Answer to Comments on "Space–Time Structure of Monsoon Interannual Variability"

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The conceptual model proposed by Khandekar aims at explaining the occurrence of good or bad Indian summer monsoons (ISM). He argues that good or bad monsoon years can be explained by three independent factors: El Niño–Southern Oscillation (ENSO), Eurasian snow cover, and the stratospheric wind quasi-biennial oscillation (QBO).

On the other hand, the results in my paper (Terray 1995) suggest that ISM interannual variability is dominated by two low-frequency modes, the biennial (B) mode with a period very close to 2 yr and the low-frequency (LF) mode with a period close to 4–6 yr. The LF mode contains more energy than the B mode, but the ocean–atmosphere coupling seems to be stronger at the B timescale over the Indian Ocean. Finally, the occurrence and intensity of exceptional ISMs depend upon the coupling or the decoupling of the B and LF modes during recent decades.

It is true that Khandekar's model for drought and flood in the Indian monsoon has some connections with my results and can be, among others, a working hypothesis for explaining them. However, there are still some issues that need to be clarified in Khandekar's model from my point of view.

- The LF and B modes described in my paper are strongly associated with the same modes of ENSO. These results may be established by cospectral analyses between various ENSO indices and EOFs presented in my paper (Terray 1992). This is consistent with a strong coupling between ISM and ENSO at both timescales and not only at the LF timescale as suggested by Khandekar. These results are not new; many recent studies suggest that ISM plays a key role in explaining low-frequency ENSO-like variability and that both phenomena are structured by the B and LF modes (Yasunari 1985; Rasmusson et al. 1990; Barnett 1991; etc.). Indeed, there is no doubt that tropospheric B variability in the Indian and Pacific areas is strongly connected to the other.
- The existence of a significant B mode in ISM variability at the surface cannot be taken as a proof of the impact of the stratospheric QBO on ISM variability. For example, the B mode is particularly well defined near 90°E both on the equatorial zonal wind (see Rasmusson et al. 1990) and on the SLP fields in the same area (Terray 1992). In this region, the energy associated with the two modes is roughly the same in recent decades. In fact, any meteorological time series in this area, if properly filtered, is a very good indicator of B variability over the Indian Ocean. However, the equatorial zonal wind QBO at 90°E shows no clear relationship with the 50-hPa wind QBO (Kane 1992, his Fig. 6). The two series are very dissimilar and show no correlation.
- Moreover, many studies have pointed out that there is no connection between the stratospheric QBO and the B mode of ENSO (Quiroz 1983; Barnett 1991; Xu 1992). This other fact seems again contradictory with the hypothesis of an association between the stratospheric QBO and the B mode of monsoon variability if we take into account the strong coherence of the B mode in the Indo–Pacific region.
- How can the transient nature of the B periodicity both in time and space (see Fig. 4 of Terray 1995) be explained by the more regular stratospheric QBO?
- How can the eastward phase propagation of the B mode at the surface (Barnett 1991) be explained by the stratospheric QBO taking into account that this stratospheric QBO has no zonal structure?
- There is neither proof nor suggestion of the independence of features like ENSO, the B mode, and Eurasian winter snow cover. Khandekar (1996) suggests that predictors of ISM that are based on premonsoon circulation patterns over the Indian subcontinent (like the monthly mean latitudinal location along 75° of the axis of the 500-hPa ridge during April) are related only to the Eurasian winter snow cover. However, a spectral analysis of the April ridge location during the 1939–84 period (Terray 1992) suggests that both the B and LF modes exist in this time series. Accordingly,

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it seems difficult to say that this parameter is independent of ENSO or of the B mode.

How can we explain these discrepancies if the conceptual model of Khandekar is correct?

All the results in my paper deal with surface data and suggest a strong coupling between ocean and atmosphere at the B timescale, even if the LF timescale contains more energy than the B mode over the Indian Ocean and subcontinent. On the other hand, the notion of such coupling is not central in Khandekar's model, which suggests, instead, a possible link between the stratospheric QBO and ISM interannual variability. Moreover, his conceptual model focuses mainly on high-level circulation in the troposphere for explaining ISM interannual variability. As a consequence, it is very difficult to establish a link between his model and my results, which are restricted to the surface.

As a conclusion, I would like to point out that the stratospheric QBO may not be necessary to explain observed tropospheric B variability in the Indian region. Coupled climate interactions between the ocean and atmosphere or, better, between the land, ocean, and atmosphere, as suggested by Meehl (1994) or Goswami (1995), may produce B variability without the intervention of the stratospheric QBO. As an illuminating example, consider the model developed by Goswami. He proposed that strong intraseasonal oscillations (such as the Madden–Julian oscillation, which is very strong over the Indian Ocean and subcontinent), interacting with the annual cycle, may produce a strong QBO in the atmosphere and that the ocean–atmosphere coupling may subsequently produce a weak QBO in the ocean. This mechanism agrees quite well with my observational results: a relatively strong QBO in the atmosphere, a strong coupling between the ocean and atmosphere at the biennial timescale, and a weak B mode in the oceanic fields.

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