Recent Activities of the ARM Radiative Processes Working Group

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2008 CERES Science Team Meeting
NASA GISS
New York City
28 October 2008
ARM Program Objectives

- Relate observed radiative energy (spectrally and temporally resolved) to temperature and composition of the atmosphere

- Develop and test parameterizations of the radiative properties and processes of water vapor, clouds, and aerosols, and incorporate these parameterizations in GCMs
Working Groups within ARM

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Overview of the ARM RPWG
Working Groups within ARM

- Radiative Processes
- Aerosol
- Cloud Properties
- Cloud Modeling
Working Groups within ARM

- Radiative Processes
- Aerosol
- Cloud Properties
- Cloud Modeling

- Several “focus groups”
  - CLOWD (clouds with low liquid water path)
  - Vertical velocity
  - BBHRP
  - Several instrument focus groups
RPWG Steering Group

- Bob Ellingson, FSU
- Chuck Long, PNNL
- Sally McFarlane, PNNL
- Andy Vogelmann, BNL

Represent about 40 RPWG members
Correcting IR loss in pyranometers

Alternate methods of correcting for IR loss are investigated for use when collocated pyrgeometer information is not available (left). Study confirms that IR loss is greater during daylight hours than at night (below).


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SW Diffuse Radiation ‘Standard’

- Carefully characterized 4 diffuse pyranometers
- Shade/unshaded calibration performed during Diffuse IOP at SGP site
- Excellent agreement in cloudy scenes, only the ‘8-48’ diverges slightly in clear skies

Michalsky et al, JGR, 2007
Measurements of Small Ice Crystals (D < 50 μm)

Cloud and Aerosol Spectrometer

Cloud Droplet Probe
- Open path
- Neither inlet nor shroud

• The same working principle and look-up table
• Do large crystals shatter on inlet or shroud of CAS?

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McFarquhar et al. (2007, GRL)
Measurements of Small Ice Crystals

(a)

CIP (D>100 μm)

\[ N_{>100} = 0.0 \text{ L}^{-1} \]

\[ 0.0 \text{ L}^{-1} < N_{>100} < 0.1 \text{ L}^{-1} \]

\[ 0.1 \text{ L}^{-1} < N_{>100} < 1.0 \text{ L}^{-1} \]

\[ 1.0 \text{ L}^{-1} < N_{>100} \]

McFarquhar et al. (2007, GRL)
Measurements of Small Ice Crystals

CAS > CDP due to shattering?
Or is CDP artificially low?

CAS/CDP Ratio Increases

CIP (D>100 μm)

\[ N_{>100} = 0.0 \text{ L}^{-1} \]

\[ 0.0 \text{ L}^{-1} < N_{>100} < 0.1 \text{ L}^{-1} \]

\[ 0.1 \text{ L}^{-1} < N_{>100} < 1.0 \text{ L}^{-1} \]

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McFarquhar et al. (2007, GRL)
Measurements of Small Ice Crystals

(a) Points where probes agree in liquid

CIP (D>100 μm)

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McFarquhar et al. (2007, GRL)
\( \frac{N_{\text{CAS}}}{N_{\text{CDP}}} \)

- \(0.98 \pm 0.69\) in liquid clouds
- \(91 \pm 127\) in ice clouds
- \(~100\%\) error in extinction!

McFarquhar et al. (2007, GRL)
Measurements of Small Ice Crystals 
(D < 50 μm)

- Latest results from ISDAC also show sensitivity to shape of the leading edge of the CDP
- Wind tunnel tests being used to evaluate different designs
- Alexei Korolev and colleagues really leading this effort

Cloud Droplet Probe
Improving Cirrus Cloud Characterization with Raman Lidar Measurements at SGP

- Algorithm to derive extinction profiles developed for RL
- Lidar extinction profiles used with MMCR to improve cirrus characterization

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Borg, Revercomb, et al.
Improving Cirrus Cloud Characterization with Raman Lidar Measurements at SGP

- Algorithm to derive extinction profiles developed for RL
- Lidar extinction profiles used with MMCR to improve cirrus characterization

**Conclusions:**
- The MMCR misses significant upper level cirrus; also many cases where lidar is attenuated before top of cirrus.
- Radar does not detect upper portion of cirrus (approximately 20-30% of the total optical depth)

Borg, Revercomb, et al.
Radiative Heating in Underexplored Bands Campaign (RHUBC)

- Emission from far-IR is ~40% of OLR
- Accurate RT modeling needed for computing mid-to-upper tropospheric radiative heating rates
- New observational capabilities recently available
- Evaluate RT models wrt water vapor and ice crystals

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Pls: Turner and Mlawer
Radiative Heating in Underexplored Bands Campaign (RHUBC)

- RHUBC-I, ARM NSA site, Barrow, AK, Feb-Mar 2007
  - min(PWV) $\sim 0.95$ mm (observed)
  - Three 183 GHz radiometers, AERI-ER, TAFTS
- RHUBC-II, Cerro Toco, Chile, Aug-Oct 2009
  - min(PWV) $\sim 0.15$ mm (anticipated)
  - AERI-ER, FIRST, REFIR-PAD, TAFTS, ASTI, Harvard FTS

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Pls: Turner and Mlawer
Radiative Heating in Underexplored Bands Campaign (RHUBC)

Clough and Iacono, JGR, 1995

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Pls: Turner and Mlawer
Clear Sky Far-IR Closure
RHUBC-I Results

Residuals after SHEBA (circa 1999, after Tobin et al.)

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Delamere et al
Clear Sky Far-IR Closure
RHUBC-I Results

Residuals before RHUBC-I (2006)

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Delamere et al
Clear Sky Far-IR Closure
RHUBC-I Results

Residuals after RHUBC-I (2008)

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Delamere et al
Assessing ARM Clear Sky BBHHP with CERES and AIRS

The RRTM calculations of clear sky OLR agree with CERES observations to ~1 W/m² with an uncertainty of ~1 W/m².
* True at SGP over 2.5 years, true globally (with some understood regional exceptions) for study day.
* True using ARM data as input to RRTM, true using AIRS sounding retrievals as input to RRTM.

Clear Sky OLR at ARM SGP site

- ARM data in RRTM
- ARM profiles w/ AIRS surface RRTM
- AIRS retrievals in RRTM

Moy, Tobin, Revercomb, et al.
Assessing ARM Clear Sky BBHRP with CERES and AIRS

The RRTM calculations of clear sky OLR agree with CERES observations to \(-1\) W/m\(^2\) with an uncertainty of \(-1\) W/m\(^2\).

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**Clear Sky OLR at ARM SGP site**

- ARM data in RRTM
- ARM profiles w/ AIRS surface RRTM
- AIRS retrievals in RRTM

**Night time Clear Sky OLR for 16Nov2002, W/m\(^2\)**

- CERES
- AIRS retrievals in RRTM

**CERES - AIRS RRTM, W/m\(^2\)**

Moy, Tobin, Revercomb, et al.
Assessing ARM Clear Sky BBHRP with CERES and AIRS

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<table>
<thead>
<tr>
<th>Spectral Range</th>
<th>Weight [%]</th>
<th>Flux [W/m(^2)]</th>
<th>Percent Residual Definition</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total OLR</td>
<td>100</td>
<td>263</td>
<td>(CERES-AIRS RRTM) / CERES</td>
<td>0.2</td>
</tr>
<tr>
<td>AIRS Spectra</td>
<td>54</td>
<td>144</td>
<td>(Flux(<em>{\text{AIRS,obs}}) - Flux(</em>{\text{AIRS,calc}})) / Flux(_{\text{AIRS,obs}})</td>
<td>0.3</td>
</tr>
<tr>
<td>Far-IR</td>
<td>45</td>
<td>116</td>
<td></td>
<td>(\sim0.3)</td>
</tr>
</tbody>
</table>

Moy et al, JGR, submitted 2008
Broadband Heating Rate Profile (BBHRP) Project

Joint effort of all ARM Working Groups

Key objectives:
- Compute radiative heating rate profiles for all ACRFs based on ARM measurement
- Evaluate new data sources through radiative closure

Core emphasis is the evaluation of cloud retrieval methods:
- SGP - Multiple retrieval approaches evaluated, more to come
- NSA - Shupe-Turner compared to Microbase
- PYE - intercomparison for CLOWD cases underway
- TWP - in pipeline
Reasonable Simple Assumptions Yield Equivalent Results

**Microbase**
MWR LWP
\[ N_d = 200/\text{cm}^3 \]

**‘Sengupta’**
MWR LWP
\[ r_{\text{eff}} = 7.5 \, \mu\text{m} \]

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**SW Diffuse Residuals at Surface at SGP Site**

Mixed-phase clouds

(all cases overcast)

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Mlawer et al.
Effect of clouds on the vertical distribution of SW absorption in the Tropics

All-sky versus clear-sky SW column absorption at Manus and Nauru

% change in layer absorption due to clouds

McFarlane et al, JGR, 2008
CLOWD

- Clouds with low liquid optical depth (LWP < 100 g/m²)
- Occur quite frequently all over the globe
CLOWD

- Clouds with low liquid optical depth (LWP < 100 g/m²)
- Occur quite frequently all over the globe

- Very important radiatively
- Small errors in LWP yield big errors in radiative flux
One Possible Ground-based Solution

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Turner, JGR, 2007
Longwave ICRCCM III: Monte Carlo vs. Independent Pixel Approx.

BOMEX Case
Cu: 0.3 to 1.0 km MSL

\[ F_{\downarrow}(3D \text{ MC}) - F_{\downarrow}(IPA) \]
at the cloud base

Kablick, Gu, Takara and Ellingson
Longwave ICRCCM III: Monte Carlo vs. Independent Pixel Approx.

BOMEX Case
Cu: 0.3 to 1.0 km MSL

LWP

Liquid water path (g/m²)

50 m res.

F↓(3D MC) – F↓(IPA)
at the cloud base

Domain averaged heating rate for 3D MC and IPA

Kablick, Gu, Takara and Ellingson
Longwave ICRCCM III: Monte Carlo vs. Independent Pixel Approx.

BOMEX Case
Cu: 0.3 to 1.0 km MSL

LWP

F↓(3D MC) – F↓(IPA) at the cloud base

Domain averaged heating rate for 3D MC and IPA

Kablick, Gu, Takara, and Ellingson

Overview of the ARM RPWG
Continuous Intercomparison of Radiation Codes (CIRC)

- Sponsored by ARM and endorsed by GEWEX Radiation Panel
- Aims to become the standard for documenting the performance of SW and LW RT codes in Large-Scale Models
- Goal is to have RT codes of IPCC models report performance against the CIRC cases
- Phase I launched summer 2008: http://www.circ-project.org

Differences from previous intercomparisons:
- Observation-tested LBL calculations to used as radiative benchmarks
- Benchmark results are publicly available
- ARM observations provide input (largely select BBHRP cases)
- Flexible structure and longer lifespan than previous intercomparisons

Core team: Oreopoulos, Mlawer, Delamere, Shippert
Improvement in Annual TOA LW Cloud Forcing at ECMWF

Zonal Means

Before RRTM

After RRTM


PIs: Iacono/Mlawer
Improvement in Annual TOA LW Cloud Forcing at ECMWF

Zonal Means

Before RRTM

After RRTM


Pls: Iacono/Mlawer
Conclusions

• ARM’s spectrally resolved and broadband radiance/flux observations have led to important new insights into cloud / aerosol / water vapor / radiation interactions

• ARM radiation observations have led to improvements in the parameterizations used in GCMs and other models

• Significant uncertainties still remain, but new instruments and experiments are addressing these issues