Impact of real observations assimilation on ocean simulations

Dr. S. Sivareddy,

ESSO-INCOIS

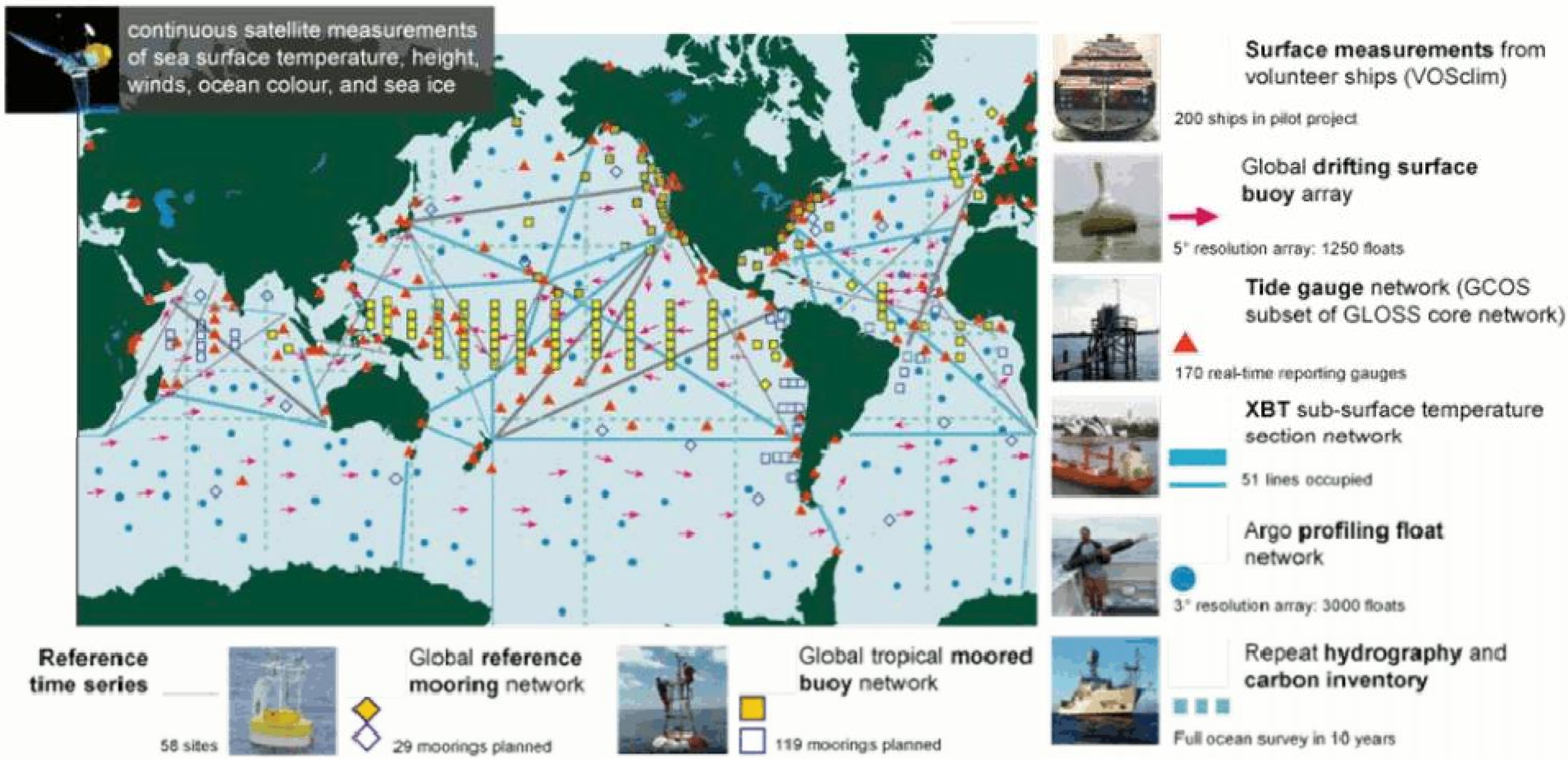
Email: ssiva@incois.gov.in

Inputs from

ESSO-INCOIS colleagues: Dr. Arya Paul, Dr. Ravichandran, Mr. Deepsankar Benerjee

Collaborators from University of Maryland, USA: Prof. Eugenia Kalnay, Mr. Travis Sluka

Ocean Observation Networks

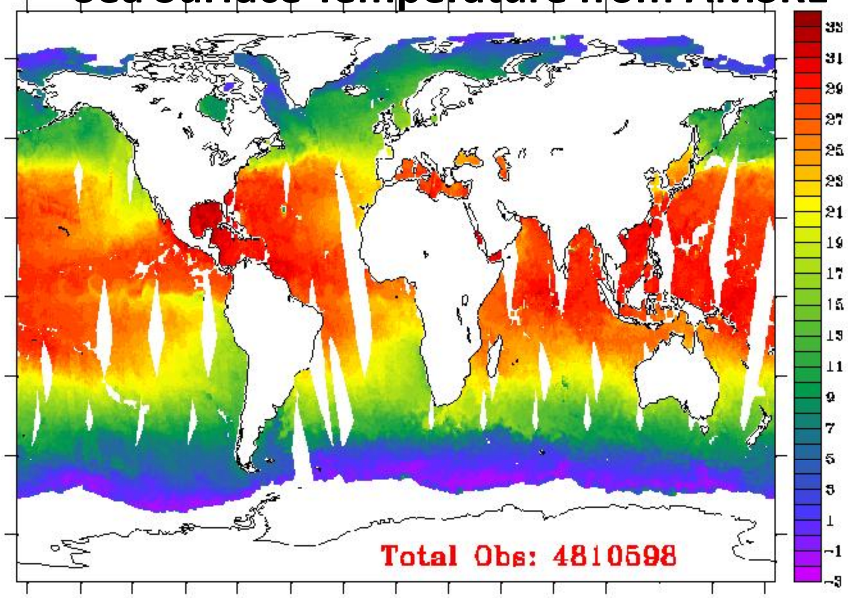


GCOS GOOS jcomm

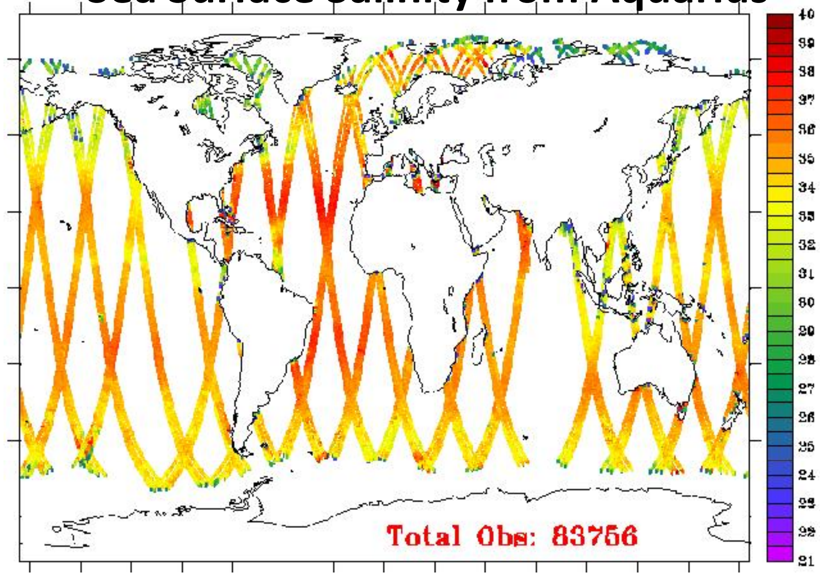
- A total of 5635 platforms are maintained globally.

Spatial Coverage from different satellites for different parameters (25th August, 2011)

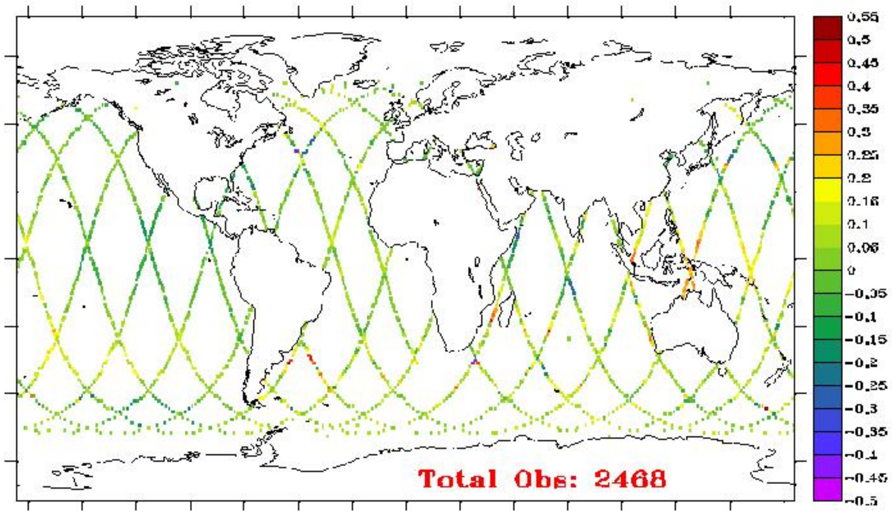
Sea Surface Temperature from AMSRE



Sea Surface Salinity from Aquarius



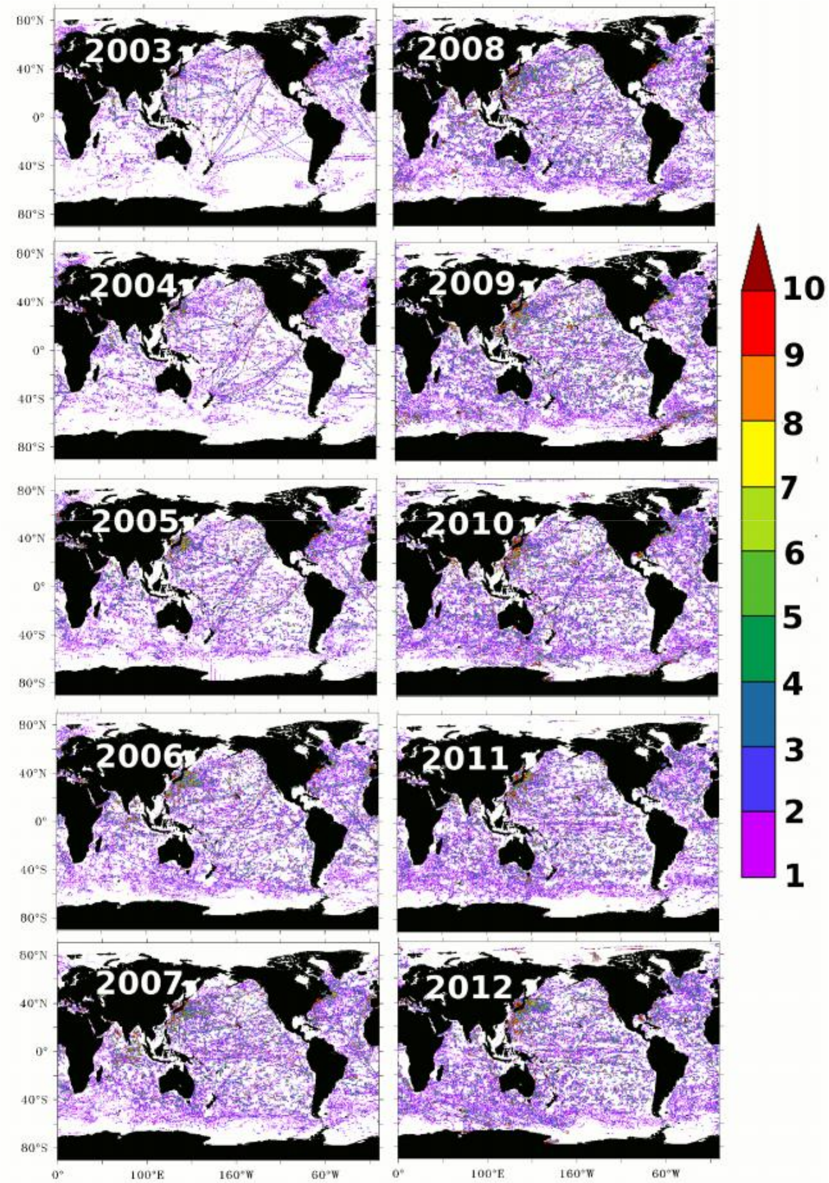
Sea Surface Height Anomaly from Altimeters

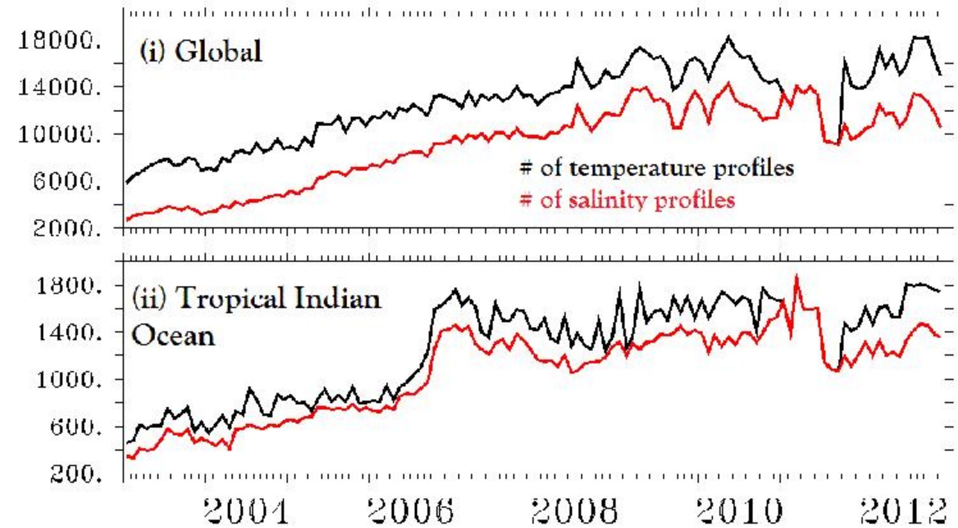


Limitation:

Cannot provide sub-surface information

Spatial coverage from different in-situ observation networks for ocean T&S profiles





Limitations:

Impossible to observe the ocean at each and every time and location.

Most of the ocean is largely under-sampled even today.

Numerical Ocean Models

Primitive Equations for ocean:

$$x{-}momentum: \frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho_0}\frac{\partial p}{\partial x}+fv+\frac{\partial}{\partial x}\left(A\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(A\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(V_E\frac{\partial u}{\partial z}\right) \quad (1.1)$$

$$y{-}momentum: \frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho_0}\frac{\partial p}{\partial y}-fu+\frac{\partial}{\partial x}\left(A\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(A\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(V_E\frac{\partial v}{\partial z}\right) \quad (1.2)$$

$$z-momentum: 0=-\frac{1}{\rho}\frac{\partial p}{\partial z}-g \quad (1.3)$$

$$continuity: \frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (1.4)$$

$$Tracer(Temperature\&Salinity)Equation: \frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=-A_h\left(\frac{\partial T}{\partial x}+\frac{\partial T}{\partial y}\right)-\kappa_h\frac{\partial T}{\partial z}+Q \quad (1.5)$$

$$Equationofstate: \rho=\rho\left(\theta,S,p\right) \quad (1.6)$$

Important Approximations:

Boussinesq

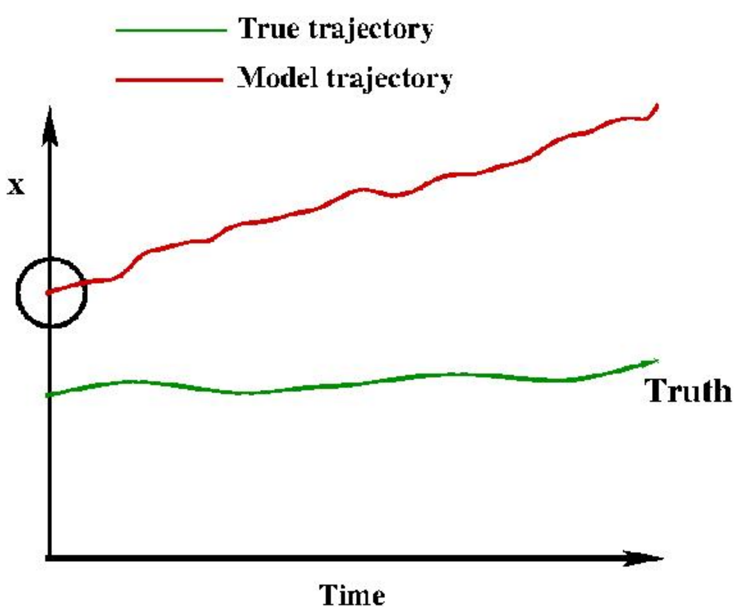
Hydrostatic

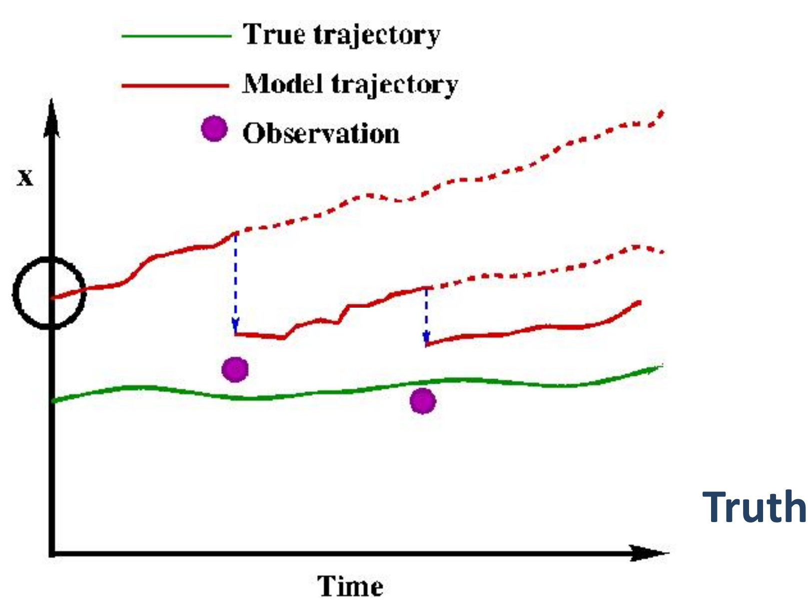
Limitations:

Inability to model all the ocean process.

Model errors aroused due to various approximations/discretizations

Flowchart of Data Assimilation





NO CORRECTION

CORRECTION

$$X^a = x^b + BH^T\left(HBH^T + R\right)^{-1}\left(y_0 - Hx^b\right)$$

$X^a \; --> \; Analysis$

$X^b \; --> \; Forecast\,/\,Background$

$Y_0 \; --> \; Observation$

B → Model background error covariance
R →Observational error covariance
H → Interpolation operator

It is best understood if we work with a scalar case with H=1

Let, $R = \pm_o^2, B = \pm_b^2$

$$x^a = x^b + \pm_b^2\left(\pm_b^2 + \pm_o^2\right)^{-1}\left(y_0 - x^b\right)$$

$$\Rightarrow x^a = \frac{\pm_0^2}{\pm_0^2 + \pm_b^2}x^b + \frac{\pm_b^2}{\pm_0^2 + \pm_b^2}y_0$$

Analysis is sensitive to both model background error covariance and observational error covariance

If $\pm_b >> \pm_0$

$x^a \approx y_0$

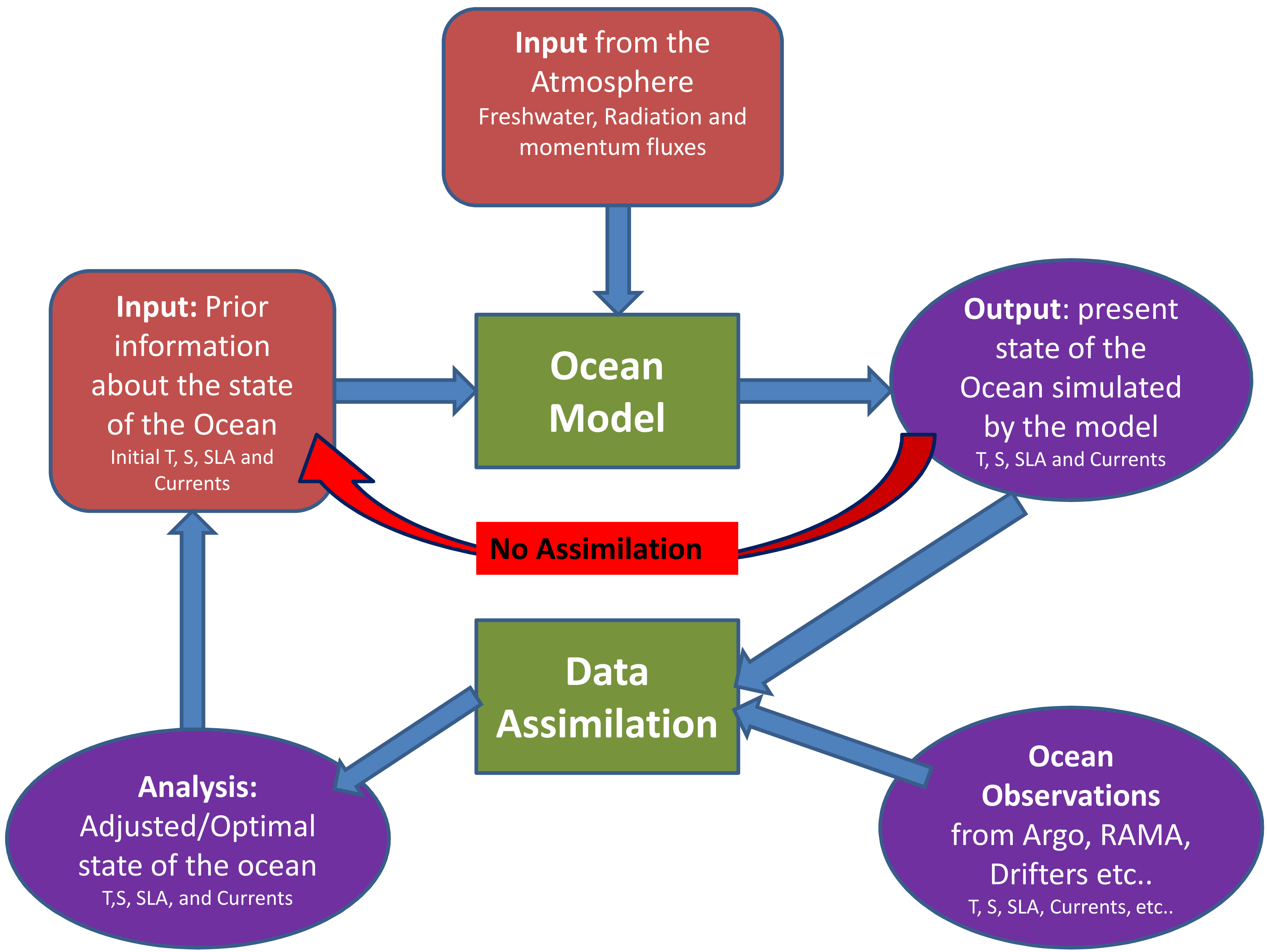
If $\pm_0 >> \pm_b$

$x^a \approx x_b$

Limitations of Assimilation Schemes:

Difficulty in prescribing the behavior of model errors, observational errors (instrument + representation)

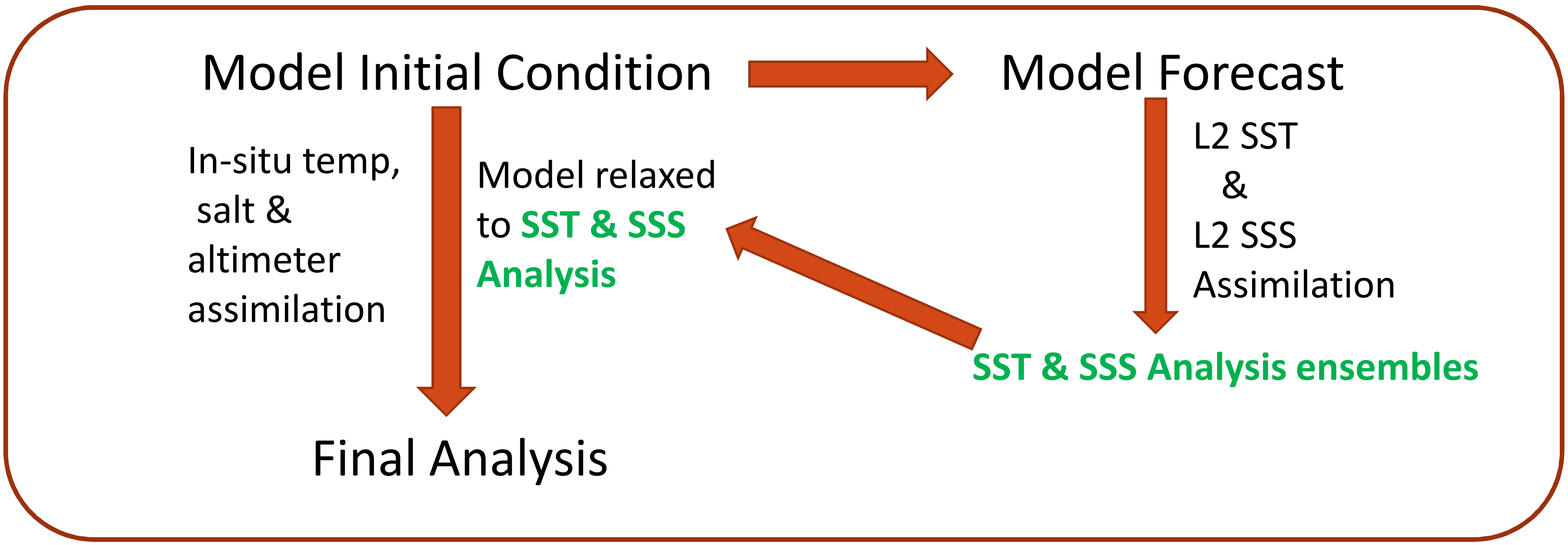
Doesn't implicitly conform with the model dynamics. It can lead to dynamically inconsistent ocean states


Input from the Atmosphere
Freshwater, Radiation and momentum fluxes
Input: Prior information about the state of the Ocean
Initial T, S, SLA and Currents
Ocean Model
Output: present state of the Ocean simulated by the model
T, S, SLA and Currents
No Assimilation
Data Assimilation
Analysis: Adjusted/Optimal state of the ocean
T,S, SLA, and Currents
Ocean Observations from Argo, RAMA, Drifters etc..
T, S, SLA, Currents, etc..

Ocean Data Assimilation systems

	INCOIS-GODAS	LETKF-NEMO	LETKF-MOM	LETKF-ROMS
OGCM	MOM-4.0	NEMO	MOM-4.1	ROMS-3.6
Assimilation Scheme	3D-VAR	LETKF	LETKF	LETKF
Domain	Global	Global	Global	Indian Ocean
Assimilation capabilities	T&S profiles	SLA and T&S profiles	SST, SSS, SLA and T&S profiles	SST, SSS, SLA and T&S profiles
Status	Operational	Toy Model	Experimental	Experimental
Original source	Adopted from NCEP	Adopted from University of Maryland	Joint efforts between University of Maryland and INCOIS	Indigenous development
Reference	Ravichandran et al., 2013 Sivareddy, 2015	Sluka et al., 2016	--	--

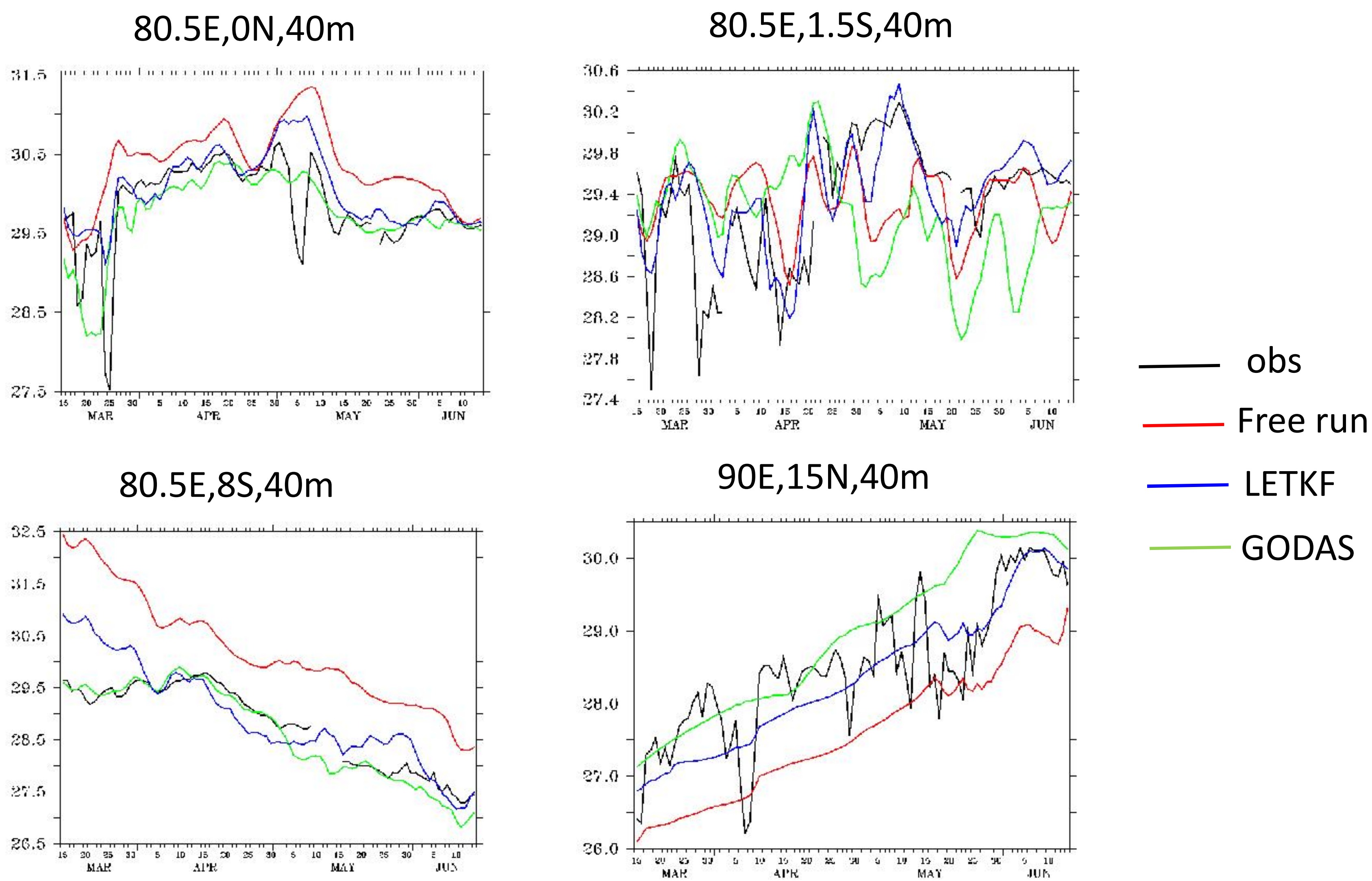
Process of SST & SSS assimilation in LETKF-MOM and LETKF-ROMS



Preliminary results from LETKF-MOM (Based 6 months simulations)

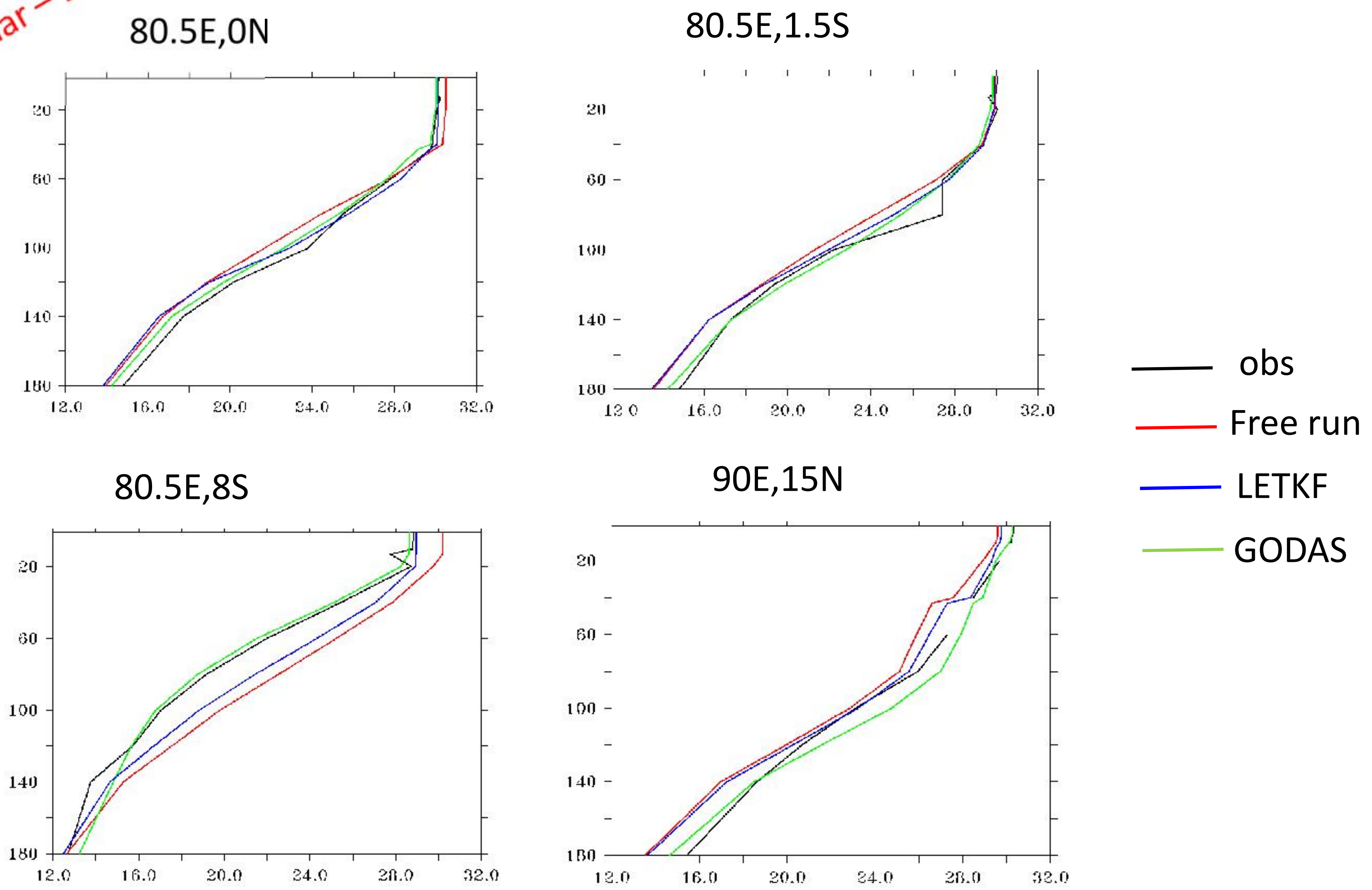
Ensembles: 32
Initial condition: wrong initial condition
Forcing: 20CR from NCEP
Assimilated Observations : Daily L2 SST & T&S profiles
Domain: Global

TEMP Time Series Results

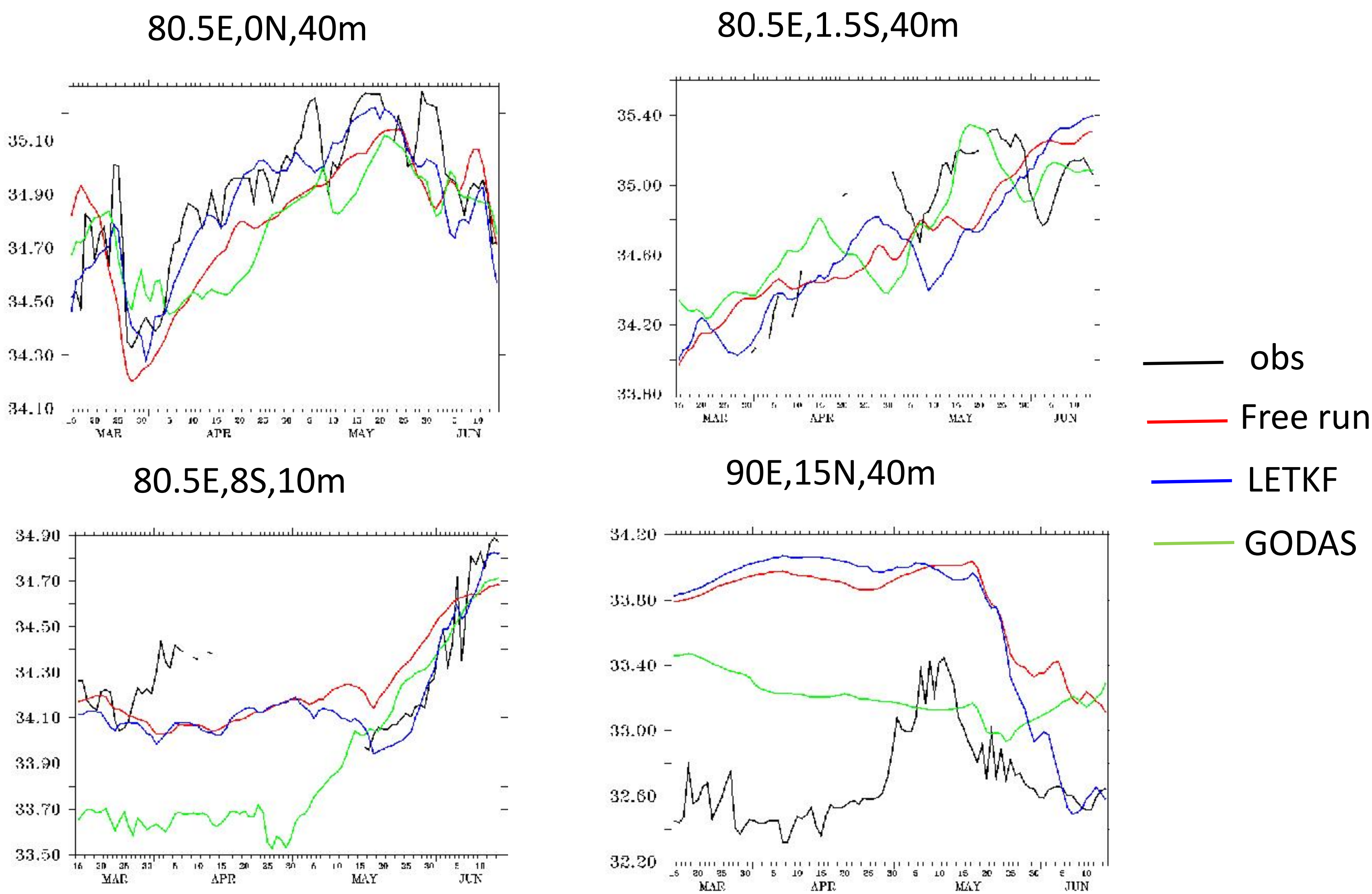


TEMP Vertical Profiles

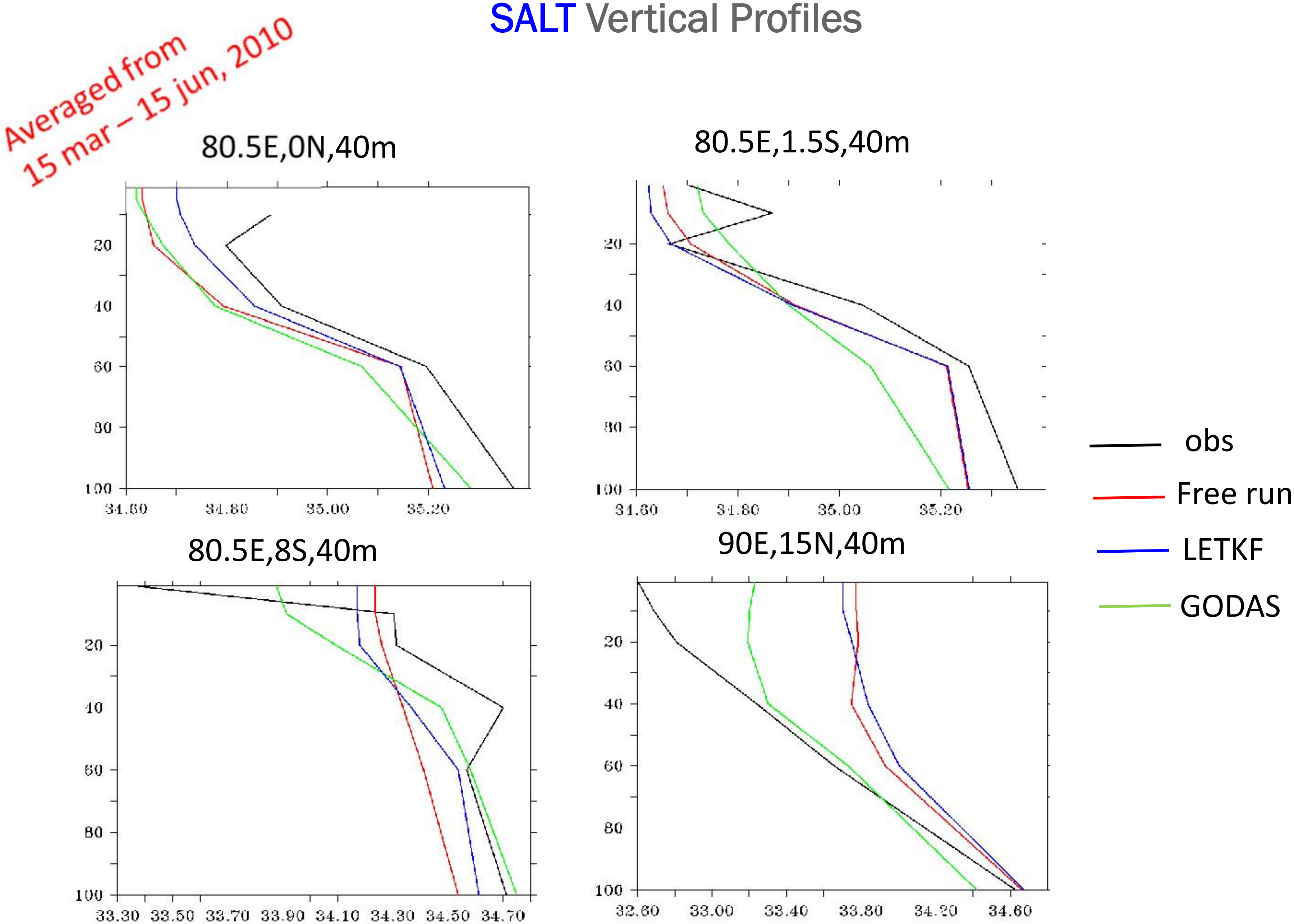
Averaged from
15 mar – 15 jun, 2010



SALT Time Series Results

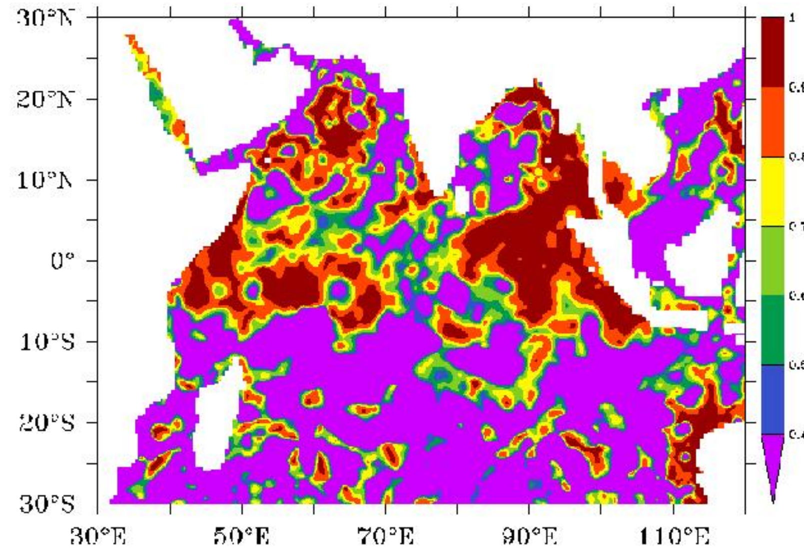


SALT Vertical Profiles

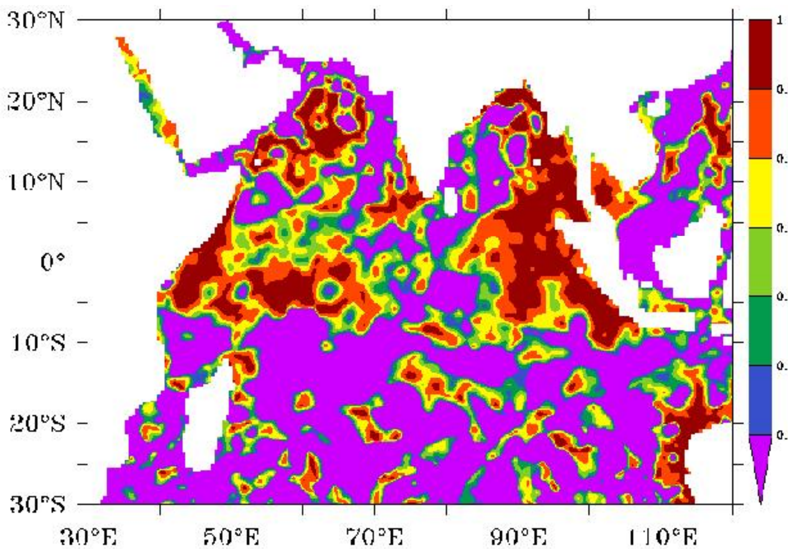


SLA Correlations with AVISO

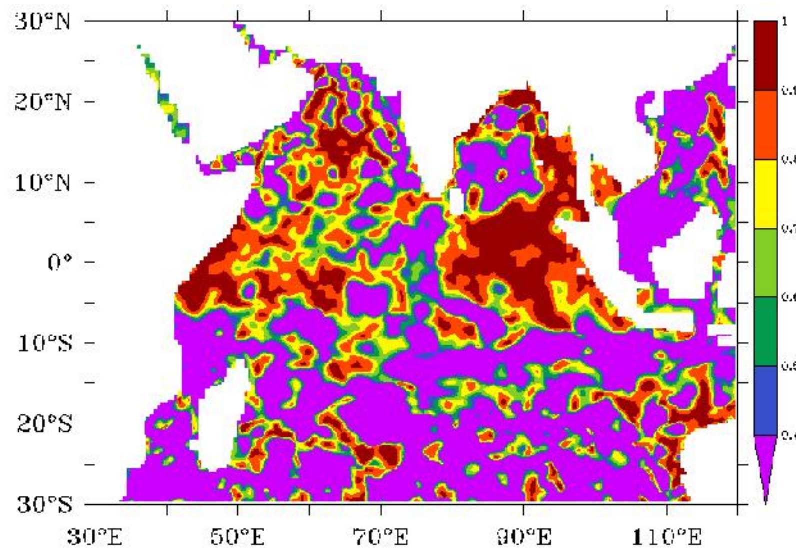
LETKF-MOM



Free Model

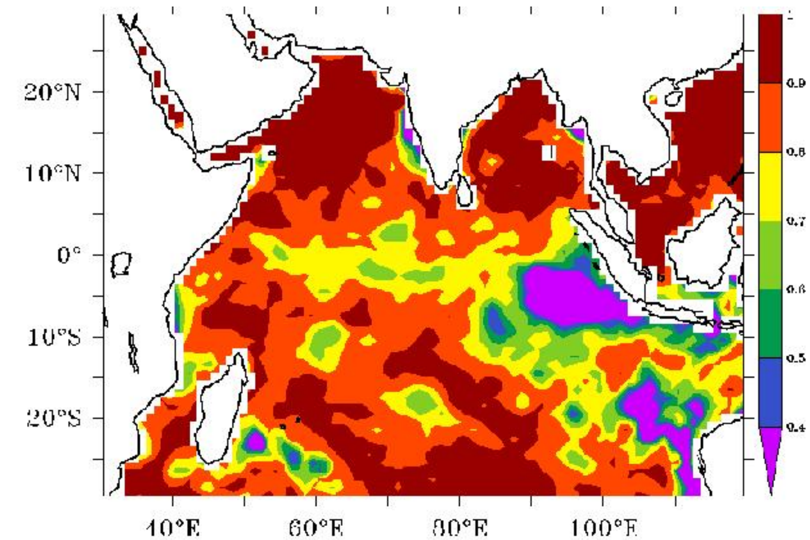


GODAS

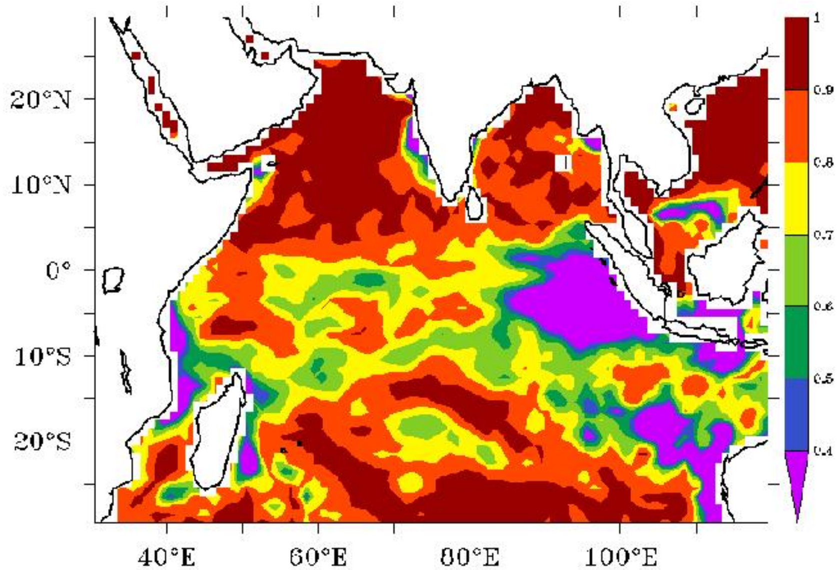


SST Correlations with REYNOLDS

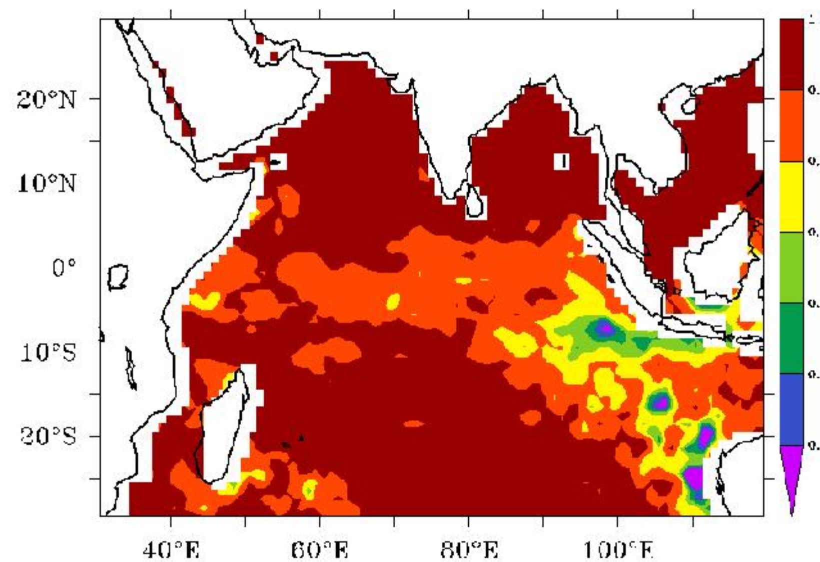
LETKF-MOM



Free Model



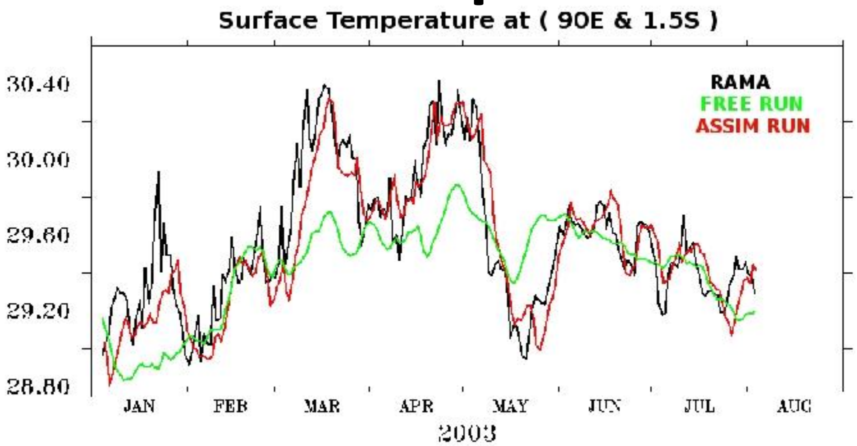
GODAS

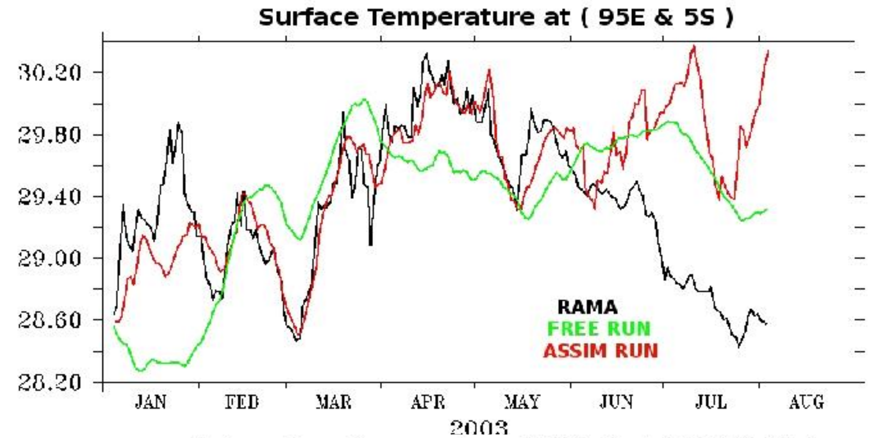


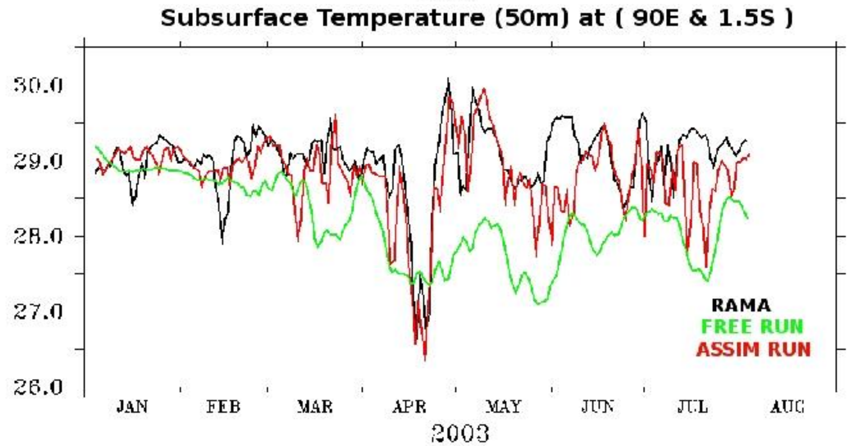
Preliminary results from LETKF-ROMS (Based on 1-year simulations)

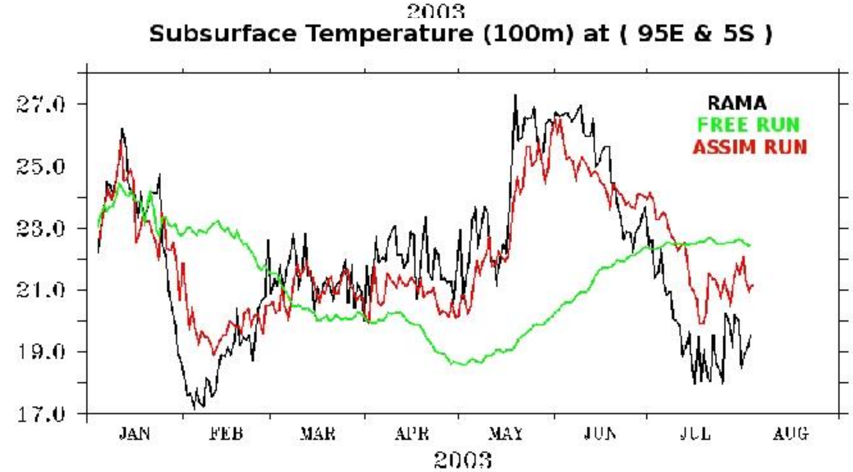
Ensembles: 32
Initial condition: in-accurate initial condition
Forcing: 20CR from NCEP
Assimilated Observations : Daily L2 SST and T&S profiles
Domain: Indian Ocean

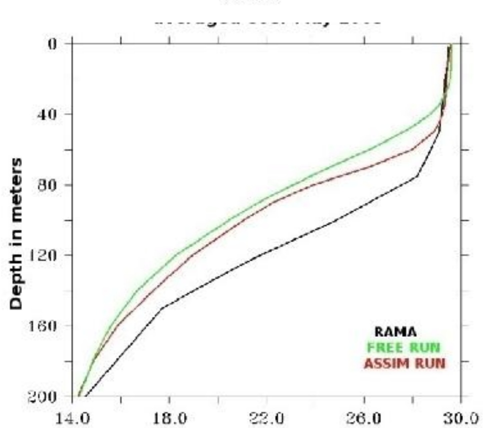
Temperature comparisons

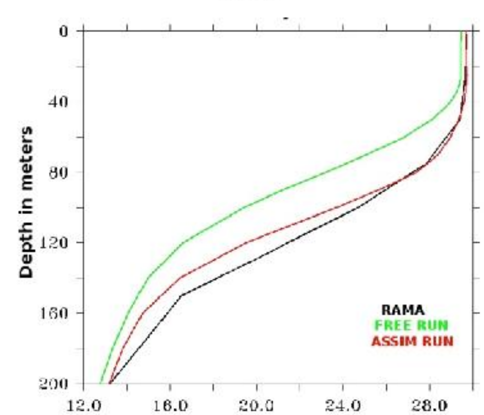




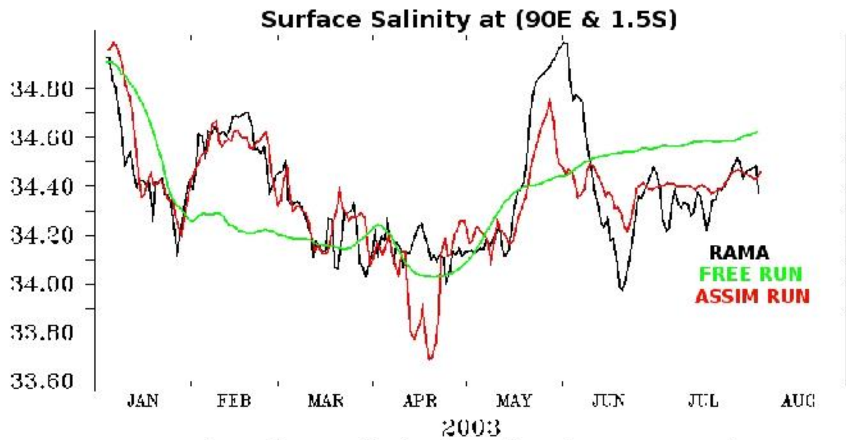


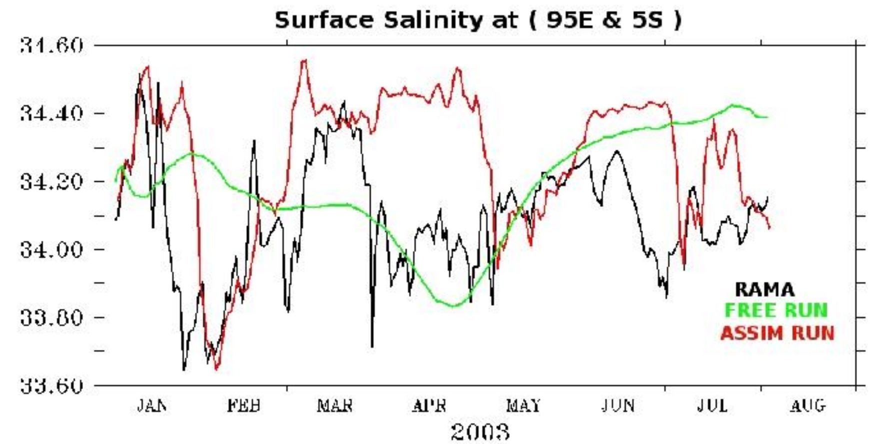


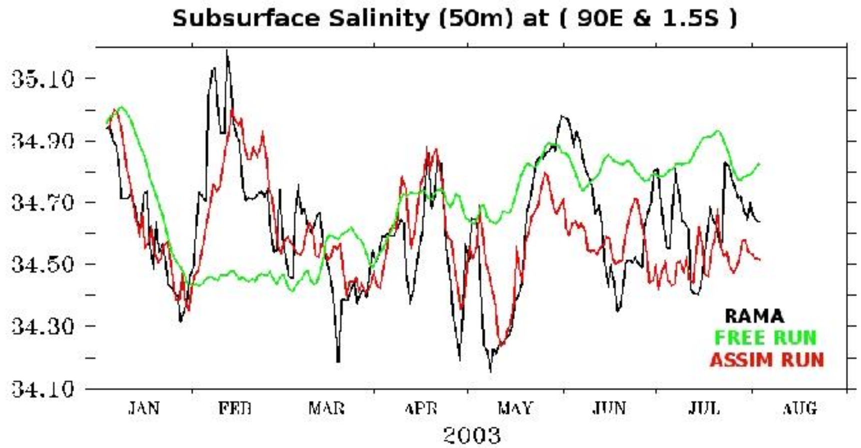


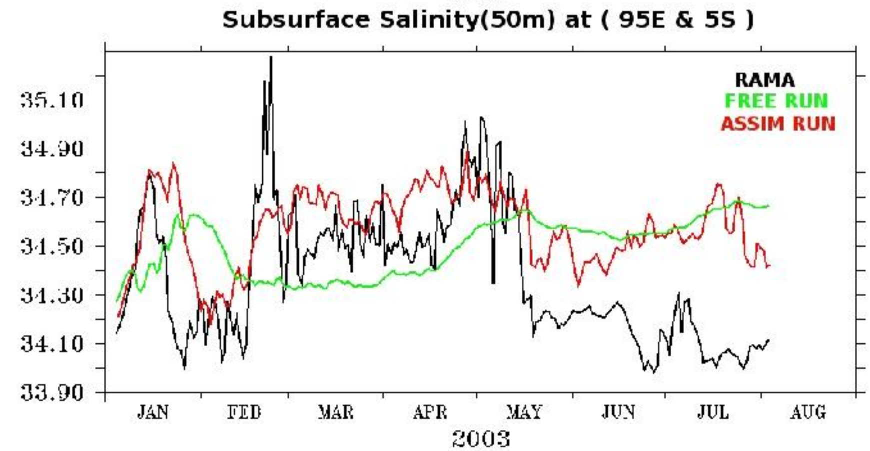


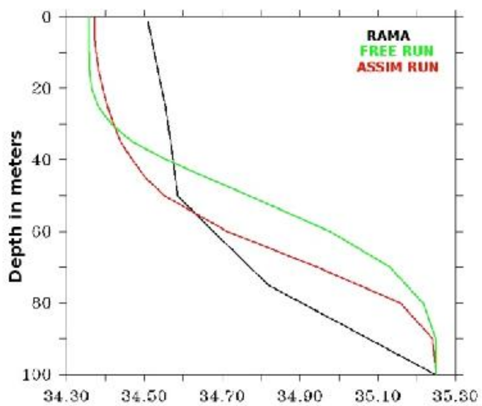
Salinity Comparisons

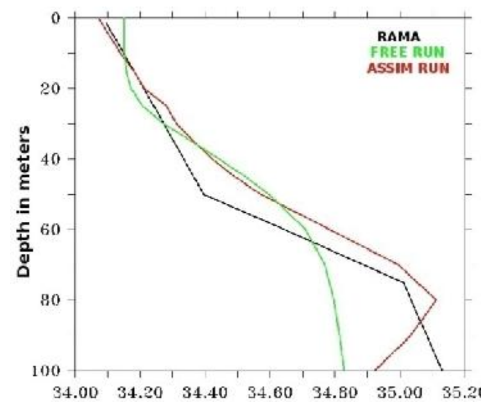




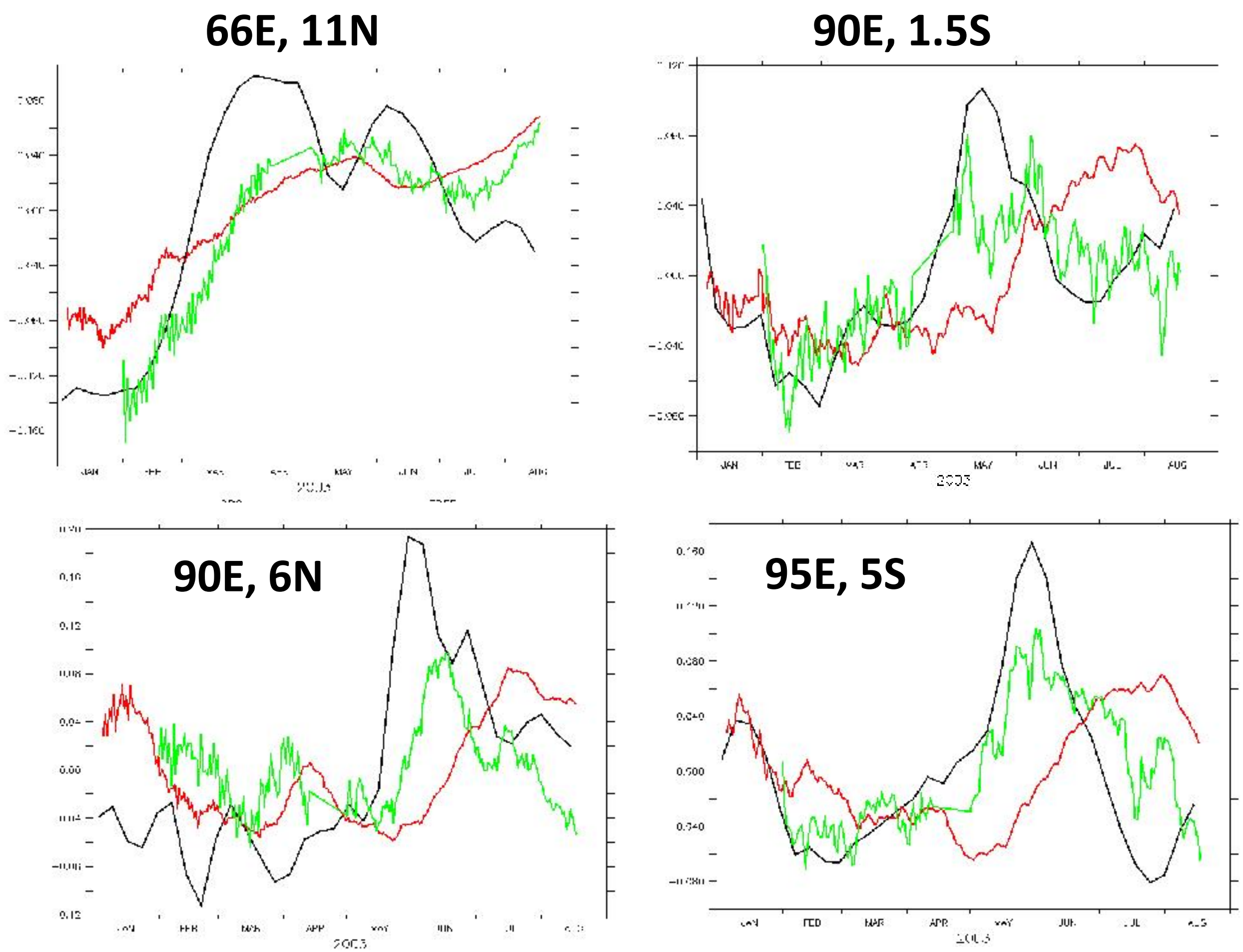








SSHA comparisons



Observation
Free
Assimilation

Summary from Preliminary Validations

- LETKF-MOM performance is comparable to INCOIS-GODAS in many aspects even though it starts from a gross initial condition.

- Results from LETKF-ROMS is encouraging. However, there is large scope for improvements in SSHA.

Operational set up of INCOIS-GODAS

Model used : MOM 4 (GFDL)

Domain: Global

Resolution: 50 km zonal and 25 km meridional, 40 vertical levels.

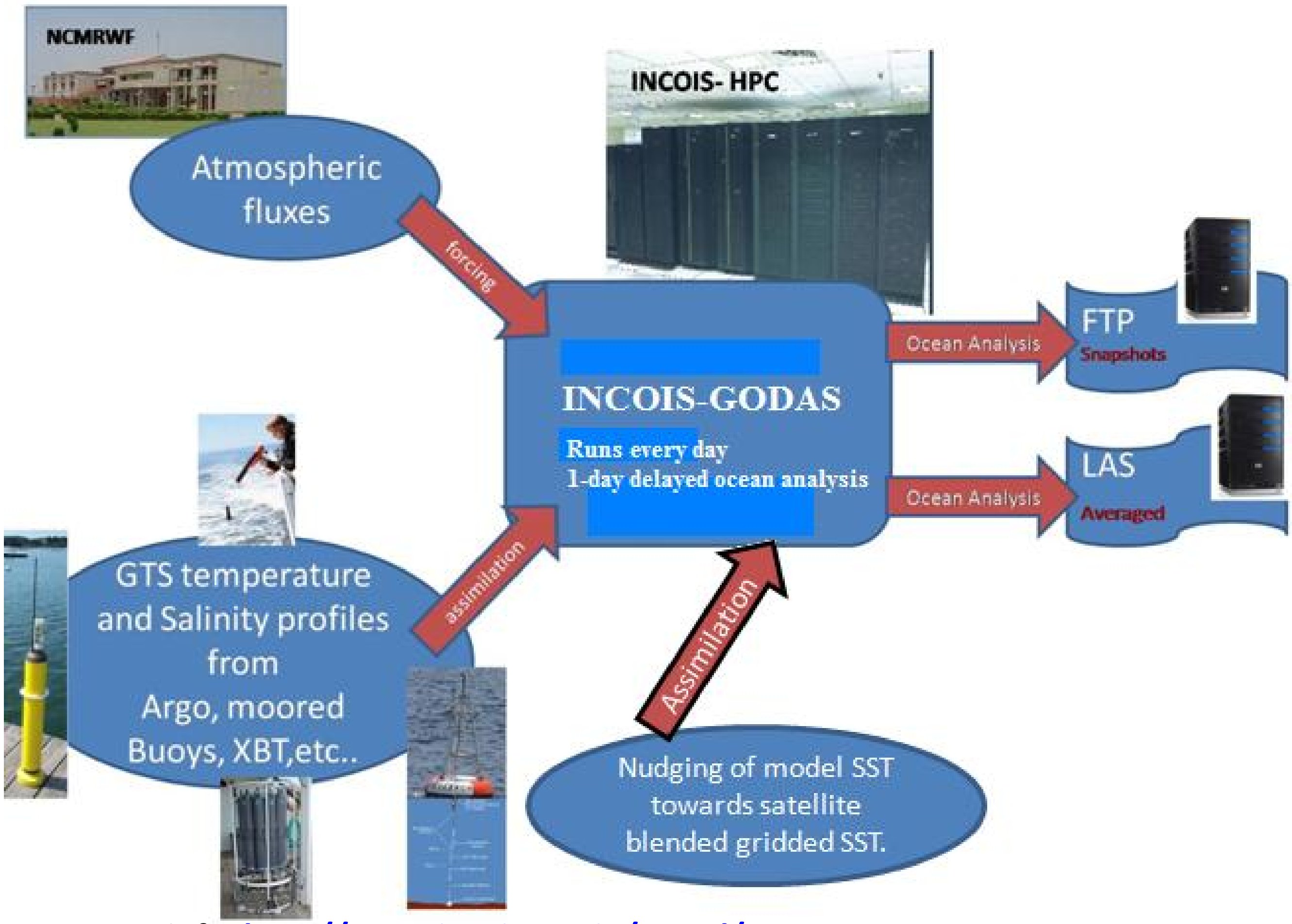
Atmospheric forcing: Fluxes from Global Assimilation Forecast System (GFS)- T574L64 run at NCMRWF.

Data assimilation scheme: 3D VAR

Parameters assimilated: Temperature and salinity profiles from Argo, XBT and RAMA moorings

Relaxation: OISST-V2 [Reynolds, 2007]

Outputs: Temperature, Salinity, SSH, and Currents



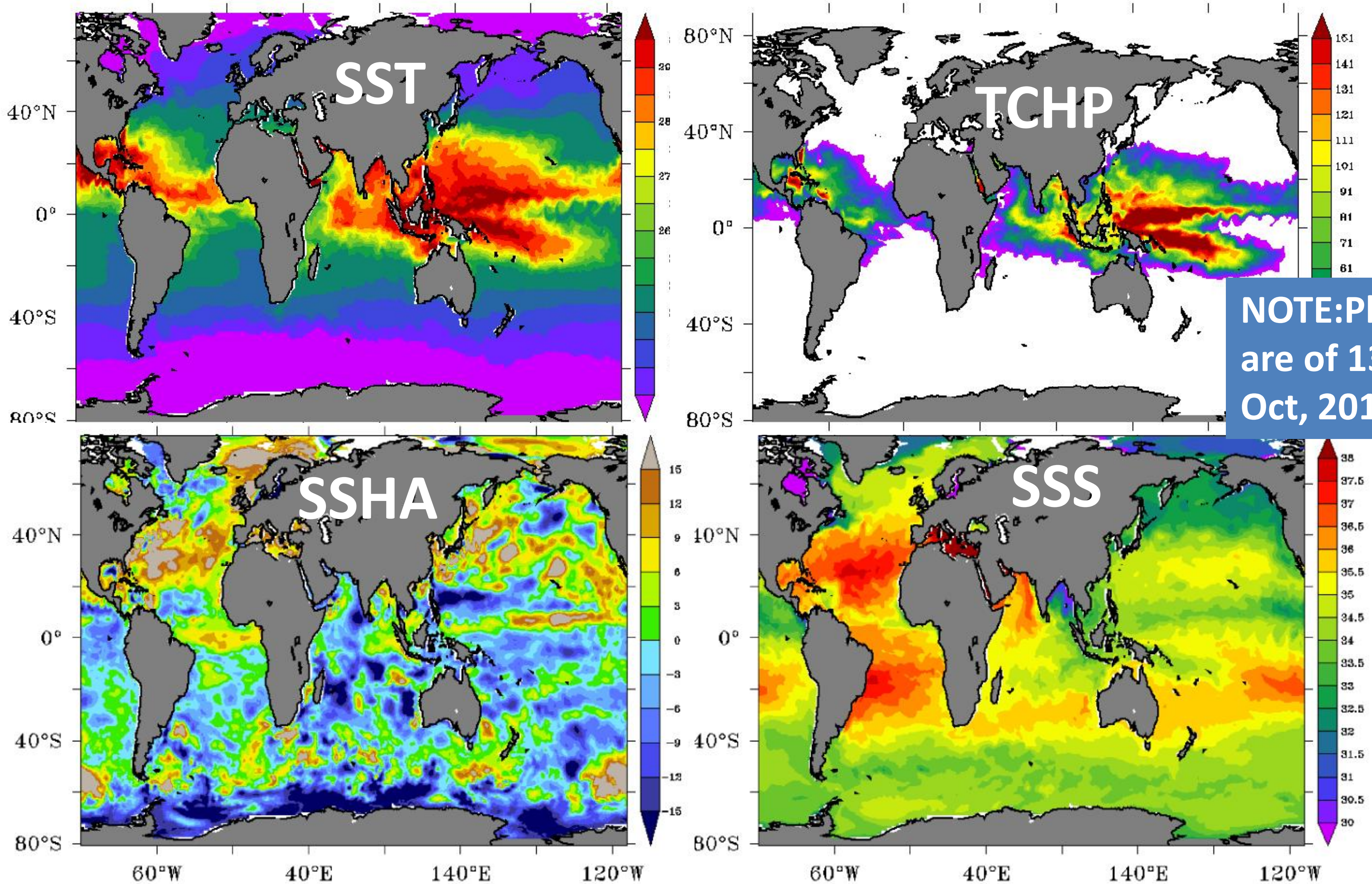
For more info: http://www.incois.gov.in/portal/GODAS

References:

1) Ravichandran et al. , 2013, Ocean Modelling

2) Sivareddy et al., 2015, PhD thesis

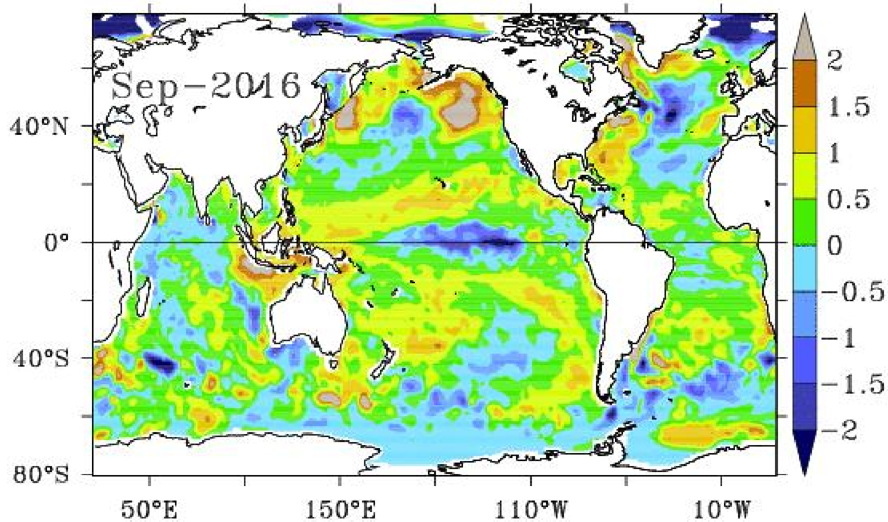
Real time (1-day delay) updates of the Global Ocean from INCOIS-GODAS: 2D fields



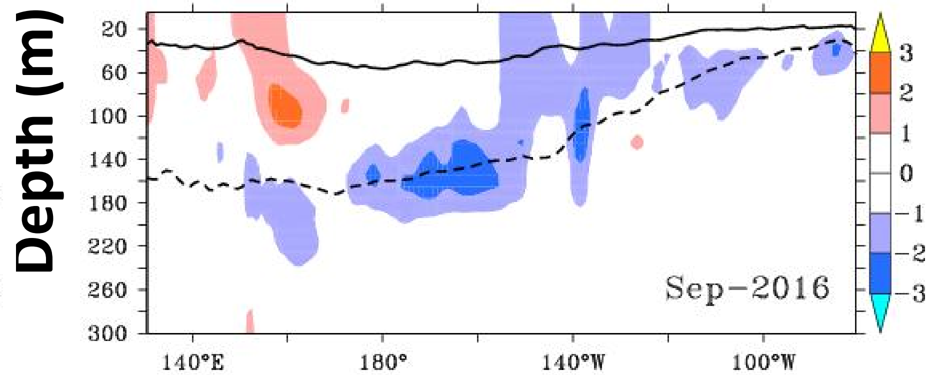
NOTE:Plots are of 13th Oct, 2016

Climate Indices from INCOIS-GODAS ocean analysis

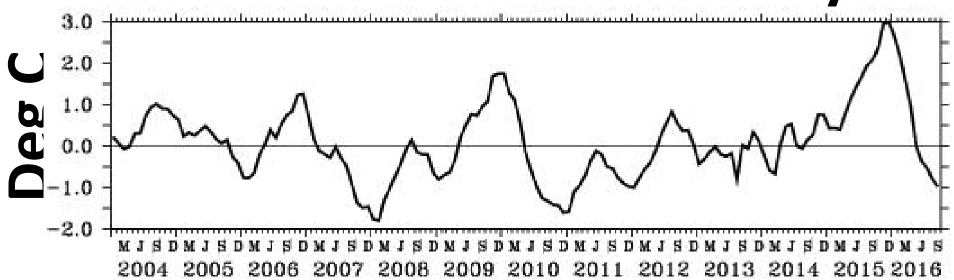
SST (degC) anomaly



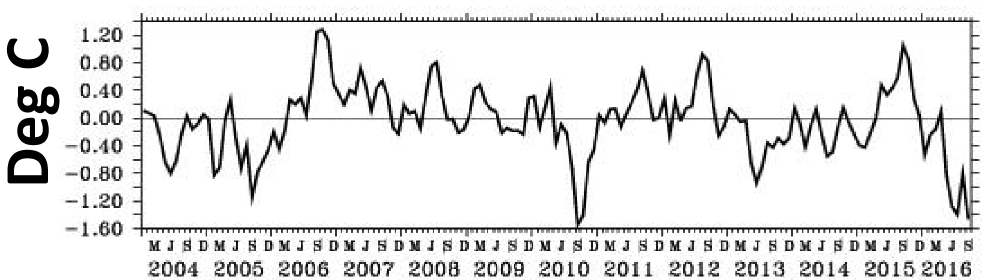
Temperature anomaly (deg C) averaged over 5S-5N latitudes



NiNO 3.4 SST anomaly



IOD index



Monthly updates of climate indices are available by 10th of each month.
Service is started in April, 2014.
The information is being disseminated from the INCOIS web site
www.incois.gov.in/portal/ElNino

Users of INCOIS-GODAS analysis

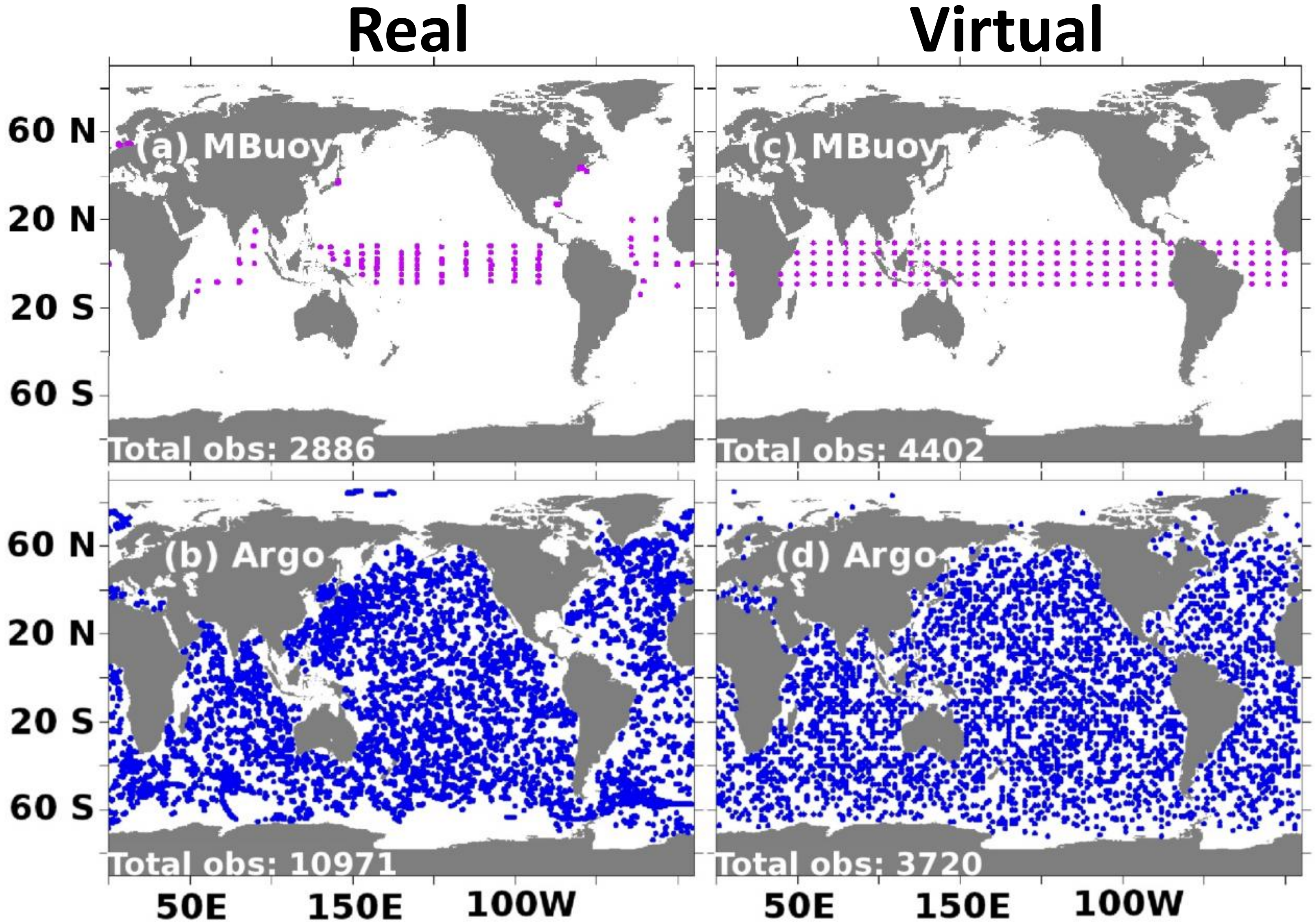
- Analysis are used as initial and boundary counditions to operational ROMS at INCOIS
- Ocean initial conditions are provided to IITM, Pune for CFS-V2
- Global maps of SST and SST anomalies are provided to IMD-Pune
- Climate indices are used in MoES-ENSO bulletins
- Researchers across globe

Is it always good to assimilate observations (blindly) ?

Real assimilation System:
INCOIS-GODAS
- **OGCM:** MOM4.0
- **Assimilation scheme:** 3DVAR
- **Observations assimilated:** Real T&S profiles
- **Forcing:** NCEP-R2

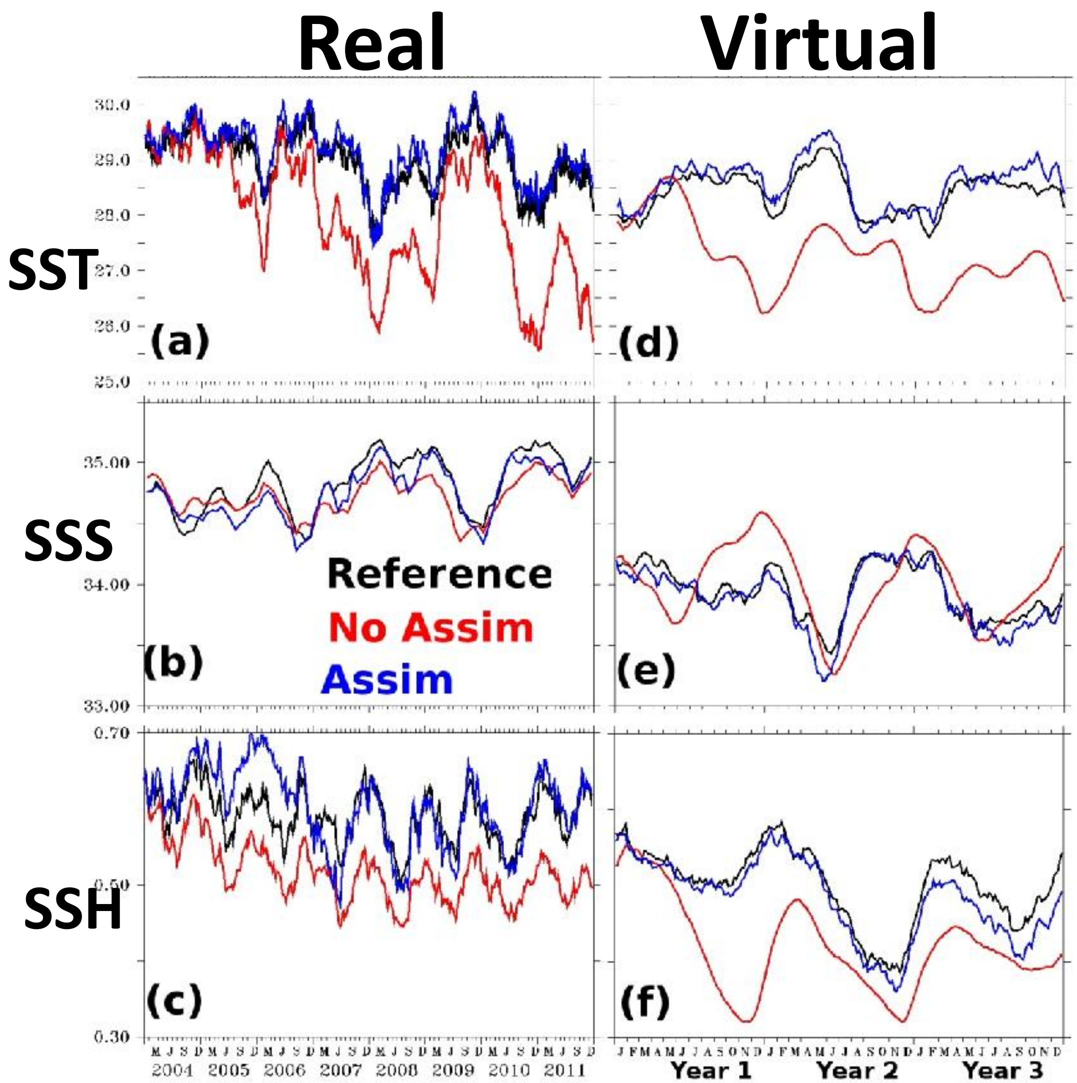
Virtual assimilation System:
NEMO-LETKF
- **OGCM:** NEMO
- **Assimilation scheme:** LETKF
- **Observations assimilated**: Simulated T&S profiles from a Nature run using SPEEDY-NEMO
- **Forcing**: Simulated imperfect ensemble forcing from SPEEDY-NEMO

Observation coverage over a typical month



Comparisons within moored buoy coverage area

Real System (INCOIS-GODAS): Reference is Reynolds for SST and for SSS and SSH the reference is from REF experiment where Argo+Mbuoy are assimilated

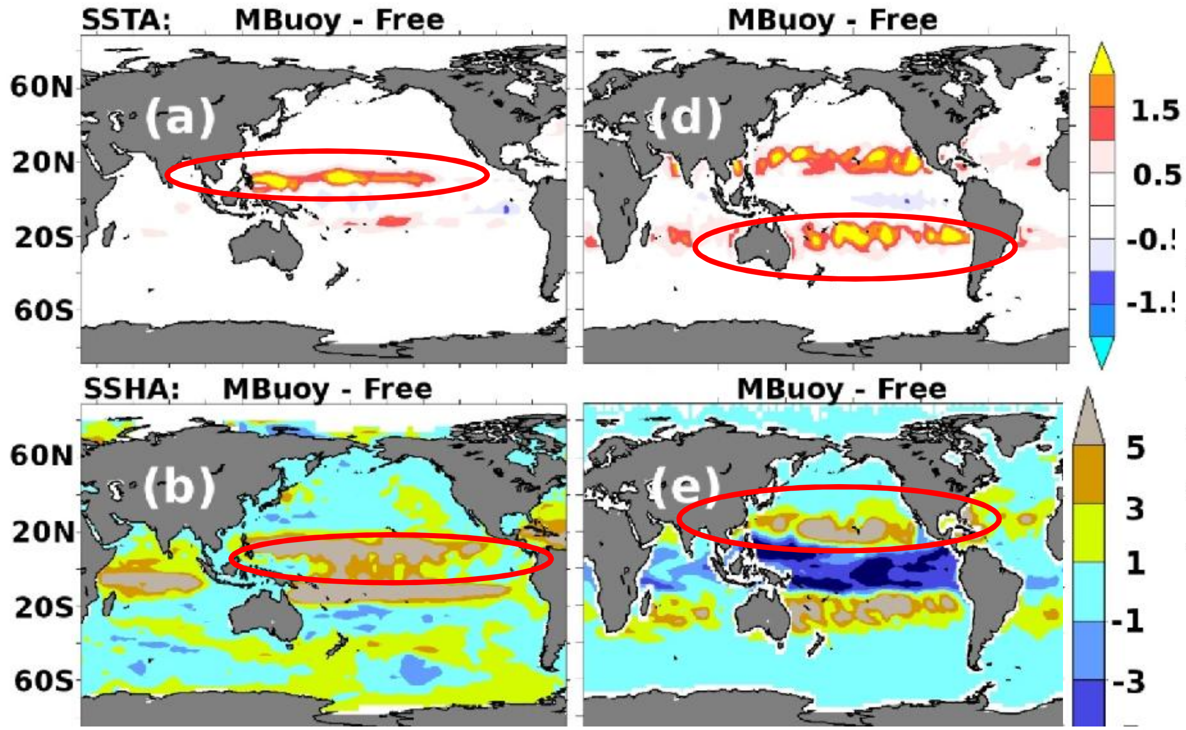


Virtual System (NEMO-LETKF): Reference is the outputs from Nature run

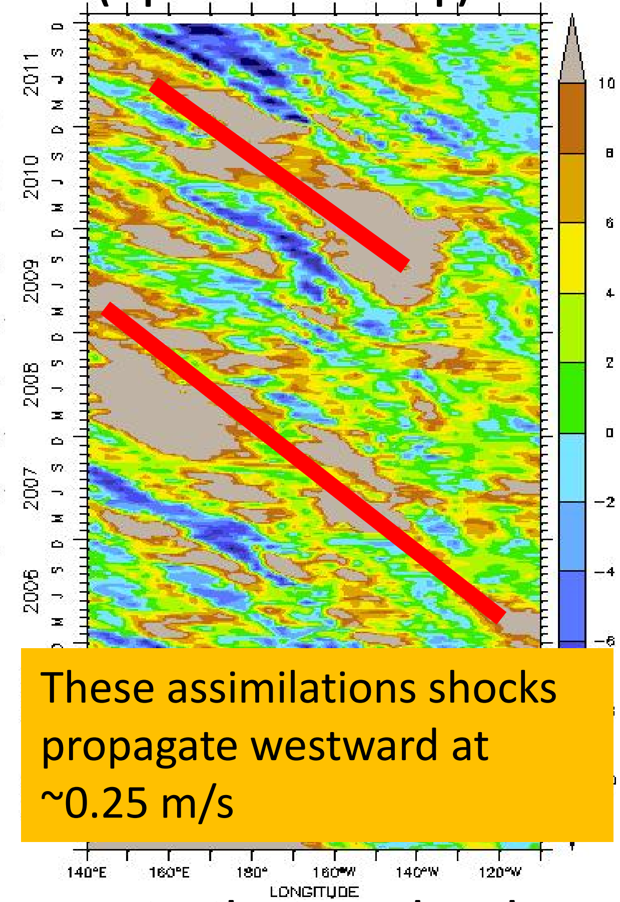
Assim is the experiment where only Moored buoy observations are assimilated

RMSE difference between free and assimilation experiment.
+ve indicates degradation due to assimilation and vice versa

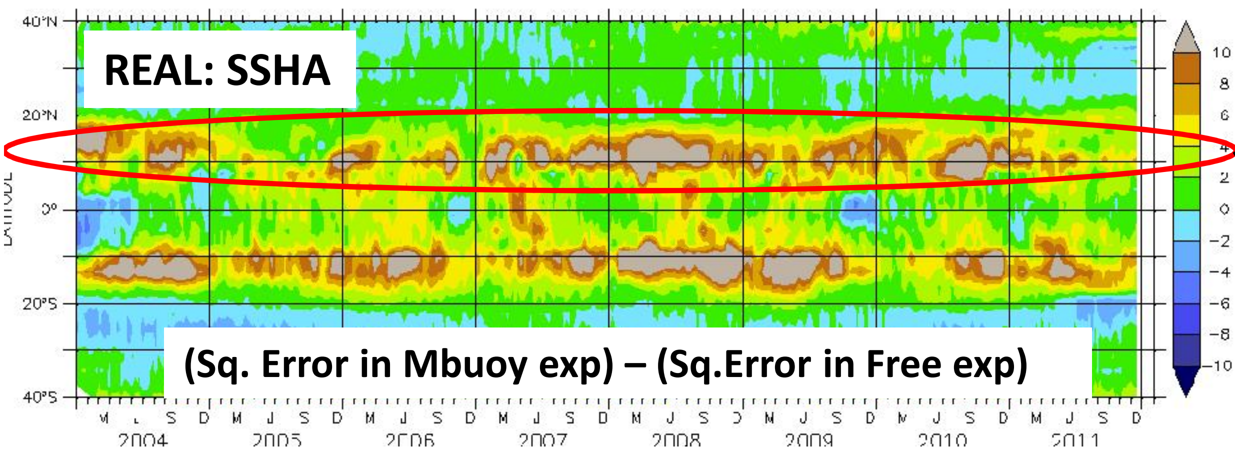
Real **Virtual**



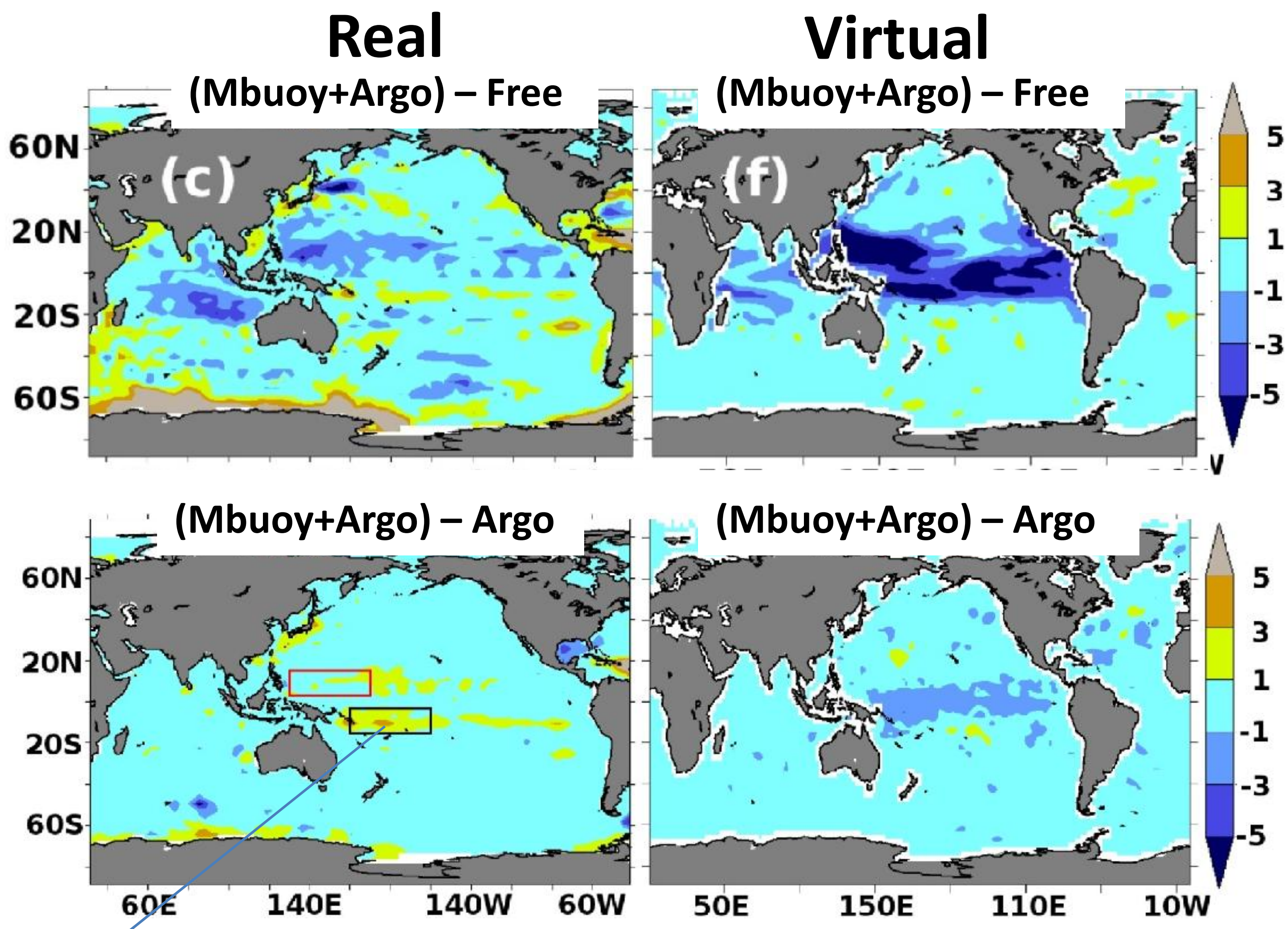
(Sq.Error in MBuoy exp) – (Sq.Error in Free exp)



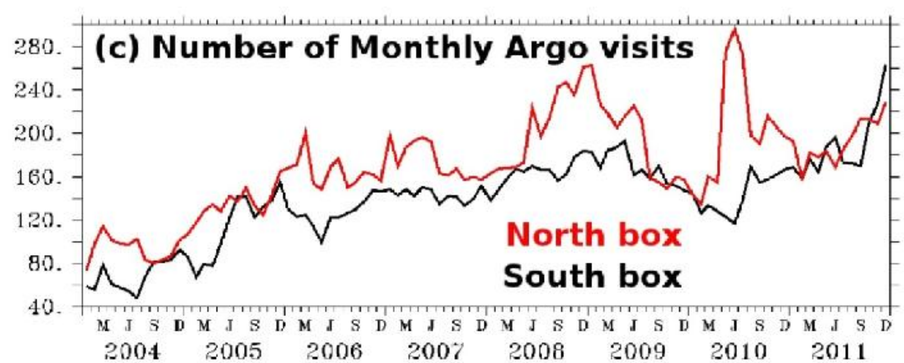
These assimilations shocks propagate westward at ~0.25 m/s



Assimilation shocks around moored buoy coverage area



Shocks introduced from real moored buoy assimilation is not fully suppressed by Argo



What went wrong?

- Imbalances amongst state variables?
  - Whether the SSH and salinity treated well while assimilating temperature? Similarly how well the velocity treated while assimilating tracers?
- Improper Representation Errors (REs)?
  - It can make the system over-believe the observations if representation errors are spuriously set to smaller values. This creates shocks. Recollect earlier scalar case equations

$$x^a = \frac{\pm_0^2}{\pm_0^2 + \pm_b^2} x^b + \frac{\pm_b^2}{\pm_0^2 + \pm_b^2} y_0$$

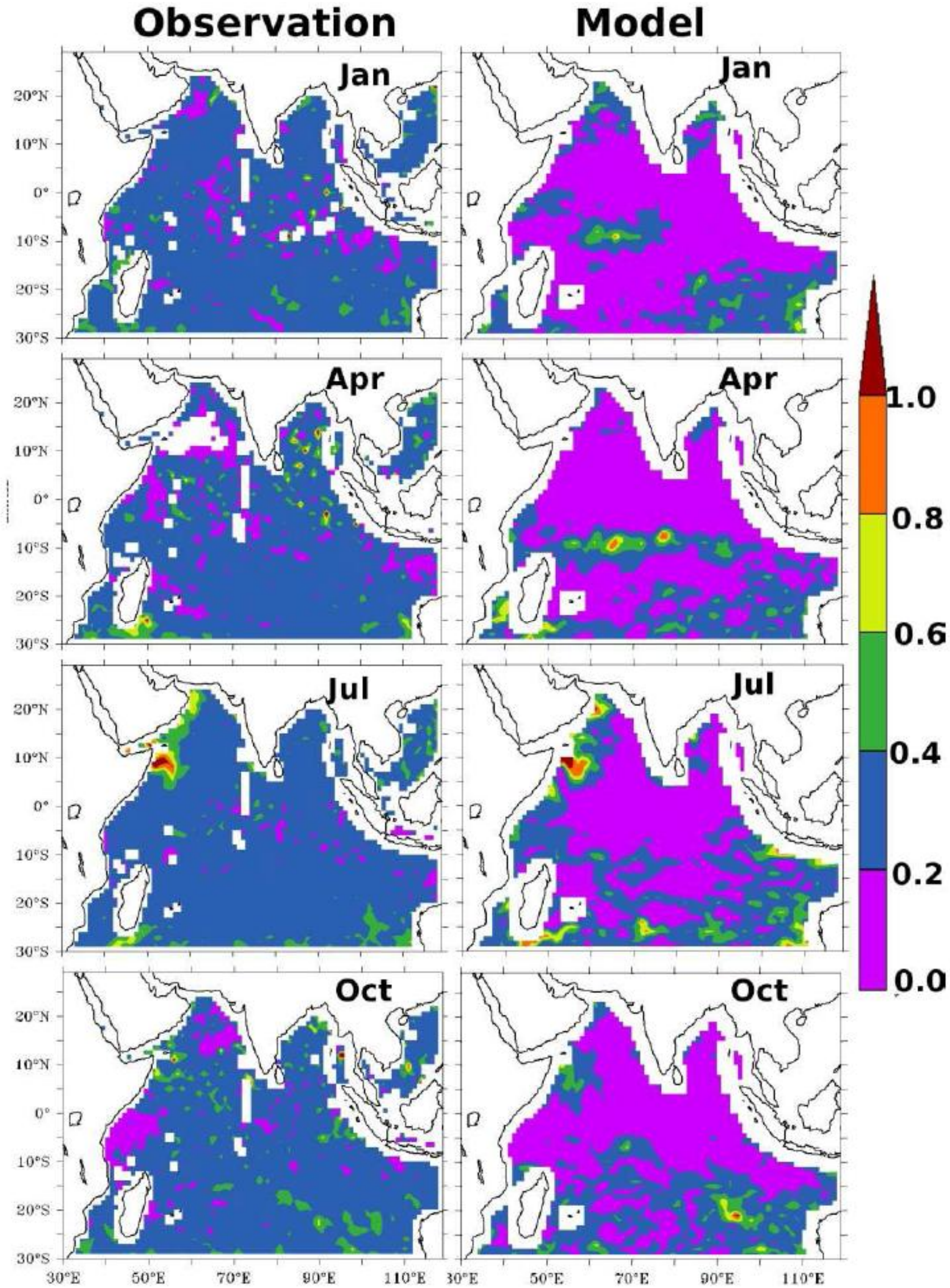
$$\text{If } \pm_b >> \pm_0 ; x^a \approx y_0$$

$$\text{If } \pm_0 >> \pm_b ; x^a \approx x_b$$

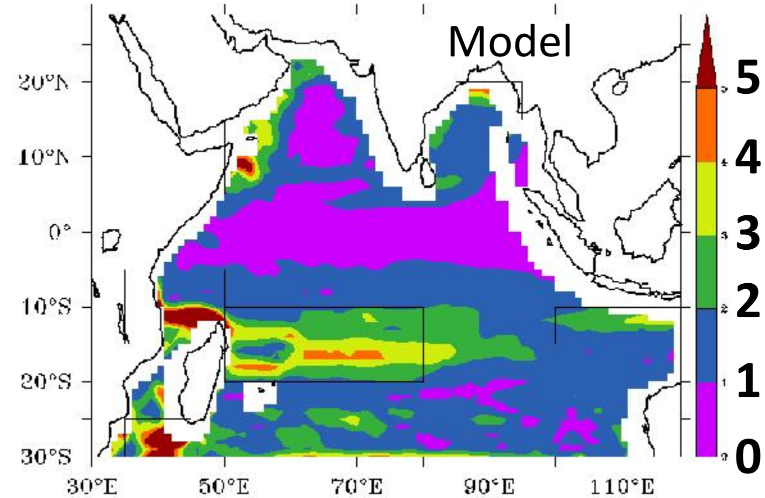
  - REs in GODAS is estimated based on only vertical gradients. However, in reality, REs have variations in the horizontal direction as well!!!!!!!!

Representation Errors

Sea Surface Temperature



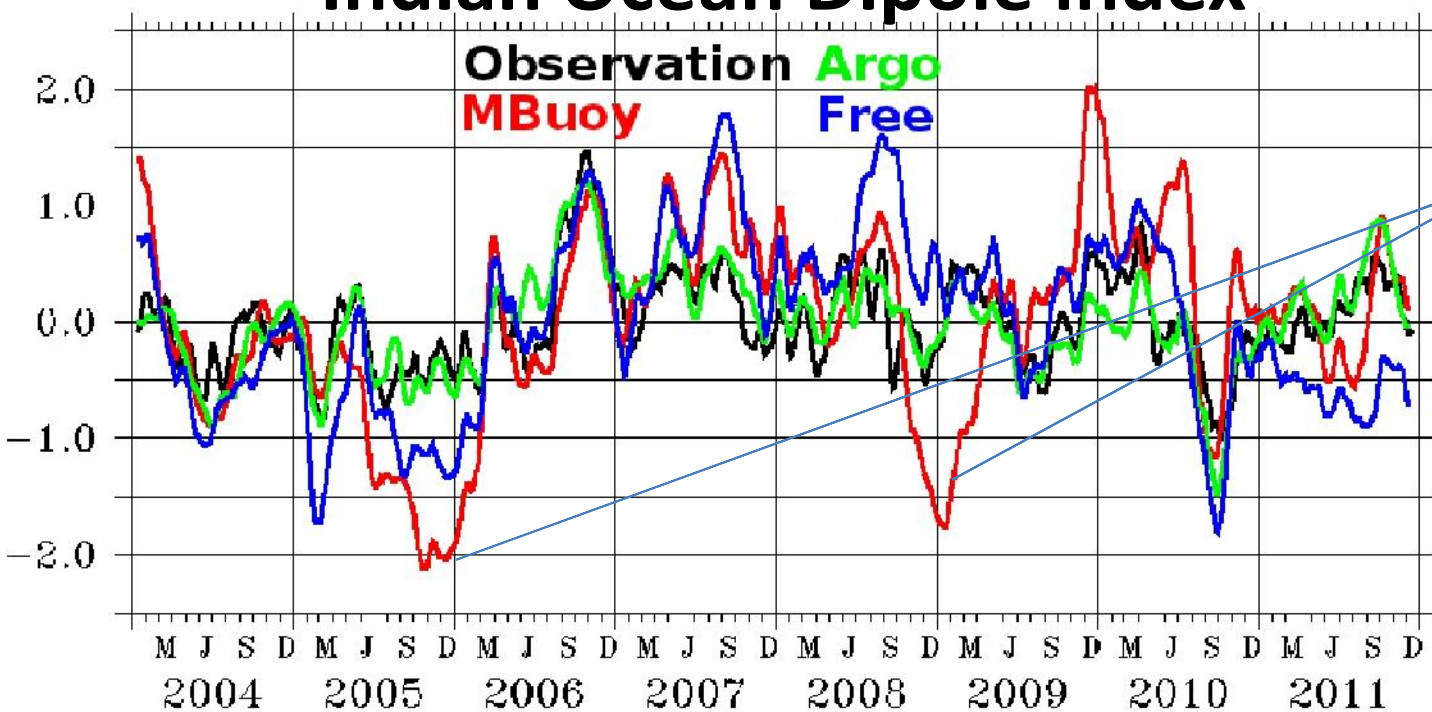
Sea Surface Height Anomaly



Why worry about assimilation shocks?

- Ocean re-analysis in the pre-Argo era may be seriously effected by these spurious shocks.

Indian Ocean Dipole index



Mbuoy exp Wrongly interpreted neutral IOD as strong –ve IOD years. Importantly, the simulation is worse than Free exp.

Summary

- Assimilating more number of observations doesn't necessarily improve ocean simulation.
- Spatial coverage is the most influential factor in the present day's assimilation systems
- Ocean re-analysis have to be used with a pinch of salt especially before Argo-era.
- More focused research has to be carried out on the fundamental deficiency of assimilation shocks in data assimilation systems

Thank You