Survey of cirrus and atmospheric properties from TOVS Path-B

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Beijing May 2005  ITWG 14
♦ 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$_2$O, CO$_2$ absorption bands

- atmospheric temperature (9 layers, $\geq 10$hPa), water vapor (5 layers, $\geq 100$hPa)
- 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 Inversion** (Chédin, Scott 1985)

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

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

*Thermodynamic Initial Guess Retrieval*
# Average cloud properties

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

<table>
<thead>
<tr>
<th>Cloud type amounts (%)</th>
<th>global</th>
<th>ocean</th>
<th>land</th>
</tr>
</thead>
<tbody>
<tr>
<td>all</td>
<td>73</td>
<td>65</td>
<td>74</td>
</tr>
<tr>
<td>Deep convection</td>
<td>2.4</td>
<td>2.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Cirrus</td>
<td>27.3</td>
<td>19.1</td>
<td>26.9</td>
</tr>
<tr>
<td>Mid-level</td>
<td>12.1</td>
<td>18.5</td>
<td>10.3</td>
</tr>
<tr>
<td>Low-level</td>
<td>30.9</td>
<td>26.7</td>
<td>35.1</td>
</tr>
</tbody>
</table>

~ 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

<table>
<thead>
<tr>
<th>Cloud type amounts (%)</th>
<th>NH midlat.</th>
<th>tropics</th>
<th>SH midlat.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep convection</td>
<td>3.0</td>
<td>3.3</td>
<td>2.5</td>
</tr>
<tr>
<td>Cirrus</td>
<td>24.7</td>
<td>20.3</td>
<td>44.8</td>
</tr>
</tbody>
</table>

- 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

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

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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)

- 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

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diurnal cycle of high cloud type frequencies

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

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

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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

\[ W = \int_{p}^{p_0} q_s \frac{dp}{g \rho} \]

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

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

\[
\ln(e_{\text{sat}}) = \frac{a_1}{T} + a_2 + a_3 T + a_4 T^2 + a_5 \ln(T) \quad (\text{Sonntag, 1990})
\]

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

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

\[
\int q_{\text{sat}}^{\text{ice}}(p)dp = \sum 0.622 \frac{e_{\text{sat}}^{\text{ice}}(T(p))}{p - (1 - 0.622)e_{\text{sat}}^{\text{ice}}(T(p))}
\]
Relative humidity distributions

in case of clear sky and thin cirrus ($Ne < 0.5$)

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

\[ UTH = \frac{\exp(a_1 + a_2 T_{HIRS12})}{a_3 + a_4 T_{HIRS6}} \]  

(Bates)
Evolution of contrails from TOVS

C. Stubenrauch, U. Schumann
♦ contrails: cold and moist ambient air, \( RH > U^*(T) \)

♦ critical rel. humidity  
TOVS: integrate over layer  
\[ U^*(\Delta p) = \frac{\int [G \cdot (T - T_{lmax}) + e_{liq}^{\text{sat}}(T_{lmax})]dp}{\int e_{liq}^{\text{sat}}(T)dp} \]

\( T_{lmax} = 230.8K \) \( e_{liq}^{\text{sat}}(T_{lmax}) = 20.6hPa \)
Kerosen: \( G = 1.5 \)

♦ Sausen et al. 1997: potential contrail if \( U_{ci} > RH > U^*U_{ci} \)

♦ separate situations:  
\( RH_{\text{ice}}(\Delta p) > 0.7 \)  
cirrus
\( RH_{\text{ice}}(\Delta p) < 0.7 \) & \( RH_{\text{liq}}(\Delta p) > 0.4U^*(\Delta p) \)  
potent. contrail
\( RH_{\text{ice}}(\Delta p) < 0.7 \) & \( RH_{\text{liq}}(\Delta p) < 0.4U^*(\Delta p) \)  
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 trend difference (%/decade) between potential contrail and cirrus / all situations

<table>
<thead>
<tr>
<th>region/season</th>
<th>Europe</th>
<th>NAF</th>
<th>NA</th>
<th>SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>all pc-all/pc-ci</td>
<td>2.8 / 3.5</td>
<td>1.6 / 4.7</td>
<td>0.6/ -0.2</td>
<td>-1.6/ -0.9</td>
</tr>
</tbody>
</table>

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