The Asian Tropopause Aerosol Layer

balloon-borne measurements, satellite observations and modeling approaches

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The Existence of the ATAL was recognized through CALIOP lidar observations

Buildup of enhanced aerosol associated with Asian Summer Monsoon anticyclone, extending from the E. Med Sea to W. China

Extends from top of convective outflow over much of SE Asia
Validation of CALIPSO observations
with balloon-borne backscatter measurements

Stratospheric aerosol layer

- COBALD backscatter data from Lhasa in August 2013 (SWOP campaign, courtesy J. Bian and F. Wienhold)
- Multiple cloud-clearing methods (using RH < 70%, Color Index < 7, Depolarization < 5%)
- Good agreement between COBALD and CALIOP
- ATAL not the result of unfiltered cirrus clouds

Vernier et al., JGR 2015
Limited in situ observations indicate aerosol composition 10-12 km in lower ATAL mainly Sulfate + Carbonaceous

CARIBIC AUG 2006–2008 elemental composition C/S (10–12 km)

CARIBIC impactor data
Martinsson et al., 2014

<table>
<thead>
<tr>
<th></th>
<th>ng S m^{-3} (STP)</th>
<th>ng C m^{-3} (STP)</th>
<th>C/S</th>
<th>PV &lt; 1 PVU; 0° &lt; lat &lt; 45°N; P &lt; 300 hPa; 20° &lt; lon &lt; 130°E</th>
</tr>
</thead>
<tbody>
<tr>
<td>median</td>
<td>12</td>
<td>25</td>
<td>1.8</td>
<td>From Vernier et al. (JGR, 2015)</td>
</tr>
<tr>
<td>mean</td>
<td>21</td>
<td>29</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Std</td>
<td>23</td>
<td>15</td>
<td>2.6</td>
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SO$_2$ in-situ observations in Asian Monsoon outflow

HALO ESMVal flight of 18 Sept. 2012, shows up to **30 ppt SO$_2$ at ~15km** in UT Asian outflow.

from A. Roiger et al. presentation to SPARC SSIROC workshop, Atlanta, GA, October, 28-30, 2013.

MIPAS shows SO$_2$ of 50-100 ppt at 14-16 km in seasonal mean maps (2002-2012), filtered for volcanic episodes.

from M. Hoepfner et al., MIPAS SO2 in the UTLS, ACPD, 2015.
Origin of ATAL

Trajectory mapping of CALIPSO observations to regions of deep convection (BT<220K from Kalpana);

Trajectory-mapped CALIPSO SR (AOI) to locations of deep convection, 1-16 Aug., 2008, indicates Northern India as key deep convective source for elevated aerosol in the ATAL.

Vernier et al., JGR 2015
BATAL 2015 : Balloon-borne measurements of the ATAL

5 weeks : July-August 2015 : 30 Launches/ 4 locations/9 Institutes involved

- King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia, Aug 15
  - 6 launches of COBALD backscatter and meteorological sondes

- 29 July-13 Aug 15 : Tata Institute for Fundamental Research Balloon facility, Hyderabad, India, 11 Launches of large and small aerosol, and chemical sensors

- 17-25 July 15: National Atmospheric Research Laboratory, Gadanki, India,
  - 6 launches of aerosol and chemical sensors

- , 15-24 Aug 15 : Banaras Hindu University, Varanasi, India
  - 7 launches of aerosol and chemical sensors
Significant enhancement of aerosol SR observed during the summer 2015

BATAL launching locations covered a large area from the southern to the northern edge of the ATAL and the convective outflow region (Arabic Peninsula)

Lower and middle stratosphere still influence by an old volcanic plume from Kelud eruption in Feb 2014.
BATAL 2015/COBALD flights

- COBALD backscatter and Temp Profiles
- Thin aerosol layers near the tropopause
- Contrast with broader layer observed from the Arabic Peninsula
- Ice clouds near the tropopause over Varanasi
Moisture transport in the UTLS, HF flight of 8/13

- Maximum of aerosol measured by COBALD found at the cold point tropopause
- Low Color Index (CI, blue line) for aerosol measured by COBALD contrasts with CI for ice clouds which is near unity (15-16.5km).
- Enhanced water vapor (up to 8-9ppmv) near 18 km likely resulting from the recent convective transport of moisture
Air masses origin

- Back-trajectories from air masses sampled by the 08/13 HF balloon flight from Hyderabad
- Influenced by deep convection over Western Burma and Eastern India previous 48-72 h.
First size distribution obtained from the ATAL

Maximum of COBALD SR coincides with peak in OPC number concentration for \( r > 75 \) nm at the cold point tropopause (data for unheated inlet shown)

~97% of particles counted lie in the size range \( 0.075 < r < 0.15 \) μm

Heated/unheated inlets on OPC instruments indicate ATAL composed primarily of very small/liquid particles
GEOS-Chem simulations

3-D CTM for gas-phase and aerosols transport and photochemistry in the troposphere, driven by GEOS-5 meteorology (www.geos-chem.org), V9.02, 2x2.5 deg. 72 levels.

**Emissions:**
**Fossil fuel:** EDGAR, with regional options, e.g. Streets (S.E. Asia);
**Carbonaceous aerosol:** Bond (2007)
**Biofuel:** Logan and Yevich (2003), with regional options
**Biogenic:** MEGAN
**Biomass Burning:** GFED3 (daily)
**Volcanic:** (SO$_2$ from AeroCom project)

**Aerosol Components:** OC, BC, SO4, dust , NO3, limited SOA in current run.

6 month simulations (1 Apr. 2008 – 1 Oct. 2008)

*Update to wet scavenging of SO$_2$ in convective updrafts:*

*Fraction of SO$_2$ subject to scavenging limited by Effective Henry’s Law equilibrium and aqueous oxidation by H2O2*
FF, BF emissions of SO2, OC, July 2008 with (left) without (right) those of south, east Asia

SO2 FF+B0080701

OC FF+B0080701

No south and east Asia emissions

NO south and east Asia emissions
G-C columns of SO4, OC, SO2
S/C mass ratio July 2008, CARIBIC observations
G-C Latitude X-sections
45-105°E average, July, 2008
G-C columns (100-230 mb), July 2008 mean
Contribution of S.E. Asian emissions

<table>
<thead>
<tr>
<th></th>
<th>Full suite of emissions</th>
<th>No S.E. Asia FF, BioF emissions</th>
<th>Percent difference</th>
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</thead>
<tbody>
<tr>
<td><strong>SO2</strong></td>
<td><img src="image1" alt="SO2 image" /></td>
<td><img src="image2" alt="SO2 (noSEA) image" /></td>
<td><img src="image3" alt="SO2 column % diff image" /></td>
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<tr>
<td><strong>SO4</strong></td>
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<tr>
<td><strong>OC</strong></td>
<td><img src="image7" alt="OC image" /></td>
<td><img src="image8" alt="OC (noSEA) image" /></td>
<td><img src="image9" alt="OC column % diff image" /></td>
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</tbody>
</table>

SO2: Peaks to 100%
SO4: Peaks to 90%
OC: Peaks to 95%

SO2, SO4, OC colm 100–230 mb 20080701
SO2 (noSEA), SO4 (noSEA), OC (noSEA) 100–230 mb 20080701
SO2 column % diff 20080701

ug C or S m⁻²

%
Conclusions

• Indian Sub-continent key place to understand ATAL’s origin

• Key results of the BATAL campaign includes:
  - First size distribution of the ATAL: Made of very small/volatile particles of less than 0.2 micron.
  - Strongly correlated with Cold Point Temperature
  - Influenced by convective moisture.
  - Likely resulting from New Particle Formation (sulfate or SOA?)

• Modeling studies indicate:
  - ATAL composition a combination of sulfate and organic carbon
  - South and East Asian sources dominant
  - Contributions of regional emissions sensitive to parameterized wet scavenging efficiency
What is the origin of ATAL?

- Modeling by Neely using WACCM suggests that the aerosol is primarily sulfate with about 30% originating in south Asia.
- Similarly, work by Fairlie suggests that it is primarily sulfate but that up to 90% of the sulfur originates in India.
- Composition and source remains a matter of debate at this time.
Improved representation wet scavenging in convective updrafts for SO2 in GEOS-Chem CTM

- MIPAS shows SO$_2$ of 50-100 ppt at 14-16 km in seasonal mean maps (2002-2012), filtered for volcanic episodes. From M. Hoepfner et al., ACP, 2015.
- SO2 in new scheme, allowed to survive convective storm and be converted into aerosol in the Upper Troposphere (consistent with satellite and a few in situ measurements)