Response of Indian Summer Monsoon Precipitation to Carbon Dioxide Removal: Subseasonal Evolution and Regional Characteristics

(under review)

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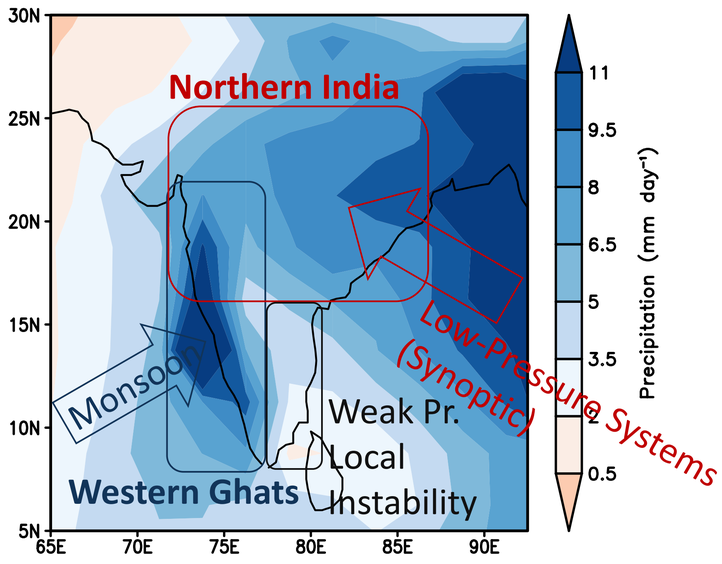
Following CO_2 removal, (i) summer monsoon weakens, (ii) stability decreases, (iii) synoptic low-pressure system (**LPS**) alterations

→ Distinct regional and subseasonal Indian summer monsoon (**ISM**) precipitation variations (Western Ghats, southeastern India, central-to-north eastern India)

→ Extreme precipitation shows similar hysteresis, more strongly affected by LPSs

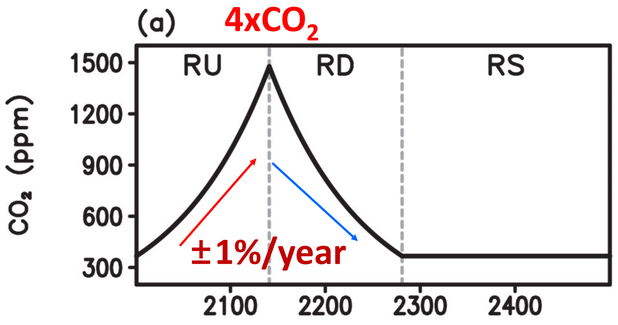
Summer (JJAS) Precipitation Climatology



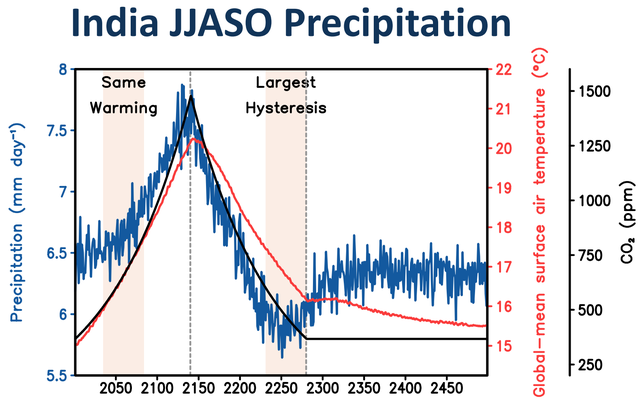
Indian summer monsoon (ISM) precipitation sourced from,

- *Summer monsoon*
- *Local instability*
- *Synoptic-scale low-pressure systems (LPSs)*

CESM1 CO_2 removal (28-runs)



India JJAS Precipitation

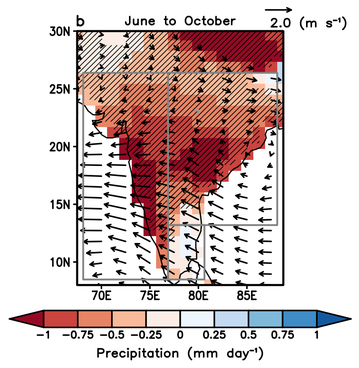


Precipitation negatively overshoots

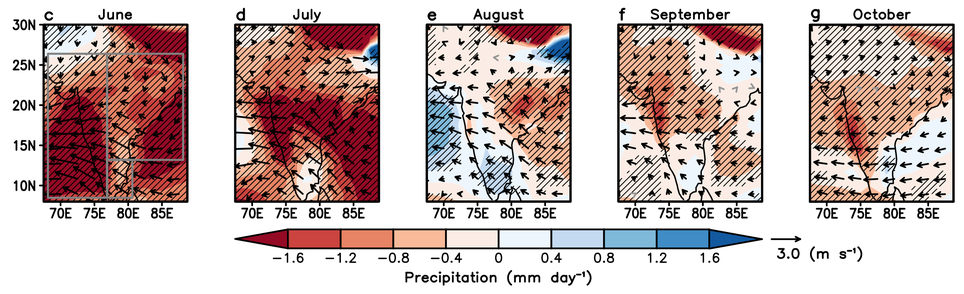
Ramp down – up

: 2231-80 minus 2035-84 (same warming)

Ramp down - up JJASO Precipitation



- **Precipitation decreases in most regions**
- **Monsoon weakening**



Distinct regional and subseasonal responses

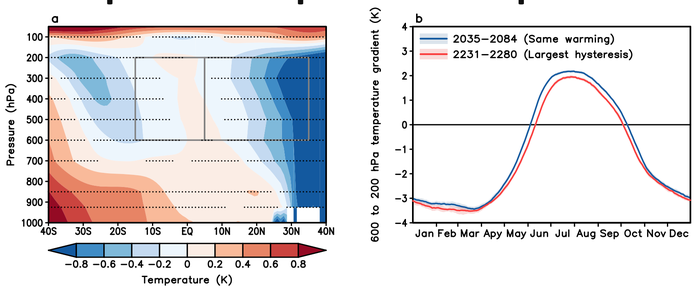
(i) Western Ghats, (ii) southeastern India

(iii) central-to-north eastern India

: Drying is weakened following initial months

: Southern India even exhibits precipitation increases

Ramp down - up JJASO Temperature



(1) Weakened NH - SH temperature

: Strong cooling in NH under lower CO_2

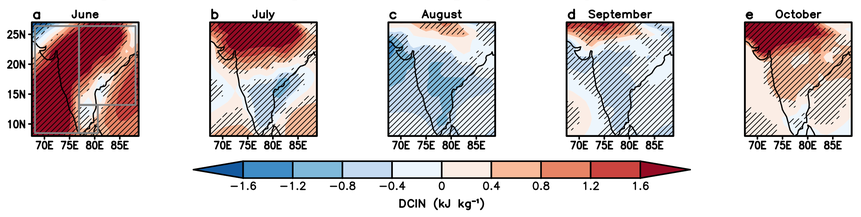
: Delayed recovery in the ocean, i.e. SH

: also, AMOC ↓, Southern Ocean warming

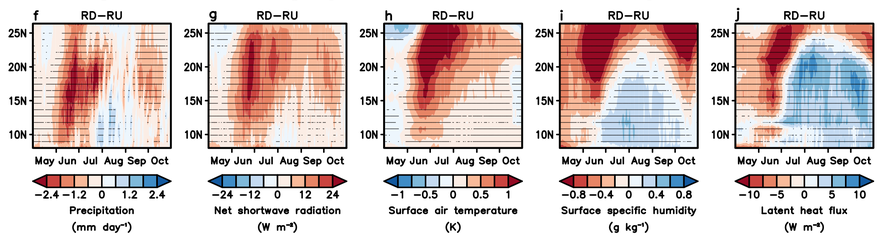
(An et al. 2021, Kug, et al. 2022)

→ **Monsoon circulation weakening**

Ramp down - up Stability (DCIN)



Ramp down - up (India zonal-mean)



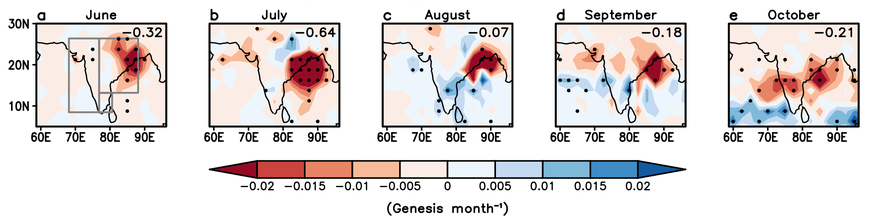
(2) Deep-convective inhibition (DCIN, stability) decreases (July to October)

: Precipitation (cloud) ↓, Shortwave flux & Temperature ↑,

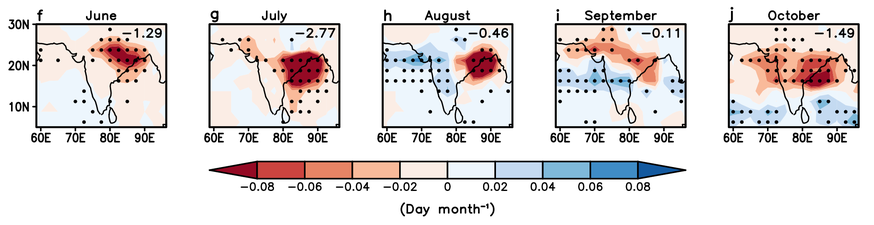
Latent heat flux & Humidity at surface ↑

→ **Thermodynamic stability decreases**

Ramp down - up LPS genesis



Ramp down - up LPS track density

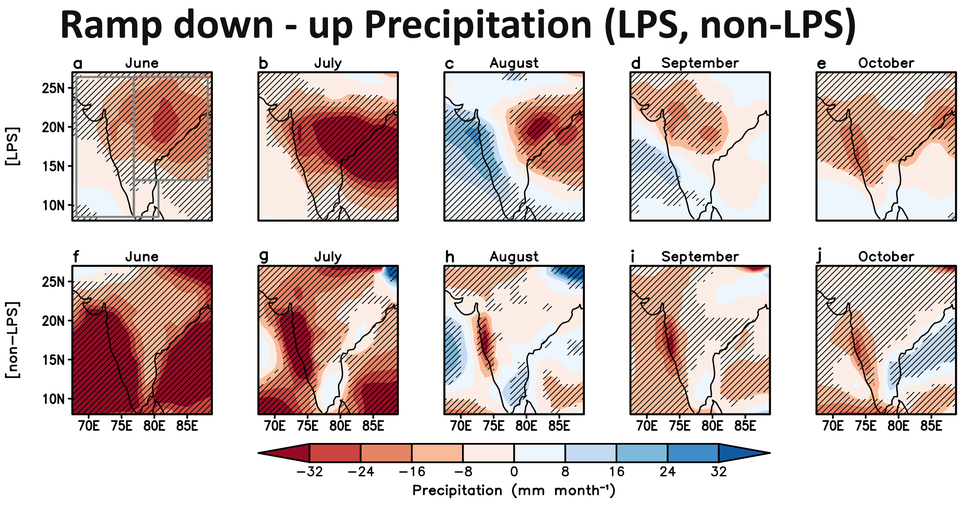


(3) ISM LPS variations

: **overall decreases** (monsoon weakening)

: In contrast, **increases over southern India, and Western Ghats during August and September**, due to stability decreases

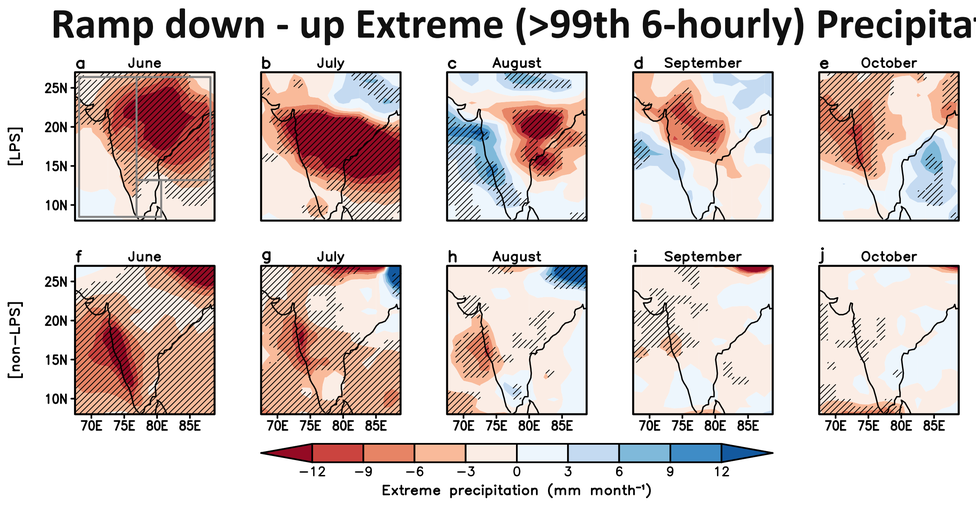
Ramp down - up Precipitation (LPS, non-LPS)



LPS contribution: Precipitation decreases, but increases in August, September over Western Ghats, southern India ~ following ΔLPS

Non-LPS contribution: Precipitation decreases (monsoon weakening), partly increases (stability decreases)

Ramp down - up Extreme (>99th 6-hourly) Precipitation



Similar patterns, but more strongly influenced by ΔLPSs