Leibniz Institute for
Tropospheric Research

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Aerosol particles in the UT/LS: Results from the CARIBIC project

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Airborne Aerosol and Cloud Science

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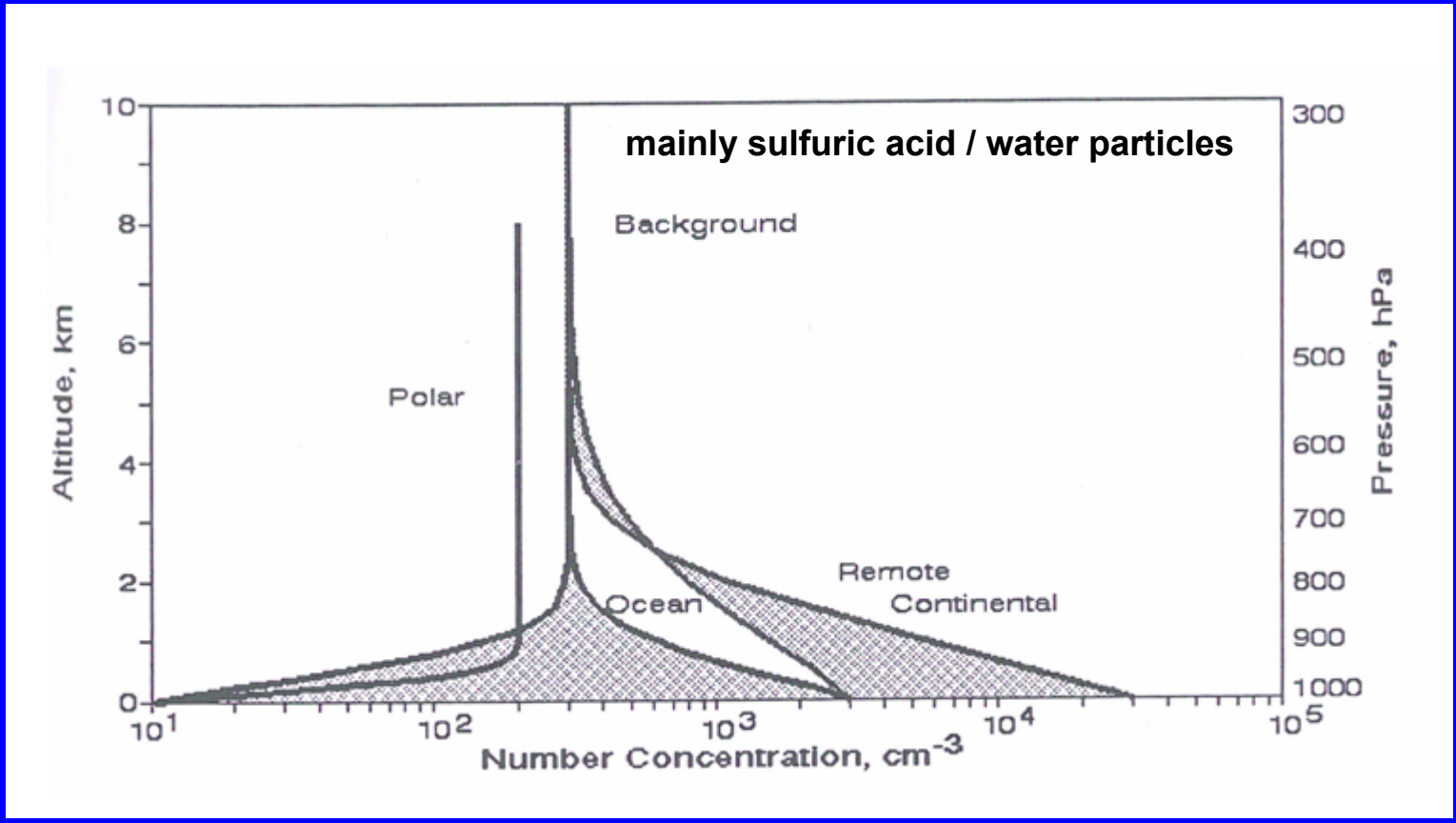
Contents

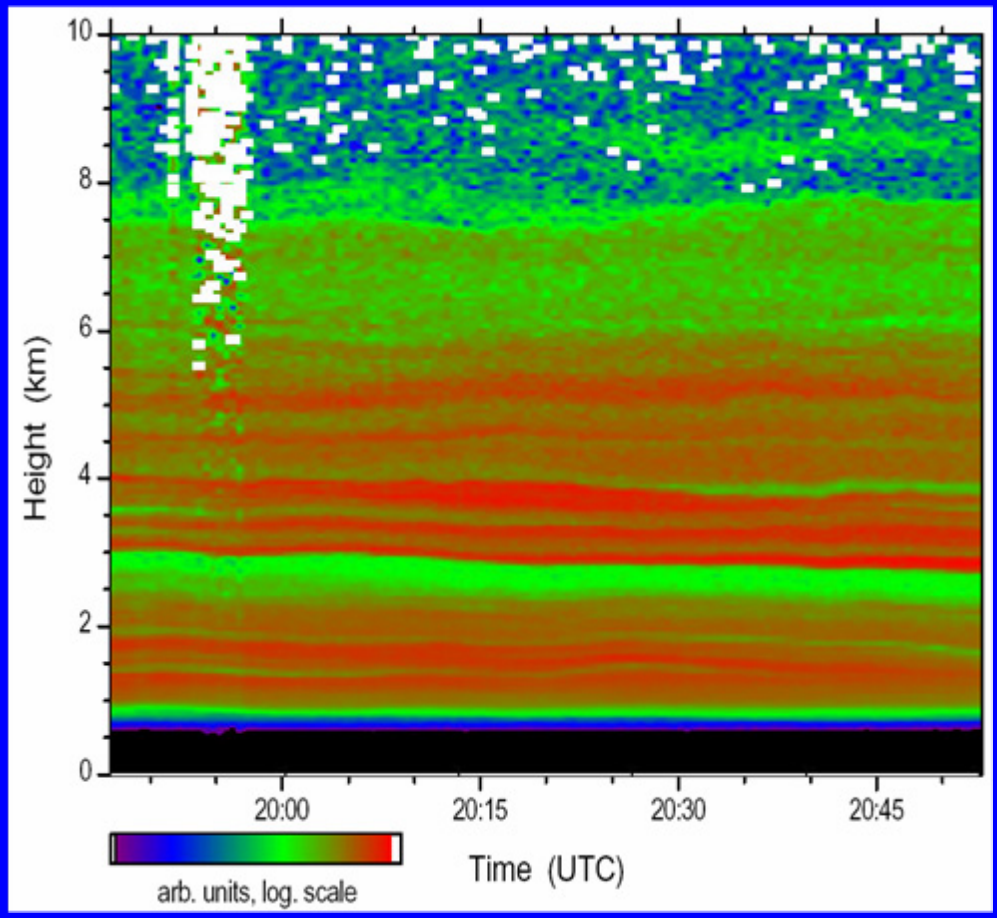
- Introduction
- CARIBIC project
- CARIBIC system
- Results
  - spatial particle distributions
  - elemental composition
  - particle sources
  - model comparison
  - aerosol-cloud interaction

Little knowledge about aerosol particles in the free troposphere before ~1980



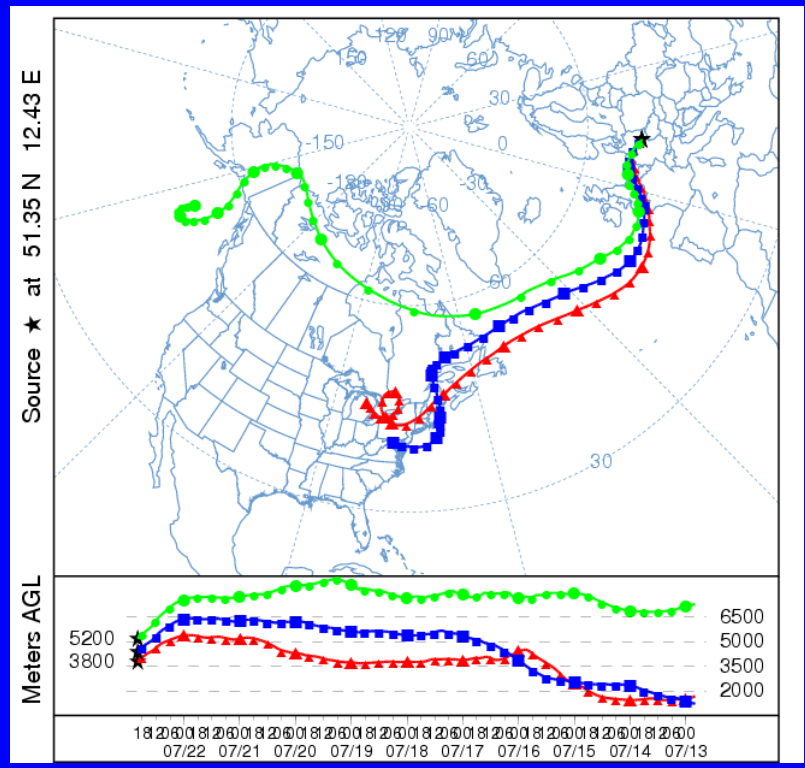
"Aerosol model" 1992

Reality!



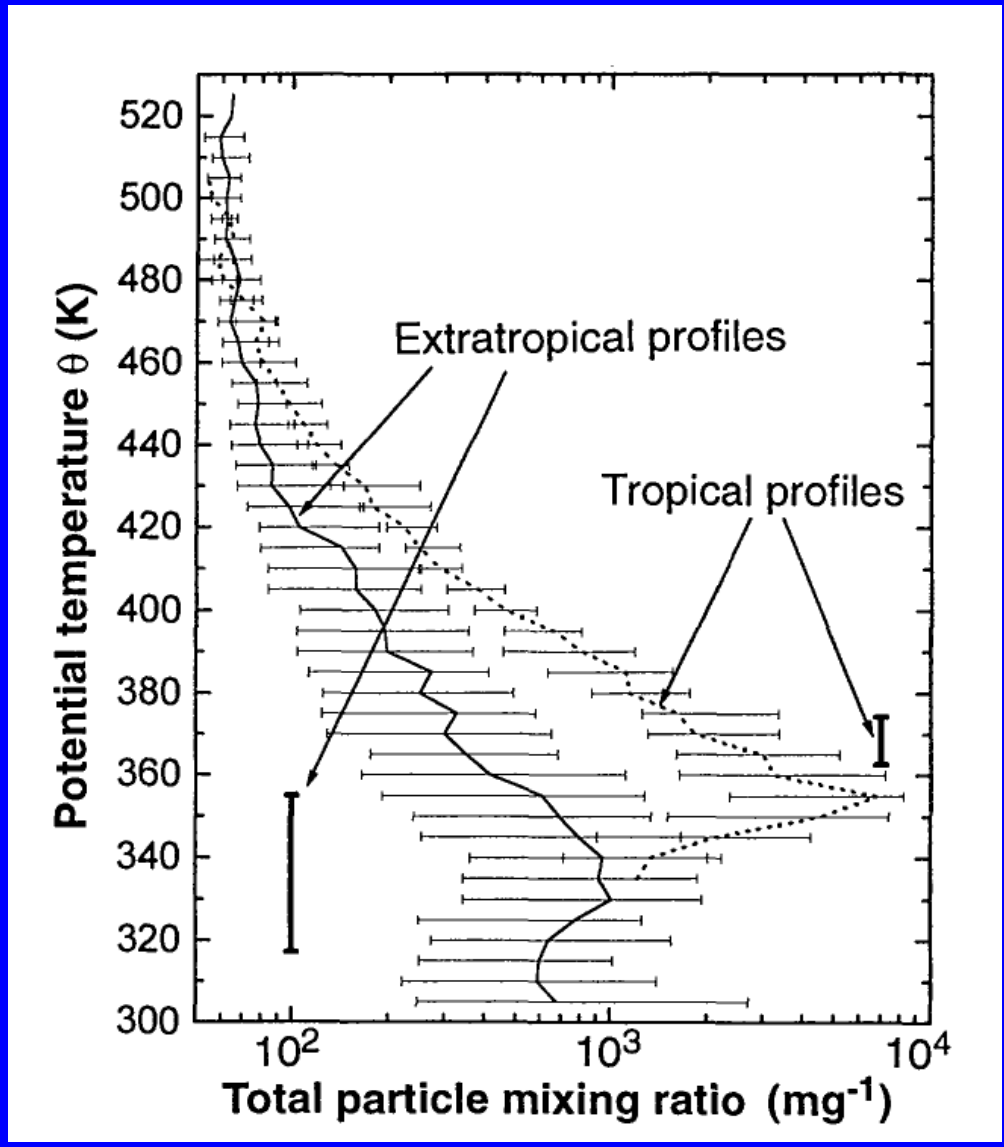
LIDAR signal, 1064 nm, Leipzig, July 2004

HYSPLIT



Ansmann, pers. com., 2007

Tropopause Maximum



Brock et al., Science, 1995

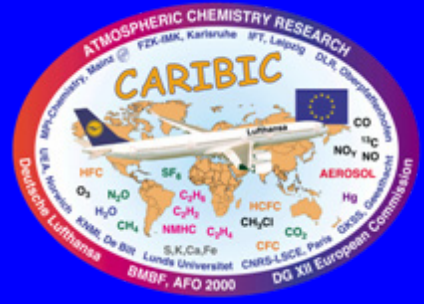
Why aerosol particles in the upper troposphere and lower stratosphere (UT/LS)?

- IPCC 2007: level of scientific understanding for aerosol particles is still low
- UT/LS: nearly no continuous measurements
- Troposphere-to-Stratosphere Transport (TST)
- Influence on heterogeneous chemistry
- Influence on cloud properties (indirect forcing)

- How is the spatial and temporal distribution of submicrometer particles in the UT/LS region?
- Which particle source processes can be identified?
- What is the relative contribution of individual source processes?
- Do atmospheric models reproduce observed structures?
- Is it possible to explain these structures using atmospheric models?

CARIBIC project

(Civil **A**ircraft for **R**egular **I**nvestigation of the atmosphere **B**ased on an **I**nstrument **C**ontainer)

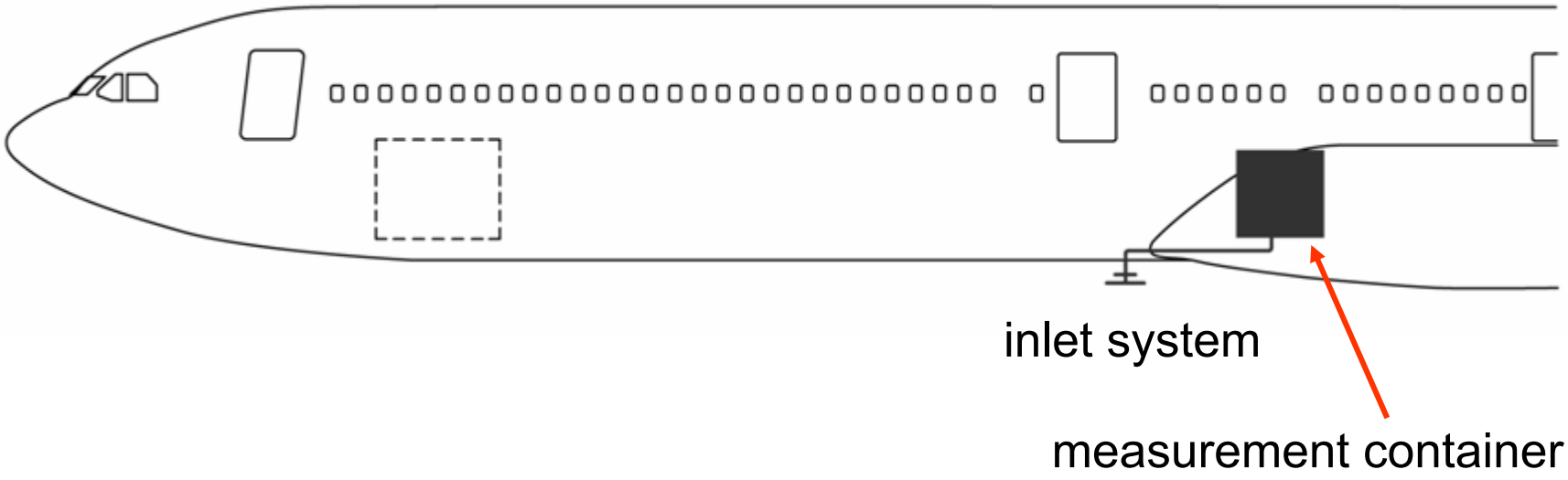


- Goal: Long-range and long-term measurements of aerosol particles and trace gases in the UT/LS
- Method: Measurement instruments are mounted in an air-freight container, which is flown regularly onboard a commercial aircraft
- History:
  - Start: 1994
  - Phase I: Nov. 1997 - Apr. 2002 LTU
  - Phase II: May 2005 - 2015+ LH

- Advantages:
  - regular flights (1-2 per month)
  - long-term measurements (> 10 years)
  - large payload $\Rightarrow$ > 60 components are measured
  - intercontinental flights (~10.000 km per flight)
  - comparatively low-costs (~ 1/10)
- Consortium:
  - 11 research institutes
  - 6 European countries
  - Lufthansa AG
- System:
  - long-range aircraft
  - inlet system
  - measurement container

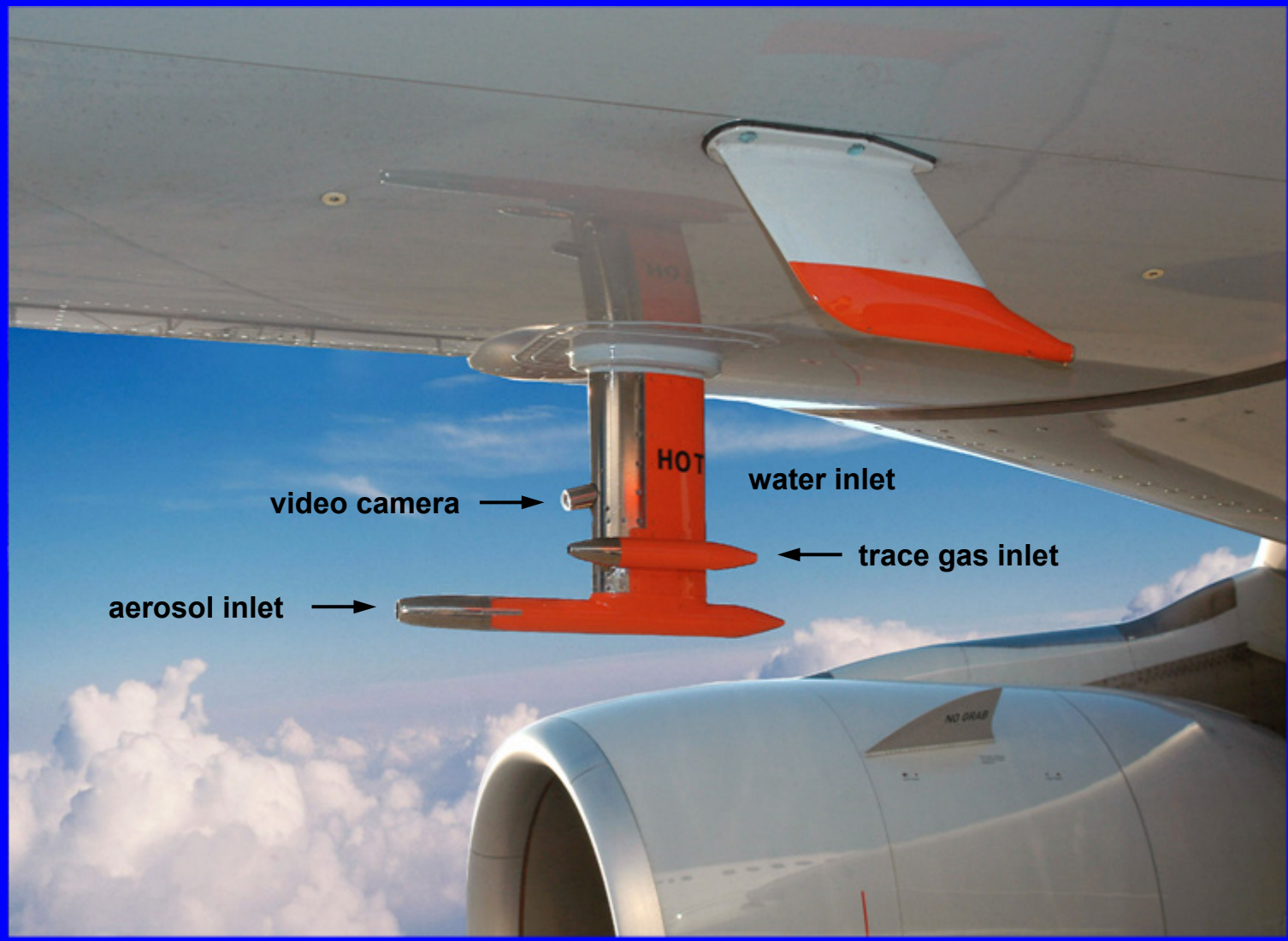
CARIBIC System

CARIBIC aircraft: Airbus A340-600




A340-600 LH D-AIHE
Lufthansa

CARIBIC Inlet



CARIBIC Container

Cockpit Panel

18 measurement instruments

1.5 t

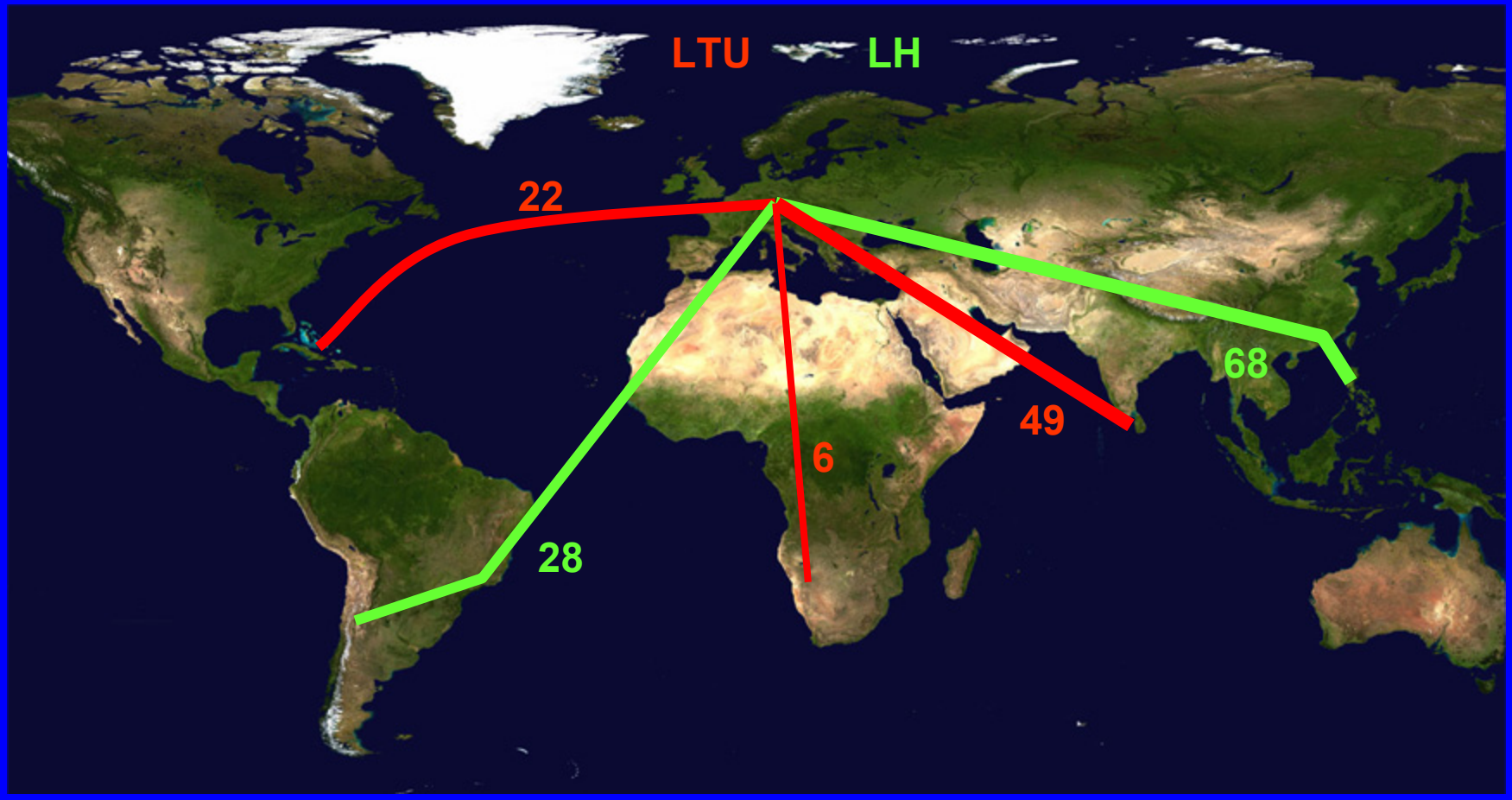
- **Condensation Particle Counters (3 CPCs)**
  - integral particle number concentration (2 s)
  - 4, 12, 18 nm < diameter < ~ 2000 nm (N_4, N_{12}, N_{18})
  - N_{12} ≈ Aitken mode particles
  - $N_{4\text{-}12} = N_4 - N_{12}$ ≈ Nucleation mode or ultrafine particles

- **Optical Particle Counter (OPC)**
  - particle size distribution (~ 1 min)
  - 150 nm < diameter < ~ 3000 nm (N_{150})

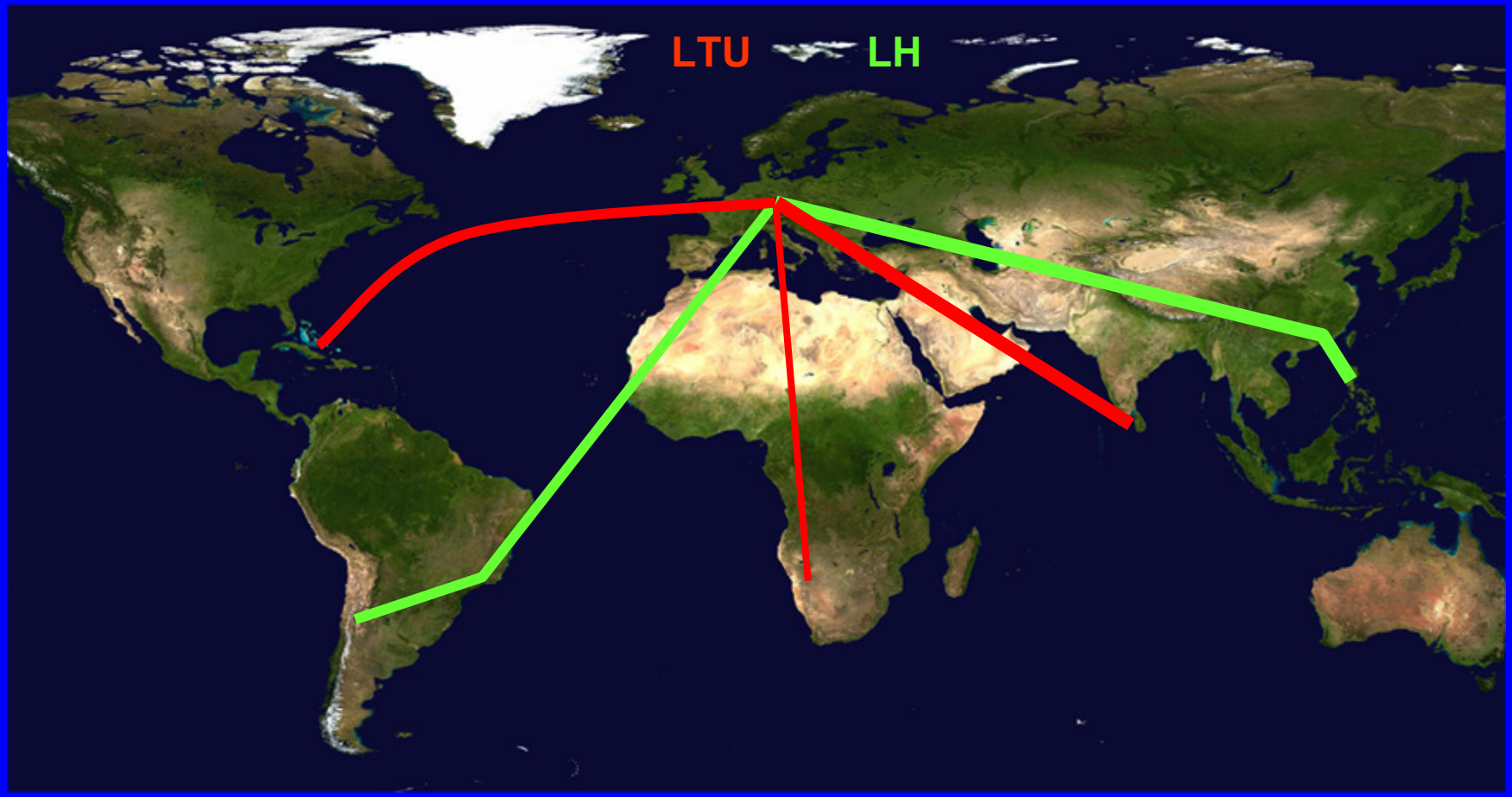
- **Particle Sampler (Bengt Martinsson, Lund University)**
  - 16 parallel impactors
  - 0.1 µm < diameter < 2.0 µm
  - time resolution 1.5 and 10 h
  - elemental particle composition using
    PIXE (Particle-Induced X-ray Emission)
    TEM (Transmission Electron Microscopy)
    PESA (Proton Elastic Scattering Analysis)

- CARIBIC ≈ submicrometer particles

Results

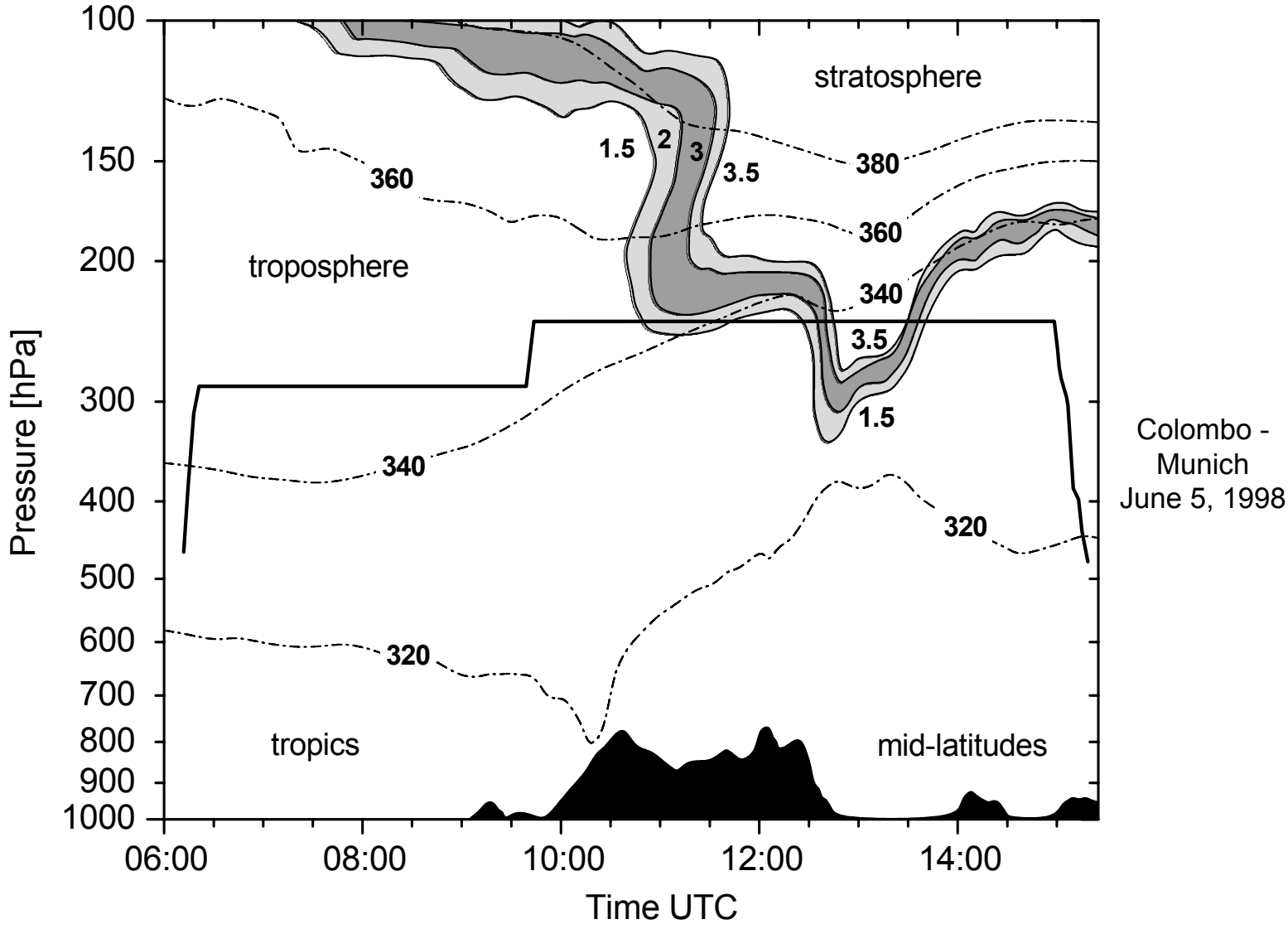


Caribbean South America Africa India South-East Asia

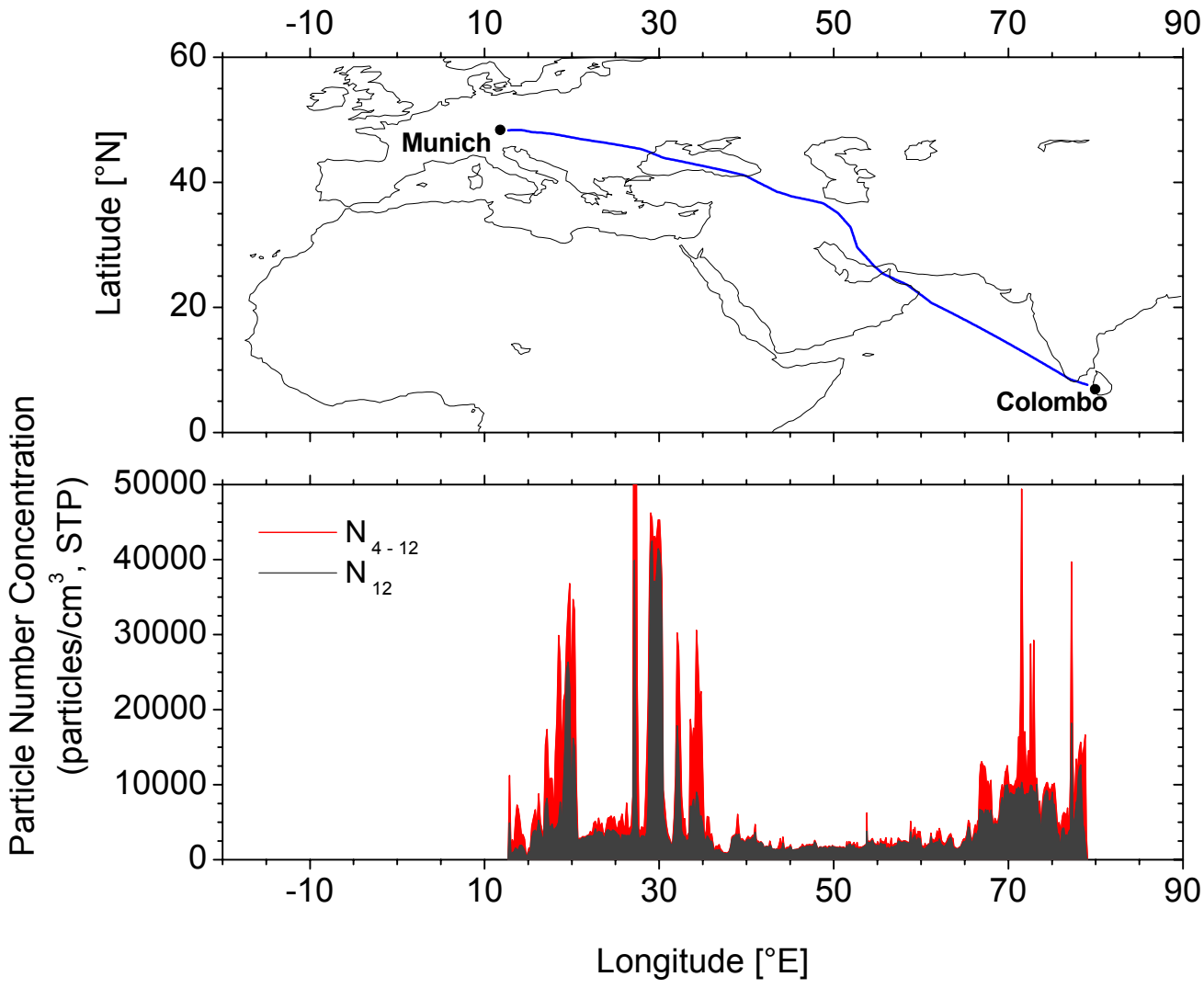


- 173 flights
- 27 times around the globe
- > 6 million data points
- > 600 particle samples

Typical Flight Track

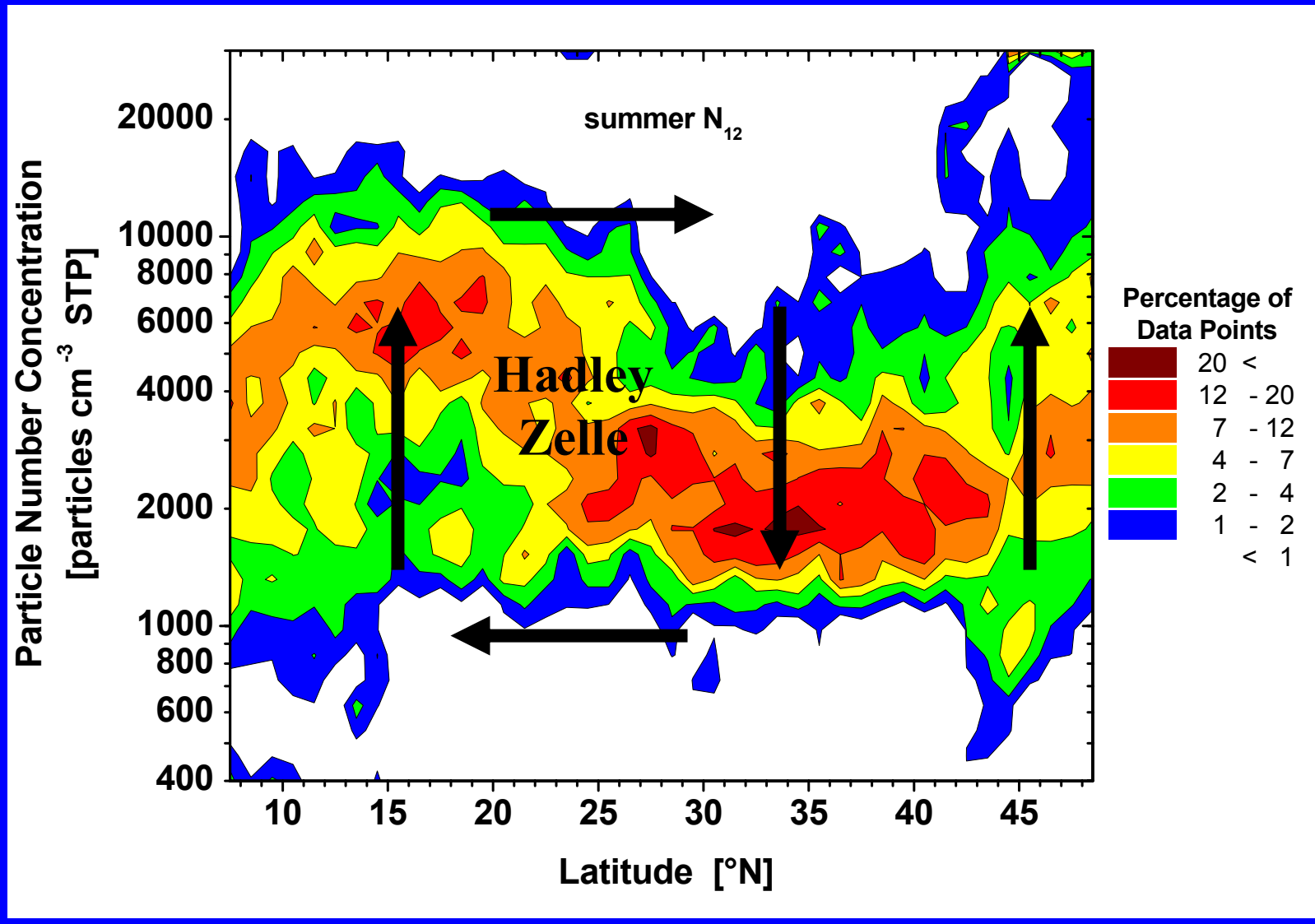


Typical Particle Distribution



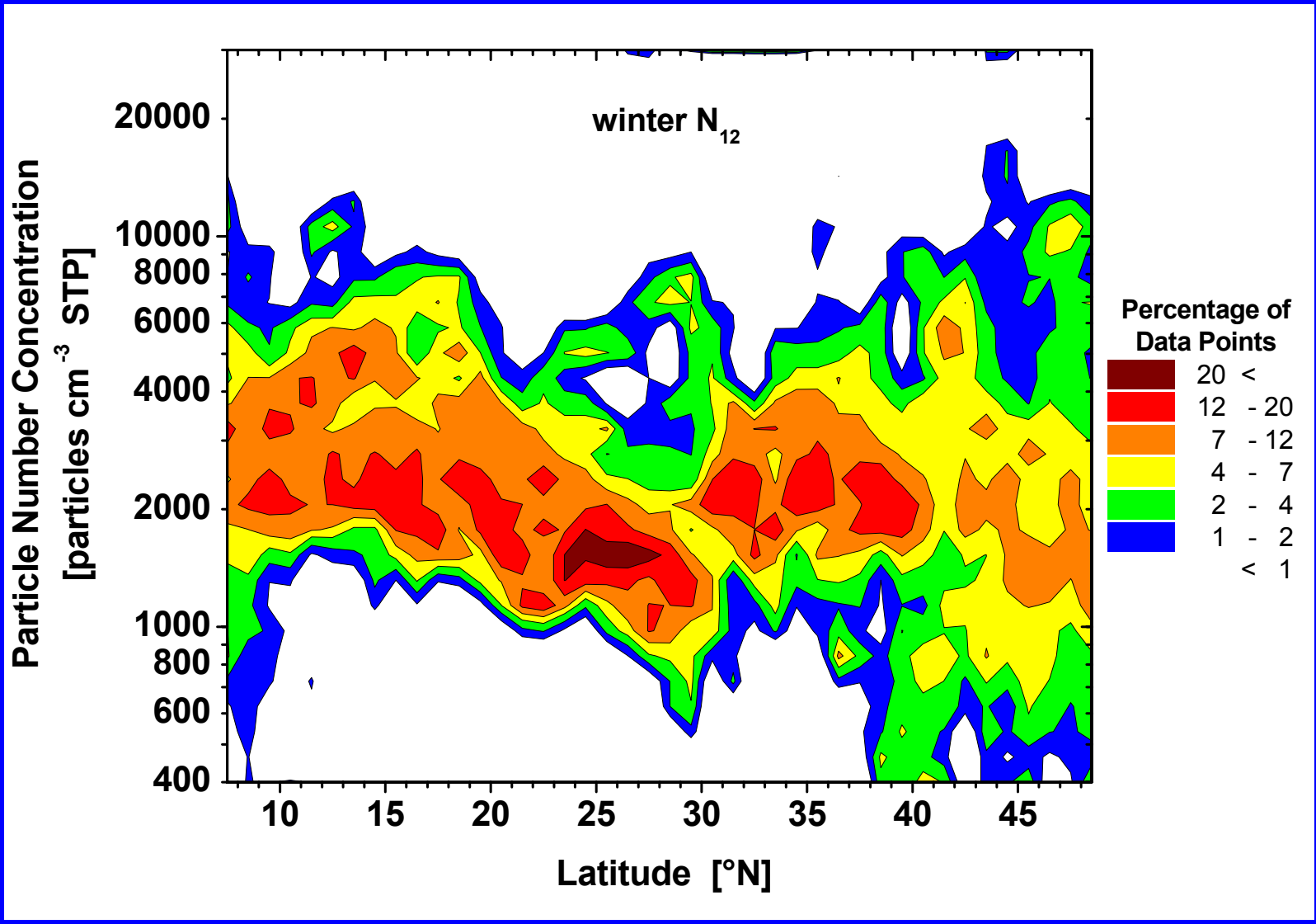
Colombo - Munich
June 5, 1998

Aitken Mode Probability Distribution



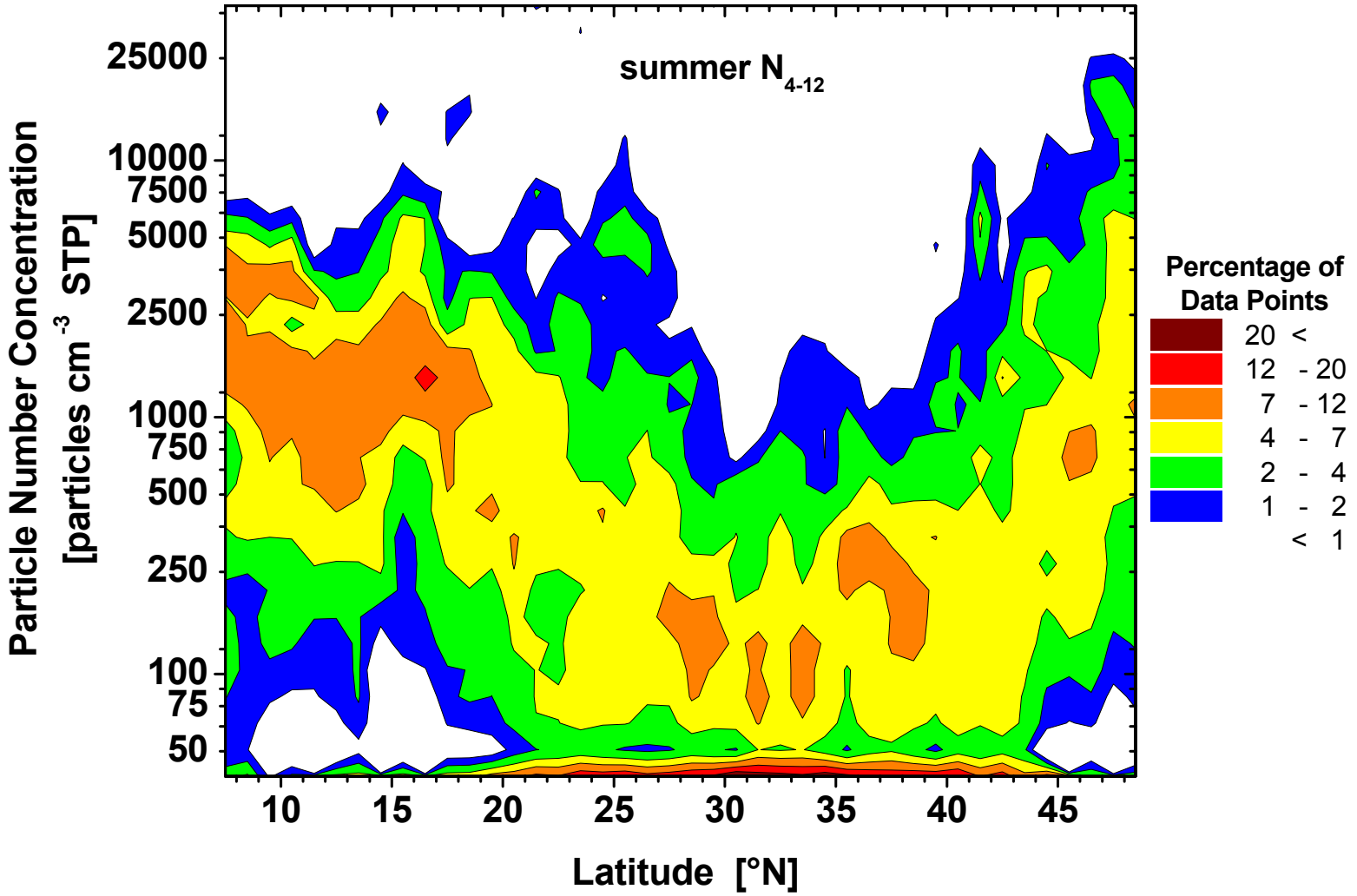
Hermann et al., JGR, 2003

Aitken Mode Probability Distribution



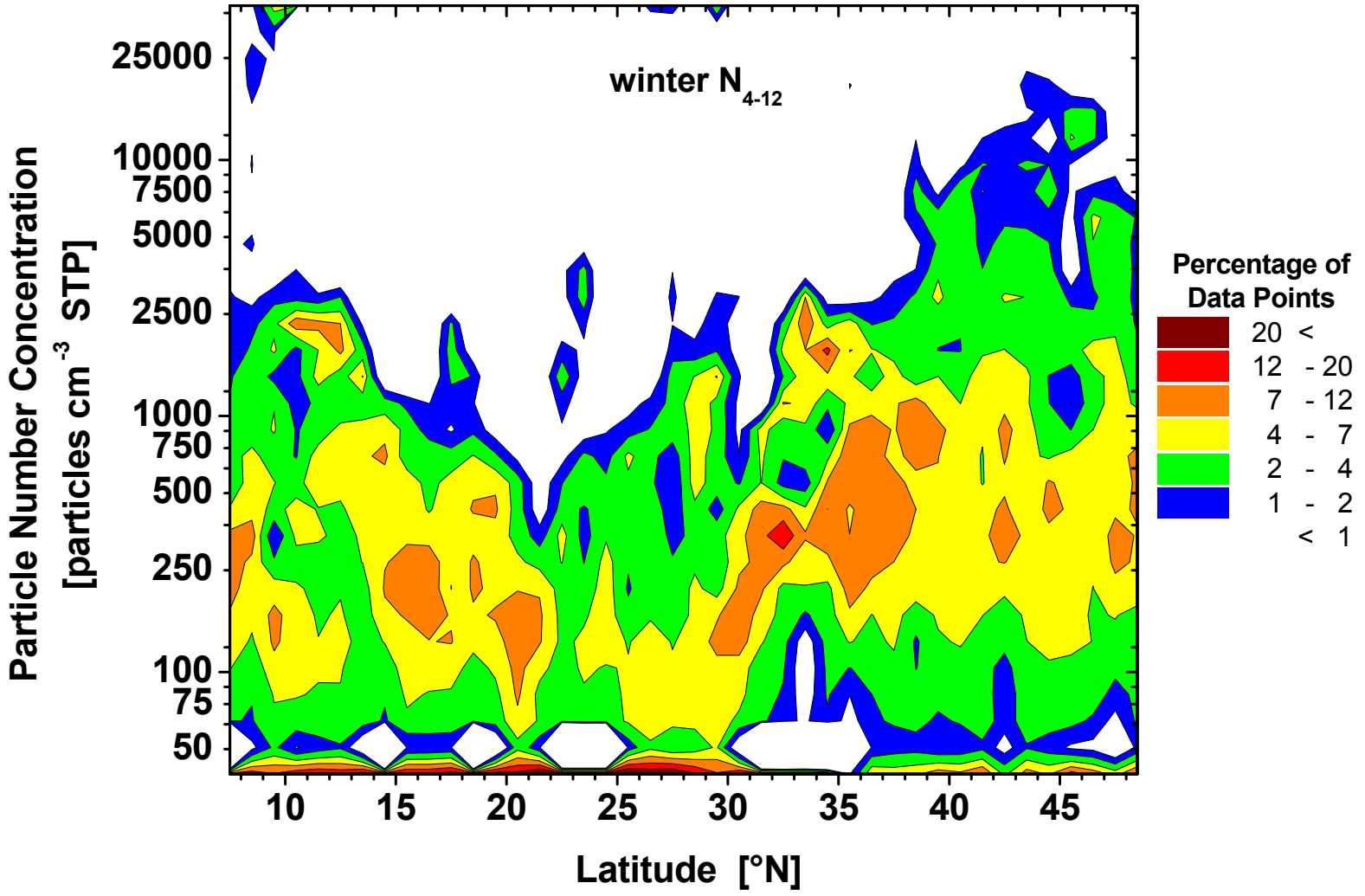
Hermann et al., JGR, 2003

Nucleation Mode Probability Distribution



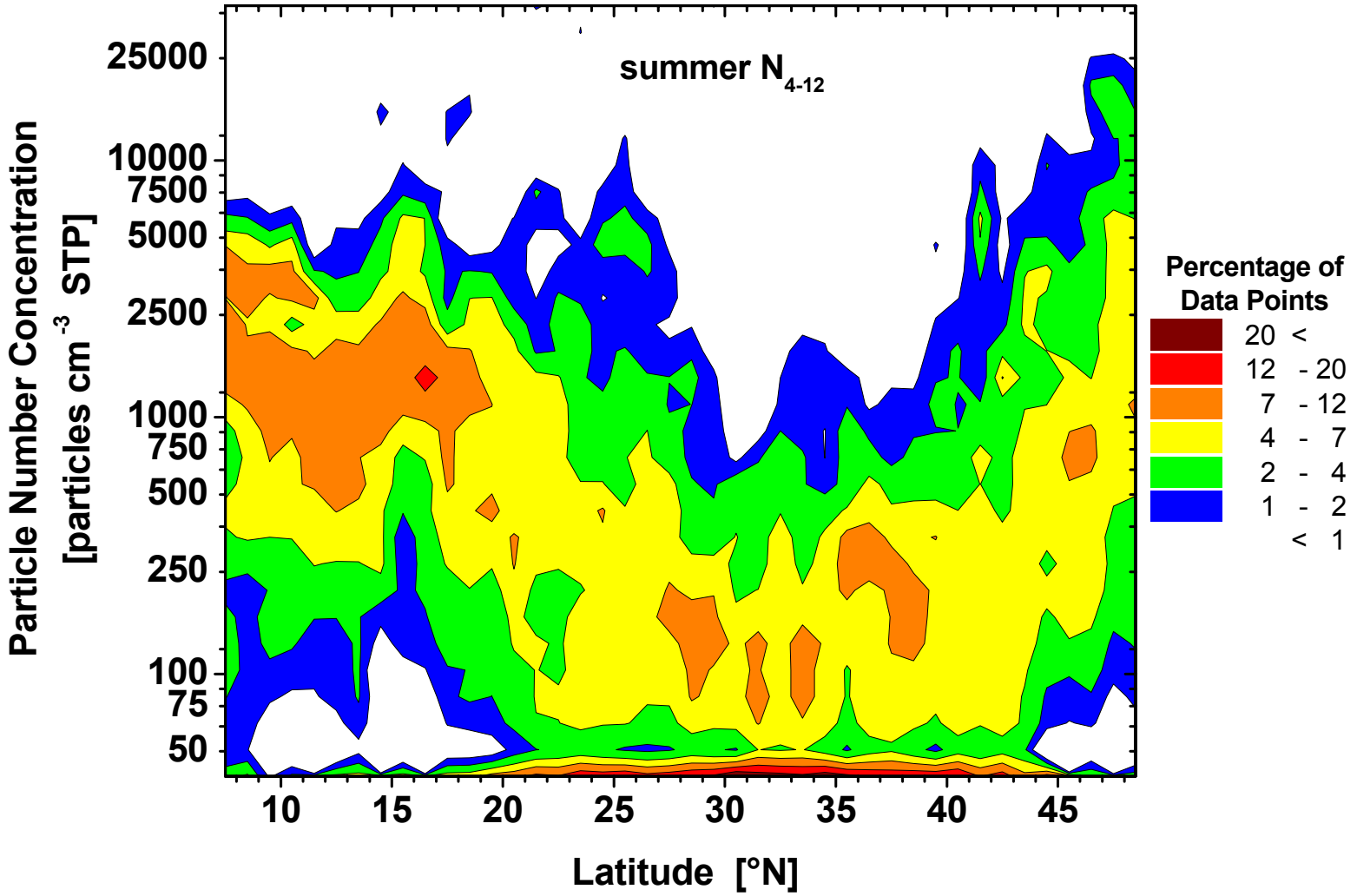
Hermann et al., JGR, 2003

Nucleation Mode Probability Distribution

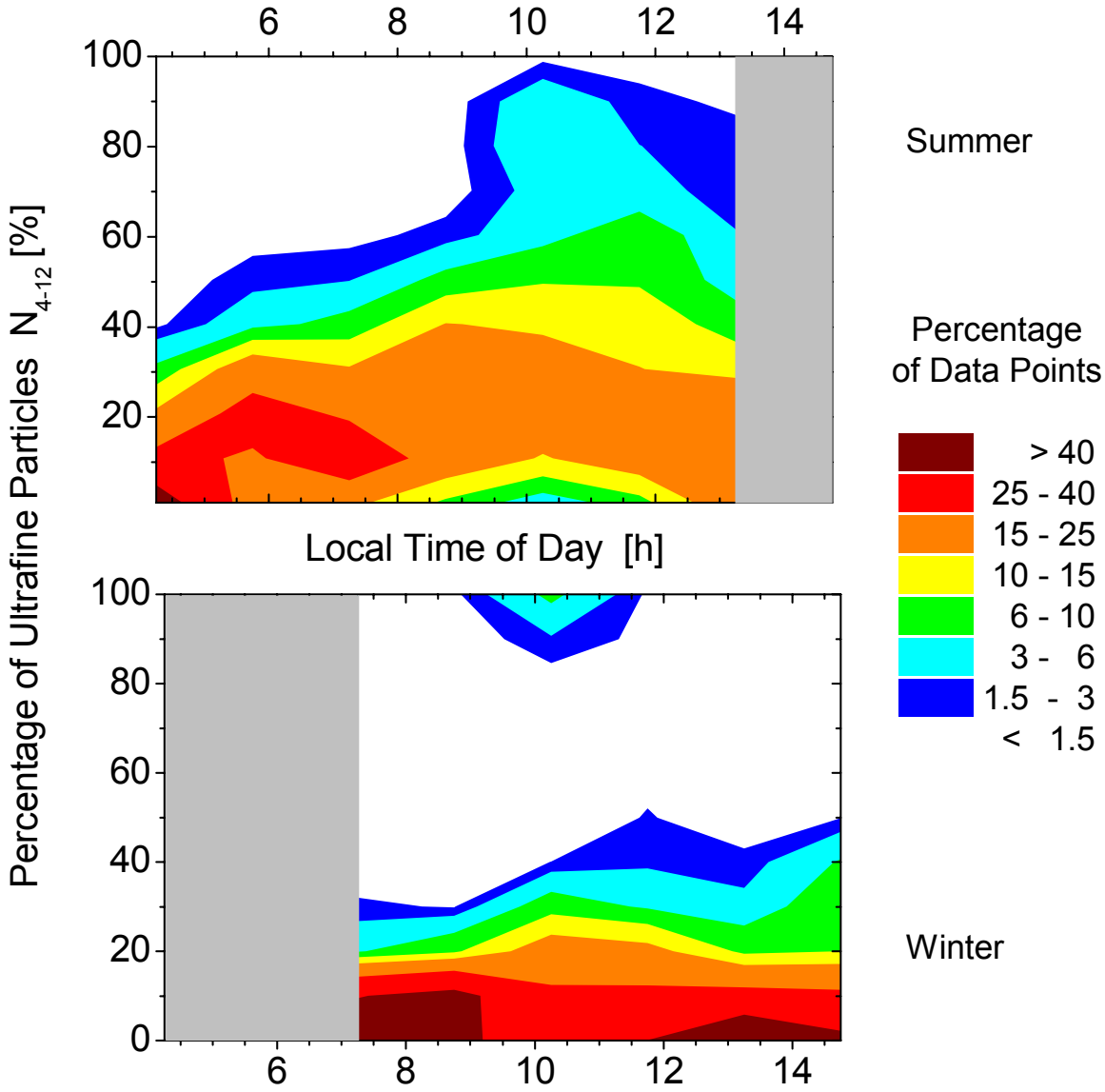


Hermann et al., JGR, 2003

Nucleation Mode Probability Distribution

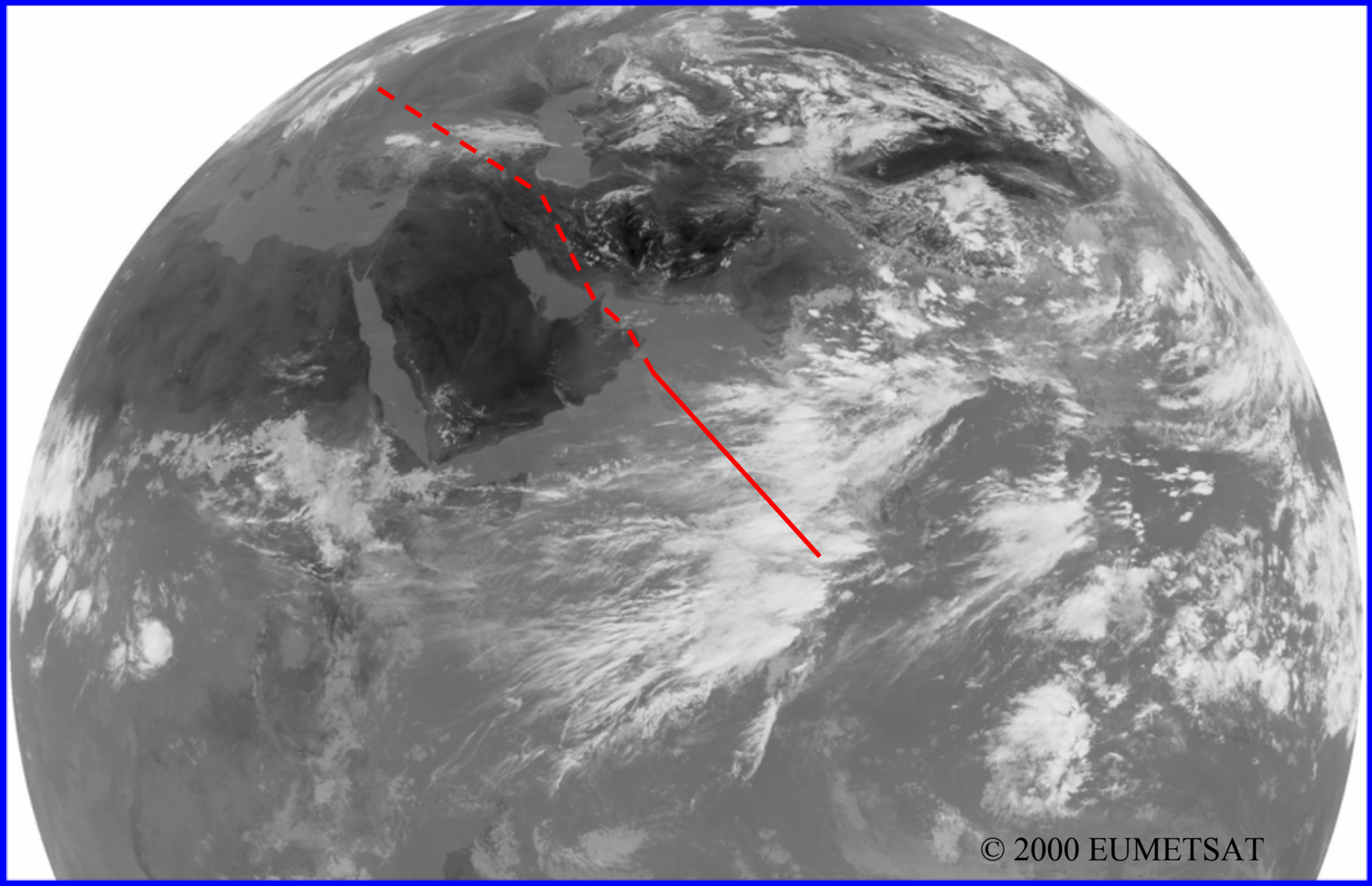


Hermann et al., JGR, 2003

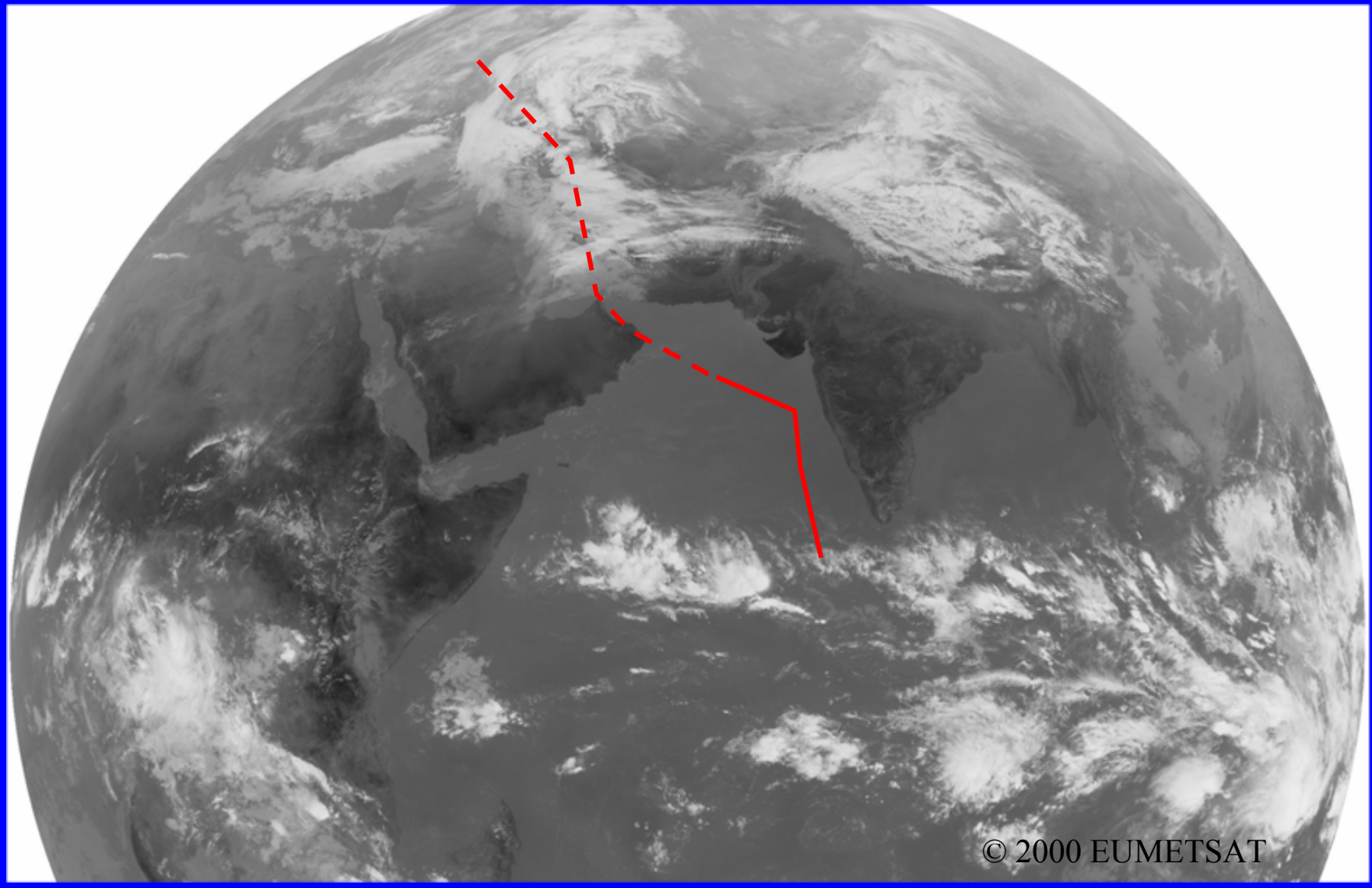


Hermann et al., JGR, 2003

Typical Summer Flight (07.07.1999)

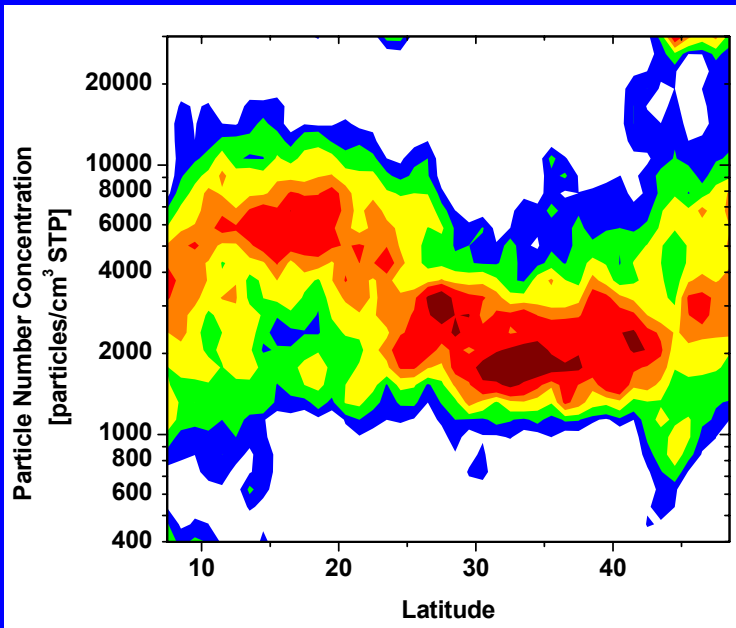


Typical Winter Flight (19.01.2000)



Particle Formation

Aitken Mode Particle Distributions



Indian

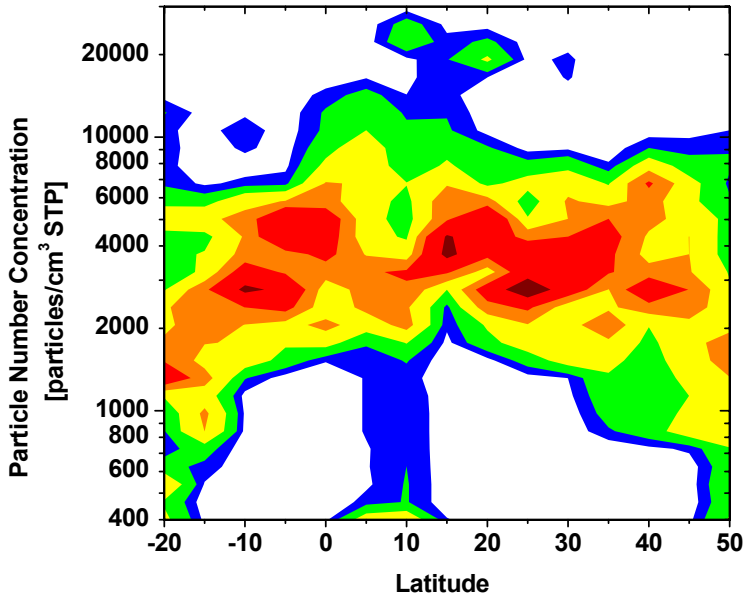
Boreal Summer

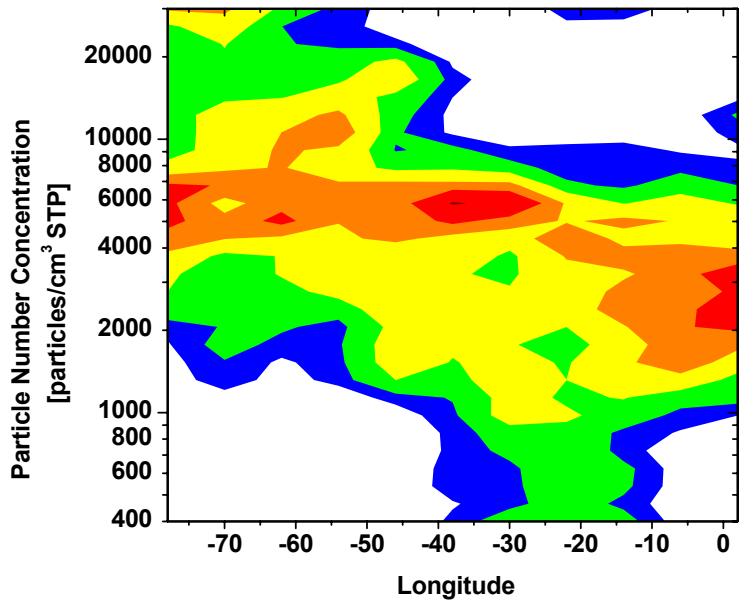
Percentage of data points

16 <
10 < 16
7 < 10
4 < 7
2 < 4
1 < 2

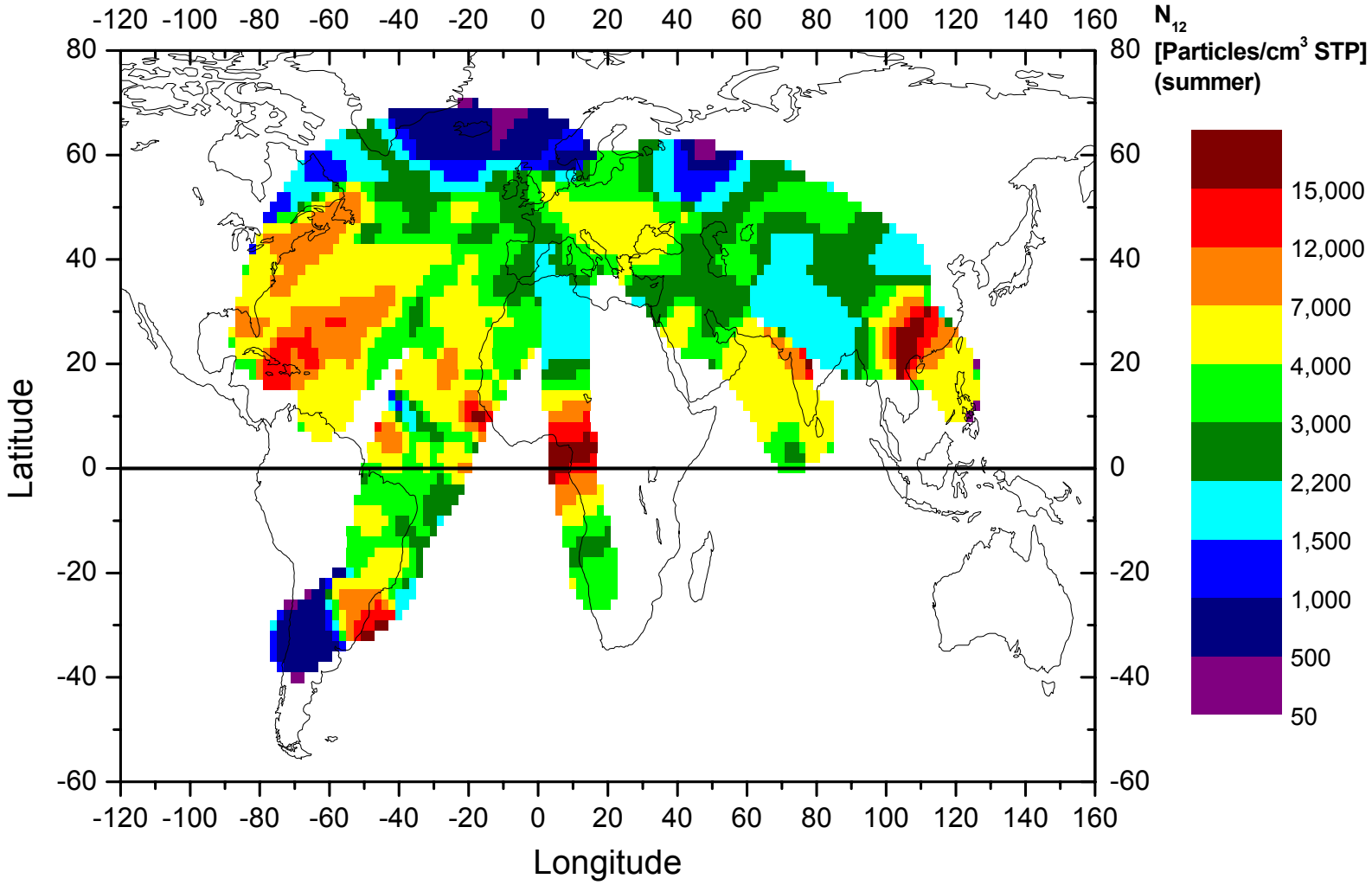
South America

Caribbean





Aitken Mode Particle Distributions



Hermann, 2008, preliminary data

PIXE: Elemental Composition

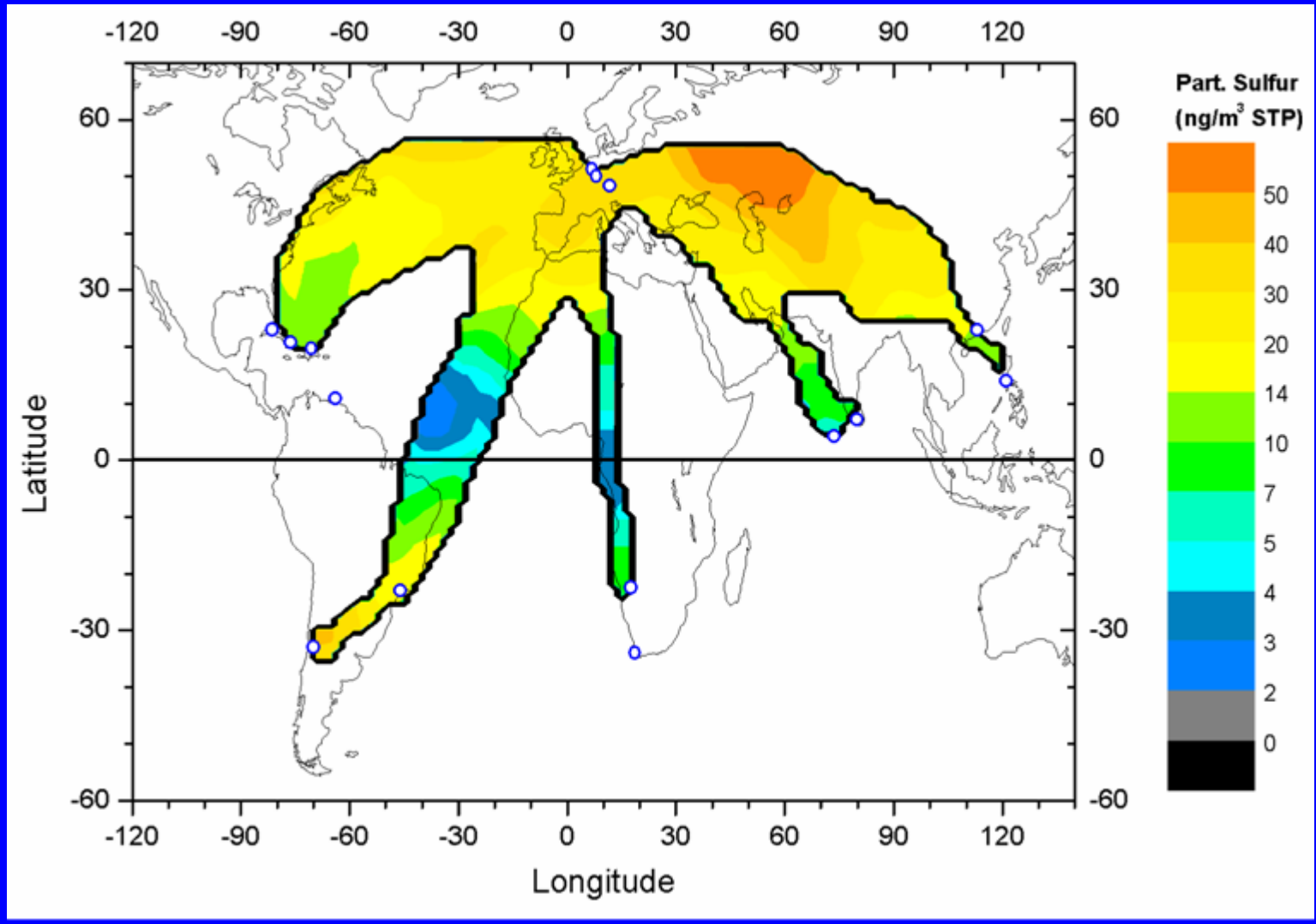
Element	Al	S	Cl	K	Ca	Ti
Mean Concentration (ng m^{-3} STP)	< 2.5	16 (100%)	< 0.33	0.31 (70%)	0.28	0.034

Element	V	Cr	Mn	Fe	Ni	Cu
Mean Concentration (ng m^{-3} STP)	< 0.010	< 0.018	< 0.0086	0.26 (57%)	< 0.016	< 0.076

Element	Zn	Ga	Ge	As	Se	Br
Mean Concentration (ng m^{-3} STP)	< 0.19	0.0077	0.0094	0.0094	0.0095	0.028

Papaspiropoulos et al., JGR, 2002

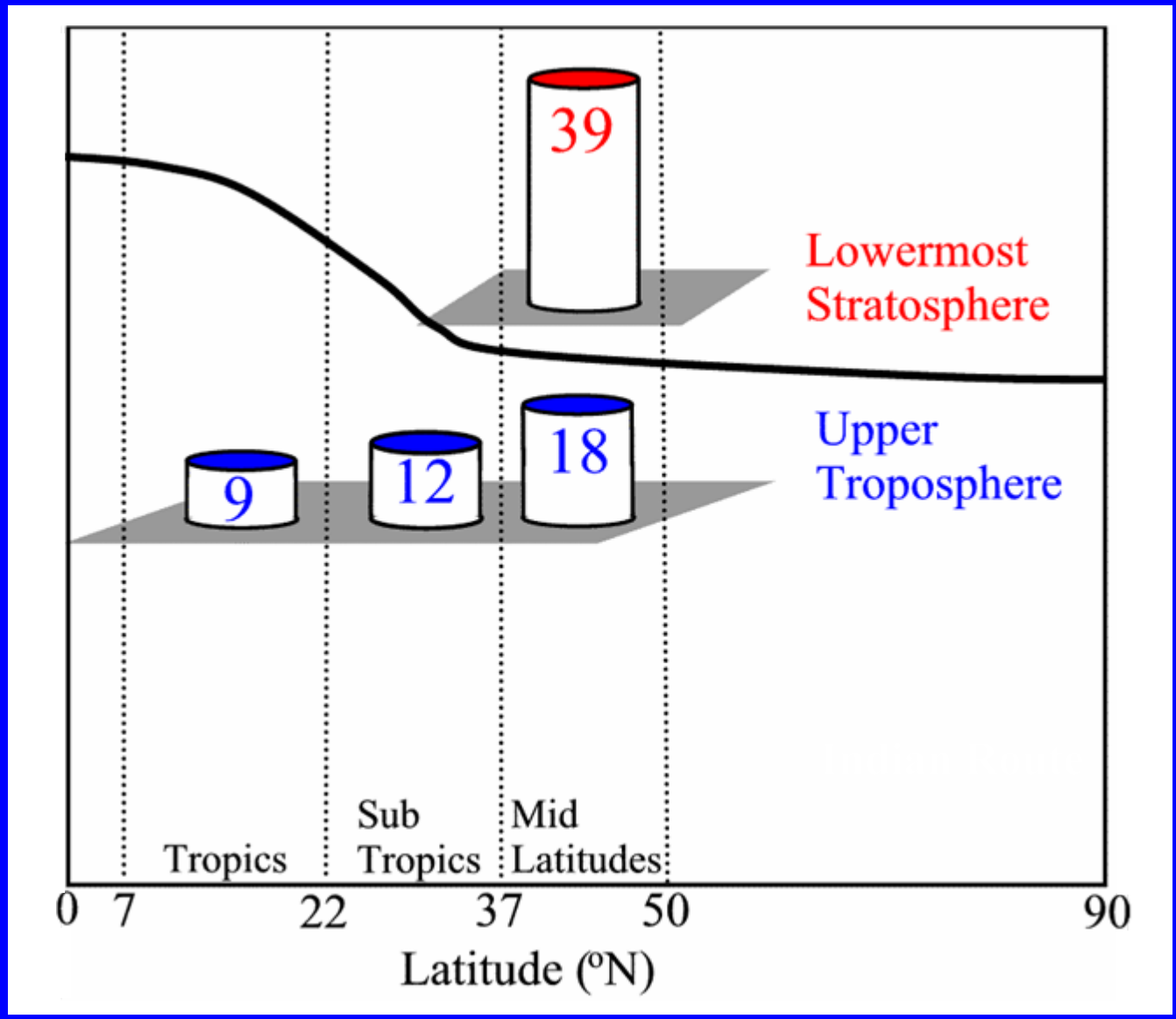
Particulate Sulfur Distribution



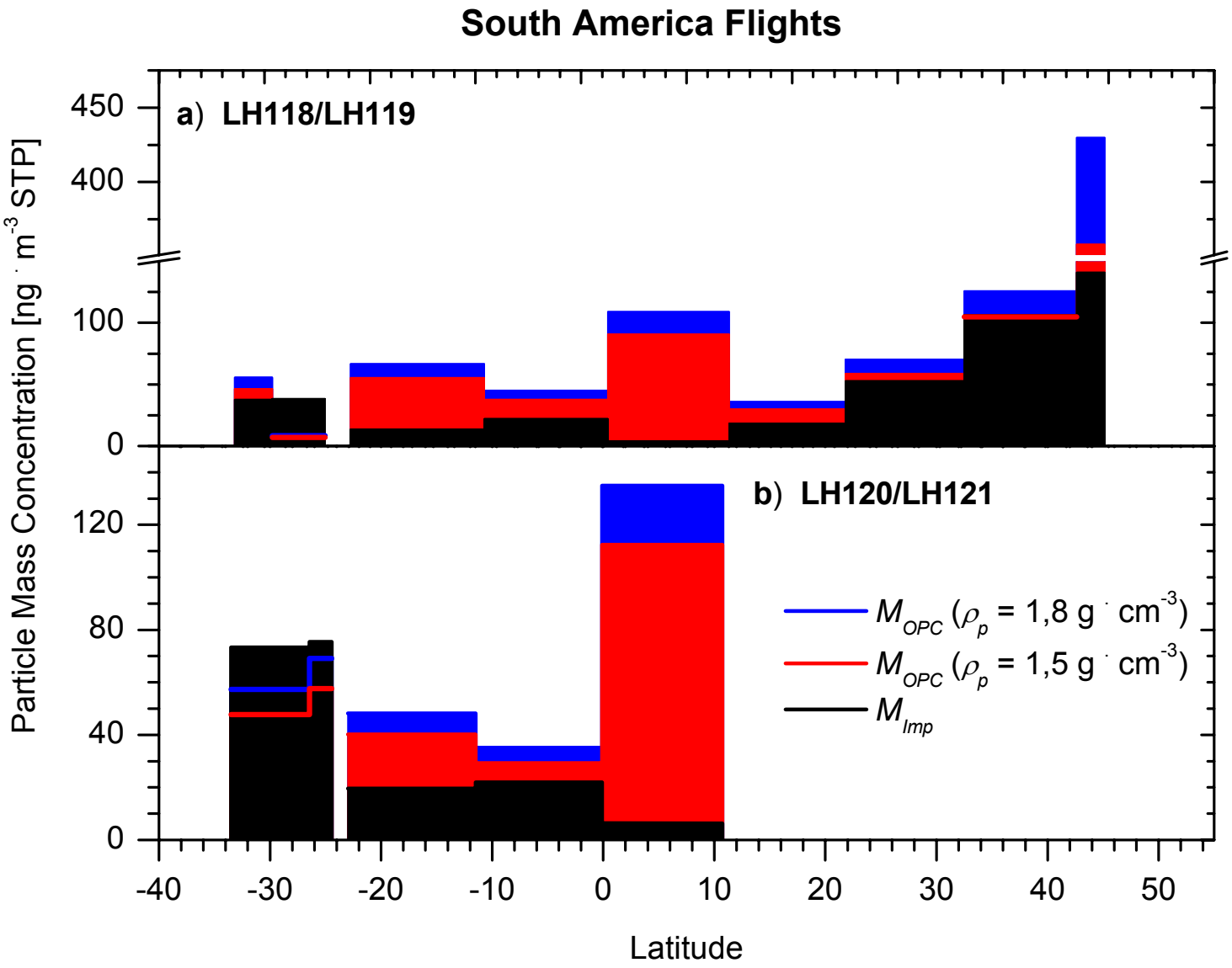
Elemental Composition

Martinsson, pers. com., 2007

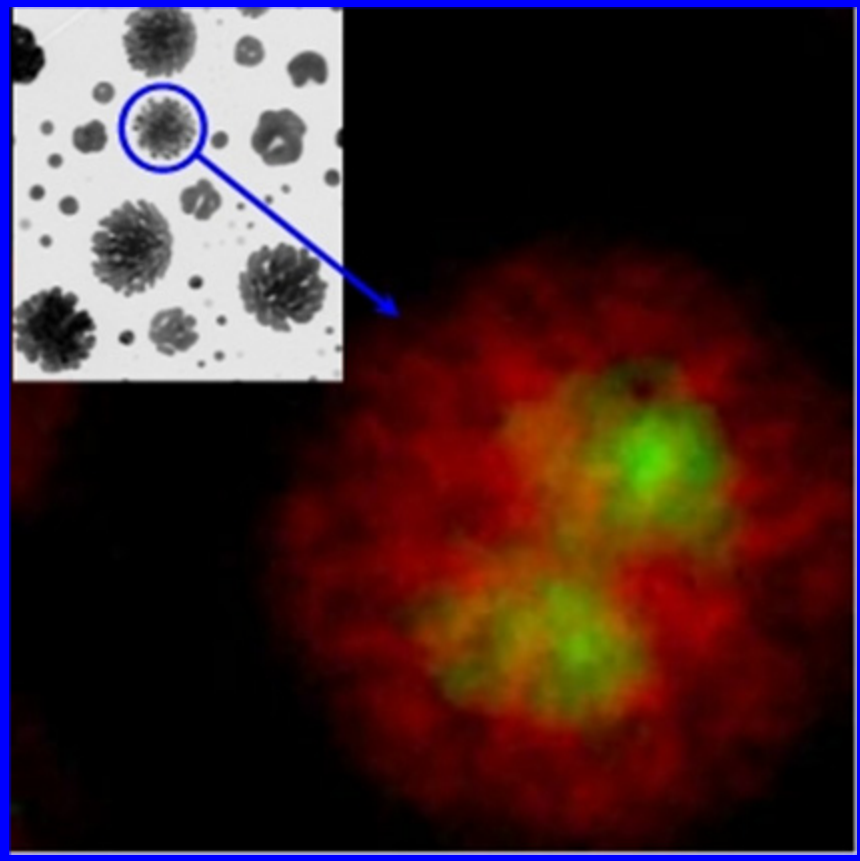
Particulate Sulfur Distribution



Papaspiropoulos et al., JGR, 2002

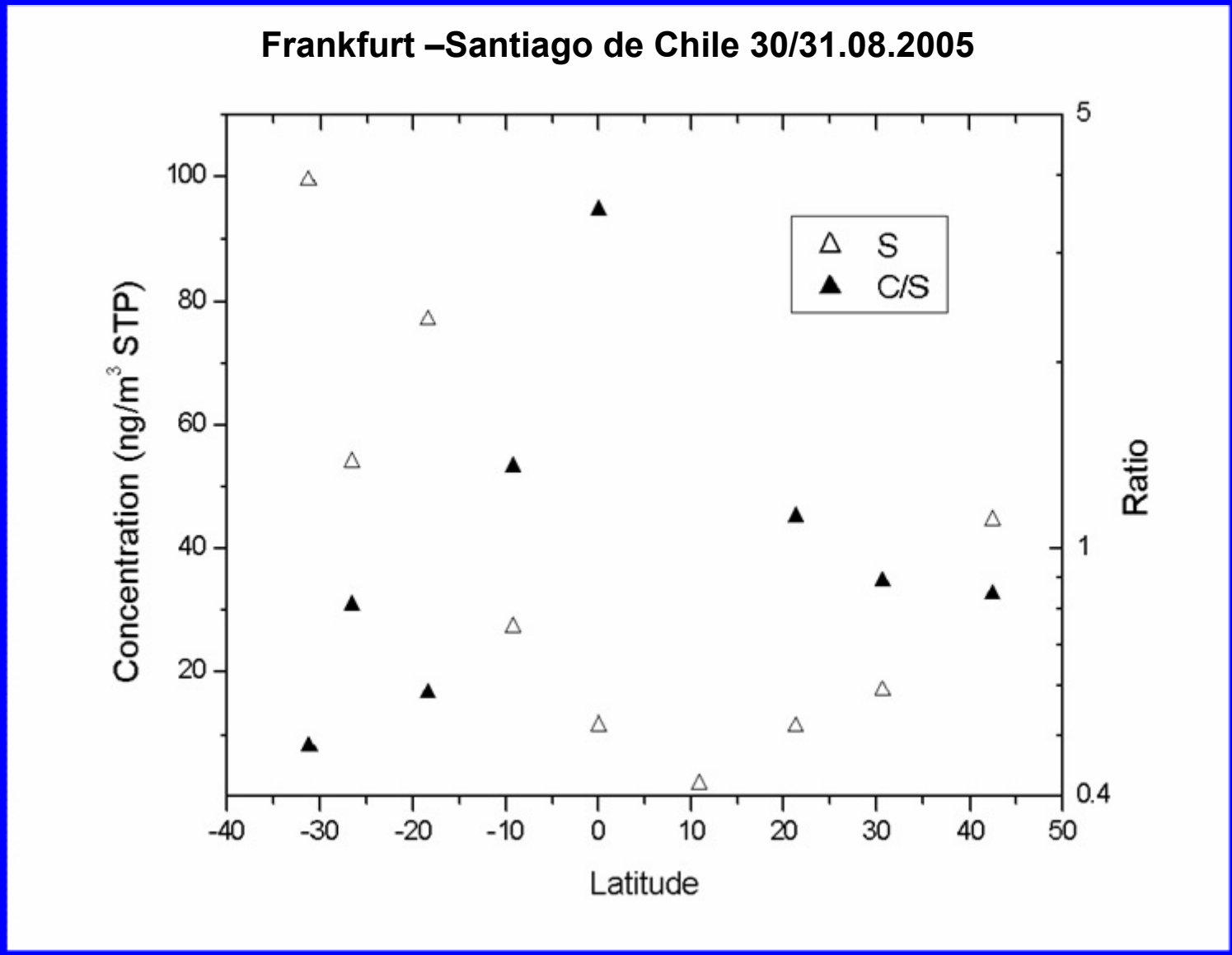


Reichelt et al., in prep., 2008



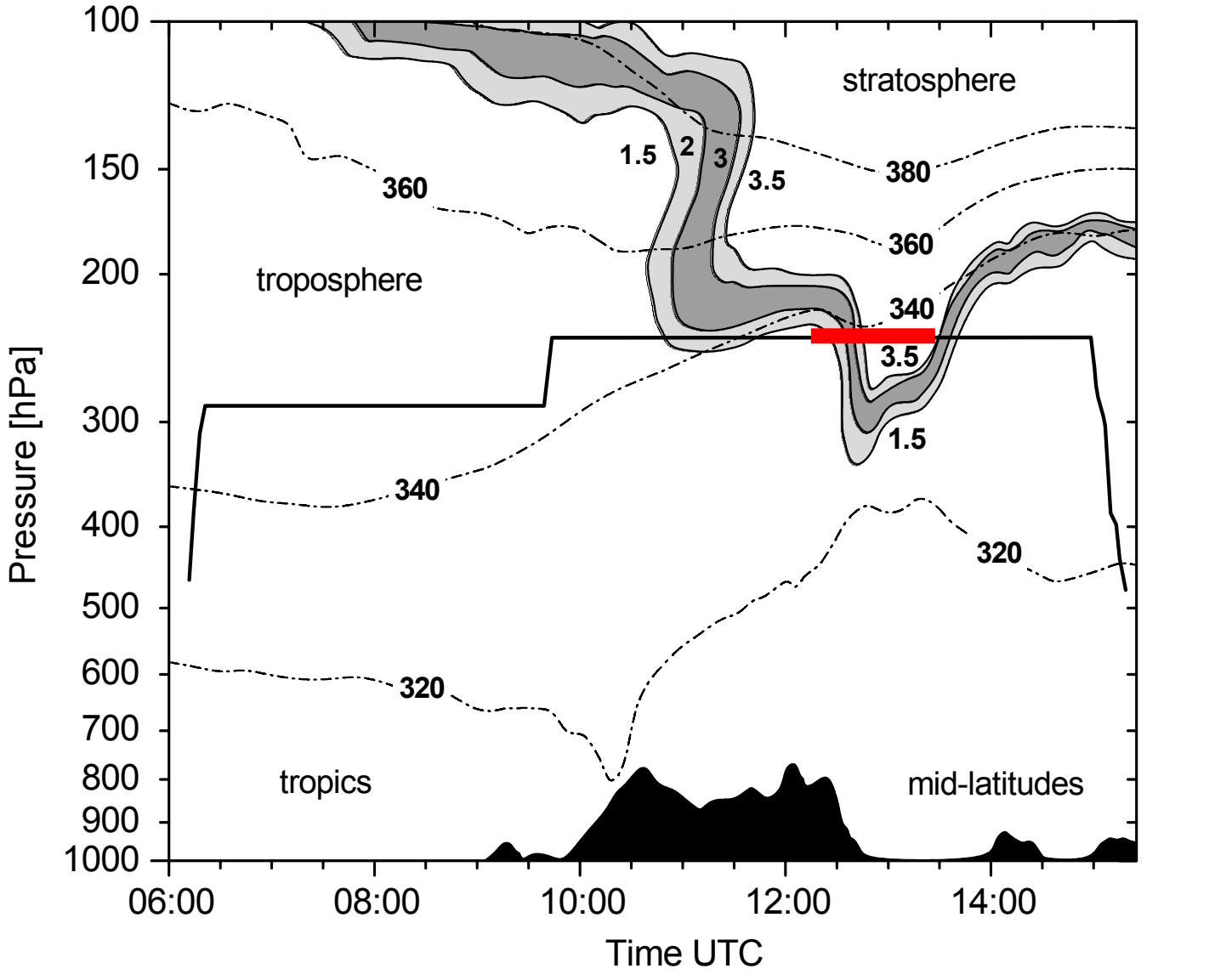
Example of results for particles taken in the LS (PV = 6.2 PVU). Left TEM. Right EFTEM, where green is sulfur and red carbon.

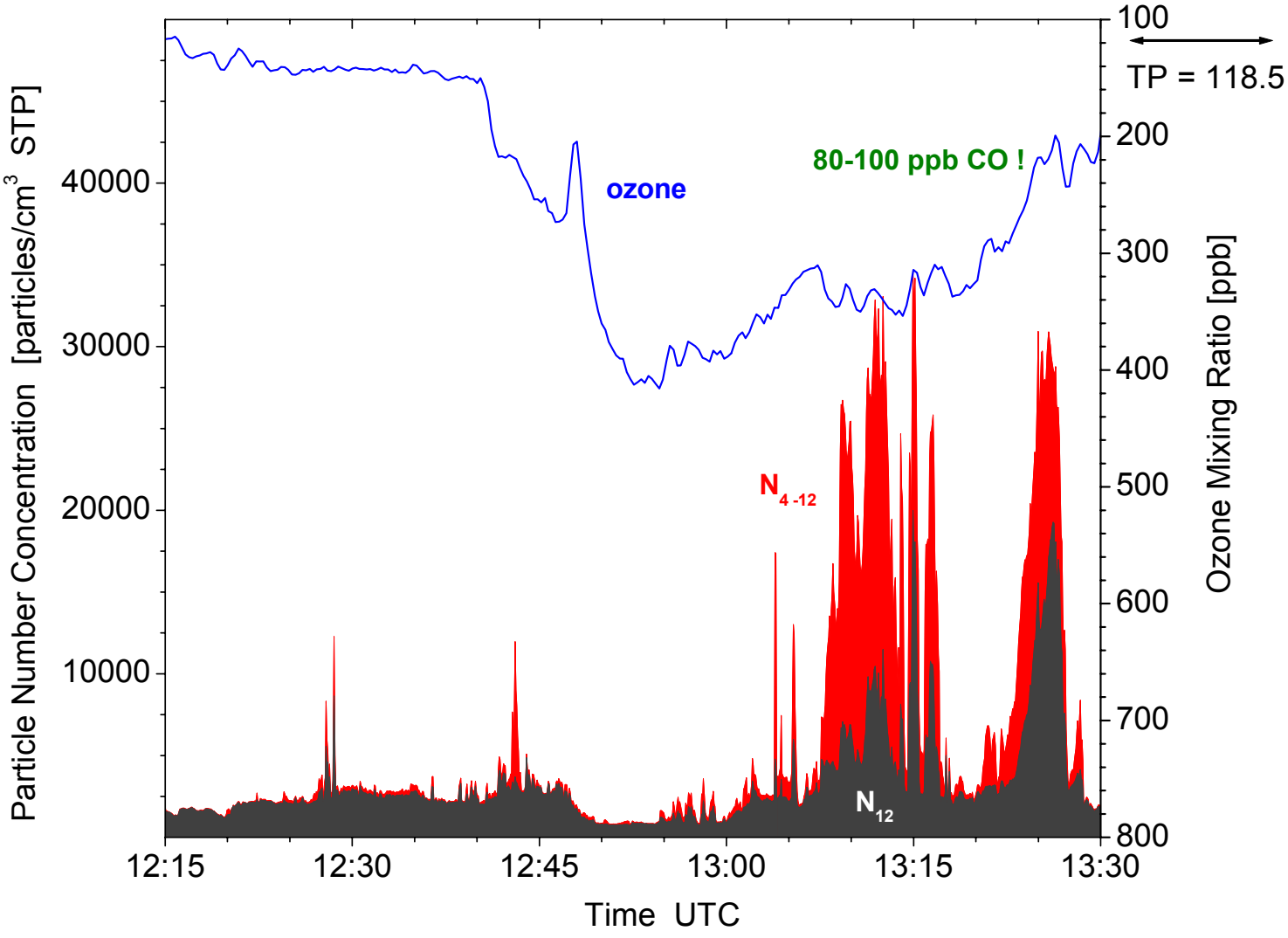
Martinsson, pers. com., 2007



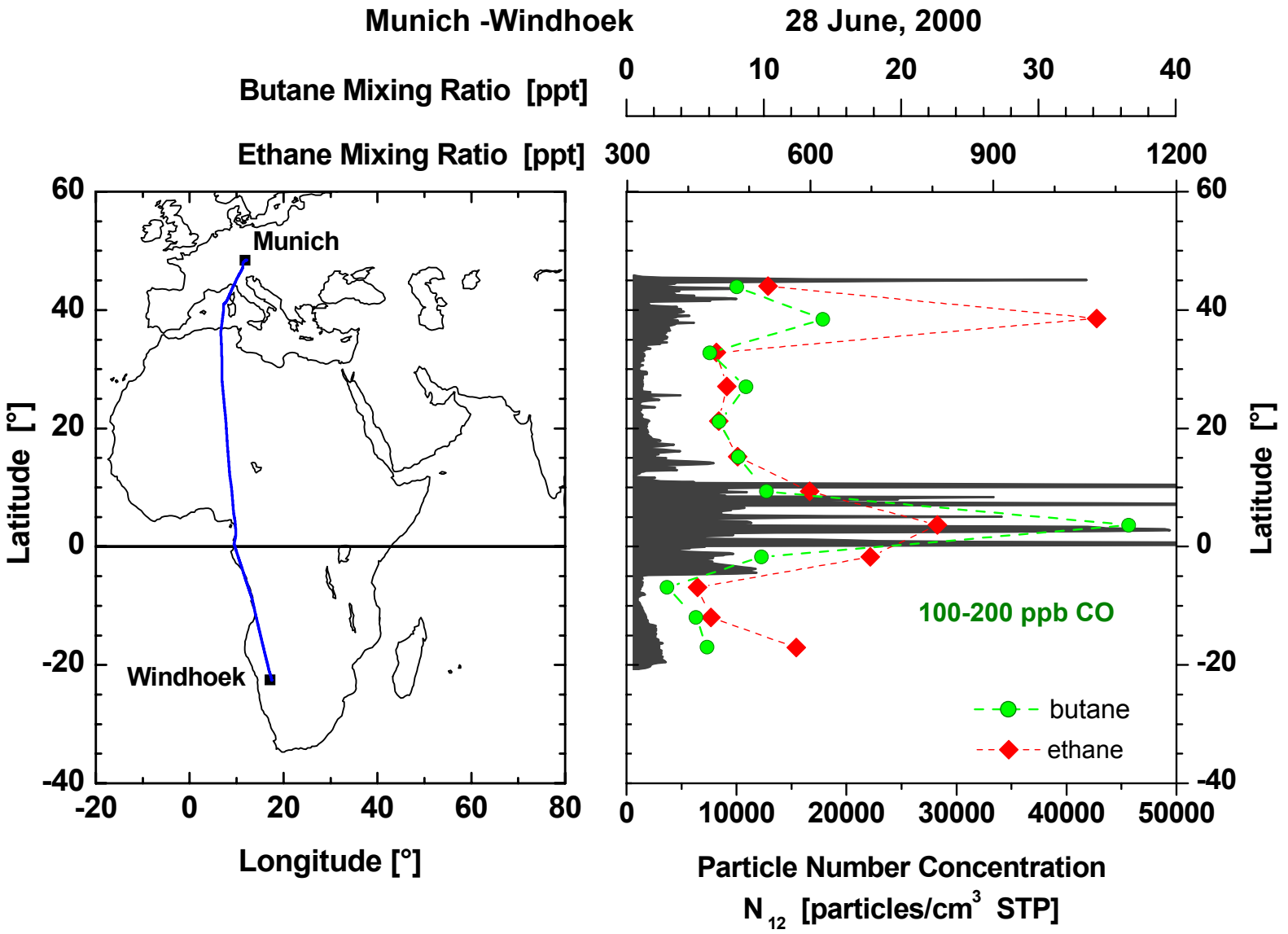
Nguyen et al., subm. JGR, 2008

Troposphere-to-Stratosphere Transport



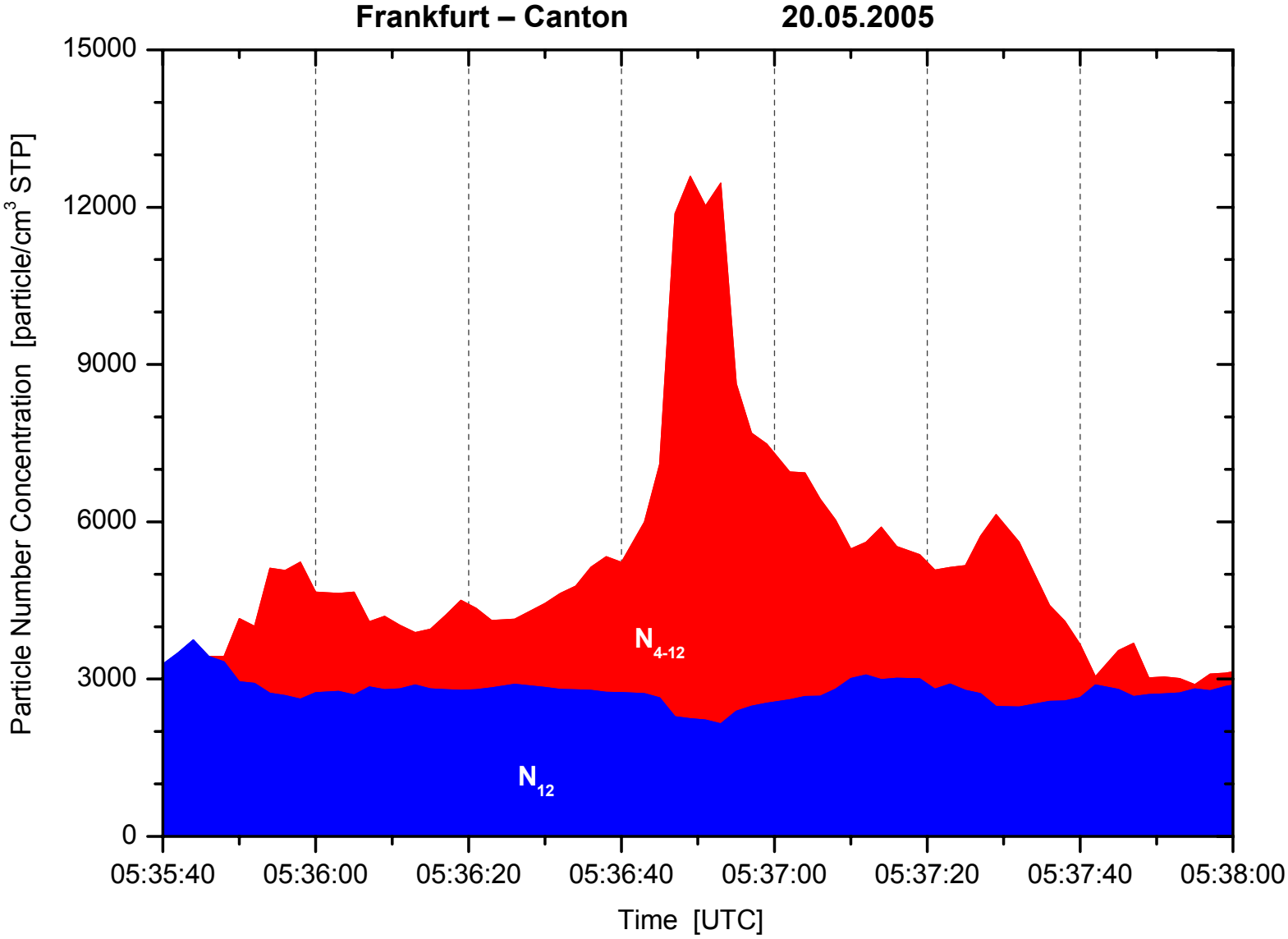


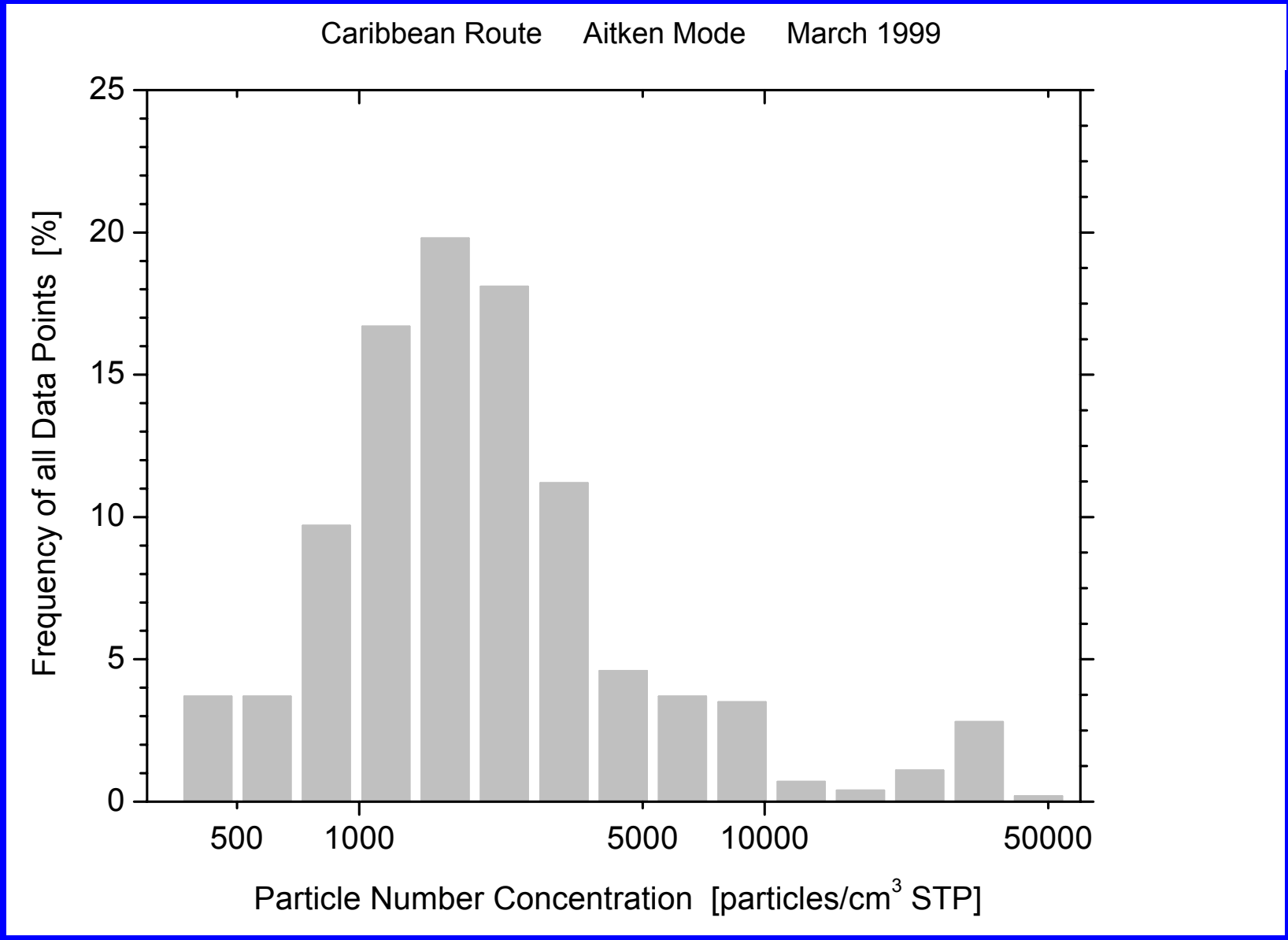
Zahn et al., JGR, 2000

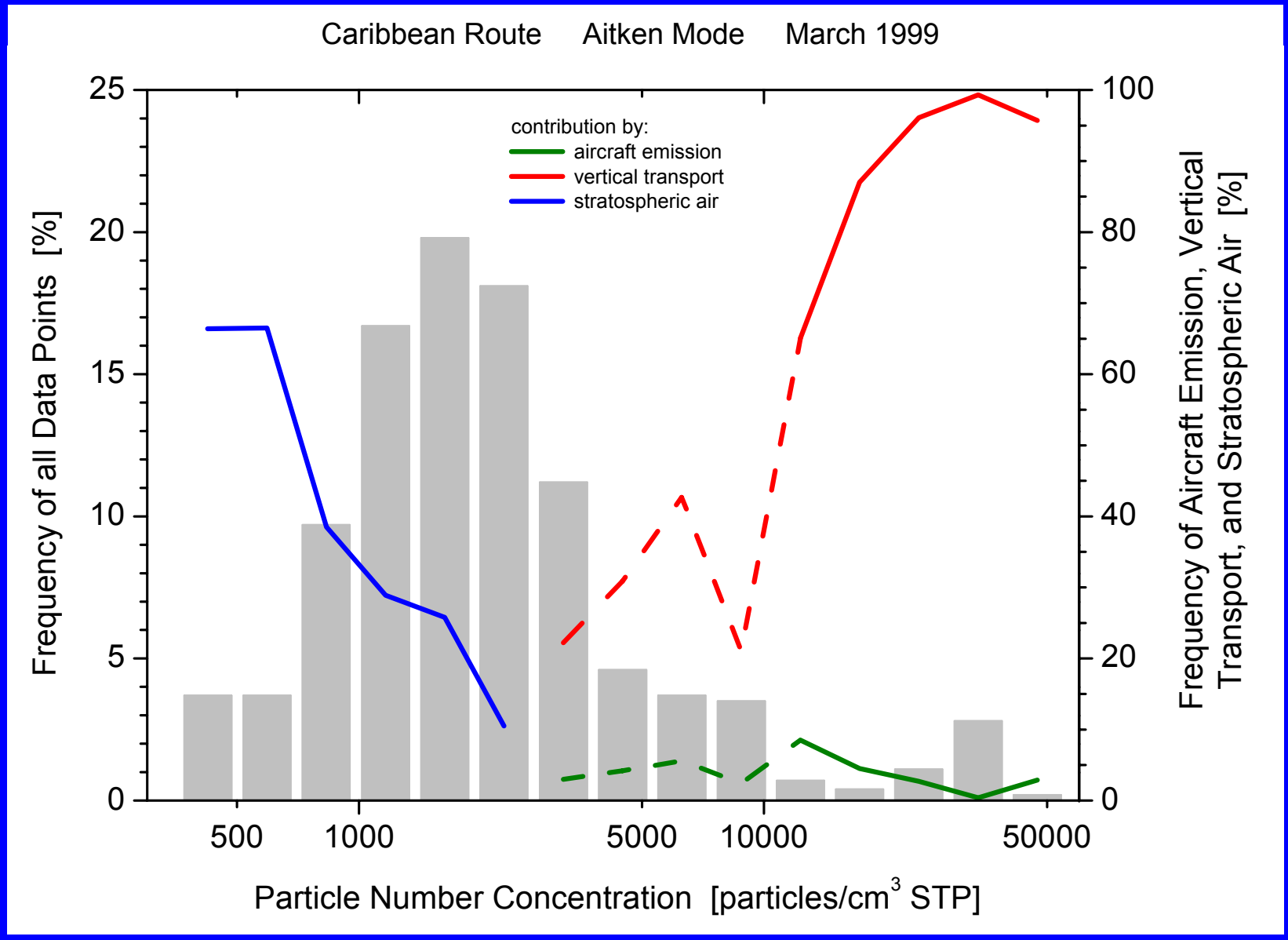


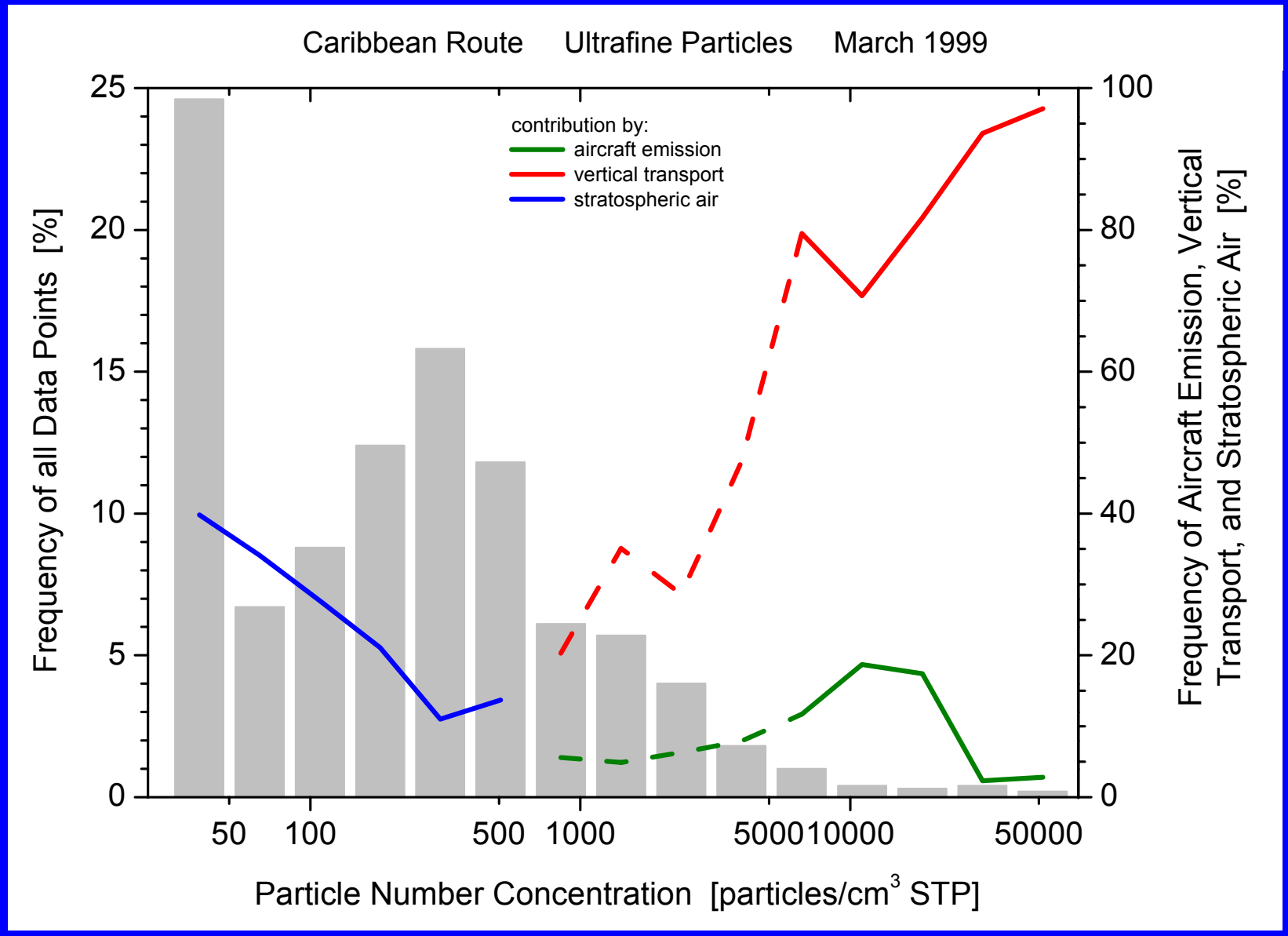
Mühle et al., GRL, 2002

Video


Frankfurt – Canton
20.05.2005
Particle Number Concentration [particle/cm3 STP]
15000
12000
9000
6000
3000
0
N4-12
N12
05:35:40
05:36:00
05:36:20
05:36:40
05:37:00
05:37:20
05:37:40
05:38:00
Time [UTC]


Caribbean Route Aitken Mode March 1999
Frequency of all Data Points [%]
0
5
10
15
20
25
500
1000
5000
10000
50000
Particle Number Concentration [particles/cm3 STP]


Caribbean Route Aitken Mode March 1999
contribution by:
aircraft emission
vertical transport
stratospheric air
Frequency of all Data Points [%]
Frequency of Aircraft Emission, Vertical Transport, and Stratospheric Air [%]
Particle Number Concentration [particles/cm3 STP]
0
5
10
15
20
25
0
20
40
60
80
100
500
1000
5000
10000
50000



Hermann et al., Tellus B, 2008

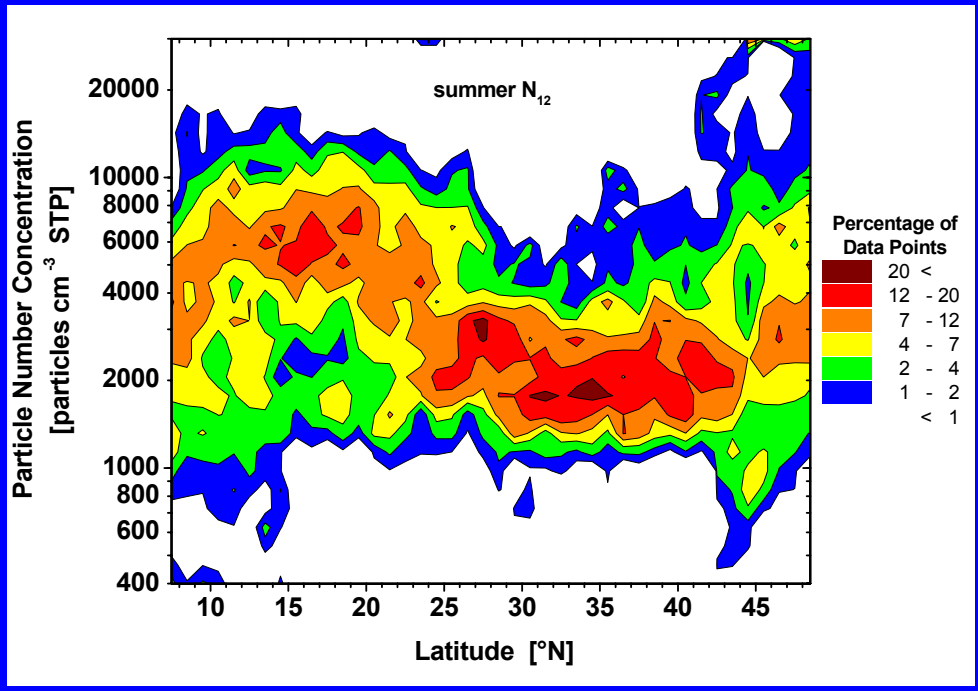
Comparison of experimental and modeling results for the Indian route

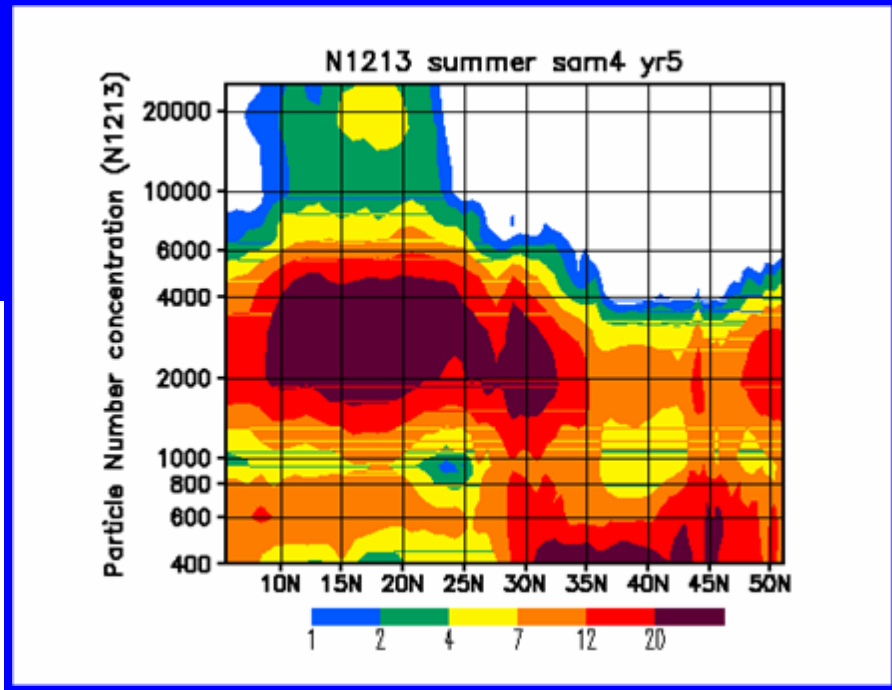
- Validation of an aerosol module within a GCM: MAECHAM4 / CHEM / SAM
- MPI für Meteorologie, Hamburg
- Sectional aerosol model with 35 bins between 0.001 and 2.6 μm particle diameter
- Prognostic variables for DMS, SO_2, SO_4^{2-}, COS, and H_2SO_4

Indian

Measured distribution

Hermann et al., JGR, 2003





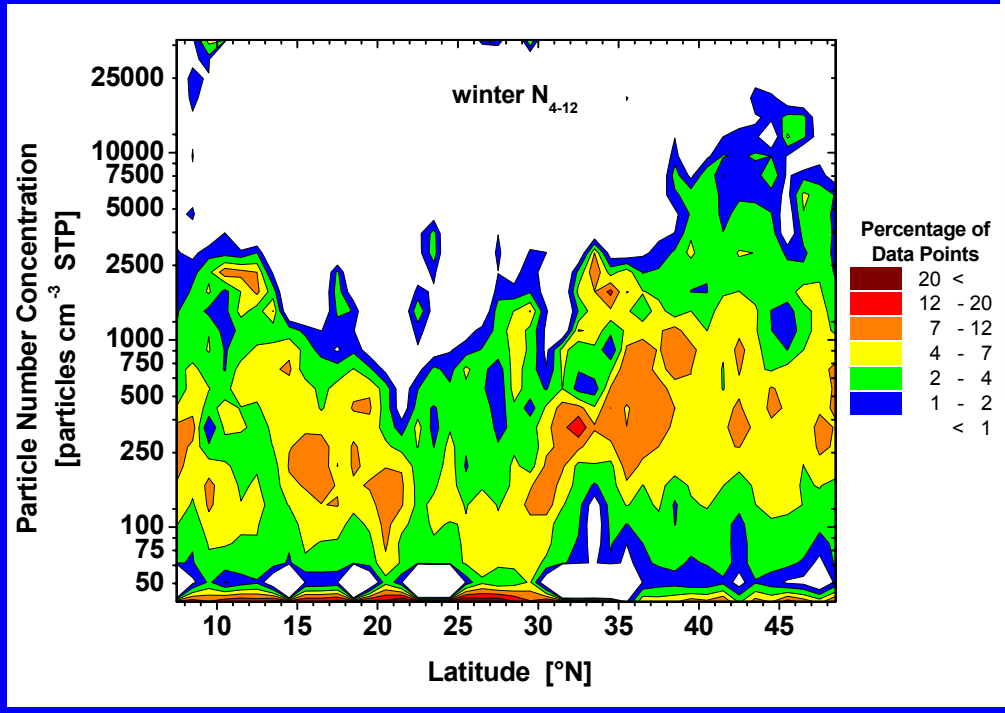
Model results

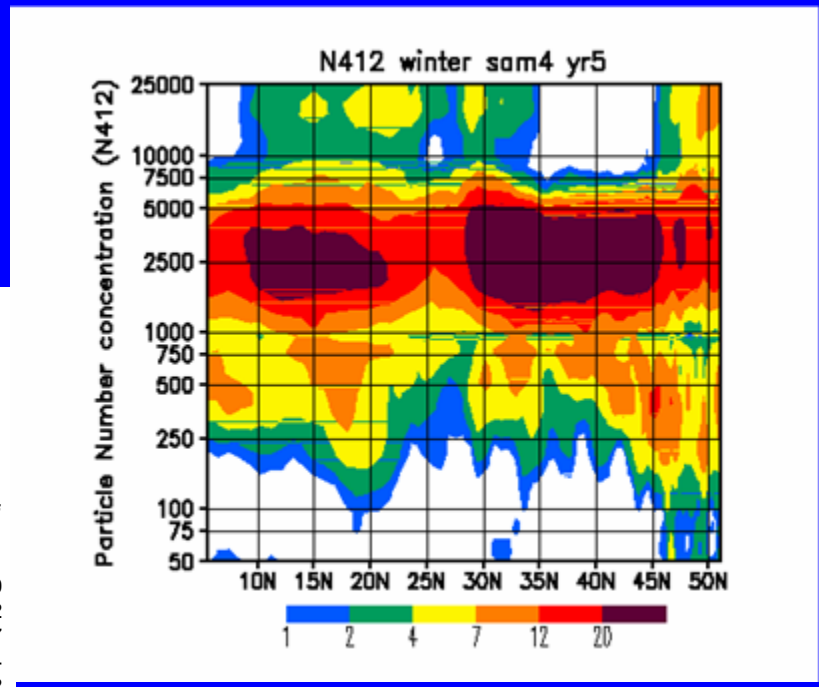
Timmreck, pers. com., 2005

Indian

Measured distribution

Hermann et al., JGR, 2003





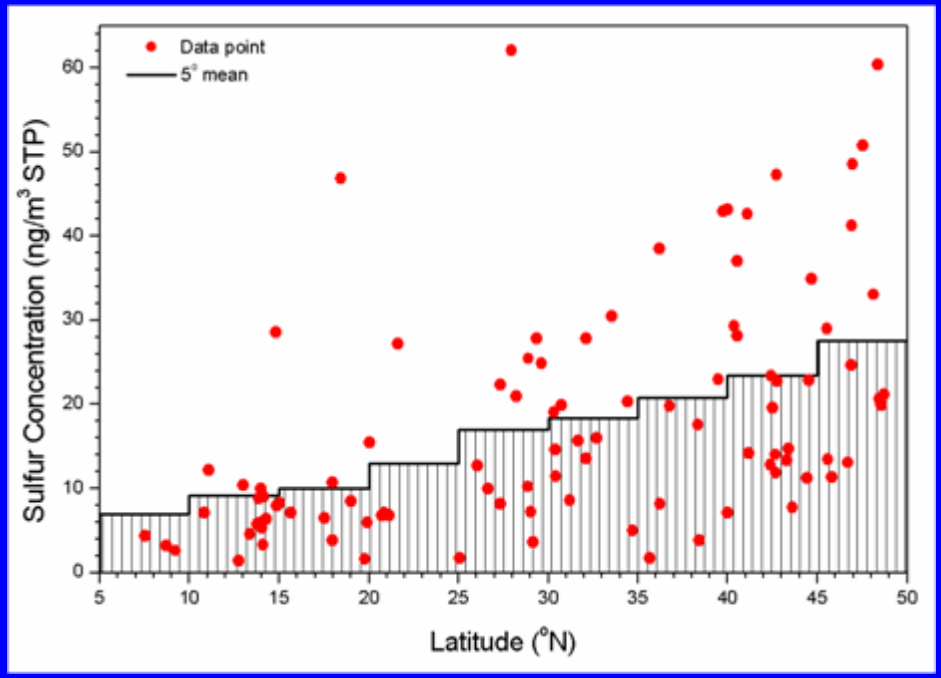
Model results

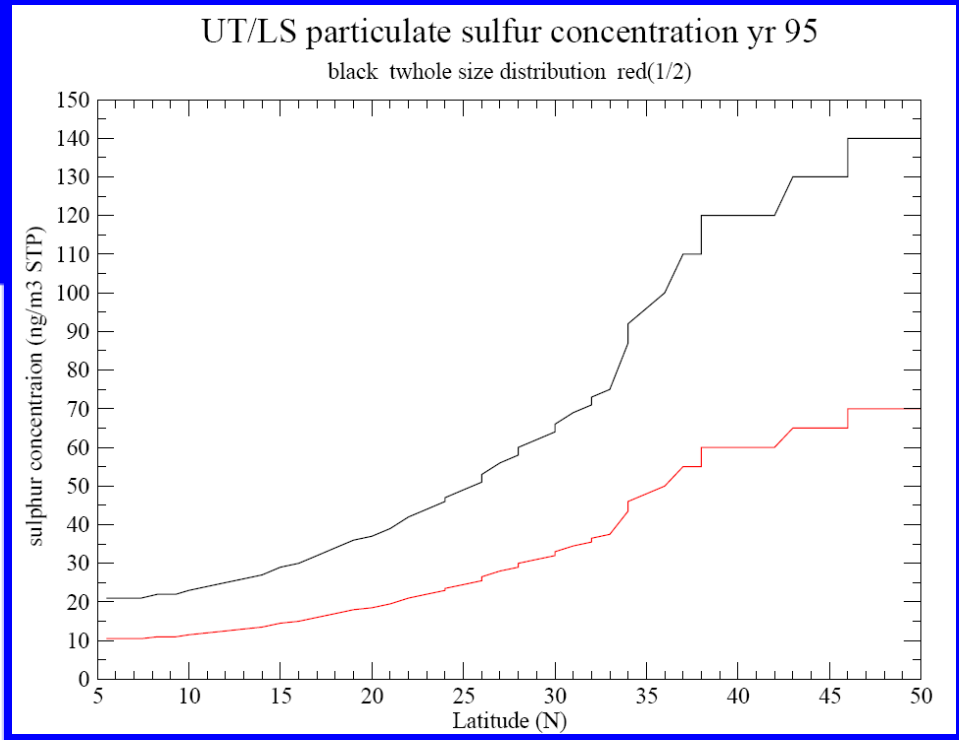
Timmreck, pers. com., 2005

Indian

Measured distribution

Papaspiropoulos et al., JGR, 2002





Model results

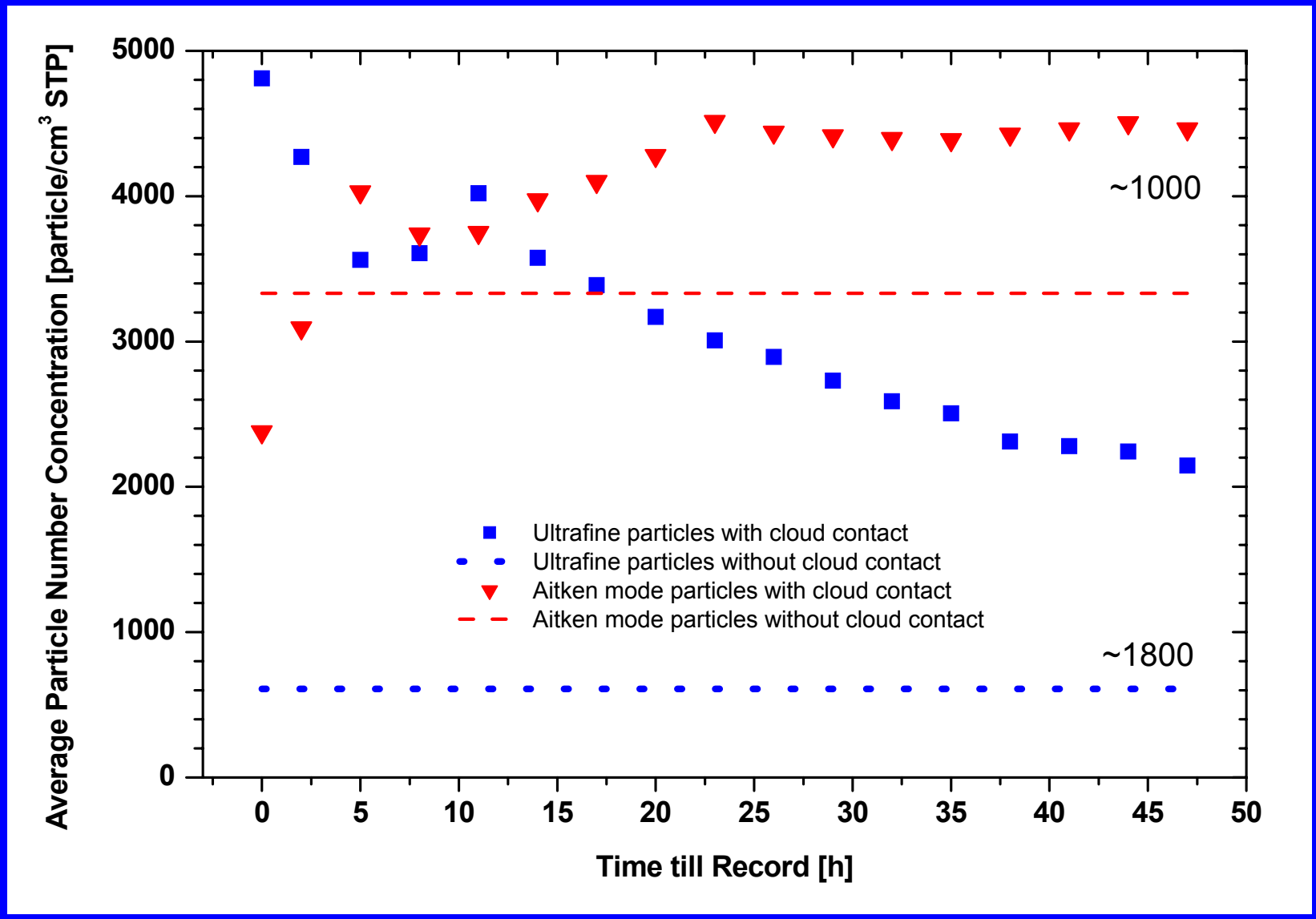
Timmreck, pers. com., 2006

Cloud Influence Investigation

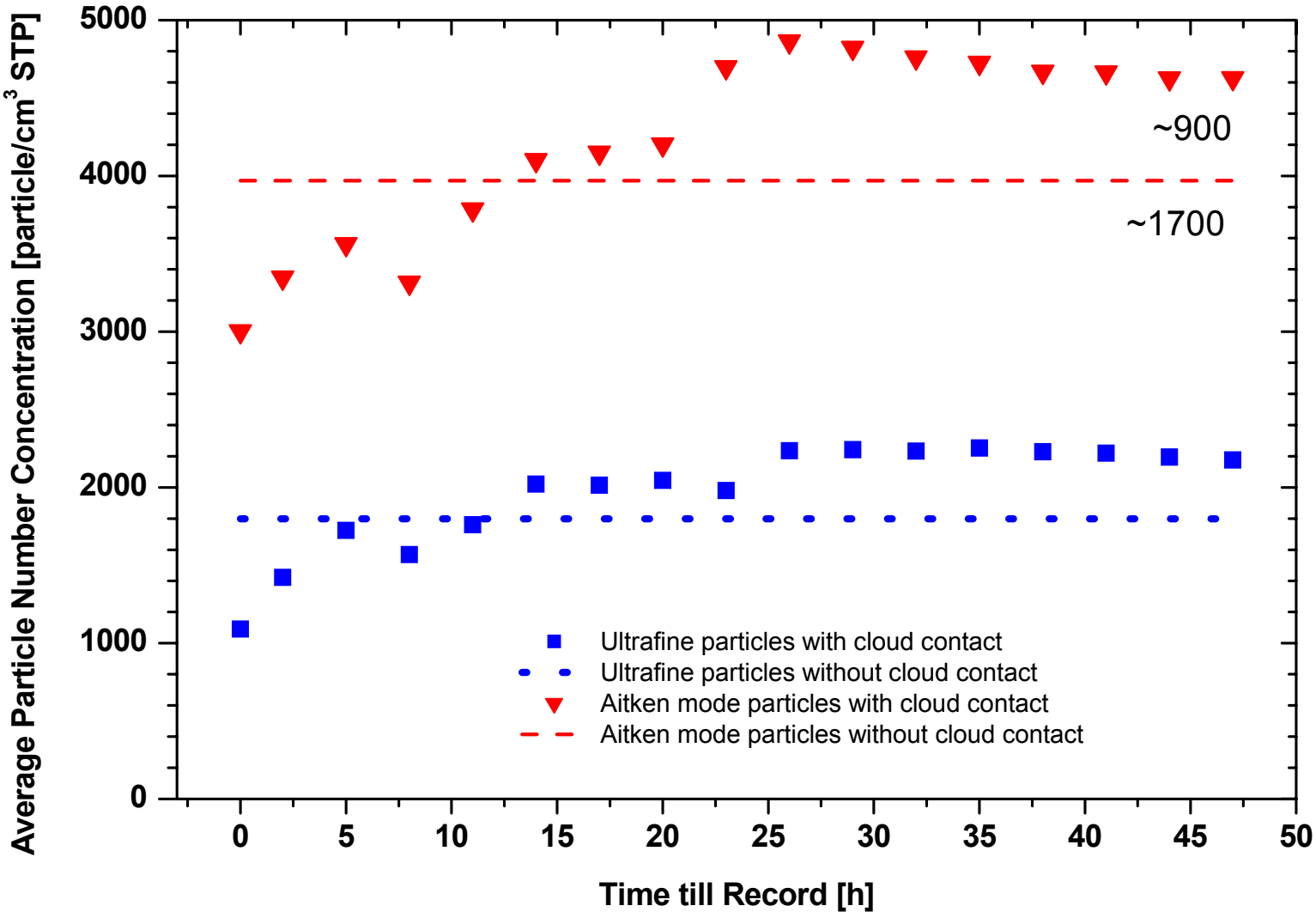
- Statistical analysis whether probed air parcels had been in contact with clouds in the last 48 hours before measurement and which influence the cloud contact had on the particle number concentration
- Five-day backward trajectories were used for air parcel history
- Cloud contact along the trajectories was checked with satellite pictures from ISCCP (International Satellite Cloud Climatology Project)

Weigelt et al., subm. JGR, 2008

- A retrieval algorithm with a wind-direction-dependent pixel search was developed, yielding the information whether and when there was a cloud contact
- Analysis was carried out for the Indian and the Caribbean route
- In principle on could think of high-altitude clouds acting as:
  - particle source
  - particle sink
  - particle transporter



Weigelt et al., subm. JGR, 2008



Weigelt et al., subm. JGR, 2008

Summary

- CARIBIC: flying laboratory for aerosol and trace gas measurements in the UT/LS
- Particle number and mass concentration distributions as well as elemental composition for submicrometer particles in the UT/LS
- Vertical transport processes, in particular deep convection, are most important to understand the distribution of UT/LS particles
- Influence of clouds on (UT/LS) particles not fully understood up to now

Thanks to …

- Lufthansa Technik and Lufthansa
- LTU International Airways
- Carl Brenninkmeijer, Dieter Scharffe, Franz Slemr, Claus Köppel, … (MPI)
- Andreas Zahn, … (FZK)
- Bengt Martinsson, … (Lund University)
- Peter van Velthoven (KNMI)
- Jost Heintzenberg, Andreas Weigelt, … (IFT)

Thanks for your attention !