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Climate Responses to Variability in Biomass Burning Emissions

Implications for Climate Prediction and Projection

29 Oct 2024 : CMIP7 Forcings Workshop
Session 3: CMIP7 DECK protocol development

Key Collaborators: N. Rosenbloom, R. Buchholz

Photo by NASA

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catalyst
Cooperative agreement to analyze variability, change and predictability in the earth system

Outline

1) Climate Responses to CMIP6 biomass emissions in CESM2 (*Fasullo et al. 2022 GRL*)
2) Climate Responses to the 2019/20 Australian Wildfires (*Fasullo et al. 2021 GRL / 2023 SA*)
3) Biomass emissions as a coupled component of ENSO (*Fasullo et al. 2024 J Climate*)
4) Coupled Climate Feedbacks to Interactive Biomass Emissions (*in prep*)

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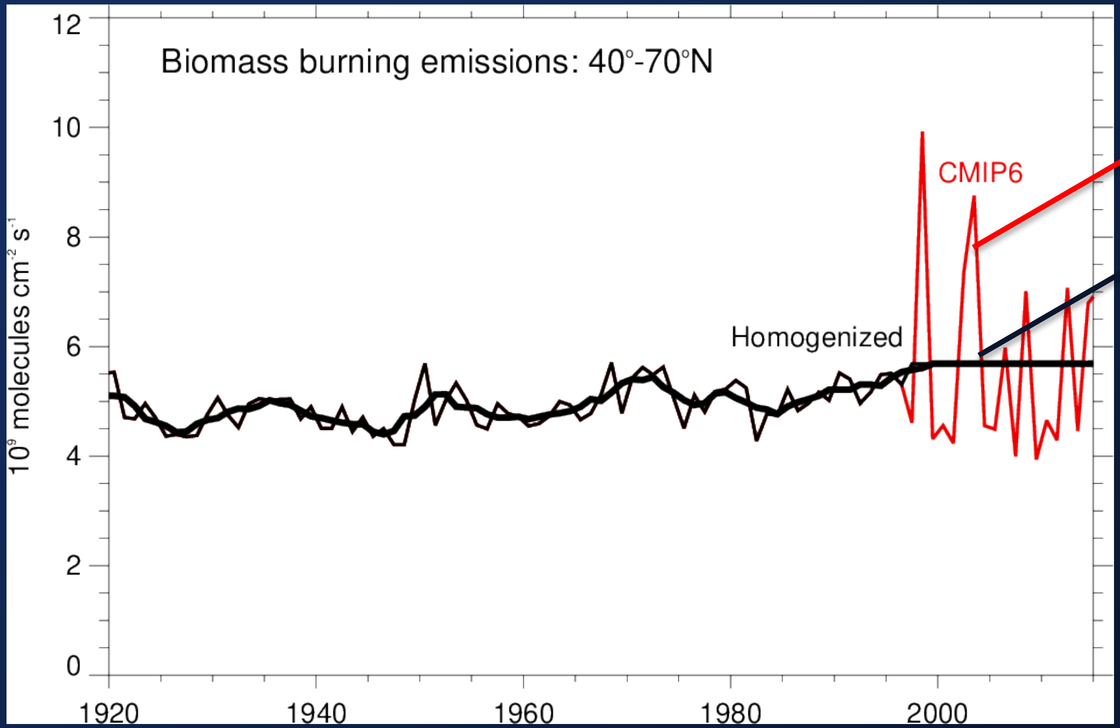
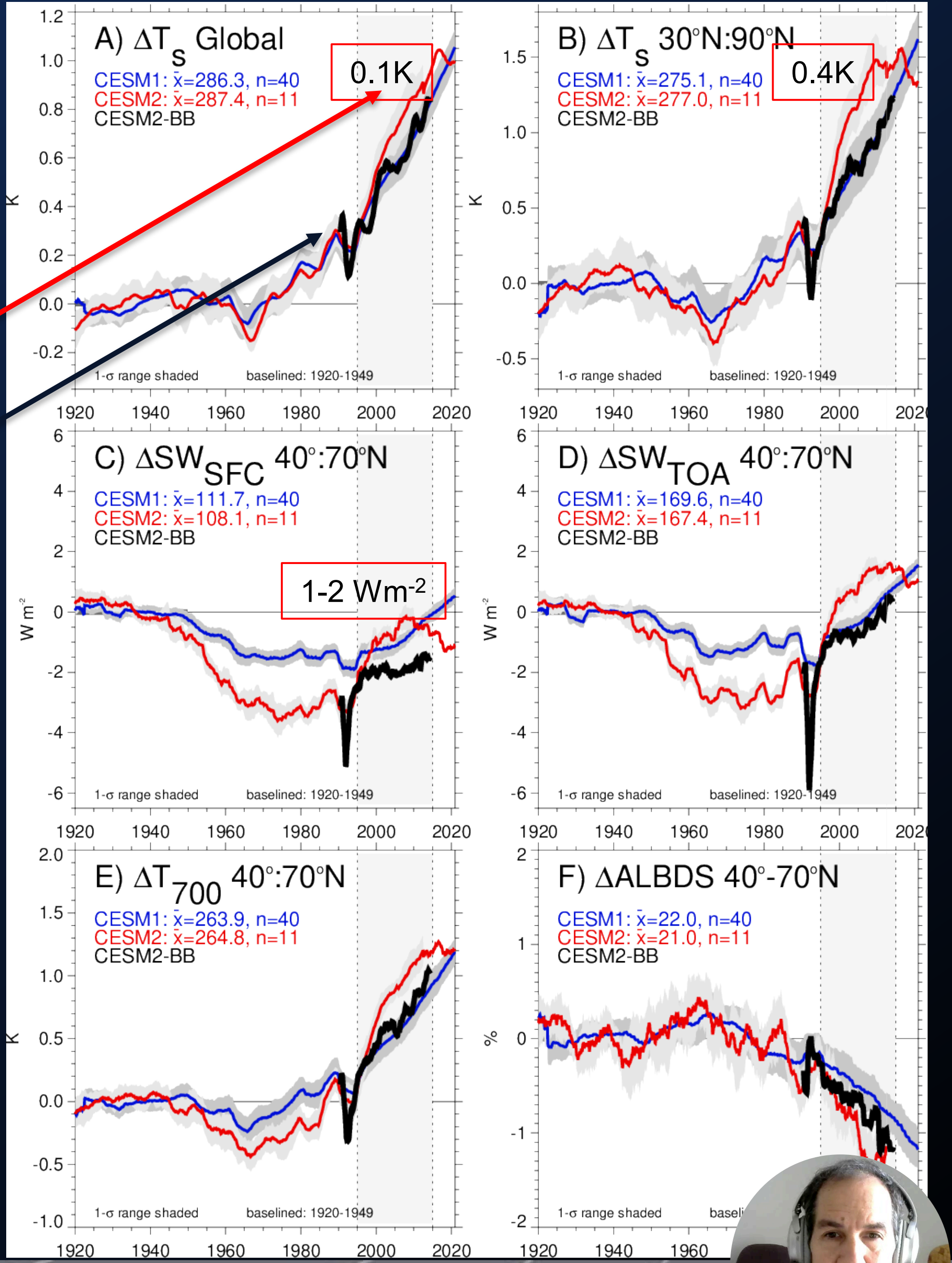
Responses to Variable Biomass Emissions: CMIP6 Forcings in CESM2 *(Fasullo et al. 2022 GRL)*



11 members

20 members



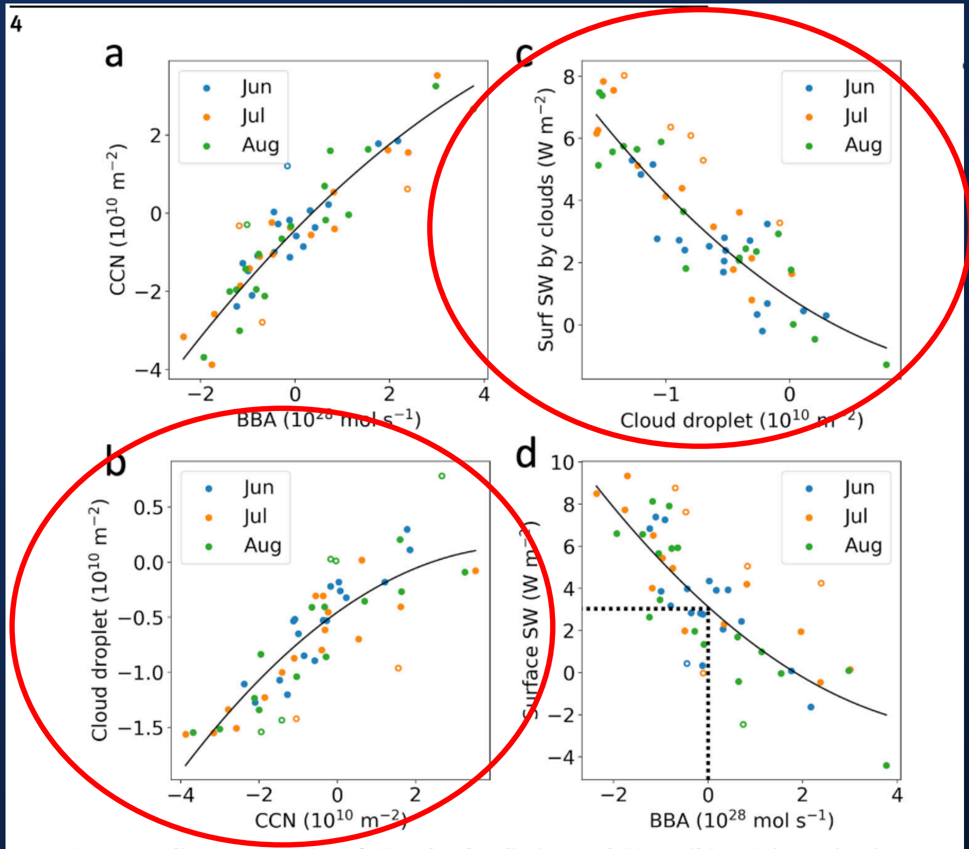
Above: CMIP6 and homogenized biomass emissions.

Right: Ensemble mean temperature and radiation fields.

Responses to Variable Biomass Emissions: CMIP6 Forcings in CESM2 *(Fasullo et al. 2022 GRL)*

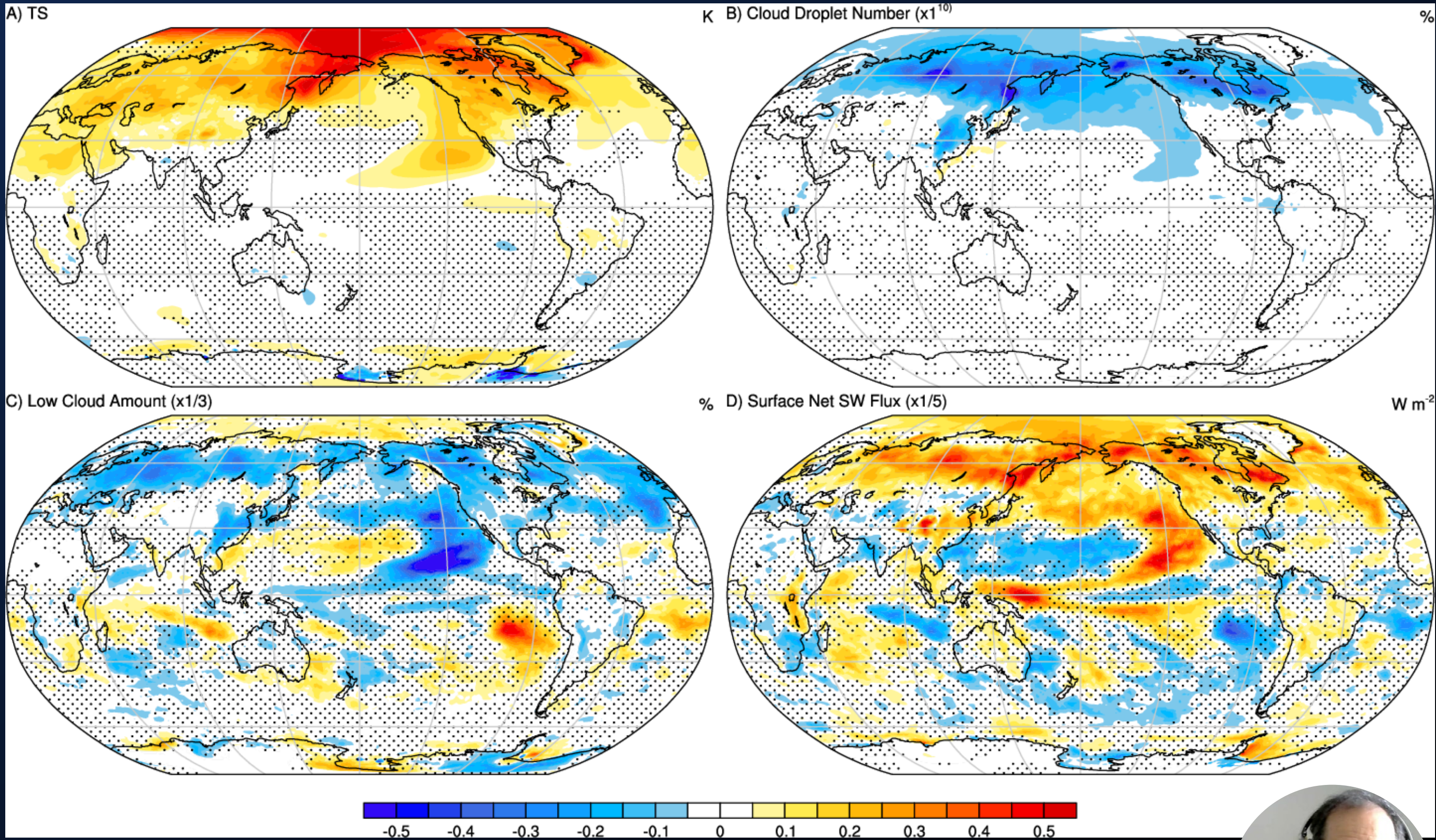
Cloud-radiation relationships are nonlinear.
At high CCN, radiative effects tail off.

Kim et al 2023, NPJ



BB climatologies are identical but variability rectifies to drive warming.

Fasullo et al 2022, GRL

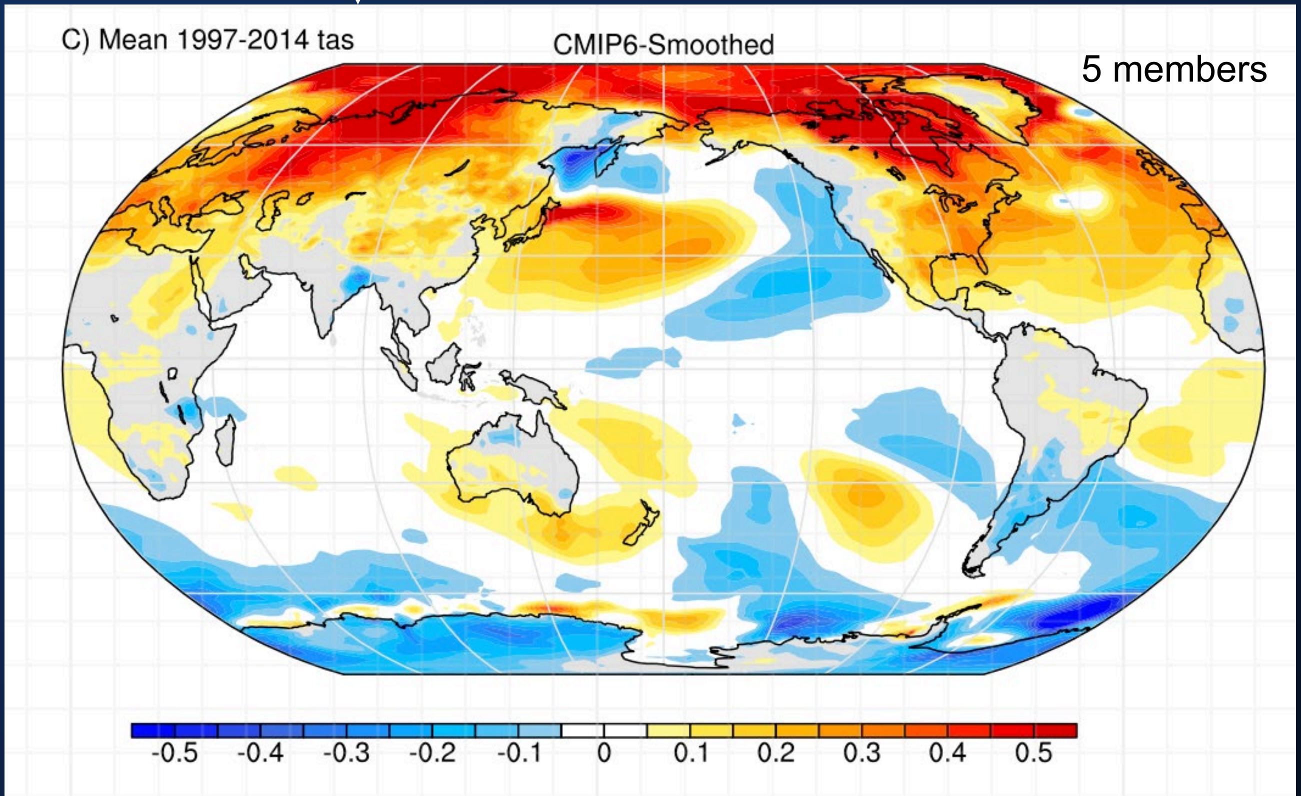


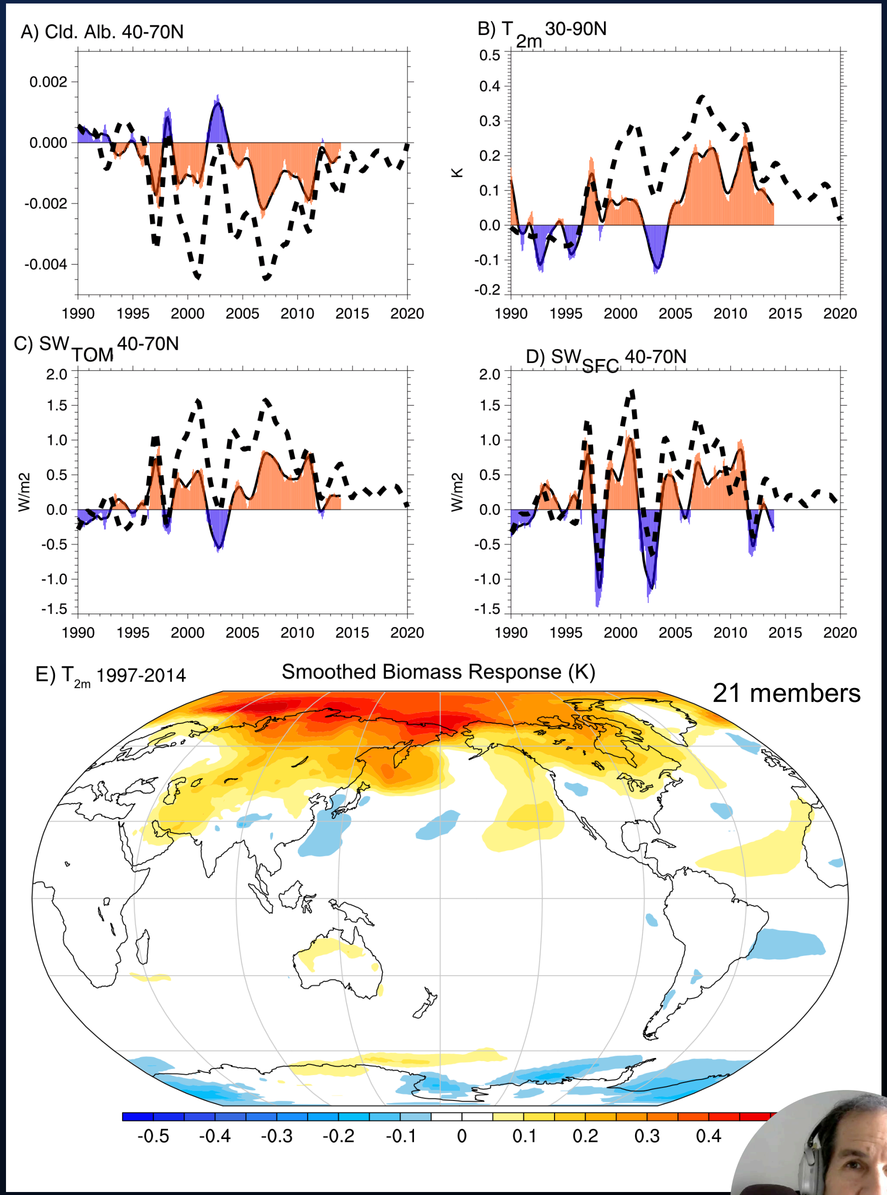
Responses to Variable Biomass Emissions: UKESM1.1 and E3SMv2 Experiments

Fasullo et al. 2024, **GMD**

UKESM1.1-LL and E3SMv2 exhibit similar sensitivities.

(Fasullo et al. in prep)

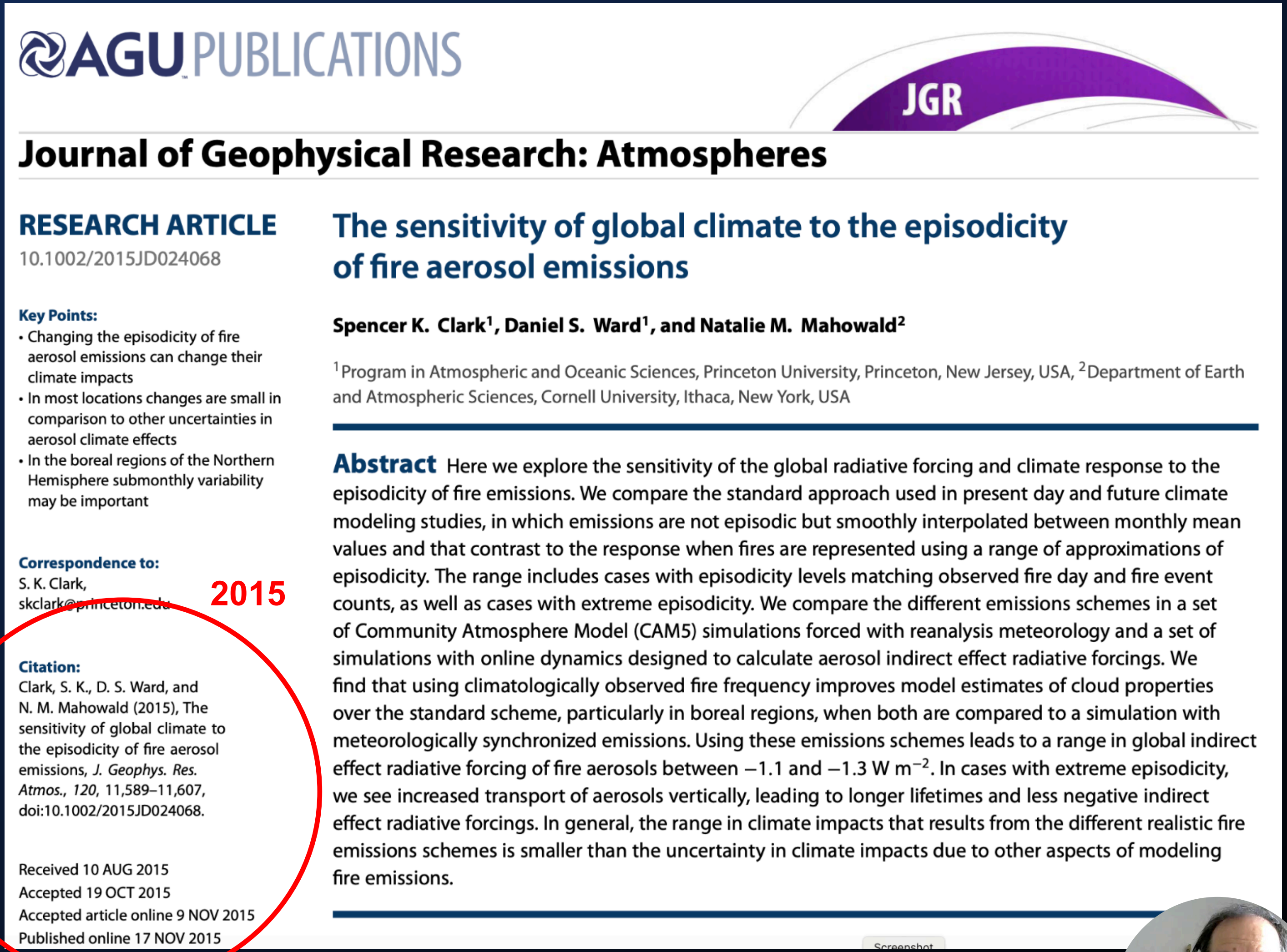




Responses to Variable Biomass Emissions: Variability -driven warming identified in 2015

Impact of fire “episodicity” is examined in nudged CAM5.

Increased episodicity leads to warming (less negative indirect effect).



AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE
10.1002/2015JD024068

The sensitivity of global climate to the episodicity of fire aerosol emissions

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Key Points:
- Changing the episodicity of fire aerosol emissions can change their climate impacts
- In most locations changes are small in comparison to other uncertainties in aerosol climate effects
- In the boreal regions of the Northern Hemisphere submonthly variability may be important

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2015

Citation:
Clark, S. K., D. S. Ward, and N. M. Mahowald (2015), The sensitivity of global climate to the episodicity of fire aerosol emissions, *J. Geophys. Res. Atmos.*, *120*, 11,589–11,607, doi:10.1002/2015JD024068.

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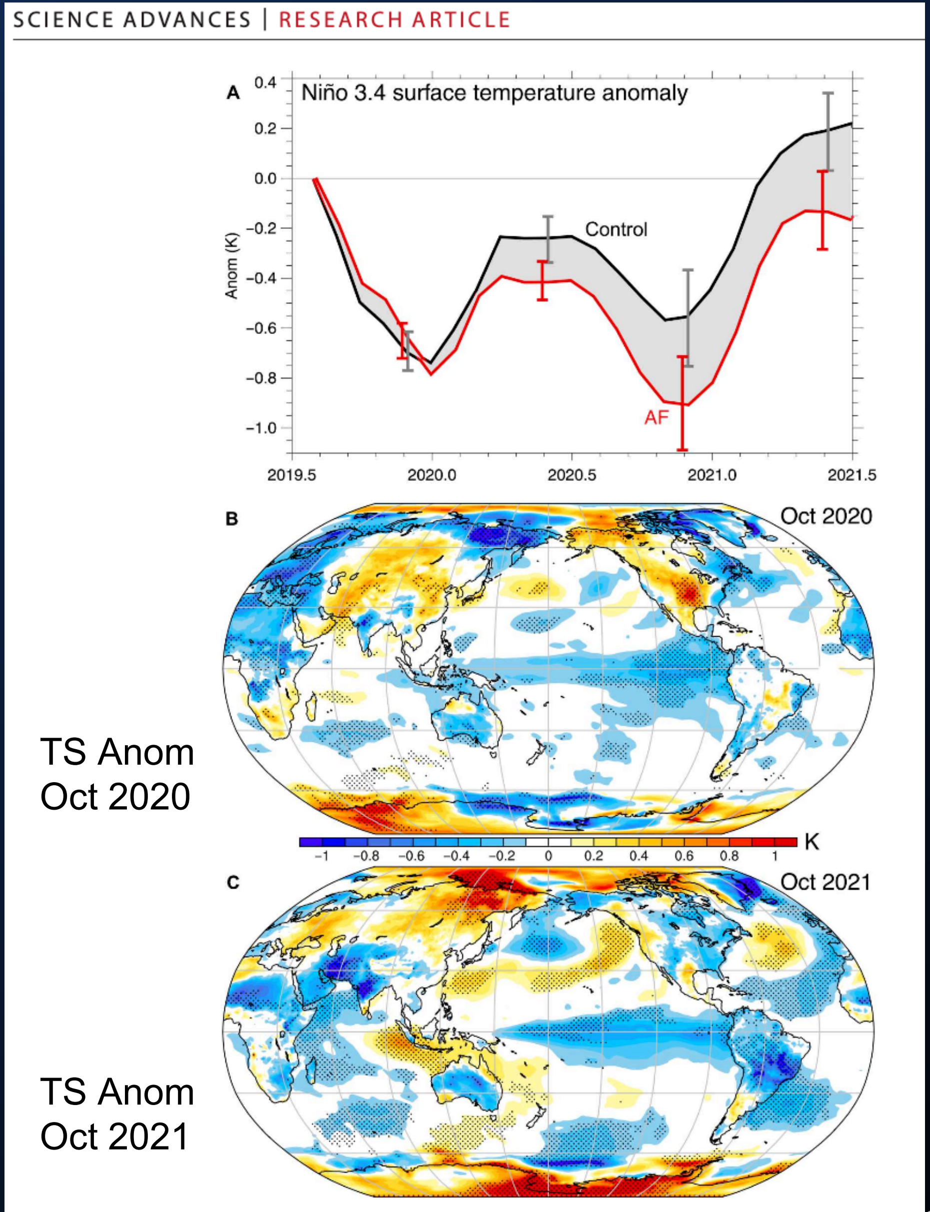
Abstract Here we explore the sensitivity of the global radiative forcing and climate response to the episodicity of fire emissions. We compare the standard approach used in present day and future climate modeling studies, in which emissions are not episodic but smoothly interpolated between monthly mean values and that contrast to the response when fires are represented using a range of approximations of episodicity. The range includes cases with episodicity levels matching observed fire day and fire event counts, as well as cases with extreme episodicity. We compare the different emissions schemes in a set of Community Atmosphere Model (CAM5) simulations forced with reanalysis meteorology and a set of simulations with online dynamics designed to calculate aerosol indirect effect radiative forcings. We find that using climatologically observed fire frequency improves model estimates of cloud properties over the standard scheme, particularly in boreal regions, when both are compared to a simulation with meteorologically synchronized emissions. Using these emissions schemes leads to a range in global indirect effect radiative forcing of fire aerosols between −1.1 and −1.3 W m^{-2}. In cases with extreme episodicity, we see increased transport of aerosols vertically, leading to longer lifetimes and less negative indirect effect radiative forcings. In general, the range in climate impacts that results from the different realistic fire emissions schemes is smaller than the uncertainty in climate impacts due to other aspects of modeling fire emissions.

A multiyear tropical Pacific cooling response to recent Australian wildfires in CESM2 SMYLE *(Fasullo et al. 2023 Sci Adv)*

Fires' forced response estimated in CESM2 initialized predictions:

> **Top:** Niño3.4 SSTa with fire (AF) and without (Control) Australian fires
>
> **Mid:** TS response, Oct 2020
>
> **Bot:** TS response, Oct 2021
>
> (note: a similar but weaker response also found in E3SMv2)



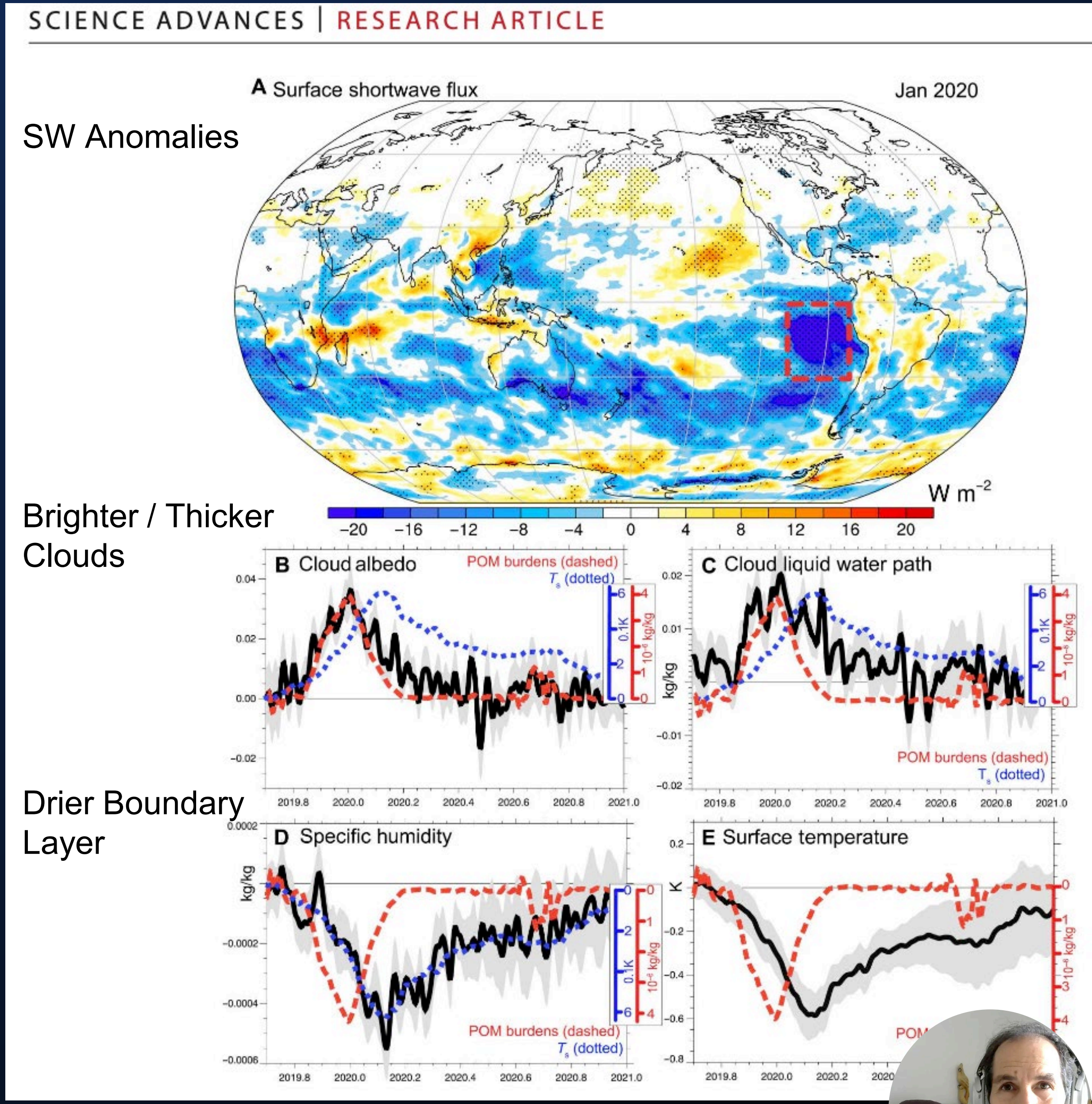
A multiyear tropical Pacific cooling response to recent Australian wildfires in CESM2 SMYLE *(Fasullo et al. 2023 Sci Adv)*

Cloud-aerosol interactions were the key mechanism.

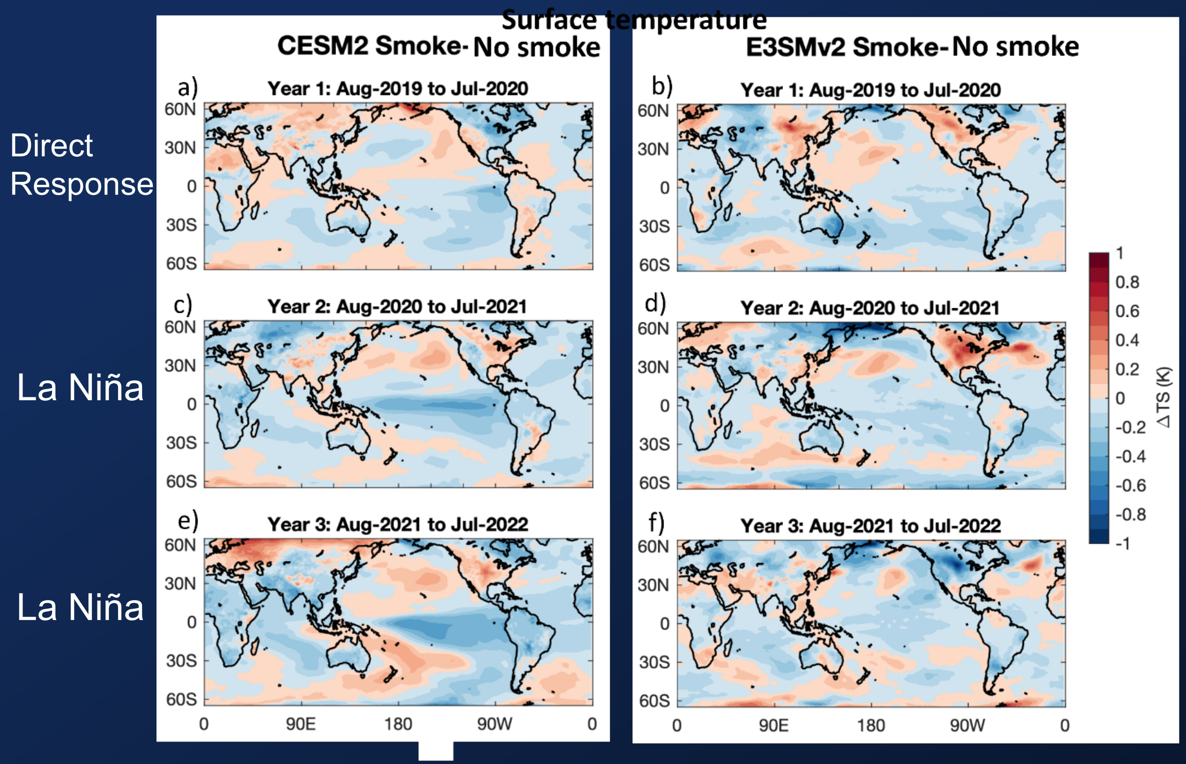
Top: Strongly reduced surface SW flux in eastern Pacific

Mid: Driven by brighter (left) and thicker (right) clouds.

Bot: Reduction in MSE advected into deep tropics, ITCZ displaced northward ⇒ Niño34 cooling.

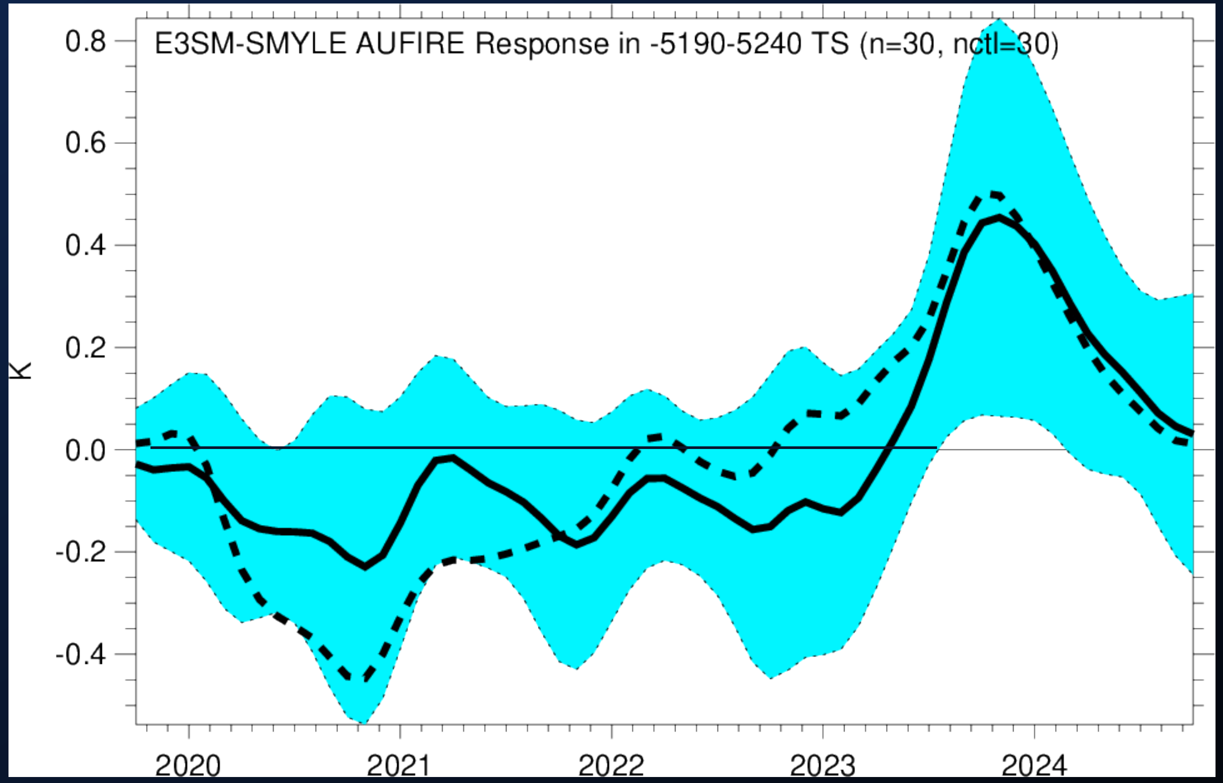


A multiyear tropical Pacific cooling response to the 2019 -2020 Australian wildfires in CESM2 and E3SMv2 *(Meehl et al. in prep)*



Tropical cooling in CESM2 (left) and E3SM2 (right) due to smoke/clouds (top) and feedbacks (middle/lower).

Fig. 2



Niño3.4 SST response in E3SM2 (solid, 20-member dashed). Cooling only about half of CESM2. Significant warming signal in 2023/24.

Responses to 2019/2020 Australian Bushfires and Implications for IPO: Mechanisms in CESM2/E3SM2 (Meehl et al., in prep)

Smoke dissipated by March 2020.

What allowed its effects to linger?

In this work we identify 2 key coupled feedbacks in the a) eastern and b) western Pacific oceans.

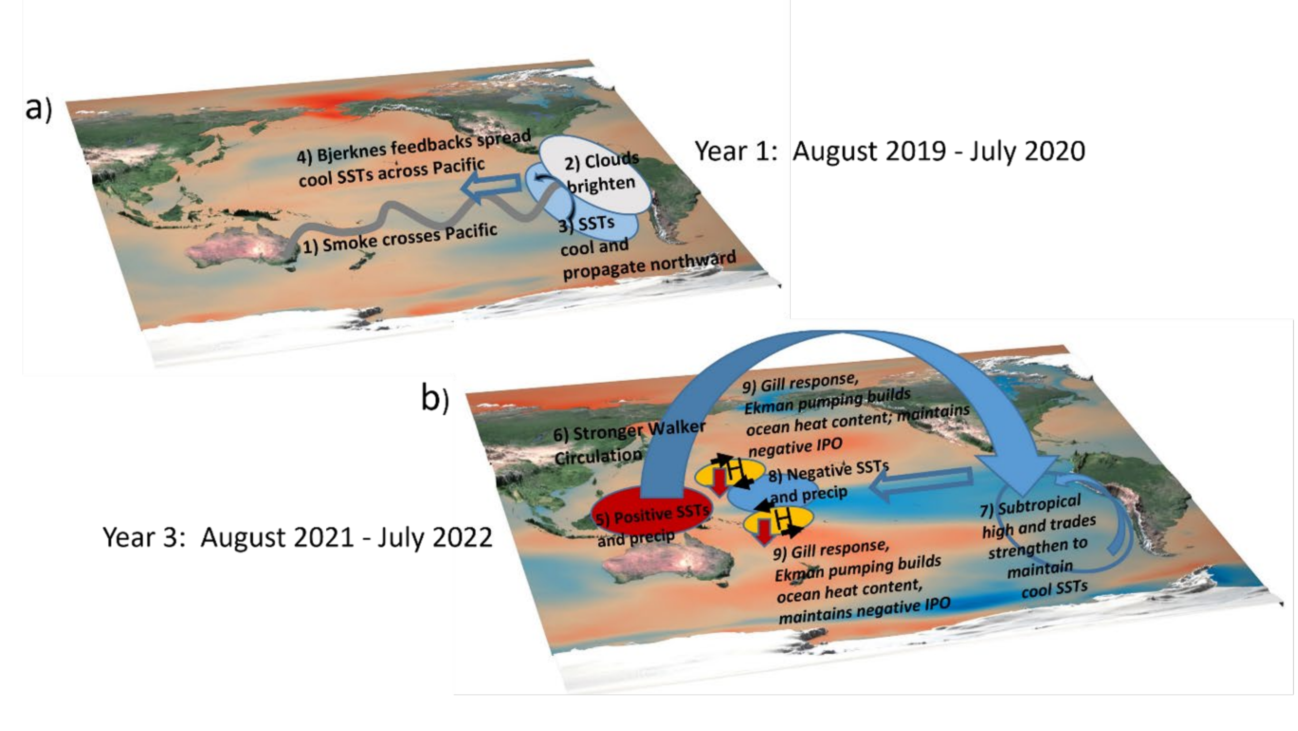
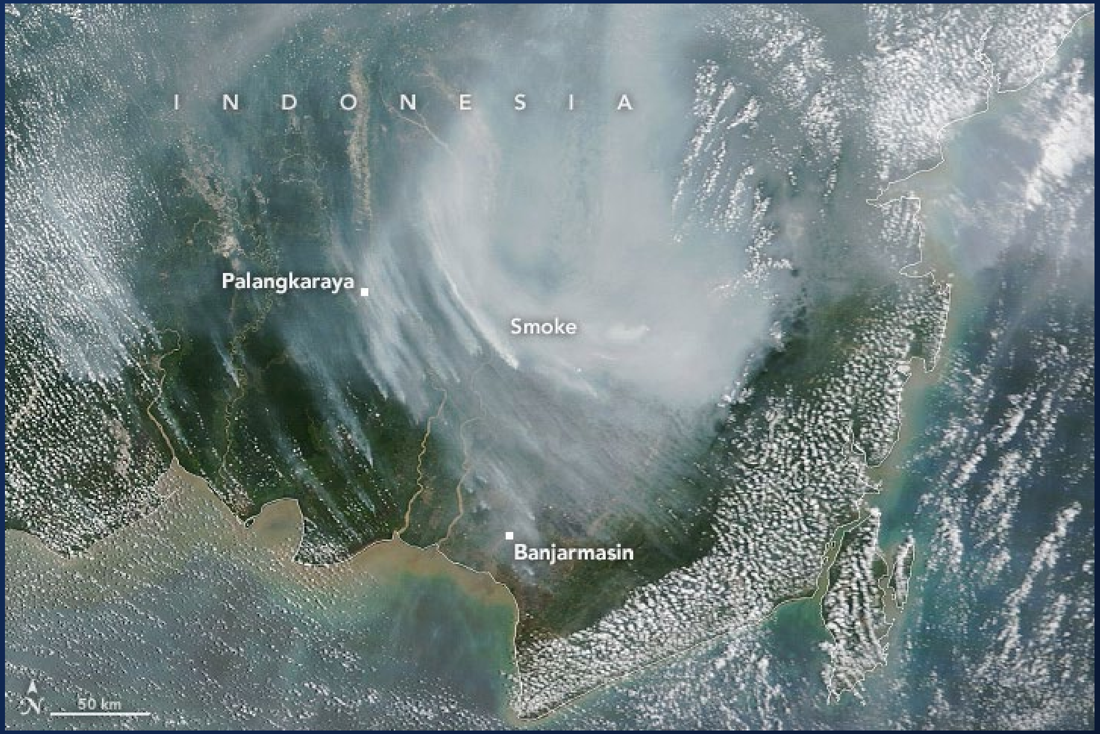


Fig. 6

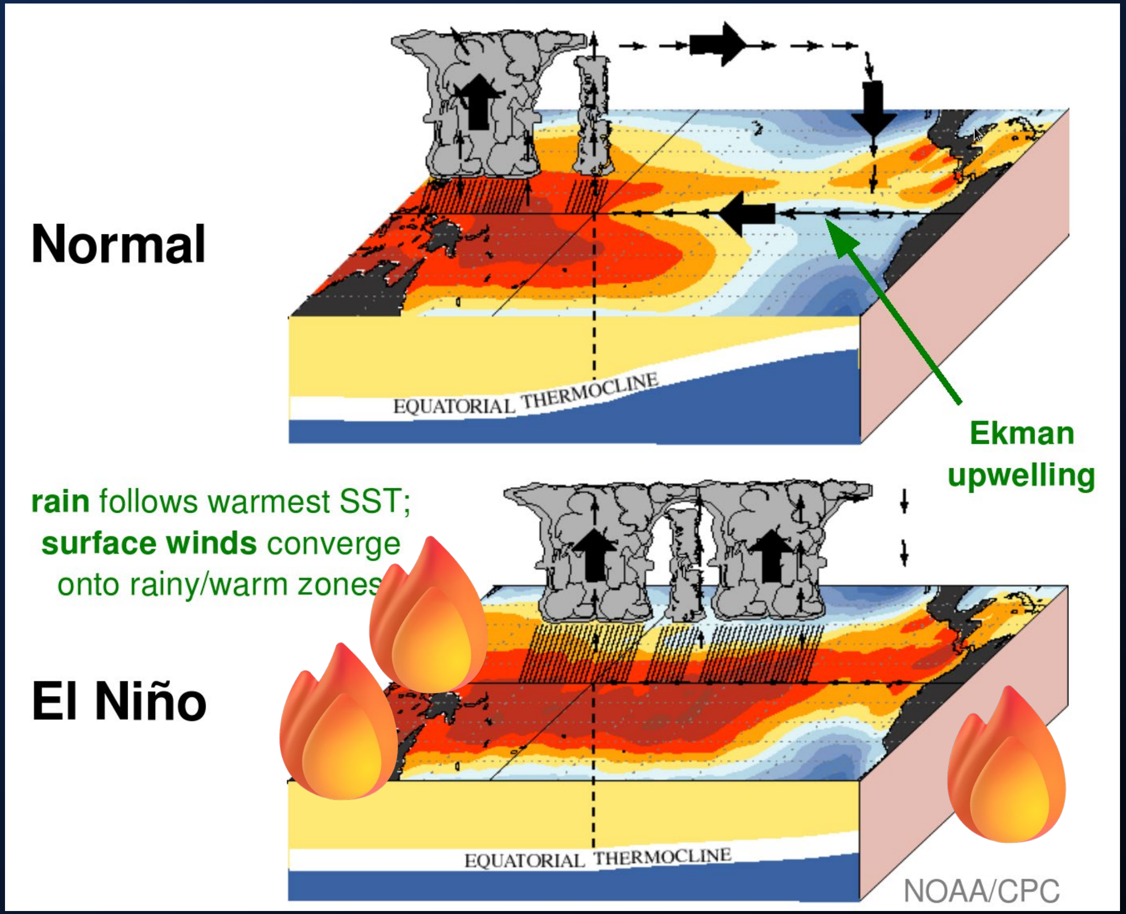
Mechanisms involved in prolonging the effects of wildfire smoke in CESM2. Key sources of persistence exist in the eastern Pacific (cold SSTs, thick cloud decks, Bjerknes) and western Pacific (off -equatorial heat uptake, Gill-response equatorial convection).

Biomass Emissions as a Coupled Component of ENSO (Fasullo et al. 2024 JCLIM)



Indonesian Fires in Oct 2023

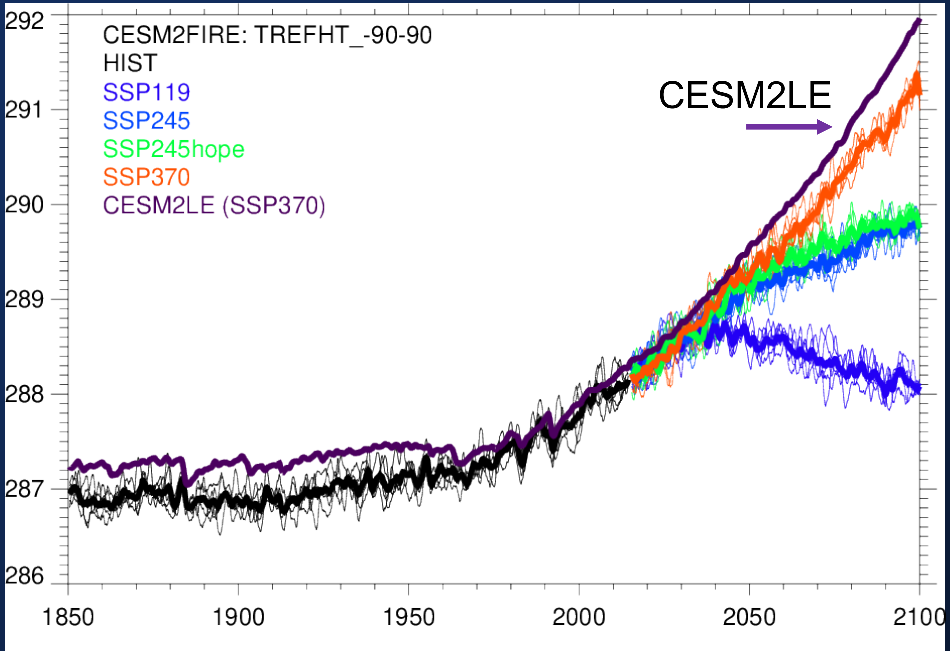
Indonesian Fires in Oct 2023, at onset of El Niño.



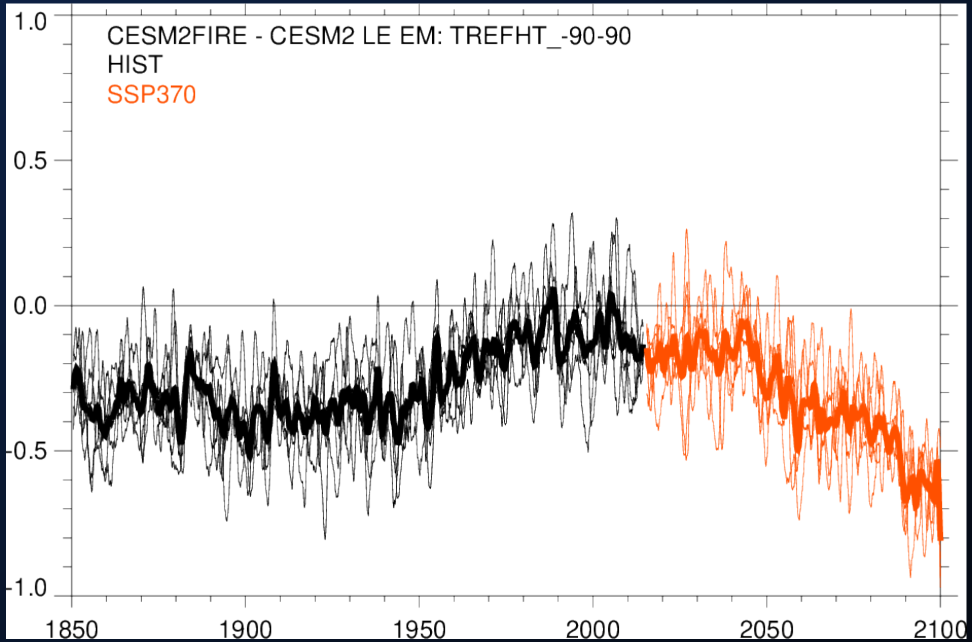
What role does fire play in ENSO? In CESM2, we fire anomalies weaken La Niña, reduce ENSO power, improve asymmetry.

What effect does it have in other models?
What is the impact of smoke on MJO? Other modes?

Historical and Projected Climate with Interactive Fires



Evolution of global T under multiple SSPs.



Difference in global T due to interactive fire vs CESM2LE. (~0.5 K in both historical and SSP370).

Conclusions

1) Variability in biomass burning emissions drives a net warming in some regions (*Fasullo et al. 2022 GRL*).

2) Some wildfires can exert an important influence on seasonal climate predictions, such as the 2019/20 Australian Wildfires (*Fasullo et al. 2021GRL/2023SA*)

3) Biomass emissions act as a coupled component of ENSO and can influence ENSO's power and diversity (*Fasullo et al. 2024J Climate*). Links to the IPO also exist *(Meehl et al.)*

4) Fire is an important coupled climate feedback, not an external forcing. Simulating the feedback will require modeling advances. Experiments with CLM have begun (*in prep*).

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