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PERSISTENT LOCALLY COUPLED ANOMALIES IN THE OCEAN-ATMOSPHERE

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1. INTRODUCTION

The coupling of atmospheric flow with slow-evolving anomalous surface boundary conditions, particularly the Sea Surface Temperature (SST), has the potential to improve the skill of short-term climate prediction (e.g. Shukla et al 2000). Because of the ocean's larger thermal inertia, the ocean can either strengthen or weaken atmospheric anomalies depending on the phase relationship between ocean and atmosphere anomalies. This in turn depends on whether the coupling is two-way or one-way, and on whether the atmosphere is predominantly forcing the ocean or vice versa. In the one-way ocean-atmosphere interaction (usually referred to "AMIP runs" for the Atmospheric Model Intercomparison Project, Gates et al, 1999), SST anomalies are always assumed to amplify/damp the atmospheric anomalies. This approach is commonly applied in the operational dynamical extended range forecasting. The skill obtained with this approach in the seasonal and interannual predictions is 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*.

Observational studies indicate that the atmosphere tends to force the ocean over the extratropics, at least on intraseasonal time scales (Palmer and Sun,1985, Wallace and Jiang 1987). Therefore, the one-way interaction configuration can produce large errors in the extratropics and even yield a wrong sign in the coupling fluxes. Masutani (1997) and Hurrell and Trenberth (1999) have revealed the evidence of wrong feedback possibly present in the AMIP runs. They show that in the NCEP/NCAR reanalysis the correlation between SST anomalies and observed precipitation is positive in the tropics (where the ocean mostly forces the atmosphere), and negative in the extratropics (where the atmosphere mostly forces the ocean), whereas it is positive everywhere in an ensemble of AMIP runs.

There is a consensus from observational studies about the local phase relationship between the atmosphere and the extratropical ocean when the atmospheric anomalies drive the SST. 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 (1991), 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 (see schematic Fig. 1). From a dynamical point of view, in “atmosphere-driving” cases the 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 rule also suggests that if we assume that the ocean always drives the atmosphere (as in AMIP runs) the ocean provides a negative feedback on those anomalies where in reality the atmosphere is driving the ocean, and this could result in a faster decay of atmospheric anomalies.

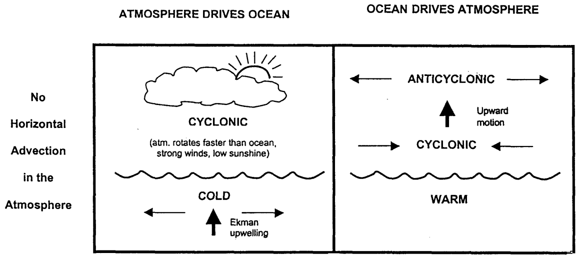

Fig. 1 Schematic of the local phase relationship between SST and the low-level atmospheric vorticity depending on whether the atmosphere drives the ocean (left) or the ocean drives the atmosphere (right).

This diagnostic rule, if correct, provides a general guidance to determine the forcing direction in locally coupled anomalies. Based on this rule, we have documented the statistics of the types of interactions in simultaneous ocean-

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atmosphere anomalies in the NCEP/NCAR reanalysis and in an NCEP AMIP run (Peña et al, 2001). The statistics show the frequency of “ocean-driving” versus “atmosphere-driving” anomalies of persistent anomalies of sub-monthly time scales. Here we present the statistics of 15-days or longer persistent atmospheric anomalies using this method and compare the results with the traditional lag time correlation technique.

2. DATA AND METHOD

This study uses 5-day average of daily 850 hPa relative vorticity and SST from both the NCEP/NCAR reanalysis (Kalnay et al 1996) and an NCEP AMIP run for the period 1980-1998 (19 years). The annual cycle, represented by the first two annual harmonics, was subtracted to the time series of each gridpoint of both fields. We considered only anomalies whose departure from the annual cycle continuously exceeded one standard deviation for at least 15 days in the 5-day average data. We refer to these high-amplitude long-lasting anomalies as locally coupled when they occur simultaneously in both the SST and the relative vorticity fields. Once the dates and locations of the simultaneous anomalies were obtained, the frequency of “ocean-driving” versus “atmosphere-driving” cases was computed according to the MK91 rule. We use the lag correlation technique of the SST and the relative vorticity of the monthly NCEP/NCAR reanalysis and a monthly NCEP AMIP run to corroborate the results. In the lag correlation technique the anomalies considered are departures from the annual cycle, rather than anomalies exceeding one standard deviation as in the dynamical method. We have deliberately reversed the sign of the relative vorticity field in the Southern Hemisphere. Thus positive vorticity anomalies are cyclonic, and negative anomalies anticyclonic in both hemispheres.

3. RESULTS

The annual average number of high-amplitude 15-day or longer persistent vorticity anomalies (not shown) ranges from 32 to 24 (out of 73 periods of 5 days in the year). There are fewer but longer lasting anomalies in the tropics than in the extratropics. In the SST data the annual average number of anomalies ranges from 4 to 10. There is a tendency of more anomalies in the subtropics than at any other latitude and fewer, much more longer lasting, anomalies in the central and eastern Equatorial Pacific. Fig. 2 shows that the tropics have a larger number of coupled anomalies and a higher percentage of coupling compare to the extratropics. Most high-amplitude persistent vorticity anomalies overlaying high-amplitude persistent SST anomalies are implied by the percentage in exceeds of 75% throughout most of the global oceans.

The relative difference in the number of coupled anomalies between the AMIP run and the reanalysis is shown in Fig. 3. The differences are within ±10 percent in most of the tropical oceanic region and in the Northern Hemisphere; however, there is a clear bias towards fewer coupled anomalies in the AMIP run than in the reanalysis, especially in the Southern Hemisphere. Fewer persistent anomalies in the AMIP suggests that in SST-driving models, in which atmospheric feedback is ignored, the ocean will tend to provide a spurious negative feedback and therefore damp the atmospheric anomaly.

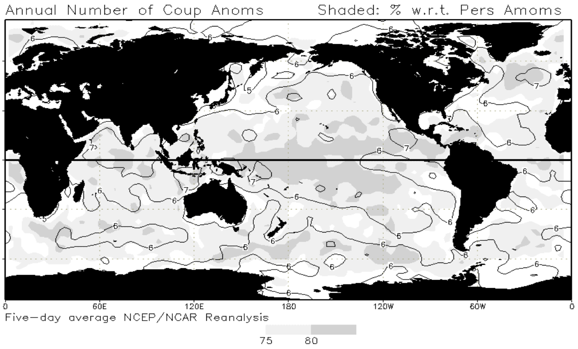

Fig. 2 Annual number of coupled anomalies (contour) and percentage (shaded) of coupled anomalies with respect to the total number of anomalies.

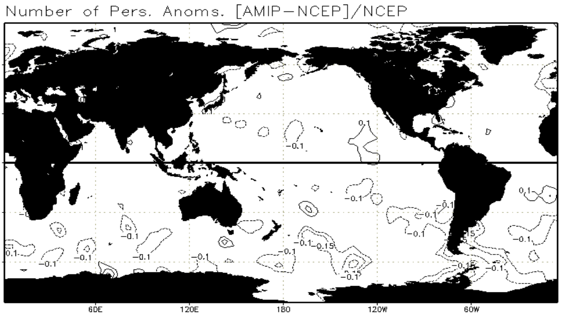

Fig. 3 Relative difference in the frequency of coupled anomalies between the AMIP run and the reanalysis.

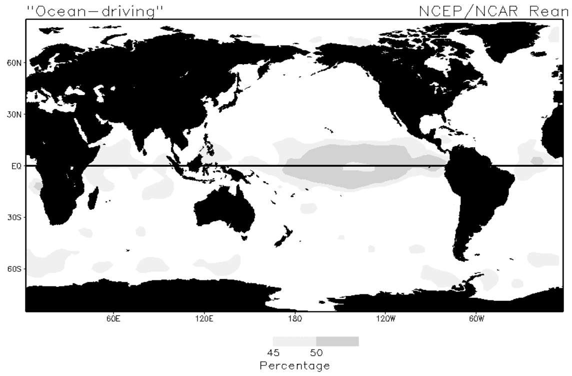

Fig. 4a Percentage of the number of cases of ``ocean-driving" anomalies that lasted longer than 15 days in the 5-day average reanalysis data.

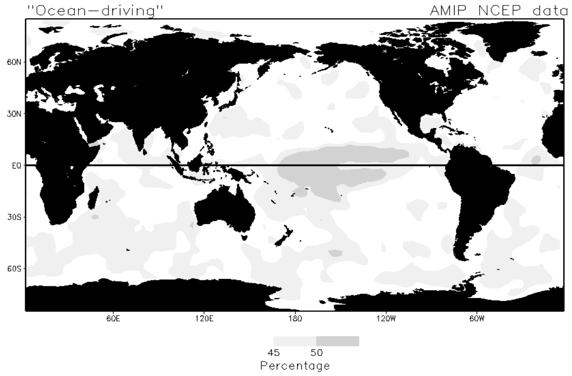

Fig. 4b Same as Fig. 4a but using AMIP run data. Notice higher percentage in the AMIP run than in the reanalysis over the extratropics.

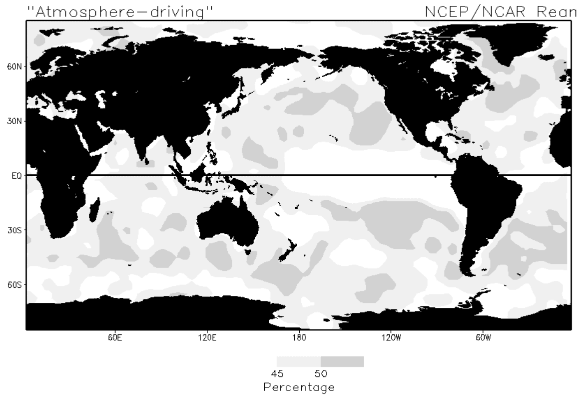

Fig.5a Percentage of the number of cases of ``atmosphere-driving" anomalies that lasted longer than 15 days in the 5-day average reanalysis data.

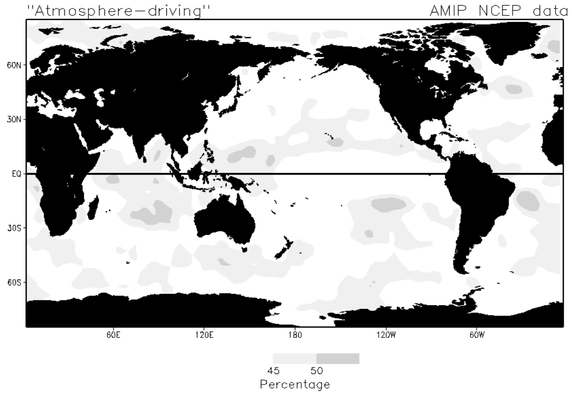

Fig.5b Same as Fig. 5a but using data from the AMIP run. Notice lower percentage in the AMIP over the extratropics than in the reanalysis.

Figs. 4a and 4b show the percentage of "ocean-driving" anomalies in both the reanalysis and AMIP run data sets. The structure of more "ocean-driving" anomalies in the tropics than in the extratropics is similar in both data sets. Not surprisingly, given that in the AMIP run the atmosphere does not influence the ocean, it presents a higher percentage of "ocean-driving" anomalies than the reanalysis. The percentage of "atmosphere-driving" anomalies in the reanalysis (Fig. 5a) and the AMIP run (Fig. 5b) shows a larger contrast with much fewer coupled anomalies in the AMIP than in the reanalysis.

Overall, the rule applied to the 5-day average data agrees well with previous studies that suggest that the atmosphere tends to force the ocean in the extratropics and the reverse in the tropics. The results given in Figs. 4 and 5 suggest that much of the difference observed in the number of persistent anomalies between the AMIP and the reanalysis (negative regions in Fig. 3) arise from ignoring the long-lasting "atmosphere-driving" anomalies.

We now compare these results with the lag correlation technique. Figs. 6a and 6b show the cross-correlations between the 850 hPa cyclonic vorticity and the SST of the monthly reanalysis data and the NCEP AMIP run. The correlation is positive in the tropics (i.e., cyclonic over warm) and negative in the extratropics (i.e., cyclonic over cold) in good agreement with the dynamical rule. The negative correlation in the extratropics is also consistent with the correlation found by Hurrell and Trenberth (1999) between SST and precipitation.

It is apparent that the central equatorial Pacific region with the highest frequency of "ocean-driving" anomalies (Fig. 6a) agrees with the largest positive correlation. In both datasets the ocean leading correlation in the tropics (not shown) remains positive, indicating that ocean precedes the atmosphere and that "ocean-driving" anomalies are long lasting. However, the ocean-leading correlation in the extratropics (Fig. 7 positive abscissa region) vanishes or even becomes positive, indicating no long-lasting "ocean-driving" anomalies in both datasets. By contrast, in the atmosphere leading correlation (Fig. 7 positive abscissa region), there is a stronger negative correlation in the reanalysis than in the AMIP run. It is apparent from the figure that the correlation reaches the maximum absolute value when the atmosphere leads, indicating not only that atmosphere anomalies tend to precede (or cause) ocean anomalies but also that there are long-lasting atmosphere-driving anomalies. Similar patterns of correlation are found in the five-day average data; however, the signal is not as strong as in the monthly data.

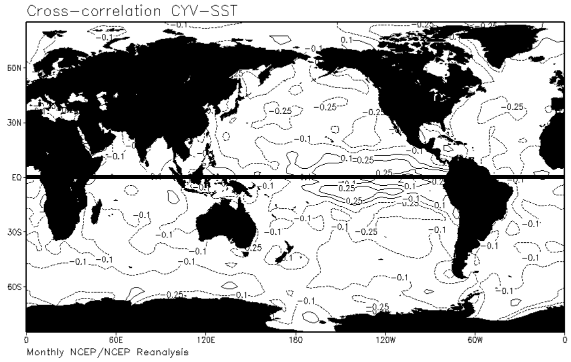

Fig. 6a Cross-correlation 850 hPa cyclonic vorticity and SST in the monthly NCEP/NCAR reanalysis data. Period: Jan 1979- Dec 1998.

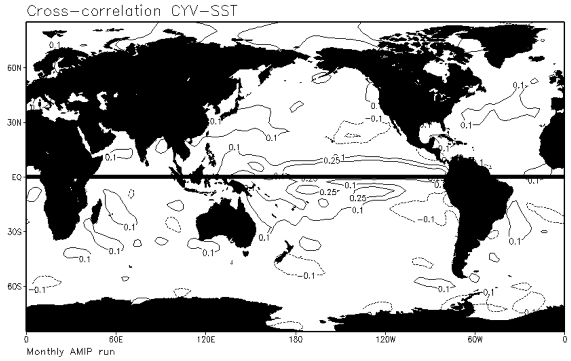

Fig. 6b Same as Fig. 6a but using data from an NCEP AMIP run. Period: Jan 1979- Dec 1998.

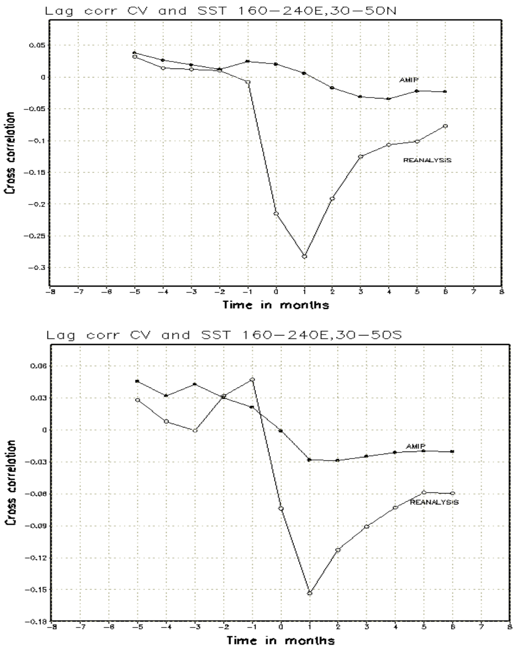

Fig. 7 Cross-correlation with different lags and lead between the 850 hPa cyclonic vorticity and the SST anomalies for an area (160-240E, 30-50N) in the Northern Hemisphere (top) and an area (160-240E, 30-50S) in the Southern Hemisphere (bottom).

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