The Global and Regional Climate and Air Pollution Effects of Fossil-Fuel Versus Biofuel Soot

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GATOR-GCMOM Model

Gas processes
- Emissions
- Photochemistry
- Gas-to-particle conversion
- Cloud removal

Aerosol processes
- Emissions
- Nucleation/condensation
- Gas dissolution
- Aqueous chemistry
- Crystallization
- Aerosol-aerosol coagulation
- Aerosol-cloud coagulation
- Dry deposition
- Sedimentation
- Rainout/washout

Meteorological processes
- Pressure, winds, temp., TKE

Cloud processes
- Subgrid clouds, size-resolved physics
- Liquid/ice growth on aerosol particles
- Liquid drop freezing/breakup
- Hydrometeor-hydrometeor coagulation
- Hydrometeor-aerosol coagulation
- Precipitation, aer./gas rainout/washout
- Below-cloud evaporation/melting
- Lightning from collision bounceoffs

Radiative transfer
- UV/visible/near-IR/thermal-IR
- Gas/aerosol/cloud scat./absorption
- Predicted snow, ice, water albedos

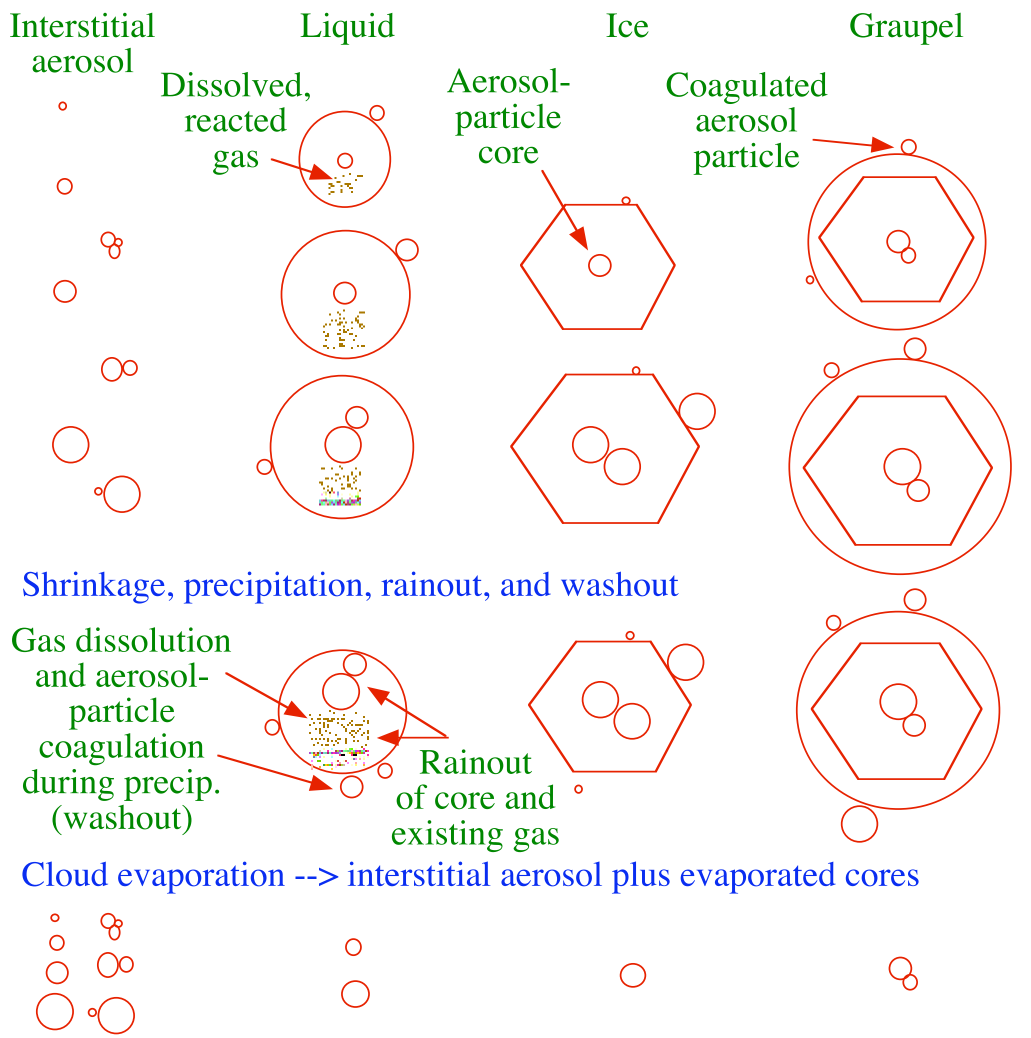
Surface processes
- Soil, water, snow, sea ice, vegetation, road, roof temperatures/moisture
- Ocean 2-D dynam., 3-D diffus/chem.
- Ocean-atmosphere exchange

Cloud Microphysical and Chemical Processes

Condensation/deposition of water vapor onto aerosol particles

Coagulation: Aerosol-aerosol, Aerosol-liquid, Aerosol-ice, Aerosol-graupel, Liquid-liquid, Liquid-ice, Liquid-graupel, Ice-ice, Ice-graupel, Graupel-graupel

Gas dissolution. aqueous chemistry, hom.-het. freezing, contact freezing



Size Distributions Treated

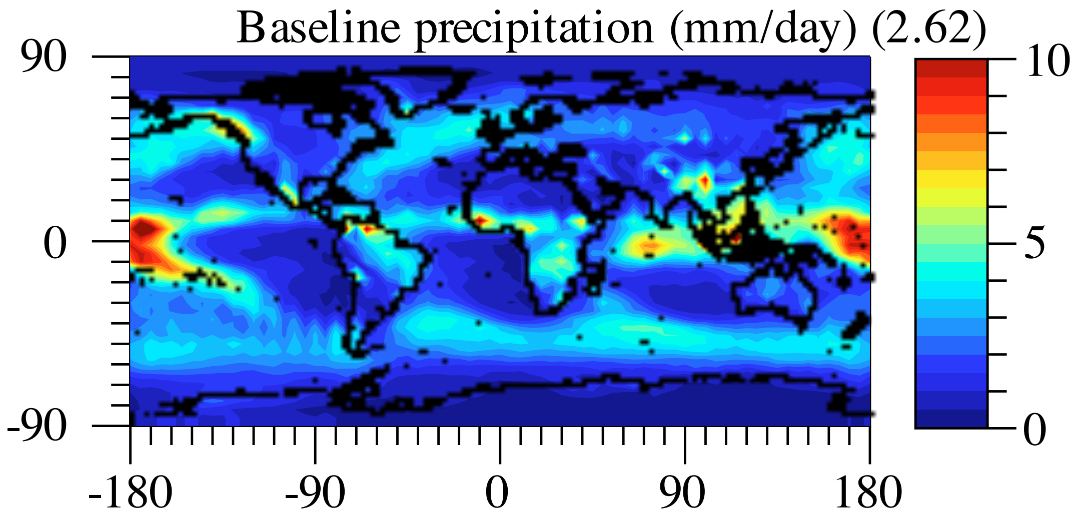
FF Soot	Intern.-mix	Liq.	Ice	Graupel
Number	Number	Number	Number	Number
BC	BC	BC	BC	BC
POM	POM	POM	POM	POM
SOM	SOM	SOM	SOM	SOM
H_2O-h	H_2O-h	H_2O-h	H_2O-h	H_2O-h
H^+	H^+	H^+	H^+	H^+
H_2SO_4	H_2SO_4	H_2SO_4	H_2SO_4	H_2SO_4
HSO_4-	HSO_4-	HSO_4-	HSO_4-	HSO_4-
NH_4^+	NH_4^+	NH_4^+	NH_4^+	NH_4^+
NO_3-	NO_3-	NO_3-	NO_3-	NO_3-
Cl-	Cl-	Cl-	Cl-	Cl-
NH_4NO_3	NH_4NO_3	NH_4NO_3	NH_4NO_3	NH_4NO_3
$(NH_4)_2SO_4$	$(NH_4)_2SO_4$	$(NH_4)_2SO_4$	$(NH_4)_2SO_4$	$(NH_4)_2SO_4$
	Na^+	Na^+	Na^+	Na^+
	Soildust	Soildust	Soildust	Soildust
	Pollen/spore	Pollen/spore	Pollen/spore	Pollen/spore
		H_2O(l)	H_2O(ice)	H_2O(ice)

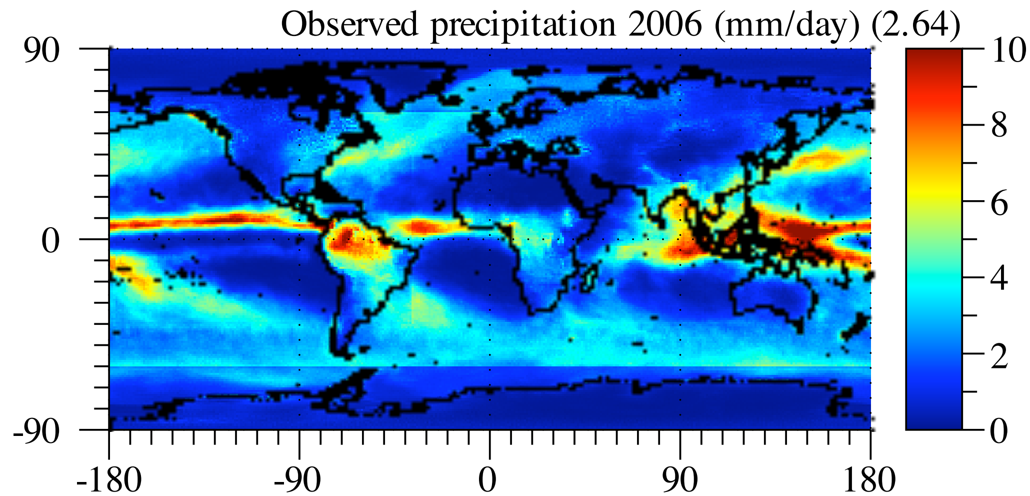
Fossil- and Bio-fuel Emissions (Tg/yr)

	Fossil-Fuel	Biofuel
BC	3.2	1.6
POC	2.4	6.5
S(VI)	0.03	0.3
Na^+		0.023
K^+ as Na^+		0.14
Ca^{2+} as Na^+		0.18
Mg^{2+} as Na^+		0.08
NH_4^+		0.018
NO_3-		0.16
Cl-		0.30
H_2O-hydrated	calculated	calculated
H+	calculated	calculated
		+ 43 gases

BC/POC from Bond et al. (2004); other emis factors Andreae, Ferek

Modeled vs. Measured Annual Precip.

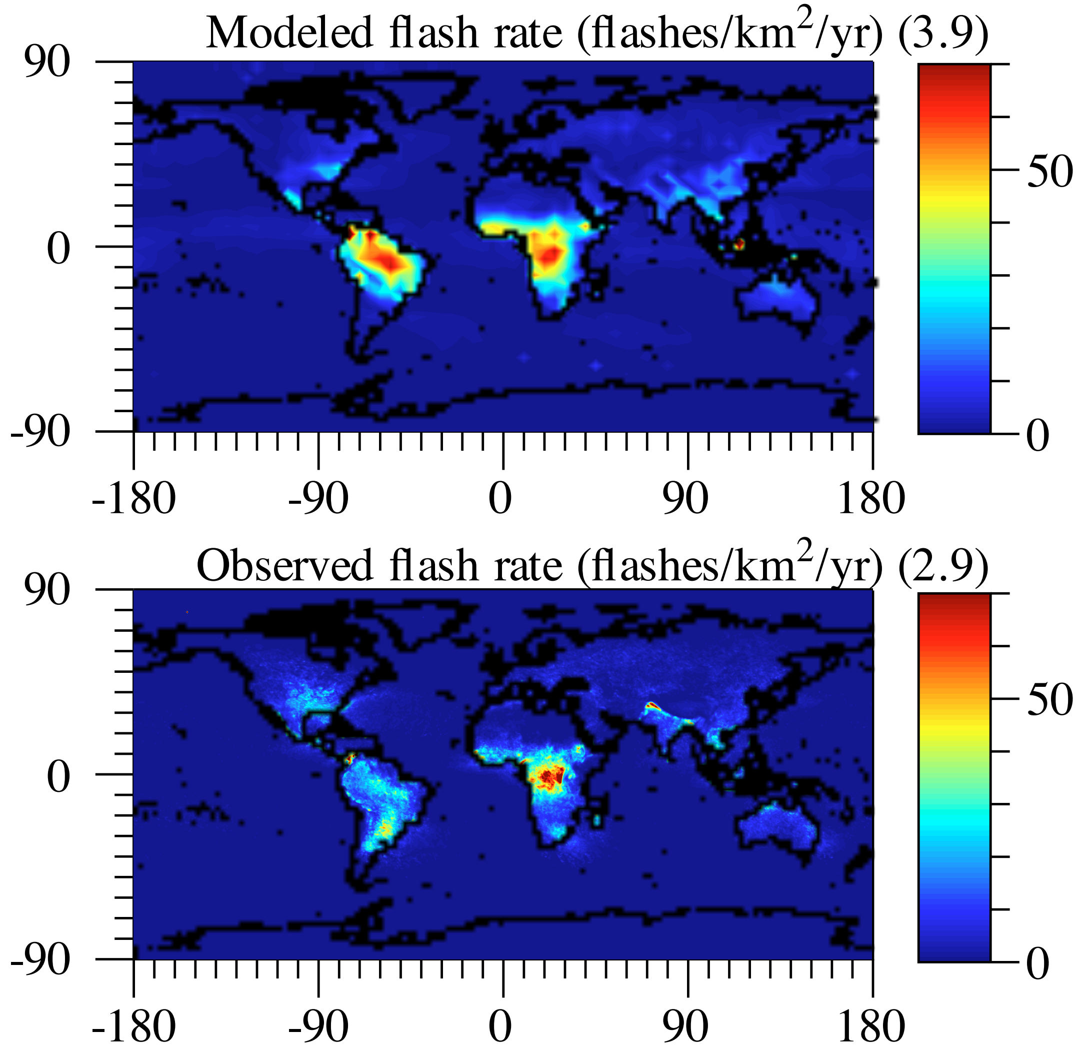




Data from Huffman et al. (2007)

Despite factor of 20 lower resolution than data, model predicts locations of main features of observed precipitation and, without any flux adjustment, correctly does not produce a double ITCZ as nearly all models at coarse resolution do.

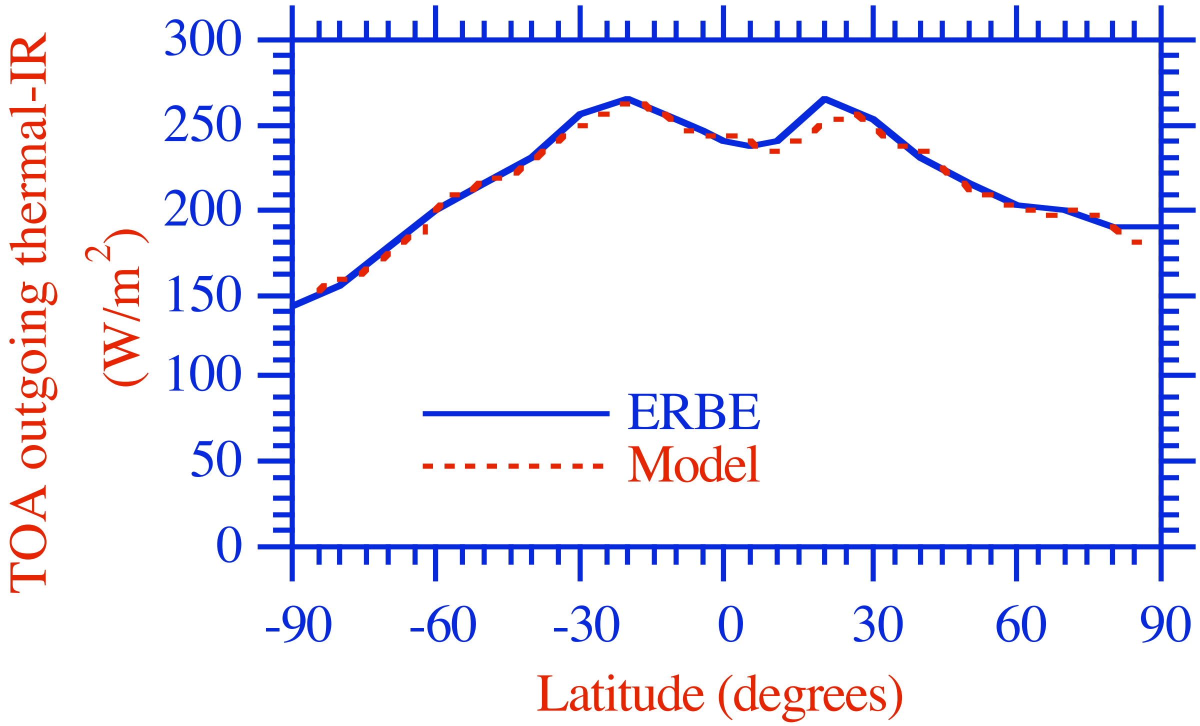
Modeled vs. Measured Annual Lightning Flash Rate



Data from NASA LIS/OTD Science Team

Model is unique in that it calculates lightning by accounting for size-resolved bounceoffs and charge separation in clouds. Model predicts nearly the magnitude and the location of the peak observed lightning (Congo) and most locations of lightning.

Modeled vs. Measured Thermal-IR

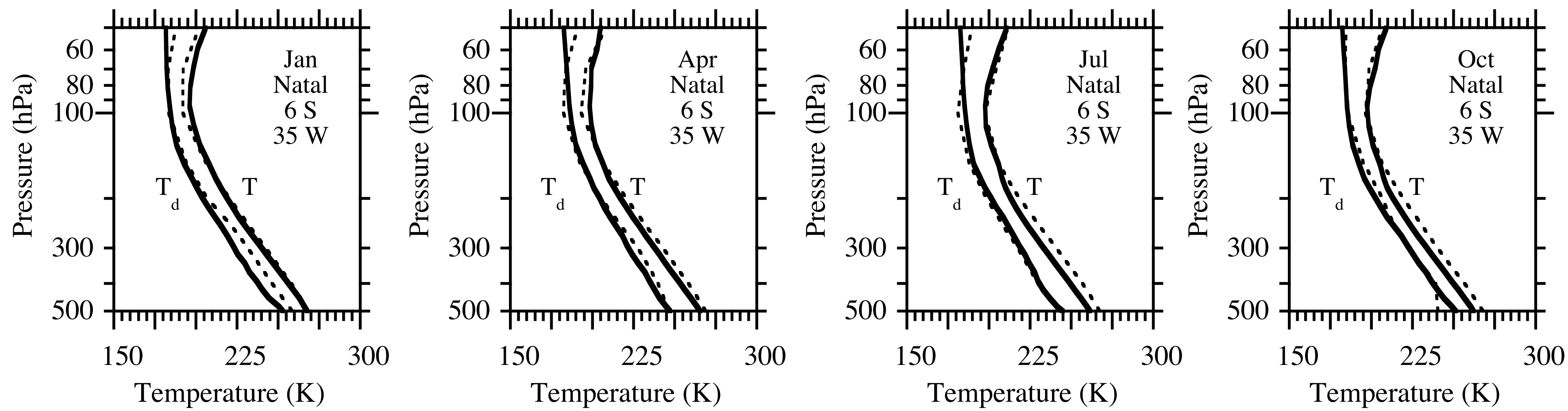


Data from Kiehl et al., 1998

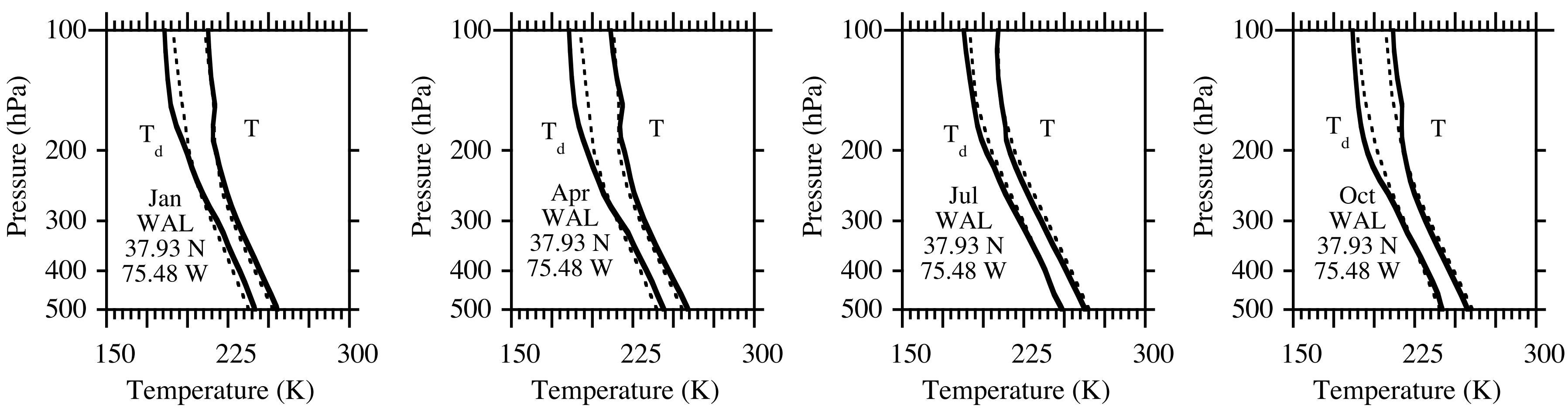
Modeled vs. Measured Paired in Space Monthly T/T_d

Global domain

Data from FSL (2008)



U.S. domain

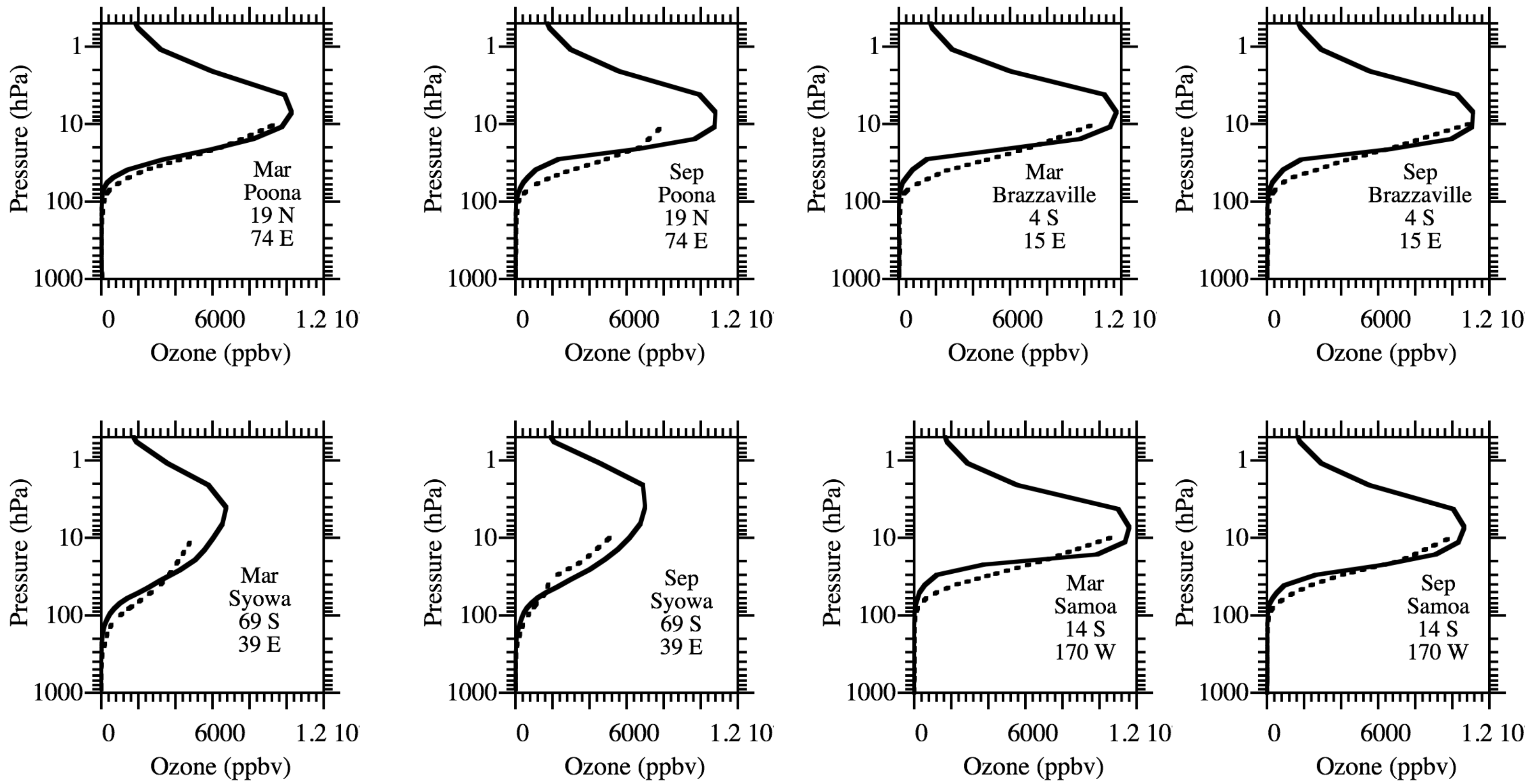


Despite coarse resolution, model captures data features at exact location of data

- Little numerical diffusion of water vapor or energy to stratosphere

Modeled vs. Measured Paired in Space Monthly O_3

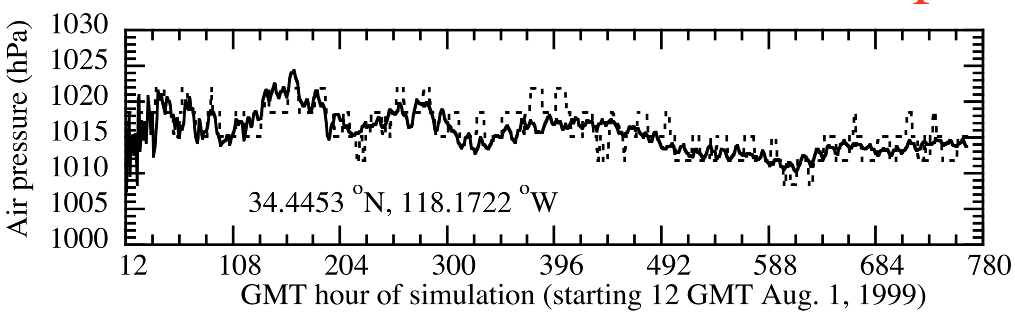
Data from Logan et al. (1999)



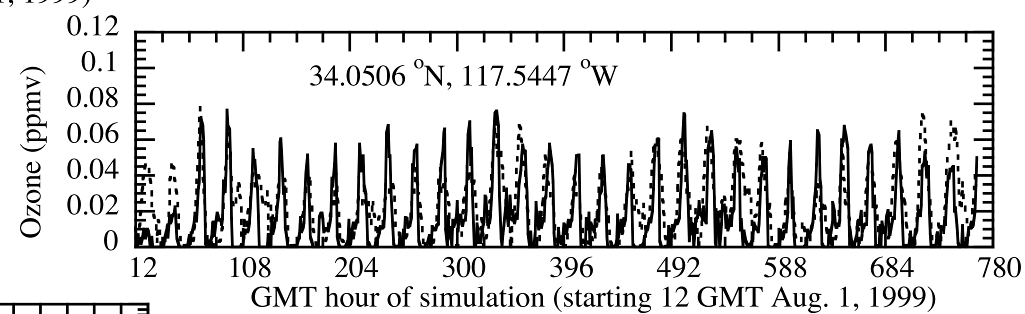
Model predicts the magnitude and altitude of the lower-stratospheric ozone layer

30-Day Weather Predictions vs. Data

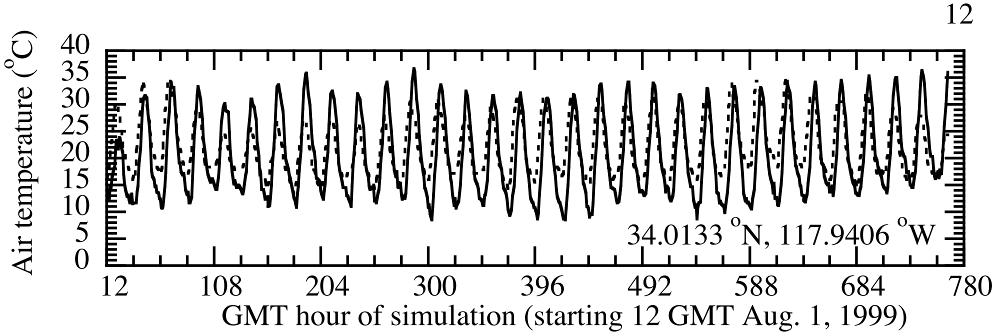
Results with no model spinup or data assimilation



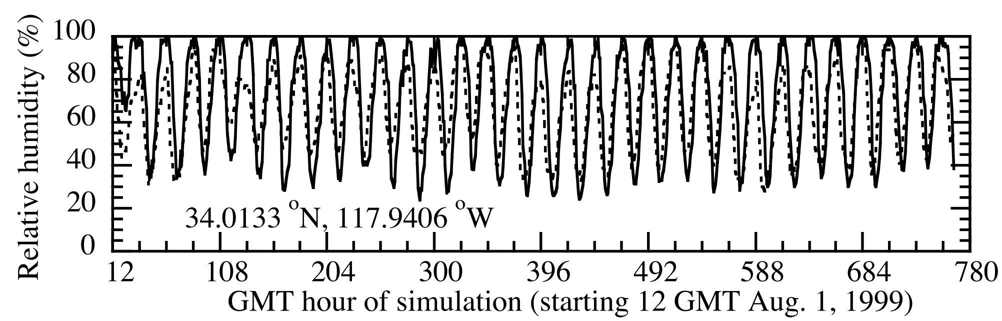
Ozone



Pressure



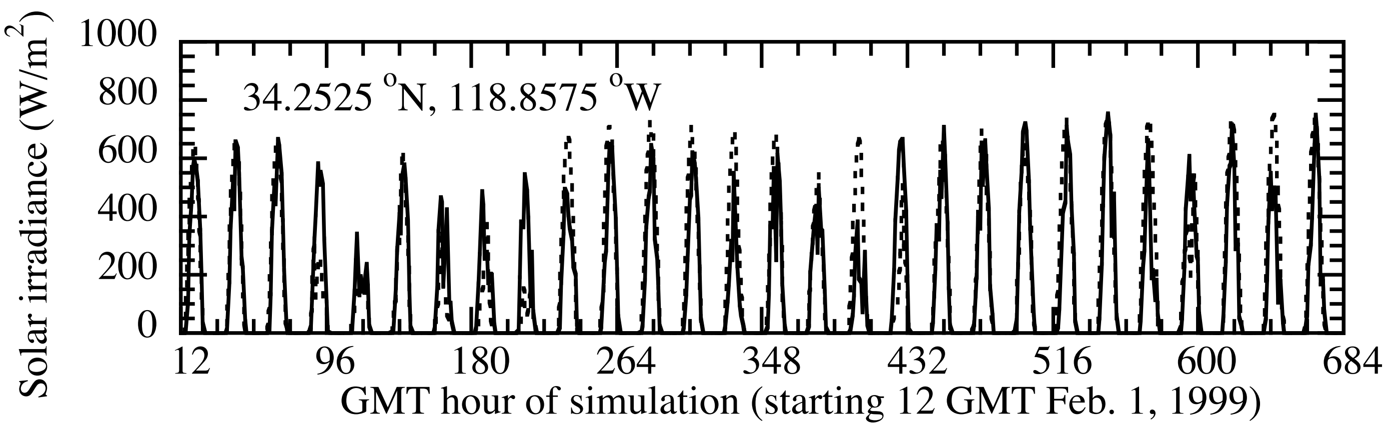
RH

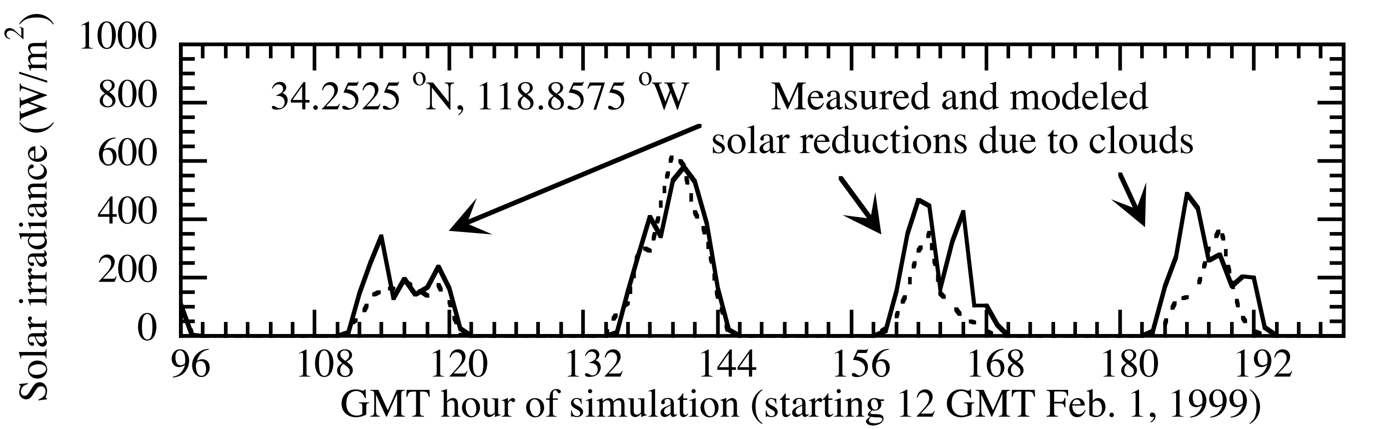


Temperature

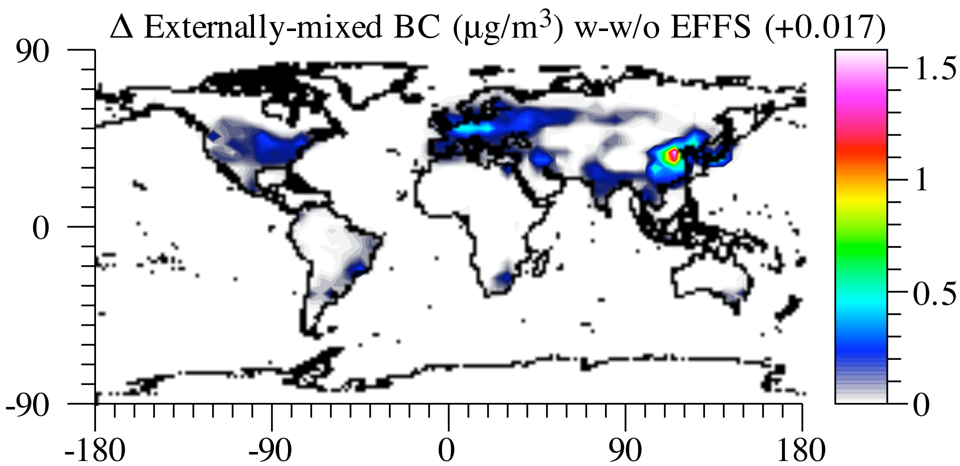
Model vs. Measured Solar Radiation

Model predicted the location and magnitude of cloud reduction of sunlight for four days in a row



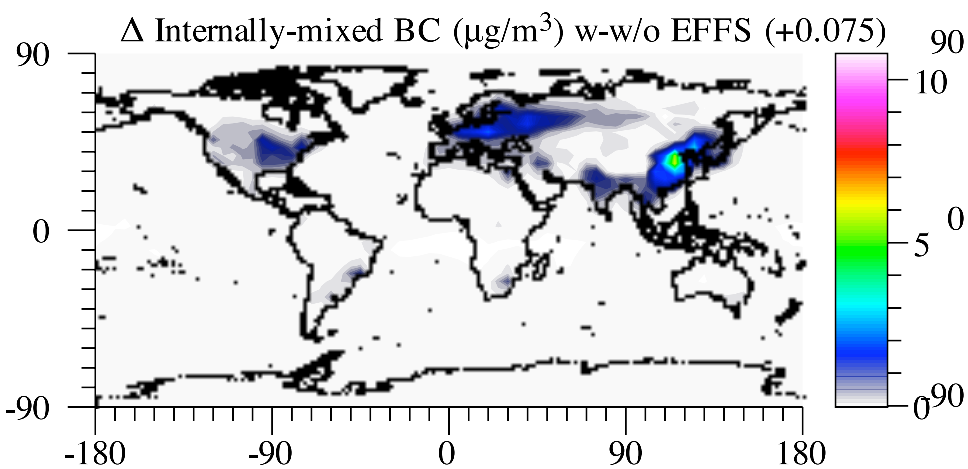


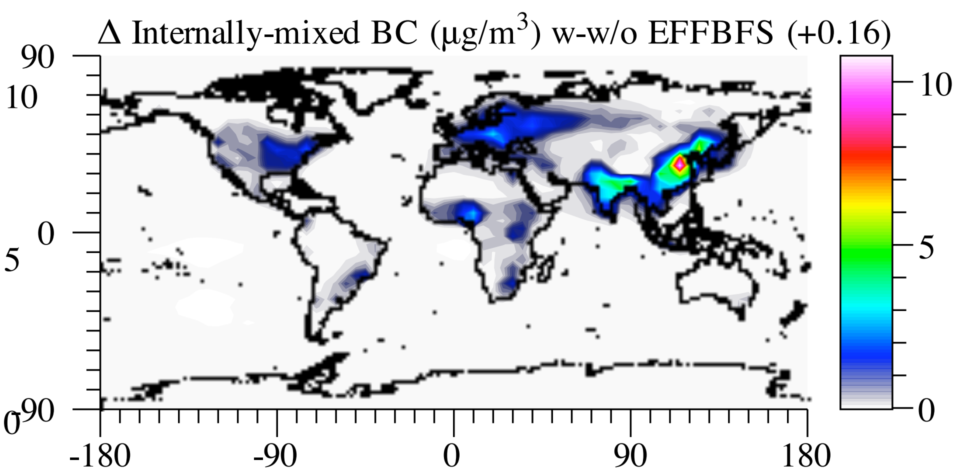
Externally- and Internally-Mixed BC Changes Due to FF +BF Soot + BF gases and to FF Soot Alone



FF soot

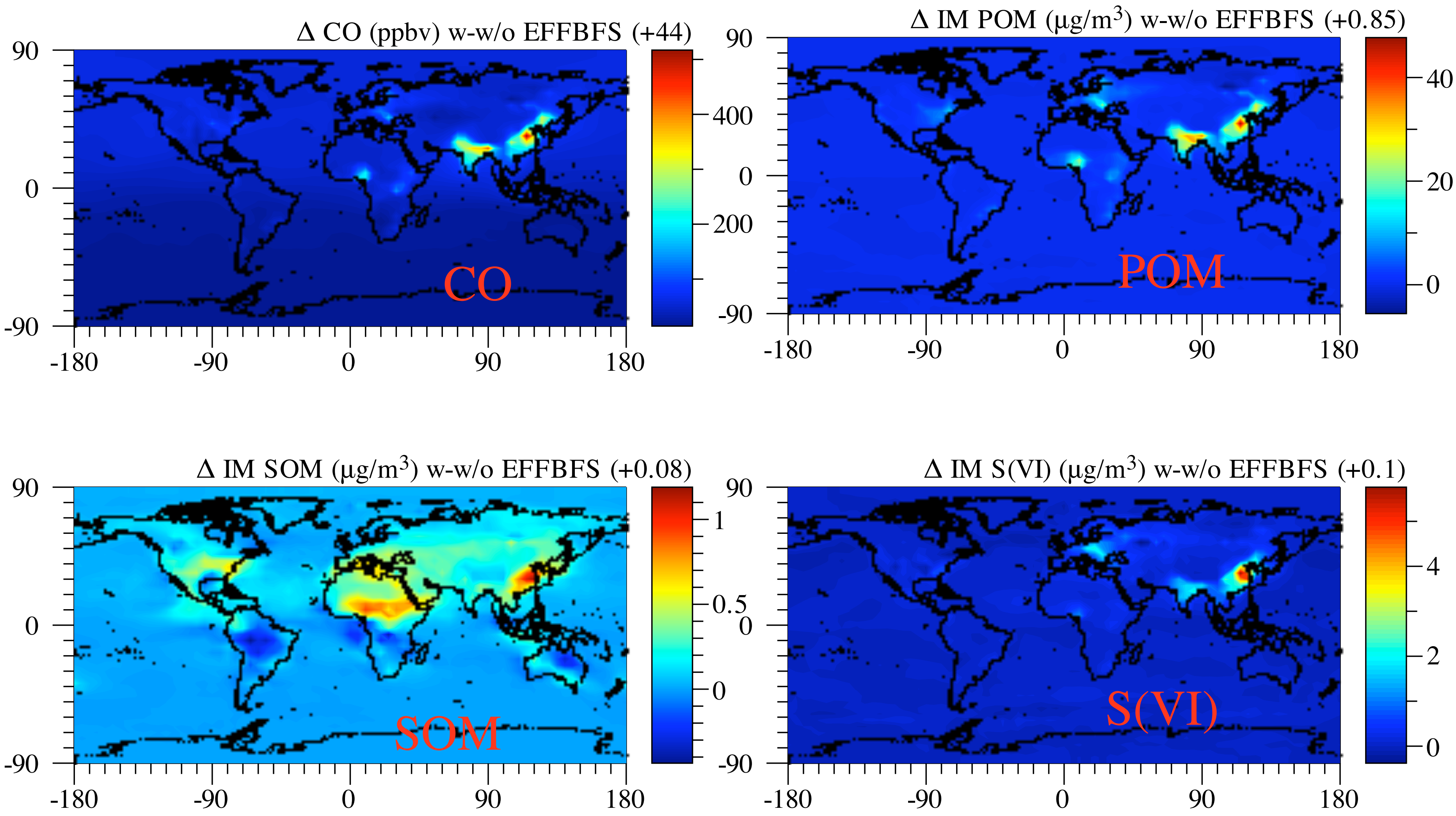
FF+BF soot + BF gases





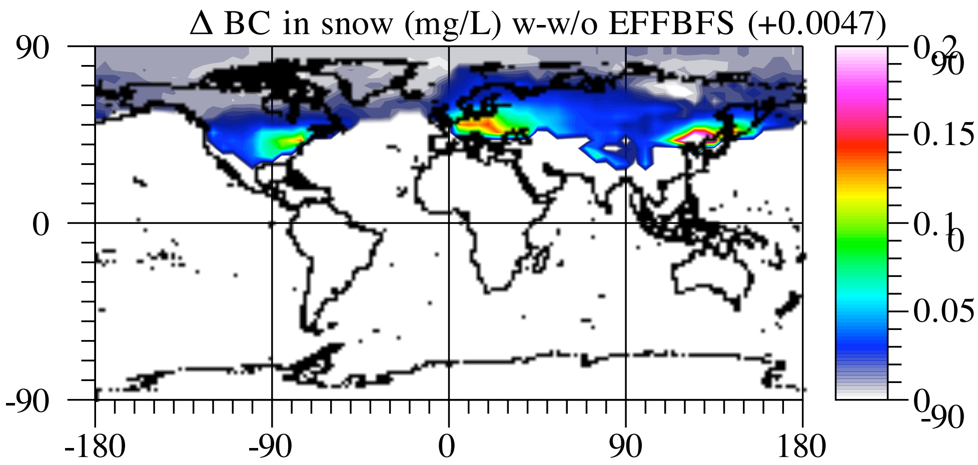
BC from FF soot about half that of BC from FF+BF soot +BF gases

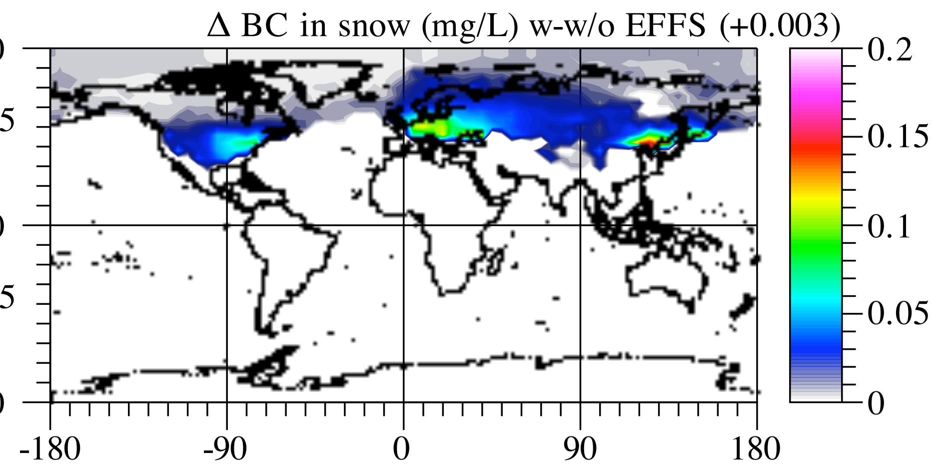
Changes in CO, Internally-mixed POM SOM, S(VI) due to FF+ BF Soot + BF gases



However, FF+BF soot +BF gases produce more other gases and particles

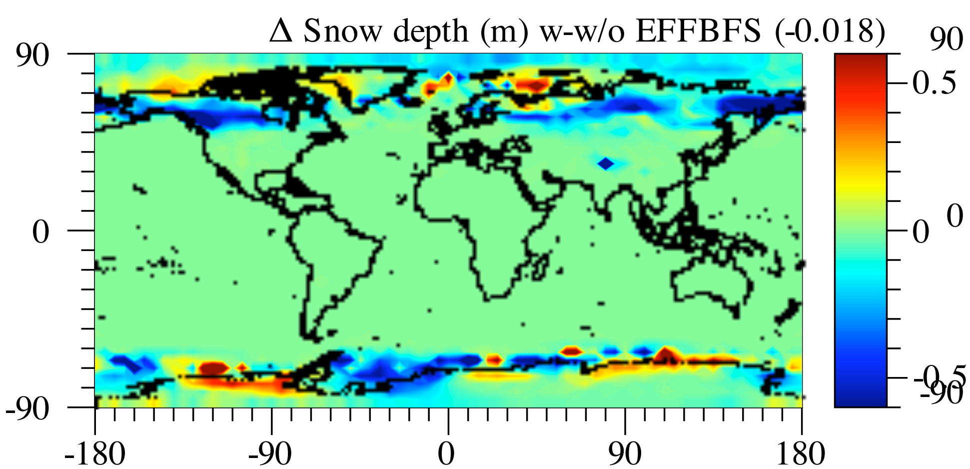
BC in Snow and Change in Snow Depth Due to FF+BF Soot + BF gases and FF Soot Alone

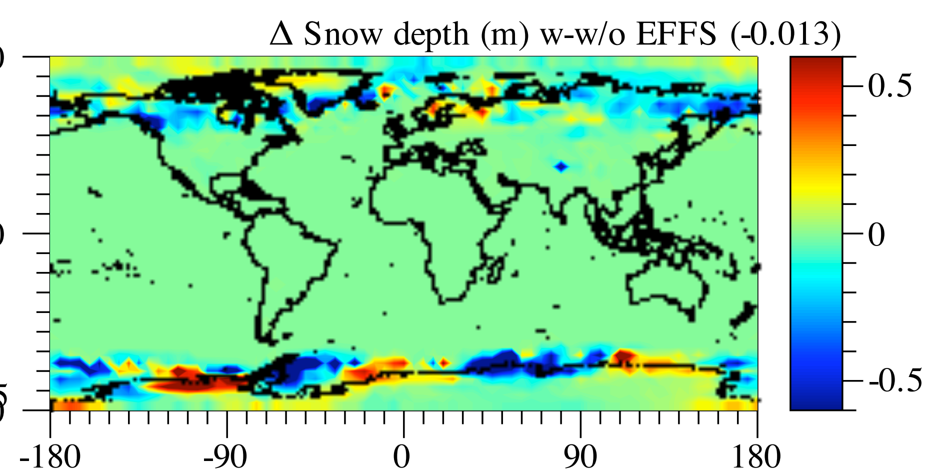




FF+BF soot + BF gases

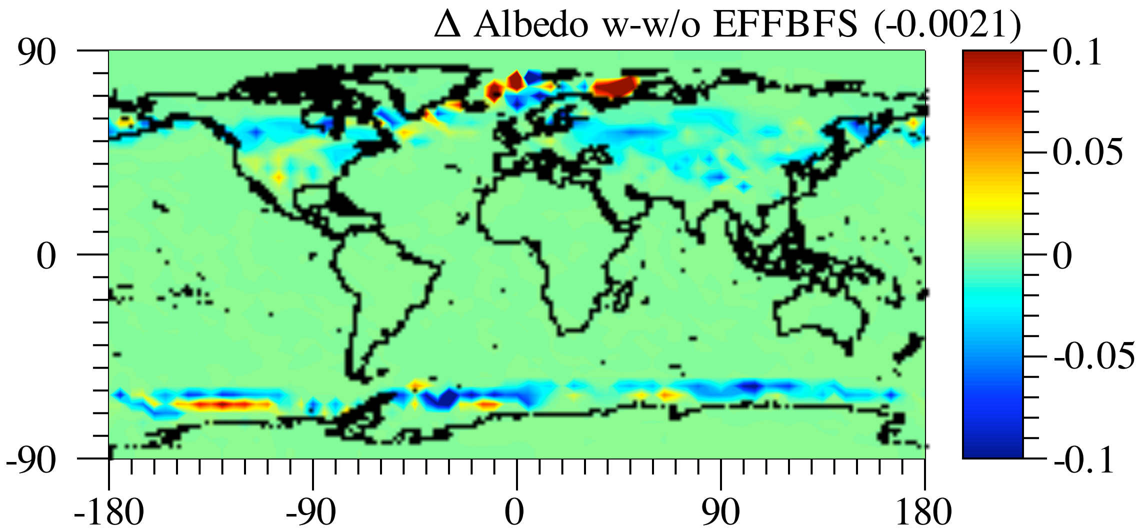
FF soot



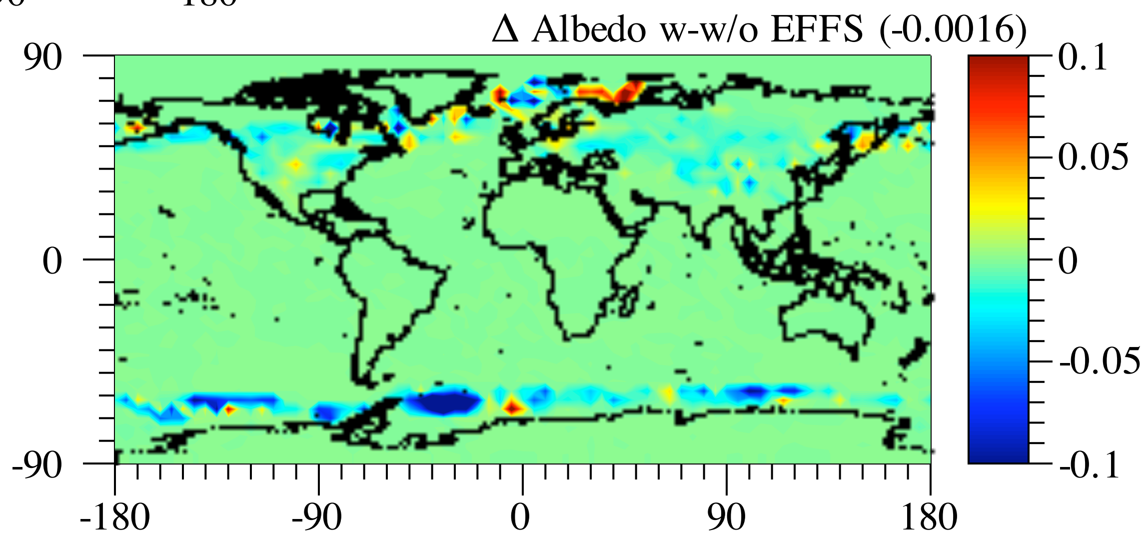


Both FF+BF soot +BF and FF soot inc. BC in snow & dec. snow depth

Surface Albedo Changes Due to FF+BF Soot + BF gases and to FF Soot Alone



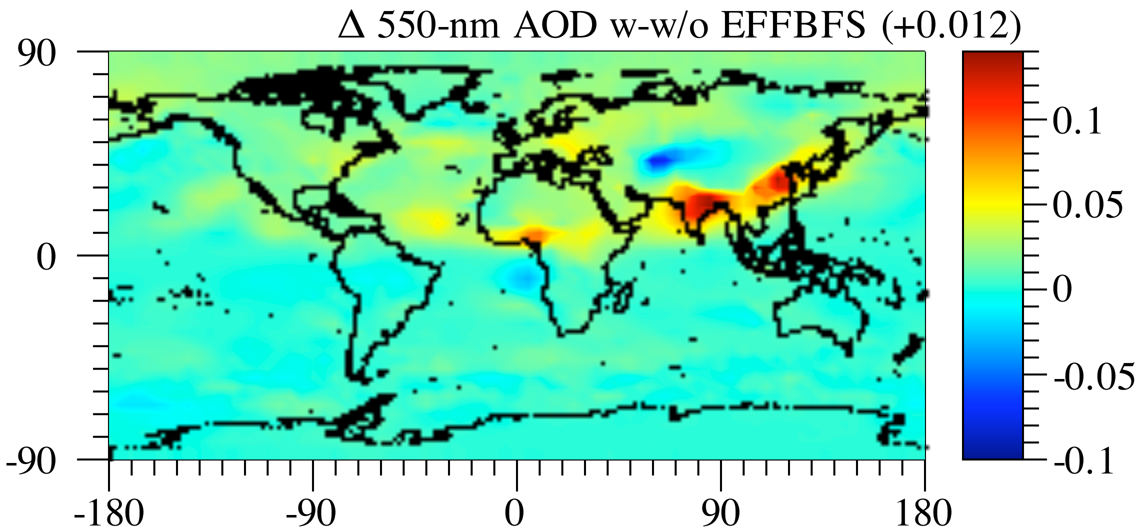
FF+BF soot + BF gases



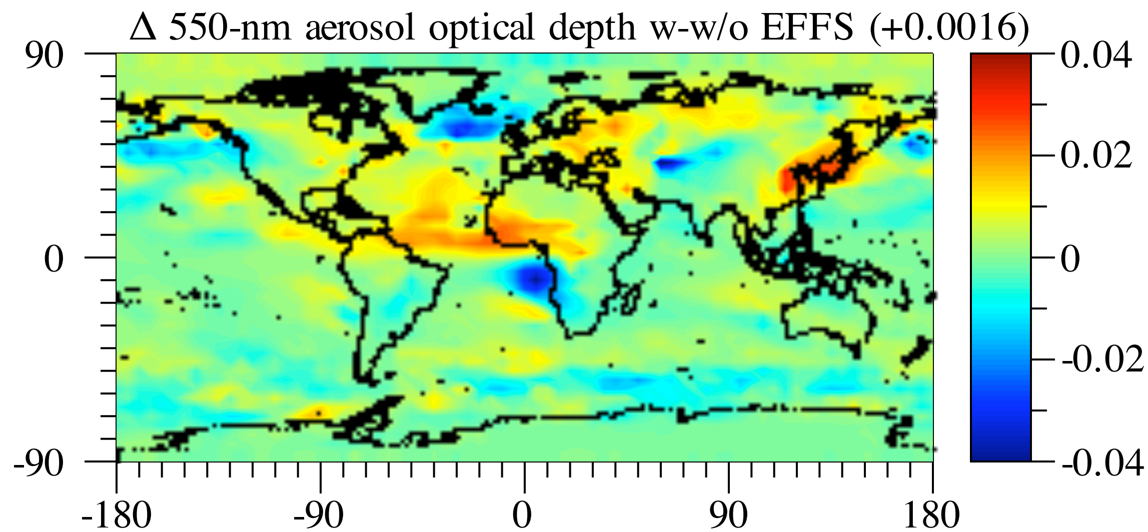
FF soot

Most albedo loss due to FF+BF soot +BF gases is due to FF soot

AOD Changes Due to FF+BF Soot + BF gases and to FF Soot Alone



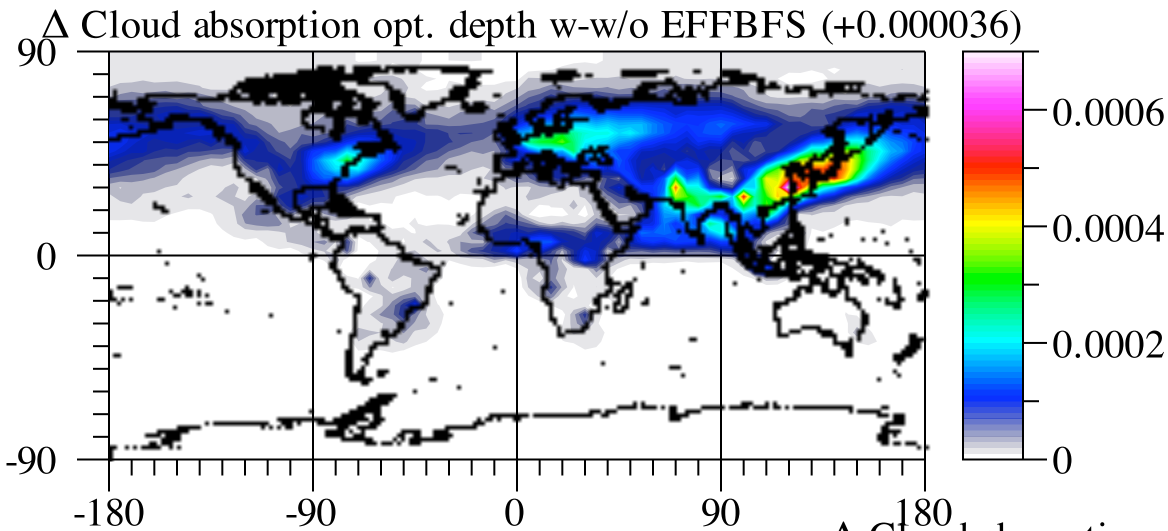
FF+BF soot + BF gases



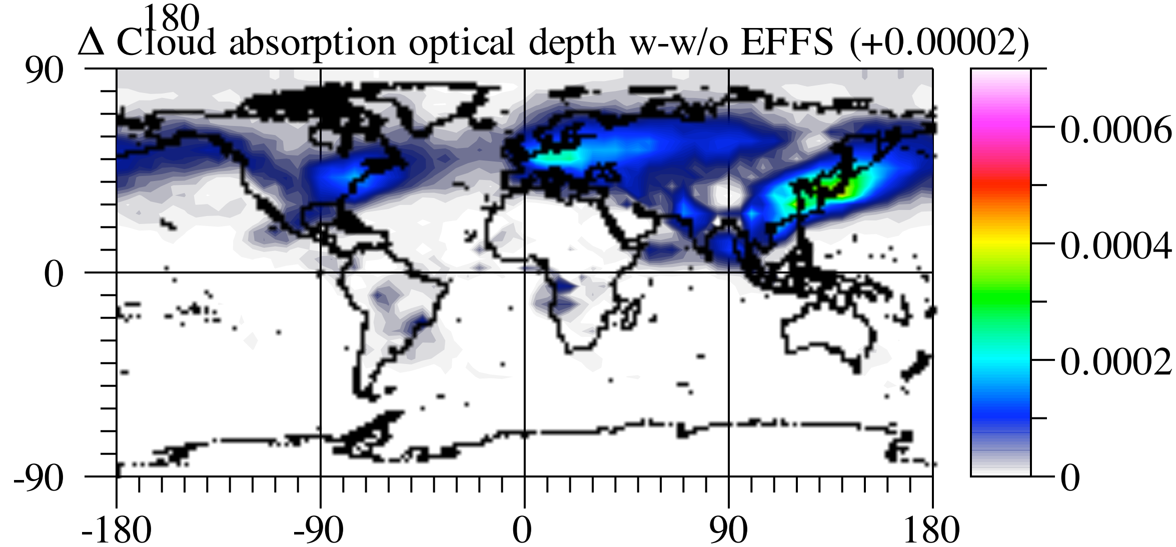
FF soot

FF+BF soot +BF gases increased AOD more than did FF soot

Cloud Absorption Due to FF+BF Soot



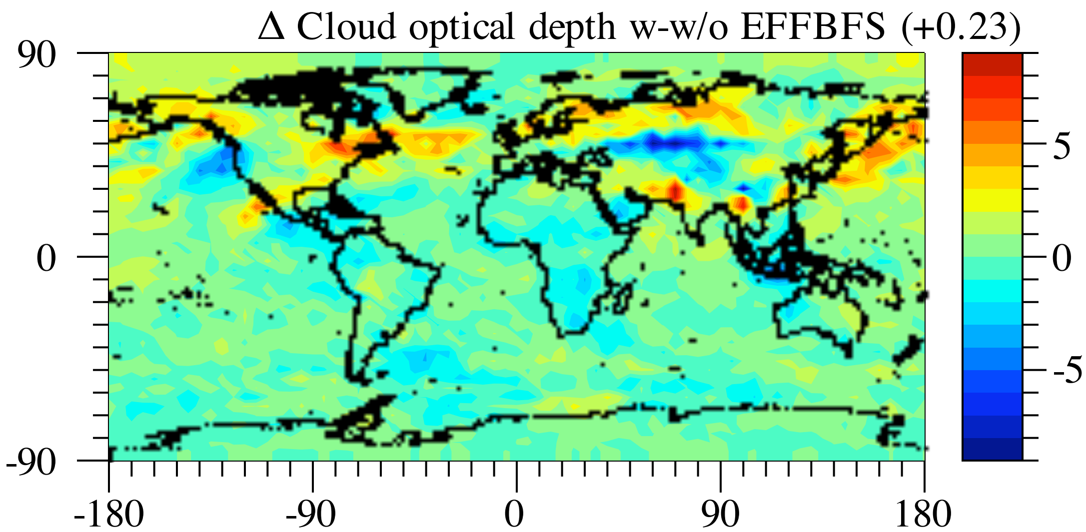
FF+BF soot + BF gases



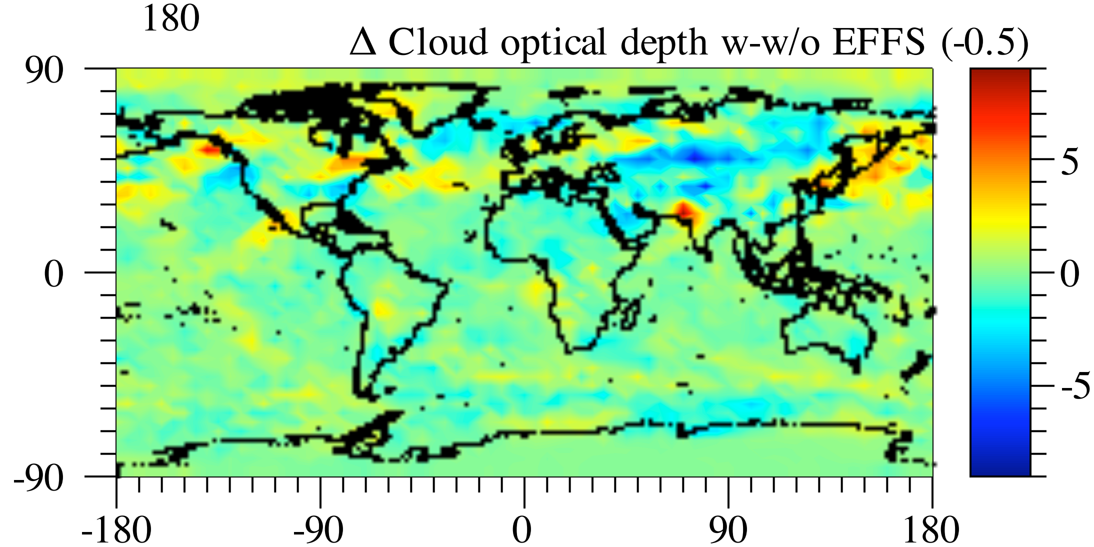
FF soot

→FF+BF soot +BF gases increased cloud absorption more than FF soot

Cloud OD Changes Due to FF+BF Soot + BF gases and to FF Soot Alone



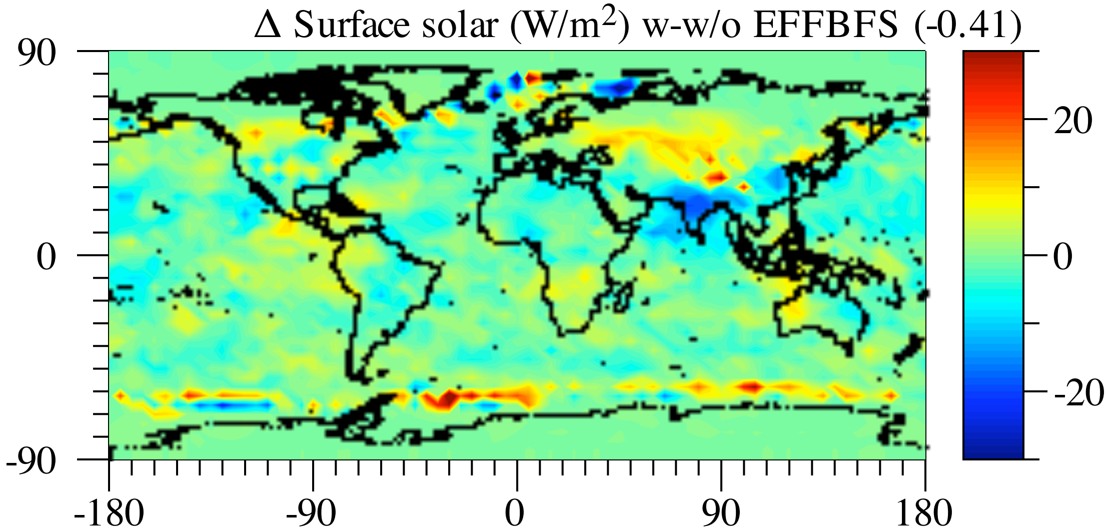
FF+BF soot + BF gases



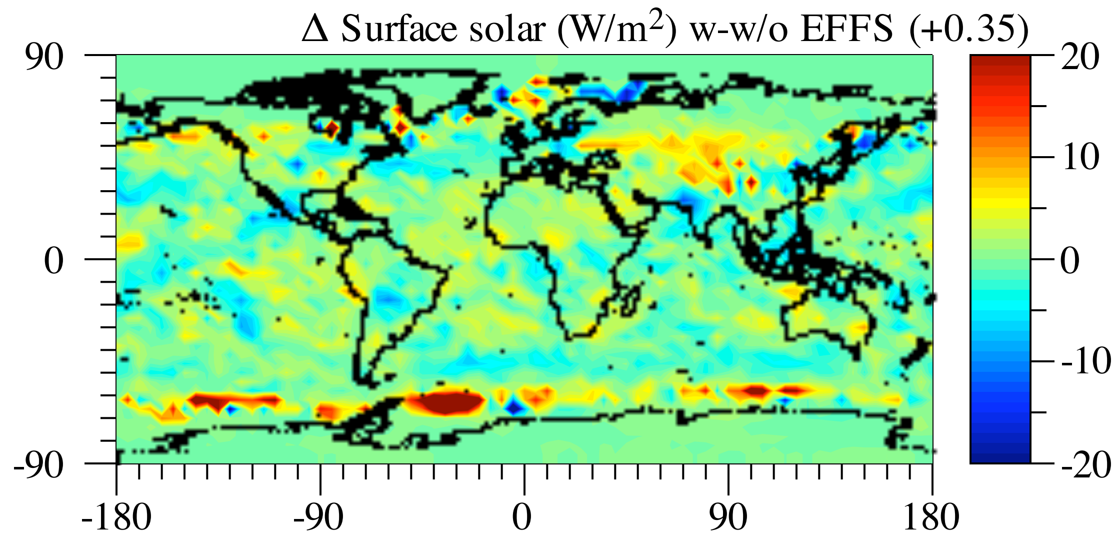
FF soot

FF+BF soot +BF gases increased COD; FF soot decreased COD

Surface Solar Changes Due to FF+BF Soot + BF gases and to FF Soot Alone



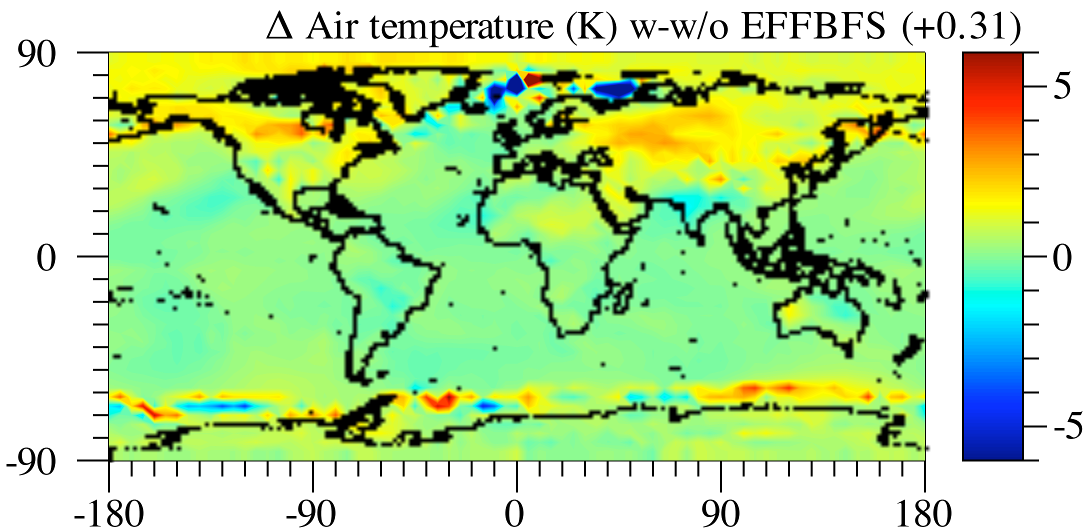
FF+BF soot + BF gases



FF soot

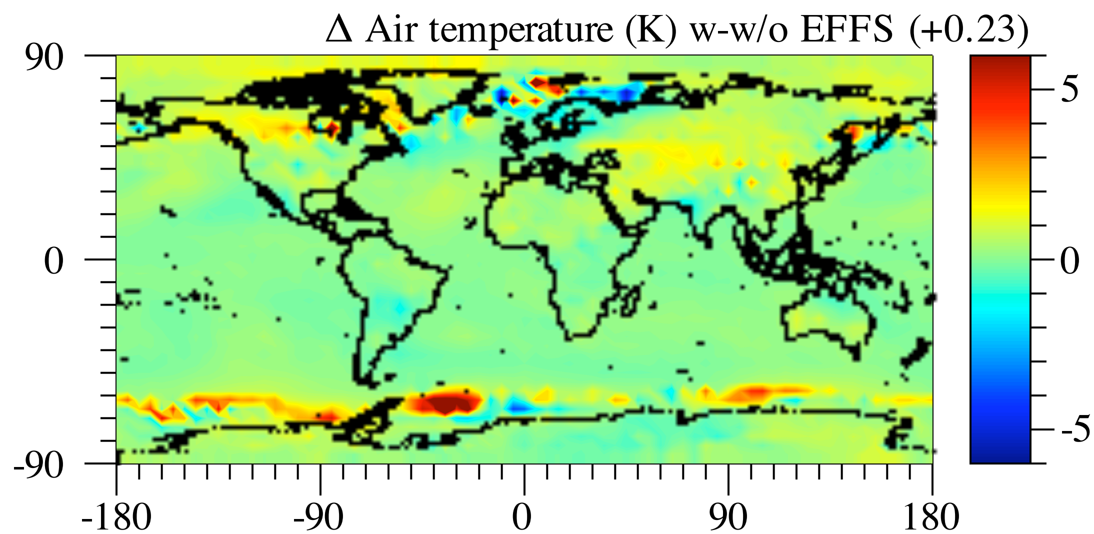
→FF+BF soot +BF gases decreased surface solar; FF soot increased it

Temperature Changes Due to FF+BF Soot + BF gases and to FF Soot Alone



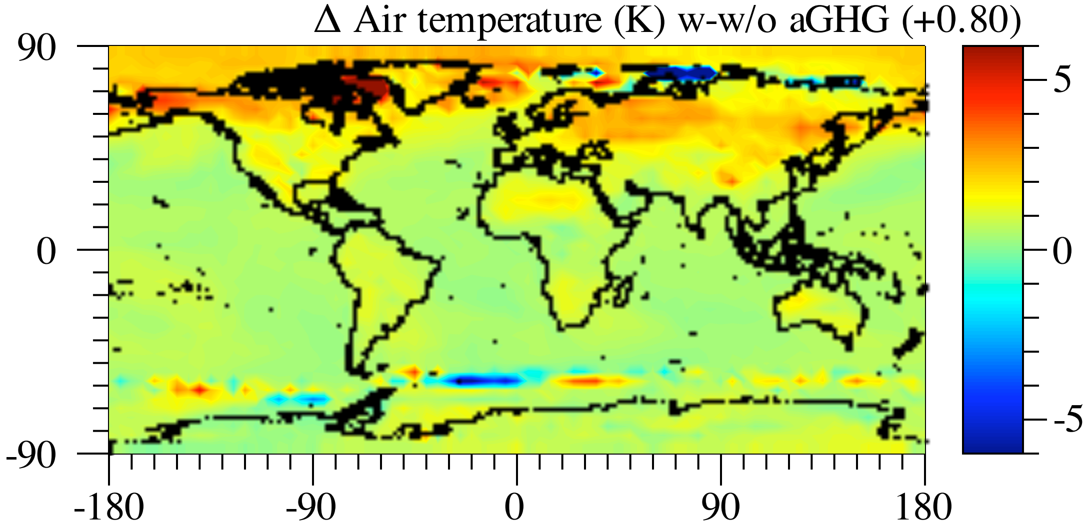
FF+BF soot + BF gases

FF soot

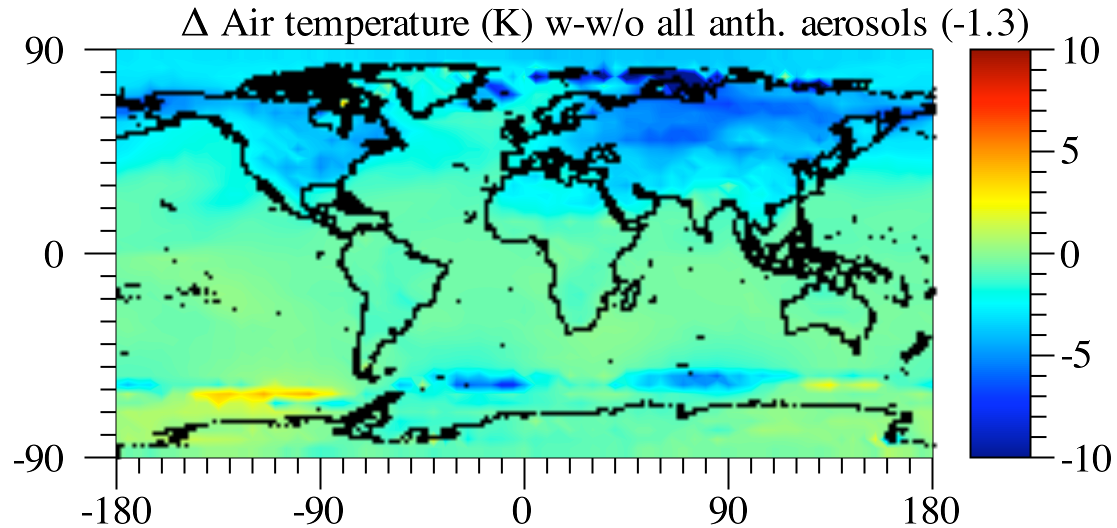


Most temperature inc. due to FF+BF soot +BF gases is due to FF soot

Temperature Changes Due to all anth. GHGs and to all anth. aerosol particles (after 3 y)



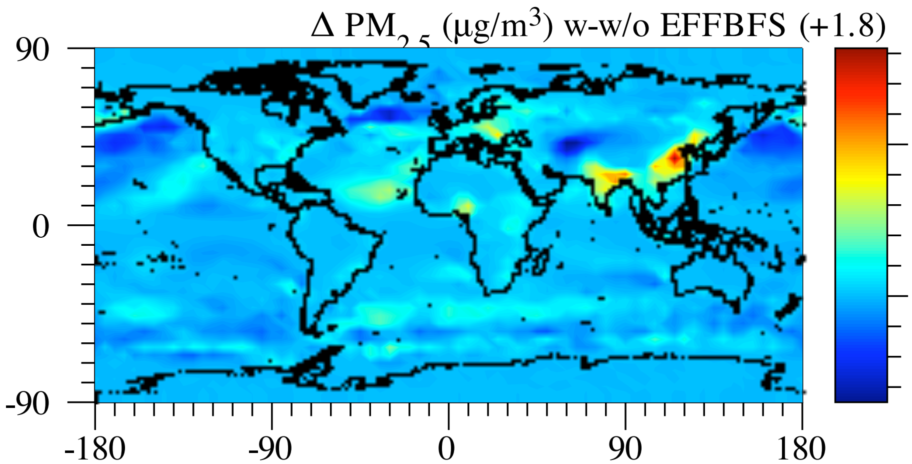
Anth. GHGs

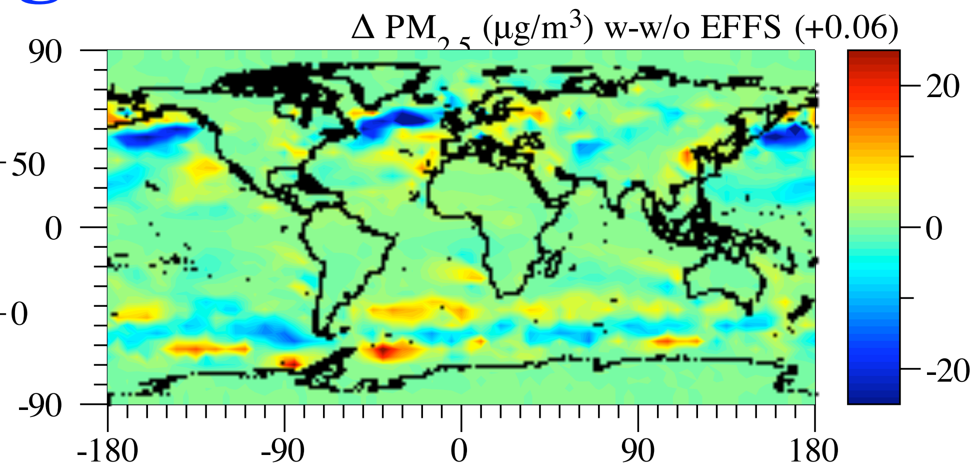


Anth. aerosol particles

All aerosols cause more cooling than FF+BF soot cause warming

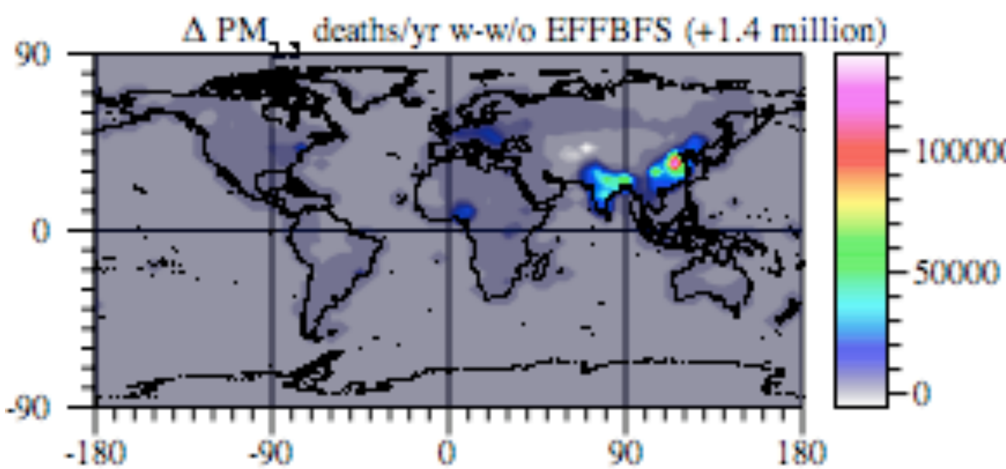
Changes in PM and Resulting Deaths due to FF+BF soot + BF gases and to FF soot

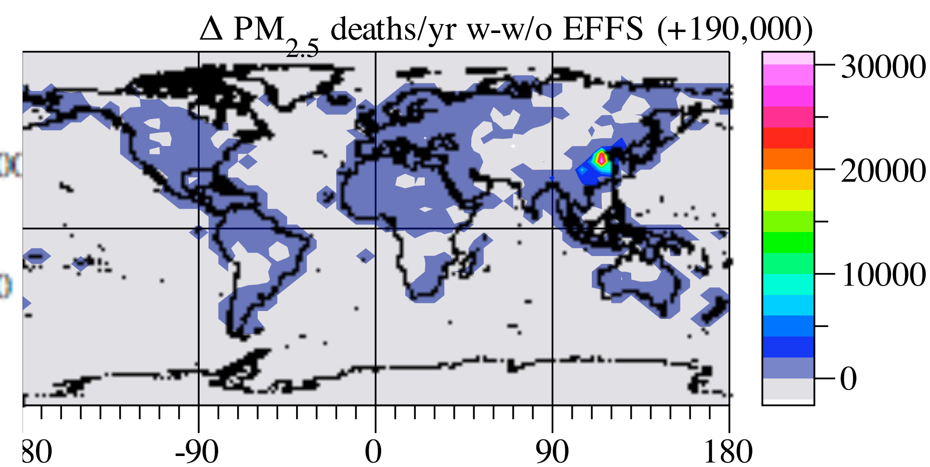




FF+BF soot + BF gases

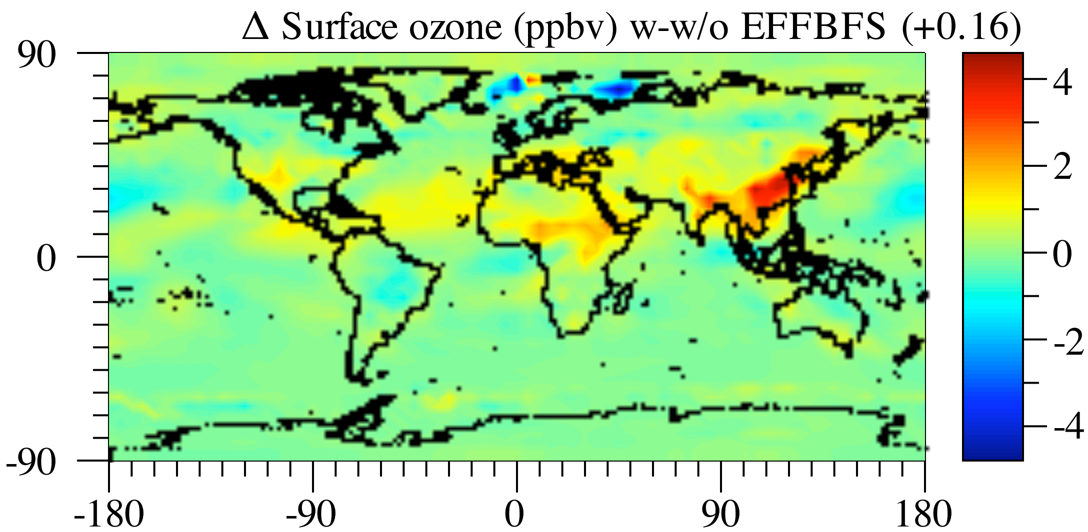
FF soot



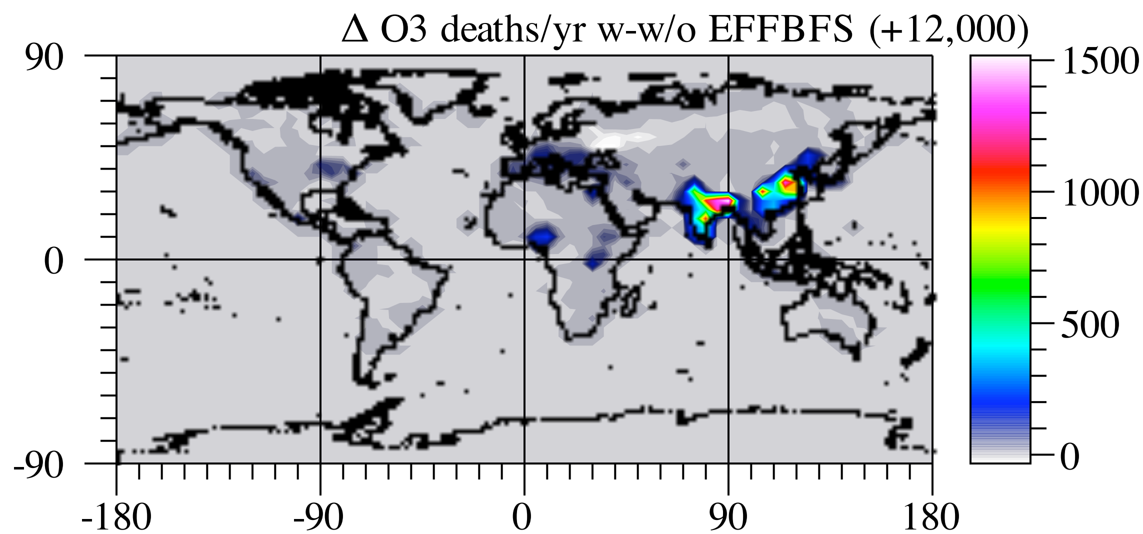


Deaths due to FF+BF soot+BF gases 10 times those due to FF soot

Changes in Ozone and Resulting Deaths due to FF+BF soot + BF gases



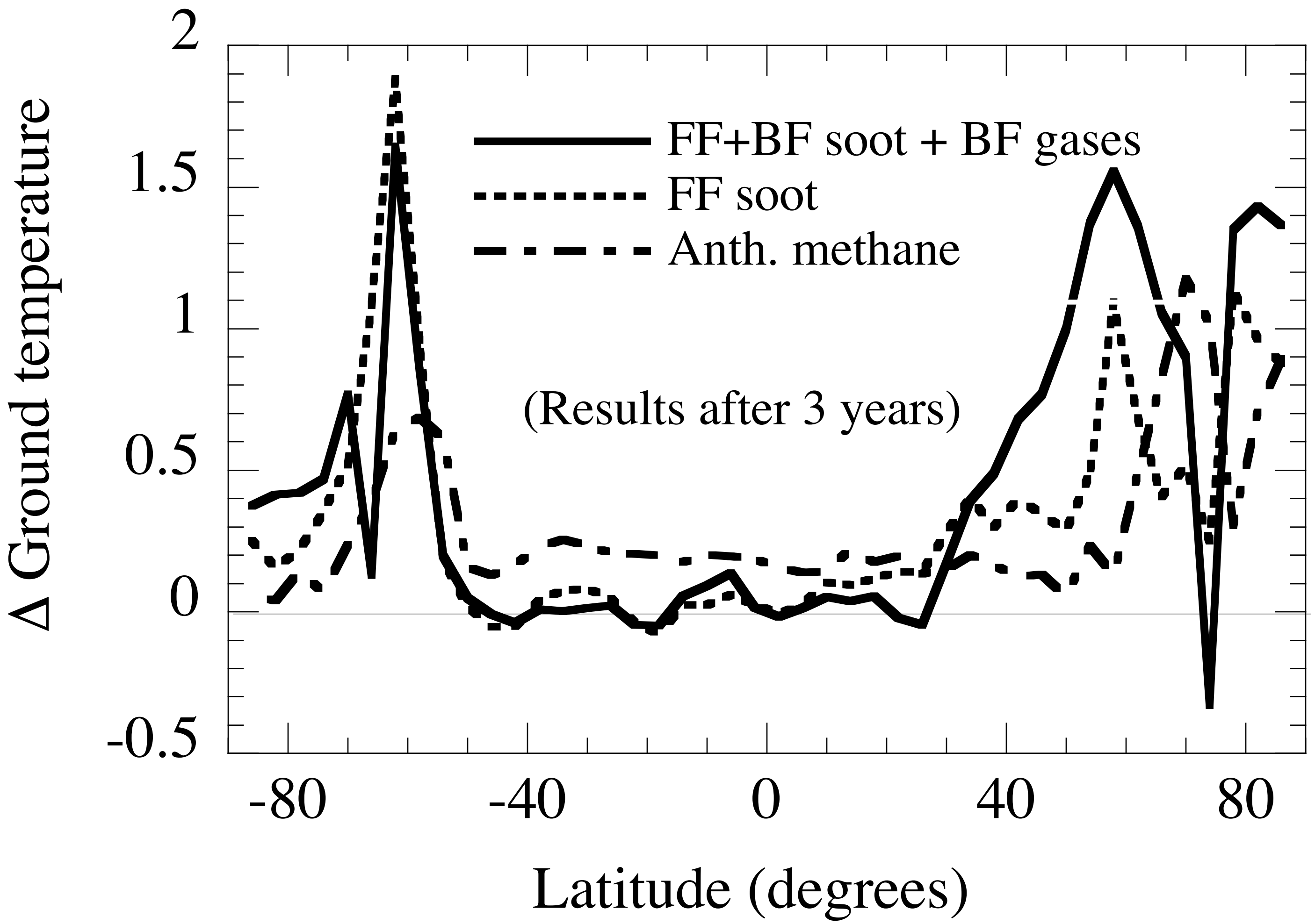
Ozone changes



Ozone deaths

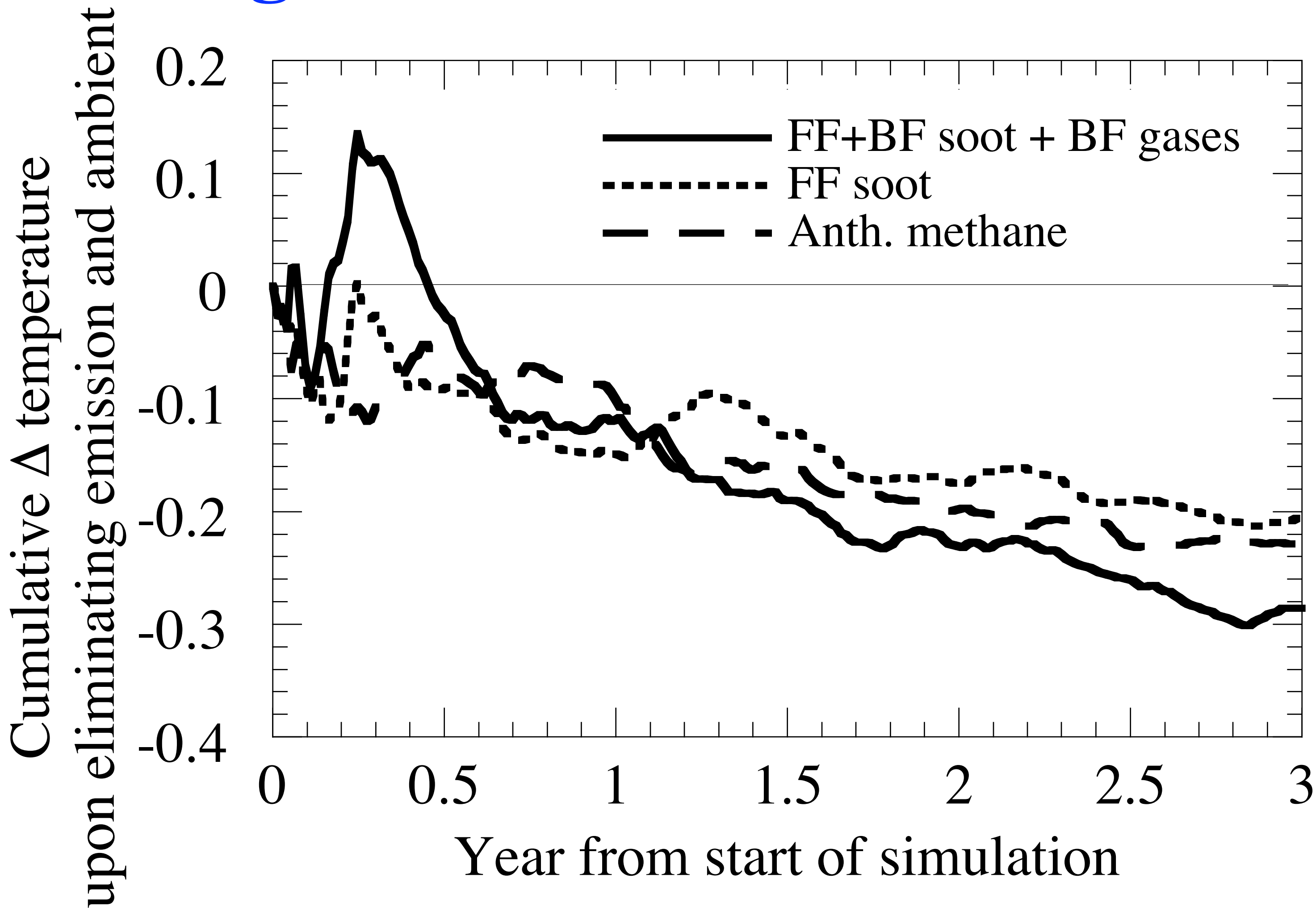
Biofuel burning increases ozone and ozone deaths

Arctic Warming Due to Ambient and Emitted Components of Global Warming



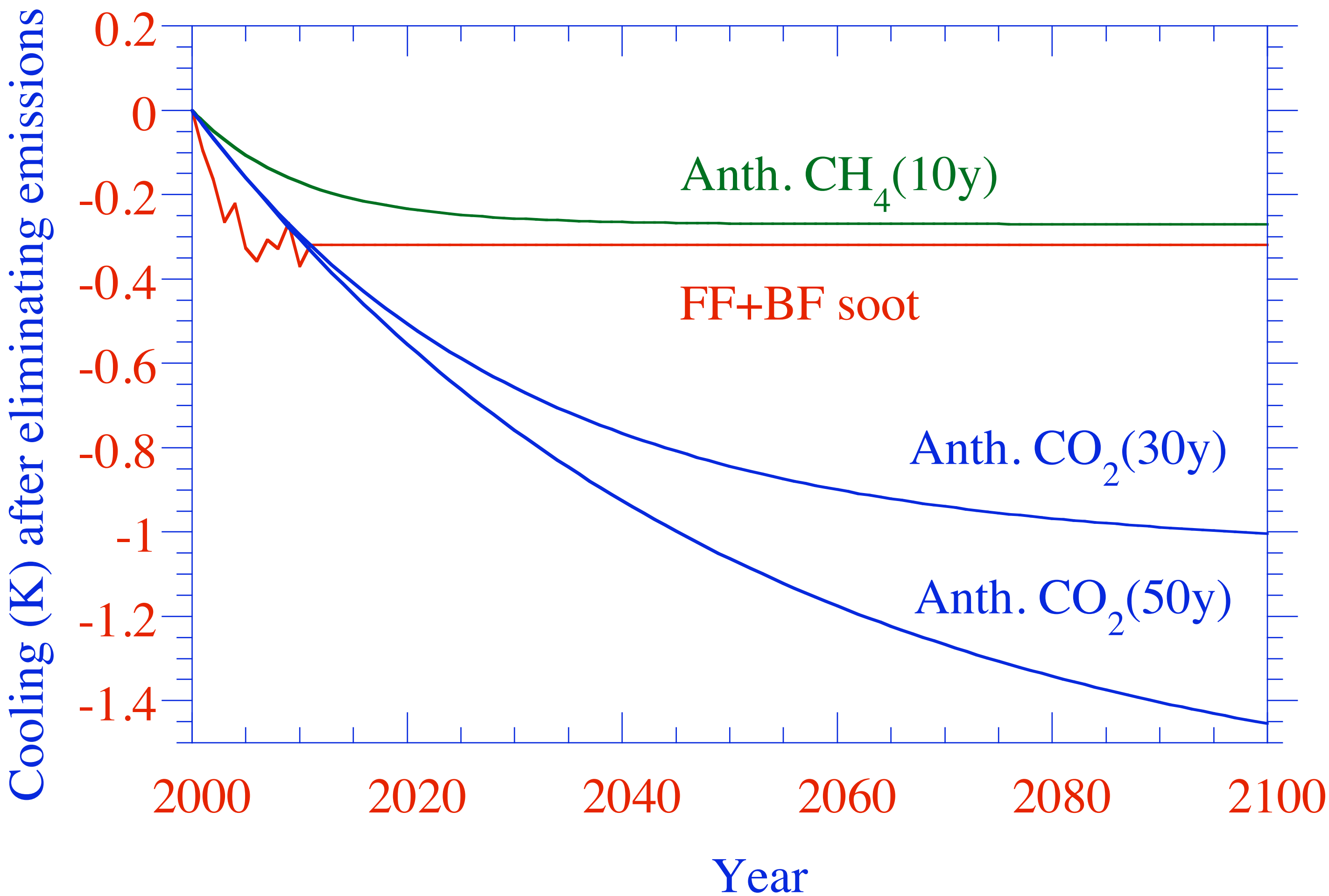
FF+BF soot + BF warm mid & high northern latitudes more than anthropogenic CH_4 or FF soot alone

Comparative Effects on Global Surface T of Eliminating Emissions and Ambient loadings

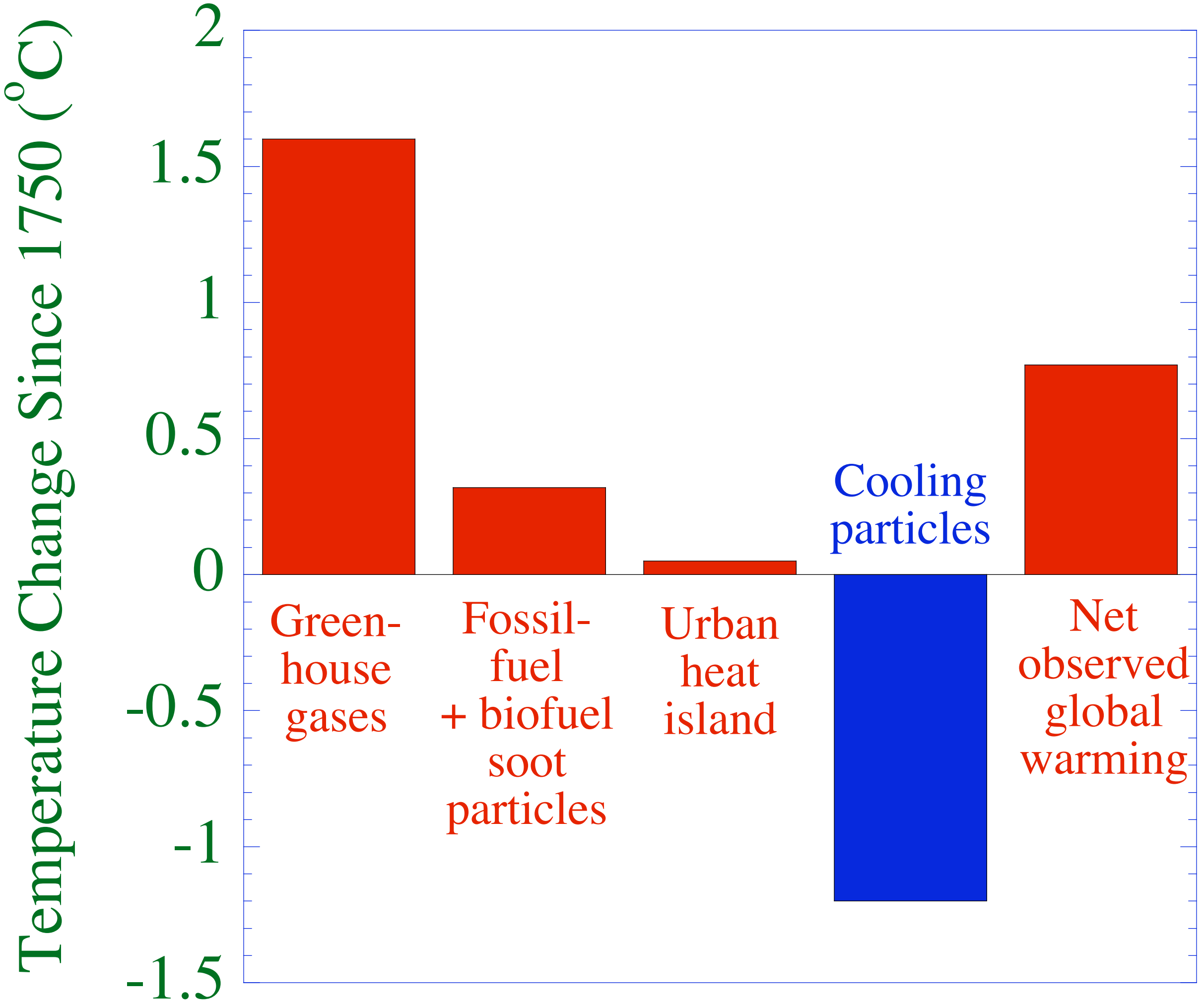


Eliminating FF+BF soot + BF gases cools climate more than eliminating anthropogenic CH_4 or FF soot alone

Global Cooling Due to Eliminating Anthropogenic CO_2, CH_4, FF+BF Soot Emissions only



Causes of Global Warming



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FF Soot, BC Global Warming Potential

20- and 100-yr warming due to FF soot (ΔT-FF soot):	0.24 K
Global FF soot emissions) (ΔE-FF soot):	5.68 Tg
20-yr warming due to anthropogenic CO_2 ($\Delta T\text{-}CO_2$):	0.5 K
100-yr warming due to anthropogenic CO_2 ($\Delta T\text{-}CO_2$):	1-1.45 K
Global CO_2 emissions (fossil+perm. deforest.) ($\Delta E\text{-}CO_2$)	29,700 Tg

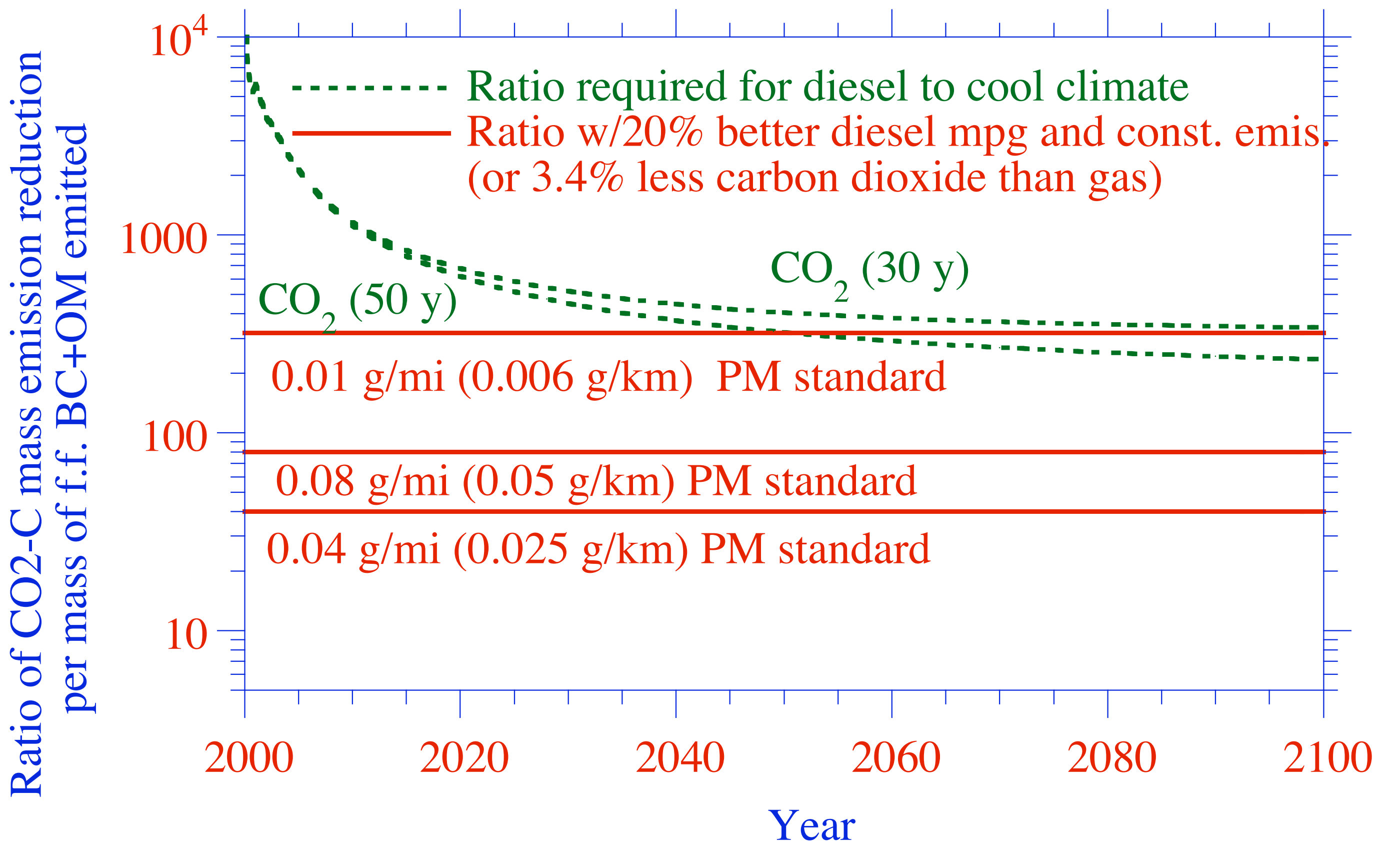
$$GWP = (\Delta T\text{-}X/\Delta E\text{-}X) / (\Delta T\text{-}CO_2/\Delta E\text{-}CO_2)$$

X	20-year GWP	100-year GWP
FF soot*	2510	865 - 1255
BC in FF soot	4480	1545 – 2240

*(56% BC+43% POC+1% sulfate)

Multiply by 12/44 for GWP relative to CO_2-C

Diesel with vs. w/o Trap; Diesel v. Gas



Diesel with a trap increases warming relative to gasoline during continuous emissions over 100 years when diesel has 18% or less mpg advantage over gasoline, and diesel PM emis.are 0.006 g/km or higher.

Summary

FF+BF soot is the second-leading cause of global warming behind CO_2 and ahead of CH_4.

FF soot causes 2/3 of the FF+BF soot warming as BF gases and higher OC from BF burning offset some BF-BC warming.

Both BF and FF soot reduce surface albedo and snow/ice depth.

The GWP of fossil-fuel soot is ~860-1260 over 100 years and ~2500 over 20 years. That due to BC in soot is ~1500-2200 over 100 years and ~4500 over 20 years.

Diesel warms climate more than gasoline for over 100 y of continuous emissions when diesel mileage is $\leq$18% better than gasoline and diesel PM $\leq$ 0.006 g/km higher than gasoline.