9.10 STATISTICS OF COUPLED OCEAN AND ATMOSPHERE INTRASEASONAL/SEASONAL ANOMALIES IN REANALYSIS AND AMIP DATA AND IMPLICATIONS ON THE SEASONAL FORECAST PREDICTABILITY

Malaquias Peña, Eugenia Kalnay, and Ming Cai
Department of Meteorology, University of Maryland
College Park, MD 20742-2425

1. INTRODUCTION

One of the major sources of short-term climate predictability (beyond the 1-2 week limit of weather predictability) is the atmospheric sensitivity to the anomalous lower boundary conditions, particularly the sea surface temperature (SST) (Shukla et al 2000). Because of the ocean's larger thermal inertia, the anomalous SST is commonly assumed (e.g. in the Atmospheric Model Intercomparison Project, AMIP runs) to either strengthen or weaken atmospheric anomalies. This one-way (ocean-driving) interaction is applied in the operational dynamical extended range forecasting (e.g. 15-day daily ensemble forecast at NCEP) and in the "two-tier" coupled model forecast system in which future SST anomalies obtained from the coupled system are then used to force an uncoupled atmosphere model to predict the atmospheric anomalies (Ji et al, 1998). This approach improves the seasonal and interannual predictions, primarily due to relatively skillful prediction of development of El Niño. However, the one-way interaction *neglects the feedback effect of the atmosphere on the ocean*. Moreover, most observational studies indicate that the atmosphere tends to force the ocean over the extratropics at least on intraseasonal time scales (e.g. Palmer and Sun, 1985; Wallace and Jiang, 1987).

Currently, two-way coupled atmosphere and ocean models have been used with moderate success in several operational centers to predict the alternating El Niño and La Niña episodes over the tropical Pacific basin as well as the associated anomalous teleconnection patterns over the extratropics. However, it remains to be demonstrated whether the coupled ocean-atmosphere models would produce skillful predictions in the absence of strong tropical SST anomalies.

There seems to be a consensus from observational studies about the phase relationship between quasi-stationary atmospheric and SST anomalies over the extratropics when the SST anomalies are driven by the atmospheric anomalies. Such a phase relationship is characterized by a low pressure/cyclonic vorticity anomaly over low SST anomaly or a high pressure/anticyclonic vorticity anomaly over high SST anomaly (Mo and Kalnay, 1991; Desser and Timlin, 1997). Mo and Kalnay, hereafter MK91, also suggested that anomalies forced by the ocean had the opposite configuration, namely a low pressure/cyclonic vorticity anomaly over warm SST, or a high pressure/anticyclonic vorticity anomaly over cold SST. MK91 interpreted this configuration between the anomalies from a dynamical point of view, namely that for atmosphere-driving anomalies a low level atmospheric cyclonic vorticity (where the atmosphere rotates faster than the ocean), produces Ekman upwelling and low temperatures in the ocean; on the other hand, for ocean-driving anomalies high SST anomalies induce upward motion and low level cyclonic vorticity. This diagnostic rule, if correct, gives a simple but powerful approach to help distinguish whether the forcing comes from the ocean or from the atmosphere. Based on this rule, in conjunction with an empirical temporal phase technique, described in the following section, and with the typical lag cross-correlation statistics, this study documents the frequency of ocean-driving versus atmosphere-driving persistent anomalies in the coupled anomalies with different time scales, for different seasons, and at different geographical locations. These techniques are applied first to the real coupled ocean-atmosphere system as it is captured by the NCEP/NCAR reanalysis data (Kalnay, et al 1996), and then to a one-way interaction model (AMIP run).

2. DATA AND METHODS

The results presented in this paper correspond to the statistics of persistent anomalies lasting at least one month in the five-day average data.

A period of 19 years (1980-1998) of daily Skin Temperature (SST over the ocean) and 850 mb cyclonic vorticity, CV, (computed from daily wind) data from the NCEP/NCAR reanalysis data has been used to study weekly to monthly persistent anomalies. The argument that the true forcing direction can be determined from the NCEP/NCAR reanalysis data is that the atmospheric variables, in particular the 850 wind data, and the ocean conditions, represented by the SST, are independent measurements. Although there are some deficiencies in the reanalysis, it provides the best estimate of the conditions of the coupled ocean-atmosphere system in the last 40 years. The study focuses on locally coupled anomalies that occur in the same location and time for both fields the SST and the CV. The first two annual harmonics were subtracted to the time series of each gridpoint of both fields. The anomalies were taken as the departures continuously exceeding one standard deviation from this annual cycle for at least 30 days. Once the dates and locations of the coupled anomalies were obtained, the frequency of ocean-driving versus atmosphere-driving cases was computed according to the MK91 rule. In addition, the statistics of the temporal phase between the two fields were also computed, that is, the number of cases when the coupled anomalies started in the ocean against the number of cases when they started in the atmosphere. These two statistical parameters yield complementary information. The MK rule is based more on physical/dynamical principles and attempts to determine the forcing direction of the anomaly, while the second is empirical and indicates the initial forcing of the anomaly. For instance, an anomaly that is initially present in the atmosphere does not imply necessarily that the forcing maintaining the anomaly comes from the atmosphere. To corroborate the phase relationship of the previous two techniques a lag cross-correlation statistics of the SST and the CV departures from the first two annual harmonics, and also the cross-correlation of the coupled anomalies were carried out. To investigate the extent to which a one-way coupling maintains realistic phase relationships, the same procedure was applied to data from an NCEP-AMIP run for the same period of years. The data was obtained from Jae-Kyung E. Schemm (CPC-NCEP, pers. commun.)

3. RESULTS

The distribution of the frequency of 30-day persistent coupled anomalies is shown in fig. 1a. The number ranges from 10 to 75 in the 19-year period. A low number of coupled anomalies were found over the western midlatitude oceans and the Antarctic circumpolar current region. The highest number of cases was found in the equatorial oceans, particularly the central Pacific Ocean. Consistent with past studies, the results obtained by applying the MK91 rule to the reanalysis data shows that, in general, the coupled anomalies are forced primarily by the ocean in the tropics (Fig.2a) and by the atmosphere in the middle latitudes (Fig.3a). This parameter also shows a longitudinal structure with a higher number of ocean-driving (atmosphere-driving) cases in the central and eastern (western) tropical Pacific. The statistics of the temporal phase suggest that most of the 30-day persistent anomalies start in the ocean specially in the tropics and in portions of the extratropical oceans including the northeast Pacific subtropics (fig. 4a).

As suggested in the introduction, both parameters convey complementary information. According to figs. 2a and 4a the coupled anomalies in the middle latitude Pacific Ocean tend to be forced by the atmosphere even though they may start in the ocean. The cross-correlation statistic of the departures from the annual mean between the CV field and the SST (Fig. 6a) indicates that in the tropics high SST anomalies are correlated with cyclonic vorticity anomalies (darker shade), and the opposite phase relation applies in the extratropics. Notice that the departures from the annual mean taken in the lag-correlation are not the necessarily the anomalies considered in the first two techniques (which are anomalies exceeding one standard deviation and lasting at least one month).

The frequency distribution of persistent coupled anomalies in the AMIP run for the same period of time shows a similar structure than that given by the NCEP reanalysis data (see figures in the right column). In agreement with the MK91 rule, the AMIP data show an overall bias towards ocean-driving scenario, however these differences are not large. The number of “atmosphere-driving” anomalies over the extratropics is clearly lower in the AMIP run than in the reanalysis data.

Differences in the number of persistent coupled anomalies were found between the reanalysis and a one-way interaction NCEP-AMIP run, but the spatial distribution is similar. As could be expected, since in an AMIP run there is no feedback to the ocean, the differences are more significant for “atmosphere-driving” anomalies in the extratropics and over the middle latitude oceans, particularly over the eastern subtropics. Surprisingly, over the Indian Ocean both the MK91 and the empirical temporal relationship indicates that the “atmosphere drives the ocean” phase relationship is observed in the AMIP runs. This suggests that perhaps in this region the circulation anomalies may be dominated by teleconnections rather than by local coupling.

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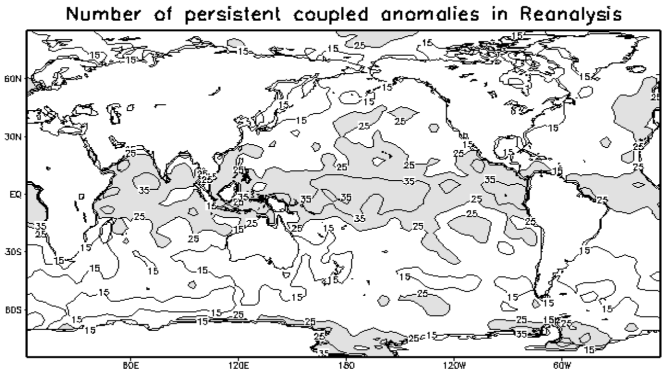
Number of persistent coupled anomalies in Reanalysis

Fig.1a Number of 30-day persistent coupled ocean-atmosphere anomalies for the period 1980-1998 in the NCEP/NCAR reanalysis data.

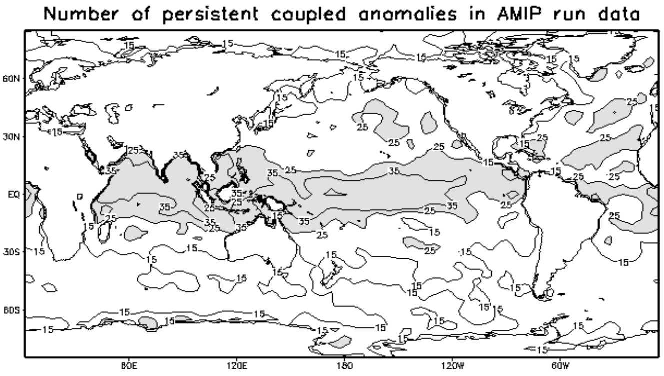
Number of persistent coupled anomalies in AMIP run data

Fig. 1b Same as Fig. 1a but using the AMIP run data.

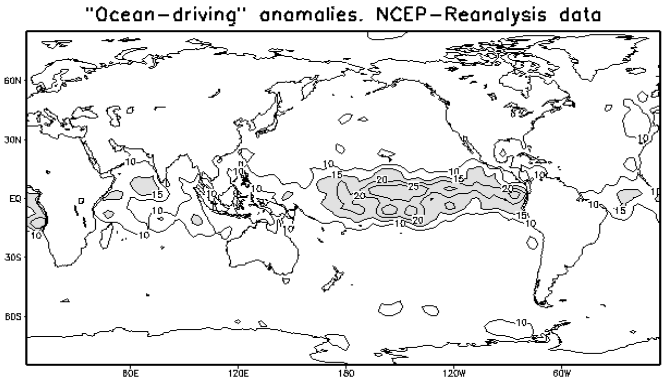
"Ocean-driving" anomalies. NCEP-Reanalysis data

Fig. 2a Frequency of Ocean-driving persistent anomalies according to the MK91 rule. The anomalies persisted a month or longer in the 5-day average data from the NCEP-Reanalysis. Shaded region represents 15 or more cases.

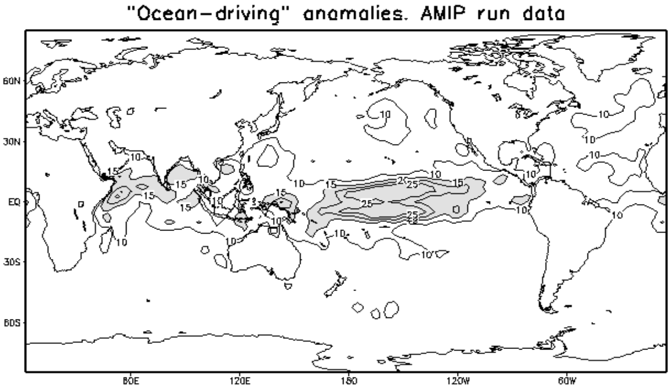
"Ocean-driving" anomalies. AMIP run data

Fig. 2b. Same as fig 2a but using AMIP run data.

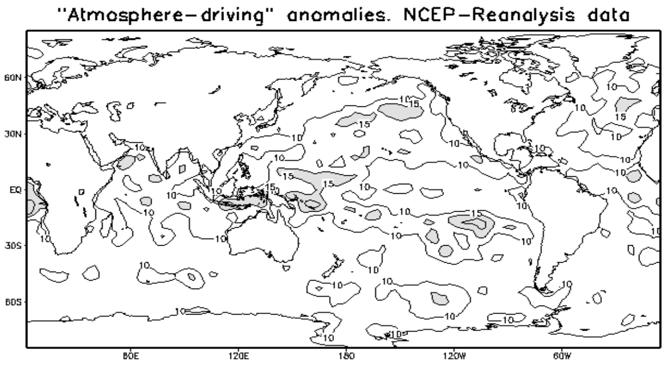
"Atmosphere-driving" anomalies. NCEP-Reanalysis data

Fig. 3a Same as Fig. 2 but for Atmosphere-driving anomalies

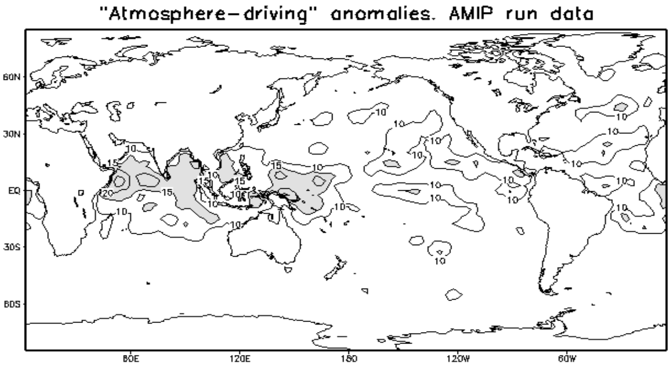
"Atmosphere-driving" anomalies. AMIP run data

Fig. 3b Same as Fig. 3a but using AMIP run data

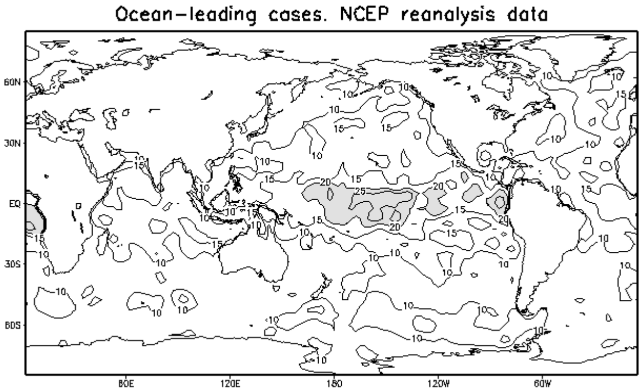

Fig. 4a Ocean-leading coupled persistent anomalies in the NCEP/NCAR reanalysis data using the temporal phase rule.

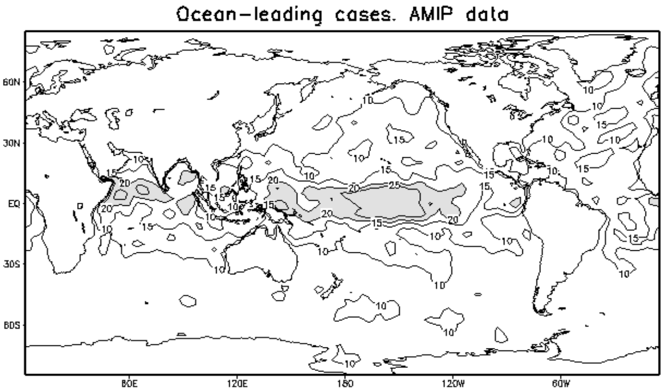

Fig.4b Same as fig. 4a but using data from the AMIP run.

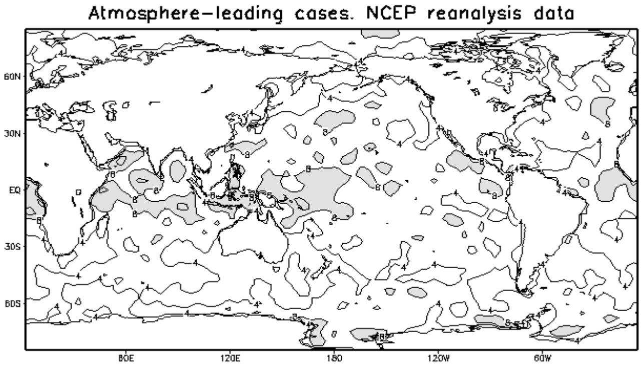

Fig. 5a Same as fig,4a but for Atmosphere-leading cases.

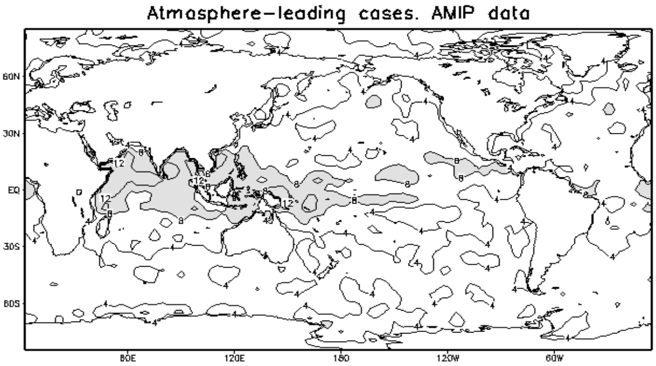

Fig. 5b Same as fig. 5a but using data from the AMIP run.

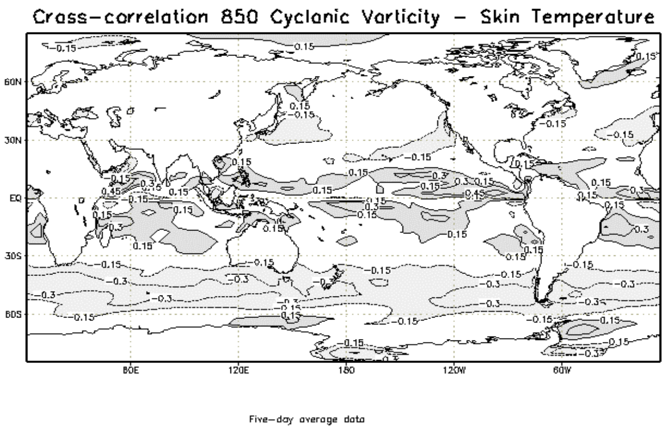

Fig. 6a Cross-correlation of CV and SST for the 5-day average of the NCEP/NCAR reanalysis data. Darker shades correspond to positive values in the correlation function.

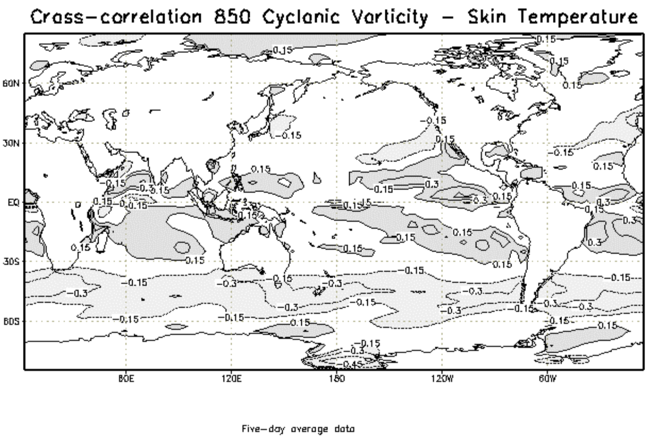

Fig. 6b. Same as fig. 5a but using data from the AMIP run