An Evaluation of Impacts from Ocean Observing Systems in NCEP GODAS in the Tropical Ocean

Hyun-Chul Lee * and Daryl Kleist **

* IMSG at NOAA/NCEP/EMC USA, ** NOAA/NCEP/EMC USA

Abstract

The currently operational Global Ocean Data Assimilation System (GODAS, Behringer, 2007) assimilates observational in situ profile data from EXpendable BathyThermograph (XBT) and Conductivity Temperature Depth (CTD), stationary fixed moorings, autonomous Argo floats, and remotely sensed sea surface temperature. With GODAS, these ocean observing systems are fundamental to NCEP's operational efforts for monitoring the ocean state and also for providing ocean initial states of forecasting multi-week to seasonal variability in the NCEP CFSv2. In order to evaluate the impact of the observation system in the NCEP operational ocean products, a series of observing system experiments (OSE, Lee, et al., 2020) have been carried out, and the observational innovations and the analysis increments associated with individual ocean observations in NCEP's GODAS were calculated. Based on these observational innovations from the OSE runs, Assimilation Impacts of Observing Systems (AIOS) and Forecast Impacts of Observing Systems (FIOS) were evaluated and applied to monitor the spatio-temporal impacts of ocean observing systems in the current operational NCEP GODAS. In this presentation,we show recent results from AIOS and FIOS in the regions of the tropical Ocean.

NCEP GODAS

The Global Ocean Data Assimilation System of NCEP (GODAS, Behringer, 2007) has been operationally provided global ocean reanalysis states from the stand-alone run and the initial ocean state for the NCEP Coupled Climate Model (CFSv2).

- The stand-alone run of GODAS is forced by the surface fluxes from the NCEP Climate Data Assimilation System (CDAS2) atmospheric reanalysis. The ocean model of the stand-alone is based on the GFDL MOM3, with a horizontal resolution of 1° by 1° enhanced 1/3° meridionally in the tropical ocean. In the vertical resolution, the model has has 40 levels, with 10 m resolution in the upper 200 m. This run of GODAS provides daily ocean reanalysis fields in the domain from 76°S to 65°N, and serves as a tool for monitoring the evolution of the global ocean state.

- The second version runs as part of the NCEP operational Climate Forecast System (CFSv2; Saha, 2010) based on the Modular Ocean Model (MOM4p0) and provides the initial states for the ocean component of CFSv2. The ocean model in the CFSR has ½ degree zonal resolution and ¼ degree in medional resolution in the Tropical region with ramping up to ½ degree in other high latitude regions. Vertically the model has 40 levels with 10 m resolution from surface to 240 meter depth.The model extends to the whole globe with the sea-ice model in the Arctic and Antarctic oceans.

- The ocean analysis of GODAS uses the 3dVAR scheme originally developed by Derber and Rosati (1989). In the GODAS (Behringer et al, 1998; Behringer, 2007) temperature and salinity fields are assimilated by minimizing the cost function as follows :

$$J = \tfrac{1}{2} (x-x_b)^T B^{-1} (x-x_b) + \tfrac{1}{2} [y-H(x)]^T R^{-1} [y-H(x)]$$

  The background error covariance (B) is horizontally modelled by the Gaussian diffusion equation extended zonally (Derber and Rosati 1997). Vertically B is modelled by a diffusion equation with length scales which is a function of level depth. The variance is proportional to the square root of local vertical temperature gradient calculated from the forecast fields. The observational error covariance (R) is assumed to be uncorrelated, and assigned vertically to the temperature profile with the depth according to the vertical temperature gradient scaled between 1°C and 2.5°C. On the salinity, the standard error is assigned as the constant by 0.1 psu. Temperature and salinity profiles are assimilated by the observations of the previous 10 day window in CFSv2 and ±15 day window in GODAS.

- The temperature observations in the GODAS are from the profiles of XBT/CTD and moored buoy data of TAO in Pacific, PIRATA in Atlantic and RAMA in Indian, and from the Argo profiles. Because of the rareness of salinity profile data, synthetic salinity data are assimilated in GODAS.

Observing System Experiments

- The temperature observations in the GODAS are from the profiles of XBT/CTD and moored buoy data of TAO in Pacific, PIRATA in Atlantic and RAMA in Indian, and from the Argo profiles. Because of the rareness of salinity profile data, synthetic salinity data are assimilated in GODAS. The synthetic salinity profiles are constructed by the temperature profiles and the local climatological T-S correlation based on the World Ocean Atlas 2009 (Locarnini et al 2010).

- In order to evaluate the impact of the observing system in the NCEP operational products, a series of traceable observing system experiments (tOSE) have been carried out, and the observational innovations and the analysis increments associated with individual ocean observations are evaluated in the ocean solo version of NCEP's GODAS. Based on each observational increment and innovation, the FIOS and AIOS are estimated in the major tropical regions of the Atlantic and Pacific oceans.

In the tOSE, the impacts of the observing systems on the GODAS are defined from the squared differences of observation innovations between 5 day and 10 day cycle runs. Fig. 1 shows a schematic diagram of the tOSE for 5 day/10 day cycle runs. At the end of the two runs, the differences are due to the updated initial states of the 5 day run. From the results of these differences, it is possible to estimate the impacts of each observing system on the GODAS, which is traceable at each observation in space and time.

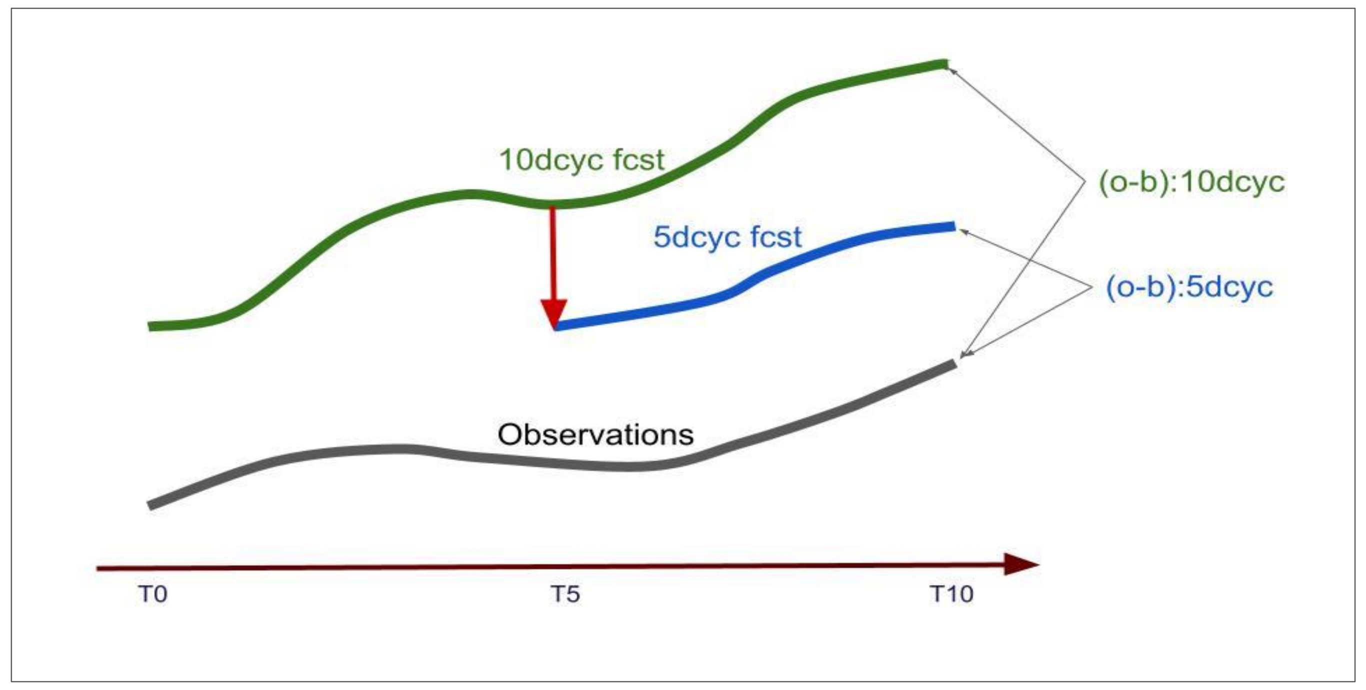

Figure 1. Schematic diagram on two trajectories of 10 day (green) and 5 day (blue) cycle runs, and real observations (black) in time. 10 day and 5 day cycle runs start at the same time, and the restart of 5 day cycle run from Analysis field (red).

- **AIOS and FIOS** : AIOS and FIOS are defined from (o-b)^2 of temperature in 5 day/10 day cycles of tOSE result in the regions, as followings:

$$AIOS = \sum_{i=1}^{N} (o-b)_i^2 \ , \ i \in \ regions$$
$$FIOS = AIOS_{10dcyc} - AIOS_{5dcyc}$$

  AIOS is positive because it is defined by the sum of *(o-b)*^{2}, which shows how much the assimilation can adjust the first-guess fields to the observations. As the impacts, larger AIOS means larger impacts of the observing system to the assimilation in GODAS. FIOS is defined by the difference between 5 day and 10 day AIOS's, and can be positive and negative. The positive (negative) FIOS means the 5 day forecast is more (less) accurate than the 10 day forecast, and larger FIOS means larger impacts of the observing system to the forecast accuracy by the assimilation. Here AIOS is obtained from the results of 5 day cycle of tOSE. The mean AIOS and mean FIOS are obtained by averaging in the regions with total number of observations of N.

- **T_{obs} and $T_{o\text{-}b}$** : Observational temperature (T_{obs}, left in Fig. 2) of each observations from ships, Argo and buoys and the temperature differences between observations and model background ($T_{o\text{-}b}$, right in Fig 2) at 25 m depth in May 2022 from the 5 day cycle tOSE runs.

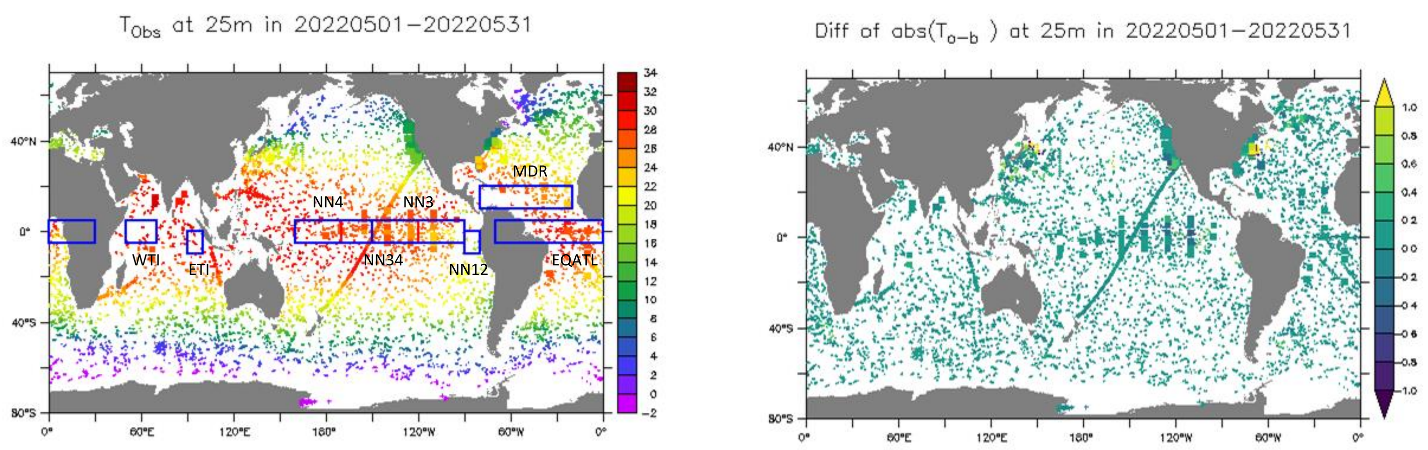

Figure 2. Observational temperature (in °C, left) and temperature difference between observation and model background (*o-b*, in °C, right) from the 5 day cycle tOSE at 25 m depth in May 2022, obtained from Argo floats (dots), moored buoys (rectangles) and XBT/CTD (cross). Blue boxes in the left panel are the averaged regions for AIOS and FIOS.

In observations of the GODAS for May 2022, it is shown that observational data from Argo float covers over the global oceans, of which observational data distributes fairly well. The observations from moored buoys (rectangles in Fig. 2 left) mainly focus on the tropical ocean of Pacific, Atlantic and Indian Oceans. In comparison of other observational systems the moored buoy observation is more temporarily more regular and has higher observational frequency. Fig. 2 (right) also shows that there occurs large temperature innovations in the western boundary extension region and in the regions of high eddy and turbulent activities.

- **Regional AIOS** (Fig. 3) : In May 2022, the AIOS of GODAS in the tropical ocean are mainly affected by the observations from moored buoy and Argo data. In this month, more moored buoys data are used by the GODAS than argo, and the total region AISO of moored buoy in the tropical Pacific is more than AIOS from Argo data, both in the mixed layer and thermocline layer. In the tropical Atlantic Ocean, the Argo data, moored buoy and ship data are main source of the observations in GODAS.

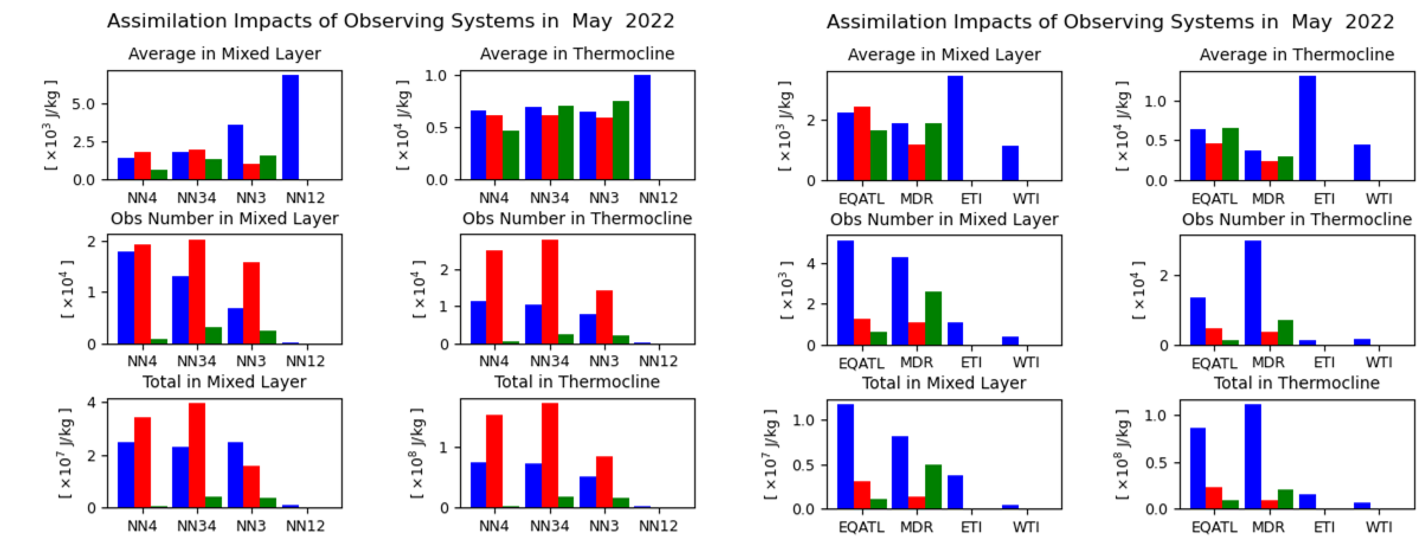

Figure 3. Regional AIOS in May 2022 at the Tropical Pacific (left) and Tropical Atlantic/Indian Oceans (right) from the observations of the Argo floats (blue), moored buoys (red) and CTD profiles (green). The averaged regions are shown in Fig. 2. Vertically, 'Mixed Layer' is the layer of temperature difference from SST is less than 0.5°C, and 'Thermocline' is the layer in the temperature range of 18 - 22°C.

- **Regional FIOS** (Fig. 4) : In tropical Pacific, observational data from moored buoy and Argo affect the model forecast. In this month, the moored buoys more improve the ocean model than Argo observations in the surface mixed layer and thermocline layer. As the AIOS, the Argo, moodred data and ship observation data are play role in the FIOS, and the FIOS from Argo are larger than FIOS from other observation systems.

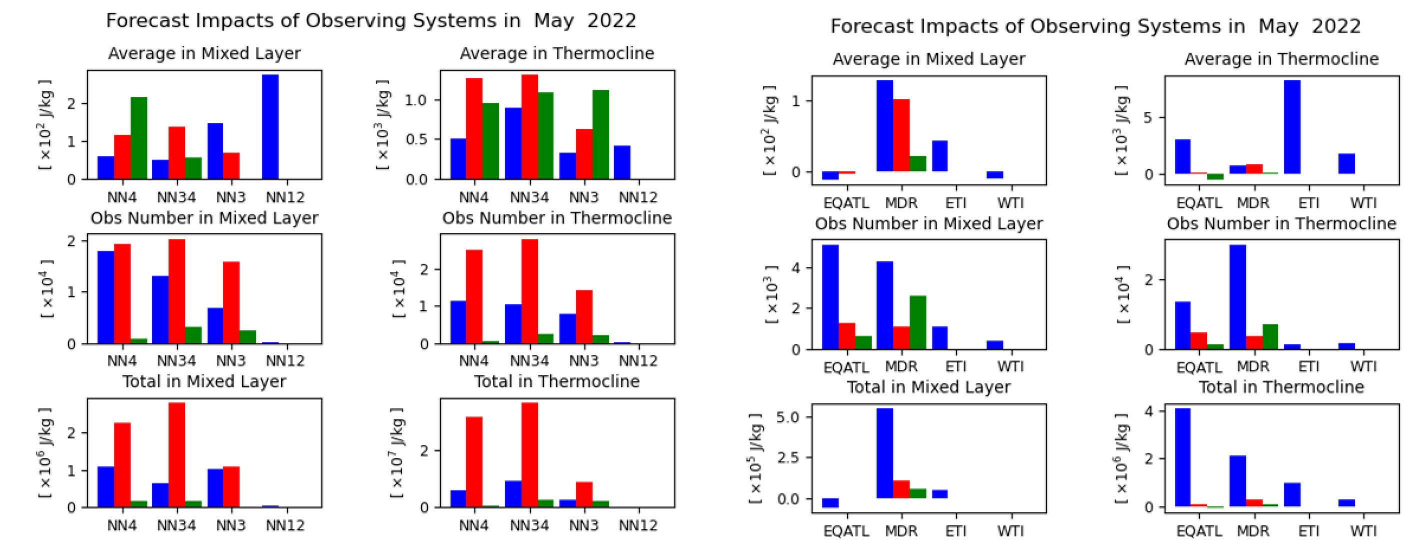

Figure 4. Same as Fig. 3 but FIOS defined by the difference of AIOS between 10 day cycle and 5 day cycle in tOSE.

Discussions

- AIOS and FIOS which are defined here, depend on the model configurations, such as vertical and horizontal resolutions of the model, and also depends on the configurations of DA systems. The qualitative/quantitative comparisons in the AIOS/FIOS would be valid only in the same model and DA systems.

- In the FIOS from the tOSE runs, it is assumed that the local advention and the nonlinear effects in the ocean model are small, which would be less than O(10cm/s) in the model configurations of the GODAS. So, the FIOS would not be valid in the western boundary regions and high eddy activate regions.

- In Fig. 4, there are negative FIOS of Argo data in EQATL region. This would be due to the coarse model resolutions of GODAS, which is 1° in zonal and ⅓° meridional direction and 10 m in upper levels in the model, which could not enough to resolve the real ocean phenomena.

- We have plans to extend to other methods as future works (e.g. FSIO/EFSIO) for the next ODA in NCEP.

Acknowledgements

- This study was supported by NOAA's Global Ocean Monitoring and Observing Program.

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