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

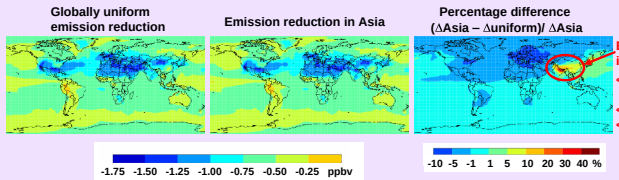
***Biogenic includes wetlands, oceans, and termites**

3. Ozone Response to Methane Controls in Idealized Scenarios

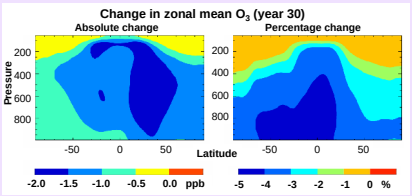
SPATIAL DISTRIBUTION

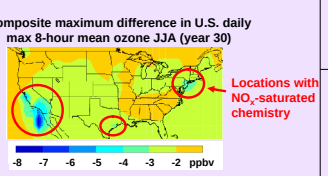
Simulations with global anthropogenic CH_4 emissions decreased by 30%, either: (1) uniformly worldwide, or (2) entirely from Asia

Decrease in global July mean O_3 at simulation year 11



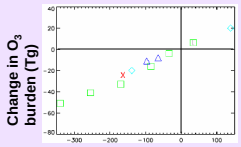
Global anthropogenic CH_4 emissions decreased uniformly by 30%





→ **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})**

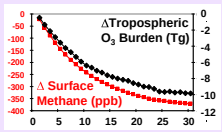
LINEARITY



△ MOZART-2 (this work; *West et al.*, 2006)
◇ TM3 [*Dentener et al.*, 2005]
□ GISS [*Shindell et al.*, 2005
X GEOS-CHEM [*Fiore et al.*, 2002]
I 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

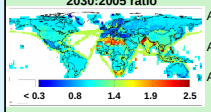


Nearing a new steady-state after 30 years

4. Future Methane Control Scenarios

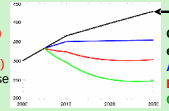
EMISSIONS

Surface NO_x emissions 2030:2005 ratio



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%)

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



CLE +29% from 2005 to 2030

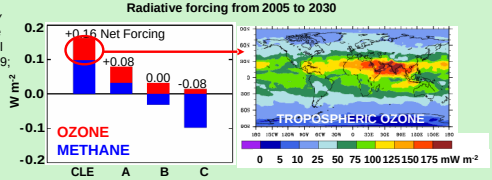
Control scenarios reduce 2030 emissions relative to CLE by:
A) -75 Tg (18%)
B) -125 Tg (29%)
C) -180 Tg (42%)

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]

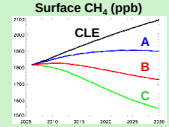
Aggressive CH_4 reductions (scenarios B and C) offset the positive forcing predicted under the CLE baseline

Radiative forcing from 2005 to 2030

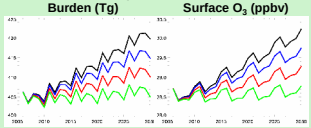


GLOBAL ANNUAL MEAN RESULTS

Surface CH_4 (ppb)



Tropospheric O_3 Burden (Tg) | Surface O_3 (ppbv)

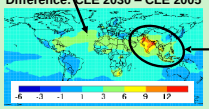


→CLE increases surface CH_4 by 240 ppbv; tropospheric O_3 by 15 Tg; surface O_3 by 1.4 ppbv (2026-30 mean – 2005-9 mean).
→ Scenario C decreases CH_4 by 540 ppb relative to CLE 2030, by 260 ppb relative to CLE 2005, and roughly stabilizes surface O_3 despite 5 Tg N yr^{-1} increase in anthropogenic NO_x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

IMPACTS ON AIR QUALITY

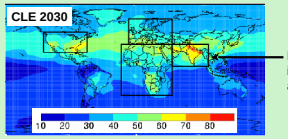
Growth in ship NO_x emissions raises O_3 by a few ppbv over the N. Atlantic (see above for NO_x emission changes)

Difference: CLE 2030 – CLE 2005



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

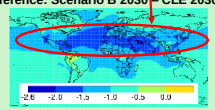
Annual Mean Daily Max 8-hr Ozone (ppbv)



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

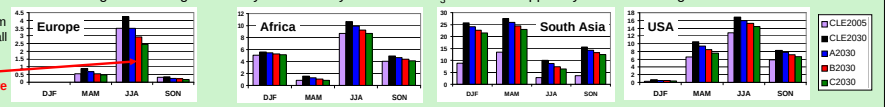
Difference: Scenario B 2030 – CLE 2030



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

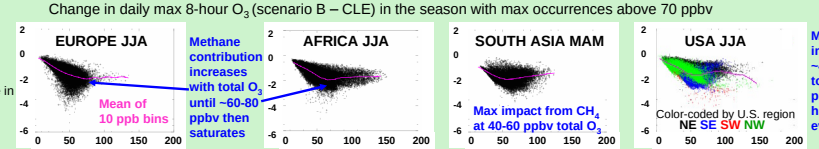
Increased incidence of O_3 > 70 ppbv in CLE from 2005 to 2030 occurs in all regions and seasons

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 impact from CH_4 at 40-60 ppbv total O_3

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

CLE 2030 daily max 8-hr average O_3 (ppbv)

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.**

Acknowledgments

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