Observational Evidence for Underestimation of BC Radiative Forcing Trends in CMIP5 Models

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Motivation

Trade-off between radiative forcing and climate sensitivity in models from Kiehl 2007 (GRL)

Models underestimate absorbing aerosol optical depth (AAOD) from Shindell et al. 2012 (ACPD)
Change in Forcing over Recent Decades

- Regions: Europe, China, and India
- All-sky monthly surface solar radiation measurements from Global Energy Budget Archive (GEBA)
  
  *Regional multidecadal clear sky record not available from surface stations or satellite*

- Remove radiative effects of cloud cover variations (interannual “noise”)
  
  ➔ “Clear-sky proxy” solar flux anomalies
    
    includes: clear sky changes
    cloud albedo changes
Station Distribution

- GEBA station
- Cloud station
- ISCCP grid box

CMIP5 output interpolated grid box centers
CMIP5 Models

- OBS
- ACCESS1-0
- ACCESS1-3
- BCC-CSM1-1
- BCC-CSM1-1-m
- BNU-ESM
- ConESM2
- CCSM4
- CESM1-BGC
- CESM1-CAM5
- CESM1-FASTCHEM
- CESM1-WACCM
- CNRM-CM5
- CSIRO-Mk3-6-0
- FGOALS-g2
- FGOALS-s2
- GFDL-CM3
- GFDL-ESM2G
- GFDL-ESM2M
- GISS-E2-H
- GISS-E2-H_p2
- GISS-E2-H_p3
- GISS-E2-H_NOIE
- GISS-E2-H-CC
- GISS-E2-R
- GISS-E2-R_p2
- GISS-E2-R_p3
- GISS-E2-R_NOIE
- GISS-E2-R-CC
- HadCM3
- HadGEM2-AO
- HadGEM2-CC
- HadGEM2-ES
- INM-CM4
- IPSL-CM5A-LR
- IPSL-CM5A-MR
- IPSL-CM5B-LR
- MIROC-ESM
- MIROC-ESM-CHEM
- MIROC4h
- MIROC5
- MPI-ESM-LR
- MPI-ESM-MR
- MPI-ESM-P
- MRI-CCCM3
- MRI-CCCM3_p2
- NorESM1-M
- NorESM1-ME

- Circle
- X
- Triangle
- Diamond
Europe Dimming and Brightening

CMIP5 simulations underestimate observed dimming prior to ~1987
CMIP5 simulations severely underestimate observed dimming prior to ~1990
India Dimming

CMIP5 simulations *severely* underestimate observed dimming
Aerosol Indirect Effects in GISS Model

prescribed aerosol no indirect effect
prescribed aerosol w/ indirect effect
prognostic aerosol w/ indirect effect v1
prognostic aerosol w/ indirect effect v2

Aerosol indirect effects appear to have small impact on clear-sky proxy trends in the GISS model

Prognostic rather than prescribed aerosol appears to have small impact on dimming in the GISS model
Trends in Sulfate Load and Clear-Sky Proxy

CMIP5 simulations with the biggest trends in sulfate load tend to have the biggest trends in clear-sky proxy flux.
Trends in AAOD and Clear-Sky Proxy

CMIP5 simulations with the biggest trends in \( \exp(-\text{AAOD}) \) tend to have the biggest trends in clear-sky proxy flux.

Clear-sky proxy trends are more highly correlated to AAOD trends than they are to sulfate trends or AOD trends.
Conclusions

- CMIP5 simulations **severely underestimate** observed decreases in surface solar radiation over Europe, China, and India.
- Comparison of GISS model versions suggests that aerosol indirect effects have small impact on surface solar radiation trends.
- CMIP5 solar radiation trends over China and India appear to be more related to trends in absorbing aerosol than trends in sulfate.
- CMIP5 simulations with the largest increases in AAOD exhibit the largest decreasing solar radiation trends.

*Black carbon appears to have had a greater radiative impact in recent decades than is currently implemented in climate models.*
Thank You!
Extra Slides
All-Sky and Clear-Sky Proxy Flux

Europe all-sky flux

Europe clear-sky proxy flux

— observations
— model ensemble mean

all-sky flux has much greater interannual variability than clear-sky proxy flux due to month-to-month changes in cloud cover