Testing hypotheses for maintaining Earth's hemispheric albedo symmetry with CERES observations of natural experiments

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Measurements of the Earth’s Radiation Budget from Satellites During a Five-Year Period. Part I: Extended Time and Space Means

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(Manuscript received 20 May 1970, in revised form 28 December 1970)

<table>
<thead>
<tr>
<th>Planetary albedo (%)</th>
<th>Northern Hemisphere</th>
<th>Southern Hemisphere</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>First generation satellites*</td>
<td>29</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>Second generation satellites**</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>
1. There is essentially identical reflection between the Northern and Southern Hemispheres (NH & SH)

2. The hemispheres are strongly out of balance in terms of clear-sky reflection
Continental contribution to albedo symmetry.

Stephens et al. (2015), Reviews of Geophysics.
Symmetry is rare when dividing the Earth into arbitrary hemispheres.

Fraction of arbitrary hemispheres that could be created (accounting for spatial autocorrelation) with a hemispheric symmetry less than some value $D$. 

Voigt et al. (2013), J Clim
Climate models do not systematically reproduce the observed albedo symmetry.
Solar reflection is symmetric, but outgoing longwave radiation is not!

Interhemispheric energy transport maintains energy balance

Energy balance arguments are untenable
Why should we care?

Broader implications

• **Epistemic:** There is a seemingly fundamental feature of the Earth system that we don’t understand at all!

• **Practical:** If there is a physical mechanism maintaining symmetry, there would be ramifications across the Earth system
  
  • Constraint on cloud feedbacks?
  
  • E.g., Jönsson et al. (2023), ACP
  
  • Implications for solar climate interventions?
  
  • Leading hypotheses involving Intertropical Convergence Zone shifts or midlatitude cloudiness strongly implicate hydrological cycle and ocean-atmosphere circulations
ITCZ hypothesis

ITCZ shift into darker hemisphere

Mechanism mediated by temperature change!

Voigt et al. (2014), J Clim
ITCZ hypothesis

Rugenstein & Hakuba (2023), GRL
Midlatitude oceans hypothesis

Datseris & Stevens (2021), AGU Adv

Jönsson & Bender (2022), J Clim
Midlatitude oceans hypothesis

Greater baroclinic activity (shading) in SH than NH; stronger (anti)cyclones have greater cloud albedo

$$E = \text{SLP}^2$$
Albedo symmetry by component

Clear-sky atmos.

Positive values = greater NH reflection

<table>
<thead>
<tr>
<th>Cloud optical thickness</th>
<th>Cloud-top pressure (hPa)</th>
<th>Shortwave reflection (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td>100</td>
<td>95.9</td>
</tr>
<tr>
<td>1.6 - 3.6</td>
<td>360</td>
<td>+0.9</td>
</tr>
<tr>
<td>23</td>
<td>680</td>
<td>+0.6</td>
</tr>
<tr>
<td>&gt;100</td>
<td>940</td>
<td>+0.1</td>
</tr>
</tbody>
</table>

CERES FluxByCldType Ed4A
Albedo symmetry by component

Part 1: Earth's strong clear-sky hemispheric albedo asymmetry is transient, not fixed

Part 2: Can we use "natural experiments" of hemispheric albedo perturbations to test hypothesized mechanisms for maintaining symmetry?
Part I:
On the rise and fall of Earth’s clear-sky albedo asymmetry

Diamond, Gristey, Kay, & Feingold (2022), Communications Earth & Environment, doi:10.1038/s43247-022-00546-y
Albedo decomposition

$A_{\text{clr}} \approx \frac{T^2}{\alpha_{\text{aer}} + \alpha_{\text{sfc}} (1 - \alpha_{\text{aer}} \alpha_{\text{sfc}})}$

$A_{\text{clr}}$ = clear-sky scene albedo; $\alpha_{\text{aer}}$ = atmospheric reflectivity; $\alpha_{\text{sfc}}$ = surface reflectivity; $T$ = atmospheric transmissivity

--CERES EBAF Ed4.1, “clr_t”
Observed clear-sky albedo asymmetry
Aerosol optical depth distribution

![Graph showing aerosol optical depth distribution with different components and regions indicated.]
Clear-sky albedo asymmetry in CMIP6 future runs

Under high emissions scenario, NH darkens from Arctic sea ice loss

Under low emissions scenario, NH darkens from AOD loss
Part II: Using cloud-type data to test hypotheses of Earth’s albedo symmetry
Albedo symmetry by component

Positive values = greater NH reflection

短波反射率 (W/m²)

Clear-sky atmos.

Cloud-top pressure (hPa)

Cloud optical thickness

CERES FluxByCldType Ed4A
FBCT methods

\[ A = \alpha_{\text{aer}} + \alpha_{\text{sfc}} + \frac{T^2}{(1 - \alpha_{\text{atm}} \alpha_{\text{sfc}})} + \sum_i C_i (A_{\text{cld},i} - A_{\text{clr}}) \]

\[ R = R_{\text{aer}} + R_{\text{sfc}} + R_{\text{Cu}} + R_{\text{Sc}} + R_{\text{St}} + R_{\text{Ac}} + R_{\text{As}} + R_{\text{Ns}} + R_{\text{Ci}} + R_{\text{Cs}} + R_{\text{Cb}} \]
Timescale of (a)symmetries
**“Natural experiments” strategy**

Can we identify distinct events favoring hemispheric asymmetry and identify possible counteracting responses?

Such events could be:

- Large magnitude but short in duration
- Moderate magnitude but longer in duration
**Trends**

![Graph showing climate trends](image)

- **ITCZ shift hypothesis not falsified**
- **Midlatitude low cloud hypothesis falsified**

**CERES FluxByCldType Ed4A**

Post-2015 Antarctic sea ice loss
Post-2015 Antarctic sea ice loss


CERES FluxByClidType Ed4A
Post-2015 Antarctic sea ice loss


- **Pre**: 0.18 W/m²
- **Post**: -0.32 W/m²

- **Sfc**: dominates SH diff.
- **SH low clouds**: reinforce sfc difference
- **SH high clouds**: show no change

CERES FluxByCldType Ed4A

COVID-19
COVID-19

NH aer decreases, but overall NH reflection has little change!

SH sfc and low cloud changes larger than NH aer change!

NH aer decreases, but overall NH reflection has little change!
Australian bushfires

Exceed max. pre-2020 values

January 2020 AOD anomaly
Australian bushfires

Fasullo et al. (2023), Sci Adv
Plausible that smoke direct and indirect effects lead to moderate SH>NH asymmetry.

ITCZ shift into the SH due to increased atmospheric absorption?
Thanks for listening!

Weakening of clear-sky hemispheric albedo asymmetry may already be moving Earth out of its current symmetric state. Evidence points against an extratropical low cloud maintenance mechanism, at least at annual-decadal scales. ITCZ shifts, perhaps lagged, still a plausible mechanism.
Measured asymmetry is indistinguishable from zero given length of CERES satellite record.

Datseris & Stevens (2021), AGU Adv
Pre-industrial vs. present-day aerosol
Past, present, and future of sea ice

Diamond et al. (2022), CEE
Arctic versus Antarctic ice loss

Diamond et al. (2022), CEE
Comparison to Stephens et al. decomposition

\( (\text{DB11 - S+15}) \text{ atmos.} \)

\( \overline{SA}_{\text{atm}} \text{ (W/m}^2\text{)} \)

\( (\text{DB11 - S+15}) \text{ sfc.} \)

\( \overline{SA}_{\text{sfc}} \text{ (W/m}^2\text{)} \)
Comparison to Stephens et al. decomposition