A new method for diagnosing effective radiative forcing from aerosol-cloud interactions in climate models

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A new method for diagnosing effective radiative forcing from aerosol–cloud interactions in climate models

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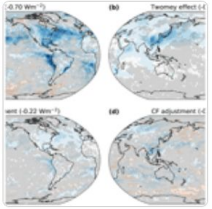

https://acp.copernicus.org/articles/25/2123/2025/

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modis_cloud_radiative_kernels

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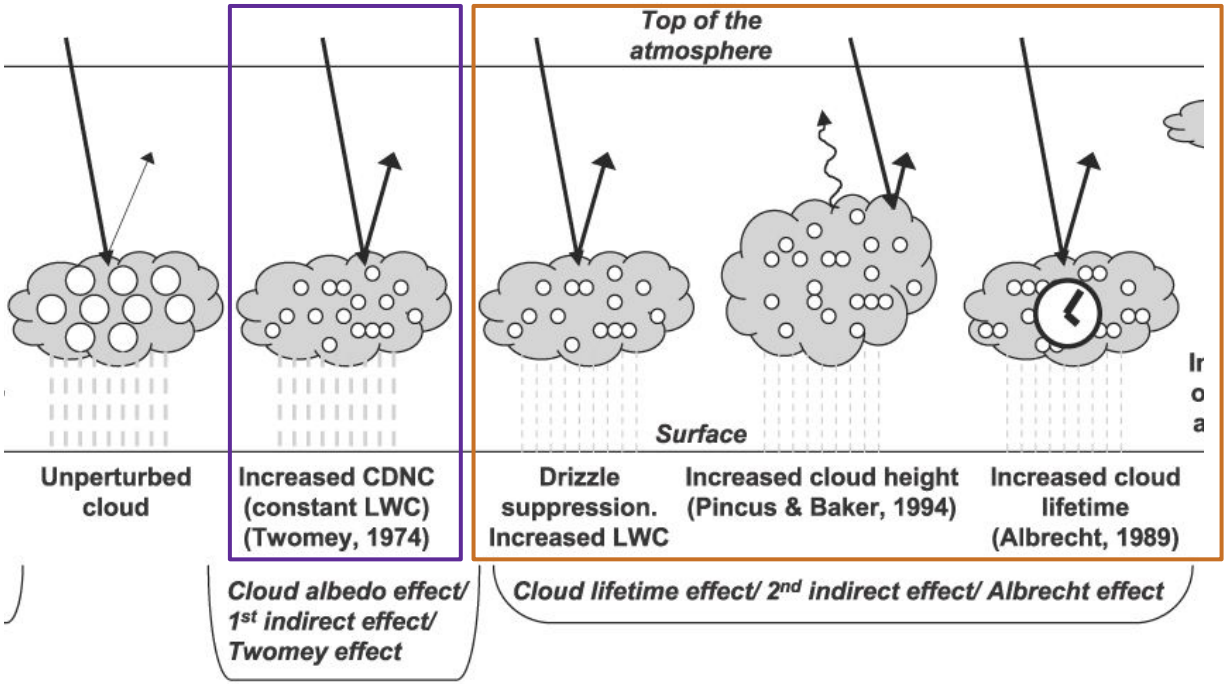
Code for decomposing the shortwave effective radiative forcing from aerosol-cloud interactions (SW ERFaci) from liquid clouds into components associated with the Twomey effect and LWP and CF adjustments is provided along with the associated SW cloud radiative kernel. The provided environment.yml file should enable the creation of a conda environment that allows the notebook to be executed.

https://github.com/brandonduran/modis_cloud_radiative_kernels

Aerosol-Cloud Interactions

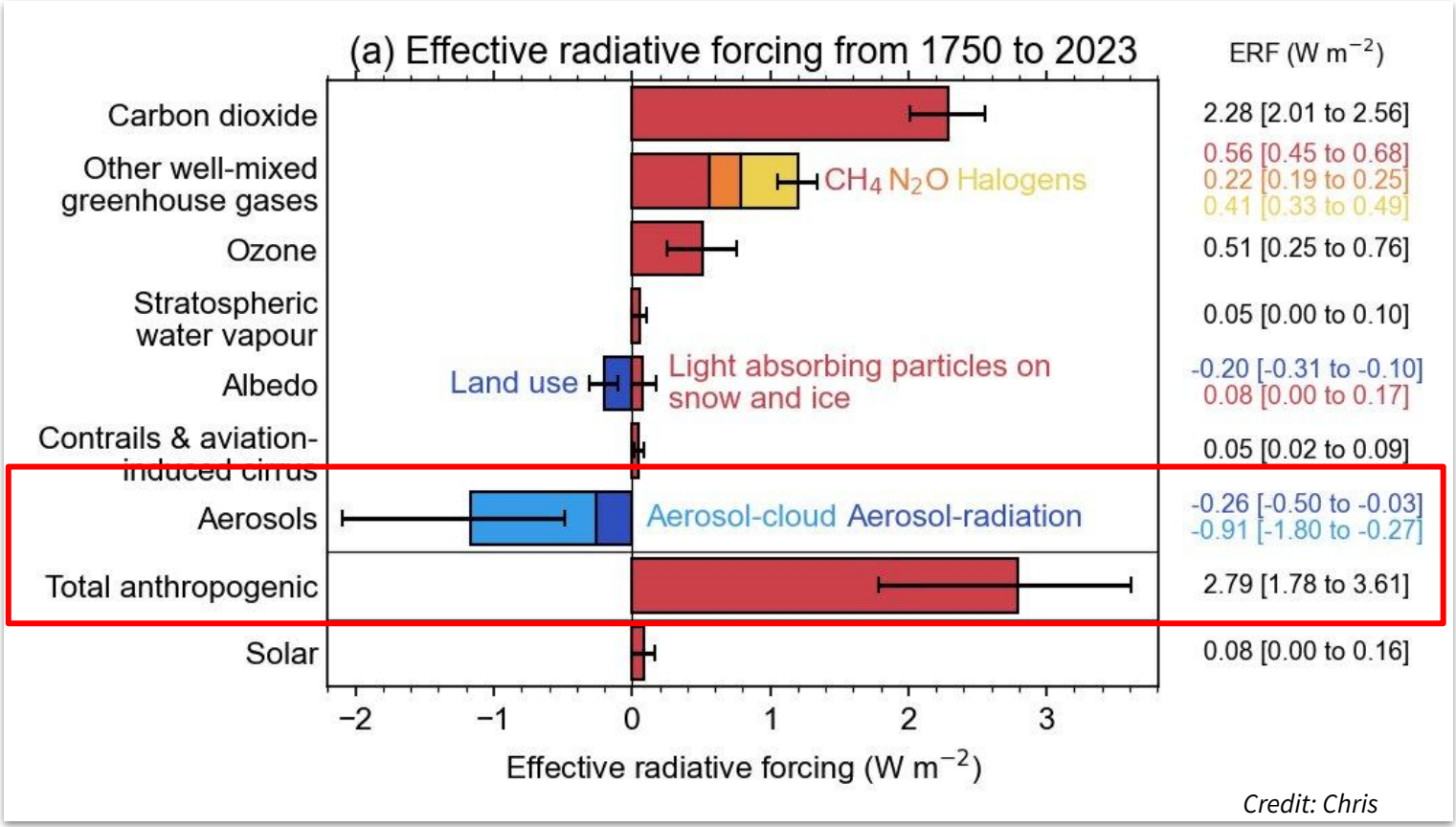
Smaller droplets → **higher reflectivity**



Smaller droplets → **enhanced evaporation, reduced precipitation**

ERFaci = Change in TOA radiative flux from Twomey effect + cloud adjustments

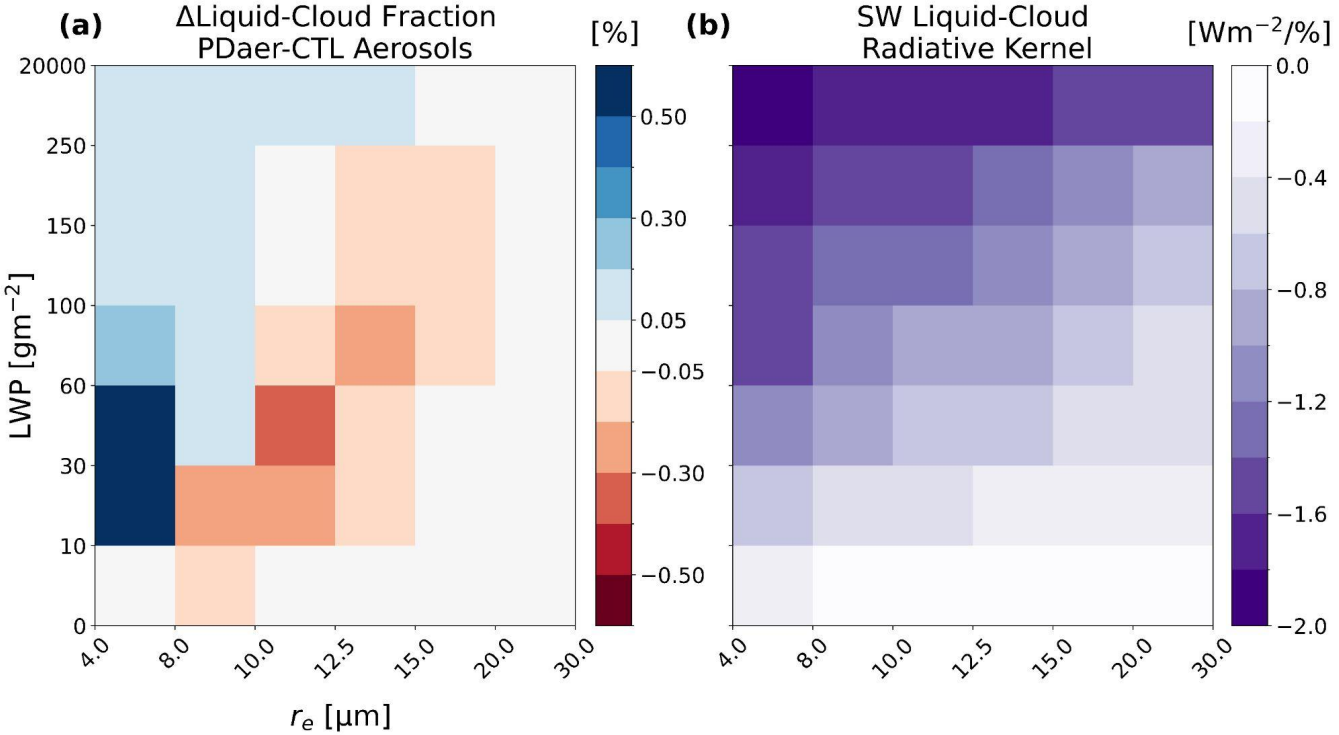
IPCC AR4



Credit: Chris Smith

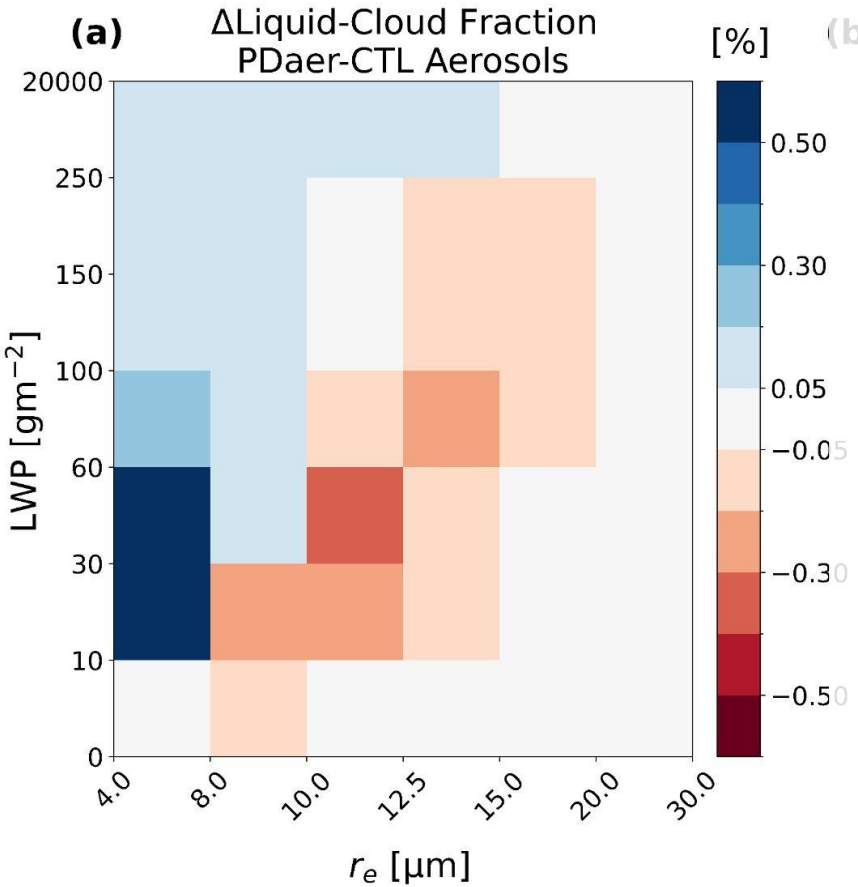
Aerosol indirect effects are the largest contributor to uncertainty in historical climate forcing!

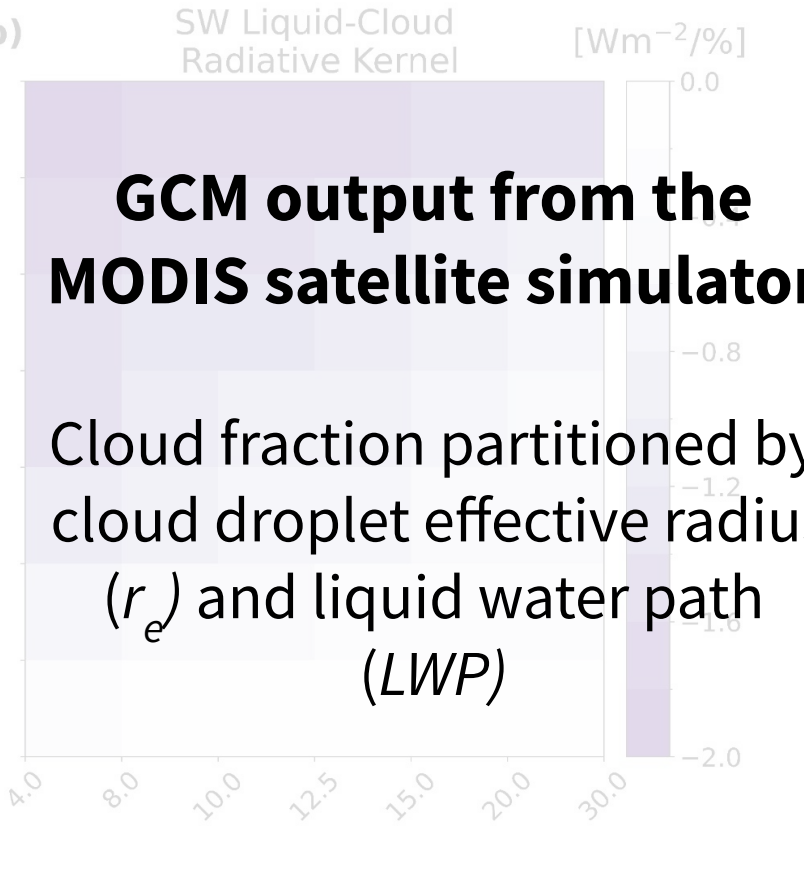
New MODIS CRK Method for Diagnosing ERFaci



Radiative kernels quantify changes to TOA radiative fluxes in response to a climate forcing

New MODIS CRK Method for Diagnosing ERFaci

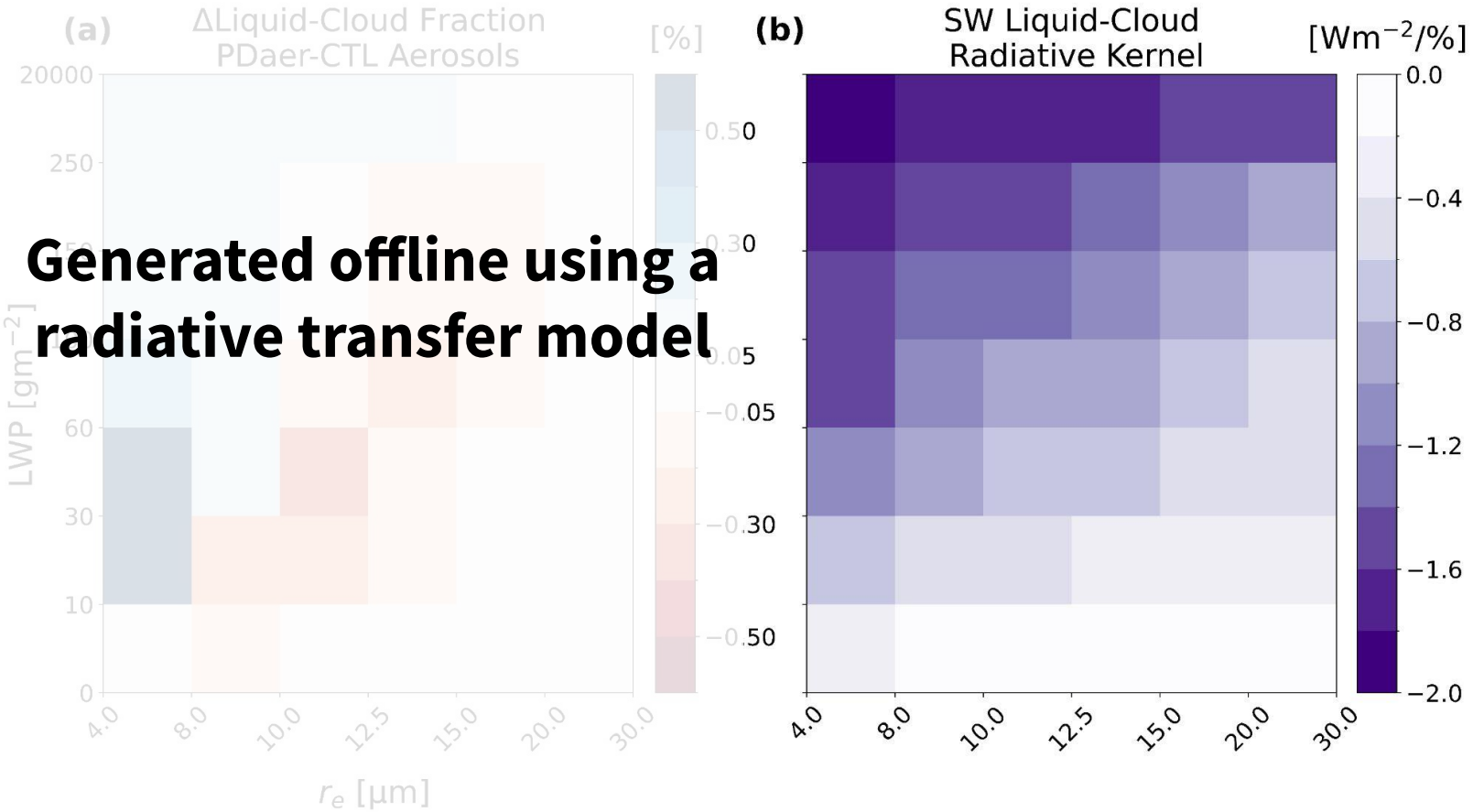




GCM output from the MODIS satellite simulator

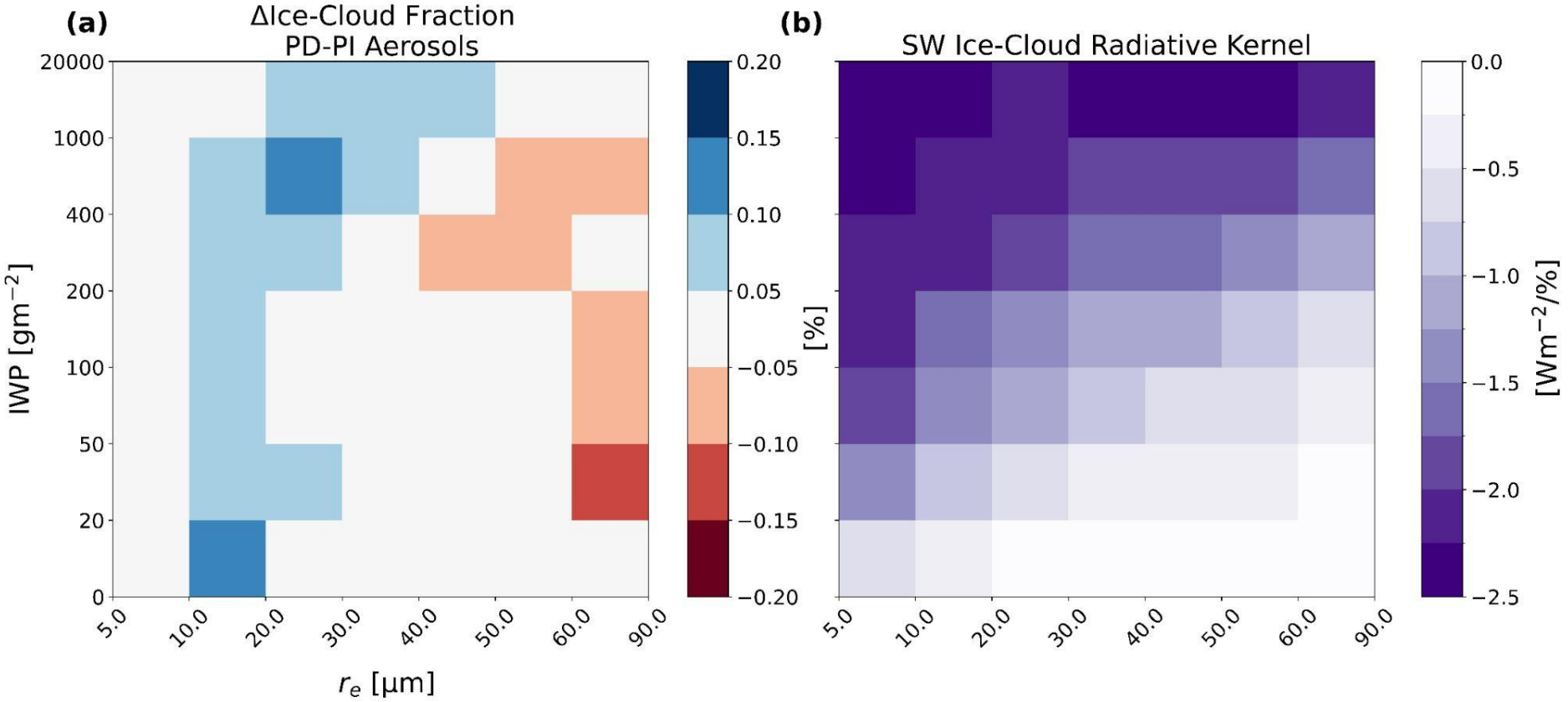
Cloud fraction partitioned by cloud droplet effective radius (r_e) and liquid water path (*LWP*)

New MODIS CRK Method for Diagnosing ERFaci

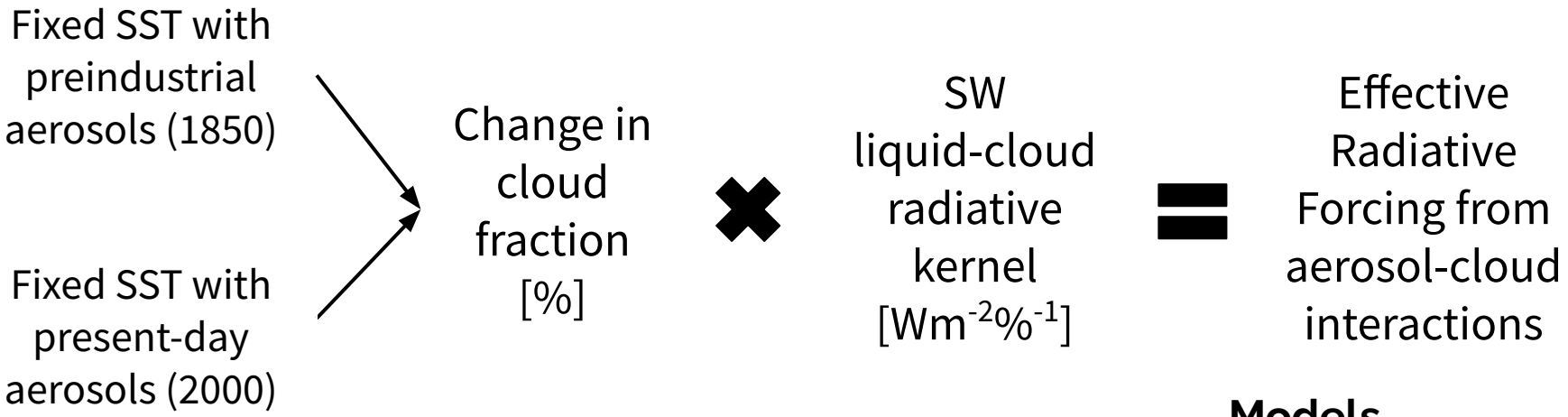


Generated offline using a radiative transfer model

Teaser: We can do the same with ice clouds!

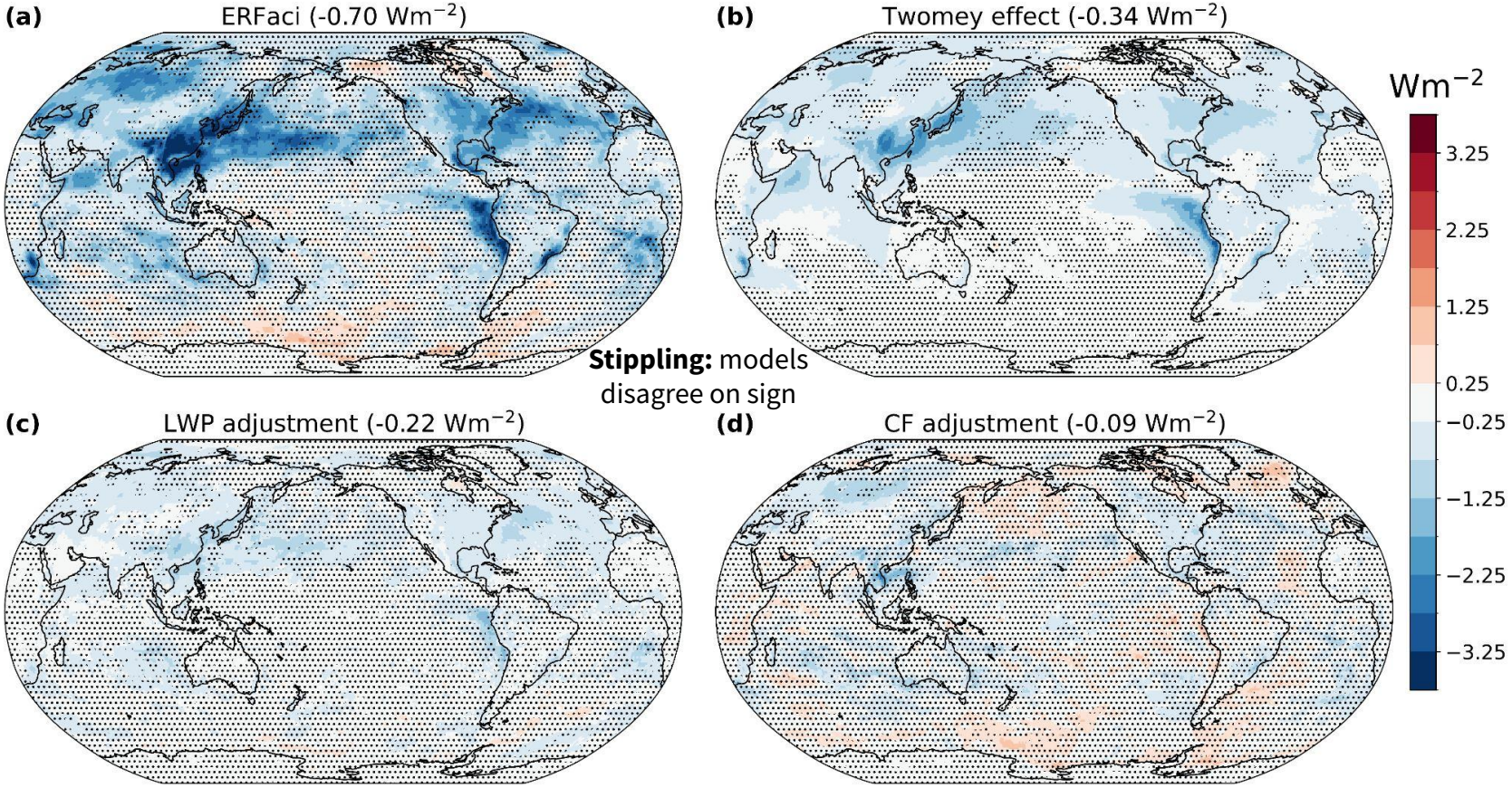


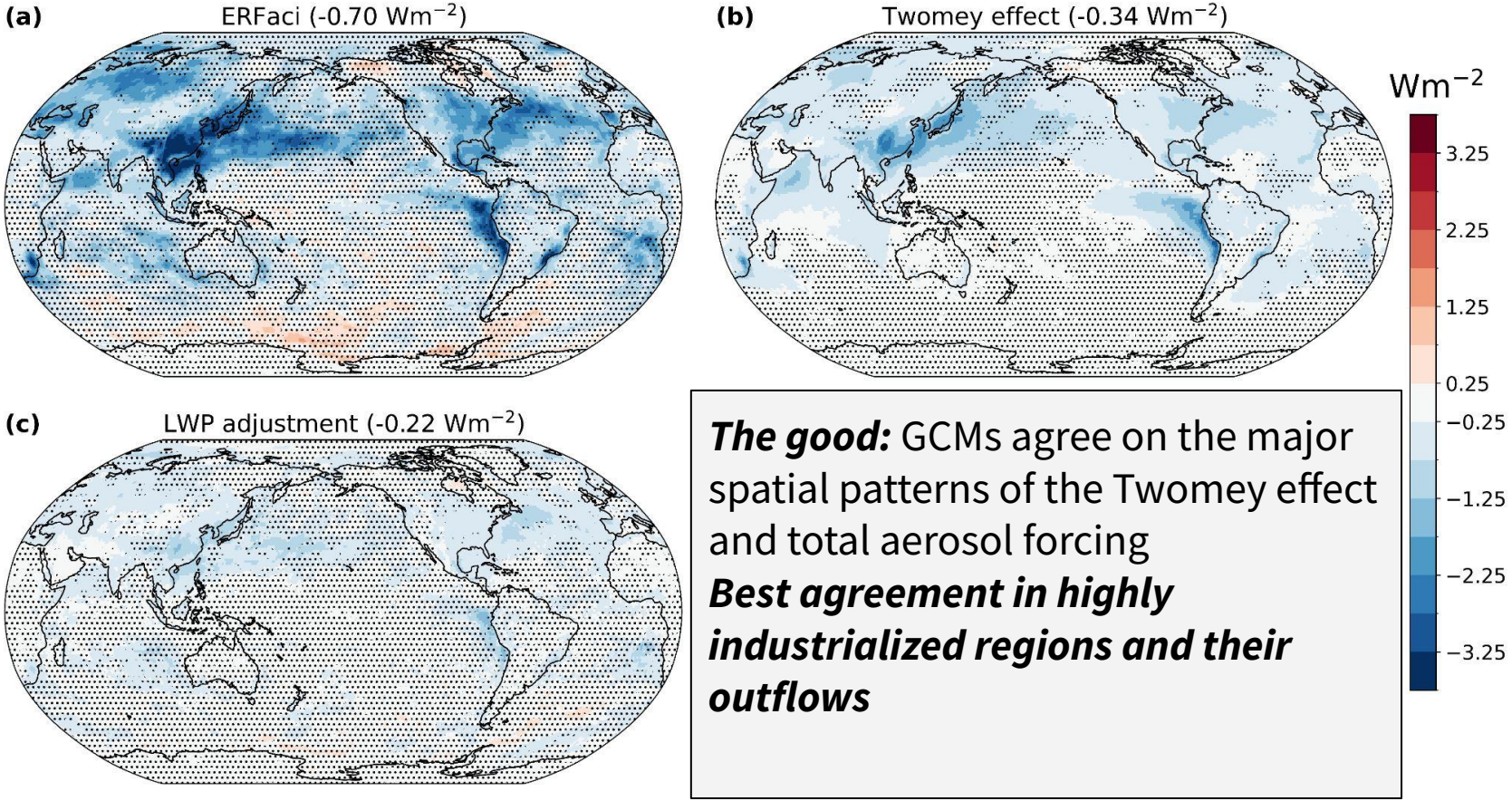
SW ERFaci Diagnosis



Models

E3SMv2
CESM2
NorESM2
MIROC6-DP
MIROC6-PP

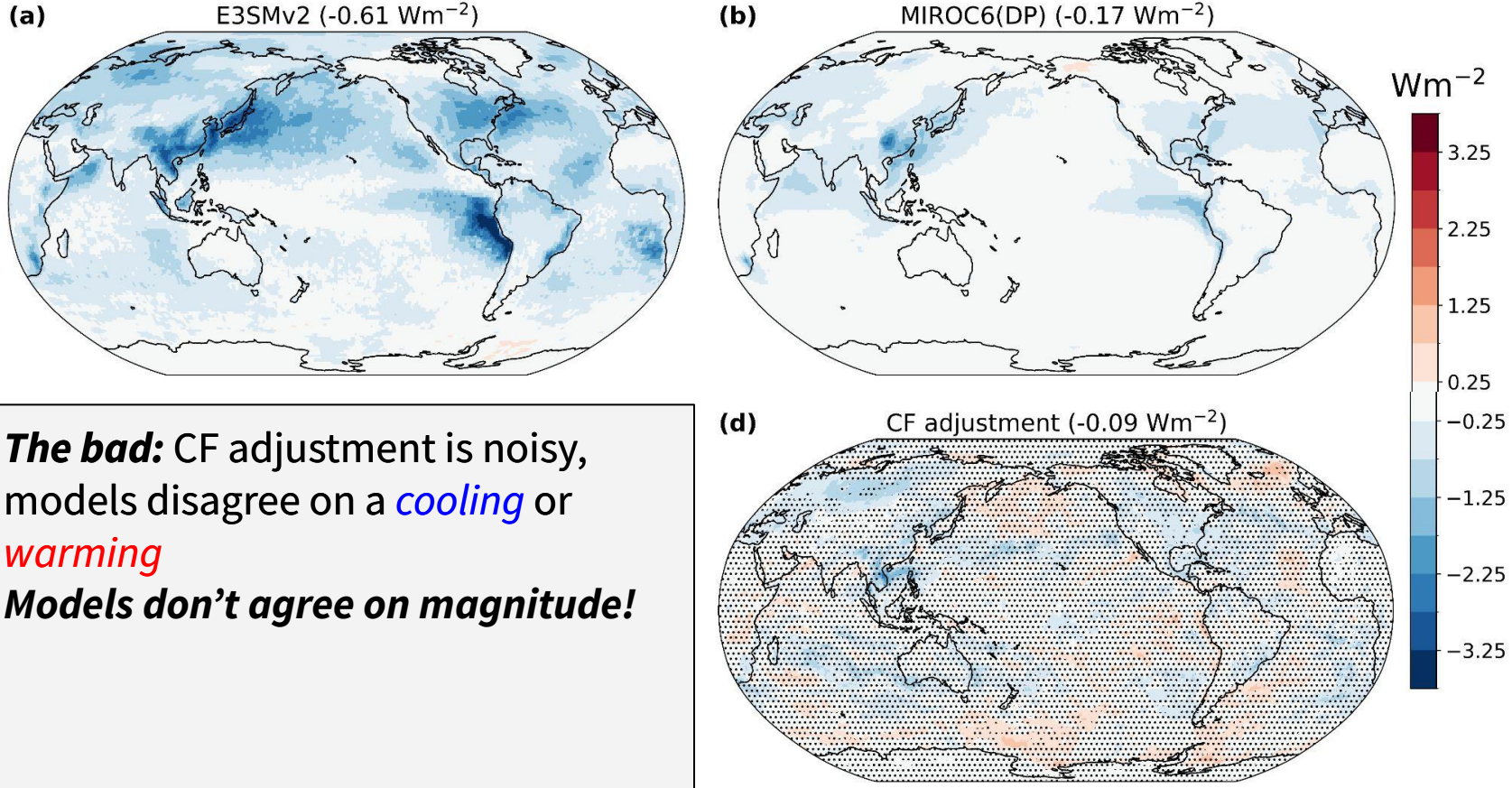

(a)
ERFaci (-0.70 Wm^{-2})
(b)
Twomey effect (-0.34 Wm^{-2})
Wm^{-2}
3.25
2.25
1.25
0.25
−0.25
−1.25
−2.25
−3.25
Stippling: models disagree on sign
(c)
LWP adjustment (-0.22 Wm^{-2})
(d)
CF adjustment (-0.09 Wm^{-2})



The good: GCMs agree on the major spatial patterns of the Twomey effect and total aerosol forcing

Best agreement in highly industrialized regions and their outflows

Twomey effect



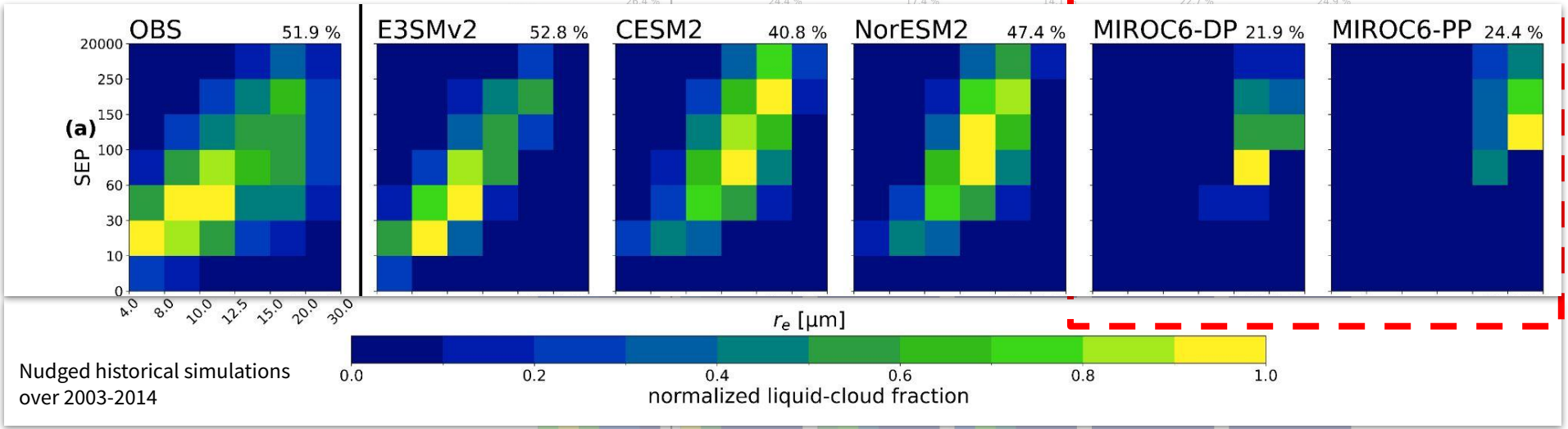
The bad: CF adjustment is noisy, models disagree on a *cooling* or *warming*

Models don't agree on magnitude!

Mean State Biases

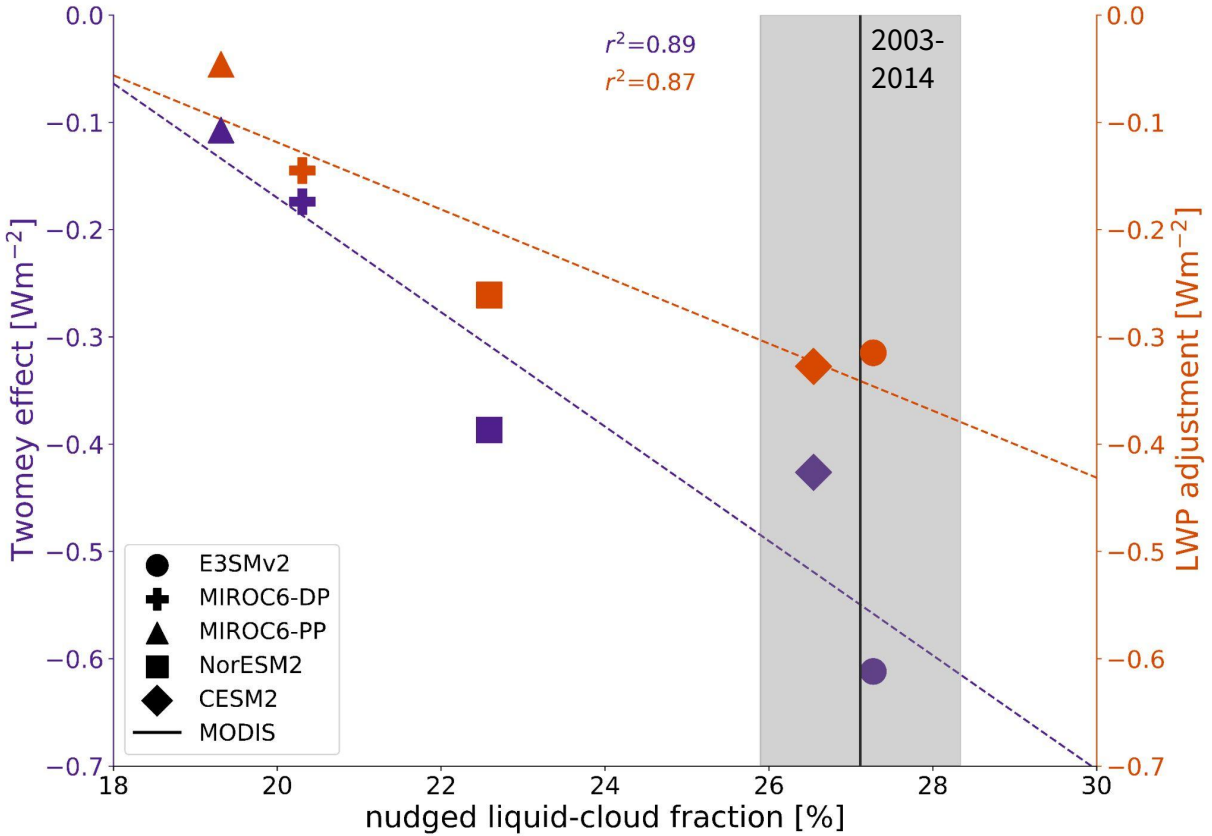
- the joint histogram as an observable

Large “undetermined” phase bias



Nudged historical simulations over 2003-2014

Use Case: Constraining components of ERFaci



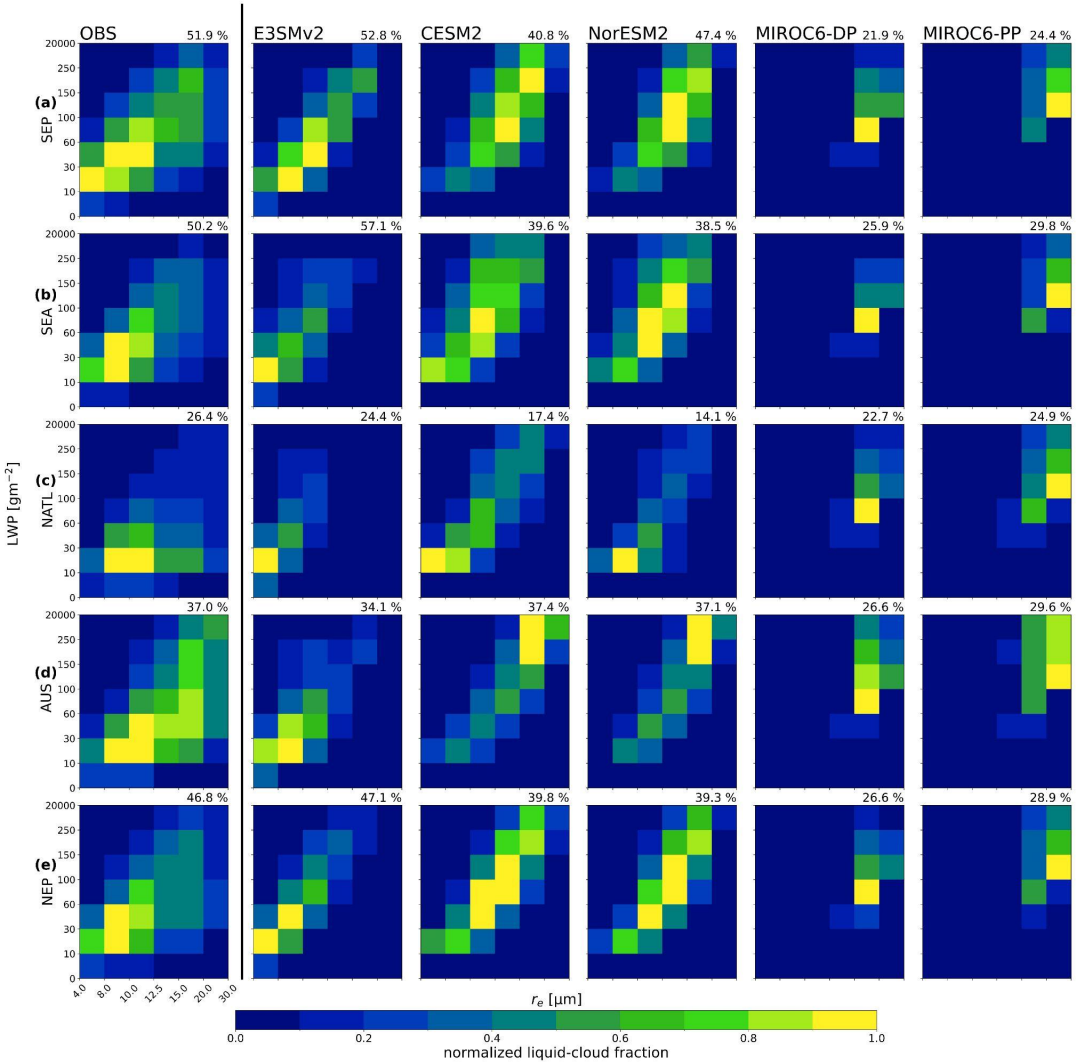
Substantial spread in ERFaci linked to mean-state cloud biases

Spatial pattern of Twomey effect shows agreement across models

Computationally efficient quantification of individual components of ERFaci

Mean State Biases - the joint histogram as an observable

Nudged historical simulations over the 2000s and 2010s



2003-2014 global, annual-mean