Tropospheric Ozone:
Global distribution and radiative forcing

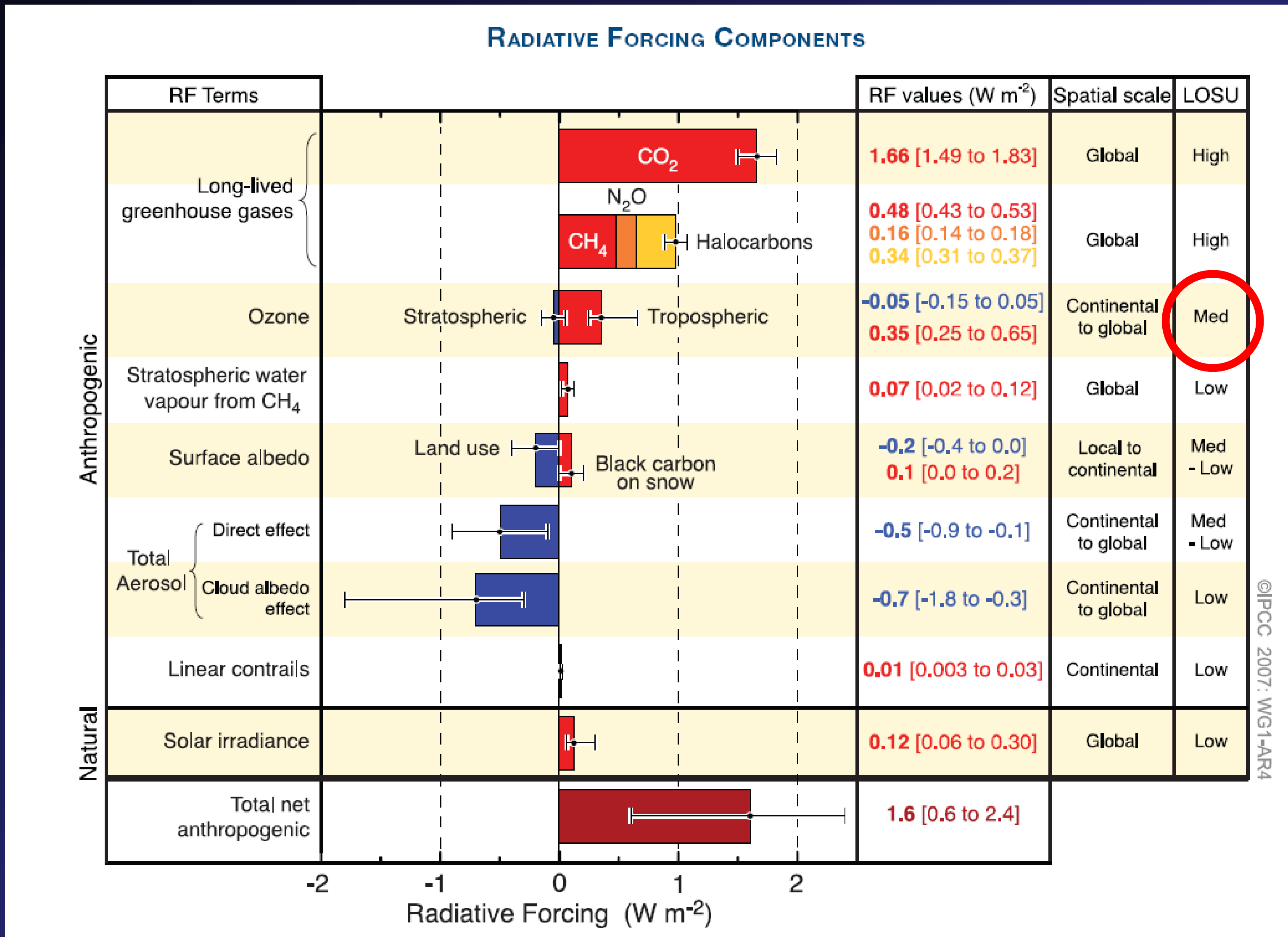
Owen R. Cooper
CIRES U. of Colorado/NOAA ESRL

1. Global distribution of tropospheric ozone

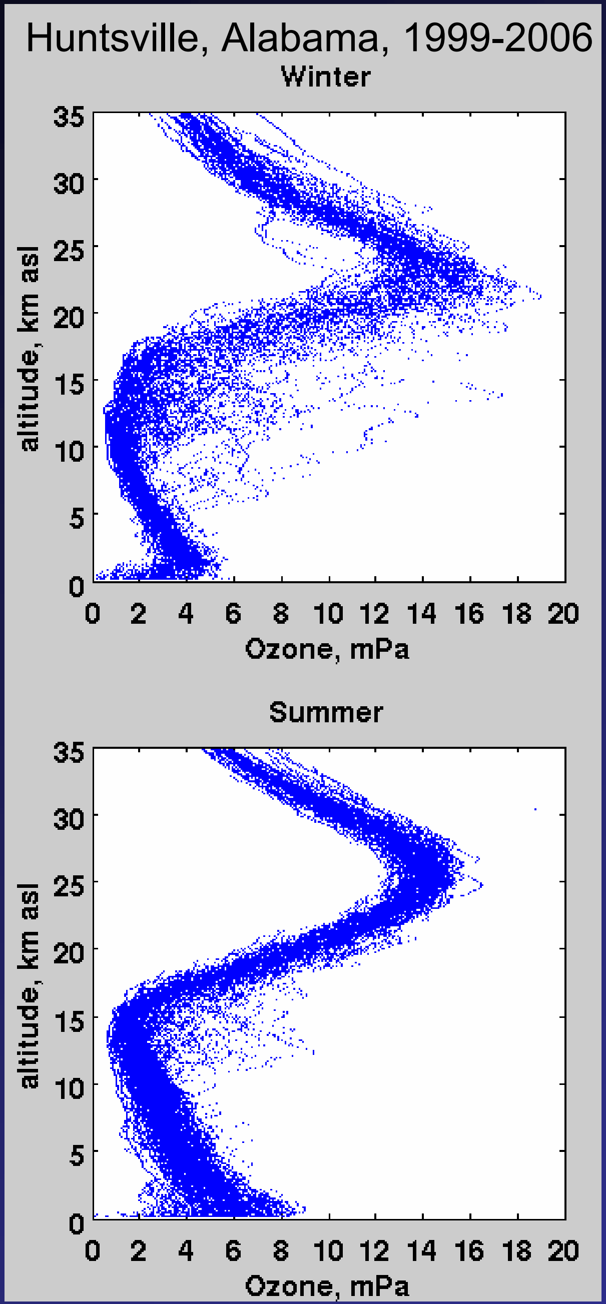
2. The increase of ozone since preindustrial times

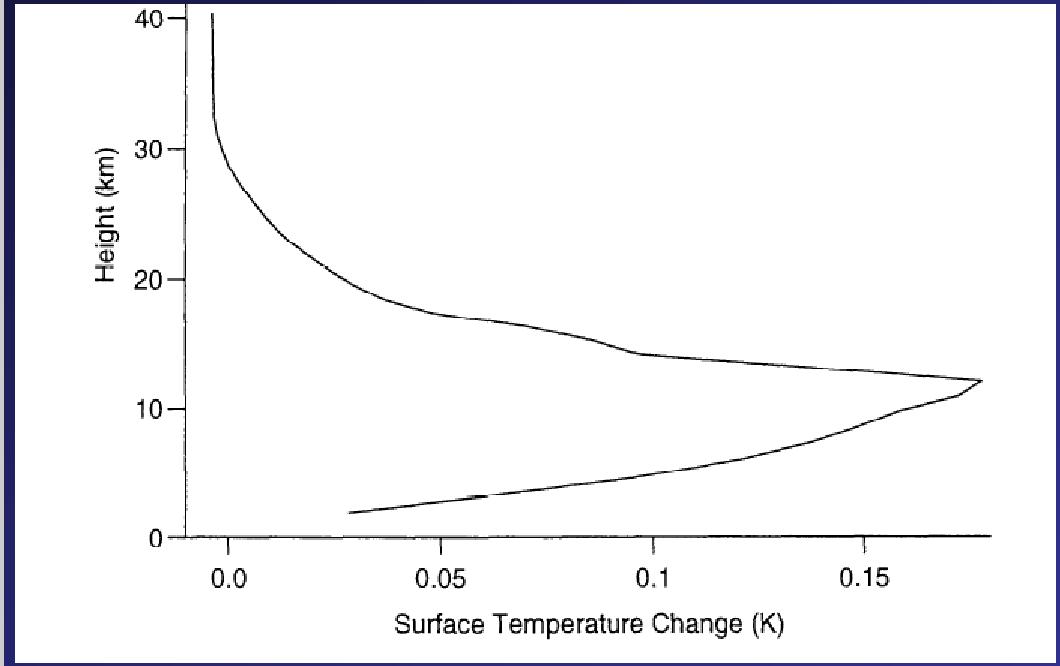
3. Present and future radiative forcing

4. The need for a comprehensive ozone monitoring network



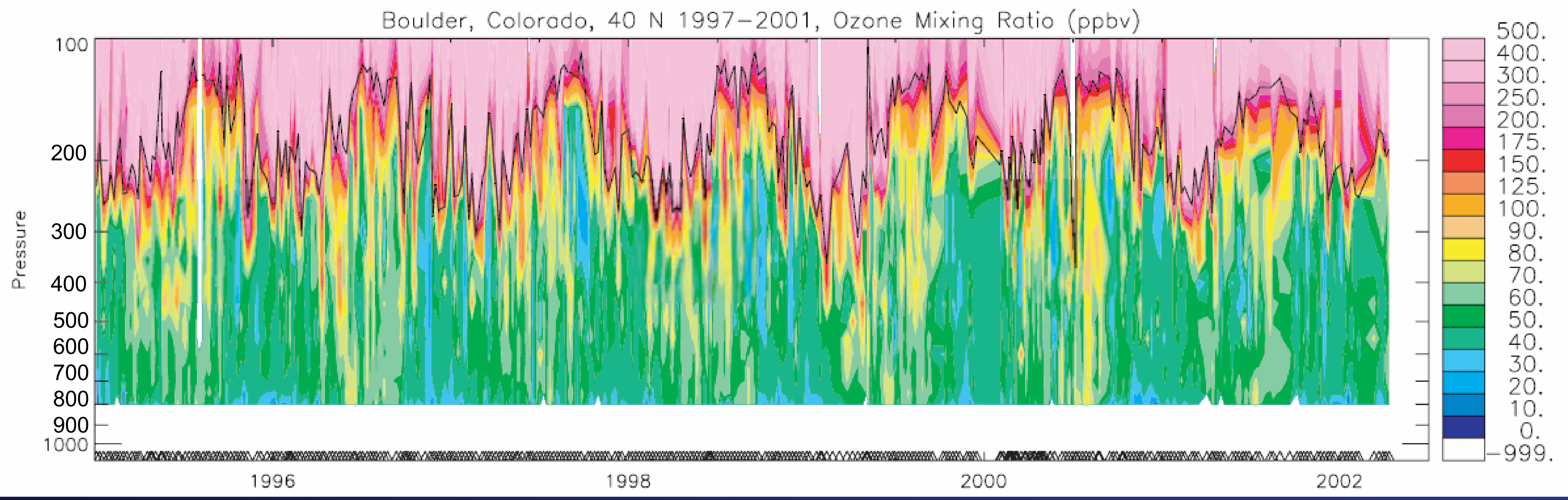
Tropospheric ozone is a short-lived greenhouse gas with a radiative forcing comparable to halocarbons.





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.

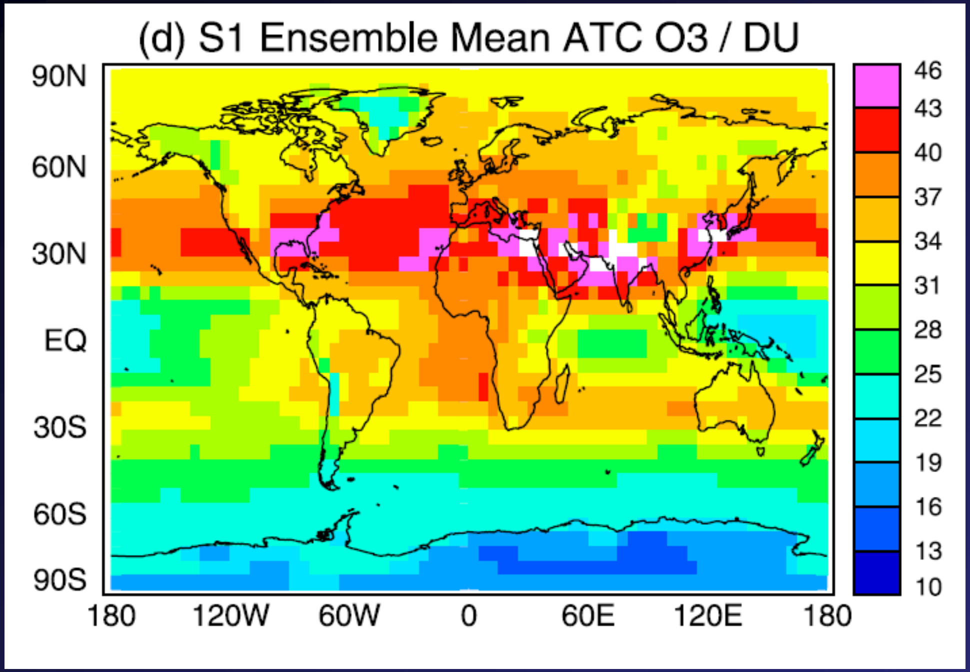
From:
Forster and Shine, Radiative forcing and temperature trends from stratospheric ozone change, *J. Geophys. Res., 102*, 1997.



8 years of weekly ozonesondes from Boulder, Colorado.

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

Newchurch et al., Vertical distribution of ozone at four sites in the United States, J. *Geophys. Res., 108*, 2003.



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

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

Stevenson et al., Multimodel ensemble simulations of present-day and near-future tropospheric ozone, J. *Geophys. Res.*, *111*, 2006.

Tropospheric Ozone Sources

Transport from stratosphere: 552 +/- 168 Tg

Chemical Production from NO_x, CH_4, CO, and hydrocarbons: 5110 +/- 606 Tg

Tropospheric Ozone Sinks

Surface deposition: 1003 +/- 200 Tg

Chemical loss: 4668 +/- 727 Tg

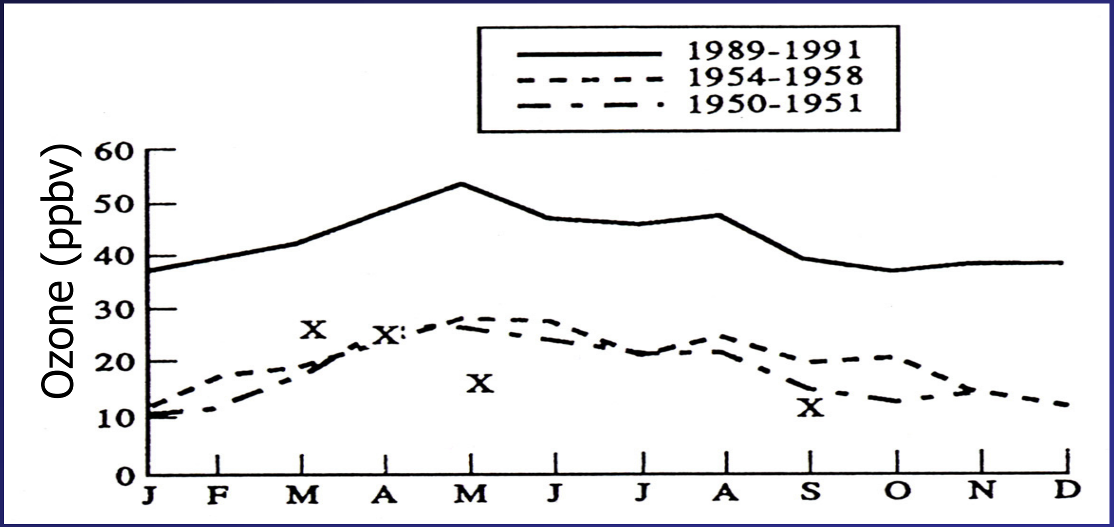
Tropospheric Ozone burden: 344 +/- 39 Tg (11%)

Tropospheric Ozone Lifetime: 22.3 +/- 2.0 days

Historical changes in Switzerland

(from Staehelin et al., 1994, *Atmos. Environ.*)

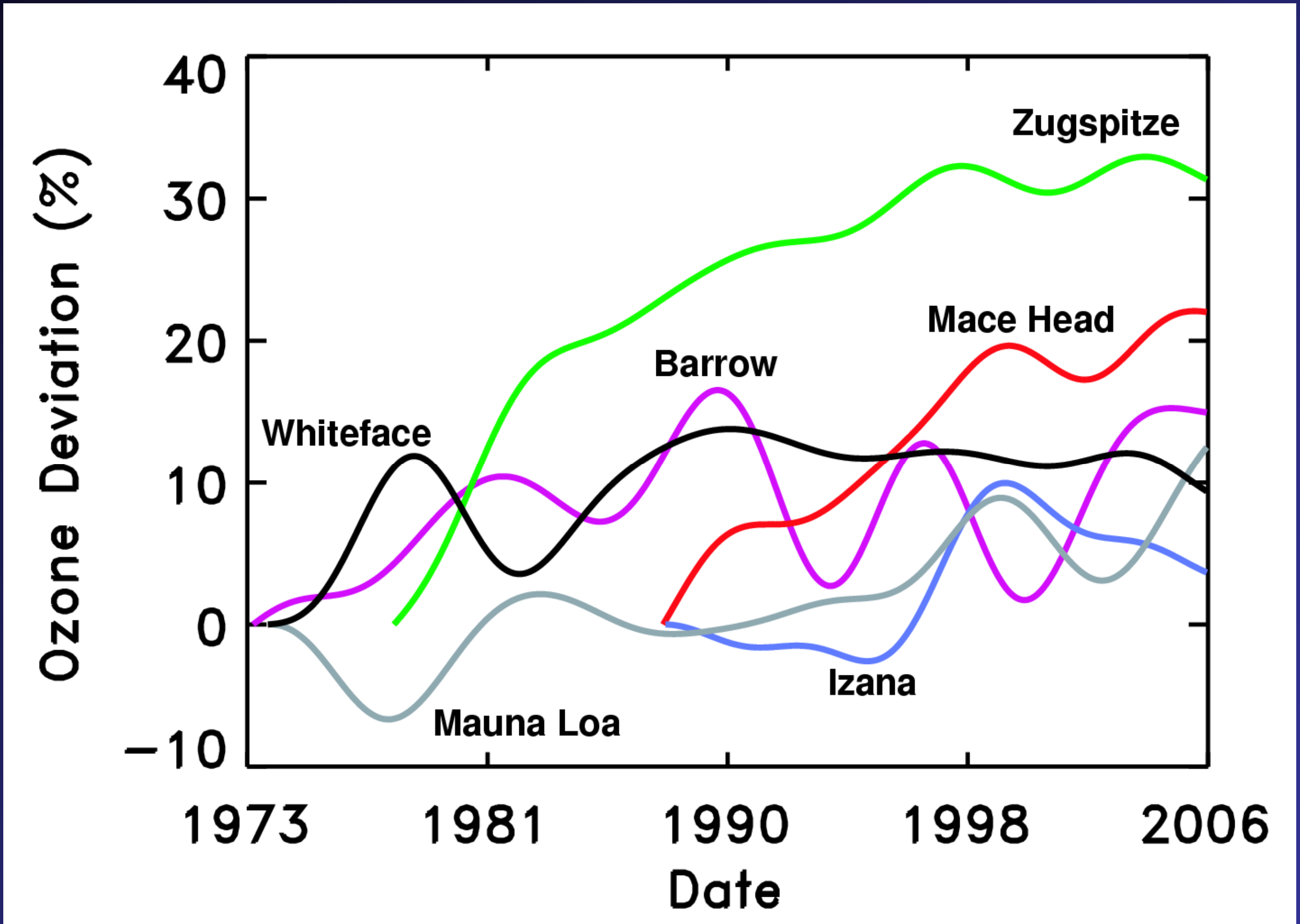
Monthly mean surface ozone at Arosa, Villa Firnelict (1950s) and Florentinum (1989-91) and individual measurements (X) at Florentinum in the 1930s.



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

[slide courtesy of Sam Oltmans, NOAA ESRL]

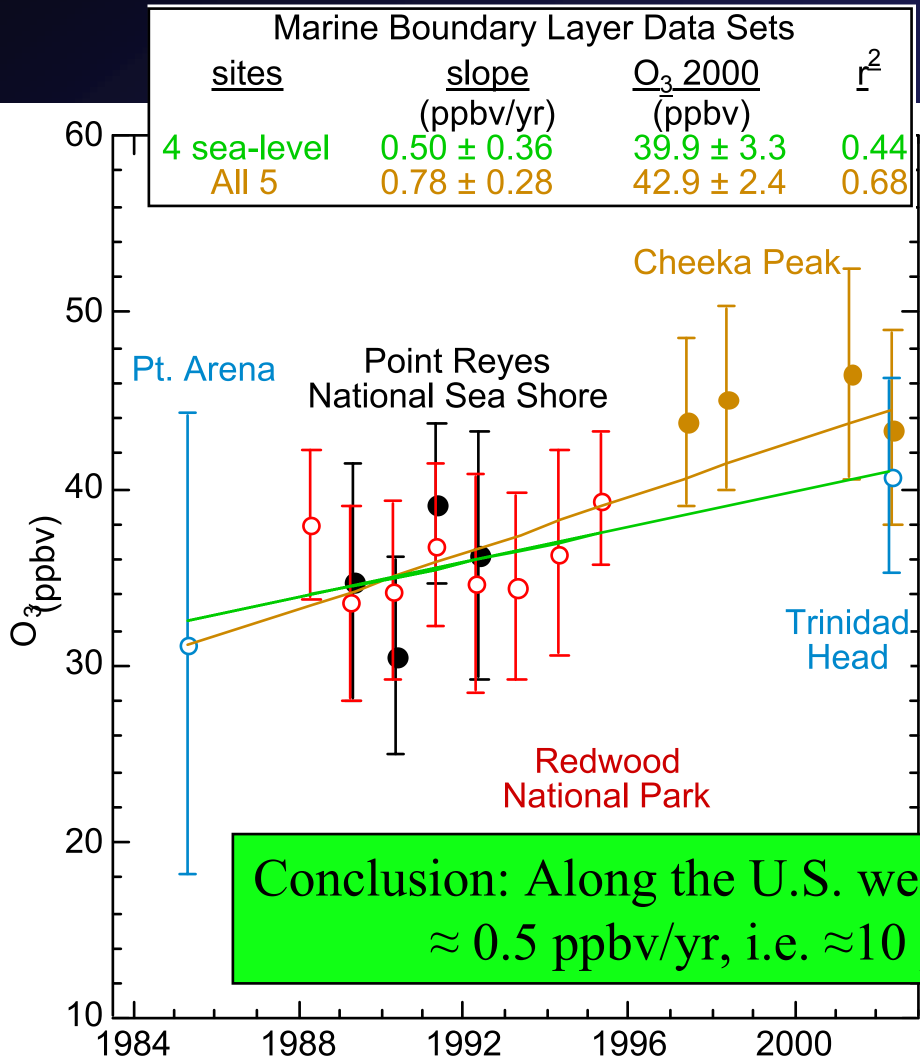
Trends of N.H. surface ozone data



[slide courtesy of Sam Oltmans, NOAA ESRL]

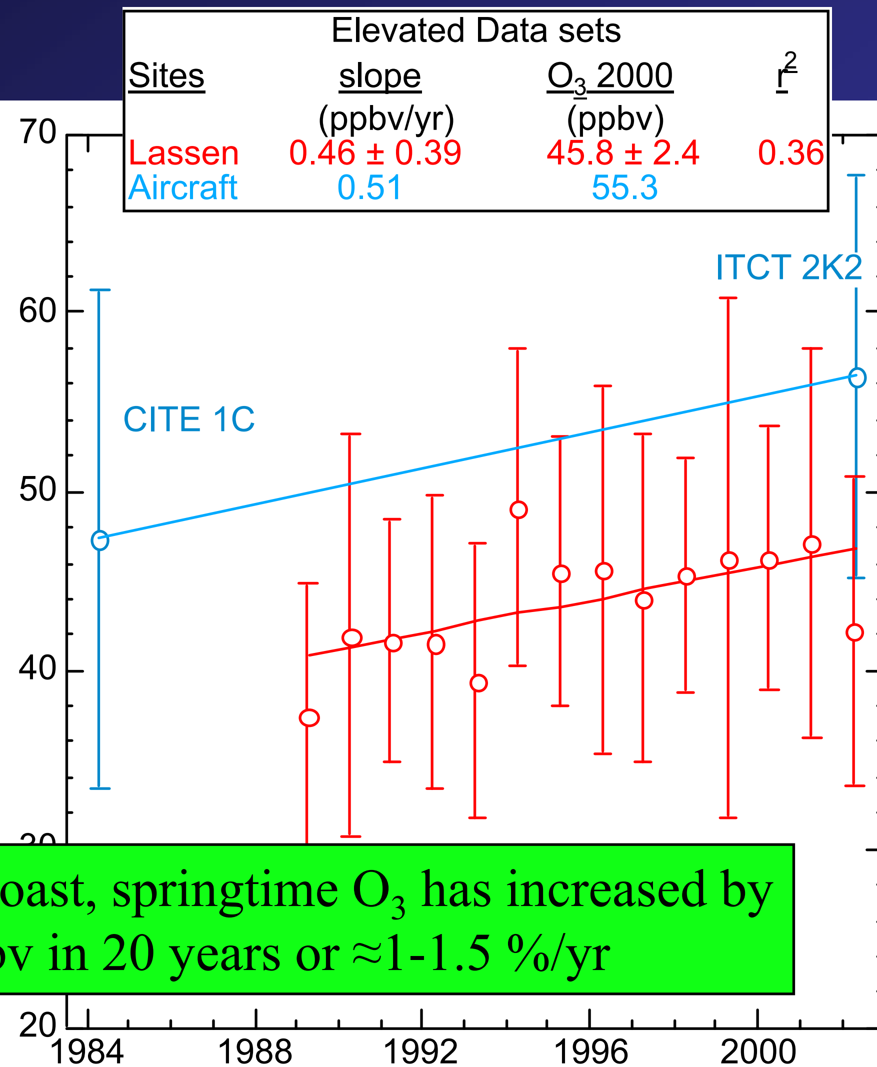
Springtime mean O_3 levels have increased on the US west coast

Jaffe et al., Increasing background ozone during spring on the west coast of North America, *Geophys. Res. Letters, 30*, 2003



Marine Boundary Layer Data Sets

sites	slope (ppbv/yr)	O_3 2000 (ppbv)	r^2
4 sea-level	0.50 ± 0.36	39.9 ± 3.3	0.44
All 5	0.78 ± 0.28	42.9 ± 2.4	0.68



Elevated Data sets

Sites	slope (ppbv/yr)	O_3 2000 (ppbv)	r^2
Lassen	0.46 ± 0.39	45.8 ± 2.4	0.36
Aircraft	0.51	55.3	

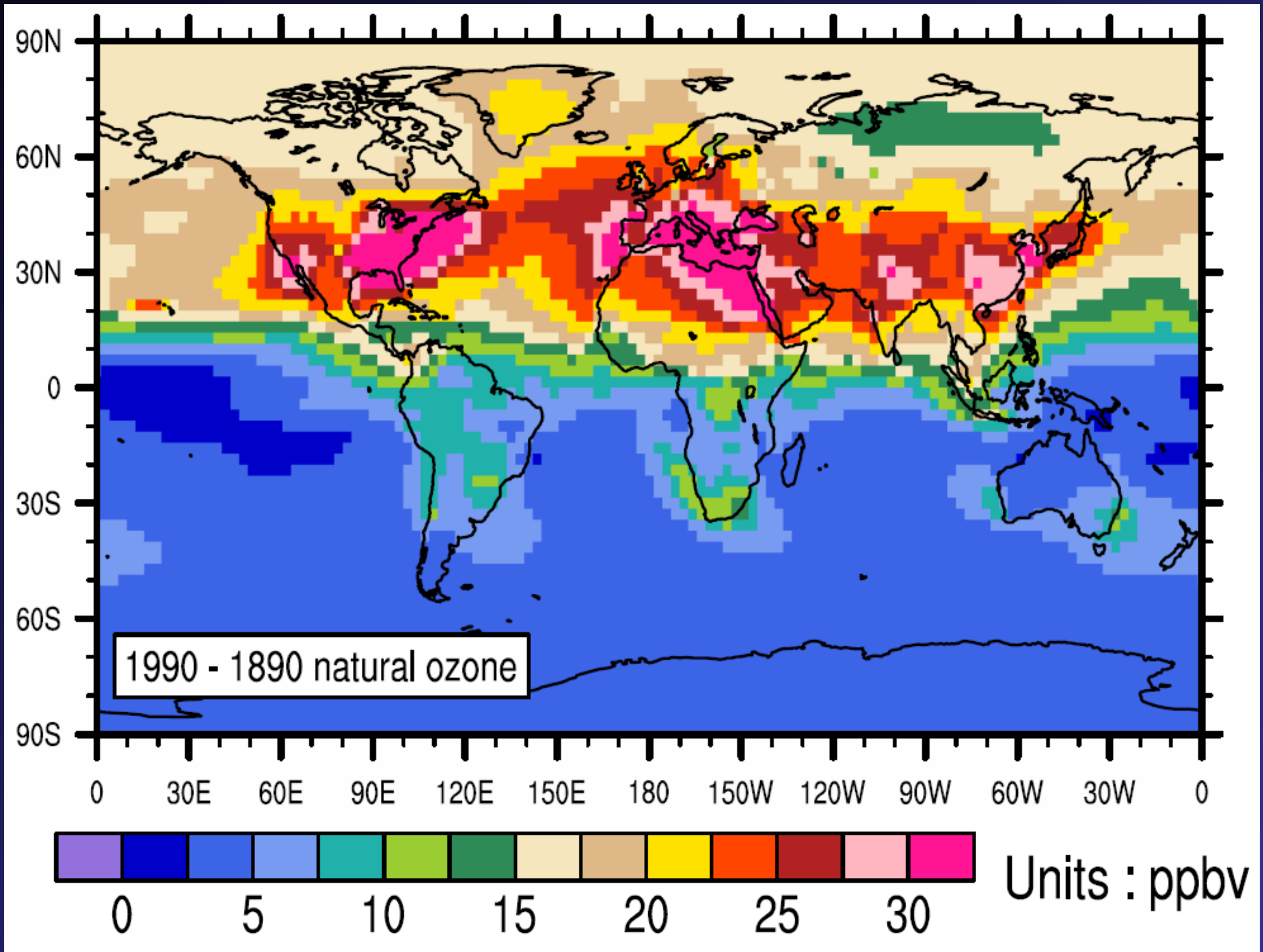
Conclusion: Along the U.S. west coast, springtime O_3 has increased by ≈ 0.5 ppbv/yr, i.e. ≈10 ppbv in 20 years or ≈1-1.5 %/yr

(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%.

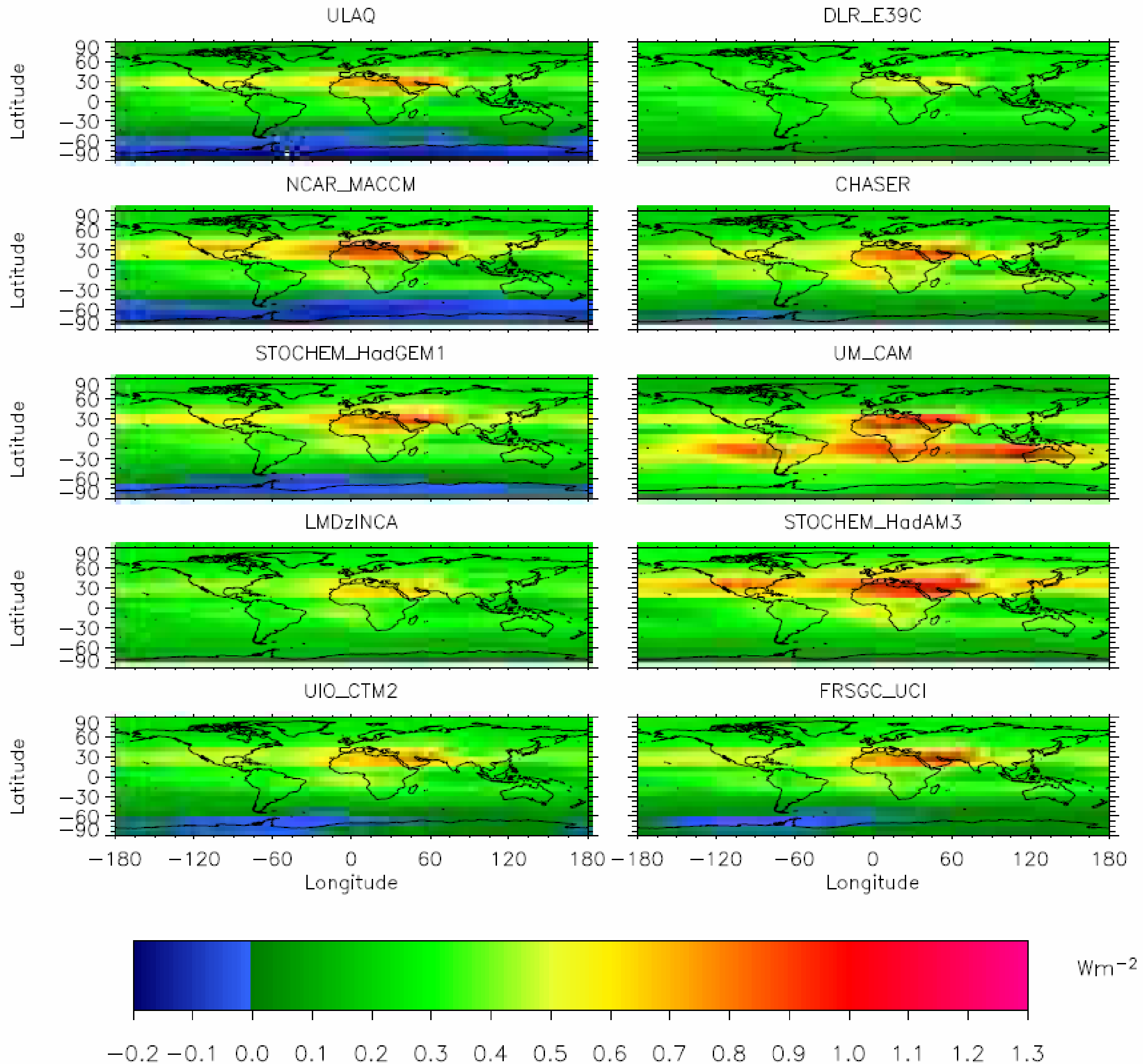


Fig. 6. Adjusted radiative forcing (Wm^{-2}) between 1850 and 2000 due to tropospheric ozone change, taking into account chemical change only (i.e. "2 minus 1c", except LMDzINCA, UM_CAM, and STOCHEM_HadAM3, for which "2 minus 1b" is shown). The radiative forcing calculation is made by the UiO-RTM and the tropopause level is based on the NCEP year 2000 reanalysis.

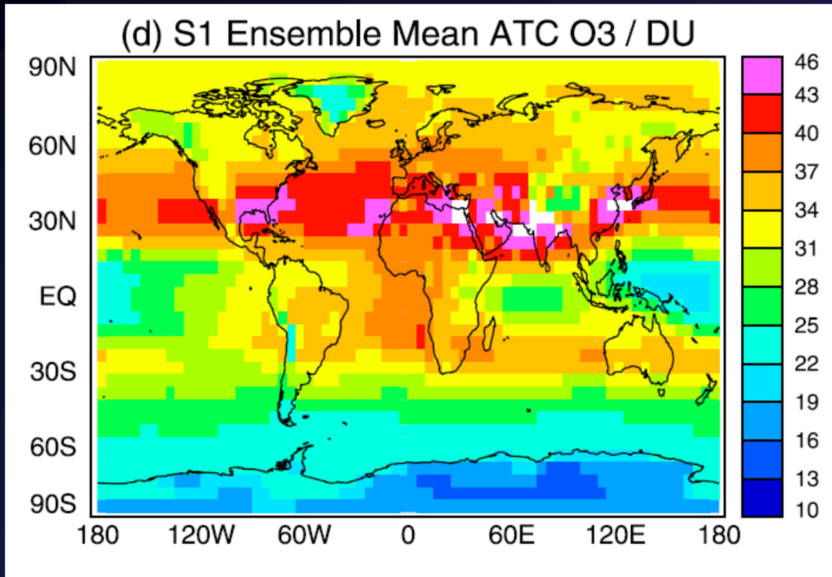
Average radiative forcing from 10 chemistry-climate models:

0.32 W m^{-2}

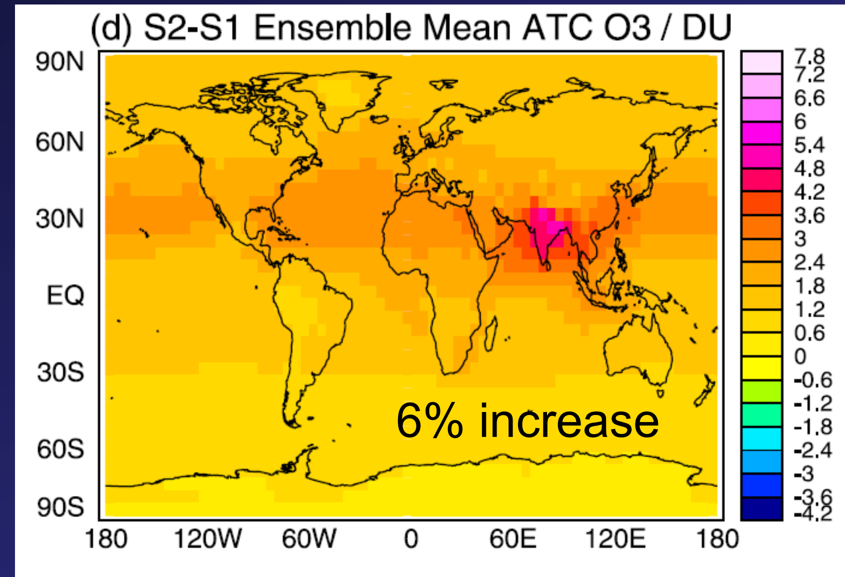
(compared to 0.35 W m^{-2} IPCC, 2007)

Gauss et al., Radiative forcing since preindustrial times due to ozone changes in the troposphere and the lower stratosphere, *Atmos. Chem. Phys., 6*, 2006.

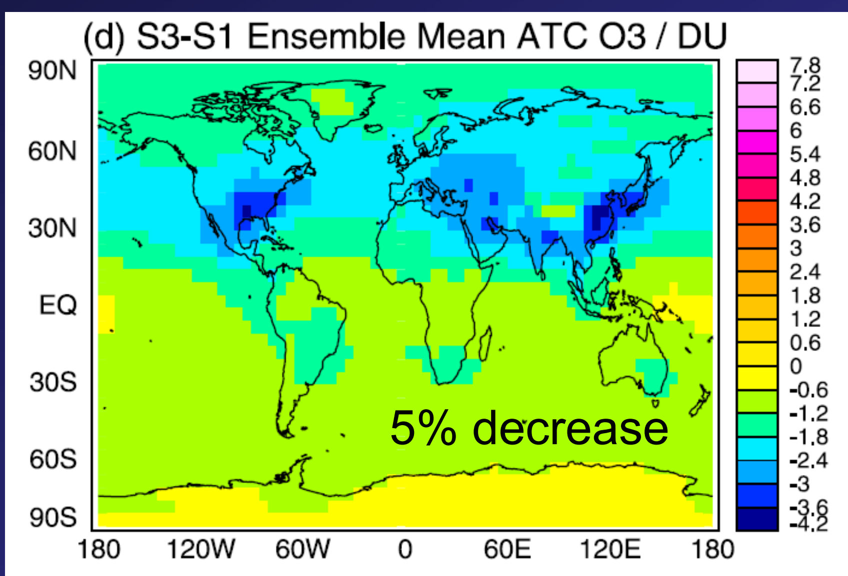
Tropospheric O3, 2000



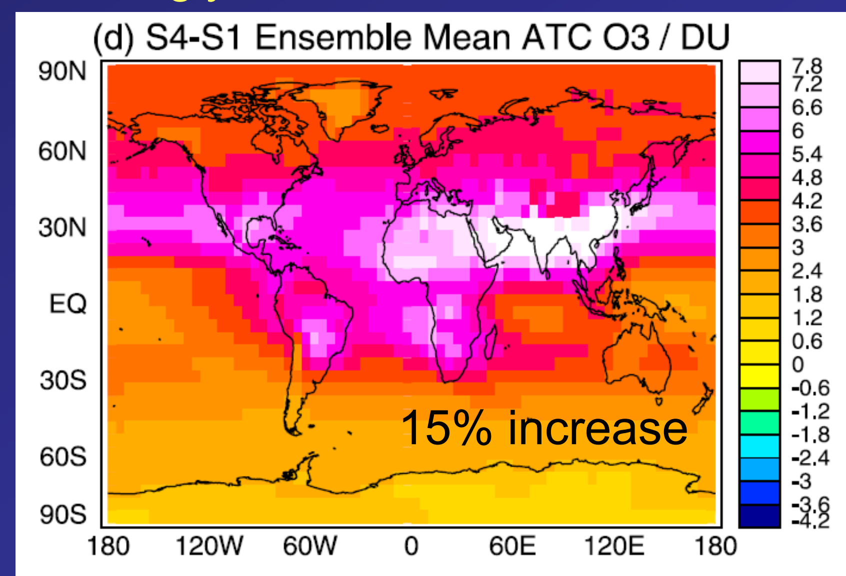
Current legislation emissions, 2030



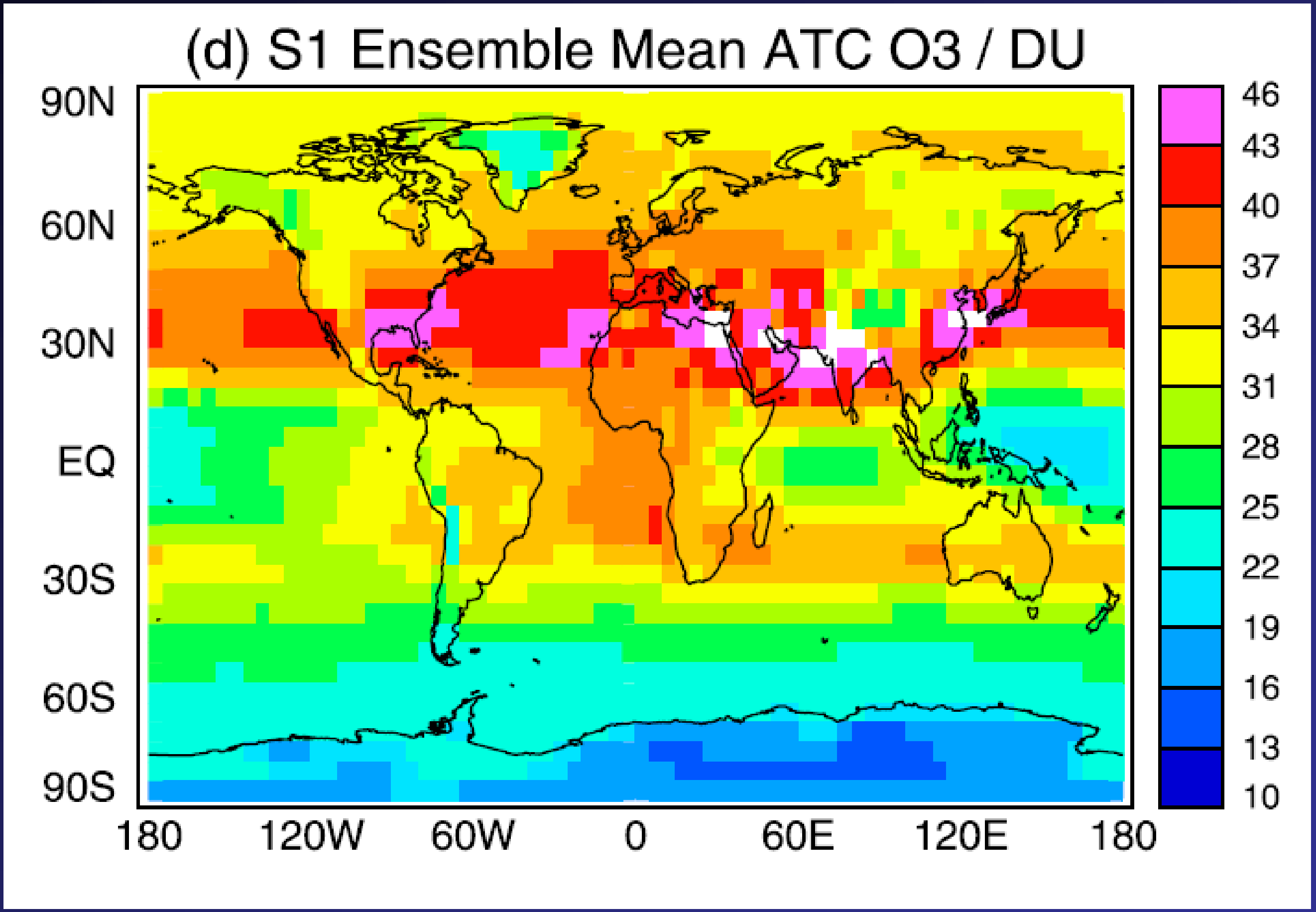
Max. feasible emission reductions, 2030



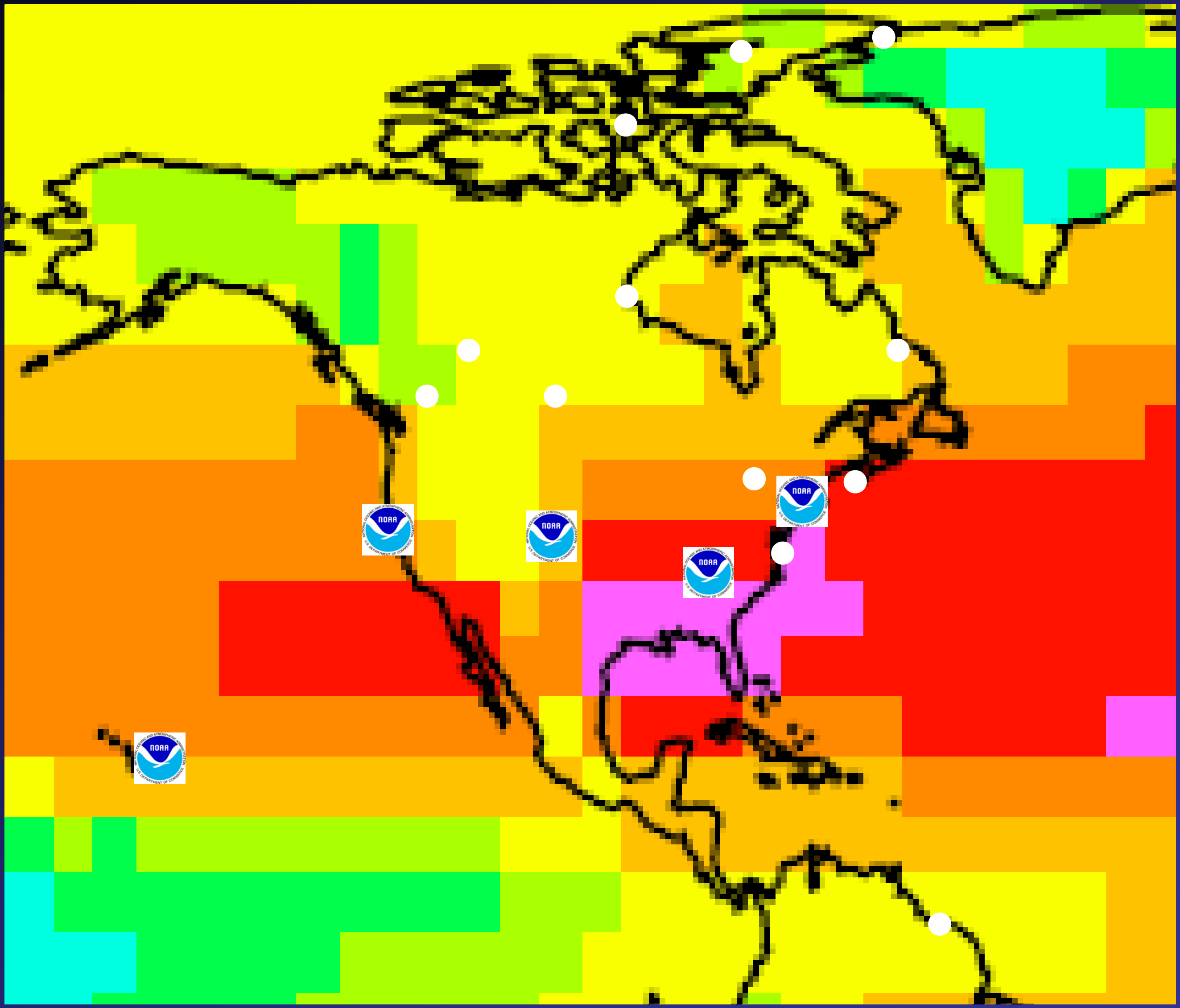
Strongly increased emissions, 2030



Stevenson et al., Multimodel ensemble simulations of present-day and near-future tropospheric ozone, J. *Geophys. Res., 111*, 2006.



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

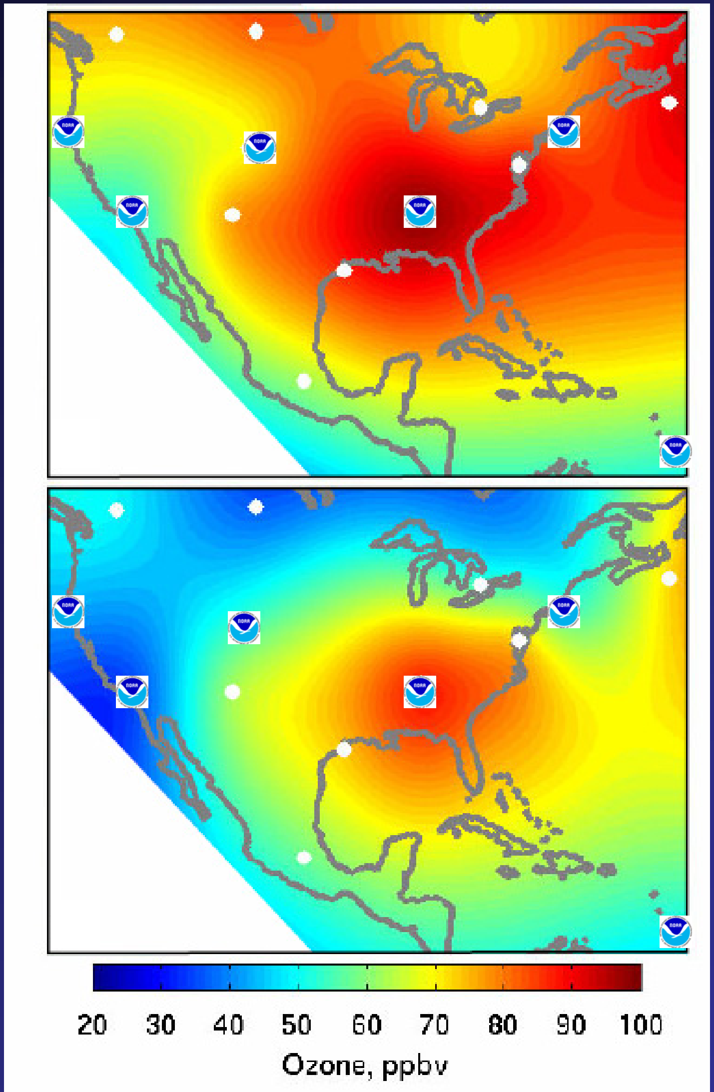


There are currently 17 sites in the Americas, north of the equator, that launch ozonesondes on a once-per-week basis.

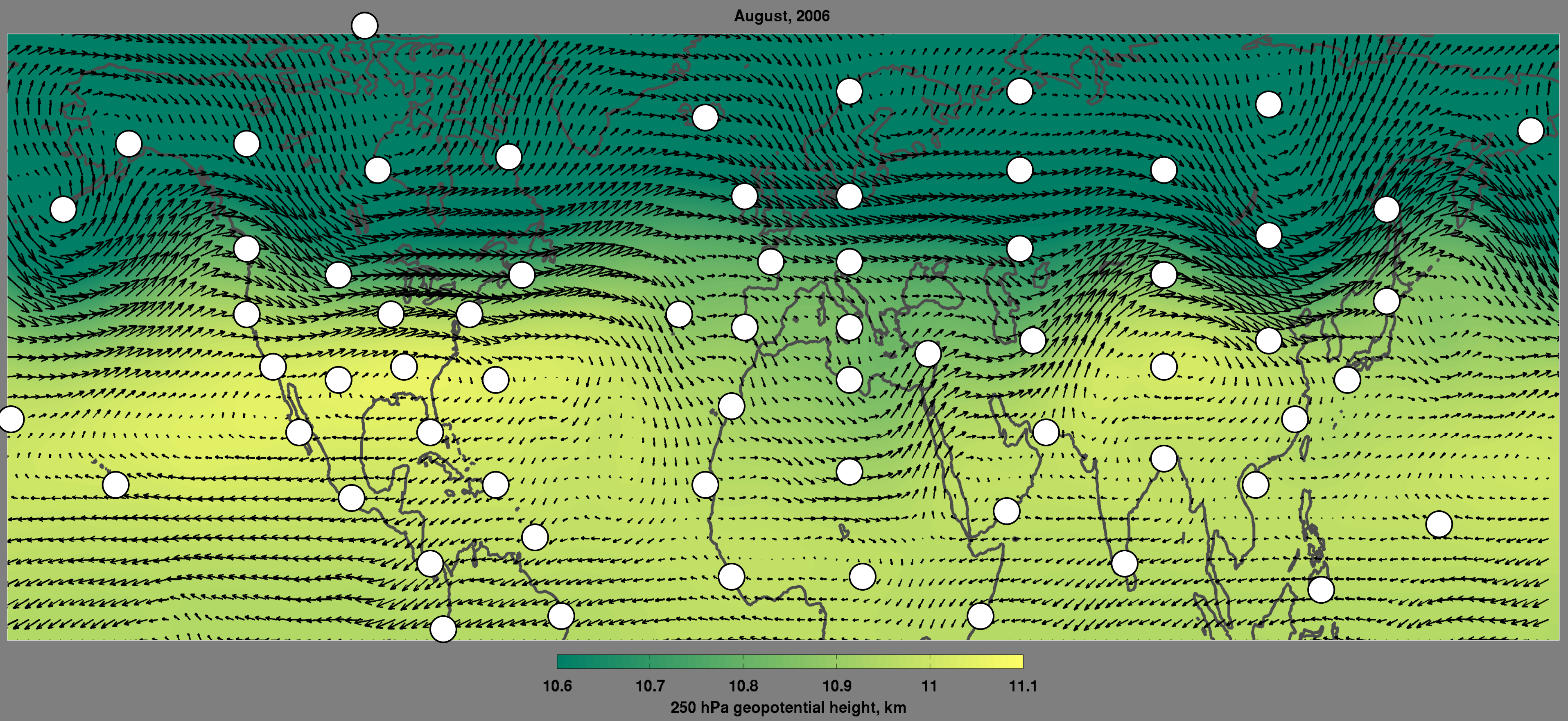
August, 2006

Tropospheric ozone at 10-11 km as measured by the IONS ozonesonde network.

Same as above but with stratospheric contribution removed.



Cooper et al., Evidence for a recurring eastern North America upper tropospheric ozone maximum, *J. Geophys. Res., in-press*, 2007.



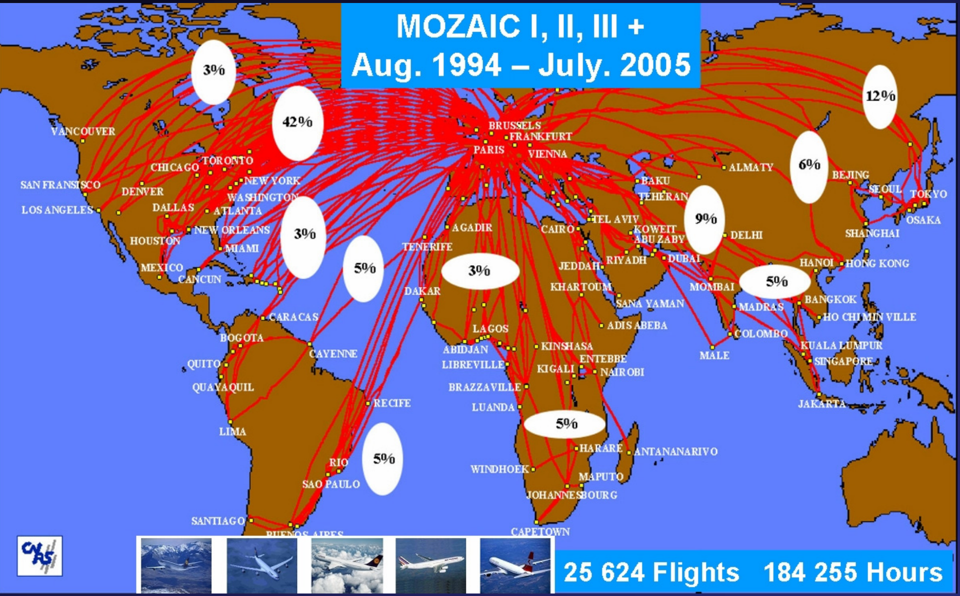
<u>Logistics for a 1-year experiment</u>

- $800 USD/ozonesonde
- 365 sondes per site
- 65 sites

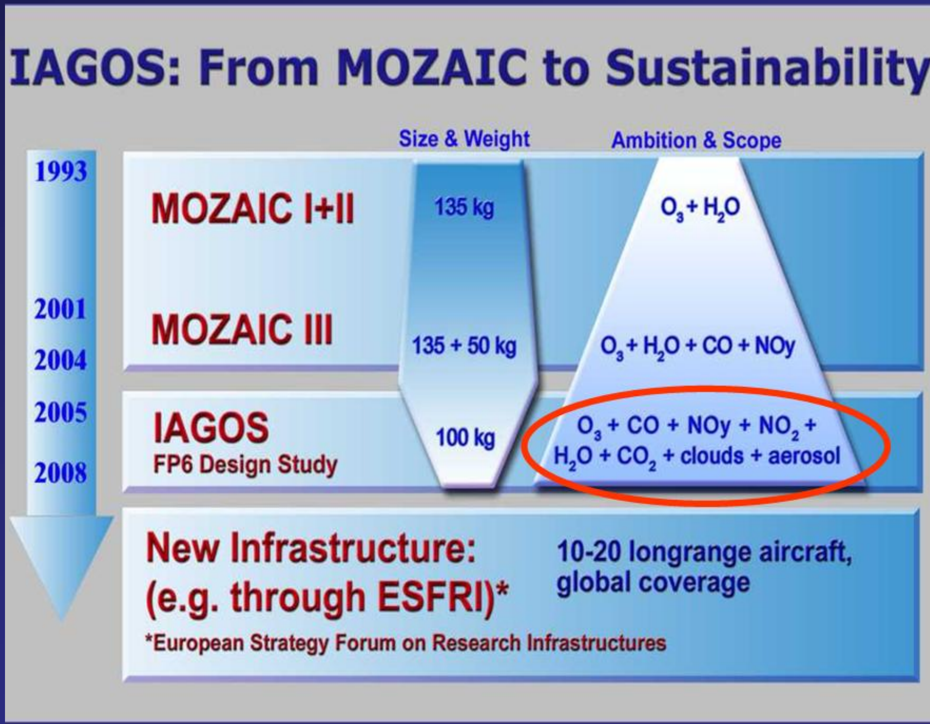
Yearly operational cost = $19,000,000

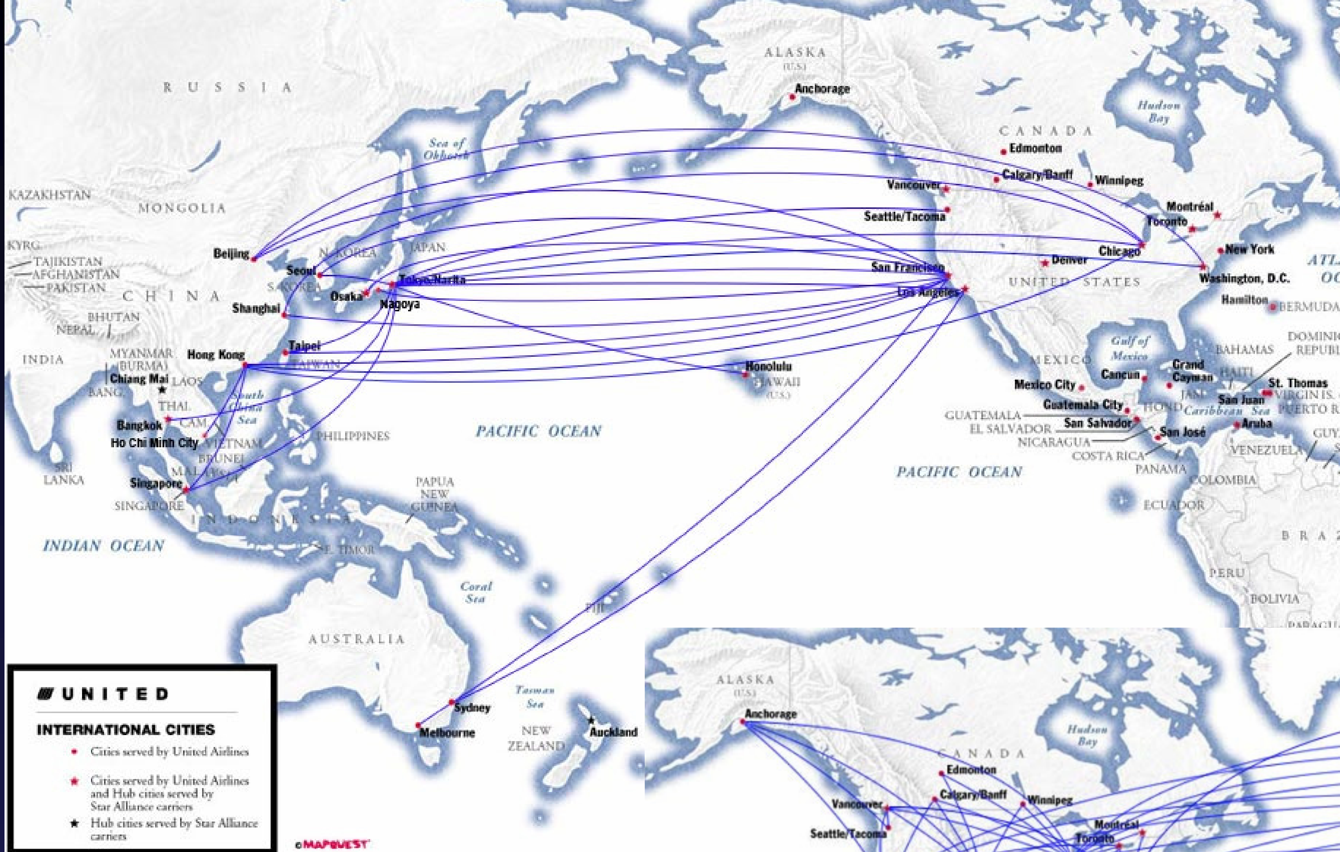
Additional funds needed for site start-up costs and project management

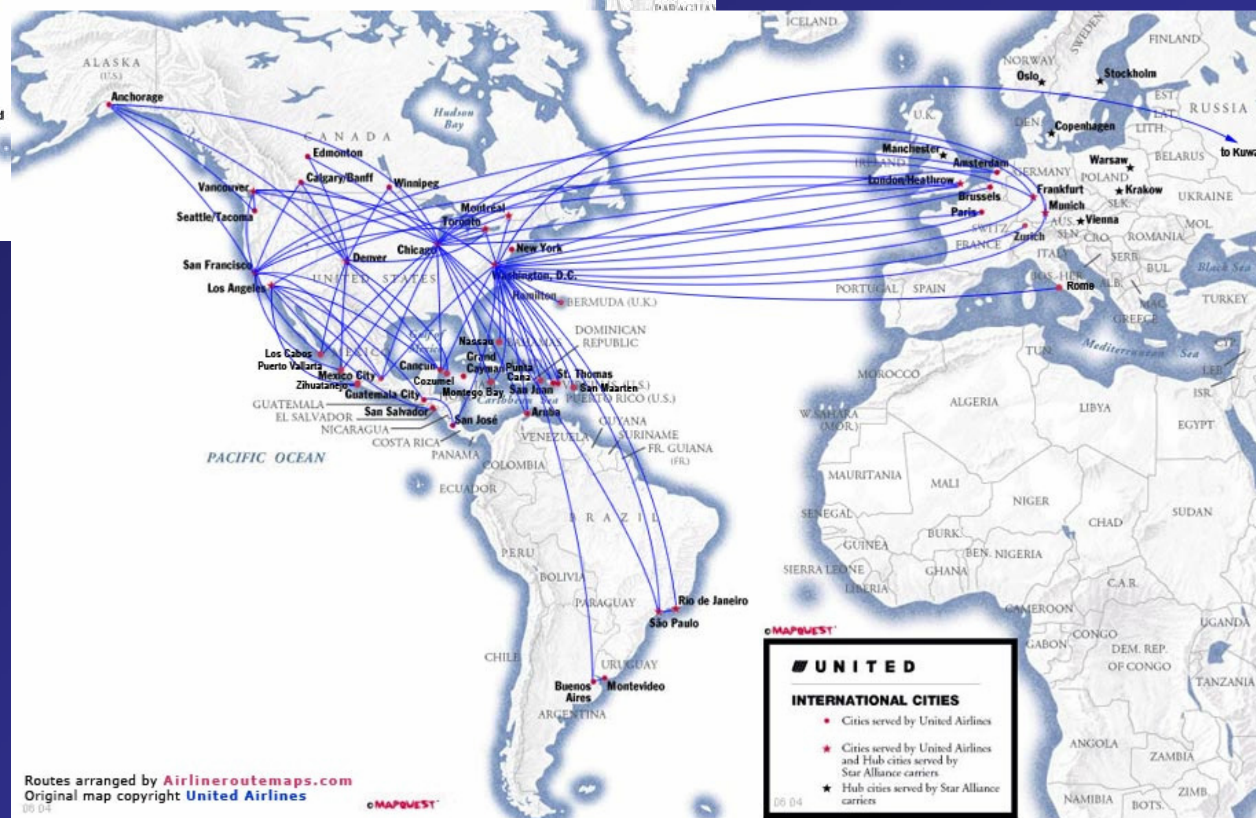
MOZAIC
Measurements of **OZ**one and water vapour by in-service **AI**rbus air**C**raft



IAGOS
Integration of routine **A**ircraft measurements into a **G**lobal **O**bserving **S**ystem




UNITED
INTERNATIONAL CITIES
Cities served by United Airlines
Cities served by United Airlines and Hub cities served by Star Alliance carriers
Hub cities served by Star Alliance carriers
MAPQUEST
PACIFIC OCEAN
INDIAN OCEAN
Beijing
Seoul
Shanghai
Osaka
Tokyo/Narita
Nagoya
Hong Kong
Taipei
Chiang Mai
Bangkok
Ho Chi Minh City
Singapore
Sydney
Melbourne
Auckland
Honolulu
Anchorage
Edmonton
Calgary/Banff
Winnipeg
Vancouver
Seattle/Tacoma
Montréal
Toronto
Chicago
New York
Washington, D.C.
San Francisco
Los Angeles
Denver
Hamilton
Mexico City
Cancun
Grand Cayman
Guatemala City
San Salvador
San José
San Juan
St. Thomas
Aruba


UNITED
INTERNATIONAL CITIES
Cities served by United Airlines
Cities served by United Airlines and Hub cities served by Star Alliance carriers
Hub cities served by Star Alliance carriers
MAPQUEST
PACIFIC OCEAN
Anchorage
Edmonton
Calgary/Banff
Winnipeg
Vancouver
Seattle/Tacoma
Montréal
Toronto
Chicago
Denver
New York
Washington, D.C.
San Francisco
Los Angeles
Hamilton
Los Cabos
Puerto Vallarta
Mexico City
Zihuatanejo
Cancun
Cozumel
Nassau
Grand Cayman
Montego Bay
Punta Cana
San Juan
St. Thomas
San Maarten
Guatemala City
San Salvador
San José
Aruba
Rio de Janeiro
São Paulo
Buenos Aires
Montevideo
Oslo
Stockholm
Copenhagen
Manchester
Amsterdam
London/Heathrow
Brussels
Paris
Frankfurt
Munich
Zurich
Vienna
Warsaw
Krakow
Rome
to Kuwait
Routes arranged by Airlineroutemaps.com
Original map copyright United Airlines

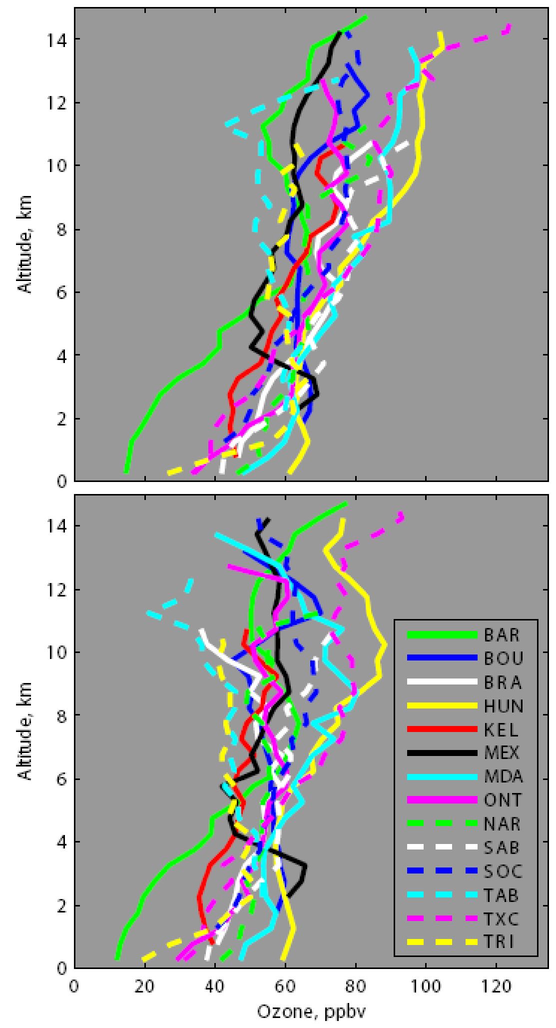


Figure 1. a) Median ozone profiles for all measurements during summer 2006 that occurred within the troposphere (PV < 1.0 pvu). b) Same as in a) but for the FTO_3 quantity which has the influence from stratospheric-origin ozone removed.

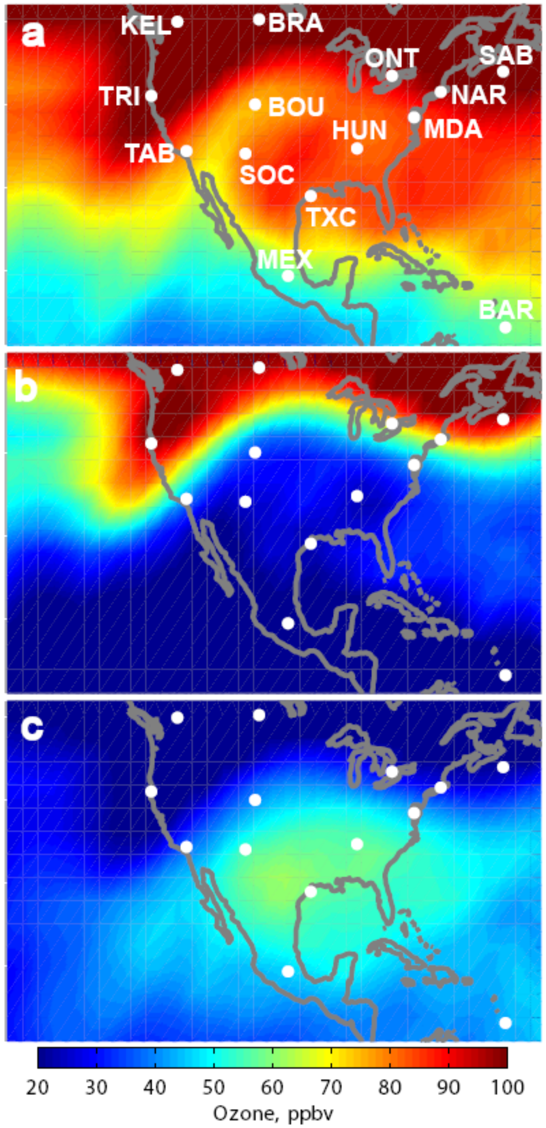


Figure 3. Model calculated a) mean ozone mixing ratios at 250 hPa during August 2006, subdivided into b) the contribution of ozone transported from the stratosphere, and c) of ozone formed within the troposphere (thus a=b+c). Note stratospheric conditions prevail north of the jet stream (north of strong ozone gradients) and tropospheric conditions to the south.

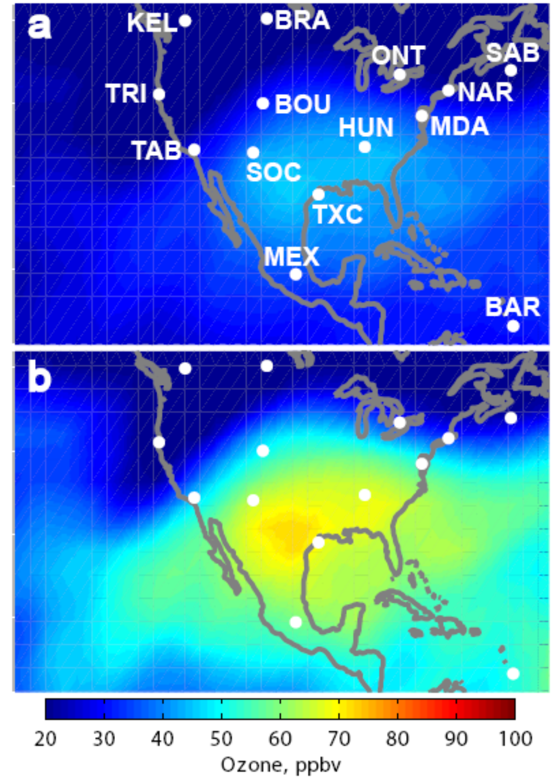


Figure 4. As in Figure 3c, but for a) global lightning emissions set to zero, and b) global lightning emissions increased by a factor of 3.

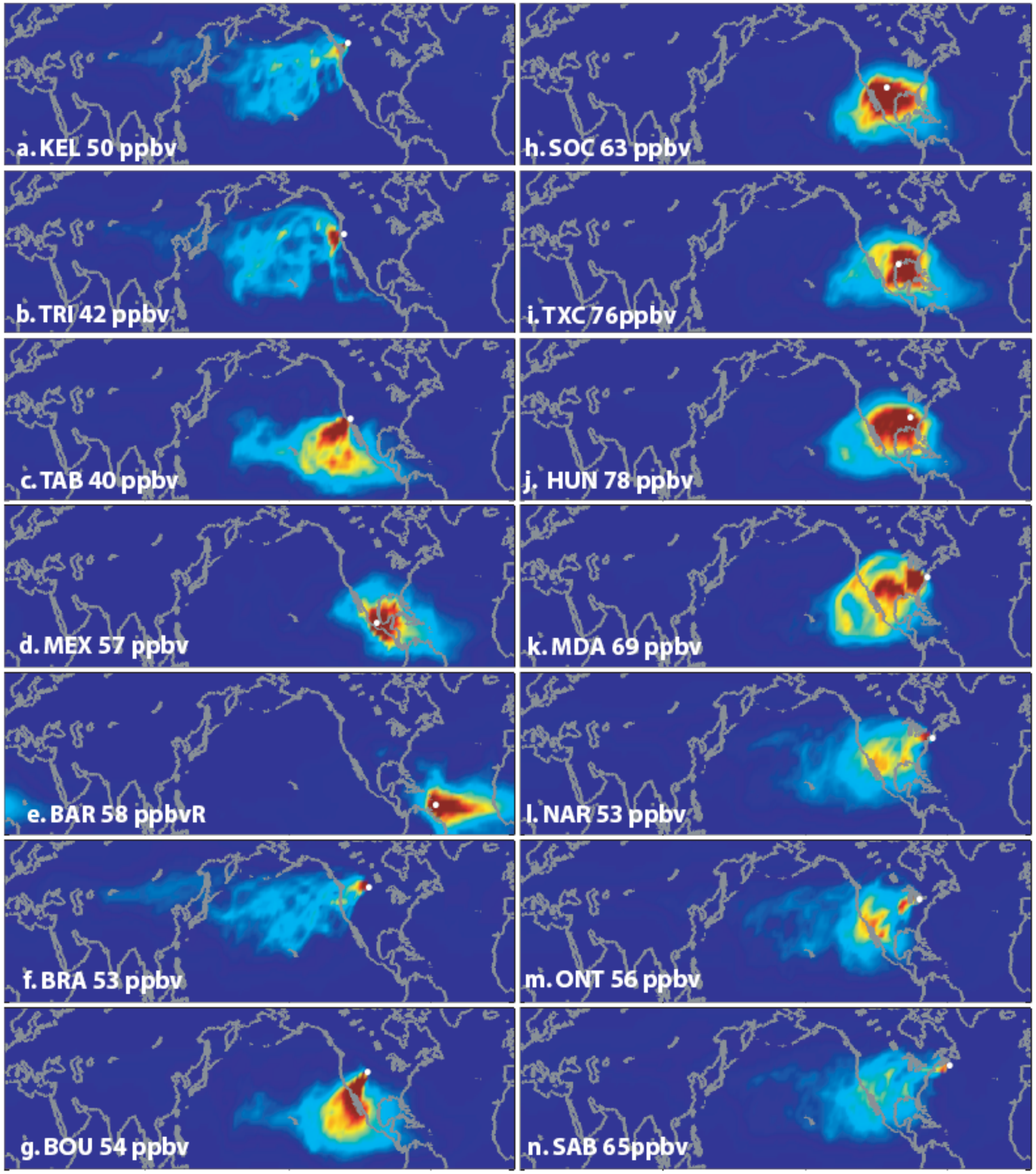


Figure 5. Average column residence time (arbitrary units) for all retroplumes released above each site (white dot) between 6-12 km within the troposphere. Each plot also indicates the median FTO_3 mixing ratio between 6-12 km above each site.

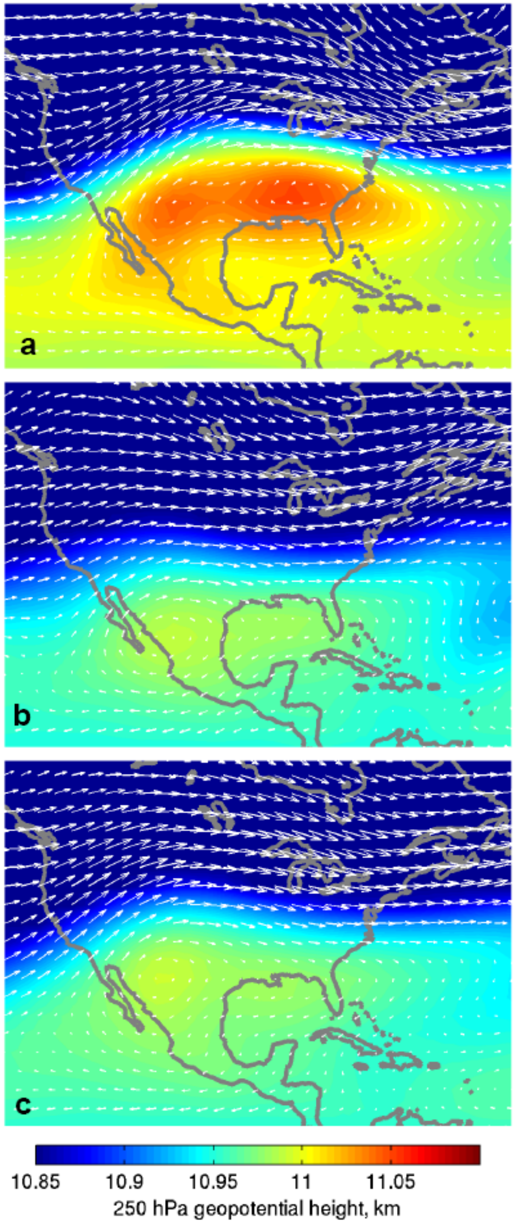


Figure 6. Average wind vectors and geopotential height of the 250 hPa surface above North America during a) August 2006, b) July-August 2004, and c) July-August 1987-2006.

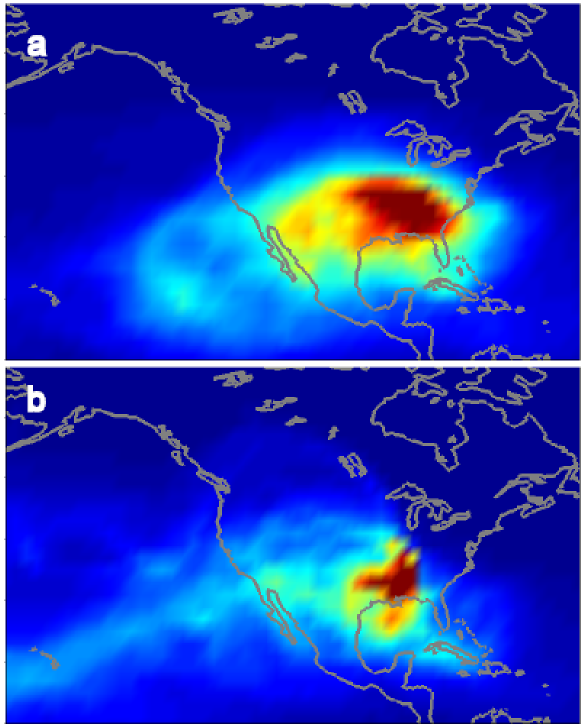


Figure 7. Average residence time (in arbitrary units) in the upper troposphere of all retroplumes released between 6-12 km above Huntsville during a) August 2006 and b) July-August 2004.

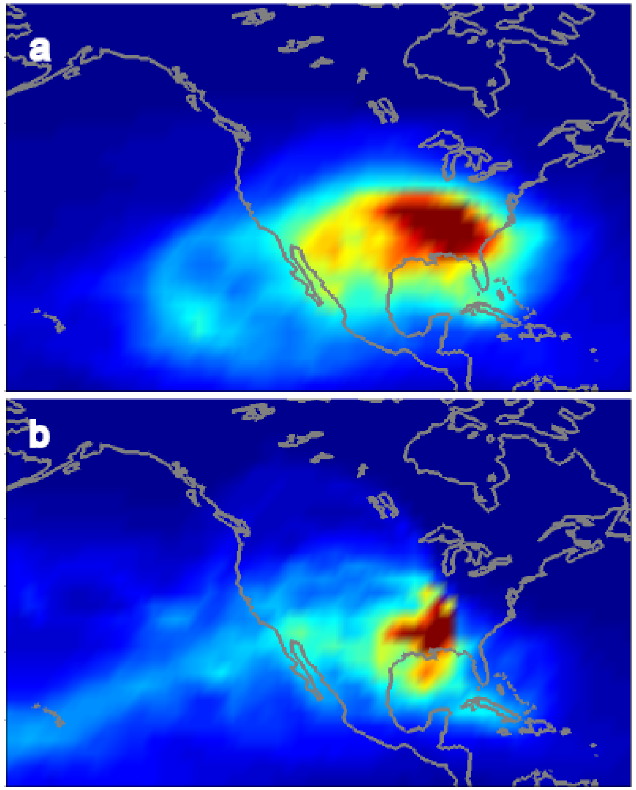
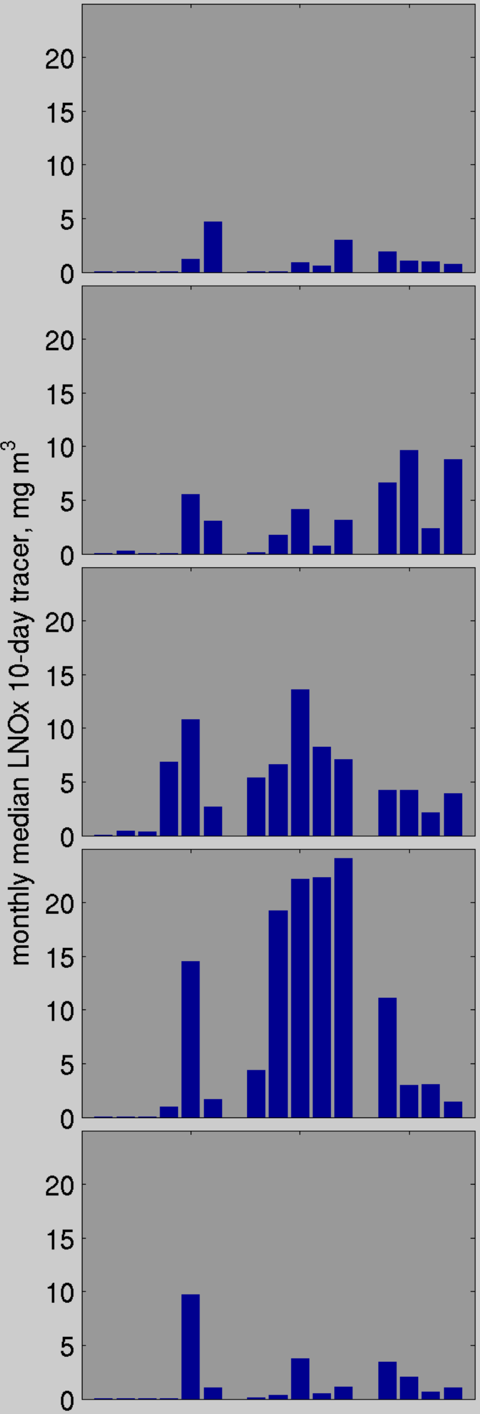
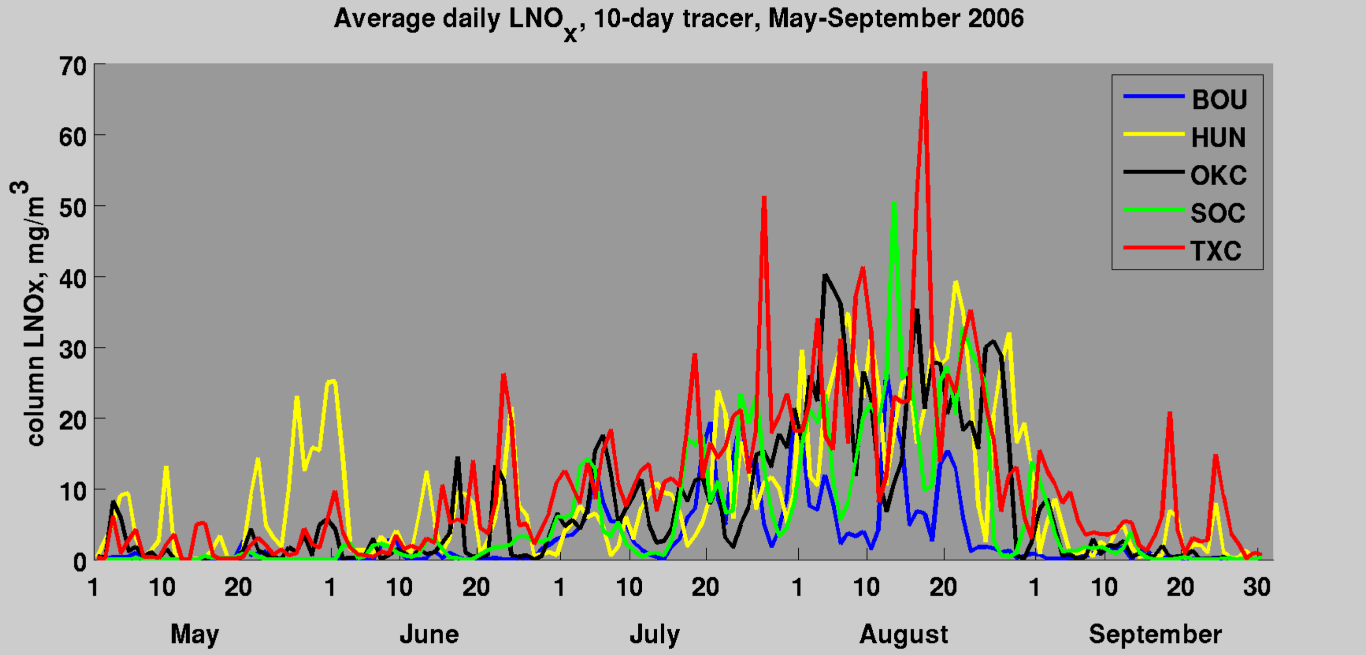


Figure 7. Average residence time (in arbitrary units) in the upper troposphere of all retroplumes released between 6-12 km above Huntsville during a) August 2006 and b) July-August 2004.


monthly median LNOx 10-day tracer, mg m3
0
5
10
15
20


Average daily LNOx, 10-day tracer, May-September 2006
column LNOx, mg/m3
BOU
HUN
OKC
SOC
TXC
0
10
20
30
40
50
60
70
1
10
20
30
May
June
July
August
September