Toward evaluating the Tropical Pacific Observing System using ocean state estimation covering 2010–2013

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Abstract

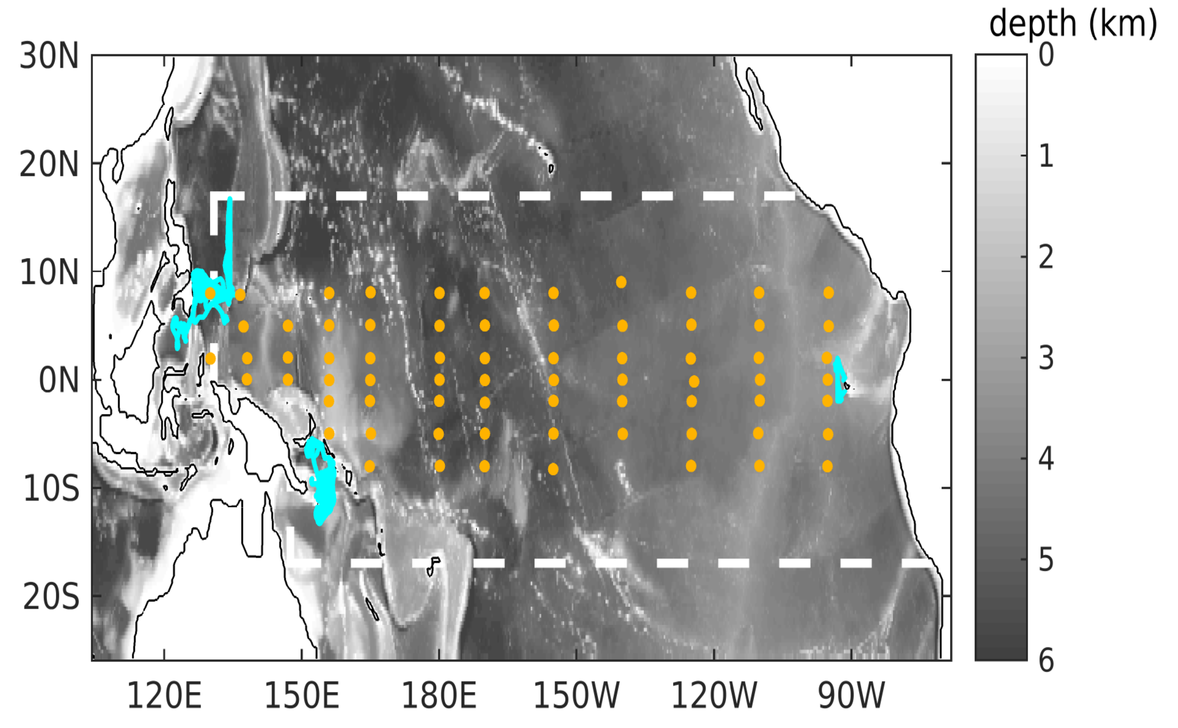
As a step toward evaluating the role of models in the Tropical Pacific Observing System (TPOS), a one-third degree regional state estimate assimilating components of the Tropical Pacific Ocean observing system was constructed for 2010 through 2013. It used the Four-Dimensional Variational (4D-Var) method to adjust initial conditions and atmospheric forcing to produce overlapping 4-month free-running model simulations, or hindcasts, that are consistent within uncertainty with satellite SSH and Argo, XBT, and CTD profiles.
This experiment asked the questions:

- Can a state estimate improve upon objective mapping from Argo?
- How much information do the TAO moorings supply beyond Argo, XBT, and altimetry?
- How long does the information from the initial conditions improve a forecast?

MITgcm model

- MITgcm-Tropical Pacific

The domain is 26°S to 30°N and from 104°E to 68°W with 1/3° resolution and 51 vertical levels (5 m vertical resolution in the upper ocean). Lateral open-ocean boundary conditions are prescribed from the global 1/12° reanalysis from the Hybrid Coordinate Ocean Model with Navy Coupled Ocean Data Assimilation (HYCOM/NCODA; http://hycom.org).



Model bathymetry. Dashed white lines bound the region in which observations were assimilated. Also shown are the locations of observations from TAO moorings (orange) and Spray gliders (blue) during the period 2010-2013.

MITgcm-ECCO 4DVAR

The MITgcm-ECCO 4DVAR system minimizes the weighted sum of squared misfits between model and observations plus the weighted sum of squared control adjustments during a specified period of time by using the adjoint model to adjust the control variables: model initial conditions for T and S, and atmospheric state.

Observations

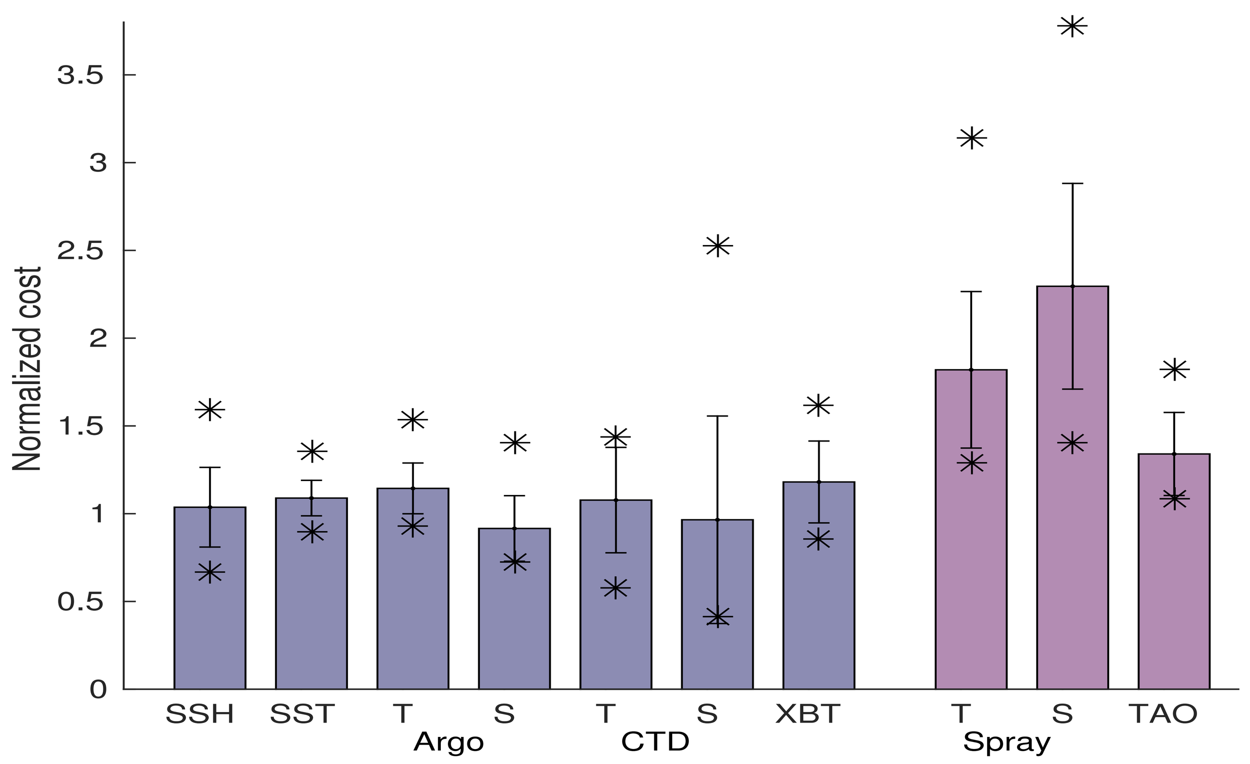
- SSH: along-track SSH anomalies from satellites: Jason1 (*J1*), Jason2 (*J2*), and Envisat (*N1*).
- SST: daily optimally interpolated product derived from the TMI-AMSRE on a 0.25° longitude ×0.25° latitude grid.
- Argo: temperature (T) and salinity (S) profiles are the most numerous in situ observations. For the period January 2010 to December 2013, 42,814 temperature profiles and 42,224 salinity profiles are found in the assimilation region from the CORIOLIS data server (`http://www.coriolis.eu.org/`).
- Only observations within 17°S to 17°N and east of 130°E, excluding the shallow area west of Papua New Guinea were used.

Controls

- Initial conditions and atmospheric state are adjusted.
- After the first estimate the prior initial condition comes from the previous state estimate.
- Smoothing is applied to enforce correlation scales of 250 km in the zonal direction, 60 km in the meridional direction, and 10 m in the vertical.
- First-guess simulations were forced with the 6-hourly atmospheric state from the ERA-Interim reanalysis.
- The surface wind, air temperature, short-wave radiation, and humidity are optimized subject to smoothness constraints.

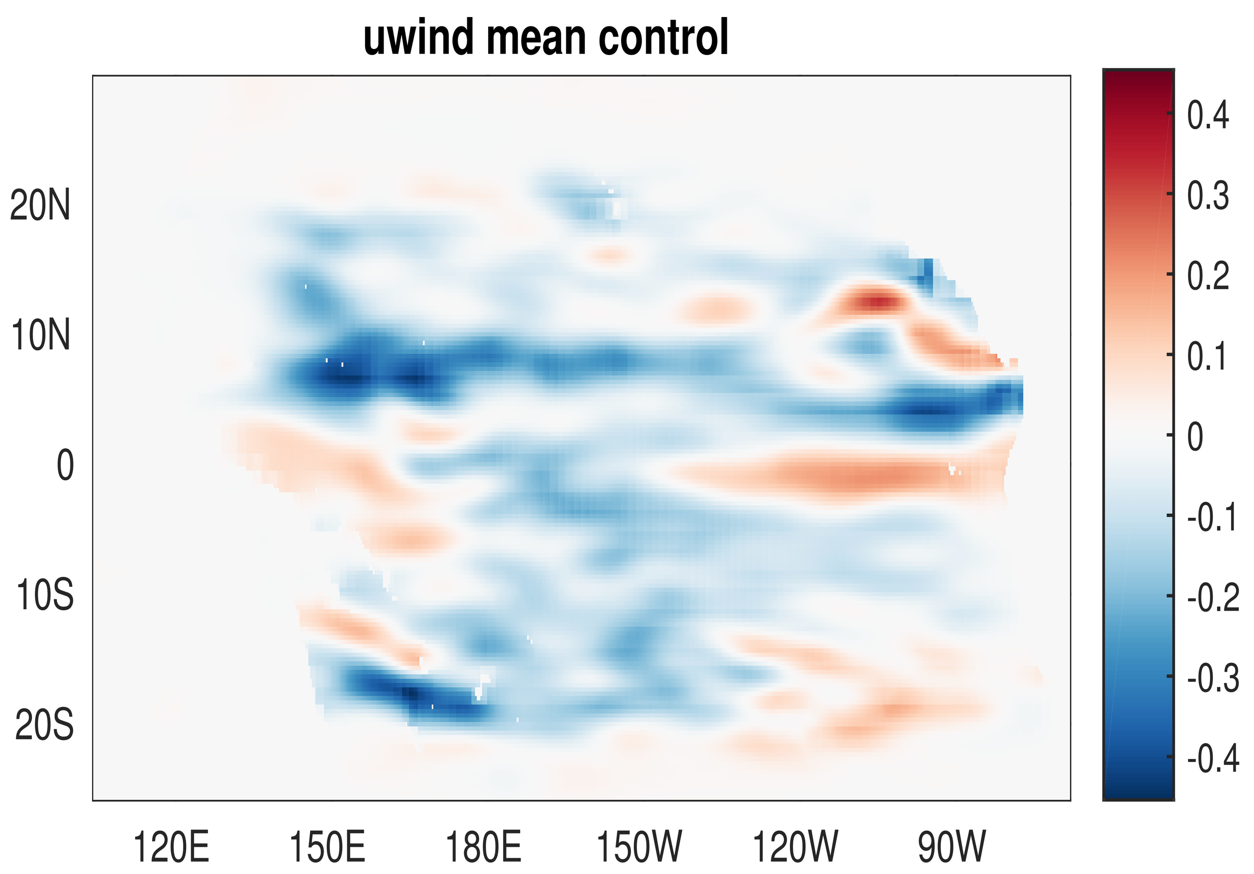
State estimate

- The normalized cost for in situ observations used as constraints (Argo, CTD, XBT) is reduced on average by 34% to 46%.
- Average normalized cost is reduced by 20% for SSH and 22% for SST.
- For (independent) TAO temperature, we get an improvement of 30%.
- The improvement is smaller for (independent) Spray observations: 19% for temperature and 5% for salinity. This may be due to the location of the glider samples near the model boundaries and complex topographic features as well as the relatively coarse model resolution.



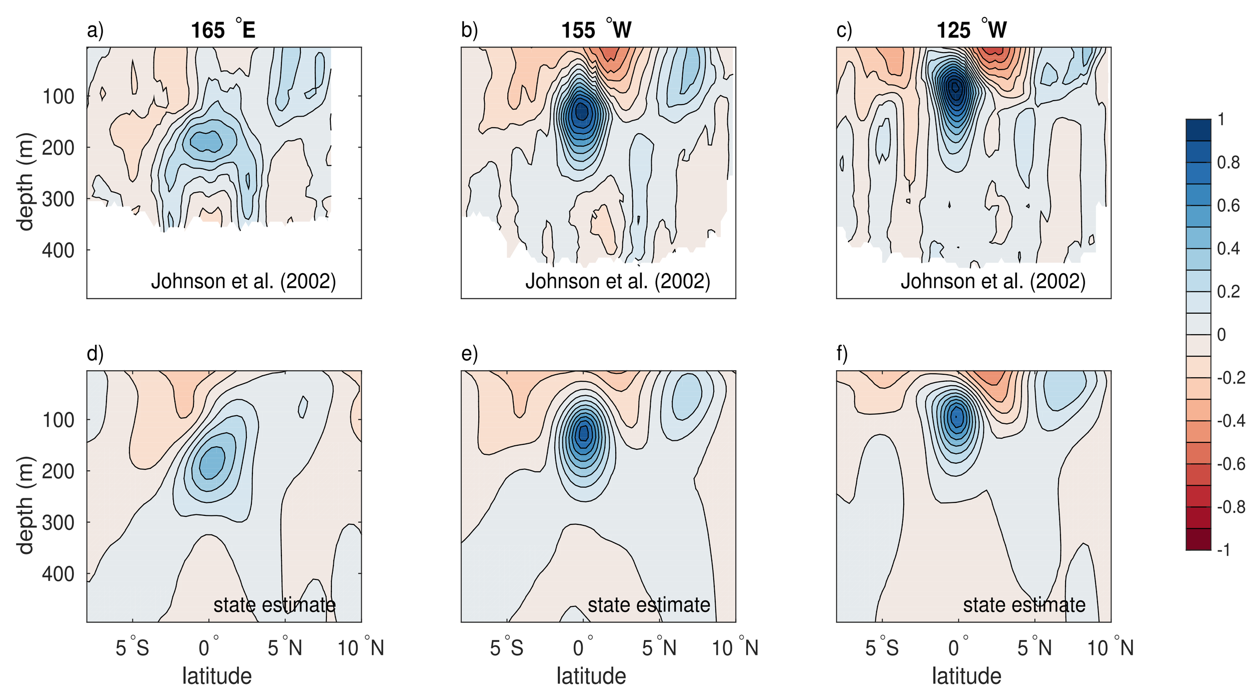
Average final misfit standard deviation normalized by expected representational error vs observation type, averaged over all the 4-month state estimates. Datasets that are assimilated are plotted in blue and independent datasets in purple. The standard deviation of misfit standard deviation (error bars) and min/max values (stars) across all estimates are also shown.

Control adjustments

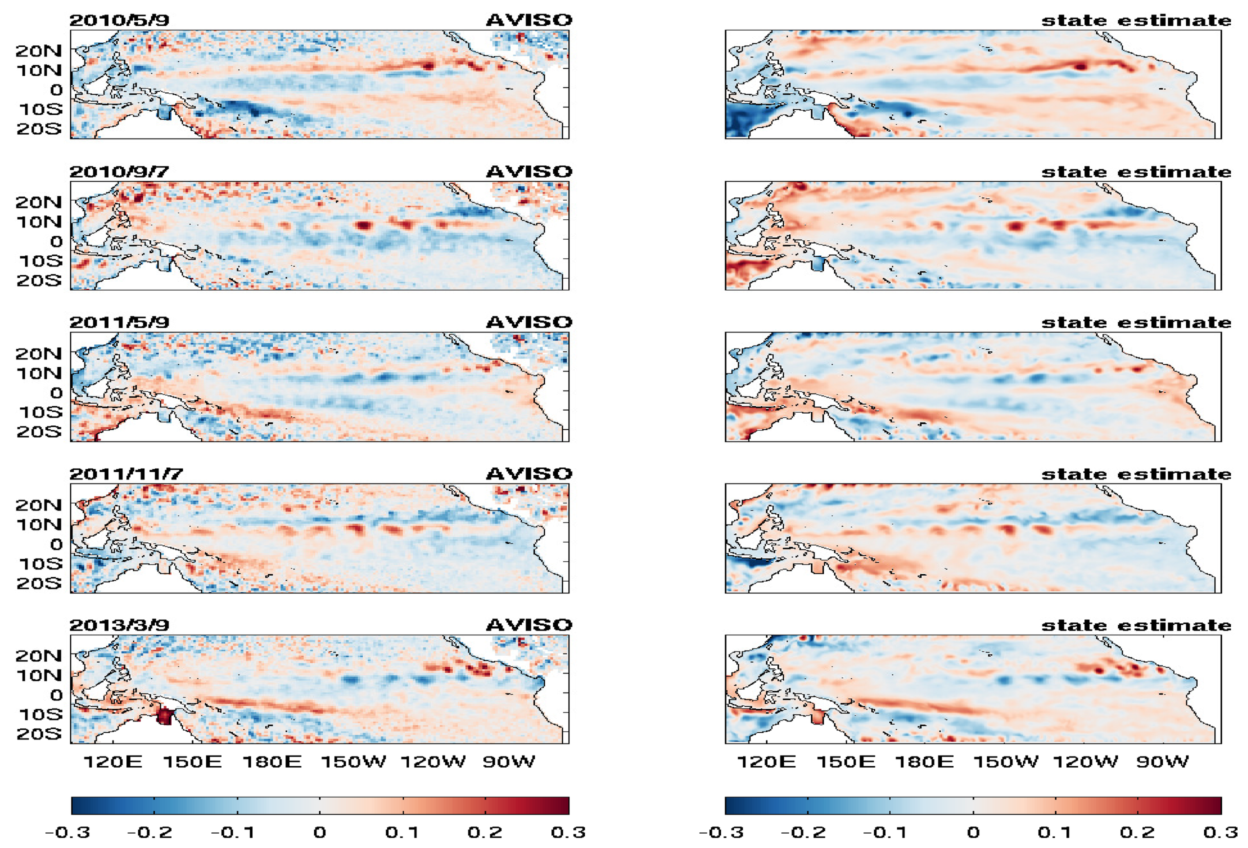


Mean zonal wind adjustments (m/s) averaged over all state estimates.

Map comparisons

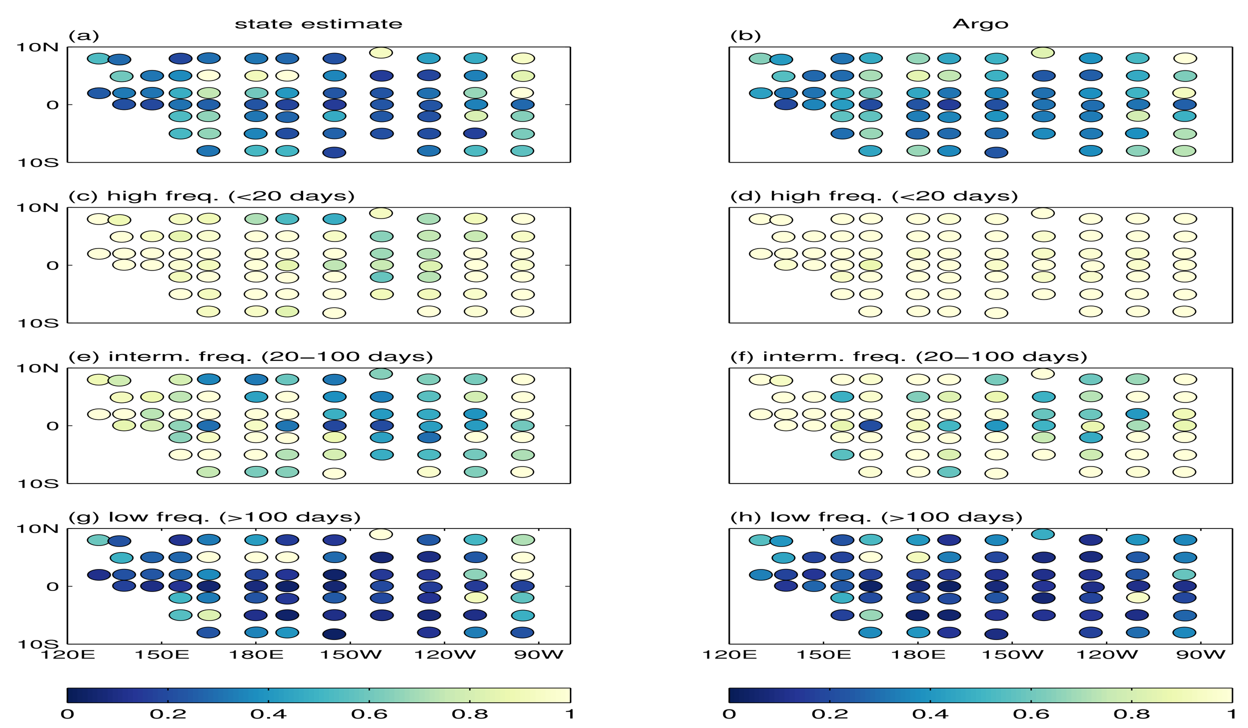


Comparison of the mean zonal velocity from [1] along several meridional sections (a-c) with the averaged state estimates (d-f). Note that the time ranges do not overlap. Current observations were not assimilated. This shows that the horizontal resolution is sufficient to resolve key dynamic balances.



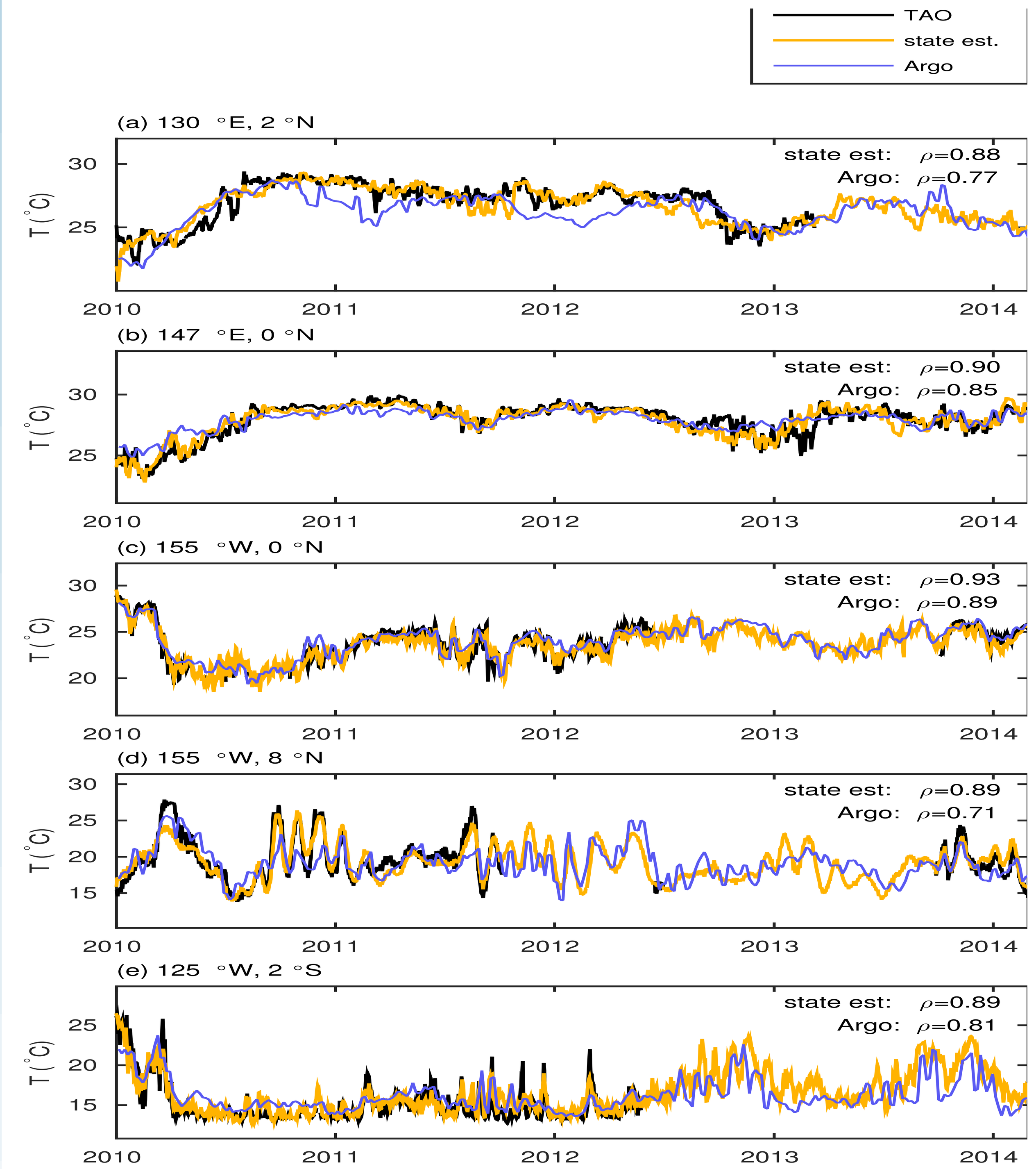
Snapshots of SSH from the AVISO observational product (left) and the state estimate (right). Note that we are not directly constraining to the mapped AVISO product, but we are assimilating the same along-track altimeter data used to make AVISO.

Comparison to TAO observations



Fractional difference variance between the 100-m temperature from TAO and the state estimate (left), and between the 100-m temperature from TAO and the Roemmich and Gilson [2] (called RG09 in the following) mapped Argo product (right) in different frequency ranges. All frequencies (a-b); high-frequency variability, <20 days (c-d); intermediate-frequency variability, 20–100 days (e-f); low-frequency variability, <100 days (g-h). A value of 0 means that all the of the variance is captured. The state estimate improves upon RG09 at timescales <100 days and even has some skill at timescales < 20 days (c). A few example time series comparisons are shown in the next figure.

Comparison to TAO observations



Time series of daily averaged temperature at 100 m from TAO observations (black), state estimate (orange), and the RG09 time-interpolated Argo mapped product (blue) at 5 mooring locations given in the titles of each panel. The correlation between observations and each of the products is also indicated in each panel. The differences between TAO and the mapped products is an indicator of the information content of the TAO observations. These results are summarized for different frequency ranges and for all moorings in the previous figure.

Conclusions

- This work quantifies the performance of a sequence of overlapping 4-month 4DVAR state estimates for the tropical Pacific.
- The state estimates were compared to independent TAO and glider observations and to the RG09 mapped Argo product.
- Comparison to the withheld TAO array showed consistency at timescales greater than 20 days, with the state estimate showing smaller differences than RG09 at timescales < 100 days.
- This improved skill suggests that dynamically-informed mapping methods can add value to the observing system.
- Large differences remained at timescales < 20 days. This is a measure of the unique information provided by the TAO array.
- SSH forecasts using reanalysis forcing had average skill above climatology for four months and for 50 days using climatological forcing.

References

[1] Johnson, Gregory C and Sloyan, Bernadette M and Kessler, William S and McTaggart, Kristene E (2002), Direct measurements of upper ocean currents and water properties across the tropical Pacific during the 1990s, *Progress in Oceanography*, *52*(1), 31–61.

[2] Roemmich, Dean and Gilson, John (2009), The 2004–2008 mean and annual cycle of temperature, salinity, and steric height in the global ocean from the Argo Program, *Progress in Oceanography*, *82*(2), 81–100.

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