Tropospheric Ozone: Global distribution and radiative forcing

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1. Global distribution of tropospheric ozone
2. The increase of ozone since preindustrial times
3. Present and future radiative forcing
4. The need for a comprehensive ozone monitoring network
Tropospheric ozone is a short-lived greenhouse gas with a radiative forcing comparable to halocarbons.
This figure shows that if a fixed amount of ozone is introduced to a 1 km layer of the atmosphere, the greatest radiative forcing will occur in the upper troposphere.

8 years of weekly ozonesondes from Boulder, Colorado.

The day-to-day variability can be as great as the weekly variability.

Tropospheric Ozone Sources
Transport from stratosphere:       552 +/- 168 Tg

Chemical Production from NO\textsubscript{x}, CH\textsubscript{4}, CO, and hydrocarbons:     5110 +/- 606 Tg

Tropospheric Ozone Sinks
Surface deposition:                     1003 +/- 200 Tg
Chemical loss:                             4668 +/- 727 Tg

Tropospheric Ozone burden:         344 +/- 39 Tg (11%)

Tropospheric Ozone Lifetime:         22.3 +/- 2.0 days

Tropospheric column ozone (Dobson units) for the year 2000.

An ensemble mean from the output of 26 atmospheric chemistry models.

Historical changes in Switzerland
(from Staehelin et al., 1994, *Atmos. Environ.*)

Monthly mean surface ozone at Arosa, Villa Firnelict (1950s) and Florentinum (1989-91) and individual measurements (X) at Florentinum in the 1930s.

Ozone increased by a factor of 2-3 from 1950 to 1990

[slide courtesy of Sam Oltmans, NOAA ESRL]
Trends of N.H. surface ozone data

Ozone Deviation (%)


Date

Zugspitze
Barrow
Mace Head
Whiteface
Mauna Loa
Izana

[slide courtesy of Sam Oltmans, NOAA ESRL]
Springtime mean $O_3$ levels have increased on the US west coast


### Elevated Data sets

<table>
<thead>
<tr>
<th>Sites</th>
<th>slope (ppbv/yr)</th>
<th>$O_3$ 2000 (ppbv)</th>
<th>$r^2$</th>
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<tbody>
<tr>
<td>Lassen</td>
<td>0.46 ± 0.39</td>
<td>45.8 ± 2.4</td>
<td>0.36</td>
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<tr>
<td>Aircraft</td>
<td>0.51</td>
<td>55.3</td>
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### Marine Boundary Layer Data Sets

<table>
<thead>
<tr>
<th>sites</th>
<th>slope (ppbv/yr)</th>
<th>$O_3$ 2000 (ppbv)</th>
<th>$r^2$</th>
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<tbody>
<tr>
<td>4 sea-level</td>
<td>0.50 ± 0.36</td>
<td>39.9 ± 3.3</td>
<td>0.44</td>
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<tr>
<td>All 5</td>
<td>0.78 ± 0.28</td>
<td>42.9 ± 2.4</td>
<td>0.68</td>
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Conclusion: Along the U.S. west coast, springtime $O_3$ has increased by 
$\approx 0.5$ ppbv/yr, i.e. $\approx 10$ ppbv in 20 years or $\approx 1-1.5 \%$/yr

(Data selected to avoid North American influence)

[slide courtesy of David Parrish, NOAA ESRL]
Contribution of anthropogenic emissions to surface ozone

(Lemarque et al., 2005, *J. Geophys. Res.*)

Anthropogenic emissions have increased the tropospheric ozone burden by 32%.

Average radiative forcing from 10 chemistry-climate models:

0.32 W m$^{-2}$

(compared to 0.35 W m$^{-2}$ IPCC, 2007)

**Fig. 6.** Adjusted radiative forcing (W m$^{-2}$) between 1850 and 2000 due to tropospheric ozone change, taking into account chemical change only (i.e. “2 minus 1c”, except LMDzINCA, UM_CAM, and STOCHEM_HadAM3, for which “2 minus 1b” is shown). The radiative forcing calculation is made by the UiO-RTM and the tropopause level is based on the NCEP year 2000 reanalysis.
Tropospheric Ozone burden: 344 +/- 39 Tg (11%)
There are currently 17 sites in the Americas, north of the equator, that launch ozonesondes on a once-per-week basis.
Tropospheric ozone at 10-11 km as measured by the IONS ozonesonde network.

Same as above but with stratospheric contribution removed.

Logistics for a 1-year experiment
- $800 USD/ozonesonde
- 365 sondes per site
- 65 sites

Yearly operational cost = $19,000,000
Additional funds needed for site start-up costs and project management
IAGOS
Integration of routine Aircraft measurements into a Global Observing System

MOZAIC
Measurements of Ozone and water vapour by in-service Airbus aircraft

IAGOS: From MOZAIC to Sustainability

<table>
<thead>
<tr>
<th>Year</th>
<th>MOZAIC I+II</th>
<th>MOZAIC III</th>
<th>IAGOS FP6 Design Study</th>
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<tr>
<td>1993</td>
<td>135 kg</td>
<td>135 + 50 kg</td>
<td>100 kg</td>
</tr>
<tr>
<td>2001</td>
<td></td>
<td>O₃ + H₂O</td>
<td>O₃ + CO + NOy + NO₂ +</td>
</tr>
<tr>
<td>2004</td>
<td></td>
<td></td>
<td>H₂O + CO₂ + clouds + aerosol</td>
</tr>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2008</td>
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New Infrastructure: (e.g. through ESFRI)* 10-20 longrange aircraft, global coverage
*European Strategy Forum on Research Infrastructures

NOy instrument certified by Lufthansa


25 624 Flights 184 255 Hours
Figure 1. a) Median ozone profiles for all measurements during summer 2006 that occurred within the troposphere (PV < 1.0 ppbv). b) Same as in a) but for the FTO$_3$ quantity which has the influence from stratospheric-origin ozone removed.
Figure 3. Model calculated a) mean ozone mixing ratios at 250 hPa during August 2006, subdivided into b) the contribution of ozone transported from the stratosphere, and c) of ozone formed within the troposphere (thus a=b+c). Note stratospheric conditions prevail north of the jet stream (north of strong ozone gradients) and tropospheric conditions to the south.

Figure 4. As in Figure 3c, but for a) global lightning emissions set to zero, and b) global lightning emissions increased by a factor of 3.
Figure 5. Average column residence time (arbitrary units) for all retropumes released above each site (white dot) between 6-12 km within the troposphere. Each plot also indicates the median FTO₃ mixing ratio between 6-12 km above each site.
**Figure 6.** Average wind vectors and geopotential height of the 250 hPa surface above North America during a) August 2006, b) July-August 2004, and c) July-August 1987-2006.

**Figure 7.** Average residence time (in arbitrary units) in the upper troposphere of all retroplumes released between 6-12 km above Huntsville during a) August 2006 and b) July-August 2004.
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