The long-term trends of land precipitation and the fast responses to BC and SO_4 aerosols in GFDL's climate models

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Motivation and Objectives

1. **Precipitation change** is critical for ecological studies and societal decisions.
2. **Aerosol effects** are one of the biggest uncertainties in climate model simulations and projections.

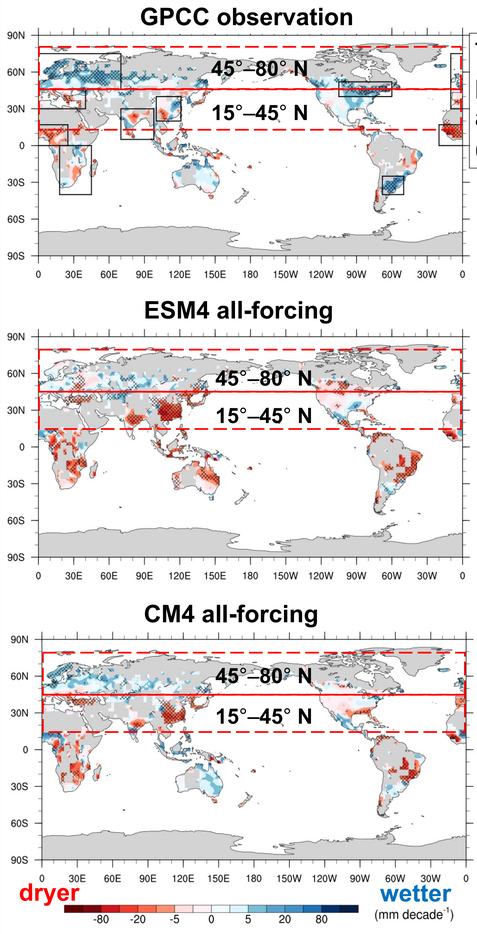
Objective

1. Assess the simulations of **long-term precipitation trends** by the GFDL **ESM4** and **CM4** models.
2. Understand the role of **anthropogenic aerosols** (**AAs**) in precipitation changes and model biases.

Point I: ESM4 and CM4 simulate dry trend bias in land precipitation, related to aerosol effects

Experiment 1

- **GFDL's climate model** (**CM4**) *(Held et al., 2019)* and **Earth System Model** (**ESM4**) *(Dunne et al., 2020)* are used to analyze the **long-term precipitation rend (1915-2014)**.
- **ESM4** and **CM4 all-forcing** and **forcing subset** experiments are driven by observed forcing agents: ***aer***, ***GHG***, ***nat.***

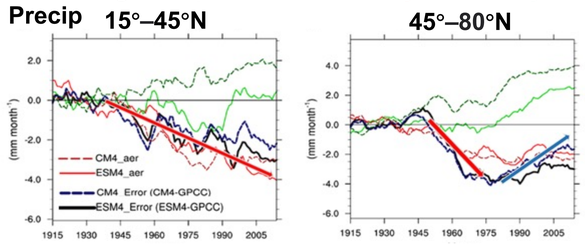


The long-term trends of precip by Obs and model all-forcing simulations **(1915–2014)**

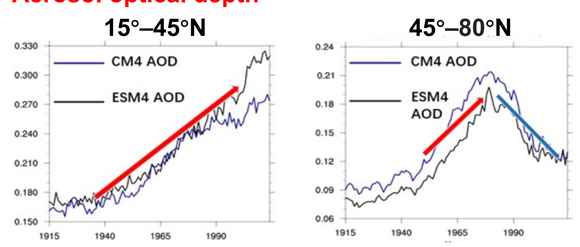
ESM4 and CM4 simulations show **significant dry trend bias** in extratropical NH:

1. The observed **increasing** trends over 45°–80°N are **underestimated**.
2. The simulated **decreasing** trend over 15°–45°N is stronger than Obs.
3. The Obs-Model discrepancies are not due to **internal variability**.

All-forcing Precip bias *vs.* **aer-only**, **GHG-only**



Aerosol optical depth



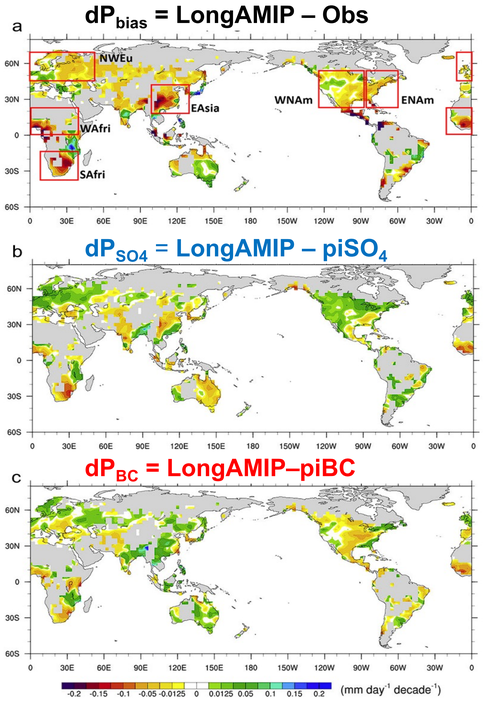
- The ESM4 and CM4 **precipitation bias** are consistent with **aerosol-only precip**.
- Model **precipitation biases** show similar evolutions as **AAs**.
- GFDL models overestimated AOD (not shown here).

Point II: The SO_4 and BC fast effects account for the model bias in some land regions (but not Europe and East North America)

Experiment 2:

ESM4 is used to study the **fast responses of precipitation** to **AAs** :

- **Historical LongAMIP** simulations (1870 - 2014) with observed sea SSTs and SIC are conducted.
- Emissions of **BC** and **SO4** are set to the pre-industrial level (**piBC** and **piSO$_4$**).



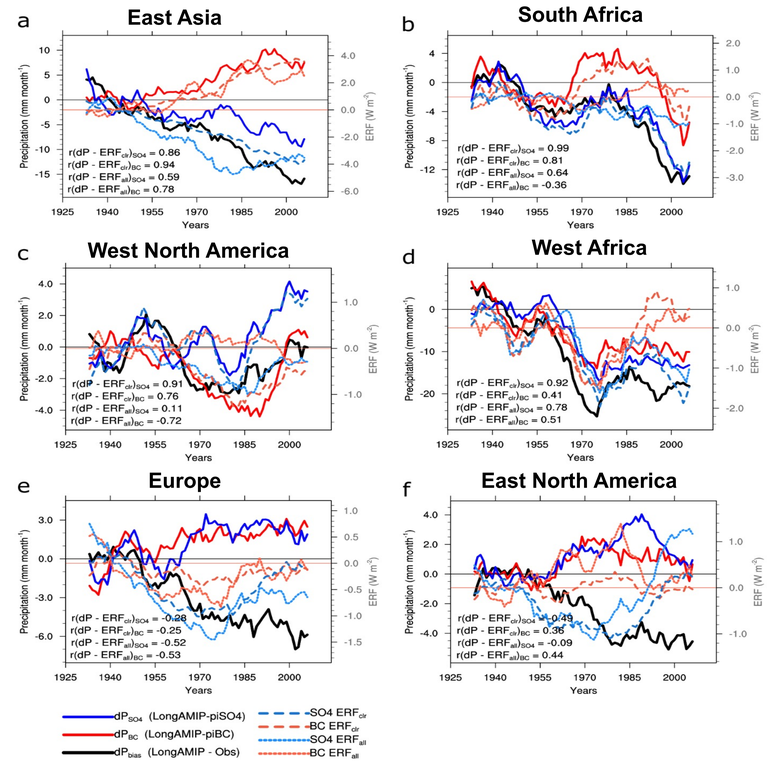
ESM4 precip trend bias (dP_{bias} **= LongAMIP - Obs**)
Fast responses to
SO_4 (dP_{SO4} **= LongAMIP–piSO$_4$**)
BC (dP_{BC} **= LongAMIP–piBC**)

← **SO4** fast effect leads to precip **decreases** over **Asia** and **Africa** and **increases** over **West North America**.

← The **evolution of BC** leads to precipitation **decreases** over **WNAm** and **Africa** and **increases** over **EAsia**.

Point III: Aerosols influence the precipitation changes (dP) through radiative effects (ERF)

Aerosol **Effective radiative forcing** in **all-sky** (ERF_{all}) and **clear-sky** (ERF_{clr}) conditions: **ERF = (ΔSW + ΔLW)$_{TOA}$**



- **The high *r(dP$_{SO4}$ -SO4 ERF$_{clr}$)***: the precip fast response to ***SO4*** is through **aerosol direct radiative effects**.
- ***The relatively lower r(dP$_{BC}$ - BC ERF$_{clr}$)***: ***BC*** influences precip through more complex physical processes.
- ***ERF$_{all}$ vs ERF$_{clr}$:*** *cloud effects lead to uncertainties in the aerosol effects on precipitation.*
- Over WNEu or ENAm, the model's trend bias or precip changes are controlled by other factors.

Take-Home Points

1. Compared to the observations, ESM4 and CM4 all-forcing precipitations show **significant dry trend biases in the extratropical NH**.
2. ESM4 and CM4 **precipitation bias** show similar evolutions as **anthropogenic aerosol**.
3. The **fast responses to SO_4 and BC** play critical roles in **precipitation changes** and **model bias** over Asia, Africa, and Western North America.
4. The fast response to **SO4** is mainly through local direct aerosol radiative effects and the **BC** impact is more complicated.

Zhang, Y., et al. (2023): The fast response of precipitation to historical black and sulfate aerosols in the GFDL ESM4 climate model (in preparation)
Zhang, Y., et al. (2023): The long-term trends of global land precipitation in GFDL's CM4 and ESM4 climate models. Journal of Climate.