Large upper tropospheric ozone enhancements above mid-latitude North America during summer

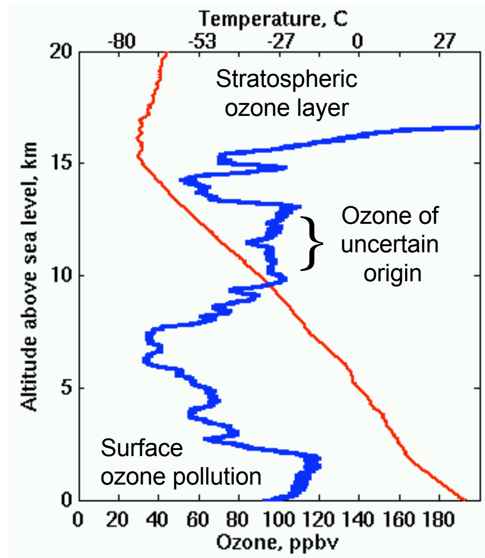
Does lightning contribute to the "ozone enhancement"?

Ozone is a key trace gas for both the chemistry and Greenhouse Effect within the troposphere, and as it is the principal pollutant associated with photochemical smog its presence in the lower atmosphere has large implications for issues of air quality.

Currently, international research programs are focusing research on the dynamics and composition of the upper troposphere and lower stratosphere (UT/LS) because of this region's influence on global climate change, with ozone once again a trace gas of primary interest.

The figure to the right shows a typical summertime ozone profile above Houston during 2004. As expected we found high levels of the so-called "bad ozone" in the lower atmosphere and high levels of the "good ozone" in the stratosphere. But we found unexpectedly high levels of ozone in the upper troposphere that was not related to strong influence from pollution.

If there is not a strong contribution by pollution to the upper tropospheric ozone enhancement, can it be explained by ozone production from NOx produced by lightning?



Ozone (blue) and temperature (red) profiles above Houston on July 15, 2004. Ozone is reported in units of parts per billion by volume, or ppbv.

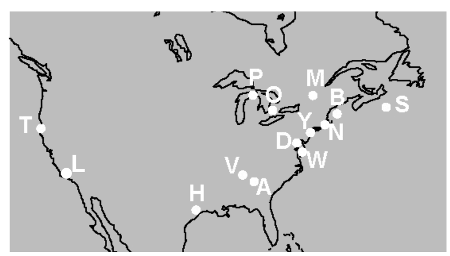
What did we do during ICARTT?

To measure the daily ozone distribution across mid-latitude North America during summer at the height of the ozone pollution season, NASA, NOAA, Environment Canada, and several US universities launched ozonesondes (balloon-borne ozone detectors) from multiple sites under the IONS (INTEX Ozonesonde Network Study) program (http://croc.gsfc.nasa.gov/intex/ions.html).

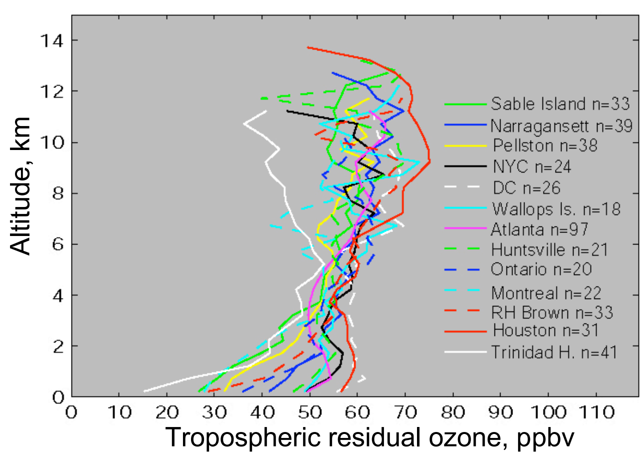
Additional ozone profiles across eastern North America were obtained from five instrumented commercial aircraft that fly between North America and Europe under the European MOZAIC program.

MOZAIC profiles were combined with ozonesonde or lidar (NASA JPL) profiles from nearby locations to form 14 monitoring sites, yielding the most detailed set of ozone measurements ever gathered across mid-latitude North America.

A particle dispersion model was used to filter out the complication of stratospheric ozone in the ozone profiles, providing us with the amount of ozone that is actually produced in the troposphere (tropospheric residual ozone).



Ozone monitoring sites



What did we learn?

A surprising result was that the upper troposphere above eastern North America contained an extra 15 ppbv of ozone compared with the more polluted surface region.

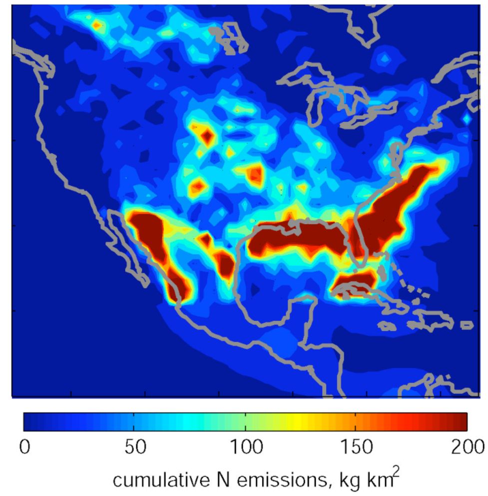
Furthermore, of the 14 ozone profile sites the two west coast sites had the least amount of ozone in the upper troposphere while Houston in the southern USA had the most. As a whole, the eastern North America sites contained an extra 16 ppbv ozone in the upper troposphere compared to the west coast. Only 2 ppbv of this enhancement can come from the direct transport of ozone from the surface to the upper troposphere. The rest must be produced in the free troposphere.

Transport studies of anthropogenic NOx emissions and MOZAIC CO (a tracer of surface pollution sources) measurements showed that the upper troposphere above Houston was less polluted or no more polluted than above eastern North America. This indicates the excess ozone above Houston must be produced in the upper troposphere from an additional source of NOx, in this case lightning.

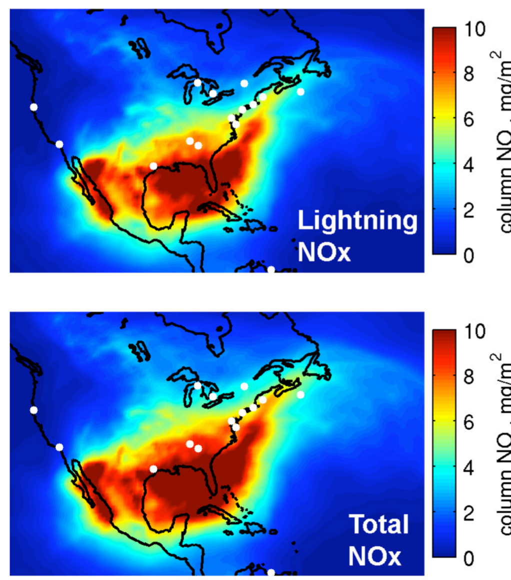
A particle dispersion model was used to simulate the transport of NOx emissions from 1) regions of lightning activity, 2) anthropogenic sources at the surface, 3) aircraft, 4) biogenic activity in soil, and 5) intense biomass burning in Canada and Alaska. Lightning was found to be the dominant source of NOx in the upper troposphere above North America.

Further photochemical modeling studies indicate that the ozone enhancement above eastern North America is consistent with the modeled NOx concentrations.

The modeling studies indicate that lightning NOx is responsible for 69-84% of the 16 ppbv ozone enhancement in the upper troposphere above eastern North America, with the remainder due to transport from the surface or production in the free troposphere from other sources of NOx.



Cumulative nitrogen emissions from lightning flashes during June 21-August 15, 2004.



Average mass of NOx in the upper troposphere due to lightning (top) and all sources (bottom). The small difference between the two plots indicates that the NOx emissions are dominated by lightning.

What does it mean?

This research indicates that lightning has a strong influence on ozone production in the upper troposphere above eastern North America.

If we are to understand the impact of human activities on the UT/LS and climate change we must first account for the influence of natural processes, both lightning and transport from the stratosphere.

This study has only given us a short 6-week snapshot of the impact of lightning and many more measurements are needed to understand its seasonal variation and its full spatial extent.

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The multi-agency ICARTT <http://www.al.noaa.gov/ICARTT/> was formed to study the sources, sinks, chemical transformations and transport of ozone, aerosols and their precursors to and over the North Atlantic Ocean. ICARTT Fact Sheets are designed to present important new science results and findings of high societal relevance to technical non-experts in the community and have been reviewed by an internal committee of peers.