Global Cloud Climatologies
from satellite-based InfraRed Sounders
(TOVS, AIRS, IASI)
+
AIRS-CALIPSO-CloudSat Synergy

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Cloud properties from space:

1) multi-spectral cloud detection 2) cloud property retrieval

**Passive remote sensing (>1980)**
- info on uppermost cloud layer (or mix)
- good spatial coverage
  - CA, p/z, T, τ_{VIS} / ε_{IR}
  - horizontal extension
  - bulk microphysical properties

**Active (A-Train, ≥2006)**
- info on all cloud layers
- sparse sampling (track/1000km)
  - z, τ_{VIS}
  - vertical extension, layering
  - microphys. prop. profiles

**IR sounders:**
- good spectral resolution -> esp. reliable Ci properties (day & night)
- atmospheric T, H_2O profiles (RH) + clouds + aerosols

**A-Train synergy (AIRS-CALIPSO-CloudSat):**
- choose variables & thresholds for AIRS cloud detection
- AIRS cloud height evaluation -> retrieval transfer to IASI
IR Sounders: TOVS, AIRS, IASI
>1980 NOAA, ≥2002 NASA, ≥2006 CNES

$I_m(\lambda_l) \quad \text{along } H_2O, CO_2 \text{ absorption bands, good spectral resolution}$

Inversion

3I - TOVS
(Scott et al. 1999)

AIRS-L2
(Susskind et al. 2003)

- atmospheric temperature & water vapor profiles, $T_{surf}$

\[
\text{min weighted } \chi^2_w(p_k)
\]
\[
\epsilon(p_k) = \sum_{i=1}^{N} \frac{I_m(\lambda_l) - I_{clr}(\lambda_l)}{I_{clr}(p_k, \lambda_l) - I_{clr}(\lambda_l)}
\]

$\epsilon_{clrd}, p_{clrd}$

\{ cirrus emissivities (8 - 12 µm) \}

\{ Simulated LUT \}

\{ De, IWP \}

+ atm. transmissivities from TIGR

Thermodynamic Initial Guess Retrieval

$I_{clr}(\lambda_l), I_{clrd}(p_k, \lambda_l) \leftarrow 4A\text{ radiative transfer } \leftarrow \text{ radiosondes}$

(http://www.noveltis.fr/4AOP)

no assumption on microphysics


$4A\text{-DISORT + SSP of ice crystals}$

(CIRAMOSA, Rädel et al. 2003, Stubenrauch et al. 2004)

Mitchell 1996; Baran 2003
Comparison with other data sets:

Geographical distributions & seasonal cycles similar

HCA depends on sensitivity to thin cirrus
CALIPSO > TOVS/AIRS > MODIS/PATMOS > ISCCP > POLDER/MISR
Zonal averages of HCA & LCA: L2 analysis

latitudinal behavior similar;
HCA: CALIPSO > TOVS ~ AIRS ~ IASI > ISCCP
LCA: differences in polar regions

CALIPSO incl subvis Ci excl subvis Ci
ISCCP day
TOVS-B day + night
AIRS-LMD IASI-LMD preliminary
zonal $T_{\text{cld}}$ distributions: \textit{GEWEX CA data base}

CALIPSO: including subvis Ci & $T$(cld top), pass remote sensing: $T$(rad. cld height), in case of multi-layer: ISCCP(VIS+IR) $\rightarrow$ mix

$T_{\text{cld}}$ distributions reflect increase of vert extent of troposphere from poles to tropics

\textbf{CALIPSO+GEO PROF} (subvis Ci excluded):

\begin{itemize}
  \item multilayer
  \item single layer
\end{itemize}

\textit{more on poster #167}
1) Evaluation of AIRS cloud height
2) Vertical extent (Δz) of high opaque clouds / Ci / thin Ci
3) Vertical insight into high opaque clouds / Ci / thin Ci
4) Cloud height relative to tropopause
5) Ci microphysics for single & multi-layer
6) Multiple scattering correction of Ci lidar signal
1) Evaluation of AIRS cloud height with CALIPSO

(highest cloud, detected at ≤5km)

good agreement with CALIPSO cld midlevel
(or pos. of max. backscatter)
properties also depend on retrieval method

Stubenrauch et al. JGR 2008, ACP 2010
in agreement with Kahn et al. 2008
1) Evaluation of AIRS cloud height with CALIPSO

(highest cloud, detected at ≤5km)

good agreement with CALIPSO cld midlevel
(or pos. of max. backscatter)
properties also depend on retrieval method
2) Vertical extent ($\Delta z$) of high opaque clouds / Ci / thin Ci

**AIRS:** cloud type

**CALIPSO:** ‘apparent’ geometrical cloud thickness

**CloudSat:** real geometrical cloud thickness

Winker / Mace et al. 2009

Good quality of AIRS cloud type identification

- $\Delta z$(thin Ci) < $\Delta z$(Ci) < $\Delta z$(hgh op)
- real $\Delta z$ much larger than apparent $\Delta z$ for high opaque cloud
- good quality of AIRS cloud type identification
A-Train: synergy of passive & active instruments

3) Vertical insight into high opaque clouds / Ci / thin Ci

AIRS: cloud type

CALIPSO: ‘apparent’ geometrical cloud thickness, position of max. backscatter

*position of max backscatter depends on ‘apparent’ Δz & can reach 2 km below cloud top, even for high opaque clouds

rel. position less dependent, 1/3 – 1/2 below top (thin Ci)

‘radiative’ height lies about 1/2 below top, for all cloud types
4) Cloud height relative to tropopause

**distance to tropopause from CALIPSO**

**Stubenrauch et al. ACP, 2010**

**Tropics: only the very thickest opaque clouds (& surrounding anvils) penetrate stratosphere**

*Rossow & Pearl 2007: larger, organized, convective systems penetrate*
5) AIRS bulk microphysical properties of semi-transparent Ci

based on spectral difference of cirrus emissivity  A. Guignard, PhD

single / multi layer cirrus (detected by CALIPSO), tropics, 2 year averages

\[ 0.3 < \varepsilon_{\text{cld}} < 0.5 \quad 0.5 < \varepsilon_{\text{cld}} < 0.7 \quad 0.7 < \varepsilon_{\text{cld}} < 0.85 \]

- \( \text{De (\mu m)} \)
- IWP (g/m²)

- De & IWP increase with \( \varepsilon_{\text{cld}} \)
- no significant difference between single / multilayer Ci in tropics
- optically thicker Ci seem to include more aggregates
6) Multiple scattering correction of cirrus lidar signal

\[ \alpha = 2 - 2.5 \]

\[ \eta = 0.47 - 0.37 \quad \text{CALIPSO L2: } \eta = 0.6 \]

slightly more multiple scattering for opt. thicker cirrus

Lamquin et al. JGR, 2008

\[ \epsilon_{\text{IR}} = 1 - \exp \left( -\frac{\tau_{\text{VIS}}}{\alpha} \right), \quad \alpha \equiv 2 - 2.5 \]

\( \alpha \) increasing with decreasing crystal size (Sassen & Comstock 2001)

\( D_e \) increases with \( T_{\text{cld}} \) (Stubenrauch et al. 2004)

\[ \Rightarrow \quad \alpha = f(T_{\text{cld}}) \]

\[ \Rightarrow \quad \tau_{\text{VIS}} = -\alpha \ln(1 - \epsilon_{\text{IR}}) \]
participate in GEWEX Cloud Assessment (poster #167)

- IR sounders passive instruments most sensitive to cirrus
globally 5-15% more Ci than ISCCP VIS+IR; however, ISCCP better diurnal sampling

- $p_{cld}$ corresponds to midlevel of apparent cloud depth
  (slightly below height of max backscatter)

- uncertainty estimation from $\chi^2$: $p_{cld}$: 40 – 50 hPa

A-Train: unique possibility to evaluate IR sounder retrieval &
to give insight into vertical structure of different cloud types

Synergy of variables & data sets extremely important
This work was supported by CNRS and CNES.

We also thank all Science teams as well as the engineers and space agencies for their efforts and cooperation in providing the data!