Relative Effects of Fossil Fuel Soot, Biofuel Soot and Gases, and Methane on Climate, Arctic Ice, and Air Pollution Human Health

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Goals of Project

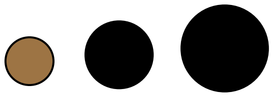
Simulate the relative effects of controlling fossil-fuel soot (FS), biofuel soot and gases (BSG), and methane on global and Arctic climate and human health.

Simulations run

1) Baseline (all gases, particles from all sources)
2) Time-dependent simulations without FS
3) Time-dependent simulation without FS or BSG
4) Equilibrium climate simulation without methane.

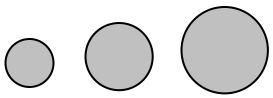
Aerosol Size Distributions

Two distributions, each with multiple size bins and components per bin



Emitted fossil-fuel soot (EFFS)

Emission sources: fossil-fuel combustion



Internally-mixed (IM)

Emission sources: biofuel burning, biomass-burning, sea spray, soil dust, road dust, volcanos, pollen, spores, bacteria

Homogeneous nucleation: H_2SO_4-HNO_3-H_2O into IM distribution

Coagulation:

EFFS + EFFS	= EFFS
EFFS + IM	= IM
IM + IM	= IM

Growth: Organic matter, H_2SO_4, HNO_3, HCl, NH_3 H_2O grow on both EFFS & IM

Clouds: Both distributions activate size-resolved liquid, ice, graupel clouds

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

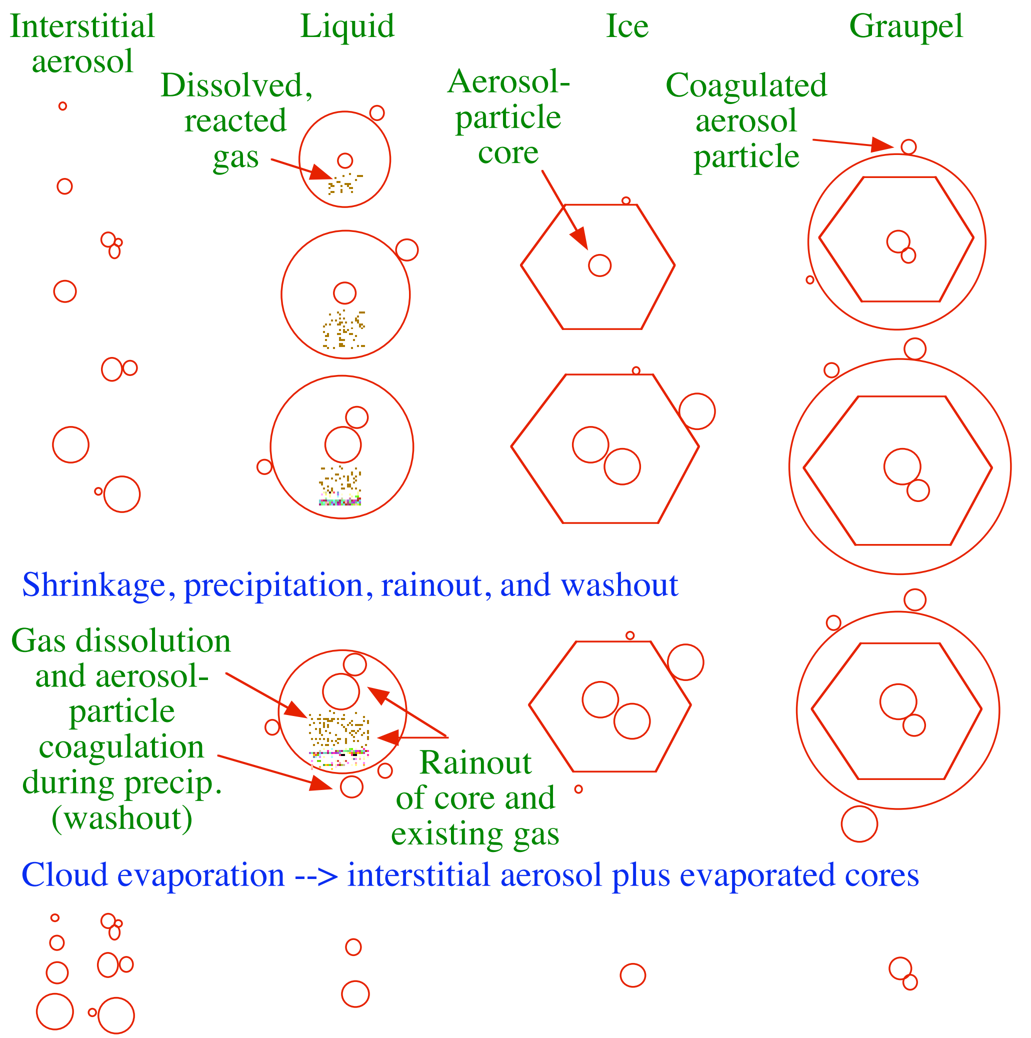
BC/POC from Bond et al. (2004); other emis factors Andreae, Ferek

Cloud Microphysical and Chemical Processes

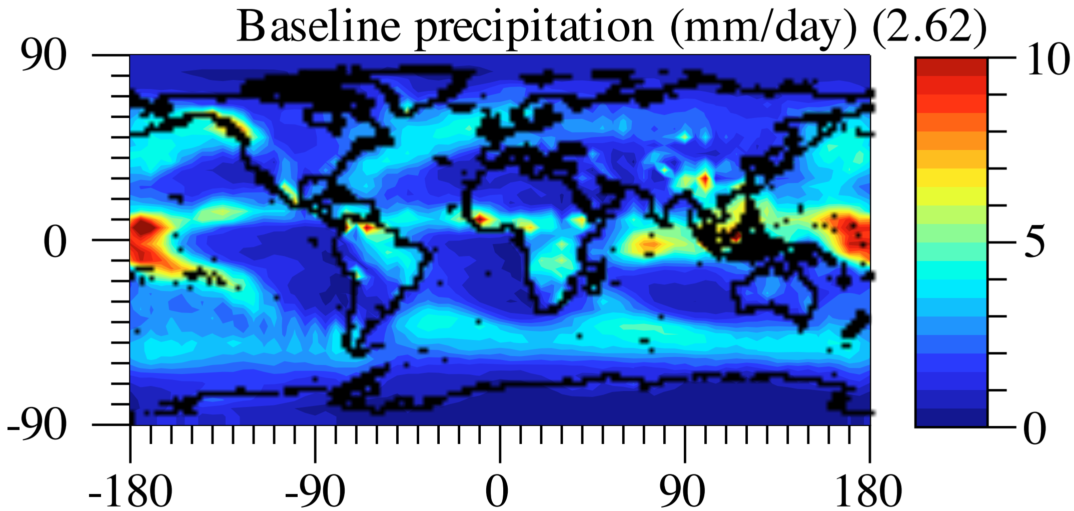
Condensation/deposition of water vapor onto aerosol particles

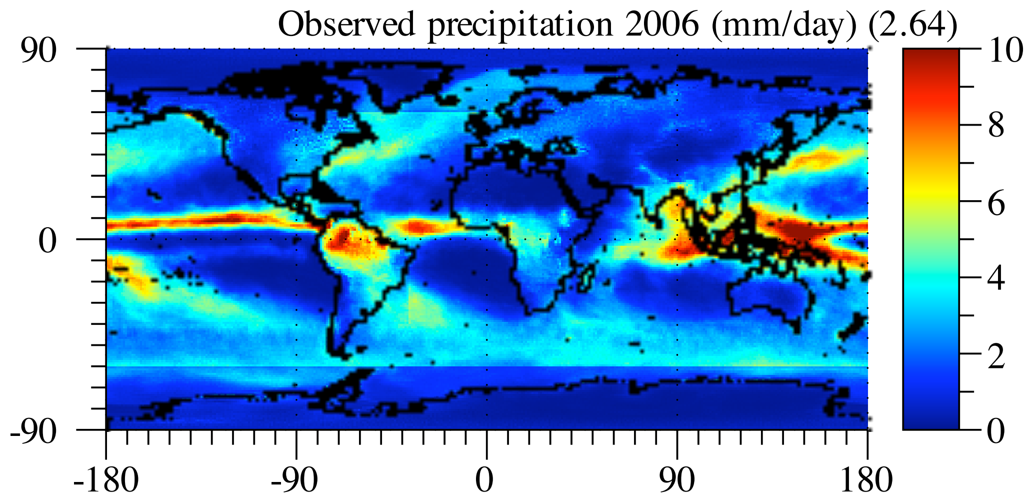
Coagulation: Aerosol-aerosol, Aerosol-liquid, Aerosol-ice, Aerosol-graupel, Liquid-liquid, Liquid-ice, Liquid-graupel, Ice-ice, Ice-graupel, Graupel-graupel

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



Baseline Modeled vs. Measured Precip.

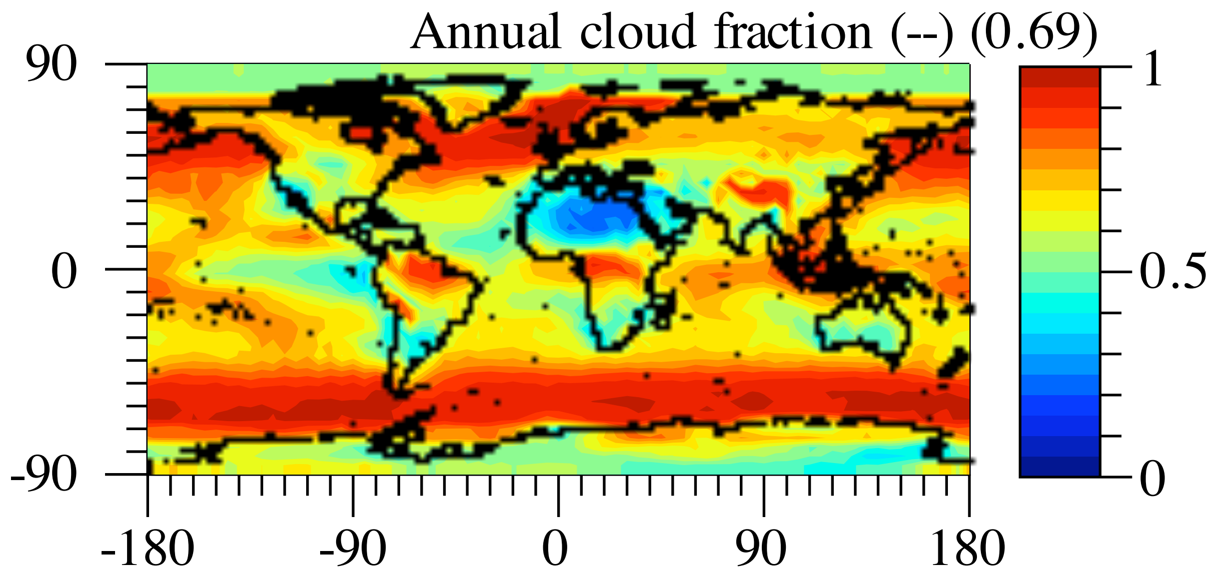


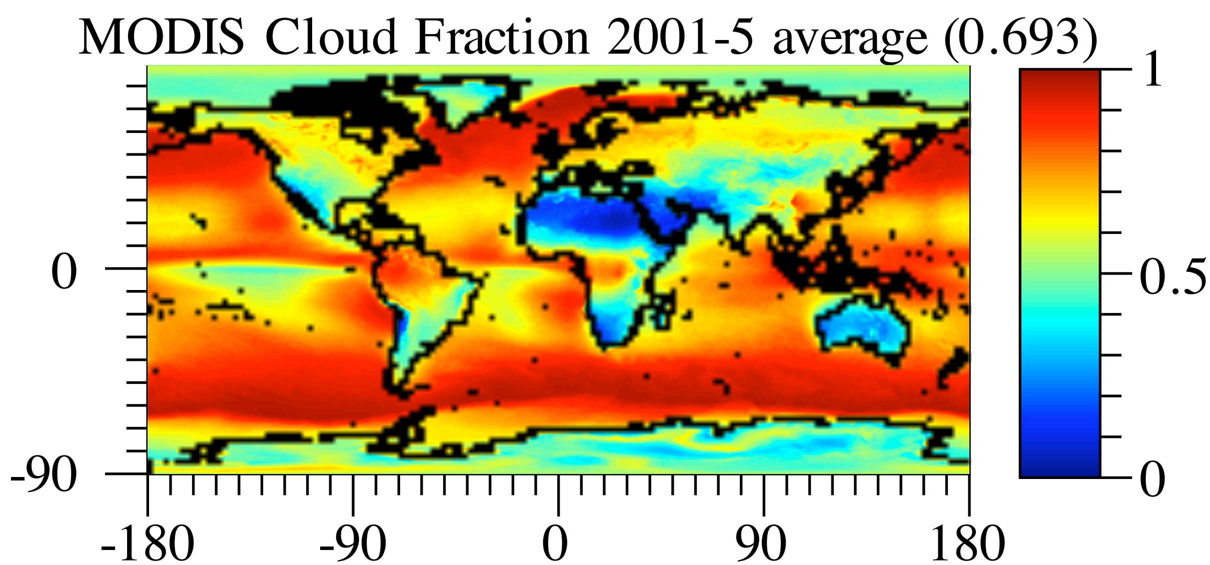


Data from Huffman et al. (2007)

Despite factor of 20 lower resolution than data, model predicts locations of main features of observed precipitation and, with no flux adjustment, correctly does not produce a double ITCZ as nearly all models at coarse resolution do.

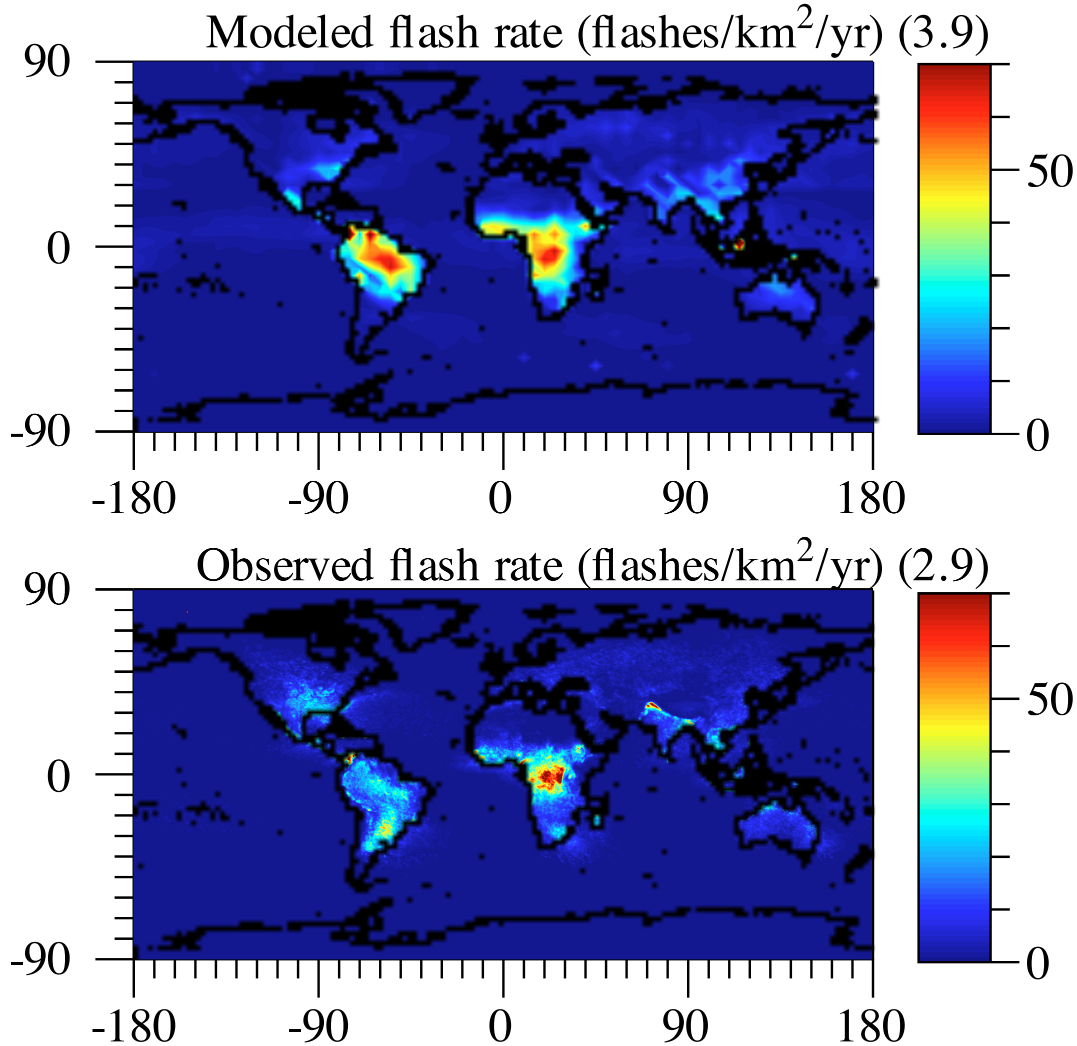
Modeled vs. Measured Cloud Fraction





Data from MODIS

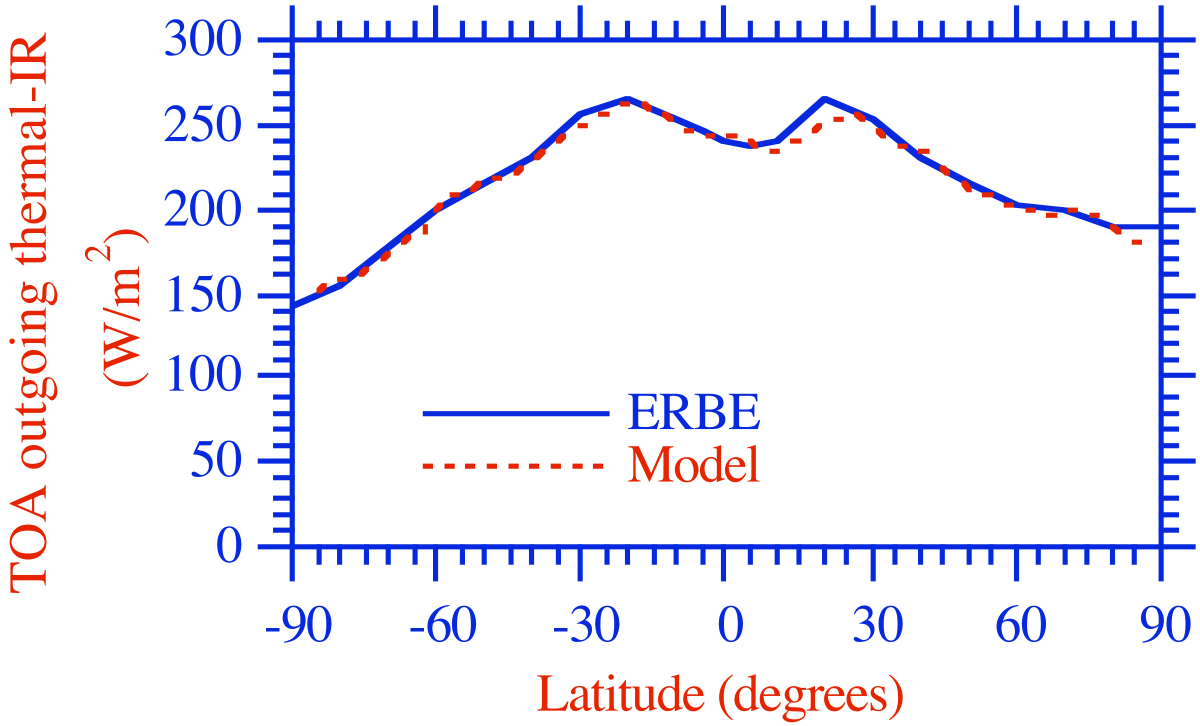
Modeled vs. Measured Annual Lightning Flash Rate



Data from NASA LIS/OTD Science Team

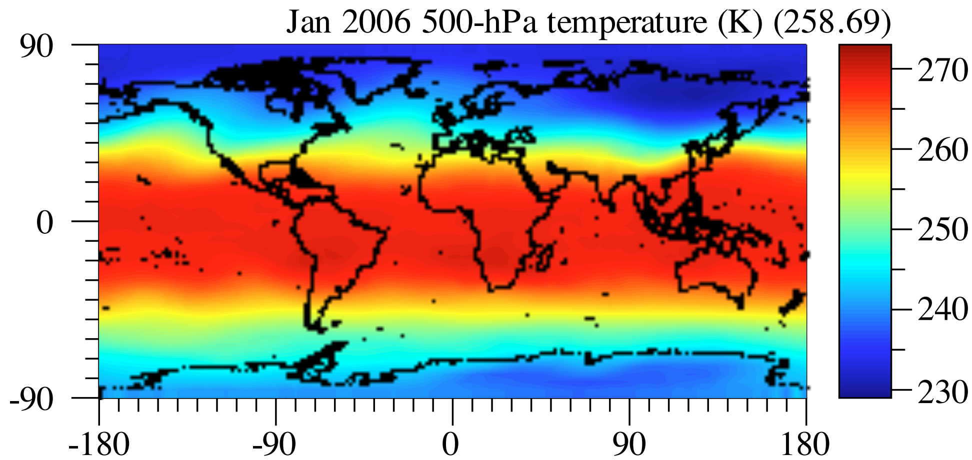
Model calculates lightning by accounting for size-resolved bounceoffs and charge separation in clouds. It predicts nearly the magnitude and the location of the peak observed lightning (Congo) and most locations of lightning.

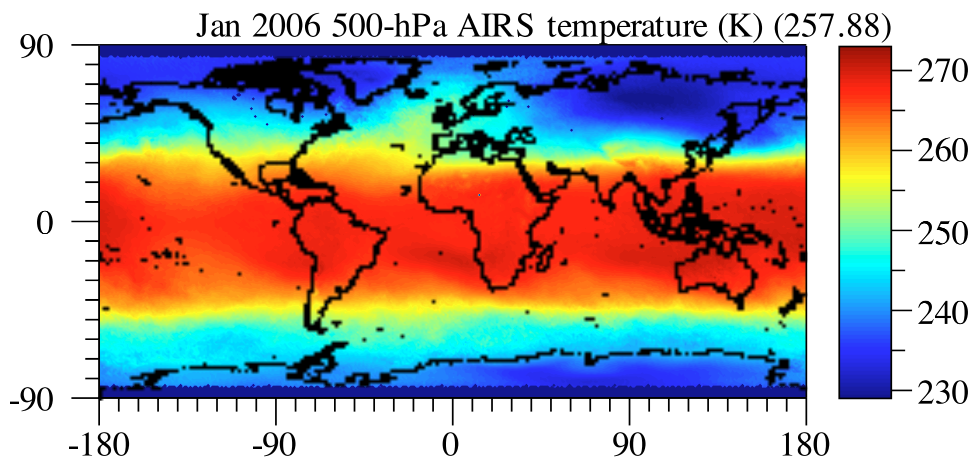
Modeled vs. Measured Thermal-IR



Data from Kiehl et al., 1998

Modeled vs. Measured 500-hPa Jan Temperature



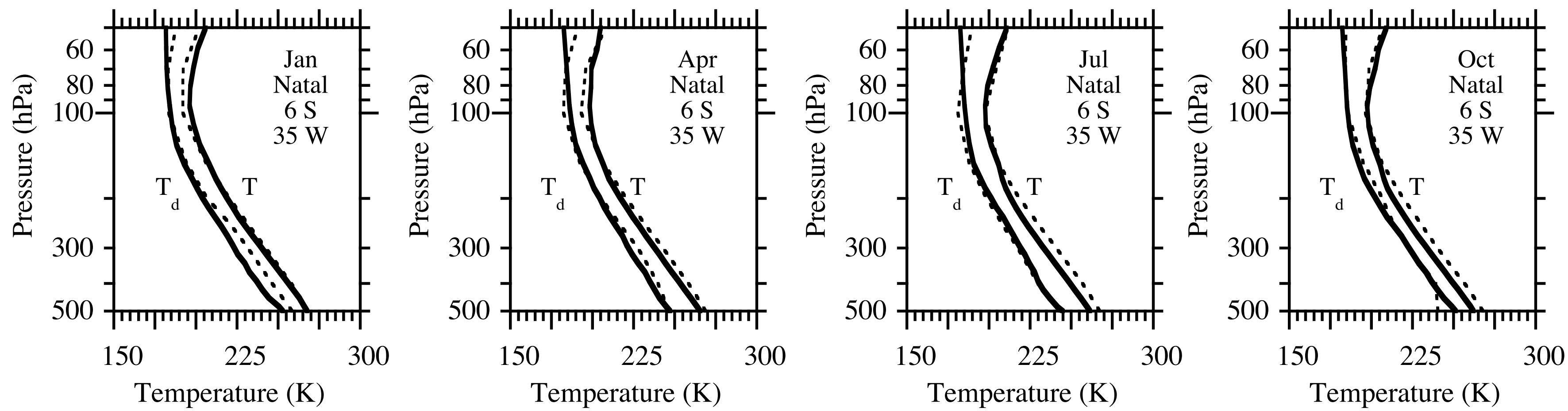


Data from AIRs

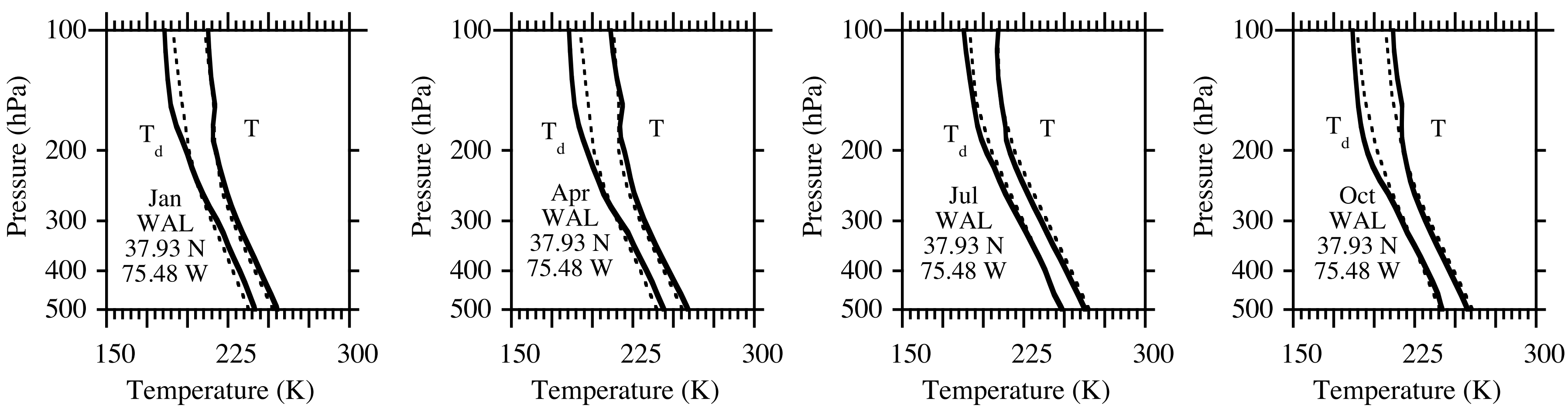
Modeled vs. Measured Paired in Space Monthly T/T_d

Global domain

Data from FSL (2008)



U.S. domain

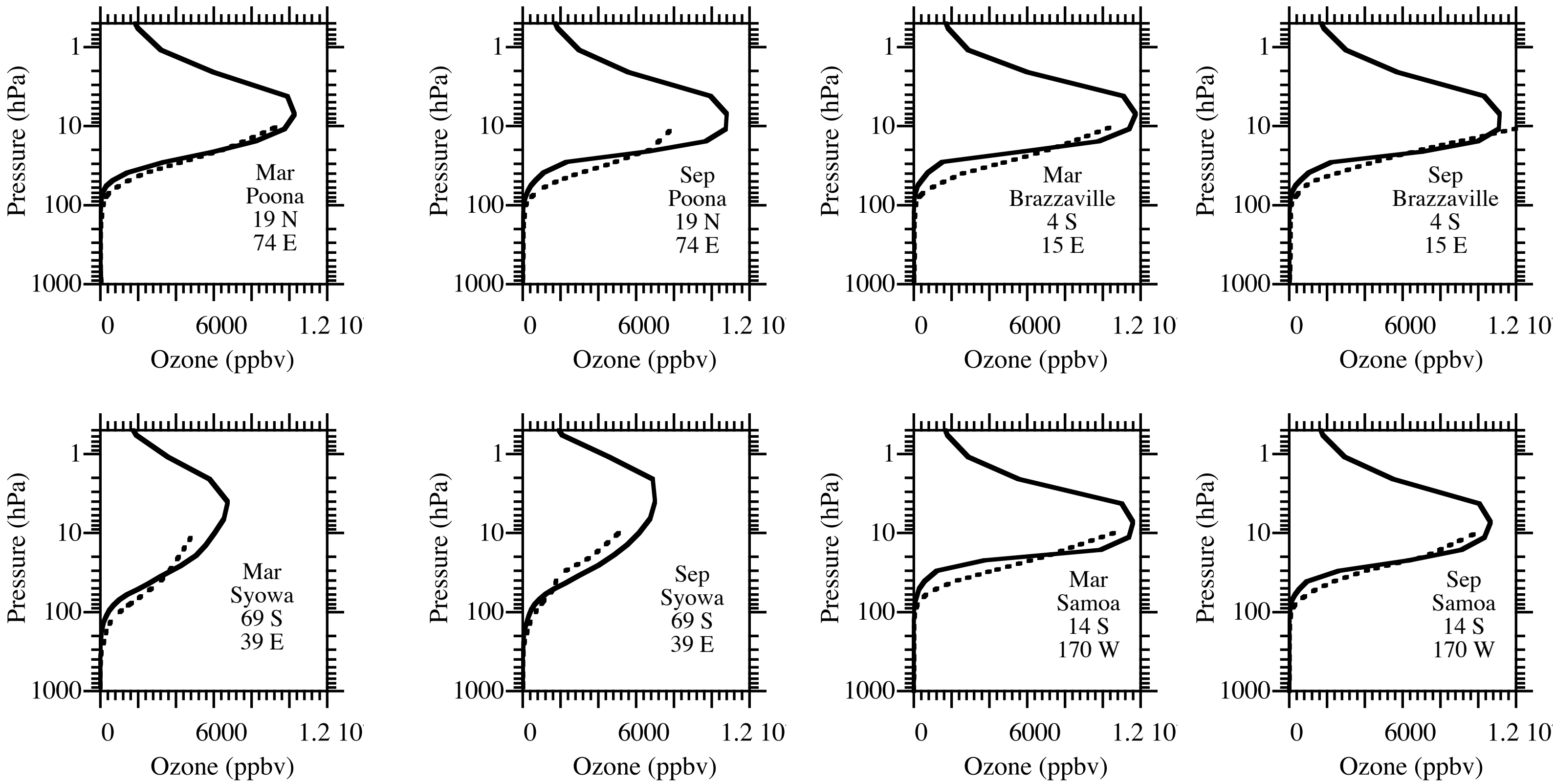


Despite coarse resolution, model captures data features at exact location of data

- Little numerical diffusion of water vapor or energy to stratosphere

Modeled vs. Measured Paired in Space Monthly O_3

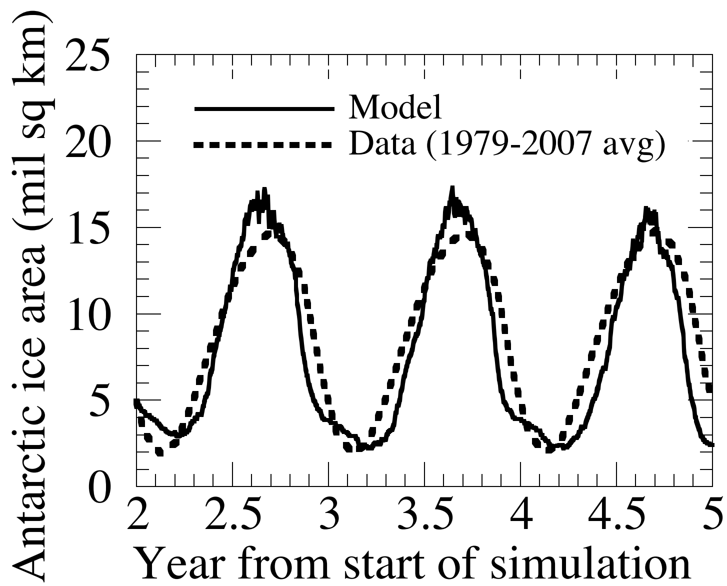
Data from Logan et al. (1999)



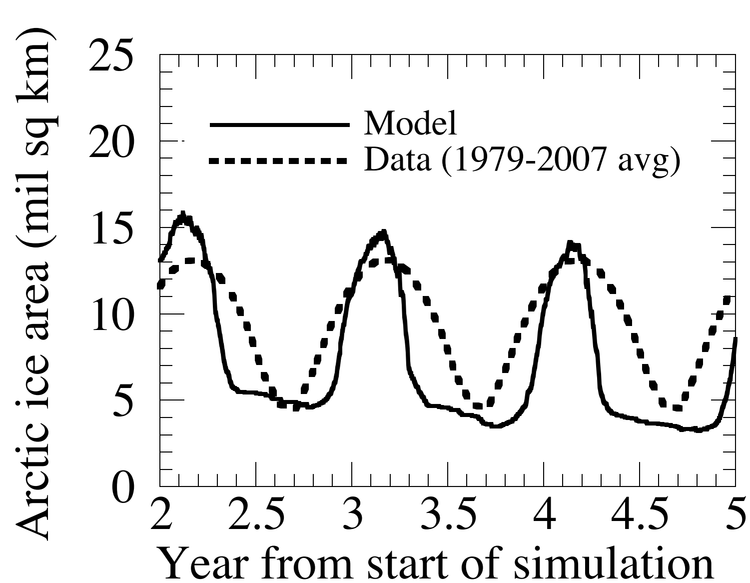
Model predicts the magnitude and altitude of the lower-stratospheric ozone layer

Modeled vs. Measured Sea Ice Area

Antarctic



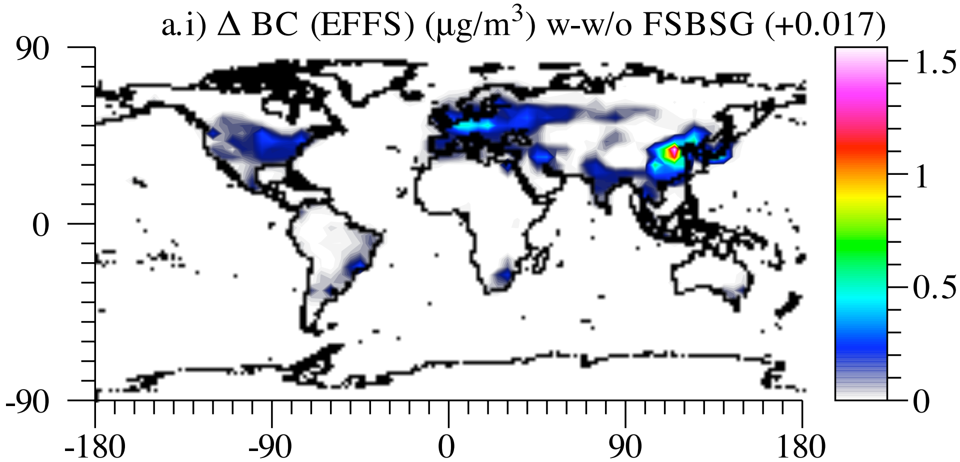
Arctic

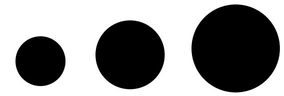


Model (at 4 x 5 degree resolution) predicts stable sea ice area after only two years of simulation

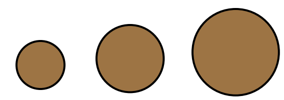
Data from NASA Team (2009)

Emitted- and Internally-Mixed BC From FF soot alone and from FF+BF Soot



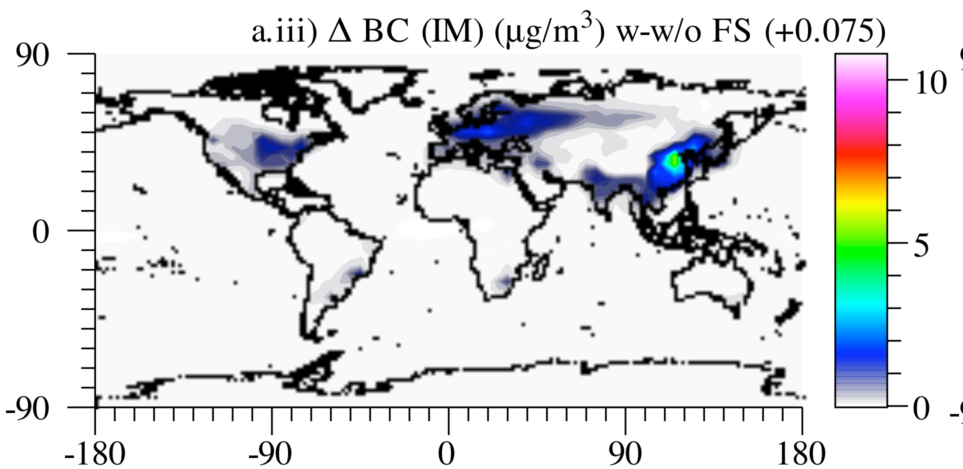


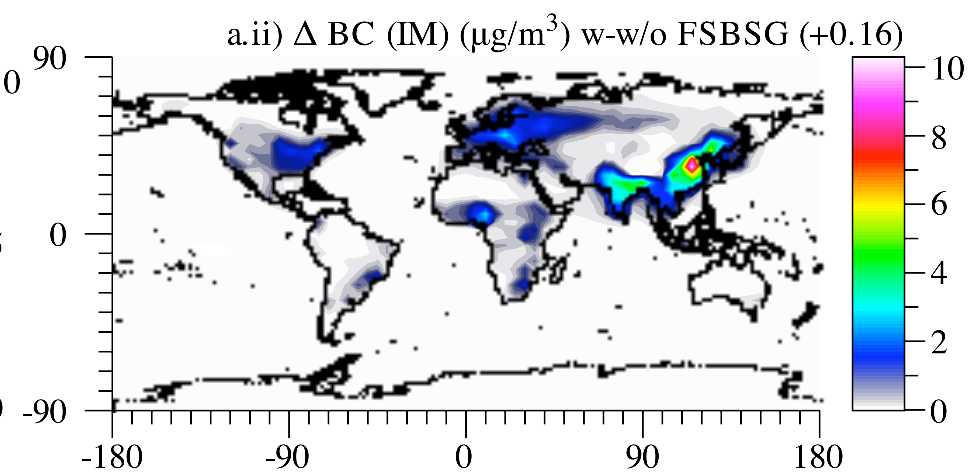
BC in emitted FF soot particles (BC+POM+SIV)



Internally-Mixed FF BC

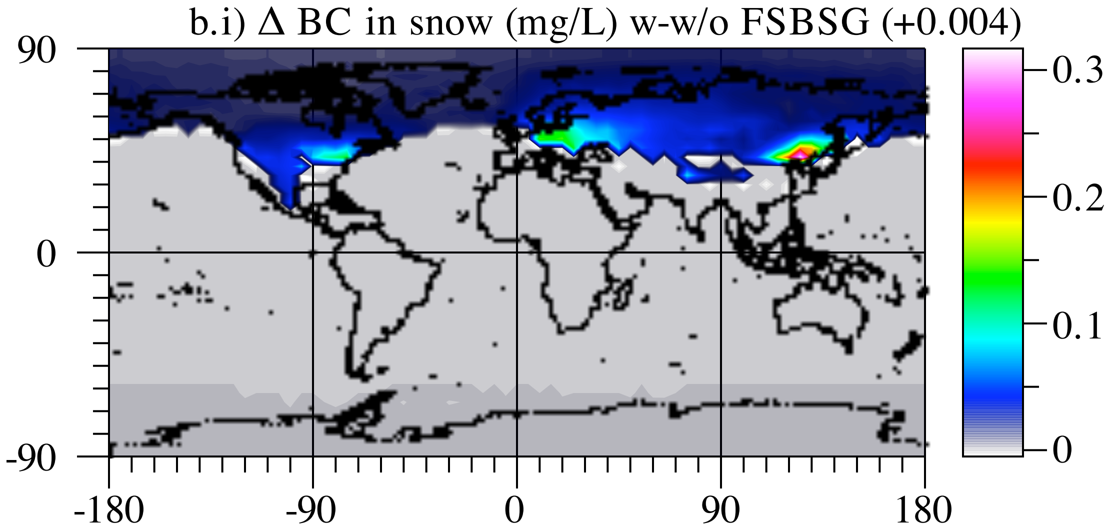
Internally-Mixed FF+BS BC





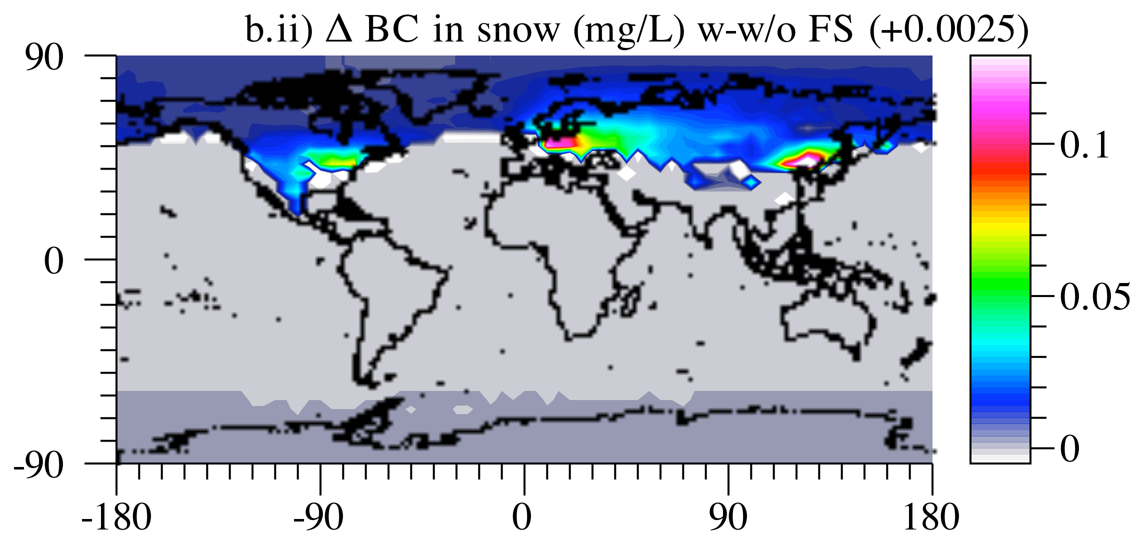
BC from FF soot is about half that of BC from FF+BF soot +BF gases

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



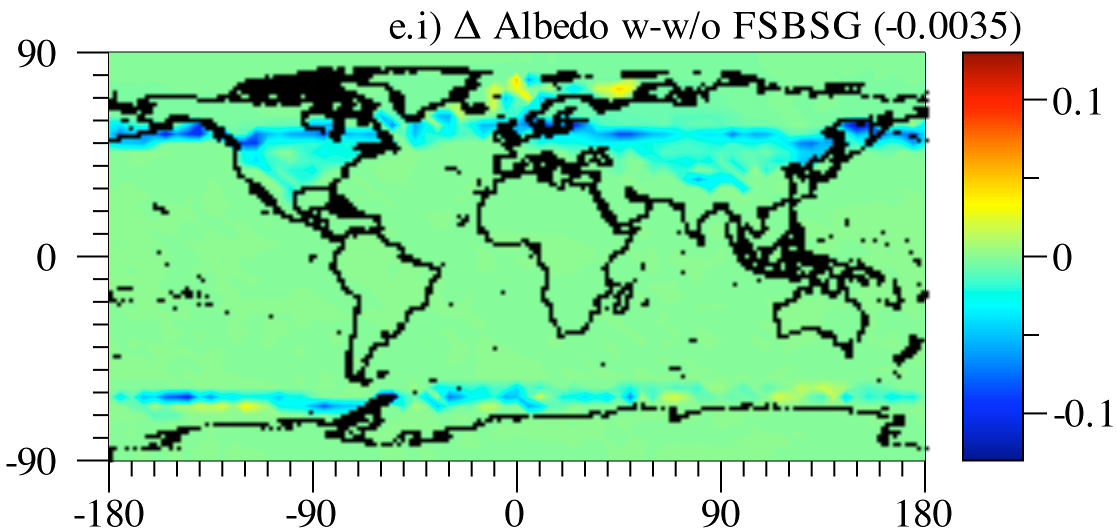
FF soot

FF+BF soot + BF gases

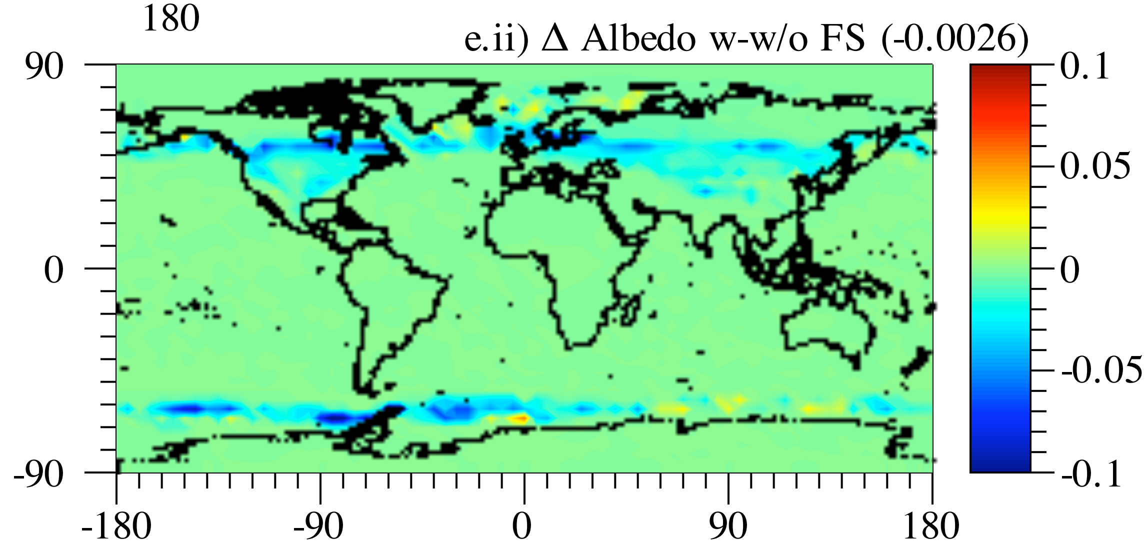


Both FF+BF soot and FF soot increase BC in snow

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



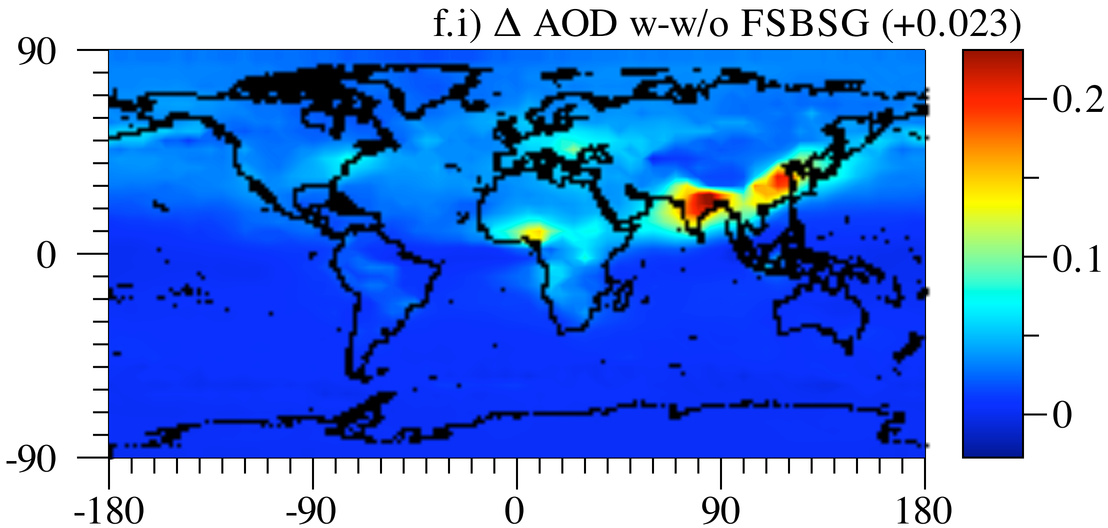
FF+BF soot + BF gases



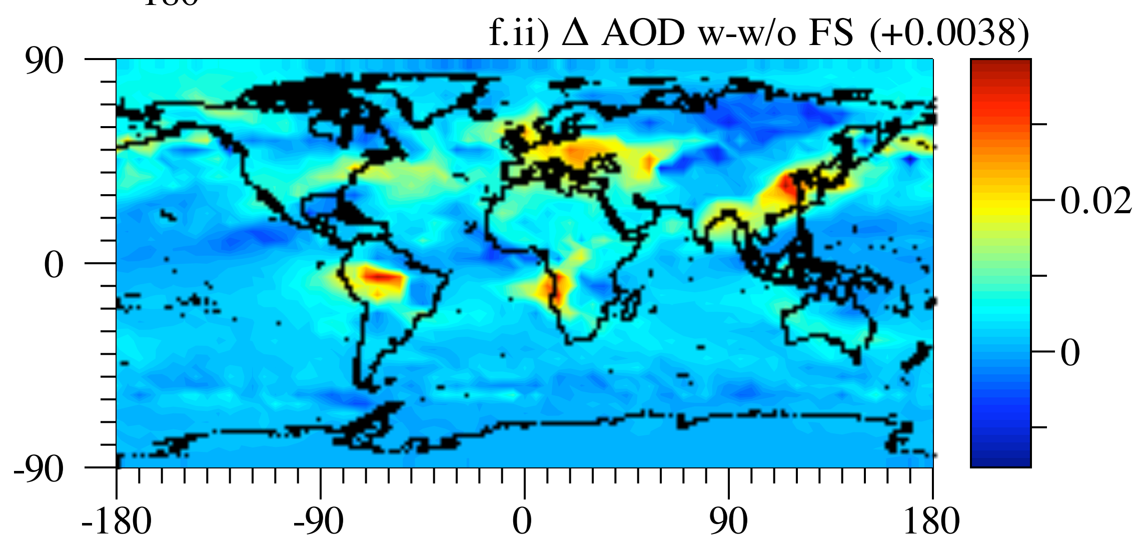
FF soot

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



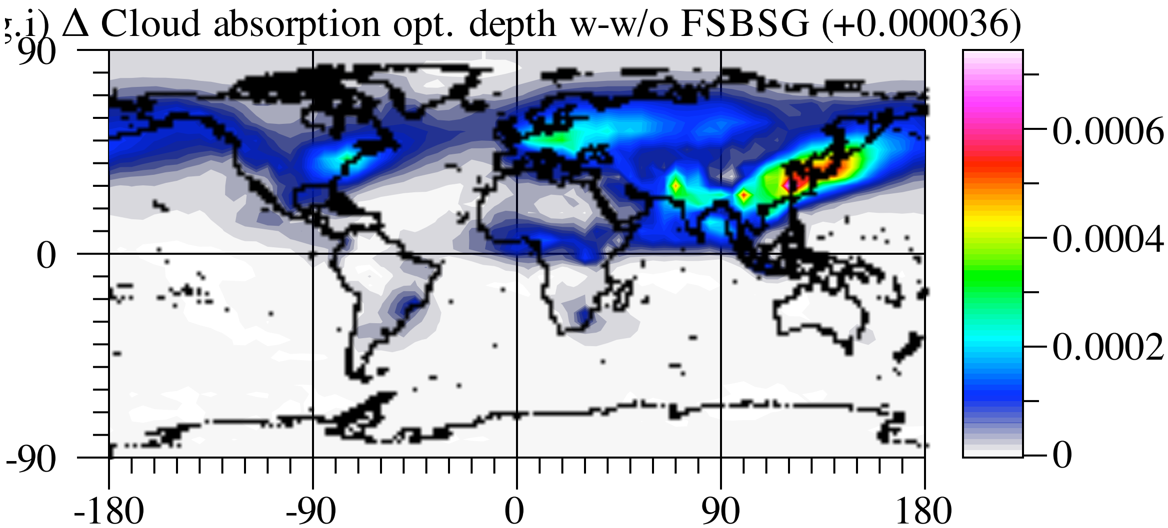
AOD change due to
FF+BF soot + BF gases



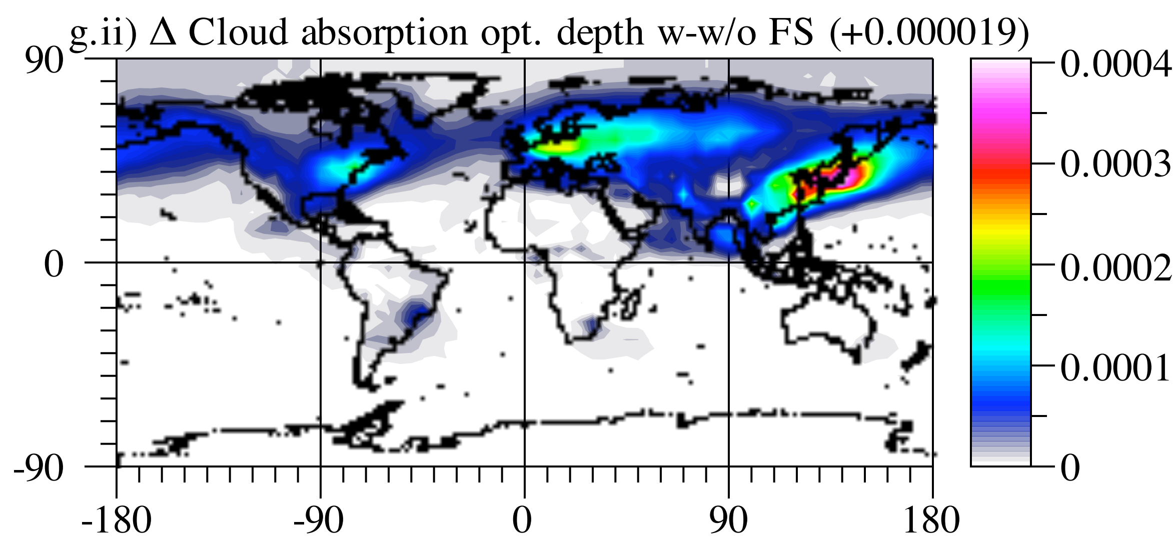
AOD change due
To FF soot

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

Cloud Absorption Due to BC Inclusions in Clouds



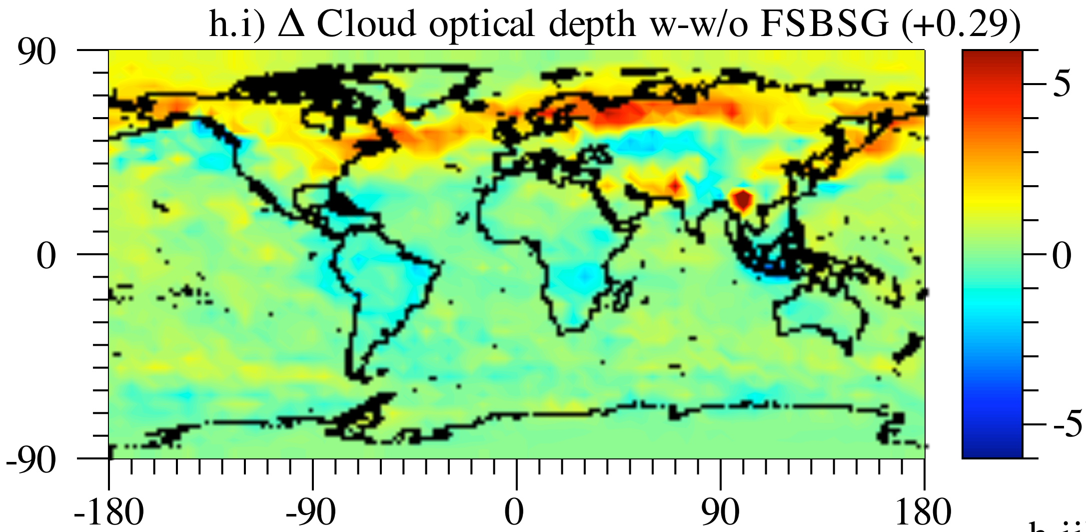
Cloud absorption OD change due to FF+BF soot + BF gases



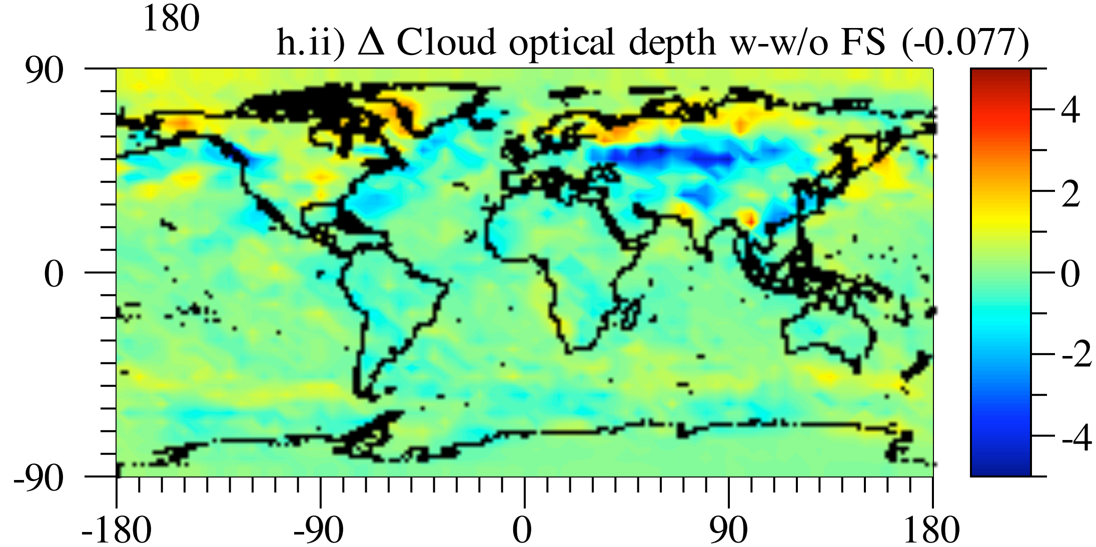
Cloud absorption OD change due to FF soot

→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



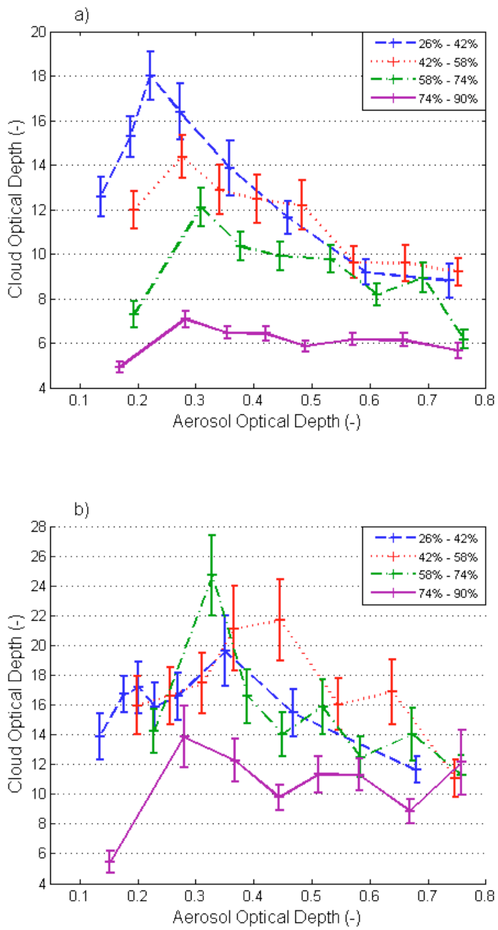
Cloud OD change due to FF+BF soot + BF gases



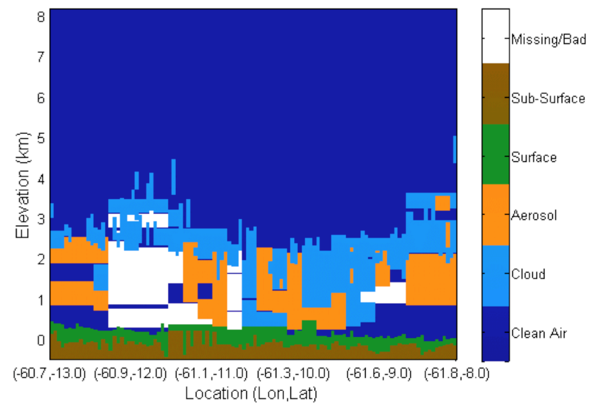
Cloud OD change due to FF soot

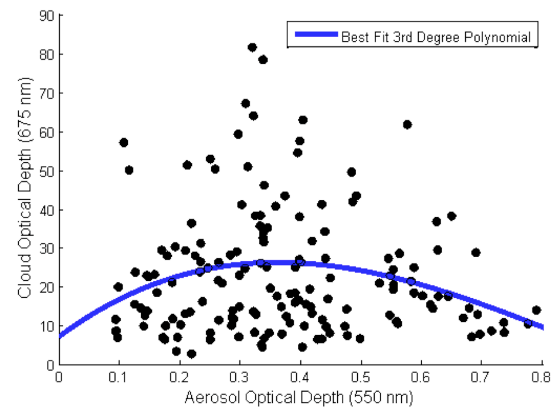
FF+BF soot +BF gases increased COD; FF soot decreased COD

Cloud Versus Aerosol Opt. Depth From Data



MODIS, binned by percentile column water vapor 2004-07

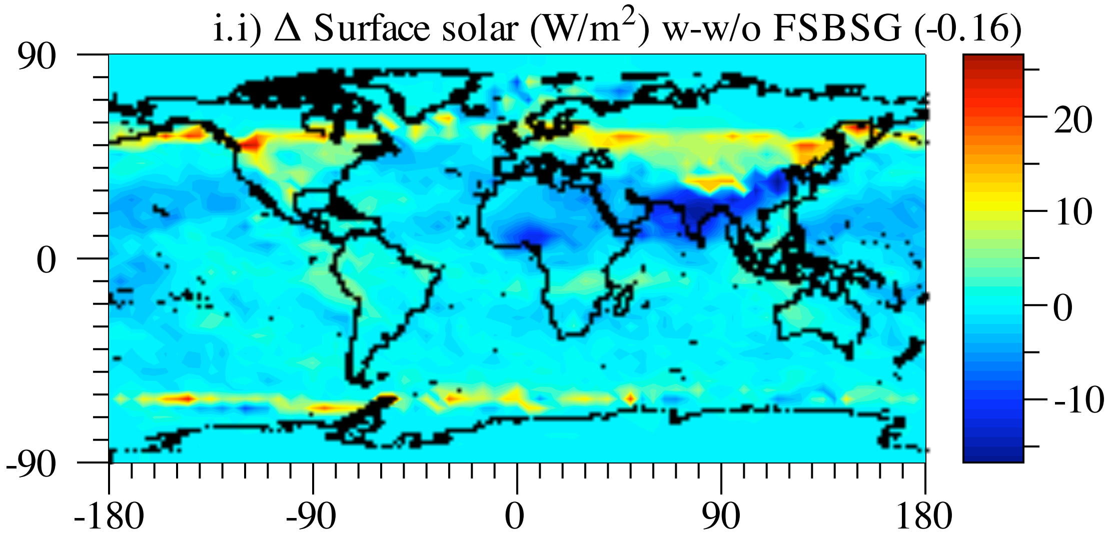




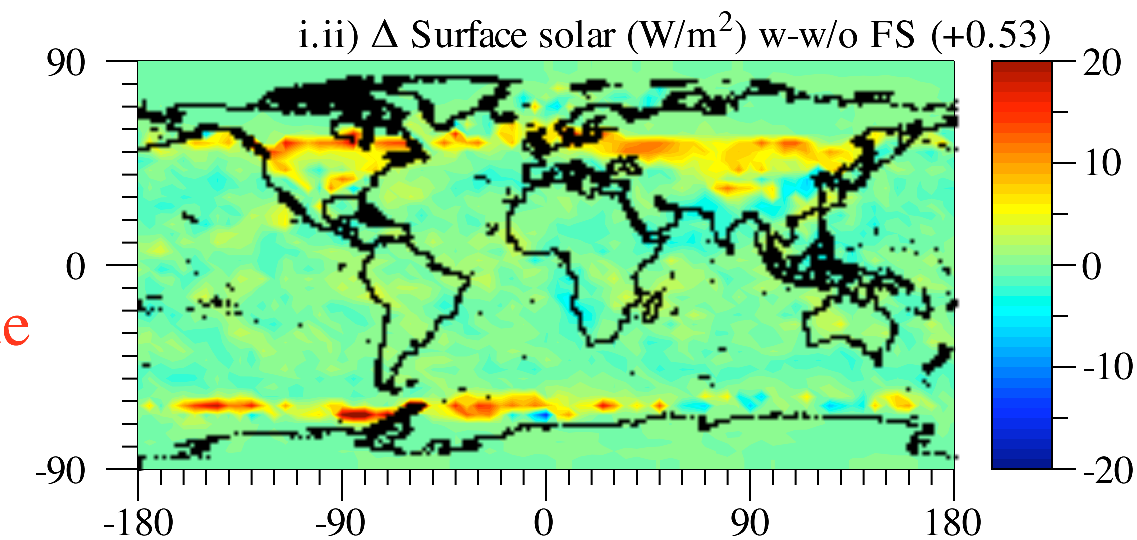
MODIS / Calipso Lidar Aug. 12, 2006

Ten Hoeve, Remer, and Jacobson (2010)

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



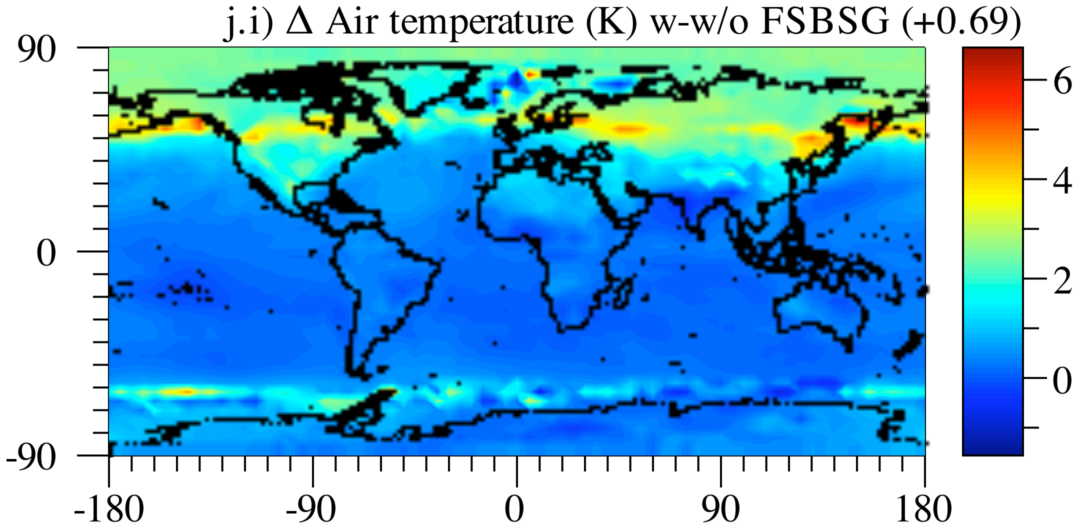
Surface solar change due to FF+BF soot + BF gases



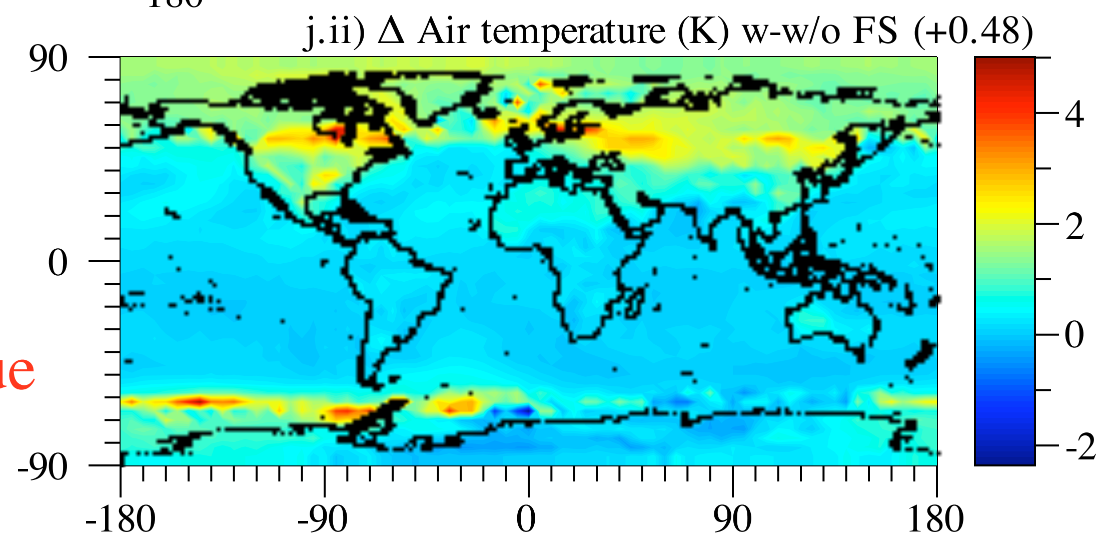
Surface solar change due to FF soot

→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



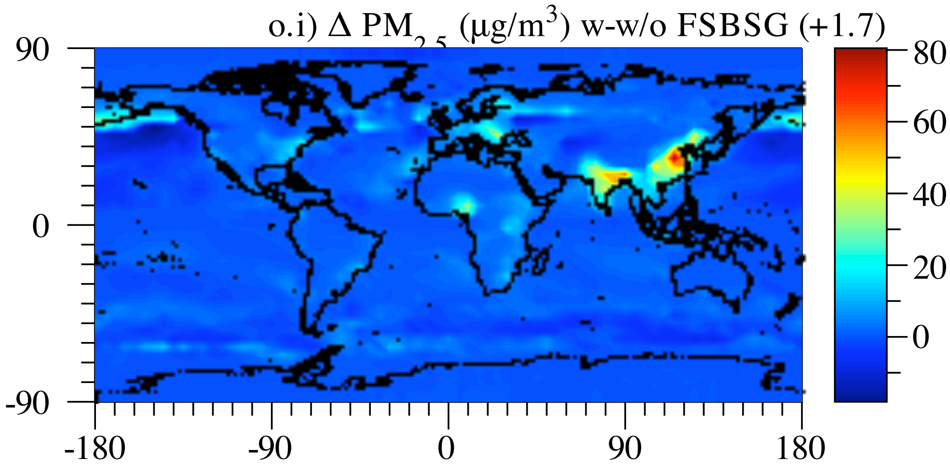
Air temperature change due to FF+BF soot + BF gases

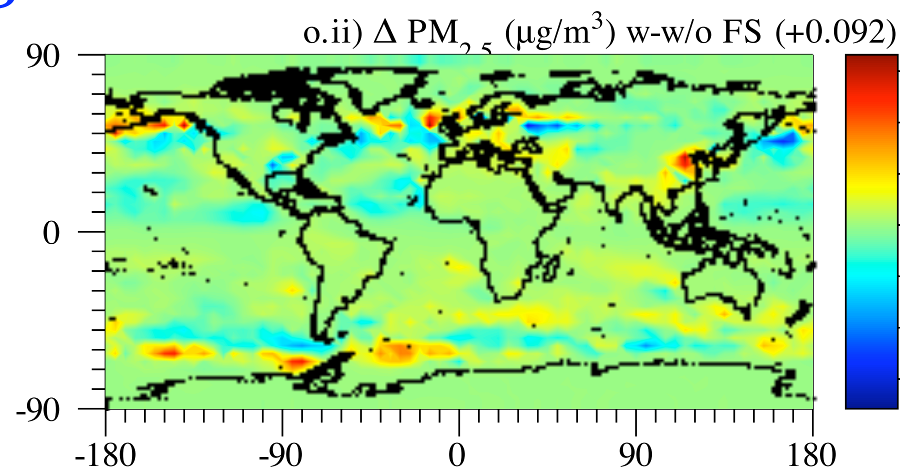


Air temperature change due to FF soot

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

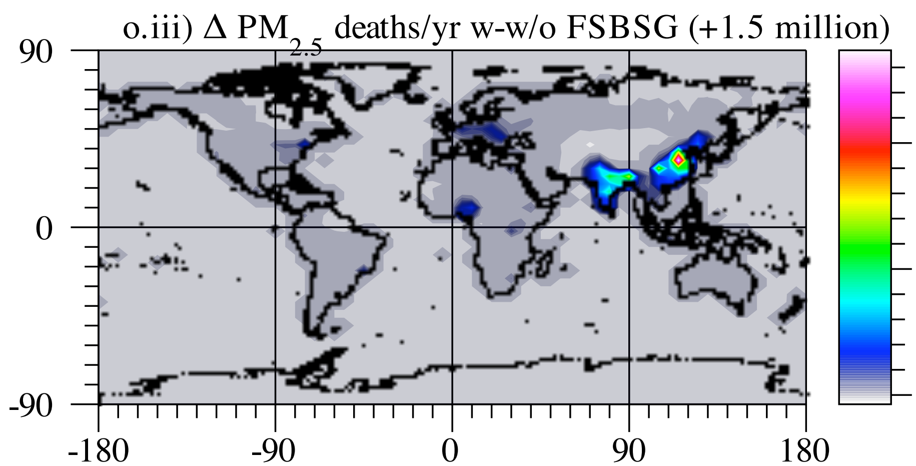
Changes in PM and Resulting Deaths due to FF+BF soot + BF gases and to FF soot

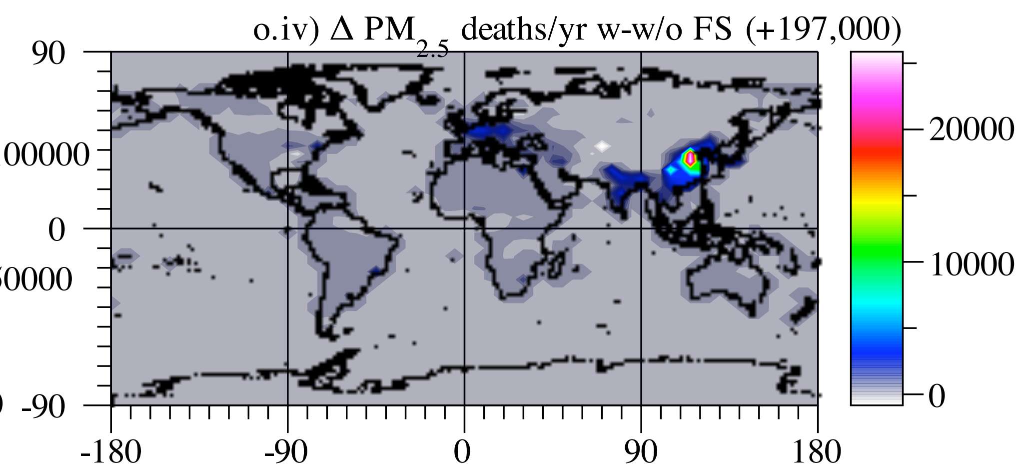




FF+BF soot + BF gases

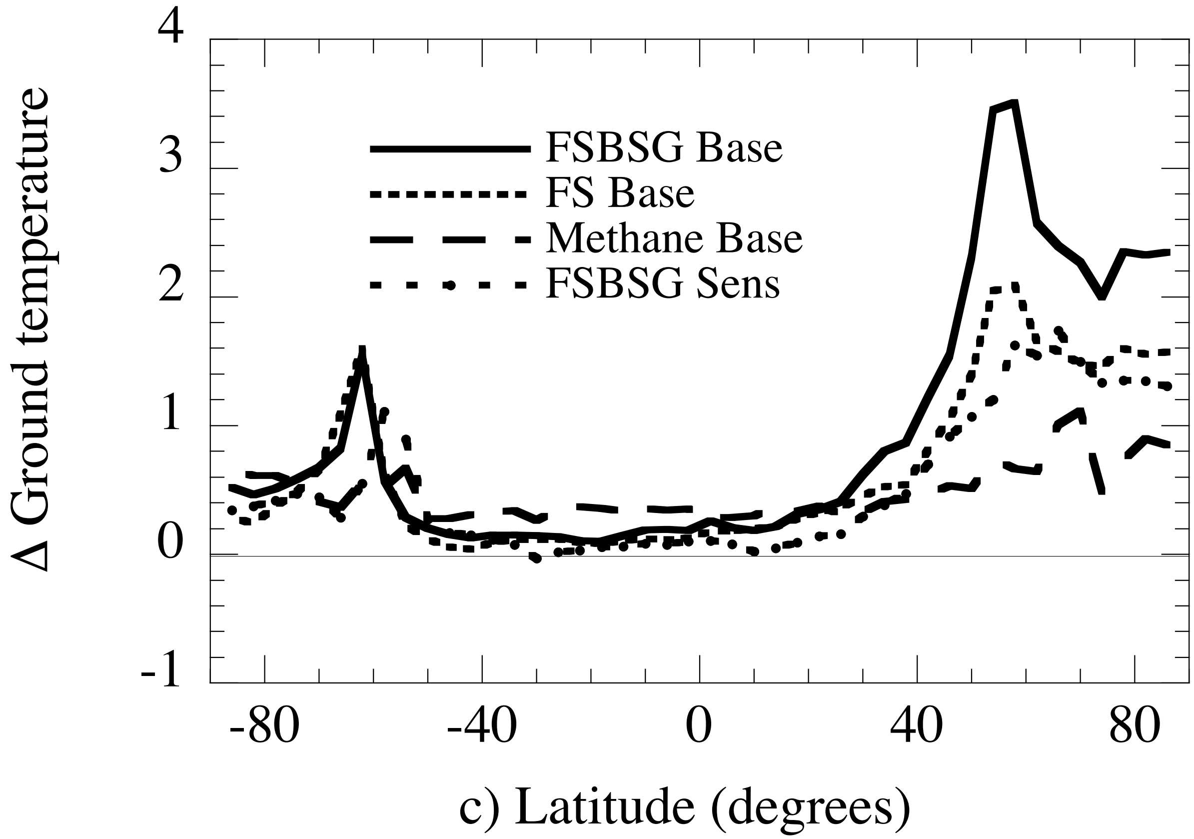
FF soot





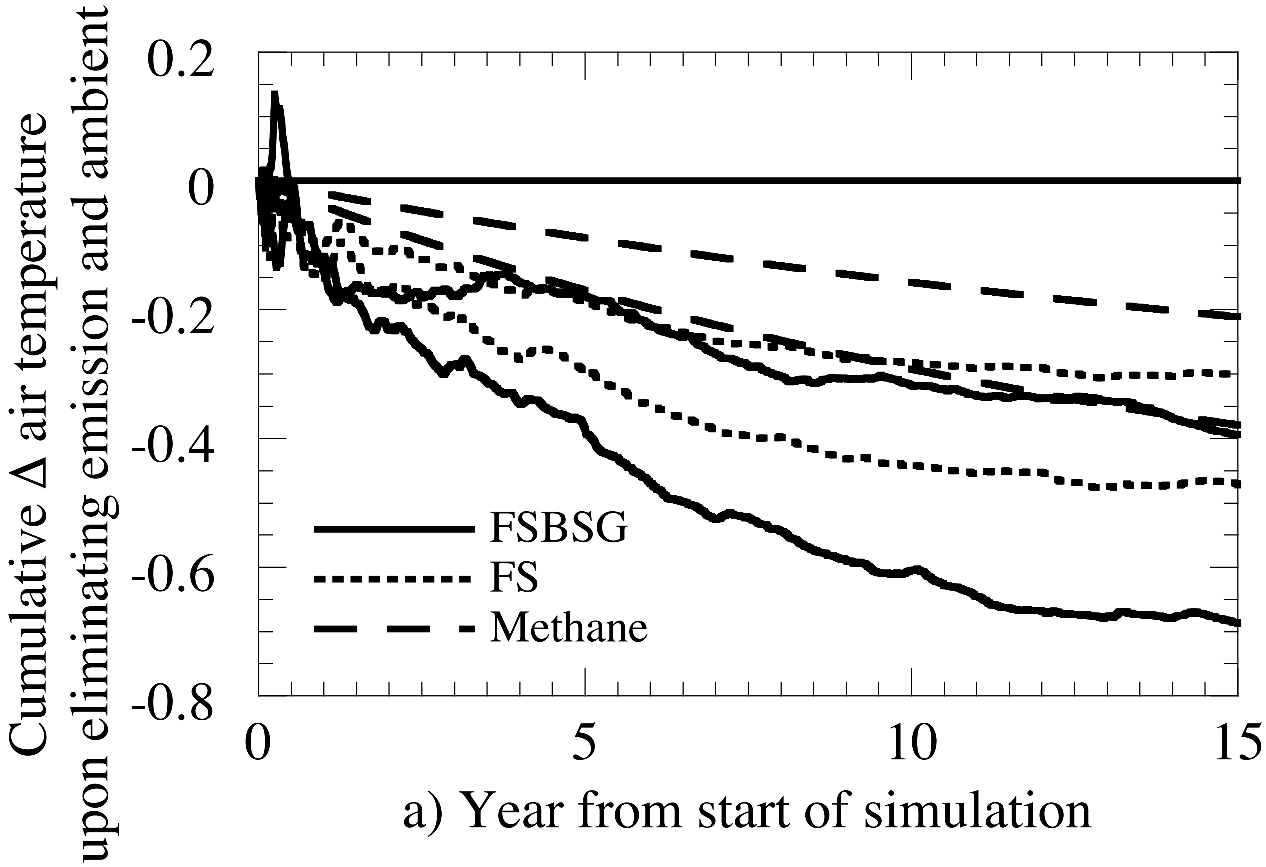
Deaths due to BF soot+gases ~7 times those due to FF soot

Arctic Warming Due to Anth. CH_4, Fossil Soot and Biofuel Soot+Gases (FSBSG), & FS

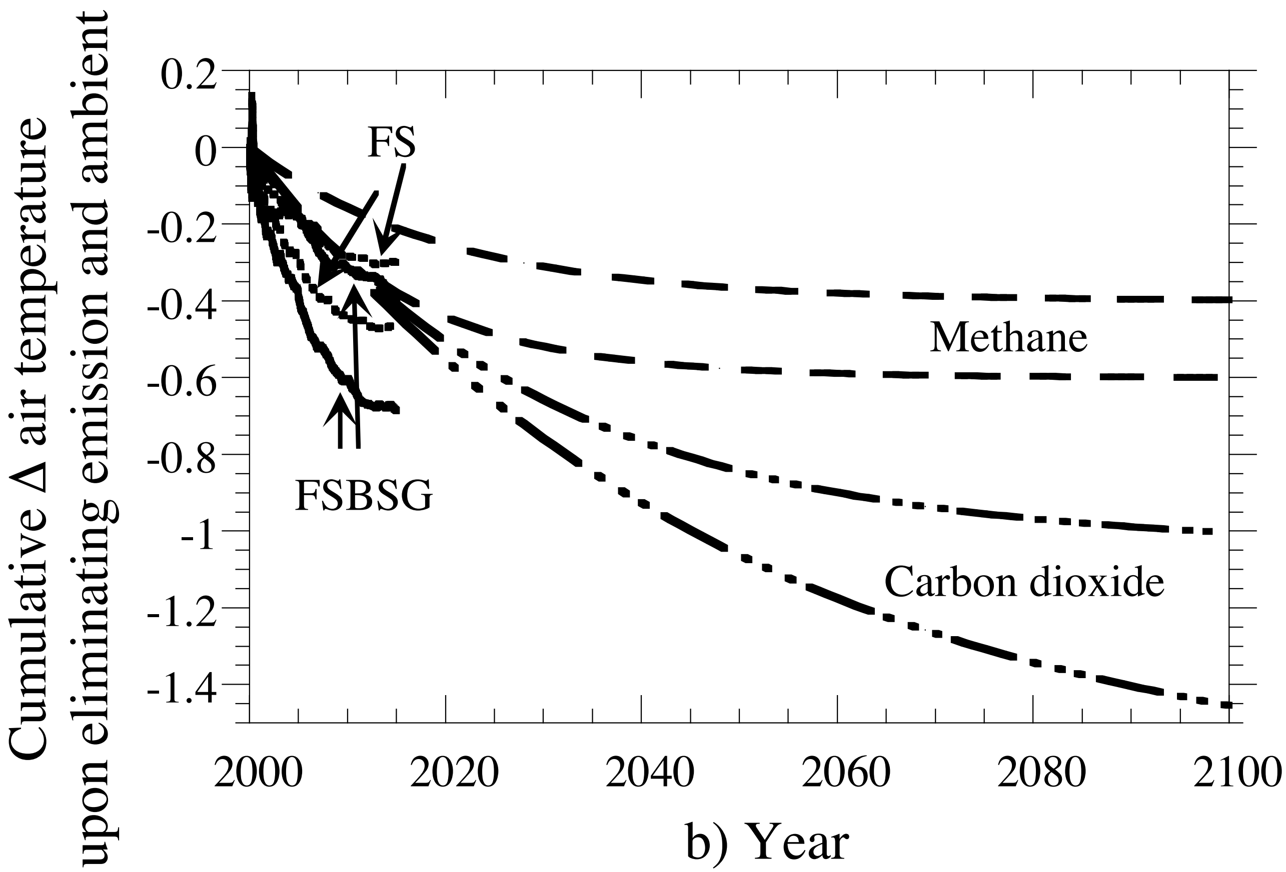


FF+BF soot + BF warm mid & high northern latitudes more than anthropogenic CH_4 or FF soot alone

Global Cooling Due to Eliminating Anthropogenic CH_4, Fossil Soot and Biofuel Soot+Gases (FSBSG) and FS Emissions only



Global Cooling Due to Eliminating Anthropogenic CO_2, CH_4, FSBSG, and FS Emissions only



FF Soot, BC Global Warming Potential

	20-yr STRE	100-yr STRE	100-yr STRM
BC+POC in FS	2400-3800	1200-1900	0.5-1.1million
BC in FS	4500-7200	2900-4600	1-2.4 million
BC+POC in BSG	380-720	190-360	36,000-100,000
BC in BSG	2100-4000	1060-2020	0.35-1 million
Methane	52-92	29-63	21-45

STRE = Near-surface temperature change after 20 or 100 years per unit continuous emission of X relative to the same for CO_2 (similar to GWP e.g., 20-, 100-yr GWPs for CH_4 are 72, 25)

STRM = Near-surface temperature change after 20 or 100 years per unit mass in the atmosphere of X relative to the same for CO_2-C.

Summary

FSBSG soot is the second-leading cause of global warming behind CO_2 and ahead of CH_4. FS causes 3 x the warming of BSG, but BSG causes ~7x more deaths than FS.

Net global warming (0.7-0.8 K) is due primarily to gross warming from FF GHGs (2-2.4 K) and FSBSG (0.4-0.7 K) offset by cooling due to non-FSBSG aerosol particles (-1.7 to -2.3 K).

FS and FSBSG may contribute to 13-16% and 17-23% of gross warming due to atmospheric pollutants.

Controlling FS, FSBSG, CH_4 in isolation may reduce warming above the Arctic Circle by ~1.2 K, ~1.7 K, 0.9 K respectively.

Control of FS, FSBSG is fastest method of reducing Arctic loss

www.stanford.edu/group/efmh/jacobson/controlfossilfuel.html