Quantifying the Effects of Aircraft on Climate With a Model that Treats the Subgrid Evolution of Contrails from all Commercial Flights Worldwide

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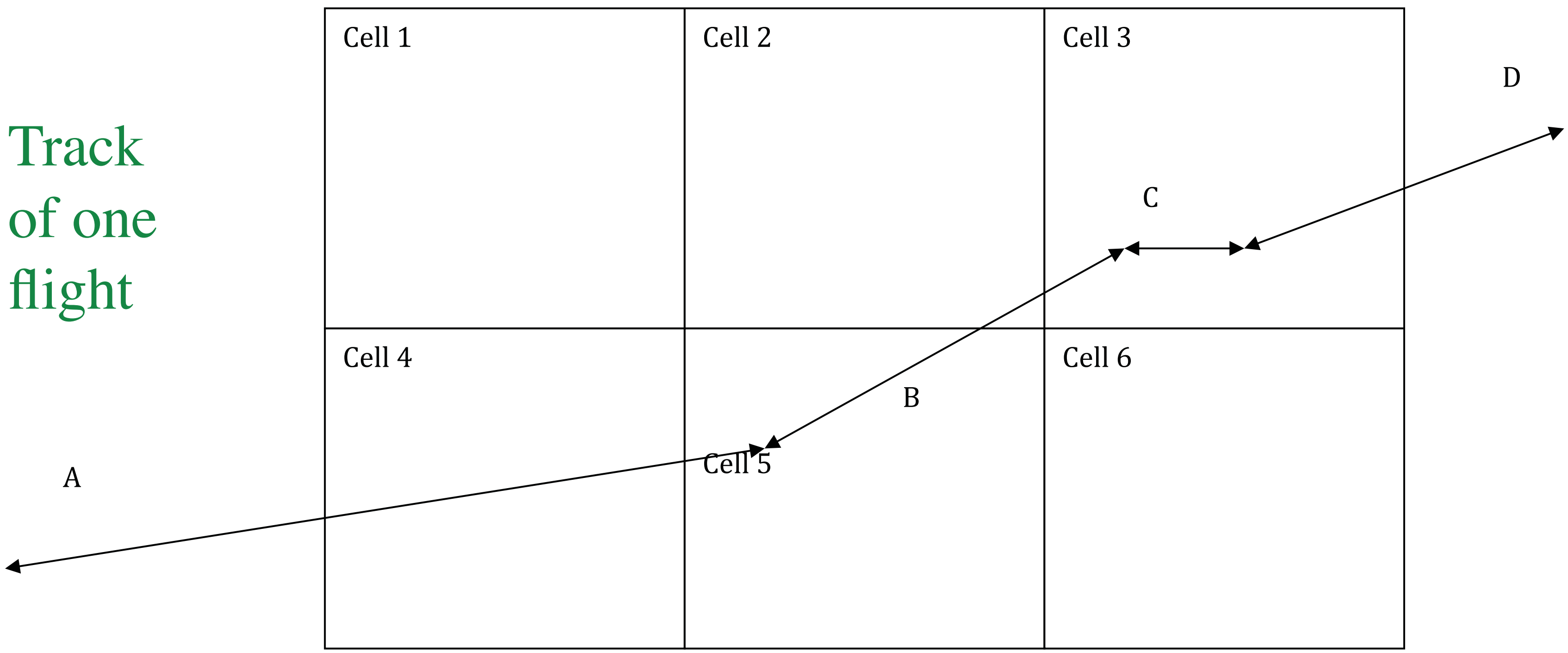
Purpose of Study

To examine the effects of aircraft emissions on climate, cirrus, and atmospheric composition with a global model that treats the exhaust plume from each aircraft flight worldwide at the subgrid scale and the microphysical evolution, spreading, and shearing of contrails within each plume.

Approach

GATOR-GCMOM was run using 2004 and 2006 emission data from Volpe, treating each of 35 million aircraft flights/yr as subgrid line-plumes with elliptical cross sections. Global resolution was 4^ox5^o. Subgrid plume shearing and spreading were calculated with a plume module; plume widths ~50 m-15 km.

Track of one flight

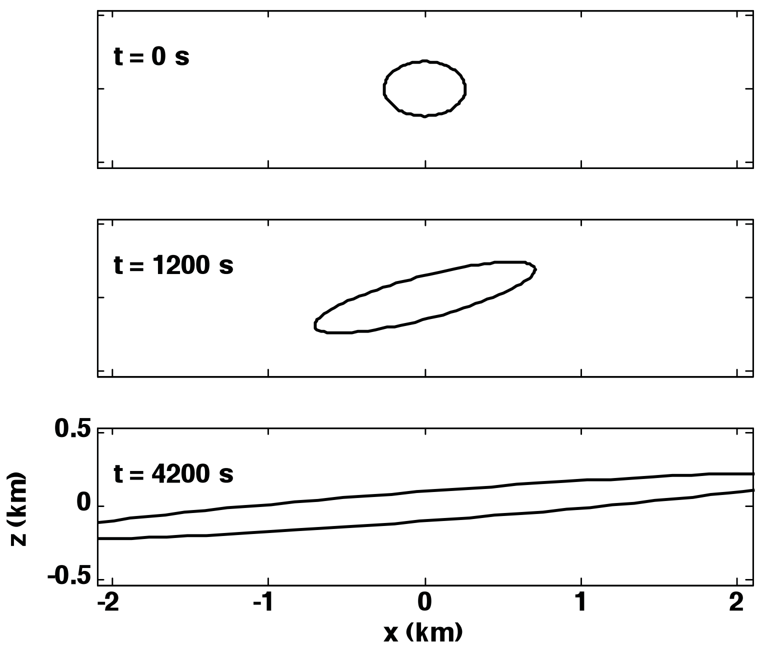


Comparison of Subgrid Plume Model (SPM) to LES under moderate shear and turbulence conditions

$s = 0.003\ s^{-1}$, $D_h = 20.0\ m^2/s$, $D_v = 0.158\ m^2/s$

Analytical Solution Subgrid Plume Mode (SPM)

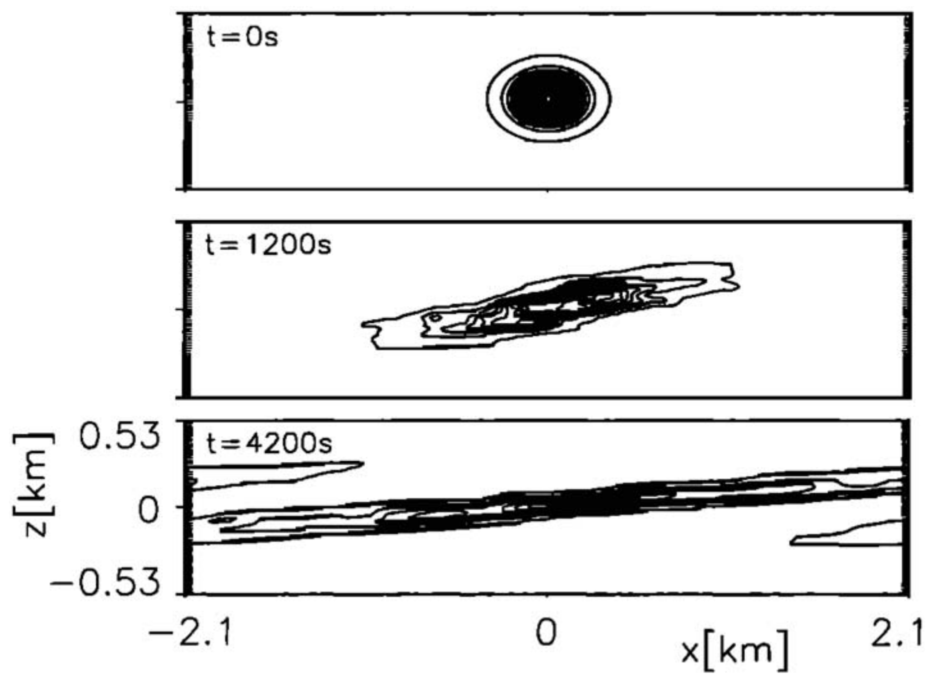
Plume cross-section



Naiman et al. (2009)

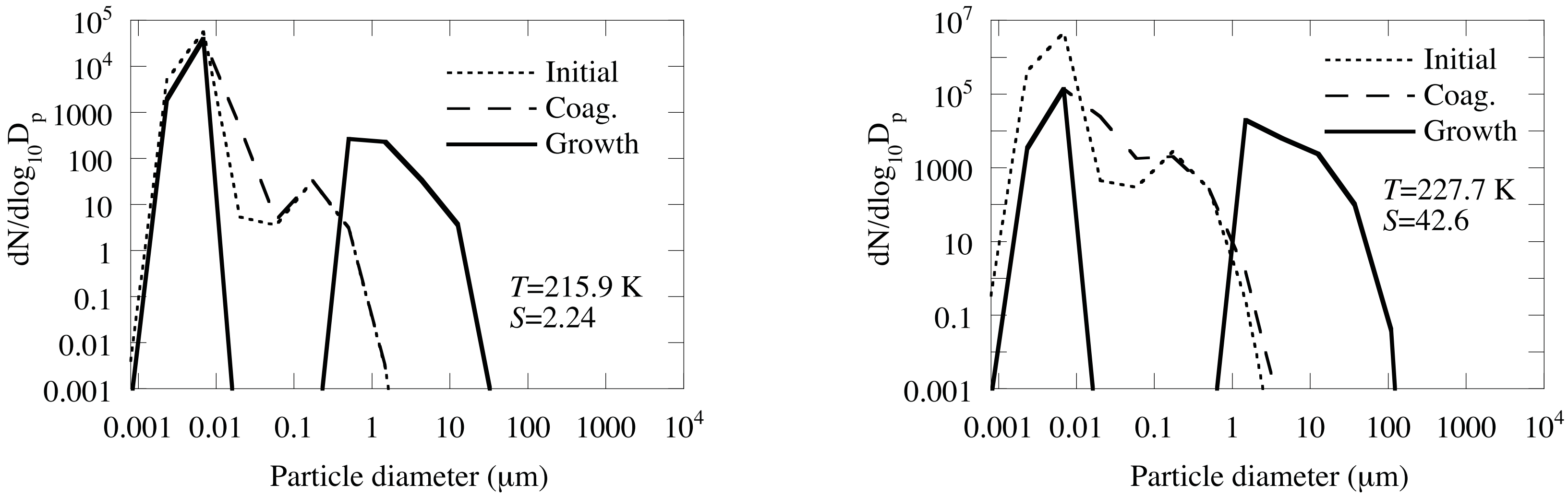
Large Eddy Simulati(LES)

Contours of exhaust concentration



Dürbeck and Gerz (1996)

One 1-hr Time Step of Line Contrail Coagulation Followed by Growth After Emissions



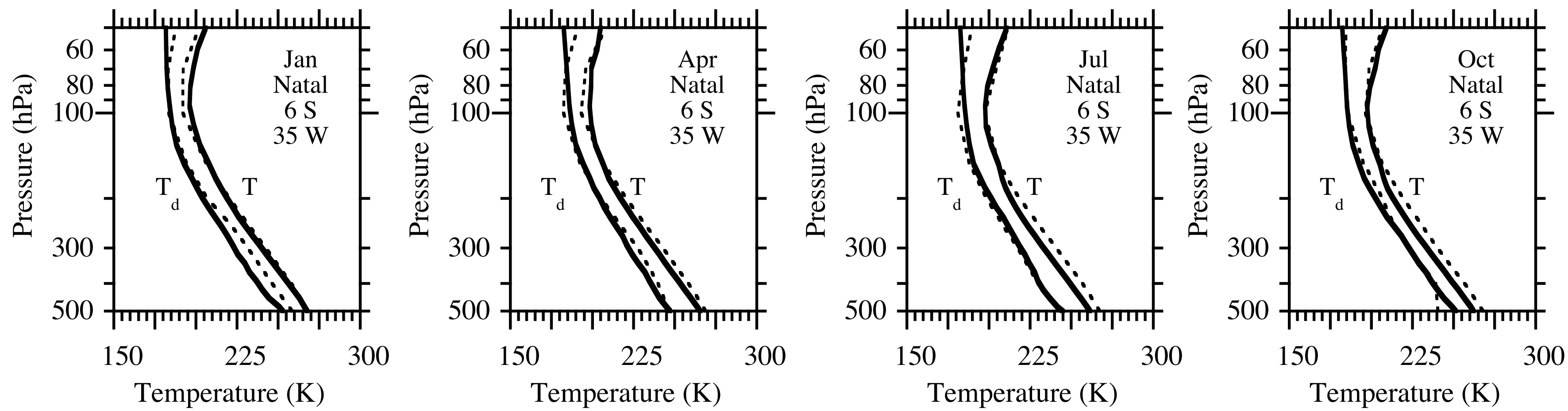
Discrete, size-resolved (16 bins) line contrails in each plume grew/ shrank by deposition/coagulation/sublimation from size-resolved aerosols. When contrails dissipated, their core aerosols were added to the grid scale to serve as CCN.

Radiative calculations accounted for subgrid contrails, subgrid cumulus, and grid-scale cirrus/stratus clouds.

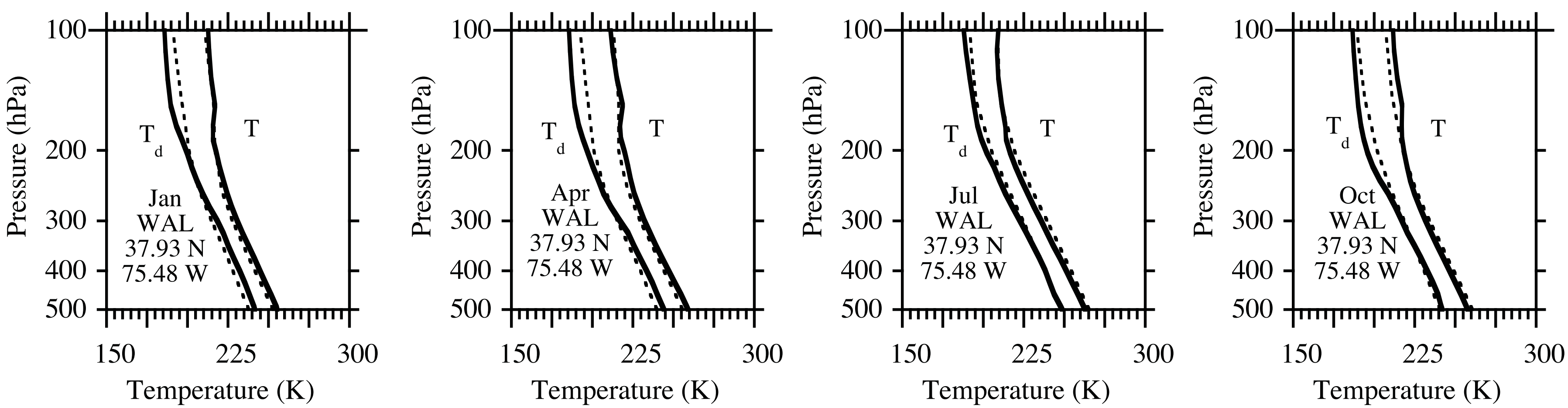
Modeled vs. Measured Paired in Space Monthly T/T_d

Global domain

Data from FSL (2008)



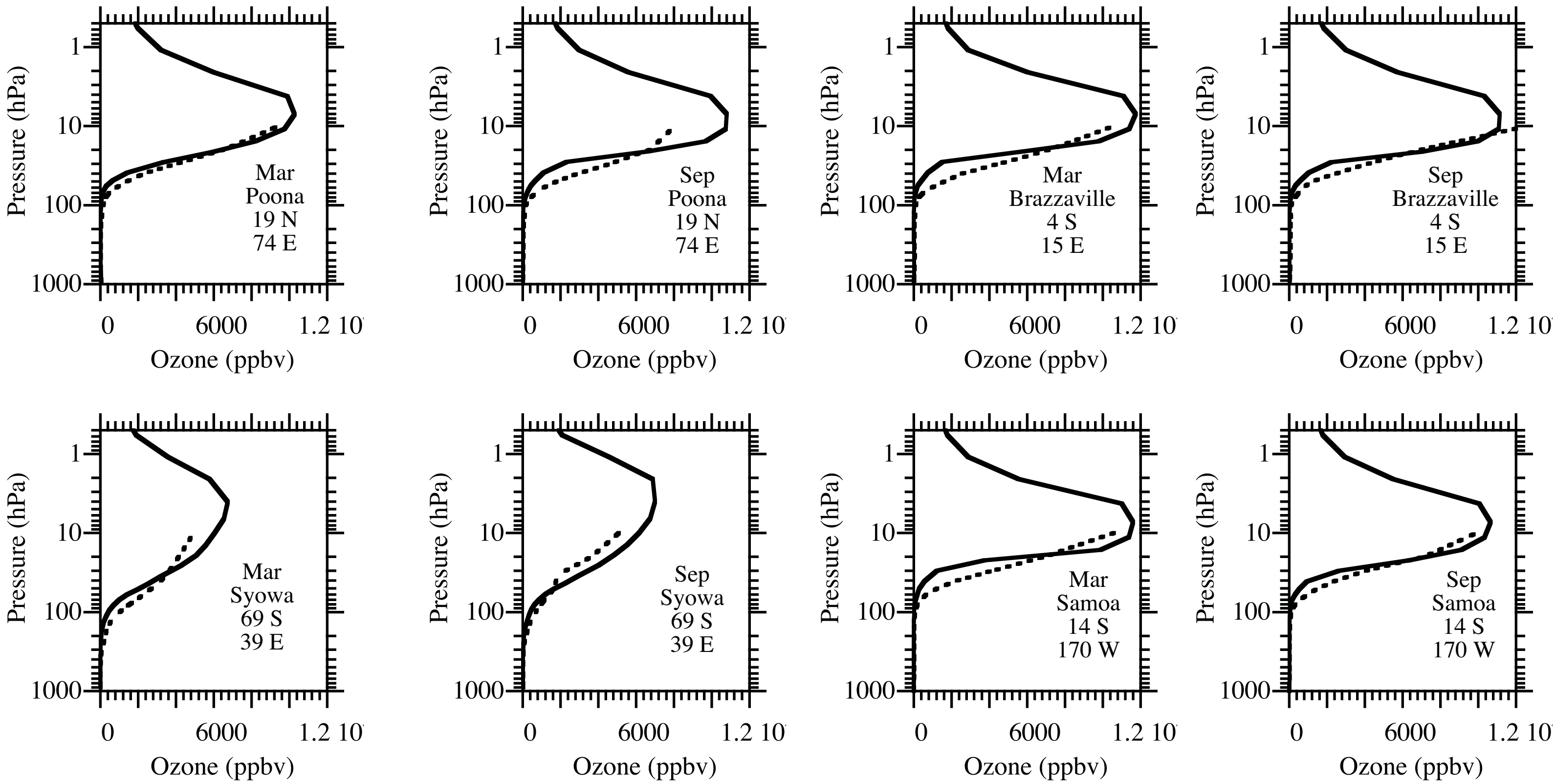
U.S. domain



Despite coarse resolution, model captures data at exact location of data- Little numerical diffusion to stratosphere; dew point data uncertainty < 2.7 K upper trop

Modeled vs. Measured Paired in Space Monthly O_3

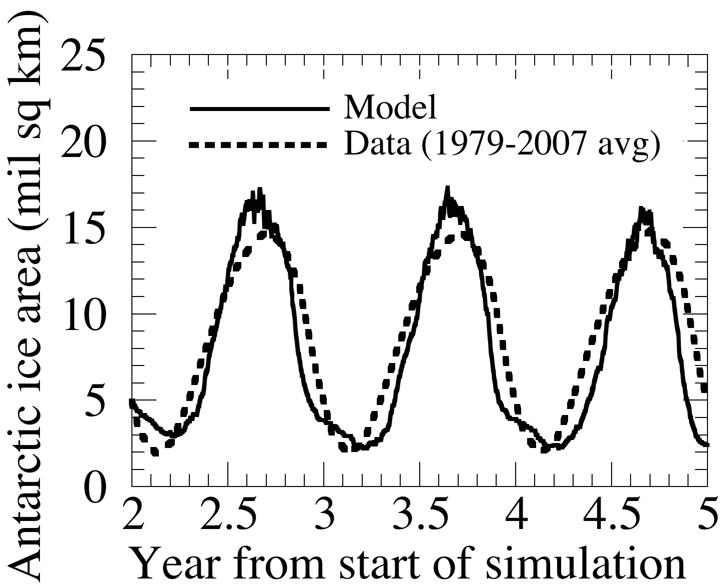
Data from Logan et al. (1999)



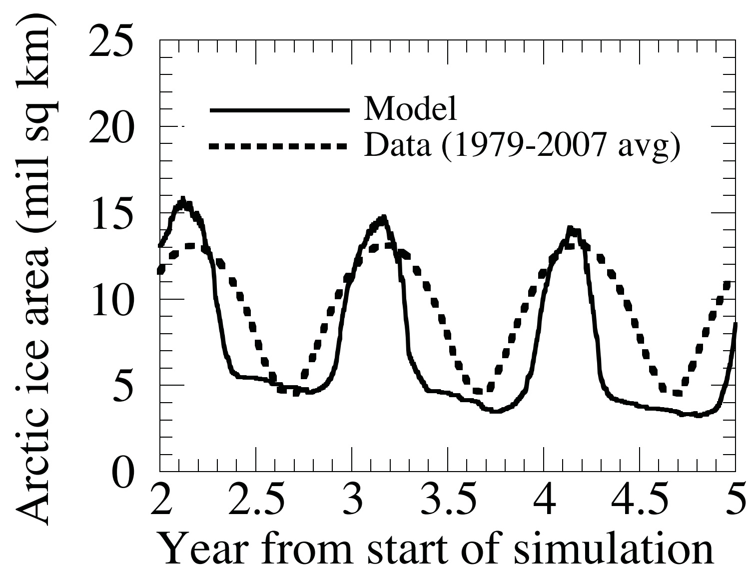
Model predicts the magnitude and altitude of the lower-stratospheric ozone layer

Modeled vs. Measured Sea Ice Area

Antarctic



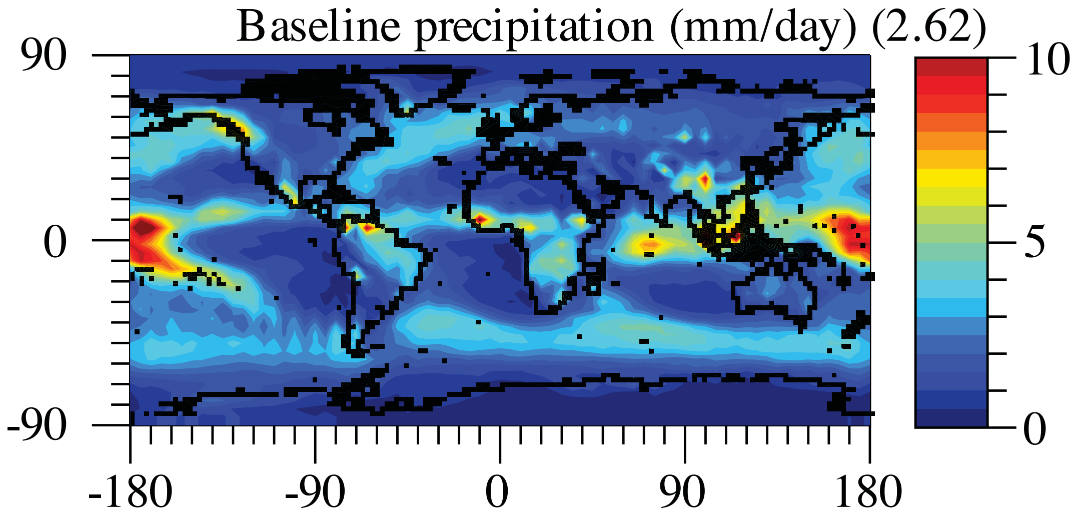
Arctic

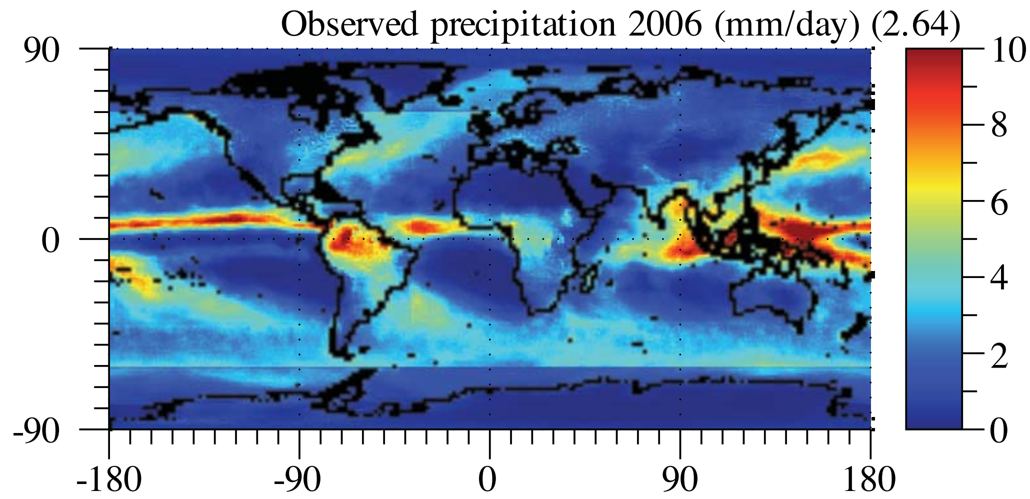


Model (at 4 x 5 degree resolution) predicts stable sea ice area after only two years of simulation

Data from NASA Team (2009)

Modeled vs. Measured Annual Precip.

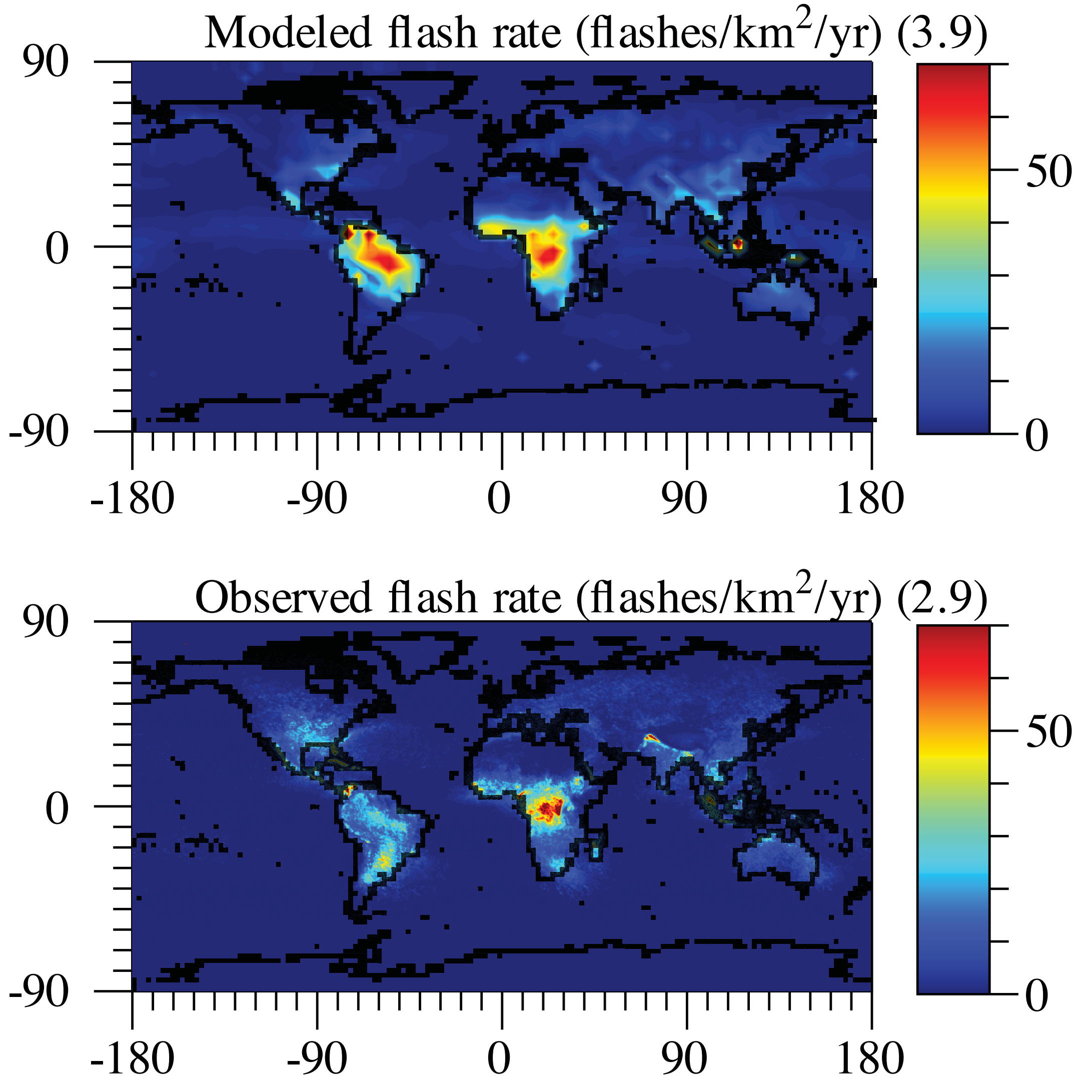




Data from Huffman et al. (2007)

Despite 20 times lower resolution than data, model predicts 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

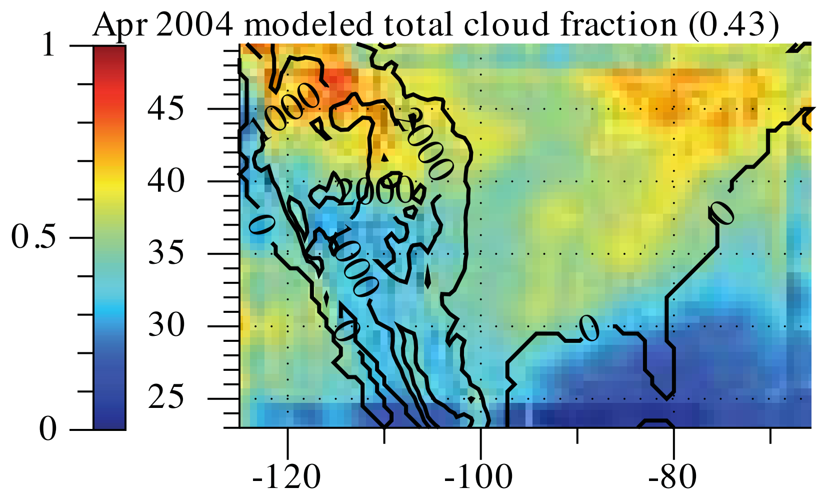


Data from
NASA LIS/OTD
Science Team

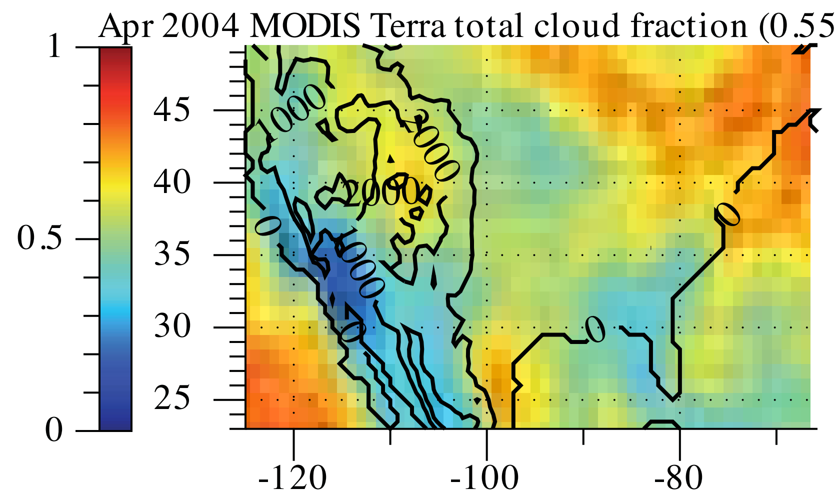
Model calculates lightning by accounting for size-resolved bounceoffs and charge separation in clouds.

Modeled vs. MODIS Total Cloud Fraction April 2004

Peak fraction in both figures is 100%
Model is 24-hr average for 2004;
MODIS is average of two instant overpasses in 24 hours



Global-domain input occurs at edges

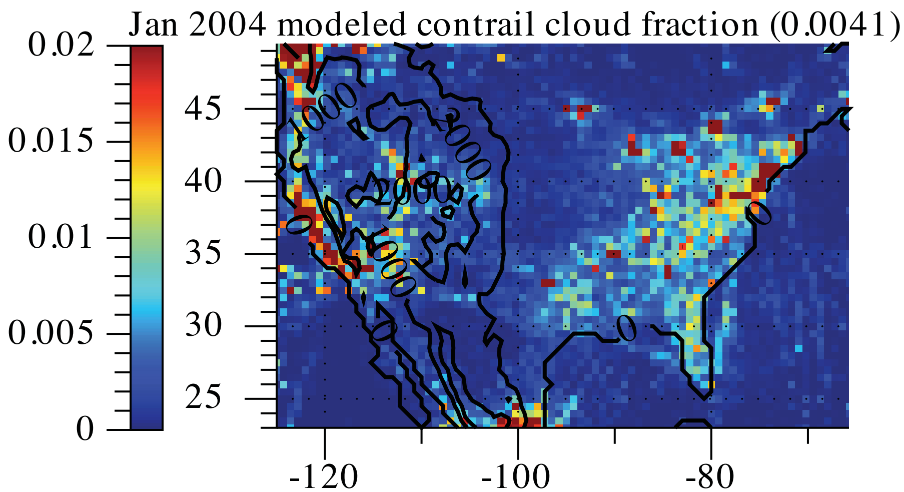


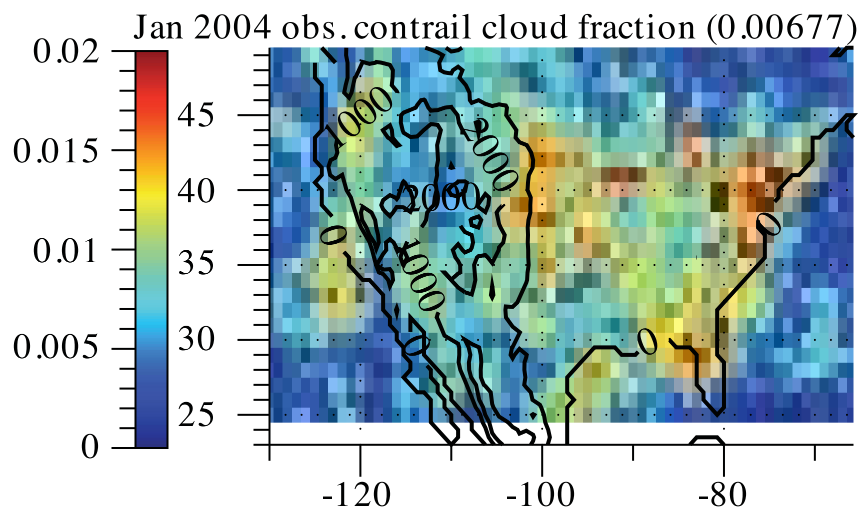
NASA (2008)

Model predicted major observed regions of high cloud fraction: Rockies, northeast U.S.

Modeled vs. Data Linear Contrail Cloud Fraction Jan 2004

Peak fraction in both figures is 2%
Model is 24-hr average for Jan 2004;
Data are average of two instant overpasses in 24 hours





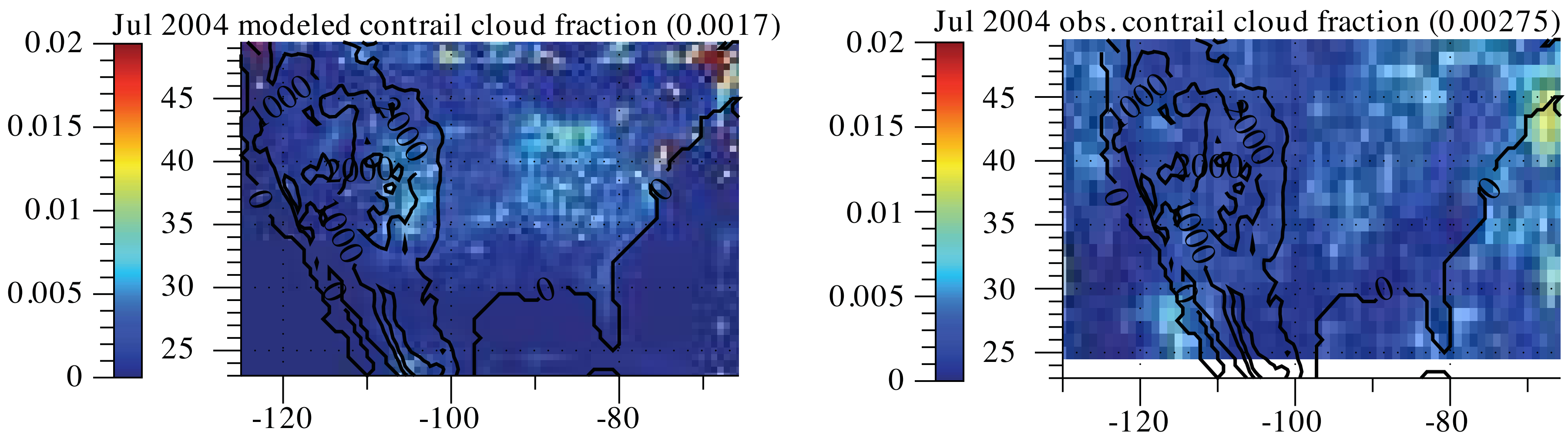
Global-domain input occurs at edges

Duda et al. (2005)

Model predicted peak magnitude and two major locations (eastern and west coast U.S. - Great Plains predictions low in Jan – possibly due to initial meteorological fields there.

Modeled vs. Data Linear Contrail Cloud Fraction July 2004

Peak fraction in both figures is 2%
Model is 24-hr average for July 2004;
Data are average of two instant overpasses in 24 hours



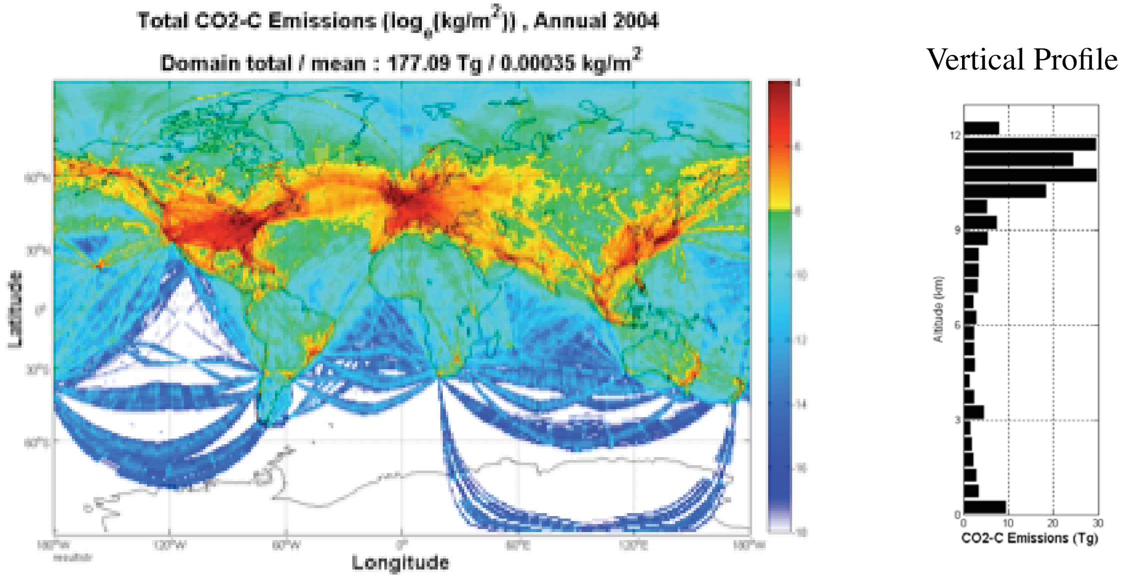
Global-domain input occurs at edges

Duda et al. (2005)

Model predicted peak magnitude and locations (Great Plains, central U.S) of observed fractions. Correctly predicted low values Texas-Ala.)

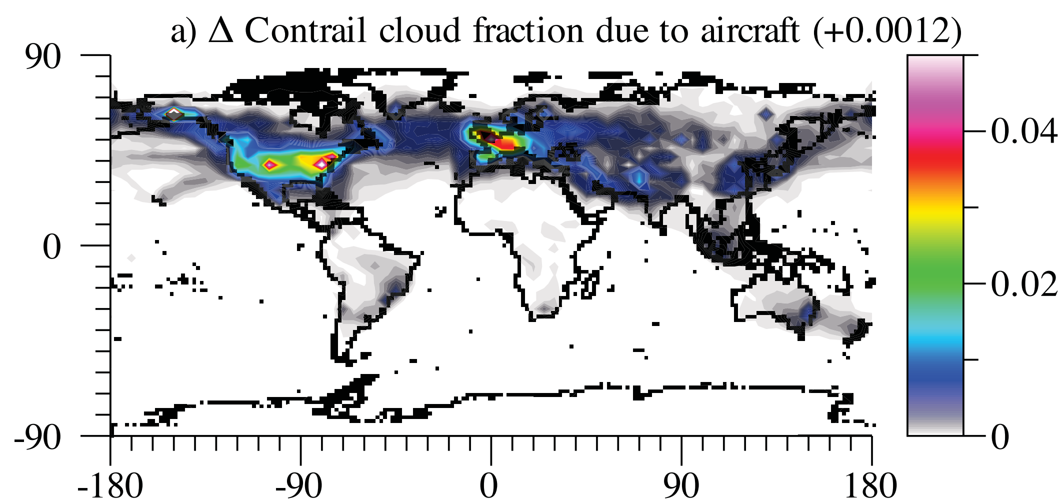
2004 Emissions and Modeled Contrail Cloud Fraction

Flight Data
Spatially and temporally located aircraft emissions for global commercial flights from Volpe (*Wilkerson, et al. 2009*)

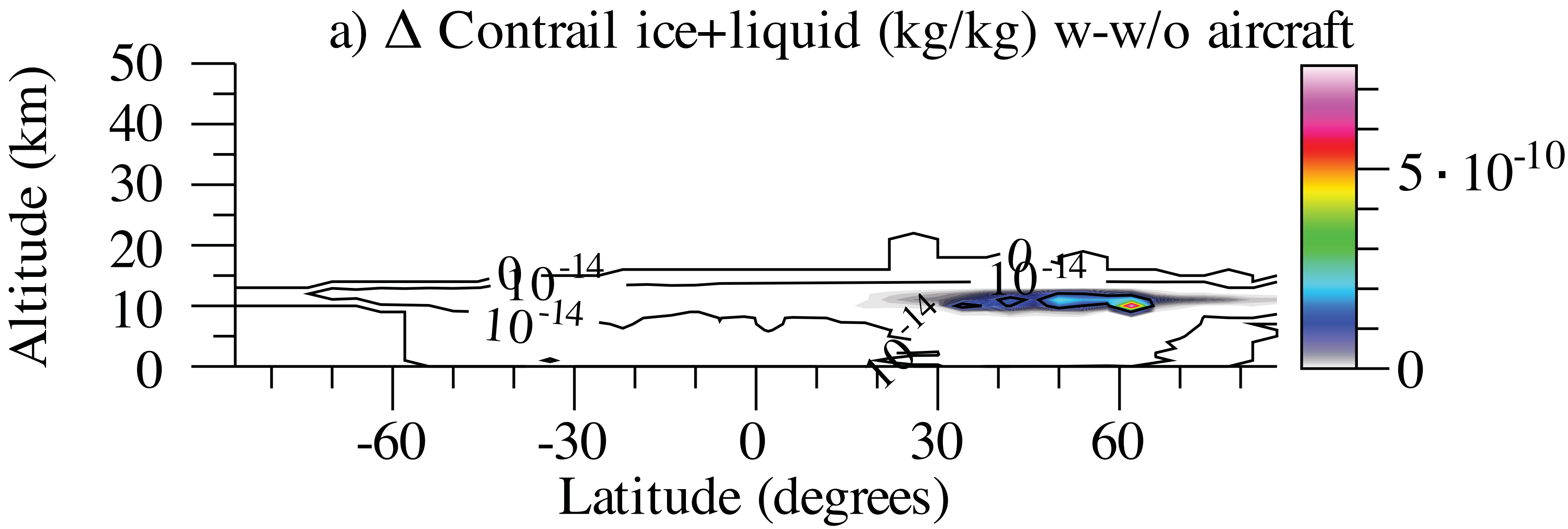


	Data* '98	Model '04
Japan:	0.0025	0.004
Thailand:	0.0013	0.0015

Results good even for SE Asia
*Meyer et al. (2007) for 1998

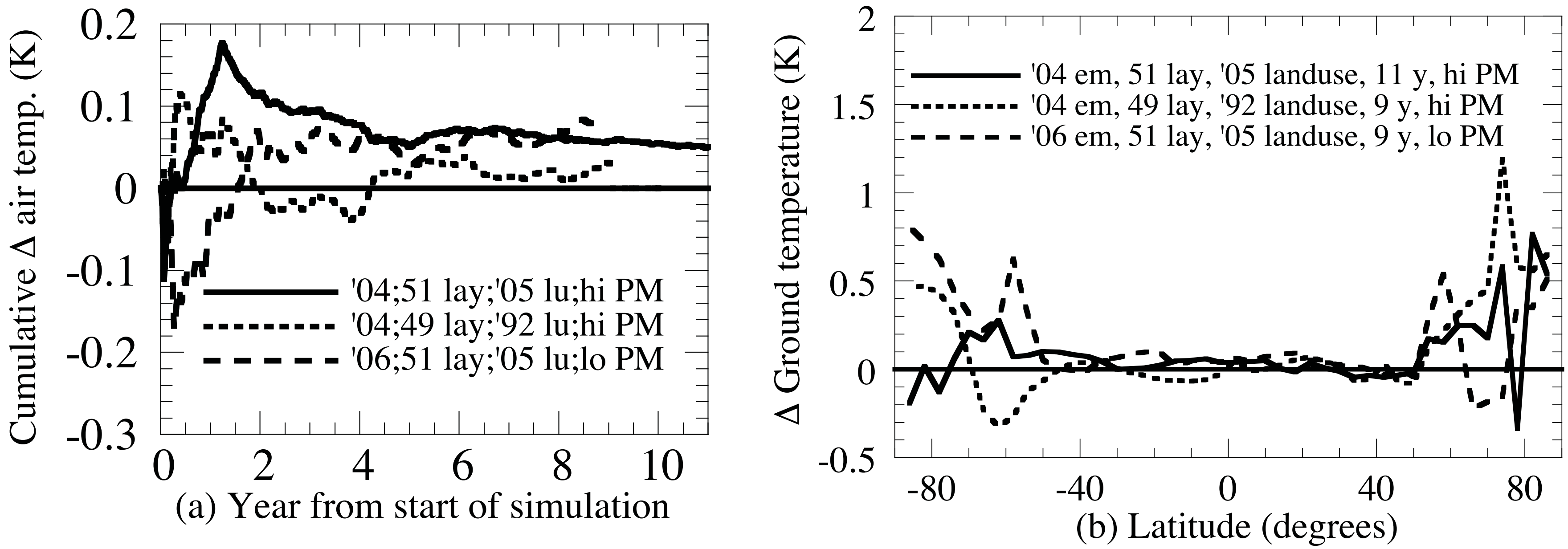


Zonal-Altitude Plot of Line Contrail Water



Subgrid line contrails formed at altitudes expected by Schmidt-Appelman criterion but calculated here from size-resolved microphysics and plume supersaturation

Effects of All Aircraft on Global Surface Temperatures Using ‘04 and ‘06 Emissions Data

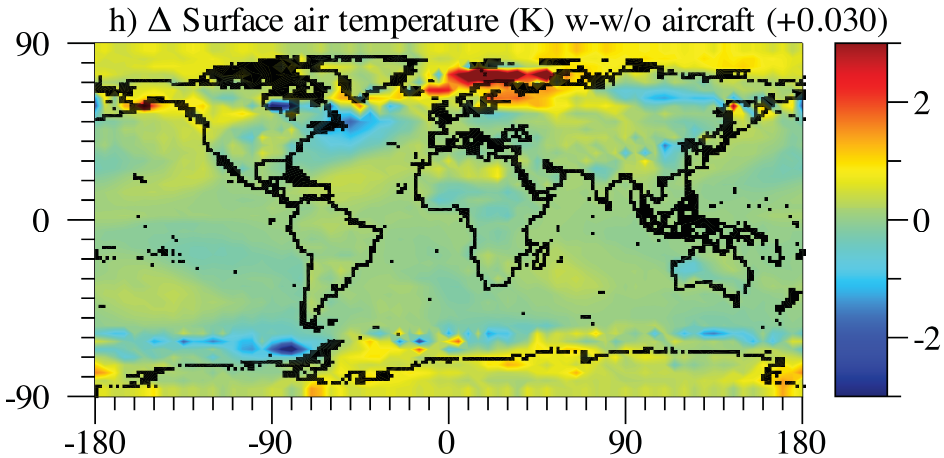


Left: Three sets of simulations under different conditions each bounded after ~5 years. Range of global warming from all is 0.03-0.06 K. Right: The 2004 emission simulations show strong Arctic warming; the 2006 simulation with ~5 times lower BC shows less warming, but hi-lat warming still strong over Arctic

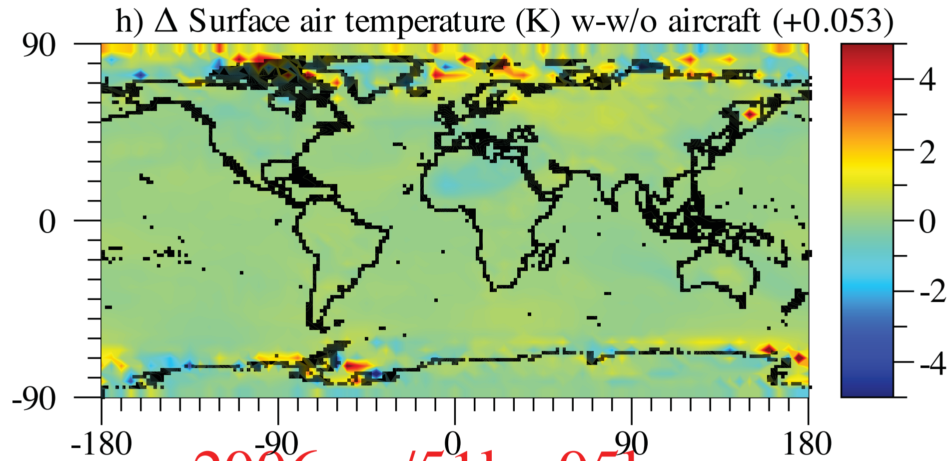
Results preliminary

Effects of Aircraft on Surface Air Temperatures

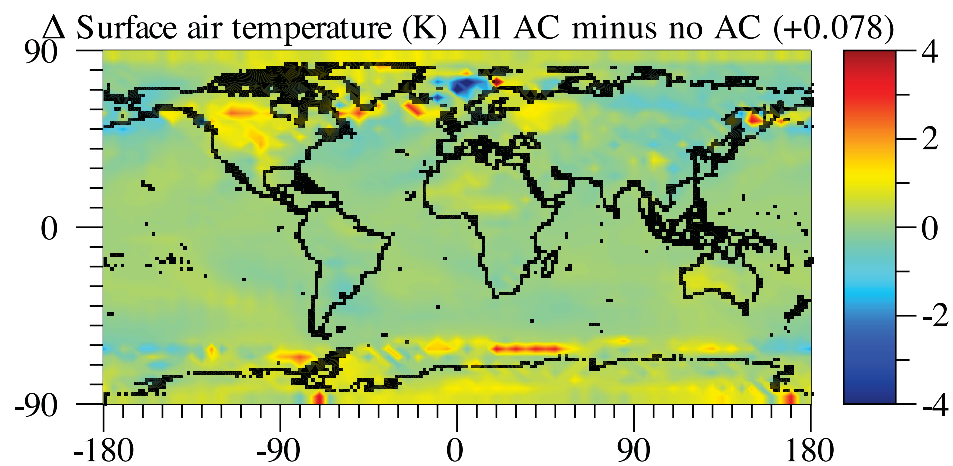
2004em/49lay/92luse



2004em/51lay/05luse



2006em/51lay05luse



Aircraft caused

~4-8% of surface warming

~14-20% of Arctic warming

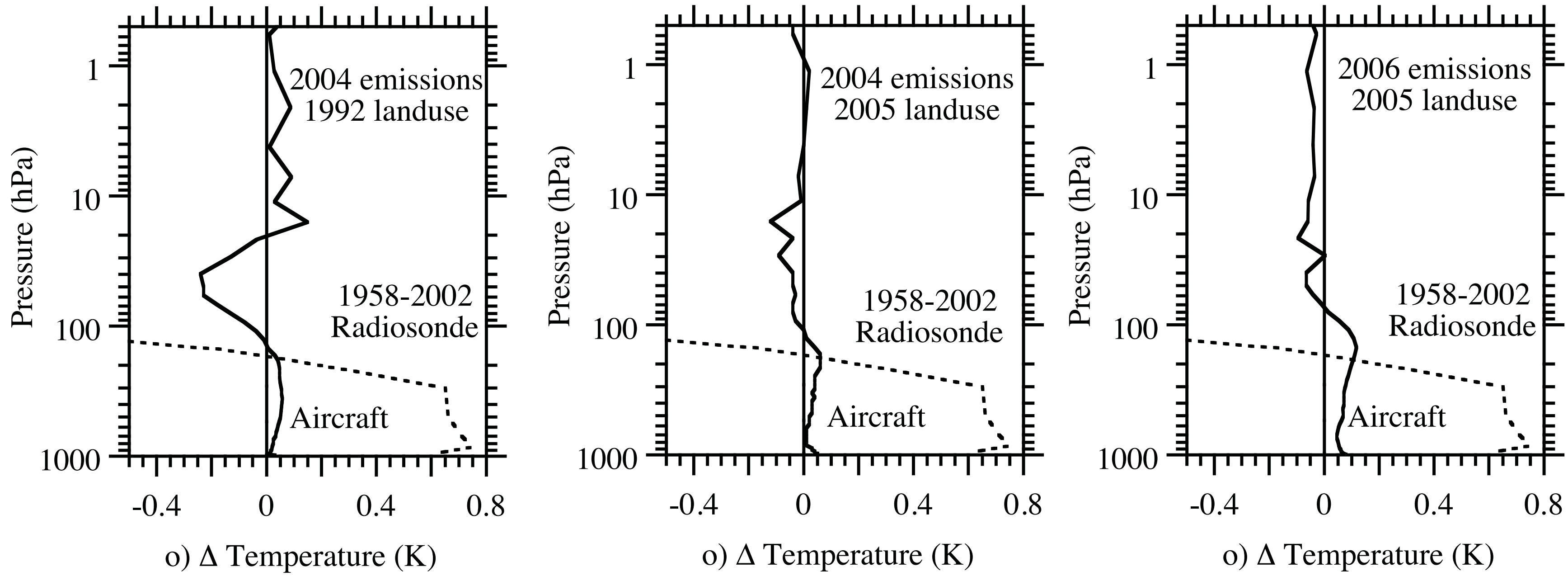
Results strongly statistically

Significant

Results preliminary

Effects of Aircraft on Global Temperature Profiles

04em/49lay/92luse 04em/51lay/05luse 06em/51lay05luse



Aircraft stabilized troposphere in all simulations

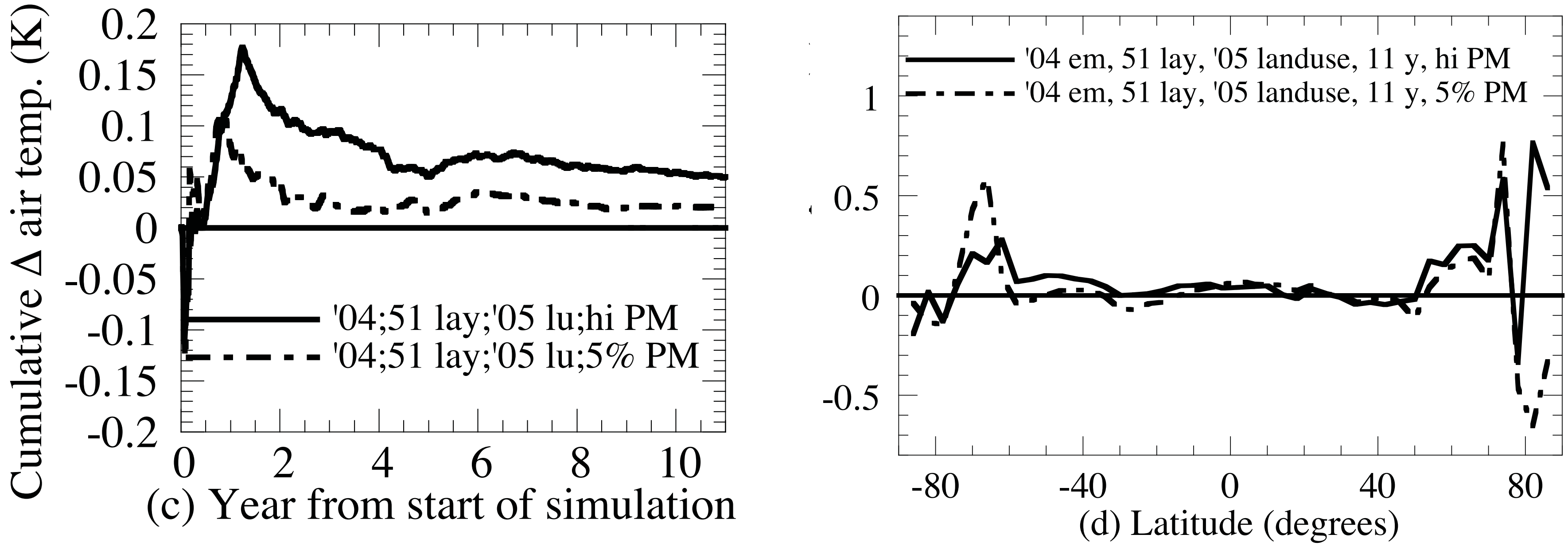
→ Reduced vertical transport/diffusion in all cases

Arcraft caused 9-15% of upper-tropospheric warming

Results preliminary. Please do not quote.

Data: Thorne et al. (2005)

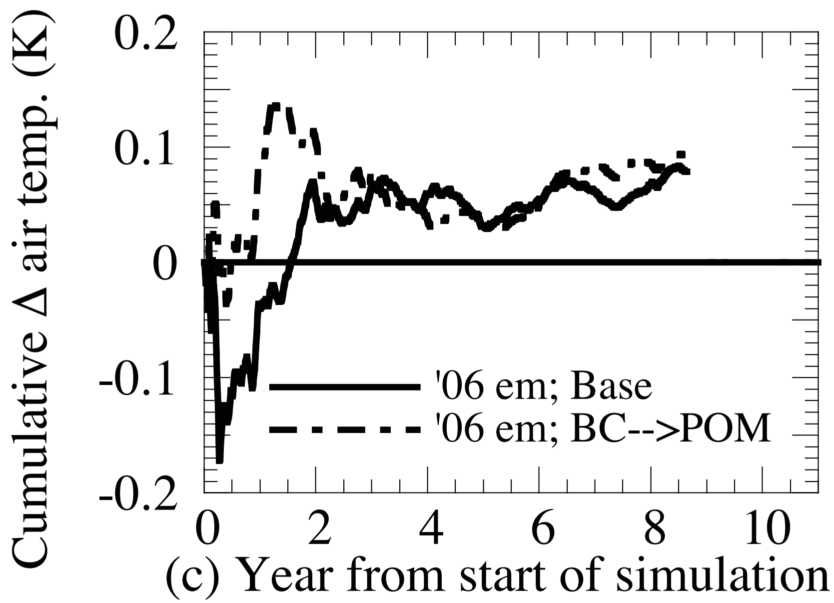
Effects of Removing Removing 95% 2004 PM

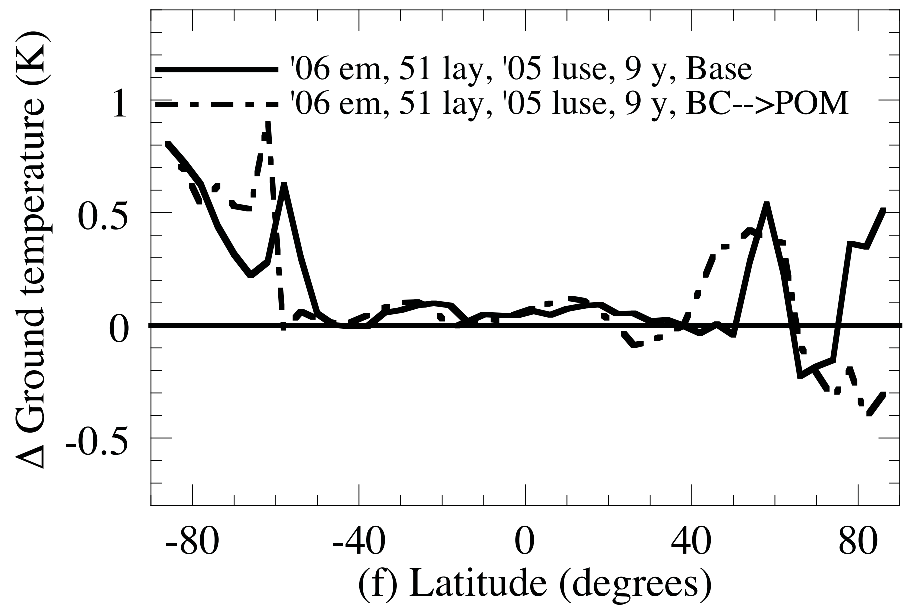


With 2004 emissions, removing 95% of PM (BC, POM, S(VI)) across the board reduced short-term Arctic warming. In this case, BC removal was 4 times greater than in the 2006 emission case, causing the elimination of polar warming

Results preliminary. Please do not quote.

Effects of Converting BC to POM 2006 Em





With 2006 emissions, converting emitted aircraft BC to POM eliminated Arctic warming similarly to eliminating 95% of all PM for 2004 emissions. This suggests BC from aircraft is main cause of short-term Arctic Warming from Aircraft, even with low BC.

Results preliminary. Please do not quote.

Summary

Simulations with 2004 and 2006 subgrid emissions suggest aircraft…

Caused a global linear contrail cloud fraction of ~0.0011-0.0016 (compared with 0.001-0.0014 in the literature)

Increased decadal-scale global surface temperatures by 0.03 to 0.06 K (4-8% of observed surface warming since 1850) (compared with 3.6-8% of forcing due to aircraft from IPCC, 2007)

Increased tropospheric stability, reducing vertical mixing and total global cloud fraction slightly although CF increased near contrails.

Increased Arctic warming by ~0.35-0.5 K, or up to 14-20% of observed Arctic warming 1880-2008 of ~2.5 K, mostly due to BC.

Results preliminary. Please do not cite or quote.

Summary

Simulations with 2004 and 2006 subgrid emissions suggest aircraft…

Reducing BC emissions by a factor of 5 (e.g., using 2006 inventory versus 2004 inventory) reduced Arctic warming but still allowed substantial warming.

Reducing 2004 BC by a factor of 20 turned Arctic warming into cooling.

Converting all 2006 BC to POM turned Arctic warming into cooling.

→ Decadal scale warming found from aircraft due mostly to BC and almost complete elimination of BC needed to eliminate warming.

Results preliminary. Please do not cite or quote.