# Global Cloud Climatologies from satellite-based InfraRed Sounders

# (TOVS, AIRS & IASI)

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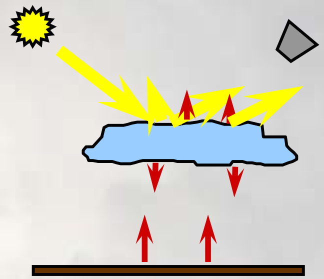
LMD/CNRS

# Cloud properties from space:



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

**Passive remote sensing (>1980)**

info on **highest cloud layer**

good spatial coverage

- **CA** (*tot, high, midlevel, low*)
- **p/z, T, $\tau_{VIS}$ / $\varepsilon_{IR}$**
- **horizontal extension**
- **bulk microphysical properties**

**Active (A-Train, >2002)**

info on **all cloud layers**

sampling every 1000km

- **z, $\tau_{VIS}$**
- **vertical extension**
- **cloud layering**
- **microphys. prop. profiles**

***IR sounders :***

- ***good spectral resolution ->*** *esp.* ***reliable Ci properties*** ***(day & night)***
- ***atmospheric T, $H_20$ profiles (RH) + clouds + aerosols***

***A-Train synergy*** (AIRS-CALIPSO-CloudSat) **:**

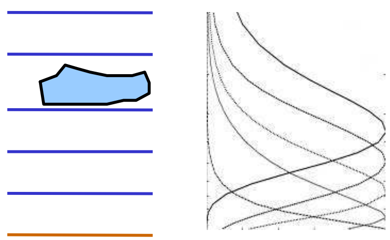
- ***choose variables & thresholds for AIRS cloud detection***
- ***AIRS cloud height evaluation -> retrieval transfer to IASI***

***TOVS-LITE*** ***(Stubenrauch et al. JGR 2005)***

# IR Sounders: TOVS, AIRS, IASI

$>$1980 NOAA, $\geq$2002 NASA, $\geq$2006 CNES

$I_m(\lambda_i)$ along $H_2O$, $CO_2$ absorption bands, *good spectral resolution*



**Inversion**

**3I - TOVS** *(Scott et al. 1999)*

**AIRS-L2** *(Susskind et al. 2003)*

- atmospheric temperature & water vapor profiles, Tsurf

+ atm. transmissivities from TIGR

*Thermodynamic Initial Guess Retrieval*

$I_{clr}(\lambda)$, $I_{cld}(p_k,\lambda)$ <- 4A radiative transfer <- radiosondes

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

**min weighted $\chi_w^2(p_k)$**

$$\varepsilon(p_k)=\sum_{i=1}^{N}\frac{I_m(\lambda_i)-I_{clr}(\lambda_i)}{I_{cld}(p_k,\lambda_i)-I_{clr}(\lambda_i)}$$

no assumption on microphysics !

$\varepsilon_{cld}$, $p_{cld}$

*(Stubenrauch et al. 1996, 1999, 2008, 2010)*

cirrus emissivities (8 - 12 µm)

*talk Anthony Guignard*

*simulated LUT*

4A-DISORT + SSP of ice crystals

*Mitchell, Baran*

De, IWP

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

# AIRS (IASI) cloud property retrieval:

v5 NASA / Ether

L2 atm. profiles ($T, H_2O$), $T_{surf}$

TIGR atm. profiles

L1b radiances $I_m$

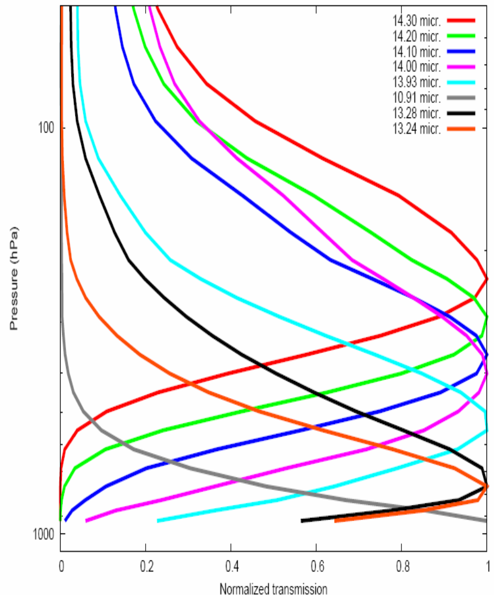
proximity recognition

TIGR transmissions

surface emissivities

*Pequignot*
*Seemann*

clear / cloudy radiances $I_{clr}$, $I_{cld}$
*of TIGR prof. close to obs*




$\chi^2$ minimization

$$\varepsilon(p_k)=\sum_{i=1}^{N}\frac{I_m(\lambda_i)-I_{clr}(\lambda_i)}{I_{cld}(p_k,\lambda_i)-I_{clr}(\lambda_i)}$$

$p_{cld}, \varepsilon_{cld}$, $T_{cld}$, $z_{cld}$, $\varepsilon_{\lambda(=8-12\ \mu m)}$

v2 Icare

**CALIPSO L1/L2 data**

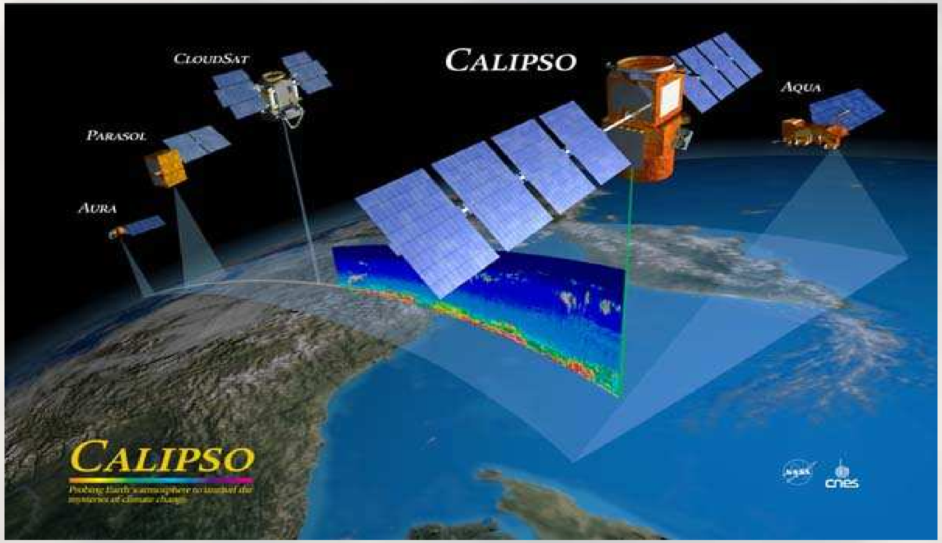
‘A posteriori’ cloud detection

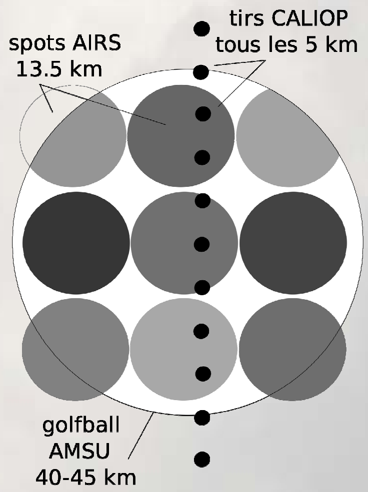
*based on spectral coherence of $\varepsilon_\lambda$*

# cloud property retrieval

| | TOVS Path-B | AIRS-LMD |
|---|---|---|
| Cloud detection: | multi-channel (+MSU) | $\sigma(\varepsilon_{cld}(\lambda))/\varepsilon_{cld}$ & $T_{cld}$-$T_{surf}$ |
| | (<NOAA15: MSU channels $\theta_v$ corrected) | a posteriori |
| Spatial resolution: | | |
| T profile: | 100 km (MSU) | 45 km (AMSU) |
| cloud detection: | 17 km | 13 km |
| cloud retrieval: | av cldy 100km | 13 km |
| Observation time: | 7h30, 19h30 – 1h30, 13h30 | 1h30, 13h30 |
| Sampling: | every MSU footprint | every AMSU footprint |

# A-Train Synergy: AIRS-CALIPSO-CloudSat




**1) Development of cloud detection method**

**2) Evaluation of AIRS cloud height**

**3) Vertical extent ($\Delta$z) of high opaque clouds / Ci / thin Ci**

**4) Vertical insight into high opaque clouds / Ci / thin Ci**

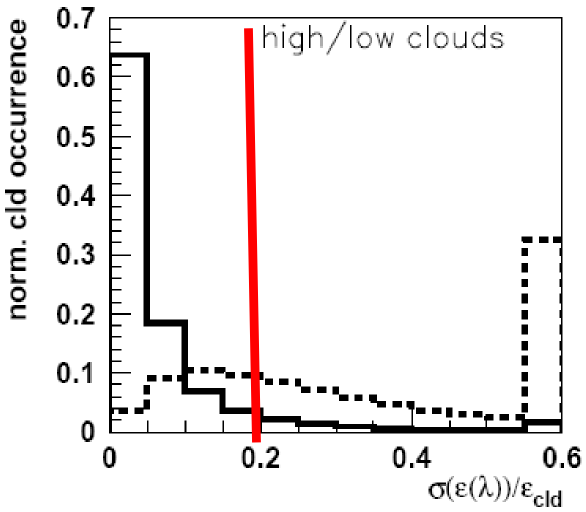
**5) Cloud height relative to tropopause**

**6) Multiple scattering correction of Ci lidar signal**

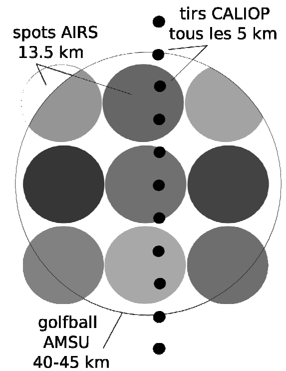

**A-Train: synergy of passive & active instruments**

# 1) Development of 'a posteriori' cloud detection

***CALIPSO sampling:** (5 km x 0.07 km ) in (13.5 km x 13.5 km)*




**CALIPSO samples indicate reality**



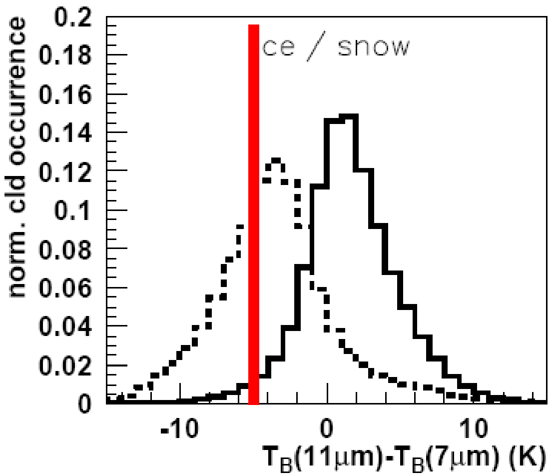

CALIPSO cloudy
CALIPSO clear sky

**cloudy:**

$\varepsilon_{cld} > 0.05$

$\sigma(\varepsilon_\lambda)/\ \varepsilon_{cld} < 0.2$ *(9 µm < λ < 12 µm)*

& over land: $T_{cld}$-$T_{surf}$ > -3K




ice/snow *(L2, detected by microwave)*:

$\sigma(\varepsilon_\lambda)/\ \varepsilon_{cld} < 0.3$ & $T_B(11\mu m)$-$T_B(7\mu m)$ > -5K

*similar to MODIS-ST (Frey et al. 2008)*

# Cloud detection comparison & sensitivity:

**agreement with CALIPSO**: 85 (80) % over ocean (sea ice)
80 (73) % over land (snow)

what is a cloudy AIRS footprint?

**global CA** : 66 % *(0% for not cloudy)* - 74% *(30% for not cloudy)*

**HCA/CA**: 40% - 36% **LCA/CA**: 42% - 47%

**agreement with LMD multi-spectral cloud detection ($\Delta T_B$):**
*(for determination of trace gases, aerosols & surface emissivity)*

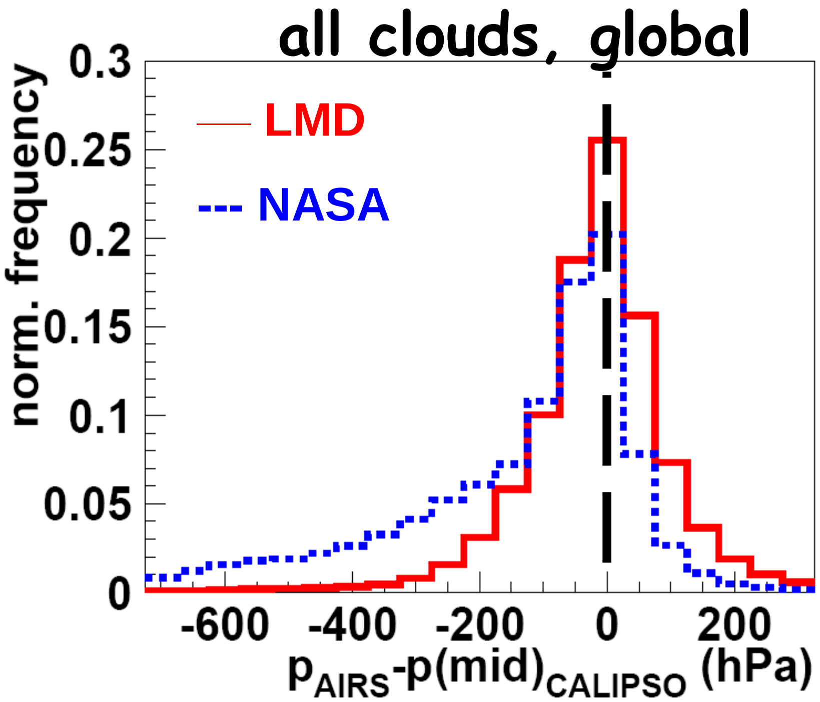
70% over ocean (30°N-30°S)
72% over land (30°N-30°S)

Multi-spectral cloud detection about 15% more cloudy footprints
*(lowlevel cloud fields)*


**A-Train: synergy of passive & active instruments**

# 2) Evaluation of AIRS cloud height with CALIPSO

*(highest cloud, detected at ≤5km)*



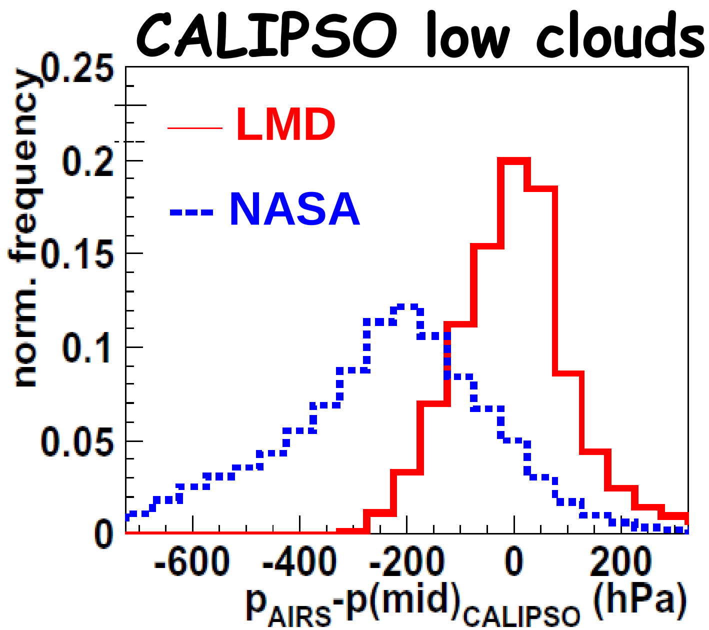

*Stubenrauch et al. JGR 2008, ACPD 2010*

in agreement with *Kahn et al. 2008*

**good agreement with CALIPSO cld midlevel**

(or pos. of max. backscatter)

**properties also depend on retrieval method**




**A-Train: synergy of passive & active instruments**

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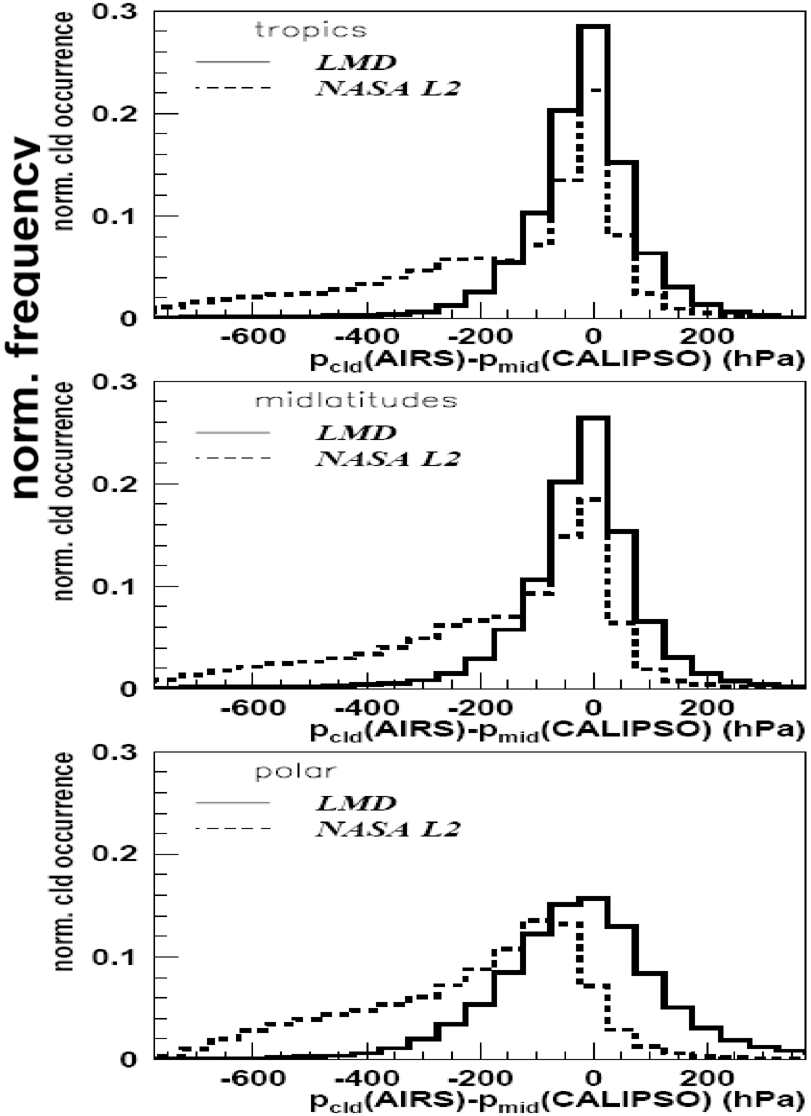


*(highest cloud, detected at ≤5km)*

**good agreement with CALIPSO cld midlevel**
(or pos. of max. backscatter)
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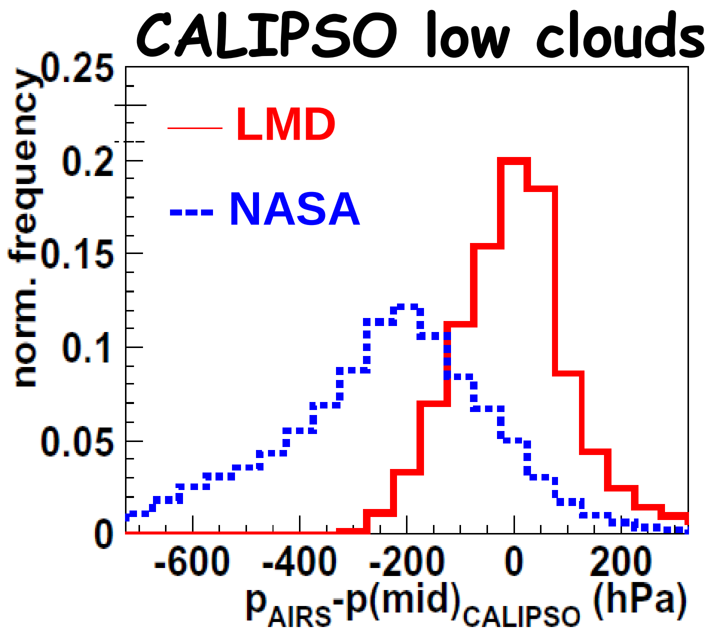

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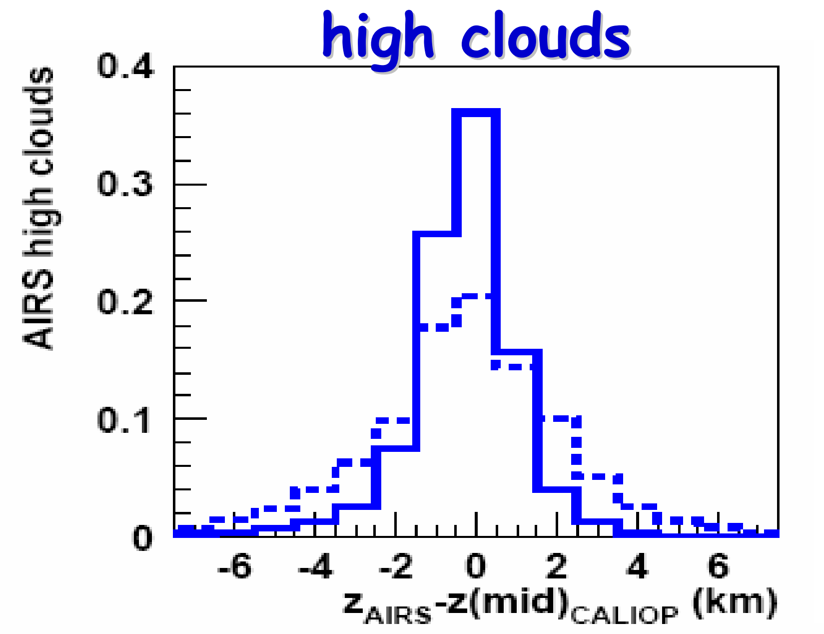
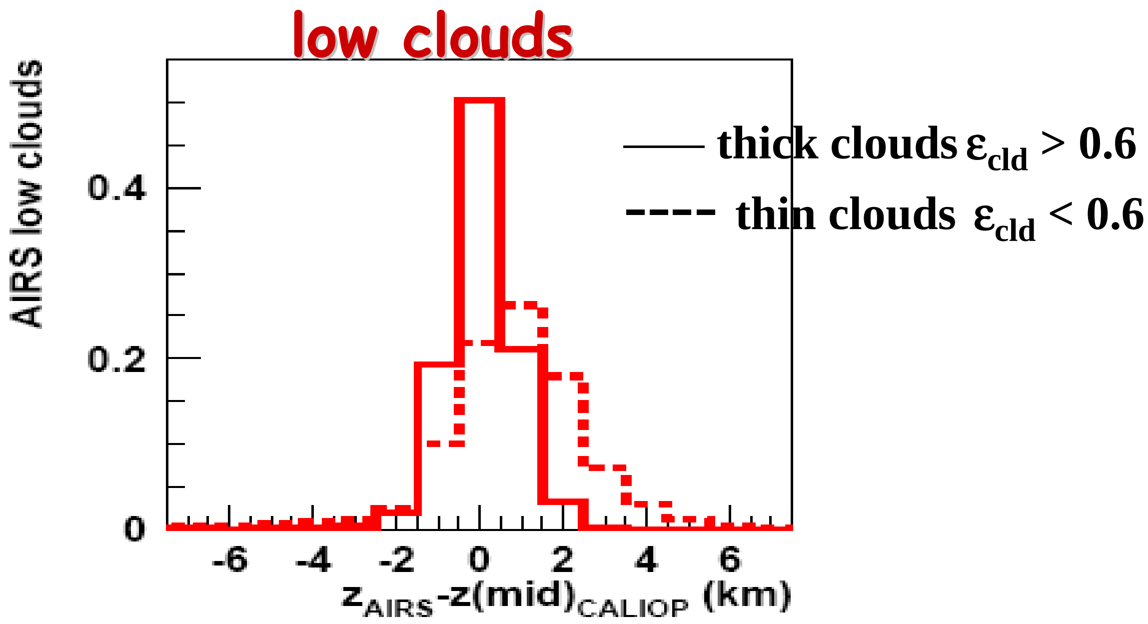
*Stubenrauch et al., JGR 2008*




**good agreement with CALIPSO midlevel of cloud** *(highest with τ>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)*

**$\Delta z_{mid}$(AIRS-CALIPSO) ± 1.5 km:**

**High: 51% 55% 66%**

**Low: 70% 74% 80%**

***hghst / hghst w τ>0.1 / closest layer***

**$\Delta p_{mid}$(AIRS-CALIPSO) ± 75 hPa:**

**High: 72% 81% (thick); 63% (thin)**

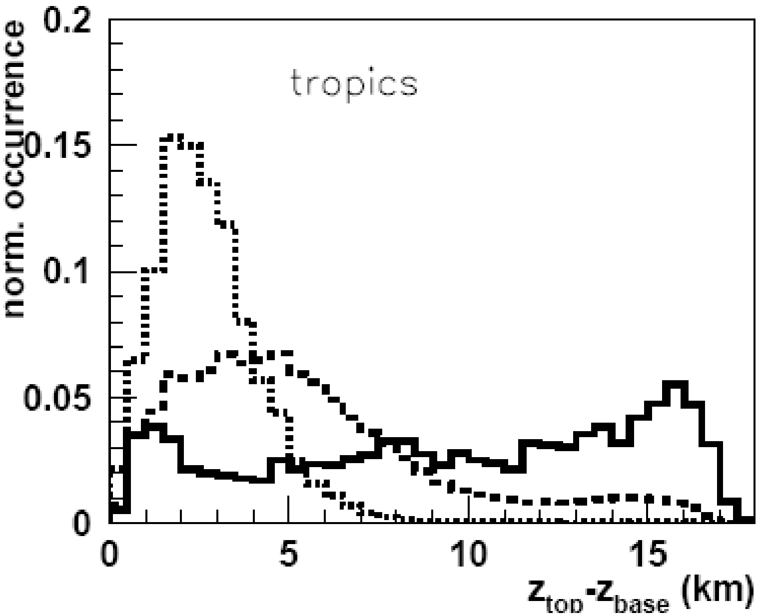
**Low: 59% 69% ; 38%**

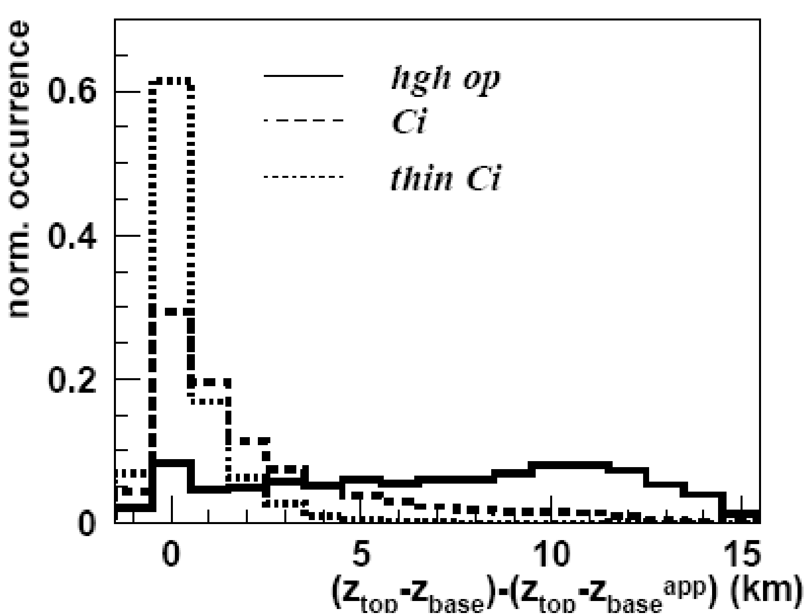

**A-Train: synergy of passive & active instruments**

# 3) Vertical extent (Δz) 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*
**GEOPROF data**
**Cloudsat.cira.colostate.edu**




- Δz(thin Ci) < Δz(Ci) < Δz(hgh op)
- real Δz much larger than apparent Δz for high opaque cloud
- good quality of AIRS cloud type identification


**A-Train: synergy of passive & active instruments**

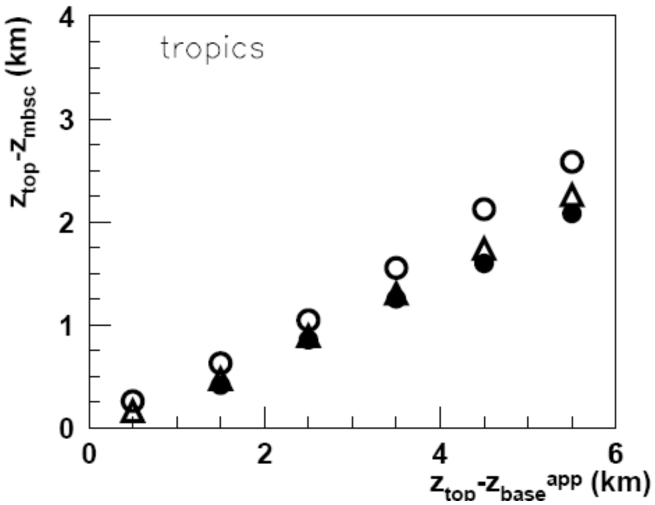
# 4) Vertical insight into high opaque clouds / Ci / thin Ci

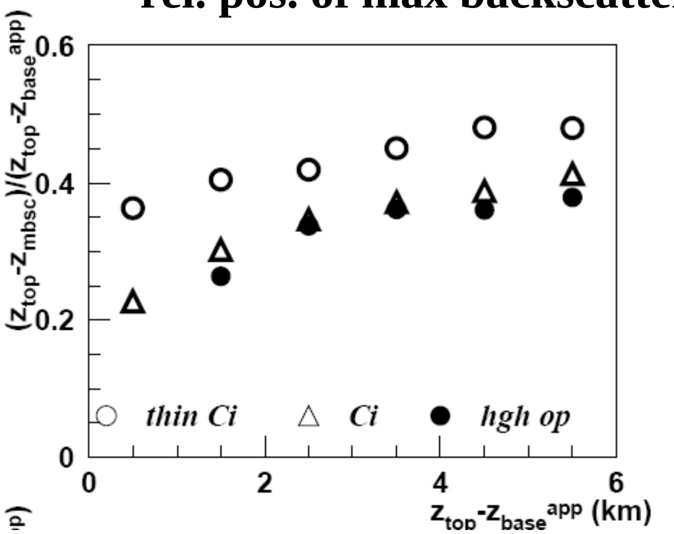
**AIRS:** cloud type

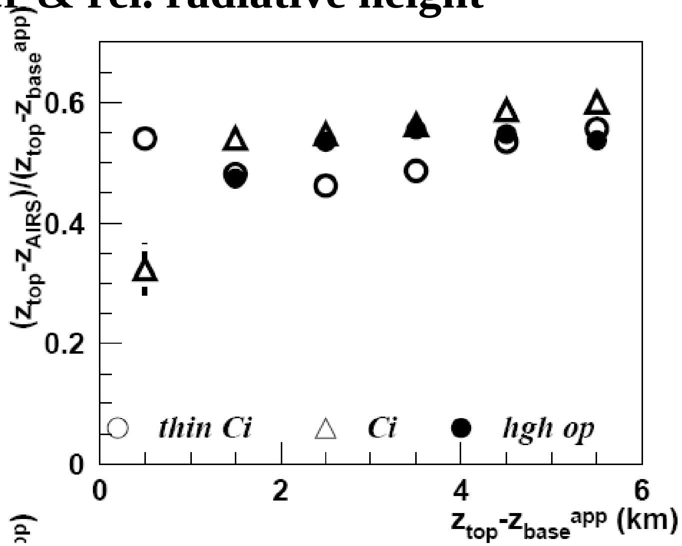
**CALIPSO:** 'apparent' geometrical cloud thickness, position of max. backscatter

**CloudSat:** real geometrical cloud thickness

**pos. of max backscatter** **rel. pos. of max backscatter & rel. radiative height**



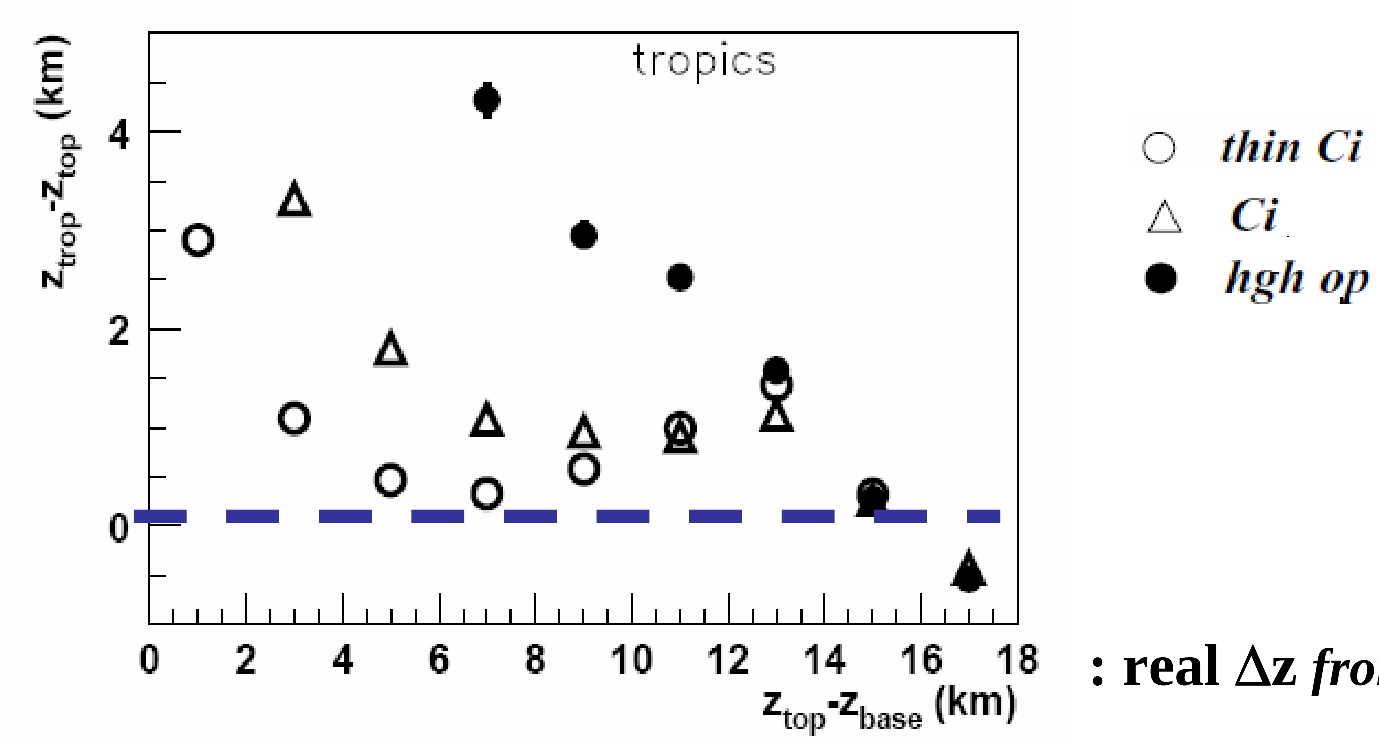




- position of max backscatter depends on 'apparent' Δz & can reach 2 km below cloud top, even for high opaque clouds
- rel. position less dependent, 1/3 – 1/2 below top (thin Ci)
- 'radiative' height lies about 1/2 below top, for all cloud types


**A-Train: synergy of passive & active instruments**

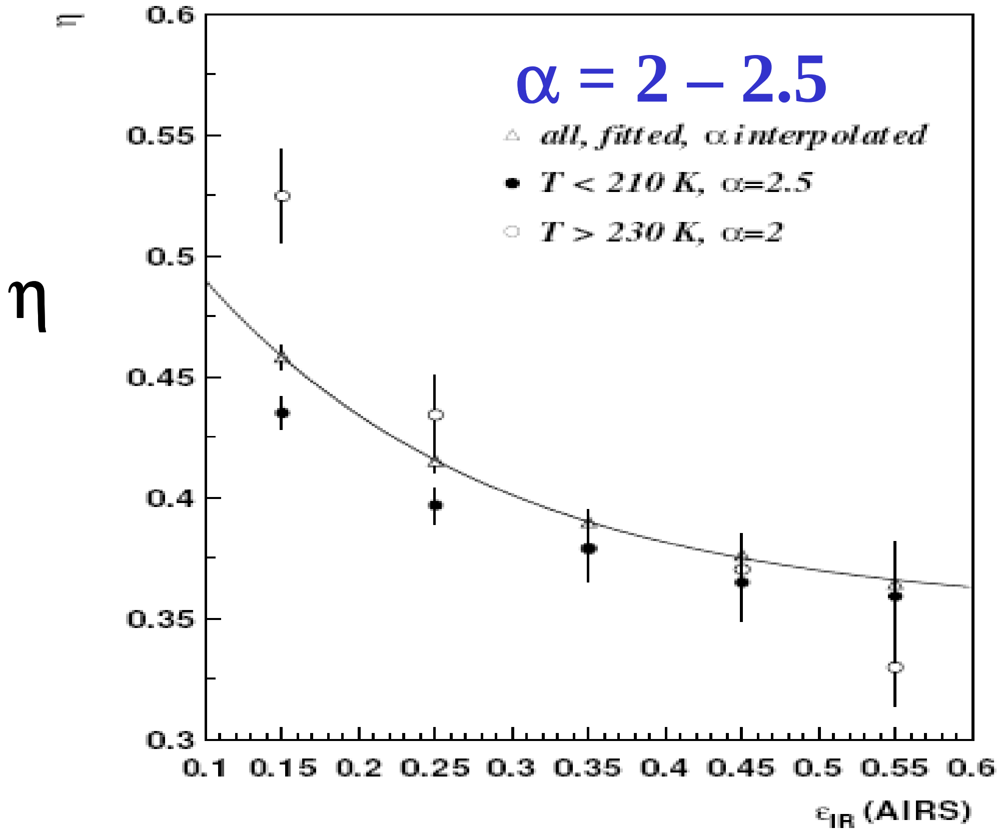
# 5) Cloud height relative to tropopause




**: real Δz** ***from GEOPROF***

**Tropics: only the very thickest opaque clouds (& surrounding anvils) penetrate stratosphere**
*Rossow & Pearl 2007:* **larger, organized, convective systems penetrate**

# 6) Multiple scattering correction of cirrus lidar signal




*Lamquin et al. JGR, 2008*

**$\varepsilon_{IR} = 1 - \exp(-\tau_{VIS}/\alpha)$, $\alpha \cong 2 - 2.5$**

α increasing with decreasing crystal size

(*Sassen & Comstock 2001*)

$D_e$ increases with $T_{cld}$,(*Stubenrauch et al. 2004*)

=> $\alpha = f(T_{cld})$

**$\varepsilon_{IR} = 1 - \exp(-\tau_{VIS}/\alpha)$**

$\tau_{VIS} = \tau_{LIDAR} / \eta$

**$\eta$ = 0.47 - 0.37** **CALIPSO L2: $\eta$ = 0.6**

**slightly more multiple scattering for opt. thicker cirrus**

## Relative amount of high clouds *according to:*

**CALIPSO** *(with-without subvis Ci)* **/ AIRS - TOVSB / HIRS/ ISCCP VIS+IR / ISCCP IR**

| CALIPSO | | / AIRS - TOVSB | / HIRS / | ISCCP VIS+IR | / ISCCP IR | |
|---|---|---|---|---|---|---|
| 51% | - 45% | / 39% - 41% | / 49% / | 34% | / 22% | NH midlatitudes |
| 66% | - 57% | / 58% - 62% | / 60% / | 46% | / 30% | tropics |
| 40% | - 34% | / 28% - 30% | / 49% / | 26% | / 17% | SH midlatitudes |

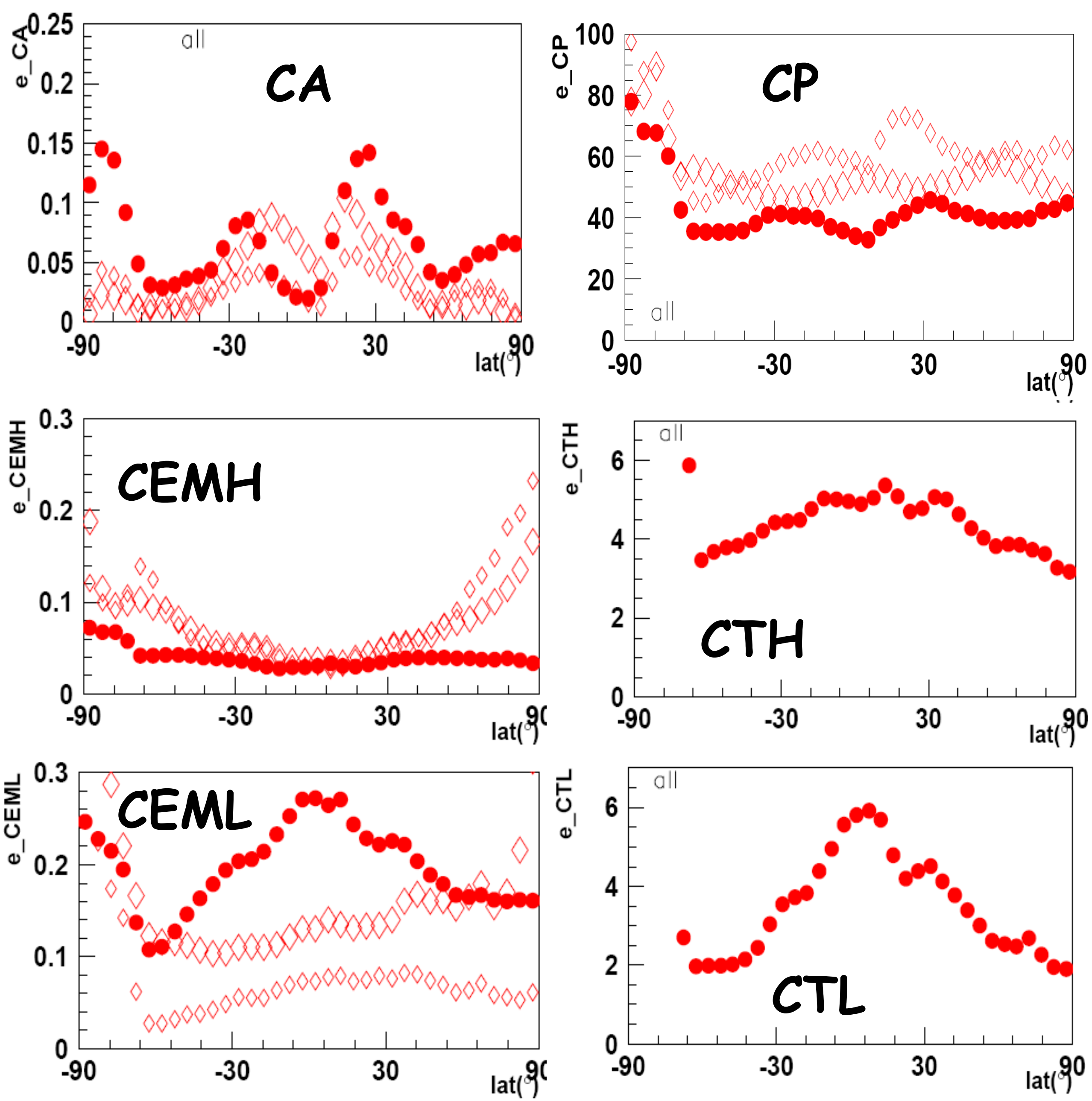
## Relative amount of low clouds *according to:*

**CALIPSO** *(with-without subvis Ci)* **/ AIRS - TOVSB / HIRS/ ISCCP VIS+IR / ISCCP IR**

| CALIPSO | | / AIRS - TOVSB | / HIRS / | ISCCP VIS+IR | / ISCCP IR | |
|---|---|---|---|---|---|---|
| 34% | - 36% | / 39% - 39% | / 33% / | 38% | / 41% | NH midlatitudes |
| 28% | - 34% | / 31% - 34% | / 30% / | 32% | / 45% | tropics |
| 51% | - 52% | / 51% - 52% | / 29% / | 49% | / 48% | SH midlatitudes |

**AIRS-LMD, TOVSB in good agreement with CALIPSO (without subvisible cirrus)**
**HIRS no difference between NH & SH midlatitudes**
**ISCCP same latitudinal behaviour, but underestimation of Ci (5-15%)**

# Uncertainties




## Estimation:

CA: CA($\varepsilon_{cld}$ < 0.05)

largest over deserts & Antarctica

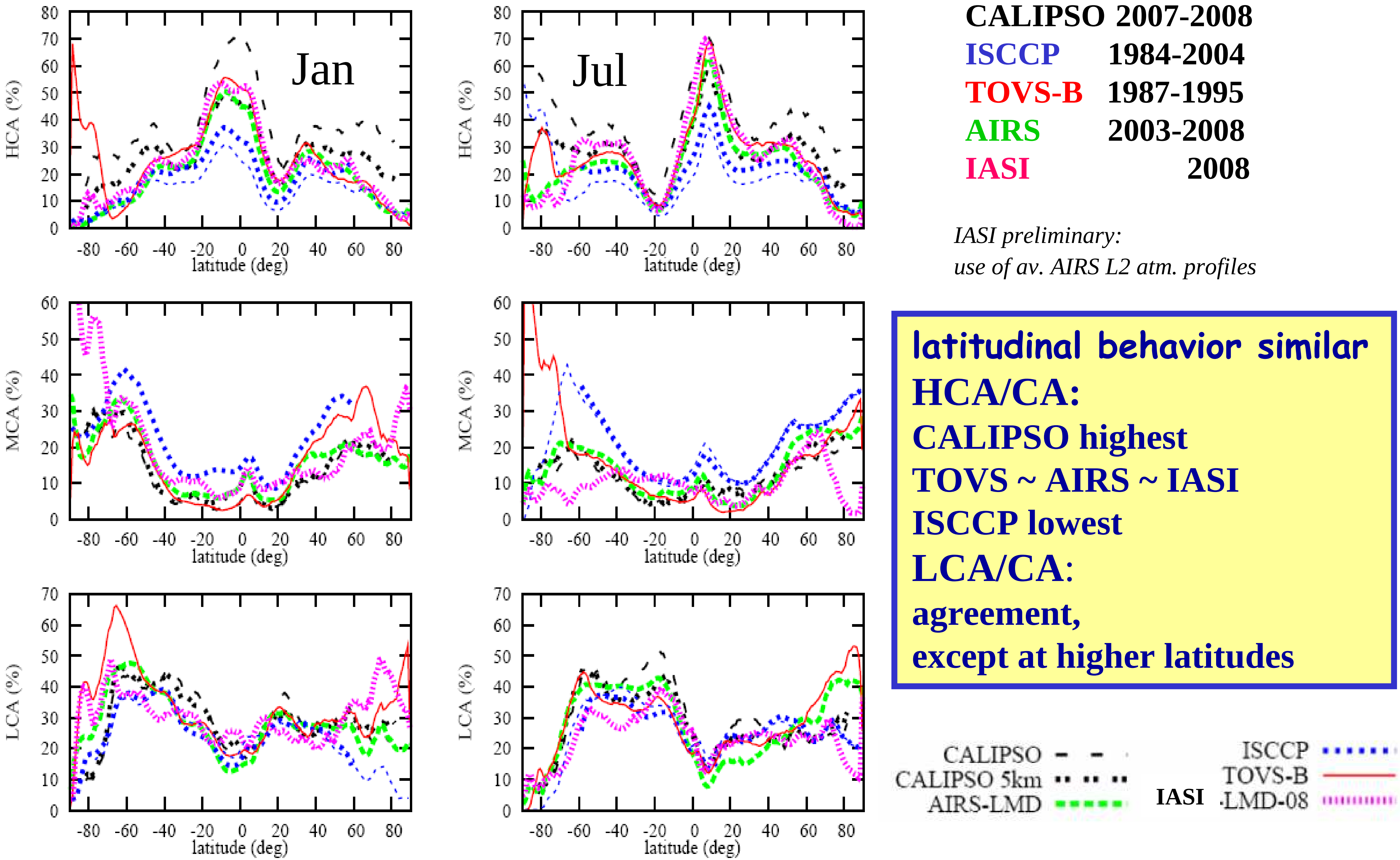
CP, CT, CEM:
difference between min $\chi^2$ & next smallest $\chi^2$

CP: ~40-50 hPa,
slightly smaller forAIRS

High clouds:
CT: 4K, CEM 0.05

Low clouds:
CT: 2–4K, CEM: 0.1–0.25
slightly smaller for TOVS

# Zonal averages of HCA, MCA and LCA




**CALIPSO 2007-2008**
**ISCCP 1984-2004**
**TOVS-B 1987-1995**
**AIRS 2003-2008**
**IASI 2008**

*IASI preliminary:*
*use of av. AIRS L2 atm. profiles*

**latitudinal behavior similar**
**HCA/CA:**
**CALIPSO highest**
**TOVS ~ AIRS ~ IASI**
**ISCCP lowest**
**LCA/CA:**
**agreement,**
**except at higher latitudes**

**TOVS Path-B** (1987-1994) **& AIRS-LMD** (2003-2009) **cloud climatologies:**

- **IR sounders passive instruments most sensitive to cirrus**

**5-15% more Ci than ISCCP VIS+IR**

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

**LMD retrieval:**

- **$p_{cld}$ corresponds to midlevel of apparent cloud depth**

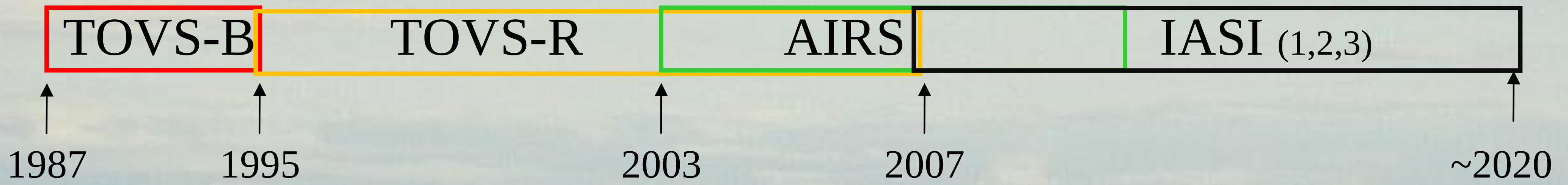
(slightly below height of max backscatter)

- **Uncertainty estimation from $\chi^2$ :**

**CP : 40 – 50 hPa**

**High clouds: CT: 4 K, CEM: 0.05**

**Low clouds: CT: 2-4K, CEM: 0.1-0.25**



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