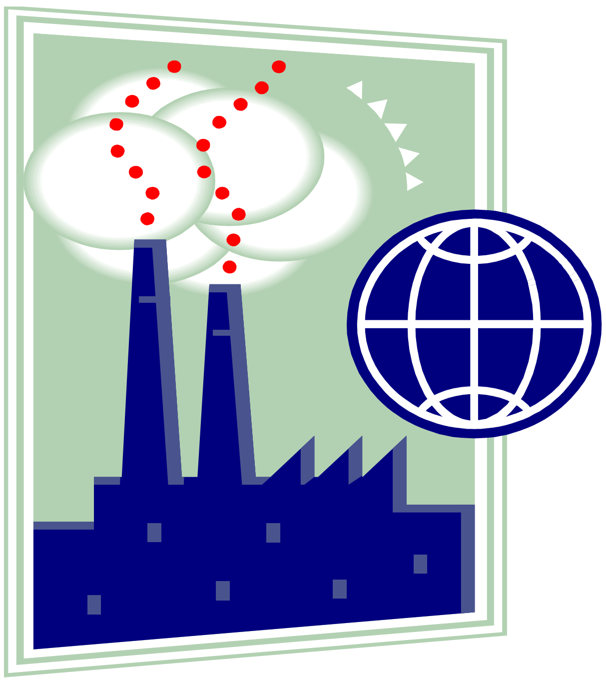
Linking regional air pollution with global chemistry and climate: The role of background ozone



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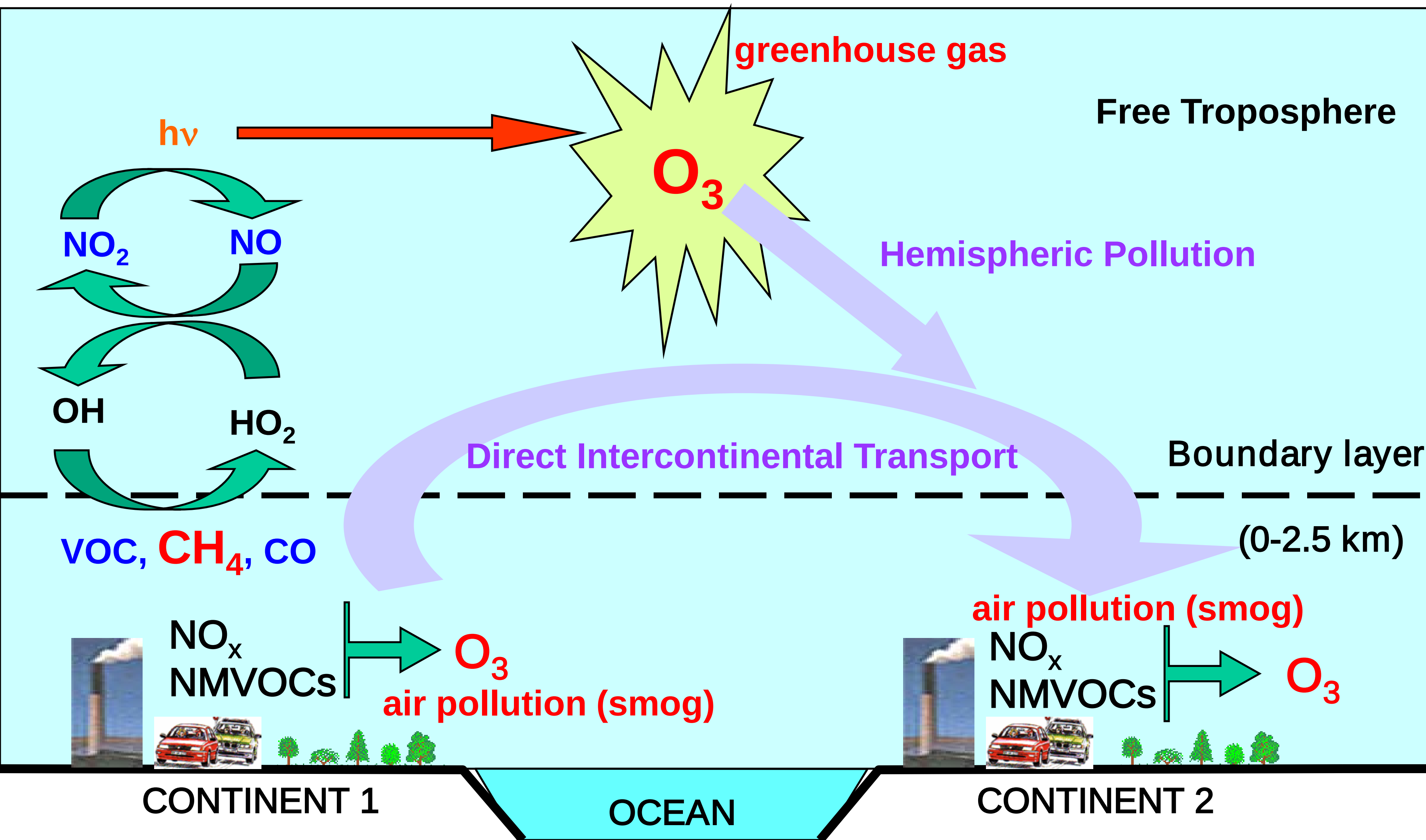
Tropospheric ozone links air pollution & climate change
(1) primary constituent of smog in surface air [*NRC*, 1991]
(2) 3rd most important greenhouse gas [*IPCC*, 2001]



Ozone abatement strategies evolve as our understanding of the O_3 problem improves

O_3 smog recognized as an URBAN problem: Los Angeles, Haagen-Smit identifies chemical mechanism

Smog considered REGIONAL problem; role of biogenic VOCs discovered

A GLOBAL perspective: role of intercontinental transport, background

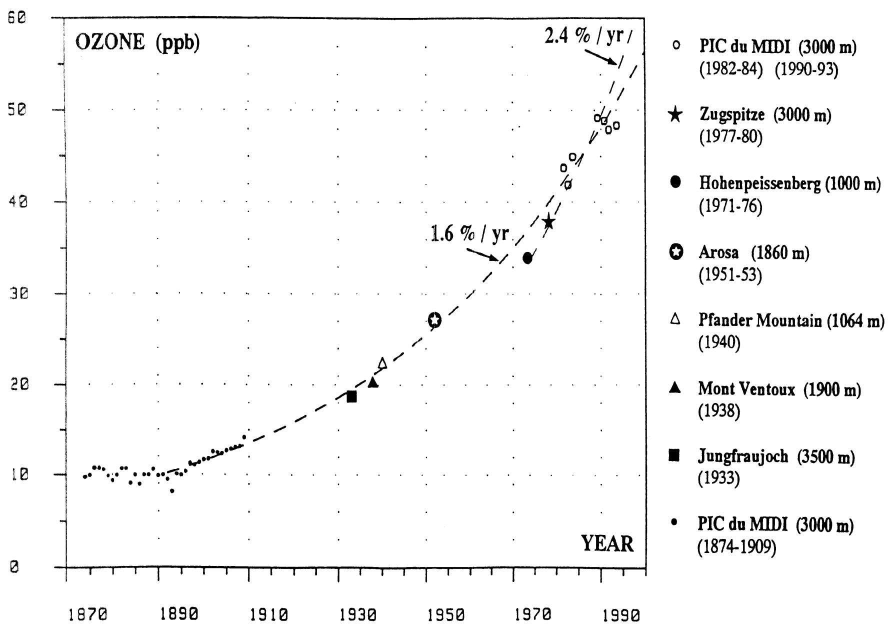
1950s → **1980s** → **Present**

Abatement Strategy:

NMVOCs + NO_x + CH_4??

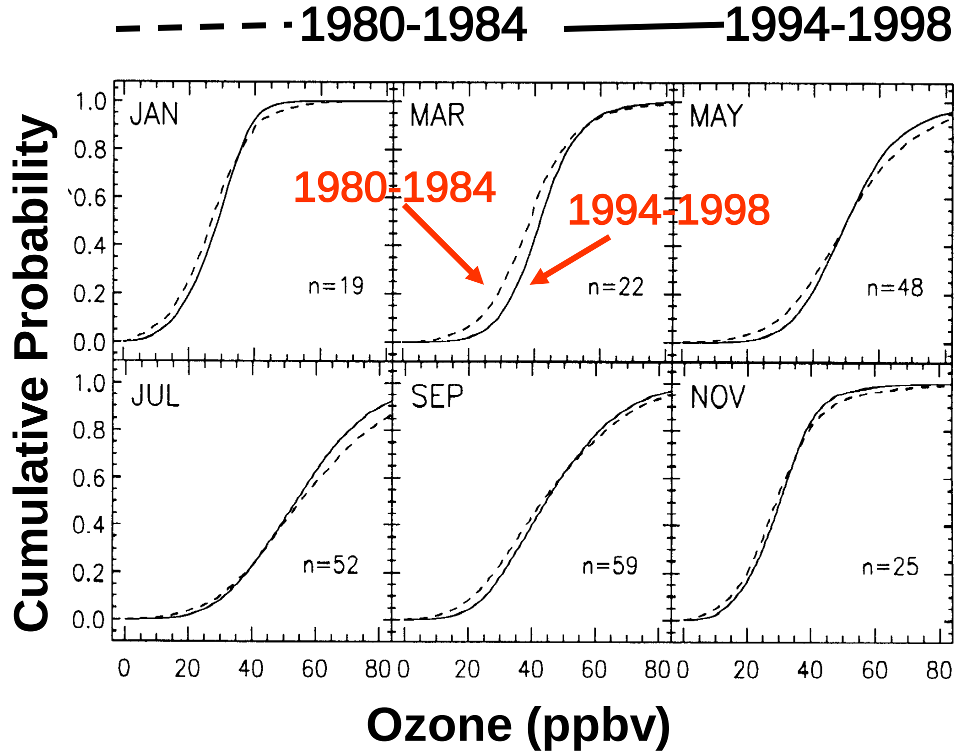
Historical and recent evidence suggest that human activities are increasing the hemispheric O_3 background

Ozone trend at European mountain sites, 1870-1990 [*Marenco et al.*, 1994]



~ 5-fold increase over past century

8-h daily maximum ozone probability distribution at rural U.S. sites [*Lin et al.*, 2000]



~ 3 ppbv increase over past 20 years

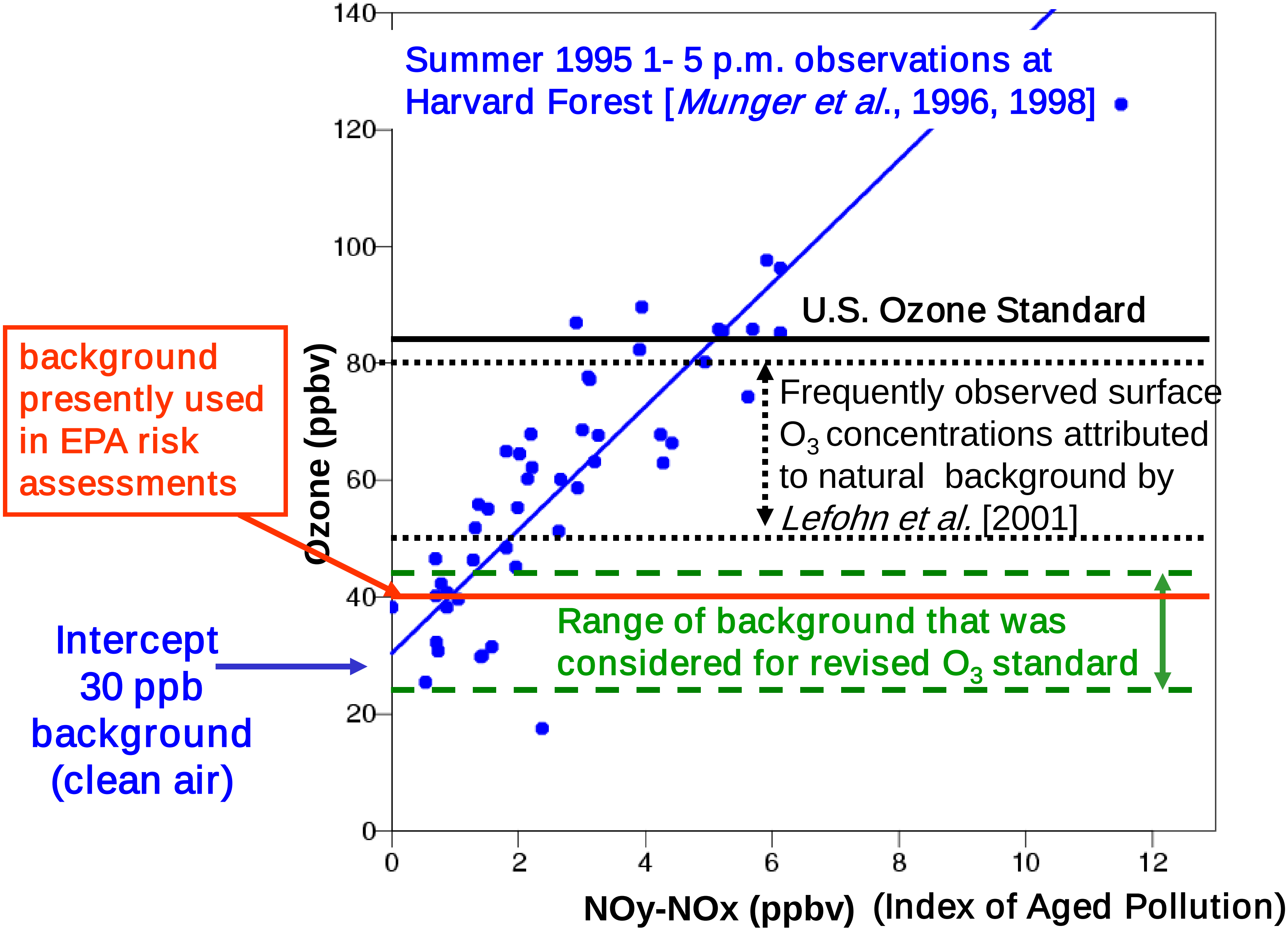
Need to quantify U.S. background O_3 in surface air for current review of National Ambient Air Quality Standard for O_3 (NAAQS)

1. What background concentrations should be used to assess the human health risk associated with exposure to O_3?
2. Is the present (or more stringent future) NAAQS too close to background concentrations?

"REGULATORY BACKGROUND" DEFINITION:
Ozone concentrations that would exist in the absence of anthrop. emissions from North America [*EPA*, 2003]

25-45 ppbv [*EPA*, 1996]

An approach for estimating O_3 background from observations



QUESTION: What role does background O_3 play in linking regional air quality with global chemistry & climate?

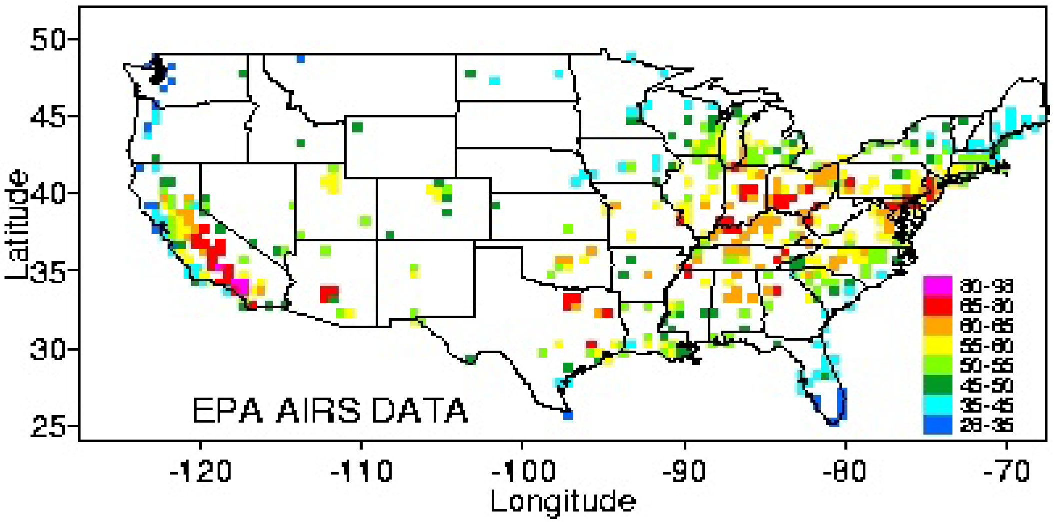
TOOL: GEOS-CHEM 3D Tropospheric Chemistry Model [*Bey et al.,* 2001]
(uses assim. met.; 20-30 σ; 4ºx5º or 2ºx2.5º horiz. resn., 24 tracers)

RESEARCH OBJECTIVES:

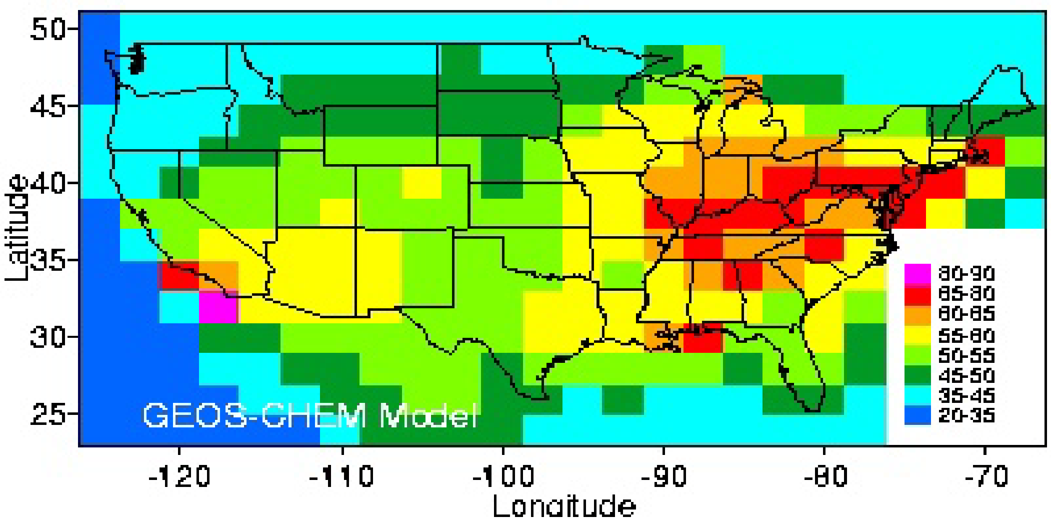
1. Assess whether GEOS-CHEM is a suitable tool for quantifying the O_3 background over the U.S.
   -- Standard statistical metrics + EOF analysis
2. Quantify background contribution to average vs. polluted days
3. Identify origin of background and variability of its sources
4. Diagnose source of high-O_3 events at remote U.S. sites in spring
5. Determine combined air quality and climatic implications of various O_3 control strategies

-- Sensitivity simulations & tagged tracers in GEOS-CHEM

Summer 1995 afternoon (1-5 p.m.) ozone in surface air over the United States



AIRS Observations

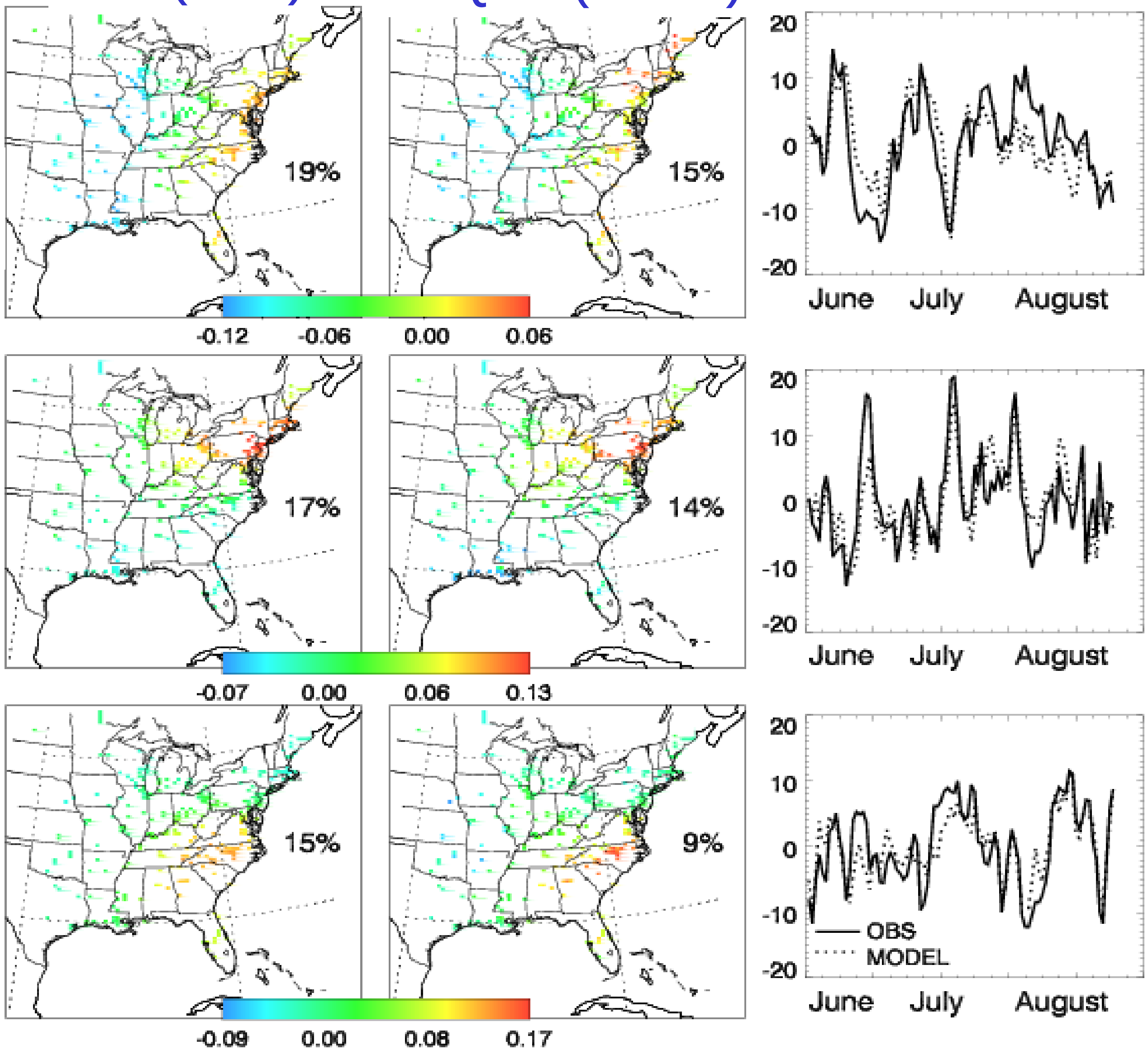


GEOS-CHEM 2ºx2.5º
r = 0.66, bias=5 ppbv

(for 4ºx5º resolution r = 0.84, bias=2 ppbv)

EOF ANALYSIS: Characterize spatiotemporal variability of surface O_3 (daily 1-5 p.m. mean concentrations in summer 1995 over eastern U.S.)

OBS (AIRS) MAQSIP (36 km^2)



East-west EOF

$r^2 = 0.86$
Slope = 1.0

$r^2 = 0.60$
Slope = 0.9

Midwest-Northeast EOF

$r^2 = 0.76$
Slope = 1.0

$r^2 = 0.57$
Slope = 0.8

Southeast EOF

$r^2 = 0.80$
Slope = 1.0

$r^2 = 0.68$
Slope = 0.7

Same fundamental, synoptic-scale processes modulate observed O_3 variability at scale of global model horizontal resolution

East-west EOF

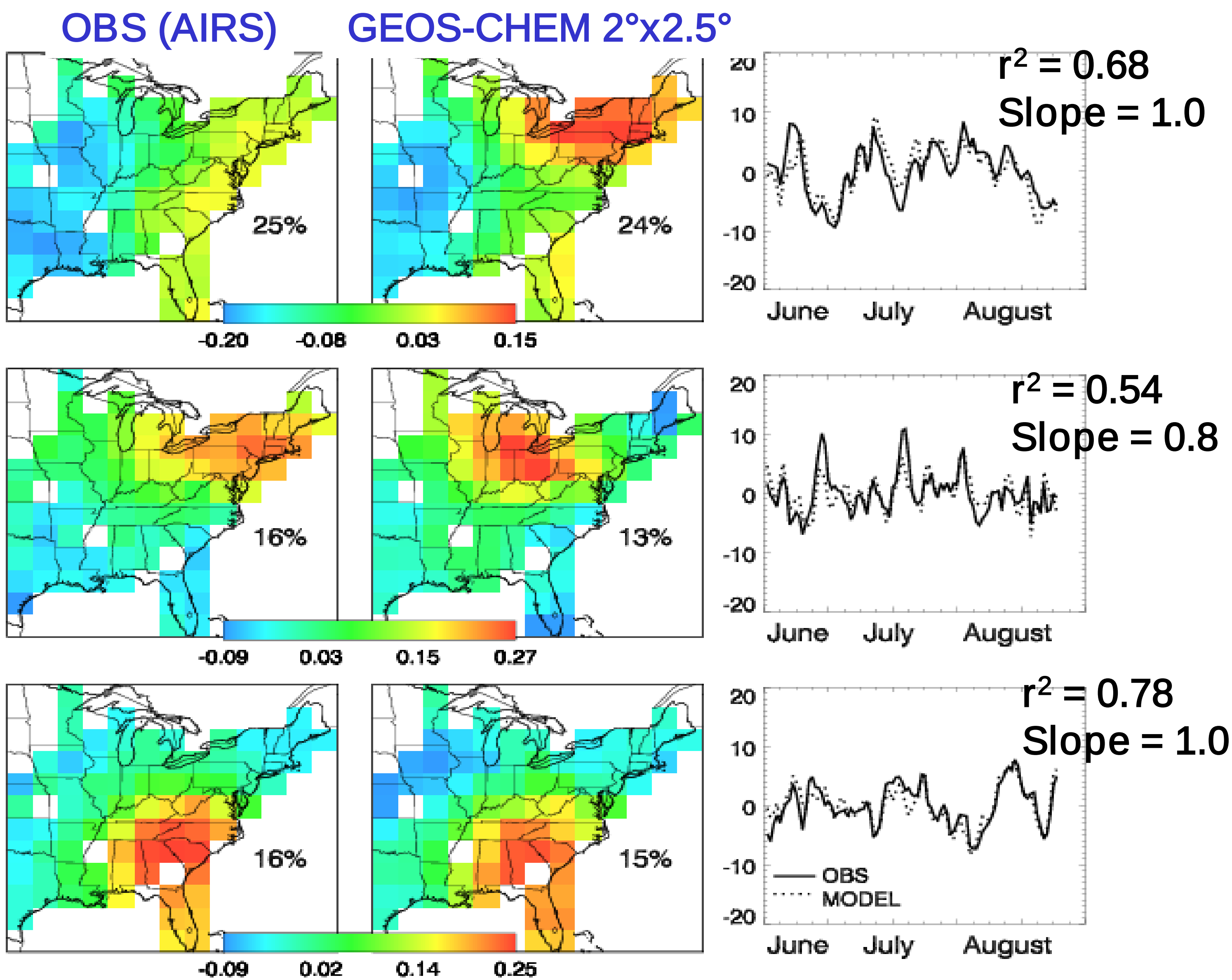
$r^2 = 0.74$
Slope = 1.2

Midwest-Northeast EOF

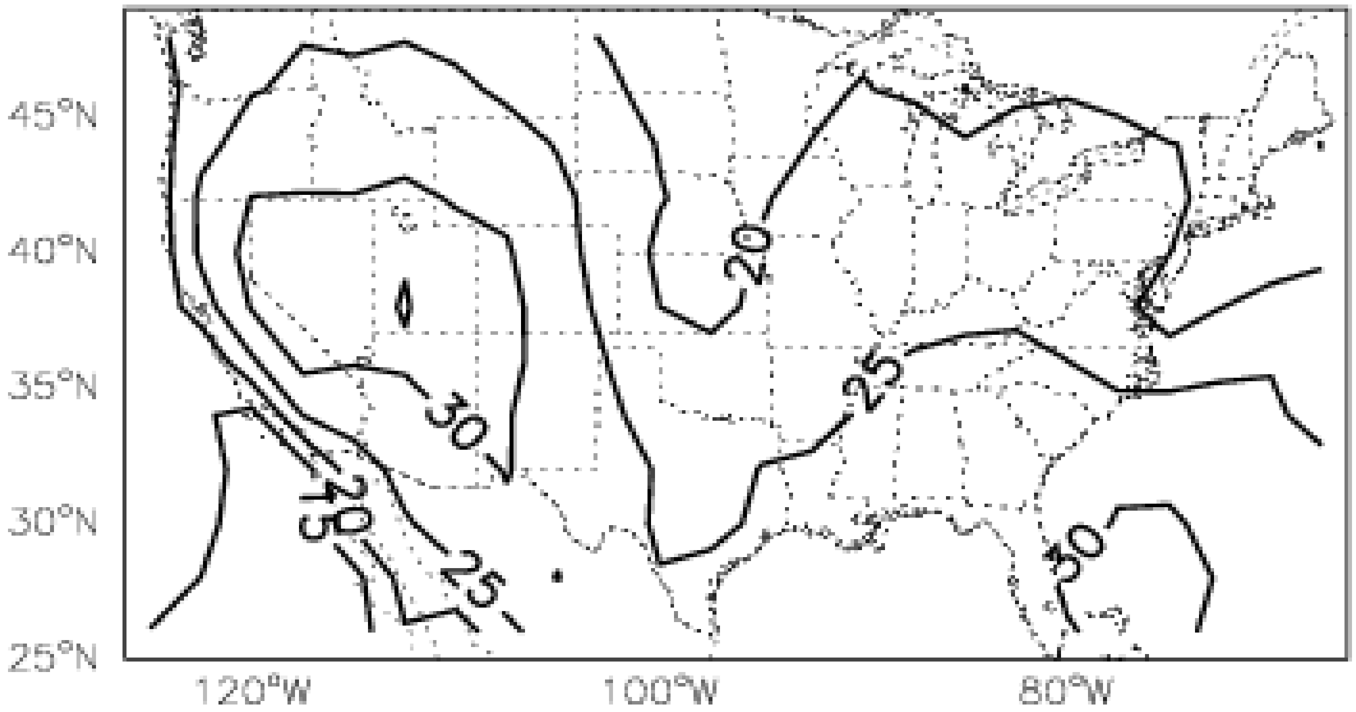
$r^2 = 0.27$
Slope = 1.0

Southeast EOF

$r^2 = 0.90$
Slope = 1.0



Mean Afternoon Surface Ozone Background (ppbv) in GEOS-CHEM model, Summer 1995



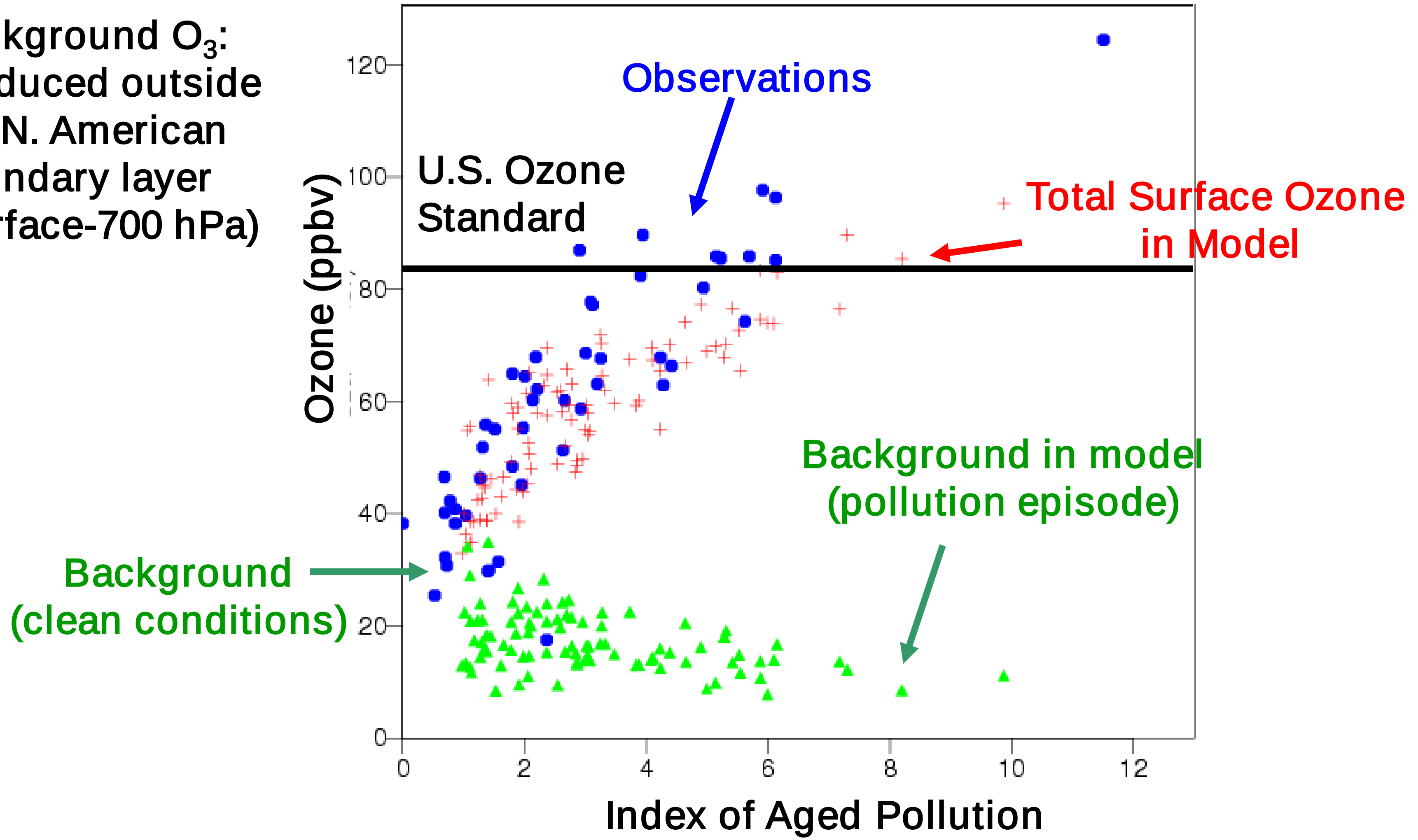
Background is tagged as ozone produced outside the N. American boundary layer (surface-700 hPa)

What is the contribution of the background to pollution episodes?

Ozone Background is depleted during regional pollution episodes (due to deposition and chemical loss under stagnant conditions)

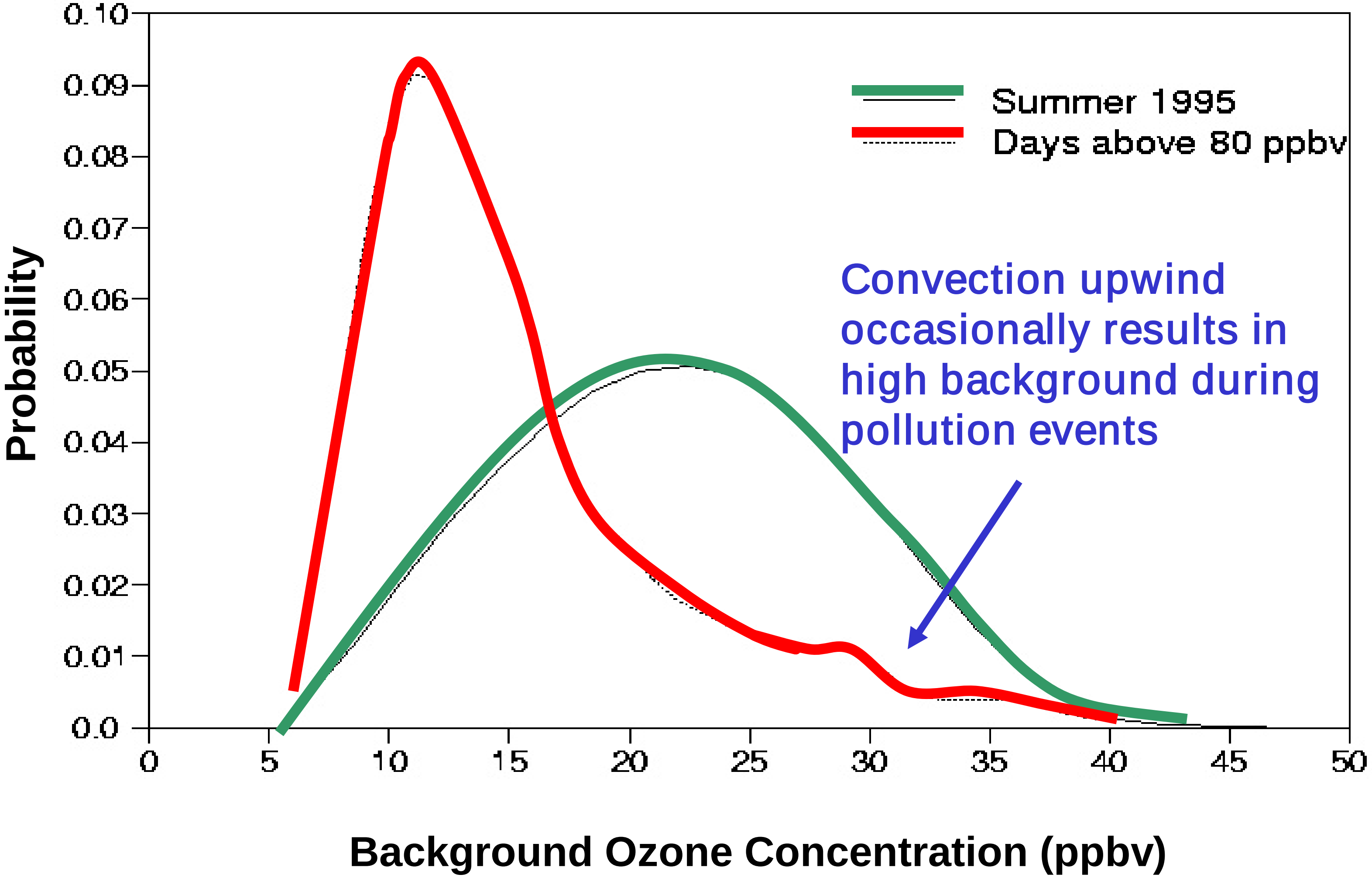
Daily mean afternoon O_3 vs. $(NO_y\text{-}NO_x)$ At Harvard Forest, MA

Background O_3: produced outside the N. American boundary layer (surface-700 hPa)



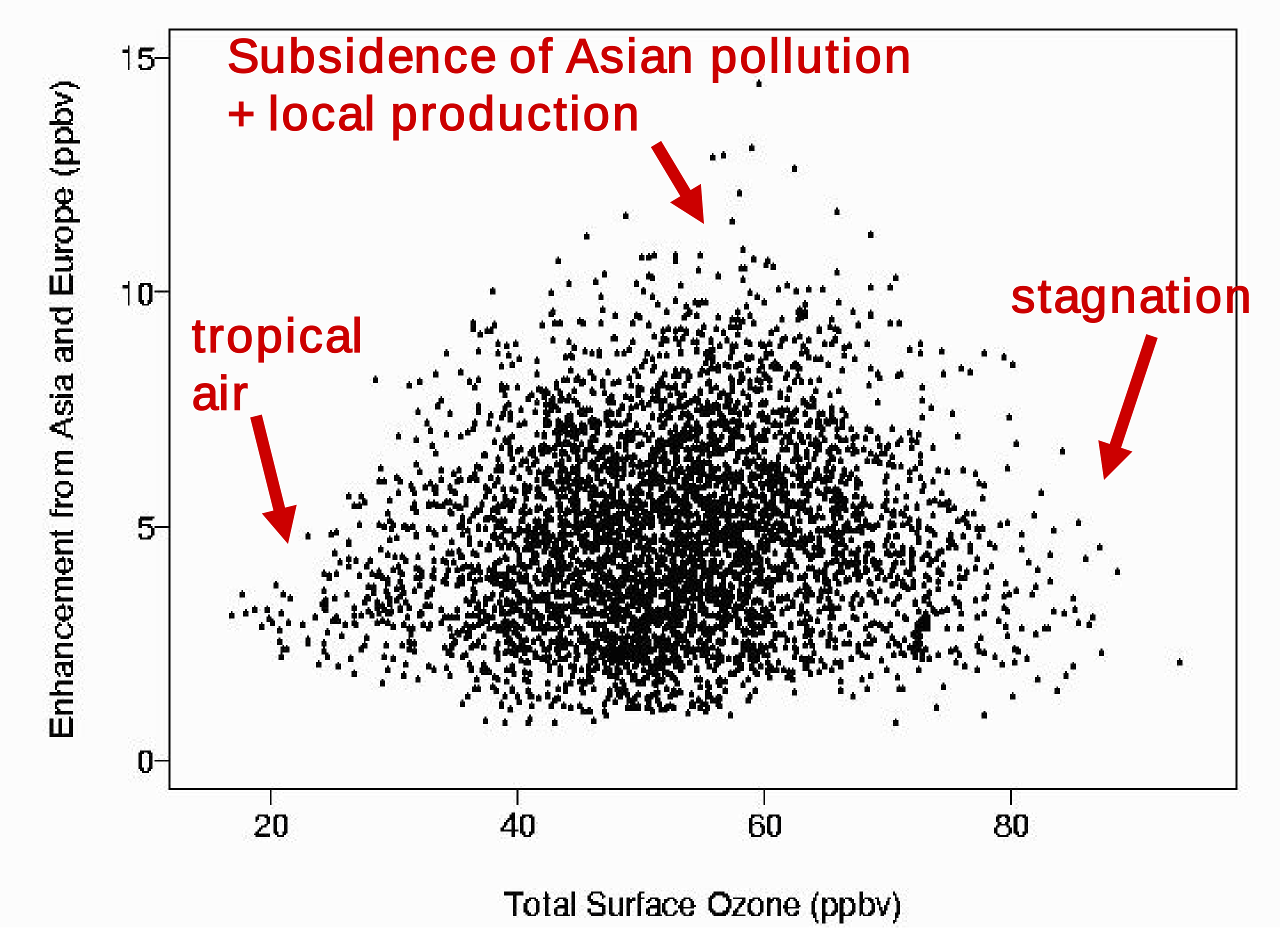
Frequency Distribution of Afternoon Background Ozone Concentrations in U.S. Surface Air Summer 1995 (GEOS-CHEM model)

summer ensemble vs. pollution events



Range of Asian/European Pollution Surface Ozone Enhancements Over the U.S. in summer

as determined from a simulation without these emissions (4°x5°)



Max Asian/European pollution enhancements (up to 14 ppbv) occur at intermediate ozone levels (50-70 ppbv)

MAJOR CONCERN
IF OZONE STANDARD
WERE TO DECREASE

Sensitivity Simulations for source attribution Mar-Oct 2001

Note: Background in the following results is as defined by EPA

- Standard simulation…..2x2.5 GEOS-CHEM, 48 sigma levels 2001
- Background……………….no anthrop. NO_x, CO, NMVOC emissions from N. America
- Natural O_3 level…………no anthrop. NO_x, CO, NMVOC emissions globally; CH_4 = 700 ppbv
- Stratospheric……………tagged O_3 tracer simulation

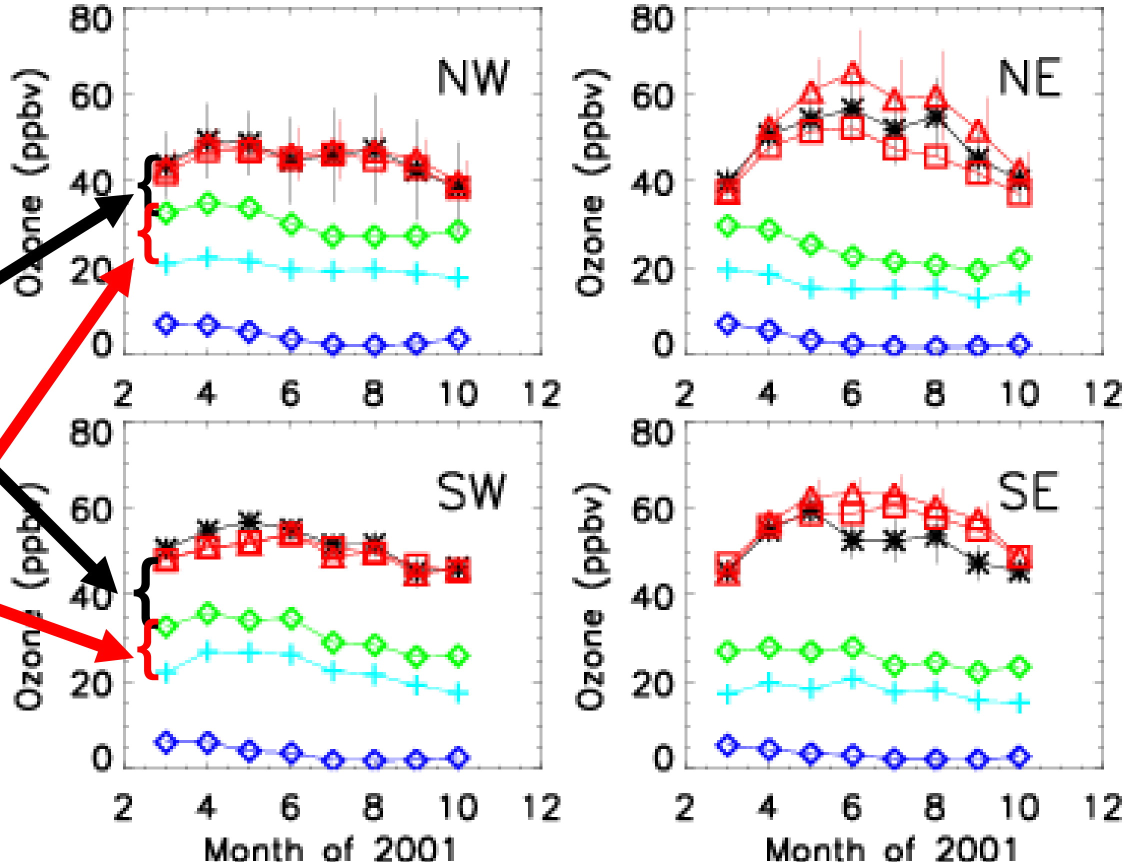
Regional Pollution = Standard – Background

Hemispheric Pollution = Background – Natural O_3 level

Use 2001 CASTNet data in conjunction with GEOS-CHEM to investigate how background O_3 varies with season and region

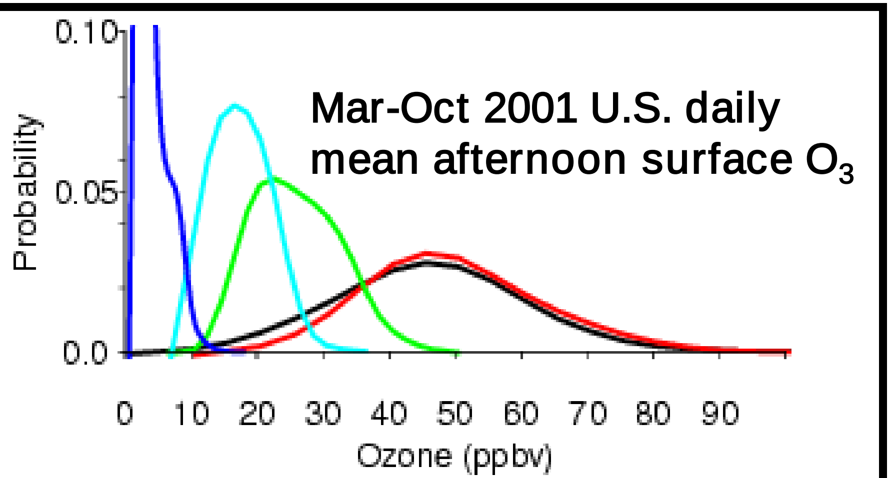
Monthly mean afternoon (1-5 p.m.) surface O_3

- * CASTNet sites
- ▲ Model at CASTNet
- ■ Model entire region
- ◆ Background
- \+ Natural O_3 level
- ◆ Stratospheric



Regional pollution from N. Am. emis. (8-30 ppbv)

Hemispheric pollution enhancement (5-12 ppbv)

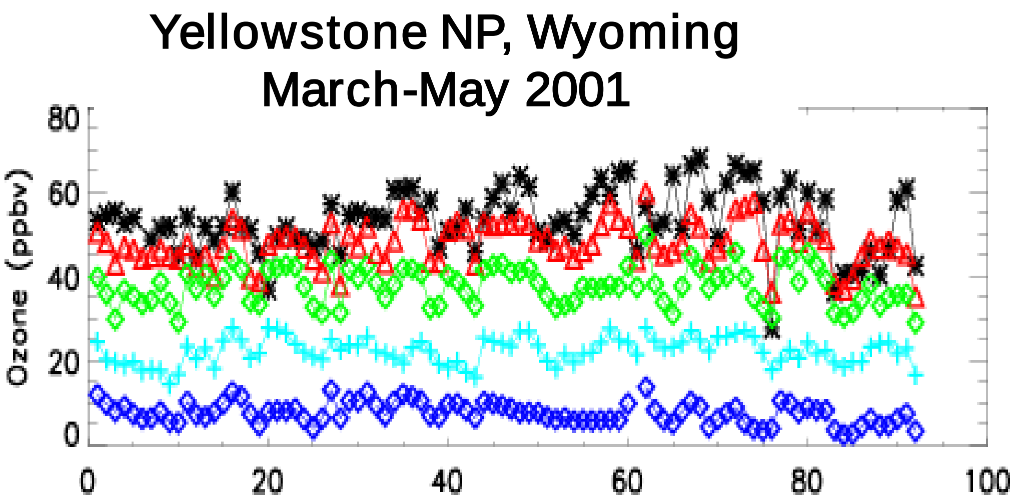


Mar-Oct 2001 U.S. daily mean afternoon surface O_3

Mean background: 20-35 ppbv
Mean natural level: 13-27 ppbv
Mean stratosphere: 2-7 ppbv

→ Background < 50 ppbv
Natural level < 40 ppbv
Stratosphere < 20 ppbv

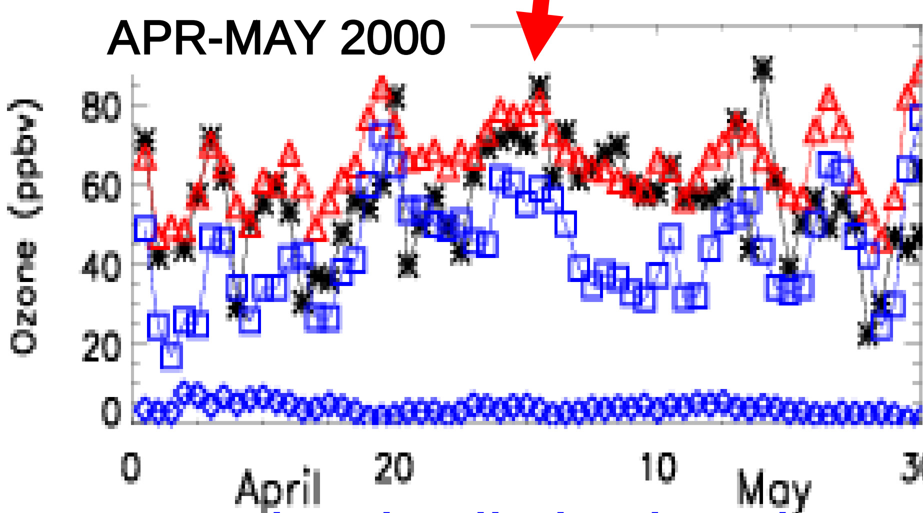
Time series at CASTNet sites where high-O_3 events in spring were previously attributed to stratospheric origin on basis of back-trajectories

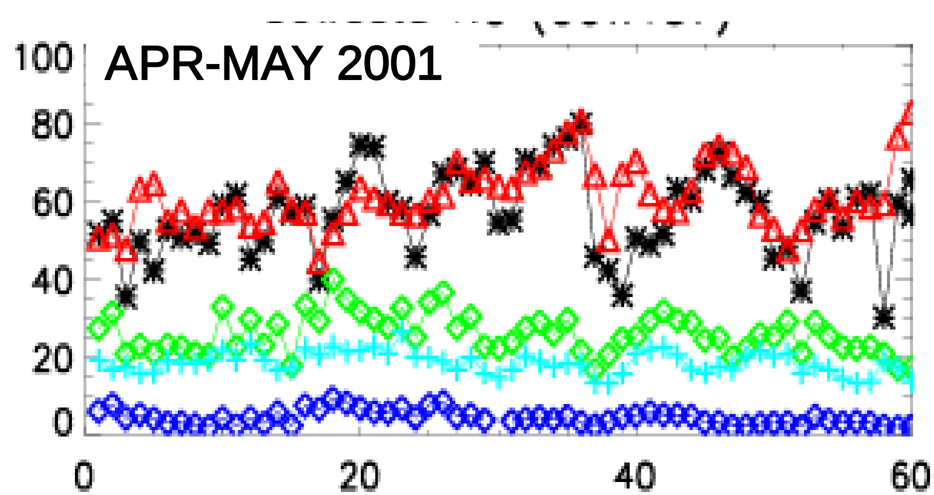


* CASTNet sites
Model
Background
Natural O_3 level
Stratospheric
Continental lower troposphere

Model – Background: Δ = Regional pollution
Background – Natural O_3 level: Δ = Hemispheric pollution

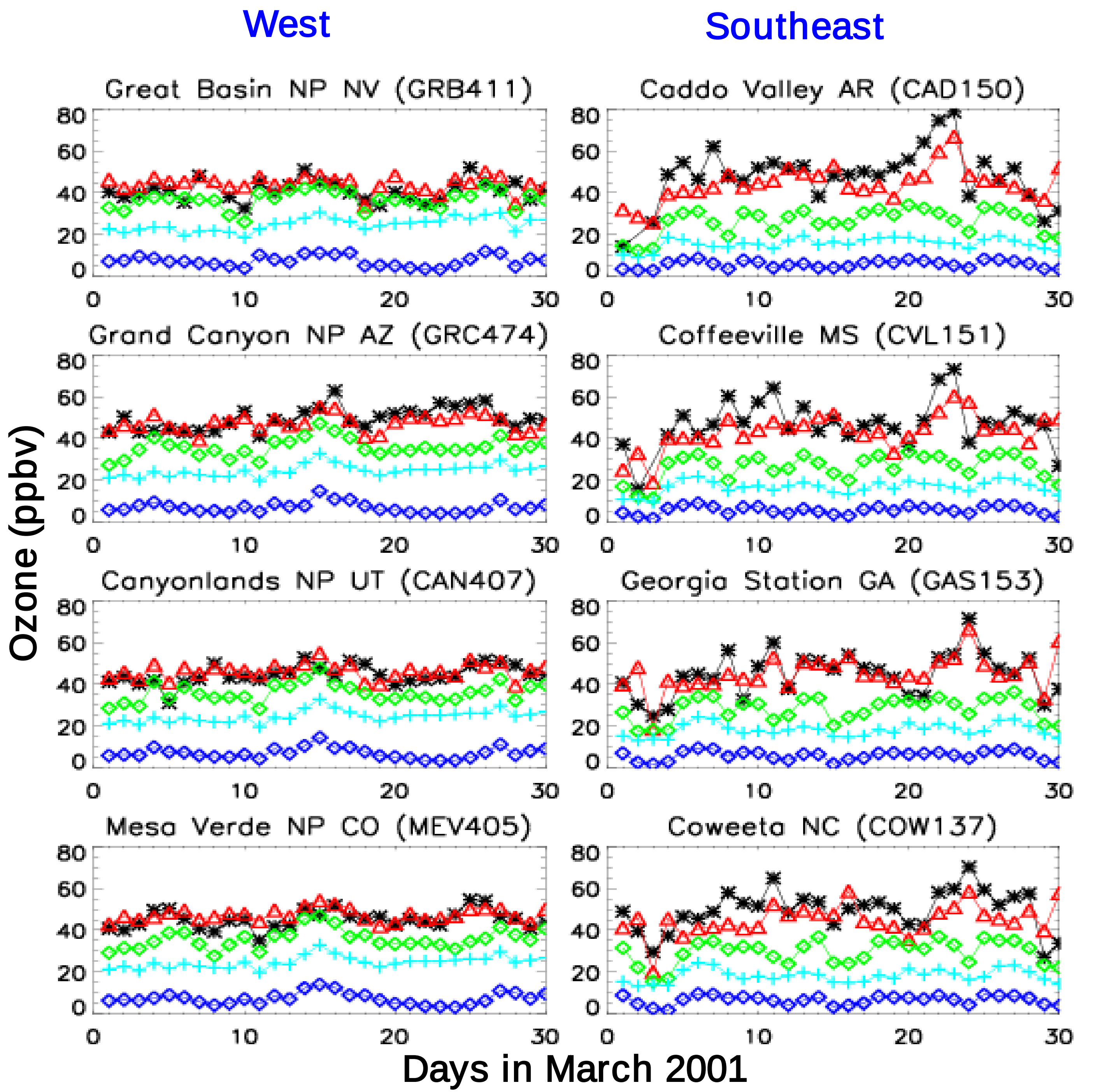
High-O_3 "Haywood County" event in North Carolina





Regional pollution largely controls high-O_3 events in spring;
Model explains these events without a large stratospheric influence

* CASTNet sites
△ Model
◆ Background
+ Natural O_3 level
◆ Stratospheric



Background increases with highest observed O_3 at western sites in March

Background decreases with highest observed O_3 at SE sites in March

* CASTNet sites
▲ Model
◆ Background
+ Natural O_3 level
◆ Stratospheric

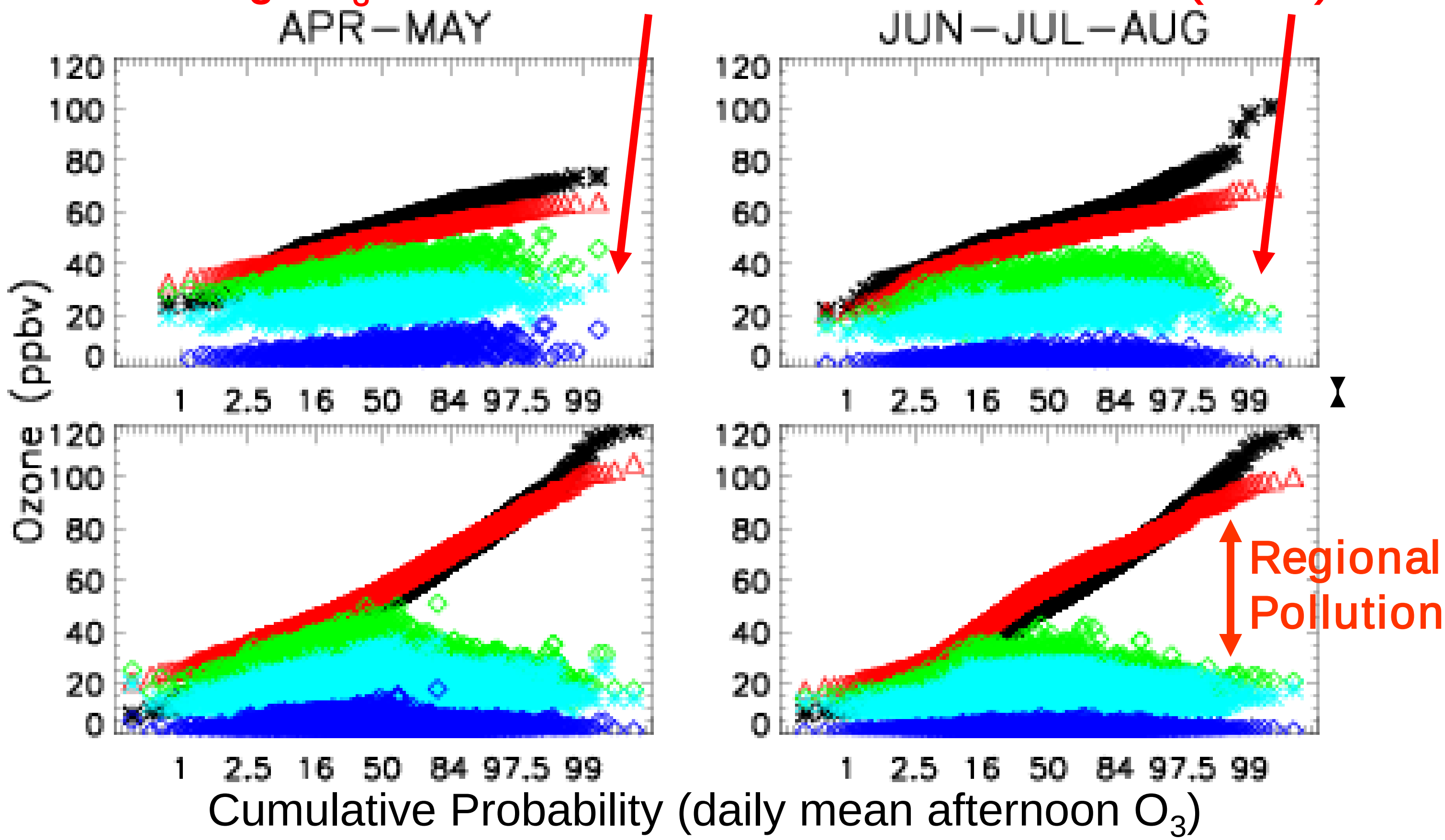
Background O_3 for risk assessment = f (season, altitude, total O_3 concentration)

Enhancement from N. Amer & hemis. pollution for high O_3 concentrations

Lower background; larger pollution influence in summer (& fall)

12 elevated sites; all in west

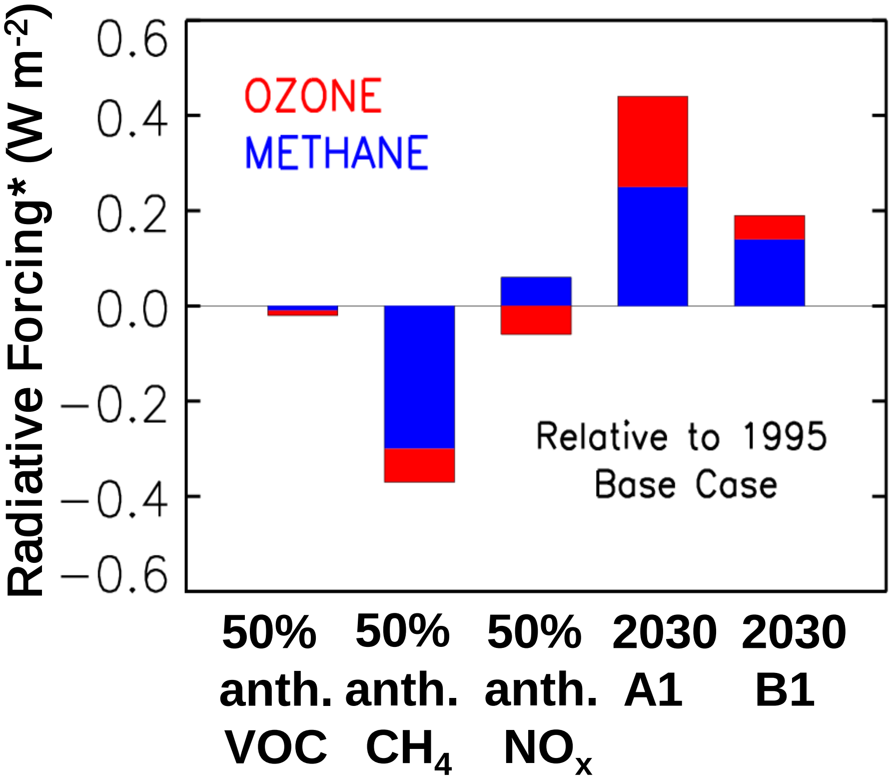
58 surface sites

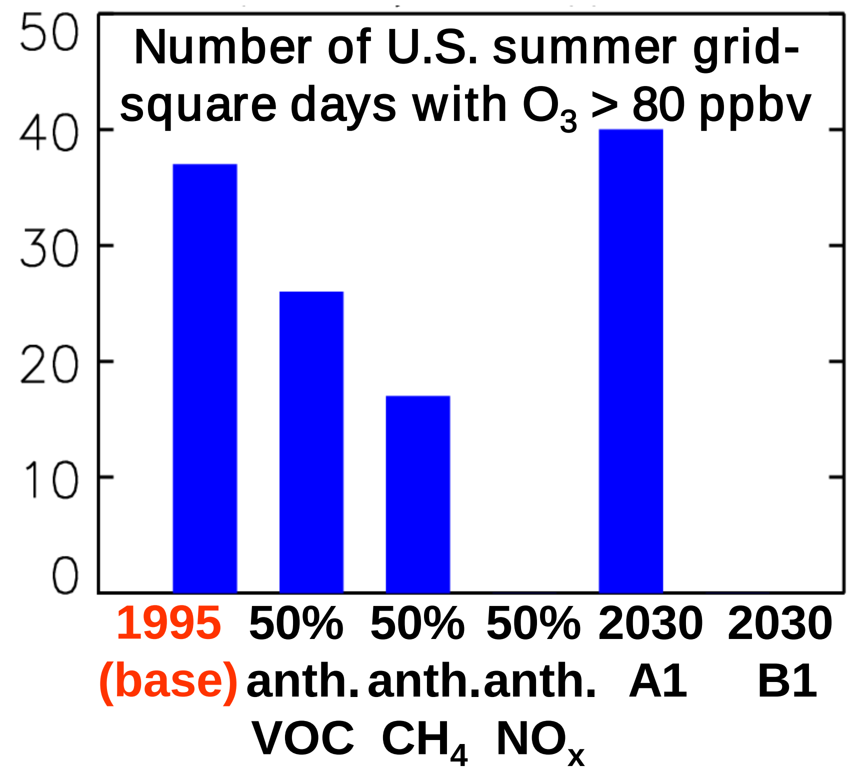


Lower background at surface sites; Maximum contribution at the center of the O_3 distribution

Using average background for pollution episodes underestimates risk to human health!

Air Quality-Climate Linkage: Impacts of future changes in global anthropogenic emissions (GEOS-CHEM; 4 x5)

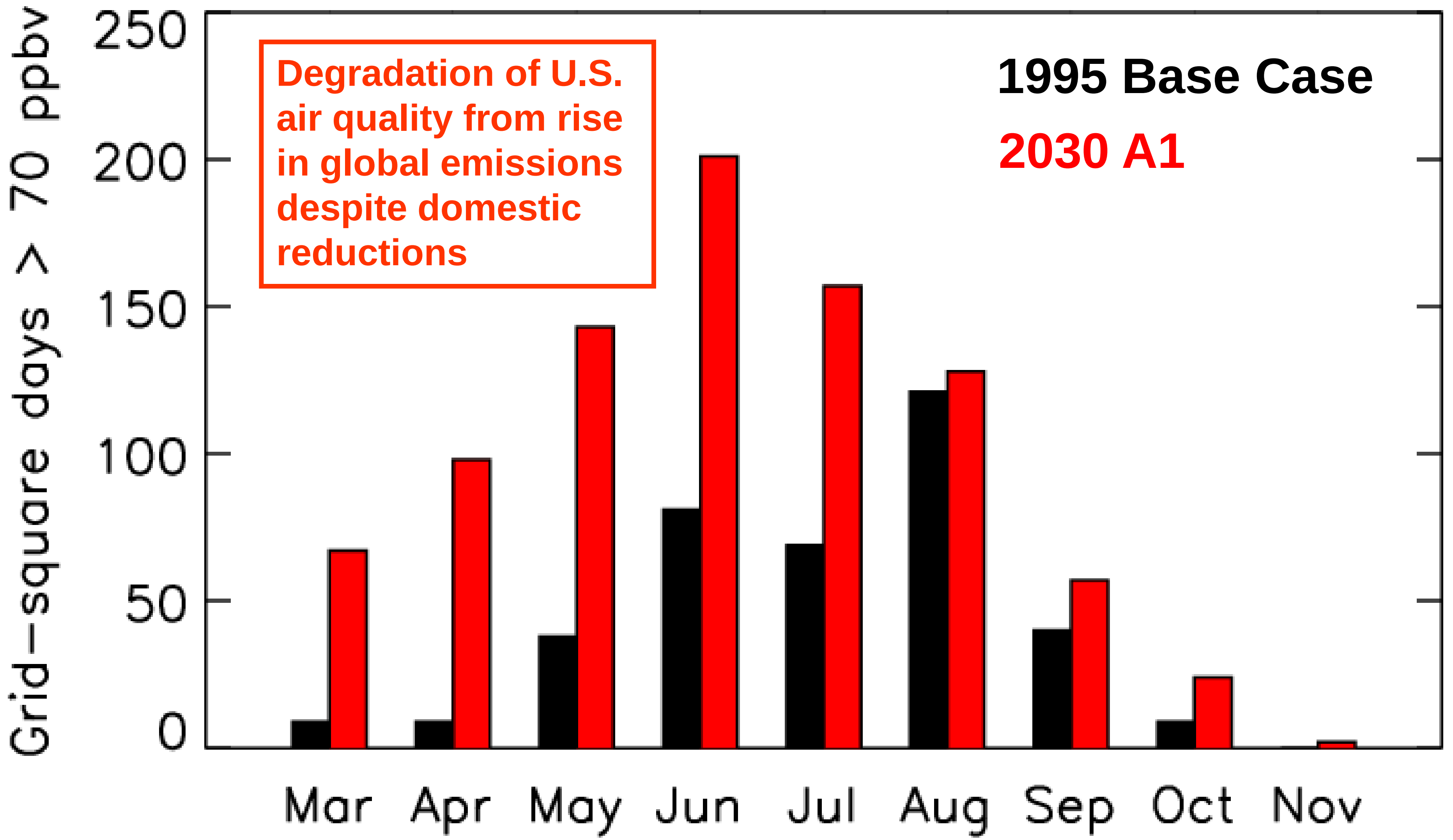




IPCC scenario	Anthrop. NO_x emissions (2030 vs. present)		Methane emissions (2030 vs. present)
	Global	U.S.	
A1	+80%	-20%	+30%
B1	-5%	-50%	+12%

CH_4 links air quality & climate via background O_3

Rising emissions from developing countries lengthen the O_3 pollution season in the United States



CONCLUSIONS and their implications for policy

1. Global models can adequately simulate the synoptic conditions important for resolving background and high-O_3 conditions

2. Background O_3 varies with season, site elevation, and total surface O_3 concentrations
   -- highest at high-altitude western U.S. sites in spring
   -- lower at surface sites and in summer
   -- depleted during polluted conditions

→ health risk from O_3 underestimated in present EPA risk assessments

3. High-O_3 events at remote U.S. sites in spring previously attributed to a natural stratospheric source are explained largely by regional pollution

→ these events should not be used to challenge legitimacy of O_3 NAAQS

4. Hemispheric pollution enhances U.S. background; may rise in future

→ international agreements to reduce hemispheric background would improve U.S. air quality & facilitate compliance w/ more stringent standards

5. Methane emission controls decrease hemispheric background & greenhouse warming

→ co-benefits for air quality & climate change mitigation objectives