A new process-based and scale-respecting desert dust emission scheme for global climate models: A case study in CESM2

EGU meeting

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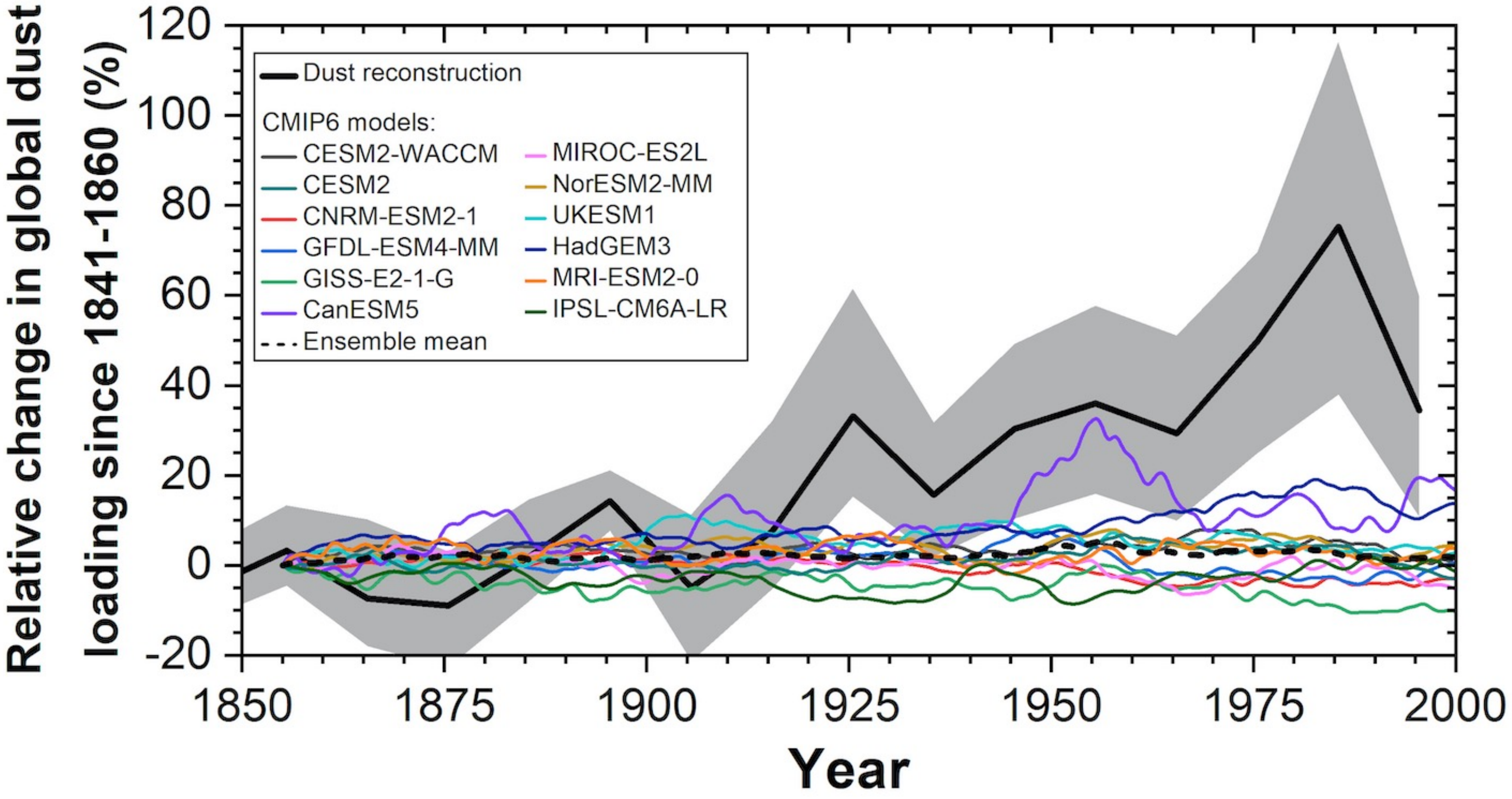
GCMs fail to capture the observed long-term trends of dust changes for the 20th–21st century.



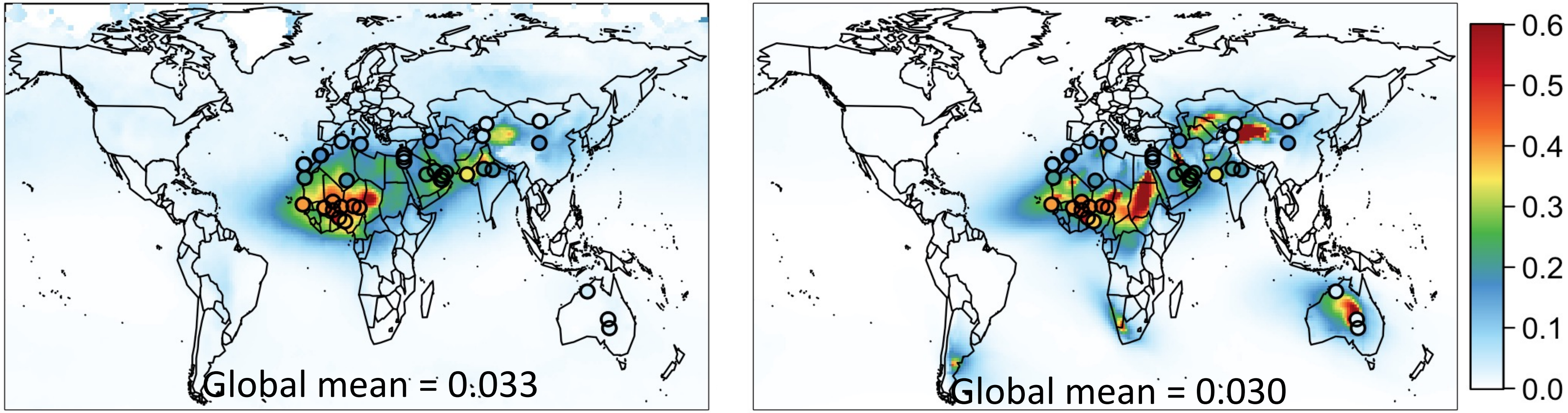
Kok et al. (in review)

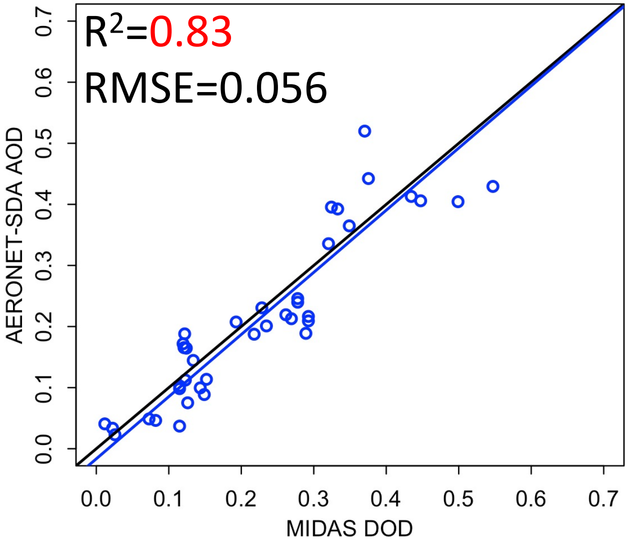
Current parameterizations do not include enough dust emission physics, resulting in poor agreements against measurements.

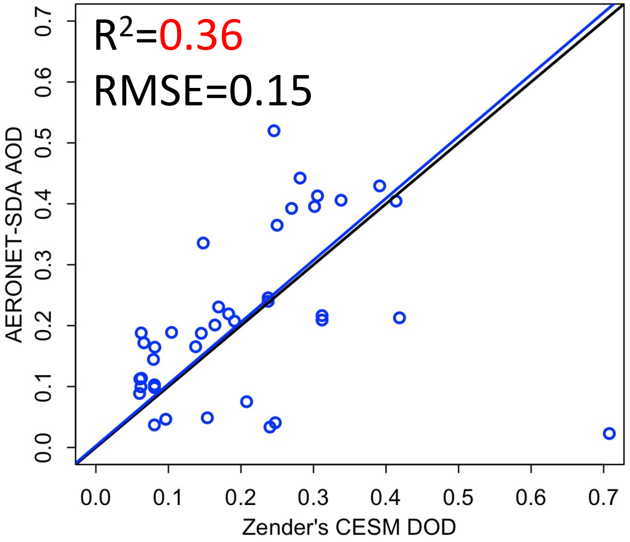
Dust aerosol optical depth

MODIS/MIDAS vs. AERONET

CESM2 vs. AERONET







Averaged across 2004–2008

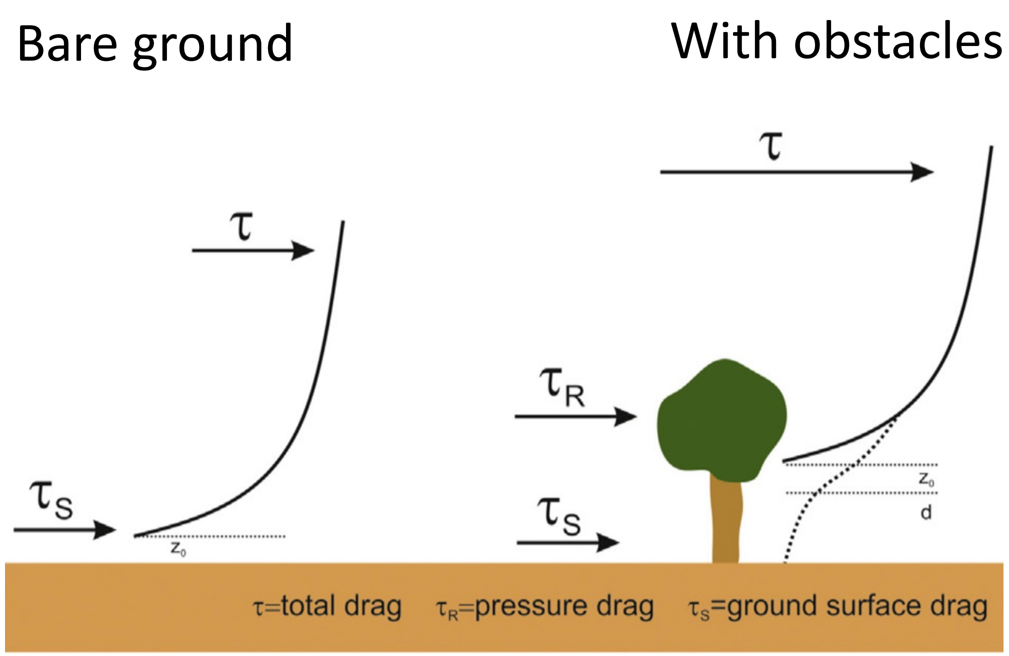
Dust schemes need:

- More dust cycle physics
- Effects of land use changes

Black: 1:1 line

Blue: fit line

We propose a novel scheme combining drag partition effects due to rocks and plants on winds, shifting modeled dust to major source regions and coupling dust with vegetation dynamics.

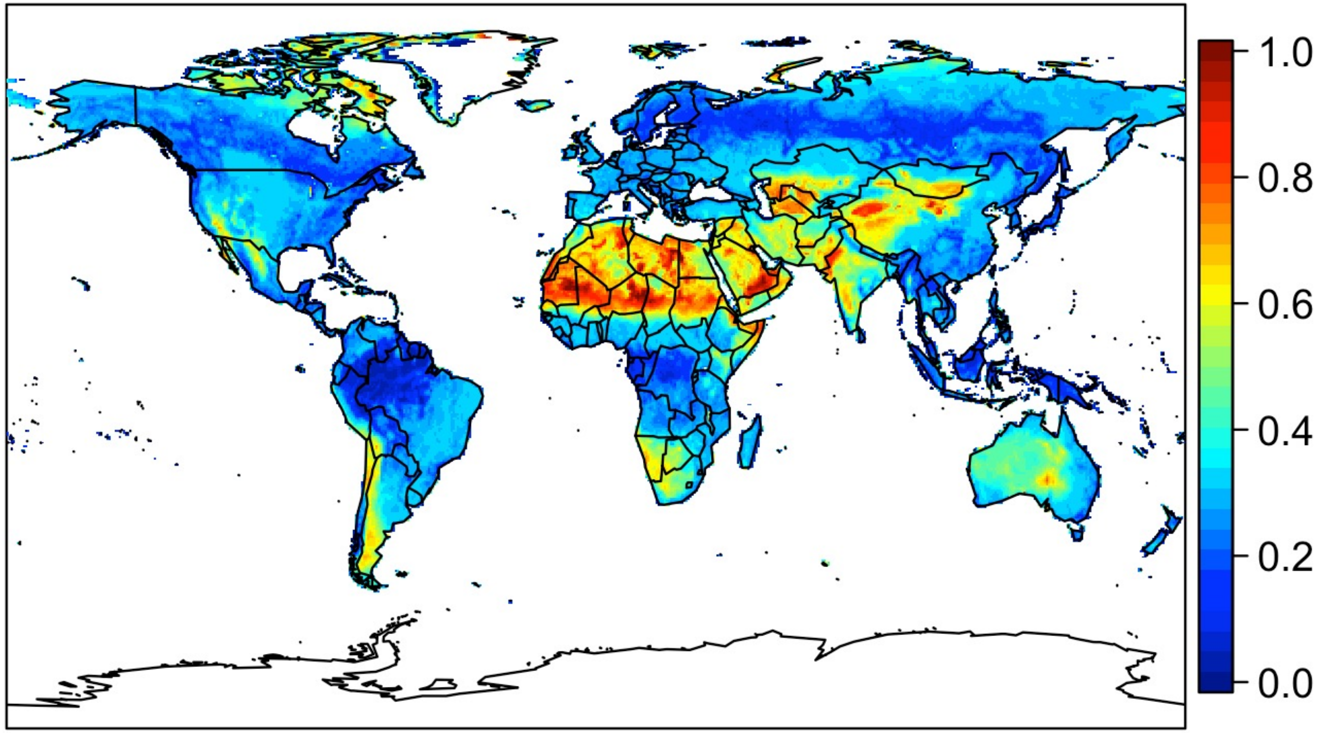


Florian Betz et al. (2015)

Wind stress absorbed by roughness elements:

$$\tau = \tau_{\mathrm{Object}} + \tau_{Soil}$$

Drag partition factor F_{eff} for 2004–2008

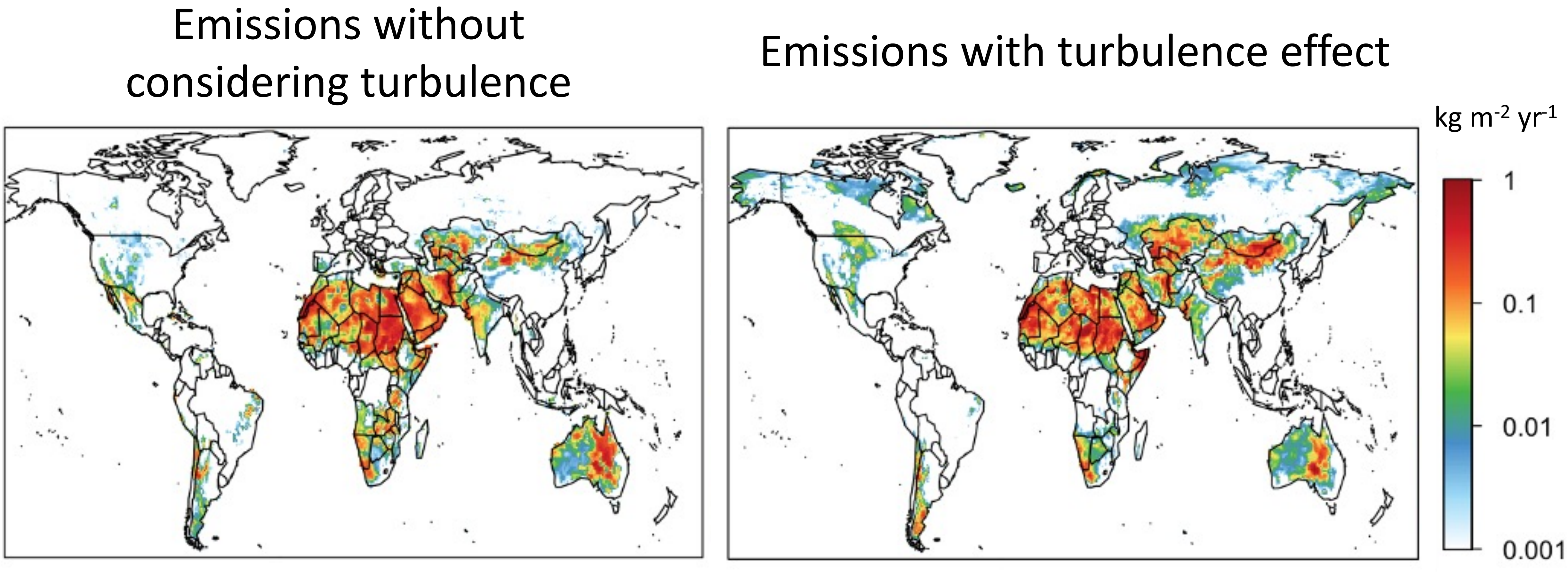


F_{eff} discounts the u_* reaching soil surface to u_{*s}:

$$u_{*s} = u_* F_{eff}$$

$$0 \le F_{eff} \le 1$$

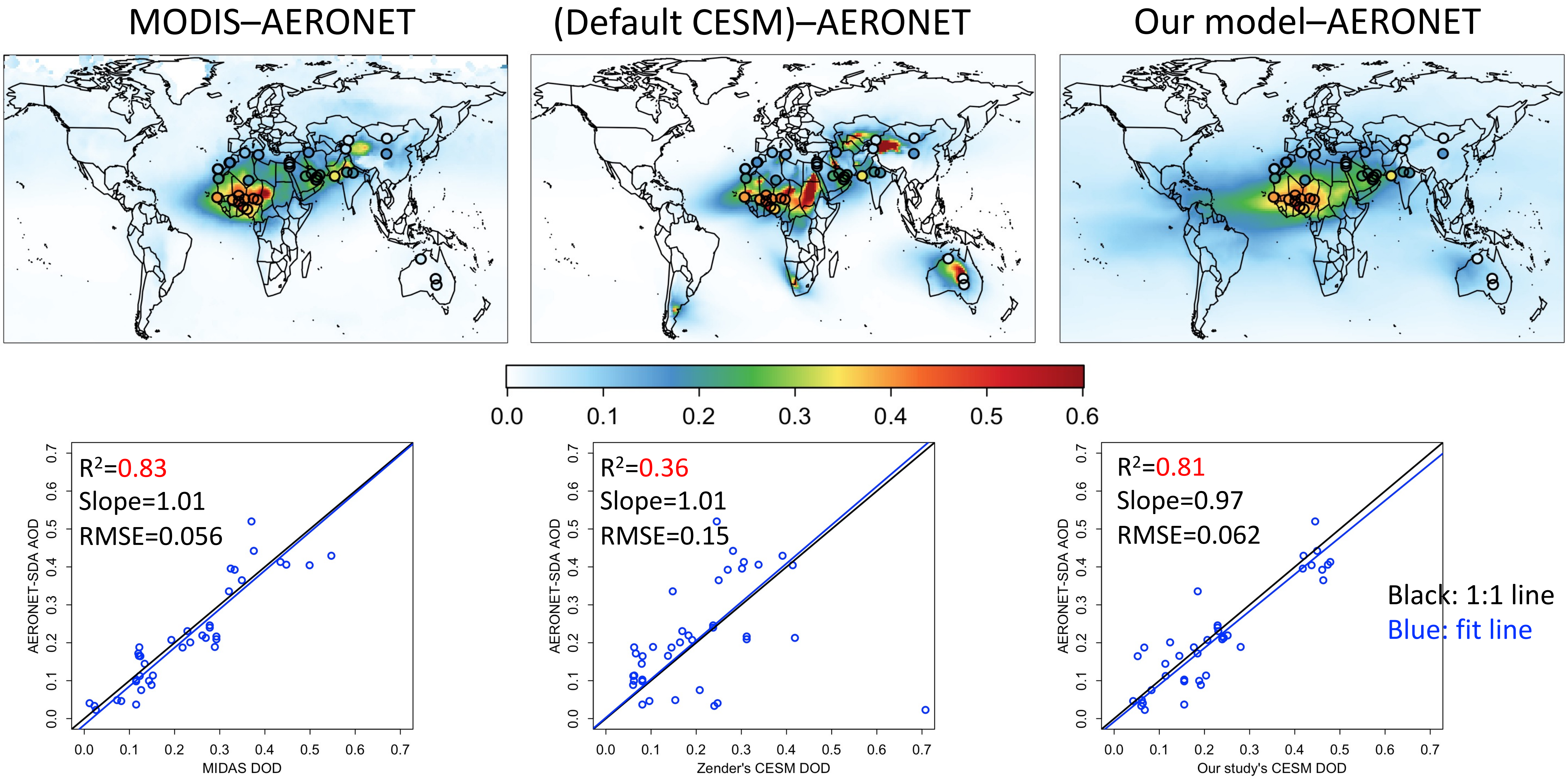
We account for turbulence, which generates emissions over marginal and high-latitude regions and couples dust to boundary-layer dynamics.



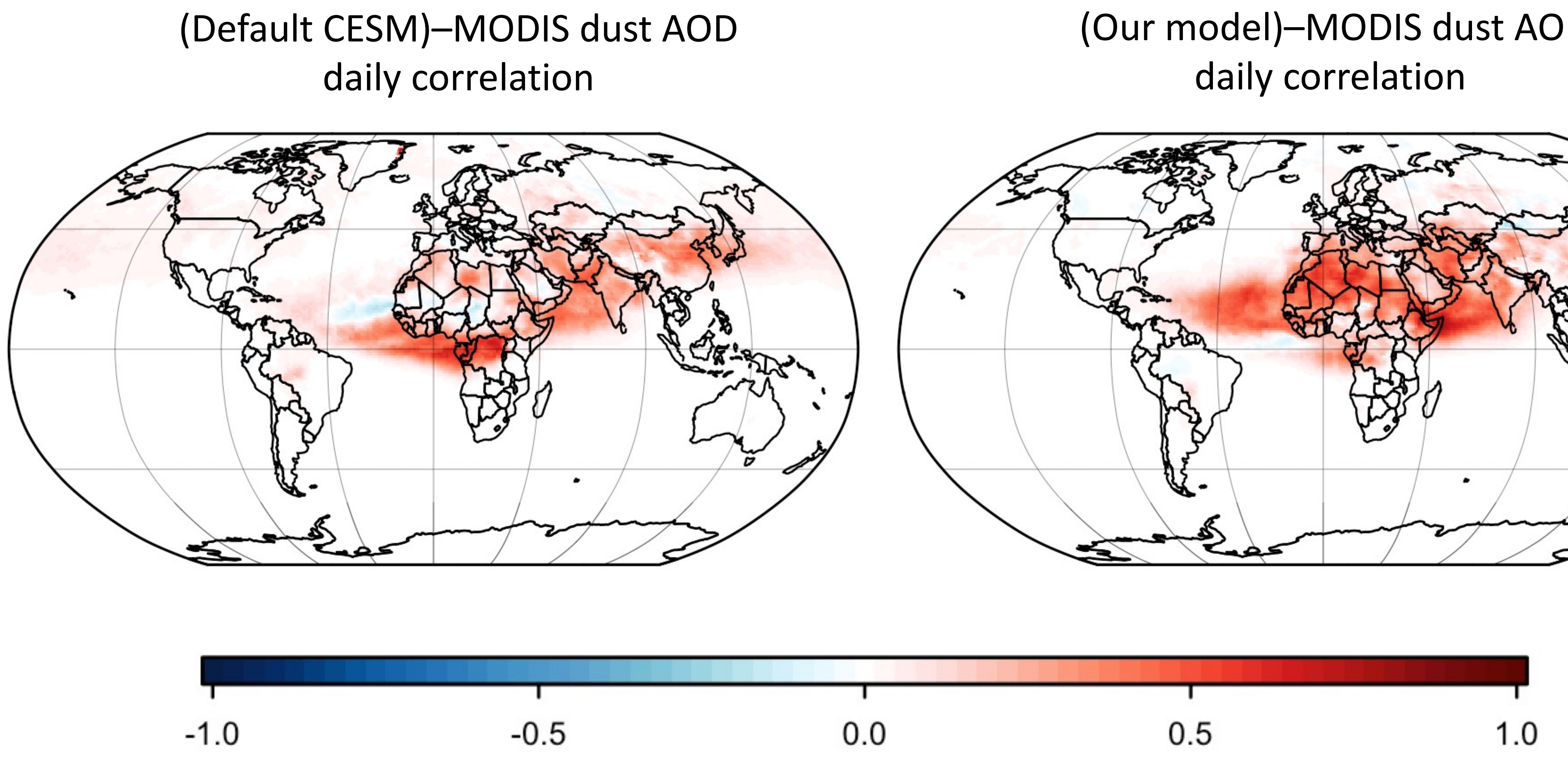
For year 2006

(The turbulence scheme follows Comola et al., 2019b)

Our scheme has much better DAOD spatial variability against AERONET AOD for 2004–08.



Our scheme shows significant improvements in day-to-day and seasonal dust variability.



- Our new scheme in CESM has a high grid-by-grid daily correlation with satellite-derived MODIS dust AOD, especially over the low-latitude dust belt over Africa and Asia.

Take-home messages

- Developed an improved dust emission scheme with multiple key physics missed from the previous schemes

- More coupling with vegetation dynamics and boundary-layer dynamics improves the spatial and temporal variability of simulated dust

- Our scheme with effects of turbulence successfully generates more high-latitude emissions as missed by most current climate models

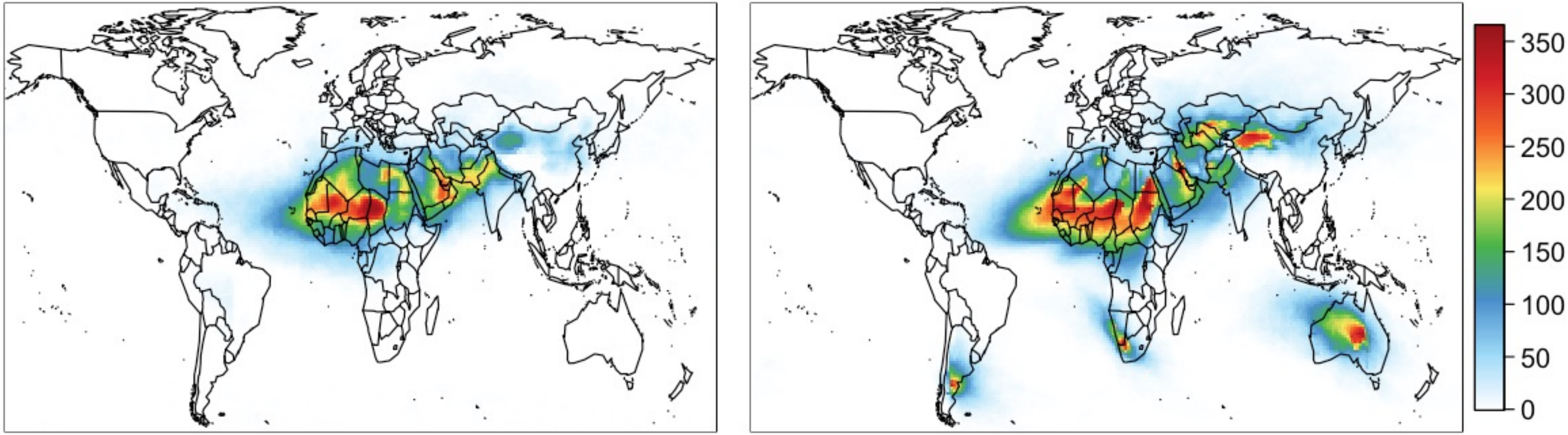
Our developments on Github NCAR/CTSM:
https://github.com/ESCOMP/CTSM/pull/1712

My complete talk on Youtube NCAR/CGD:
https://youtu.be/b6y-NdjbtR0?t=4857

Models activates dust emissions more frequently than satellite observations.

MIDAS dust activation frequency (number of days/year)

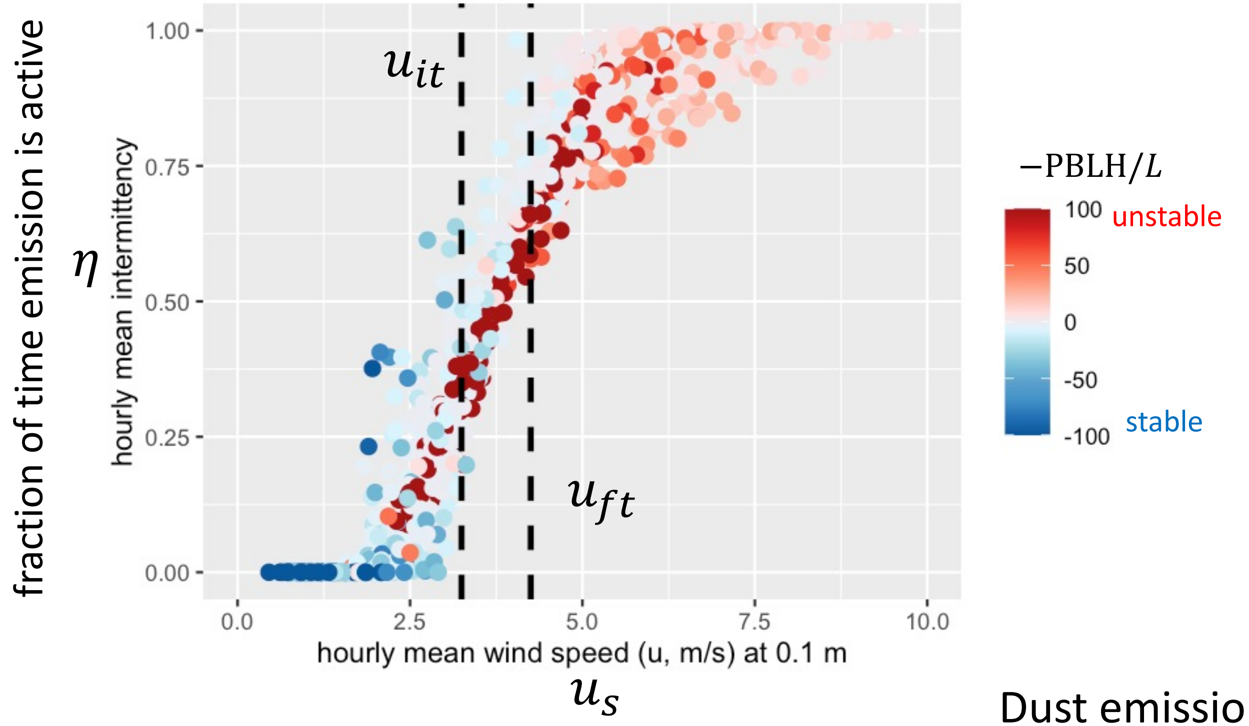
CESM dust activation frequency (number of days/year)



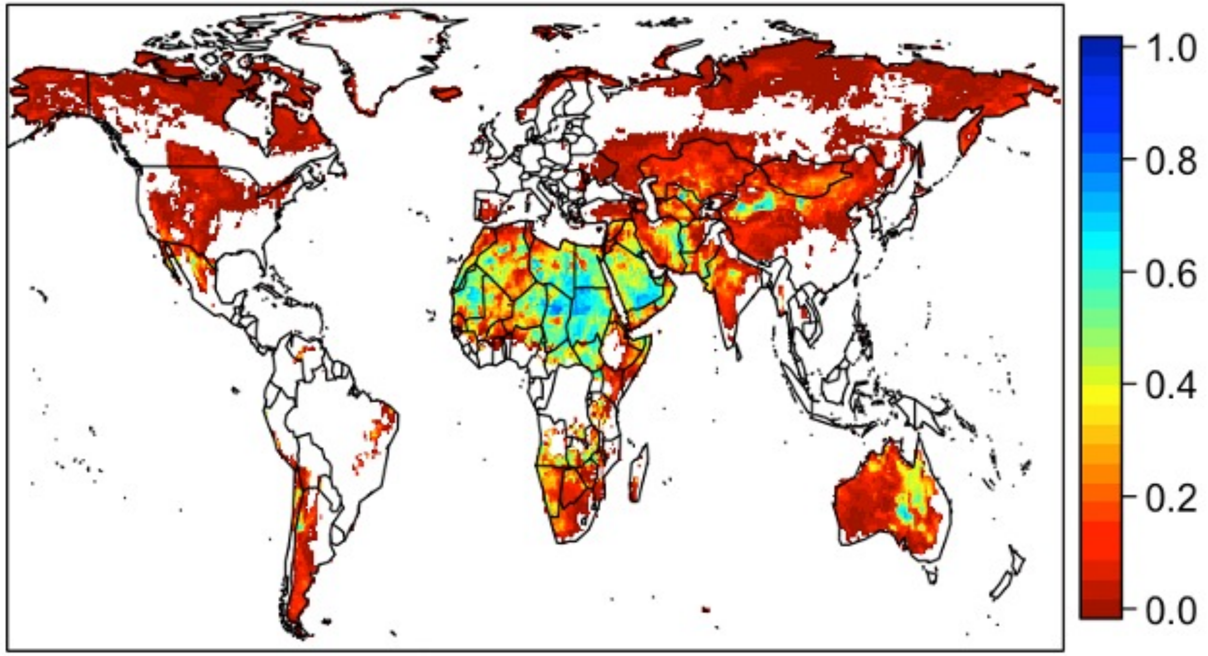
- We calculate frequency of occurrence (FoO) following Ginoux et al. (2012): number of days with DAOD > 0.2.
- Continuous dust emission activation!

We account for turbulence, which generates emissions over marginal and high-latitude regions and couples dust to boundary-layer dynamics.

Modeled hourly η in Bodélé Depression, Chad for 2006



Fraction of time emission is active η (when $F_d > 0$) for 2006



u_s = wind speed (m s^{-1})
η = fraction of time emission is active
u_{it} = impact threshold (m s^{-1})
u_{ft} = fluid threshold (m s^{-1})
F_d = dust emission flux (kg m^{-2} s^{-1})

Dust emission flux (kg m^{-2} s^{-1}):

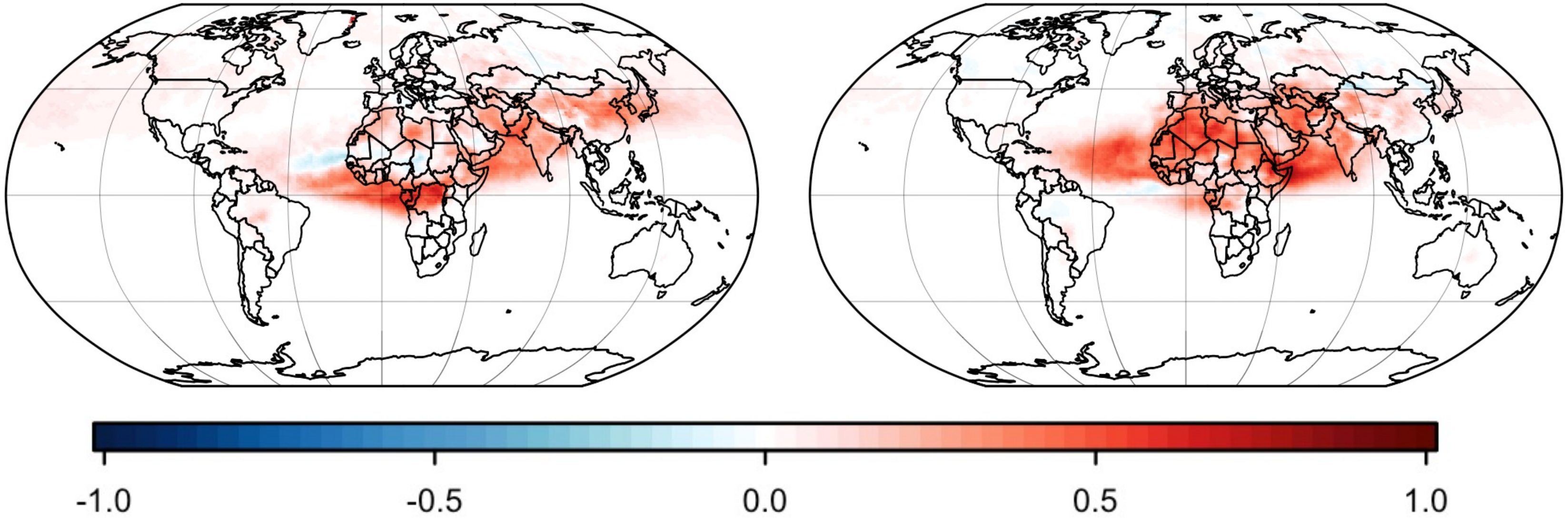
$F_{d,\eta} = \eta F_d$, where $\eta = \eta(u, \sigma_{\tilde{u}}, u_{ft}, u_{it})$

Turbulent wind fluctuations (m s^{-1}):

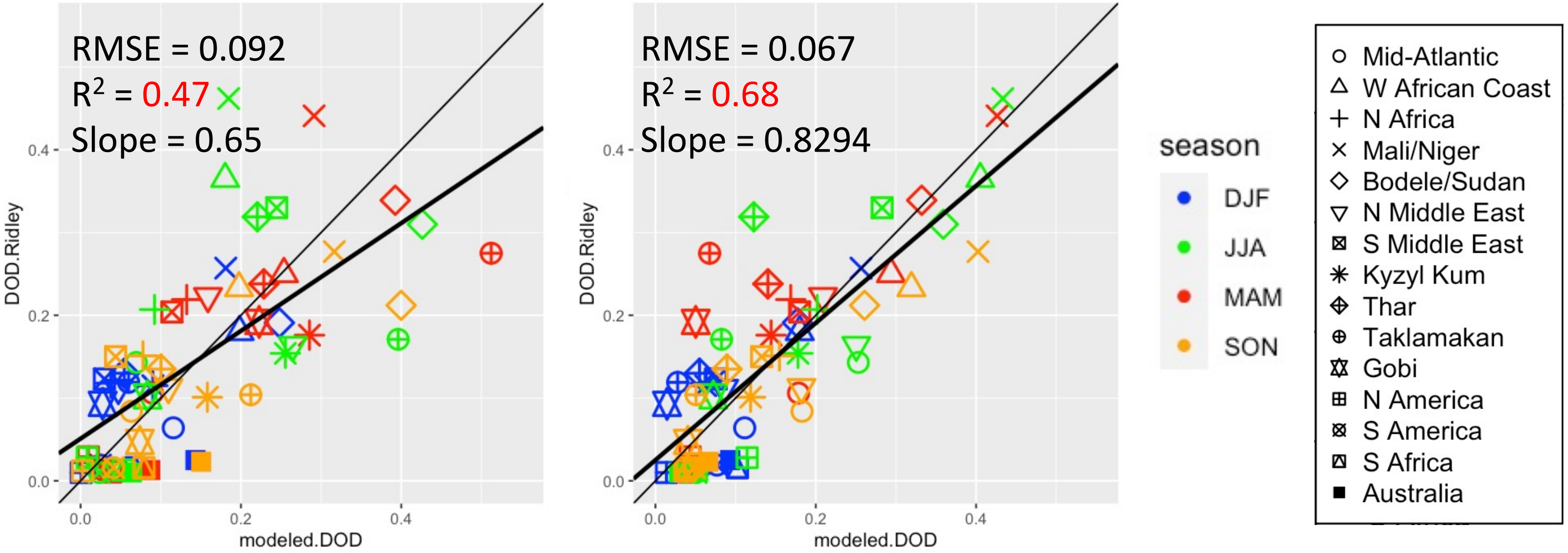
$\sigma_{\tilde{u}} = u_{*s}\left(12 - 0.5\frac{z_i}{L}\right)^{1/3}$ (similarity theory, Panofsky, 1979)

Our scheme shows significant improvements in day-to-day and seasonal dust variability.

Default CESM–MIDAS dust AOD corr. (Our study)–MIDAS dust AOD corr.



- Our new scheme in CESM has a high grid-by-grid daily correlation with satellite-derived MIDAS dust AOD.



- When averaging to seasonal and regional data, our scheme in CESM also outperforms the default CESM scheme in matching satellite MIDAS dust.