Columbia University in the City of New York

Lamont-Doherty Earth Observatory
Columbia University | Earth Institute

# Fast adjustments of the Asian summer monsoon to anthropogenic aerosols

Xiaoqiong (Sage) Li, Mingfang Ting, Dong Eun Lee

*Lamont-Doherty Earth Observatory*

*Columbia University*

22nd Annual CESM Workshop
Jun. 19 – 22, 2017
Boulder, CO

*Li et al. 2017: Fast adjustments of the Asian summer monsoon to anthropogenic aerosols, in prep.*

xqli@ldeo.columbia.edu
http://www.ldeo.columbia.edu/~xqli/

# Aerosol effects on climate

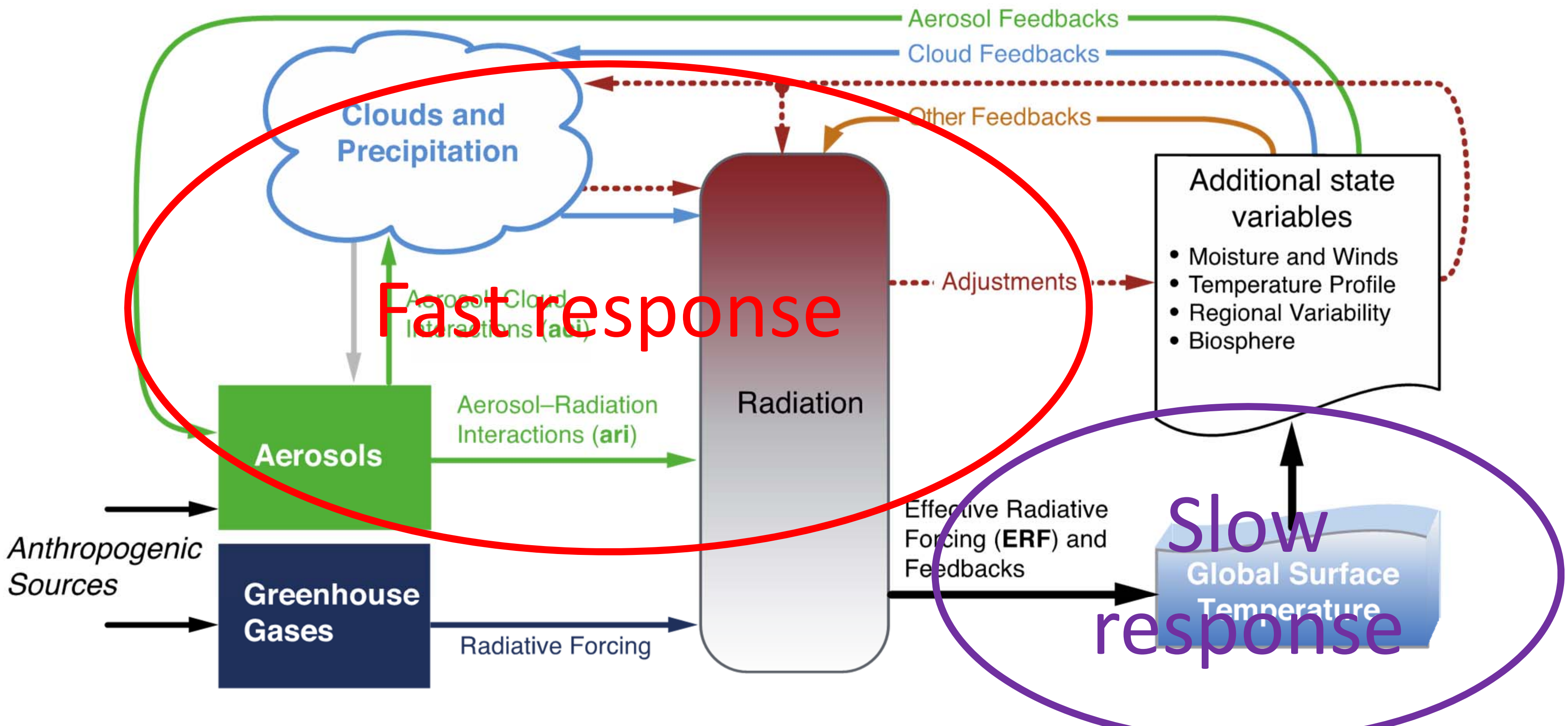
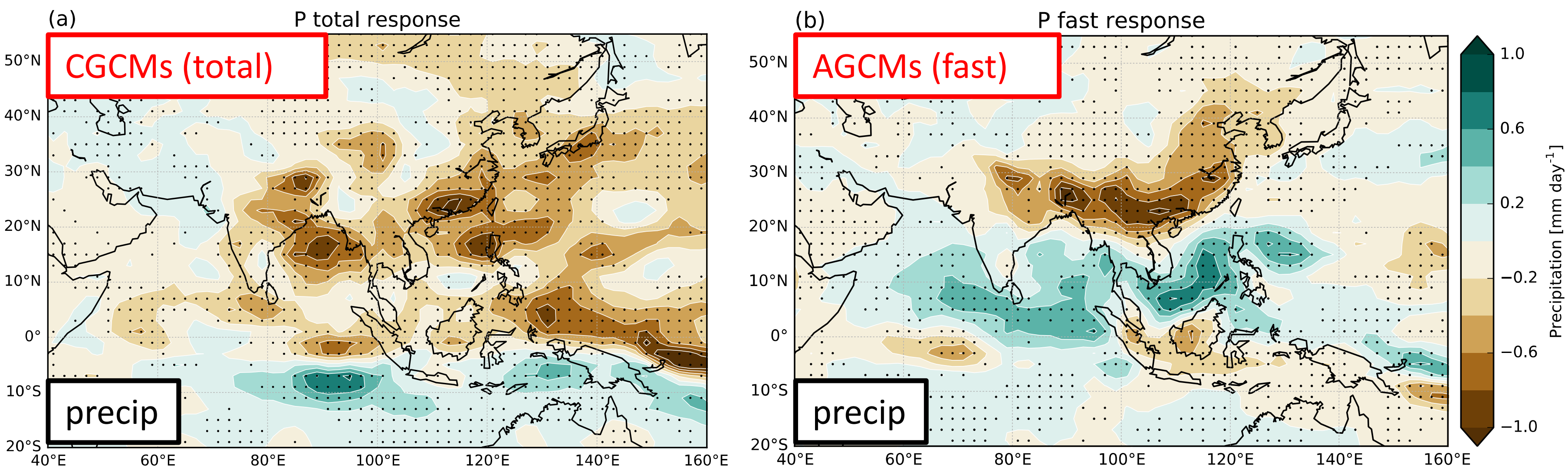



**Figure 7.1 |** Overview of forcing and feedback pathways involving greenhouse gases, aerosols and clouds. Forcing agents are in the green and dark blue boxes, with forcing mechanisms indicated by the straight green and dark blue arrows. The forcing is modified by rapid adjustments whose pathways are independent of changes in the globally averaged surface temperature and are denoted by brown dashed arrows. Feedback loops, which are ultimately rooted in changes ensuing from changes in the surface temperature, are represented by curving arrows (blue denotes cloud feedbacks; green denotes aerosol feedbacks; and orange denotes other feedback loops such as those involving the lapse rate, water vapour and surface albedo). The final temperature response depends on the effective radiative forcing (ERF) that is felt by the system, that is, after accounting for rapid adjustments, and the feedbacks.

*IPCC AR5 2013*

# Monsoon rainfall (June-August) response in CMIP5 CGCMs vs. fast adjustments in fixed-SST AGCMs



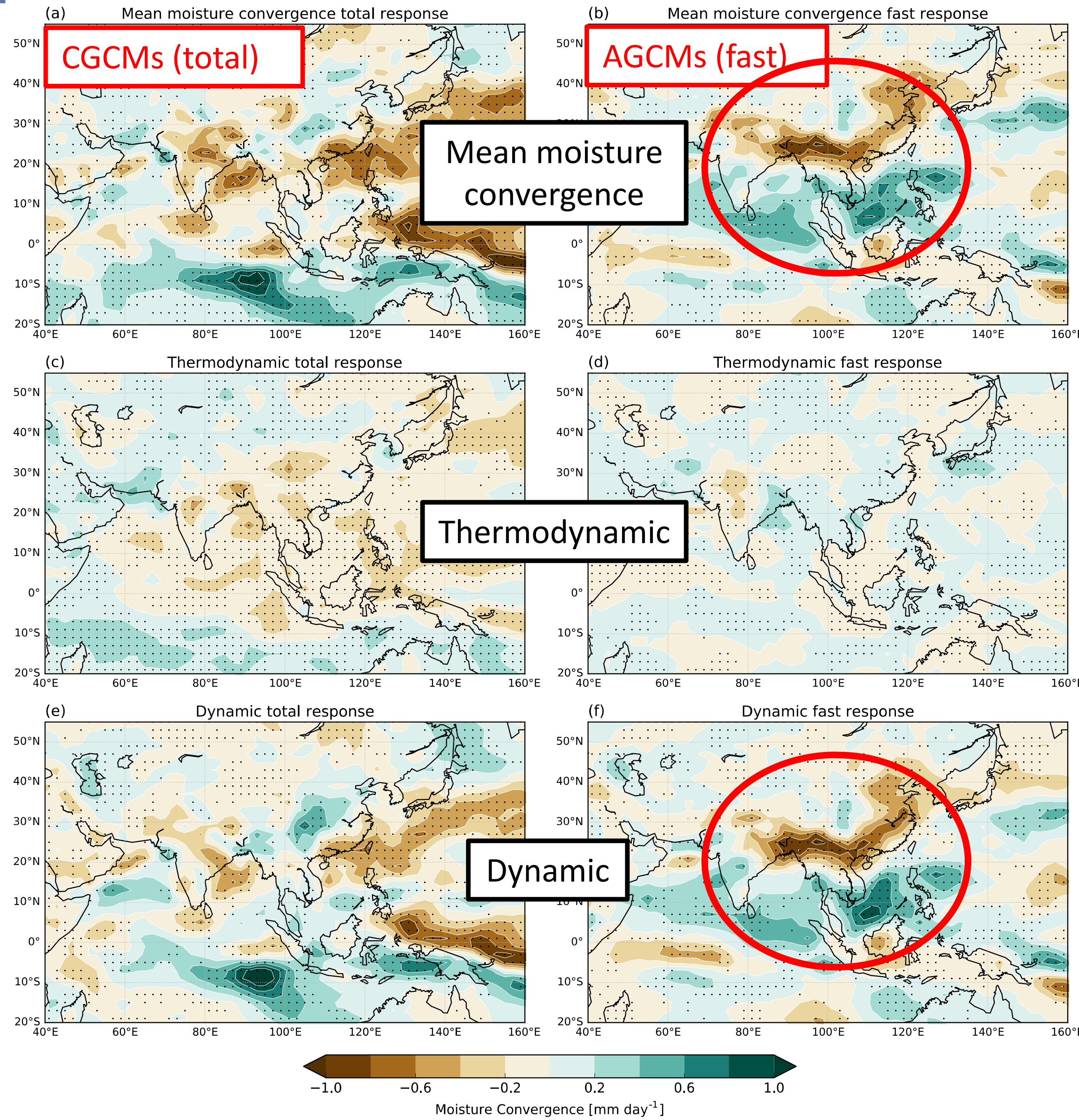

## Total response

- Couple model simulations (CGCMs)
- CMIP5 historical aerosol-only
- 5 common models
- (1981-2005) minus (1861-1885)

## Fast response

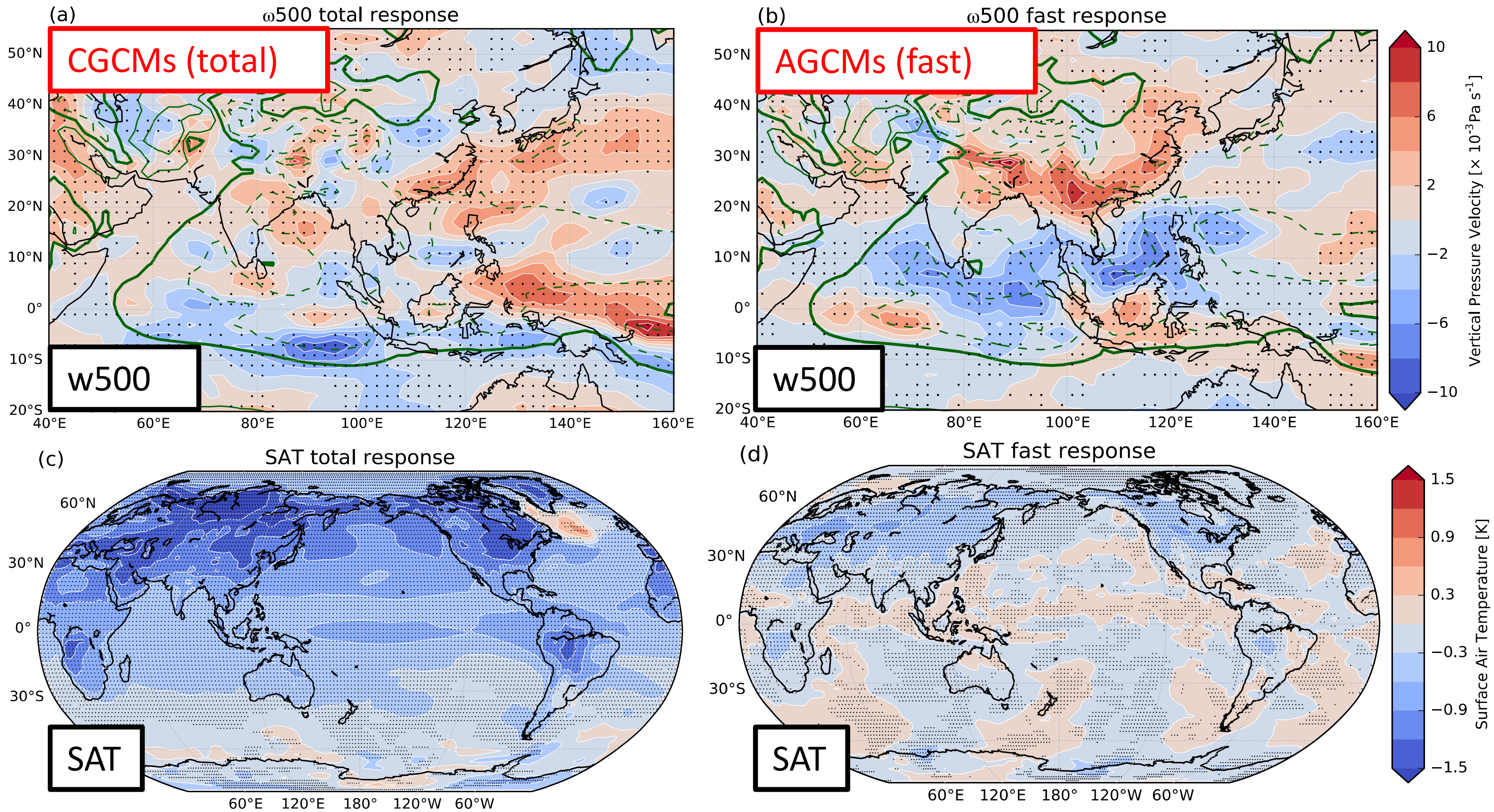
- AGCMs with climatological SST/sea ice
- Control (“sstclim”): preindustrial aerosols
- Forced (“sstclimAerosol”): year 2000 aerosols
- 5 common models
- Forced – Control

# The moisture budget response




- Total response involves both thermodynamic and dynamic contributions
- Fast response dominated by the dynamic component

# Vertical motion response and the role of the meridional temperature gradient



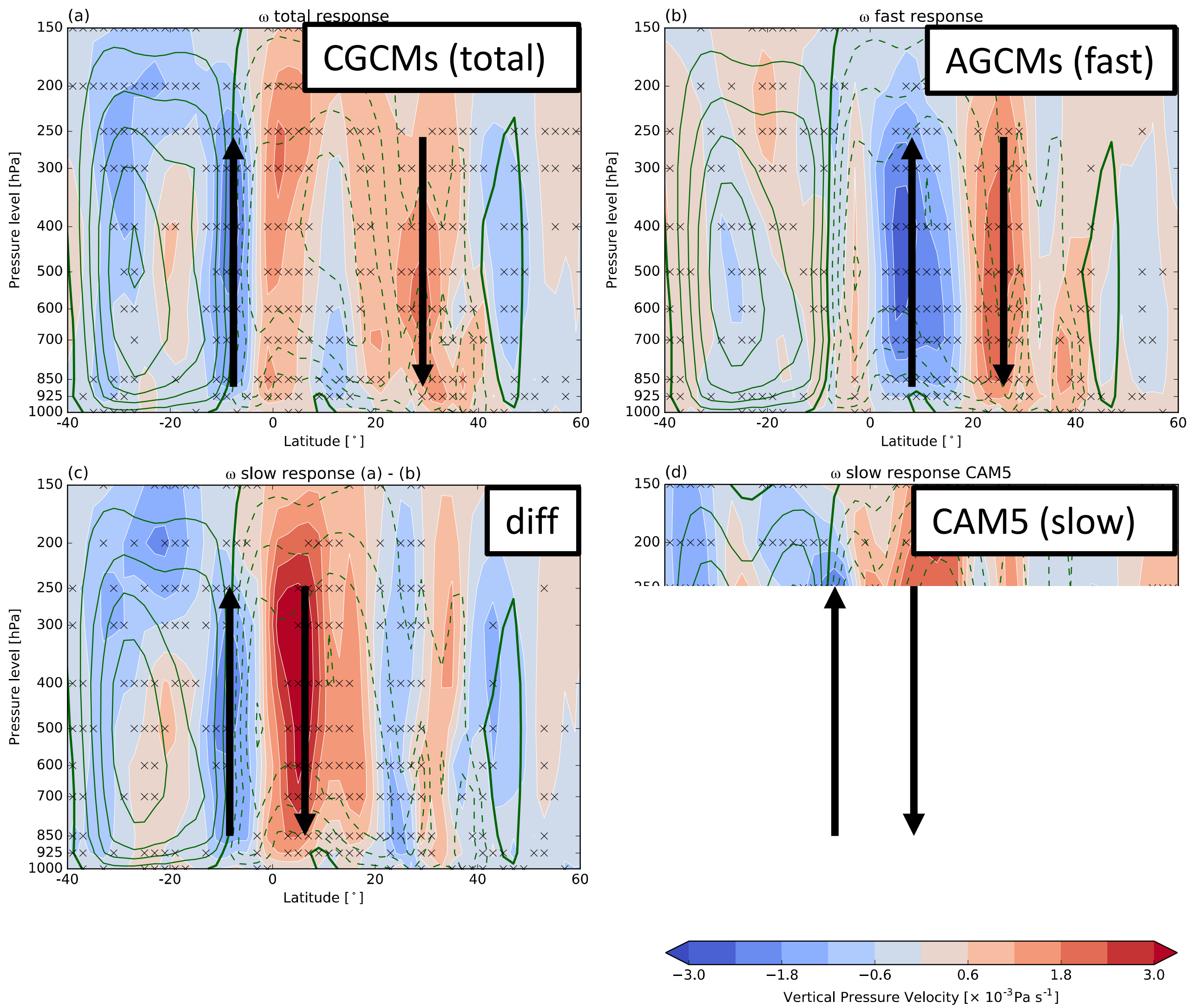

## Total response: overall sinking

- Anomalous sinking over the convective region
- Anomalous rising south of Equator

## Fast response: meridional dipole structure

- Anomalous sinking over land north of 20N
- Anomalous rising over ocean 0-20N

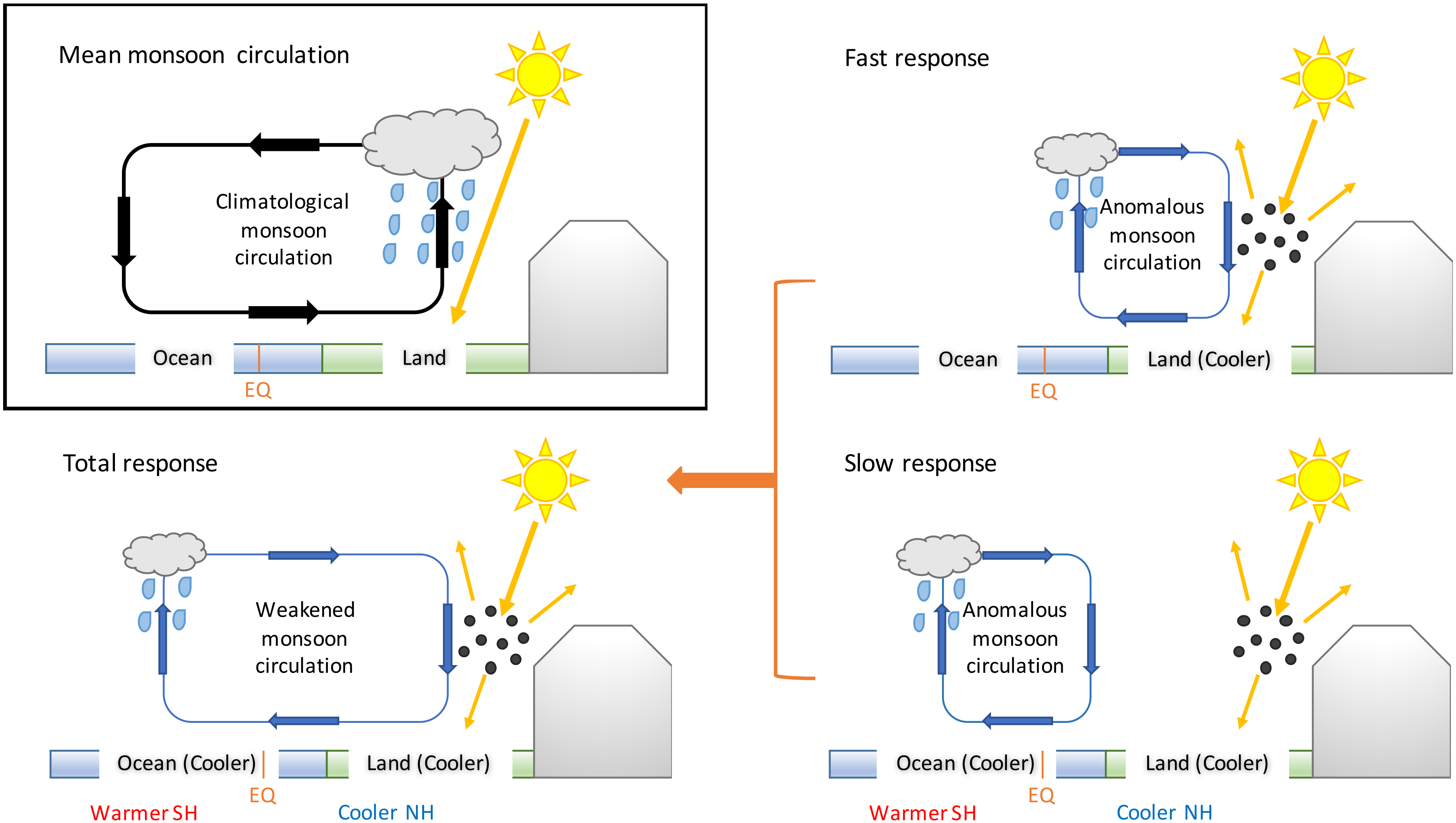
# Local overturning circulation response (60E-140E average vertical motion)




CAM5 prescribed-SST experiment

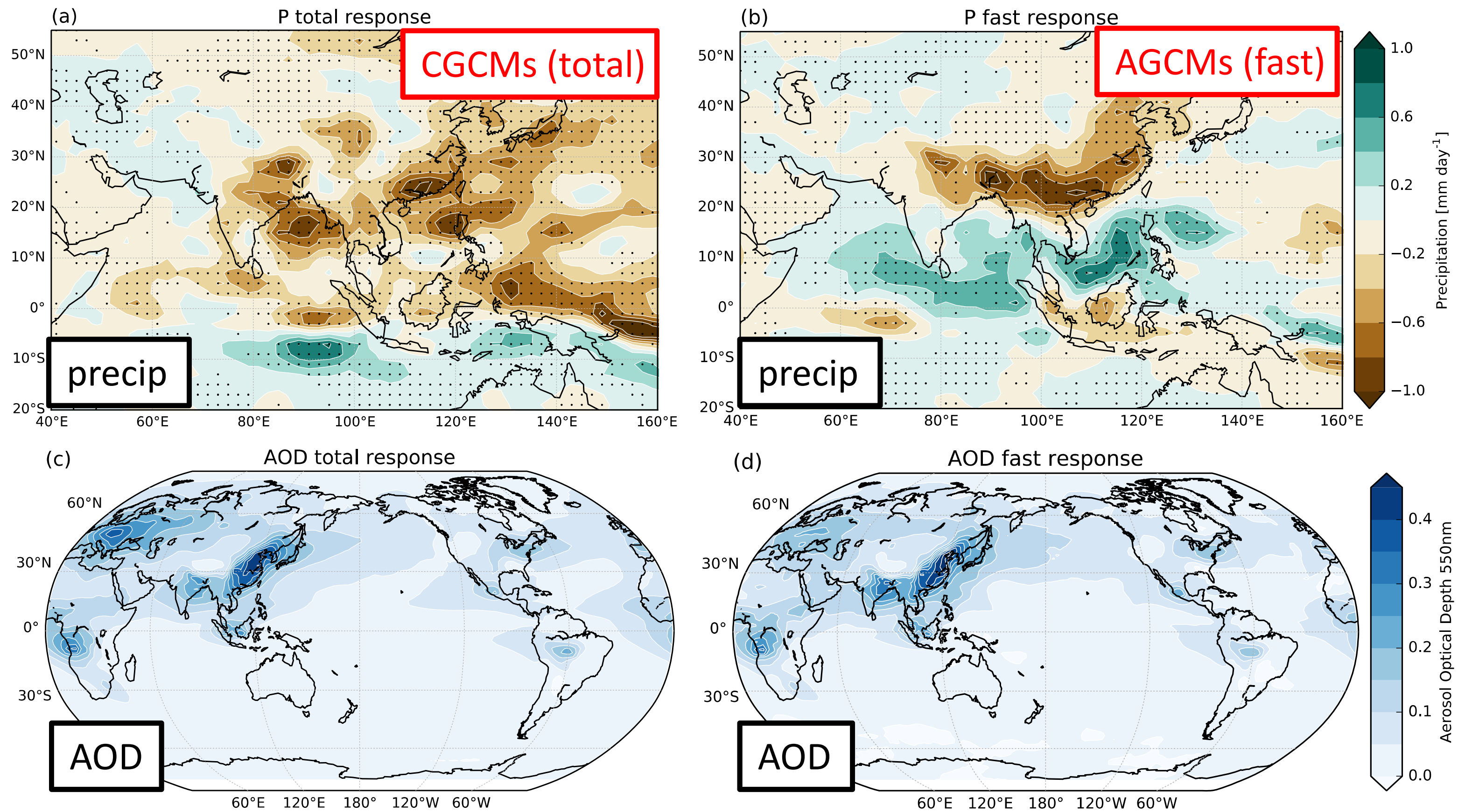
- Preindustrial aerosols
- Control: observed climatological SST
- Forced: Add SST anomaly derived from CMIP5 historical aerosol-only simulations

# Summary: fast vs. slow monsoon response to anthropogenic aerosols



# ADDITIONAL SLIDES

# Total coupled response in 5 CMIP5 CGCMs vs. fast adjustments in fixed-SST AGCMs



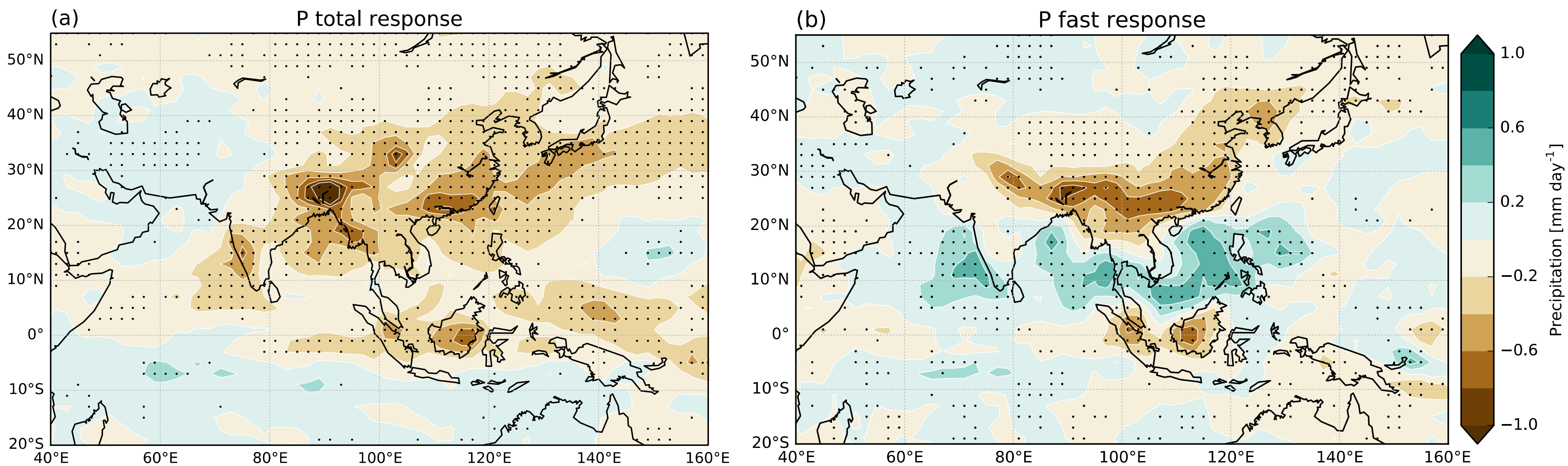

CMIP5 historical aerosol-only simulations

- (1981-2005) minus (1861-1885)

AGCMs with climatological SST/sea ice

- "sstclim": preindustrial aerosols
- "sstclimAerosol": year 2000 aerosols

# 13 CGCMs (43 runs), 11 AGCMs



# Model simulations

| Model | CGCM | AGCM |
|---|---|---|
| CanESM2 * | 5 | 1 |
| CCSM4 (p10) | 3 | - |
| CESM1-CAM5 | 3 | - |
| CSIRO-Mk3-6-0 * | 5 | 1 |
| FGOALS-g2 | 1 | - |
| GFDL-CM3 * | 3 | 1 |
| GFDL-ESM2M | 1 | - |
| GISS-E2-H (p107) | 5 | - |
| GISS-E2-H (p301) | 5 | - |
| GISS-E2-R (p107) | 5 | - |
| GISS-E2-R (p301) | 5 | - |
| IPSL-CM5A-LR * | 1 | 1 |
| NorESM1-M * | 1 | 1 |

# Moisture budget analysis

Atmospheric moisture budget:

$$\overline{P} - \overline{E} = -\frac{1}{g\rho_w}\nabla\cdot\overline{\int_0^{p_s}\mathbf{u}q\,dp} \approx -\frac{1}{g\rho_w}\nabla\cdot\sum_{k=1}^{K}\overline{\mathbf{u}}_k\overline{q}_k\,\overline{\Delta p_k} - \frac{1}{g\rho_w}\nabla\cdot\sum_{k=1}^{K}\overline{\mathbf{u}'_k q'_k}\,\overline{\Delta p_k}$$

Precipitation minus Evaporation

Mean moisture convergence

Transient eddies

Separate the change of the total mean moisture convergence into thermodynamic and dynamic components:

$$\delta\Big[-\frac{1}{g\rho_w}\nabla\cdot\sum_{k=1}^{K}\overline{\mathbf{u}}_k\overline{q}_k\,\overline{\Delta p_k}\Big] \approx \delta\Big[-\frac{1}{g\rho_w}\nabla\cdot\sum_{k=1}^{K}\overline{\mathbf{u}}_{k,c}\overline{q}_{k,a}\,\overline{\Delta p_k}\Big] + \delta\Big[-\frac{1}{g\rho_w}\nabla\cdot\sum_{k=1}^{K}\overline{\mathbf{u}}_{k,a}\overline{q}_{k,c}\,\overline{\Delta p_k}\Big]$$

fixed changing

changing fixed

Mean moisture convergence

Thermodynamic component

Dynamic component

*Trenberth and Guillemot, 1995; Seager and Henderson, 2013*

# Summary

- Total response
  - Overall reduced rainfall and circulation
- Fast response
  - Reduced rainfall over land (eastern China, northern India) and increased rainfall over the adjacent ocean
  - Anomalous atmospheric overturning circulation
- Slow response
  - Uniform cooling + meridional gradient
  - Further work using idealized AGCM experiments