Incorporation of Aerosol Optical Properties into Climate Models

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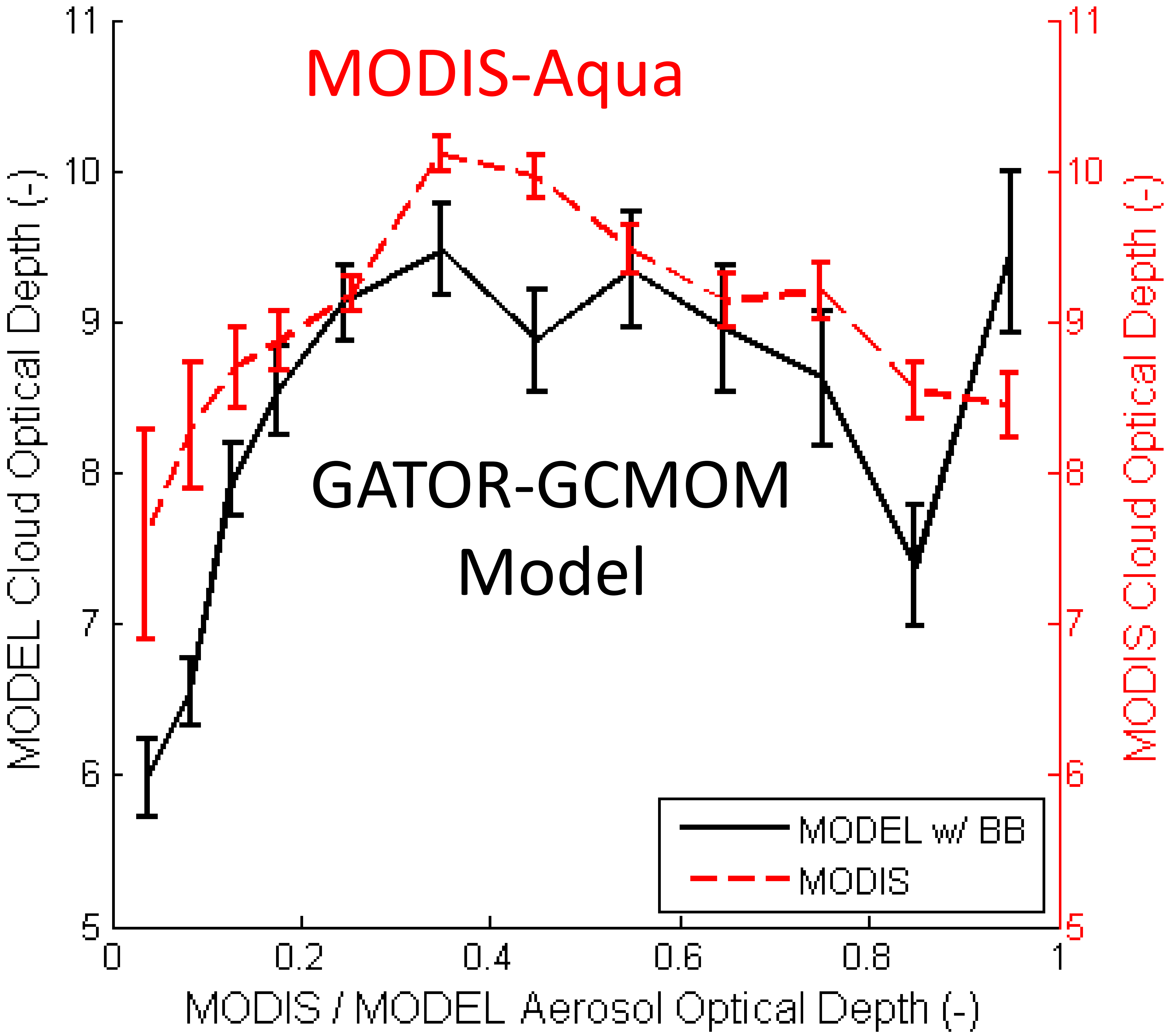
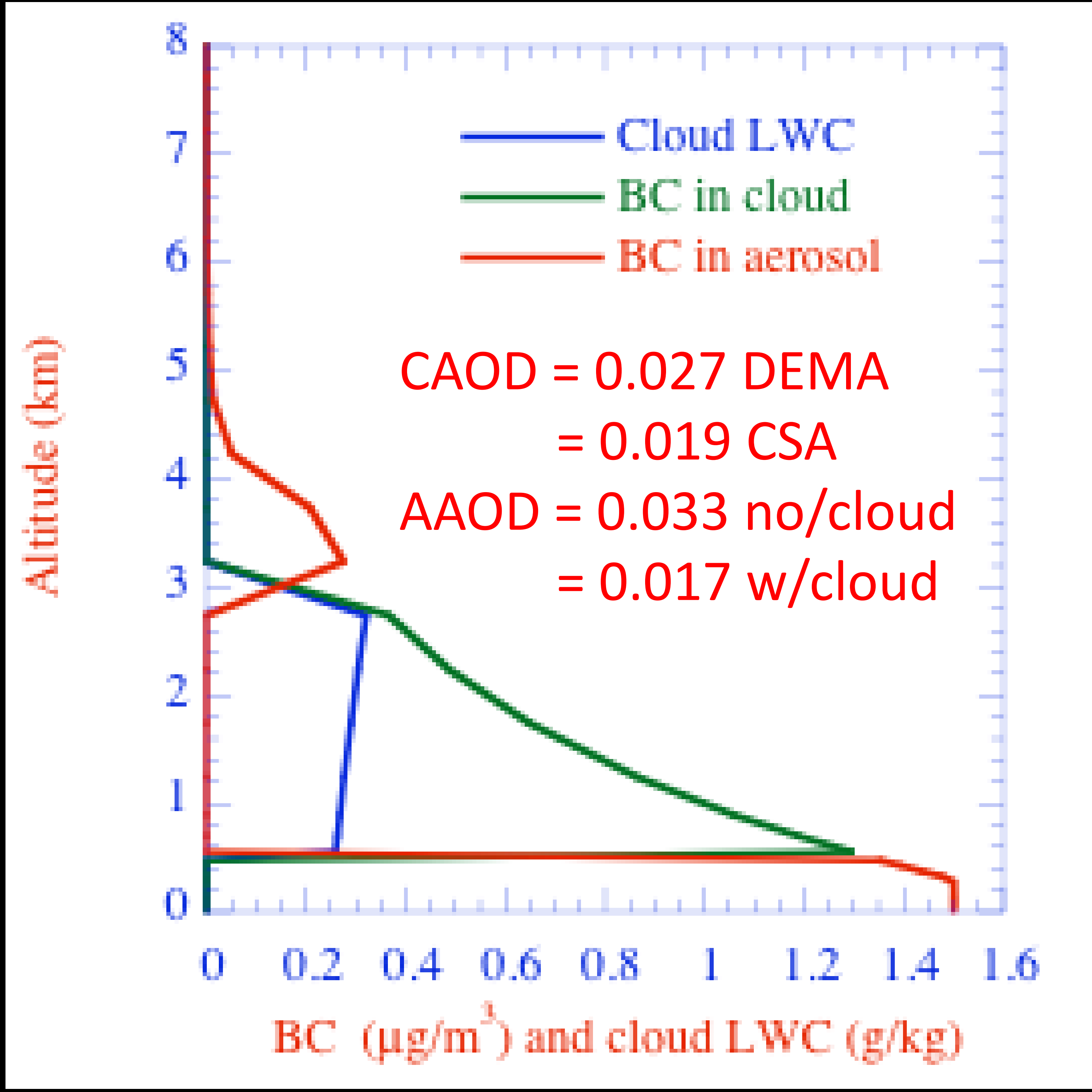
Boomerang Effect: Indirect + Cloud Absorption+ Semidirect Effects Can't be Separated

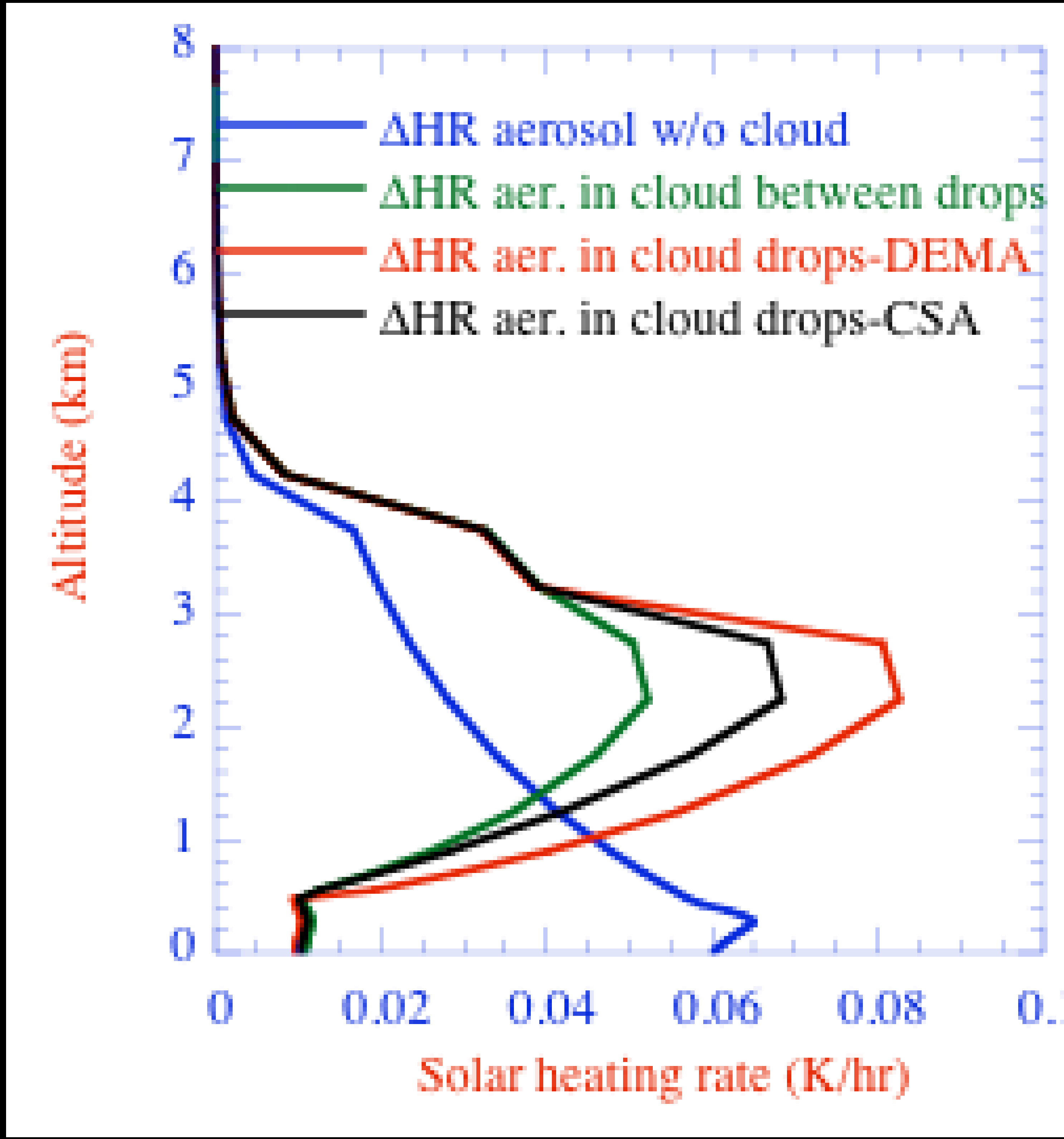


In-cloud COD v. AOD Over Bio-Burning in Brazil Sept '06

Ten Hoeve, Remer, Jacobson (2010)

Greater Solar Heating Rate of In-Cloud-Drop BC Over Interstitial Cloud BC Over Clear-Sky BC For Same Aerosol Profile





BC Inclusions Can Double Heating Rate Compared With Interstitial BC

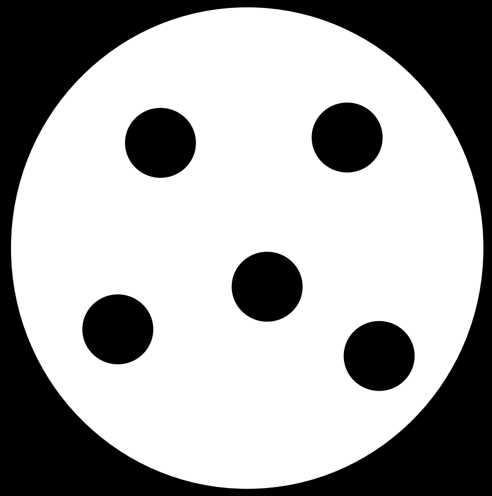
Why Does In-Cloud-Drop BC Heat More Than Interstitial Cloud (IC) BC and IC BC More Than Clear-Sky BC?

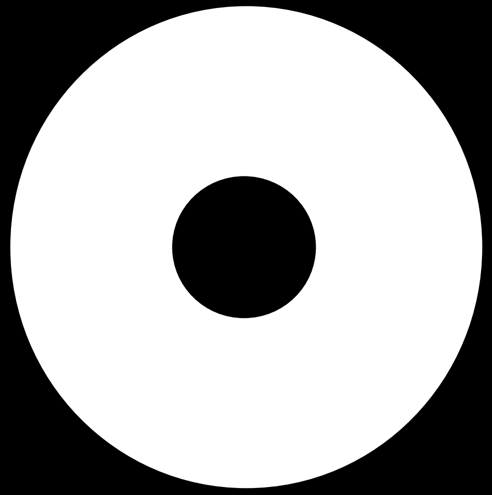
1) Internally-mixed aerosol BC enhances heating over externally-mixed aerosol BC due to optical focusing effect.

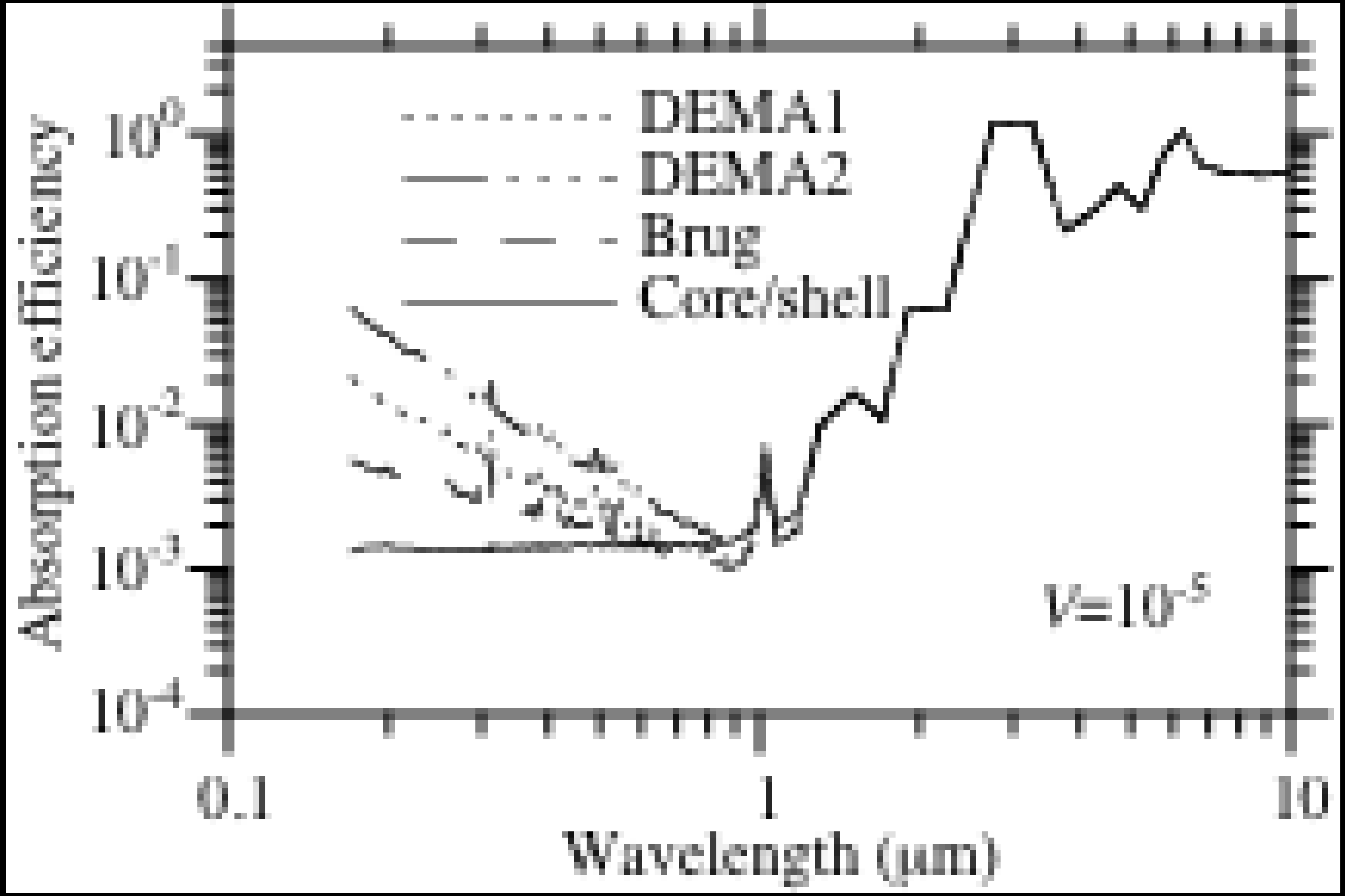
2) BC between cloud drops (interstitial) heats more than aerosol BC due to enhanced scattering of light between cloud drops thus more photons hitting BC in the cloud than outside the cloud.

3) BC in cloud drops heats more than BC between cloud drops due to optical focusing of enhanced scatter cloud light into drops and multiple internal reflections of such light to BC inclusions.

Cloud Absorption Should be Treated with DEMA (Multiple BC Inclusions in Drops)







Jacobson, J. Phys. Chem. (2006)

Absorption Efficiency 12.6-Micron Cloud Drops

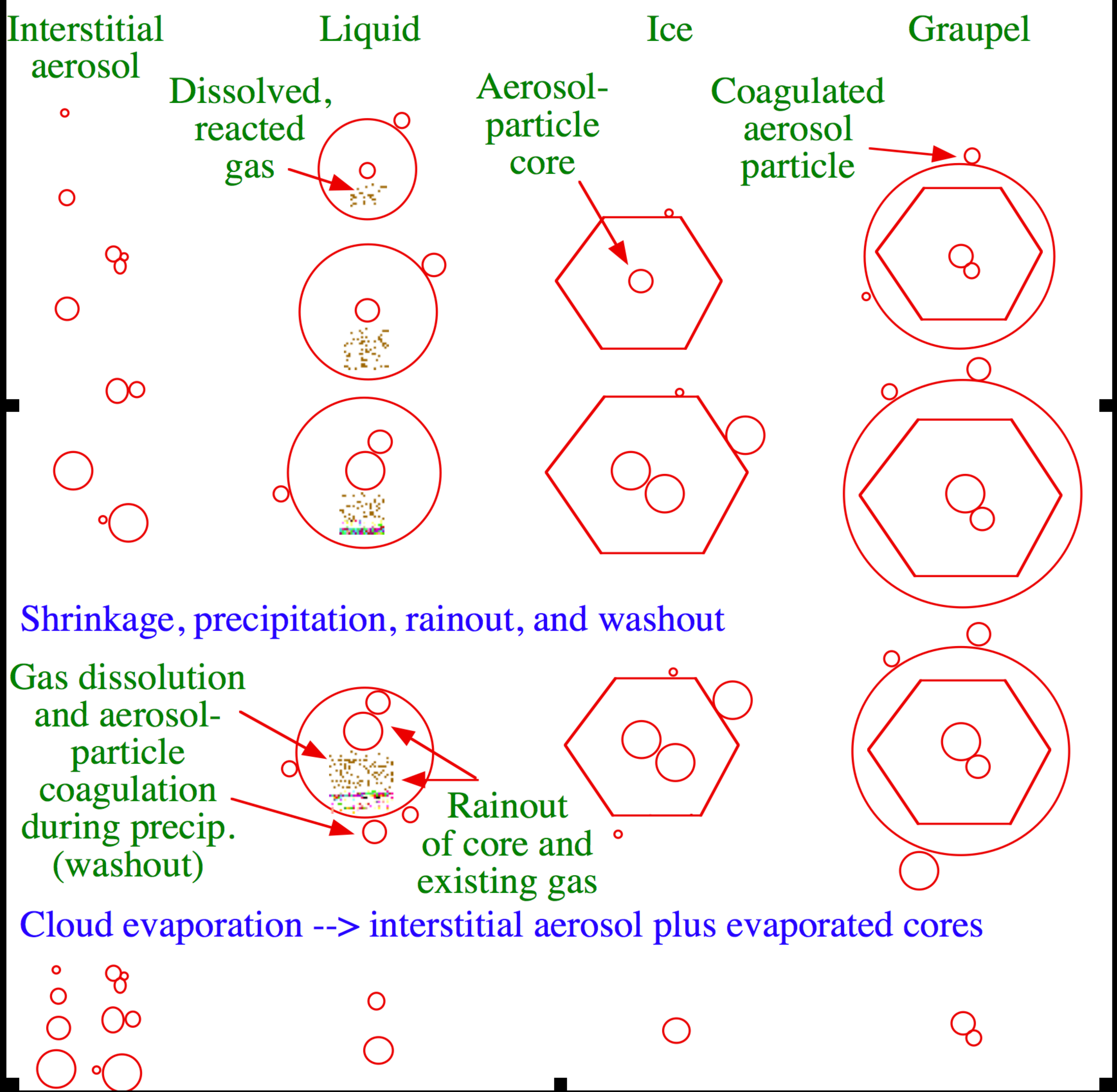
DEMA1,2=0.1-, 0.2-micron BC inclusions; Brug=Bruggeman (BC well-mixed); Core/shell=single BC core

Cloud Microphysical and Chemical Processes

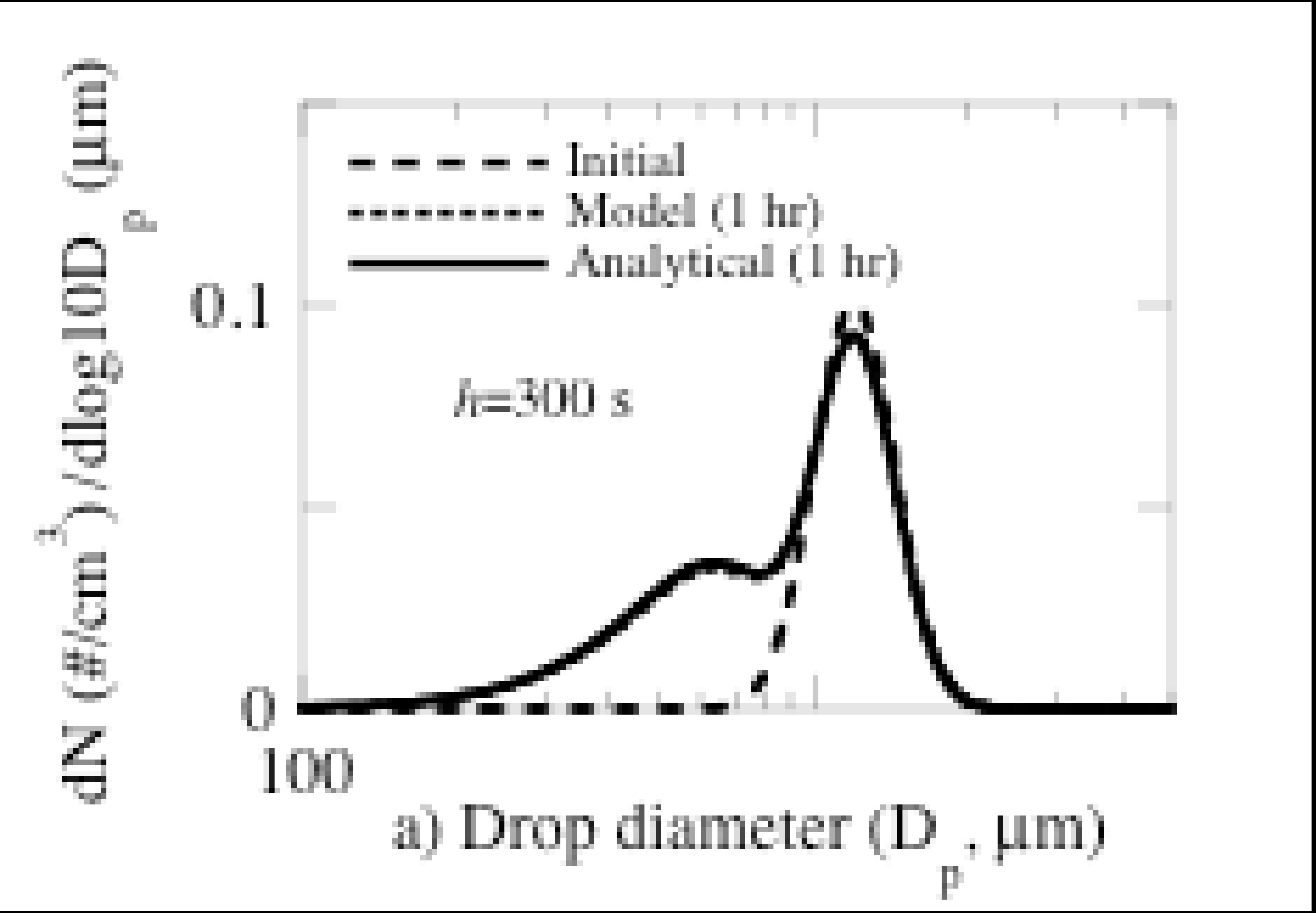
Condensation/deposition of water vapor onto aerosol particles

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

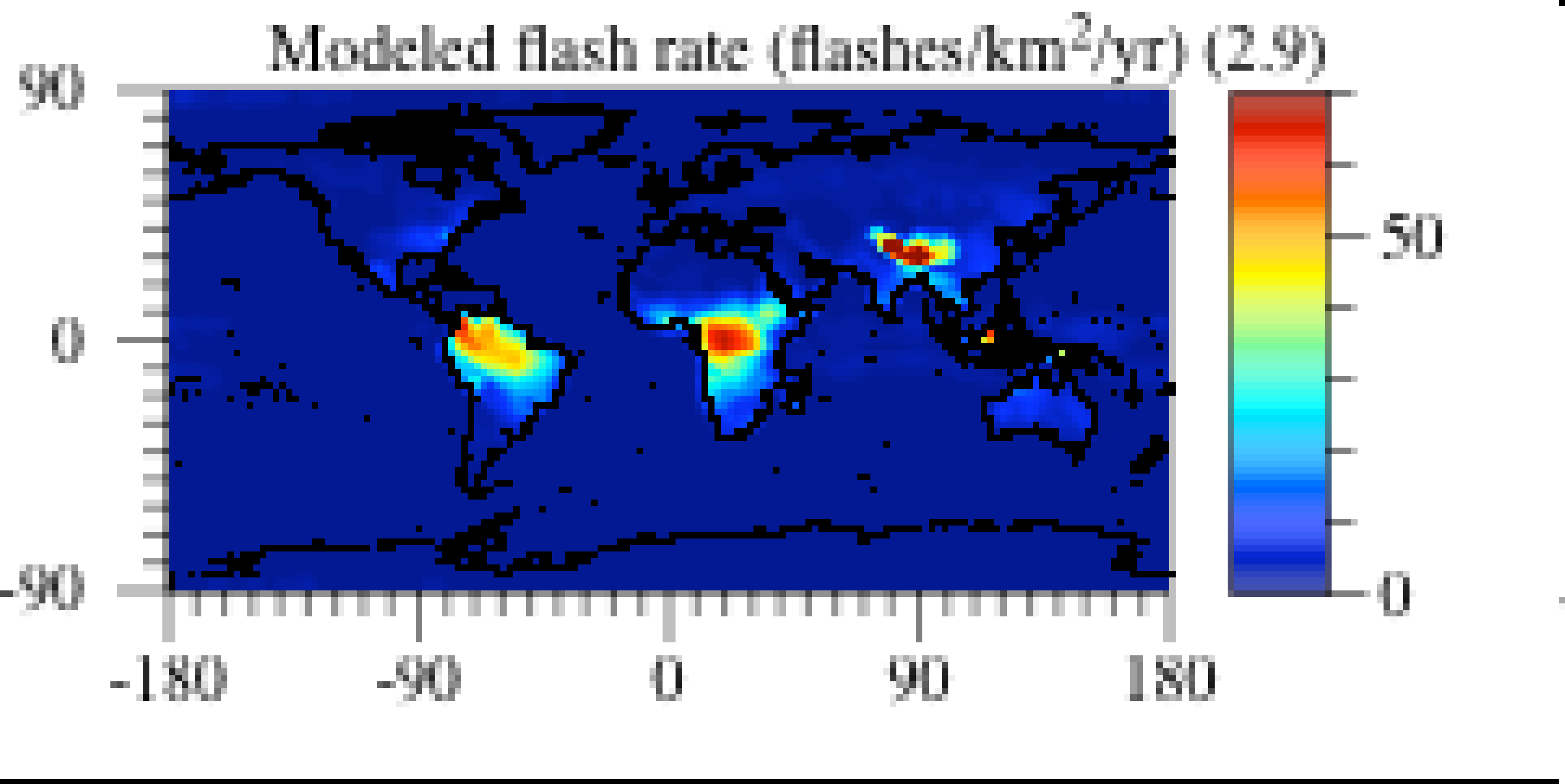


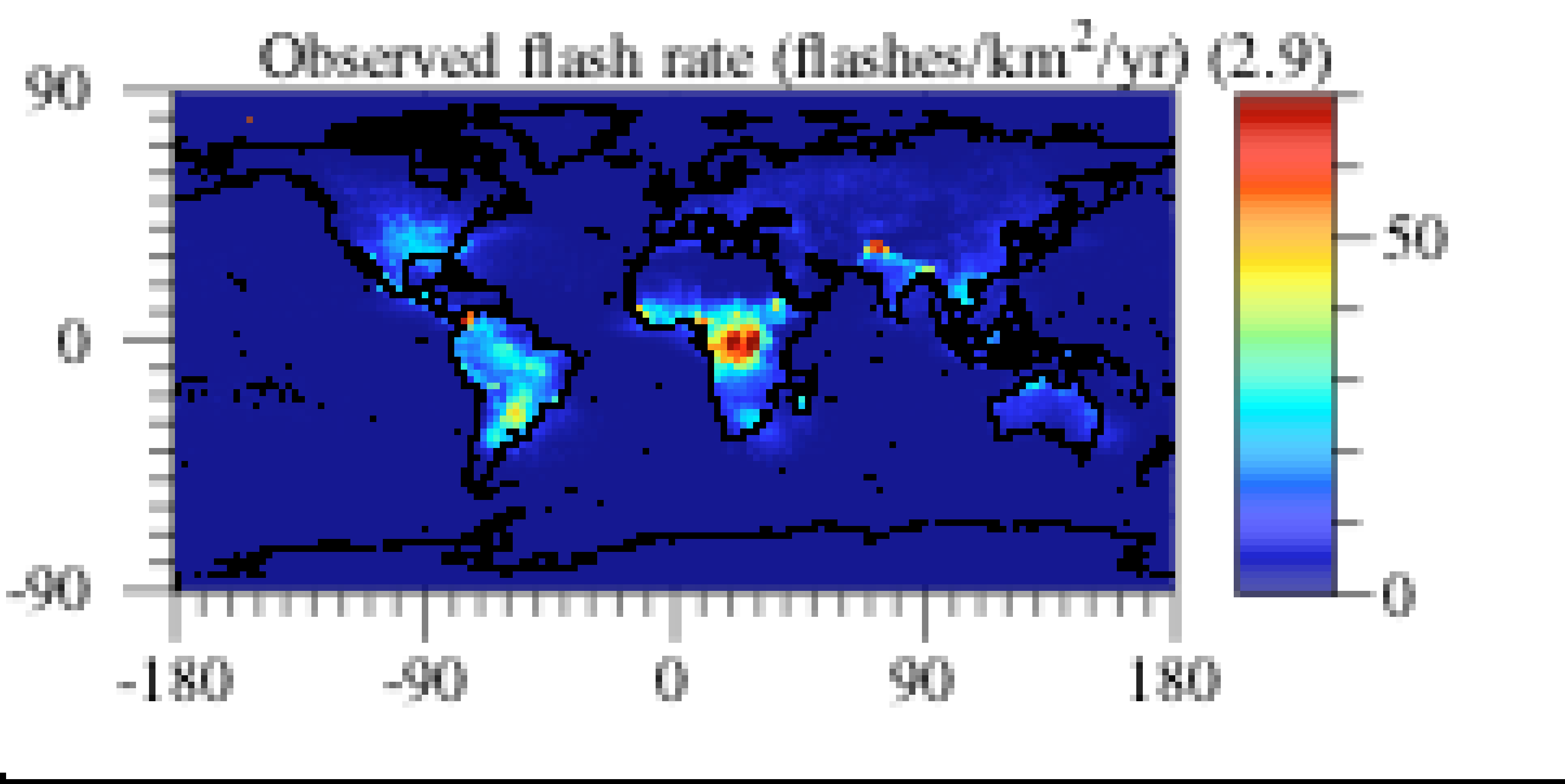
Model vs. Analytical Solution to Drop Breakup



Jacobson, JAS, 2010, in press; analytical solution from Feingold et al., 1988

Modeled vs. Measured Annual Lightning Flash Rate

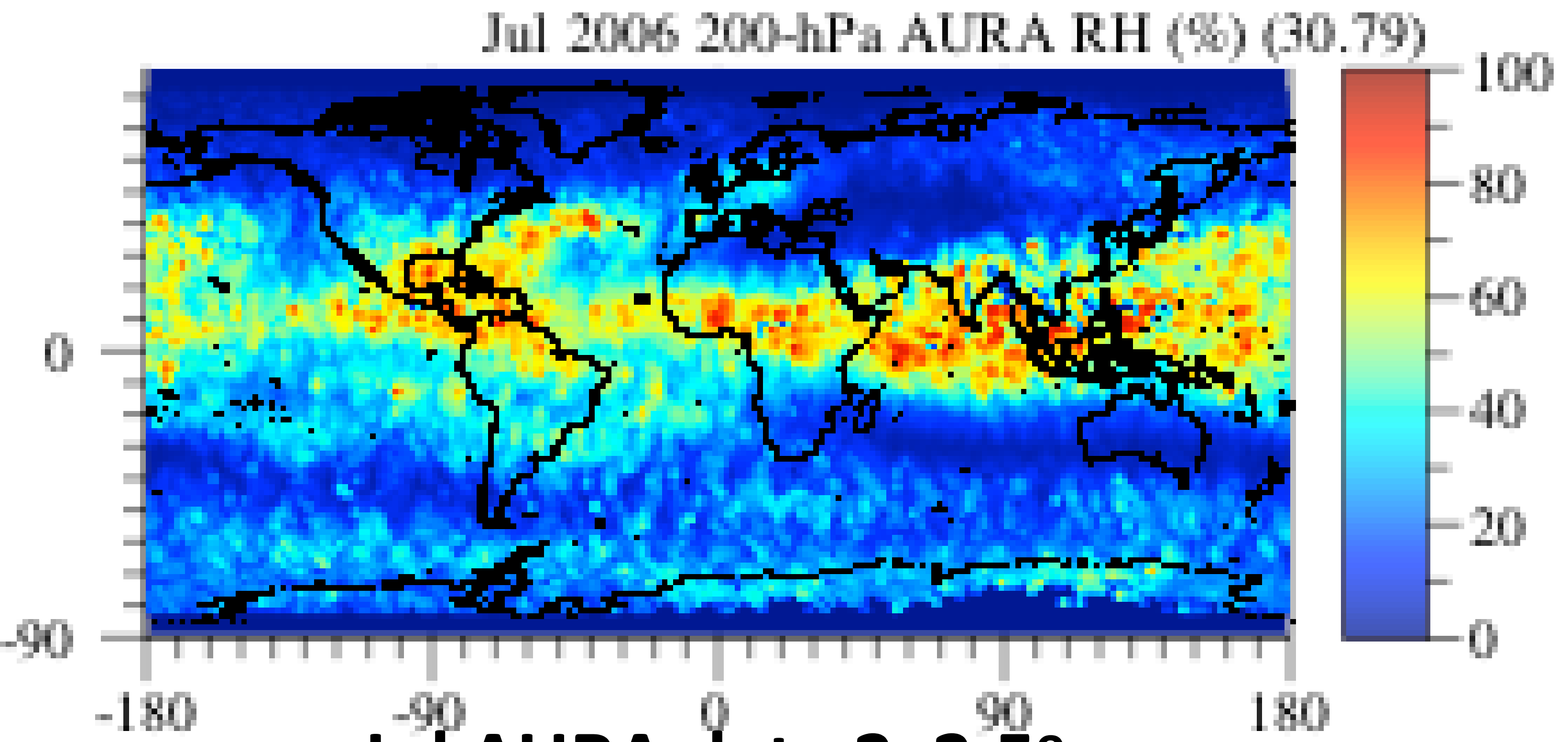




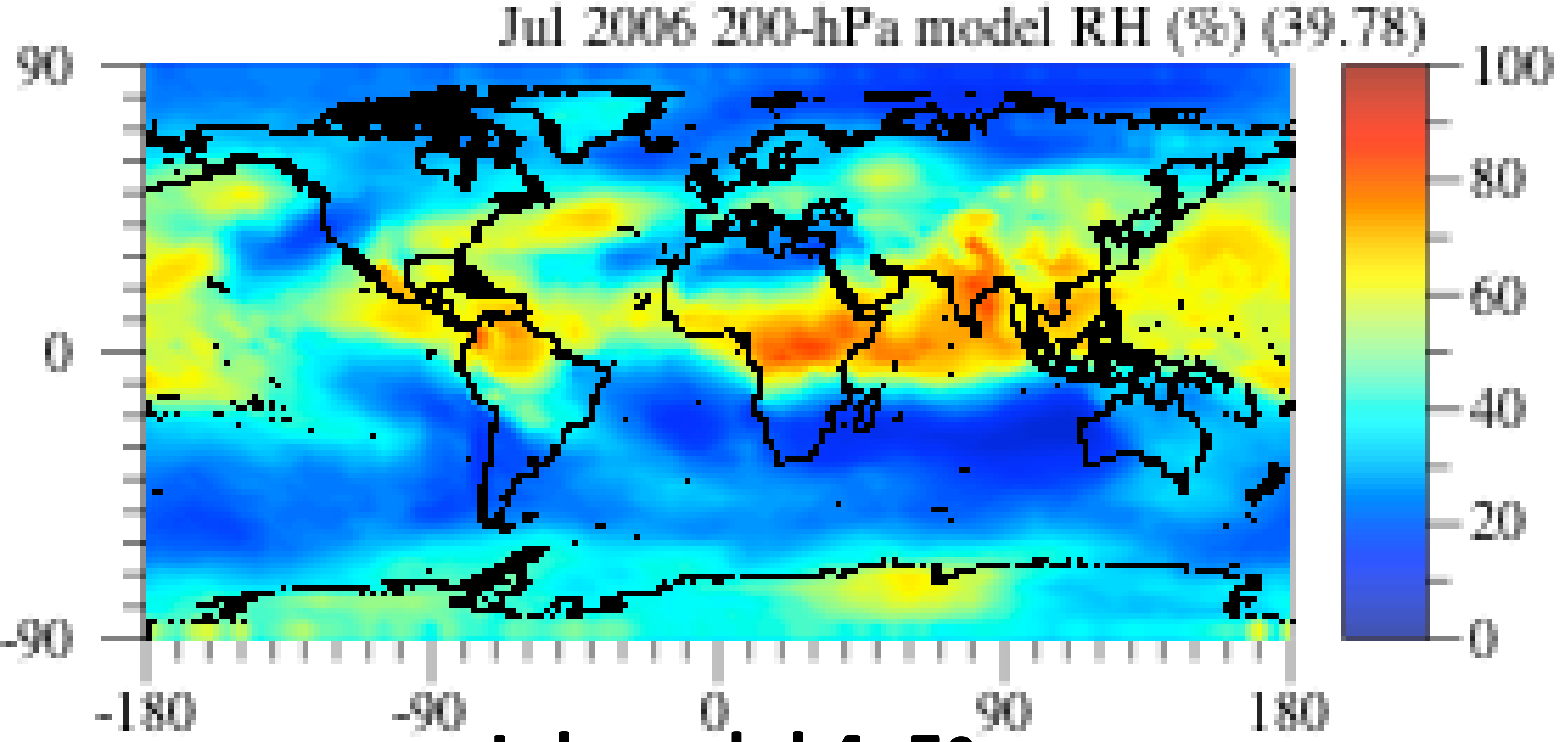
Data from NASA LIS/OTD Science Team

Model (4ºx5º resolution) calculates lightning by accounting for size-resolved bounceoffs and charge separation in clouds. Results follow from new drop breakup algorithms.

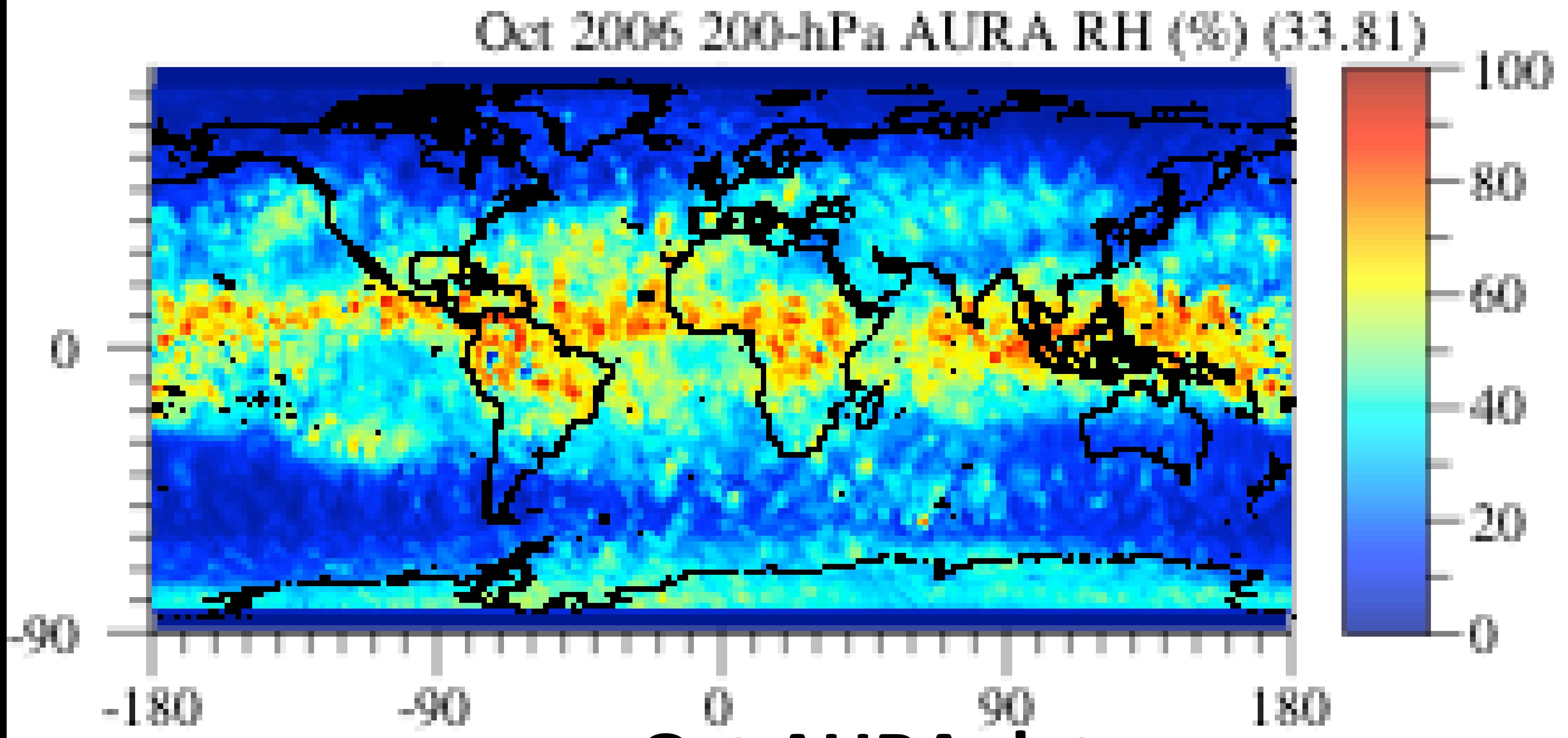
Model v. Data for RH at 200 hPa



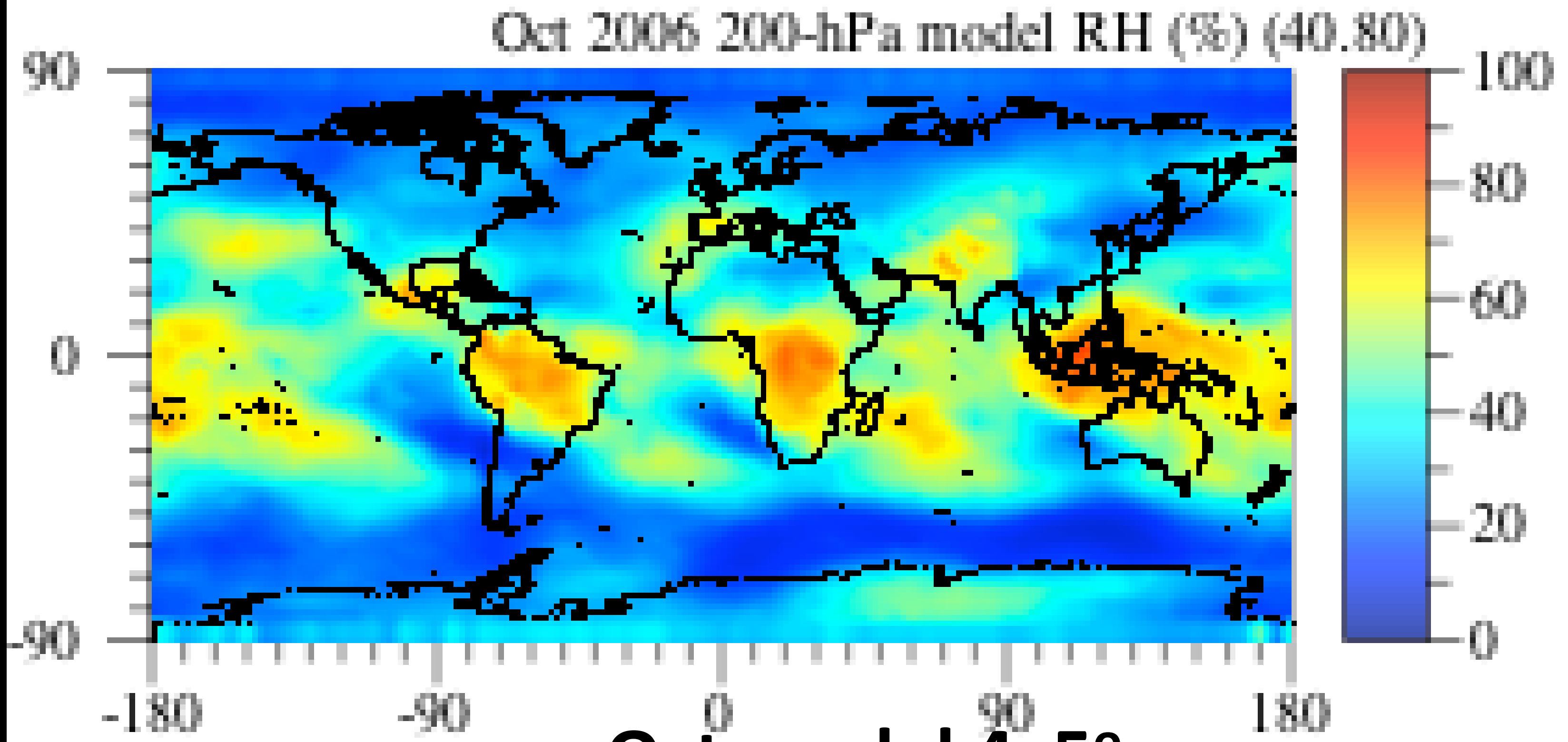
Jul AURA data 2x2.5°



Jul model 4x5°



Oct AURA data



Oct model 4x5°

Excellent agreement given data and model uncertainties and missing high-lat data

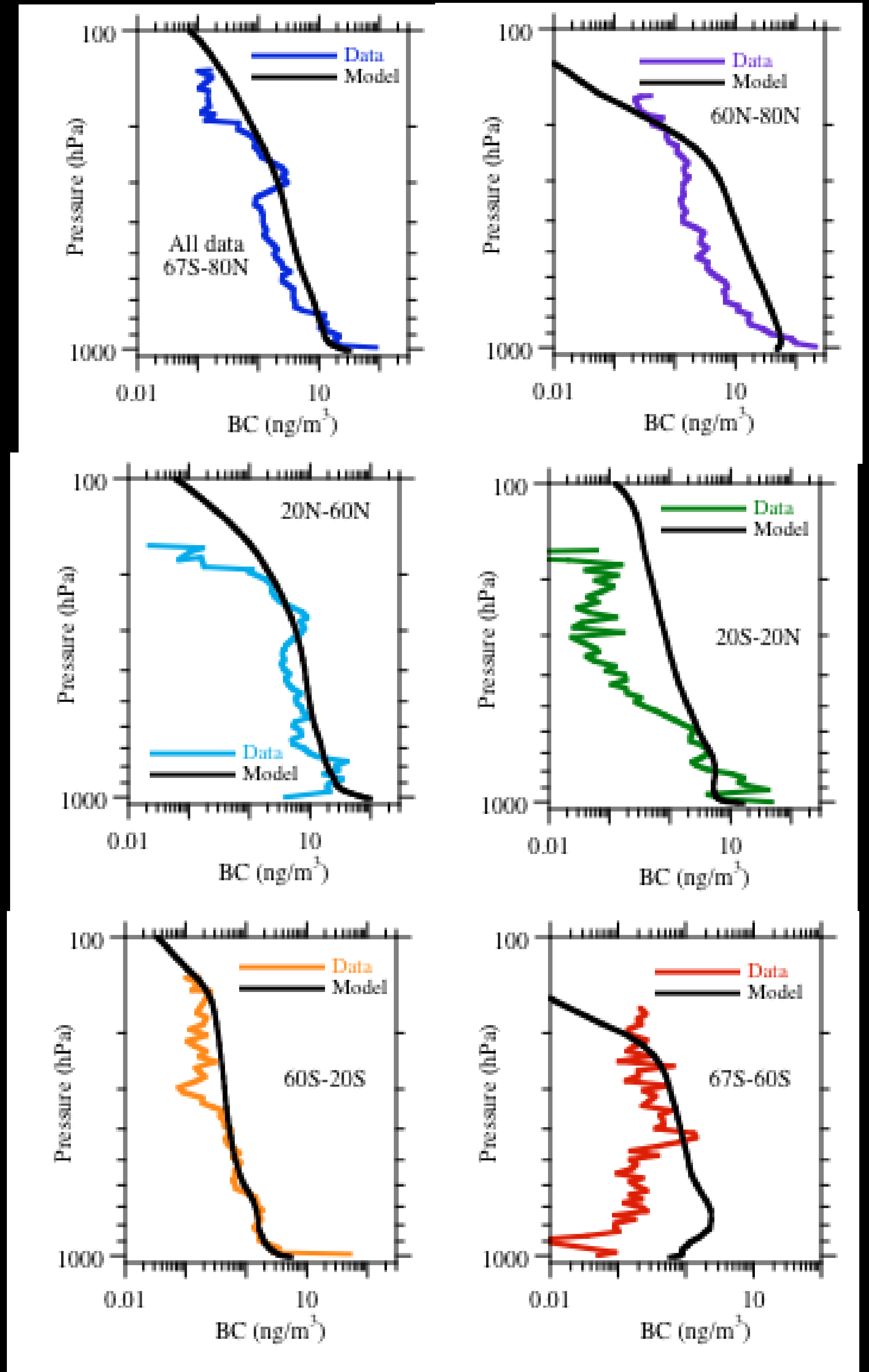
Models v. HIPPO BC Data Pacific

GATOR-GCMOM vs HIPPO (1.4% column diff. all data)

All Data | 60 - 80N

20 - 60N | 20S - 20N

60 – 20S | 67 - 60S

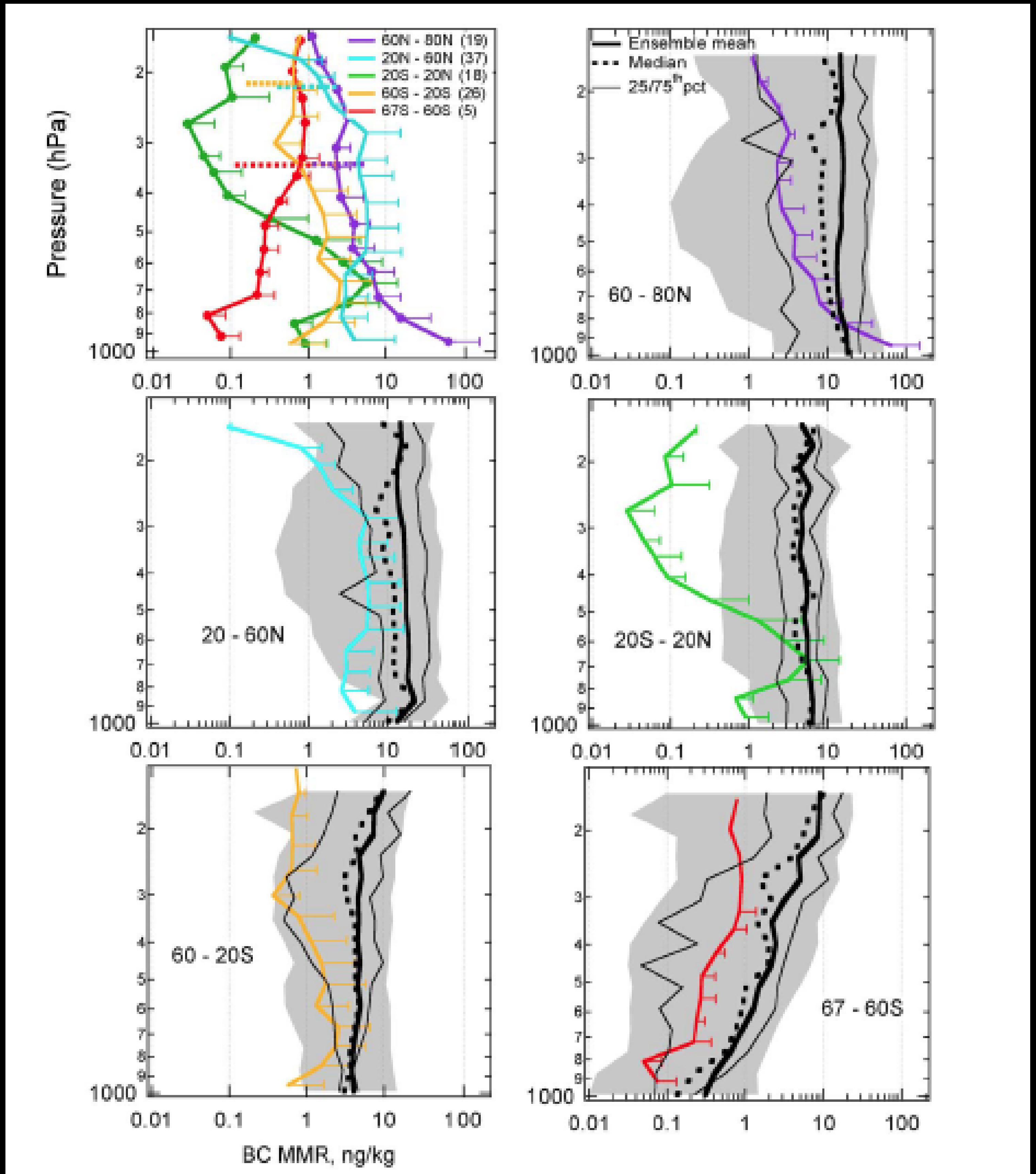


Schwartz et al. (2010) 14 Models vs. HIPPO ("Models overpredict by factor of five")

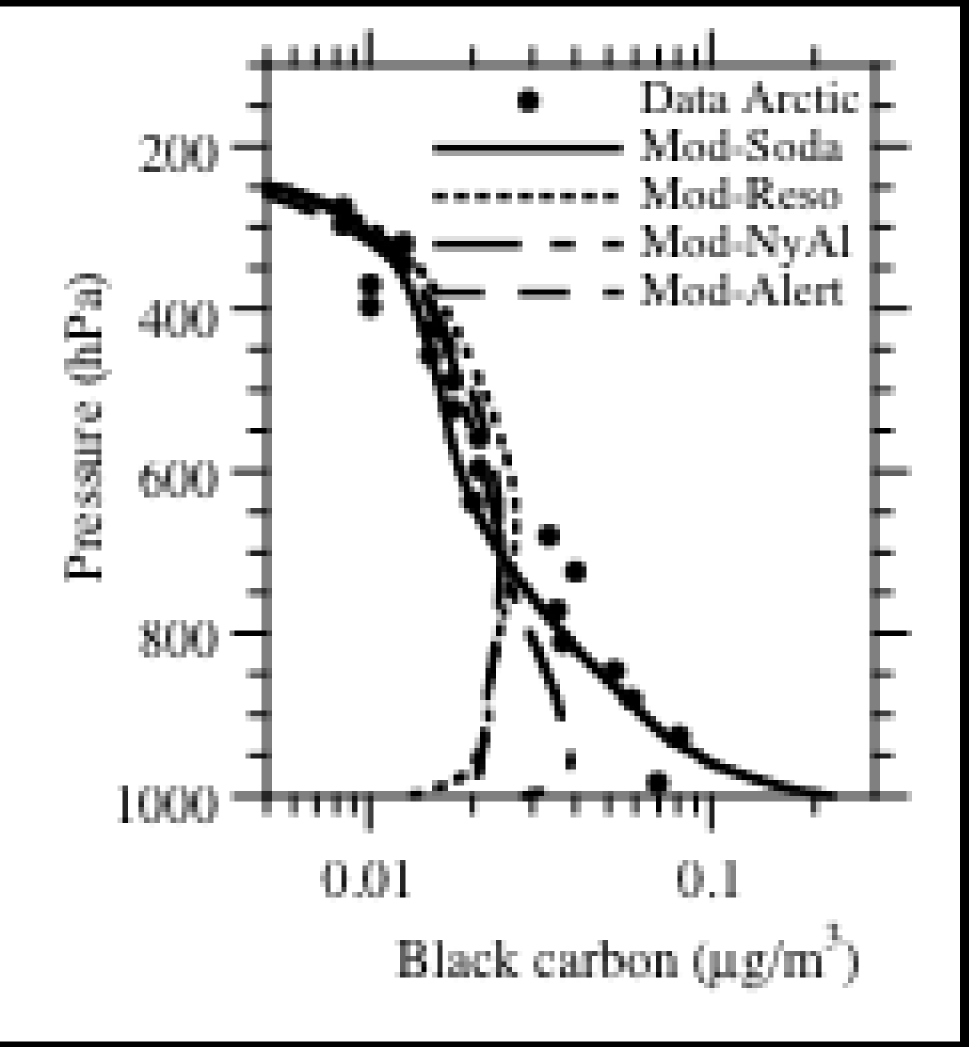
All Data | 60 - 80N

20 - 60N | 20S - 20N

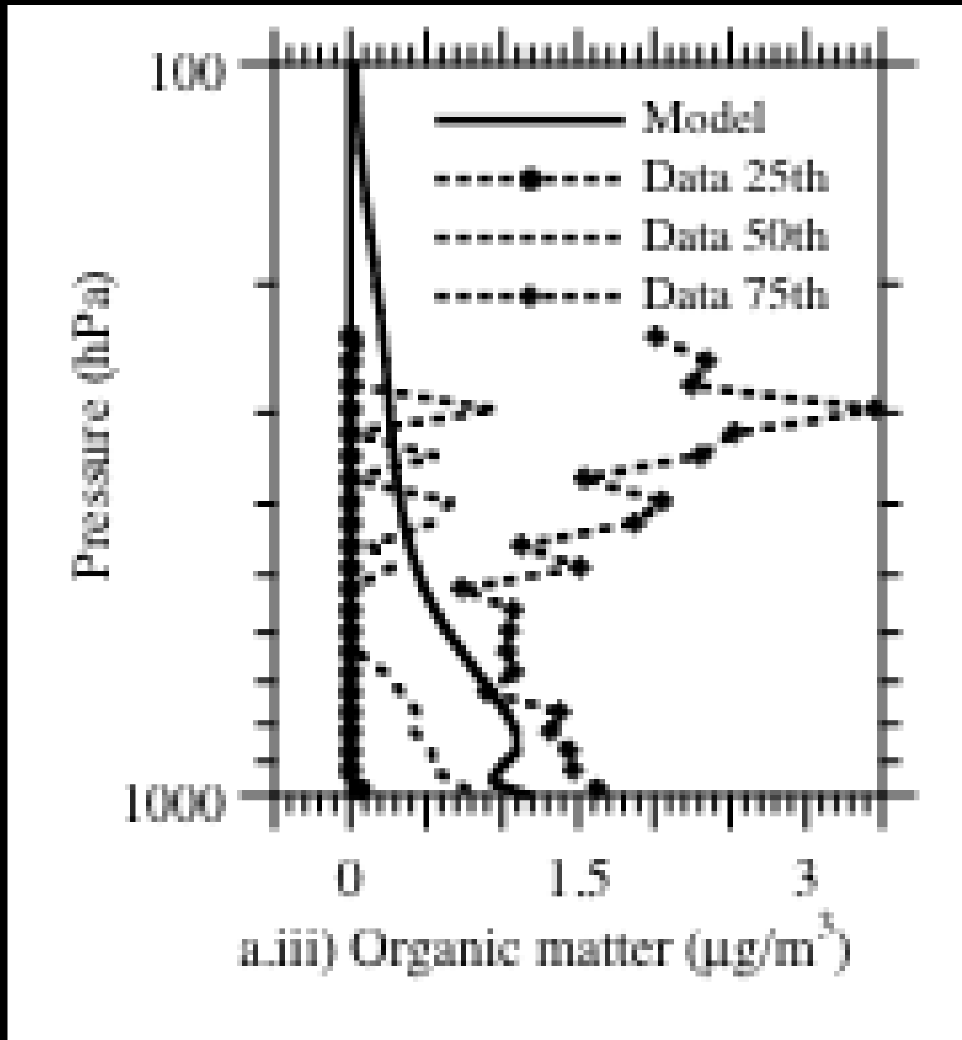
60 – 20S | 67 - 60S



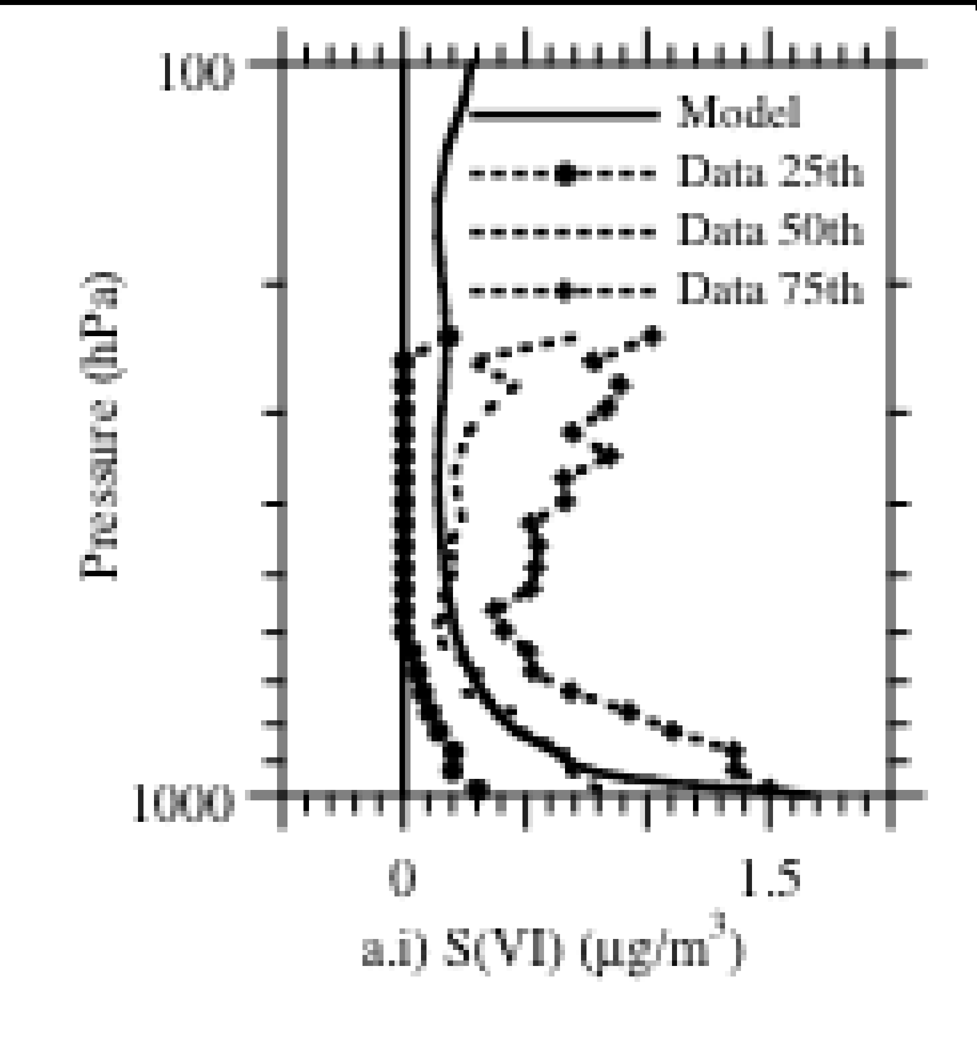
Comparison of Modeled Vertical Profiles with Data



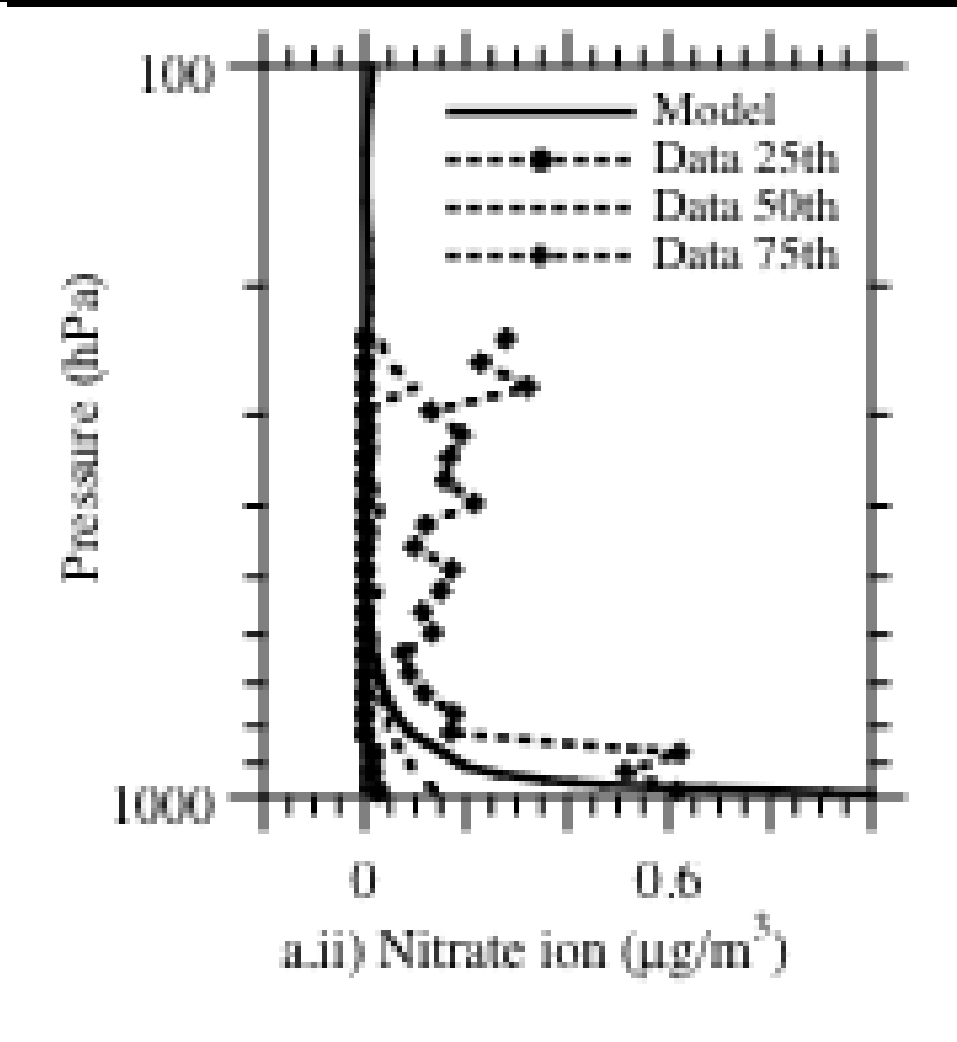
BC



Organic Matter



Sulfate

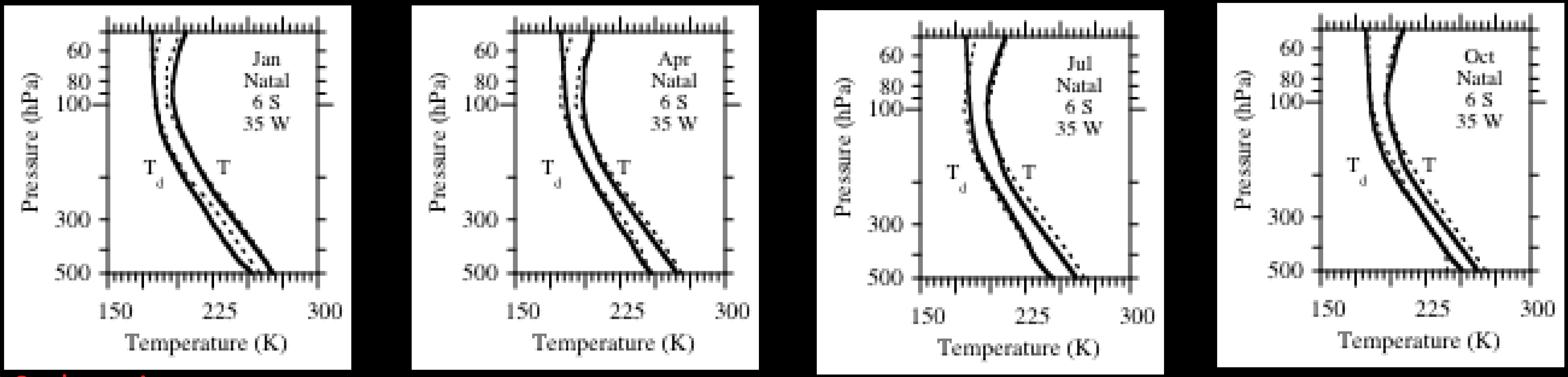


Nitrate

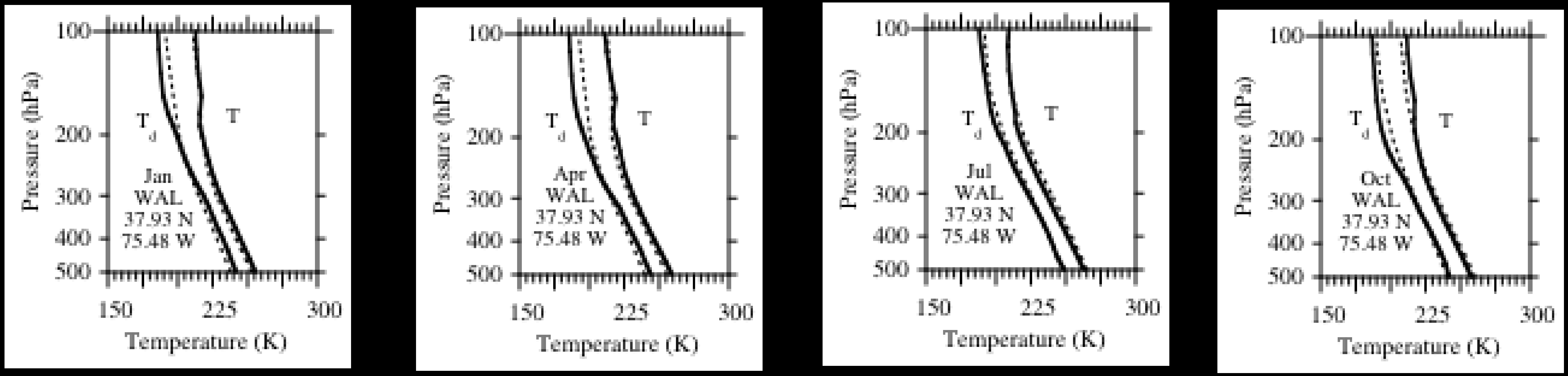
BC: Hansen and Novakov, 1989; Quinn 2007; Others: Morgan et al., 2009

Modeled vs. Measured Paired in Space Monthly T/T_d

Global domain



U.S. domain

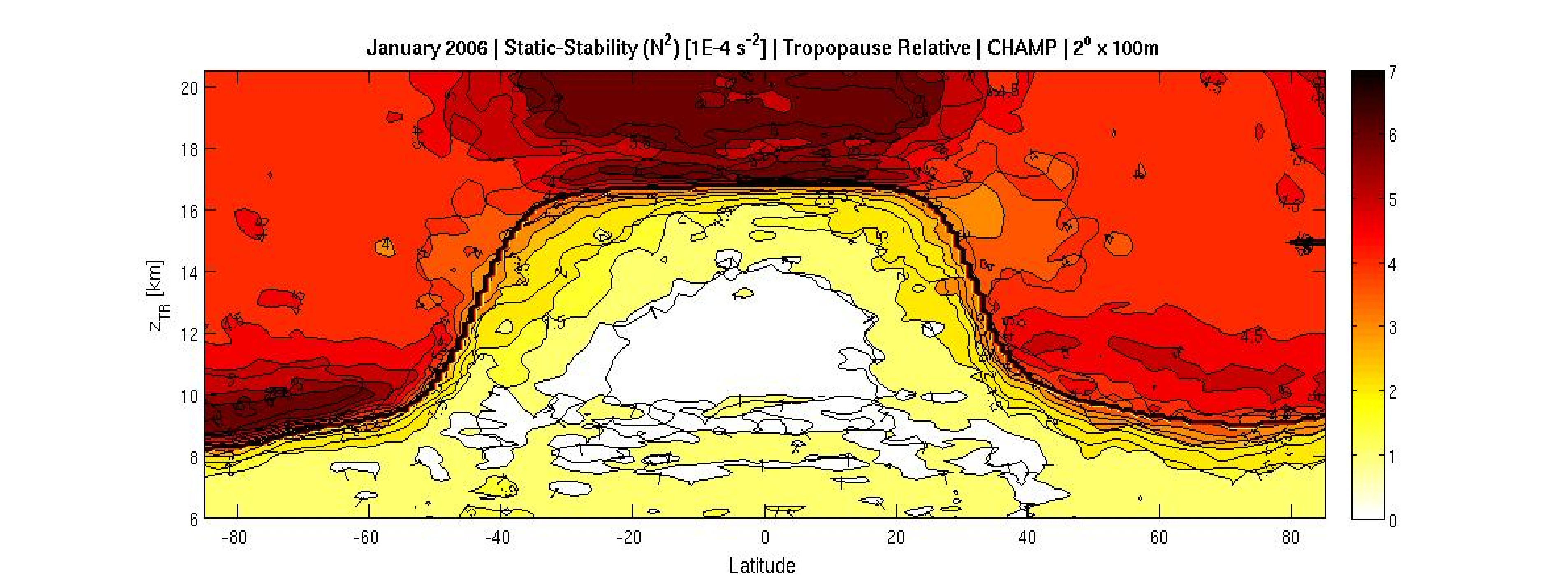


Little numerical diffusion of water vapor or energy to stratosphere

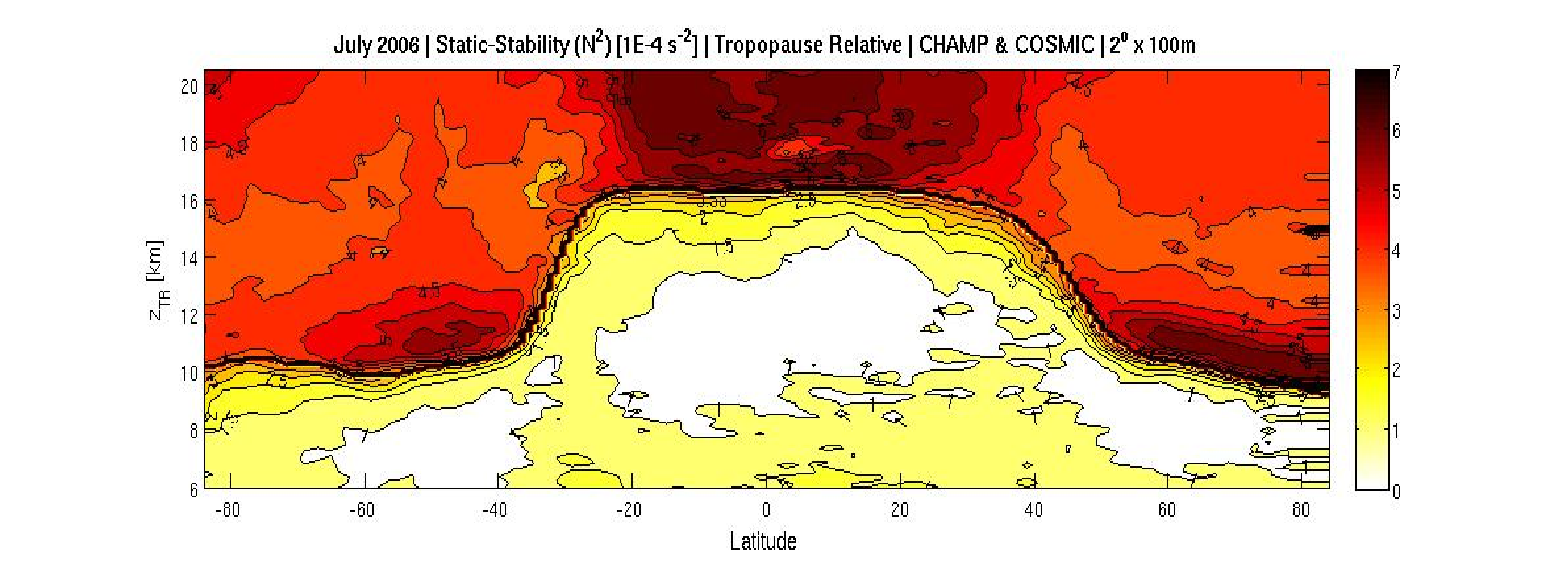
Data from FSL (2008)

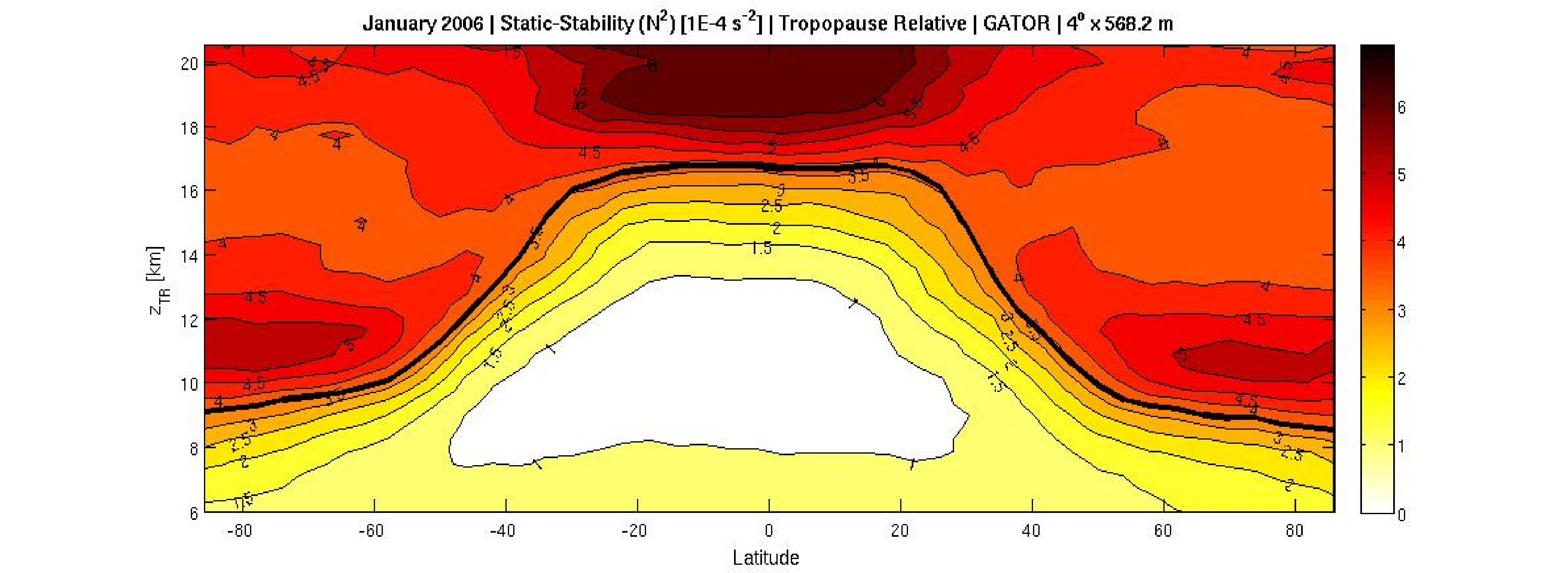
Model v. Data for BV Freq/Trop Height

Jan COSMIC/CHAMP data 2x20º 100 m

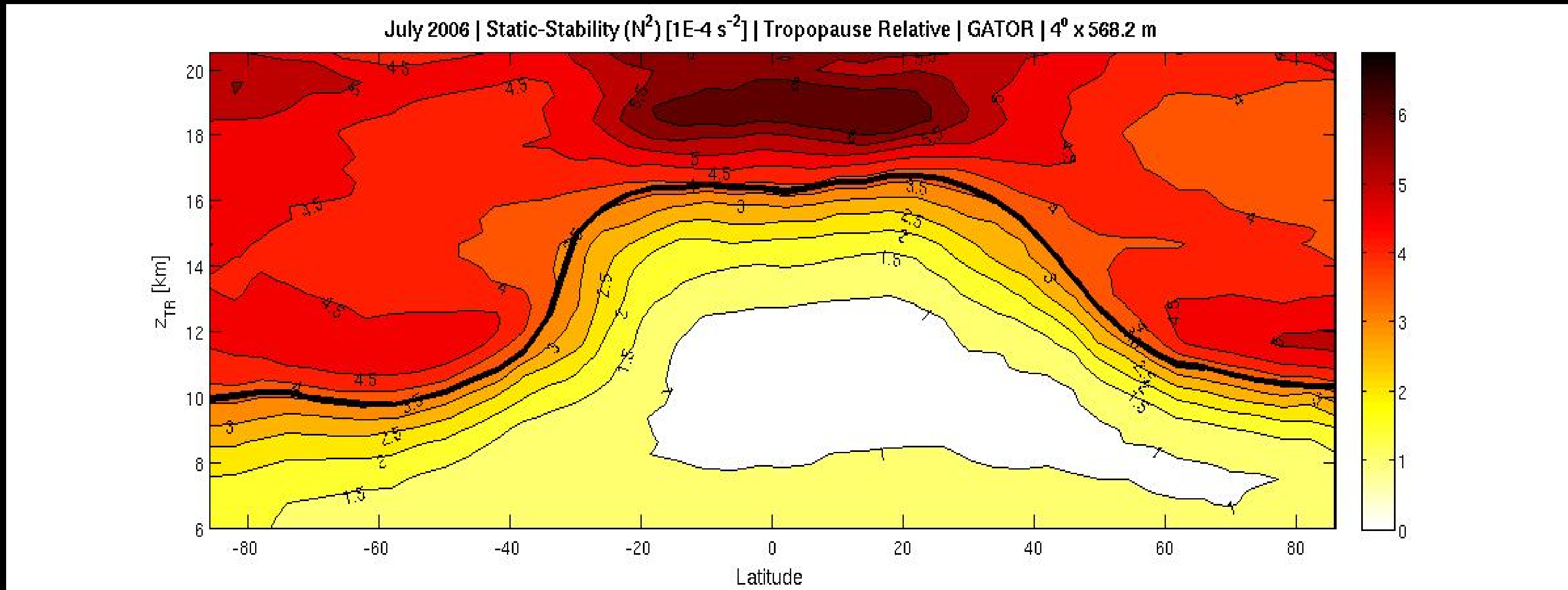


Jul COSMIC/CHAMP data





Jan model 4x5º x 500 m

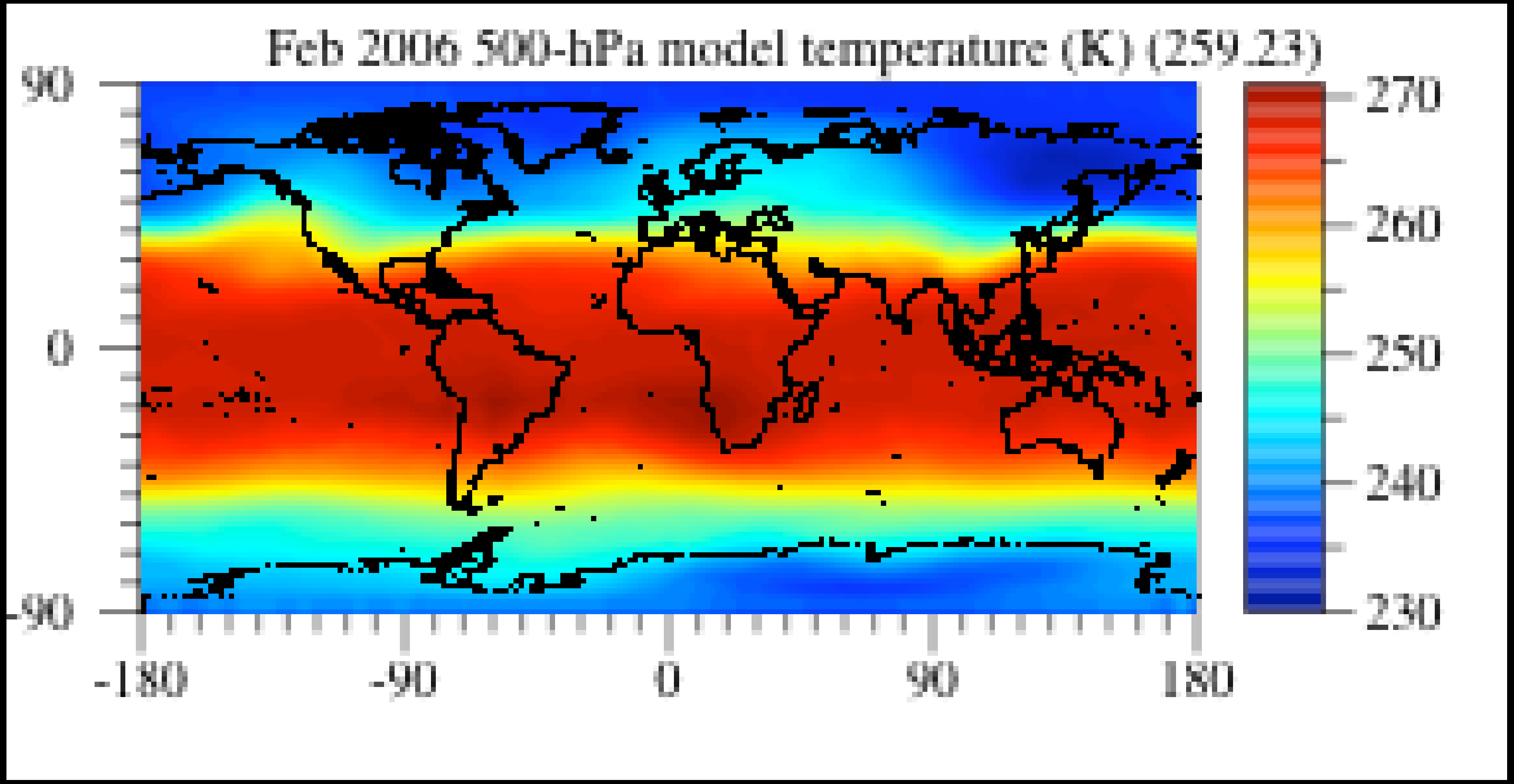


Jul model 4x5 degrees

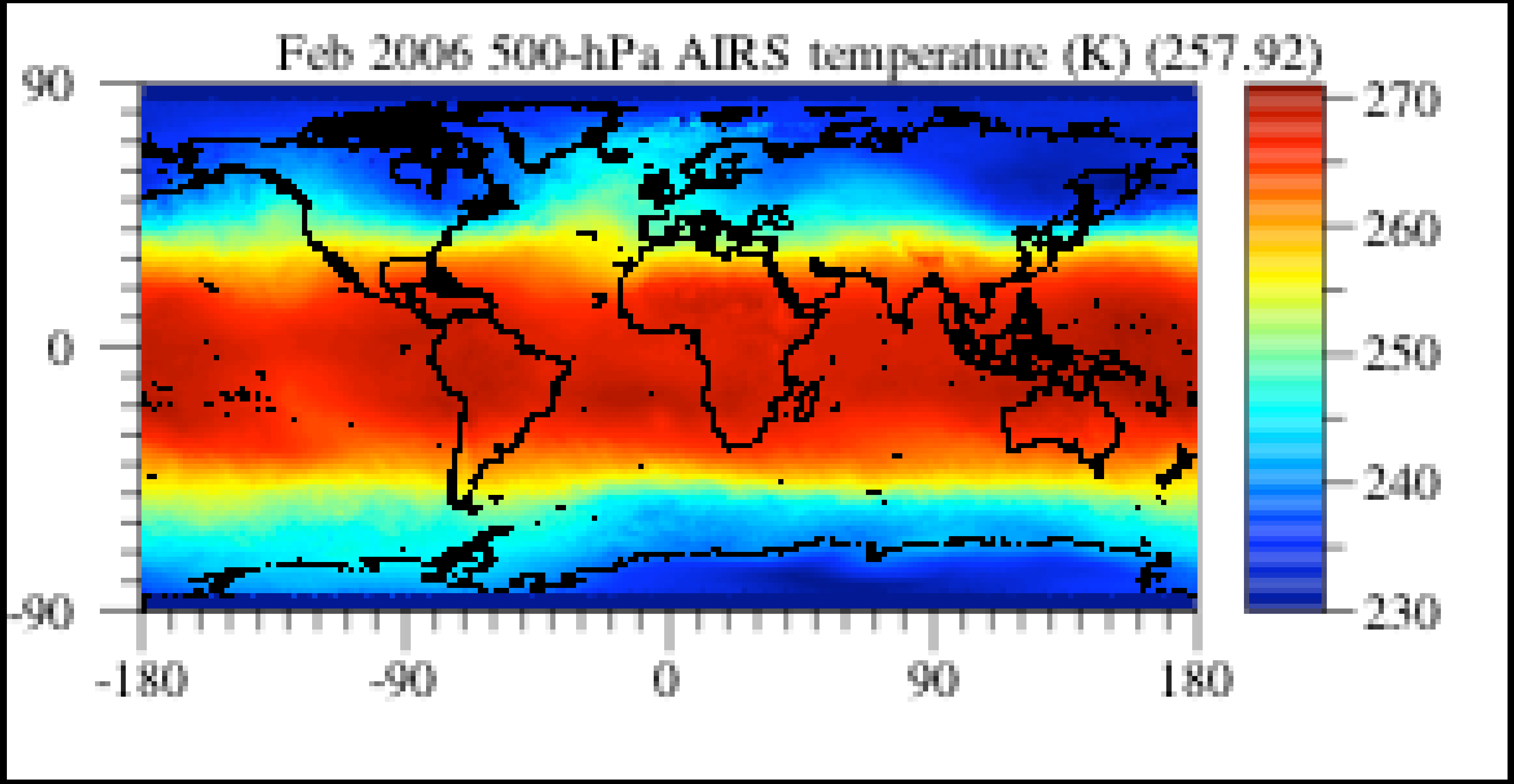
Tropopause-relative coordinates (Whitt et al., 2011)

Modeled vs. Measured 500-hPa January Temperature

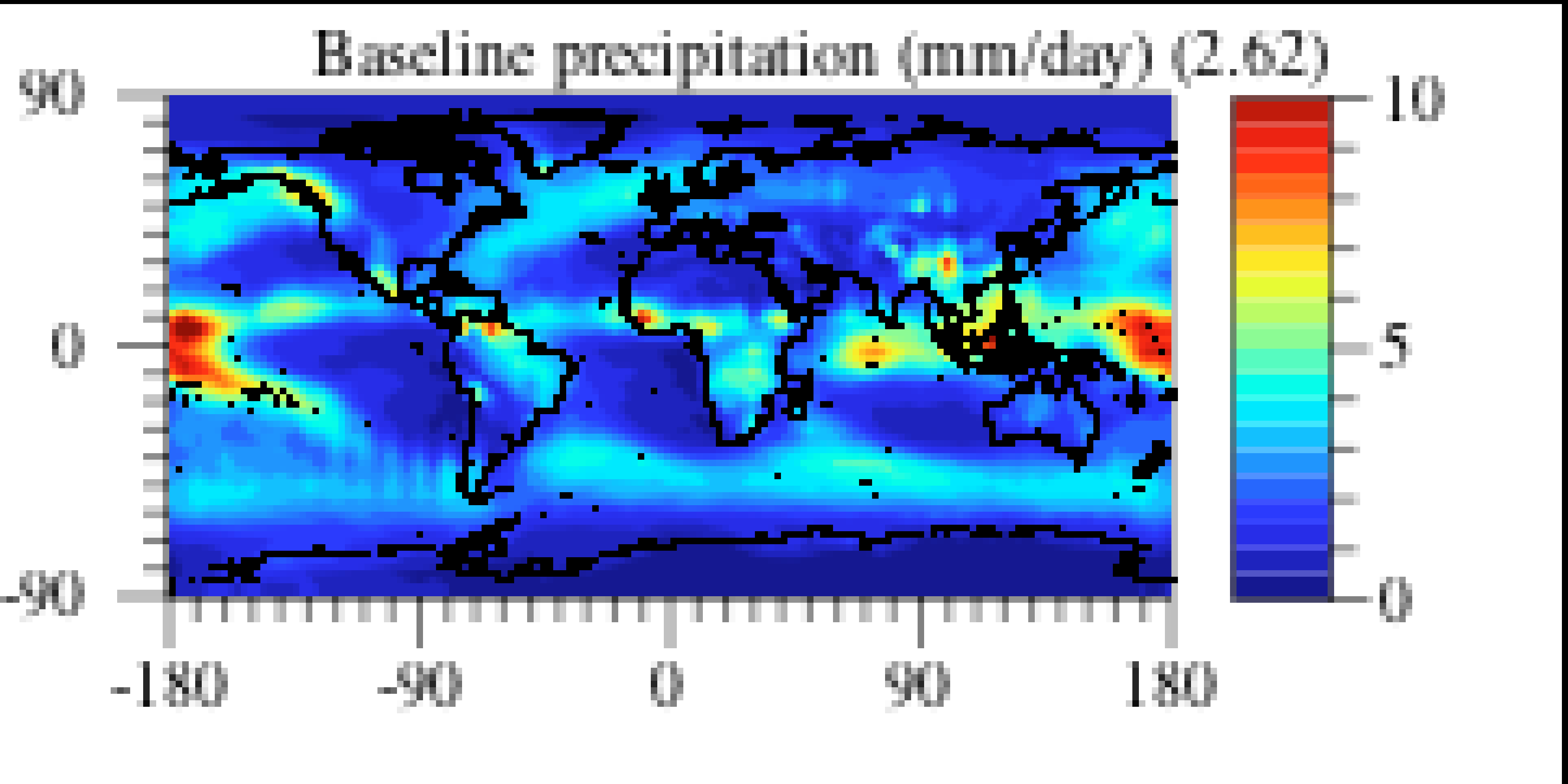
Model

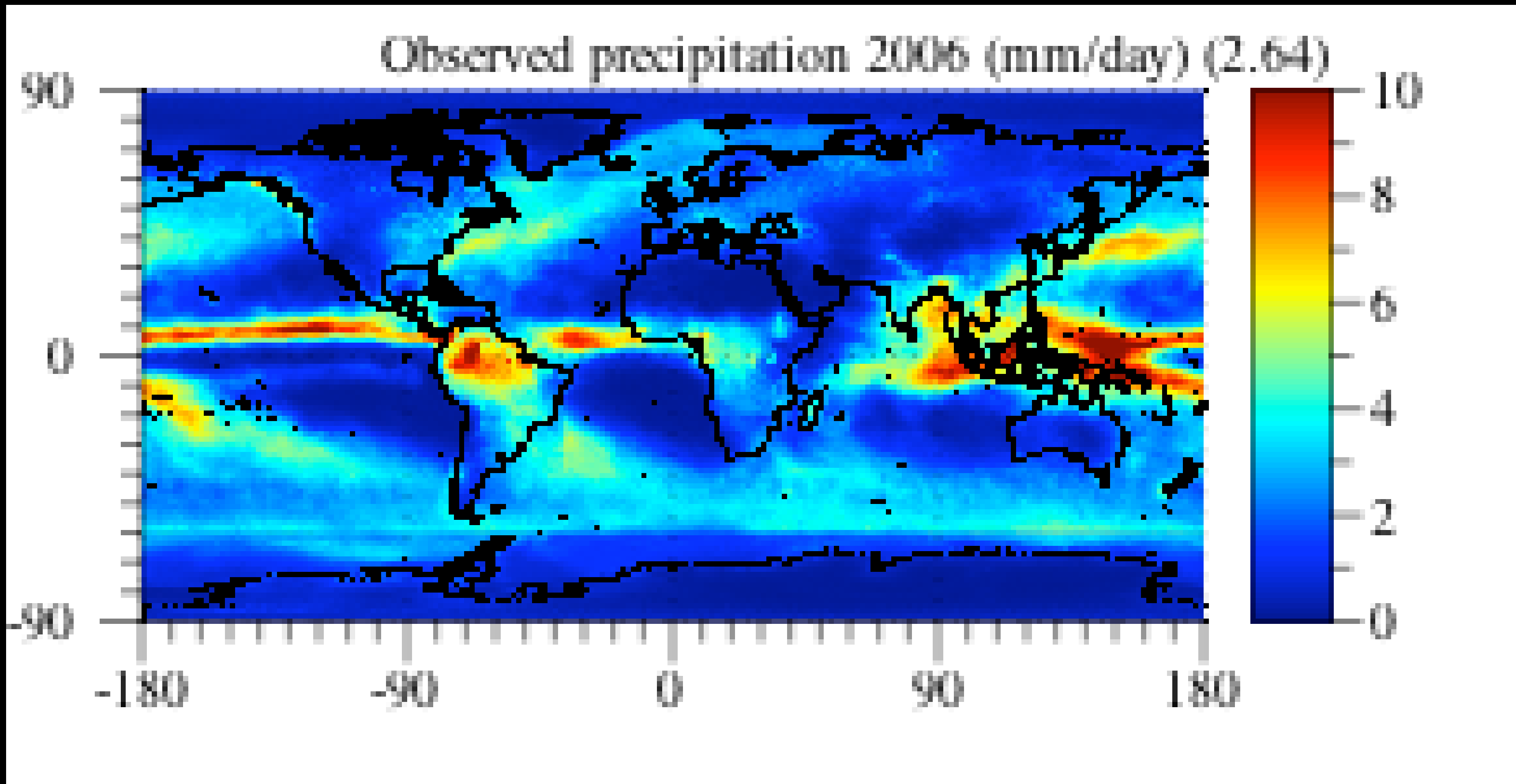


AIRs Satellite



Modeled vs. Measured Precipitation



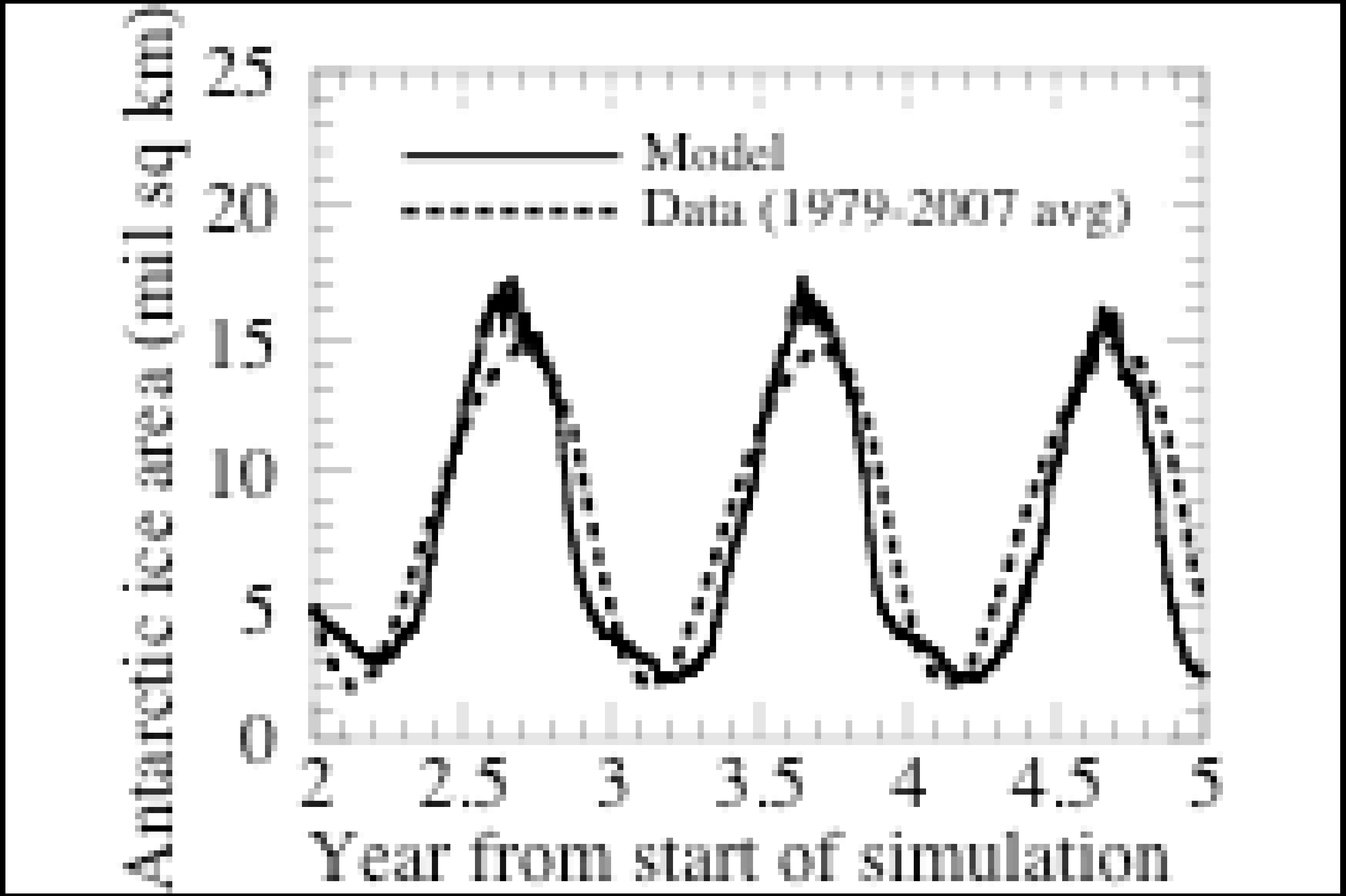


Data from Huffman et al (2007)

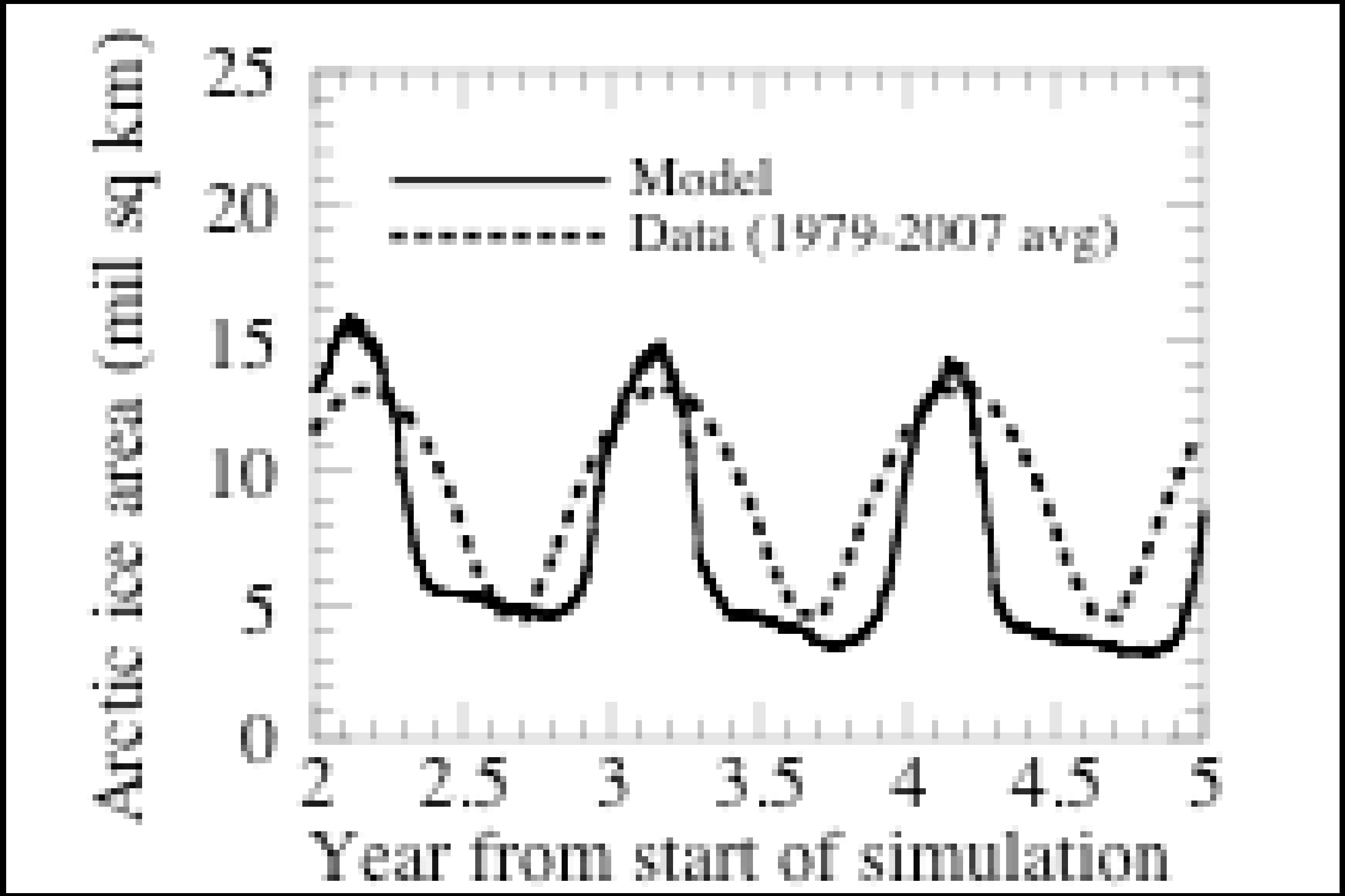
Despite factor of 20 lower resolution than data, model predicts locations of main features of observed precipitation and, with no flux adjustment, correctly does not produce a double ITCZ

Modeled vs. Measured Sea Ice Area

Antarctic



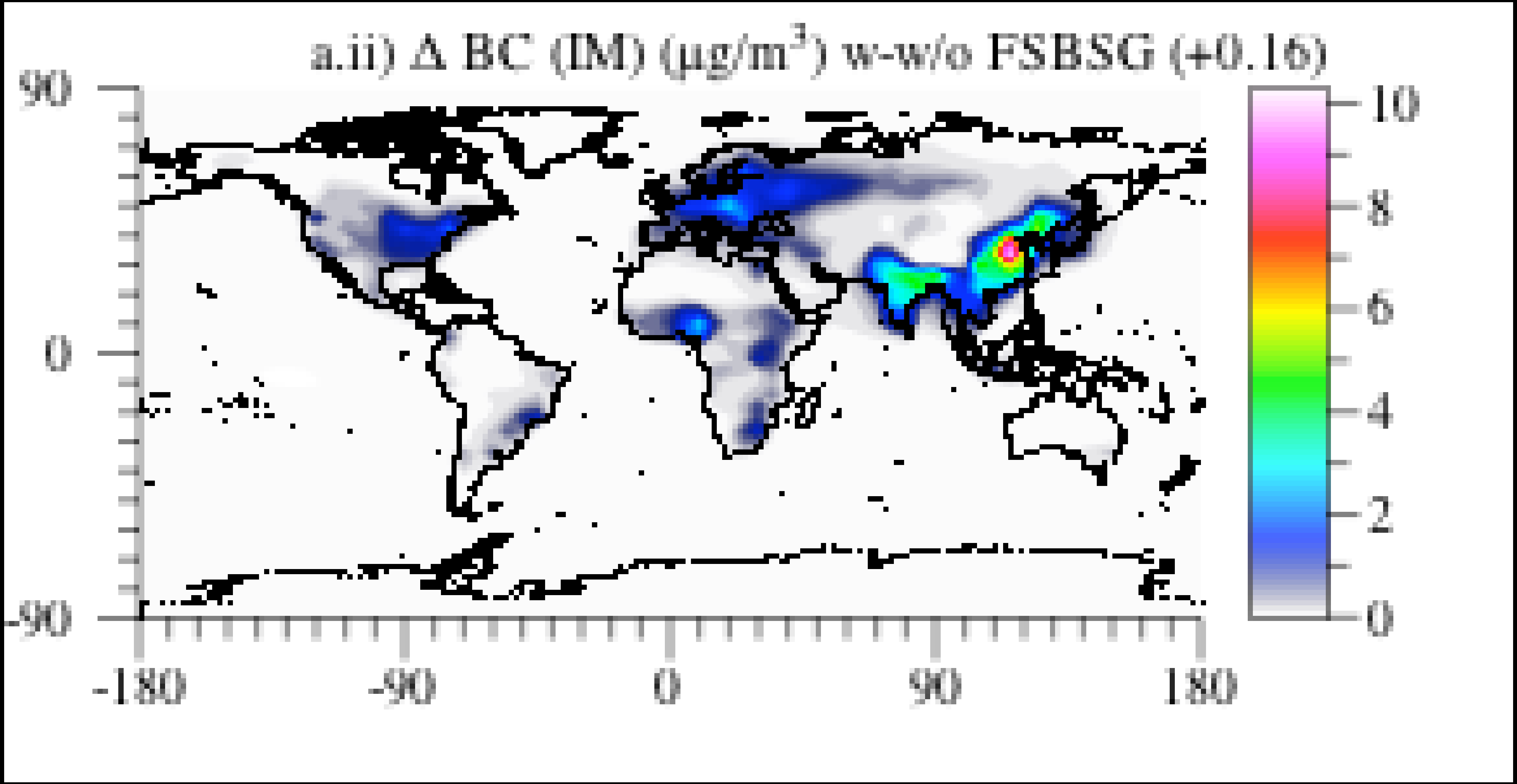
Arctic



Model (at 4 x 5 degree resolution) predicts stable sea ice area

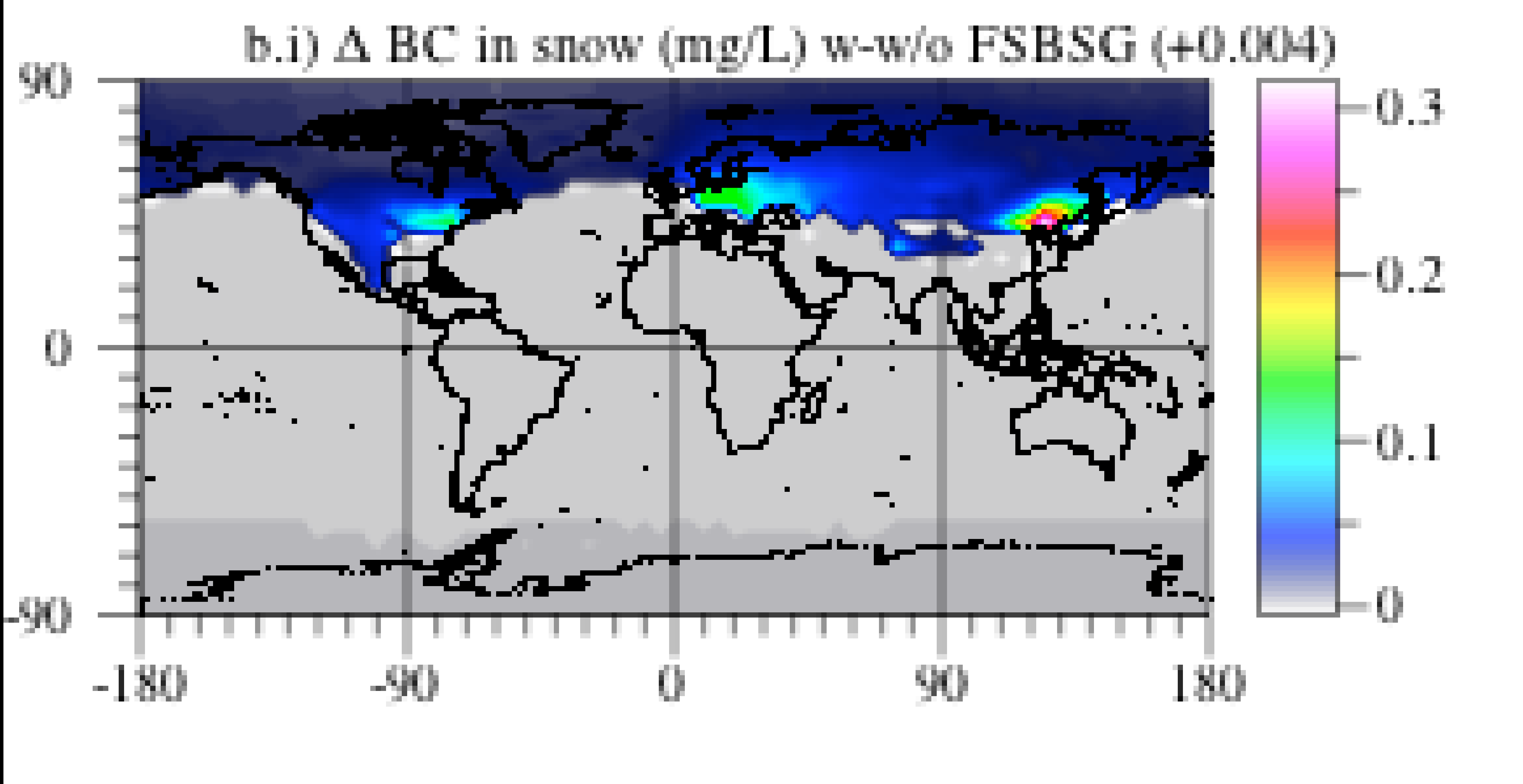
Data from NASA Team (2009)

Black Carbon From Fossil- and Bio-fuel Soot

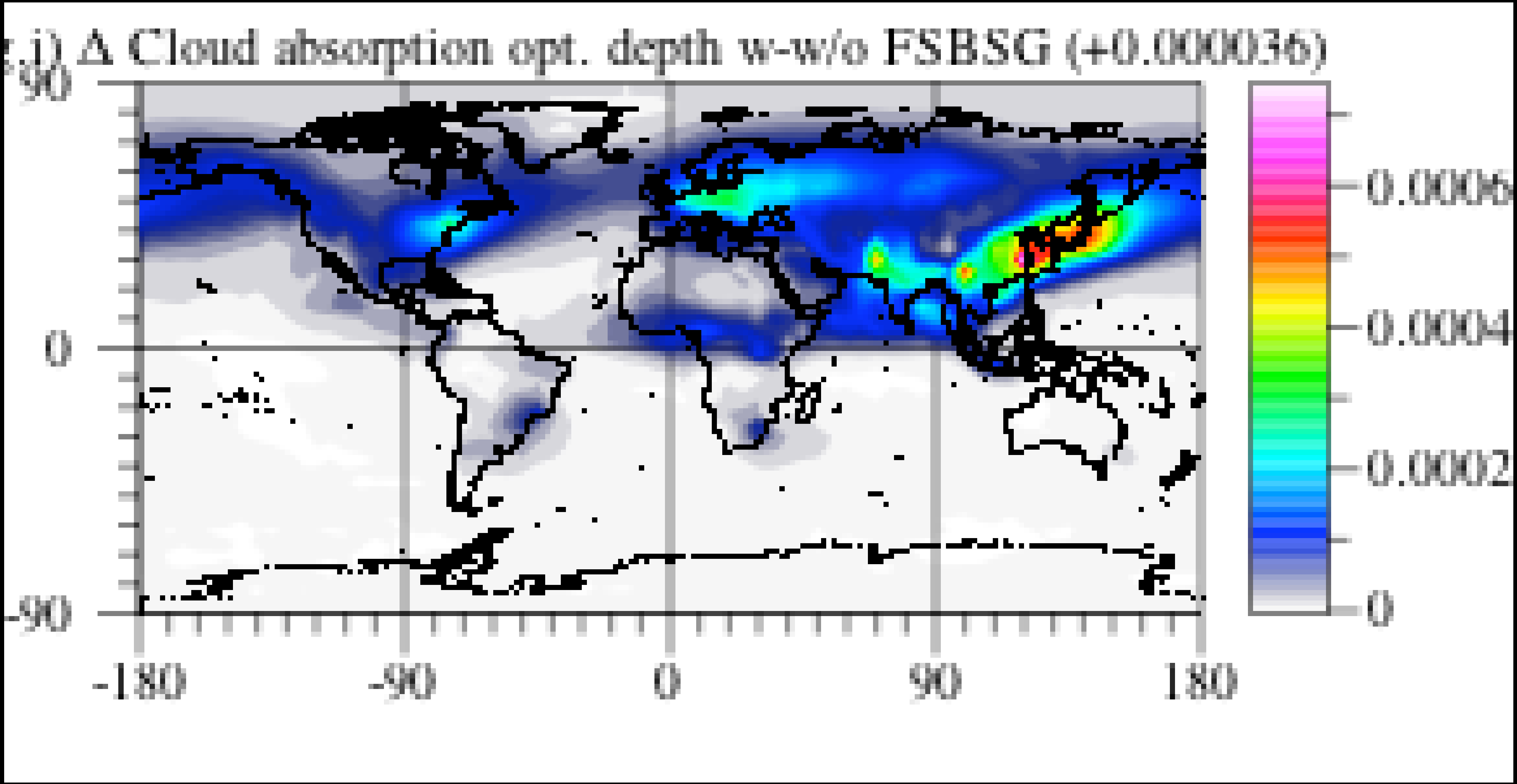


BC from FF soot is about half that of BC from FF+BF soot

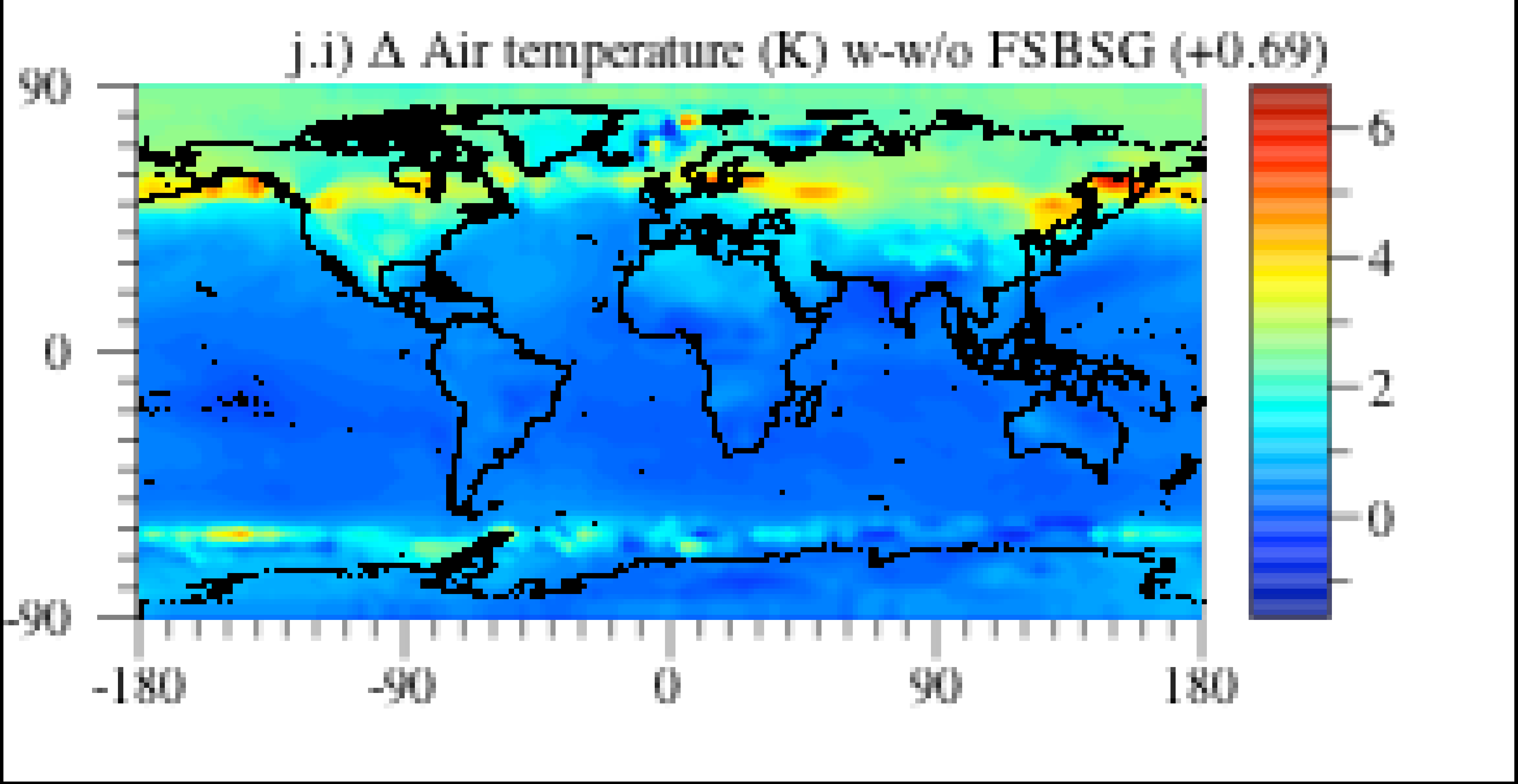
Black Carbon in Snow and Sea Ice



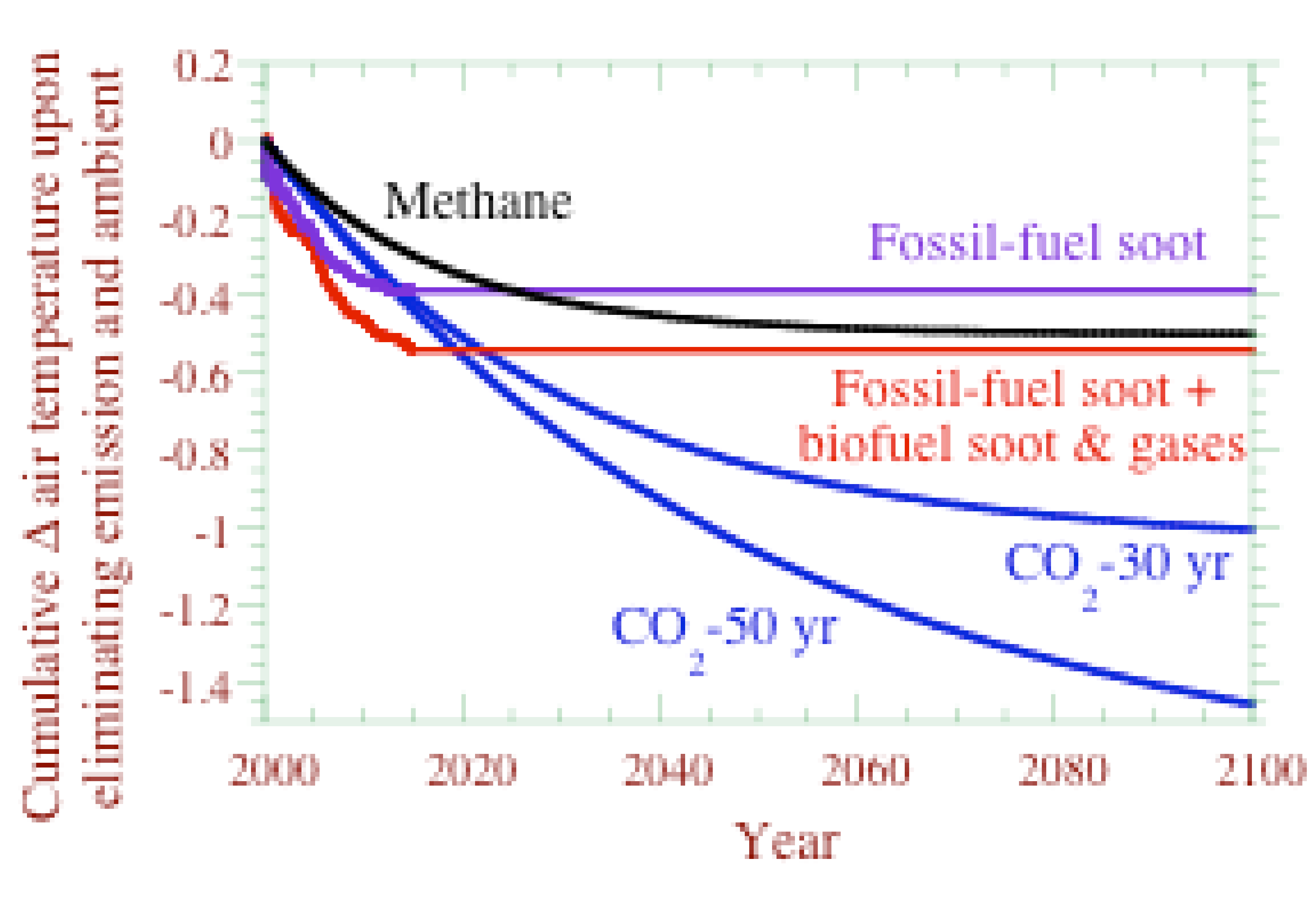
Black Carbon Absorption in Clouds



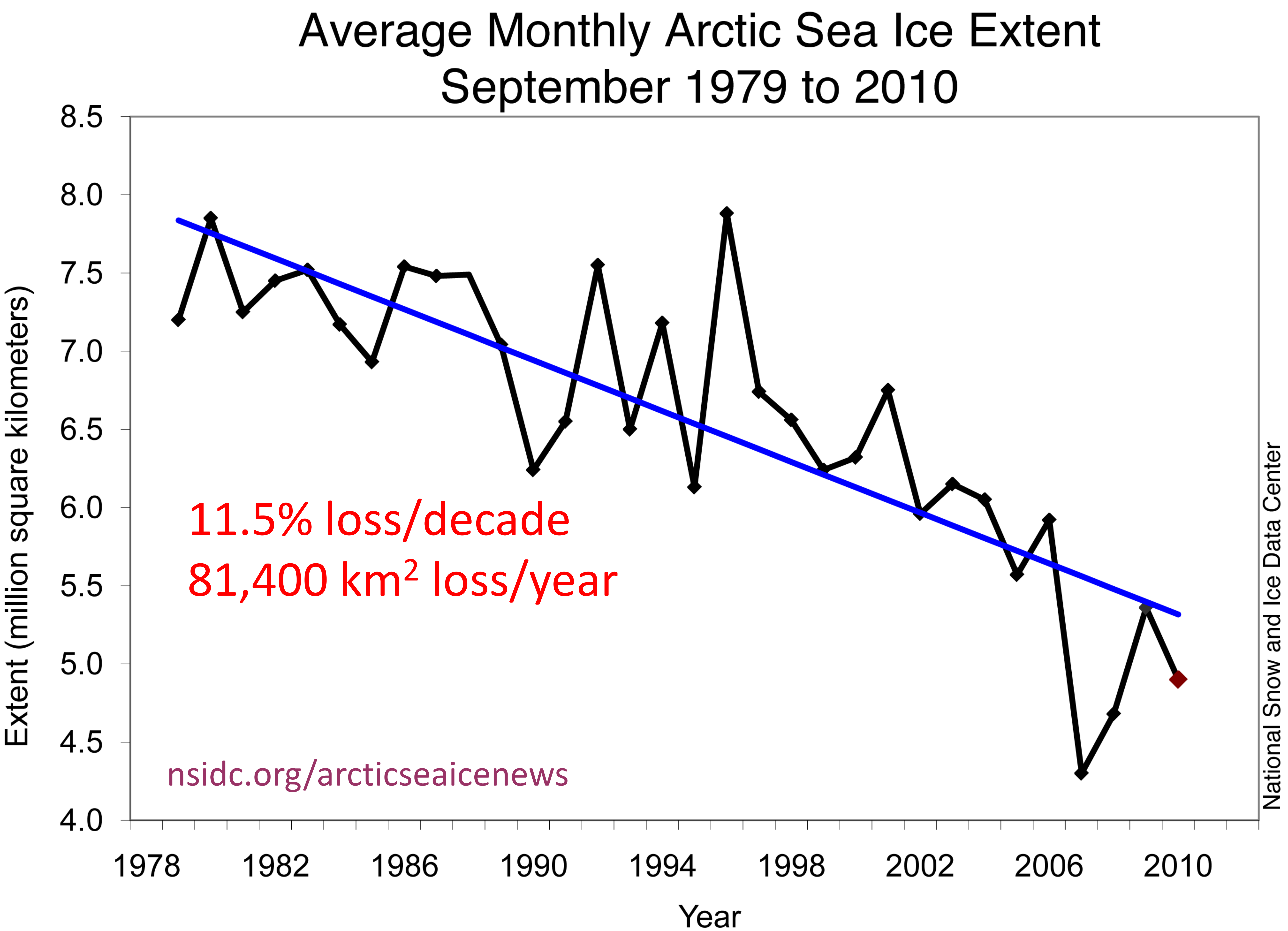
Surface Air Temperature Changes Due Fossil-Fuel Soot Plus Biofuel Soot and Gases



Fossil-Fuel Soot and Biofuel Soot & Gas Controls may be Fastest Method of Slowing Global Warming and Saving Arctic Ice

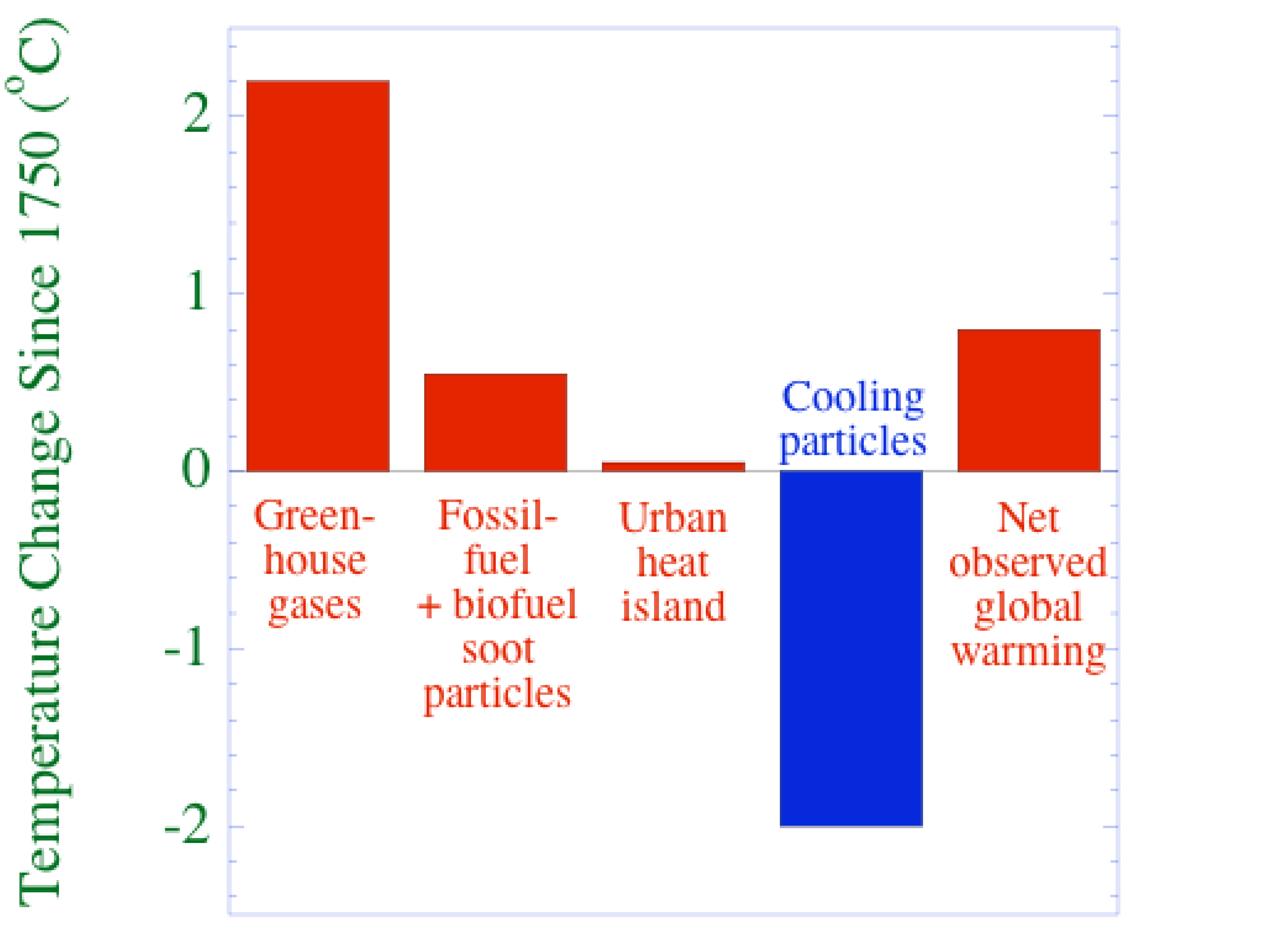


www.stanford.edu/group/efmh/jacobson/controlfossilfuel.html



Average Monthly Arctic Sea Ice Extent
September 1979 to 2010
Extent (million square kilometers)
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
11.5% loss/decade
81,400 km² loss/year
nsidc.org/arcticseaicenews
1978
1982
1986
1990
1994
1998
2002
2006
2010
Year
National Snow and Ice Data Center

Contributors to Global Warming



Jacobson (2010, JGR 115, D14209)

Some Climate Response Estimates of BC

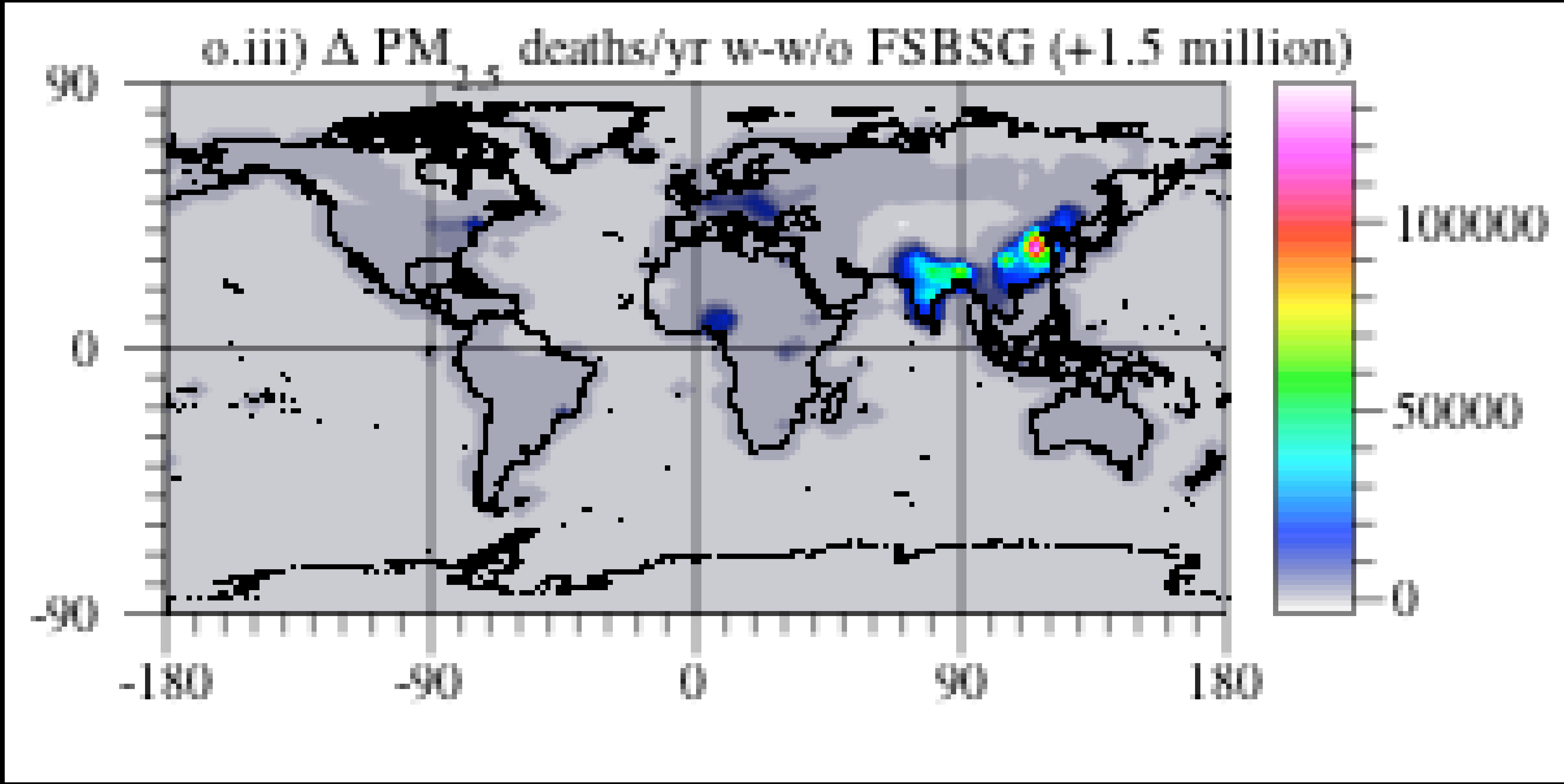
Ramanathan and Carmichael (2008) 0.5-1 K (all BC)

Chung and Seinfeld (2005) 0.37 K (all BC internally mixed)

Hansen et al. (2005) > 0.3 K (BC from fossil fuels)

Jacobson (2010) 0.4-0.7 K (BC, organic matter, and other particle components from fossil fuels and biofuels)

Annual Deaths Due to Fossil-Fuel and Biofuel Soot



Deaths due to BF soot (1.5 million/yr) ~7 times those due to FF soot (200,000/yr)

Summary

FSBSG soot may be 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.

Strong warming mainly due to cloud absorption effect, semidirect effect, internal mixing of aerosol, snow absorption effect, and feedback to water evaporation.

Net global warming (0.7-0.8 K) appears 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.

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

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

FF Soot, BC Global Warming Potential

	20-yr STRE (GWP)	100-yr STRE
BC+POC in FS	2400 - 3800	1200 - 1900
BC in FS	4500 - 7200	2900 - 4600
BC+POC in BSG	380 - 720	190 - 360
BC in BSG	2100 - 4000	1060 - 2020
Methane	52-92	29 - 63

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)