Balloon-borne measurements of water vapor, aerosol backscatter and ozone in Nainital (India) in August and November 2016

Simone Brunamonti, Teresa Jorge, Frank G. Wienhold, Beiping Luo, Maxi Böttcher, Linda Füzer, Yann Poltera, Thomas Peter
Swiss Federal Institute of Technology (ETH), Zürich, Switzerland

Bhupendra Bahadur Singh, Ravi Kumar, Sunil Sonbawne, Suvarna Fadnavis
Indian Institute of Tropical Meteorology (IITM), Pune, India

Sree Harsha Hanumantu
Forschungszentrum Jülich (FZJ), Jülich, Germany

Peter Oelsner, Ruud Dirksen
German Weather Service (DWD) / GRUAN Lead Center, Lindenberg, Germany

Deepak Singh and Manish Naja
Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, India

ACAM-3 Workshop, Jinan University, Guangzhou (China), 8 June 2017
The Asian summer monsoon UTLS anticyclone: a gateway to the global stratosphere?

Impact of Asian summer monsoon on stratospheric H2O trends? And on stratospheric aerosols?

ACAM-3 Workshop, Jinan University, Guangzhou (China), 8 June 2017
The StratoClim balloon campaign in Nainital (India)

Launching site: 29.35° N, 79.46° E, 1800 m a.s.l.

Southern slopes of Himalaya highly relevant region for H2O transport to the UTLS anticyclone (Fu et al., 2006; Fadnavis et al., 2013; Heath and Fuelberg, 2014)

Monsoon campaign

30 balloon soundings in August 2016 with payload:
- Pressure, temperature, winds (RS41)
- Ozone (ECC)
- Water vapor (CFH)
- Aerosol backscatter (COBALD)

Post-monsoon campaign

5 balloon soundings in November 2016, same payload.
The StratoClim balloon campaign in Nainital (India)

Launching site: 29.35° N, 79.46° E, 1800 m a.s.l.

ECMWF analysis (0.125° res), 2 August 2016, 1200 UTC

380 K ≈ 100 hPa

Nainital mainly on the southern edge of the ASMA circulation → UTLS easterly flow
Totex TX1500 Balloon
Ascent rate ≈ 5 m/s
Burst altitude ≈ 34 km

Receiving system (VAISALA MW41)
Data frequency = 1 Hz
Vertical resolution ≈ 5 m
Sounding NT002 - Launched 3 August 2016, 1520 UTC
Sounding NT004 - Launched 6 August 2016, 1757 UTC

Onset of double tropopause: Rossby wave breaking
Fadnavis et al., submitted to ACP

Thin cirrus

H2O asc desc
O3 asc desc

T asc desc
Sice asc desc

BSR940nm asc desc
BSR455nm asc desc

ATAL
Sounding NT015 - Launched 17 August 2016, 1530 UTC

Developing cirrus cloud?
Swollen aerosol?

Temperature (°C) vs. Pressure (hPa)
H2O asc desc
O3 asc desc

O3 partial pressure (mPa)
BSR940nm asc desc
BSR455nm asc desc

Ice saturation
T asc desc
Sice asc desc

Backscatter ratio
Swollen aerosol?

Developing cirrus cloud?
Sounding NT017 - Launched 18 August 2016, 1604 UTC

- Very thin cirrus (~ 150 m) at CP-TP

- Ice saturation
- O3 partial pressure (mPa)
- Backscatter ratio

- T asc desc
- Sice asc desc
- BSR940nm asc desc
- BSR455nm asc desc
- H2O asc desc
- O3 asc desc

- Very thin cirrus (~ 150 m) at CP-TP
UTLS clouds vs aerosols: COBALD interpretation

\[
CI = \frac{\text{BSR}@940\text{nm} - 1}{\text{BSR}@455\text{nm} - 1}
\]

Assuming a single lognormal size distribution, color index is independent of number density and can be used as an indicator of particle size.

H$_2$SO$_4$/H$_2$O aerosol

Ice (spherical)

Likely ice

Likely no ice

Thick cirrus

\[CI \approx 30\] (geometric limit)

\[\rightarrow\text{crystal size} >> 4 \mu m\]

BSR@940nm >> 100

55nm -1)

distribution, iber density

particle size
High-altitude, optically-thin cirrus clouds observed in 7/16 COBALD soundings in August 2016

Low BSR → Low number density → Heterogeneous nucleation?

Future work: microphysical box modeling simulations
COBALD clear-sky aerosol backscatter (455 nm)

All COBALD data from August 2016 (16 soundings) and mean profile after subtracting in-cloud data

Cloud-filtering threshold:
- BSR@940nm < 2.5
- Color index < 7
- Ice saturation < 0.7

similar to Vernier et al. (2015)

Further refinement planned:
- RHw < 95% for T > 0 °C
  (to show boundary layer aerosols)
Campaign overview: mean profiles T, O3, H2O, aerosol BSR

August (30 soundings) vs November (5 soundings)

(A) Temperature from RS41, (B) ozone mixing ratio from ECC, (C) water vapor mixing ratio from CFH, (D) clear-sky aerosol backscatter ratio (BSR) at 455 nm from COBALD (cloud filtering threshold: color index < 7, BSR 940 nm < 2.5, ice saturation < 0.7). Horizontal lines: mean cold-point tropopause (CP-TP) and WMO tropopause (WMO-TP: lapse rate < 2 °C/km for at least 2 km).
August vs November: meteorological situation (ECMWF analysis data)

Subtropical westerly jet moves south and intensifies in winter.

Jet stream moves south and intensifies in winter.

340 K

80°E

8 Aug 00 UTC

16 Aug 12 UTC

8 Nov 06 UTC
Nainital campaign overview: August vs November 2016

**August**: moist troposphere, sharp cold-point tropopause «tropical»

**November**: dry troposphere, jet stream, smooth transition between trop-strat «mid-latitude»

**August**: more tropospheric O3 in Nov vs Aug: enhanced NOx washout during monsoon season?

95% less water vapor in the lower troposphere in November vs August: dry vs monsoon season

**ATAL** aerosol BSR increased by 100% in Aug vs Nov: secondary aerosol formation? growth of background aerosol? transport from boundary layer?

**Strat temp annual cycle**

**Aug**: 7 ppm H2O at 100 hPa
→ 4.5 ppm more UTLS H2O in Aug vs Nov: convection + confinement by ASM anticyclone

**Nov**: 2.5 ppm H2O at 100 hPa
ATAL optical modeling [work in progress]

Assume pre-existing aerosol population (N=100 cm$^{-3}$) and simulate the change in size due to higher humidity in August vs November (diffusional growth model). Then calculate the resulting change in aerosol BSR (Mie-theory model).

Change in size due to diffusional growth is not sufficient to reproduce the BSR difference observed in Aug vs Nov (independent of number density assumed).

This implies that either secondary aerosol formation or transport of particulate matter by convection is involved in ATAL formation.

Sulfuric acid: growth factor from diffusional growth model
Humic acid: growth factor parameterization from Badger et al. (2006)
Lagrangian match measurements: Lhasa-Nainital

1. Balloon launched from upwind station (Lhasa, SWOP campaign)
   LAGRANTO trajectories along ECMWF analysis (6-hourly) + forecast (1-hourly) data, resolution 0.125°

2. Forward trajectories initialized from balloon track based on ECMWF forecast

3. Optimize launch time at downwind station (Nainital) for best match with trajectories

Match #1
Lhasa LH104 – 2 Aug 1532 UTC
Nainital NT002 – 3 Aug 1520 UTC

Match #2
Lhasa LH109 – 10 Aug 1928 UTC
Nainital NT007 – 11 Aug 1857 UTC

Match #3
Lhasa LH113 – 18 Aug 1732 UTC
Nainital NT018 – 19 Aug 1728 UTC

Time = 0
Lhasa LH113 – 18 Aug 1732 UTC
Nainital NT018 – 19 Aug 1728 UTC

Trajectories: LAGRANTO based on ECMWF analysis (6-hourly) + forecast (1-hourly), resolution 0.125°

Diabatic correction: vertical motion calculated with Fu and Liou [1993] model for heating rates by cirrus clouds

Match distance ~ 40 km In LS
UTLS H2O: CFH vs ECMWF

**CFH:** all data from 29 soundings (2-31 August 2016)

**ECMWF:** analysis (6-hourly) + forecast (1-hourly) data, 0.125° resolution, August 2016 (entire month)

ECMWF slightly overestimates UTLS H2O
UTLS Temp: RS41 vs ECMWF

RS41: all data from 29 soundings (2-31 August 2016)

ECMWF: analysis (6-hourly) + forecast (1-hourly) data, 0.125° resolution, August 2016 (entire month)
In summary

- 30 balloon-borne profiles of T, H2O, O3 and aerosol BSR measured in Nainital, India (southern slopes of Himalaya) in August 2016 + 5 in November 2016

- Many high-resolution observations of optically-thin cirrus clouds inside the ASMA

Future work: microphysical simulations to estimate ice number density

- In-situ observations of Asian tropopause aerosol layer (ATAL)

- High quality H2O measurements up to the middle stratosphere: 4.5 ppm more H2O at the UTLS in August vs. November

- Statistical comparison of UTLS H2O and T with ECMWF analysis

- 3 match measurements with SWOP campaign in Lhasa, China

- New campaign in July-August 2017, coordinated with Geophysica-M55