The composition of the Asian monsoon upper troposphere: a synergy of satellite and air-borne remote sounding

Michael Höpfner (1), Jörn Ungermann (2), Reinhold Spang (2), Sören Johansson (1), Felix Friedl-Vallon (1), Johannes Orphal (1), Martin Riese (2), Gabriele Stiller (1), Fred Stroh (2), Sylvia Bucci (3), Bernard Legras (3), Ingo Wohltmann (4)

(1) Karlsruhe Institute of Technology, Institute of Meteorology and Climate Research, Karlsruhe, Germany (michael.hoepfner@kit.edu)
(2) Institut für Energie und Klimaforschung, Stratosphäre, IEK-7, Forschungszentrum Jülich, Jülich, Germany
(3) Laboratoire de Météorologie Dynamique, UMR8539, IPSL, UPMC/ENS/CNRS/Ecole Polytechnique, Paris, France
(4) Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany
Two nobel prices 100 years ago

Max Planck

The Nobel Prize in Physics 1918 was awarded to Max Planck: "in recognition of the services he rendered to the advancement of Physics by his discovery of energy quanta."
Prize share 1/1

Fritz Haber

The Nobel Prize in Chemistry 1918 was awarded to Fritz Haber: "for the synthesis of ammonia from its elements."
Prize share 1/1
Significance of ammonia (NH₃)

- Main alkaline species in the atmosphere
- Formation of aerosols by neutralization of acids: ammonium sulfate and ammonium nitrate depending on the availability of H₂SO₄ and HNO₃.
- Increase of NH₃ emissions in the future: compensation of aerosol radiative forcing change by reduction of SO₂ emissions.
- Important for the initial nucleation of sulfate aerosols under cold temperatures.

**But**: Difficult to measure in-situ.

---

Role of sulphuric acid, ammonia and galactic cosmic rays in atmospheric aerosol nucleation.
Infrared emission limb sounding

MIPAS 2002-2012

GLORIA@
Geophysica 2017
MIPAS/Envisat: first detection of NH$_3$ in the Upper Troposphere

- First evidence for the presence of ammonia in the upper troposphere (Höpfner et al., 2016)
- Enhanced 3-monthly mean values of up to ~30 pptv within the Asian monsoon upper troposphere
MIPAS: new NH$_3$ retrievals

@ 16 km @ 30° - 40°N
MIPAS NH$_3$ 2002-2011

Total mass within
10°- 110°E, 20°- 40°N, 13 -17 km
The StratoClim campaign 2017

- Russian M55 Geophysica research aircraft
  - Altitude up to 21 km
  - Range up to 4000 km
- Basis: Kathmandu (Nepal)
- July and August 2017
- 8 local research flights (4 with GLORIA on board)
Kathmandu campaign impressions
Flights with GLORIA
STROTOCLIM: Cloud determination

- Visible clouds clearly identified in spectral signal
- Sub-visible clouds / haze observed between top cirrus layer and lower clouds

IR field of view in visible image (dotted line: flight altitude)
Spectral detection of NH₃

MIPAS/Envisat

Höpfner et al., 2016

GLORIA/Geophysica

13.68 km 1.53680e+00 rad 20170731 041450

Radiance / nW cm⁻² sr⁻¹ cm⁻¹

Wavenumber / cm⁻¹

40 nW...

300 nW...
Backtrajectories
2017-07-31

- Different origin of the air encountered on the southbound vs. the northbound flight leg at 13 km altitude
- Same origin at 17 km
Density of backward trajectories originating at position of convection weighted by the observed NH$_3$ concentrations.
Why is NH$_3$ not washed out during convection?

- ph – dependence of NH$_3$ solubility in liquid water
- “Convective clouds are hardly acidic so that NH$_3$ is only partly dissolved and removed by precipitation“ (Metzger et al., 2002)

A molecular perspective for global modeling of upper atmospheric NH$_3$ from freezing clouds

Cui Ge$^a$, Chongqin Zhu$^a$, Joseph S. Francisco$^{b,2}$, Xiao Cheng Zeng$^{b,2}$, and Jun Wang$^{b,2}$

- Study trying to explain the MIPAS NH$_3$ observations
- “We show that the NH$_3$ dissolved in liquid cloud droplets is prone to being released into the UTLS upon freezing during deep convection.”

Ge et al., PNAS 2018
Summary

- Temporal evolution of NH₃ in the UT during monsoon revealed by MIPAS
- First observations of ammonia concentrations > 1 ppbv in the upper troposphere by airborne IR limb imaging
- Source region: NW-India, N-Pakistan
- Upward transport by convection
  → how does NH₃ survive rainout/washout?
- Importance of ammonia induced aerosol formation for ATAL and e.g. cirrus formation to be investigated (e.g. aerosol/cloud processes in models, correlation with GLORIA aerosol retrievals)
- Export out of the monsoon (ammonia and/or ammonium-containing aerosols)?