9.6 Benefit Assessment of Using Bred Vectors for ENSO Prediction

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The breeding method (Toth and Kalnay, 1993) is used to obtain the bred vectors of the Zebiak-Cane atmosphere-ocean coupled (ZC) model, which can be regarded as the proxies of the time varying leading local Lyapunov's vectors of the ZC model. The purpose of this study is to demonstrate the potential benefits of using bred vectors for improving coupled model data assimilation system and ensemble forecasting skill for ENSO prediction.

We have made two long integrations with the ZC model, referred to as the control run (1010 years) and perturbation run (1000 years), respectively. The differences between the two runs are called bred vectors. The perturbation run initially starts from the initial condition derived from the control run at the beginning of the 11th year plus a small amount of random perturbation (10% of the variability of the control run). After that, the initial perturbation for the perturbation run is rescaled back to the same amplitude (10%) every three months to prevent the perturbation from reaching nonlinear saturation.

It is found that the spatial structure and growth rate of the bred vectors are strongly related to the background ENSO evolution. The bred vectors of the ZC model tend to have largest growth rate several months prior to and after an El Nino event (Fig. 1). At the mature stage of a warm event, the growth rate of bred vector is slightly negative. Accordingly, the spatial structure of the bred vectors is more coherent when the growth rate is larger. As displayed in Fig. 2, the composite bred vectors exhibit a very large-scale ENSO-like spatial pattern over much of the equatorial Pacific basin between the two extreme phases of the background ENSO events.

The applications of using the bred vectors for ENSO predictions have been explored in two contexts: data assimilation and ensemble forecasts. In the forecast experiments to be discussed below, we have used the control run as the verification (in a perfect model scenario).

It has been argued that the errors in data assimilation are made primarily of growing errors that resemble very much to bred vectors because a data assimilation cycle, in essence, behaves like a breeding cycle. To demonstrate the potential benefits of using the bred vectors in a coupled data assimilation system, we have made three forecasting experiments and their errors are plotted in Fig.3. It is seen that by removing bred vectors (BV-removed in Fig.3b or CBV-removed in Fig. 3c) from the initial error fields consisting of random maps (the STANDARD experiment in Fig. 3a), the ENSO forecast errors can be reduced as much as 30% and the “spring barrier” for ENSO prediction is much less noticeable. We argue that within a data assimilation cycle, together by removing “systematic dynamic errors” inherited in data assimilation, this reduction of errors would accumulate to an even a larger value.

Fig. 4 compares the forecast error reductions of using bred vectors as initial ensemble perturbations versus using a pair of random perturbations. The ensemble forecasts with a pair of “positive/negative” bred vectors improve systematically the forecast skill, particularly over the areas where the forecast errors grow most vigorously. The ensemble forecasts with a pair of random perturbations, however, have a much smaller improvement.

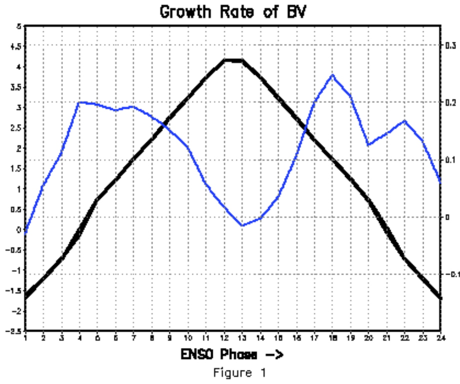

Fig. 1 Composite background Nino-3 index (heavy curve) and the composite growth rate of the bred vectors (thin curve). Abscissa is the bin number for the ENSO composite and time span between two adjacent bins is about 1.5-2 months. The ordinate label on the left is for the Nino-3 index (^{o}C) and the ordinate label on the right is for the growth rate in units of month^{-1}.

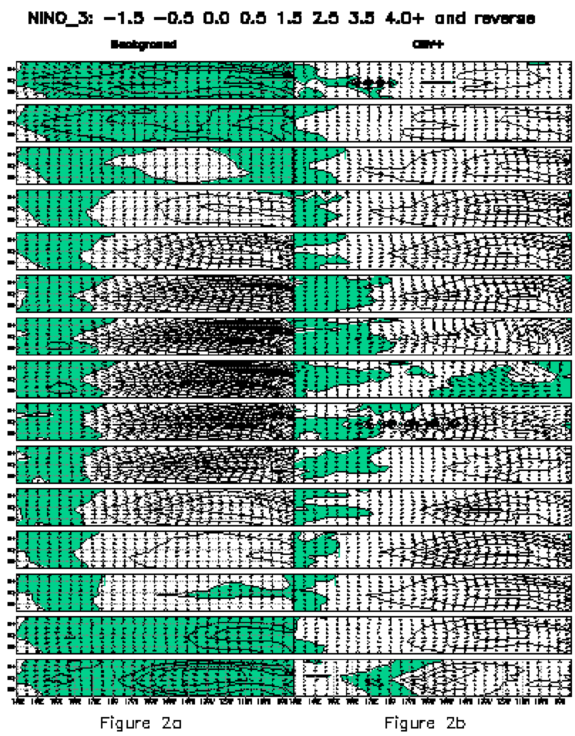

Fig. 2. (left). Background ENSO cycle. The contour interval (SST anomaly) is 0.5 ^{o}C and the unit vector (wind anomaly) is 4m/sec.. (right) Composite bred vector (positive sign only). The contour interval (SST) and unit length of the vector (wind) in the right are arbitrary, but they are the same for all maps in the right panels.

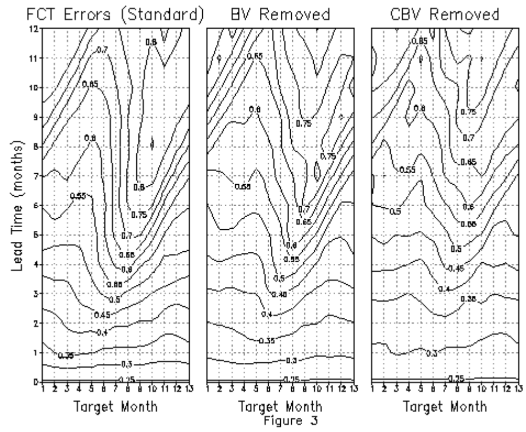

Fig. 3 Forecast error as a function of the forecast lead time and the target month. Contour interval is 0.05 in a dimensionless unit. (a) Initial errors are made of random maps. (b) As in (a) except that the bred vectors are removed. (c) As in (a) except that the composite bred vector has been removed.

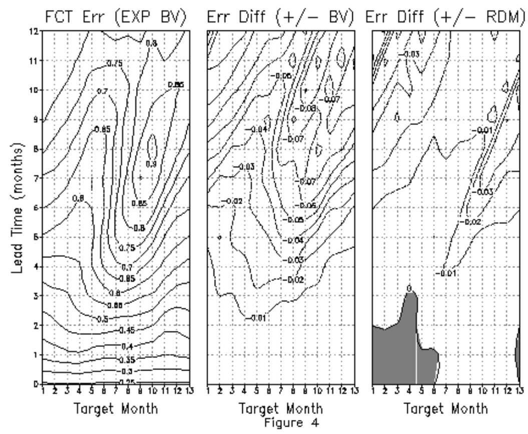

Fig. 4. (a) As in Figure 3a, except the initial errors are made of bred vectors. (b) Error difference between the ensemble forecasts with a pair of bred vectors and the control forecasts shown in (a). (c) As in (b) except for the ensemble forecasts with a pair of random maps. Improvements are unshaded.