The CO_2 inhibition effect on isoprene emissions: Implications for U.S. ozone air quality in the future atmosphere

sweetgum

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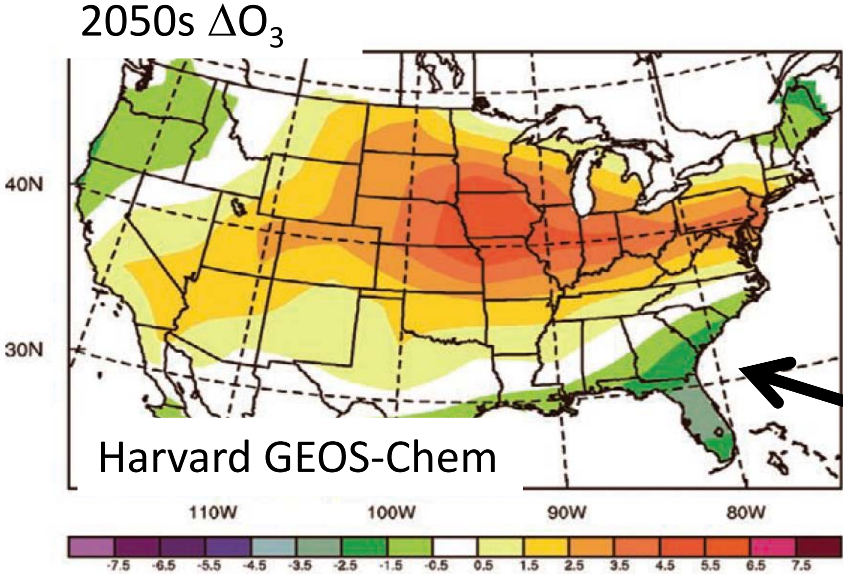
Tai et al., ms in preparation.

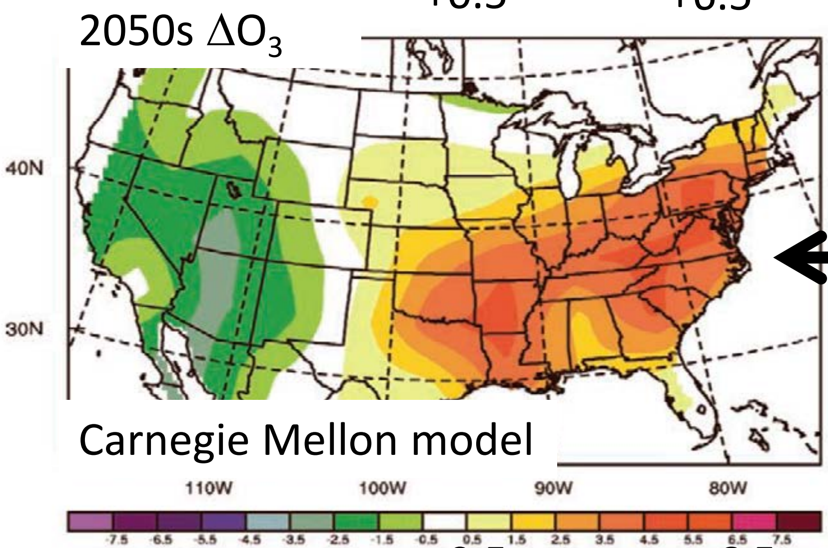
Projections of climate penalty on U.S. surface ozone depends in part on treatment of isoprene chemistry.



2000-2050 change in summertime MDA8 surface ozone due to climate change only.

Increasing temperature increases isoprene emissions.

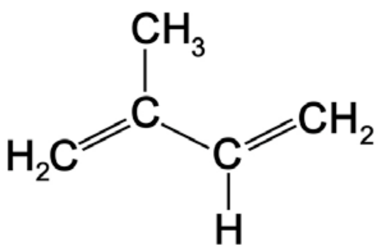
If isoprene nitrate is treated as a terminal sink of NOx, ozone over Southeast stays constant or even declines in 2050s.



When isoprene nitrate is allowed to recycle, ozone increases across the East by as much as 7 ppb.

Weaver et al., 2009

Significance of Isoprene in Atmospheric Chemistry



Isoprene

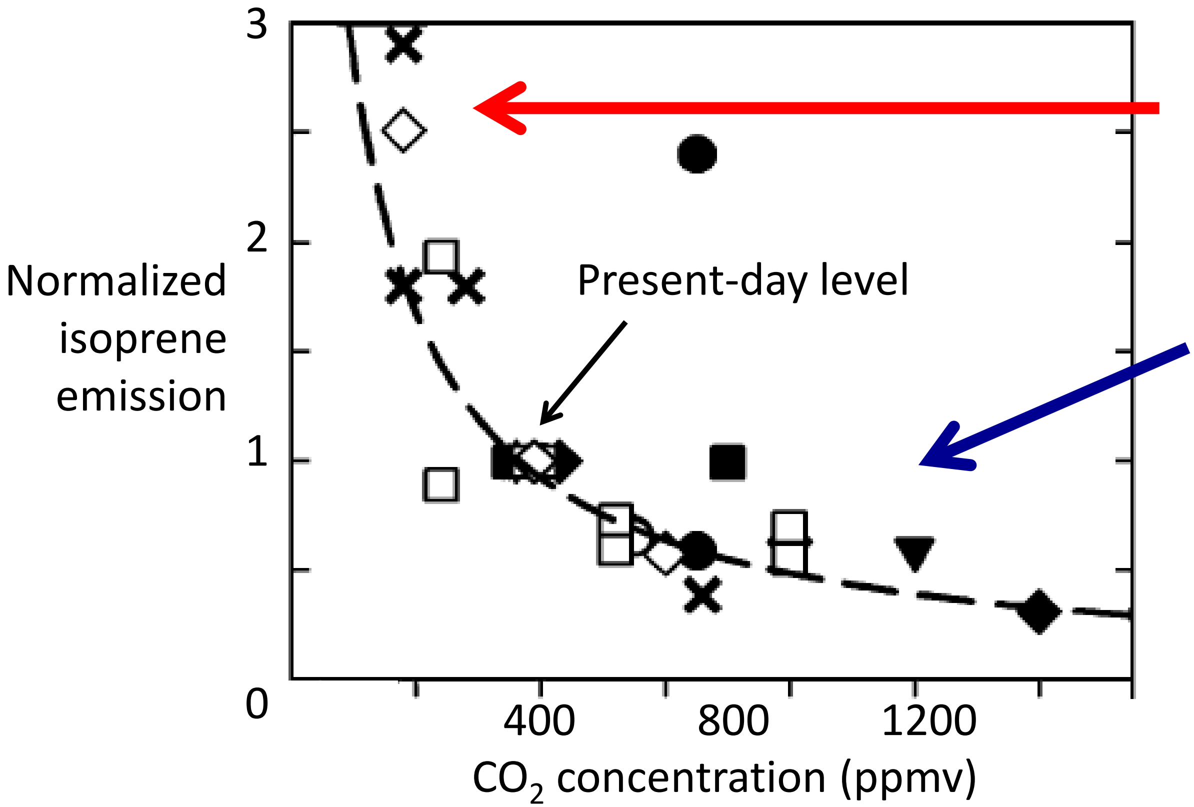
~1/3 of all hydrocarbons emitted into the atmosphere

high-NO_x	↑	Ozone	(by being precursor)
low-NO_x	↓	Ozone	(by direct ozonolysis and NO_x sequestration)
oxidation	↑	SOA	(secondary organic aerosol)
oxidation	↓	Global OH	(increases lifetime of CH_4)

CO_2 Inhibition of Isoprene Emissions

Observations show that isoprene emissions vary with changing ambient CO_2 levels.

Field and laboratory observations of leaf isoprene emissions at a range of CO_2 levels



Isoprene emissions are:

Enhanced at low CO_2 levels (Last Glacial Maximum)

Suppressed at elevated CO_2 levels (21st century)

Possell & Hewitt 2011

Calculation of isoprene emissions in GEOS-Chem

- In many atmospheric chemistry and vegetation models, VOC emissions are modeled by some semi-empirical, semi-mechanistic parameterization schemes.

- Isoprene emission scheme represented in Model of Emissions of Gases and Aerosols from Nature (MEGAN):

$$E_{\text{isop}} = \gamma_{PAR}\gamma_{LAI}\gamma_{T}\gamma_{soil}\gamma_{age}\sum_{j}\varepsilon_{j}\,\chi_{j}$$

Fraction coverage (χ_j) for each plant function type

Isoprene emission rate in each grid cell

Activity ("scaling") factors due to time-dependent variation in:

- Light (PAR)
- Leafiness (LAI)
- Temperature
- Soil moisture
- Leaf age

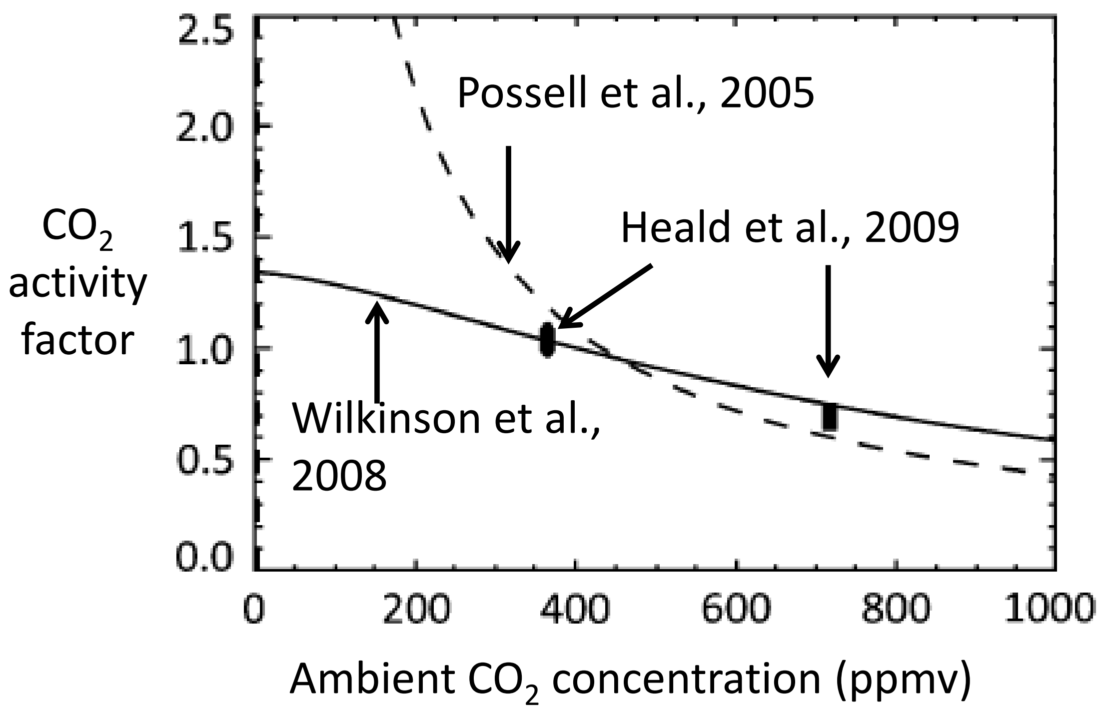
Base emission (ε_j) for each plant functional type

Inclusion of CO_2 inhibition in MEGAN

CO_2 inhibition effect can be represented as an activity factor (γ_C) in MEGAN:

$$E_{\text{isop}} = \gamma_{\text{other factors}} \left(\gamma_{C_a} \gamma_{C_i}\right) \sum_j \varepsilon_j \chi_j$$

γ_C = CO_2 activity factor



Ca – ambient CO_2 levels
Ci – intercellular CO_2 levels

Plant models show that the variation in C_i contributes little to variability of CO_2 activity factor.

Heald et al. (2009) suggest setting $C_i = 0.7C_a$.

Simulation of Air Quality in 2050 Climate

- We ran 4°×5° GEOS-Chem with:
  - NASA GISS GCM present-day (1998-2002) and future (2048-2052) climate driven by IPCC A1B scenario
  - 2000 anthropogenic emissions in all simulations
  - Two sets of vegetation cover (represented by LAIs and biogenic emission factors):
    - MODIS satellite data ("observed")
    - LPJ-GUESS vegetation model (modeled; evolving with climate)

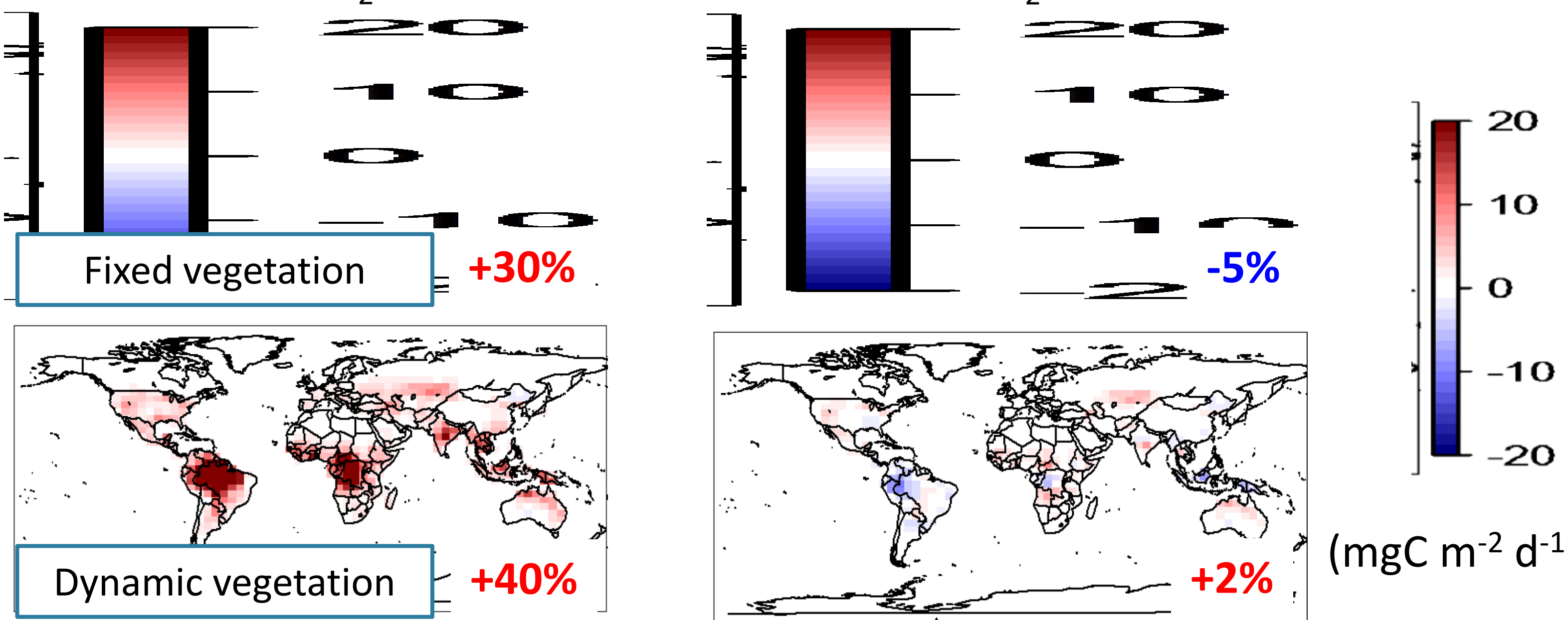
GEOS-Chem simulations	Fixed vegetation ("observed")	Dynamic vegetation (modeled)
2000 climate	•	•
2050 climate	•	•
2050 climate + CO_2 inhibition	•	•

CO_2 Effect on Isoprene Emission in 2050 Climate

2000-2050 change in isoprene emission

Without CO_2 effect

With CO_2 effect



Isoprene emissions increase in a warming world.

With dynamic vegetation model, increase is even greater as the extent of deciduous trees expands and LAI increases

Including CO_2 effect offsets the increases due to warmer temperatures and increased LAI.

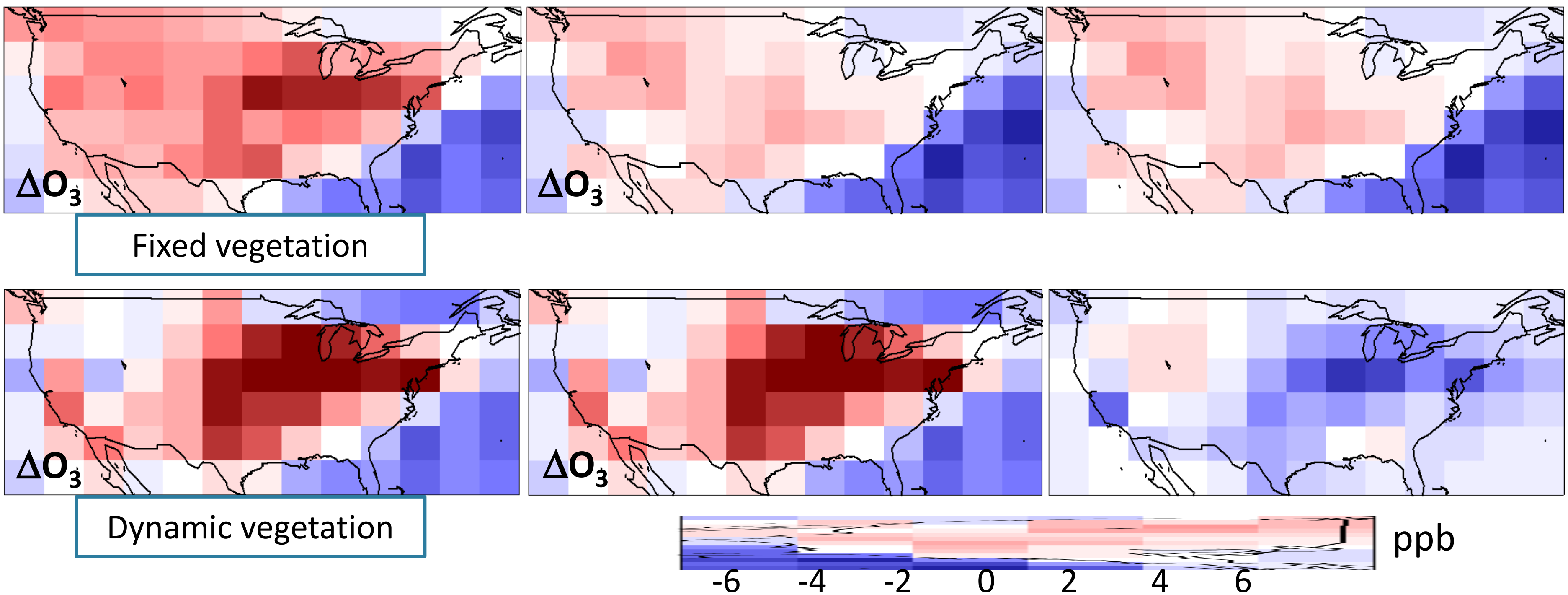
CO_2 levels = 520 ppm

Tai et al., ms. in preparation

CO_2 Effect on Ozone in 2050 Climate

2000-2050 change in mean JJA daily maximum 8-h average O_3

Without CO_2 effect | With CO_2 effect | With minus without CO_2



- CO_2 effect can diminish the climate penalty on surface ozone in the 2050s atmosphere, especially in high-NO_x environments.
- Vegetation change can influence the sensitivity of ozone to isoprene and NO_x.

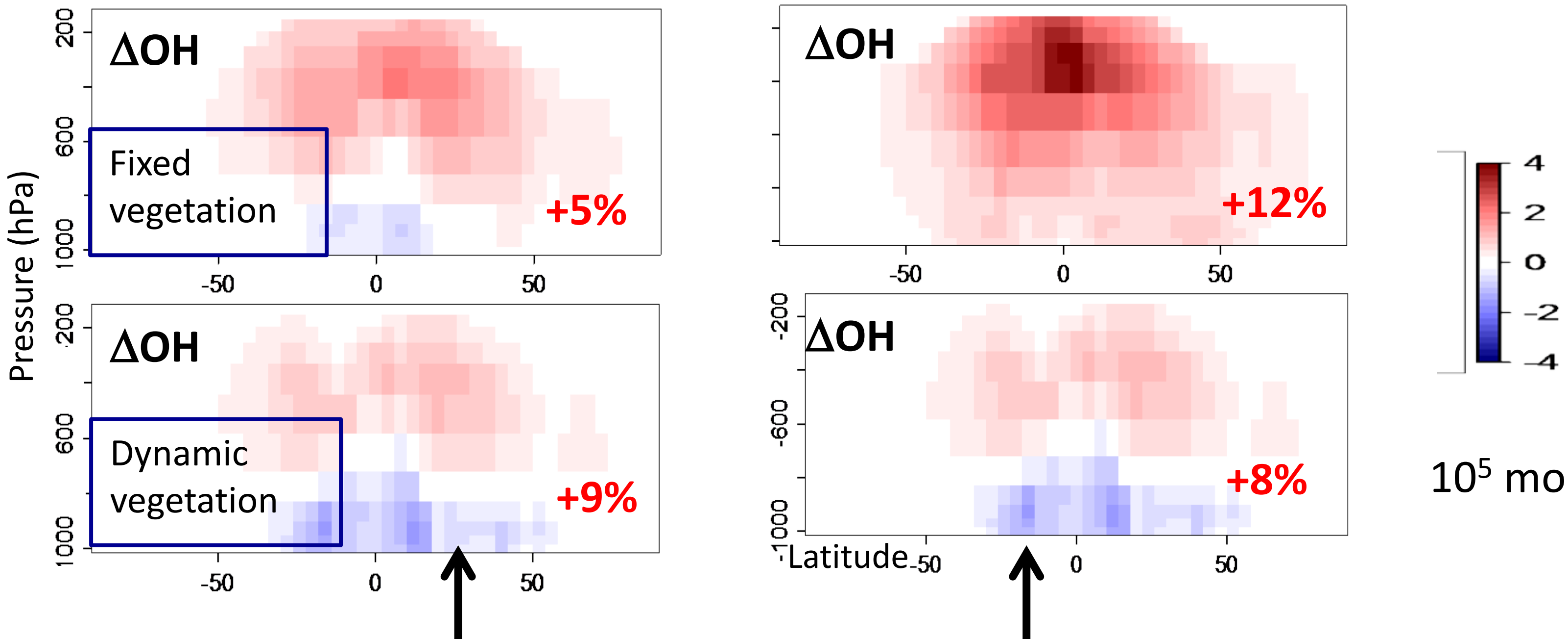
Tai et al., ms. in preparation

CO_2 Effect on global OH in 2050s Climate

2000-2050 change in mean OH tropospheric profile (10^5 molec cm^{-3})

Without CO_2 effect

With CO_2 effect



10^5 molec cm^{-3}

OH increases aloft in future atmosphere due to increased water vapor.

Increased isoprene in future atmosphere can decrease OH close to surface in dynamic veg model.

With CO_2 effect, isoprene emissions diminish, and OH increases even more.

So CO_2 effect may further decrease CH_4 lifetime by ~1/2 year.

Tai et al., ms. in preparation

Take home messages:

- Consideration of the CO_2 inhibition effect diminishes the climate penalty for surface ozone, at least in high NOx regions.
- The CO_2 inhibition effect may lead to a climate benefit through increasing global OH.
- Inclusion of the CO_2 inhibition effect in air quality models could improve projections of future ozone levels.

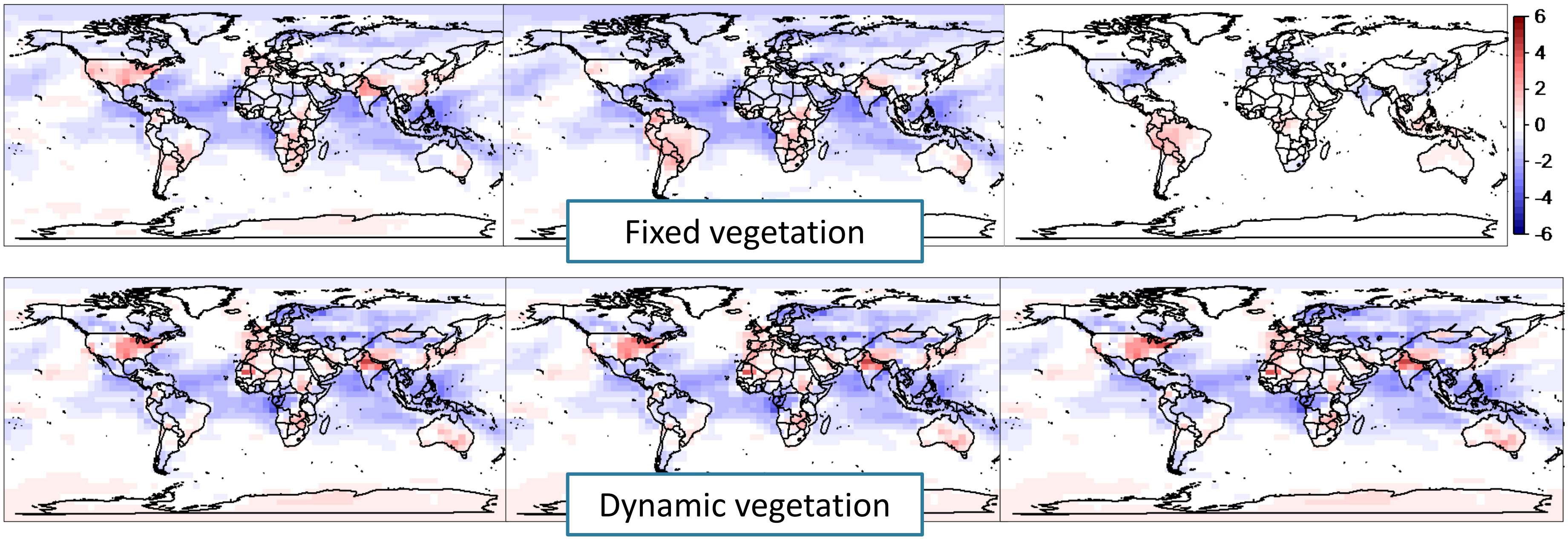
oak

Tai et al., ms. in preparation

CO_2 Effect on Ozone in 2050 Climate

2000-2050 change in annual mean surface afternoon O_3

Without CO_2 effect | With CO_2 effect | With minus without CO_2

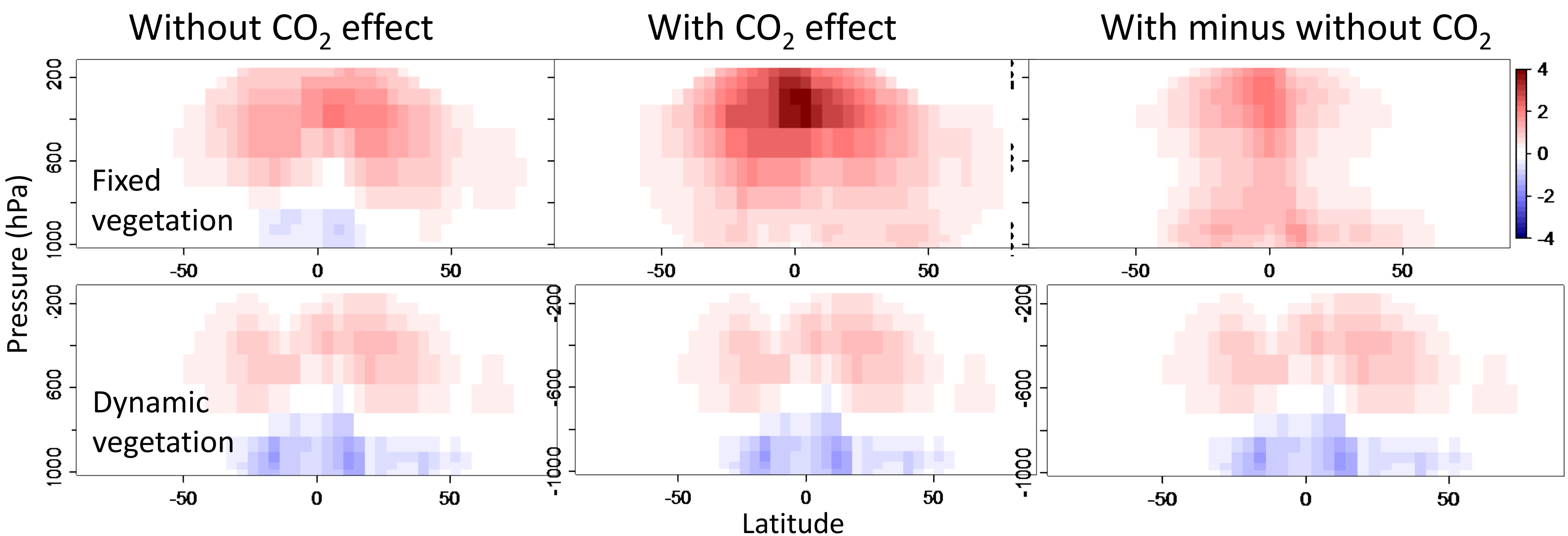


ppb

Tropospheric ozone burden (Tg)	Fixed vegetation ("observed")	Dynamic vegetation (modeled)
2000 climate	325	321
2050 climate	330 (+1.7%)	327 (+2.1%)
2050 climate + CO_2 inhibition	330 (+1.8%)	328 (+2.5%)

CO_2 Effect on OH in 2050 Climate

2000-2050 change in mean OH tropospheric profile (10^5 molec cm^{-3})



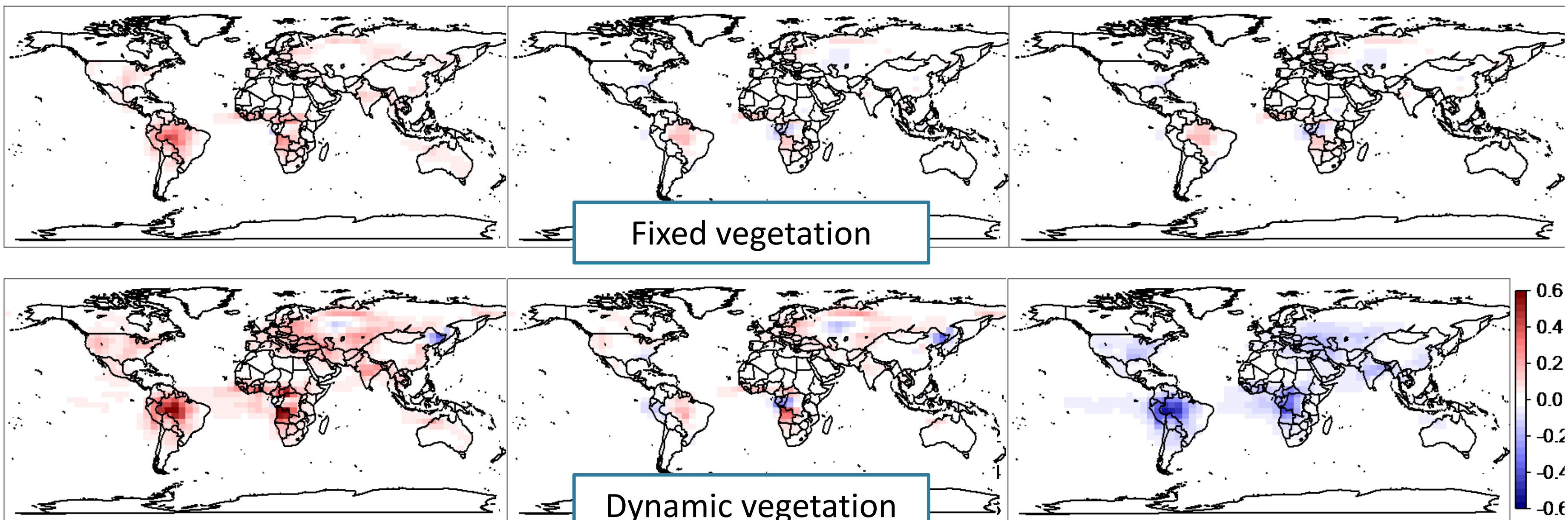
Global mean OH (10^5 molec cm^{-3})	Fixed vegetation ("observed")	Dynamic vegetation (modeled)
2000 climate	12.5	11.7
2050 climate	13.0 (+4.5%)	11.9 (+1.5%)
2050 climate + CO_2 inhibition	13.6 (+9.2%)	12.7 (+8.2%)

- CO_2 effect may modify CH_4 lifetime by a few months.

CO_2 Effect on SOA in 2050 Climate

2000-2050 change in annual mean surface SOA (μg m^{-3})

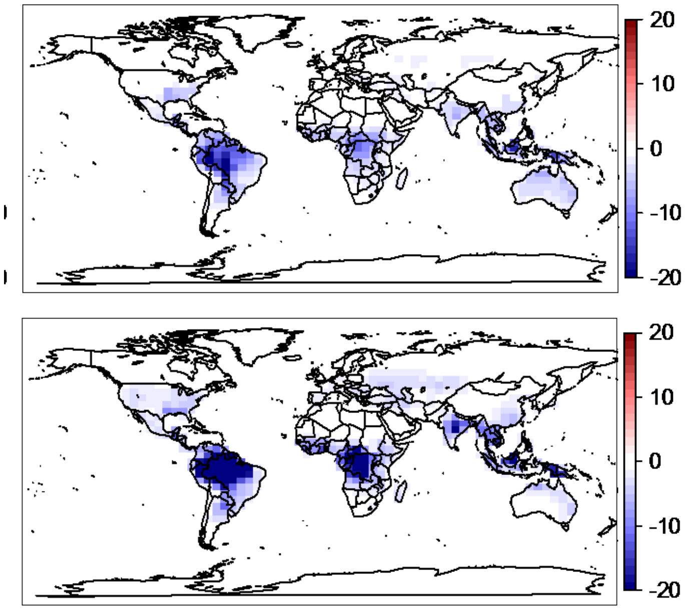
Without CO_2 effect | With CO_2 effect | With minus without CO_2



(μg m^{-3})

Tropospheric SOA burden (Tg)	Fixed vegetation (“observed”)	Dynamic vegetation (modeled)
2000 climate	0.37	0.69
2050 climate	0.40 (+6.9%)	0.83 (+20%)
2050 climate + CO_2 inhibition	0.30 (-19%)	0.58 (-16%)

With minus without CO_2



(mgC m^{-2} d^{-1})