Particle formation in the troposphere from up to 12 km from CPC observations with the DLR Falcon research aircraft

Andreas Minikin
Institut für Physik der Atmosphäre, DLR Oberpfaffenhofen, Germany
Main question:

Where in the vertical column of the troposphere does particle formation (particles > 4 nm) occur?

Data:

Multi-channel Butanol-CPCs flown on the DLR Falcon aircraft (in polar regions also on AWI Dornier-228)

Information is available (only) from CPCs with cut-off >4 and >10 nm (sometimes >5 and >14 nm)

This presentation:

Not much analysis, just a collection of observations made during various field campaigns (campaigns were in general all targeted at other objectives)
Aircraft field experiments with DLR aerosol measurements

2006 annual average of MODIS AOT (@ 550 nm)

Image of the Week - February 18, 2007
Institut für Physik der Atmosphäre

aerosol inlet

gas inlets (CO, ozone)

Nose boom
(meteorological measurements)

window for nadir looking lidar
(aerosol & water vapor profiles)

optical aerosol & cloud probes
(PCASP & FSSP-300)

broad-band radiometer

DLR Falcon 20
max. flight altitude: 12 km
max. endurance: 4 hours
Aerosol instrumentation

- PCASP-100X
- FSSP-300
- multi-channel CPC
- DMA

nucleation mode
Aitken mode
accumulation mode
coarse mode

\( \text{dN} / \text{dlog D} \ (\text{cm}^{-3}) \)

particle diameter (\(\mu\text{m}\))
Falcon measurements over the boreal forest near Hyytiälä?
Sorry, no. We only flew once over boreal forest and that was in Sweden (before and after refueling in Kiruna)
EUCAARI-LONGREX in May 2008
Observations over Central Europe

- DLR Falcon flight track
- Location for vertical profiling with Falcon
- EUSAAR ground stations
- Oberpfaffenhofen (operation base)
EUCAARI-LONGREX campaign
Falcon, flight 080521a
21-May-2008

number concentration (cm$^{-3}$)

flight altitude (km)

21.05.2008 07:30 21.05.2008 08:30 21.05.2008 09:30 21.05.2008 10:30 21.05.2008 11:30
Particle formation event in the upper troposphere over Germany, May 21, 2008

~300 km

Particle formation event in the upper troposphere over Germany, May 21, 2008

~300 km

~300 km
Variability in vertical aerosol distribution over Europe during May 2008

Total CN (>10 nm) number concentration for all Falcon vertical profiles
Median number concentration profiles & statistics (EUCAARI-LONGREX)

- Profiles: Median, 10-, 25-, 75-, 90-percentiles per 800 m height interval
- Logarithmic concentration scale (except NUCL), concentrations corrected to standard conditions (stp)
- In-cloud data excluded from data set

see also Hamburger et al., ACPD, 2010
More mid-latitude aerosol vertical profiles over central Europe

UES 2000 summer

LACE 1998 summer

number concentration (cm$^{-3}$ stp)
Mid-latitude autumn aerosol vertical profiles: southern & northern hemisphere (rather marine influence)

- AITK
- NUCL
- ACC

INCA NH 2000 autumn

INCA SH 2000 autumn
When does particle formation NOT occur in the free troposphere?

High pressure system in first half of May 2008 → subsidence of air
Large-scale subsidence of air over the Mediterranean in summer

MINOS
east Mediterran.
polluted marine
summer
July/Aug. 2001
Observations of particle formation in the tropics
(in the vicinity of deep convection)
AMMA campaign, West Africa, 11-Aug-2006
Probing of MCS outflow near Ouagadougou
Probing the outflow with increasing outflow age: Wet removal – particle formation – particle growth

particle number concentration

Nukleations mode

Aitken mode

non-volatile

flight altitude /hPa

stp concentration /(particles/cm$^3$)

time UTC /sec after midnight

STPN4
STPN10
STPN10 non volatile
STPF3NHAZE (1-3 µm)
STPF3NCLOUD (>3 µm)
Probing the outflow with increasing outflow age:
Wet removal – particle formation – particle growth

Particle number concentration

- Nukleations mode
- Aitken mode
- Non-volatile

Legend:
- Pressure height
- thetaE
- STPN4
- STPN10
- STPN10 non volatile
- STPF3NHAZE (1-3 µm)
- STPF3NCLOUD (>3 µm)
Probing the outflow with increasing outflow age: Wet removal – particle formation – particle growth (Size distributions)
Measurements in Antarctica (coastal region)
Number concentration of (ultra)fine particles:
Seasonal cycle of condensation particles at Neumayer & South Pole

South Pole data: GAW World Data Centre for Aerosols - http://rea.ei.jrc.it/netshare/wilson/WDCA/
Neumayer data: R. Weller, AWI
25-Dec-2006 case: particle nucleation at low level

ANTSYO II / AGAMES
Polar 2, flight 061225a
25-Dec-2006

Nucleation mode particles

 ambient concentration (particles/cm³)

 N413
 flight altitude

 date & time (UT)

 Preliminary data.
To be used only for quicklook purposes.

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Particle nucleation at Neumayer

... was observed at low level predominantly over water

... was observed mostly at low level (below 1.5 km) with only few, but notable, cases of layers in the free troposphere
25-Dec-2006 case: air mass origin

Footprint emission sensitivity in global domain for p2_061225a
Start time of sampling 20061225 135533  End time of sampling 20061225 135551
Lower release height 658 hPa  Upper release height 650 hPa
Meteorological data used are from ECMWF

Column-integrated emission sensitivity in global domain for p2_061225a
Start time of sampling 20061225 135533  End time of sampling 20061225 135551
Lower release height 658 hPa  Upper release height 650 hPa
Meteorological data used are from ECMWF

above layer

Footprint emission sensitivity in global domain for p2_061225a
Start time of sampling 20061225 131220  End time of sampling 20061225 131248
Lower release height 969 hPa  Upper release height 968 hPa
Meteorological data used are from ECMWF

Column-integrated emission sensitivity in global domain for p2_061225a
Start time of sampling 20061225 131220  End time of sampling 20061225 131248
Lower release height 969 hPa  Upper release height 968 hPa
Meteorological data used are from ECMWF

in layer

"footprint"

"column"
31-Dec case: high altitude particle nucleation

ANTSYO II / AGAMES
Polar 2, flight 061231a
31-Dec-2006

Nucleation mode particles

ambient concentration (particles/cm$^3$)

31-Dec-2006 16:30 31-Dec-2006 17:30 31-Dec-2006 18:30 31-Dec-2006 19:30
date & time (UT)

presssure altitude (km)

0 200 400 600 800 1000 1200 1400 1600 1800 2000

Vertical aerosol profiles

number concentration (cm$^{-3}$ stp)

0 200 400 600 1000 1400 1800 2200 2600

Preliminary data.
To be used only for quicklook purposes.
Footprint emission sensitivity in global domain for p2_061231a
Start time of sampling 20061231.173519  End time of sampling 20061231.173642
Lower release height 547 hPa  Upper release height 539 hPa
Meteorological data used are from ECMWF

Column-integrated emission sensitivity in global domain for p2_061231a
Start time of sampling 20061231.170139  End time of sampling 20061231.170208
Lower release height 708 hPa  Upper release height 700 hPa
Meteorological data used are from ECMWF

31-Dec case: high altitude particle nucleation, air mass origin

above layer

in layer

below layer

"footprint"

"column"
First airborne observations of sub-3 nm neutral atmospheric particles during EUCAARI-LONGREX with airborne NAIS

Mirme et al, ACP, 2010
Median concentration profiles total and charged clusters and particles + corresponding concentration ratios between total and charged cluster/particles

EUCAARI-LONGREX campaign, May 2008

Mirme et al, ACP, 2010
Conclusions of NAIS measurements with DLR Falcon aircraft

- First-time aircraft deployment of a NAIS instruments on the DLR Falcon during EUCAARI
- Abundant presence of both neutral and charged sub-2 nm clusters at all altitude levels
- Growth of particles into sizes >4 nm does happen only under certain conditions apparently
- No indication of an enhanced role of ion-induced nucleation toward the tropopause region
Summary

Particle formation observed from aircraft with CPCs (~4 nm lowest cut-off); during EUCAARI first time deployment of NAIS.

Particle formation events are observed in the troposphere in BL and UT, (almost) never inbetween. Occurrence is patchy; high variability of number concentrations. Atmospheric dynamics is important.

Aitken mode concentrations profiles in the FT are shaped by particle formation events.

In mid-latitudes UT properties are usually controlled by long-range transport. Particular origin of particle formation events often not clear.

In the tropics particle formation in the UT is connected to deep convective processes (either uplift of precursors or wet removal of pre-existing aerosol or both).

From aircraft measurements alone it is very difficult to arrive at a process understanding, but observations are well suited to test models.
Thank you!

And thanks to:
A. Petzold, M. Fiebig, T. Hamburger, R. Krejci, H. Rüba & many others
CPC minimal detectable particle size: controlled by Butanol super-saturation (temperature difference between warm & cold part)

Cut-off size (defined by 50 % sampling efficiency) can be selected in the range 4...20 nm
Pressure dependence of sampling efficiency of Butanol-based CPC at different temperature settings (= different lower cut-off sizes) at 40 nm