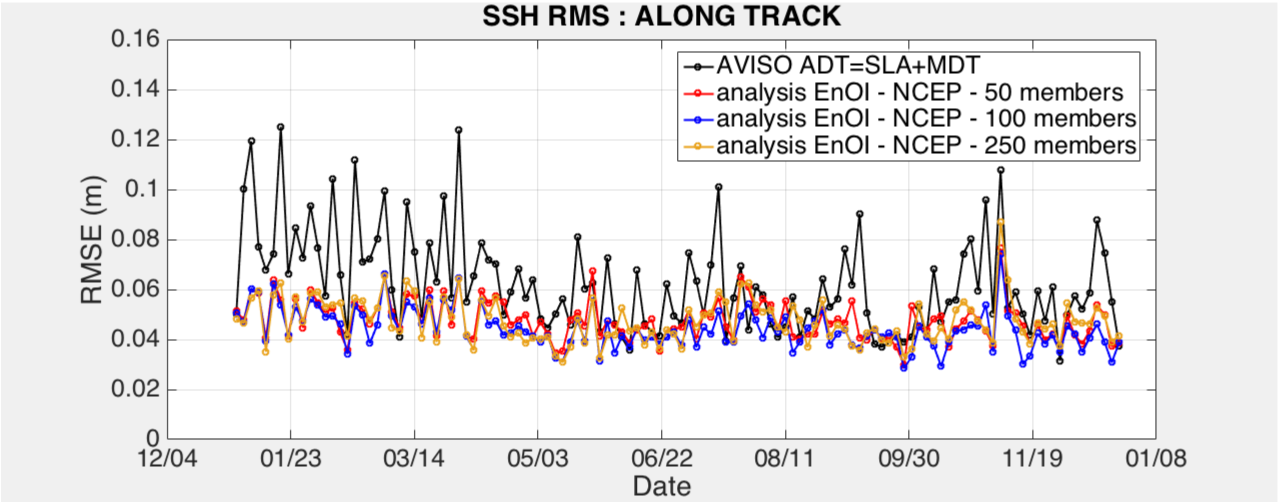


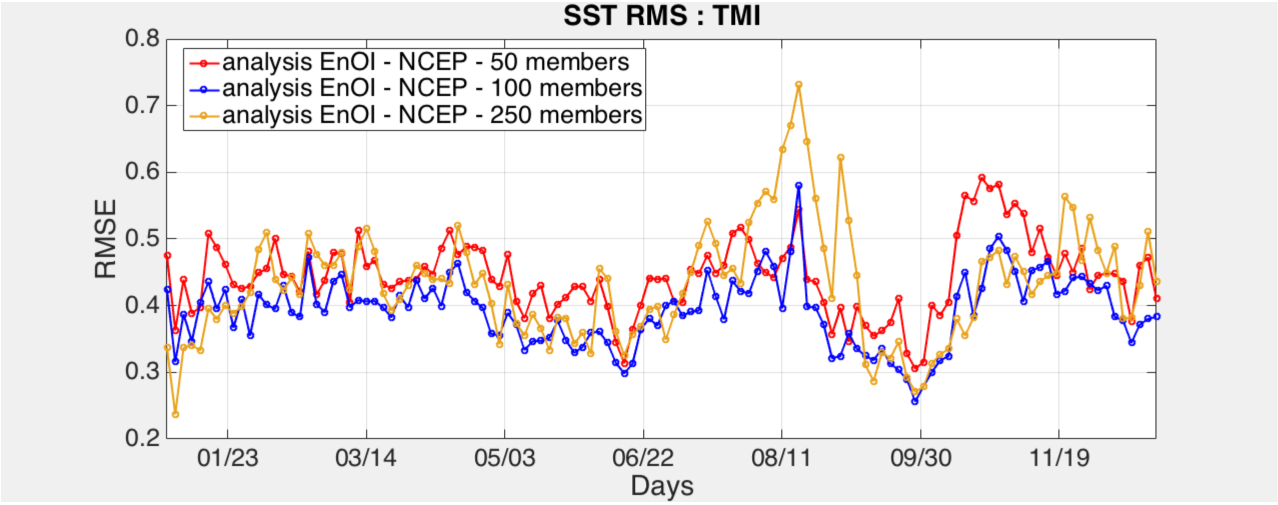
Impact of ensemble size in EnKF



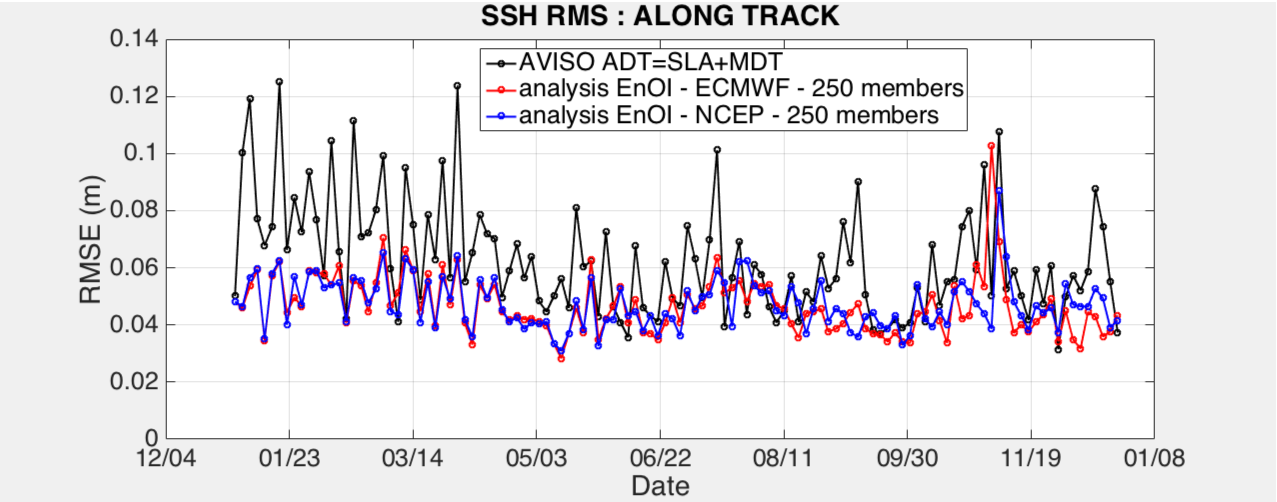


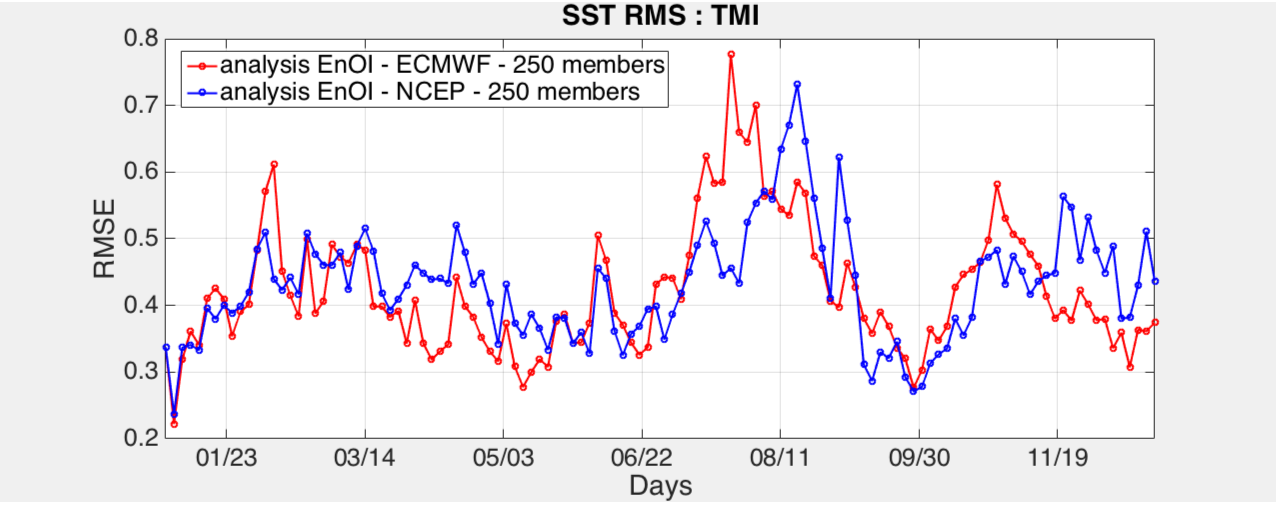
Impact of ensemble size in EnOI



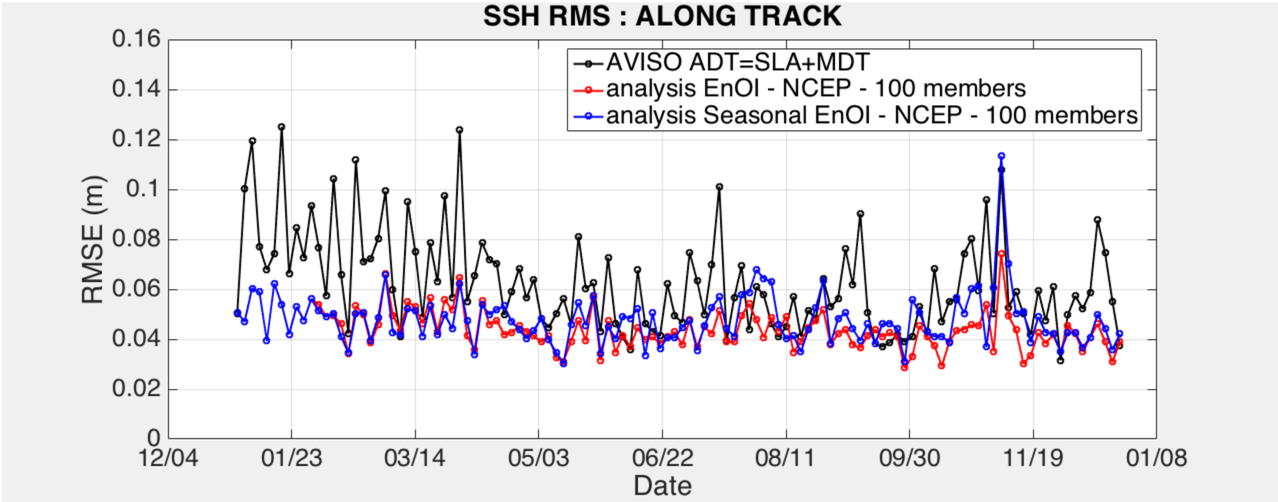


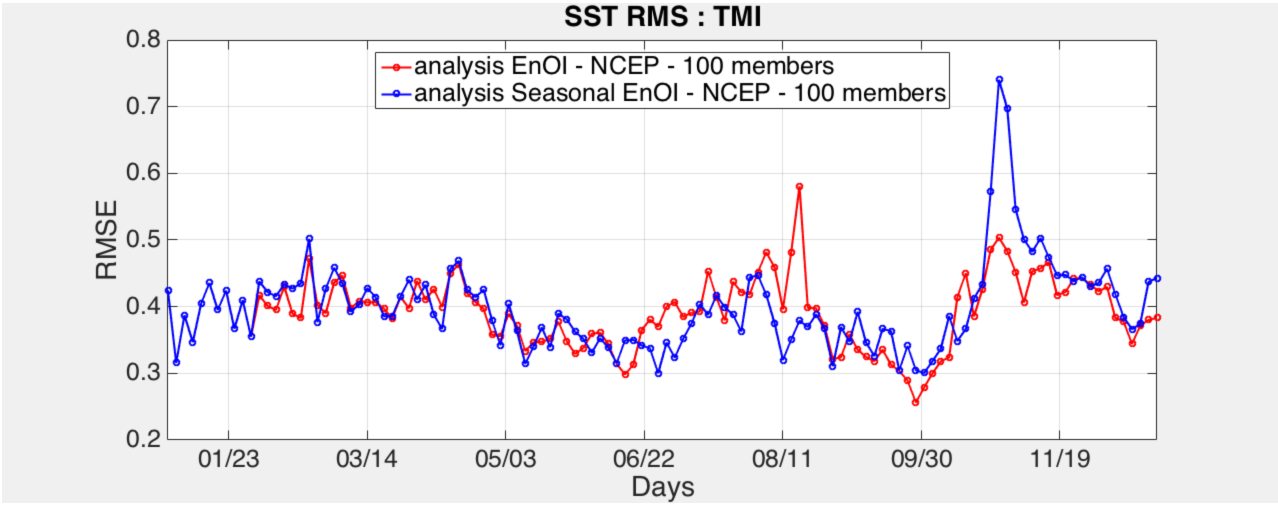
Impact of different forcings in EnOI



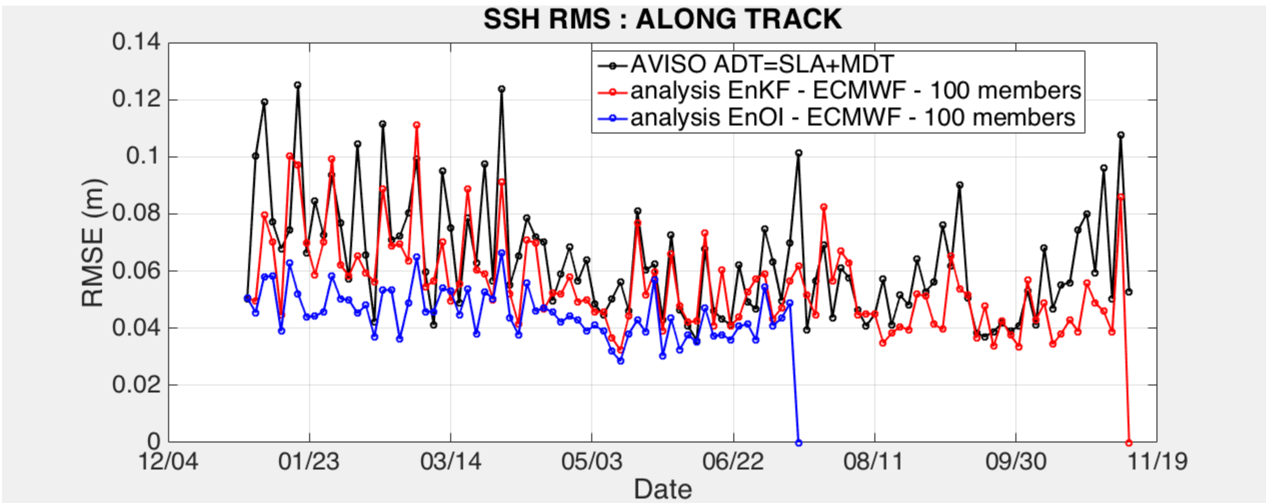


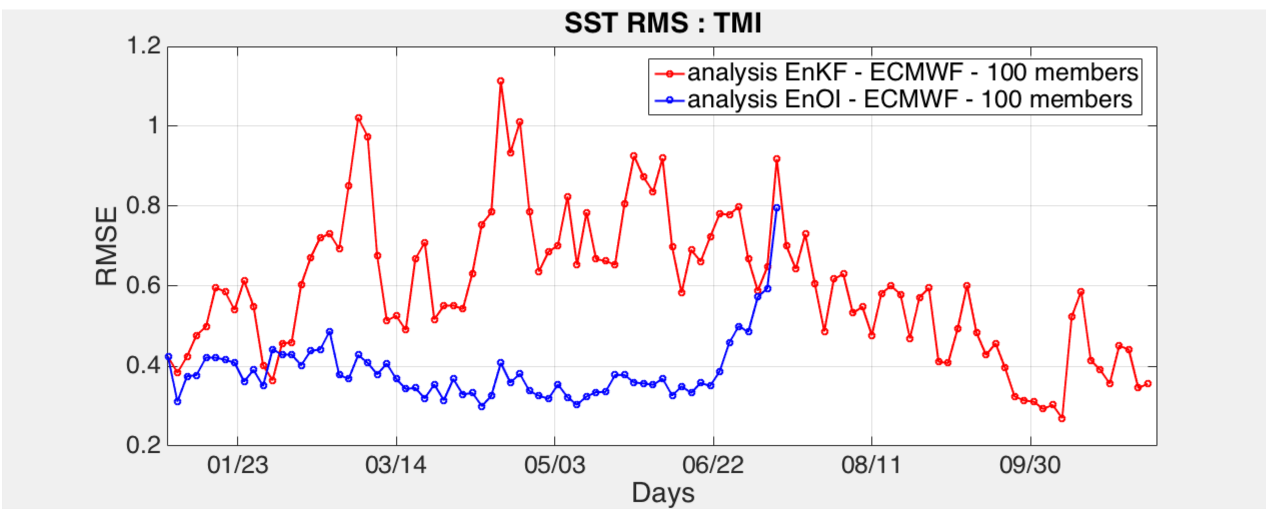
EnOI vs Seasonal EnOI



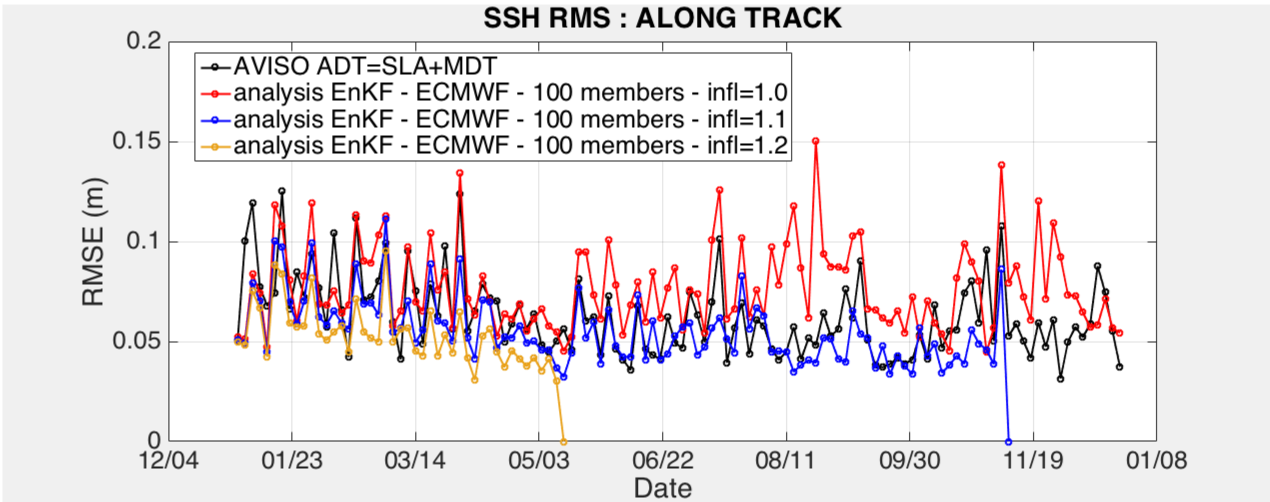


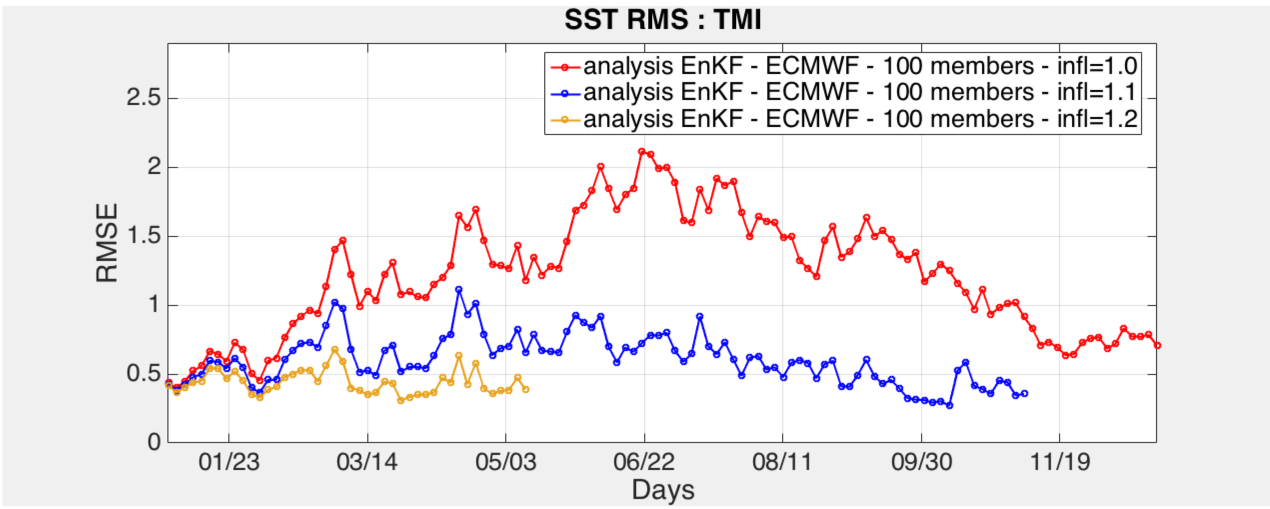
EnOI vs EnKF


SSH RMS : ALONG TRACK
AVISO ADT=SLA+MDT
analysis EnKF - ECMWF - 100 members
analysis EnOI - ECMWF - 100 members
RMSE (m)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
12/04
01/23
03/14
05/03
06/22
08/11
09/30
11/19
Date

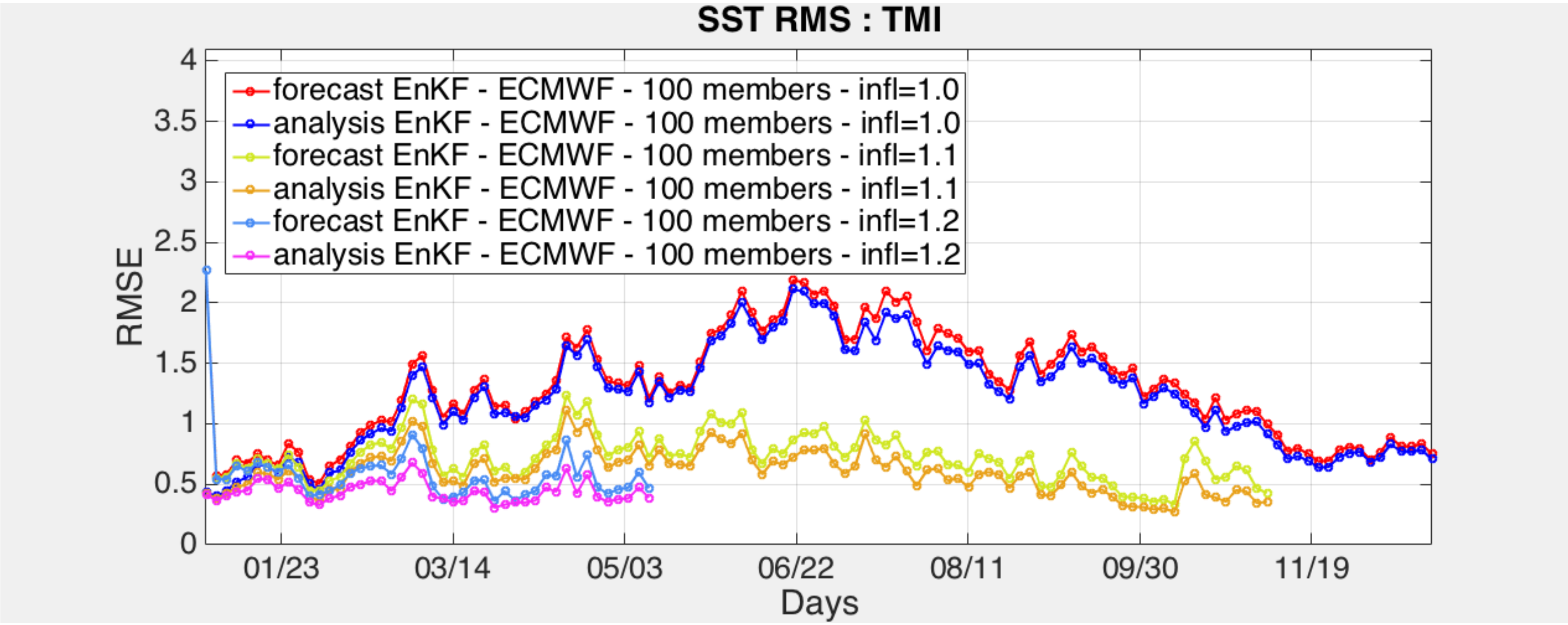

SST RMS : TMI
analysis EnKF - ECMWF - 100 members
analysis EnOI - ECMWF - 100 members
RMSE
1.2
1
0.8
0.6
0.4
0.2
01/23
03/14
05/03
06/22
08/11
09/30
Days

Impact of inflation in EnKF



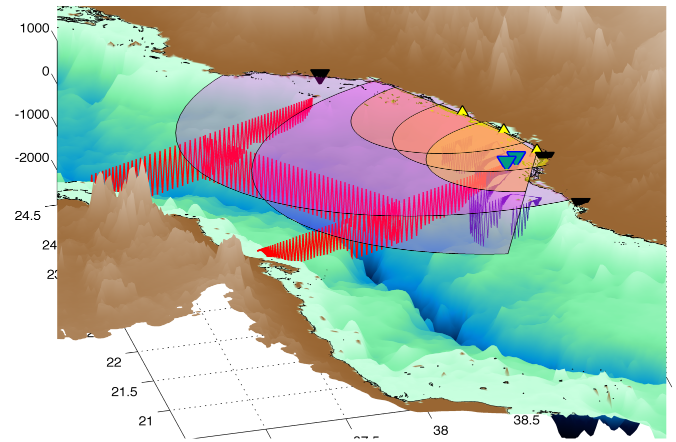


Impact of inflation in EnKF (SST forecast and analysis)



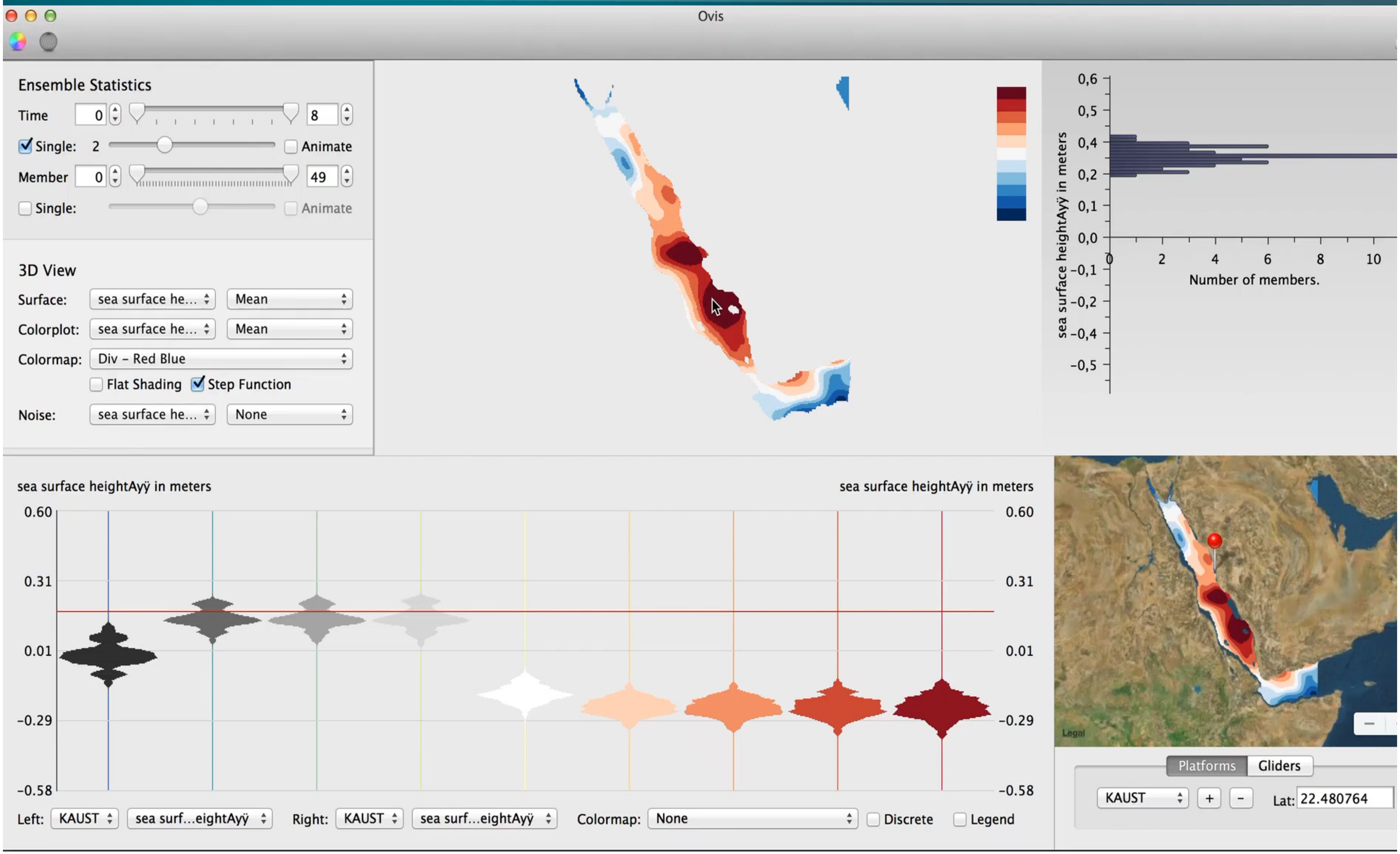
Future work

- We are currently testing an adaptive EnOI scheme that automatically selects members from a large dictionary
- We will also use this scheme to make the EnKF "fault-free"
- Hybrid EnKF/SEnOI scheme
- Ensemble atmospheric forcing & perturbed parameterizations
- Assimilate gliders and HF-radars data



This research was supported by KAUST and made use of the resources of the Supercomputing Laboratory and computer clusters at KAUST

Interactive Ensemble Visualization in 5D
Thank you!



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Thank you!