Assessment of Global Cloud Climatologies

project of GEWEX Radiation Panel / WCRP

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GEWEX cloud assessment group

(S. Ackerman, R. Eastman, A. Evan, A. Heidinger, N. Lamquin, B.
Maddux, P. Minnis, J. Norris, W. B. Rossow, S. Sun-Mack,
P.-H. Wang, S. Warren, D. Winker, D. Wylie...)

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June 2008 GCSS
Satellite radiometers measure:

emitted, reflected, scattered radiation

INVERSION

cloud detection
inverse radiative transfer

cloud properties

GEO (3hrs) + polar
ISCCP
IR, VIS

polar satellites (12/6 hrs)
PATMOS-x
IR, NIR, VIS

HIRS-NOAA, TOVS Path-B
IR Vertical Sounder: CO₂-band

MODIS
AIRS

June 2008
GCSS
Longterm cloud climatologies:

**ISCCP**  *GEWEX cloud dataset*  1983-2006  *(Rossow et al. 1999)*

**PATMOS-x**  *AVHRR*  1981-2006  *(NESDIS/ora; Heidinger)*

**HIRS-NOAA**  *13h30/1h30*  1985-2001  *(Wylie et al. 2005)*

**TOVS Path-B**  *7h30/19h30*  1987-1995  *(Stubenrauch et al. 2006)*


**EOS cloud climatologies (since 2000, 2002):**

**MODIS-ST** (Ackerman et al.)  **MODIS-CE** (Minnis et al.)

**AIRS** (Susskind et al. 2003; Stubenrauch et al. 2008)

**+ A-Train (since 2006):**

**CALIPSO L2 data (V2)** (Winker et al.)  *active lidar*

Evaluation & analysis of cloud properties:
average, regional, seasonal variations, diurnal cycle

**Correlation between cloud properties**
**ISCCP** *(Rossow & Schiffer BAMS, 1999)*

**night:** +75 hPa $p_{\text{clld}}$ bias *(Stubenrauch et al. 1999)*

**uncertainties depend on cloud type:**
- *Stratus ($\tau_{\text{clld}}$>5):* $p_{\text{clld}}$ 25-50 hPa within radiosonde meas., ~ -65 hPa bias; err $T_{\text{clld}}$<1.5 K
- *high clouds ($\tau_{\text{clld}}$>5, with diffuse top):* $p_{\text{clld}}$ 150 hPa (trp)/ 50 hPa (midl) above top
- *isolated thin Cirrus:* difficult to detect
- *thin Cirrus above low clouds:* often identified as midlevel or lowlevel cloud

15% $\tau_{\text{clld}}$ decrease for doubling droplet size

**TOVS Path-B** *(Stubenrauch et al. J. Clim. 2006)*

$p_{\text{clld}}$ uncertainty 25 hPa over ocean, 40 hPa over land *(2nd $\chi^2$ solution)*

$p_{\text{clld}} = \text{mid-cloud} p_{\text{clld},2}$: 600m/ 2 km below cloud-top (low/high clouds) *(LITE, Stubenrauch et al. 2005)*

Sensitivity study for $D_e$ of Ci *(Rädel et al. 2003)*


$p_{\text{clld}}$ 70 hPa above top *(lidar, Wylie & Menzel 1989)*

100 hPa above for transmissive cloud overlying opaque cloud *(Menzel et al. 1992)*

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A-Train: synergy of passive and active instruments

active instruments -> vertical structure of clouds
idar sensitive to very thin cirrus

Cloud/Aerosol Classification (Vertical Feature Mask) (Calipso - Lidar)

Clouds  Aerosols  Stratospheric Clouds  Total Attenuation

NASA Giovanni:
online data visualization & analysis tool
http://disc.sci.gsfc.nasa.gov/techlab/giovanni
Evaluation of AIRS-LMD cloud height with 1 year collocated CALIPSO data

retrieval based on weighted $\chi^2$ method as in TOVS-B  

Stubenrauch et al., JGR 2008

![Graph showing high and low clouds](image)

- high clouds
- low clouds
- thick clouds $\varepsilon_{\text{cld}} > 0.6$
- thin clouds $\varepsilon_{\text{cld}} < 0.6$

Good agreement with CALIPSO midlevel of cloud (highest with $\tau > 0.1$)
slightly broader distributions for optically thinner clouds, but no bias

Sampling: (5 km x 0.07 km) in (13.5 km x 13.5 km)

$\Delta p_{\text{mid}}$(AIRS-CALIPSO) $\pm$ 75 hPa:
- High: 72% 81% (thick); 63% (thin)
- Low: 59% 69% GCSS; 38%

June 2008
Cloud properties depend also on retrieval method!

![Graph showing single layer AIRS-L2 clouds](chart.png)
HCA geographical distributions

January  ISCCP  July

TOVS Path-B

winter strom tracks

ITCZ

UW-HIRS

June 2008
HCA geographical distributions

CALIPSO

PATMOS-x

MODIS-CE

June 2008

GCSS
Average CA

<table>
<thead>
<tr>
<th>CA (%)</th>
<th>glo bal</th>
<th>oce an</th>
<th>la nd</th>
</tr>
</thead>
<tbody>
<tr>
<td>all</td>
<td>66 73 70 75 95 76 66 61 67 61 64 70 74 74 77 95 84 72 66 73 65 69 58 69 61 70 97 63 50 50 59 51 54</td>
<td></td>
<td></td>
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<td>Thick Ci</td>
<td>3 2 1 2</td>
<td>3 2 1 1</td>
<td>3 4 2 5</td>
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<td>Cirrus</td>
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<td>18 27 31 33</td>
<td>21 27 30 29</td>
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<td>HCA/CA</td>
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<td>30 39 42 44 44</td>
<td>35 37 27 18 17</td>
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<tr>
<td>MCA/CA</td>
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<td>26 14 12 14 18 12 17 14 15 29 42</td>
<td>31 25 20 17 25 20 25 20 29 43 48</td>
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<td>LCA/CA</td>
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<td>41 47 42 42 38 42 49 51 59 52 80</td>
<td>29 30 23 34 29 19 29 26 34 27 48</td>
</tr>
</tbody>
</table>

diurnal sampling, time period for ISCCP / TOVS-B: 1% effect; low-level over land: 2% (Stubenrauch et al. 2006)

~ 70 % (±5%) cloud amount: 5-15% more over ocean than over land
PATMOS, MODIS-CE low (land), SAGE CA (200km, clds τ>0.03) 1/3 higher

40% single-layer low clouds: more over ocean than over land; SOBS
40% high clouds: only 3% thick Ci; more over land than over ocean

IR sounders ~ 10% more sensitive to Ci than ISCCP (15% in trps)
SAGE cloud vertical structure in good agreement with IR sounders

HCA/CA: CALIPSO > SAGE, TOVS/HIRS > MODIS-CE > PATMOS > ISCCP<sub>day</sub> > MODIS > ISCCP<sub>IR</sub>

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HCA/CA seasonal cycle

Seasonal cycles similar:

25% in SH tropics to 5% in SH midlatitudes
stronger over land than over ocean
LCA/CA seasonal cycle over ocean

Small seasonal cycle; exception: SH subtropics stratocumulus regions (20%)
SOBS: 18% more LCA and smaller seas. cycle over ocean
   => LCA seas. cycle from satellite modulated by HCA & MCA seas. cycle

CALIPSO
HIRS-NOAA
TOVS-B
ISCCP
PATMOS-x
SOBS
MODIS-ST
MODIS-CE
diurnal cycle of clouds  Cairns, Atm. Res. 1995

ISCCP C2, Complex Empirical Orthogonal Functions,

project. on distorted diurnal harmonics

- **Low clouds over land:** significant diurnal cycle, max early afternoon

- **Low clouds over ocean:** max in early morning

- **High clouds:** max in evening

- **Mid clouds:** max in early morning or late at night (cirrus -> TOVS)
TOVS-B diurnal cycle of high clouds

Stubenrauch et al. J. Climate 2006

NOAA10/12 7h30 AM&PM, NOAA11 2h00 AM&PM (1989-90) NOAA11 4h30 AM&PM (1994-95)

strongest diurnal cycles over land, in tropics (& in midlat summer)

- max Cb (ISCCP) in early evening
- max. thick (large-scale) cirrus & cirrus in evening
- cirrus occurrence continues during night & decreases during day
- max. thin cirrus in early afternoon

June 2008
Seasonal cycle of high $T_{\text{clcd}}$ decreases from polar (15°), midlat (10°) to tropics (5°)
low $T_{\text{clld}}$

CALIPSO: thin high clouds colder than thicker high clouds ($\tau > 0.1$), esp. in tropics
differences: temperature profiles, uncertainties in cloud height determination

$\Rightarrow$ auxiliary data, retrieval method
monthly variability of cloud temperature

TOVS-B
ISCCP: time, time & space
AIRS: av. 1°, pixel O
CALIPSO: pixel, τ>0.1 O

CALIPSO largest variability:
small pixels & good vertical resolution
slightly larger than AIRS & TOVS
ISCCP slightly lower (Std_{time} > Std_{space})
av $T_{cld}$ over 1° reduces Std more than retrieval over 1°?

preliminary
Cirrus effective ice crystal diameter

MODIS-CE (2003-2005)

TOVS: semi-transparent cirrus (0.3 < ε_{cld} < 0.85)
IR method sensitive up to D_eff ≈ 80 μm
MODIS-CE: VIS-NIR method, all cirrus

very preliminary

June 2008
Synergy of retrieved cloud properties & model:
Cirrus radiative flux analysis

TOVS atmospheric profiles
D_e = 10-90 μm; D_e = f(IWP), = f(T)

eliminate multi-layer clouds

cirrus properties

radiative transfer model:

♦ p_cld = p(mid-cloud) ∆p = 100 hPa (∼ 2 km)

♦ Single scattering properties (SSPs) = f(λ, D_e)
for hex. columns, aggregates

♦ choose IWP with ε(IWP,D_e) ≈ ε_{cld}^{IR}
look-up tables ε_{cld}^{IR}(IWP,D_e), depending on θ_φ, ∆ω, SSPs

1500 ScaRaB fluxes ↔ simulated fluxes

α^{SW} (θ_0) = \frac{\pi L^{sw}}{R(θ_0, θ_v, φ, τ, phase, het) E_0 \cos θ_0} GCSS
Coherence between IR IWP and SW albedo

Stubenrauch et al. J. Clim. 2007

best fit to data:
increase of $D_e$ with IWP

columns only fit data at small IWP,
aggregates at larger IWP

effect on TOA SW flux: $\sim 2$ Wm$^{-2}$

June 2008

GCSS
Satellite observations:
- unique possibility to study cloud properties over long period
  -> climatological values of CA, HCA, MCA & LCA
    (also variabilities $T_{\text{cl d}}, \epsilon, \tau, D_{\text{eff}}, WP$) to help evaluate climate models

- 70% ($\pm 5\%$) clouds: ~ 40% high clouds & ~40% single-layer low clouds

- in general geographical cloud structures agree quite well:
  max of high clouds in ITCZ (up to 60%),
  few single-layer midlevel clouds in tropics (5%), most in NH midlat winter (15%)
  low clouds over ocean: seasonal cycle in Stratocumum regions in good agreement

- Seasonal cycle of LCA from SOBS smaller and abs value 20% higher
  -> multilevel clouds

- CALIPSO L2 analysis confirms:
  IR sounders are the passive instruments most sensitive to cirrus
  They only miss 10%/5% subvisible cirrus in tropics/midlat
  (These are caught by limbsounding SAGE & active CALIPSO)

ISCCP miss 15%/10% in tropics/midlat compared to IR sounder, (included in MCA)

PATMOS, MODIS still in validation process, but will miss more thin Ci than TOVS/HIRS, AIRS, IASI
- **Diurnal cycle**: well determined by ISCCP (midlevel clds - cirrus -> TOVS)

- **CALIPSO-CLoudSat** to determine vertical structure of clouds & help to evaluate other cloud properties

- Synergy of different variables & data sets important for evaluation of climate models

- Evaluation continues & WMO report in preparation (next meeting 21-23 July in New York)