Delayed onset of the 2002 Indian monsoon

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[1] We show that there is a set of dynamical predictors, which facilitate forecasting of a delayed monsoon onset. The main dynamical contributor is the early May propagation of the "bogus onset Intraseasonal Oscillation" which triggers a set of events precluding the climatological monsoon onset. We analyze in detail the 2002 monsoon onset and show that it followed a pattern described in our previous study. We notice that the 2003 monsoon onset followed very similar pattern and was delayed. *INDEX TERMS:* 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3339 Meteorology and Atmospheric Dynamics: Ocean/atmosphere interactions (0312, 4504); 3374 Meteorology and Atmospheric Dynamics: Tropical meteorology. **Citation:** Flatau, M. K., P. J. Flatau, J. Schmidt, and G. N. Kiladis, Delayed onset of the 2002 Indian monsoon, *Geophys. Res. Lett.*, *30*(14), 1768, doi:10.1029/2003GL017434, 2003.

1. Introduction

[2] As discussed by *Pant and Rupa Kumar* [1997] a sustained increase in rainfall and cessation of rainfall activity have been traditionally used to demarcate the beginning and end of monsoon circulations. The calendar dates of these seasonal demarcations have considerable inter-annual variability, of the order of 1–2 weeks. The specification of objective criteria for fixing the onset has several difficulties and it is a subjective decision based on overall judgment taking into account the changes in circulation features, seasonal reversal of winds, and a sustained increase in rainfall over Kerala (southernmost tip of India). The problem is confounded by the fact that Kerala frequently witnesses widespread rainfall activity due to pre-monsoonal thundershowers, which may be difficult to differentiate from the monsoon rains. In the past it was observed that there are considerable differences between the real-time dates issued by the India Meteorological Department (IMD) and those fixed by a post-mortem examination of rainfall sequences. This has necessitated a re-examination of past data to decide on the onset date based on some objective criteria, in order to make the onset dates useful for scientific investigations. *Pant and Rupa Kumar* [1997] conclude that although the use of upper-air and satellite data has considerably reduced the subjective errors in deciding on the dates of onset, one has to rely on the rainfall data alone to generate long-term series of onset data.

[3] In this note we focus on the case of the 2002 monsoon onset. We show that the 2002 monsoon was delayed, and that its development followed the scenario outlined in *Flatau et al.* [2001]. Our assertion contradicts the statement by the India Meteorological Department that declared the monsoon onset over Kerala on May 29, 3 days earlier than the climatological (June 1) onset date, but it agrees with *Joseph* [personal communication, 2002] who predicted a 2 week delay of the monsoon onset in his experimental forecast issued in mid-May. It is the purpose of this note to contribute to a more quantitative forecasting of the monsoon onset in the future and to show the usefulness of the set of dynamical predictors described in *Flatau et al.* [2001] and termed there as "double monsoon onset". A double monsoon onset occurs when strong convection in the Bay of Bengal is accompanied by a monsoon-like circulation, generally appearing in the Indian Ocean in early May, which is about 3 weeks earlier than the climatological onset date. The initial "bogus onset"' is followed by flow weakening or reversal near the surface and clear-sky and dry conditions over the monsoon region. The *Joseph et al.* [1994] and *Flatau et al.* [2001] studies indicate that the development of bogus onsets depends on the timing of intraseasonal oscillations in the Indian Ocean and the propagation of convective episodes into the western Pacific. There is evidence that the sea surface temperature (SST) evolution in the Bay of Bengal and the western Pacific also plays an important role in this phenomenon. *Flatau et al.* [2001] suggested that in the case of the double monsoon onset it is possible to predict hot and dry conditions in India before the real monsoon onset.

2. Methods

[4] We make use of several observational and modeling resources. The satellite observations are based on data from the radiometer onboard the Tropical Rainfall Measuring Mission (TRMM) satellite (see Acknowledgements). The entire data set includes sea surface temperatures (SST), surface wind speeds derived using two different radiometer channels, atmospheric water vapor, liquid cloud water, and precipitation rates. The TRMM data used here are 3-day running means. We also use the data from the NCEP/NCAR reanalysis and an 81 km mesoscale analysis based on the Naval Research Laboratory's Coupled Ocean/Atmosphere Mesoscale Prediction System [*COAMPS*, *Hodur*, 1997], run in non-coupled mode, using boundary conditions based on the Navy's global model.

3. Results

[5] As described in *Flatau et al.* [2001], an intraseasonal oscillation (ISO) in convective activity is often observed over the equatorial Indian Ocean in early May, and can be associated with a "bogus onset" of the Indian monsoon. As is well-known, the ISO is composed of a variety of higher

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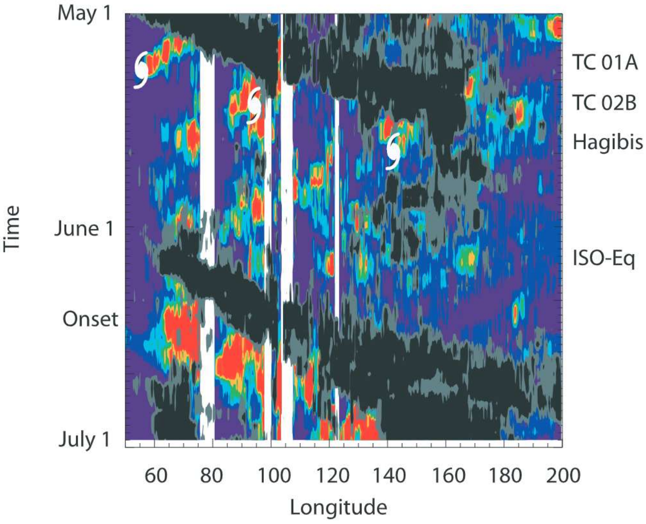

Figure 1. Time-longitude diagram (3-day running average) of the TMI total liquid water content averaged over the 5°–15°N latitude belt (color) and 5°S–5°N equatorial belt (indicated by black and gray). Days are from May 1, 2002. ISO-Eq stands for ISO propagation on the Equator. Approximate position of the tropical cyclones 01A and 01B and typhoon Hagibis are indicated by hurricane symbols. Red color indicates strong convection.

frequency disturbances [*Nakazawa*, 1988]. Along with convectively coupled Kelvin and mixed Rossby gravity waves, the ISO is known to modulate the occurrence of tropical depressions over the Asian monsoon region (see *Straub and Kiladis*, 2003 and references therein).

[6] The evolution of ISO activity during May–June 2002 is illustrated in a time-longitude diagram (Figure 1) of TRMM Microwave Imager (TMI)-derived liquid water content off- (red, green, and blue) and on- the equator (black and gray). The May ISO propagated eastward at 12–15 m/s, a phase speed more typical of a Kelvin wave than the 5–10 m/s Madden-Julian Oscillation or MJO [*Wheeler et al.*, 2000]. As it propagated towards the western Pacific, the May ISO spawned a tropical "cyclone pair", with twin disturbances on either side of the equator. One of them, the TC-01A, moved into the Arabian Sea on May 6. As it continued to push on eastward, the ISO led to the formation of yet another cyclone pair by May 10. Thus, "quadruplet cyclones" were observed in the Indian Ocean after May 9, 2002. TC 02B (10–12 May), moved northward into Myanmar and subsequently a depression formed over the Bay of Bengal. The southern systems moved off the equator as Rossby gyres and were subsequently absorbed into cyclones in the storm track over the South Indian Ocean.

[7] After TC-02B made landfall on May 11, 2002, convection persisted in the central Bay of Bengal until May 20, leading to the "bogus onset". The intense convection lead to a temperature decrease of the order of 3°C in the upper 30 m of the Bay of Bengal between May 11, 2002 and May 27, 2002 (Figure 2). Such cooling of the Bay of Bengal right before the climatological onset of the monsoon was hypothesized by *Flatau et al.* [2001] to be one of the precursors of the delayed onset. The ISO activity continued eastwards into the Pacific Ocean and was associated with the formation of Super Typhoon Hagibis in the North-West Pacific in the following two weeks. As shown in *Flatau et al.* [2001] the propagation of the ISO from the Indian Ocean to the Western Pacific is necessary for the break in the monsoon activity after the initial "bogus monsoon onset".

[8] In 2002 the break was observed between May 20–30, when the wind speed subsided over the Bay of Bengal leading to a gradual warming of the uppermost waters of the Bay by early June. At that time a second ISO that was associated with the real monsoon onset was visible on the Equator around June 4, 2002 in (Figure 1). This disturbance propagated eastward at a more MJO-like speed of around 7 m/s, reaching the longitude of Kerala, India on June 13.

[9] The scenario described above is very similar to the double onset cases examined in *Flatau et al.* [2001]. To quantify the comparison further, we calculate the monsoon indices that reflect the intraseasonal circulation changes. As in *Flatau et al.* [2001] the NCEP reanalysis winds are used in these calculations. To define multiple monsoon onset we use two criteria: (a) the kinetic energy of the surface winds averaged over 5°–20°N and 40°–110°E; and (b) A Monsoon Circulation Index (MH), based on the strength of the local Hadley cell and defined as the shear between 850 and 200-hPa meridional winds, averaged over 10°–30°N and 70°–110°E. The kinetic energy criterion is closest to that used by *Fieux and Stommel* [1977] since surface winds are used to determine the beginning of the monsoon. However, to avoid the influence of local disturbances we use the value averaged over the large area and smooth the data using a 5-day running mean. The broad-scale circulation MH index, introduced by *Goswami et al.* [1999], measures the strength of the local Hadley circulation created by off-the-equator monsoon heating. Figure 3 shows the Monsoon Circulation Index (MH) for 2002 (solid thick line) and 1995 (dashed line) as well as 2002 kinetic energy index (TKE). The peak

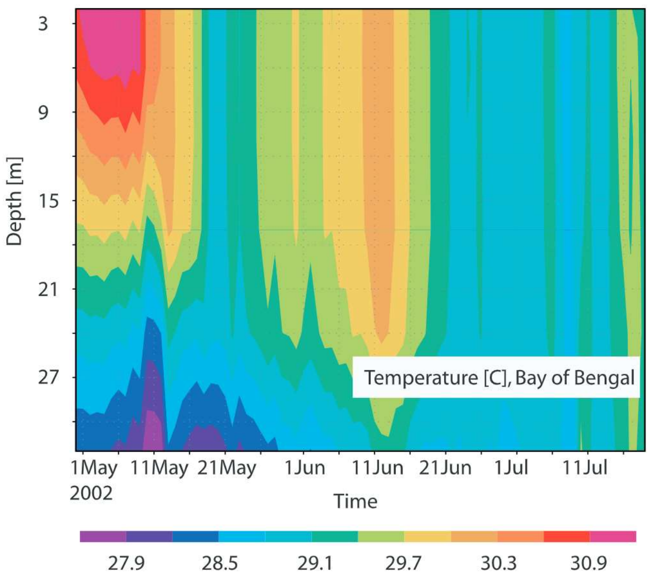

Figure 2. Temperature in the upper 30 m in the central Bay of Bengal (85°E–90°E. 10°N–15°N) from the Navy experimental global ocean analysis system. Large cooling in the Bay of Bengal is visible in the mid-May, 2002.

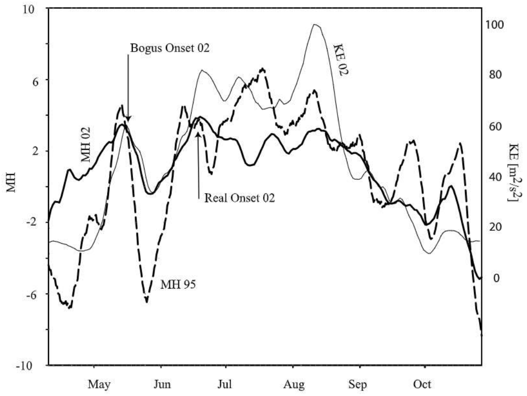

Figure 3. Monsoon Circulation (MH) averaged over 10°–30°N and 70°–110°E based on the NCAR/NCEP reanalysis data for 2002 (solid line) and 1995 (dashed line). Kinetic Energy (KE) index for 2002 (thin solid line).

values of the MH and TKE index (Figure 3) in May and June correspond to the bogus monsoon onset and the real monsoon (peak around June 13, 2002) onset. Interestingly, the 1995 delayed monsoon onset (dashed line) had a very similar MH index pattern, however the reversal preceding the onset was stronger in 1995.

[10] Another indicator of monsoon onset is the well-established low-level Findlater jet [*Findlater*, 1969; *Rao*, 1976]. This jet is responsible for cross Equatorial flow and carries moisture from the equatorial regions toward the Indian subcontinent. Figure 4 (based on the surface winds derived from the TMI data) shows the time-longitude diagram of wind speed for the 5°–15°N latitude belt. Superimposed is the equatorial liquid water content associated with the ISO propagation (white). Note that the strong surface winds located near the axis of the low-level Findlater jet developed between the longitudes of 50°–60°E only after ISO convection reached the Bay of Bengal and subsequently propagated northward (Figure 1), in agreement with discussion in *Joseph et al.* [1994].

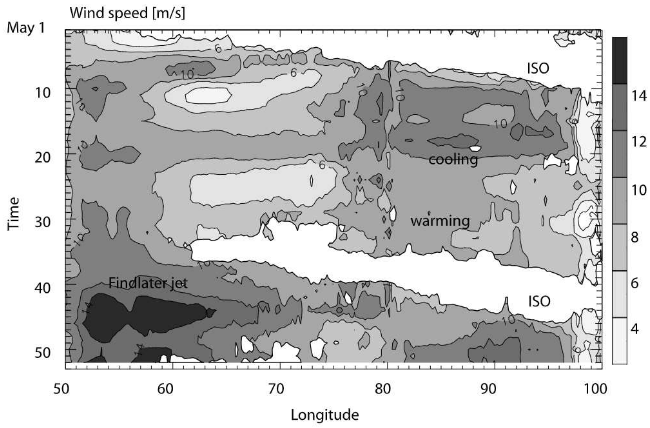

Figure 4. Surface wind speed [m/s] (3-day average) averaged over the 5°–15°N latitude belt overlapped with the 5°S–5°N equatorial latitude belt of total liquid water content (white contour for liquid water content >1 mm, 3-day running average). Cooling in the Bay of Bengal and warming during calm winds are indicated. The equatorial convection (ISO) precedes the stronger off-equatorial winds. The Bay of Bengal trough associated with the second ISO sets the low-level jet.

[11] To further quantify the delay of monsoon onset we present data from the COAMPS mesoscale reanalysis. As we indicated previously, we use the model to assimilate the data. The main reason to use the mesoscale data assimilation is that we can (a) present results on relatively fine grid over the oceanic regions, (b) use an isentropic surface to show the low level jet stream, and (c) indicate when the jet reached sufficient strength to provide sustained cross-equatorial flow of moist air. Figure 5 shows two panels of modeled horizontal winds on (a) May 29, 2002 and (b) June 13, 2002. These fields were constructed from interpolation of the model data to the 306 K isentropic surface. The flow along this particular isentropic surface was chosen because it corresponds well with the height of the maximum wind speed in the modeled Findlater jet. The Findlater jet is clearly established at 10°–15°N by June 13, 2002 (Figure 5b) the same day both the model and actual observations show widespread precipitation over India (not presented). The maximum wind speed within the jet at this time is shown

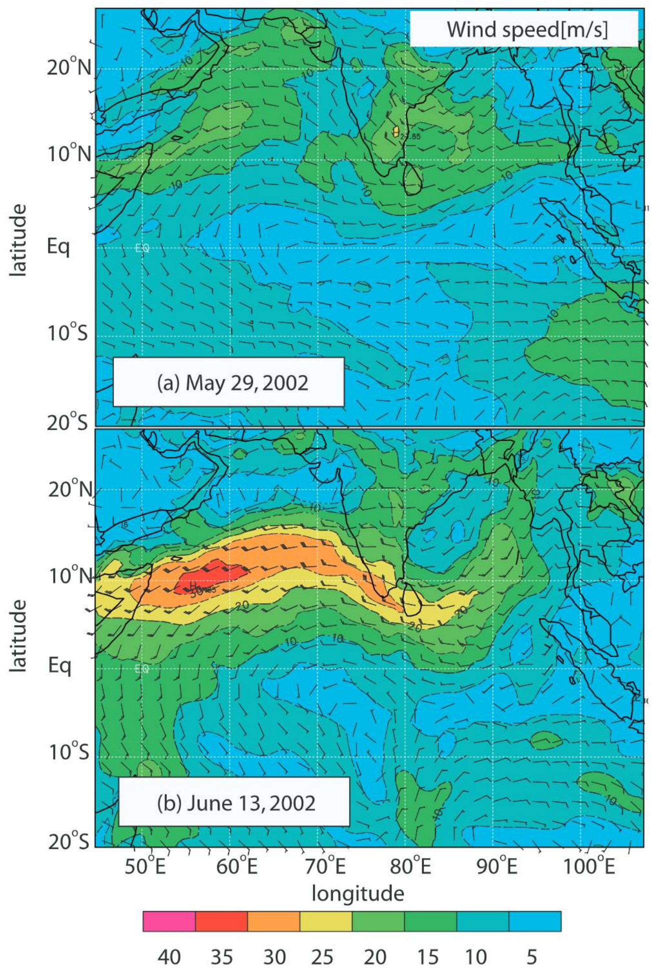

Figure 5. Twelve hour forecast fields of the wind speed [m/s] along the 306 K isentropic surface for (a) the May 29, 2002 and (b) the June 13, 2002. The two plots show the general intensification of the Findlater Jet during the period of interest.

to reach a value in excess of 35 m/s, over double the magnitude found to be present at this level in late May and in the averaged surface wind fields plotted in Figure 3. The enhancement in the flow evident by 13 June both at the surface and within the jet axis is more representative of the actual onset typically associated with these events [*Rao*, 1976].

4. Discussion

[12] The main purpose of this note is to show that the 2002 monsoon followed the pattern described in *Flatau et al.* [2001] as ‘‘double monsoon onset’’ and that consideration of large scale dynamics associated with intraseasonal oscillations in convection provides important forecasting clues. In *Flatau et al.* [2001] we proposed that two conditions are important for the formation of ‘‘bogus onset’’ and subsequent delayed real monsoon onset: (a) an early May propagation of the ISO leading to intense convection and SST decreases in the Bay of Bengal, (b) further propagation of an ISO into the Western Pacific, leading to an enhanced Walker circulation and suppressed convection in the Indian Ocean in the late May. We show that these conditions were satisfied in the case of 2002 monsoon. In addition, it is evident that in 2002 the May ISO leading to the bogus onset could be attributed to a convectively coupled Kelvin wave [*Wheeler et al.*, 2000] rather than an MJO-like disturbance that has been typically associated with the real monsoon onset in the past (and in 2002 as well). This raises questions about the nature of the relationship between Kelvin waves and ISO activity that may be tied to monsoon onset. Such issues certainly warrant further investigation.

[13] Another question concerns the potential for ISO convection in the Western Pacific to trigger westward propagating waves that may the formation of a subsequent ISO in the Western Indian Ocean. While this development happened in 2002 monsoon and some other ‘‘double onset’’ cases analyzed in *Flatau et al.* [2001], the westward propagating perturbations do not constitute necessary condition for a delayed monsoon onset and represent only one of the many possible triggers for the second ISO. The development of the large scale circulation leads us to argue that the 2002 monsoon was delayed and that the real onset over Kerala occurred on June 13 and not on May 29, 2002 as declared by the IMD. It appears that the increase of convection on May 29th was associated with local transient thunderstorms, as evidenced by the rainfall pattern, by analysis of the low-level jet strength, and MH index. The factors governing this failure of the monsoon are currently the subject of scrutiny by the scientific community [*Jayaraman*, 2002].

[14] It is worth noting that the monsoon onset in 2003 followed similar pattern to that described above. In the early May an equatorial disturbance (MJO) developed in the western Indian Ocean. It spawned the tropical cyclone TC-01B in the Bay of Bengal on the May 11 which drifted slowly northward. The cyclone made landfall along the west central coast of Myanmar (Burma) on the May 19, 2003. A severe heat wave in India followed. The real monsoon onset in 2003 followed the pattern of 2002 and was delayed by one week, arriving in Kerala on June 8, 2003.

[15] **Acknowledgments.** Our interest in the 2002 onset was heightened by the forecast of Dr P. V. Joseph who in mid-May 2002 predicted a delayed onset. We would like to thank ‘‘The Hindu’’ journalist Mr Raj for keeping us informed about fascinating social and political issues in India associated with onset in both 2002 and 2003. TMI data and images are produced by Remote Sensing Systems and sponsored by NASA’s Earth Science Information Partnerships (ESIP): a federation of information sites for Earth Science; and by NASA’s TRMM Science Team. The Office of Naval Research supported this research under the ONR Program Element 0602435N. PJF was supported in part by the National Science Foundation Climate Dynamics program.

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