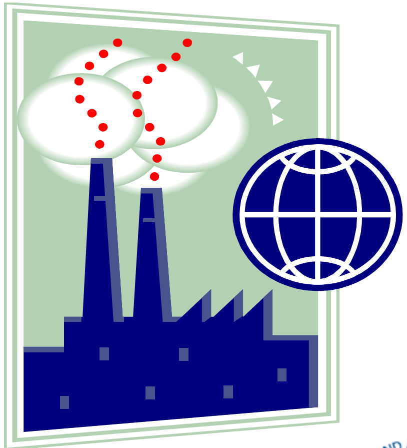

Tropospheric ozone response to methane emission controls: Implications for climate and global air quality

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Acknowledgments:
Larry Horowitz, Chip Levy (NOAA/GFDL)
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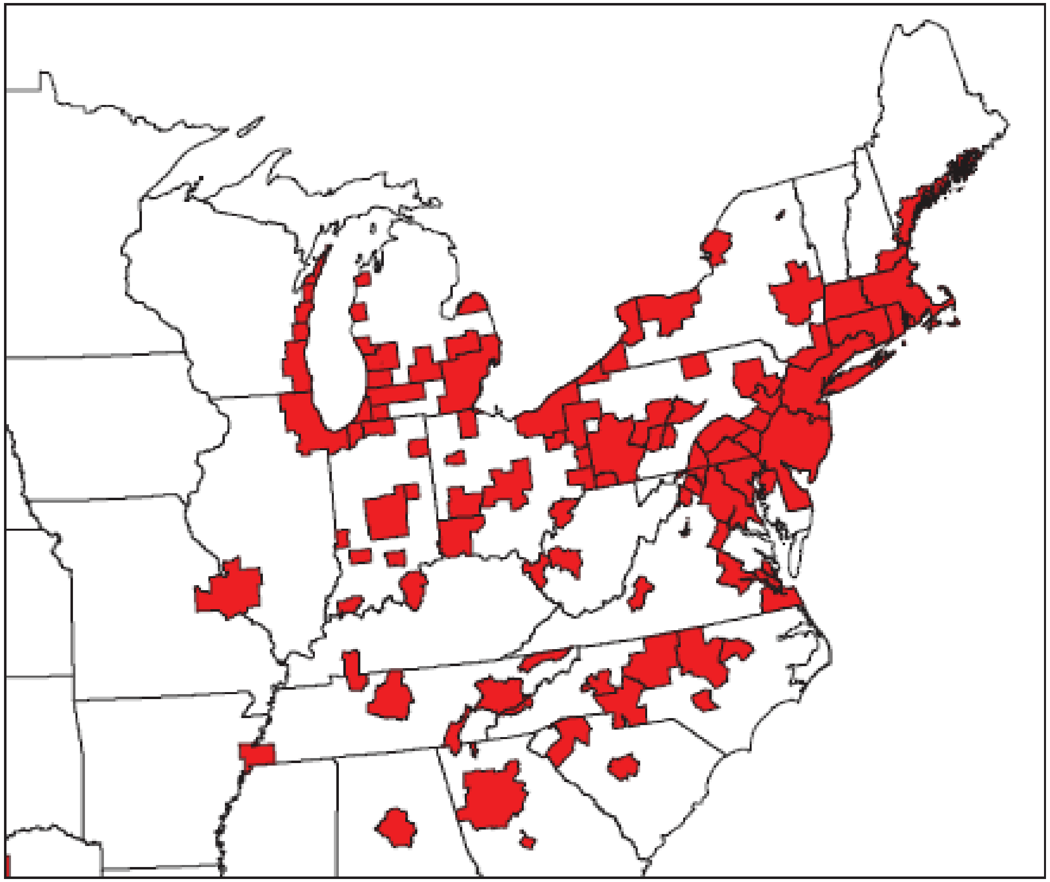
Frank Dentener, Kees Cuvelier (JRC, Italy)
The TF HTAP Modeling Team

Funding from Luce Foundation via Clean Air Task Force

IGERT Joint Program Colloquium, Columbia University
April 5, 2007

The U.S. ozone smog problem is spatially widespread, affecting >100 million people

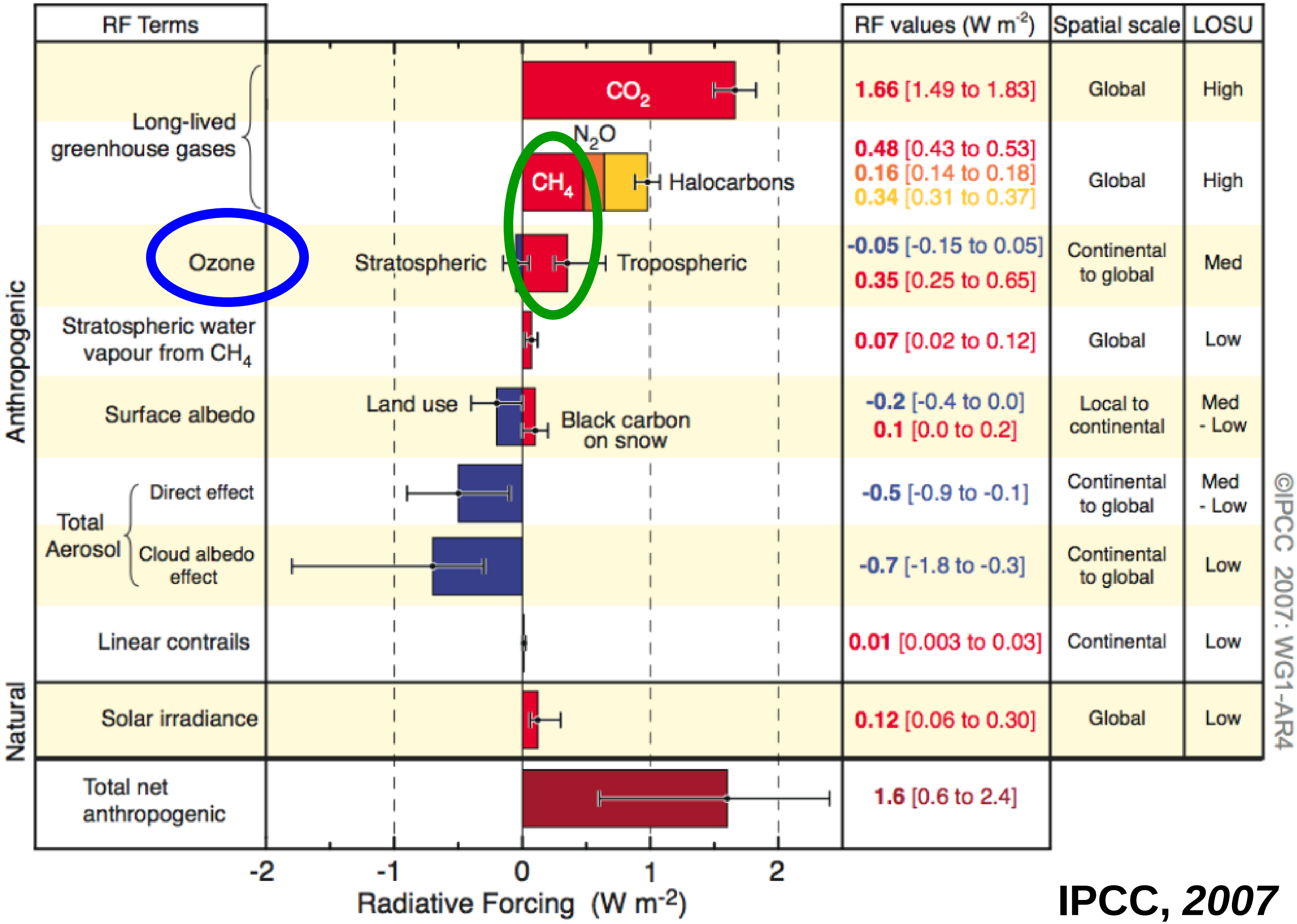
Nonattainment Areas (2001-2003 data)



U.S. EPA, 2006

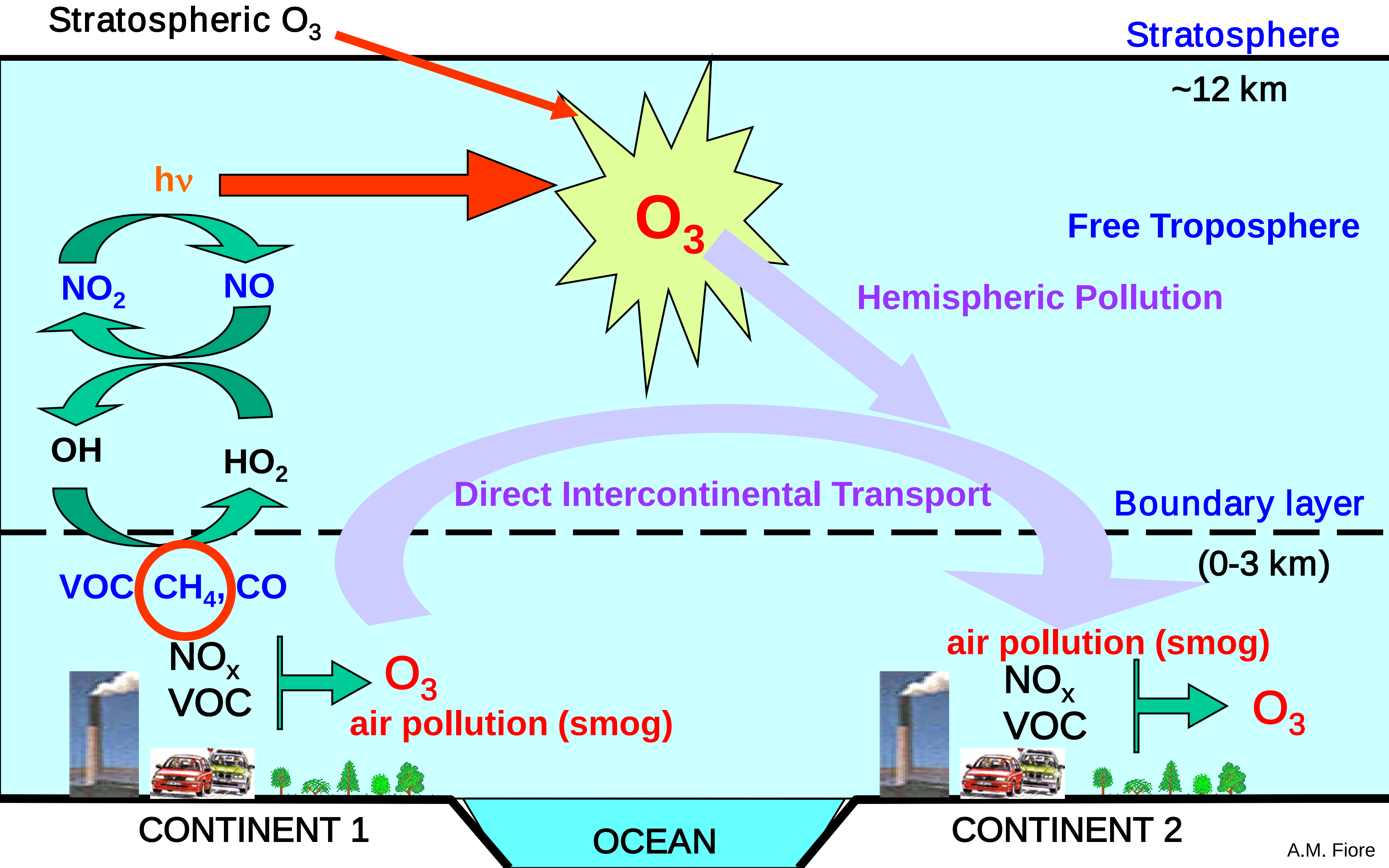
4th highest daily max 8-hr mean O_3 > 84 ppbv

Radiative forcing of climate (1750 to present): Important contributions from methane and ozone



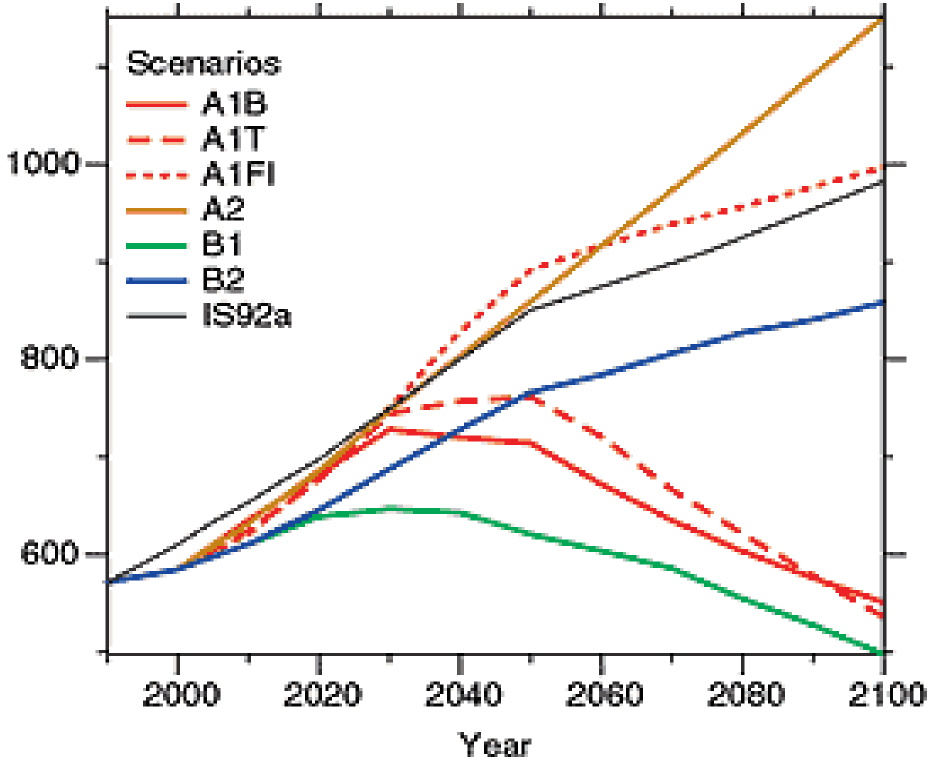
IPCC, *2007*

Air quality-Climate Linkage:
CH_4, O_3 are greenhouse gases
CH_4 contributes to background O_3 in surface air

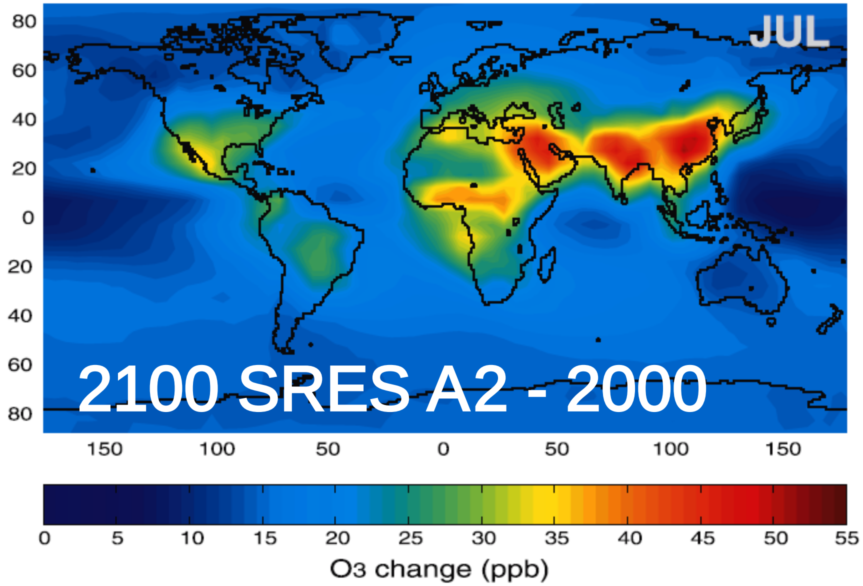


IPCC [2001] scenarios project future growth

Projections of future CH_4 emissions ($Tg\ CH_4$) to 2100



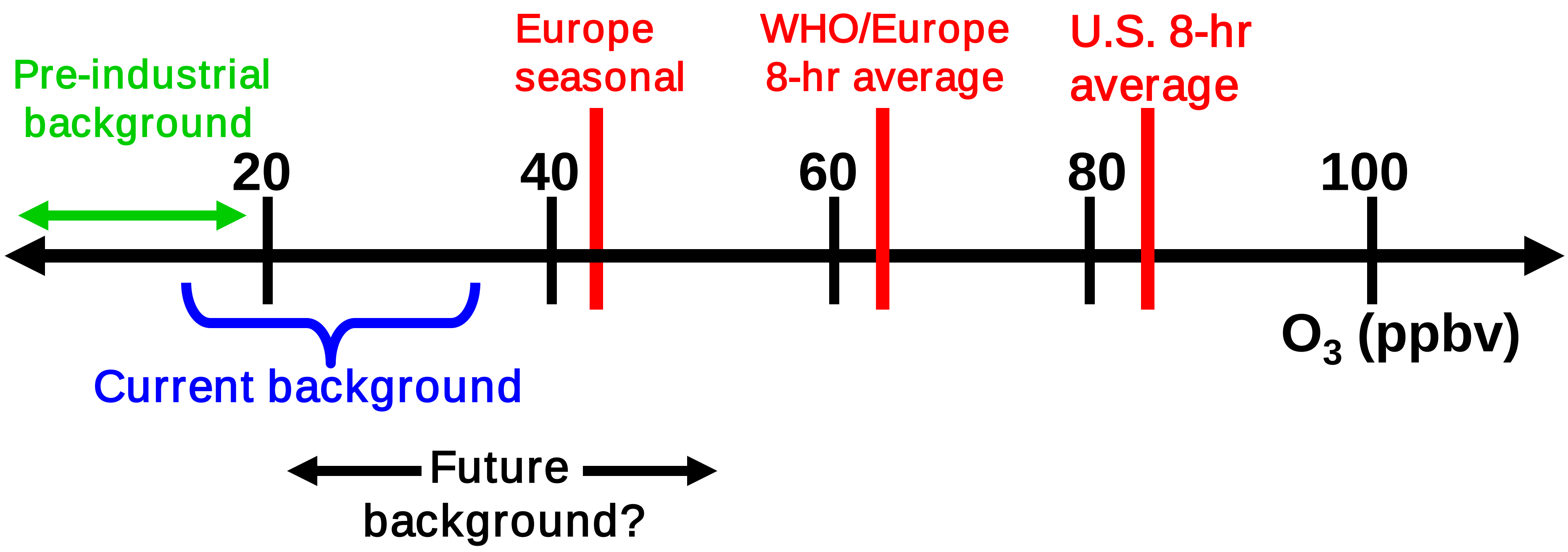
Change in 10-model mean surface O_3



Attributed mainly to increases in methane and NO_x [*Prather et al.*, 2003]

Rising background O_3 has implications for attaining air quality standards

Recent observational analyses suggest that surface O_3 background is rising
[e.g. *Lin et al*., 2000; *Jaffe et al*., 2003, 2005; *Vingarzan*, 2004; *EMEP/CCC-Report 1/2005*]



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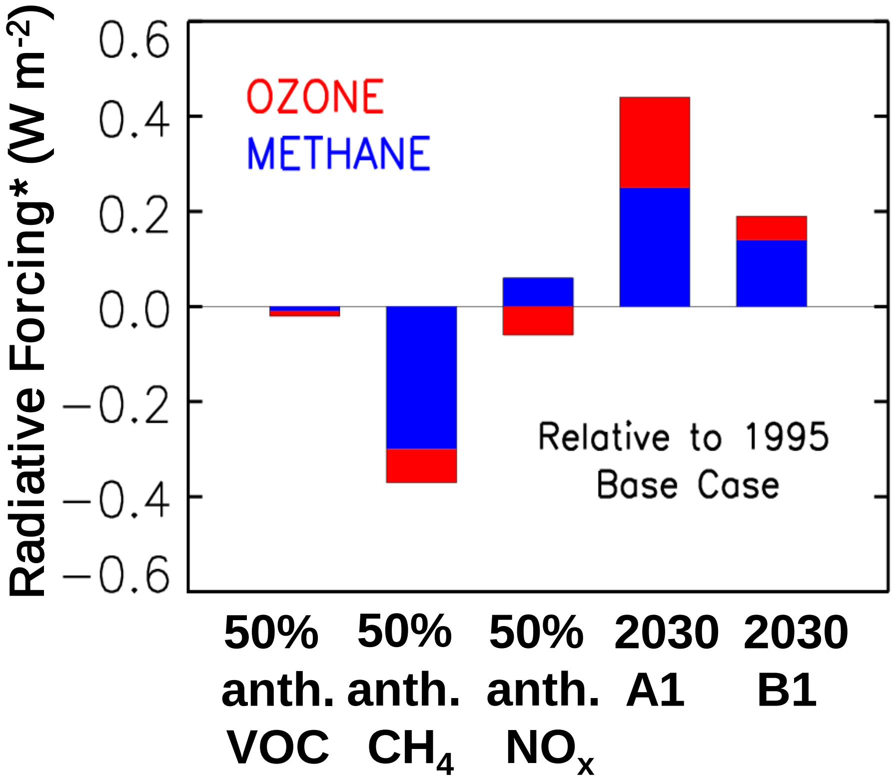
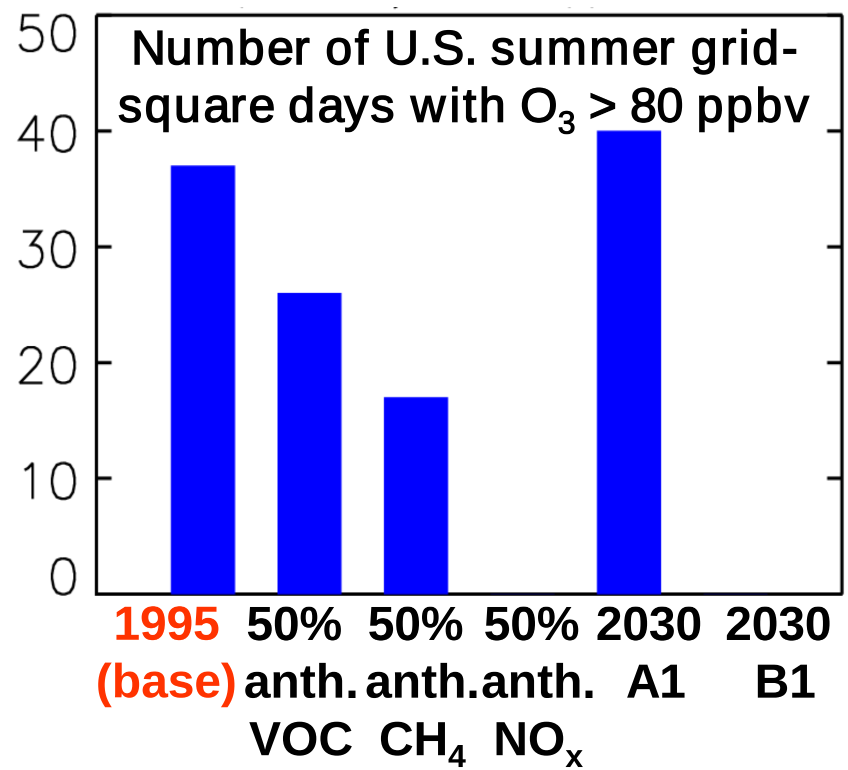
Double dividend of Methane Controls: Decreased greenhouse warming and improved air quality





GEOS-Chem Model (4°x5°)

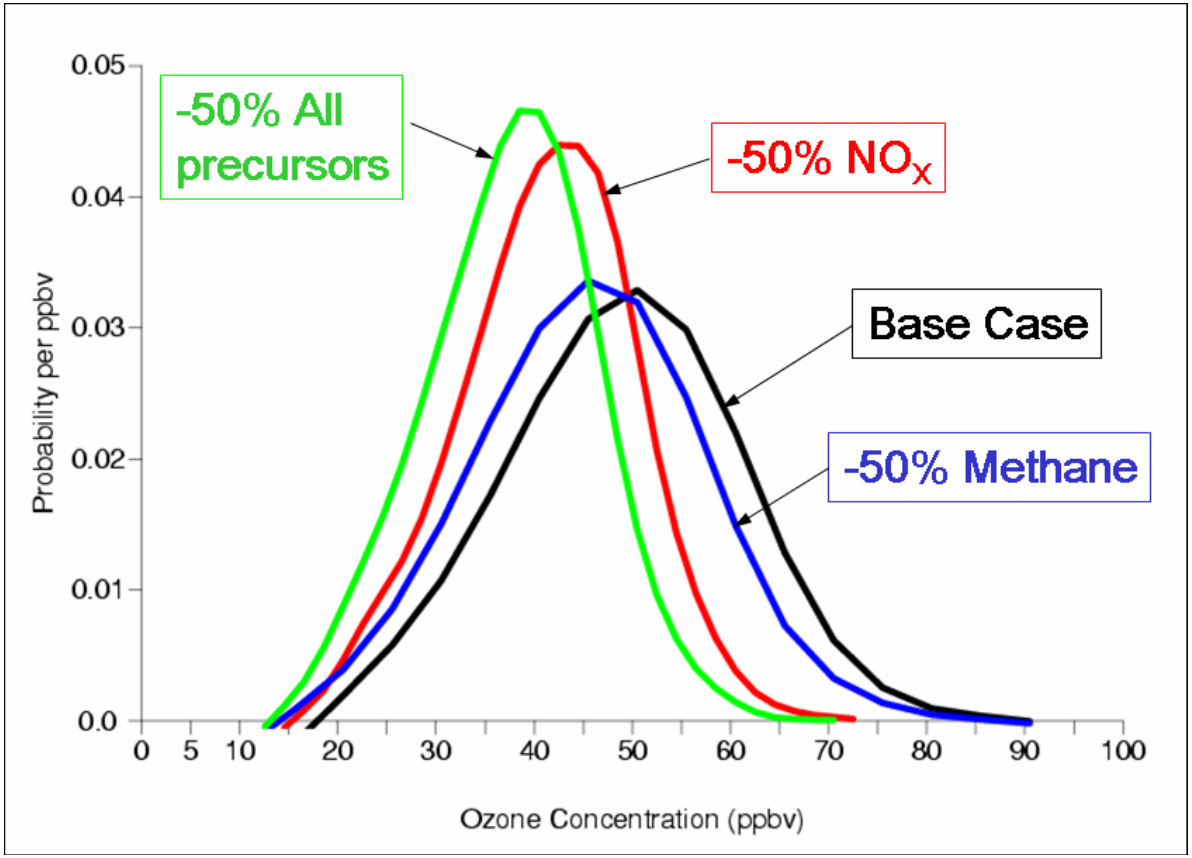
IPCC scenario	Anthrop. NO_x emissions (2030 vs. present) Global	U.S.	Methane emissions (2030 vs. present)
A1	+80%	-20%	+30%
B1	-5%	-50%	+12%

CH_4 links air quality & climate via background O_3

Fiore et al., GRL, 2002

Impacts of O_3 precursor reductions on U.S. summer afternoon surface O_3 frequency distributions

GEOS-Chem Model Simulations (4°x5°)



NO_x controls strongly decrease the highest O_3 (regional pollution episodes)

CH_4 controls affect the entire O_3 distribution similarly (background)

Results add linearly when both methane and NO_x are reduced

Fiore et al., 2002; West & Fiore, ES&T, 2005

Methane trends and linkages with chemistry, climate, and ozone pollution

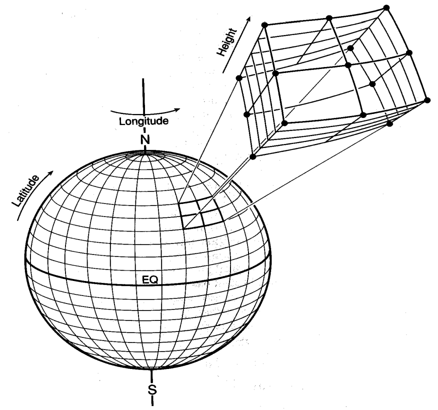
1) Climate and air quality benefits from CH_4 controls

- Characterize the ozone response to CH_4 control
- Incorporate methane controls into a future emission scenario

2) Recent methane trends (1990 to 2004)

- Are emission inventories consistent with observed CH_4 trends?
- Role of changing sources vs. sinks?

Research Tool:



3D model structure

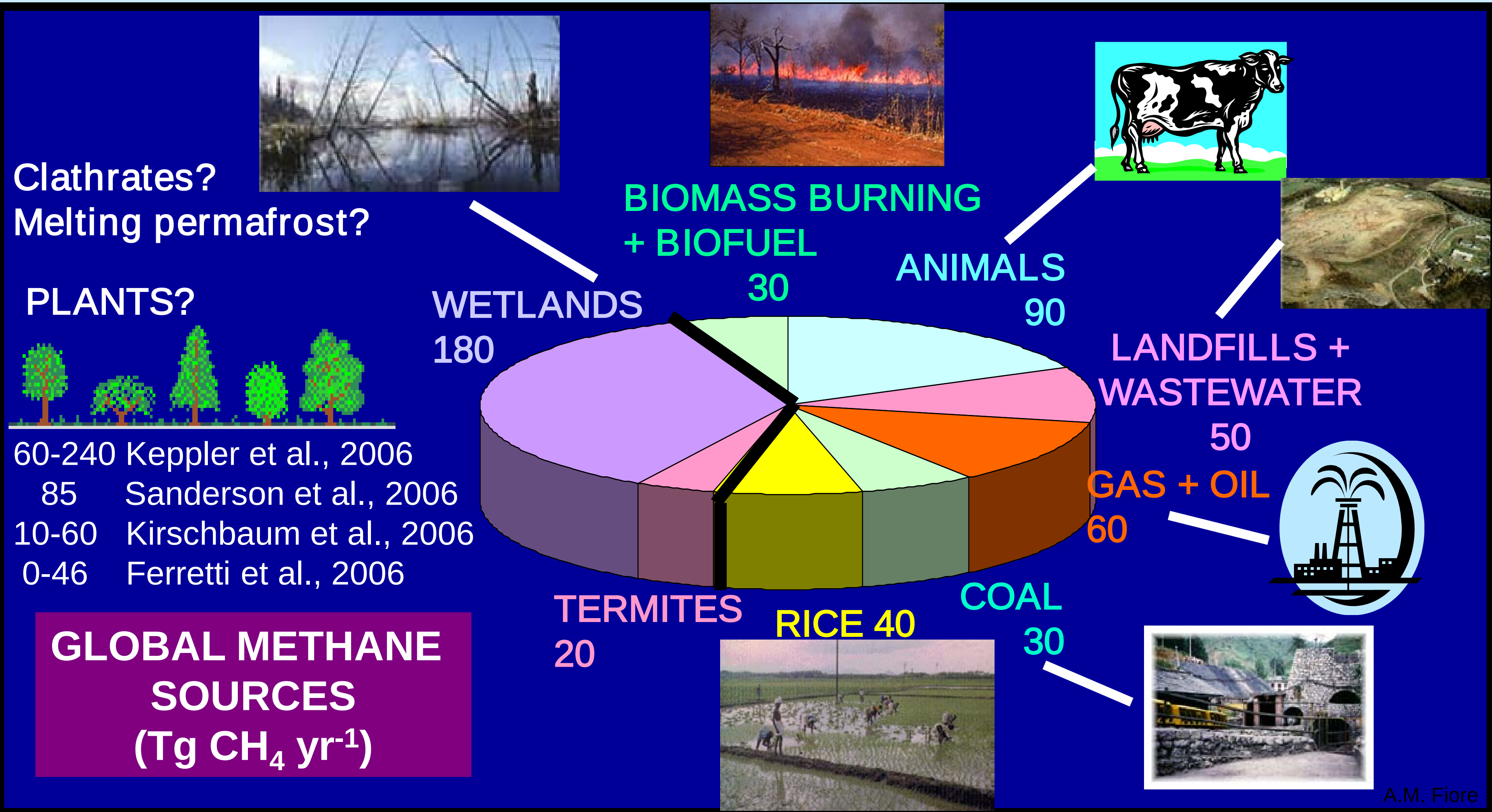
MOZART-2 Global Chemical Transport Model [*Horowitz et al.*, 2003]

NCEP, 1.9°x1.9°, 28 vertical levels

→ **Fully represent methane-OH relationship**
→ **Test directly with observations**

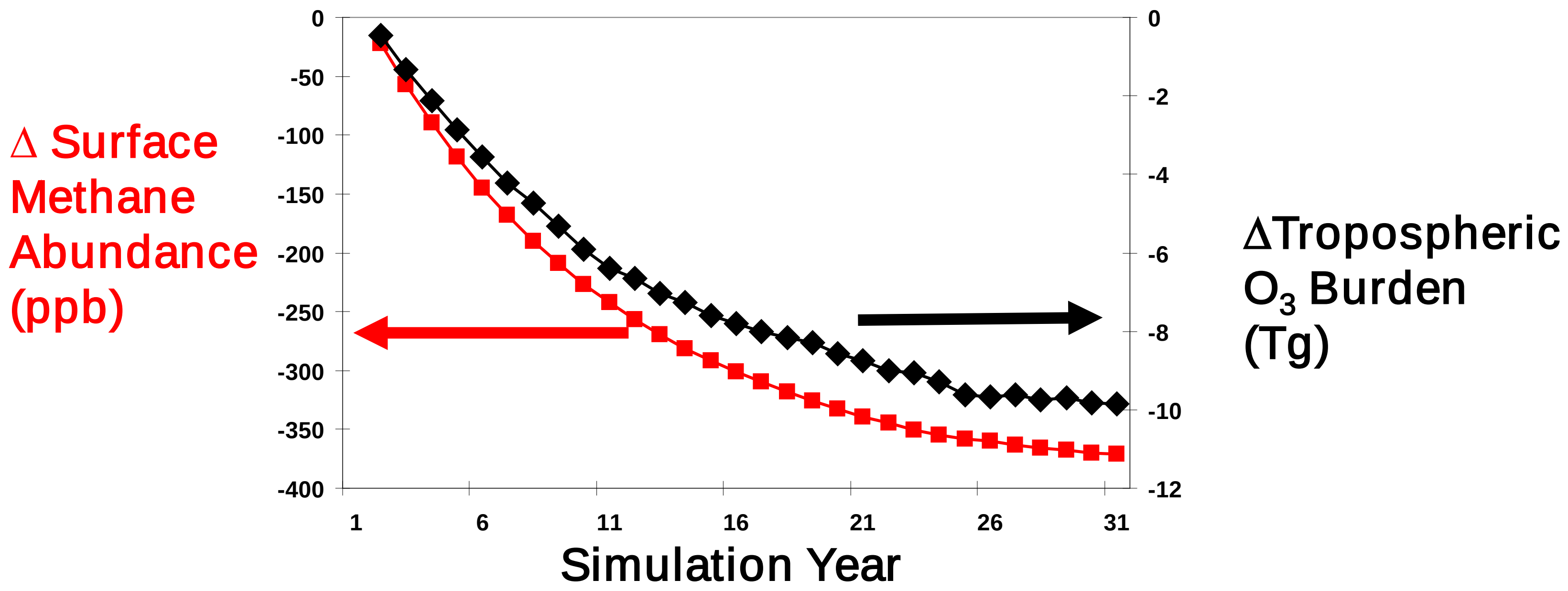
More than half of global methane emissions are influenced by human activities

~300 Tg CH_4 yr^{-1} Anthropogenic [EDGAR 3.2 Fast-Track 2000; *Olivier et al.*, 2005]
~200 Tg CH_4 yr^{-1} Biogenic sources [*Wang et al.*, 2004]
>25% uncertainty in total emissions



Characterizing the methane-ozone relationship with idealized model simulations

Reduce global anthropogenic CH_4 emissions by 30%



Model approaches a new steady-state after 30 years of simulation

Is the O_3 response sensitive to the location of CH_4 emission controls?

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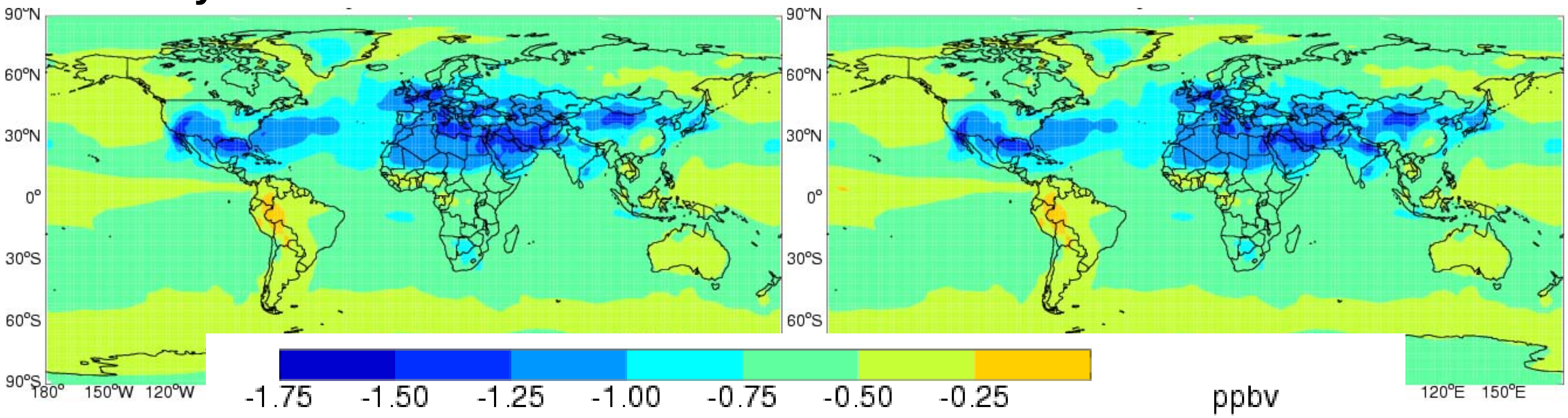
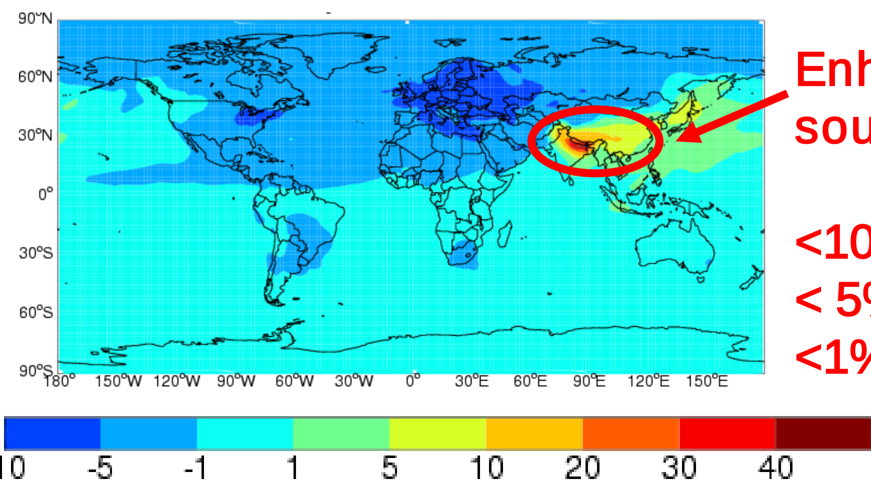
Change in July surface O_3 from 30 % decrease in anthropogenic CH_4 emissions

Globally uniform emission reduction | **Emission reduction in Asia**



Percentage Difference:

$$\frac{\Delta Asia - \Delta uniform}{\Delta Asia}$$



Enhanced effect in source region

<10% other NH source regions
< 5% rest of NH
<1% most of SH

→ Target cheapest controls worldwide

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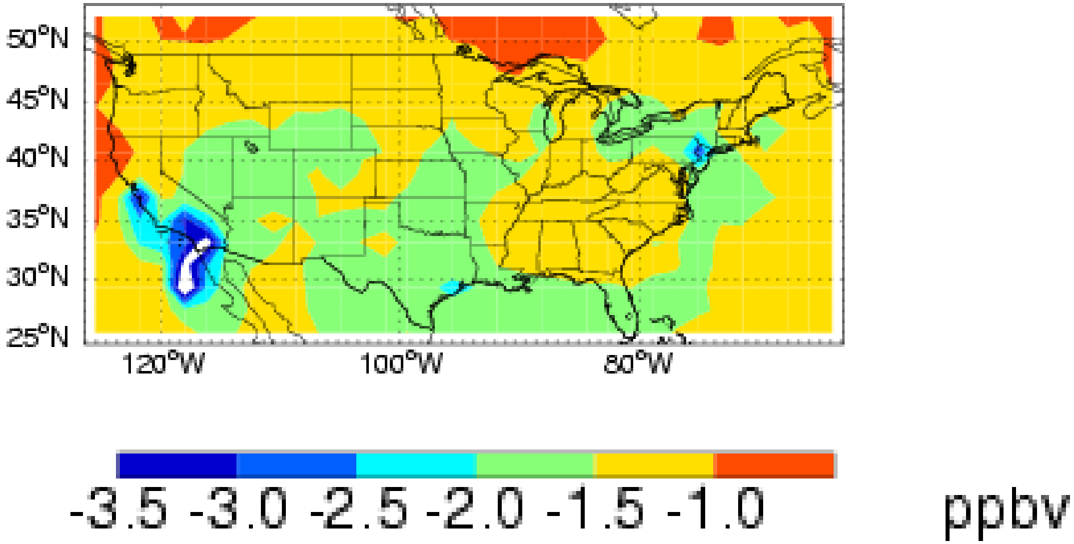
Decrease in summertime U.S. surface ozone from 30% reductions in anthrop. CH_4 emissions

MAXIMUM DIFFERENCE
(Composite max daily afternoon mean ozone JJA)

NO ASIAN ANTH. CH_4



→ Largest decreases in NO_x-saturated regions

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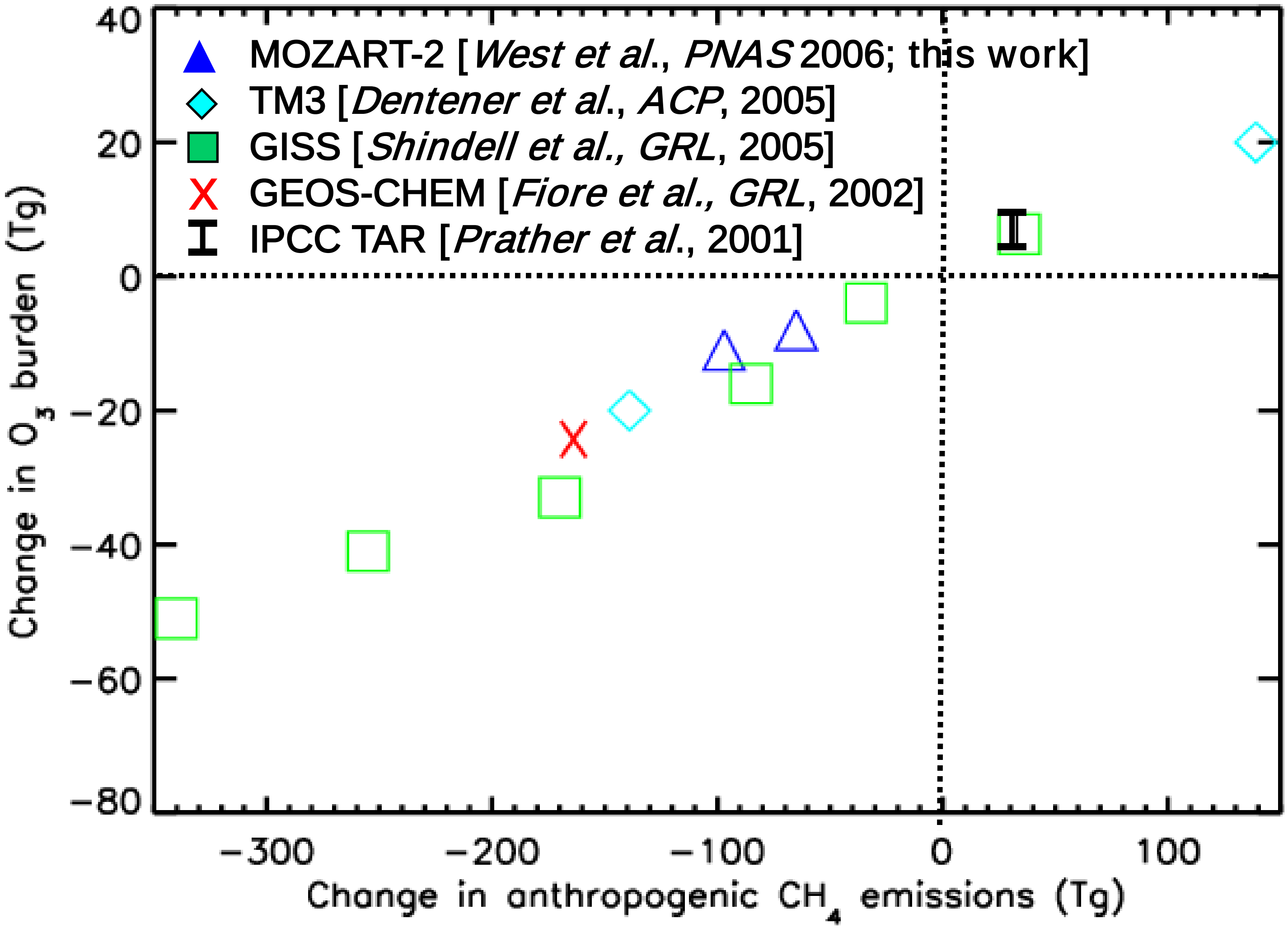
Tropospheric O_3 responds approximately linearly to anthropogenic CH_4 emission changes across models



Anthropogenic CH_4 contributes ~50 Tg (~15%) to tropospheric O_3 burden

~5 ppbv to global surface O_3

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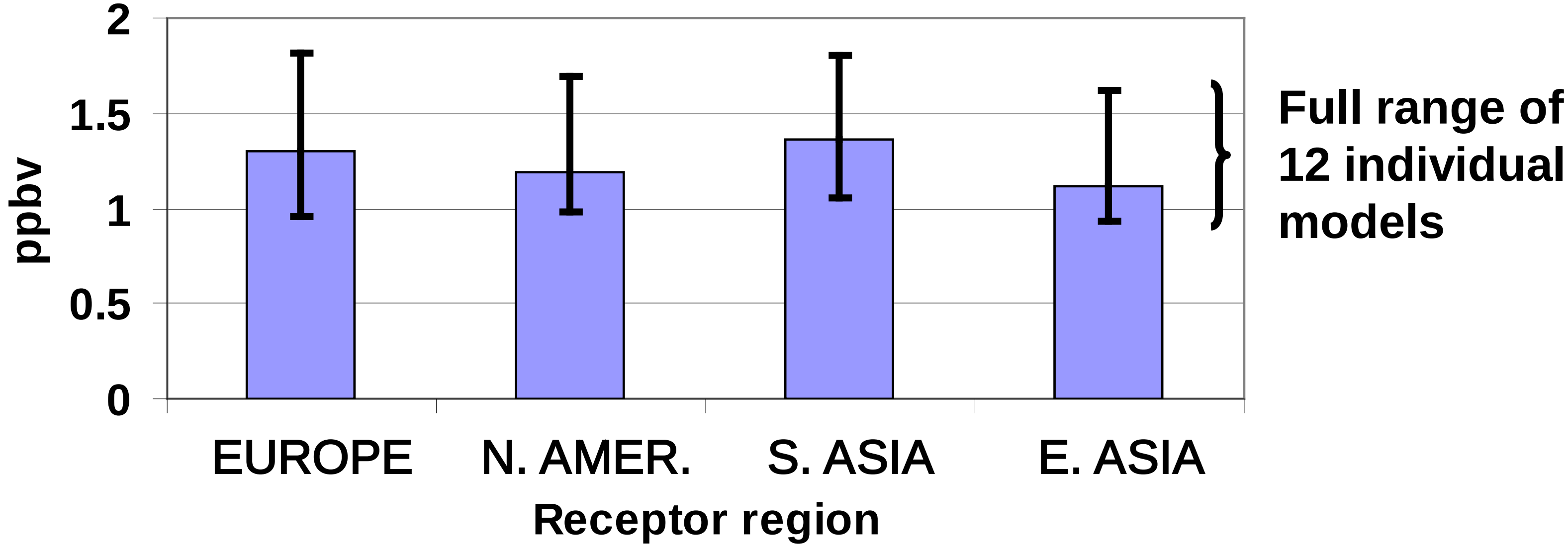
Multi-model study shows similar surface ozone decreases over NH continents when global methane is reduced

Task Force on Hemispheric Transport of Air Pollution

ANNUAL MEAN OZONE DECREASE FROM 20% DECREASE IN GLOBAL METHANE



→ >1 ppbv O_3 decrease over all NH receptor regions

→ Consistent with prior studies

TF HTAP 2007 Interim report draft available at www.htap.org

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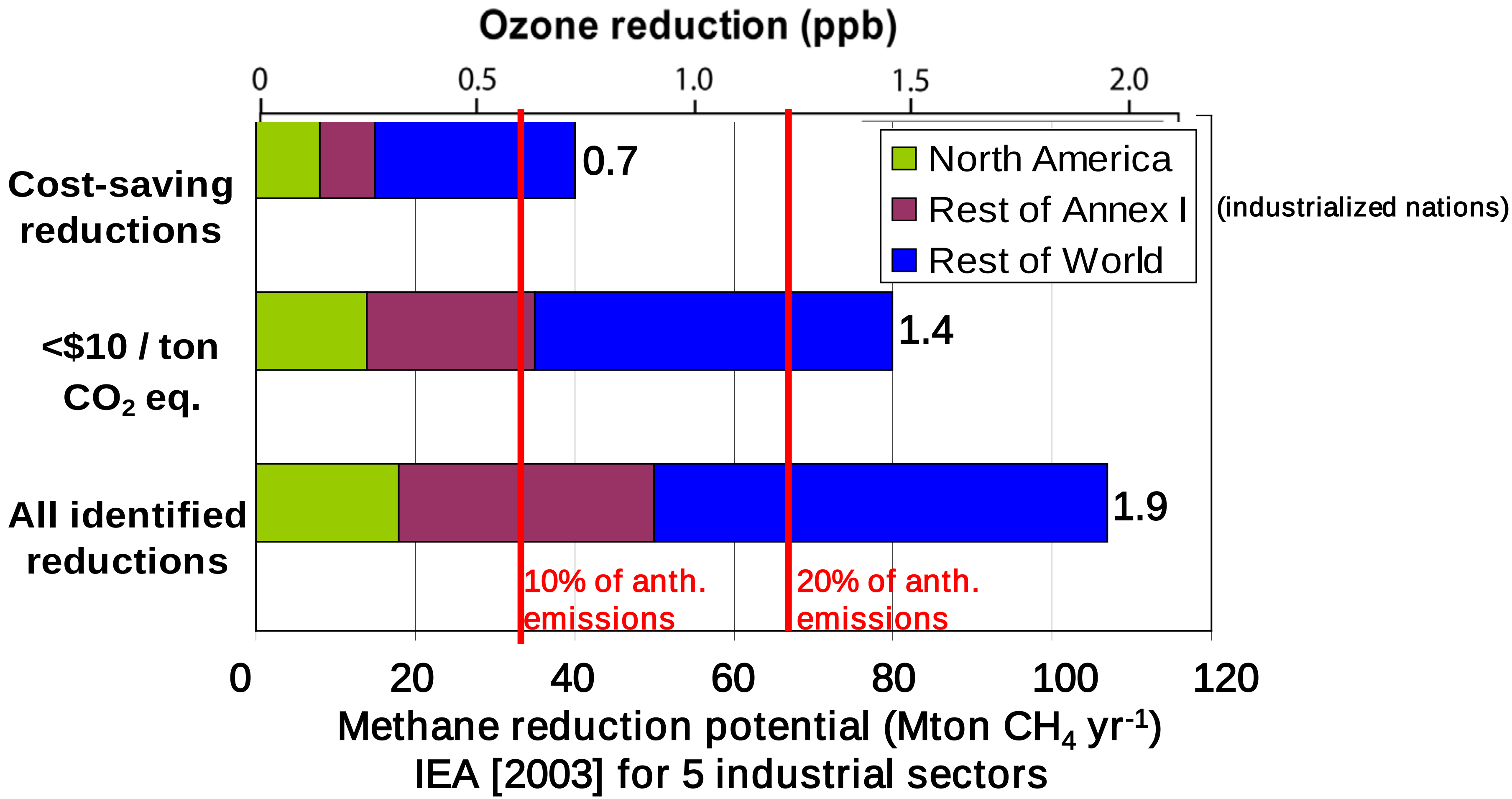
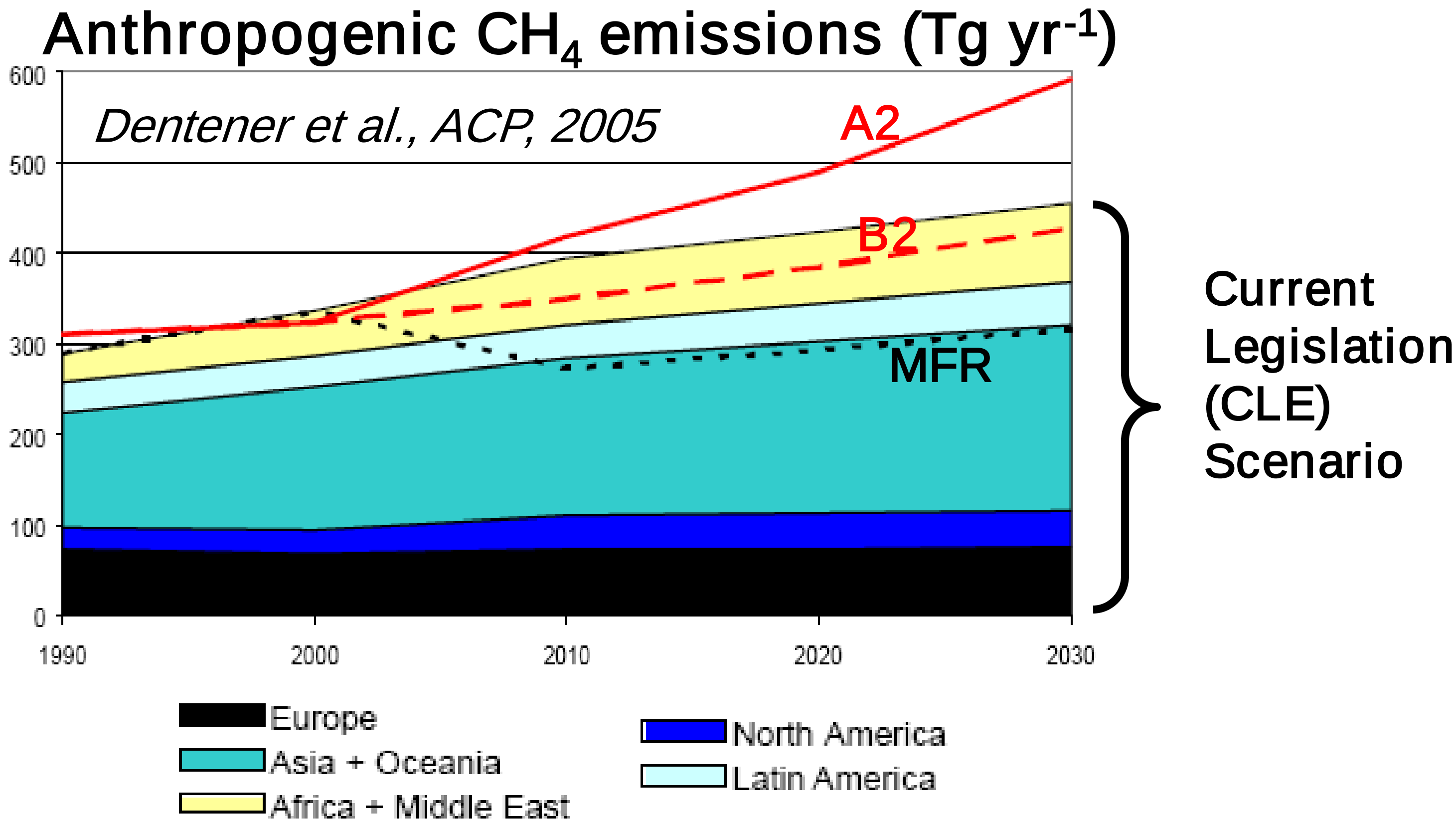
How much methane can be reduced?



Comparison: Clean Air Interstate Rule (proposed NO_x control) reduces 0.86 ppb over the eastern US, at \$0.88 billion yr^{-1}

West & Fiore, ES&T, 2005

Will methane emissions increase in the future?

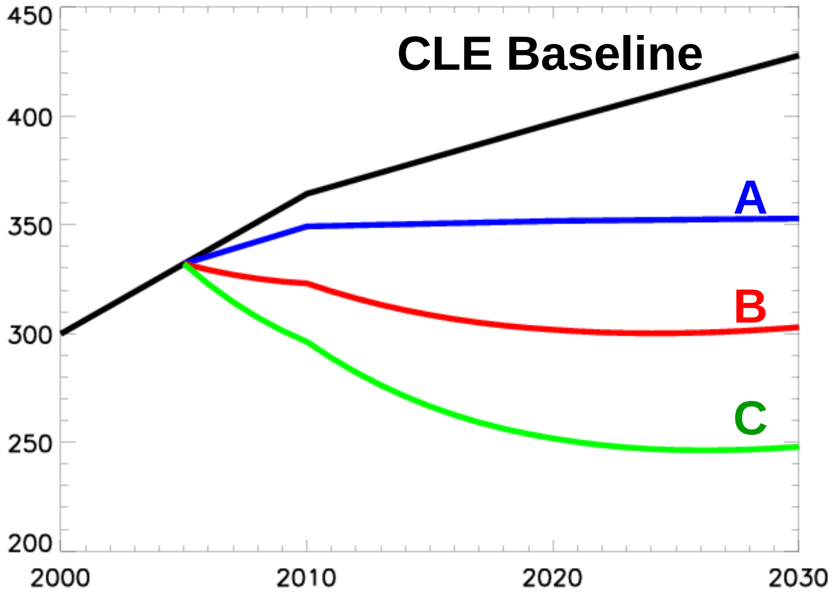


PHOTOCOMP for IPCC AR-4 used CLE, MFR, A2 scenarios for all O_3 precursors
[Dentener et al., 2006ab; Stevenson et al., 2006; van Noije et al., 2006; Shindell et al., 2006]

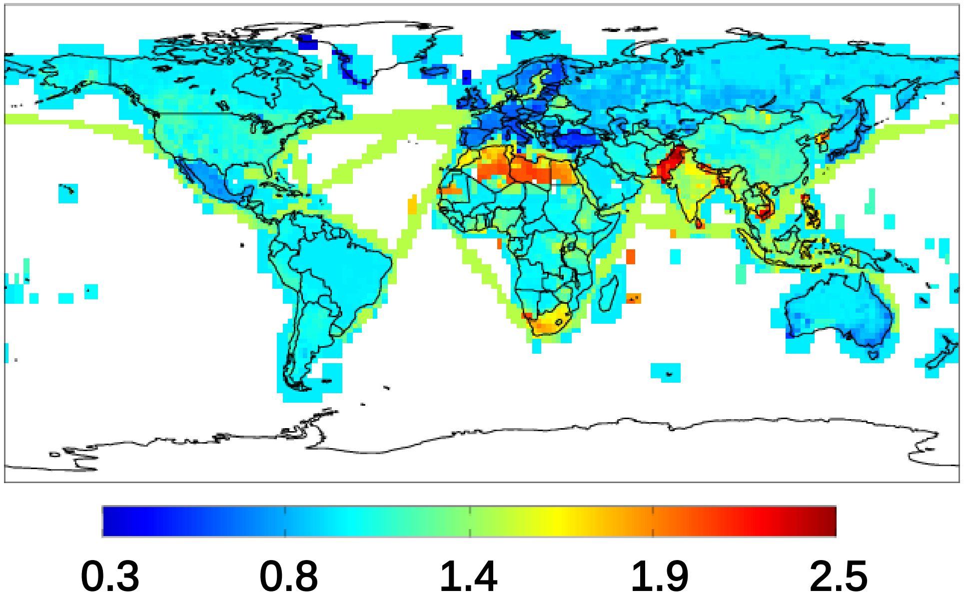
Our approach: use CLE as a baseline scenario & apply methane controls

Emission Trajectories in Future Scenarios (2005 to 2030)

Anthropogenic CH_4 Emissions ($Tg\ yr^{-1}$)



Surface NO_x Emissions 2030:2005 ratio



Control scenarios reduce 2030 CH_4 emissions relative to CLE by:

A) -75 Tg (18%) – cost-effective now

B) -125 Tg (29%) – possible with current technologies

C) -180 Tg (42%) – requires new technologies

Additional 2030 simulation where CH_4 = 700 ppbv ("zero-out anthrop. CH_4")

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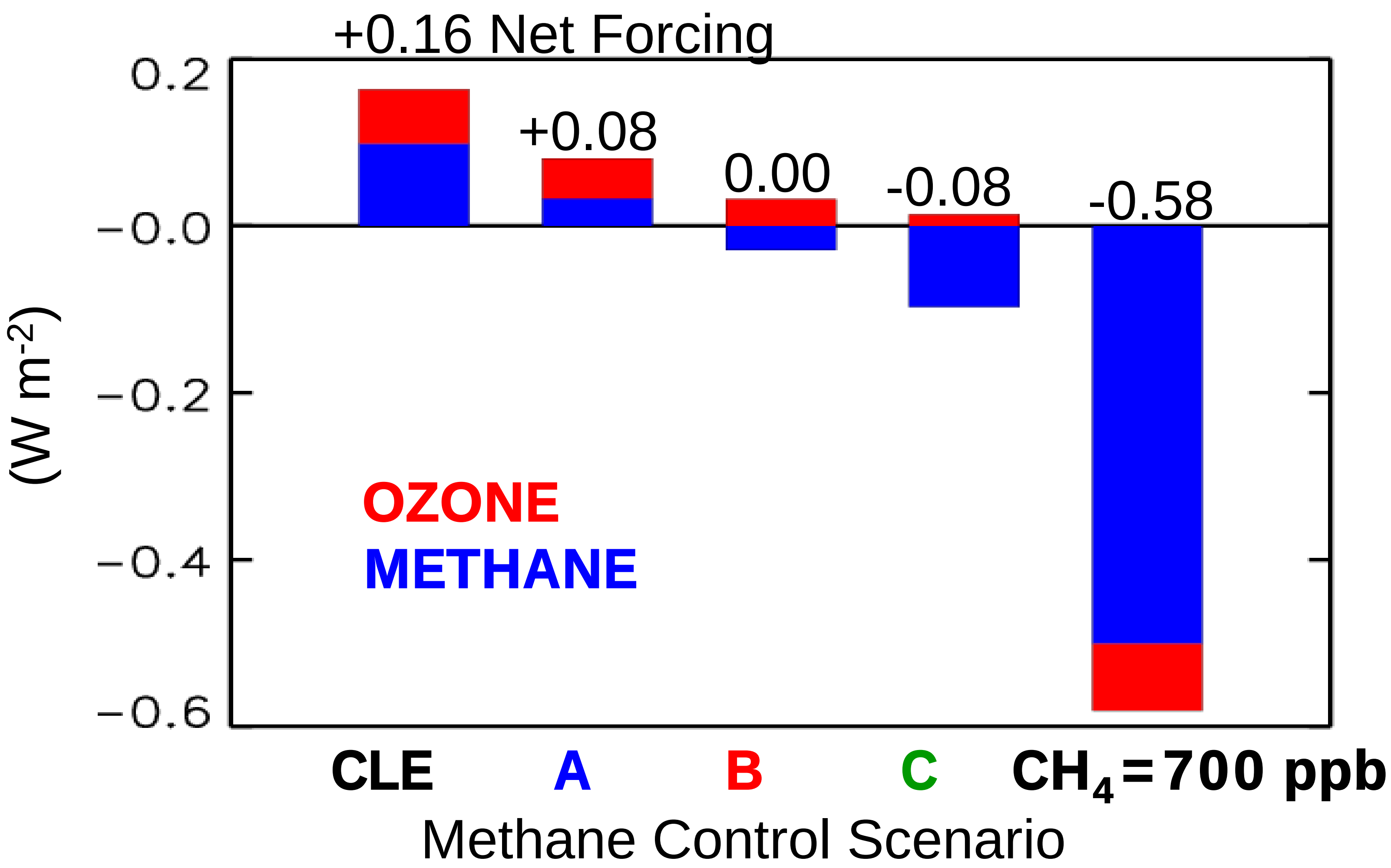
Reducing tropospheric ozone via methane controls decreases radiative forcing (2030-2005)



→ More aggressive CH_4 control scenarios offset baseline CLE forcing

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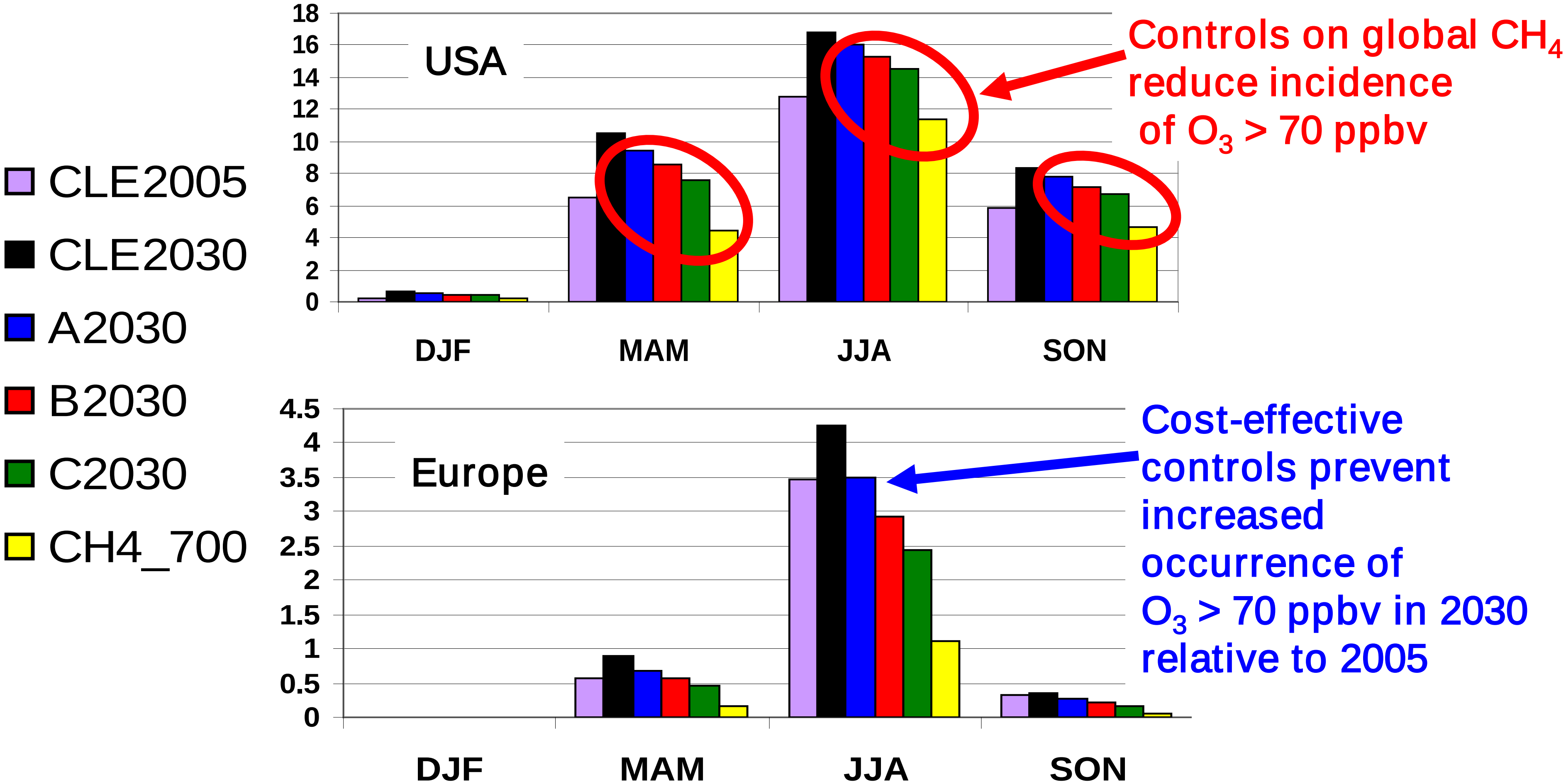
Future air quality improvements from CH_4 emission controls

Percentage of model grid-cell days where surface ozone > 70 ppbv



2030 European high-O_3 events under CLE emissions scenario show stronger sensitivity to CH_4 than in USA

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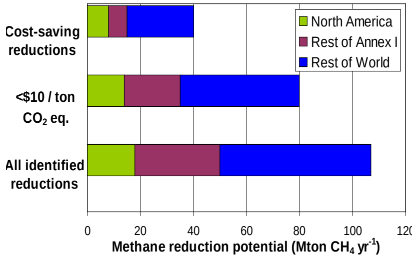
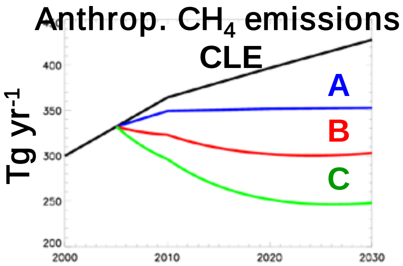
Summary: Connecting climate and air quality via O_3 & CH_4





CLIMATE AND AIR QUALITY BENEFITS FROM CH_4 CONTROL

- Independent of reduction location (but depends on NO_x)

→Target cheapest controls worldwide

- Robust response over NH continents across models

→~1 ppbv surface O_3 for a 20% decrease in anthrop. CH_4

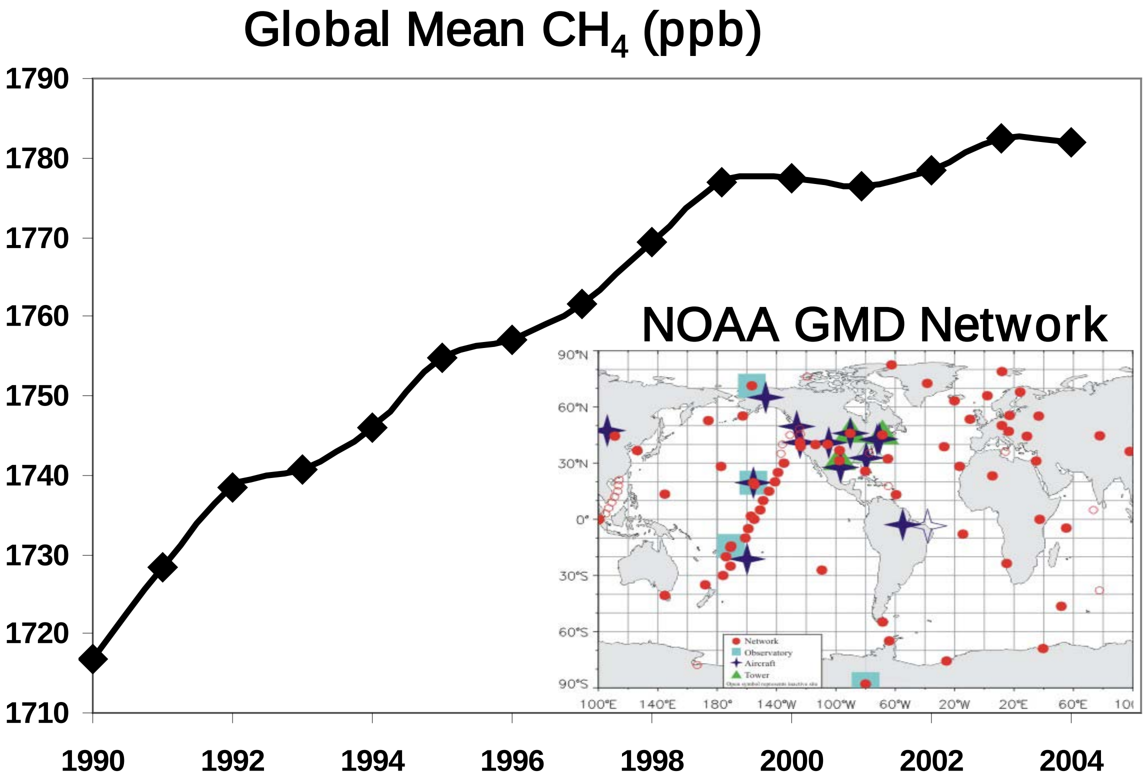
- Complementary to NO_x, NMVOC controls
- Decreases hemispheric background O_3

→ Opportunity for international air quality management

How well do we understand recent trends in atmospheric methane?

How will future changes in emissions interact with a changing climate?

Observed trend in surface CH_4 (ppb) 1990-2004



Data from 42 GMD stations with 8-yr minimum record is area-weighted, after averaging in bands 60-90N, 30-60N, 0-30N, 0-30S, 30-90S

Hypotheses for leveling off discussed in the literature:

1. Approach to steady-state

2. Source Changes
   - Anthropogenic
   - Wetlands/plants
   - (Biomass burning)

3. (Transport)

4. Sink (CH_4+OH)
   - Humidity
   - Temperature
   - OH precursor emissions
   - overhead O_3 columns

Can the model capture the observed trend (and be used for attribution)?

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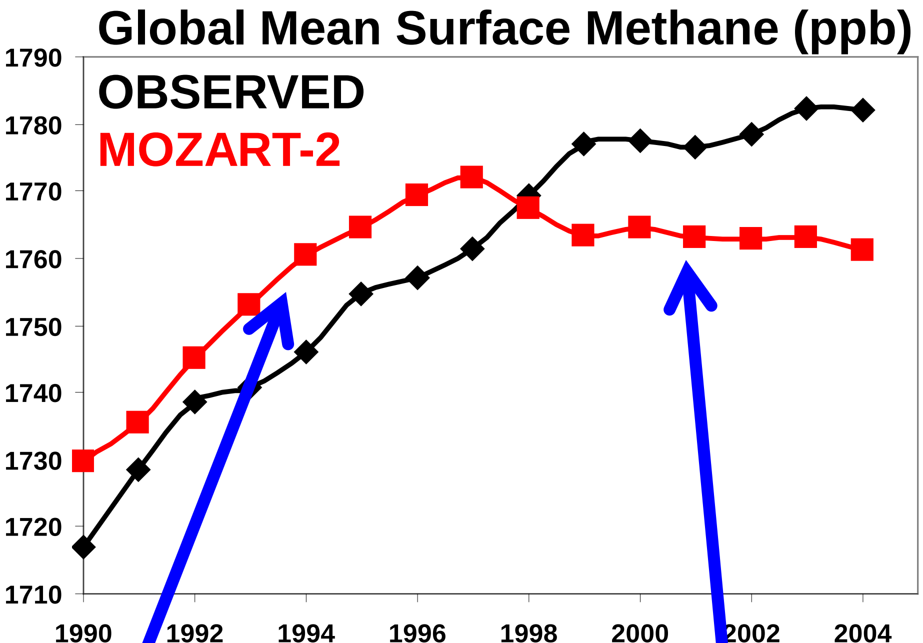
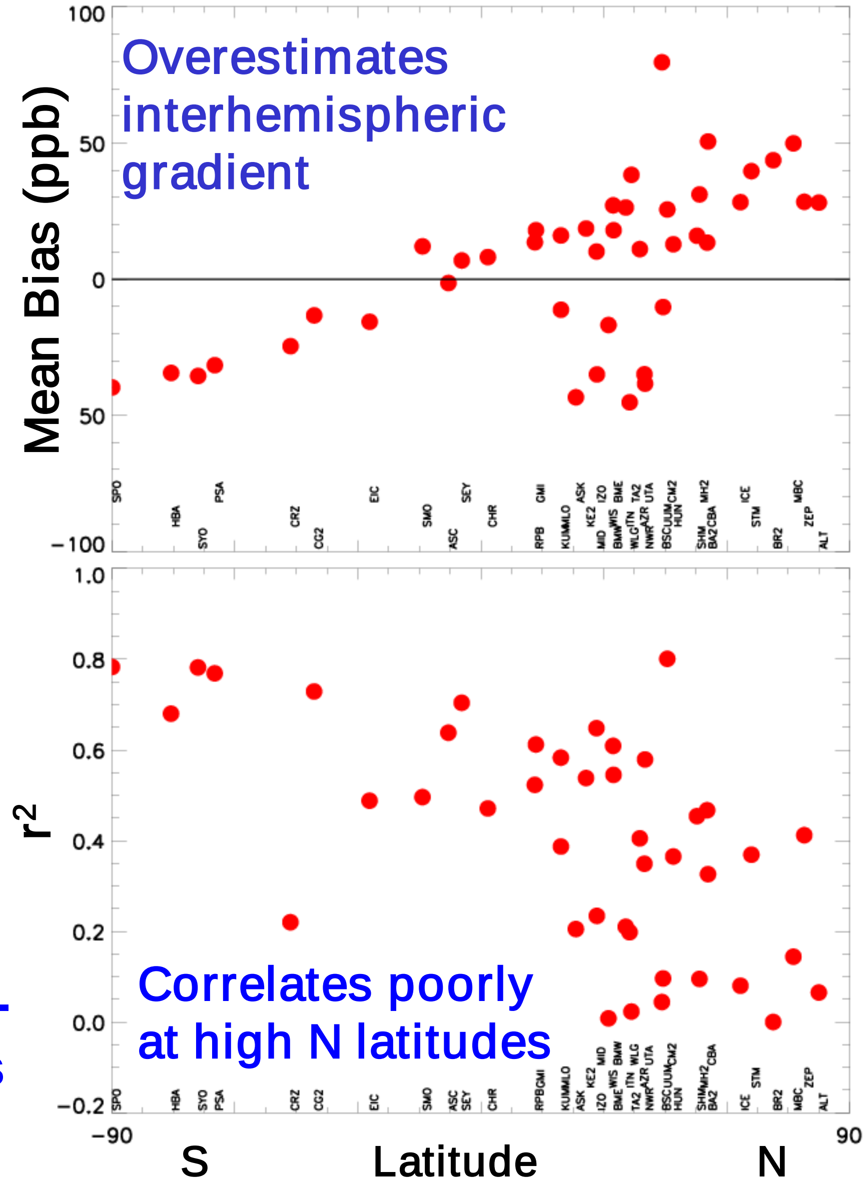
Bias and correlation vs. observed surface CH_4: 1990-2004

BASE simulation
EDGAR 2.0 emissions held constant



Overestimates 1990-1997 but matches trend

Captures flattening post-1998 but underestimates abundance



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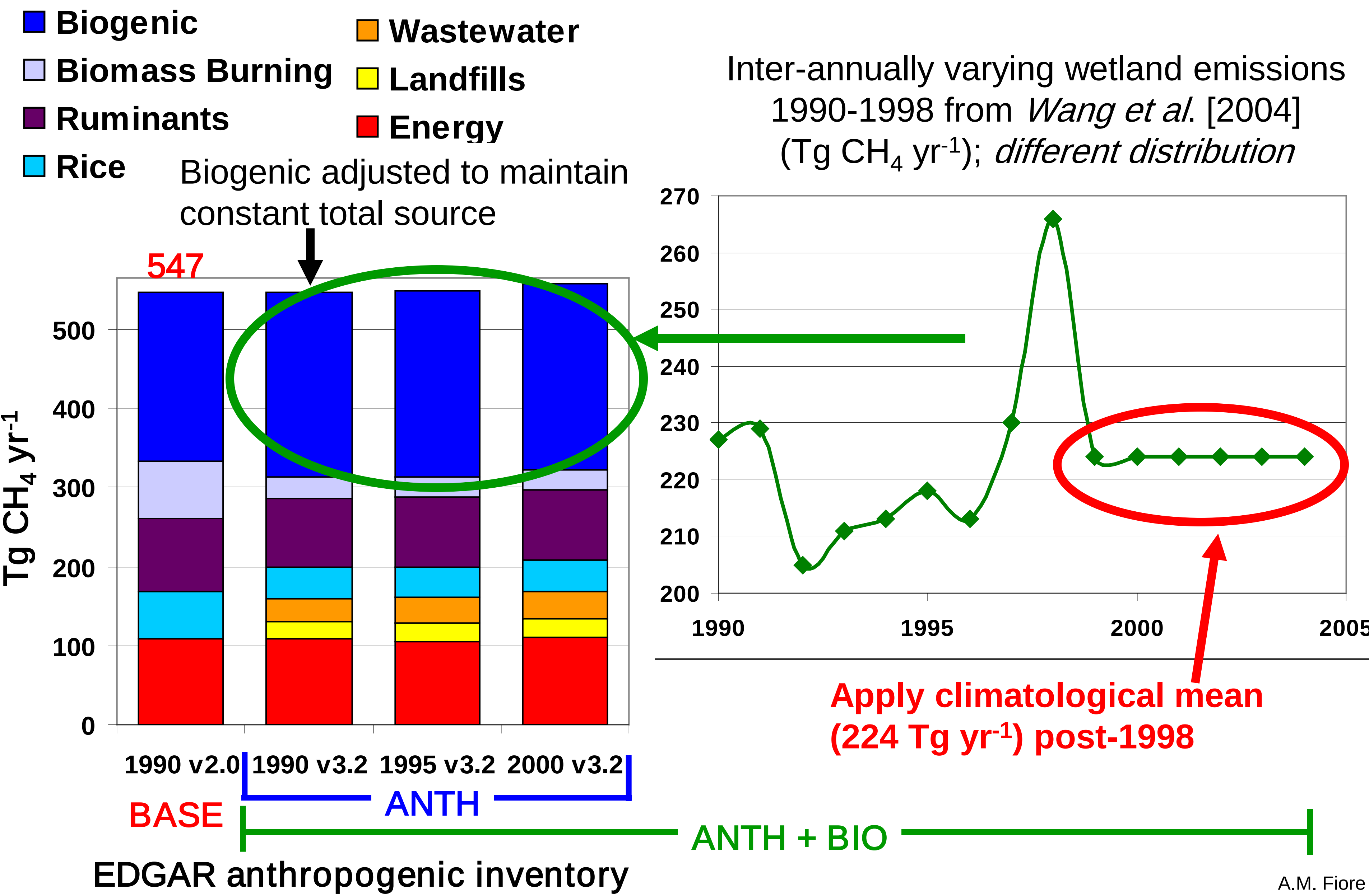
Estimates for changing methane sources in the 1990s



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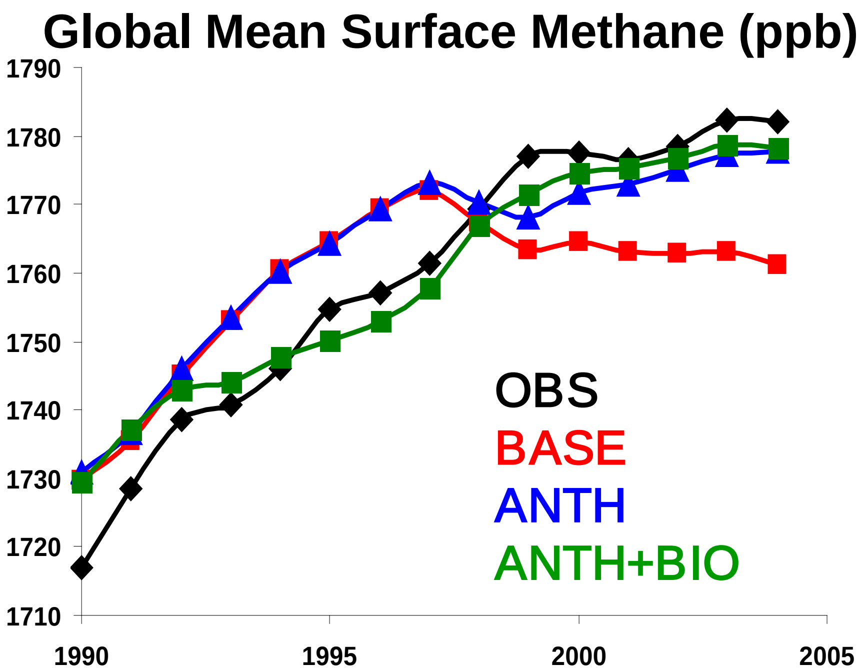
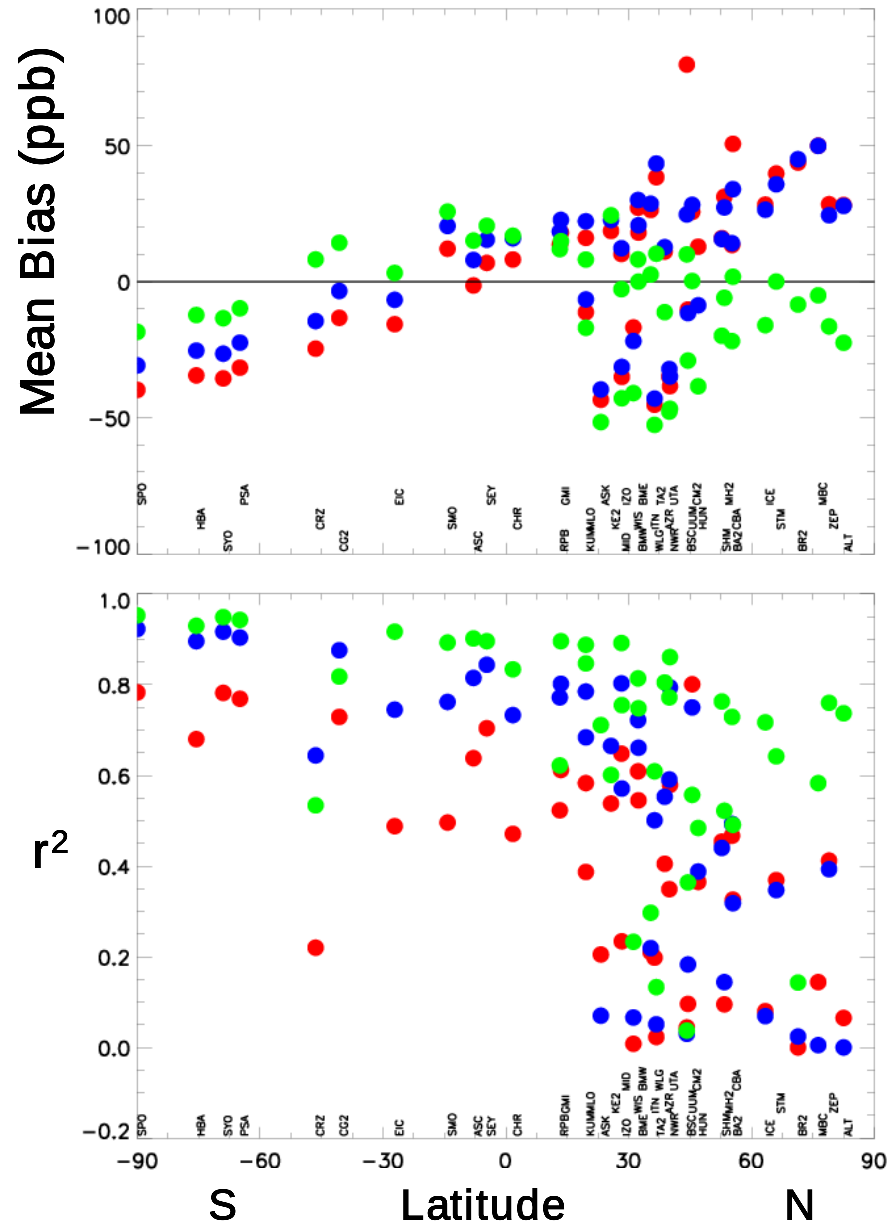
Bias & Correlation vs. GMD CH4 observations: 1990-2004





ANTH+BIO simulation with time-varying EDGAR 3.2 + wetland emissions improves:

→ Global mean surface conc.

→ Interhemispheric gradient

→ Correlation at high N latitudes

Fiore et al., GRL, 2006

How does meteorology influence methane abundances?

Why does BASE run with constant emissions level off post-1998?

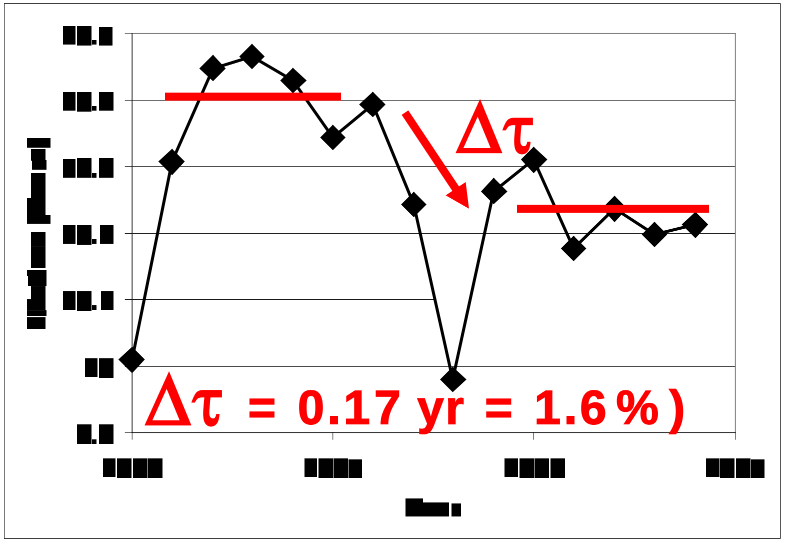
→ Examine sink

$$\tau = \frac{[CH_4]}{k[OH][CH_4]}$$

Temperature
(88% of CH_4 loss
is below 500 hPa)

Humidity
Photolysis
Lightning NO_x

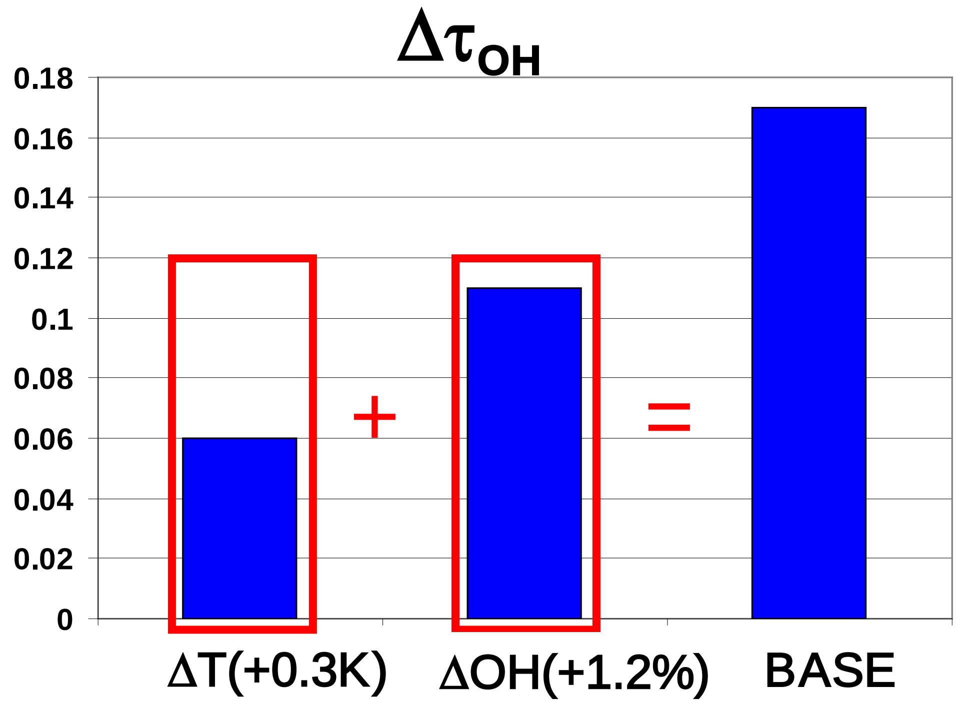
CH_4 Lifetime (τ) against Tropospheric OH

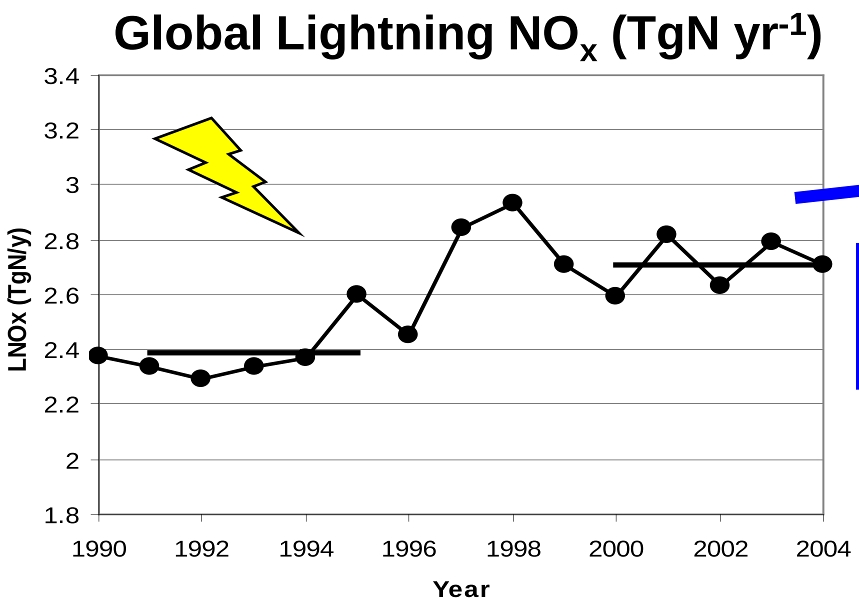


What drives the change in methane lifetime in the model?

Small increases in temperature and OH shorten the methane lifetime against tropospheric OH

Deconstruct $\Delta\tau$ (-0.17 years) from 1991-1995 to 2000-2004 into individual contributions by varying OH and temperature separately





An increase in lightning NO_x drives the OH increase in the model

But lightning NO_x is highly parameterized …how robust is this result?

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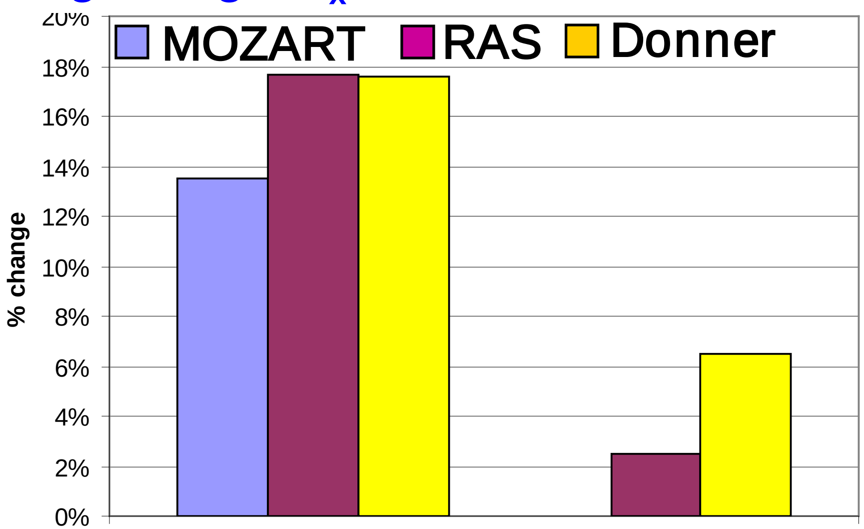
Additional evidence for a global lightning NO_x increase?

Estimate lightning NO_x changes using options available in the GFDL Atmospheric General Circulation Model:
- **Convection schemes (RAS vs. Donner-deep)**
- **Meteorology (free-running vs. nudged to NCEP reanalysis)**

Lightning NO_x % change (91-95 to 00-04)

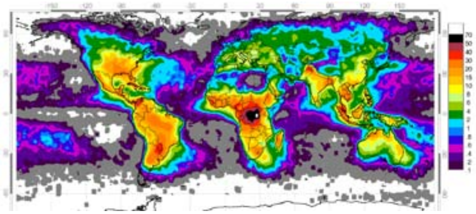


Lightning NO_x increase robust; magnitude depends on meteorology

c/o L.W. Horowitz

→**More physically-based lightning NO_x scheme** [Petersen et al., 2005]

→**Evidence from observations?**

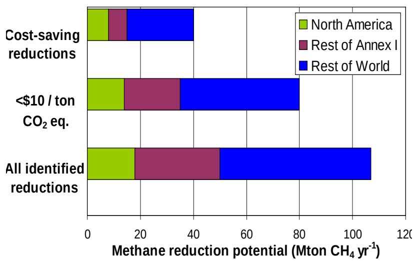


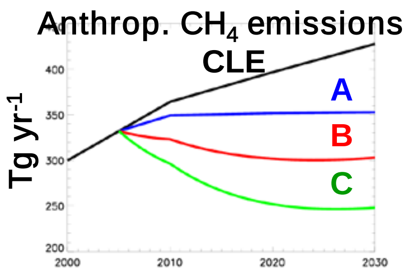
LIS/OTD Flash counts

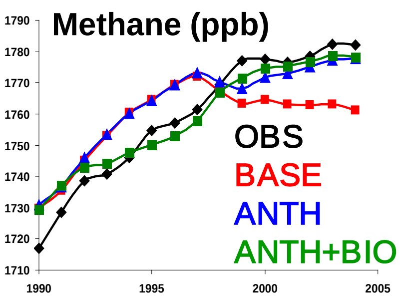
Magnetic field variations in the lower ELF range [*e.g.* Williams, 1992; Füllekrug and Fraser-Smith, 1997; Price, 2000]

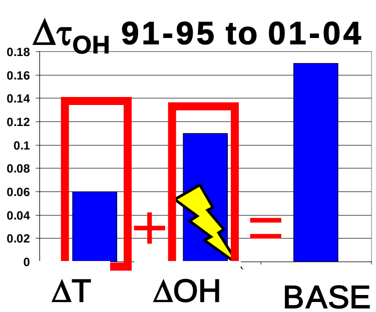
Negev Desert Station, Israel

Summary: Connecting climate and air quality via O_3 & CH_4









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METHANE TRENDS FROM 1990 TO 2004

- Simulation with time-varying emissions and meteorology best captures observed CH_4 distribution
- Model trend driven by increasing T, OH
- Trends in global lightning activity?

→ Potential for climate feedbacks (on sources and sinks)

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