Recent Changes in Eastern U.S. Forests: Implications for Air Quality

Arlene M. Fiore

Seminar at the
Center for Sustainability and the Global Environment (SAGE)
University of Wisconsin-Madison

December 8, 2004

Acknowledgments

GFDL Geophysical Fluid Dynamics Laboratory
Princeton, NJ

Larry Horowitz
Chip Levy

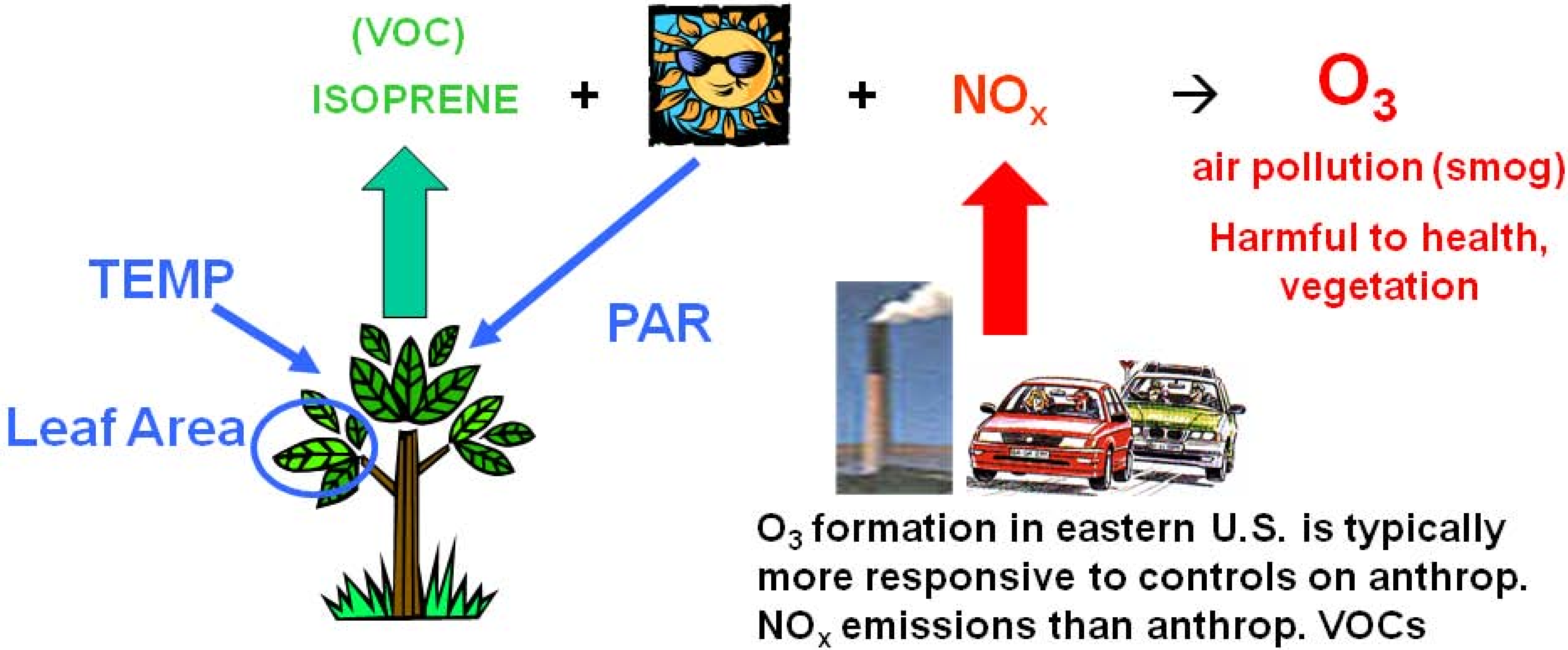
Princeton University

Drew Purves
Steve Pacala

Harvard University
Atmospheric Chemistry Modeling Group

Mat Evans
Qinbin Li
Bob Yantosca
Yuxuan Wang

Isoprene Emissions are generally thought to contribute to O_3 production over the eastern United States [*e.g.Trainer et al.*, 1987; *NRC* 1991]



Vegetation changes → Impact on O_3?

-- Climate

-- Land-use

Future scenario for conversion of agricultural lands to poplar plantations for biofuels

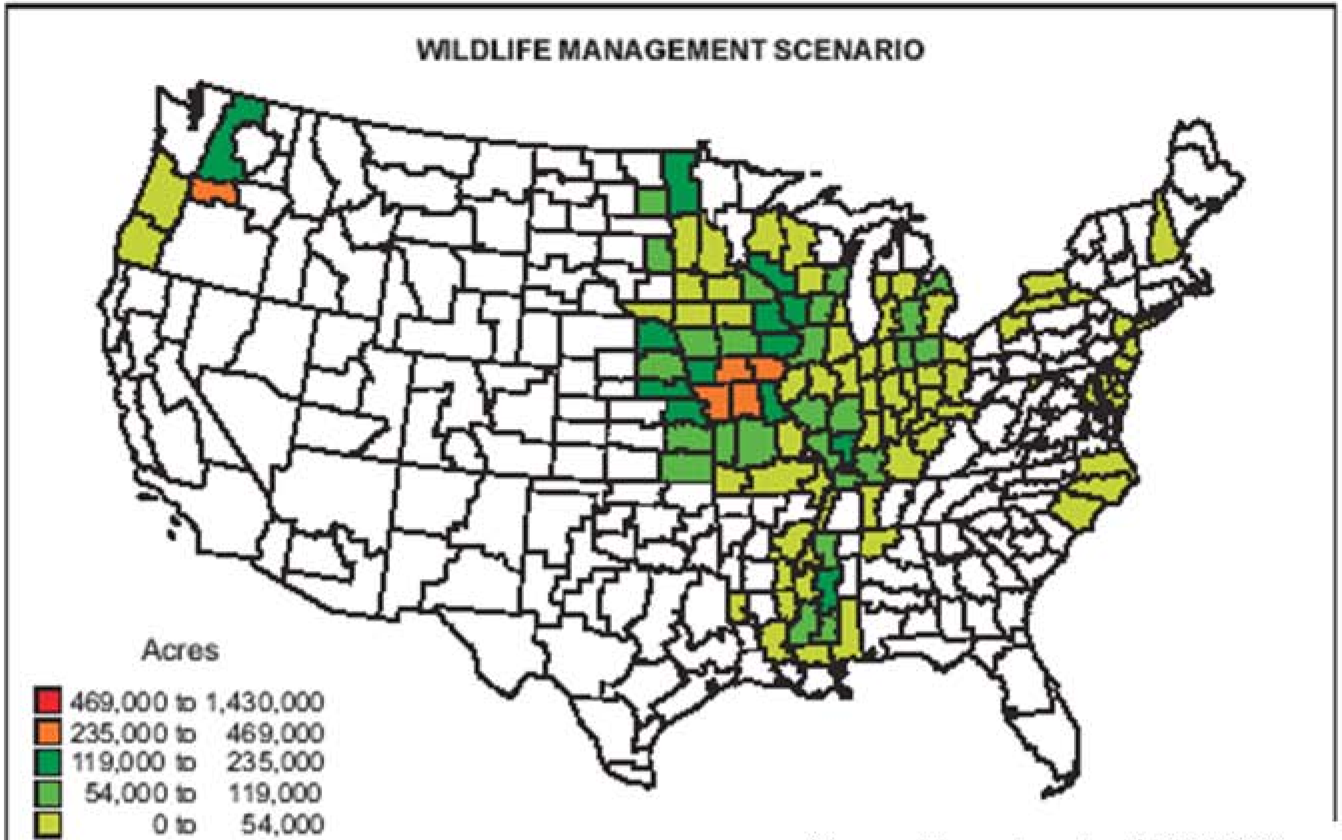


Figure 8. Poplar plantings on cropland From Ugarte *et al.* (2003)

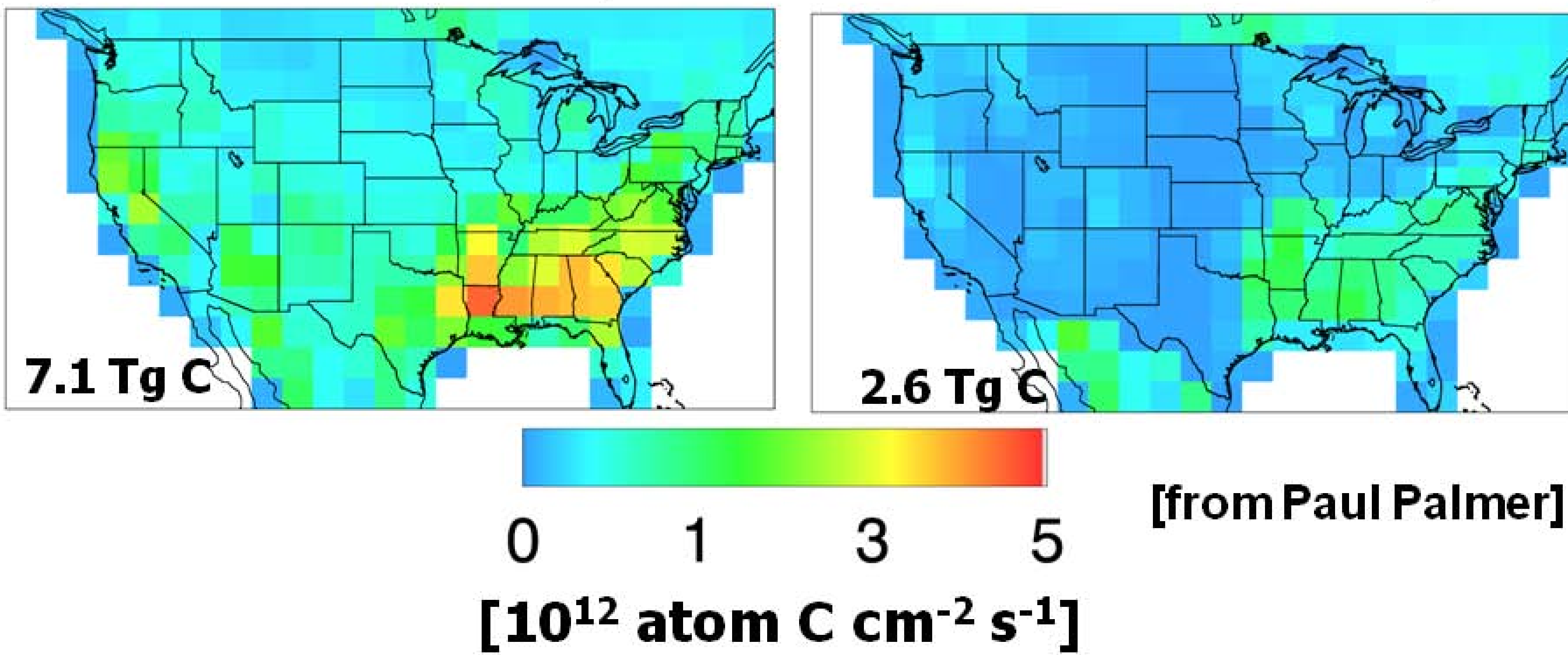
Poplars are high-isoprene emitting trees
→ land-use decisions have implications for air quality

from D. Purves

Isoprene Emission Inventories uncertain by at least a factor of 2

Isoprene emissions – July 1996

GEIA: Global Isoprene Emission Inventory | **BEIS2: Regional Isoprene Emission Inventory**



[from Paul Palmer]

... and there is new evidence for decadal changes

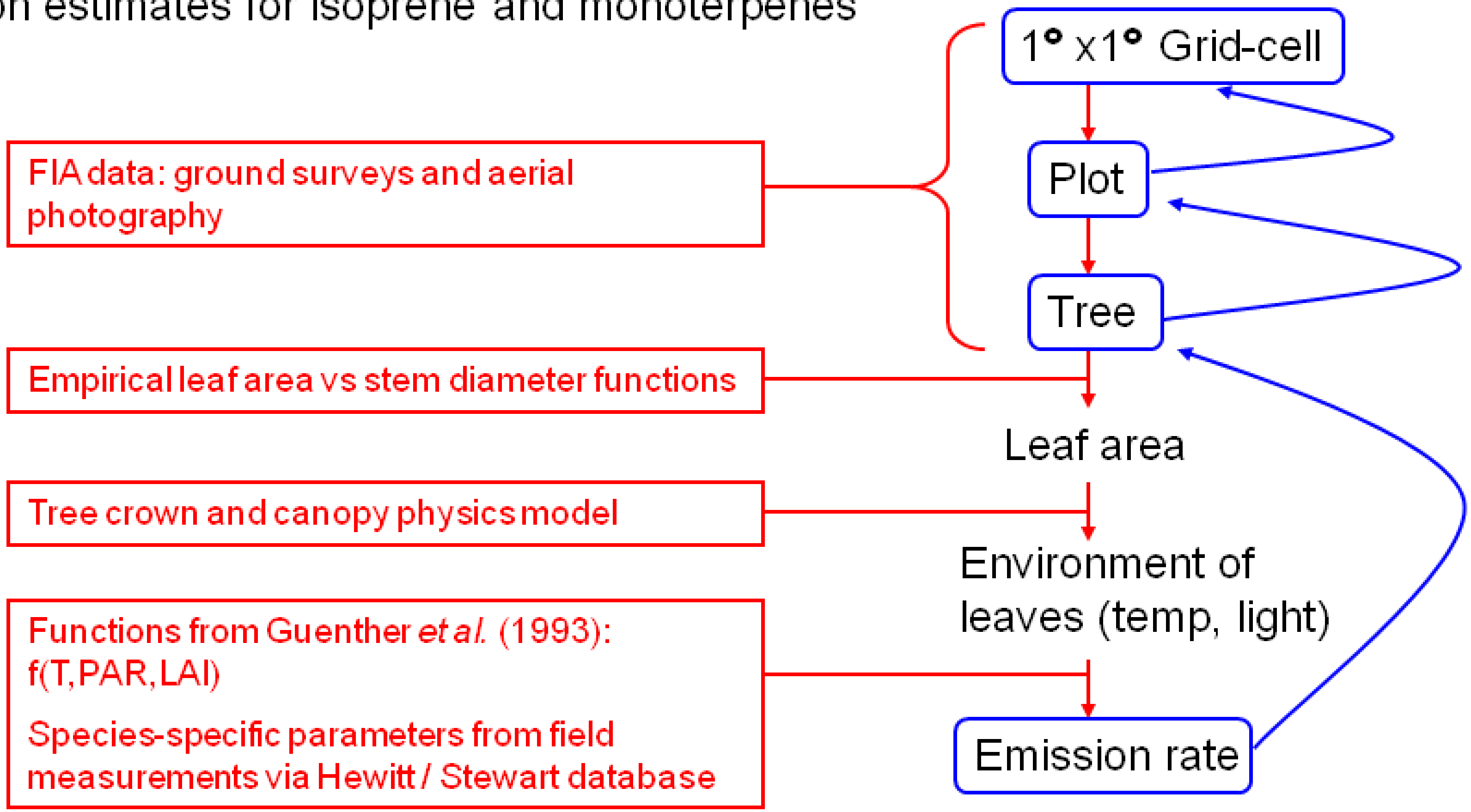
Purves et al. [2004]: observation-based biogenic VOC (BVOC) emission estimates for mid-1980s and mid-1990s

Minimal complexity approach

Empirical rather than mechanistic / physiological

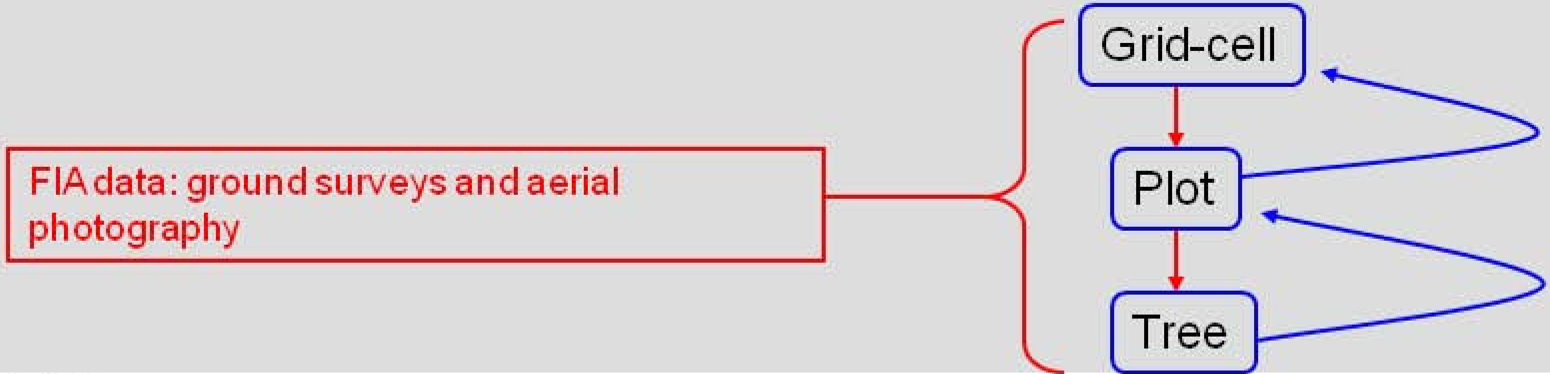
Based on USDA **F**orest **I**nventory **A**nalysis data

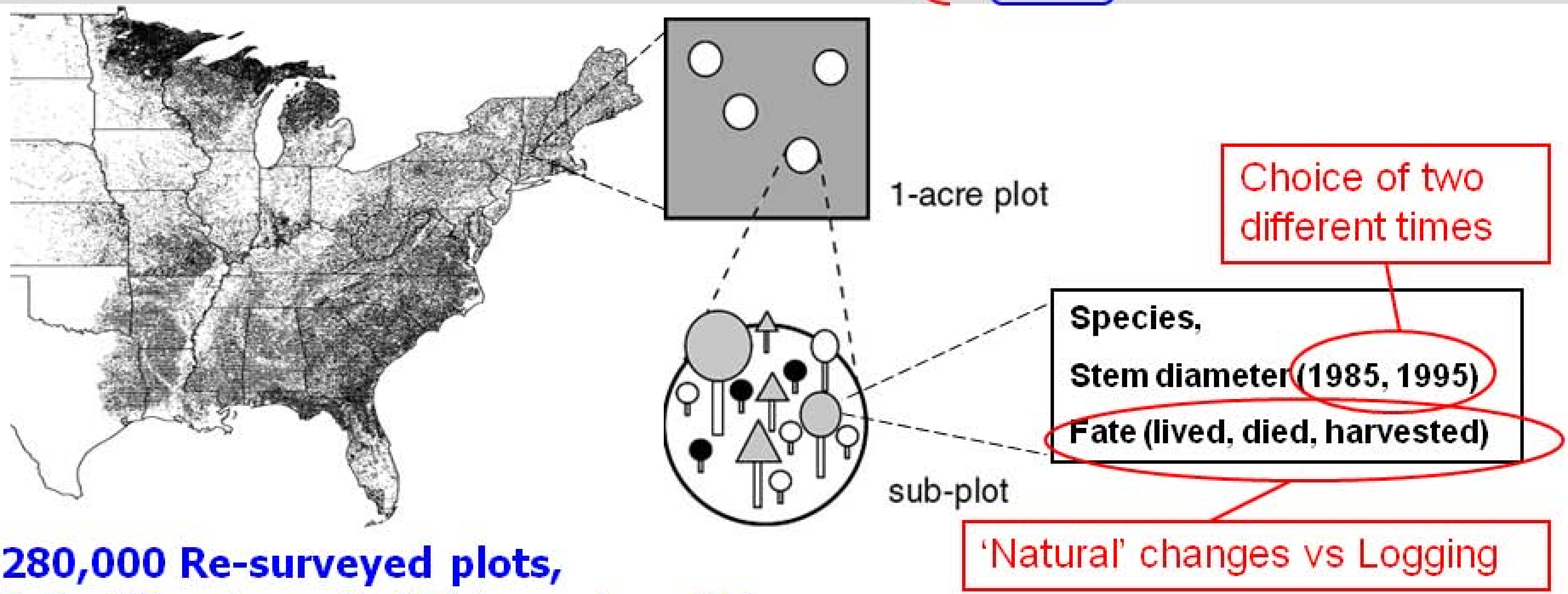
Emission estimates for isoprene and monoterpenes



from D. Purves

Purves et al. [2004]: observation-based BVOC emission estimates for mid-1980s and mid-1990s





280,000 Re-surveyed plots,
2.7 million trees in FIA in eastern U.S.

→Estimate recent changes in isoprene and monoterpene emissions
→Purves Base isoprene inventory similar to BEIS2

from D. Purves

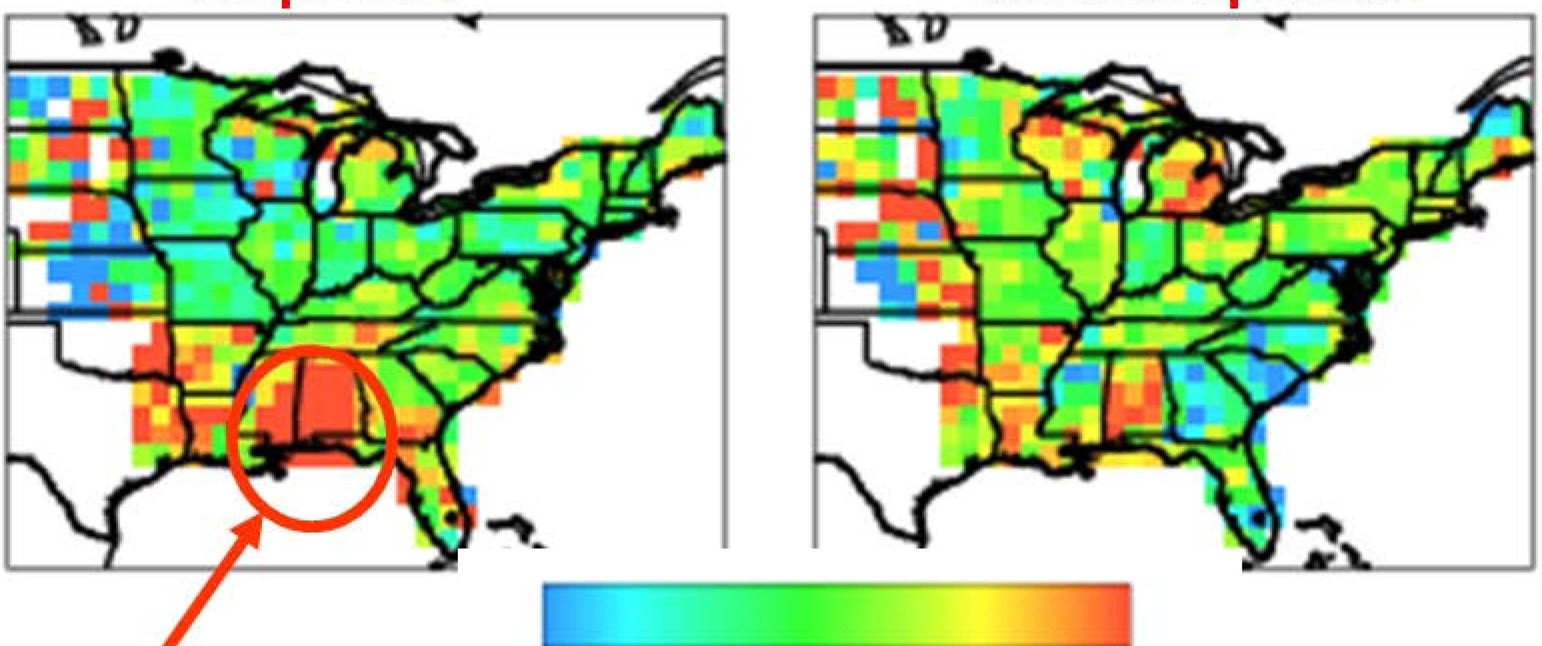
Recent Changes in Biogenic VOC Emissions

[*Purves et al.*, *Global Change Biology*, 2004]

→ **Substantial isoprene increases in southeastern USA largely driven by human land-use decisions**

→ **Land-use changes not presently considered in CTMs**

Isoprene | Monoterpenes



Sweetgum Invasion of Pine plantations

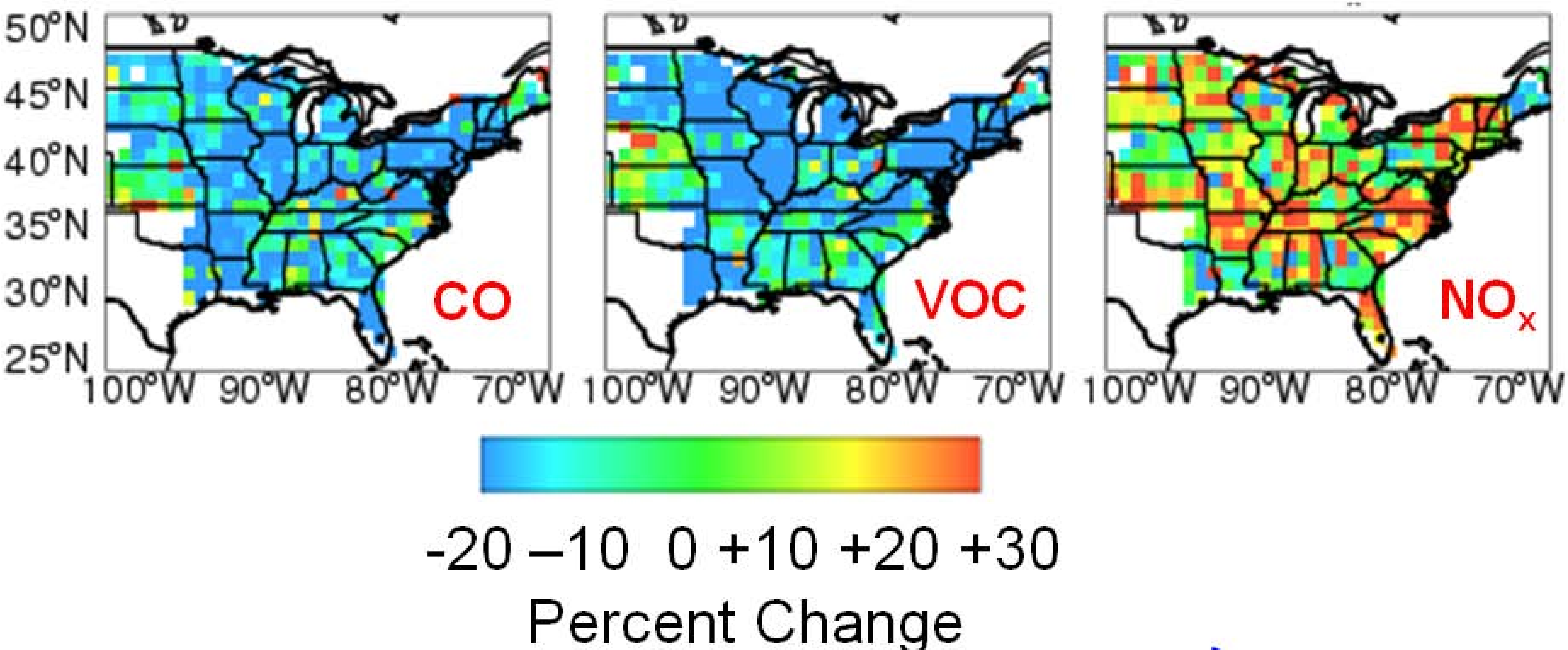
-20 –10 0 +10 +20 +30

Percent Change mid-1980s to mid-1990s

Trends in anthropogenic precursors?

Trends in Anthropogenic Emissions: 1985 to 1995

from US EPA national emissions inventory database
(http://www.epa.gov/air/data/neidb.html)



→Large decreases in CO and VOC Emissions
→Some local increases in NO_x
→Higher biogenic VOCs

Net effect On O_3?

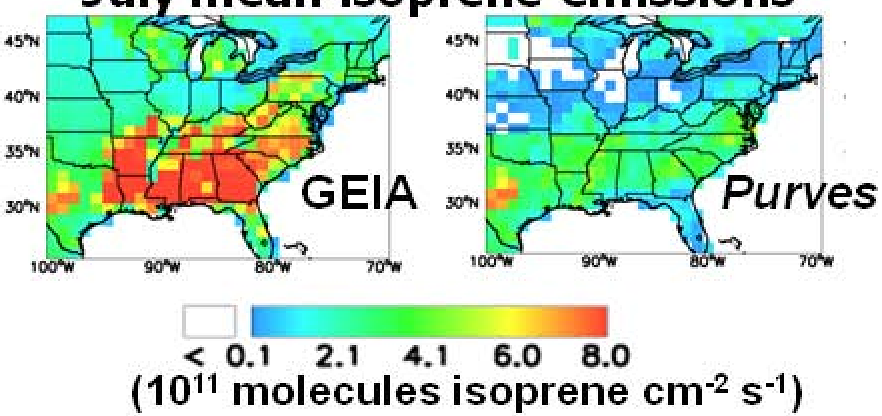
Approach: Insights from two chemical transport models

GEOS-CHEM

1. Quantify O_3 response to reported biogenic and anthropogenic emissions changes

2. Determine sensitivity to uncertainties in isoprene emissions

July mean isoprene emissions



MOZART-2

1. Test whether results are model-dependent

2. Determine sensitivity to uncertainties in isoprene-NO_x-O_3 chemistry

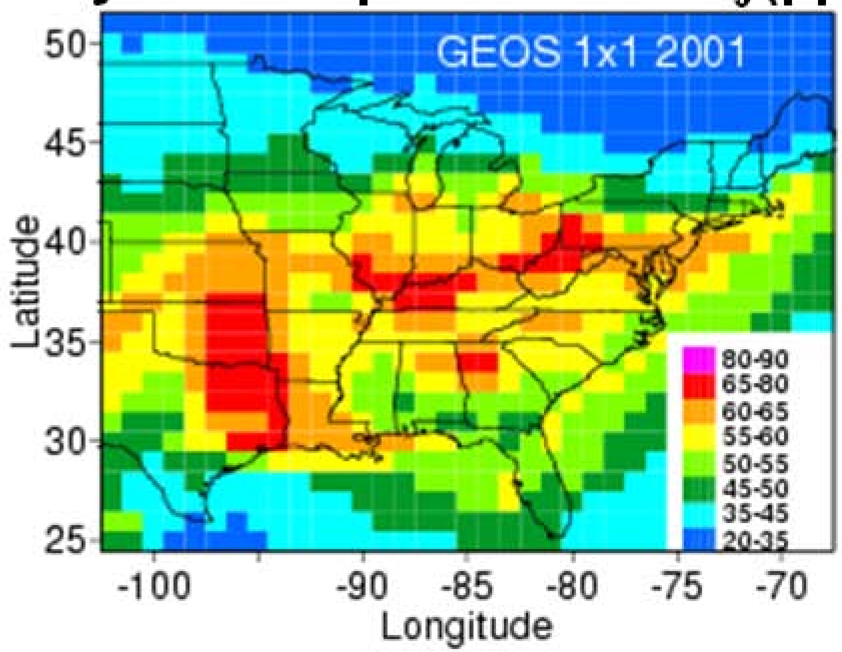
→Isoprene + NO_x may lock up NO_x (as isoprene nitrates), suppressing O_3 formation

→Assumed in GEOS-CHEM but not in MOZART-2

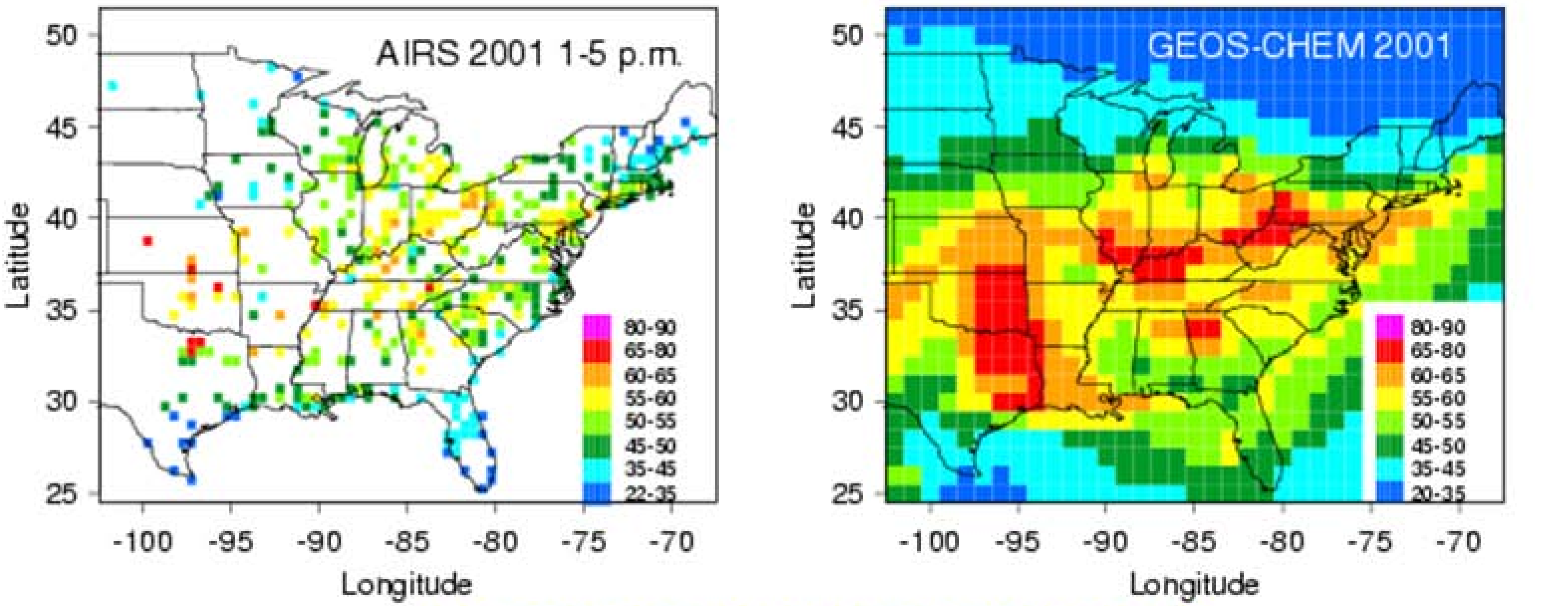
Tool #1: GEOS-CHEM tropospheric chemistry model [*Bey et al.*, 2001]

- Uses assimilated meteorology: GEOS-3 1°x1° fields for 2001
- 48 vertical levels (9 below 2 km)
- Regridded to 4°x5° for global spinup and boundary conditions for **nested 1°x1° over North America** [*Wang et al.*, 2004; *Li et al.*, 2004]
- 31 tracers; NO_x-CO-hydrocarbon-O_3 chemistry coupled to aerosols
- GEIA isoprene emission algorithms [*Guenther et al.*, 1995]
- v. 5-07-08 (http://www-as.harvard.edu/chemistry/trop/geos/index.html)

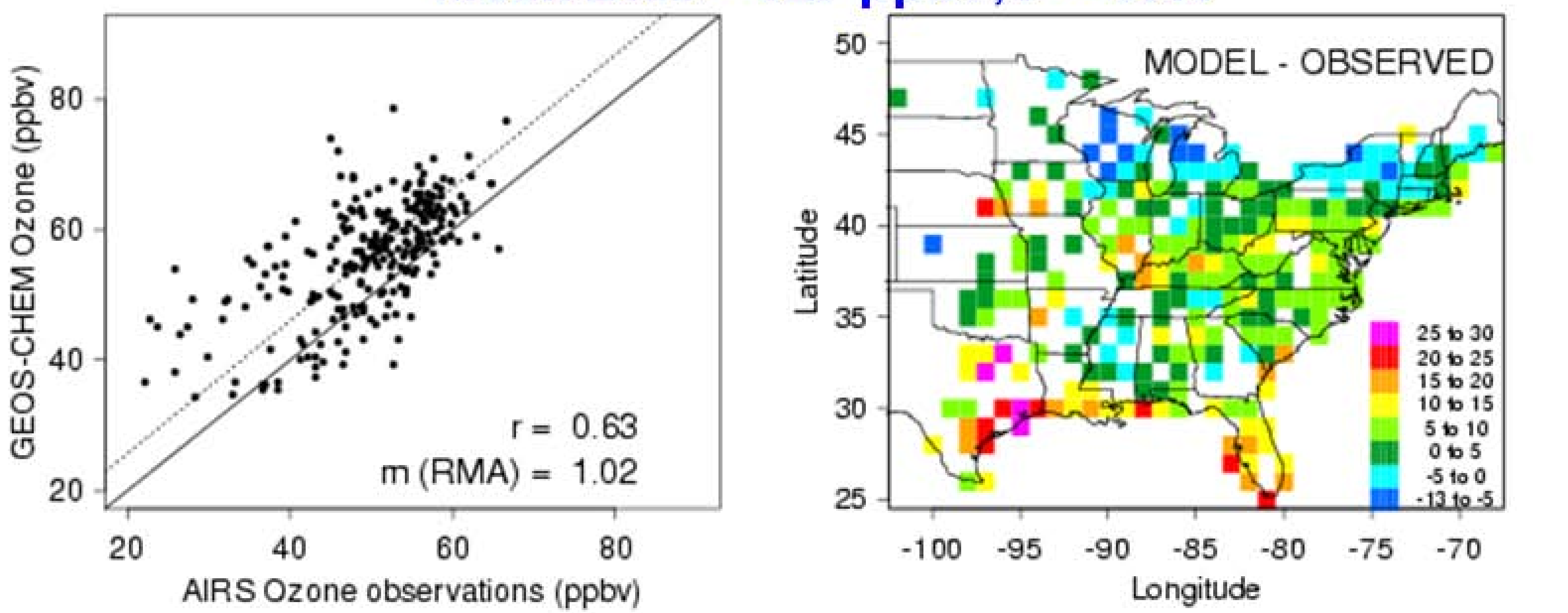
July 2001 1-5 p.m. Surface O_3 (ppbv)



GEOS-CHEM Evaluation: July 2001 1-5 p.m. Surface O_3 (ppbv)

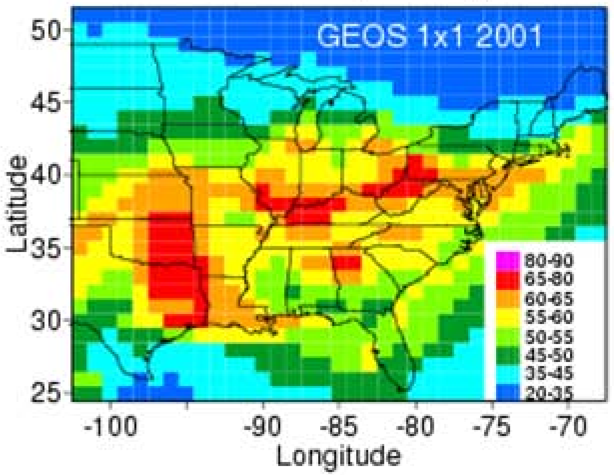


Mean Bias = 6±7 ppbv; r^2 = 0.40



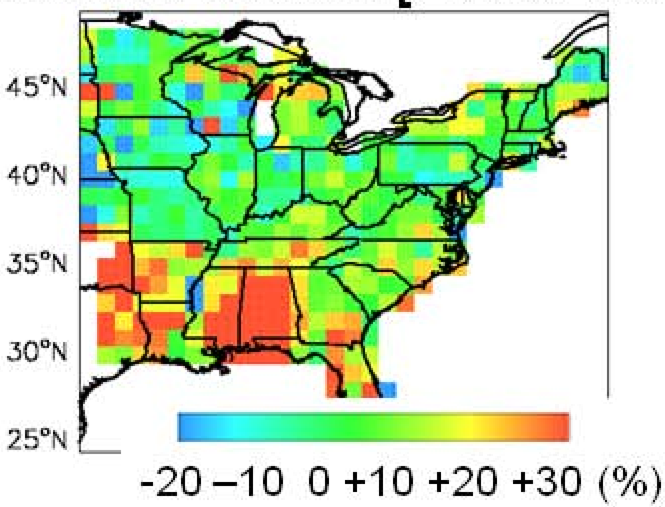
Increases in isoprene emissions reduce surface O_3 in Southeastern US

GEOS-CHEM July 1-5 p.m. O_3

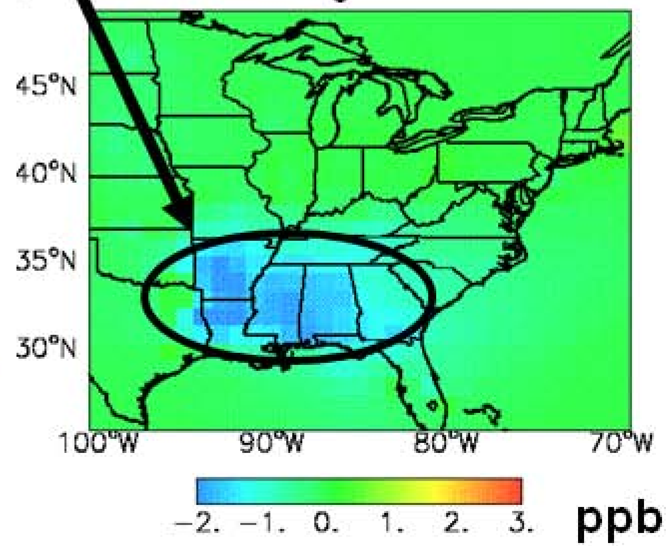


+

Isoprene emission changes from mid-80s to mid-90s [*Purves et al.*, 2004]



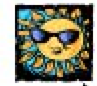
Change in July 1-5 p.m. surface O_3



Complicated Chemistry…

Complications to Chemistry: Isoprene may also decrease surface O_3 in low-NO_x, high isoprene settings

ISOPRENE +  + NO_x → O_3

ISOPRENE —(very fast) OH→ RO_2 —NO→ NO_2  ⇒ O_3 ↑ High-NO_x

RO_2 + NO ⇢ Isoprene nitrates. Sink for NO_x?

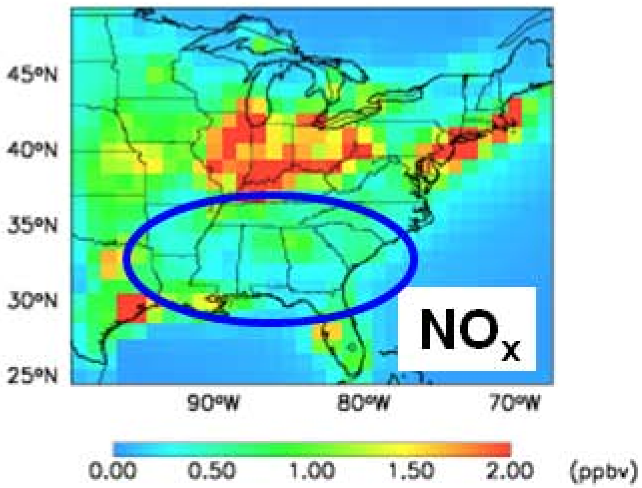
ISOPRENE —O_3 (slower)→ O_3 ↓ Low-NO_x, high-isoprene

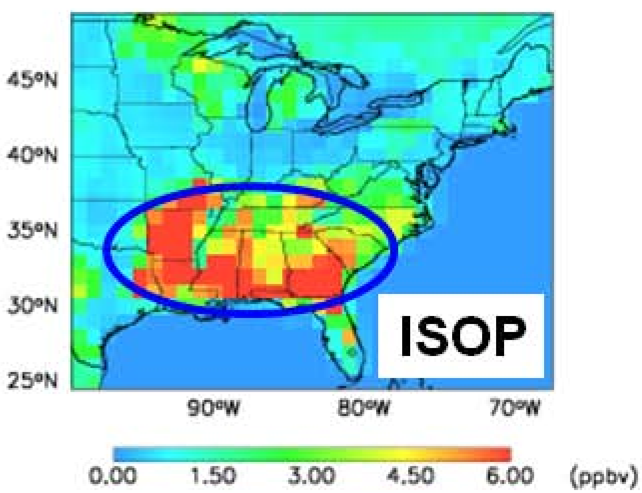
Thought to occur in pre-industrial [*Mickley et al.*, 2001]; and present-day tropical regions [*von Kuhlmann et al.*, 2004]

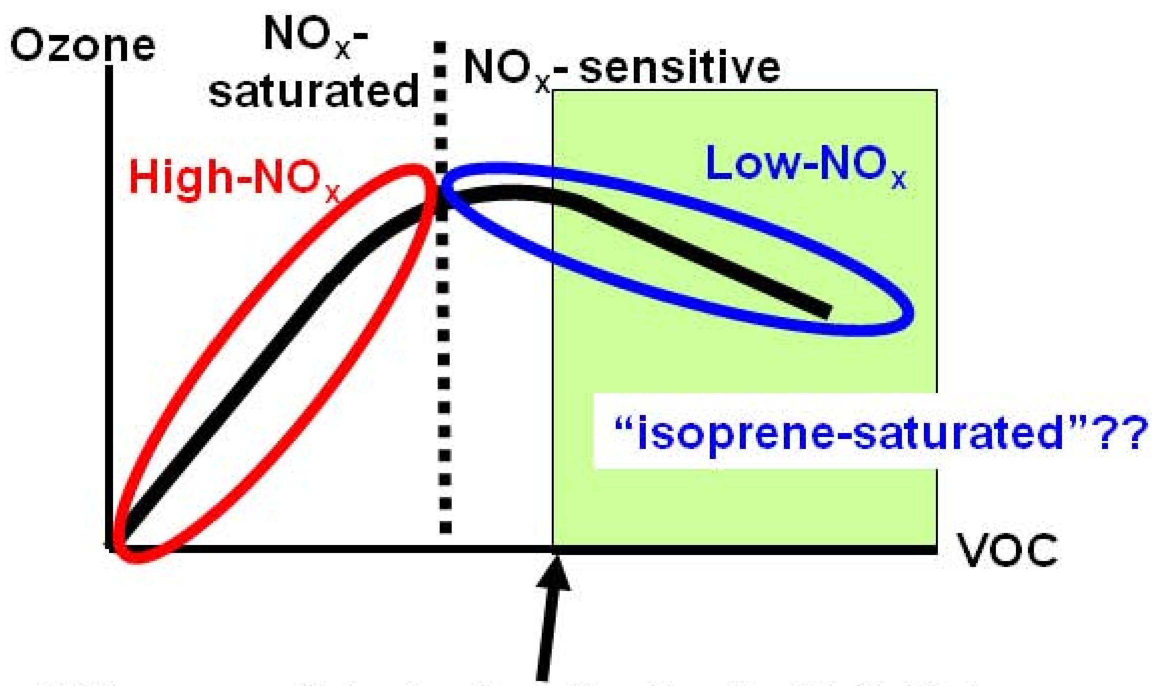
Isoprene does react directly with O_3 in our SE US GEIA simulation: O_3+biogenics (10d) comparable to O_3+HO_x (16d), $O_3+h\nu$ -> OH (11d)

Increasing Isoprene Decreases O_3 in Low-NO_x, High-isoprene regions

GEOS-CHEM base-case
July 1-5 p.m. mean





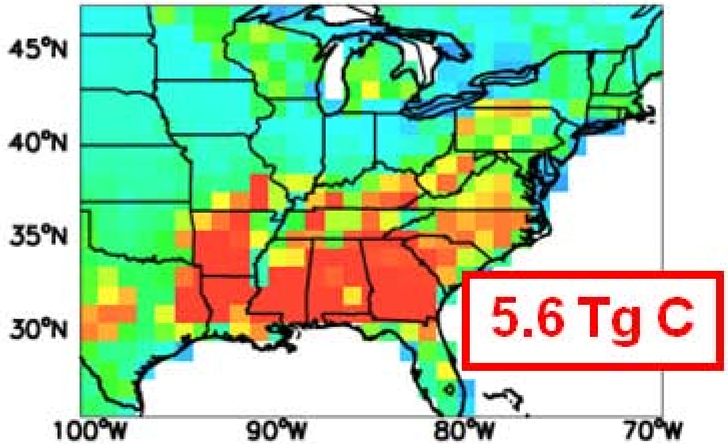


Other model studies indicate SE US is near "maximum VOC capacity point", beyond which VOCs suppress O_3 formation [*Kang et al.*, 2003].

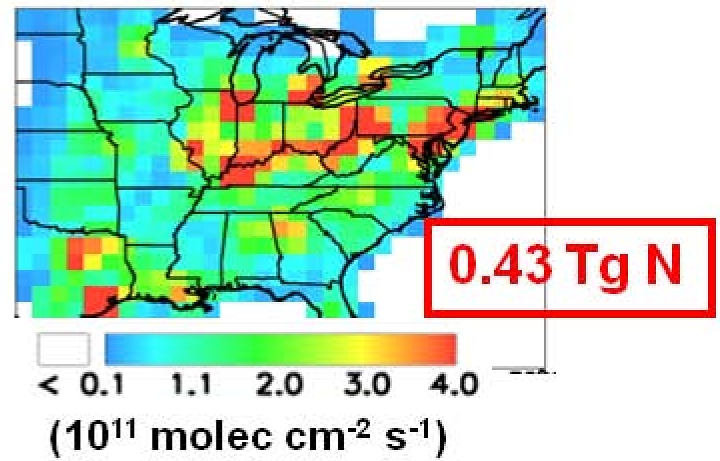
Choice of isoprene inventory critical for predicting base-case O_3

July isoprene emissions

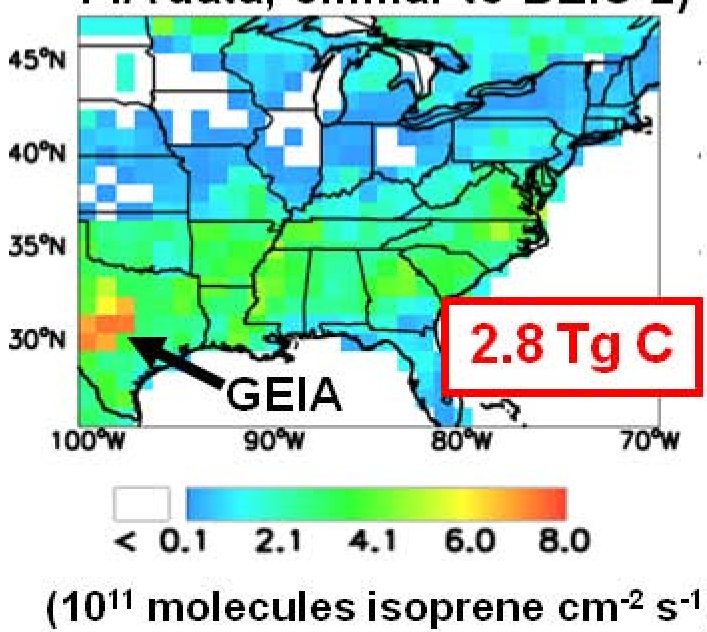
GEIA: global inventory



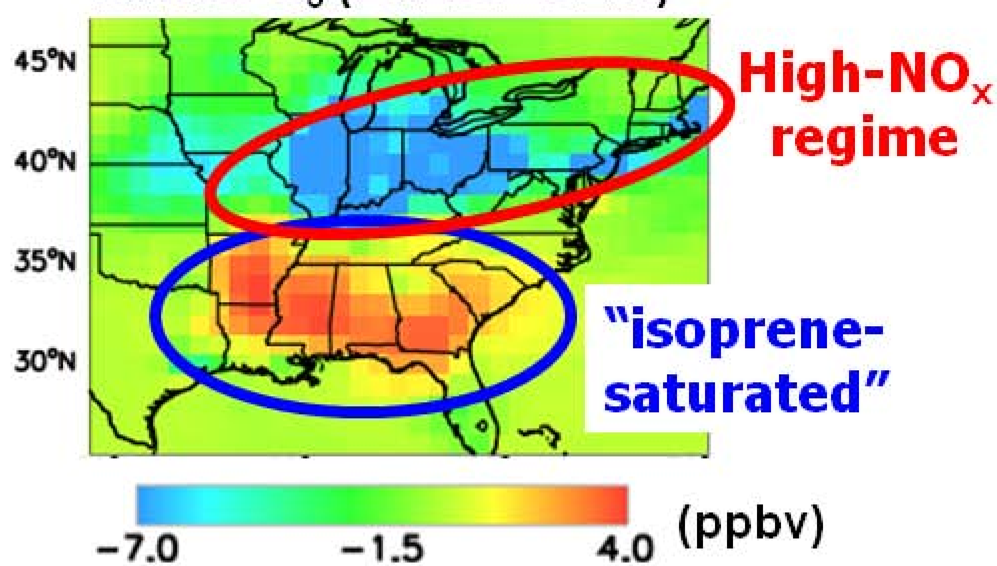
July Anthrop. NO_x emissions



Purves et al., [2004] (based on FIA data; similar to BEIS-2)



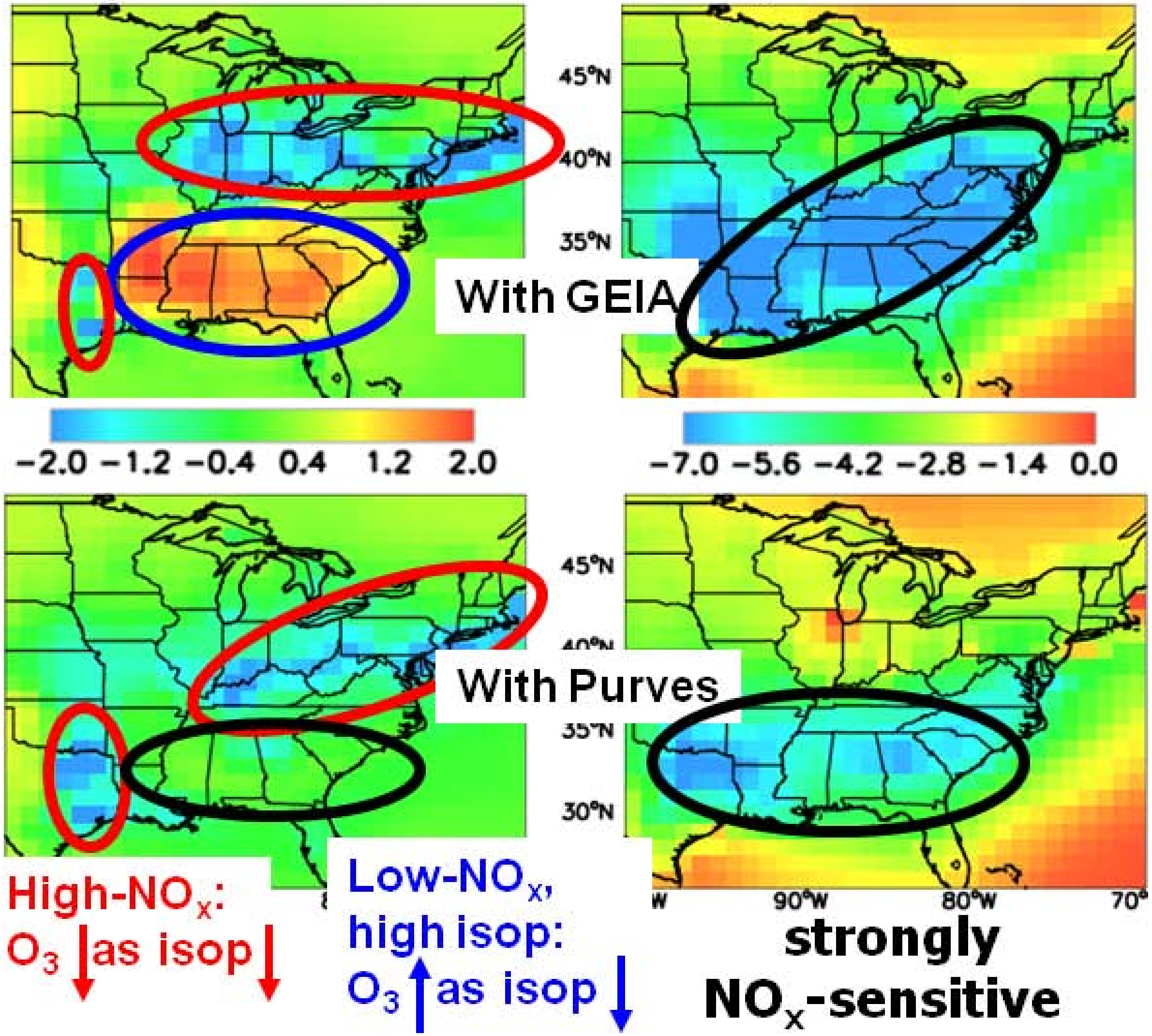
Difference in July 1-5 p.m. surface O_3 (Purves–GEIA)



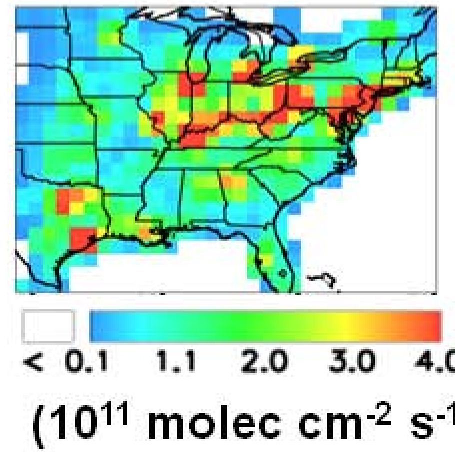
Identify O_3 chemistry regime with precursor emissions reductions

Change in July O_3 (ppbv; 1-5 p.m.)

Isoprene reduced 25% | NO_x reduced 25%

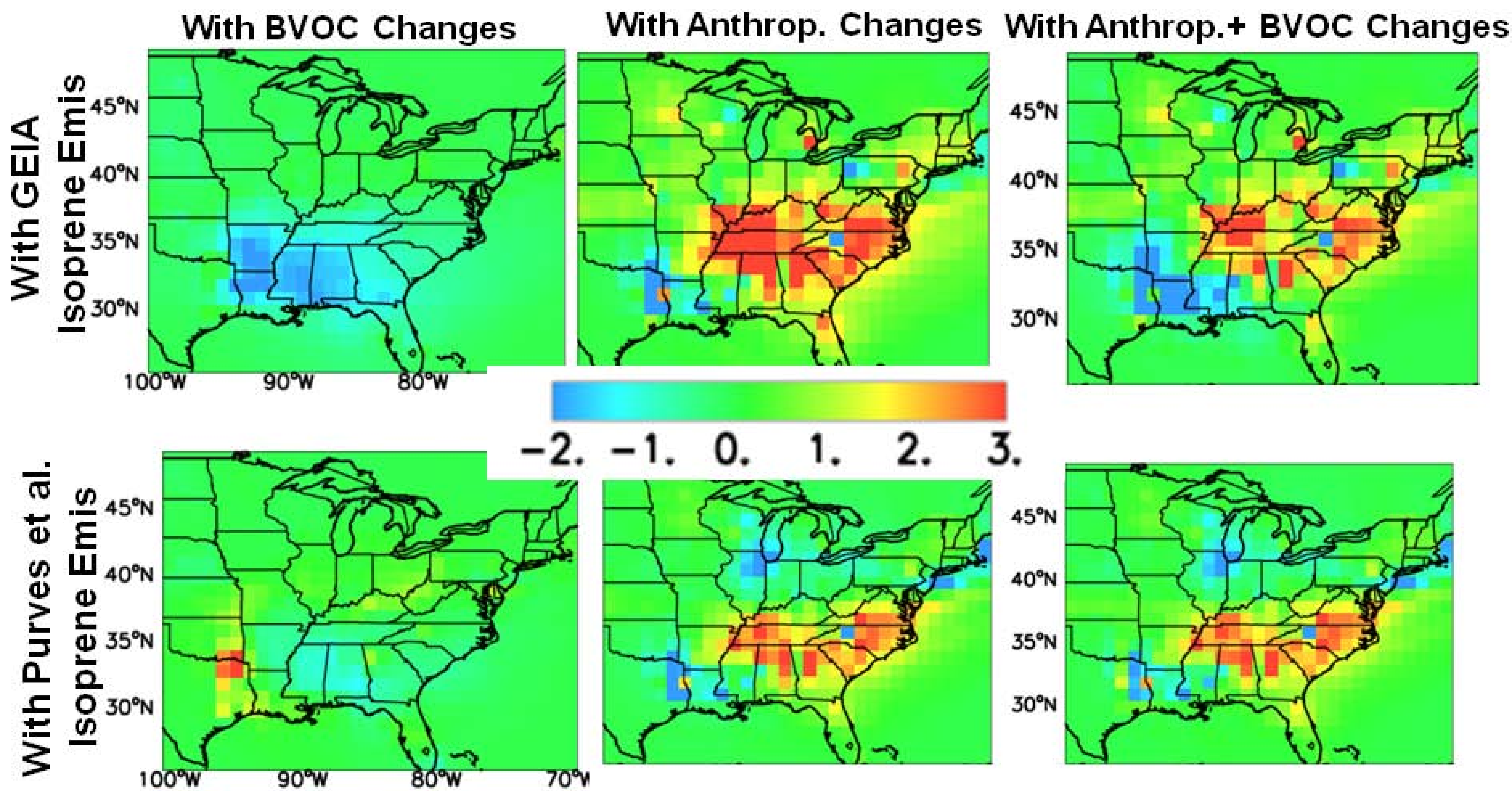


July Anthropogenic NO_x Emissions



Choice of isoprene inventory also critical for predicting O_3 response to changes in isoprene and anthropogenic NO_x emissions

Change in Mean July Surface O_3 (ppbv; 1-5 p.m.) reflecting 1980s to 1990s emissions changes



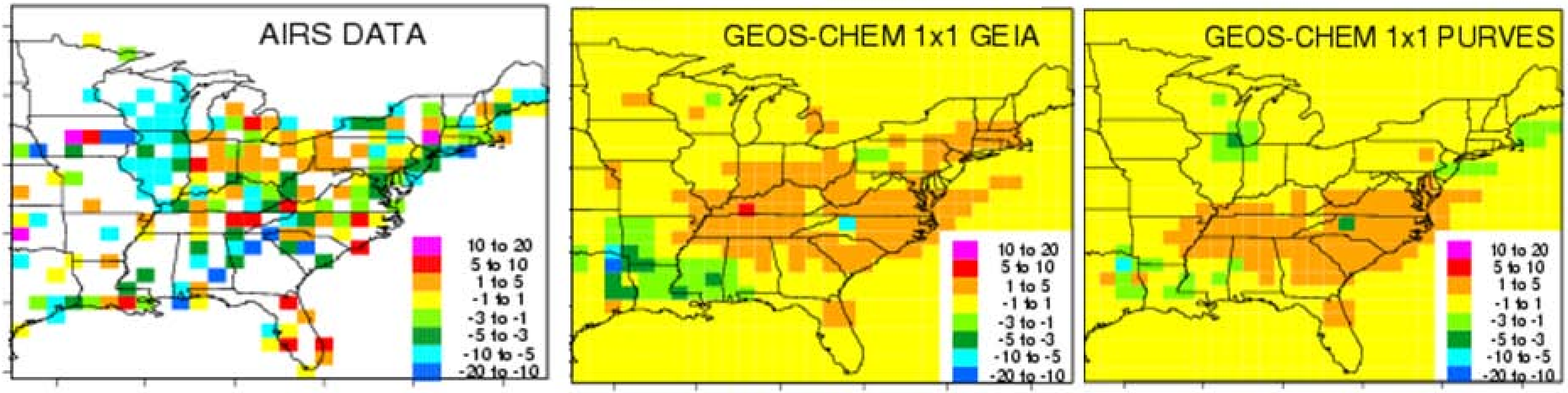
Changes in Anthropogenic NO_x emissions dominate O_3 response

But response depends upon choice of isoprene emission inventory

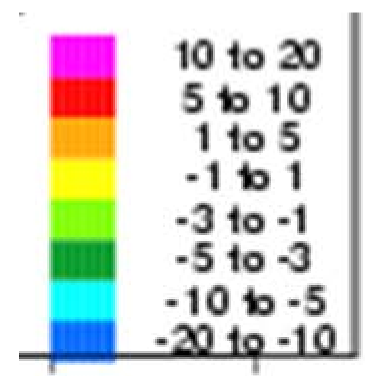
Comparison with observed changes? Impact on high-O_3 events?

Model vs. Obs.: Change in July O_3 1980s to 1990s (ppbv; 1-5 p.m.)

Obs: EPA AIRS | GEOS-CHEM: GEIA | GEOS-CHEM: Purves



(1993-1997) – (1983-1987)

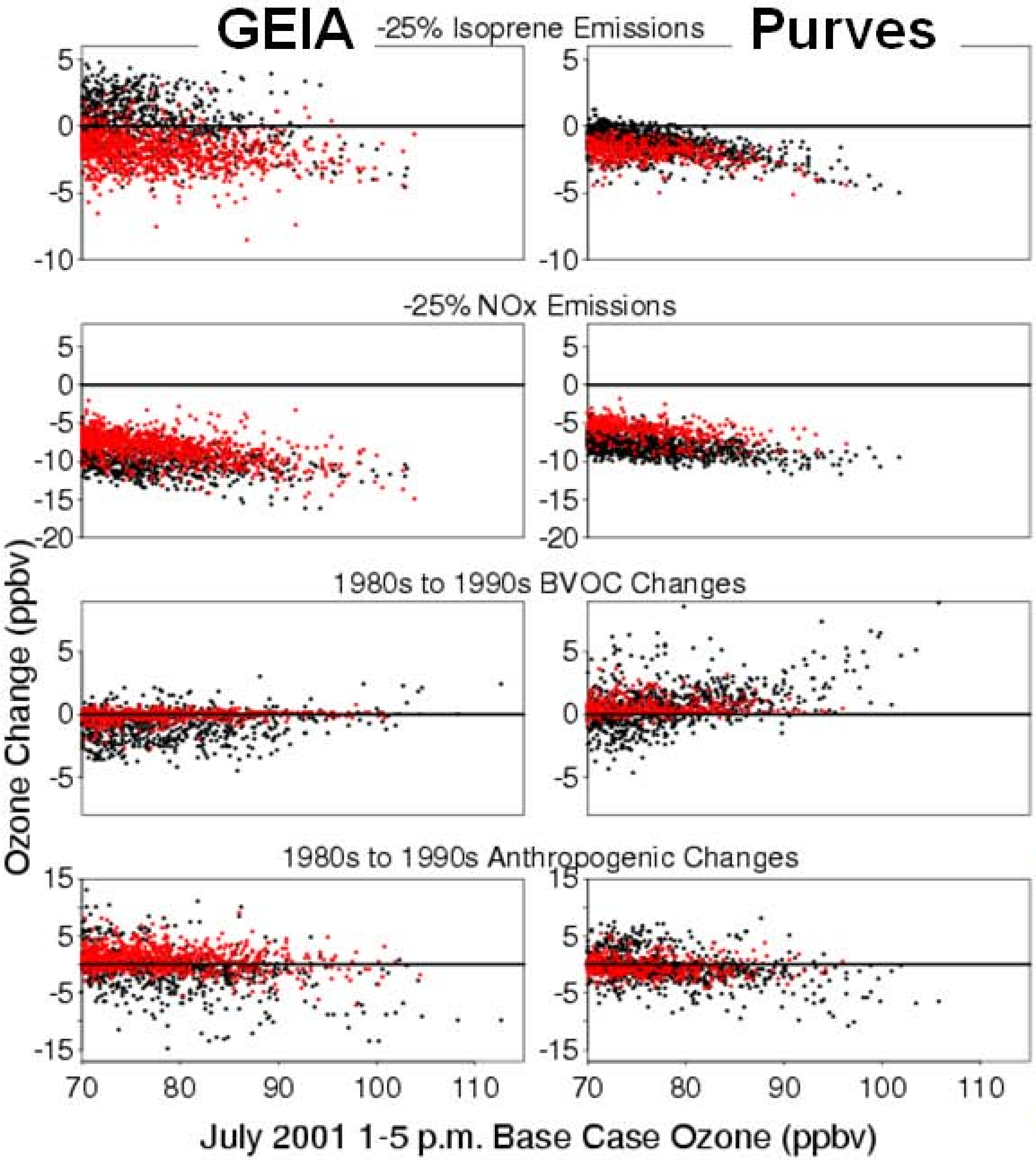


Poor correlation (r^2 ~ 0) between observed and simulated changes

Observed changes in O_3 are not explained by regional emission changes alone…

Impact of Sensitivity Simulations on High-O_3 Events:

● Northeast
● Southeast



- decrease with isoprene except for GEIA SE
- decrease with NO_x, larger response with GEIA
- dominated by anthrop. (NO_x) emissions but BVOC changes may offset for most extreme events

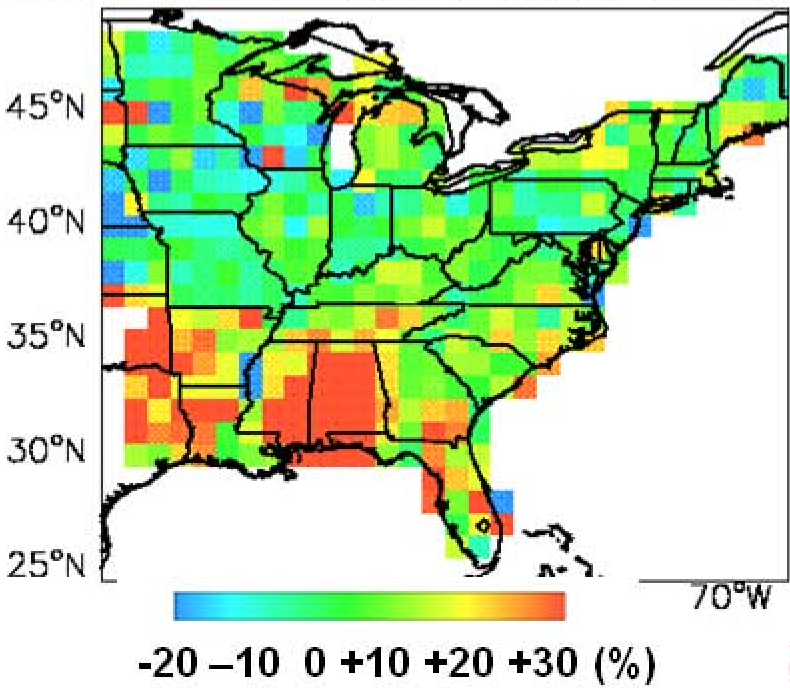
Unclear whether recent BVOC emission changes mitigated / exacerbated high-O_3 events

<u>Tool #2</u>: MOZART-2 tropospheric chemistry model [*Horowitz et al.*, 2003]

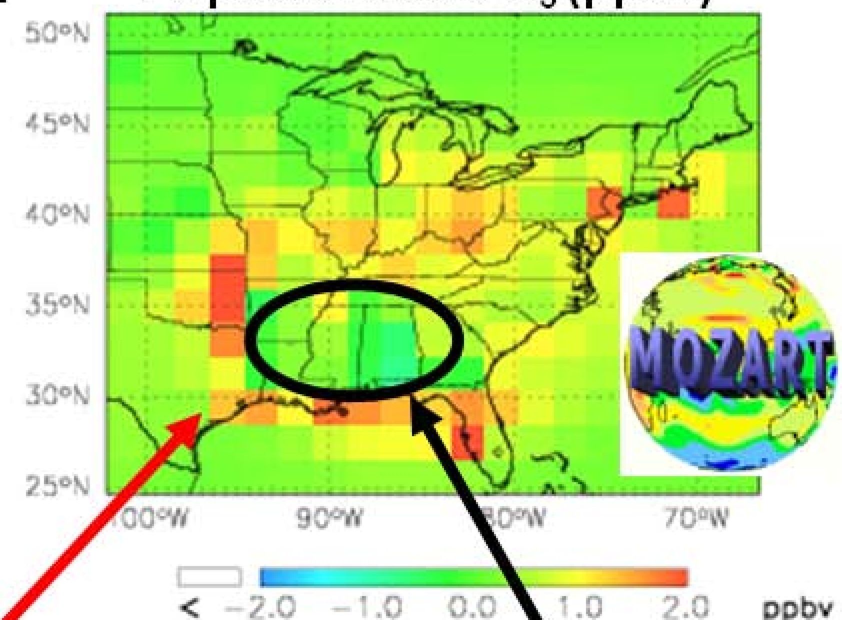
- **assimilated meteorology: NCEP T62 (~1.9°) 2001 ; 28 vertical levels**
- **GEIA isoprene inventory [*Guenther et al.*, 1995]**

Does MOZART-2 also predict decreases in O_3 resulting from increases in isoprene emissions?

Isoprene emission changes from mid-80s to mid-90s [*Purves et al.*, 2004]



MOZART-2: Change in July 1-5 p.m. surface O_3 (ppbv)

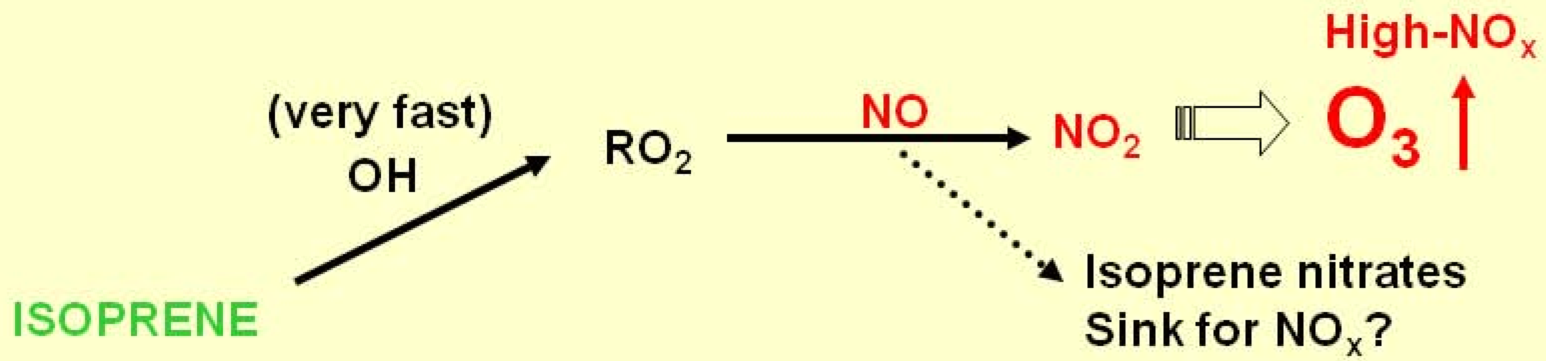


O_3 increases (1-2 ppbv)

Little change (NO_x-sensitive)

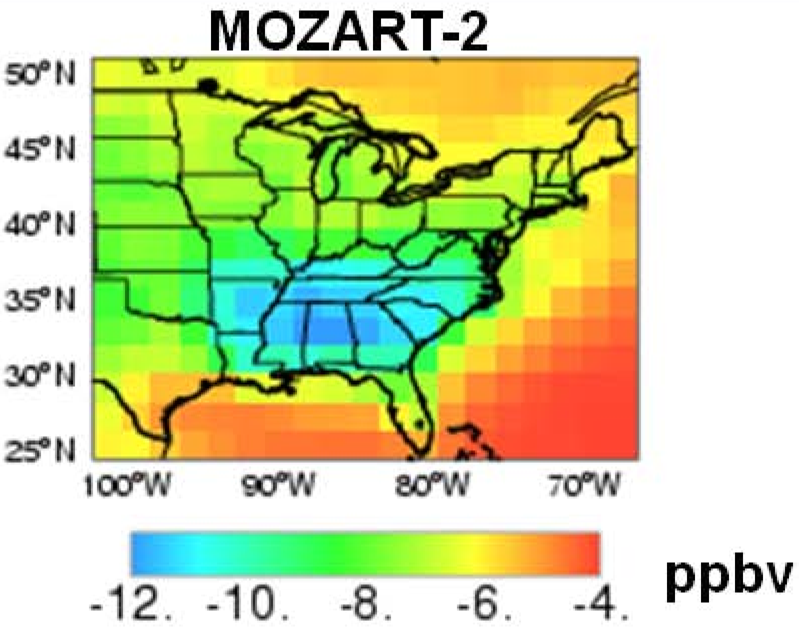
Isoprene nitrates are not a NO_x sink in MOZART-2: O_3 Sensitivity?

What is the O_3 sensitivity to the uncertain fate of organic isoprene nitrates?



Change in July mean 1-5 p.m. surface O_3 when isoprene nitrates act as a NO_x sink

→ 6-12 ppbv impact!



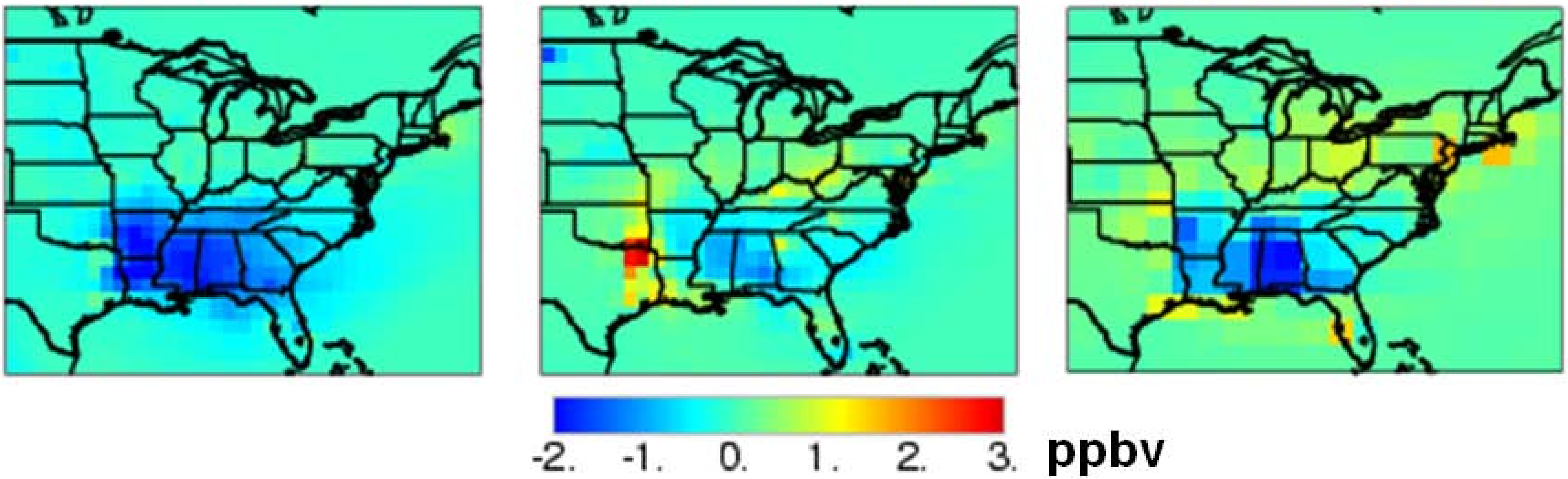
Revisit O_3 response to isoprene changes with this assumption

Chemical uncertainty: MOZART-2 shows similar results to GEOS-CHEM if isoprene nitrates are a NO_x sink

Change in July 1-5 p.m. surface O_3 (ppbv)
(due to isop emis changes from mid-1980s to mid-1990s)

With 12% yield of isoprene nitrates

GEOS-CHEM: GEIA | **GEOS-CHEM: Purves** | **MOZART-2: GEIA**



⇒ Understanding fate of isop. nitrates essential for predicting sign of response to changes in isoprene emissions

Conclusions and Remaining Challenges

- Better constrained isoprene emissions are needed to quantify:
  1. isoprene contribution to E. U.S. surface O_3
  2. how O_3 responds to both anthrop. and biogenic emission changes (deserves consideration in planning biofuel plantations)

  → Utility of satellite CH_2O columns?
  → New inventories (MEGAN, BEIS-3) more accurate?
  → Aircraft observations from recent ICARTT campaign?

- Recent isoprene increases may have reduced surface O_3 in the SE

  → Does this regime actually exist?
  → Fate of organic nitrates produced during isoprene oxidation?
  → Results consistent in MOZART-2 and GEOS-CHEM

- Reported regional emission changes from 1980s to 1990s alone do not explain observed O_3 trends
  → Are anthropogenic emissions inventories sufficient to support trend studies? (*Parrish et al., JGR* 2002)
  → Decadal shifts in meteorology?
  → Changing global O_3 background?