# Understanding the regional anthropogenic signature in weakening of the south Asian Summer Monsoon

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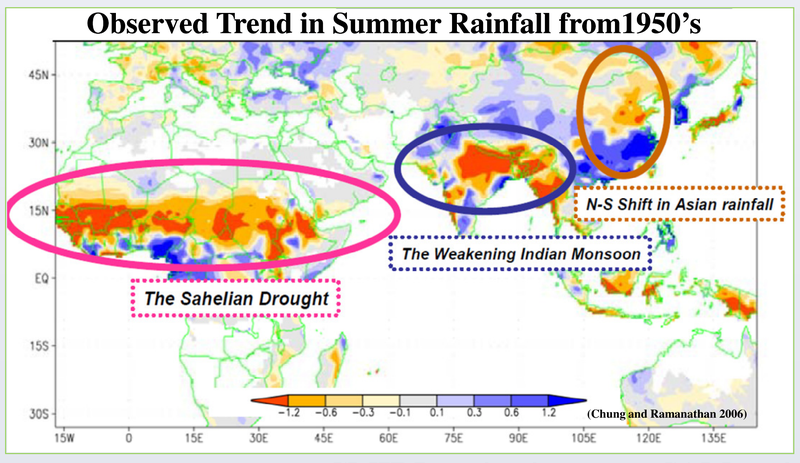
## ABSTRACT

The evidence from observation shows that South Asia underwent a widespread drying from the last five to six decades during the summer. The underlying reasons are unclear, whether this trend is due to natural or anthropogenic activities. Using a state-of-the-art global variable resolution climate model with high-resolution zooming over South-Asia, we decomposed the regional factors responsible for the weakening of monsoon circulation and rainfall. To address this issue we conducted several long simulations from 1886 to 2095, with and without anthropogenic forcing. The simulation provides key information about the regional responses to changes in south Asian summer monsoon (SAM), which leads to the decline in mean monsoon, and enhancement in the occurrence of localized extreme precipitation events in a warming climate. Further the 21st century climate projection using the same high-resolution model indicates persistent decrease of monsoonal rains due to land-atmosphere feedbacks in a warming environment. This would have severe impacts on agriculture, water resources and ecosystem over South Asia.

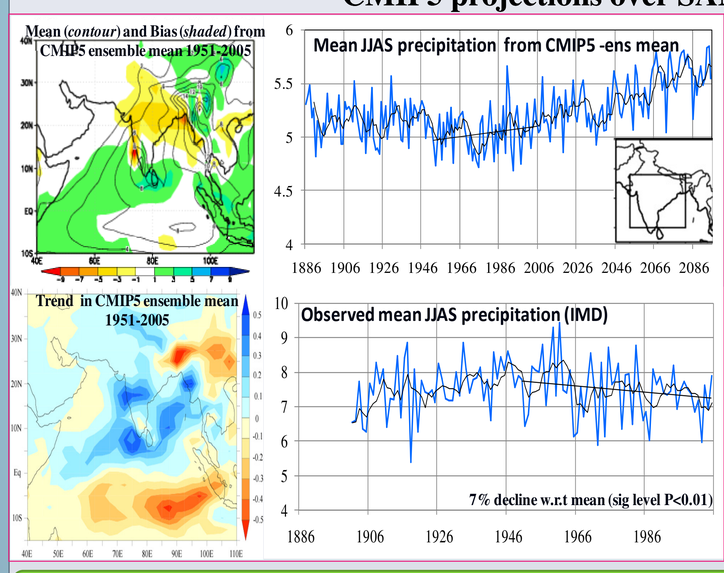
## BACKGROUND

### Observed Trend in Summer Rainfall from1950's




The observed linear trend shows widespread decrease in rainfall over the Indo Gangetic Plane (IGP) and mountainous west-coast. The increasing trend over southeastern China and adjoining areas is also observed. The prominent drought over the Sahel region is also evident from the decreasing trend.

### CMIP5 projections over SAM region



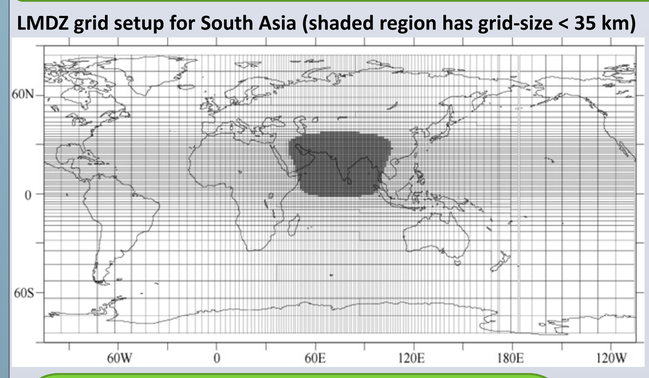

- ➢CMIP5 models shows significant dry bias over the subcontinent, more pronounced over Western Ghats and IGP.
- ➢CMIP5 Simulations fail to capture the decreaseing trend in SAM during the post-1950s
- ➢Thermodynamic effects predominantly reflectes in many CMIP5 simulations that enhance SAM precipitation in a warming climate despite weakening of large-scale circulation.
- ✓Rapid increase of atmospheric moisture → enhances precipitation
- ✓Increase in static-stability → weakens the large-scale circulation

This highlights the necessity of finer resolution models for

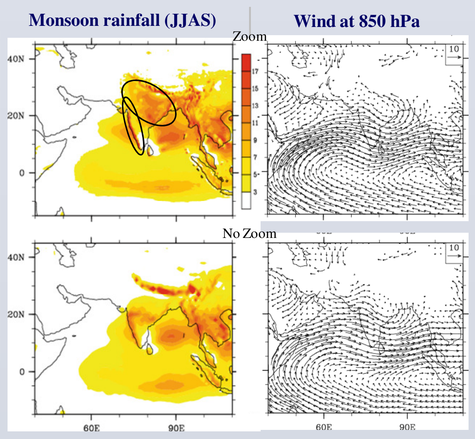
- ✓resolving the narrow orography of the western Ghats
- ✓a realist wind-precipitation feedback

**Thus we used a variable resolution global atmospheric model with a telescopic zooming over South Asia to understand the SAM hydro-climate**

### LMDZ grid setup for South Asia (shaded region has grid-size < 35 km)



Monsoon rainfall (JJAS) — Wind at 850 hPa




- ➢The LMDZ experiments realistically simulate the mean monsoon precipitation.
- ➢The high resolution leads to a realistic representation of the heavy orographic precipitation of Western Ghats and north-eastern India.
- ➢The zooming provides a key value-addition especially in terms of the observed coupling between wind and precipitation over the MT region.

*Hence we used this configuration for the long climate experiments to address the regional climate change issues associated with SAM*

## LMDZ Experiments

***Historical (1886-2005):***
*Includes natural and anthropogenic (GHG, aerosols, land cover etc) climate forcing during the historical period.*

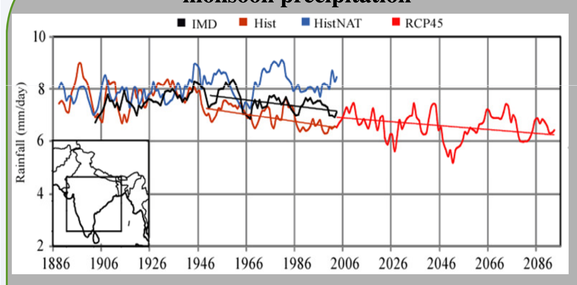
***Historical Natural (1886 – 2005):***
*Includes only natural climate forcing during the historical period.*

***GHG only (1950-2005)***
*Natural and GHG-only forcings. Land use and aerosol fields set to 1886 values.*

***RCP 4.5 (2006-2095):***
*Future projection includes both natural and anthropogenic forcing based on the IPCC AR5 RCP4.5 climate scenario. The evolution of GHG and anthropogenic aerosols in RCP 4.5 scenario produces a global radiative forcing of + 4.5 W m$^{-2}$ by 2100.*

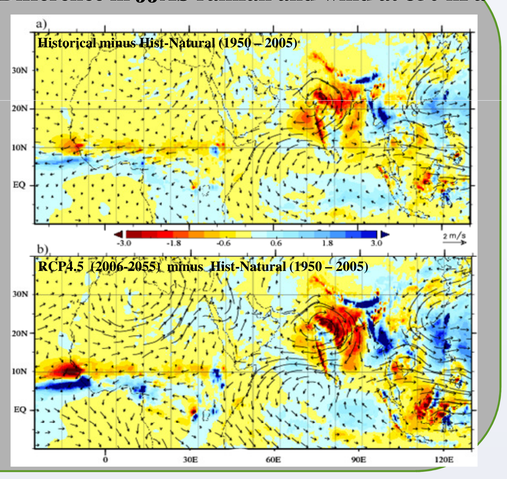
***Pre Industrial GHG (1950-2005)***
*Includes Natural variations, Aerosol forcing and Land-use change. The concentration of GHGs are set to 1886 values.*

### 5-year running mean of seasonal (JJAS) monsoon precipitation

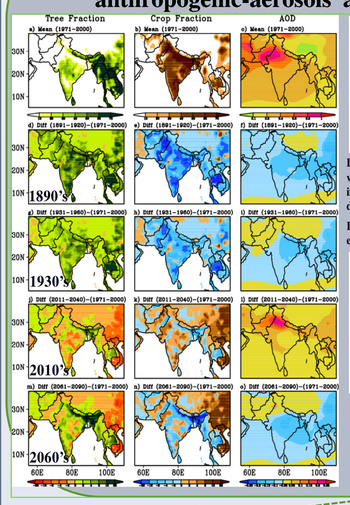


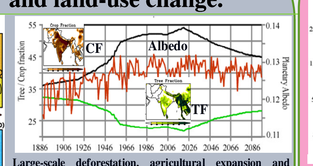

| | Rainfall trend | Mean rain | % change | P value |
|---|---|---|---|---|
| IMD dataset | -0.55 (55 years)$^{-1}$ | 7.5 | -7% | P < 0.01 |
| HIST1 | -1.1 (55 years)$^{-1}$ | 6.9 | -16% | P < 0.01 |
| HIST2 | -0.55 (55 years)$^{-1}$ | 6.3 | -9% | P < 0.01 |
| HISTNAT1 | -0.03 (55 years)$^{-1}$ | 8.3 | -0.3% | P = 0.54 |
| HISTNAT2 | -0.1 (55 years)$^{-1}$ | 6.9 | -1% | P = 0.2 |
| RCP4.5 | -1.1 (55 years)$^{-1}$ | 6.6 | -17% | P < 0.01 |
| RCP4.5 | -0.29 (90 years)$^{-1}$ | 6.6 | -5% | P < 0.01 |

### Difference in JJAS rainfall and wind at 850 hPa



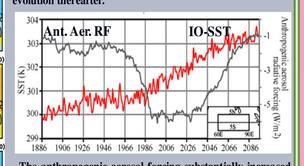

### In addition to increasing GHGs, the South-Asian region underwent prominent changes in other forcing such as anthropogenic-aerosols and land-use change.




Large-scale deforestation, agricultural expansion and wetland clearance, led to a massive decline (~47%) of forest in the last century while agricultural land-area nearly doubled as that of 1880s.

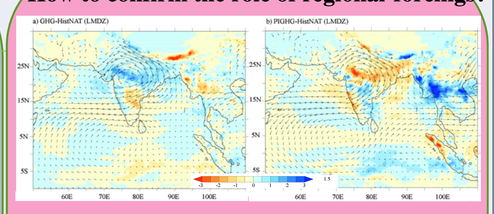
Increase in planetary-albedo until 1990s and a stationary evolution thereafter.




The anthropogenic aerosol forcing substantially increased over the South-Asian region from 1950s, continues till mid-2030 and decreases thereafter following RCP4.5 scenario.

Another distinct regional-forcing signal is the warming of IOSST at a rate of 0.5°-1°C over the last 5 decades and which persistently increase in future.

### How to confirm the role of regional-forcings?

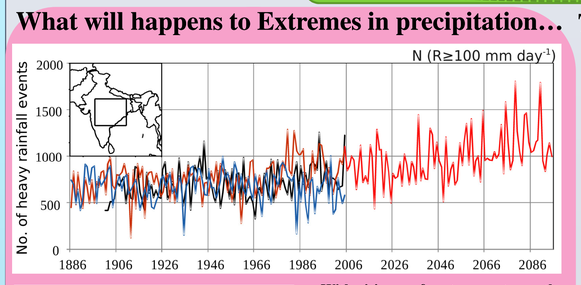


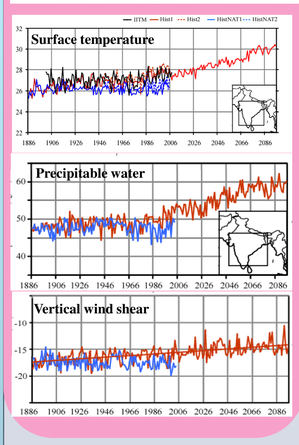
- ➢GHG (*Natural and GHG forcings. Land use and aerosol fields set to 1886 values*) only simulation shows a enhancement in SAM.
- ➢The PI-GHG (*Includes Natural variations, Aerosol forcing and Land-use change. GHG concentration set to 1886*) simulations exhibit a weakening of SAM circulation and decreased rainfall over the subcontinent for the post-1950's.
- ➢This confirming the potential role of regional-forcing elements in influencing the monsoon precipitation changes in recent decades.

### The decreasing trend in monsoon is happening through…

- ➢The direct radiative effect of anthropogenic aerosol-forcing leads to reduction in insolation at the surface, which weaken the SAM through decreasing meridional temperature gradient.
- ➢The changes in land-use pattern and aerosol forcing increase the planetary-albedo which can potentially decrease monsoon precipitation through anomalous subsidence required to compensate enhanced radiative cooling.
- ➢Besides this, the Indian ocean SST warming leads to a pronounced weakening of the large-scale monsoon circulation.

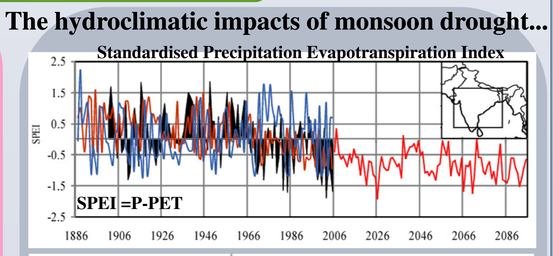
### What will happens to Extremes in precipitation…

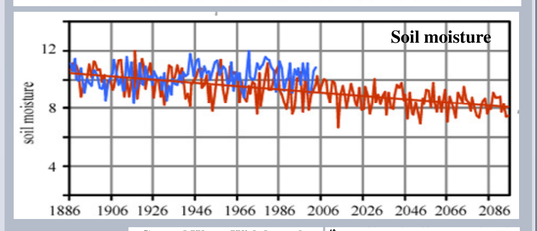


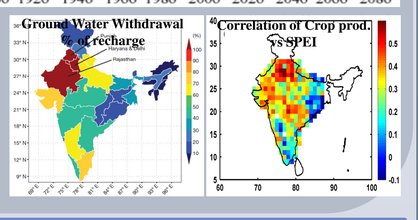




With rising surface temperatures, the simulated atmospheric moisture content over the subcontinent increased substantially by ~24% during 1886-2095. The vertical wind shear reduced nearly by the same amount. Such a weakly sheared environment with high humidity levels favors enhanced localized convection and leads to the increasing frequency of precipitation extremes .

### The hydroclimatic impacts of monsoon drought...



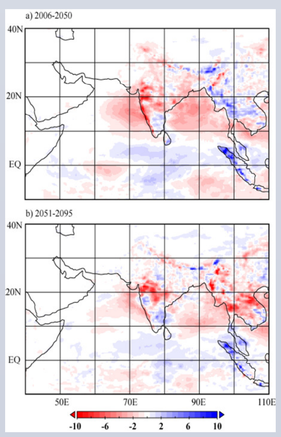



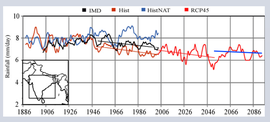




The decline of monsoon precipitation tends to deplete soil-moisture by ~23% during 1886-2095. Persistence of soil-moisture deficiencies over the SAM region, an identified hot-spot of land atmosphere coupling to precipitation, can in turn reduce evapotranspiration particularly in soil moisture limited regimes and semi-arid transition zones and impact crop-production. Furthermore, on decadal and centennial time-scales, soil moisture-climate feedbacks can also induce shifts in vegetation and thereby contribute to climate change.

### Whether the SAM will recover in the future.....

Trend in seasonal monsoon rainfall from the RCP4.5 mm/day (45 years) $^{-1}$



- ➢It is also noted that the projected monsoonal rains tend to recover in the later part of the 21st century, although drier conditions continue to prevail over the subcontinent.
- ➢This possibility, however, is still not clear especially in the light of the persistent IOSST warming in the future projection.
- ➢This implies that, in addition to mitigating the effects of anthropogenic aerosols and land-use changes, a slow down of the IOSST warming trend may hold the key for the SAM revival .

| | Rainfall trend | Mean rain | % change | P value |
|---|---|---|---|---|
| RCP4.5 | -1.1 (55 years)$^{-1}$ | 6.6 | -17% | P < 0.01 |
| RCP4.5 | -0.29 (90 years)$^{-1}$ | 6.6 | -5% | P < 0.01 |

## CONCLUSIONS

- ➢ The use of high-resolution simulations has enabled us to draw new insights about the key regional feedbacks associated with the 20th century and likely future monsoonal changes.
- ➢The findings highlight the collaborative influences of regional land-use change, anthropogenic-aerosol forcing and accelerated IOSST warming, which conspired to weaken the SAM.
- ➢Increase of planetary-albedo potentially leads to the decrease in SAM precipitation through anomalous subsidence required to compensate enhanced radiative cooling.
- ➢Even though the mean monsoon shows a decreasing trend the the frequency of heavy precipitation events over central India shows an increasing trend during the post-1950s and further increase in future.
- ➢ An important hydrological ramification of the changing monsoon rainfall is the significant depletion of soil-moisture by ~23% during 1886-2095. Rising temperatures and declining soil-moisture levels can severely impact crop-production through extended agricultural droughts.
- ➢The projected monsoonal rains tend to recover in the later part of the 21st century, although drier conditions prevail over the subcontinent. This possibility, however, is still not clear especially in the light of the persistent IO-SST warming in the future projections.
- ➢In addition to mitigating the effects of anthropogenic aerosols and land-use changes, a slow down of the IO-SST warming trend may hold the key for SAM revival.