Evaluation of the Tropical Pacific Observing System from the Ocean Data Assimilation Perspective in the TPOS2020 workshop

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1. Introduction

☆ TPOS2020 workshop (www.ioc-goos.org/tpos2020)

- ✓ 27-30th January, 2014 at the Scripps Institute of Oceanography
- ✓ To make a reaction for the TAO/TRITON crisis.
- ✓ Achievements with TAO/TRITON array is reviewed.
- ✓ Potential requirements of operational and research activities (including ocean Data Assimilation (DA) systems) for the Tropical Pacific Observing System (TPOS) are summarized. (Here, TPOS includes not only TAO/TRITON array, but also other platforms observing tropical Pacific (e.g., Argo floats))
- ✓ Evaluation of the impacts of TPOS on the ocean DA systems was one of the important agenda of the workshop because DA systems are main tools to convert the observation data to the effective information for the society.

  ⇨ Fujii et al., 2014: Evaluation of the Tropical Pacific Observing System from the Ocean Data Assimilation Perspective, TPOS2020 White Paper #5 (available from the TPOS2020 home page)

  We also submitted a paper to QJRMS, and are revising it according to supportive reviewers' comments now.
- ✓ In order to reorganize TPOS to an effective and sustainable system under the international corporation, TPOS2020 project is proposed. (The project is launched as Neville introduced in the previous talk. See http://tpos2020.org/)
- ✓ Modelling and Assimilation is one of four task teams proposed under the project.

☆ Purpose/way of the Evaluation

- ✓ Discuss requirements of Tropical Pacific Observing System from the ocean Data Assimilation (DA) perspective
- ✓ Mainly discuss on observations of physical parameters for ocean interior states.
- ✓ Magdalena summarized on weather-to-decadal forecasting including atmospheric parameters. Other two white papers summarized on biogeochemical parameters.
- ✓ Evaluate results of Observing System Evaluation (OSEval) activities mainly in order to seek answers for the following questions.
  - ➢ To what extent are these requirements being delivered by existing networks?
  - ➢ What role is being played by TAO/TRITON in meeting this requirement?
- ✓ Classify the purpose of Ocean DA systems into
  1. Seasonal-to-Interannual (SI) forecasting
  2. Short-medium range ocean forecasting
  3. Ocean state estimation and decadal forecasting
- ✓ Discuss on ocean DA systems associated with each purpose, separately.
- ✓ Requirements for validations, which is common for all purposes are also discussed.

2. Current Status and Requirements

☆ Ocean DA systems for S-I forecasting

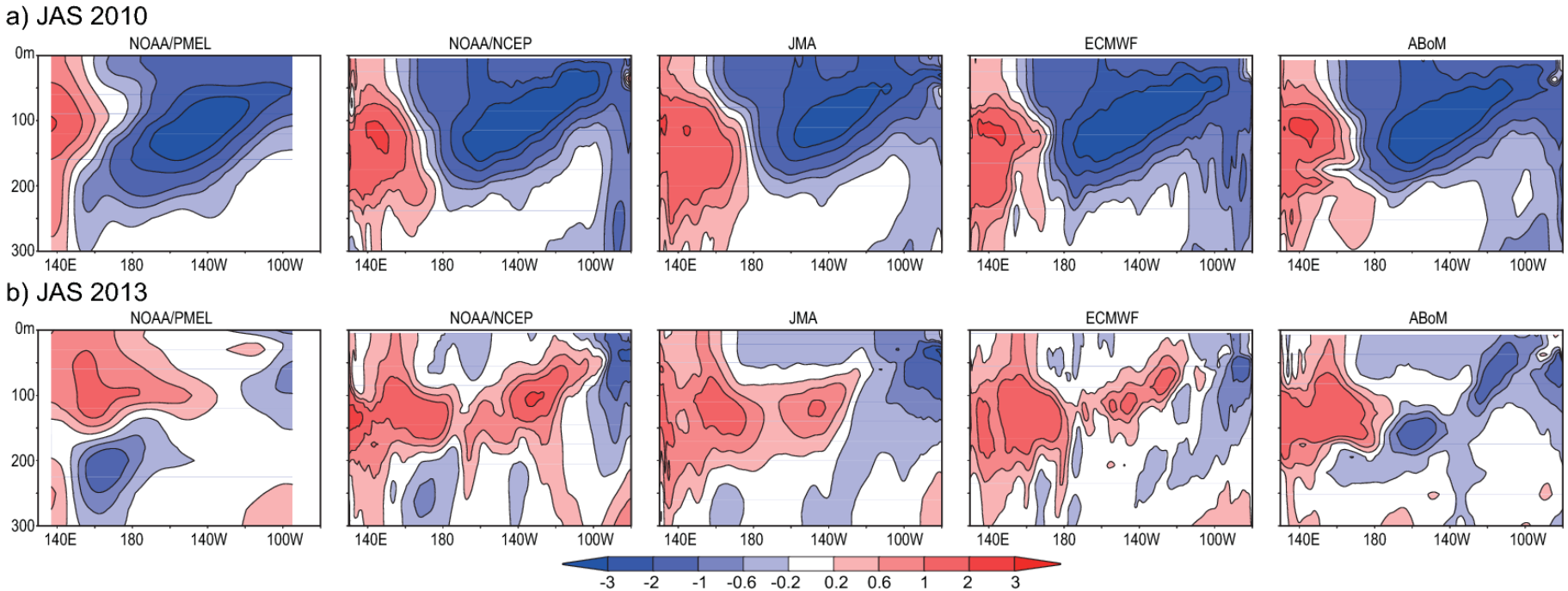
- ✓ Ocean DA systems are an essential component of general S-I forecasting systems in operational centers as well as Coupled ocean-atmosphere General Circulation Models (CGCMs)
- ✓ The estimation of the tropical Pacific Ocean state through ocean DA is vital for S-I forecasting system because most predictability for S-I forecasts comes from ENSO.
- ✓ Ocean DA systems are also employed in operational centers for monitoring the equatorial wave activity, variability of the thermocline along the equator, and other ocean phenomena associated with ENSO.

Typical specification of current operational ocean DA systems for S-I forecasts

- ✓ Resolution: 0.5-1˚ in horizontal (no eddy model), 10 m in vertical
  - ➢ It is desirable to be used in ensemble forecasts as a part of CGCMs.
    ⇨ It needs to be light for computing.
  - ➢ But UKMO started to use a 1/4˚ resolution ocean model, recently.
- ✓ Assimilation scheme: 3DVAR (NCEP, JMA, ECMWF, UKMO), EnOI (ABoM), SEEK (Mercator)
- ✓ NCEP uses a "weakly coupled" data assimilation scheme.

☆ Gaps emerging after the recent TAO crisis

Comparison of the T anomaly in the equatorial Pacific (2˚S-2˚N) vertical (0-300m) section



- ✓ The T analysis fields seem to be more diverse in 2013 than in 2010.
- ✓ The analysis by PMEL, which people thought observed features were reflected in most, is not reliable in 2013 due to the lack of the TAO data.
- ✓ NOAA, JMA and ECMWF started the real-time comparison of the equatorial Pacific temperature fields since Mar. 2014. (Some other groups joins now.)

☆ Requirements of SIDA systems

- ✓ Baseline requirement of the resolution for detecting ENSO variability

Zonal:	500-1000km	Meridional:	200km
Vertical:	5-10m	Temporal:	1-5-daily

- ➢ Higher resolution is favorable for detecting TIW, equatorial upwelling, etc.
- ✓ TAO-TRITON array
  - ➢ The horizontal resolution is suitable for detecting the ENSO variability but the vertical resolution is insufficient to detect the thermocline accurately.
  - ➢ Often time-averaged before assimilated. (The hourly data is not fully used.)
- ✓ Argo floats
  - ➢ The vertical resolution is well sufficient.
  - ➢ Salinity data → Useful for detecting the equatorial salinity front and the barrier layer
  - ➢ They are complementary to the TAO-TRITON array.
- ✓ SST: Although 1˚ and 1 day resolution is typically used currently, 1/4˚ resolution will be required for next generation systems.
- ✓ Satellite Altimetry Data:
  - ✓ Useful for detecting variability of the thermocline depth.
  - ✓ Sub-surface TS profiles are required for effective assimilation of the altimetry data.
- ✓ SSS observations from satellites may support the detection of the SSS variability associated with ENSO, and migration of the SSS fronts.

☆Ocean Forecasting Systems

- ✓ They serve as backbone for a variety of applications of ocean security, search and rescue, monitoring of marine eco-systems, sonar operations, etc.
- ✓ Resolution: 1/12-1/4˚ in horizontal (eddy-permitting/resolving model)
- ✓ Typically forecasts of 5-days to 1-month are performed routinely.

Requirements

- ✓ The systems generally assimilate in-situ TS including those observed by TAO/TRITON array and ARGO floats, and SST and SSH from satellites.
- ✓ The systems require TAO/TRITON data, as well as ARGO profiles, for constraining the ocean heat content, stratification and circulation in the tropics.
- ✓ However, observations with a higher resolution than that of current in-situ observing system seem to be favorable for those systems because
  - ➢ they are generally designed to reproduce the variability associated with meso-scale eddies
  - ➢ the eddy activities (e.g., TIW, the Mindanao eddy, etc.) are very vigorous in the northern Tropical Pacific.
- ✓ High frequency measurements of TAO/TRITON can be beneficial for some short-time forecasting systems (e.g., US-Navy NCODA system.)

☆ Ocean State Estimation and Decadal Forecasts

- ✓ Ocean State Estimation: To make a historical records of the ocean state variation, which is physically well balanced, for climate researches.
- ✓ Physically well balanced ocean initial state is probably also essential to predict slowly varying climate phenomena in decadal forecasts.
- ✓ The majority is relatively low-resolution (no-eddy) model, but some systems apply eddy-permitting/resolving models.
- ✓ Toward coupled data assimilation

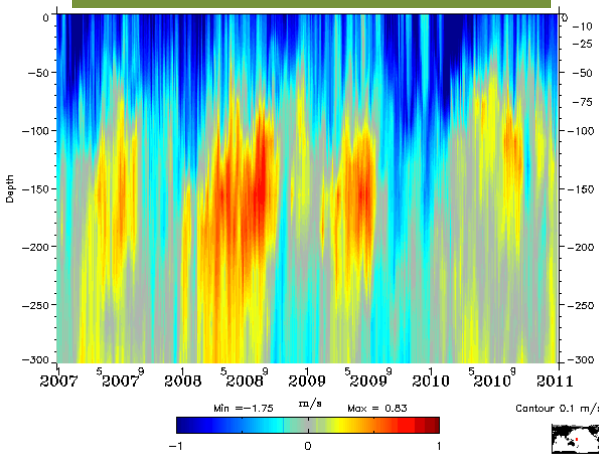
Requirements

- ✓ Most systems assimilate in-situ TS profiles and SSH derived from satellite altimetry.
- ✓ TAO/TRITON mooring data provide an important constraint to these systems.
- ✓ Observing systems stably sustained for a long period (or permanently if possible !!) are desirable for a long-term ocean estimation.
  - ➢ Changes in observing systems induce temporal data gaps in the estimated ocean fields.
- ✓ Observation data with very small biases are desirable.
- ✓ The ocean and surface meteorology measurements from the tropical mooring array will become more and more important toward coupled data assimilation

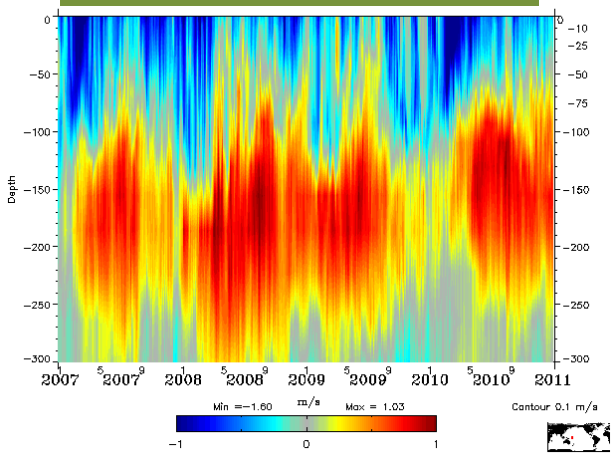
☆ Requirements for Validations

Validation of the zonal currents at 165˚E-0 ˚ N (t-z section) of the old and new GLORYS reanalysis against the TAO observations in Mercator

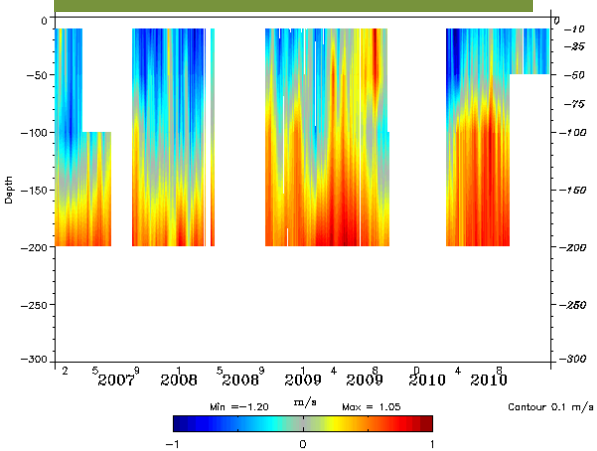
Old system



New system



Observation



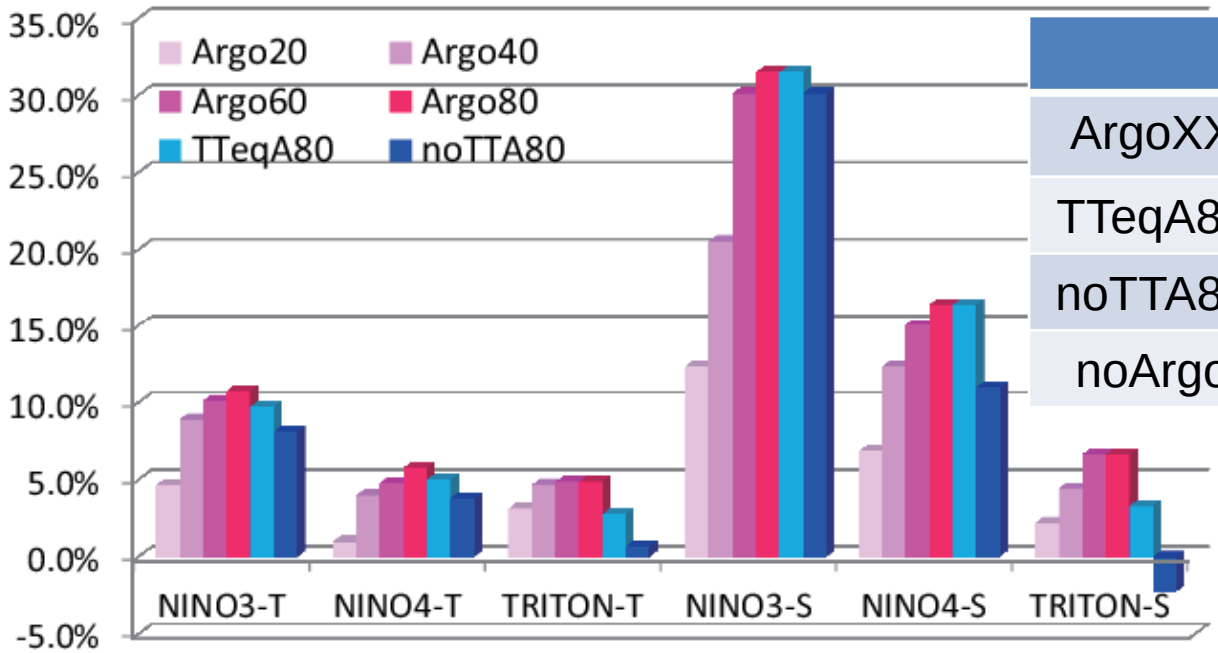
- ✓ The long time series provided by TAO moorings are extremely valuable to validate long-term simulations.
- ✓ Current measurements by moorings are also important as independent data.
- ✓ The multiple-parameter measurements of oceanic and atmospheric variables by moorings are important in the evaluation of the ocean state estimation systems and the corresponding heat budget analysis.

- ✓ Snapshots of the vertical section from the ship observation are useful to grab the image of the structures of TS fields and validate the DA results.

4. OSEval Studies

★ Impacts on ENSO analysis skill in JMA's system

Normalized reduction of RMSE from noArgo



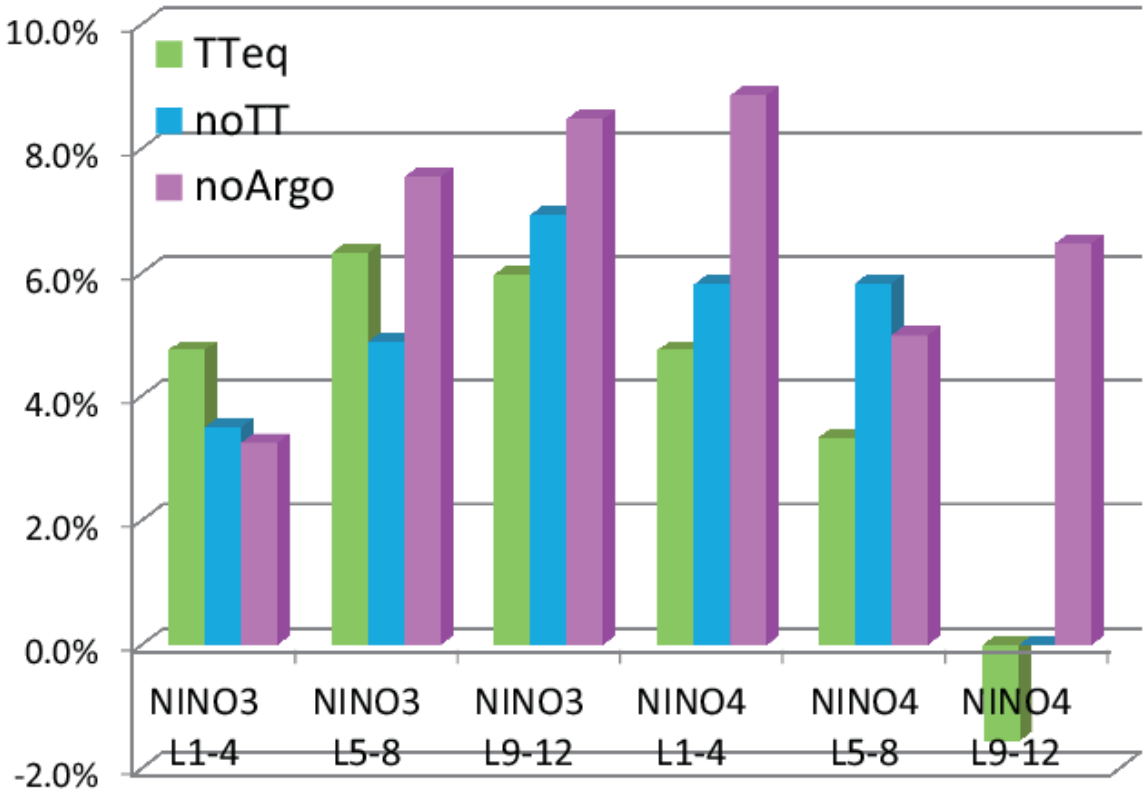
	TAO/TRITON	Argo
ArgoXX	ALL	XX%
TTeqA80	2˚S-2˚N alone	80%
noTTA80	None	80%
noArgo	ALL	None

RMSE is calculated respect to 20% of Argo data withheld in all runs.

- ✓ The more Argo data are assimilated, the larger the impact becomes. But the impact of additional data becomes mild when large number of data are already assimilated.
- ✓ In TRITON area, the impact of TAO/TRITON is relatively large, and comparable with the impacts of the 80% of Argo data.
- ✓ The impact of buoys near the equator is about half of the impact of all buoys, except for salinity in NINO3 and NINO4 regions.

★ Impacts on ENSO forecasting skill in JMA's system

Normalized Increase of RMSE from REGULAR

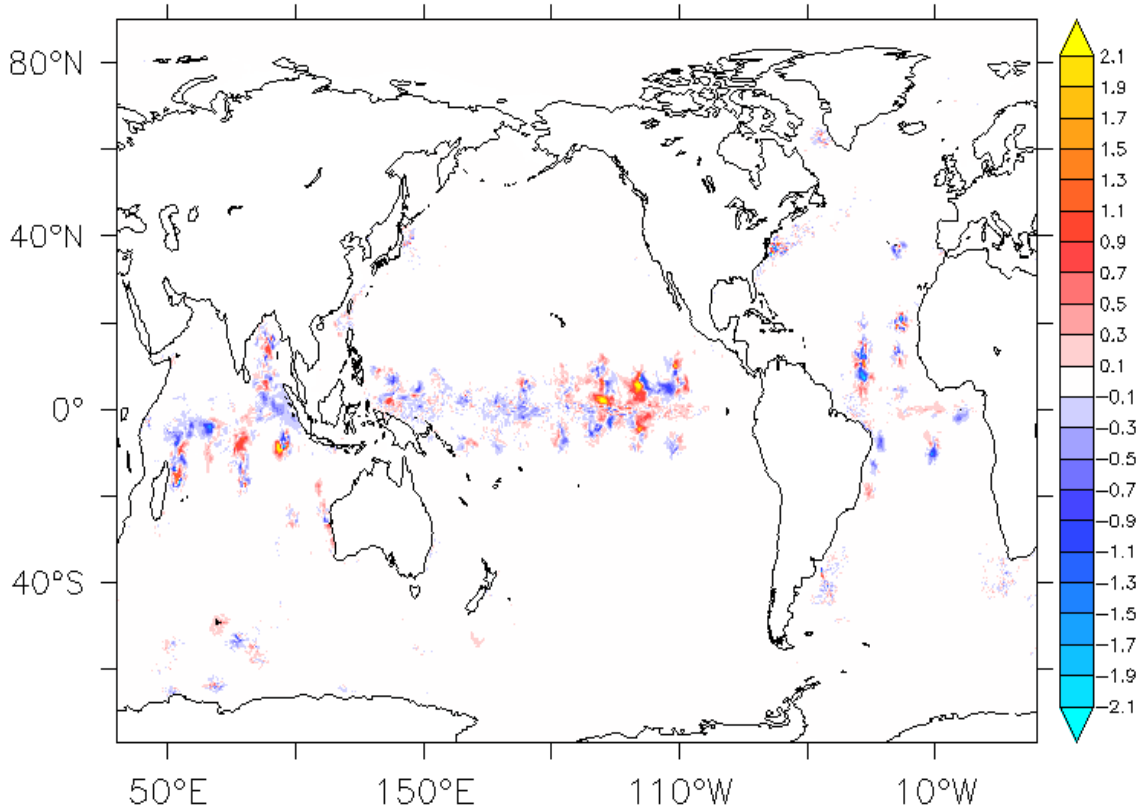


	TAO/TRITON	Argo
REGULAR	ALL	ALL
TTeq	2˚S-2˚N alone	ALL
noTT	None	ALL
noArgo	ALL	None

- ✓ Impact of Argo is positive for all lead times.
- ✓ Impact of TAO/TRITON is also positive except for 9-12 month lead time forecasts of the NINO4 index.
- ✓ Impacts of TAO/TRITON and Argo are comparable for L1-4 NINO3, and L5-8 NINO4 forecasts.
- ✓ Assimilating Buoy data near the equator alone improves forecasts skills of NINO3 for 9-12 months and NINO4 for L1-4 and L5-8 months although degrading short forecasts of NINO3.

☆ Near-Real-Time (NRT) OSE

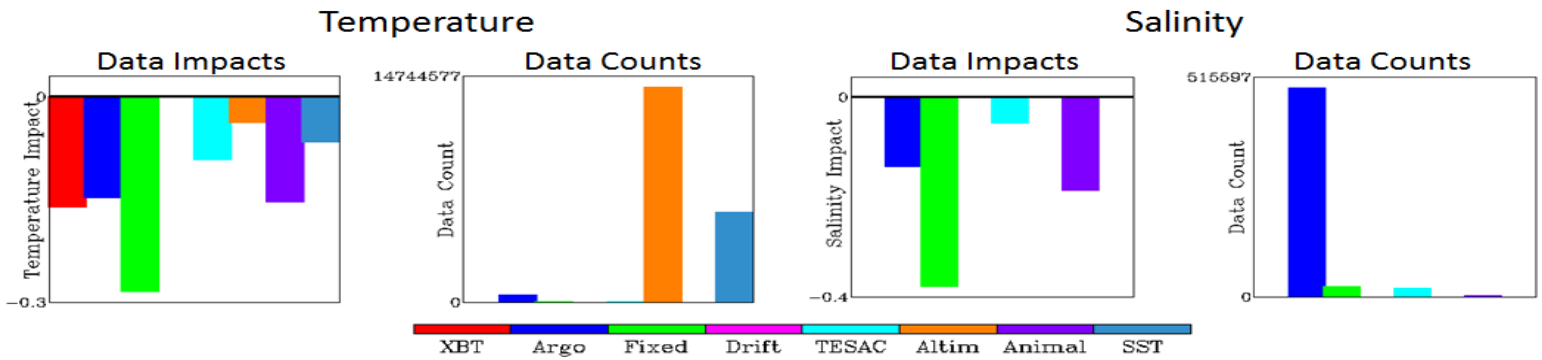
T differences at 100m depth on the last day of the month between OSE experiments with and without TAO/TRITON data.



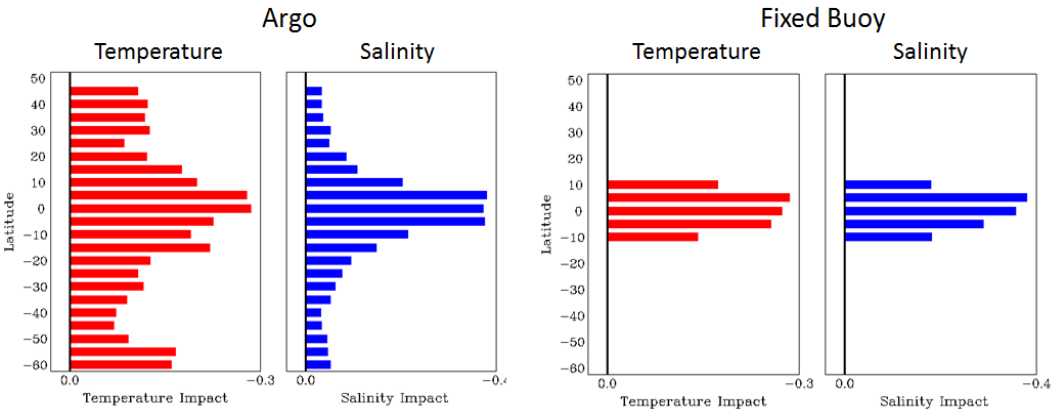
- ✓ The OSEval TT plans to set up NRT OSEs in order to achieve routine monitoring of current observing systems.
- ✓ Mercator have conducted a NRT OSE for March 2013 following this initiative.
- ✓ Important differences are visible at and around the moorings and can reach 2˚C.
- ✓ This is consistent with the results from another NRT OSEs in UKMO.

☆ Evaluation of the forecast sensitivities

Per observation Impacts of T and S on reducing HYCOM 48-hour forecast error using adjoint method (Pacific Ocean, 16 Sep - 30 Nov 2012)



Per observation impacts of Argo and fixed buoy arrays for T and S partitioned by 5˚ latitude bands.



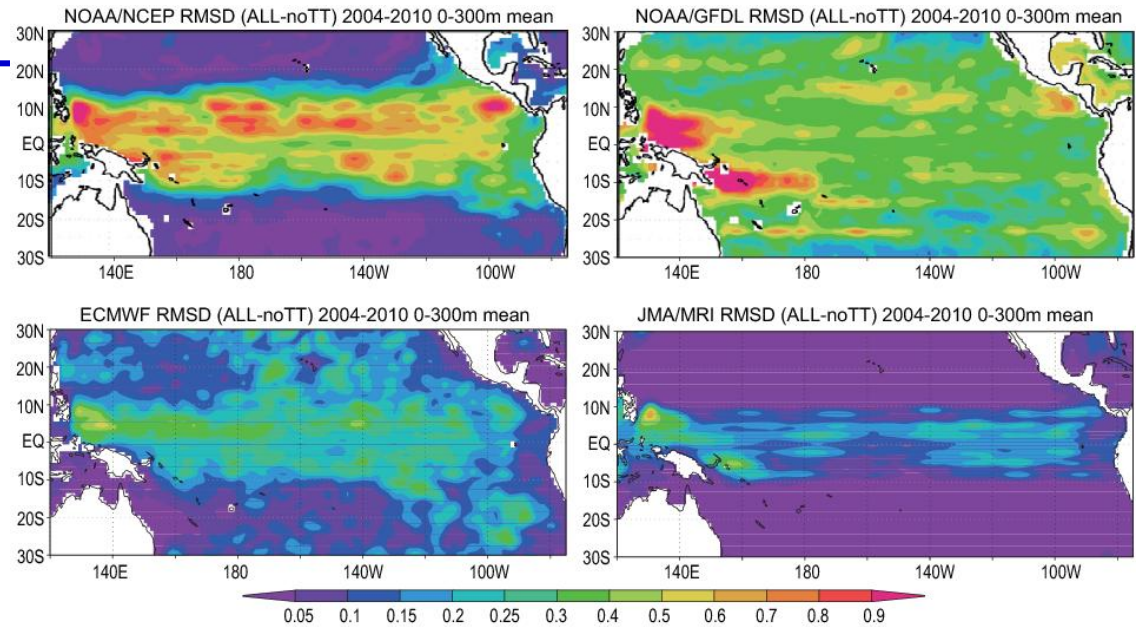
- ✓ Impacts of temperature and salinity from all observing systems are beneficial.
- ✓ Most effective data type on a per observation basis are the tropical fixed moorings (TAO/TRITON array).
- ✓ The impact of Argo is comparable to the impact of the moorings in the tropics.

☆ Cautions on OSEval studies

- Results of OSEs severely depend on the quality and characteristic of ocean DA systems and the forecasting models.
  - ✓ Coupled model still have large mode errors and biases.
    - ➢ model biases can destroy the observation impacts.
  - ✓ A sophisticated model or data assimilation scheme may reduce the impacts of observations.
    - ➢ It may be able to subtracts information enough from small data.
- OSE and other observing system evaluation studies can evaluate only the impacts of data that are assimilated in the DA system.
  - ➢ Although atmospheric data observed by TAO/TRITON can also affects ocean DA systems, the impacts are not evaluated in the all studies.
- It should be also noted that historical observation data are often used for the calculation of statistical parameters and bias correction schemes in DA systems.
  - ➢ The impacts of those data is likely to be underestimated.

★ Multi-System OSE

0-300m averaged RMSD of temperature (˚C) between ALL and noTT in 2004-2011 (2004-2010) for NCEP and GFDL (ECMWF and JMA/MRI).



- ✓ NOAA, JMA and ECMWF start collaboration on the multi-system OSE recently in order to examine the consistency among the results of OSEs in different centers.
- ✓ Impacts of TAO moorings are strongest (weakest) on NCEP (JMA) analysis, indicating large sensitivities to TAO data input on the assimilation system.
- ✓ For example, the figure indicated that the averaged RMSD of temperature between ALL and noMoor/noTT in 0-300m is relatively large in the far western equatorial Pacific, and around 8˚S-160˚E.
  - ➢ Regions where the model accuracy is relatively low?
- ✓ The RMSDs are also large in the zonal band along 5˚N probably due to the energetic eddy activities.
- ✓ OSEval TT should support this kind of collaboration studies.

5. Summary

☆ Summary

- The impacts of TAO/TRITON are generally in the same level with, and sometimes larger than those of Argo in the equatorial Pacific.
- We assume that a further loss of TAO/TRITON data will lead to a degradation of the forecast skill and will have a detrimental impact on many applications based on ocean DA systems.
- We are assured that continued deployment and maintenance of the tropical mooring arrays in all ocean basins is highly desirable.
- However, given funding constraints, a re-design of the mooring array might be appropriate and timely, taking into account the complementarity of other observing systems such as Argo.
  - This effort should be aided by an internationally coordinated multi-model effort in (tropical) observing system evaluation and design.
- The recent crisis of the TAO array provides the rationale for commencing new studies in evaluating the tropical Pacific observing system.
  - Follow-up of these studies should be carried out by the GODAE Ocean View OSEval task team
- TPOS2020 workshop recommended multisystem analysis activities for observing system evaluations
  - Intecomparison of real-time ocean analysis and the multi-system OSE.

Thank you!