

## Reassessment of Historical Fire Trends Based on an Antarctic-wide Array of Ice Cores and Fire Modeling

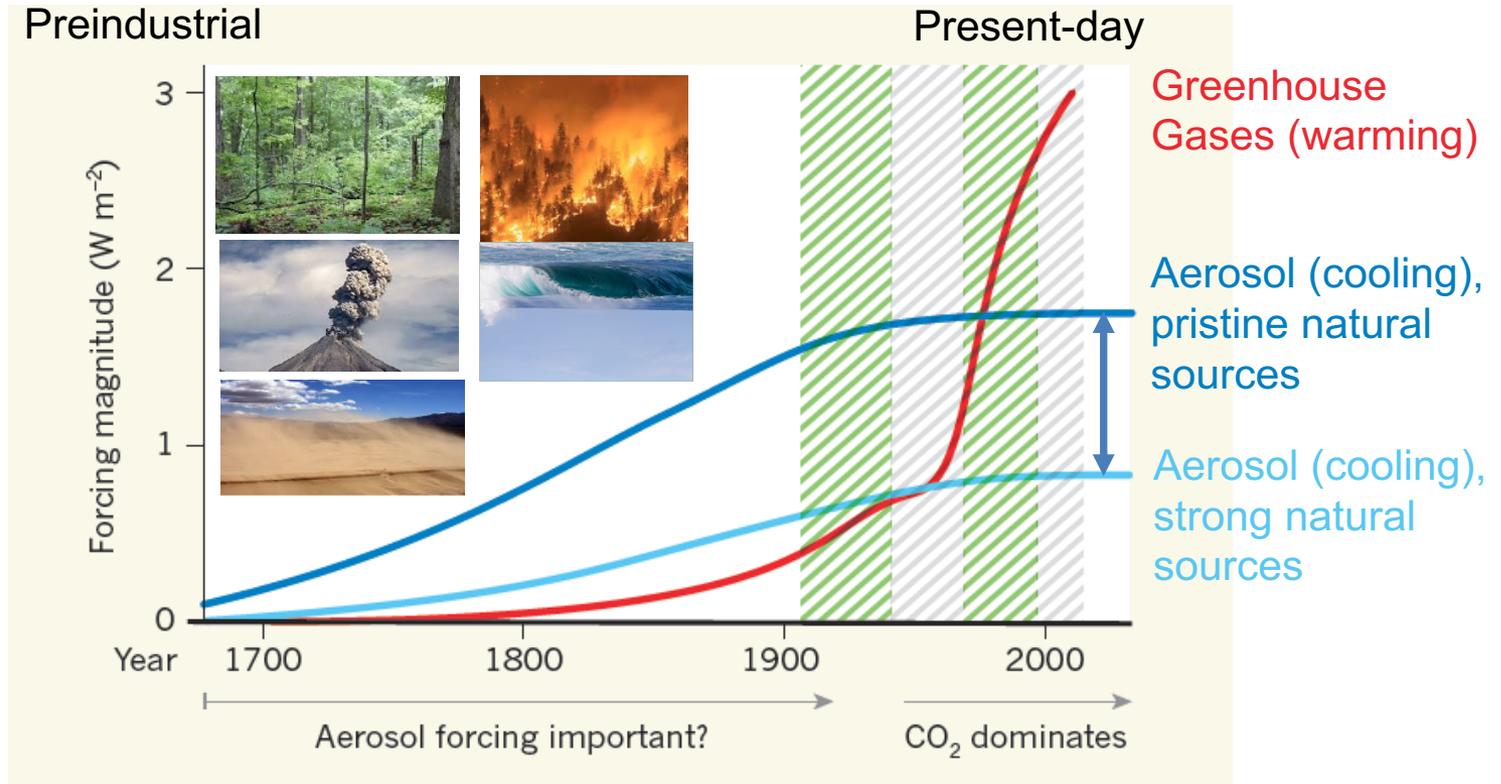
---



Pengfei Liu, Loretta J. Mickley, Yang Li, John (Jack) K. Kodros, Jeffery R. Pierce, Michael Sigl, Jed O. Kaplan, and Joseph R. McConnell

Harvard University  
IGC9, May 7, 2019

# A large uncertainty of the aerosol cloud albedo forcing is from preindustrial fires

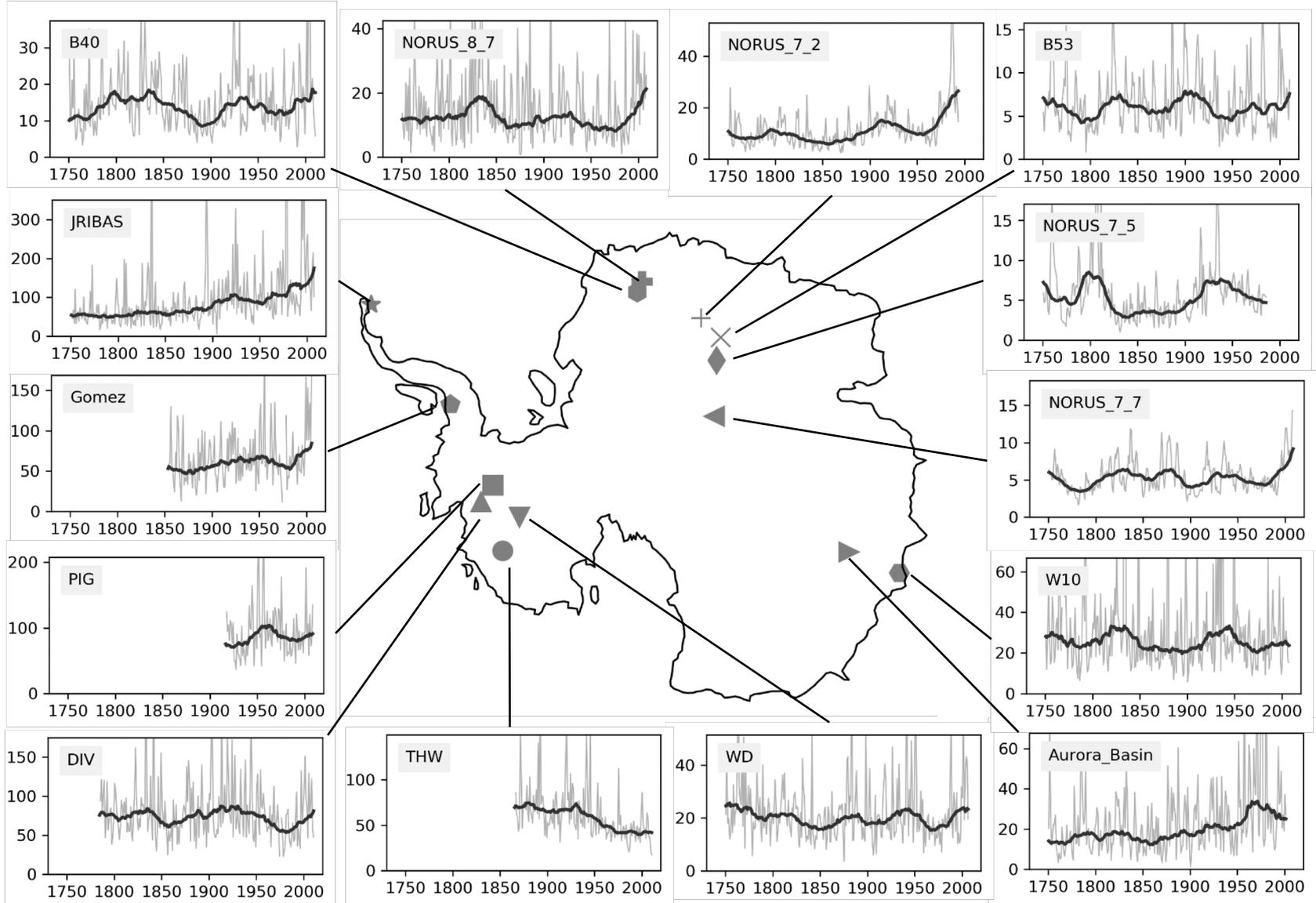


[Carslaw et al., *Nature*, 2013; and the commentary article by Bjorn Stevens; Hamilton et al., *Nature Communications*, 2018]

A holistic understanding of aerosol climate forcing requires better knowledge of **preindustrial aerosol** emissions, such as fires.

# Black carbon records from an Antarctic-wide array of ice cores (data source: Joe R. McConnell @ DRI)

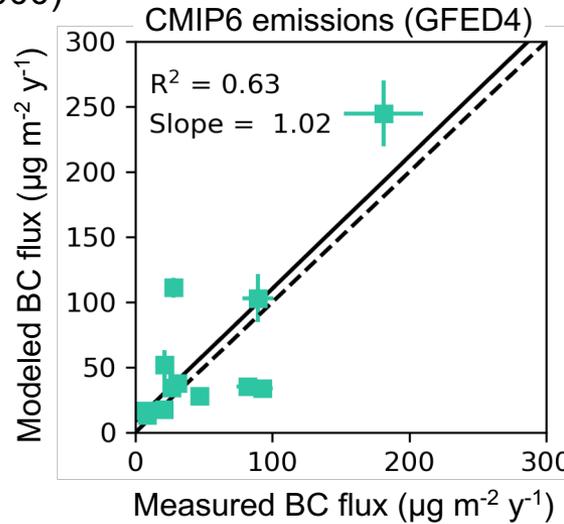
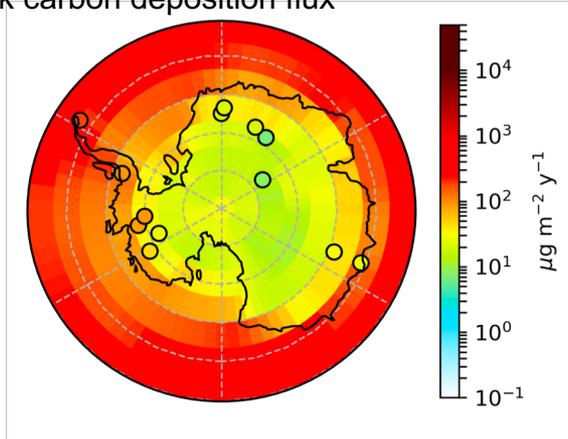
## Black carbon deposition fluxes from 14 Antarctica ice cores (unit: $\mu\text{g m}^{-2} \text{y}^{-1}$ )



# Black carbon deposition fluxes over Antarctica: GEOS-Chem-TOMAS versus ice cores

Present day (2000)

Black carbon deposition flux

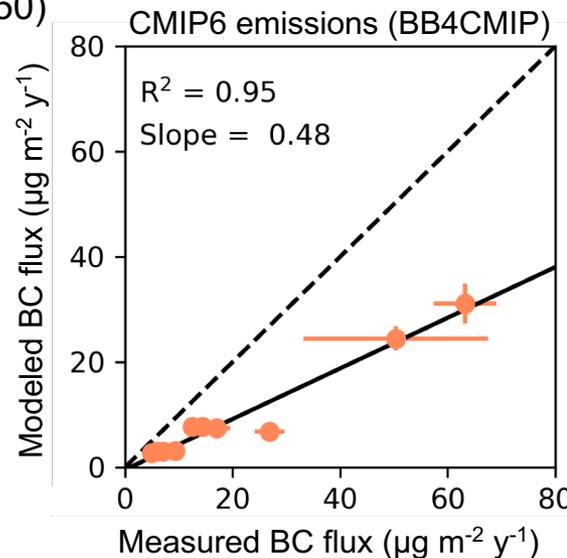
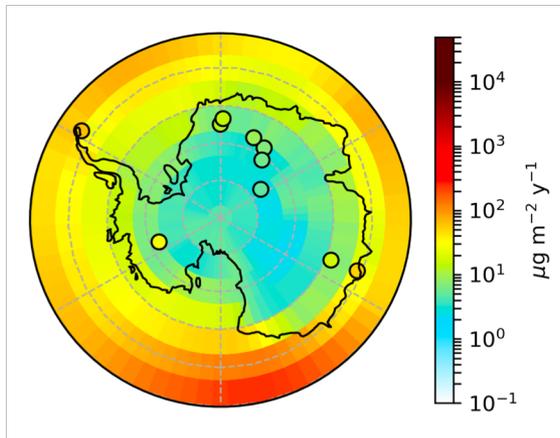


**Present-day:**  
Good agreement

Measured BC flux = BC  
concentration in ice  $\times$   
accumulation rate

Modeled BC flux =  
wet deposition +  
dry deposition

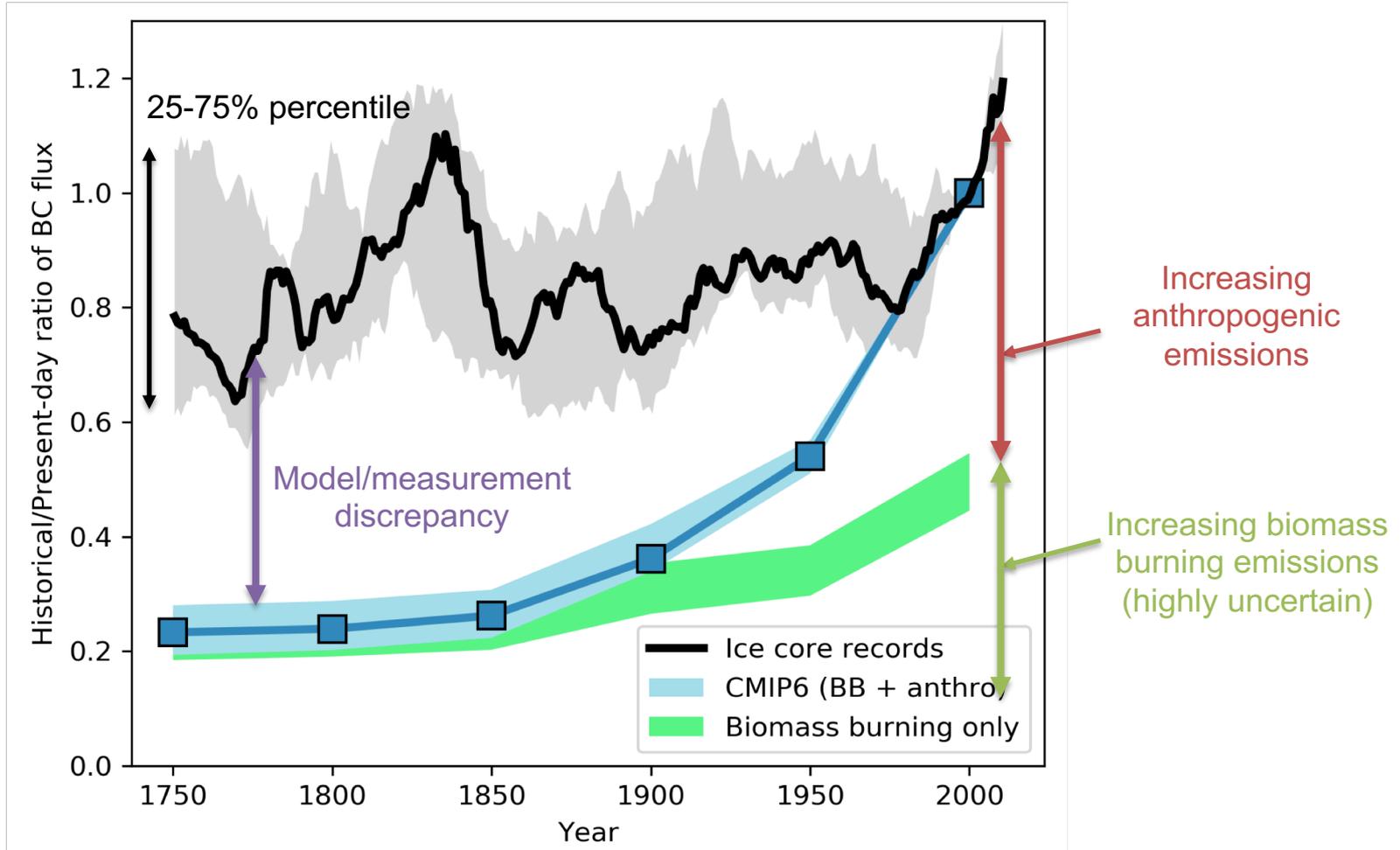
Preindustrial (1750)



**Preindustrial:**  
Model is biased low

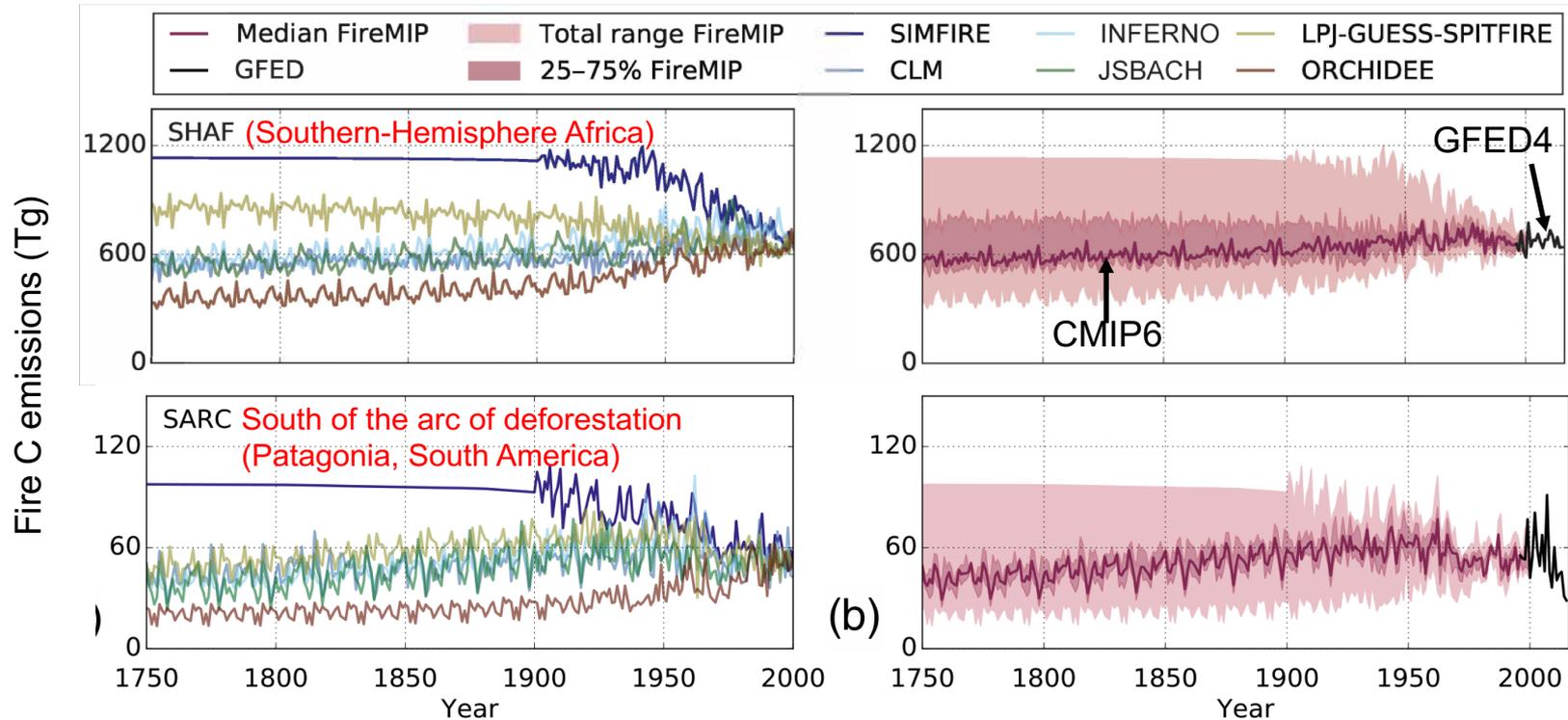
# The modeled trend of black carbon flux using CMIP6 emissions does not agree with ice core measurements

Modeled vs. measured black carbon deposition mass fluxes collocated at ice core sites (normalized by the present-day values)



# Key uncertainty: How does **human activity** affect the wildfire?

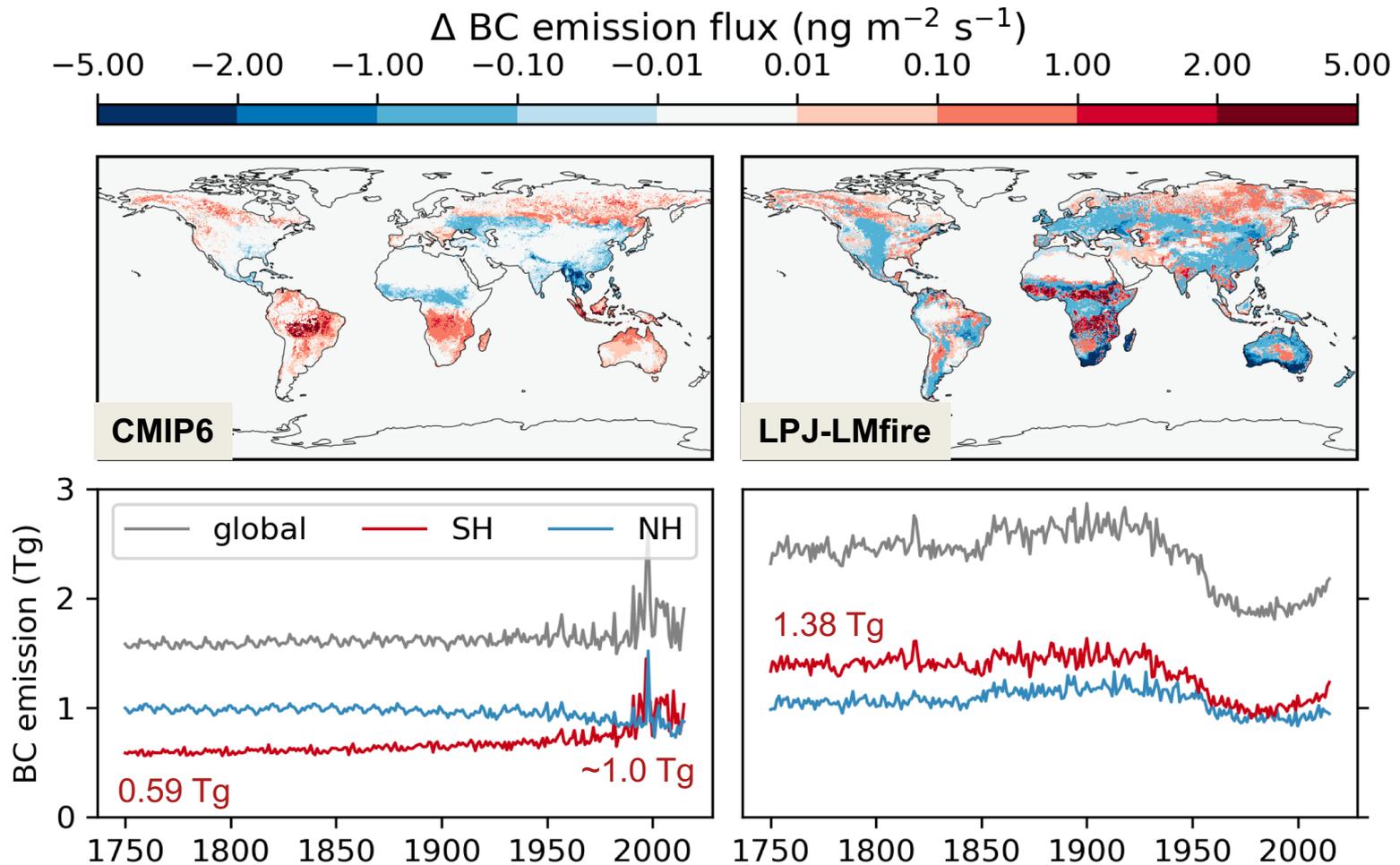
## Fire Modeling Intercomparison (FireMIP)



van Marle et al., 2017

- **Traditional understanding:** Fire activity increases with population density, because most fire ignitions are caused by human
- **New understanding:** Human can suppress fire [e.g., *Andela et al., Science, 2017*; *Hamilton et al., Nat. Comm., 2018*]
  - Global burned area decreased 24% from 1998 to 2015
  - landscape fragmentation, agriculture, fire management

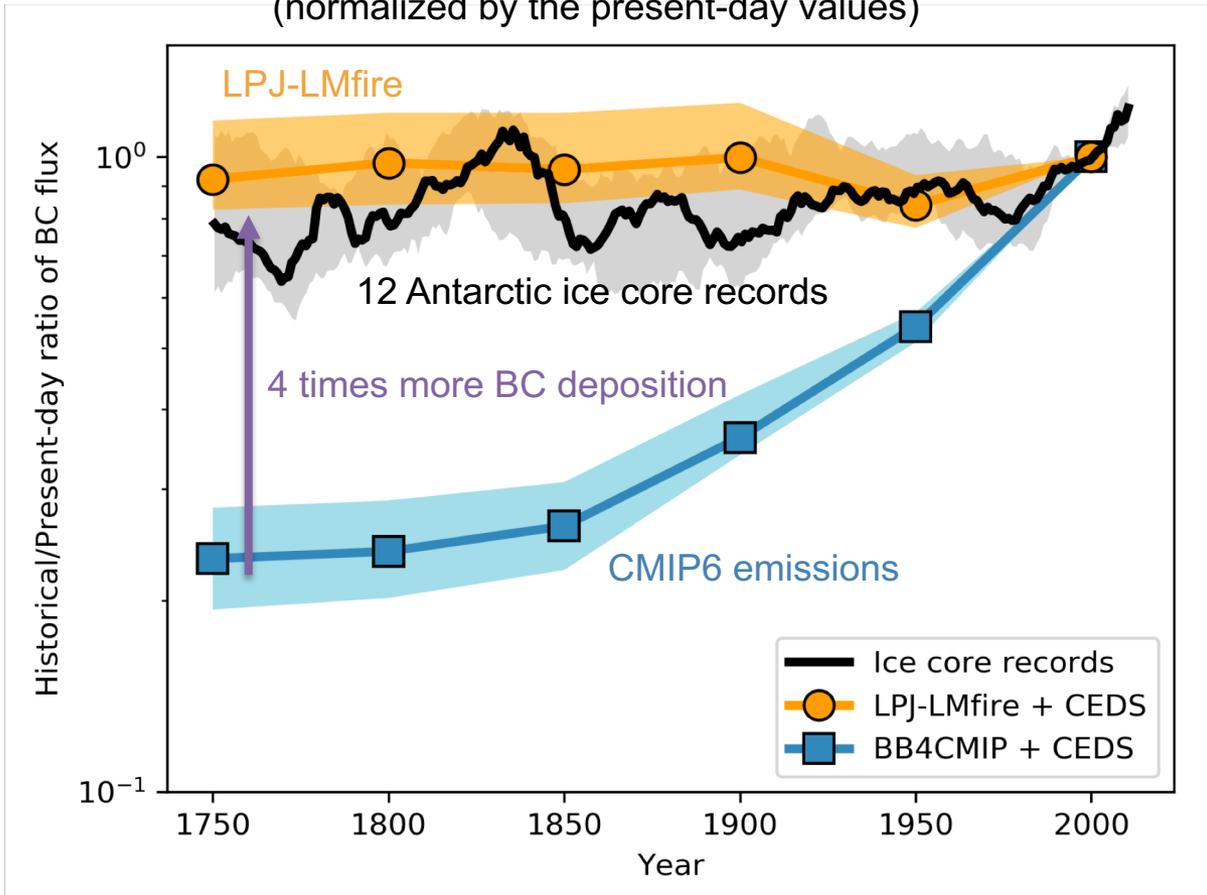
# Preindustrial (1750) to present-day (2000) changes in BC emissions: CMIP6 vs. LPJ-LMfire



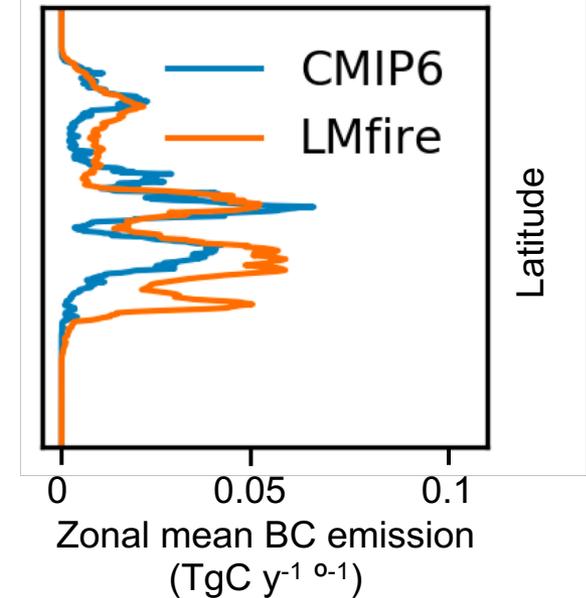
- LPJ-LMfire results are scaled to the present-day burned area observed by satellite
- CMIP6: SH BB emission in the PD is **60% higher** than that in the PI
- LPJ-LMfire: SH BB emission in the PD is **25% lower** than that in the PI
- NH BB emissions are similar

# Simulations using LPJ-LMfire agree with the Antarctica ice core records

Modeled vs. measured black carbon deposition mass fluxes (normalized by the present-day values)



BC emissions in the preindustrial era

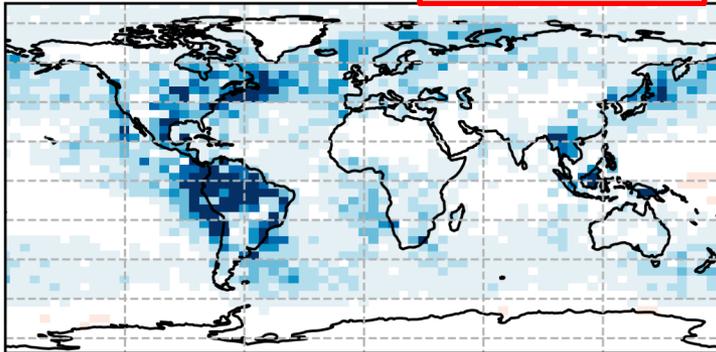


- Southern hemisphere BC emission in LMfire is 2.3 times as high as that in CMIP6
- Compared with the CMIP6, fire locations in LMfire are closer to the Antarctica

# Cloud albedo forcing of anthropogenic and fire aerosols (2000 relative to 1750)

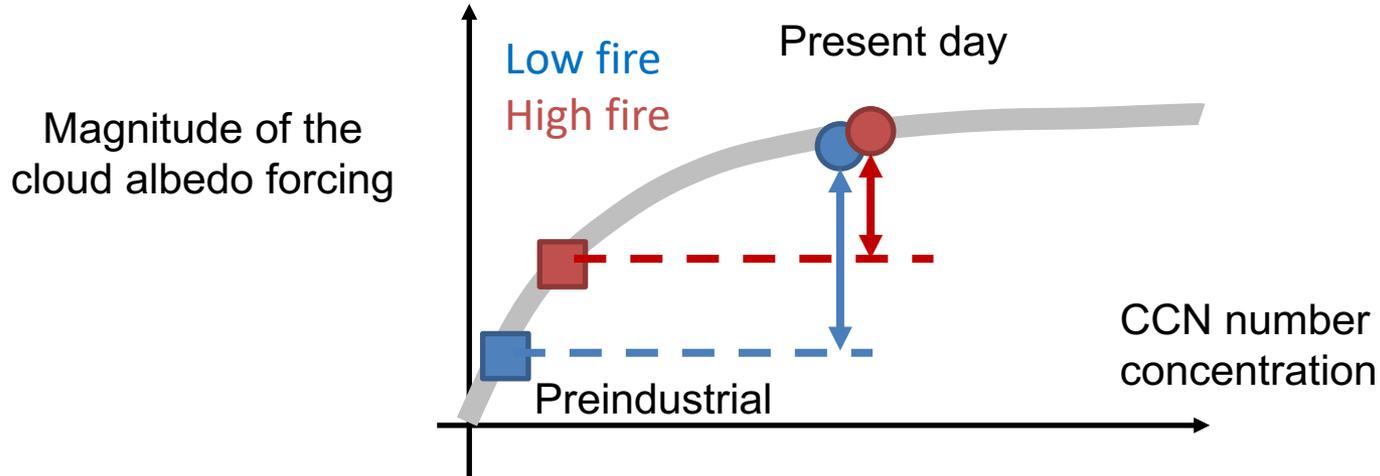
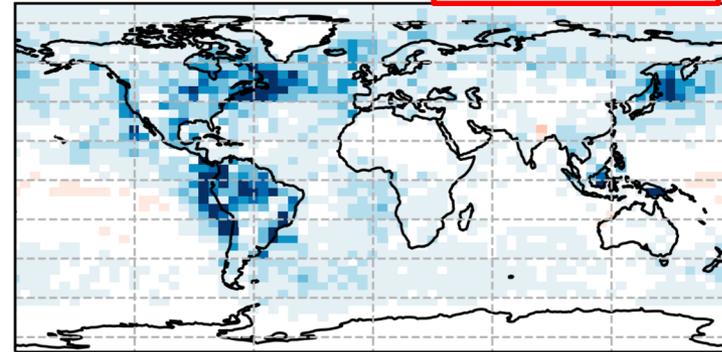
Low PI fire, CMIP6

GLOB: -0.63; NH: -0.70; SH: -0.56  $\text{W m}^{-2}$



High PI fire, LPJ-LMfire

GLOB: -0.46; NH: -0.59; SH: -0.33  $\text{W m}^{-2}$



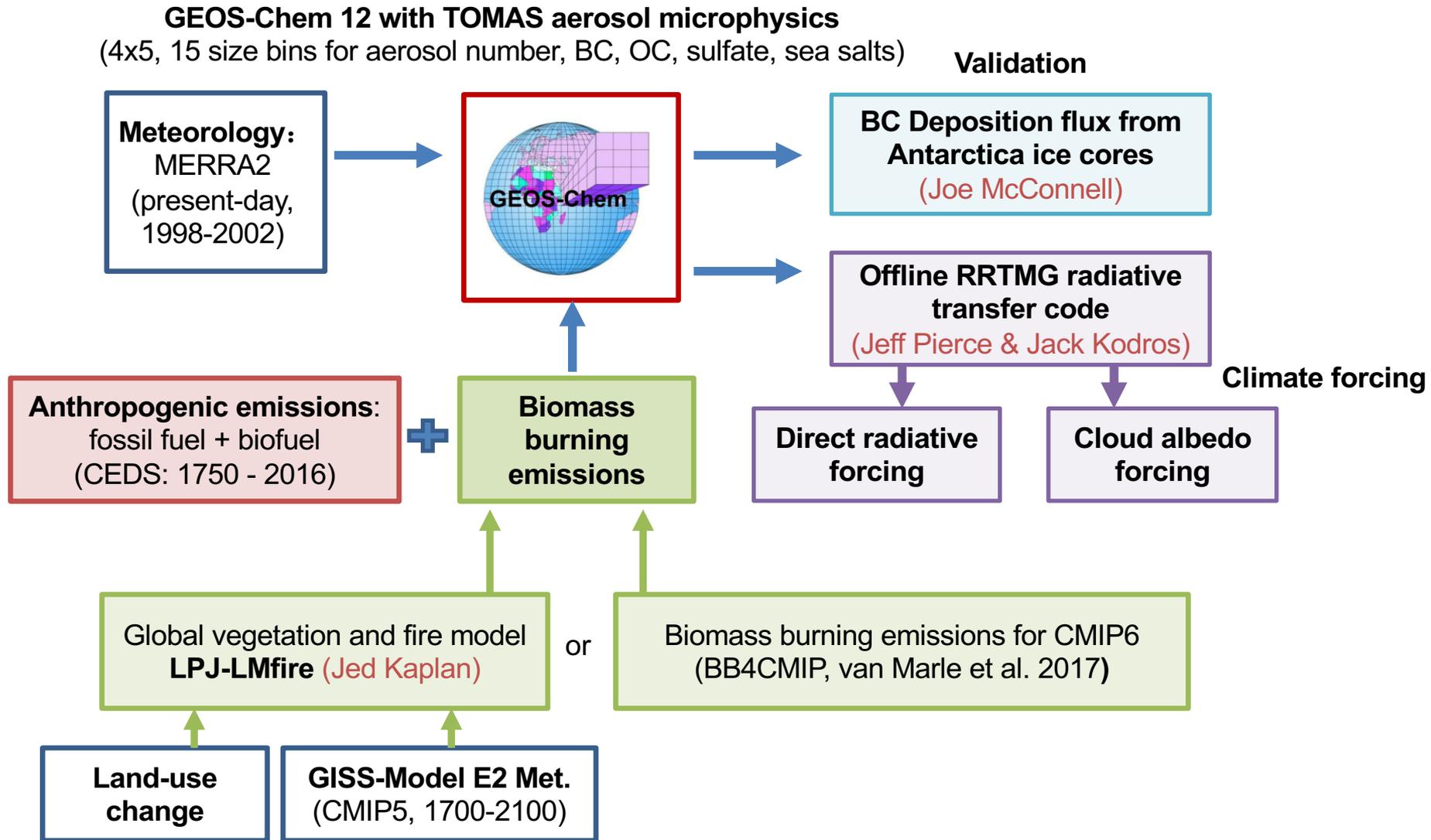
Compared with the CMIP6, higher fire emissions in the LPJ-LMfire can attenuate the magnitude of SH mean cloud albedo forcing by 40%

# Summary

---

- Black carbon records from the Antarctica ice cores suggest that preindustrial fire might be higher than the current level;
- CMIP6 emissions may underestimate the preindustrial fire strength in the southern hemisphere;
- GEOS-Chem simulation with improved fire modeling (LPJ-LMfire) considering the human-induced passive suppression can reconcile the observed BC trends in ice cores;
- New fire emissions can attenuate the cloud albedo forcing by 40% in the southern hemisphere.

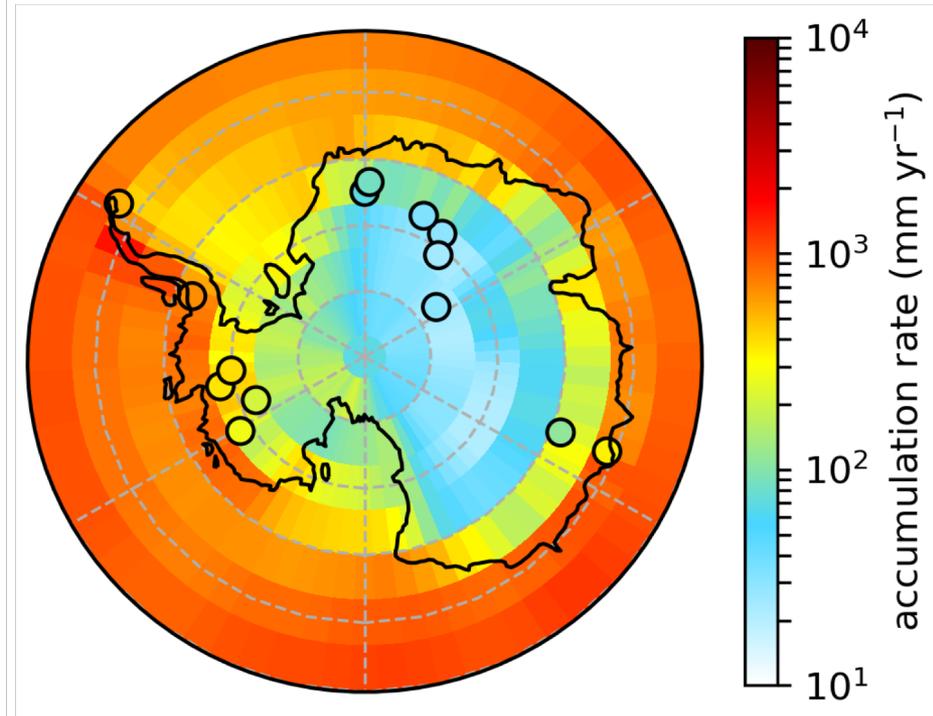
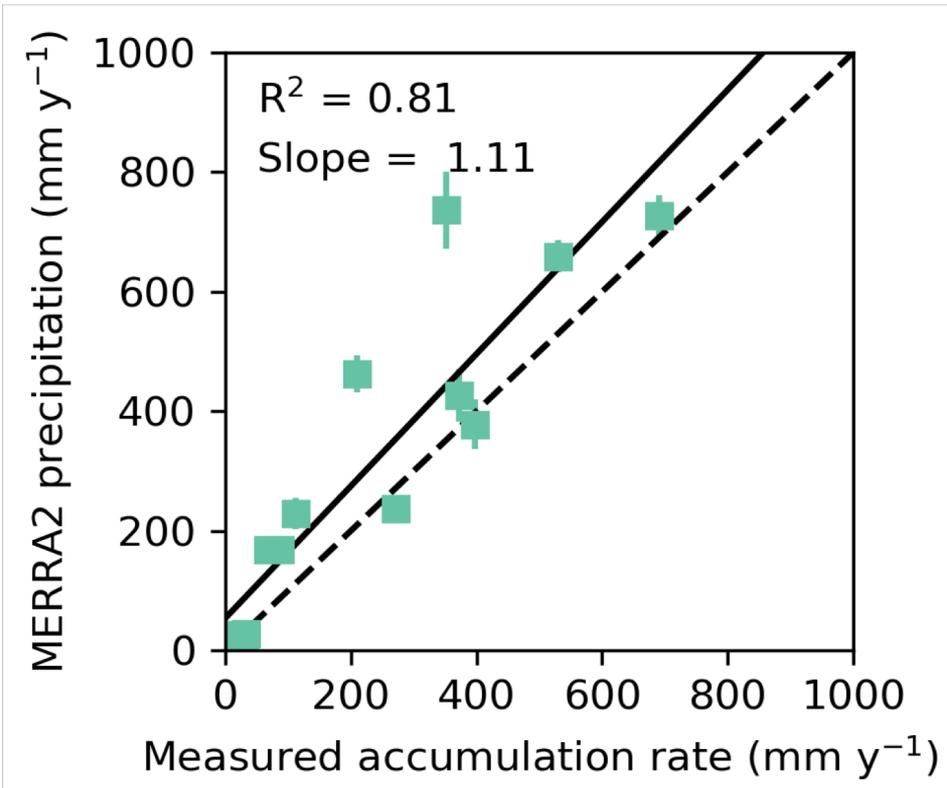
# Model framework of historical aerosol simulations (1750-2000)



Simulations for 6 time slices from 1750 to 2000 at 50-year intervals

# Model validation: Present-day MERRA2 annual precipitation agrees well with accumulation rates derived from ice core annual layers

MERRA2 precipitation vs. ice core accumulation rates



measured accumulation rate  
from annual layer of conductivity

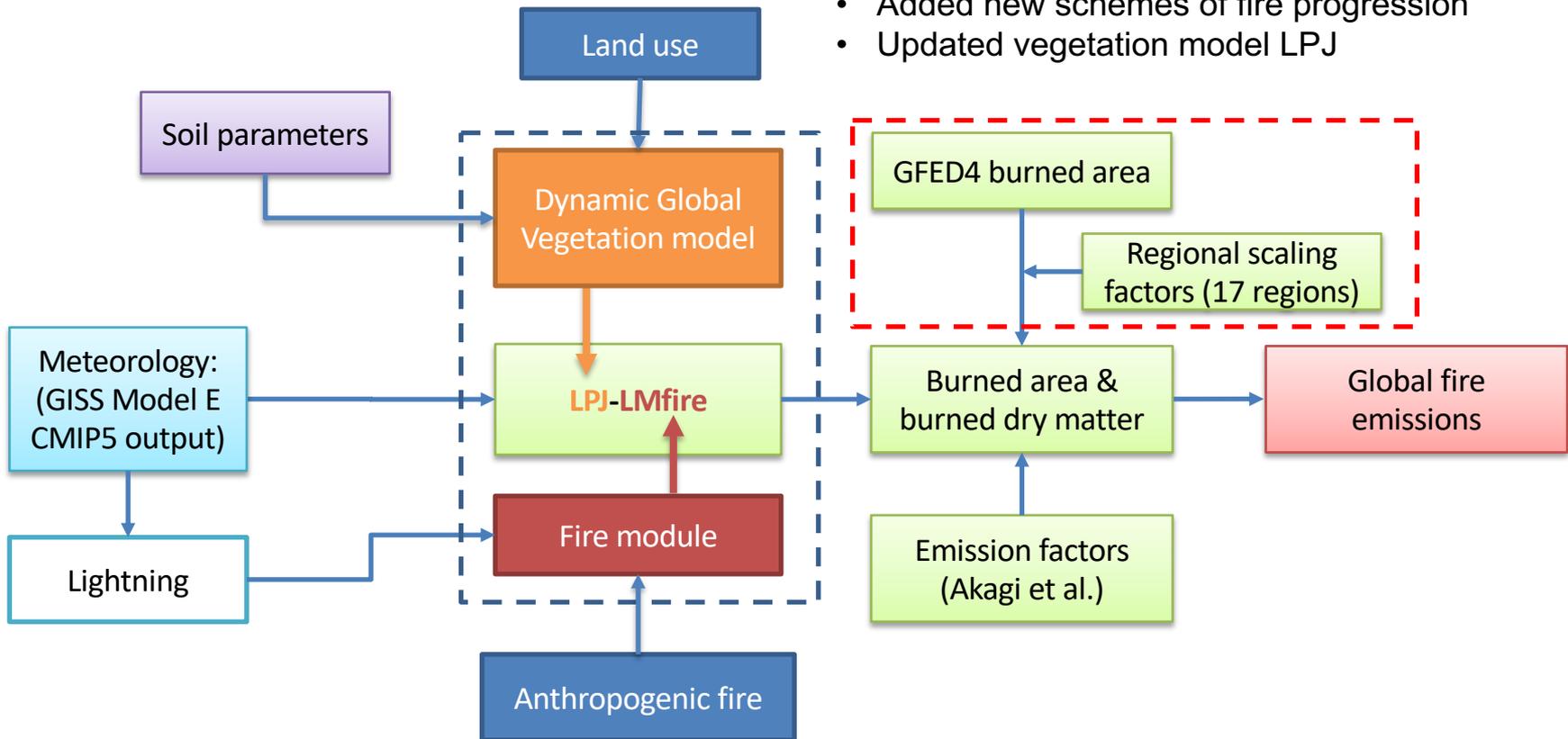


Measured BC flux = BC concentration in ice × accumulation rate

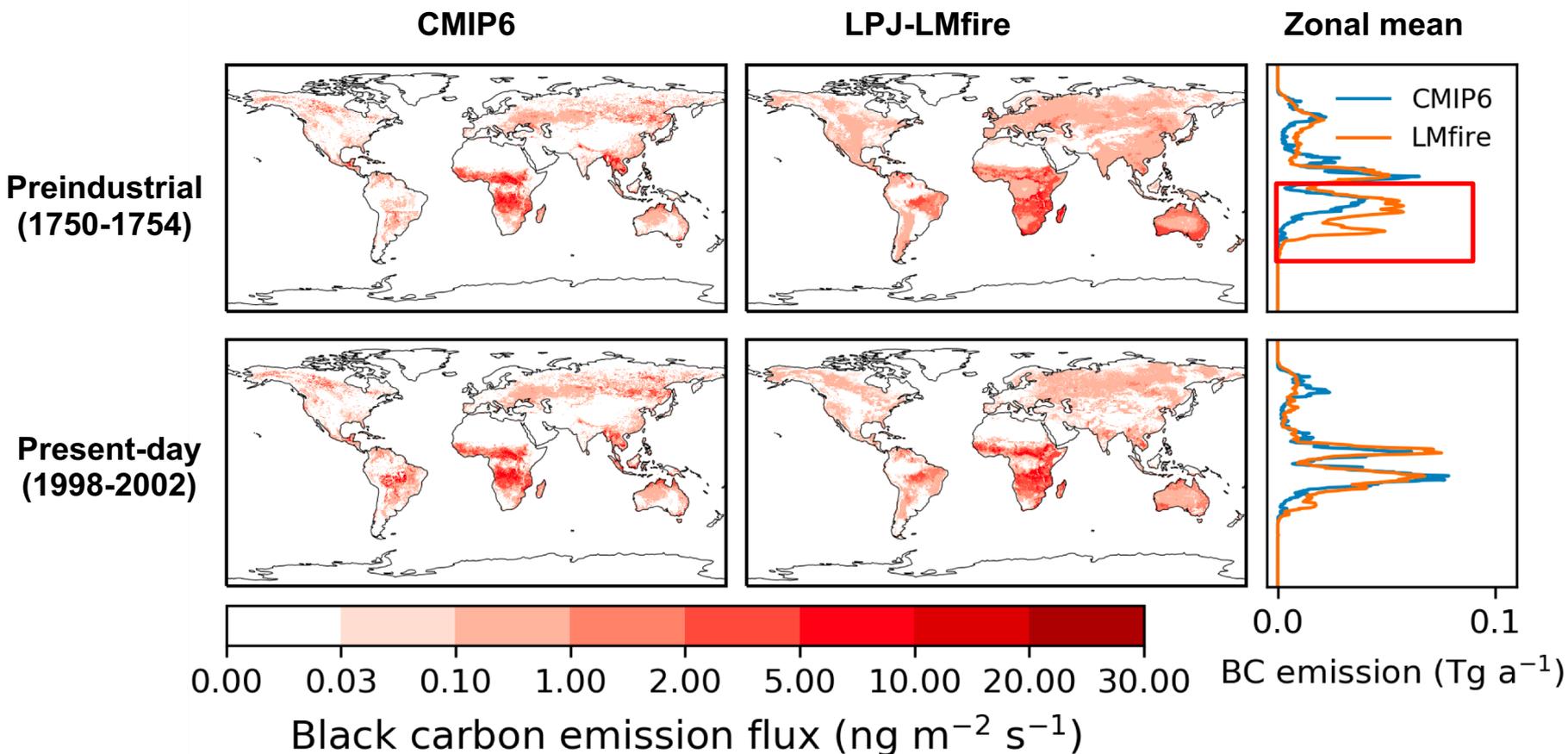
# Improved modeling of global fire activity (LPJ-LMfire, 1700-2100, collaborator: Jed Kaplan)

LPJ-LMfire (an improved version of LPJ-SPITFIRE)

- Improved anthropogenic fire scheme
- **Considered passive fire suppression by landscape fragmentation**
- Added new schemes of fire progression
- Updated vegetation model LPJ



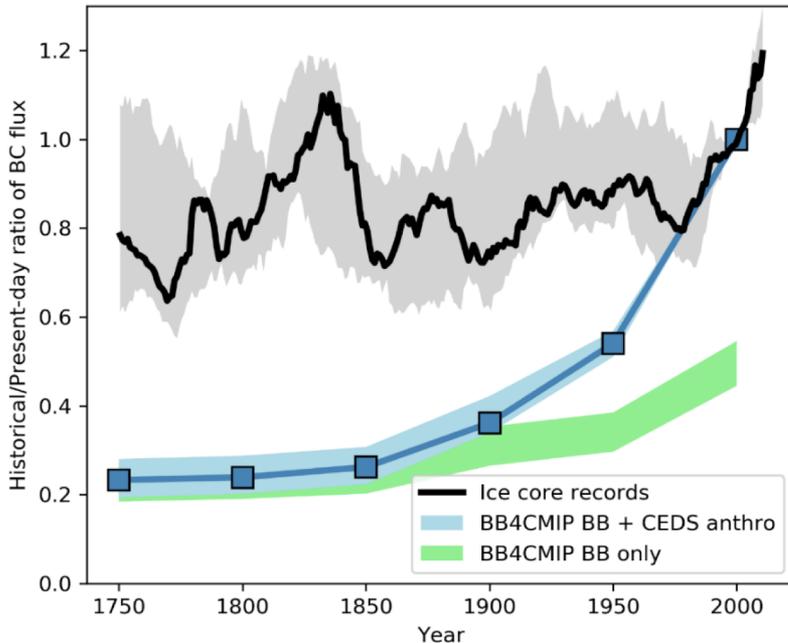
# Historical fire emissions: LPJ-LMfire (high PI fire) vs. CMIP6 (low PI fire)



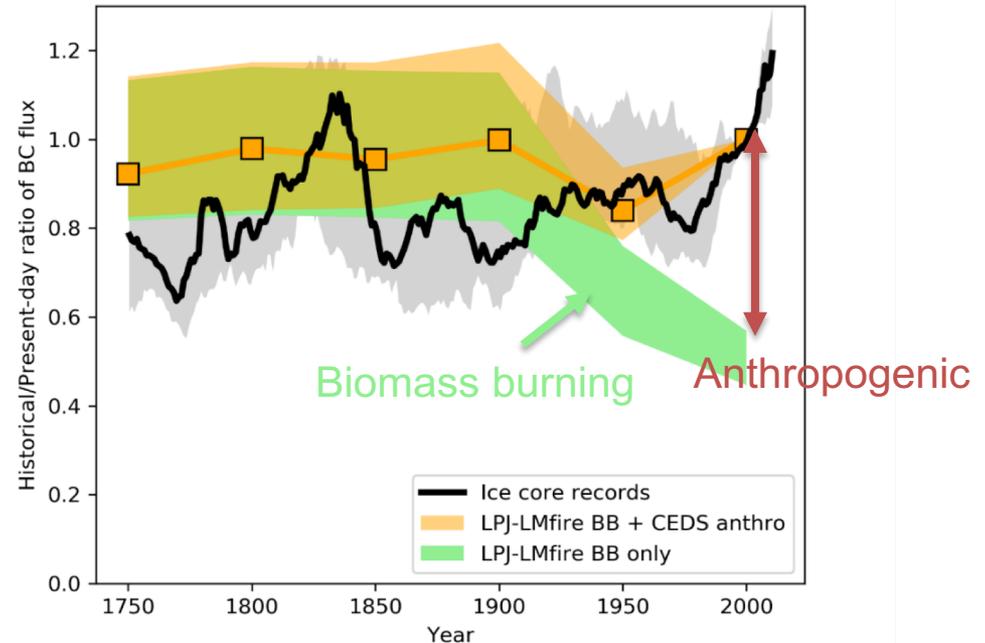
- Preindustrial:
  - SH BB emission in the LPJ-LMfire is ~2.3 times of that in the CMIP6
  - Two inventories have similar total emissions in the NH
- Present-day
  - Emissions are similar because the burned area from the LPJ-LMfire is calibrated to that in GFED4

# Comparison of the BC flux ratios simulated using two biomass burning emission inventories

CMIP6 (biomass burning) +  
CEDS (biofuel + fossil fuel)



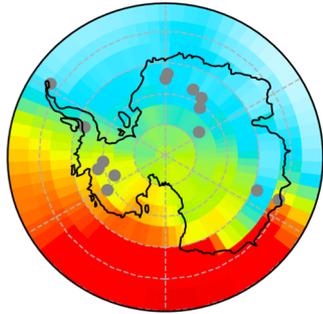
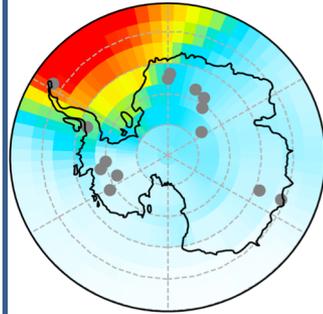
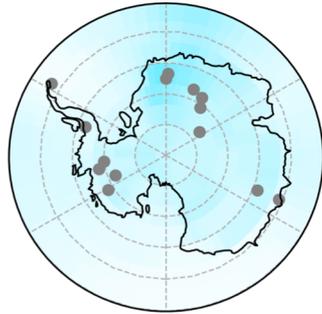
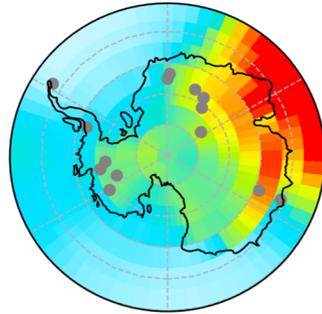
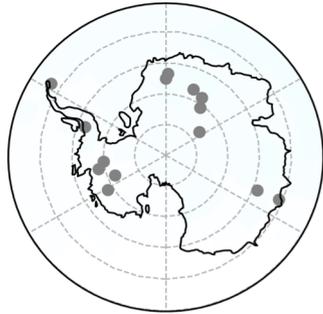
LPJ-LMfire (biomass burning) +  
CEDS (biofuel + fossil fuel)



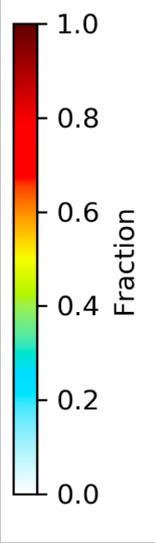
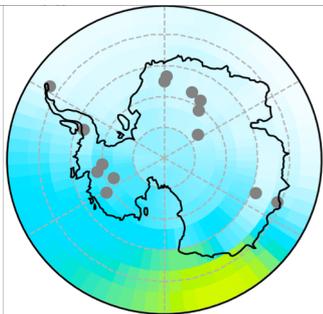
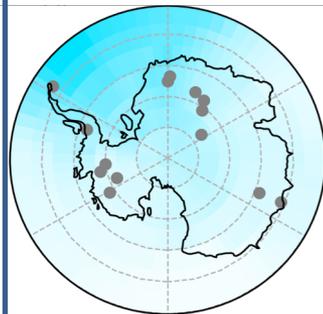
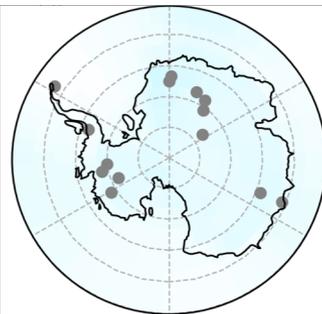
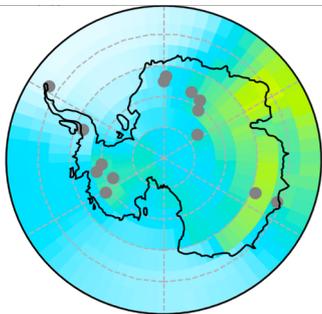
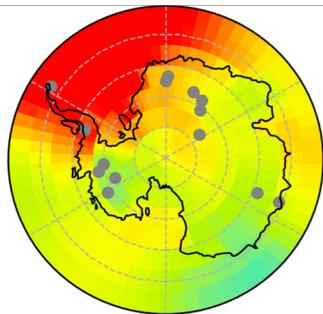
- Total BC deposition flux over the Antarctica did not change much from the preindustrial to the present day.
- In the LPJ-LMfire, the decrease in biomass burning can compensate the increase in anthropogenic emissions.

# The contribution of Antarctic BC deposition from anthropogenic emissions and biomass burning from different regions (CEDS + LPJ-LMfire)

Preindustrial (1750)



Present-day (2000)



Anthropogenic

Southern Hemisphere  
Africa (SHAF)

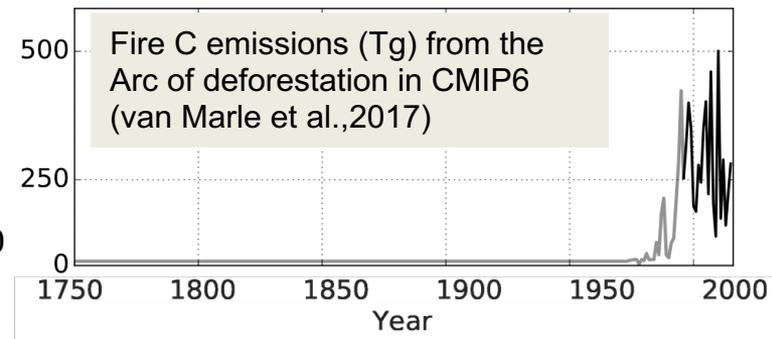
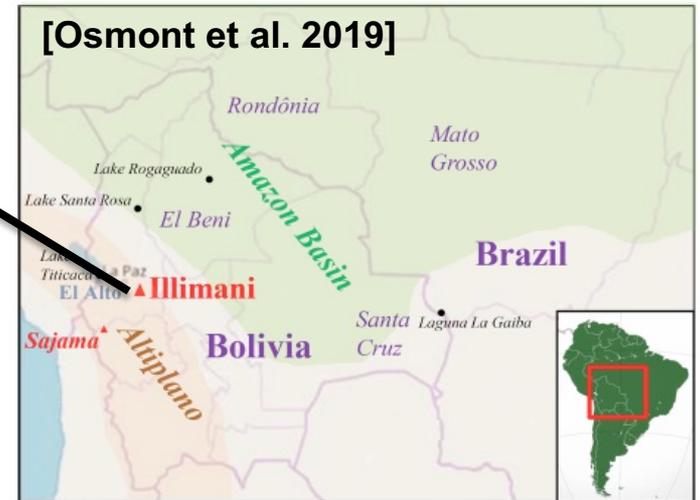
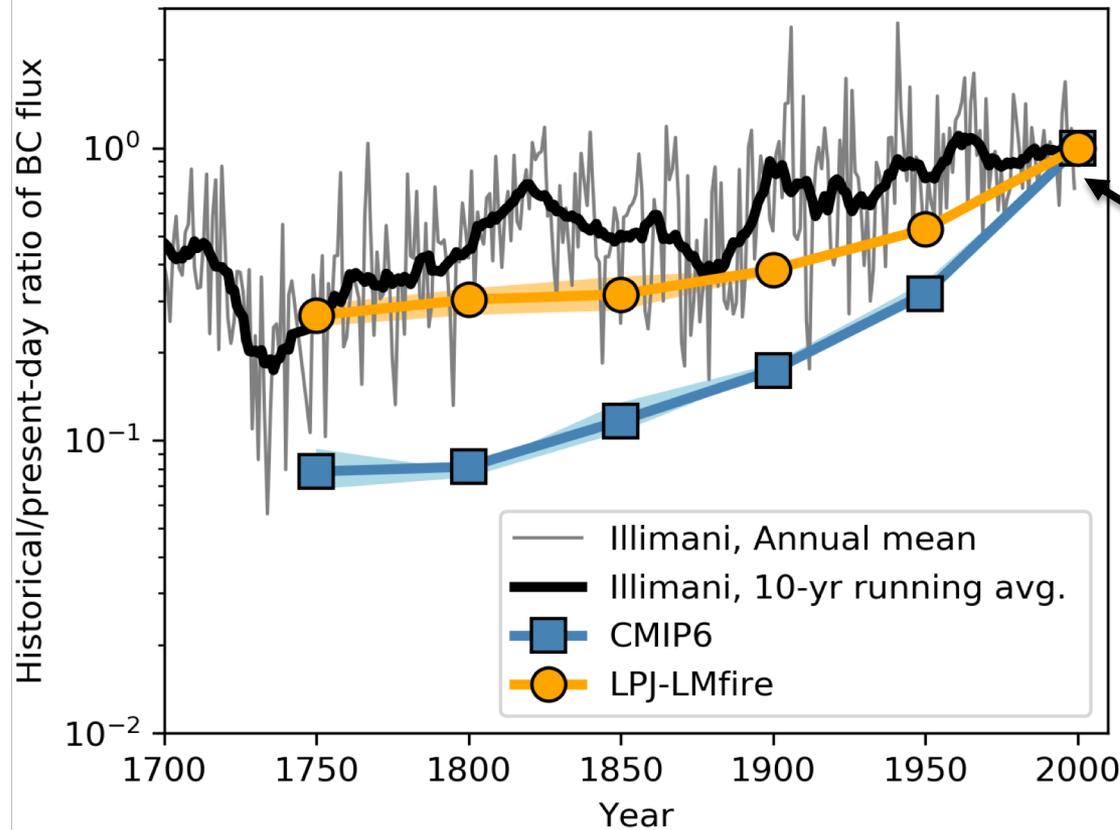
Arc of Deforestation  
(ARCD)

South of the Arc of  
Deforestation (SARC)

Australia (AUST)

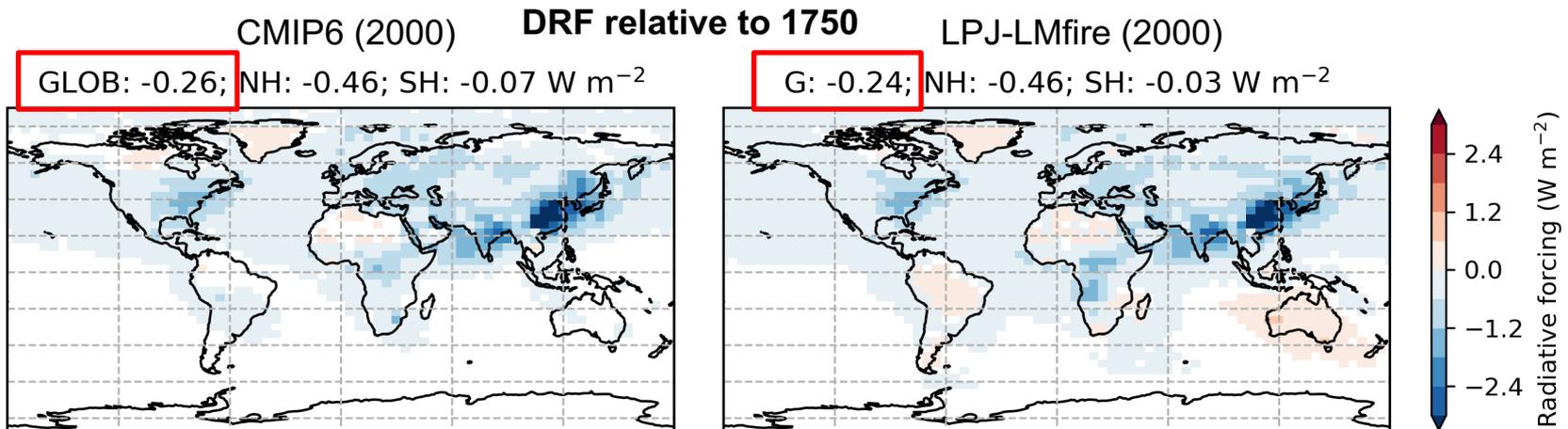
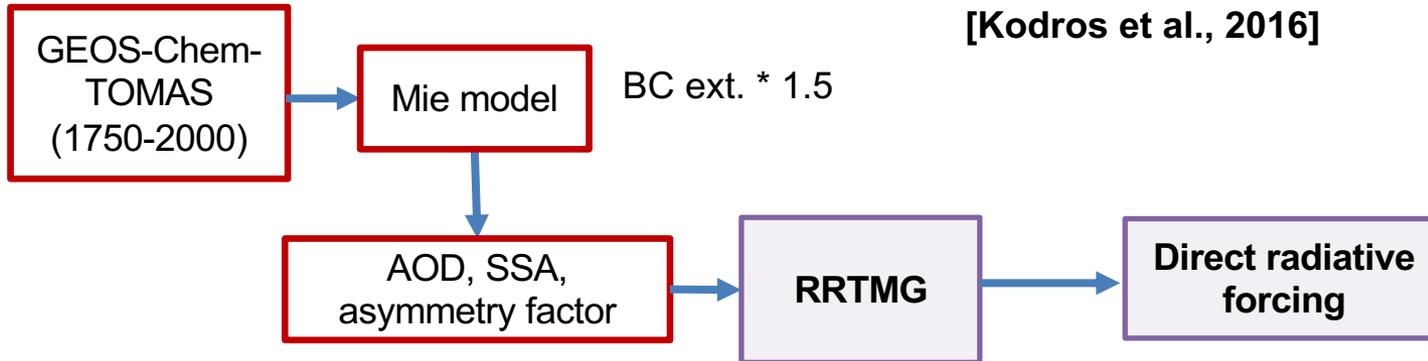
Caveat: Fire emissions from the Amazonia region are poorly constrained by the Antarctica ice core records.

# Comparison with an Andean ice-core record near the Amazon Basin (Data source: Michael Sigl)



- Comparison with an Andean ice core suggests that the CMIP6 emission inventory may underestimate preindustrial biomass burning emissions from the Amazon basin.
- The increase of BC deposition can be mainly explained by the increasing anthropogenic emissions.

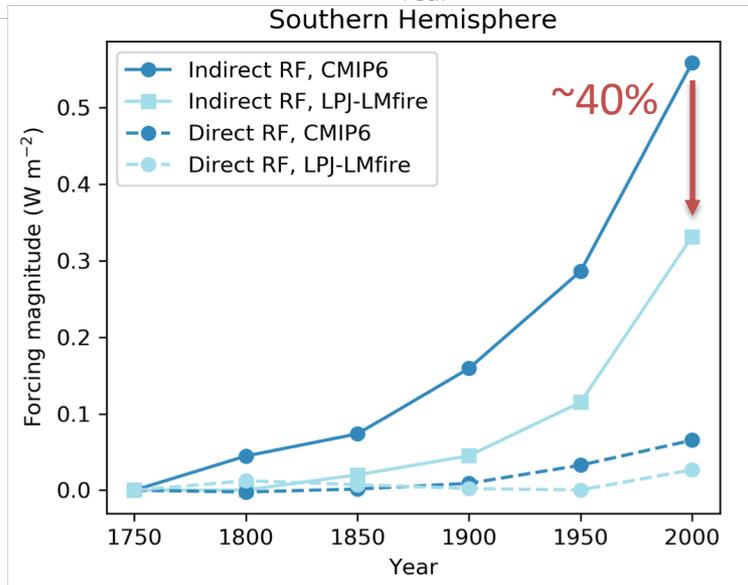
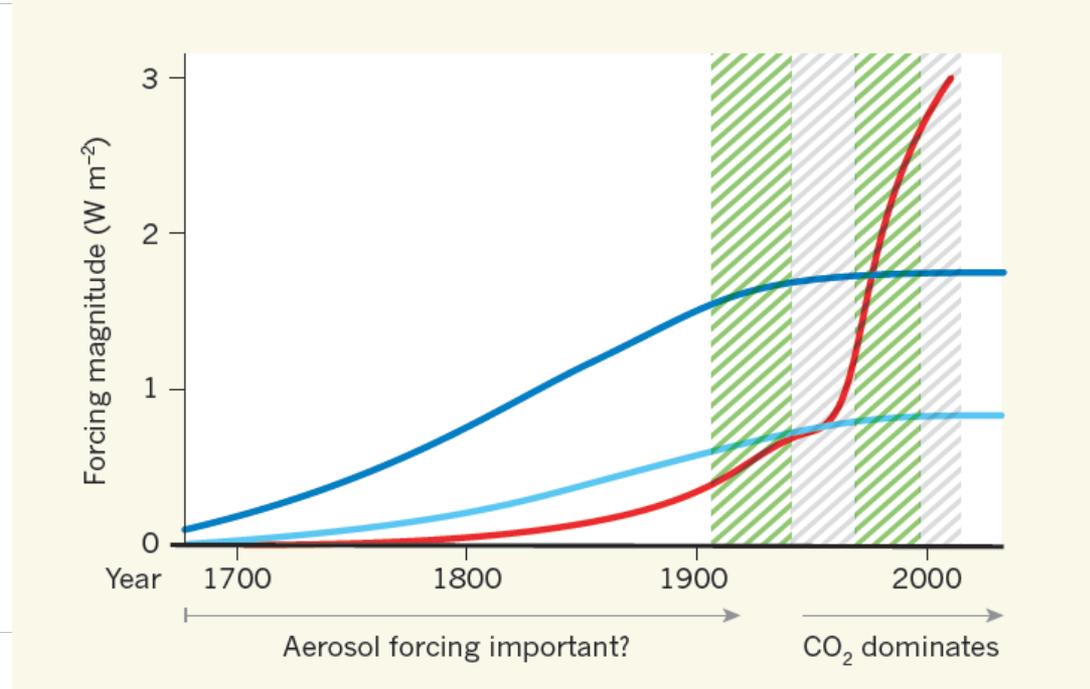
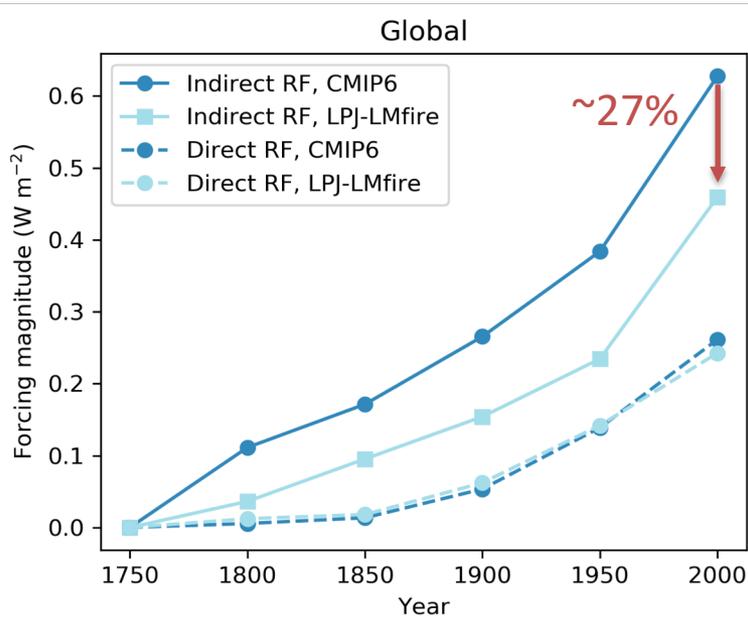
# Offline scheme for direct radiative forcing (DRF)



## CMIP6 to LPJ-LMfire:

- The magnitude of global mean DRF decreases  $0.02 \text{ W m}^{-2}$
- May change the sign of DRF in some regions of the SH, e.g., Australia, South America, because of the difference in fire trends
- Caveat: BB DRF is uncertain, sensitive to the assumption of optical properties

# Fire emissions can significantly influence the magnitude and history of cloud albedo forcing



CLIMATE SCIENCE

Uncertain then, ✓  
irrelevant now ?

[Stevens, Nature, 2013]