Presentation to the WESTAR Ozone Background & Transport Workshop, August 20, 2015

Key drivers of western US ozone means & extremes: Climate variability, stratospheric intrusions, and Asian pollution

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List of relevant papers for the talk

Lin, M., A.M. Fiore, L.W. Horowitz *et al* (2012a): ***Transport of Asian ozone pollution into surface air over the western United States in spring*** (PDF)

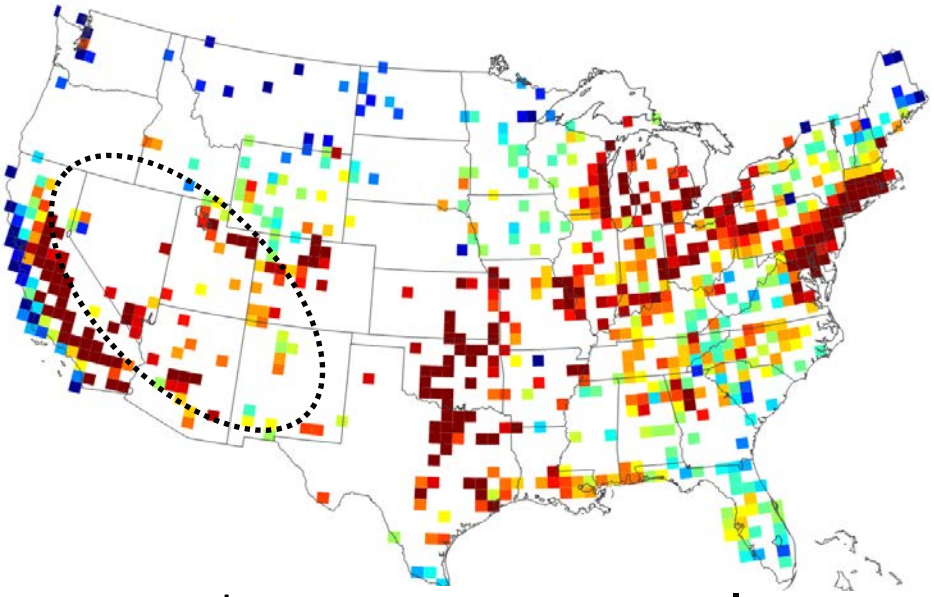
Lin M., A. M. Fiore , O. R. Cooper *et al* (2012b): ***Springtime high surface ozone events over the western United States: Quantifying the role of stratospheric intrusions*** (Full Text)

Lin, M., L.W. Horowitz, S. J. Oltmans *et al* (2014): ***Tropospheric ozone trends at Manna Loa Observatory tied to decadal climate variability*** (PDF)

Lin, M., A.M. Fiore, L.W. Horowitz *et al* (2015): ***Climate variability modulates western U.S. ozone air quality in spring via deep stratospheric intrusions*** (PDF, Supplemental Info)

Lin, M., L.W. Horowitz, O.R. Cooper *et al*: ***Revisiting the evidence of increasing springtime ozone mixing ratios in the free troposphere over western North America***, in review, July 15, 2015. (PDF)

Major challenges for WUS air quality management

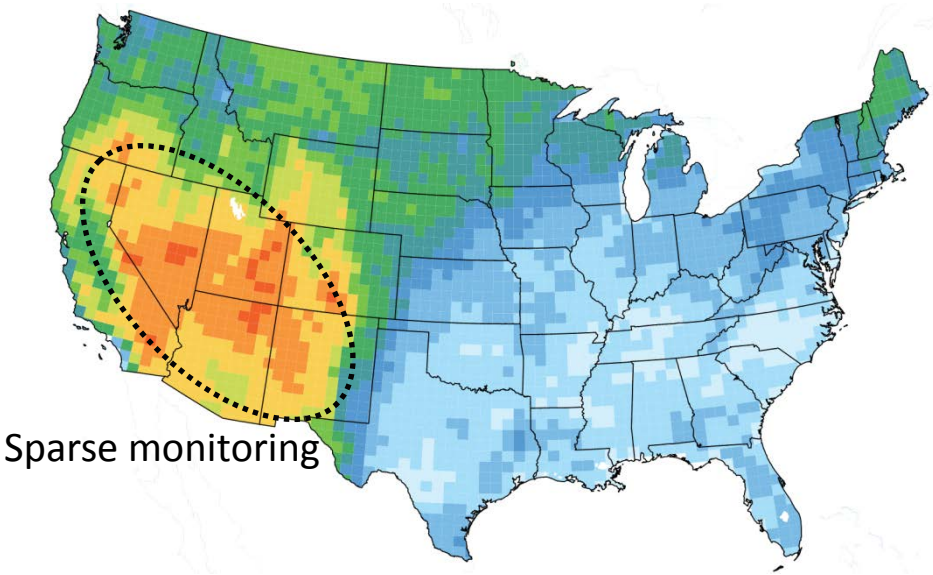


Annual 4th Hi MDA8 O_3
(2011-2013 AQS)

55 60 65 70 75 ppb

Current standard

Future standard?



Mean background, Apr-Jun
(zeroing out NA anthrop emis in AM3, 0.5°)

30 35 40 45 50 55 60 65 ppb

MAJOR CHALLENGES:

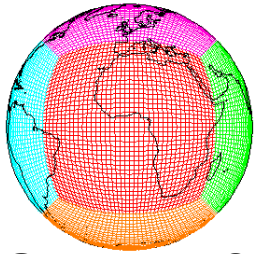
-Frequency of stratospheric intrusions (SI) in spring [e.g. *Langford et al*. 2009; *Lin et al*., 2012]

-More frequent wildfires in summer [e.g. *Westerling et al*. 2006; *Jaffe 2011; T. Moore*]

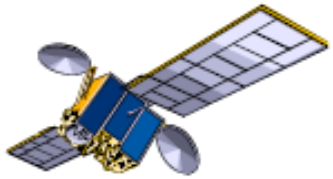
-Rising Asian emissions and global CH_4 [e.g. *Jacob et al*. 1999]

NEED PROCESS-LEVEL UNDERSTANDING ON DAILY TO MULTI-DECADAL TIME SCALES

The NOAA GFDL-AM3 Chemistry-Climate Model

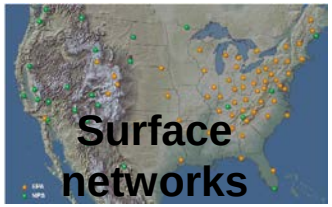


GFDL-AM3



Satellites

In situ



Surface networks

Key model features:

- **Cubed-sphere grid at ~50, 100, or 200 km resolution**
- **Full strat & trop chem** [*Donner et al., 2011*]
  as opposed to using a climatological stratosphere in prior CTMs
- **Stratospheric O_3 tracer (O_3Strat) defined relative to a dynamically varying e90 tropopause, accounting for tropospheric loss** [*Lin et al., 2012b*]
  → Robust for Δ variability; upper limit for means
- **Historical emissions up to 2000** [*Lamarque et al., 2010*]; **IPCC RCP8.5 beyond 2005**

Today's talk on WUS ozone:

- **Role of climate variability** (FIXEMIS)
- Long-term trends in mean baseline level (BASE)

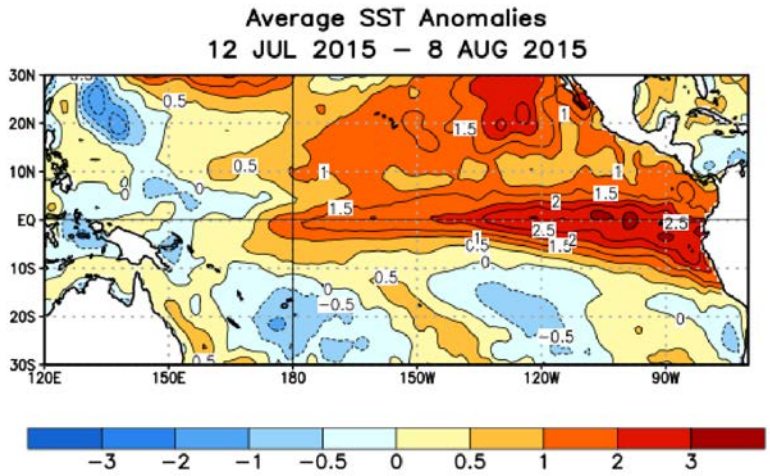
Severe El Niño forecasted for winter 2015-16

ENSO Alert System Status: El Niño Advisory

El Niño conditions are present.*

Positive equatorial sea surface temperature (SST) anomalies continue across most of the Pacific Ocean.

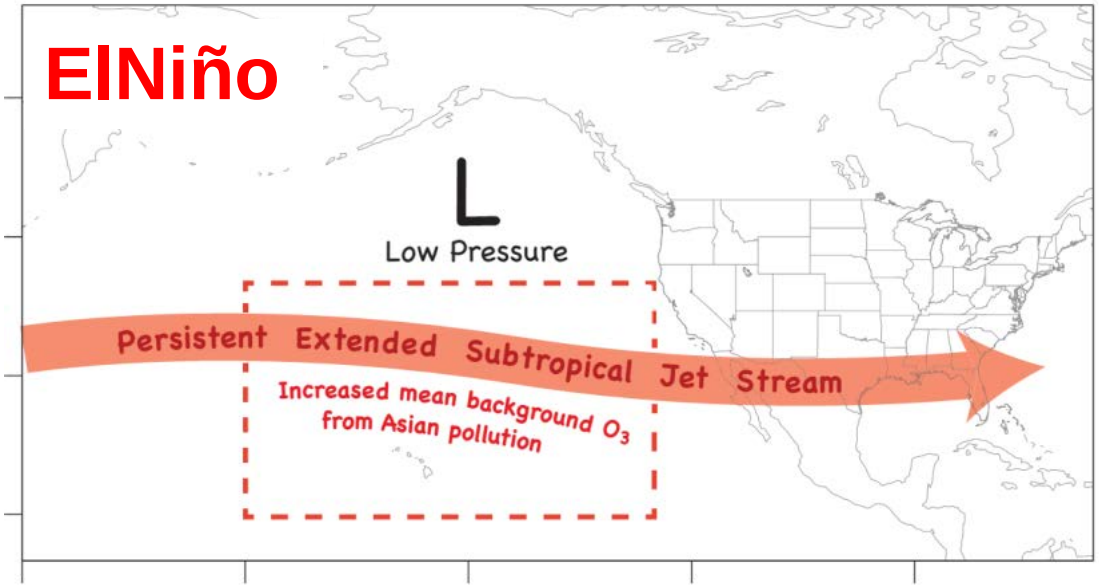
There is a greater than 90% chance that El Niño will continue through Northern Hemisphere winter 2015-16, and around an 80% chance it will last through early spring 2016.*



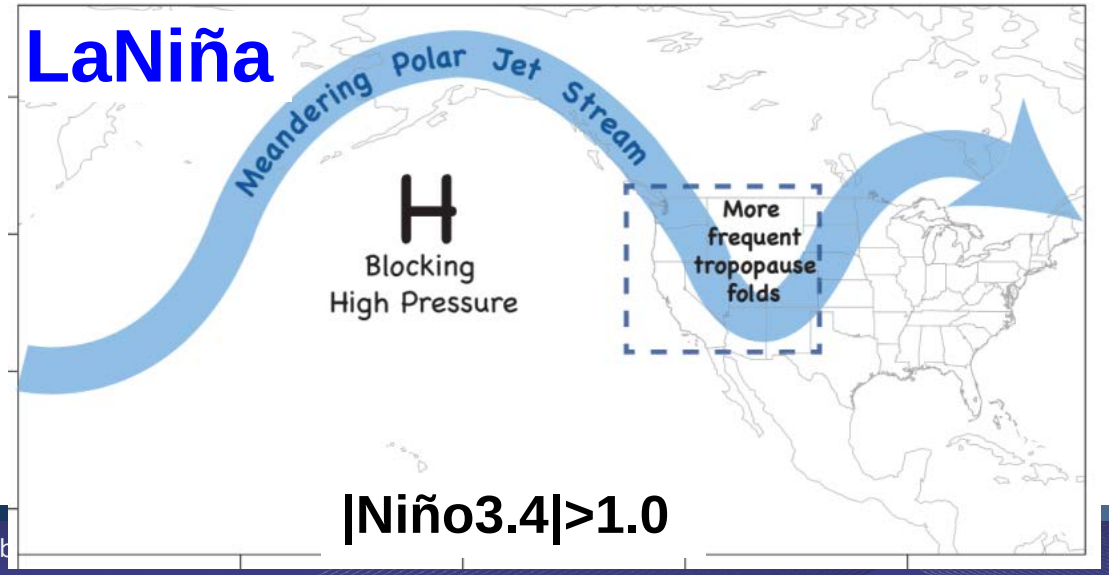
→ **Ozone over WUS in spring 2016?**

→ **Implications for AQ planning?**

ENSO and sources of springtime ozone variability over western N. America

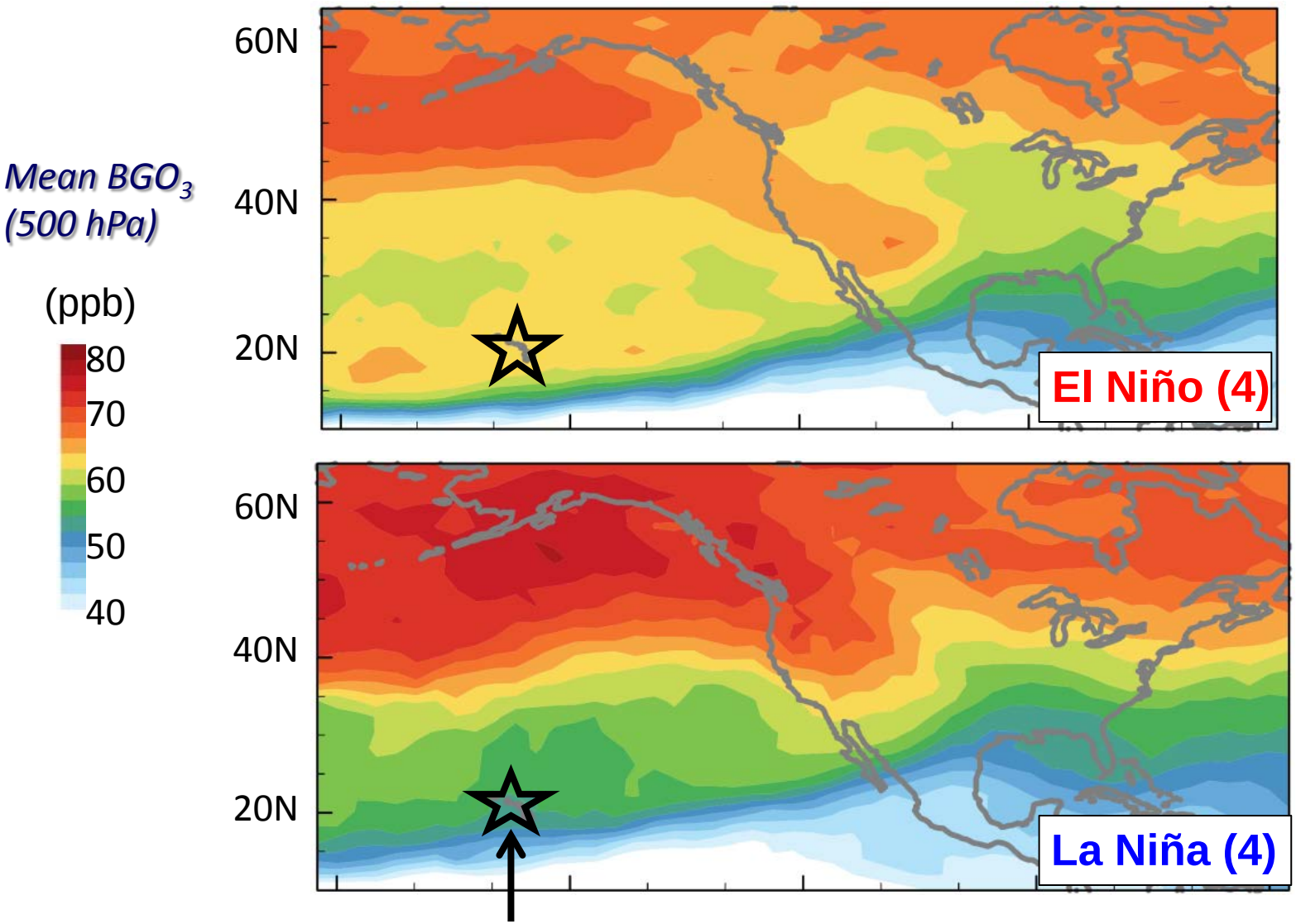


Expected in spring 2016!



|Niño3.4|>1.0

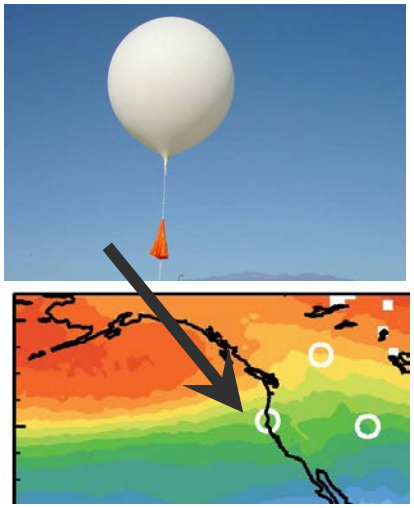
Following El Niño, increased pollution transport from Asia towards the SWUS in spring

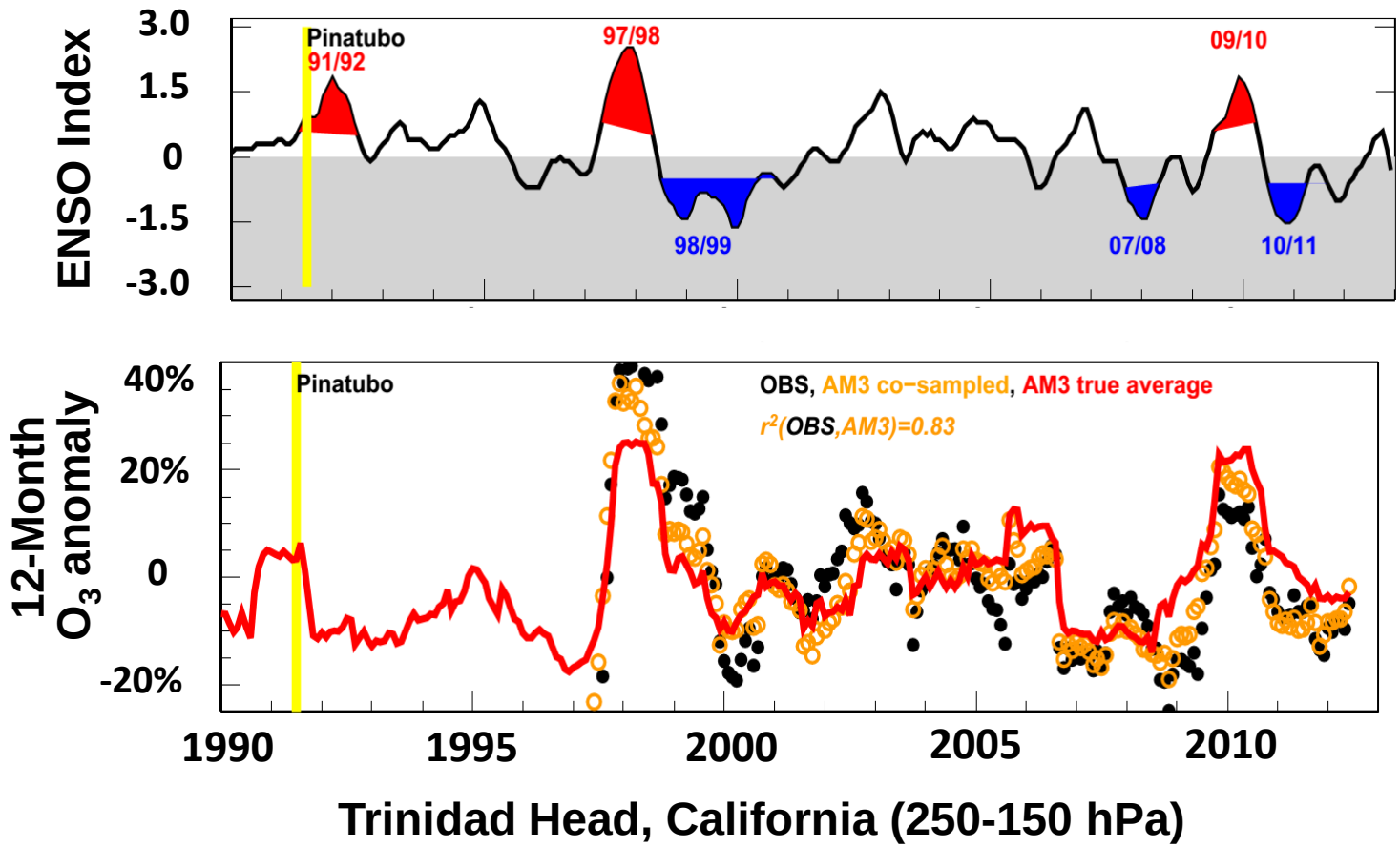


Expected in spring 2016!

nature geoscience *Lin et al. [2014]*

Following El Niño, increased UT/LS O_3 burdens over WUS





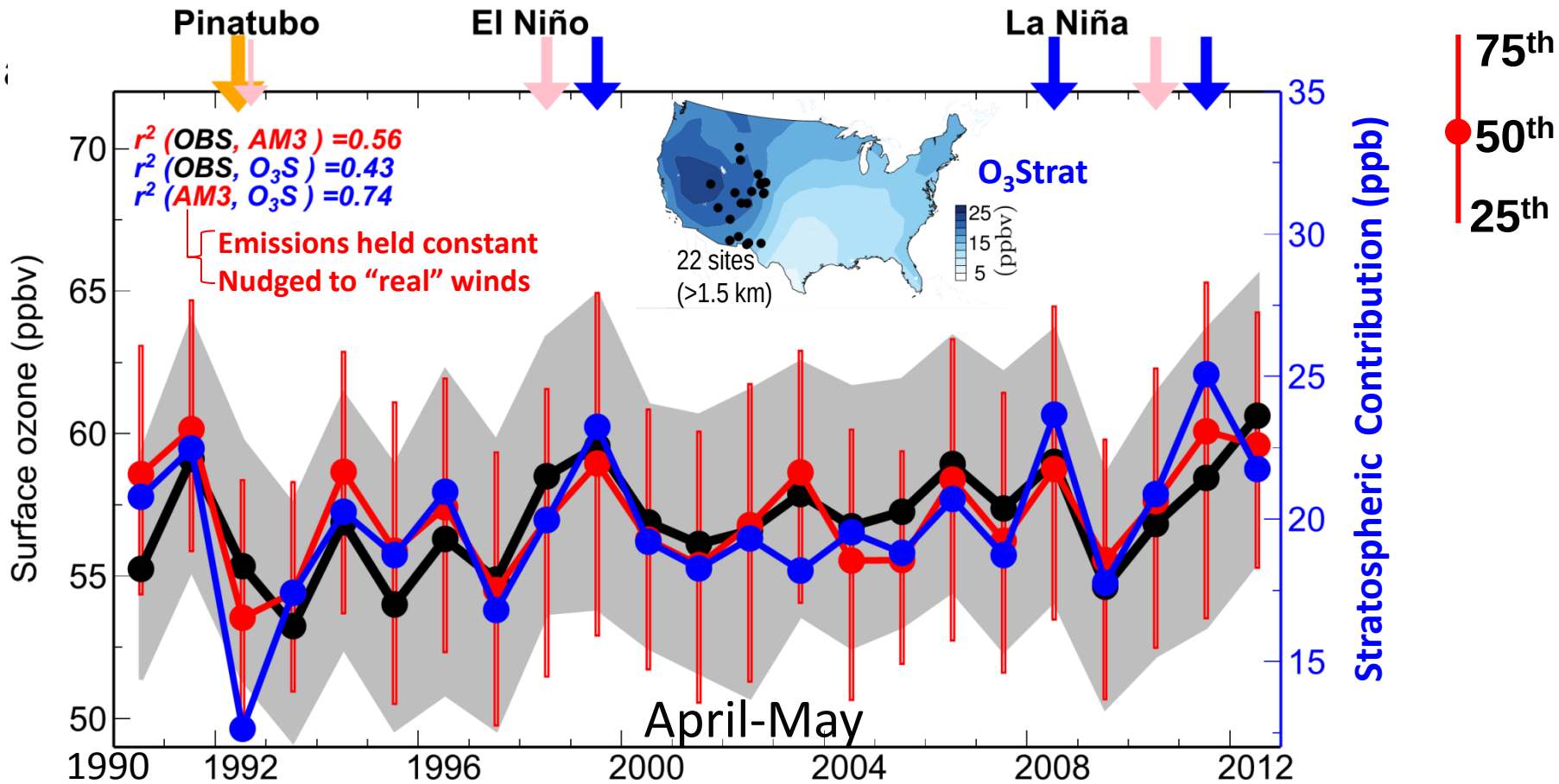
→ Due to changes in stratospheric circulation *[Bronnimann et al.2004, Nature]*

→ Consistent with an ozone lidar record for 1993-1998 *[Langford1999]*

→ **BUT, this influence does not reach WUS surface air!!!**

[*Lin M. et al., Nature Communications, 2015*]

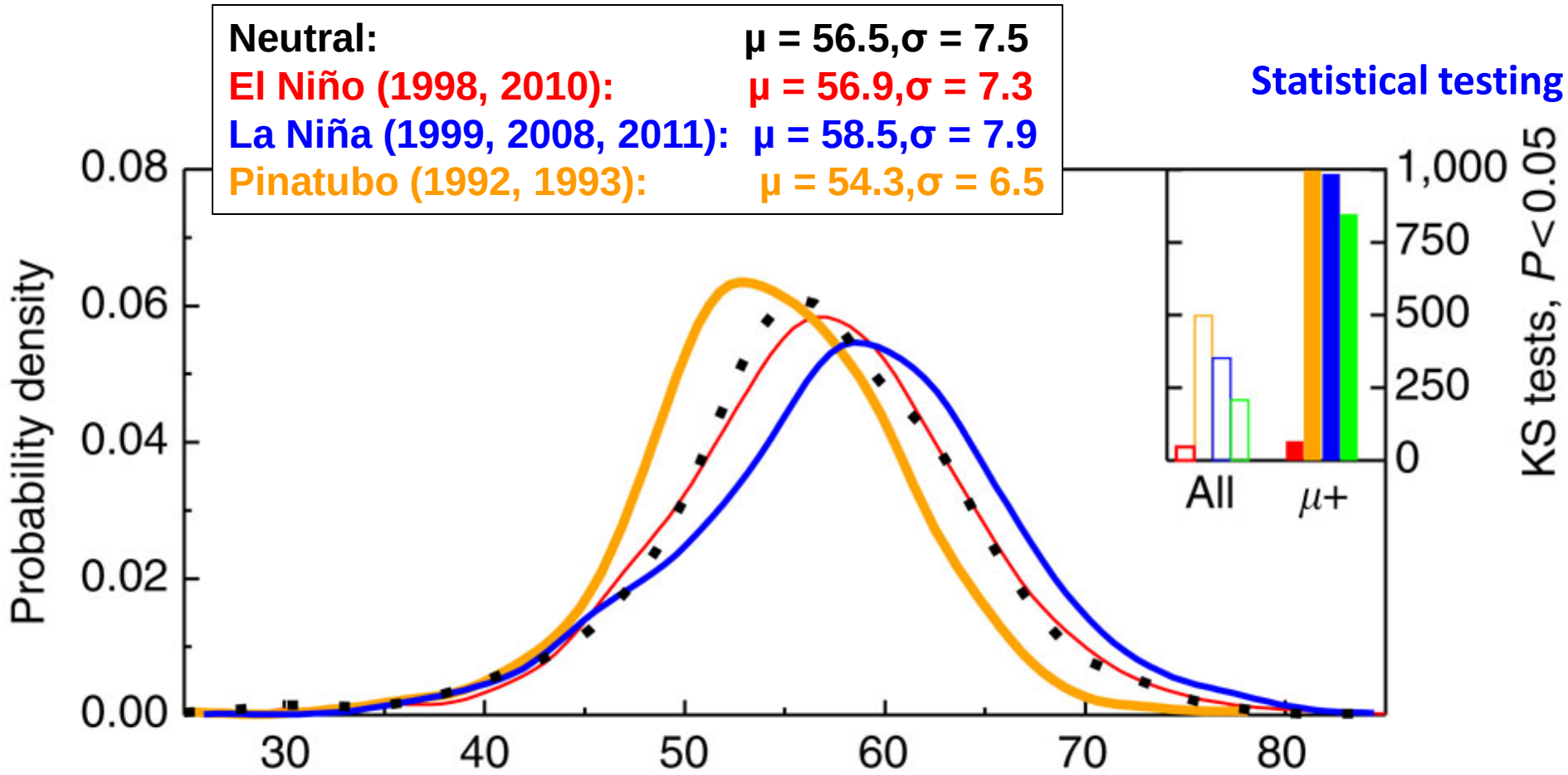
La Niña modulates WUS surface O_3 via deep stratospheric intrusions



- **Strong stratospheric influence on WUS surface O_3 IAV**
- **Tied to jet meandering as occurs following La Niña (spring 2017?)**

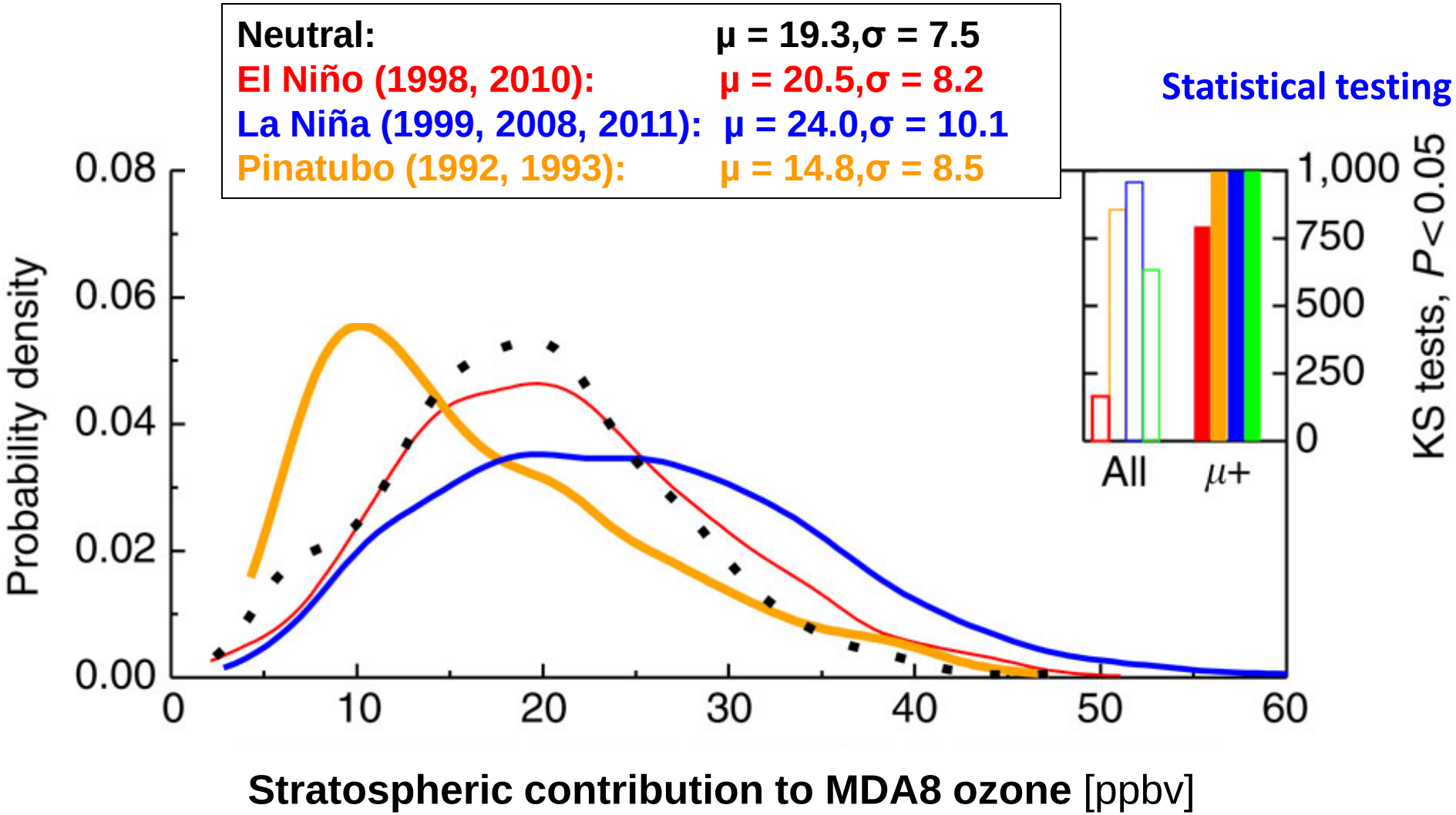
Lin MY et al (Nature Communications, 2015)

The high tail of the observed daily surface O_3 distribution over WUS increases during La Niña springs

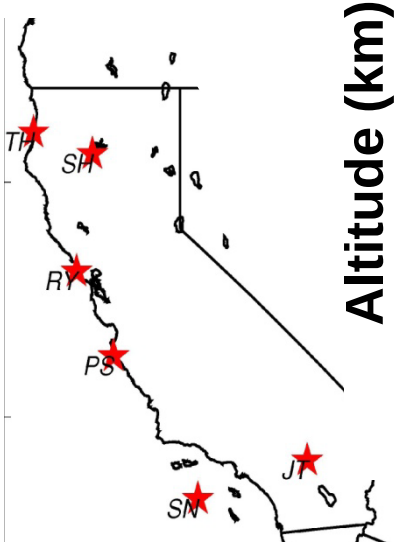


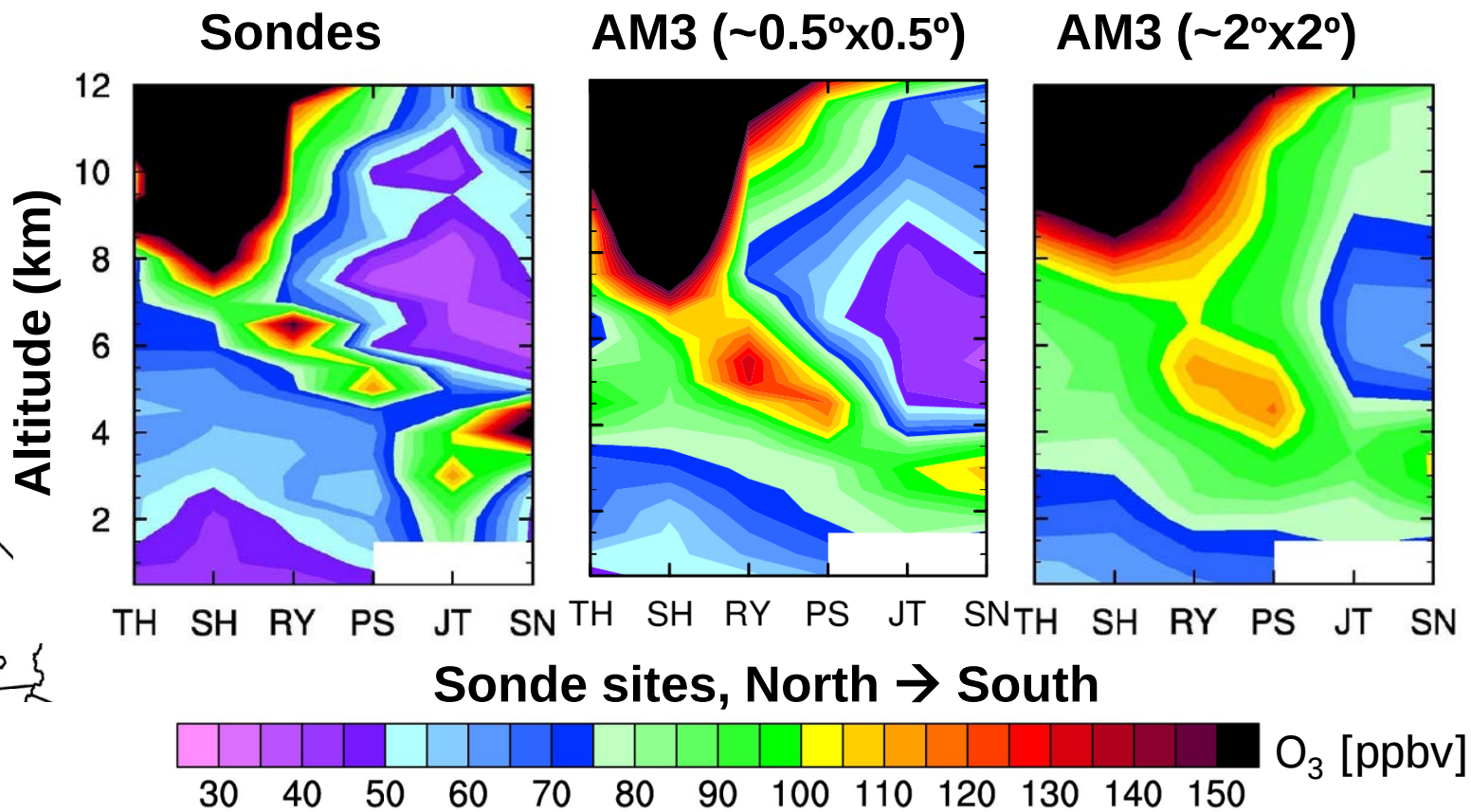
Observed daily max 8-h average (MDA8) ozone [ppbv]

Simulated increases in stratospheric contribution during La Niña springs



Simulations of deep SI events in GFDL-AM3
(May 28, 2010 example)



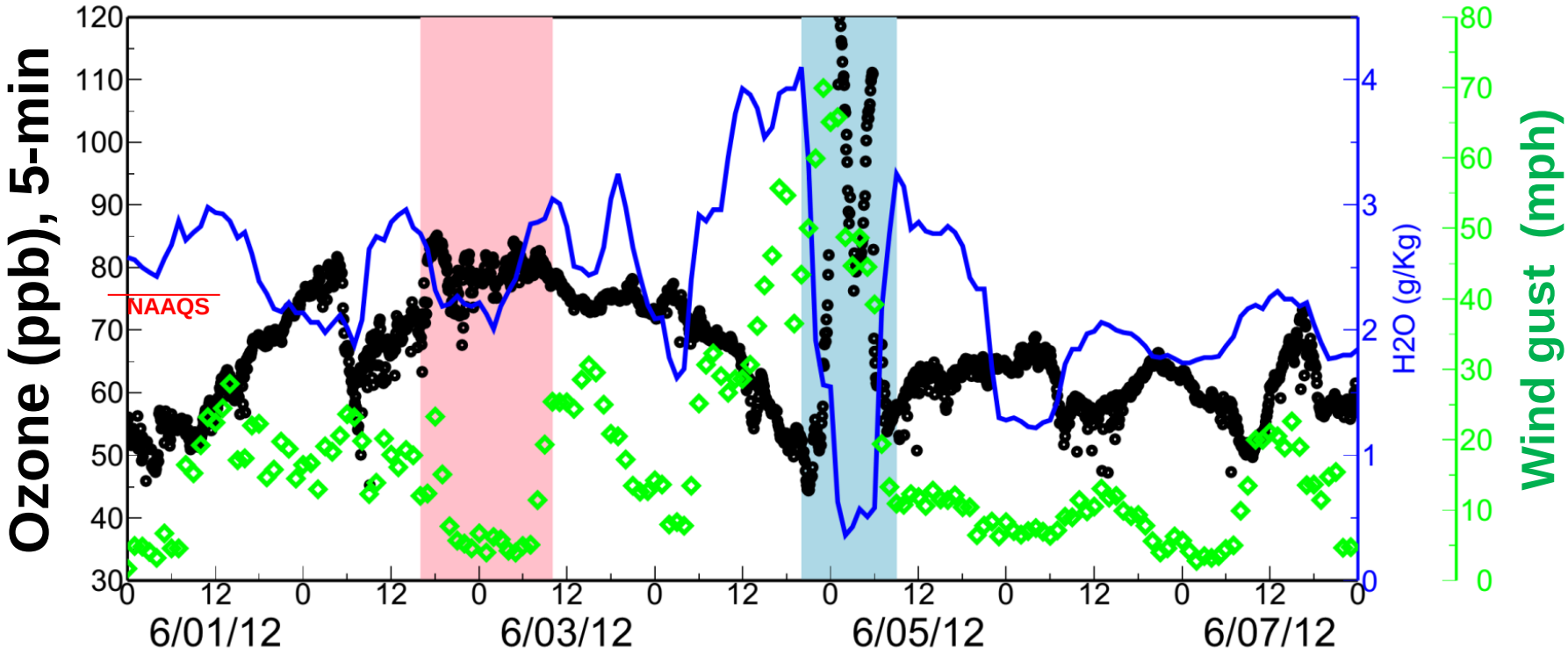


- 0.5° model better captures vertical structure
- 2° model reproduces the large-scale view

Lin MY et al (JGR, 2012b): *Springtime high surface ozone events over the WUS …*

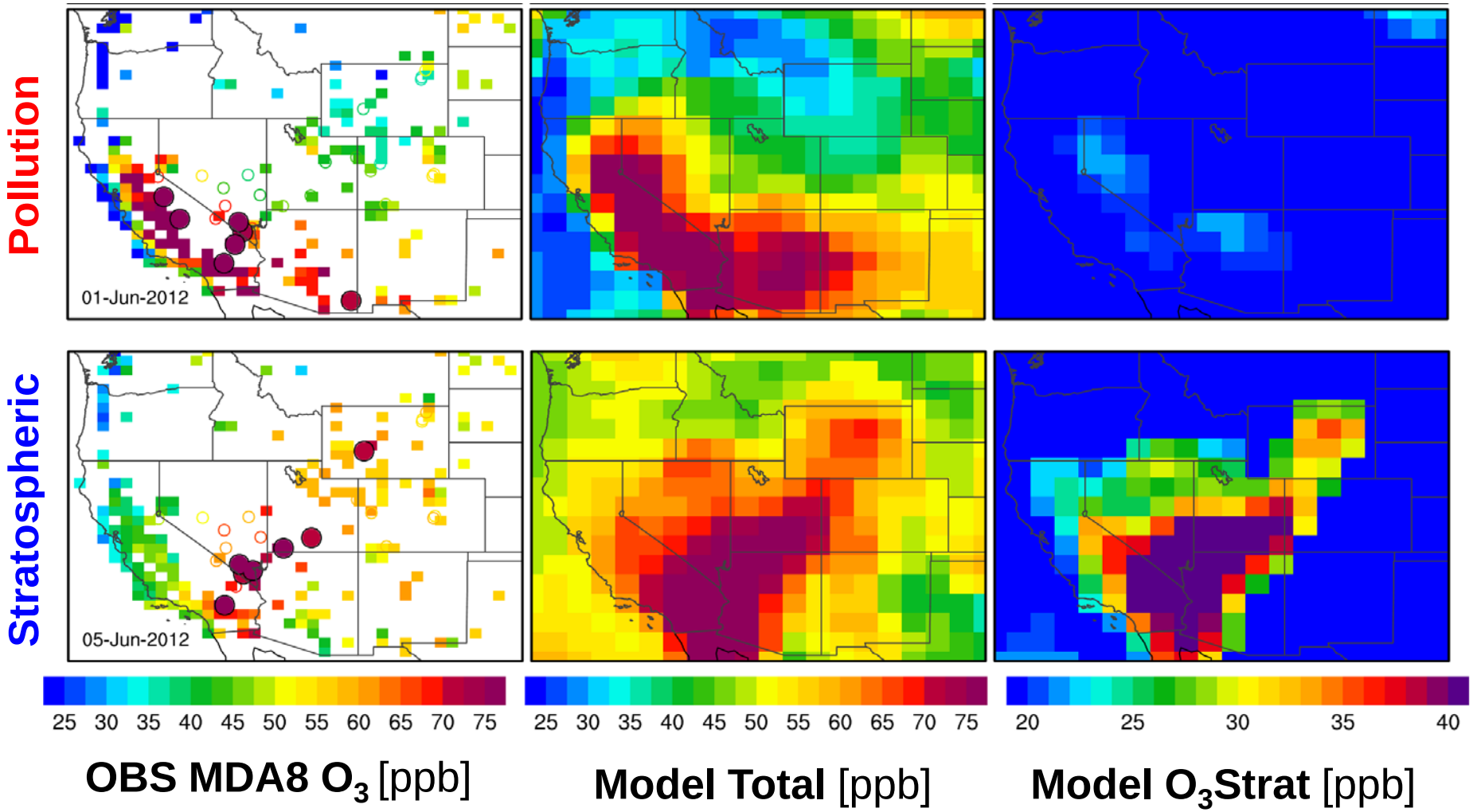
Observed evidence of high-O_3 events from regional pollution vs stratospheric intrusions

Spring Mtn Youth Camp, Nevada (2.6 km altitude)

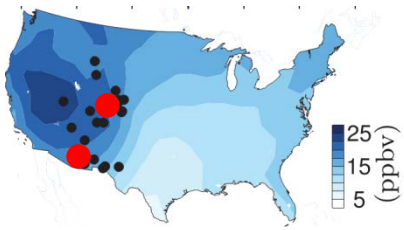


- *Ozone data (Zheng Li, Nevada Clark County)*
- *Meteorological data (NOAA Desert Research Institute)*

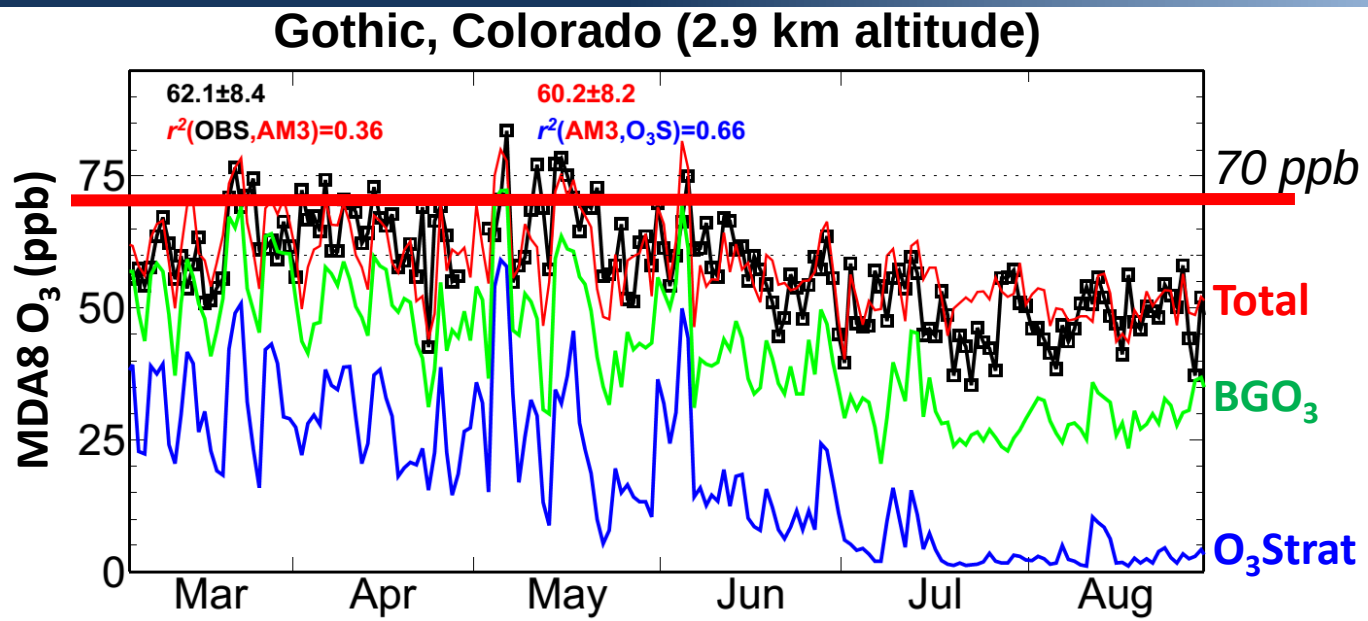
Simulated high-O_3 events from regional pollution vs stratospheric intrusions



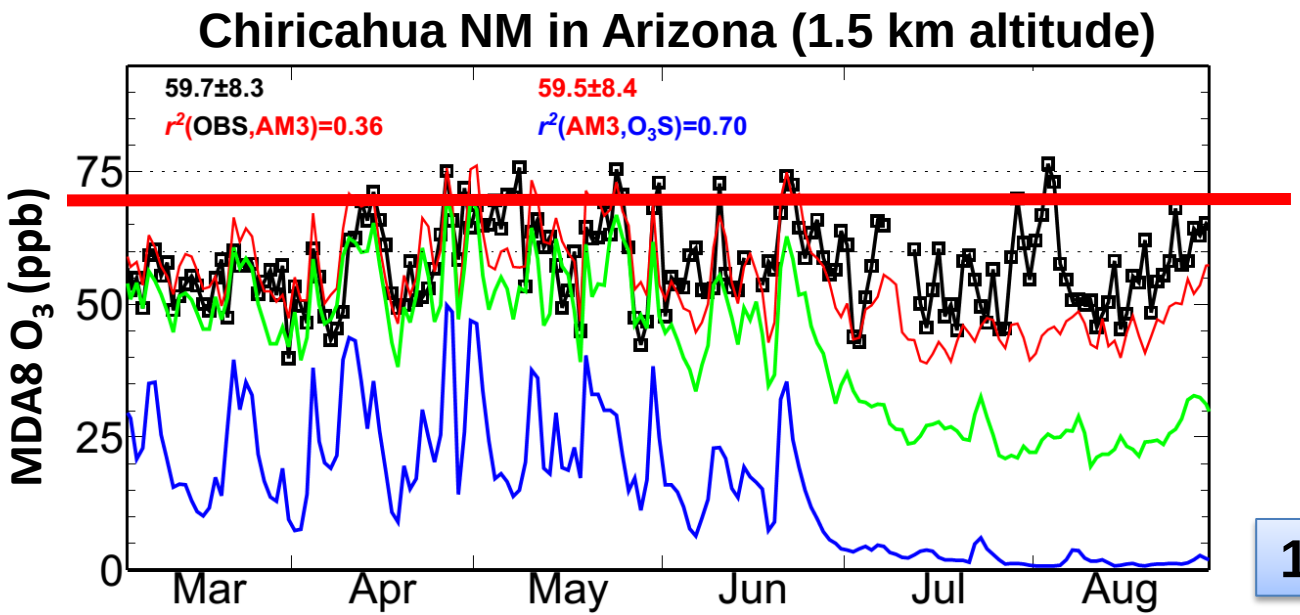
Following La Niña, deep SI may occur with sufficient frequency as to confound O_3 attainment



1999 (La Niña)

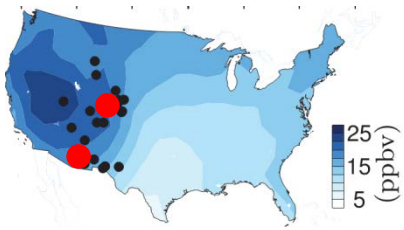


2011 (La Niña)



Lin MY et al
(Nature Commun., 2015)

Not so "exceptional" events under a 65-ppbv NAAQS level?



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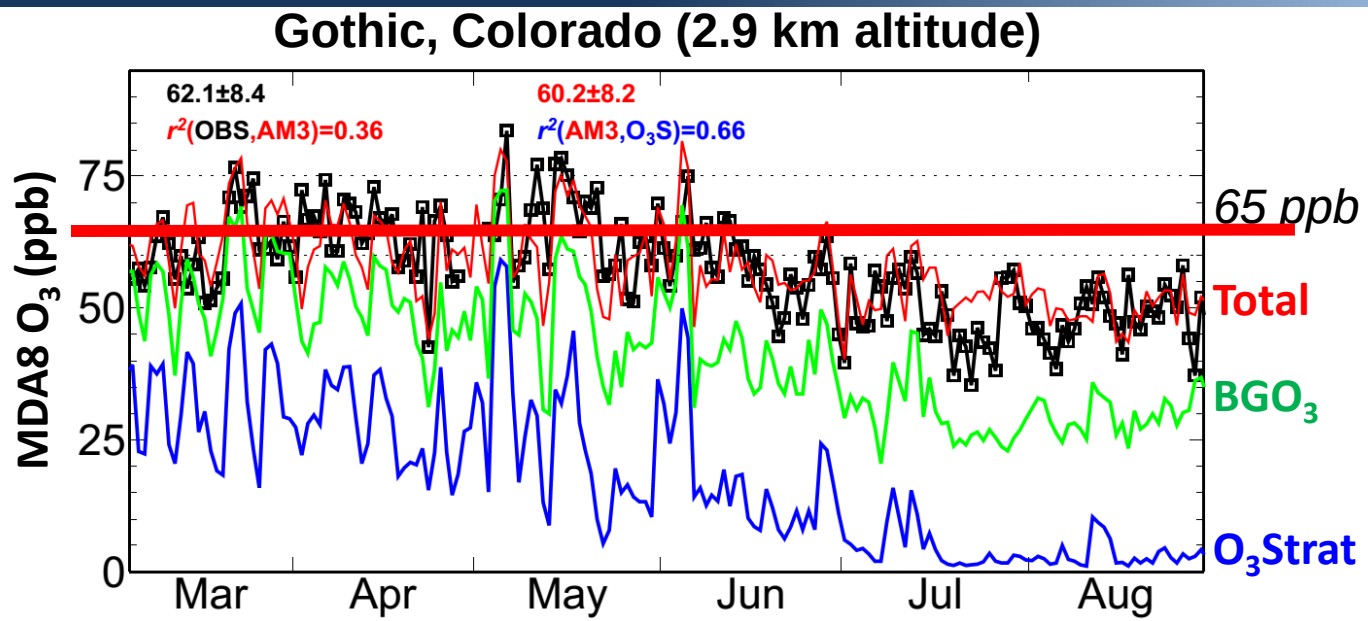
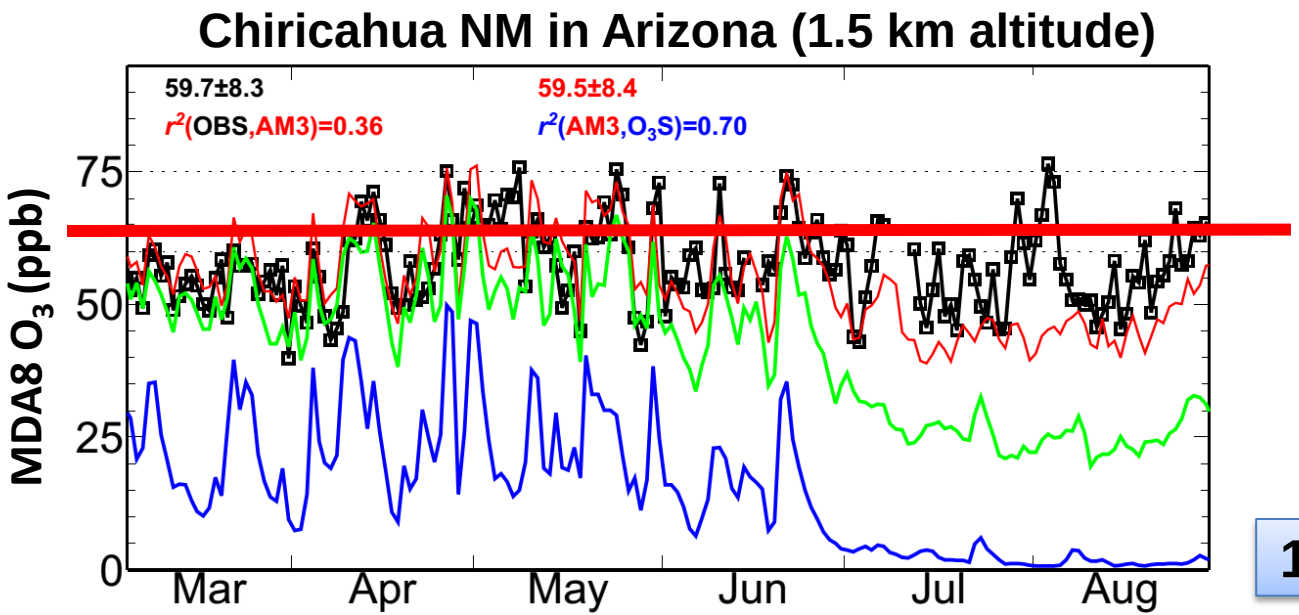


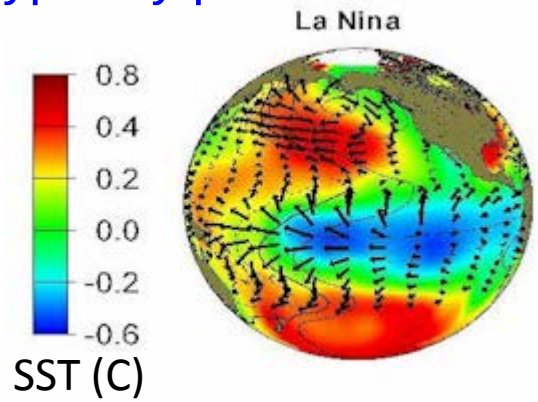
2011 (La Niña)



Lin MY et al
(Nature Commun., 2015)

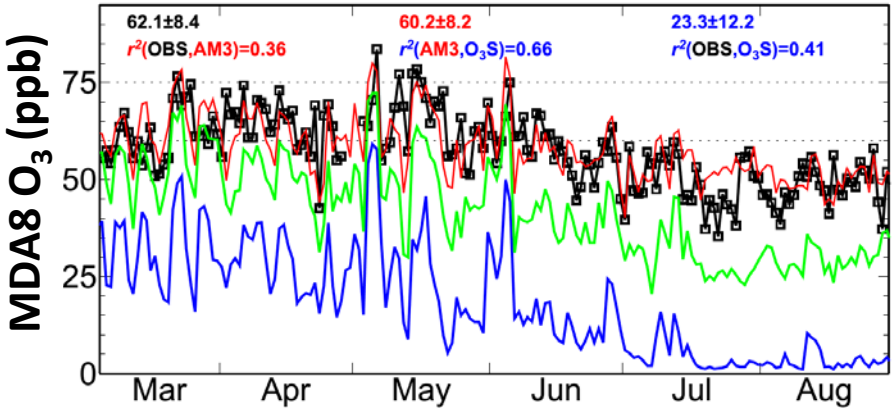
Developing ozone seasonal forecasts to aid WUS AQ planning

Tropical SST cooling typically peaks in **winter**



Winter 2016-17?

More frequent stratospheric intrusions expected in **the following spring** over WUS?



Gothic 1999 (2017?)

Regional preparations for an active stratospheric intrusion season

- **Deploy targeted measurements aimed at identifying "exceptional events"**
  (Daily ozonesonde/lidar measurements; collocated CO/O_3/H_2O monitors at select WUS sites)
- **Conduct daily forecast for public health alerts**

Meiyun Lin et al (Nature Communications, 2015)

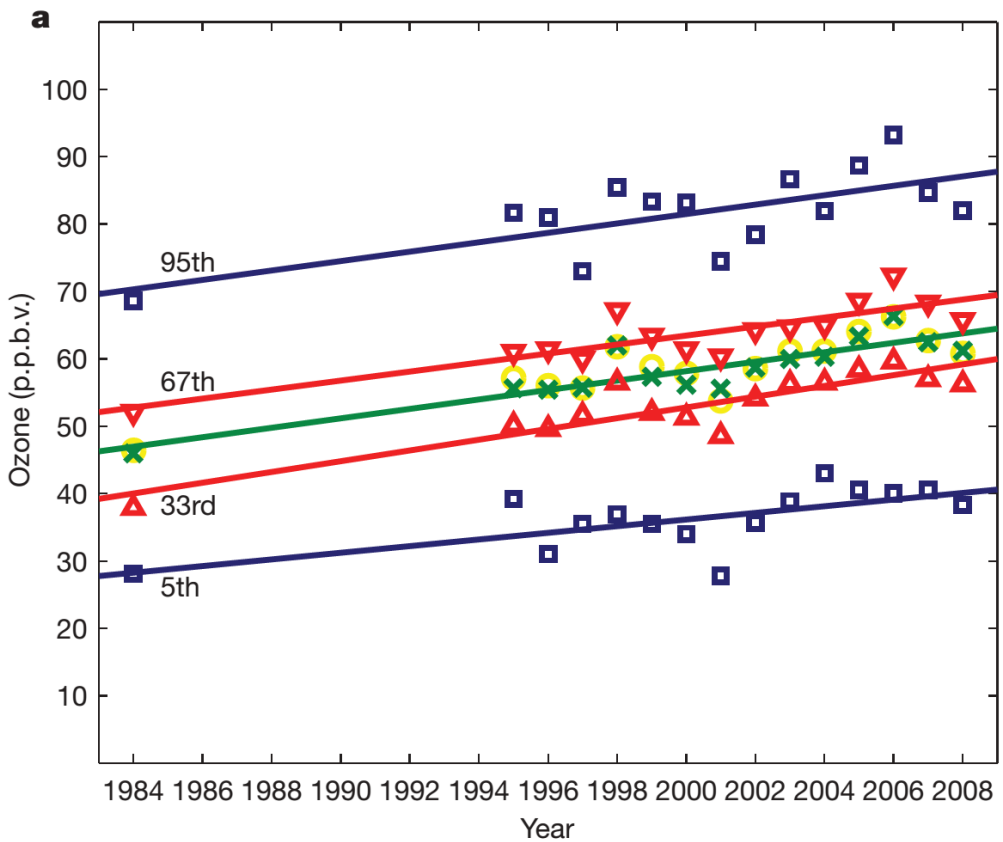
Long-term trends

nature Vol 463|21 January 2010|doi:10.1038/nature08708

LETTERS

Increasing springtime ozone mixing ratios in the free troposphere over western North America

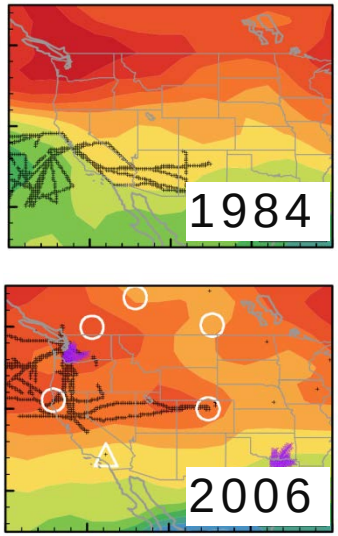
O. R. Cooper[1,2], D. D. Parrish[2], A. Stohl[3], M. Trainer[2], P. Nédélec[4], V. Thouret[4], J. P. Cammas[4], S. J. Oltmans[2], B. J. Johnson[2], D. Tarasick[5], T. Leblanc[6], I. S. McDermid[6], D. Jaffe[7], R. Gao[2], J. Stith[8], T. Ryerson[2], K. Aikin[1,2], T. Campos[9], A. Weinheimer[9] & M. A. Avery[10]

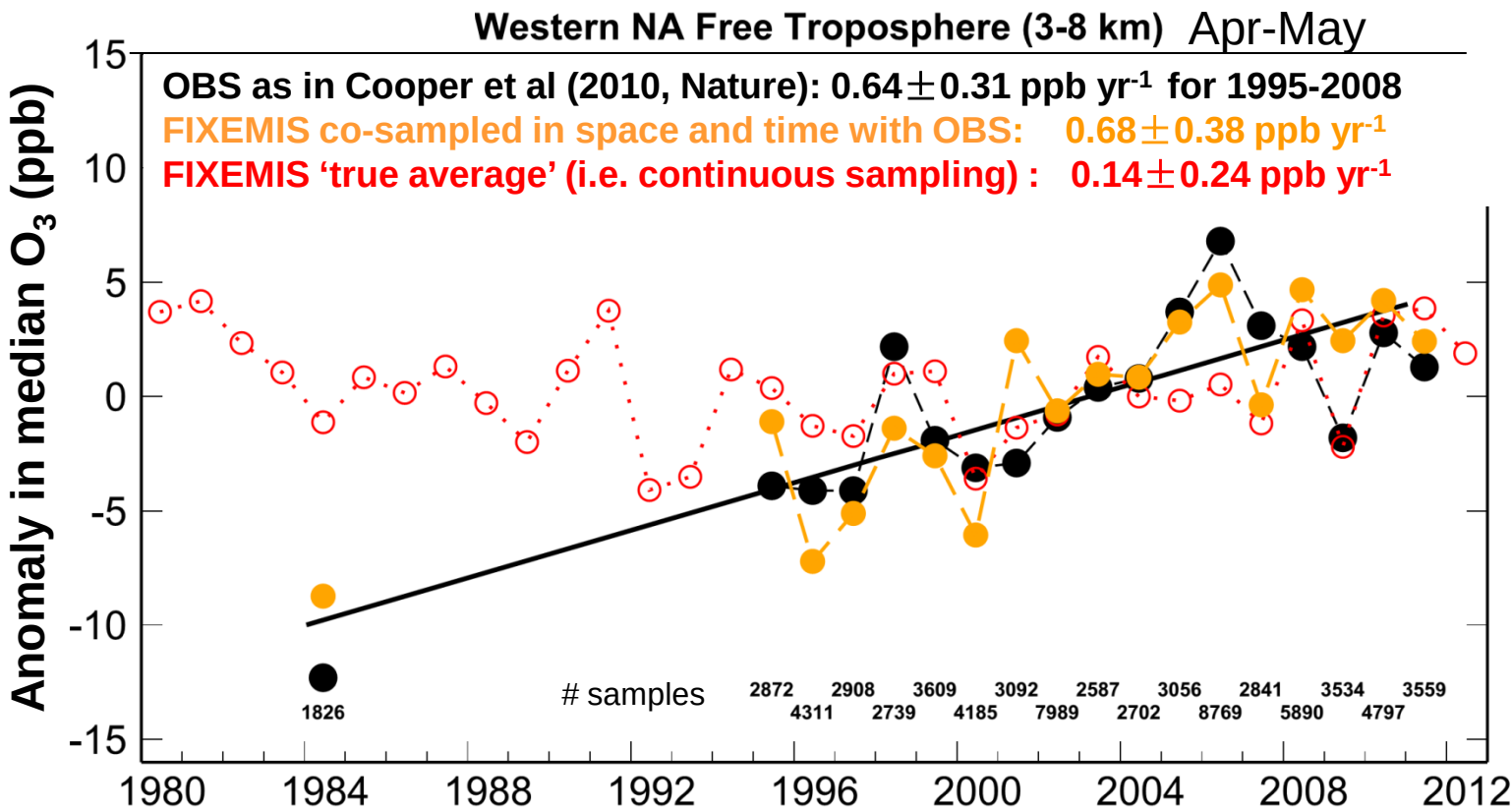


Percentile	1995–2008 increase (p.p.b.v. yr^{-1})	*P*
95th	0.56 ± 0.71	0.11
67th	0.62 ± 0.39	0.00
50th	0.63 ± 0.34	0.00
33rd	0.64 ± 0.35	0.00
5th	0.48 ± 0.53	0.07

Percentile	1984–2008 increase (p.p.b.v. yr^{-1})	*P*
95th	0.70 ± 0.45	0.01
67th	0.67 ± 0.25	0.00
50th	0.70 ± 0.22	0.00
33rd	0.80 ± 0.24	0.00
5th	0.49 ± 0.34	0.01

Large meteorological variability and sparse in-situ sampling can complicate O_3 trend estimates

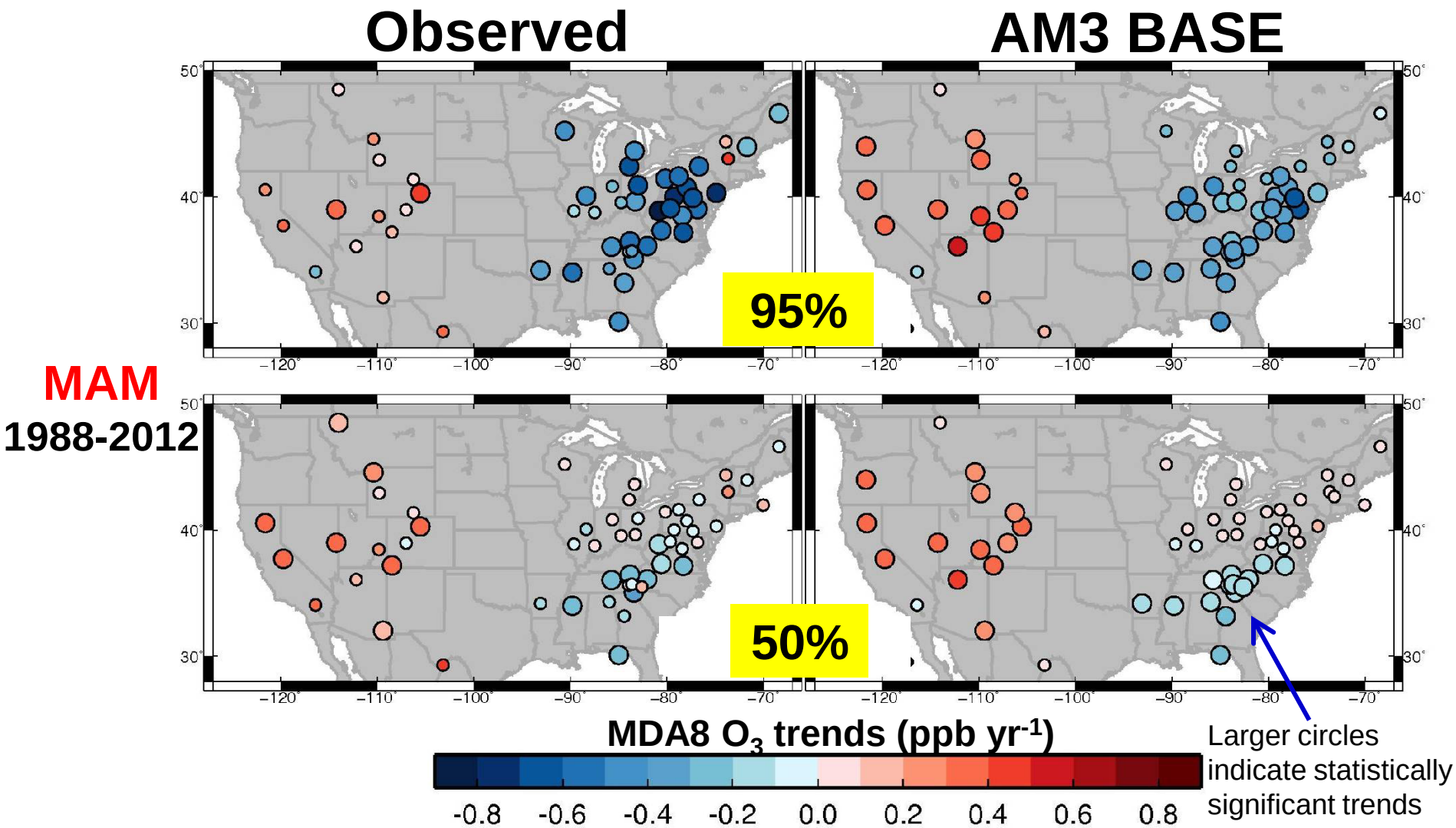




→The need for improvements in the current observation network

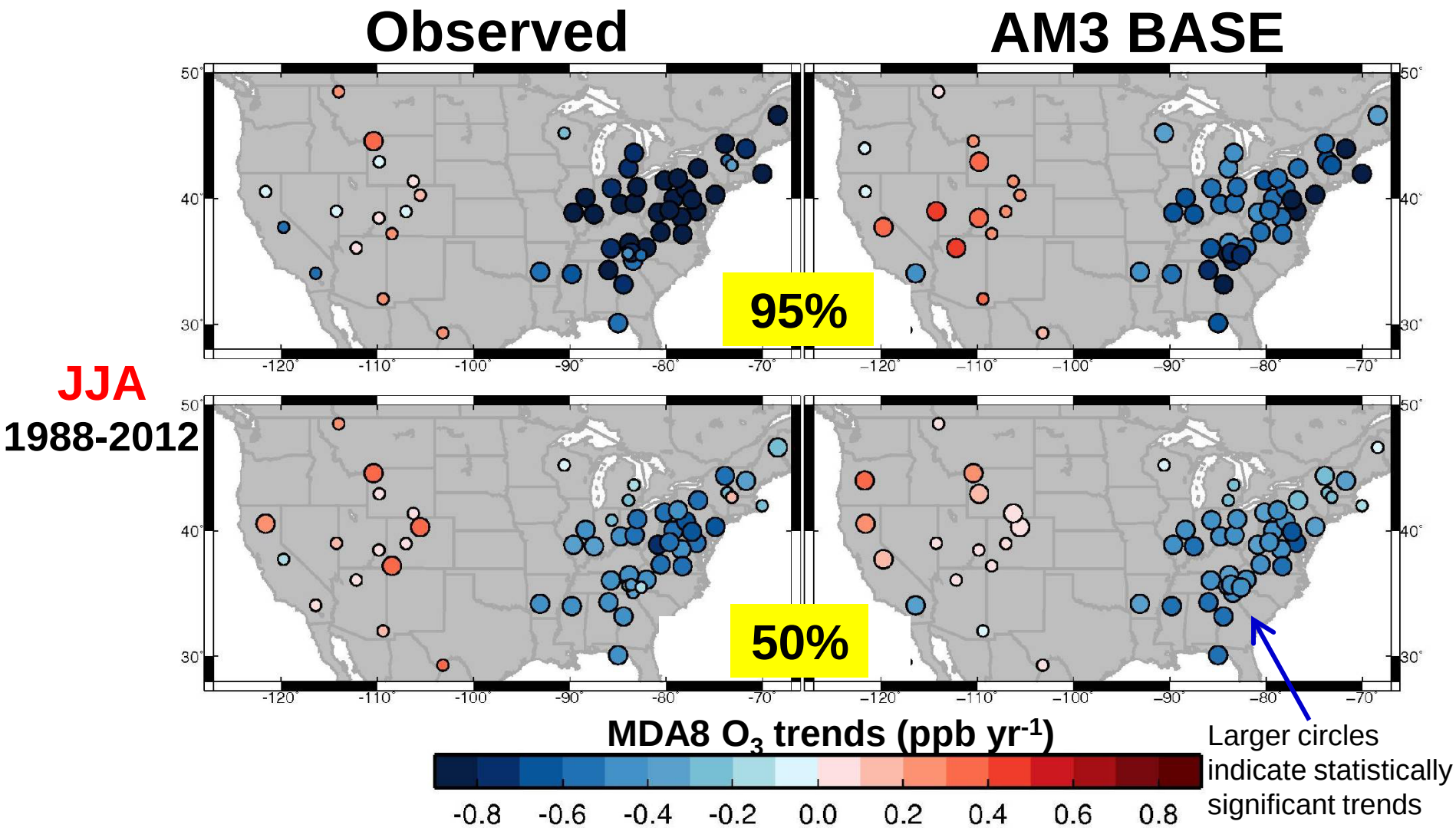
Lin MY et al [Geophysical Research Letter, in review, July 2015]

SPRING U.S. surface O_3 trends: Do domestic NO_x reductions work?



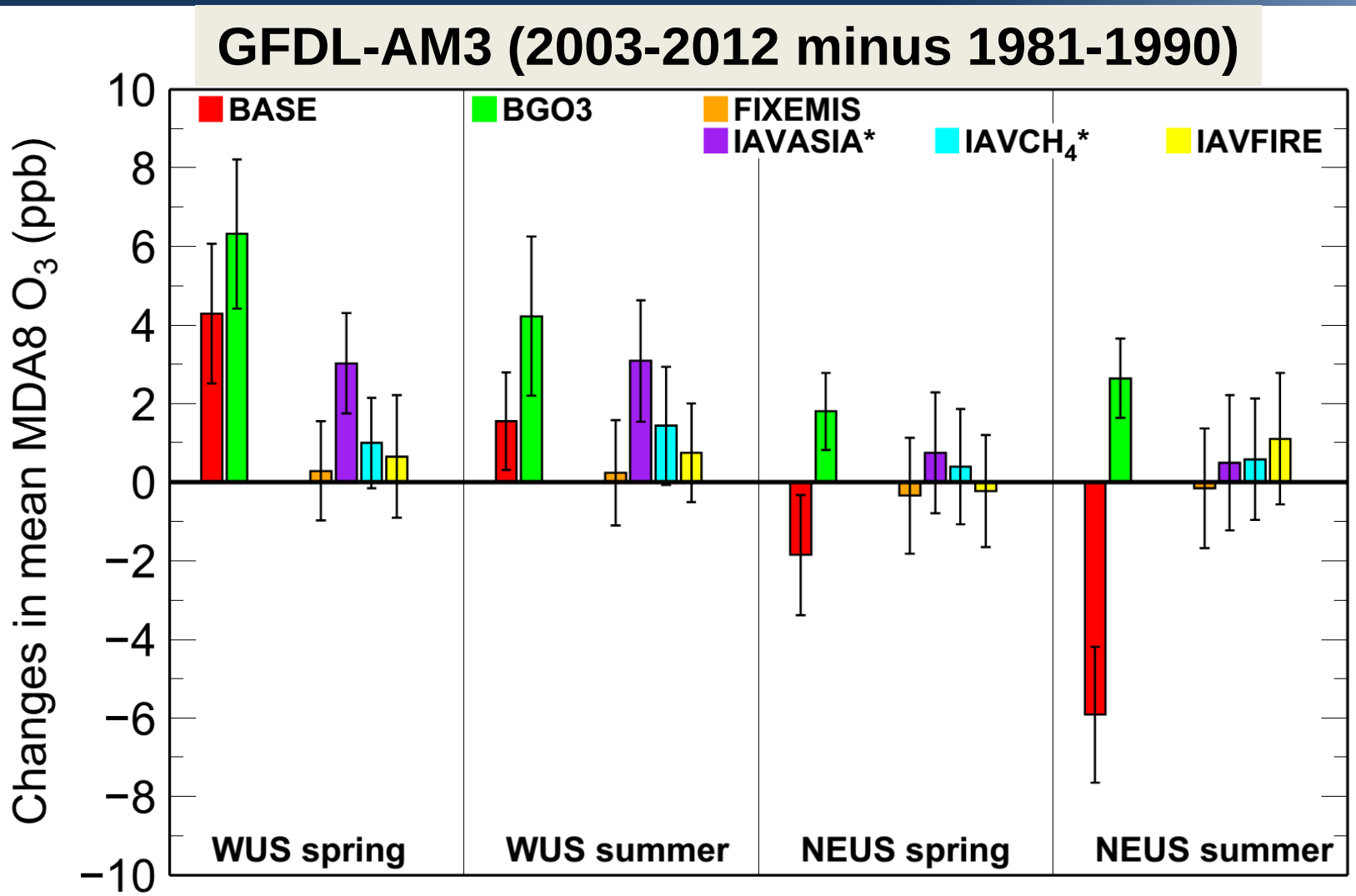
WUS { Model filtered to be more representative of observed conditions
High background, thus little response to local NO_x reductions

SUMMER U.S. surface O_3 trends: Do domestic NO_x reductions work?



MY Lin and LW Horowitz, *et al* (in prep, 2015)

Decadal mean background O_3 over WUS has increased by ~4-6 ppbv from 1980s to 2000s



WUS { Attributed in part to rising Asian emissions and global methane
U.S. domestic emission controls offset 2-3 ppb

Lin et al [in prep; 2015]

Some Final Thoughts on Western US ozone

- **Strong stratospheric influence on interannual variability**
  - → Contribute to the highest observed surface O_3 events
  - → More frequent following strong La Niña winters
  - → Potential to develop seasonal forecast

- **Decadal mean background O_3 over WUS has increased by ~6 ppbv from 1980s to 2000s**
  - → Attributed in part to rising Asian emissions & global CH_4

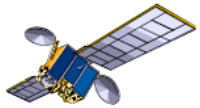
- **Detecting IAV in background O_3 means and extremes requires improvements in the current observation network**

GFDL-AM3

Meiyun.Lin@noaa.gov

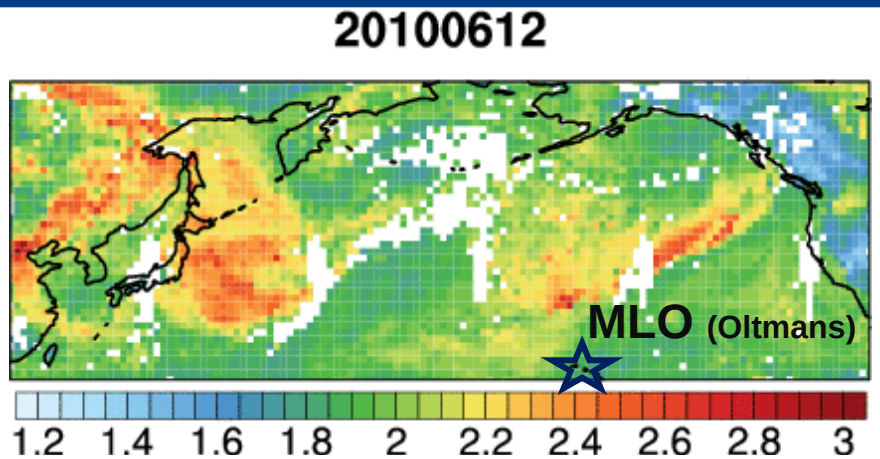
Additional Slides for Discussions

Asian pollution contribution to WUS high-O_3 events during spring 2010 (El Niño)

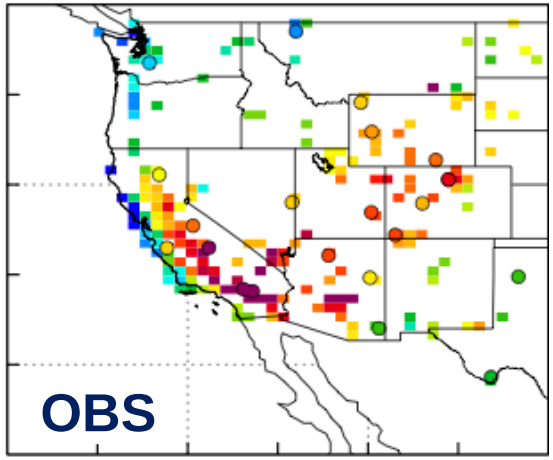


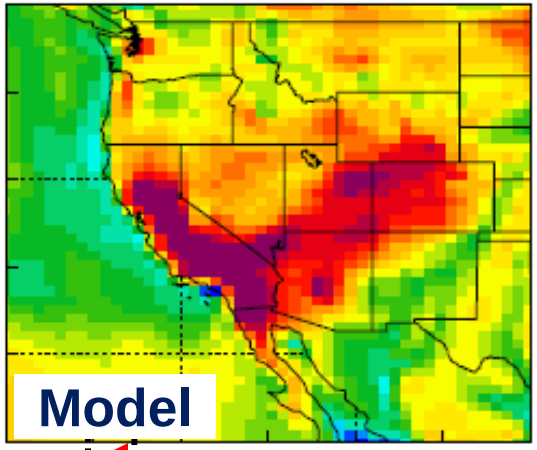
satellites

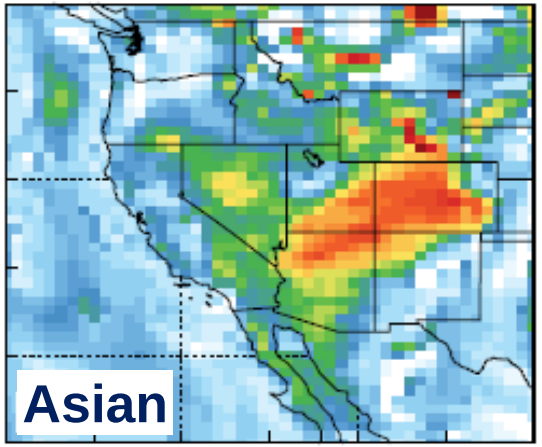
AIRS CO
[10^{18} molecules cm^{-2}]



22-June-2010







Future NAAQS?

Surface MDA8 O_3

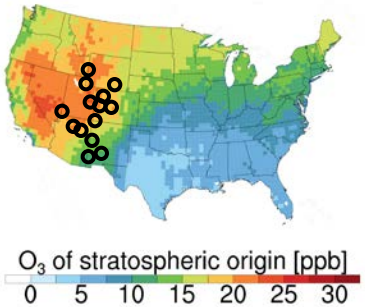
25 35 45 55 65 75 [ppb]

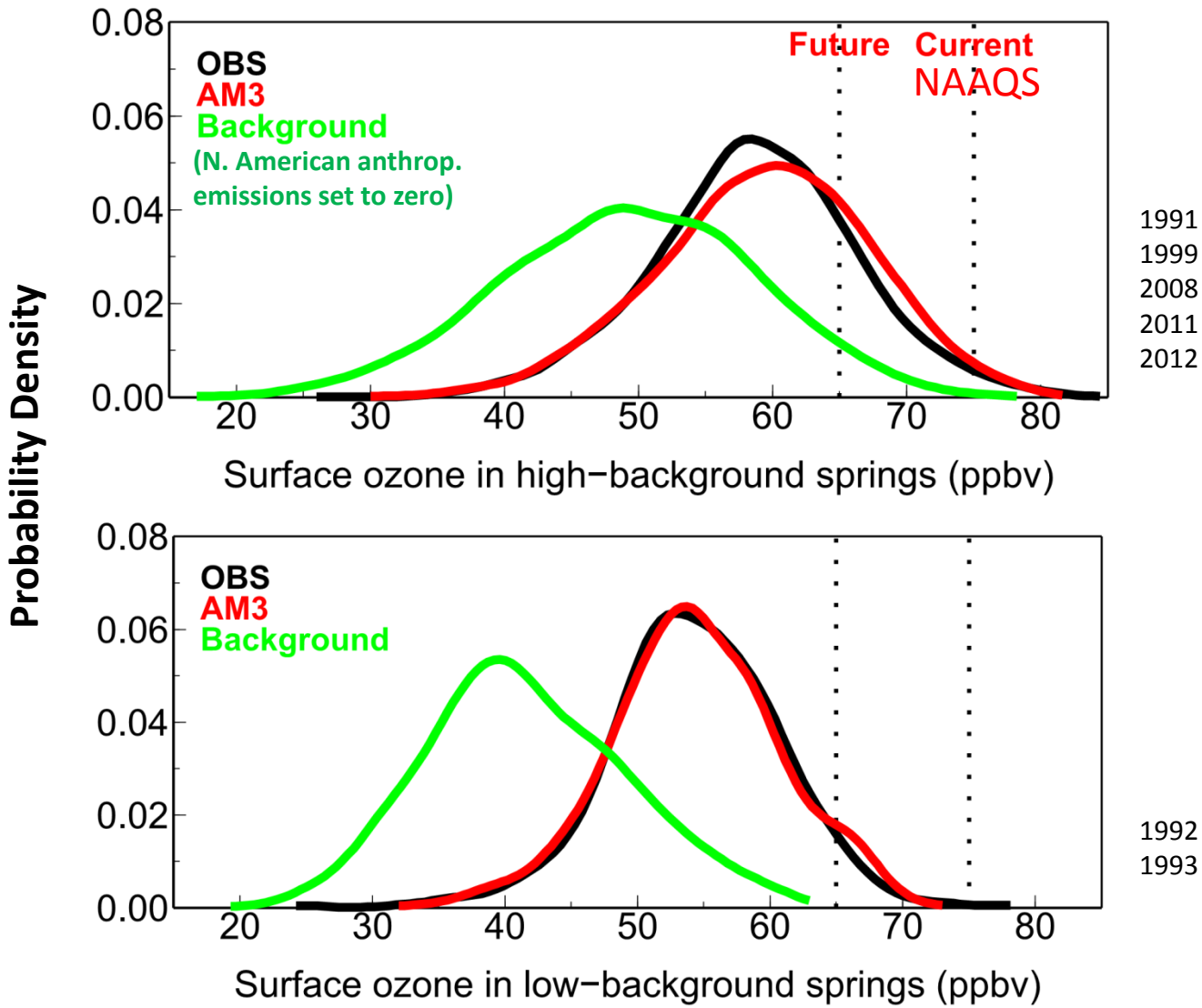
0 2 4 6 8 10 12 14 [ppb]

Asian pollution can contribute ~20% on days when OBS > 65 ppb

Meiyun Lin *et al* [JGR, 2012a]: Transport of Asian O_3 pollution into surface air over the WUS

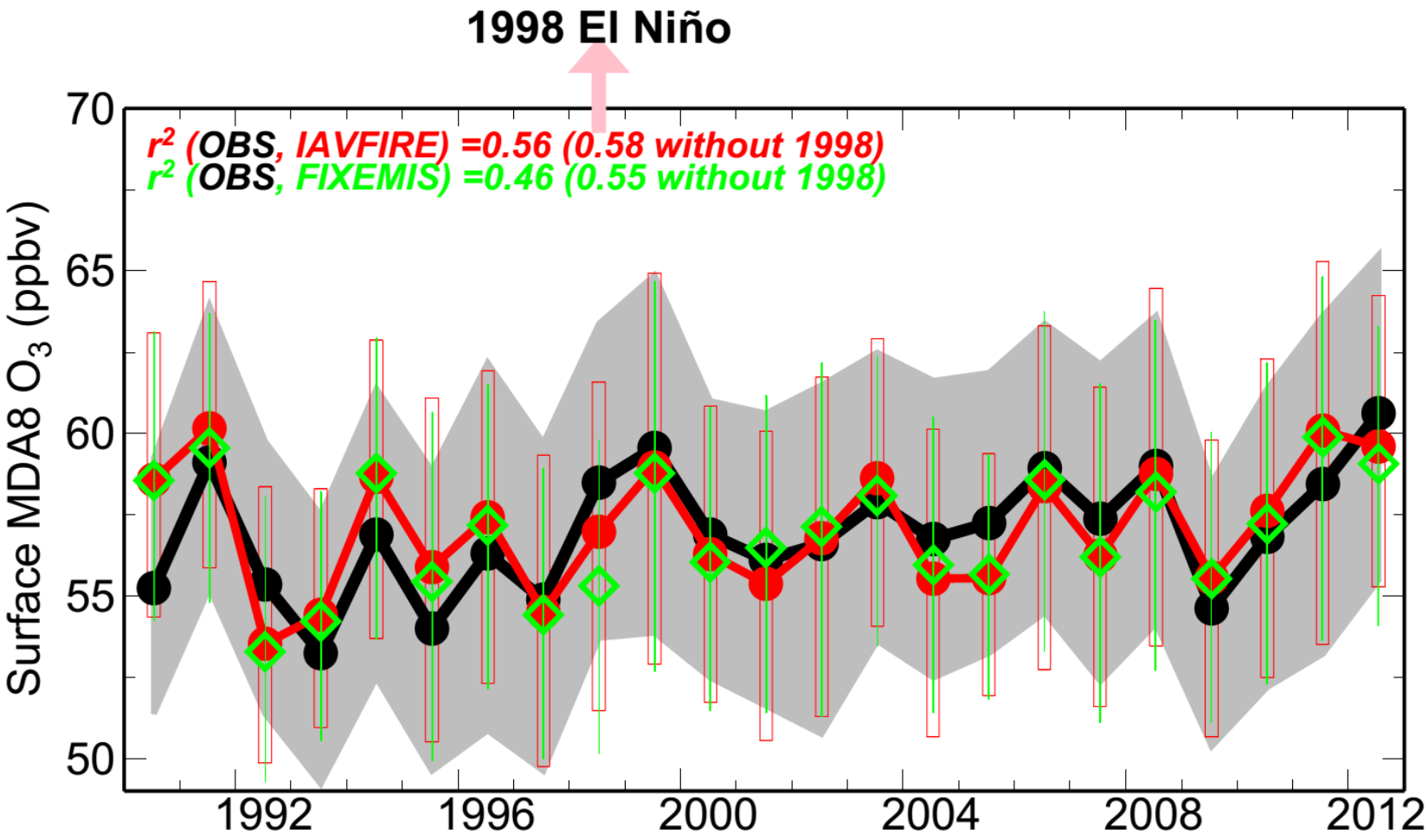
Surface O_3 distribution in high vs low background springs





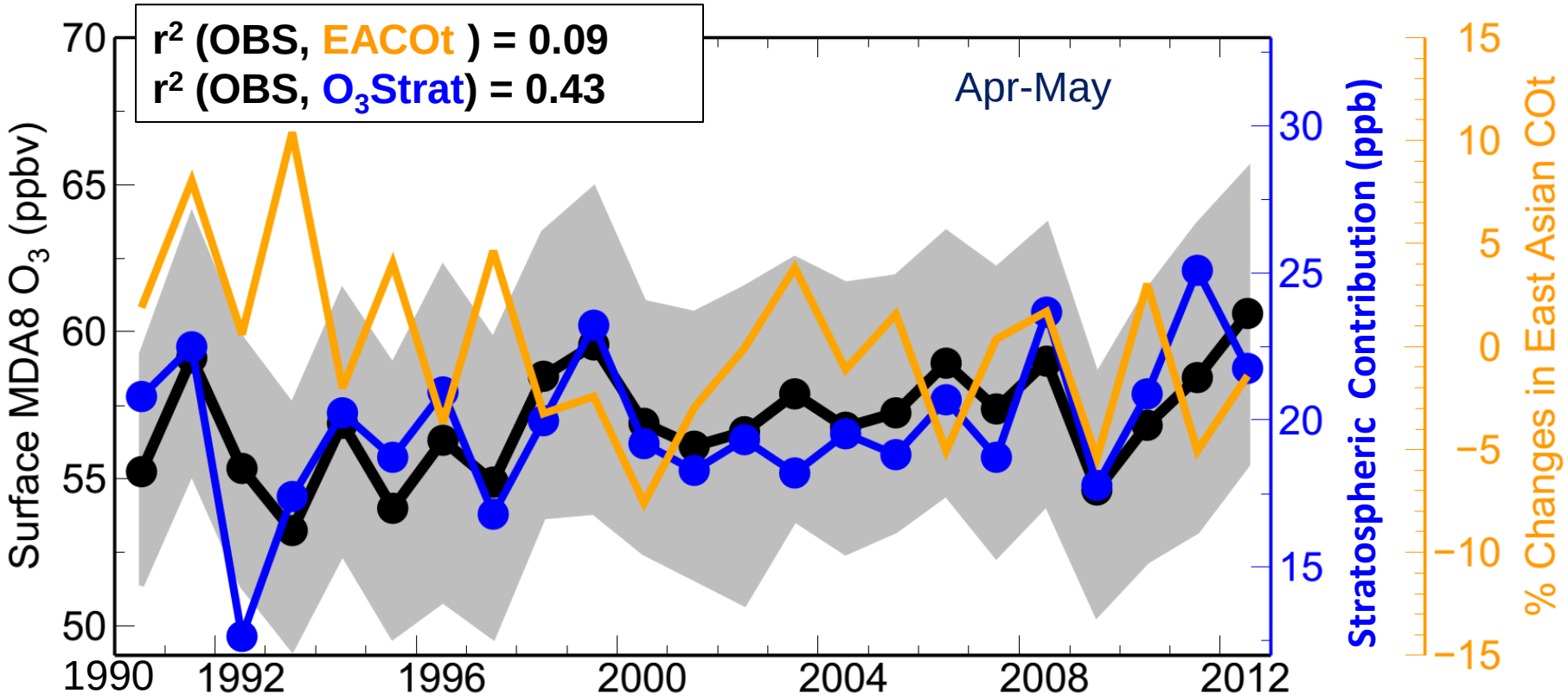
Meiyun Lin et al (Nature Communications, 2015)

Minor influence from wildfire emissions on inter-annual variability of springtime surface ozone over WUS



Meiyun Lin et al (Nature Communications, 2015)

Asian pollution contributes less to WUS surface ozone inter-annual variability than the stratospheric influence



Airflow from Eurasia towards the WUS in spring has weakened in the 2000s

→ **Consistent with declines in Radon-222 and O_3 observed at Mauna Loa, Hawaii (3.4 km altitude) during spring**

→ **Too small to be discernable from surface O_3 observations over WUS**

nature geoscience *Lin MY et al* (2014)