An Overview of the Radiation Budget in the Lower Atmosphere

P. Pilewskie
University of Colorado
Laboratory for Atmospheric and Space Physics
Department of Atmospheric and Oceanic Sciences

With help from: S. Schmidt, S. Platnick, O. Hofmann, M. Wendisch, J. Redemann
Energy budget within the atmosphere after *Kiehl and Trenberth* [1997]. The numbers give the globally and annually averaged solar (left side of the figure) and longwave (right side) irradiances [W m⁻²].
Outline

1. Radiative properties of ice clouds

   Smaller ice crystals?
   Radiance → irradiance validation.

2. Aerosol Radiative Forcing

   Observation-based direct spectral forcing.
   An aerosol effect on clouds or an aerosol effect on cloud retrievals?
Small ice crystals?

Garrett et al., 2003
Cirrus Regional Study of Tropical Anvils and Cirrus Layers – Florida Area Cirrus Experiment: CRYSTAL-FACE

MAS MODIS AIRBORNE SIMULATOR

SSFR Solar Spectral Flux Radiometer

Albedo

1835 UTC

350 nm → 1700 nm

1901 UTC

Radiance → Irradiance

Cloud/atmo properties → Energetics
No evidence of small ice crystals from optical remote sensing during CRYSTAL-FACE

Pilewskie et al., 2004, 2006
Net Radiative Cloud Forcing

Annual ISCCP C2 Inferred Stratus Cloud Amount

Net Cloud Forcing from CERES/Terra
July 2000

Net Radiative Cloud Forcing

stratus cover

net cloud forcing
Application of cloud retrievals to TOA energy budget

How well do the simulated irradiance fields based on satellite retrieved cloud properties match with direct measurements?

• Infer 2-3D cloud structure from MAS radiance measurements + auxiliary data

• 3D RT calculations \( \rightarrow \) compare to actual irradiance measured simultaneously
  - Two cloud cases, three modeling methods:
    A) Spherical (Mie phase functions)
    B) Nonspherical phase functions
    C) Nonspherical HG: \( g + HG \) phase function
  - (B&C: Yang, 2000)
  - Two 3D MC codes: GRIMALDI (Scheirer & Macke)
    MYSTIC (Mayer)

• Compare with SSFR irradiance along flight track
Cloud simulated from MAS, lidar and radar data

...cloud made from:

A) MAS retrieval IWP → horizontal structure

B) LIDAR/RADAR vertical structure → IWC vertical distribution

C) In-situ vertical profile – for vertically distributing TWP
3-d irradiance simulation

\[ \lambda = 505 \text{ nm} \]

- Measurement (SSFR)
- Nonspherical (P. Yang)
- Spherical (Mie)
3-d irradiance simulation

\( \lambda = 1625 \text{ nm} \)

- Measurement (SSFR)
- Nonspherical (P. Yang)
- Nonspherical \( r_{\text{eff}}/2 \)

\( r_{\text{e}} = 12.5 \text{ \mu m} \)

\( r_{\text{e}} = 25 \text{ \mu m} \)
3-d irradiance simulation

Domain averaged spectral albedo

- Model
- Measurement

<table>
<thead>
<tr>
<th>Wavelength [nm]</th>
<th>Model</th>
<th>Measurement</th>
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</table>
Cloud generator: overcast St and broken Cu

3-D Modeled irradiance

overcast St – domain averaged spectra above/below layer

broken Cu – horizontal structure of modeled irradiance

Schmidt et al., 2006
Cloud retrievals in the presence of aerosol

Cloud-aerosol interactions (indirect effects) or aerosol affecting the retrievals?
International Consortium for Atmospheric Research on Transport and Transformation (ICARTT)

09 July 2004 NOAA WP-3D Flight with MODIS Terra overpass
Cloud retrievals in the presence of aerosol
20 July 2004 TERRA 15:40-15:45 UTC

Below aerosol layer:
- \( z: 700 \text{ m} \)
- \( \tau_a: 0.27 \)
- \( r_e: 9.9 \mu\text{m} \)
- \( \tau_c: 10.3 \)
- \( \text{LWP}: 68 \text{ g cm}^{-2} \)

Above aerosol layer:
- \( z: 3500 \text{ m} \)
- \( \tau_a: 0.034 \)
- \( r_e: 12.2 \mu\text{m} \)
- \( \tau_c: 10.5 \)
- \( \text{LWP}: 85 \text{ g cm}^{-2} \)
Above Aerosol

MODIS overpass

Below Aerosol

20 July 2004

\[ \tau : 10.3 \ 10.5 \ 8.8 \]

\[ \tau_e : 9.9 \ 12.1 \ 11.6 \ \mu m \]
Haywood results: for MODIS bands, overlying aerosol layers decrease retrieved optical depth and effective radii

Why do SSFR retrievals increase $r_e$ ($\tau$ unchanged)?
- SSFR retrieval uses 7 bands; Haywood has shown that the MODIS bias is band specific
- SSFR measures irradiance; aerosol influence may be greater

SSFR forward model incorporating aerosols – sensitivity tests of retrieved $r_e$, $\tau$ may explain bias due to absorbing aerosol

Direct Aerosol Spectral Radiative Forcing

Aerosol gradient method:
• Derive aerosol radiative forcing from simultaneously measured radiative flux and AOD gradients
• Aerosol radiative forcing efficiency:
  \[ E_\lambda = \frac{\Delta F_\lambda}{\Delta \tau} \text{ [W m}^{-2} \text{ nm}^{-1} \text{ AOD}^{-1}] \]
• Aerosol relative forcing efficiency:
  \[ e_\lambda = \frac{E_\lambda}{F_\lambda} \]
Figure 6. Derived instantaneous spectral net relative aerosol radiative forcing efficiency as a function of wavelength for the 10 ICARTT cases.

Redemann and Pilewskie et al, 2006
## Diurnally Averaged Direct Radiative Forcing Efficiency

<table>
<thead>
<tr>
<th>Campaign</th>
<th>$\lambda$ Range (nm)</th>
<th>Mean (W m$^{-2}$)</th>
<th>Std. Dev (W m$^{-2}$)</th>
<th>Reference</th>
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<td>300-3810</td>
<td>-73</td>
<td>9.6</td>
<td>Bush and Valero, 2003</td>
</tr>
</tbody>
</table>

Visible broadband
Aerosol spectral absorption

Single scattering albedo derived from layer spectral absorption measurements

Pilewskie et al., 2003; Bergstrom et al., 2003, 2004

Spectral absorption optical depth

Pilewskie et al., 2005
Summary

• No evidence of small (~ 5 μm) cirrus ice crystal effective radius from optical remote sensing
• Spectral irradiance simulated (using 3-d rad. transfer) from satellite retrieved cloud fields matches observations – within limits (scene dependent).
• Aerosol effects on cloud retrievals must be distinguished from aerosol effects on cloud radiative properties in order to quantify globally the indirect effects of aerosols on clouds.
• Relative aerosol spectral forcing efficiency derived directly from observations obeys simple a linear dependence with wavelength.