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# POTENTIAL PREDICTABILITY OF THE MONSOON SUBCLIMATE SYSTEMS

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## 1. INTRODUCTION

While El Niño/Southern Oscillation (ENSO) phenomenon can be predicted with some success using coupled oceanic-atmospheric models, the skill of predicting the tropical monsoons is low regardless of the methods applied. The low skill of monsoon prediction may be either because the monsoons are not defined appropriately or because they are not influenced significantly by boundary forcing. The latter characterizes the importance of internal dynamics in monsoon variability and leads to many eminent chaotic features of the monsoons.

In this study, we analyze results from nine AMIP-type ensemble experiments with the NASA/GEOS-2 general circulation model to assess the potential predictability of the tropical climate system. We will focus on the variability and predictability of tropical monsoon rainfall on seasonal-to-interannual time scales. It is known that the tropical climate is more predictable than its extratropical counterpart. However, predictability is different from one climate subsystem to another within the tropics. It is important to understand the differences among these subsystems in order to increase our skill of seasonal-to-interannual prediction.

We assess potential predictability by comparing the magnitude of internal and forced variances as defined by Harzallah and Sadourny (1995). The internal variance measures the spread among the various ensemble members. The forced part of rainfall variance is determined by the magnitude of the ensemble mean rainfall anomaly and by the degree of consistency of the results from the various experiments.

## 2. RESULTS

Figure 1 shows the mean (1979-1995) patterns of forced and internal parts of June-August (JJA) precipitation variance. The difference between two variances is given in the figure (Fig. 1c) as well. Several features are

visible. First, the location of large forced variance is usually the region where internal variance is large. An impressive feature of the internal variance is the two-wing structure over the Pacific. This does not appear from the pattern of the forced variance. Secondly, regions where forced variance is larger than internal variance are located in the tropics-subtropics only (Fig. 1c). This indicates that the tropical climate is more predictable than the extratropical counterpart. However, in the Asian monsoon region including

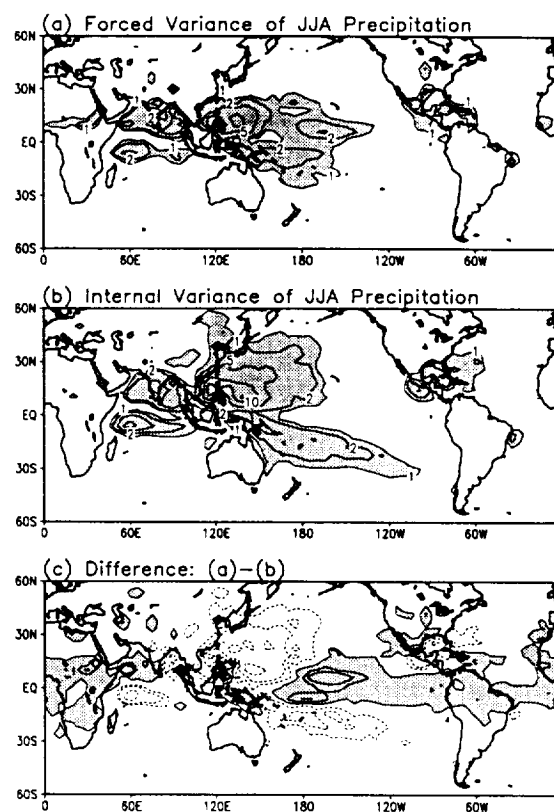


FIG. 1. 17-year (1979-1995) average of the forced and internal variances ((a) and (b)) of JJA precipitation and their difference (c). In (c), contour levels are -10, -5, -2, -1, 0, 1, 2, 5, and 10, and positive values are shaded. Units are  $\text{mm}^2/\text{d}^2$ .

part of the western Pacific, the potential predictability diminishes remarkably. Here, the largest relative importance of internal dynamics to boundary forcing occurs. Furthermore, over the central equatorial Pacific, the forced variance is significantly larger than the internal part. Interestingly, this feature does not appear over the Niño-3 region.

Most of the above-described features are also visible during December-February (DJF; figure not shown). Compared to JJA, the central-eastern Pacific sector is more predictable during DJF. In particular, the predictability over the Niño-3 region increases significantly. However, predictability decreases apparently in the Atlantic-Africa-Indian Ocean sector.

The relatively large predictability of the tropical climate is largely accounted for by boundary forcing like SST anomaly. Although a linear forcing-response relationship does not exist, large climate signals usually occur when SST forcing is strong. Figure 2 shows the composite differences between the forced variance and internal variances of JJA precipitation for warm (1982, 1983, 1987, and 1991), normal (1980, 1986, 1990, and 1992), and cold (1984, 1985, and 1988) cases. The classification of the groups are based on the JJA SST anomalies in the Niño-3 region. The figure demonstrates the relative magnitude of the forced and internal variances for the different phases of SST variations. The most impressive feature of Fig. 2 is that the predictability of the tropical climate is larger in the warm and cold events than in the normal events. This is especially true for the precipitation over the central tropical Pacific. In the warm cases, predictability increases clearly in the tropical region within 50°-150°E.

While SST forcing plays an important role in modulating the variability of the tropical monsoons, it is not necessary that each monsoon is linked closely to the Niño-3 SST anomalies. We have calculated the correlation between each area-averaged monsoon and the global SST at each grid point. It is found that except for the Asian and South American monsoons, other monsoons link only moderately or weakly to the Niño-3 SST. The Australian monsoon links not only to the central-eastern Pacific SST but also to the SST of the adjacent oceans. In Fig. 3, we show, for each year, the values of internal and external variances for the various monsoons as a function of the SST anomalies averaged within a region where SST is strongly correlated to a specific monsoon. The relationship between the

Asian monsoon (averaged within 2°-26°N, 60°-130°E) and ENSO is clear. For example, during all the years when the forced variance is larger than the internal variance, the Niño-3 SST changes more than half a degree from normal. For the Australian monsoon (22°-6°S, 120°-

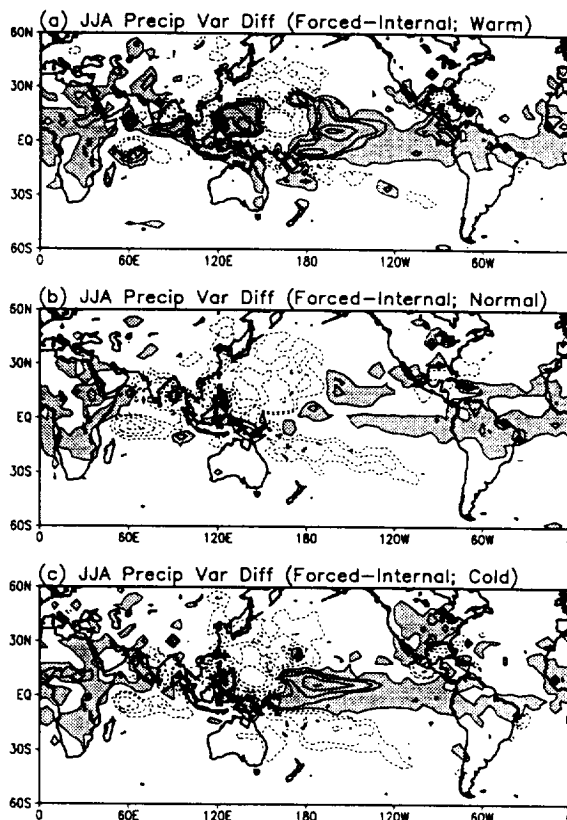


FIG. 2. Differences between the forced and internal variances of JJA precipitation for warm (1982, 1983, 1987, and 1991), normal (1980, 1986, 1990, and 1992), and cold (1984, 1985, and 1988) events of Niño-3 SST. Contour levels are the same as those in Fig. 1(c).

150°E), three of the four years when the monsoon is potentially predictable occur when the southeastern Asian SST anomaly is large (1984, 1988, and 1992). However, for each monsoon, there exist years when predictability is low in spite of strong regional SST forcing.

Figure 3 shows that the internal variance is small in the regional monsoons in Africa (6°-22°N, 15°W-40°E) and North America (22°-38°N, 120°-100°W). Like the rainfall over the Niño-3 region, these monsoons are potentially predictable. However, while the former is a large

function of the central-eastern Pacific SST, the monsoon is not strongly sensitive to any regional SST anomaly. Nevertheless, our result indicates that the African monsoon is moderately correlated to the SST of southeastern Pacific, consistent with the result of Xue and Shukla (1998). In South America ( $14^{\circ}$ - $2^{\circ}$ S,  $60^{\circ}$ - $30^{\circ}$ W), 62% (5 out of 8) of the monsoon rainfall is predictable when the Niño-3 SST anomaly is  $\geq 0.5^{\circ}$ .

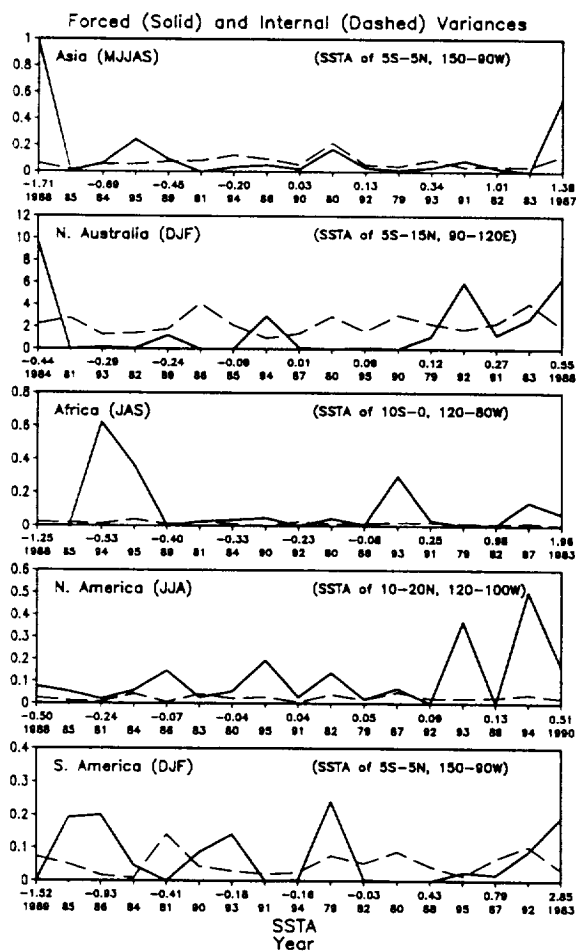


FIG. 3. Yearly values of the forced and internal variances of the various area-averaged monsoons (see the text for detail). The x-coordinate is in an ascending order of the regional SSTA (shown in the figure) that is most strongly correlated with the specific monsoon.

An analysis of predictability on monthly time scales indicates that, in most monsoon regions, the rainfall is more predictable in summer than in other seasons. This is different from the rainfall over the Niño-3 region. In Asia,

a semi-annual feature appears. The variability of rainfall is chaotic in winter, late spring, and summer. Predictability increases moderately in fall and early spring. The reason for this feature is unclear yet.

### 3. SUMMARY

Most of the tropical monsoon climate subsystems are more potentially predictable than the extratropical climate systems. However, the Asian summer monsoon and the Australian winter monsoon are less predictable than other regional monsoons.

The tropical monsoons are more predictable when SST forcing is strong. Different monsoons are linked to the SST anomalies of different regions. While the Asian and South American monsoons are associated with the Niño-3 SST, the variability of the Australian monsoon is regulated strongly by the SST of the adjacent oceans. The North American monsoon is associated with the SST anomaly of the northeastern Pacific and the African monsoon shows a moderate relationship with the southeastern Pacific SST. For many monsoons, predictability increases from winter to summer.

### REFERENCES

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Xue, Y., and J. Shukla, 1998: Model simulation of the influence of global SST anomalies on Sahel rainfall. *Mon. Wea. Rev.*, in press.