What did we learn from the GEWEX Cloud Assessment ?

Claudia Stubenrauch

Laboratoire de Météorologie Dynamique, IPSL/CNRS, France

&

GEWEX Cloud Assessment Team:

S. Kinne, W. B. Rossow, S. Ackerman, G. Cesana, H. Chepfer, L. Di Girolamo, B. Getzewich, A. Guignard, A. Heidinger, B. C. Maddux, W. P. Menzel, P. Minnis, C. Pearl, S. Platnick, C. Poulsen, J. Riedi, S. Sun-Mack, A. Walther, D. Winker, S. Zeng, G. Zhao

Outline

- Challenges to retrieve cloud properties
- GEWEX Cloud Assessment (2005-2012)
- GEWEX Cloud Assessment Database (≥ Nov 2012)
  L2 -> L3 aggregation
- What do we know about clouds from satellite retrievals ?
- Challenges in longterm monitoring
- How to use satellite cloud data for climate model evaluation?
- How to get a more complete cloud picture?
- Conclusions and recommendations

Challenges to retrieve cloud properties

Clouds are extended objects
of many very small liquid / ice particles

***Cirrus** (high ice clouds)*

satellite radiometers

↓

bulk quantities

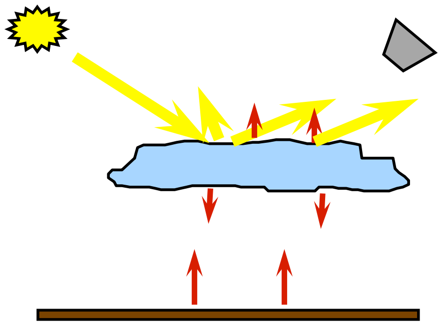
at spatial & temporal scales
to resolve
weather & climate variability

Cloud structures over Amazonia

***Cumulonimbus** (vertically extended)*

***Cumulus** (low fair weather clouds)*

Cloud properties from space



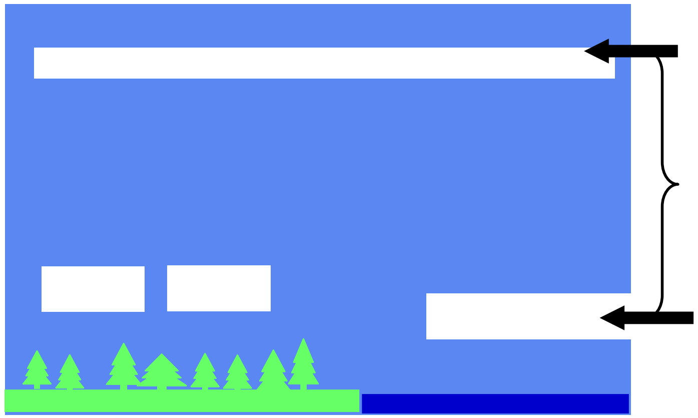
lidar – radar : *vertical structure of clouds*

IR-NIR-VIS Radiometers, IR Sounders,
multi-angle VIS-SWIR Radiometers
exploiting different parts of EM spectrum

- information on uppermost cloud layers
- 'radiative' cloud height
- perception of cloud scenes depends on instrument

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

thin Ci over low clouds : Interpretation of Cloud height



≤ 20% of all cloudy scenes (CALIPSO)

How does this affect climatic averages & distributions ?

GEWEX Cloud Assessment

GEWEX Cloud Assessment Milestones

Assessments essential for climate studies & model evaluation

initiated by GEWEX Radiation panel (GRP)

2005-2010: 4 workshops :

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

2009-2011: Preparation and quality check of common L3 data base

monthly statistics (averages, variability, histograms) in netCDF format

2012: Results & description of datasets : WCRP report, BAMS article

opening of L3 data base to public

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

Datasets & Teams

global gridded L3 data (1° lat x 1° long) : monthly averages, variability, Probability Density Functions

ISCCP ***GEWEX cloud dataset***	***1984-2007***	*(Rossow and Schiffer 1999)*
MODIS-ScienceTeam	***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)*
HIRS-NOAA	***1982-2008***	*(Wylie, Menzel et al. 2005)*

relatively new retrieval versions:

PATMOS-x (*AVHRR*)	***1982-2009***	*(Heidinger et al. 2012, Walther et al. 2012)*
ATSR-GRAPE	***2003-2009***	*(Sayer, Poulsen et al. 2011)*

complementary cloud information:

CALIPSO-ScienceTeam	***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)*

Data base

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

➢ **facilitates assessments, climate studies & model evaluation**

properties:	(GCOS ECV's)		
• cloud amount	CA	*(0.01-0.05)*	+ rel. cloud type amount
• pressure/ height	CP/CZ	*(15-50 hPa)*	
• temperature	CT	*(1-5 K)*	
• IR emissivity	CEM		
• eff cloud amount	CAE	*(= cloud amount weighted by emissivity)*	
• VIS optical depth	COD		
• Water path	CLWP/CIWP	*(25%)*	
• eff part. radius	CRE	*(5-10%)*	

1° x 1° monthly statistics per obs time:

● averages, ●monthly variability, ● histograms

distinguish : tot, High, Mid, Low Water, Ice

CP< 440 hPa, CP>680hPa CT>260K, CT<260 / 230K

GEWEX CA L2 -> L3 Aggregation at specific local time

What are the properties of the cloud when present within 1°x1°?

discussed & agreed upon at workshop in 2010

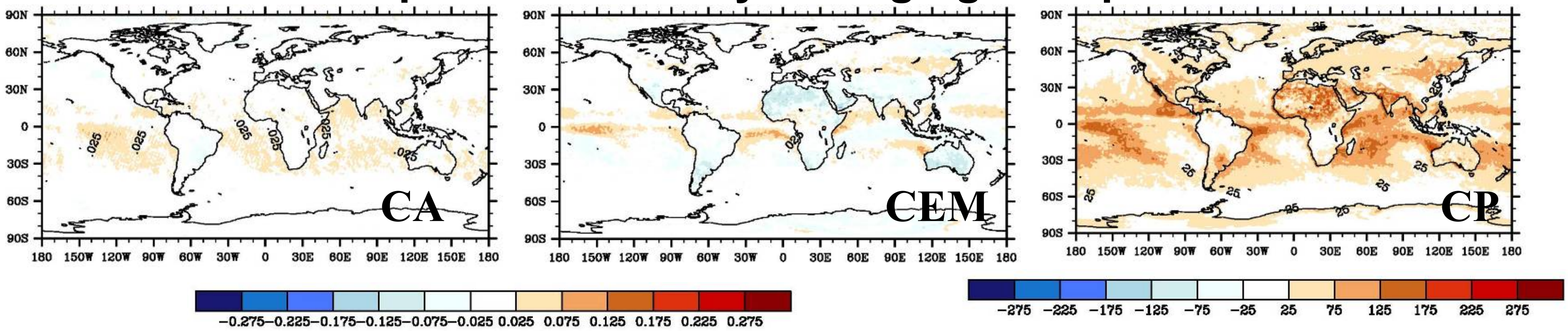
✓ **first average over space (1° x 1°) & then over time (month)**

✓ at higher latitudes with orbit overlaps, choose measurements closest to local observation time (keep data with smallest viewing angle)

Data processing by teams (Fortran program was provided)

- cloud properties do not depend on instantaneous measurement & cloud grid coverage
- appropriate way to compare data of different spatial resolution and to compare to climate models

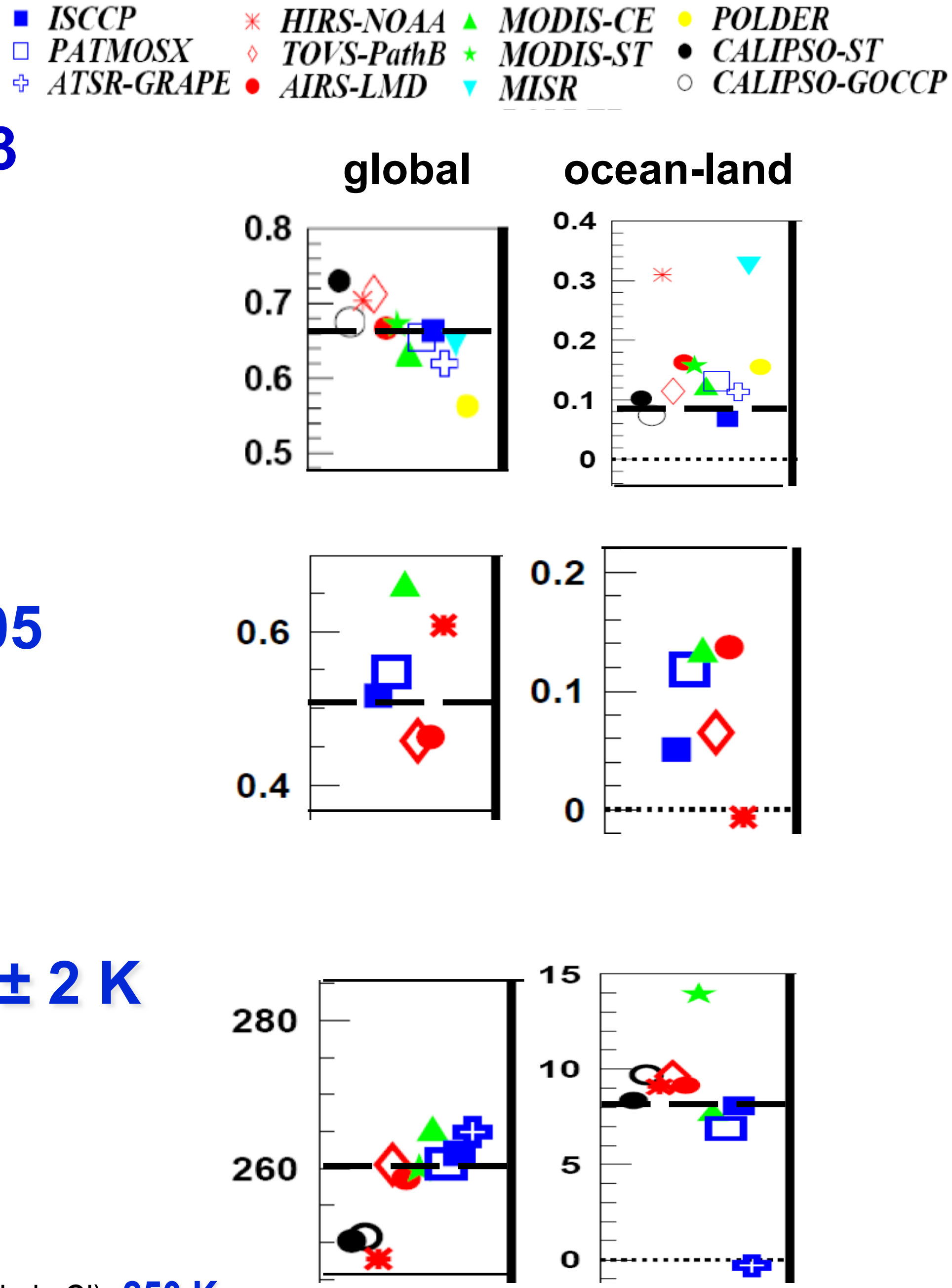
Differences compared to monthly averaging over pixels: *ex AIRS-LMD*



difference in CA small, but larger (& systematic) for other properties, depending on cloud scenes

Key results

Global averages & ocean-land differences



Cloud Amount (Cover): 0.68 ± 0.03

for clouds with COD>0.1

+ 0.05 subvisible Ci, -> 0.56 (clds with COD > 2)

synoptic (day-to-day) variability : 0.25-0.30
inter-annual variability : 0.025

0.10-0.15 larger over ocean than over land

Effective Cloud Amount: 0.50 ± 0.05

(weighted by cloud IR emissivity)
synoptic (day-to-day) variability : 0.26-0.28

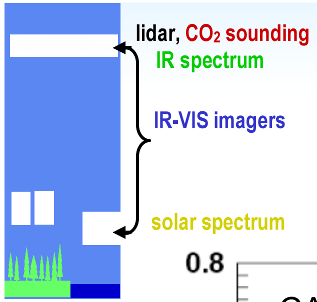
0.05-0.12 larger over ocean than over land

Cloud 'radiative' Temperature: 260 ± 2 K

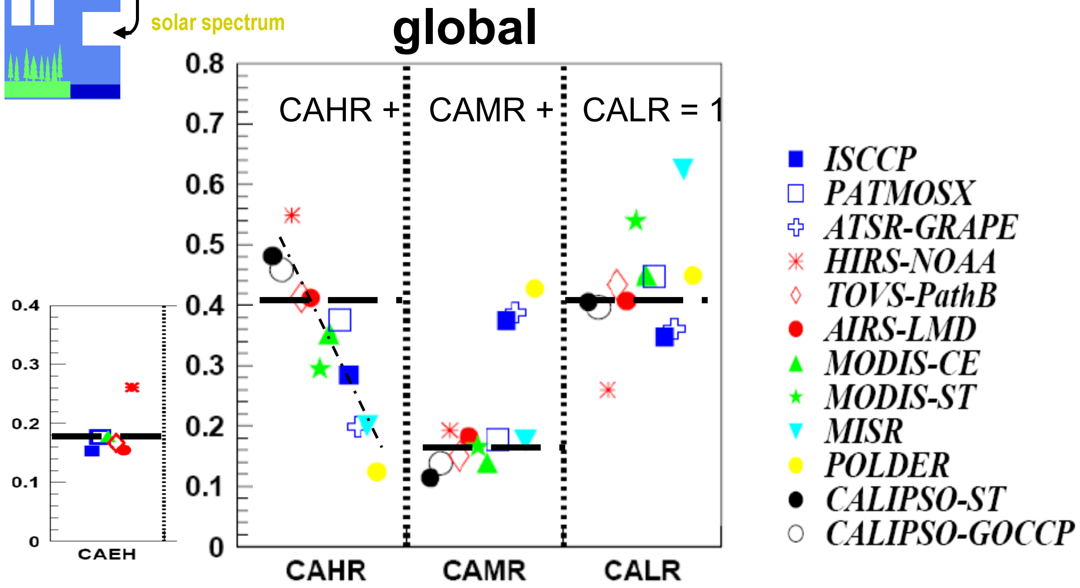
synoptic (day-to-day) variability : 15-20 K
inter-annual variability : 2 K

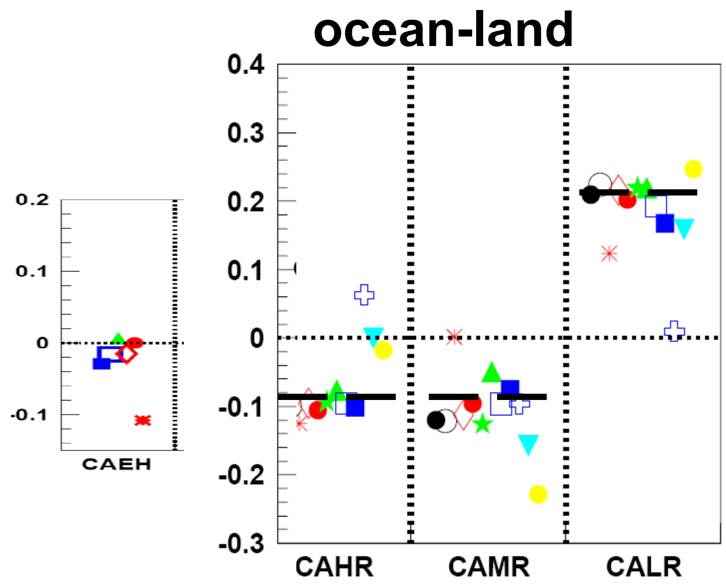
7-9 K warmer over ocean than over land

Cloud Top Temperature (including subvis Ci): **250 K**



How many of detected clouds are high, midlevel & low clouds?





CALIPSO only considers uppermost layers to better compare with other datasets

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

42% are **high clouds** (COD>0.1) **->** 20% with COD>2 (MISR, POLDER)

eff high cloud amount agrees : 0.17 -> another sign of missing thin cirrus

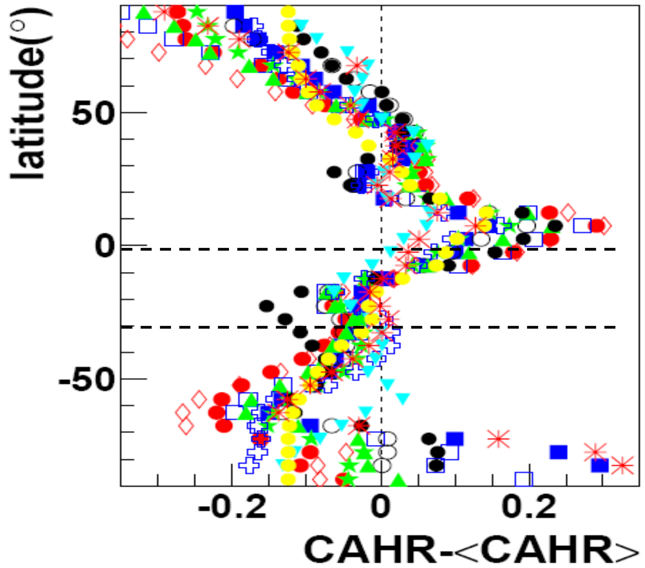
16% (±5%) are **midlevel clouds**

thin Ci over low cloud misidentified as midlevel clouds by ISCCP, ATSR, POLDER

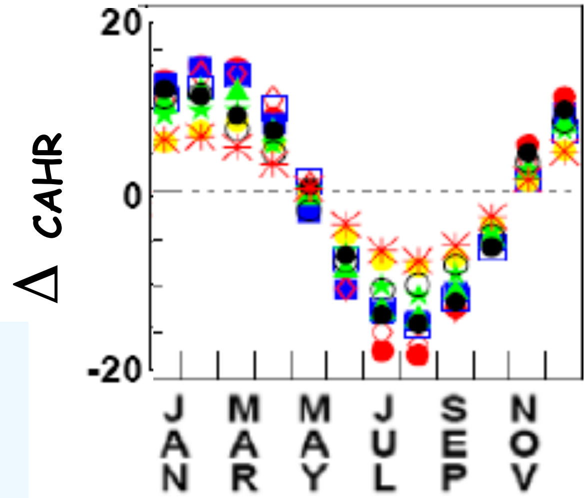
42% are **single-layer low clouds, 60%** are **low clouds** (MISR, CALIPSO, surface observer)

20% **more low clouds over ocean;** 10% **more high / midlevel clouds over land,**
optically thinner over land, -> effective cloud amount similar

Latitudinal & seasonal variations

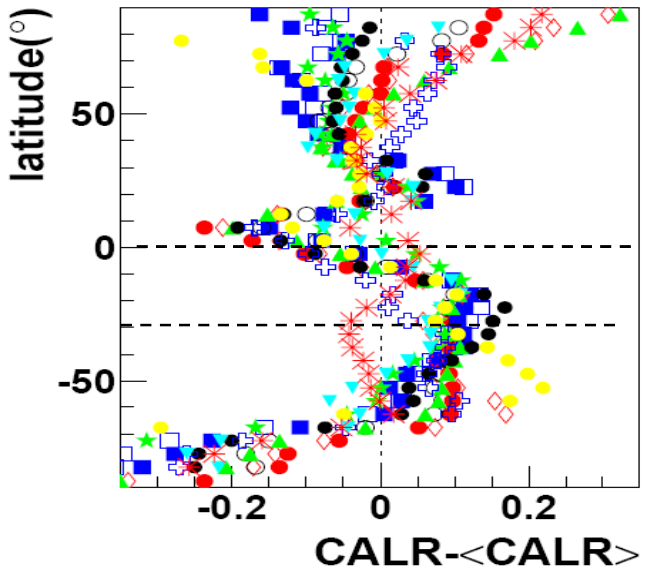


high-level clouds

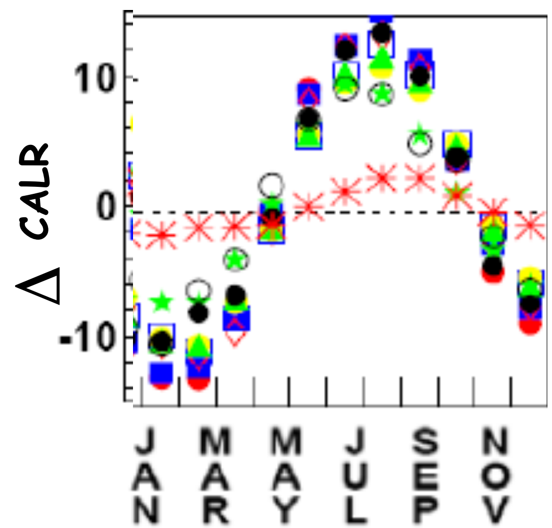


latitudinal & seasonal variations similar !

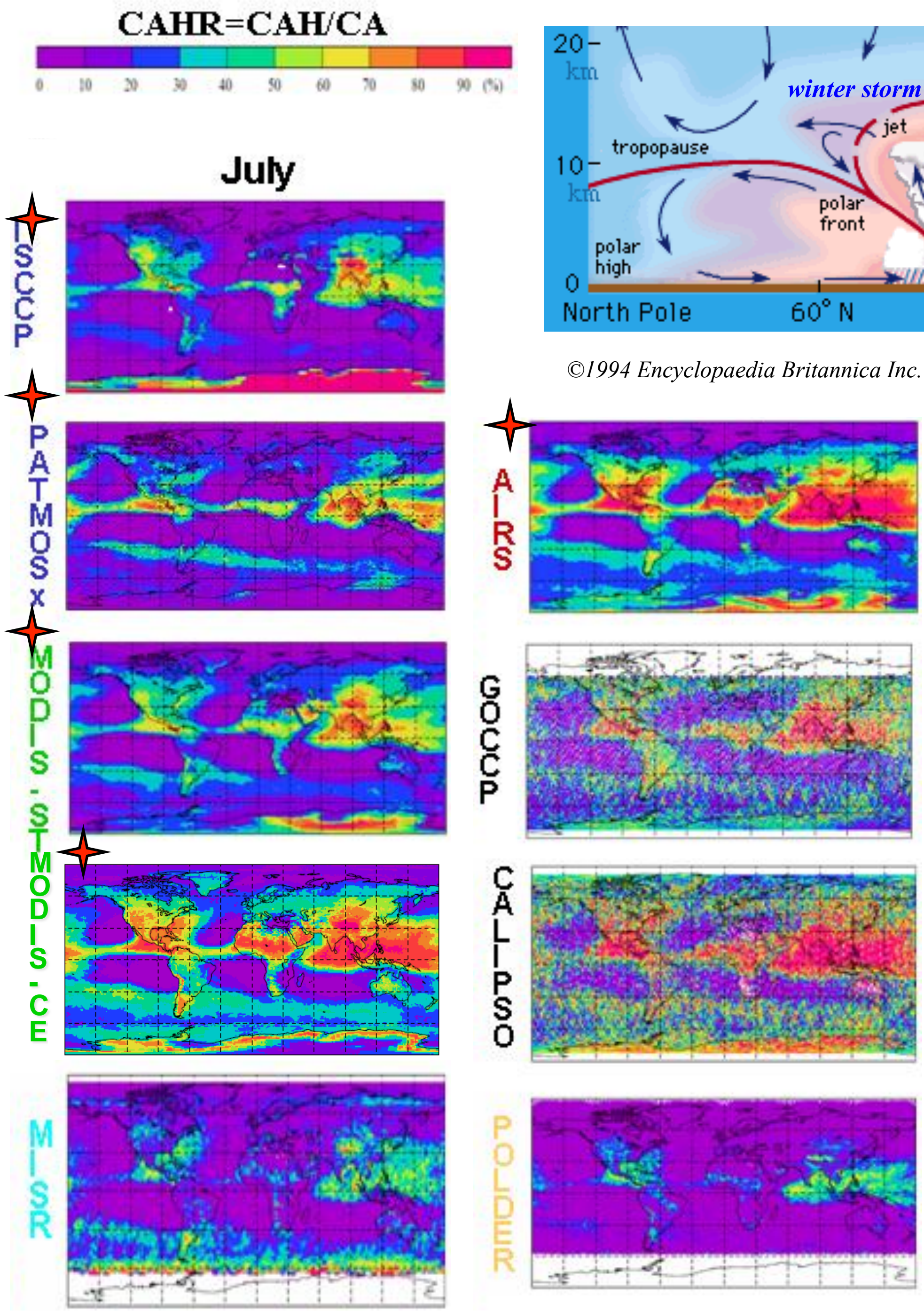
(except polar regions & HIRS CALR over ocean)

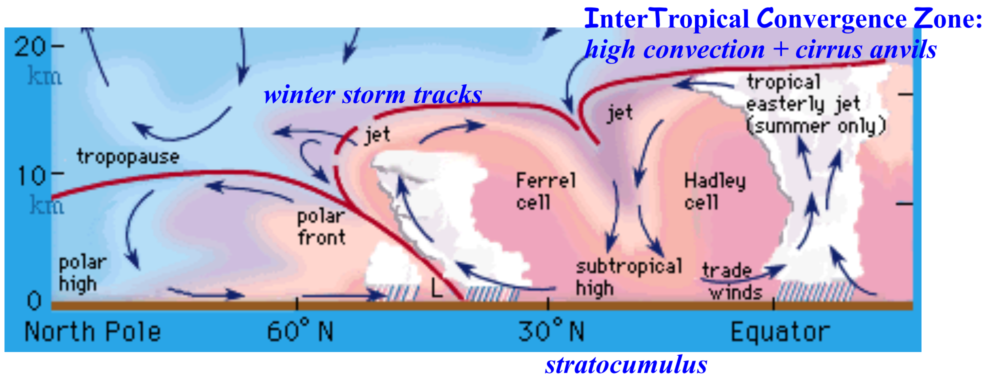


single-layer low clouds



Even if absolute values depend on Ci sensitivity, geographical cloud distributions agree





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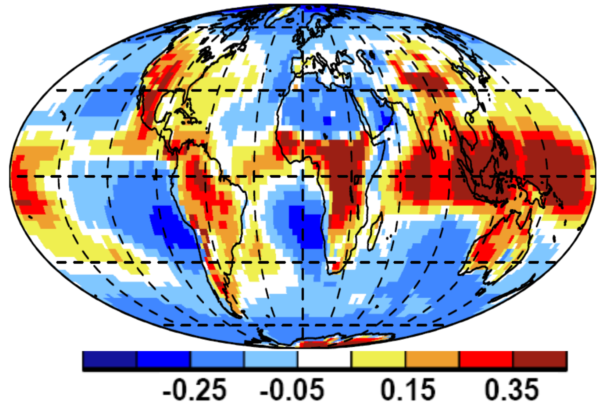
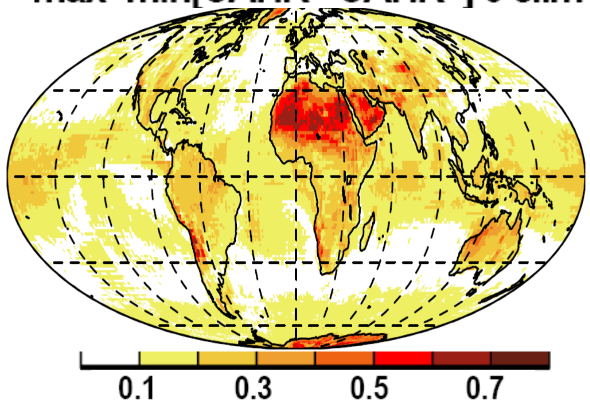
CAHR - <CAHR> ISCCP

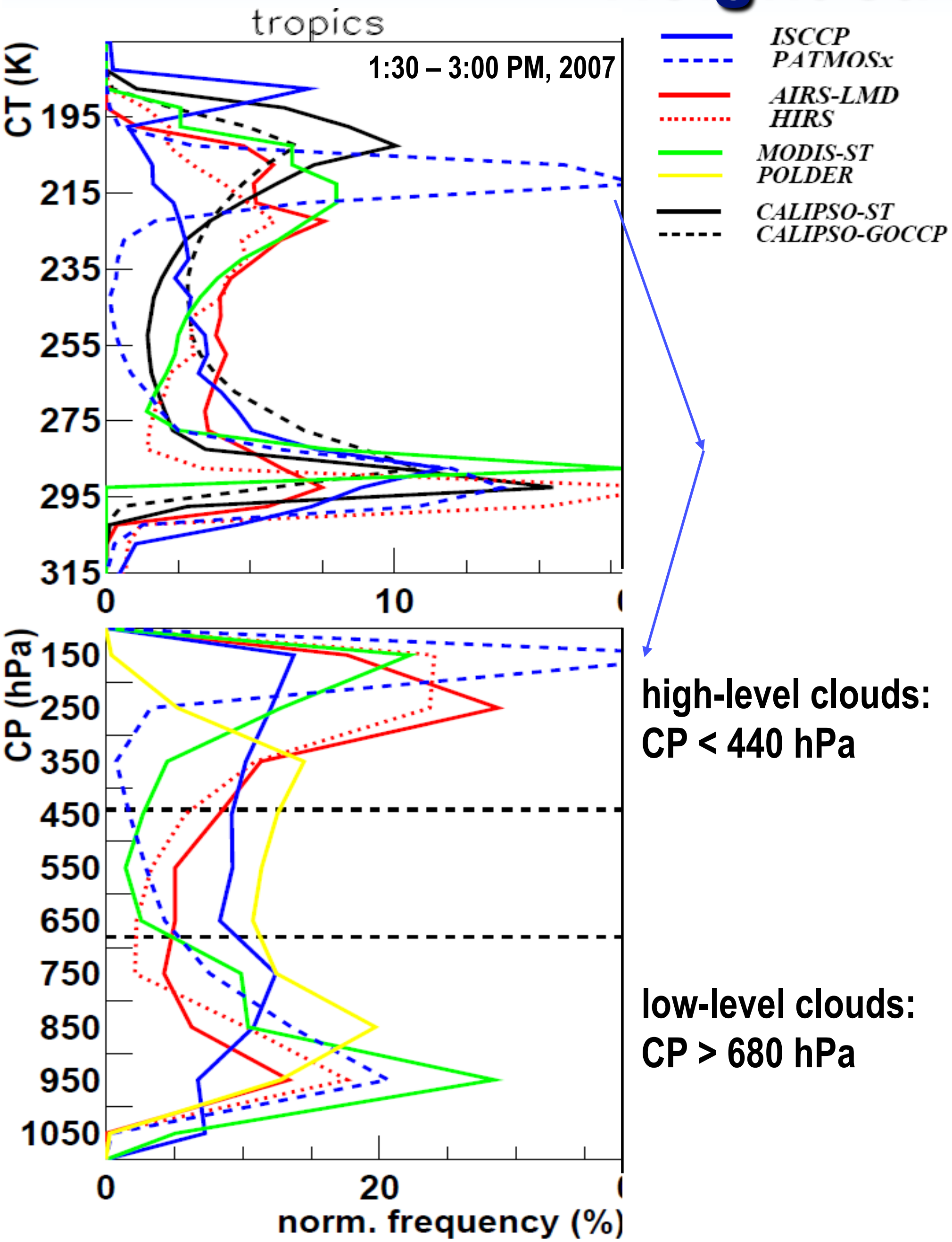


uncertainty on regional variability:

max–min[CAHR-<CAHR>] 6 clim



Height stratification



Retrieval of T, p or z:

T : *ISCCP, PATMOSx, MODIS-CE*

p : *AIRS, HIRS, MODIS-ST, POLDER, ATSR*

z : *CALIPSO, MISR*

&

atmospheric profiles : T->p, p->T,z->T

retrieved (Op. TOVS, TOVS Path-B, AIRS)

reanalysis (NCEP), forecast (GMAO, ECMWF)

bimodal T/p distributions in tropics

CALIPSO -> cloud top + sensitive to subvis Ci

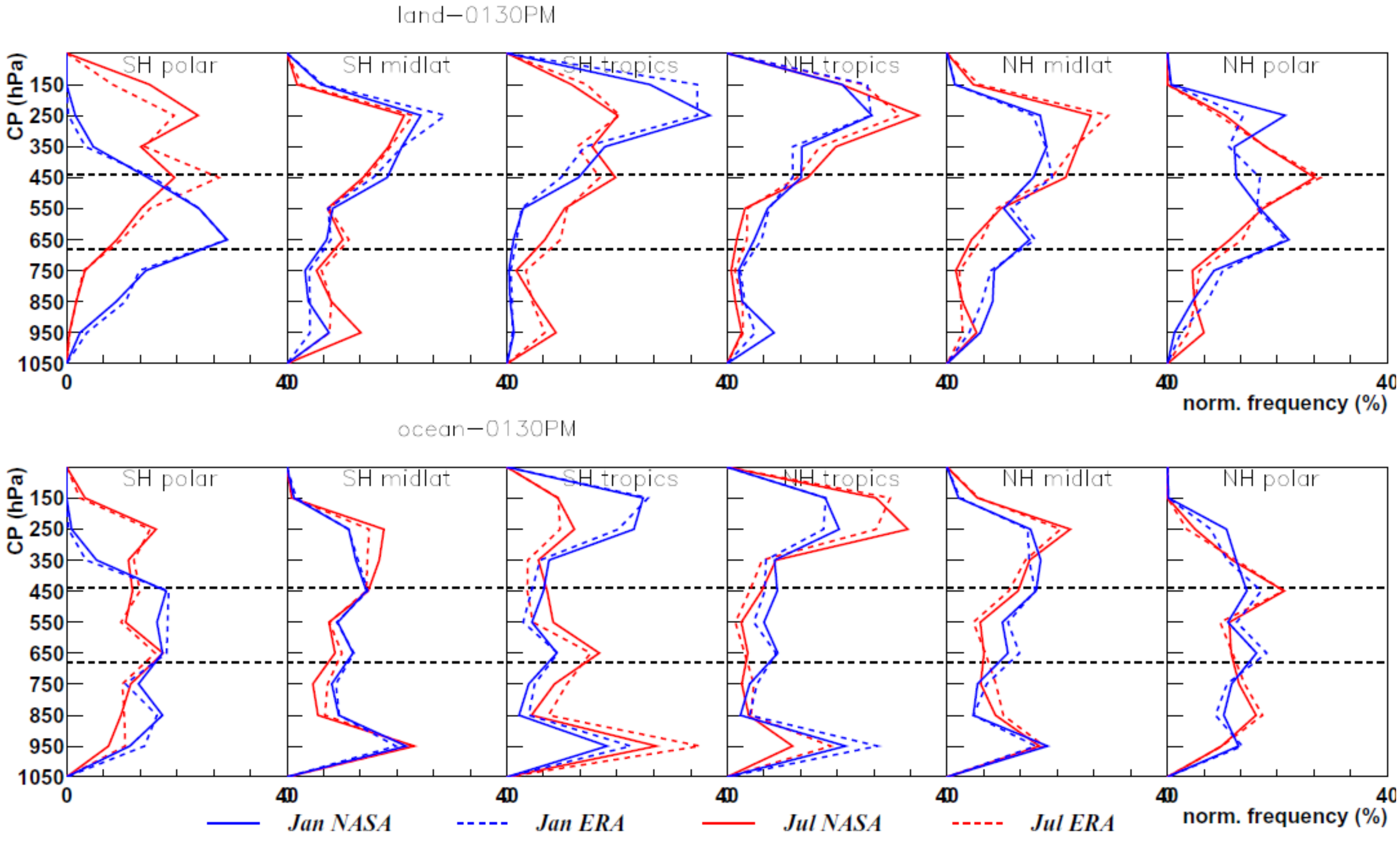
=> should point to coldest CT

- ISCCP peak at smaller CT corresponds to very thin Ci which has been put to the tropopause

- 5 K spread for low- level clouds
- **15 K spread for high-level clouds: diffusive cloud tops**

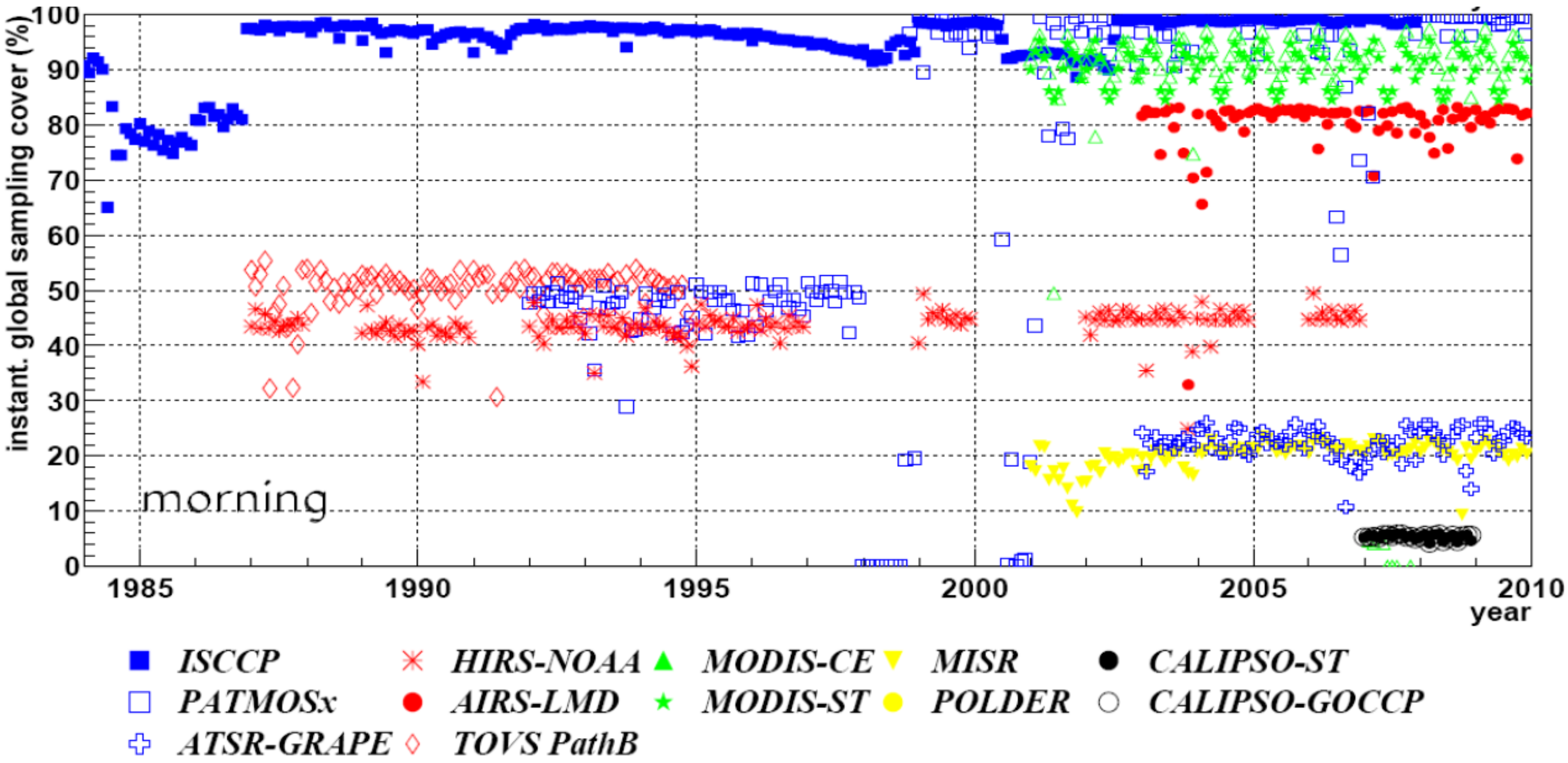
Influence of atmospheric profiles on CP

example AIRS-LMD: NASA V6 profiles, ERA Interim



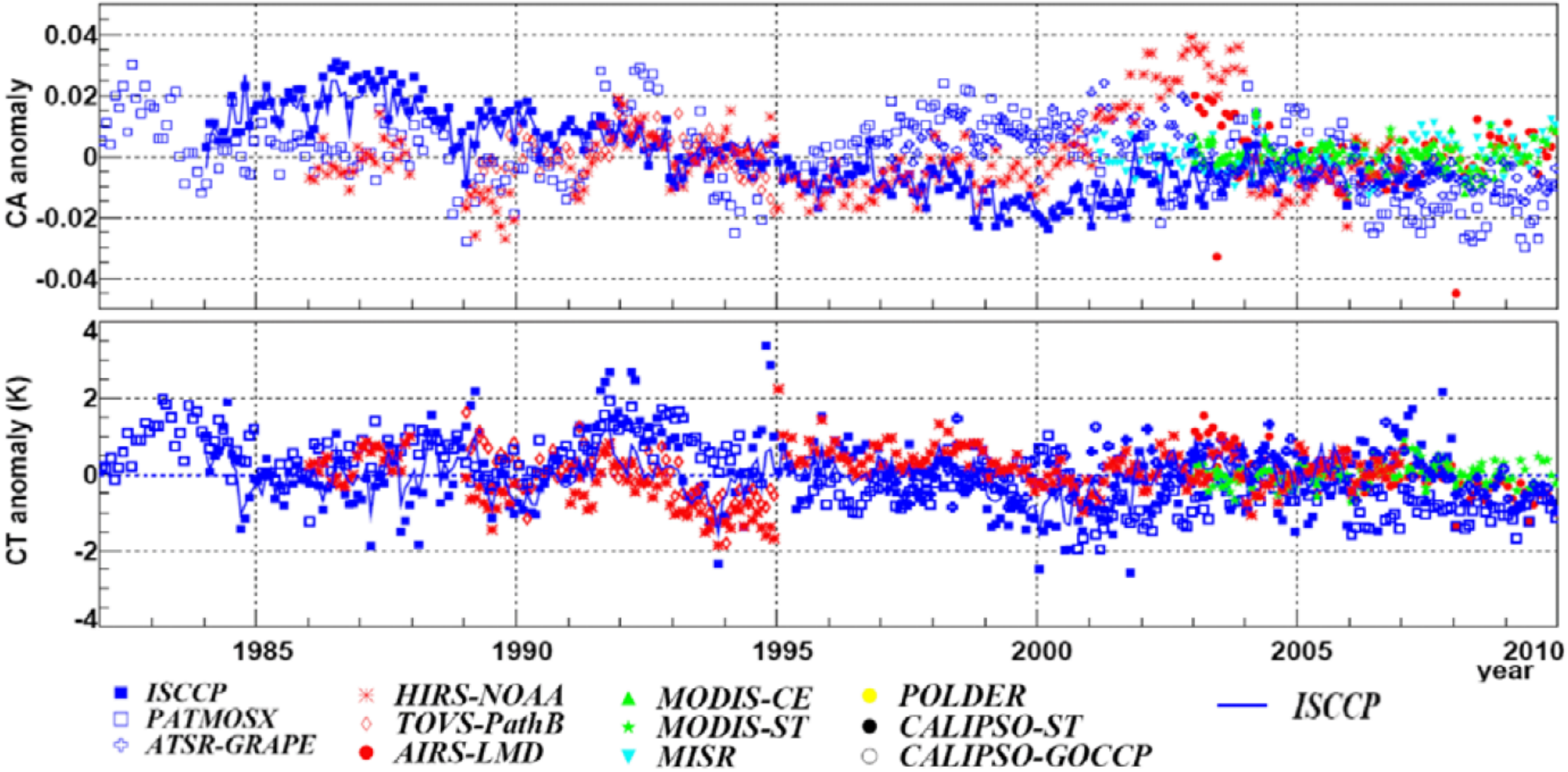
Challenges in longterm monitoring

Monitoring of Earth coverage / day at specific obs



- ➢**climate change studies**: be aware of temporal changes in coverage!
- ➢Interannual variability increases with decreasing Earth coverage!

Global CA / CT anomalies in time



global CA within ±0.025, CT within ±2K (~ interannual mean variability)

Investigation of possible artifacts in ISCCP cloud amounts (W. B. Rossow, Ann. 2 of WCRP report)
Changes in radiance calibration, geographic & day-night coverage, satellite viewing geometry reduce magnitude of CA variation only by 1/3

merging different instruments / satellites challenging

-> look at histograms / regions

Applications:

assessment of other datasets

evaluation of climate models

cloud radiative effects

Cloud Assessment Database to assess other datasets

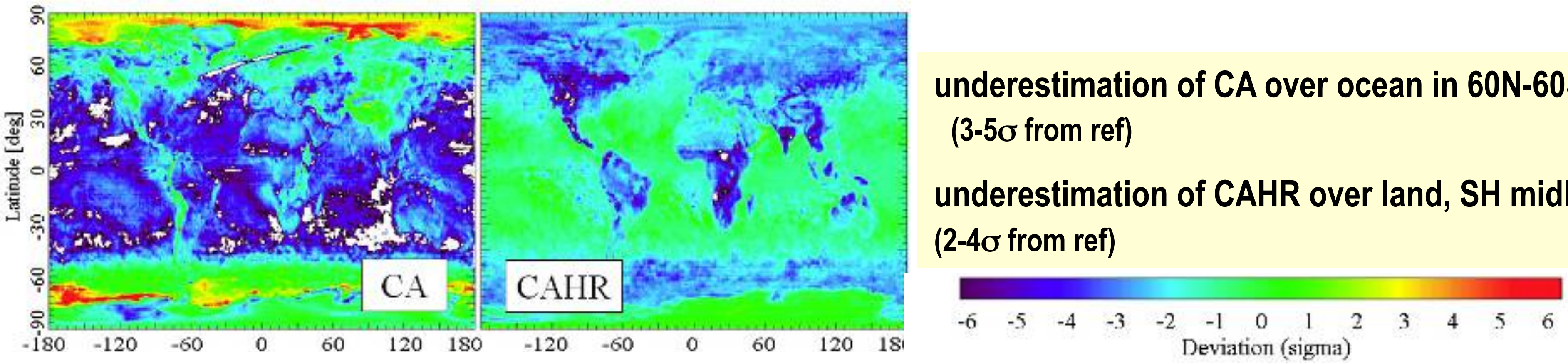
ESA Cloud CCI: creating longterm cloud dataset from AVHRR, MODIS, ATSR

(Retrieval based on Optimal estimation)

compare to GEWEX CA reference:

ISCCP, PATMOSx, MODIS-ST, MODIS-CE, AIRS-LMD

$$(x_{ESACCI} - \langle x \rangle_{GEWEX}) / \sigma x_{GEWEX}$$

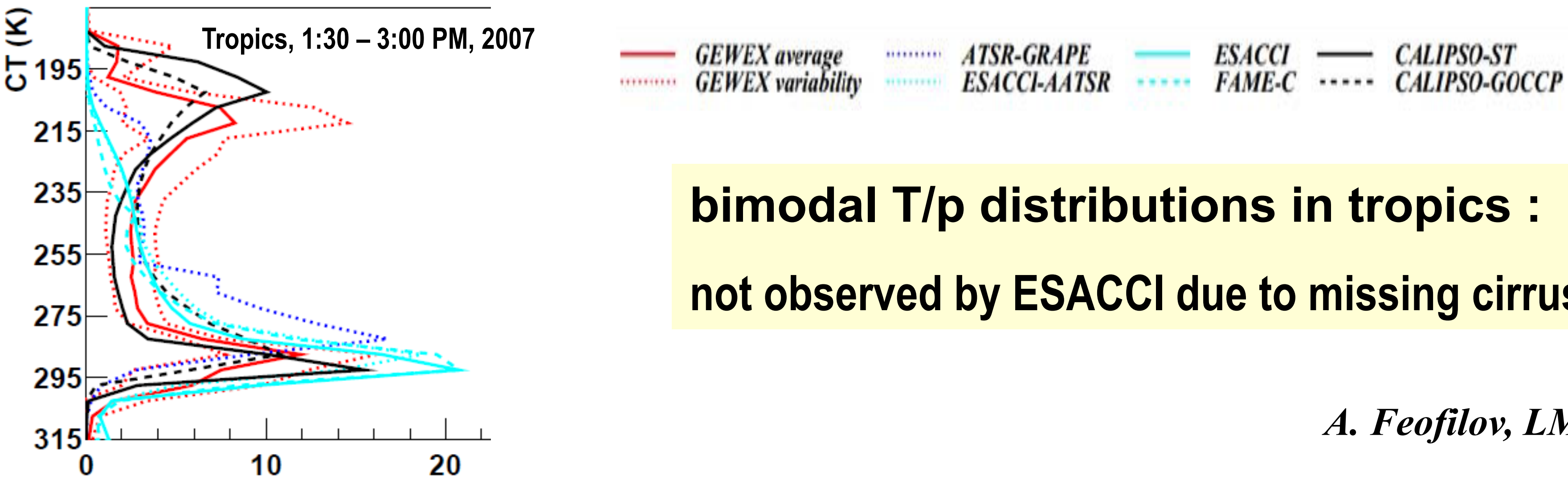


underestimation of CA over ocean in 60N-60S

(3-5σ from ref)

underestimation of CAHR over land, SH midlat.

(2-4σ from ref)



bimodal T/p distributions in tropics :

not observed by ESACCI due to missing cirrus

A. Feofilov, LMD

Comparison to climate models

Satellite observations view clouds from above:

- **passive remote sensing only gives information on uppermost clouds**
- **observations at specific local time**
- **instrument & retrieval method sensitivity, retrieval filtering, partial cloudiness may lead to biases**

Climate models prescribe cloudiness per pressure layer (H_2O saturation)

- clouds built from adjacent layers & max / random overlap per lat x long grid

⇓

✓ **filter local time, cloud detection sensitivity (in optical thickness)**

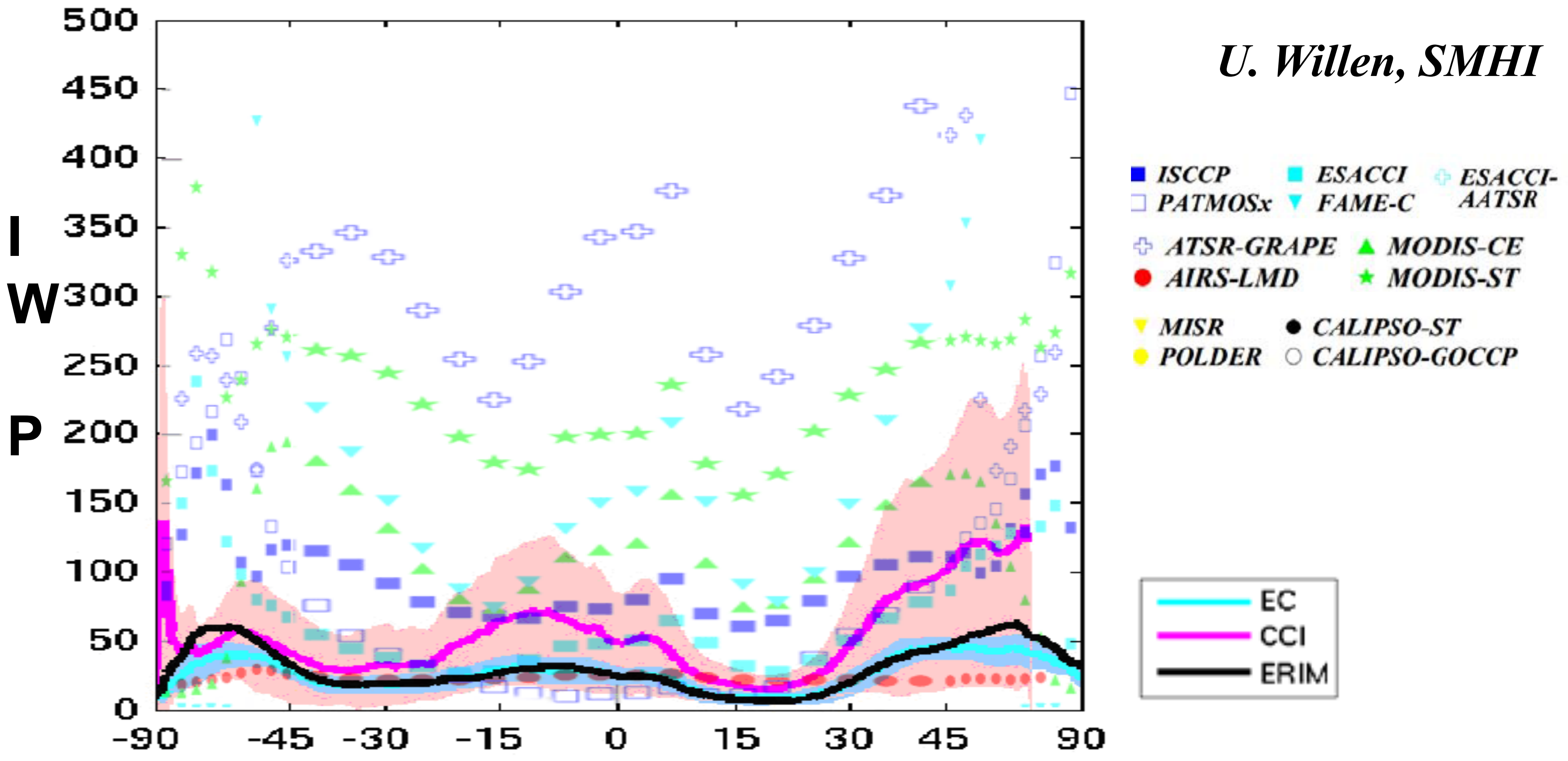
✓ **cloud property grid averages from cloud overlap scheme**

Satellite Simulators or simpler methods take care of these issues
However, they can not repair insufficient instrument / retrieval sensitivity

IWP: latitudinal average

EC-Earth Model

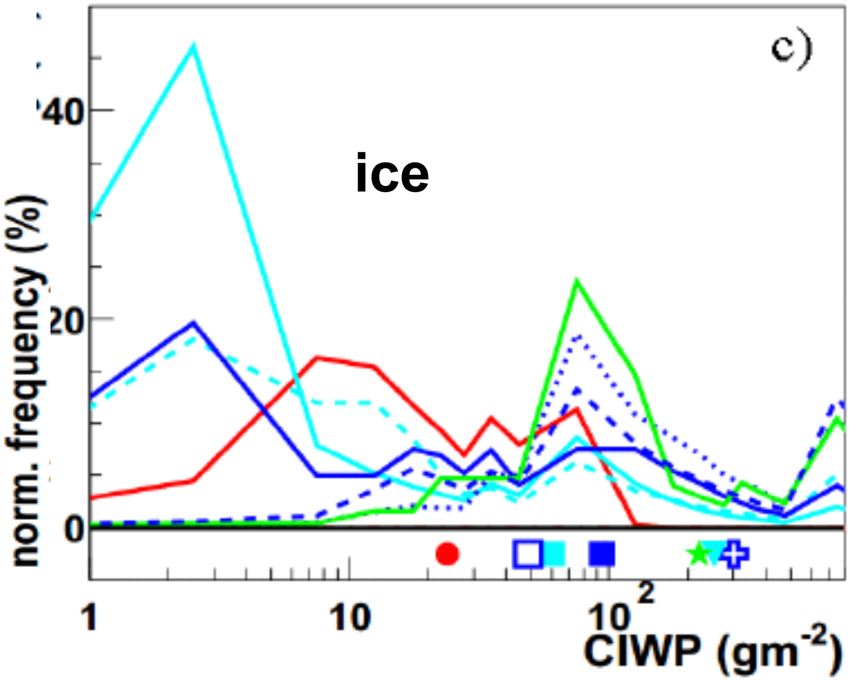
U. Willen, SMHI



IWP averages are difficult to compare, large spread between datasets

IWP histograms

Single scattering properties in radiative transfer depend on thermodynamical phase / particle shape



Cloud Water Path:

Liquid: **40 – 120 gm^{-2}** **Ice:** **25 – 300 gm^{-2}**

averages & distributions strongly depend on retrieval filtering & partly cloudy fields

(MODIS-ST, ATSR retrieval filtering COD > 1, AIRS COD < 4)

essential to be taken into account when comparing to models!

Cloud Assessment Database to determine cloud radiative effects

assessing cloud climatologies in terms of TOA fluxes

(ESA Cloud CCI phase 2)

1) determine radiative fluxes of 7 x 7 cloud types over the globe, at different seasons

Cloud Radiative Effect per cloud type *(Chen et al. 2000)*

CP (440, 680 hPa) vs. COD (3.6, 23)

SW CRE

-25	-87	-126
-29	-81	-99
-34	-75	-85

LW CRE

31	60	61
13	22	21
4	8	8

net CRE

5	-28	-66
-16	-59	-78
-30	-67	-77

or radiative flux kernels of *(Zelinka et al. 2012)*

2) weight fluxes by COD-CP histograms *(monthly 1° x 1° map resolution)*

ISCCP

0.21	0.09	0.04
0.13	0.11	0.03
0.19	0.18	0.03

PATMOSx

0.13	0.17	0.08
0.03	0.08	0.06
0.24	0.18	0.03

AIRS-LMD

0.29	0.11	0.0
0.12	0.06	0.0
0.17	0.24	0.0

differences in COD-CP distributions lead to differences in radiative effects
(transformation of IR emissivity to COD -> COD < 10 => underestimation of SW effect)

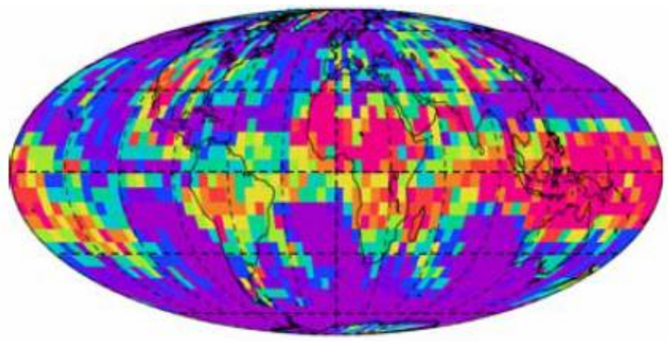
IR-VIS Synergy

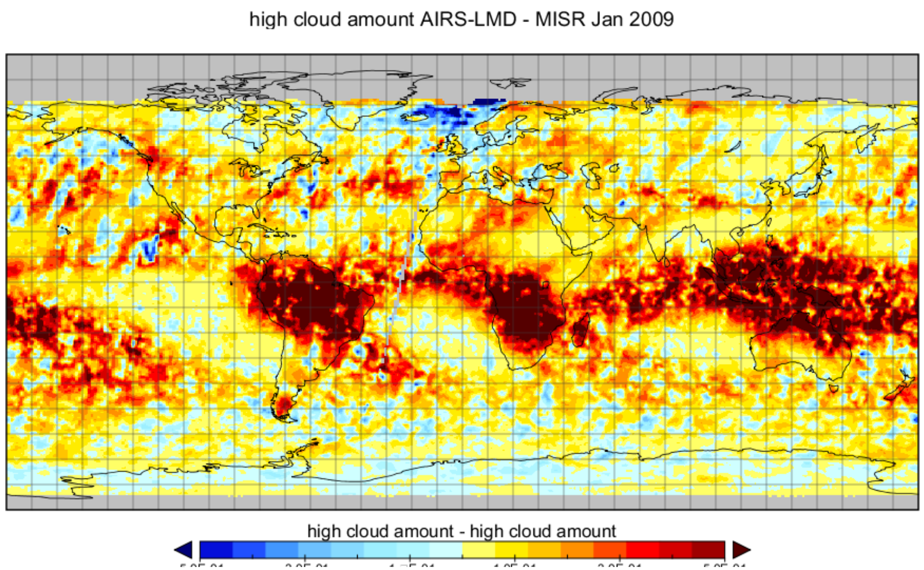
-> multi-layer clouds

IR Sounder - Imager Synergy: multi-layer situations in daylight

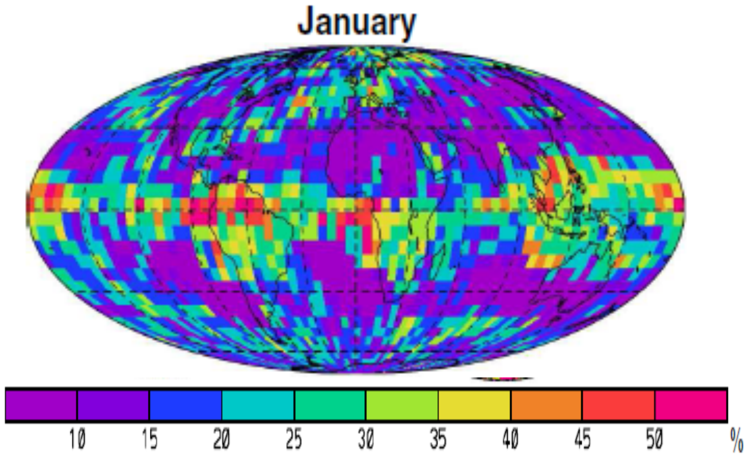
from CALIPSO-ST :

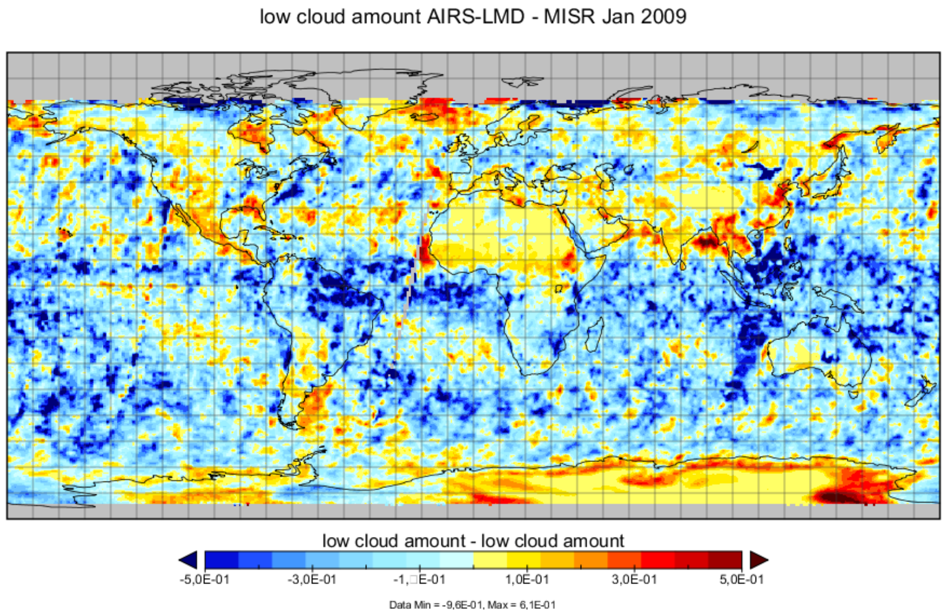
single-layer semi-transparent Cirrus (COD<3)





semi-transparent Cirrus above lowlevel clouds





IR sounding provides high-level & VIS provides low-level clouds

Conclusions

GEWEX Cloud Assessment (2005-2012):

- **first coordinated intercomparison of L3 cloud products of 12 global 'state of the art' datasets**
- **common database facilitates further assessments, climate studies & model evaluation**

➢ **tremendous joint effort to build consistent database:**

1) developing of strategy for L2 -> L3 processing ***(2010 workshop)***

2) each team followed given code for L2 -> L3 processing

3) Iterative process:

analyses -> problems in some variables (averages or histograms) -> feedback to teams -> correction by teams & sending in new data

some inconsistencies in L2->L3 processing remained in MODIS; MODIS-CE histograms not usable…

building of database was necessary, because not many coherent publications for comparison

utility of database so far:

➢ **worthwhile for improvement of existing datasets & for assessment of new datasets**

➢ **too early to see impact on model evaluation & climate studies**

(questions arising from users)

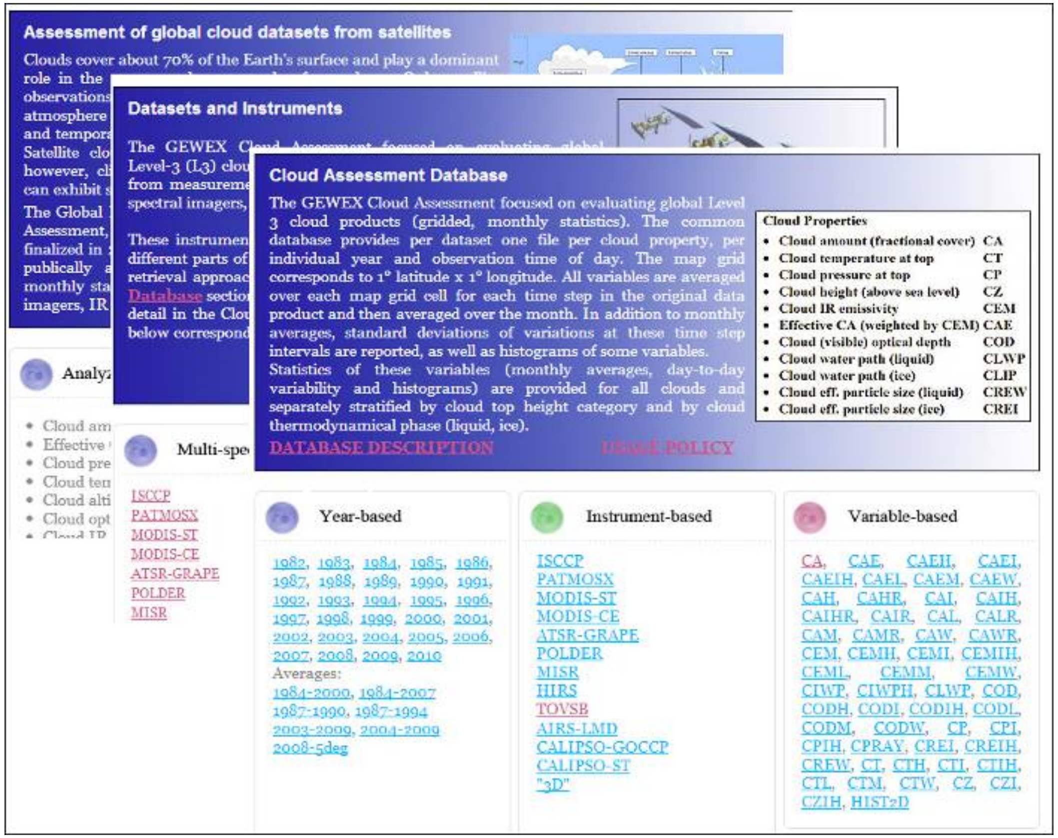
➢ **This kind of assessment should be repeated when enough new material available; building of database should be much easier, because of GEWEX Cloud Assessment heritage**

Update & Maintenance of Database

agreed with IPSL ClimServ:

➢all participating teams are welcome to provide updated (published) versions

➢New teams may send in their data, if processed in the same manner (like ESA Cloud CCI data)



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

Recommendations to CRCREW

- CREW workshops give an excellent platform for exchange

Interconnection of teams inbetween ?

- detailed L2 assessments are essential

especially when well synthesized :

coordinated investigations on:

impact of atmospheric profiles (T, Tsurf)

phase misidentification

horizontal / vertical inhomogeneity

- estimation of L2 uncertainties is very important

biases are often scene dependent; difficulty lies in knowing the scene

- L2->L3 aggregation:

in general, it would be good to take into account strategies already developed

most appropriate method depends on application

study will be very useful for uncertainty propagation

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						
CEMI/CREI	x	x		x	x							

56 variables

a: averages

s: variability

h: histogram

12 datasets

2 – 25 years

≤ 4 observation times

zipped: 160 Gb

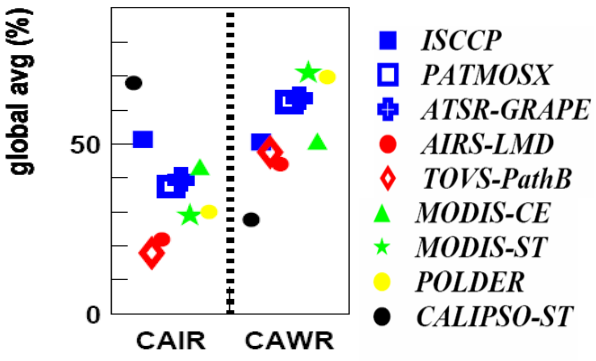
unzipped: 1.4 Tb

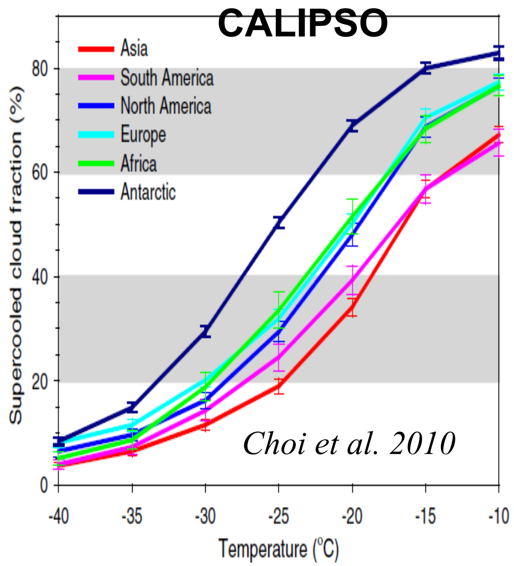
histograms of MODIS-CE not usable

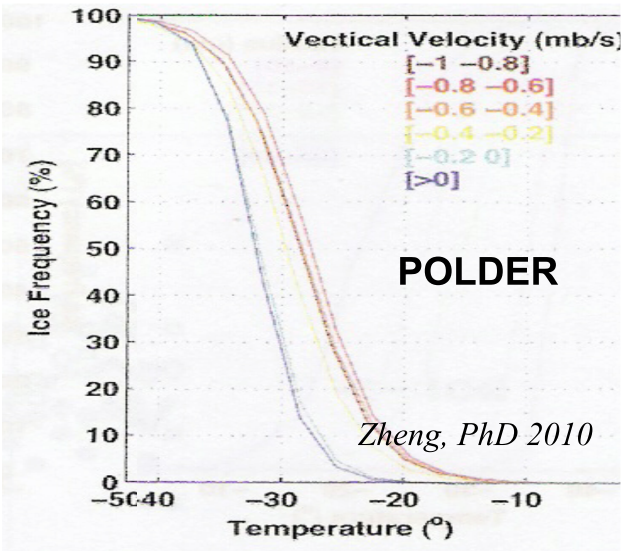
Thermodynamic phase & retrieval of optical / microphysical properties

Retrieval of optical / bulk microphysical properties needs thermodynamic phase distinction:

- polarization (POLDER, CALIPSO)
- multi-spectral (PATMOS-x, MODIS, ATSR)
- temperature (ISCCP, AIRS, TOVS)







R_{VIS} -> COD

R_{VIS} & R_{SWIR} -> COD & CRE (smaller particles reflect more)

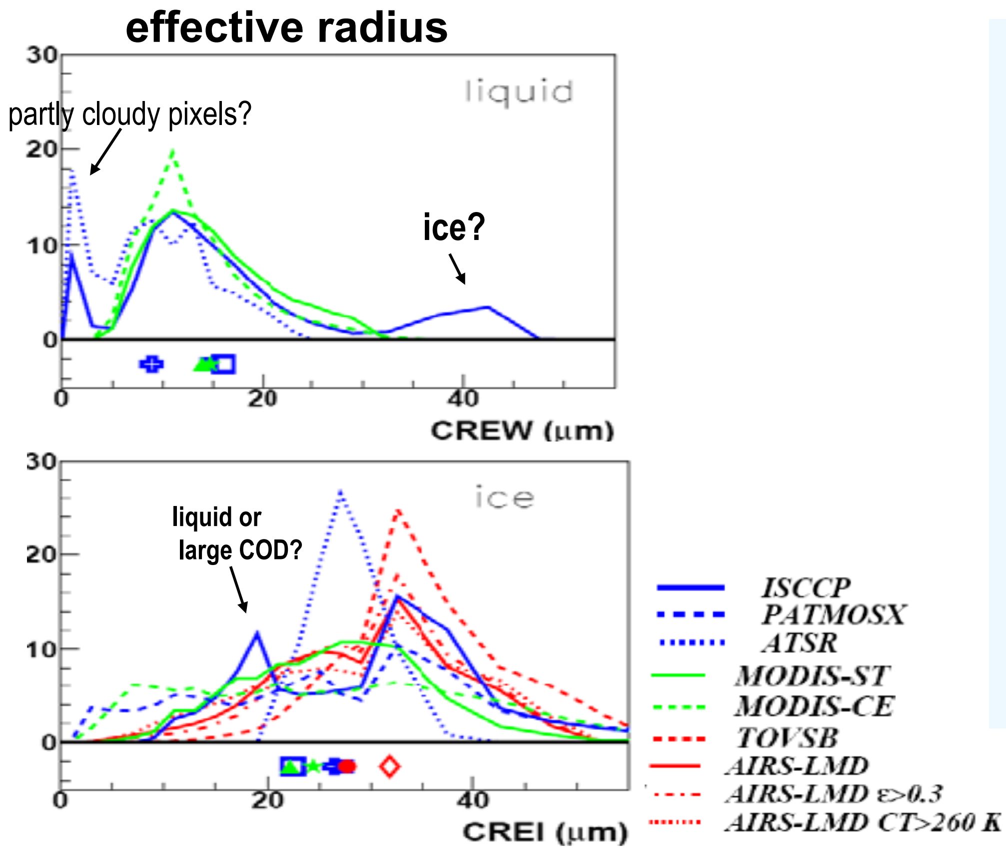
assumptions in radiative transfer: particle habit, size distribution, phase

WP = 2/3 x COD x ρ x CRE (vertically hom.)

IR: small ice crystals in semi-transparent Ci lead to slope of CEM's between 8 & 12 μm

Bulk microphysical properties

Single scattering properties in radiative transfer depending on thermodynamical phase / particle shape



Effective Cloud Particle radii:

Liquid: 14 ± 1 μm

Ice: 25 ± 2 μm

differences
linked to retrieval filtering of optically thicker clouds
& less to different channels (3.7 / 2.1 / 1.6 μm)
-> only retrieved near cloud top

When considering *retrieval filtering* or *partly cloudy pixels / ice-water misidentification*, distributions agree well .