Trends in northern hemisphere ozone since the 1970s and the rise in baseline ozone observed across western North America

Owen R. Cooper
CIRES, University of Colorado, Boulder
NOAA Earth System Research Laboratory, Boulder

Presentation to the WESTAR Ozone Background & Transport Workgroup, July 8, 2015

Background vs Baseline ozone

Baseline ozone

- Ozone transported to a location (i.e. Mt Bachelor, OR) from all upwind sources (i.e., natural and anthropogenic) before modification by recent, localized U.S. emissions.
- includes aged ozone, produced many days earlier from U.S. emissions, that is returned to the U.S. after circling the globe.
- can be directly observed by surface or airborne instrumentation along the west coast or U.S. political borders; can also be observed above the inland regions of the western U.S. in air masses not influenced by recent US emissions.

Global or hemispheric background ozone

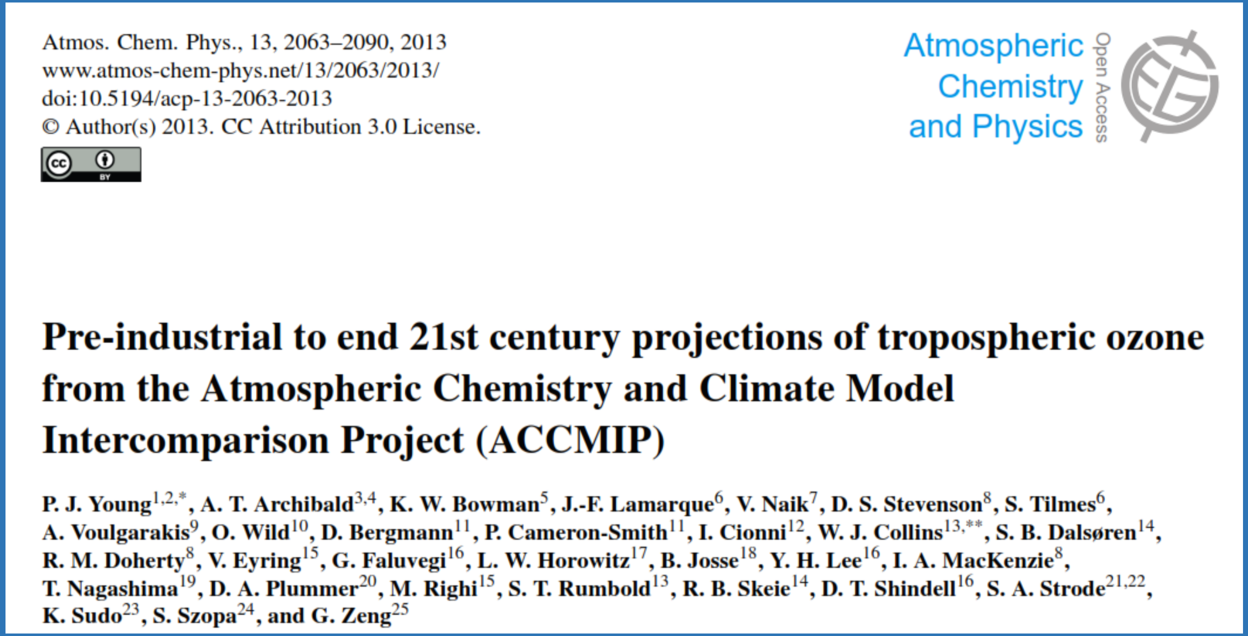
- a model construct that estimates the atmospheric concentration of a pollutant due to natural or a combination of natural and anthropogenic sources.

Background vs Baseline ozone

US EPA definitions of background ozone

- Prior to 2006, ozone measurements from remote monitoring sites were used to estimate background.
- In 2006, EPA used models to estimate Policy-Relevant Background (PRB) ozone, which includes ozone from global anthropogenic and natural sources in the absence of North American (i.e., U.S., Canada, and Mexico) anthropogenic emissions.
- EPA now refers to PRB as North American Background (NAB).
- In 2013, EPA introduced U.S. background (USB) ozone by including anthropogenic contributions from Canada and Mexico. The difference between NAB and USB is small.

How has global tropospheric ozone changed since pre-industrial times?

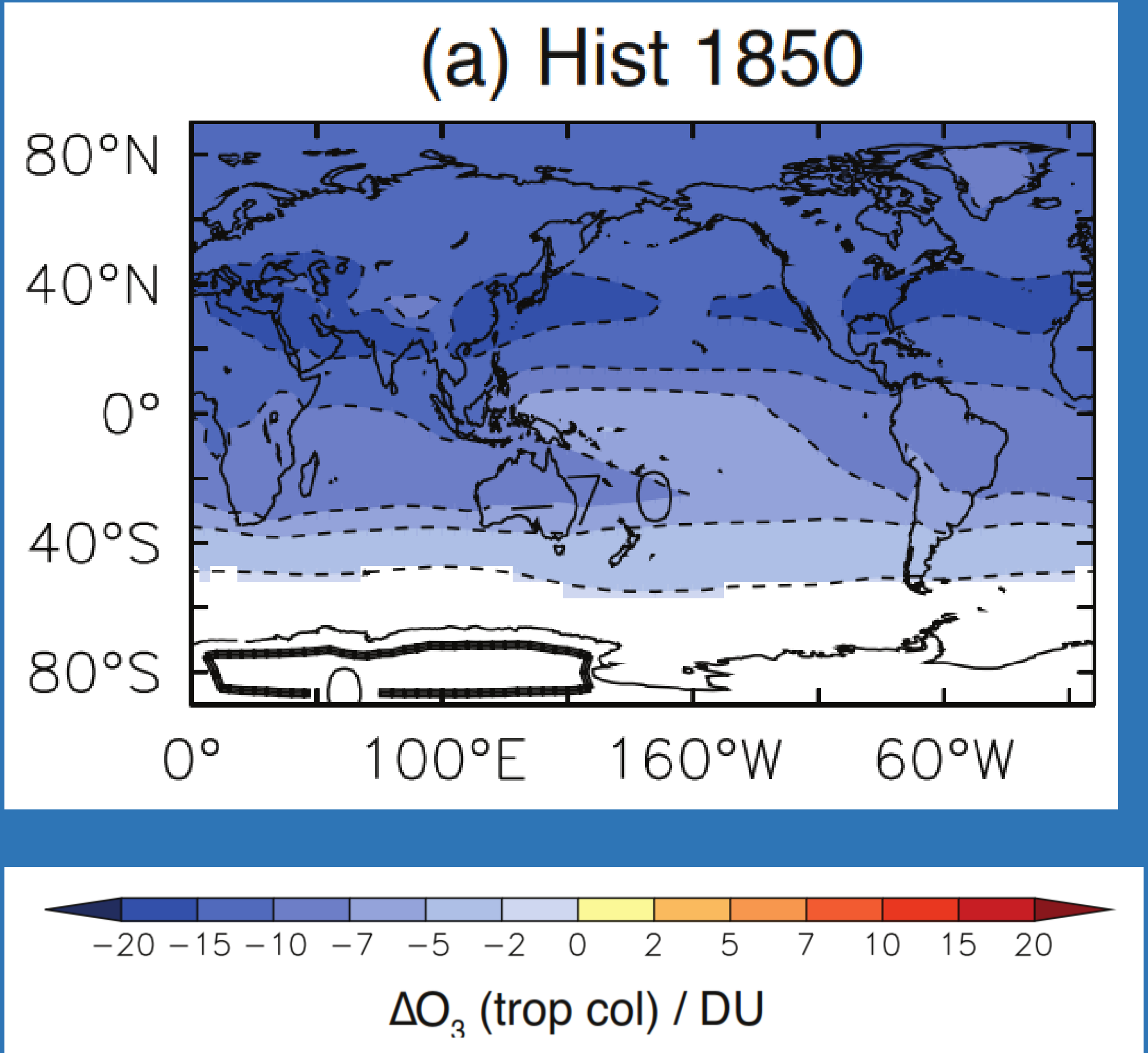


Atmos. Chem. Phys., 13, 2063–2090, 2013
www.atmos-chem-phys.net/13/2063/2013/
doi:10.5194/acp-13-2063-2013

Atmospheric Chemistry and Physics
Open Access

Pre-industrial to end 21st century projections of tropospheric ozone from the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP)

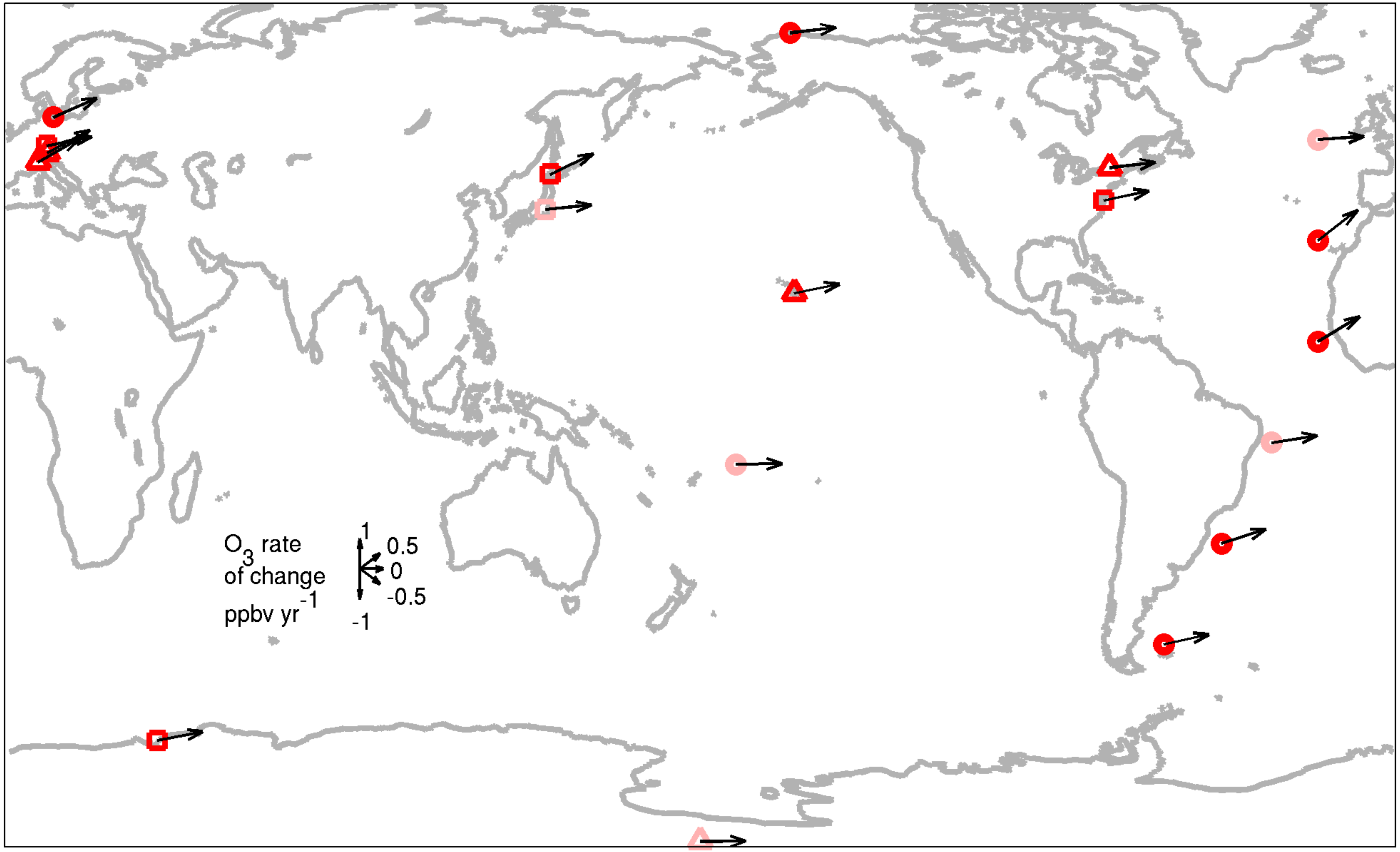
P. J. Young[1,2,*], **A. T. Archibald**[3,4], **K. W. Bowman**[5], **J.-F. Lamarque**[6], **V. Naik**[7], **D. S. Stevenson**[8], **S. Tilmes**[6], **A. Voulgarakis**[9], **O. Wild**[10], **D. Bergmann**[11], **P. Cameron-Smith**[11], **I. Cionni**[12], **W. J. Collins**[13,**], **S. B. Dalsøren**[14], **R. M. Doherty**[8], **V. Eyring**[15], **G. Faluvegi**[16], **L. W. Horowitz**[17], **B. Josse**[18], **Y. H. Lee**[16], **I. A. MacKenzie**[8], **T. Nagashima**[19], **D. A. Plummer**[20], **M. Righi**[15], **S. T. Rumbold**[13], **R. B. Skeie**[14], **D. T. Shindell**[16], **S. A. Strode**[21,22], **K. Sudo**[23], **S. Szopa**[24], and **G. Zeng**[25]



Ensemble of 15 global models:

Tropospheric ozone burden increased by 40% from 1850 to present day.

Annual surface ozone trends: 1950s through 2000-2010 (from the peer-reviewed literature)



● **significant increase**
● **insignificant increase**
● **significant decrease**
● **insignificant decrease**

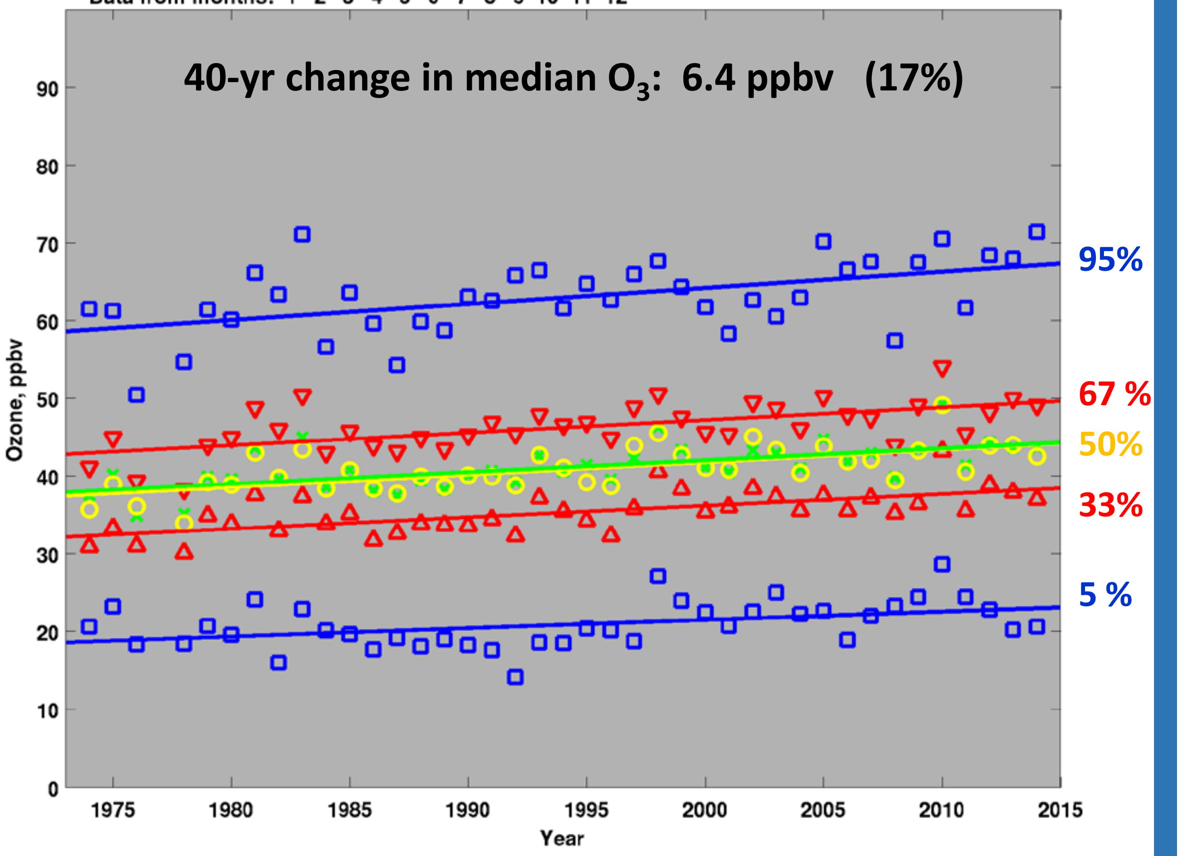
□ ozonesonde site
○ low elevation site
△ high elevation site

42 years of ozone observations at Mauna Loa, Hawaii (*NOAA GMD, Boulder*)

Ozone trend at Mauna Loa Observatory, Hawaii, 3.4 km above sea level

Data from years: 1974 - 2014

Data from months: 1 2 3 4 5 6 7 8 9 10 11 12



40-yr change in median O_3: 6.4 ppbv (17%)

Green - mean

Yellow - median

Blue - 5th & 95th percentiles

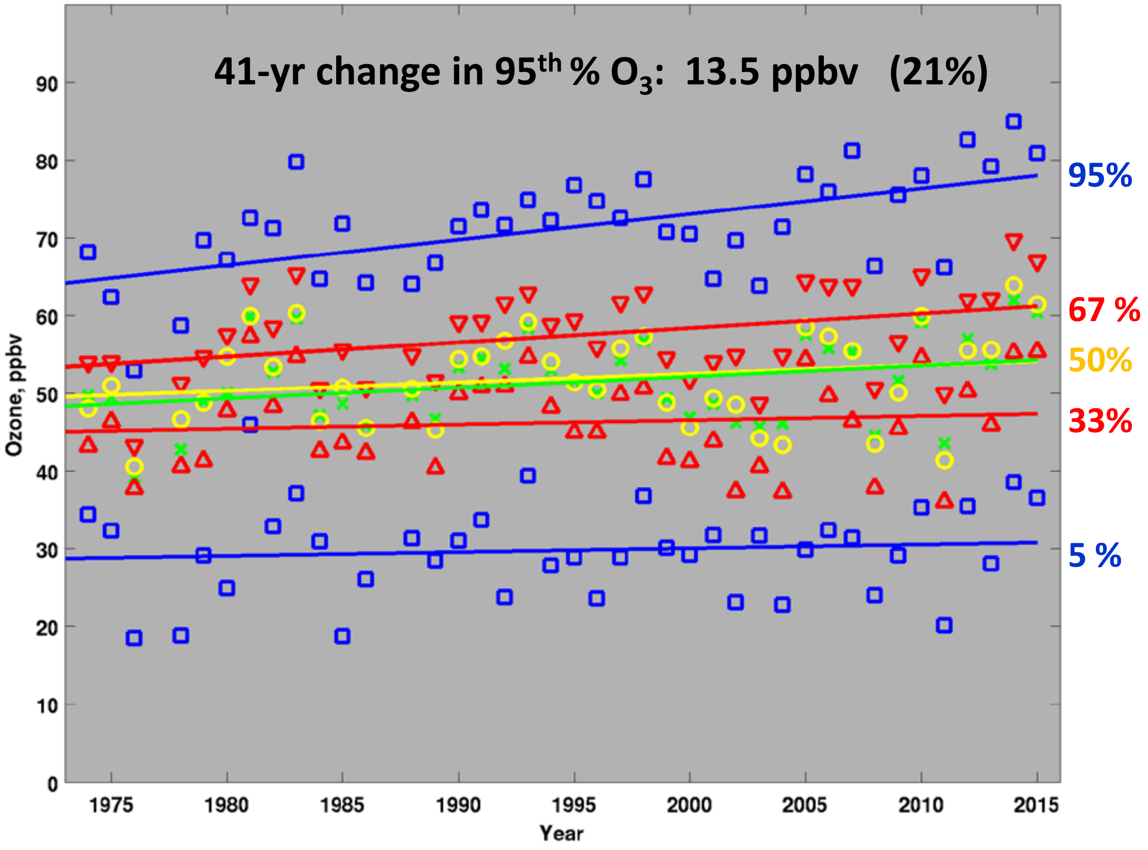
Red - 33rd and 67th percentiles

O_3 percentile	increase ppbv yr^{-1}	p value
95^{th} %:	0.21	0.00
67^{th} %:	0.16	0.00
50^{th} %:	0.16	0.00
33^{th} %:	0.15	0.00
05^{th} %:	0.11	0.01

Nighttime O_3 trend at Mauna Loa Obs., Hawaii, 3.4 km above sea level

Data from years: 1974 - 2015

Data from months: 4 5



41-yr change in 95^{th} % O_3: 13.5 ppbv (21%)

Green - mean

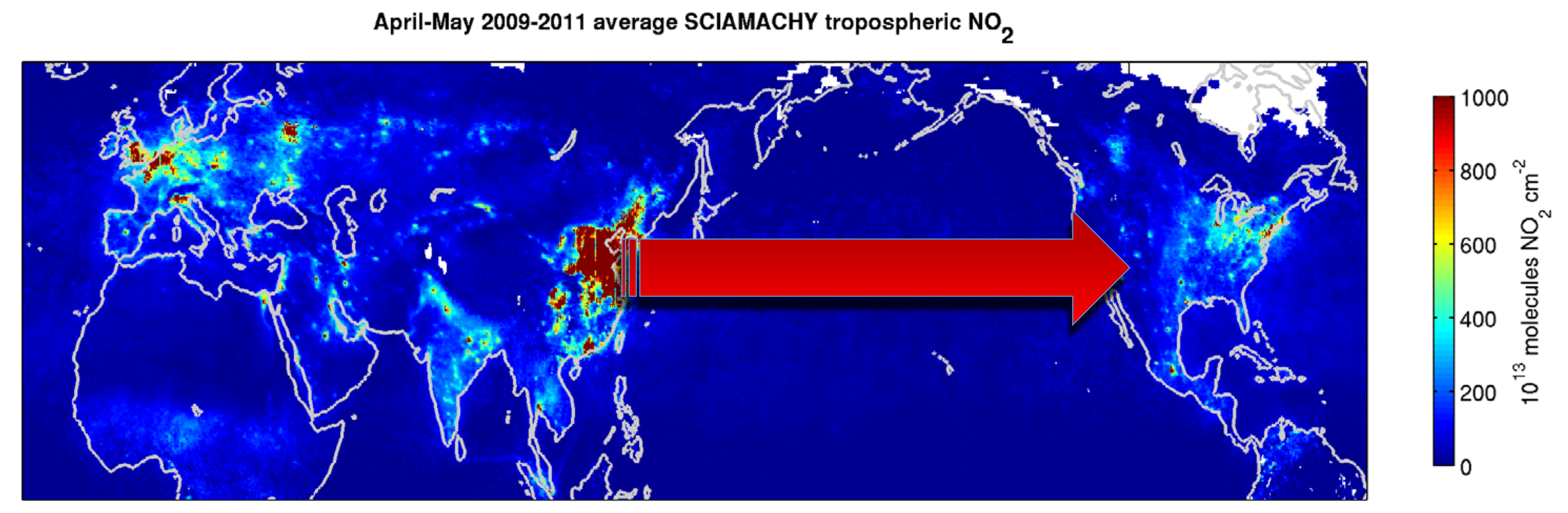
Yellow - median

Blue - 5th & 95th percentiles

Red - 33rd and 67th percentiles

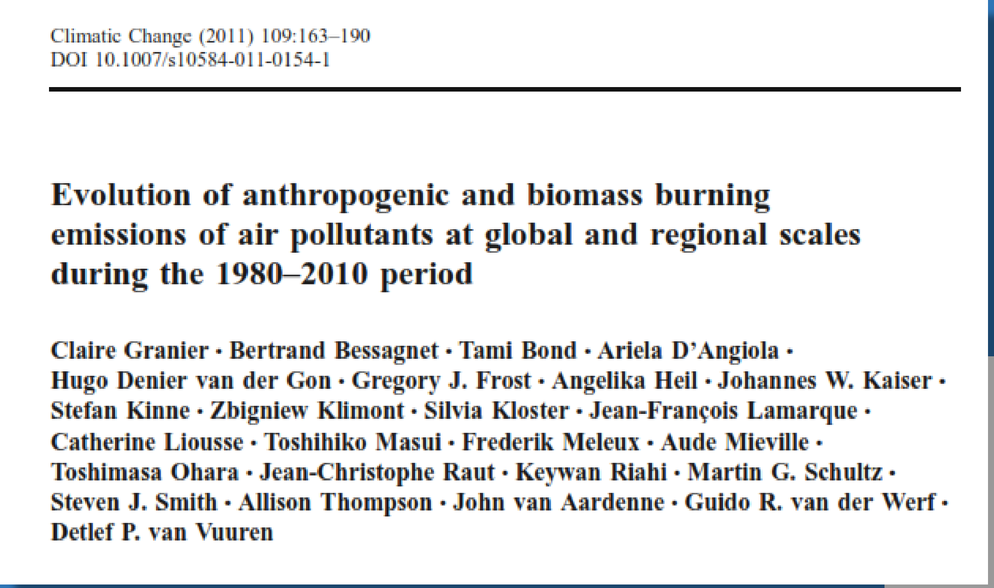
O_3 percentile	increase ppbv yr^{-1}	p value
95^{th} %:	0.33	0.00
67^{th} %:	0.19	0.01
50^{th} %:	0.11	0.17
33^{th} %:	0.05	0.49
05^{th} %:	0.05	0.55

Anthropogenic emissions upwind of the USA are changing rapidly



Tropospheric NO_2 column data from the GOME and SCIAMACHY sensors were freely downloaded from: www.temis.nl

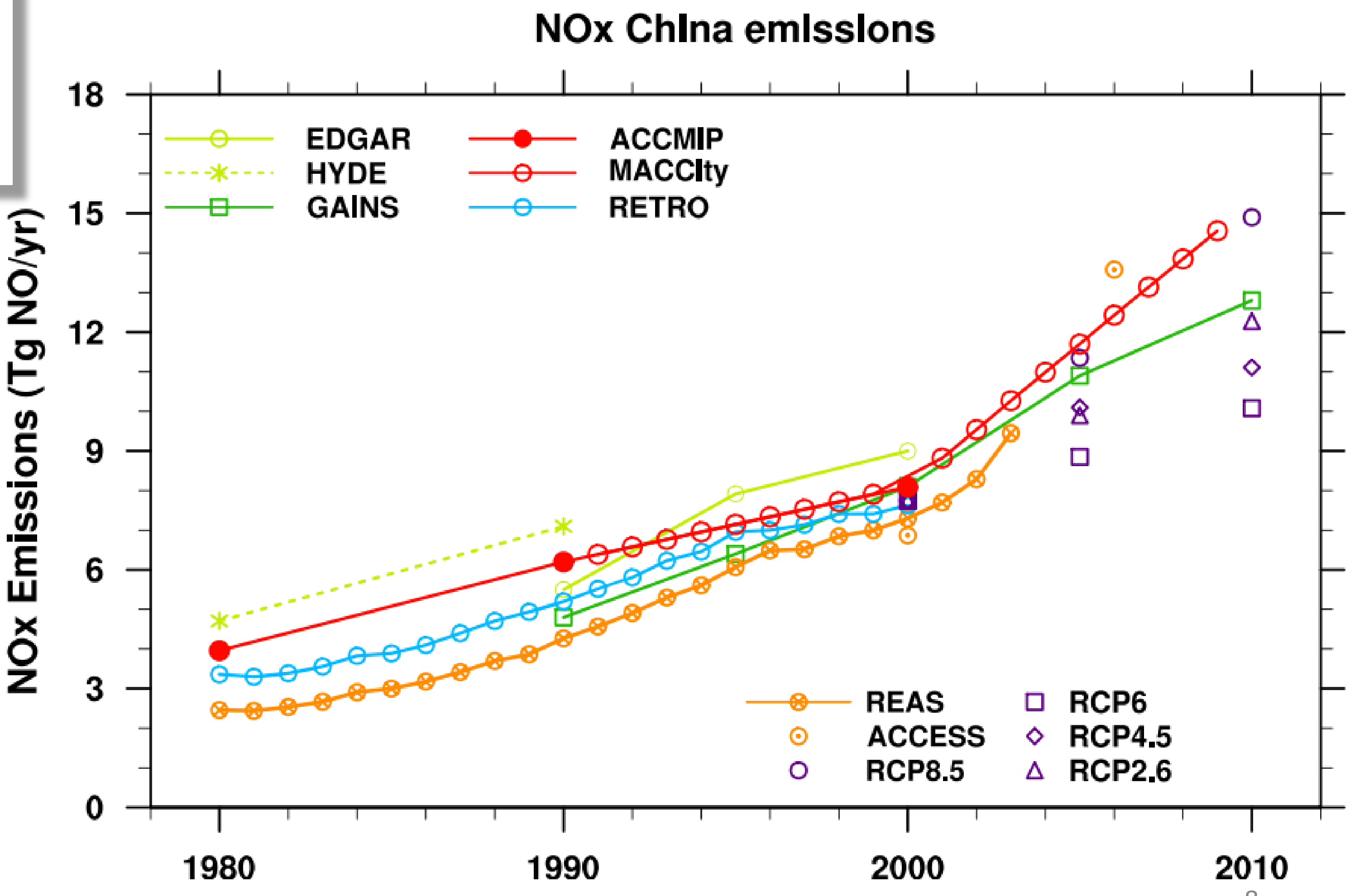
For methodology see:
Boersma, K. F., et al. (2004), Error analysis for tropospheric NO2 retrieval from space, J. Geophys. Res., 109, D04311,
Richter, A., et al.(2005), Increase in tropospheric nitrogen dioxide over China observed from space, Nature, 437



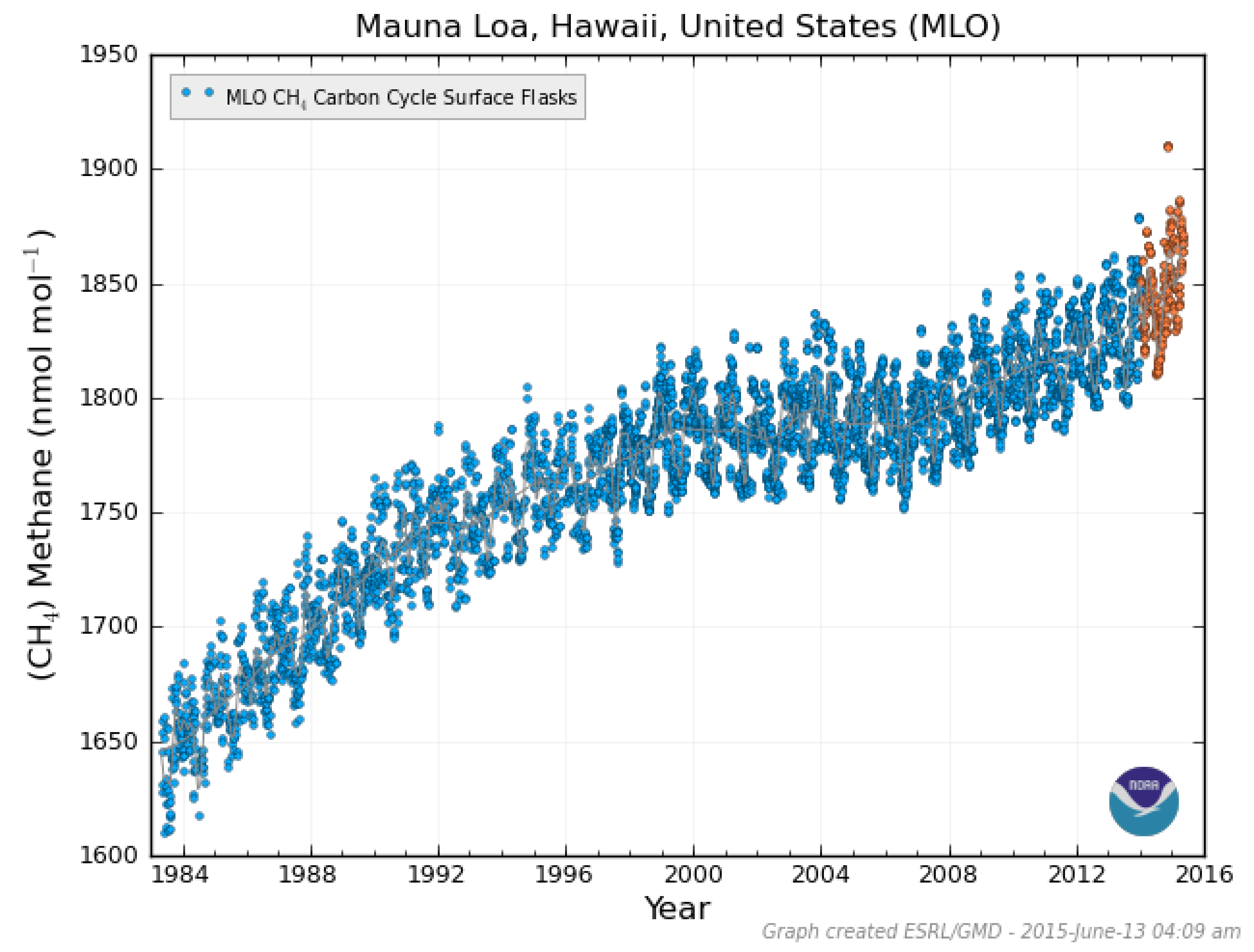
Climatic Change (2011) 109:163–190
DOI 10.1007/s10584-011-0154-1

Evolution of anthropogenic and biomass burning emissions of air pollutants at global and regional scales during the 1980–2010 period

Claire Granier · Bertrand Bessagnet · Tami Bond · Ariela D'Angiola ·
Hugo Denier van der Gon · Gregory J. Frost · Angelika Heil · Johannes W. Kaiser ·
Stefan Kinne · Zbigniew Klimont · Silvia Kloster · Jean-François Lamarque ·
Catherine Liousse · Toshihiko Masui · Frederik Meleux · Aude Mieville ·
Toshimasa Ohara · Jean-Christophe Raut · Keywan Riahi · Martin G. Schultz ·
Steven J. Smith · Allison Thompson · John van Aardenne · Guido R. van der Werf ·
Detlef P. van Vuuren



Methane continues to increase



Methane has increased by 12% since 1984

Impact of Asia on springtime ozone across the N. Pacific Ocean and North America

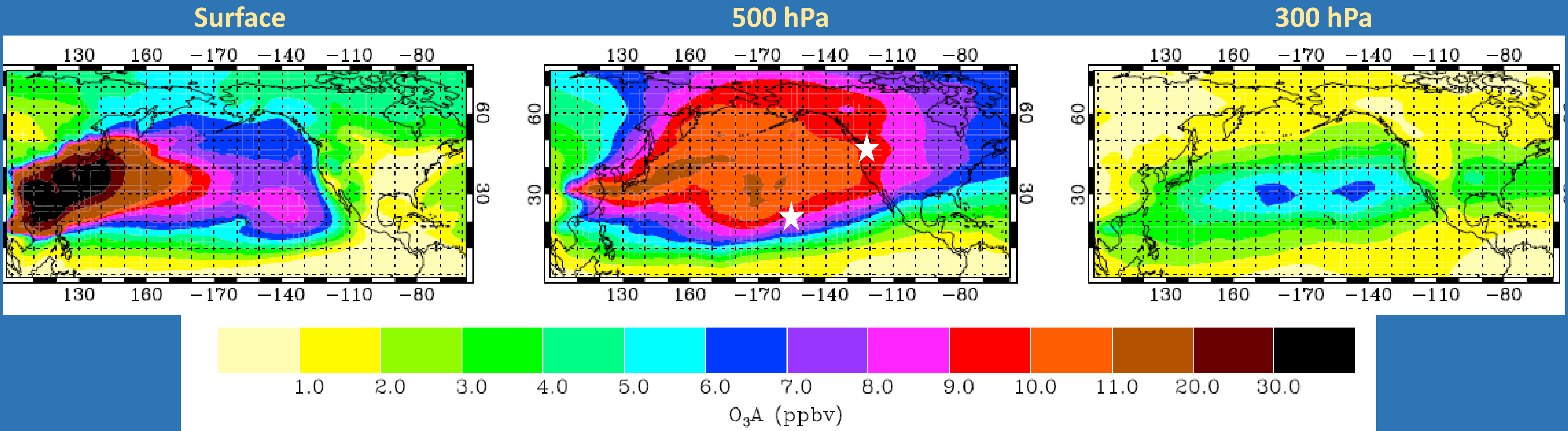


Figure 1. Seasonal five-year average of O_3A over the Pacific Basin and North America at the surface, 500 hPa (approximately 5 km), and 300 hPa (approximately 10 km) taken from the 2001–2005 model results.

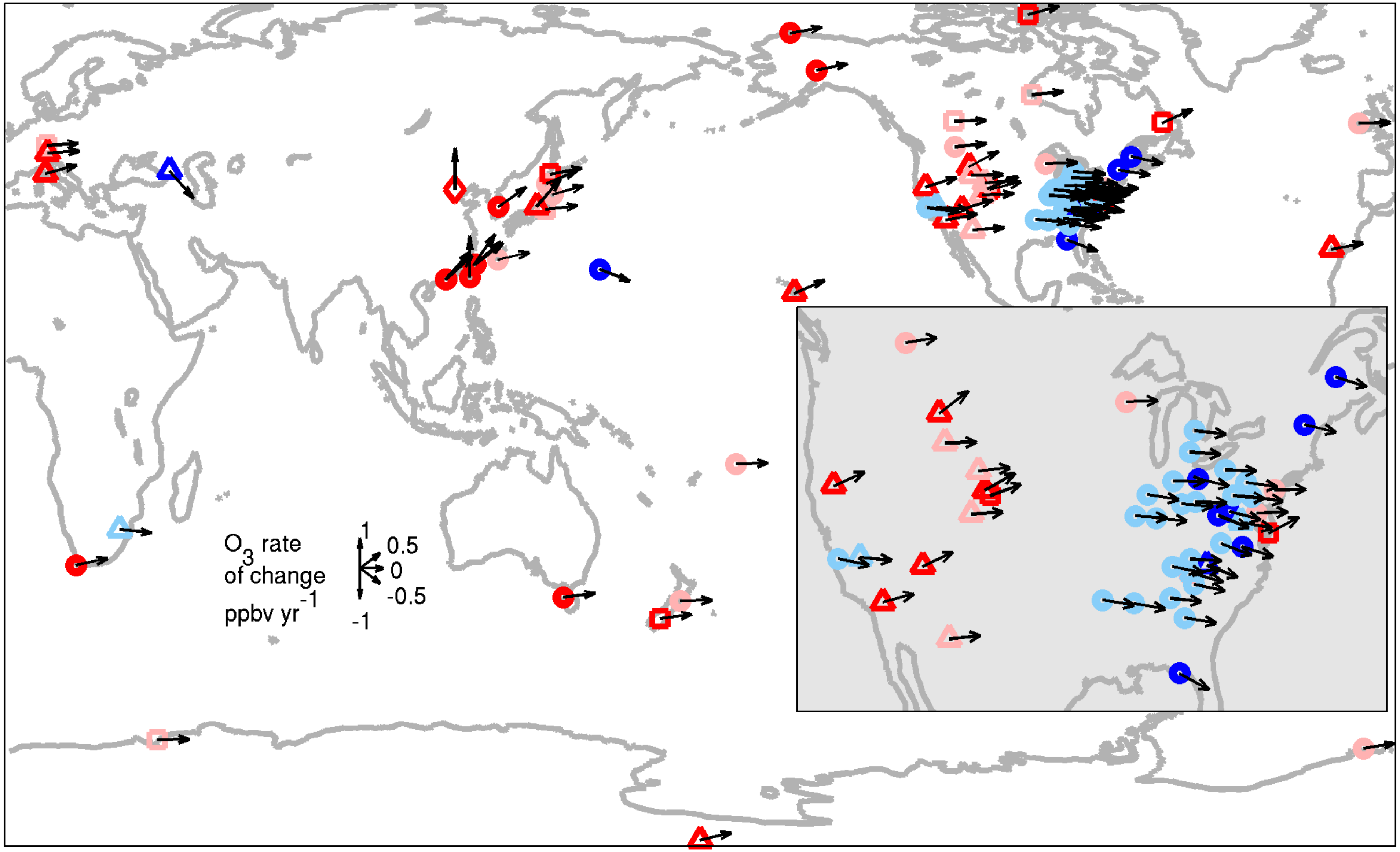
Ozone transport from Asia is at a maximum during spring.

The “sphere of influence” of Asian ozone is strongest in the mid-troposphere and reaches Hawaii and western North America.

Only continuous US free tropospheric baseline monitoring sites downwind of Asia:
Mauna Loa, Hawaii, and Mt Bachelor, Oregon

Brown-Steiner, B., and P. Hess (2011), Asian influence on surface ozone in the United States: A comparison of chemistry, seasonality, and transport mechanisms, *J. Geophys. Res., 116*, D17309, doi:10.1029/2011JD015846.

Annual surface ozone trends: 1990s through 2000-2010 (from the peer-reviewed literature)



● **significant increase**

● **insignificant increase**

● **significant decrease**

● **insignificant decrease**

□ ozonesonde site

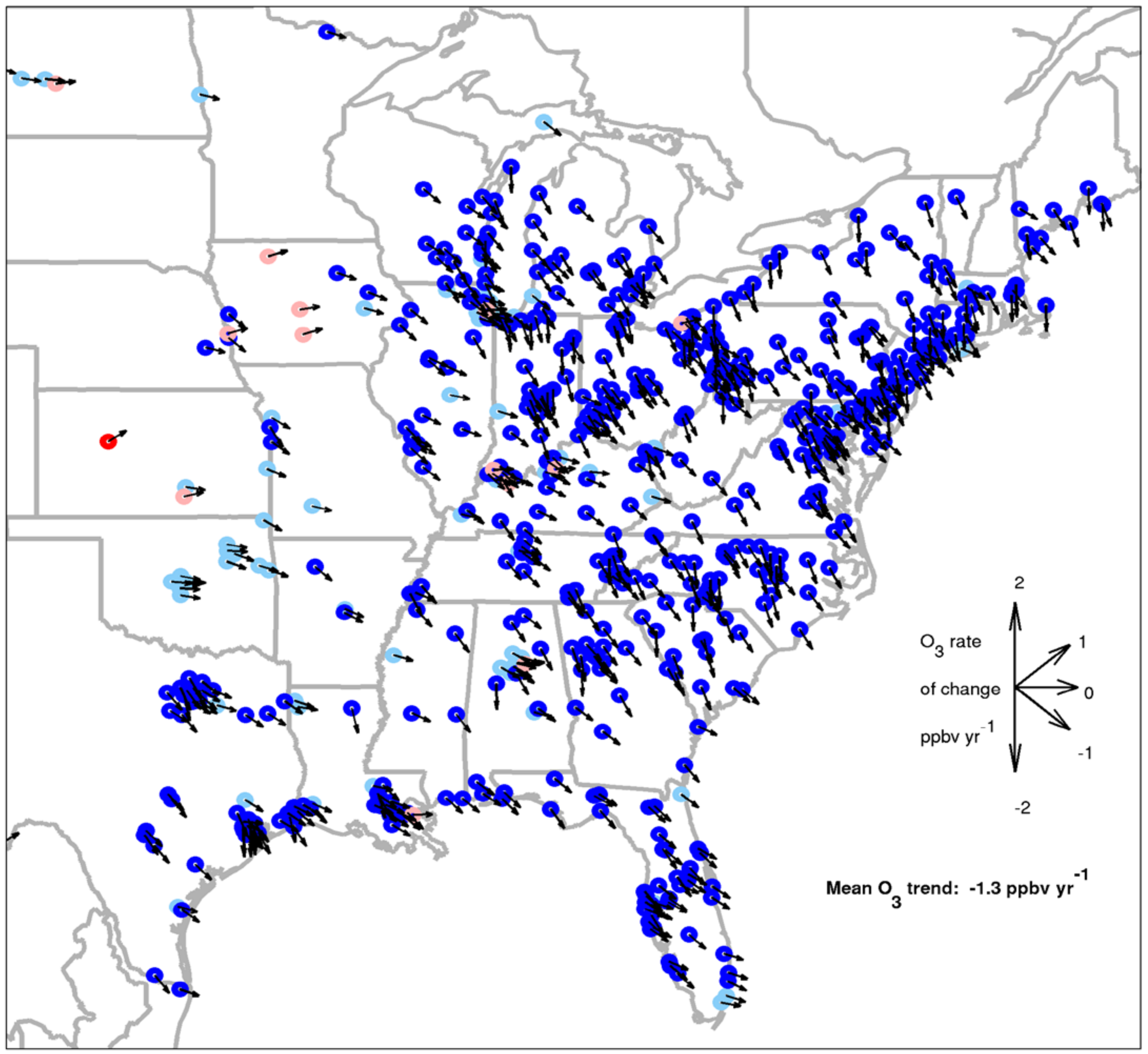
○ low elevation site

△ high elevation site

Ozone design values: annual fourth-highest daily maximum 8-hr ozone mixing ratio, averaged over 3 years

Calculated by EPA
www.epa.gov/airtrends/values.html

During 2003-2013 ozone decreased in the eastern US by -1.3 ± 0.6 ppbv yr^{-1} (trend range is 1 standard deviation).



● **significant increase**　● **insignificant increase**　● **significant decrease**　● **insignificant decrease**

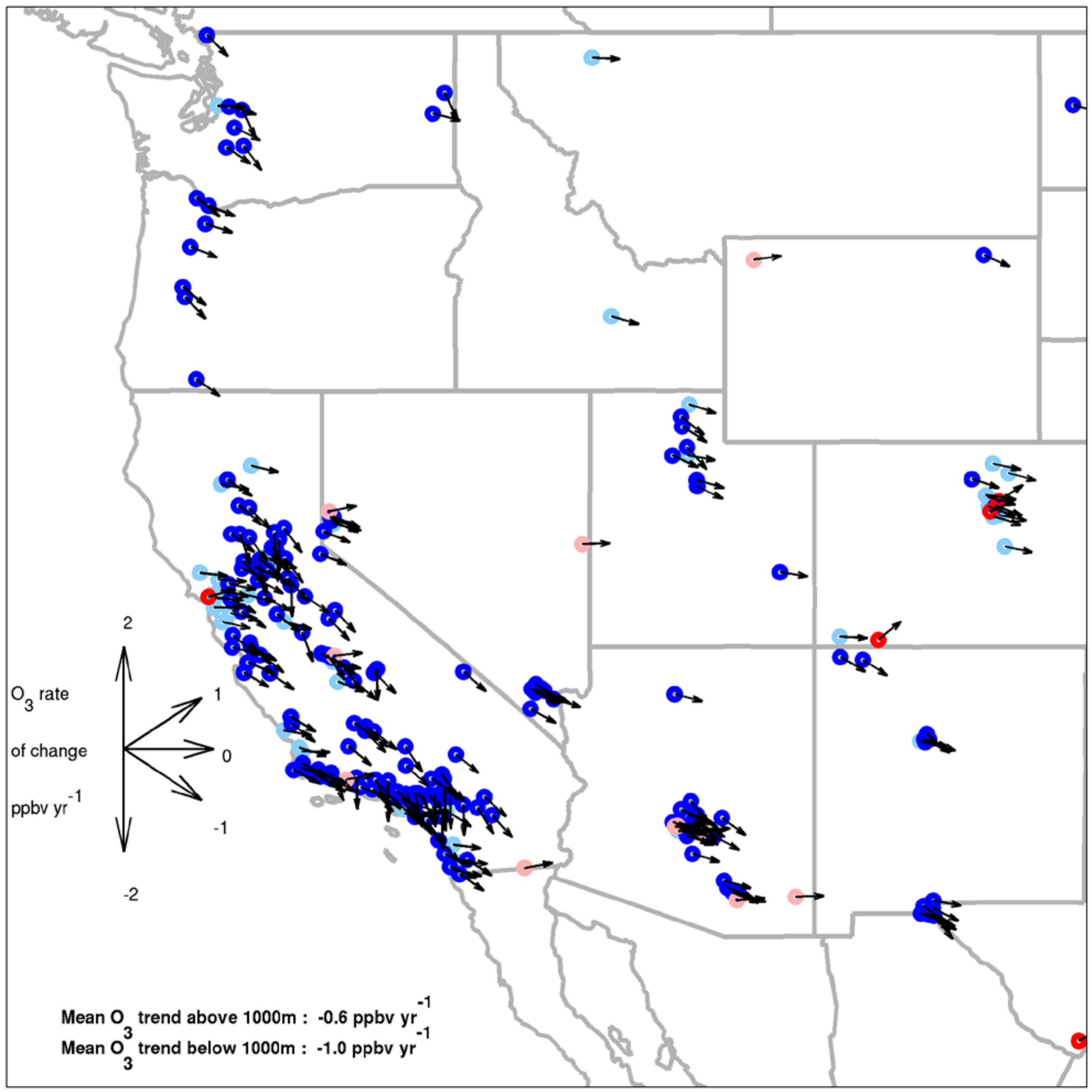
During 2003-2013 ozone decreased in the western US by:

-1.0 ± 0.6 ppbv yr^{-1}
below 1 km

-0.6 ± 0.7 ppbv yr^{-1}
above 1 km

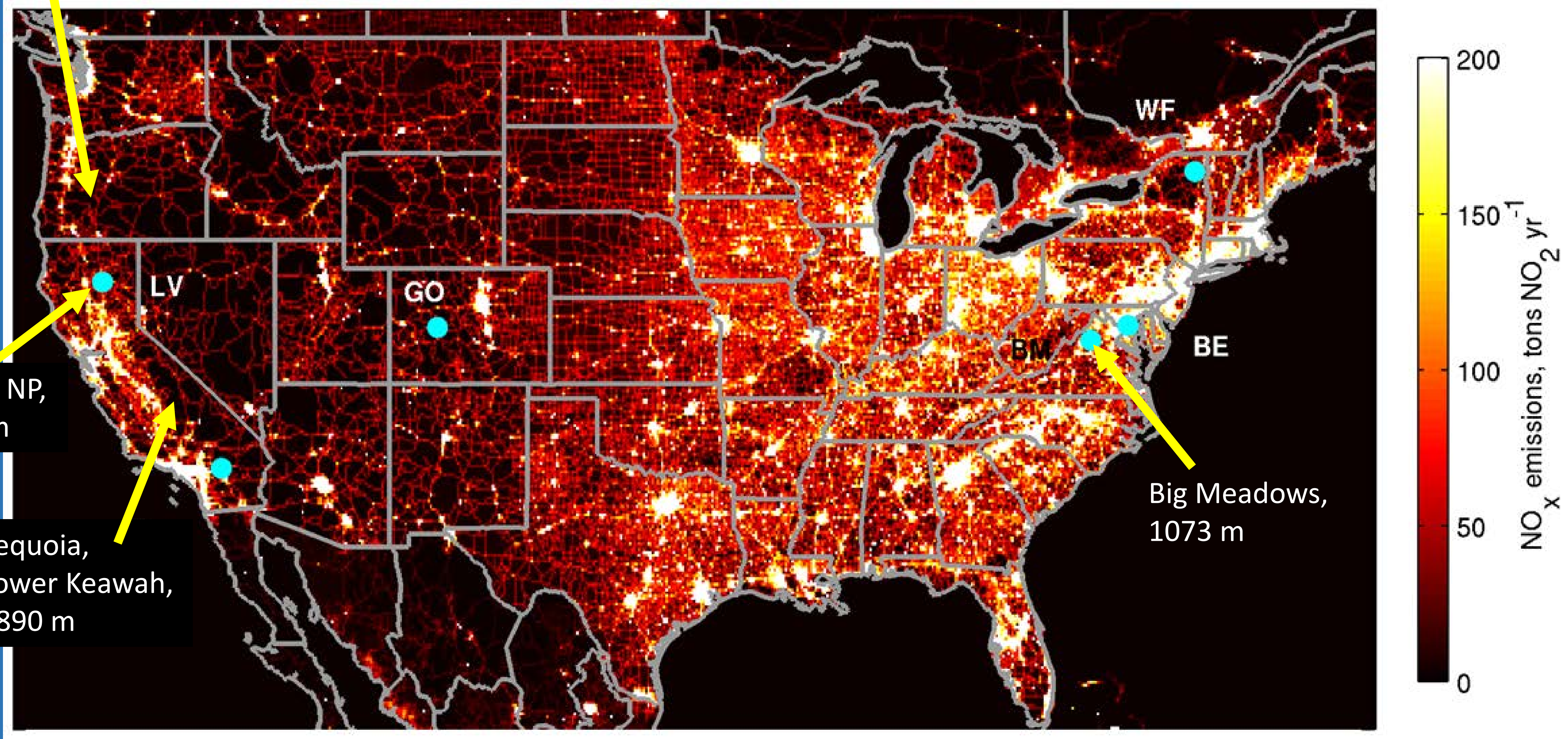
-0.4 ± 0.7 ppbv yr^{-1}
high elevation rural sites

-0.2 ± 0.6 ppbv yr^{-1}
Northern Colorado Front Range



● **significant increase**
● **insignificant increase**
● **significant decrease**
● **insignificant decrease**

A comparison of ozone trends at four high elevation rural sites



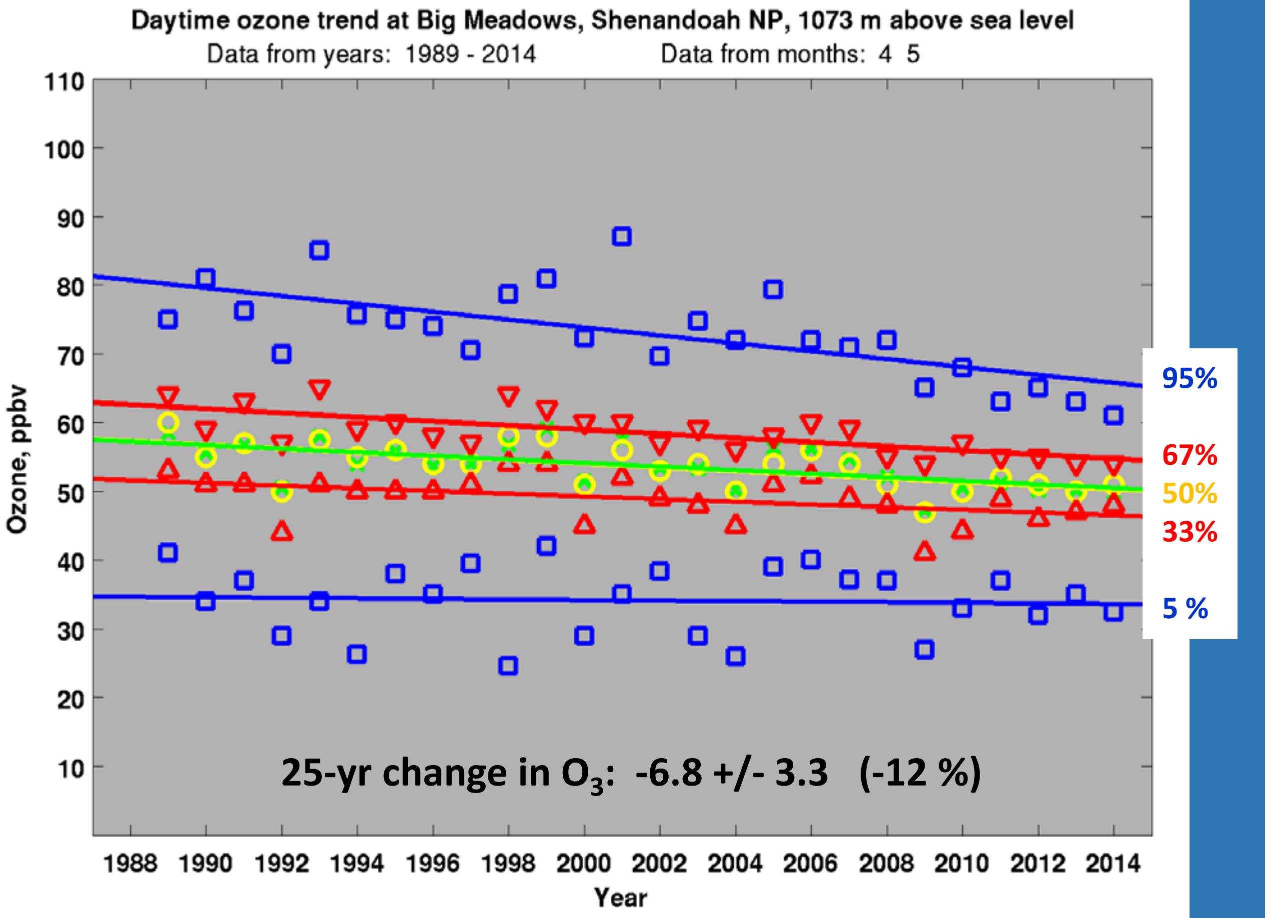
Mt Bachelor,
2763 m

Lassen NP,
1756 m

Sequoia,
Lower Keawah,
1890 m

Big Meadows,
1073 m

O_3 is decreasing in the eastern US in spring and summer, in response to emissions reductions

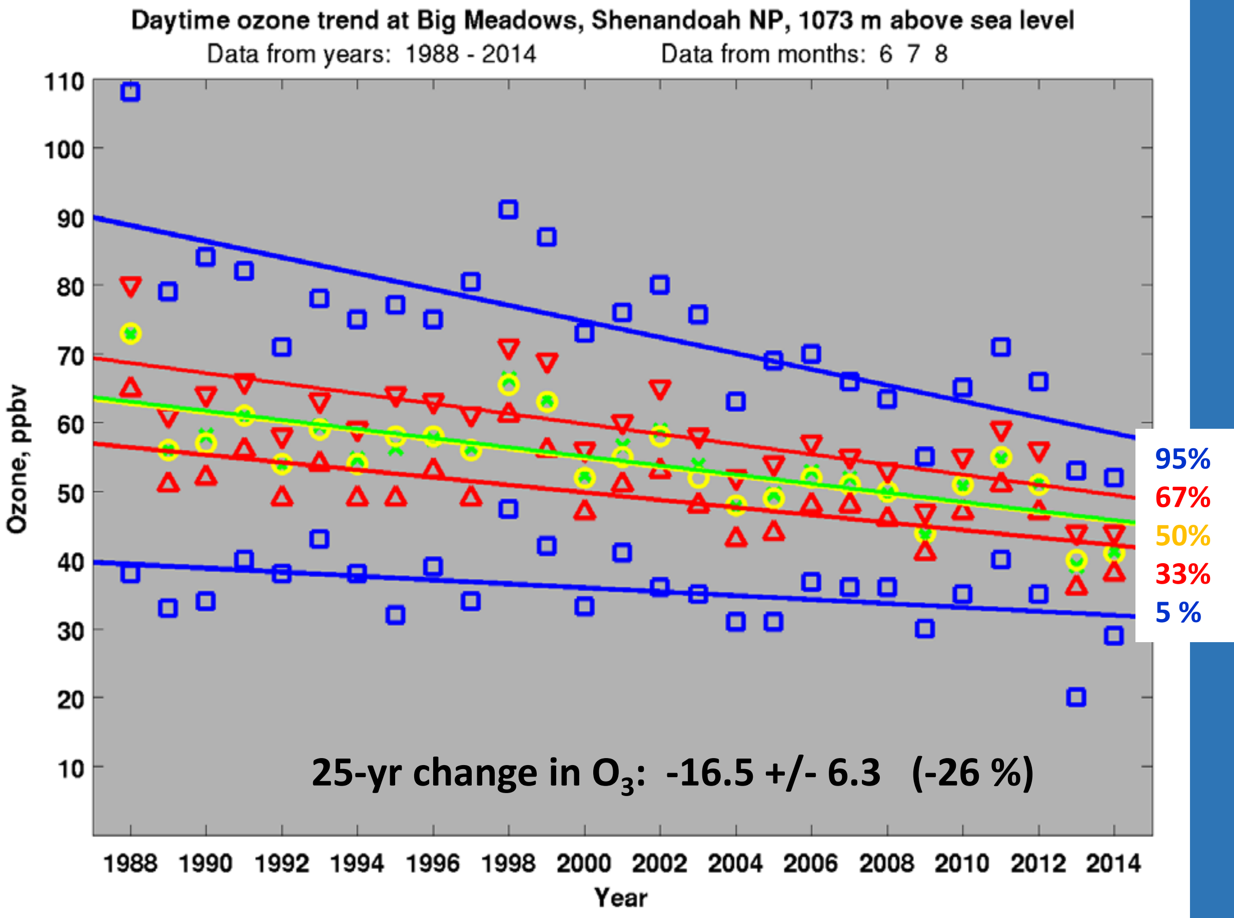

Daytime ozone trend at Big Meadows, Shenandoah NP, 1073 m above sea level

Data from years: 1989 - 2014 Data from months: 4 5

25-yr change in O_3: -6.8 +/- 3.3 (-12 %)

Green - mean
Yellow - median
Blue - 5th & 95th percentiles
Red - 33rd and 67th percentiles

	increase ppbv/year	p value
O_3 95th %:	-0.58 +/- 0.27	0.00
O_3 67th %:	-0.30 +/- 0.12	0.00
O_3 50th %:	-0.27 +/- 0.13	0.00
O_3 33th %:	-0.19 +/- 0.16	0.02
O_3 05th %:	-0.04 +/- 0.27	0.77


Daytime ozone trend at Big Meadows, Shenandoah NP, 1073 m above sea level

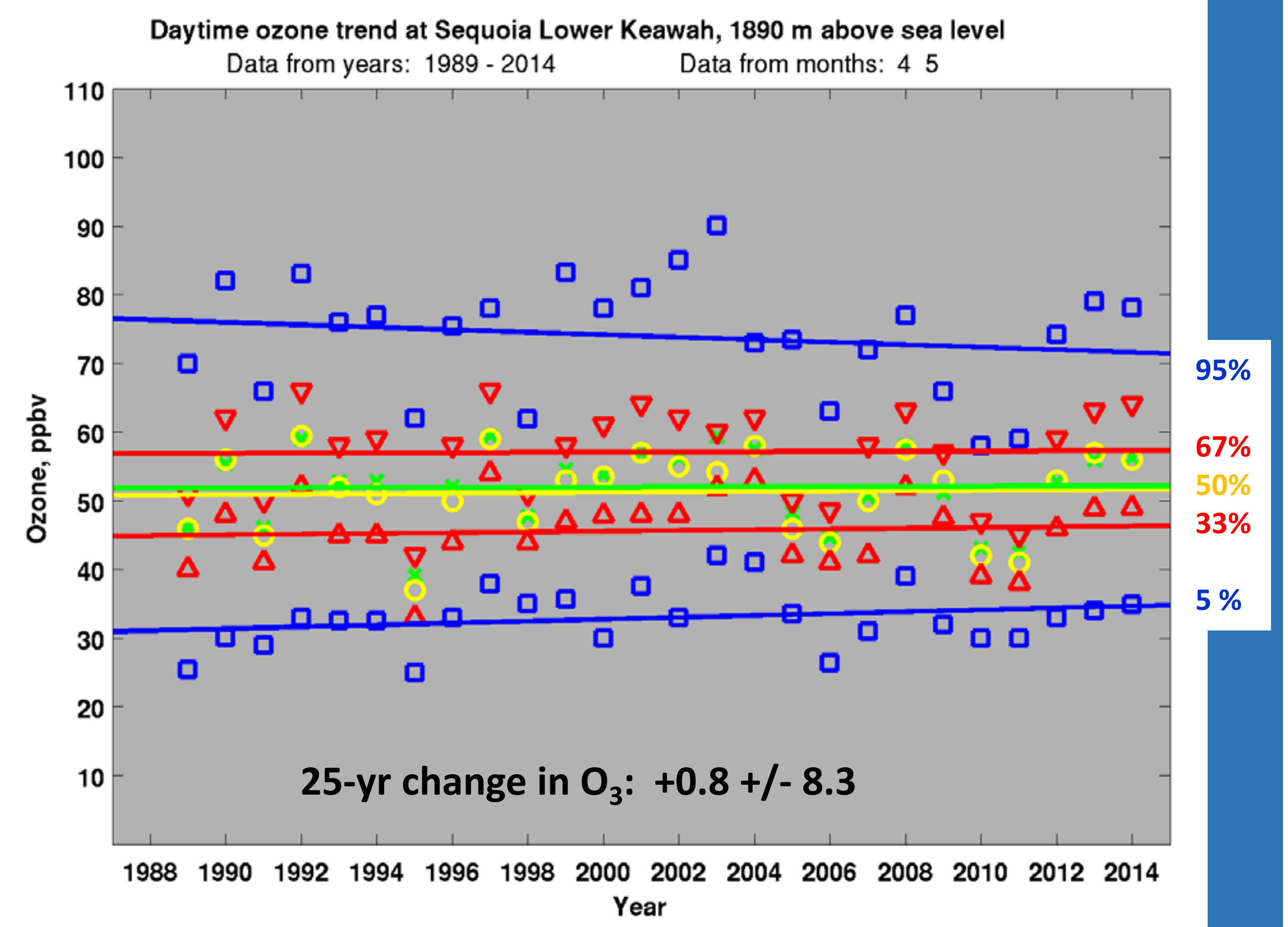
Data from years: 1988 - 2014 Data from months: 6 7 8

25-yr change in O_3: -16.5 +/- 6.3 (-26 %)

Green - mean
Yellow - median
Blue - 5th & 95th percentiles
Red - 33rd and 67th percentiles

	increase ppbv/year	p value
O_3 95th %:	-1.16 +/- 0.39	0.00
O_3 67th %:	-0.74 +/- 0.27	0.00
O_3 50th %:	-0.66 +/- 0.25	0.00
O_3 33th %:	-0.54 +/- 0.23	0.00
O_3 05th %:	-0.28 +/- 0.25	0.03

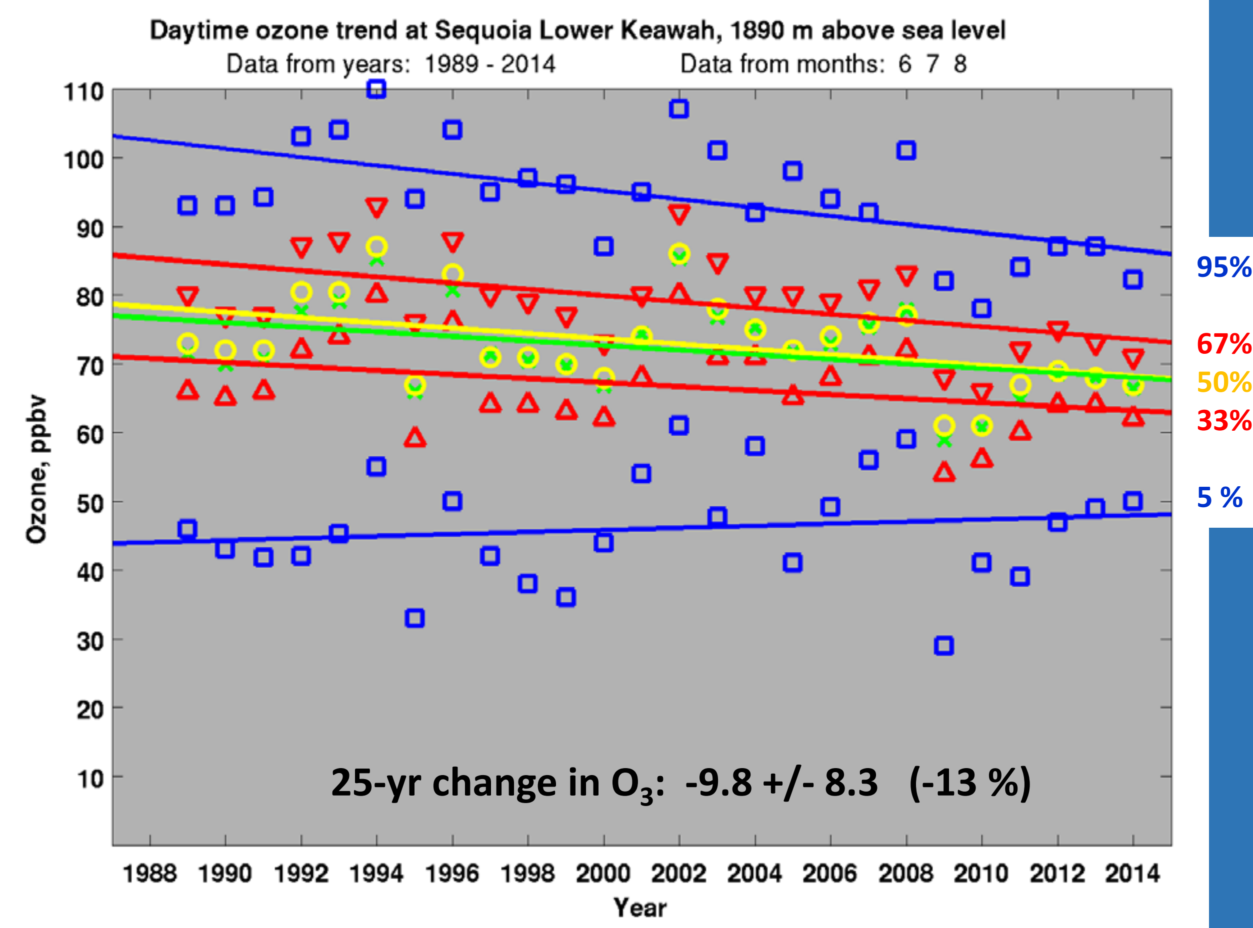
O_3 is decreasing in Sequoia NP in summer but not spring; emissions are coming down



25-yr change in O_3: +0.8 +/- 8.3

Green - mean
Yellow - median
Blue - 5th & 95th percentiles
Red - 33rd and 67th percentiles

	increase ppbv/year	p value
O_3 95th %:	-0.18 +/- 0.46	0.43
O_3 67th %:	0.02 +/- 0.37	0.93
O_3 50th %:	0.03 +/- 0.33	0.84
O_3 33th %:	0.05 +/- 0.28	0.70
O_3 05th %:	0.14 +/- 0.23	0.23

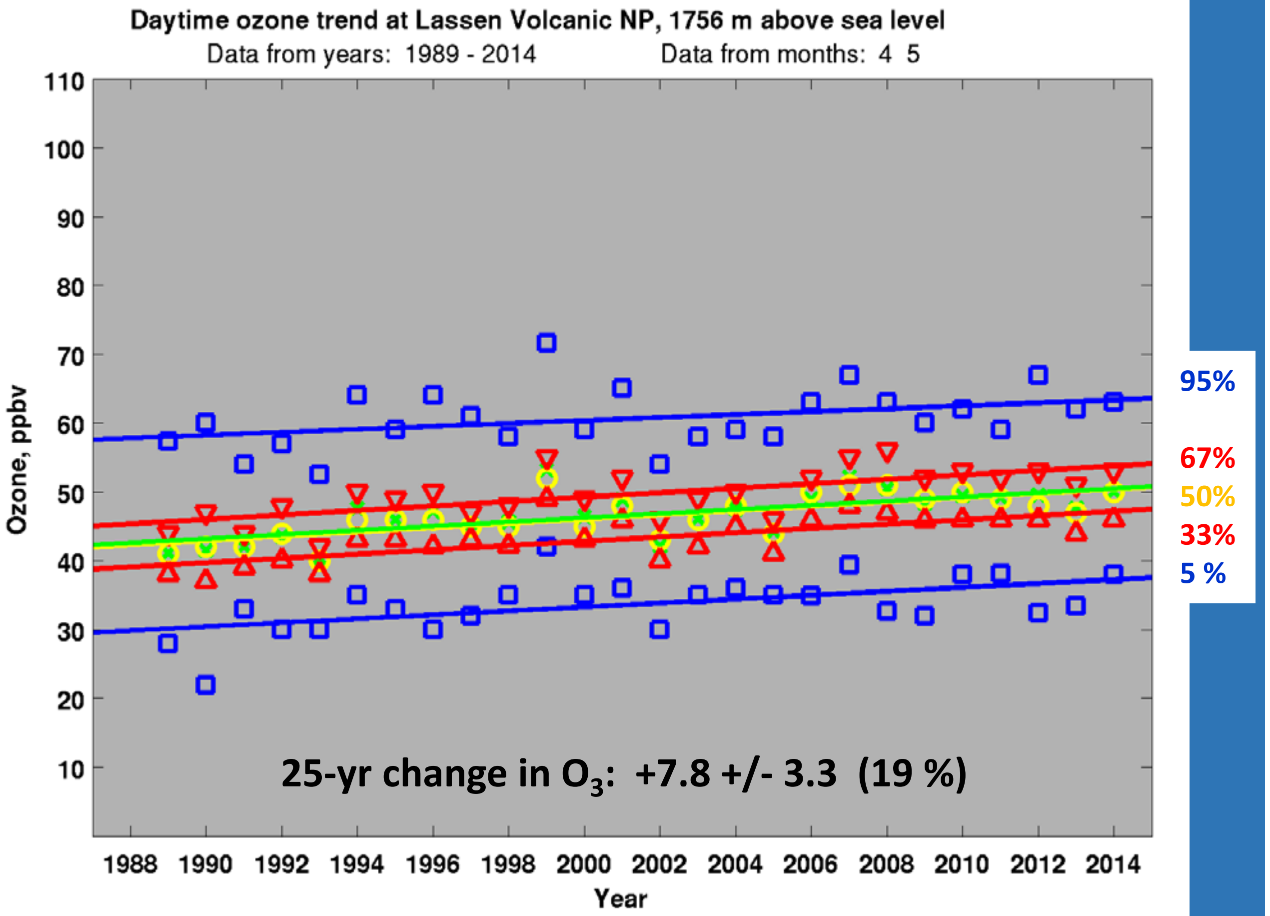


25-yr change in O_3: -9.8 +/- 8.3 (-13 %)

Green - mean
Yellow - median
Blue - 5th & 95th percentiles
Red - 33rd and 67th percentiles

	increase ppbv/year	p value
O_3 95th %:	-0.61 +/- 0.36	0.00
O_3 67th %:	-0.45 +/- 0.32	0.01
O_3 50th %:	-0.39 +/- 0.33	0.02
O_3 33th %:	-0.29 +/- 0.34	0.09
O_3 05th %:	0.15 +/- 0.44	0.48

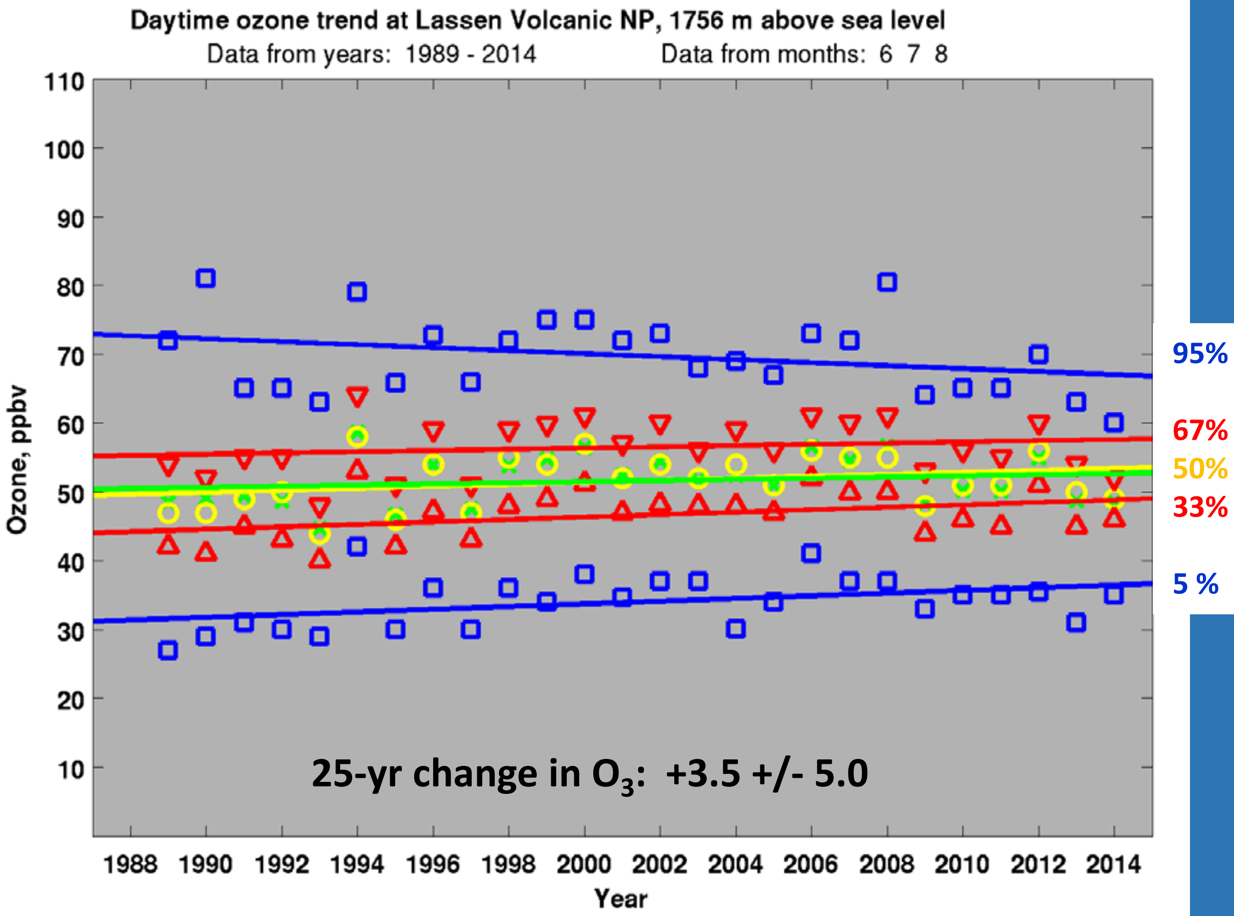
Despite emissions reduction, O_3 is increasing at Lassen NP in spring



25-yr change in O_3: +7.8 +/- 3.3 (19 %)

Green - mean
Yellow - median
Blue - 5th & 95th percentiles
Red - 33rd and 67th percentiles

	increase ppbv/year	p value
O_3 95th %:	0.21 +/- 0.22	0.06
O_3 67th %:	0.32 +/- 0.14	0.00
O_3 50th %:	0.31 +/- 0.13	0.00
O_3 33th %:	0.31 +/- 0.12	0.00
O_3 05th %:	0.29 +/- 0.19	0.00

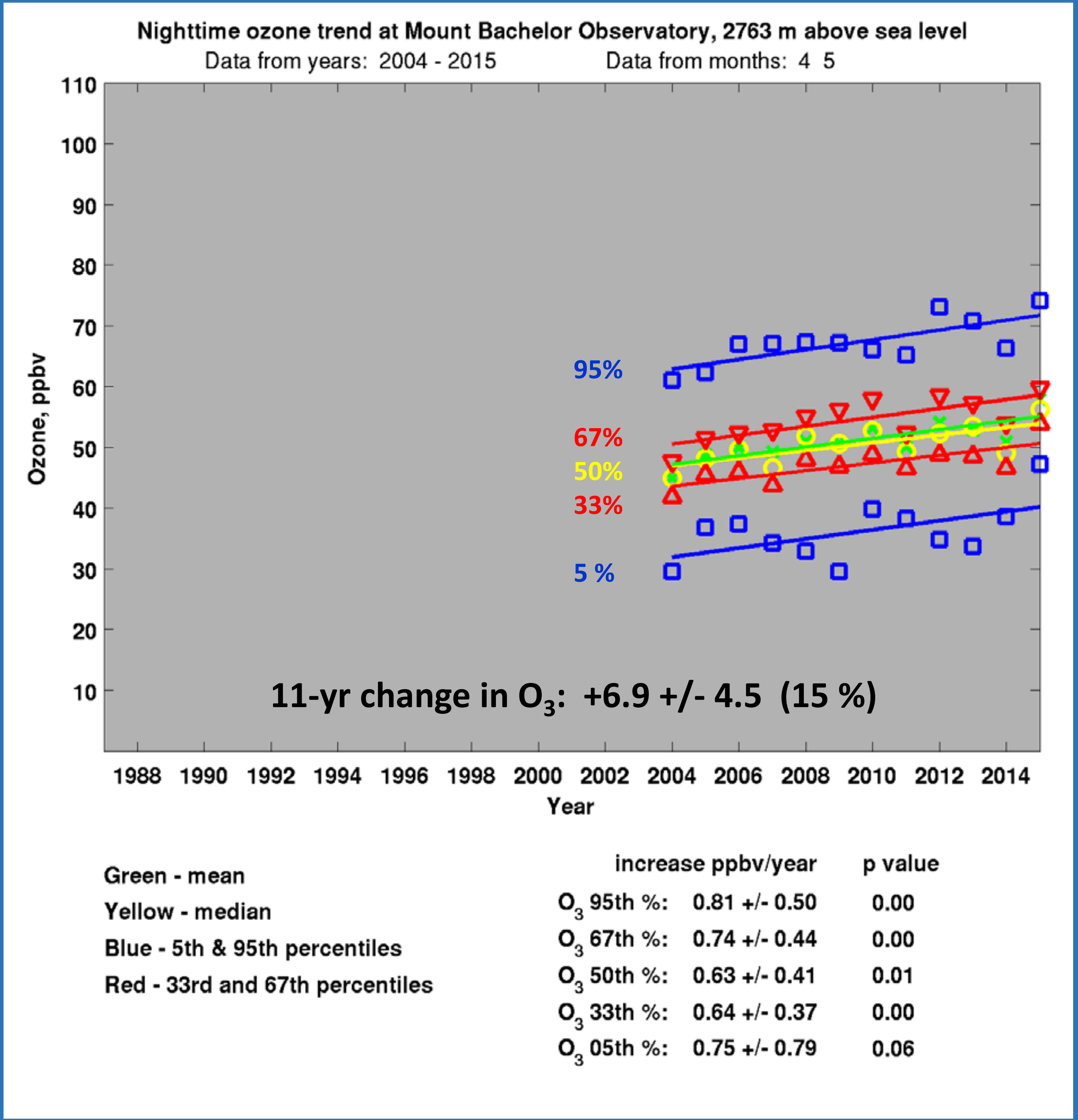


25-yr change in O_3: +3.5 +/- 5.0

Green - mean
Yellow - median
Blue - 5th & 95th percentiles
Red - 33rd and 67th percentiles

	increase ppbv/year	p value
O_3 95th %:	-0.22 +/- 0.29	0.14
O_3 67th %:	0.09 +/- 0.21	0.39
O_3 50th %:	0.14 +/- 0.20	0.14
O_3 33th %:	0.18 +/- 0.18	0.05
O_3 05th %:	0.19 +/- 0.19	0.05

Mt Bachelor samples the lower free troposphere at night (*Dan Jaffe, U. of Washington*)



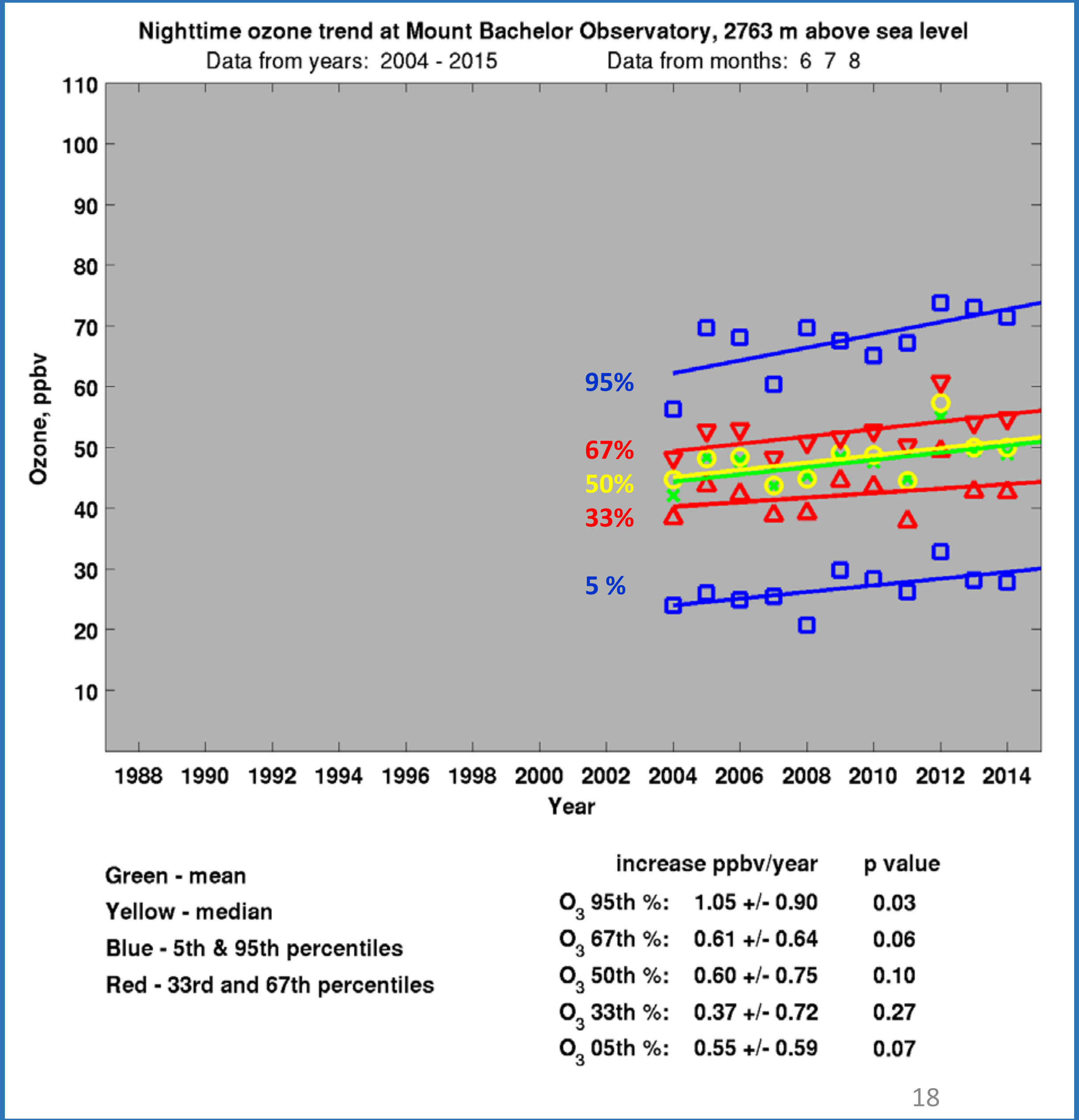
Nighttime ozone trend at Mount Bachelor Observatory, 2763 m above sea level

Data from years: 2004 - 2015   Data from months: 4 5

11-yr change in O_3: +6.9 +/- 4.5 (15 %)

Green - mean
Yellow - median
Blue - 5th & 95th percentiles
Red - 33rd and 67th percentiles

	increase ppbv/year	p value
O_3 95th %:	0.81 +/- 0.50	0.00
O_3 67th %:	0.74 +/- 0.44	0.00
O_3 50th %:	0.63 +/- 0.41	0.01
O_3 33th %:	0.64 +/- 0.37	0.00
O_3 05th %:	0.75 +/- 0.79	0.06



Nighttime ozone trend at Mount Bachelor Observatory, 2763 m above sea level

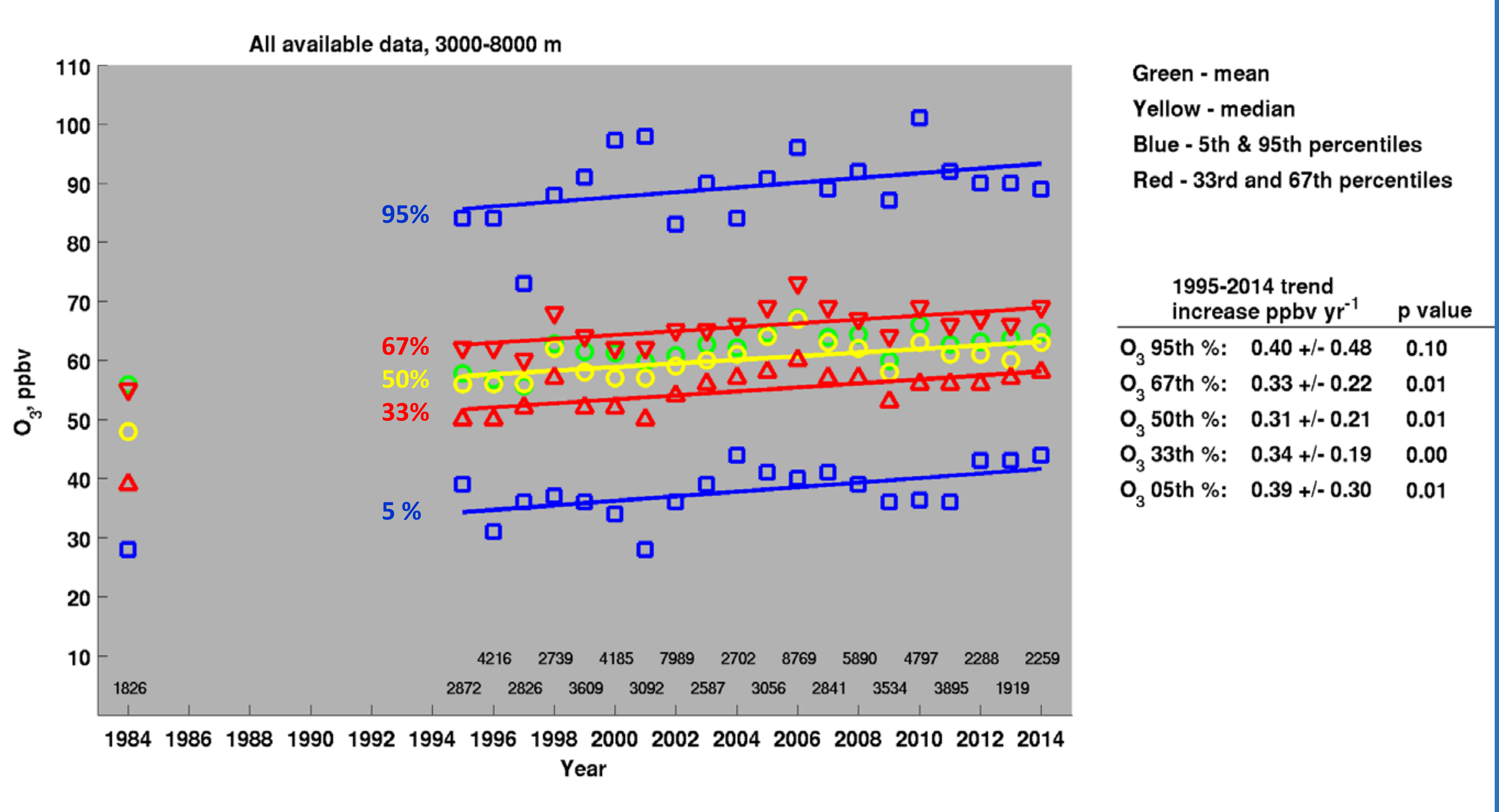
Data from years: 2004 - 2015   Data from months: 6 7 8

Green - mean
Yellow - median
Blue - 5th & 95th percentiles
Red - 33rd and 67th percentiles

	increase ppbv/year	p value
O_3 95th %:	1.05 +/- 0.90	0.03
O_3 67th %:	0.61 +/- 0.64	0.06
O_3 50th %:	0.60 +/- 0.75	0.10
O_3 33th %:	0.37 +/- 0.72	0.27
O_3 05th %:	0.55 +/- 0.59	0.07

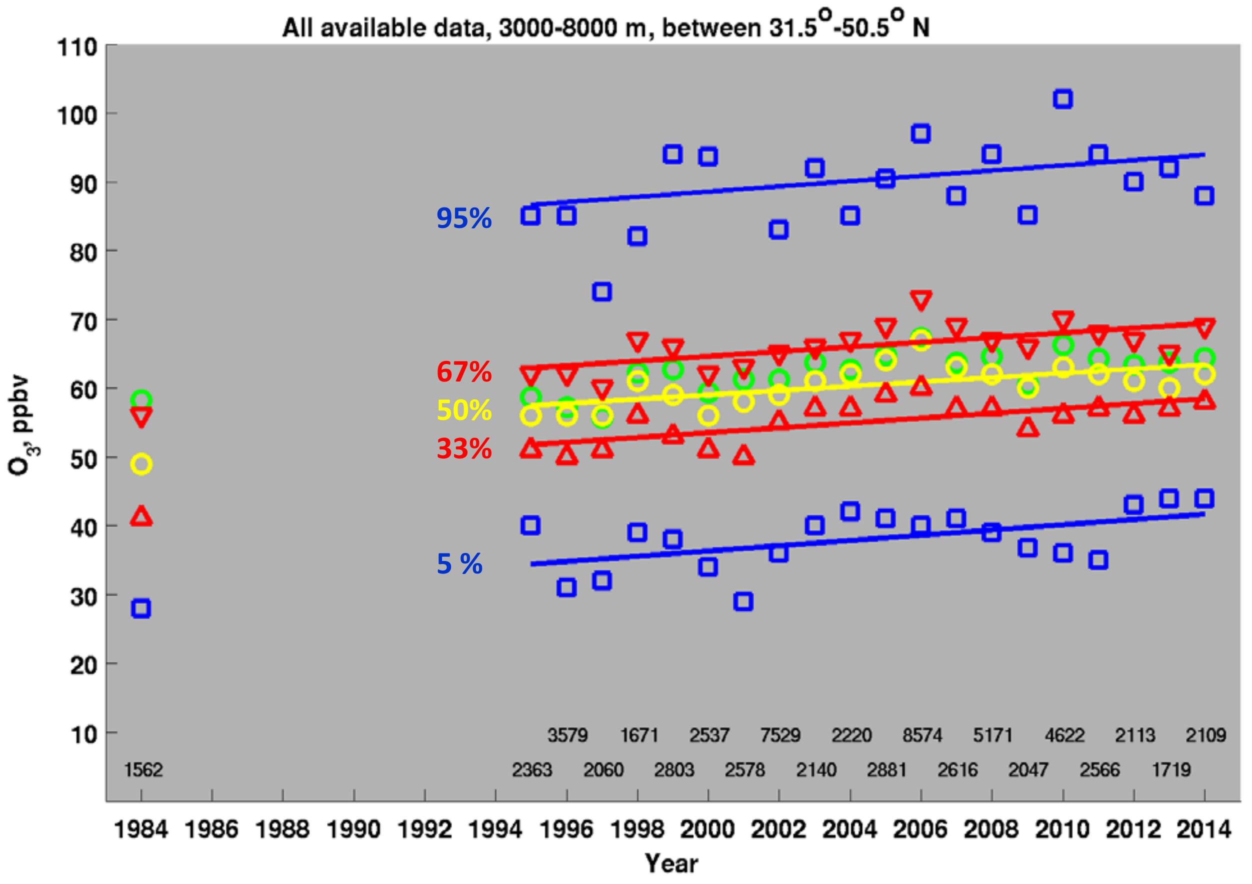
20 years of free tropospheric ozone observations are now available above western North America during springtime

(*O. Cooper, U. of Colorado/NOAA, Boulder*)



	1995-2014 trend increase ppbv yr^{-1}	p value
O_3 95th %:	0.40 +/- 0.48	0.10
O_3 67th %:	0.33 +/- 0.22	0.01
O_3 50th %:	0.31 +/- 0.21	0.01
O_3 33th %:	0.34 +/- 0.19	0.00
O_3 05th %:	0.39 +/- 0.30	0.01

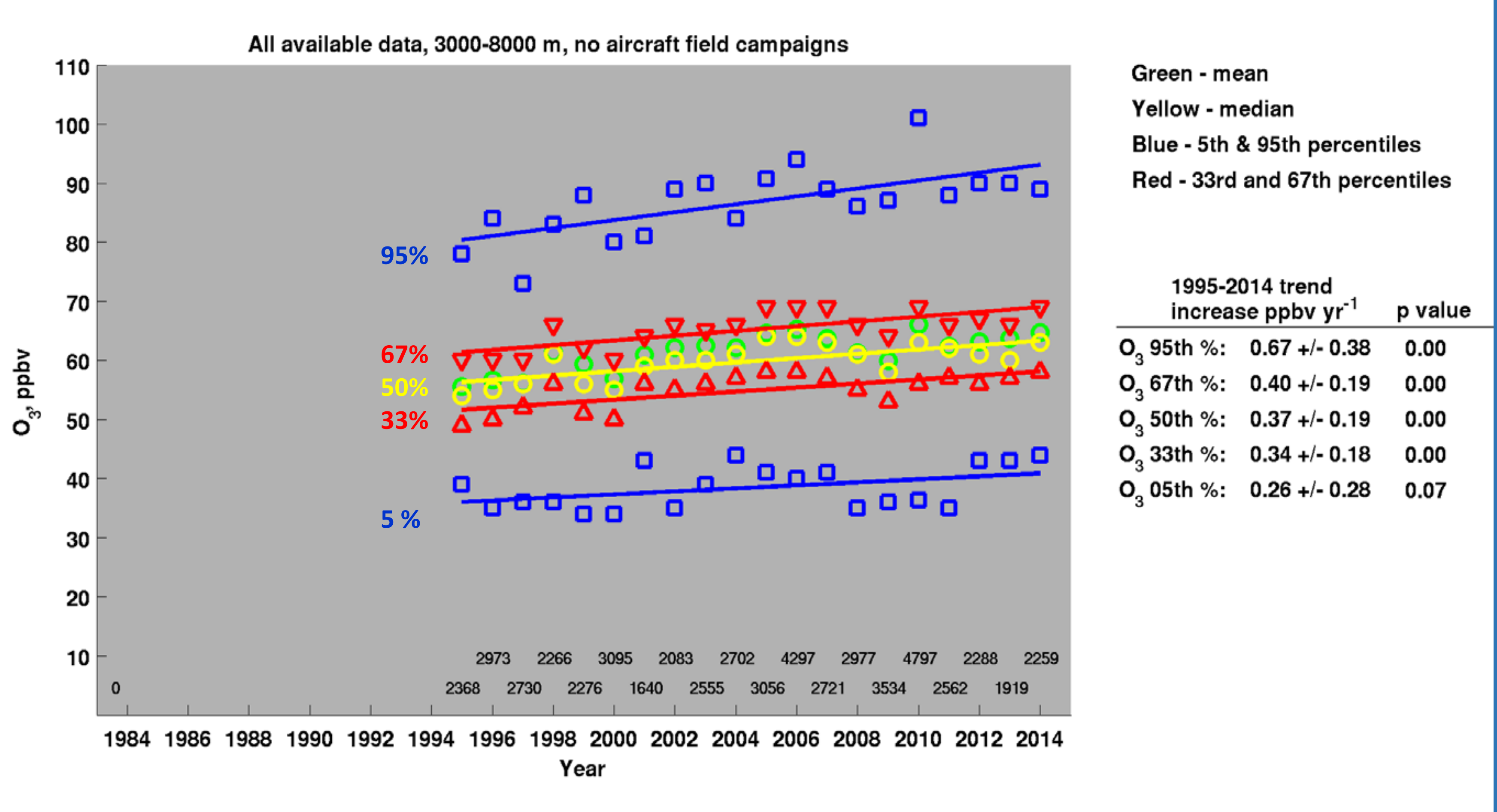
19-yr change in O_3: +5.9 +/- 4.0 (10 %)



Green - mean
Yellow - median
Blue - 5th & 95th percentiles
Red - 33rd and 67th percentiles

	1995-2014 trend increase ppbv yr^{-1}	p value
O_3 95th %:	0.38 +/- 0.63	0.22
O_3 67th %:	0.34 +/- 0.21	0.00
O_3 50th %:	0.31 +/- 0.19	0.00
O_3 33th %:	0.35 +/- 0.19	0.00
O_3 05th %:	0.38 +/- 0.30	0.02

19-yr change in O_3: +5.9 +/- 3.6 (10 %)



	1995-2014 trend increase ppbv yr^{-1}	p value
O$_3$ 95th %:	0.67 +/- 0.38	0.00
O$_3$ 67th %:	0.40 +/- 0.19	0.00
O$_3$ 50th %:	0.37 +/- 0.19	0.00
O$_3$ 33th %:	0.34 +/- 0.18	0.00
O$_3$ 05th %:	0.26 +/- 0.28	0.07

19-yr change in O$_3$: +7.1 +/- 3.6 (12 %)

Atmos. Chem. Phys., 14, 913–937, 2014
www.atmos-chem-phys.net/14/913/2014/
doi:10.5194/acp-14-913-2014

Atmospheric Chemistry and Physics
Open Access

A global climatology of stratosphere–troposphere exchange using the ERA-Interim data set from 1979 to 2011

B. Škerlak, M. Sprenger, and H. Wernli
ETH Zurich, IAC, Universitätstrasse 16, 8092 Zürich, Switzerland

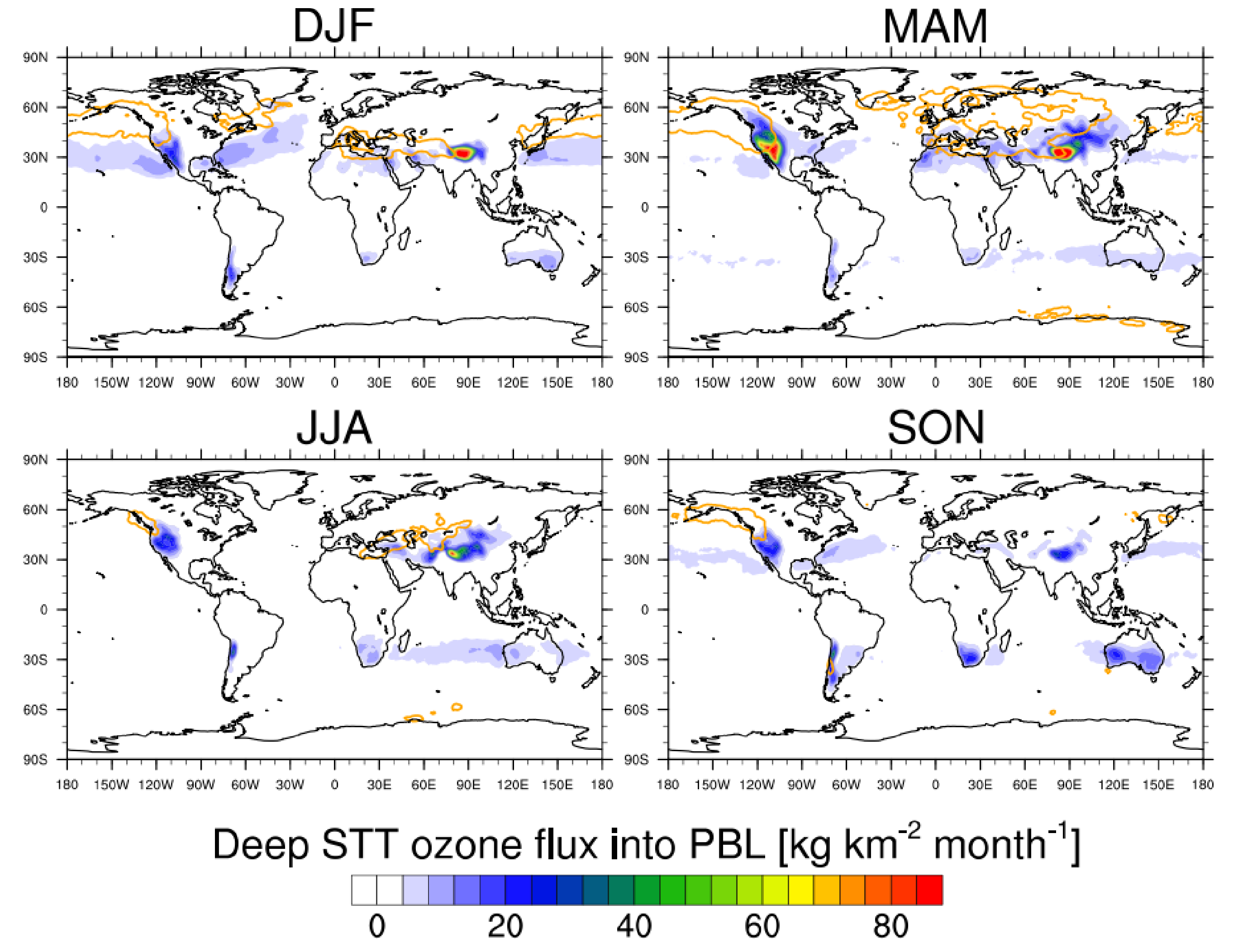


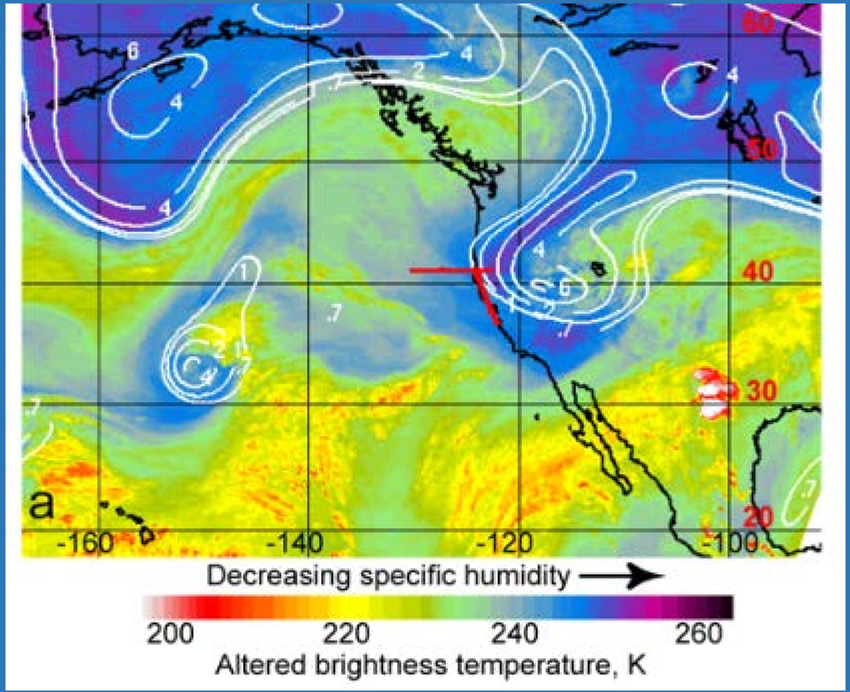
Fig. 17. Seasonally averaged deep STT ozone flux into the PBL for 1979–2011. For this calculation, the ozone concentration is kept constant along the trajectories after crossing the tropopause. The orange contours indicate areas where the ozone flux across the tropopause due to deep STT is higher than 7 kg km^{-2} month^{-1}.

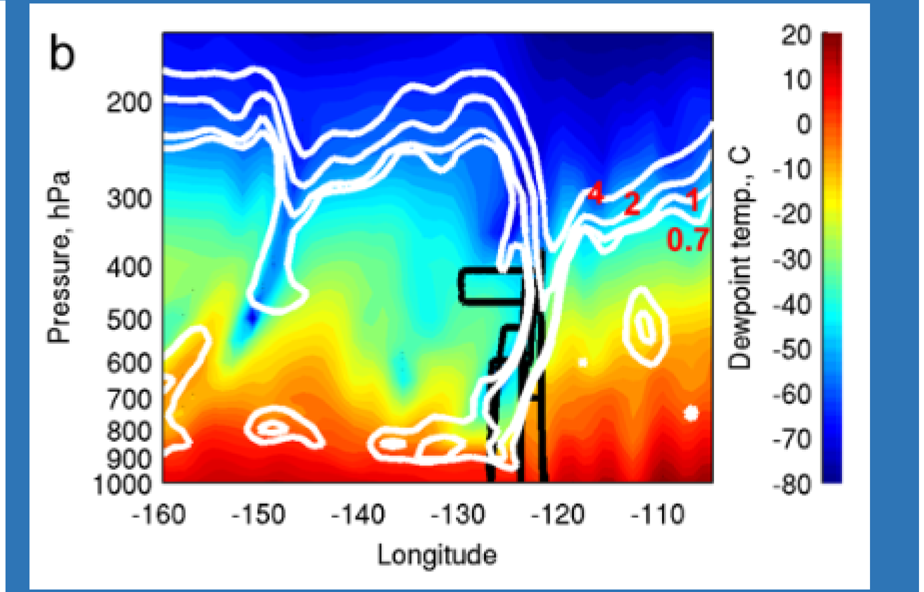
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 109, D23S09, doi:10.1029/2003JD004006, 2004

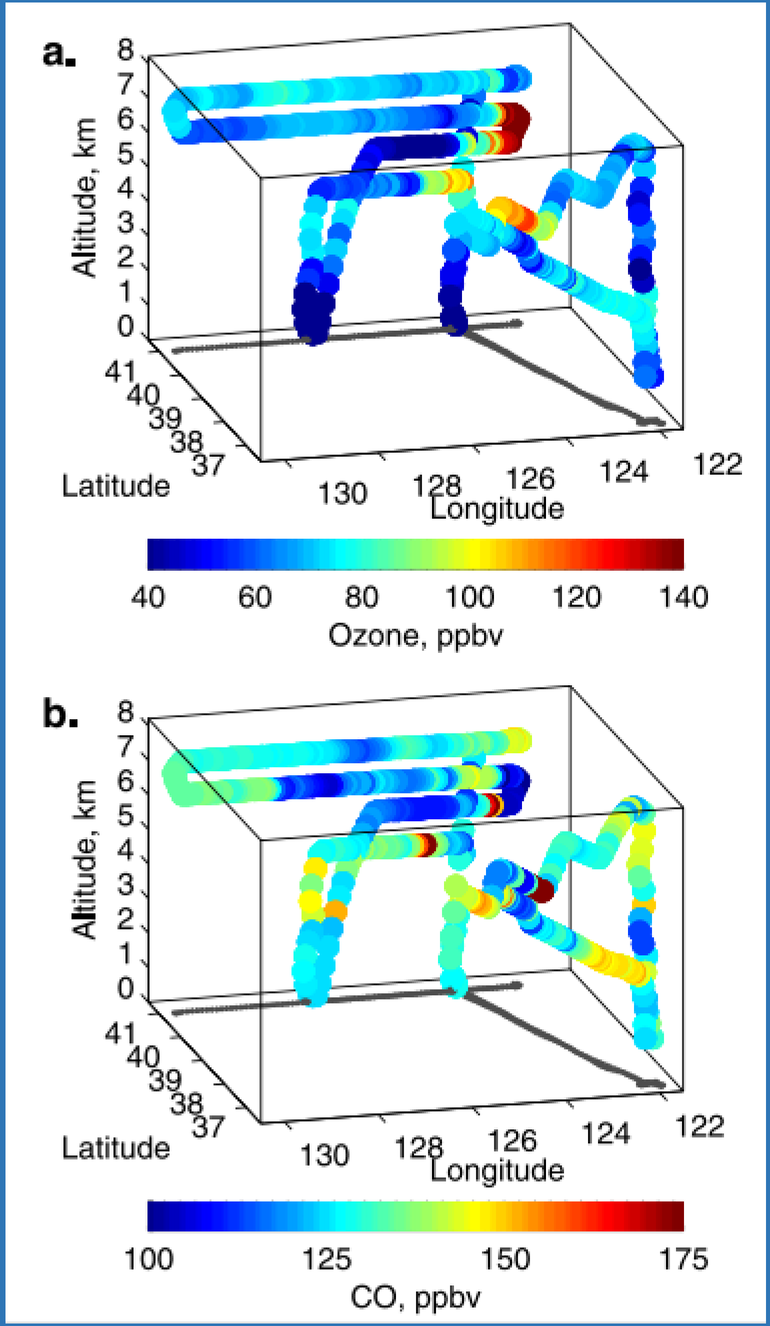
On the life cycle of a stratospheric intrusion and its dispersion into polluted warm conveyor belts

O. Cooper,[1,2] C. Forster,[3] D. Parrish,[2] E. Dunlea,[2,4] G. Hübler,[1,2] F. Fehsenfeld,[2]
J. Holloway,[1,2] S. Oltmans,[5] B. Johnson,[5] A. Wimmers,[6,7] and L. Horowitz[8]

NOAA P3 flight off the California coast, May 11, 2002





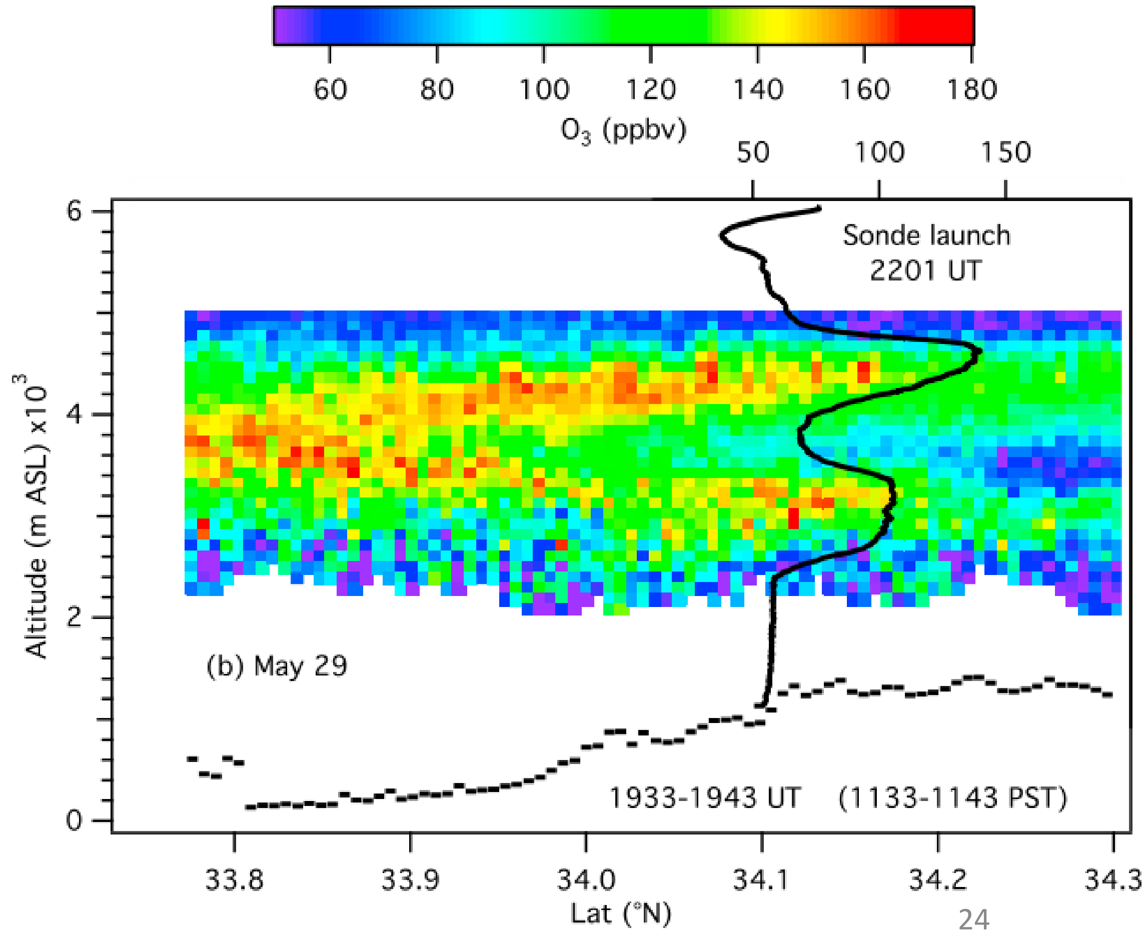


JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, D00V06, doi:10.1029/2011JD016766, 2012

Stratospheric influence on surface ozone in the Los Angeles area during late spring and early summer of 2010

A. O. Langford,[1] J. Brioude,[1,2] O. R. Cooper,[1,2] C. J. Senff,[1,2] R. J. Alvarez II,[1]
R. M. Hardesty,[1] B. J. Johnson,[3] and S. J. Oltmans[3]

Received 24 August 2011; revised 28 November 2011; accepted 4 December 2011; published 4 February 2012.



Observations from the TOPAZ airborne ozone lidar aboard the NOAA Twin Otter on May 29.

Shown is a north-south transect 10 km west of Joshua Tree National Park. The solid black curve shows the May 29 ozonesonde profile.

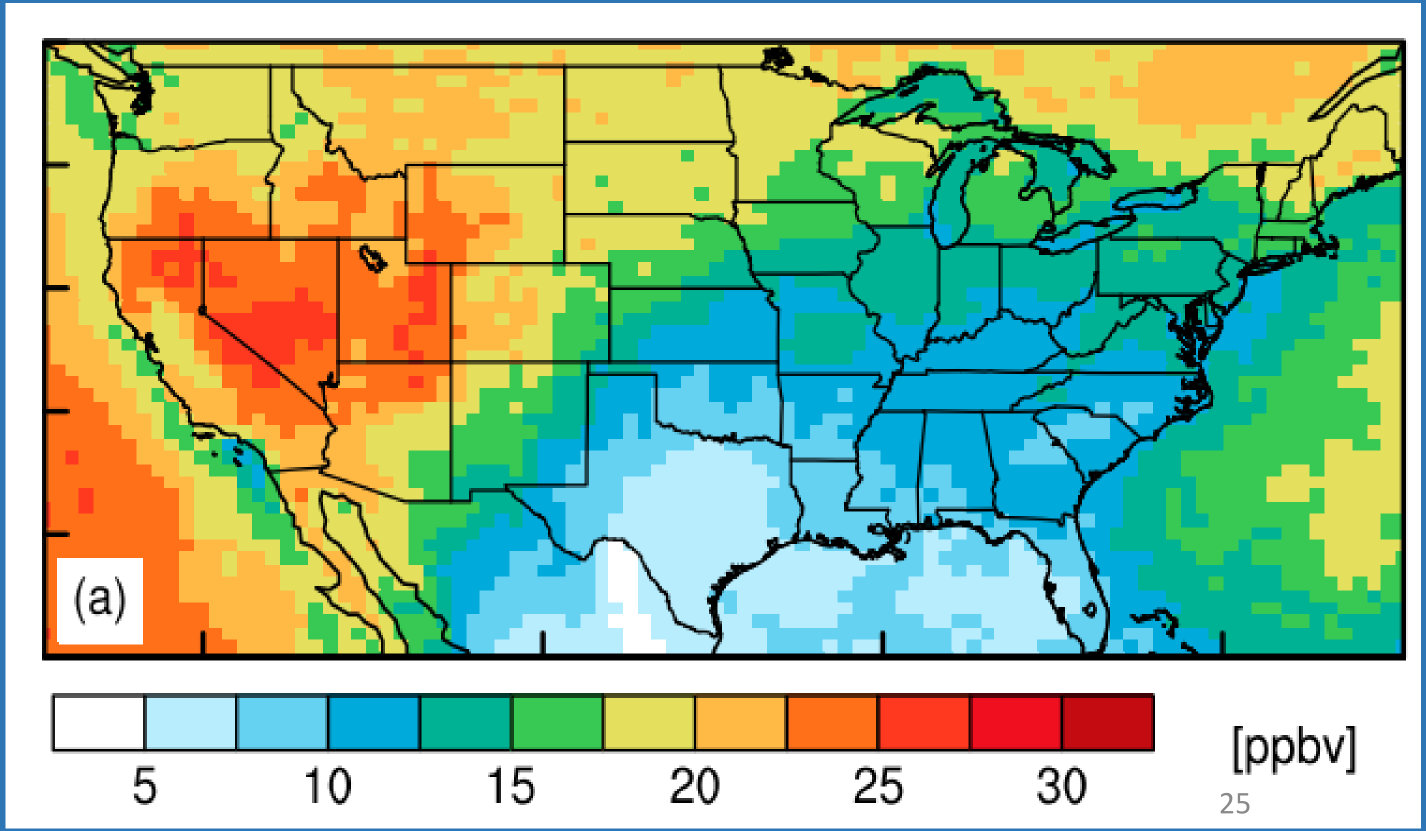
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, D00V22, doi:10.1029/2012JD018151, 2012

Springtime high surface ozone events over the western United States: Quantifying the role of stratospheric intrusions

Meiyun Lin,[1,2] Arlene M. Fiore,[3] Owen R. Cooper,[4,5] Larry W. Horowitz,[2]
Andrew O. Langford,[5] Hiram Levy II,[2] Bryan J. Johnson,[5] Vaishali Naik,[2,6]
Samuel J. Oltmans,[4] and Christoph J. Senff [4,5]

Received 21 May 2012; revised 29 August 2012; accepted 4 September 2012; published 12 October 2012.

Continental U.S. distributions of median stratospheric contribution to MDA8 surface ozone from April–June 2010 as estimated by the NOAA GFDL AM3 model.



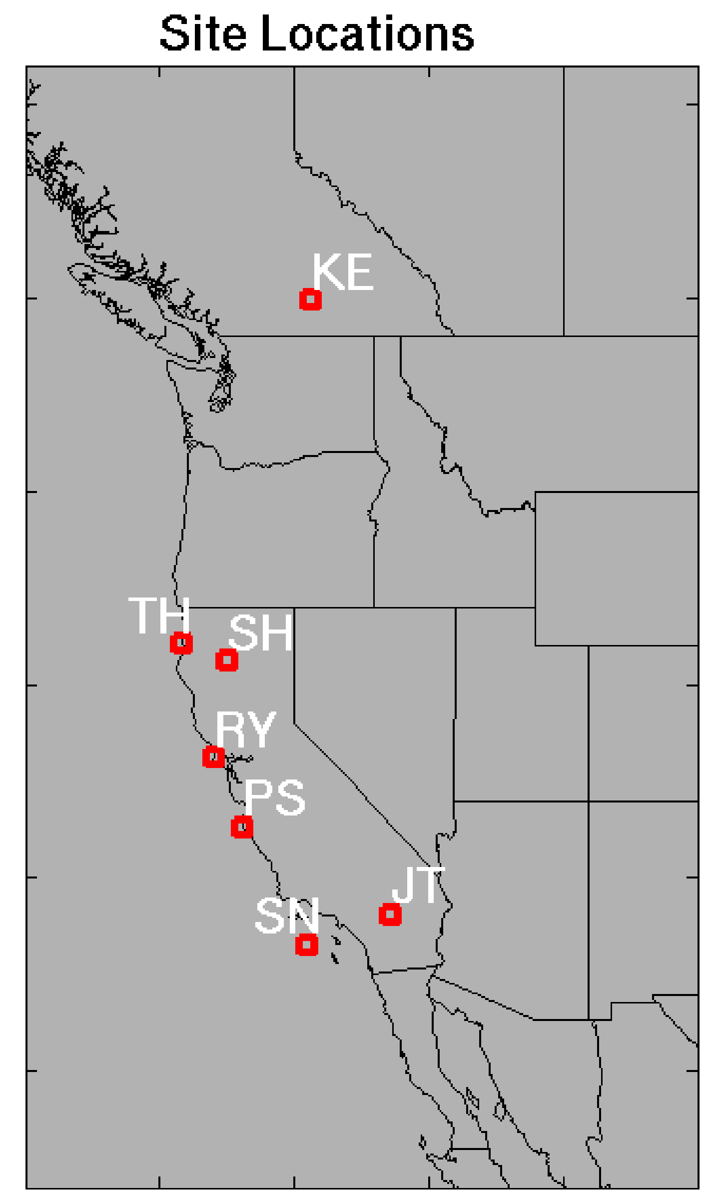
IONS-2010 ozonesonde network

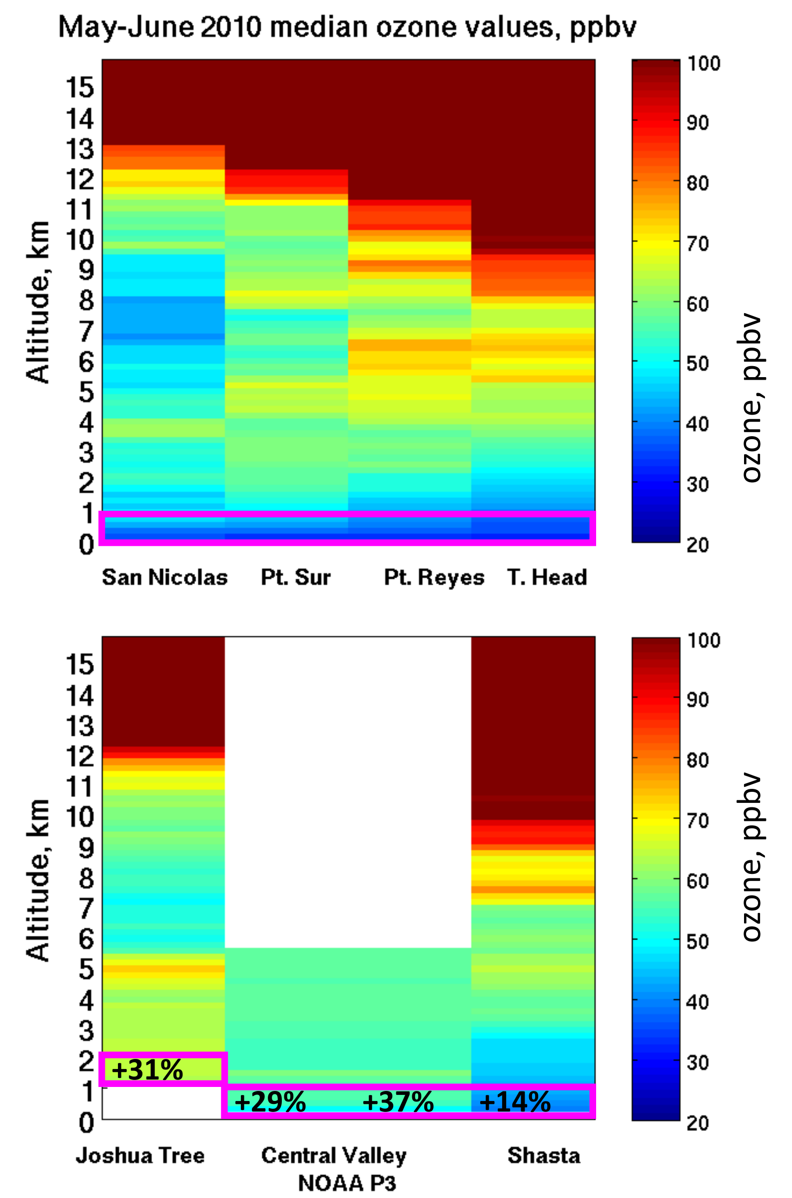
Near daily ozonesondes were launched from 7 sites between May 10 - June 19, 2010.

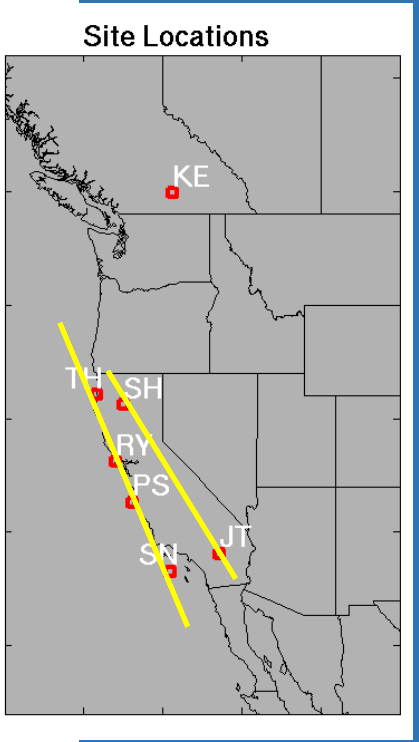
A total of 230 sondes were launched, the most in any western North America field campaign.

Funding, operations and support provided by:

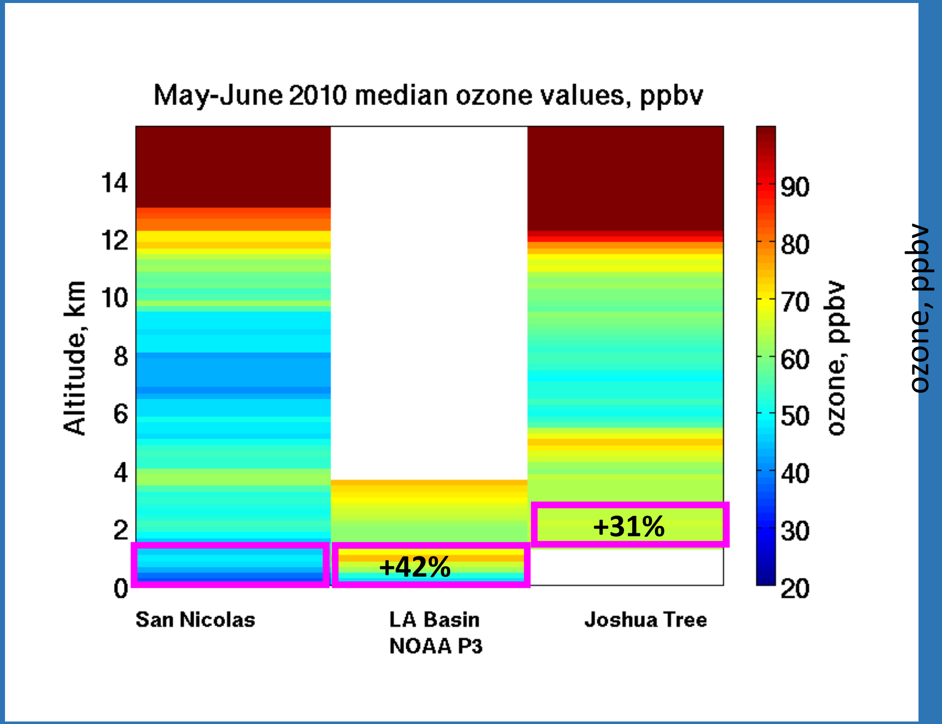
NOAA ESRL Health of the Atmosphere Program
NASA Tropospheric Chemistry Program
U. S. Navy
Environment Canada
NOAA National Weather Service
National Park Service
California State Parks
Naval Postgraduate School (Monterey)
Federal Aviation Administration

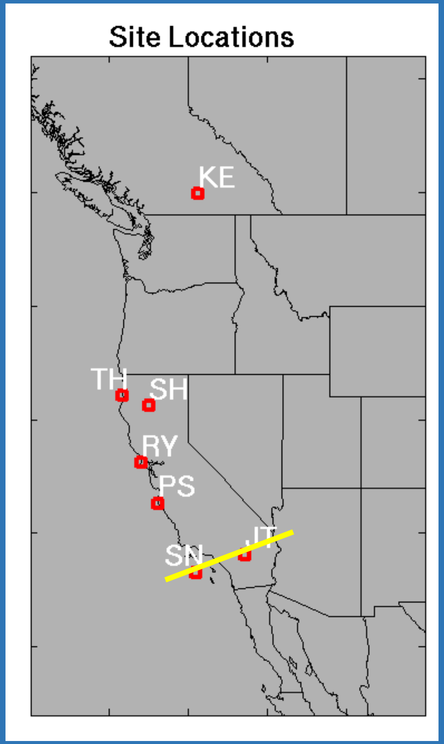






Percent difference in total mass of ozone in the lowest km of the atmosphere, for inland sites in comparison to coastal sites at similar latitude.





Percent difference in total mass of ozone per km (0-1.0 km a.g.l.) for:

LA Basin and Joshua Tree compared to San Nicolas Island.

ATMOSPHERE

Challenges of a lowered U.S. ozone standard

Source attribution science can help areas of the U.S. west

By **Owen R. Cooper,**[1,2*] **Andrew O. Langford,**[2] **David D. Parrish,**[1,2] **David W. Fahey**[2]

At Earth's surface, ozone is an air pollutant that causes respiratory health effects in humans and impairs plant growth and productivity (*1*). The Clean Air Act (CAA) of 1970 mandates that the U.S. Environmental Protection Agency (EPA) assess the ozone standard every 5 years and revise when necessary to protect human health.

POLICY

With a decision expected in October 2015 as to whether the standard will be toughened, we discuss limitations of ozone and precursor observations that hinder the ability of state and local air pollution–control agencies to accurately attribute sources of ozone within their jurisdictions. Attaining a lower standard may be particularly challenging in high elevations of the western United States, which are more likely to be affected by ozone that has been transported long distances or that originated in the stratosphere.

Understanding the origins of surface ozone is complicated by its multitude of sources. Ozone is transported to the surface from the natural reservoir in the stratosphere or produced from precursor gases [nitrogen oxides (NO_x) and volatile organic compounds] that react in the presence of sunlight. Ozone precursors have natural sources—such as vegetation, wildfires, and lightning—and are also emitted by human activity—such as combustion of fossil fuels and human-caused biomass burning.

The current primary (health-based) EPA standard is 75 parts per billion by volume (ppbv), with 227 U.S. counties, home to 123 million people, classified as not having attained the standard (www.epa.gov/airquality/greenbook/index.html). In November 2014, EPA proposed a revised primary ozone standard in the range of 65 to 70 ppbv in order to improve public health protection (*2*). The most recent ozone "design values" were used to determine whether ozone observations comply with the standard (which is based on

---

[1] Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO 80309, USA. [2] Chemical Sciences Division, NOAA Earth System Research Laboratory, Boulder, CO 80305, USA.
*Corresponding author. E-mail: owen.r.cooper@noaa.gov

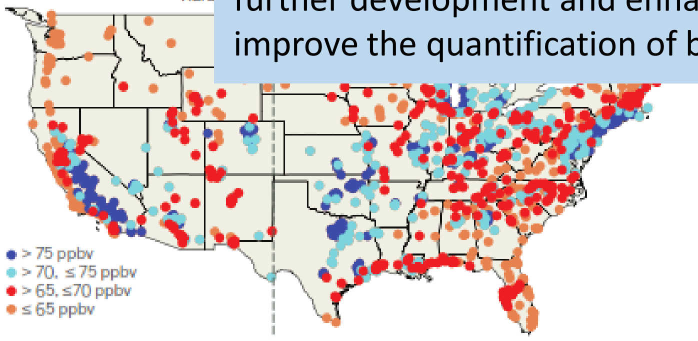
THE CHALLENGE

EPA has stated that "[e]xisting and up-coming EPA regulations and guidance will assist states in ensuring background ozone does not create unnecessary control obligations".

However, these mechanisms require states and EPA to be able to quantify the overall contribution and sources of background ozone.

The role of scientists is to inform the decision-making by conducting research to accurately quantify background ozone.

The challenges are model accuracy and limited observations of baseline ozone, which require further development and enhancement in order to improve the quantification of background ozone.



Ozone design values at all EPA ozone monitors operating during 2011–2013. The vertical dashed line separates the high-elevation regions (>1.5 km) of the west from the east. Western sites are divided into those above and below 1 km above sea level, with a separate overlapping category of rural sites. [Ozone values source: www.epa.gov/airtrends/values.html]

(*10–12*) and ozone observations above the California coast (*9*) and rural Nevada (*6*) also indicate substantial baseline ozone at low-elevation rural and urban (<1.5 km) sites in the western United States.

EPA is aware of ozone variations across the western United States and has con-

However, these mechanisms require states and EPA to be able to quantify the overall contribution and sources of background ozone. The role of scientists is to inform the decision-making by conducting research to accurately quantify background ozone. The challenges are model accuracy and limited observations of baseline ozone, which require further development and enhancement in order to improve the quantification of background ozone. A comparison of two global models shows that they differ in their estimates of monthly mean background ozone by as much as 10 ppbv and produce different seasonal cycles (*12*). Global models also have deficiencies in re-

MOTIVATION

From both scientific and regulatory points of view, a lower ozone standard will motivate air quality–control planners to seek more accurate and precise attribution of observed ozone to local, upwind, and stratospheric sources of ozone to determine how much domestic emissions must be reduced in order to attain that standard….

…..Accurate quantification of background ozone under this new paradigm would require enhanced baseline ozone observations at a spatial density and temporal frequency adequate for evaluating and improving the models.

seek more accurate and precise attribution of observed ozone to local, upwind, and stratospheric sources of ozone to determine how much domestic emissions must be reduced in order to attain that standard. A lower ozone standard will also increase the probability that the standard will be exceeded in springtime, which would require the attribution of ozone episodes beyond the typical summertime period of concern. Accurate quantification of background ozone under this new paradigm would require enhanced baseline ozone observations at a spatial density and temporal frequency adequate for evaluating and improving the models. Once the models can replicate baseline ozone, greater confidence can be placed in their estimates of background and locally produced ozone.

Additional observations include routine vertical ozone profiles at multiple coastal and inland sites using balloon-borne ozonesondes, ground-based ozone lidars, or, possibly, commercial aircraft. Related options include augmenting the U.S. Tropospheric Ozone Lidar Network (TOLNet), the U.S. National Oceanic and Atmospheric Administration (NOAA) Global Greenhouse Gas Reference Network aircraft program, or the European In-Service Aircraft for a Global Observing System (IAGOS). New

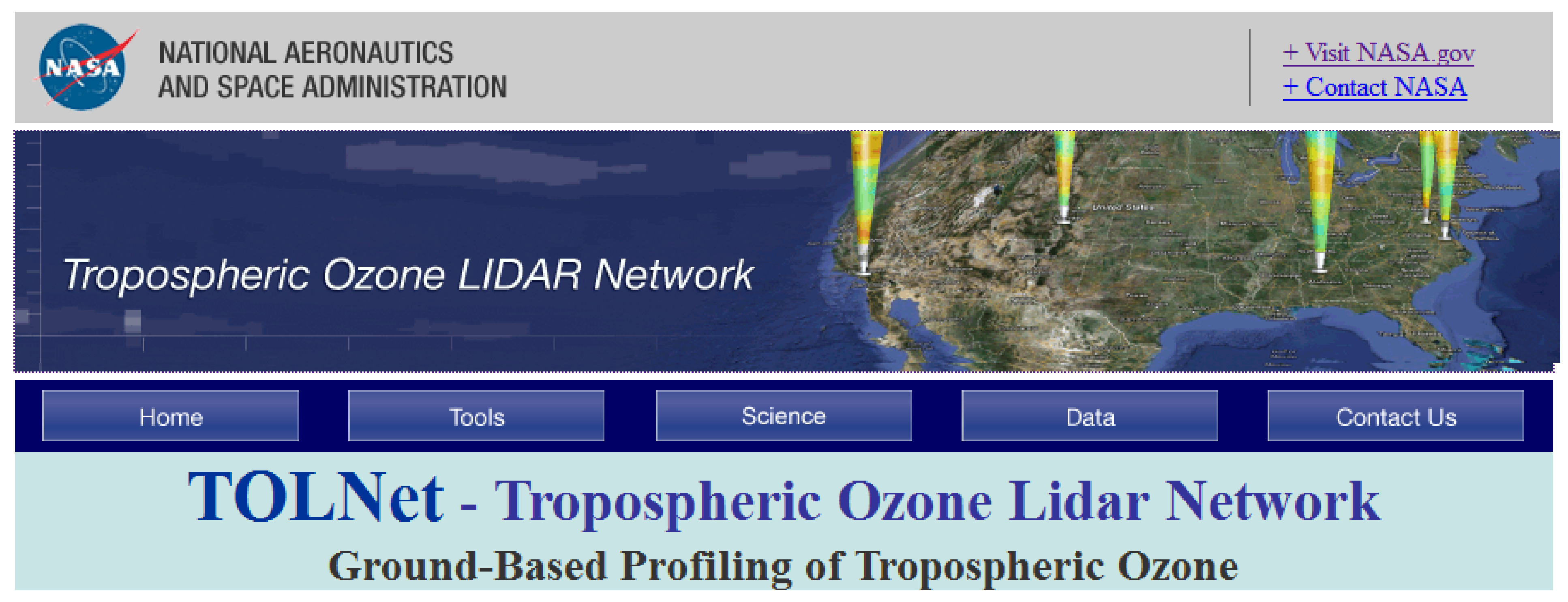
quality standards for ozone: Proposed rule." 45 Code of Federal Regulations (C.F.R.), Parts 50, 51, 52, 53, and 58 (2014).
3. EPA, *Regulatory Impact Analysis of the Proposed Revisions to the National Ambient Air Quality Standards for Ground-*

Free tropospheric monitoring

- Ozonesondes
- Lidar (TOLNet)
- Research and commercial aircraft (IAGOS, NOAA GMD)

The opinions expressed here are those of the authors and not their institutions. The authors acknowledge support from NOAA's Health of the Atmosphere and Atmospheric Chemistry and Climate Programs. T. Keating and G. Tonnesen, U.S. EPA, provided comments.

10.1126/science.aaa5748


NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

+ Visit NASA.gov
+ Contact NASA

Tropospheric Ozone LIDAR Network

TOLNet - Tropospheric Ozone Lidar Network

Ground-Based Profiling of Tropospheric Ozone

One of TOLNet's goals:

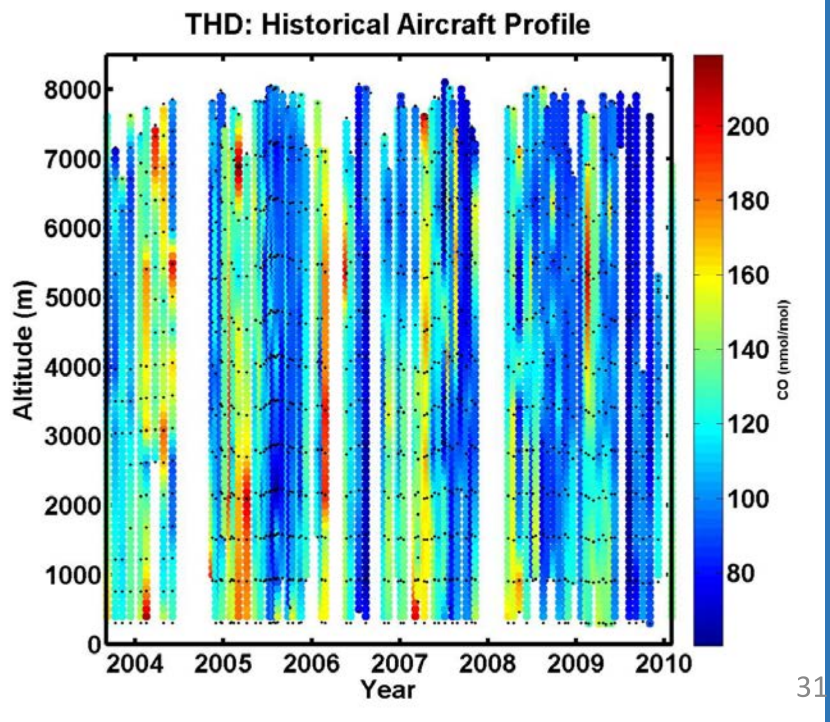
Advance our understanding of processes controlling regional background atmospheric composition (including STE and long range transport) and their effect on surface air quality to prepare for the GEO-CAPE era.

U.S. Department of Commerce / National Oceanic & Atmospheric Administration / NOAA Research

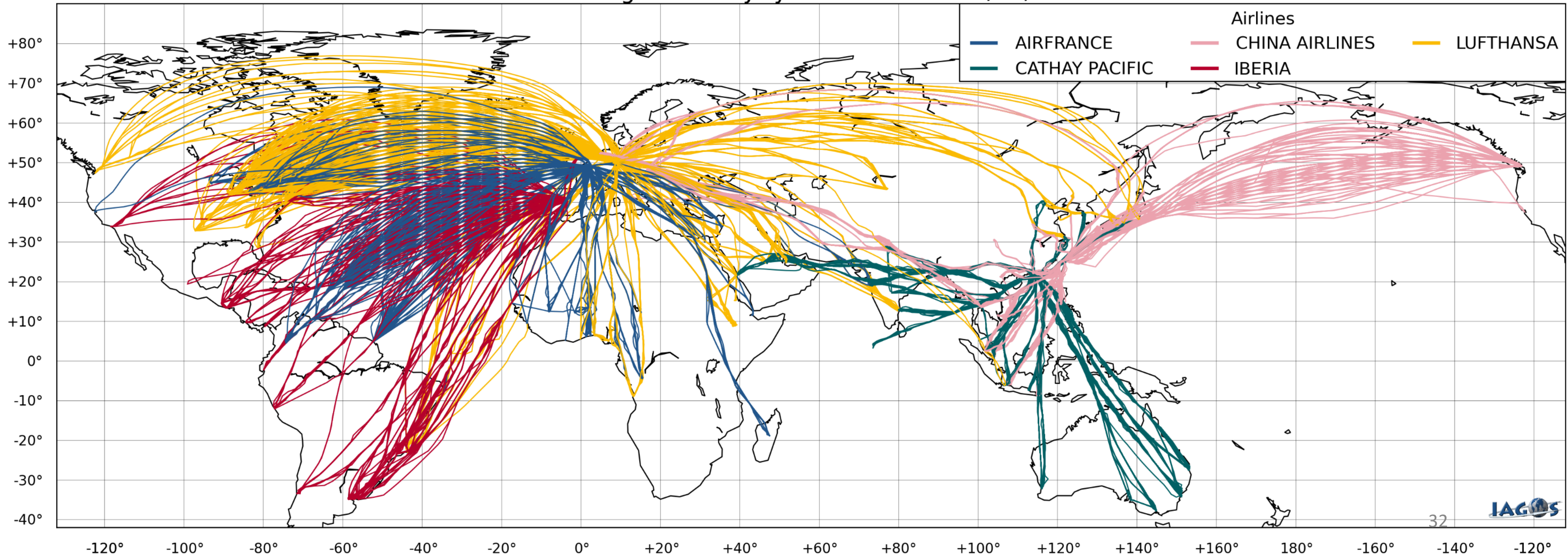
Earth System Research Laboratory
Global Monitoring Division

NOAA Earth System Research Lab Aircraft Program

Greenhouse gases plus ozone up to 8 km



5732 flights since July 2011 - Status 30/03/2015

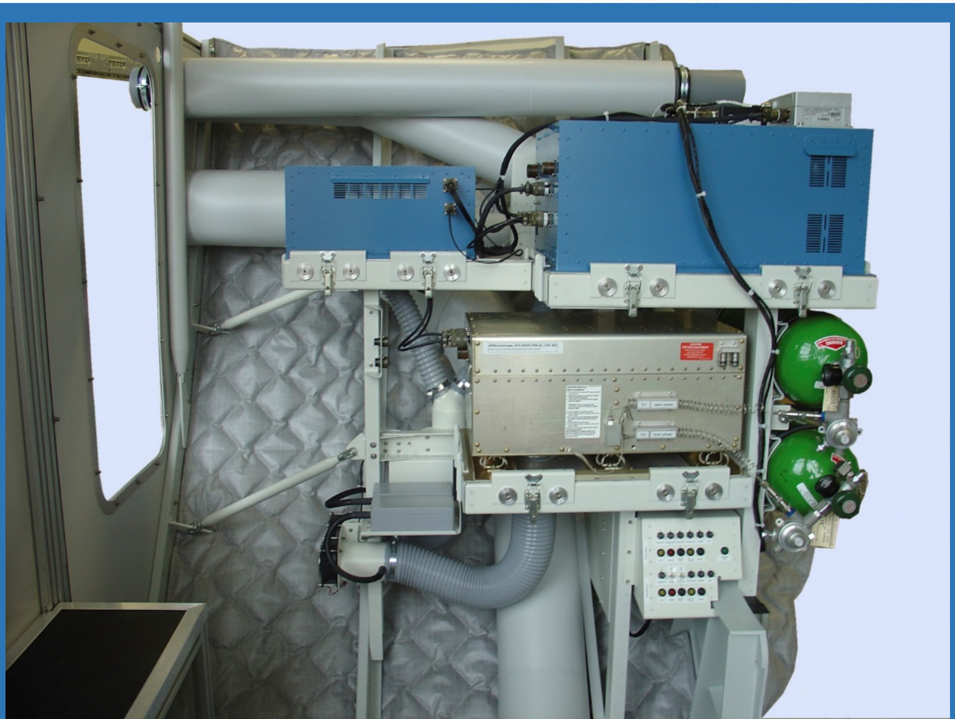


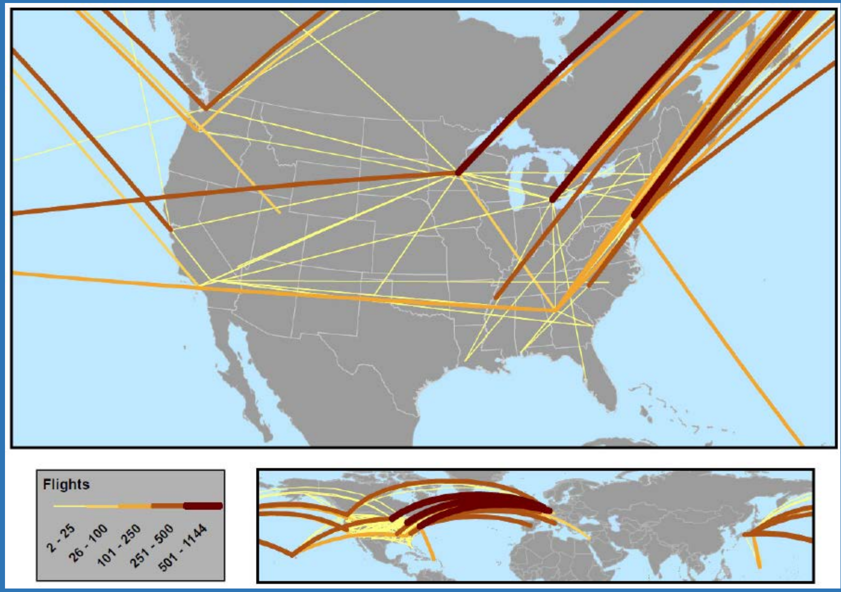
IAGOS equipment is designed for installation in the avionics compartment of Airbus A330 aircraft.

Species that can be measured include:

ozone
carbon dioxide
methane
particulate matter
carbon monoxide
nitrogen oxides
total reactive nitrogen
water vapor
cloud droplet backscatter

© AIRBUS S.A.S. 2008 - COMPUTER RENDERING BY FIXION - GWLNSD

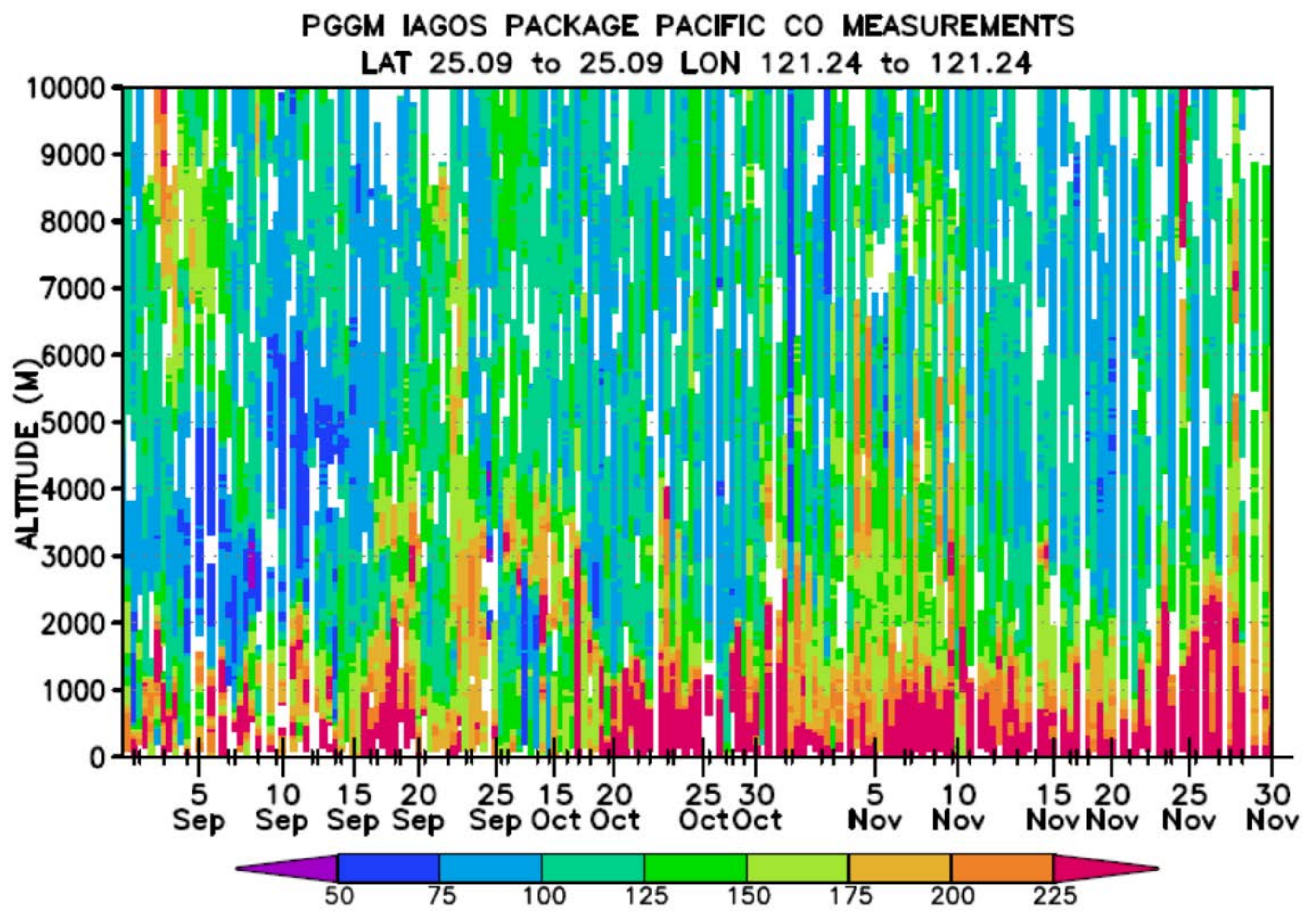




Flight tracks and flight frequency during 2009 of all A330 aircraft based in the United States. *Figure produced by S. D. Jacob, FAA.*

An example of IAGOS CO profiles above Taipei, Taiwan

Figure by Kuo-Ying Wang, National Central University, Taiwan



California GDP in 2012: 1,959 billion USD

Taiwan GDP in 2012: 465 billion USD

Scientific Aviation

Dr. Stephen Conley

CO2, CH4, and ozone among other trace gases up to 8 km

Contact Scientific Aviation

Email: sconley@scientificaviation.com

Main: (916) 217-1107

1608 Old Hart Ranch Road
Roseville, CA 95661

National Aeronautics and Space Administration

spacer

- \+ NASA Earth Sciences
- \+ NASA Home
- \+ Ames Home
- \+ Low Bandwidth

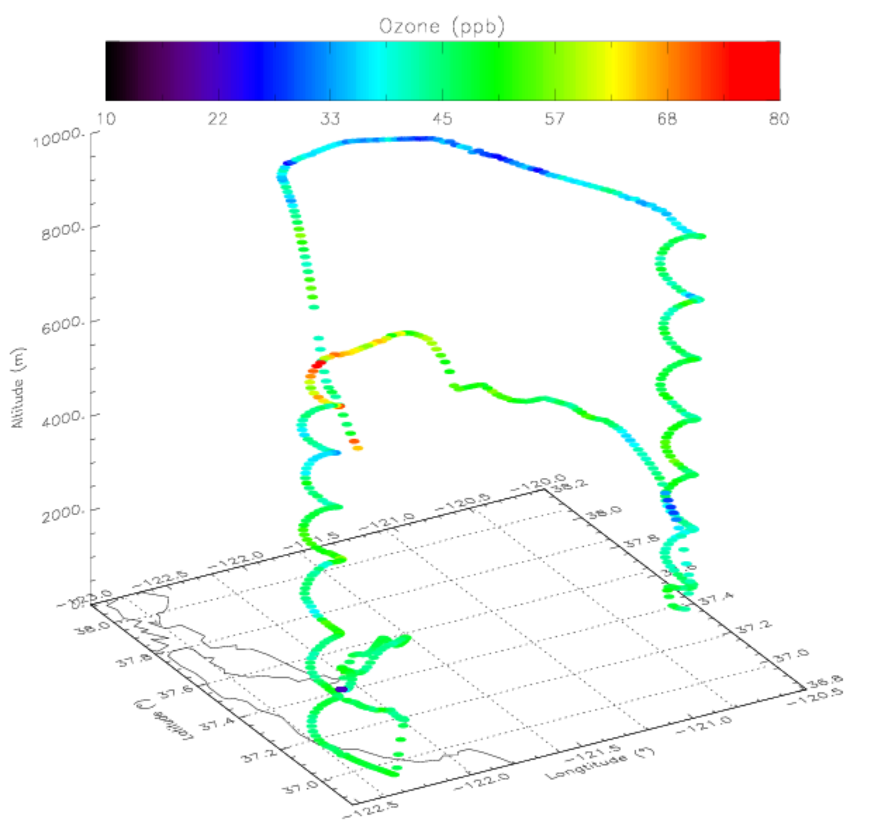
FIND IT @ NASA :

+ GO

\+ SG Home

Earth Science Division

- \- EARTH SCIENCE DIVISION
- \+ ATMOSPHERIC SCIENCE
- \+ BIOSPHERIC SCIENCE
- \+ AIRBORNE SCIENCE OFFICE
  - \+ ESPO
  - \+ ASTL



Baseline Ozone Network Design

Surface monitoring:
Take advantage of existing Trinidad Head MBL and Chews Ridge mountain top ozone monitors.

Add MBL ozone monitors to Pt Reyes and Vandenburg AFB.

Add a mountain top site west of Redding.

Daily Vertical Profiles:
Highest priority is an ozone lidar at Pt Reyes or Bodega Bay.

Lidars at Trinidad Head and Vandenburg AFB are also needed.

Launch ozonesondes on cloudy days