AEROSOL INFLUENCE ON CLOUD OPTICAL DEPTH AND ALBEDO OVER THE NORTH ATLANTIC SHOWN BY SATELLITE MEASUREMENTS AND CHEMICAL TRANSPORT MODELING

Stephen E. Schwartz and Carmen M. Benkovitz

Harshvardhan

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AEROSOL INFLUENCES ON RADIATION BUDGET AND CLIMATE

**Direct Effect (Clear sky)**
- Light scattering -- Cooling influence
- Light absorption -- Warming influence, depending on surface

**Indirect Effects (Aerosols influence cloud properties)**
- More droplets -- Brighter clouds (Twomey)
- More droplets -- Enhanced cloud lifetime (Albrecht)

**Semi-Direct Effect**
- Absorbing aerosol heats air and evaporates clouds
DEPENDENCE OF CLOUD ALBEDO ON CLOUD DEPTH

Influence of Cloud Drop Radius and Concentration

LWC = 0.3 g m\(^{-3}\)

\(g = 0.858\)

SENSITIVITY OF ALBEDO AND FORCING TO CLOUD DROP CONCENTRATION

Schwartz and Slingo (1996)
SHORTWAVE FORCING, ANNUAL AVERAGE

GHG's + O₃ + Sulfate (Direct and Indirect)

Two Formulations of Cloud Droplet Concentration

Kiehl et al., JGR, 2000
CLIMATE FORCING COMPONENTS OVER THE INDUSTRIAL PERIOD

Climate Change Science
An Analysis of Some Key Questions
Committee on the Science of Climate Change
National Research Council
June 6, 2001
THIS STUDY

• Uses a chemical transport and transformation model to identify a situation where a strong aerosol influence on cloud albedo might be expected.

• Examines for this signal in satellite data in two one-week episodes in which the model indicates transport of anthropogenic sulfate from Europe or North America to mid North Atlantic.

• Finds a strong signal in cloud drop radius.

• Does not find an immediate strong signal in cloud albedo: Why?

• Offers an explanation: Inherent variability in cloud liquid water path on a given day and from day to day.

• Quantifies the perturbation in cloud albedo.
MODELED SULFATE COLUMN BURDEN

\[ \int [\text{SO}_4^{2-}] \, dz \]

April 2-8, 1987


MODELED SULFATE CONCENTRATION PROFILE AND COLUMN BURDEN (\( \int [\text{SO}_4^{2-}] dz \))

25°-30°W, 50°-55°N, April 2-8, 1987
AVHRR IMAGES APRIL 2-8, 1987

Channel 4, Thermal IR, 10.3-11.3 μm
AVHRR DATA
Screening for Spatial Coherence

April 2, 1987  50-55N/25-30W  1628 UTC

**DETERMINING CLOUD OPTICAL THICKNESS AND EFFECTIVE DROP RADIUS FROM SATELLITE RADIANCE MEASUREMENTS**

<table>
<thead>
<tr>
<th>IN</th>
<th>Visible and IR radiance</th>
<th>LOOK-UP TABLE</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Channel 1 (0.58-0.68 µm)</td>
<td>Based on Radiative Transfer Calculations</td>
<td>Cloud optical thickness (0.63 µm)</td>
</tr>
<tr>
<td></td>
<td>Channel 3 (3.6-3.9 µm)</td>
<td>( f(\theta_0, \theta, \phi) )</td>
<td>( \tau_c )</td>
</tr>
</tbody>
</table>

\[
\tau_c = \frac{\mu_3}{\mu_2}
\]

**Diagram:**
- CH1 Radiance (W/m²/sr/µm)
- CH3 Radiance (W/m²/sr/µm)

\[\theta = 40^\circ, \theta_0 = 60^\circ, \phi = 50^\circ\]

EFFECTIVE RADIUS VS. CLOUD OPTICAL DEPTH

AVHRR Data: 50-55°N, 25-30°W, 2-8 April, 1987

2002
**DERIVED MICROPHYSICAL QUANTITIES**

**Primary measured quantities:**

- Effective radius at top of cloud \( r_e \)
- Cloud optical depth \( \tau_c \)

**Derived quantities:**

- Liquid water path \( W = \frac{2 \rho_w \tau_c \bar{r}_e}{3} \)
  
  where \( \bar{r}_e \) is mean drop radius in cloud, taken as \((5/6)r_e\), and

- Cloud spherical albedo \( \alpha_{sph} \approx \frac{\tau_c(1 - g) + 0.097}{\tau_c(1 - g) + 1.43} \)
  
  where \( g \) is asymmetry parameter ranging from 0.834 for \( r_e = 6 \ \mu\text{m} \) to 0.872 for \( r_e = 19 \ \mu\text{m} \).
CLOUD OPTICAL DEPTH

Dependence on Liquid Water Path

25°-30°W, 50°-55°N      April 2-8, 1987
CLOUD-TOP ALBEDO
Dependence on Liquid Water Path
25°-30°W, 50°-55°N April 2, 5 and 7, 1987

Spherical Albedo (0.25 - 1.19 µm)

Liquid Water Path, g m⁻²
CLOUD-TOP ALBEDO DIFFERENCE
April 5 relative to April 2, 1987
Evaluated for LWP of April 5 Data

Liquid Water Path, g m^{-2}
CLOUD PROPERTIES AND SULFATE COLUMN BURDEN

25°-30°W, 50°-55°N, April 2-8, 1987

Sulfate, µmol m⁻²

Eff. Rad., µm

Optical Depth

Sph. Albedo

LW Path, g m⁻²

∆ Sph. Albedo

Date, April, 1987
CONCLUSIONS

• Satellite-derived cloud microphysical properties are correlated with modeled sulfate loading.

• *Aerosol exerts substantial influence* on cloud optical depth and albedo.

• Approach relies on ability to *simultaneously determine liquid water path and optical depth*.
  
  - Takes advantage of variability in LWP.

• This approach may be *broadly applicable* to examining aerosol influences on cloud microphysical properties and radiative forcing.