Survey of cirrus and atmospheric properties from TOVS Path-B

Claudia Stubenrauch

+ Atmospheric Radiation Analysis (ARA) group

IPSL - Laboratoire de Météorologie Dynamique, France

- **TOVS Path-B Dataset**
  & average cloud properties

- **Variability of cirrus properties**

- **Reanalysis**

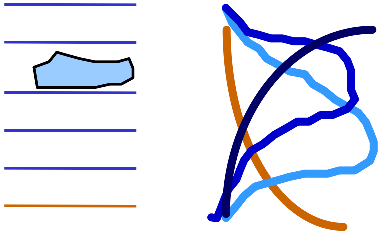
- **Upper trop. humidity + evolution of contrails**

  (collaboration with U. Schumann, DLR)

TOVS Path-B climatology:…, 1987- 1995, …

Scott et al., BAMS, 1999

MSU+HIRS $R_m(\lambda_i,\theta)$ **along H_2O, CO_2 absorption bands**



3I Inversion *(Chédin, Scott 1985)*

- atmospheric temperature (9 layers, ≥10hPa), water vapor **(5 layers, ≥100hPa)**
- **effective cloud amount (ECA), cloud top pressure** *(Stubenrauch et al. 1999)*
- **D_e, IWP of cirrus** *(CIRAMOSA, poster Eddounia et al.)*
- **horizontal extent of high clouds** (*G. Rädel*)
- **upper tropospheric relative humidity**

3I based on: *controlled use of a priori information:* radiosondes – radiative transfer

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

Thermodynamic Initial Guess Retrieval

Average cloud properties

8 years (1987-1995) **TOVS Path-B** / ***ISCCP***

Cloud type amounts (%)	global		ocean		land	
all	*73*	*65*	*74*	*71*	*69*	*58*
Deep convection	*2.4*	*2.8*	*1.9*	*2.8*	*3.5*	*2.7*
Cirrus	*27.3*	*19.1*	*26.9*	*18.0*	*27.8*	*21.7*
Mid-level	*12.1*	*18.5*	*10.3*	*18.4*	*16.6*	*18.5*
Low-level	*30.9*	*26.7*	*35.1*	*30.6*	*20.5*	*17.7*

~ 70 % cloud amount: *more over ocean than over land*

~ 30% low clouds: *more over ocean than over land*

~30% high clouds: *same over ocean and land*

Vertical sounders more sensitive to Cirrus clouds (8% more than ISCCP)

Observed Global Climate, Chap. 'Clouds', June 2005, Springer

Average regional high cloud properties

8 year (1987-1995) **TOVS Path-B** / ***ISCCP***

Cloud type amounts (%)	NH midlat.		tropics		SH midlat.	
Deep convection	**3.0**	***3.3***	**2.5**	***3.5***	**2.4**	***3.0***
Cirrus	**24.7**	***20.3***	**44.8**	***24.9***	**21.8**	***16.5***

- **only 3% convection**
- **IR vertical sounders:**

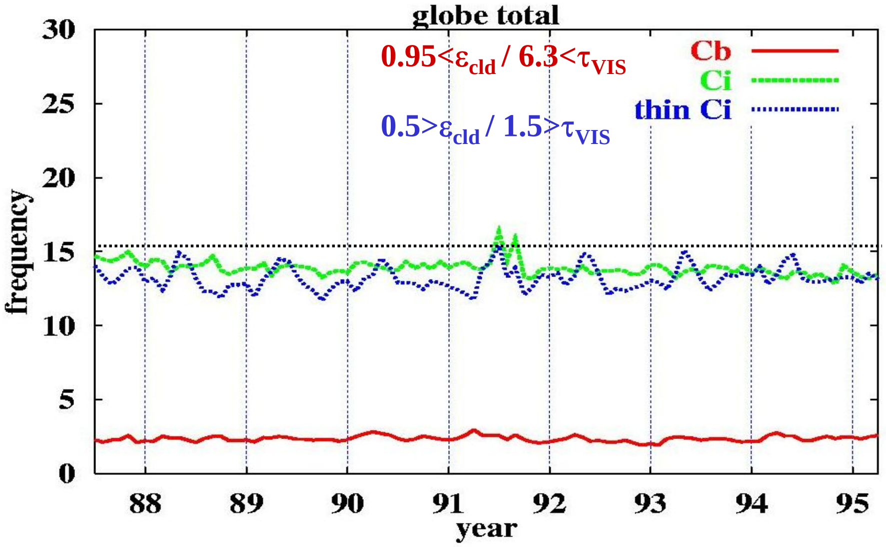
  identify Ci day + night

  more sensitive to Ci: *midlat.* +4%

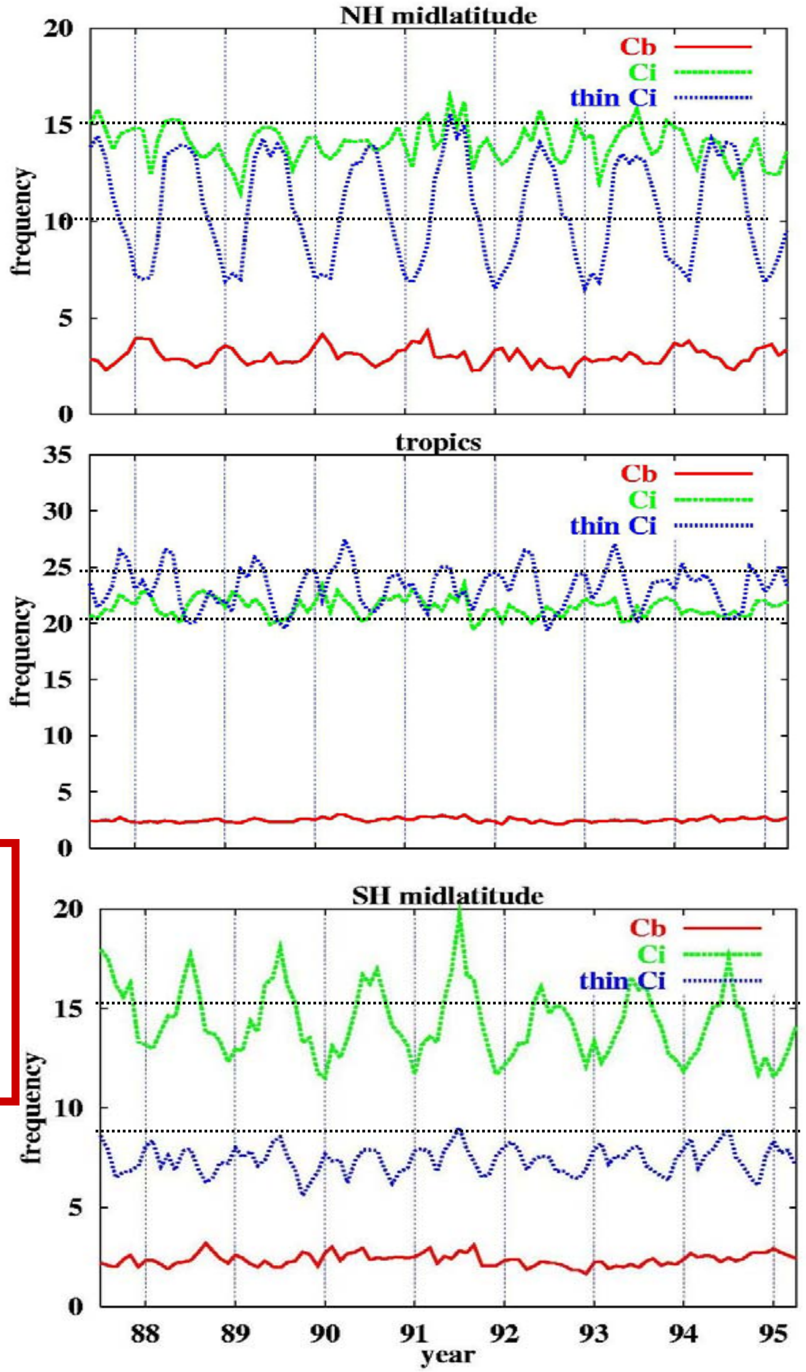
  tropics +20%

Time series of TOVS Path B high cloud frequencies

NOAA10/12 7h30 AM&PM



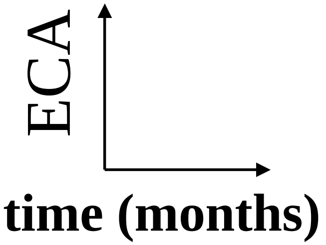
- stable over 8 years within 2%
- NH mid: strong seasonal cycle of thin Ci
- SH mid: seasonal cycle of Ci

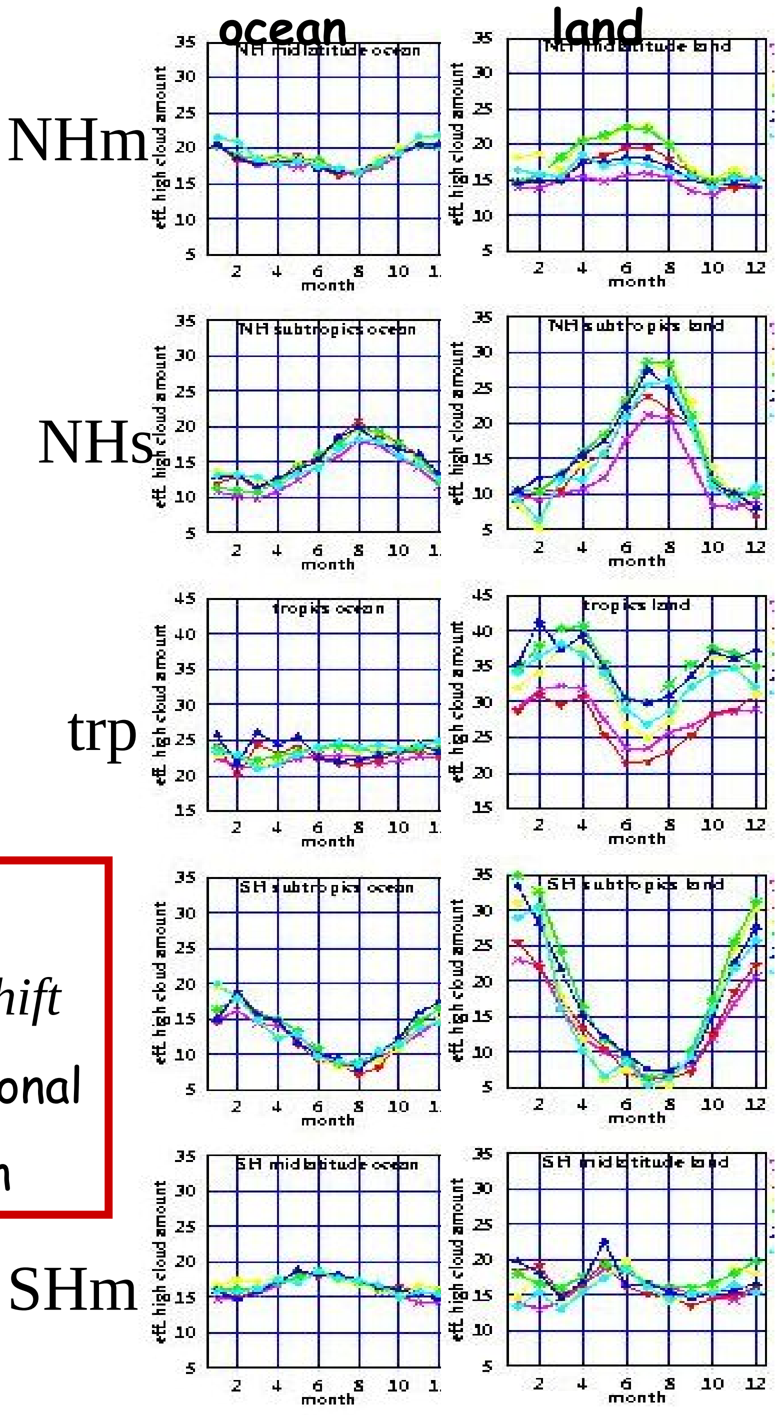


Seasonal & diurnal variations of effective high cloud amount

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

- **7h30 AM** ···×···
- **2h00 PM** —▼—
- **4h30 PM** ···✱···
- **7h30 PM** ···●···
- **2h00 AM** ···▲···
- **4h30 AM** ···◆···

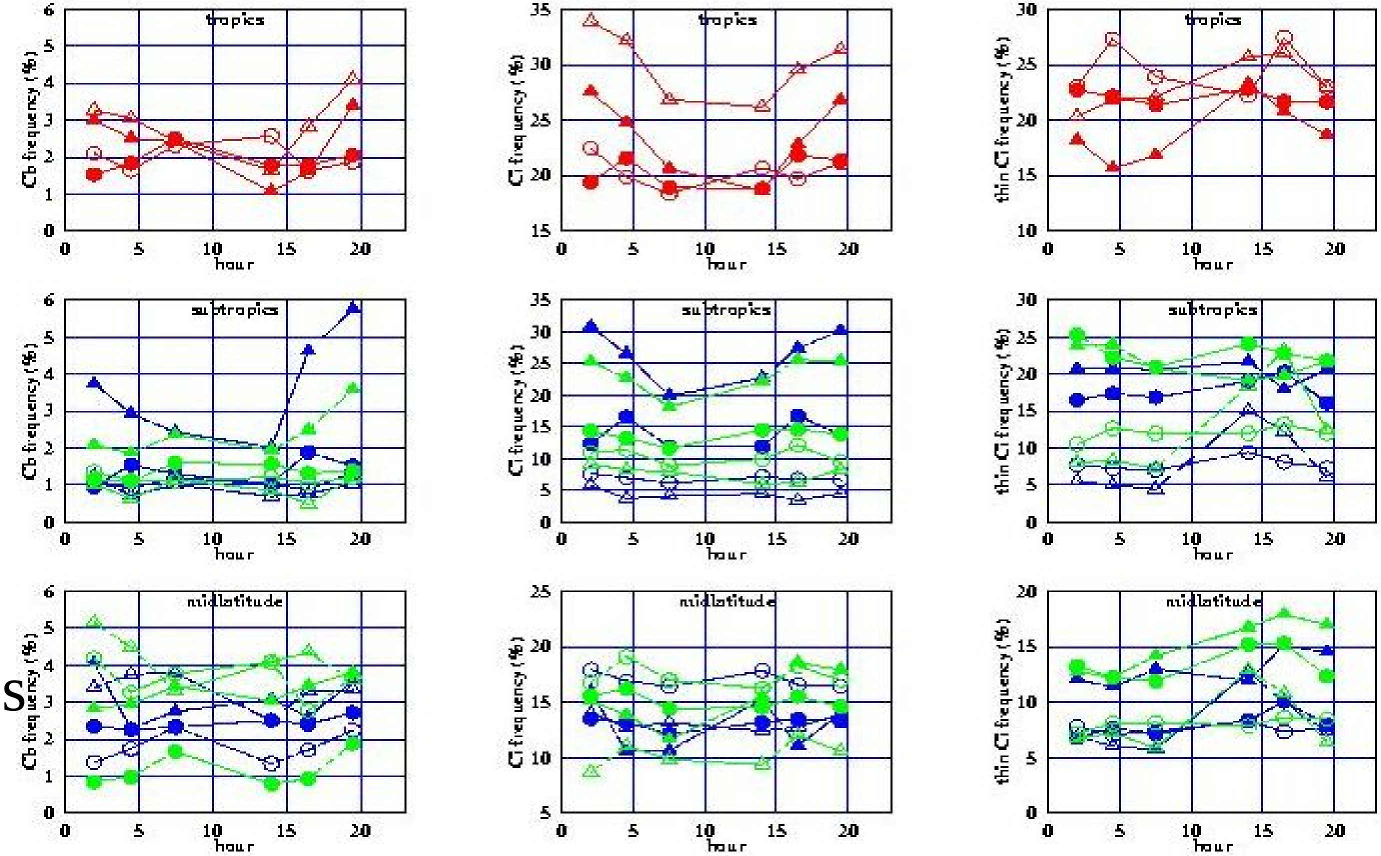




- ➢cycles stronger over land than over ocean
- ➢seasonal cycle strongest in subtropics: *ITCZ shift*
- ➢ tropics: diurnal variability stronger than seasonal
- ➢NH land: seasonal cycle strongest in afternoon

diurnal cycle of high cloud type frequencies

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



tropics

subtropics

NH, **SH**

midlatitudes

NH, **SH**

Δ land

• Sea

sum

win

- ➢ strongest diurnal cycles over land in tropics and in summer
- ➢ convection strongest in evening
- ➢ more cirrus during night and more thin cirrus in afternoon

❖Reanalysis of entire TOVS data at LMD:

Improved TIGR database

- extention from 1763 to 2311 atmospheric profiles (in tropics)
- new 4A model (spectroscopy, continuum) for T_B computation
- new surface emissivities *(FASTEM-2, S. English)*
- O_3 profiles from UGAMP climatology
- new extrapolation of T and H_2O towards stratosphere from ATMOS

3I Inversion

- scheme adapted to new TIGR
- new neural network inversion for $H_2O(p)$ and T_{surf}

Adjustment constants (« deltacs »)

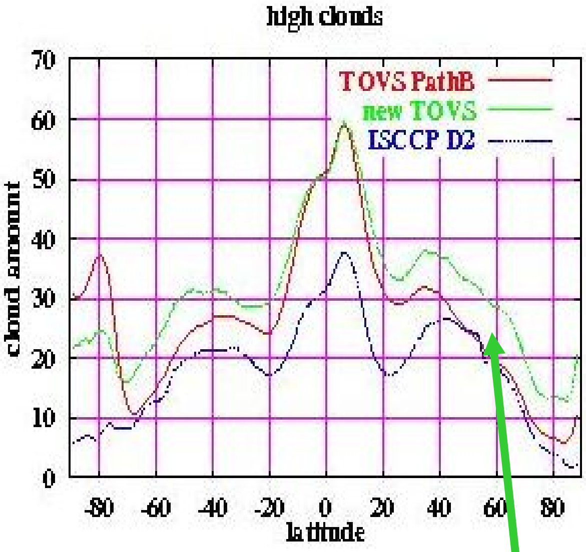
1987-1995: ***DSD5*** radiosonde-TOVS dataset from NOAA : clear /cloudy

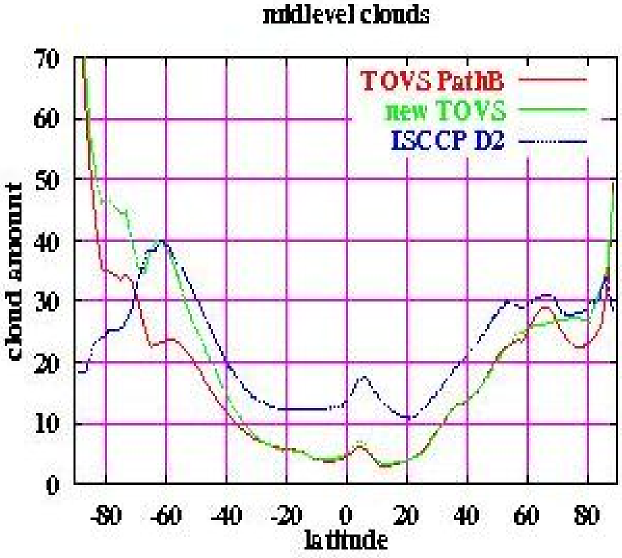
1979-2004: ***ERA-40*** « cleaned » radiosonde-TOVS data collocated,
clear sky determination

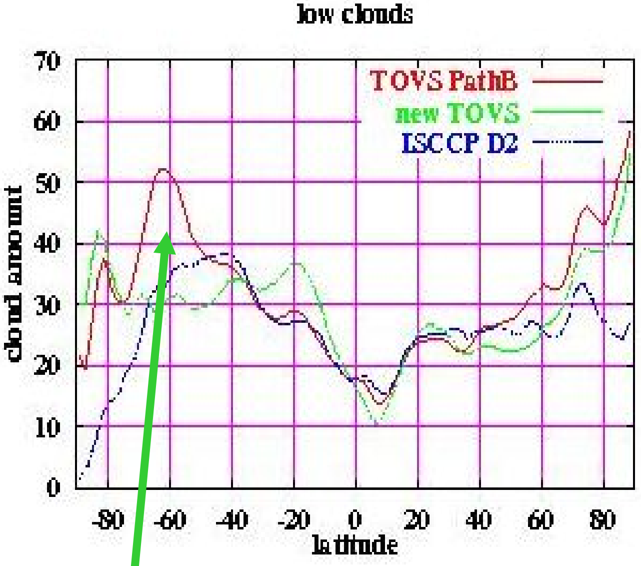
(radiosonde temperatures during day not corrected in stratosphere)

TOVS Reanalysis: 1 year of cloud data (1990)

preliminary







tropics: nearly no change

subtropics- midlat.: slightly more high clouds

SH midlat. ocean: up to 20% less low clouds (closer to ISCCP)

Determination of TOVS relative humidity (per layer)

- **TOVS Path-B precipitable water column: 300 - 100 hPa**

$$\mathbf{W} = \int_{p}^{p0} q_{s} \frac{dp}{g\rho}$$

=> rel. humidity per layer: $RH^{ice}(\Delta p) = g\rho\, W / \int q_{sat}^{ice}(p)dp$

1) 3I retrieved atmospheric T profile (30 levels) -> $e_{sat}^{ice}(T)$

$$\ln(e_{sat}) = \frac{a_1}{T} + a_2 + a_3 T + a_4 T^2 + a_5 \ln(T)$$ *(Sonntag, 1990)*

at 86, 106, 131, 162, 200, 223, 248, 276 and 307 hPa

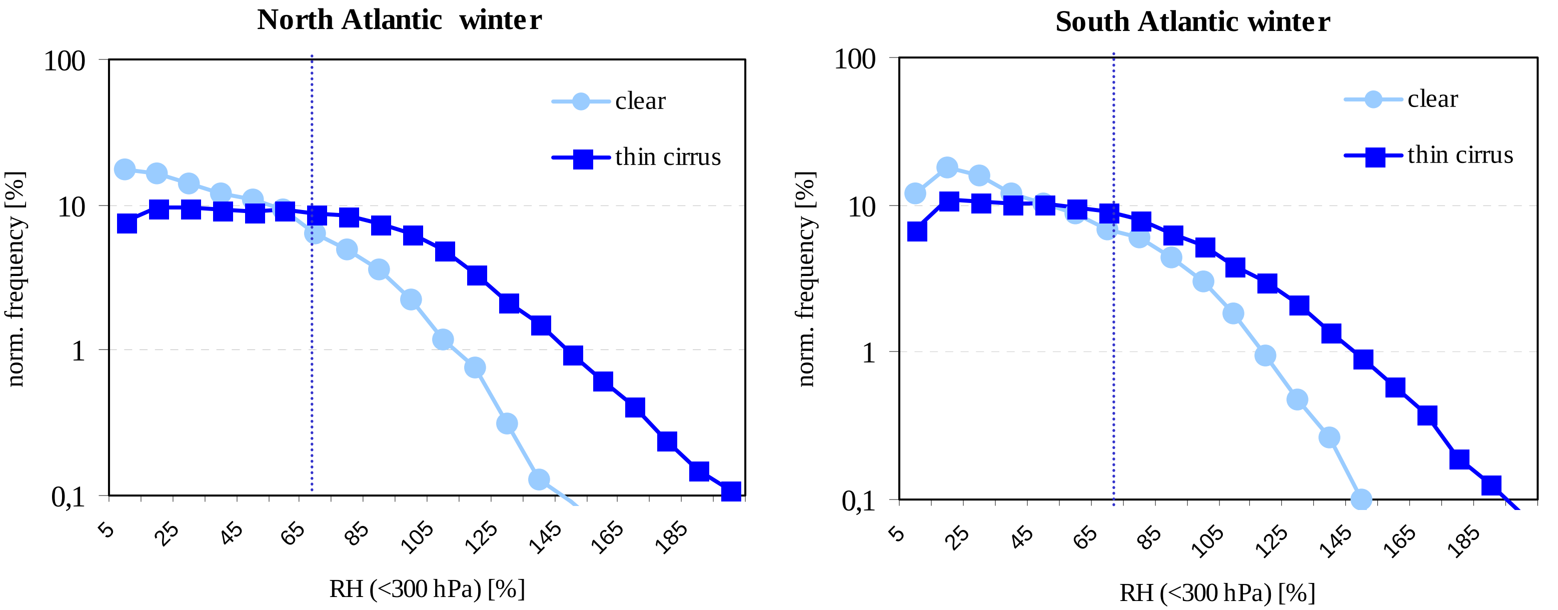
2) integrate q_{sat}^{ice} over column *(in steps of 1hPa)* **:**

$$\int q_{sat}^{ice}(p)dp = \sum 0.622 \frac{e_{sat}^{ice}(T(p))}{p - (1 - 0.622)e_{sat}^{ice}(T(p))}$$

Relative humidity distributions

in case of clear sky and thin cirrus ($N\varepsilon < 0.5$)

over 8 years

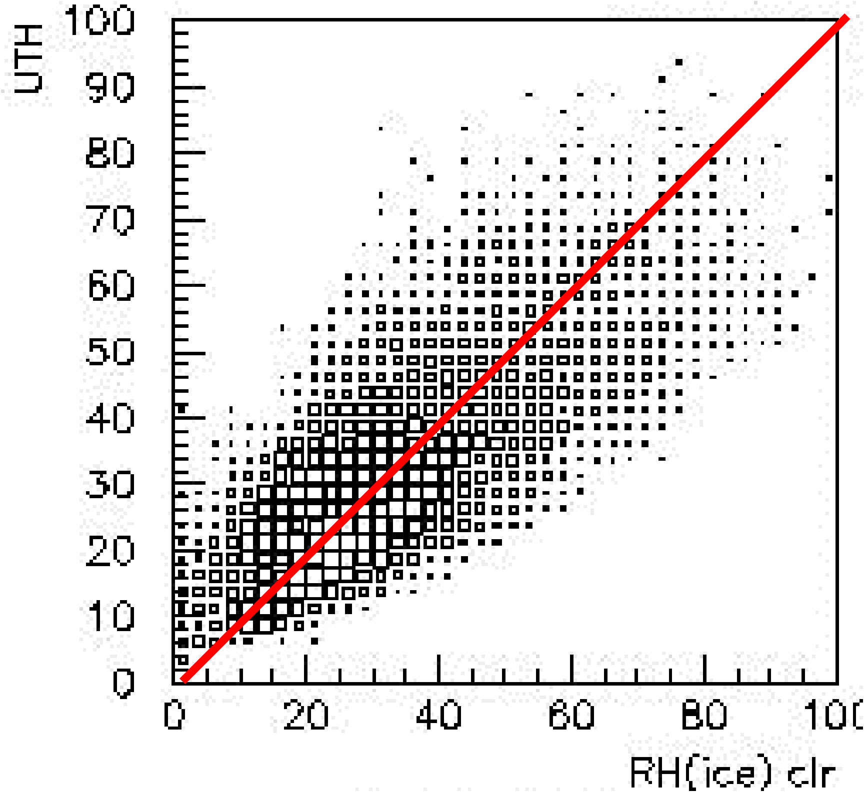


- ◆ Thin cirrus have broader RH distributions than clear sky
- ◆ However, clear sky can also be ice saturated *(in agreement with Gierens et al. 1999)*

3I relative humidity (300-500hPa) - UTH

in case of clear sky and thin cirrus

$$UTH = \frac{\exp(a_1 + a_2 T_{HIRS12})}{a_3 + a_4 T_{HIRS6}} \qquad (Bates)$$



Evolution of contrails from TOVS

C. Stubenrauch, U. Schumann

- **contrails: cold and moist ambient air, RH > U*(T)**

Schmidt, 1941
Schumann 1996

- **critical rel. humidity** TOVS: integrate over layer

$T_{l\max}=230.8K$ $e_{sat}^{liq}(T_{l\max})=20.6hPa$
Kerosen: $G = 1.5$

$$U^*(\Delta p) = \frac{\int\limits_{100-300hPa}[G\cdot(T-T_{l\max}) + e_{sat}^{liq}(T_{l\max})]dp}{\int\limits_{100-300hPa} e_{sat}^{liq}(T)dp}$$

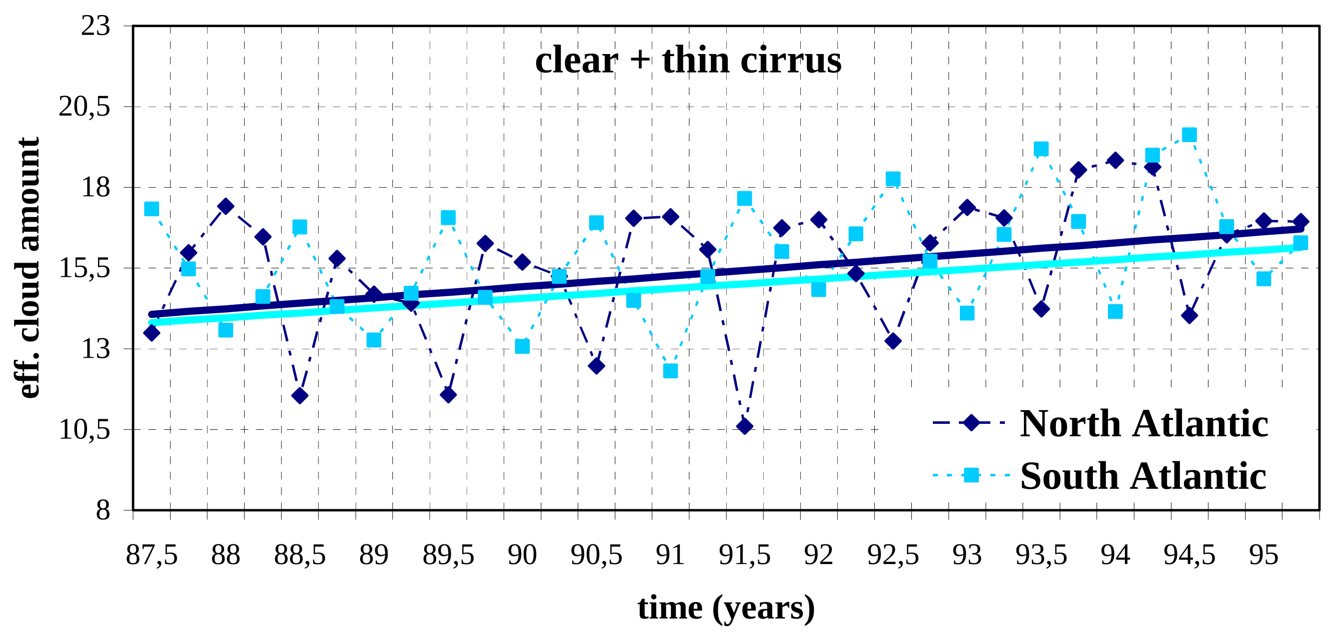
- *Sausen et al. 1997:* **potential contrail if $U_{ci} > RH > U^*U_{ci}$**

- **separate situations:** $RH^{ice}(\Delta p) > 0.7$ **cirrus**

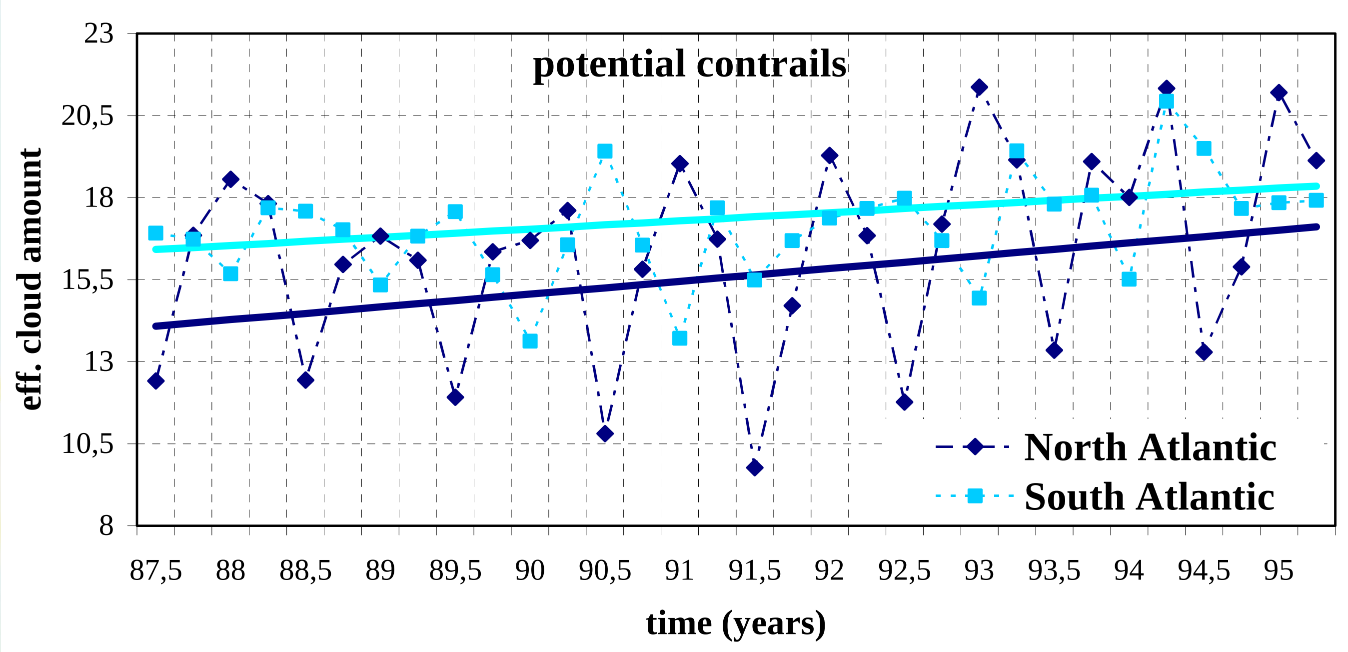
  $RH^{ice}(\Delta p) < 0.7$ & $RH^{liq}(\Delta p) > 0.4U^*(\Delta p)$ **potent. contrail**

  $RH^{ice}(\Delta p) < 0.7$ & $RH^{liq}(\Delta p) < 0.4U^*(\Delta p)$ **clear**

- **Difference in trends of effective high cloud amount between**
  situations of potential contrails – cirrus and
  situations of potential contrails – all



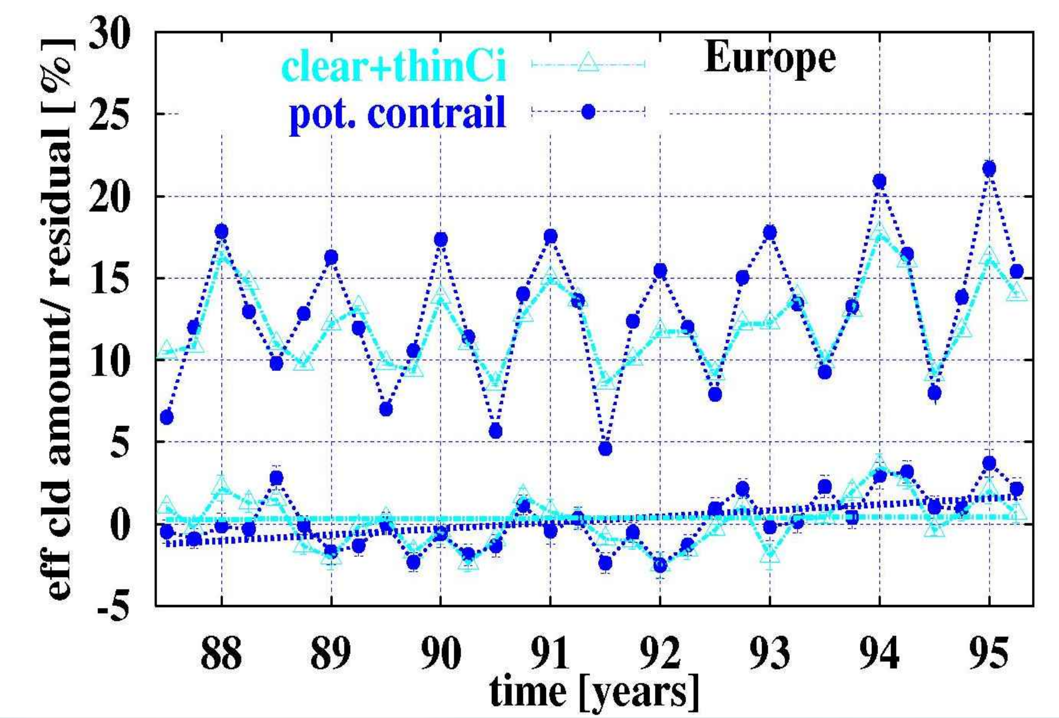
increase of thin Ci in both hemispheres



stronger increase of Ci related to contrails in NH

Cirrus: $RH_{ice} > 70\%$

Pot. Contr.: $RH_{wat} > 0.4\ U^*_{wat}$



ECA increase per decade for potential contrail situations

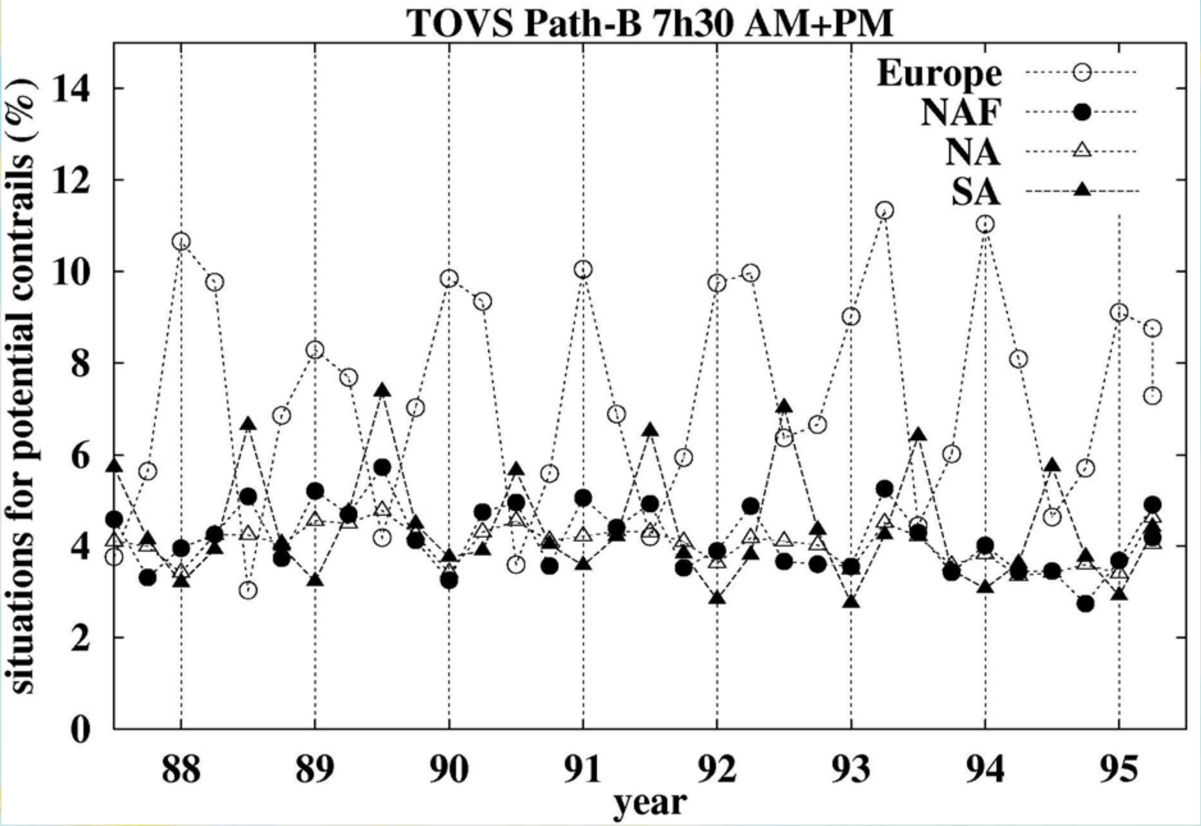
ECA trend difference (%/decade) between potential contrail and cirrus / all situations

region/season	Europe	NAF	NA	SA
all pc-all/pc-ci	**2.8 / 3.5**	**1.6 / 4.7**	**0.6/ -0.2**	**-1.6/ -0.9**

uncertainty estimates 1.5%/decade (from threshold variations)

Stubenrauch + Schumann, GRL 2005 in revision

However:
Occurrence of pot. contrail situations is small: 5 – 10%



Overall effect: over Europe ~0.19% - 0.25% per decade

over NAF ~0.08% - 0.24% per decade

Satellite observations:

- unique possibility to study cloud properties over long period

  30% high clouds, stable within 2% over globe

- **seasonal and diurnal variabilities in high clouds:**

  - strongest seasonal cycles over land in subtropics *(ITCZ shift)*
  - strongest diurnal cycles over land in tropics & summer
  - convection in evening, cirrus during night, thin cirrus in afternoon

- **TOVS reanalysis** : understand small changes in summer midlat. cloud properties

- **Contrail analysis:**

  only by extracting situations of potential contrails

  -> positive trend of εN in regions of high air traffic

  in general small: ~0.2% per decade