On the origin of Monsoon: Conventional theory vs. new findings

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1. Introduction

Monsoon, the sudden arrival of rainy season after months of hot dry weather has been an age-old puzzle in meteorology. It has been believed for centuries that continental-scale land-sea contrast is the main reason for monsoon since the time of Halley (1686; e.g., Wallace and Hobbs 1977, which was adopted by Holton 1992; Webster et al. 1998), although some authors (e.g., Chao and Chen 2001) challenged this view and argued that the existence of land is not a necessary condition for the presence of monsoon. Basic idea of this paper is to scrutinize the long held fundamental idea about the origin of monsoon. The main mechanism of this conventional idea about monsoon is that in summer the thermal heating of the continent gives rise to a continental scale thermal low (figure 0) and surrounding this low the low level wind blows from southwest. This low level inflow

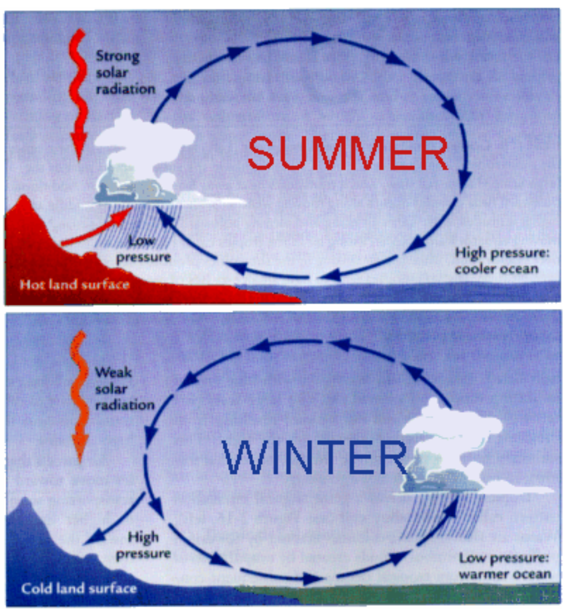

Figure0. Conventional mechanism of monsoon circulation.

creates a convergence of moisture and cumulus convection occurs. On the other hand, during winter the radiative cooling gives rise to continental-scale thermal high and surrounding this high the low-level wind is from northeast. This leads to divergence of dry air.

There is no doubt that the continental scale land-sea thermal contrast exists. But it not has been tested in numerical experiments whether it really acts as the main driving force of the monsoon. So it is very important to know the answer of this age-old puzzle. In this project there will be some paper review supporting and arguing about this experimental result. The main paper reviewed is Chao and Chen 2001.

2. Method:

Through general circulation model experiments Winstone Chao and Baode Chen (Chao et all 2001) demonstrate that this belief should be changed. The Asian and Australian summer monsoon circulations are largely intact in an experiment in which Asia, maritime continent, and Australia are replaced by ocean. It is also shown that the change resulting from such replacement is in general due more to the removal of topography than to the removal of land-sea contrast. Therefore, land-sea contrast plays only a minor modifying role in Asian and Australian summer monsoons. This also happens to the Central American summer monsoon. However, the same thing cannot be said of the African and South American summer monsoons. In Asian and Australian winter monsoons land-sea contrast also plays only a minor role. Their interpretation for the origin of monsoon is that the summer monsoon is the result of ITCZ's (Intertropical Convergence Zones) peak being substantially (more than 10 degrees) away from the equator. In their paper the origin of the ITCZ explains the monsoon circulation. The longitudinal location of the ITCZ's is determined by the distribution of surface conditions. ITCZ's favor locations of high SST as in western Pacific and Indian Ocean, or tropical landmass, due to land-sea contrast, as in tropical Africa and South America. Thus, they argued that the role of landmass in the origin of monsoon can be replaced by ocean of sufficiently high SST. Furthermore, the ITCZ circulation extends into the tropics in the other hemisphere to give rise to the winter monsoon circulation there. Also through the equivalence of land and-sea contrast and high SST, it is argued that the basic monsoon onset mechanism proposed by Chao is valid for all monsoons.

2. Model and experiments

In the experiment carried by Chao and Chen 2001, the Goddard Earth Observing System General circulation model (version 2) is used. This is a model of 4^0 lat x 5^0 long grid size and has 20 vertical levels with 4 levels below 850 hpa. There are several different parameterization is used in this model. But the most important one which makes this model very significant is the convectional scheme. The relaxed Akawa- Schubert scheme (RAS) is a main feature of this model.

1 January 1987 reanalysis of European Center for Medium-Range Weather Forecast is used for the initial condition of the model. The model was run for 4 years with observed boundary condition including observed SST. Only the last 3 years run is used for analysis.

Figure 1 show the control run of this model which shows that the model simulates Australian and Asian summer monsoon pretty well.

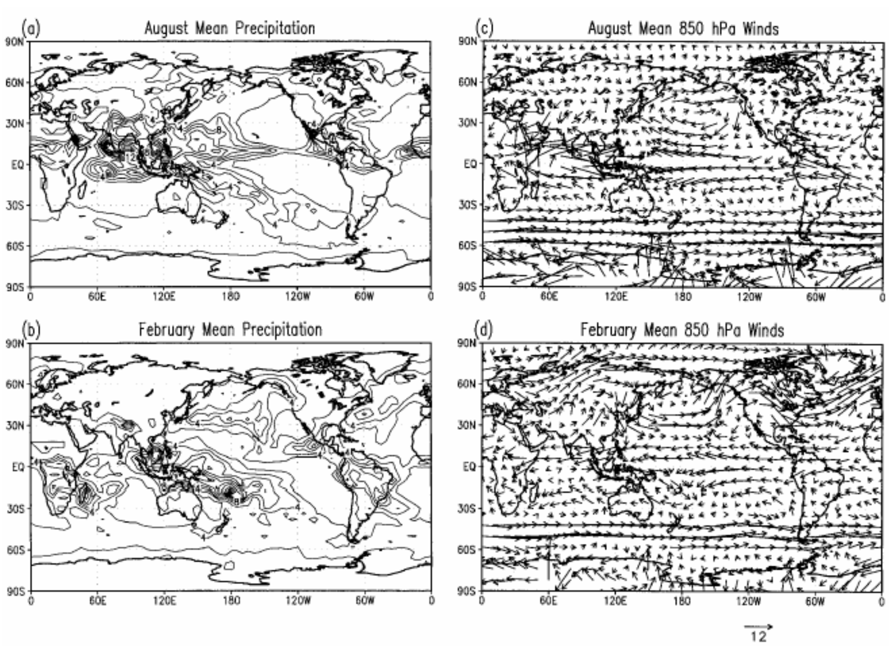

FIG. 1. (a) Aug and (b) Feb precipitation and (c) Aug and (d) Feb 850-hPa winds averaged over last 3 yr of the control run.

After the control run an experiment E1 was carried with all land grid between 60^0E and 180 replaced by ocean and the SST of each affected grid is specified as that of the first grid on its east side that is an ocean grid in the control.

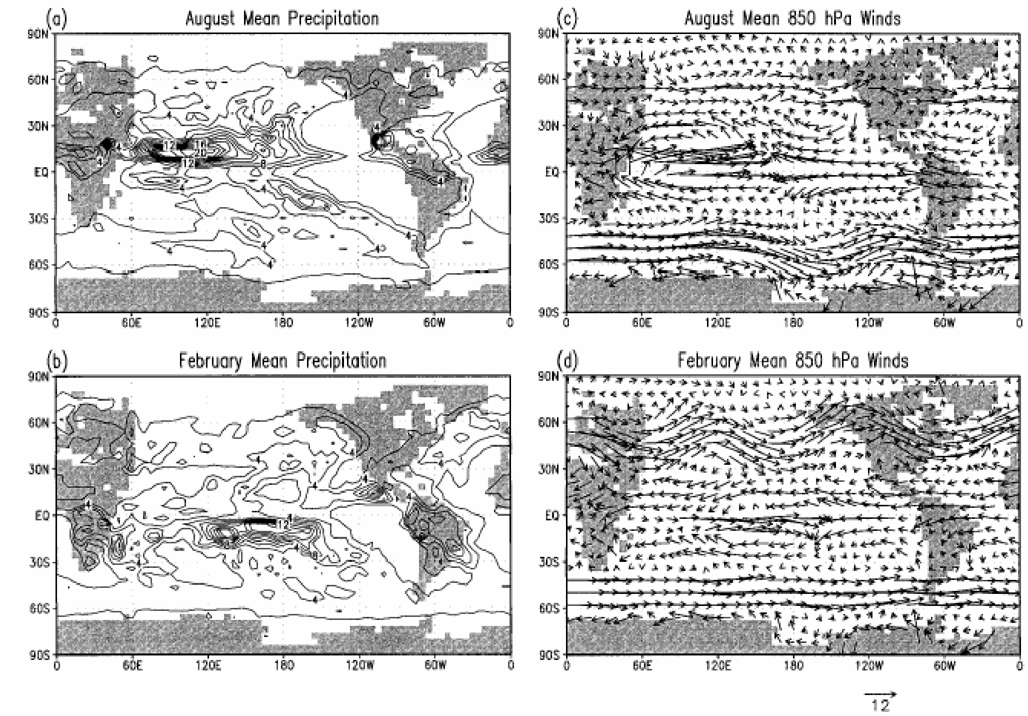

FIG. 2. Same as Fig. 1 but for the experiment where Asia, the maritime continent, and Australia are replaced by ocean.

Figures 2a and 2c show the August rainfall and 850 hpa wind arrows of E1 averaged over the last 3 years. August ppt reduced in southern Indian Ocean. The ITCZ or the rainy region associated with Asian summer monsoon clearly exists in E1.Precipitation region does not extend as far to the north as in the control run. High ppt in the Arabian sea and Bay of Bengal lessens. ppt patterns in Indian ocean and western pacific becomes more zonally uniform. The ITCZ and the associated circulations exist in the southern hemisphere. Asian landmass is not a necessary condition for Indian monsoon and the associated ITCZ.

In experiment E1 the removal of landmass removes both land-sea contrast and topography. So see their individual effects and experiment E2 is performed where all grids changed in E1 remains land grid except the topography is reduced to zero. Figure 3 shows the result of this simulation.

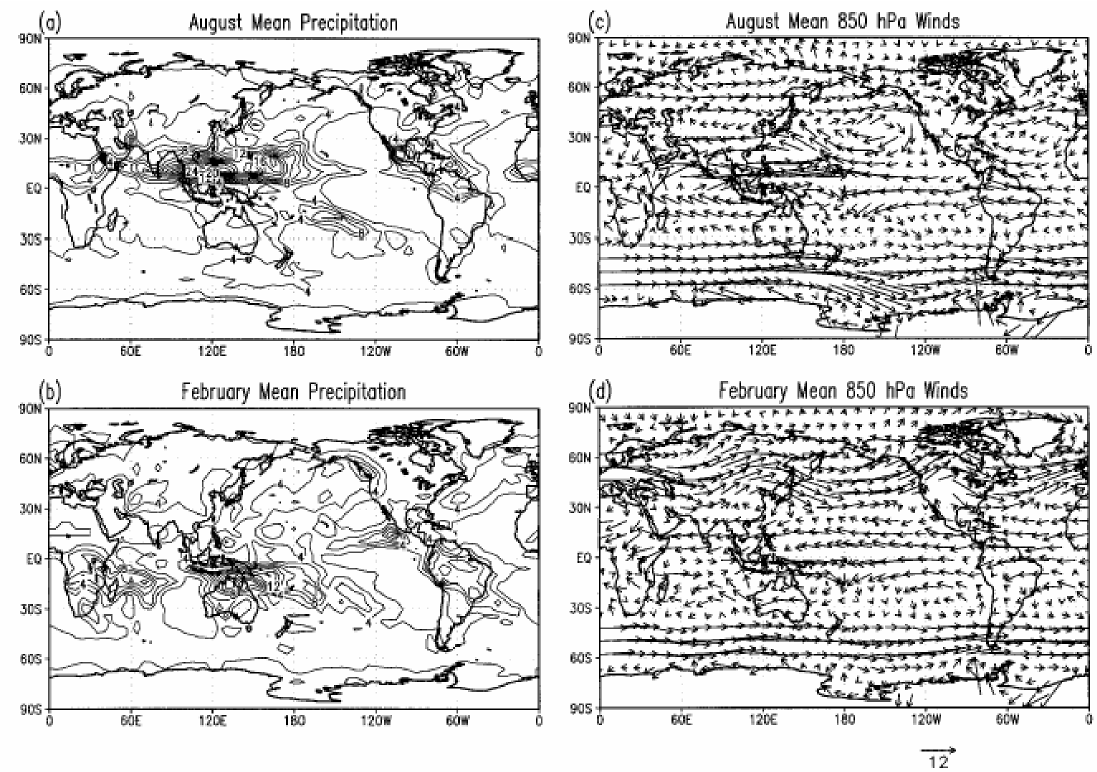

FIG. 3. Same as Fig. 1 but for the experiment where the topography of Asia, the maritime continent, and Australia is reduced to 0.

Ppt field in Indian Ocean and western pacific still exists. Shifted eastward. Westerlies associated with ITCZ shifted eastward changing fromE1 to E2. August ppt further reduced. Easterly regions at low level over Tibet and china extended further eastward. Effect of topography is more than the effect of land-sea contrast in most areas. Features of Asian winter monsoon exist in both E1 and E2. Thus the results shows that the effect of removing Asian landmass is due much more to the removal of topography than removal of land-sea contrast.

It has been shown that a basic feature of monsoon is in Indian summer monsoon regions upper topospheric meridional temperature gradient south of Tibetan plateau reversed (Flohn 1975; He et al.1987, Yanai et al. 1992). Figure 4 shows the result of August 200-500 hpa mass-weighted average temperature for control, E1 and E2.

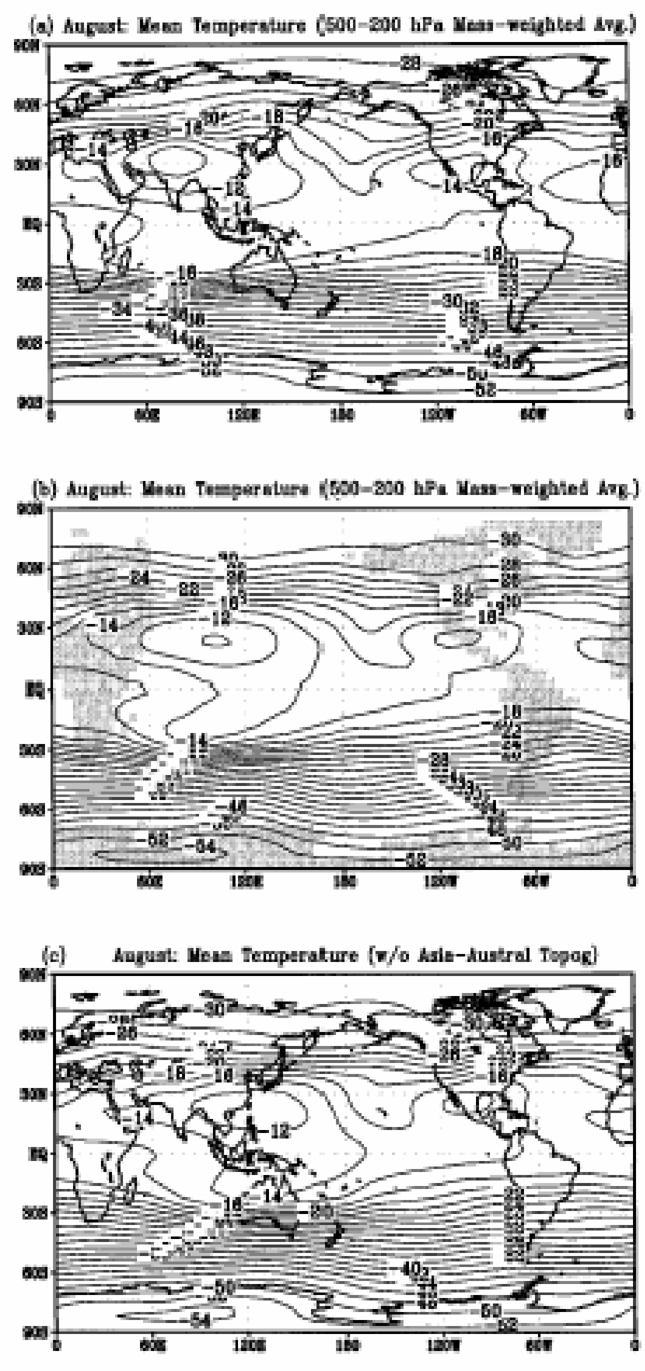

FIG. 4. Aug 200–500-hPa mass-weighted average temperature for (a) control, (b) E1, and (c) E2 averaged over the last 3 yr.

All three simulations have such temperature gradient. Maximum is over Tibetan plateau. Maximum moves eastward and equator ward in E1. Moves further eastward in E2. Can conclude that heating of Tibetan Plateau is not a necessary condition for such a reversal. Other experiments similar to E2 when removing the landmass of

Americas shows that August ppt remains in central America but reduced over Mexico. February ppt region in South America disappears. ppt regions in eastern pacific enhanced. The experiment with removal of topography in America shows that both August and February the results in this case are similar as the control. Can conclude, land-sea contrast plays a major role in the South American monsoon but not in the central American monsoon. For the Mexican monsoon both topography and land-sea contrast appear to be important.

The difference in model simulation can be due to the topography in the model. Better resolved in Asian continent. Not well resolved in Central America and Mexico. The impact of topography in Central America and Mexican monsoon should be studied with a musicale model. Same thing can probably true for the monsoon of Africa and South America. The results in case of removal of African landmass and topography show that land-sea contrast plays a major role in African monsoon. ppt in the location of Africa disappears in removal of African landmass. ppt in the Asian and Central American location increases. But the African monsoon reappears when the landmass of Africa is replaces by ocean of sufficiently high SST. Thus the role of land-sea contrast, when important can be replaced by sufficiently high SST.

To summarize the results it is shown that Land-sea contrast plays a minor role in monsoons in Asia (including India), Australia and Central America. Plays an important role in monsoons in Africa (excluding southern Africa), south America and Mexico. The role of land-sea contrast, when important, can be replaced by ocean of sufficiently high SST. The conventional interpretation for the origin of monsoon which depicts land-sea contrast on the continental-scale as the main cause is problematic.

3. Monsoon as off-equator ITCZ and its associated circulation

Monsoon is off-equator ITCZ and its associated circulation. A monsoon is in a time mean sense (say, monthly) a continental-size convective system in the tropics. It is also a predominate southwesterly flow at the low levels converging towards the continental-scale precipitation region. At the upper level the wind direction reverse, northeasterly. Large vertical wind shear exists, not found elsewhere in the tropics. A monsoon contains a sizeable ppt area and its associated circulation field. Chao's experiment with aqua planet setting with constant solar zenith angle and with uniform SSt wit RAS shows the monsoon features. Numerical experiment with such setting shows doubling of ITCZ, one is at around 150 away from the equator. This experiment clearly shows characteristics of monsoon circulation i.e., southwesterly at low-levels converging towards the ppt area and large vertical wind shear in monsoon area. So it can be concluded that earth's rotation itself is sufficient to generate monsoon.

4. Summary

To summarize the paper it can be found that monsoon is interpreted as circulation associated with ITCZ substantially away (more than 100)from the equator. The existence of ITCZ and therefore monsoon does not rely on land-sea contrast. Land-sea contrast can only provide a favorable longitudinal location of ITCZ.

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