Tropical Belt Width Proportionately More Sensitive to Aerosols Than Greenhouse Gases

Xueying Zhao[1]

[1]University of California Riverside

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Abstract

The tropical belt has widened during the last several decades, and both internal variability and anthropogenic forcings have contributed. Although greenhouse gases and stratospheric ozone depletion have been implicated as primary anthropogenic drivers of tropical expansion, the possible role of other drivers remains uncertain. Here, we analyze the tropical belt width response to idealized perturbations in multiple models. Our results show that absorbing black carbon (BC) aerosol drives tropical expansion, and scattering sulfate aerosol drives contraction. BC, especially from Asia, is more ecient per unit radiative forcing than greenhouse gases in driving tropical expansion, particularly in the Northern Hemisphere. Tropical belt expansion (contraction) is associated with an increase (decrease) in extratropical static stability induced by absorbing (scattering) aerosol. Although a formal attribution is dicult, scaling the normalized expansion rates to the historical time period suggests that BC is the largest driver of the Northern Hemisphere tropical widening but with relatively large uncertainty.

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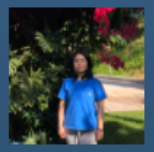
Xueying Zhao1 (presenter), Robert J Allen1, Tom Wood2, Amanda Maycock2

1 University of California Riverside, Department of Earth and Planetary Sciences, Riverside, CA, United States
2 University of Leeds, School of Earth and Environment, Leeds, UK



Highlights

- Idealized large single-forcing PDRMIP experiments from nine fully coupled climate models are used to quantify individual anthropogenic driver, including co_2, black carbon (BC) and sulfate, impact on tropical belt edge location variation, as well as the corresponding physical mechanisms.
- Global and regional anthropogenic driver effects on tropical belt width are quantified.

Methods

Perturbation Experiments

- Baseline simulation is forced with all forcings at the year 2000 level.
- Global perturbation experiments include co_2x2, bcx10, and sulx5.
- Regional perturbation experiments include bcx10 Asia, sulx10 Europe (EU), and sulx10 Asia.
- Fixed SST (fSST) experiments are used to estimate effective radiative forcing (ERF) and fast response of the tropical belt width.

Tropical Width Metrics

Global and Regional Annual Mean Tropical Belt Width Response

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Tropical Belt Edge Response in Global Perturbation

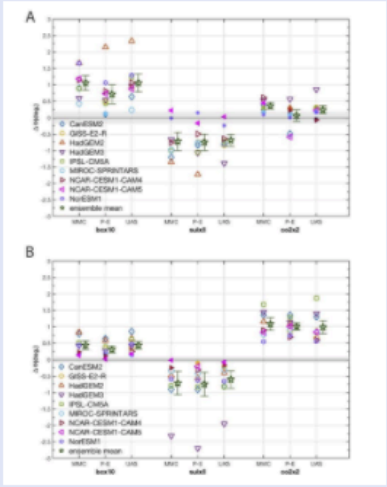

Fig.1. Annual mean tropical belt edge response in global perturbation experiments. *(A) Northern Hemisphere and (B) Southern Hemisphere tropical belt edge change (◦ latitude) in response to bcx10*

Efficiency of anthropogenic driver and Dynamic Response

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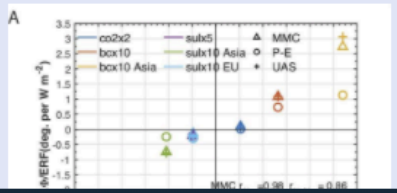
- To estimate the efficiency of GHG vs anthropogenic aerosol in perturbing tropical belt width, the annual mean ensemble mean tropical belt width response ($\Delta\Phi$) is normalized by the corresponding global ERF.
- Then we investigate the corresponding physical mechanisms. Under a scaling relation that the edge of the Hadley Cell is sensitive to the gross static stability and the tropopause height near the poleward boundary of the circulation. The extratropical static stability is estimated as the potential temperature difference between the tropopause and surface $\Delta S=\Delta(\theta_{TP}-\theta_{SFC})$, averaged over 30^0-60^0. It is normalized by the corresponding global ERF as well in Fig. 3.



Mechanisms of Perturbing Extratropical Static Stability: fast vs slow response

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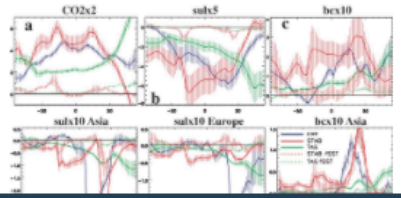

Conclusions

- Absorbing BC aerosol drives tropical expansion, and scattering sulfate aerosol drives contraction.
- BC, especially from Asia, is more efficient per unit radiative forcing than greenhouse gases in driving tropical expansion, particularly in the NH.
- Tropical belt expansion (contraction) is associated with an increase (decrease) in extratropical static stability induced by absorbing (scattering) aerosol.
- A simple scaling of the normalized expansion rates to the historical time