Assessment of Global Cloud Climatologies

project of GEWEX Radiation Panel / WCRP

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+
GEWEX cloud assessment group
(S. Ackerman, R. Eastman, A. Evan, A. Heidinger, N. Lamquin, B. Maddux, P. Minnis, J. Norris, W. B. Rossow, S. Sun-Mack, P.-H. Wang, S. Warren, D. Winker, D. Wylie…)

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

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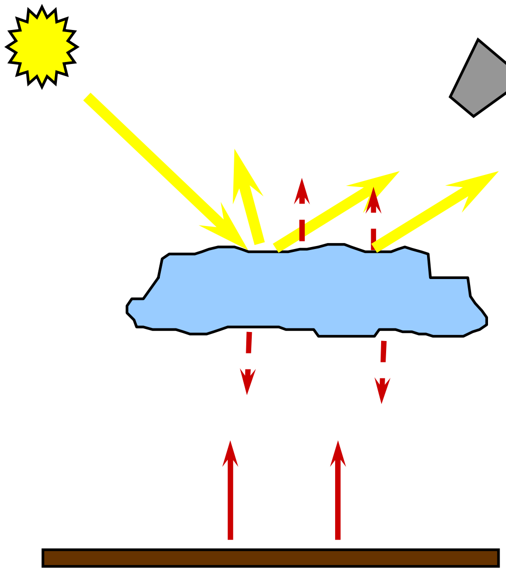
(≥ 2006) **C. Stubenrauch,** *CNRS/IPSL - Laboratoire de MétéorologieDynamique, France*
(≥ 2008) **S. Kinne,** *MPI Hamburg, Germany*

Satellite radiometers measure:



emitted, reflected, scattered

radiation

INVERSION

cloud detection
inverse radiative transfer

cloud properties

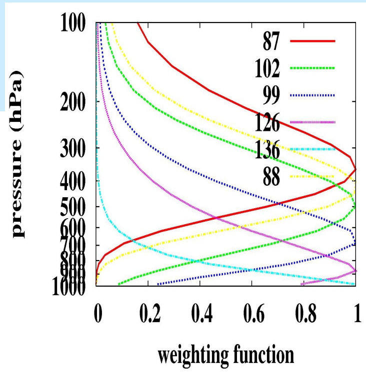
GEO (3hrs) *+polar* | *polar satellites* (12/6 hrs)

ISCCP
IR, VIS

PATMOS-x
IR, NIR, VIS

HIRS-NOAA, TOVS Path-B
IR Vertical Sounder: CO_2-band

MODIS **AIRS**



Longterm cloud climatologies:

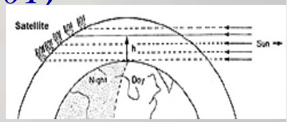
ISCCP ***GEWEX cloud dataset*** ***1983-2006*** *(Rossow et al. 1999)*

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

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 *(Susskind et al.2003; Stubenrauch et al. 2008)*

+ A-Train *(since 2006)*:

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

Evaluation & analysis of cloud properties:

average, regional, seasonal variations, diurnal cycle

Correlation between cloud properties

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

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)*

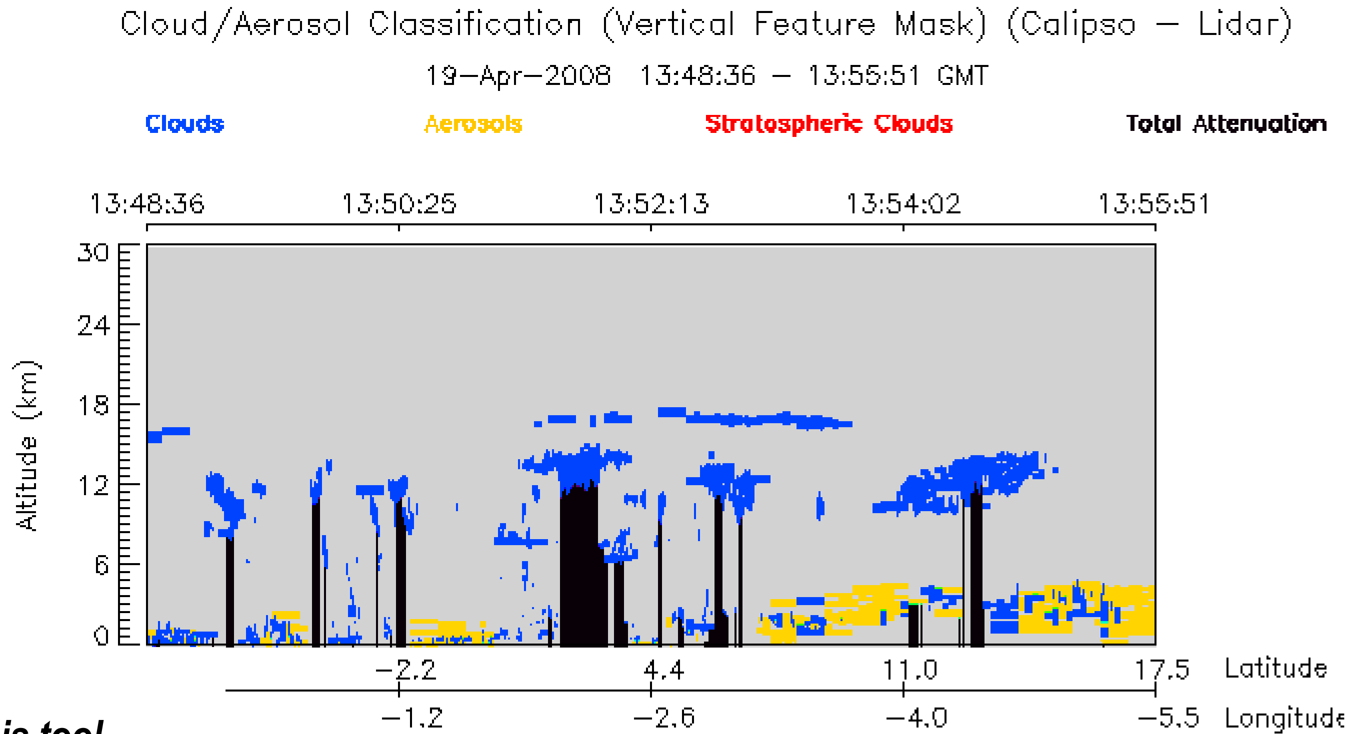
HIRS-NOAA *(Wylie & Menzel J. Clim. 1999, not yet Wylie et al. J. Clim. 2005)*

p_{cld} 70 hPa above top (lidar, *Wylie & Menzel 1989*)

100 hPa above for transmissive cloud overlying opaque cloud *(Menzel et al. 1992)*

A-Train: synergy of passive and active instruments

active instruments -> vertical structure of clouds
lidar sensitive to very thin cirrus

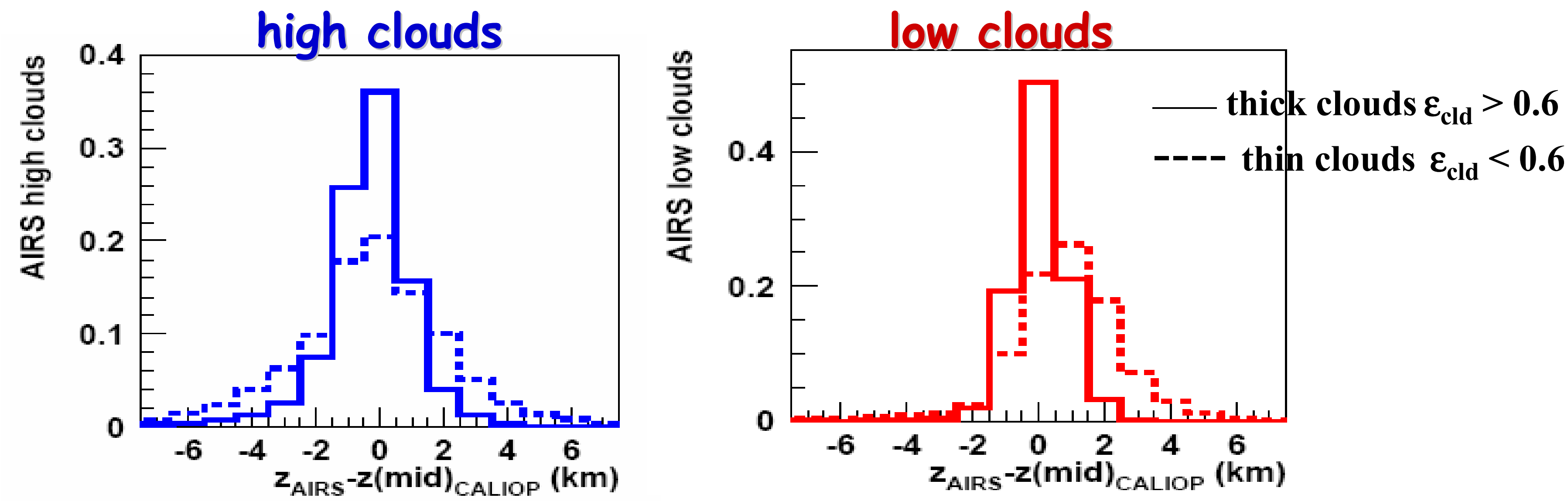


NASA Giovanni:
online data visualization & analysis tool

http://disc.sci.gsfc.nasa.gov/techlab/giovanni

Evaluation of AIRS-LMD cloud height with 1 year collocated CALIPSO data

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

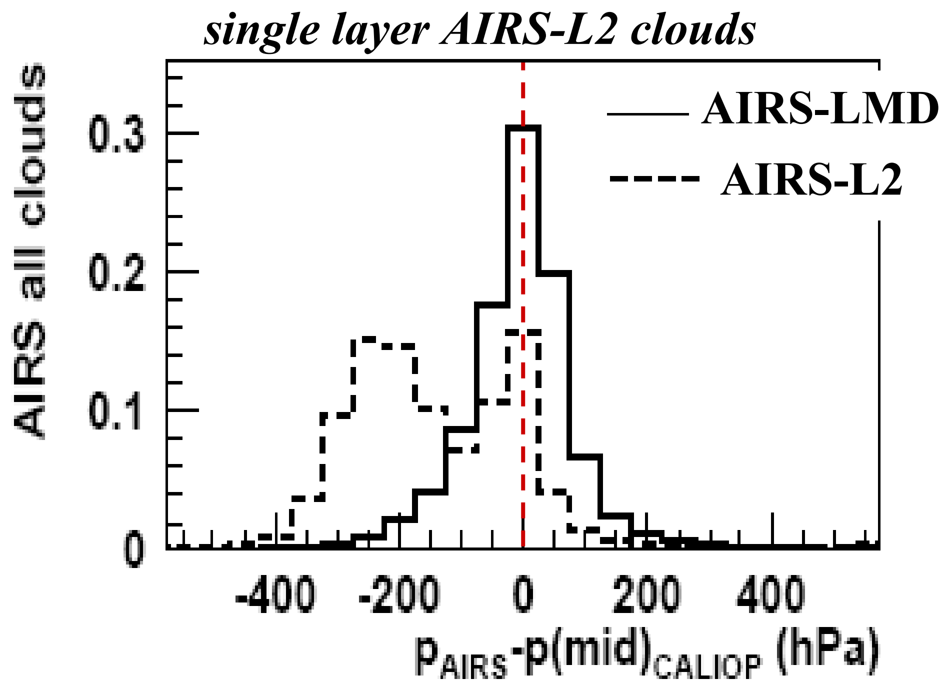


good agreement with CALIPSO midlevel of cloud *(highest with τ>0.1)*
slightly broader distributions for optically thinner clouds,
but no bias

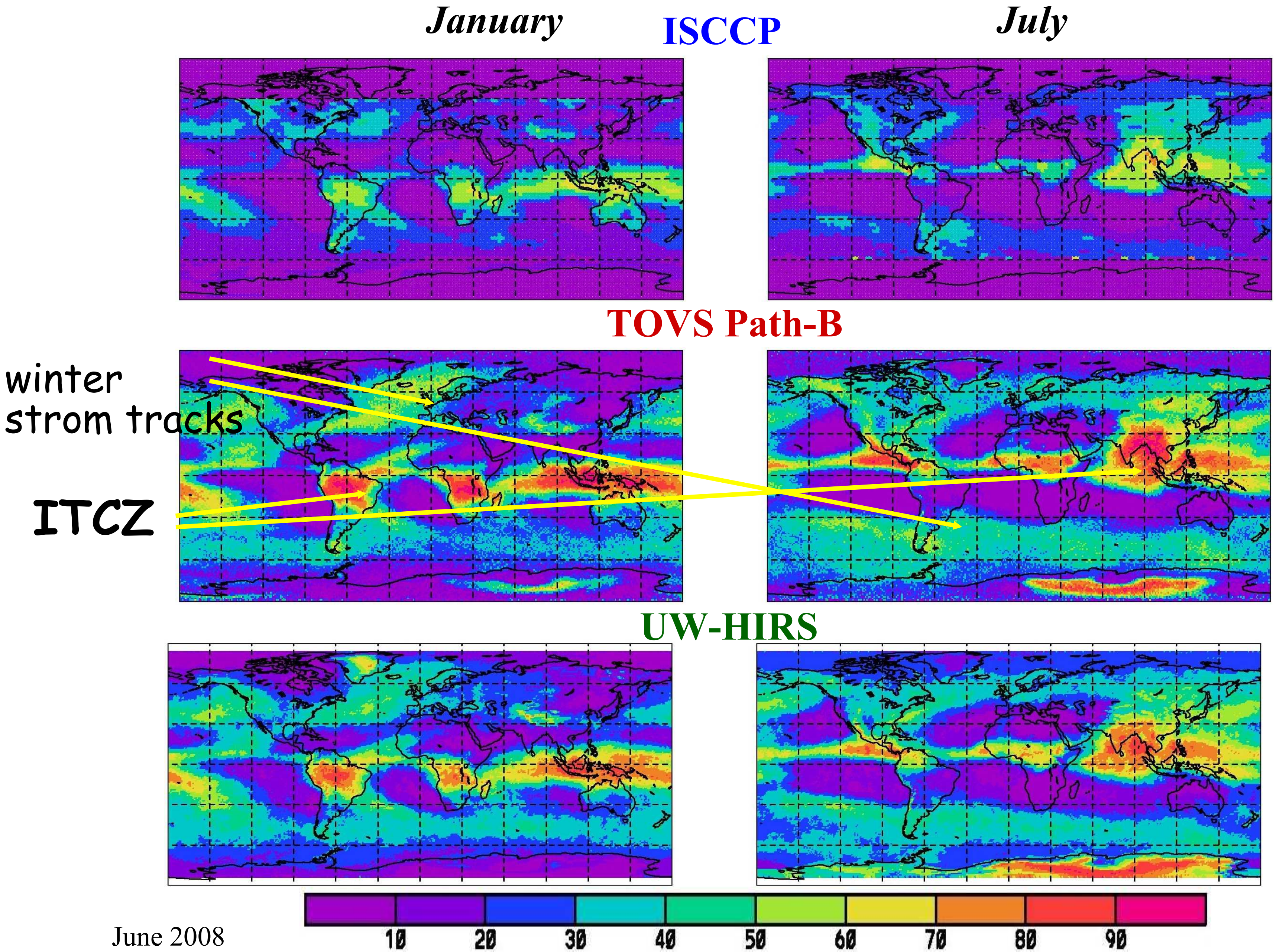
sampling: *(5 km x 0.07 km) in (13.5 km x 13.5 km)*

Δp_{mid}(AIRS-CALIPSO) ± 75 hPa:
High: 72%   81% (thick); 63% (thin)
Low: 59%   69% ; 38%

Cloud properties depend also on retrieval method!

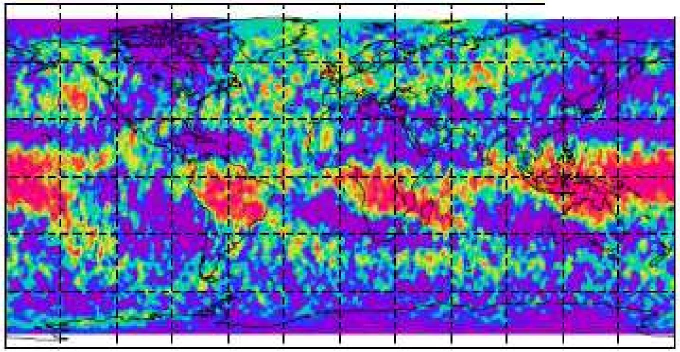


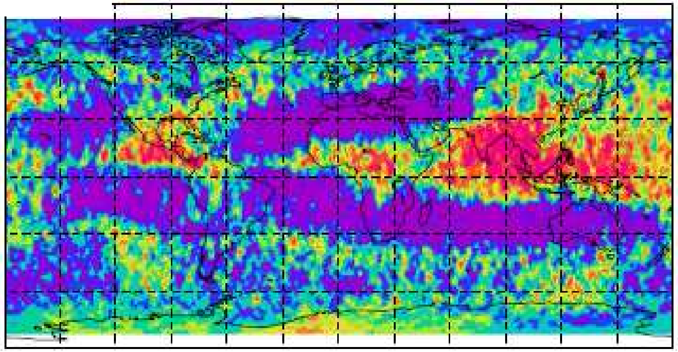
HCA geographical distributions



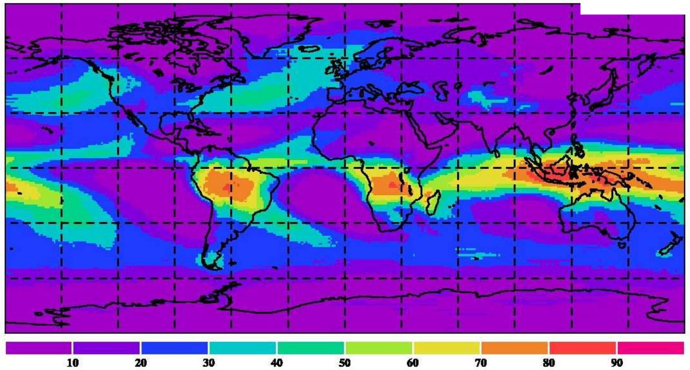
HCA geographical distributions

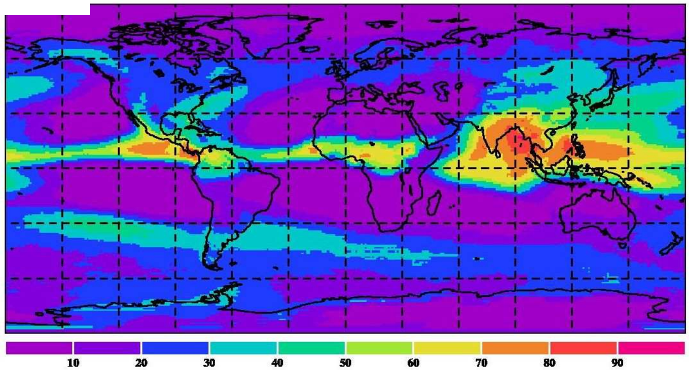
CALIPSO



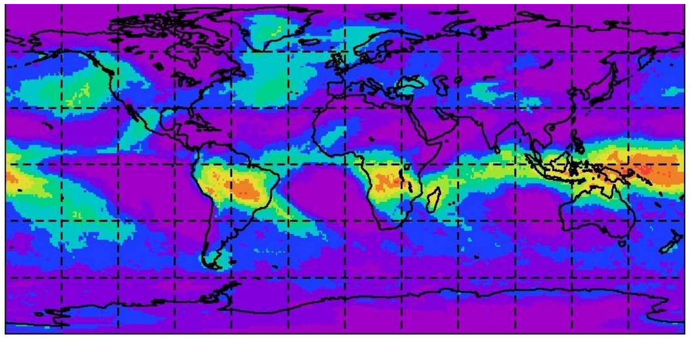


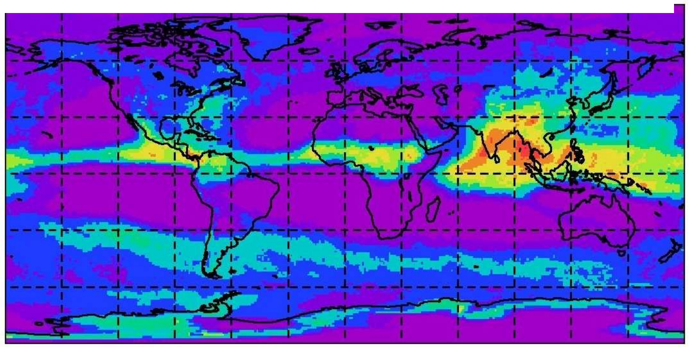
PATMOS-x





MODIS-CE





Average CA

ISCCPday(84-04) TOVS-B, TOVS rean(87-95) HIRS-NOAA(85-01) 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 (%)	global										
all	66	73	70	75	95	76	66	61	67	61	64
Thick Ci	3	2	1	2							
Cirrus	19	27	31	31							
HCA/ CA	33	41	45	44	44	50	38	42	30	21	23
MCA / CA	27	16	14	16	20	14	19	16	19	33	44
LCA / CA	39	42	37	37	36	35	44	44	52	46	72

CA (%)	ocean										
all	70	74	74	77	95	84	72	66	73	65	69
Thick Ci	3	2	1	1							
Cirrus	18	27	31	33							
HCA/ CA	30	39	42	44	44	46	35	37	27	18	17
MCA / CA	26	14	12	14	18	12	17	14	15	29	42
LCA / CA	41	47	42	42	38	42	49	51	59	52	80

CA (%)	land										
all	58	69	61	70	97	63	50	50	59	51	54
Thick Ci	3	4	2	5							
Cirrus	21	27	30	29							
HCA/ CA	41	45	53	49	45	61	47	56	37	29	43
MCA / CA	31	25	20	17	25	20	25	20	29	43	48
LCA / CA	29	30	23	34	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***

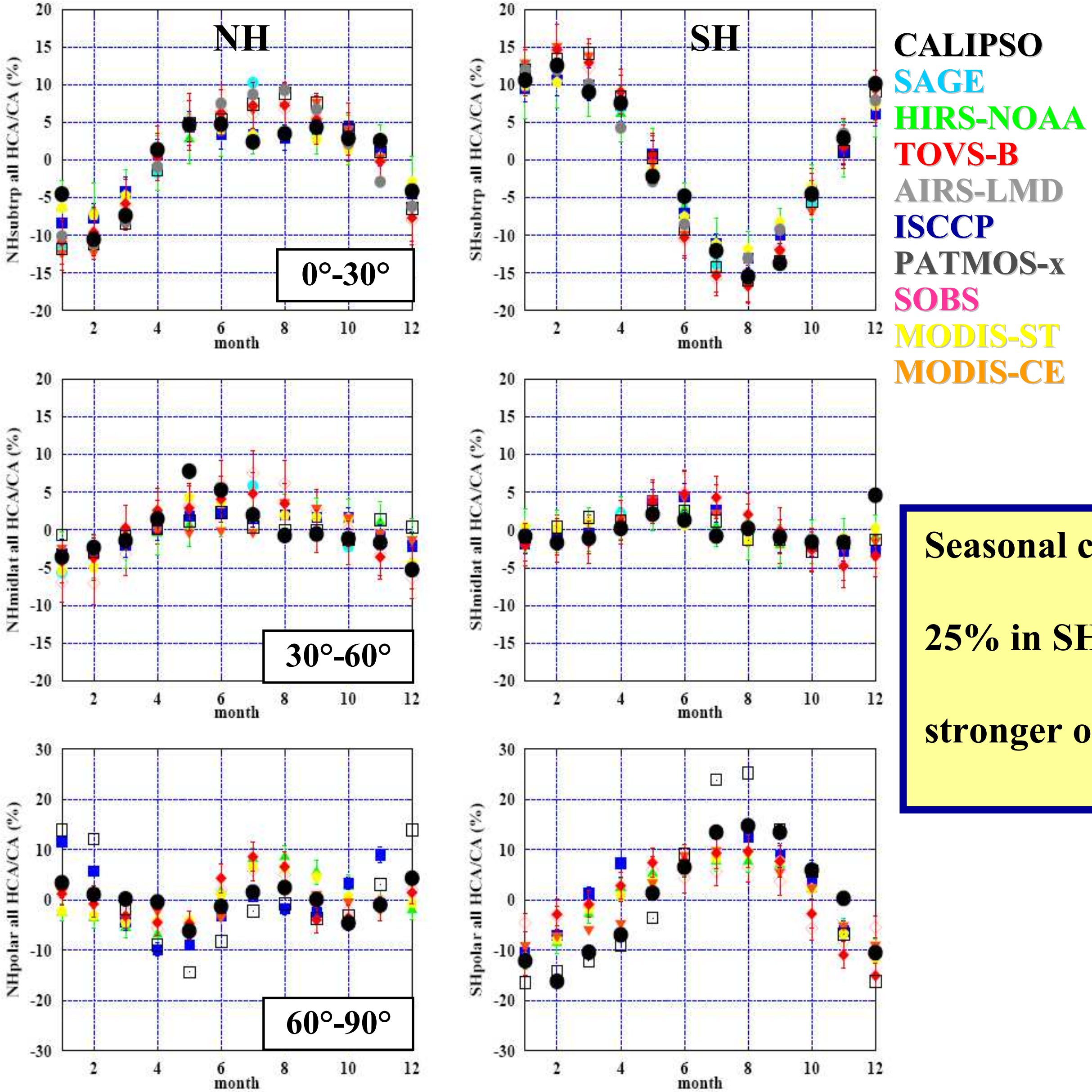
40% high clouds: ***only 3% thick Ci; more over land than over ocean***

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/CA seasonal cycle

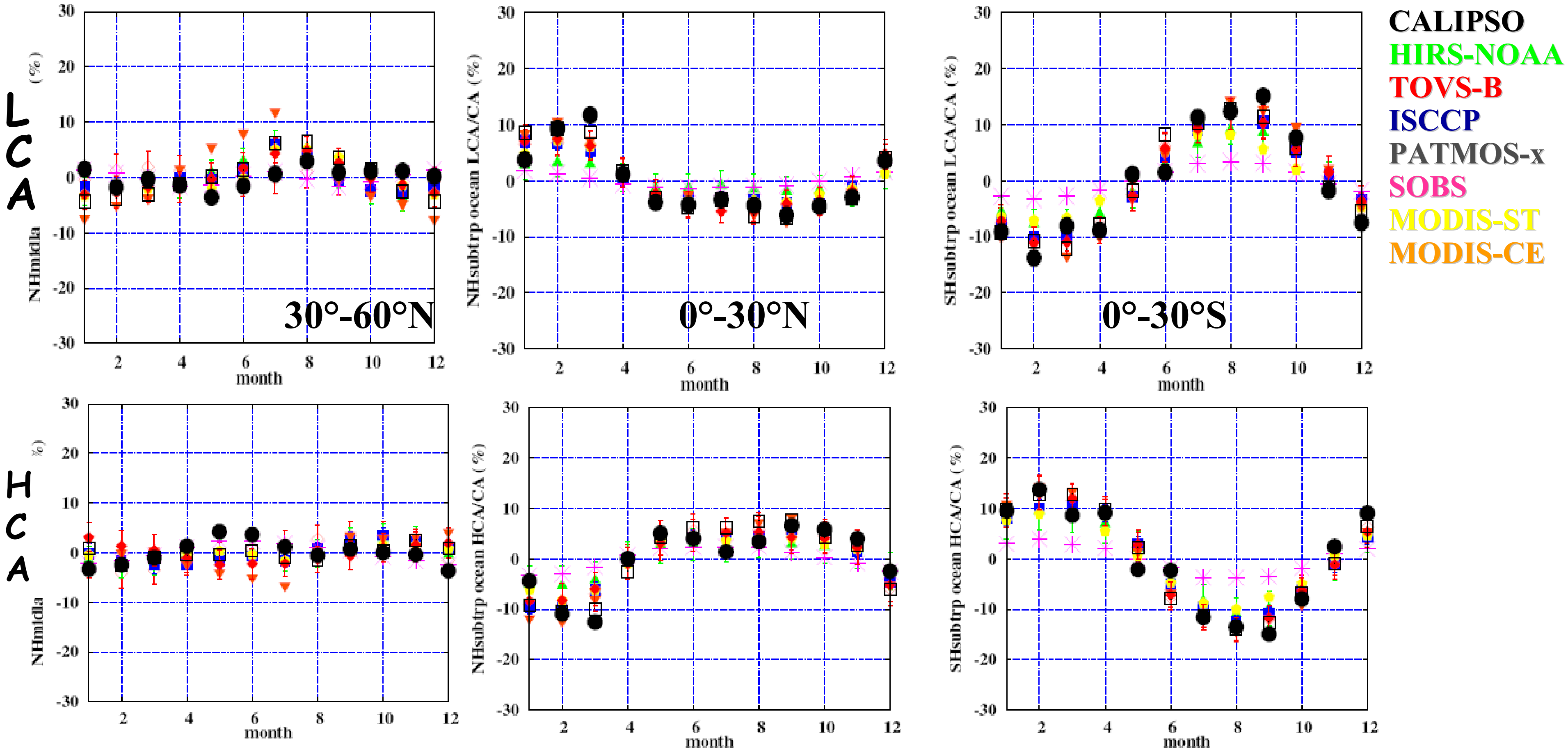


Seasonal cycles similar:

25% in SH tropics to 5% in SH midlatitudes

stronger over land than over ocean

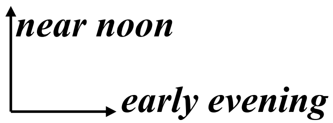
LCA/CA seasonal cycle over ocean



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



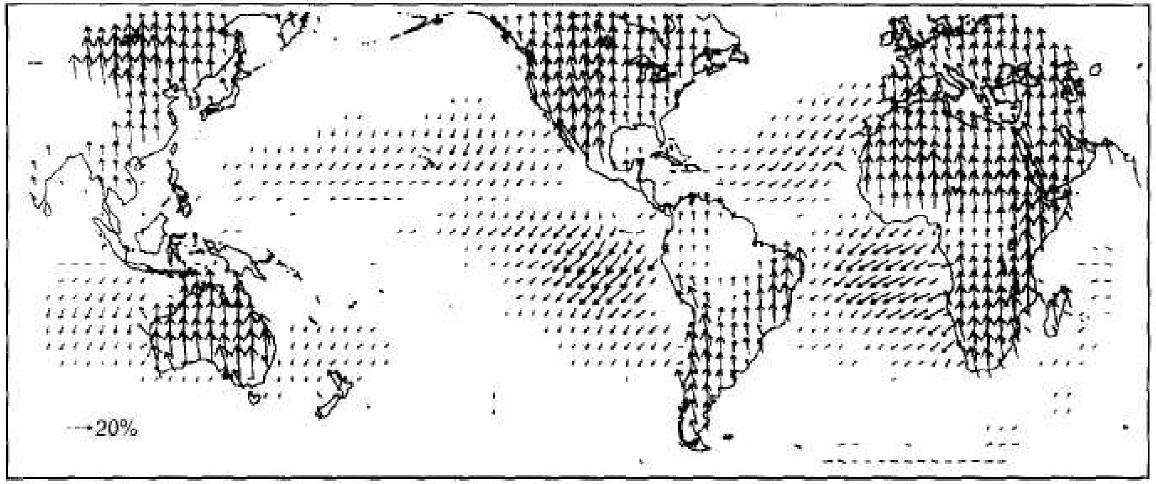
diurnal cycle of clouds

Cairns, Atm. Res. 1995

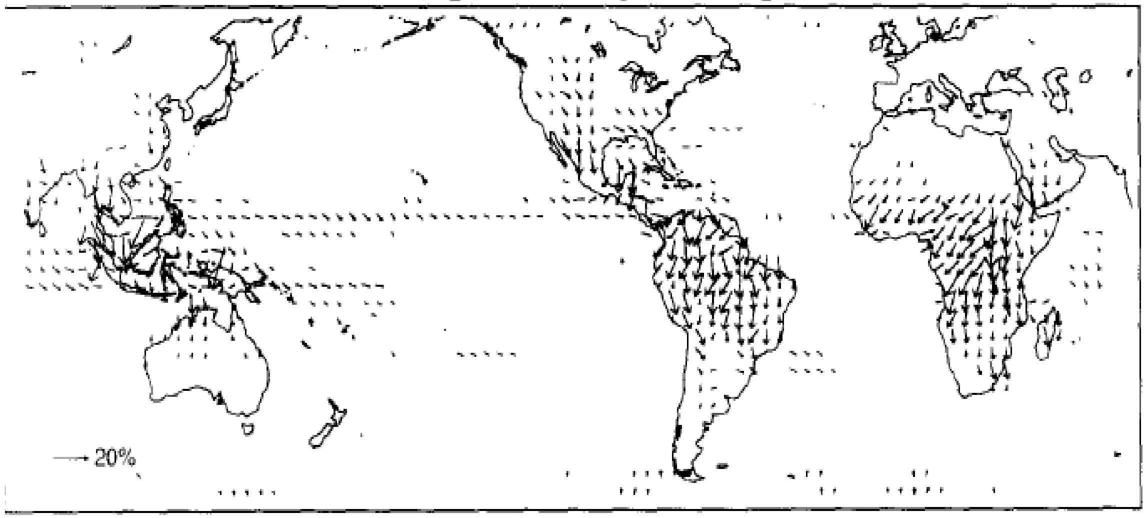
ISCCP C2, Complex Empirical Orthogonal Functions,

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

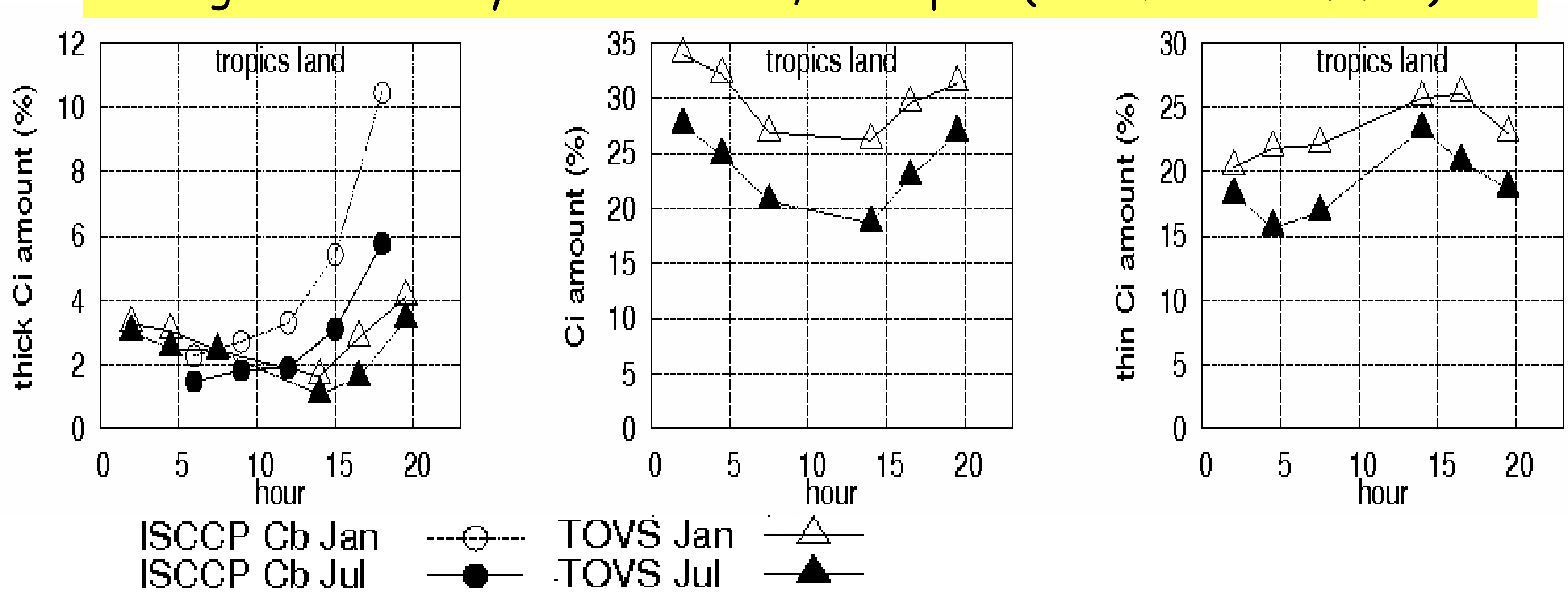
- **Mid clouds:**
  max in early morning
  or late at night
  (cirrus -> TOVS)

TOVS-B diurnal cycle of high clouds

Stubenrauch et al. J. Climate 2006

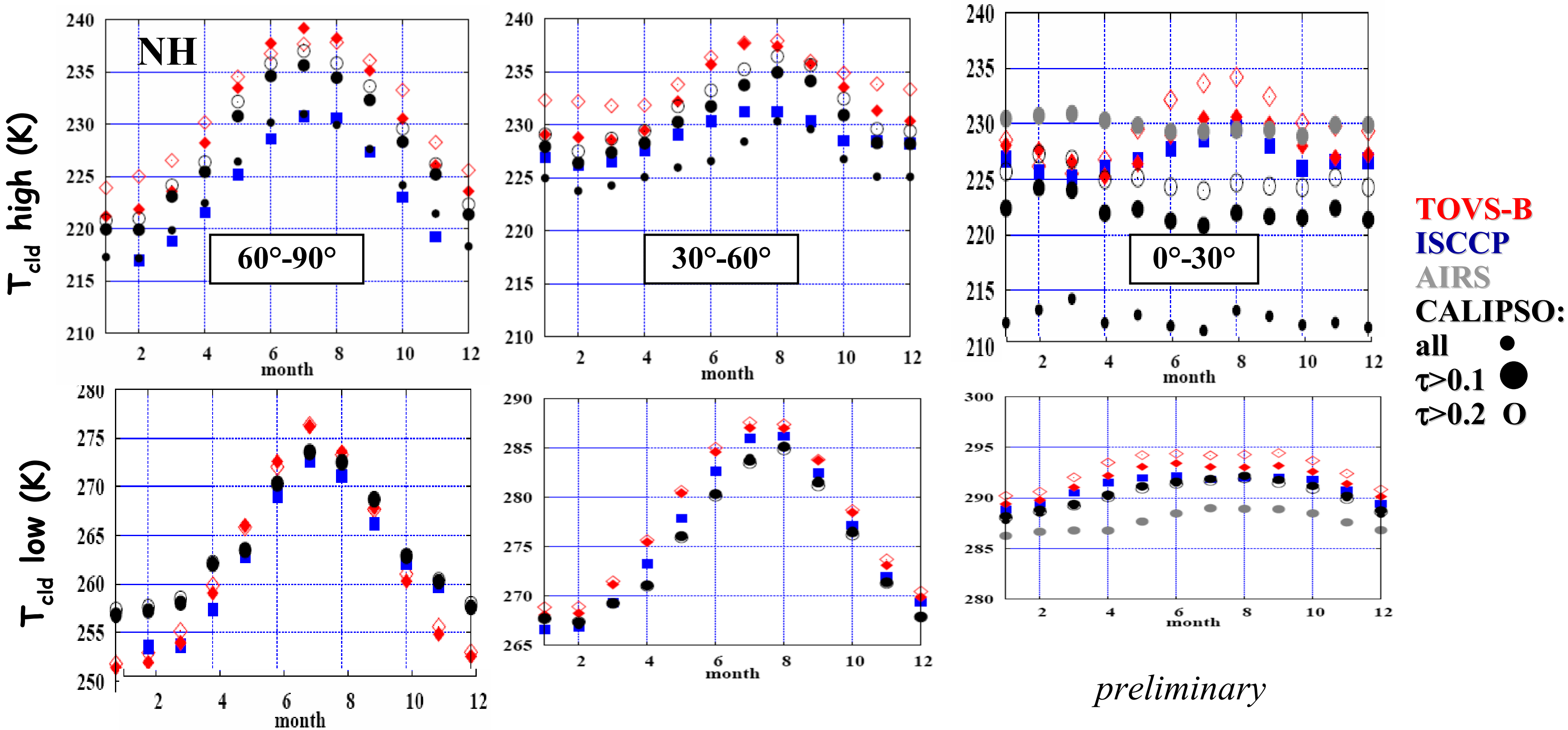
NOAA10/12 7h30 AM&PM, NOAA11 2h00 AM&PM(1989-90) NOAA11 4h30 AM&PM(1994-95)

strongest diurnal cycles over land, in tropics (& in midlat summer)



- max Cb (ISCCP) in early evening
- max. thick (large-scale) cirrus & cirrus in evening
- cirrus occurrence continues during night & decreases during day
- max. thin cirrus in early afternoon

cloud temperature of high and low clouds



preliminary

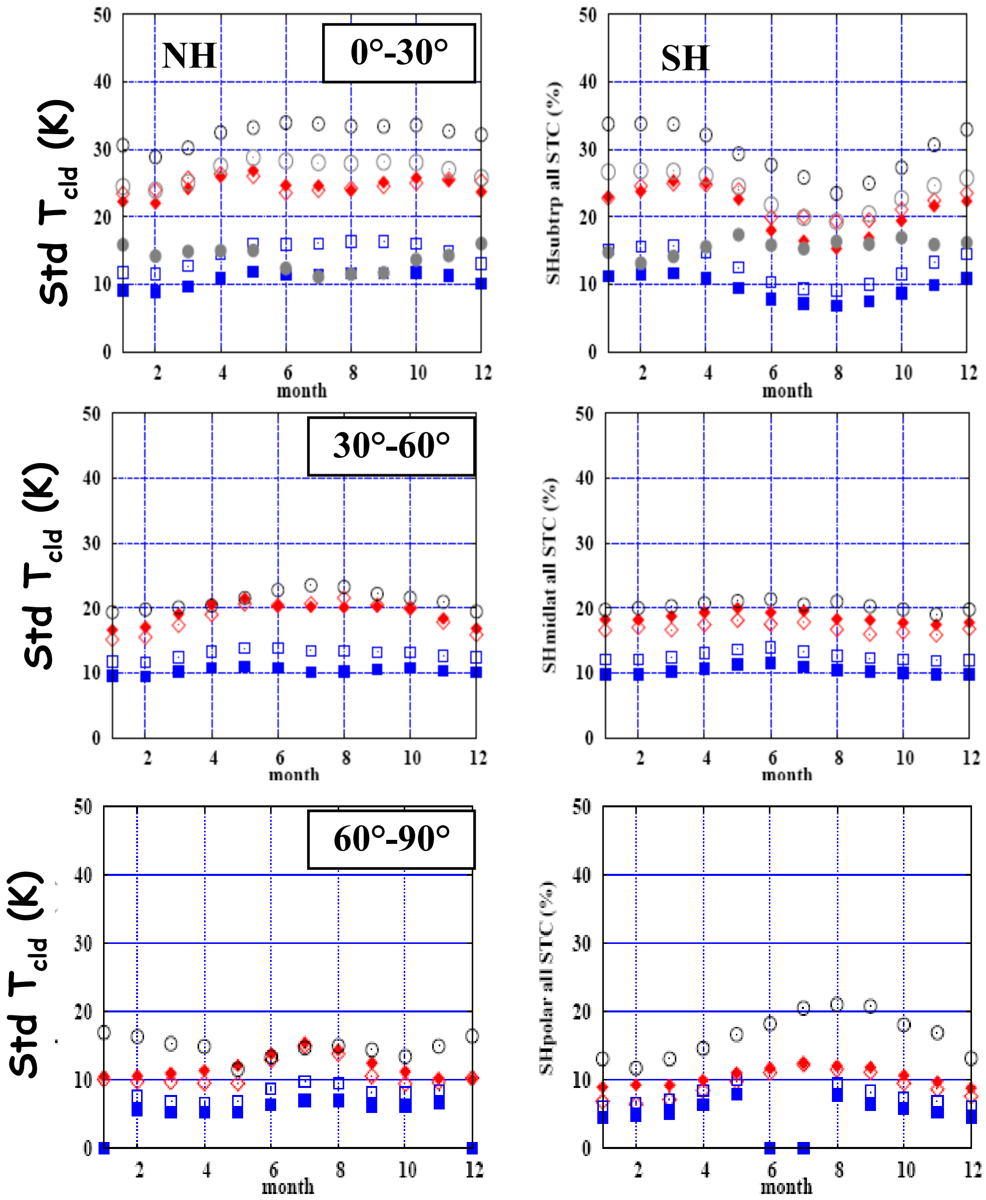
Seasonal cycle of high T_{cld} decreases from polar (15°), midlat (10°) to tropics (5°)
low T_{cld} (20°) (20°) (5°)

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

differences : temperature profiles, uncertainties in cloud height determination

-> auxiliary data, retrieval method

monthly variability of cloud temperature



TOVS-B
ISCCP: time ■, time & space □
AIRS: av. 1° ●, pixel O
CALIPSO: pixel, τ>0.1 O

CALIPSO largest variability:
small pixels & good vertical resolution

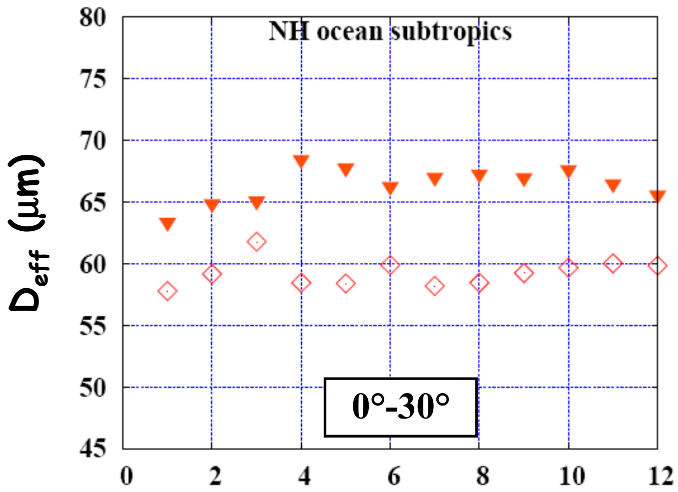
slightly larger than AIRS & TOVS

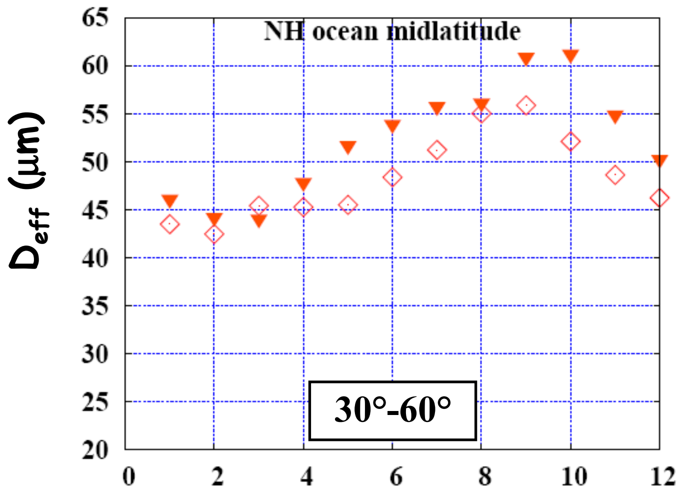
ISCCP slightly lower (Std_{time} > Std_{space})

av *T_{cld}* over 1° reduces *Std* more than retrieval over 1° ?

preliminary

Cirrus effective ice crystal diameter





TOVS-B (1987-1991)
MODIS-CE (2003-2005)

TOVS: semi-transparent cirrus ($0.3 < \varepsilon_{cld} < 0.85$)
IR method sensitive up to $D_{eff} \cong 80$ µm
MODIS-CE: VIS-NIR method, all cirrus

very preliminary

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

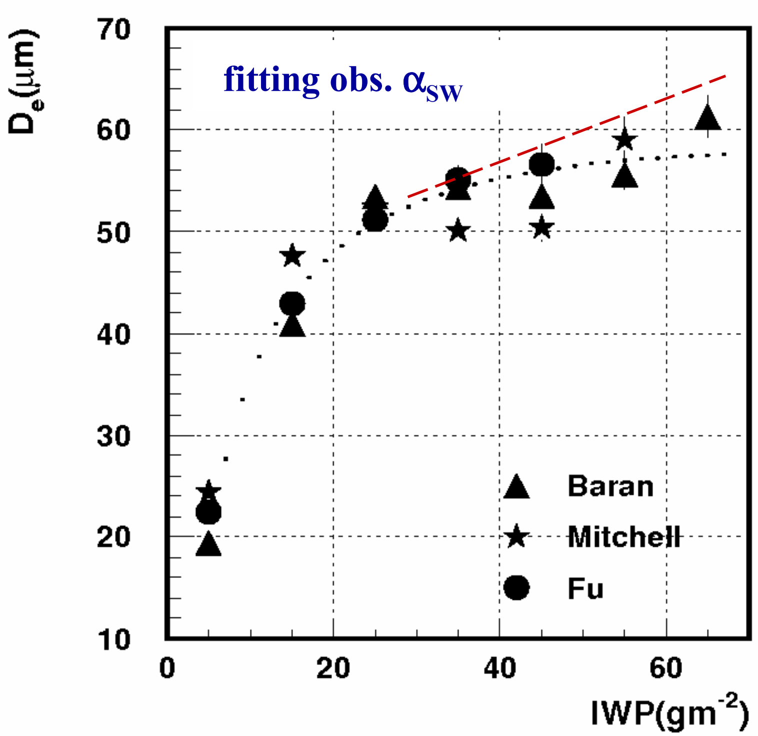
ADMs

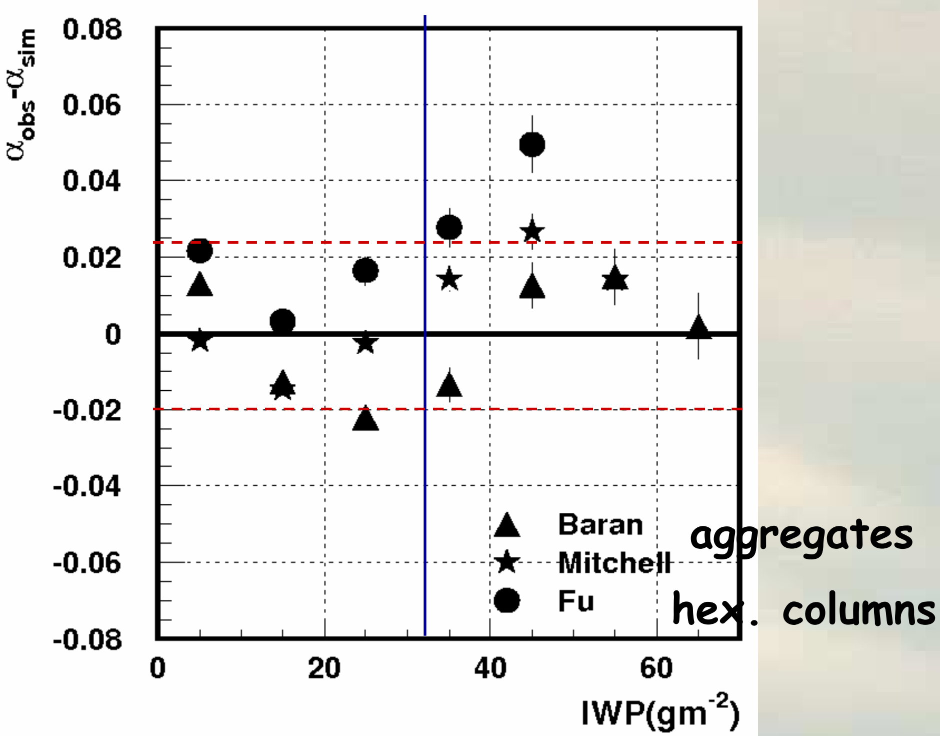
1500 ScaRaB fluxes ⟷ *simulated fluxes*

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

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

effect on TOA SW flux : ~2 Wm^{-2}

Satellite observations:

❖ unique possibility to study cloud properties over long period

-> climatological values of CA, HCA, MCA & LCA
(also variabilities, T_{cld}, ε, τ, D_{eff}, WP) to help evaluate climate models

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

❖**in general geographical cloud structures agree quite well:**

max of high clouds in ITCZ (up to 60%),

few single-layer midlevel clouds in tropics (5%), most in NH midlat winter (15%)

low clouds over ocean: seasonal cycle in Stratocum regions in good agreement

❖Seasonal cycle of LCA from SOBS smaller and abs value 20% higher

-> multilevel clouds

❖**CALIPSO L2 analysis confirms:**

IR sounders are the passive instruments most sensitive to cirrus

They only miss 10%/5% subvisible cirrus in tropics/midlat

(These are caught by limbsounding SAGE & active CALIPSO)

ISCCP miss 15%/10% in tropics/midlat compared to IR sounder, (included in MCA)

PATMOS, MODIS still in validation process, but will miss more thin Ci than TOVS/HIRS, AIRS, IASI

- **diurnal cycle**: well determined by ISCCP (midlevel clds –cirrus -> TOVS)

- **CALIPSO-CLOUDSAT to determine vertical structure of clouds & help to evaluate other cloud properties**

- **Synergy of different variables & data sets important for evaluation of climate models**

- **Evaluation continues & WMO report in preparation**
  (next meeting 21-23 July in New York)