MODULATIONS OF THE INDIAN SUMMER MONSOON BY THE HOT SUBTROPICAL DESERTS: INSIGHTS FROM COUPLED EXPERIMENTS

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I. BACKGROUND, MOTIVATION AND SCIENTIFIC RATIONALE

❑ During boreal summer, the South Asian monsoon (i.e. Indian summer monsoon; ISM) and subtropical deserts coexist as twins over the subtropical latitudes of African-Asian continent.

❑ Previous studies have tried to explain the mutual relationships between these two very different climates (e.g. Rodwell and Hoskins 1996, 2001; Tyrlis et al. 2013; Cherchi et al. 2014. ...).

❑The recent model based studies show interestingly a significant relationship between the monsoon rainfall biases and surface temperature, albedo and humidity biases over the adjacent subtropical deserts in current state-of-the-art climate models (Samson et al. 2016; Agrawal and Chakraborty 2016; Terray et al. 2017).

❑In short, these studies collectively demonstrate that the changes of surface heating over the hot subtropical desert can affect the ISM.

❑ Moreover, the desert amplification over NH subtropics during boreal summer is one of the main modes of surface temperature warming associated with anthropogenic climate change (Zhou 2016; Wei et al. 2017).

❑These considerations motivate our re-examination of the ISM-desert paradigm and so this study aims to unravel new facets on the role of the hot subtropical desert on ISM.

❑Here, we seek to revisit this ISM-desert paradigm using a coupled modeling framework by imposing different sets of surface land albedo over the hot subtropical desert to the west of the South Asian domain in an ocean-atmosphere coupled model.

II. DATA AND MODELS

❖Observational and reanalysis data sets

➔ERA-interim reanalysis (Dee et al. 2011)

➔GPCP Rainfall (Huffman et al. 2008)

➔CERES-EBAF (Kato et al. 2013) surface and TOA radiative fluxes from Clouds and Earth's Radiant Energy System (CERES); Energy Balance and Filled (EBAF) top-of-the atmosphere and surface fluxes version 2.8; Kato et al. 2013)

❖ Coupled models:

➔Long control experiments and a large set of sensitivity experiments with two high resolution global coupled models: The SINTEX-F2 (Masson et al. 2012) and the CFSv2 (Saha et al. 2014). Both models are extensively used for seasonal forecasts in Japan, India and the US. SINTEX is also included in CMIP5.

➔CFSv2 is used mainly for checking robustness of the results using as an independent coupled model.

❖ Details of coupled model experiments performed

Experiment name	Length of integration (years)	Experimental setup
CTRL	110	Control experiment using background snow-free broadband shortwave albedo prescribed from MODIS products (Terray et al. 2017)
Desert_m20	60	Similar to CTRL with the exception that the background land MODIS albedo has been artificially decreased by -20% over the hot subtropical desert (15°-40°N, 20°W-75°E)
Desert_p20	60	Same as Desert_m20, but with an increase in background albedo of +20% over the hot subtropical desert (15°-40°N, 20°W-75°E)
Desert_Arab_m20	60	Similar to CTRL, but with a decrease in background albedo of -20% over the Arabia and Middle-East deserts only (15°-40°N, 35°E-75°E)
Desert_Arab_p20	60	Same as Desert_Arab_m20, but with an increase in background albedo of +20% over the Arabia and Middle-East deserts (15°-40°N, 35°E-75°E)
Desert_Sahara_m20	60	Similar to CTRL, but with a decrease in background albedo of -20% over the Sahara desert only (15°-40°N, 20°W-35°E)
Desert_Sahara_p20	60	Same as Desert_Sahara_m20, but with an increase in background albedo of +20% over the Sahara desert (15°-40°N, 20°W-35°E)

III. RESULTS AND DISCUSSIONS

A. ISM RESPONSE TO ARTIFICIAL DECREASE IN SURFACE ALBEDO OVER THE HOT SUBTROPICAL DESERT

❑ Darkening the surface of the deserts and arid regions to the west of the South Asian domain leads to an increase in radiative heating of the surface over there.

❑ Interestingly, this additional heating is not solely due to the surface's albedo direct effect on solar absorption, but also to an increase of the net long-wave radiation budget.

❑This suggests the existence of a positive feedback amplifying the original surface warming due solely from the surface albedo perturbation.

❑ This excess (or reduced loss) of energy over the deserts leads to modifications of the energy budget over the ISM region and an increase of ISM rainfall in Desert_m20 or Desert_Arab_m20

❑ Both the experiments show an early ISM onset with a well-organized rainfall band between 5º-15ºN occurring as soon as in May. The ITCZ has already moved to the north in May itself, thus occupying the eastern Arabian Sea and then extending to BoB region.

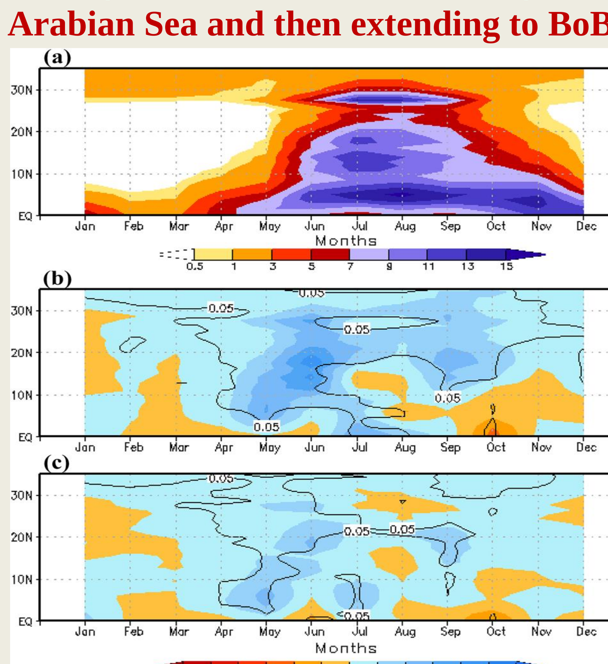

Figure 1: (a) Rainfall evolution along 70º-90ºE from CTRL. In (b) and (c), anomalous rainfall response along 70º-90ºE (against the CTRL) from Desert_m20 and from Desert_Arab_m20, respectively. In (b) and (c), significant responses above the 95% confidence level are encircled (estimated through a permutation test).

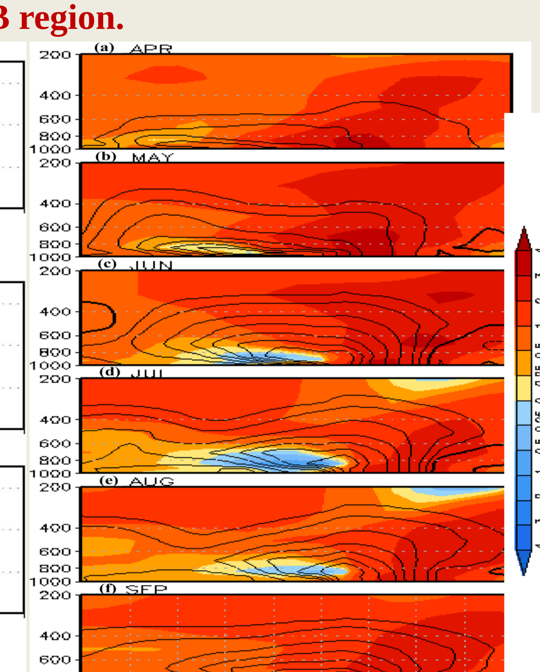

Figure 2: Time evolution of response in temperature (shading, Deg C) and specific humidity (contours, x 10^{-3} Kg Kg^{-1}) along a pressure-latitude plane over the longitudes 55º-75ºE, for Desert_m20 experiment.

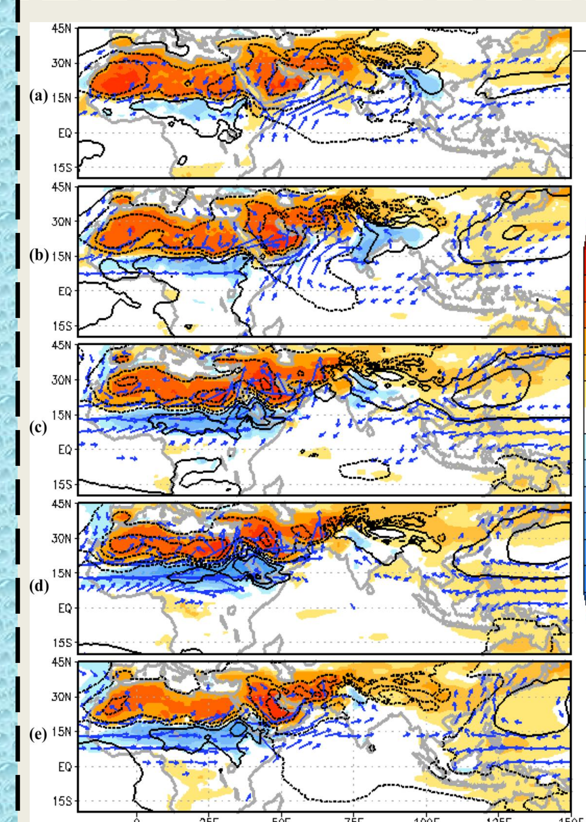

Figure 3: Evolution (May to September) of response in MSLP (contours, hPa), TS (shading, Deg C) and 850-hPa wind (ms^{-1}) from Desert_m20. Wind vectors of magnitudes exceeding 1 ms^{-1} are only drawn.

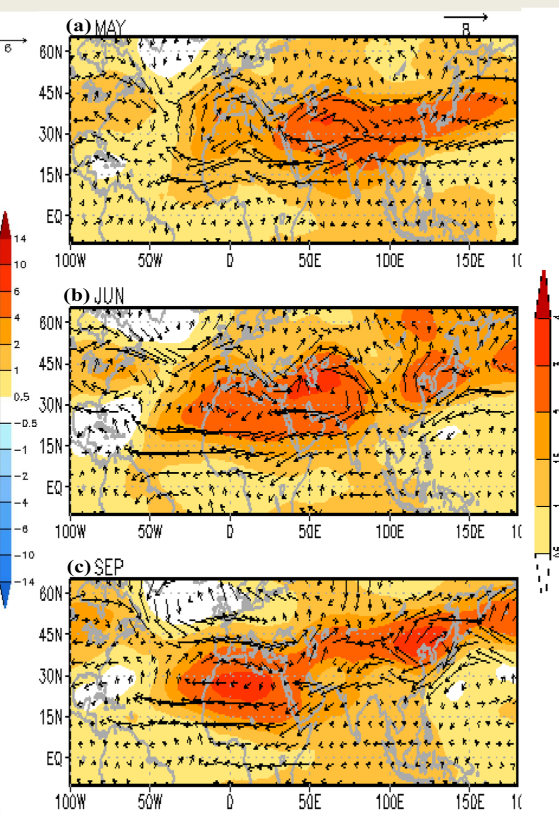

Figure 4: Map of the anomalous responses in wind and temperature at 300-hPa for (a) May, (b) June and (c) September, from Desert_m20 experiments. The anomalous response is against the CTRL climatology.

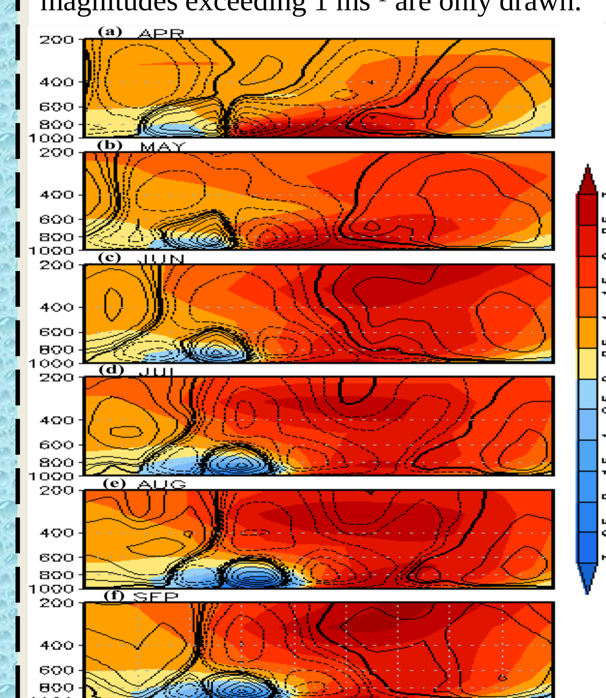

Figure 5: Time evolution of response in temperature (shading, Deg C) and vertical component of velocity (contours, units is 10^{-2} Pa s^{-1}) along a pressure-latitude plane averaged over the longitudes 20ºW-30ºE, for Desert_m20

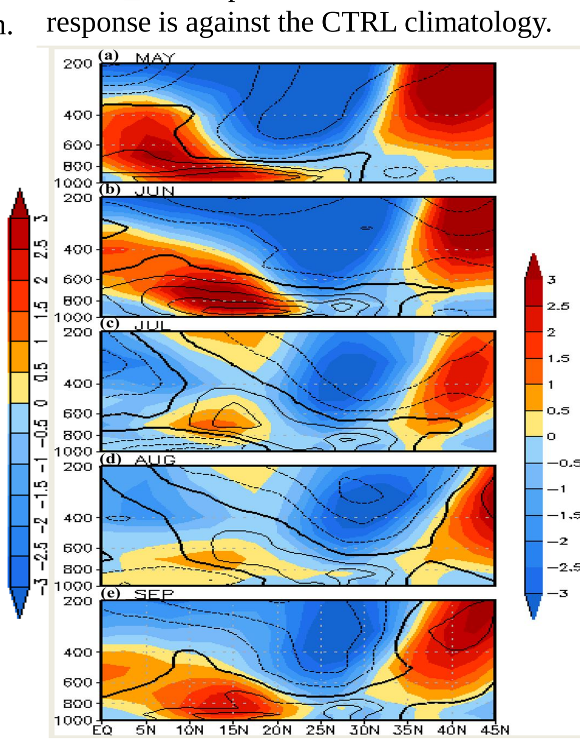

Figure 6: Time evolution of response in horizontal component of wind (zonal wind in shading and meridional wind in contours, ms^{-1}) along a pressure-latitude plane averaged over the longitudes 55-75ºE, for Desert_m20

✓The tropospheric warming over desert generates a baroclinic atmospheric response with cyclonic (anticyclonic) wind anomalies in the surface (middle and upper troposphere).

✓This tropospheric warming results also in warmer upper and middle troposphere over the northern latitudes of the Indian subcontinent due to warm advection by the STJ in the upper troposphere.

✓This leads to an increased MTTG over the South Asian domain, which favors a strengthening of the easterly vertical wind shear during the first and last phases of ISM.

B. ISM RESPONSE TO ARTIFICIAL INCREASE IN SURFACE ALBEDO OVER THE HOT SUBTROPICAL DESERT

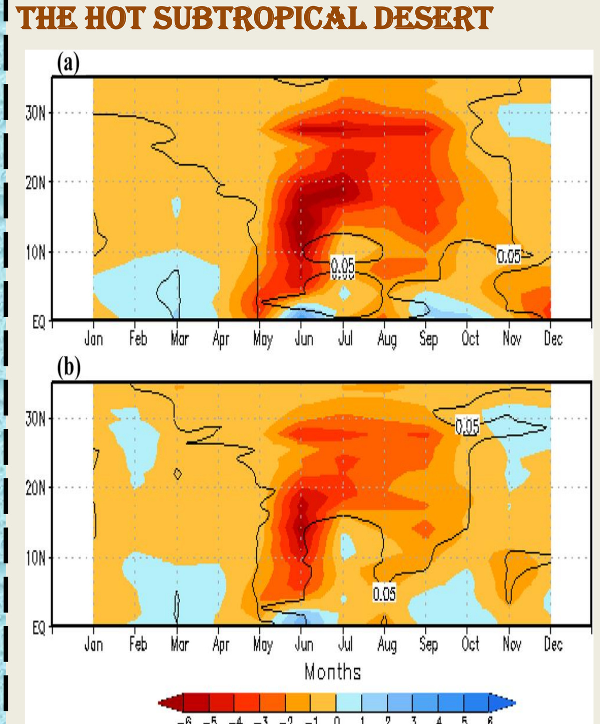

Figure 7: (a) and (b), anomalous rainfall response along 70º-90ºE (against the CTRL) from Desert_p20 and from Desert_Arab_p20, respectively. Significant responses above the 95% confidence level are encircled.

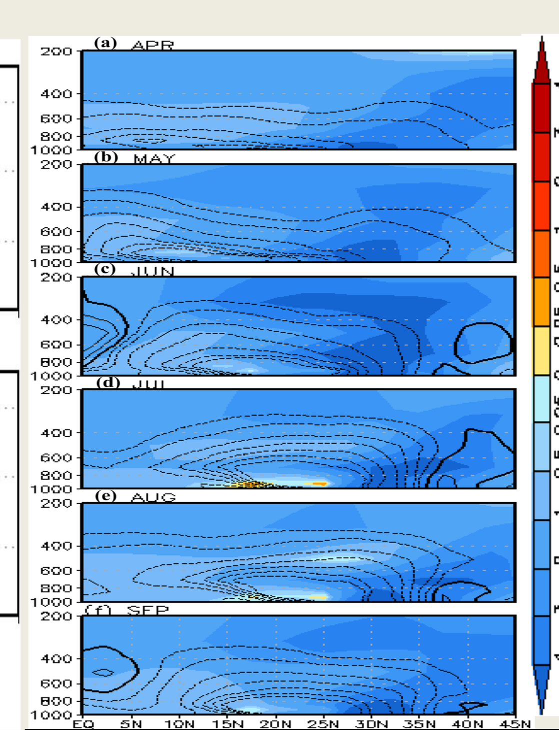

Figure 8: Time evolution of response in temperature (shading, Deg C) and specific humidity (contours, x 10^{-3} Kg Kg^{-1}) along a pressure-latitude plane averaged over the longitudes 55º-75ºE, for Desert_p20 experiment.

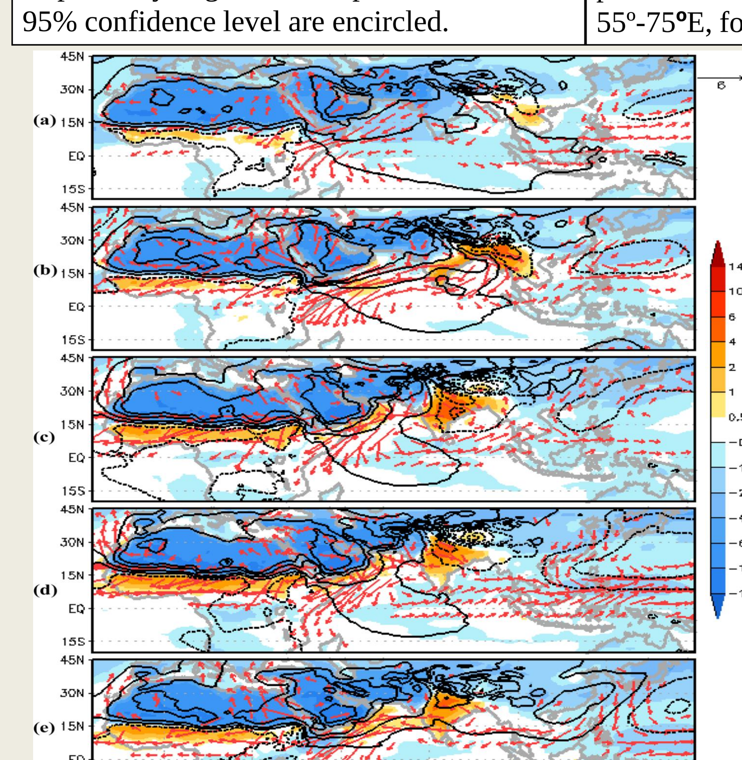

Figure 9: Time evolution of response in MSLP (contours, hPa), TS (shading, Deg C) and 850-hPa wind (ms^{-1}) from Desert_p20. Negative (dashed) and positive (continuous) contours correspond respectively to magnitudes of 0.5, 1.5, 3, 4 and 6 units. Wind vectors of magnitudes exceeding 1 ms^{-1} are only drawn.

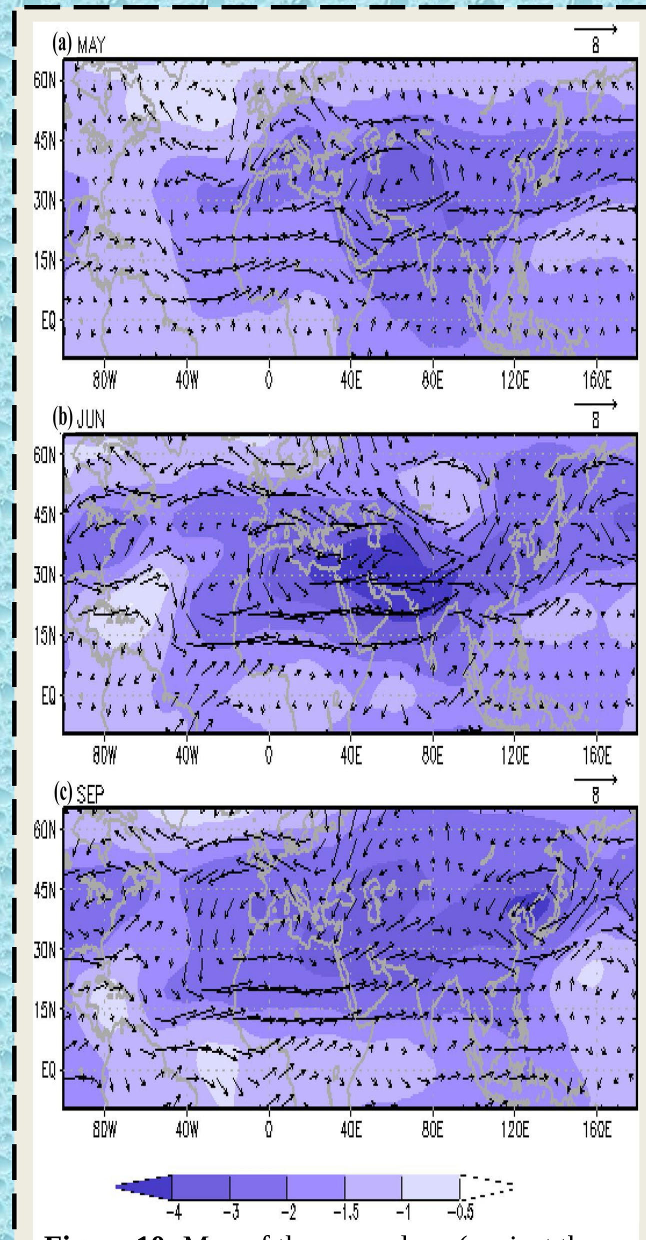

Figure 10: Map of the anomalous (against the CTRL climatology) responses in wind and temperature at 300-hPa for (a) May, (b) June and (c) September, from Desert_p20 experiments.

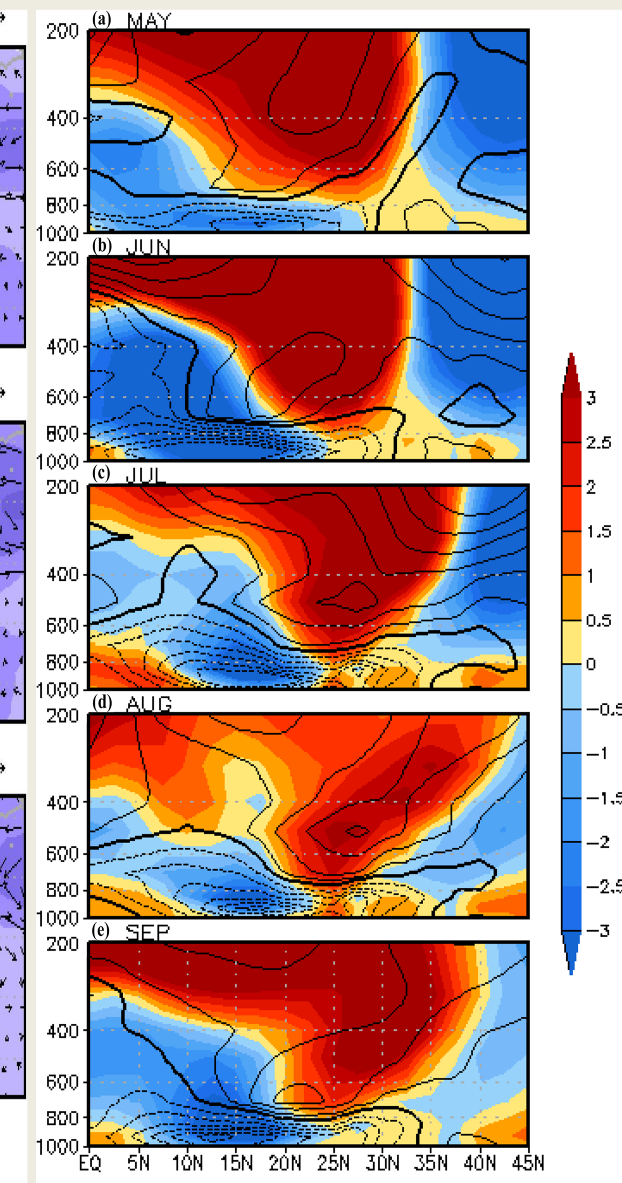

Figure 11: Time evolution of response in wind (zonal wind in shading and meridional wind in contours, ms^{-1}) along a pressure-latitude plane averaged over the longitudes 55-75ºE, for Desert_p20

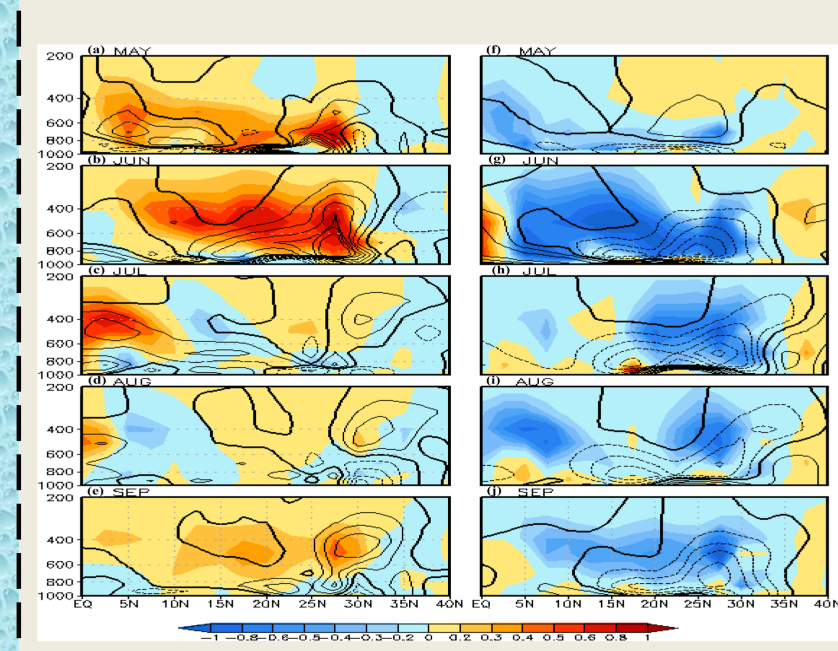

Figure 12: (Left Panel, a-e) Seasonal evolution (May to September) of response in vertical moisture advection (shading, units is 10^{-3} Kg Kg^{-1} day^{-1}) and horizontal moisture advection (contours, x10^{-3} Kg Kg^{-1} day^{-1}) along a pressure-latitude plane over the longitudes 75º-90ºE, for Desert_m20 experiment. Right panel (f-j), same as (a-e), but for Desert_p20 experiment.

(C) ROBUSTNESS OF THE RESULTS

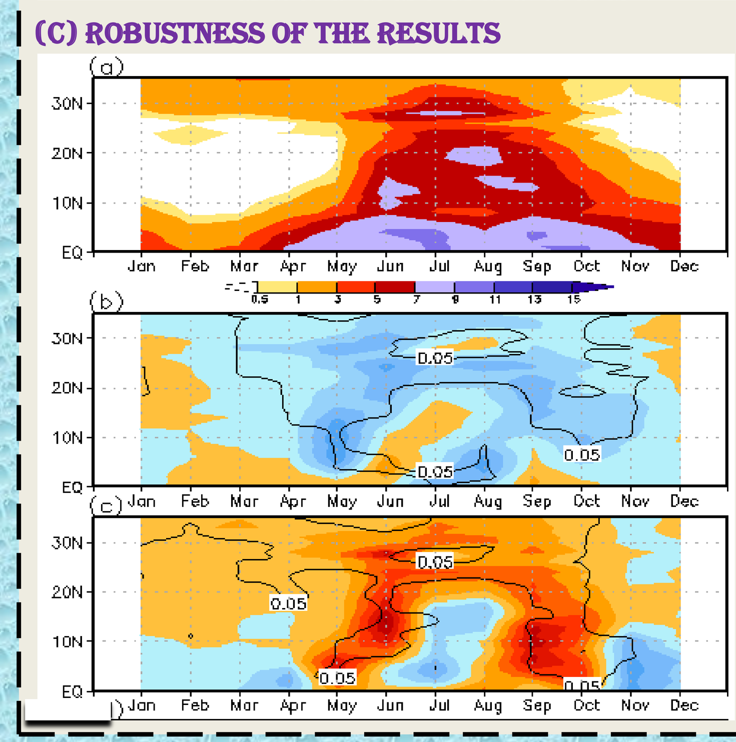

Figure 13: (a) Rainfall evolution along 70º-90ºE from CTRL. In (b) and (c), anomalous rainfall response along 70º-90ºE (against the CTRL) from Desert_m20 and from Desert_p20. CTRL, Desert_m20 and Desert_p20 runs, in this figure are conducted using CFSv2 coupled model (see Terray et al. 2017).

IV. SUMMARY OF THE RESULTS

✓ Our key finding is that the ISM evolution and intensity are significantly affected with opposite polarity to prescribed negative and positive albedo perturbations over the whole hot subtropical desert lying west of ISM.

✓The darkening of the deserts (negative albedo perturbations) leads to advancement of the ISM onset by one month, with a rapid northward propagation of the rainfall band over the Indian domain.

✓The positive albedo perturbations show non-linear response in ISM with significantly larger amplitude.

✓Insights from moisture budget show that the nonlinearity in advection moisture tendencies manifests in nonlinearity of the ISM response.

V. CONCLUDING REMARKS AND PERSPECTIVE

➔ Desert amplification, especially over Sahara and Arabia, is one of the main modes of global warming

➔The robustness of the relationship between the ISM and the neighboring deserts to its west found here hence suggests that these driest regions may play an increasingly significant role in the ISM evolution in the future climate through the modulation of their intense surface warming!

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For more details, see

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