Impact of Altimeter Data Assimilation with SSHA in improving the monsoon forecast

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New frontiers of altimetry

Chronology

- Introduction
- The data Used
- The method / technique adapted
- Results and inferences
- Conclusion

Introduction

- Reliable monsoon forecast has been one of the ***key challenges*** faced by the meteorological communities

- To better the forecast we may either attempt to **improve the representations of physical processes** by the forecast models. These are lasting but are more **difficult to achieve** and take enormous effort .

- Or in the context of *recent advances in **observational networks and the availability of altimeter observations***, we can also take advantage of the existing data assimilation techniques which have a promising role in improving the seasonal and extended range forecasts

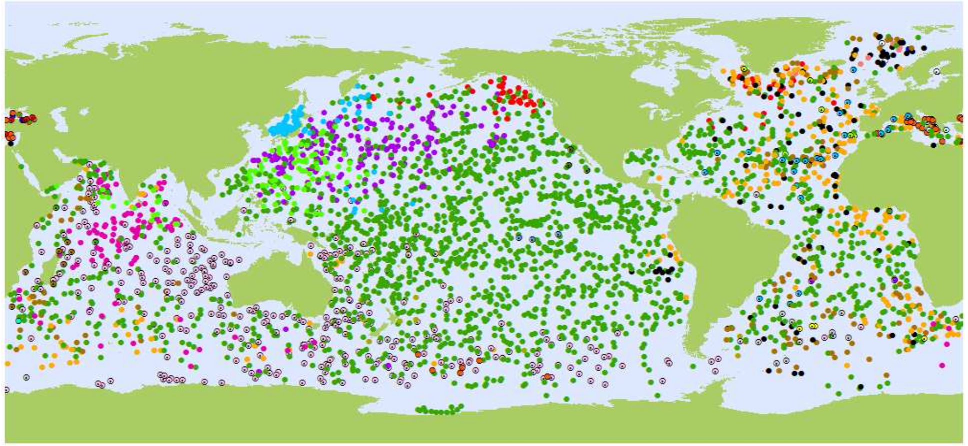
- Earlier modelling studies have highlighted the **significance of better initial conditions**, particularly with regard to the upper ocean thermal structure for improving the skill of model forecasts at the seasonal time scale. (Balmaseda et al., 2009)

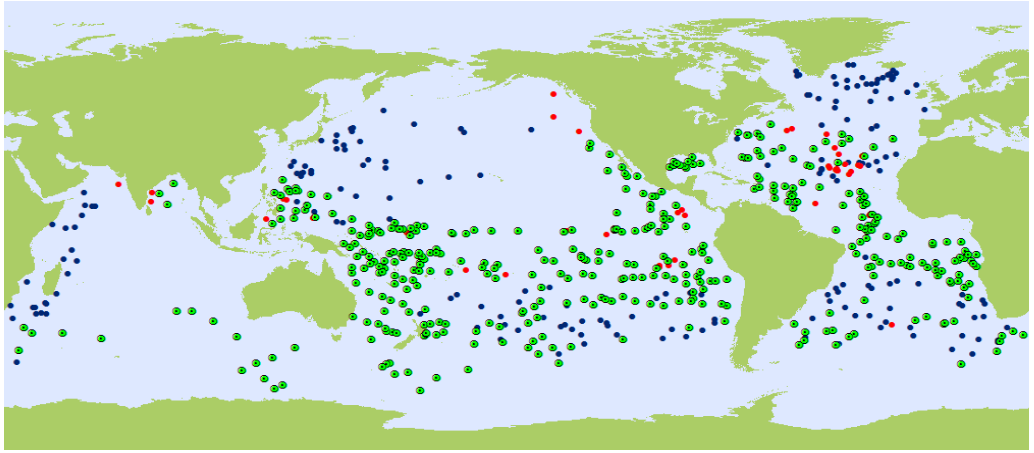
- Any change in the upper ocean thermal structure, particularly in the SST strongly influences the atmospheric circulation in the coupled model (Balmaseda et al., 2009).

- The present study investigates the **role of altimeter data assimilation in improving the SST analysis** and consequently CFS- based monsoon forecast.

The Motivation

➢ Even though a large network of in-situ observations such as ARGO profiles are in place, they are still **not enough** to provide a **continuous** global data set, due to **limitations** such as 10 day repeat cycle, coarser resolution, non availability in oceanic economic zones, pirate affected regions like Somalian region (western IO), etc.





All Argo profiles as of Sept 2014

Surface Argo profiles as of Sept 2014

http://argo.jcommops.org/maps.html

- Some of these major limitations can be avoided with the use of satellite data. Thus information derived from ***satellite measurements serve as a complementary data sets*** with a very high resolution of observations, albeit on a surface level.

- Our aim is to derive the subsurface information as well, from the surface observations so that an accurate representation of the ocean structure will be generated which can serve as a better initial condition for the coupled forecast system

- Specifically, we have attempted to **derive synthetic profiles of Temperature and salinity**, from the surface information of Temperature salinity and SSHA.

The data Used

- For the surface, the data from the SSHA anomalies from the **SARAL/AltiKa**[$] (GDR) were used and temperature from ERA-interim[#]

- For the purpose of subsurface *training*, the data from the global network of ARGO* and multi mission merged Aviso MDT[%] is used.

- RAMA[@] data has been used for comparison study

$ → SARAL data has been accessed from the http://www.mosdac.gov.in/ server

\# → ERA-interim data used in this study have been obtained from the ECMWF data server *http://data-portal.ecmwf.int/data/d/interim_daily/*

** → Argo data* were collected and made freely available by the Coriolis project *(http://www.argo.ucsd.edu, http://argo.jcommops.org).* (http://www.coriolis.eu.org)%

→ merged multi mission MDT from Aviso (http://www.aviso.altimetry.fr/en/data/data-access/gridded-data-extraction-tool.html)

@ → RAMA data was accessed from NOAA server.

http://www.pmel.noaa.gov/tao/disdel/frames/main.html

Methodology

- Buongiorno Nardelli And Rosalia Santoleri have demonstrated the method for the Reconstruction of Vertical Profiles from Surface Data using a technique called Multivariate EOF technique.

(*Nardelli and Santoleri,2004,J. Atmos. Oceanic Technol,Vol:22*)

(*Nardelli and Santoleri, 2005, Reconstructing Synthetic Profiles from Surface Data, J. Atmos. Oceanic Technol., Vol: 21, 693:703)*

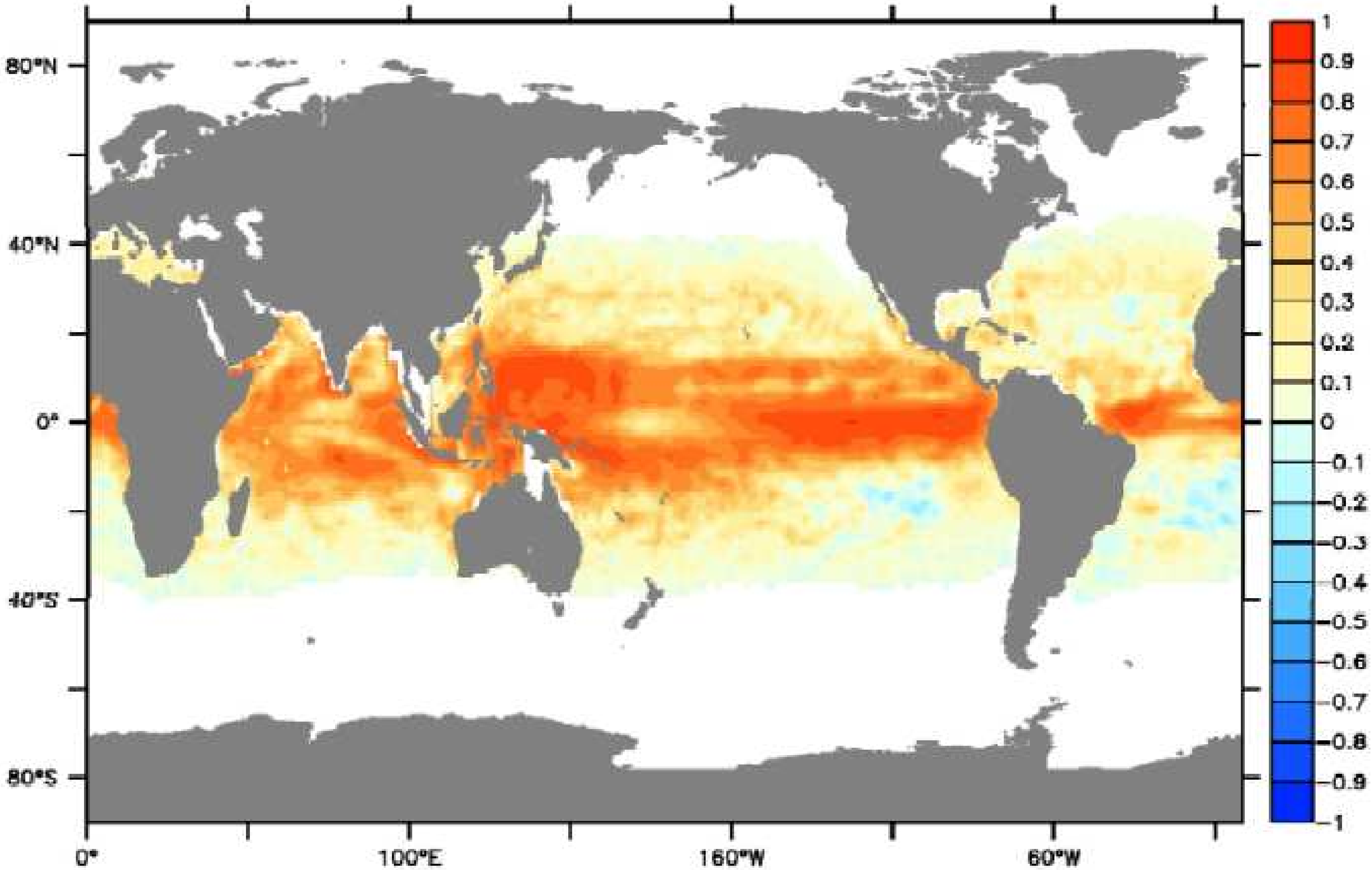
- The mEOF technique was explained by *Bretherton, C. Smith, and J. M. Wallace, 1992: An inter-comparison of methods for finding coupled patters in climate data. J. Climate, 5, 541–560*

The m-EOF technique

- **Multivariate EOF** ***Reconstruction*** **(m-EOF-R)** consists of:

- The multivariate Empirical Orthogonal Functions (m-EOF) ***decomposition*** for the ***identification of the multi-coupled modes*** of variability between datasets of vertical profiles.
- Reconstruct using significant modes
- **Hypothesis**: few coupled modes explain the major part of the multi-variability.

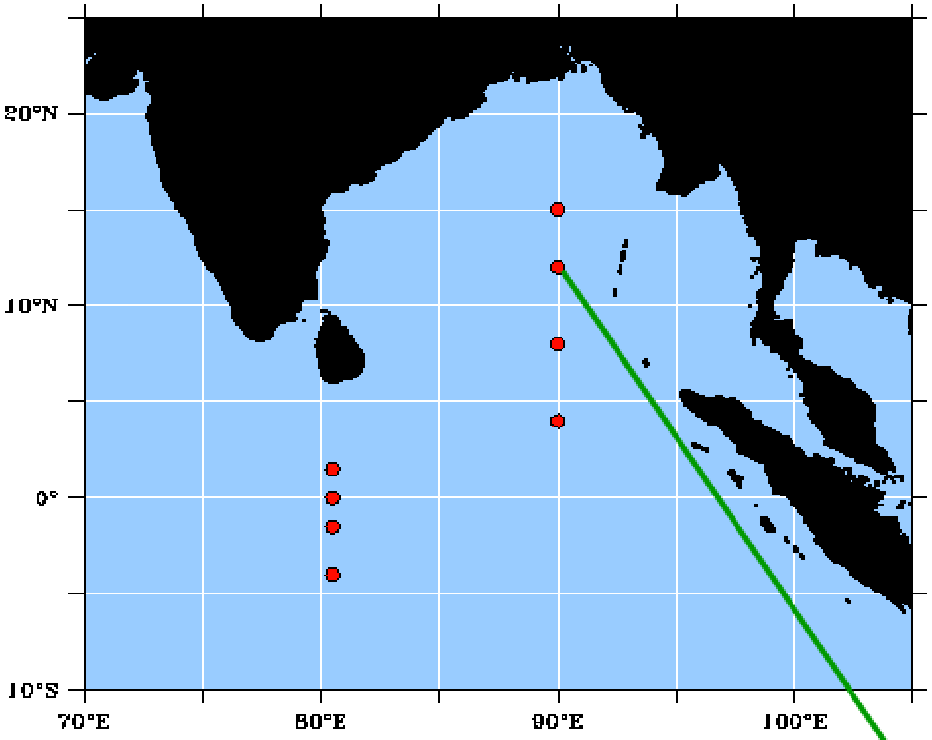
- For this hypothesis to work there need to sufficient correlation between surface and subsurface oceanographic parameters.



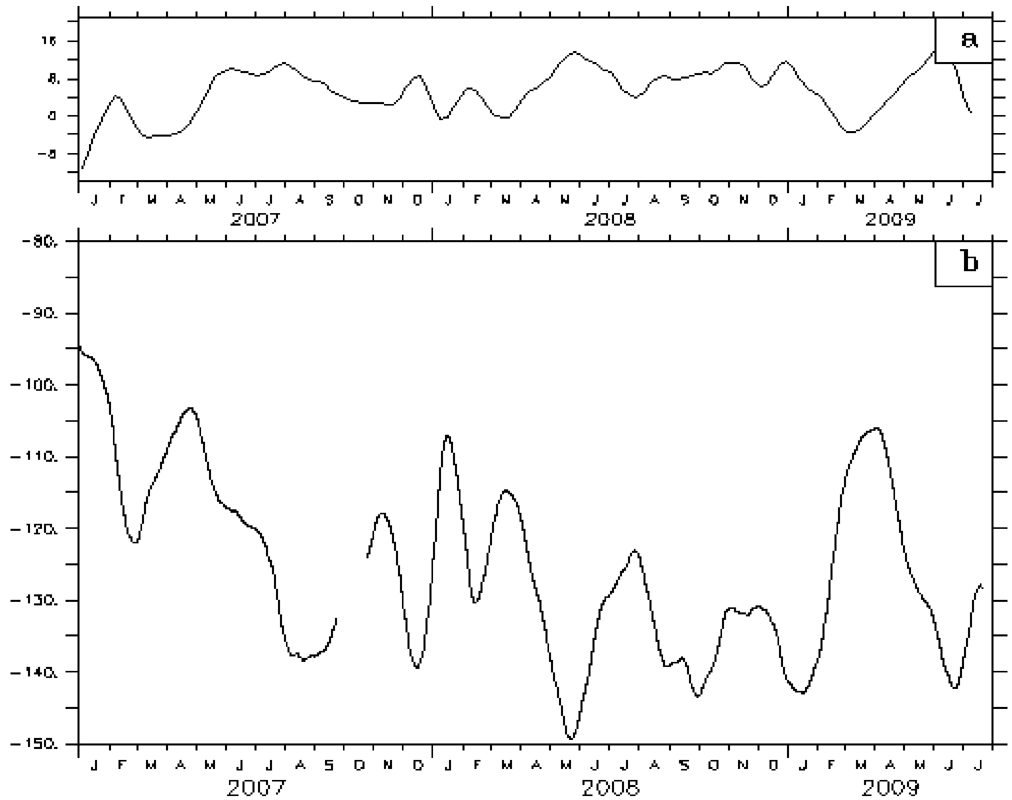
Correlation between D20 (depth of 20^0 C isotherm) and SSHA

Data from SODA(http://apdrc.soest.hawaii.edu/) and merged mission product from Aviso

SSHA mirrors the changes in the thermocline



Buoy location	Correlation between SSHA and d20
(90° E, 12° N)	0.77
(90° E, 8° N)	0.80
(90° E, 4° N)	0.72
(80.5° E, 1.5° N)	0.85
(80.5° E, 0°)	0.70
(80.5° E, 1.5° S)	0.74
(80.5° E, 4° S)	0.66



$$X = \begin{bmatrix} T(o,t_1) & T(o,t_2) & \dots & T(o,t_n) \\ \vdots & \vdots & \dots & \vdots \\ T(z_m,t_1) & T(z_m,t_2) & \dots & T(z_m,t_n) \\ S(o,t_1) & S(o,t_2) & \dots & S(o,t_n) \\ \vdots & \vdots & \dots & \vdots \\ S(z_m,t_1) & S(z_m,t_2) & \dots & S(z_m,t_n) \\ GH(o,t_1) & GH(o,t_2) & \dots & GH(o,t_n) \\ \vdots & \vdots & \dots & \vdots \\ GH(z_m,t_1) & GH(z_m,t_2) & \dots & GH(z_m,t_n) \end{bmatrix}$$

- The *first step* is to construct a multivariate matrix **X,** putting the following three sets of data in a single matrix .
- (anomalies of *Temp, Sal, and Geopotential ht (GH)* profiles)

- The anomalies of GH is analogous physical quantity to dynamic topography in the sub surface, and calculated as follows

$$GH = \Phi_2 - \Phi_1 = -\int_1^2 \alpha(T,S,p)dp$$

Where α is the specific volume of water expressed as a polynomial in T,S and p (Knudsen, 1901)

Step -2

Then a SVD decomposition of the multi-variance matrix $\mathbf{\Gamma_x}$ ($\mathbf{\Gamma_x} = XX^T$) is performed.

The SVD decomposition is an eigen value problem where the result is the generation of the eigen vectors of the multi-variate matrix $\mathbf{\Gamma_x}$

$$\boldsymbol{\Gamma_X U = UA} \quad where \quad \boldsymbol{A} = a\,\boldsymbol{I} \quad \& \quad \boldsymbol{U} = \begin{pmatrix} L_k(z) \\ M_k(z) \\ N_k(z) \end{pmatrix}$$

Eigen Value Problem

Diagonal matrix of Eigen Values

Multi coupled Eigen vectors

The three variables can be reconstructed from the eigen-vectors as shown

Which will contain the time dependent amplitude function and the time independent modes

$$T(z,t) = \sum_{k=1}^{n} a_k(t) L_k(z)$$

$$S(z,t) = \sum_{k=1}^{n} a_k(t) M_k(z)$$

$$GH(z,t) = \sum_{k=1}^{n} a_k(t) N_k(z)$$

Step -3

Now we considered only the *first three modes (considering the computational intensity), ie, we set k= 3,* we can obtain the amplitude functions a(t) from three sets of surface parameters

.

$$a_1(t)L_1(0) + a_2(t)L_2(0) + a_3(t)L_3(0) = T(0, t)$$

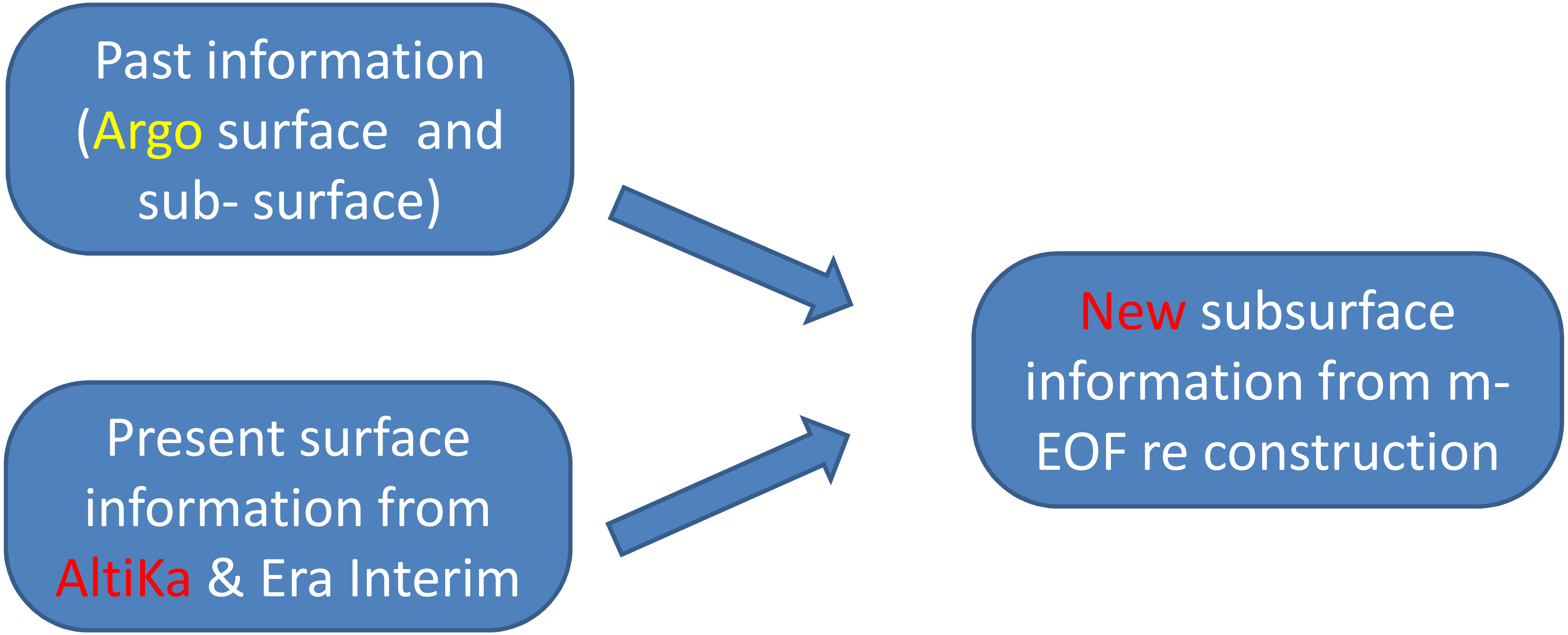
$$a_1(t)M_1(0) + a_2(t)M_2(0) + a_3(t)M_3(0) = S(0, t)$$

$$a_1(t)N_1(0) + a_2(t)N_2(0) + a_3(t)N_3(0) = GH(0, t)$$

This forms a set of 3 leniar equations in 3 unknowns which we can solve for the amplitude functions $a_k(t)$ which are the coefficients for the whole eigen vector .

.

Then we can reconstruct back the entire sub-surface profiles from the first 3 modes for each of the depths as $a_k(t)$ is the same for all depths


Past information (Argo surface and sub- surface)
Present surface information from AltiKa & Era Interim
New subsurface information from m-EOF re construction

Surface Information used to reconstruct subsurface profiles

(The $z = 0$ part)

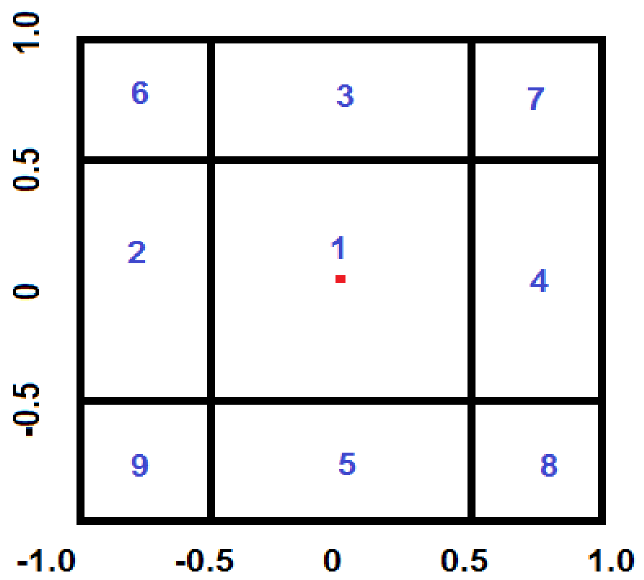
- Temperature : Surface temperature fields obtained from ERA interim.
- Salinity : Surface Salinity fields obtained from GODAS product of IITM,Pune
- Surface Geo-potential height : Geo-potential anomalies at surface is equivalent to dynamic topography, which is obtained from the Saral-AltiKa dataset as combination of SSHA and MDT

< The ‘t’ part in a(t) >

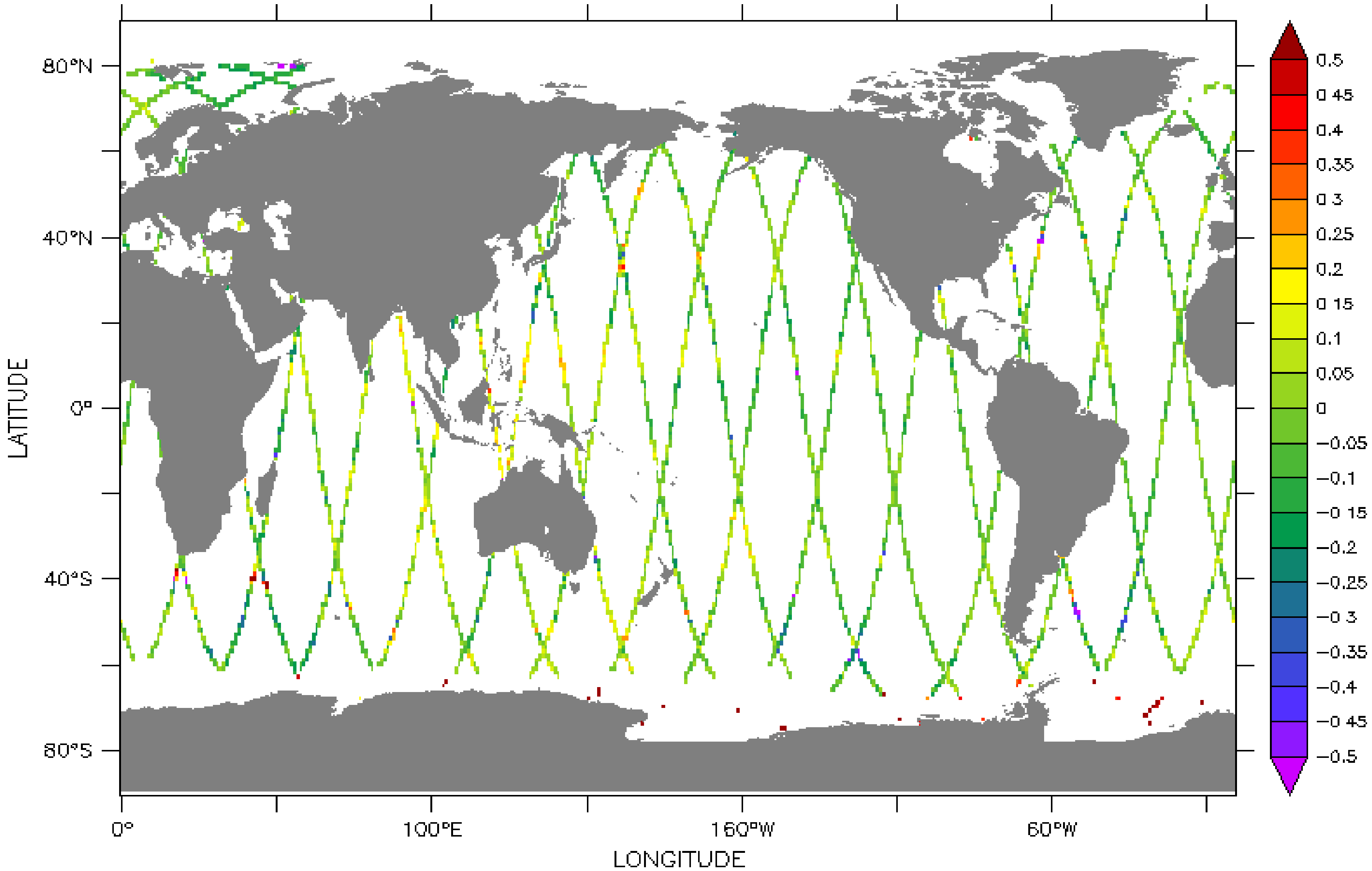
•Since the ocean state varies over a period of 2 to 3 days, for our purpose a time step of 1 day will be sufficient for analysis, and consequently all observations in a given day are considered to be at the same time.

- As the available Saral data is along track data, we decided to make a 1°X1° gridded product which consists of each time step referring to one day.
- Obviously not all observations of SSHA fall on the grid points (1°X1°), so in order to assign the correct grid point to each observation, the following scheme was used; an equivalent scheme for *any resolution* can be devised. (We wrote a Fortran code to implement this scheme)

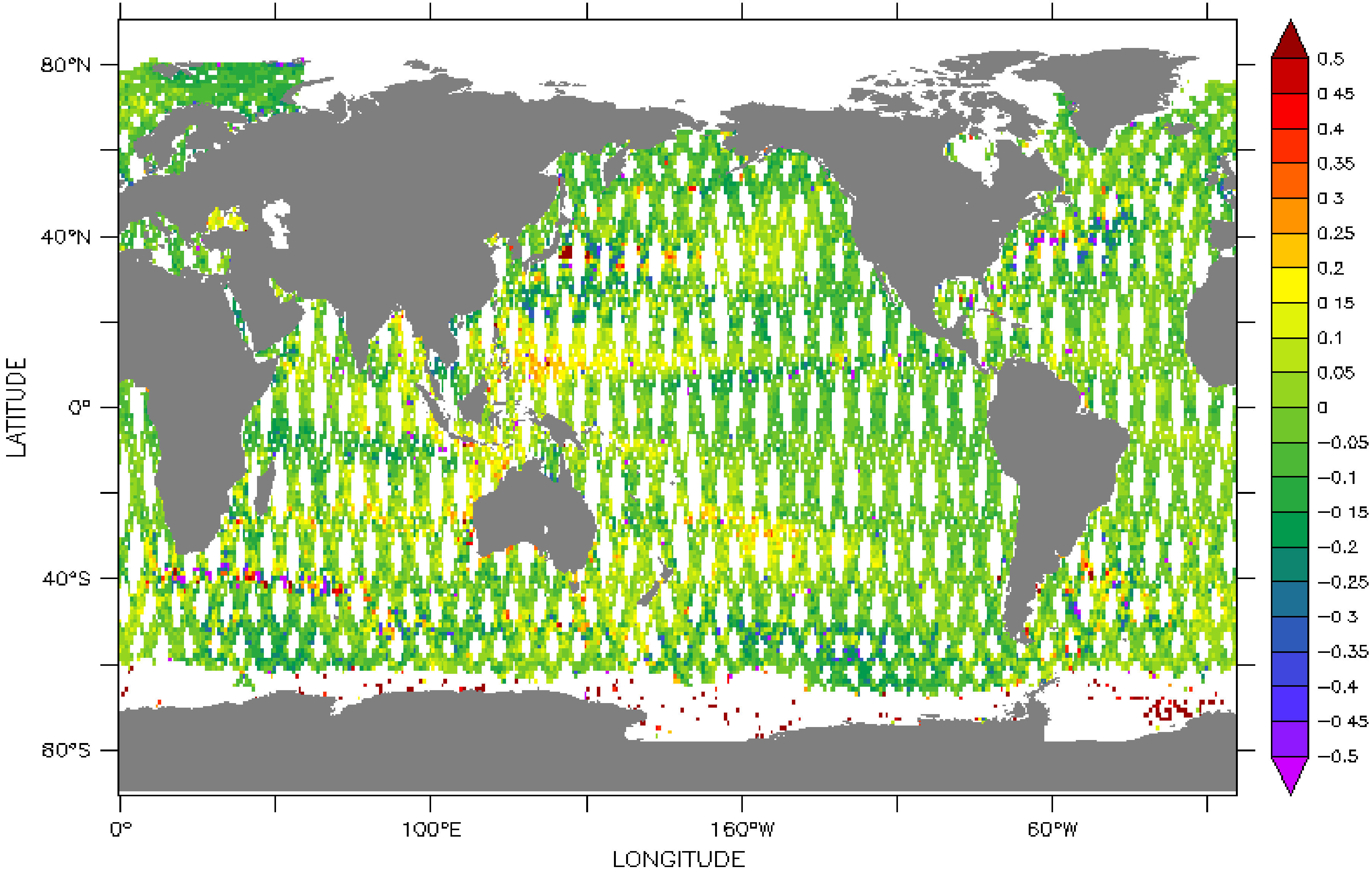
•If the decimal value for either latitude or longitude falls between [-0.5 to 0.5] then it is assigned to the integer part of it , if it falls in (0.5 to 1) then it is assigned to the next integer and if it falls between (-1 to 0.5) then it is assigned to the previous integer



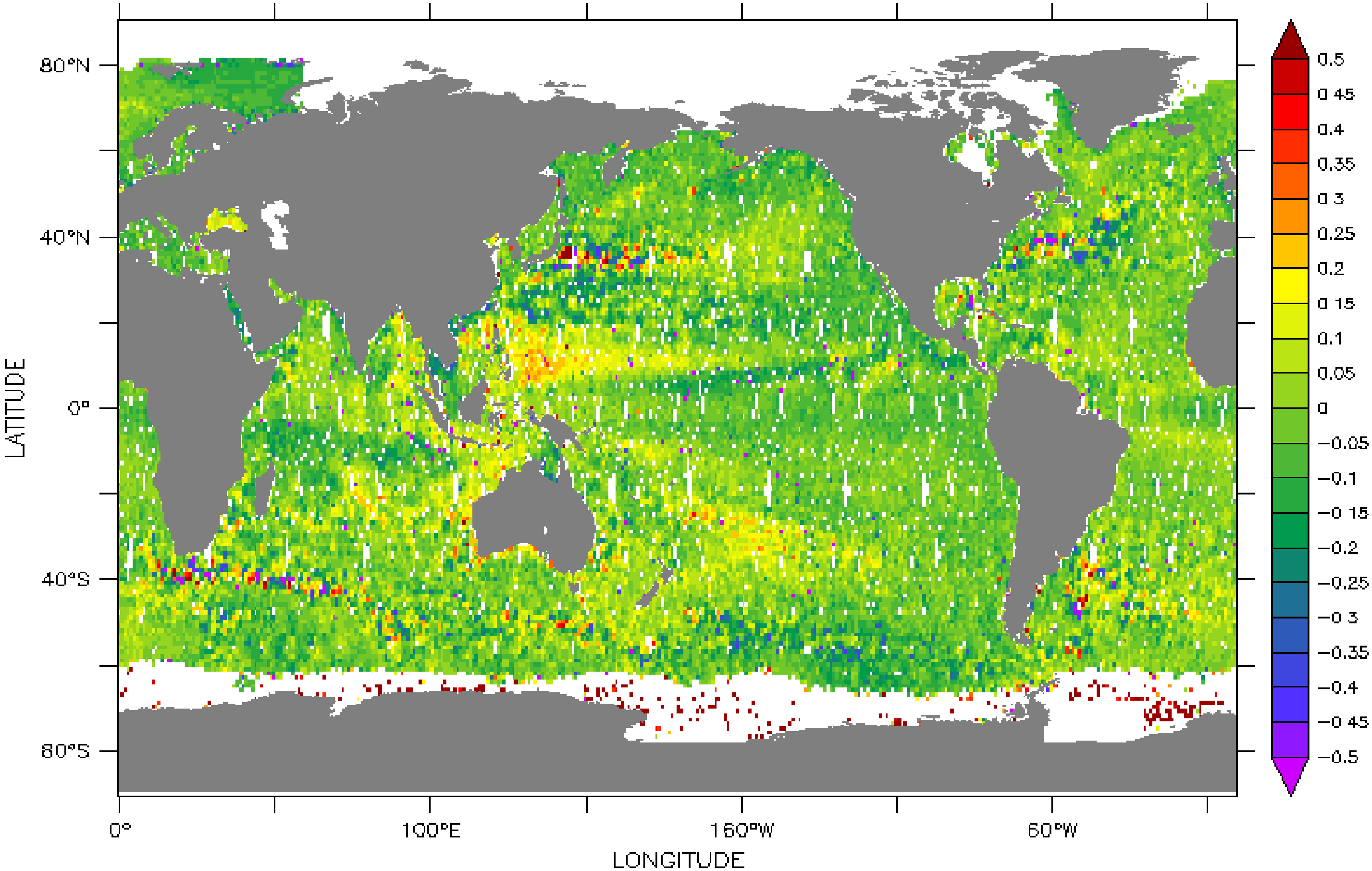
So for example, a latitude longitude of {10.756^0 N, 62.347^0 E} will be re-gridded to {11^0 N ,62^0 E}



SSHA from Saral AltiKa gridded at 1 degree resolution, for time duration of 1 day (here, 22-June-2013)



SSHA from Saral AltiKa gridded at 1 degree resolution, for time duration of 1 week(here, 22-June-2013 to 28-June-2013)



SSHA from Saral AltiKa gridded at 1 degree resolution, for time duration of 2 weeks(here, 22-June-2013 to 05-July-2013)

Reconstructed Synthetic Profiles

- Within this frame work setup, The subsurface profiles were derived using the m-EOF technique.

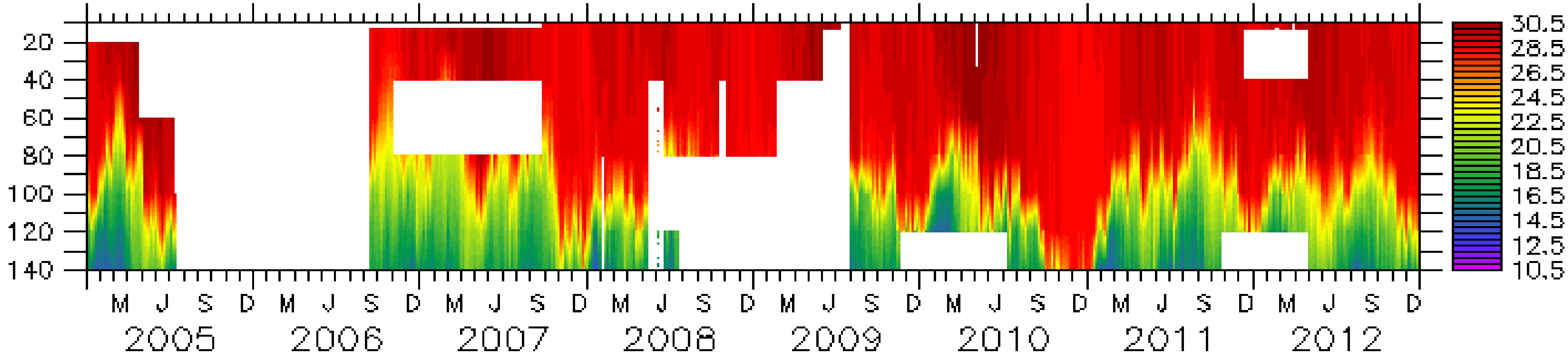
- Once the subsurface synthetic profiles are derived a quality control check has been performed on them with the following criteria, as mentioned in the argo manual.

  - Temperature should be in range of −2.5 to 40.0°C and Salinity in range of 2 to 41.0 PSU)
  - The temperature gradient may not go below -1^{o}C / 5 meters

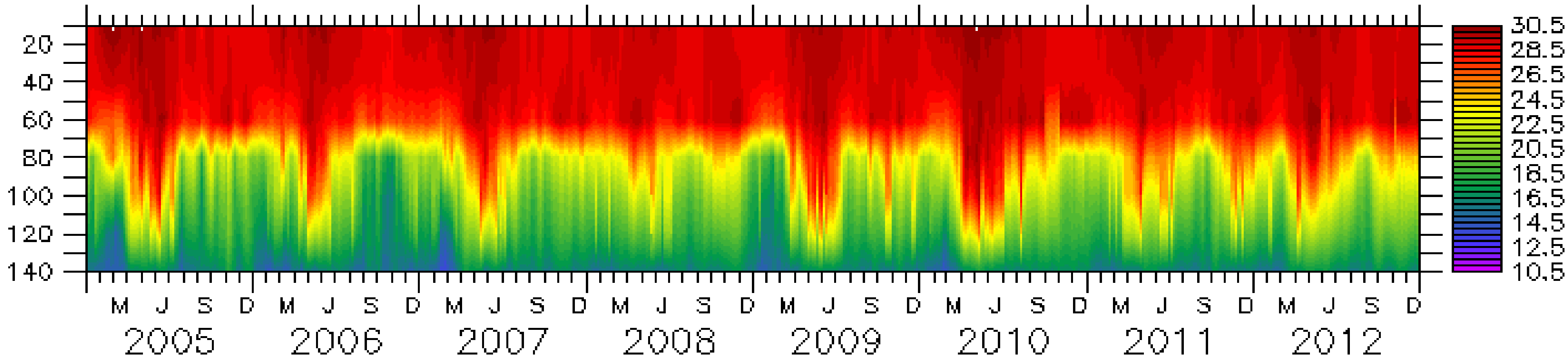
  - Any profiles with inversion above 1.5 degrees are removed

Temperature at 90^0 E and equator

RAMA



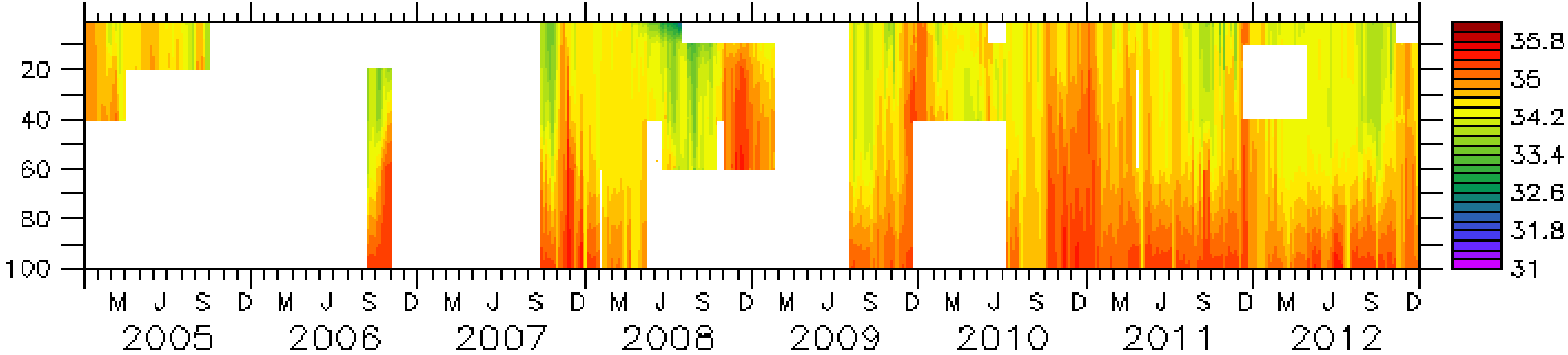
Synthetic profiles from Altimeter



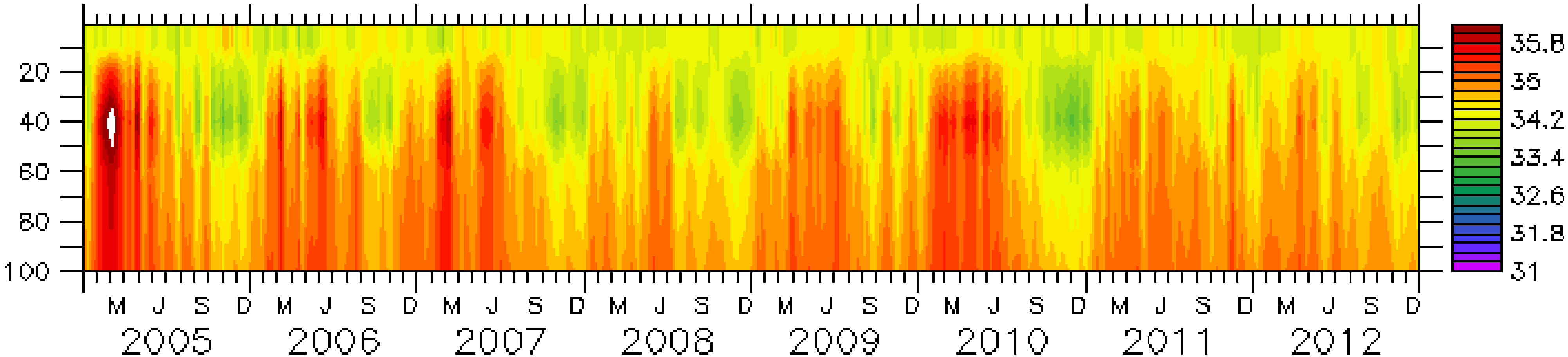
A case study

Salinity at 90^0 E and equator

RAMA



Synthetic profiles from Altimeter



A case study

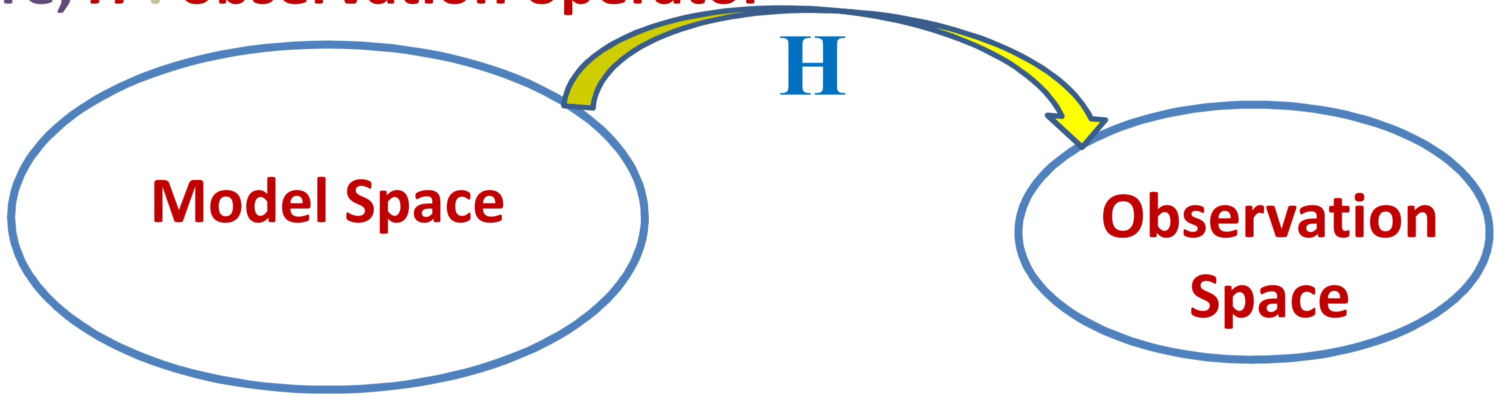
GODAS (Global Ocean Data Assimilation System)

- "3DVar data assimilation scheme" [Derber and Rosati, 1989]

- Problem is to find optimal analysis x_a
  which minimizes a cost function
  (proportional to 'the square of the distance between the analysis and both background and the observations, both weighted by the inverse of the respective error covariance')

$$J = \frac{1}{2}\{[\mathbf{y}^o - H(\mathbf{x})]^T R^{-1}[\mathbf{y}^o - H(\mathbf{x})] + (\mathbf{x} - \mathbf{x}^b)^T B^{-1}(\mathbf{x} - \mathbf{x}^b)\}$$

where, *H* : observation operator



(Kalnay, 2003)

Climate Forecast System version 2 (CFSv2)
(couple ocean atmosphere model)

Consists of 2 forecast models and 2 data assimilation system

CFSv2

Atmosphere

Global Forecast System (GFS)
[Moorthi et al. (2001)]

→ resolution: T126

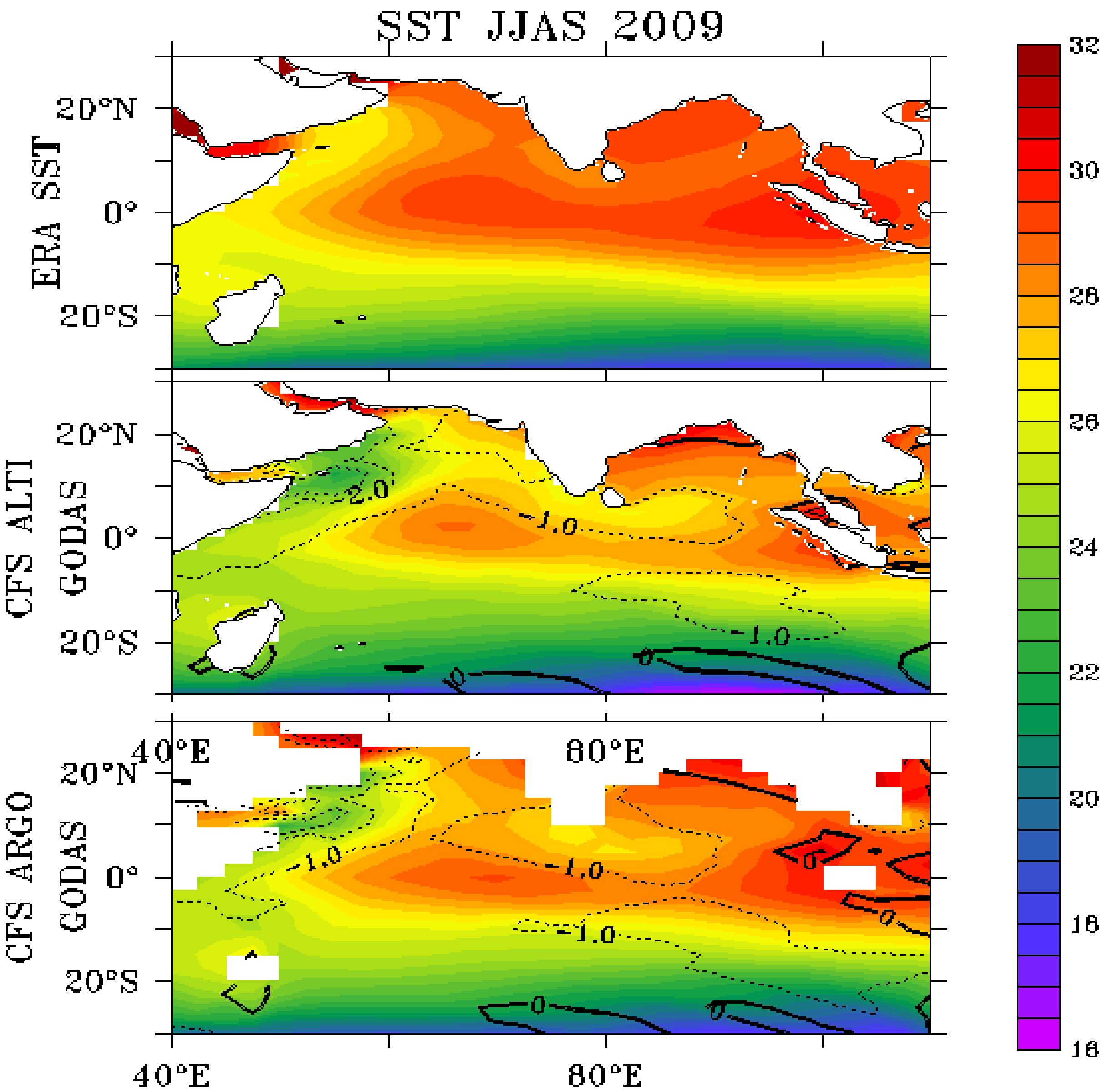
→ vertical 64 sigma layers

Ocean

Modular Ocean Model (MOM4p0)
[Griffies et al. (2014)]

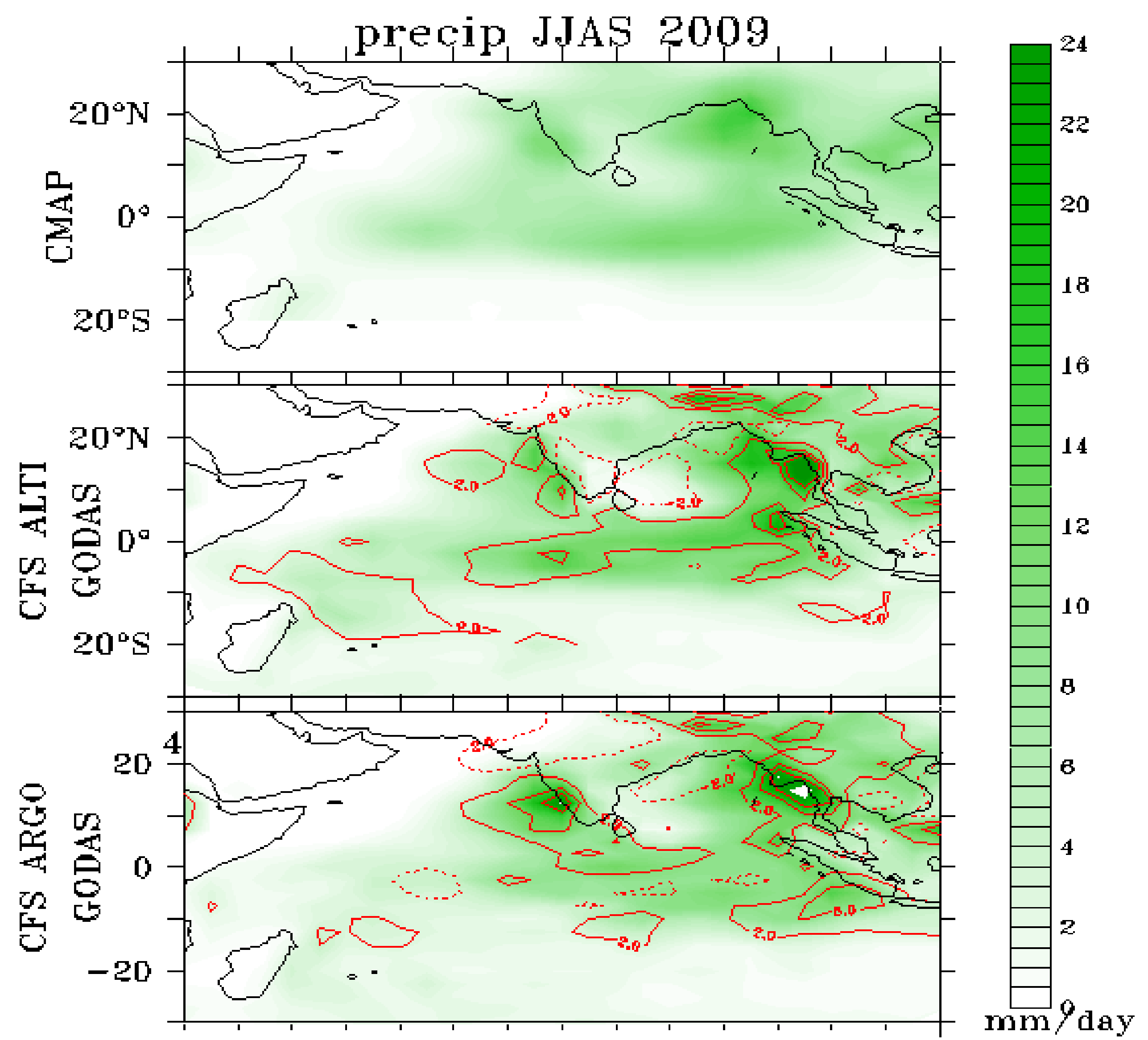
→ resolution: 0.5°x0.5° (0.25° within 10° of the equator).

→ The vertical grid has 40 Z-levels with variable resolution (23 levels in the top 230 meters)



SST JJAS 2009
ERA SST
CFS ALTI GODAS
CFS ARGO GODAS
20°N
0°
20°S
40°E
80°E
-2.0
-1.0
0
32
30
28
26
24
22
20
18
16

A case study


precip JJAS 2009
CMAP
CFS ALTI
GODAS
CFS ARGO
GODAS
20°N
0°
20°S
20
0
−20
4
2.0
24
22
20
18
16
14
12
10
8
6
4
2
0
mm/day

A case study

Conclusion

- From a preliminary analysis, it can be inferred that the CFS forecast made from altimeter assimilated initial conditions are comparable with at least the Argo assimilated CFS forecast, even for a 3 mode reconstructed profiles.

- Owing to the relatively greater spatial network being available for SARAL observations, the CFS forecast made with the SARAL assimilated ocean initial conditions are expected to be better.

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Thank You!