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# BRED VECTORS AND FORECAST ERROR IN THE NASA COUPLED GENERAL CIRCULATION MODEL

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## 1. INTRODUCTION

For the seasonal to interannual prediction, the forecast skill is strongly influenced by the model's ability to describe the SST variations. Ensemble prediction system is designed to capture such SST uncertainties. The evolution of the ensemble perturbations needs to carry the coupled characteristics since the climate system is dominated by the slow, ocean-atmosphere coupled processes (i.e. ENSO). Therefore, the initial ensemble perturbations should capture the growth of such slowly varying, coupled instability in order to project the perturbations onto the seasonal-to-interannual related uncertainties.

The breeding technique (Toth and Kalnay 1993, 1997) has been applied in simple coupled models (Cai et al., 2003, Peña and Kalnay 2004). Their studies show that breeding is able to identify the slowly varying coupled instability when choosing physically meaningful breeding parameters. Yang et al (2005) examine the characteristics of bred vector from the CGCM of NASA seasonal to interannual prediction project (NSIPP) under the perfect model scenario. They show that the bred vector has coupled properties related to the background ENSO variations and may have potential impact on ENSO prediction.

In the present study, we perform breeding experiments with a much more challenging system: the operational CGCM with real observations involved. As the first step to explore the potential application in ensemble forecasting, we examine the relationship between bred vectors, one month forecast errors and the background anomalies.

## 2. Breeding in the NSIPP operational CGCM

The NSIPP coupled model is a fully coupled global ocean-atmosphere-land system developed at NASA Goddard Space Flight Center (GSFC) (http://nsipp.gsfc.nasa.gov). It is comprised of the NSIPP-atmospheric general circulation model (AGCM) the Poseidon ocean model (OGCM), and the Mosaic land surface. The initial state of the OGCM uses the analysis fields from the optimal interpolation assimilation scheme. The AGCM uses with the AMIP atmospheric state as the initial state.

The procedure of a breeding cycle is done as in Yang et al. (2005) and the bred vector is the differences between the perturbed and unperturbed runs. In our experiments, the oceanic-bred perturbations are added to oceanic analysis fields, and atmospheric bred perturbations are added to AMIP restart fields. The bred perturbation is measured by the rms of the BV SST in the Niño3 region and rescaled to the magnitude of 0.085°C. Also, the rescaling period is chosen to be one month, which is important to capture the slow coupled instability. The experiments are performed from January 1993 to November 1998.

## 3. BRED VECTOR AND ONE-MONTH FORECAST ERROR

Our results suggest that bred vectors show structure similar to the one-month forecast errors, which are defined as the difference between the analysis and the one-month forecast. We first examine the time series of the background Niño3 index, the forecast error of SST in the Niño3 region and the bred vector growth rate. Both the forecast error and the bred vector growth rate are very sensitive to the ENSO phases, showing low frequency variations, and their temporal evolutions agree with each other very well. For example: the SST forecast error and the bred vector growth rate is particularly small during the strong 1997 El Niño event and large when the background anomaly is at its neutral state. The statistical analysis of these three quantities (Fig. 1) suggests that the pattern correlation between the bred vector and the forecast errors is particularly good when the bred vector growth rate is large.

The subsurface temperature of bred vector and the one-month forecast error also show a strong sensitivity to the phase of an ENSO event as shown in Fig. 2. For the 1997 warm event, the forecast error appeared in the subsurface of the western Pacific at the early stage, then propagated to the eastern Pacific and amplified. Bred vectors capture well where the large forecast error is located, including its dynamically eastward propagation. We applied the EOF analysis to represent the dominant structures (Fig. 4 and Fig. 5) of the bred vector and forecast error and compared with the ENSO modes of the background subsurface temperature anomaly along the equator (Fig. 3). Our results show that the dominant structures in the bred vector and forecast error are very similar. The structure is large-scale and largely projects on the variability associated with the ENSO variability. We also found that such property remains when using different rescaling norms because the ENSO evolution is dominated by just two leading EOFs, and this constrains the error structure. The three different rescaling norms we used measure the growth of the perturbations based on (1) SST norm in the Niño3 region and breeding globally, (2) the thermocline in the tropical Pacific and (3) the SST norm in the Nino3 region but breeding only in the tropics.

Based on the three set of BV SSTs, we calculate locally (~300km×300km) how much they can explain

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the forecast error. We found that the local projection of the forecast error on the subspace spanned by three bred vectors is larger than the subspace spanned by three operational perturbations, which are represented by the differences between two randomly selected analysis states. The result is valid for both tropics and extra-tropics.

## 4. SUMMARY

In this study, we examined the characteristic and relationship between bred vector and the one-month forecast error in order to explore potential applications to use the bred vector as initial coupled ensemble perturbations. Our results indicate that the one-month forecast error and the bred vector share many similar characteristics in the SST and subsurface temperature structure in both space and time. Our results indicate that the one-month forecast error in NSIPP CGCM is dominated by dynamical errors whose shape can be captured by bred vectors. Such agreement is especially good when the BV growth rate is large. The results suggests the potential impact from using the bred vector as initial ensemble perturbations for capturing the uncertainties related with seasonal-to-interannual variability when performing ensemble forecasting.

In addition, the ability of bred vectors to detect the month to month forecast error variability should allow us to improve oceanic data assimilation by augmenting the background error covariance with features associated with seasonal-to-interannual variability in the subsurface.

## 5. REFERENCES


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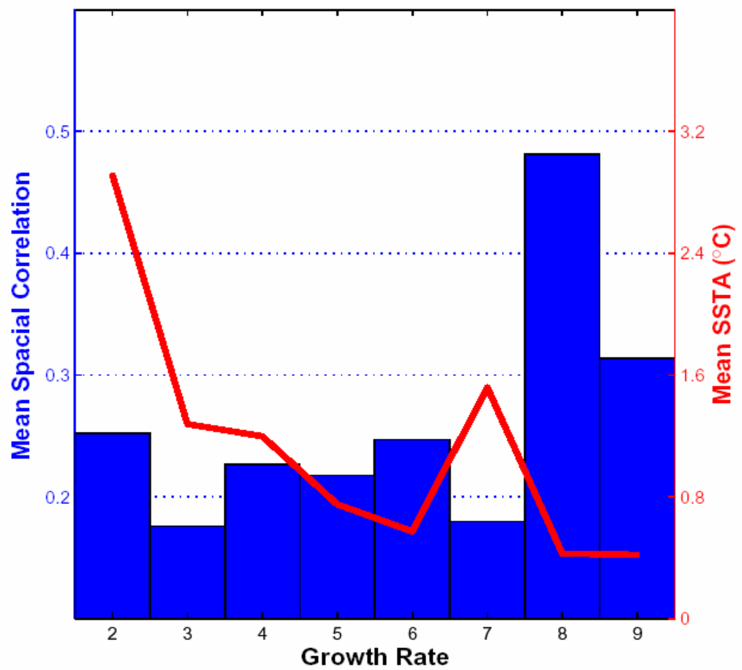


**Fig. 1:** Mean value of the pattern correlation (bar) and the Niño3 index (red line) in bins defined by the BV growth rate. Pattern correlation and the Niño 3 index are also grouped based on their corresponding growth rate. Pattern correlation is defined as the spatial correlation between the bred vector and one- month forecast error in the Niño3 region and the absolute value is used for both the pattern correlation and the Niño3 index. The figure shows that large SSTA are associated with low growth rate, and large correlations between bred vectors and forecast errors occur when there is large growth rate.

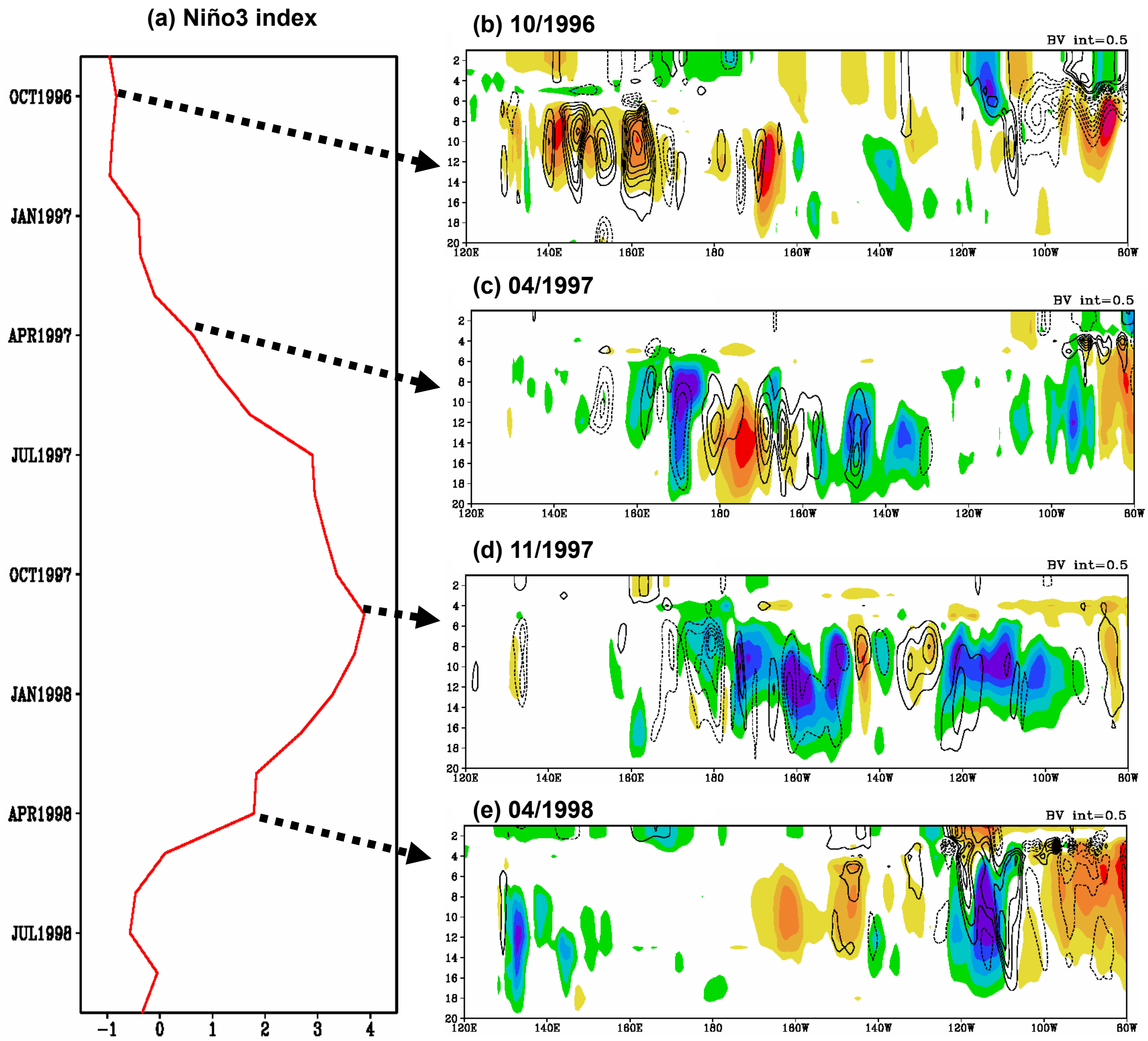


**Fig. 2:** (a) Background Niño3 index (°C) and vertical cross-section of temperature forecast error (°C, color) and BV temperature (°C , contour) corresponding to (a) October 1996, before warming developed (b) April 1997, warming started (c) November 1997, warming is strongest, and (d) April 1998, warming diminished. Contours are plotted only when |BV temperature| is larger than 0.5 °C.

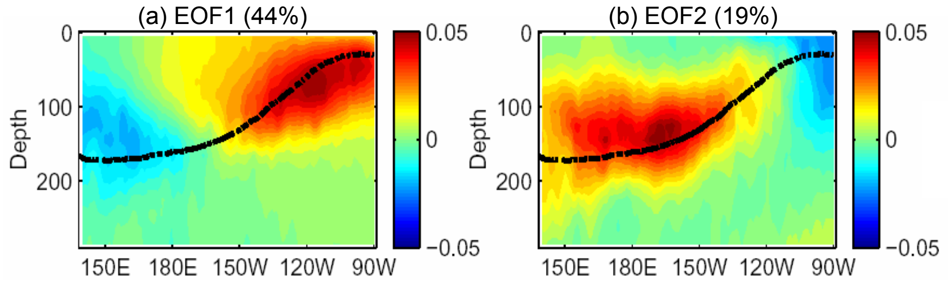


**Fig. 3** First two EOF modes of the equatorial temperature anomaly representing 44% and 25% of the variance. The thick dashed line is the depth of the mean thermocline. EOF modes are normalized.

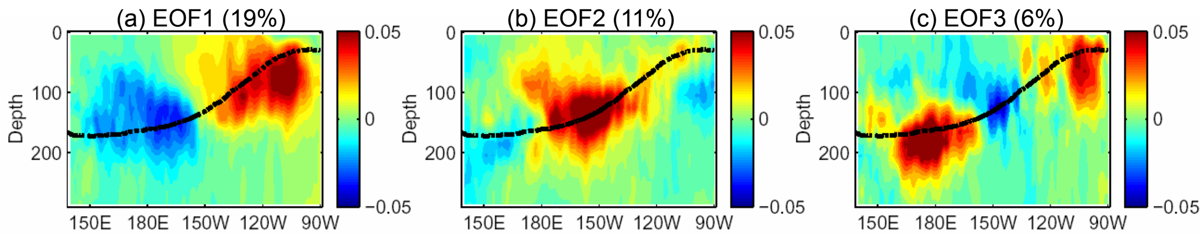


**Fig. 4** First three EOF modes of equatorial temperature of one-month forecast error.

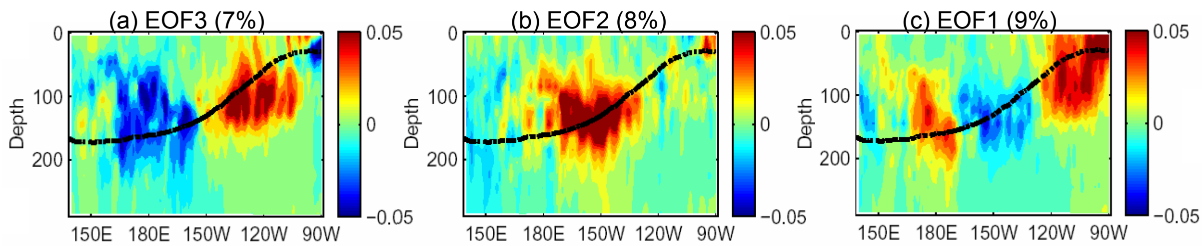


**Fig. 5** First three EOF modes of equatorial temperature of the unrescaled bred vector, in reversed order.