Surface, Atmospheric, TOA radiation budgets over ARM SGP and TWP sites

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Chuck Long and Tom Ackerman\ Flux data and suggestions
Sally Benson and Jay Mace\ ARM Cloud heights
Chuck Pavloski and Eugene Clothiaux\ Monte Carlo simulations
Fred Rose and Tom Charlock \ Fu-Liou code
Outline

1) SGP results
2) TWP results
3) Comparison with Model calculations
4) Error analysis
Data

Surface data
Cloud-base and -top heights from ARM lidar/radar measurements, SW fluxes from Chuck Long’s best estimate flux VAP.

CERES data on TERRA
TOA albedo, effective cloud height, optical depth.

Samples and Time periods:
\ARM SGP:
30 deep cumulus clouds from March 2000 to May 2003.

\ARM TWP (Nauru:0.52° S, 166.92° E; Manus:2.06° S, 147.43° E)

\NO AUQA data, and NO TWP surface data in 2003.
Averaging/calculating methods

Surface data were averaged over a 1-hour period centered at the time of the *Terra* overpass.

CERES cloud and radiation properties were averaged in a $1^\circ \times 1^\circ$ box centered on the ARM surface sites.

$$A_{col} = 1 - R_{TOA} - T_{sfc}$$
TOA/SFC/Atmosphere Radiation Budgets over the ARM SGP Site

(a) Optical depth
Mean = 51.7, Std = 23

(b) TOA Albedo
Mean = 0.62, Std = 0.054

(c) Surface Transmission
Mean = 0.16, Std = 0.077

(d) Atmospheric Absorp
Mean = 0.22, Std = 0.06
Comparison between observations and model calculations

Model calculated $R_{TOA}$ is 7% higher and $A_{col}$ is 7% lower than data.
Cloud top

Model calculations
Plane parallel

Observations with photons
Leak at the sides of Cu

$A_{\text{col}}=20$ photons
$A_{\text{col}}=25$ photons

Cloud base

When Cu height=10 km, size=100 km, the side leaking is $\sim$5%
What are quantitative relationships between $R_{TOA}$, $T_{sfc}$, and $A_{col}$ with cloud optical depth?
When $\Delta T_{sfc}$ increases 0.1, $\Delta R_{TOA}$ decreases 0.0435
Why they are so small?
Why cloud absorptions in the cases 5 and 6 are so small?
Cases 5 and 6 MODIS images
Comparison between observations and Fu/Liou calculations

(a) Optical depth

(b) TOA Albedo

(c) Surface Transmission

(d) Atmospheric Absorp

Sample number
Their relationships are very similar to their counterparts at SGP.
When $\Delta T_{sfc}$ increases 0.1, $\Delta R_{TOA}$ decreases 0.0201
Error analysis

1) Water vapor below cloud base and above cloud top
2) Surface albedo impact
3) Precipitation:
   Most of cases at SGP without precipitation, but it is opposite at TWP sites.
Almost NO water vapor above cloud top, and cloud base is close to ground.
When $\Delta R_{sfc}$ increases 20%, $\Delta T_{sfc}$ increases 2.7%
Conclusions

1) Deep cumulus clouds are selected at the ARM SGP and TWP sites with averaged cloud-base height ~1 km, top height ~ 10 km.

2) Their averaged TOA albedo is ~0.6, most are 0.5 \( 0.7 \)
   - Surface transmission is ~0.17, most are 0.05 \( 0.3 \)
   - Atmospheric absorption is ~0.23, most are 0.1 \( 0.3 \)

3) At SGP, Model \( R_{TOA} \) is 7% higher, \( A_{col} \) is 7% lower than data
   At TWP, Model \( R_{TOA} \) is 7% higher, \( A_{col} \) is 3% lower than data

4) The negative correlation between TOA albedo and surface transmission is stronger at SGP than at TWP

5) Error analysis shows:
   - Water vapor contributes little to SW absorption in this study
   - Surface albedo impact is almost negligible in this study
<table>
<thead>
<tr>
<th></th>
<th>Feb. 27, Abt</th>
<th>2000 Abs(Wm(^{-2}))</th>
<th>March Abt</th>
<th>20, 2000 Abs(Wm(^{-2}))</th>
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<tbody>
<tr>
<td>TSBR tower</td>
<td>0.134</td>
<td>116</td>
<td>0.132</td>
<td>136</td>
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<td>TSBR aircraft</td>
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<td>105</td>
<td>0.127</td>
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<td>CM22 tower</td>
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<td>0.137</td>
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<td>CM22 aircraft</td>
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<td>CM21 tower</td>
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<td>SBDART mineral</td>
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<td>105</td>
<td>0.128</td>
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</tbody>
</table>

Ackerman et al. 2003, JGR
### Table 3: Cloudy-sky measured and modeled values of Absorptance (Abt) and Absorption (Abs) [ARESE II]

<table>
<thead>
<tr>
<th></th>
<th>March Abt</th>
<th>03 Abs</th>
<th>March Abt</th>
<th>21 Abs</th>
<th>March Abt</th>
<th>29 Abs</th>
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<td>195</td>
<td>0.206</td>
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<td>TSBR aircraft</td>
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<td>211</td>
<td>0.230</td>
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<tr>
<td>CM22 tower</td>
<td>0.178</td>
<td>167</td>
<td>0.208</td>
<td>211</td>
<td>0.214</td>
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<td>CM22 aircraft</td>
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<tr>
<td>CM21 tower</td>
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<tr>
<td>RAPRAD</td>
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</tbody>
</table>

Acknowledgment: Ackerman et al. 2003, JGR
Thanks for your attention!

This is our future work!

SGP

TOA/SFC/Atmosphere Radiation Budgets over the ARM SGP Site

(a) Mean = 51.7, Std = 23

(b) Mean = 0.62, Std = 0.054

(c) Mean = 0.16, Std = 0.077

(d) Mean = 0.22, Std = 0.06

Sample number

TWP

TOA/SFC/Atmosphere Radiation Budgets over the ARM TWP Sites

(a) Mean = 40, Std = 22

(b) Mean = 0.57, Std = 0.075

(c) Mean = 0.18, Std = 0.1

(d) Mean = 0.25, Std = 0.11

Sample number
Comparison between observations and model calculations

Comparison between observations and Fu/Liou calculations

(a) SGP

(b) TWP

Sample number

Optical depth

TOA Albedo

Surface Transmissivity

Atmospheric Absorp.
Relationship of $R_{\text{TOA}}$, $T_{\text{sc}}$ and $A_{\text{col}}$ with cloud optical depth

**SGP**

**TOA Albedo**

$Y = 0.089 \ln(X) + 0.285$

$\text{Corr} = 0.82$

**Surface Transmission**

$Y = -0.114 \ln(X) + 0.59$

$\text{Corr} = 0.72$

**Atmospheric Absorption**

$Y = 0.0006X + 0.189$

$\text{Corr} = 0.24$

**TWP**

**TOA Albedo**

$Y = 0.1204 \ln(X) + 0.1412$

$\text{Corr} = 0.90$

**Surface Transmission**

$Y = -0.0913 \ln(X) + 0.5023$

$\text{Corr} = 0.51$

**Atmospheric Absorption**

$Y = -0.0009X + 0.2907$

$\text{Corr} = 0.19$
When $\Delta T_{sfc}$ increases 0.1, $\Delta R_{TOA}$ decreases 0.0435

When $\Delta T_{sfc}$ increases 0.1, $\Delta R_{TOA}$ decreases 0.0201
Monte Carlo Simulations

Given values: \( \text{Tau}=64 \), \( \text{Cloud thickness}=10 \text{ km} \),
\( \text{Solar zenith angle}=5^\circ \), run Monte Carlo simulations at \( \text{wavelength}=0.67 \ \mu\text{m} \)

Results:
When \( \text{Cu size is 10 km} \), the side photon leaking is \( \sim 25\% \)
When \( \text{Cu size is 100 km} \), the side photon leaking is estimated around 5\%.