What did we achieve from global cloud satellite observations?

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I P S L

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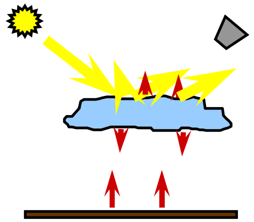
LMD/CNRS

Cloud properties from space:



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**

sampling every 1000km

- **z, τ_{VIS}**
- **vertical extension**
- **cloud layering**
- **microphys. prop. profiles**

➢ Intercomparisons and what we learn from them

➢ Synergy of datasets and of datasets & modelling

(examples, see also talks of 25year ISCCP Symposium)

Longterm cloud climatologies:

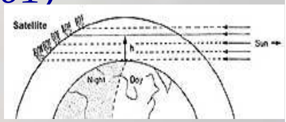
ISCCP ***GEWEX cloud dataset*** ***1983-2006*** *(Rossow et al. 1999)*

PATMOS-x ***AVHRR*** ***1981-2006*** *(NESDIS/ORA; Heidinger et al.)*

HIRS-NOAA ***13h30/1h30*** ***1985-2001*** *(Wylie et al. 2005)*

TOVS Path-B ***7h30/19h30*** ***1987-1995*** *(Stubenrauch et al. 2006)*

SAGE ***limb solar occultation*** ***1984-1991,1993-2005*** *(Wang et al. 1996, 2001)*



SOBS (Surface Observations): ***1952-1996(sea), 1971-1996(land)*** *(Hahn & Warren 1999; 2003)*

EOS cloud climatologies *(since 2000, 2002)*:

MODIS-ST *(Ackerman et al.)* **MODIS-CE** *(Minnis et al.)*

AIRS-LMD *(Stubenrauch et al. 2008)*

+ A-Train *(since 2006)*:

CALIPSO L2 data (V2) *(Winker et al. 2007)* ***active lidar***

CloudSat *(Mace)* **POLDER** *(Riedi)* **MISR** *(DiGirolamo)* **ATSR2** *(Poulsen)*

Global Energy and Water Cycle Experiment GEWEX WCRP

Cloud Assessment

co-chairs:
C. Stubenrauch, S. Kinne

http://climserv.ipsl.polytechnique.fr/gewexca

ISCCP *(Rossow & Schiffer BAMS, 1999)*

Evaluation

night: +75 hPa p_{cld} bias *(Stubenrauch et al. 1999)*

uncertainties depend on cloud type:

- ***Stratus (τ_{cld}>5):*** p_{cld} 25-50 hPa within radiosonde meas., ~ -65 hPa bias; err T_{cld}<1.5 K
- ***high clouds (τ_{cld}>5, with diffuse top):*** p_{cld} 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

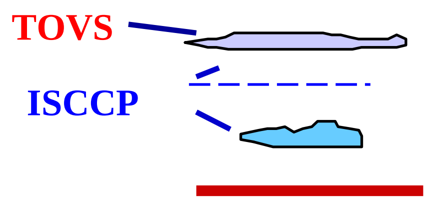
15% τ_{cld} decrease for doubling droplet size

ISCCP – TOVS comparison

agreement for homogeneous scenes

remaining discrepancies: cirrus at night / partly cloudy / multi-layer clouds

IR Sounder good spectral resolution -> properties of uppermost cloud



TOVS Path-B *(Stubenrauch et al. J. Clim. 2006)*

p_{cld} uncertainty 25 hPa over ocean, 40 hPa over land (2nd χ^2 solution)

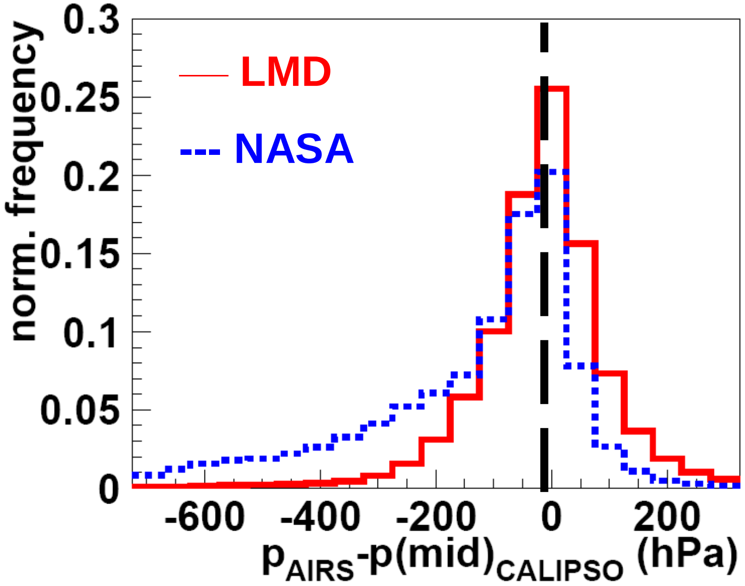
p_{cld} = mid-cloud $p_{cld,}$: 600m/ 2 km below cloud-top (low/high clouds) (LITE, *Stubenrauch et al. 2005*)

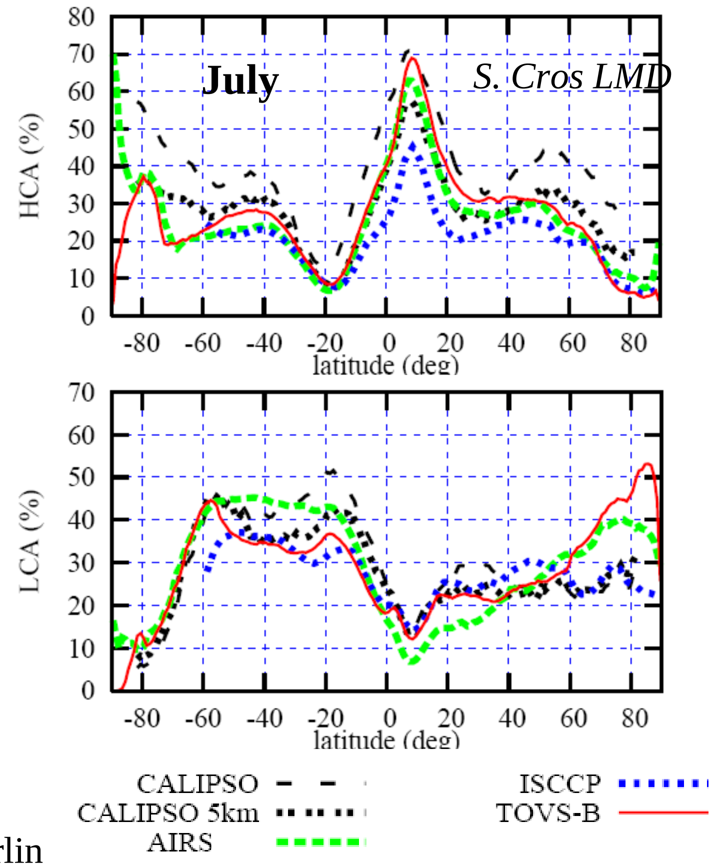
Sensitivity study for D_e of Ci *(Rädel et al. 2003)*

Evaluation of AIRS cloud height with CALIPSO

AIRS-LMD: retrieval based on weighted χ^2 method as in TOVS-B *Stubenrauch et al., JGR 2008*

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





good agreement with CALIPSO cld midlevel

(highest, detected at ≤5km)

properties also depend on retrieval method

Average CA

ISCCPday(84-04) TOVS-B(87-95) HIRS-NOAA(85-01) AIRS-LMD(03-08) SAGE(85-99) CALIPSO(06-07) PATMOS-x(81-06) MODIS-CE(03-05) MODIS-ST(02-06) ISCCP-IR(84-04) SOBS(84-04)

CA (%)	glo bal											oce an											la nd										
all	66	73	75	63	95	76	66	61	67	61	64	70	74	77	66	95	84	72	66	73	65	69	58	69	70	57	97	63	50	50	59	51	54
Thick Ci	3	2	2	4								3	2	1	3								3	4	5	4							
Cirrus	19	27	31	23								18	27	33	23								21	27	29	24							
HCA/ CA	33	41	44	43	44	50	38	42	30	21	23	30	39	44	39	44	46	35	37	27	18	17	41	45	49	50	45	61	47	56	37	29	43
MCA / CA	27	16	16	11	20	14	19	16	19	33	44	26	14	14	10	18	12	17	14	15	29	42	31	25	17	15	25	20	25	20	29	43	48
LCA / CA	39	42	37	46	36	35	44	44	52	46	72	41	47	42	50	38	42	49	51	59	52	80	29	30	34	35	29	19	29	26	34	27	48

diurnal sampling, time period for ISCCP / TOVS-B: 1% effect; low-level over land: 2% (Stubenrauch et al. 2006)

~ 70 % (±5%) cloud amount: 5-15% ***more over ocean than over land***

PATMOS, MODIS-CE low (land), SAGE CA (200km, clds τ>0.03) **1/3 higher**

40% single-layer low clouds: ***more over ocean than over land; SOBS***

40% high clouds: ***only 3% thick Ci; more over land than over ocean***

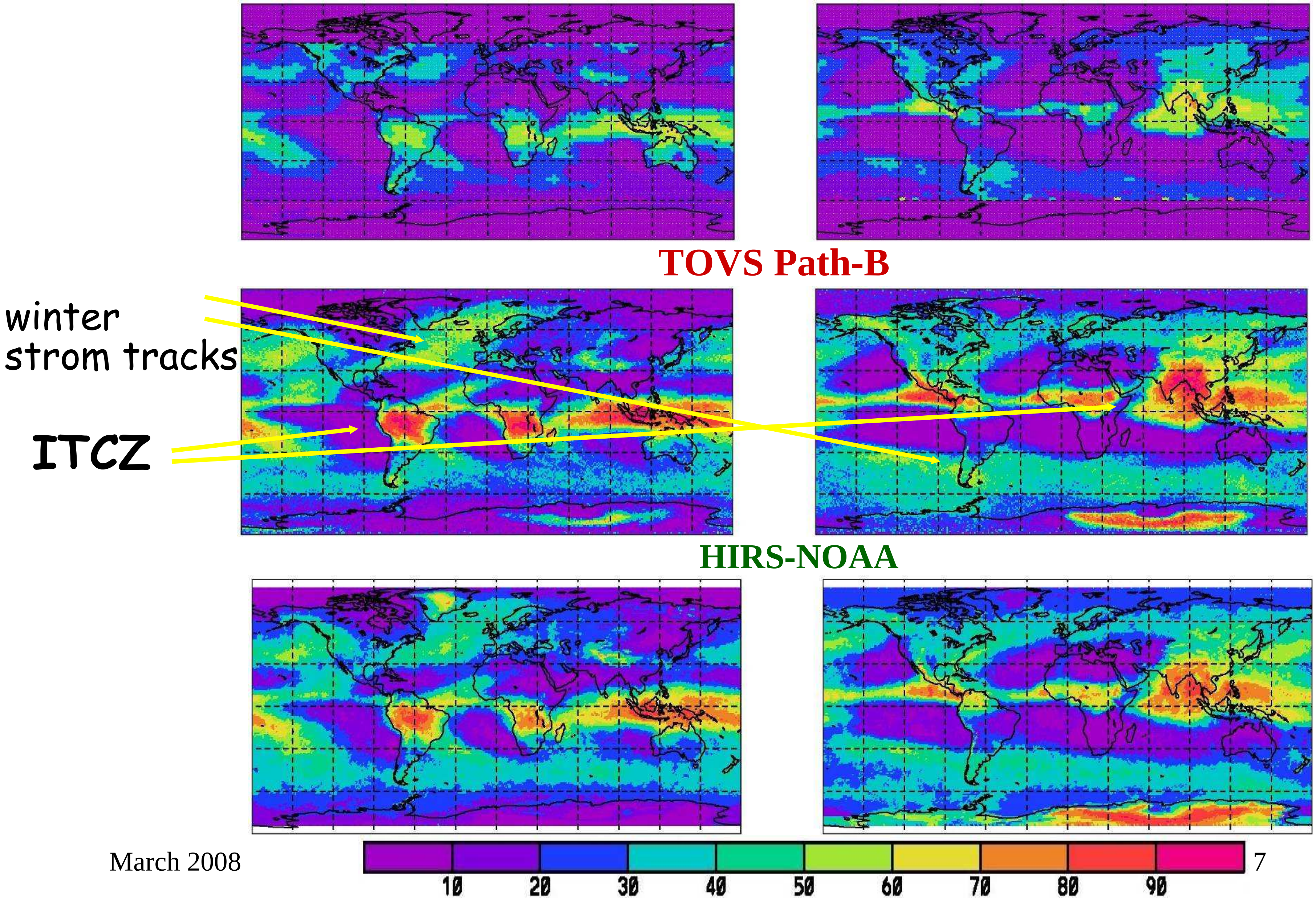
IR sounders ~ 10% more sensitive to Ci than ISCCP (15% in trps)

SAGE cloud vertical structure in good agreement with IR sounders

HCA/CA: CALIPSO>SAGE,TOVS/HIRS > MODIS-CE > PATMOS > $ISCCP_{day}$ > MODIS > $ISCCP_{IR}$

HCA geographical distributions

January **ISCCP** *July*

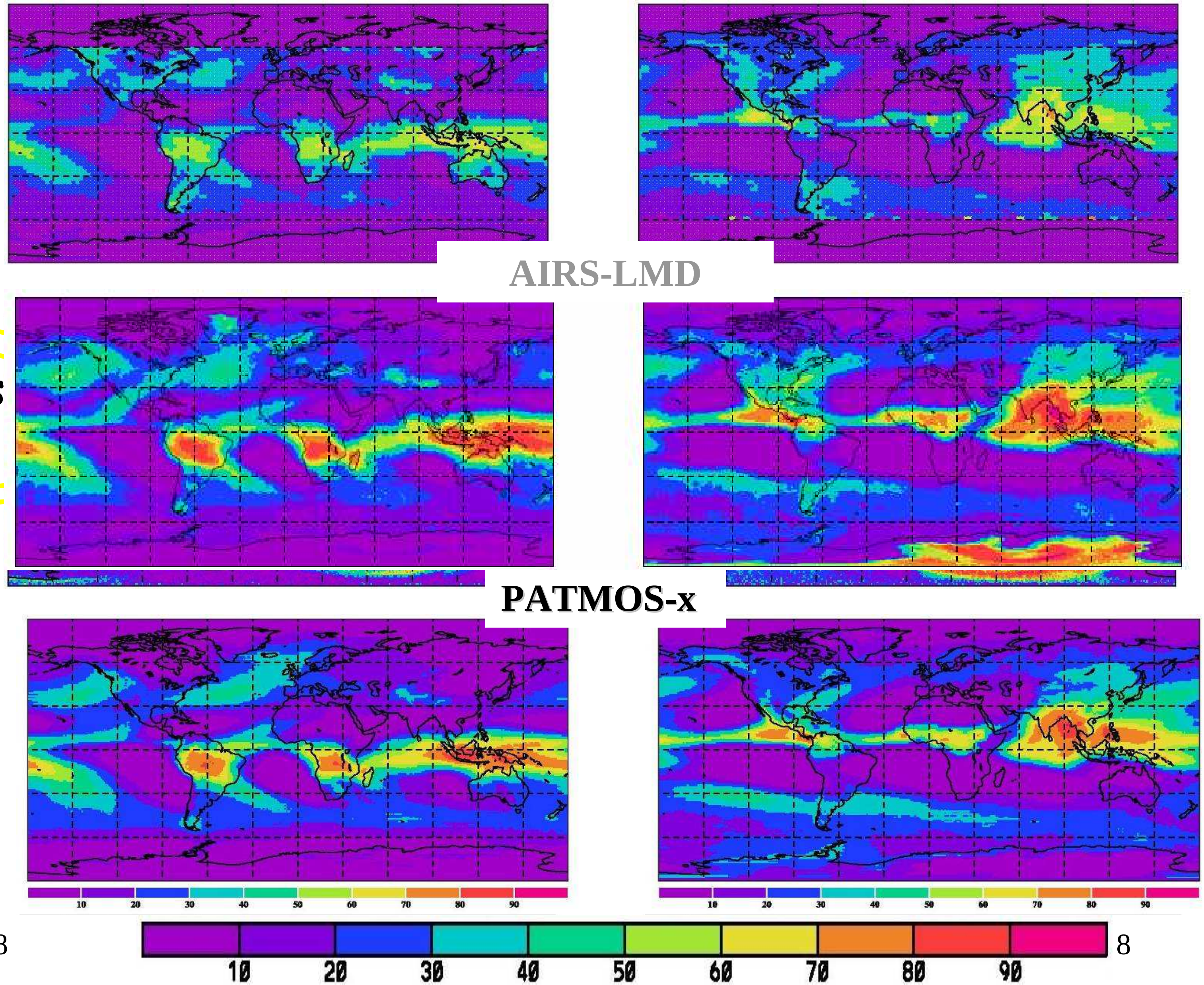


HCA geographical distributions

January **ISCCP** *July*

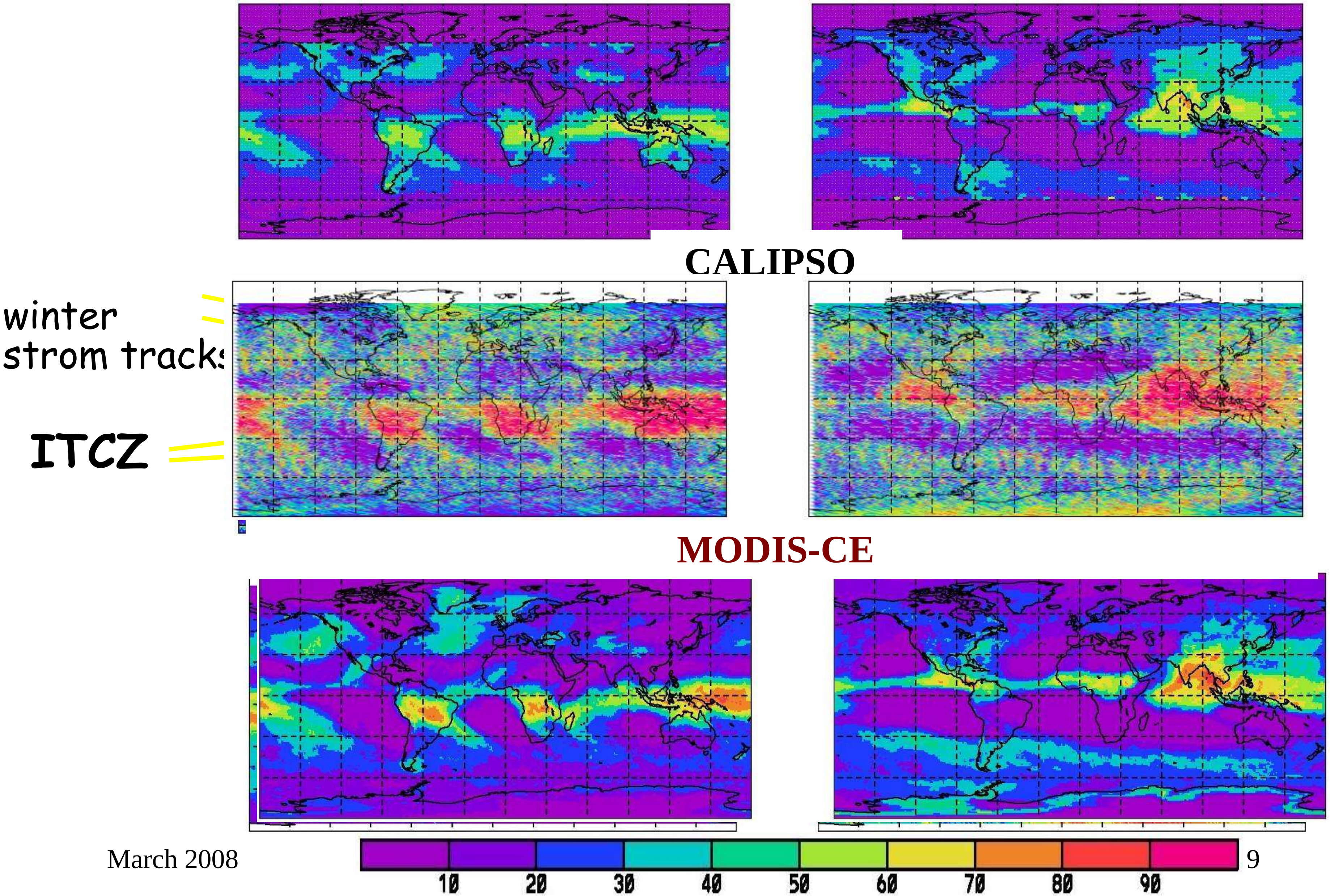
winter
strom tracks

ITCZ

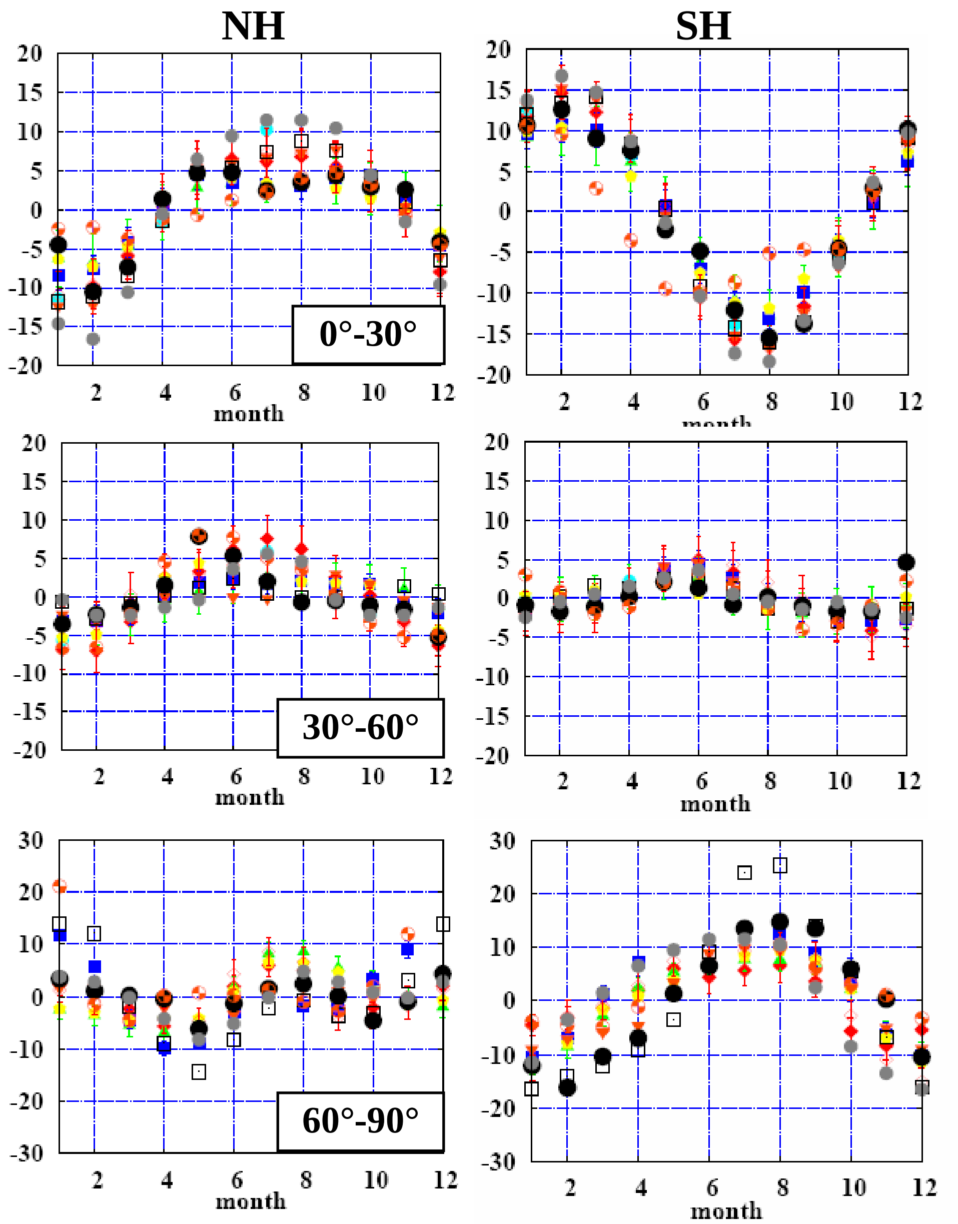


HCA geographical distributions

January **ISCCP** *July*



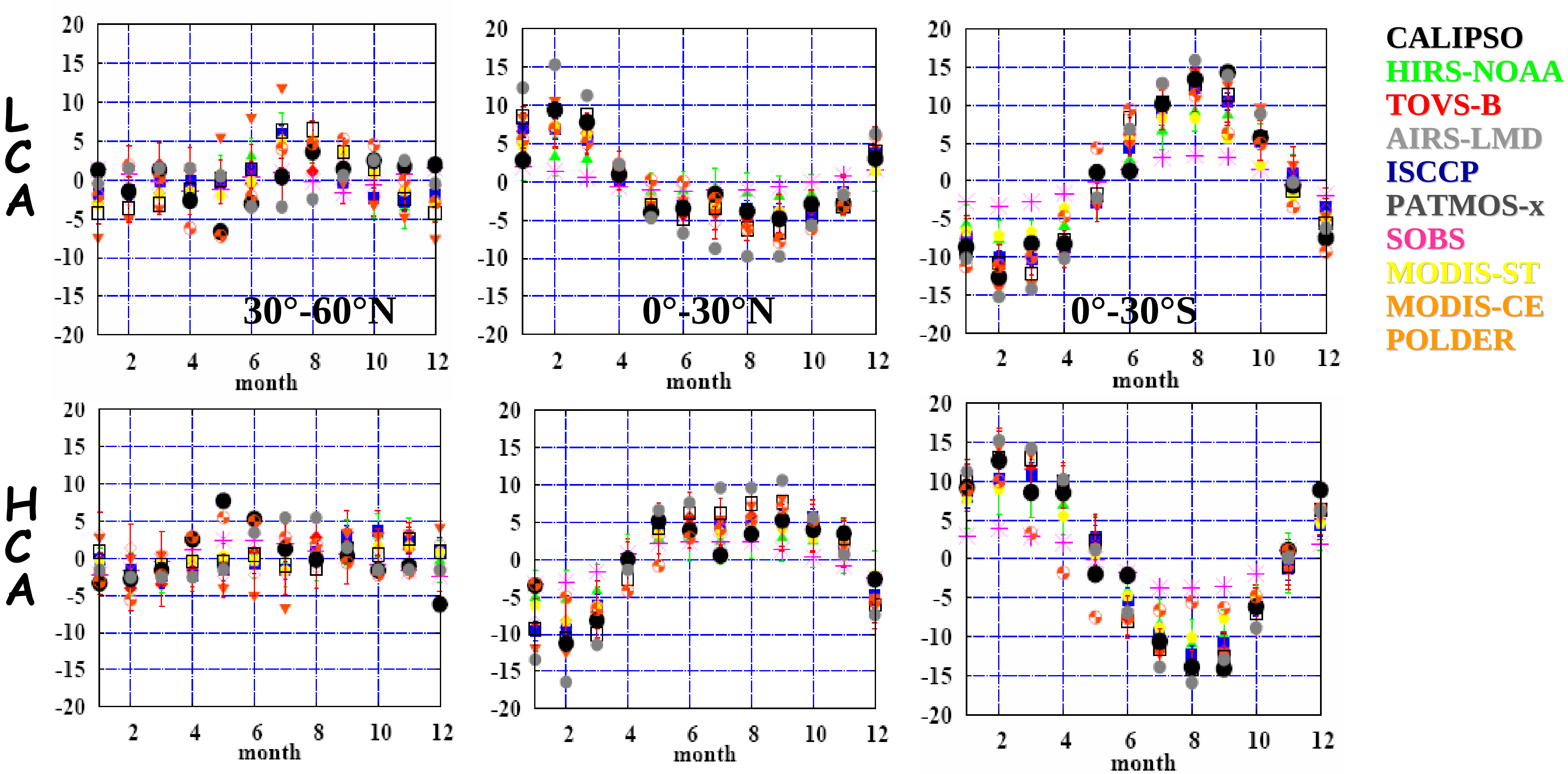
HCA/CA seasonal cycle



Seasonal cycles similar:

30% in SH tropics to 5% in SH midlatitudes

LCA/CA seasonal cycle over ocean

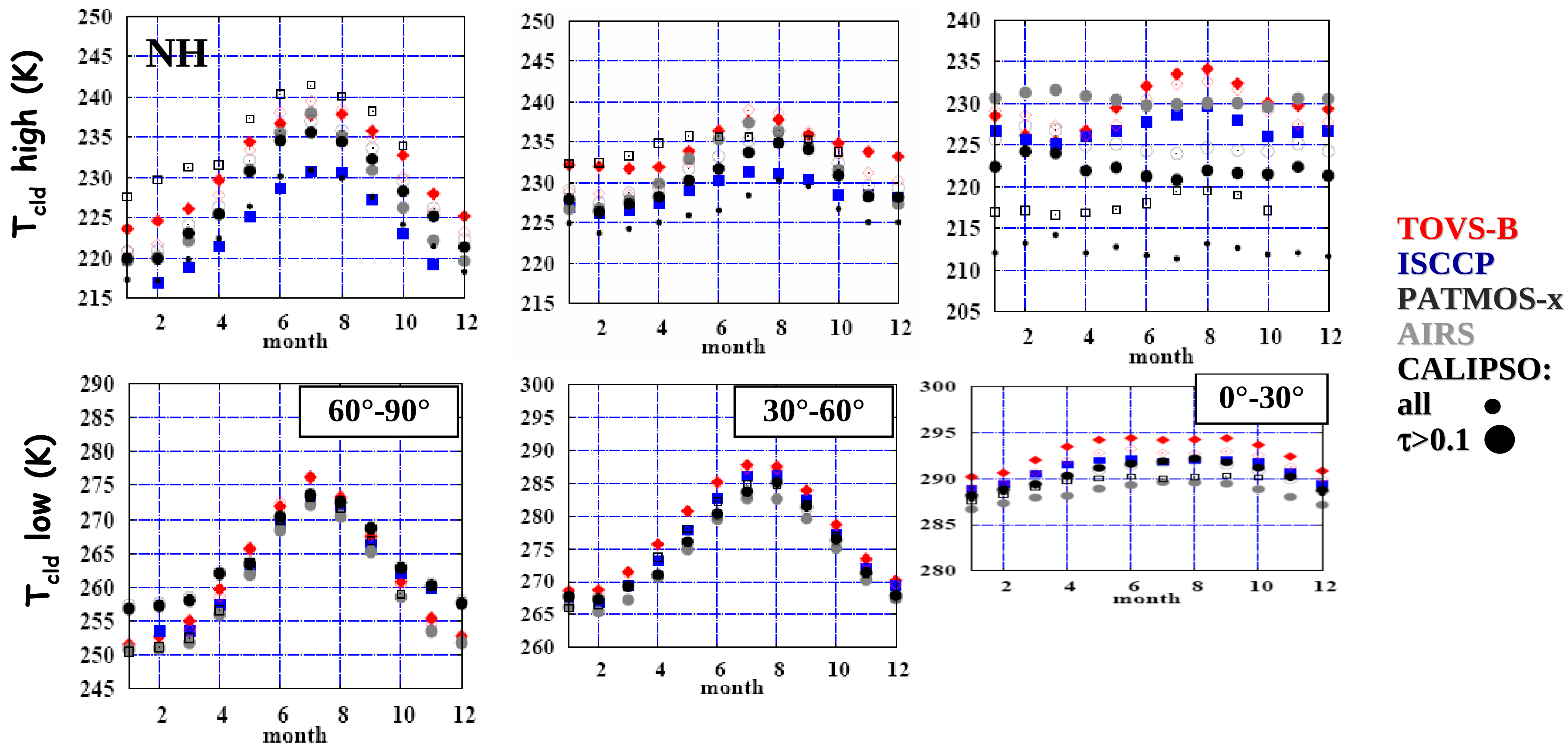


small seasonal cycle; exception: SH subtropics stratocumulus regions (20%)

SOBS: 18% more LCA and smaller seas. cycle over ocean

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

cloud temperature of high and low clouds



Seasonal cycle of high T_{cld} decreases from polar (15°), midlat (10°) to tropics (5°)
low T_{cld} (20°) (20°) (5°)

CALIPSO: thin high clouds colder than thicker high clouds (τ>0.1), esp. in tropics

differences : largest for high clouds in tropics, very good agreement for low clouds

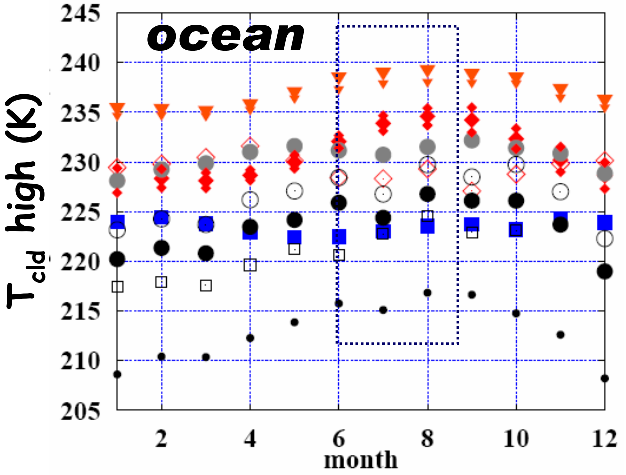
uncertainties in cloud height determination (esp. thin cirrus), T profiles

Tropical high clouds: T_{cld} distributions

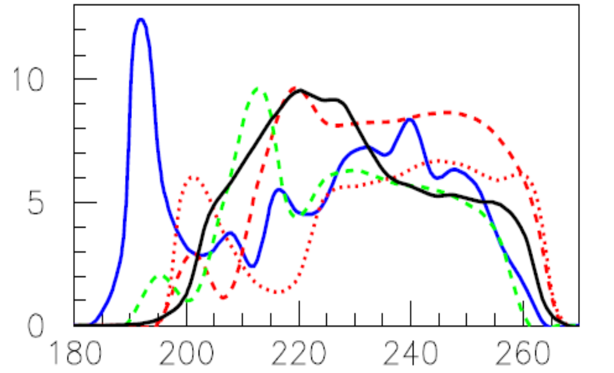
SH

0°-30°

TOVS-B
ISCCP
PATMOSX
MODIS-CE
AIRS
CALIPSO:
all •
τ>0.1 ●
τ>0.2 O



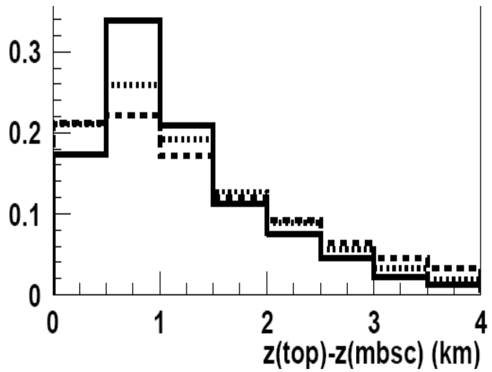
ISCCP CALIPSO TOVS AIRS

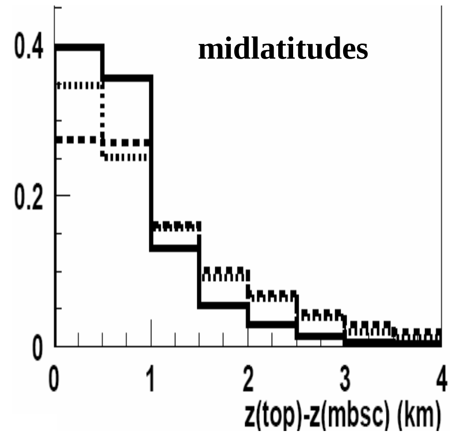


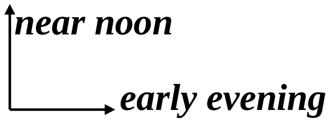
Clouds in tropics have diffuse cloud tops:

CALIPSO max backscatter ≥ 1km below cloud top

AIRS-LMD:
— ε_{cld} > 0.95
--- 0.95 > ε_{cld} > 0.50
···· 0.50 > ε_{cld} > 0.05







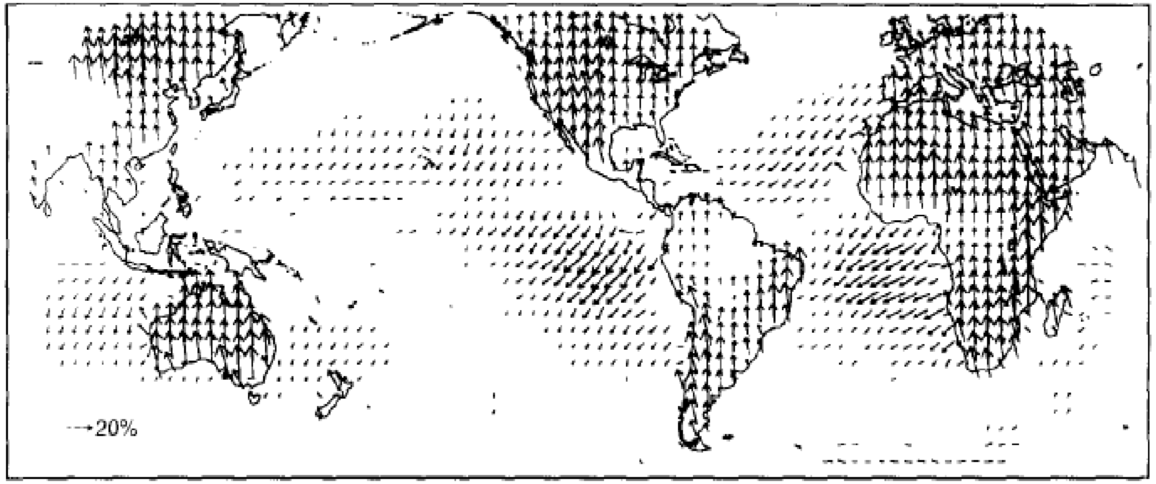
diurnal cycle of clouds

Cairns, Atm. Res. 1995

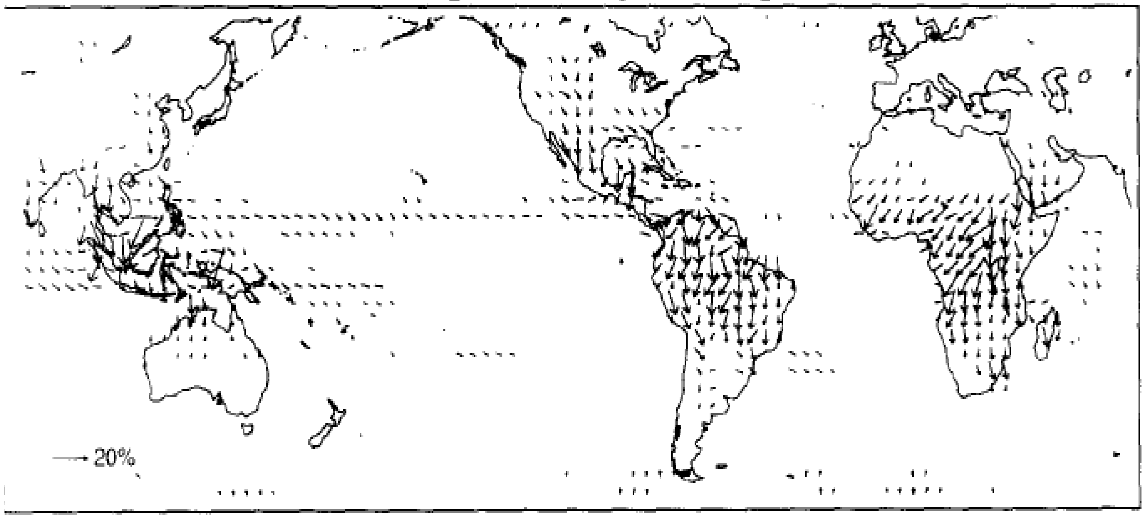
ISCCP C2, Complex Empirical Orthogonal Functions,

project. on distorted diurnal harmonics

Annual Average Diurnal Cycle for Low Cloud



Annual Average Diurnal Cycle for High Cloud



- **Low clouds over land:**
  significant diurnal cycle,
  max early afternoon

- **Low clouds over ocean:**
  max in early morning

- **High clouds:**
  max in evening

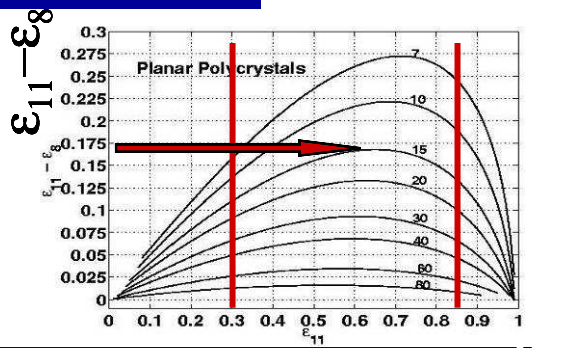
- **Mid clouds:**
  max in early morning
  or late at night
  (-> cirrus : TOVS analysis)

Stubenrauch et al. 2006

effective ice crystal diameter

semi-transparent cirrus **TOVS Path-B, 87-91** *(Rädel et al. JGR 2003)*

cloud properties	60N-60S	ocean	land
D_e [μm]	55.3	54.7	56.8
ε	0.59	0.58	0.60
IWP [gm^{-2}]	30	30	31



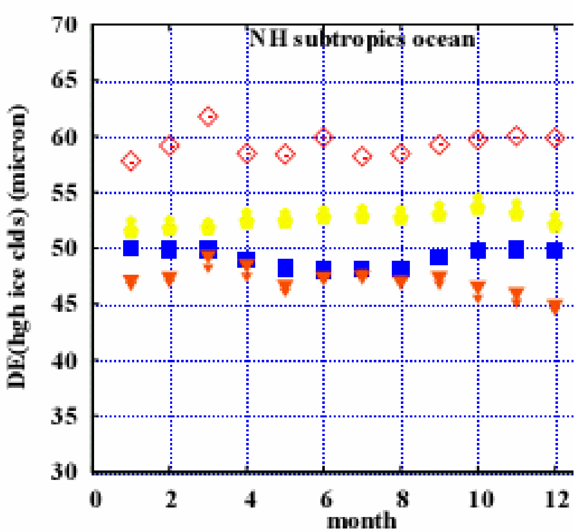
ε_{11}

D_e similar over land & ocean

high clouds **MODIS-ST, 02-05** *(Hong et al. J. Appl. Met. 2007)*

cloud properties	30N-30S	ocean	land
D_e [μm]	53.0	55.6	47.0
ε	0.69	0.70	0.66

D_e slightly larger over ocean



ISCCP
TOVS-B
MODIS-CE
MODIS-ST

preliminary

NIR-VIS:
D_e near cloud top

IR:
D_e averaged over cloud depth

Uncertainties on ice crystal size retrieval

Rädel et al., JGR 2003

Overestimation of D_e:

up to 25%

- ♦ **thin Ci with underlying water cloud**
- ♦ **partial cover of thick Ci**
- ♦ **hexagonal colmuns instead of polycrystals**

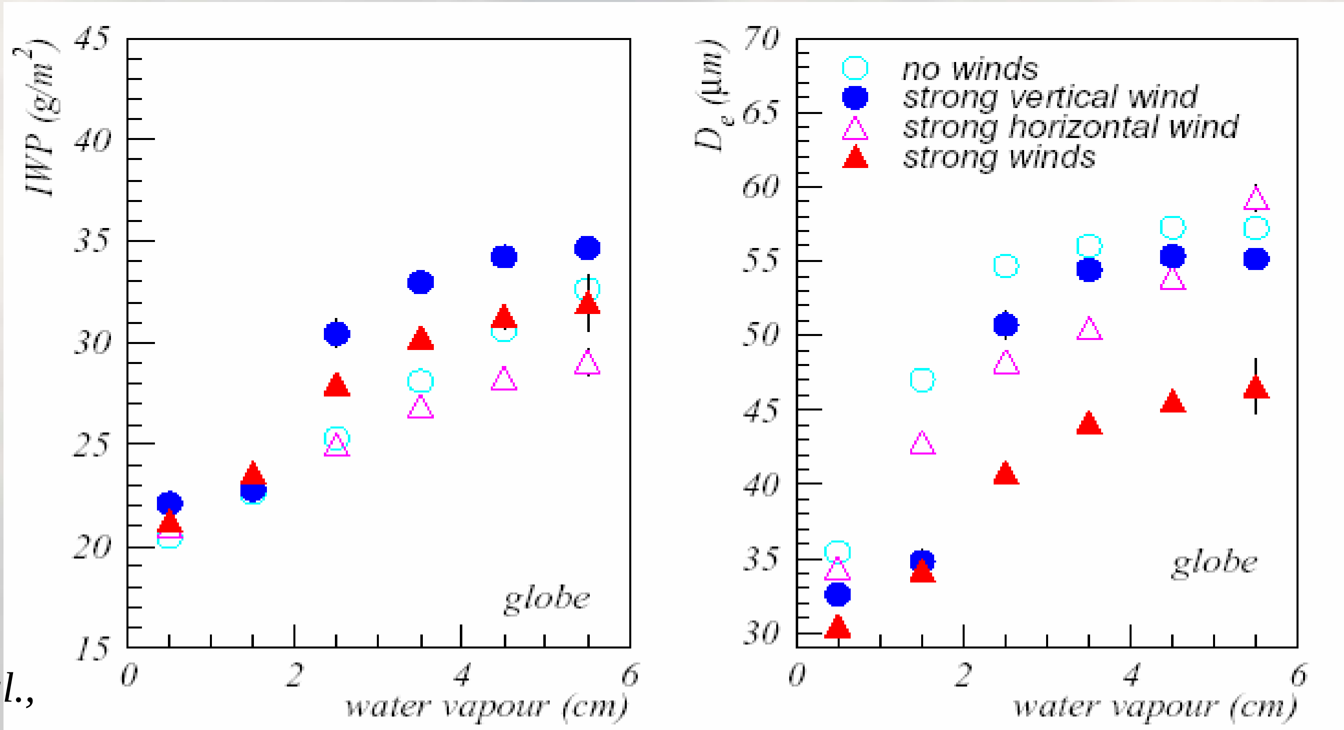
Underestimation of D_e:

up to 25%

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

D_e & IWP as function of humidity & wind

Large-scale semi-transparent cirrus 60°N – 60°S, 4 year averages



Stubenrauch et al., Atm. Res.2004

TOVS -ERA40

IWP and D_e increase with atmospheric water vapour
IWP largest in case of strong large-scale vertical updraft
D_e smallest in case of strong large-scale hor. & vert. winds

Longterm datasets

➢**trend analysis :**

➢***be very careful of artificial satellite features***

➢***use synergy of different variables***

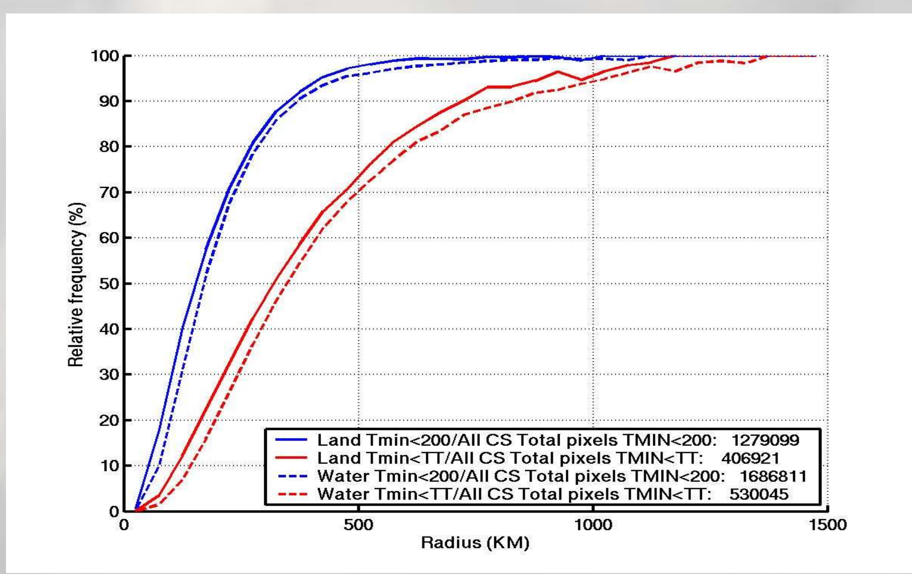
➢**explore rare events :**

tropical convection penetrating into the lower stratosphere

cluster analysis of ISCCP DX data (***Rossow & Pearl GRL 2007)***

⬇

occurrence predominantly in larger, organized mesoscale convective systems

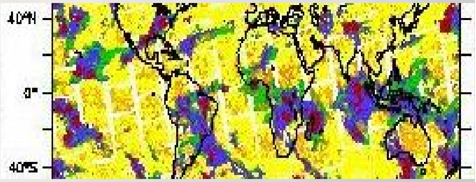


Instantaneous global coverage

➢**explore horizontal extension of cloud systems**
& relation with thermodynamic and dynamic properties:

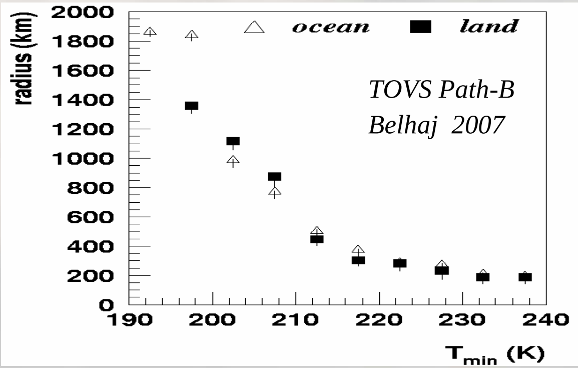
cluster analyses (ISCCP: *Rossow & Jakobs, GRL 2005*; TOVS Path-B: *Rädel 2004*)

30/12/1989 7:30 PM

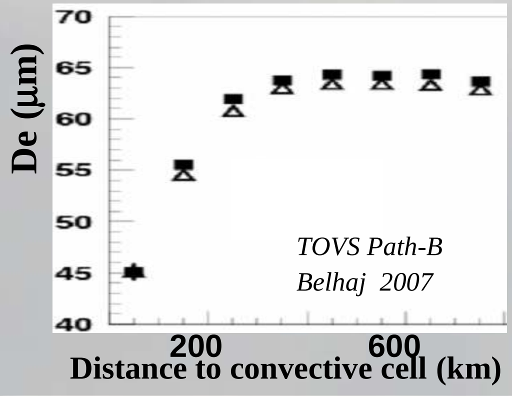


Tropical systems

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



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



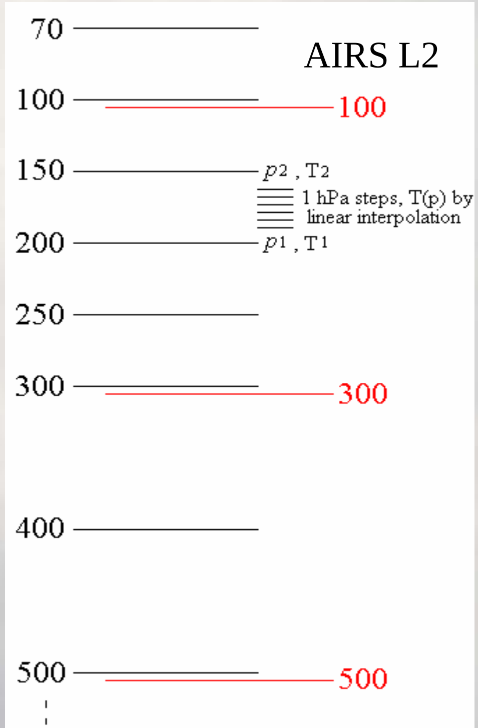
Evolution of D_e during life cycle of convective system

➢D_e increases with distance from convective cell

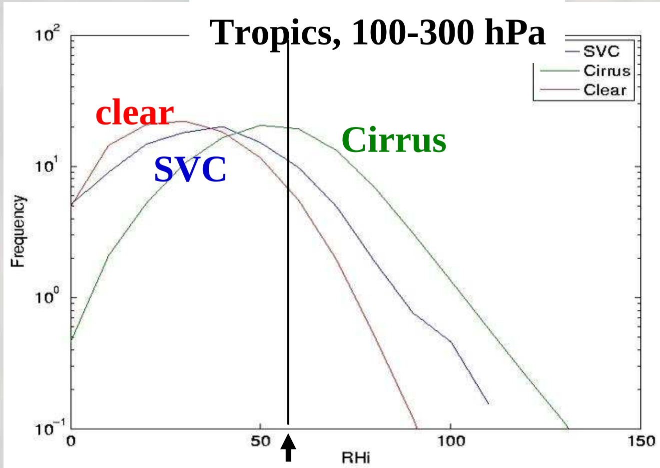
➢D_e increases during life cycle of system

How can we detect ice supersaturation from satellite observations ?

TOVS/AIRS humidity: per layer

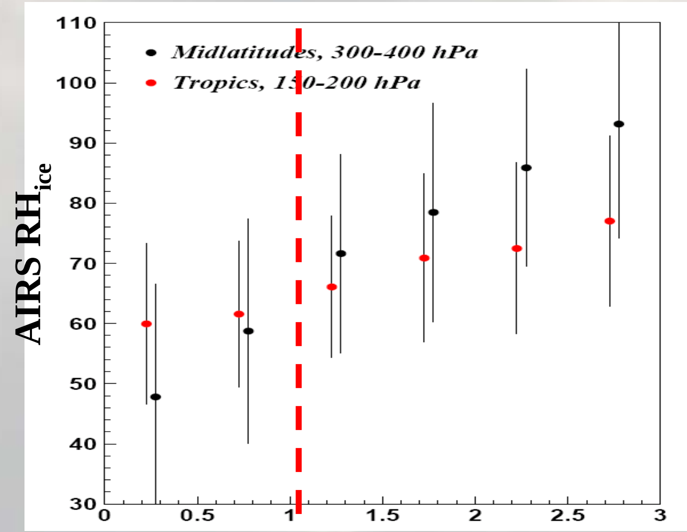


RH_{ice} distributions



Stubenrauch & Schumann GRL 2005
Kahn et al. Atmos. Chem. Phys. 2007

ice supersaturation : RH_{ice} > 60% (peak for Ci)



Lamquin et al. JGR 2008

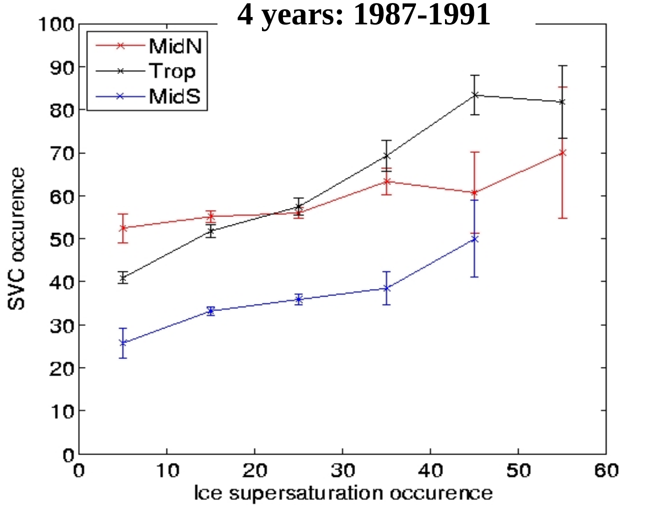
RH_{ice} increases with Δz_{cld}
but: $\langle RH_{ice} \rangle \approx 65\%$
even if whole layer is filled

Influence of ice supersaturation on cirrus occurrence

RH_{ice} : TOVS Path-B

subvis. Ci (SVC) : SAGE II

(P.-H. Wang)

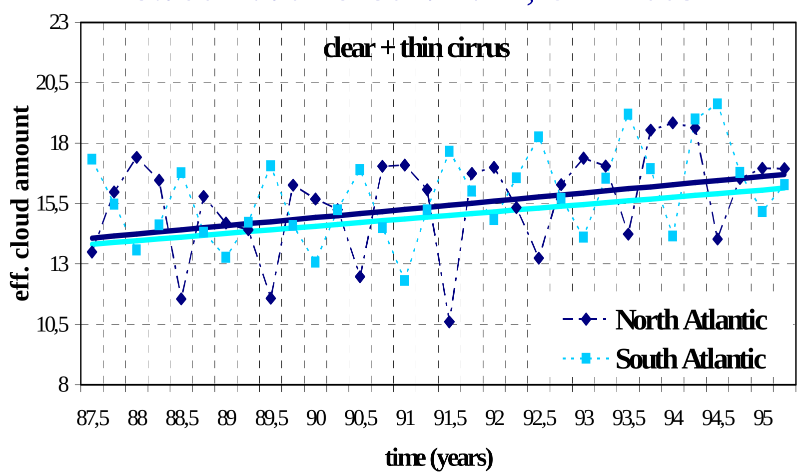


Lamquin et al. EGU 2007

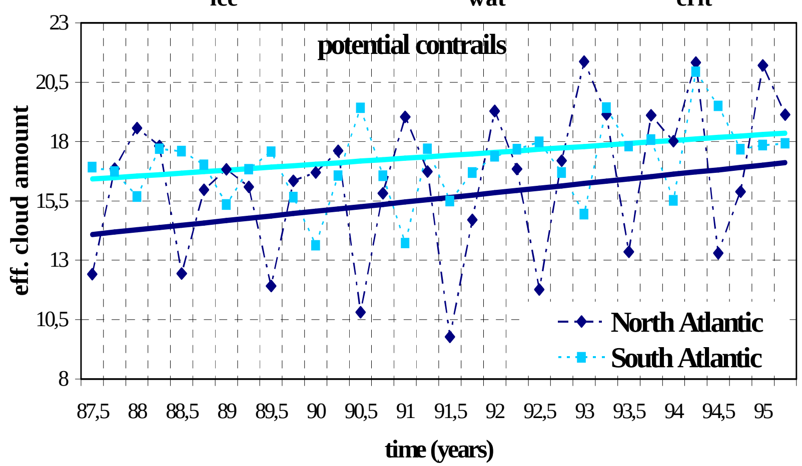
extending results of *Gierens (2000)* *(using MOZAIC data in NH midlat)*

Contrail occurrence

Stubenrauch & Schumann, GRL 2005



$RH_{ice} < 70\%$ & $RH_{wat} > 0.4\ RH^*_{crit}$



increase of thin Ci in both hemispheres

stronger increase related to contrails in NH

Synergy of retrieved cloud properties & model :

Cirrus radiative flux analysis

eliminate multi-layer clouds

TOVS
atmospheric profiles
cirrus properties

D_e=10-90μm; D_e=f(IWP),= f(T)

radiative transfer model:

Met Office

- p_{cld} = p(mid-cloud) Δp = 100 hPa(≈ 2 km)
- *Single scattering properties (SSPs) = f(λ, D_e)*
  for hex. columns, aggregates
- choose IWP with $\varepsilon(IWP,D_e) \approx \varepsilon_{cld}^{IR}$
  look-up tables $\varepsilon_{cld}^{IR}(IWP,D_e)$,depending on θ_v, Δz, SSPs

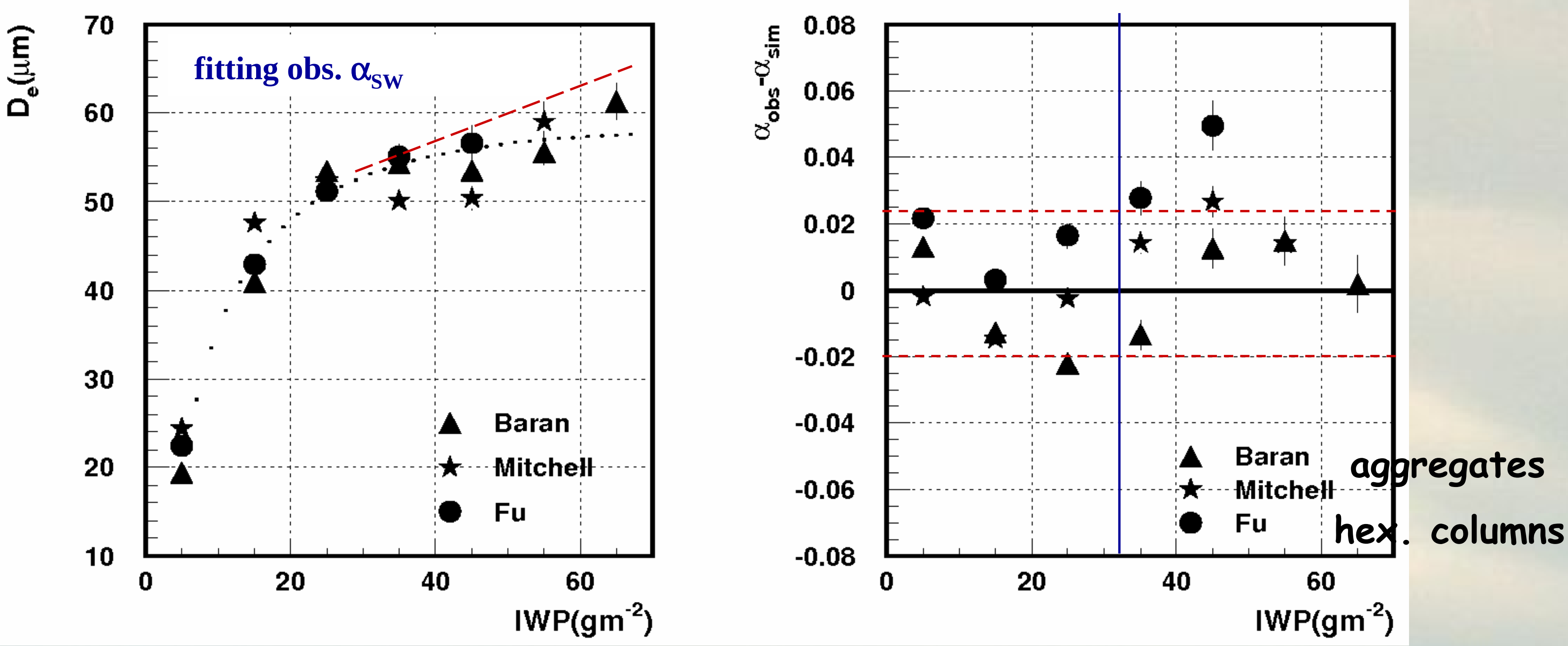
ADMs

1500 ScaRaB fluxes ⟷ *simulated fluxes*

$$\alpha^{SW}(\theta_0) = \frac{\pi L^{SW}}{R(\theta_0, \theta_v, \phi, \tau, phase, het)\, E_0 \cos\theta_0}$$

Coherence between IR IWP and SW albedo

Stubenrauch et al. J. Clim. 2007



best fit to data:
increase of D_e with IWP

columns only fit data at small IWP, aggregates at larger IWP

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

❖70% (±5%) clouds: ~ 40% high clouds & ~40% single-layer low clouds

❖geographical cloud structures and seasonal cycles agree quite well

❖absolute values depend on instrument sensitivity (& retrieval method)

❖GEWEX Cloud Assessment: WMO report in preparation *(end 2009)*

❖ monthly mean cloud parameters (CA,HCA,MCA,LCA,T_{cld},ε,τ, D_{eff},WP), variabilities, uncertainties will be available in netcdf at:

http://climserv.ipsl.polytechnique.fr/gewexca

❖ Synergy of different data sets & variables very important:
Evaluation of climate models by comparing correlations!

⇒ important to synchronize satellite missions (A-Train)

EarthCARE (1:30AM/PM) – IASI Metop (10AM/PM) synergy ?