IMPERIAL

Causes of a recent decrease in global low-cloud albedo

EarthCARE workshop, University of Reading

Paulo Ceppi

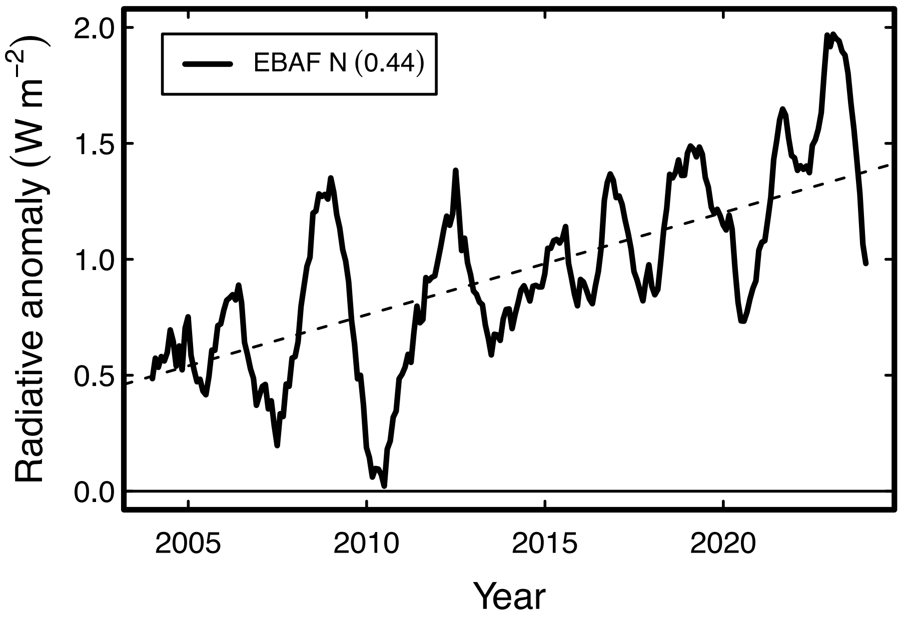
6 June 2025

Earth's energy imbalance

CERES-EBAF global satellite observations, 7/2003 – 6/2024 (21 years)

Net energy imbalance:

- Imbalance = absorbed SW – outgoing LW
- Mean imbalance = +0.9 W m^{-2}
- But strong increasing trend (+0.44 W m^{-2} $decade^{-1}$)



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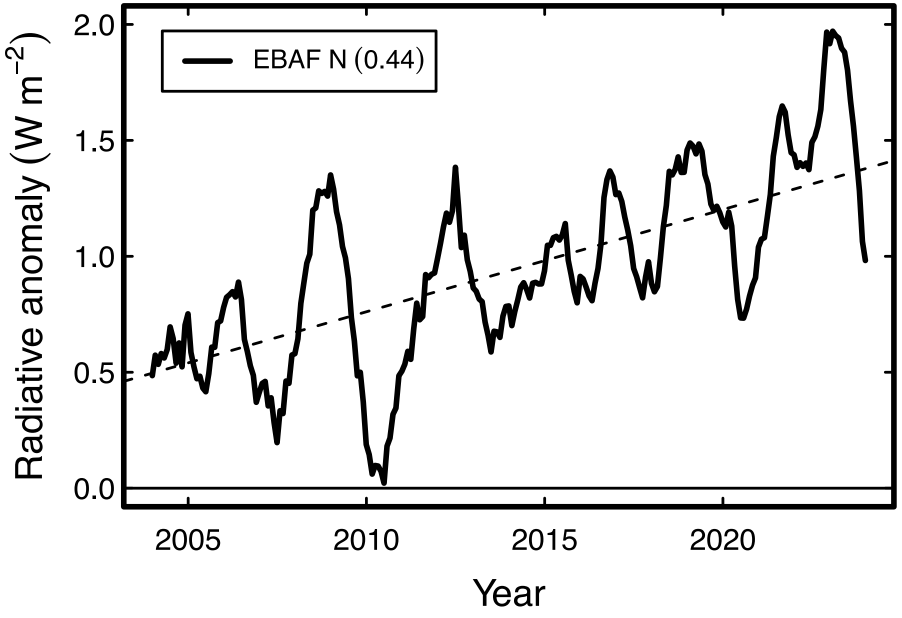
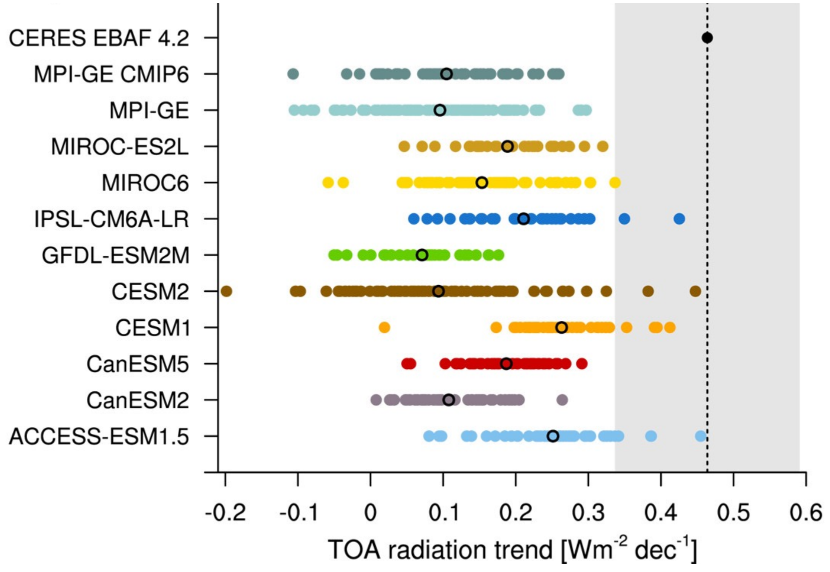


- And stronger than simulated by climate models (Olonscheck and Rugenstein 2024, *GRL*)



Contribution of low clouds

GLOBAL WARMING

Recent global temperature surge intensified by record-low planetary albedo

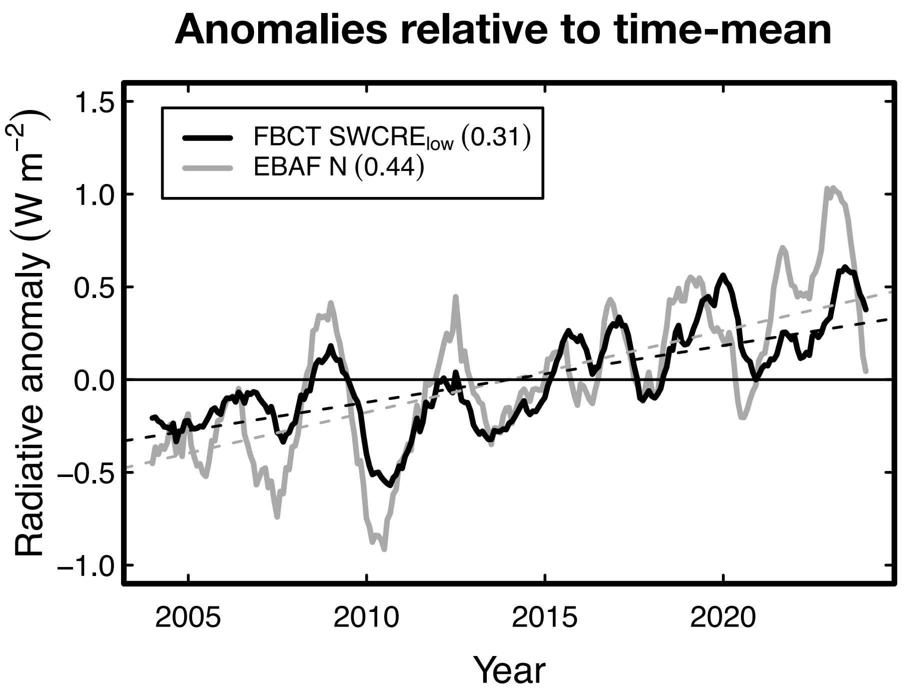
Helge F. Goessling[1]*, Thomas Rackow[2], Thomas Jung[1,3]

In 2023, the global mean temperature soared to almost 1.5 kelvin above the preindustrial level, surpassing the previous record by about 0.17 kelvin. Previous best-guess estimates of known drivers, including anthropogenic warming and the El Niño onset, fall short by about 0.2 kelvin in explaining the temperature rise. Using satellite and reanalysis data, we identified a record-low planetary albedo as the primary factor bridging this gap. The decline is apparently caused largely by a reduced low-cloud cover in the northern mid-latitudes and tropics, in continuation of a multiannual trend. Further exploring the low-cloud trend and understanding how much of it is due to internal variability, reduced aerosol concentrations, or a possibly emerging low-cloud feedback will be crucial for assessing the present and expected future warming.

Goessling et al. 2025, *Science*

Contribution of low clouds

- Can use **CERES Flux-By-Cloud-Type (FBCT)** to distinguish between cloud regimes
- **Low clouds account for ~70% of the trend in N**



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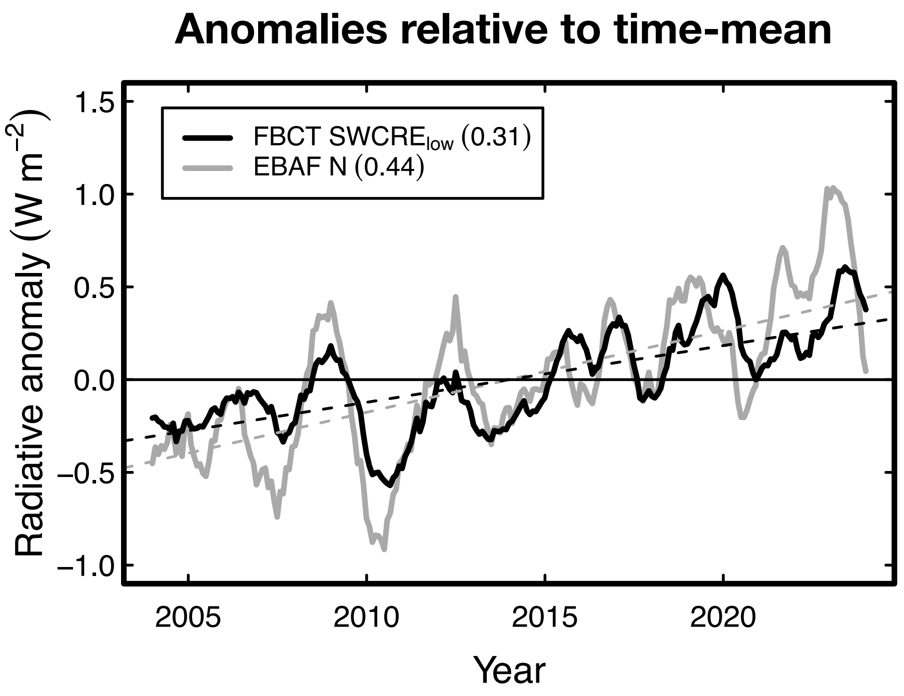
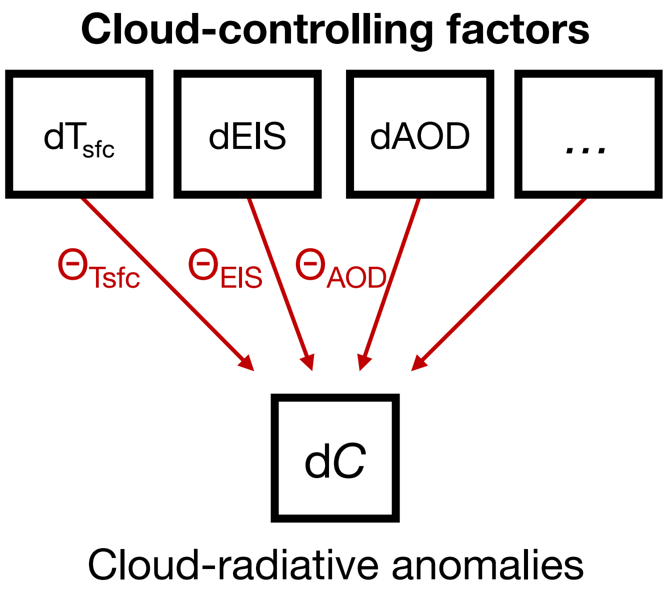
What's causing the low-cloud reduction?

- Natural variability?
- Less aerosol? (cf. 2020 shipping emissions reduction)
- Low-cloud feedback?



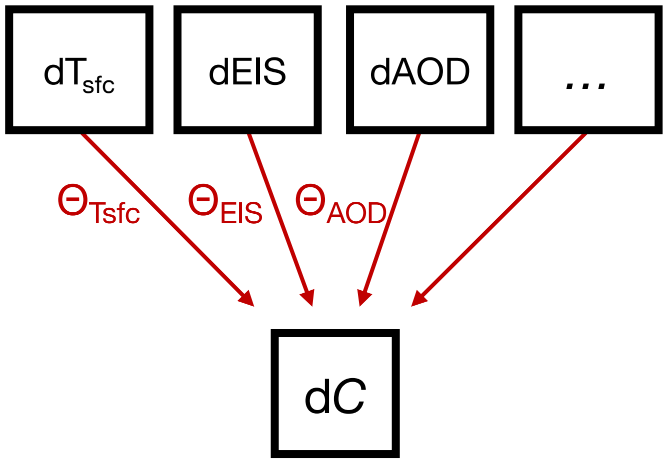
Cloud-controlling factor analysis



- Use **ridge regression** to learn the **sensitivities Θ_i** at each location r (Ceppi et al. 2024, GRL)
- Train on detrended data, predict trend

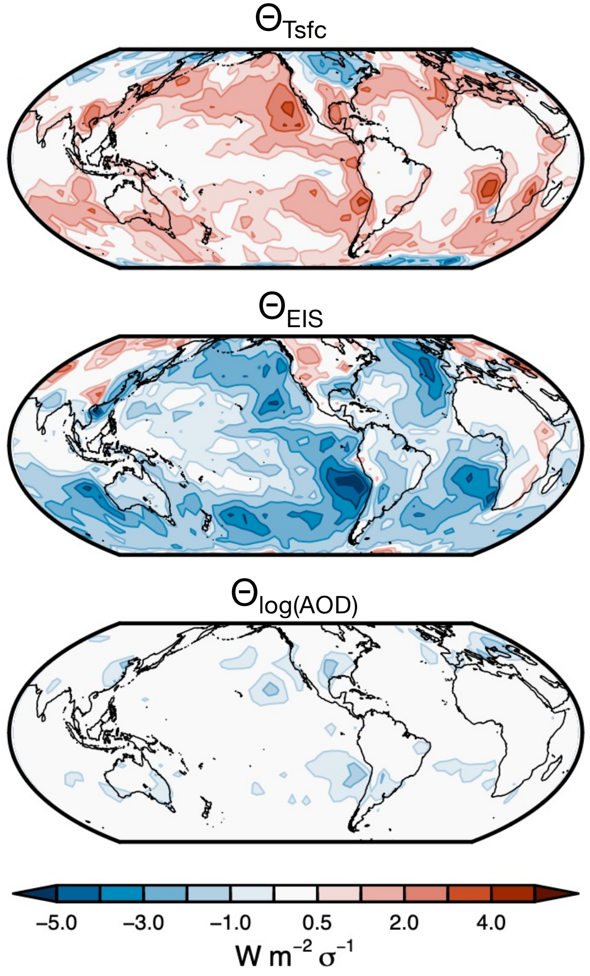
Cloud-controlling factor analysis

Cloud-controlling factors



Cloud-radiative anomalies

Maps of the sensitivities Θ



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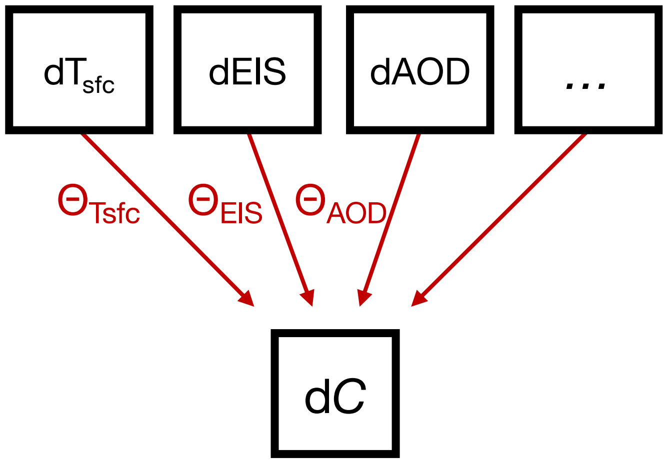

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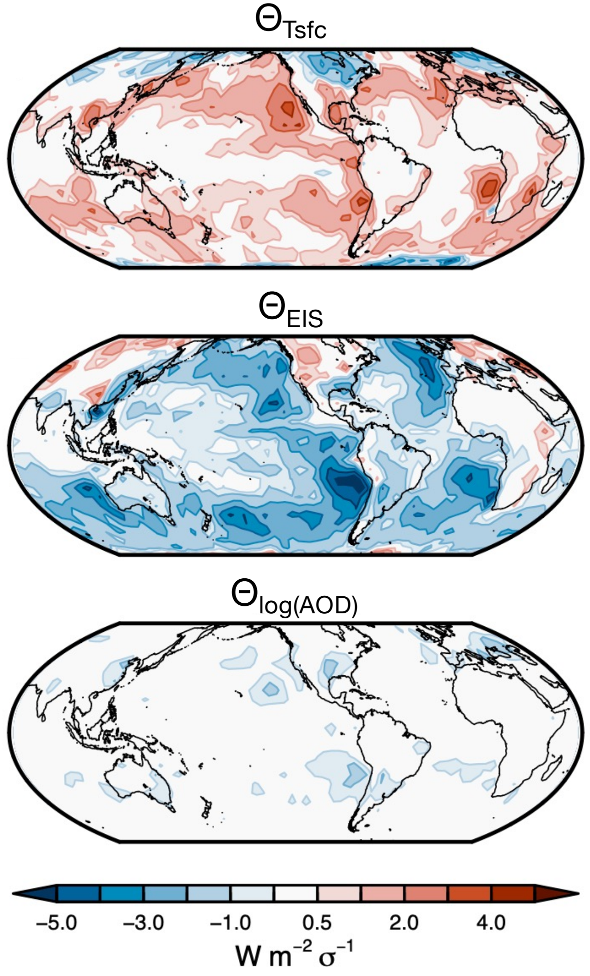

Prediction model for cloud-radiative trends

$$\frac{\mathrm{d}C(r)}{\mathrm{d}t} \approx \sum_{i=1}^{M} \mathbf{\Theta}_i(r) \cdot \frac{\mathrm{d}\mathbf{X}_i(r)}{\mathrm{d}t}$$

Interpreting the cloud-radiative trend
Controlling factor contributions

Can use controlling factor analysis to interpret the CRE trend:

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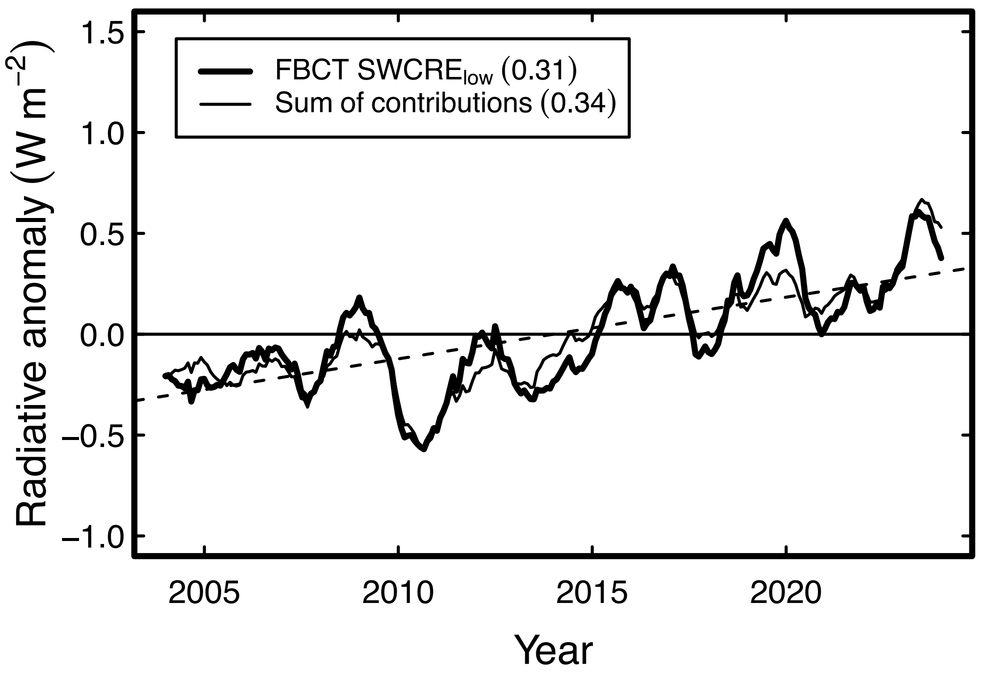

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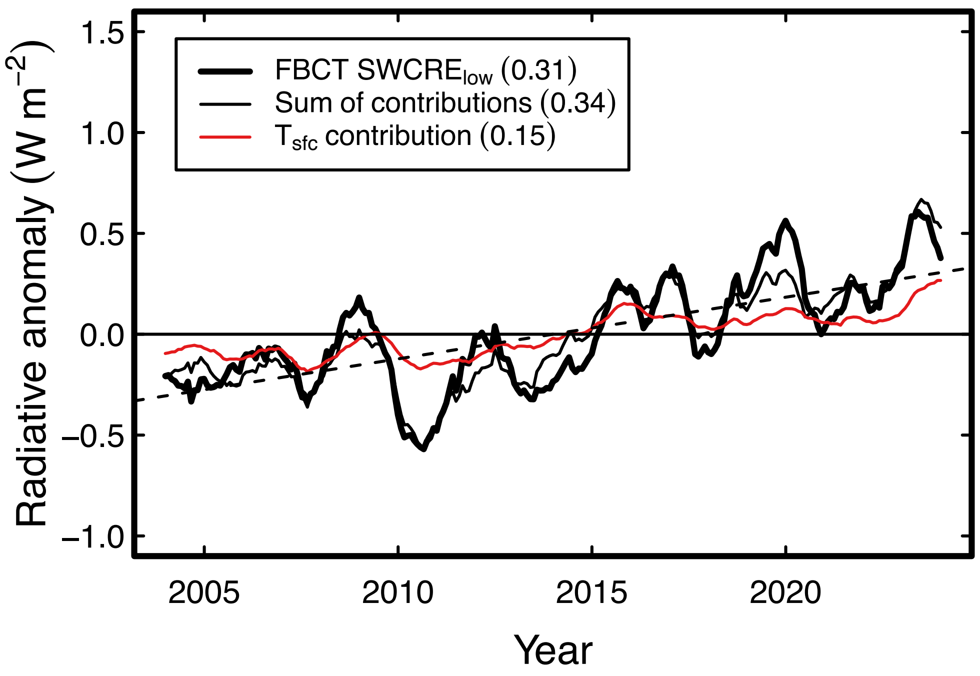
Main contribution is from surface warming (T_{sfc}, ~45%) → **emerging cloud feedback**



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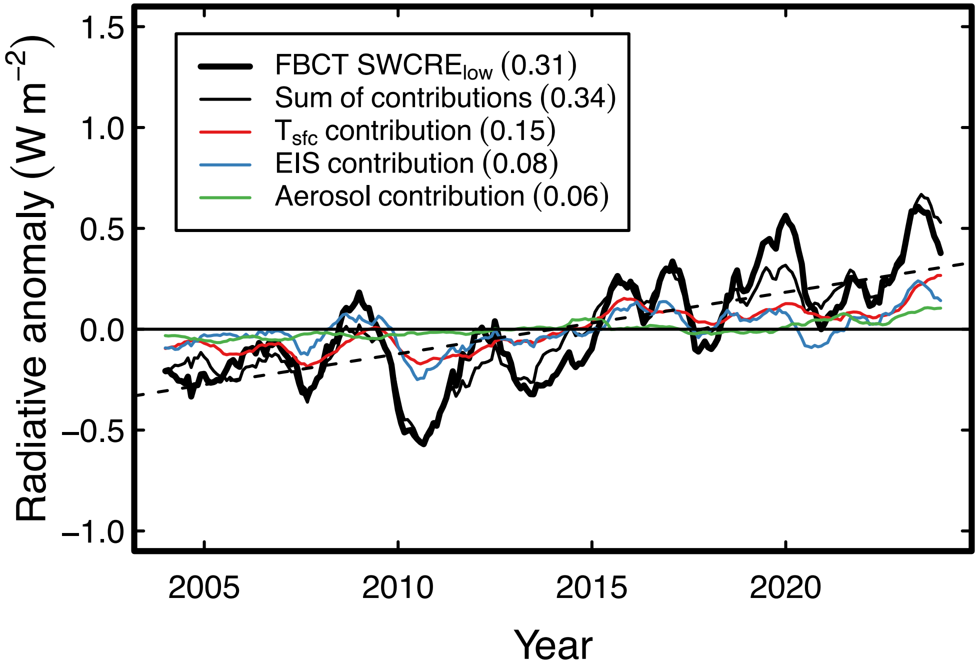
Additional contributions from

- Estimated inversion strength (EIS) → **likely a pattern effect**
- Aerosols



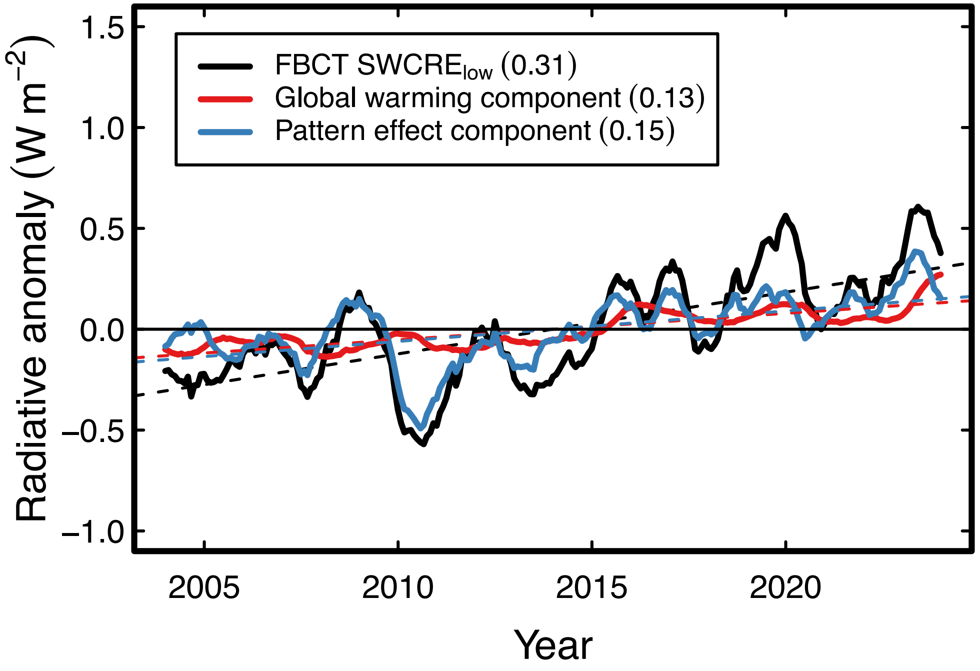
Global warming and pattern effect contributions

Decomposition into contributions from:

- **Global warming**
  - Calculated from scaled abrupt-4xCO2 controlling factor responses
  - Assumed mostly forced

- **Pattern effect**
  - Calculated as a residual
  - Assumed mostly unforced

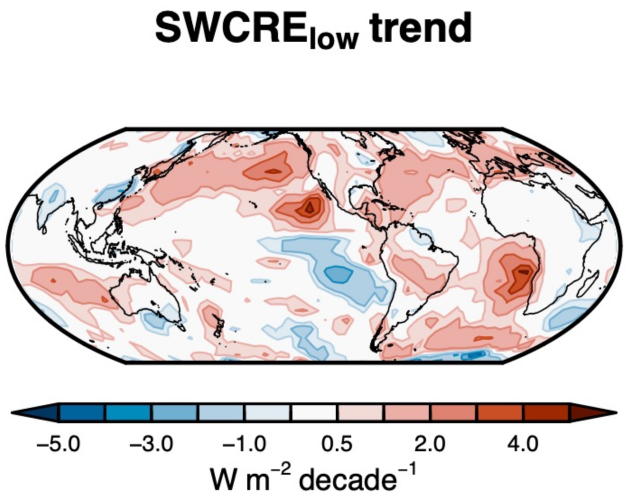
- Both equally important
- Suggests similar roles for forced response versus unforced variability

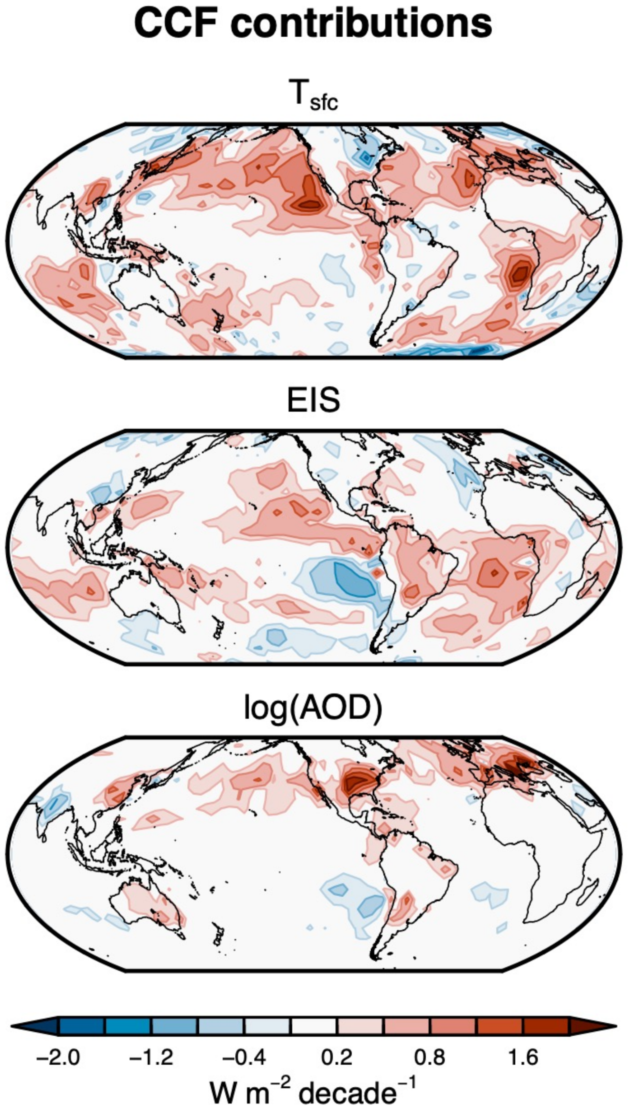


Interpreting the cloud-radiative trend

Controlling factor contributions

- Surface warming (T_{sfc}) dominates
- Estimated inversion strength (EIS) decreases
  - → less low cloud → additional SWCRE increase
- Aerosols also contribute regionally (mainly NH)



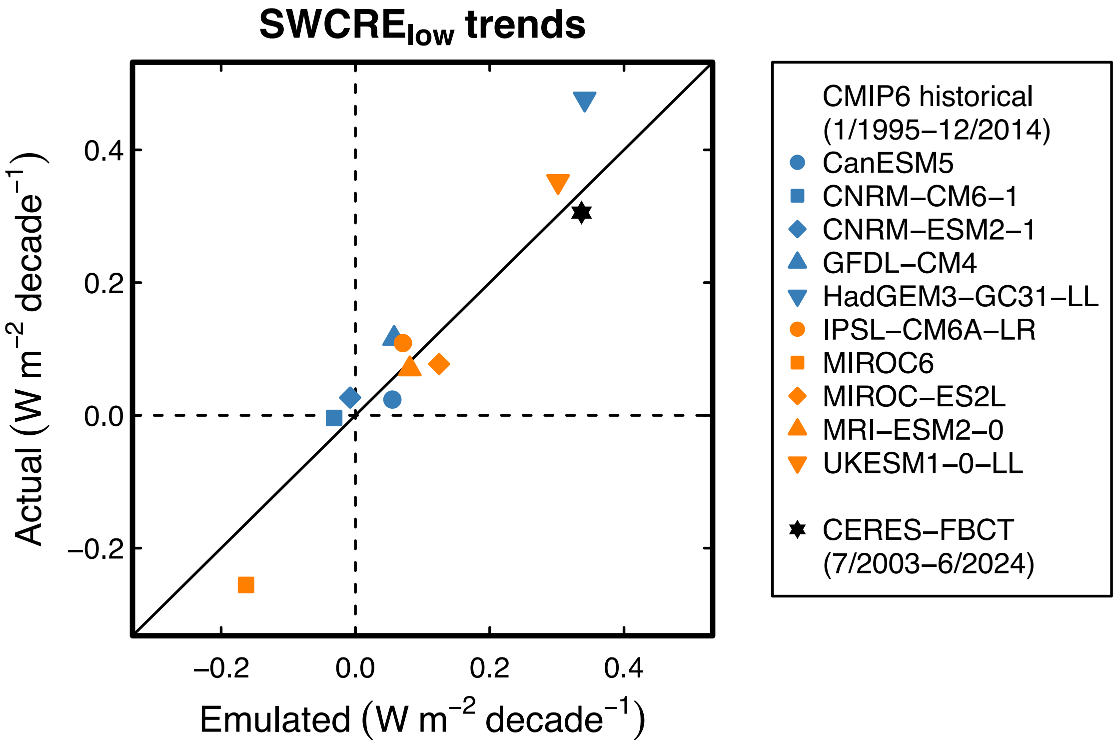


Validating the method with CMIP6 simulations

- Can apply the method to CMIP6 models as a test

- Used historical simulations, 1995–2014
- Trained on detrended data, predict trend

- Works very well across models
- **Observed trend within CMIP6 range** (though at upper end)



Conclusions

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- Large contribution of surface warming → suggests emerging (forced) cloud feedback
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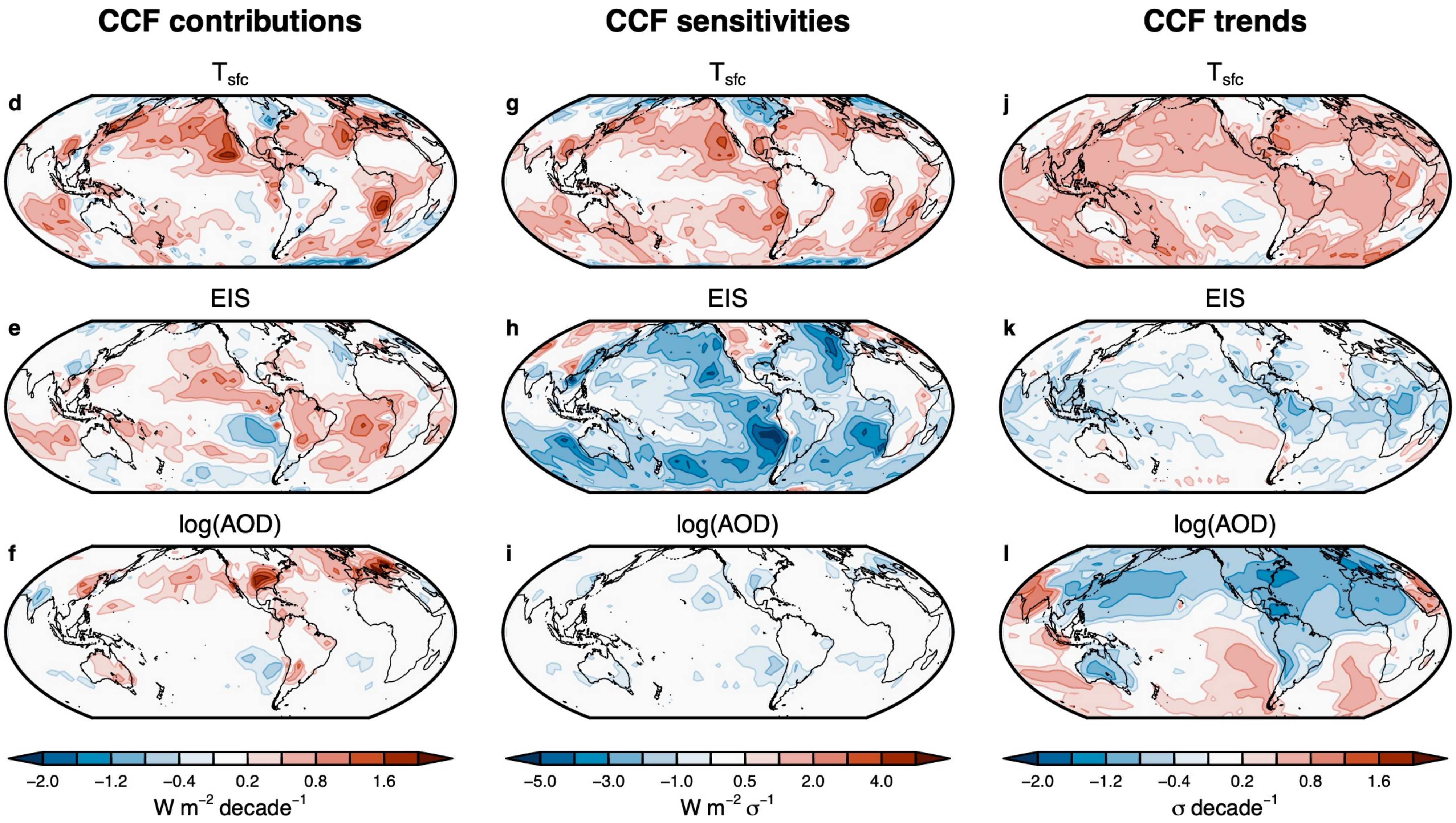
Similar controlling factor analyses possible with EarthCARE cloud and aerosol products?

Extra slides

Trend maps


CCF contributions
CCF sensitivities
CCF trends
Tsfc
EIS
log(AOD)
d
e
f
g
h
i
j
k
l
−2.0 −1.2 −0.4 0.2 0.8 1.6
W m−2 decade−1
−5.0 −3.0 −1.0 0.5 2.0 4.0
W m−2 σ−1
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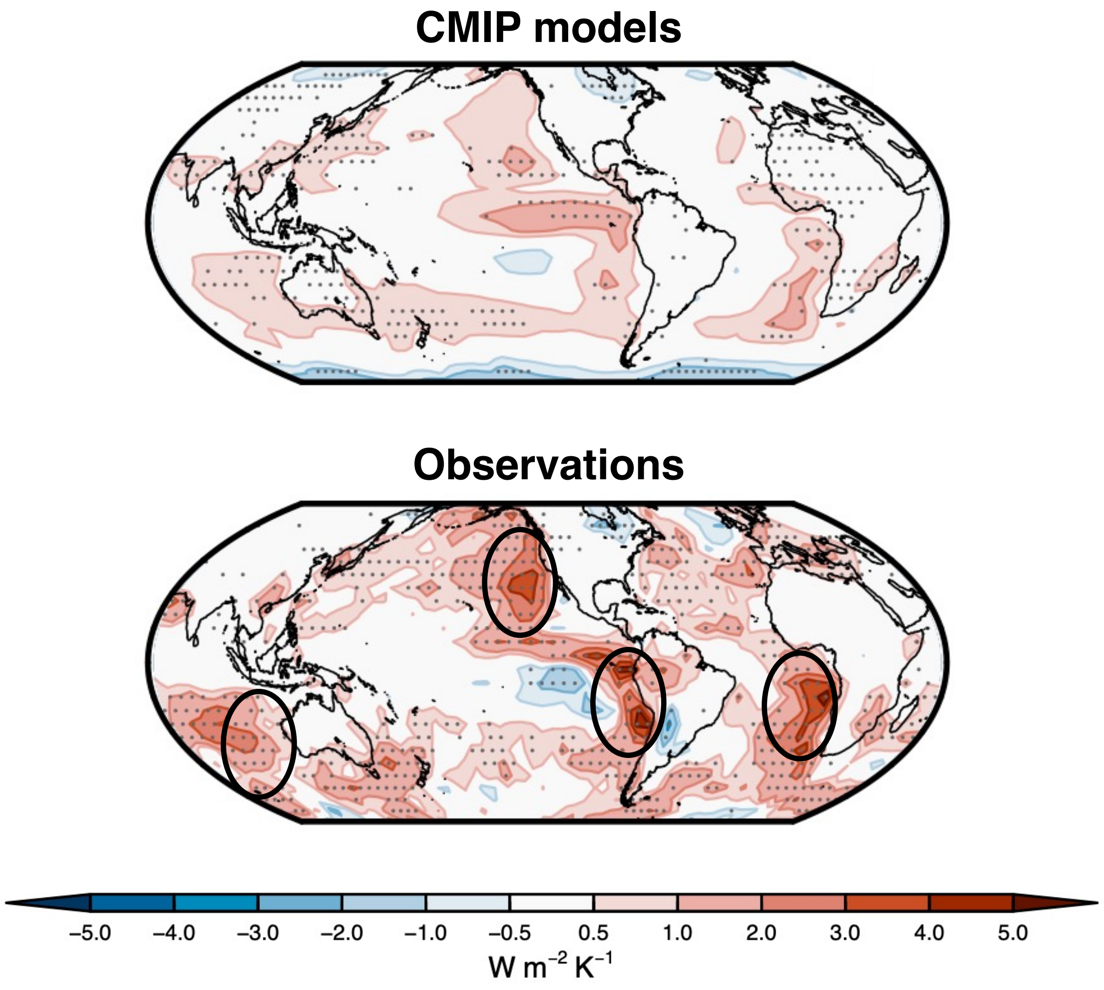
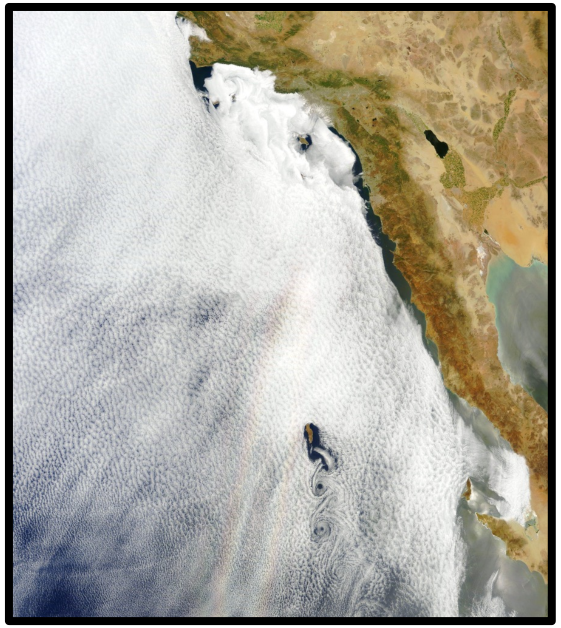
σ decade−1

Observational constraint on low-cloud feedback



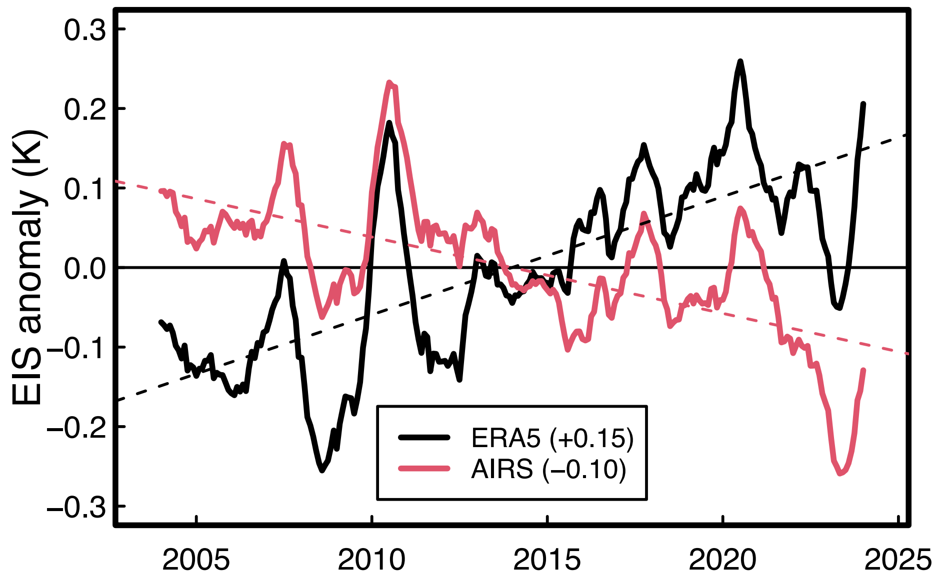


Low-cloud feedback is stronger than simulated by most climate models – especially in stratocumulus regions

Ceppi et al. 2024, *GRL*

EIS trends

- ERA5 EIS trends are dodgy!
- AIRS (NASA instrument) retrieves tropospheric temperature from space and should be well-calibrated
- Indicates opposite trend to ERA5
- So which is right?



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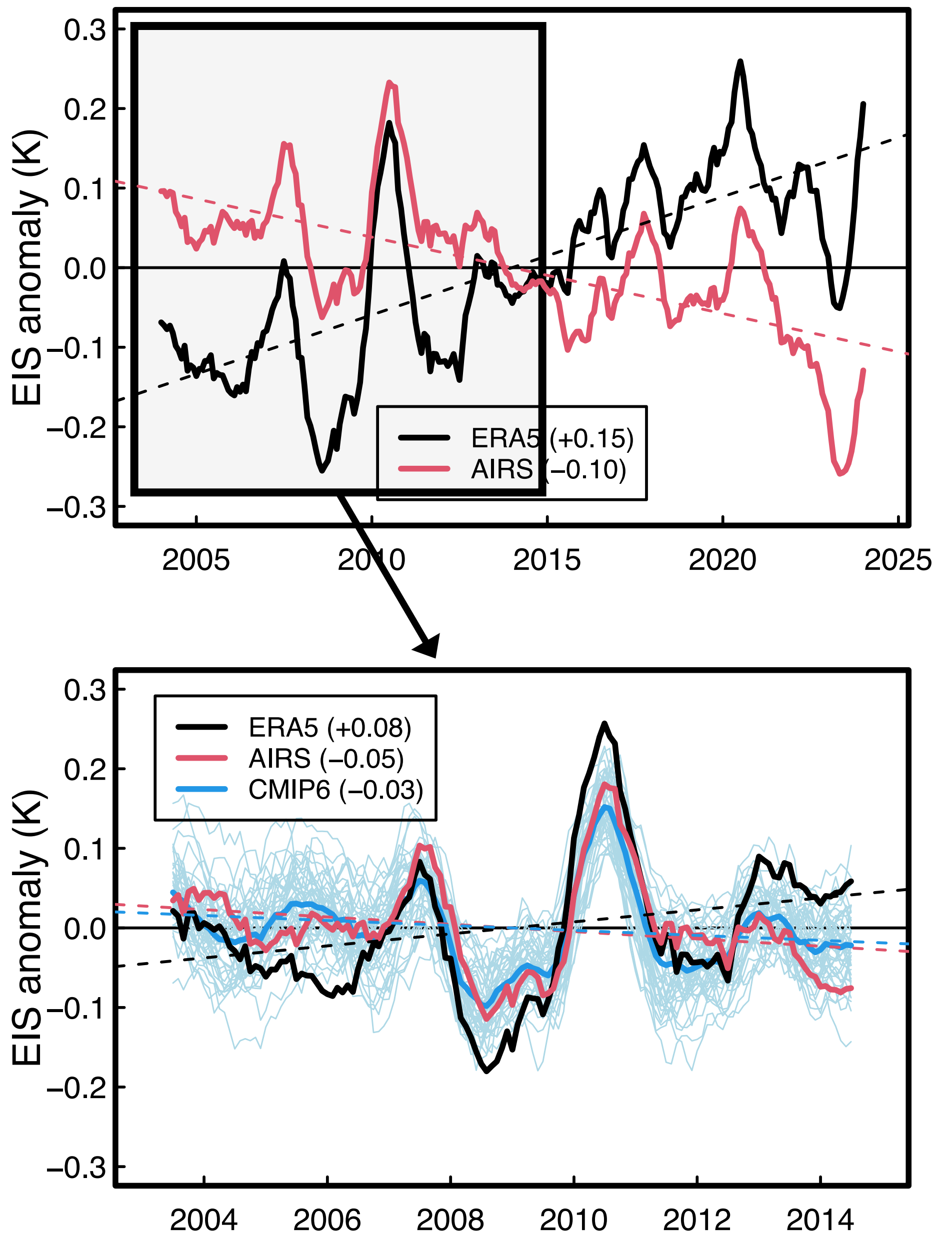
- Can check against CMIP6 AMIP simulations up to 2014
- They agree much better with AIRS



ERA5 results

- The surface warming contribution (T_{sfc}) explains most of the overall trend
- But the total reconstruction (T_{sfc} + 5 other controlling factors) substantially underestimates the trend
- This is because of a large negative EIS contribution