# Propriétés des nuages et leur variabilité à partir des observations spatiales

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I P S L

05/2008

## Clouds & radiation

**longterm cloud climatologies (≥ *1981*)**

**EOS cloud climatologies (≥ *2000, 2002*)**

**A-Train (≥ *2006*): 2 active instruments**

**radiation/atmospheric circulation -> geographical cloud distributions**

Global Energy and Water Cycle Experiment GEWEX WCRP Cloud Assessment

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

## Evaluation & analysis of cloud properties:

**average, regional, seasonal variations, diurnal cycle**

**Variations of solar activity (-> galactic cosmic rays)**

**Climate monitoring:** **trends and where they can originate from**

# Clouds as from surface observer:

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

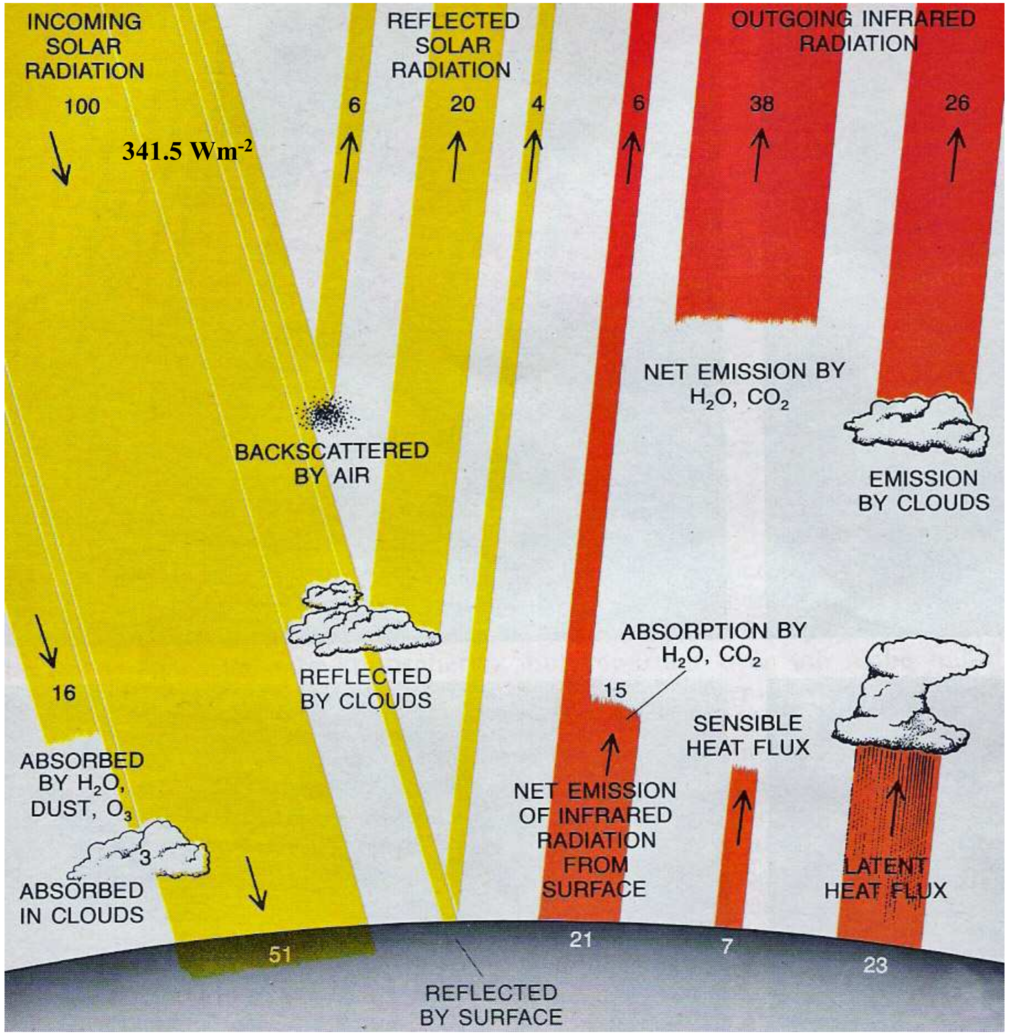
***Cumulus** (low fair weather clouds)*

***Cumulonimbus** (vertically extending cloud)*

**Climatology:** *Warren et al. 1986, 1988*

# Role of *clouds* in Energy and Water transfer

*: driving force for weather and climate*




*Source: Scientific American, Sep. 1983*

**radiative effects of clouds:**

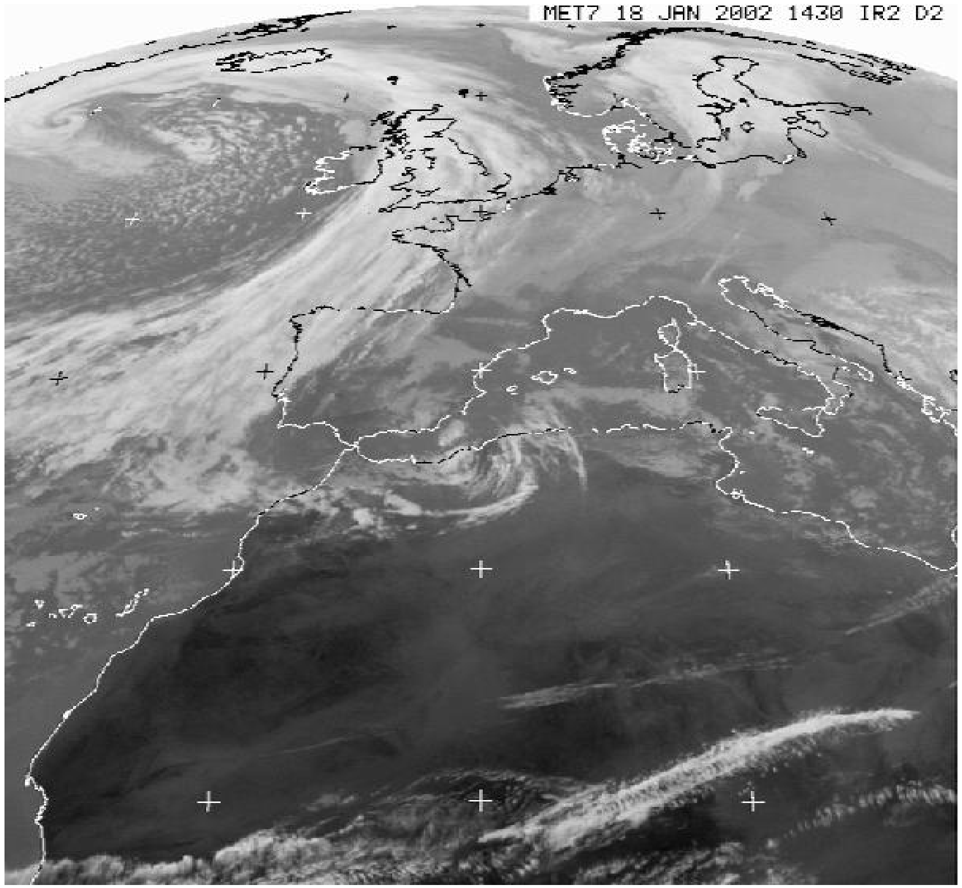
**cooling** **warming**

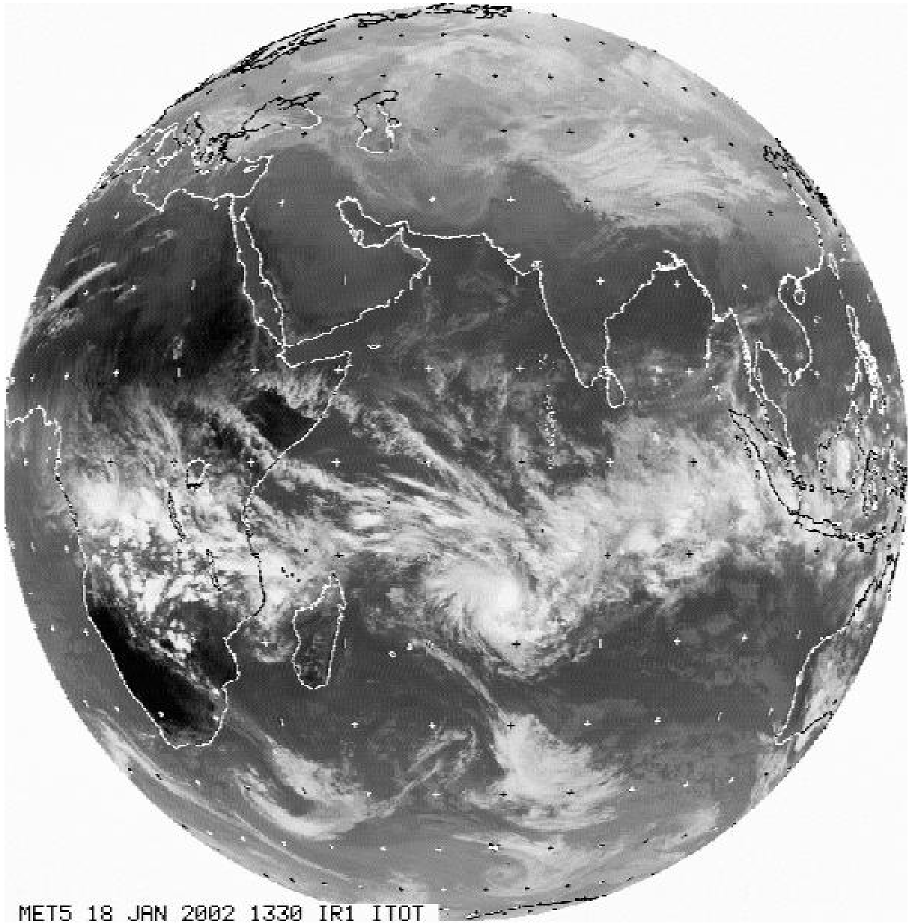
***cloud height, thickness, microphysics***

overall **cooling** **- 20 $Wm^{-2}$**

(ERBE, *Harrison et al. 90*)

# *Meteosat cloud images*

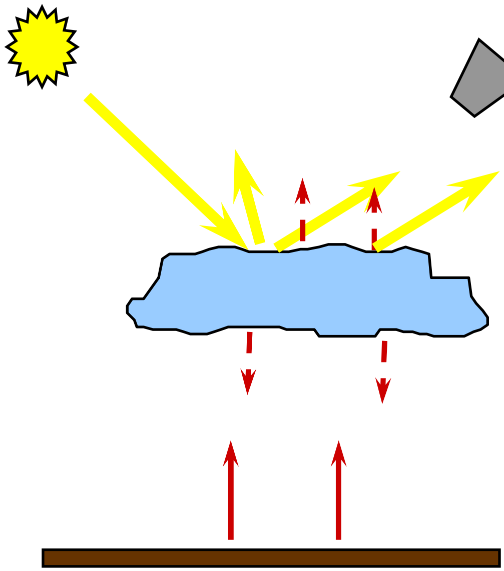





Images -> physical properties ?

# Satellite radiometers measure:



emitted, reflected, scattered

**radiation**

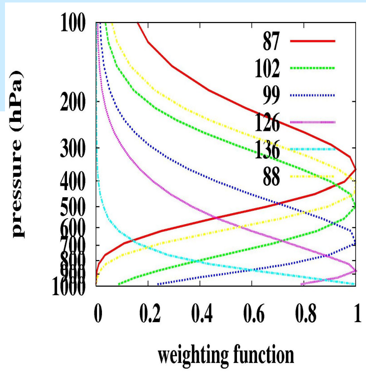
**INVERSION**

cloud detection
inverse radiative transfer

**cloud properties**

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

| ISCCP | PATMOS-x | HIRS-NOAA, TOVS Path-B |
|---|---|---|
| *IR, VIS* | *IR, NIR, VIS* | *IR Vertical Sounder: $CO_2$-band* |
| | MODIS | AIRS |

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# 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.; Stubenrauch et al. 2008)*

# + A-Train *(since 2006)*:

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

Global Energy and Water Cycle Experiment GEWEX WCRP

**Cloud Assessment**

**co-chairs:**
**C. Stubenrauch, S. Kinne**

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

# ISCCP

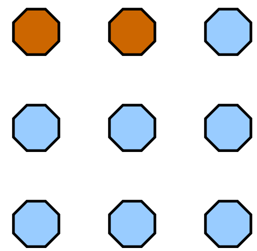
International Satellite Cloud Climatology Project

## ♦ Cloud detection

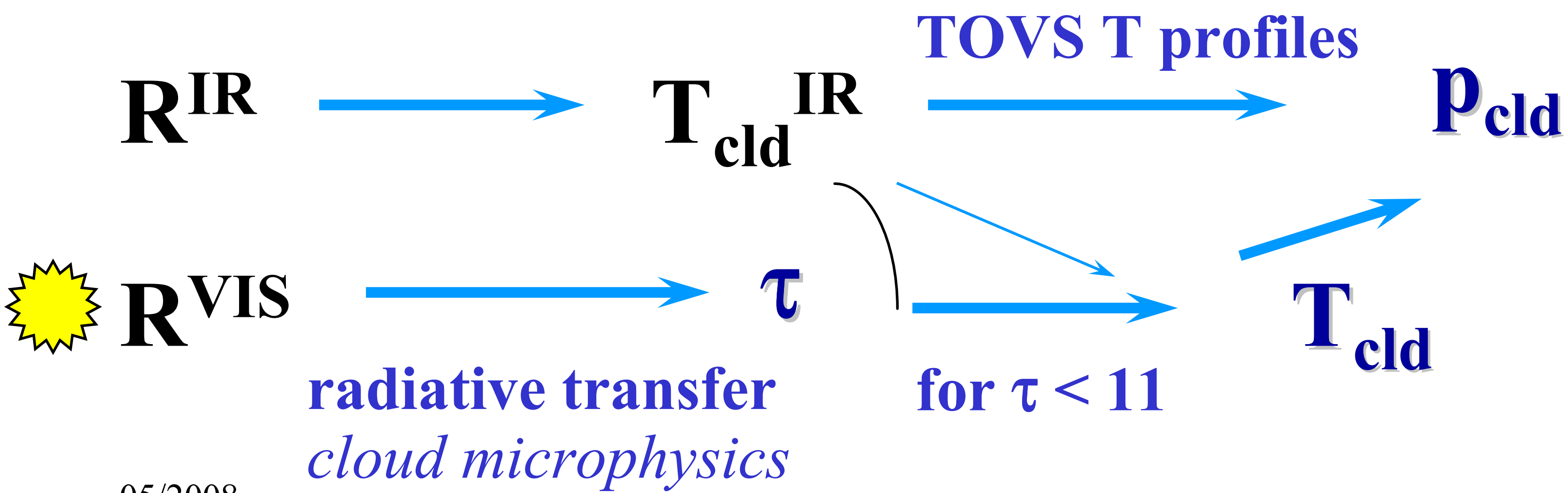
**IR spatial and temporal variability**

➡ VIS, IR composite clear sky statistics

*relative threshold tests*



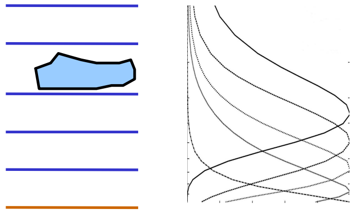
## ♦ Cloud property retrieval



# IR Sounders: TOVS, AIRS, IASI

>1980 NOAA, >2002 NASA, >2006 CNES

$I_m(\lambda_i)$ along $H_2O$, $CO_2$ absorption bands, *good spectral resolution*



**Inversion** *(Chédin, Scott 1985; Scott et al. 1999)*

- atmospheric temperature & water vapor profiles, Tsurf

$$\varepsilon_{cld}(p_k) = \sum_{i=1}^{N} \frac{I_m(\lambda_i) - I_{clr}(\lambda_i)}{I_{cld}(p_k, \lambda_i) - I_{clr}(\lambda_i)}$$

**min weighted $\chi_w^2(p_k)$**

- **eff. cloud emissivity, cloud pressure** *(Stubenrauch et al. 1999, 2008)*
- **$D_e$, IWP of semi-transparent cirrus** *(EU project CIRAMOSA 2001-2004)*

*controlled use of a priori information:* radiosondes – 4A radiative transfer

**TIGR dataset:** $T(p_k)$, $H_2O(p_k)$, $T_s$ - $I_{clr}(\lambda_i)$, $I_{cld}(\lambda_i,p_k)$

***T**hermodynamic **I**nitial **G**uess **R**etrieval*

**ISCCP** *(Rossow & Schiffer BAMS, 1999)* **Evaluation**

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

***uncertainties depend on cloud type:***

- ***Stratus ($\tau_{cld}$>5):*** $p_{cld}$ 25-50 hPa within radiosonde meas., ~ -65 hPa bias; err $T_{cld}$<1.5 K
- ***high clouds ($\tau_{cld}$>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% $\tau_{cld}$ 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 $\chi^2$ 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)*

# ISCCP – TOVS comparison

*Stubenrauch et al. J. Clim. 1999*

**agreement for homogeneous scenes**

remaining discrepancies:

- **Atmospheric temperature profiles**

**(1 operational TOVS profile per day - retrieved or TIGR)**

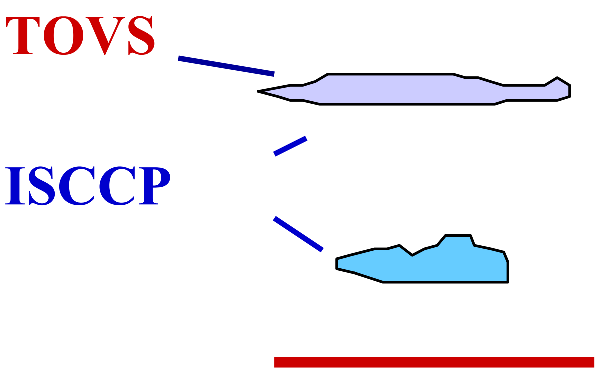
-> mid - lowlevel misidentification

- **Small scale heterogeneities**

- **horizontal:** **vertical:**

**partly cloudy** **multi-layer clouds**

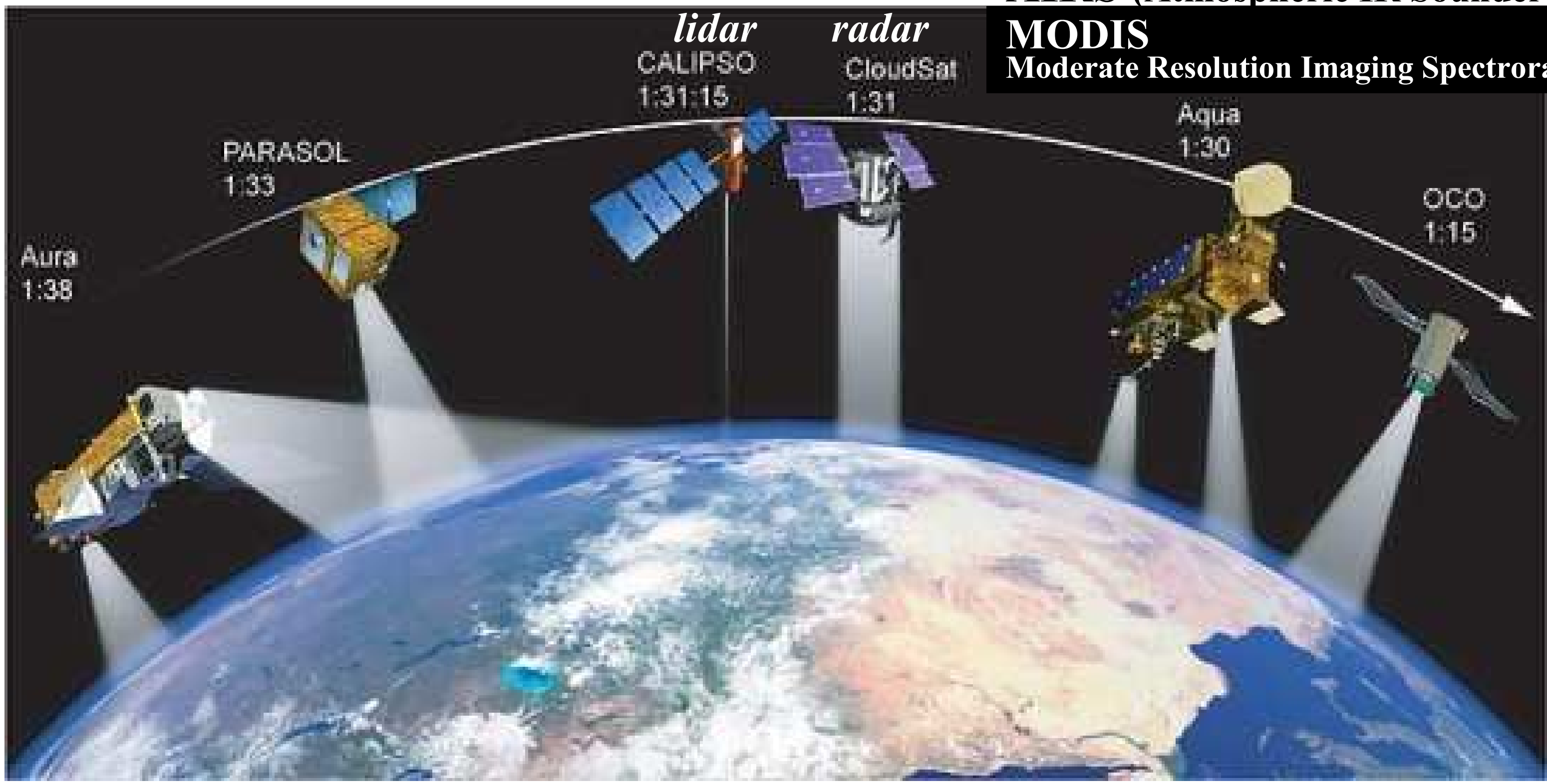
-> cirrus misidentification




TOVS more reliable due to better spectral resolution

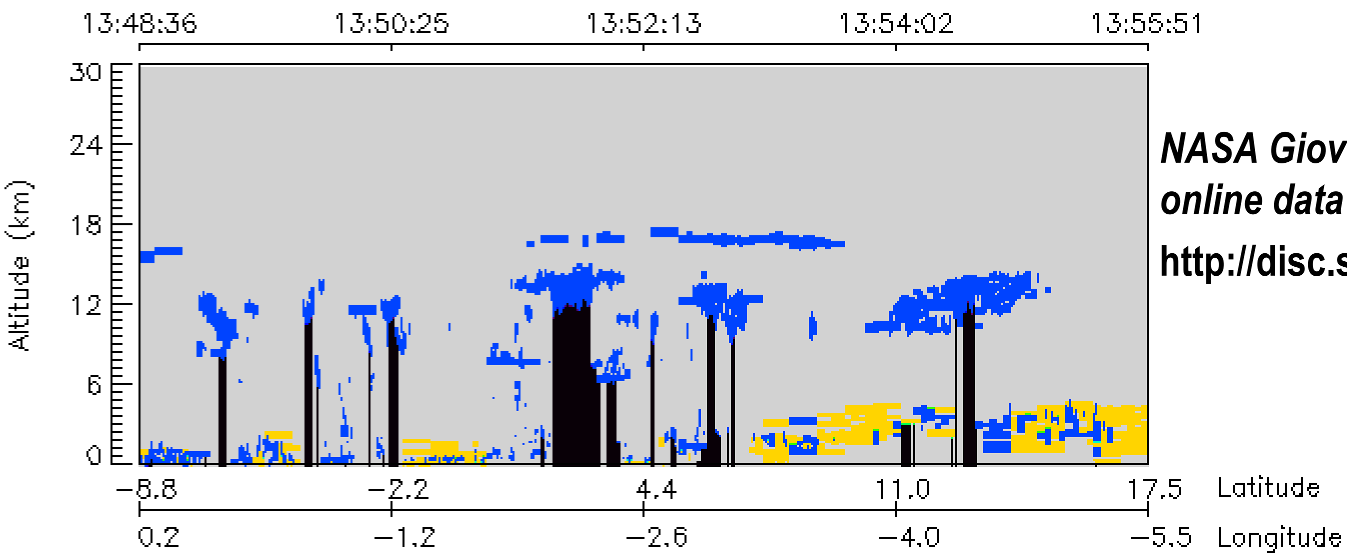
# A-Train: synergy of passive and active instruments

**since June *2006***




active instruments -> vertical structure of clouds

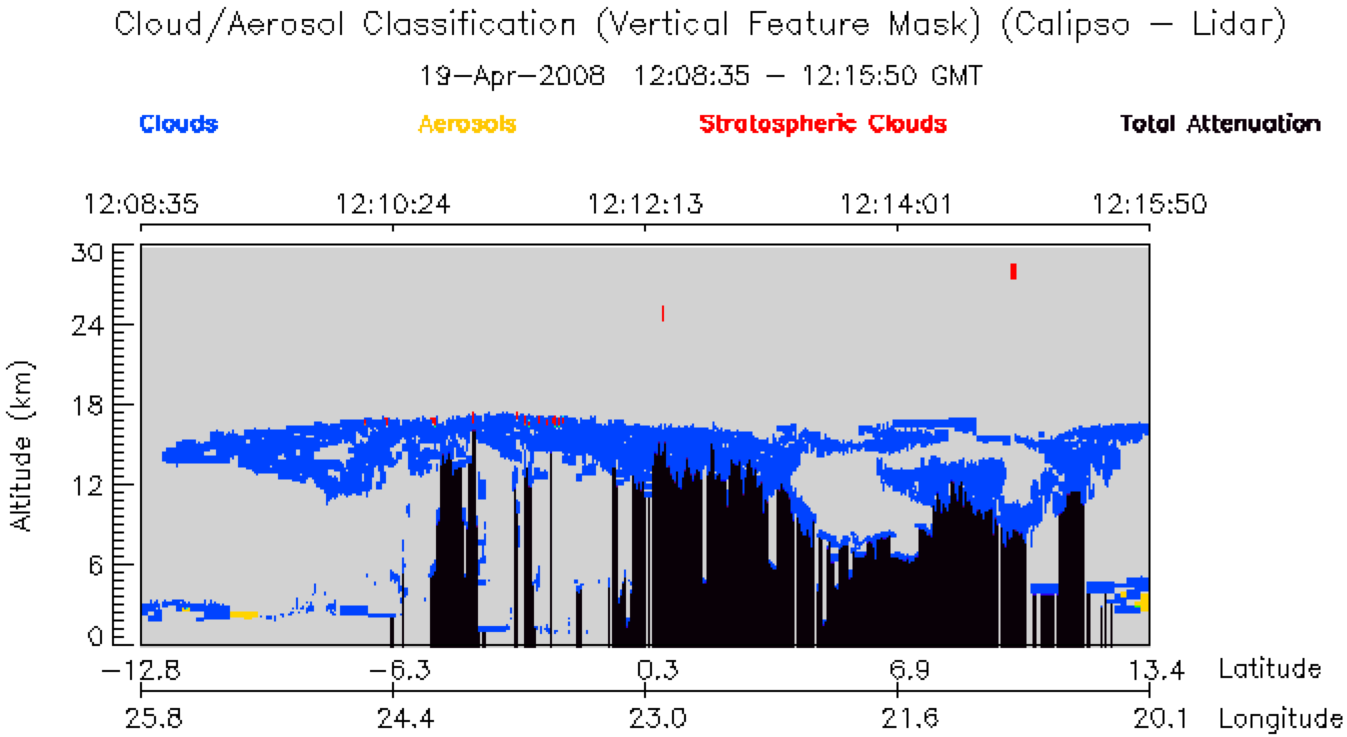
lidar sensitive to very thin cirrus




***NASA Giovanni:***

***online data visualization & analysis tool***

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

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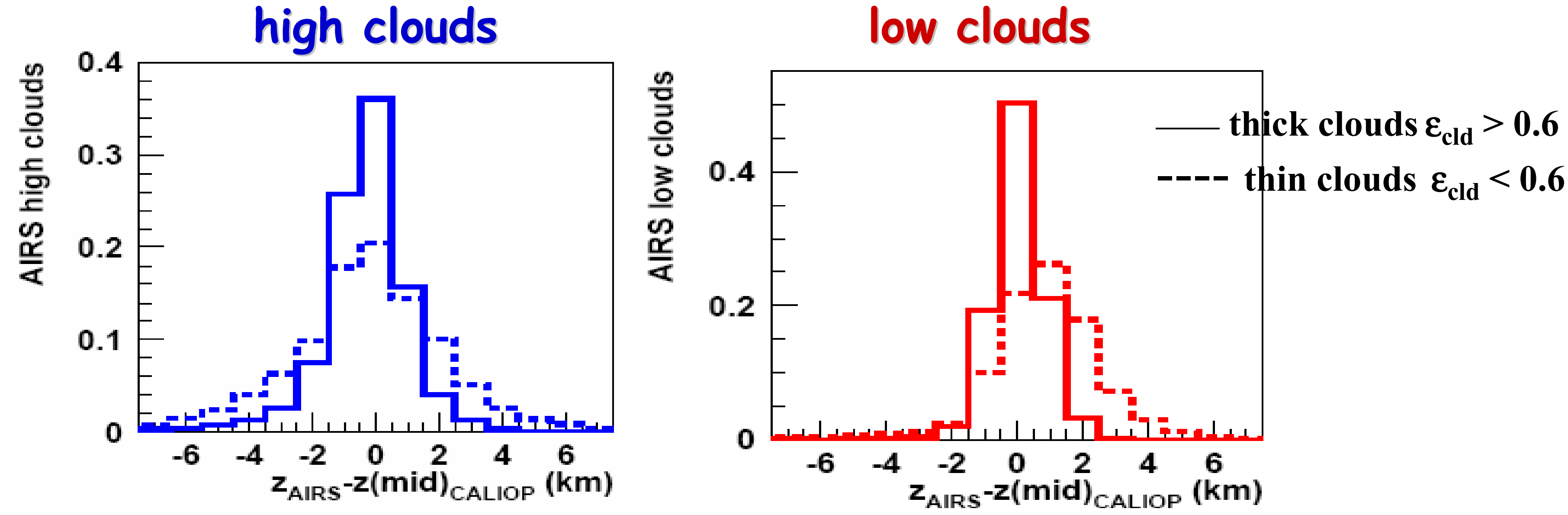
# Evaluation of AIRS-LMD cloud height with 1 year collocated CALIPSO data

*Stubenrauch et al., JGR 2008*




**good agreement with midlevel of cloud**

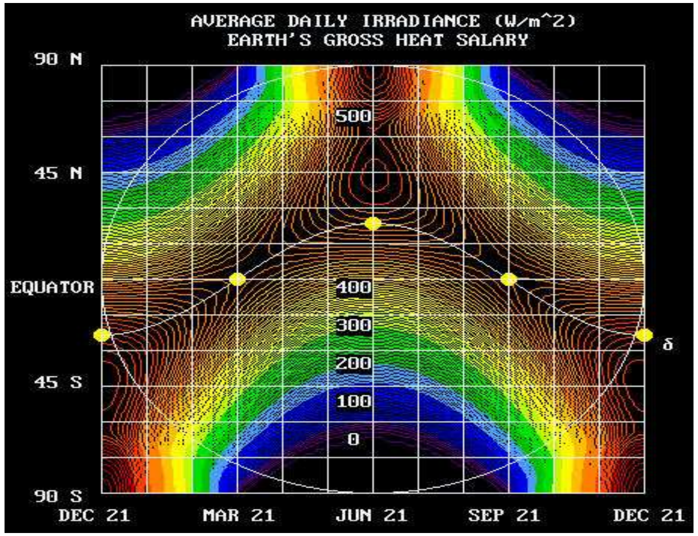
**slightly broader distributions for optically thinner clouds, but no bias**

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

# sun / atmospheric circulation

## geographical cloud distributions

*av. daily irradiance ($Wm^{-2}$)*

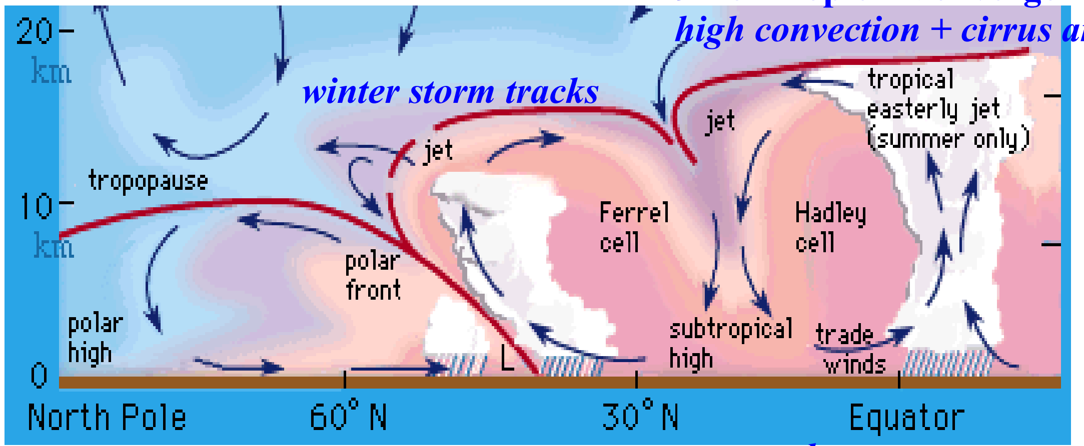



**www.sci.ccny.cuny.edu/~stan/e31_sunl.ppt#10**

Earth axial tilt (obliquity) -> seasons

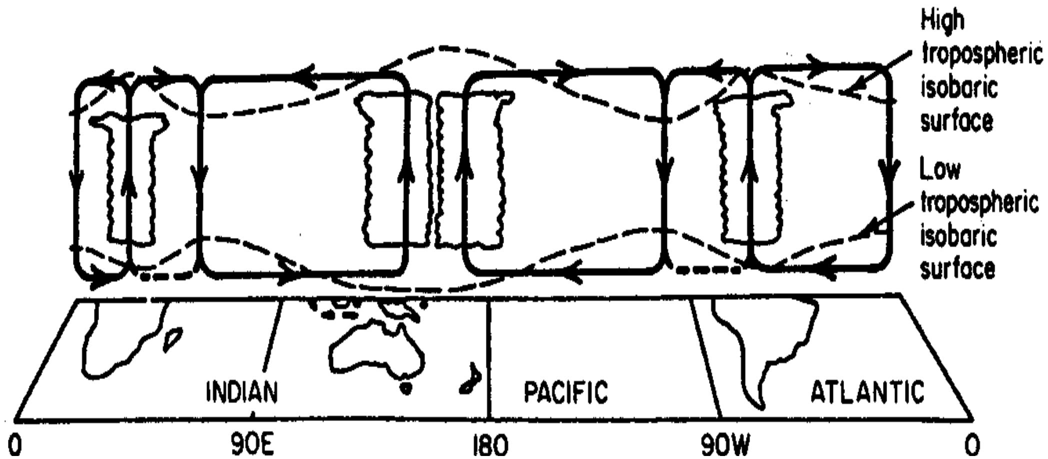
**InterTropical Convergence Zone:**
***high convection + cirrus anvils***

***winter storm tracks***



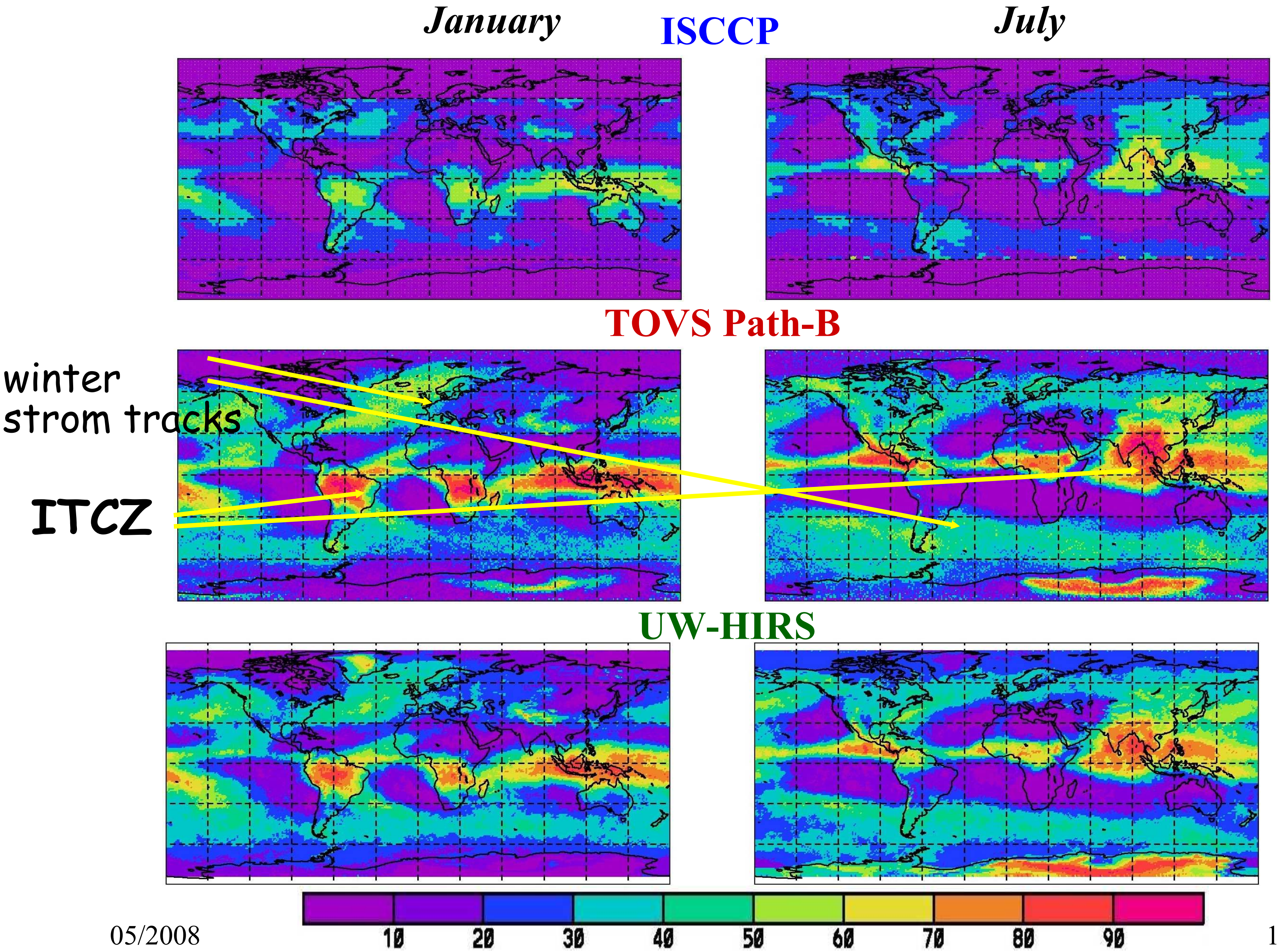

*©1994 Encyclopaedia Britannica Inc.*

***stratocumulus***



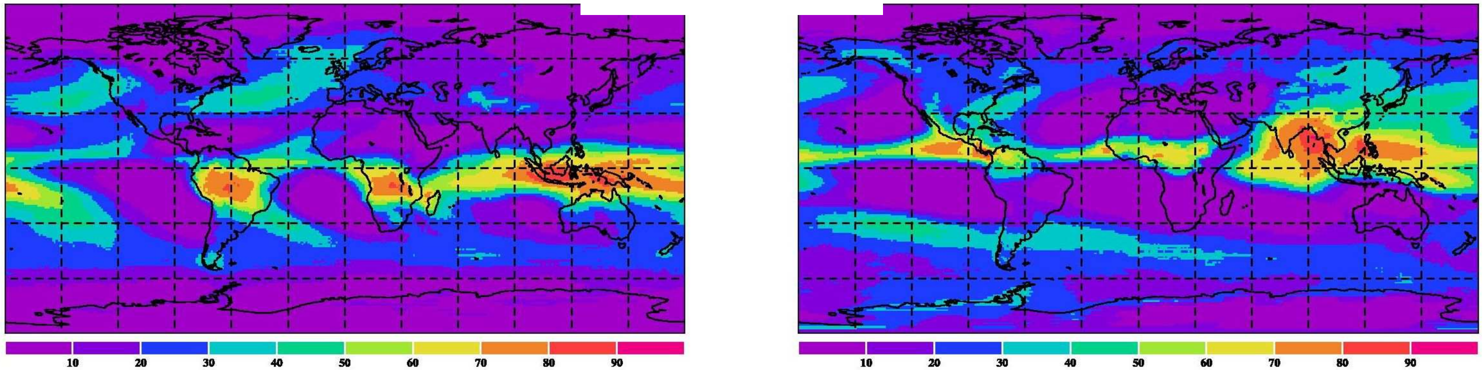

Schematic view of the east-west Walker circulation along the equator *(from Webster 1987)*

# HCA geographical distributions

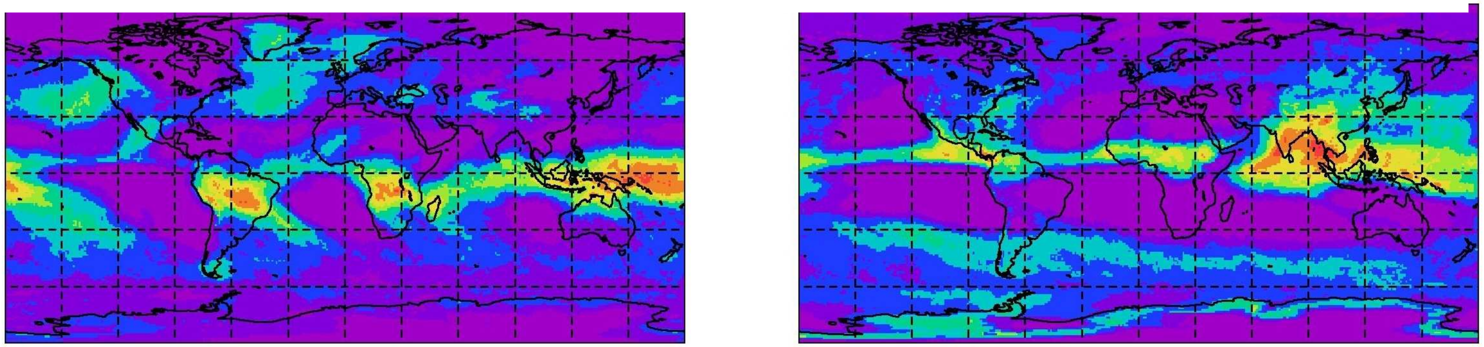


# HCA geographical distributions

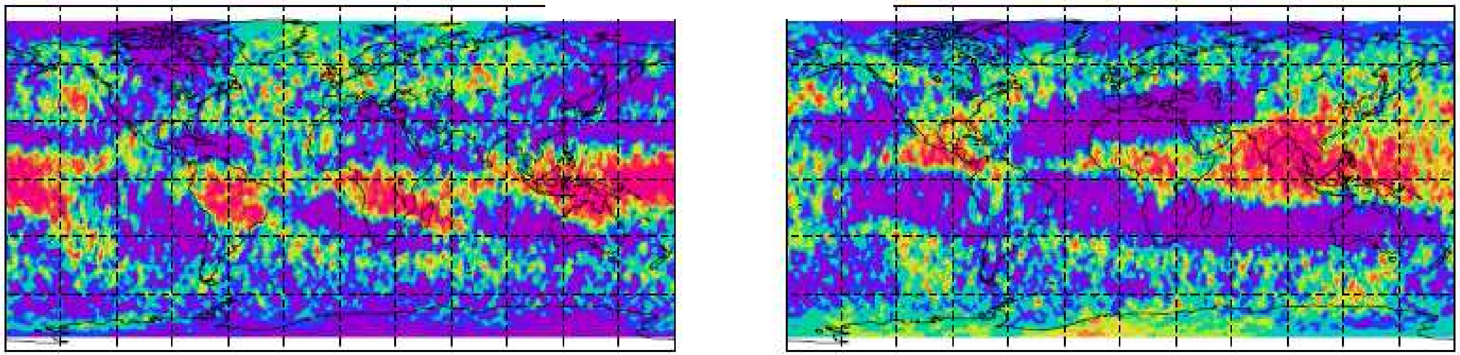
## PATMOS-x




## MODIS-CE



## CALIPSO



# 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 $\tau$>0.03) **1/3 higher**

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

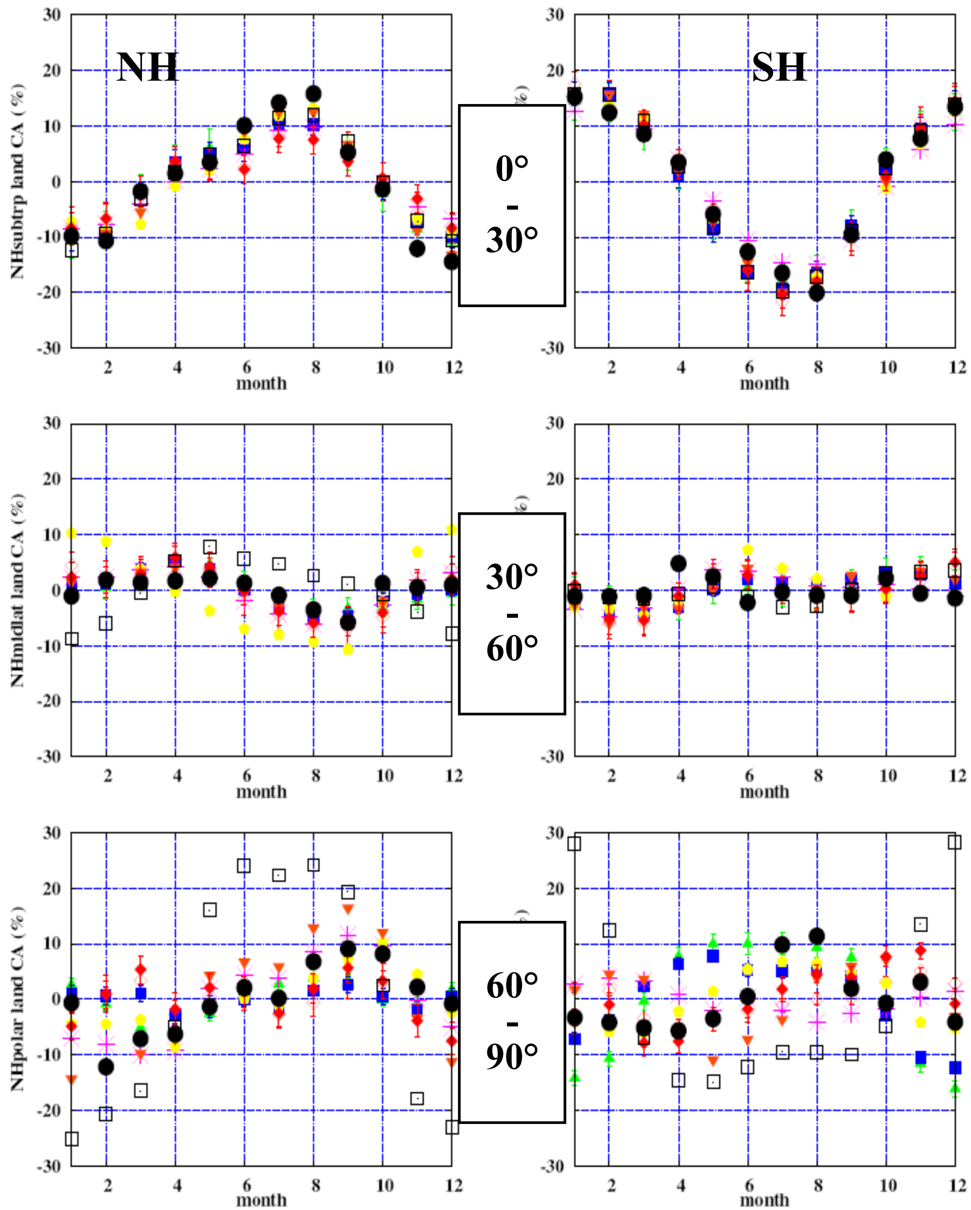
**40% high clouds:** ***only 3% thick Ci; more over land than over ocean***

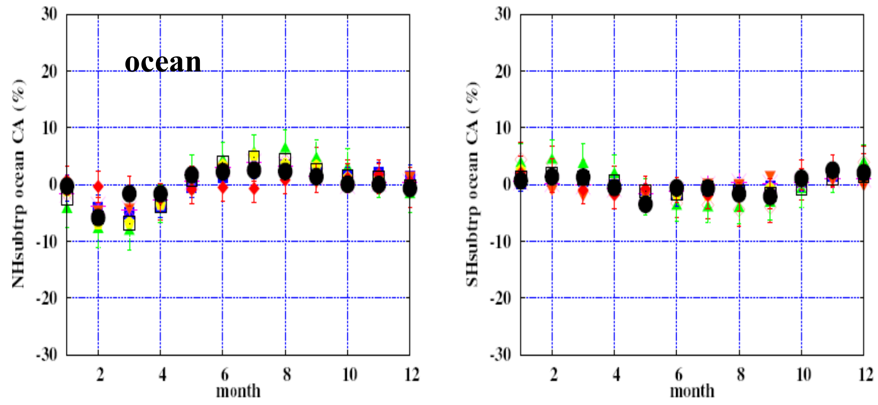
**IR sounders ~ 10% more sensitive to Ci than ISCCP (15% in trps)**

**SAGE cloud vertical structure in good agreement with IR sounders**

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

# CA seasonal cycle over land

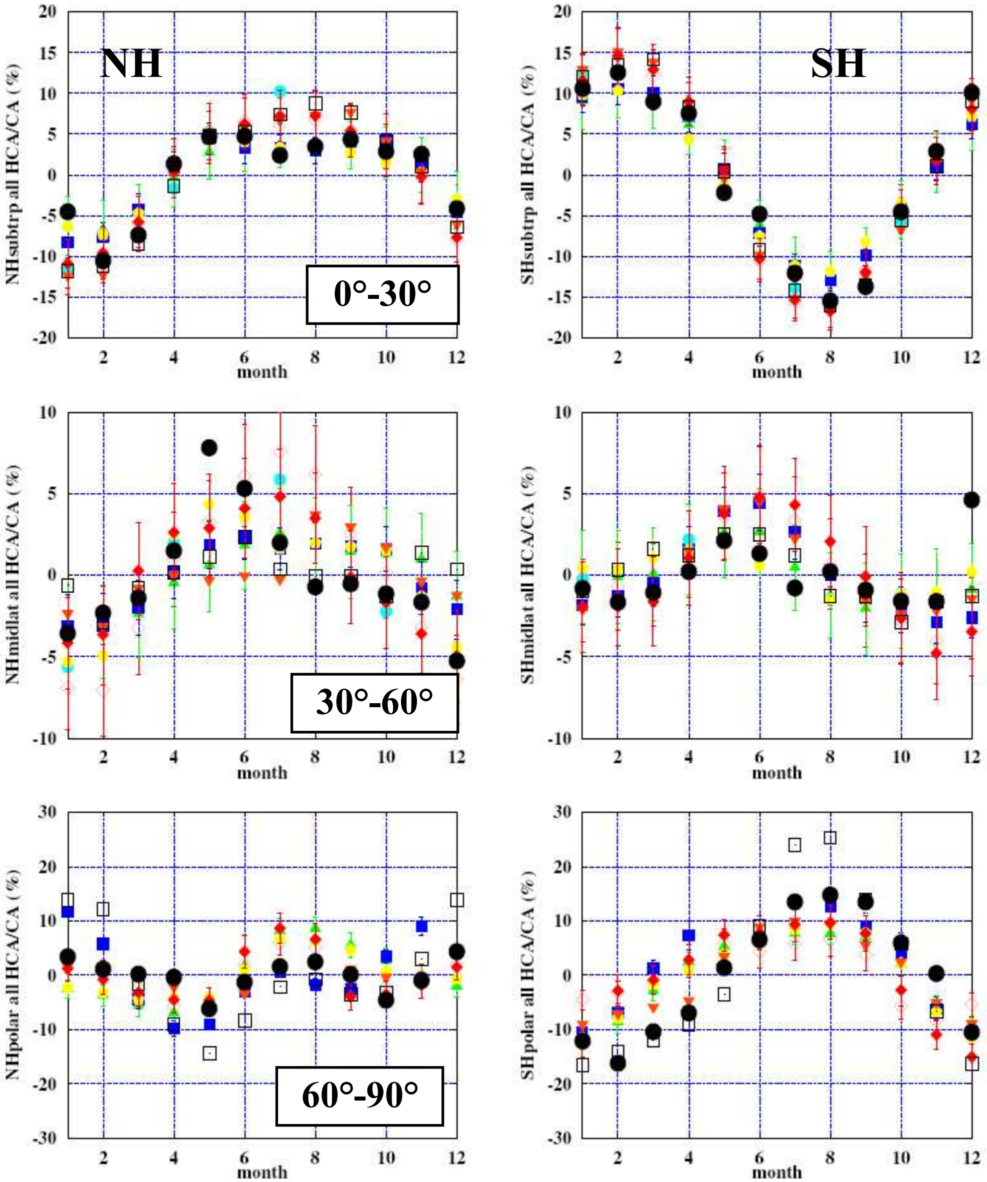



**Seasonal (& diurnal) cycles:**
- ❑ **stronger over land than over ocean**
- ❑ **strongest in subtropics**

**Seasonal cycles very similar**
<u>exception</u>: *SH polar land*
*& newer datasets* (PATMOS, MODIS-ST)

# HCA/CA seasonal cycle



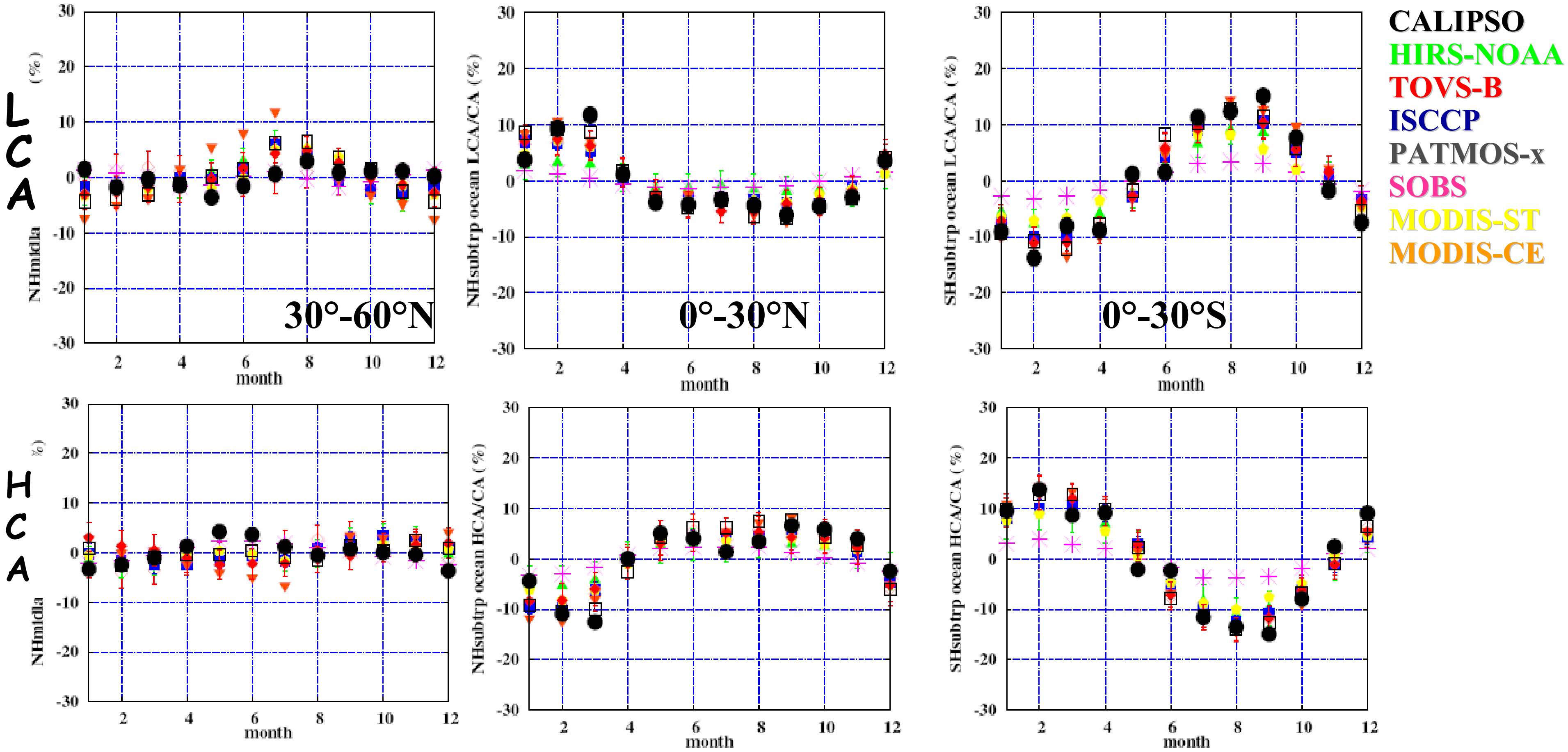

CALIPSO
SAGE
HIRS-NOAA
TOVS-B
AIRS-LMD
ISCCP
PATMOS-x
SOBS
MODIS-ST
MODIS-CE

**Seasonal cycles similar:**

**25% in tropics to 5% in SH midlatitudes**

**again 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**

# Solar heating & cloud formation

**warm air rises, expands, cools** ➡ ***condensation***

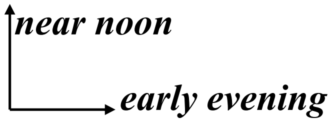
**cumulus:**

form in unstable atmosphere [large lapse rate (~11°C/km)]
(warming of the Earth's surface or cooling of air aloft)
***summer afternoon***, *tropics*

*Source: NASA Visible Earth*

**stratus:**

form in stable atmosphere [small lapse rate (~4°C/km)]
(cooling of the Earth's surface or warming of air aloft)
***early morning***, *subsidence*



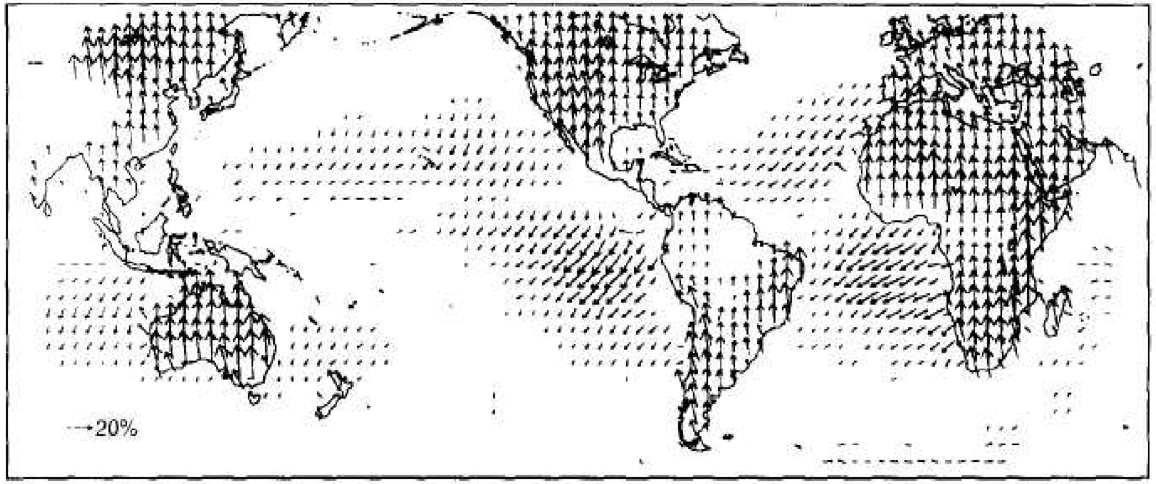

# diurnal cycle of clouds

*Cairns, Atm. Res. 1995*

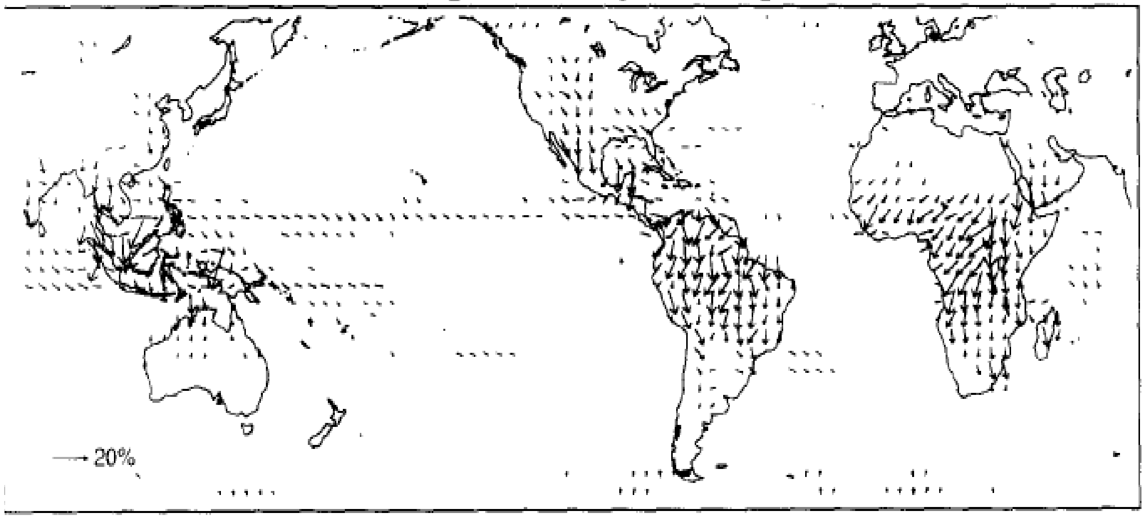
**ISCCP, Complex Empirical Orthogonal Functions,**

project. on distorted diurnal harmonics

Annual Average Diurnal Cycle for Low Cloud




Annual Average Diurnal Cycle for High Cloud



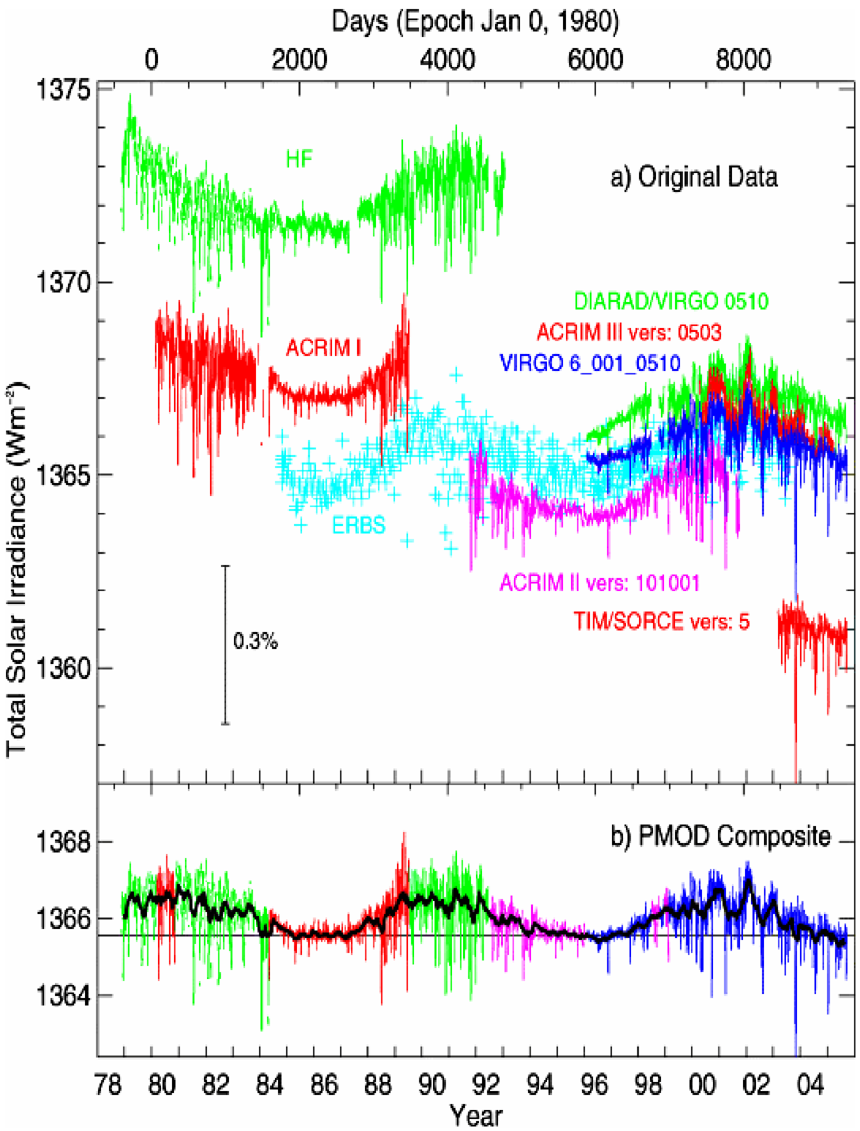

- **Low clouds over land:**
  significant diurnal cycle,
  *max early afternoon*

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

- **High clouds:**
  *max in evening*

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

# Sun activity variations: 11 yr solar cycle



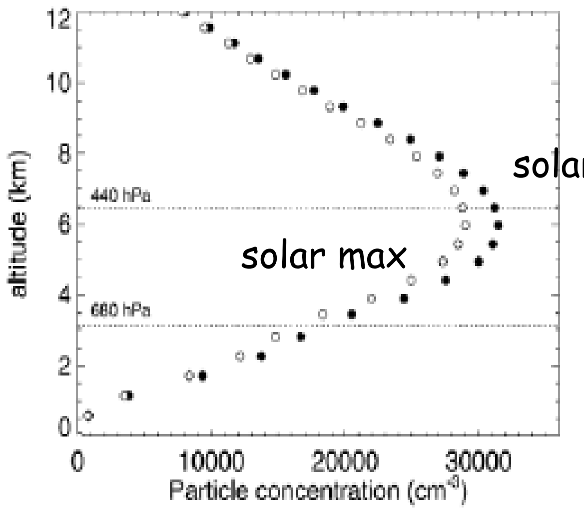

*Courtesy: C. Froehlich,* http://www.pmodwrc.ch

S = 1366.5 $Wm^{-2}$

**different satellites measurements**

*Froehlich & Lean (1998); Quinn & Froehlich (1999)*

**galactic cosmic ray flux modulated by solar wind**




*Kazil & Lovejoy JGR (2004)*
kinetic aerosol model, r > 3nm

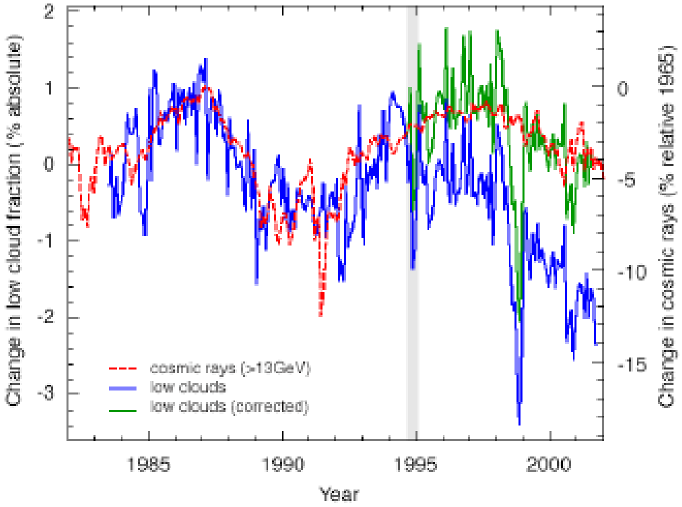
**cosmic rays -> ions -> nucleation -> clouds**

*Svensmark 1998, Marsh & Svensmark 2003*

*Gray et al. 2005*

**Analysis of ISCCP IR low clouds**

***at higher latitudes in upper troposphere***




**correlation with low clouds!**

**other sources influence cloud amount:**

***NAO (North Atlantic Oscillation)***

***ENSO (El Niño Southern Oscillation)***

***QBO (Quasi-Biennial Oscillation)***

***aerosols from volcanic eruptions***

***anthropogenic aerosols***

*Kristjansson et al. 2002, 2004:*

**IR low clouds & daytime low clouds**

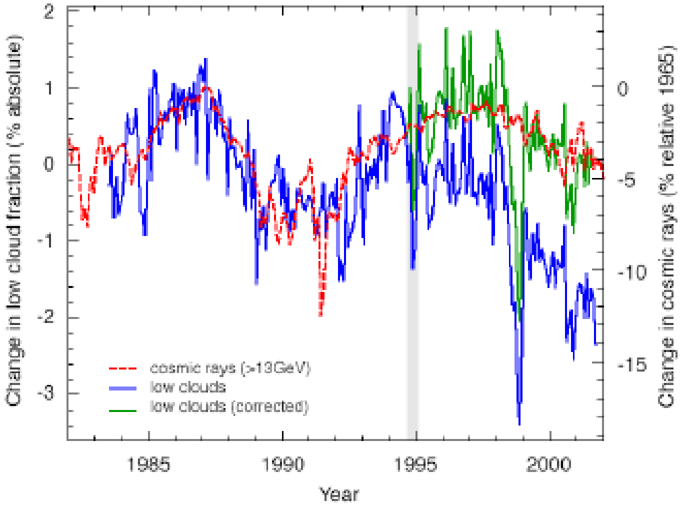
*Pallé & Butler, 2002, 2004, etc*

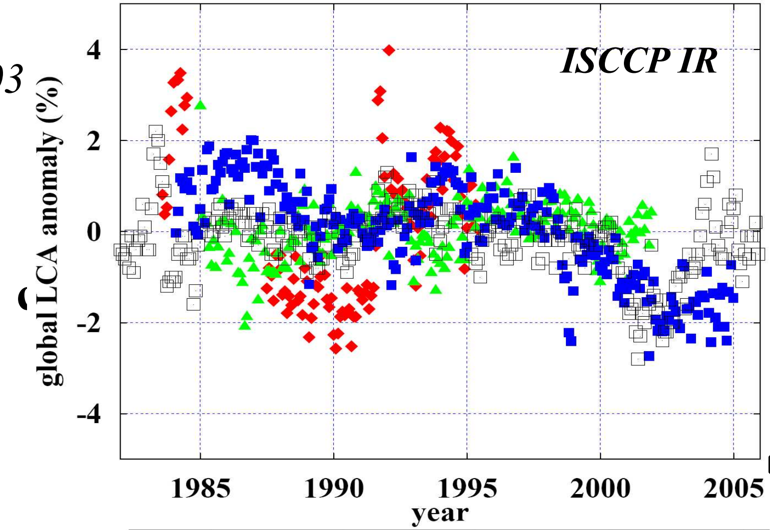
## cosmic rays -> ions -> nucleation -> clouds

*Svensmark 1998, Marsh & Svensmark 2003*

*Gray et al. 2005*

**Analysis of ISCCP IR low clouds**

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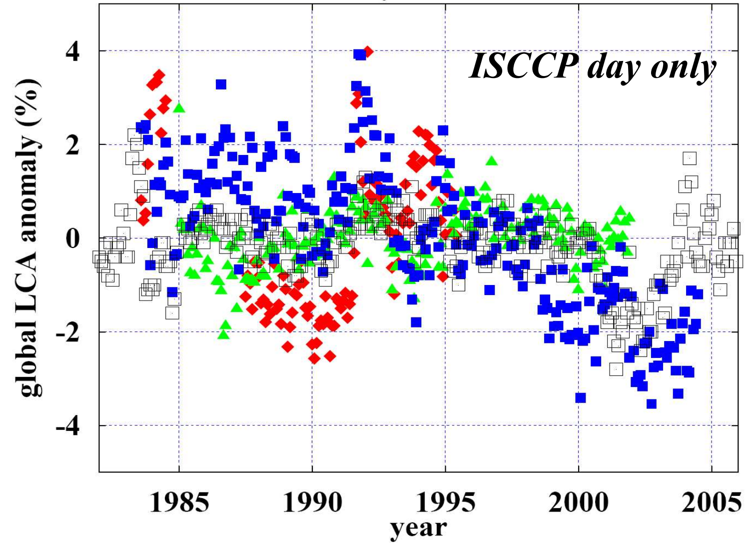



*Kristjansson et al. 2002, 2004:*

**IR low clouds & daytime low clouds**

*Pallé & Butler, 2002, 2004, etc*

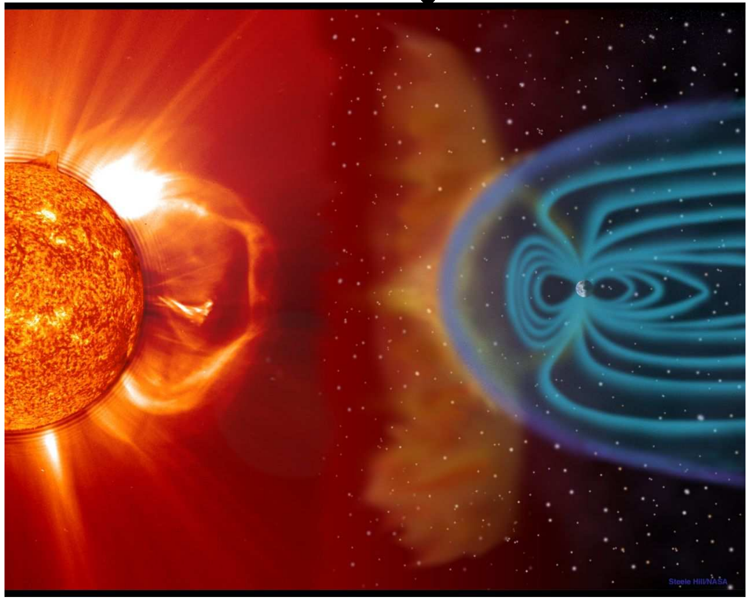
**no correlation within uncertainties**

# another way to study influence of solar activity on clouds:

*J. Čalogović (Master dissertation) 2006, 108 pp, EAWAG, Zürich, supervisor Prof. J. Beer*

**Forbush decrease events (several days):**

**coronal mass ejections -> decrease of cosmic ray intensity (10-25%)**



*NASA website*

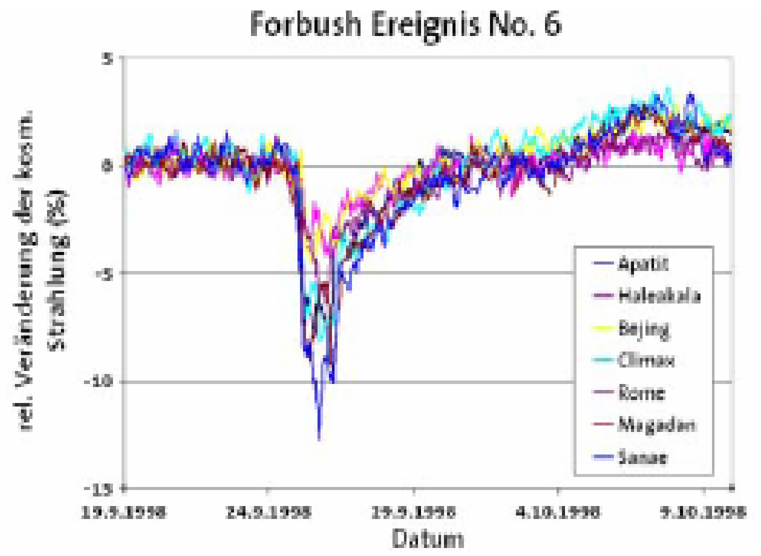
**6 largest events 1983 - 2001**

| date | strength |
|---|---|
| 24/03/1991 | 21.3 |
| 28/10/1991 | 17.4 |
| 13/03/1989 | 16.6 |
| 27/11/1989 | 15.4 |
| 26/02/1992 | 9.7 |
| 24/09/1998 | 9.2 |

Flux density measured by neutron monitors

data available at http://spidr.nggdc.noaa.gov,

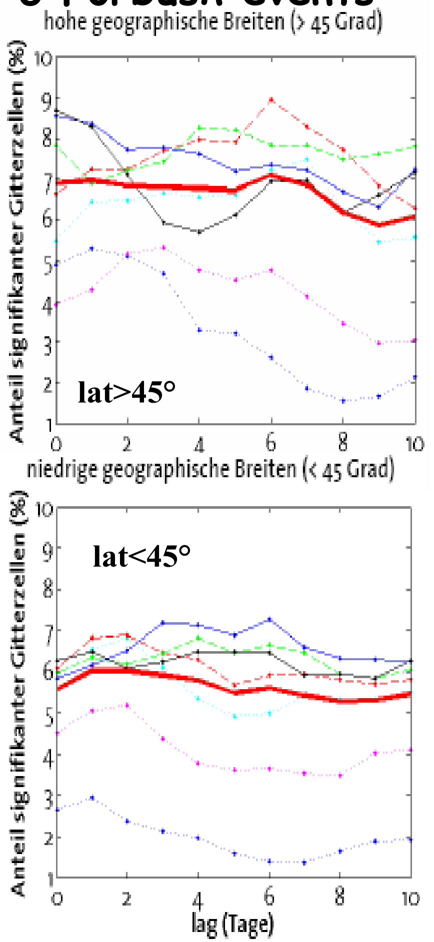
*National Geophysical Data Center Boulder*



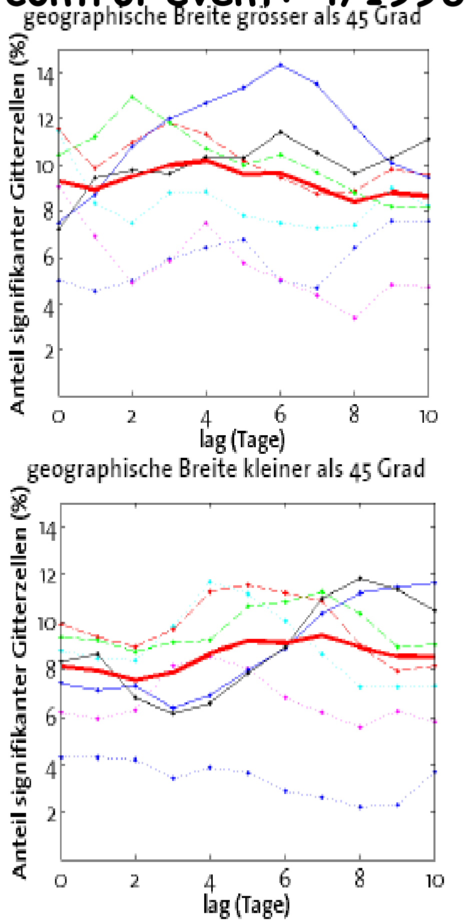
*J. Čalogović (Master dissertation) 2006, 108 pp, EAWAG, Zürich, supervisor Prof. J. Beer*

# Analysis of correlations between flux and CA at different heights using ISCCP D1 data, 20 days per evt

**6 Forbush events**




**control event: 4/1996**





no conclusive correlation between cosmic ray flux decrease & ISCCP CA

*Other studies of Forbush events:*

*Sloan & Wolfendale 2008,*

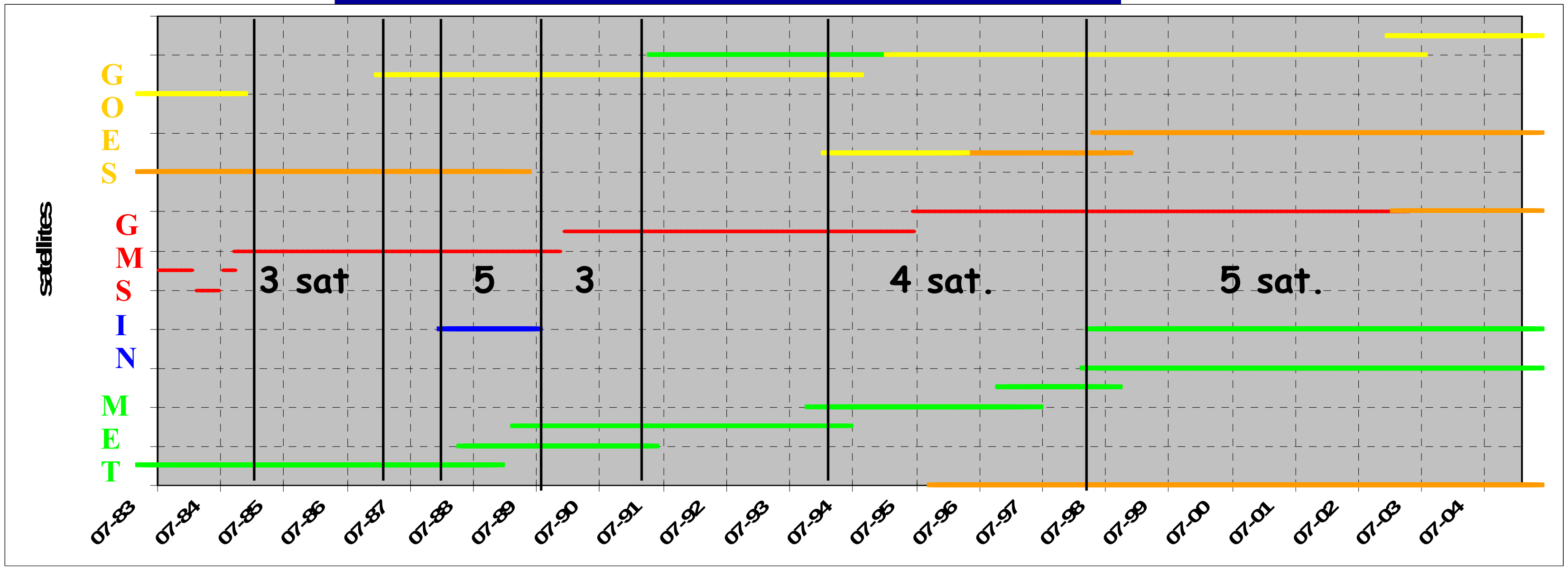
*Kristjansson et al. EGU 2008*

# Climate monitoring

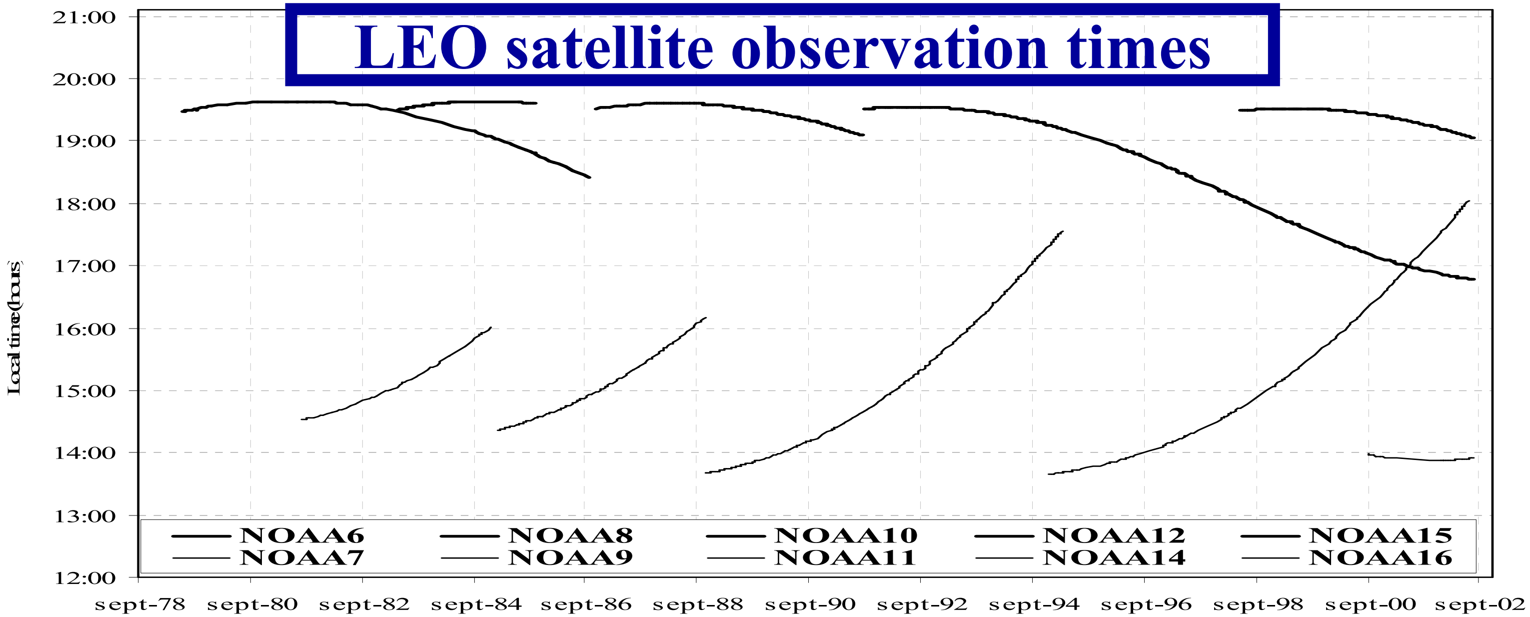
uncertainties due to

satellite intercalibration, satellite drifts, etc.

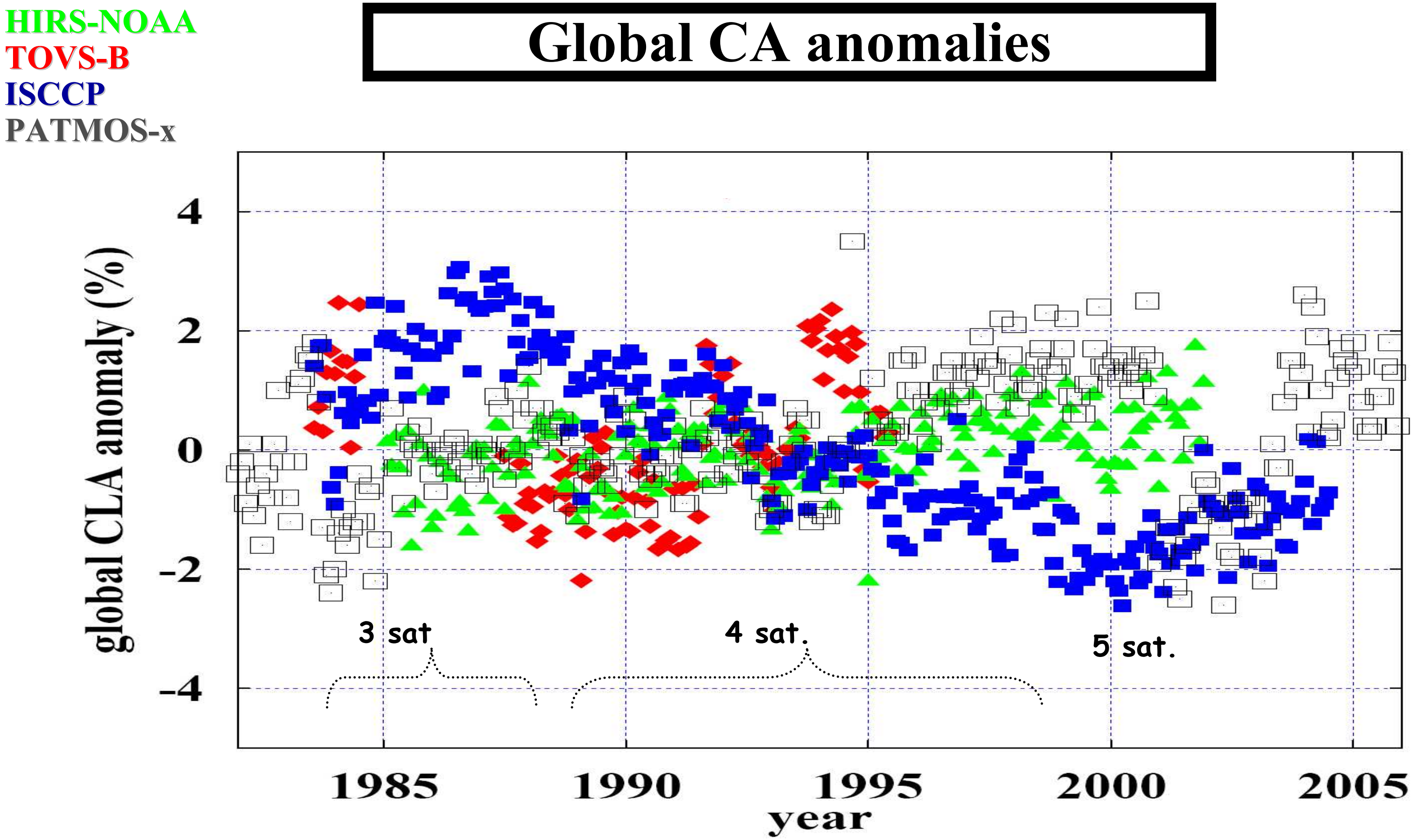
# GEO Satellite positions




# LEO satellite observation times



# Global CA anomalies

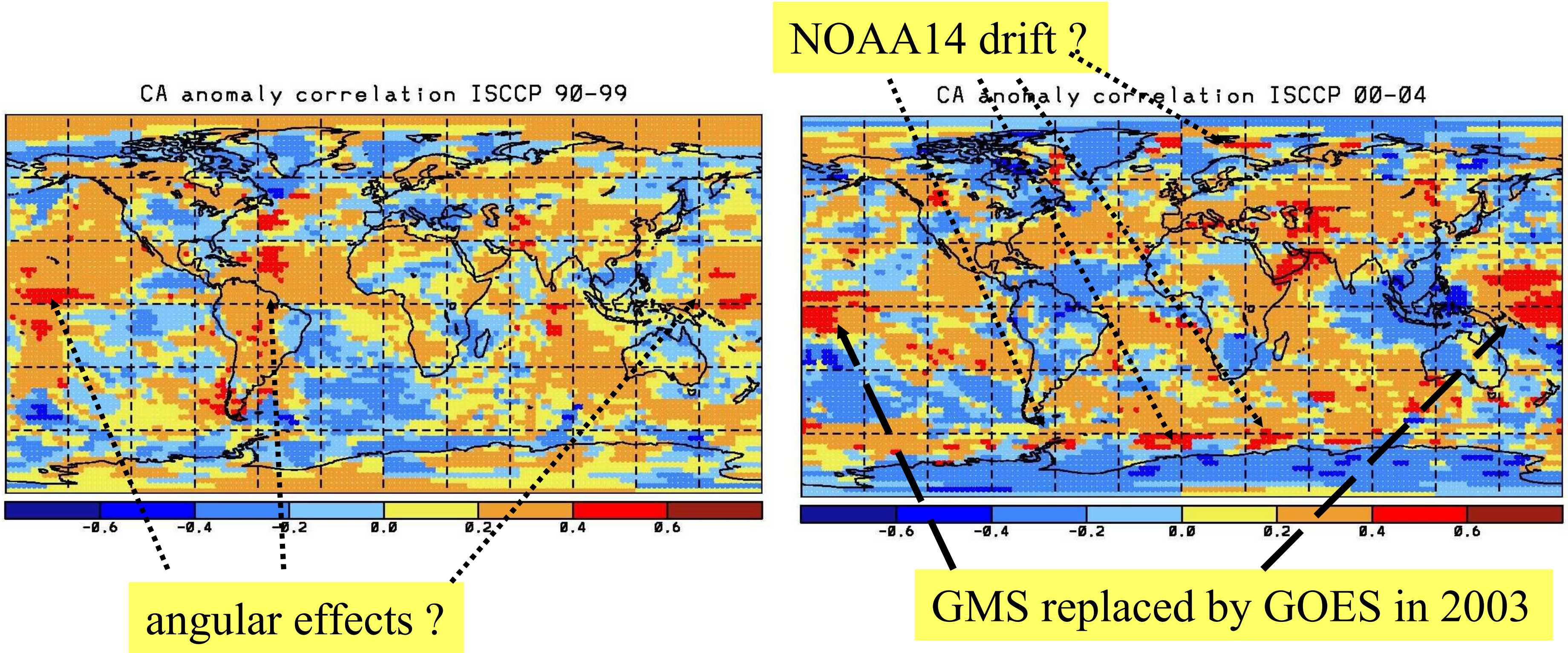



**global CLA within ±2.5%**
HIRS-NOAA: more or less stable
ISCCP: ~5% decrease from 1987 to 2000
related to increasing nb of GEO satellites ?

SOBS: increasing over ocean, stable over land >1985 *(Warren et al. J. Clim. 2006)*

## Correlation between global and regional anomaly:

1. calculate anomaly maps per month and per year: *A(i,j,m,y)*
2. calculate global anomaly per month and per year: *AG(m,y)*
3. determine map of (linear) correlation coefficients: *r(i,j)*



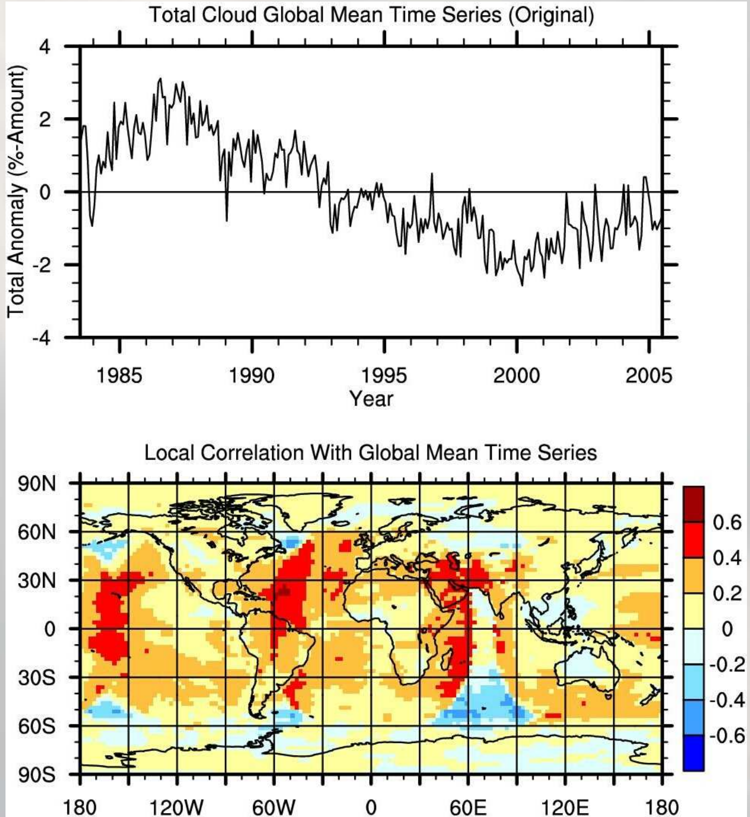
# CA change : cluster analysis correcting for artefacts

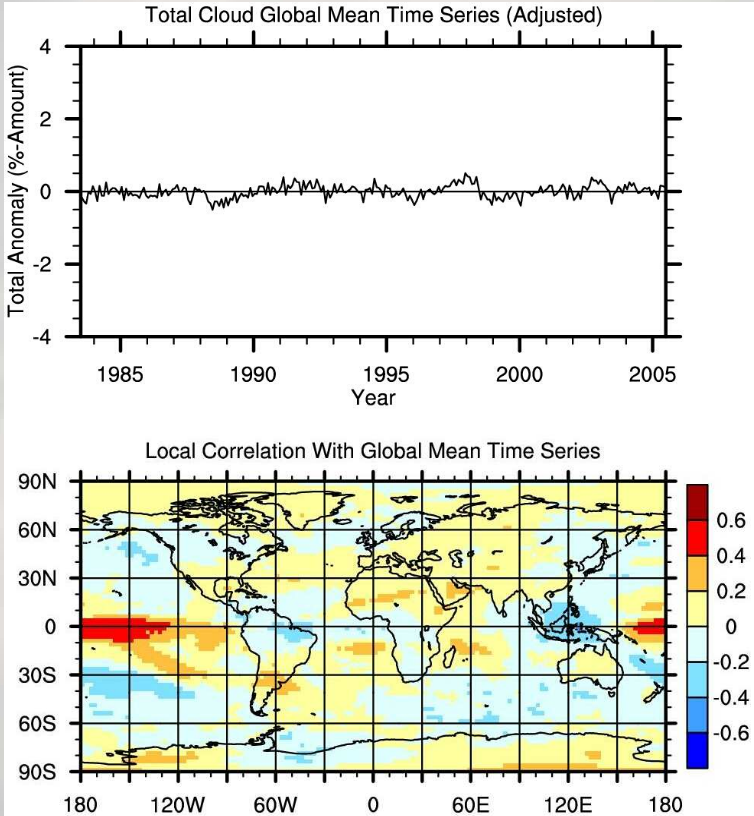
***J. Norris***

**http://meteora.ucsd.edu/~jnorris/isccp_artifacts.html**

**6 clusters out of 7 related to artificial satellite features:**
***sea-ice: Oct-Dec 2004, high lat land: > Oct 2001(NOAA16)***
***nb of GEOs - view angle, GEO view area***

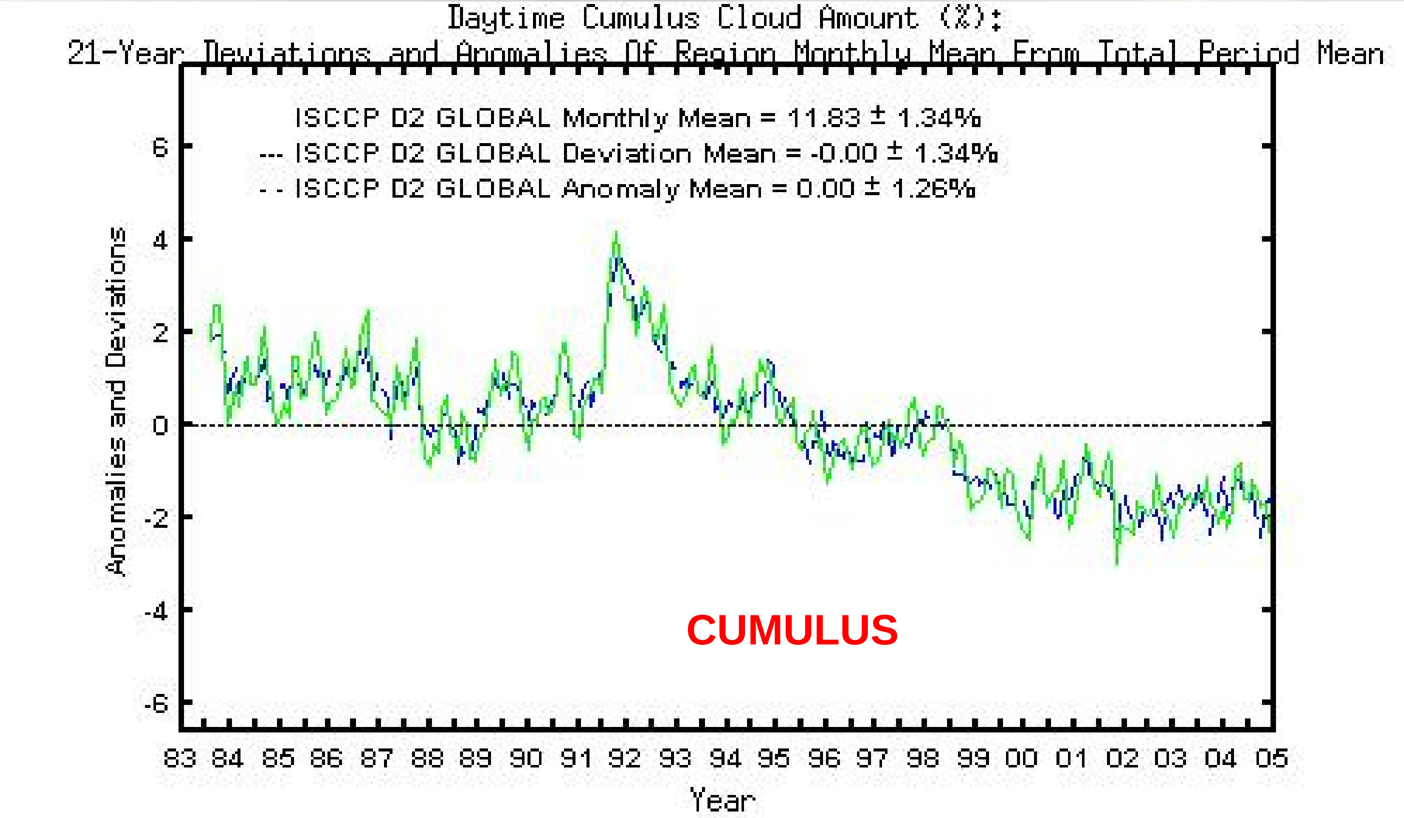
*also*
*(Evan et al. GRL 2007)*



# Anomaly per cloud type

*W. B. Rossow*



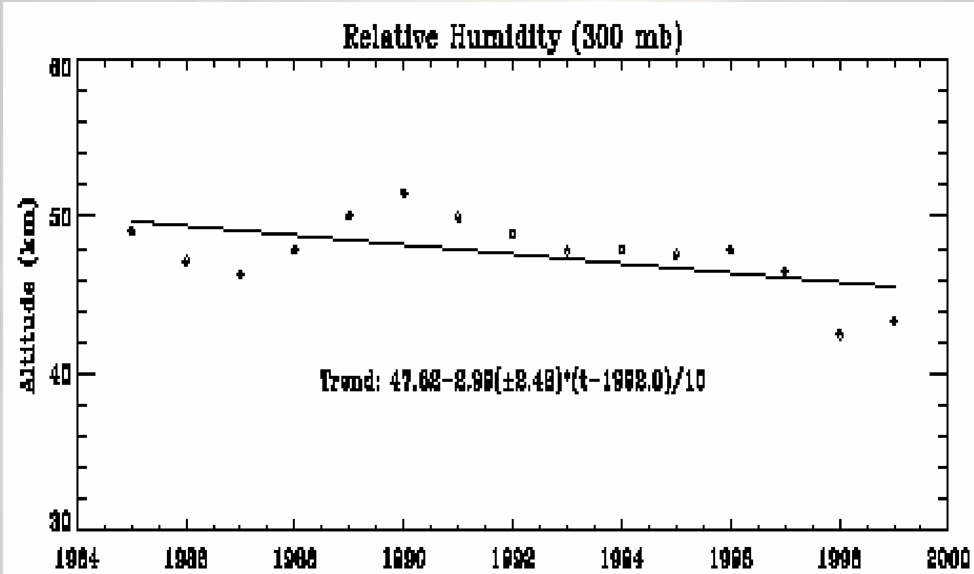

**Changes in Cloud Property Distribution :** decreasing τ of low clouds -> below detection (*Tselioudis et al. 1992*: τ decreases with T)

# Trend analysis of high clouds: synergy of different variables

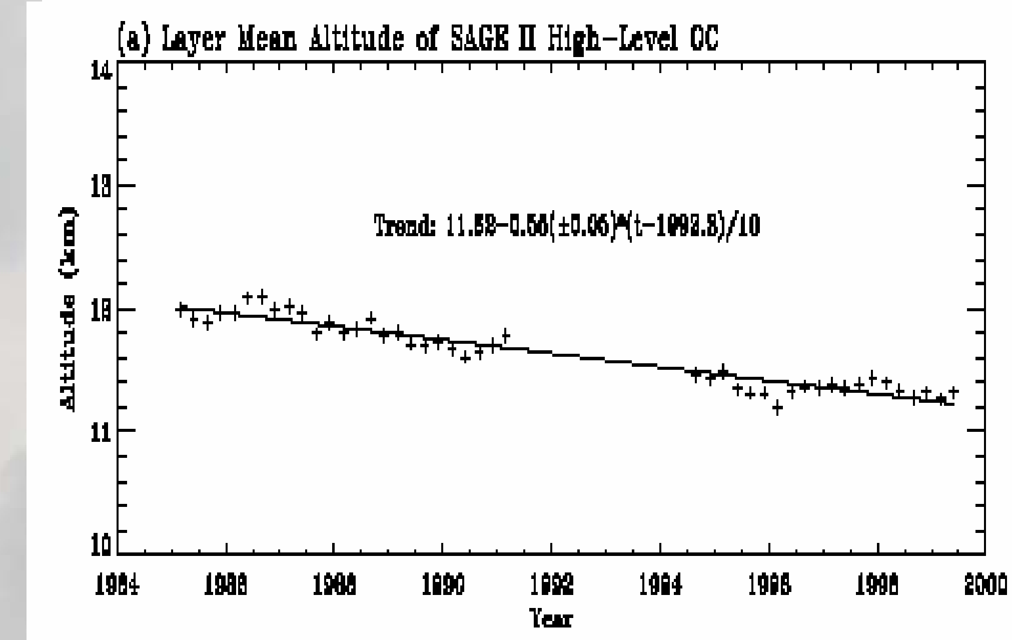
**Tropics** *(Pi-Huan Wang et al., 2007)*:

- NCEP reanalysis:

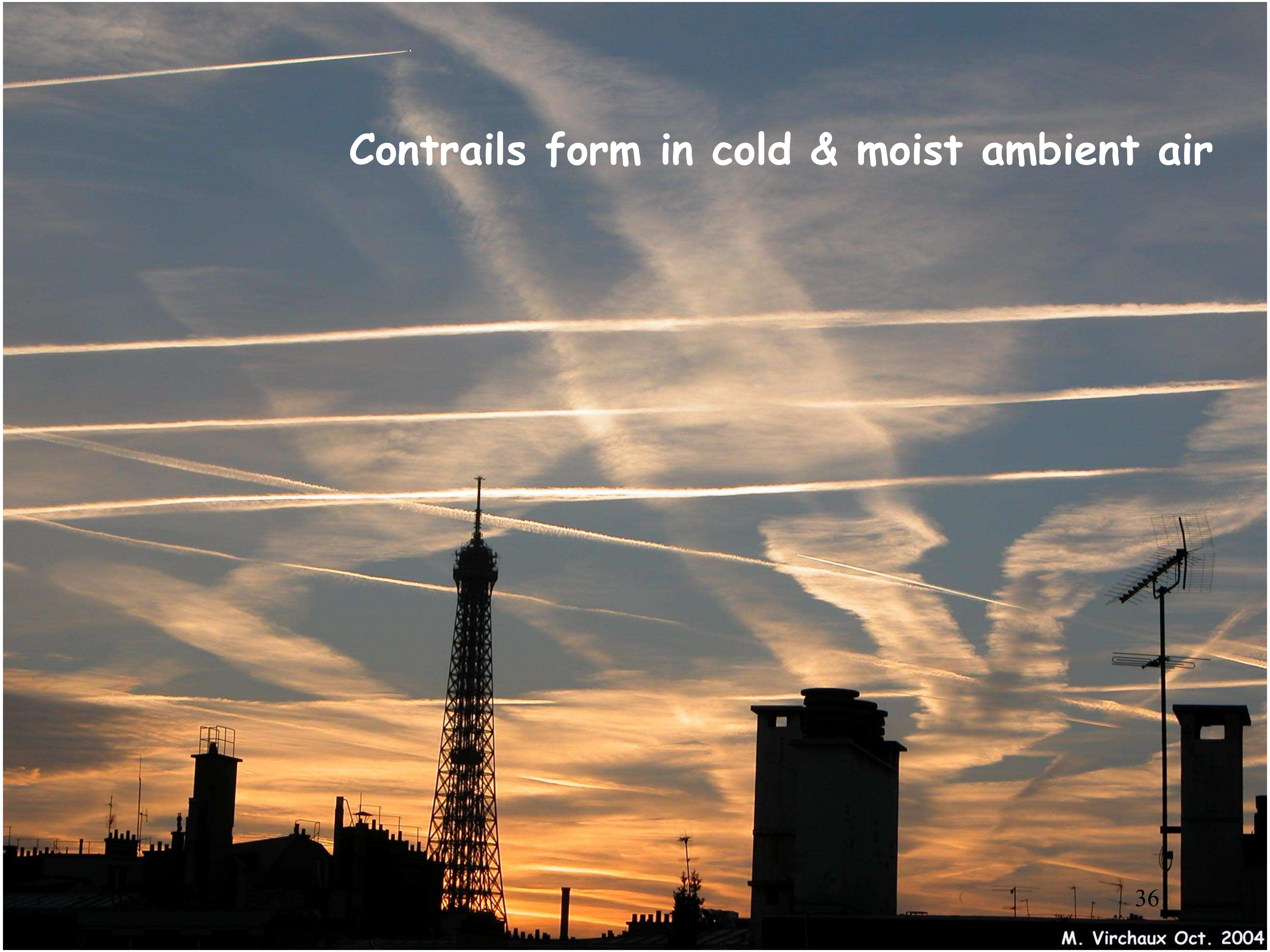
upper tropospheric rel. humidity decrease
-> decrease in HCA

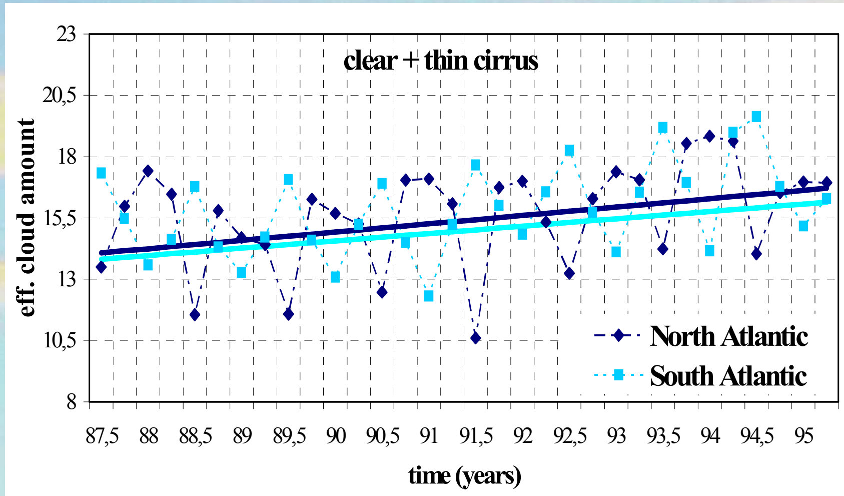



SAGE:
decrease of emissivity (not shown)
& altitude of high clouds
rather than simple HCA decrease

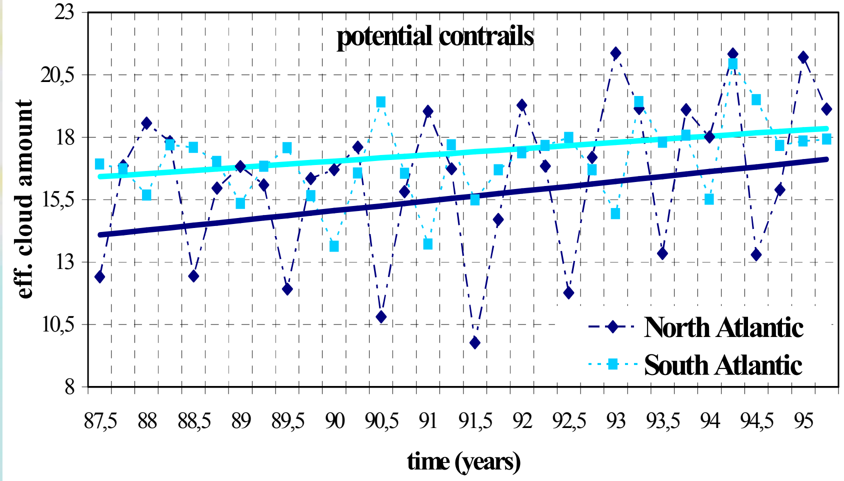



- *cause of UTH drop? Is it real?*


Contrails form in cold & moist ambient air
36
M. Virchaux Oct. 2004

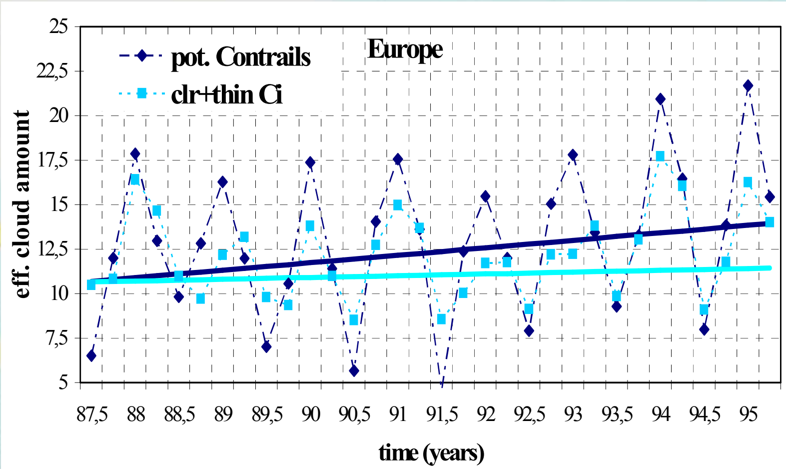



$RH_{ice} < 70\%$ & $RH_{wat} > 0.4\ RH^*_{crit}$




**increase of thin Ci in <u>both</u> hemispheres**

**stronger increase related to contrails in NH**




**<u>Europe</u>:**
**stronger ECA increase for potential contrail situations than for all situations:**

**2.8-3.5% (±1.5%) per decade**

**However: Occurrence of pot. contrail situations is small: 5 - 10%**
**=> Overall effect over Europe ~0.19% - 0.25% per decade**

## Satellite observations:

❖ unique possibility to study cloud properties over long period
**-> climatological values of CA, HCA, MCA and LCA (also ε, τ) 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 and active CALIPSO)

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

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

❖ **CALIPSO-CLOUDSAT to determine vertical structure of clouds!**

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

❖ **Trend analysis:** careful of satellite drifts, calibration etc.
synergy of different variables important !

❖ **Sun activity (GCR) correlations:**

- difficult to distinguish, because also other phenomena influence clouds
- interannual variabilities & uncertainty of longterm datasets in latitude bands of same magnitude as possible effect
- analyzing Forbush decrease events avoids problems with satellite changes, but so far no effect could not be affirmed

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