Evaluation of Aerosol-Cloud Interactions in the GISS-E2 GCM Using ARM Observations

Gijs de Boer¹,²,³, Surabi Menon³, Susanna Bauer⁴,⁵, Tami Toto⁶, Andrew Vogelmann⁶, Maureen Cribb⁷

(1) CIRES (2) NOAA (3) Berkeley Lab (4) NASA
(5) The Earth Institute, Columbia University (6) Brookhaven National Laboratory (7) University of Maryland

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Introduction

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**Simulations**

**GISS-2E Simulations:**
- Global simulation from 2002-2009, nudged by winds from MERRA reanalysis
- 30 minute model time step
- $2\degree \times 2.5\degree$ resolution, 40 vertical layers
- GISS-E2 is coupled to MATRIX aerosol microphysics and chemistry ([Bauer et al. 2008 [ACP] and 2010 [ACP]](#))
- First Indirect Effect only (just through activation based on aerosol concentration) ([Menon et al., 2010 [ACP]](#))
- Cloud droplet activation through Köhler theory for stratiform clouds and parameterized for cumulus clouds
- First rounds of simulations have been completed -- more are currently underway.
### Measurement Campaigns

<table>
<thead>
<tr>
<th>Campaign</th>
<th>Location</th>
<th>Dates</th>
<th>Key Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosol IOP</td>
<td>SGP</td>
<td>05/2003</td>
<td>Sfc. CCN, Sfc. CN, LWP, AOD, Aerosol/Cloud Profiles, Sfc. Meteorology</td>
</tr>
<tr>
<td>MASRAD</td>
<td>Pt. Reyes, CA</td>
<td>03-09/2005</td>
<td>Sfc. CCN, LWP, AOD, Cloud OD, Sfc. Meteorology</td>
</tr>
<tr>
<td>MASE</td>
<td>Pt. Reyes, CA</td>
<td>07/2005</td>
<td>All MASRAD + profiles of aerosol and cloud information</td>
</tr>
<tr>
<td>AMF China</td>
<td>Shouxian, China</td>
<td>05-12/2008</td>
<td>Sfc. CCN, Sfc. CN, LWP, AOD, Cloud OD, Sfc. Meteorology</td>
</tr>
<tr>
<td>RACORO</td>
<td>SGP</td>
<td>02-06/2009</td>
<td>Sfc. CCN, Sfc. CN, LWP, AOD, Sfc. Meteorology, profiles of aerosol and cloud information</td>
</tr>
</tbody>
</table>
The Challenge

Taking localized measurements and applying them to the climate scale (see McComiskey and Feingold, 2012 [ACP]).
The Challenge

\[ ACI_\tau = -\left. \frac{\partial \ln r_e}{\partial \ln N_{CCN}} \right|_{LWC} \]

(McComiskey et al., 2009 [JGR])
The Challenge

\[ ACI_T = -\left. \frac{\partial \ln r_e}{\partial \ln N_{CCN}} \right|_{LWC} \]

(McComiskey et al., 2009 [JGR])

The diagram shows the time evolution of \( N_{CCN} \) and \( R_e \) over a 12-hour period, with a trend line indicating the relationship between the two variables. The values 0.043 and 0.243 are noted, possibly representing significant parameters in the context of the study.
The Challenge

\[ ACI_{\tau} = -\frac{\partial \ln r_e}{\partial \ln N_{CCN}} \bigg|_{LWC} \]  

(McComiskey et al., 2009 [JGR])

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**N_{CCN}**

**Re**

**10s 1m 10m**

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The Challenge

\[ ACI_\tau = - \left. \frac{\partial \ln r_e}{\partial \ln N_{CCN}} \right|_{LWC} \]

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The Challenge

\[ ACI_\tau = - \frac{\partial \ln r_e}{\partial \ln N_{CCN}} \right|_{LWC} \]

(McComiskey et al., 2009 [JGR])

\[ N_{CCN} \]

\[ R_e \]
How do we cover the entire grid box at every time step?
• 2° is ~220 km, which means at 10 m/s we would need to average over roughly 6-7 hours.
• This assumes stationary atmosphere.
How do we cover the entire grid box at every time step?
• Alternatively we can look at shorter windows that still capture internal variability (~1 hour)
• This assumes limited sub-grid scale variability.
The Challenge

How do we cover the entire grid box at every time step?
• We can sample a large area rapidly using aircraft.
\[ ACI_\tau = -\left. \frac{\partial \ln r_e}{\partial \ln N_{CCN}} \right|_{LWC} \]

MASRAD

\[ CCN_{sfc} - R_e \]

(\( LWP < 40 \)) \hspace{1cm} (\( 40 \leq LWP < 60 \)) \hspace{1cm} (\( 60 \leq LWP < 80 \))

(\( 80 \leq LWP < 100 \)) \hspace{1cm} (\( 100 \leq LWP < 120 \) \text{ gm}^{-2}) \hspace{1cm} (\( LWP \geq 120 \))

**From 7hr. Avg. COD, LWP, CCN**

**7 hr. Aggregated Process**

\[ 0.58 \quad 0.84 \quad 0.46 \]
\[ 0.22 \quad 0.32 \quad 0.22 \]

\[ 0.23 \quad 0.70 \quad 0.61 \]
\[ 0.27 \quad 0.26 \quad 0.20 \]
\[ \text{CCN}_{\text{sfc}} - R_e \]

(LWP < 40) \hspace{1cm} (40 \leq \text{LWP} < 60) \hspace{1cm} (60 \leq \text{LWP} < 80) \hspace{1cm} (80 \leq \text{LWP} < 100) \hspace{1cm} (100 \leq \text{LWP} < 120 \text{ gm}^{-2}) \hspace{1cm} (\text{LWP} \geq 120)

**MASRAD**

7 hr. Aggregated Process

From 7hr. Avg. COD, LWP, CCN

1 hr. Aggregated Process

From 1hr. Avg. COD, LWP, CCN

0.58 0.84 0.46
0.22 0.32 0.22

0.23 0.70 0.61
0.27 0.26 0.20

0.03 0.02 0.26
0.15 0.21 0.16

0.21 0.31 0.21
0.15 0.17 0.20

(LWP < 40) \hspace{1cm} (40 \leq \text{LWP} < 60) \hspace{1cm} (60 \leq \text{LWP} < 80) \hspace{1cm} (80 \leq \text{LWP} < 100) \hspace{1cm} (100 \leq \text{LWP} < 120 \text{ gm}^{-2}) \hspace{1cm} (\text{LWP} \geq 120)
Droplet Activation

Cumulus, land: \( 174.8 + 1.151 N_a^{0.886} \)
Cumulus, ocean: \( -29.6 + 4.92 N_a^{0.694} \)
Stratiform, land: \( -598 + 298 \log(N_a) \)
Stratiform, ocean: \( -273 + 162 \log(N_a) \)
Cumulus, land: \[174.8 + 1.151 N_a^{0.886}\]
Cumulus, ocean: \[-29.6 + 4.92 N_a^{0.694}\]
Stratiform, land: \[-598 + 298 \log(N_a)\]
Stratiform, ocean: \[-273 + 162 \log(N_a)\]
Effective Radius

\[ R_e = \beta R_v \]

\[ R_e = 0.6 \left( \frac{LWC}{N_{liq}} \right)^{\frac{1}{3}} \]

\[ R_e = 0.65 \left( \frac{LWC}{N_{liq}} \right)^{\frac{1}{3}} \]

\[ R_e = 0.7 \left( \frac{LWC}{N_{liq}} \right)^{\frac{1}{3}} \]
Effective Radius

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\[ R_e = 0.7 \left( \frac{LWC}{N_{liq}} \right)^{\frac{1}{3}} \]
Global Impact

Southern Great Plains

Pt. Reyes

China

Cloud Fraction > 20%

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Summary

• The NASA GISS ModelE2 GCM is being evaluated using cloud and aerosol measurements from several ARM campaigns
• Issues of scale and sampling make a fair evaluation challenging as aggregation of measurements can result in altered (and sometimes non-physical!!) relationships
• These issues must continue to be addressed from the perspectives of observational campaign planning, simulation evaluation and parameterization development
• Scale-aware evaluation results in altered performance of specific parameterizations
• Minor changes to parameterizations may have large impacts on global climate

FUNDING:


Meteorology

Differences between observed and simulated meteorological quantities
Correlations

Simulated and observed correlations between variables of interest

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Correlations

Simulated and observed correlations between variables of interest

GISS ModelE vs. Observations

Aerosol IOP

MASRAD

MASE

AMF China

RACORO

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Effective Radius

Aerosol IOP

\[ R_e = \beta R_v \]

\[ R_e = 0.6 \ (LWC/N)^{1/3} \]

\[ R_e = 0.65 \ (LWC/N)^{1/3} \]

\[ R_e = 0.7 \ (LWC/N)^{1/3} \]

\[ \text{slope} = 0.73 \]

\[ \text{slope} = 0.96 \]

\[ \text{slope} = 0.97 \]

\[ \text{slope} = 0.97 \]

MASE

\[ \text{slope} = 0.73 \]

\[ \text{slope} = 0.97 \]

RACORO

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\[ ACI_T = - \left. \frac{\partial \ln r_e}{\partial \ln N_{CCN}} \right|_{LWC} \]

\[ CCN_{sfc} - R_e \]

(McComiskey et al., 2009 [JGR])

0.03 (LWP<40)
0.02 (40 \leq LWP<60)
0.26 (60 \leq LWP<80)
0.15 (80 \leq LWP<100)
0.21 (100 \leq LWP<120 \text{ gm}^{-2})
0.16 (LWP \geq 120)

0.11 (107 \leq LWP<118)
0.10 (118 \leq LWP<130 \text{ gm}^{-2})
0.14 (130 \leq LWP<143 \text{ gm}^{-2})
Effective Radius

\[ R_e = \frac{\int_{r_1}^{r_2} \pi r^3 n(r) \, dr}{\int_{r_1}^{r_2} \pi r^2 n(r) \, dr} \]
Effective Radius

\[ R_e = \frac{\int_{r_1}^{r_2} \pi r^3 n(r) dr}{\int_{r_1}^{r_2} \pi r^2 n(r) dr} \]

\[ R_e = \alpha \left( \frac{LWC}{N_{liq}} \right)^{\frac{1}{3}} \]

\[ \alpha = 66.83 \]

62.04 70.89

(Bower and Choularton, 1992 [Atmos. Res.])

(Martin et al., 1994 [JAS])
Effective Radius

\[ R_e = \frac{\int_{r_1}^{r_2} \pi r^3 n(r) \, dr}{\int_{r_1}^{r_2} \pi r^2 n(r) \, dr} \]

\[ R_e = \alpha \left( \frac{LWC}{N_{liq}} \right)^{\frac{1}{3}} \]

\[ \alpha = 66.83 \quad 62.04 \quad 70.89 \]

(Bower and Choularton, 1992 [Atmos. Res.])

(Martin et al., 1994 [JAS])

\[ R_v = \left( \frac{3LWC}{4N_{liq} \pi \rho_l} \right)^{\frac{1}{3}} \]

(Liu and Daum, 2002 [Nature])

\[ \beta = \frac{\left( 1 + 2 \left( 1 - 0.7 \exp \left( -0.003N_{liq} \right) \right)^2 \right)^{\frac{2}{3}}}{\left( 1 + 2 \left( 1 - 0.7 \exp \left( -0.003N_{liq} \right) \right)^2 \right)^{\frac{1}{3}}} \]