Aerosol Effects on Climate:
Part 1. Direct, Indirect and BC-albedo

"Distinguishing Aerosol Impacts on Climate Over the Past Century", *J. Clim*, in review

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October 8, 2008 **Reykjavik, Iceland**

Model Simulation

GISS ModelE GCM: 4°x5° x 20 levels

Equilibrium climate simulations, with a slab ocean.

By running the model to equilibrium it is easier to see significant aerosol-climate effects.

SIX pairs of

"Pre-industrial" 1890 control and 1995 perturbation experiments

Successive experiment pairs allow isolation of aerosol effects:

1. Aerosol Direct Effect (DE) only
2. + Indirect Effect (IE)
3. + BC snow Albedo Effect (BAE)

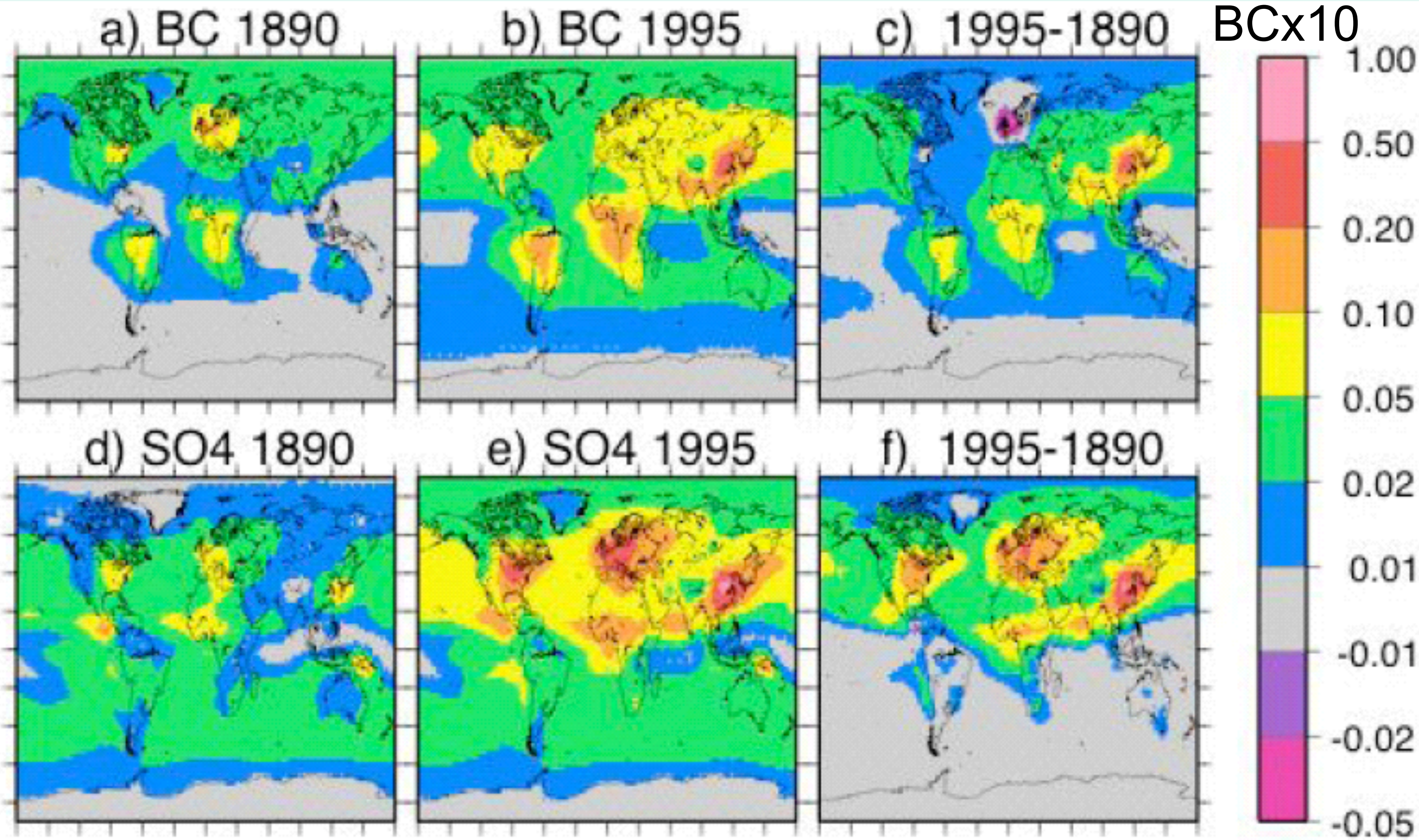
Aerosols: sulfate, BC, OC, sea salt

To see how GHG changes affect aerosol effects:

First 3 pairs: GHGs at 1990 (control and perturb).

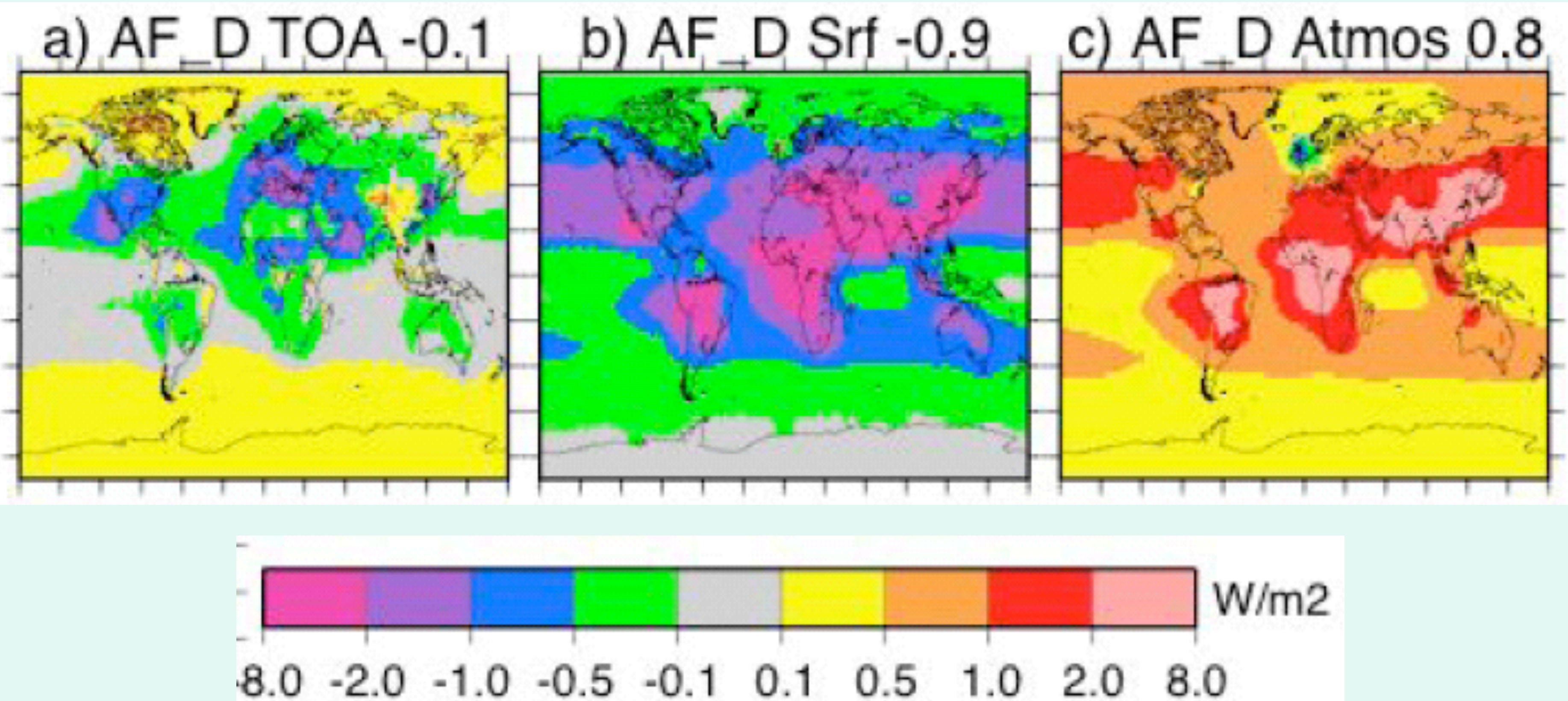
Second 3 pairs: GHG is 1890 (control) and 1990 (perturb)

Change in Aerosol burdens



Direct Effects

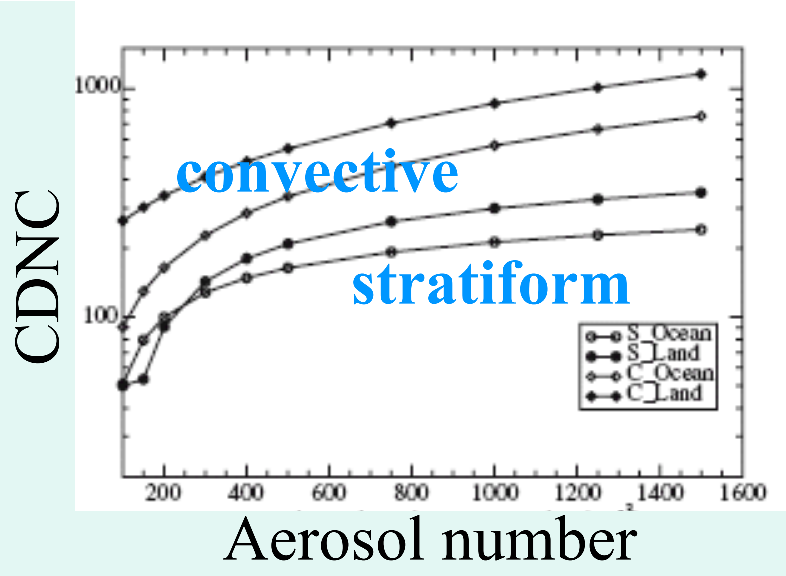
TOA Surface Atmospheric absorption



Indirect Effect:

Menon and Rotstayn (2005)

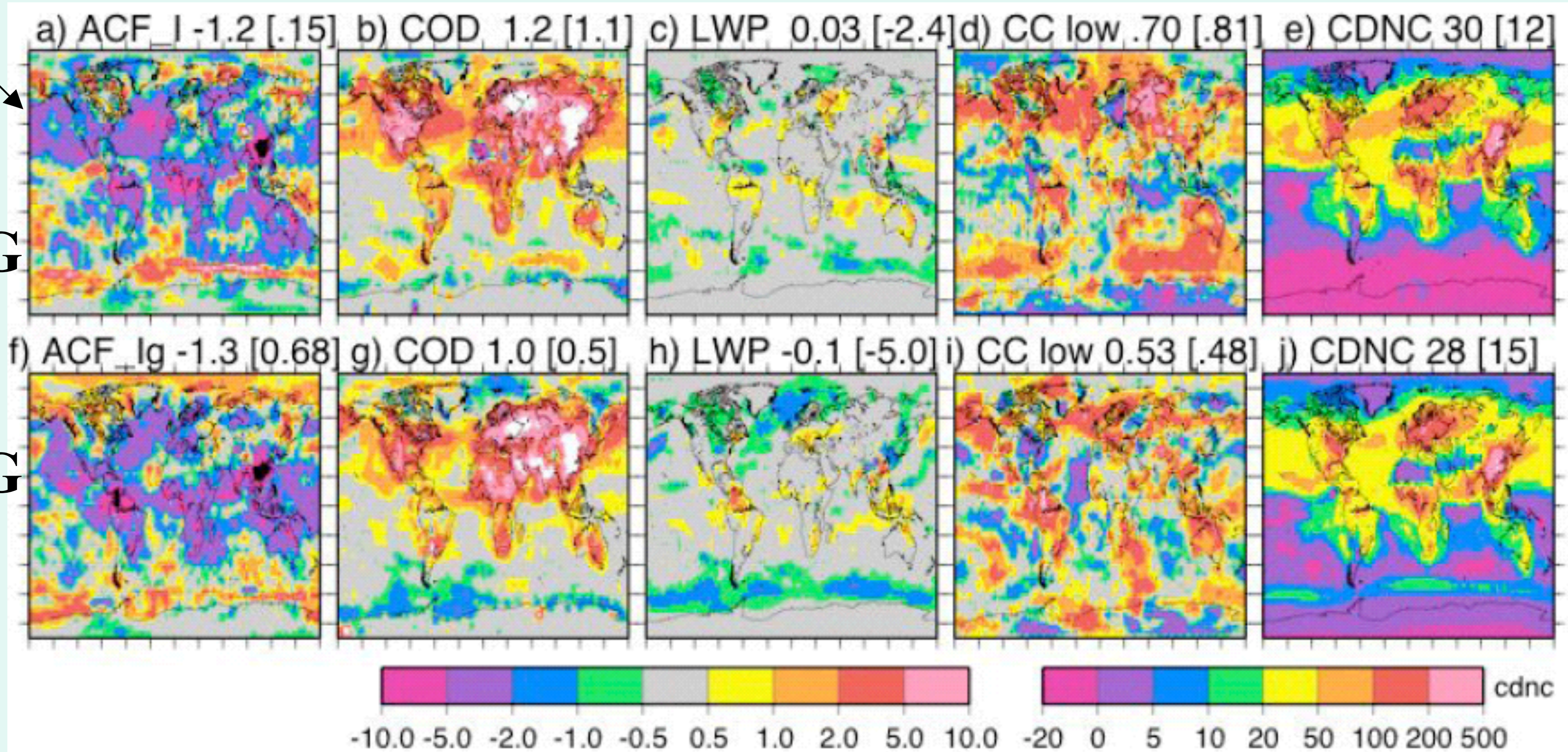
Prognostic relations between CDNC and aerosol number for stratiform & convective over land & ocean



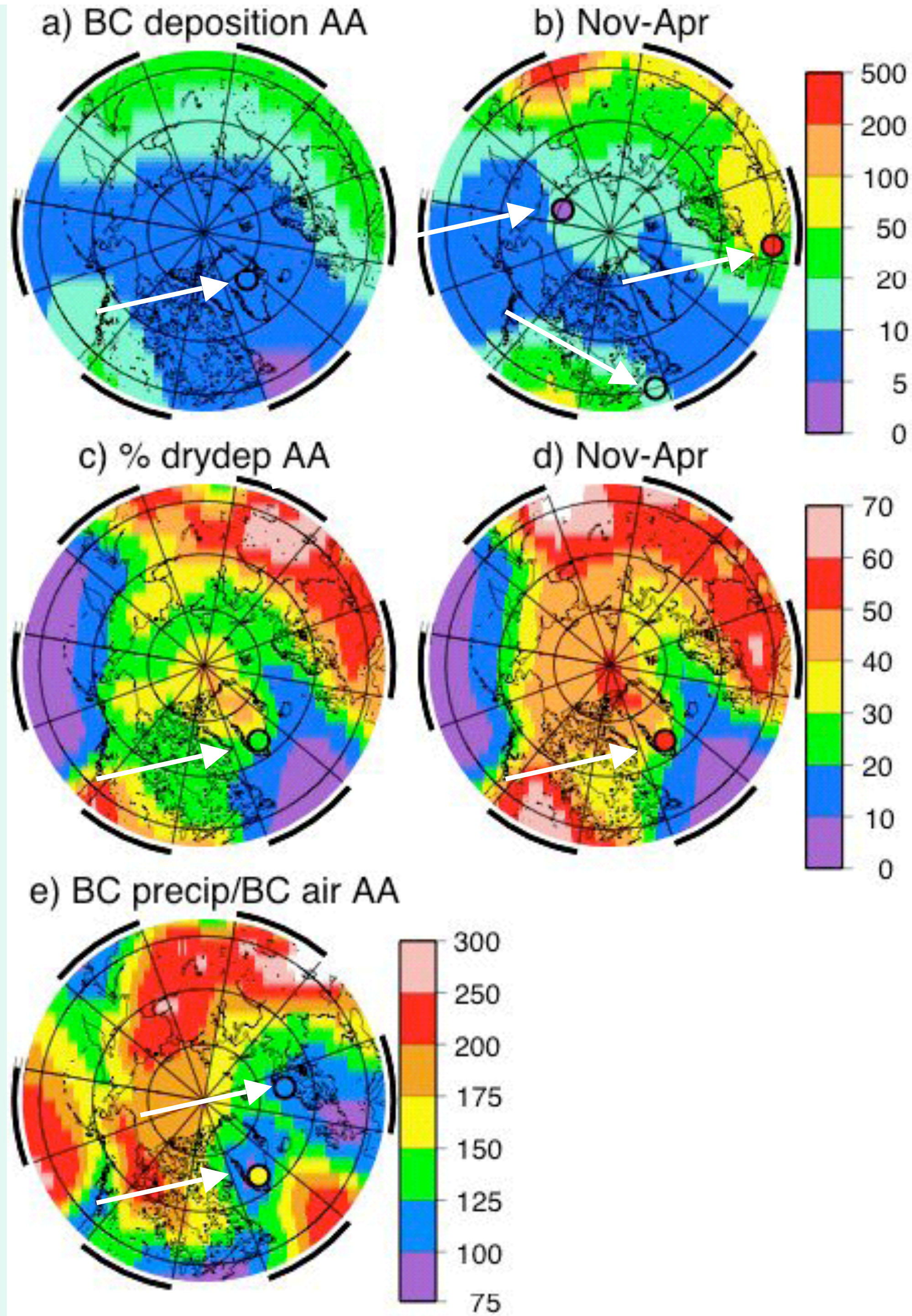
Indirect Effect

No ΔGHG

ΔGHG



Black Carbon effect on snow albedo



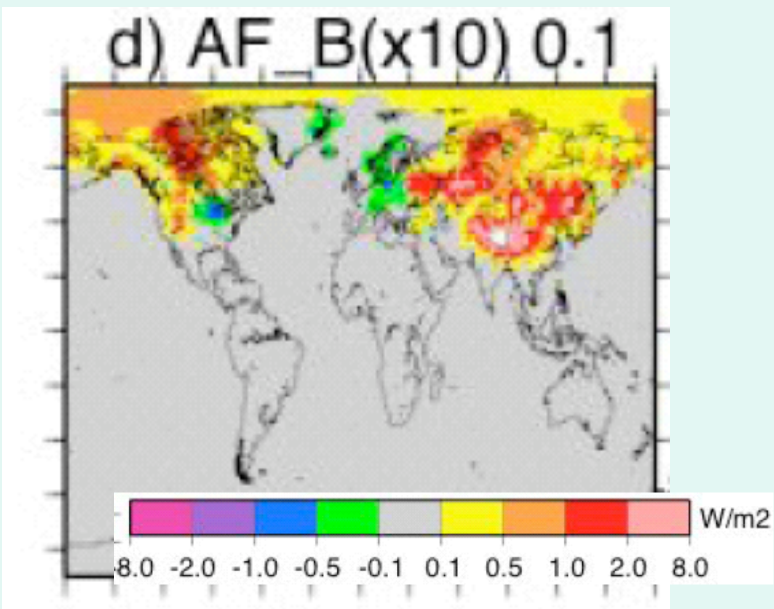
First we checked (and adjusted) BC deposition

Black Carbon effect on snow albedo

1. Model Δalbedo depends upon model BC snow concentration (Warren and Wiscombe, 1985)

2. Snow grain size as a function of snow age and surface air temperature is calculated from Marshall (1989)

BAE radiative forcing:



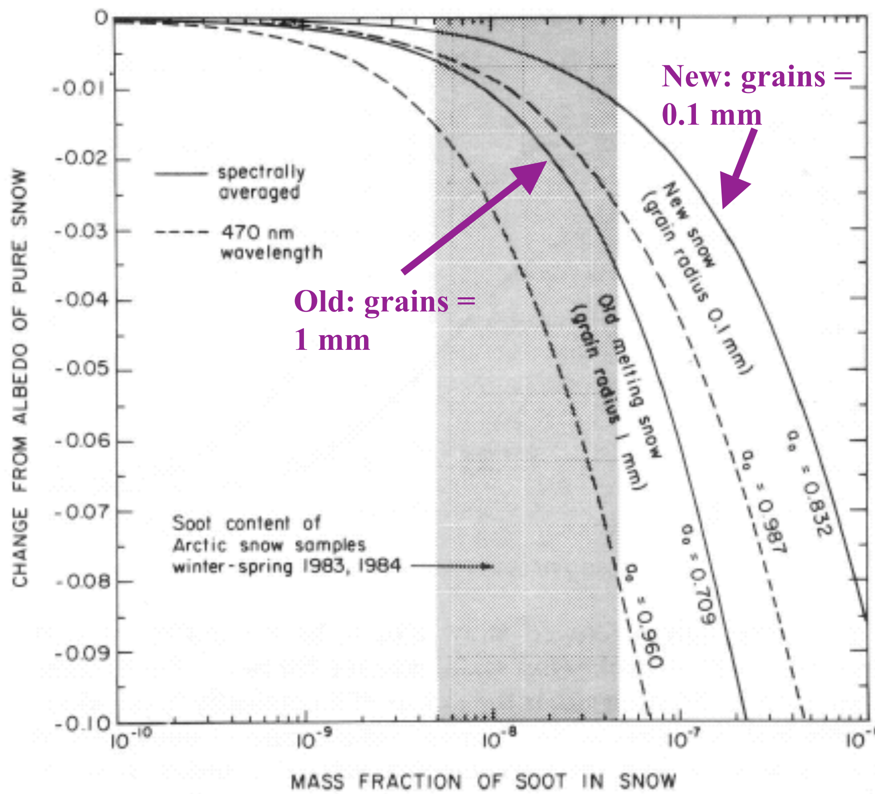
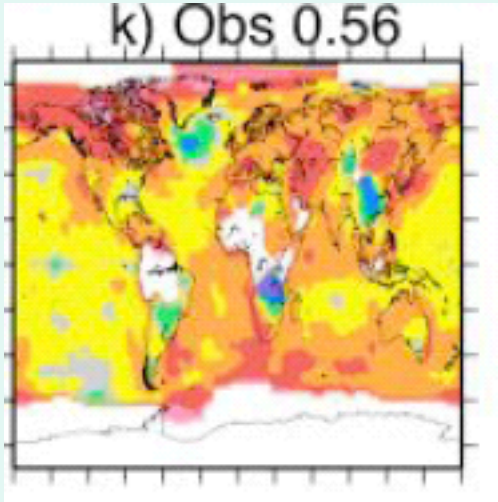


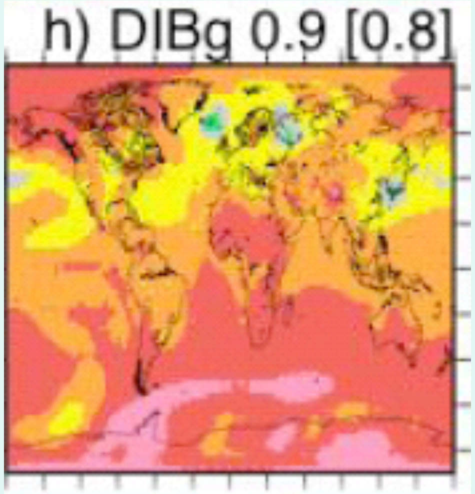
Fig. 2 Computed effects on snow albedo caused by small mass fractions of soot. Soot size distribution and refractive index, snow grain sizes and solar radiation spectrum are the same as used in Fig. 1. The changes from the albedo values of pure snow, a_0, are plotted; the spectrally-averaged changes (solid lines) correspond to the left-most portion of the plots in Fig. 1, on an expanded vertical scale here. The dashed lines are calcuations at the wavelength where snow albedo is most sensitive to soot content ($\lambda = 470$ nm). The reduction in spectrally-averaged albedo is thus approximately half that at visible wavelengths. The shaded region indicates the range of soot concentrations determined[26] in 12 samples of snowfall collected from Arctic Canada, Alaska, Greenland and Svalbard during winter and spring 1983–84. To ensure consistency between soot measurement and albedo calculation, they have been multiplied here by the factor 0.85; previously[26], a mass absorption coefficient $k_{abs} = 8.5\ m^2\ g^{-1}$ for ambient soot at $\lambda = 525$ nm was assumed, whereas the Mie calculation for the soot parameters used here gave $k_{abs} = 10.0\ m^2\ g^{-1}$.

Surface Air Temperature changes
1890 to 1995

Observed

Model with all effects

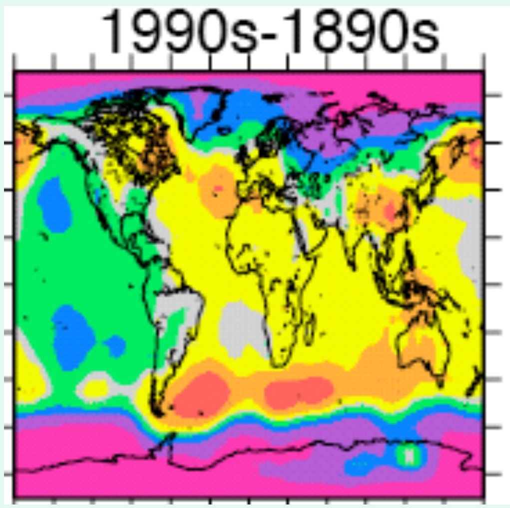




Model overestimates warming, but it is equilibrium climate and there are observation gaps in the polar region

Sea-level pressure changes
1890 to 1995

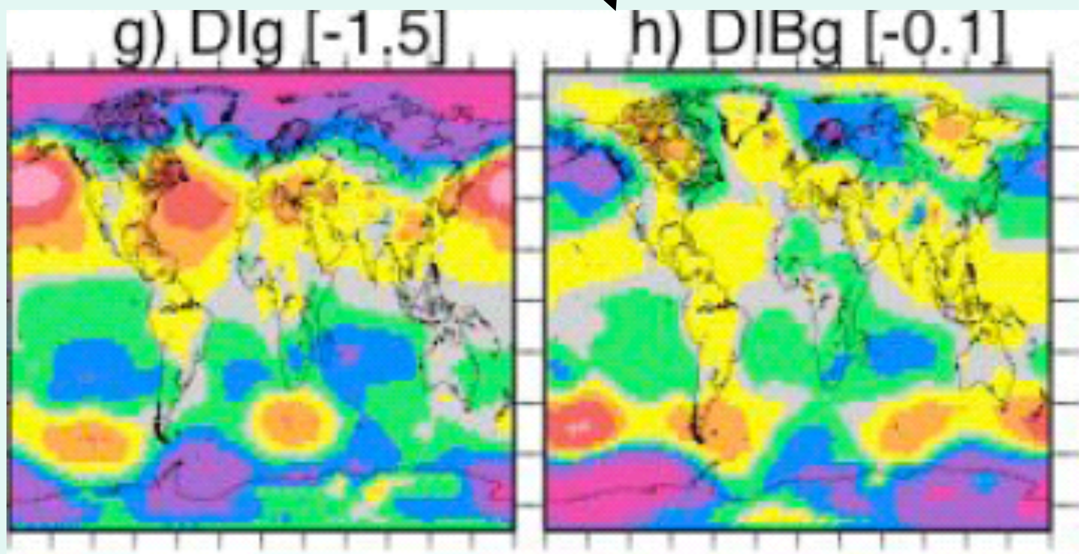
Observed



http://hadobs.metoffice.com/hadslp2/

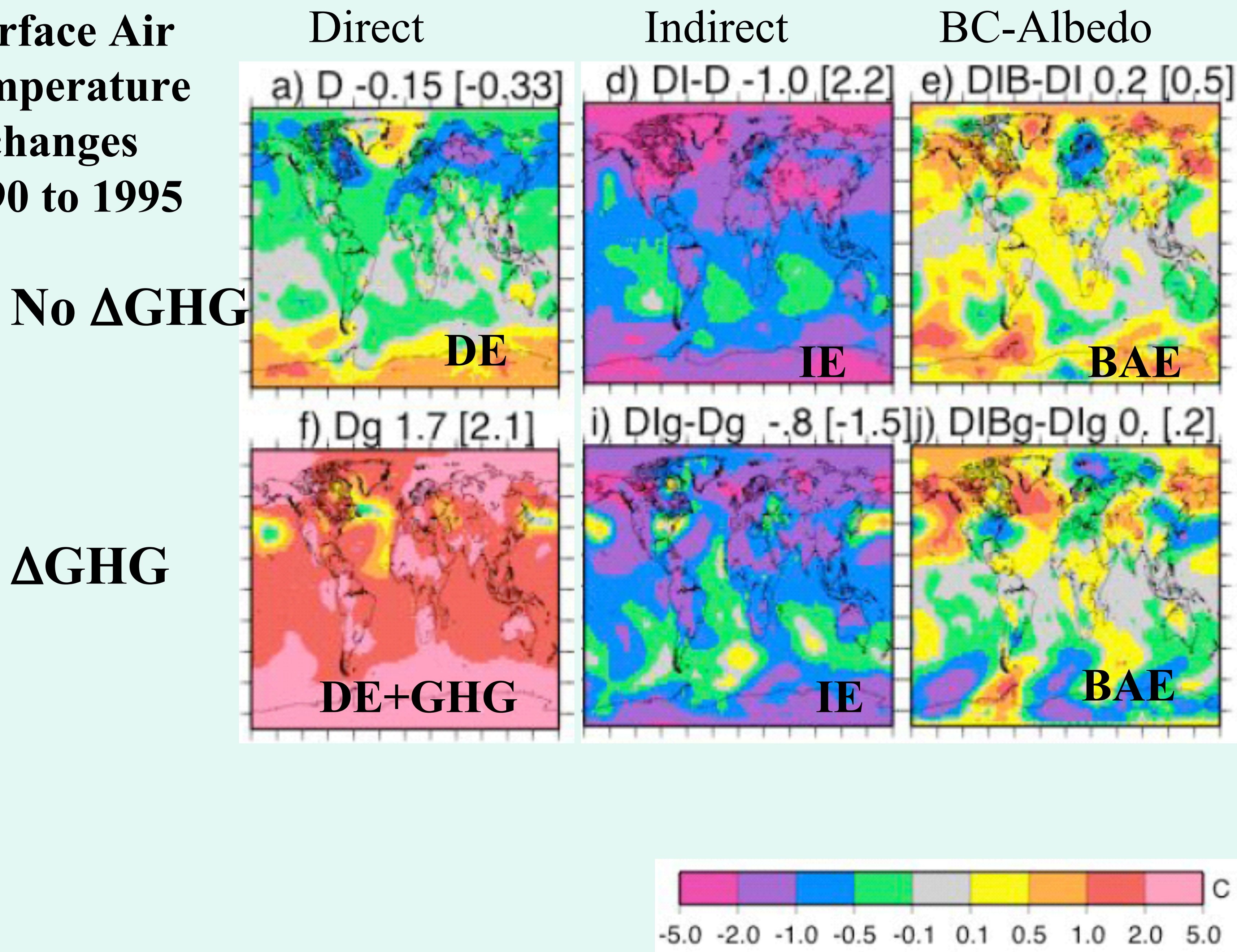
Model with all effects

No BC-albedo effect

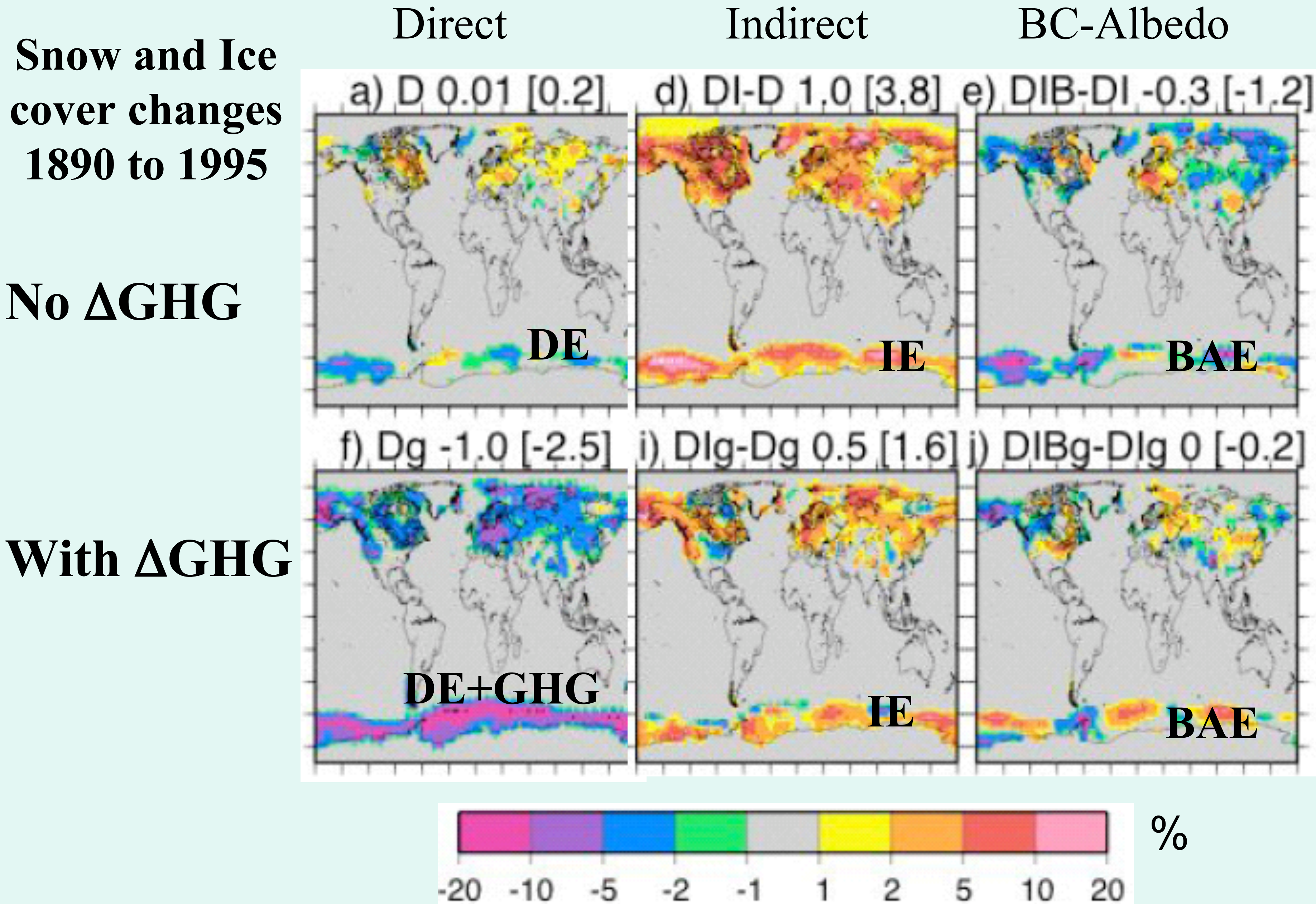


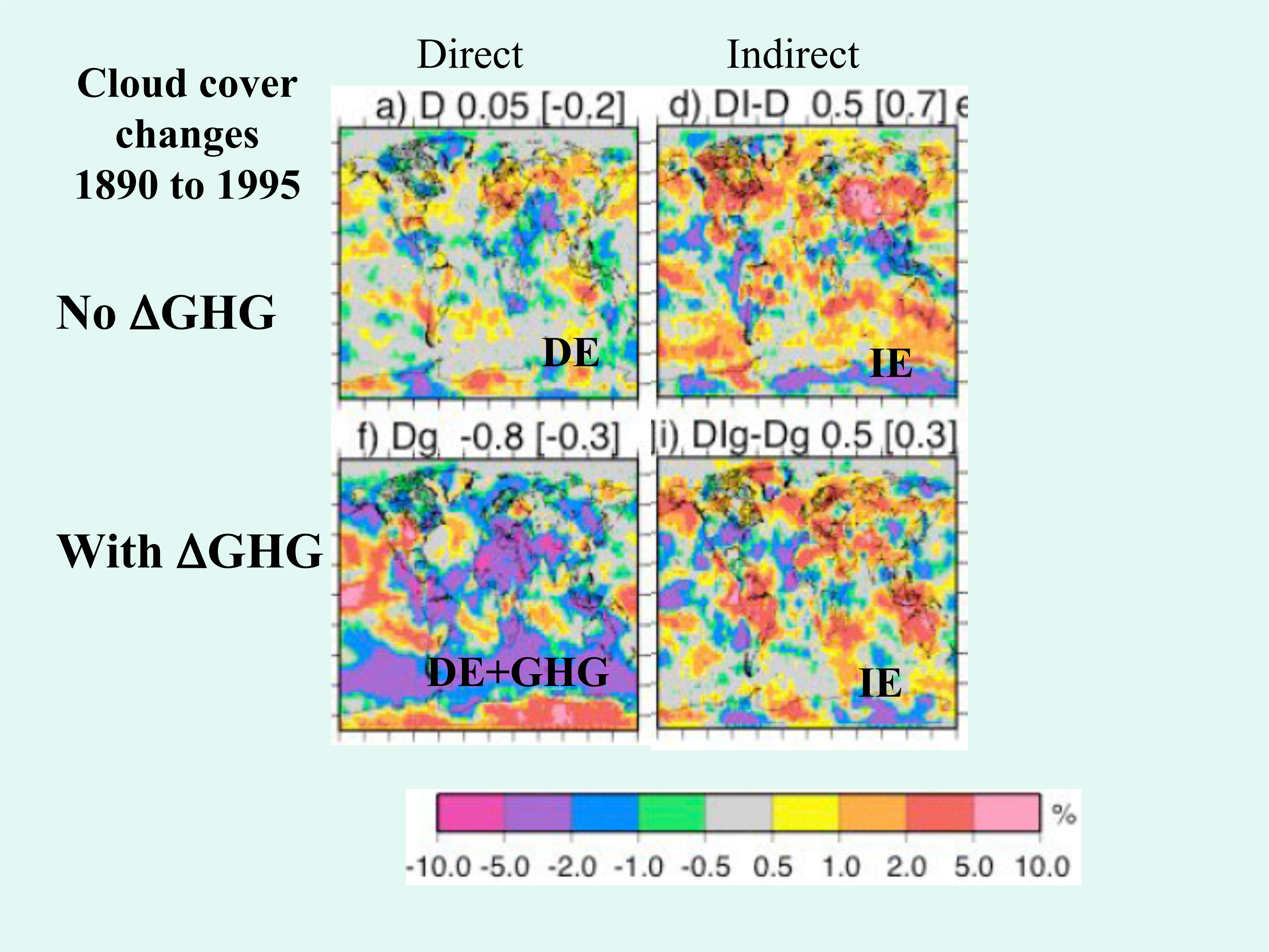
Model captures some features, but the BC-albedo effect seems to increase Arctic SLP too much

Surface Air Temperature changes 1890 to 1995

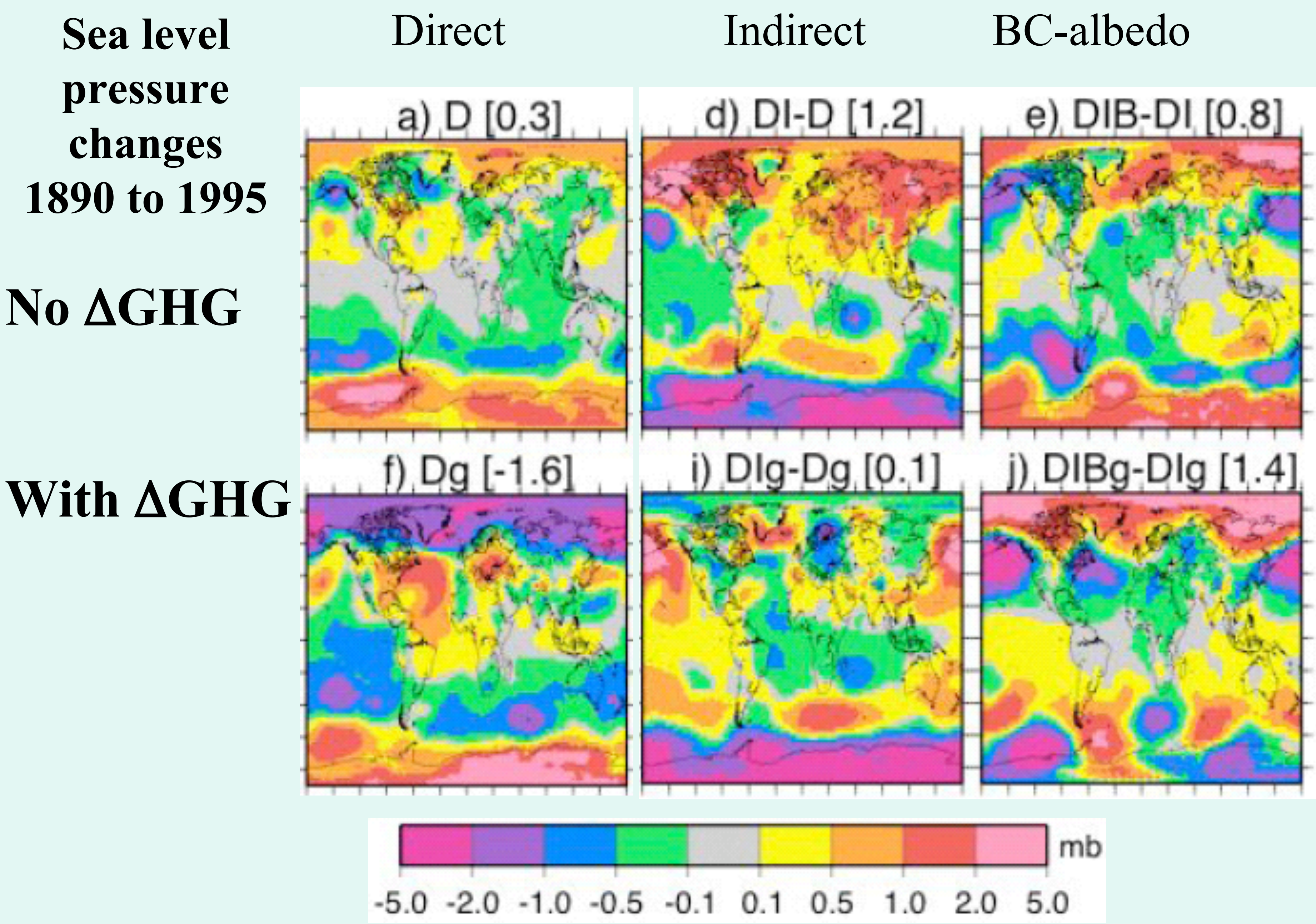


Snow and Ice cover changes 1890 to 1995




Cloud cover changes 1890 to 1995
Direct
Indirect
No ΔGHG
With ΔGHG
a) D 0.05 [-0.2]
d) DI-D 0.5 [0.7]
f) Dg -0.8 [-0.3]
i) DIg-Dg 0.5 [0.3]
DE
IE
DE+GHG
IE
%
-10.0 -5.0 -2.0 -1.0 -0.5 0.5 1.0 2.0 5.0 10.0

Sea level pressure changes 1890 to 1995



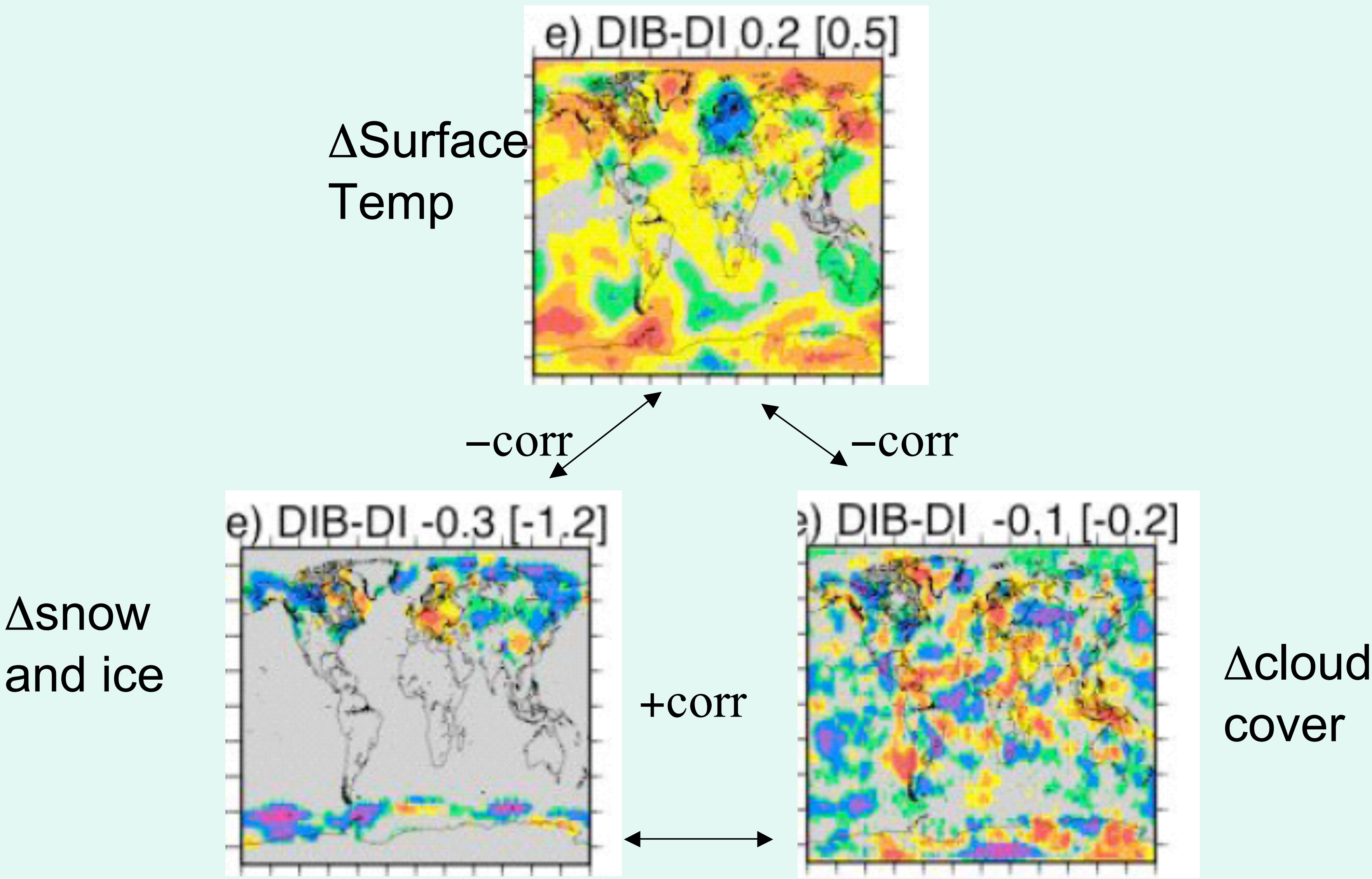
Correlations among impacts

TABLE 3. Correlations Among Global [Arctic] Changes from 1890 to 1995

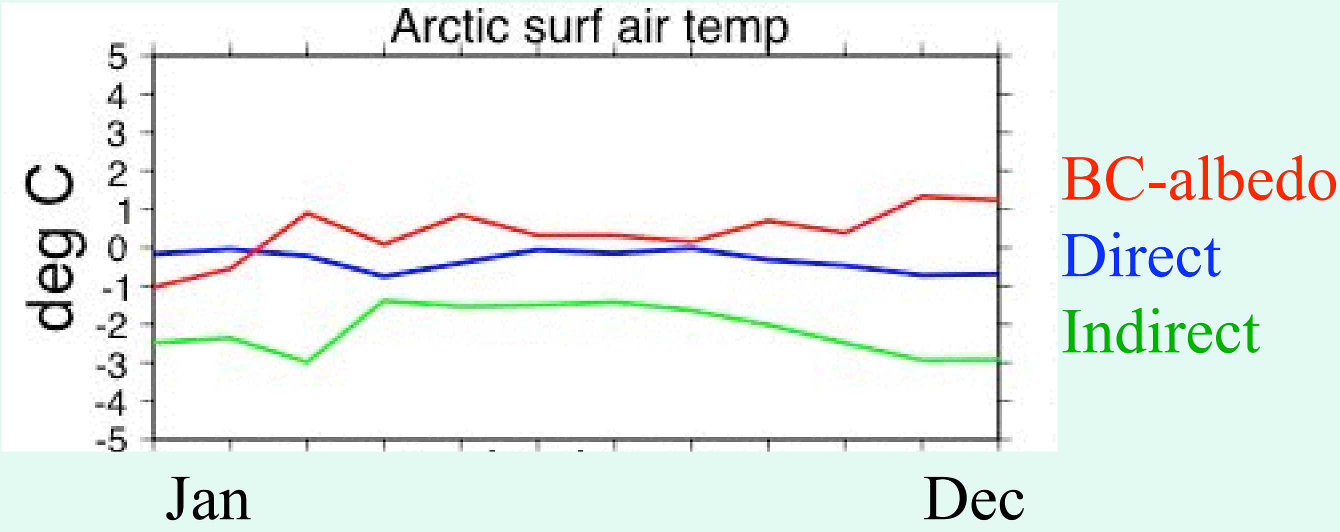
	Direct	Indirect	BC-albedo	Direct	Indirect	BC-albedo
					with GHG changes	
Fields	D	DI	DIB	Dg	DIg	DIBg
CLD vs SAT	-0.22[-0.24]	-0.33[0.06]	-0.35[-0.06]	-0.27[-0.18]	-0.31[0.05]	-0.29[-0.42]
LOW CLD vs SAT	-0.34[-0.33]	-0.53[0.10]	-0.54[-0.07]	-0.41[-0.15]	-0.48[0.01]	-0.47[-0.45]
SAT vs SNO/ICE	-0.40[-0.46]	-0.48[-0.25]	-0.51[-0.37]	-0.32[-0.49]	-0.31[-0.31]	-0.33[-0.34]
CLD vs SNO/ICE	0.16[0.33]	0.32[0.44]	0.35[0.34]	0.13[0.22]	0.15[0.28]	0.21[0.27]
SLP vs SAT	0.22[-0.27]	-0.67[-0.40]	-0.55[-0.09]	-0.11[-0.21]	-0.31[-0.44]	-0.08[0.27]

- Correlations among low cloud changes, SAT, snow changes from aerosols effects
- These correlations are weaker if GHG's change too

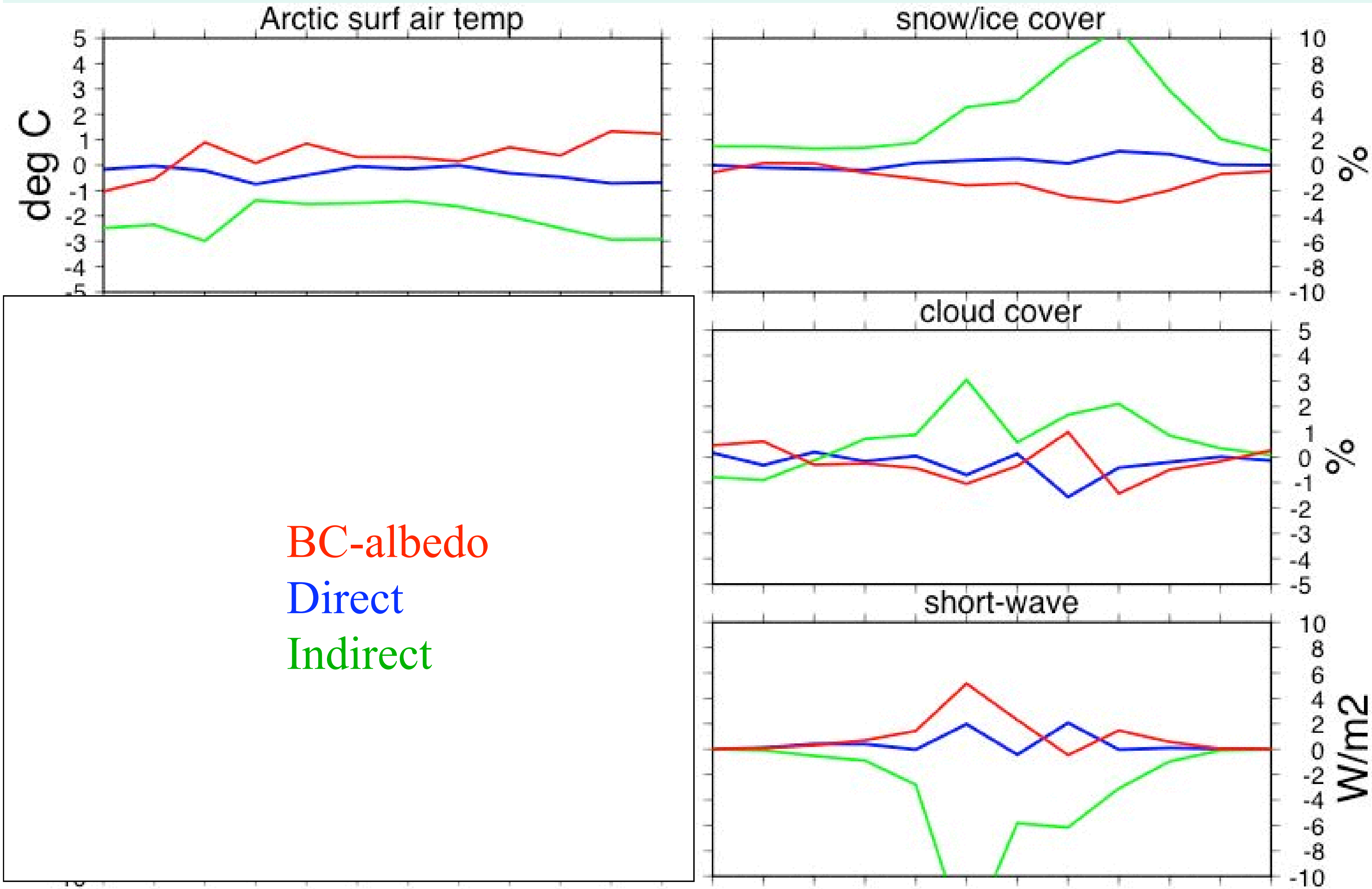
E.g. effects of BC-snow albedo



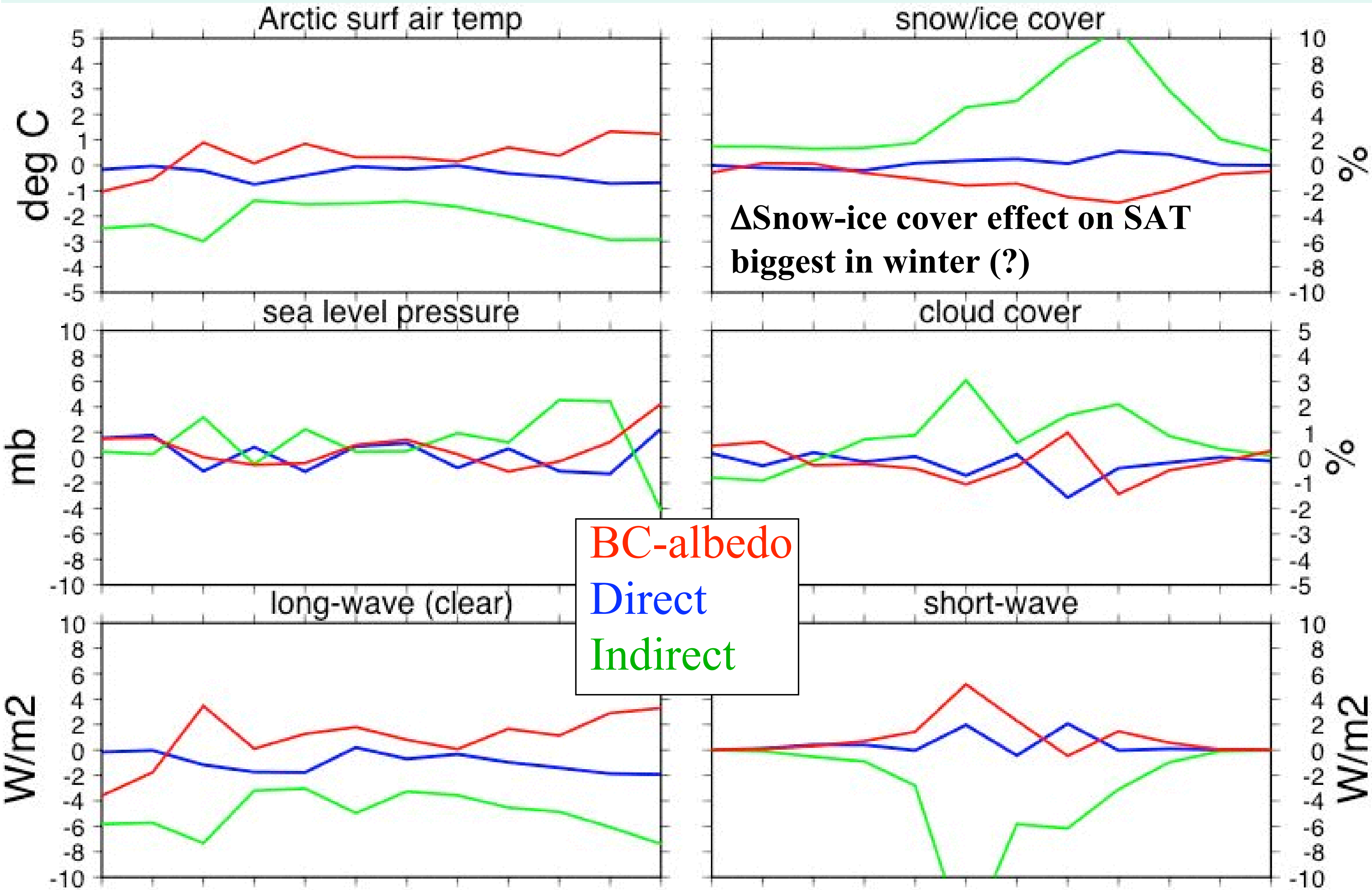
Arctic seasonalities



Arctic seasonalities



Arctic seasonalities



Part 2. Transient climate experiments with fully coupled aerosol-gas-climate (deep ocean) for 20th century (and beyond)

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and Shindell, Bauer, Miller, Faluvegi, Ruedy, Bond, Schmidt, Unger

October 8, 2008 **Reykjavik, Iceland**

Aerosol-gas-climate transient model setup

Transient run should give "realistic" climate change and bring us to correct present-day climate dis-equilibrium.

Signal/forcing is weak, need ensemble of simulations

Species run "on-line" to get all feedbacks, especially important for indirect and BC-albedo effects.

Aerosols: sulfate, BC, OC, sea-salt, nitrate, dust (including heterogeneous dust-nitrate-sulfate chemistry)

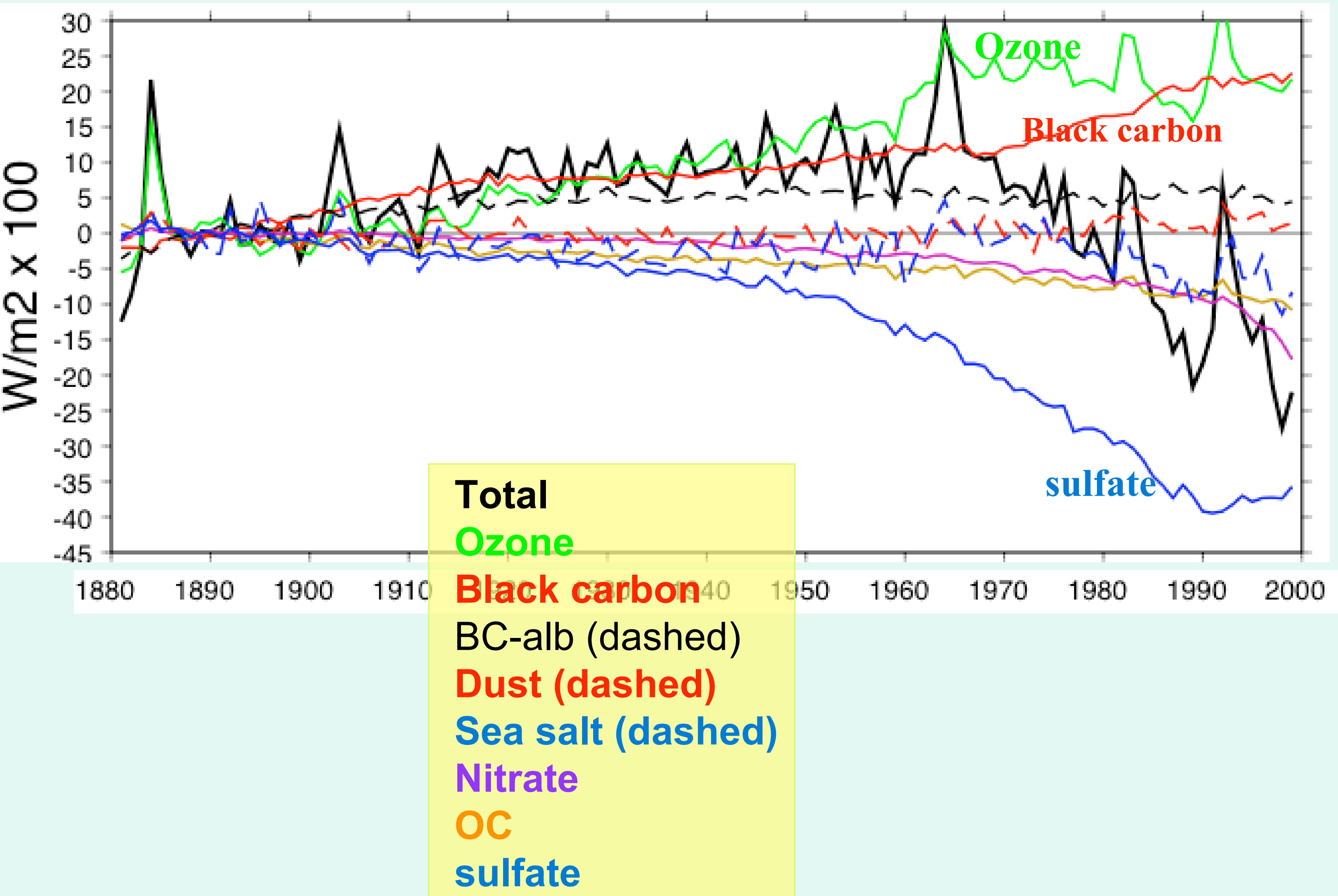
Coupled to ozone chemistry

No aerosol indirect effect (yet), but includes BC-albedo and direct effects

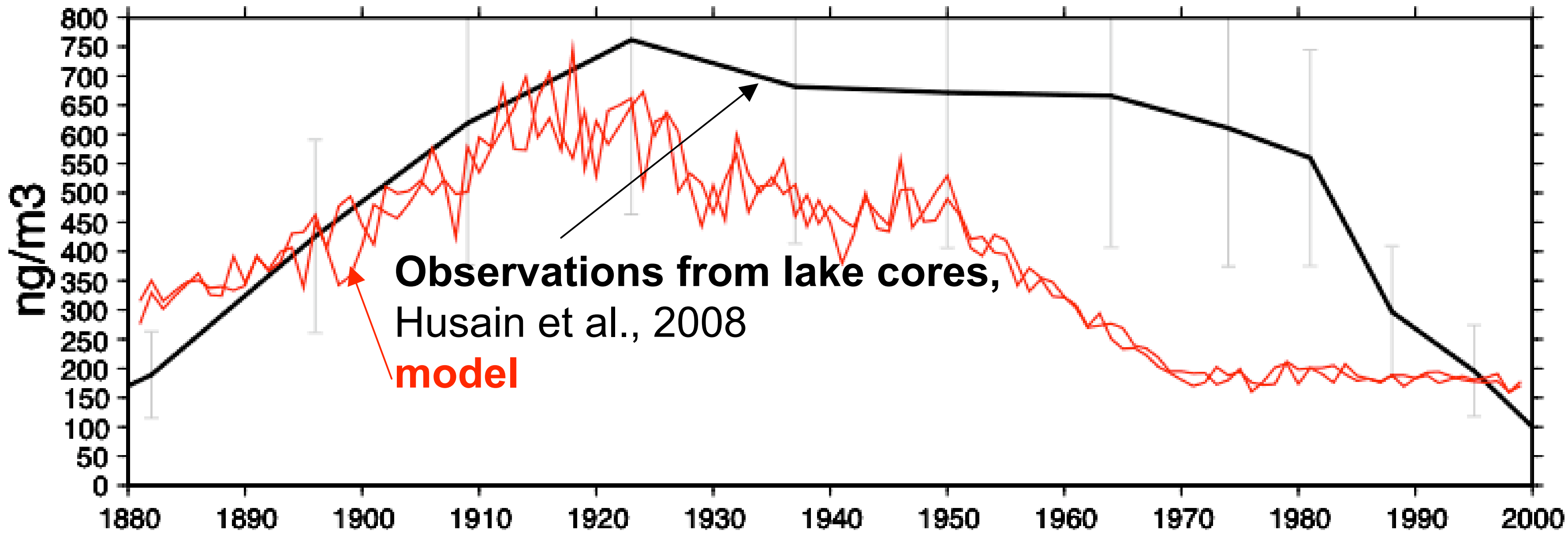
We couple to simulation with deep ocean:

1) Initial condition: very well equilibrated (offline-tracer) run from the Hansen et al late 1800's climate spin-up.
2) Turn on tracers, run 1890 for several decades to spin-up
3) Run for 20th century

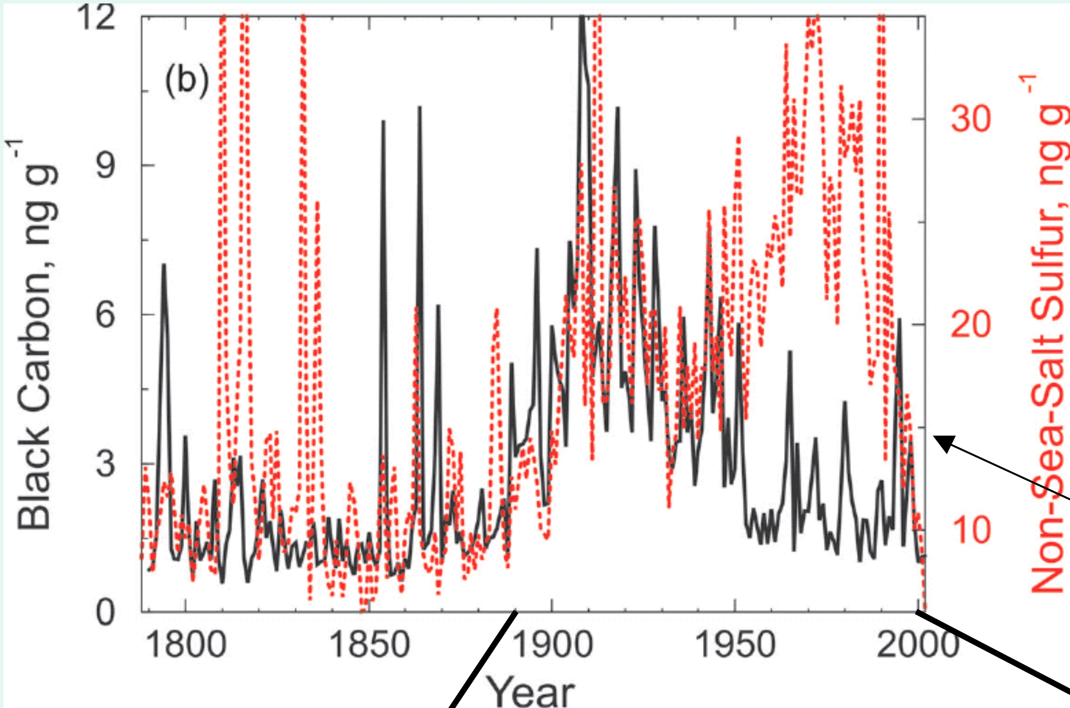
Global radiative forcing trends for short-lived species



Black Carbon at Whiteface Mountain, NY



Husain, L., A. J. Khan, T. Ahmed, K. Swami, A. Bari, J. S. Webber, and J. Li (2008), Trends in atmospheric elemental carbon concentrations from 1835 to 2005, J. Geophys. Res., 113, D13102, doi:10.1029/2007JD009398.

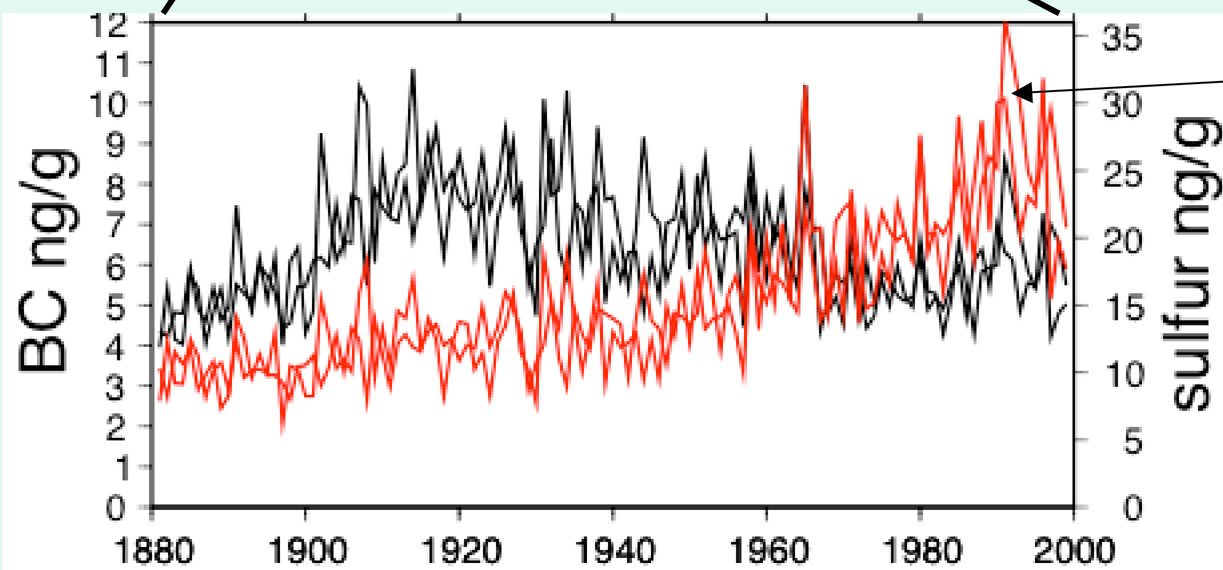


McConnell *et al.*, 2007

20th-Century Industrial Black Carbon Emissions Altered Arctic Climate Forcing

www.sciencexpress.org / 9 August 2007 / 10.1126/science.1144856

Black Carbon and sulfate in Greenland ice core

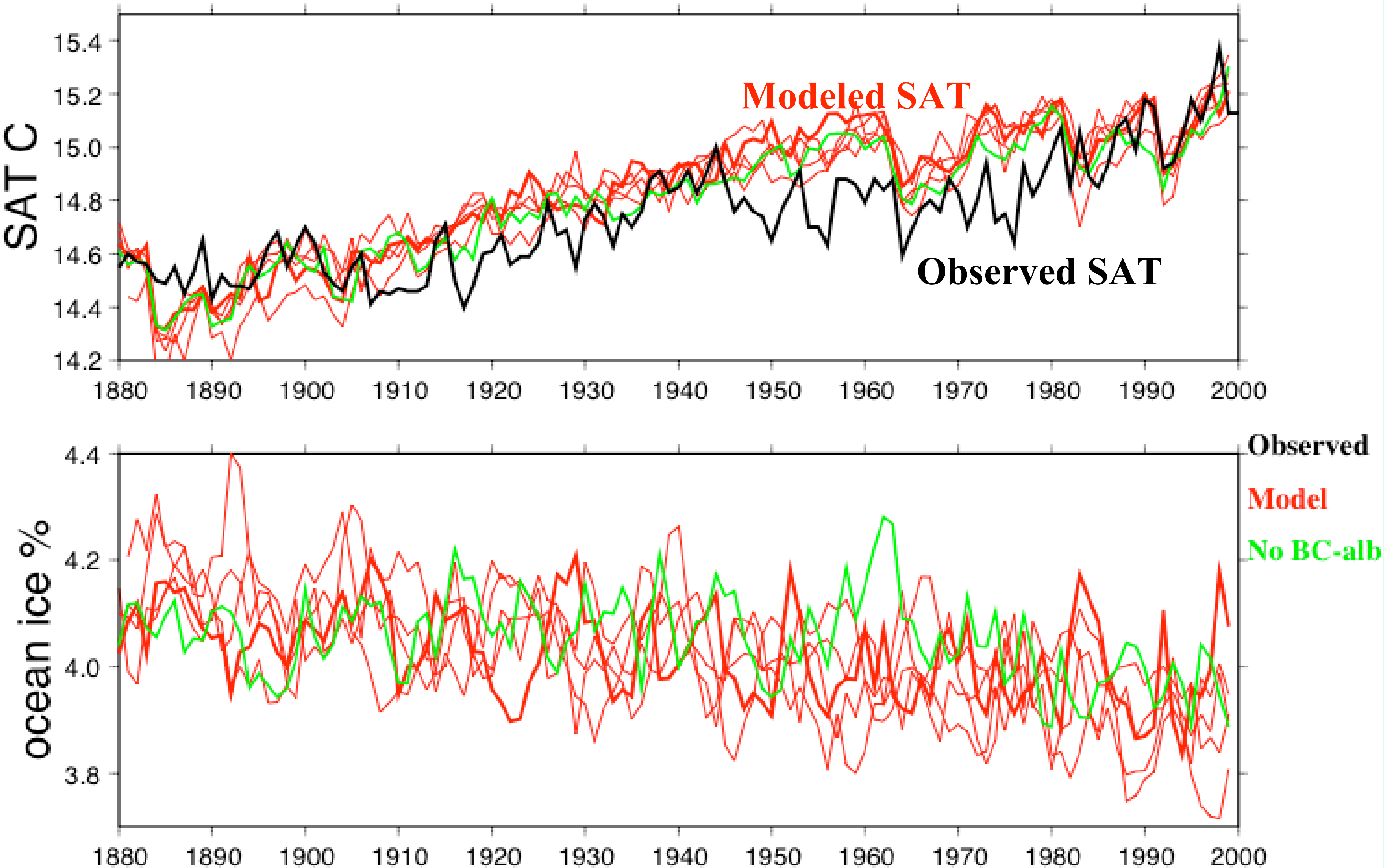


Model

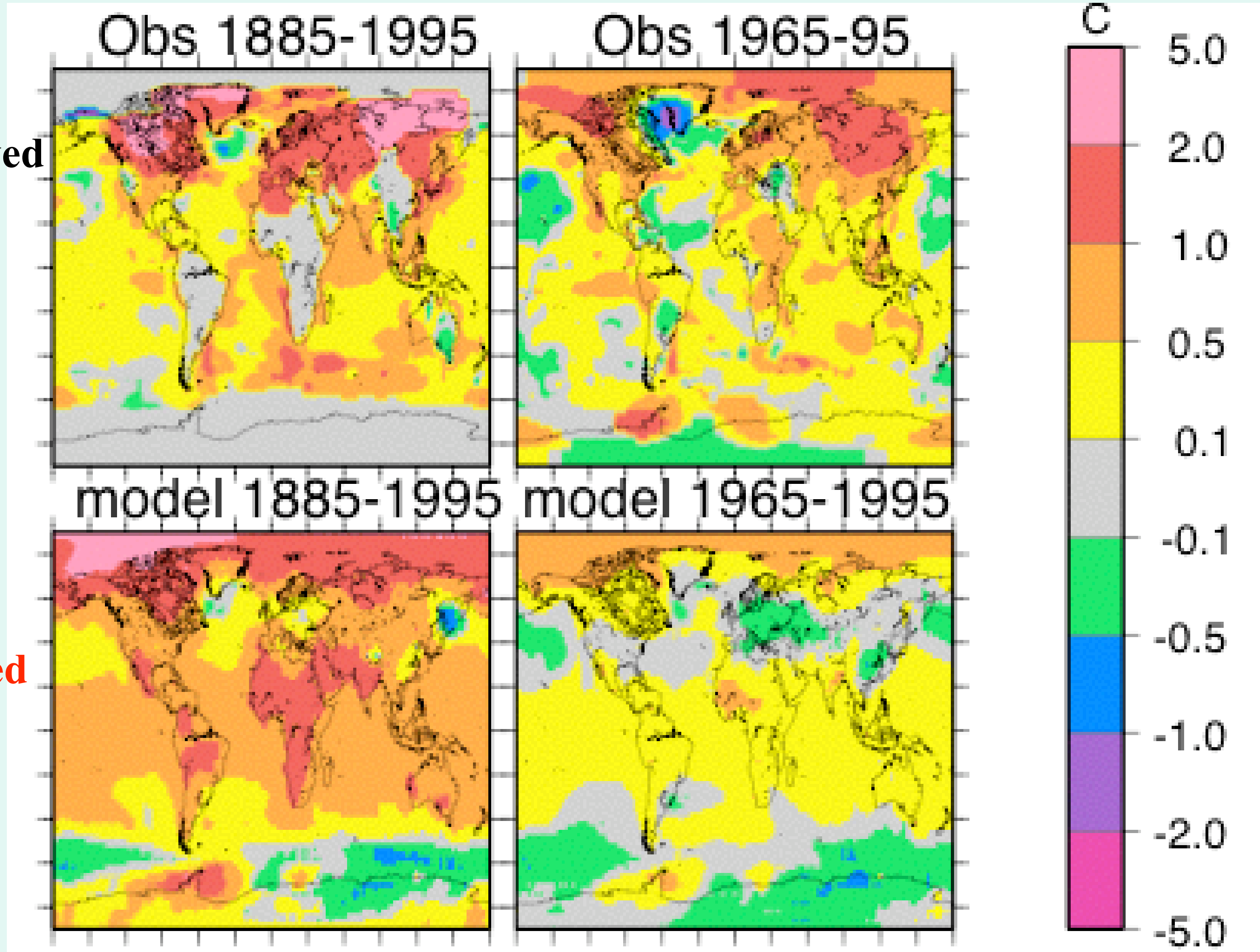
BC: too much after 1950

Sulfate: not enough from 1910-1940

Model results: Trends in Surface Air Temperature and Ocean ice



Observed and modeled surface temperature changes



Observed ΔSAT

Modeled ΔSAT

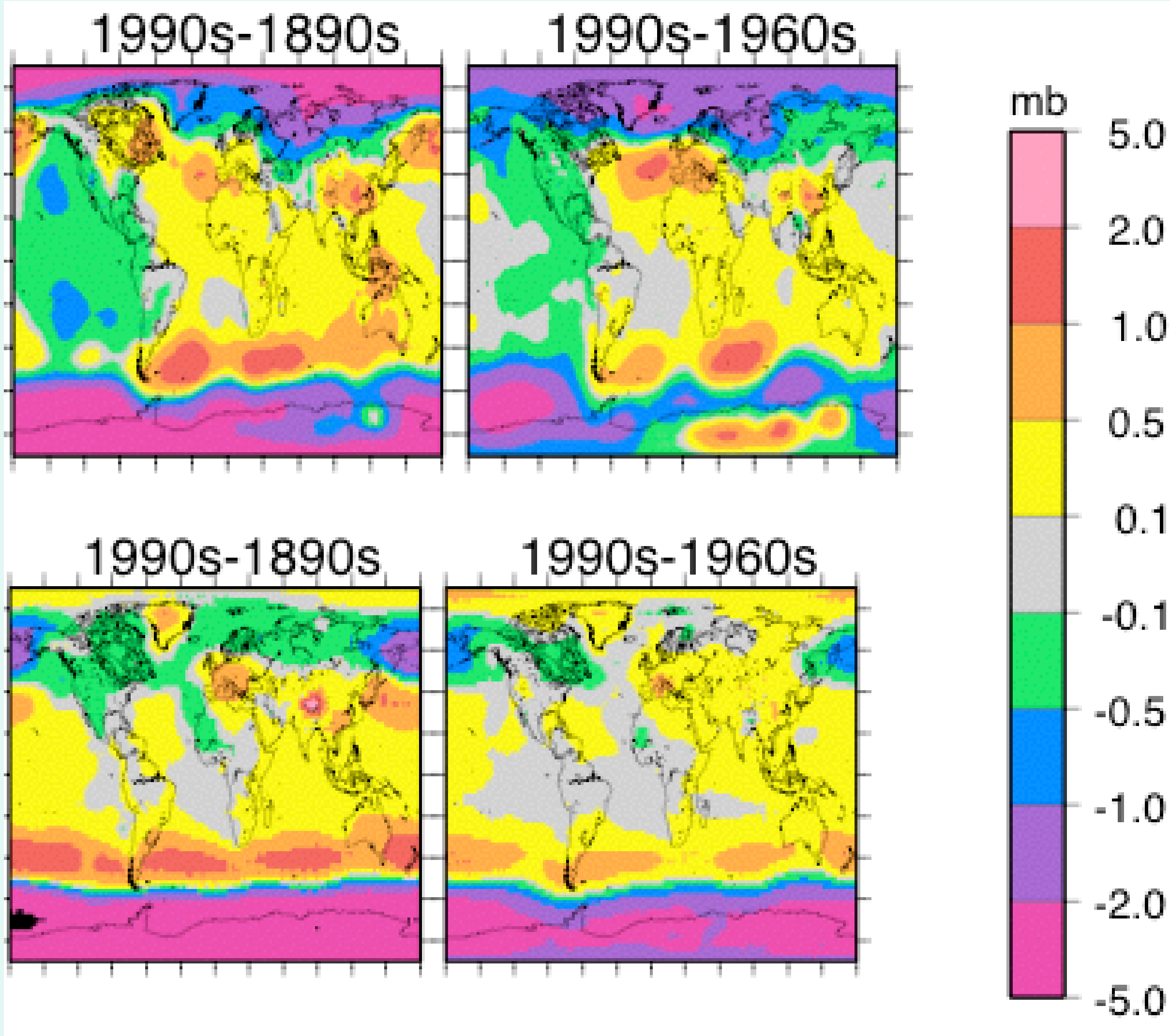
century

60's to 90's

Observed and modeled sea level pressure changes

Observed
ΔSLP

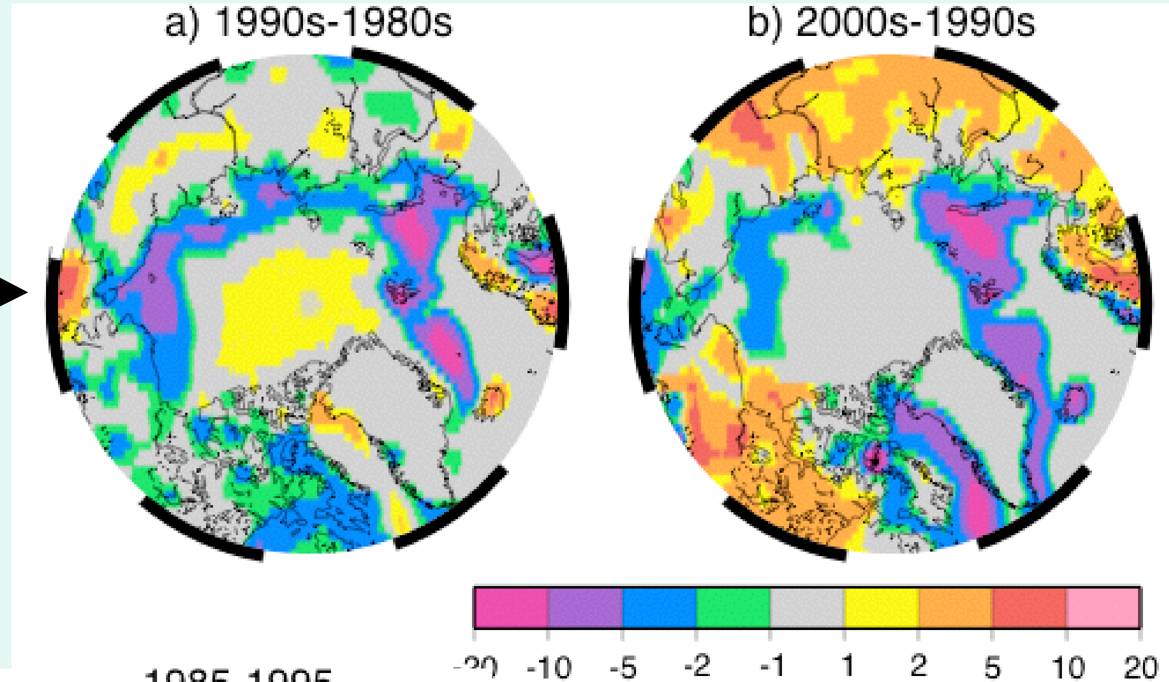
Modeled
ΔSLP

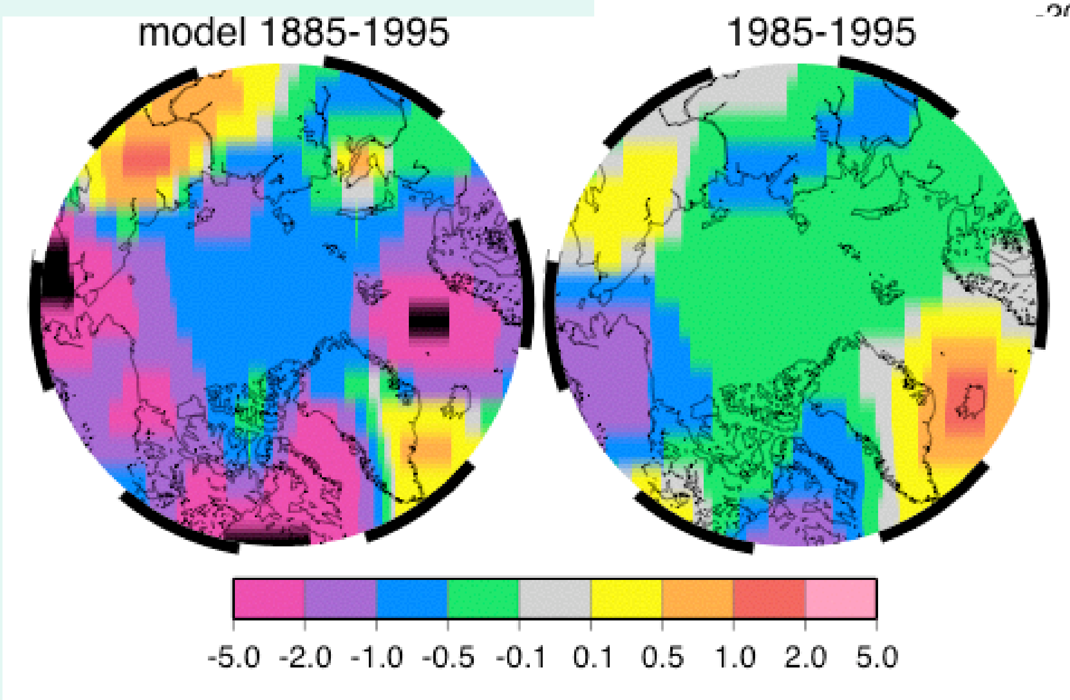


century **60’s to 90’s**

Artic snow and ice cover (%)

Observed

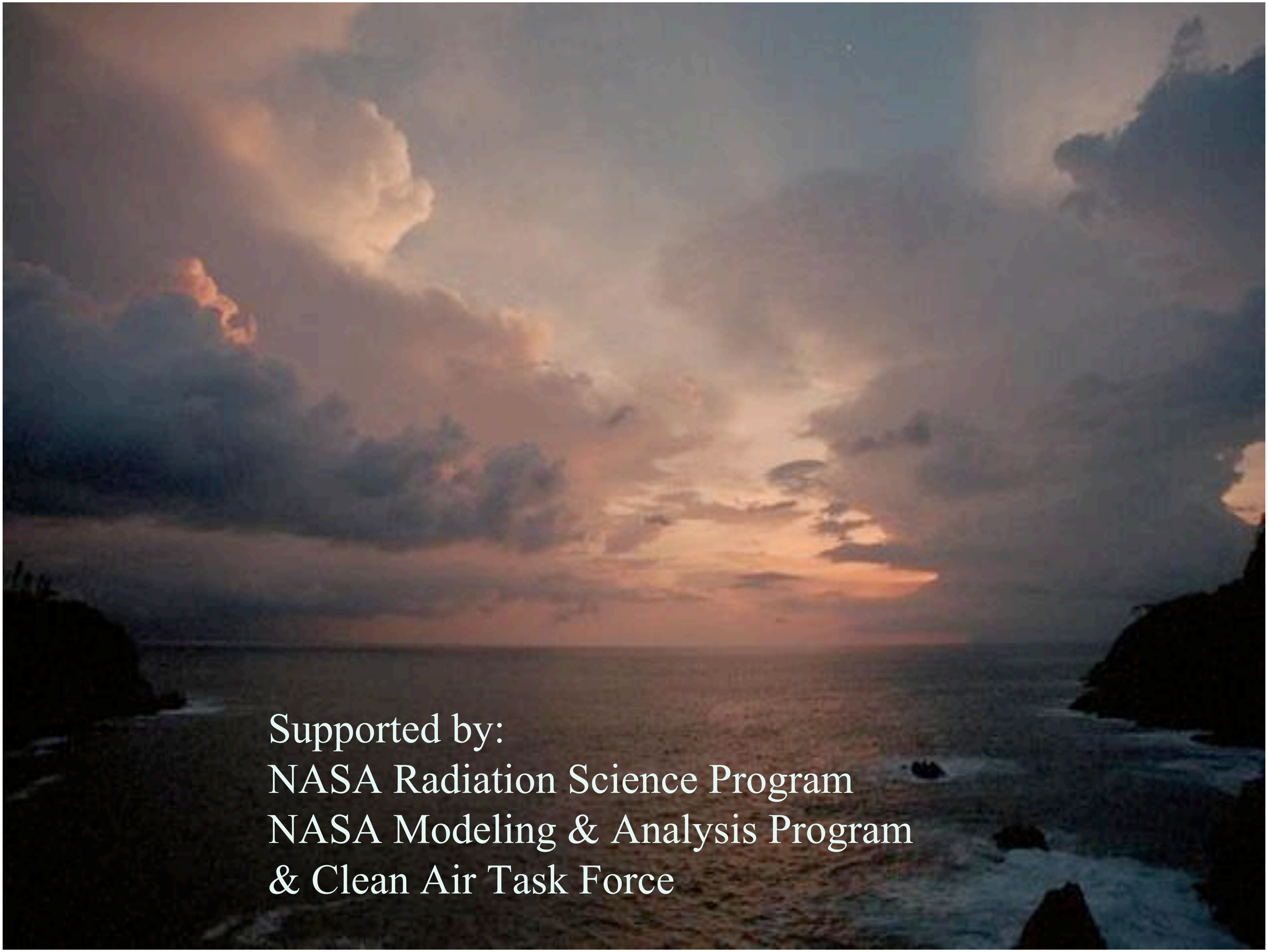




Model

Next steps

- Include indirect effect in transient experiments
- Continue forward with future (mitigation) experiments
- Isolate effects during past 2 decades (requires multiple ensembles)
- Study how coupled species/effects affect climate sensitivity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