# A21E-0863 Connecting Climate and Air Quality: Tropospheric Ozone Response to Methane Emission Controls

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## 1. Introduction

Methane ($CH_4$) oxidation in the presence of nitrogen oxides ($NO_x$) contributes to tropospheric ozone ($O_3$), raising baseline levels of ozone pollution in surface air globally. Since methane is also a potent greenhouse gas, controls on methane offer a strategy for jointly addressing air pollution and climate goals [*e.g.*, *Fiore et al.*, 2002; *Dentener et al.*, 2005; *West and Fiore*, 2005; *EMEP*, 2005].

### Objectives

- **Characterize the $O_3$ response to $CH_4$ control**
- **Quantify the climate and air quality benefits from $CH_4$ controls**
- **Evaluate $CH_4$ controls in future emission scenarios where emissions of other $O_3$ precursors are also changing**

## 2. Transient Methane Simulations with MOZART-2

- global 3D model of tropospheric chemistry
- ~100 gas and aerosol species, ~200 reactions
- 1.9º latitude x 1.9º longitude x 28 vertical levels
- multi-decadal, full-chemistry simulations
- **Idealized scenarios**: Emissions representative of early 1990s, as described in *Horowitz et al.* [2003] except for wetland emissions which we increased by 58 Tg $yr^{-1}$ to match recent estimates; 1990-2004 NCEP meteorology recycled after 15 years
- **Future scenarios**: Current Legislation Emissions (CLE) 2000 to 2030 [*Dentener et al.*, 2005]; biomass burning GFED v.1 [*van der Werf et al.*, 2003]; wetland distribution from *Wang et al.* [2004]; 2000-2004 NCEP meteorology recycled every 5 years

**Methane emissions in MOZART-2**

| | Standard (1990s) | CLE (2005) | CLE (2030) |
|---|---|---|---|
| Simulations | Idealized | Future | |
| Anthrop. | 261 | 332 | 428 |
| Biogenic* | 214 | 222 | 222 |
| Biomass Burning | 72 | 23 | 23 |
| Total | 547 | 577 | 673 |

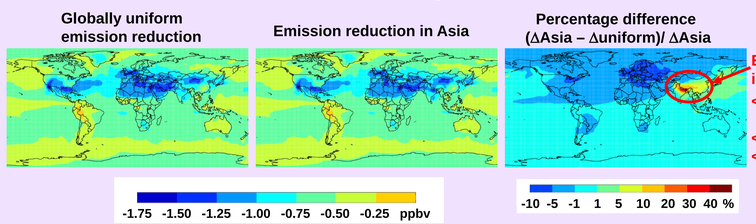
*Biogenic includes wetlands, oceans, and termites

## 3. Ozone Response to Methane Controls in Idealized Scenarios

### SPATIAL DISTRIBUTION

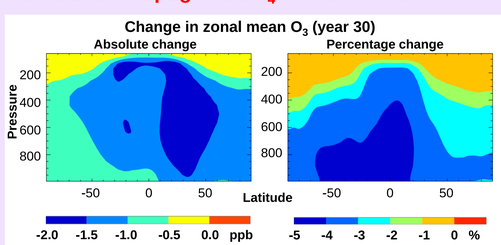
**Simulations with global anthropogenic $CH_4$ emissions decreased by 30%, either: (1) uniformly worldwide, or (2) entirely from Asia**

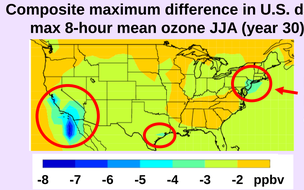
**Decrease in global July mean $O_3$ at simulation year 11**




Enhanced effect in source region
<10% other NH source regions
<5% rest of NH
<1% most of SH

**Global anthropogenic $CH_4$ emissions decreased uniformly by 30%**

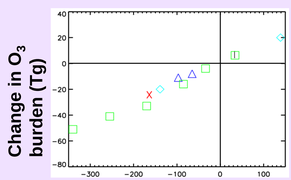



Locations with $NO_x$-saturated chemistry

- → **Methane source location has little influence on the surface (or tropospheric) $O_3$ distribution (<10% globally except for localized effect in Asian source region)**
- → **Larger ozone response in downwelling regions and locations with $NO_x$-saturated chemistry**
- → **Largest % decreases occur in lower troposphere (due to T dependent $k_{OH-CH4}$)**

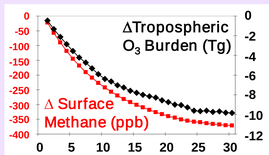
### LINEARITY




- MOZART-2 (this work; *West et al.*, 2006)
- TM3 [*Dentener et al.*, 2005]
- GISS [*Shindell et al.*, 2005
- GEOS-CHEM [*Fiore et al.*, 2002]
- IPCC TAR [*Prather et al.*, 2001]

**Anthropogenic $CH_4$ contributes: ~50 Tg (~15%) to tropospheric $O_3$ burden ~5 ppbv to surface $O_3$**

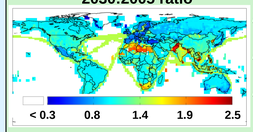
### TIME SCALE



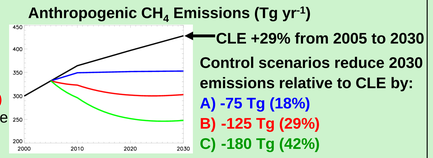

**Nearing a new steady-state after 30 years**

## 4. Future Methane Control Scenarios

### EMISSIONS




Anthrop. $NO_x$ increases by 5.3 Tg N $yr^{-1}$ (+19%)
Anthrop. CO decreases by 44 Tg CO $yr^{-1}$ (-10%)
Anthrop. NMVOC increase by 3 Tg C $yr^{-1}$ (+3%)




**CLE +29% from 2005 to 2030**

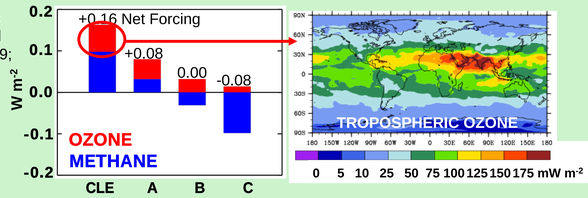
**Control scenarios reduce 2030 emissions relative to CLE by:**
**A) -75 Tg (18%)**
**B) -125 Tg (29%)**
**C) -180 Tg (42%)**

### IMPACTS ON CLIMATE

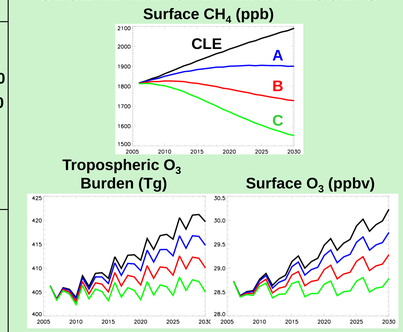
We calculate $CH_4$ forcing from an analytical expression [*Ramaswamy et al.*, 2001] and $O_3$ forcing with the GFDL AM2 radiative transfer model [*Freidenreich and Ramswamy*, 1999; *Schwarzkopf and Ramaswamy*, 1999; *GFDL GAMDT*, 2004]

**Aggressive $CH_4$ reductions (scenarios B and C) offset the positive forcing predicted under the CLE baseline**

**Radiative forcing from 2005 to 2030**




### GLOBAL ANNUAL MEAN RESULTS

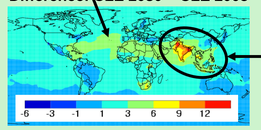



**→CLE increases surface $CH_4$ by 240 ppbv; tropospheric $O_3$ by 15 Tg; surface $O_3$ by 1.4 ppbv (2026-30 mean – 2005-9 mean).**
**→ Scenario C decreases $CH_4$ by 540 ppb relative to CLE 2030, by 260 ppb relative to CLE 2005, and roughly stabilizes surface $O_3$ despite 5 Tg N $yr^{-1}$ increase in anthropogenic $NO_x$ emissions.**

### IMPACTS ON AIR QUALITY

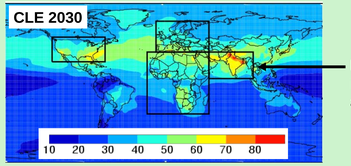
Growth in ship $NO_x$ emissions raises $O_3$ by a few ppbv over the N. Atlantic (see above for $NO_x$ emission changes)

**Difference: CLE 2030 – CLE 2005**




Largest increases occur over SE Asia (up to 20 ppbv).

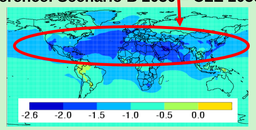
Annual Mean Daily Max 8-hr Ozone (ppbv)




Black boxes indicate regions analyzed below

**Surface $O_3$ at N tropics and mid-latitudes shows largest response to $CH_4$ controls; largest decreases occur in high-$NO_x$ areas**

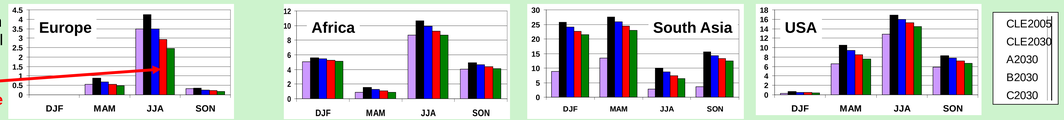
**Difference: Scenario B 2030 – CLE 2030**




Percentage of model grid box-days where daily max 8-hour $O_3$ exceeds 70 ppbv by season and region

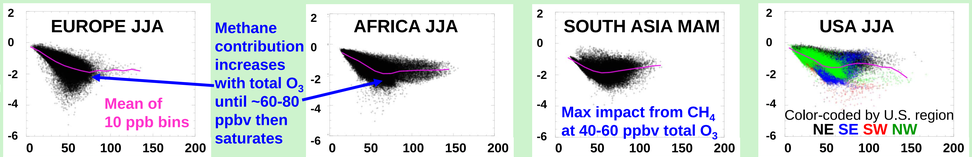
Increased incidence of $O_3$ > 70 ppbv in CLE from 2005 to 2030 occurs in all regions and seasons

**Aggressive $CH_4$ controls (B and C) more than offset projected increases in high-$O_3$ events in Europe**




Change in daily max 8-hour $O_3$ (scenario B – CLE) in the season with max occurrences above 70 ppbv

Each point represents one daily maximum 8-hour average $O_3$ value in one model grid cell from Jun 1 to Aug 31




**Methane contribution increases with total $O_3$ until ~60-80 ppbv then saturates**

**Max $CH_4$ impact at ~40-70 ppbv total $O_3$, plus some high-$O_3$ events**

## 5. Conclusions

- **Spatial pattern of $O_3$ response is largely independent of $CH_4$ source location, but depends strongly on $NO_x$ distribution**
- **Magnitude of the $O_3$ response is approximately linear with reductions in anthropogenic $CH_4$ emissions (~0.1 Tg tropospheric $O_3$ per Tg $yr^{-1}$ anthropogenic $CH_4$ reduced)**
- **$O_3$ decrease from $CH_4$ controls is typically maximum near the middle of the total $O_3$ distribution, (*e.g.* 40-70 ppbv total $O_3$), but also extends to the high end of the distribution in $NO_x$-saturated conditions (Los Angeles, Houston)**
- **Future $CH_4$ controls relative to the CLE baseline (scenarios B or C) would offset the projected positive climate forcing and reduce the incidence of high-$O_3$ events in all regions, even improving air quality in Europe relative to 2005.**

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