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Role of the air-sea interaction processes on the Indian southwest monsoon dynamics

SETHU RAMAN, KIRANKUMAR ALAPATI and RANGARAO V. MADALA[1]

Department of Marine, Earth and Atmospheric Sciences, North Carolina State University,
Raleigh, NC 27695-8208, U.S.A.
[1]Atmospheric Science Branch, Naval Research Laboratory, Washington, D.C. 20375

Abstract - Surface turbulent heat fluxes over the Arabian Sea and the Indian Ocean during the Indian southwest monsoon depends primarily on the sea surface temperatures (SST). Effect of the variation in the sea surface temperature on the wind structure and the precipitation pattern over the monsoon area is investigated using a nested regional model. Sea surface temperature is found to influence the monsoon structure. Increase in SST causes increase in precipitation due to increase in convection. But there appears to be a critical SST beyond which winds do not intensify further and precipitation does not increase.

INTRODUCTION

The Indian southwest monsoon is characterized by a strong northward cros equatorial flow of moist air off the eastern coast of Africa as indicated in several studi (e.g., Saha and Bavadekar, 1973; Cadet and Reverdin, 1981) along with a low-level j over the Arabian Sea. One of the important characteristics of the summer compone of the monsoon system is the development and organization of cross-equatorial flo over the Indian Ocean. Two specific features of the monsoon region are (1) change the direction of the prevailing winds by at least 120° between winter and summer ar (2) spells of heavy rainfall during the monsoon period. Based on these criteria, tl area between 25° S to 35° N and 30° E to 170° E can be considered as the monsoc region (Ramage, 1971). Lower level monsoon westerlies approach the west coast India almost at right angles to the mountain ranges after travelling thousands kilometers over the warm Indian Ocean and the Arabian Sea. Prevailing local convecti instability triggers deep convection giving rise to large rainfall over the Indian su continent.

Also, summer monsoon flow is associated with a low level jet called Somali j over the Arabian Sea whose roots originate in the Mozambique Channel (Van de Booga and Rao, 1984). The core of the Somali jet is situated at altitudes between 1.5 and 2 km and its separation from African coast appears to occur around 10° N. Analyzir the aircraft data over the Arabian Sea, Holt and Raman (1985) showed that monsoc boundary layer is markedly different from the trade wind boundary layer. Ocean-A mosphere interactions over the Arabian Sea play an important role affecting the dynami and the thermodynamics of the monsoon region. Kusuma and Goswami (1988) four that the sea surface temperature (SST) over the Arabian Sea and the rainfall over Ind are strongly correlated. Unlike the trade winds, the southwest monsoon flow is n steady and wind surges regularly travel from the Southern Hemisphere across tl Arabian Sea. The estimated average movement of these surges is about 4 degrees latitude per day. It has been shown that the spells of rainfall over the west coast the India can be attributed to these wind surges (Grossman and Durran, 1984). Air-S interaction processes can be greatly influenced by these wind surges. In addition, chang

RESULTS AND DISCUSSION

Figure 1 shows the domains covered by CM model and FM model with FM domain located over the Indian subcontinent. There are 61 X 53 X 10 and 97 X 73 X 10 grid points in the CM and FM domains respectively with 1.5° and 0.5° horizontal resolution. Coastal line in both the CM and FM domains were determined based on the topography data and thick solid lines in all figures represent the coastal lines. Three numerical experiments were performed, using the initial conditions from FGGE data. Integrations were carried out for 48 hours.

Figure 2 shows the climatological sea surface temperature distribution for the month of July. We will refer the results pertaining to the experiment where climatological SST is used as N-case (normal SST) and the results pertaining to the experiments where the warmer sea surface temperatures of 31° and 35°C are specified as W1-case and W2-case respectively. Near-surface streamline pattern for the initial conditions used in the model at 00 UTC June 24 1979 are shown in Figure 3 which were obtained from FGGE data.

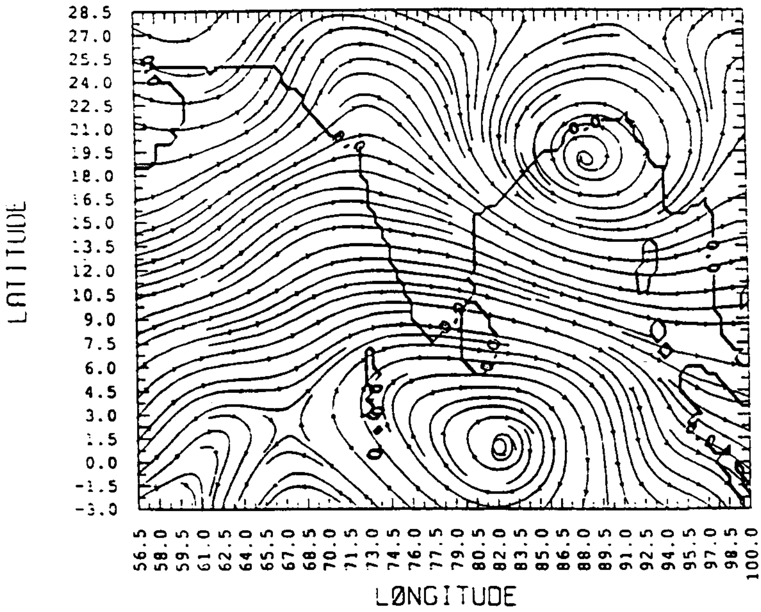

Fig. 3. Near-surface streamline pattern for the initial conditions used in the model at 00 UTC June 24 1979 obtained from FGGE data.

Simulated wind speed near surface for the N-case at 48 h is shown in Figure 4 a and corresponding values for the W1-case is shown in Figure 4 b. In the N-case wind surge is located over the central Arabian Sea with a maximum of 16.5 m/s With a warmer uniform temperature of 31°C over the oceans, maximum winds ove the Arabian Sea increases to about 20 m/s. The SST of 31°C is large as compared to climatological value of SST for June, by about 3°C over the eastern Arabian Sea an about 5°C over the upwelling areas offshore of the African coast. Further increase o the SST to 35°C (W2-case), an extreme value, does not appear to increase the winds appreciably as can be seen in Figure 4 c. Maximum winds are about 20.3 m/s. Two

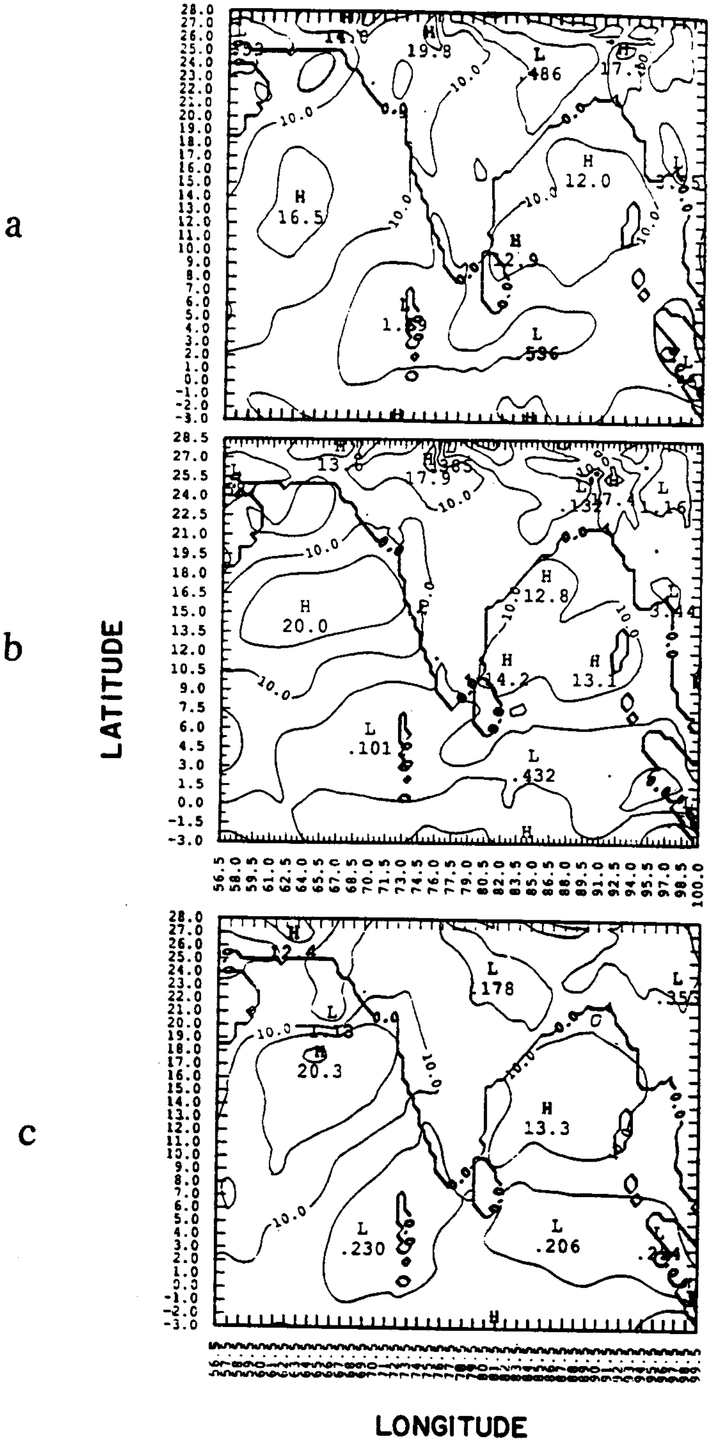

Fig. 4. Simulated wind speed near surface at 48 hours for (a) the N-case, (b) the W1-case, and (c)W2-case.

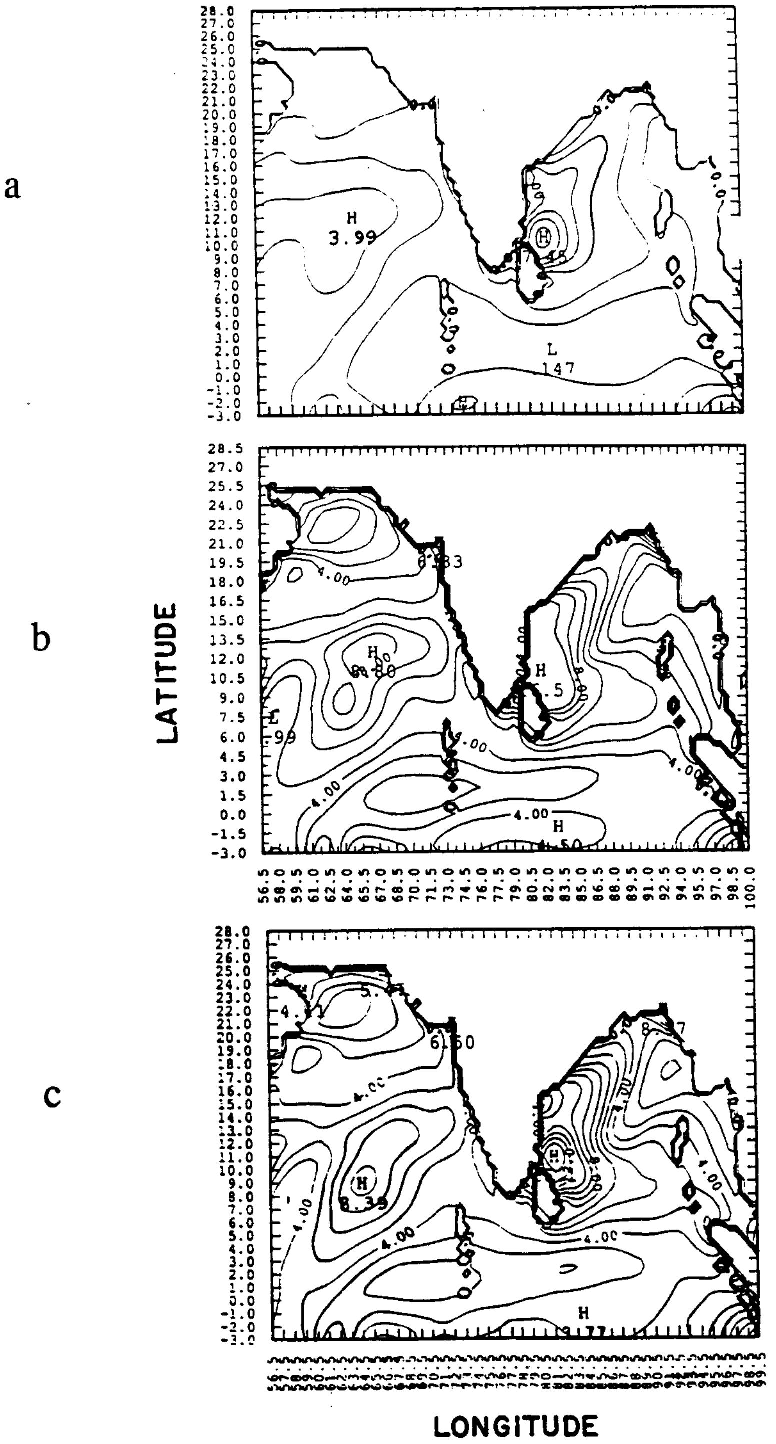

Fig. 5. Cumulative evaporation during the second day of simulation (mm/day) for (a) the N-case, (b) the W1-case, and (c)W2-case.

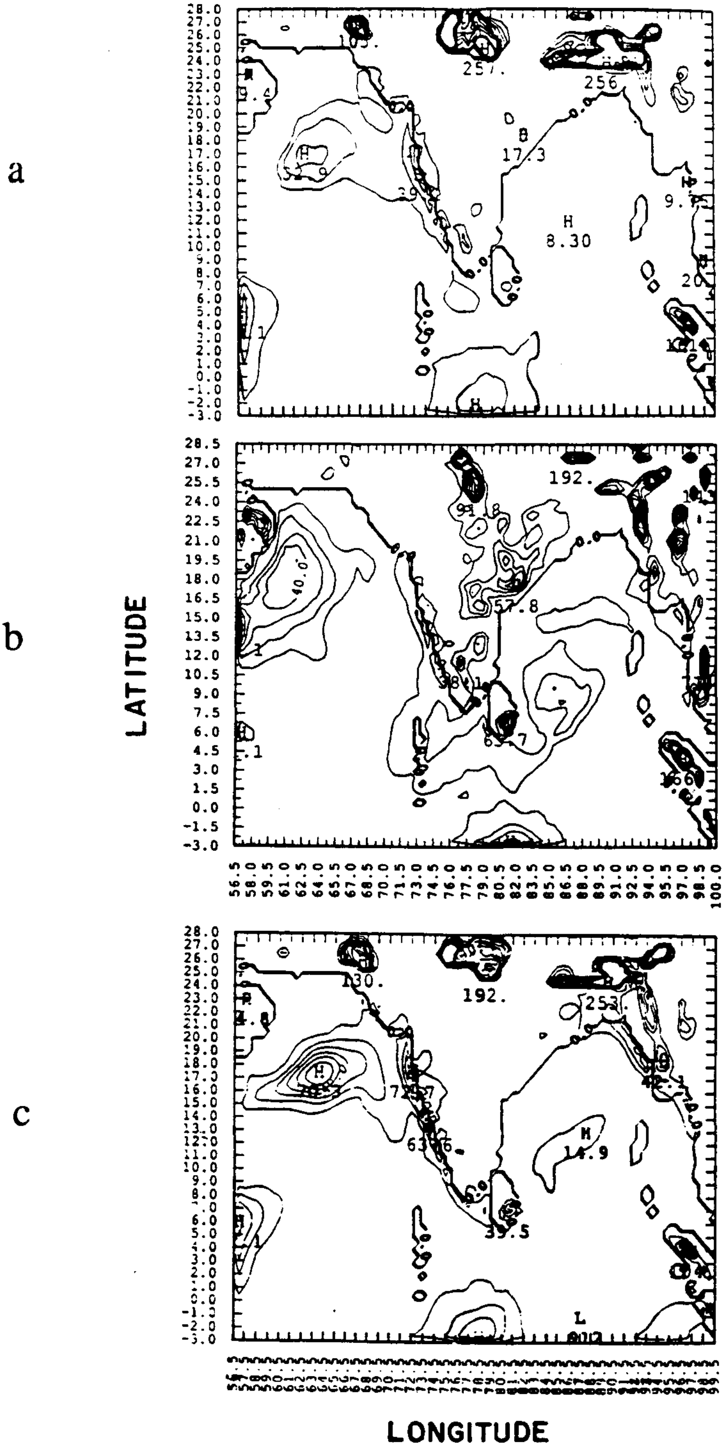

Fig. 6. Predicted rainfall (mm/day) during the second day of simulation for (a) the N-case, (b) the W1-case, and (c)W2-case.

significant results are apparent. First, an increase in the SST produces larger winds in the surge, possibly due to an increase in convection which can influence the dynamics of the monsoon through larger latent heat release and land-ocean interactions along the African coast. Further increase in the SST does not seem to have an effect on the wind pattern which suggests an optimum sea surface temperature at which air-sea interaction processes reach an equilibrium condition and further increase produces little effect. Horizontal extent of the wind surge is also larger in W1- case and W2-case over the Arabian Sea. The observed wind maximum is about 15 m/s and the pattern of the wind distribution in the N-case is closer to the observation. In general, the winds are stronger for the warmer SST over the Arabian Sea and the Bay of Bengal. A major difference is the wind distribution over the northern part of India. Winds are stronger for the N-case and became weaker for the W1-case and W2-case. This is probably due to the decrease in the land-sea temperature difference for the warmer SST.

Figures 5 a, b and c show the cumulative evaporation during the second day of simulation (mm/day) for the N-case, W1-case and W2- case respectively. As expected, evaporation is larger in the W1- case and W2-case. Over the Arabian Sea, maximum accumulated evaporation in the N-case is 3.99 mm/day and it is 8.0 and 8.39 mm/day for the W1-case and W2-case respectively. Warmer SST of 31 C almost doubled evaporation although further increase did not produce an appreciable increase in evaporation. In the W1-case there is a region of high evaporation over the central Arabian Sea (Fig. 5 b) which is absent in W2-case (Fig. 5 c). Over the Bay of Bengal close to the east coast of the India evaporation is about 3 times higher in the W1-case and W2-case than in the N- case. Maximum difference in the sea surface temperatures over the domain among the three cases over the Arabain Sea is about 9°C. This lead to an increase in evaporation by a factor of two over the Arabian Sea region. Even though the SST magnitude and distribution are quite different among the three cases there is some similarity in the evaporation pattern probably due to the identical initial air temperature pattern. Warmer SST (31°C) does produce stronger horizontal gradients in evaporation as compared to the normal SST distribution (Fig. 5 a).

Figures 6 a, b and c show the predicted rainfall (mm/day) during the second day of simulation for the N-case, W1-case and W2-case respectively. In the W1-case and W2-case stronger winds leads to larger evaporation over the Arabian Sea resulting in higher rainfall upwind of the Western Ghat mountains (Fig. 6 b, c). In the N-case predicted rianfall over Western Ghats region is about 39.2 mm/day but in the W1-case it is about 65.5 mm/day. Stronger winds and increase in the moisture flux from the surface resulted in larger rainfall rates in the W1-case. Though in the W2-case relatively warmer SST (4 C warmer) is used, slightly higher rainfall rate over the oceanic region and lesser over the continental region is predicted than in the W1-csae. Over the Arabian Sea predicted rainfall rate in the N-case is about 32.9 mm/day and in the W1-case and W2-case it is about 69.8 and 70.3 mm/day respectively. Thus rainfall rates are about 2 times higher for the warmer SST (W1 and W2 cases). This increase is consistent with the variation in evaporation rates over this region. Increased evaporation over the Bay of Bengal in W1-case and W2- case produced increased precipitation. Large rainfall rates are predicted in all cases over northern parts of the domain where the topography is steep. Since the model is unable to resolve these mountenous regions, the predicted rainfall over these regions is probably more numerical than physical. Further smoothening of the topography over the steep mountenous areas and inclusion of diurnal variation of the land surface temperature may alleviate these spurious amounts of rainfall.

CONCLUSIONS

Sea surface temperature is found to be an important parameter in the dynamics and the thermodynamics of the monsoon flow. Increase in SST affects the monsoon processes differently over the ocean and over the land. There is an increase in evaporation over the Arabian Sea and the Bay of Bengal caused by an increase in the near surface wind speeds. Wind surges over the Arabian Sea get intensified and occupy a larger area for warmer SSTs. This increases the evaporation and orographically induced convection over the Arabian Sea leading to increased precipitation. But there appears to be a critical SST beyond which winds do not intensify further and precipitation does not increase and this needs to be investigated further. Over land, differences in the rainfall are possibly caused by smaller land-sea temperature contrast and the change in the track of the monsoon depression. This problem needs to be looked at using a model with better resolution in the planetary boundary layer. A coupled ocean- atmosphere model will be the most appropriate one to include the effects of the upwelling and other feedback processes.

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