Influence and estimation of 2-D solar radiative processes in clouds

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• Oklahoma: 1999-2001
• Alaska: 2005-2007
• Papua New Guinea: 2003-2004
ARM cloud observations

Cloud radar, Lidar, Microwave radiometer, Radiosonde, Radar wind profiler

LWC, IWC, $R_e$(liq), $R_e$(ice)

Liquid water content (g/m³), Ice water content (g/m³), $R_e$(liq), $R_e$(ice)

SGP 2004-10-04
Radiative transfer simulations

Vol. ext. coeff.

Absorption (A)

\[ A_{2-D} - A_{1-D} \]
Limitations

- Uncertainties in input cloud structures
- Not 3-D
- 1-D biases of coarse resolution models not included
  (Median resolution: NSA: 86 m, SGP: 141 m, TWP: 74 m)
Overall average results

Multiyear full-day (24 hour) average difference between 2-D and 1-D calculations of reflected sunlight

-0.3 W/m²  -1.2 W/m²  -4.1 W/m²
Influence of 2-D effects on the average reflection of 1 m² cloud

-0.5 W/m²  -2.5 W/m²  -5.7 W/m²
Influence of solar elevation

Reflection

$F_{2-D} - F_{1-D}$ (W/m$^2$)

Solar zenith angle (°)

High sun
diffusion to thin areas

Low sun
cloud side illumination

SGP, March 2, 1999, ~22:30 UTC
Cloud types at SGP site

Mean altitude, $\tau$

<table>
<thead>
<tr>
<th>Cloud type</th>
<th>Altitude (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hi</td>
<td>1</td>
</tr>
<tr>
<td>As</td>
<td>17</td>
</tr>
<tr>
<td>Ac</td>
<td>17</td>
</tr>
<tr>
<td>St</td>
<td>42</td>
</tr>
<tr>
<td>Sc</td>
<td>17</td>
</tr>
<tr>
<td>Cu</td>
<td>29</td>
</tr>
<tr>
<td>Ns</td>
<td>180</td>
</tr>
<tr>
<td>Dc</td>
<td>300</td>
</tr>
</tbody>
</table>

Frequency of cloud types

<table>
<thead>
<tr>
<th>Cloud type</th>
<th>Number of columns</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>As</td>
<td>$6 \times 10^5$</td>
</tr>
<tr>
<td>Ac</td>
<td>$5 \times 10^5$</td>
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<tr>
<td>St</td>
<td>$4 \times 10^5$</td>
</tr>
<tr>
<td>Sc</td>
<td>$3 \times 10^5$</td>
</tr>
<tr>
<td>Cu</td>
<td>$2 \times 10^5$</td>
</tr>
<tr>
<td>Ns</td>
<td>$1 \times 10^5$</td>
</tr>
<tr>
<td>Dc</td>
<td>$10^5$</td>
</tr>
</tbody>
</table>
2-D effects and cloud type

Cloud absorption

Surface absorption within 10 km of clouds

Cloud type

Cloud type
Histogram of 2-D effects

Cloud absorption in 1 km² columns

Surface absorption in 10 km areas

Cumulative histogram value

\[(F_{2-D} - F_{1-D}) / F_{1-D} \text{ (\%)}\]

\[F_{2-D} - F_{1-D} \text{ (W/m²)}\]
Cloud variability parameters

Difference between 2-D & 1-D fluxes

Variability parameters:
Gradients (up to 10 km) in $\tau, F_{1D}, Z$

$F_{TICA} - F_{ICA}$
Initial results

Surface absorption at 1 km resolution, at TWP site

Solar zenith angle: 5-10°

Solar zenith angle: 48-52°
Large-scale effects at TWP

10 km regions

35 km regions
Effects at NSA and SGP sites

10 km regions

35 km regions
Simulations show 2-D radiative effects increasing multiyear average total (cloudy and clear, day and night, surface and atmospheric) solar absorption by 4.1, 1.2, 0.5 W/m² at the three ARM sites, respectively.

These are rather conservative estimates of 1-D errors: no cloud variability in cross-wind direction and no plane-parallel bias for coarse-resolution models.

2-D effects are locally often much larger than these average values, especially for high sun and for convective clouds.

Neural-net based parameterizations show promise in improving the 1-D solar flux calculations of dynamical simulations by adjusting them for 2-D radiative effects.

ARM scanning radars will offer new opportunities for examining full 3-D effects, which in earlier case studies were about 30% stronger than 2-D effects.
Considered Ci cases

Water content (g/m³)