6A.2 A HYDROLOGICAL DEFINITION OF INDIAN MONSOON ONSET AND WITHDRAWAL

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1. INTRODUCTION

The onset of the broad-scale monsoon occurs in many stages and represents a significant transition in the large-scale atmospheric and ocean circulations in the Indo-Pacific region (e.g. Rao, 1976, Hsu et al., 1999). While there exists no precise definition of monsoon onset, at the surface the transition is recognized as a rapid, substantial, and sustained increase in rainfall over a broad scale. Typically, rainfall amounts increase from below 5 mm day^{-1} prior to the onset to over 15 mm day^{-1} for several days following the onset (Anathakrishnan and Soman, 1988, hereafter AS, Soman and Kumar, 1993). The evolution of the monsoon onset can also unfold in a variety of ways with abrupt, gradual, or multiple transitions occurring in various years that together encompass different timings and spatial patterns (e.g. Flatau et al, 2001).

Despite the motivations for using district rainfall as a basis for monsoon onset, there also exist a number of challenges posed by its use. Precipitation is among the most difficult fields to monitor, involving complex spatial and temporal variability. Also, rainfall over a single district of India at times does not reflect accurately planetary-scale variability and rainfall within a district is highly susceptible to “false” or “bogus” monsoon onsets (Flatau et al., 2001). Errors in onset date determination stem from both the subjective nature of the IMD’s decision and the susceptibility of objective methods to synoptic variability.

AS show the potentially large disagreements that can arise in comparing objective and subjective assessments of onset. Moreover, other years, such as 1979 and 1995, are associated with bogus onsets that objective methods can misdiagnose by up to three weeks (Flatau et al., 2001). Any studies of onset and its variability must be able to resolve accurately the onset with a precision that is small relative to year to year variations while at the same time being resilient to the occurrence of bogus monsoon onsets.

Though speculation exists that the onset may be related to other aspects of climate such as the overall strength of the monsoon season and ENSO (e.g. Joseph et al., 1994), the relationships between onset dates based on existing criteria and other climate features are weak and insignificant. Thus one is faced with the questions: Is the monsoon onset really unrelated to the strength of the overall monsoon season and ENSO or do inaccuracies in the onset date mask relationships that exist nature?; and are the indices currently used really appropriate for assessing the onset of the monsoon?

2. METHOD AND DATA

The hydrological cycle can be most generally described by the vertically integrated moisture transport (VIMT) into and out of a region, and the precipitation (P), evaporation (E), and precipitable water (PW) within the region. The NCEP/NCAR reanalyses from 1948 through the present time are used to estimate variability in the hydrologic cycle. Niño-3 SST is taken from GISST, Reynolds SST and Reconstructed Reynolds SST anomalies in the Niño-3 region averaged over the months of June, July, August, and September (JJAS). Convective available potential energy (CAPE) is derived from the NCEP-NCAR reanalysis.

3. CREATION OF AN ONSET INDEX

There are several requirements of any onset criterion. The criterion should:

- be associated with the establishment of the large-scale processes that drive the monsoon circulation,
- be relatively insensitive to individual synoptic disturbances, bogus monsoon onsets, and active-break transitions that occur within the monsoon season,
- be based on fields that have been well observed over an extended period so that the method can be used to describe onset over an extended climatology,
- be based on fields that experience large and rapid variability during the monsoon onset.

To meet these criterion, the VIMT and CAPE fields are used to create a hydrologic onset and withdrawal index (HOWI). The fields are derivatives of Class A and B fields from the NCEP/NCAR reanalysis and are strongly moderately influenced by observed quantities, respectively. Large-scale averages of the fields in regions that are particularly sensitive to monsoon onset are combined into a single index and normalized. The regions chosen span portions of the Indian Ocean and peninsula and will be described in more detail during the oral presentation. The timeseries are normalized so that their climatological seasonal cycle fluctuations in a range between -1 and 1. It should be emphasized that the scale over which the fields are averaged is very large

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with each spanning portions of the Indian Ocean and India that cover more than $3*10^6$ km^2.

4. Performance of the HOWI

Despite the different methodologies used, interannual variability in onset as determined by existing methods and HOWI agree closely. RMS difference between the onset methods is approximately 5 to 6 days, however, which is of the same magnitude as interannual variability in the onset date. Thus, while sharing a modest degree of variability, the onset methodologies do contain substantive differences.

The HOWI has been found to be robust in its resilience to “bogus” monsoon onsets and active-break transitions of the monsoon. During none of the years from 1948 to 2000 does the index signal a monsoon onset during a “bogus” event. Also the index does not signal the end of the monsoon during a prolonged “break” in the monsoon and during most years from 1948 to 2000 the transition of the index across zero is monotonic and gradual.

Among the principle science motivations for developing an improved index of monsoon onset is the role such an index may play in clarifying the relationships between the monsoon onset and withdrawal, the strength of the monsoon season, and ENSO.Table 1 shows the correlations between the onset as identified by HOWI, JJAS Indian rainfall, and JJAS Niño-3 SST. Warmer (cooler) SST in the east Pacific Ocean is associated with a delayed (early) monsoon onset and early (delayed) withdrawal. Also shown in Table 1 are the correlations achieved when fields from the ECMWF reanalysis (Gibson et al., 1999) are used to construct the HOWI. The ECMWF reanalysis data spans from 1979 to 1993. The strength of the onset and withdrawal relationships with total Indian rainfall is echoed by the reanalysis results with correlations of -0.37 and 0.52, respectively. However the associations with ENSO are weaker. A likely cause of the weakened relationship is the generally weak relationship between ENSO and the monsoon which emerged during the ECMWF reanalysis period. However more study will have to be done before a definitive conclusion can be made.

5. Conclusions

An index of monsoon onset and withdrawal based on key features of the monsoon hydrologic cycle has been developed that provides new insight into the instigation and termination of the Indian monsoon and their relationships to both total monsoon rainfall and ENSO. The index is intended to act as an indicator of the large-scale monsoon system rather than a localized onset and withdrawal criterion. The findings are consistent with the possibility that the method of the IMD and objective methods based on district rainfall are influenced in part by synoptic variability or subjective judgements that are not the indicative of the large-scale transition in the monsoon system. An objective criterion is developed that spans very large spatial scales and is thus less sensitive to synoptic variability while being highly sensitive to the rapid transitions that occur during monsoon onset. The newly developed HOWI index reveals markedly increased and statistically significant relationships between both the monsoon onset and withdrawal and total monsoon rainfall and ENSO. The performance of the newly derived HOWI index is found to be resilient to bogus onsets and active-break monsoon transitions during monsoon seasons of the past 50 years. Future work includes the development of an operational mode of monsoon onset and withdrawal identification and further investigations of the potentially significant linkages that exist between the onset and withdrawal of the Indian monsoon and other components of the climate system.

Table I: Correlation of the hydrologic onset and withdrawal index (HOWI) with All India Rainfall, and JJAS Niño-3 SST. Correlations based on ECMWF reanalysis are shown in parentheses and correlations exceeding 99% significance are shown in bold.

Index	All India	Niño-3 SST
HOWI-Onset	**-0.36** (**-0.37**)	**0.40** (0.23)
HOWI-Withdrawal	**0.45** (**0.52**)	**-0.25** (0.07)

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