

Feedbacks between Climate and Fire Emissions

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Tech Session 1A:
Role of Fire in the Carbon Cycle under Climate Change

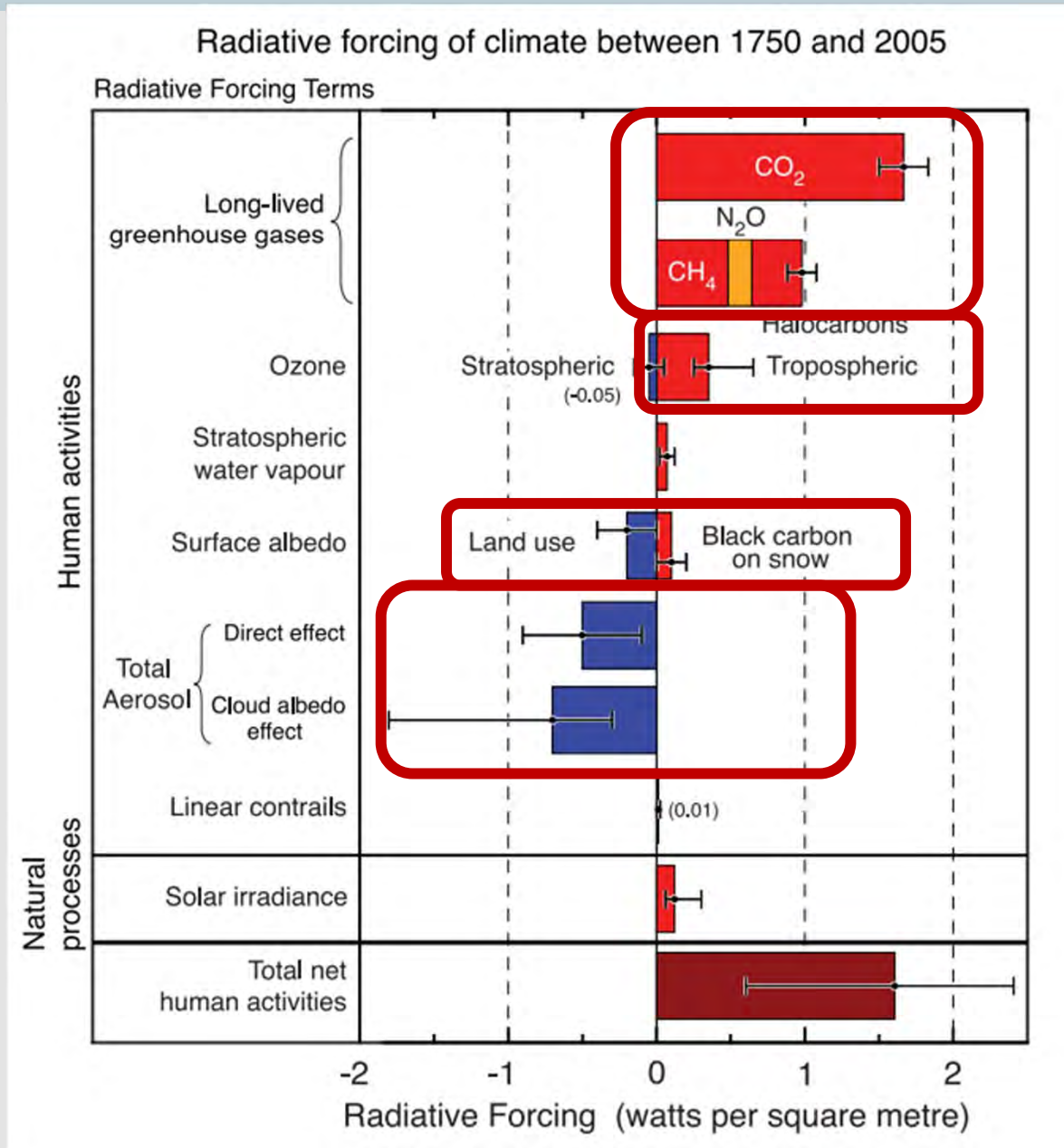
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14. ABSTRACT Fires emit significant amounts of trace gases and particulate matter to the atmosphere. These emissions include greenhouse gases, such as CO2 and methane, reactive gases that include a suite of non-methane organic compounds, and various particulate species, including black and organic carbon. Quantifying these emissions and constraining our understanding of their impacts on the atmosphere continues to be an on-going challenge. Recent advances in measurement techniques, remote sensing observations and modeling tools have enabled much better constraints on these processes, yet, large uncertainties remain. There are feedbacks between the fire and climate systems that can control the emissions from fires. Further, once in the atmosphere, fire emissions not only impact atmospheric composition and air quality, but can also influence the climate system in various ways. For example, particulate matter emitted to the atmosphere from fires can have direct radiative effects that can influence local meteorology, as well as processes that control atmospheric chemistry. This talk will address the various emissions from fires to the atmosphere and their controls, including climatic controls. The impacts of fires on the climate system will also be highlighted and the results from recent studies presented.					
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FEEDBACKS BETWEEN CLIMATE AND FIRE EMISSIONS

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Fires emit significant amounts of trace gases and particulate matter to the atmosphere. These emissions include greenhouse gases, such as CO₂ and methane, reactive gases that include a suite of non-methane organic compounds, and various particulate species, including black and organic carbon. Quantifying these emissions and constraining our understanding of their impacts on the atmosphere continues to be an on-going challenge. Recent advances in measurement techniques, remote sensing observations and modeling tools have enabled much better constraints on these processes, yet, large uncertainties remain. There are feedbacks between the fire and climate systems that can control the emissions from fires. Further, once in the atmosphere, fire emissions not only impact atmospheric composition and air quality, but can also influence the climate system in various ways. For example, particulate matter emitted to the atmosphere from fires can have direct radiative effects that can influence local meteorology, as well as processes that control atmospheric chemistry. This talk will address the various emissions from fires to the atmosphere and their controls, including climatic controls. The impacts of fires on the climate system will also be highlighted and the results from recent studies presented.

Radiative Forcing of Climate



1. Long-lived
GHG emissions

3. Ozone
production

4. Change in
surface properties

2. Short-lived
climate forcers:
particles

Fires Impacts on the Climate System

1. Emission of long lived greenhouse gases

- CO_2
 - ~ 6-7 Pg CO_2 annually released to atmosphere from open burning
- N_2O
- CH_4

Global CO₂ Emissions Estimates

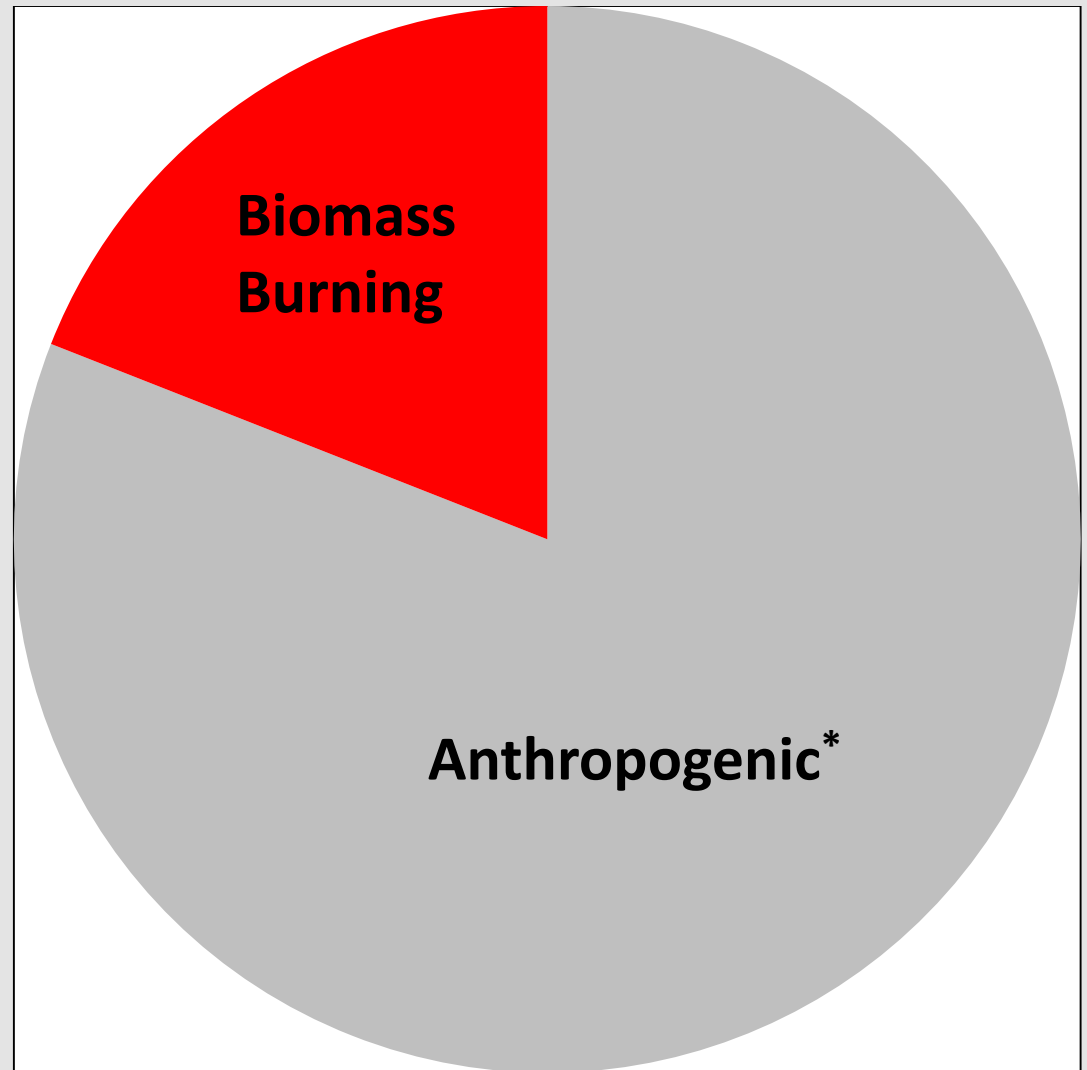
2007 Global CO₂ emissions

Total:

38 Pg CO₂

*Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement

Source: Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, U.S.

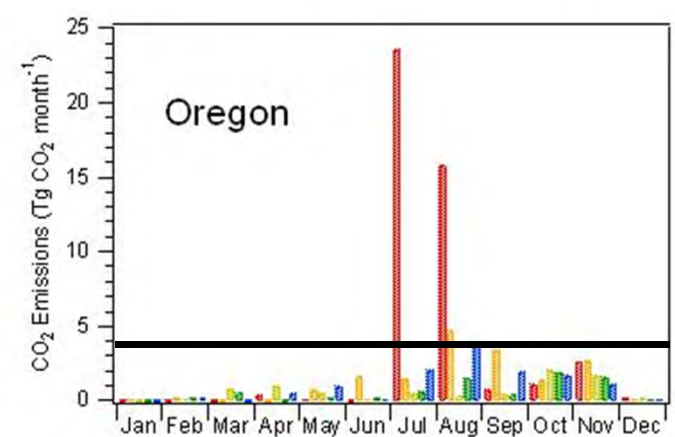
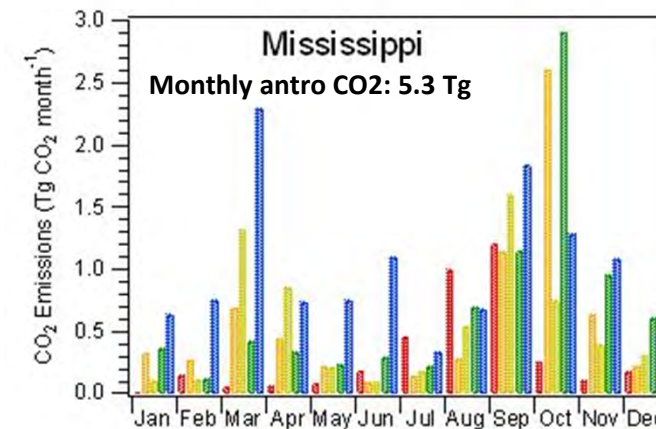
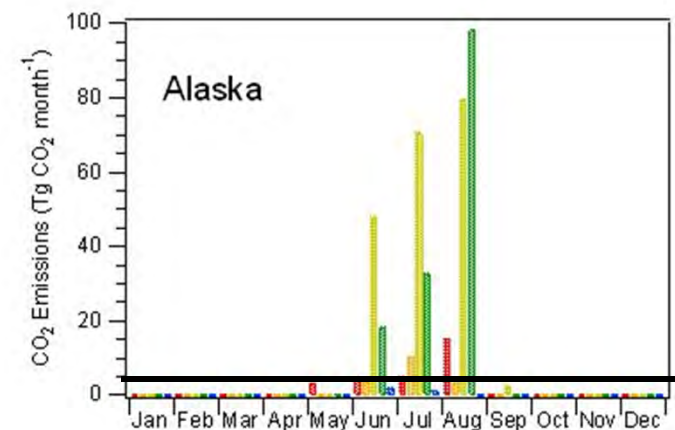
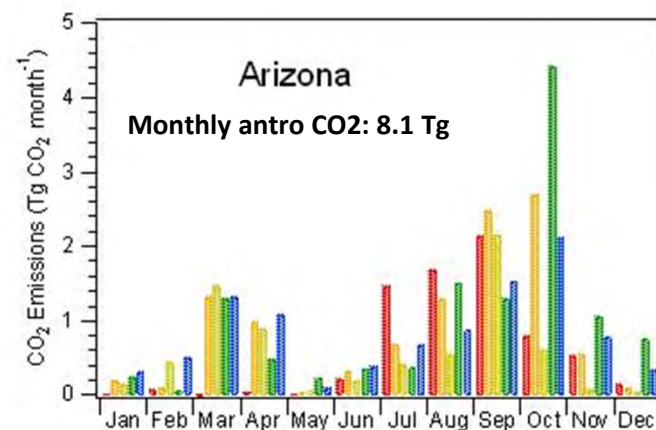
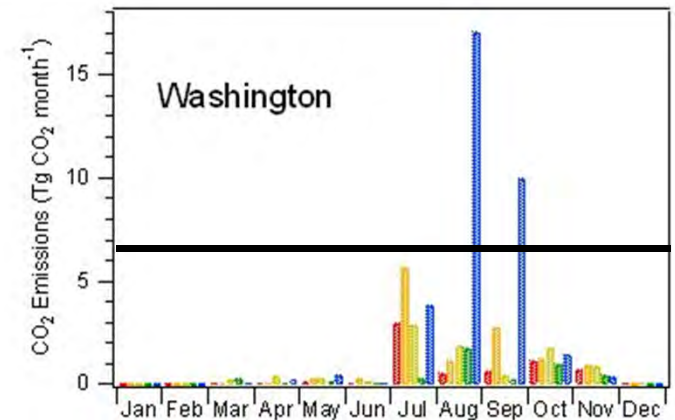
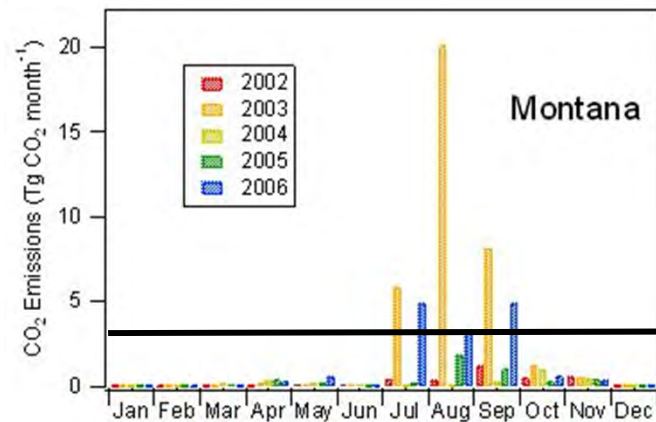


CO₂ Emissions from open fires across the U.S.

Note:
temporal &
spatial
variability

Wiedinmyer and Neff,
CBM, 2007

Black lines represent
monthly CO₂ emissions
from fossil fuel
combustion (U.S. Energy
Information
Administration)



Fires Impacts on the Climate System

1. Emission of long lived greenhouse gases
 - CO_2
 - ~ 6-7 Pg CO_2 annually released to atmosphere from open burning
 - N_2O
 - CH_4
2. Direct emission of short-lived climate forcers
 - Black Carbon
 - Particulate organic matter
3. Production of tropospheric ozone and secondary organic particulate matter

Emissions from Fires

Carbon Dioxide (CO₂)

Methane (CH₄)

Nitrous Oxide (N₂O)

Carbon Monoxide (CO)

Acetylene (C₂H₂)

Ethylene (C₂H₄)

Ethane (C₂H₆)

Propadiene (C₃H₄)

Propylene (C₃H₆)

Propyne (C₃H₄)

Propane (C₃H₈)

n-Butane (C₄H₁₀)

1-Butene (C₄H₈)

1,3-Butadiene (C₄H₆)

n-Pentane (C₅H₁₂)

3-Methyl-1-Butene (C₅H₁₀)

Isoprene (C₅H₈)

Cyclopentane (C₅H₁₀)

n-Hexane (C₆H₁₄)

Heptane (C₇H₁₆)

Benzene (C₆H₆)

Toluene (C₆H₅CH₃)

Xylenes (C₈H₁₀)

Ethylbenzene (C₈H₁₀)

1,3,5-Trimethylbenzene (C₉H₁₂)

α-Pinene (C₁₀H₁₆)

Ethanol (CH₃CH₂OH)

Methanol (CH₃OH)

Phenol (C₆H₅OH)

Formaldehyde (HCHO)

Glycolaldehyde (C₂H₄O₂)

Acetaldehyde (CH₃CHO)

Acrolein (C₃H₄O)

Furaldehydes

Propanal (C₃H₆O)

Acetone (C₃H₆O)

Methyl Vinyl Ether (C₃H₆O)

Methacrolein (C₄H₆O)

Crotonaldehyde (C₄H₆O)

2,3-Butanedione (C₄H₆O₂)

Furan (C₄H₄O)

3-Methylfuran (C₅H₆O)

Formic Acid (HCOOH)

Acetic Acid (CH₃COOH)

Methyl Bromide (CH₃Br)

Methyl Iodide (CH₃I)

Trichloromethane (CHCl₃)

Hydrogen Cyanide (HCN)

Methyl Nitrate (CH₃ONO₂)

Ethyl Nitrate (C₂H₅NO₃)

Ammonia (NH₃)

Hydrogen (H₂)

Sulfur Dioxide (SO₂)

Nitrous Acid (HONO)

Nitrogen Oxides (NO_x as NO)

Total Particulate Carbon

Total Suspended Particulate (TSP)

PM_{2.5}

PM₁₀

Black Carbon (BC)

Organic Carbon (OC)

Oxylate (C₂O₄)

Nitrate (NO₃)

Phosphate (PO₄)

Sulfate (SO₄)

Ammonium (NH₄)

Cl

Ca

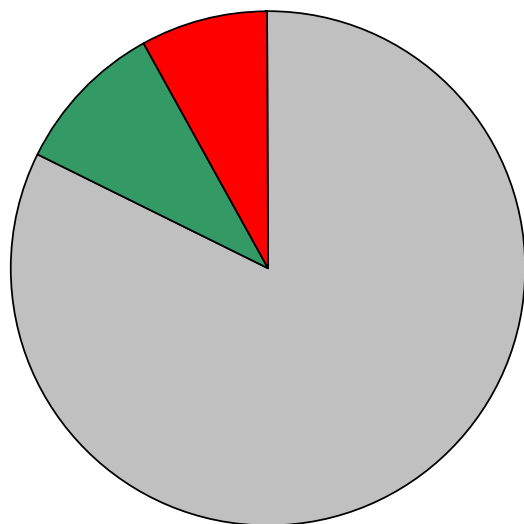
Mg

Na

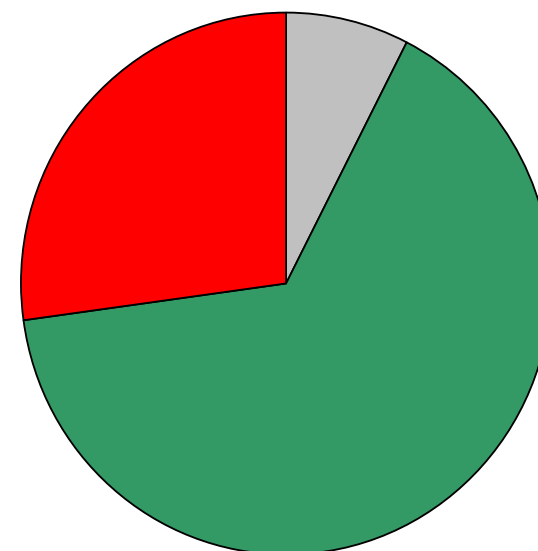
K

Global Trace Gas Emissions Estimates

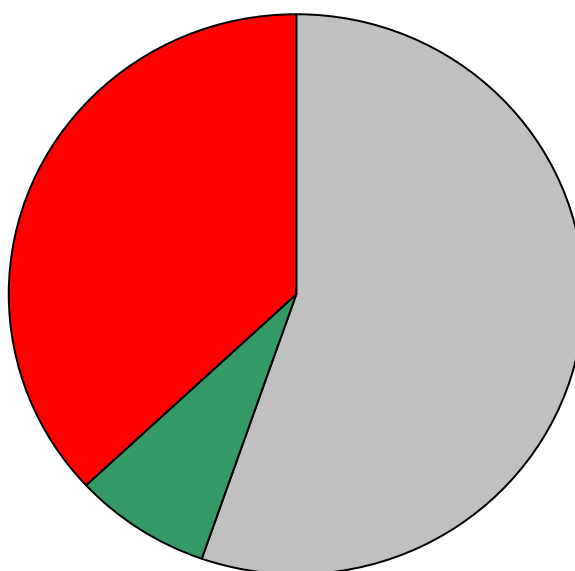
NO₂



NMOC



CO



Yokelson et al., ACP, 2008

EDGARFT2000

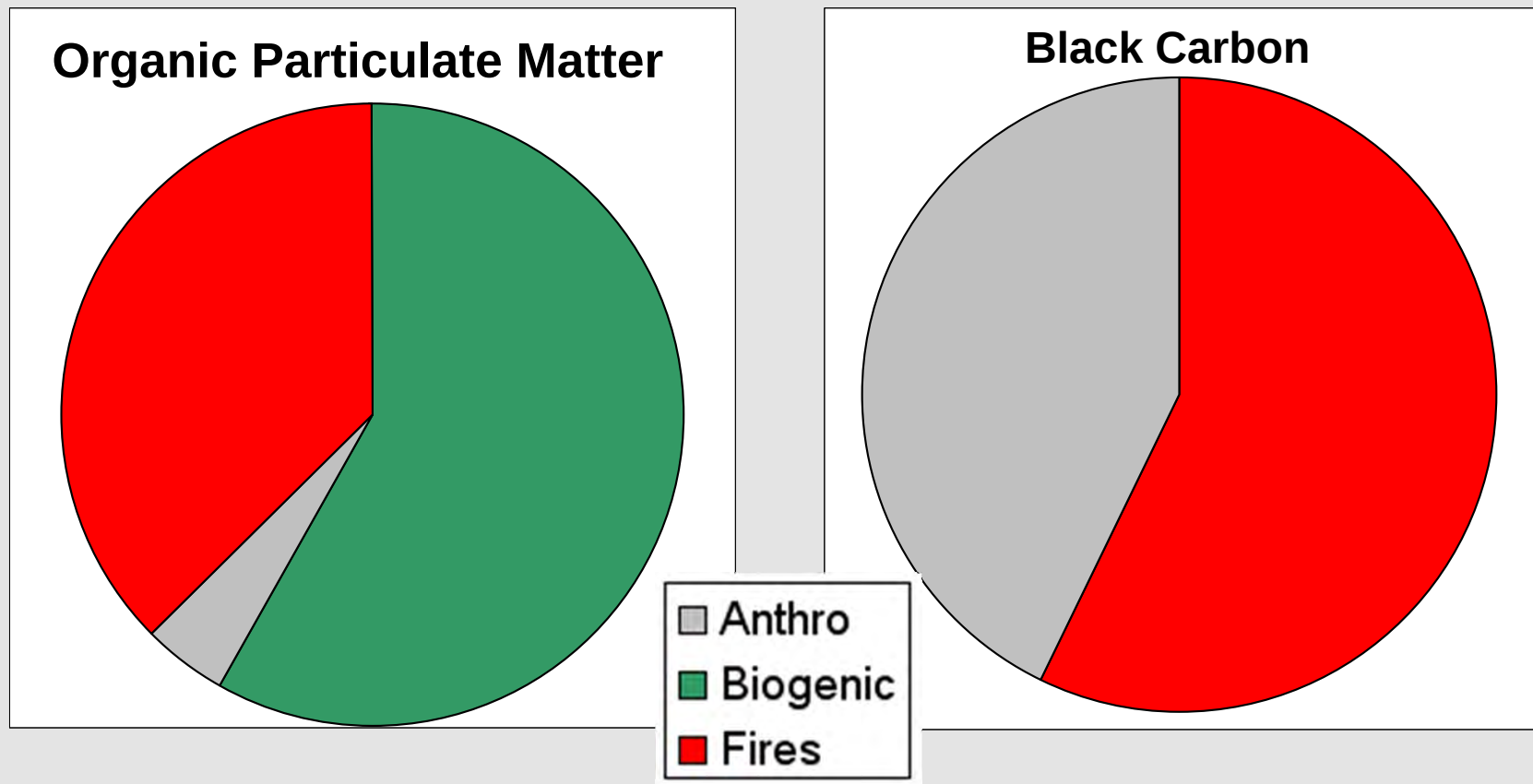
Yan et al, GBC, 2005

Guenther et al., 1995; 2006; pers. comm.

GFEDv2 (van der Werf et al., 2006)

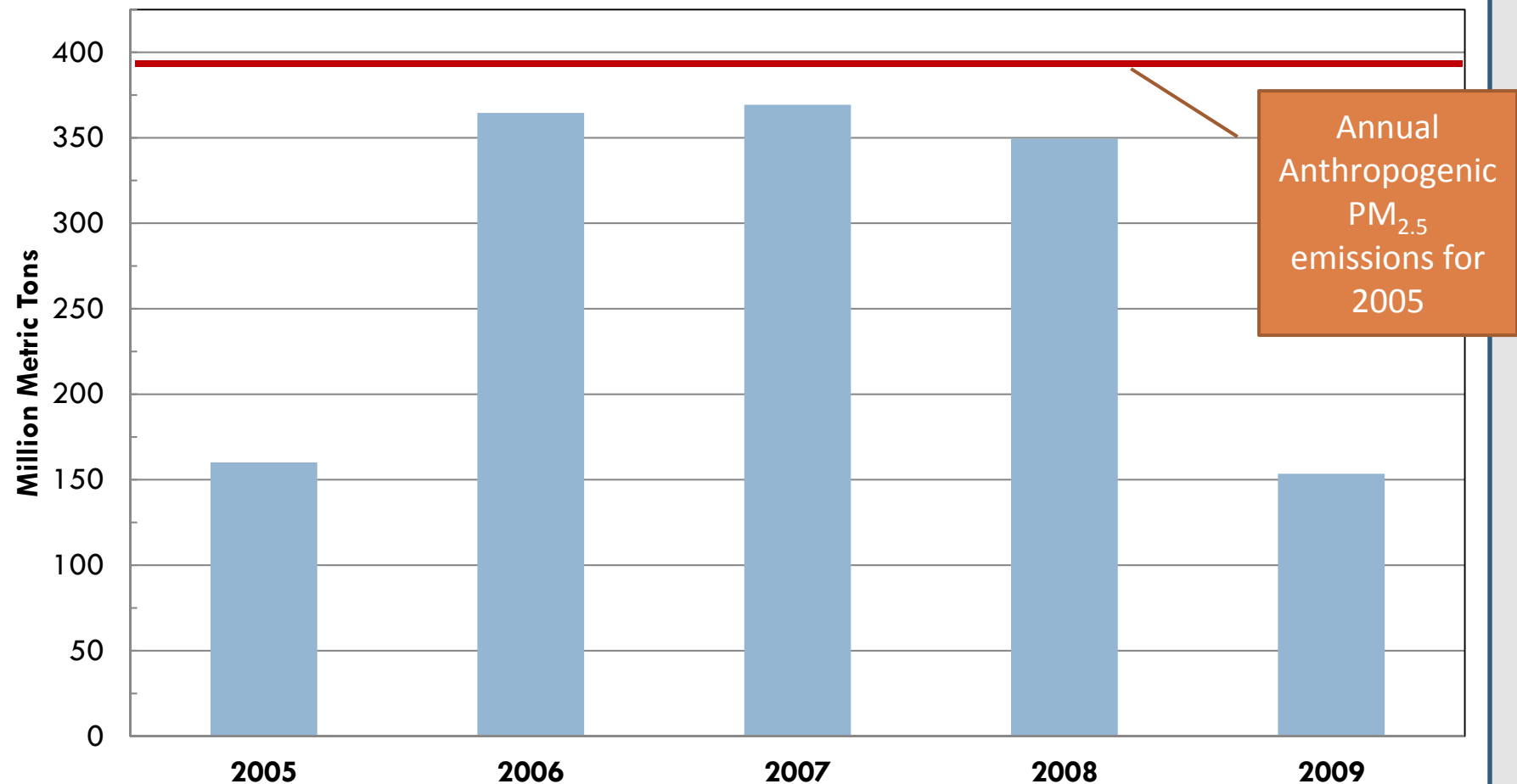
Andreae and Merlet, GBC, 2001

Global Particulate Matter Emissions

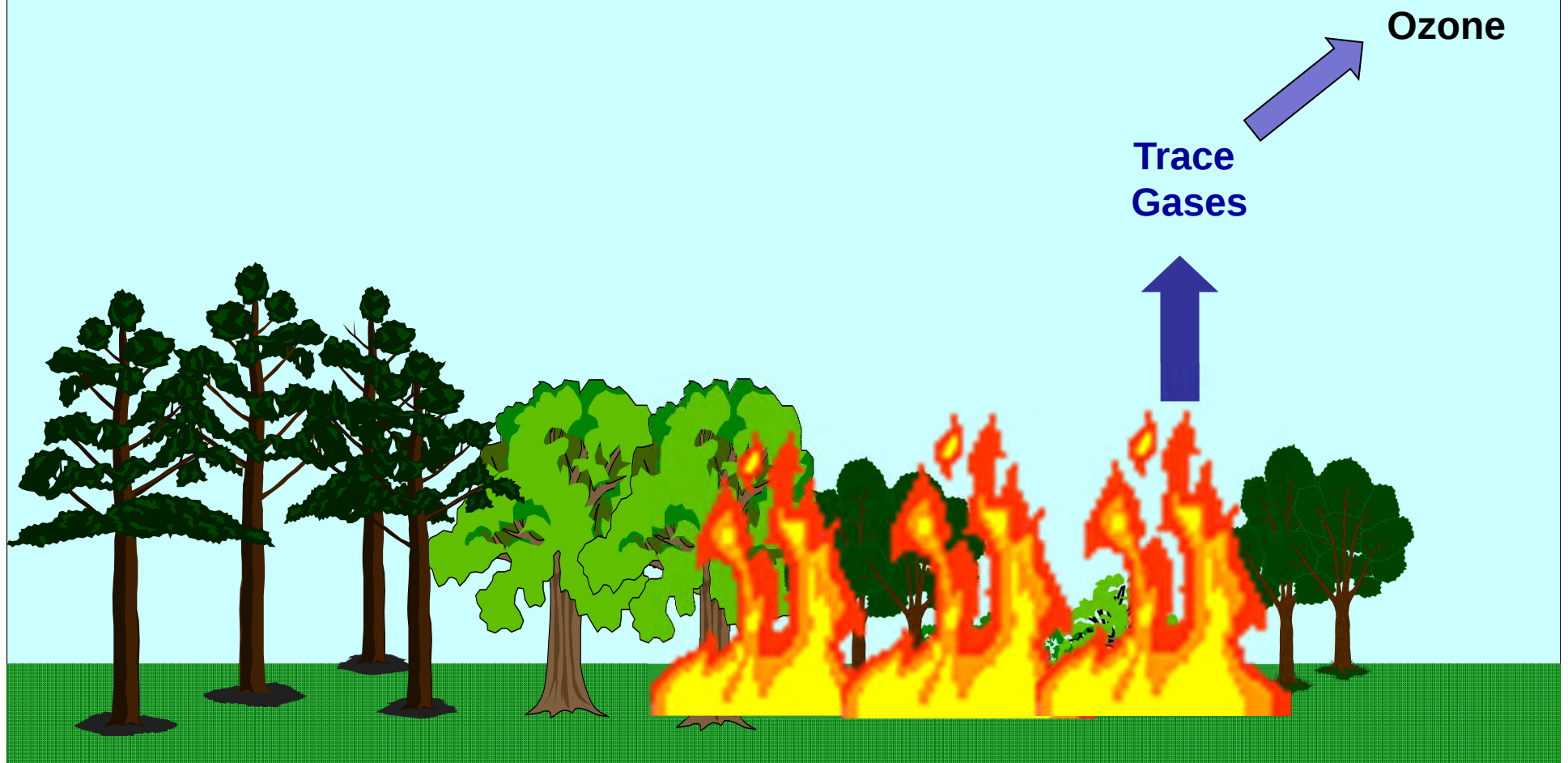


Emission Estimates in the U.S.

Fine Particulate Matter (PM_{2.5}) Emissions from Fires in Western U.S.



Atmospheric Impacts of Emissions



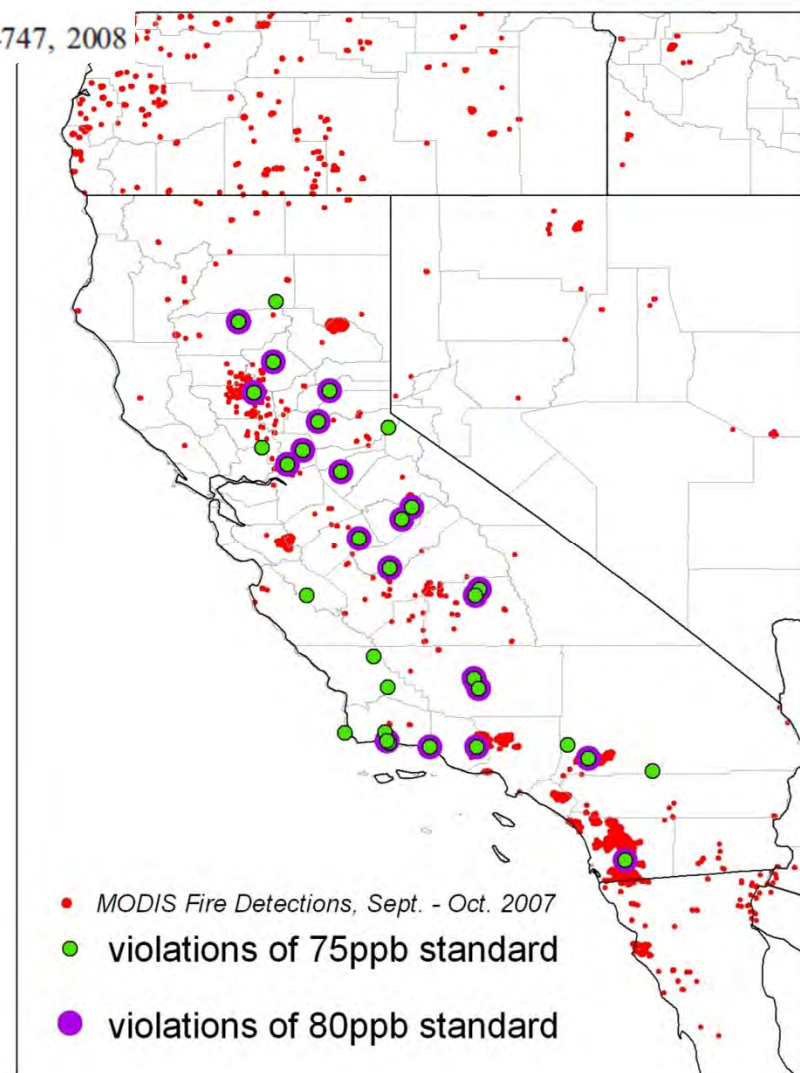
Fire Emissions and Ozone

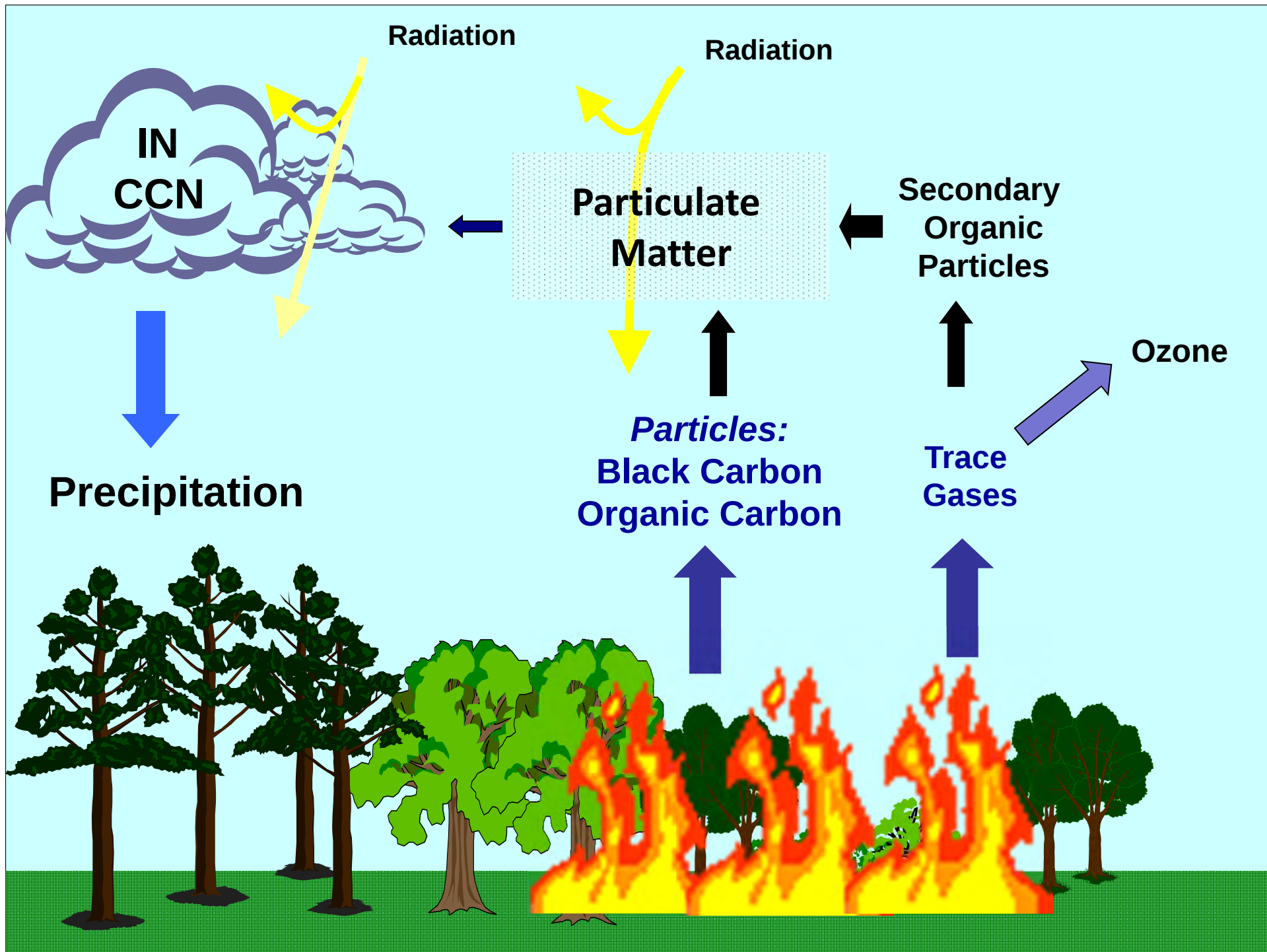
Impacts of the fall 2007 California wildfires on surface ozone: Integrating local observations with global model simulations

G. G. Pfister,¹ C. Wiedinmyer,¹ and L. K. Emmons¹

GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L19814, doi:10.1029/2008GL034747, 2008

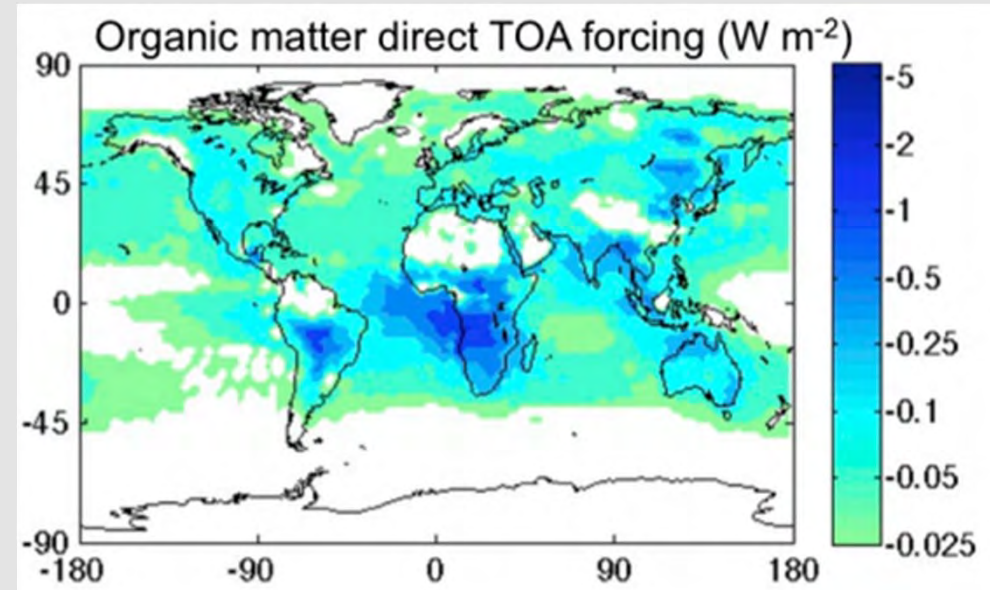
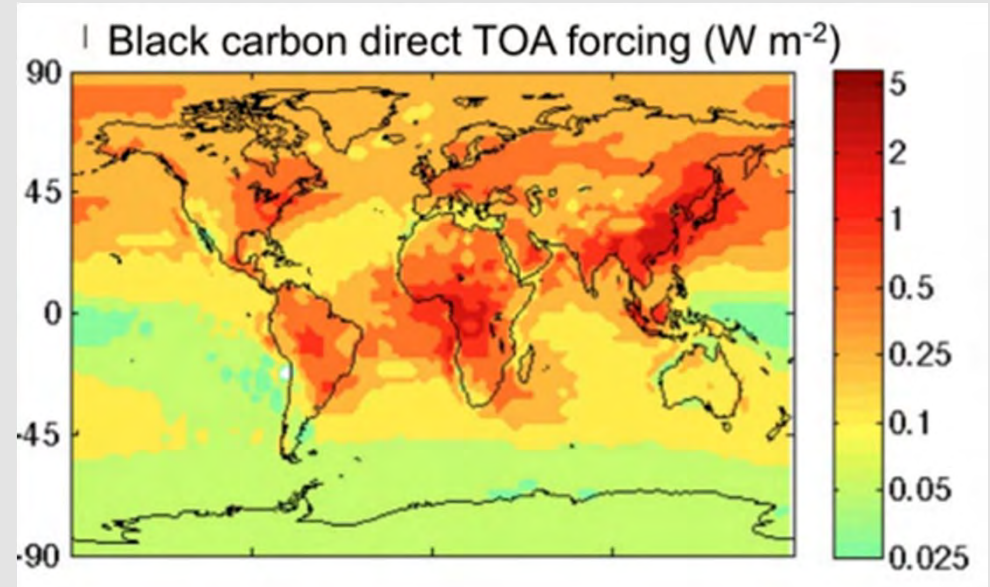
Violations in O₃ health standards in rural areas happened three times more likely because of pollution from the wildfires.





Radiative Forcing of Particulate Carbon

Total Black Carbon and
Particulate Organic Matter
Top of the Atmosphere (TOA)
forcing

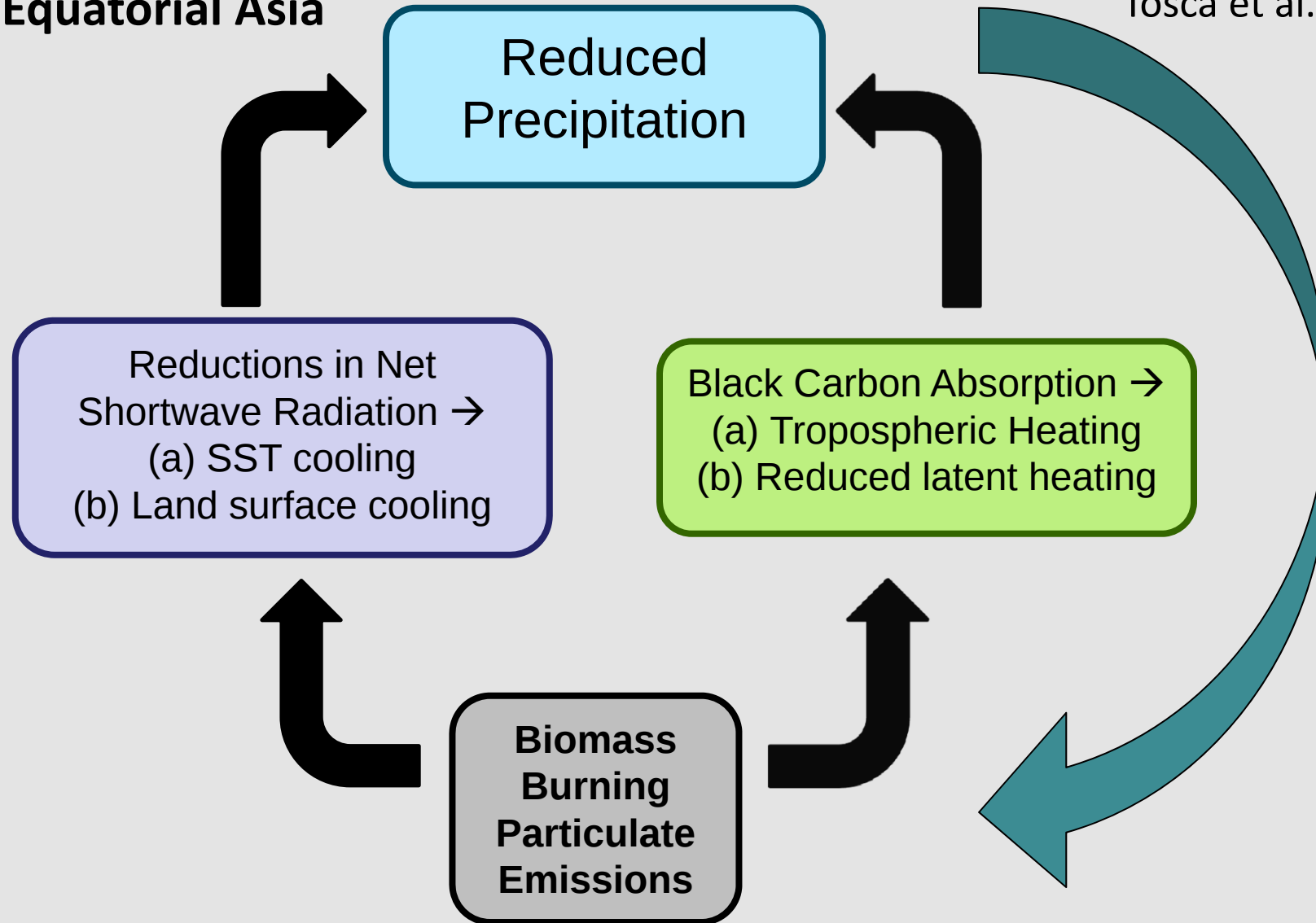


Bond et al., *ACP*, 2011

Regional Climate Feedbacks from Fires

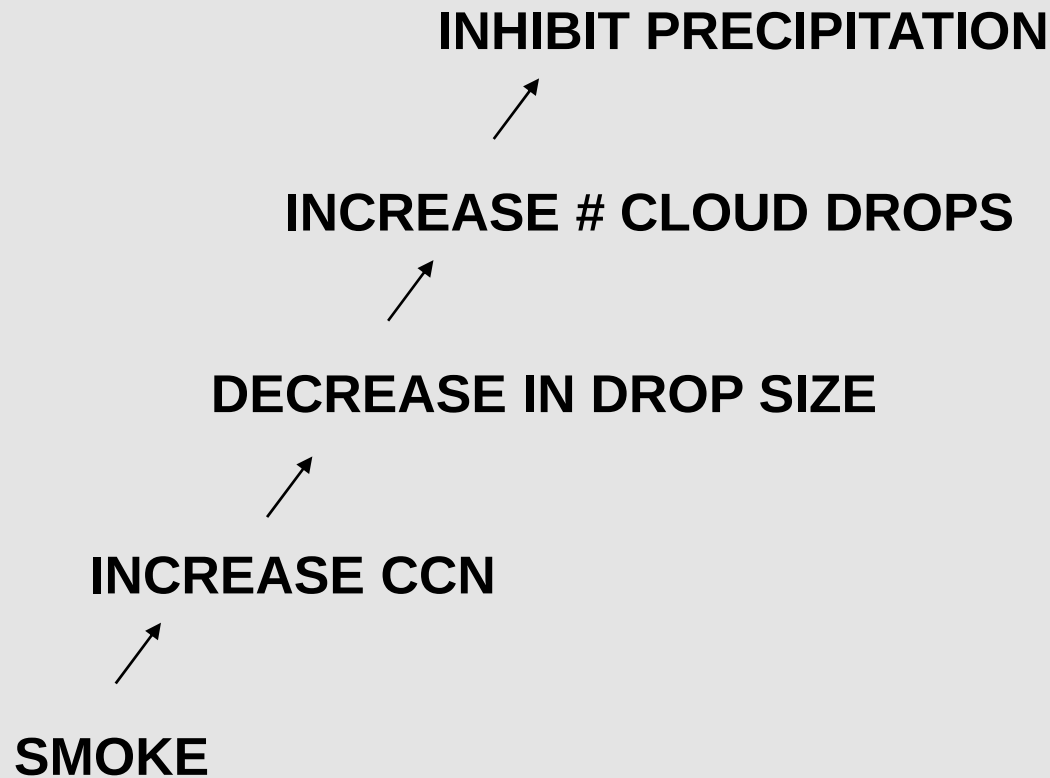
Equatorial Asia

Tosca et al., *ACP*, 2010



During El Nino- drought and increased fire emissions

Regional Climate Feedbacks from Fires



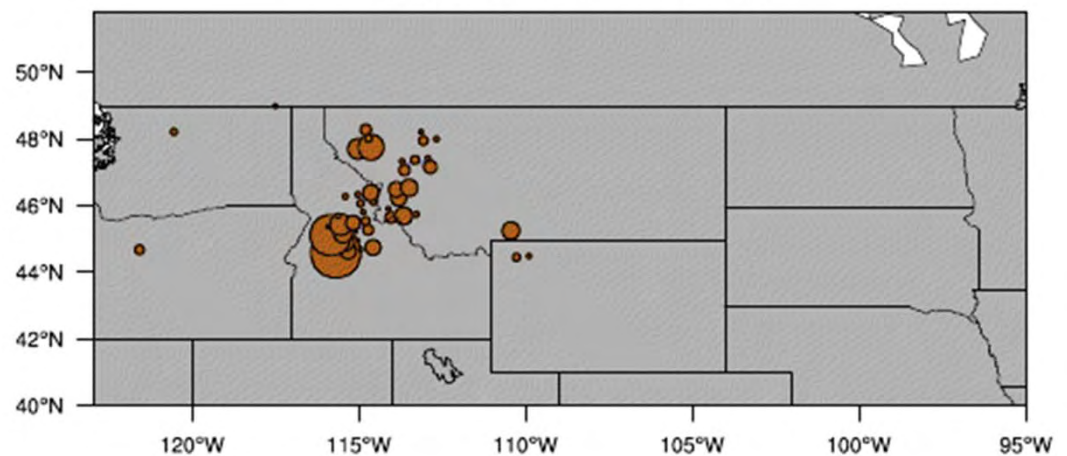
(e.g., Andreae et al., 2004; Rosenfeld 1999)

Regional feedbacks to weather and chemistry

Use coupled weather-chemistry model to investigate the feedbacks between the fire emissions, weather, and chemistry



a). Fires captured on August 13, 2007 by MODIS
PM2.5 (ranging from 0.2 to 3.0 $\mu\text{g}/\text{m}^3$ m/s)



Regional feedbacks to weather and chemistry

- Inclusion of fire particulate emissions:

09:00-16:00 LST August 15

Surface air temperature (K)

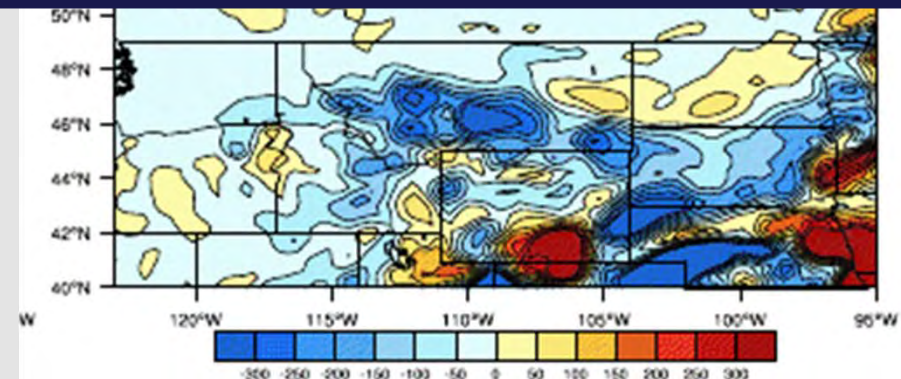


Fire emissions have regional climate impacts:

- Meteorology and chemistry
- Local and regional effects
- Short-lived impacts

water vapor mixing ratio

- Change ozone concentrations

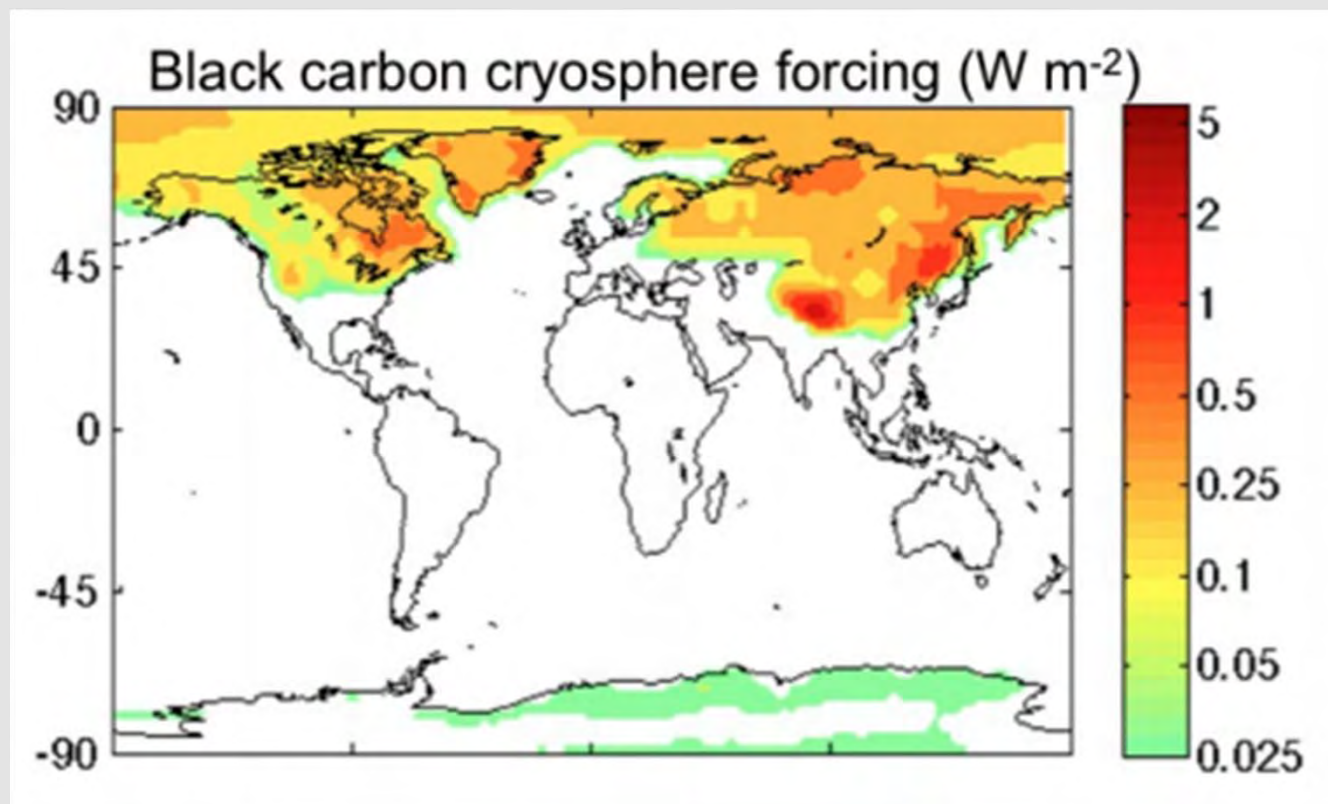


Jiang, Wiedinmyer, and Carlton, *in preparation*

Fires Impacts on the Climate System

1. Emission of long lived greenhouse gases
 - CO_2
 - ~ 6-7 Pg CO_2 annually released to atmosphere from open burning
 - N_2O
 - CH_4
2. Emission of short-lived climate forcers
 - Black Carbon
 - Particulate organic matter
3. Production of tropospheric ozone and secondary organic particulate matter
4. Changes in land surface properties
 - Black carbon on snow
 - Albedo

Radiative Forcing of Black Carbon on Snow

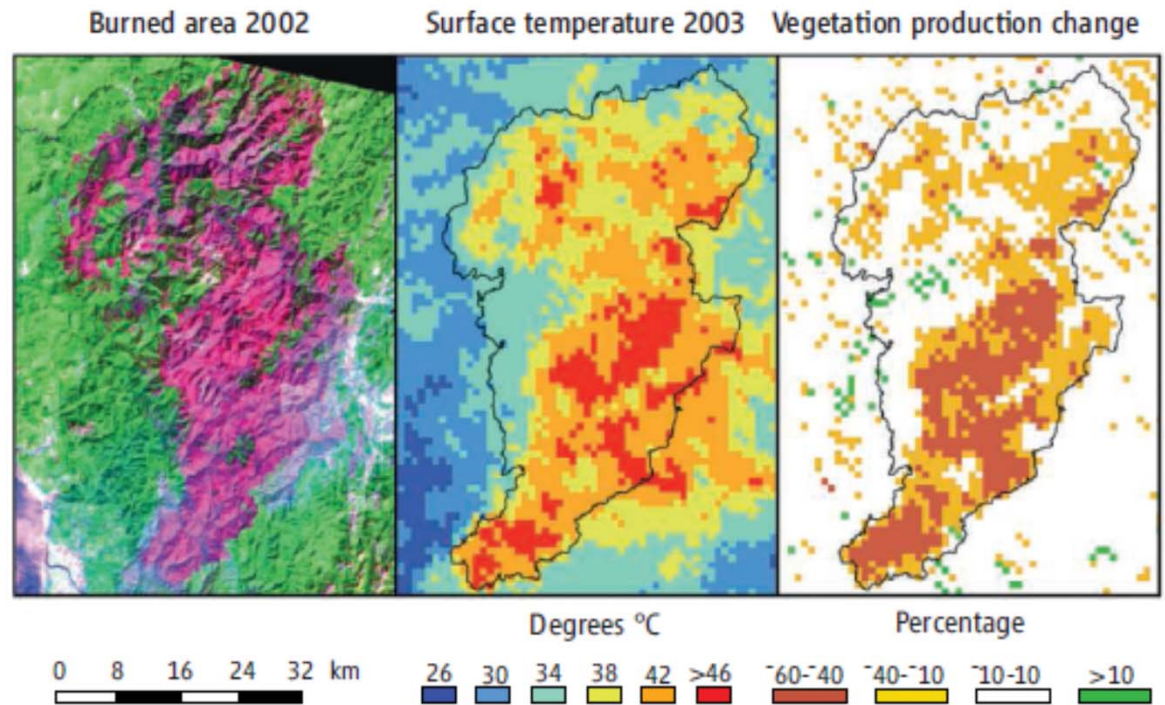


Bond et al., *ACP*, 2011

Fire impacts on climate: Land Cover Change

Post Fire Impacts:

- Surface temperature
- Vegetation production
- Albedo



Impact of fire disturbance on land surface energy and carbon balances. In the summer of 2002, the Biscuit Fire in Oregon destroyed 2000 km² of temperate evergreen forests (left). A Moderate Resolution Imaging Spectroradiometer (MODIS) satellite image taken on 28 July 2003 (middle) shows land surface radiometric temperatures of 46° to 50°C in the area burned the summer before, whereas temperatures in the adjacent unburned forests range from 27° to 32°C. Annual vegetation production measured from MODIS (4) (right) was 20 to 60% lower in the burned area in 2003 to 2004 than before the wildfire.

Concluding Remarks

- Emissions from open biomass burning are substantial – at global and regional scales
- Fires can have many impacts on the regional and global climate system
 - Highly non-linear
 - Impacts occur on various time scales
- Our range in understanding of the emissions and their feedbacks remains large

Acknowledgements

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Annmarie Carlton (Rutgers University)

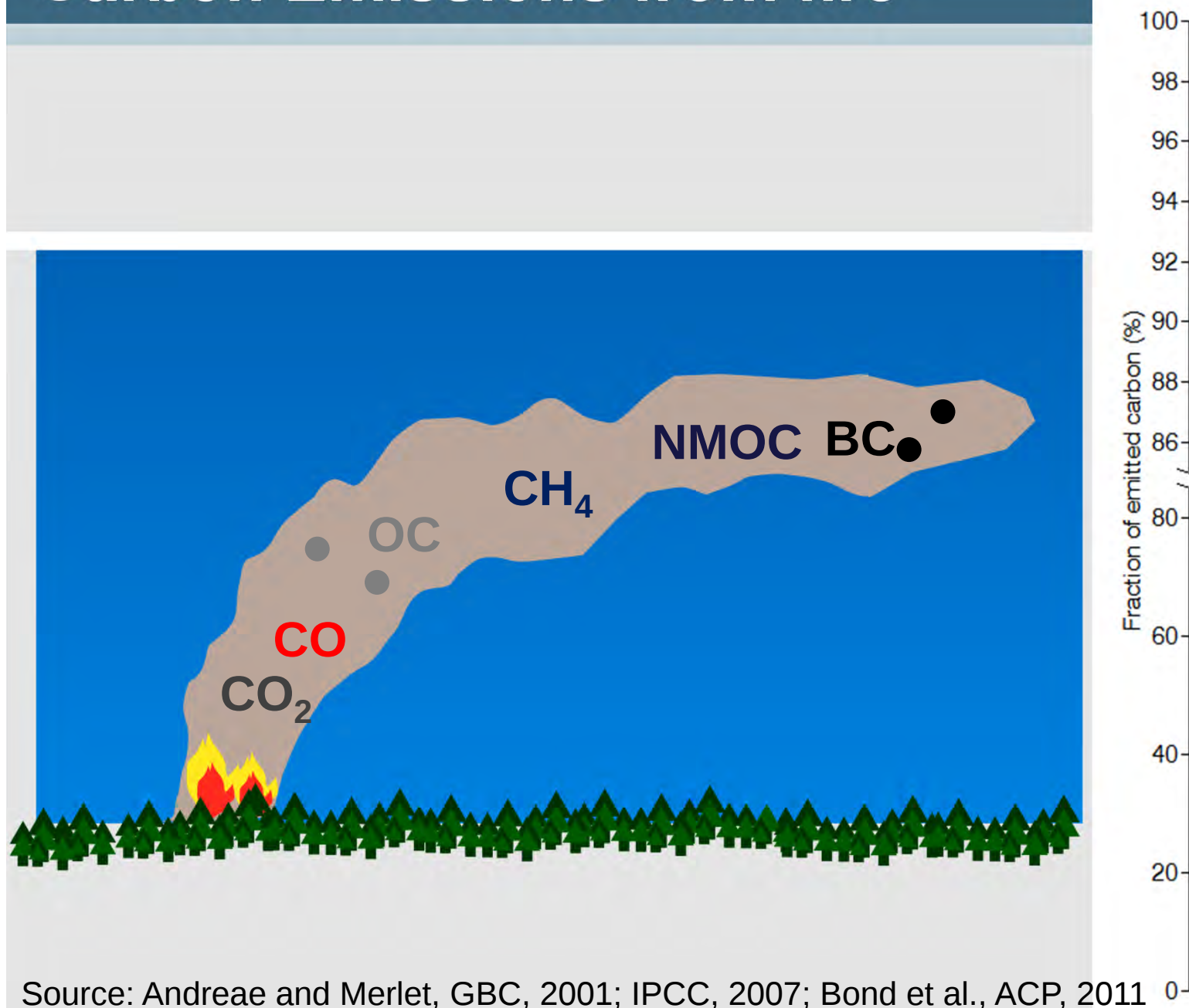
Xiaoyan Jiang (Los Alamos National Lab/NCAR)

Louisa Emmons, Gabi Pfister (NCAR)

Jason Neff (University of Colorado)

Additional Slides

Carbon Emissions from fire



Source: Andreae and Merlet, GBC, 2001; IPCC, 2007; Bond et al., ACP, 2011

Aerosol effects

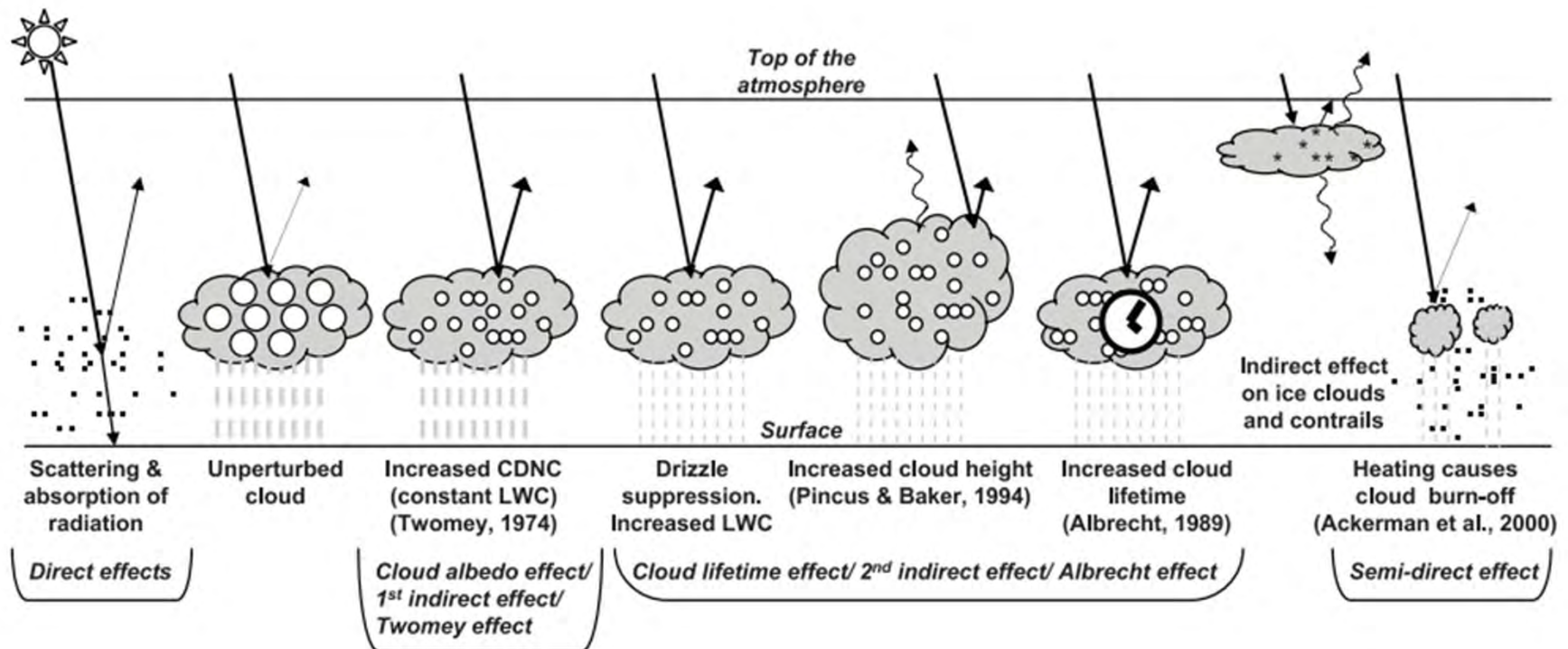
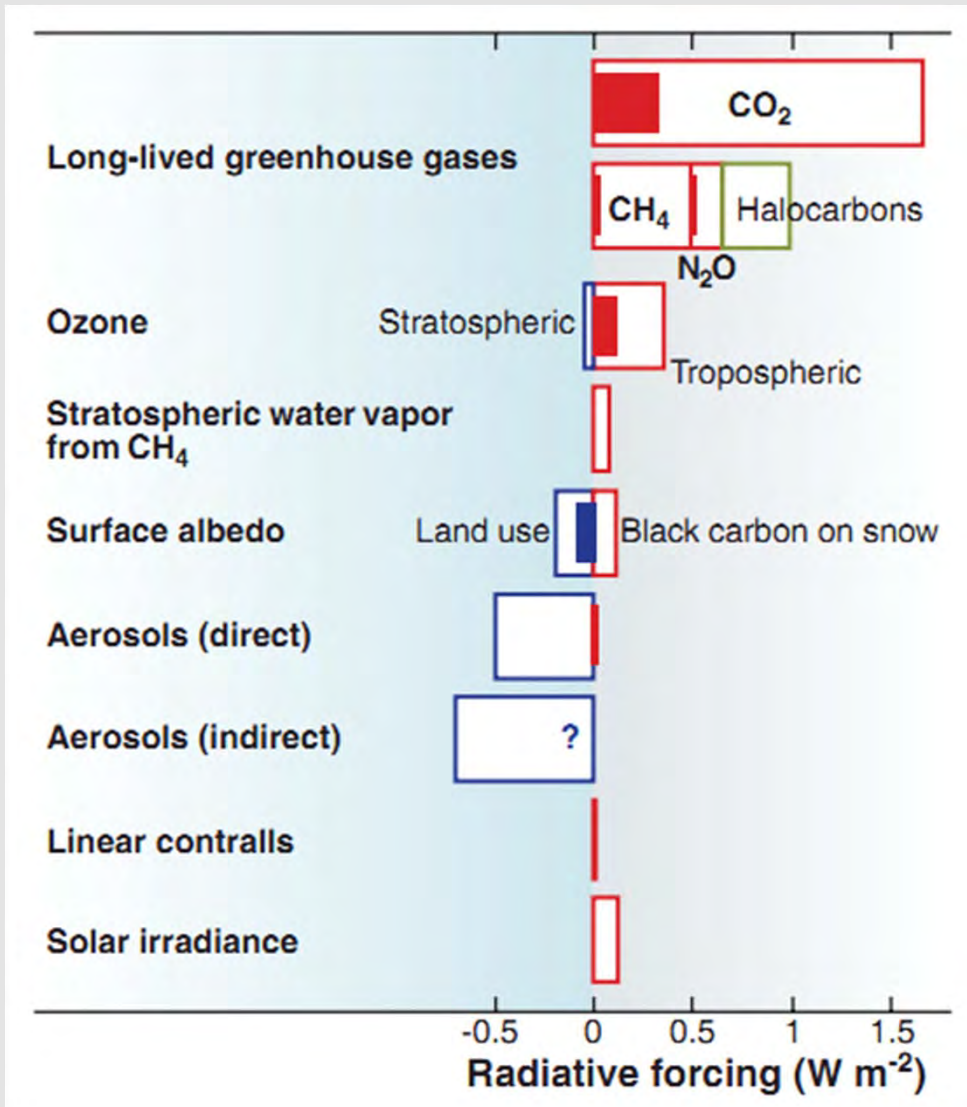


Figure 2.10. Schematic diagram showing the various radiative mechanisms associated with cloud effects that have been identified as significant in relation to aerosols (modified from Haywood and Boucher, 2000). The small black dots represent aerosol particles; the larger open circles cloud droplets. Straight lines represent the incident and reflected solar radiation, and wavy lines represent terrestrial radiation. The filled white circles indicate cloud droplet number concentration (CDNC). The unperturbed cloud contains larger cloud drops as only natural aerosols are available as cloud condensation nuclei, while the perturbed cloud contains a greater number of smaller cloud drops as both natural and anthropogenic aerosols are available as cloud condensation nuclei (CCN). The vertical grey dashes represent rainfall, and LWC refers to the liquid water content.

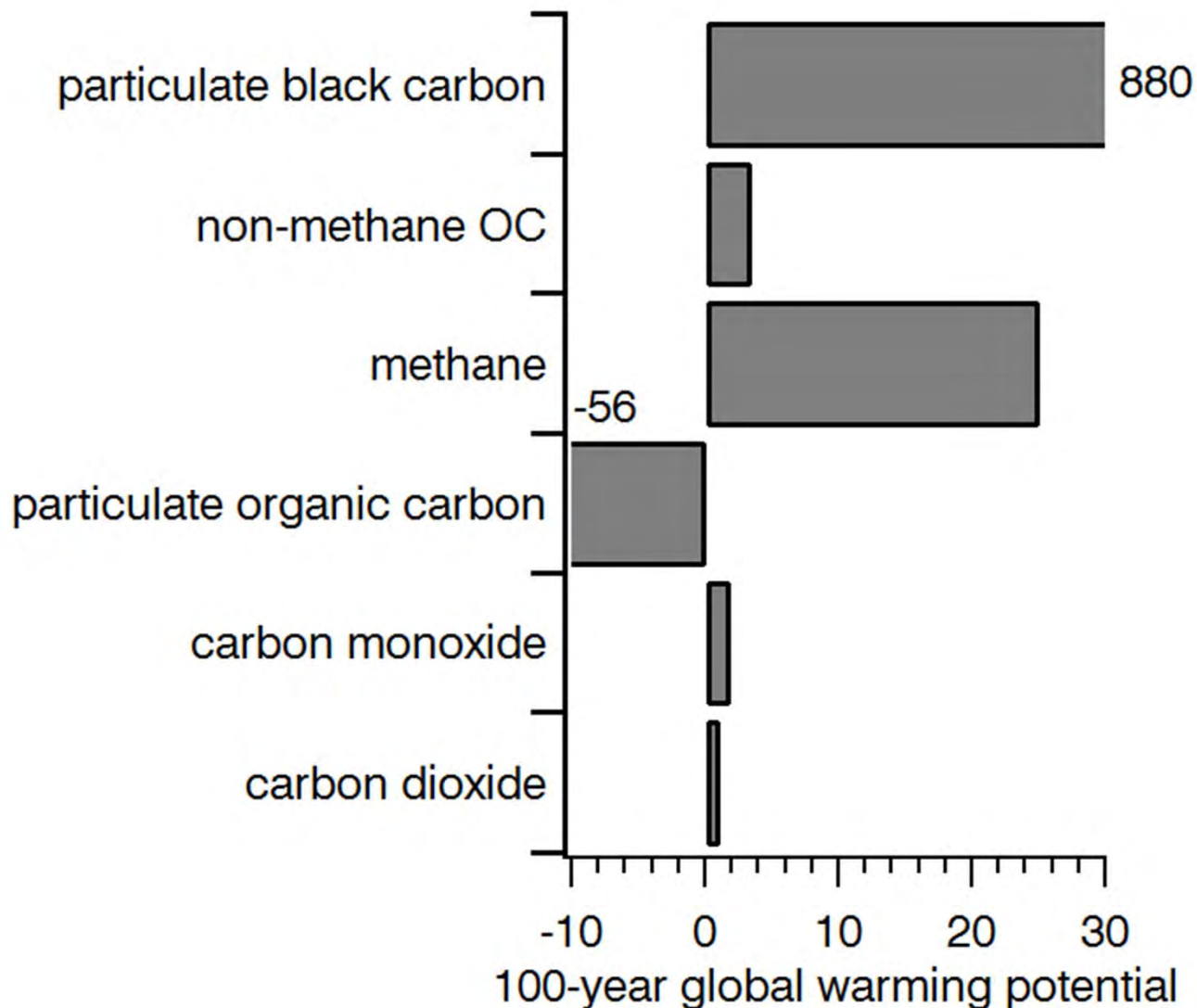
Radiative Forcing of Climate



Estimated contribution of fire associated with deforestation to changes in radiative forcing

Bowman et al., *Science*, 2009

Emissions from Fires: Global Warming Potential



Andreae and Merlet, GBC, 2001; IPCC, 2007; Bond et al., ACP, 2011

Models to Predict Emissions from Fires

- Fire-Specific Models
 - Biscuit Fire (Campbell et al., 2007)
- Regional Models
 - North America (Wiedinmyer et al., *AE*, 2006)
 - Asia (Song et al., *ERL*, 2010)
 - Western Africa (Liousse et al., 2010)
 - Western U.S. (Urbanski, *ACPD*, 2011)
- Global Models
 - GFED (van der Werf et al., *AC&P*, 2010)
 - FINN (Wiedinmyer et al., *GMD*, 2011)

Estimating Emissions from Fires

$$\text{Emission}_i = f(\text{ef}_i, \text{Biomass Burned})$$

Emission Factor

- Vegetation
 - Type
 - Condition
- Fire
 - Intensity

Biomass Burned

- Vegetation
 - Type
 - Condition
 - Density
 - Loading
- Fire
 - Intensity
 - Duration

Global Emissions from Open Biomass Burning

	2005	2006	2007	2008	2009
CO₂	7590	7723	7275	6433	6886
CH₄	18	20	18	16	17
CO	375	400	372	330	347
NMOC	81	92	81	71	75
NO	13	13	12	11	12
SO₂	2	3	2	2	2
OC	23	24	23	21	22
BC	2	2	2	2	2

* Emissions in Tg year⁻¹