Long-term trends of tropospheric ozone over South and East Asia

A. Gaudel, O. R. Cooper, B. Hassler, H. Petetin, D. Tarasick, V. Thouret

NOAA ESRL GMD 44th Global Monitoring Annual Conference, May 18, 2016
Mission:
To provide the research community with an up-to-date scientific assessment of tropospheric ozone’s global distribution and trends from the surface to the tropopause.

Deliverables:
1) The first tropospheric ozone assessment report based on the peer-reviewed literature and new analyses.
2) A database containing documented data on ozone exposure and dose metrics at hundreds of measurement sites around the world (urban and non-urban), freely accessible for research on the global-scale impact of ozone on climate, human health and crop/ecosystem productivity.
Nighttime lights of the world in 1992

Global population (United Nations): 5.5 billion

DMSP-OLS nighttime lights (V4) detected by The Defense Meteorological Satellite Program:  http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html
Data collected by US Air Force Weather Agency, processed by NOAA NGDC and plotted by Owen Cooper, CIRES, U. of Colorado/NOAA ESRL
Nighttime lights of the world in 2013

Global population (*United Nations*): 7.2 billion (30% increase)


Data collected by US Air Force Weather Agency, processed by NOAA NGDC and plotted by Owen Cooper, CIRES, U. of Colorado/NOAA ESRL
During 1994-2014 the global CO₂ emission rate from fossil fuels and industry increased by 60%.

CO₂ emissions over China and India are increasing, whereas CO₂ emissions over USA and Europe are decreasing.
Changes in OMI tropospheric column NO$_2$ above China, 2004-2014.

OMI/MLS tropospheric column ozone and trends, 2005-2015: Annual

Lower panel: White dots indicate grid cells with statistically significant trends

The strongest increases in ozone are at low latitudes, especially over the growing emissions regions of India and south east Asia.

Are the satellite-detected increases above Asia confirmed by in situ observations?

OMI/MLS tropospheric column ozone product produced by Jerry Ziemke, Morgan State University/NASA GSFC
IAGOS observations over Asia
1994-2014

3 regions:
- India
- South-East Asia
- East Asia

About 500 flights per season for the 20-year period

IAGOS data freely provided by the IAGOS Team, http://www.iagos.org/
IAGOS observations over Asia 1994-2014

3 regions:
- India
- South-East Asia
- East Asia

About 500 flights per season for the 20-year period

IAGOS data freely provided by the IAGOS Team, http://www.iagos.org/
IAGOS observations over Asia 1994-2014

3 regions:
- India
- South-East Asia
- East Asia

About 500 flights

40-50 profiles per season, mostly after 2005

High quality, in situ data sets to evaluate the 2005-2015 satellite data.
In situ observations require a longer time period (1994-2014) to achieve robust sampling statistics.

SHADOZ ozonesonde data freely provided by A. Thompson and J. Witte, NASA GSFC, http://croc.gsfc.nasa.gov/shadoz/
South East Asia
50\textsuperscript{th} percentile


Except in DJF in the lower troposphere

$\Delta O_3 \sim 10$ to 20 ppbv

or

$\sim 15$ to 60%

500-300 hPa: $\Delta O_3 = 20$ ppbv

975-875 hPa: $\Delta O_3 = 20$ ppbv
South East Asia
95th percentile


Except in DJF in the lower troposphere

\[ \Delta O_3 \sim 10 \text{ to } 50 \text{ ppbv} \]
or
\[ \sim 10 \text{ to } 55\% \]

975-875 hPa: \( \Delta O_3 = 20 \text{ ppbv} \)

975-875 hPa: \( \Delta O_3 = 50 \text{ ppbv} \)

975-875 hPa: \( \Delta O_3 = 30 \text{ ppbv} \)
South East Asia
5th percentile


$\Delta O_3 \sim 10$ ppbv
or
$\sim 20$ to 75%
### East Asia \( \Delta O_3 \) (ppbv) and % change between both time period 1994-2004 and 2005-2014

* Indicate statistically significant difference between averages

<table>
<thead>
<tr>
<th>( \Delta O_3 ) (ppbv) % change</th>
<th>DJF</th>
<th>MAM</th>
<th>JJA</th>
<th>SON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure level (hPa)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg</td>
<td>Avg</td>
<td>Avg</td>
<td>Avg</td>
<td>Avg</td>
</tr>
<tr>
<td>500-300</td>
<td>1.1</td>
<td>2.2</td>
<td>7.1*</td>
<td>5.4*</td>
</tr>
<tr>
<td></td>
<td>2%</td>
<td>3%</td>
<td>9%</td>
<td>9%</td>
</tr>
<tr>
<td>700-500</td>
<td>0.5</td>
<td>2.9*</td>
<td>4.9*</td>
<td>5.1*</td>
</tr>
<tr>
<td></td>
<td>1%</td>
<td>4%</td>
<td>8%</td>
<td>9%</td>
</tr>
<tr>
<td>875-700</td>
<td>3.4*</td>
<td>6.8*</td>
<td>8.5*</td>
<td>7.6*</td>
</tr>
<tr>
<td></td>
<td>7%</td>
<td>10%</td>
<td>14%</td>
<td>14%</td>
</tr>
<tr>
<td>975-875</td>
<td>1.6</td>
<td>9.1*</td>
<td>20.4*</td>
<td>9.9*</td>
</tr>
<tr>
<td></td>
<td>4%</td>
<td>14%</td>
<td>30%</td>
<td>19%</td>
</tr>
</tbody>
</table>
East Asia  ΔO3 (ppbv) and % change between both time period 1994-2004 and 2005-2014
* Indicate statistically significant difference between averages

<table>
<thead>
<tr>
<th>ΔO3 (ppbv)</th>
<th>DJF</th>
<th>MAM</th>
<th>JJA</th>
<th>SON</th>
</tr>
</thead>
<tbody>
<tr>
<td>% change</td>
<td>Avg</td>
<td>Avg</td>
<td>Avg</td>
<td>Avg</td>
</tr>
<tr>
<td>Pressure level (hPa)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500-300</td>
<td>1.1</td>
<td>2.2</td>
<td>7.1*</td>
<td>5.4*</td>
</tr>
<tr>
<td></td>
<td>2%</td>
<td>3%</td>
<td>9%</td>
<td>9%</td>
</tr>
<tr>
<td>700-500</td>
<td>0.5</td>
<td>2.9*</td>
<td>4.9*</td>
<td>5.1*</td>
</tr>
<tr>
<td></td>
<td>1%</td>
<td>4%</td>
<td>8%</td>
<td>9%</td>
</tr>
<tr>
<td>875-700</td>
<td>3.4*</td>
<td>6.8*</td>
<td>8.5*</td>
<td>7.6*</td>
</tr>
<tr>
<td></td>
<td>7%</td>
<td>10%</td>
<td>14%</td>
<td>14%</td>
</tr>
<tr>
<td>975-875</td>
<td>1.6</td>
<td>9.1*</td>
<td>20.4*</td>
<td>9.9*</td>
</tr>
<tr>
<td></td>
<td>4%</td>
<td>14%</td>
<td>30%</td>
<td>19%</td>
</tr>
</tbody>
</table>

- High increase of ozone in MAM through SON in the lower troposphere
<table>
<thead>
<tr>
<th>ΔO3 (ppbv) % change</th>
<th>DJF</th>
<th>MAM</th>
<th>JJA</th>
<th>SON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure level (hPa)</td>
<td>Avg</td>
<td>Avg</td>
<td>Avg</td>
<td>Avg</td>
</tr>
<tr>
<td>500-300</td>
<td>2.8*</td>
<td>5.6*</td>
<td>-3.4</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>6%</td>
<td>8%</td>
<td>-6%</td>
<td>1%</td>
</tr>
<tr>
<td>700-500</td>
<td>1.9*</td>
<td>5*</td>
<td>-3.7</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>4%</td>
<td>8%</td>
<td>-8%</td>
<td>3%</td>
</tr>
<tr>
<td>875-700</td>
<td>3.8*</td>
<td>4.9*</td>
<td>-2</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>8%</td>
<td>9%</td>
<td>-6%</td>
<td>4%</td>
</tr>
<tr>
<td>975-875</td>
<td>3.9*</td>
<td>3.1</td>
<td>-0.9</td>
<td>-1.6</td>
</tr>
<tr>
<td></td>
<td>8%</td>
<td>7%</td>
<td>-4%</td>
<td>-4%</td>
</tr>
</tbody>
</table>

* Indicate statistically significant difference between averages
Conclusions

• **South East Asia**: Increase for 50\textsuperscript{th}, 95\textsuperscript{th}, 5\textsuperscript{th} for all altitudes and seasons except in DJF in the lower troposphere, specifically for 95\textsuperscript{th} percentile

• **East Asia**: Maximum of increase of the ozone means in MAM through SON in the lower troposphere

• **India**: Increase of ozone means in DJF/MAM. Also in the mid-troposphere in JJA/SON
  
  + Decrease of ozone means in JJA, but not statistically significant

Direct comparison between in situ and satellite observations is not possible, however:

- Ozone changes in South East Asia and East Asia are consistent with OMI/MLS results
- Ozone changes over India need to be studied further
OMI tropospheric column NO\textsubscript{2} and trends, 2005-2015: May-October

Lower panel: White dots indicate grid cells with statistically significant trends

The total mass of tropospheric NO\textsubscript{2} in the N. Hemisphere increased by 5% from 2005-2007 through 2013-2015.

2/3 of the increase occurred at low latitudes (0-30 N) where ozone production efficiency is greatest.

*OMI tropospheric NO\textsubscript{2} data freely provided by www.temis.nl*

*Boersma et al., An improved retrieval of tropospheric NO\textsubscript{2} columns from the Ozone Monitoring Instrument, Atmos. Meas. Tech., 4, 1905-1928, 2011*
The global (60°N – 60°S) tropospheric ozone burden has increased by 9% (25 Tg) over 11 years (2005-2015).

Also shown is the NOAA CPC Niño 3.4 Index which is the monthly sea surface temperature anomaly in the Niño 3.4 region (5°N-5°S, 120°-170°W) of the east-central tropical Pacific Ocean.


NOAA CPC Niño 3.4 Index and Oceanic Niño Index (ONI) can be downloaded from:
http://www.cpc.ncep.noaa.gov/data/indices/

For further information on the variability of ozone with ENSO, see:
OMI/MLS tropospheric column ozone and trends, 2005-2015: Seasonal