Global all-sky direct radiative forcing of anthropogenic aerosols from combined satellite observations and GOCART simulations

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Natural/Pre-Industrial Aerosols
Total/Present Day Aerosol

- Anthropogenic = Total - Natural  (Present Day - Pre Industrial)
Direct aerosol radiative effect/forcing

- Direct aerosol radiative effect (DARE) is the mean radiative flux perturbation due to the presence of aerosols (both natural and anthropogenic).

- Direct aerosol radiative forcing (DARF) is the anthropogenic component of DARE.

- DARE has been estimated from satellite measurements, but mostly for clear-sky.

- Estimating DARF from satellite measurements is more challenging.

- We combine cloud properties and TOA fluxes in CERES product with natural and anthropogenic aerosols in GOCART to derive all-sky DARF.
CERES synoptic radiative fluxes and clouds product

- Cloud properties (3-hourly)
  - MODIS and geostationary satellite retrievals
- Aerosol optical depths
  - MODIS and MATCH aerosol assimilation model
- Aerosol composition and profile
  - MATCH model
- Radiative transfer calculations provide fluxes at the TOA and surface
  - 3-hourly radiative fluxes
    - Pristine: \( F_{c,p} \)
    - clear-sky: \( F_{c,t} \)
    - all-sky: \( F_{a,t} \)
    - all-sky no-aerosol: \( F_{a,p} \)

\[
\begin{align*}
DARE_c &= F_{c,t} - F_{c,p} \\
DARE_a &= F_{a,t} - F_{a,p}
\end{align*}
\]
Clear-sky DARE from CERES SYN

Clrsky SYN TOA DARE for JJA 2004 (-6.29 W m⁻²)

Clrsky Atmos. DARE for JJA 2004 (3.90 W m⁻²)

Clrsky Sfc DARE for JJA 2004 (-...
All-sky DARE from CERES SYN

Allsky SYN TOA DARE for JJA 2004 (-3.37 W m⁻²)

Allsky Atmos. DARE for JJA 2004 (3.78 W m⁻²)

Allsky Sfc DARE for JJA 2004 (-
GOCART model

- Daily 1° x 1.25° GOCART output contains:
  - AOD of total organic carbon, black carbon, sea salt, dust, and sulfate; and their vertical profiles
  - AOD of natural organic carbon, black carbon, and sulfate; and their vertical profiles
Anthropogenic fraction ($\tau_a/\tau$) from GOCART
Combine CERES SYN and GOCART to derive all-sky DARF

- First run radiative transfer model with inputs of:
  - 3-hourly cloud properties and surface albedo from CERES SYN
  - Daily-mean TOTAL aerosol optical depth and vertical distribution from GOCART
Combine CERES SYN and GOCART to derive all-sky DARF

- Then run radiative transfer model with inputs of
  - 3-hourly cloud properties and surface albedo from CERES SYN
  - Daily-mean **NATURAL** aerosol optical depth and vertical distribution from GOCART
Combine CERES SYN and GOCART to derive all-sky DARF

\[
DARF_{SYN}^{all} = DARF_{SYN}^{all} \times \frac{DARF_{GOCART}^{all}}{DARF_{GOCART}^{all}}
\]
Clear-sky DARF is derived using the same method

\[
\text{DARF}_{\text{SYN}}^{\text{clr}} = \text{DARE}_{\text{SYN}}^{\text{clr}} \times \frac{\text{DARF}_{\text{GOCART}}^{\text{clr}}}{\text{DARE}_{\text{GOCART}}^{\text{clr}}}
\]

Clrsky SYN TOA DARF for JJA 2004 (-1.70 W m^{-2})
GOCART underestimates clear-sky DARF by 23%

<table>
<thead>
<tr>
<th>Region</th>
<th>SYN (Wm$^{-2}$)</th>
<th>GOCART (Wm$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60S~60N</td>
<td>-1.55</td>
<td>-1.19</td>
</tr>
<tr>
<td>Ocean</td>
<td>-1.39</td>
<td>-1.08</td>
</tr>
<tr>
<td>Land</td>
<td>-1.98</td>
<td>-1.50</td>
</tr>
<tr>
<td>NH</td>
<td>-1.86</td>
<td>-1.53</td>
</tr>
<tr>
<td>SH</td>
<td>-1.25</td>
<td>-0.86</td>
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GOCART underestimates all-sky DARF by 67%

<table>
<thead>
<tr>
<th>DARF (Wm^-2)</th>
<th>SYN</th>
<th>GOCART</th>
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<tbody>
<tr>
<td>60S~60N</td>
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<td>-0.17</td>
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<tr>
<td>Ocean</td>
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<td>-0.15</td>
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<tr>
<td>Land</td>
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<td>-0.23</td>
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<tr>
<td>NH</td>
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<td>-0.29</td>
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<tr>
<td>SH</td>
<td>-0.35</td>
<td>-0.06</td>
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Aerosol optical depth in SYN is larger than in GOCART

**Table:**

<table>
<thead>
<tr>
<th>Region</th>
<th>SYN</th>
<th>GOCART</th>
</tr>
</thead>
<tbody>
<tr>
<td>60S~60N</td>
<td>0.18</td>
<td>0.14</td>
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<tr>
<td>Ocean</td>
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<td>0.11</td>
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<tr>
<td>Land</td>
<td>0.28</td>
<td>0.22</td>
</tr>
<tr>
<td>NH</td>
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<td>0.19</td>
</tr>
<tr>
<td>SH</td>
<td>0.13</td>
<td>0.09</td>
</tr>
</tbody>
</table>
Aerosols in GOCART are more absorbing than in SYN
Clouds reduce DARF, but not the difference
DARF is more sensitive to aerosol absorption and vertical distribution under all-sky conditions

Loeb and Su (2010)
Summary

- Clear-sky and all-sky DARF are computed from two methods
  - Observational based: CERES SYN
  - Model based: GOCART

- Global (60°N-60°S) mean CLEAR-sky DARF from CERES SYN is -1.55 Wm⁻², and is -1.19 Wm⁻² from GOCART

- Global (60°N-60°S) mean ALL-sky DARF from CERES SYN is -0.51 Wm⁻², and is -0.17 Wm⁻² from GOCART

- The presence of clouds amplifies the sensitivity of DARF to aerosol single scattering albedo and aerosol vertical distribution.