Cloud Assessment

Final status report

Coordinators:
Claudia Stubenrauch *Laboratoire de Météorologie Dynamique, IPSL/CNRS, France*
Stefan Kinne *Max Planck Institute for Meteorology, Hamburg, Germany*

http://climserv.ipsl.polytechnique.fr/gewexca
http://cua-nasa-gsfc.info/feofilov/CloudAssessment/index.html

GEWEX Cloud Assessment Milestones

initiated in 2005 by GEWEX Radiation panel (GRP)

2005-2010: **4 workshops :** *(2xMadison, New York, Berlin)*

2005: focus on longterm anomalies ***(co-chairs: G. Campbell, B. Baum)***

2006: focus on cloud amount ***(co-chairs: B. Baum, C. Stubenrauch)***

2008: first intercomparison of cloud property statistics ***(co-chairs: C. Stubenrauch, S. Kinne)***

2010: first assessment using L3 monthly gridded cloud data and revision of L2 -> L3 procedure

2009-2011: **Preparation and quality check of common L3 data base**
monthly statistics (averages, variability, histograms) in netCDF format

2012: **WCRP report**
(191 pages, submitted for review by GDAP in Apr, sent to WCRP in Sep)
BAMS article *(abstract accepted in June, article submitted in July)*
revision of website
opening of database to public *(after this meeting)*

Participating Datasets

ISCCP	***GEWEX cloud dataset***	***1984-2007***	*(Rossow and Schiffer 1999)*
MODIS-Science**T**eam		***2001-2009***	*(Menzel et al.2008; Platnick et al. 2003)*
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)*

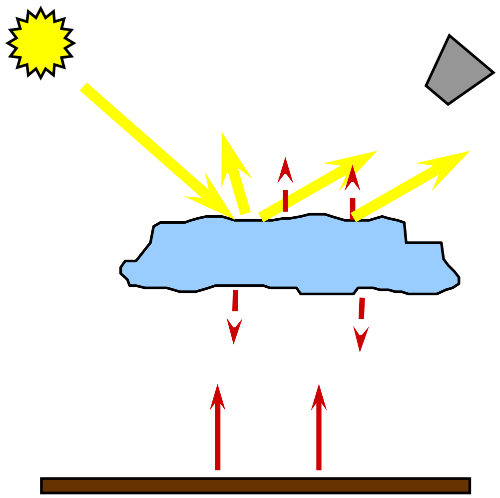
relatively new retrieval versions:

PATMOS-x	**(*AVHRR)***	***1982-2009***	*(Heidinger et al., Walther et al. 2012)*
ATSR-GRAPE		***2003-2009***	*(Sayer et al. 2011)*
HIRS-NOAA		***1982-2008***	*(Wylie et al. 2005)*

complementary cloud information:

CALIPSO-Science**T**eam	***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)*

cloud properties from space



Satellite radiometers measure (>1980)

emitted, reflected, scattered

radiation

cloud detection
inverse radiative transfer

cloud properties

- **information on uppermost cloud layers**
- **'radiative' cloud height**
- **perception of cloud scenes depends on instrument / retrieval performance on thin Ci**

=> cloud property accuracy scene dependent :
most difficult scenes: thin Ci overlying low clouds, low contrast with surface (thin Ci, low cld, polar regions)

Active instruments (A-Train, > 2005)

lidar – radar synergy -> information on all cloud layers; however: sparse sampling

lidar : **sensitive to thin (subvis) Ci, however: only apparent cloud base (COD<3)**

IR-NIR-VIS Radiometers

good spatial resolution (1-5km), 1 to 5 radiometric channels: depending on day-night

1) COD,CT *(assumption on microphysics)* 2) spectral difference (VIS-NIR) -> CRE, CWP

IR Sounders

15km res, sounding CO_2 abs band (5-8 channels): sensitive to thin Ci (COD>0.1), day&night

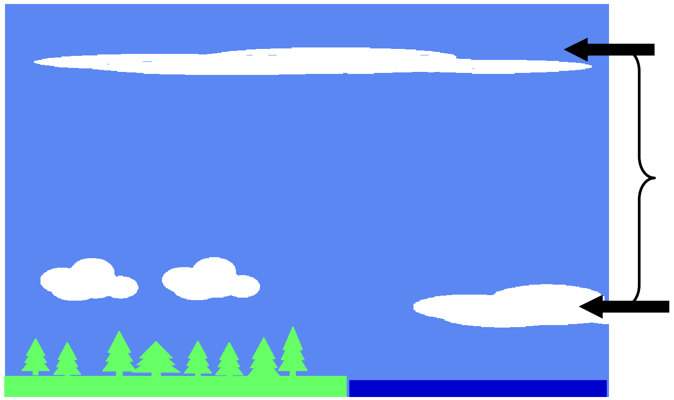
1) CP,CEM *(**no** assumption on microphysics)* 2) spectral difference (8-12μm) -> CRE, CWP (only Ci)

multi-angle VIS Radiometers

1/20km res, only day, only sensitive to clouds with COD>2: Ci over low cld -> low cld

multi–angle scattering –> cloud top polarization –> CT independent phase

Ci over low clouds : Interpretation of Cloud height



≤ 20% of all cloudy scenes *(from CALIPSO)*

Retrieval characteristics

Dataset	Spatial Resolution	Cloud Detection	Variables	Retrieval Method	Ancillary Input
ISCCP	5 km, 30 km (sampled) 100 km clear sky estimation	1 VIS 1 IR window + 1 NIR over ice time – space variances	COD, CT -> CP, CZ	TB(11 μm)-> CT, VIS->COD, CT correction for COD<5	*TOVS profiles (operational)*
			Phase (W/I)	ice: CT < 260 K	rad transfer+particle model
			CWP	fct(COD, phase, fixed CRE)	surf properties
			CRE	VIS/NIR LUT approach (0.6, 3.7 μm)	rad.transfer + particle model
PATMOS-x	1 km x 5 km	6 Bayesian classifiers derived from CALIPSO	CEM, CT -> CP	Optimal Estimation (11,12 μm)	*NCEP reanalysis profiles (V1)*
			phase (W/I)	spectral differences	MODIS snow mask
			COD, CRE	LUT approach (0.6, 3.7 μm)	rad. transfer + particle model
			CWP	CLWP=fct(CODW, CREW); CIWP=fct(CODI)	(mixed habits for ice)
HIRS-NOAA	17 km	1 IR, time – space variances	CP, CEM -> CT	CO_2 slicing for CP<650 hPa, TB(11 μm)	*NCEP reanalysis profiles*
TOVSB	17 km (detection) 100 km (retrieval)	multi-spectral IR + MW clear sky estimation	CEM, CP -> CT, COD	weighted χ^2 method on CO_2 channels, COD = -2ln(1-CEM)	*TOVS profiles (TOVS Path B)*
			phase (W/I)	ice: CT < 230 K	spectral surf. emissivities
			CREIH -> CIWPH	fct(CEM(8 μm),CEM(11 μm)), fct(CREIH,CEM(11 μm))	rad transfer + ice crystal model (aggregates)
MODIS-ST	1 km (detection, COD, CRE, CWP, phase) 5 km (CP, CT, CEM)	multi-spectral IR/NIR/VIS (16 channels) + time-space variances	CP, CEM -> CT	CO_2 slicing for CP<650 hPa, TB(11 μm)	*NCEP GDAS profiles, 16day spectral surf. albedo climatology*
			phase (W/I)	VIS/NIR/IR spectral differences	rad. transfer+particle model
			COD, CRE	LUT approach (0.7, 0.9, 1.2, 1.6 μm), (1.6, 2.1, 3.7 μm)	(mixed particle habits for ice)
			CWP	fct(COD,phase, CRE)	
MODIS-CE	1 km, 4 km (sampled) 32 km clear sky estimation	multi-spectral IR/NIR/VIS (5 channels similar to VIRS)	CEM, CT -> CZ, CP	IR split-window; lapse rate (7.1 K/km) + T profile	*GEOS profiles*
			phase, COD, CRE	CT + LUT approach (0.6, 2.1 μm), (3.8 μm)	rad. transfer+particle model
			CWP	CWP=fct(COD,CRE,phase)	(mixed habits for ice)
AIRS-LMD	14 km	spectral emissivity coherence (a posteriori)	CEM, CP -> CT, CZ, COD	weighted χ^2 method, virt. T profile for CZ, COD=-2ln(1-CEM)	*AIRS profiles (NASA, V5)*
			phase (W/I)	ice: CT < 230 K	spectral surf. emissivities (AIRS,MODIS)
			CREIH, CIWPH	LUT approach on 6 spectral emissivities (9-12 μm)	rad. transfer+ice crystal model (hex. columns, aggregates)
CALIPSO-ST	0.06 km x 0.34 km	lidar VIS backscatter horizontal averaging	CZ -> CT	cloud top, uppermost cloud layer (for GEWEX)	*GMAO profiles*
			phase (W/I)	ice: 532 nm depolarization	
CALIPSO-GOCCP	0.48 km x 0.34 km	lidar VIS backscatter vertical averaging	CZ -> CT	cloud mean altitude,	*GMAO profiles*
				uppermost cloud layer (for GEWEX)	
POLDER	6 km (detection) 20 km (retrieval)	multi-spectral+ angle VIS/NIR threshold tests	phase (W/I), COD	VIS/NIR polarization, LUT approach	rad. transfer+ particle model
			CP	O_2-A band (763,765 nm), Rayleigh (490, 865 nm)	(inhom. hex. columns for ice)
MISR	1 km	multi-specral+angle VIS/NIR	CZ	stereoscopic cloud top height	
ATSR-GRAPE	1 km (detection) 4 km (retrieval)	VIS/NIR/IR optimal estimation	COD, CP, CRE, phase -> CT	Optimal Estimation on VIS/NIR/IR (0.7,0.9,1.6,11,12 μm)	*ECMWF profiles*
			CWP	fct(COD,CRE,phase)	rad. transfer + particle model

cloud property uncertainty estimates

(from Annex I)

Dataset	**CA**	**CT**	**CP**	**CEM**	**COD**	**CLWP**	**CIWP**	
ISCCP	0.05	2 K	100 hPa		10%	10%	30%	42 publications
PATMOS-x	0.07				20 – 30%	30%	50%	OE / CALIPSO
HIRS-NOAA	0.15	5 K	50 hPa	0.05 - 0.15				comparisons
TOVS PathB	0.05	5 K	50 hPa	0.1				χ2 solutions, LITE
AIRS-LMD	0.08	4 K	40 hPa	0.05 – 0.20				χ2 solutions, CALIPSO

Cloud Assessment L3 Database

to facilitate assessments, climate studies & model evaluation

properties:

cloud amount	**CA**, total & stratified by height
cloud height	pressure **CP**, temperature **CT**, altitude **CZ**
radiative properties	VIS optical depth **COD**, IR emissivity **CEM**, effective cloud amount **CAE** **(CA weighted by CEM)**
bulk microphysical properties	liquid & ice: water path **CLWP/CIWP**, effective particle radius **CRE**

monthly statistics per observation time at 1° latitude x 1° longitude :

● averages ● variability ● histograms

Height stratified statistics defined by: High CP<440hPa Low CP>680hPa

Distinction between liquid & ice clouds (W/I) by: CT, polarization, multi-spectral

L2 - > L3 netCDF : Fortran program provided to participants (AIRS-LMD example)

first average over space (1° x 1°) & then over time (month)

(after discussions at GEWEX CA workshop in 2010)

variable	ISCCP	PATMOSx	HIRS-NOAA	TOVSB	AIRS-LMD	MODIS-ST	MODIS-CE	MISR	POLDER	ATSR-GRAPE	CALIPSO-ST	CALIPSO GOCCP
CA	ash	as	a	ash	ash	ash	ash	a	ash	ash	ah	ah
CAH	as	as	a	as	as	as	as	a	ash		a	a
CAM	as	as	a	as	as	as	as	a	ash		a	a
CAL	as	as	a	as	as	as	as	a	ash		a	a
CAW	as	as		as	as	as	as		ash		a	
CAI	as	as		as	as	as	as		ash		a	
CAIH	as	as		as	as		as		ash		a	
CAE	ash	as	a	ash	ash	ash	ash		ash			
CAEH	as	as	a	as	as		as					
CAEM	as	as	a	as	as		as					
CAEL	as	as	a	as	as		as					
CAEW	as	as		as	as		as					
CAEI	as	as		as	as		as					
CAEIH	as	~~as~~		as	as		as					
CAHR	as	a	a	as	as	a	as	a	ash	as	a	a
CAMR	as	a	a	as	as	a	as	a	ash	as	a	a
CALR	as	a	a	as	as	a	as	a	ash	as	a	a
CAWR	as	a		as	as	a			ash	as	a	
CAIR	as	a		as	as	a			ash	as	a	
CAIHR	as	a		as	as	a			ash		a	
CP	ash	ash	ah	ash	ash	ash	as		ash	ash		
CZ	ash				ash		ash	ah			ah	ah
CT	ash	ash	ah	ash	ash	ash	as			ash	ah	ah
CTH	ash	ash	a	ash	ash		as			ash	ah	ah
CTM	ash	ash	a	ash	ash		as			ash	ah	ah
CTL	ash	ash	a	ash	ash		as			ash	ah	ah
CTW	ash	ash		ash	ash	ash	as			ash	ah	
CTI	ash	ash		ash	ash	ash	as			ash	ah	
CTIH	ash	ash		ash	ash		as			ash	ah	
CEM	ash	ash	a	ash	ash	ash	as			ash		
CEMH	ash	ash	a	ash	ash		as			ash		
CEMM	ash	ash	a	ash	ash		as			ash		
CEML	ash	ash	a	ash	ash		as			ash		
CEMW	ash	ash		ash	ash		as					
CEMI	ash	ash		ash	ash		as					
CEMIH	ash	ash		ash	ash		as					
COD	ash	ash		ash	ash	ash	ash		ash	ash		
CODH	ash	ash		as	ash	ash	as		ash	ash		
CODM	ash	ash		as	ash	ash	as		ash	ash		
CODL	ash	ash		as	ash	ash	as		ash	ash		
CODW	ash	ash		as	ash	ash	ash		ash	ash		
CODI	ash	ash		as	ash	as	ash		ash	ash		
CODIH	ash	ash		as	ash	ash	as		ash	ash		
CLWP	ash	ash				ash	ash			ash		
CIWP	ash	ash				ash	as			ash		
CIWPH	ash	ash		ash	ash		as			ash		
CREW	ash	ash				ash	ash			ash		
CREI	ash	ash				ash	ash			ash		
CREIH	ash			ash	ash	ash	as			ash		
COD/CP	x	x		x	x				x	x		
CODW/CP						x						
CODI/CP				x	x	x						
CEM/CP	x	x		x	x	x						
CODW/CREW	x	x				x						
CODI/CREI	x	x		x	x	x						
CEM/CREI	x	x		x	x							

56 variables

a: averages

s: variability

h: histogram

12 datasets

2 – 25 years

≤ 4 observation times

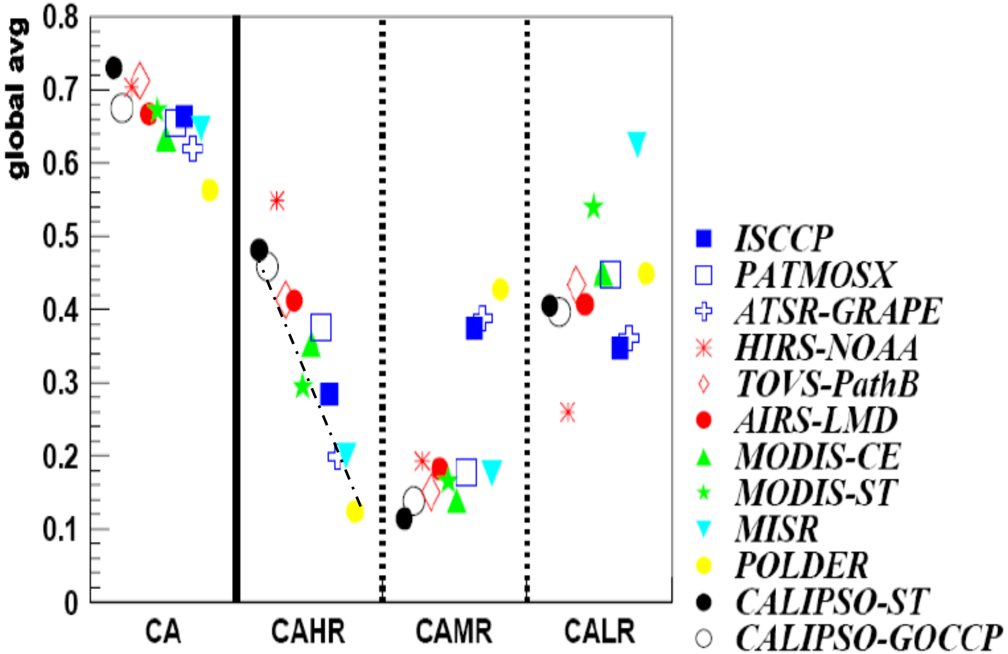
zipped: 160 Gb

unzipped: 1.4 Tb

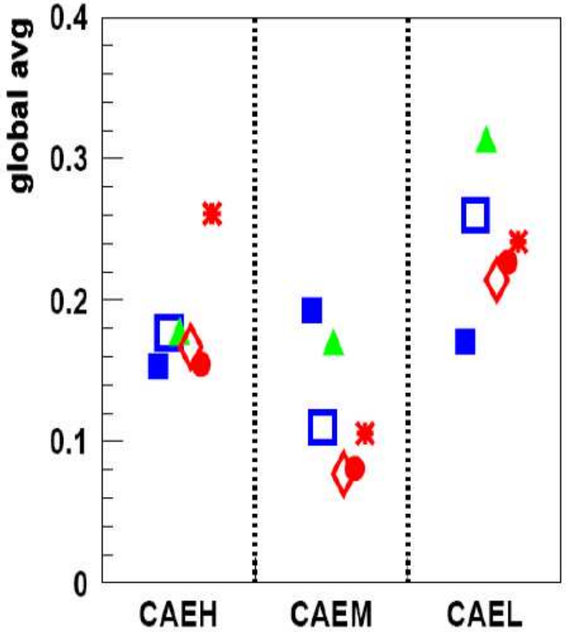
Amount, Height, Temperature, Emissivity

Global Averages: total & height-stratified

Cloud Amount



Effective Cloud Amount



CALIPSO only considers uppermost layers to better compare with the other datasets

CA 0.68 ± 0.03 (+ 0.05 subvisible Ci); global monthly variability: 0.27; interannual variability: 2-4%

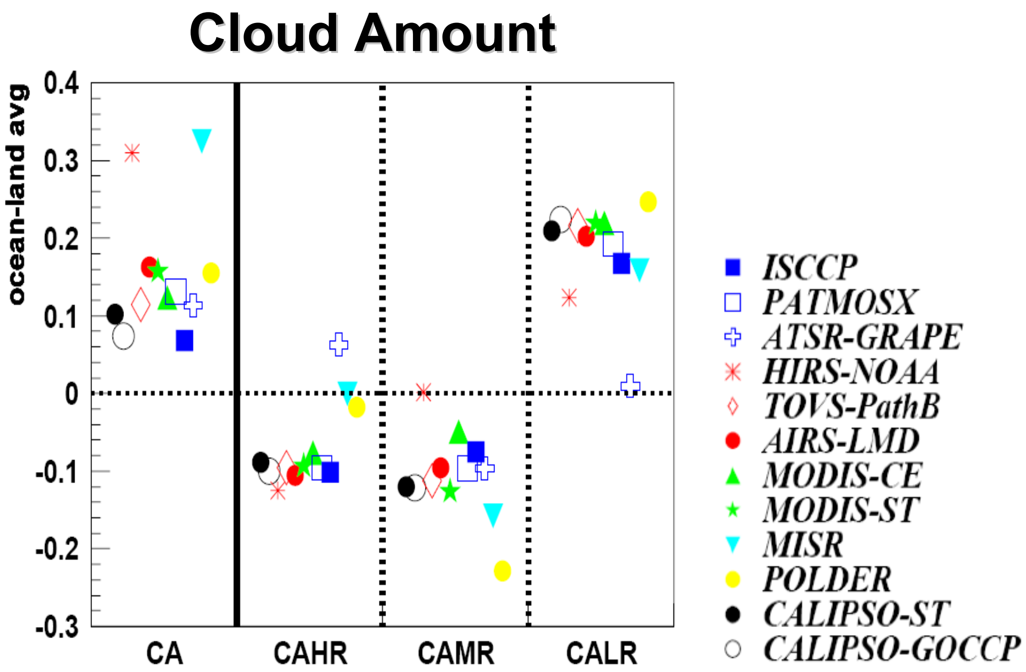
CAHR (hgh clds out of all clds) **depends on sensitivity to thin Ci (30% spread)**

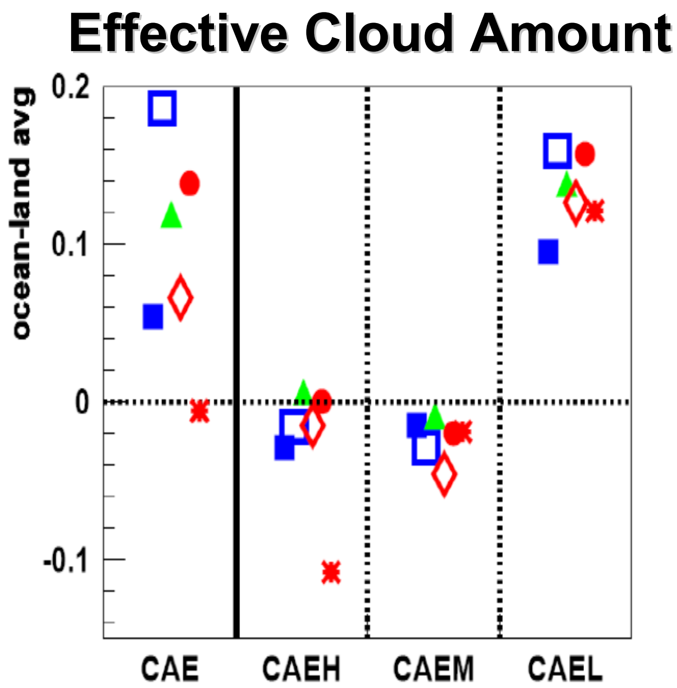
(misidentified as midlevel clouds by ISCCP, ATSR, POLDER)

CAHR ≅ 50% (incl. subvis Ci), ≅ 42% (COD>0.1), ≅ 20% (COD>2); **CAMR** ≅ 16% (±5%); **CALR** ≅ 42% (±5%)

CAEH (CAH weighted by CEMH) agrees better : 0.17

ocean - land differences

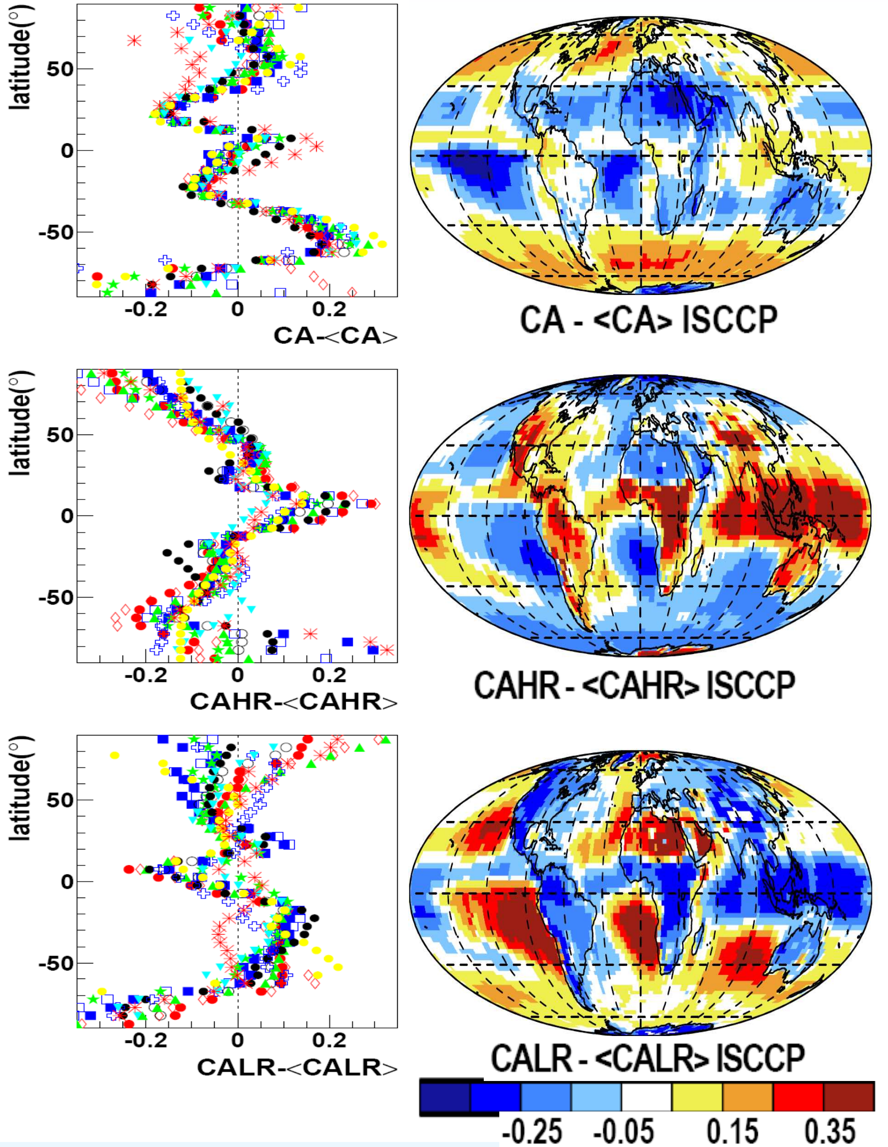




10-15% more clouds over ocean than over land (low clouds)

more high and midlevel clouds over land,
but these are optically thinner over land, so that their effective cloud amount is similar

Latitudinal & regional variation



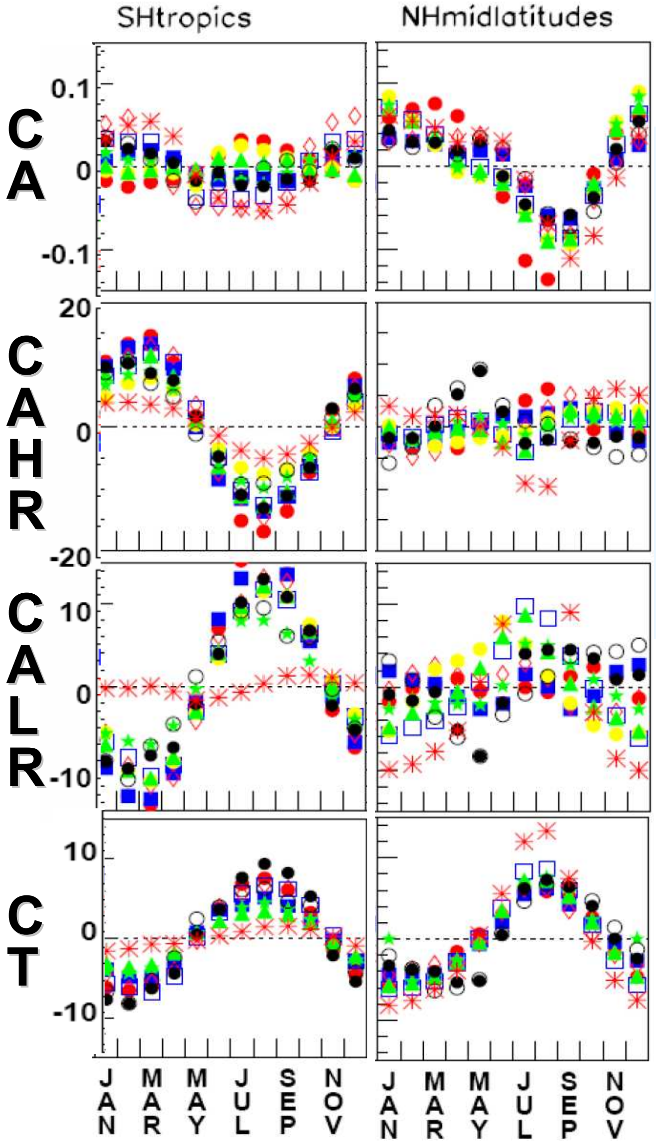
latitudinal variations similar *(except polar regions & HIRS CA, CALR)*

Max−Min(ISCCP, PATMOS-x, MODIS-ST & -CE, AIRS-LMD, TOVSB):

CA: variation < 0.1, absolute value < 0.2; CAHR, CALR: variation < 0.2, absolute value < 0.4

Seasonal variations

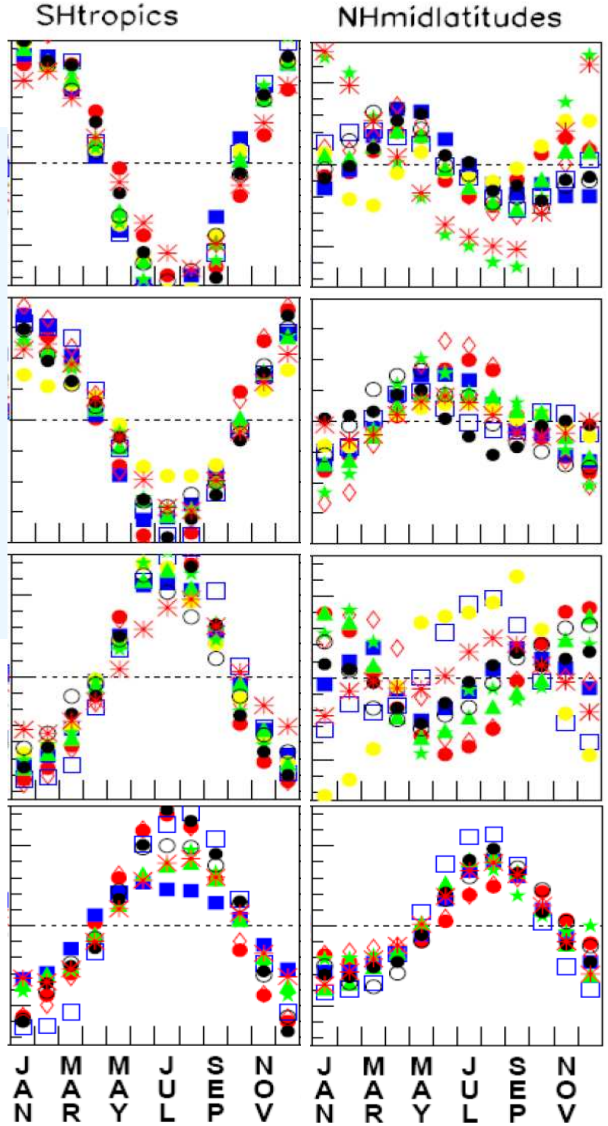
ocean



seasonal cycles similar
(except HIRS-NOAA for low clouds over ocean, PATMOSx, POLDER over midlat. land)

largest in ±30°latitude:
- **shift of ITCZ**
- **stronger over land**
  (amplitude 40% in CAHR)

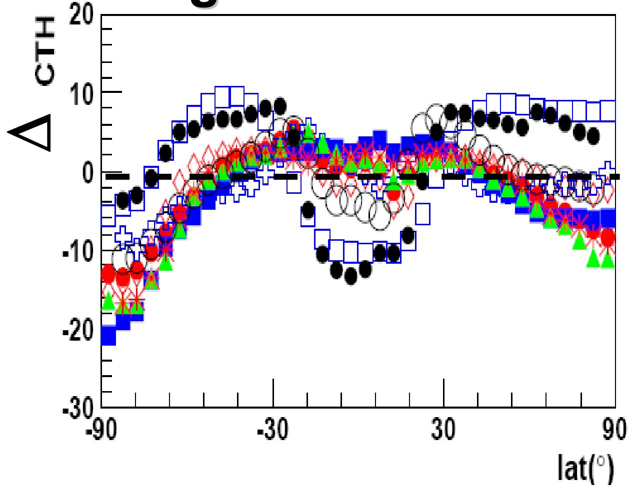
land



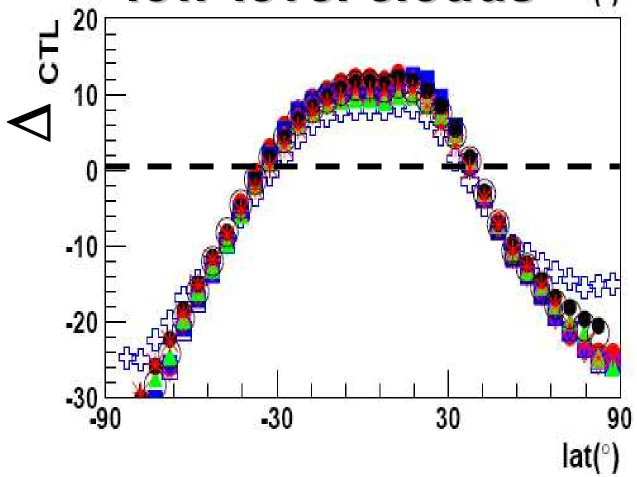
Cloud temperature

latitudinal variation & distributions

high-level clouds



low-level clouds



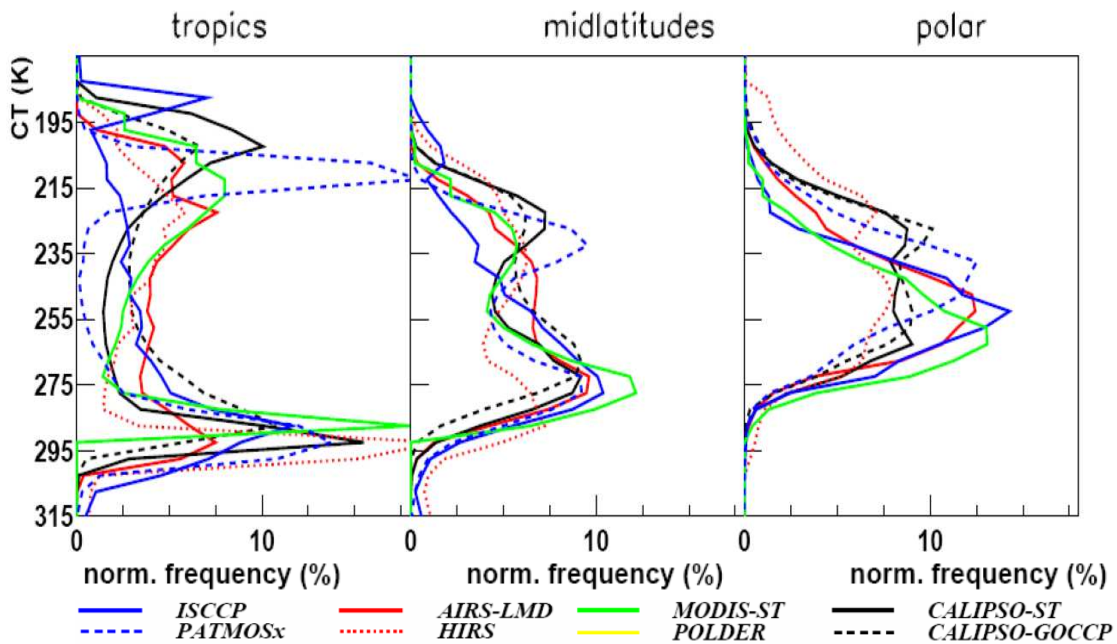
CALIPSO: including subvis Ci, T(cld top)

passive remote sensing: T(rad. cld height)

=> CTH(CALIPSO-ST) should be lowest & nearest to tropopause, largest latitudinal variability

(PATMOSx CTH latitudinal variation like CALIPSO-ST for high clouds, because retrieval was trained)

better agreement for low-level clouds because these are less diffusive



CT distributions -> decrease of vertical extent of troposphere from tropics to poles
bimodal in tropics, quite good agreement, esp. CALIPSO-AIRS-MODIS

Diurnal cycle of clouds

Cairns, 1995

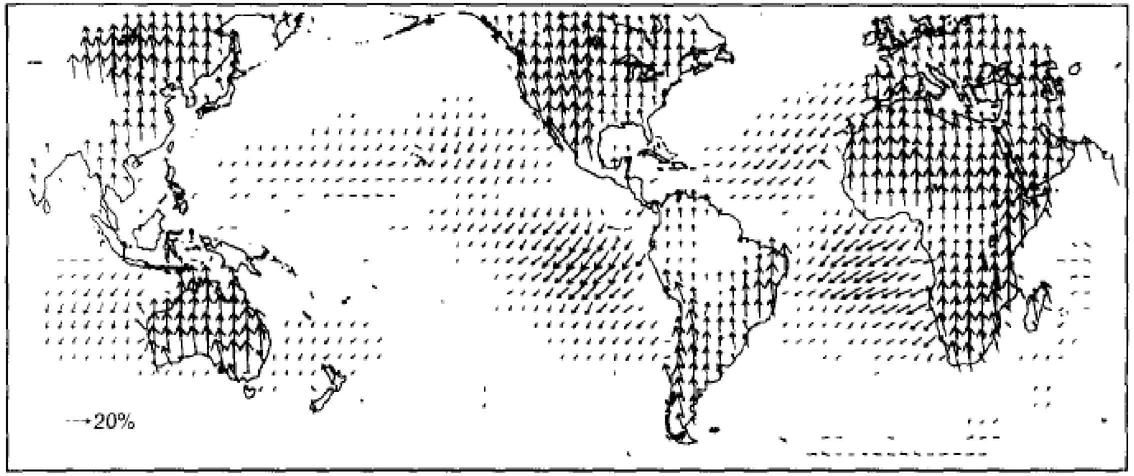
near noon

early evening

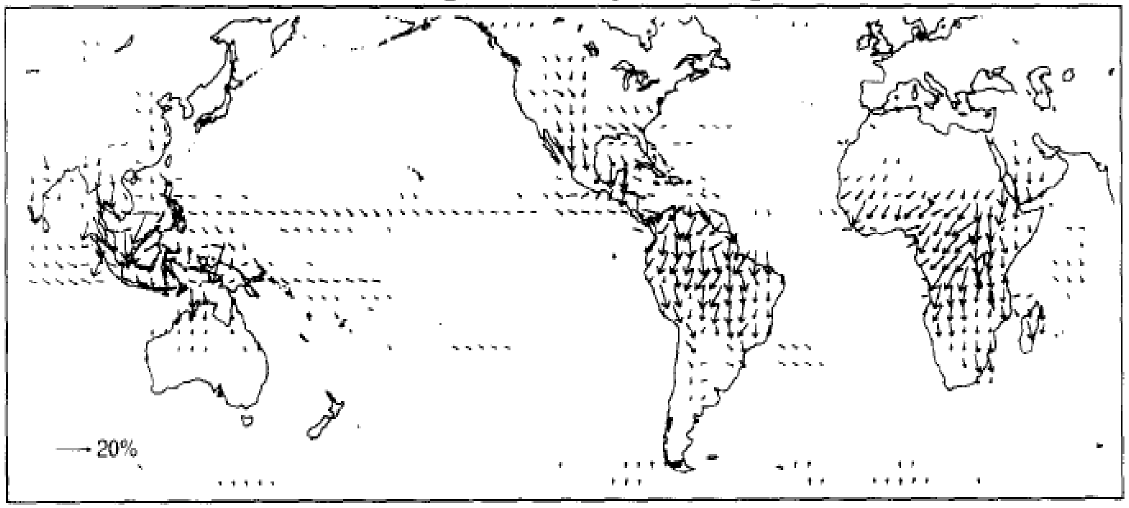
ISCCP C2, Complex Empirical Orthogonal Functions,

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

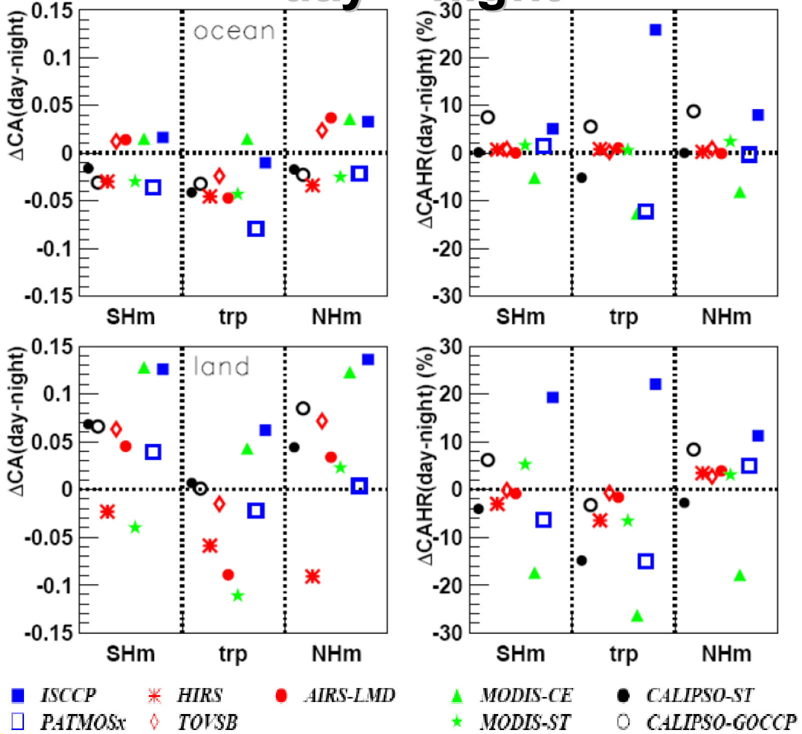
- **Cirrus:**
  increase during afternoon
  & persist during night, thickening

TOVS analysis *Stubenrauch et al. 2006*

Diurnal differences

methods with no day-night change in method: IR sounders & lidar
ISCCP, PATMOSx, MODIS-CE include solar spectrum during day

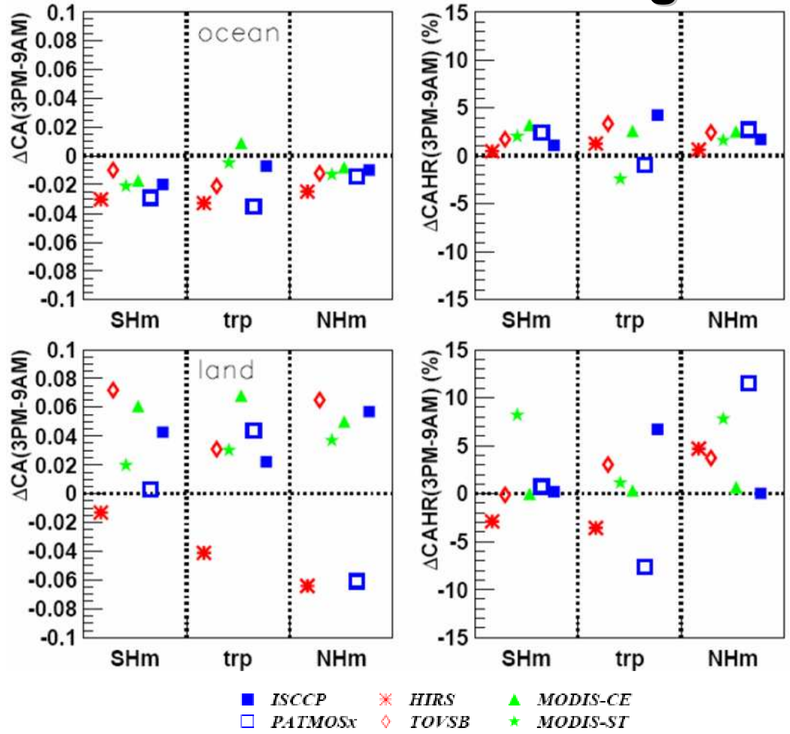
day – night



CA within ±5% (except tropical land, ISCCP/MODIS-CE over land)
20-25% CAHR difference of ISCCP (especially tropics) due to better identification during day (+VIS)

diurnal sampling:

afternoon – morning



slightly more clouds in the morning over ocean, more clouds in the afternoon over land (except HIRS-NOAA / PATMOSx)

CAHR difference negligible over ocean, slightly larger in the afternoon over NH midlatitude land

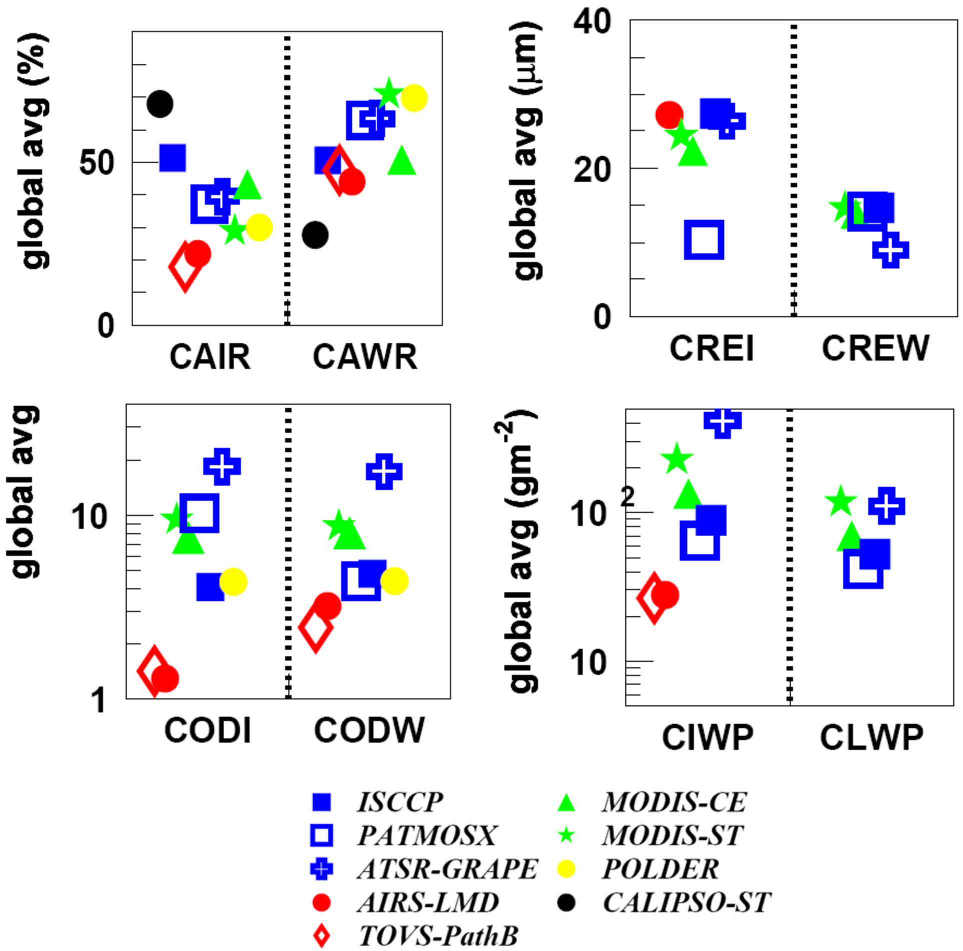
Cloud Optical

&

Bulk Microphysical Properties

Global Averages: ice - liquid

Retrieval of bulk microphysical properties needs thermodynamical phase distinction:
- polarization (POLDER, CALIPSO)
- multi-spectral (PATMOS-x, MODIS, ATSR)
- temperature (ISCCP, AIRS, TOVS)

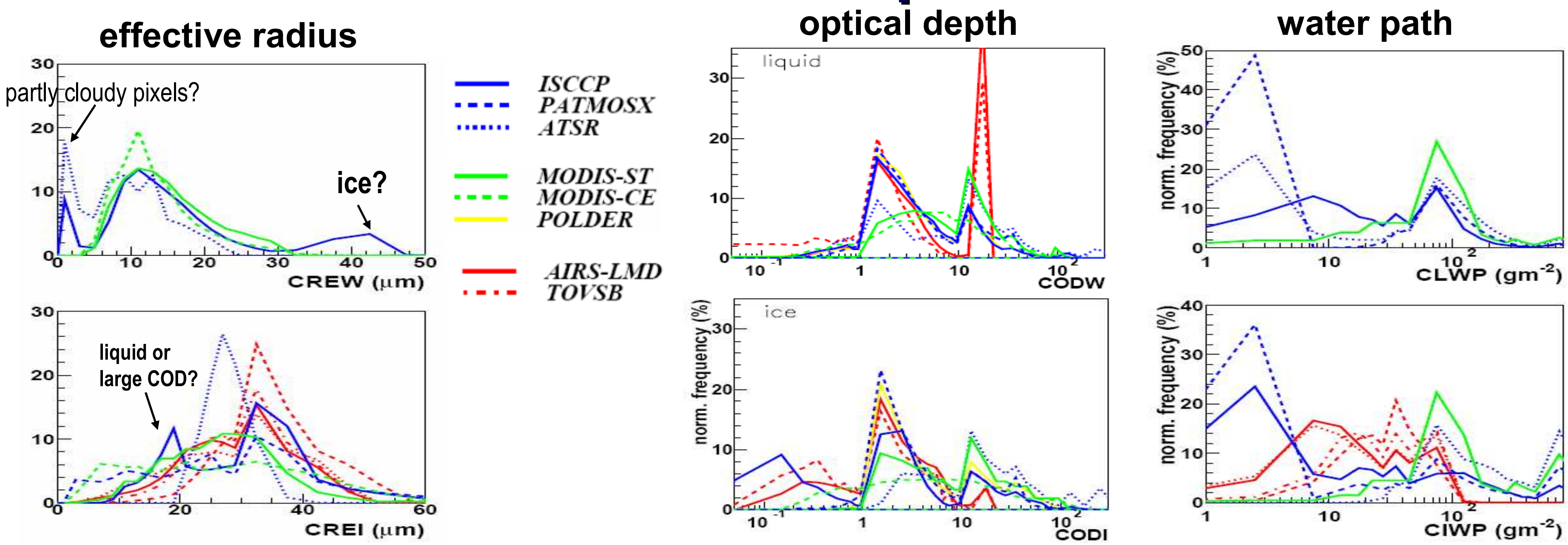


CAIR+CAWR=100%
(except AIRS/TOVS: ice < 230K, liquid > 260K; missing 35% correspond to mixed phase clouds)

CREI, CREW agree quite well:
25 µm (± 2 µm) / 14 µm (± 1 µm)

CWP / COD depend on retrieval filtering:
- ATSR OE valid only for 40% of all clouds
- MODIS-ST only for COD > 1
- AIRS / TOVS ice < 230 K, semi-transp. cirrus

Distributions: liquid - ice



CREW distributions agree quite well:
large peak ~ 11μm

CREI: IR sounders, ISCCP: large peak at 32μm,
peaks of MODIS-ST / ATSR-GRAPE at 27μm
linked to sub-sampling of optically thicker clouds
& not to different channels (3.7 / 2.1 / 1.6 μm)
-> only retrieved near cloud top

COD: majority between 1 and 20

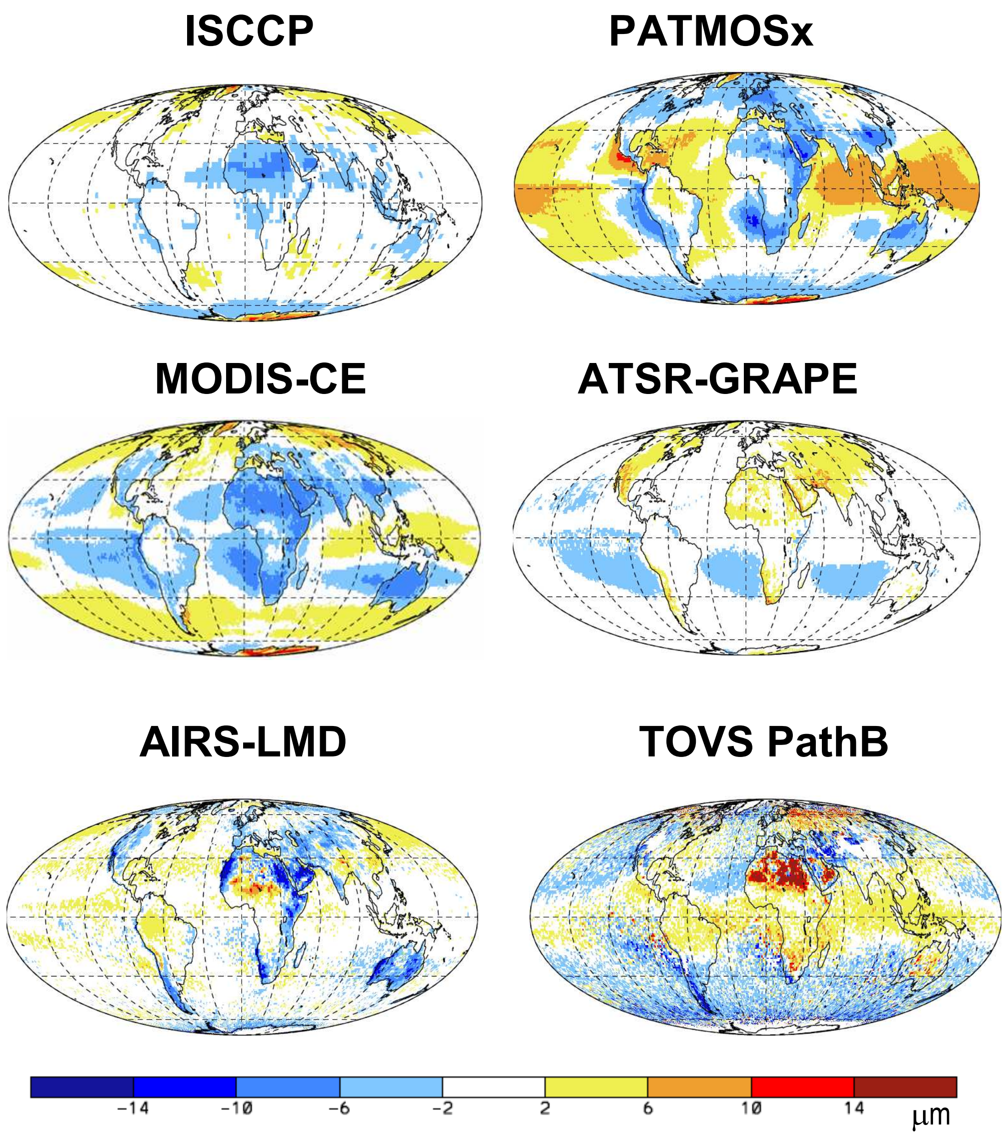
- **IR sounders: CEM -> COD** (limited to 10); **sensitive to cirrus**
- **MODIS-ST, ATSR retrieval filtering COD > 1**

distributions depend on retrieval filtering & partly cloudy fields

IWP:

- AIRS/TOVS compact distributions 5 - 100 gm^{-2}
- MODIS-ST distribution starts at 10 gm^{-2}
- ISCCP, PATMOSx additional large peak at 4 gm^{-2}

Regional variability: CREI

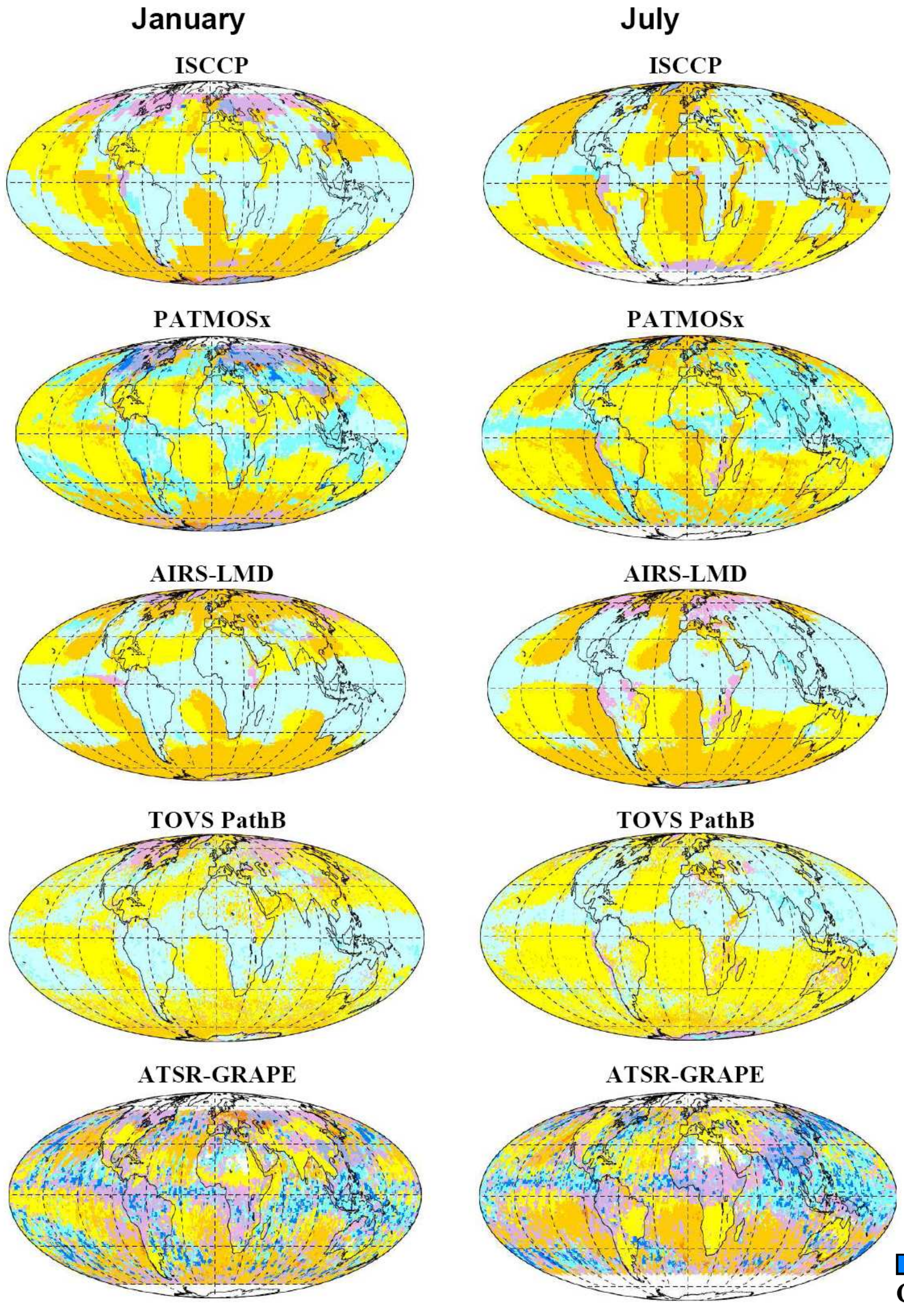


Distributions vary in contribution of large and small values

Mean regional variability differs between datasets

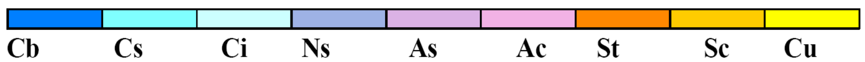
- ISCCP, ATSR, AIRS relatively small variations
- PATMOSx, MODIS-CE, TOVS large variations

COD-CP Histograms



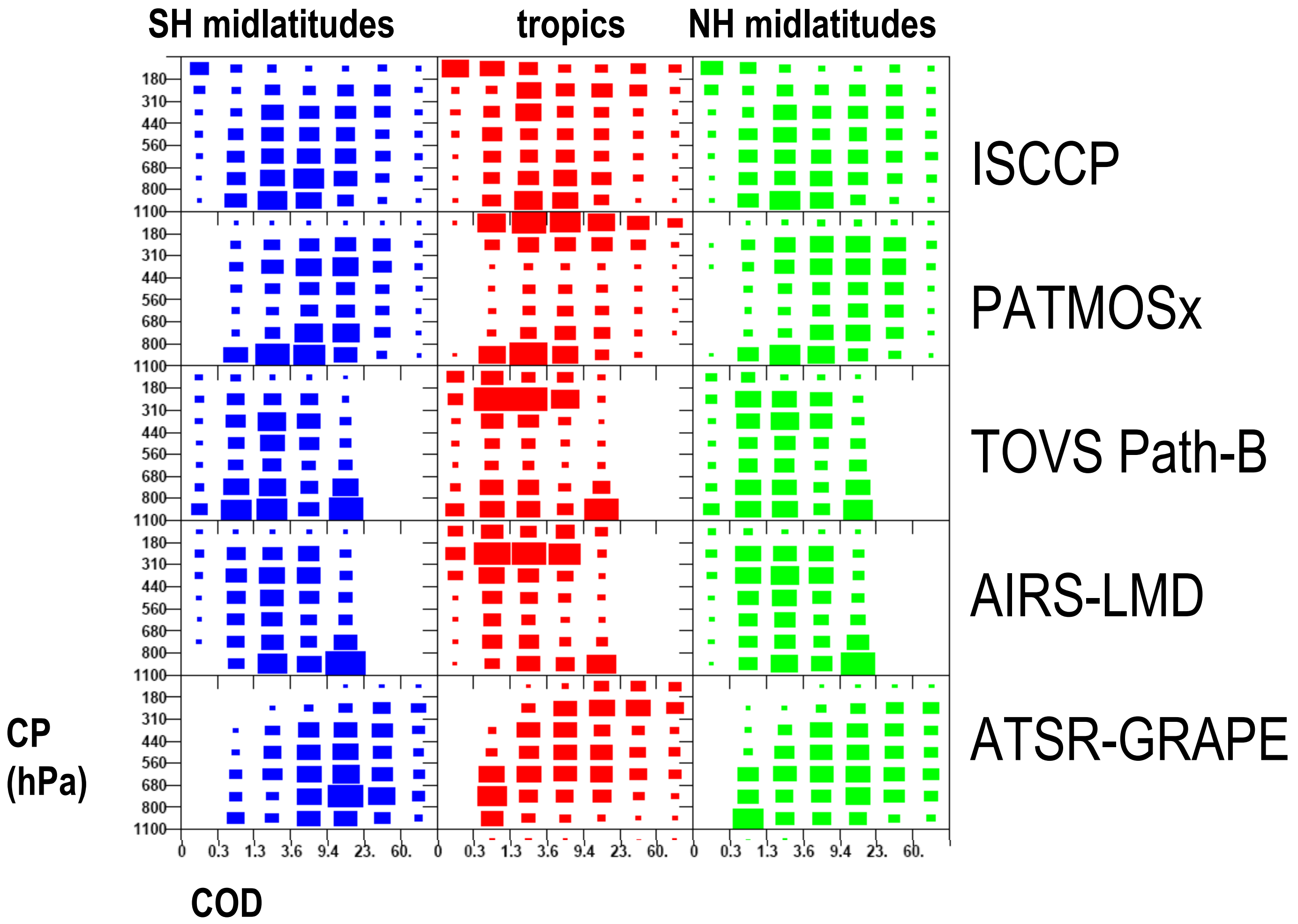
most frequent cloud types
from 2 dimensional COD-CP histograms:

- similar geographical distributions
- ATSR OE retrieval success mostly for thick clouds
- PATMOSx OE also yields optically thicker high clouds
- TOVS retrieval spat. res. (100 km) -> lower CODL



Outlook: Evaluation by comparing TOA fluxes

use 2 dimensional COD-CP histograms *(at monthly 1° x 1° map resolution)*



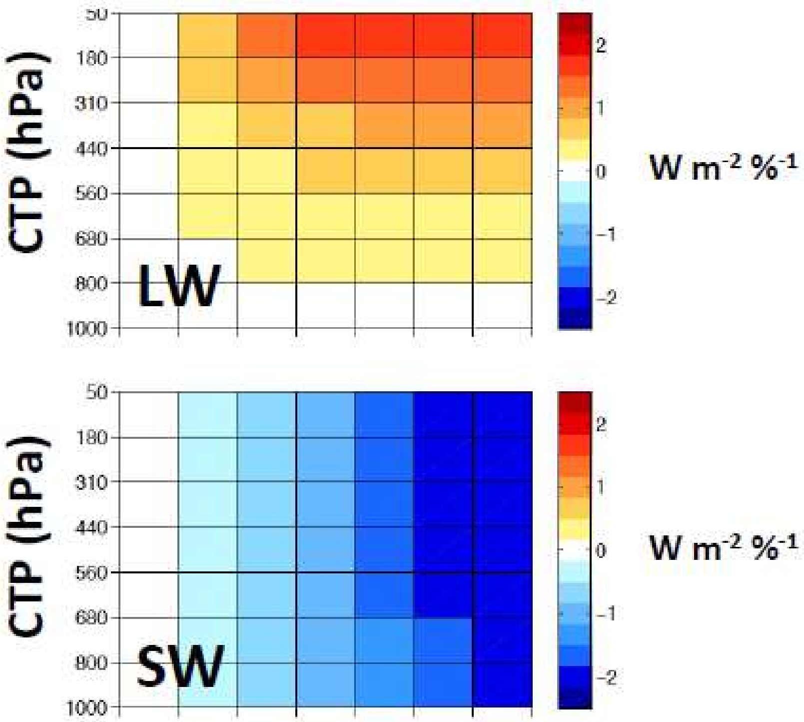
Outlook: Evaluation by comparing TOA fluxes 2

and cloud radiative kernels *(at monthly 1° x 1° map resolution)*

Zelinka et al. J. Climate 2012: use COD-CP histograms to study cloud feedbacks

-> computation of **cloud radiative kernels** by using radiative transfer code of *Fu & Liou*

fixed re (L: 10µm, I: 30µm), transform COD to LWC / IWC for corresponding CP layer



from Zelinka et al. J. Climate 2012

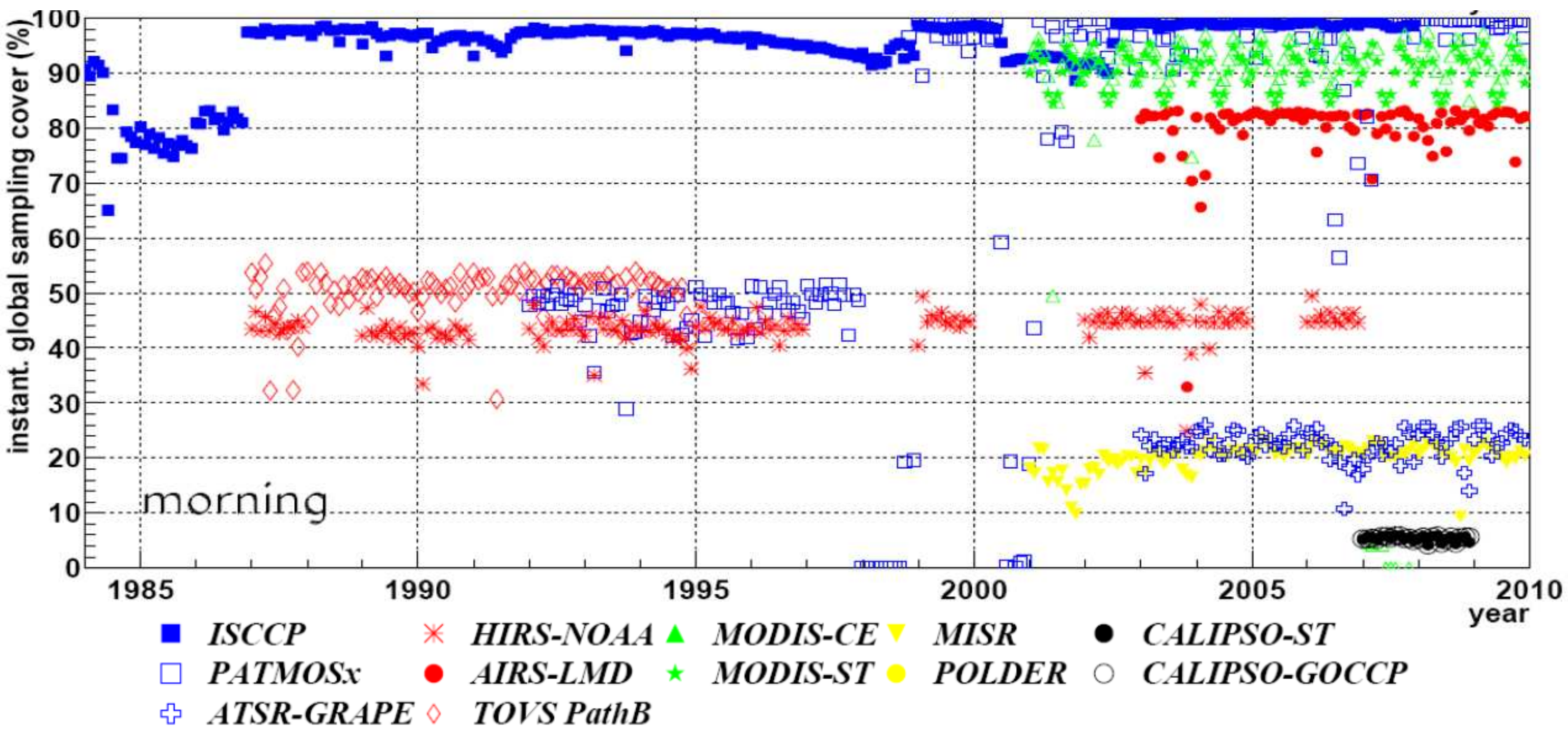
Cloud radiative kernels:
flux per % of cloud cover change

Evaluation of cloud properties:

- weight by histograms of GEWEX L3 data **at monthly 1° x 1° map resolution**
- compare resulting fluxes of different climatologies

Use of longterm datasets

Monitoring of Earth coverage



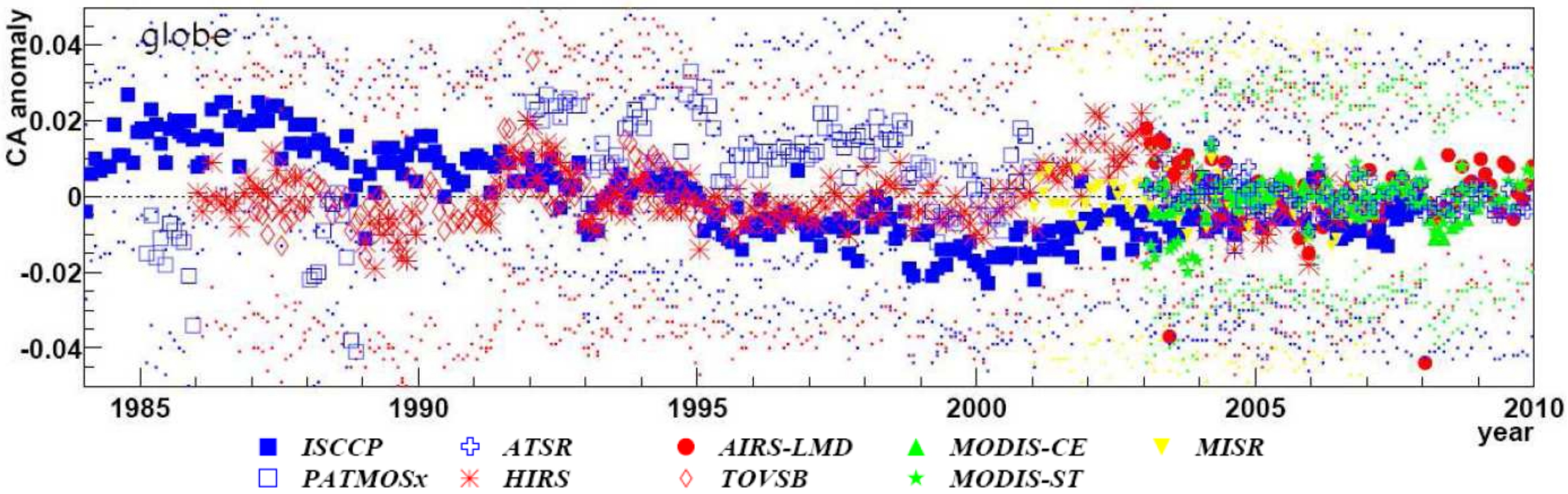
➢**climate change studies**: be aware of temporal changes in coverage!

MODIS at high latitudes more than 1 orbit passages, all others have kept only 1 passage

ISCCP nearly 100% coverage – MISR / ATSR 20% – CALIPSO ≤5%

➢**Interannual variability increases with decreasing Earth coverage!**

Global CA anomalies



global CA within ±0.025 (~ interannual mean variability)

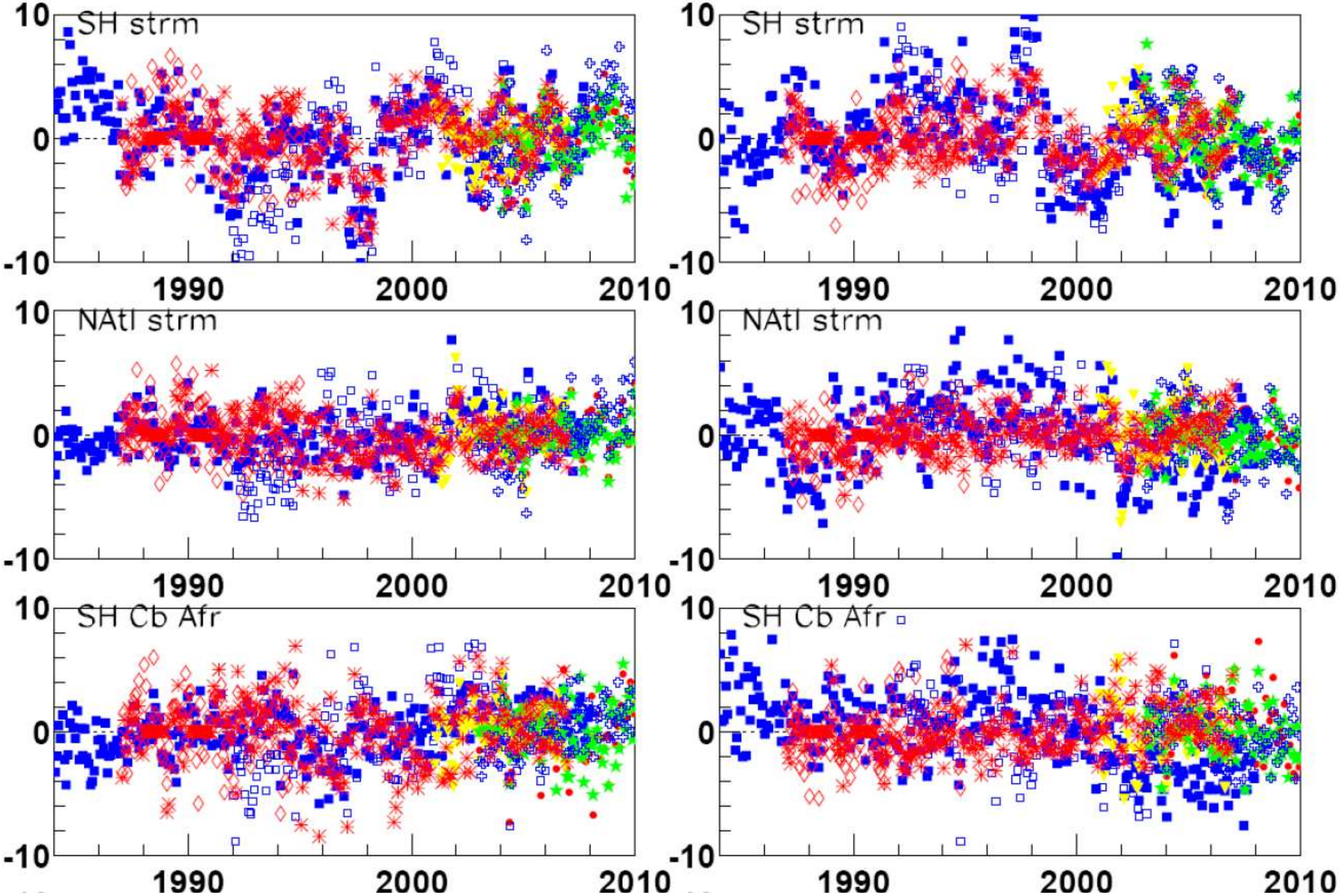
<u>Annex II: Investigation of possible artifacts in ISCCP cloud amounts</u> (by W. B. Rossow)

- radiance calibration changes
- geographic coverage changes
- day-night coverage changes
- satellite viewing geometry changes

Conclusion: these causes not enough to explain the magnitude of the CA variation

Regional CAHR/CALR anomalies

CAHR CALR



increase in natural variability when considering smaller regions

Conclusions

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

➢ **GEWEX Cloud Assessment:** for the first time

- coordinated intercomparison of L3 cloud products of 12 global ‘state of the art’ datasets
- common database facilitates further assessments, climate studies & model evaluation,
- available through IPSL Climserv ftp server and website
- results summarized in BAMS article and WCRP report

ISCCP: only dataset that directly resolves diurnal cycle (3hourly) & covers whole globe; thoroughly evaluated (≥ 42 articles)

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)

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

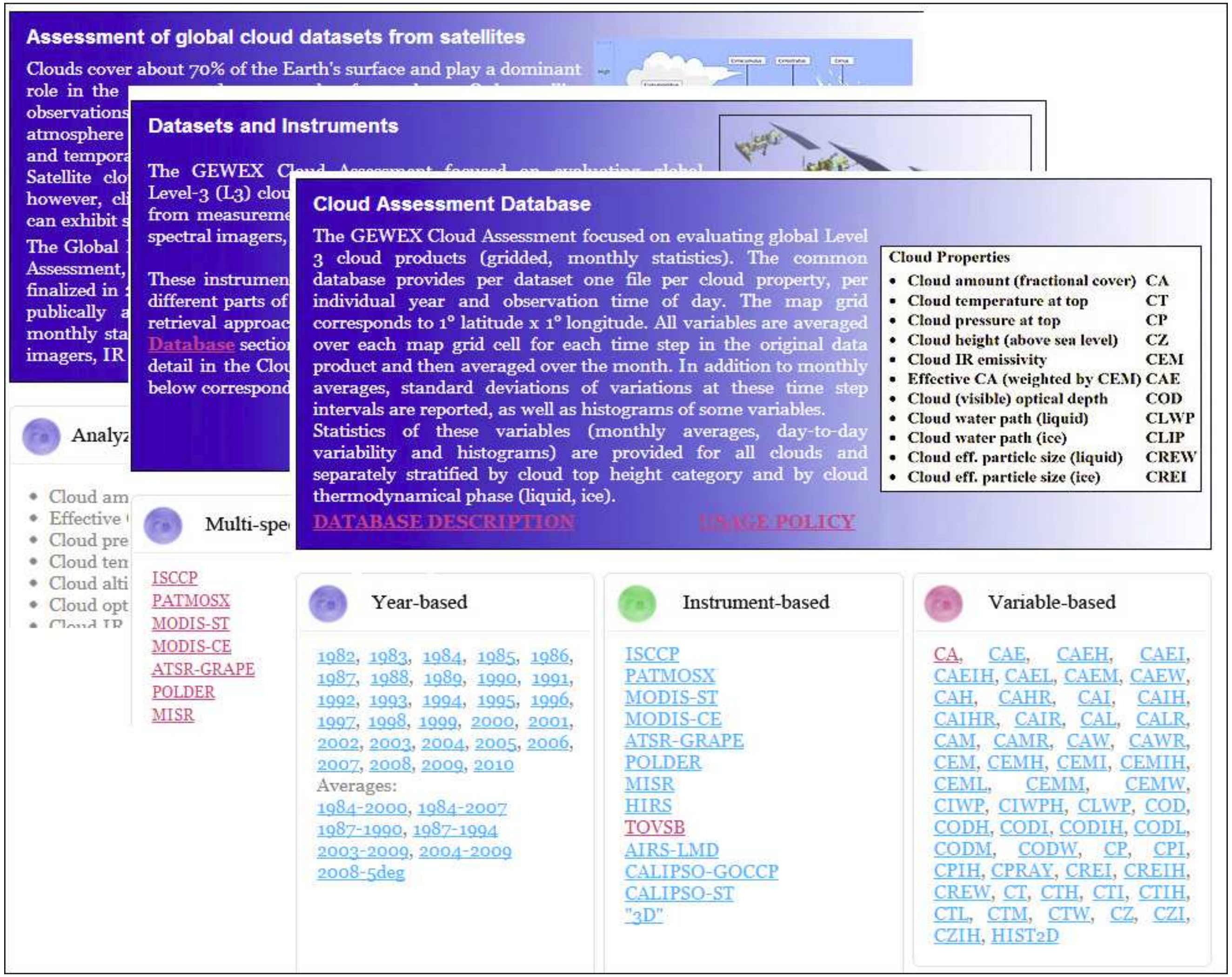
global monitoring of cloud properties very difficult (study effect of artifacts due to changes, see appendix II)

- **even if instantaneous cloud properties are not very accurate, the synergy of different variables (& specific analysis methods) provide invaluable potential for improving our understanding of clouds**
- **synergy of different datasets & variables also important for model evaluation:**
  compare correlations of physical variables or
  compare statistics organized by weather states

Heritage of GEWEX cloud assessment

- **Cooperation of 12 cloud teams**
- **Insight of how clouds are perceived by different instruments and how this affects averages and distributions**
- **Strategy to build L3 cloud products**
- **Common L3 database of cloud property statistics for climate studies & for assessment of new data sets**

New GEWEX Cloud Assessment Web-site



- **General sections:** description, meetings, publications, etc
- **"Datasets" provides links to individual descriptions: so far AIRS-LMD, TOVS Path-B, MISR, CALIPSO-ST**
- **"Database" contains links to output files: netCDF gzipped, all types of grouping, ftp-accessed.**
- **Registration and contacts – TBD?!**

http://climserv.ipsl.polytechnique.fr/gewexca - permanent address
http://cua-nasa-gsfc.info/feofilov/CloudAssessment/index.html - temporary address for tests