Invited talk at AIRS Spring Science Team Meeting (21-April-2015)

Challenges in quantifying sources and variability of lower tropospheric ozone over western N. America: Perspectives from satellites and models

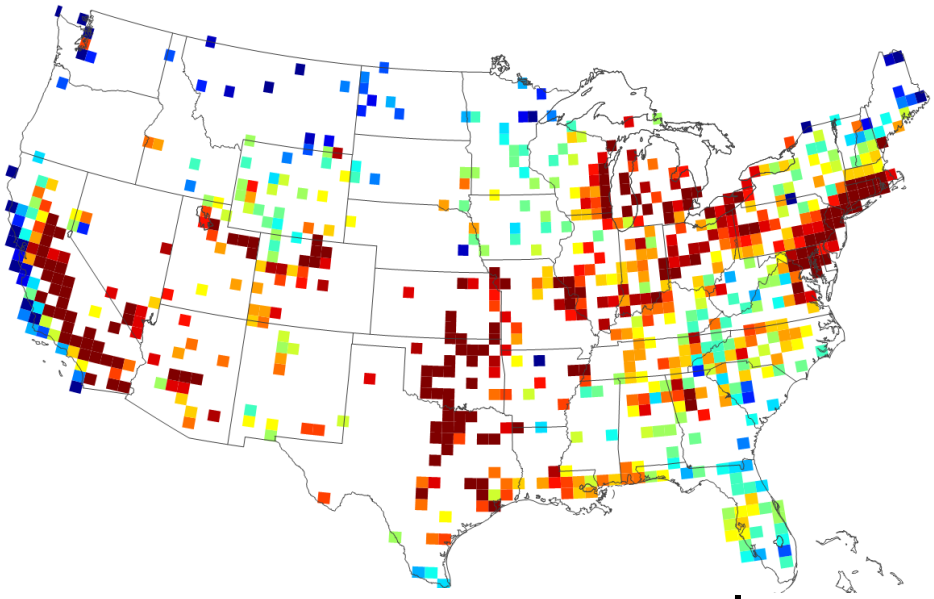
Meiyun Lin

(Princeton Univ & NOAA GFDL)

Acknowledgements: L.W. Horowitz (*NOAA GFDL*), **A.M. Fiore** (*Columbia/LDEO*), **O.R. Cooper** (*NOAA ESRL*), **A.O. Langford** (*NOAA ESRL*), **S. J. Oltmans** (*NOAA ESRL*), **Harald Rieder** (*Univ of Graz-Austria*), **AIRS Science Team: Juying Warner** (*Univ of Maryland*), **Laura Pan** (*NCAR*) …

Geophysical Fluid Dynamics Laboratory

Major challenges for Western U.S. air quality management

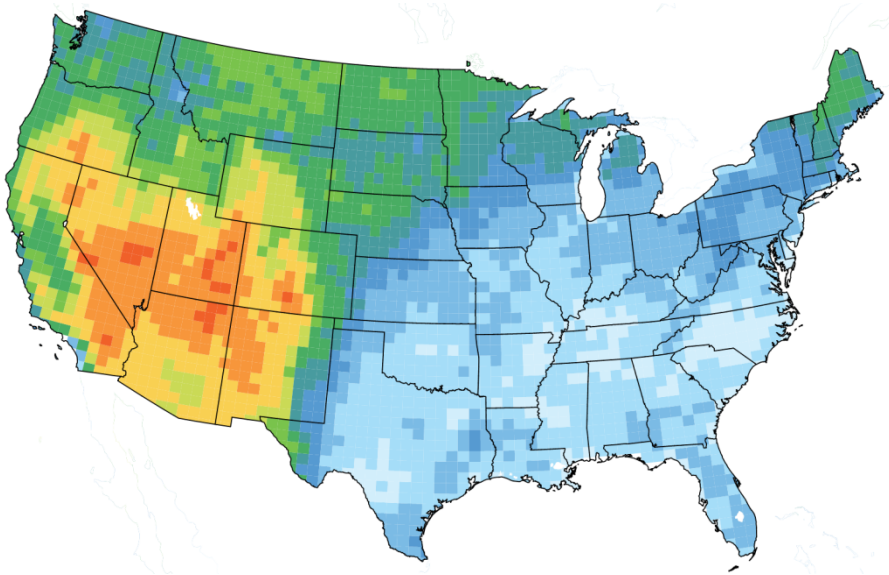


Annual 4th Hi MDA8 O_3
(2011-2013 AQS)

55 60 65 70 75 ppb

Current NAAQS

Future NAAQS?



Mean background, Apr-Jun
NA anthrop emis off in GFDL AM3 (~0.5°x0.5°)

30 35 40 45 50 55 60 65 ppb

MAJOR CHALLENGES:

-Rising Asian emissions and global CH_4

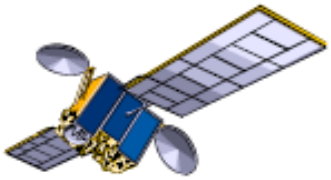
-More frequent wildfires in summer

-Frequency of stratospheric intrusions (STT) in spring

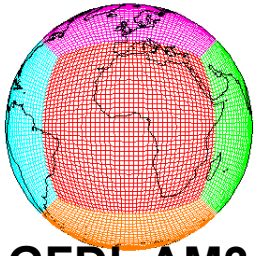
uncontrollable "exceptional events"

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

Addressing the challenges:
How can NASA satellites help?

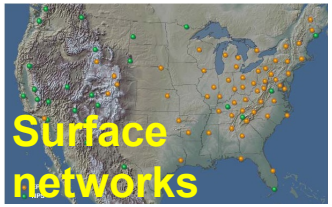


Satellites



GFDL AM3

In situ



Surface networks

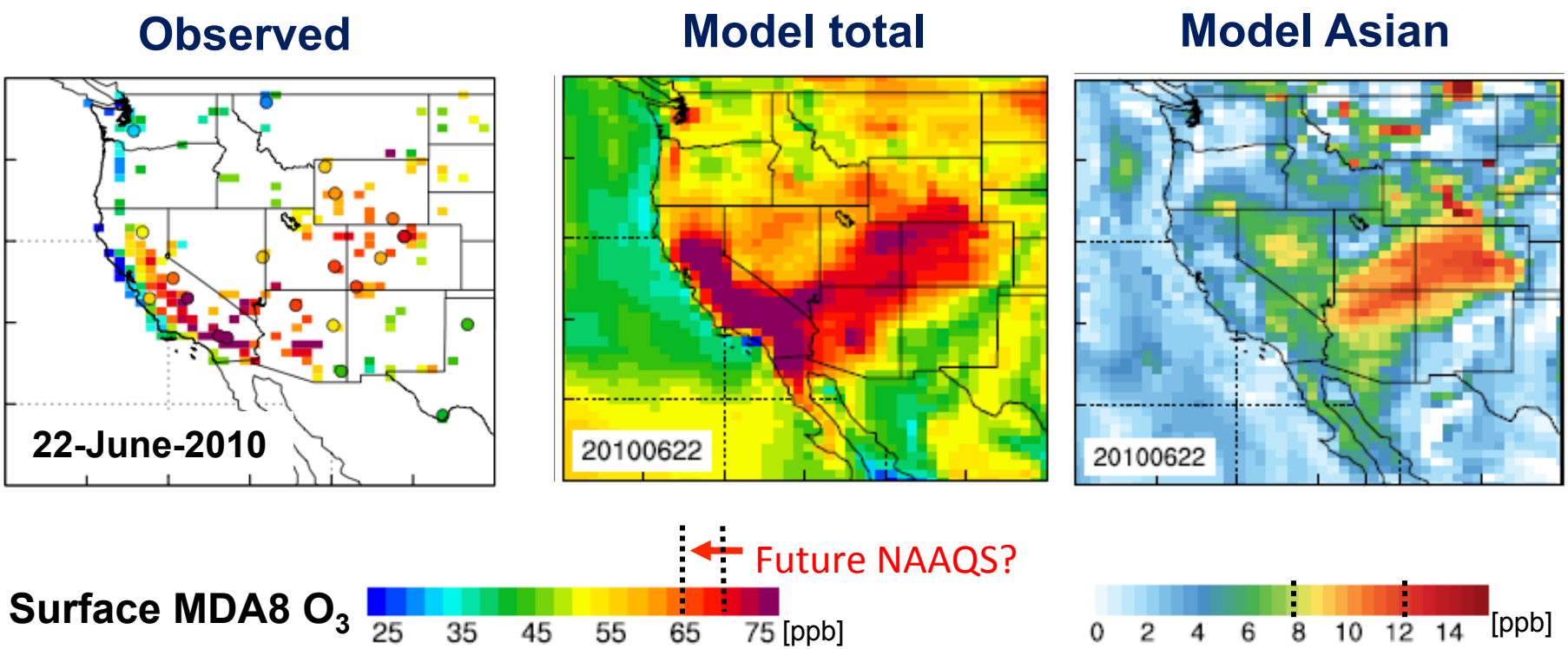
- Capture variability in chemical composition associated with synoptic-scale weather patterns
- Vast spatial coverage at near-daily intervals (e.g. AIRS, OMI, IASI)
- **BUT** very little vertical information (CO & O_3); Lack of sensitivity in the lower troposphere

Today's talk

Upper-level info from space → **?** → **Downwind surface influence**

Daily
Inter-annual

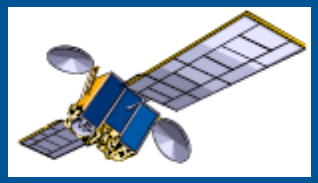
Asian pollution contribution to WUS high-O_3 events



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

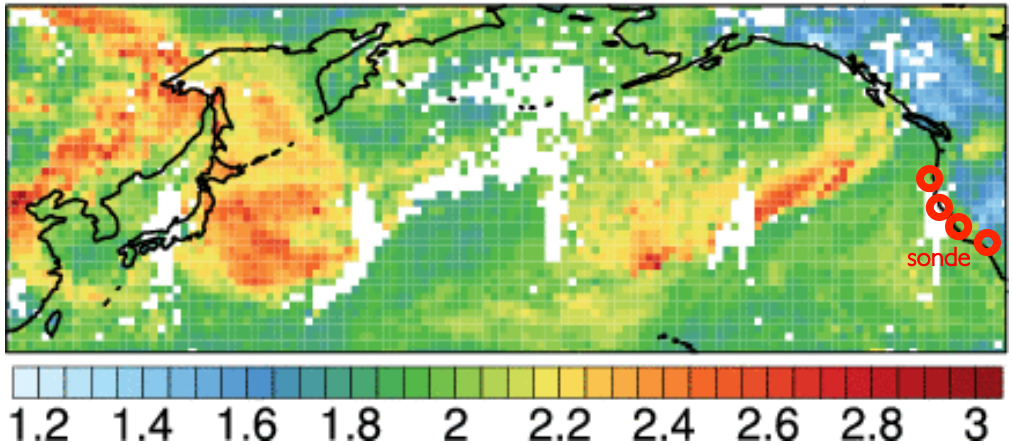
→ How can AQ managers identify such events?

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



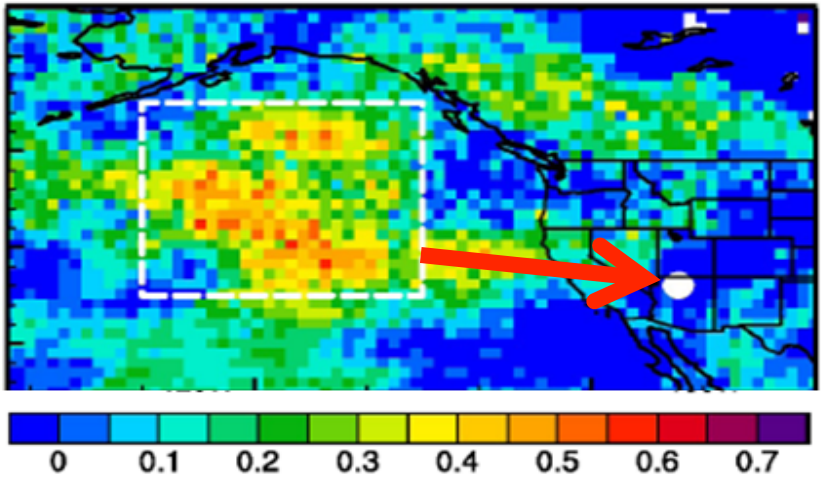
Asian pollution "forecasting" with daily AIRS CO data

20100612



Animation of daily AIRS CO columns [10^{18} molecules cm^{-2}]

May-June 2010



Correlation coefficient (*r*)

model Asian O_3 at Grand Canyon
AIRS CO columns 2 days prior

Why CO?

→ Indicate potential downwind influence
→ Data assimilation to improve forecasts
→ Daily exceedance attributions (qualitatively)
→ Quantitative estimates require models

Meiyun Lin *et al.* [JGR, 2012a]: Transport of Asian O_3 pollution into surface air over the WUS in spring
Publicity: AGU Editors' Highlight, *Nature News*, *ScienceShot*)

NATURE | NEWS

Emissions from Asia put US cities over the ozone limit

Satellite data could warn of incoming air pollution.

Katherine Rowland

05 March 2012

Rights & Permissions

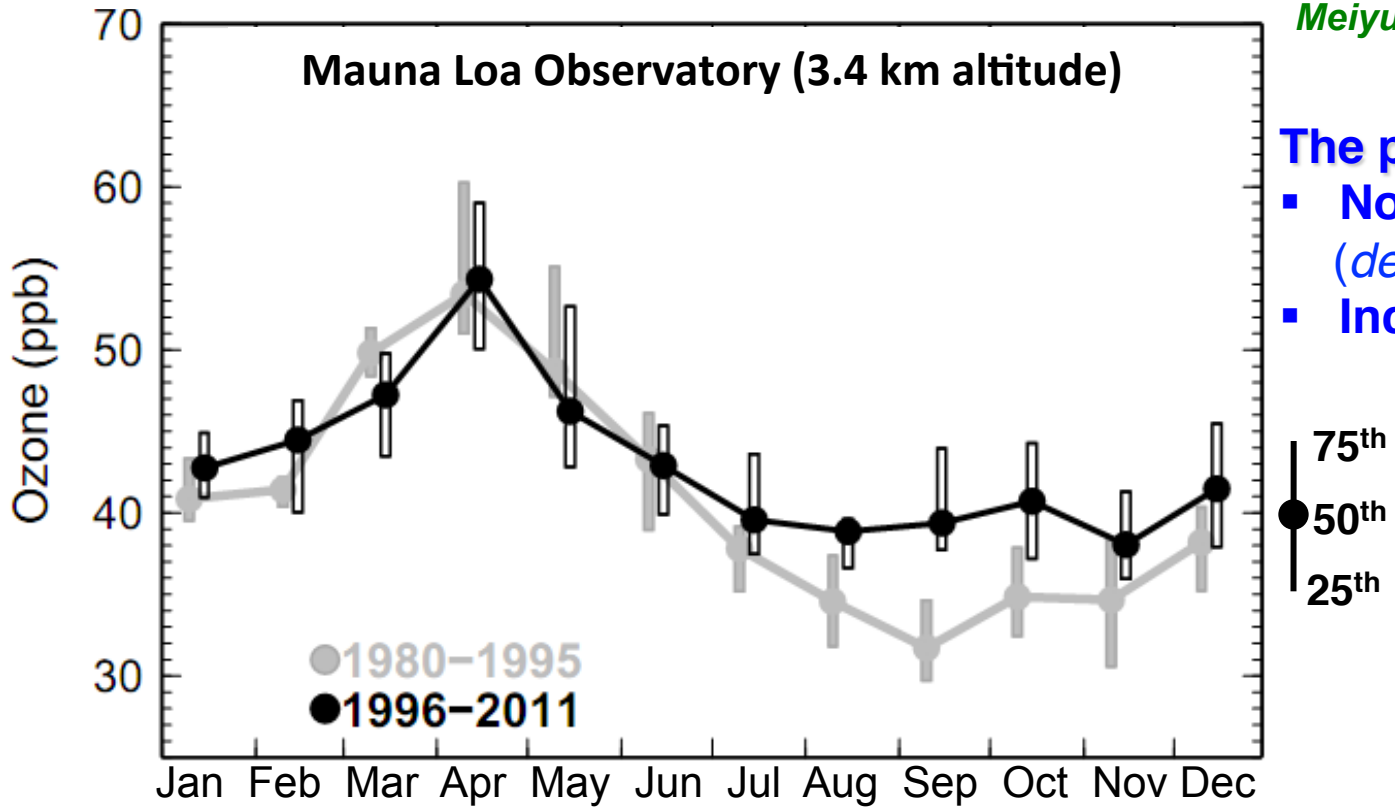
As plumes of pollution rise over the booming industrial towns of Asia, satellite data could help to alert people in other regions to the approach of drifting smog.

Top story

nature geoscience

Tropospheric ozone trends at Mauna Loa Observatory tied to decadal climate variability

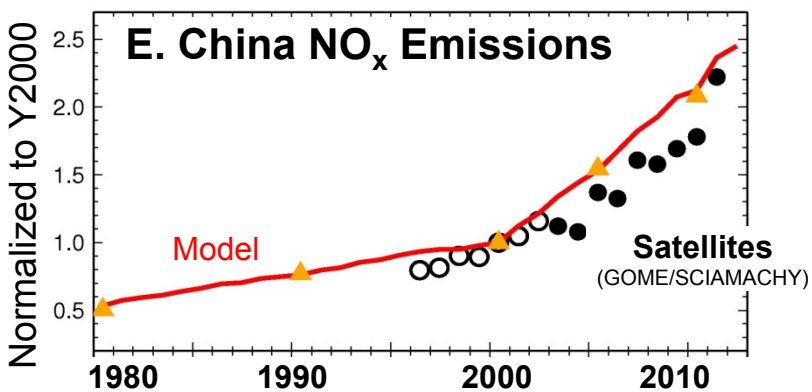
Meiyun Lin et al (2014)

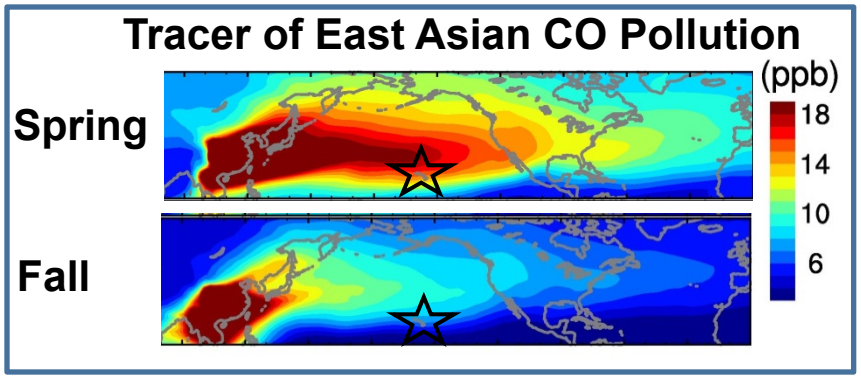


The puzzle:

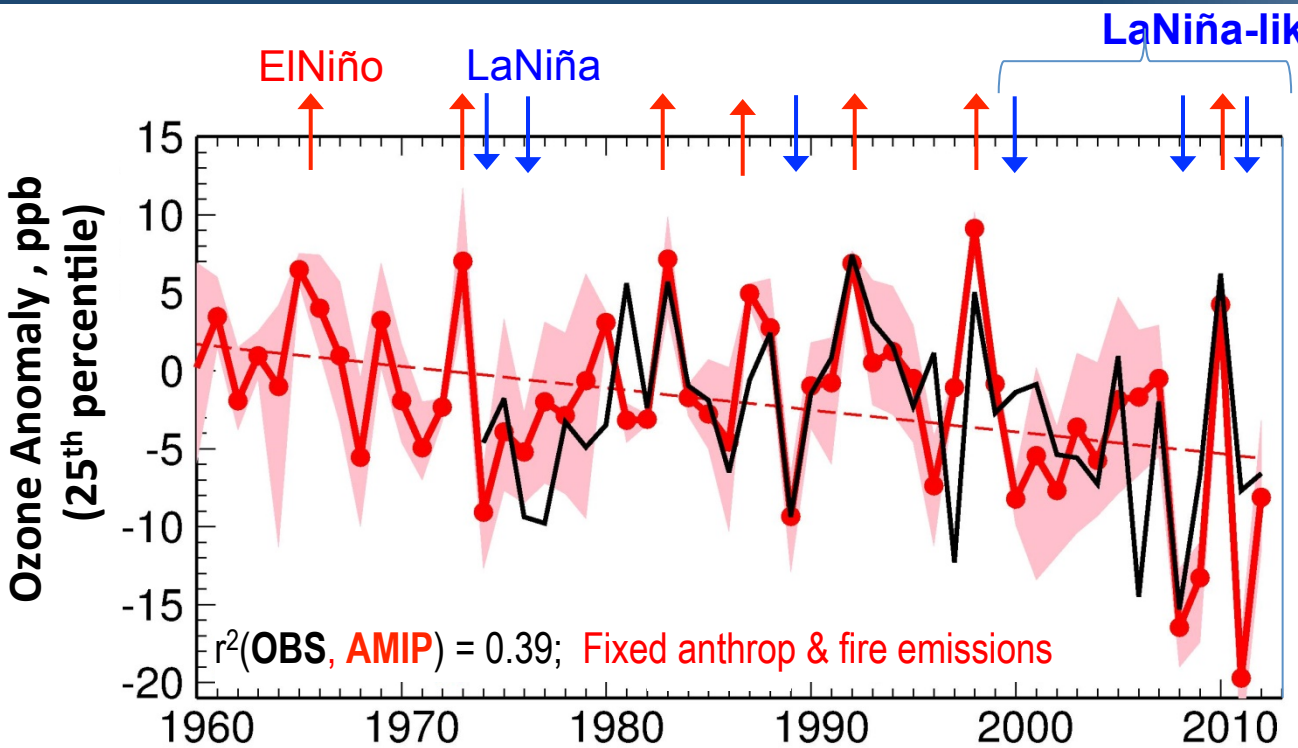
- **No trend in spring** (*decrease in 25th*)
- **Increase in fall**

75th
50th
25th

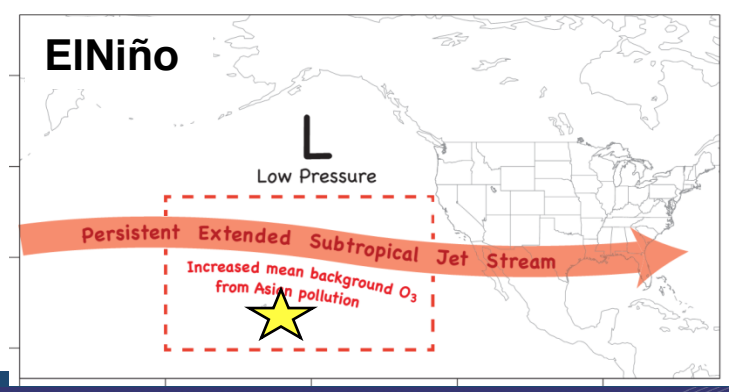


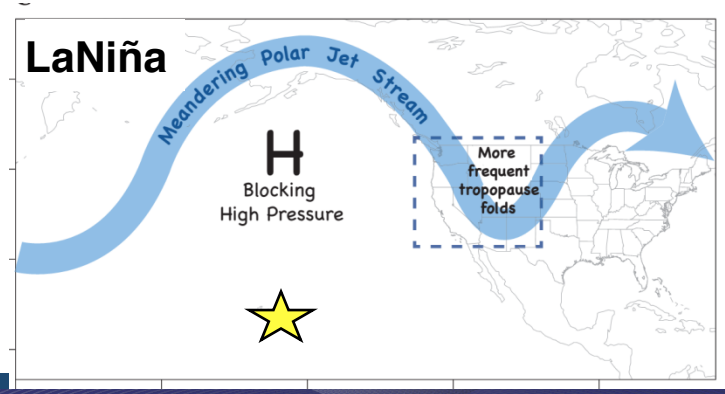


Springtime airflow from Eurasia towards the NE Pacific weakens in 2000s, offsetting rising O_3 from Asian emissions



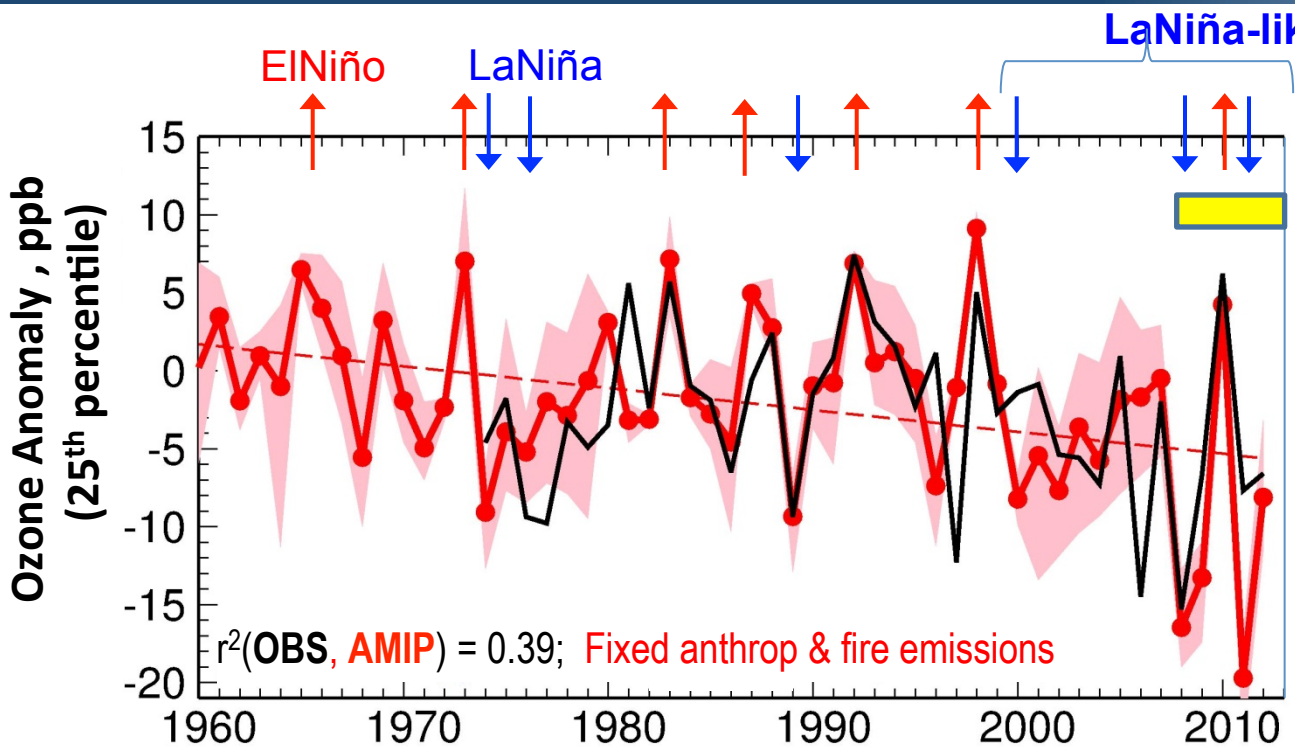
- Key role of circulation shifts
- Minor influence from fires

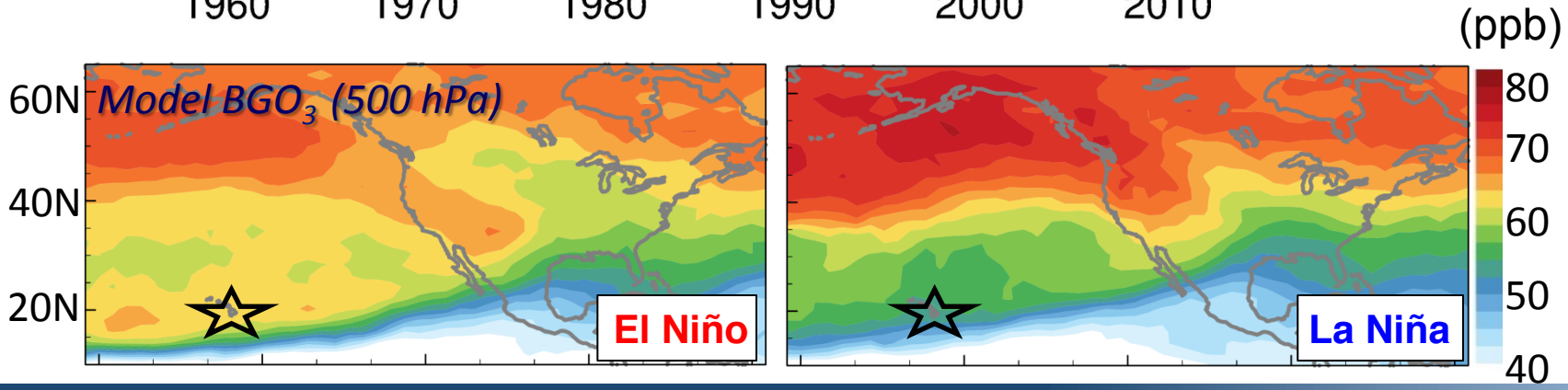




Meiyun Lin et al (Nature GeoSci., 2014)

Springtime airflow from Eurasia towards the NE Pacific weakens in 2000s, offsetting rising O_3 from Asian emissions

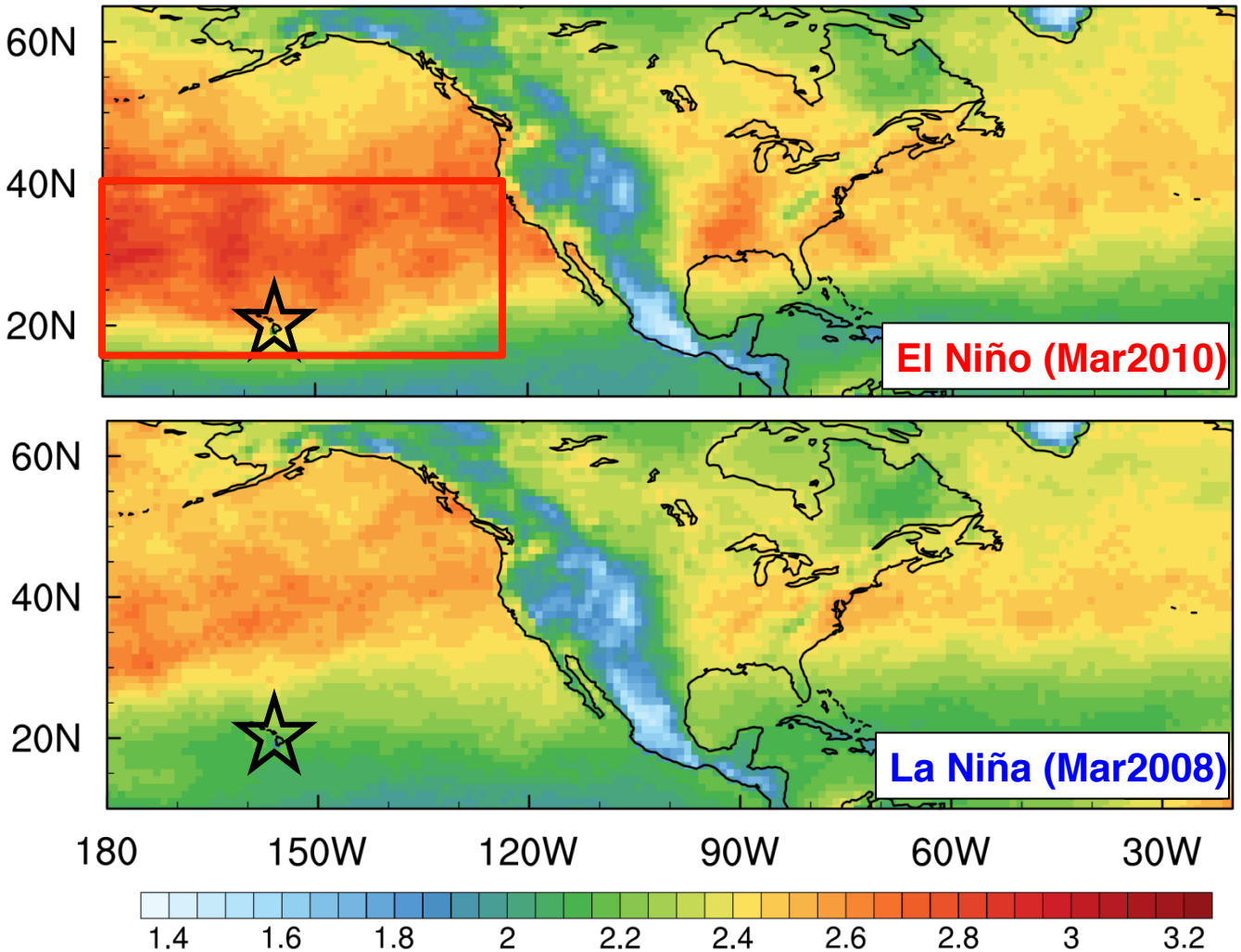




Meiyun Lin et al (Nature GeoSci., 2014)

satellites

ENSO-driven changes in the Asian pollution signal measured by AIRS CO



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

[**Data:** V6; AIRS Science Team/Joao Texeira 2013]

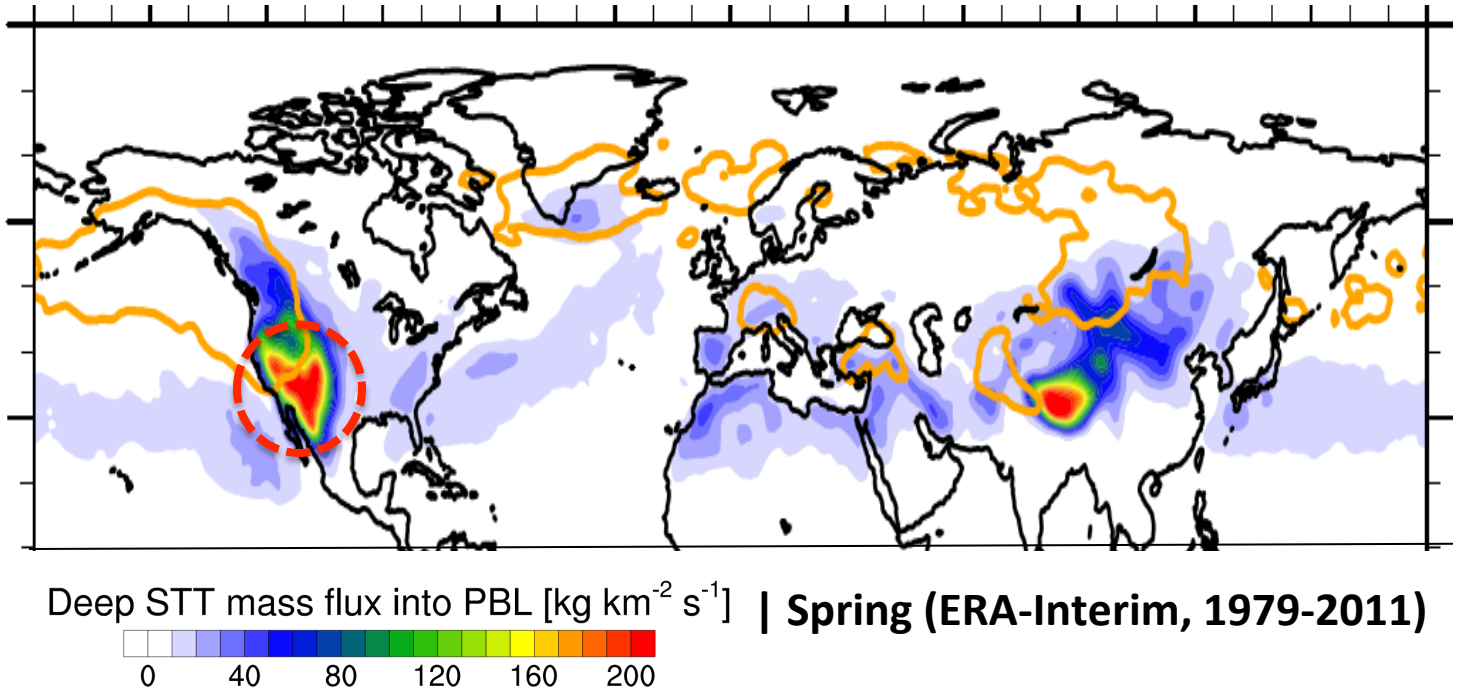
Rise in O_3 + CO

→ The subtropical jet shift modulates hemispheric pollution transport, rather than STT

Stratospheric O_3 intrusions (STT)

Southwest US is global hotspot for *deep* STT

(Proximity to N. Pacific storm track exit and high-elevation)



| Spring (ERA-Interim, 1979-2011)

B. Škerlak, M. Sprenger, and H. Wernli , ACP, 14, 913–937, 2014

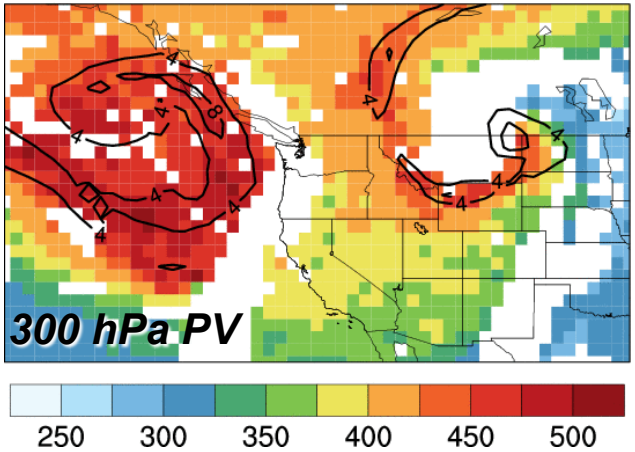
- **AIRS/IASI/OMI O_3 retrievals can capture upper-level dynamics conducive to stratospheric intrusions** [*Pan et al. 2007; Pittman et al., 2009; Wei et al., 2010*]

→ **Link to potential influence in the lower troposphere?**

AIRS column O_3 enhancements can indicate potential downwind surface influence

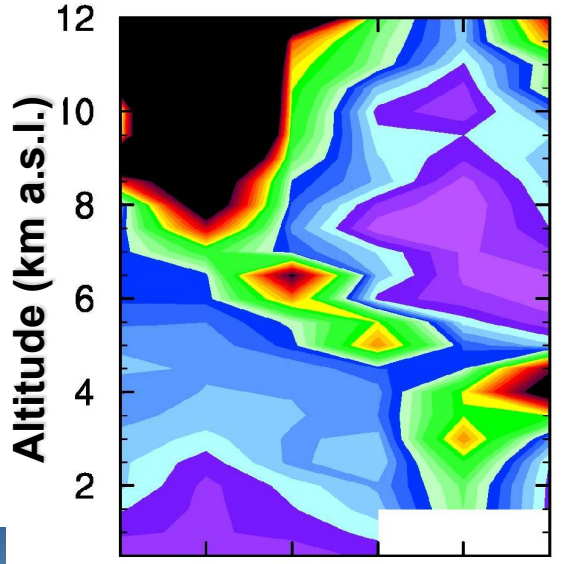
AIRS, May 25-29

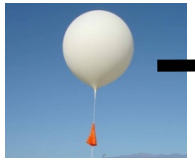
2010.05.25T01:30am



Total column O_3 [DU]

Sonde O_3, May 28

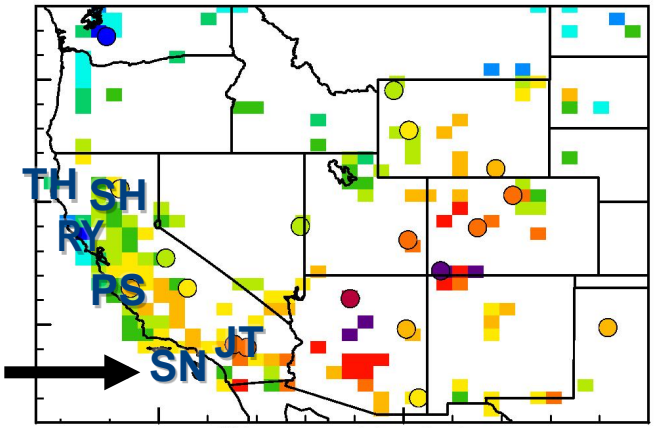




North → South

[ppb] 30 60 90 120 150

Surface O_3, May 29



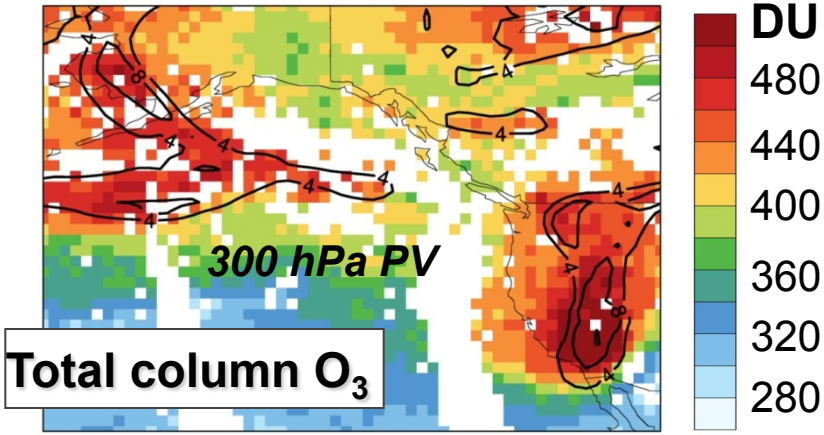
25 35 45 55 65 75

Daily max 8-hr O_3 [ppb]

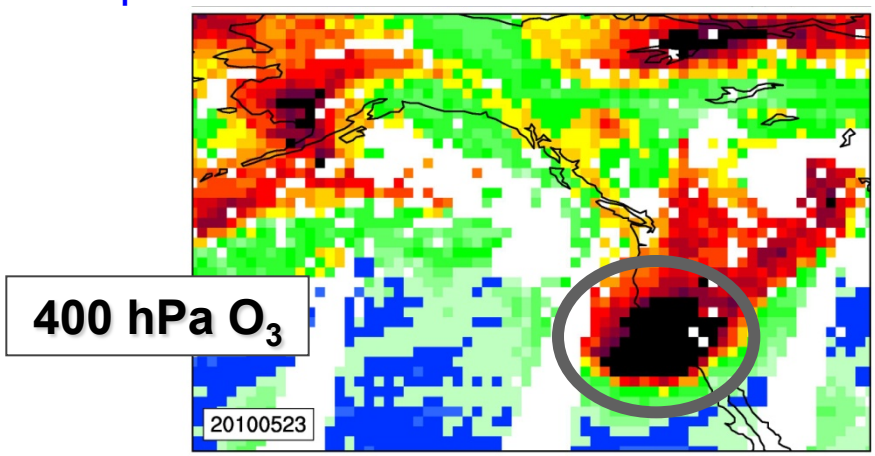
Meiyun Lin et al (JGR, 2012b): *Springtime high surface ozone events over the western United States: Quantifying the role of stratospheric intrusions*

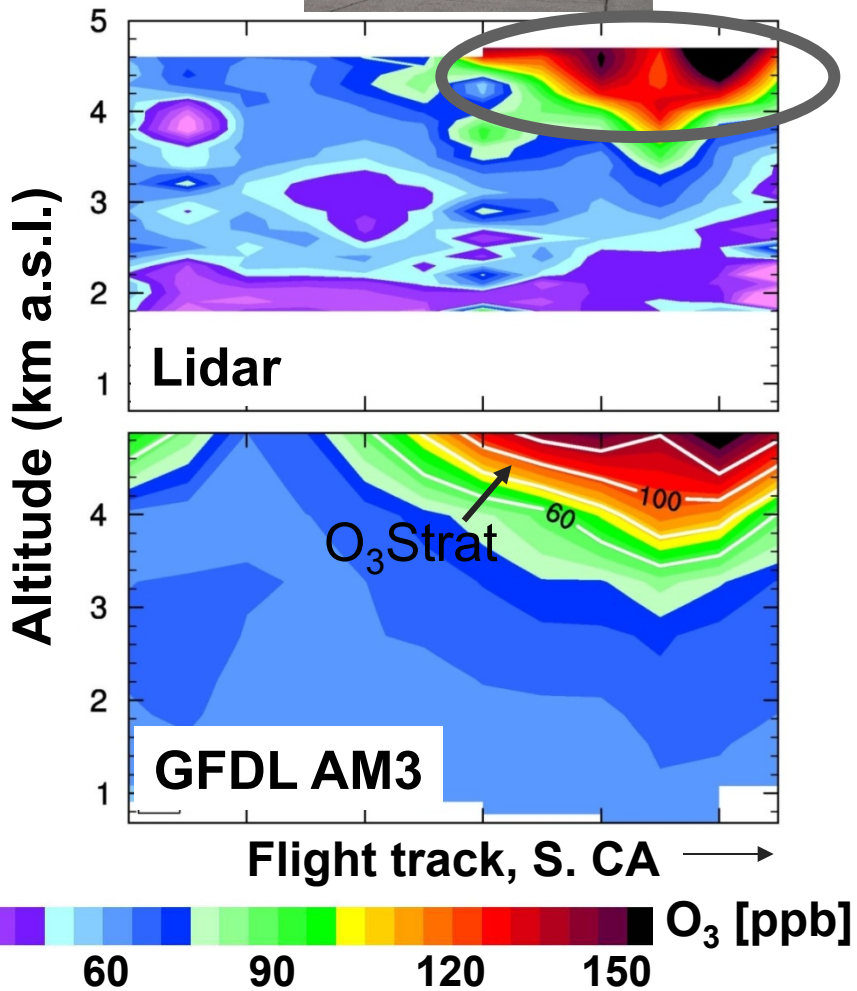
An unusually large tropopause fold over Southern California (May 23, 2010)

Aqua AIRS Ascending



V5 products

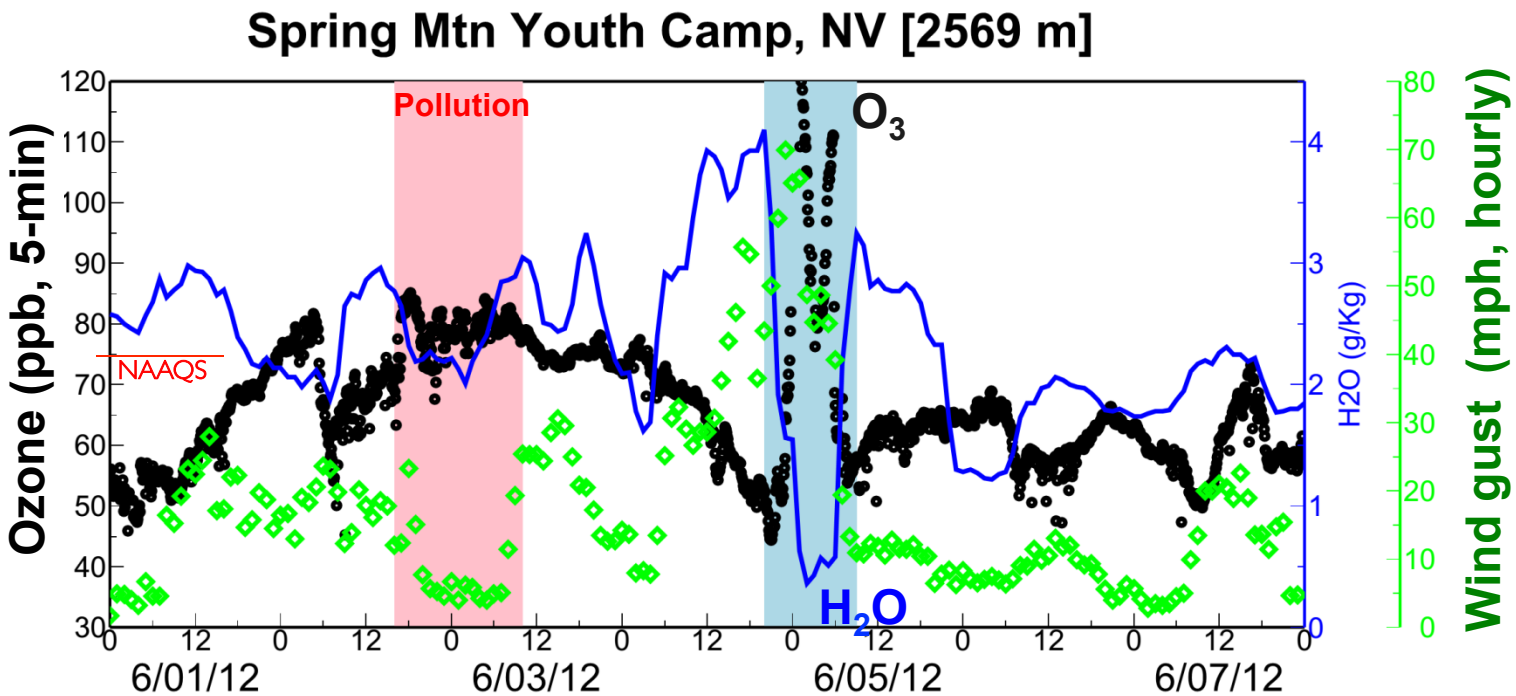


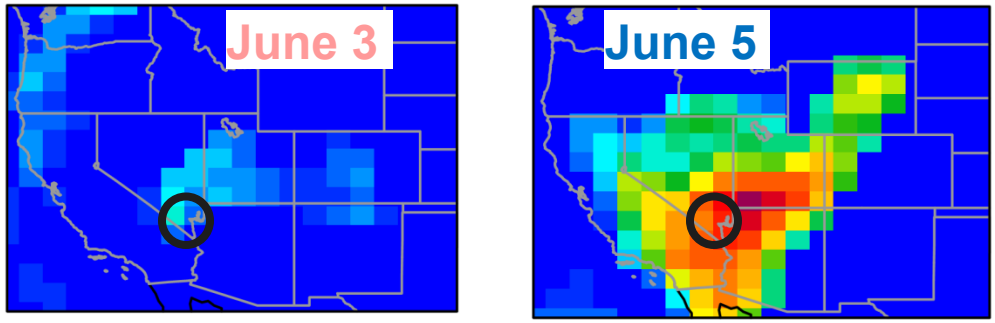


- Led to surface ozone exceedances in Colorado on the following day

Lin MY et al (JGR, 2012b): *Springtime high surface ozone events over the western United States: Quantifying the role of stratospheric intrusions*

Observed evidence of stratospheric O_3 impact on surface air quality





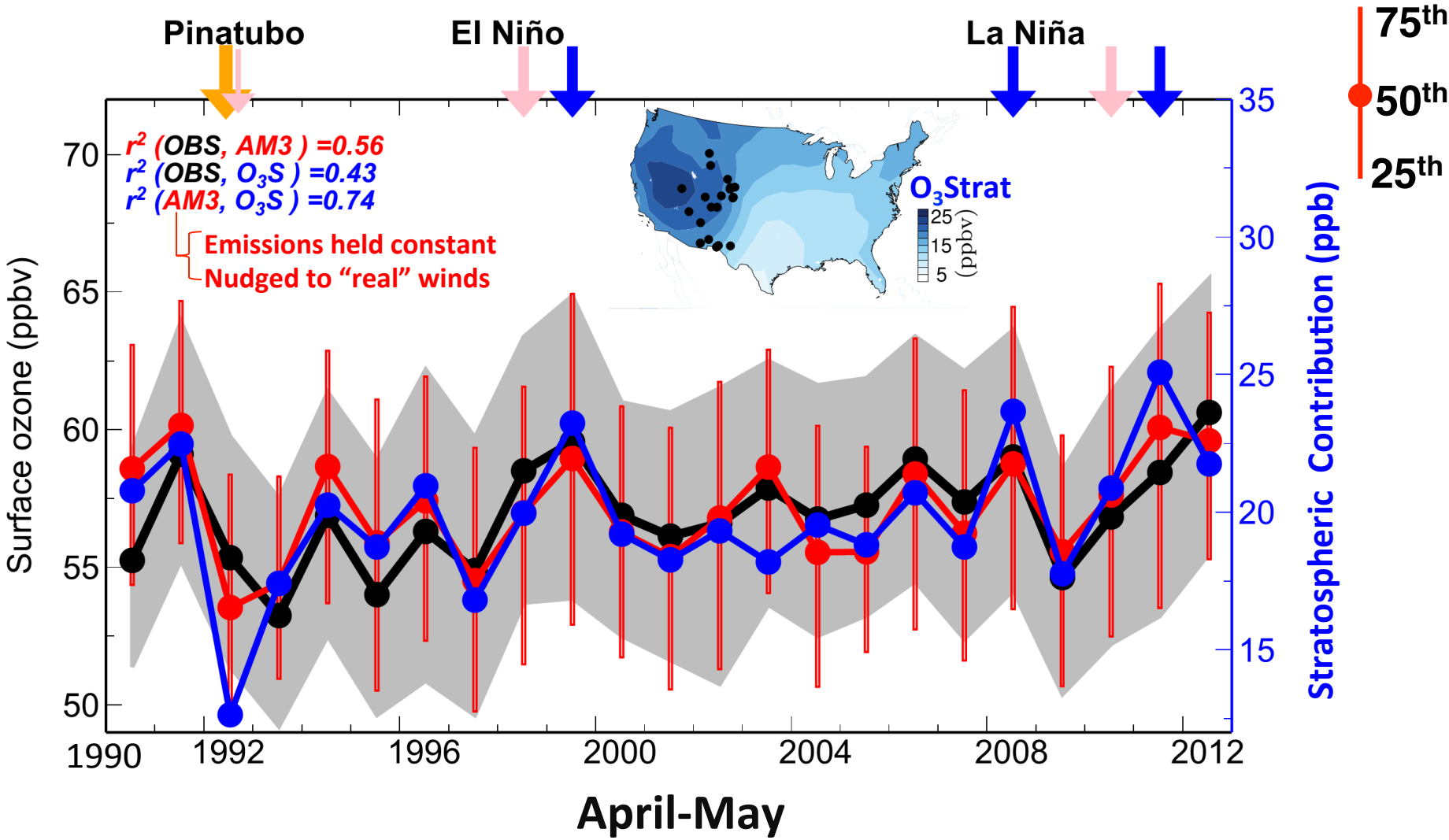
Data c/o Zheng Li (Nevada DAQ)
Lin MY et al (in prep, 2015)

Model O_3Strat (ppb, 8-h average)
Baseline level (~20 ppb) likely represents an upper limit.

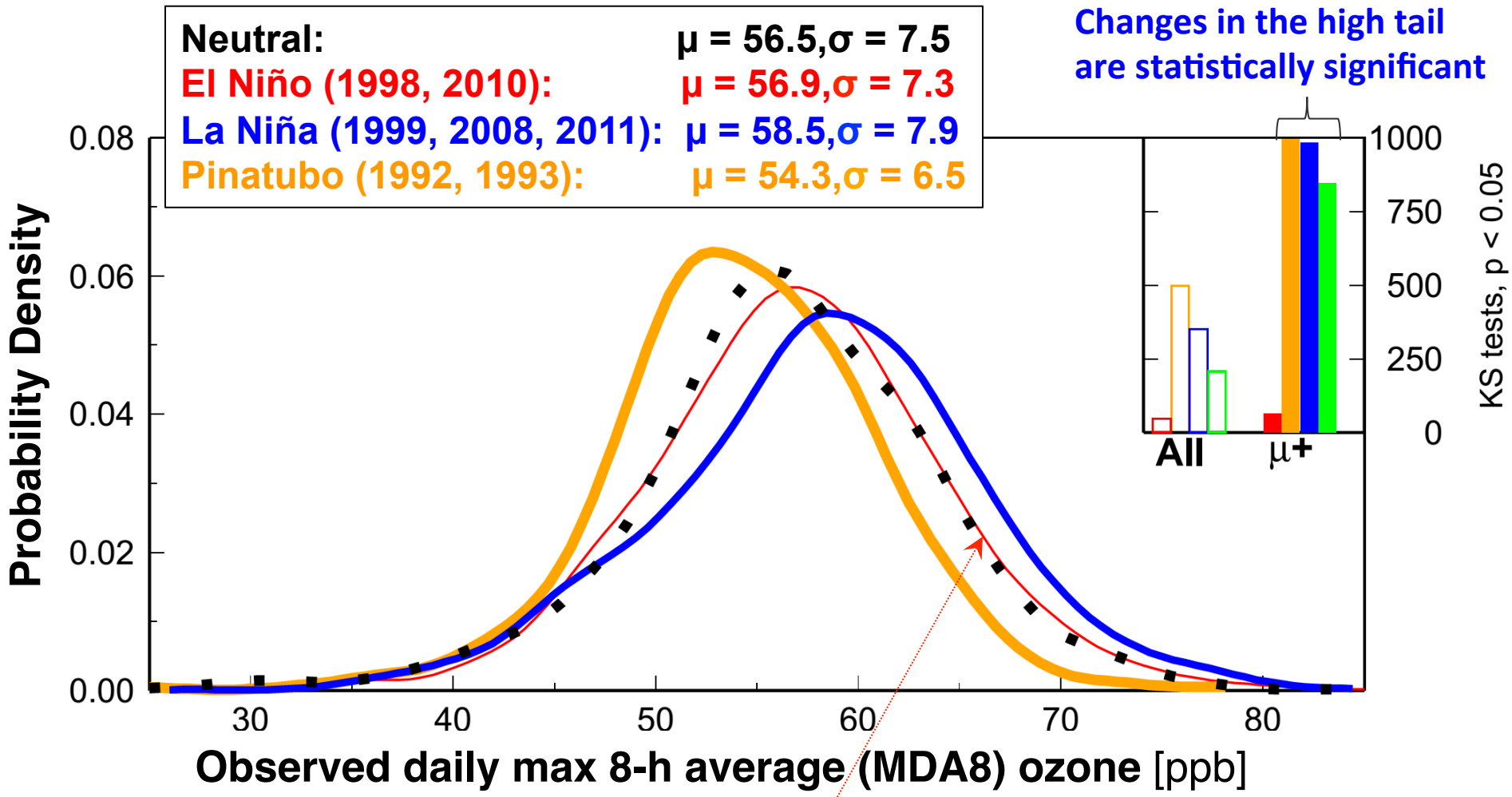
➢ **How do such intrusion events vary from year to year?**

nature COMMUNICATIONS

Climate variability modulates western U.S. ozone air quality via deep stratospheric intrusions



The high tail of the observed daily surface O_3 distribution over Western U.S. increases during La Niña springs



El Niño → Little change in WUS surface O_3 despite higher UTLS O_3 levels

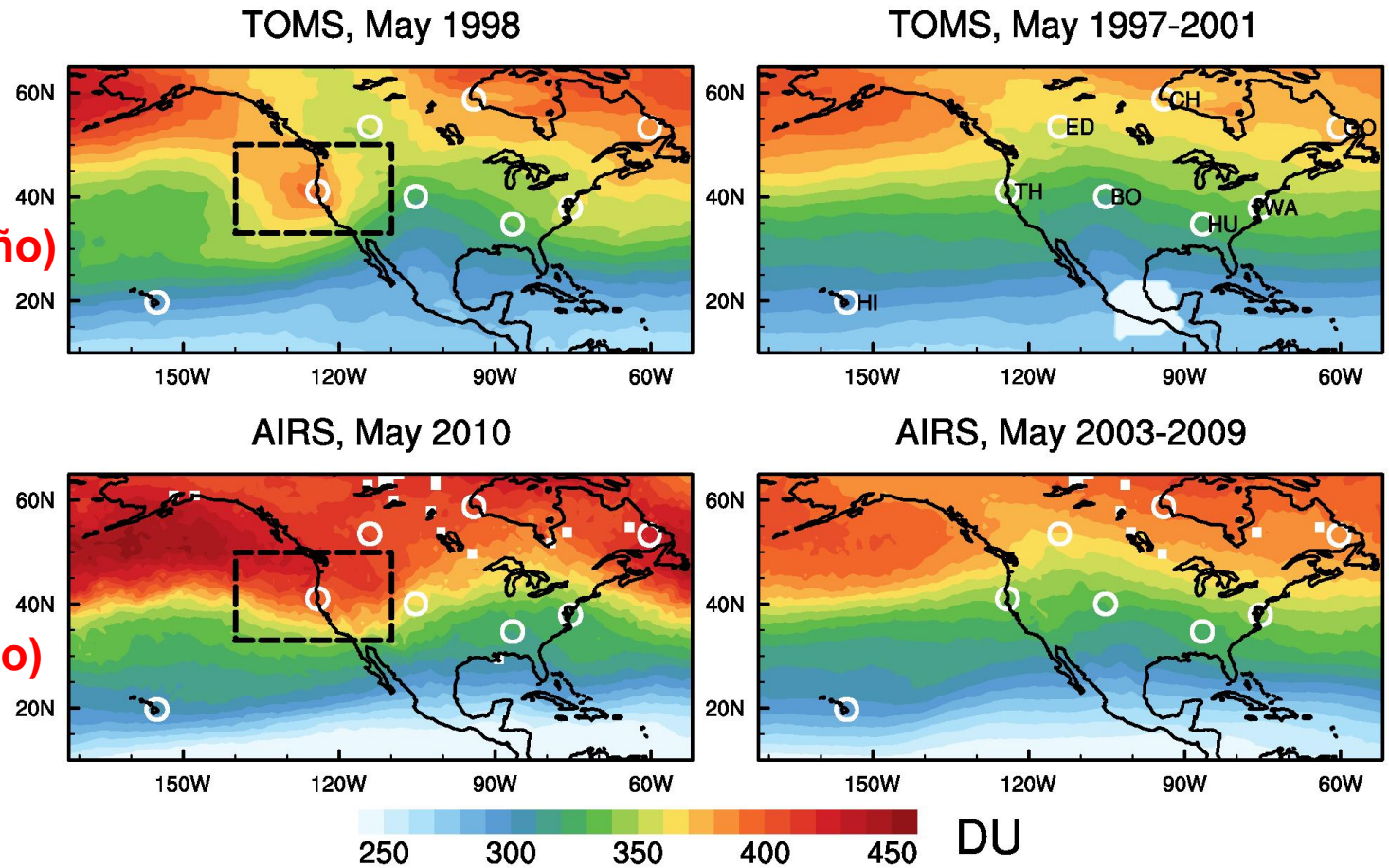
Following an El Niño, enhanced total ozone columns over the Northwest U.S. in the late spring

TOMS

(1997/1998 El Niño)

AIRS

(2009/2010 El Niño)

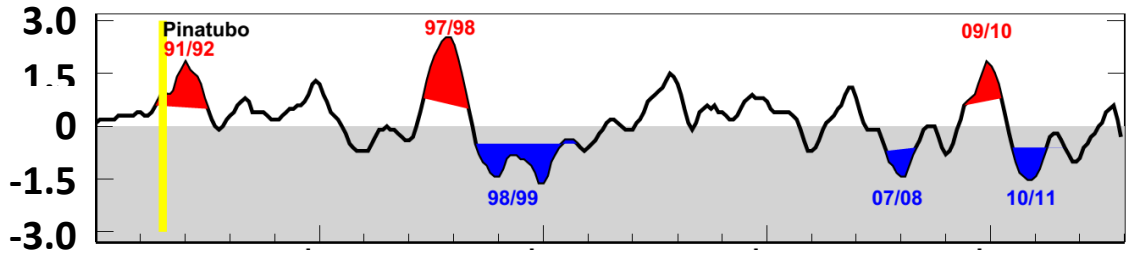


- Changes in stratospheric overturning circulation that increases extratropical UTLS O_3 burdens (*Bronnimann2004; Randel2009; Calvo2010;* ***Neu2014***), but …(next slide)

Lin MY et al (Nature Communications, in press, 2015), Supplemental Info

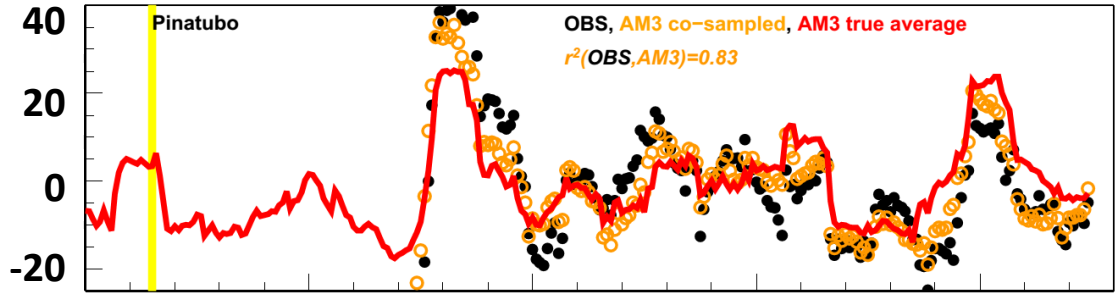
Western US surface O_3 variability correlates poorly with O_3 burdens in the UTLS but strongly with that in the Free Trop

Niño 3.4 Index



12-mon running mean 250-150hPa O_3 anomaly (%)

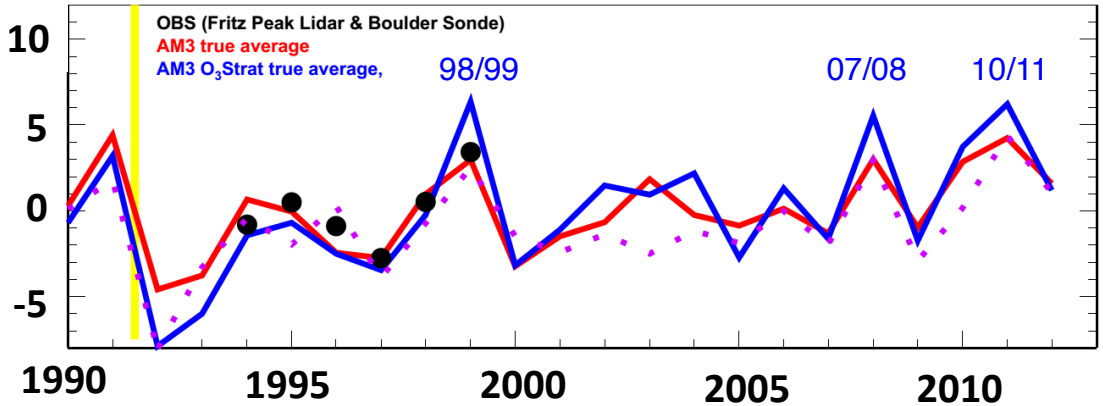
r^2(UTLS, Surface) = 0.07



Trinidad

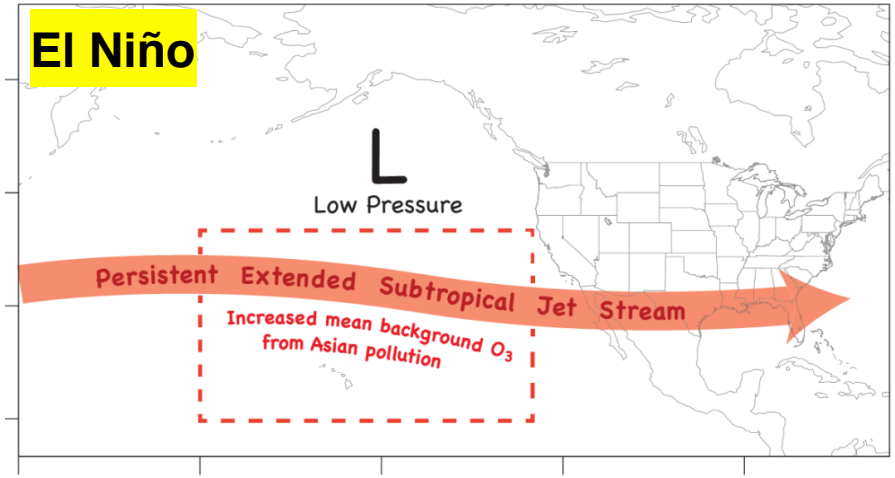
Apr-May mean FreeTrop & Surface O_3 anomaly (ppb)

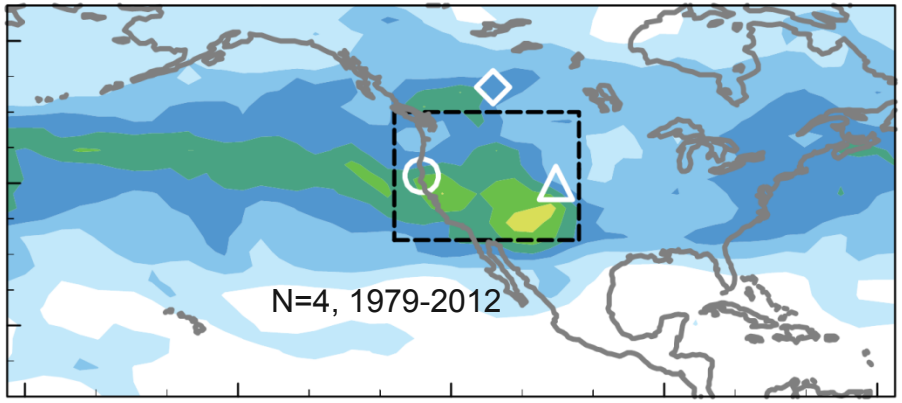
r^2(FreeTrop, Surface) =0.74



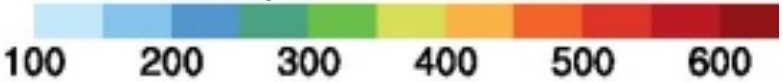
- Langford1999 noted **positive correlations** btw FreeTrop and UTLS O_3 observed at Fritz Peak **during 1994-1998** (without La Niña years)**:** AM3 captures the observed relationship (r^2=0.69) for this short record but indicates **little correlation** (r^2=0.18) **for the entire 1990-2012 period.**

ENSO-related jet characteristics and their impacts on lower trop. ozone variability over western NA

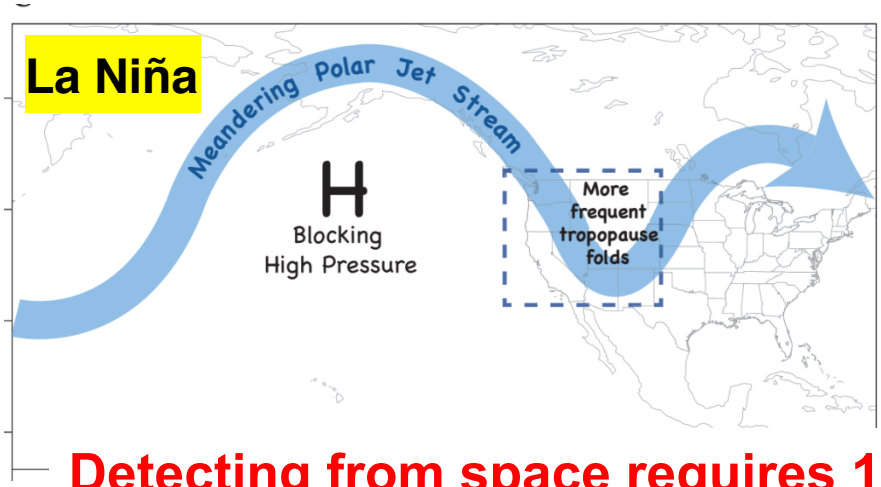


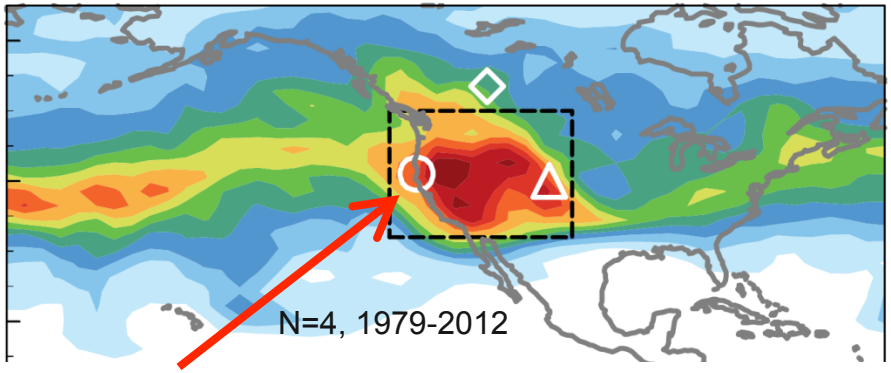


σ^2 (daily O_3Strat), 500 hPa, Apr-May



ppb^2

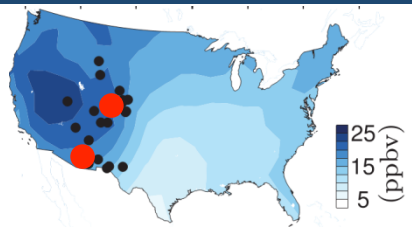




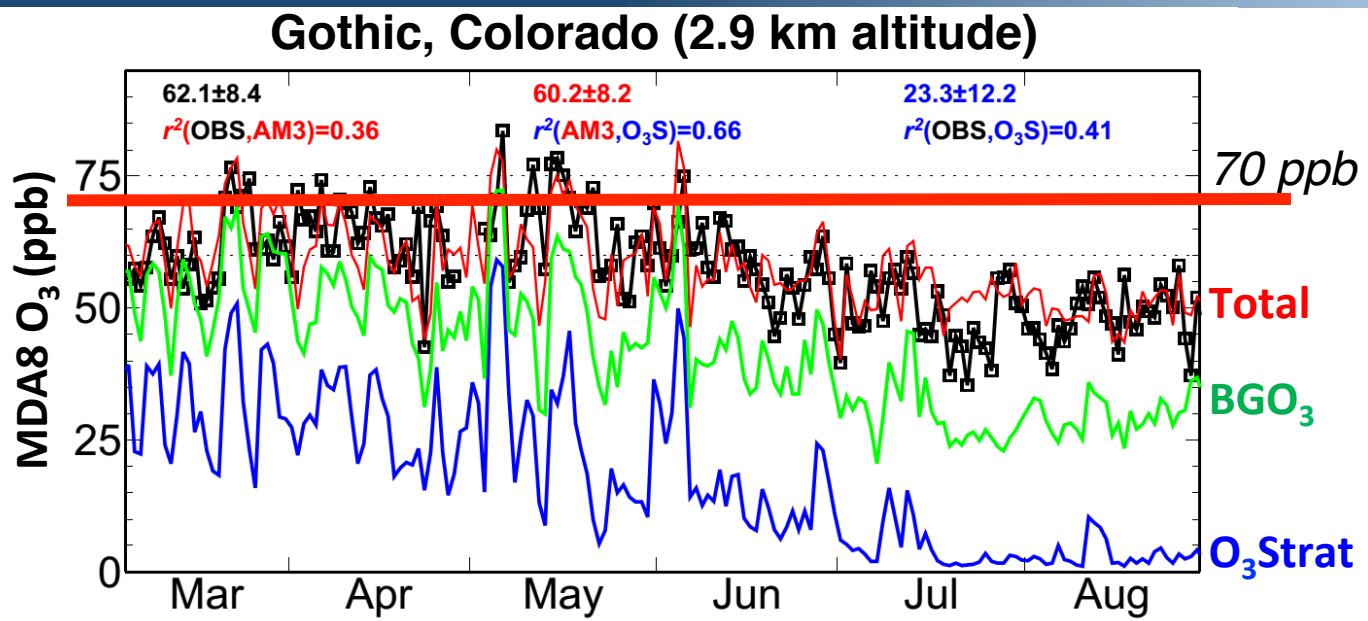
Detecting from space requires 1) strong sensitivity in mid-trop
2) vast spatial coverage at daily intervals; not in TES

Lin MY et al (Nature Communications, in press, 2015)

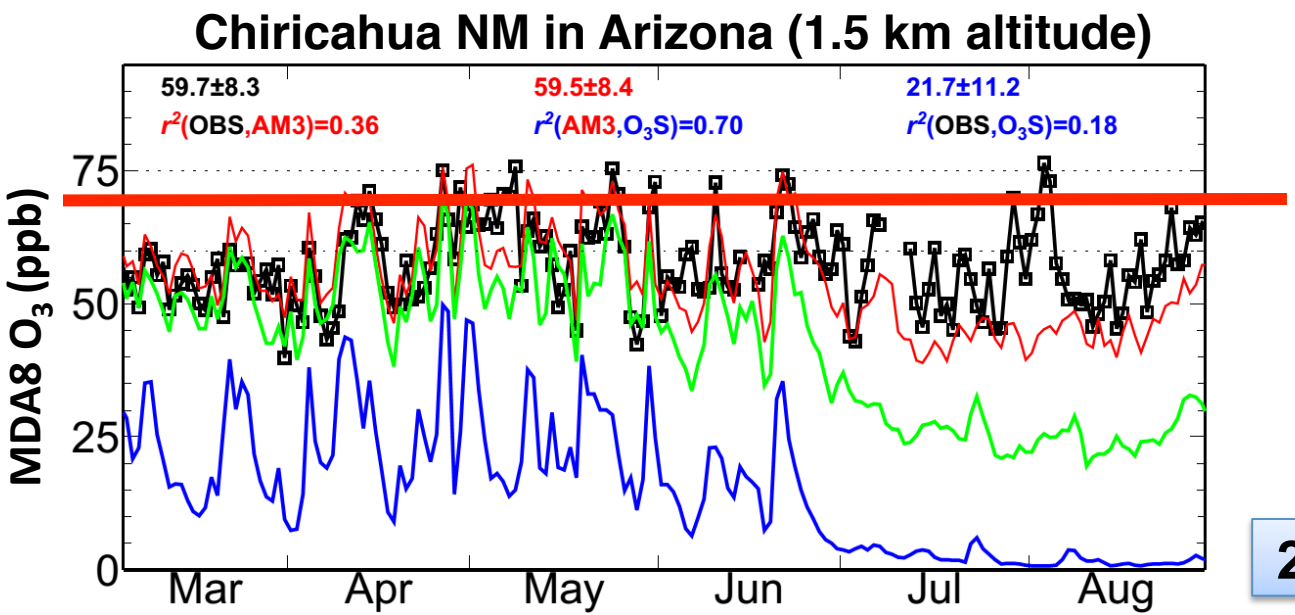
Following strong La Niña, deep STT may occur with sufficient frequency as to confound ozone attainment



1999 (La Niña)



2011 (La Niña)



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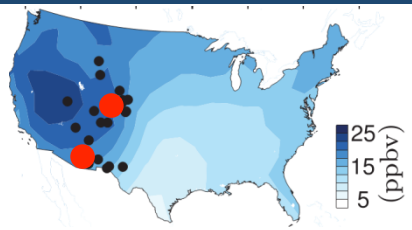

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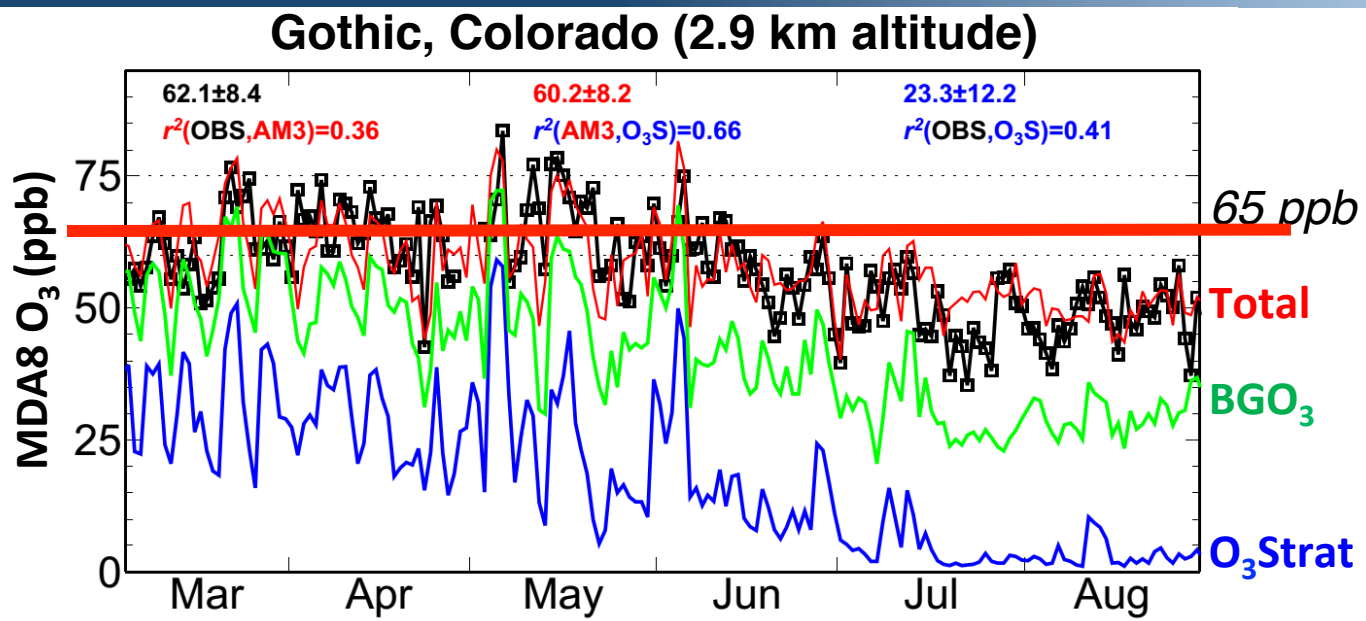

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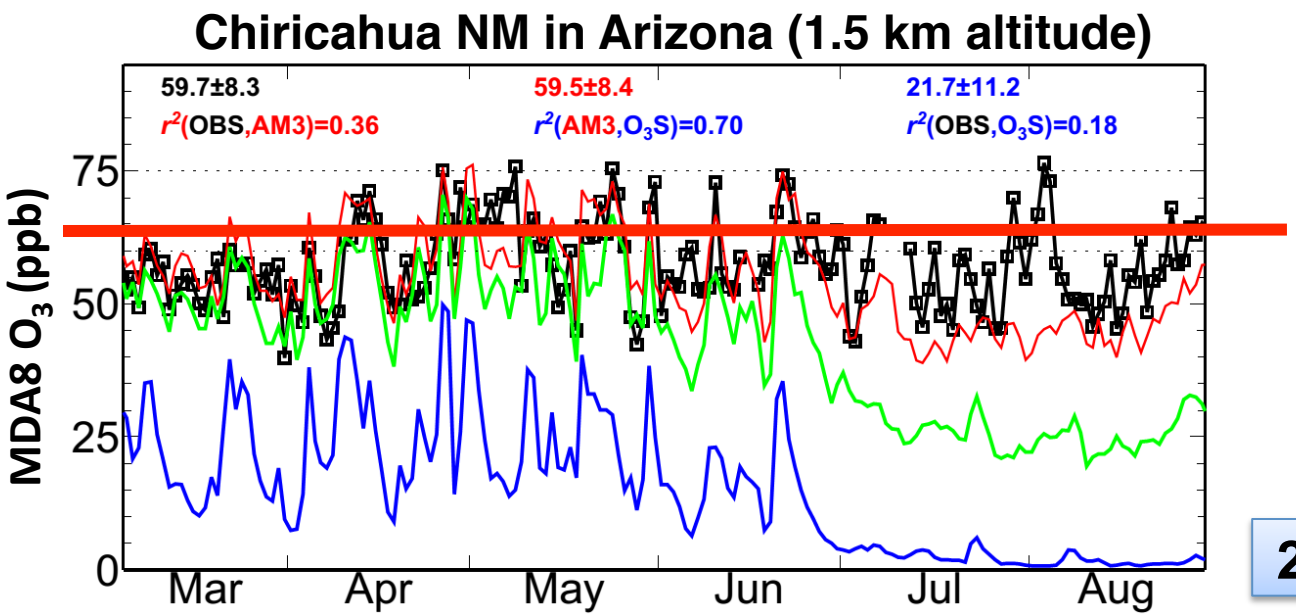
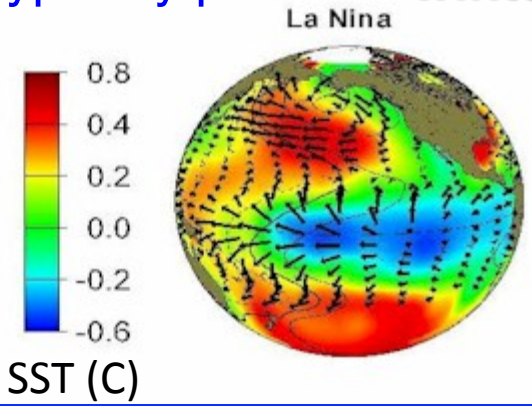


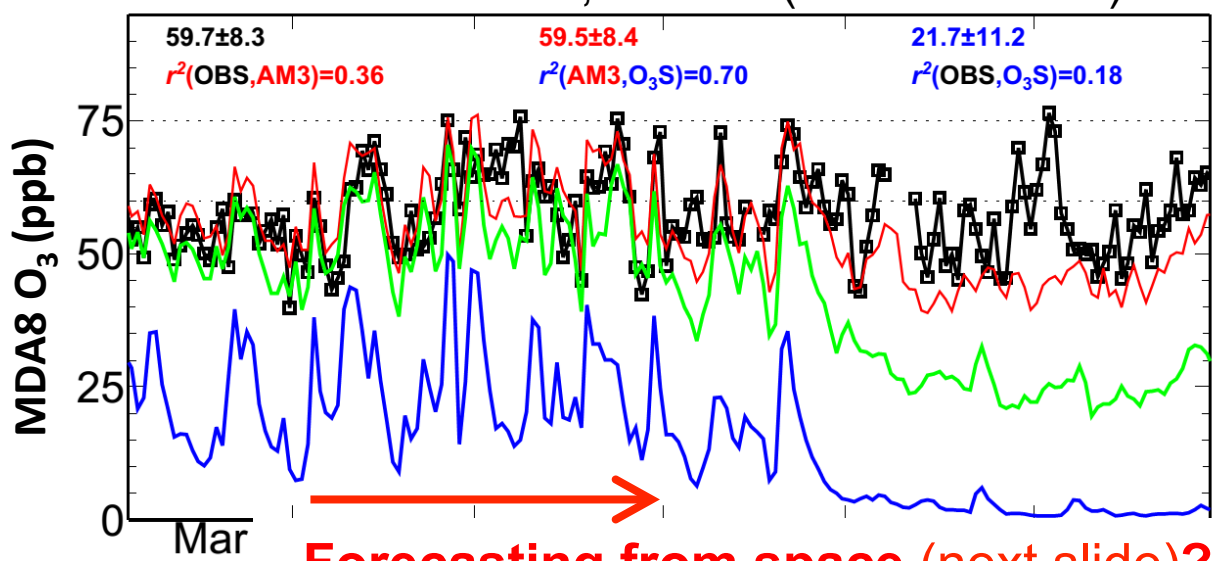
Developing seasonal predictions with a few months of lead time to aid Western U.S. AQ planning?

Tropical SST cooling typically peaks in **winter**



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

Chiricahua NM, Arizona (1.5 km altitude)



Forecasting from space (next slide)**?**

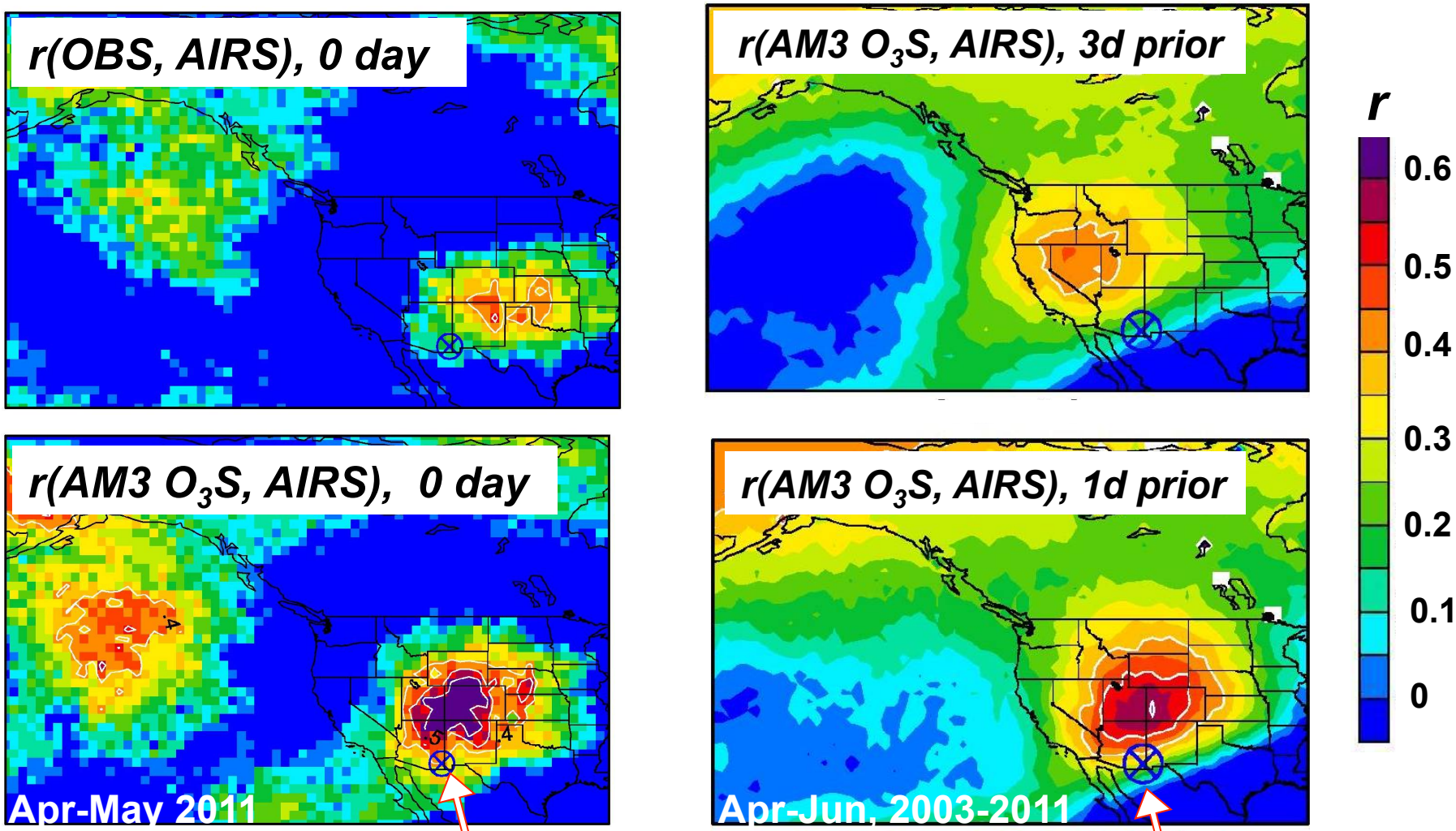
The winter-spring link could allow regional preparations, e.g.

- Deploying targeted measurements aimed at identifying "exceptional events"
- Conducting daily forecast for public health alerts

Lin MY et al (Nature Communications, in press, 2015)

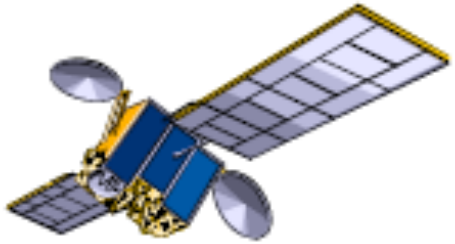
Stratospheric intrusion "forecasting" from space

(Correlations of daily AIRS UT/LS ozone and surface ozone)



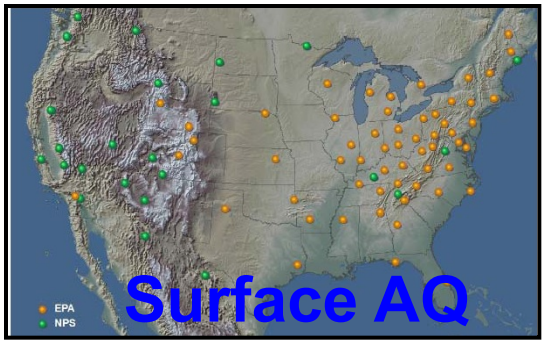
→ Stronger potential for accurate prediction in ~1 day
→ Uncertain as to where the intrusion will reach the WUS surface
→ Useful for exceptional event demonstrations

Challenges for satellite instruments going forward: perspectives from the air quality applied sciences



satellites

Inform transported "background"



- Time average; big-picture
- Global-to-regional scale
- Upper-level dynamics

- Episodic
- Regional-to-local scale
- Vertically refined

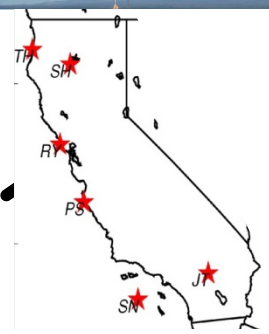
Future?

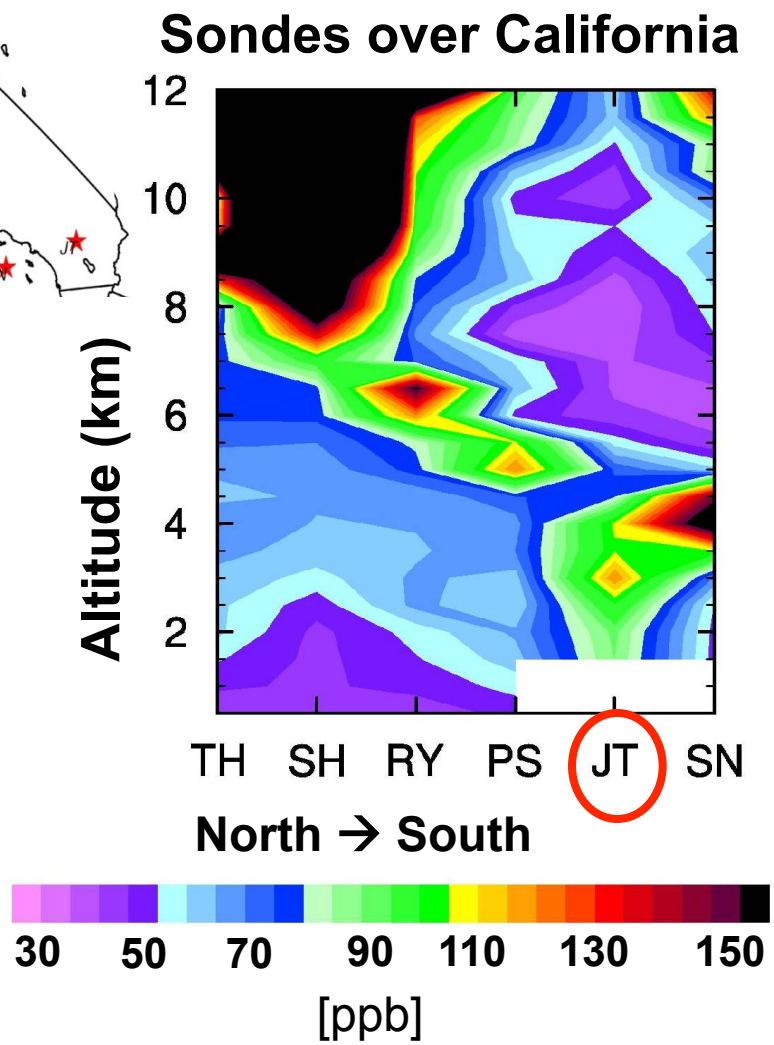
- ***Need to improve sensitivity in the mid- & lower troposphere***
- ***Vast spatial coverage at Hi-Res and at near-daily intervals; GEO-CAPE?***
- ***Ability to quantitatively relate pollutant concentrations to their sources and transport on synoptic time scales***
- ***Providing data to improve air quality forecasts***

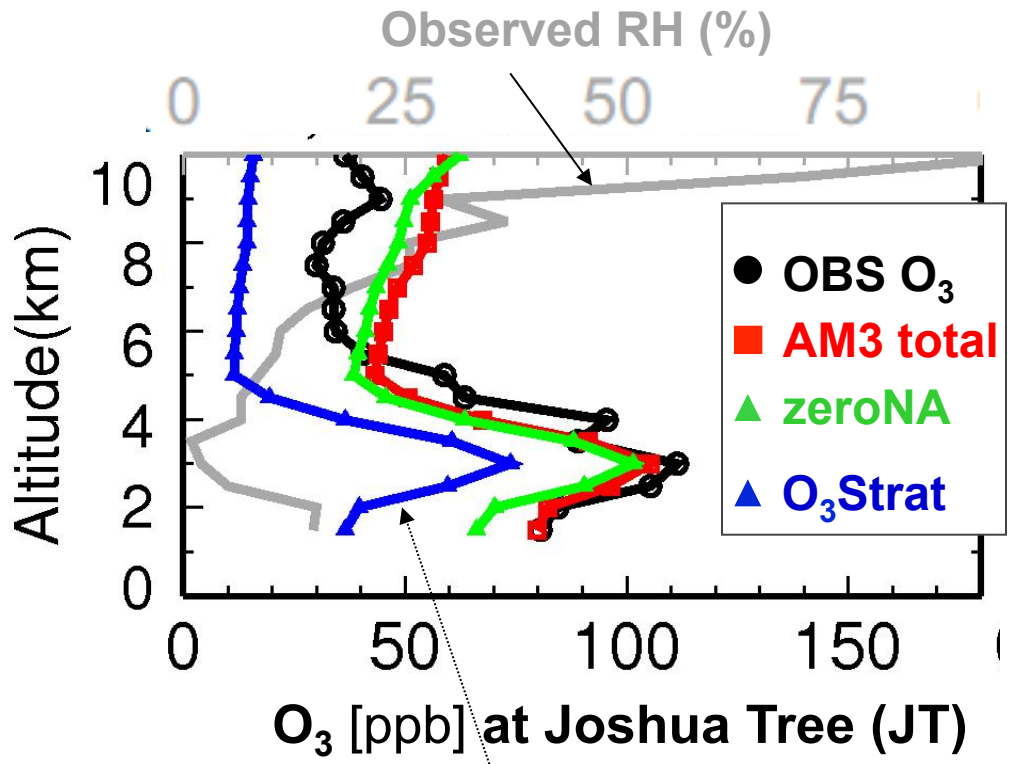
Thank you! (Meiyun.Lin@noaa.gov)

Additional Slides for Discussions

Subsidence of stratospheric O_3 to the lower trop of S. California (May 28, 2010)

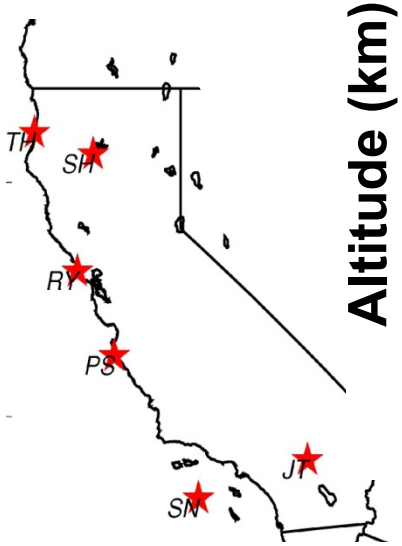


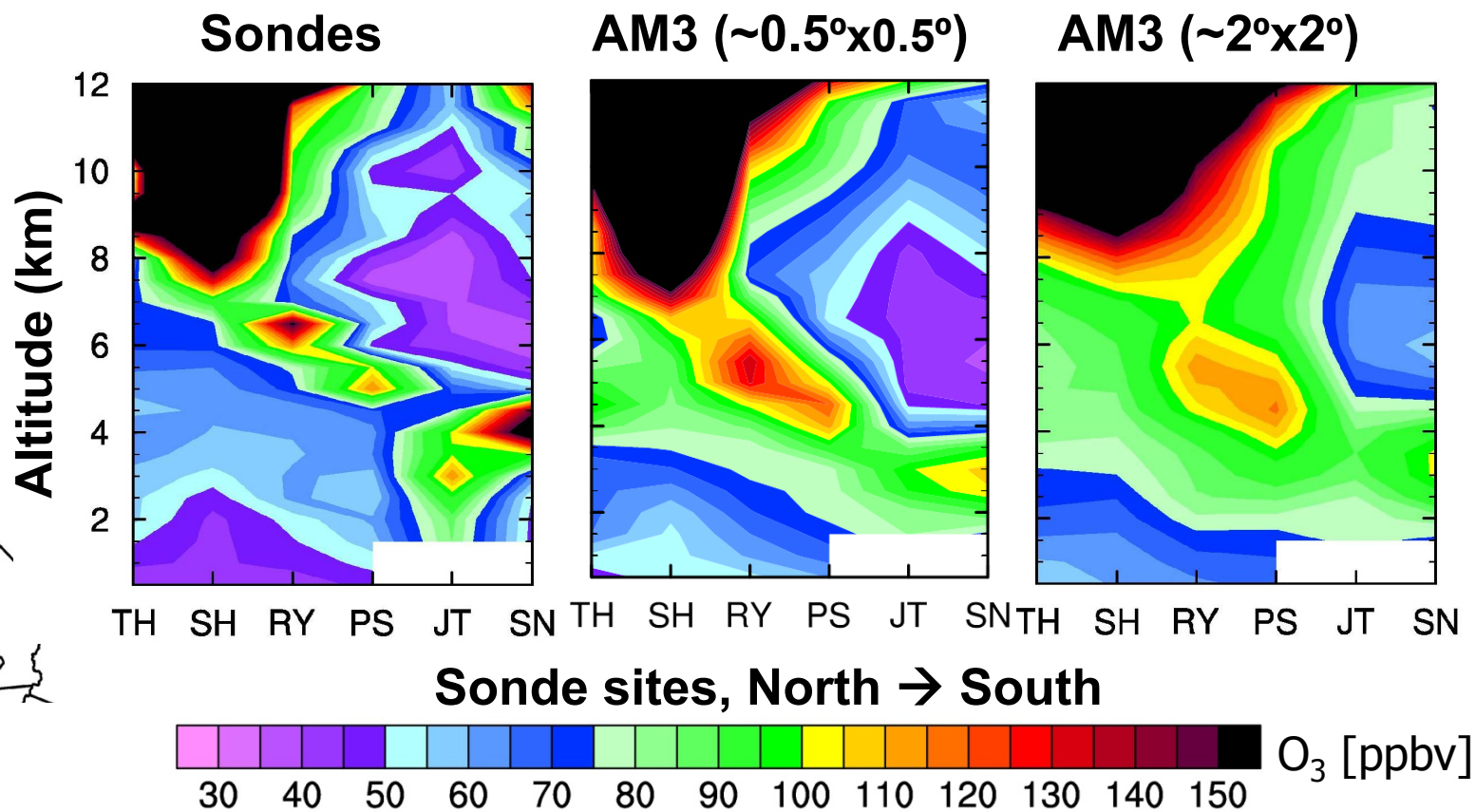




- **Simulated enhancements of O_3Strat consistent with observed low RH**
- **Reaching surface air on the following day**

Simulating deep stratospheric intrusions: role of model resolution (May 28, 2010 example)

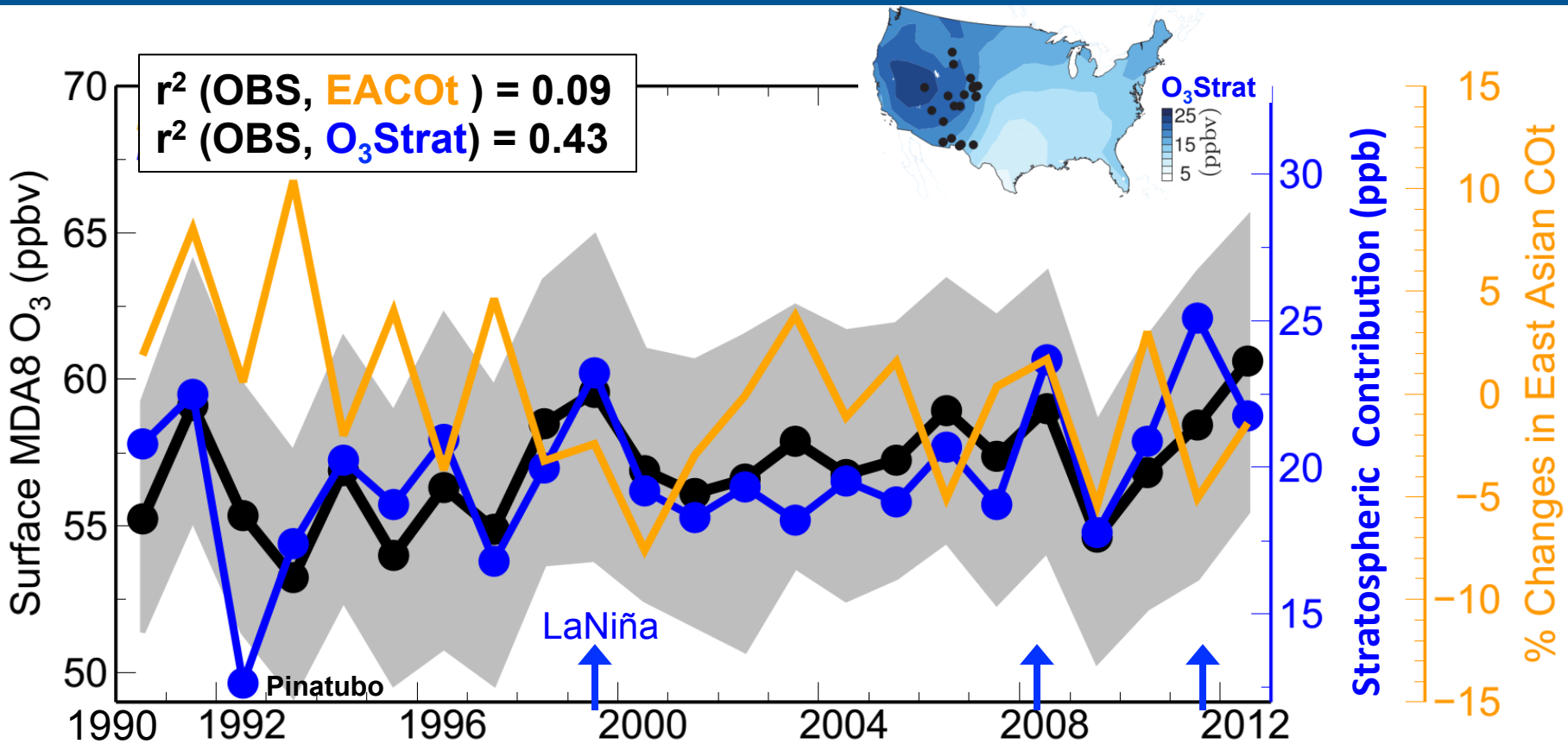




- 0.5° model better captures vertical structure
- 2° model reproduces the large-scale view
  → Establishing its suitability for exploring interannual variability

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

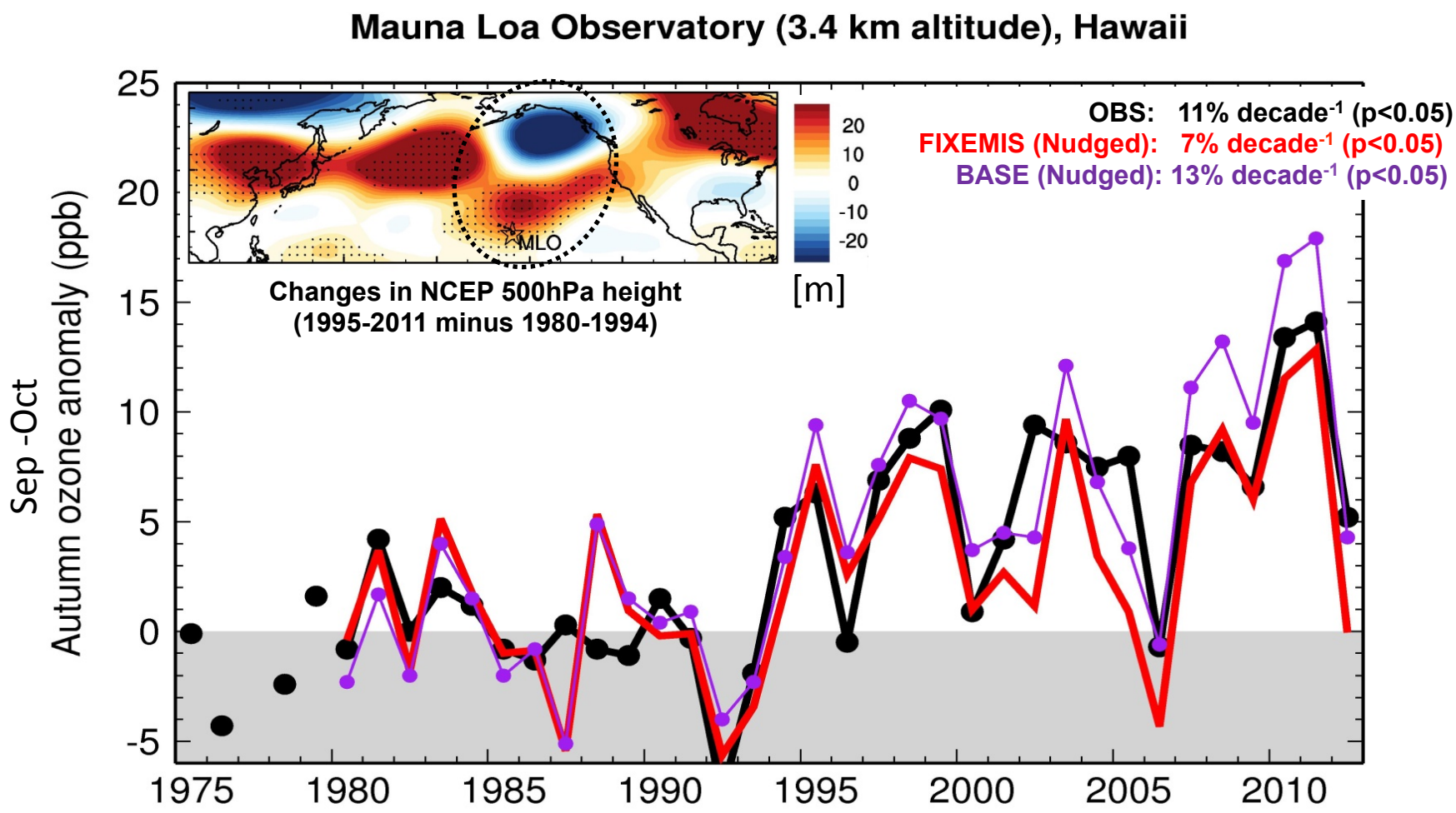
Inter-annual variability of Western U.S. surface ozone in April-May



- **Strong stratospheric influence on WUS O_3 IAV**: Greater following strong La Niña events; Can complicate attribution of O_3 trends in short records
- **In contrast, Asian influence (FixEmis) is minor; Weakened in the 2000s**

Lin MY et al: Climate variability modulates Western U.S. ozone air quality via deep stratospheric intrusions, ***Nature Communications***, *in press*, 2015.

Increasing ozone at Mauna Loa in FALL tied to a shift in circulation patterns since the mid-1990s



→ **Must consider decadal climate variability for attribution of pollutant trends**

Lin M.Y. et al (Nature GeoSci., 2014)

List of relevant papers

Lin, M., A.M. Fiore, L. W. Horowitz, O. R. Cooper, V. Naik, J. Holloway, B. J. Johnson, A. M. Middlebrook, S. J. Oltmans, I. B. Pollack, T. B. Ryerson, J. X. Warner, C. Wiedinmyer, J. Wilson, B. Wyman: **Transport of Asian ozone pollution into surface air over the western United States in spring**, *Journal of Geophysical Research*,117, D00V07, 2012, doi: 10.1029/2011JD016961 (PDF)

Lin M., A. M. Fiore , O. R. Cooper , L. W. Horowitz , A. O. Langford , Hiram Levy II , B. J. Johnson , V. Naik , S. J. Oltmans , C. Senff (2012): **Springtime high surface ozone events over the western United States: Quantifying the role of stratospheric intrusions**, *Journal of Geophysical Research*, 117, D00V22, doi:10.1029/2012JD018151 (Full Text)

Lin, M., L.W. Horowitz, S. J. Oltmans, A. M. Fiore, Songmiao Fan (2014): ***Tropospheric ozone trends at Manna Loa Observatory tied to decadal climate variability***, **Nature Geoscience**, 7, 136-143, doi:10.1038/NGEO2066 (PDF)

Lin, M., A. M. Fiore, L.W. Horowitz, A. O. Langford, S. J. Oltmans, D. Tarasick, H. E. Rieder (2015): **Climate variability modulates western U.S. ozone air quality in spring via deep stratospheric intrusions**, Nature Communications, in press, 2015