WESTAR/Western Ozone Transport Conference, Oct 10-12, 2012

Daily to decadal variability in sources of springtime ozone over the western U.S.: Stratospheric intrusions, Asian pollution, and wildfires

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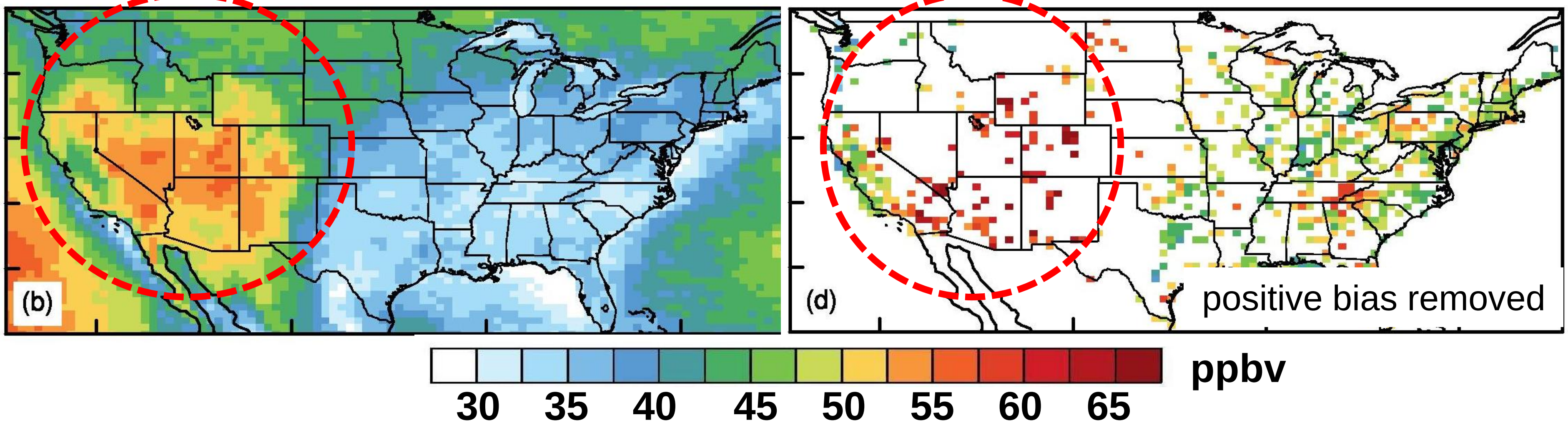
U.S. Background Ozone in Spring: Strongest in the high-elevation Western U.S.

Daily max 8-hr O_3 in surface air (April-June 2010)

Median **Maximum**



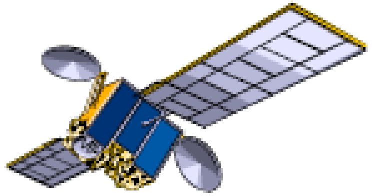
Estimated by turning off NA anthrop emissions in AM3 (~50x50 km^2)

Maximum values can reach 60-75 ppb: Challenge to stay below NAAQS

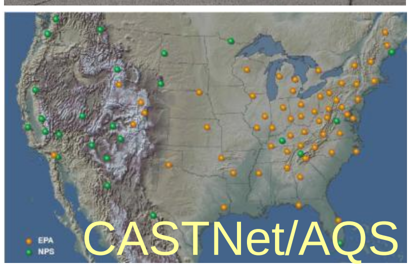
MAJOR CHALLENGES:

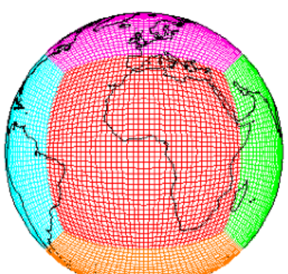
1. **Frequency of natural events,** ***e.g.*** **stratospheric** [Langford et al., 2009]; **wildfires** [Pfister et al. 2008]
2. **Rising Asian emissions** [e.g., Jacob et al., 1999; Richter et al., 2005; Cooper et al., 2010]
3. **Climate variability and changes** [e.g. Langford et al., 1998; Collins et al., 2003; Hegglin et al., 2009]

→ Need for process-level understanding from daily to multi-decadal time scales



satellites

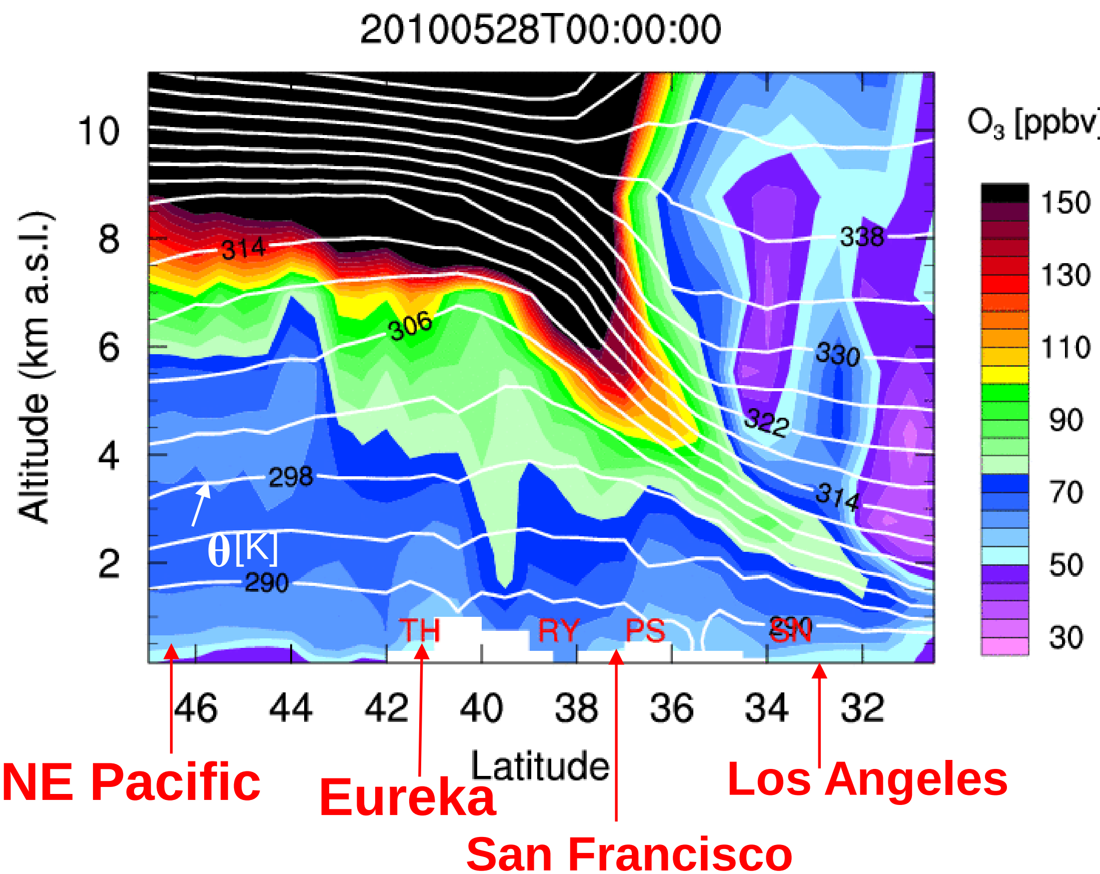




GFDL AM3

An integrated analysis using model and multi-platform observations

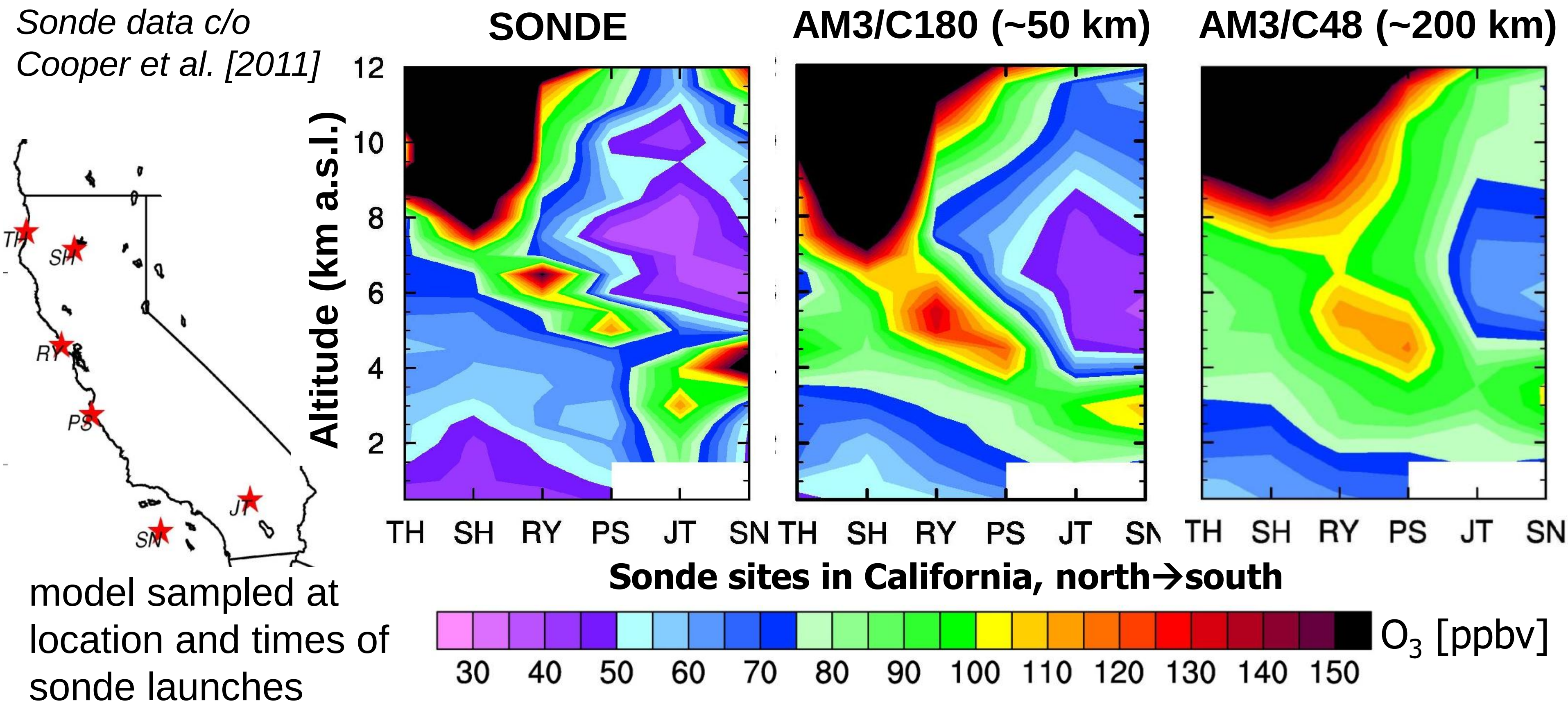
Deep stratospheric ozone intrusions in
the new, global high-resolution GFDL AM3 model



1) **Fully coupled strat & trop chem** [*Donner et al., 2011*]
2) **Nudged to "real winds"** [*Lin et al., 2012a; 2012b*]

Subsidence of stratospheric ozone to the lower troposphere of southern California (May 28, 2010)

Sonde data c/o Cooper et al. [2011]



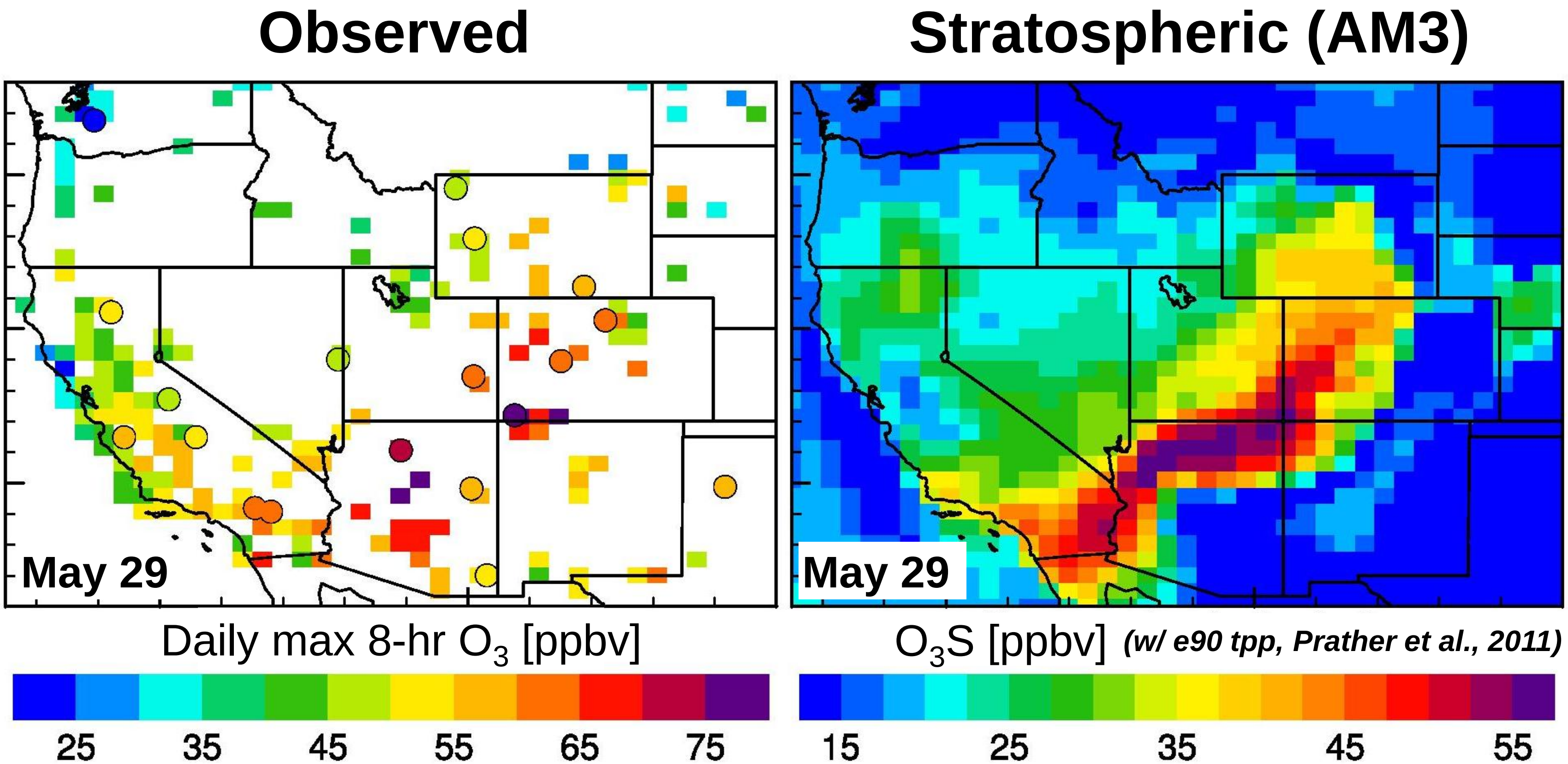
model sampled at location and times of sonde launches

- **High O_3 mixing ratios (100-150 ppbv) just 2-4 km above Southern California**
- **AM3/C180 better captures vertical structure**
- **AM3/C48 reproduces the large-scale view**

→ Utility of multi-decadal simulations

M. Lin et al., in prep.

Transport of stratospheric O_3 to the surface (May 29, 2010)



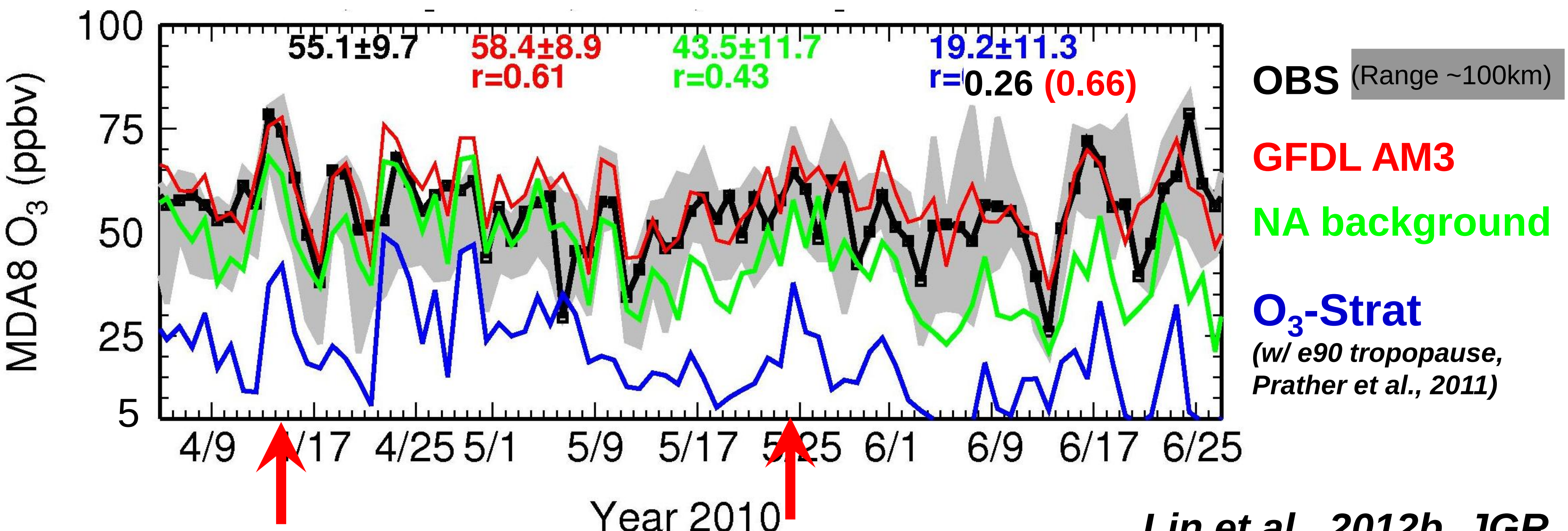
- **Observed MDA8 O_3 over the four corners region reaches 70-82 ppb coincident with a substantial decrease in humidity and colder afternoon temperature**
- **The model estimates a stratospheric contribution of 35-55 ppb**

→ How frequent are such events in spring?

Lin et al., 2012b, JGR

Stratospheric intrusions drive a substantial portion of springtime high surface O_3 events in U.S. West

Daily max 8-hr surface O_3 at Boulder (~2 km a.s.l.), Colorado



Lin et al., 2012b, JGR

- Stratospheric intrusions can episodically increase surface MDA8 O_3 by 20-40 ppb, including on days when observed O_3 exceeds the 75 ppb NAAQS threshold
- In notable contrast to prior work concluding that stratospheric influence on high surface O_3 events is rare [e.g. *Fiore et al., 2003; U.S. EPA, 2007*]

→ **Insights from satellite images, ozonesondes, and lidar measurements**

Thirteen intrusions in Apr-Jun 2010 enhanced daily max 8-hour ozone to 70-86 ppbv at WUS surface sites

Events	Synoptic conditions in satellite imagery	Descent captured in ozonesondes, lidar, aircraft	Major surface impact regions
Apr. 6-7	AIRS /GFS PV	Not measured	Colorado, New Mexico
Apr. 9-10	**AIRS/GFS PV**	**Not measured**	**Wyoming**
Apr. 12-15	**AIRS/GFS PV**	**Not measured**	**Four Corners Region**
Apr. 21-23	AIRS/GFS PV	Not measured	Colorado, New Mexico
Apr. 28-29	AIRS/GFS PV	Not measured	Colorado, Wyoming
May 11-13	AIRS/GOES	Sonde, P-3 aircraft	Arizona, New Mexico, W. Texas
May 18-21	AIRS/GOES	Sonde	Wyoming
May 22-24	**AIRS/GOES**	**Sonde and lidar**	**Colorado, New Mexico**
May 27-29	**AIRS/GOES**	**Sonde and lidar**	**Arizona, California, Colorado**
Jun. 7-8	**AIRS/GOES**	**Sonde**	**Idaho, Utah, Wyoming**
Jun. 9-14	AIRS/GOES	Sonde	Spread in Southwest
Jun. 16-17	AIRS/GOES	Sonde	Colorado
Jun. 22-23	**AIRS/GFS PV**	**Not measured**	**Colorado**

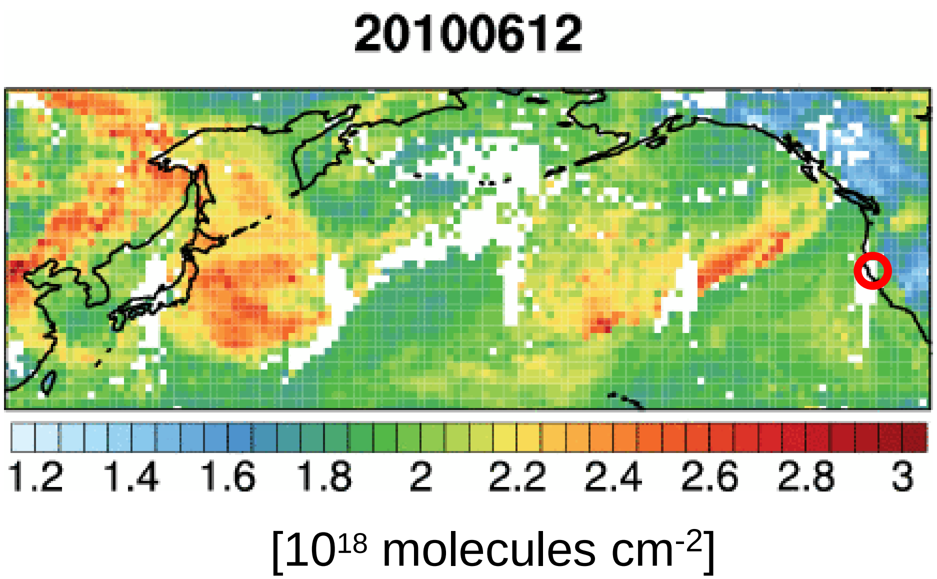
→ A total of 27 exceedances of NAAQS occurred during six of these events

→ **Two events occurred one day prior to arrival of an Asian pollution plume**

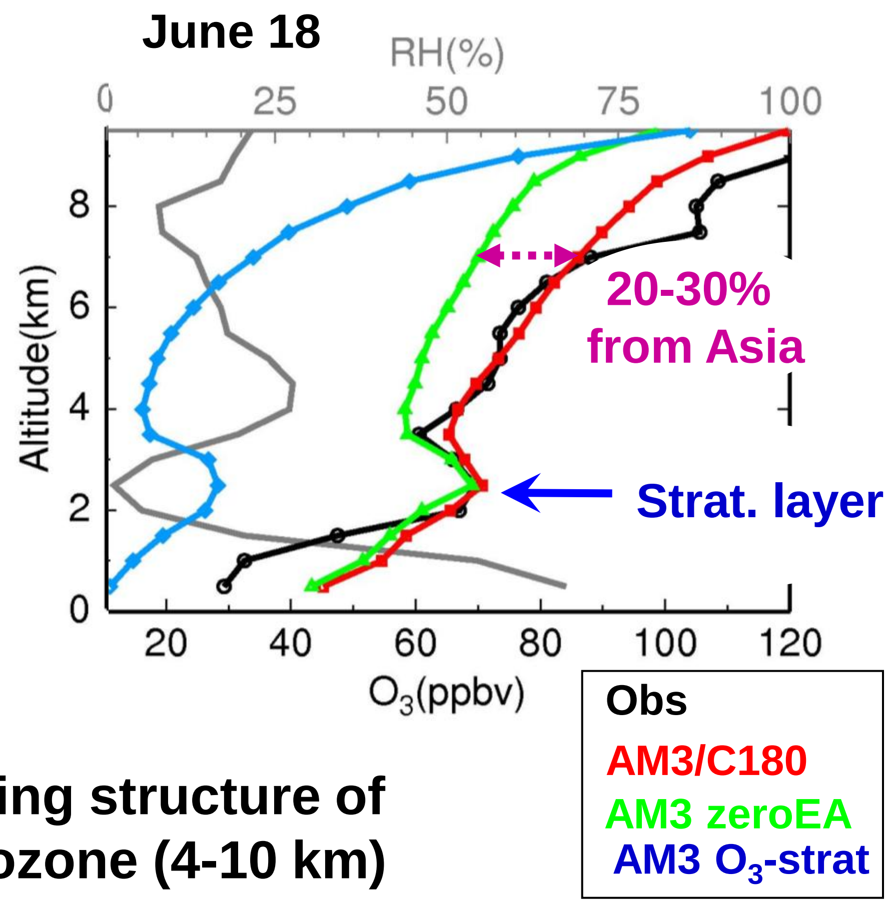
Trans-Pacific Asian pollution plumes

The view from satellites

(AIRS CO columns)



Point Reyes Sonde, CA



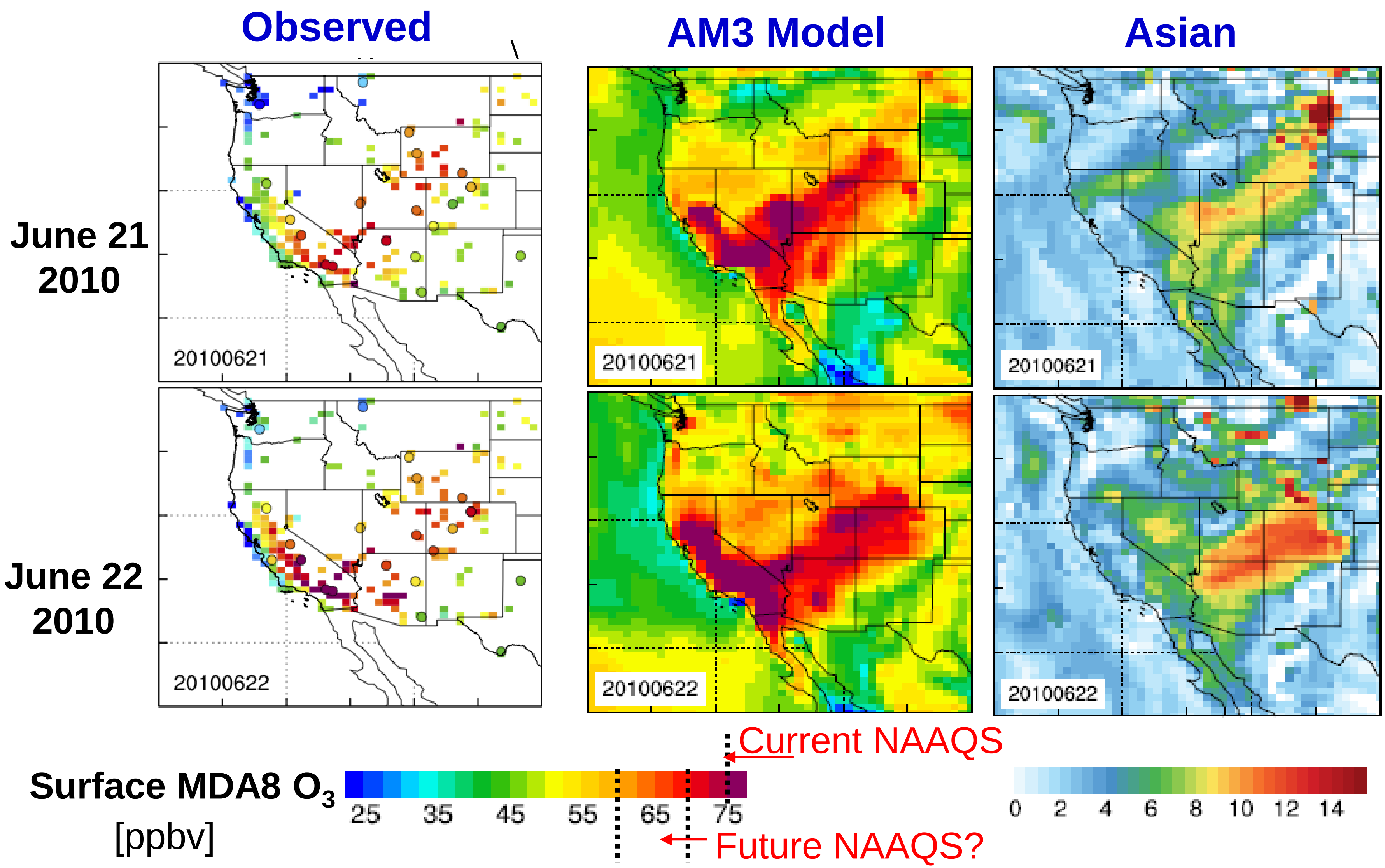
→ **AM3 model captures the interleaving structure of stratospheric (2-4 km) and Asian ozone (4-10 km)**

→ **How important is Asian influence in surface air?**

… 3 days after …

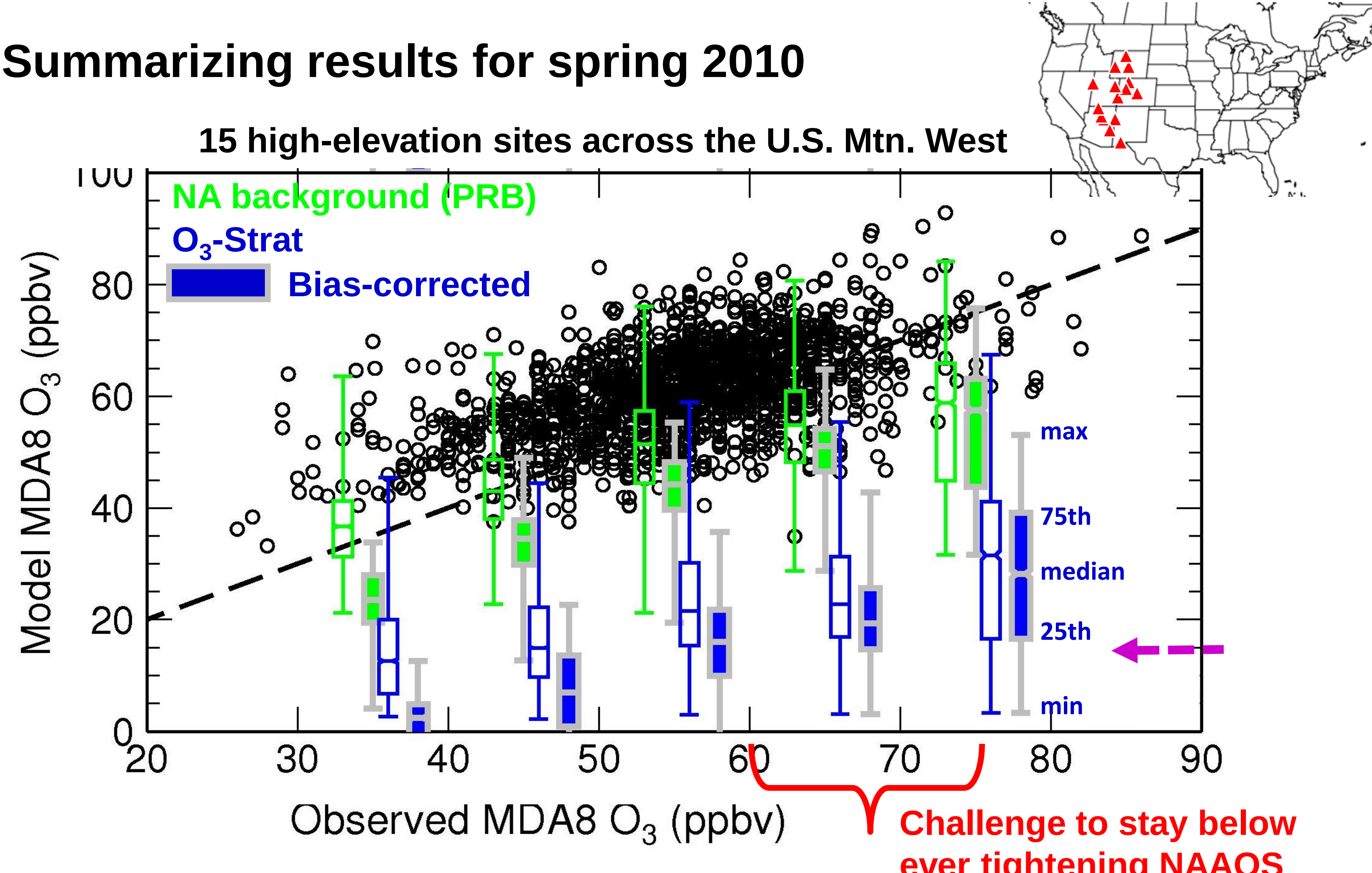
Lin, et al., 2012, JGR

Asian influence on surface high-O_3 episodes over the western U.S may confound efforts to attain tighter standards



Lin, et al., 2012a, JGR **(AGU Editors' Highlight, Featured in Science, Nature News)**

Summarizing results for spring 2010



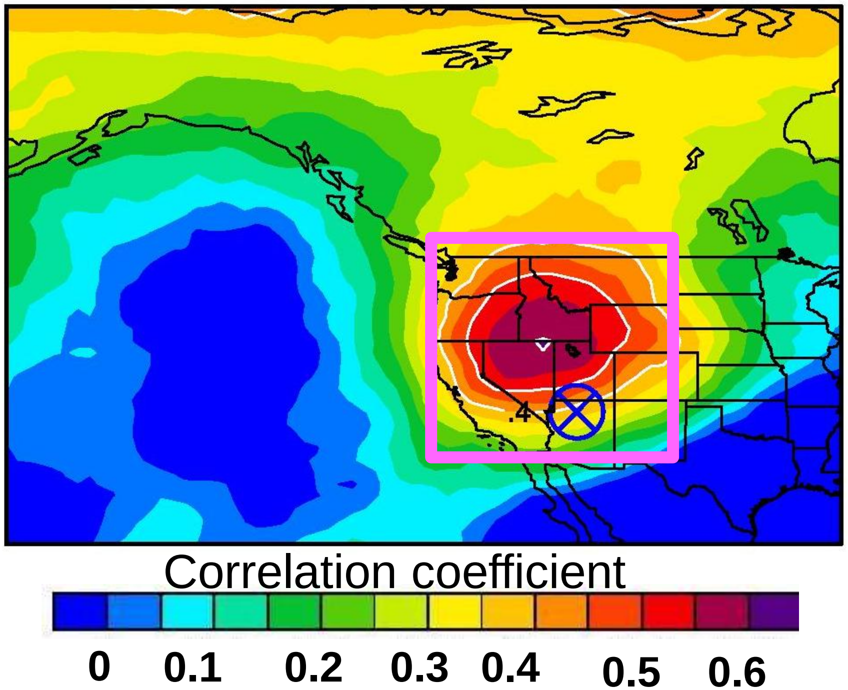
- NA background (and its stratospheric component) increases with increasing O_3
- Stratospheric O_3 contributes more than O_3 produced from Asian anthrop emissions (<15 ppb)

→Need to enhance forecasting capability

Using satellite data to predict stratospheric intrusions and Asian pollution events at WUS sites (Grand Canyon NP example)

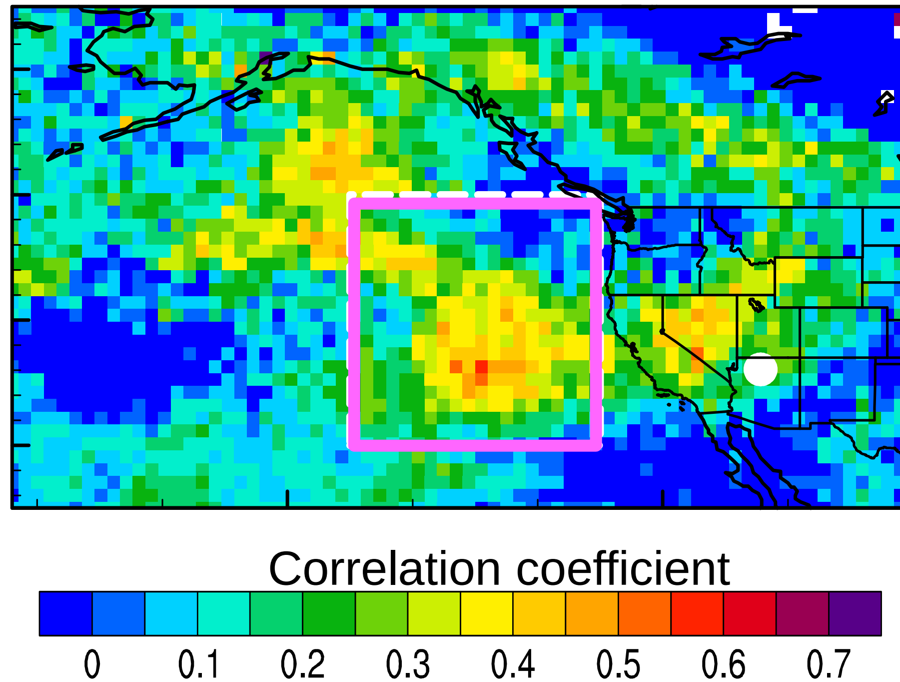
***r* (Surface O_3-Strat, AIRS O_3 columns)**

Lag = 1 day



***r* (Surface Asian O_3, AIRS CO columns)**

Lag = 1 day



Potential AQ Applications: 1) Screening of "exceptional events"

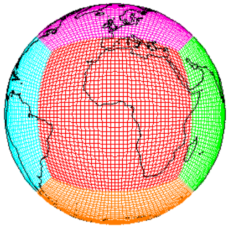
2) Advanced warning of regional high-O_3 events

→ **Qualitatively promising …ongoing work for a quantitative relationship ($\triangle O_3$)**

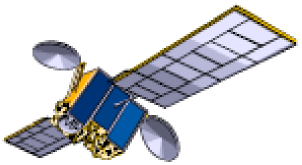
What are the drivers of inter-annual variability?
→ Crucial for regional preparation for a potential high-O_3 season

5 slides of unpublished results have been removed.

Some final policy-relevant messages …high-elevation WUS in spring…



GFDL AM3



satellites

Stratospheric Intrusions:

- Drives a substantial portion of day-to-day variability in Western U.S. ozone in spring

→ *Challenges for staying below current NAAQS*

→ *Satellite UT/LS O_3 products may provide advanced warning*

- Enhanced during ENSO …

→ *Implications for regional preparation for a high-O_3 season*

Asian pollution:

- Contributes to surface high-O_3 events in WUS…though less than stratospheric O_3

→ *Satellite CO products may provide advanced warning, but need further testing, e.g. tied to Pb isotopes*

- May counteract with domestic emission controls …but need to maintain multi-decadal observational records

Wildfires:

- Not a major driver for inter-annual variability based on preliminary analysis

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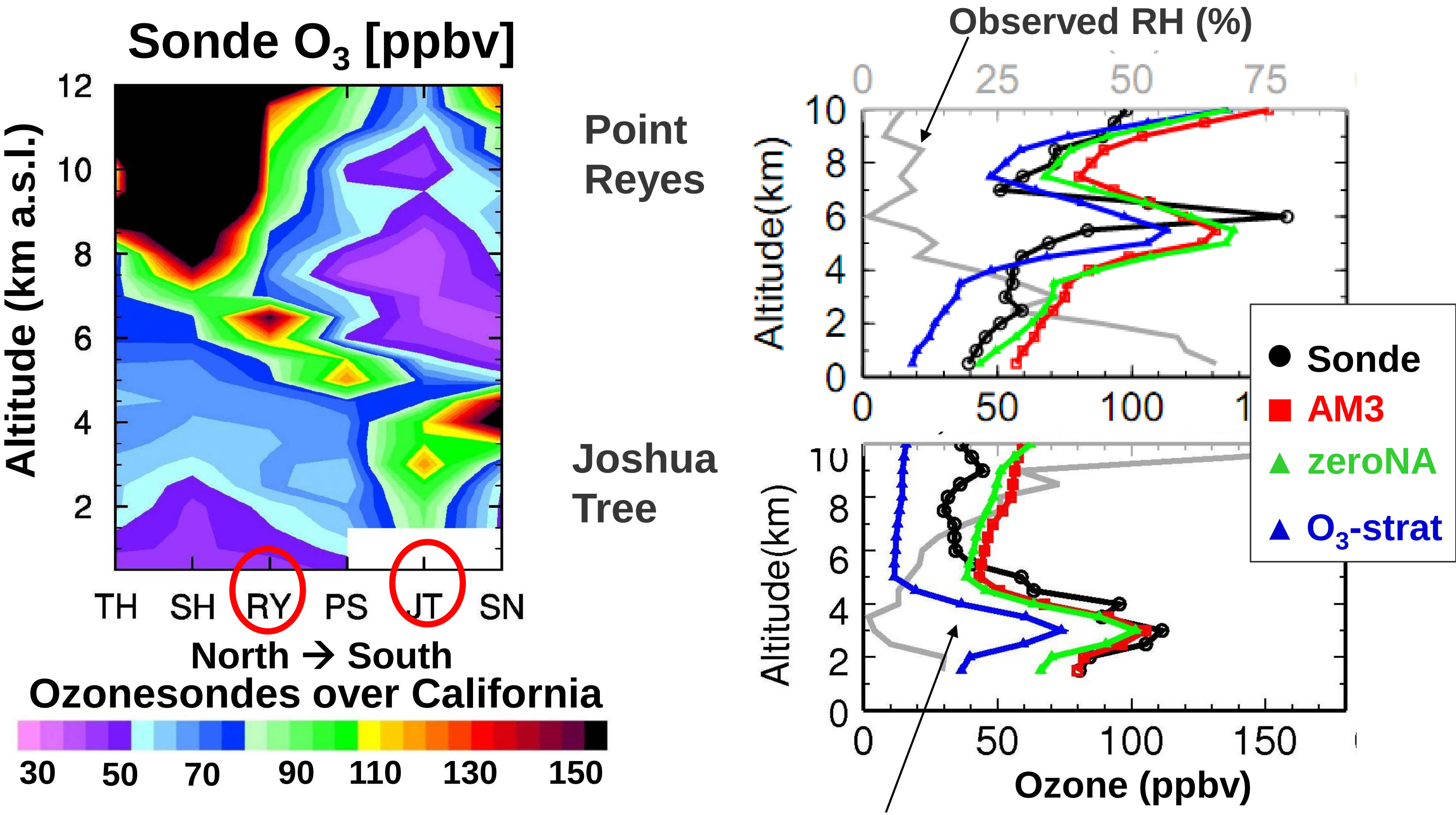
Additional slides

Lin, M., et al. (2012), Transport of Asian ozone pollution into surface air over the western United States in spring, J. Geophys. Res., 117, D00V07, doi:10.1029/2011JD016961

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

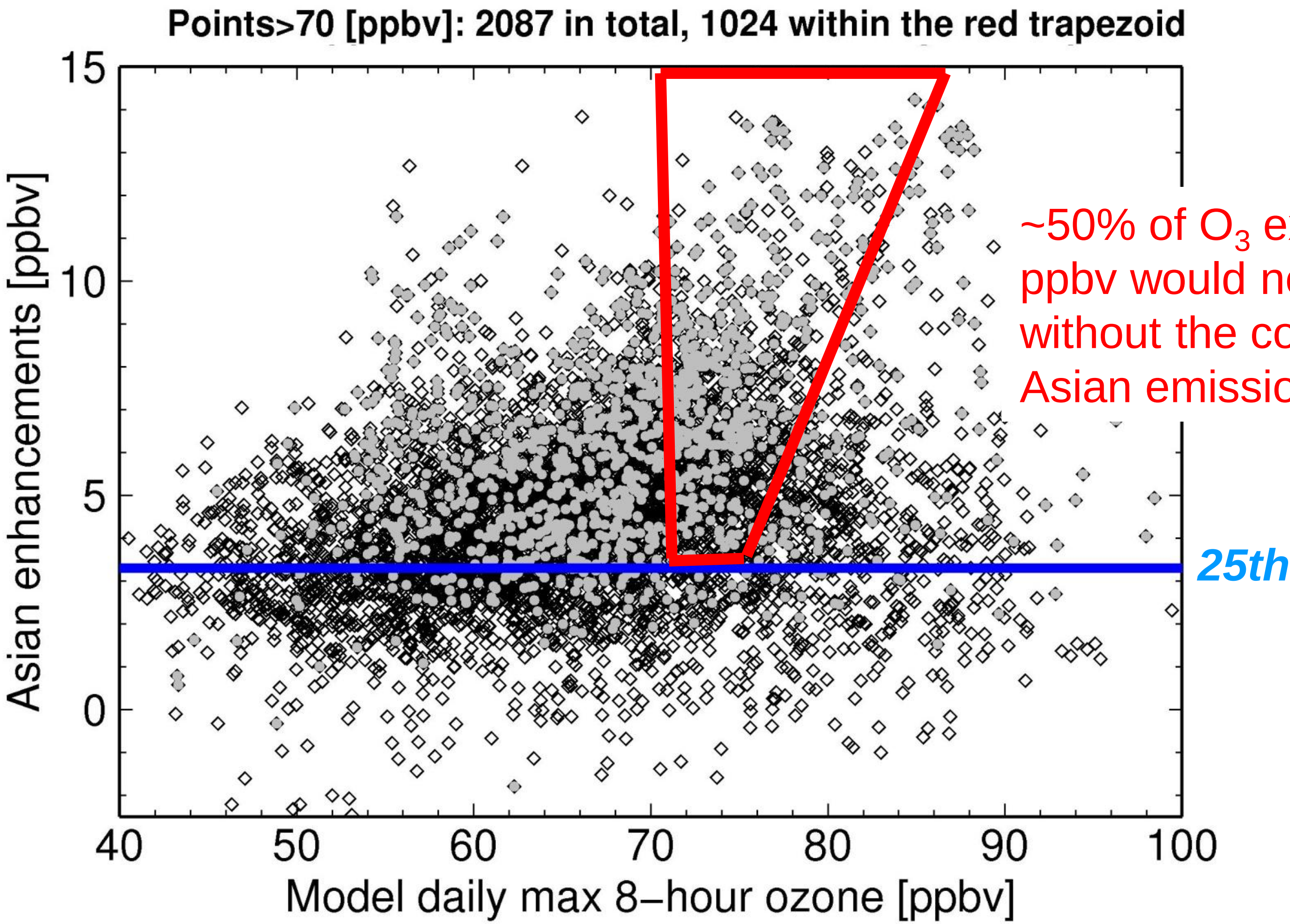
Subsidence of stratospheric O_3 to the lower trop of S. California (May 28, 2010)



→ O_3-strat contributes ~75% to enhanced O_3 >100 ppbv at 2-5 km a.s.l.

→ Consistent with observed low humidity; NA emissions contribute little

Simulated Asian pollution contribution to high surface O_3 events over Southern California



~50% of O_3 exceedances of 70 ppbv would not have occurred without the contribution from Asian emissions

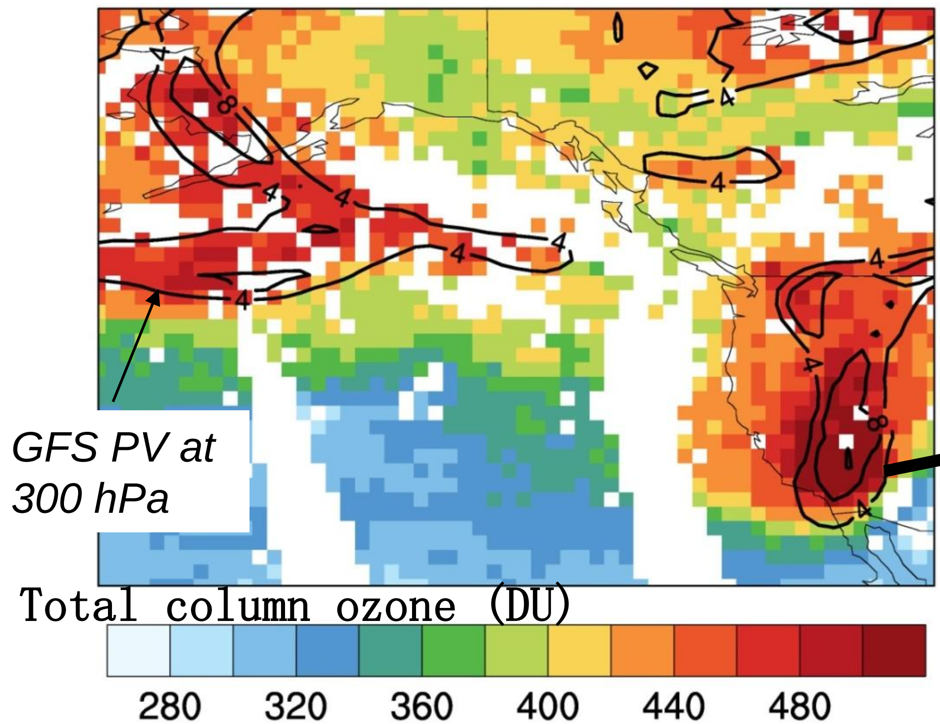
→ Asian emissions contribute no more than 20% of total O_3 (local influence dominates)

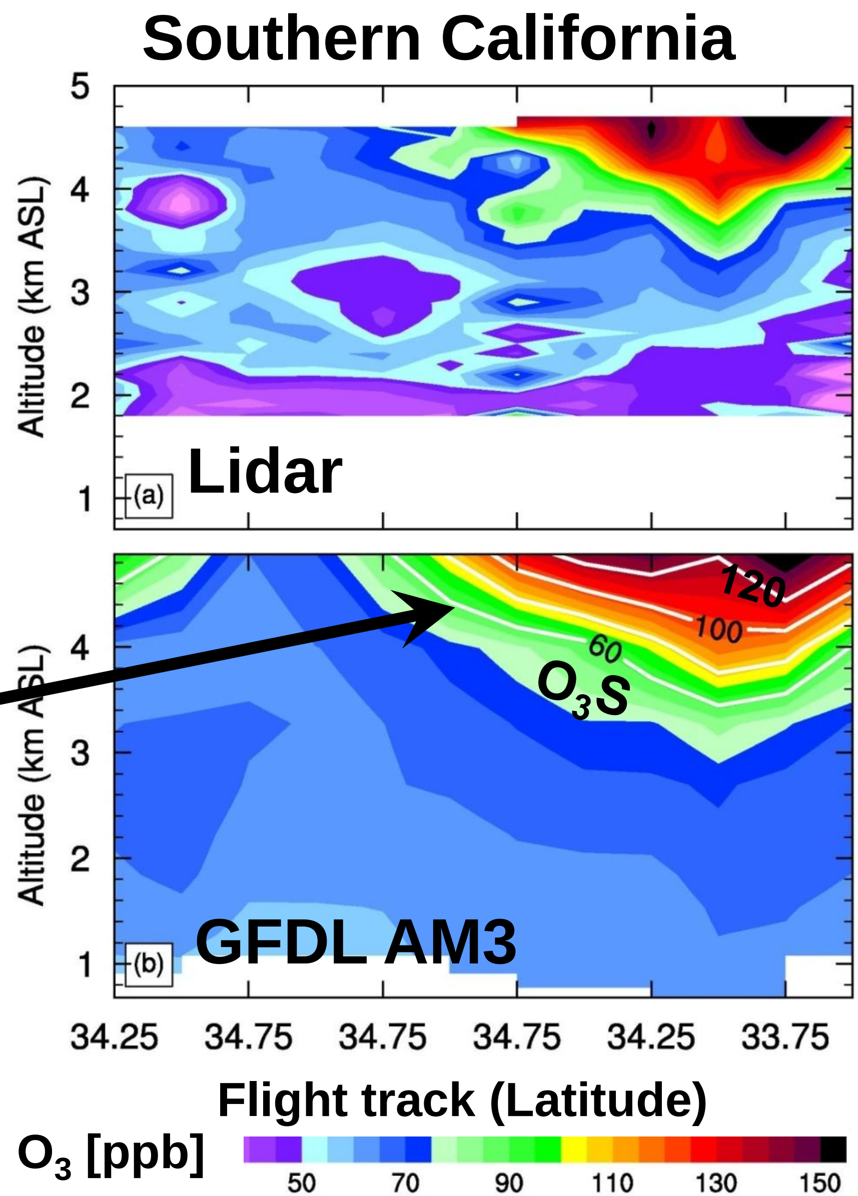
→ **Asian enhancements increase for total ozone in the 70-90 ppbv range**

Lin et al., 2012a, JGR (AGU Editors' Highlight; featured in Science, Nature News)

Total column O_3 retrievals capture the **dynamical variability** of O_3 due to a stratospheric intrusion (N→S)

Aqua AIRS Ascending, May 23, 2010
[V5.2; *Susskind et al., 2003*]

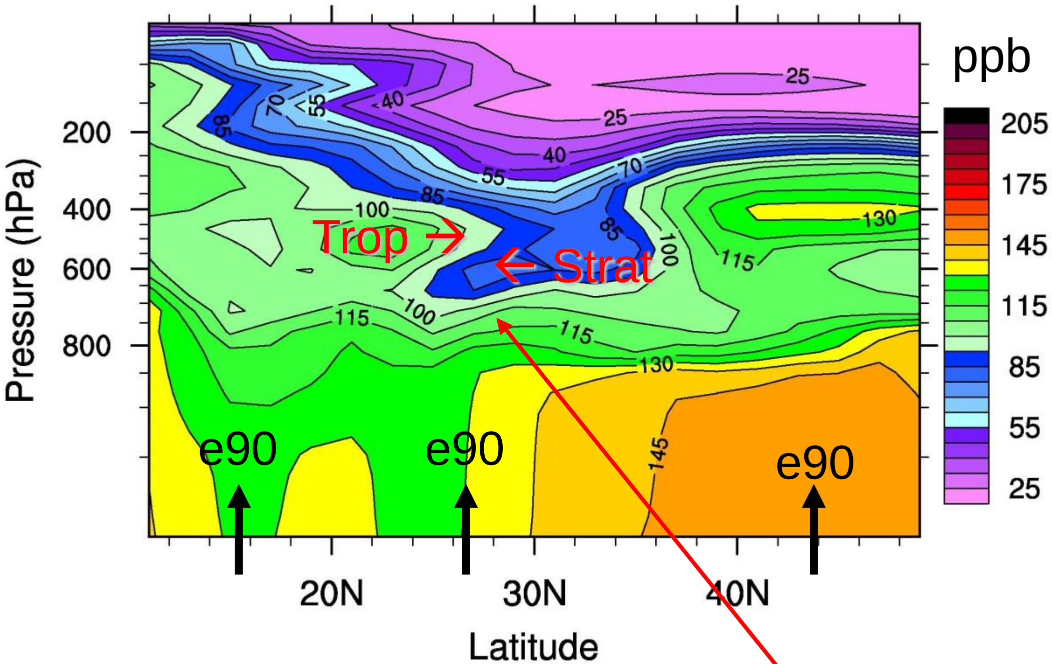




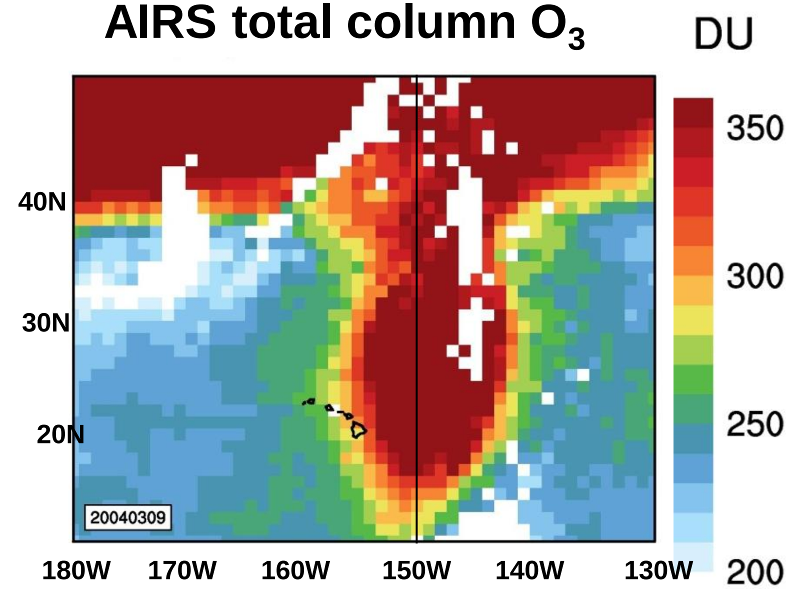
Consistent dynamic features in AIRS, PV, model and lidar measurements
[see also *Pan et al., 2007; Pittman et al., 2009; Wei et al., 2010*]

e90 tropopause tracer and O_3-Strat tagging in GFDL AM3: showing a deep intrusion over Hawaii on March 9, 2004

e90 vertical cross-section at 150W



AIRS total column O_3



Dynamically varying e90 tropopause tracer *[Prather et al., 2011]:*

1) *Emitting at the surface uniformly and statically; 90-day e-folding lifetime*
2) Differentiate **stratospheric** (< 85 ppb) vs. **tropospheric** (>= 85 ppbv) air

Stratospheric O_3 tracer (O_3S) *[Lin et al., 2012b]:*

1) Set to simulated O_3 in stratospheric air; allowing multiple tropopauses
2) Subject to chemical and depositional loss in tropospheric air

…Transport of O_3, O_3S, and e90 fully driven by meteorology…