Microphysical properties of semi-transparent cirrus from AIRS and TOVS

Anthony Guignard

C. Stubenrauch,S. Cros, N. Lamquin

Atmospheric Radiation Analysis (ARA) team

Atmosphere Biosphere Climate per remote sensing ABC(t)

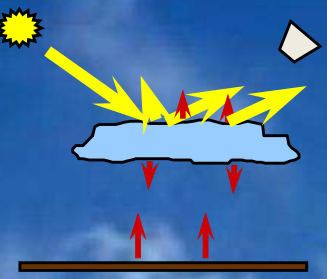
IPSL - Laboratoire de Météorologie Dynamique, France

+ **A. Baran**

MetOffice, UK

(SSP's for cirrus microphysics)

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, τ_{VIS} / ε_{IR}**
- **horizontal extension**
- **bulk microphysical properties**

Active (A-Train, >2002)

info on **all cloud layers**

sparse sampling (track/ 1000km)

- **z, τ_{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) :**

- ***evaluation of cloud property retrieval*** *(Stubenrauch et al. ACPD 2010)*
- ***distinction between single and multi-layer clouds***

Synergy between AIRS and CALIOP

A-Train

observations at 01.30 and 13.30 LT

AIRS

atmospheric profiles (T, Rh): 45km

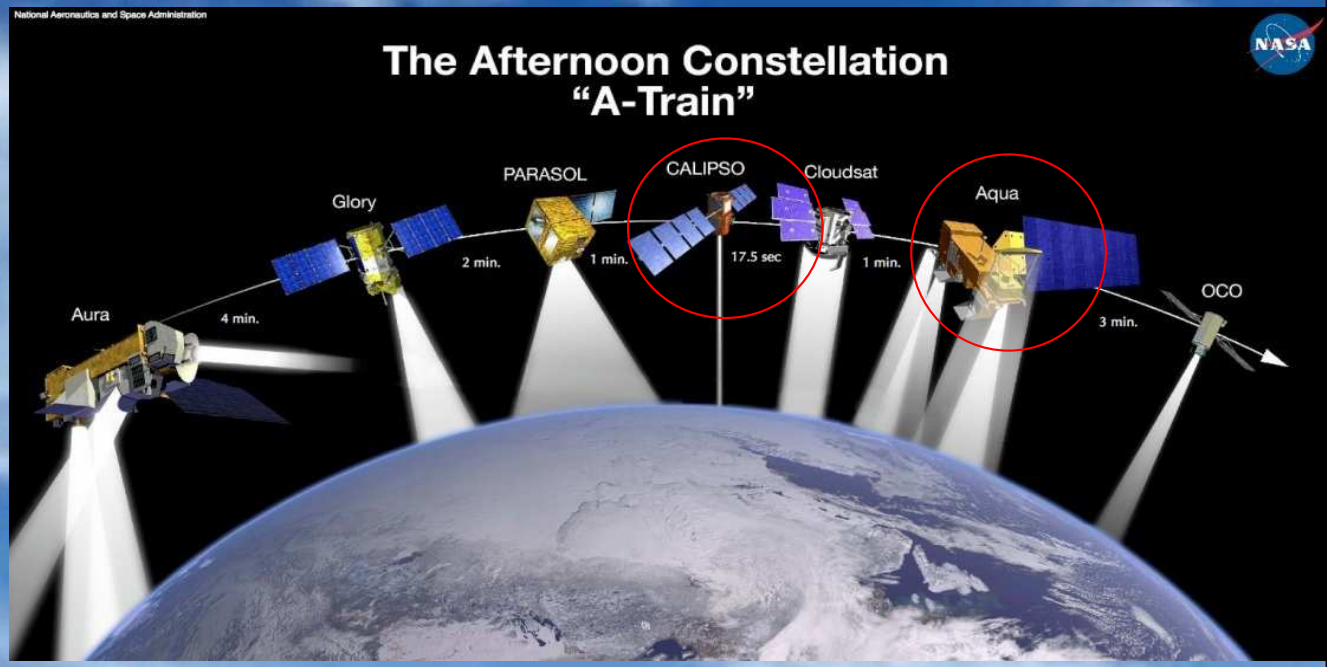
cloud properties: 13.5 km

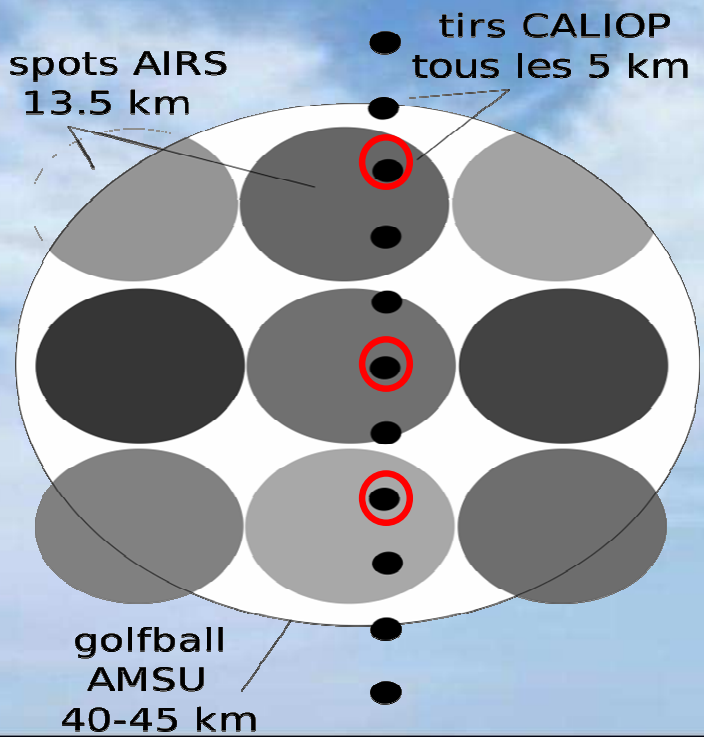
CALIPSO

Cloud vertical structure per CALIPSO segment: 90m x 5km

Colocalation

CALIPSO shot closest to AIRS spot





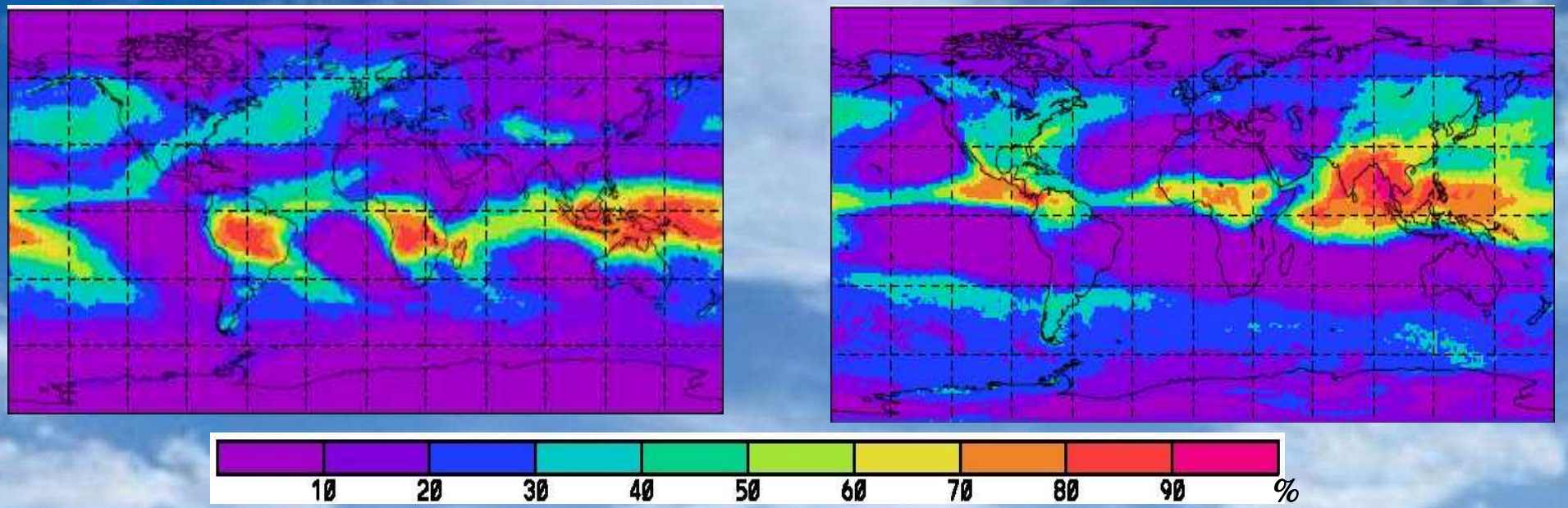
geographical distribution of high cloud amount

AIRS-LMD

January

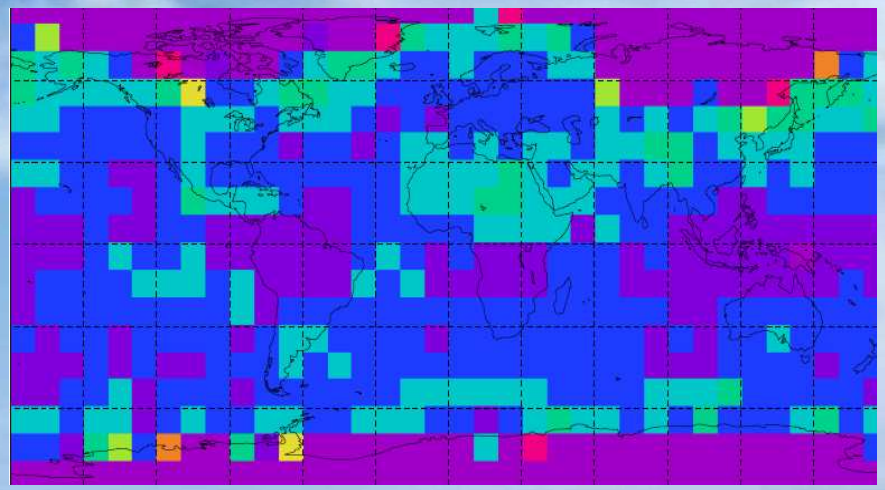
July

2003-2008



(Stubenrauch et al., ACP Disc. 2010)

single layer high clouds



AIRS-CALIPSO *DJF 2007-2008*

-high cloud : p_{cld} < 440 hPa

~40% of all clouds are high clouds
(5-10% more over land than over ocean)

- stormtracks in winter midlatitudes

-more Ci over land in summer midlatitudes

v5

AIRS / IASI cloud property retrieval:

L1b radiances I_m

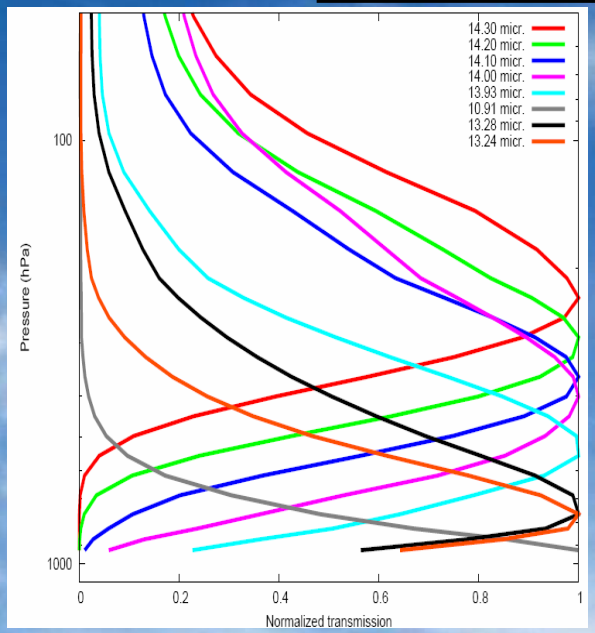
L2 atm. profiles (T,H_2O), T_{surf}

TIGR atm. profiles

proximity recognition

surface emissivities

Pequignot, Seemann



TIGR transmissivities

χ^2 minimization

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

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

'A posteriori' cloud detection
Based on spectral coherence ε_λ

4A-DISORT

SSP of ice cristals

Mitchell, Baran

Simulated LUT

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

De, IWP

by retrieving cirrus emissivities, the atmosphere is taken into acount
=> no need to simulate LUT's for different atmospheres

4A-DISORT simulation of Cirrus emissivities

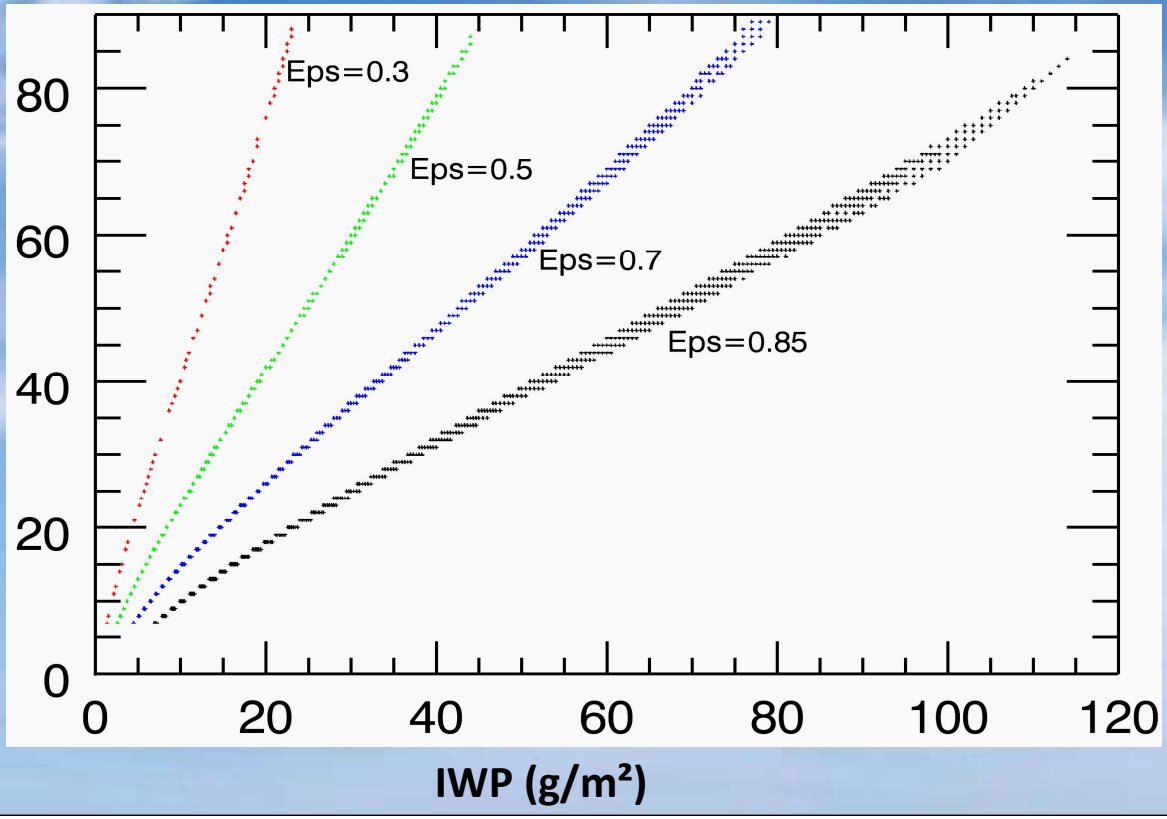
Assumptions:

-vertical cloud extent of **1 km** , cloud height at **10km**, vertical homogeneity

-single scattering properties (β_{ext},ω_0,g) of ice **columns** & **aggregates** *(Baran et al. 2003)*

-apply bimodal size distribution *(Mitchell et al. 1996)* $D_e = 2\frac{\int \frac{3V}{4\pi} n(r)\,dr}{\int \frac{P}{\pi} n(r)\,dr} = \frac{3}{2}\frac{IWC}{\rho_i P}$

$\varepsilon_{12\,\mu m}$ = f(De, IWP)



the use of one emissivity leads to multiple solutions

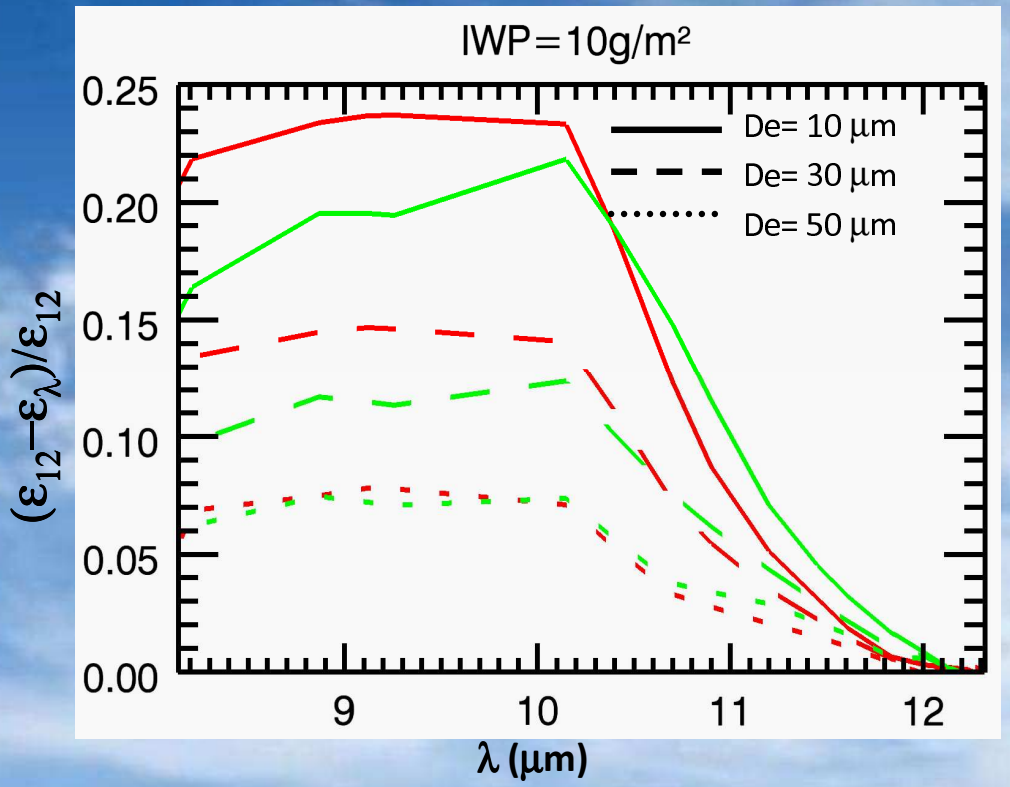
A spectral information is necessary

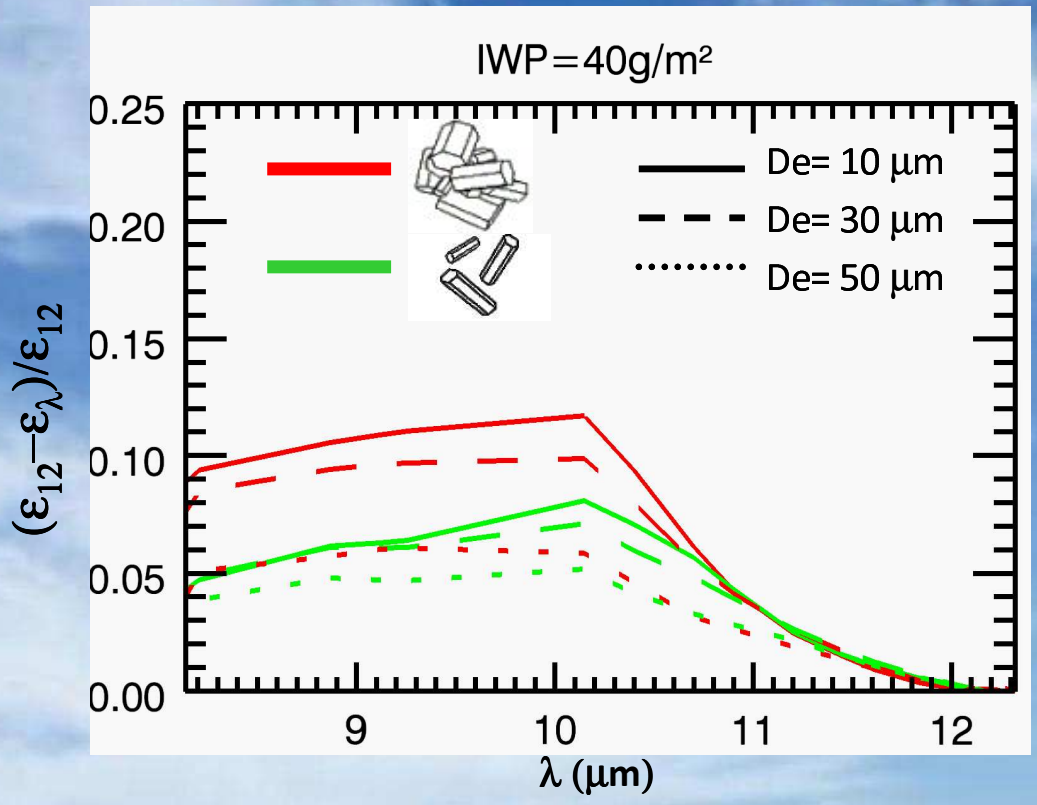
to retrieve De & IWP

Simulation of Cirrus emissivities

De retrieval based on spectral cirrus emissivity variation

Examples of normalized ε differences for fixed IWP:





ε difference increases with decreasing De, stronger effect for small IWP

for $0.3 < \varepsilon_{12\mu m} < 0.85$ **sensitivity up to** $D_e \leq 90\mu m$

$0.7 < \tau_{VIS} < 3.8$

cloud property retrieval

	TOVS Path-B	AIRS-LMD
Cloud detection:	multi-channel (+MSU)	$s(e_{cld}(l))/e_{cld}$ & T_{cld}-T_{surf}
	(<NOAA15: MSU channels q_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
Microphysics property retrieval		
SSP	Mitchell	Baran
Shape	**polycristals**	**agregates and columns**
# channels	**2 channels**	**7 channels (8-12 µm)**

Sensitivity studies for TOVS

Rädel et al., JGR 2003 for TOVS (8-11μm) : uncertainties up to 25% (from simulations)

Underestimation of D_e:

- **increasing D_e with cloud depth**
- **broader size distribution**

Overestimation of D_e:

- **hexagonal columns instead of aggregates**
- **partial cover of thick Ci**
- **thin Ci with underlying water cloud**

AIRS: -7 spectral channels should help to distinguish between shapes

- use only overcast golfballs

- distinguish single & multi-layer clouds with CALIPSO

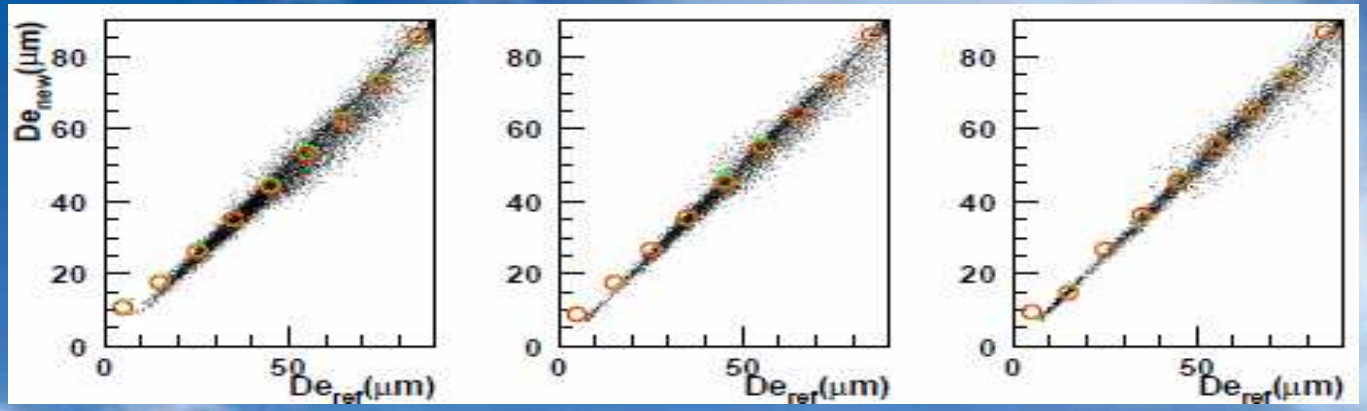
Uncertainties on ice crystal size retrieval

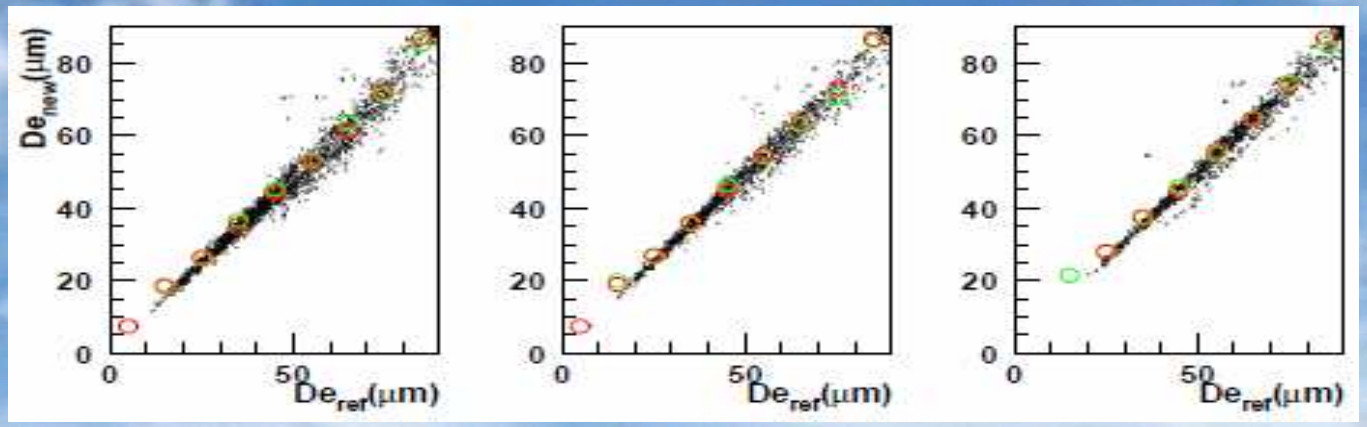
Reference: homogeneous cloud, T_{cld}=237K, z=1km,T_{surf}=300K, polycrystals, bimodal-G size distribution

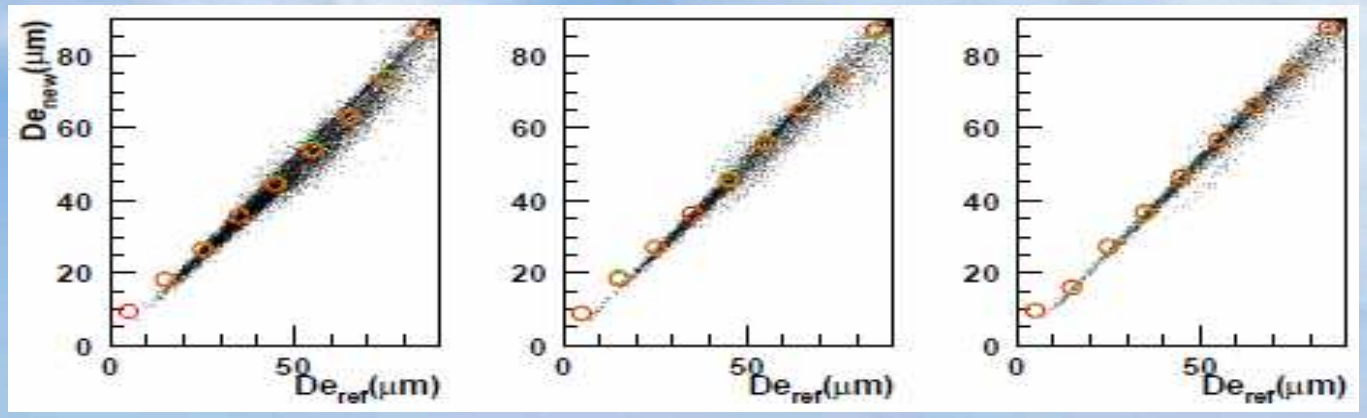
parameter	changed to/by	$(D_e^{standard}-D_e')/D_e^{standard}$	
		15μm	60μm
crystal shape	spheres	+15%	+30%
	hexagonal columns	+15%	+25%
size distribution	tropical	-20%	-28%
Rädel et al., JGR 2003		thin cirrus 15μm 60μm	thick cirrus 15μm 60μm
horiz.heterogeneity	90% cloud cover	+7% +2%	+25% +12%
vert. heterogeneity	$D_e^{low}=2\ D_e^{high}$	-15% –20%	-15% –20%
+ water cloud	r_e=7μm;LWC=0.2g/m^3	+25% +25%	+15% +15%
lapse rat	6.5 -> 11˚/km	+3% +3%	+5% +5%
Δh_{cld}, ΔT_{surf}, Δz	+4km, -15K, +1km	-6% to +10%	

Sensitivity studies for AIRS

$0.3 < \varepsilon_{cld} < 0.5$	$0.5 < \varepsilon_{cld} < 0.7$	$0.7 < \varepsilon_{cld} < 0.85$







All

Multi

Single

Vertical extent

ΔZ=2km / ΔZ=1km

Cloud base altitude

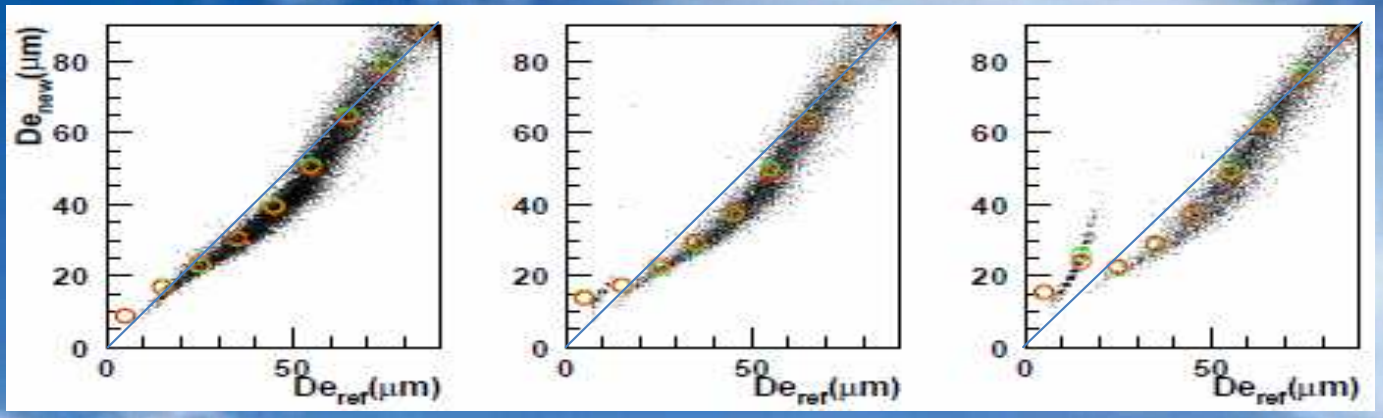
Hcld=14km / Hcld=10km

Midlatitudes atmospheric profiles

midlatitudes /tropical

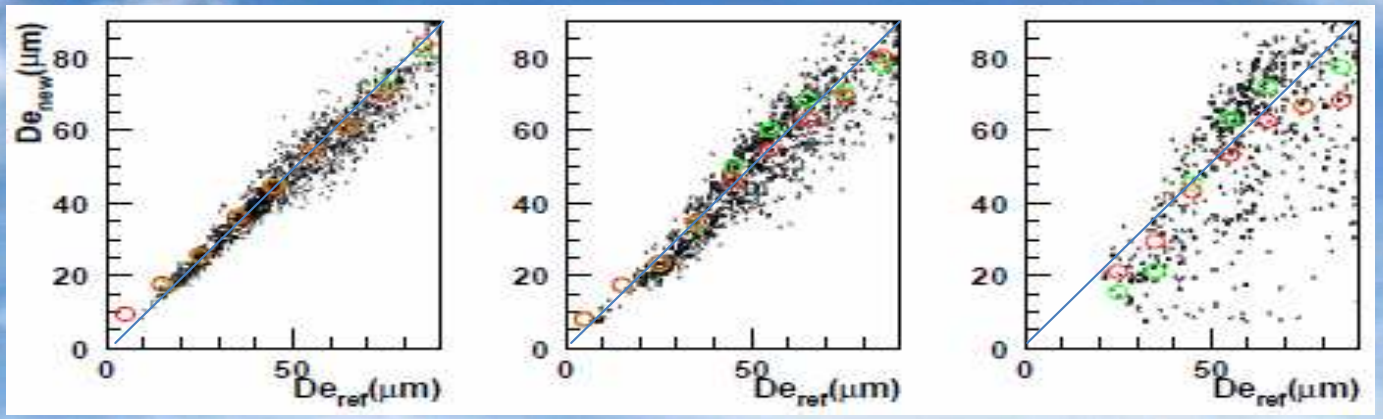
Sensitivity studies for AIRS

$0.3 < \varepsilon_{cld} < 0.5$	$0.5 < \varepsilon_{cld} < 0.7$	$0.7 < \varepsilon_{cld} < 0.85$



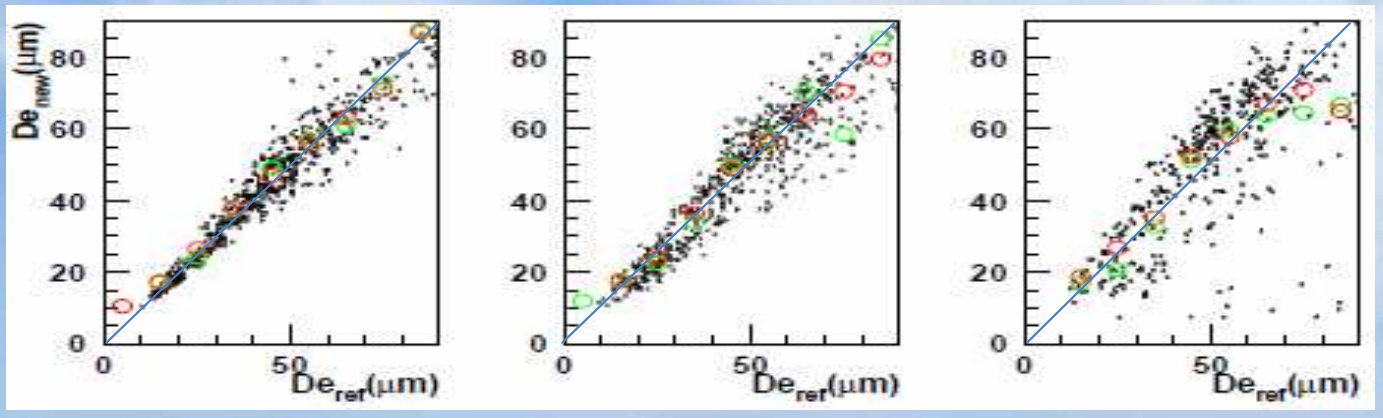
Cristal shape

- columns / aggregates



Retrieval method

- deps_norm / eps



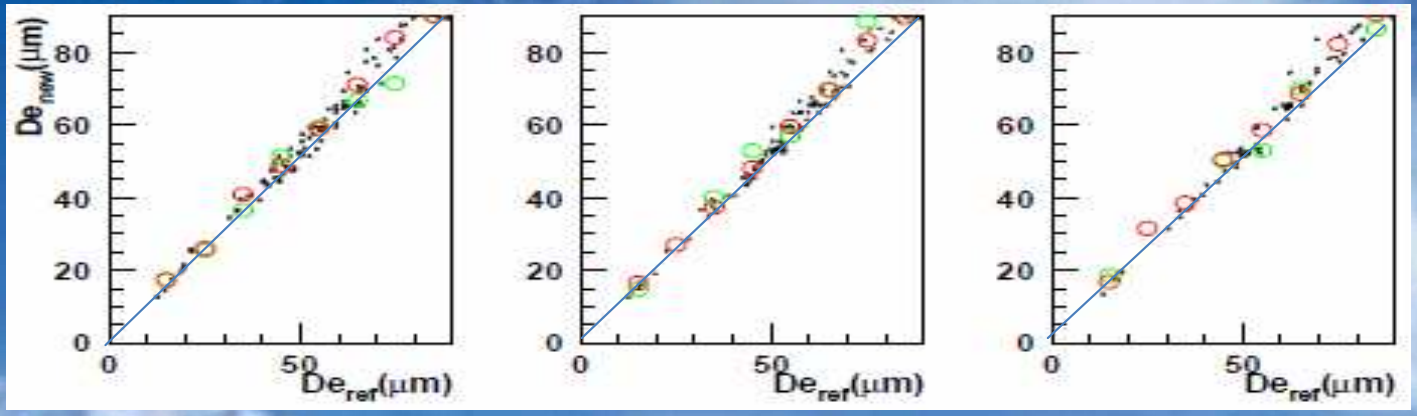
Number of channels

- 2 channels / 7 channels

Sensitivity to SSP

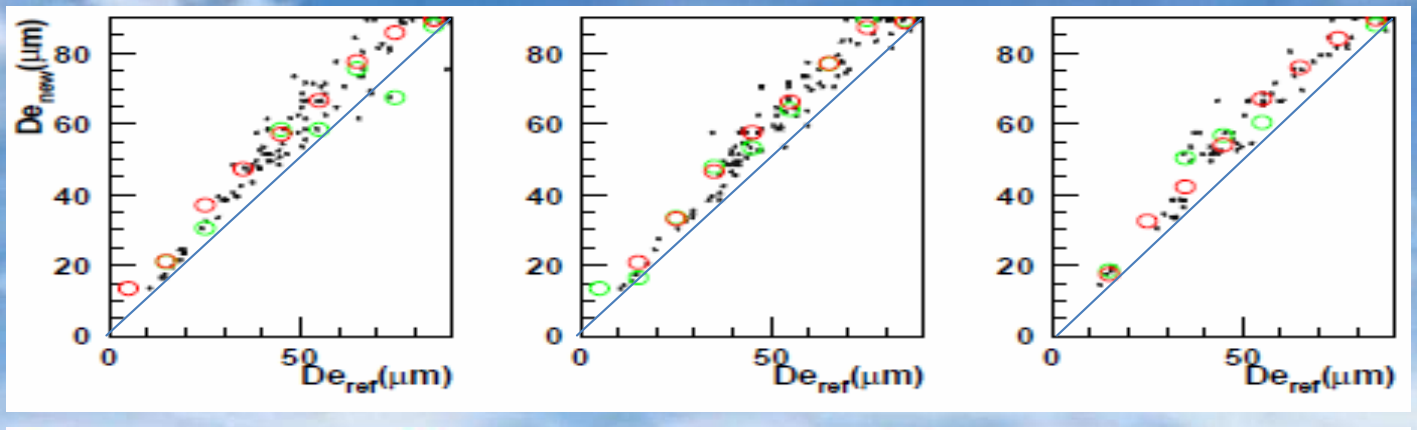
$0.3< \varepsilon_{cld}<0.5$	$0.5< \varepsilon_{cld}<0.7$	$0.7< \varepsilon_{cld}<0.85$

Mitchell: Anomalous diffraction Analysis (ADA)
Baran: T-Matrix



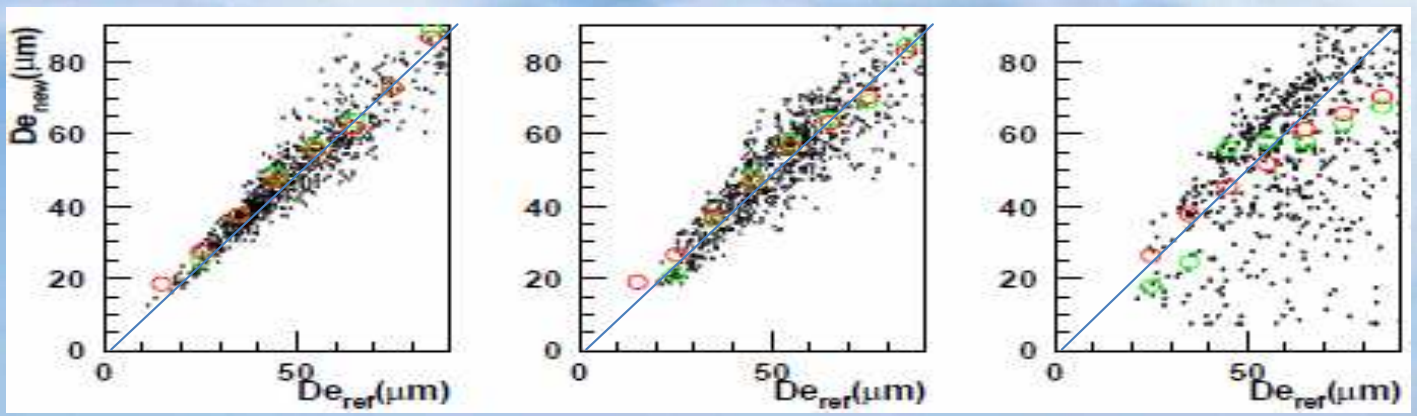
Aggregats

Mitchell / Baran



Columns

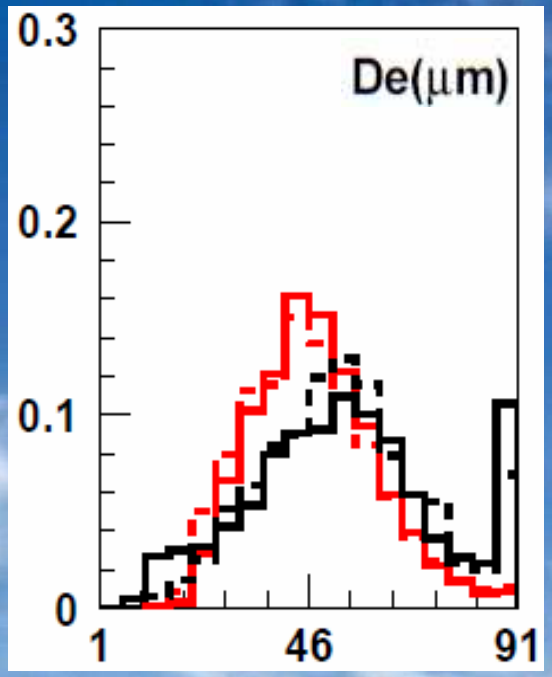
Mitchell / Baran



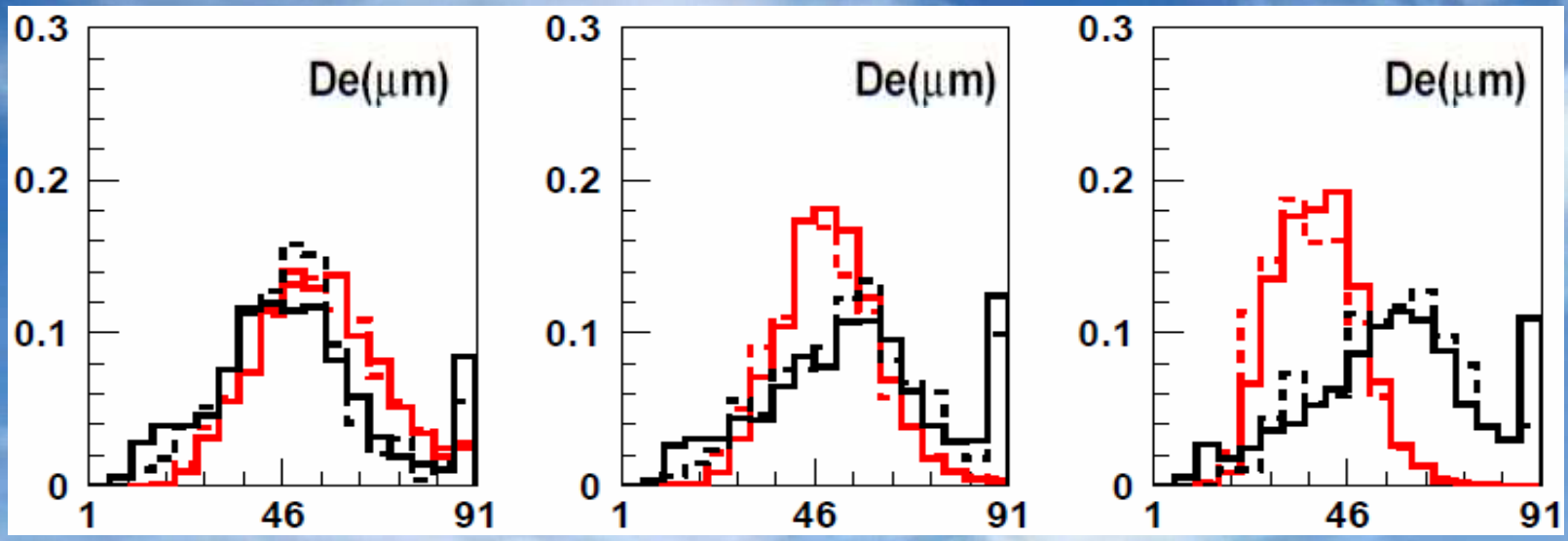
Mix

Mitchell / Baran

De distributions for thin to medium thick Ci



$0.3 < \varepsilon_{cld} < 0.5$	$0.5 < \varepsilon_{cld} < 0.7$	$0.7 < \varepsilon_{cld} < 0.85$

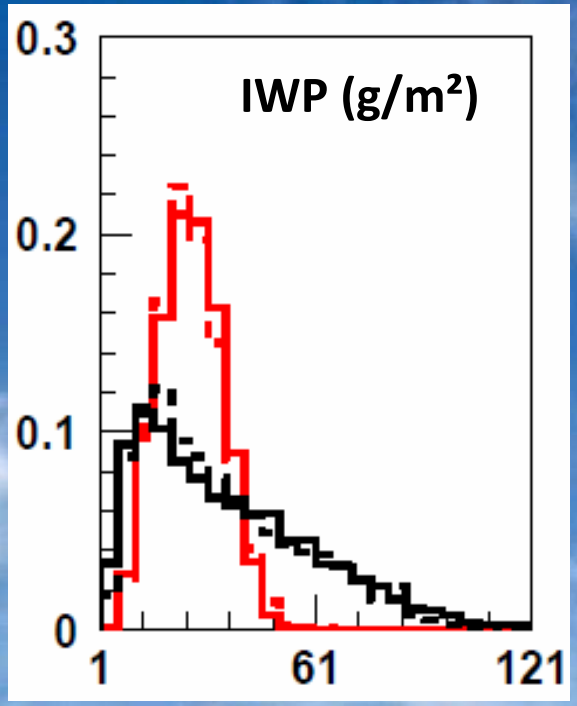


Airs 4A sp — *Tovs Streamer*

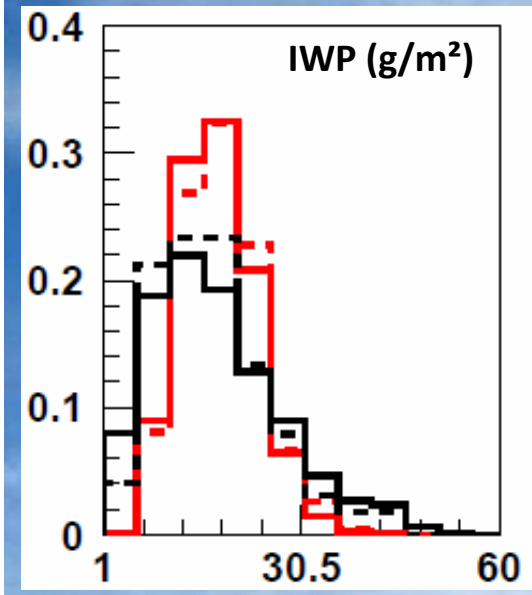
Airs 4A gb — *Tovs Streamer nodeltac*

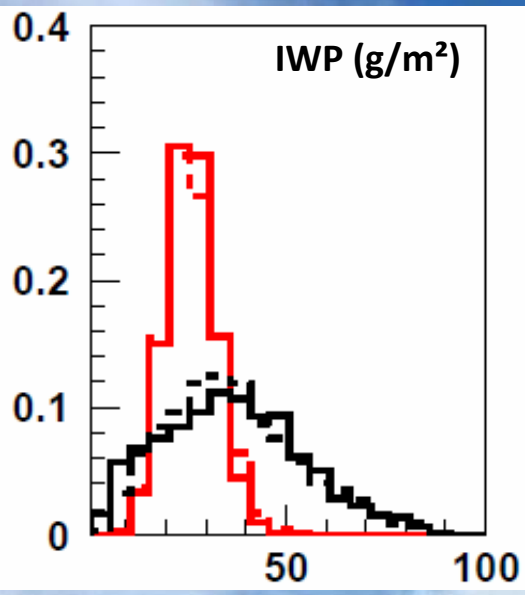
- negligeable effects of spatial resolution and RTM calibration (deltac)
- similary distributions with differences increasing with cloud thickness
- Tovs: Mitchell polycristals
- Airs: Baran aggregates and columns (90% of retrieved De within sensitivity limits)

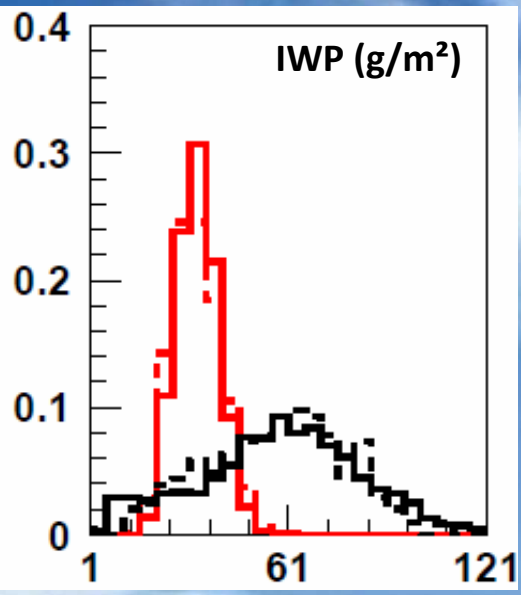
IWP distributions for thin to medium thick Ci



$0.3 < \varepsilon_{cld} < 0.5$ $0.5 < \varepsilon_{cld} < 0.7$ $0.7 < \varepsilon_{cld} < 0.85$







Airs 4A sp — *Tovs Streamer*

Airs 4A gb — *Tovs Streamer nodeltac*

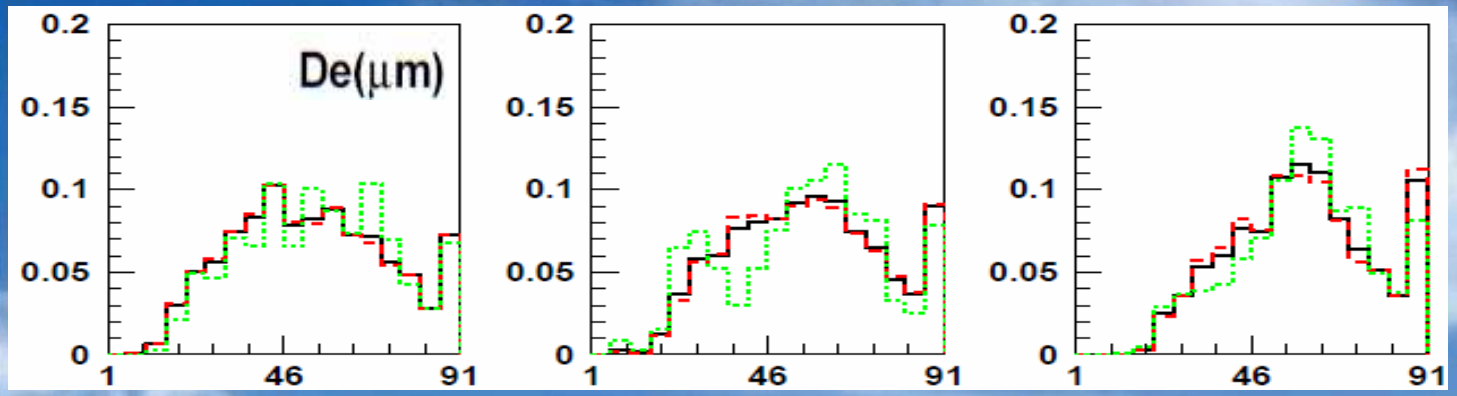
- Tovs : increasing IWP and « slimming » of distributions with increasing ε_{cld}

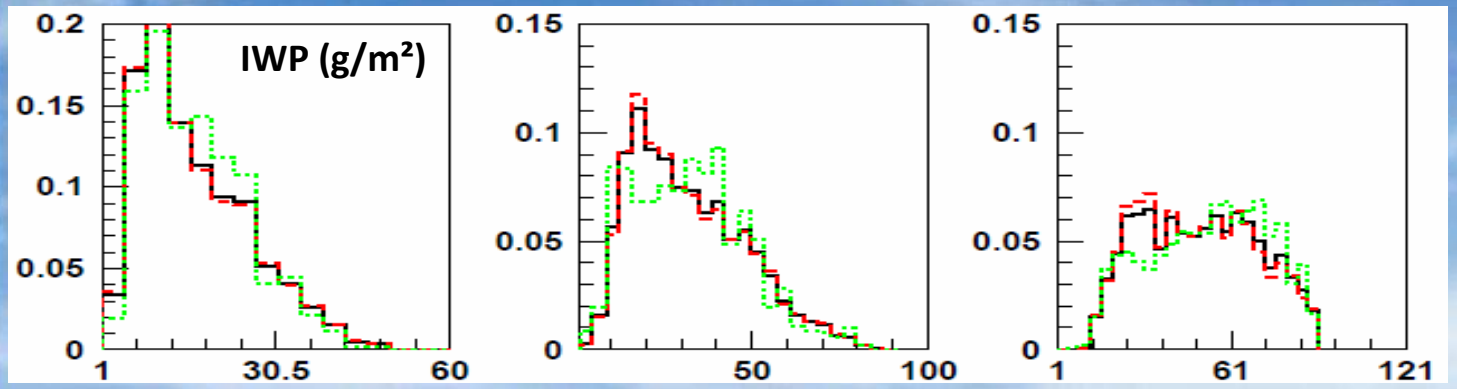
- Airs: increasing IWP and broading of distributions with increasing ε_{cld}

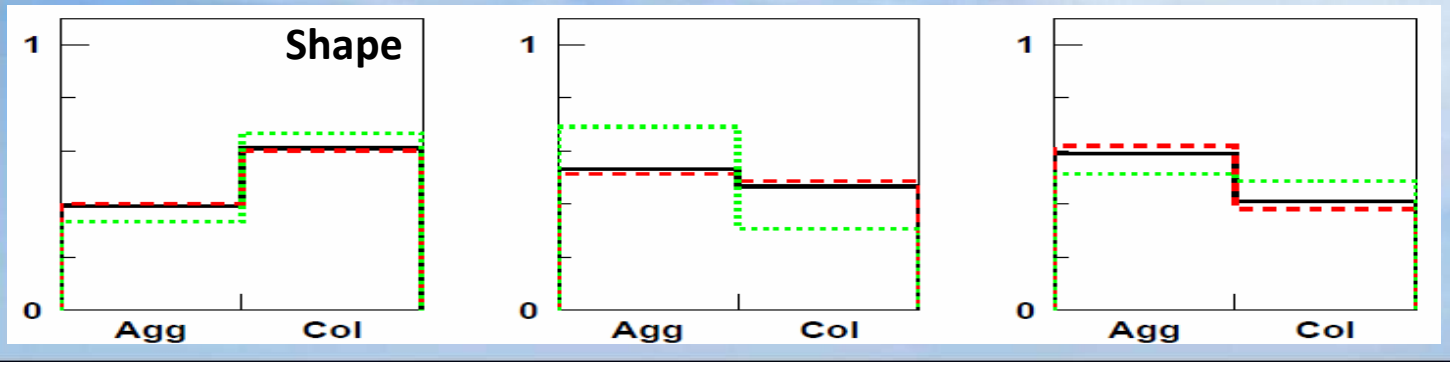
De, IWP and shape retrieval for thin to medium thick Ci

single layer cirrus **(detected by CALIPSO)** **, *in tropics 2 year averages***

$0.3< \varepsilon_{cld}<0.5$	$0.5< \varepsilon_{cld}<0.7$	$0.7< \varepsilon_{cld}<0.85$







All

Multi

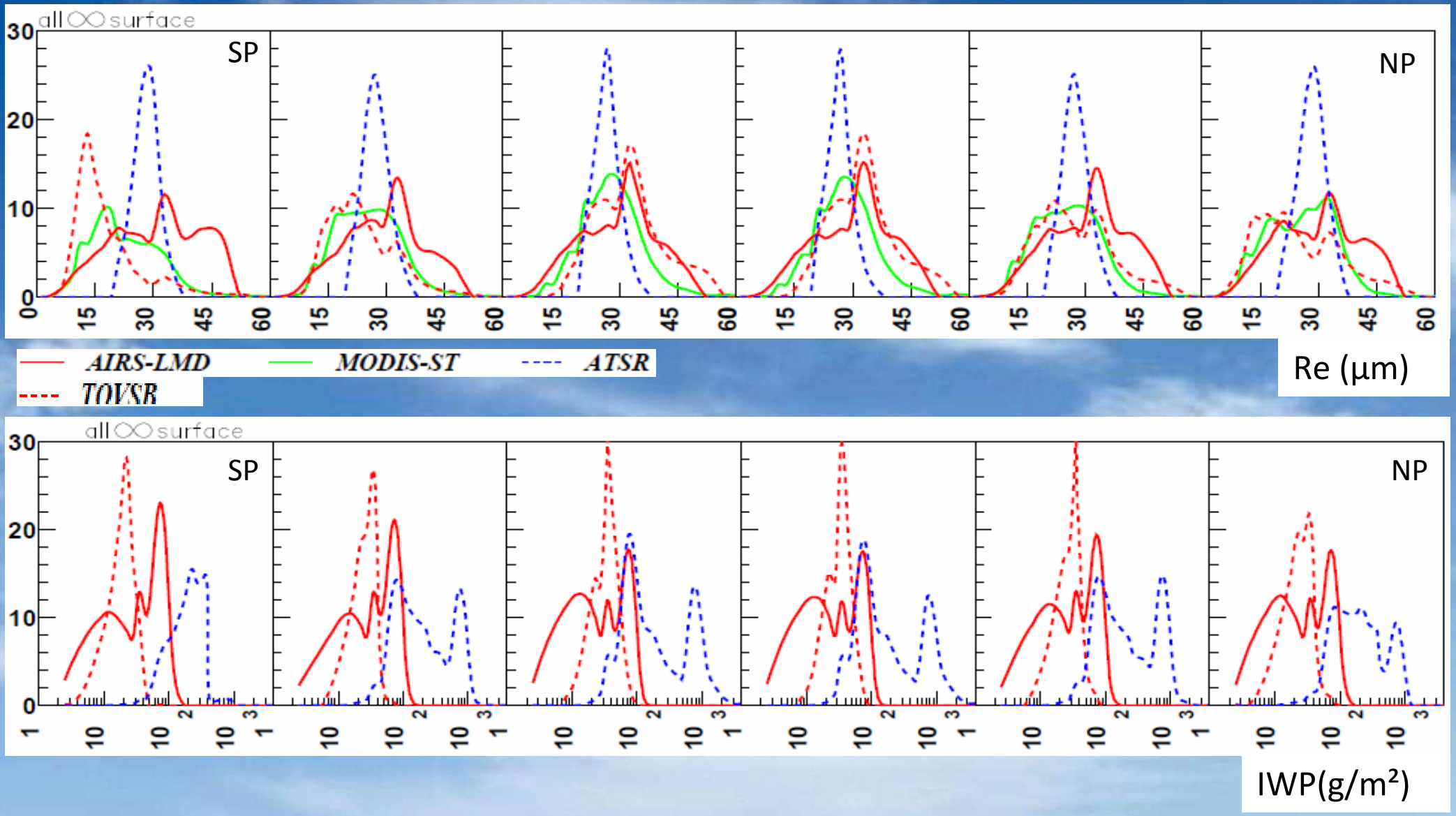
Single

-De and IWP increase with ε_{cld}

-no significant differences between single and multi-layer clouds

-optically thicker Ci seem to contain more aggregates than columns

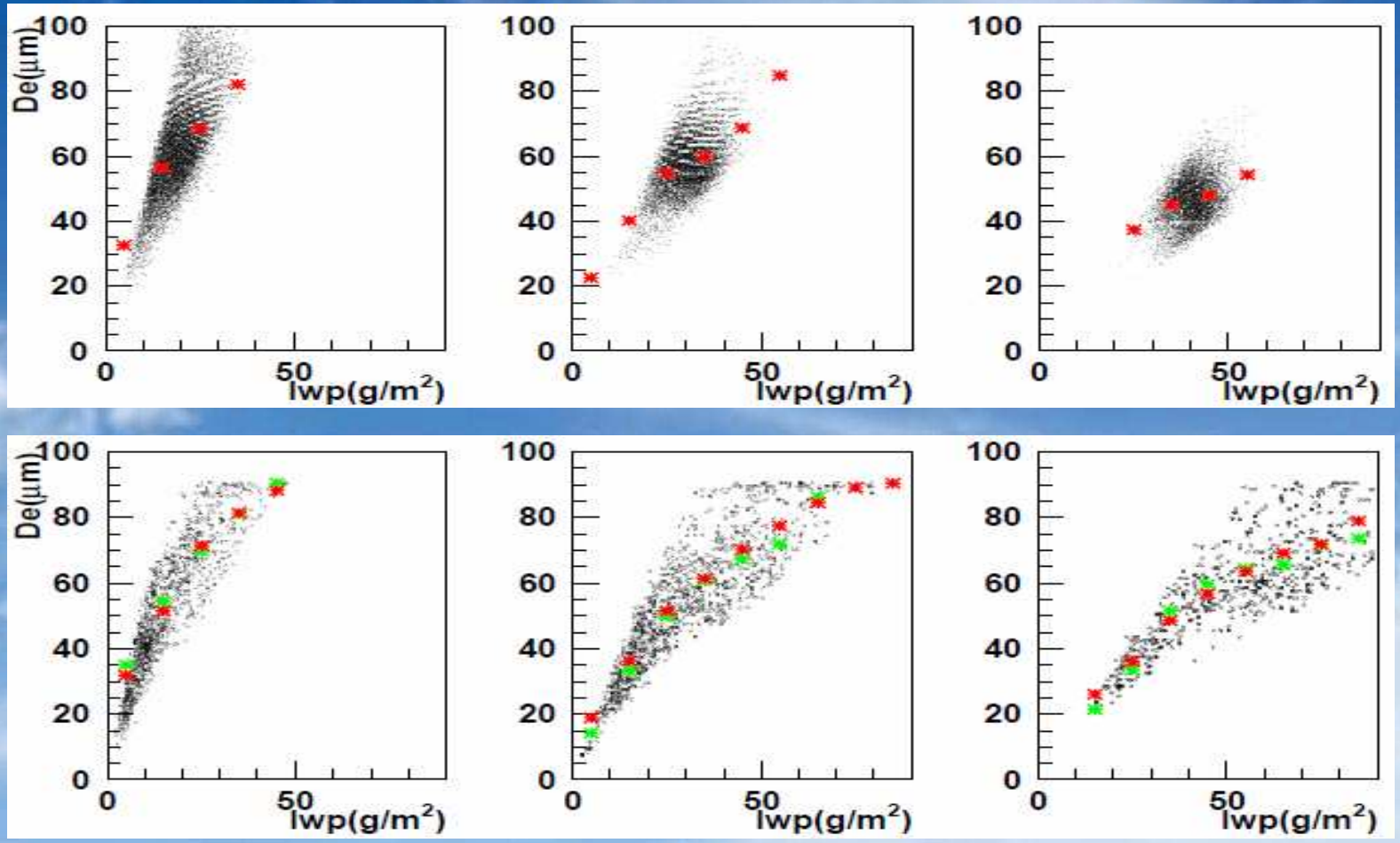
Re and IWP Comparisons with Gewex datasets



-Re: good agreement beteween Airs, Tovs and Modis especially in the tropics
-IWP: bimodal distributions and broader distributions for AIRS

De – IWP correlations

$0.3 < \varepsilon_{cld} < 0.5$	$0.5 < \varepsilon_{cld} < 0.7$	$0.7 < \varepsilon_{cld} < 0.85$



Tovs tropics

Airs tropics

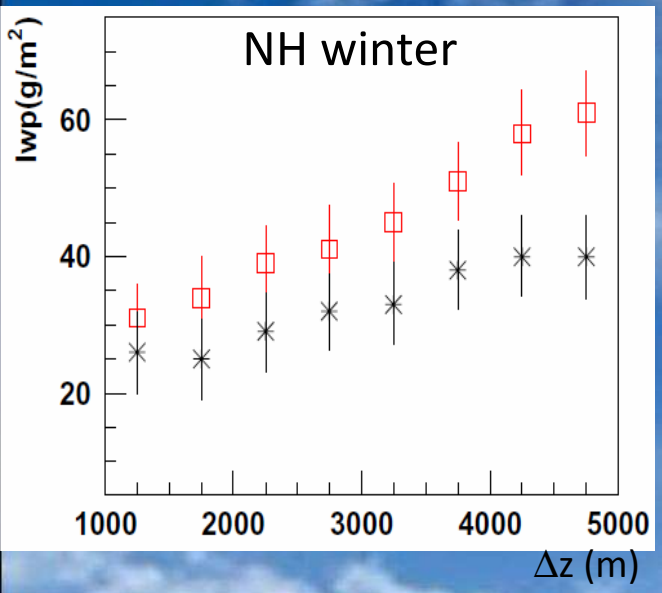
- *Scatter Plot*
- *De Mean Multi layer*
- *De Mean Single layer*

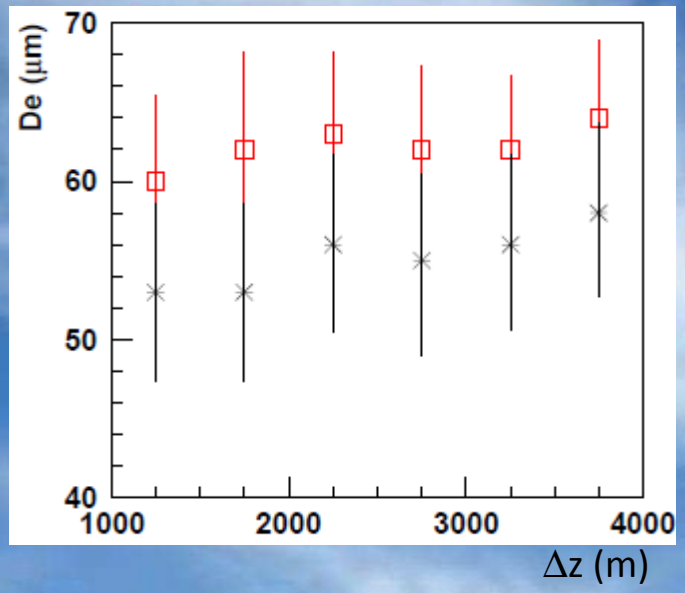
- De increases with IWP stronger increase up to IWP = 40 g/m²

- similar behavior for single / multi layer in summer / winter

in agreement with *(Stubenrauch et al. 2004, 2007 and Pesselt et al.2009)*

IWP,De - Δz correlations



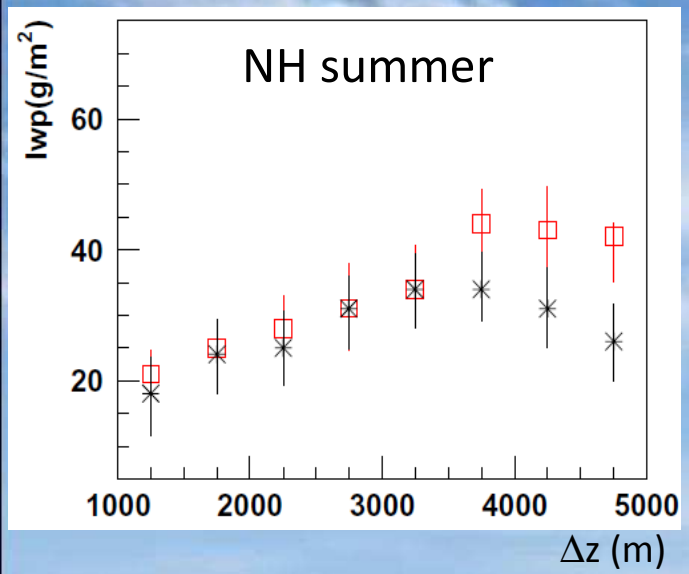


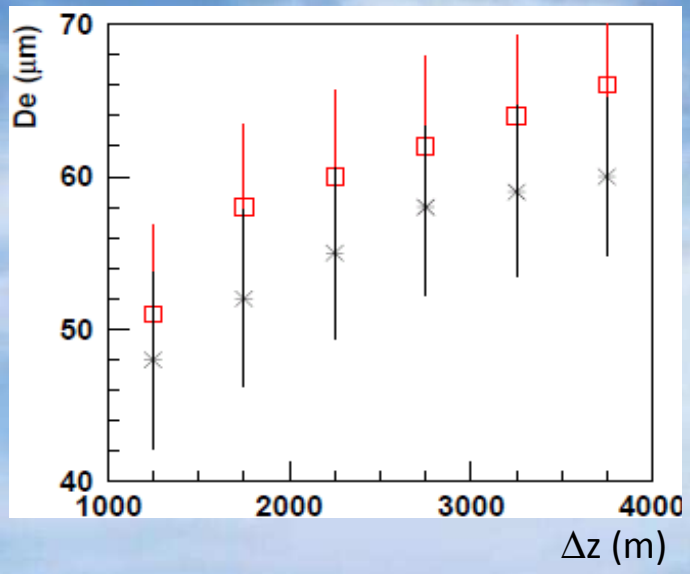
Single-layer cirrus

Multi-layer cirrus

IWP

positive correlation in summer & winter





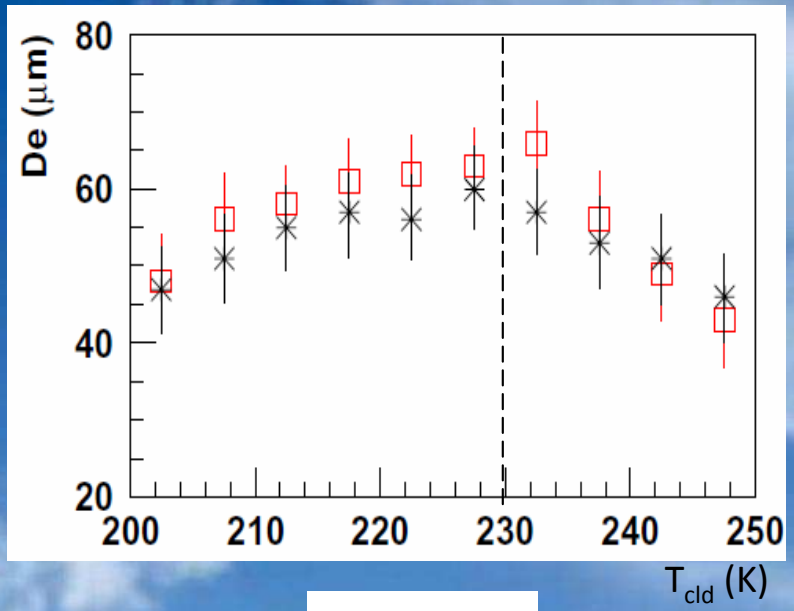
De

positive correlation in summer & winter

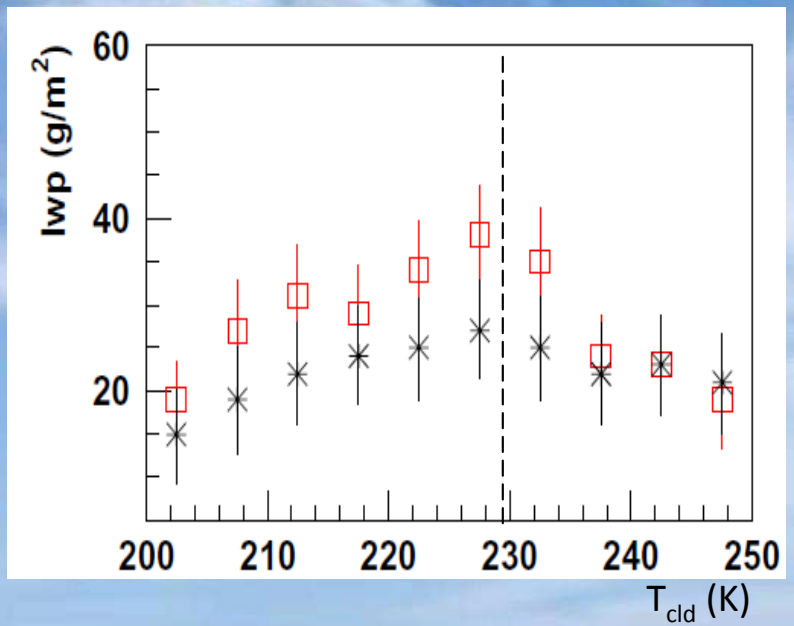
SL have larger De than ML

no correlation in tropics

De, IWP - Tcld correlations



tropics



Single-layer cirrus

Multi-layer cirrus

De and IWP slightly increase with T_{cld} for T_{cld} < 230K

for T_{cld} > 230K :mixed phase

⇒retrieval less reliable

Summary

- AIRS is capable to give estimates of DE / IWP of semi-transparent cirrus,
  on a global scale (50 μm, 30 g/m^2), from 2002 onwards
  in agreement with TOVS retrievals (1987-1990)

- correlations seem to be more robust:
  optically thicker ci have in general larger De and IWP;
  they also seem to contain more aggregates

- De increases with IWP (stronger for IWP < 40g/m^2)

-IWP increases with cloud geometrical thickness
-De only in summer midlatitudes
  similar behavior between single and multi layer cloud systems

- correlation between De / IWP and T_{cld} less pronounced,
  in contrast to in situ measurements
  linked to the fact that T in in situ measurements corresponds to position inside cloud

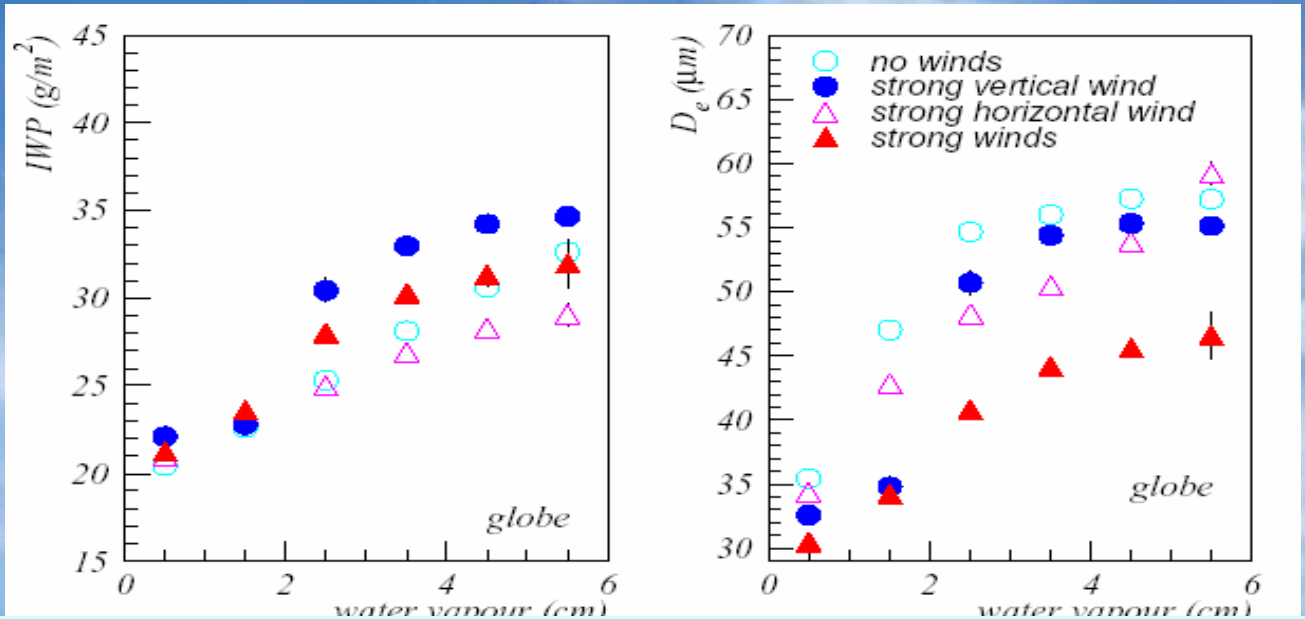
Outlook

-difficult to find reference data sets for our evaluation,

-probably the best way is to compare relationships with those found in situ

- study the differences in relations by distinguishing different dynamical situations

and origin of air masses (Lagrangian study)



Stubenrauch et al., Atm. Res.2004

TOVS ERA-40

IWP largest in case of strong large-scale vertical updraft

D_e smallest in case of strong large-scale hor. & vert. winds