Assessment of Global Cloud Properties

Co-chairs:
Bryan Baum,  SSEC, University of Wisconsin, USA

Claudia Stubenrauch,  CNRS/IPSL - Laboratoire de MétéorologieDynamique, France

+ input from participants of GEWEX cloud assessment


9-13 Oct 2006  GEWEX Radiation Panel, Frascati, Italy
2nd Cloud Climatology Assessment Workshop
6-7 July 2006 in Madison, USA: 20 presentations, 50 participants

Longterm cloud climatologies:
ISCCP
TOVS Path-A, TOVS Path-B, UW-HIRS
Surface observations
SAGE
PATMOS-X

EOS cloud climatologies:
MODIS
AIRS
MISR
Polar cloud datasets

Summary and evaluation of cloud properties:
average cloud properties, regional, interannual, seasonal, diurnal variations

Climate monitoring: trends and where they can originate from
**Longterm cloud datasets:**

1) **Imagers** on geostationary (GEO) and polar (LEO) satellites:

**ISCCP** *(Rossow et al., BAMS 1999)*  
1983-2005
- 2 radiances during daylight (IR + VIS)
- every 3 hours, 5 km resolution sampled to 30 km, 2.5°
- \( CA, T_{cld}, \tau_{cld}, p_{cld}, CA \text{ per cloud type} \rightarrow HCA, MCA, LCA; r_e, LWP / IWP \)

2) **Vertical IR sounders (TOVS)** on polar satellites:

**TOVS Path-A** *(Susskind et al., BAMS 1997)*  
reanalysis: 1985-2001
- cld clearing, cld properties: from 5 radiances along \( CO_2 \) absorption band & 2 FOVs
- \( ECA, p_{cld} \text{ weighted by } ECA \)

**TOVS Path-B** *(Stubenrauch et al., J. Clim. 2006)*  
...,1987-1995,...
- cld detection: MSU-HIRS, cld properties: \( \chi^2 - N_e \) for 5 radiances along \( CO_2 \) absorption band
- morning *(NOAA10,12)* + afternoon satellites *(NOAA11)*, 20 km resolution, averaged over 1°
- \( CA, T_{cld}, \epsilon_{cld}, p_{cld}, ECA, CA \text{ and } ECA \text{ per cloud type} \rightarrow HCA, MCA, LCA \)
- \( D_e, IWP \text{ for semi-transparent cirrus} \)

**UW-HIRS** *(Wylie et al., J. Clim. 2005)*  
1985-2001
- cld detection: IR window + \( CO_2 \) screening, cld properties: \( CO_2 \) slicing
- afternoon satellites, nadir ± 18°, correction for satellite drifting, \( CO_2 \) correction
- \( CA, HCA, MCA, LCA \)

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3) Analysis using surface weather reports:

**SOBS ocean** (Hahn & Warren 1999) 1952-1996  
- every 6 to 3 hours, 5°  
- CA, LCA; MCA, HCA (random overlap assumed), cloud base

4) Cloud occurrence from solar occultation:

**SAGE** (Wang et al. 1996, 2001)  
- at sun rise and sun set: 2.5 x 200 km hor. & 1 km vert. resolution  
- extinction 2x10^-4 – 2x10^-2 km^-1: subvisible cirrus, 2x10^-2 km^-1: opaque cloud  
- Occurrence per 1km layer, T_{cld}, p_{cld}

5) Radiometers (AVHRR) on polar satellites:

**PATMOS-X** (NESDIS/ORA; Heidinger)  
Jan, Apr, Jul, Oct 1984-2004  
- 0.63μm, 0.86μm, 3.75μm, 10.8μm and 12μm  
- afternoon satellites + morning satellites (1995-2004), 4 km resolution, averaged over 0.5°  
- CA, T_{cld}, ε_{cld}, p_{cld}, cloud type, HCA, MCA, LCA
**ISCCP** *(Rossow & Schiffer 1999)*

**night:** +75 hPa $p_{\text{clld}}$ bias

**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**

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

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

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

**UW HIRS** *(for Wylie & Menzel 1999)*

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

$p_{\text{clld}}$ 100 hPa above for transmissive cloud overlying opaque cloud *(Menzel et al. 1992)*

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**Average CA**

PATMOS averages by A. Heidinger  
SAGE averages by P.-H. Wang, preliminary

<table>
<thead>
<tr>
<th>ISCCP (84-04)</th>
<th>TOVS-B (87-95)</th>
<th>UW-HIRS (85-01)</th>
<th>PATMOS (JAO04)</th>
<th>SAGE (85-99)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud amounts (%)</td>
<td>glo bal</td>
<td>oce an</td>
<td>land</td>
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</tr>
</tbody>
</table>
| Thick Cirrus | 3 | 2 | 2 | | 3 | 2 | 1 | | 3 | 4 | 5 |\n| Cirrus | 19 | 27 | 31 | | 18 | 27 | 33 | | 21 | 27 | 29 |\n| High-level / CA | \textit{33} | \textit{41} | \textit{44} | \textit{37} | \textit{43} | \textit{30} | \textit{39} | \textit{44} | \textit{44} | \textit{41} | \textit{45} | \textit{49} | \textit{48} | \textit{45} |\n| Mid-level / CA | \textit{27} | \textit{16} | \textit{16} | \textit{18} | \textit{20} | \textit{26} | \textit{14} | \textit{14} | \textit{14} | \textit{19} | \textit{31} | \textit{25} | \textit{17} | \textit{24} | \textit{25} |\n| Low-level / CA | \textit{39} | \textit{42} | \textit{37} | \textit{45} | \textit{36} | \textit{41} | \textit{47} | \textit{42} | \textit{42} | \textit{37} | \textit{29} | \textit{30} | \textit{34} | \textit{28} | \textit{30} |\n
\textit{diurnal sampling, time period for ISCCP / TOVS-B: 1\% effect; low-level over land: 2\% can be more important if using afternoon satellites (D. Wylie, A. Evan)}

\textit{\approx 70 \% (\pm 5\%) cloud amount: 5-12\% more over ocean than over land}

PATMOS CA low, esp. over land; SAGE CA (clds $\tau > 0.03$) 1/3 higher (200 km path)

25-30\% low clouds: 8-15\% more over ocean than over land

\textit{\approx 33\% high clouds: only 3\% thick Ci; more over land than over ocean?}

IR sounders \textit{\~10\% more sensitive to Ci than ISCCP&PATMOS}

SAGE op. cloud vertical structure in good agreement with IR sounders

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### Regional CA

<table>
<thead>
<tr>
<th></th>
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<tr>
<td><strong>Cloud amounts (%)</strong></td>
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<td><strong>NH</strong></td>
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<td>73</td>
<td>75</td>
<td>68</td>
<td>73</td>
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<tr>
<td><strong>mi</strong></td>
<td>63</td>
<td>71</td>
<td>75</td>
<td>63</td>
<td>71</td>
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<td><strong>dl</strong></td>
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<td>65</td>
<td>95</td>
<td>75</td>
<td>65</td>
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<td><strong>SH</strong></td>
<td>74</td>
<td>79</td>
<td>83</td>
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<td><strong>mi</strong></td>
<td>79</td>
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<td>83</td>
<td>76</td>
<td>88</td>
<td>83</td>
<td>76</td>
</tr>
<tr>
<td><strong>Thick Cirrus</strong></td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td><strong>Cirrus</strong></td>
<td>20</td>
<td>25</td>
<td>26</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td><strong>High-level / CA</strong></td>
<td>34</td>
<td>38</td>
<td>44</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td><strong>Mid-level / CA</strong></td>
<td>31</td>
<td>22</td>
<td>17</td>
<td>22</td>
<td>29</td>
</tr>
<tr>
<td><strong>Low-level / CA</strong></td>
<td>38</td>
<td>37</td>
<td>40</td>
<td>43</td>
<td>26</td>
</tr>
<tr>
<td><strong>IR sounders &amp; SAGE more sensitive to Ci: 5%-20% (midlat/tropics)</strong></td>
<td>exception : SAGE (sampling?)</td>
<td>CA: SHm&gt;NHm&gt;trp</td>
<td>8-11% difference</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>HCA: trp&gt;NHm≥SHm</strong></td>
<td>14-36% difference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LCA: SHm&gt;NHm&gt;trp</strong></td>
<td>2-19% difference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>UW-HIRS, SAGE less latitudinal variation than TOVS-B:</strong></td>
<td>NCEP - retrieved atmos. profiles</td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>
## Average + regional cloud properties

<table>
<thead>
<tr>
<th>ISCCP (84-04) TOVS-B (87-95) TOVS-A (85-01)</th>
<th>global</th>
<th>ocean</th>
<th>land</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{cld}}$ (K)</td>
<td>261</td>
<td>265</td>
<td>263</td>
</tr>
<tr>
<td>$p_{\text{cld}}$ (hPa)</td>
<td>577</td>
<td>544</td>
<td>616</td>
</tr>
<tr>
<td>ECA (%)</td>
<td>55</td>
<td>47</td>
<td>40</td>
</tr>
</tbody>
</table>

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<tr>
<th>ISCCP (84-04) TOVS-B (87-95) TOVS-A (85-01)</th>
<th>NH</th>
<th>midl</th>
<th>tropics</th>
<th>SH</th>
<th>midl</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{cld}}$ (K)</td>
<td>257</td>
<td>259</td>
<td>265</td>
<td>259</td>
<td>259</td>
</tr>
<tr>
<td>$p_{\text{cld}}$ (hPa)</td>
<td>552</td>
<td>594</td>
<td>583</td>
<td>544</td>
<td>513</td>
</tr>
<tr>
<td>ECA (%)</td>
<td>58</td>
<td>48</td>
<td>45</td>
<td>50</td>
<td>41</td>
</tr>
</tbody>
</table>

- $T_{\text{cld}}$ within 2K / 5K for ocean / land
- Clouds lower + thicker over ocean than over land: 135/85/2 hPa + 13/3/6 %
- $P_{\text{cld}}$: ECA: $\text{trp}<\text{NHm}<\text{SHm}$: 8/80/150 hPa 70/55/20 hPa + 8/7/13 % 16/6/14 %
- **TOVS-A much smaller $p_{\text{cld}}$ and ECA in tropics than TOVS-B!**

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EOS Dataset Comparisons:
CA, $p_{cld}$ : MOD08 *(MODIS Team) – CERES inversion
  
  *P. Minnis*

\[ p_{cld} (\text{MOD08}) > p_{cld} (\text{CERES}) \]

Tropics: $\Delta \sim 75$ mb

\[ \text{tropics (15°N-15°S)} \]
HCA  27-31%  (T-A)
MCA   5%
LCA  22-26%

*Analysis by P. Yang*

much smaller HCA than TOVS!

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MOD08–AIRS (LMD retrieval) – ISCCP – TOVS B

CA (MOD08) > CA (ISCCP)  ECA (AIRS) ~ ECA (TOVS)

\[ P_{\text{cld}}(\text{MOD08}) > P_{\text{cld}}(\text{ISCCP}) > P_{\text{cld}}(\text{AIRS}) \sim P_{\text{cld}}(\text{TOVS}) \]

AIRS cloud retrieval preliminary

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CA, $p_{cl_d}$: MOD08 – AIRS (AIRS team)

G. Molnar, J. Susskind

$p_{cl_d} (MOD08) \geq p_{cl_d} (AIRS)$,
but intra-seasonal variations similar (corr. coef. 0.84)
**CA seasonal cycle:** NH–SH subtropics, midlatitudes, polar regions

Seasonal (and diurnal cycles) stronger over land than over ocean, strongest in subtropics
Seasonal cycles similar, exception: SH polar land

TOVS/HIRS absolute values 5-12% larger than ISCCP
SOBS close to ISCCP, better agreement over land than over ocean (prob. statistics)
HCA seasonal cycles in latitude bands

SOBS averages by R. Eastman, S. Warren

HCA seasonal cycle: 7-15%, 10-27%, 18-45% over land

ISCCP underestimates seasonal cycle of HCA by up to 20%

UW-HIRS slightly smaller seasonal cycle than TOVS-B

SOBS HCA seasonal cycle modulated by clouds underneath: HCA min in NH midlat. when LCA max

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LCA seasonal cycles in latitude bands

**SOBS averages by R. Eastman, S. Warren**

Seasonal cycle LCA: 5%, 5-7%, 8-12% over ocean
UW-HIRS slightly smaller seasonal cycle
SOBS: 18% more LCA and smaller seas. cycle over ocean

=> LCA seas. cycle from satellite modulated by HCA & MCA seas. cycle

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CA seasonal cycle over selected regions

TOVS-B did not pick up seas. cycle of low clouds (not detected), improved detection does

Very good agreement with SOBS

regional differences can be larger
reasons have still to be explored

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Polar Datasets: Taneil Uttal, Xuanji Wang, Jeff Key, Axel Schweiger

APPX 1998-2000
CERES TEAM 2000-2003
Radar data 1998-2004
TOVS data 1997-2006
PATMOSX 1998 to 2004

Barrow

Alert

Eureka

Tiksi

Ny-Alesund

Abisko

Sammultunturi

cloud optical depth more important than CA in defining radiative impact of clouds on the surface

subregions with significant differences in cloud properties

=> no latitudinal averaging
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 and in summer

- max. thin cirrus in early afternoon
- max. cirrus and thick cirrus in evening
- cirrus occurrence continues during night and decreases during day
  TOVS-B extends ISCCP during night

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Global CA anomalies

global CLA within ±2.5%
UW-HIRS: more or less stable
ISCCP: ~5% decrease from 1987 to 2000 related to increasing nb of GEO satellites?

Correlation between global and regional anomaly:
1. calculate anomaly maps per month and per year: \( A(i,j,m,y) \)
2. calculate global anomaly per month and per year: \( AG(m,y) \)
3. determine map of (linear) correlation coefficients: \( r(i,j) \)

similar results by J. Norris, A. Evan
Study on causes for spurious CA changes

W. B. Rossow

- Radiance Calibration effects: <0.5% on ISCCP CA; <1% on CA per type
- Satellite Viewing Geometry effect: 1%
  **BUT**: pattern of $\theta_v$ variations does not match CA changes
- Changes in Cloud Property Distribution: decreasing $\tau$ of low clouds -> below detection

  *(Tsilioudis et al. 1992: $\tau$ decreases with T)*

- Changes in Sampling Distribution & Coverage: check for other datasets

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**HCA Comparison with EOS Climatologies (37°N-37°S) 1998-2003**

*P. Minnis*

**Land**
- ISCCP HCA trend consistent with recent dataset
- Decent correlation with humidity

**Ocean**
- ISCCP HCA trend different
- Only weak correlation with NCEP RH
  - Decreasing humidity suggests decrease in HCA
- SAGE analysis: response includes thinner clouds in tropics & drop in mean height rather than simple HCA decrease
  - Cause of UTH drop? Is it real?

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**I** - ISCCP
**T** - Terra CERES
**A** - Aqua CERES
**V** - VIRS

Time [months since 12/97]

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*Wang et al., J. Clim., submitted*
Satellite observations:
- unique possibility to study cloud properties over long period

Intercomparisons:
- **average cloud properties**: in general good agreement
  - 70% (±5%) clouds: 25-30% low clouds,
  - 30% high clouds (+ ~15% subvisible Ci), stable within 2%
- **seasonal cycle**: CA good agreement (except SH polar land)
  - ISCCP HCA cycle in tropics underestimated
  - SOBS LCA cycle over ocean smaller; absolute value 18% larger
- **regional differences** (latitudinal, ocean/land):
  linked to cirrus sensitivity: IR sounders & SAGE: HCA +4% (midl) to +20 % (trp)
  atmos. profiles: TOVS B less HCA in SH compared to SAGE & HIRS
- **diurnal cycle**: TOVS-B extends ISCCP during night
- EOS datasets still in validation process
- **Trend analysis**: careful of satellite drifts, calibration etc.
  -many processes important,
  - synergy of different variables important!
- **Intercomparison continues** (esp. polar) & **WMO report in preparation**

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