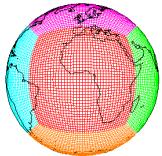


Analyzing western U.S. air quality with models and satellite data



Arlene M. Fiore

Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

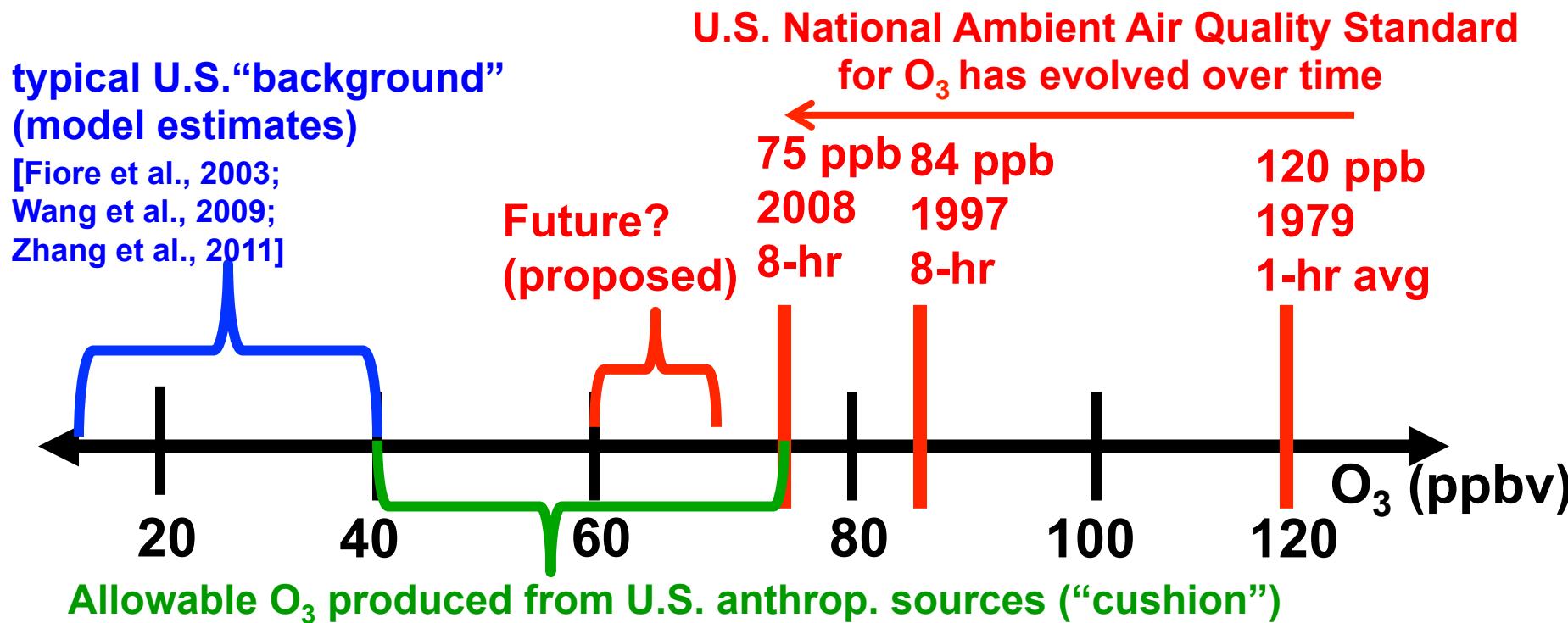
COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

Acknowledgments. Meiyun Lin (Princeton), Vaishali Naik (GFDL), Larry Horowitz (GFDL), Jacob Oberman (U WI), Harald Rieder (CU/LDEO)



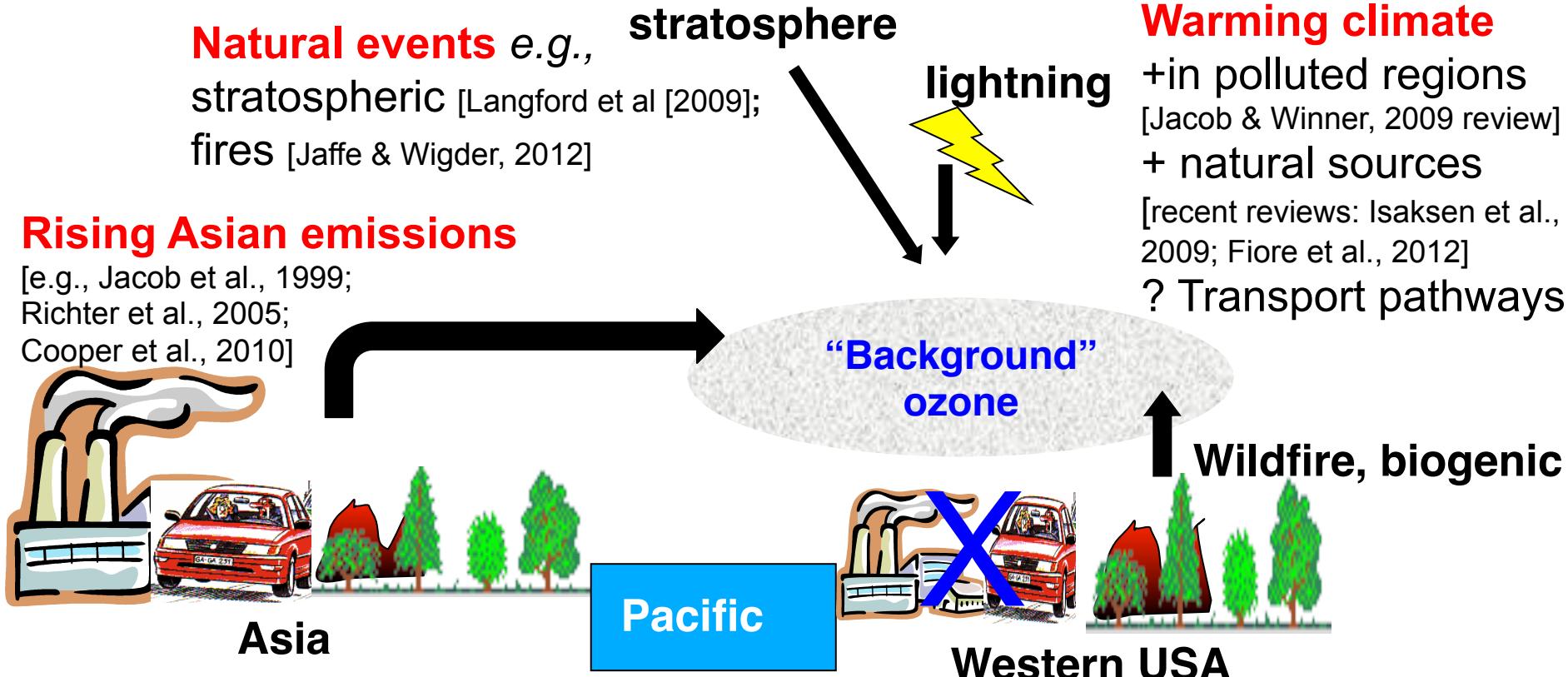
WESTAR Council & University of Nevada
Conference on Western Ozone Transport
Reno, NV, October 11, 2012

The Problem



Lowering thresholds for U.S. O₃ NAAQS implies thinning cushion
between regionally produced O₃ and background

Some challenges for WUS O₃ air quality management



Need process-level understanding on daily to multi-decadal time scales

- Today's talk:
- 1) Intro: satellites + models
 - 2) NASA AQAST Overview
 - 3) Results for WUS from two collaborative AQAST projects
 - 4) Air quality projections in a warming climate

Satellite instruments for tropospheric O₃ and its precursors

Nadir viewing; near-polar, sun-synchronous, low Earth orbits

Table 2.1. Current nadir-viewing satellite remote sensing of tropospheric ozone and its precursors

Instrument	Platform	Meas. Period	Typical Nadir Res. (km)	Equator Crossing Time ^a	Global coverage (days) ^b	Spectral Range (μm)	NO ₂	HCHO	CO	O ₃
MOPITT	Terra	2000-	22x22	10:30	3.5	 2.3, 4.7			X	
AIRS	Aqua	2002-	14x14	1:30	1	 3.7-16			X	
SCIAMACHY	Envisat	2002-	60x30	10:00	6	 0.23-2.3	X	X	X	X
OMI	Aura	2004-	24x13	1:45	1	 0.27-0.50	X	X		X
TES	Aura	2004-	8x5	1:45	n/a	 3.3-15.4			X	X
GOME-2	MetOp	2006-	80x40	9:30	1	 0.24-0.79	X	X		X
IASI	MetOp	2006-	12x12	9:30	0.5	 3.6-15.5			X	X

^aCrossing time occurs at both AM and PM.

^bValue given for clear-sky conditions. Clouds impede the retrieval.

^cMOPITT: Measurements Of Pollution In The Troposphere; AIRS: Atmospheric Infrared Sounder;
SCIAMACHY: SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY; OMI: Ozone Monitoring Instrument; TES: Tropospheric Emission Spectrometer; GOME: Global Ozone Monitoring Experiment; IASI: Infrared Atmospheric Sounding Interferometer

HTAP 2010, Part A

Solar backscatter

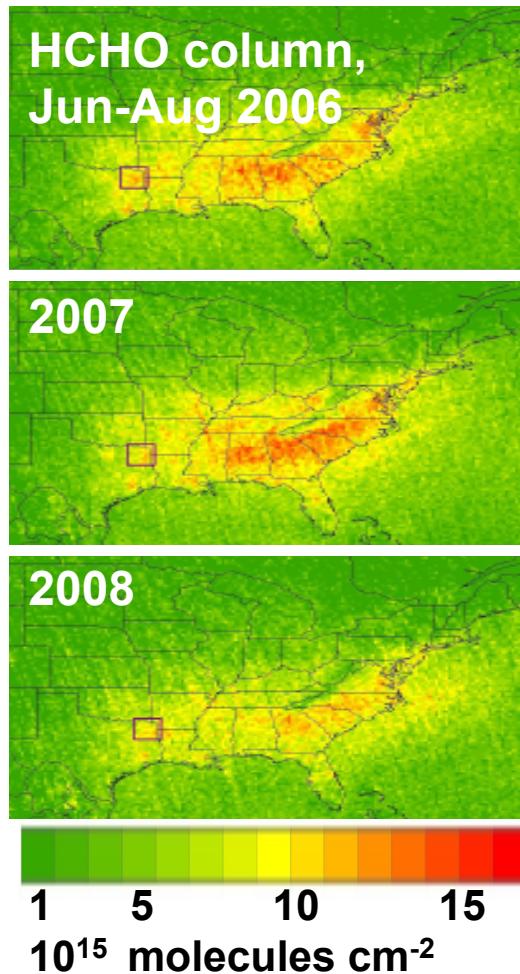
Thermal Emission

See also reviews: Martin et al., Atm. Env, 2008; Fishman et al., BAMS, 2008

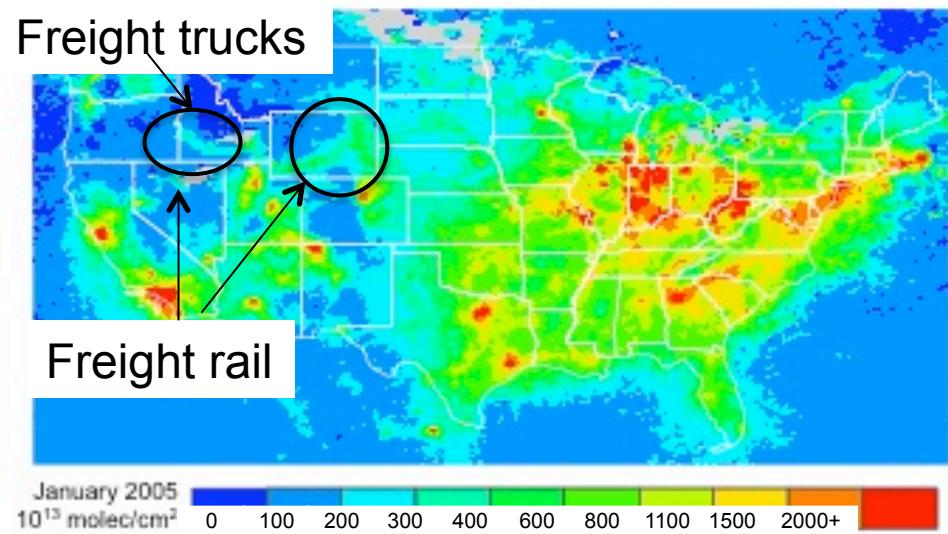
How can satellite data help address AQ challenges?

Examples: Improve regional source characterization

OMI HCHO → isoprene emissions



OMI NO₂ columns → NOx emissions



Erica Bickford & Tracey Holloway, UW-Madison

AQAST PI: Holloway

- Improved spatial & temporal source information
- Improved emissions for SIP modeling and AQ forecasting
- National NO₂ monitoring to fill in AQS gaps

Lei Zhu, Harvard

AQAST PIs: Mickley, Cohan

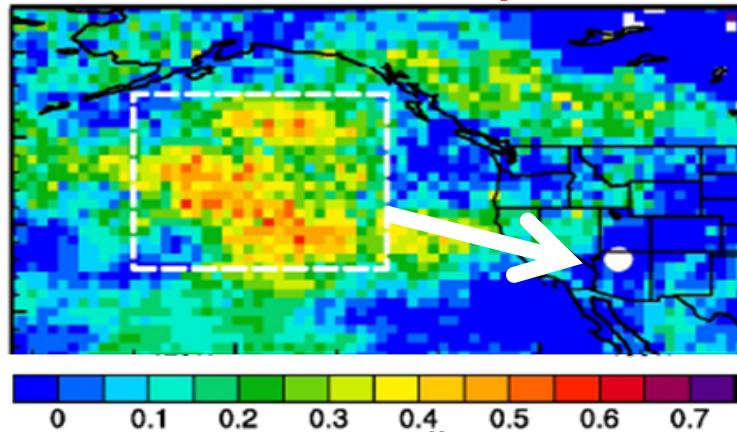


Satellite products indicate potential for contributions from transported “background”

Fires: MODIS

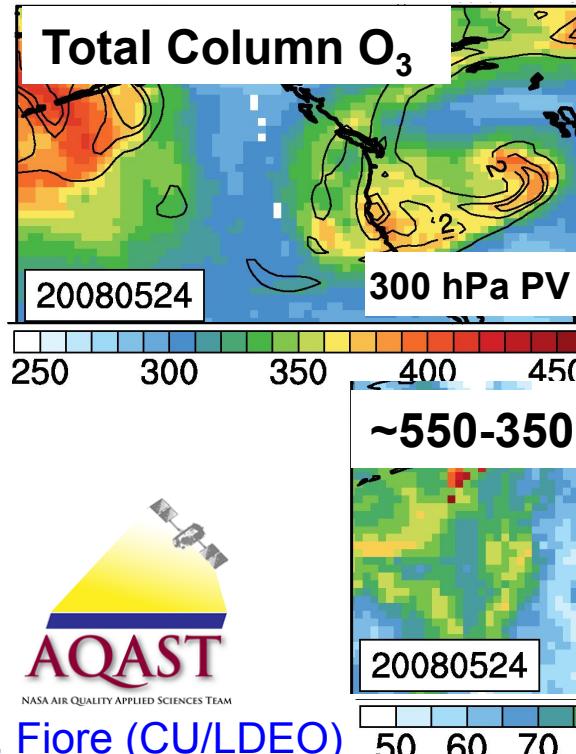


Intercontinental transport: AIRS

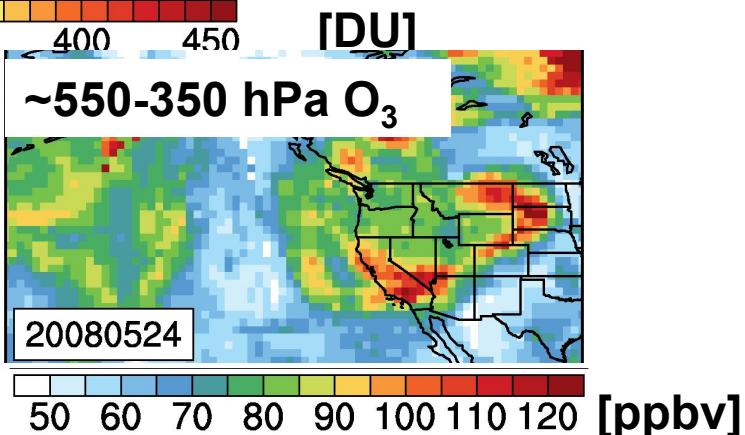


Asian pollution forecasting with
AIRS CO columns (Lin et al., 2012a)

Stratospheric intrusions: OMI



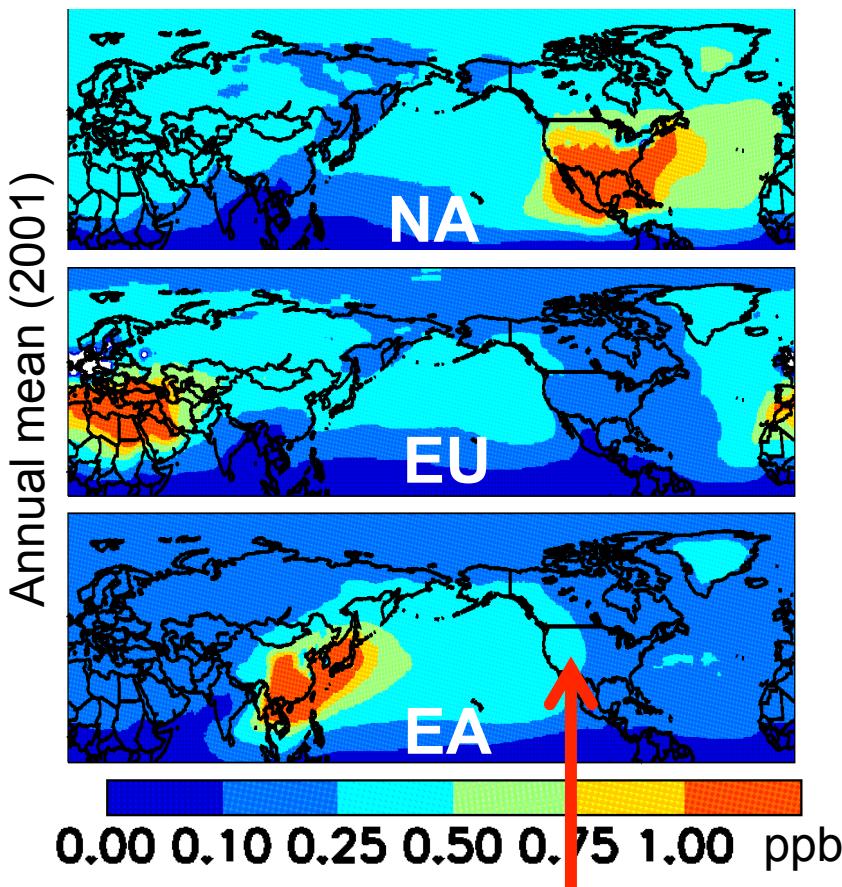
A. Fiore (CU/LDEO)
M. Lin (Princeton)



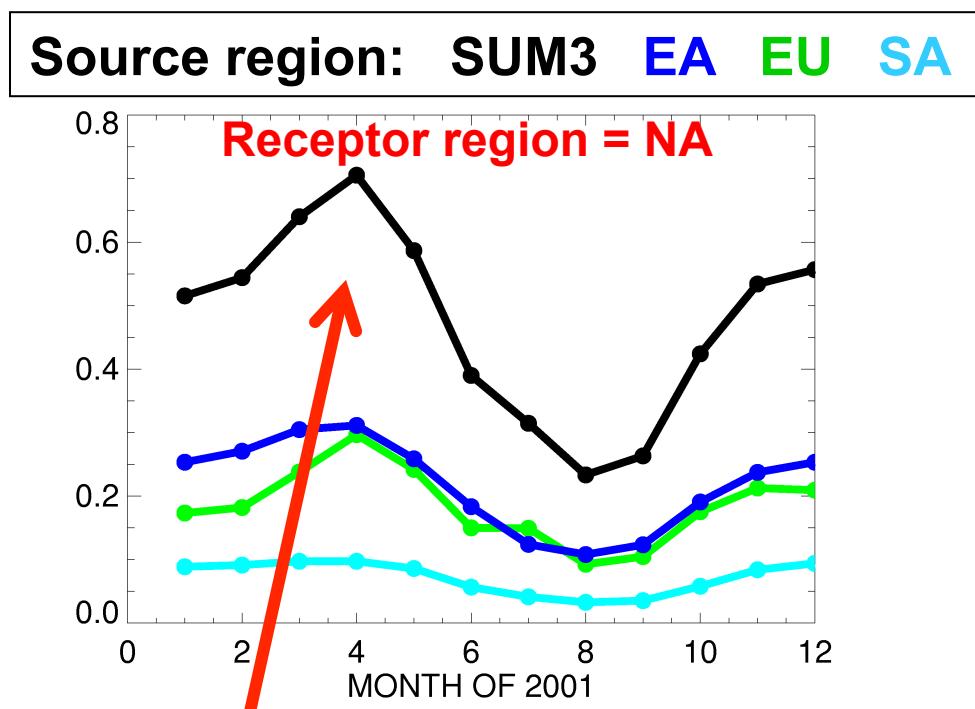
- Indicate potential downwind influence
- Public health alerts
- Identify exceptional events
- Quantitative estimates require models

Model estimates for components of background: Intercontinental O₃ transport

15- MODEL MEAN SURFACE O₃ DECREASE (PPBV)
when regional anthrop. O₃ precursor emissions are reduced by 20%



Spatial variability over receptor region
[also Reidmiller et al., 2009; Lin et al., 2010]



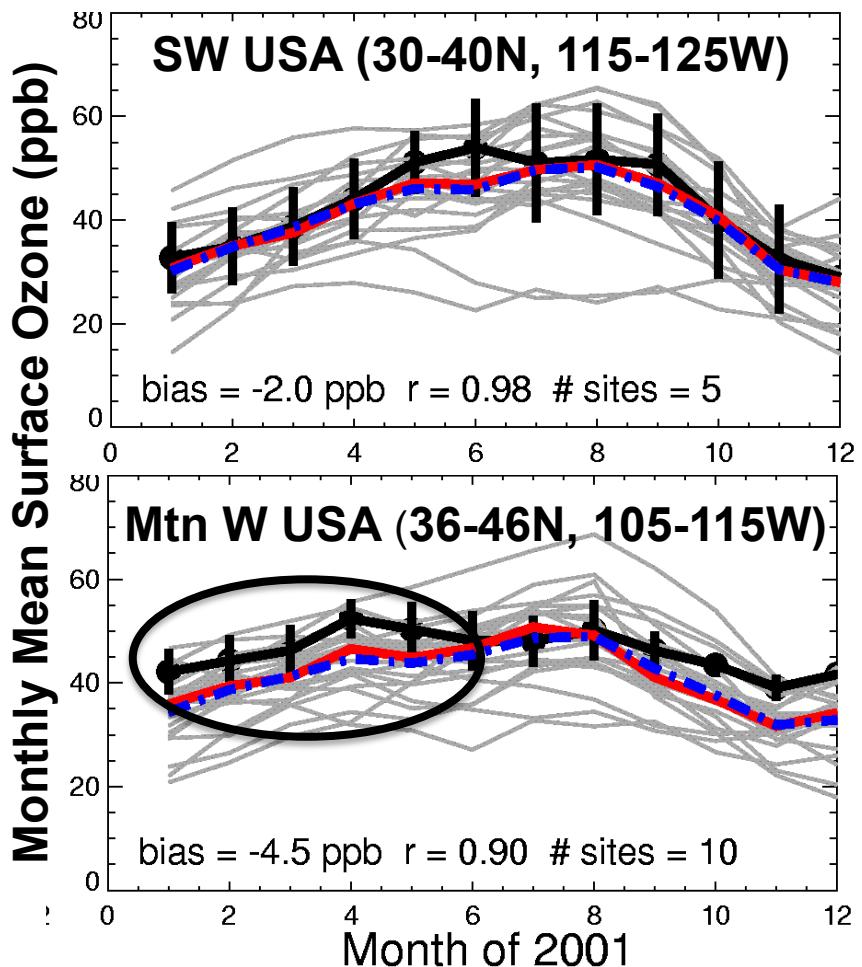
Spring max (longer lifetime, efficient transport) [e.g., Wang et al., 1998; Wild and Akimoto, 2001; Stohl et al., 2002]



Task Force on Hemispheric Transport of Air Pollution

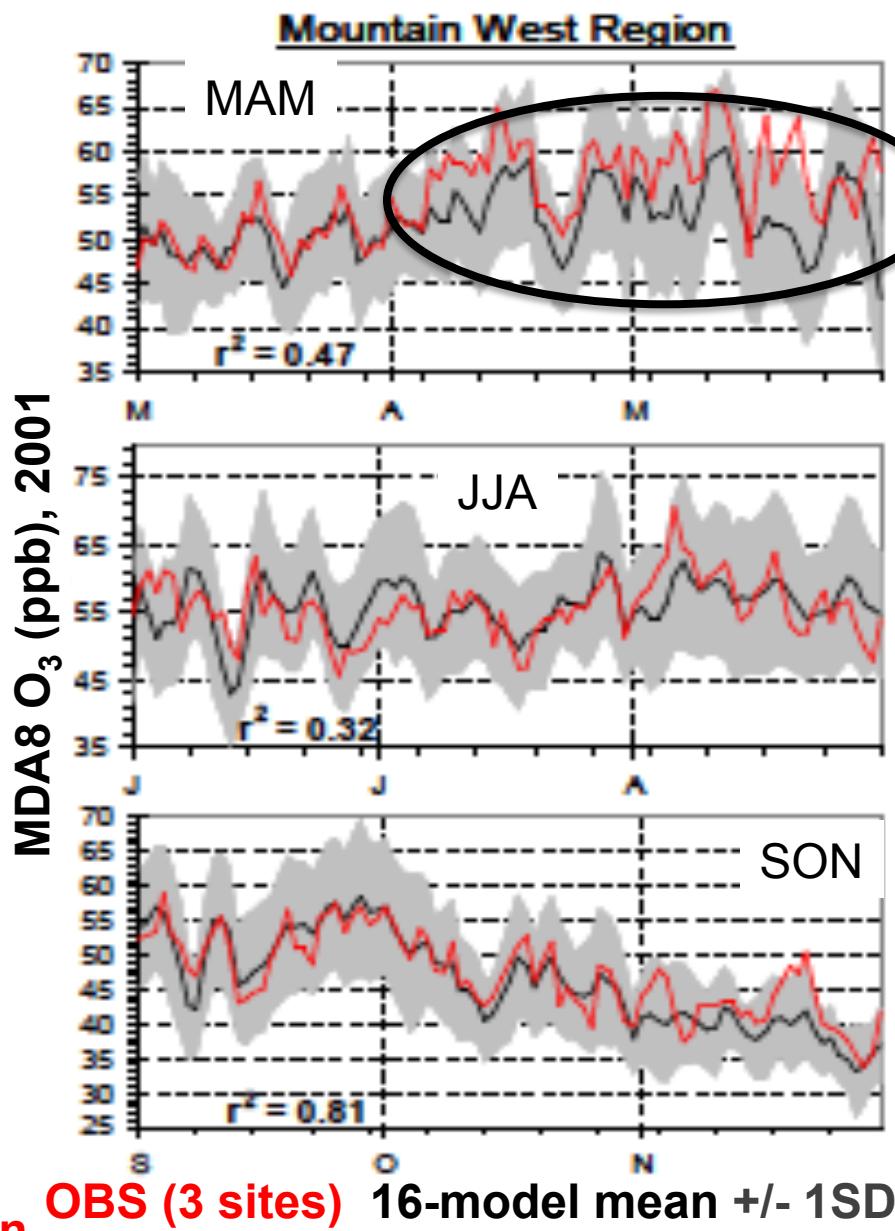
Fiore et al., JGR, 2009; TF HTAP 2010

Model evaluation with obs. crucial to identify problems/robust features



OBS Individual models Model Median/Mean

Fiore et al., 2009



OBS (3 sites) 16-model mean +/- 1SD

Reidmiller et al., 2009

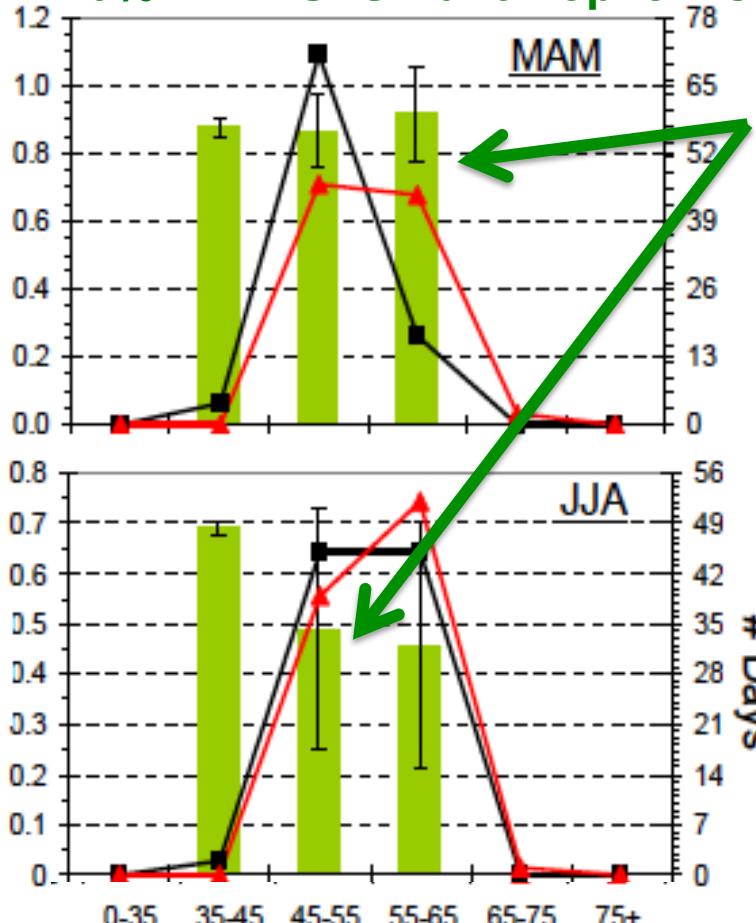
Response of surface ozone over Mountain West to foreign vs. domestic emission reductions binned by total O₃ level

Reidmiller et al., ACP, 2009

■ # Days_Multi-model mean

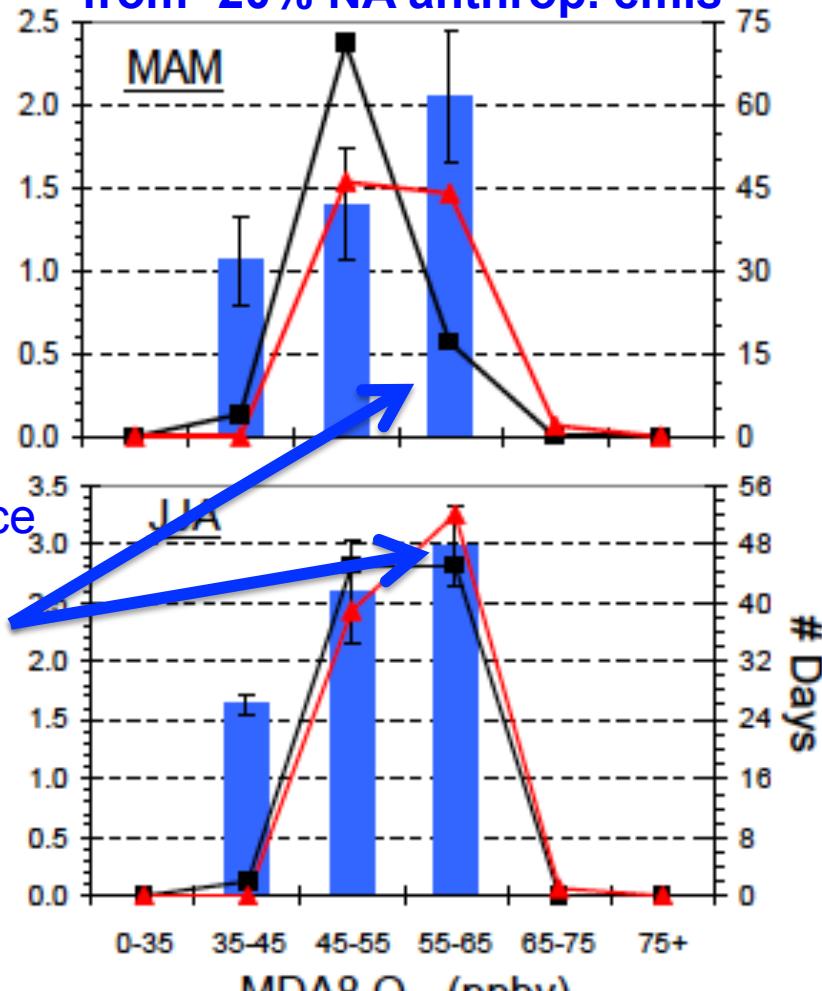
↑ # Days_Obs

Decrease in surface O₃ (ppb) from -20% EA+EU+SA anthrop. emis



Response to foreign emissions similar throughout distribution; declines in summer

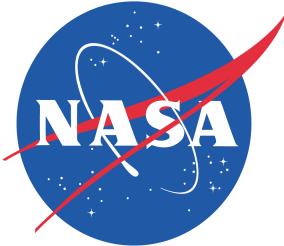
Decrease in surface O₃ (ppb) from -20% NA anthrop. emis



NA influence largest for highest events + increases spring to summer

MDA8 O₃ (ppbv)

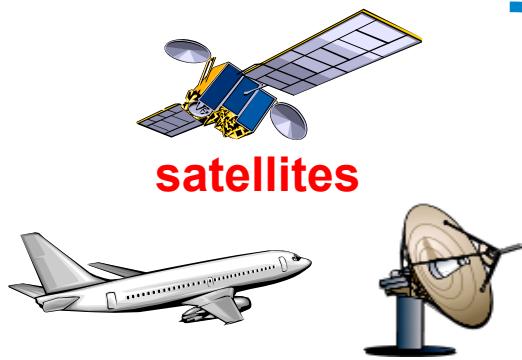
→ Need to evaluate/constrain processes



Air Quality Applied Sciences Team (AQAST)

NASA initiative, begun in 2011, builds a bridge between Earth science resources and air quality management needs.

Earth science resources



satellites



suborbital platforms



models



Air Quality Management Needs

- Pollution monitoring
- Exposure assessment
- AQ forecasting
- Source attribution of events
- Quantifying emissions
- Nat & foreign influences
- AQ processes
- Climate-AQ interactions

AQAST members

- **Daniel Jacob (leader)**, Loretta Mickley (Harvard)
- **Greg Carmichael** (U. Iowa)
- **Dan Cohan** (Rice U.)
- **Russ Dickerson** (U. Maryland)
- **Bryan Duncan**, Yasuko Yoshida, Melanie Follette-Cook (NASA/GSFC); Jennifer Olson (NASA/LaRC)
- **David Edwards** (NCAR)
- **Arlene Fiore** (Columbia/LDEO); Meiyun Lin (Princeton)
- **Jack Fishman**, Ben de Foy (Saint Louis U.)
- **Daven Henze**, Jana Milford (U. Colorado)
- **Tracey Holloway**, Steve Ackerman (U. Wisconsin); Bart Sponseller (Wisconsin DRC)
- **Edward Hyer**, Jeff Reid, Doug Westphal, Kim Richardson (NRL)
- **Pius Lee**, Tianfeng Chai (NOAA/NESDIS)
- **Yang Liu**, Matthew Strickland (Emory U.), Bin Yu (UC Berkeley)
- **Richard McNider**, Arastoo Bazar (U. Alabama – Huntsville)
- **Brad Pierce** (NOAA/NESDIS)
- **Ted Russell**, Yongtao Hu, Talat Odman (Georgia Tech); Lorraine Remer (NASA/GSFC)
- **David Streets** (Argonne)
- **Jim Szykman** (EPA/ORD/NERL)
- **Anne Thompson**, William Ryan, Suellen Haupt (Penn State U.)

AQAST organization



- AQAST members are appointed for five years (starting May 2011)
- **Investigator Projects (IPs) with core funding, adjusted annually to reflect AQ needs**
- **Tiger Team Projects (TTPs) competed on annual basis to address urgent air quality management needs.**
- All AQAST projects involve partnerships with air quality managers and have deliverable air quality management outcomes
- Biannual AQAST meetings provide forums for dialogue with air quality managers: NCAR (May 2011), EPA (Nov 2011), U. Wisconsin (Jun 2012), Cal/EPA (Nov 2012)
- AQAST workshops, AQAST representation at air quality meetings, four special sessions and Town Hall at the Fall 2012 AGU...

Scope of current AQAST projects

Partner agency

- **Local:** RAQC, BAAQD
- **State:** TCEQ, MDE, Wisconsin DNR, CARB, Iowa DNR, GAEPD, GFC
- **Regional:** LADCO, EPA Region 8
- **National:** EPA, NOAA, NPS

Theme



Earth Science resource

AQAST products for AQ managers & public outreach

1. Easily obtain useful data in familiar formats

Custom OMI NO₂ “Level 3” products on any grid in netCDF with WHIPS (*Holloway*)

Annual NO₂ shapefiles - OMI & CMAQ on CMAQ grids
(AQAST *Tiger Team*)

Google Earth

2. Find easy-to-use guidance & example scripts for understanding OMI products and comparing to simulated troposphere & PBL concentrations

One-stop user portal (*Holloway & AQAST Tiger Team*)

OMI NO₂ & SO₂ guidance, field campaign example case studies (*Spak & AQAST Tiger Team*)

3. Obtain OMI observational operators for assimilation & emissions inversion in CMAQ

- NO₂ in GEOS-Chem → CMAQ (*Henze, Pye*)
- SO₂ in STEM → CMAQ (*Spak, Kim*)
- O₃ in STEM → CMAQ (*Huang, Carmichael, Kim*)

PI: Duncan, AQAST Lenticular



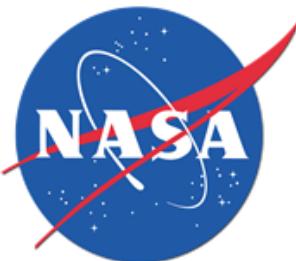
PI: Jack Fishman, Ozone garden at the Missouri Botanical Gardens



AQAST PIs: Carmichael, Spak c/o D.J. Jacob

COMMUNICATION TOOLS

- Website: <http://acmg.seas.harvard.edu/aqast>



AIR QUALITY APPLIED SCIENCES TEAM (AQAST)

EARTH SCIENCE SERVING AIR QUALITY MANAGEMENT NEEDS

AQAST is a NASA team of atmospheric scientists working in partnership with US air quality managers to exploit the power of Earth Science tools to address air quality issues. We conduct a wide range of projects using satellite data, suborbital data, and models, and work with air quality agencies from the local to the national level. Please browse through this web site to see what AQAST is all about!

[Home](#) [What is AQAST?](#) [Members](#) [Projects](#) [Publications](#) [Events](#) [Newsletter](#)

- **Newsletter: subscribe through website**



AQAST newsletter January 2012

Welcome to the January 2012 newsletter of the NASA Air Quality Applied Sciences Team (AQAST). This bimonthly newsletter keeps you up to date on AQAST publications, activities, and events. Catch up by reading [previous newsletters](#). Visit regularly the [AQAST website](#) for more detailed information on ongoing projects. Subscribe/unsubscribe to this newsletter by email to [Bob Yantosca](#).

If you have a specific problem for which you need information or assistance please contact team leader Daniel Jacob (Harvard U).

Tiger Team activity: Key factors contributing to differences in model estimates for O₃ “background”

Problem: Poorly quantified errors in background distributions complicate NAAQS-setting and interpreting SIP attainment simulations

To date, EPA NAB estimates have been provided by one model.

Approach:

- 1) Compare GFDL AM3 and GEOS-Chem NAB (regional, seasonal, daily)
- 2) Process-oriented analysis of factors contributing to model differences

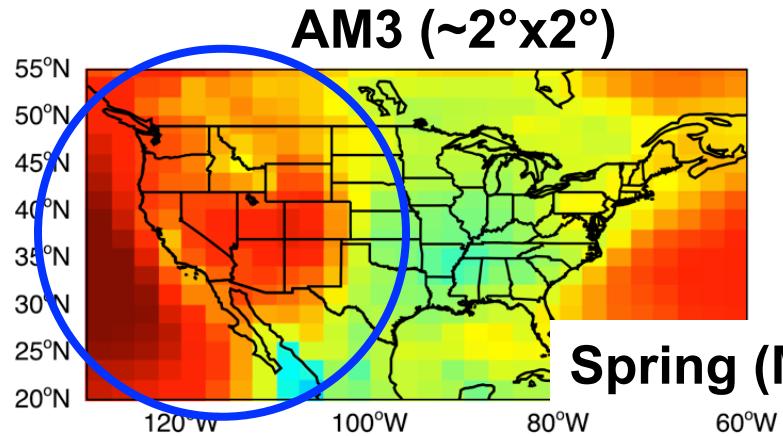
YEAR 2006	GEOS-Chem	GFDL AM3
Resolution	$\frac{1}{2}^\circ \times \frac{2}{3}^\circ$ (and $2^\circ \times 2.5^\circ$)	$\sim 2^\circ \times 2^\circ$
Meteorology	Offline (GEOS-5)	Coupled, nudged to NCEP U and V dynamics
Strat. O ₃ & STE	Parameterized	
Isoprene nitrate chemistry	18% yield recycling	IO _x recycling (obs + al, 2007)
Lightning NO _x	tied to model convective clouds, scaled to obs. flash climat; higher NO _x at N. mid-lat	tied to model convective clouds
Emissions	NEI 2005 + 2006 fires (emitted at surface)	ACCMIP historical + RCP4.5 (2005, 2010); vert. dist. climatological fires

ALL DIFFERENT!

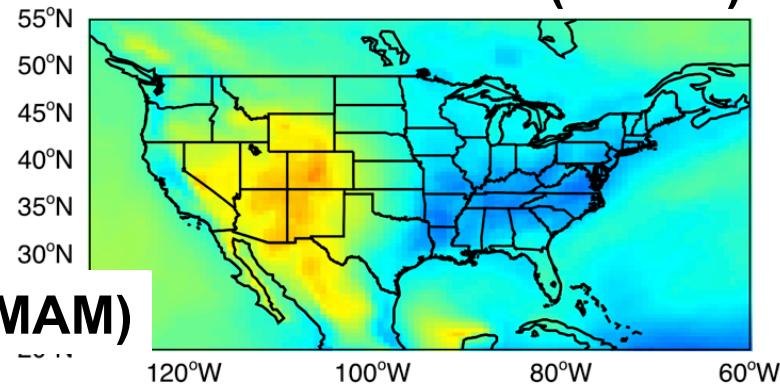
Models differ in estimates of North American background (estimated by simulations with N. American anth. emissions set to zero)

North American background (MDA8) O₃ in model surface layer 2006

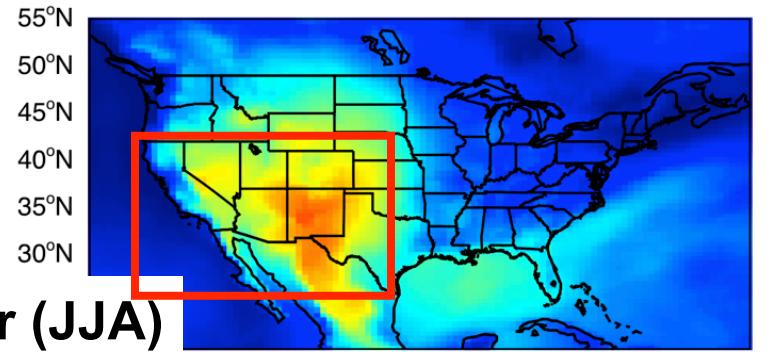
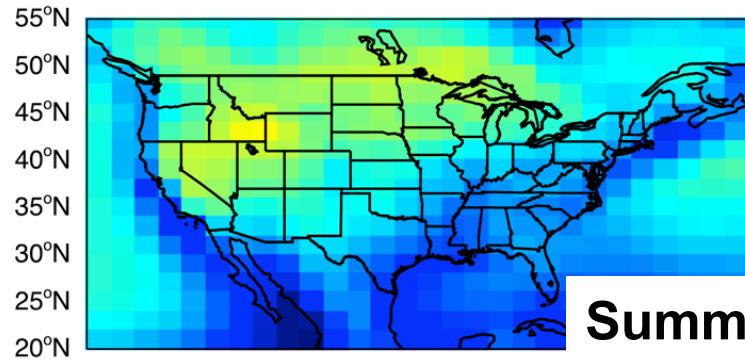
**AM3: More
O₃-strat +
PBL-FT
exchange?**



GEOS-Chem (1/2°x2°/3°)



**GC: More
lightning NO_x
(~10x over
SWUS;
too high)**



J. Oberman

15

25

35

45

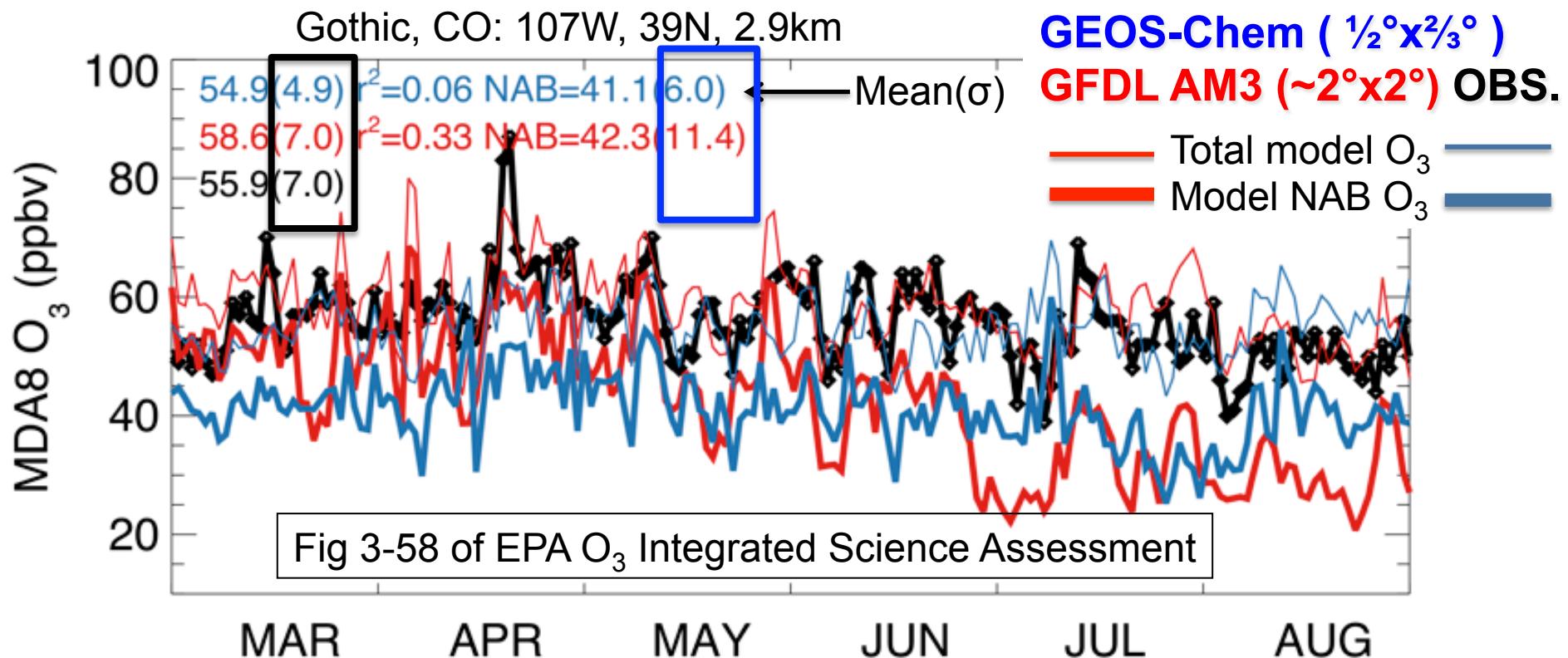
55

ppb



TTP PI: Fiore

Models differ in day-to-day and seasonal variability of N American background



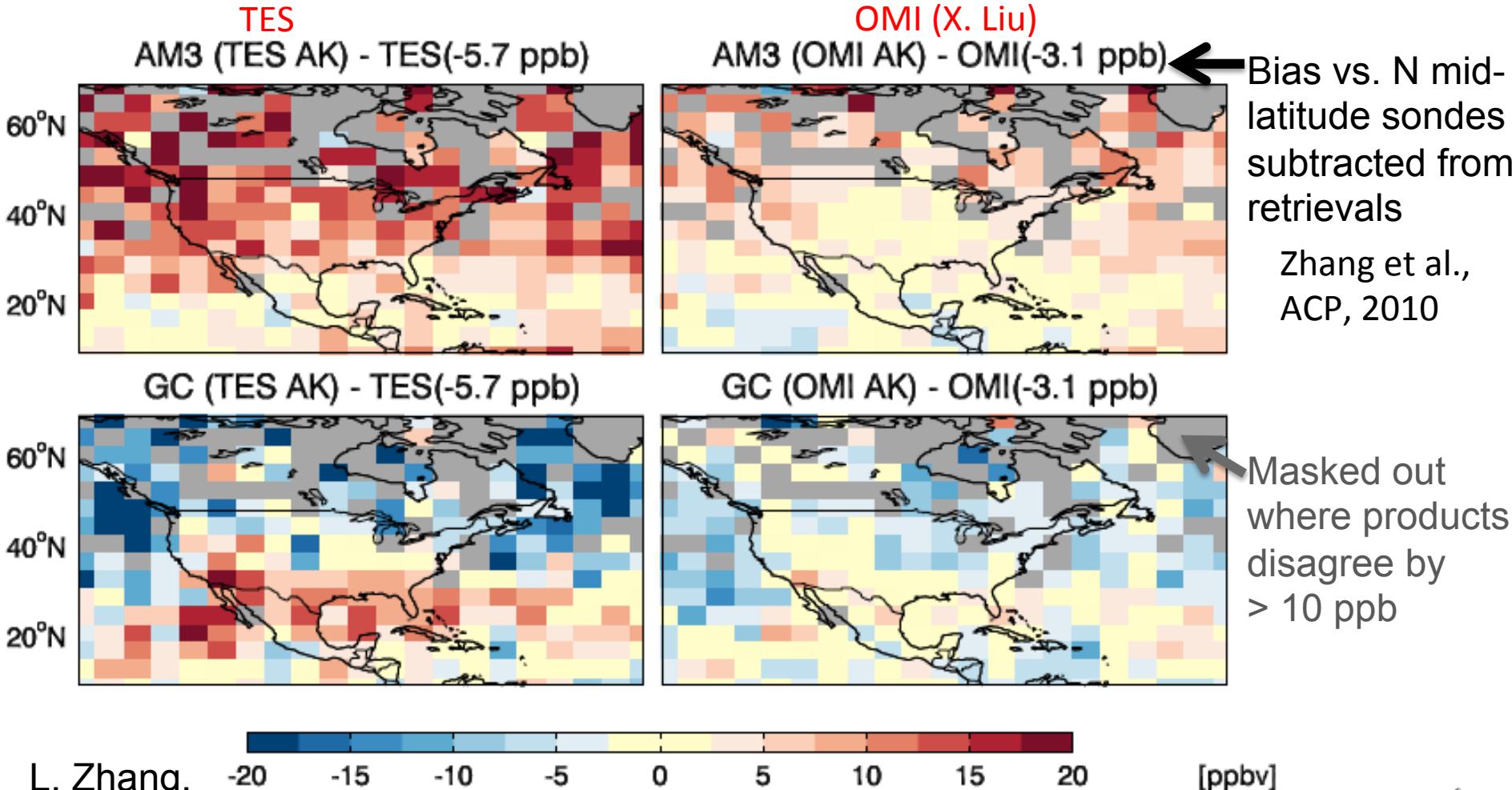
→ Models bracket OBS; similar mean N. American background

→ GC N. American background ~2x smaller σ than AM3

→ AM3 NAB > GC NAB in MAM (strat. O_3 ?); reverses in JJA (lightning)

Constraints on background O₃ from OMI and TES mid-tropospheric products

TES and OMI 500 hPa ozone for spring 2006 compared to AM-3 and GEOS-Chem



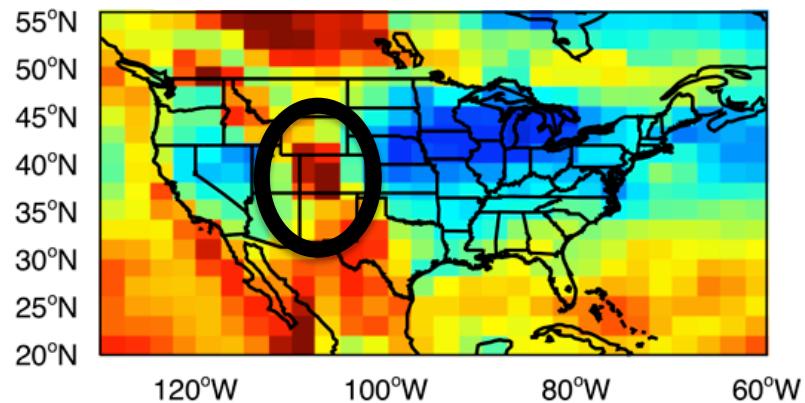
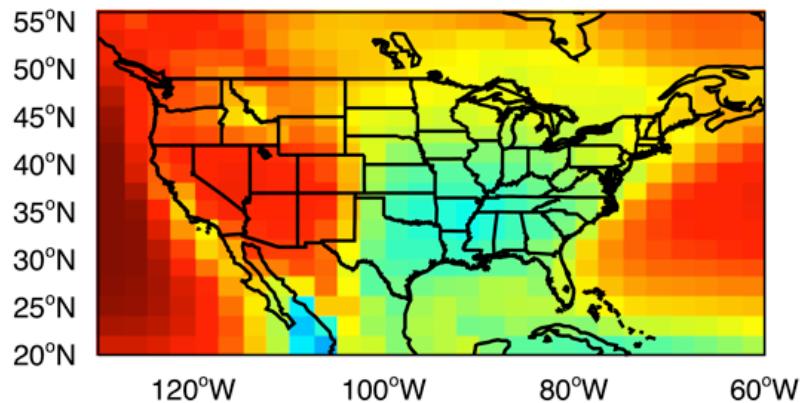
L. Zhang, Harvard → AM3 generally high; GEOS-Chem low

→ Implies that the models bracket the background

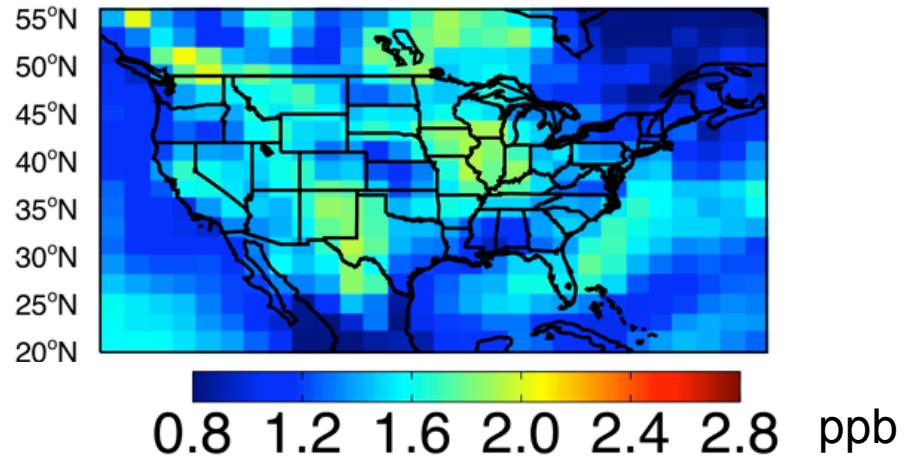
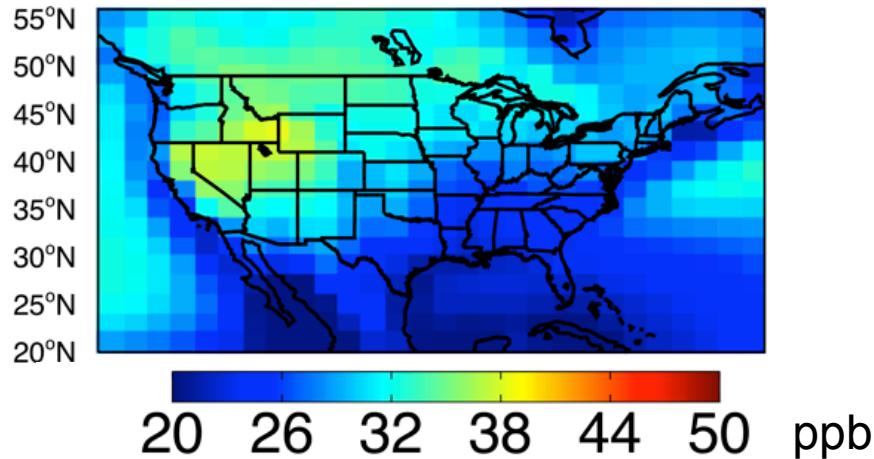
Variability in springtime O₃ background

GFDL AM3 simulation with N. American anthrop. emissions shut off (1981-2007)

MEAN OVER 27 YEARS MAR-APR-MAY STANDARD DEVIATION



JUN-JUL-AUG

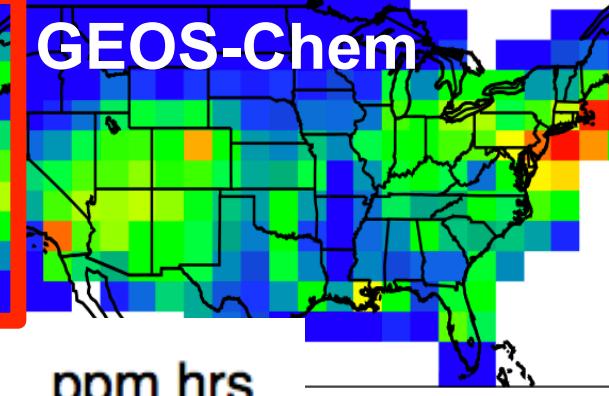
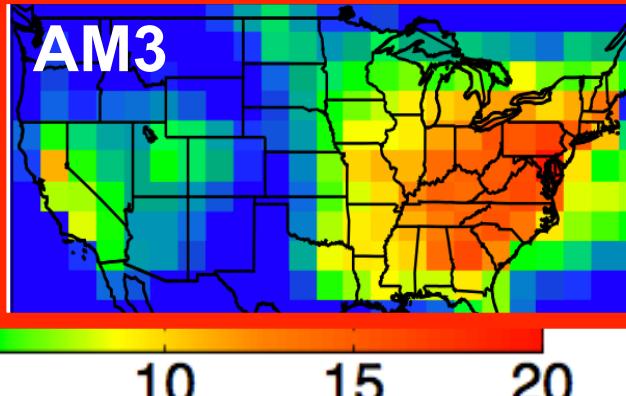
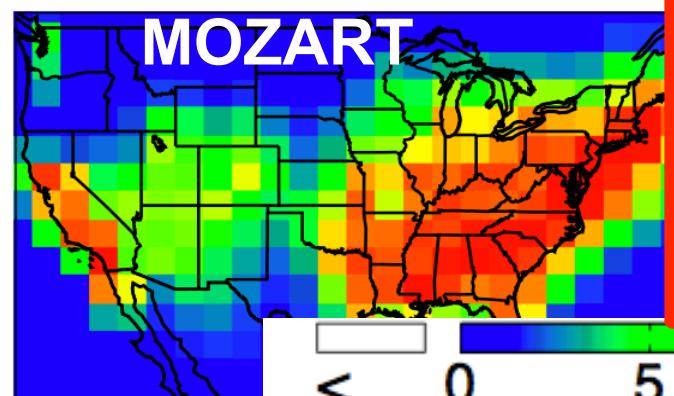
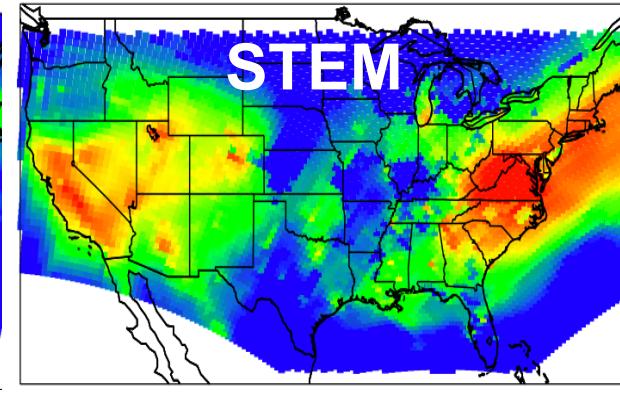
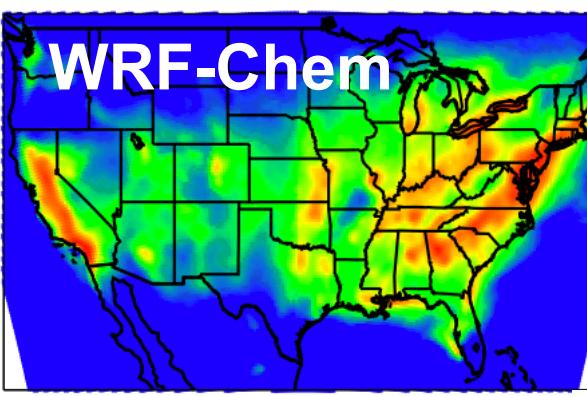
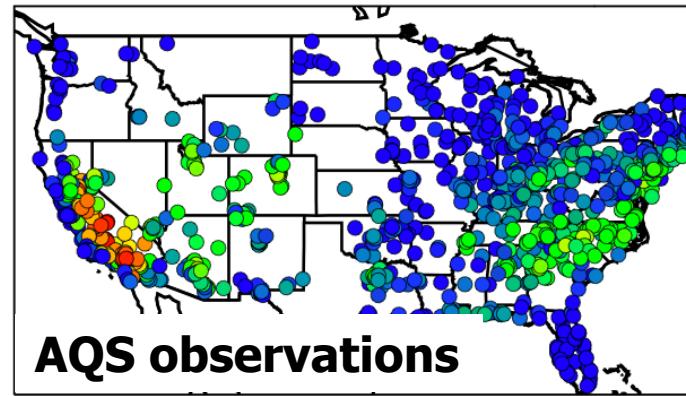
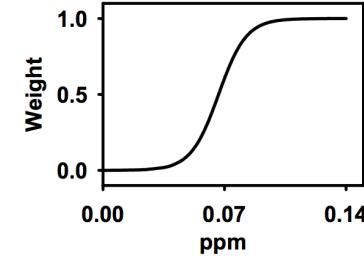


TTP: Model intercomparison of proposed secondary standard (vegetation) W126 metric

PI: Daven Henze, U Colorado



$$W126 \text{ (ppm-hr)} = \frac{1}{3} \sum_{a=1}^3 \left(\sum_{i=1}^n w_{i,a}([O_3]_{i,a}) \right)$$



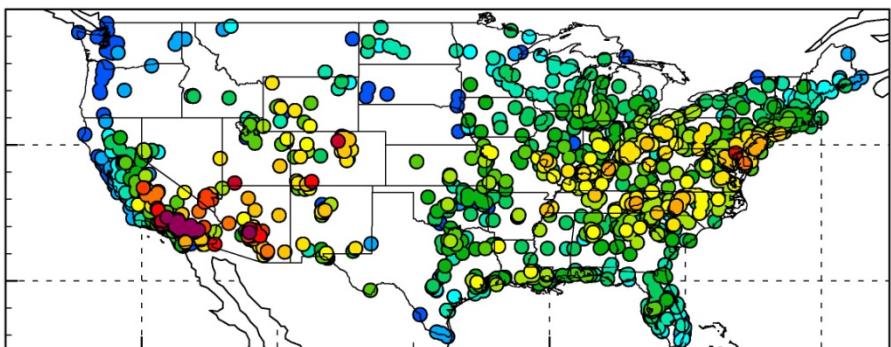
< 0 5 10 15 20
W126 in mid-June – mid-July 2008

ppm hrs
c/o Kateryna Lapina

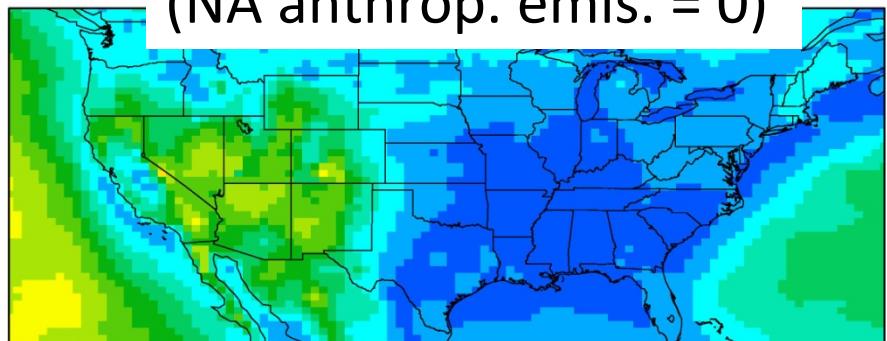
Simulated W126 Source Contributions

GFDL AM3 $\sim 50 \text{ km}^2$ global model, April-June 2010

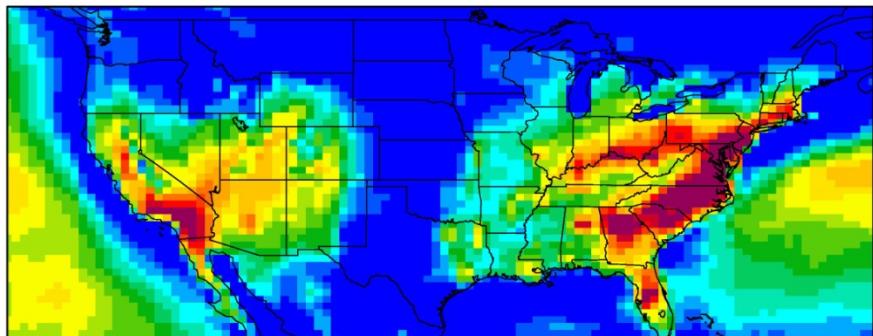
AQS OBSERVATIONS



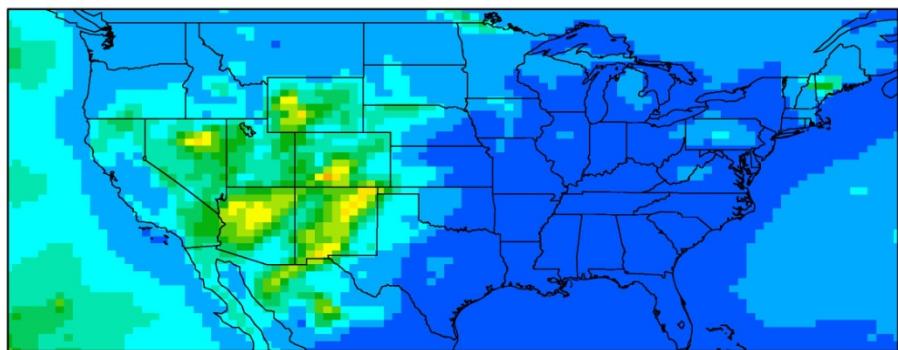
AM3 NA background
(NA anthrop. emis. = 0)



AM3 (total – 10 ppm-hours)

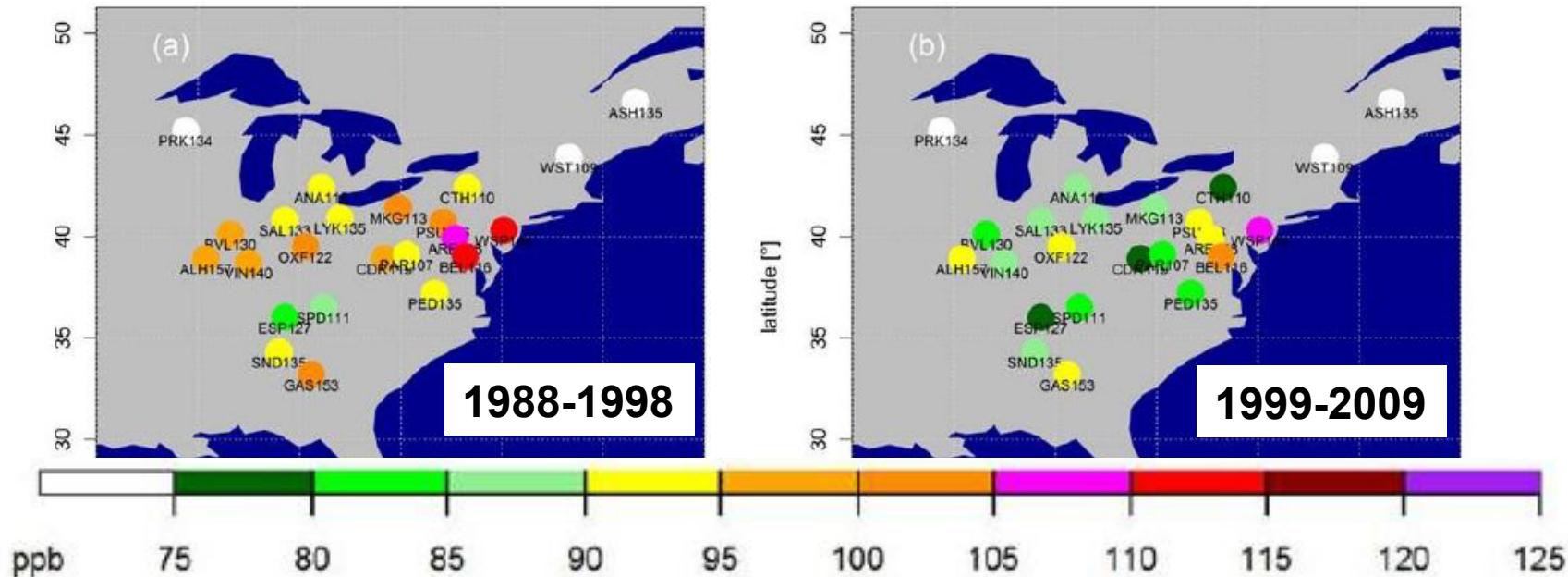


AM3 stratospheric * e^3



Quantifying extreme O₃ events in probabilistic terms: Initial application to Eastern USA

1-year return O₃ values at CASTNet measurement sites
(Statistical methods from extreme value theory)



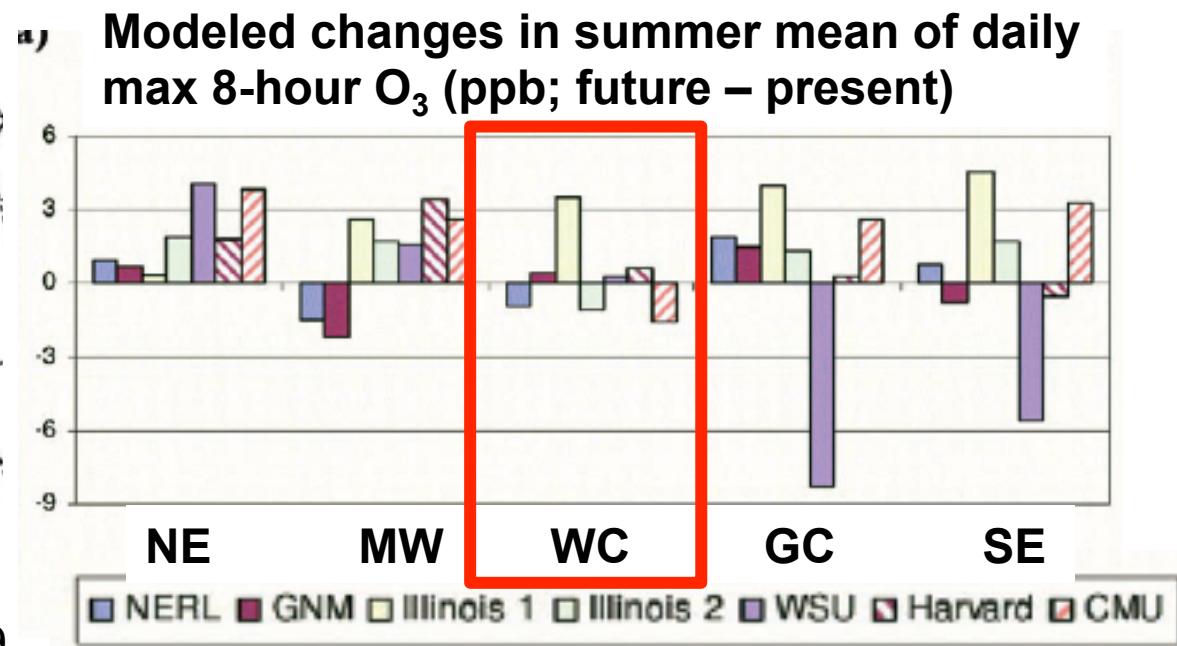
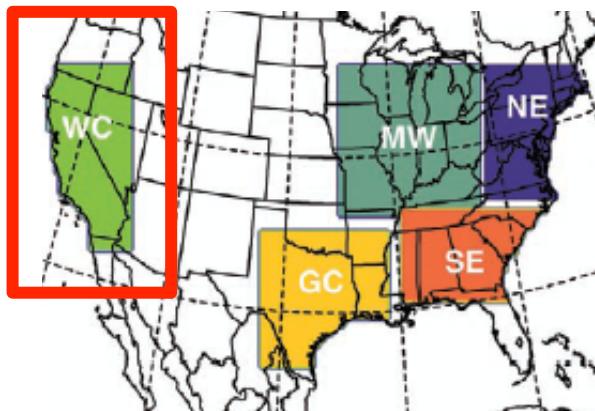
→ Dramatic decreases in 1-year return levels following NO_x SIP call

Rieder et al., submitted to ERL



How might climate warming influence
extreme pollution events?

Model estimates of climate change influence on U.S. surface ozone over Western U.S. disagree in sign



Weaver et al., BAMS, 2009

ROBUST FINDINGS:

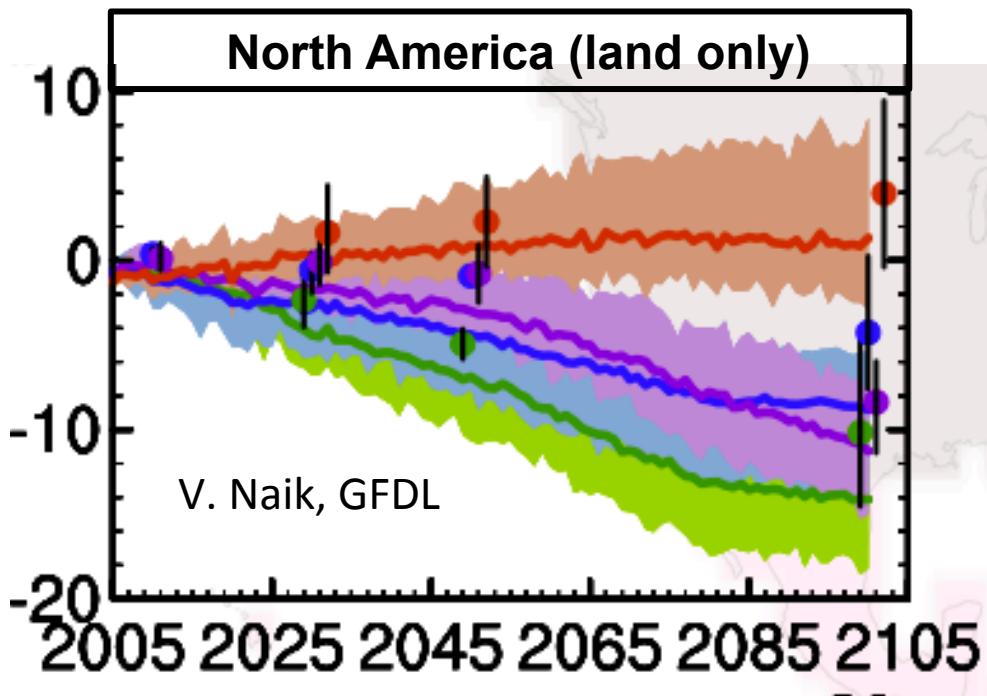
1. Increased summer O₃ (2-8 ppb) over large U.S. regions
2. Increases are largest during peak pollution events

→ Gap in analysis over much of Region 8

→ Should consider changes in fire frequency, strat. intrusions

First look: 21st century AQ projections from new generation chemistry-climate models – North America

Change in O₃ (ppb) from combined changes in emissions + climate



4 CMIP5 models (transient; Ref 1986-2005)
1-10 ACCMIP models (Time slice; Ref (1980+2000)/2)

— RCP8.5	●
— RCP6.0	○
— RCP4.5	○
— RCP2.6	○

Fiore et al., Chem. Soc. Rev., 2012

- Harness statistical power (decades of simulation years) to identify robust changes in key drivers [e.g., Turner et al., ACPD, 2012]
- Regional scale analyses, connect with regional chemistry-climate models
- Process-oriented evaluation (long-term chemical + meteorological obs)
New CCMI initiative (watch for AGU EOS meeting summary)

Integrated analyses of models, satellite, in situ data yielding insights to processes controlling Western U.S. Air Quality



NASA Air Quality Applied Science Team (AQAST)

Earth science resources → AQ management needs

Advancing understanding of WUS background O₃:

-- process-oriented approaches

background components: Asian, strat., fires

-- harness strengths of multiple models + obs.

focus on AQ metrics (MDA8, W126)

identify exceptional events, improve SIP modeling

-- developing forecast tools

simple correlations to chemical data assimilation

-- impacts from climate warming

shifting balance of local vs. transported O₃?

