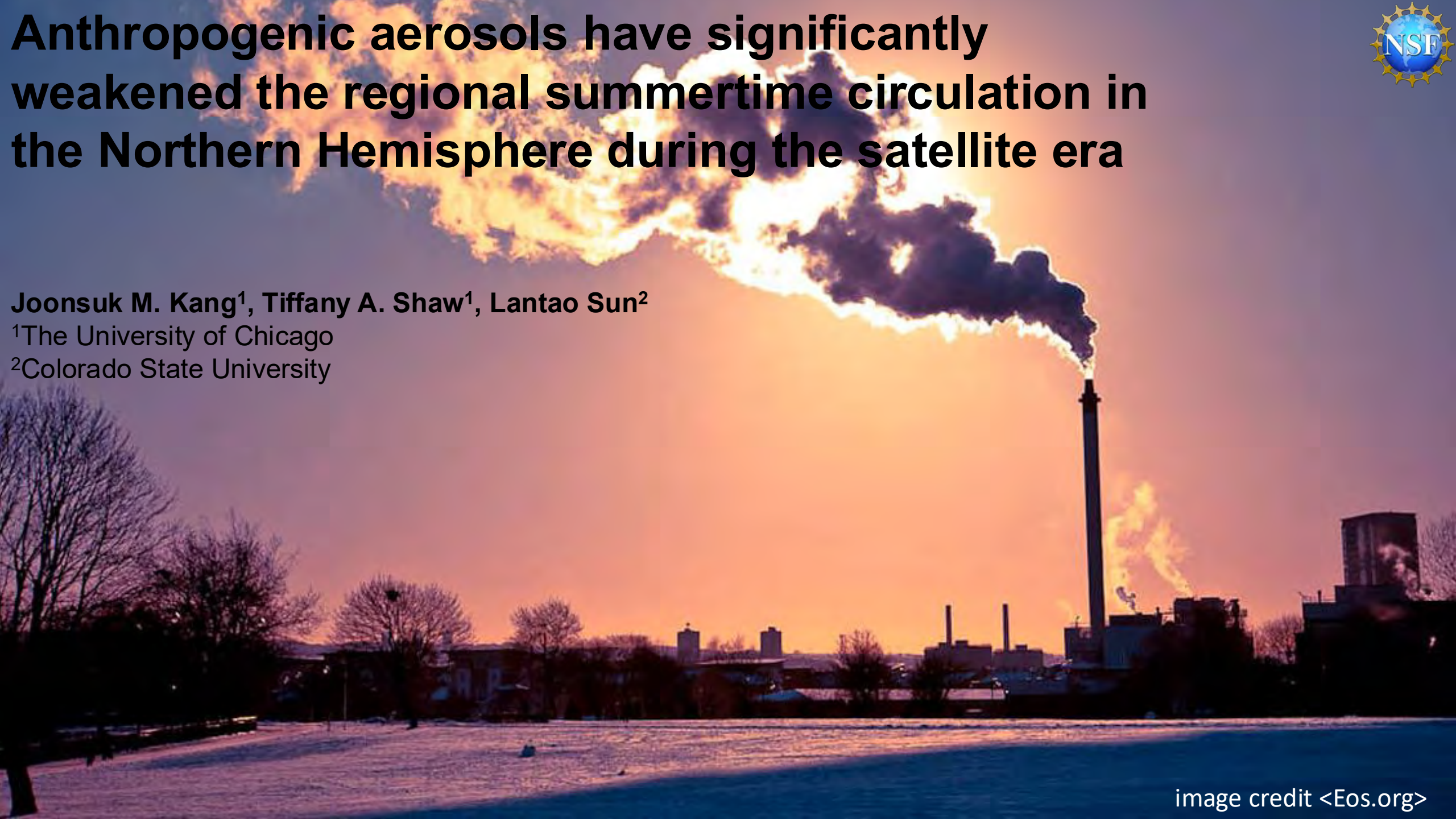
Anthropogenic aerosols have significantly weakened the regional summertime circulation in the Northern Hemisphere during the satellite era

Joonsuk M. Kang[1], Tiffany A. Shaw[1], Lantao Sun[2]
[1]The University of Chicago
[2]Colorado State University



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Emerging Climate Change Signals in Atmospheric Circulation

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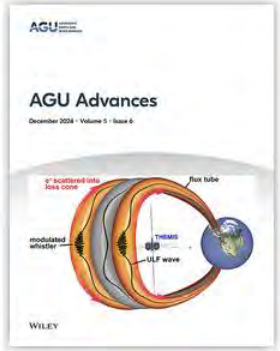

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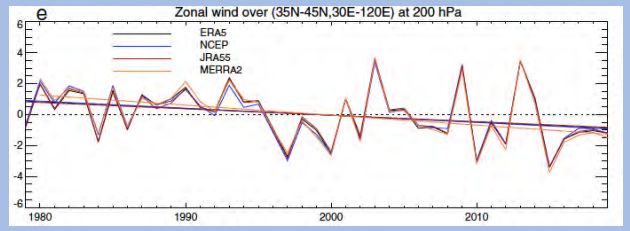
Highlight

Research Spotlight—Bringing Climate Change's Effects on Atmospheric Circulation to Light

Robust regional summertime circulation trends in the satellite era

Weaker Eurasian Jet Stream



Dong et al. (2022)

See also Coumou et al. (2015), Gertler & O'Gorman (2019), Chemke & Coumou (2024)

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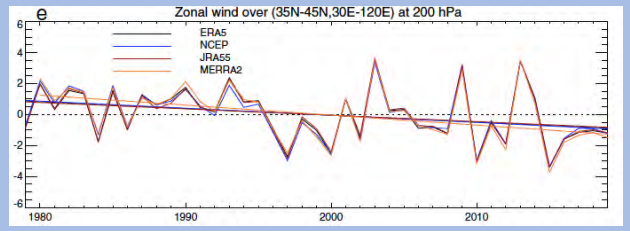
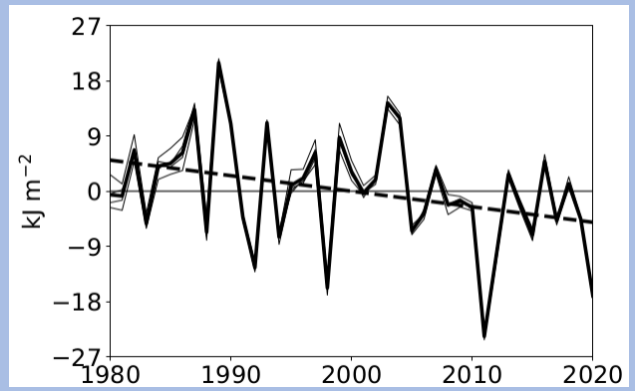


Dong et al. (2022)

Weaker Pacific storm track



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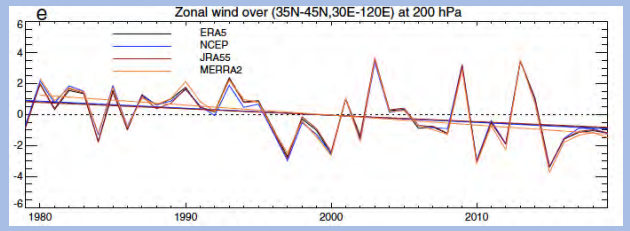

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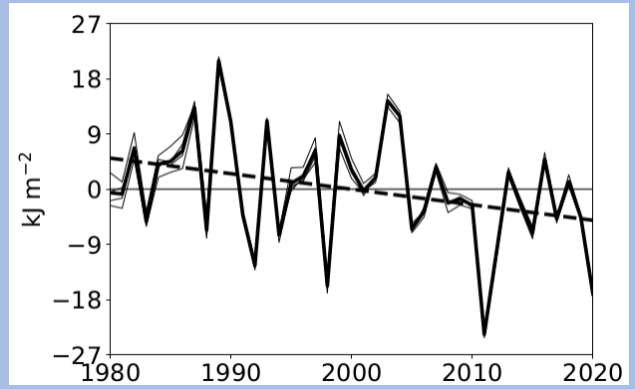
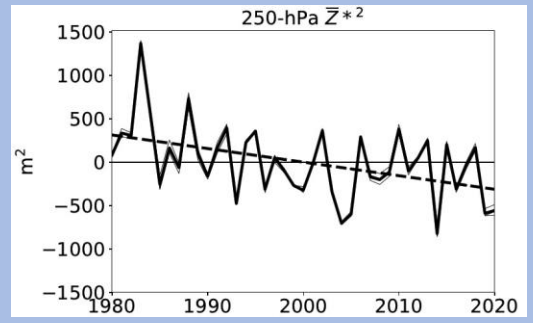


Kang et al. (2024)

Weaker meridional flow/waviness over Eurasia

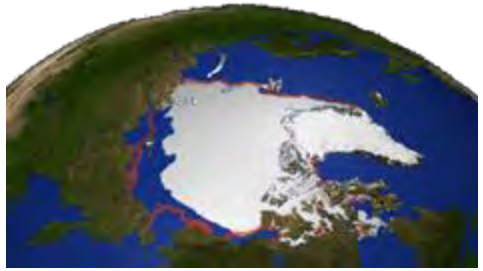


Di Capua & Coumou (2016)

See also Coumou et al. (2015), Gertler & O'Gorman (2019), Chemke & Coumou (2024)

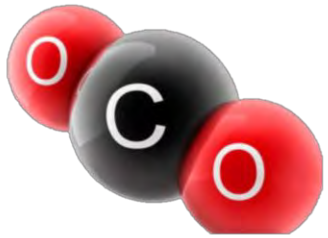
Various drivers can affect summertime weakening

Arctic sea ice loss



Coumou et al. (2015, Science)

Direct CO_2



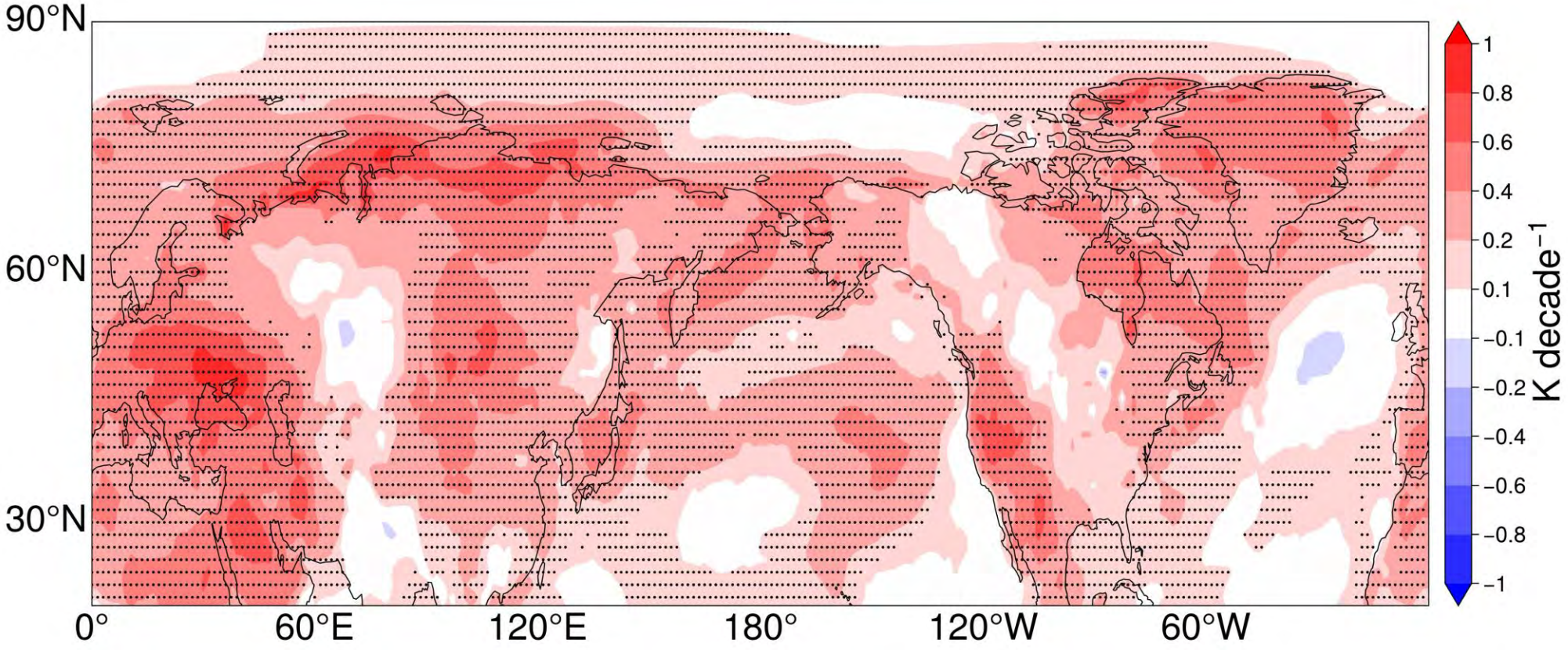
Shaw and Voigt (2015, Nature Geoscience)

Aerosols

Dong et al. (2022, Nature Comm.)

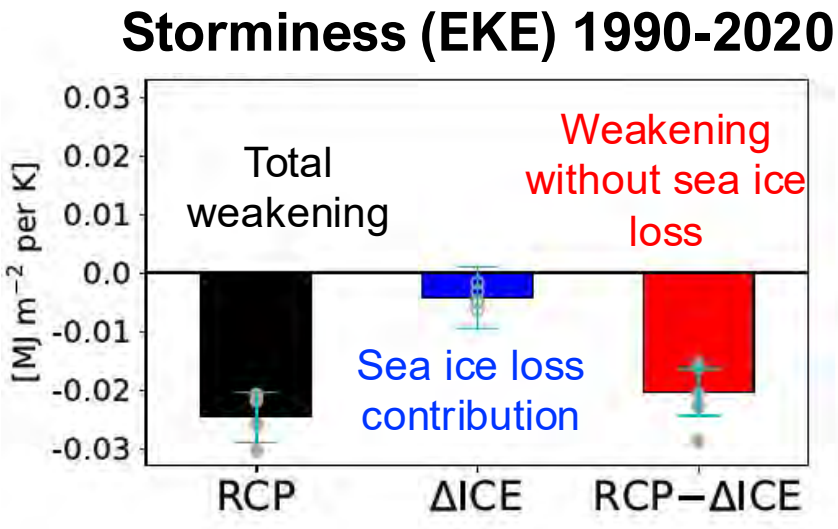
Robust summertime temperature trends do not reflect Arctic warming

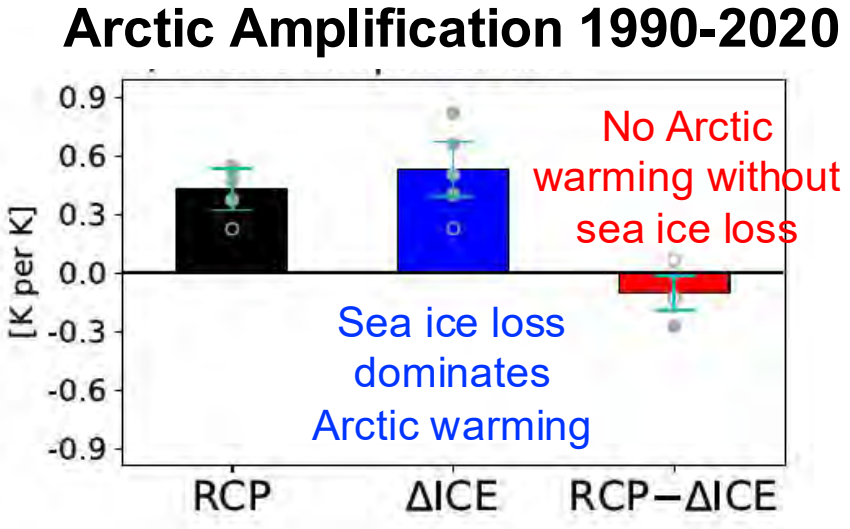
Summertime mean surface temperature trend JJA 1979-2020



Kang et al. (2025, in prep.)

Mechanism denial simulations suggest Arctic warming is not a dominant factor





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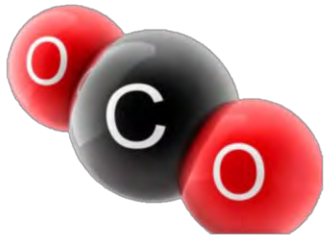

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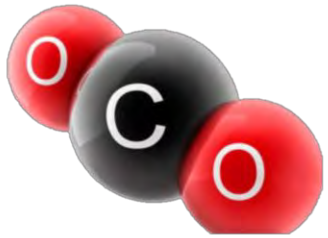

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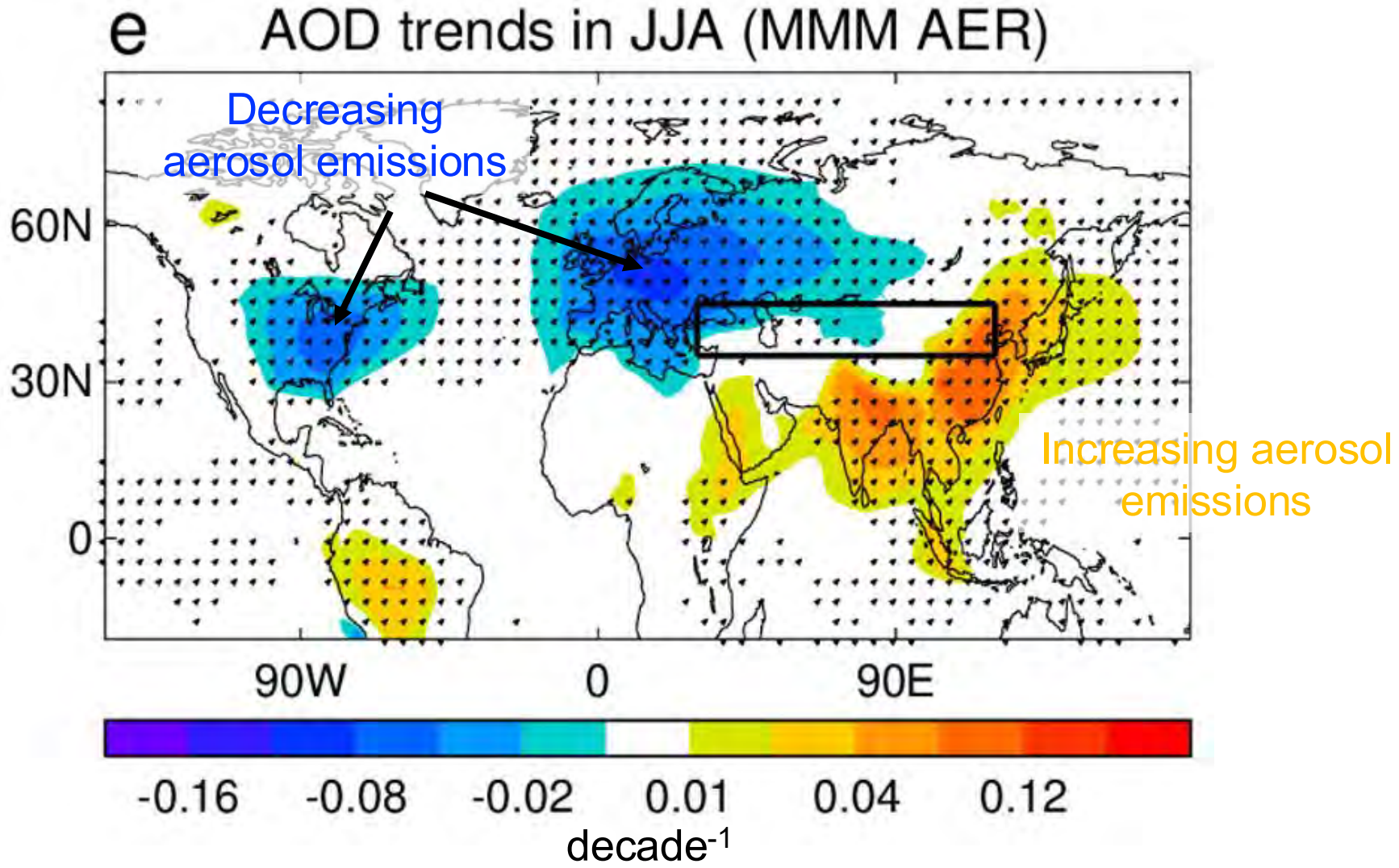
Dong et al. (2022, Nature Comm.)

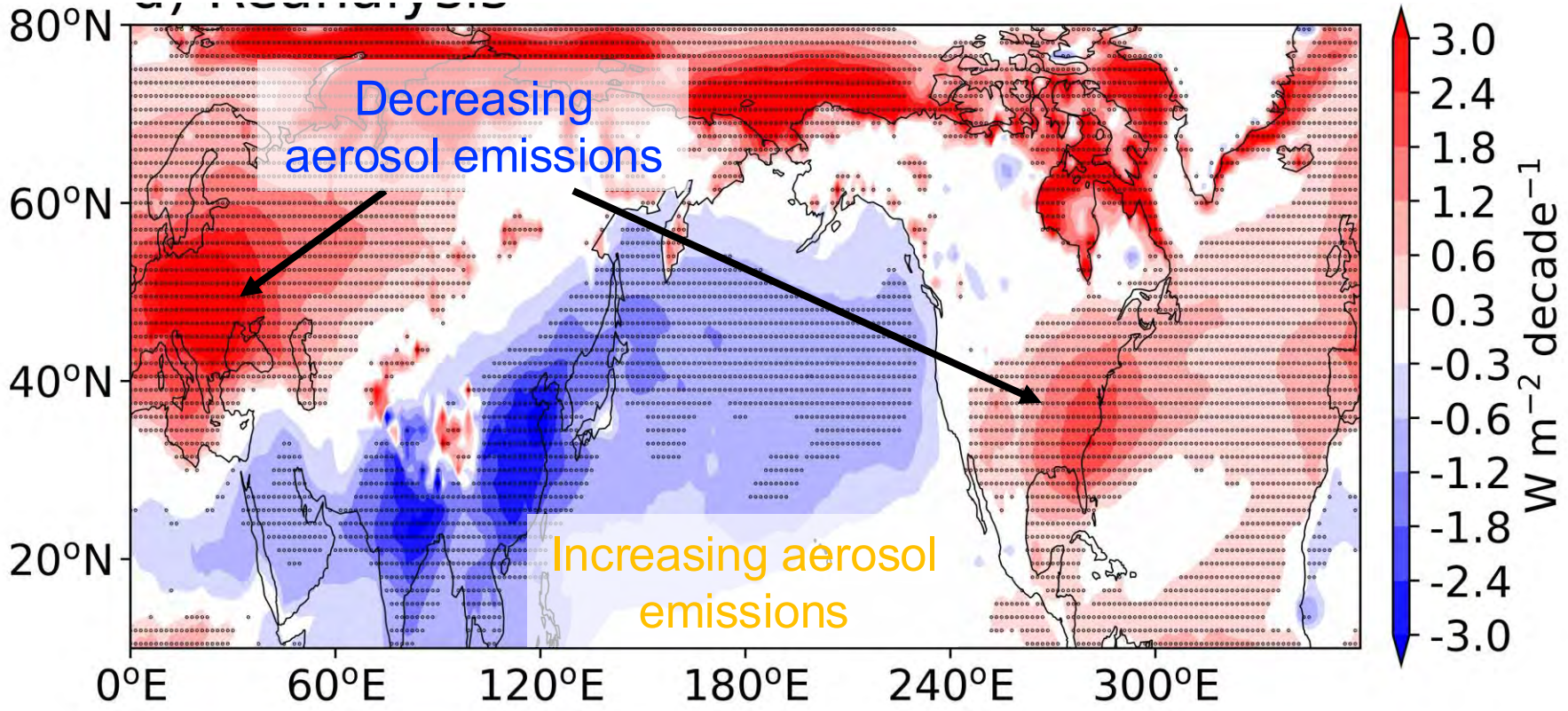
Aerosol emissions led to regional optical depth trends



Dong et al. (2022, Nature Comm.)

Robust summertime surface shortwave radiation trend reflects aerosol trends

Surface clear-sky shortwave radiation trend ERA5 1979-2020*



*Reanalysis trends agree with CERES

Kang et al. (2024, AGU Advances)

Single forcing DAMIP simulations can be used to quantify the role of aerosols

ScenarioMIP

historical+
ssp245

All forcings

DAMIP Gillett et al. (2016)

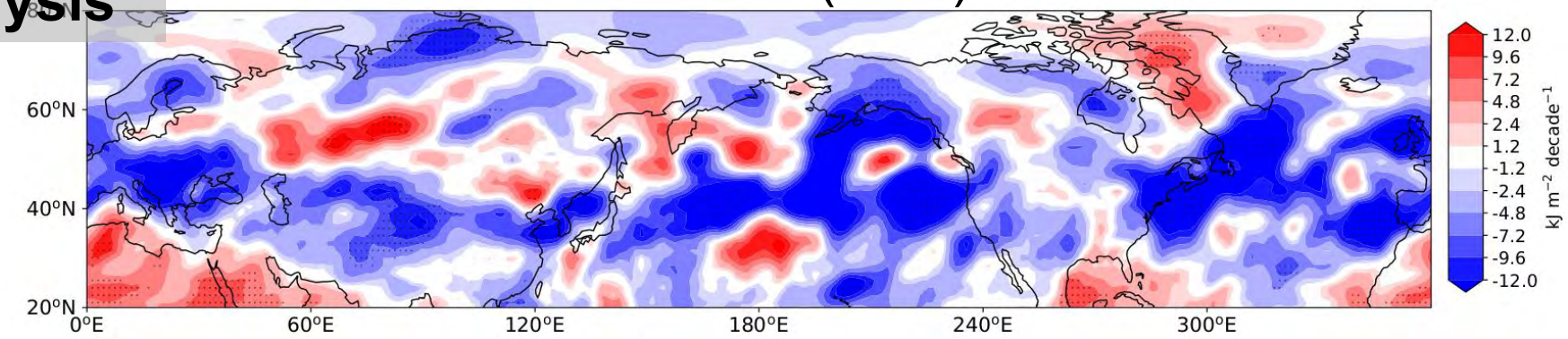
hist-GHG
hist-aer
hist-nat

Single forcing

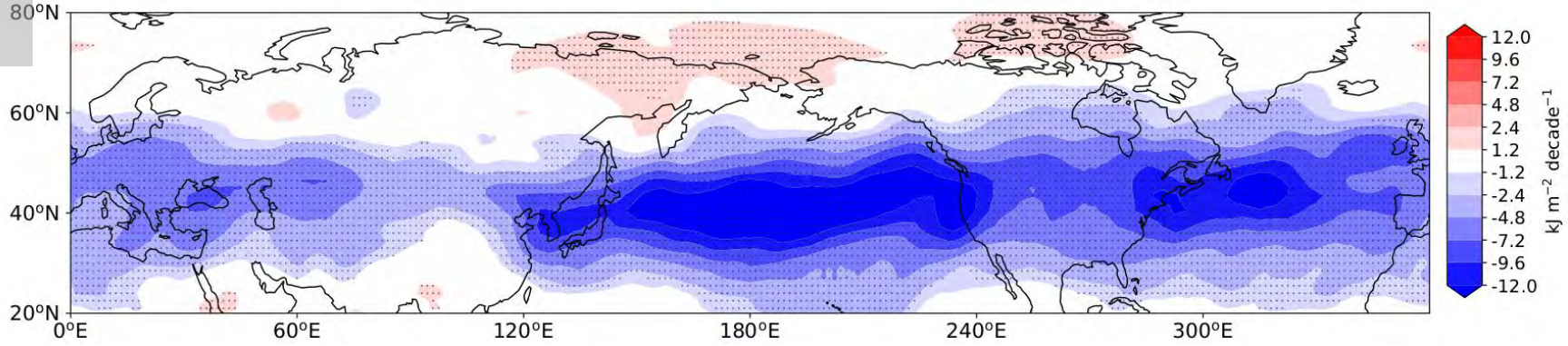
Storminess weakening is captured by climate models

Reanalysis

Summertime storminess (EKE) trends 1979-2020



ALL



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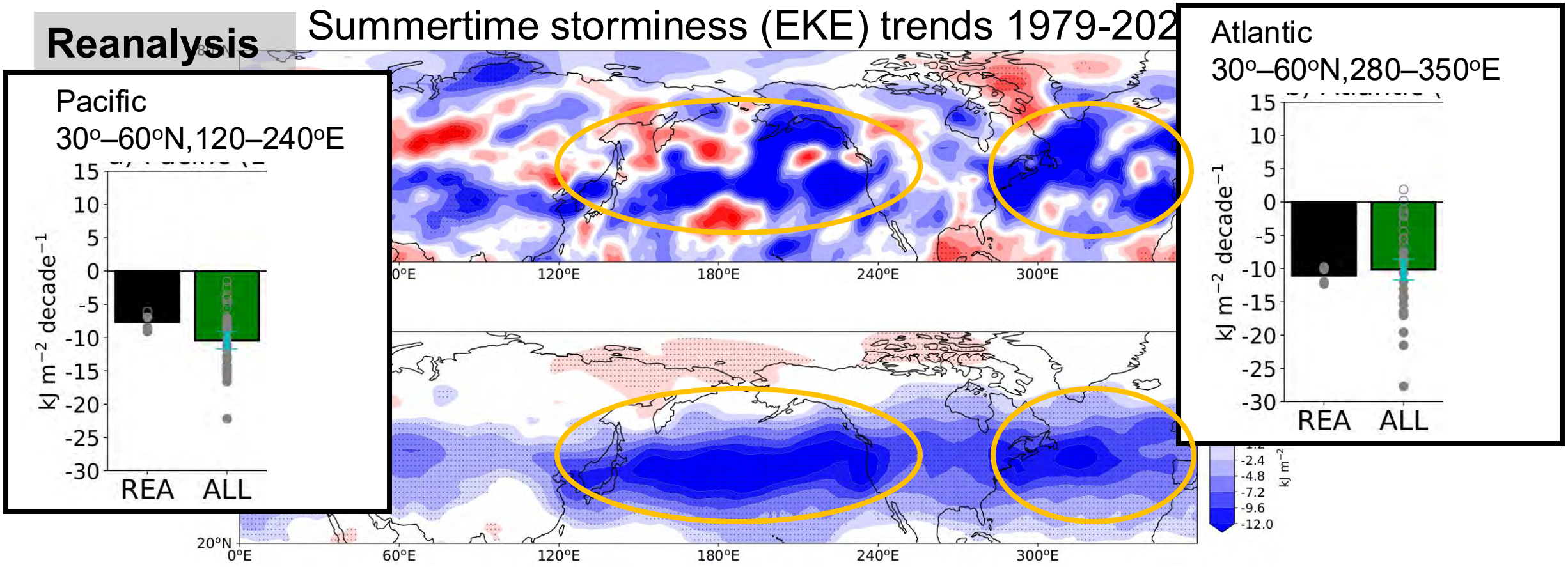
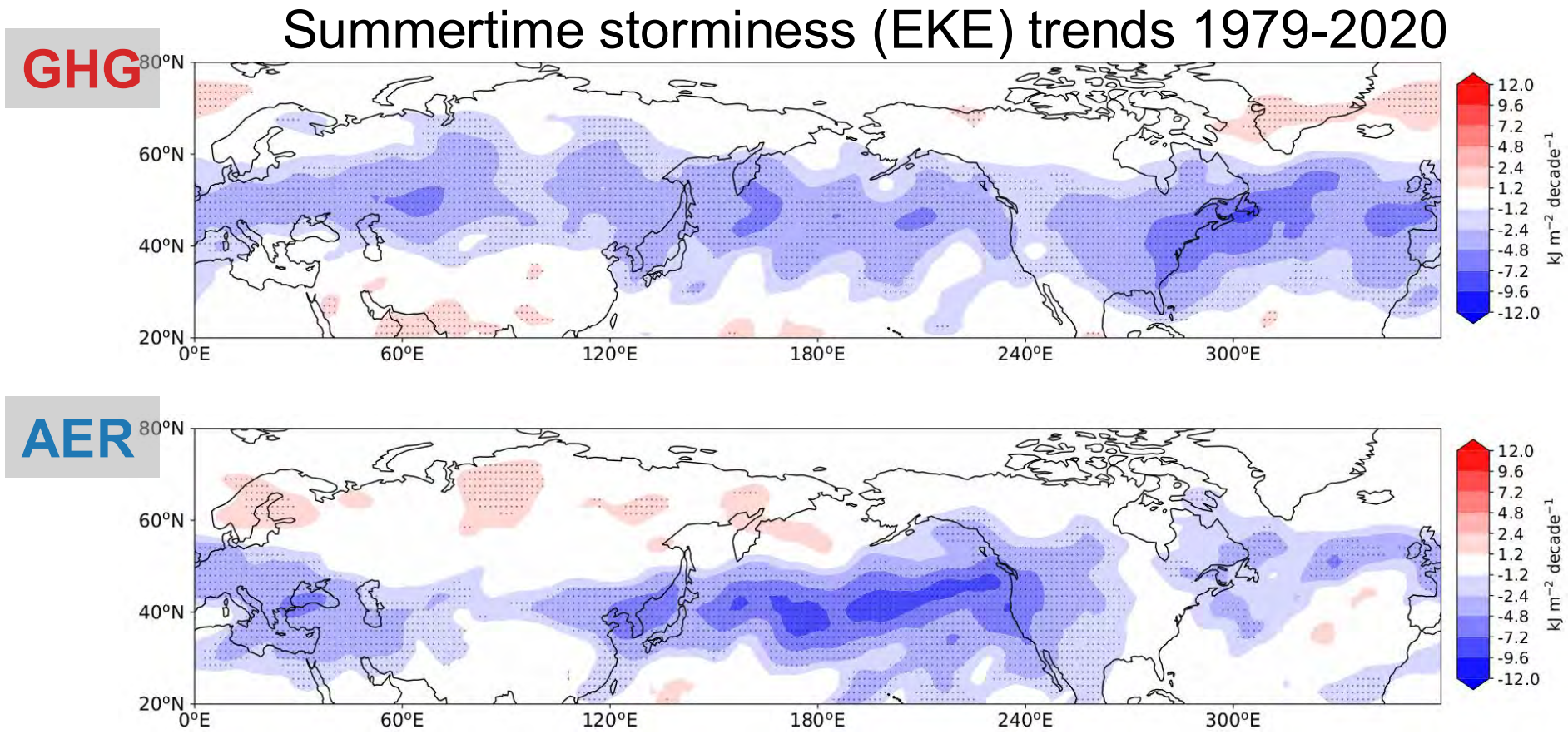
Storminess weakening is captured by climate models



Kang et al. (2024, AGU Advances)

Aerosol forcing significantly weakens the Pacific storm track



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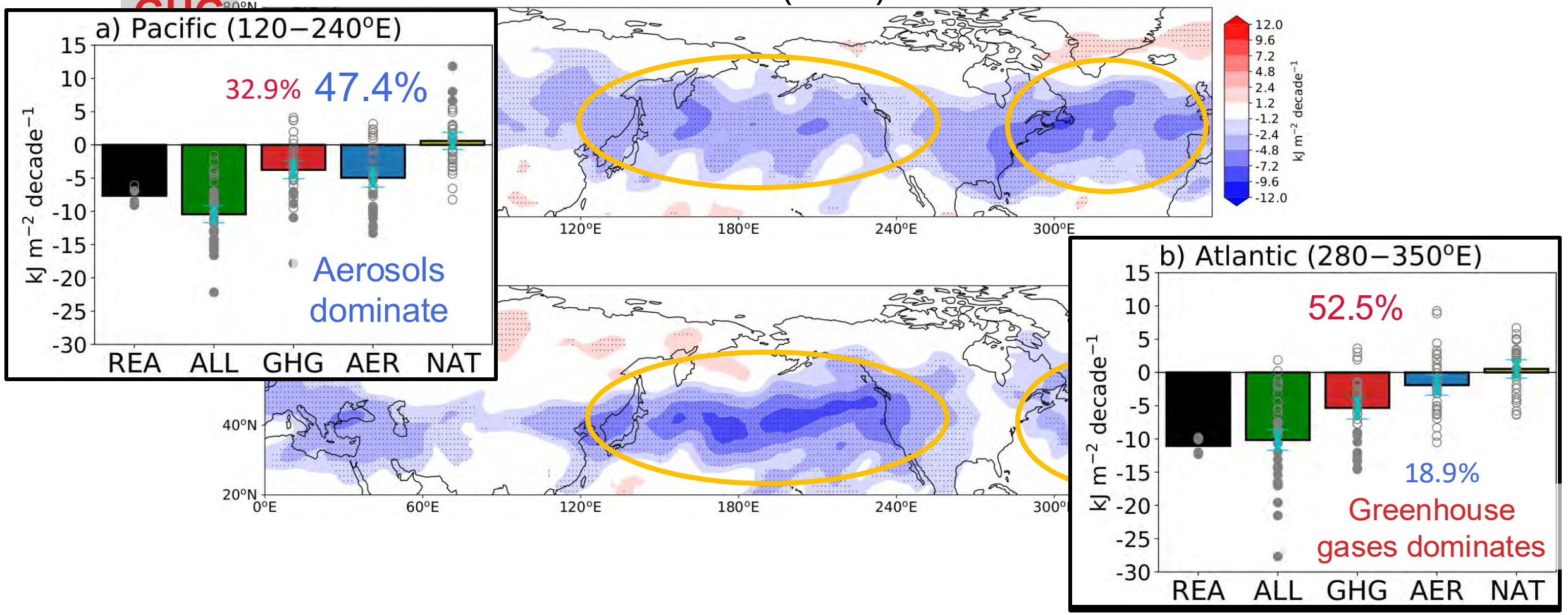
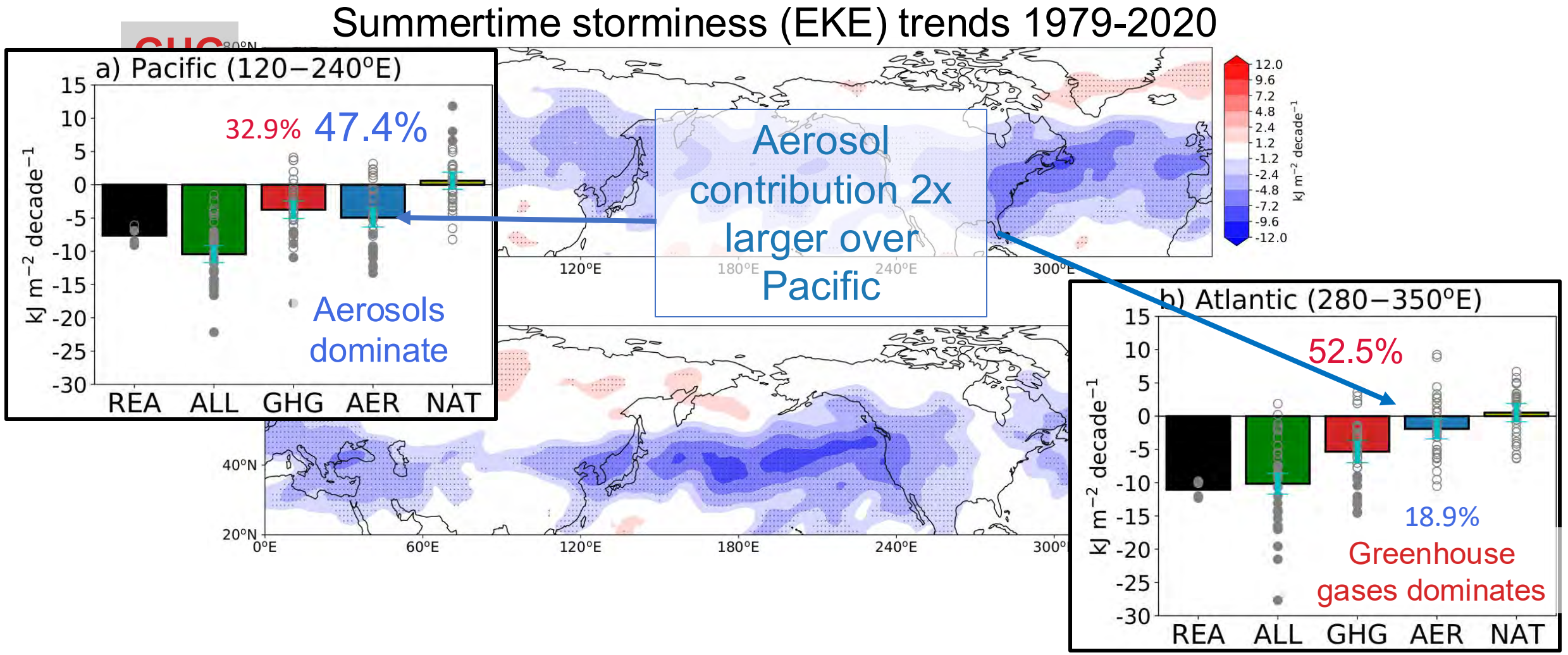
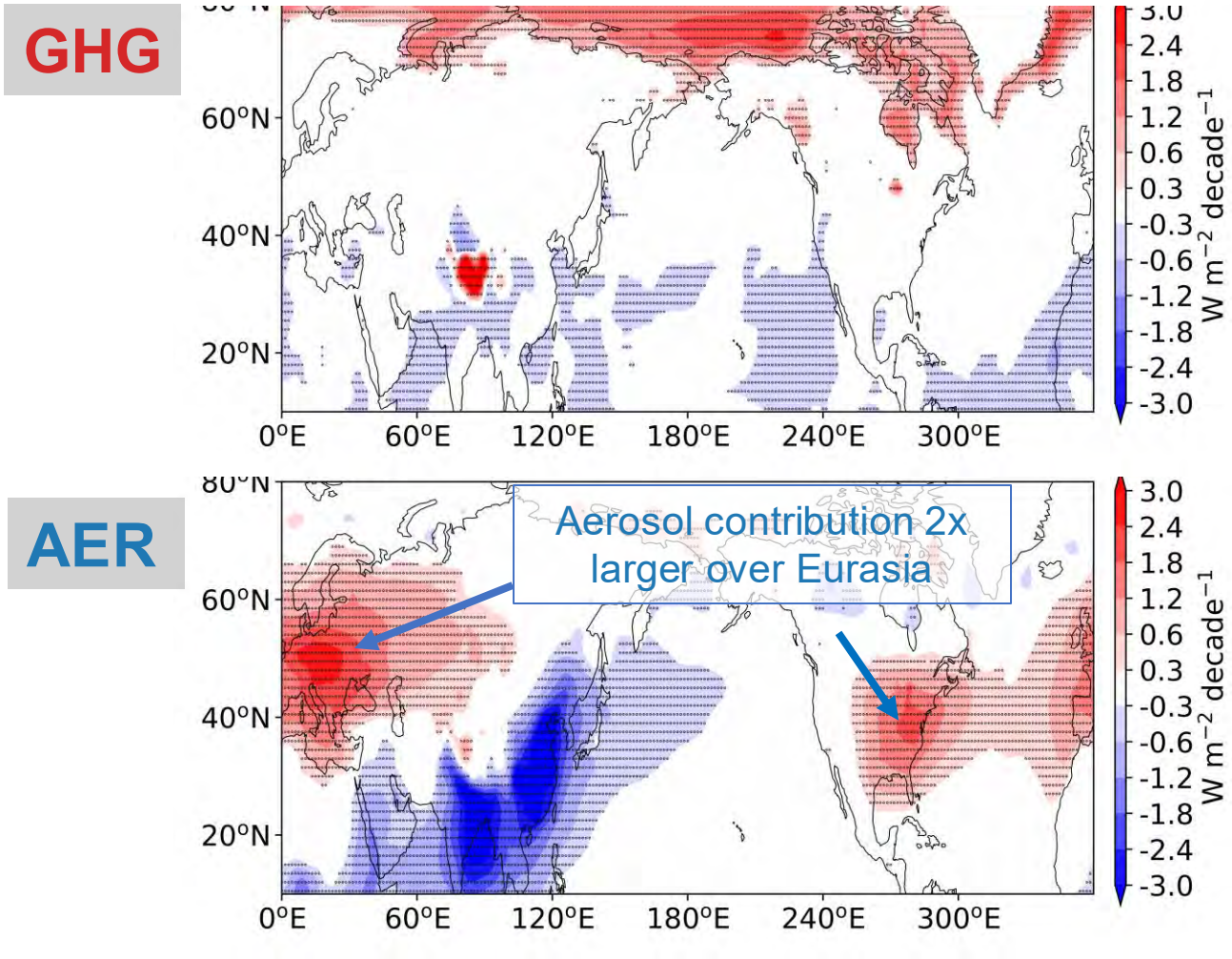


Aerosol forcing significantly weakens the Pacific storm track



Aerosol surface shortwave trend over Eurasia is twice as large as over N America

Surface shortwave radiation trends



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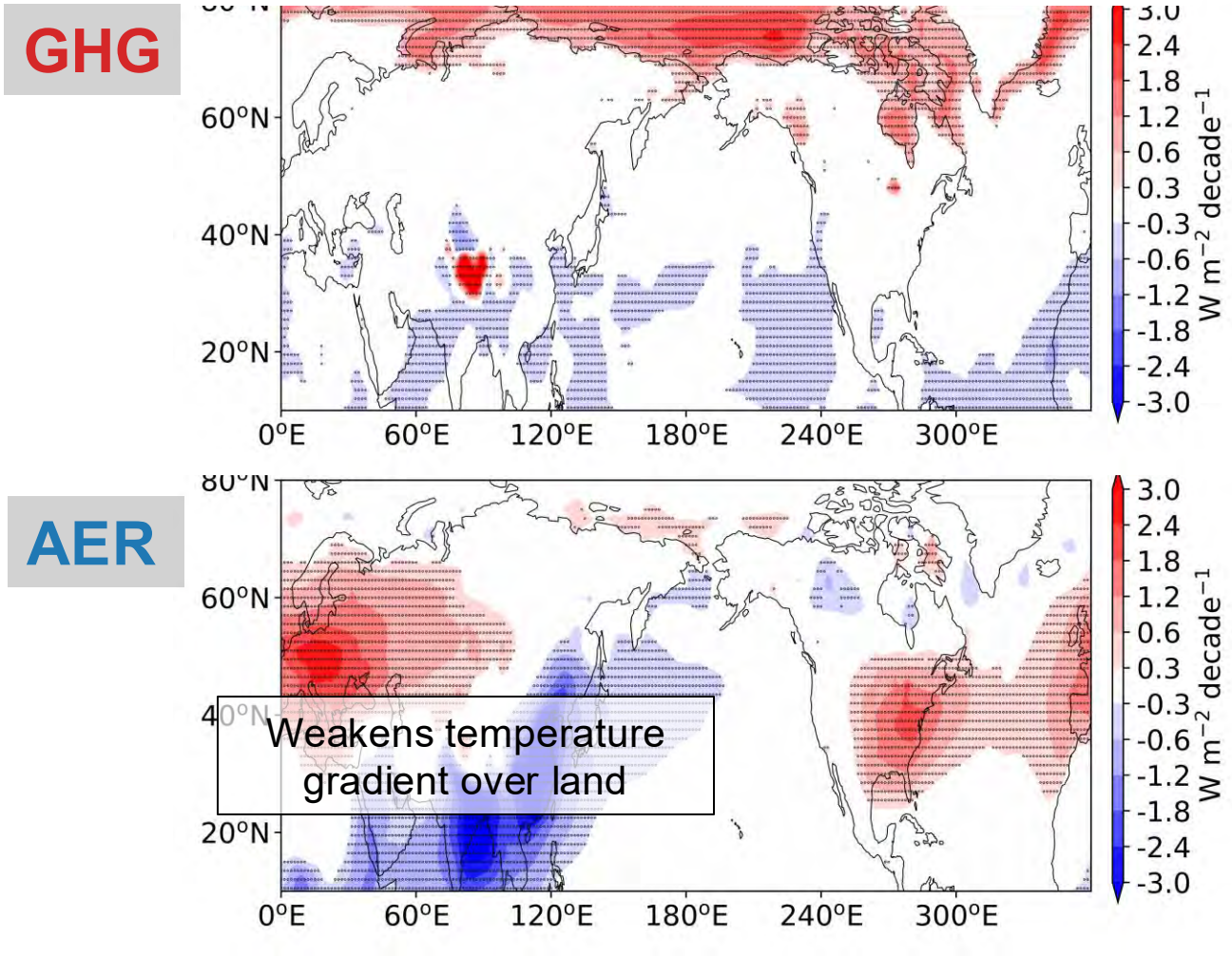
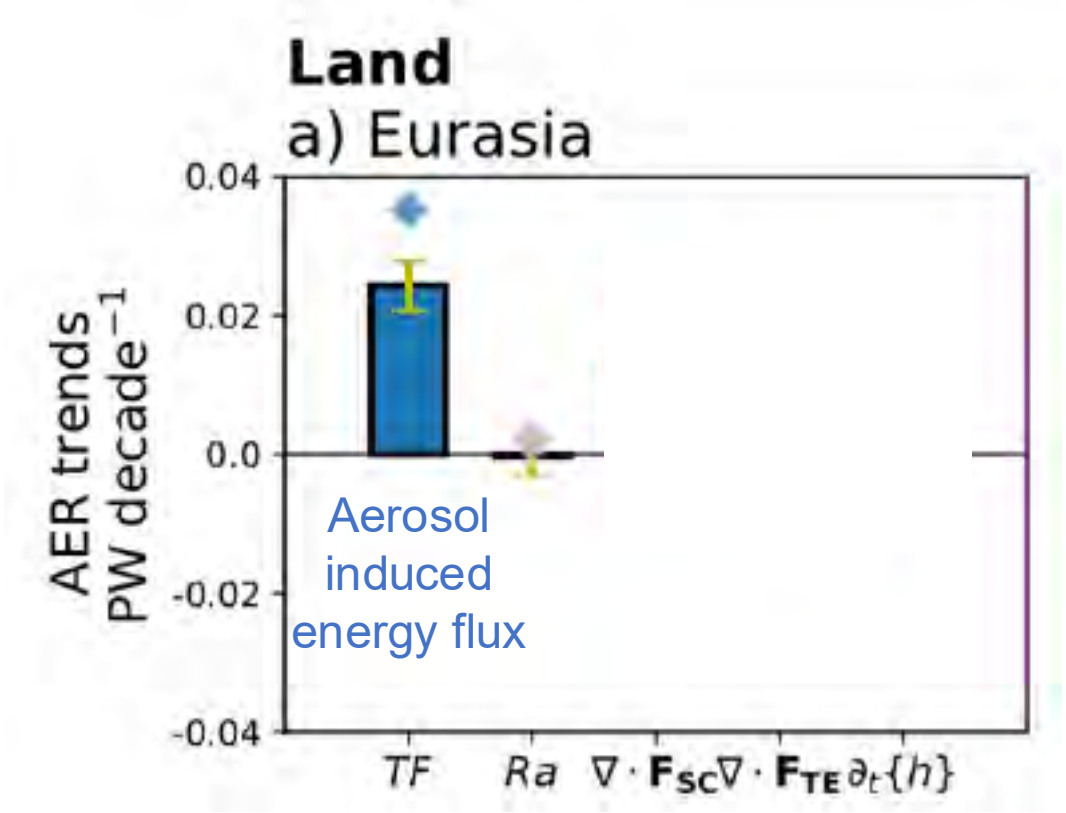
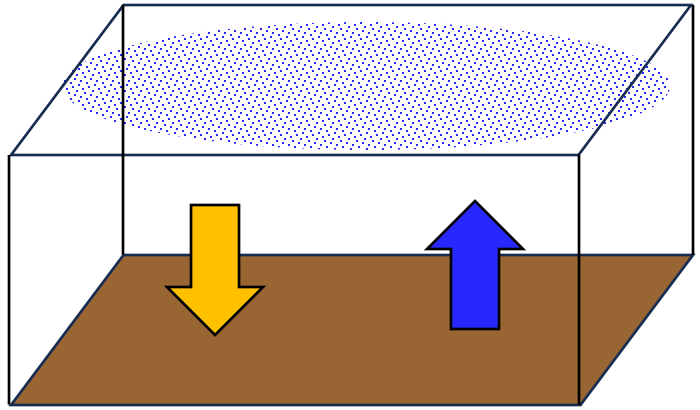


Kang et al. (2024, AGU Advances)

Increased sunlight over land leads to increased turbulent flux



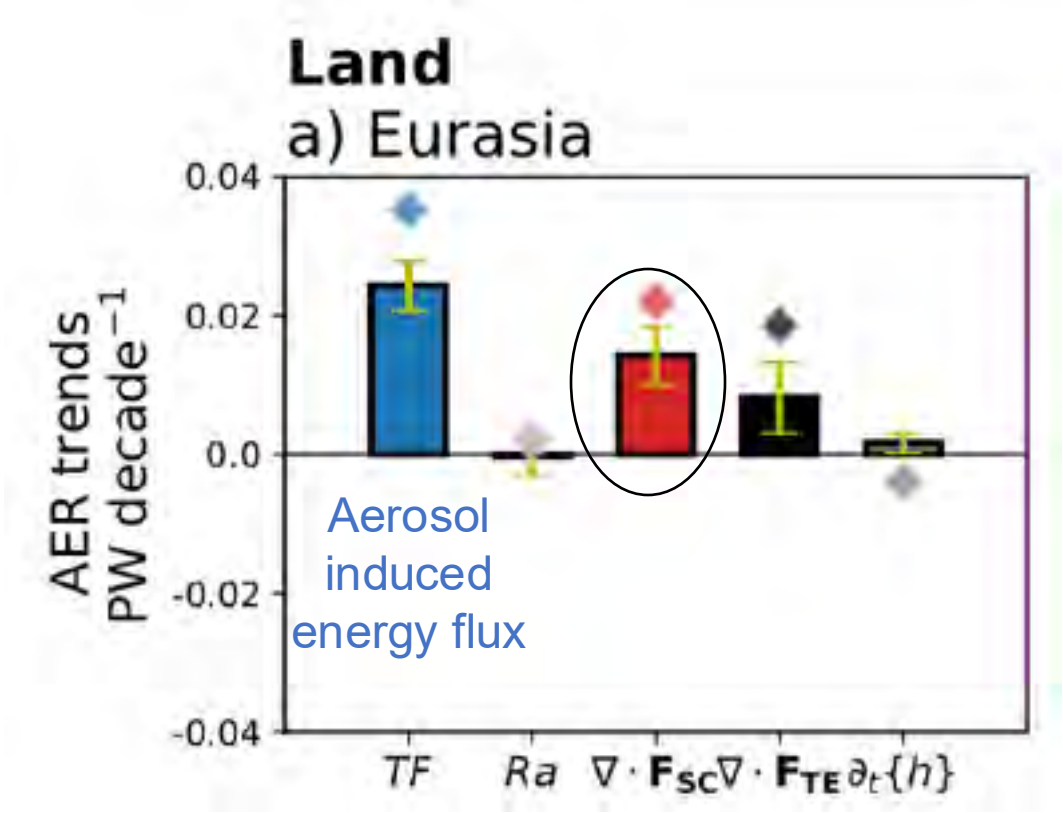


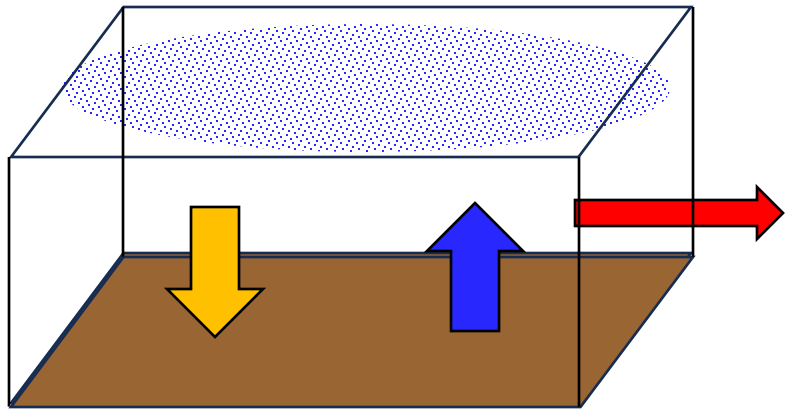
ΔSW > 0 to surface

ΔTF > 0 to atmosphere

Kang et al. (2024, AGU Advances)

Increased energy flux over land leads to energy export by stationary circulation



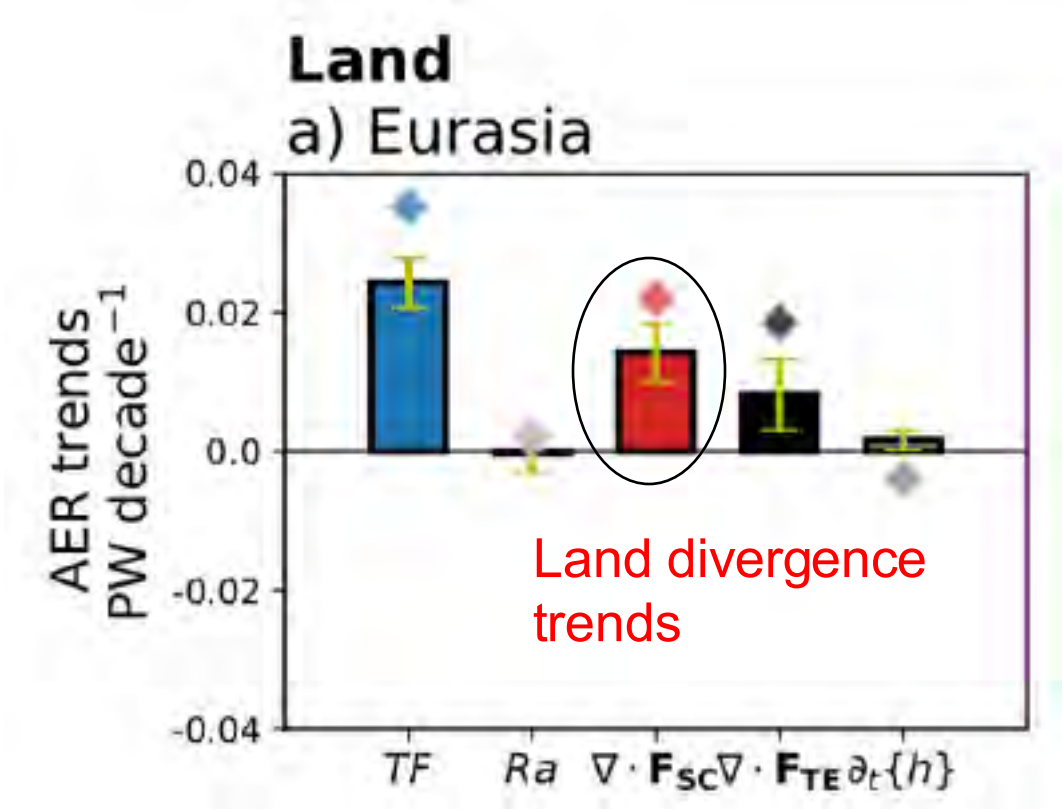


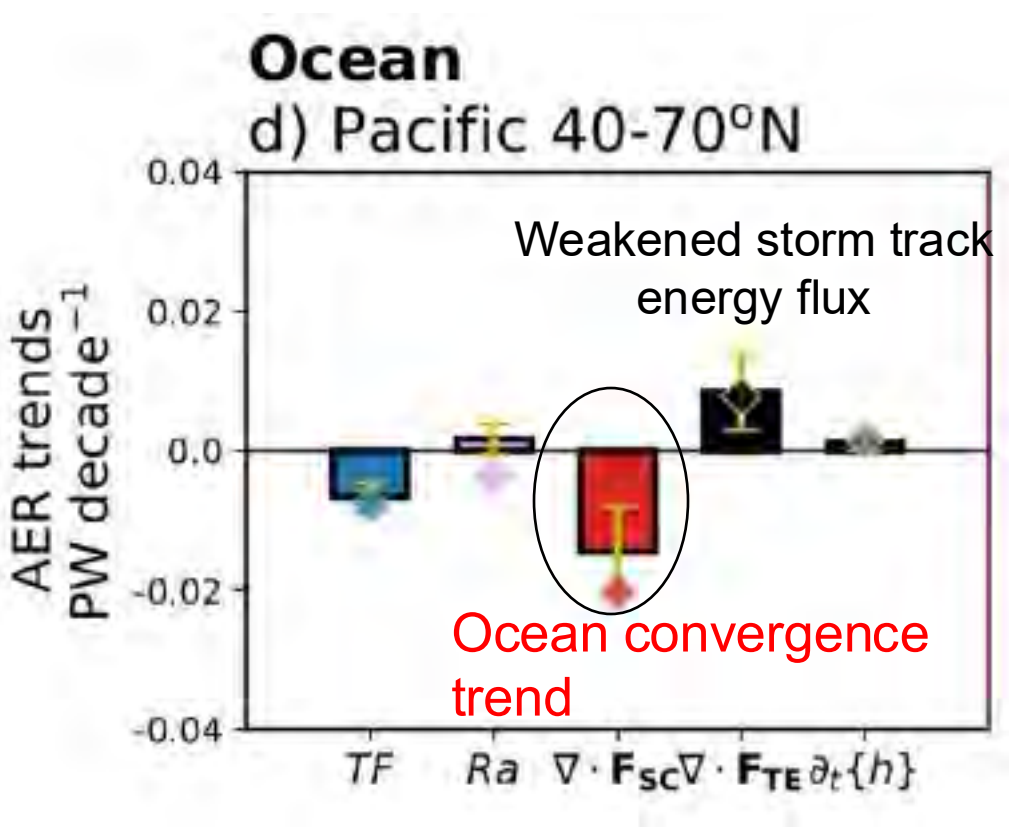
ΔSW > 0
to surface

ΔTF > 0
to atmosphere

Kang et al. (2024, AGU Advances)

Energy flux converges over the ocean weakening storm tracks





Similar to seasonal cycle (Donohoe & Battisti 2013, J. Clim.) and idealized experiments (Kaspi & Schneider 2011, J. Clim.)

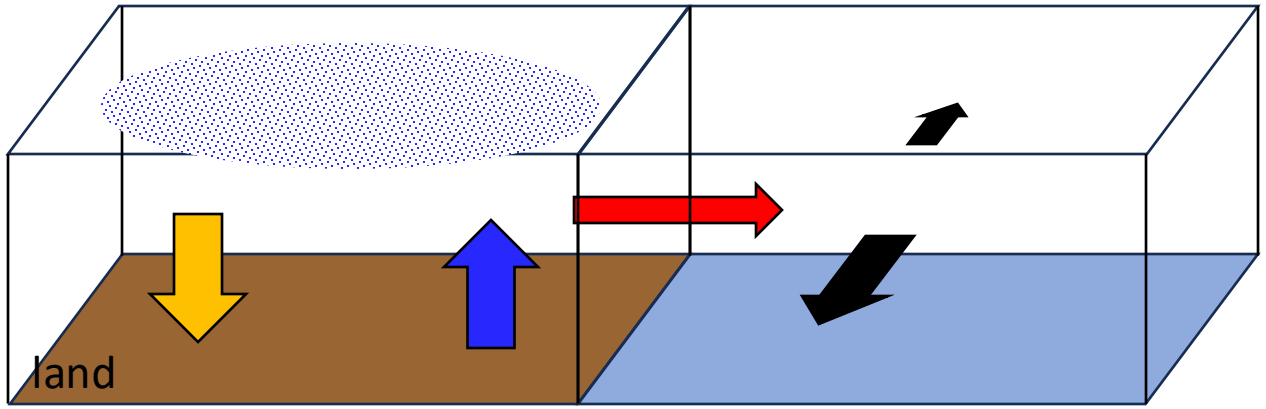
Kang et al. (2024, AGU Advances)

Aerosol forcing over land weakens the oceanic storm tracks through land-ocean energy coupling

Upstream Land

Downstream Ocean

Land energy export 2x larger over Eurasian than N America



Storm track weakening 2x larger over Pacific than Atlantic*

ΔSW > 0 to surface

ΔTF > 0 to atmosphere

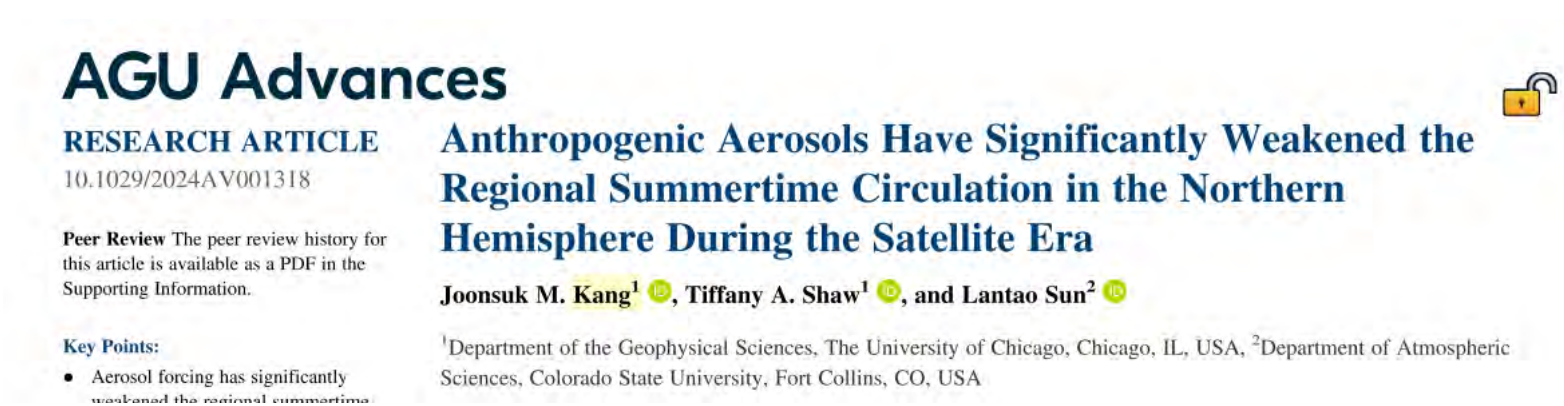
$$\Delta(\nabla \cdot \mathrm{F_{SC}}) \approx -\Delta(\nabla \cdot \mathrm{F_{TE}})$$

*Weakening can be predicted following energy balance model of Boos & Korty (2016, Nature Geosc.)

Kang et al. (2024, AGU Advances)

Take-Away Messages

- Anthropogenic aerosols significantly weakened the summertime circulation in the satellite era, contributing to almost half of storm track weakening.
- Aerosol induced shortwave radiation strengthens land-to-ocean energy contrast and leads to energy export from land.
- Aerosol induced energy export from the land weakens the oceanic storm tracks, particularly in the Pacific due to large aerosol forcing upstream.



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RESEARCH ARTICLE
10.1029/2024AV001318

Peer Review The peer review history for this article is available as a PDF in the Supporting Information.

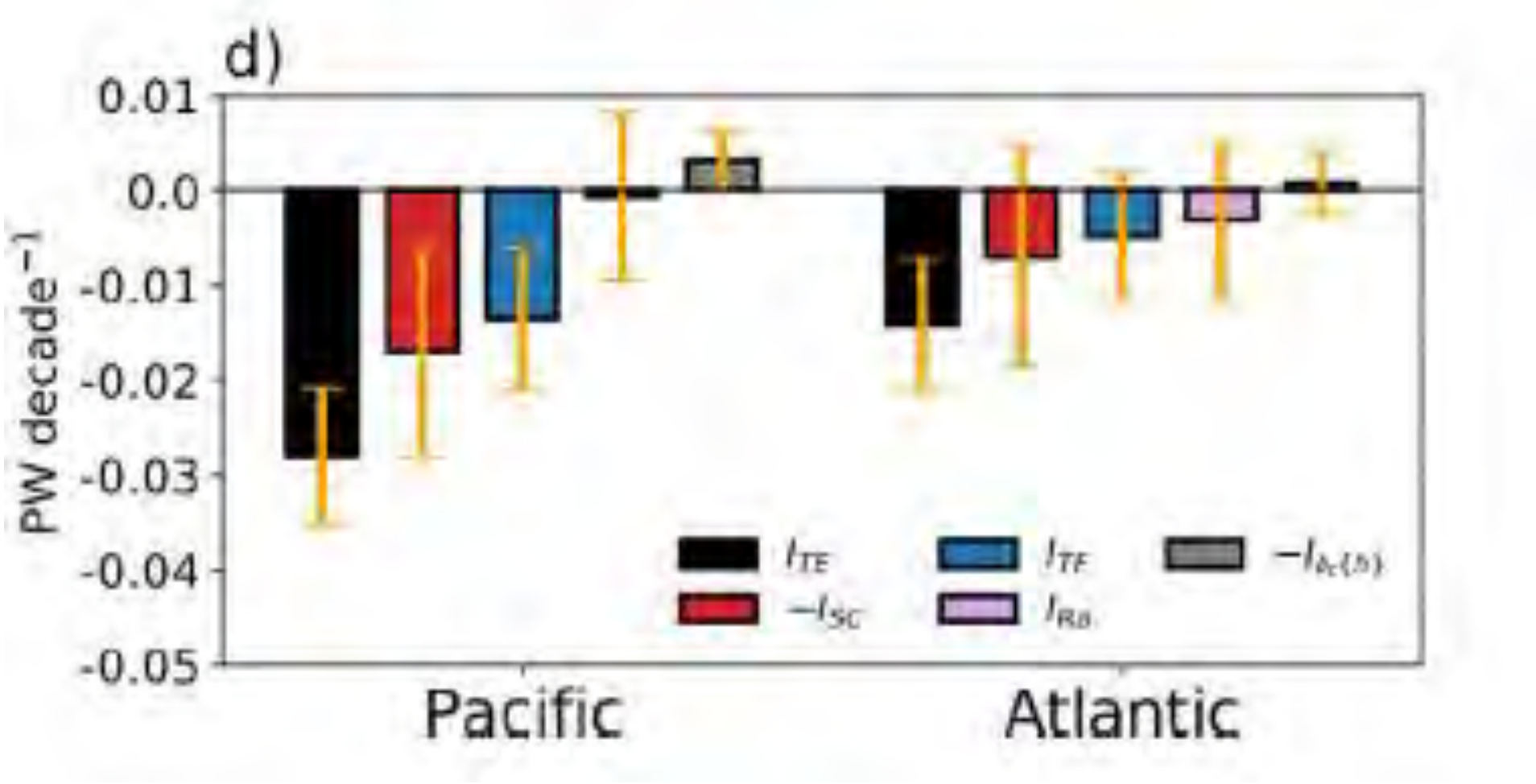
Key Points:
- Aerosol forcing has significantly

Anthropogenic Aerosols Have Significantly Weakened the Regional Summertime Circulation in the Northern Hemisphere During the Satellite Era

Joonsuk M. Kang[1], Tiffany A. Shaw[1], and Lantao Sun[2]

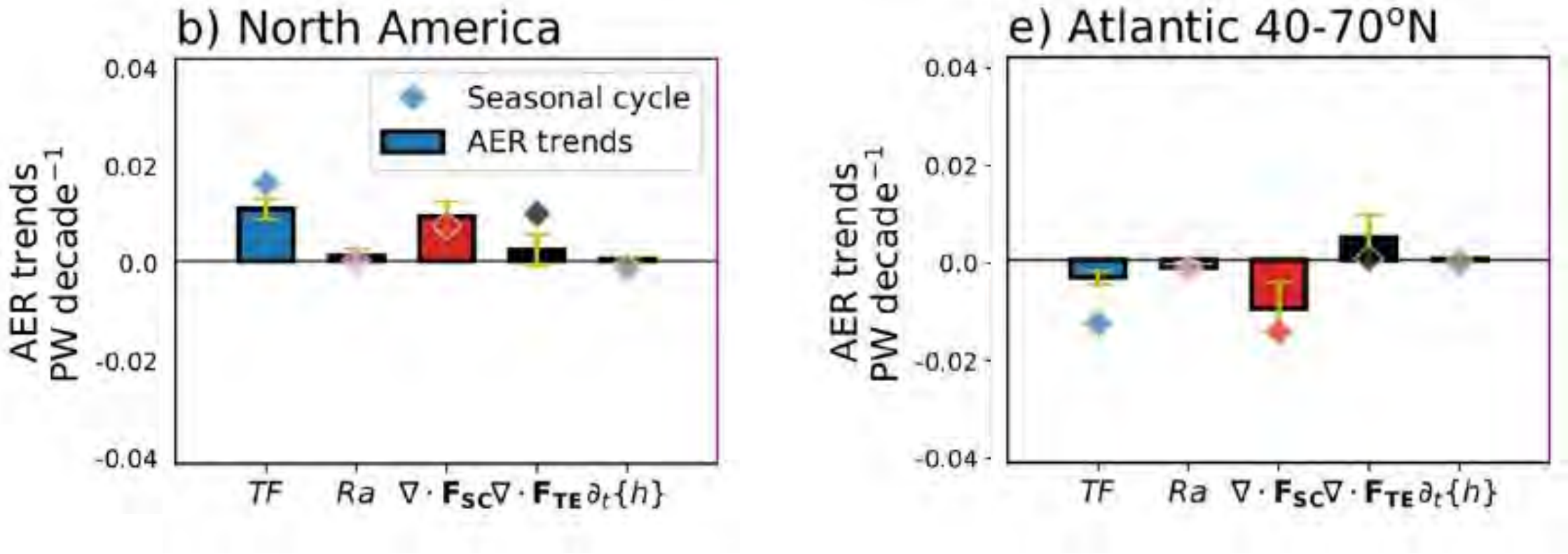
[1]Department of the Geophysical Sciences, The University of Chicago, Chicago, IL, USA, [2]Department of Atmospheric Sciences, Colorado State University, Fort Collins, CO, USA

Predicted weakening of storm tracks given aerosol forcing over land



Kang et al. (2024, AGU Advances)

Weakening is smaller over the Atlantic because upstream aerosol-induced trend is smaller



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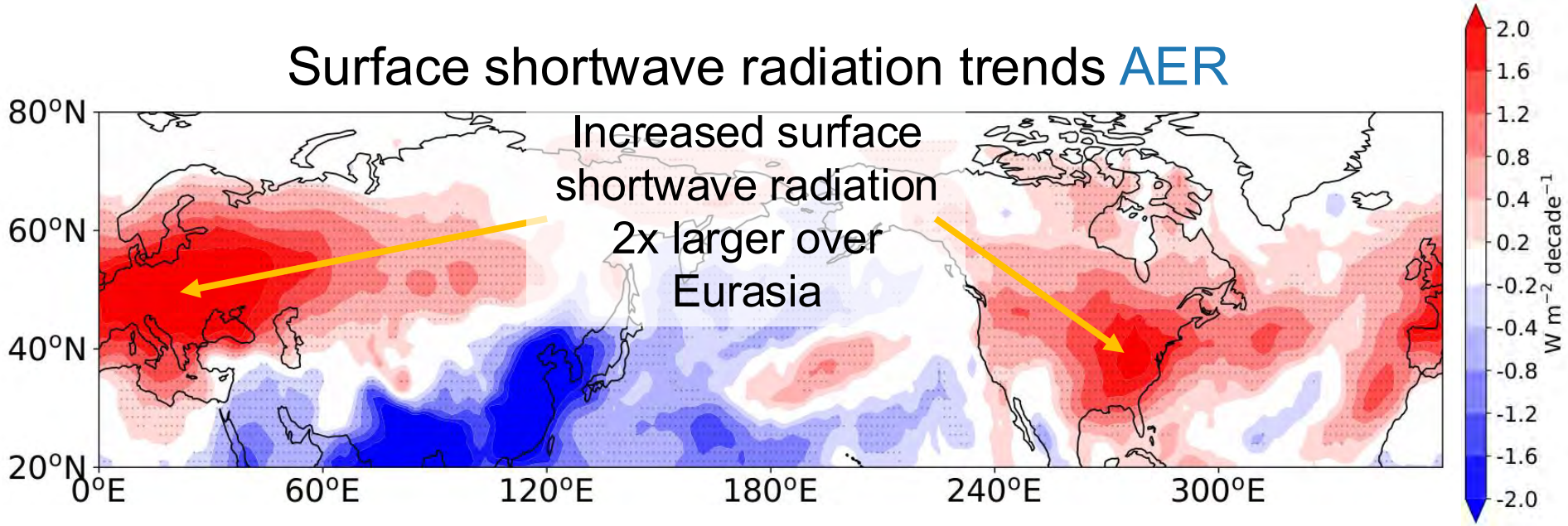
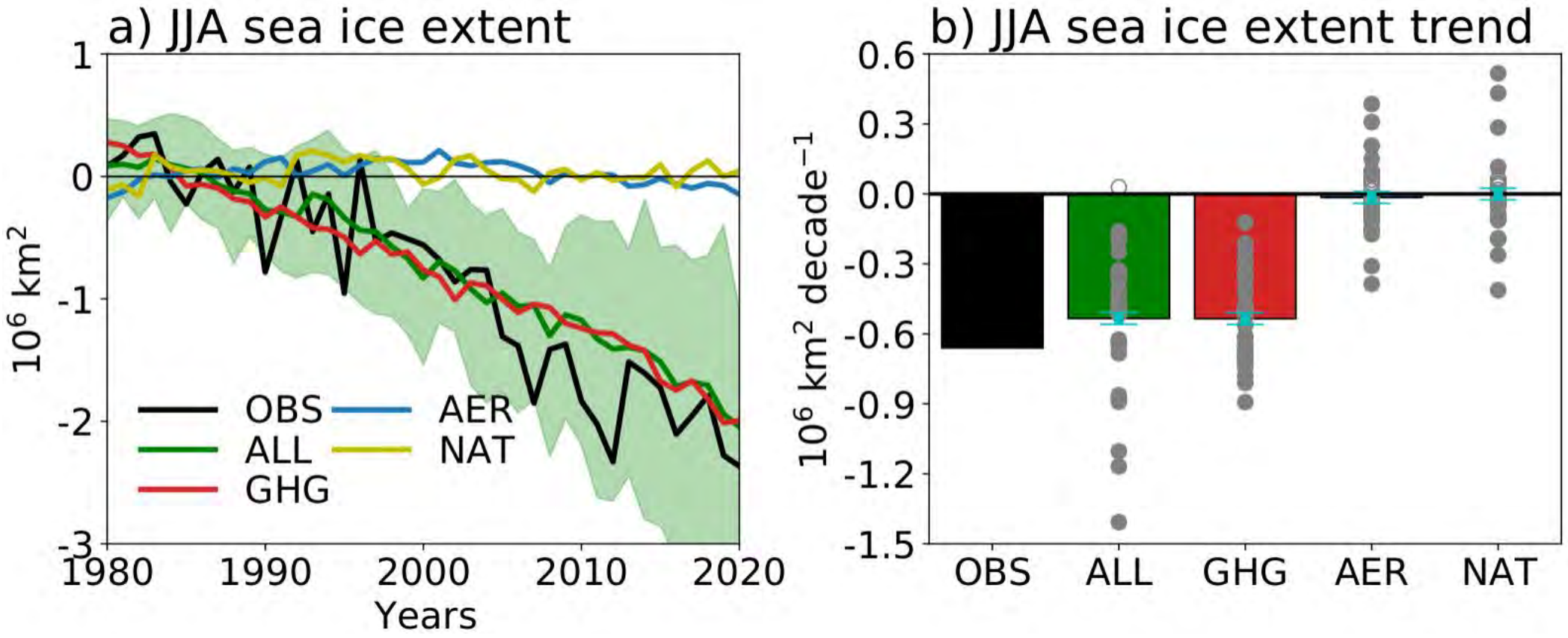


Kang et al. (2024, AGU Advances)

Sea ice loss is dominated by GHG



Zonal mean temperature trend is consistent with storm track weakening