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# A Coupled Ensemble Data Assimilation System for Seasonal Prediction in Australia

**Yonghong Yin, Oscar Alves, Debra Hudson, Li Shi and Harry Hendon**
*Centre for Australian Weather and Climate Research – a partnership between CSIRO and the Bureau of Meteorology, Melbourne, Australia*
**y.yin@bom.gov.au**

## 1 Introduction

A coupled ensemble-based data assimilation system called the POAMA (http://poama.bom.gov.au) Ensemble Coupled Data Assimilation System (PECDAS) has been developed. PECDAS is an approximate form of ensemble Kalman filter system. It is based on the multivariate ensemble optimum interpolation of Oke et al (2005), but uses covariances estimated from a time evolving model ensemble. The first version of the PECDAS is weakly coupled, only ocean observations (T, S) are assimilated into the coupled model and the atmospheric component is nudged towards pre-existing atmospheric analyses (U, V, Q, T from ERA-Interim). A reanalysis from 1980 to present has been completed with this system. Both in situ temperature and salinity observations are assimilated, and ocean current corrections are generated based on the ensemble covariances.

## 2 System description

PECDAS is a variation of the Ensemble Kalman Filter (EnKF). It includes the routine generation of an ensemble of forecasts, and a state-dependent estimate of the background error covariance. PECDAS differs from traditional EnKF in that only a single analysis is computed for a central forecast. A schematic of a typical integration of PECDAS is presented below.

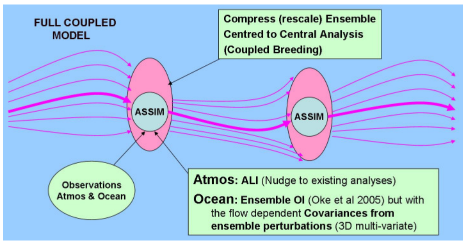


**Figure 1.** The Schematic diagram of the assimilation system.

The construction of the ensemble in PECDAS represents errors in the coupled system through using the coupled model to project the ensemble forward in time. Following the atmospheric nudging and ocean assimilation, the forecast perturbations of each ensemble member are rescaled with respect to the estimated analysis error and centred to the updated central analysis. Considering the different characteristics of the time scales of variability in the ocean and atmosphere and their strong spatial dependence, different rescaling norms that are functions of space are used for each component. Zonally-averaged root mean square difference (RMSD) of 10 m zonal wind (u10) and three dimensional (3-D) RMSD of ocean temperatures have been selected as the atmospheric and oceanic rescaling norms respectively. The rescaling factor for each ensemble member is defined as the ratio of the norm calculated from the estimated analysis error variance and the norm of the forecast perturbations. If the variance of the ensemble perturbations about the central member does not exceed the estimated analysis error variance, then no rescaling for that day is applied. The analysis error of u10 is estimated by the RMSD of u10 between ALI (Hudson et al. 2011) and ERA-40. The 3-D analysis error of oceanic temperature is estimated by the ensemble spread from PEODAS (Yin et al. 2011).

## 3 Characteristics of the system

(a) u10 analysis error (b) u10 ensemble spread (c) Zonal mean

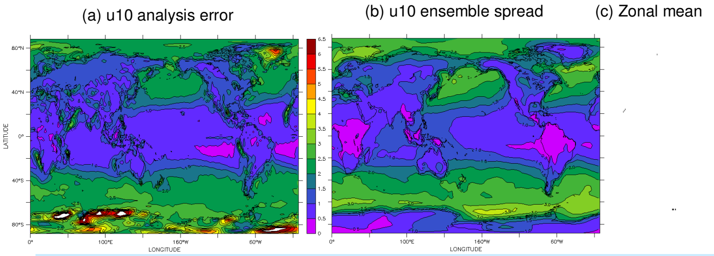

**Figure 2.** (a) Estimated analysis error of 10 m zonal wind (m/s) from ALI, (b) annual mean of ensemble spread from the CEI system, (c) zonal-average of analysis error (black) and ensemble spread (red)

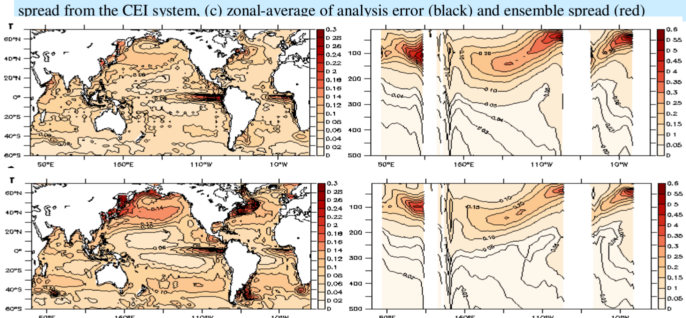

**Figure 3. Ensemble spread of** temperature (ºC) at surface (left) and vertical section along equator (right) for a non-coupled reanalysis PEODAS (upper panel) and PECDAS (lower panel)

## 4 Comparisons with Observations

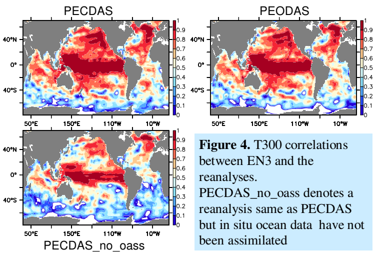


**Figure 4.** T300 correlations between EN3 and the reanalyses. PECDAS_no_oass denotes a reanalysis same as PECDAS but in situ ocean data have not been assimilated

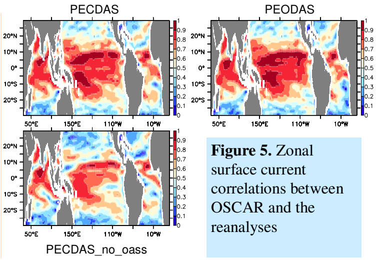


**Figure 5.** Zonal surface current correlations between OSCAR and the reanalyses

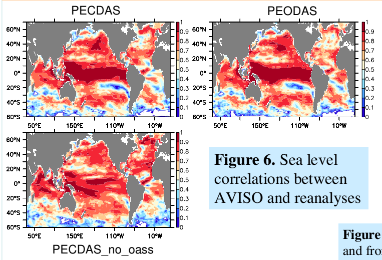


**Figure 6.** Sea level correlations between AVISO and reanalyses

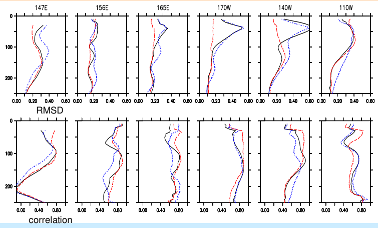


**Figure 7.** RMSD and correlation between zonal currents from TAO ADCP and from PECDAS (black), PEODAS (red), and PECDAS_no_oass (blue)

## 5 Forecast skill

| | POAMA-2M | POAMA-2.5 |
|---|---|---|
| Atmospheric nudging | Every 6 hours<br>Coefficient 0.5<br>ERA-40 (ALI) | Once per day<br>Coefficient 0.9<br>ERA Interim (PECDAS) |
| Ocean assimilation | EnKF into the ocean model forced with ERA-40<br>Assimilation every 3 days with observations over a 3 day window (PEODAS) | EnKF into free coupled model<br>Assimilation every day with observations of a one day window (PECDAS) |
| Covariance Ensemble | Perturbed forcing for ocean model and additive inflation | Free coupled model |
| Breeding | 11 unique initial conditions<br>Compressed or rescaled daily with different rescaling norms for ocean and atmosphere respectively. | As part of EnKF<br>33 unique initial conditions<br>Compressed or rescaled daily with different rescaling norms for ocean and atmosphere respectively |

**Table1.** Features of POAMA-2.5 compared with POAMA-2M

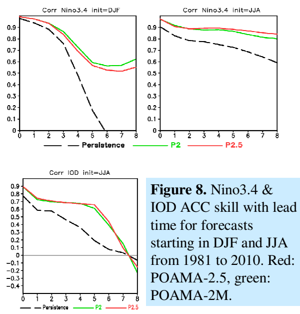


**Figure 8.** Nino3.4 & IOD ACC skill with lead time for forecasts starting in DJF and JJA from 1981 to 2010. Red: POAMA-2.5, green: POAMA-2M.

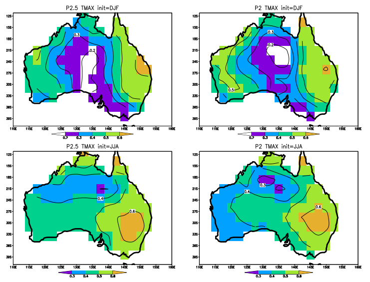


**Figure 9.** Correlation of the ensemble mean for forecasts of seasonal mean Tmax. Top row: Forecasts starting in DJF. Bottom row: Forecasts starting in JJA from POAMA-2.5 (left) and POAMA-2M (right).

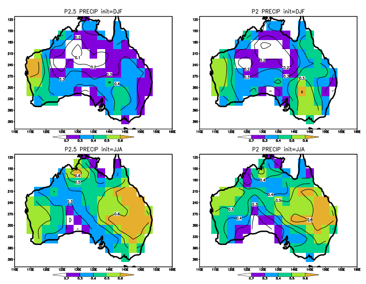


**Figure 10.** The same as Figure 10. but for the precipitation.

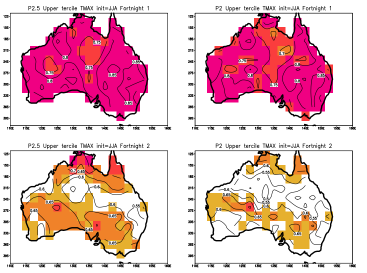

**Figure 11.** ROC area for forecasts of Tmax above upper tercile starting in JJA from POAMA-2.5 (left) and POAMA-2M (right). Top first fortnight and bottom second fortnight. Shaded are significant at the 5% significance level.

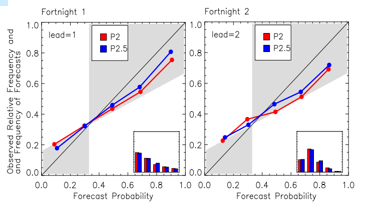


**Figure 12.** Attributes diagram for forecasts of rainfall in the upper tercile in the first fortnight (left) and second fortnight (right) for forecasts starting in JJA. The inset histogram represents the frequency of forecasts in each forecast probability bin (bins are 0.2 wide). Red – POAMA-2M, Blue – POAMA-2.5

## 6 Summary

The ocean component of the coupled assimilation, PECDAS, performed similar to the ocean assimilation, PEODAS. However, PECDAS produced spurious currents in the central Pacific along the equator, and this was due to atmospheric model systematic errors rather than the assimilation itself.

Improvements for El Nino and the IOD are somewhat neutral. So too are the impacts on seasonal climate. However, improvements are seen in terms of both skill and reliability on multi-week timescales.

PECDAS will be interfaced with the ACCESS model to form POAMA-3 and that, subject to performance, it should be the Bureau's next operational seasonal prediction model.

## References

**[1] Oke, P. R., A. Schiller, D. A. Griffin and G. B. Brassington, 2005: Ensemble data assimilation for an eddy-resolving ocean model of the Australian region. *Quart. J. Roy. Meteor. Soc.*, 131, 3301-3311.**
**[2] Yin, Y., O. Alves, and P. R. Oke, 2011: An ensemble ocean data assimilation system for seasonal prediction. *Mon. Wea. Rev.*, 139, 786-808.**
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**[4] Hudson, D., Marshall, A.G., Yin, Y., Alves, O., Hendon, H.H. 2013. Improving intraseasonal prediction with a new ensemble generation strategy. *Mon. Wea. Rev.*, doi:10.1175/MWR-D-13-00059.1, In press**