Role of Assimilation of Salinity Data in Tropical Pacific Ocean Simulations

E. Hackert, J. Ballabrera, A.J. Busalacchi and R. Murtugudde

ESSIC, University of Maryland, College Park, Maryland

This study focuses on the added value of salinity data with respect to other conventional data specially for the 2002 El Niño. A Reduced Order Kalman filter (ROKF) is used to investigate the impact of the assimilation of salinity and temperature observations to constrain tropical Pacific dynamics and thermodynamics of the reduced-gravity, sigma-coordinate, ocean model of Gent and Cane (1989). In these experiments, subsurface data (T_z, S_z) from the Global Temperature Salinity Profile Project (GTSPP) are assimilated. Assimilation of conventional subsurface data (CSD - defined as all subsurface observations except TAO and Argo) is compared with results using Argo only. In addition, a new SSS dataset, which is derived from an OI of S_z data, has been created and included for data assimilation.

MULTIVARIATE REDUCED ORDER KALMAN FILTER

Multivariate state vector, $\mathbf{x} \in R^n$

Observations, $y \in R^p$

Kalman filter analysis equation:

$$\mathbf{x}_k^a = \mathbf{x}_k^b + \mathbf{PH}^T\left[\mathbf{HPH}^T + \mathbf{R}\right]^{-1}\left(\mathbf{y}_k^o - \mathbf{Hx}_k^b\right)$$

$$\mathbf{P} \in R^{n\times n}, \quad \mathbf{H} \in R^{p\times n}, \quad R \in R^{p\times p}$$

Truncation of error covariance:

$$\mathbf{P} = \mathbf{S\Lambda S}^T, \quad \Lambda \in R^{r\times r}$$

Ensemble estimate

$$\Lambda_k$$

Parameterization truncation error

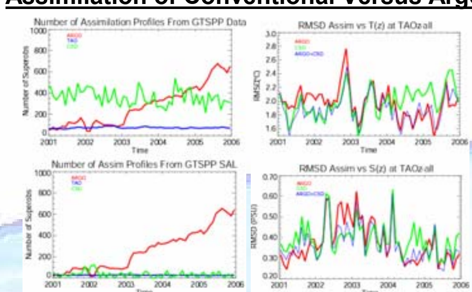
$$\mathbf{Q} \in R^{r\times r}$$

$$\mathbf{x}_k^a = \mathbf{x}_k^f + \mathbf{S}\cdot\boldsymbol{\mu}$$

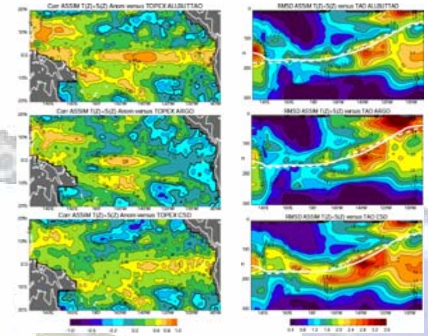
$$\left[\Lambda_k^{-1} + (\mathbf{HS})^T \mathbf{R}^{-1}(\mathbf{HS}) + \mathbf{Q}\right]\cdot\boldsymbol{\mu} = (\mathbf{HS})^T \mathbf{R}^{-1}\left(\mathbf{y}_k^o - \mathbf{H}\overline{\mathbf{x}}\right)$$

The ROKF algorithm is based on the truncation of the multivariate covariance of a 20-year simulation of the model, providing analysis fields with the same spatial resolution as the numerical model. The leading multivariate EOFs of the model are used to statistically project the information of the data correction to all the variables of the model. For example, assimilation of a T_z profile impacts the entire state vector (SL, H, T, S, U, V) including salinity.

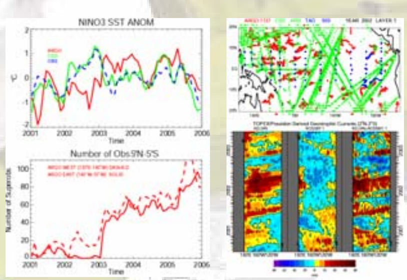
Assimilation of Conventional Versus Argo



Conventional data (CSD) is defined as all subsurface observations except Argo and TAO (which is withheld for validation). Data coverage plots (top left) show the number of T_z Argo profiles (red) surpasses CSD (green) in 2004 while CSD provide practically no salinity information (bottom left). Experiments which assimilate both Argo and CSD (top right) are compared to withheld TAO observations using RMS difference. Note that as the number of observations increases, the RMS decreases and that Argo RMS (red) is lower after 2004 for both T_z (top) and S_z (bottom). Also note that the overall best results assimilates both the CSD and Argo data (light blue lines).

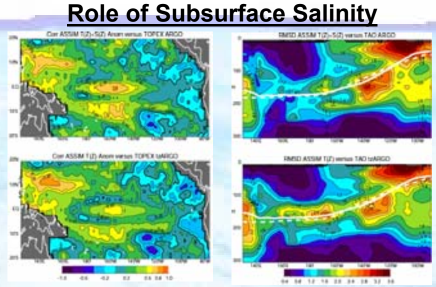


Correlation of Jason-1 SL versus SL from assimilation experiments (left column) shows that combined Argo+CSD (top left) does better than either single data type. Correlation is higher in the western basin for the Argo results (middle left) while CSD (bottom left) does better in the eastern basin. Plots on the right show the RMS difference of the assimilation results versus the longitude depth OI of TAO data (withheld). The error in the western Pacific at the thermocline depth for CSD (bottom right) is significantly larger as opposed to Argo (middle right). The error at the surface in the cold tongue region is due to deficient sampling provided by Argo during the 2002 El Niño.



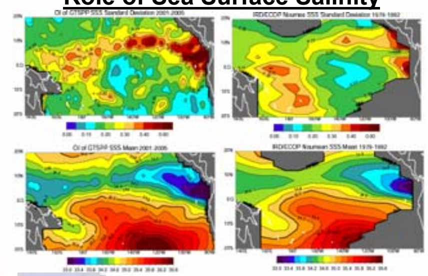
The poor results of the Argo assimilation for the Nino3 region SST' (red curve, top left) is directly attributed to the lack of observations in the eastern half of the basin (bottom left) and the oversampling of the off-equatorial region (top right - red dots) for the 2002 El Nino. The bottom right figure shows the Kelvin and Rossby wave decomposition derived from Jason-1 currents. The Rossby wave (middle panel, bottom right) was overemphasized while the Kelvin wave (left panel, bottom right) went undetected by the Argo observations.

Role of Subsurface Salinity

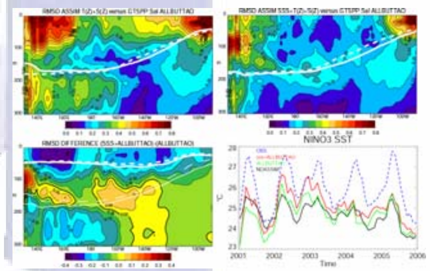


SL correlation drops when S_z is withheld (bottom left) as compared to the full T_z+S_z Argo assimilation (top left) . Note the significant error for the no-salinity experiment (bottom right) in the west at the level of the thermocline. This pattern of RMSD is similar to the CSD results shown earlier which is not surprising since CSD contains very few S_z measurements.

Role of Sea Surface Salinity



OI of GTSPP data for SSS standard deviation (top left) and mean (bottom left) for the 2001-2005 period. The OI has been cross validated with an error estimate of 0.23 PSU (the expected error of Aquarius is 0.2 PSU). These OI results are compared to the product of Delcroix (1998) using conventional subsurface data for 1979-1992 (right). Although the periods are different, the overall pattern of SSS variability and mean are similar for the two products.



Experiments that assimilate T_z+S_z (top left) and SSS+T_z+S_z (top right) are compared to an OI of the longitude versus depth sections of the GTSPP S_z data using RMSD. The bottom left panel shows the results of the top right minus the top left figures. Cool colors (green-purple) show the regions where assimilating SSS improves the simulation. The solid and dashed lines (SSS+T_z+S_z, T_z+S_z assimilation, respectively) represent the mean thermocline depth (light lines) and MLD (heavy thick lines). Note that adding SSS improves the salinity structure below the MLD and below the thermocline. Assimilating SSS also improves the NINO3 SST as is demonstrated by the bottom right figure.

CONCLUSIONS

- **•Combined assimilation (ARGO+CSD) gives best overall simulation and more data improves the simulation - *ARGO after 2003*.**
- **•Assimilation of CSD data improves in the east whereas ARGO improves in the west – *suboptimal performance of ARGO in the east due to lack of data in wave-guide for the 2002 El Nino*.**
- **•Assimilation of ARGO S_z improves other variables including SL' and T_z especially in the west (*poor performance of CSD in west partially due to lack of salinity observations*).**
- **•Assimilation of SSS constrains overall salinity structure and improves subsurface salinity in layers just below the MLD and thermocline and improves the SST bias in the NINO3 region.**

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Contact: Eric Hackert (ehackert@essic.umd.edu) or http://essic.umd.edu/~ehackert