Quantifying emission and radiative forcing of anthropogenic dust

Xiaohong Liu[1], Yang Shi[1,2], Chenglai Wu[3], Zheng Lu[1], Kai Zhang[4], Po-Lun Ma[4]

[1] Texas A&M University, USA

[2] Now at MIT, USA

[3] Institute of Atmospheric Physics, CAS, China

[4] Pacific Northwest National Laboratory, USA

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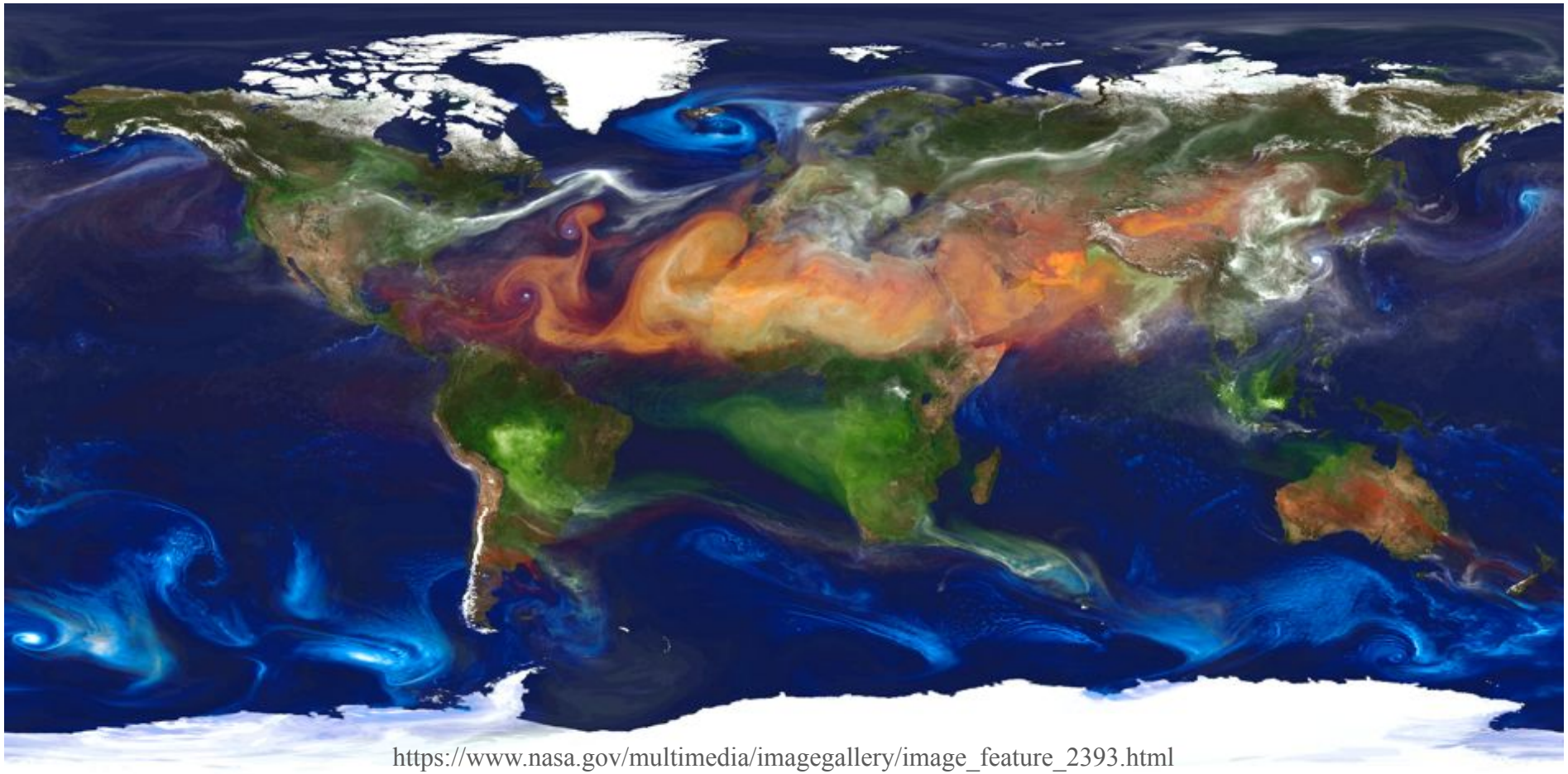
U.S. DEPARTMENT OF ENERGY

Dust aerosols have critical impacts on global climate

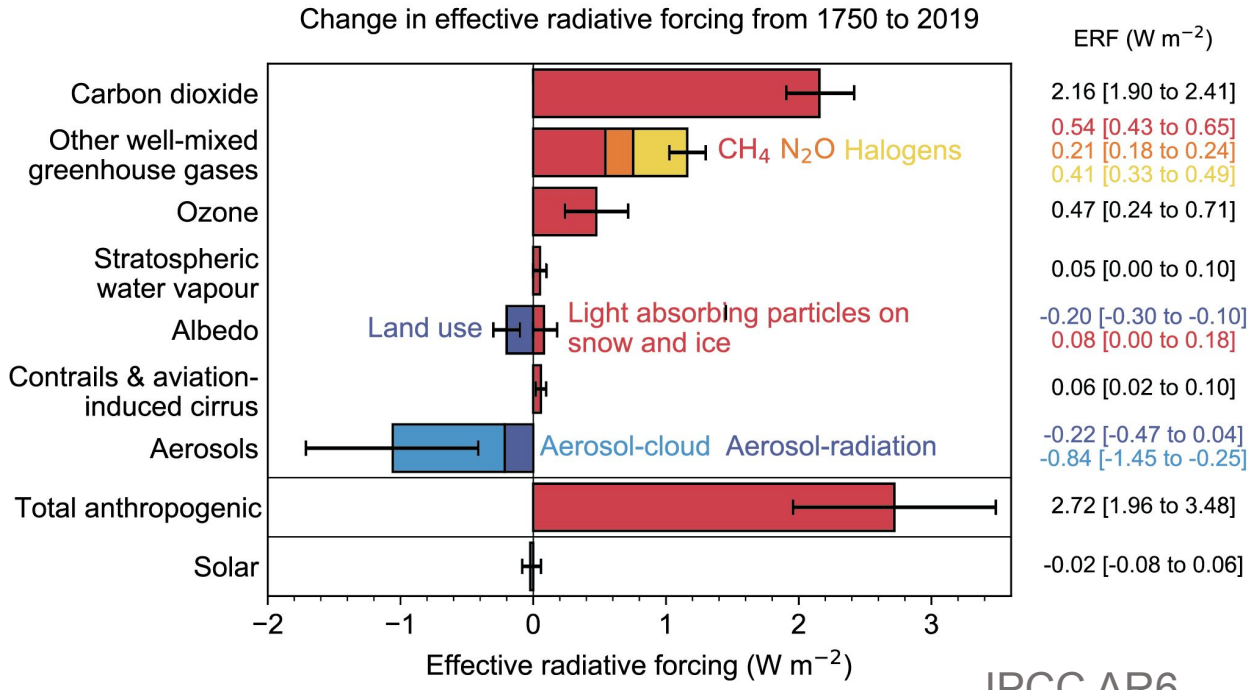


https://www.nasa.gov/multimedia/imagegallery/image_feature_2393.html

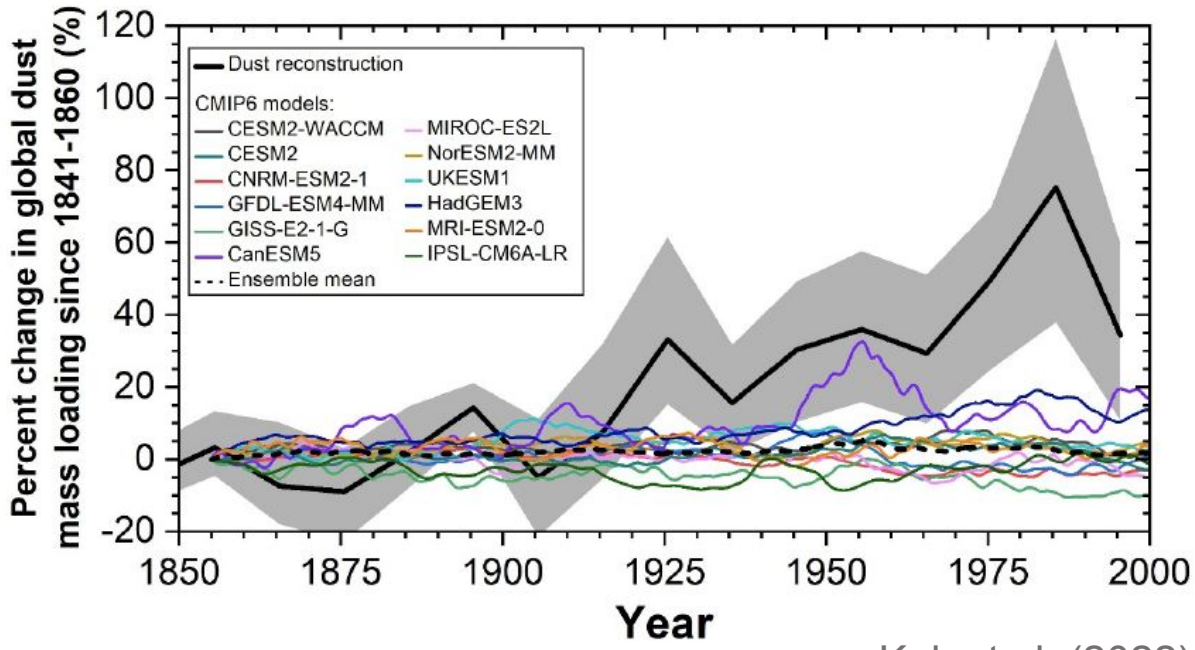
Dust: red;
Sea Salt: blue;
Black carbon: green;
Organic carbon: green;
Sulfate: white

- Dust is the most abundant aerosol in the atmosphere.
- Dust was generally regarded as natural aerosols (i.e., natural dust (ND)).

Global dust burden from pre-industrial (PI) to present day (PD)



IPCC AR6



Kok et al. (2022)

IPCC AR6 does not consider dust when estimating aerosol effective radiative forcing.

Dust burden increases from PI to PD, which cannot be captured by global climate models.

How are dust emissions related to anthropogenic activities?

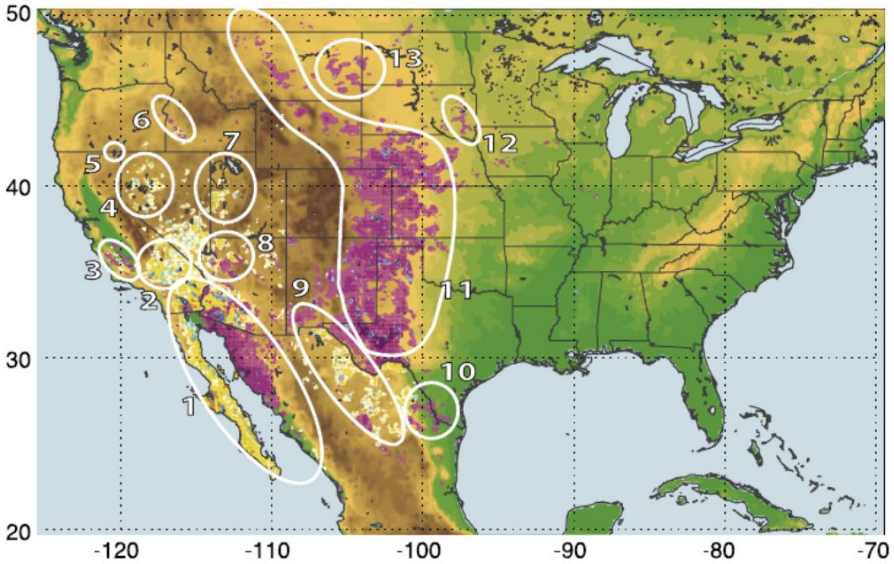
Wind erosion caused by **land use** change

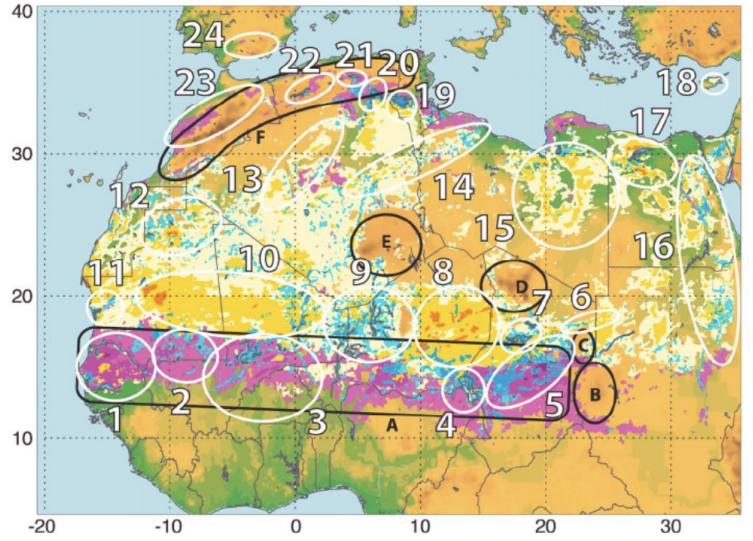
Direct emission by anthropogenic activities

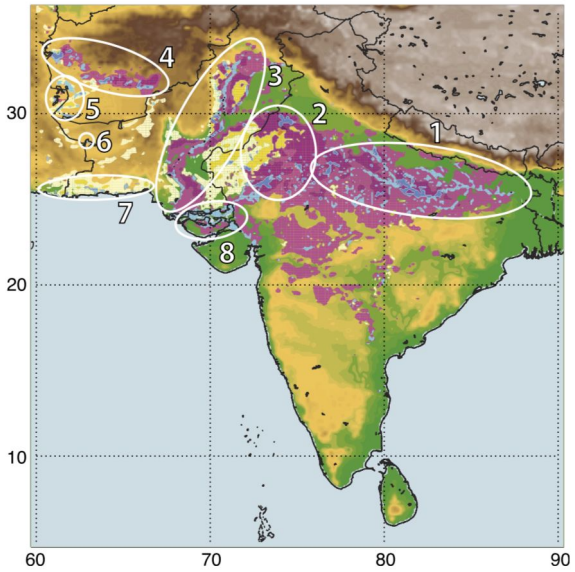
Dust emission indirectly related to **climate change**

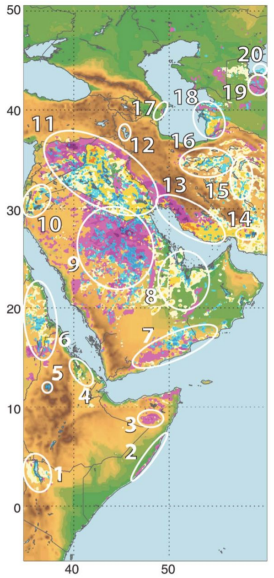
Soil moisture, wind, vegetation cover change due to climate change

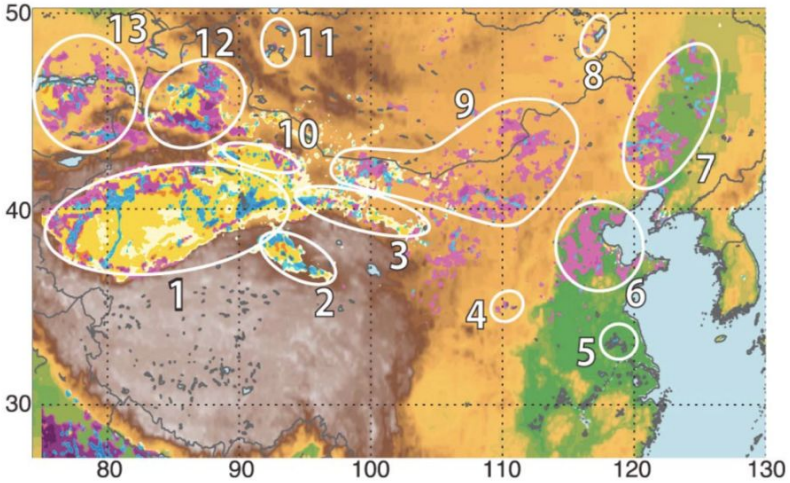
Estimate of land use change related anthropogenic dust (AD) sources by Ginoux et al. (2012)











AD sources in purple.

- Based on MODIS dust optical depth and a land use dataset
- AD sources account for 25% of global dust emission.

Represent **agricultural** anthropogenic dust (AD) in DOE's Energy Exascale Earth System Model version 1 (E3SMv1)

Zender et al. (2003) – dust emission parameterization used in E3SMv1

$$F = TS_{geo} f_m \alpha Q_s$$

T	Global tuning factor
S_{geo}	Soil erodibility factor
f_m	Grid cell fraction of exposed bare soil
α	Sandblasting mass efficiency
Q_s	Total horizontally saltating mass flux

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$$F = TS_{geo} f_m \alpha Q_s \quad \square \quad F = T_{AD} f_{m,AD} \alpha Q_{s,AD} + TS_{geo} f_{m,ND} \alpha Q_s$$

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$$F = TS_{geo} f_m \alpha Q_s$$

Grid cell fraction of exposed bare soil

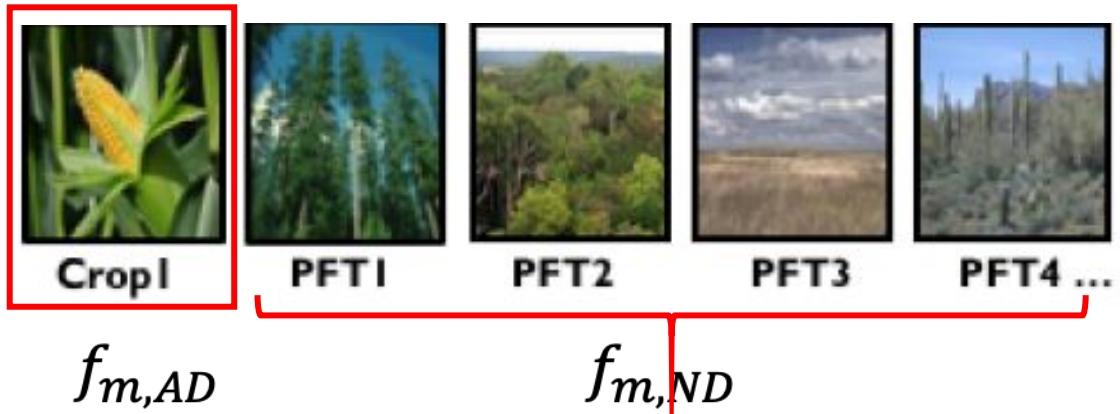
$$f_m = f(\textit{leaf area index})$$

$$F = T_{AD} f_{m,AD} \alpha Q_{s,AD} + TS_{geo} f_{m,ND} \alpha Q_s$$

No S_{geo}

Tuned based on soil moisture

Plant function types (PFTs) in land component



By using different land use dataset, we can investigate the dust emission in the past and the future climate.

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$$F = TS_{geo} f_m \alpha Q_s \quad \square \quad F = T_{AD} f_{m,AD} \alpha Q_{s,AD} + TS_{geo} f_{m,ND} \alpha Q_s$$

Experiments	**CTRL**	**NEW**
Runtime period	2001 to 2010	
Resolution	1 degree, 72 vertical layers	
Meteorology	Horizontal winds nudged to MERRA2 data	

Both simulations use 2000 land surface dataset in the land component of the model.

AD emission is added to a separate tracer in NEW to explicitly track it in the model

Dust emissions in present day (PD)

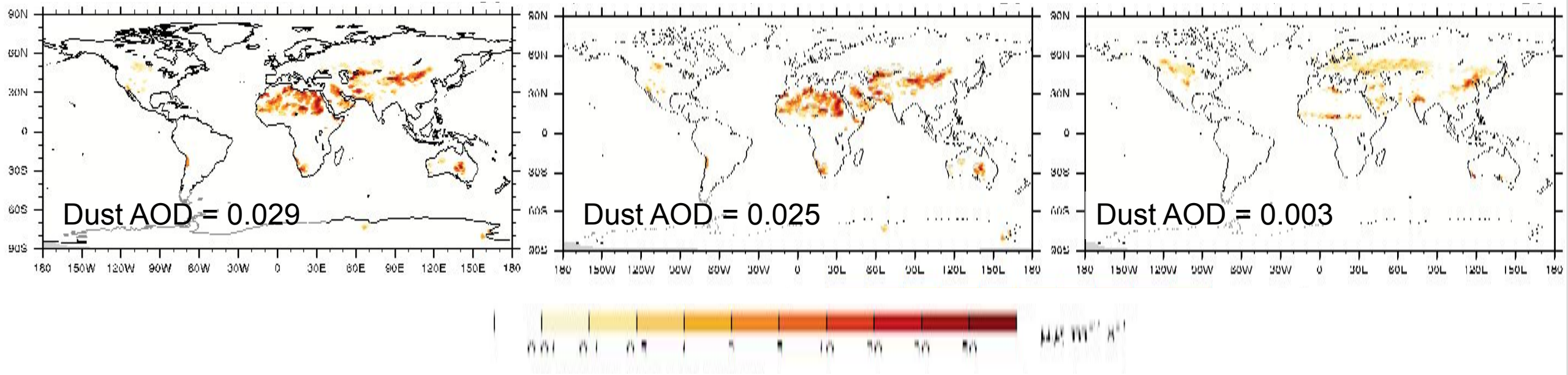
CTRL

NEW

Dust emission (4106 Tg/yr)

ND emission (3695 Tg/yr)

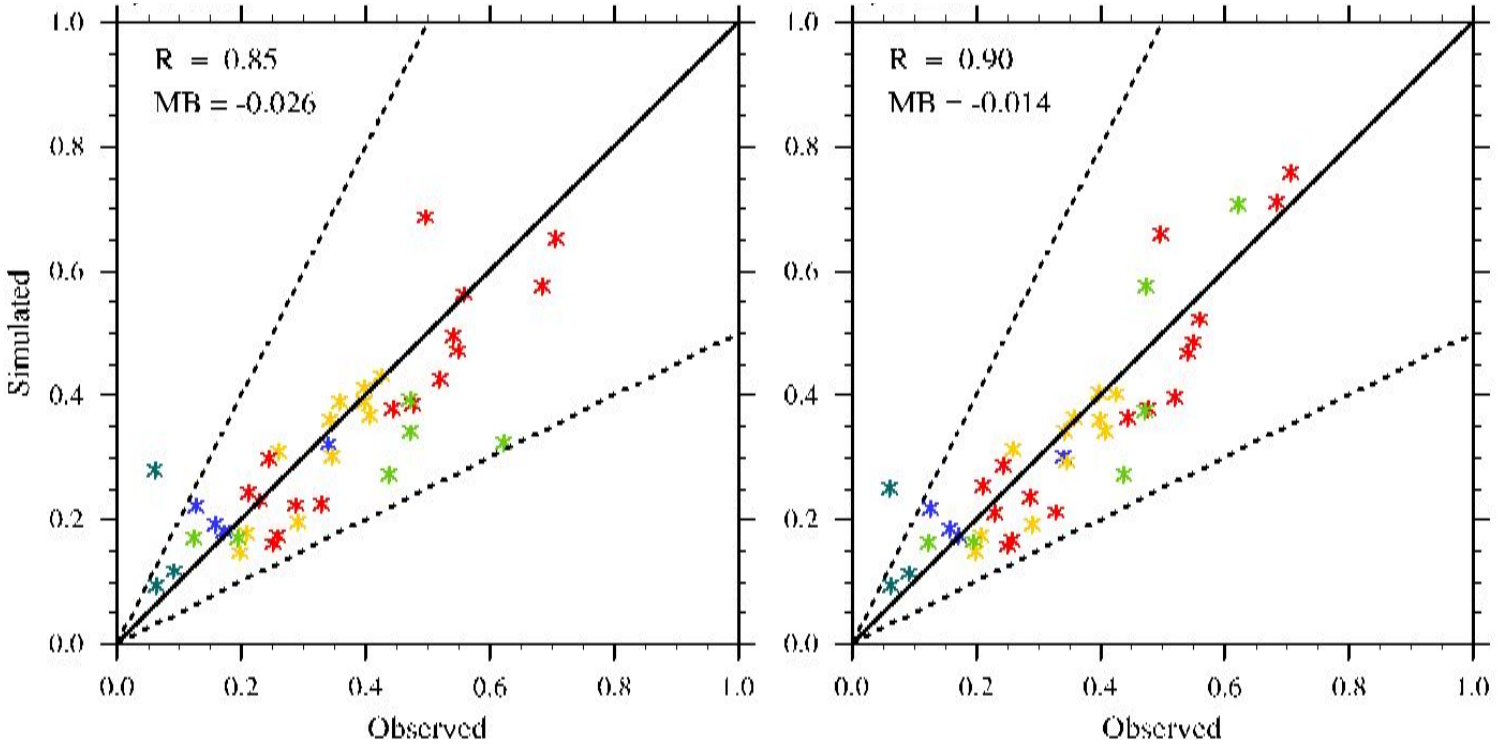
AD emission (567 Tg/yr)



Our method can generally capture the AD sources. The AD emissions contribute ~13% of global dust emissions.

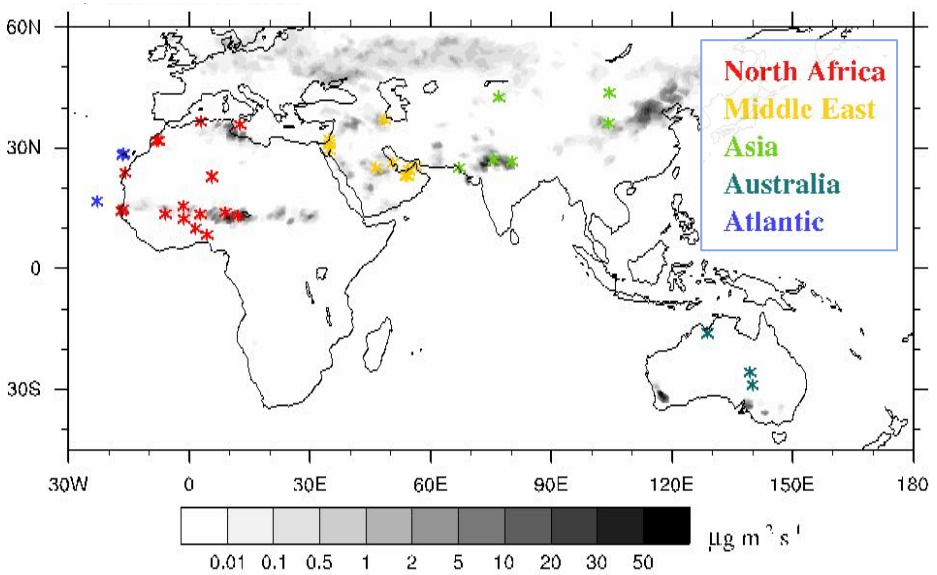
AERONET aerosol optical depth (AOD) comparison

CTRL



NEW

Location of AERONET sites



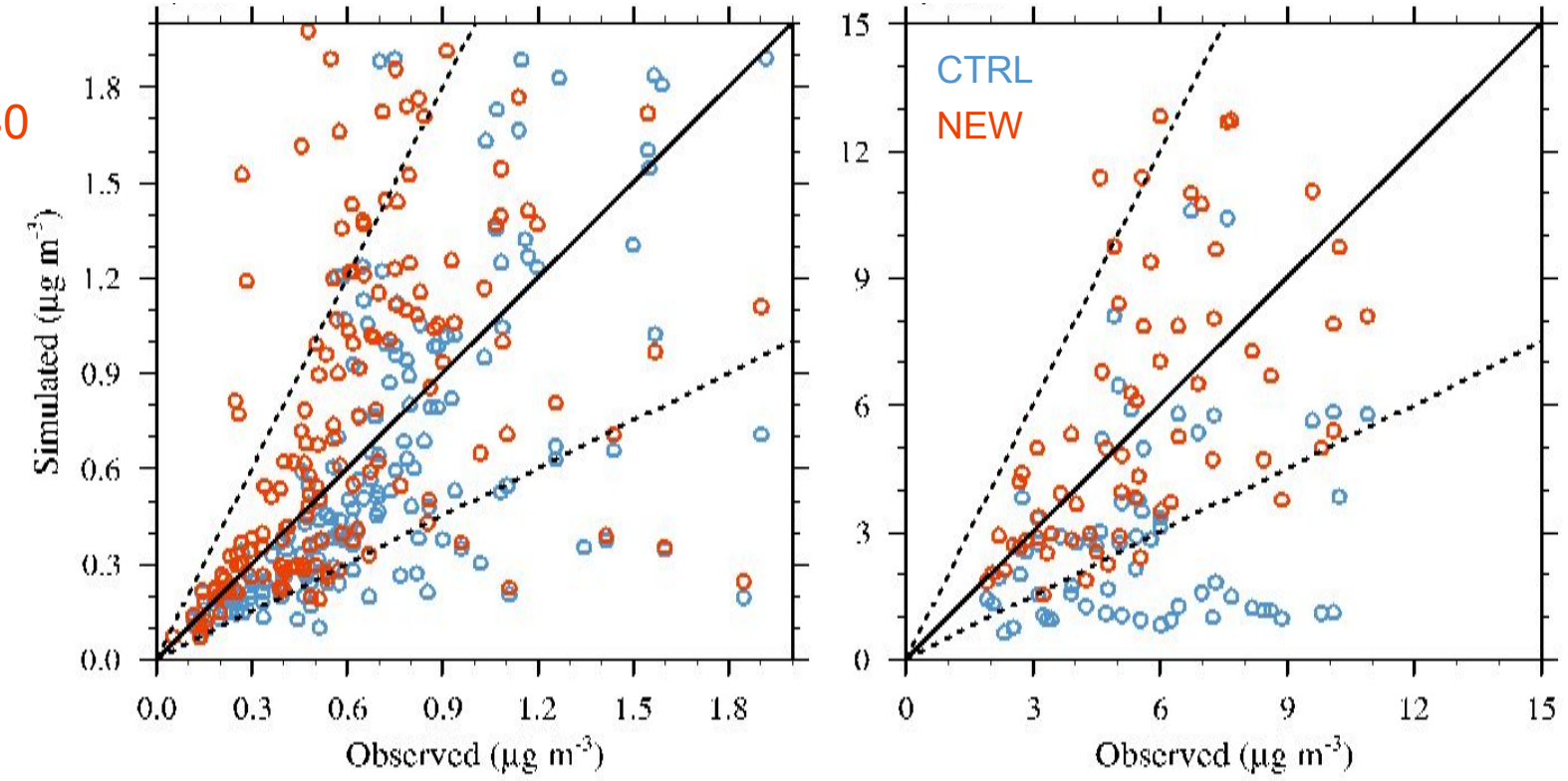
Compared to baseline E3SMv1, our parameterization shows slight improvement of simulating AOD near dust source regions.

Comparison with the US IMPROVE network

Fine dust mass
(PM2.5)

Coarse aerosol mass
(PM2.5 – PM10)

R = 0.68, 0.50
MB = -0.10, 0.40



R = 0.36, 0.48
MB = -3.23, -0.44

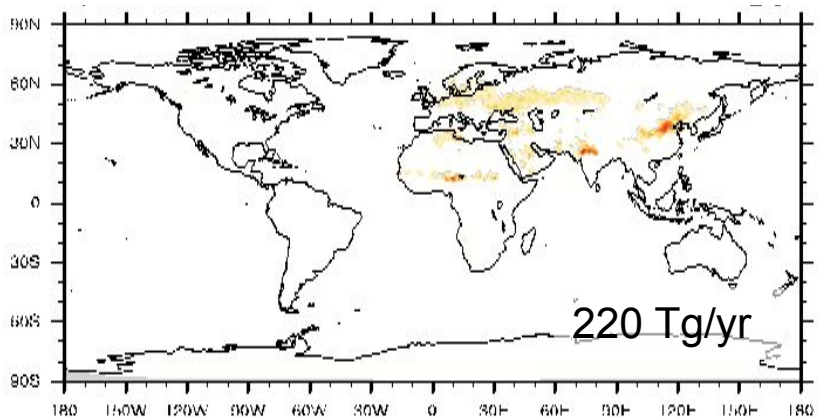
NEW shows overestimation in fine dust mass compared to CTRL, while the mean bias in simulating coarse aerosol mass decreases in NEW.

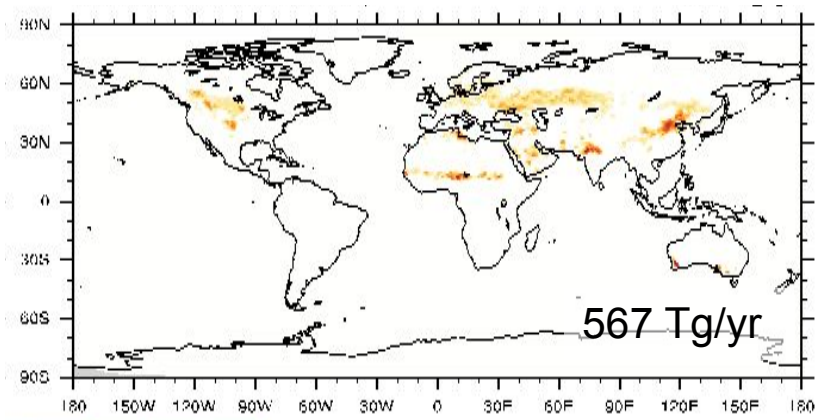
AD emission change from PI to PD

PI (Same as NEW, but w/ PI land use)

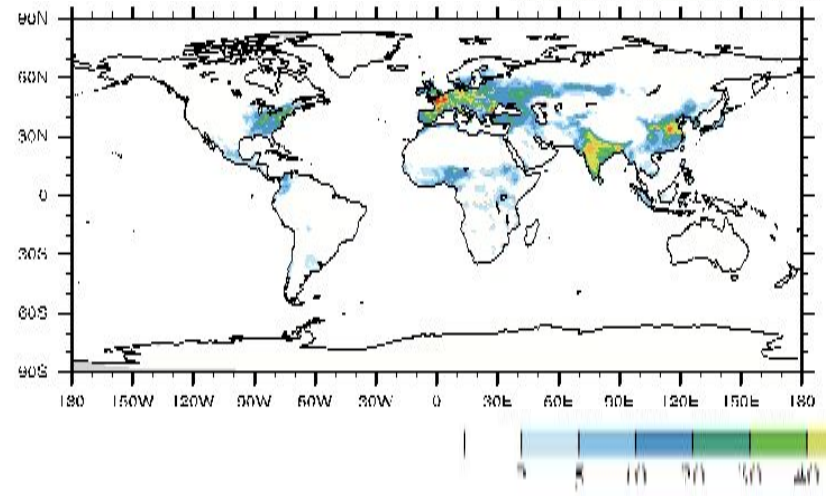
PD (NEW experiment)

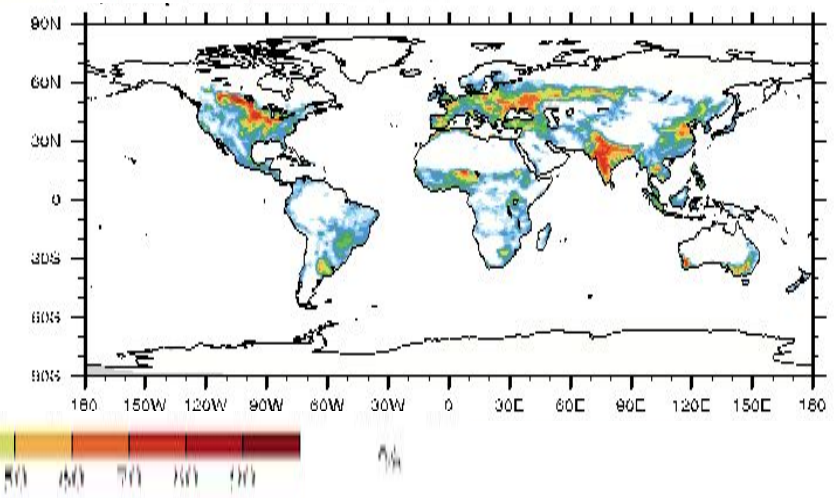
AD emission





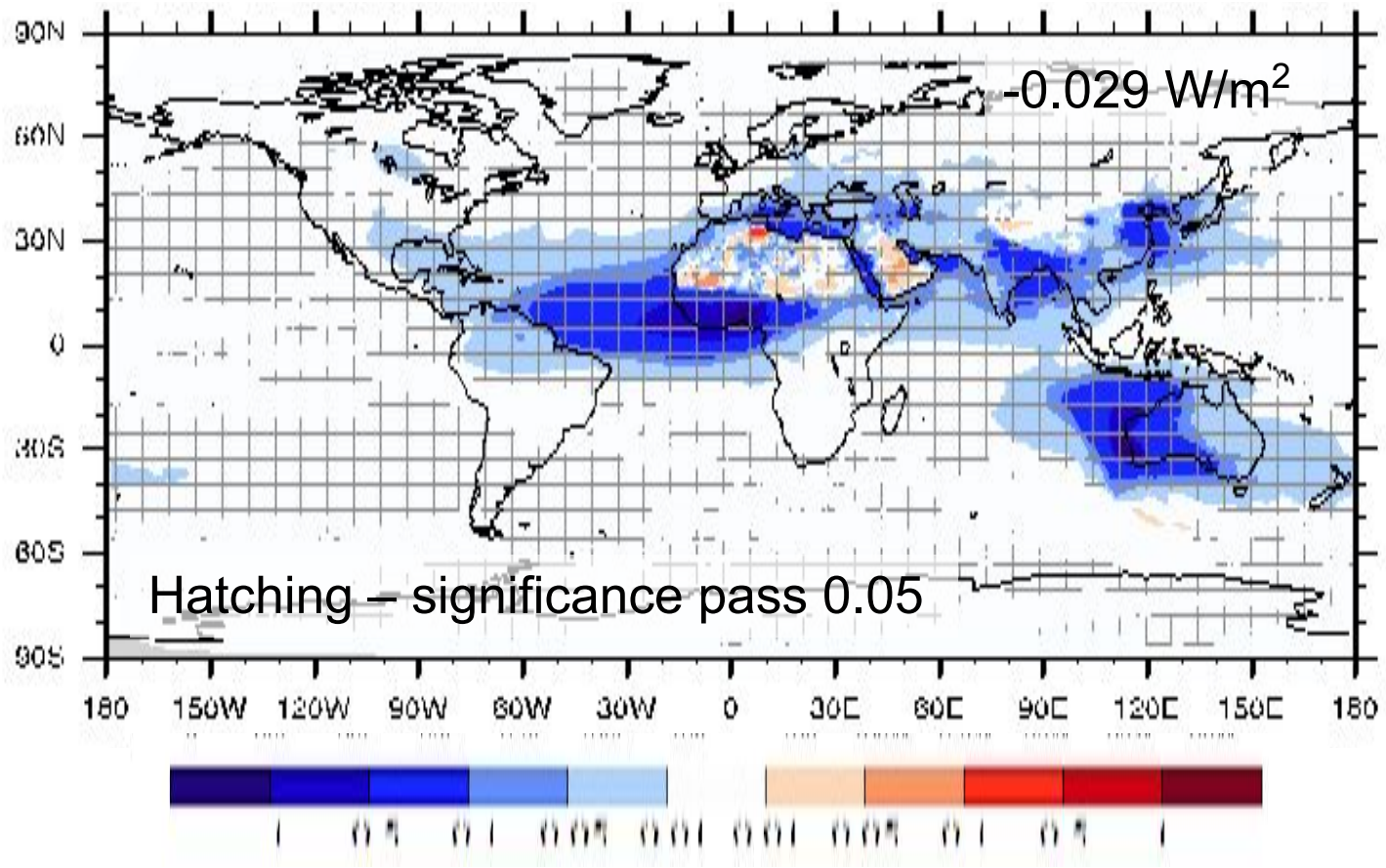
Crop PFT fraction





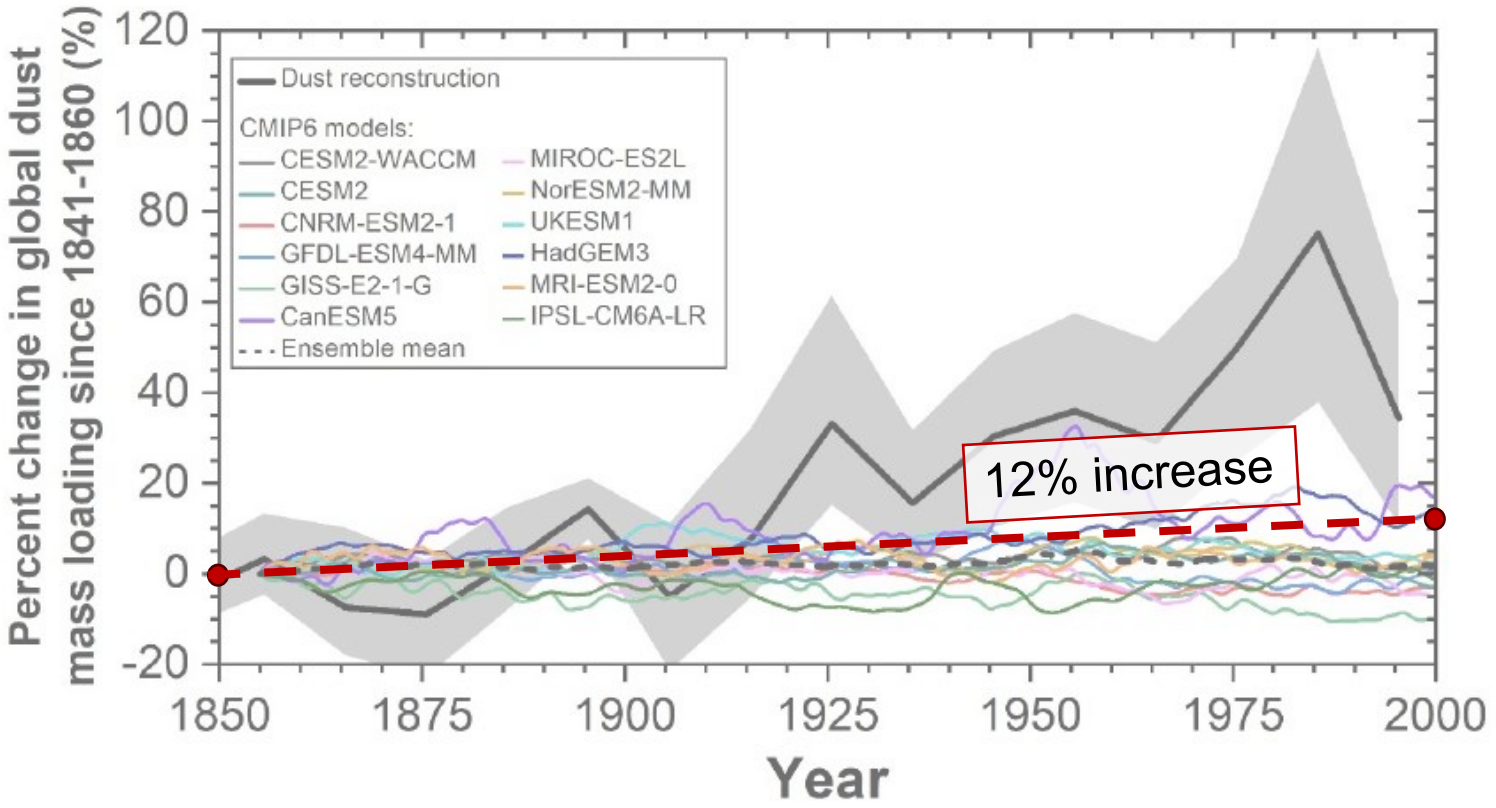
AD emissions increase by more than 300 Tg/yr (157%) from PI to PD. (ND only changes by 4%)

AD direct radiative forcing from PI to PD



The AD direct radiative forcing is more than 10% of the total aerosol direct radiative forcing estimated by IPCC AR6 (-0.22 W/m^2), which indicates that dust is a non-negligible forcing agent.

Discussion



Wind erosion caused by **land use** change	√ X
Direct emission by anthropogenic activities	X
Dust emission indirectly related to **climate change**	X
Natural variability	X

We do not represent all the dust emission related to anthropogenic activities.
Therefore, the AD direct radiative forcing may be higher than our estimate.

Summary

- We represent anthropogenic dust emission related to agricultural land use in E3SMv1 model.
- According to our method, anthropogenic emission accounts for 13% of global dust emission in PD.
- Global anthropogenic dust emission increases by 300 Tg/yr (157%) from PI to PD, which results in a direct radiative forcing of -0.029 W/m^2.
- The magnitude of anthropogenic direct radiative forcing is more than 10% of thetotal aerosol direct radiative forcing estimated by IPCC AR6, indicating the non-negligible role of dust in regional and global climate change.

Contact: xiaohong.liu@tamu.edu; yangshi@mit.edu

Thanks!

Dust emission scheme in ELM

Zender et al. (2003):

F_j: dust emission flux for size bin j
T: global tuning factor (=5x10^{-4})
***S*: source erodibility factor**
f_m: grid cell fraction of exposed bare soil
α: sandblasting mass efficiency
Q_s: total horizontally saltating mass flux
$M_{i,j}$: mass fraction of size bin j in each source mode i (total I=3)
M_{clay}: mass fraction of clay particles in the soil

c_s: saltation constant (=2.61)
ρ_{atm}: air density
g: acceleration of gravity
u_{*s}: friction velocity (wind)
u_{*t}: threshold friction velocity (accounting for soil moisture and surface cover)