Clouds from Satellite Observations: GEWEX Cloud Assessment
IR Sounder – Lidar – Radar Synergy

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Challenges to retrieve cloud properties

GEWEX Cloud Assessment & Database (2005-2012):
first coordinated intercomparison of L3 cloud products of 12 global ‘state of the art’ datasets
database facilitates assessments, climate studies & model evaluation

What do we know about clouds from satellite retrievals?

Atmospheric properties from IR Sounders
upper tropospheric humidity – cirrus, horizontal extent of cloud systems

Synergy passive - active remote sensing:
How to get a more complete cloud picture?
How to use satellite cloud data for climate model evaluation?
Clouds are extended objects of many very small liquid / ice particles

**Cumulus** (low fair weather clouds)

**Cirrus** (high ice clouds)

Satellite radiometers

↓

Bulk quantities

At spatial & temporal scales to resolve weather & climate variability

**Cumulonimbus** (vertically extended)

Cloud structures over Amazonia

**Cumulus** (low fair weather clouds)
Cloud properties from space

- **lidar – radar**: *vertical structure of clouds*
- **IR-NIR-VIS Radiometers, IR Sounders**, **multi-angle VIS-SWIR Radiometers**
  - exploiting different parts of EM spectrum

- Information on uppermost cloud layers
- ‘Radiative’ cloud height
- Perception of cloud scenes depends on instrument

=> Cloud property accuracy scene dependent:

- Most difficult scenes: thin Ci overlying low clouds, low contrast with surface (thin Ci, low cld, polar regions)

**Thin Ci over low clouds**: Interpretation of Cloud height

- **lidar, CO₂ sounding, IR spectrum**
- **IR-VIS imagers**, **ISCCP**
- **solar spectrum**

≤20% of all cloudy scenes (CALIPSO)

How does this affect climatic averages & distributions?
global gridded L3 data (1° lat x 1° long) : monthly averages, variability, Probability Density Functions

- **ISCCP** GEWEX cloud dataset 1984-2007 (Rossow and Schiffer 1999)
- **MODIS-CERES** 2001-2009 (Minnis et al. 2011)
- **TOVS Path-B** 1987-1994 (Stubenrauch et al. 1999, 2006; Rädel et al. 2003)
- **AIRS-LMD** 2003-2009 (Stubenrauch et al. 2010; Guignard et al. 2012)
- **HIRS-NOAA** 1982-2008 (Wylie et al. 2005)

**relatively new retrieval versions:**

- **ATSR-GRAPE** 2003-2009 (Sayer et al. 2011)

**complementary cloud information:**

- **CALIPSO-ScienceTeam** 2007-2008 (Winker et al. 2009)
- **CALIPSO-GOCCP** 2007-2008 (Chepfer et al. 2010)
- **MISR** 2001-2009 (DiGirolamo et al. 2010)
- **POLDER** 2006-2008 (Parol et al. 2004; Ferlay et al. 2010)
GEWEX Cloud Assessment Web-site

Interprétation des propriétés nuageuses

- General sections: description, meetings, publications, etc
- "Datasets": provides individual descriptions
- "Database": contains links to zipped netCDF files, grouped per variable, instrument and year, ftp-accessed.

Updated Datasets will be posted (ISCCP, CALIPSO, MODIS, AIRS-LMD)

http://climserv.ipsl.polytechnique.fr/gewexca
**GEWEX CA L2 -> L3 Aggregation**

at specific local time

**What are the properties of the cloud when present within 1°x1°?**

*discussed & agreed upon at workshop in 2010*

- **first average over space (1° x 1°) & then over time (month)**
- at higher latitudes with orbit overlaps, choose measurements closest to local observation time (keep data with smallest viewing angle)

**Data processing by teams** (Fortran program was provided)

- cloud properties do not depend on instantaneous measurement & cloud grid coverage
- appropriate way to compare data of different spatial resolution and to compare to climate models

**Differences compared to monthly averaging over pixels:** *ex AIRS-LMD*

- difference in CA small, but larger (& systematic) for other properties, depending on cloud scenes
Cloud Amount: 0.68 ± 0.03

How many of detected clouds are high, midlevel, and low clouds?

CAHR depends on sensitivity to thin Ci (30% spread)

42% are high clouds (COD>0.1)

-> 20% with COD>2 (MISR, POLDER)

thin Ci over low cloud misidentified as midlevel clouds by ISCCP, ATSR, POLDER

42% are single-layer low clouds,

60% are low clouds (MISR, CALIPSO, surface observer)

0.10-0.15 larger over ocean than over land

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Even if absolute values depend on Ci sensitivity, geographical cloud distributions agree

InterTropical Convergence Zone:
high convection + cirrus anvils

winter storm tracks

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uncertainty on regional variability:

max-min[CAHR-<CAHR>] 16 clim
Height stratification

Retrieval of $T$, $p$ or $z$:
- $T$: ISCCP, PATMOSx, MODIS-CE
- $p$: AIRS, HIRS, MODIS-ST, POLDER, ATSR
- $z$: CALIPSO, MISR

& atmospheric profiles: $T$-$p$, $p$-$T$, $z$-$T$
retrieved (Op. TOVS, TOVS Path-B, AIRS)
reanalysis (NCEP), forecast (GMAO, ECMWF)

bimodal $T/p$ distributions in tropics
CALIPSO -> cloud top + sensitive to subvis Ci
=> should point to coldest CT
- ISCCP peak at smaller CT corresponds to very thin Ci
  which has been put to the tropopause
- 5 K spread for low-level clouds
- 15 K spread for high-level clouds:
  diffusive cloud tops
Climate monitoring with IR Sounders

TOVS, ATOVS, AIRS, CrIS, IASI (1,2,3), IASI-NG


local observation time: 7:30 AM/PM, 1:30 AM/PM, 9:30 AM/PM

- long time series -> climate studies
- increasing spectral resolution:
  -> increasing vertical resolution (H₂O in UT)
- retrieval day & night
- RH_{ice}, aerosols & cirrus

A-Train synergy (AIRS-CALIPSO-CloudSat):
- unique opportunity for global retrieval method validation
- vertical structure of cloud types

AIRS-IASI synergy: diurnal cycle of high clouds

TOVS Path-B & AIRS-LMD L3 cloud data available at http://climserv.ipsl.polytechnique.fr/gewexca
AIRS-LMD L2 cloud data distributed by ICARE: http://www.icare.univ-lille1.fr/
Cloud property retrieval: AIRS -> IASI

**build modular code: LMD-CRIS** (Cloud Retrieval from Infrared Sounders)  
A. Feofilov

- used for AIRS, IASI (at LMD) & for TOVS/ATOVS (CM-SAF), etc
- makes it also easy to include different ancillary data!
- improvement of computation of radiative transfer for layers close to ground
- improved clear sky radiances

**channel selection:**

\[ p_{\text{cld}}/T_{\text{cld}}/\epsilon_{\text{cld}} \] Retrieval

\[ \text{CO}_2 \] channels closest to AIRS in \( T_B \)

‘a posteriori’ cloud detection & Cirrus microphysics

**ancillary data:**

- atmospheric \( T \) & \( H_2O \) profiles, \( T_{\text{surf}}, p_{\text{surf}} \), ice/snow

*instantaneous L2 if good quality, else 1° x 1° averages* (interpolated in time, longitude)

*or ERA Interim*

\( T \) & \( H_2O \) profiles used to determine most similar TIGR profile

- spectral weights, spectral transmissivities of IASI channels computed for TIGR profiles

\( T \) profile & \( T_{\text{surf}} \) used for radiative transfer

- spectral surface emissivities (monthly climatologies over land):

  AIRS-LMD, else MODIS (interpolation of channels), IASI-LERMA

- tropopause determined from atm. profiles *(Reichler et al. 2003)*
Cloud Retrieval: choice of ancillary data

- AIRS- IASI: using similar ancillary data reduces biases (diurnal cycle = small signal)
- reanalysis of AIRS, IASI (LMD) & TOVS / ATOVS (cooperation CM-SAF)

LMD cloud retrieval based on spectral coherence of cloud emissivities estimated from radiances along CO$_2$ absorption band (4A radiative transfer, TIGR data base) (Stubenrauch et al. 1999)

clear sky radiance = $f(T_{surf}, \epsilon_{surf}, \tau(\lambda, atm, \theta_v))$

NASA AIRS L2 (V6) & NOAA IASI L2, GEWEX (NOAA HIRS-NN, ISCCP $T_{surf}$), ERA-Interim

Impact on CP distributions:

CP distributions similar for AIRS L2 / ERA, slightly less high clouds & more low clouds for GEWEX (GEWEX warmer $T_{surf}$ in afternoon)
Occurrence of high clouds \((p_{\text{cld}} < 440 \text{ hPa})\)

CAH depends on sensitivity to thin Ci
active lidar \(>\) IR sounders \(>\) VIS-NIR-IR imagers

40-45% of all clouds are high clouds \((\text{COD}>0.1)\)

\[
\text{CAH}(\text{AIRS}) \approx 0.33-0.35 \text{ (glob)}, \ 0.45-0.50 \text{ (trp)}
\]

(depending on atmospheric & surf ancillary data)

➢ geographical distributions similar

➢ land – ocean : +10%
**Diurnal cycle of high-level clouds**

**ISCCP** (3-hourly): *max of high clouds in evening* (significant over tropical land) *(Cairns Atm. Res. 1995)*

**TOVS** (2 sat, time drift): *Cirrus increase during afternoon & persist during night, thickening* *(Stubenrauch et al. J. Climate 2006)*

...on average smaller than latitudinal & seasonal variations, often localized

=> when using 2 different instruments (AIRS-IASI synergy), use same ancillary data (ERA-Interim)

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**ITCZ**: high-level clouds develop during the evening & persist during night *(in agreement with TOVS)*

**NH winter land**: cirrus develop in the morning / afternoon
Detection of ice supersaturation (ISS)

**ISS important for understanding Ci formation & for detecting regions where persistent aviation contrails may develop**

IR Sounders retrieve water vapour within atmospheric layers of km’s

=> underestimation of \( R_{\text{H, ice}} \) : AIRS peak for cirrus at 70% (instead of 100%)

*improved spectral resolution*: IASI peak for cirrus at 80-85%

ISS often occurs in vertical layers < 500 m
**T.2.15  A-Train Synergy: variables & datasets**

**AIRS-LMD**: \( p, \varepsilon \) of uppermost cloud \( \rightarrow \) cloud types
De, IWP of semi-transparent cirrus, aggregates/columns

**CALIPSO V3 5km** *(Winker et al. 2012)*: sub-visible Ci, cloud top, apparent base, thermodynamical phase.

**Lidar-Radar GEOPROF V4** *(Mace et al. 2009)*: number of cloud layers, cloud top & base height

**liDARradDAR** *(Delanoë and Hogan 2010)*: OE retrieval profiles of thermodynamical phase, IWC, De.
### IWC profile classes & dependency on IWP

Clouds with same IWP may have different IWC / De profiles

-> influence on radiation?

Is it possible to give a profile probability in dependence of cloud properties or atmospheric properties?

![Diagram](image)

#### AIRS-GEOPROF-liDARraDAR data

(Delanoë & Hogan 2010)

<table>
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<th>IWP (g/m²)</th>
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<th>trapecia</th>
<th>increas</th>
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<td>33%</td>
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</tr>
</tbody>
</table>

**Const & trapecia ≈ 80% of all profiles**

Lower triangle increases with IWP from 10 to 26%

Upper triangle only for IWP < 30 g/m²

Independent of location / season!

Strong vertical winds only affect lower triangles

Study radiative effects with RRTM

Feofilov et al., in prep.
Comparison of De with other datasets

- DE distributions from passive remote sensing similar, differences due to retrieval subsampling

- AIRS DE centered around ~55 μm, retrieval sensitive up to max 90 μm
- DARDAR DE increases from top to base: 56 / 60 / 67 μm
- Radar less sensitive to De < 30μm
Horizontal extent of high cloud systems: TOVS

~50% of Ci originate from convection
(Luo & Rossow, J. Climate 2004)

determine adjacent grids containing
Cb (ε>0.95), Ci (0.95>ε>0.5)
or thin Ci (0.5>ε>0.3) (Rädel 2004)

anvil size increases continuously with decreasing $T_{min}$
ISCCP Machado & Rossow 1993
but also depends on dynamics; Chen et al. 1997 Belhaj et al.2007

Evolution of $D_e$ during life cycle of convective system

➤$D_e$ increases during life cycle of system (esp land)
• Only mature clouds (Cb fraction 0.08-0.3) were selected
• tropics: horizontal extent strongly depends on $T_{\text{min}}$
• midlatitudes: the dependence is weaker

•Next step: include vertical information of CALIPSO-CloudSat
Conclusions on GEWEX Cloud Assessment

- Satellite instruments: unique possibility to study cloud properties over long period

- GEWEX Cloud Assessment:
  - first coordinated intercomparison of L3 cloud products of 12 global ‘state of the art’ datasets
  - common database facilitates further assessments, climate studies & model evaluation

- geographical distributions, latitudinal & seasonal variations agree well

- accuracy is scene & instrument dependent (interpretation of cloud height):
  - differences can be mostly understood by different performance to identify Ci
  - (problems in some retrieval methods, misidentification water-ice clouds)
  - IR Sounders passive instruments most sensitive to Ci

- histograms are important (esp. for optical and microphysical properties)

- cloud products adequate for model evaluation & monitoring regional variability

- longterm datasets -> robust statistics & explore rare events

- global monitoring of cloud properties very difficult

- even if instantaneous cloud properties are not very accurate, synergy of different variables provides invaluable potential for improving understanding of clouds

next step: GEWEX integrated dataset
Conclusions on Clouds from IR Sounders

- IR sounders sensitive to cirrus (also for multi-layered cloud systems, day & night)
  -> climate data records AIRS, IASI, TOVS/ATOVS

- Diurnal cycle analysis from different instruments requires common ancillary data

- 40-45% of all clouds are high-level clouds (→ radiative effects)

\[ \text{RH}_{\text{ice}} \text{ determined over coarse atmospheric layers} \]

- \[ \text{RH}_{\text{ice}} \text{ of Ci peaks at } 70\% \text{ for AIRS} / 85\% \text{ for IASI (instead of } 100\% \text{ in-situ)} \]
  -> probability of ice supersaturation occurrence

- Ci occurrence increases with ISS occurrence

- NOAA IASI atmospheric profiles only valid in tropics so far

- Cloud classes show distinct vertical cloud extent (increases with CP & CEM)

- Most ice clouds can be approximated by constant / trapezoid IWC profile

- IWC increase from top to base for clouds with large IWP

Cloud Systems:
- Organisation of cloud structure from clustering promising
Outlook

relate properties of cloud systems (vert, hor extent, microphys) to state of atmosphere using A-Train synergy (AIRS-MODIS-CALIPSO-IIR-CloudSat) & reanalyses to build cloud system parameters for a better understanding of development of convection

-> GEWEX PROES (Process Evaluation Study) project

explore ISS, dust loading & Cirrus (from synergetic climate database) by linking to atmospheric flow (Lagrangian studies) for a better understanding of development of cirrus

-> CISSA (Cirrus,IceSuperSaturation & Aerosols) project

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Pre-proposal ANR