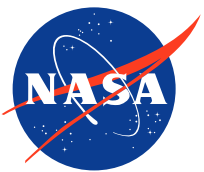
# SARB Update: Plans and Status

## CESM3/CAM7 CERESMIP and Aerosol Forcing

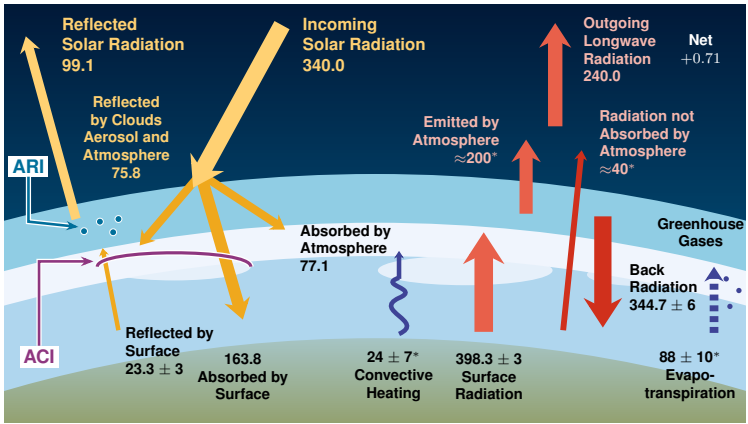
David Fillmore
NSF National Center for Atmospheric Research

45th CERES Science Team Meeting
NASA Langley Research Center, Hampton, Virginia
2026 October 27



# Earth's energy balance: ARI and ACI




CERES EBAF Ed4, July 2005–June 2015; Kato et al. (2018), Table 5.
Fluxes: W m$^{-2}$; $\pm 1\sigma$; * non-CERES. Net $+0.71$: ocean-heat-content constraint.
Forcing: IPCC AR6, Table 7.8 (5–95% ranges); direct effect: Matus et al. (2019).

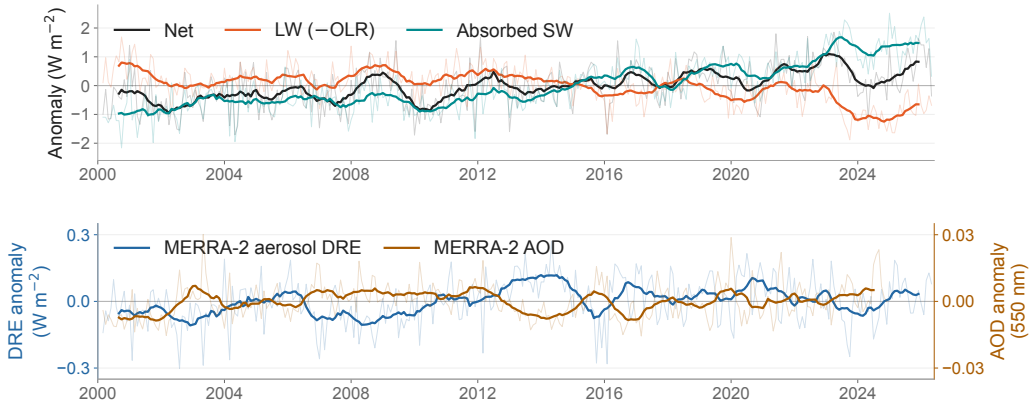
**Aerosol forcings** $F_{\mathrm{aer}}$
(natural + anthro) − natural

**ARI: aerosol–radiation**
Scattering and absorption
$-0.22$ W m$^{-2}$
$[-0.47, +0.04]$

**ACI: aerosol–cloud**
Droplet / cloud changes
$-0.84$ W m$^{-2}$
$[-1.45, -0.25]$

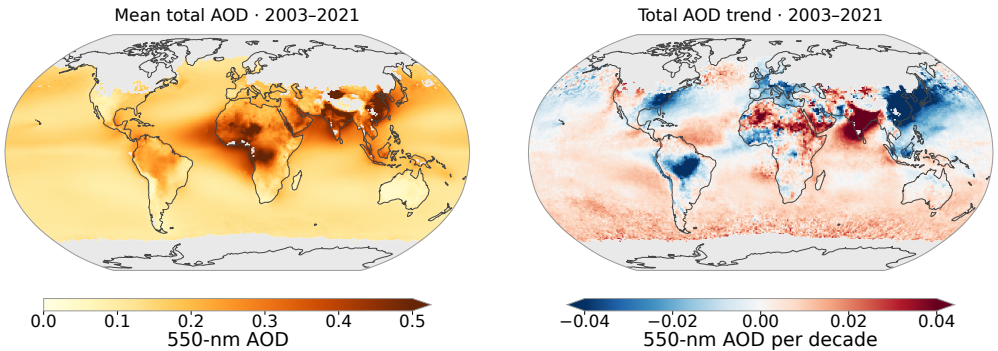
**All-aerosol direct effect**
$\sim 2$ W m$^{-2}$ of the $\sim 76$
Net reflection; cloud overlap.

# CERES EBAF



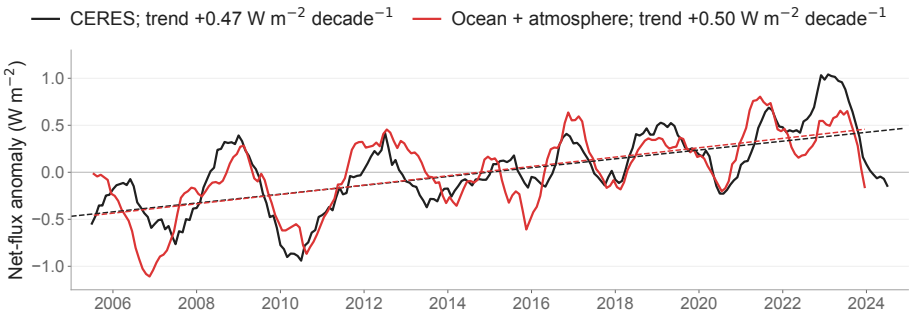

After Ringberg (2026), Fig. 2. Local CERES EBAF Ed4.2.1, March 2000–May 2026.
MERRA-2 global means: all-sky TOA SW DRE through May 2026; 550 nm AOD through December 2024.
Anomaly climatology: 2001–2014. Bold: 12-month means.

# MODIS AOD: regional structure and change




- CERES/SARB MODIS C7: total column AOD at 550 nm, 2003–2021
- Regional increases and decreases underlie the small ocean-mean trend

# CERES and ocean–atmosphere heat uptake




- CERES trend: $+0.47$ W m$^{-2}$ decade$^{-1}$ over 2005–2024
- Heat uptake supports the increase seen by CERES

Heat-uptake datasets in Mayer et al. (2026):
RFROM v2.2 / ORAS5 ocean heat content + ERA5 atmospheric energy.

# Can SARB constrain aerosol forcing trends?

## Radiative trends: W m$^{-2}$ per decade

- CERES EEI **trend**: $\dot{N} \simeq +0.47$, close to the AR6-based forcing **trend**: $\dot{F} \simeq +0.55$ (anthro-dominated).[1]
- Taken at face value, these trends imply climate sensitivity $\sim \mathbf{3}\times$ the CMIP6 model mean.[2]
- **Is the forcing trend correct?**
- Aerosol forcing **trend** estimates range from $\dot{F}_{\mathrm{aer}} \simeq +0.03$ (obs)[3] to $\simeq +0.20$ (models).[4]
- **Can SARB constrain these aerosol forcing trends?**

[1] 0.55 is the updated AR6 net forcing trend: Ringberg (2026), §3.1.
[2] Illustrative, with zero pattern-effect trend: $S = 3.93 \times 0.25/(0.55 - 0.47) \simeq 12$ K; CMIP6 mean $3.9$ K. IPCC AR6, Table 7.4; Ringberg (2026), §3.1; Zelinka et al. (2020).
[3] Ceppi et al. (2026): obs low-cloud aerosol adjustment, $+0.03 \pm 0.03$ (2003–2024).
[4] Hodnebrog et al. (2024): modeled total aerosol ERF, $+0.20 \pm 0.10$ (2001–2019).

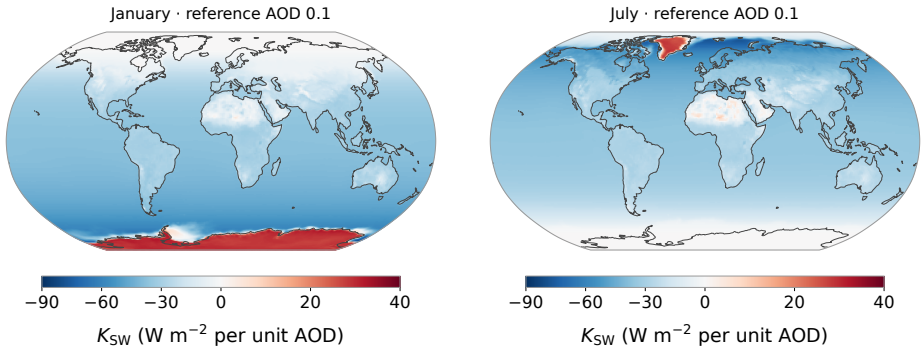
# From MODIS AOD to the direct SW pattern

## Direct SW response: $\Delta N_{\mathrm{SW,clr}} \simeq K_{\mathrm{SW}}\, \Delta\tau_{550}$

- $N_{\mathrm{SW}}$ is **net incoming shortwave radiation**:
  incoming sunlight minus reflected sunlight.
- $K_{\mathrm{SW}}$ gives the change in $N_{\mathrm{SW,clr}}$ per unit change in AOD.
- RRTMGP: vary AOD by $\pm 0.02$, holding other inputs fixed; divide the resulting flux difference by $0.04$, then average over the day.[1]
- Bright surfaces weaken or reverse the kernel; here albedo comes from MERRA-2.
- Apply monthly kernels to MODIS AOD anomalies, then fit the direct SW trend.
- Less AOD usually means more absorbed SW; cloud responses are excluded.

[1] RTE+RRTMGP: Pincus, Mlawer & Delamere (2019), *JAMES*, 11, 3074–3089. doi:10.1029/2019MS001621.

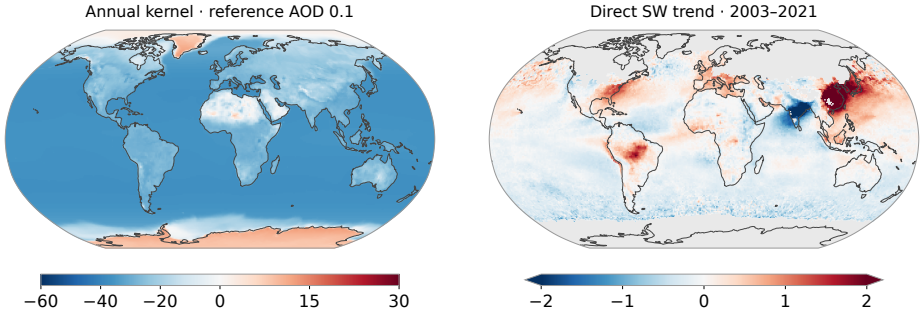
# Aerosol SW kernels: seasonal structure




- Seasonal solar geometry and local albedo; reference AOD fixed at 0.1

RRTMGP clear-sky SW response; MERRA-2 monthly surface albedo, 2003–2021.
SSA 0.95; water 25 kg m$^{-2}$. Polar night: zero response. Common scale; no cloud response.

# From MODIS AOD to the direct SW pattern




- SW trend: positive where AOD fell, negative over India and the Arabian Sea
- Global mean, 2003–2021: $-0.04$ [$-0.12$, $+0.04$] W m$^{-2}$ decade$^{-1}$ (87% sampled)

Left: global annual kernel at AOD 0.1; day-weighted mean, including polar night.
Right: monthly kernels at local AOD applied to stratospheric-AOD-subtracted MODIS anomalies.
RRTMGP; MERRA-2 albedo; SSA 0.95; water 25 kg m$^{-2}$; no cloud response. Grey: no support.

# CERESMIP: forcing and response attribution

## Scientific objective

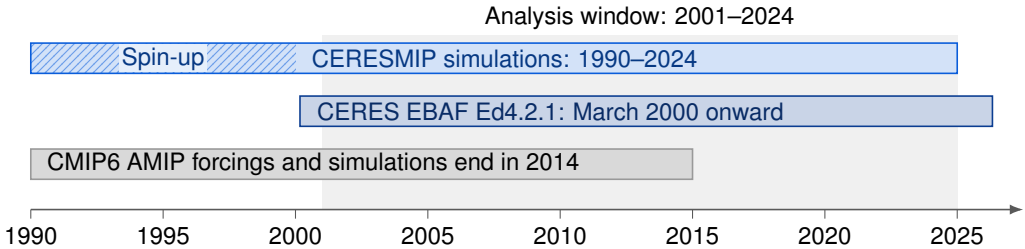
- Attribute CERES-era top-of-atmosphere radiative trends to external forcing, sea surface temperature patterns and internal atmospheric variability.

## Experimental design

- Atmosphere-only runs with prescribed observed SST and sea ice.
- Updated forcings and emissions; single-forcing and all-but-one experiments isolate forcing contributions and interactions.
- Evaluate shortwave, longwave and net fluxes, clear-sky/all-sky contrasts and cloud diagnostics. Initial-condition ensembles quantify internal variability.

Schmidt et al. (2023), Frontiers in Climate, 5:1202161.
Project description and experiment requests, updated 2 February 2026.

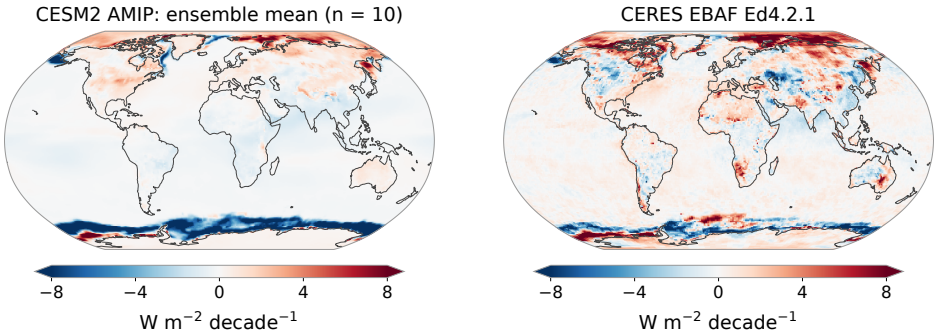
# CERESMIP: simulation and analysis periods




- **Tier 1:** one all-forcings AMIP simulation, 1990–2024, with observed sea surface temperatures and sea ice.
- **Tier 2:** initial-condition ensembles, single-forcing and all-but-one experiments, and fixed-SST forcing diagnostics.

Schmidt et al. (2023); current experiment requests, updated 2 February 2026.
The 1990–1999 spin-up reduces stratospheric and land-surface drift before the analysis period.

# CESM2: clear-sky shortwave trend bias




- Global $\dot{N}_{\mathrm{SW,clr}}$: $-0.31$ (CESM2), $+0.23$ (CERES)
- Direct SW trend calculated from MODIS AOD: $-0.16$ [$-0.31$, $-0.01$]

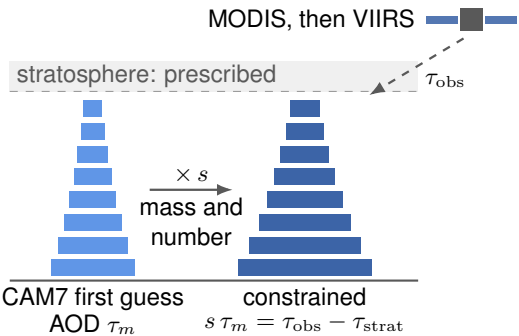
March 2000–December 2014; 10-member CESM2 AMIP ensemble; CERES EBAF Ed4.2.1.
Clear-sky TOA absorbed shortwave trends ($\dot{N}_{\mathrm{SW,clr}}$), W m$^{-2}$ decade$^{-1}$; positive downward.
RRTMGP kernel on MODIS AOD; 86% of globe; 95% interval; no cloud response; Terra only to mid-2002.

# Summary: constrain aerosol forcing trends

## Constrain aerosol trends and radiative responses

- CERES constrains the net TOA radiative trend;
  uncertainty in the **aerosol forcing trend** limits attribution.
- CESM2's clear-sky shortwave trend over 2000–2014 is $-0.31$ W m$^{-2}$ decade$^{-1}$, opposite in sign to CERES ($+0.23$). The direct SW trend calculated from MODIS AOD changes ($-0.16$) does not explain the CERES increase.
- **SARB:** evaluate aerosol trends, direct radiative effects and aerosol–cloud responses.
- **CESM3/CAM7:** paired emissions-driven and satellite-AOD-constrained ensembles with identical sea surface temperatures, sea ice, physics and non-aerosol forcings. Diagnose shortwave/longwave, clear-sky/all-sky and cloud-response differences.

# SARB plans: AOD-constrained CESM3/CAM7




## Constrained

- 550-nm column AOD, where retrieved
- One factor: size, species, profile kept
- CCN follow AOD; increments transported

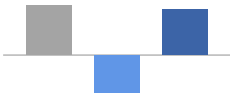
## Not constrained

- Size, absorption, aerosol origin
- Cloudy, polar, bright surfaces: $s \to 1$

f1: MAM4 from CEDS emissions; f2: constrained. Same physics, SST, forcings, initial state; 1990–1999 free. MODIS to March 2022, then NOAA-20 VIIRS, as in EBAF. Rescale tested in CAM7 (2008); f2 in progress.

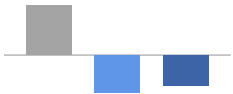
# SARB plans: what the paired runs can answer

**Clear-sky SW trend**



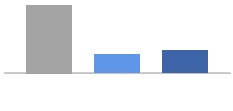

f2 closes the gap:
aerosol amount was wrong

**Clear-sky SW trend**




f1 $\approx$ f2: not aerosol amount;
optics, water vapour, surface

**All-sky SW trend**




Only clear sky closes:
cloud response or SST pattern

**Aerosol forcing trend:** the f2 $-$ f1 ERF difference isolates the aerosol trajectory. Compare $+0.03$ (obs) and $+0.20$ (models)

**Oct 27–29**
CERES STM, NASA LaRC: now

**Dec 2–4**
CERESMIP workshop, Vancouver

**Dec 7–11**
AGU26 EEI session poster

# Questions?

# Backup: CERES clear-sky SW trend in published context

## CERES EBAF Ed4.2.1, March 2000–December 2014 (W m$^{-2}$ decade$^{-1}$)

- Global clear-sky absorbed SW: $+0.23 \pm 0.12$ ($1\sigma$), i.e. less reflection; all-sky $+0.36$

## Published context (W m$^{-2}$ decade$^{-1}$ unless noted)

- Fixed-SST models: imbalance trend 10–40% weaker than CERES, 2001–2019; the clear-sky SW trend, not the cloud SW trend, appears underestimated.[1]
- Absorbed solar: $+0.9 \pm 0.3$ W m$^{-2}$ between the first and latest decades since 2000.[2]
- Absorbed solar, 2003–2024: $+0.86$; low clouds $\approx 1/4$; rest includes albedo, $H_2O$.[3]
- Aerosol–radiation share of the SW trend, 2003–2023: $+0.03 \pm 0.02$.[4]

Our trend is about $2\sigma$ and endpoint-sensitive; no published global clear-sky value for this window found.
[1] Hodnebrog et al. (2024); see also Chen et al. (2026). [2] Loeb et al. (2024). [3] Ceppi et al. (2026).
[4] Park & Soden (2025), *Sci. Adv.*; our MODIS-kernel value, 2003–2021: $-0.04$ [$-0.12$, $+0.04$].

# Backup: building the aerosol SW kernels with RRTMGP

## Column radiative transfer

- RTE+RRTMGP 1.9.2: 112 SW g-points, clear sky, delta-scaled aerosol
- One RCEMIP 300 K, 60-layer atmosphere everywhere; water vapour rescaled
- Aerosol: $\tau \propto \lambda^{-1.3}$; SSA and $g = 0.7$ the same in all bands; exponential profile, 2 km scale height
- One albedo: direct and diffuse, all bands

## Daily-mean tangent kernel

- TOA reflectance $R$ at $\tau \pm 0.02$: central difference $\partial R/\partial\tau$ at 13 $\mu_0$ values
- $K_{\uparrow} = S_0 f_d \sum_h w_h \, \mu_{0,h} \, \partial R/\partial\tau$; mid-month sun, 16-point Gauss–Legendre
- Table: month, latitude, albedo, SSA, water vapour, AOD
- MODIS: local AOD, MERRA-2 albedo, SSA 0.95, water 25 kg m$^{-2}$; $K_{\mathrm{SW}} = -K_{\uparrow}$

$CO_2$ 390 ppm, $CH_4$ 1.8 ppm, $N_2O$ 320 ppb, RCEMIP ozone. $S_0 = 1361$ W m$^{-2}$; $f_d$: Earth–Sun distance. Checks: climlab RRTMG within 16% (reference case); six CMIP6 models: $r = 0.96$–$1.00$, 3 of 6 within 30%. Pincus et al. (2019); RCEMIP: Wing et al. (2018).