BOSA workshop, Denver, March 28-29, 2017

Processes controlling U.S. background ozone extremes and trends over 1980-2015

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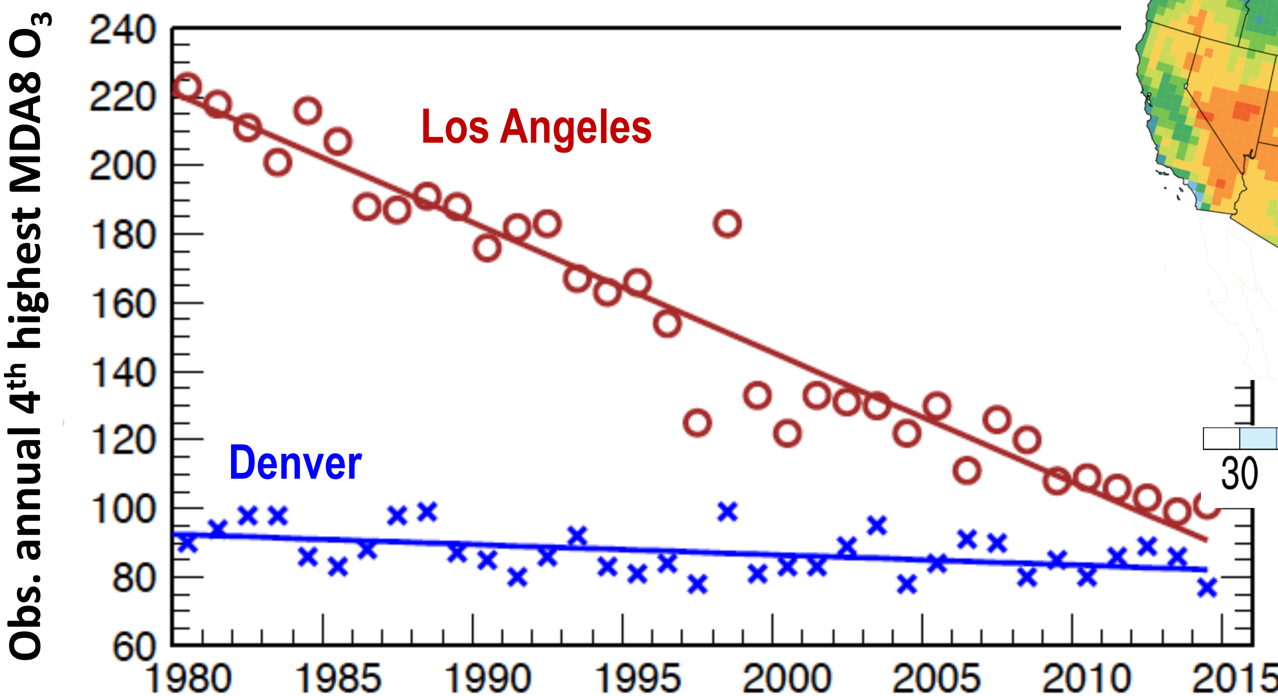
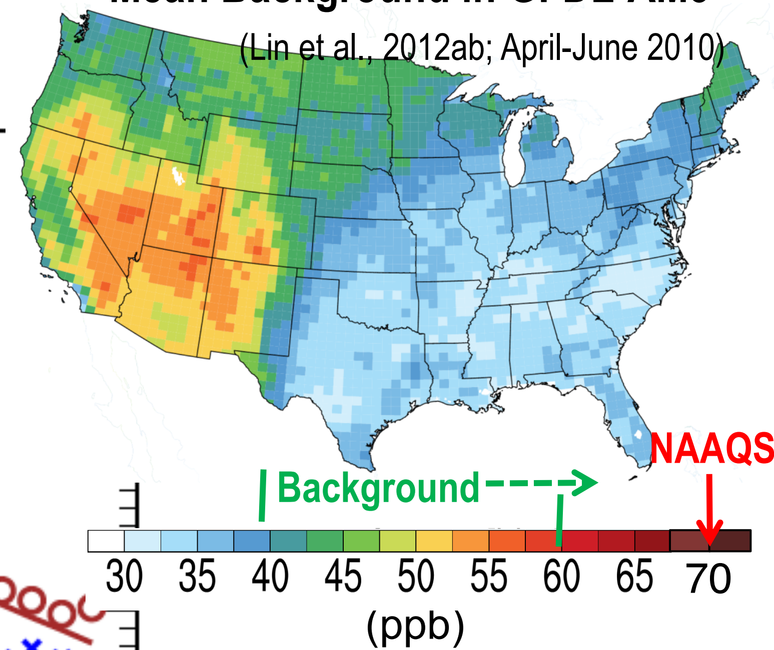
Major challenges for western U.S. air quality management

Fig. 17 from Lin et al. (ACP, 2017), data c/o R. Payton (EPA)



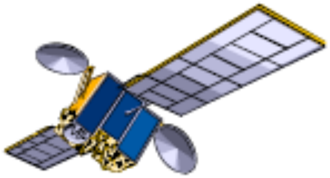
Mean Background in GFDL-AM3



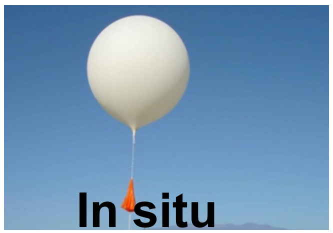
MAJOR CHALLENGES: (1) Deep stratospheric intrusion events in spring
(2) Rising Asian emissions and global CH_4
(3) More frequent wildfires in summer
(4) Warming climate

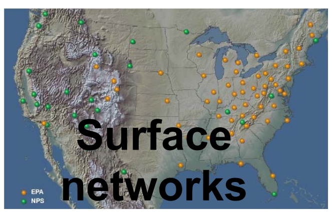
→ **NEED PROCESS-LEVEL UNDERSTANDING ON DAILY TO MULTI-DECADAL TIME SCALES**

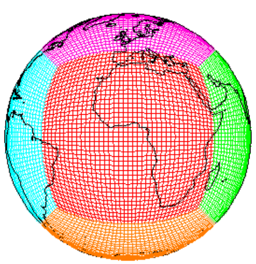
Today's presentation



Satellites







GFDL-AM3

- Stratospheric versus Asian influences on **springtime high-O_3 events** over the WUS

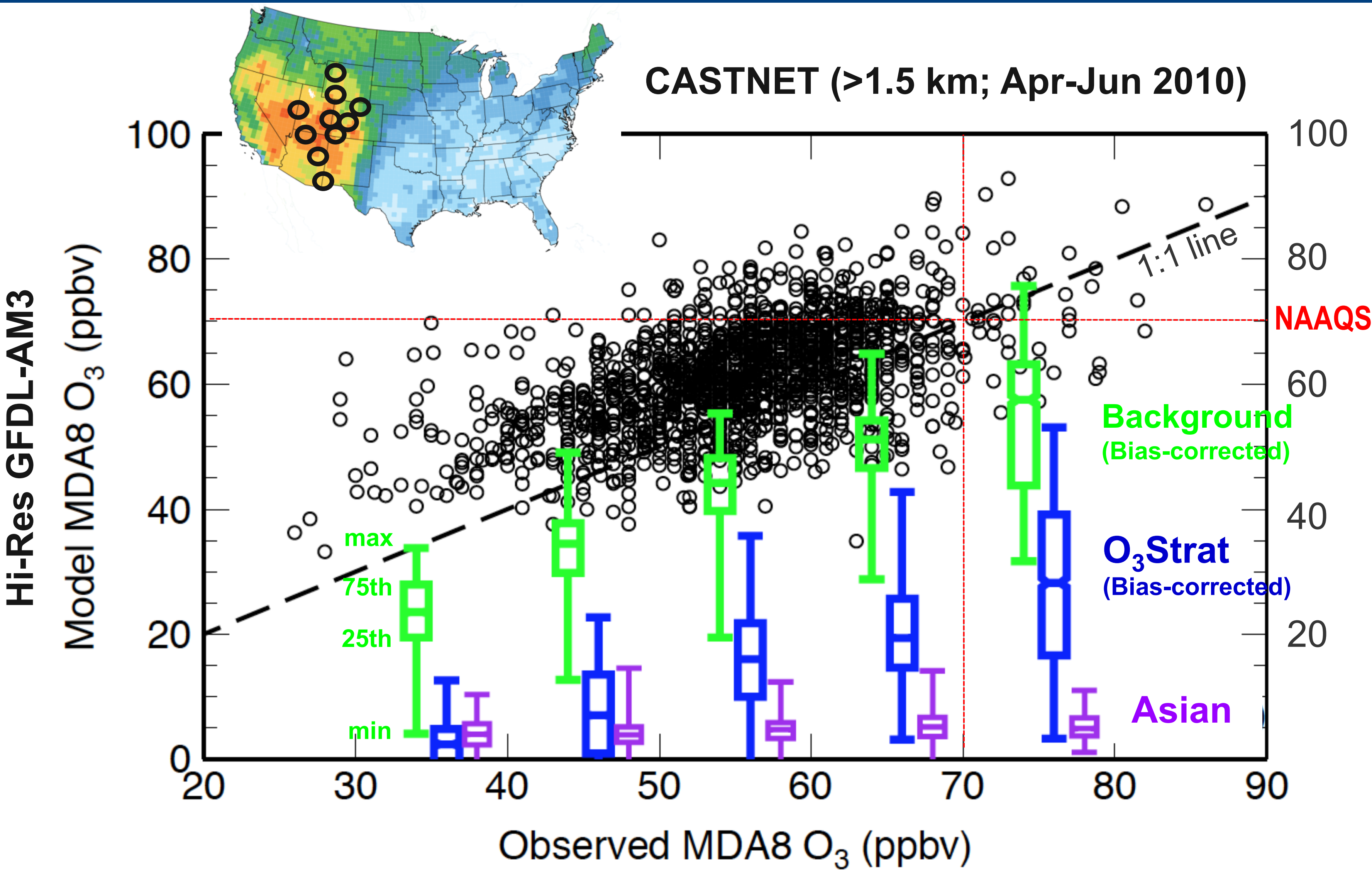
- How does **interannual variability of meteorology** modulate transport pathways of Asian pollution and stratospheric intrusions?

- **Long-term trends** of ozone in US surface air and aloft
  → Reconciling observations and models
  → Roles of rising Asian emissions versus US domestic controls

- To what extent **wildfire** emissions contribute to WUS summertime O_3 variability?

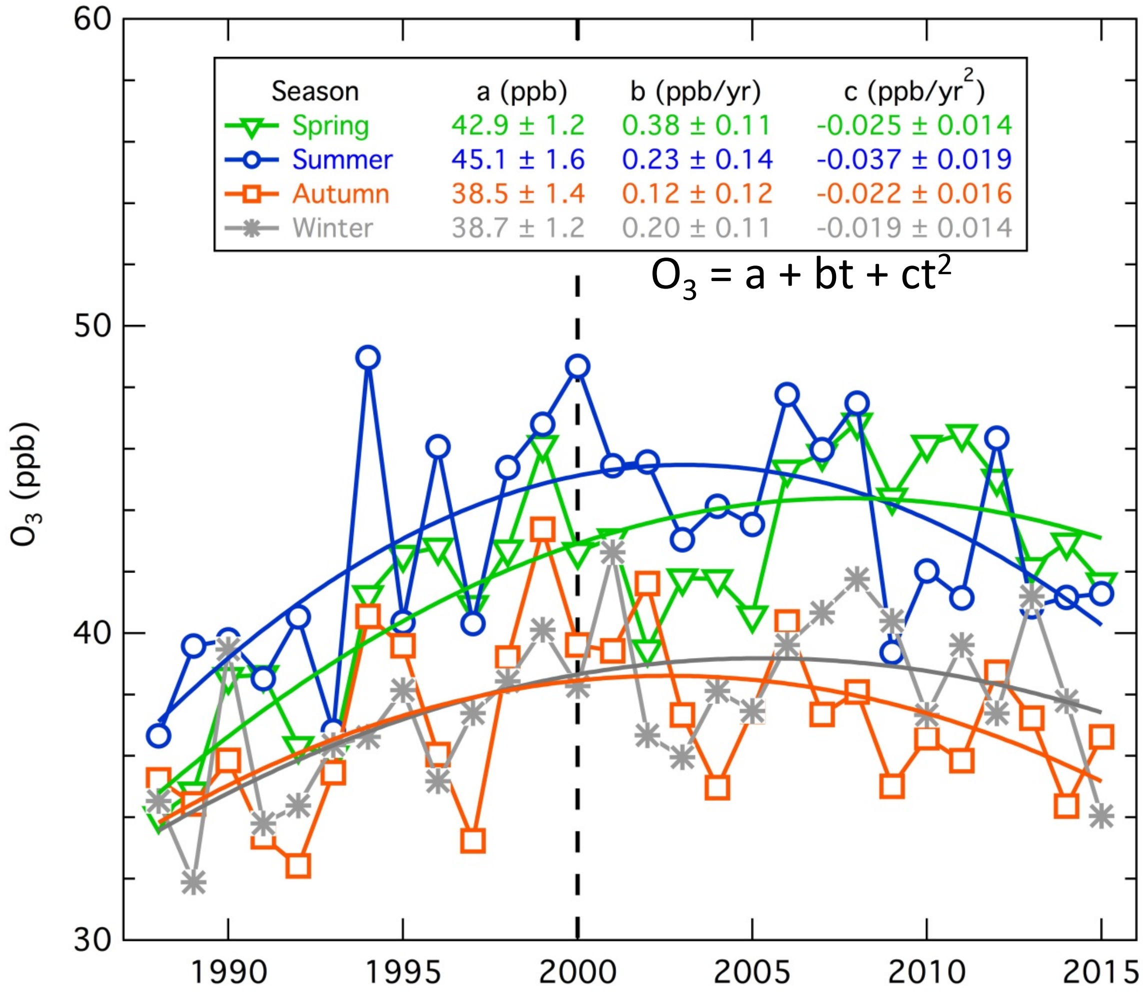
- Summary of policy-relevant messages

Asian and stratospheric influences on springtime high-O_3 events at IMW sites



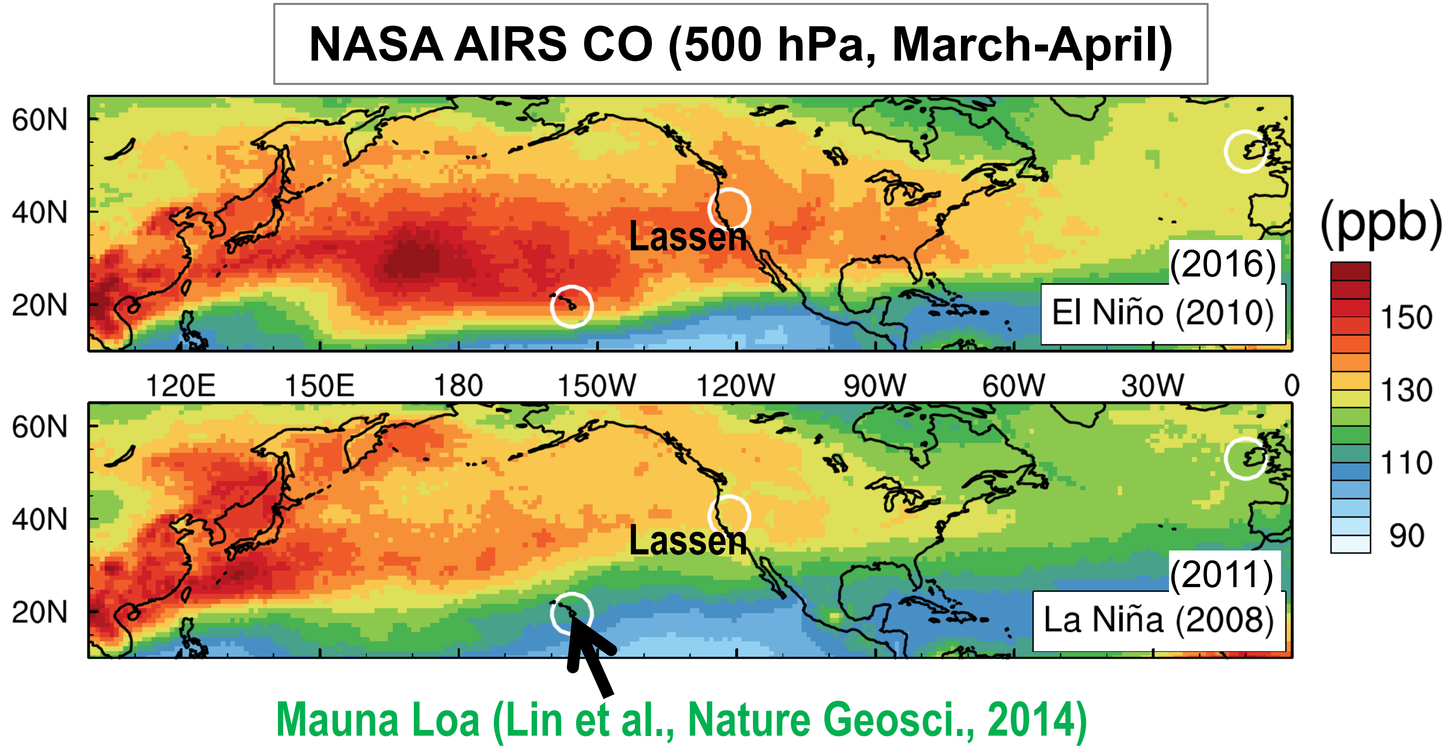
Lin et al. (JGR, 2012a, 2012b)

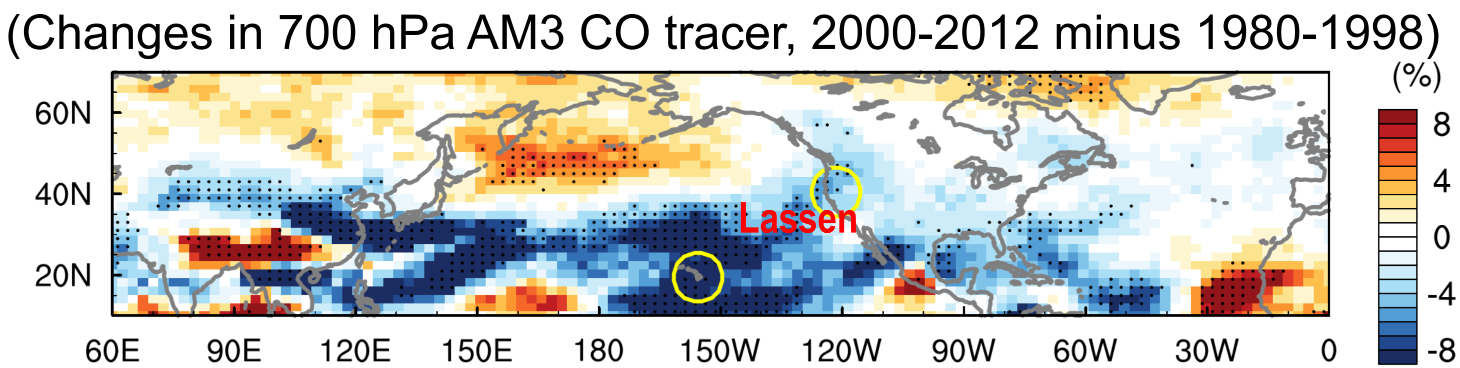
Why does ozone measured at Lassen California show a leveling-off trend in the 2000s?



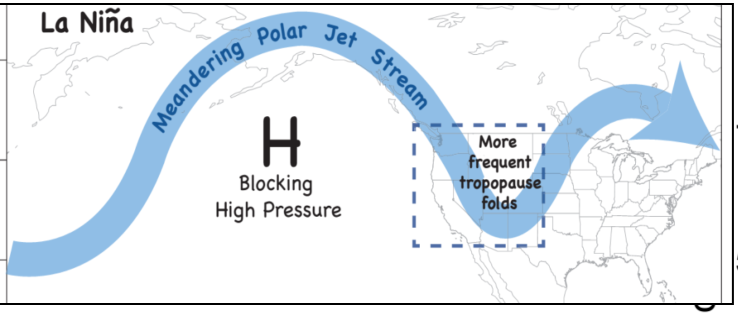
(Figure c/o D.D. Parrish)

A poleward shift in transport pathways of Asian pollution in the 2000s plays a role



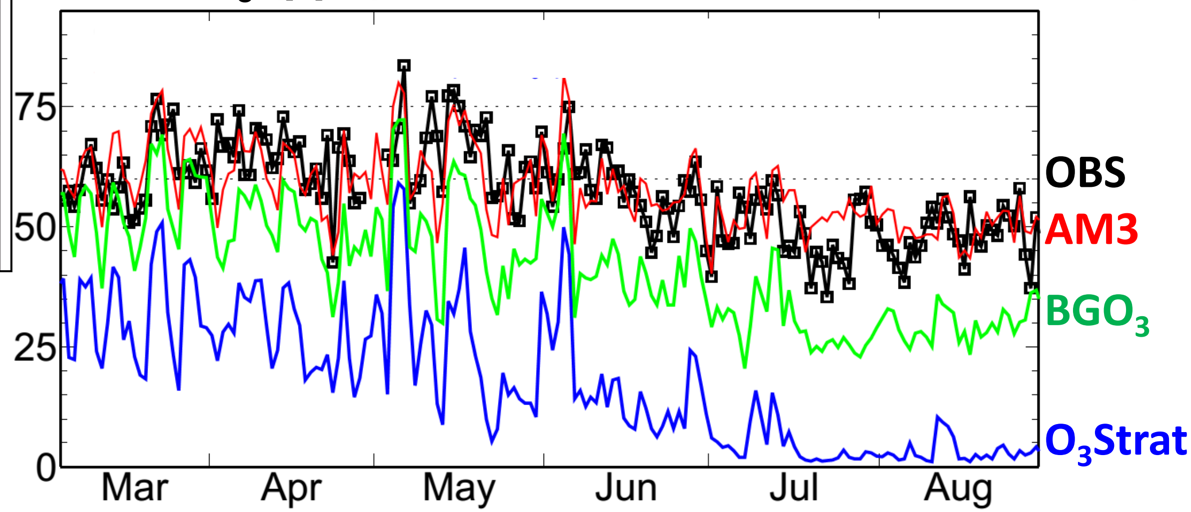


Following a La Niña **winter**, more frequent stratospheric intrusions reaching IMW sites in **spring**



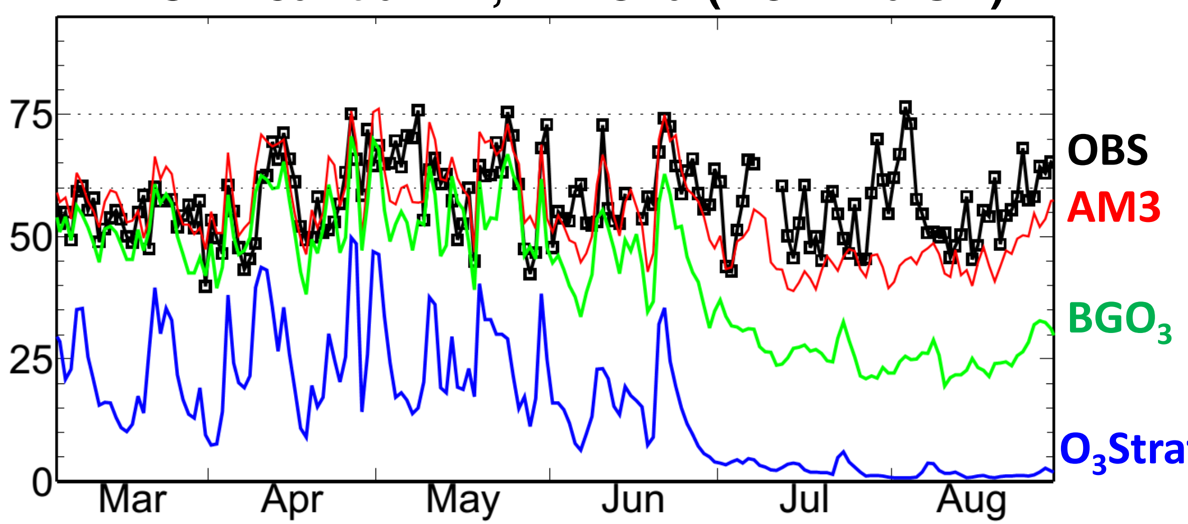
1999 (La Niña) →

MDA8 O_3 (ppb) at Gothic Colorado (2.9 km a.s.l.)



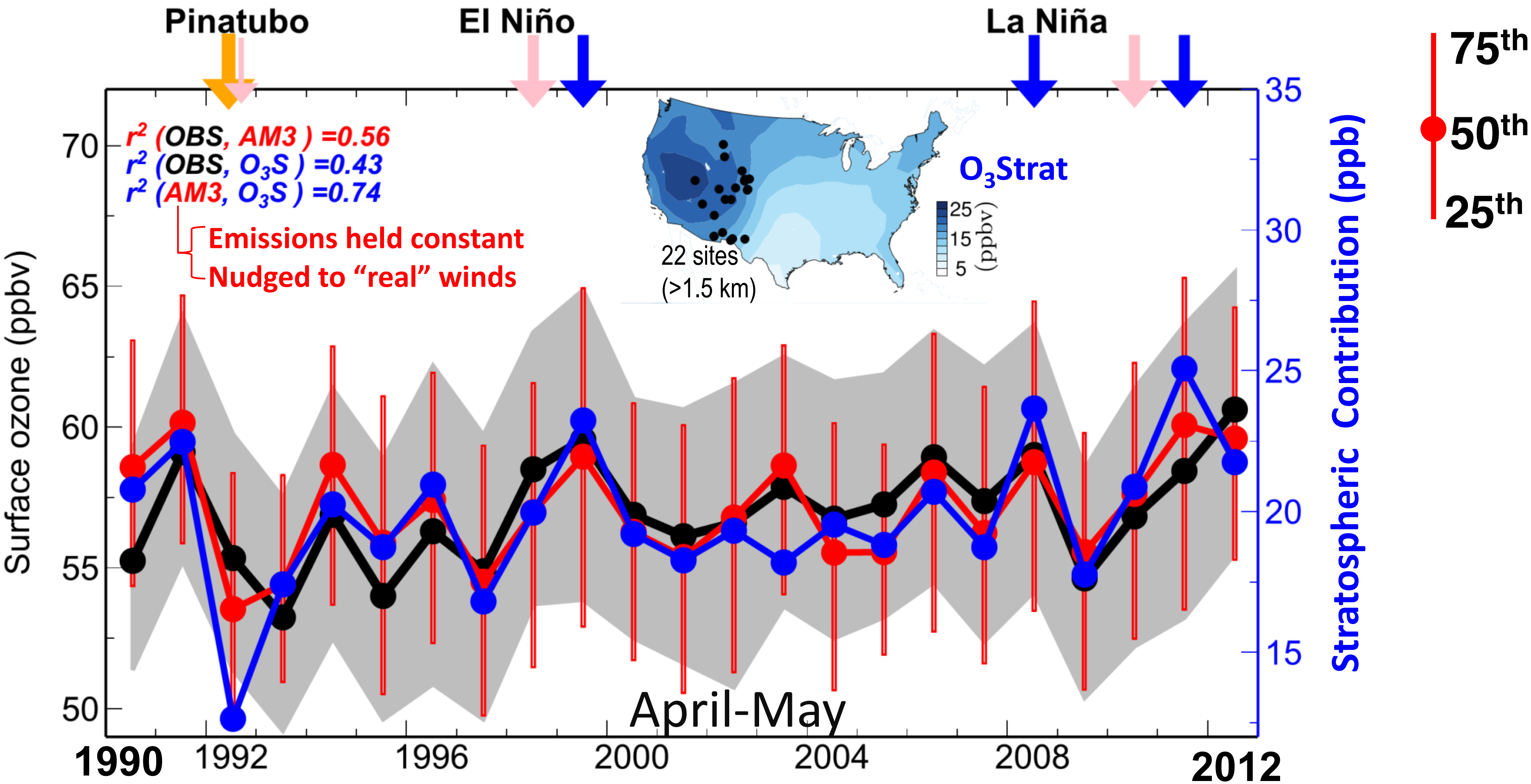
2011 (La Niña) →

Chiricahua NM, Arizona (1.5 km a.s.l.)



→Potential for developing seasonal prediction [Lin et al., Nature Commun., 2015]

Year-to-year variability in springtime high-O_3 events over WUS tied to stratospheric influence



- **Large IAV due to STT can confound attribution of observed O_3 trends calculated over short record length**

Changes in anthropogenic emissions of NO_x

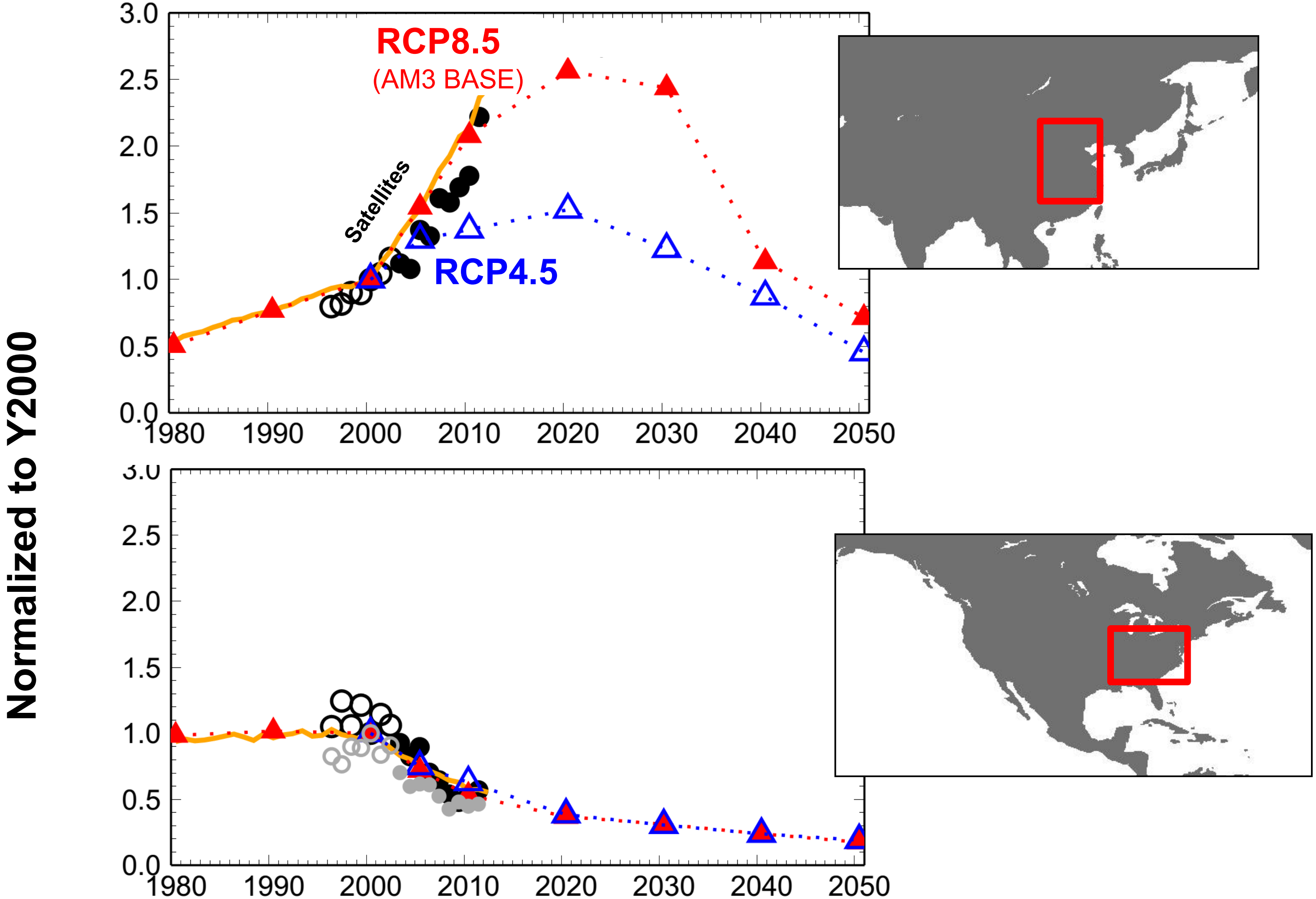
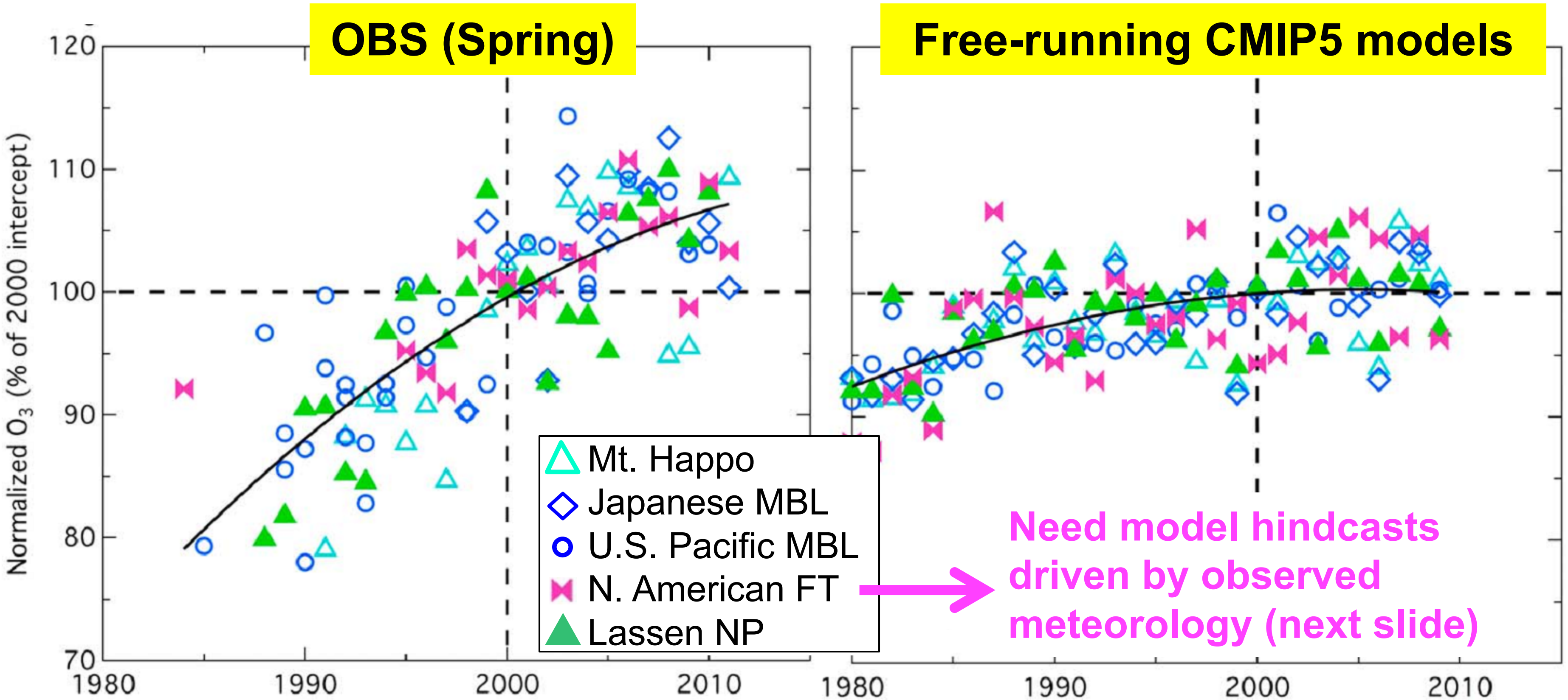


Figure 1 of Lin et al. (ACP, 2017): Emission data from Lamarque et al. (2010, 2012); Satellite (GOME/SCIAMACHY) data from KNMI (www.temis.nl)

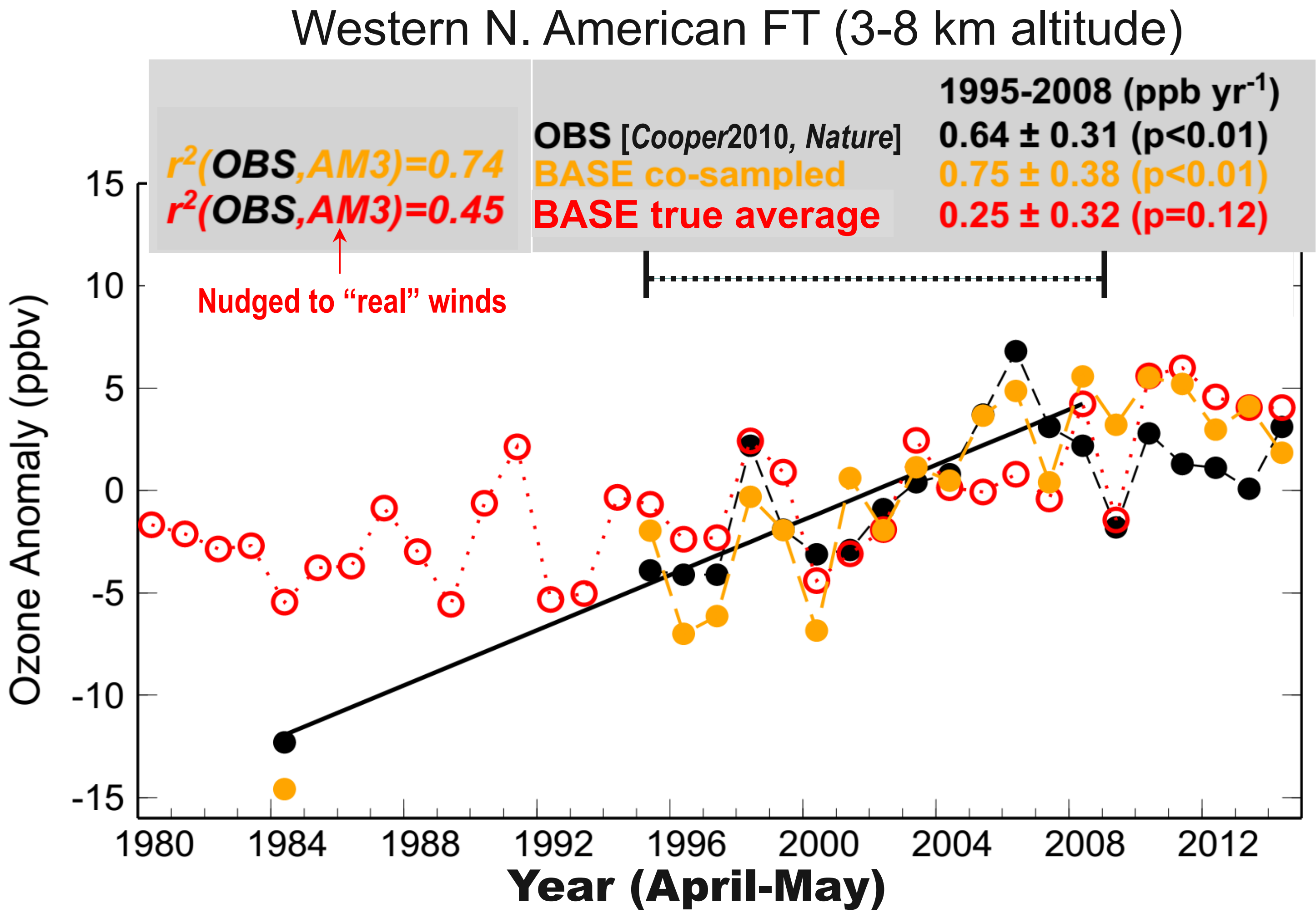
Baseline O_3 trends derived from observations and free-running chemistry-climate models differ by a factor of 2 (Parrish et al., 2014)

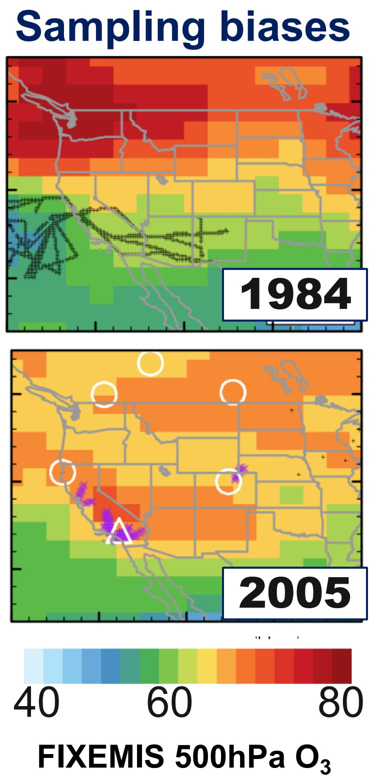


These discrepancies reflect a combination of factors:

(1) Internal climate variability (Lin et al., 2014; 2015a; Barnes et al., 2016)
(2) Measurement sampling biases (Lin et al., 2015b)
(3) Model difficulty resolving observed remote baseline conditions (Lin et al., 2017)

Influence of measurement sampling biases





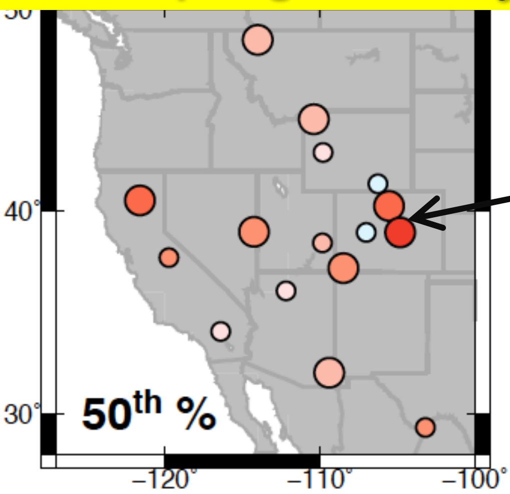
→ 15-year trends driven by internal climate variability can be as large as emission-driven trends.

→ Even with co-sampling, free-running CCMs are not expected to reproduce the trends.

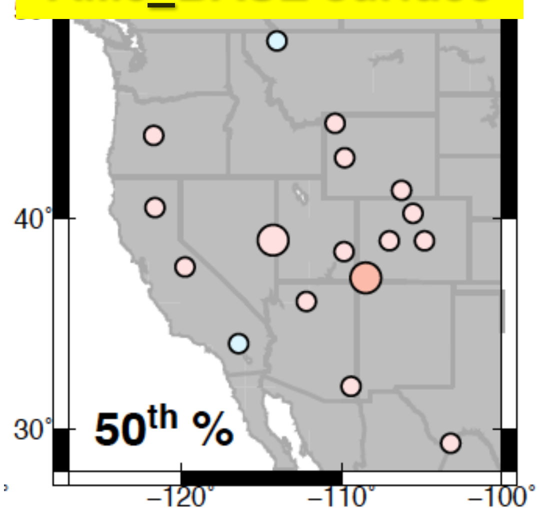
Model baseline sampling approach for evaluating O_3 trends at IMW sites

Within a ~200x200 km^2 model grid cell

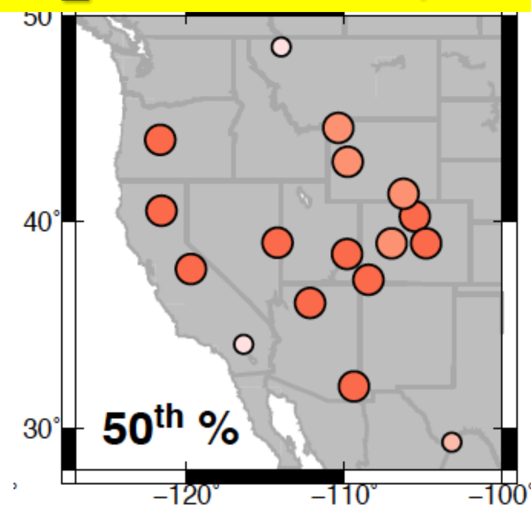
Observed spring MDA8 O_3 trend 1988-2014

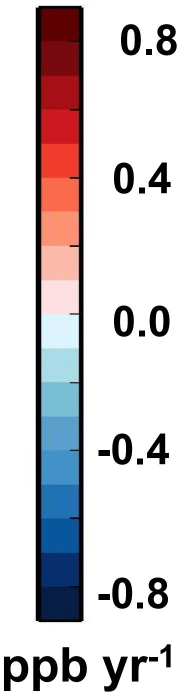


AM3_BASE surface



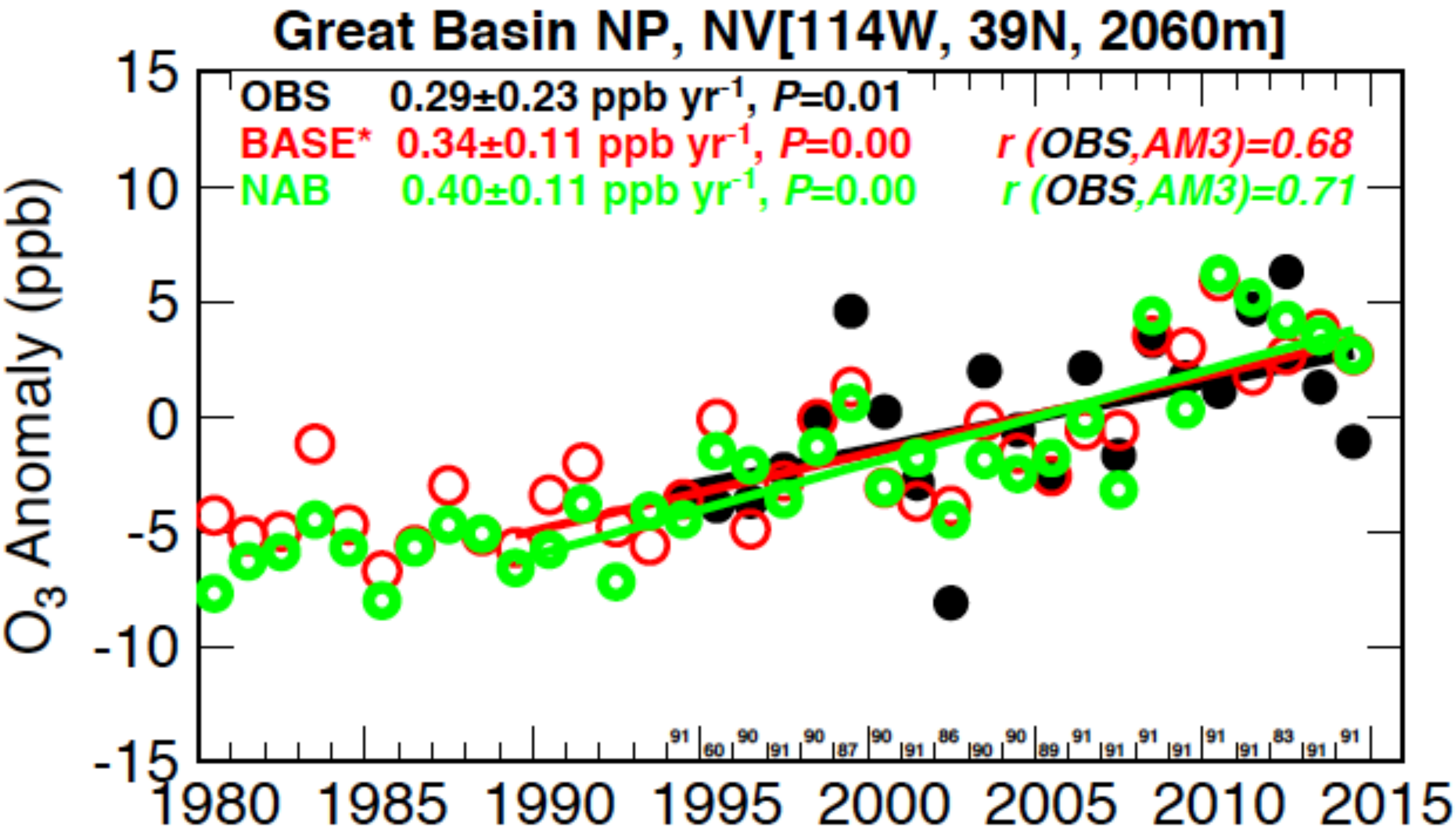
AM3_BASE 700 hPa, filtered





Lin, M., Horowitz L.W., Payton, R., Fiore, A.M., Tonnesen, T. [ACP, 2017]

Median springtime MDA8 O_3 trends at Great Basin NP



→ **Most of the observed variability reflect changes in the background**

→ **The effects of US NO_x controls (BASE minus NAB) are < 0.1 ppb yr^{-1}**

See Figure 13 of Lin et al. (ACP, 2017) for additional analysis for other sites

SPRING US surface MDA8 O_3 trends over 1988-2014

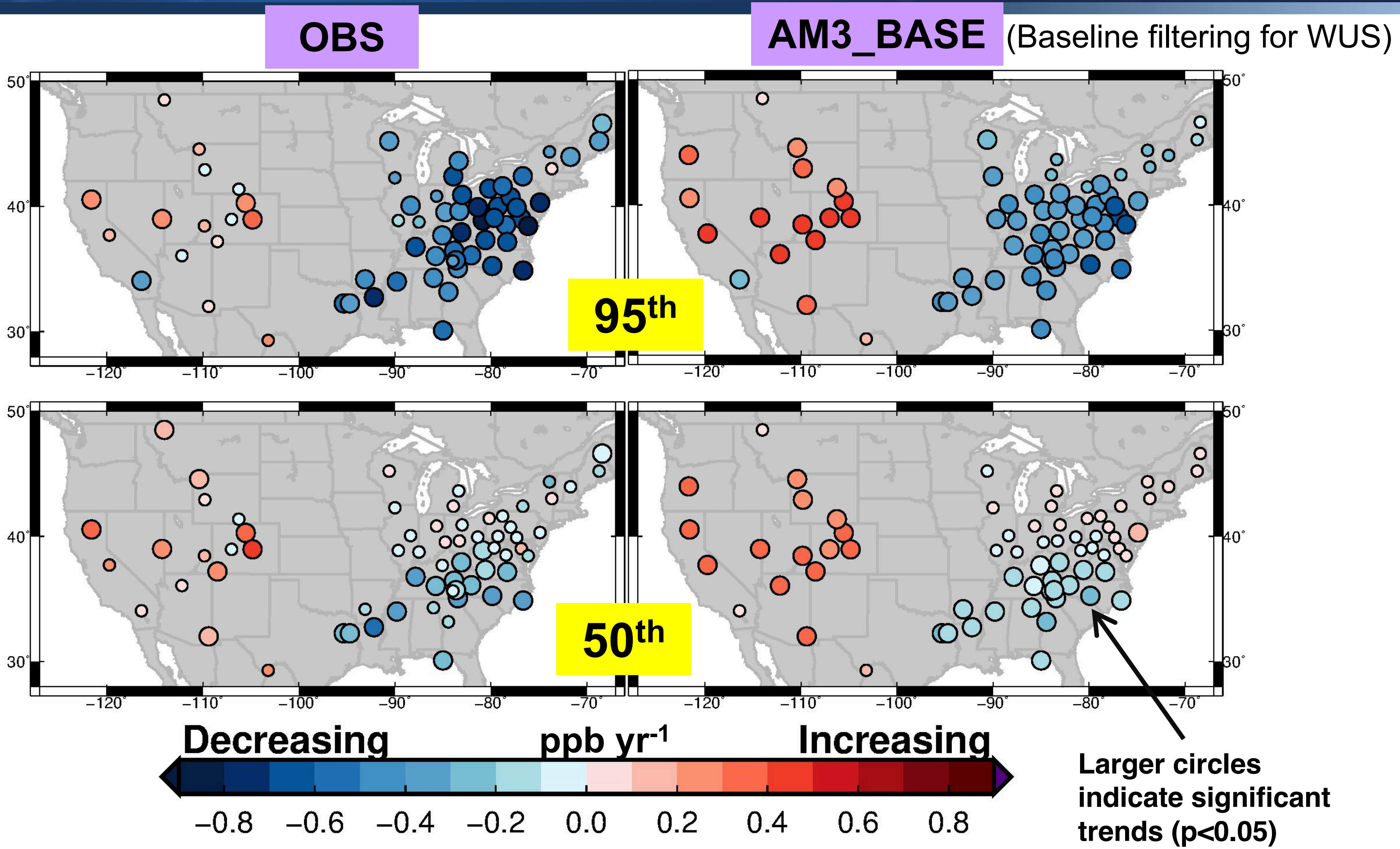


Figure 7 from Lin et al. [ACP, 2017]

SPRING US surface MDA8 O_3 trends over 1988-2014

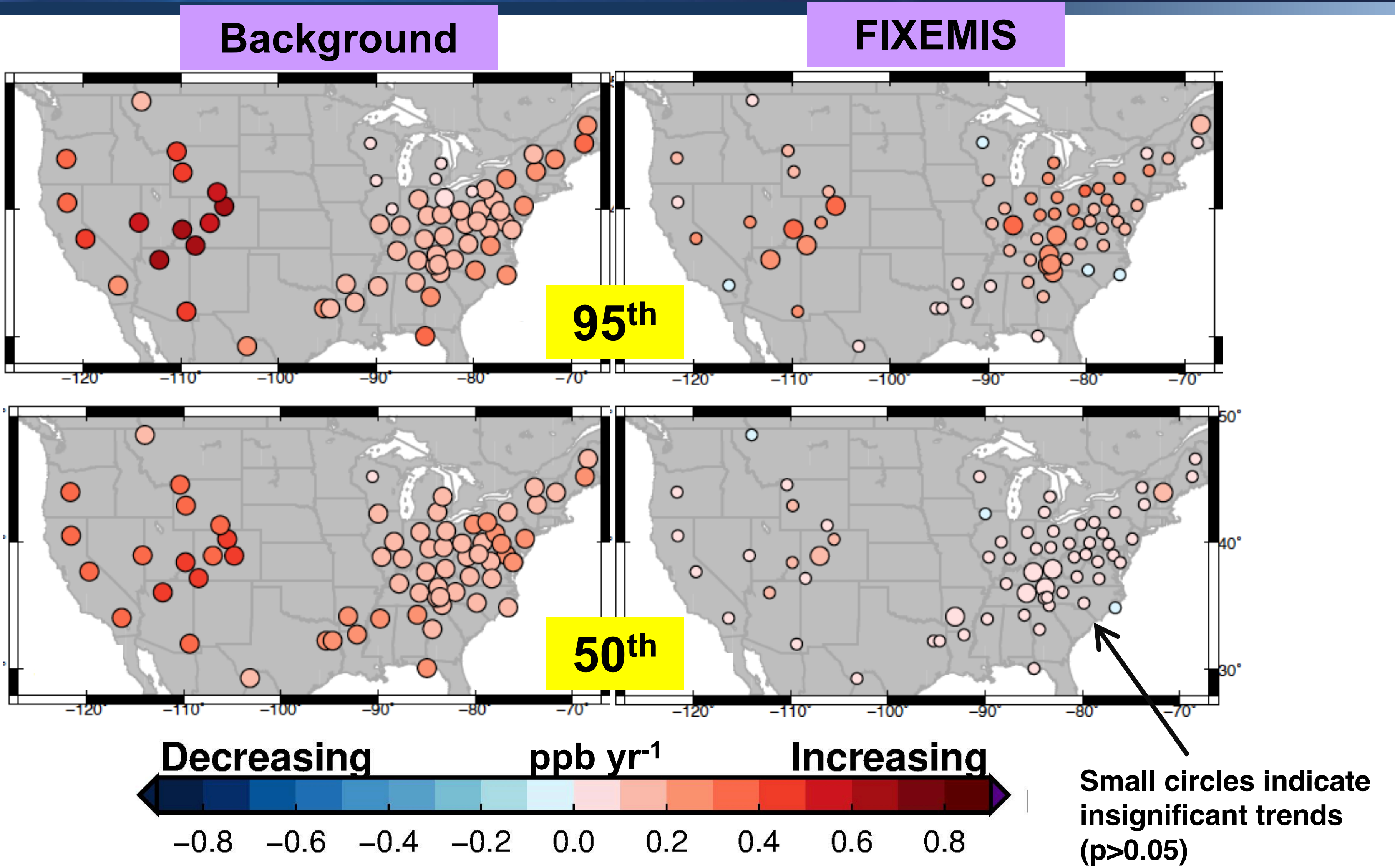
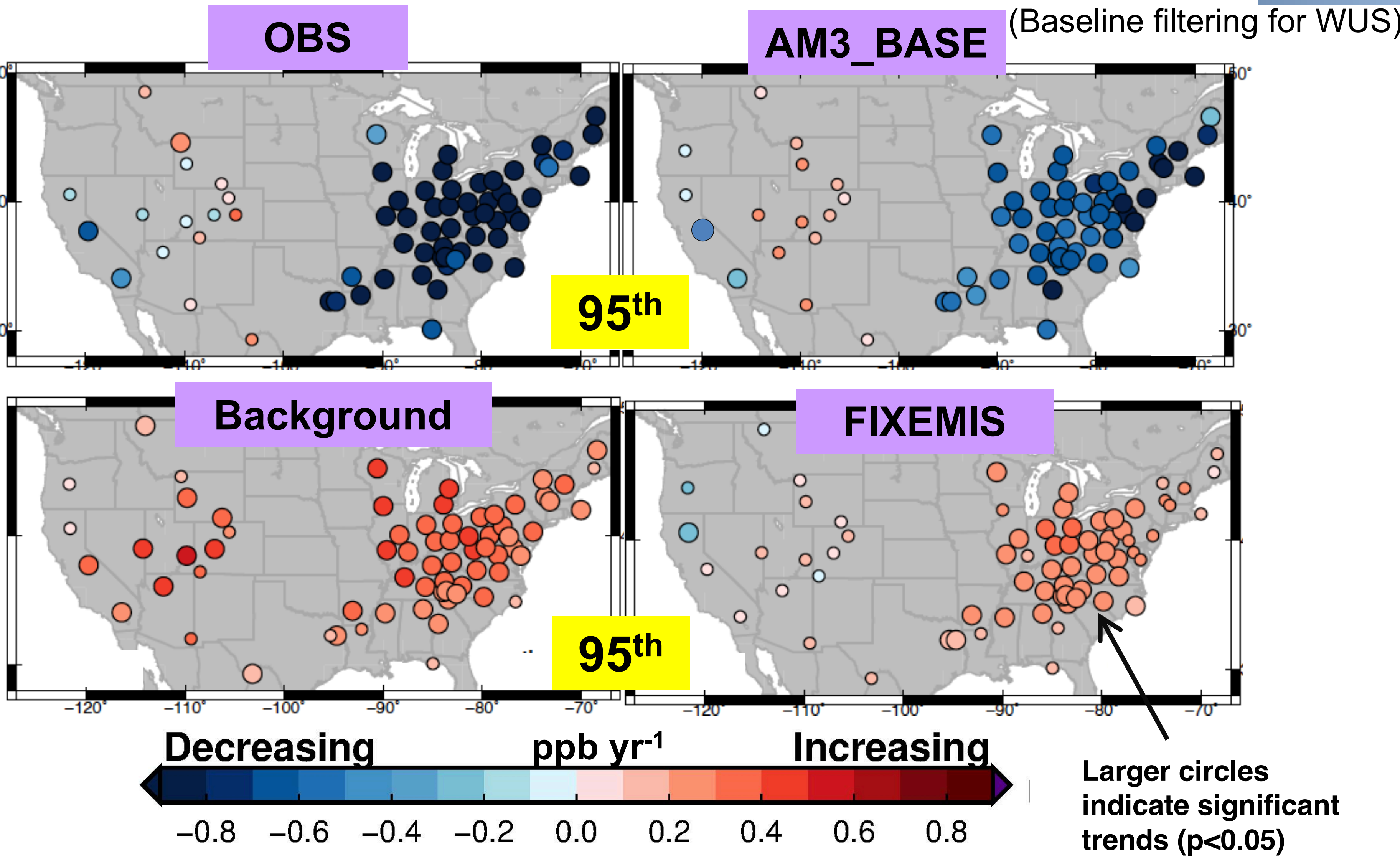


Figure 10 from Lin et al. [ACP, 2017]

SUMMER US surface MDA8 O_3 trends over 1988-2014



Figures 8 and 11 from Lin et al. [ACP, 2017]

Summarizing drivers of decadal mean O_3 changes from 1981-1990 to 2003-2012 over WUS

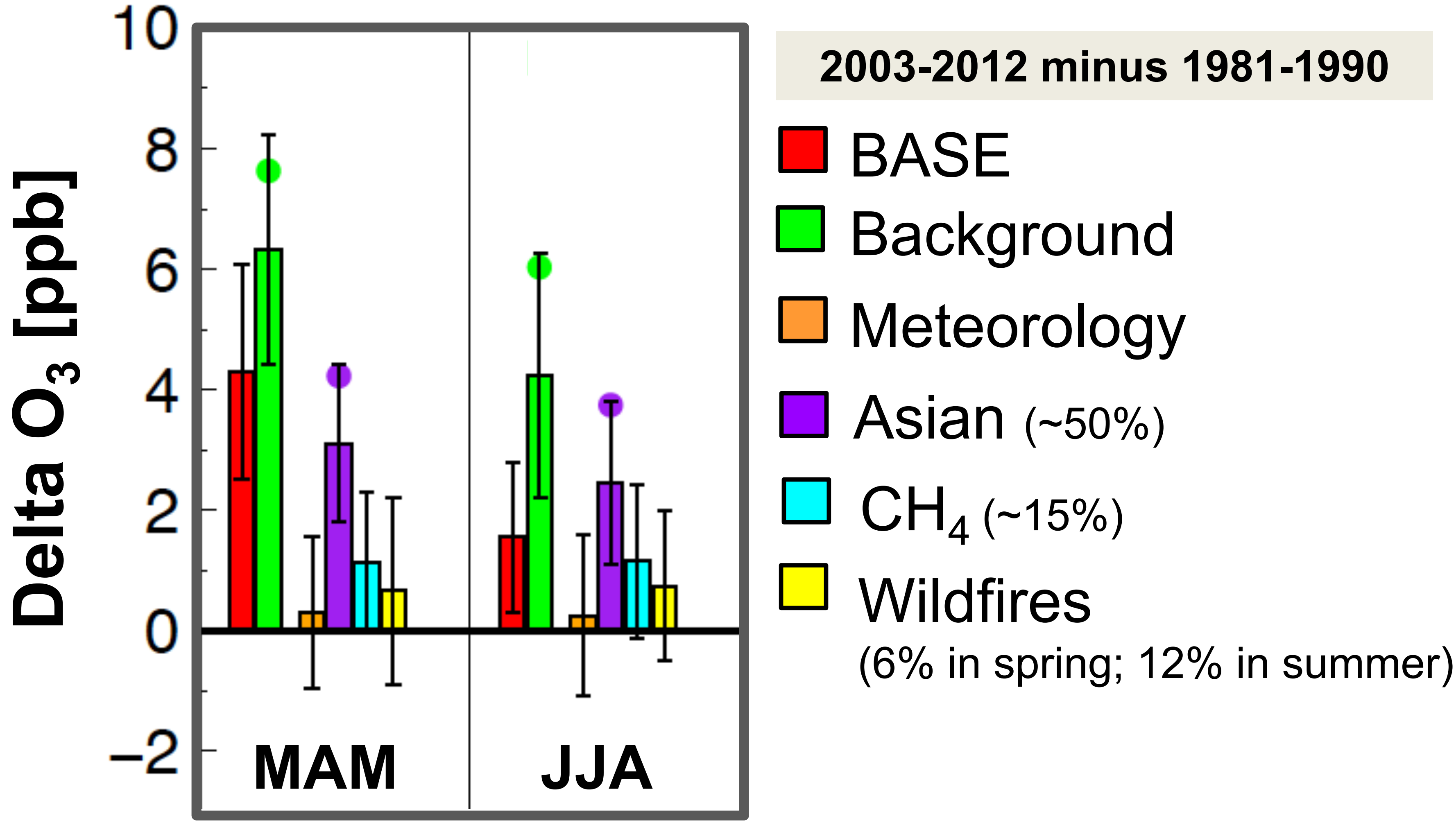
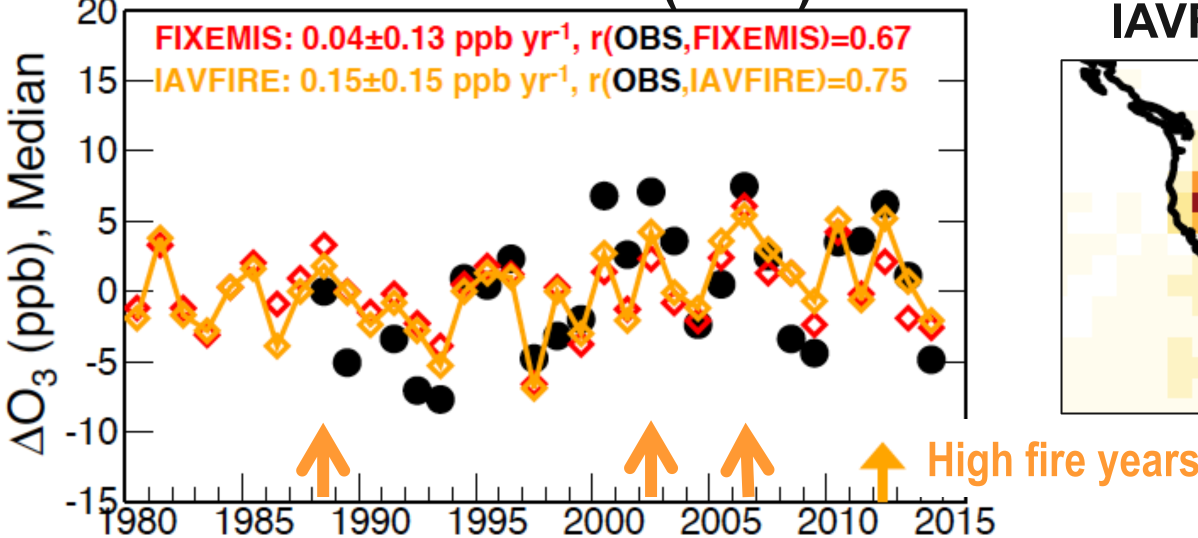


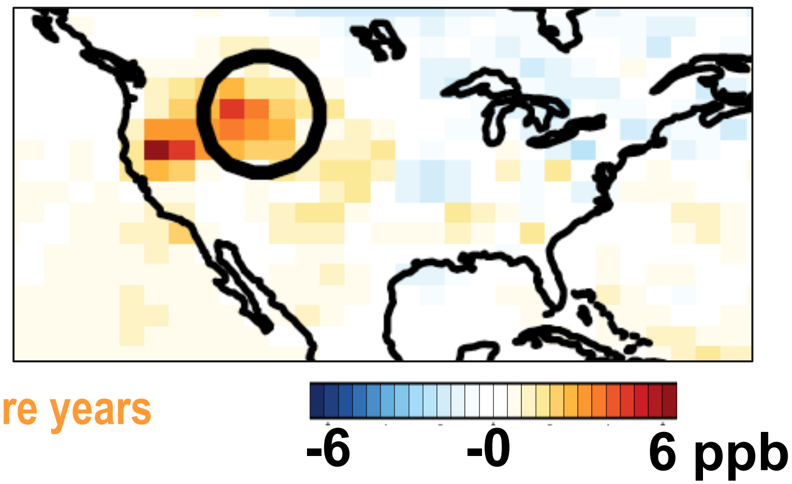
Figure 20 from Lin et al. [ACP, 2017]

Wildfires: NOT the primary driver of summer O_3 IAV over WUS?

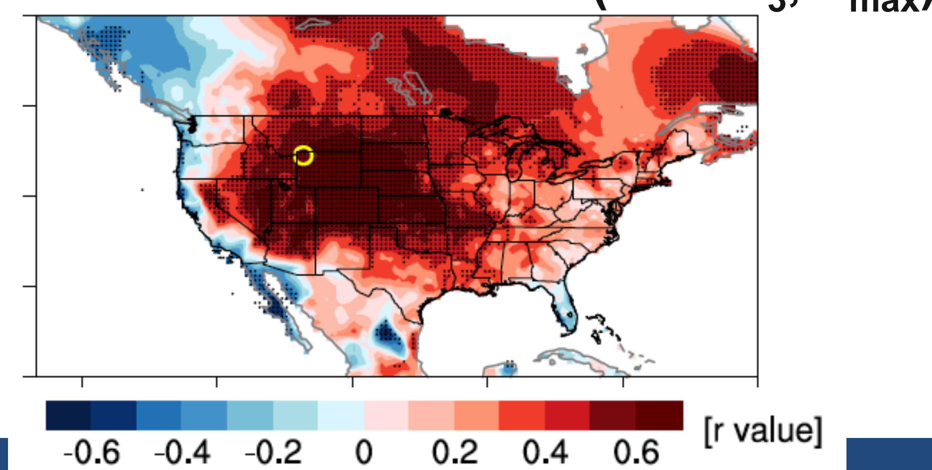
Yellowstone NP (AUG)



IAVFIRE – FIXEMIS (Aug2012)



Interannual correlations (YEL O_3, T_{max})



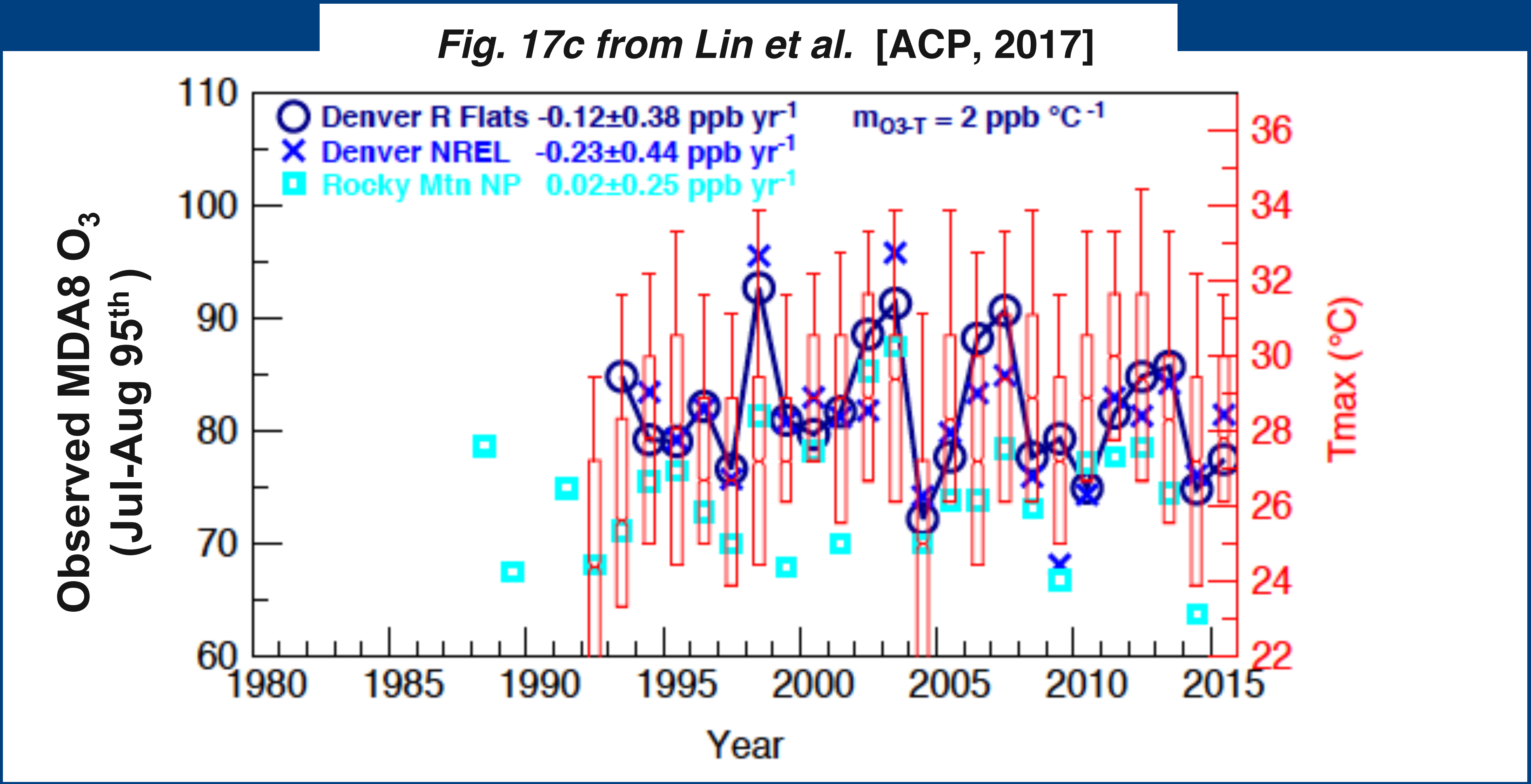
Hot and dry summers:

→ deeper PBLH allowing more O_3 to mix down to the surface (see also Zhang et al., 2014)

→ The buildup of O_3 produced from regional anthropogenic emissions (e.g., Denver / Rocky Mountain NP)

Figs 15 and 16 from Lin et al. [ACP, 2017]

Summertime O_3 in Denver correlates with temperature



- Role of VOCs from fires + urban NO_x (Jaffe & Wigder,2012; Baker et al., 2016)?
- **The 2017 Fires, Asian and Stratospheric Transport – Las Vegas Ozone Study**

→ Funded by Clark County (Zheng Li)
→ NOAA ESRL measurement team (A.O. Langford) + NASA AJAX?
→ GFDL-AM4 and GEOS-Chem modeling (PI: Meiyun Lin; now hiring post-doc)

Some final policy-relevant messages

Stratospheric intrusions	• can episodically increase surface MDA8 O_3 by 20-40 ppb above the baseline level (~20 ppb) • The key driver of observed year-to-year variability in springtime high-O_3 events >70 ppb
Asian pollution	• contributes ~5 ppb to mean WUS O_3 background in spring • The key driver of multi-decadal WUS background O_3 increases (~65%; 0.2 ppb/yr)
Rising global methane	• contributes 15% of the WUS background O_3 increase
Wildfires	• can enhance monthly mean MDA8 O_3 at individual sites by 2-8 ppb in some summers • but not the primary driver of observed O_3 year-to-year variability at rural sites
More frequent hot extremes & rising BVOC emissions	• contribute to raising background O_3 over EUS • would have worsened the highest O_3 events over EUS if NO_x emissions had not declined

Additional Slides for Q & A Discussions

Springtime ozone observed in Denver has increased at a rate similar to remote rural sites

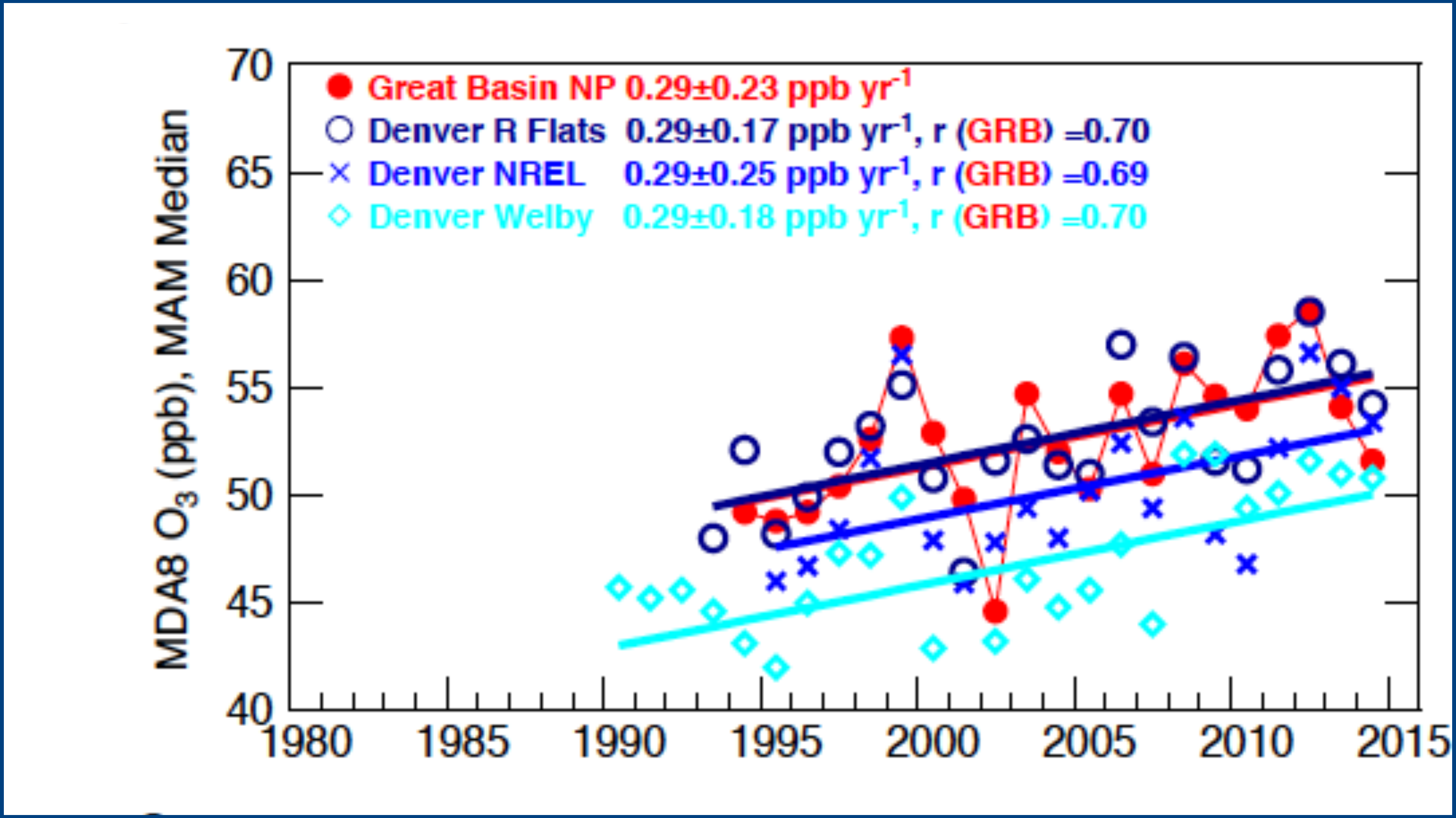
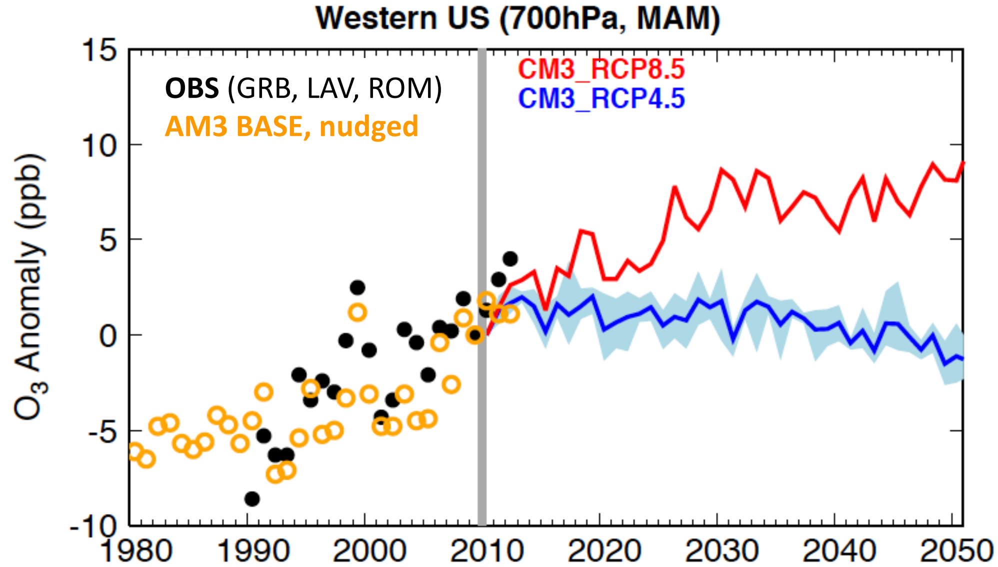
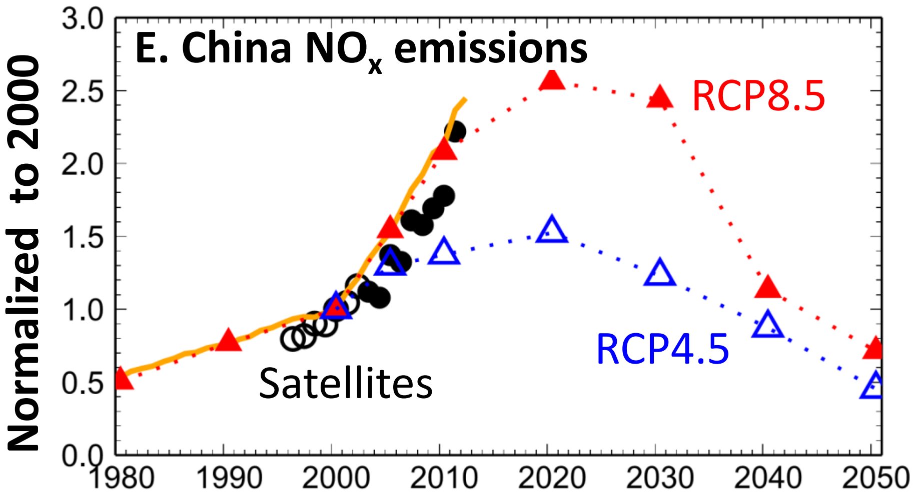


Figure 17 from Lin et al. **[ACP, 2017]**

Projections of near-term changes in WUS lower trop. ozone in spring (March-April-May)





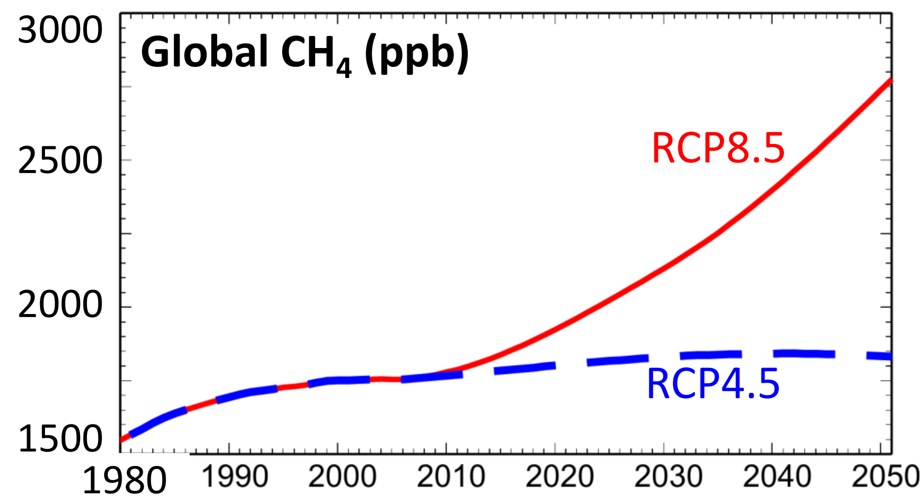
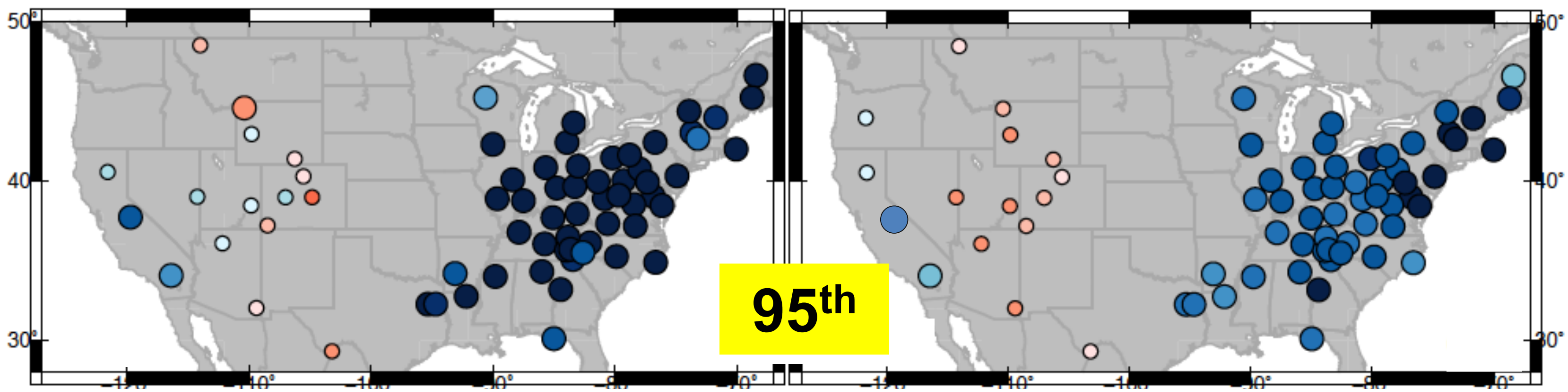


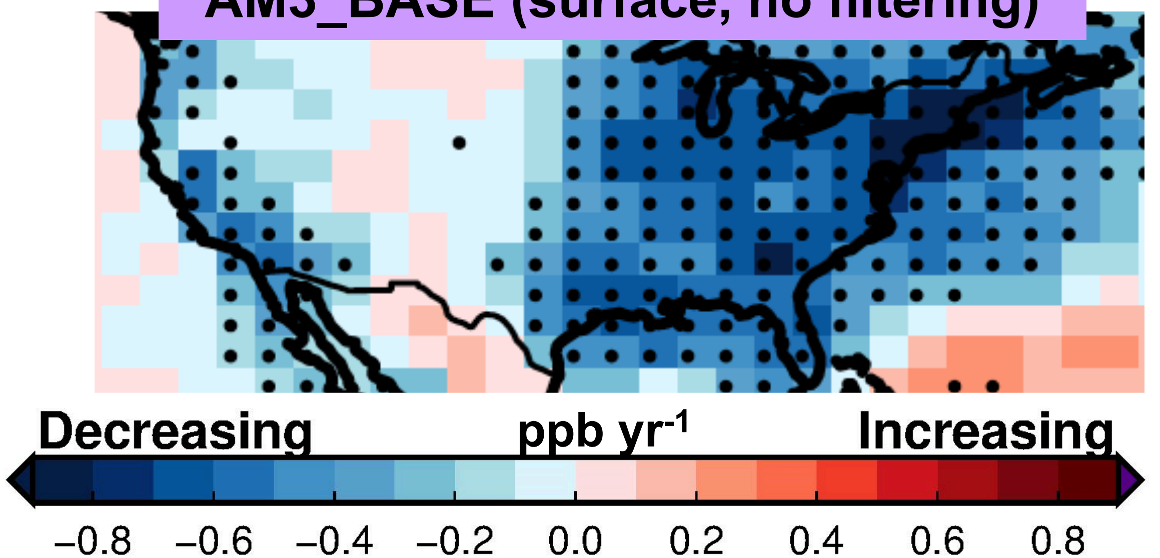
Figure 14 from Lin et al. [ACP, 2017]

SUMMER US surface O_3 trends over 1988-2014

OBS **AM3_BASE** (Baseline filtering for WUS)

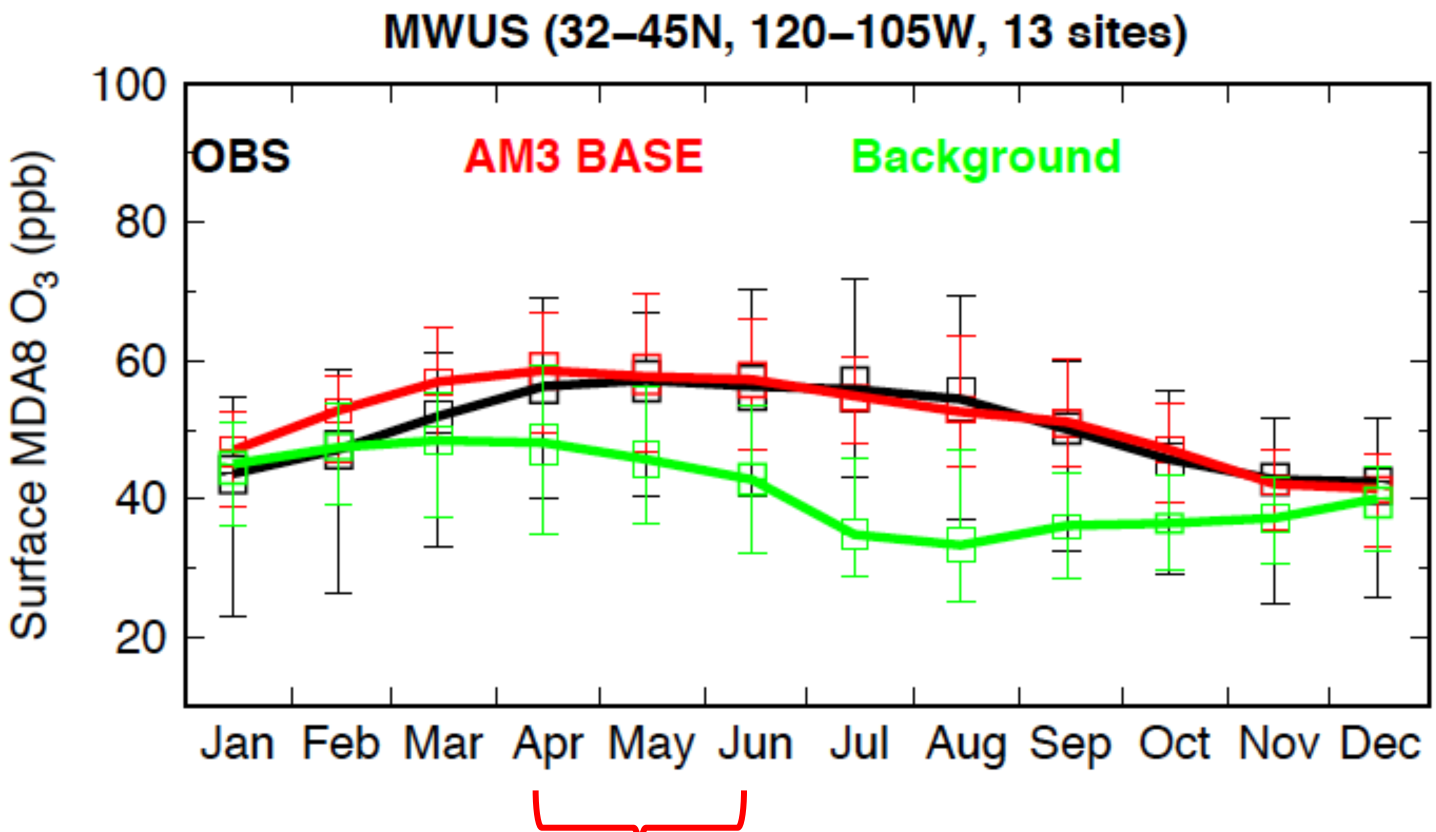


AM3_BASE (surface, no filtering)



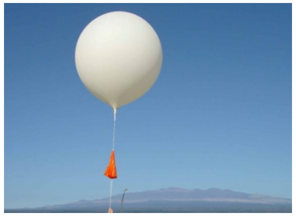
Figures 4 and 8 from Lin et al. [ACP, 2017]

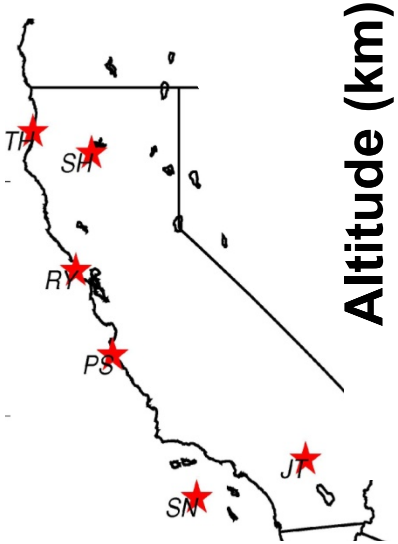
Why does AM3 in Lin et al. (2012, 2015) show smaller biases than in Fiore et al. (2014)?

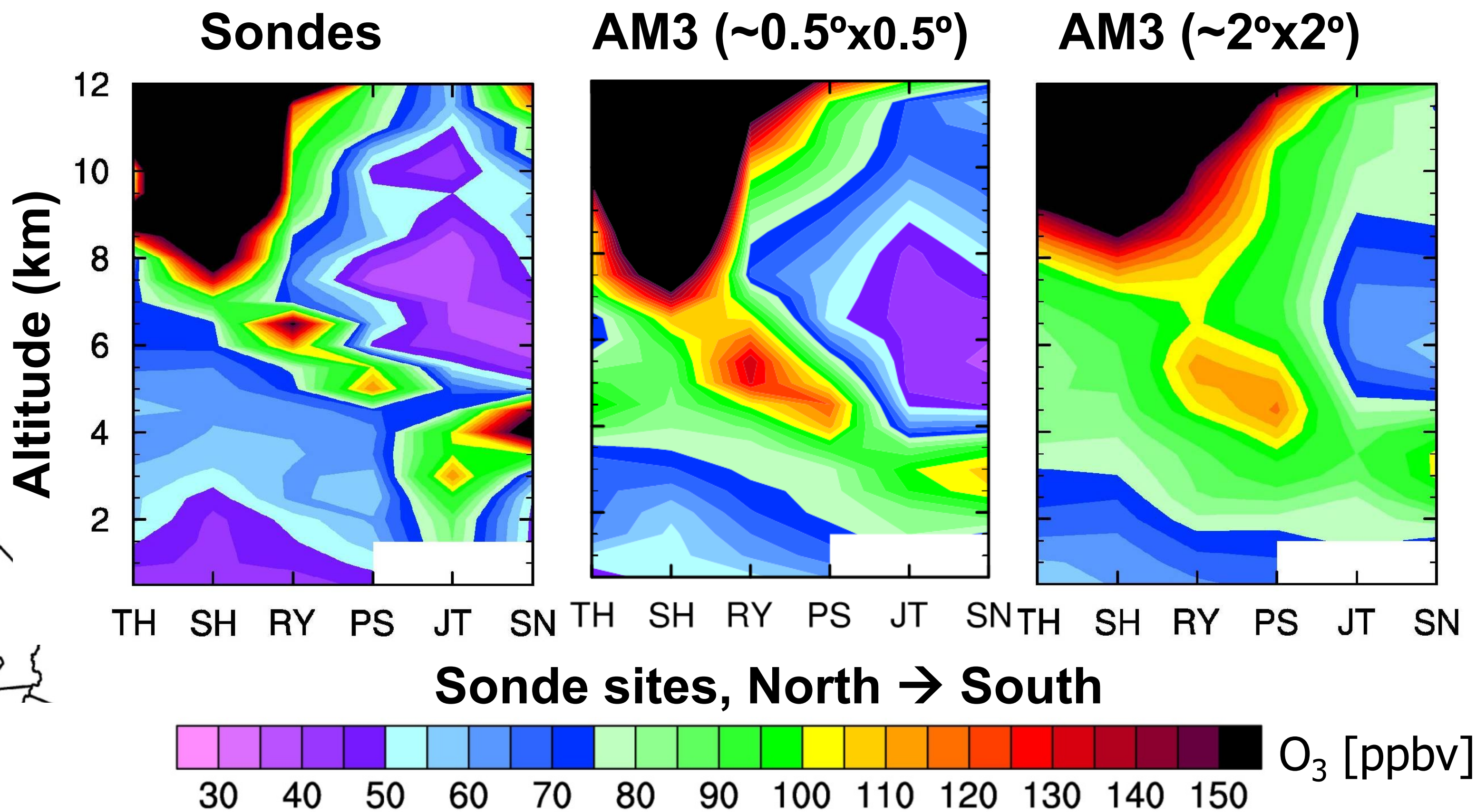


- → Lin et al. focus on late spring (April to early June) when the model has better skills in representing deep mixed layers
- → Higher resolution (Lin et al. 2012a,b), greater skills in representing observations at high end
- → FIXEMIS simulation in Lin et al. (2015a) applies the 1970-2010 climatological mean emissions
- → Differences in wildfire emissions may also contribute

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



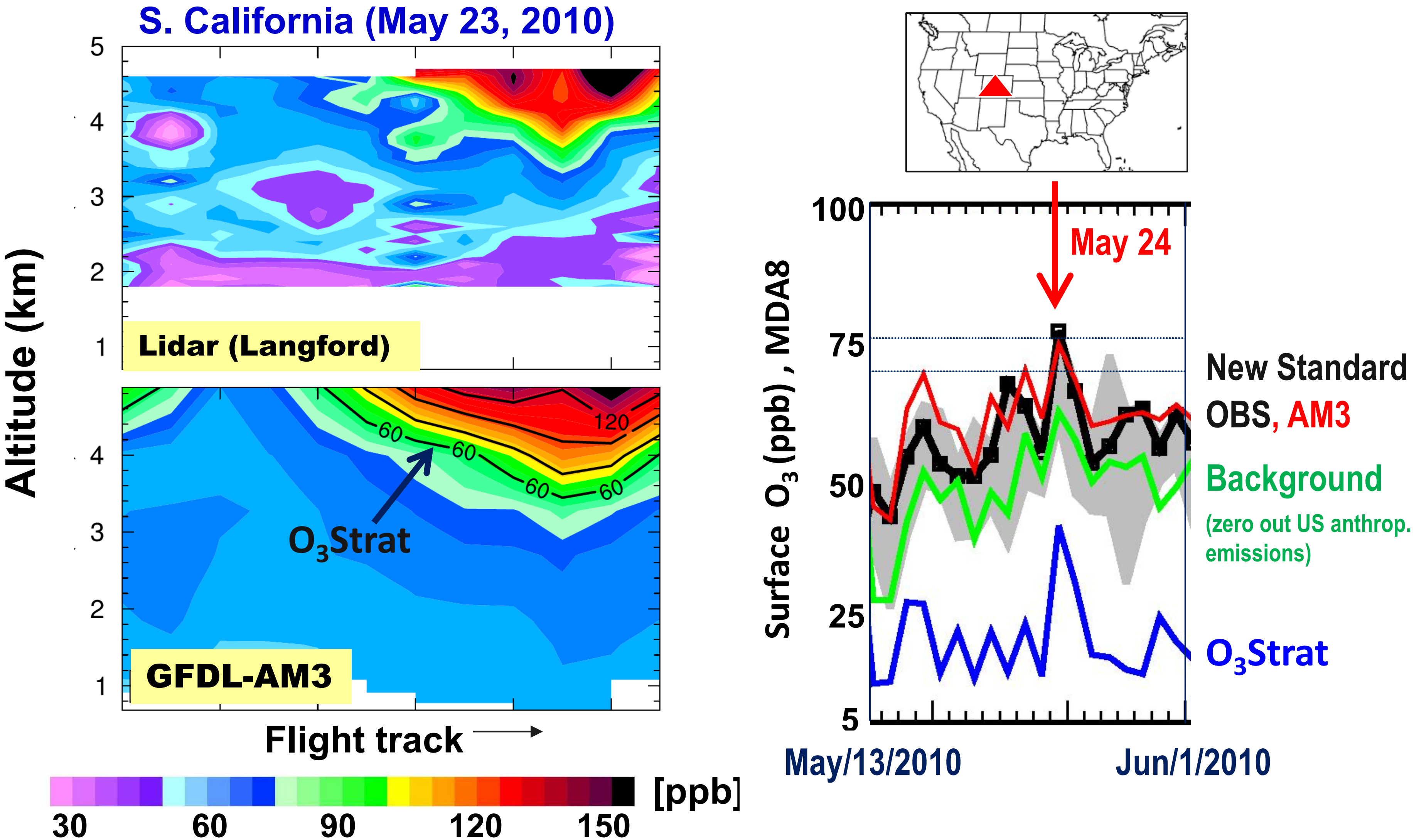




- 0.5° model better captures vertical structure
- 2° model reproduces the large-scale view

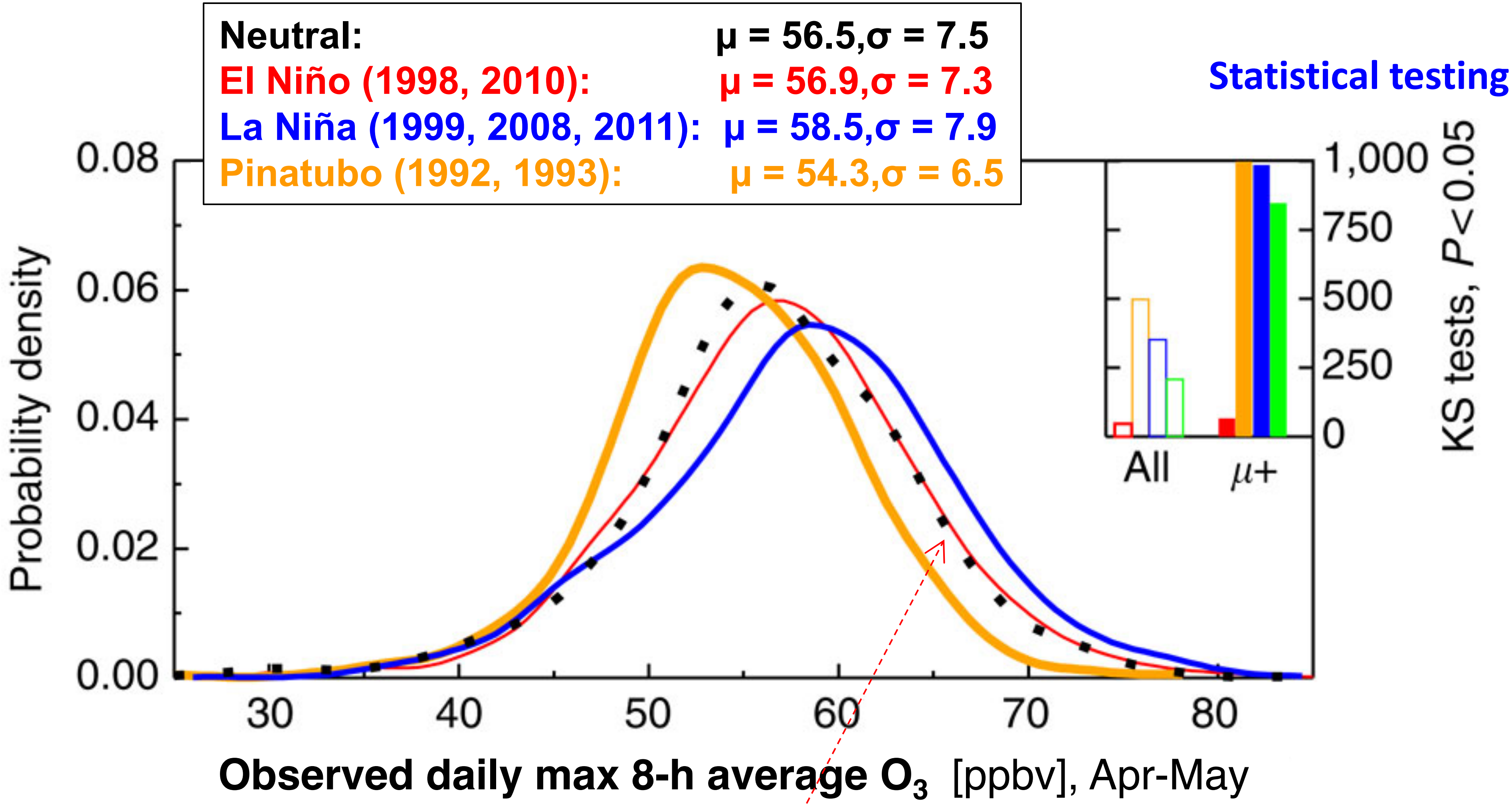
Lin MY et al (JGR, 2012b): *Springtime high surface ozone events over the WUS …*

GFDL-AM3 model captures observed deep stratospheric intrusions over WUS



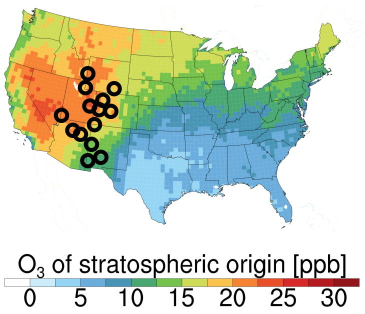
Lin M.Y. et al (JGR, 2012b), Springtime high surface ozone events over the WUS: Quantifying the role of stratospheric intrusions

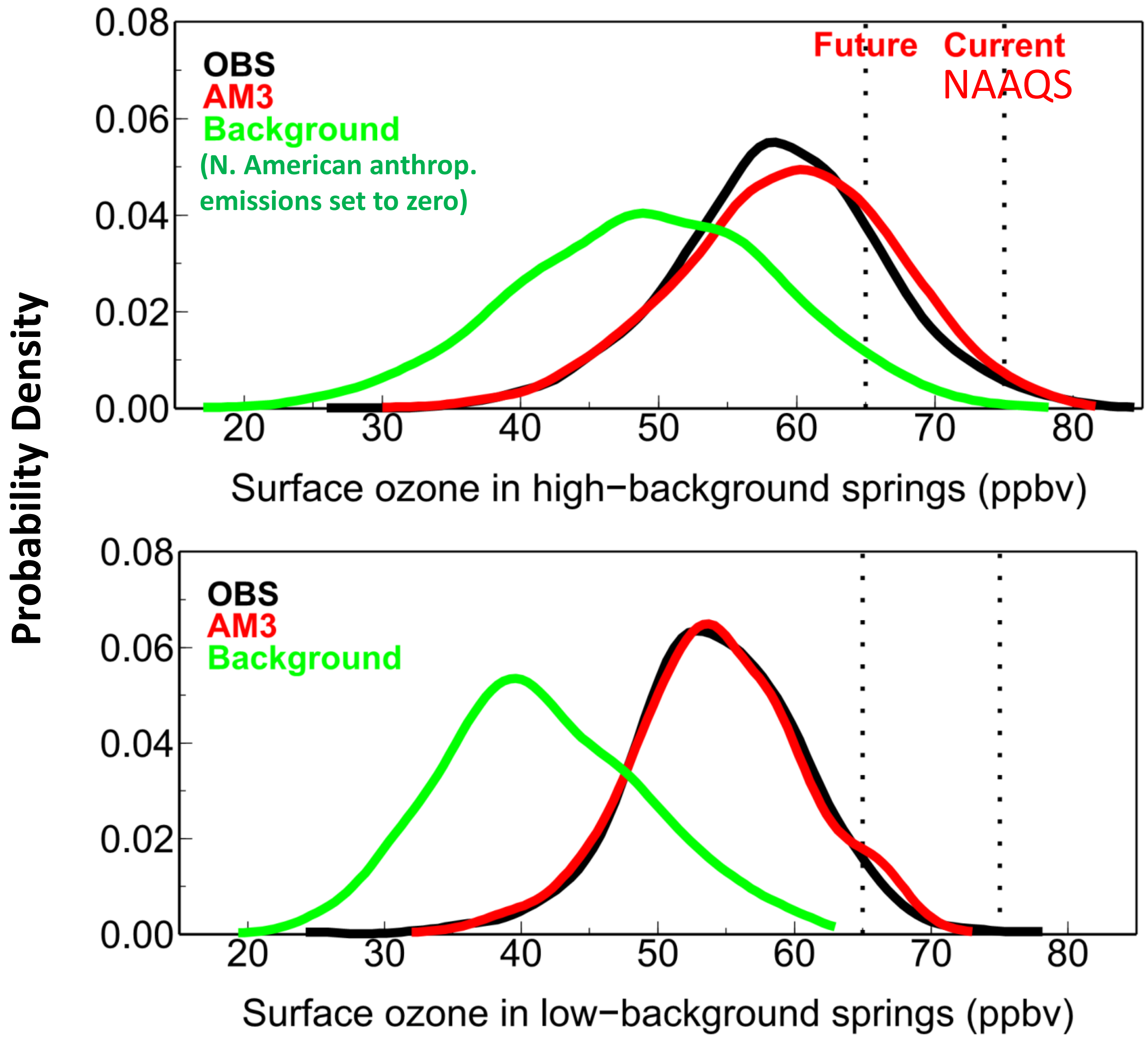
Observed changes in surface O_3 distribution, particularly in the upper tail



- **Little change in WUS surface air during El Niño despite increased UTLS O_3 burdens reported previously** [e.g. Langford1998; Bronnimann2004; Neu2014].

Surface O_3 distribution in high vs low background springs



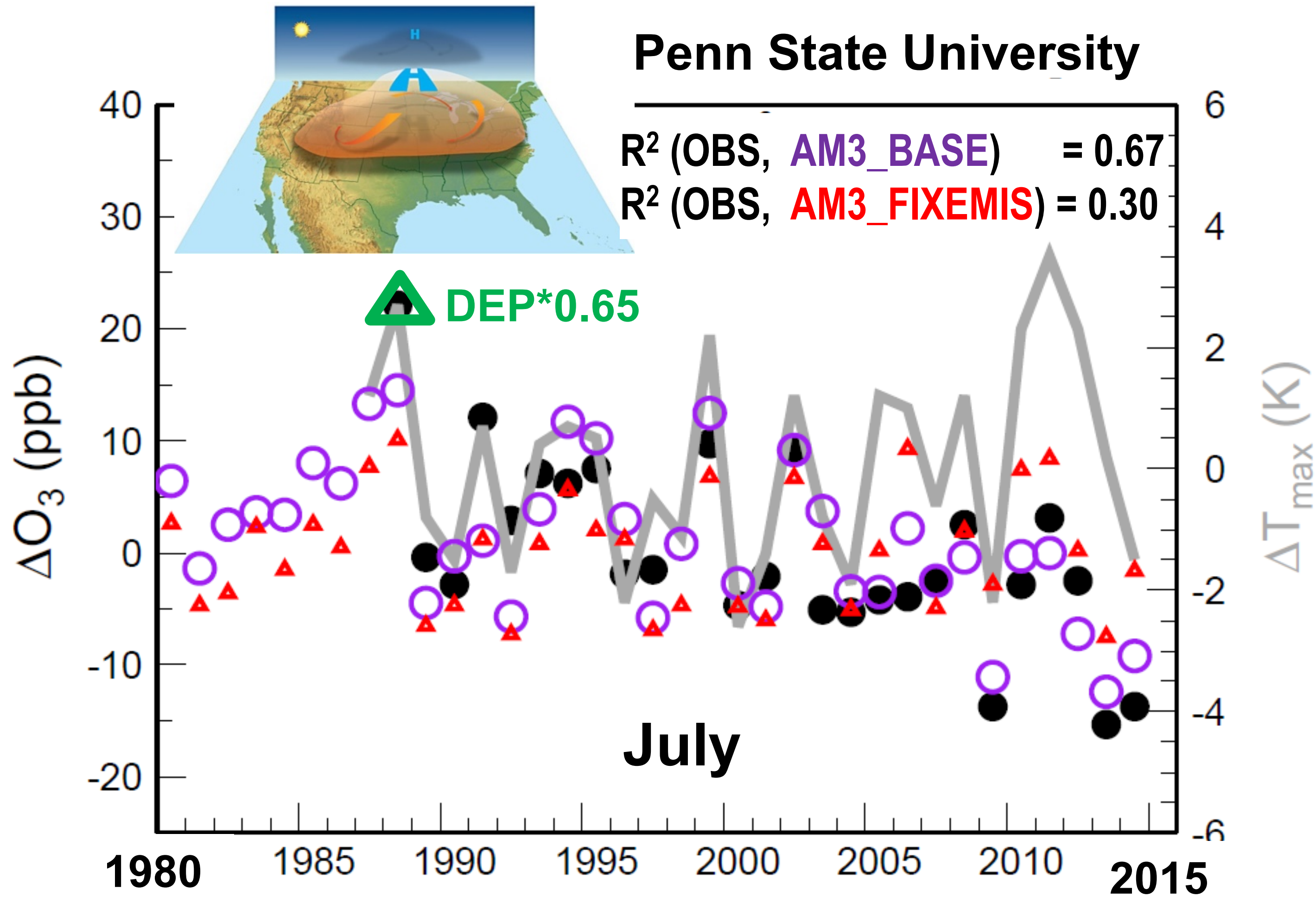


1991
1999
2008
2011
2012

1992
1993

Meiyun Lin et al. (Nature Communications, 2015)

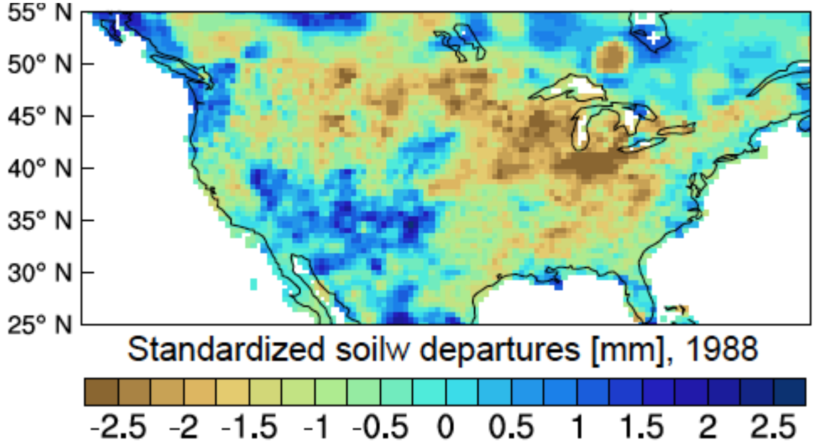
GFDL-AM3 captures interannual variability of O_3 anomalies associated with high temperatures

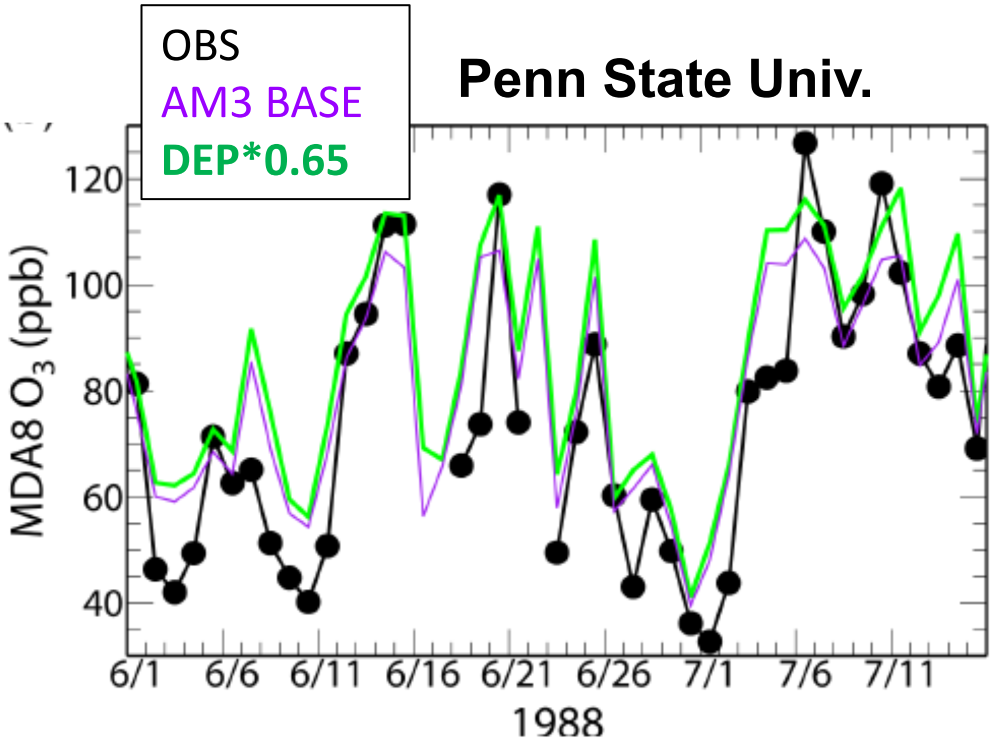


→ **But O_3 deposition sink to vegetation must be reduced by 35% to match the observed anomaly during the severe drought of 1988**

Meiyun Lin et al. [ACP, 2017]

Influence of droughts on ozone removal

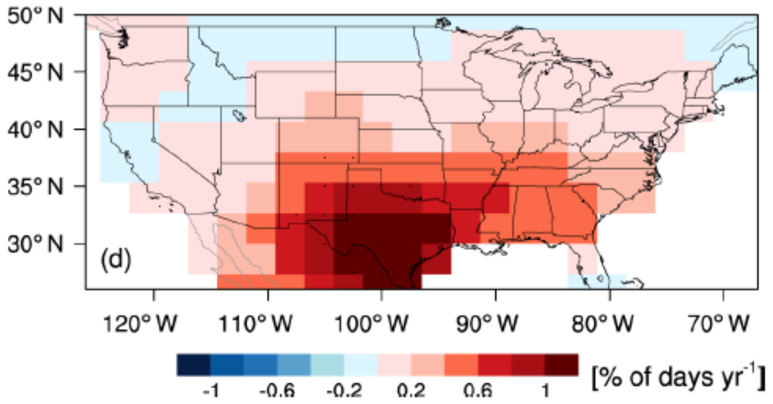




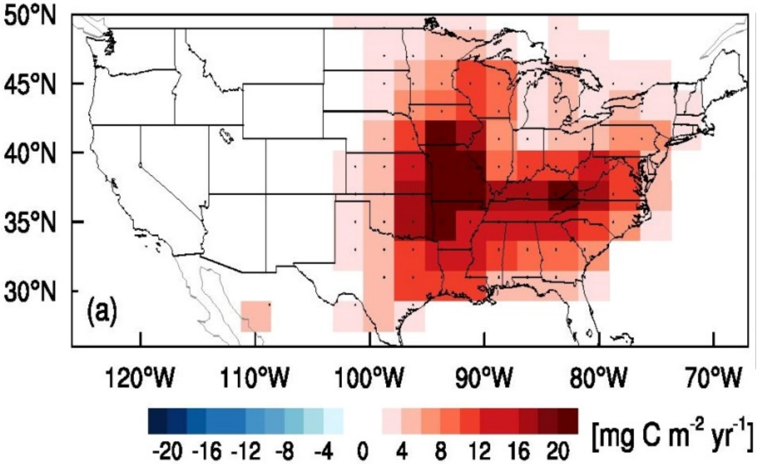
- → Reduced stomatal uptake under drought stress
- → Influence the highest ozone events
- → Model challenges in simulating such land-biosphere couplings (not represented in the Wesley scheme)

If NOx emissions had not declined, more frequent hot extremes since 1990 would have worsened the highest O_3 events over EUS

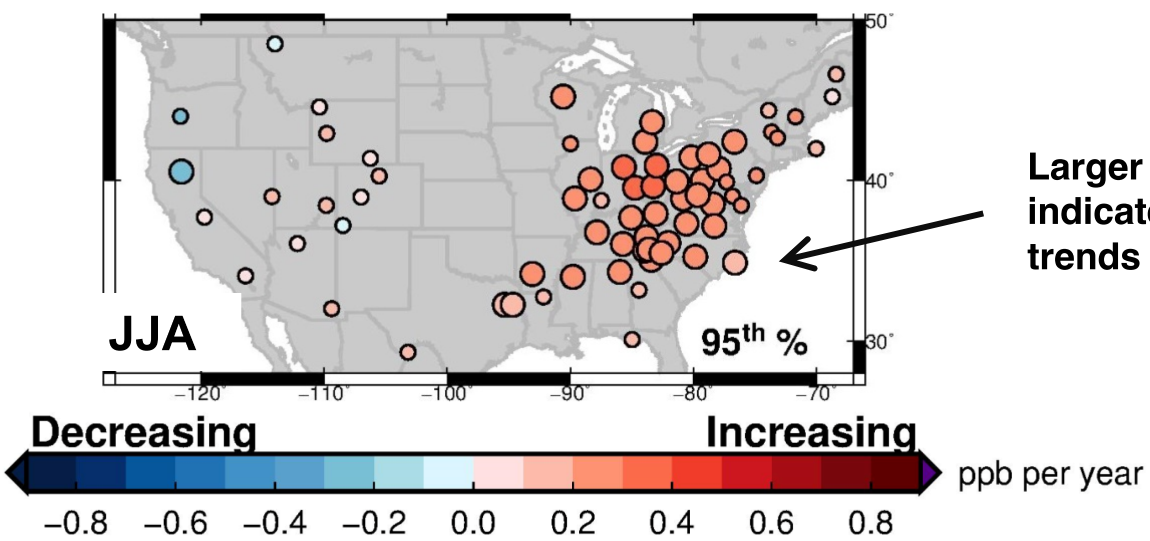
1990-2012 trend in the frequency of warm days (above the 90th percentile for 1961-1990 base)



1990-2012 trend in biogenic isoprene emissions



95th percentile MDA8 O_3 trend in AM3_FIXEMIS



Larger circles indicate significant trends ($p<0.05$)

***Meiyun Lin et al.* [ACP, 2017]**