New Assessment of Aerosol-Cloud Interactions with ORAC-(A)ATSR

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Aerosol Indirect Effect in Warm Cloud

Aerosol indirect effects pose one of the largest sources of uncertainty in climate projections.

- Highlighted Satellite: $-0.85 \text{ [-0.93 to -0.45] } W \text{ m}^{-2}$
- Highlighted GCMs: $-1.38 \text{ [-1.68 to -0.81] } W \text{ m}^{-2}$
- How do we close this gap between models and observations?
- What improvements can we make in satellite derived datasets or in models?

- The recipe for progress lies in improving satellite retrievals of aerosol and cloud and in understanding these physical processes that can improve model parameterizations.
## Data (JJA-2008)

### Satellite

<table>
<thead>
<tr>
<th>Product: ORAC v2.0 (September, 2015)</th>
<th>Parameter</th>
<th>Spatial Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AATSR - Cloud</strong></td>
<td>$R_e$, $\tau_{\text{CLD}}$, Cloud mask, cloud top pressure, cloud top temperature, phase, surface reflectance</td>
<td>1 km</td>
</tr>
<tr>
<td><strong>AATSR - Aerosol V3.02</strong></td>
<td>AOD, Å, aerosol index ($\text{AI}=\text{AOD} \times \text{Å}$), quality flag</td>
<td>10 km</td>
</tr>
</tbody>
</table>

### Model

<table>
<thead>
<tr>
<th>Product</th>
<th>Parameter</th>
<th>Spatial Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ECHAM6</strong></td>
<td>Prognostic variables for cloud and aerosol</td>
<td>1.875°x1.875° (T63)</td>
</tr>
<tr>
<td><strong>HAM2</strong></td>
<td></td>
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</tbody>
</table>
Aerosol-Cloud Collocation Method

Region: California Time: 2008/06/20 22:11

Joint Aerosol-Cloud Cloud-to-aerosol 10 km

Aerosol Optical Depth Retrieval

Distance to nearest aerosol pixel (km)

Nearest Neighbor Aerosol-Cloud Mask (Cloud retrieved within 150 km of nearest aerosol pixel)

0.75% coverage

AOD > 0 QFLAG = 1

43.8% coverage

**Criteria:** low-level (CTP > 500 hPa), liquid cloud over dark surface ($A_{sfc} < 0.15$) within 150 km of aerosol retrieval
Cloud Distance Impact on Aerosol Optical Depth Retrieval

MEAN AOD (no cloud distance threshold)

MEAN AOD (distance from cloud > 15 km)

• AOD is artificially large near cloud edges.

• Use aerosol-cloud pairs in which the aerosol is located at least 15 km from cloud edge and located at least 150 km from the nearest cloud pixel.
Statistical relationships between aerosol and cloud properties

\[
\frac{d \ln (R_e)}{d \ln AI} = -0.1
\]

\[
\frac{d \ln (\tau)}{d \ln AI} = 0.06
\]

\[
\frac{d \ln LWP}{d \ln AI} \approx 0
\]

\[
\frac{d \ln A}{d \ln AI} = 0.02
\]

Data
- Aerosol index: product of aerosol optical depth and angstrom exponent is a proxy for cloud condensation nuclei.
- Aerosol-cloud pairs gridded into 1°×1° regions.
- Each region contains ~40,000 data L2 cloud-aerosol data points.
- Aerosol (ATSR) properties are paired to 1-km cloud pixels through nearest neighbor method.

How do these observations vary with meteorology?
Statistical relationships between aerosol and cloud properties

- Effective Droplet Radius
- Cloud Optical Depth
- Liquid Water Path
- Cloud Albedo

How do these observations compare with the ECHAM6 HAM model?

**ECMWF ERA-INTERIM**

- **DRY**: FTH < 40%
- **Moist**: FTH > 40%
- **Stable**: LTS > 17 K
- **Unstable**: LTS < 17 K
- **Raining**: Re > 14 um
- **Non-raining**: Re < 14 um

Meteorology has only slight impact on aerosol-cloud susceptibilities.
Satellite Model Comparisons

60S° – 60° N (Ocean only)

**ATSR – JJA 2008**

Cloud Droplet Number Concentration

\[ \text{ACI}_N = \frac{d \ln N_d}{d \ln AI} = 0.09 \]

Cloud Water Path

\[ \text{ACI}_L = \frac{d \ln LWP}{d \ln AI} = 0.02 \]

**ECHAM6-HAM2 – JJA 2008**

\[ \frac{d \ln (N_d)}{d \ln (AI)} = 0.22 \pm 0.27 \]

\[ \frac{d \ln (LWP)}{d \ln (AI)} = 0.33 \pm 0.43 \]
Main Points: 1. Model derived LWP & τ susceptibilities are significantly larger than satellite-derived values.
   2. Precipitation state and meteorology slightly influence the strength of the indirect effect.

What impact do these susceptibilities have on the aerosol indirect forcing?
**Aerosol Indirect Radiative Forcing Estimation**

**Low-level cloud fraction**
- Water cloud below 500 hPa (~5.5 km)

**Anthropogenic Aerosol Fraction**
- Grid: 1.25° x 1.25° - 8 times daily
- AOD for: Black Carbon, Dust, Organic Carbon, Sea Salt, Sulphate
- MACC-II estimates the anthropogenic contribution to the aerosol optical depth (Bellouin et al., 2013).

**Annual Solar Insolation**
- Coakley et al. 1979

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**Cloud albedo effect (intrinsic changes to cloud)**

\[
RF = -C_m \frac{dA}{d \ln AI} \Delta \alpha F_{dn}
\]

- **RF**: Radiative forcing
- **C_m**: warm low-level cloud fraction
- **A**: cloud albedo
- **AI**: aerosol index
- **\Delta \alpha**: anthropogenic aerosol fraction
- **F_{dn}**: mean incoming solar insolation

**Method**: Chen et al. (2014)
Aerosol Indirect Radiative Forcing Estimation

AATSR

\[ \Delta F \text{ (global mean} = -0.18 \text{ W/m}^2 \]

ECHAM6-HAM2

\[ \Delta F \text{ (global mean} = -1.2 \text{ W/m}^2 \]

MODIS

Intrinsic indirect effect (W m\(^{-2}\))

-1.2 -0.8 -0.4 0 0.4 0.8 1.2

1\(^{st}\) Indirect Forcing Estimates

- Quaas et al. 2008
- Lebsock et al. 2008
- Chen et al. 2014
- AATSR 1° - This study 1°
- AATSR - This study
- ECHAM6 - This study

0.18 W/m\(^2\)

1.2 W/m\(^2\)

Aerosol Indirect Forcing (W/m\(^2\))
Summary

• Aerosol and cloud products retrieved using ORAC are combined together using a nearest-neighbor approach to limit cloud contamination and to study aerosol-cloud susceptibilities under various meteorological regimes.

• AATSR satellite retrieved susceptibilities are in general agreement (using only 3 months of data) with those derived using A-TRAIN (e.g., MODIS/CERES/CloudSat) data.

• Comparison with ECHAM6 HAM2 simulations reveal significantly larger susceptibilities in the model compared to the satellite derived values.

• Larger model susceptibilities lead to significantly larger aerosol indirect radiative forcing estimates.

• Further testing of the model parameterization schemes are needed in order to determine causes for the large susceptibilities and aerosol indirect radiative forcing estimates in the model.

• Use full extent of the (A)ATSR mission to examine the stability of aerosol-cloud susceptibilities over 17 years of observations.