Global Energy and Water Cycle Experiment
GEWEX WCRP Cloud Assessment

Scope and status of cloud property products

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

Global Energy and Water Cycle Experiment GEWEX WCRP

Cloud Assessment

co-chairs: C. Stubenrauch, S. Kinne

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

initiated in 2005 by GEWEX Radiation panel (GRP)

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

2009-2011: Preparation of common data base *(monthly statistics in netCDF format)*

2011: WCRP report, BAMS article & opening of data base to public

Assessments essential for climate studies & model evaluation

- Homogenized documentation on
  - *sensor, calibration*
  - *retrieval method, ancillary data*
  - *sampling*
  - *evaluation*
- state strength & limitations & suitable applications for each dataset
- make clear statements for each of the cloud properties

(global averages & distributions, regional variability, seasonal cycles, diurnal cycle, interannual variations, longterm anomalies)

Cloud Assessment common data base

to facilitate assessments, climate studies & model evaluation

properties:	(GCOS ECV's)	
• cloud amount	CA	+ rel. cloud type amount
• pressure/ height	CP/CZ	
• temperature	CT	
• IR emissivity	CEM	
• eff cloud amount	CAE	*(= cloud amount weighted by emissivity)*
• VIS optical depth	COD	
• Water path	CLWP/CIWP	
• eff part. radius	CRE	

1° x 1° monthly statistics per obs time:

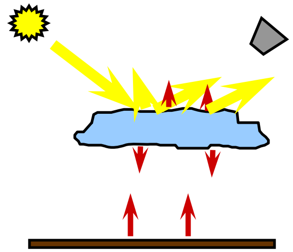
- **averages,**
- **monthly variability,**
- **histograms**

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

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

Cloud properties from space:

1) multi-spectral cloud detection 2) cloud property retrieval (based on radiative transfer)



Passive remote sensing (>1980)

info on **uppermost cloud layer**
good spatial coverage

- **p/z, T** (radiative height) τ_{VIS} / ε_{IR}
- **horizontal extension**
- **bulk microphysical properties**

➢IR-NIR-VIS radiometers, IR Sounders, multi-angle VIS radiometers **perceive clouds differently !**

➢**cloud property accuracy scene dependent !**
most difficult scenes: low contrast with surface (thin Ci, low cld, polar regions), multi-layer Ci

➢Global : generalized vs optimized retrievals

Active (A-Train, >2006)

info on **all cloud layers**
sparse sampling (track/1000km)

- **z** (top) τ_{VIS}
- **vertical extension**
- **microphys. prop. profiles**

lidar, radar
perceive clouds differently

lidar : sensitive to thin (subvis) Ci, apparent cloud base (COD<5)
-> lidar – radar synergy

IR-NIR-VIS radiometers

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

1) COD,CT *(assumption on microphys)* 2) spectral diff (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

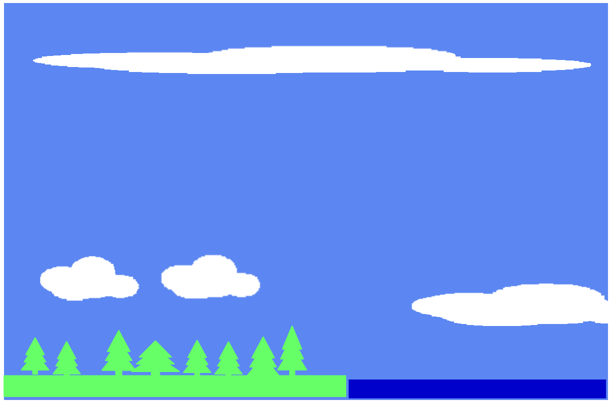
1) CP,CEM *(no assumption on microphys)* 2) spectral diff (8-12μm) -> CRE, CWP (only Ci)

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 -> cld top

polarization -> CT independent phase



CALIPSO, HIRS,TOVS,AIRS, MODIS

ISCCP, ATSR

MISR, POLDER

Participating datasets:

ISCCP ***GEWEX cloud dataset***	***1984-2007***	*(Rossow et al.)*
TOVS Path-B	***1987-1994***	*(Stubenrauch et al.)*
AIRS-LMD	***2003-2009***	*(Stubenrauch et al.)*
MODIS-ScienceTeam	***2001/3-2009***	*(Ackerman et al.; Platnick et al.)*
MODIS-CERES	***2001/3-2006***	*(Minnis et al.)*

relatively new retrieval versions:

PATMOS-x ***(AVHRR)***	***1982-2009***	*(Heidinger et al.)*
ATSR-GRAPE	***1999/2003-2009***	*(Poulsen et al.)*

only CA or CAE & CT:

HIRS-NOAA	***1982-2008***	*(Wylie et al., Menzel et al.)*
CALIPSO-ScienceTeam	***2007-2008***	*(Winker et al.)*
CALIPSO-GOCCP	***2007-2008***	*(Chepfer et al.)*

complementary cloud information:

MISR	***2001-2007***	*(DiGirolamo et al.)*
POLDER ***(O_2 & Rayleigh)***	***2006-2008***	*(Riedi et al.)*

Global Climate Observing System Target Requirements: Cloud Essential Climate Variables (2011 update)

Variable	Horizontal Res	Vertical Res	Temporal Res	Accuracy	Stability (/decade)
CA	50km	N/A	3hr	0.01 – 0.05	0.003 – 0.03
CP	50km	NA	3hr	15hPa – 50hPa	3hPa -15hPa
CT	50km	NA	3hr	1K – 5K	0.2K – 1K
CWP	50km	NA	3hr	25%	5%
CRE	50km	NA	3hr	5-10%	1-2%

assuming cloud feedback similar to rad forcing of 0.3Wm^{-2} (~ 20% of current GHG forcing)

radiative forcing depends on CAE (and not CA)

=> target ranges (opt thick/ low clouds - opt thin Ci (CEM=0.2))

based on NISTIR 7047 report (March 2004)

current uncertainties & accuracies ?

ISCCP cloud property uncertainty estimates

(Rossow)

Quantity	± instantaneous	/ mean error	/ accuracy
• CA	± 0.05-0.10	0.01-0.03	0.10-0.15
• CT	± 3-6K	2K	1-3 K
• CTL	±1-2K	1-2K	
• CTH	±3-6K	3-6K	
• CZ	± 0.5-2 km	0.3 km	
• COD	± 25%	10%	<10%
• CLWP	± 10%	10%	
• CIWP	± 30%	30%	
• CREL	± 1-2 μm	1 μm	1-2 μm
• CREI	± 3-6 μm	2- μm	3-7 μm

from detailed intercomparisons with different datasets

(≥ 37 articles)

Surface observations:

(Warren)

•CT base	± 3-6K	2 K
•CZ base	± 0.5-1 km	0.3 km

-> CALIPSO-CloudSat

TOVS PathB/AIRS-LMD cloud property uncertainty estimates

CA: 0.05 – 0.15

largest over deserts & Antarctica

CP: ~40-50 hPa

slightly smaller for AIRS

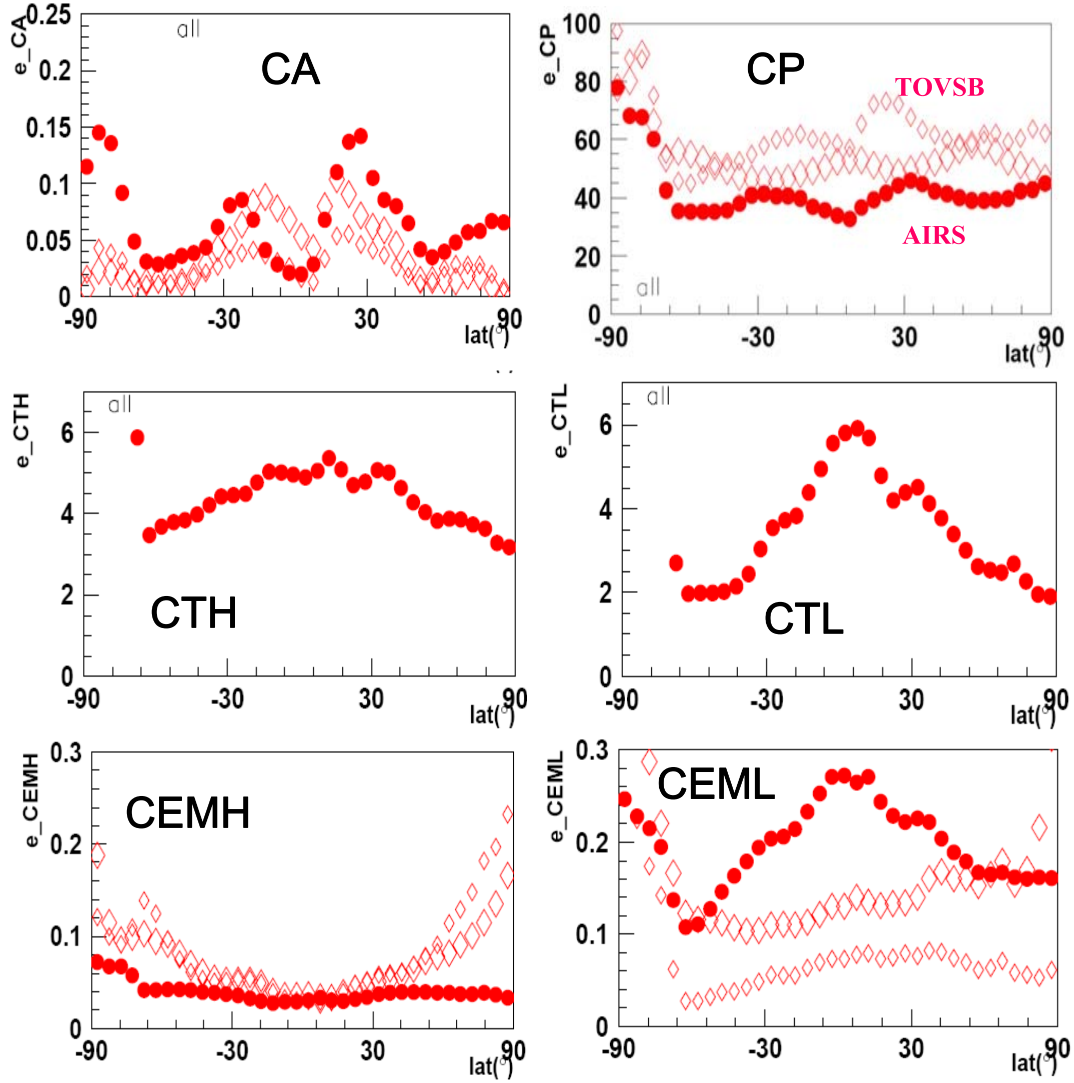
hgh / low clds:

CT: 4 K / 2-4 K

CEM: 0.05 / 0.10-0.25

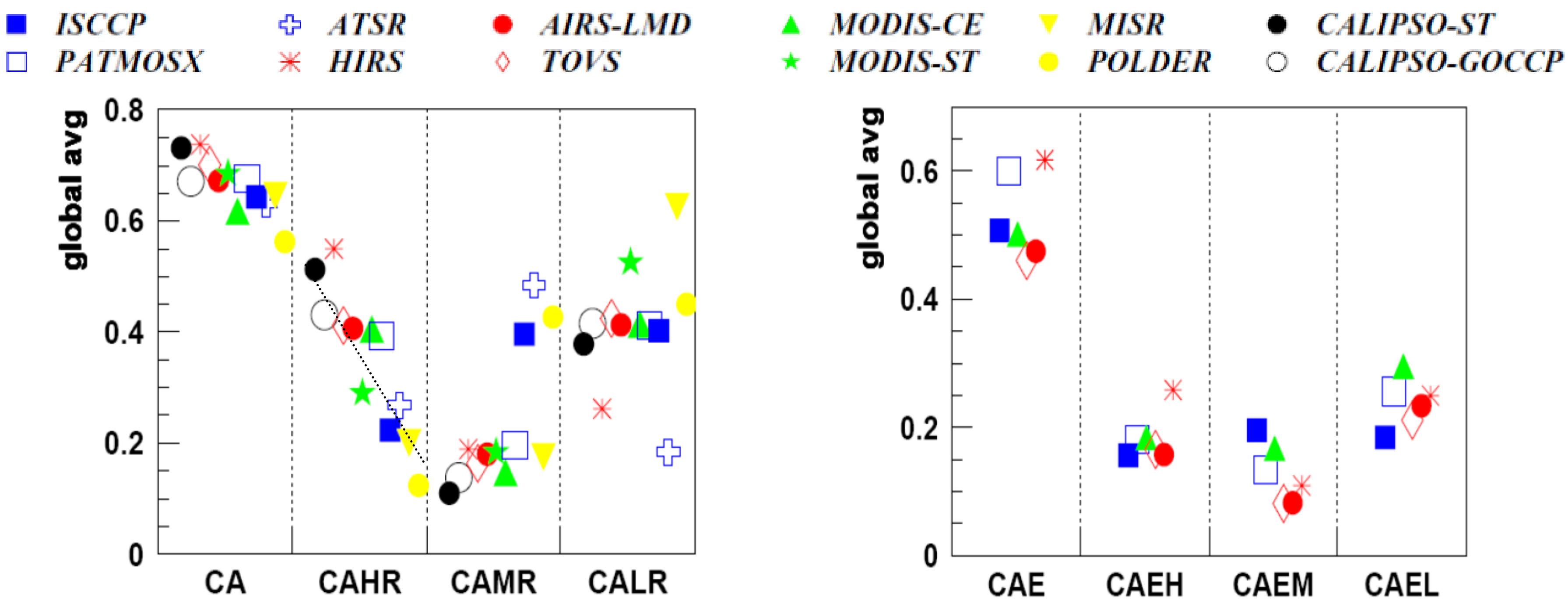
from χ^2 solutions

uncertainty slightly better for high clds & slightly worse for low clds than ISCCP



Amount, Height, Temperature, Emissivity

Interpretation of cloud properties from satellite observations



CALIPSO only considers uppermost layers to better compare with the other data sets

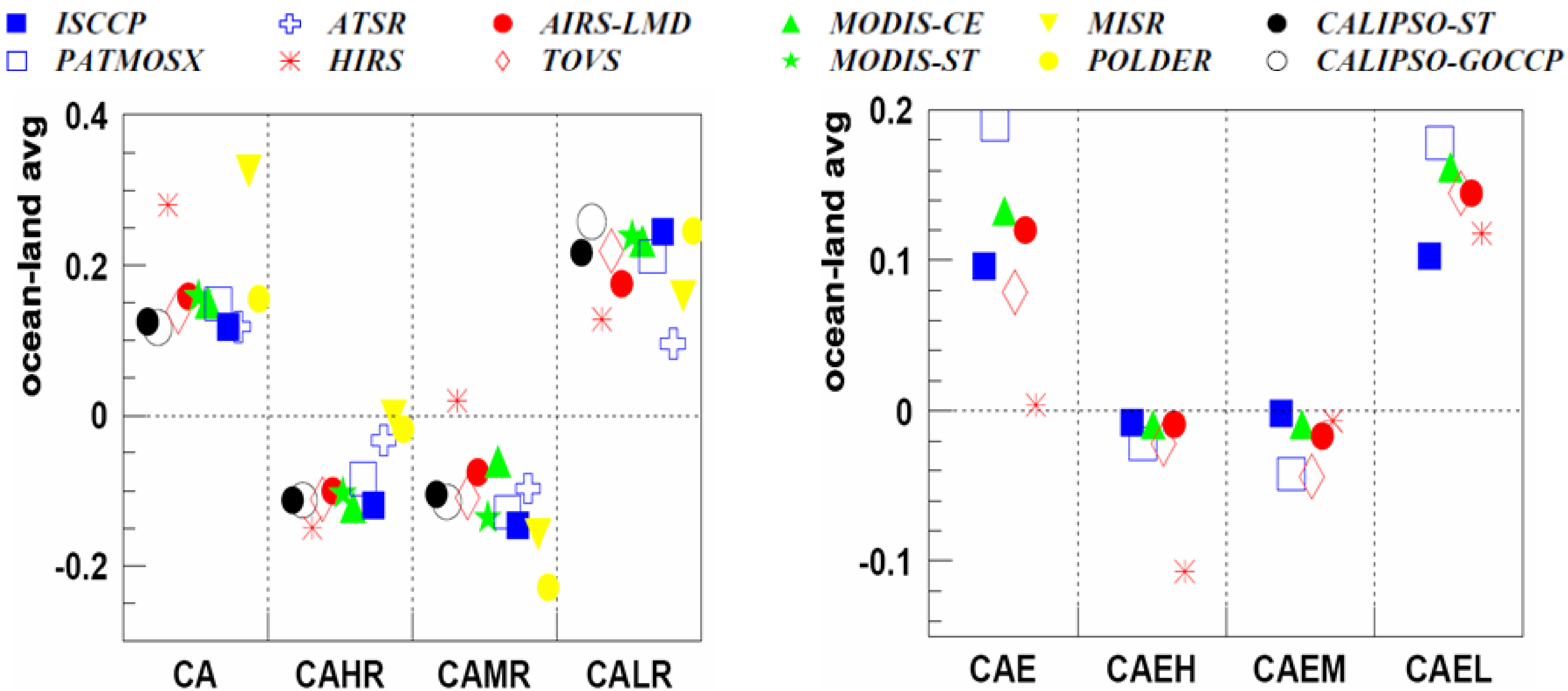
global CA 65-70% (+ 5% subvisible Ci) : 40% high , 40% single layer low

CAHR (hgh clds out of all clds) depends on sensitivity to thin Ci (30% spread)
(misidentified as midlevel clouds by ISCCP, ATSR, POLDER)

CAE (effective CA=CA weighted by cld emissivity) agrees better : 50%

global monthly variability of CA: 20%-30% of CAE: 0.25-0.30

Differences ocean - land

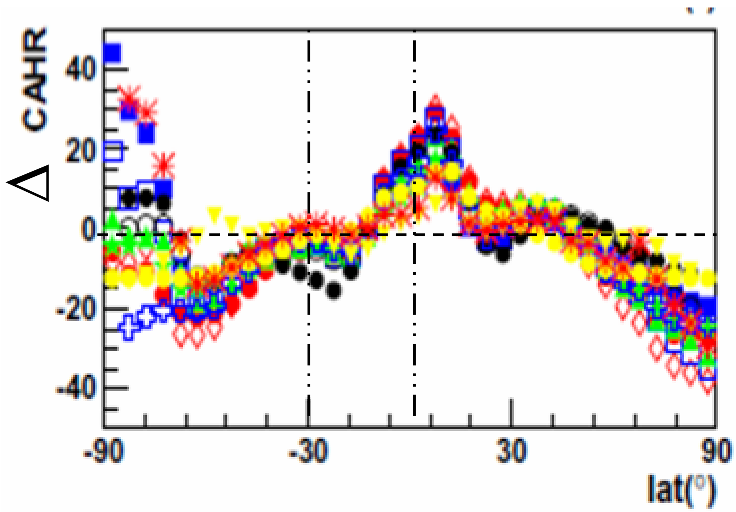


15% more clouds over ocean than over land (low clouds)

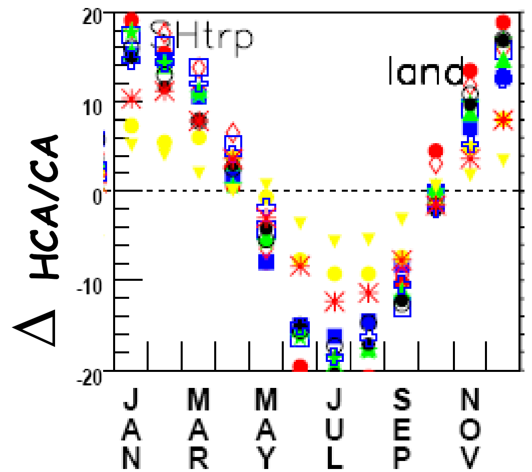
whereas over land there are more high and midlevel clouds

the latter are optically thinner over land, so that effective cloud amount of those is similar

Latitudinal & seasonal variation of uppermost cloud layers

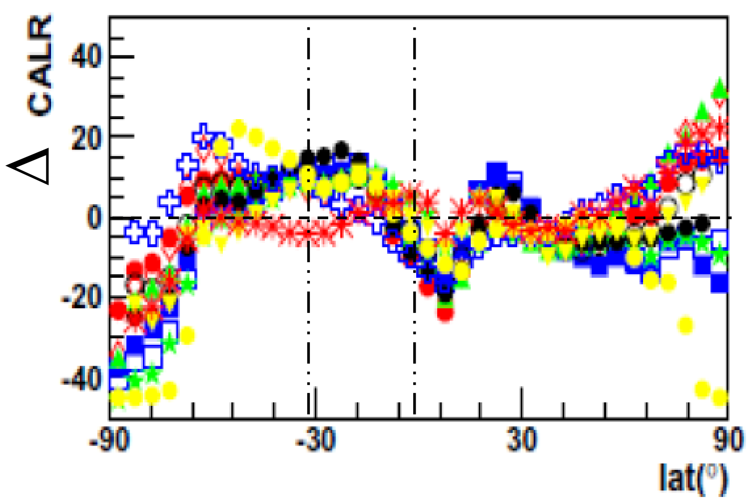


high clouds

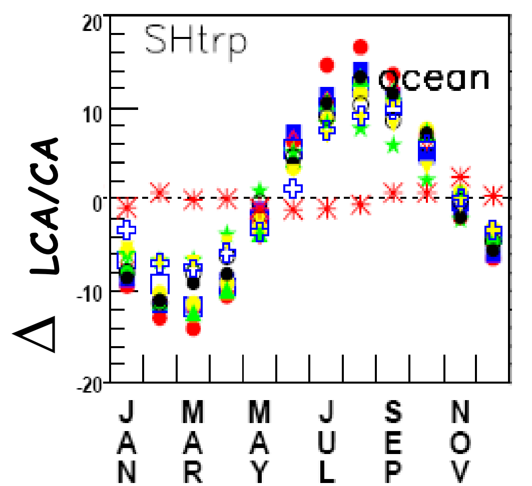


latitudinal & seasonal variations similar

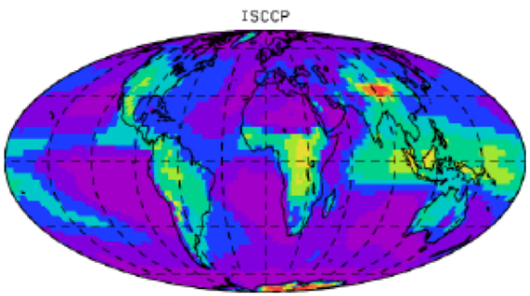
(except polar regions & HIRS CALR in SHtrp)

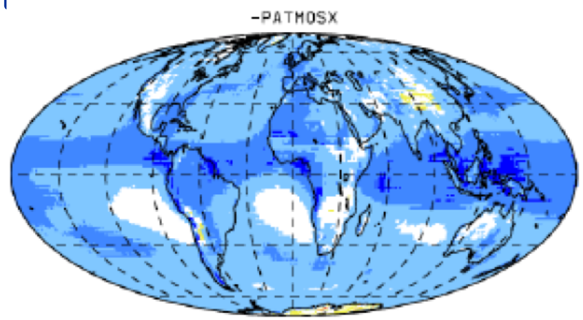


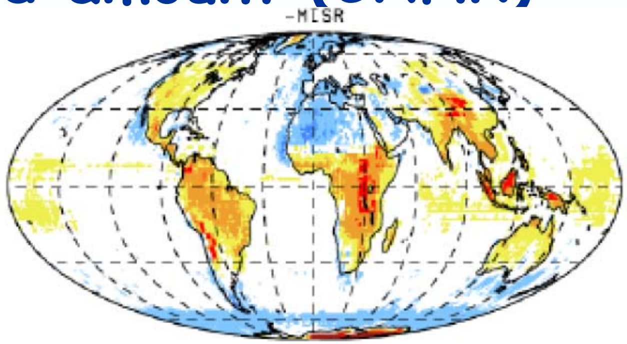
single layer low clouds

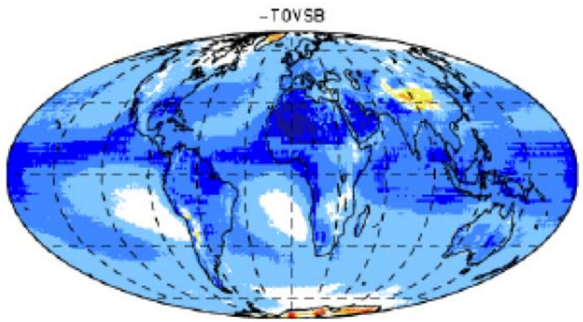


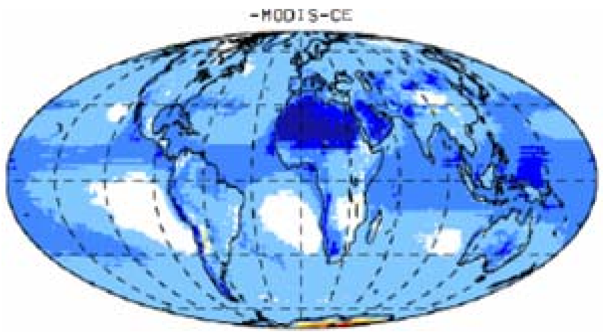
Geographical maps: Relative High cloud amount (CAHR)

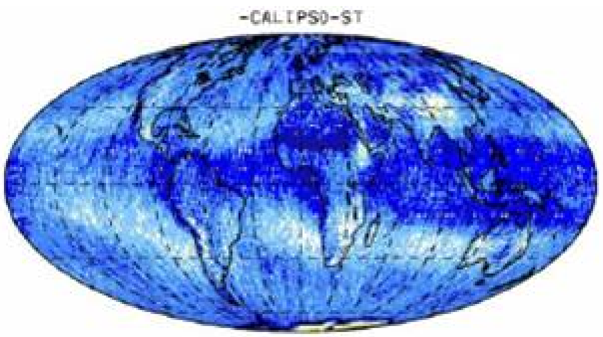


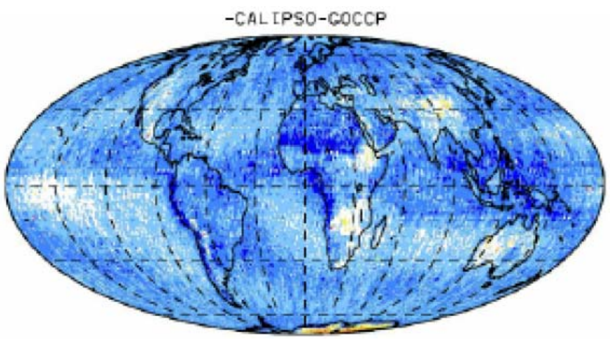












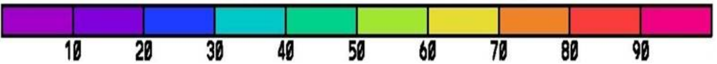
CAHR depends on sensitivity to thin Ci:

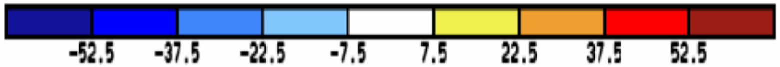
CALIPSO > TOVS/AIRS
MODIS/PATMOSx
> ISCCP > MISR

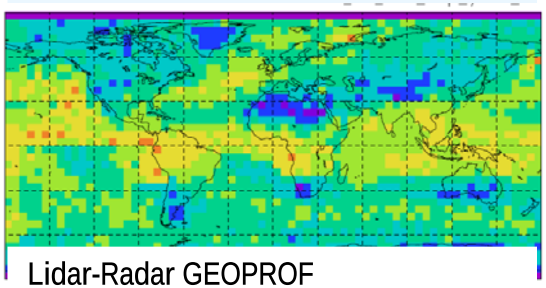
Geographical distributions similar

except desert: Ci – low

MISR: -> more multi-layer clds in tropics

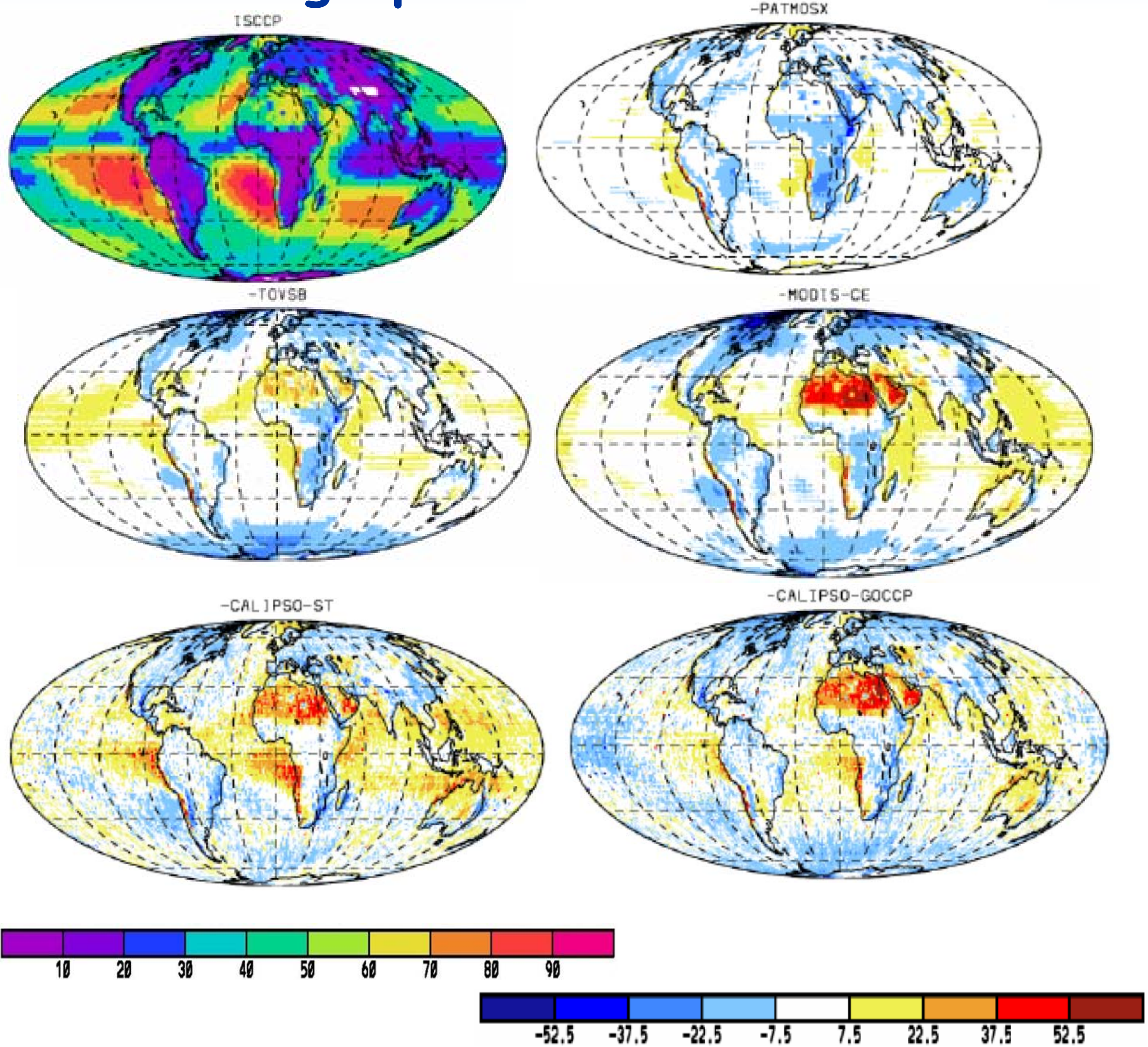






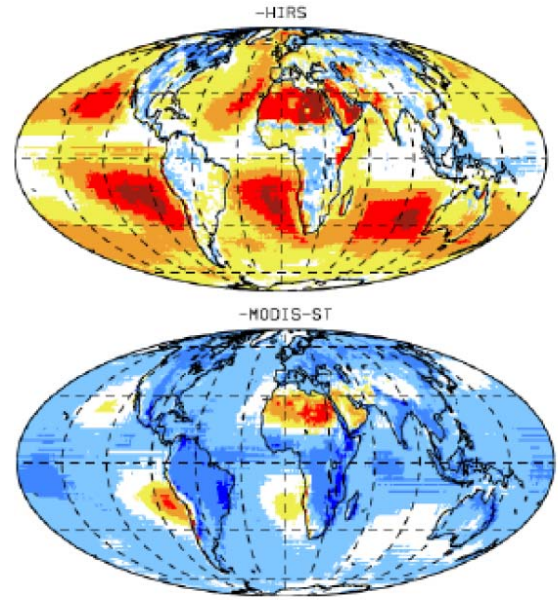
Lidar-Radar GEOPROF
occurrence of high multi-layer clouds

Geographical maps: Relative Low cloud amount



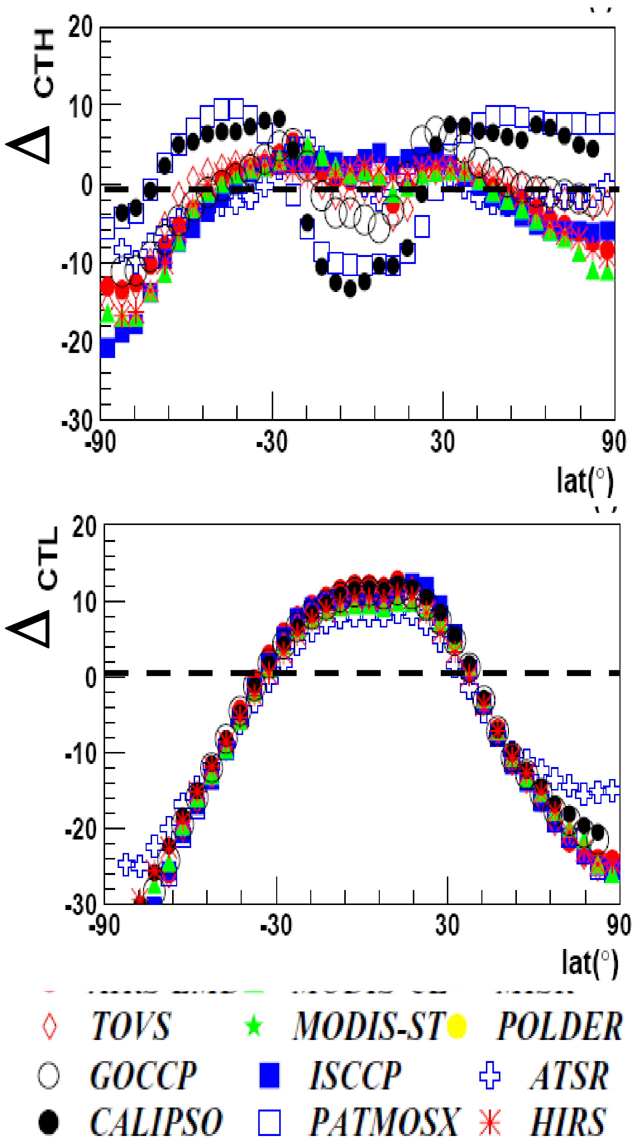
geographical distributions similar
except desert: Ci – low

(MODIS-ST: -> more low clds everywhere, except StrCum regions
HIRS CO2 slicing not possible for low clds)



Cloud temperature:

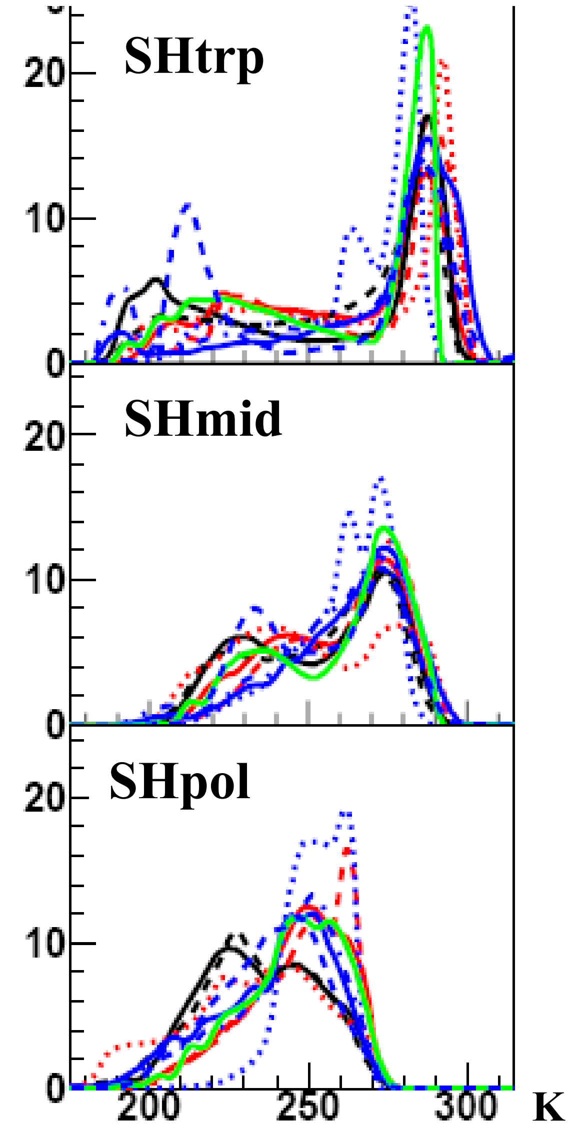
latitudinal variation & distributions



CALIPSO:
including subvis Ci, T(cld top)
passive remote sensing:
T(rad. cld height)

=> CTH(CALIPSO) should be lowest
& nearest to tropopause,
largest latitudinal variability
(PATMOSX should not be like CALIPSO for high clouds)

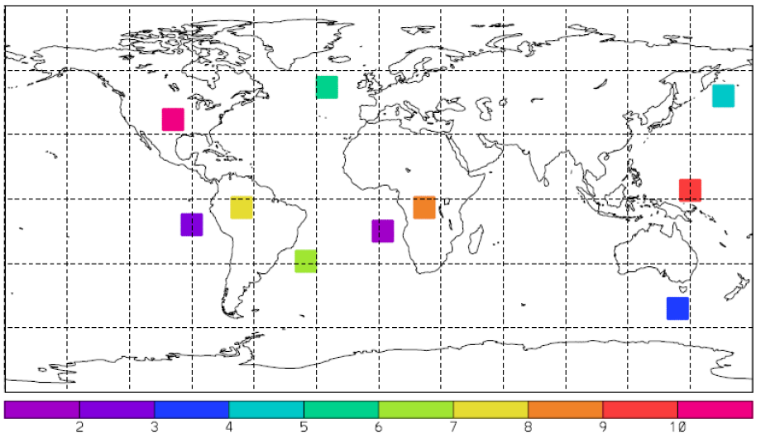
CT distributions reflect decrease of vertical extent of troposphere from tropics to poles



Specific regions, compared to globe

Rossow et al. J. Clim. 2002

10° x 10° regions of typical climate regimes with increasing small scale variations: (1 – <COD(rad)>/<COD(lin)>)



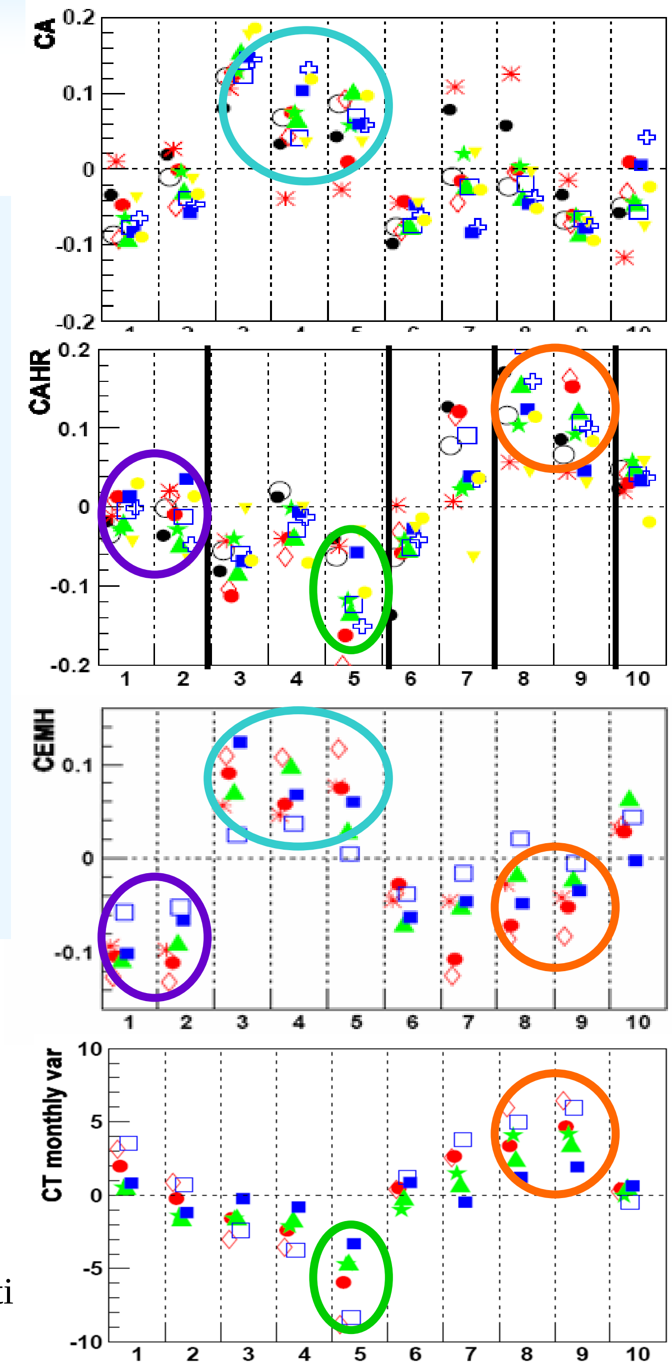
Strcum regions (1,2): average CAHR, but optically thin

Storm regions (3,4,5): largest CA

NAtlantic (5): smaller CAHR & monthly CT variability

ITCZ (8,9): largest CAHR *(small CEMH, linked to Ci)* & largest monthly CT variability

1: SH Str Africa 2: SH Str America
3: SH midlat 4: NH EPacific 5: NAtlantic storms
6: SH Ci off America 7: SH Ci Amazon
8: SH Cb Africa 9: NH Cb Indonesia
10: ARM Southern Great Plain



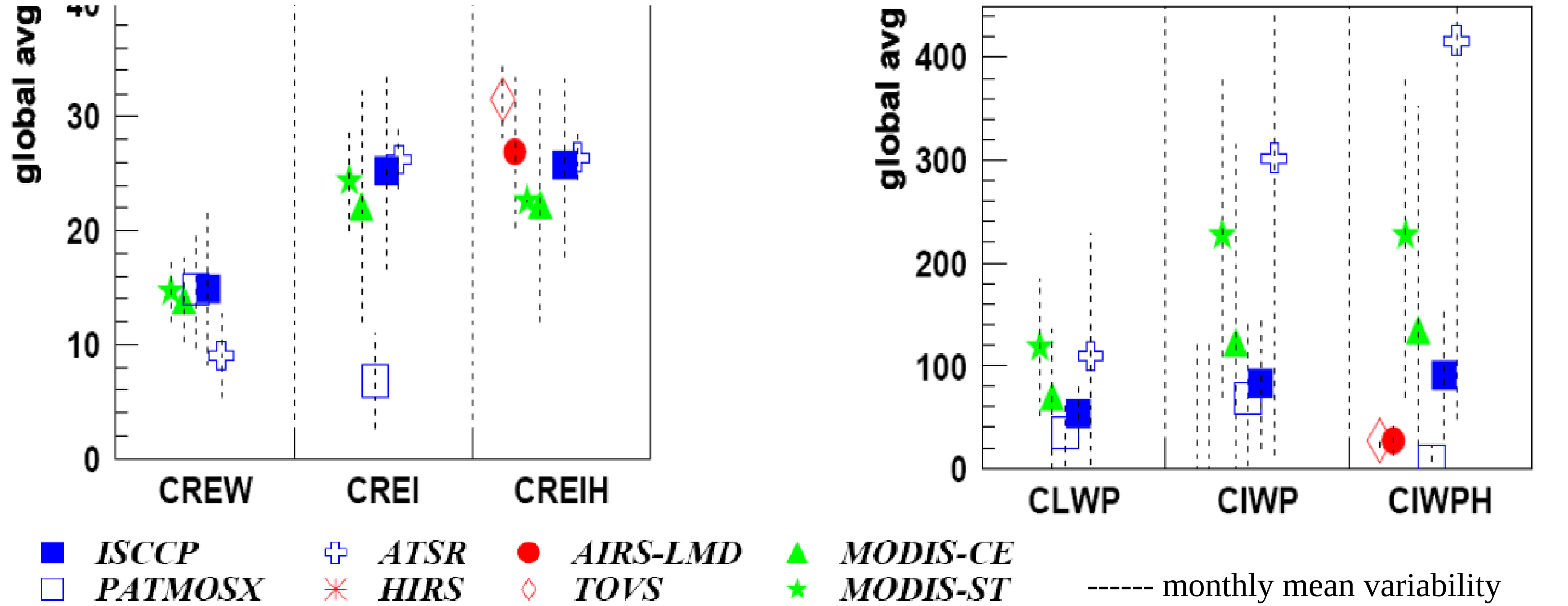
● *CALIPSO-ST*
○ *CALIPSO-GOCCP*

■ *ISCCP* □ *PATMOSX* ✚ *ATSR* ✳ *HIRS* ● *AIRS-LMD* ◇ *TOVS* ▲ *MODIS-CE* ★ *MODIS-ST* ▼ *MISR* ● *POLDER*

Bulk microphysical properties

Bulk microphysical properties:

eff. liquid / ice particle radius & liquid / ice water path



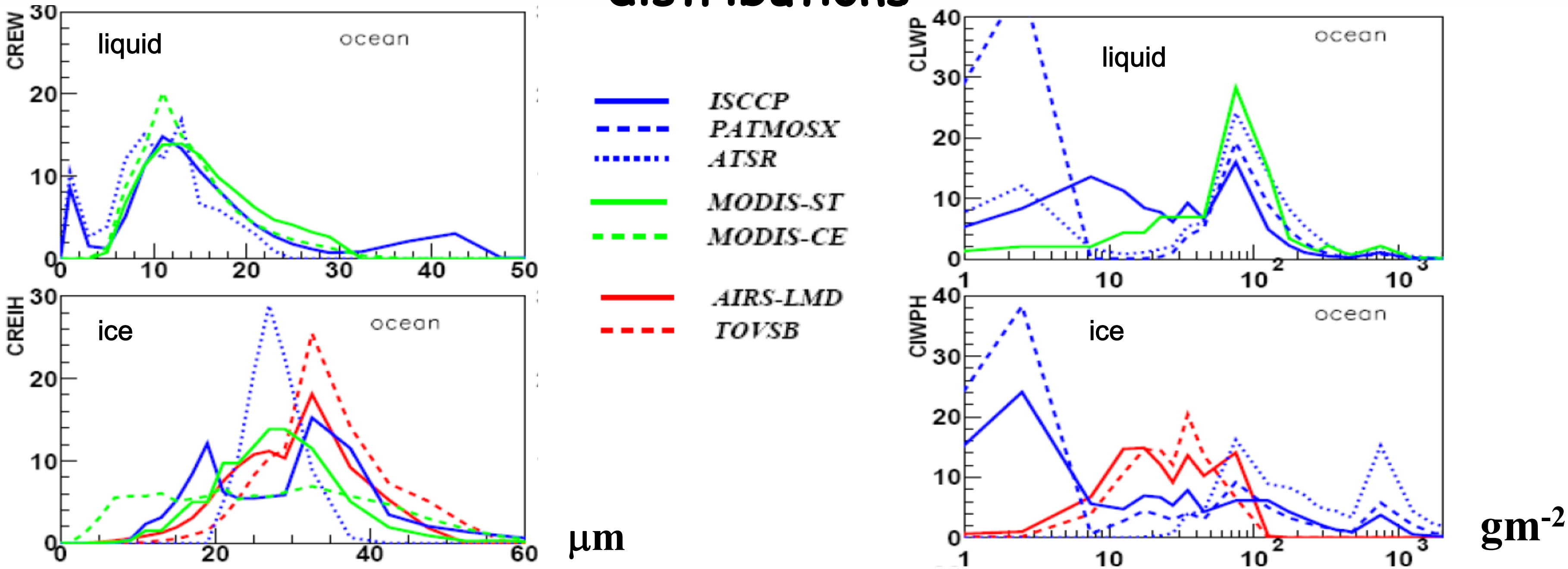
Whereas CA, CEM,CT, CP of the data base are well understood,
differences in CRE and CWP have still to be further explored

Global averages of CREW / CREI(H) agree quite well with 15µm / 25µm

IR sounders determine CREIH, CIWPH only for a subsample: semi-transparent ice clouds
⇒CIWPH is much smaller (25 gm^{-2}) than averaged over all ice clouds (~100gm^{-2})
VIS-IR methods: MODIS-ST / ATSR-GRAPE much larger values than ISCCP / MODIS-CE / PATMOSX

distributions are not Gaussian ….

eff. particle radius & water path distributions



CREW distributions agree quite well,
with a large peak around 11µm,
small peak at 42 µm from ISCCP
(perhaps W-I misidentification)
CREIH: IR sounders, ISCCP: large peak at 32 µm,
second peak of ISCCP at 18 µm (perhaps
misidentified W-I or at top for opt thick clouds)
peaks of MODIS-ST and ATSR-GRAPE at 27 µm
(3.7 / 2.1 / 1.6 µm)

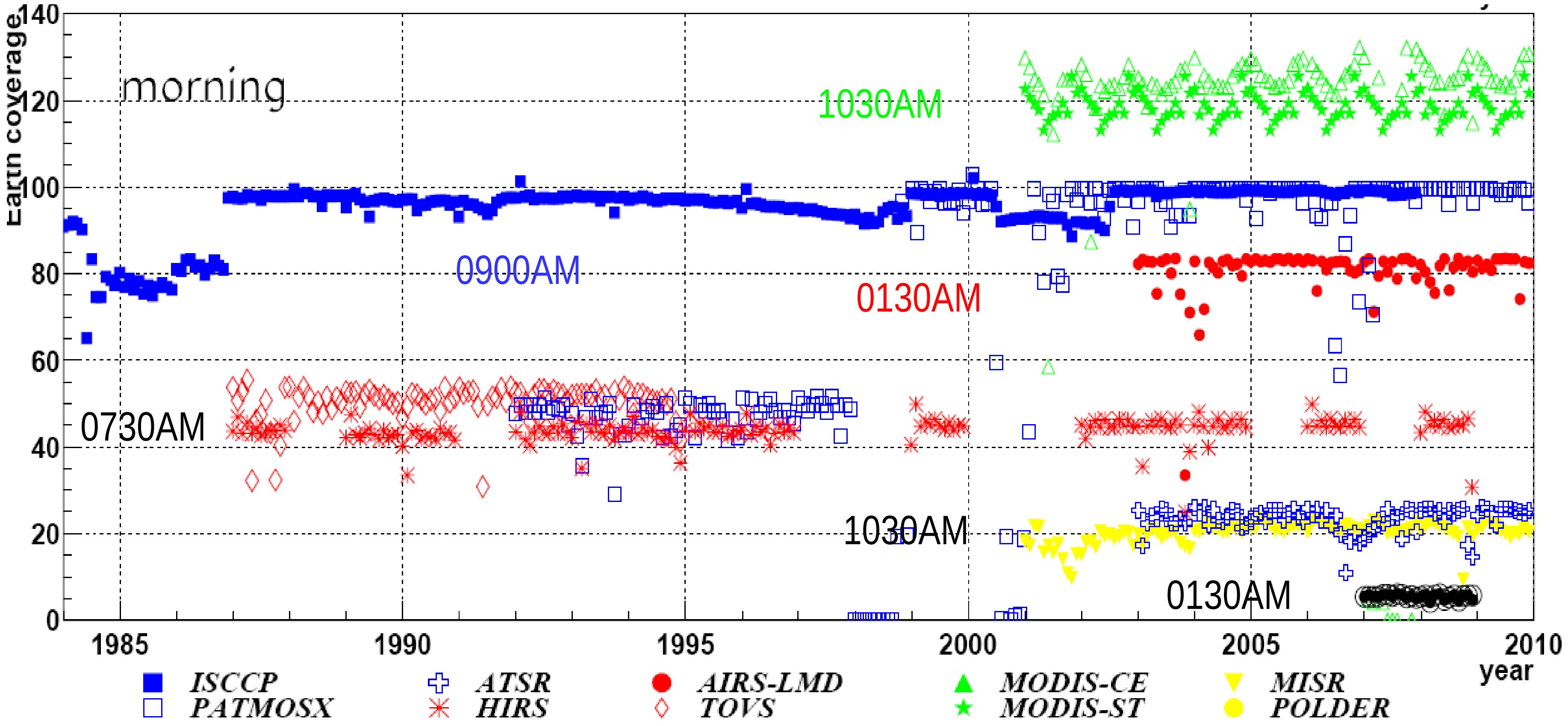
CLWP: large peak at 80 gm^{-2}

CIWPH: AIRS, TOVS compact distribution
between 5 & 100 gm^{-2};
ISCCP, PATMOSx large peak at 4 gm^{-2}
(regions with low clouds clouds?)

further investigations necessary!

Use of longterm datasets

Monitoring of Earth coverage



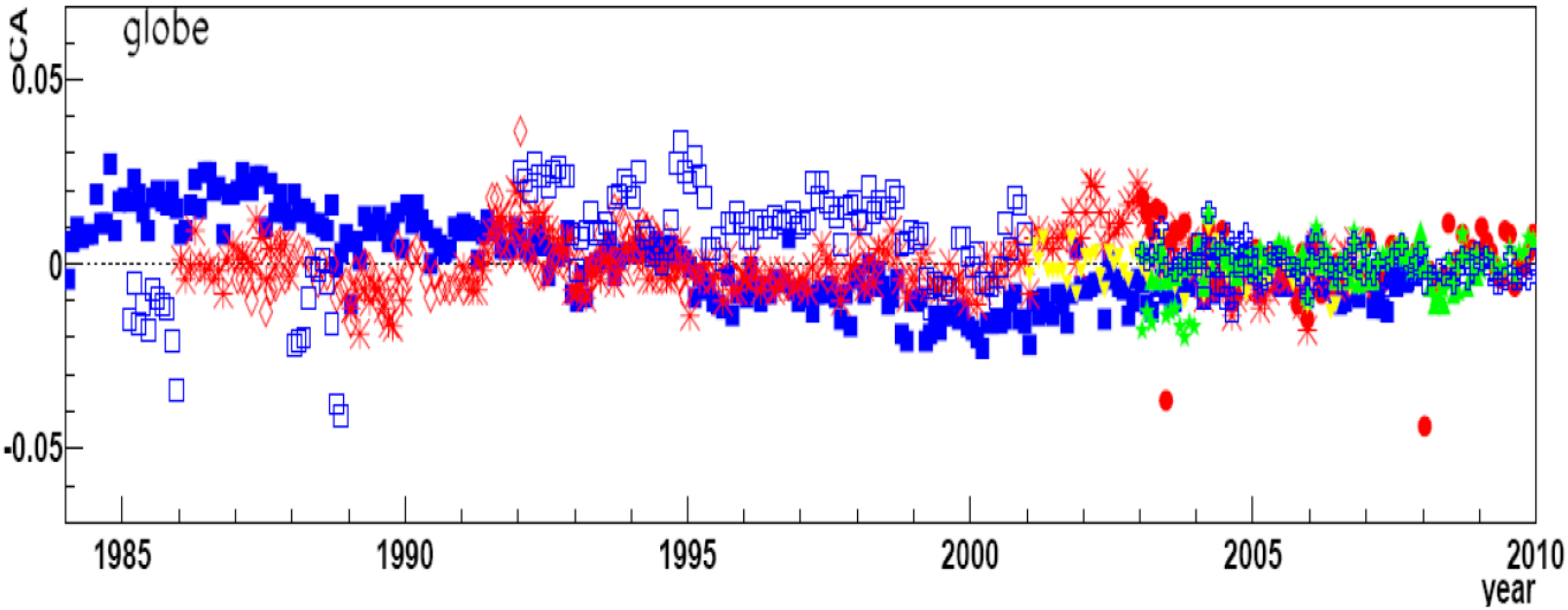
➢**climate change studies**: be aware of temporal changes in coverage!

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 ±2.5% (~ interannual & monthly mean variability)
possible origins of variability:
- changing average view angle (decreasing with nb of covering geo sat for ISCCP)
- satellite drift (for NOAA polar afternoon satellites)
- change in Earth coverage, …..

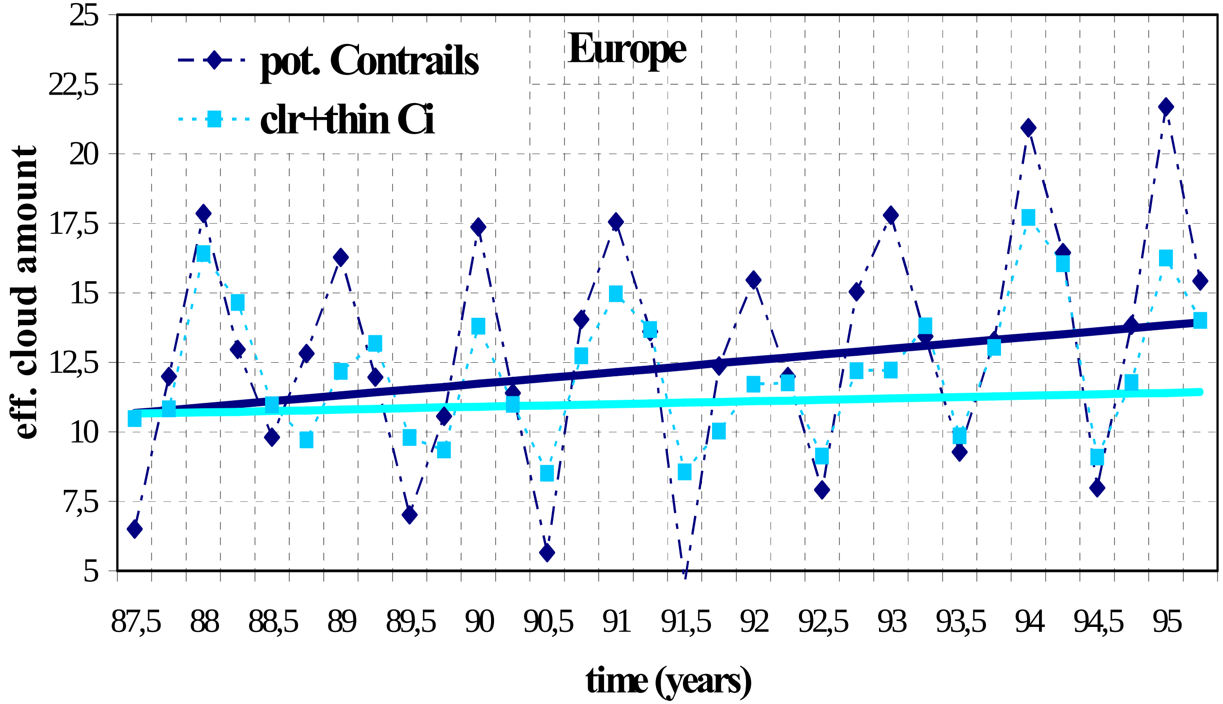
trend analysis -> synergy of different variables

example: <u>persistent contrails</u>

use TOVS upper tropospheric relative humidity to extract meteorological situations favorable for contrail formation

-> detection of increase of thin cirrus over Europe (& North Atlantic Flight corridor)
2.8-3.5% (±1.5%) per decade
~0.19% - 0.25% per decade (all situations)

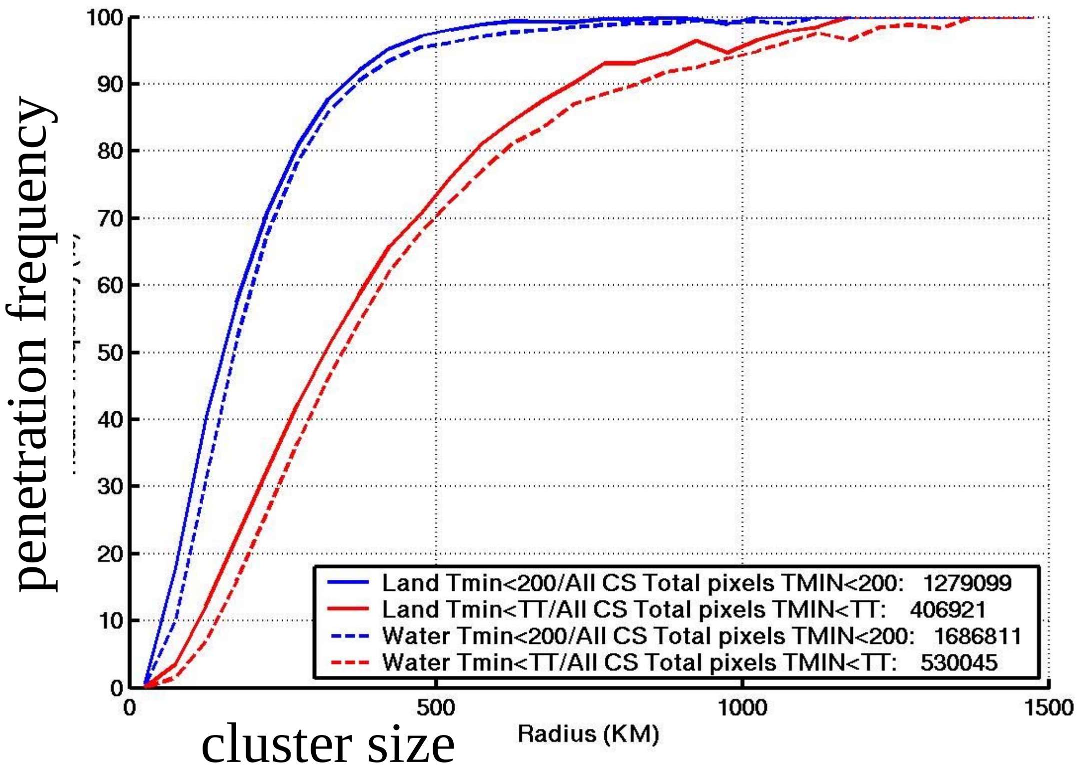
Stubenrauch and Schumann GRL 2005



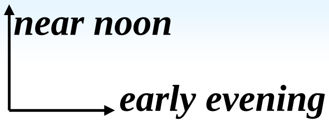
Longterm datasets -> explore rare events

example: **tropical convection penetrating into the lower stratosphere**

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



mostly larger, organized, convective systems penetrate stratosphere



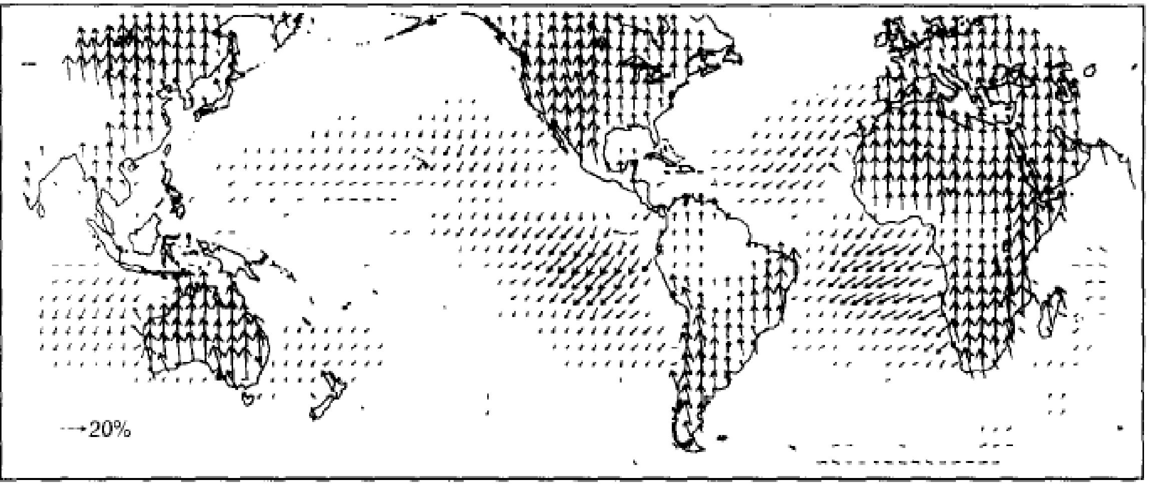
Diurnal cycle of clouds

Cairns, Atm. Res. 1995

ISCCP C2, Complex Empirical Orthogonal Functions,

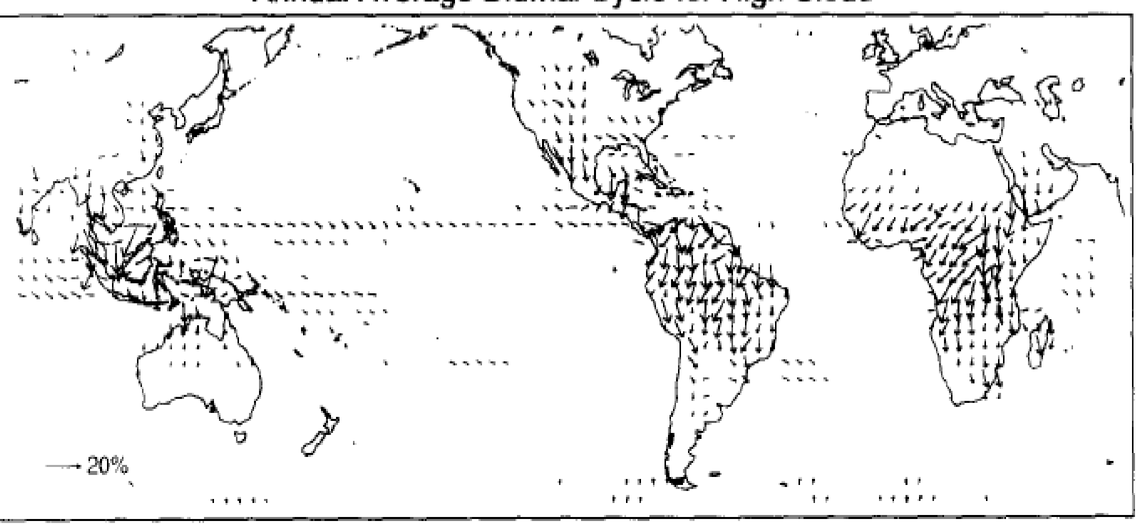
project. on distorted diurnal harmonics

Annual Average Diurnal Cycle for Low Cloud



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

Annual Average Diurnal Cycle for High Cloud



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

Stubenrauch et al. 2006

Conclusions

- Satellite instruments:
  unique possibility to study cloud properties over long period
- ISCCP : only dataset that directly resolves diurnal cycle & covers whole globe; thoroughly evaluated (≥ 37 articles) & extremely valuable for cloud studies
  (keeping in mind underestimation of Ci)
- GEWEX Cloud Assessment: Report (2011) & data base (12 datasets):
  facilitates assessments, climate studies & model evaluation
- geographical distributions, latitudinal & seasonal variations agree well
- differences can be mostly understood by different sensitivities to Ci,
  (problems in some retrieval methods, misidentification water-ice clouds)
- cloud products adequate for model evaluation & monitoring regional variability
- longterm datasets -> robust statistics & explore rare events
- monitoring of cloud properties very difficult *(need synergy of different variables)*

Conclusions & Outlook

- accuracy is scene & instrument dependent (interpretation of cloud height)
- 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 statistics organized by weather states or correlations!
- A-Train -> 3-dimensional structure of clouds

- ESA Cloud_CCI project (Climate Change Initiative) includes assessment activities

& another cloud assessment workshop is foreseen at the end of the project (2013)