Aerosol-Chemistry-Climate Interactions in Transient 20th Century Simulations with GISS ModelE

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Climate Simulations Setup

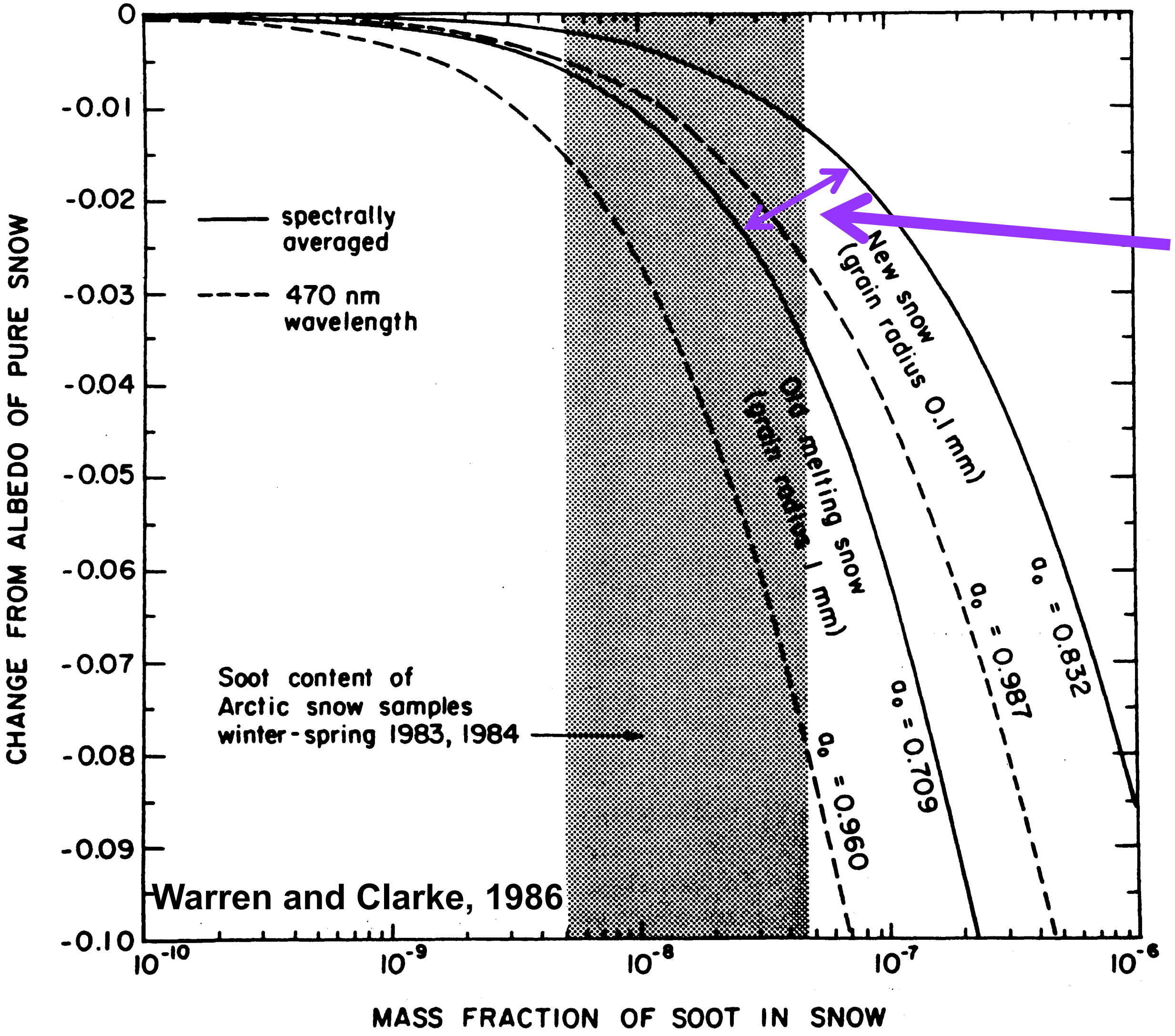
1. **Transient simulations for 1890 to 2000**, with on-line aerosols-gas-phase chemistry fully coupled to deep ocean. Simulations are:
    a) STD (direct, BC-albedo)
    b) IE (direct, BC-albedo, indirect)
    c) no BC-albedo (direct)

Spin-up: a) 1st used a well-equilibrated 1850 simulation with off-line ozone/ aerosols from Hansen et al. (2007), GISS AR4.
b) Interactive species/effects were turned on and the model spin-up extended another 100 years to equilibrium.

Ensemble of 3-5 transient simulations, with prescribed long-lived greenhouse gases, volcanic aerosols, solar and land-cover changes.
Aerosol (mass), gases: sulfur, BC/OC, sea-salt, dust, nitrate, ozone chemistry

This study is part II of Koch et al., J. Clim., 2009:
Q-flux equilibrium simulations for 1890 and 2000. Slab ocean, on-line aerosols.

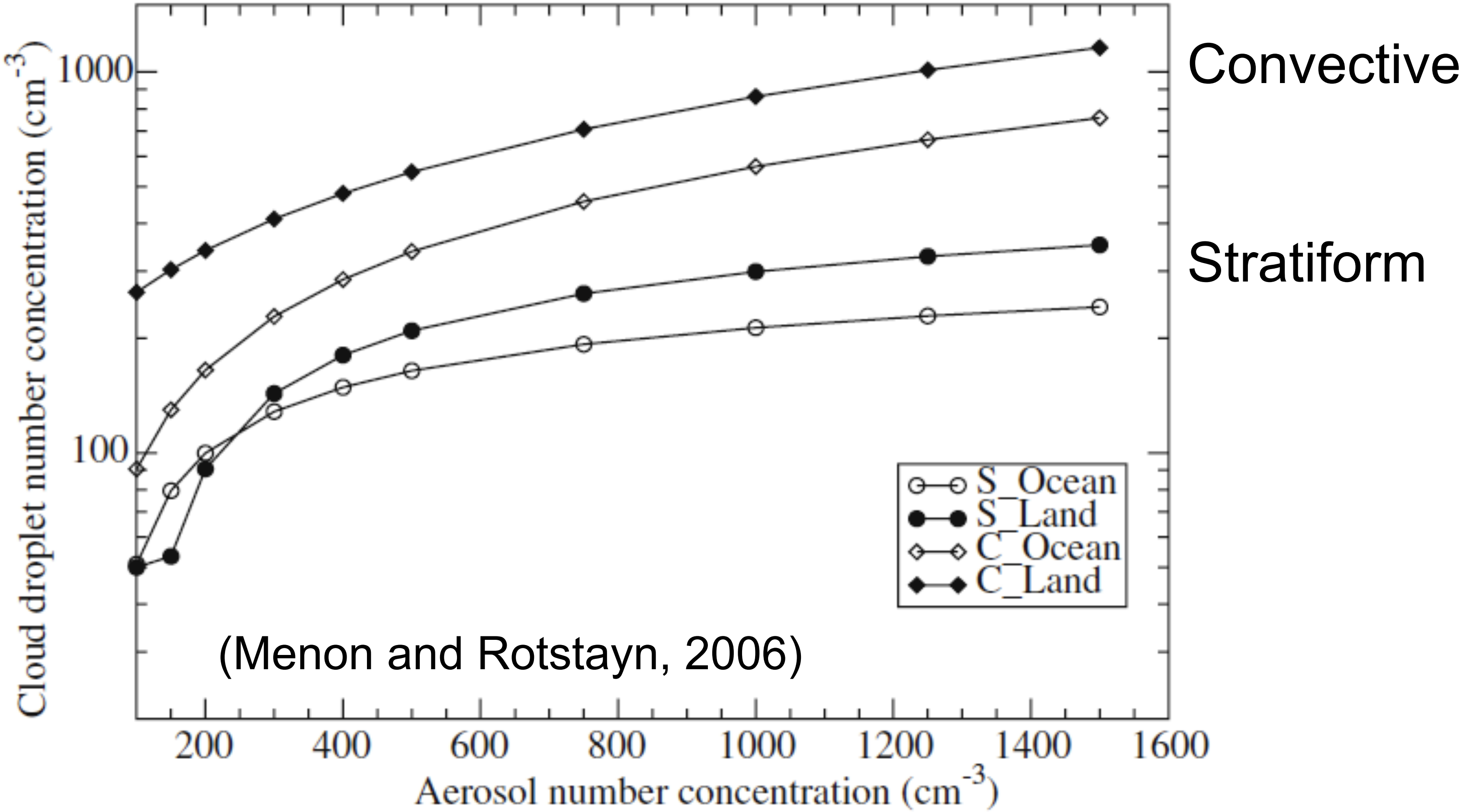
BC-albedo scheme



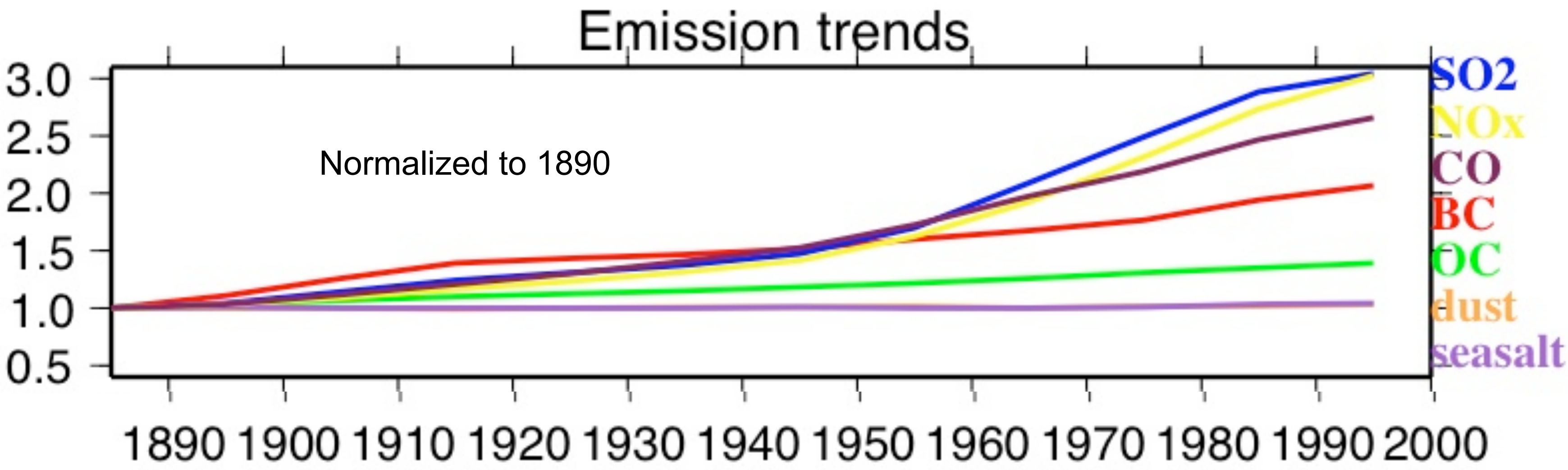
Model snow grain size = f(snow age, air temperature). Marshall (1989)

Koch et al., J. Clim, 2009

Aerosol Indirect Effect (AIE), (warm clouds only)

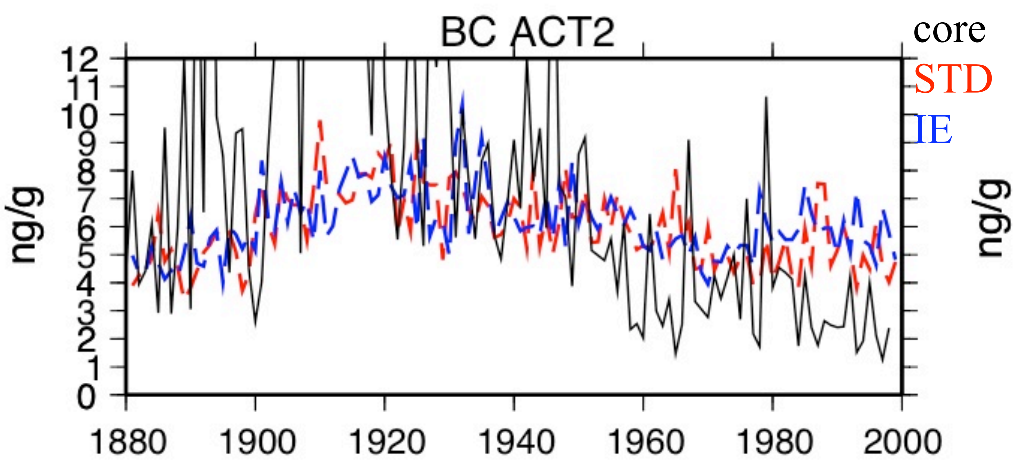


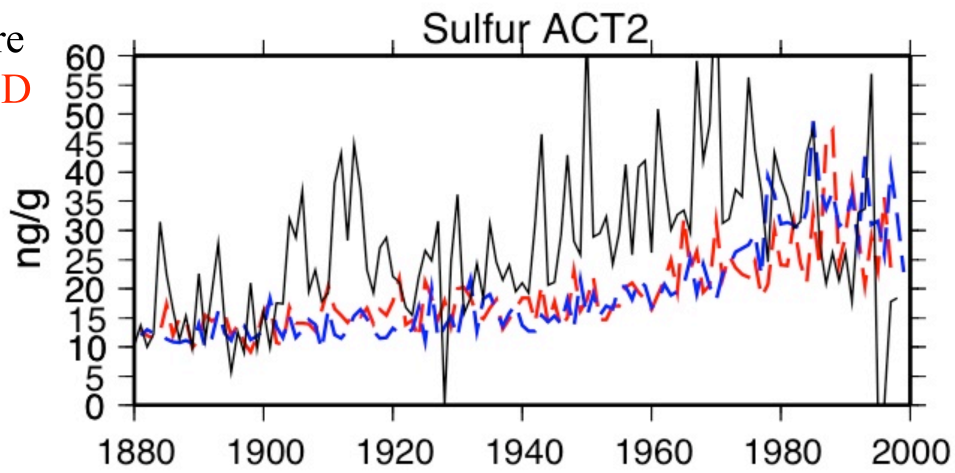
Emissions Trends

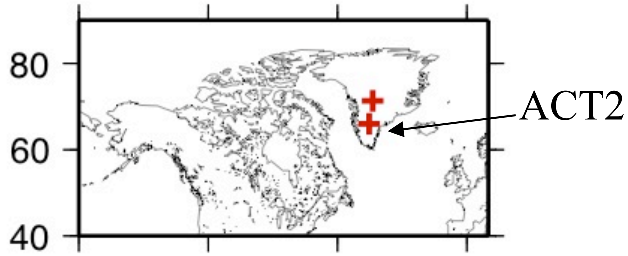


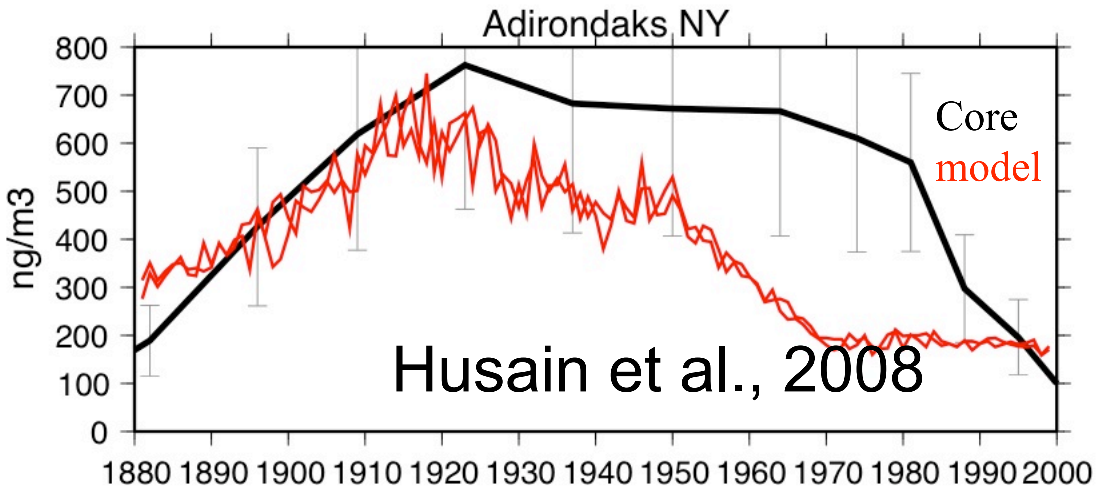
. Emissions are EDGAR (van Aardenne et al., 2001; EDGAR32_FT), except BC/OC from Bond et al. (2006), and biomass burning from GFED (scaled to 1/2 in tropics for 1880, increasing linearly to 2000), natural sources.

BC, sulfate model trends vs McConnell et al. Greenland ice core data



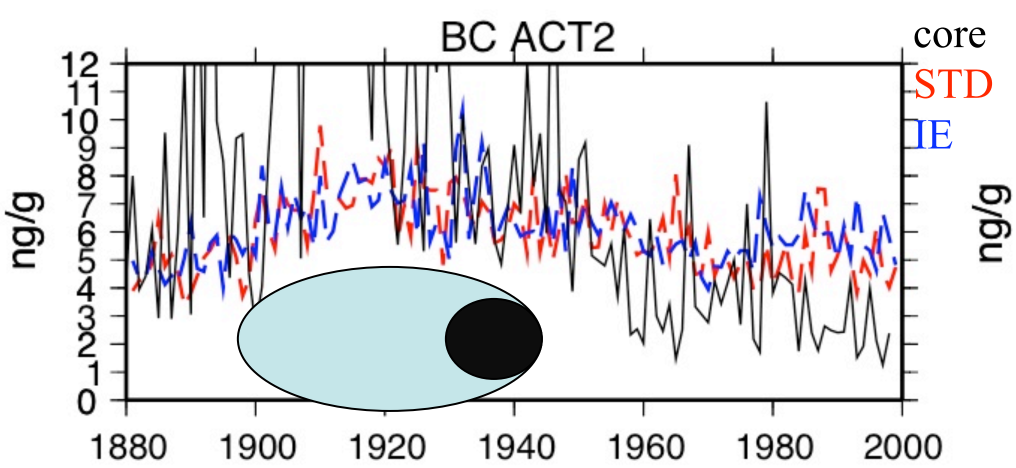


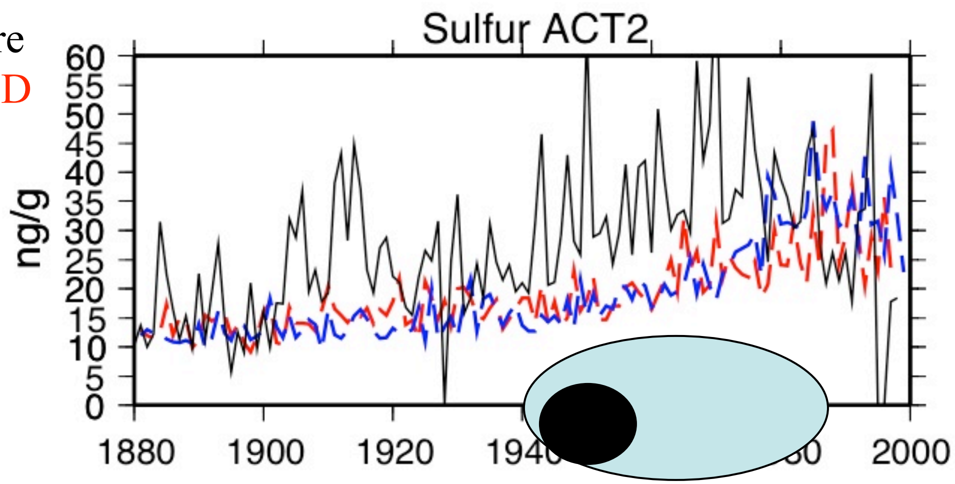


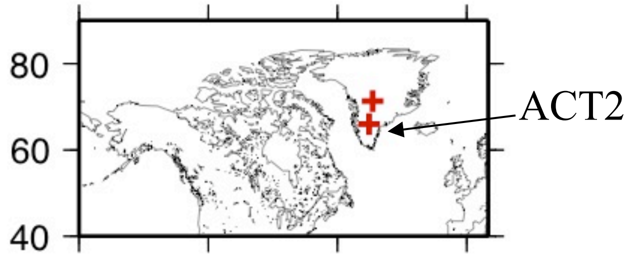


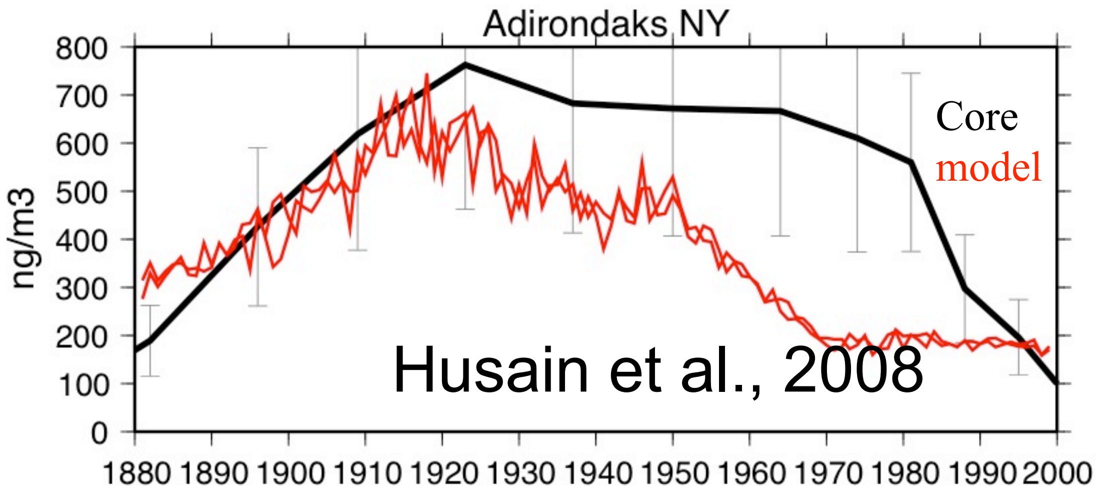
BC air concentration history derived from NY lakecore BC

BC, sulfate model trends vs McConnell et al. Greenland ice core data









BC air concentration history derived from NY lakecore BC

SO2 Emissions (Smith et al., 2004)

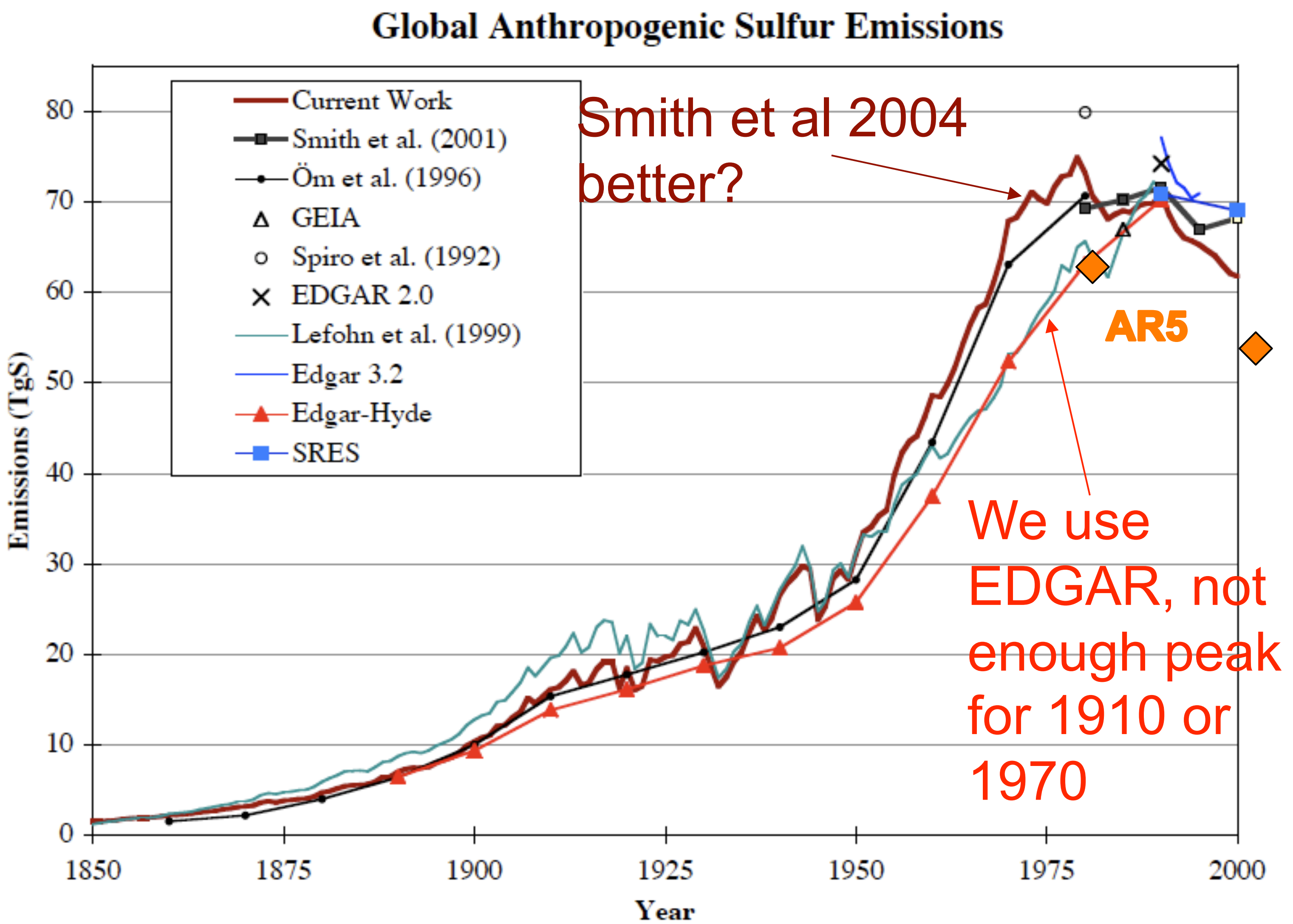
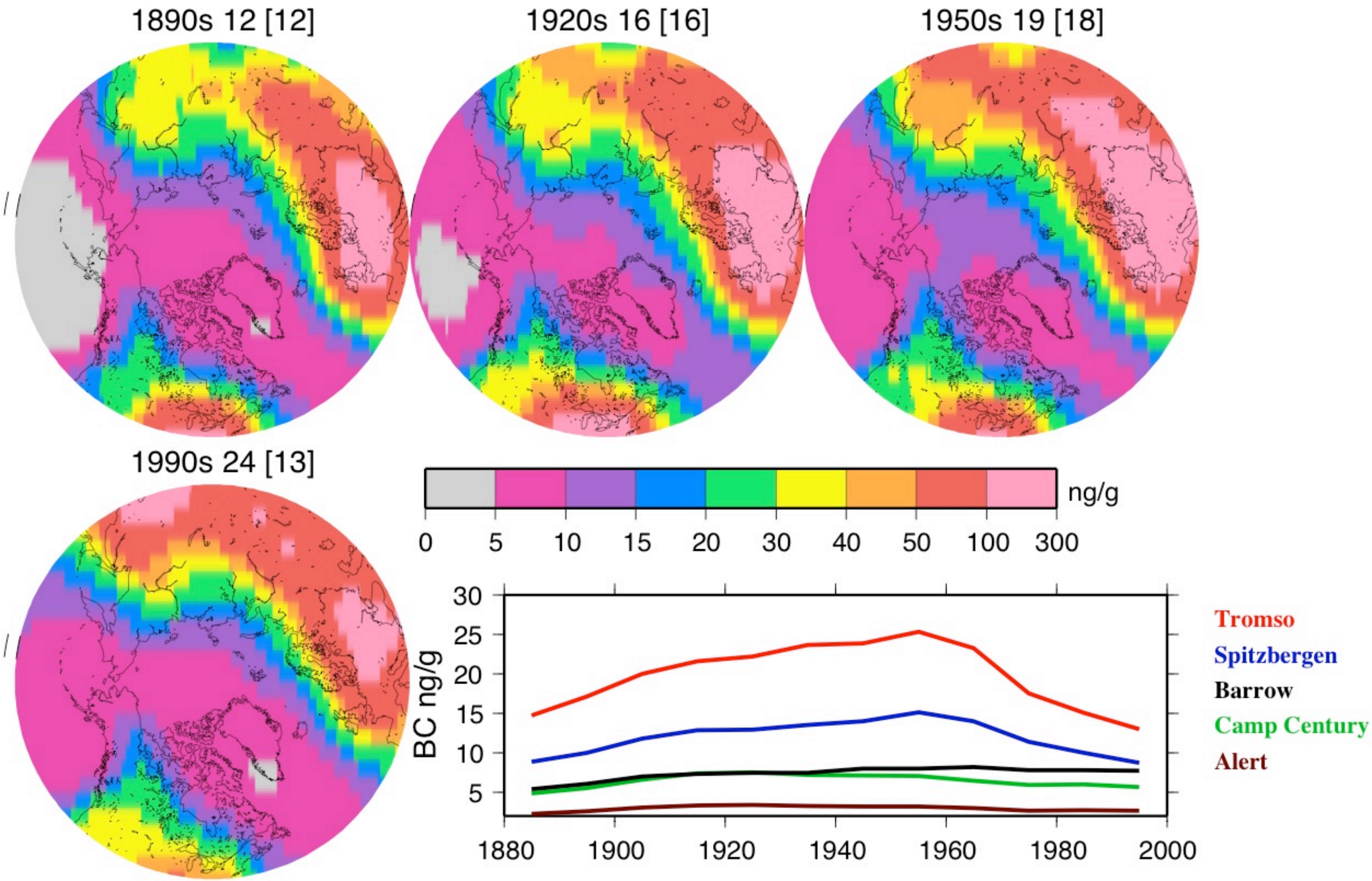


Figure 1–Global sulfur dioxide emissions from this study (thick line) and several other recent estimates (see text). Note that the Lefohn *et al.* estimate does not include all anthropogenic emissions sources. References not shown on the cart are: GEIA (Benkovitz *et al.*1996); EDGAR 2.0 (Olivier *et al* 1996); EDGAR 3.2 (Olivier and Berdowski, 2001); EDGAR-HYDE (Van Aardenne *et al.* 2001); and SRES (Nakicenovic and Swart 2000).

BC Arctic deposition

Compares decently with field data for 1980s, 2000s



deposition

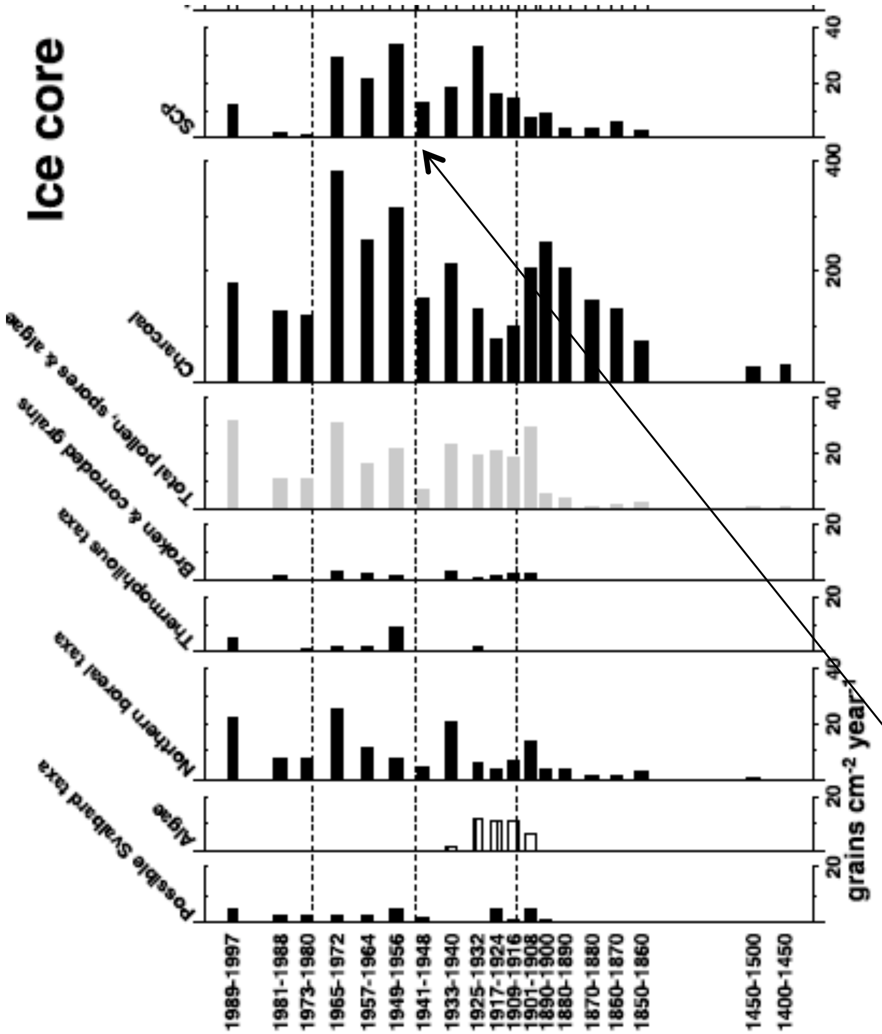
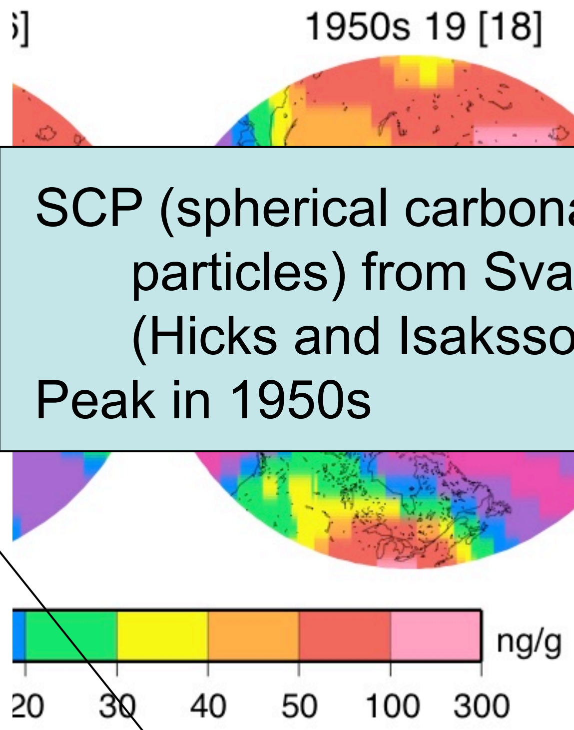
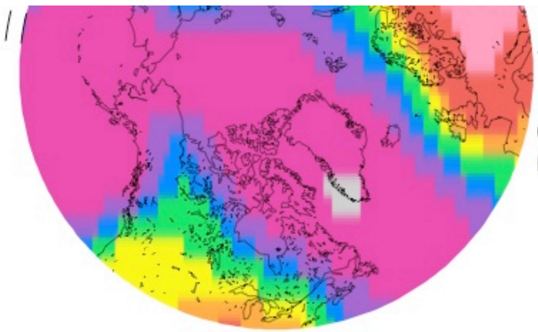


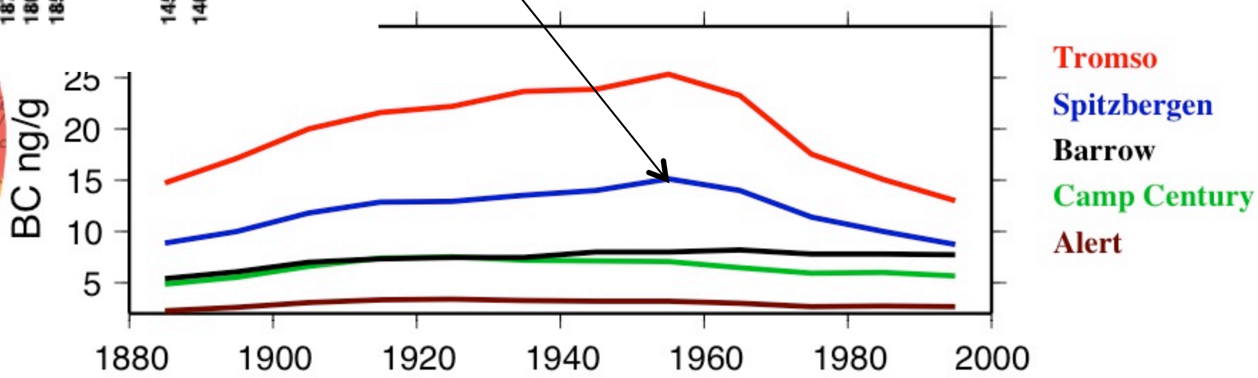
Figure 2



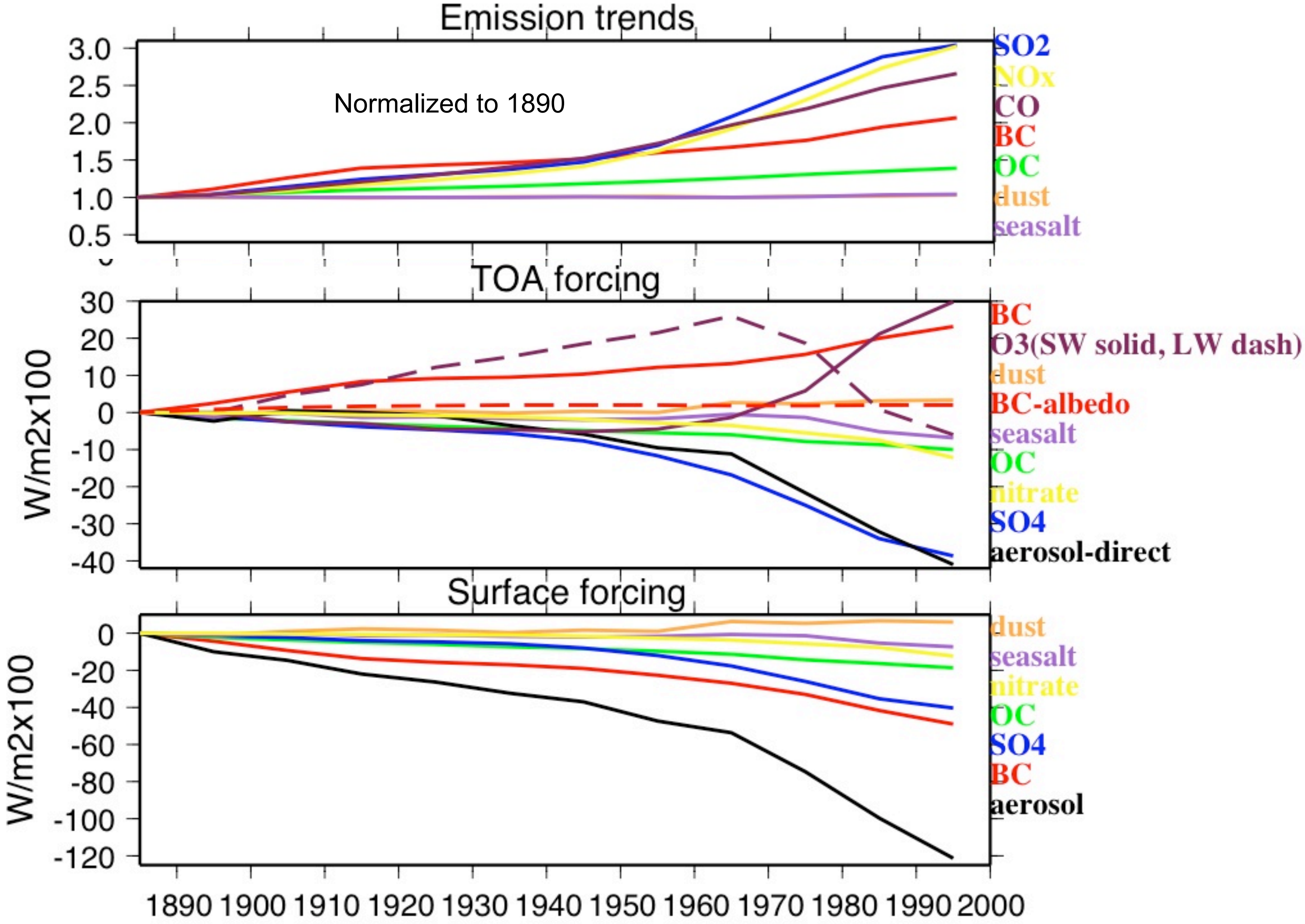
SCP (spherical carbonaceous particles) from Svalbard (Hicks and Isaksson, 2006)

Peak in 1950s

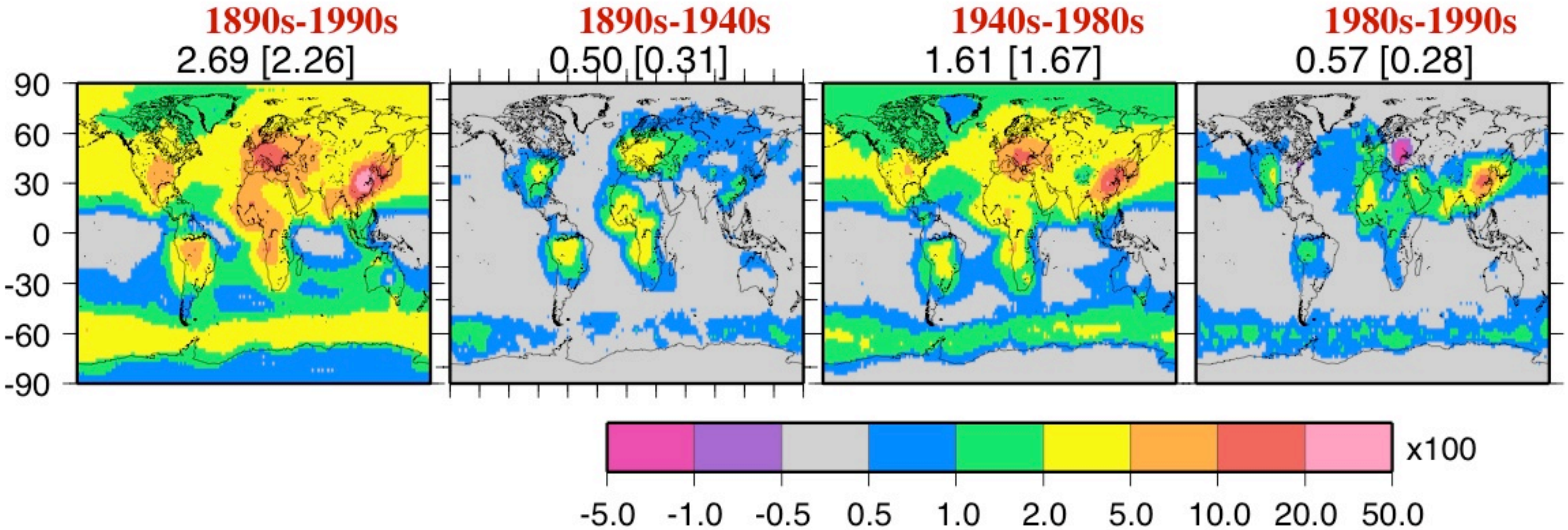




Emissions, Forcing Trends

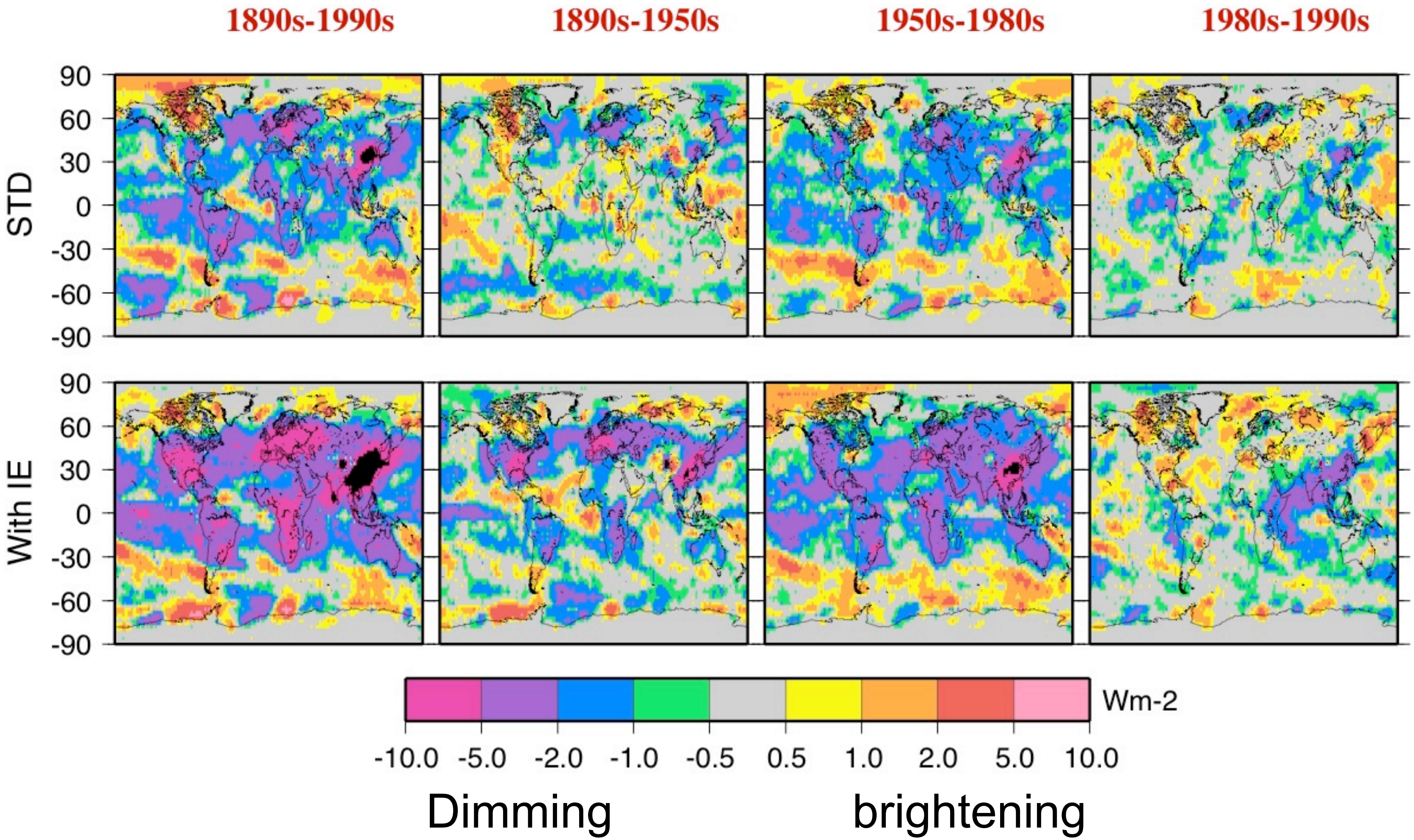


AOD changes

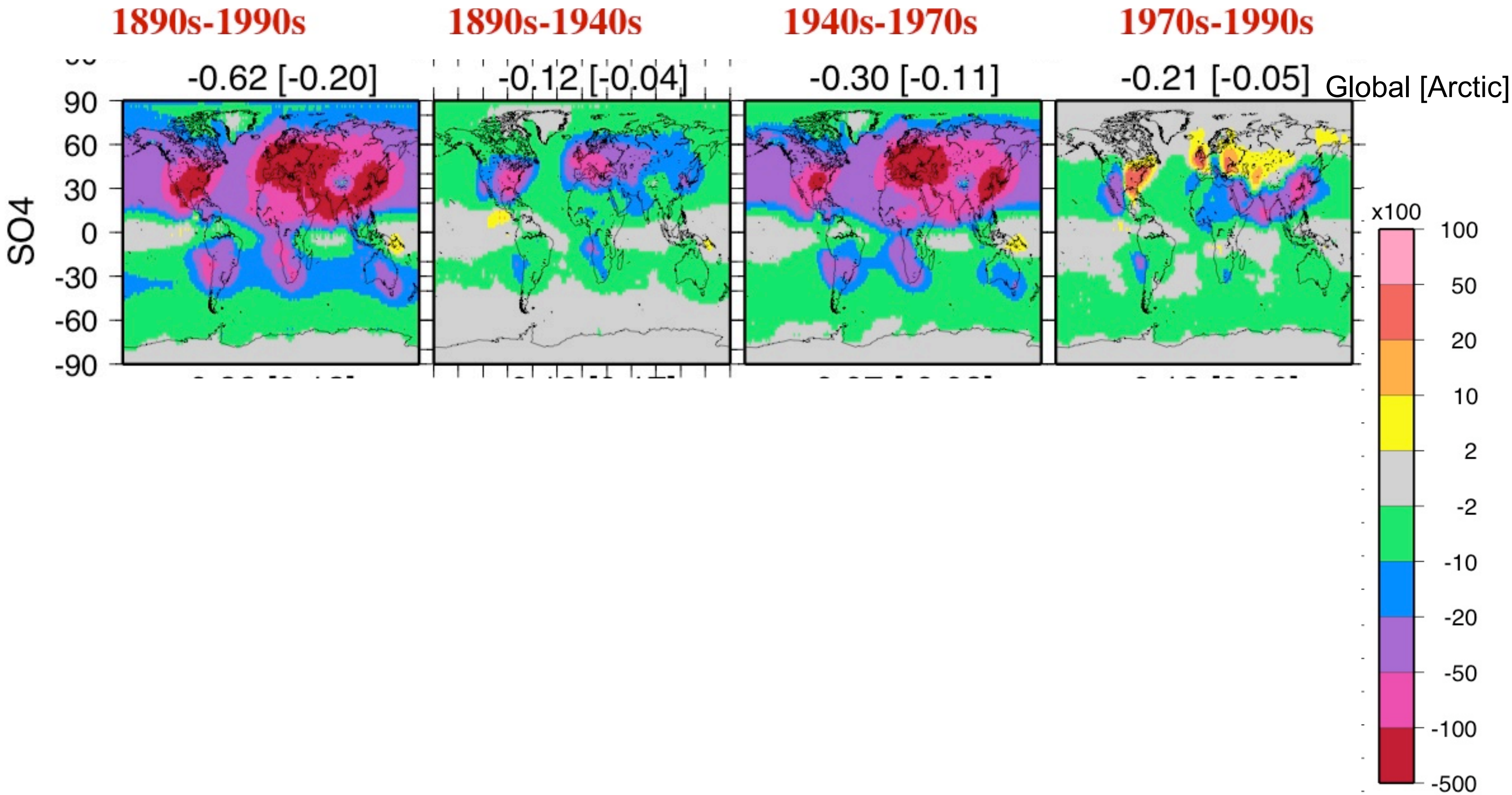


1890s-1990s
2.69 [2.26]
1890s-1940s
0.50 [0.31]
1940s-1980s
1.61 [1.67]
1980s-1990s
0.57 [0.28]
90
60
30
0
-30
-60
-90
x100
-5.0
-1.0
-0.5
0.5
1.0
2.0
5.0
10.0
20.0
50.0

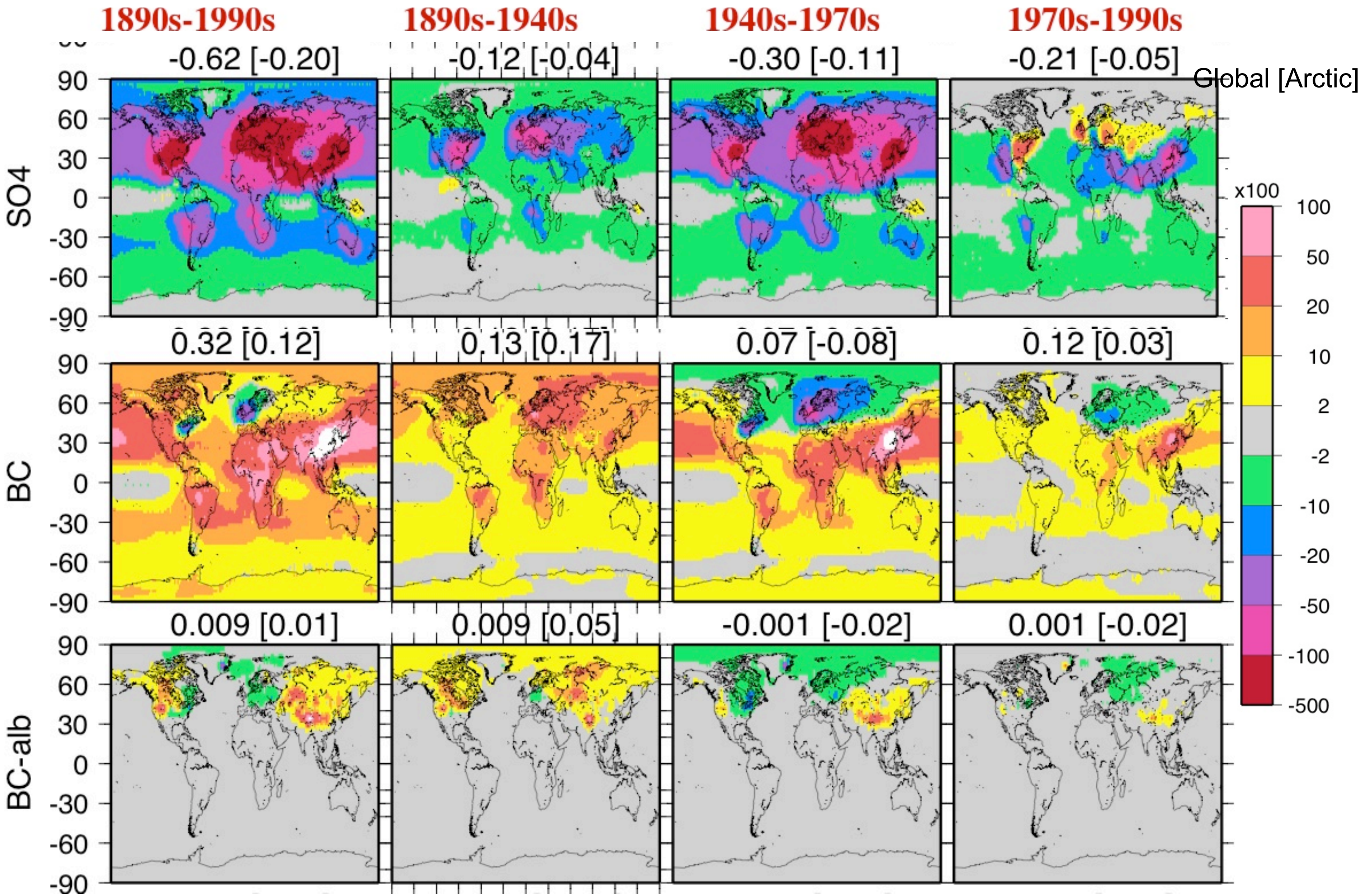
Dimming/brightening changes



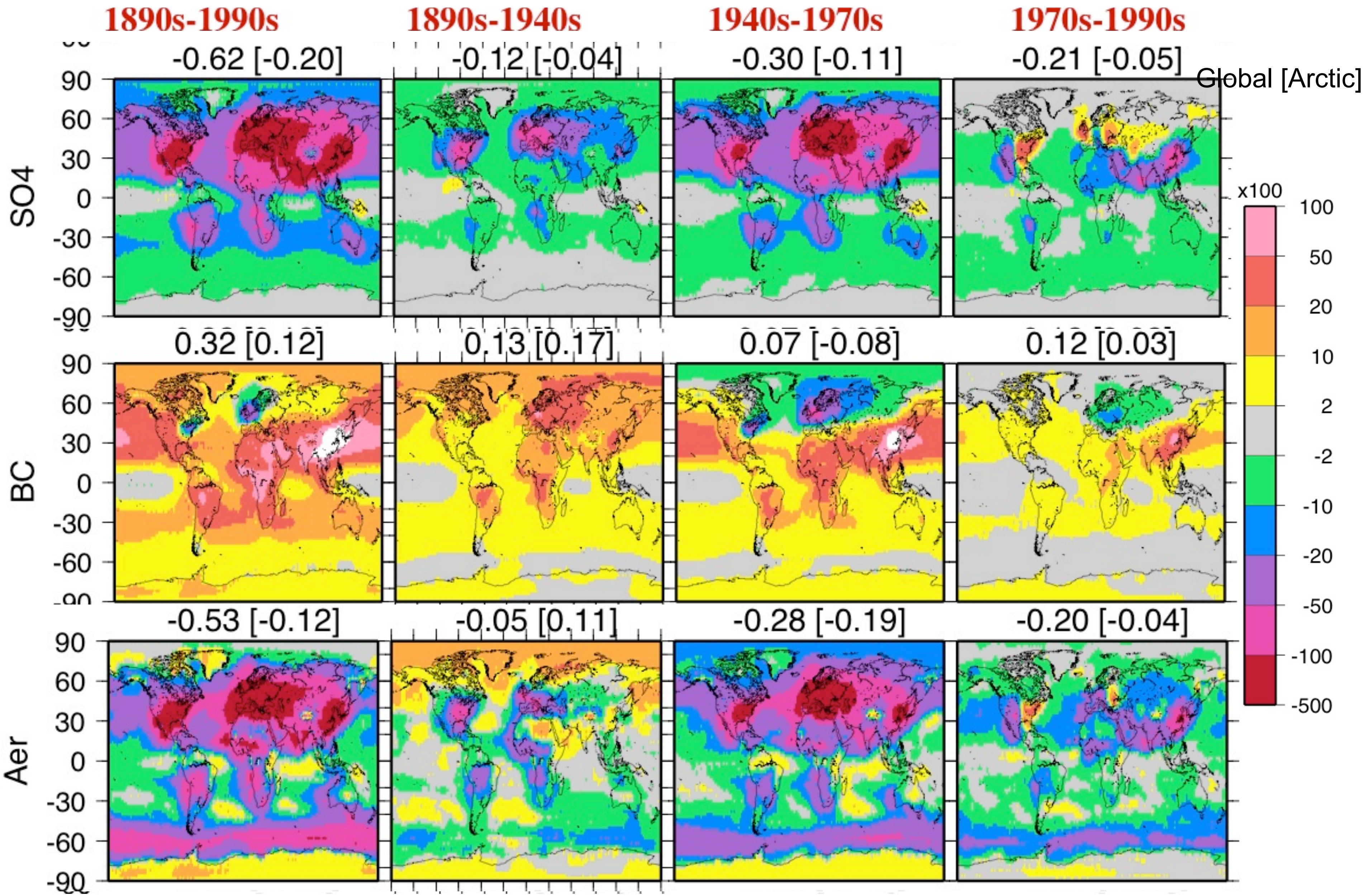
TOA forcing changes



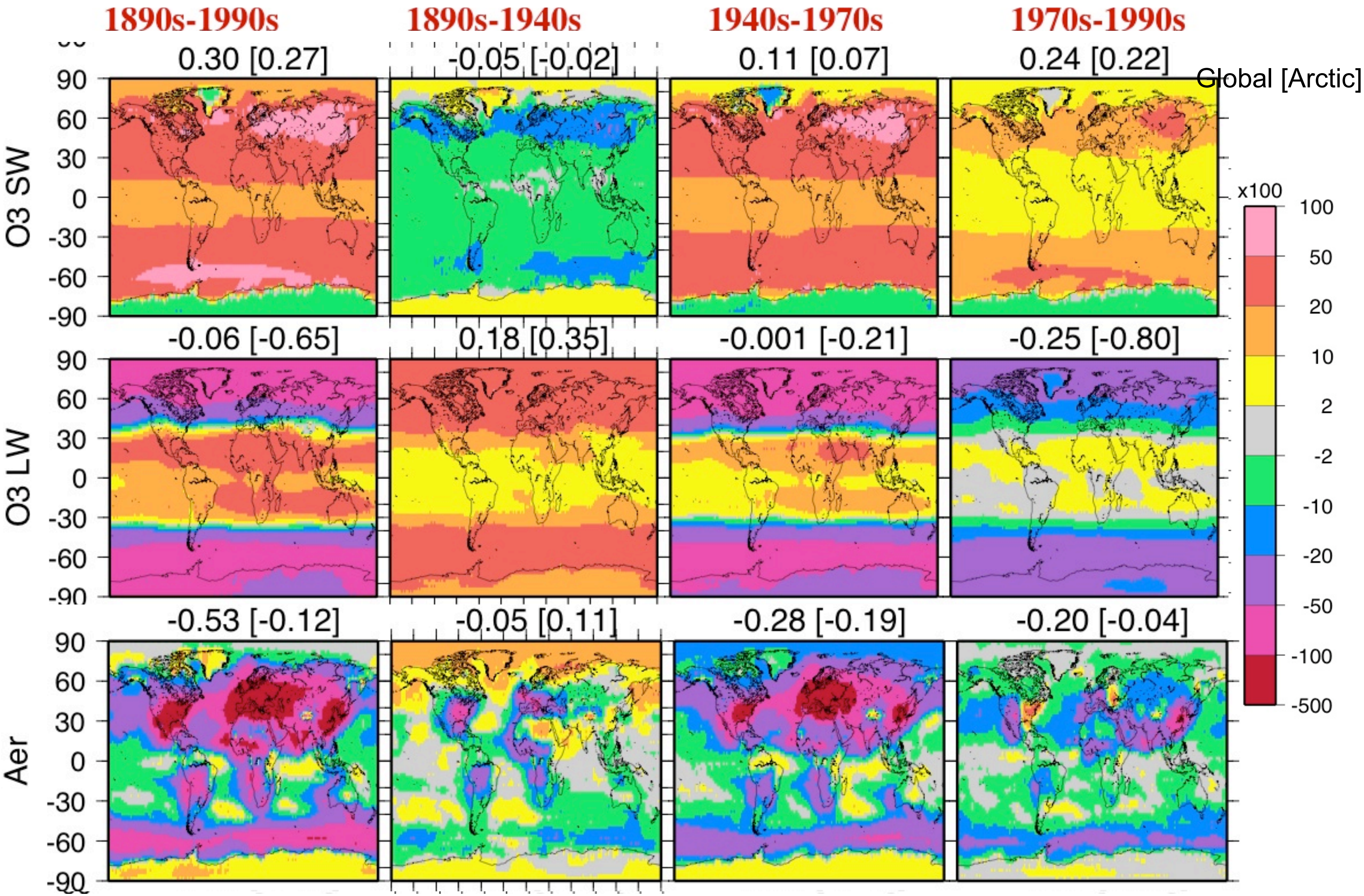
TOA forcing changes



TOA forcing changes



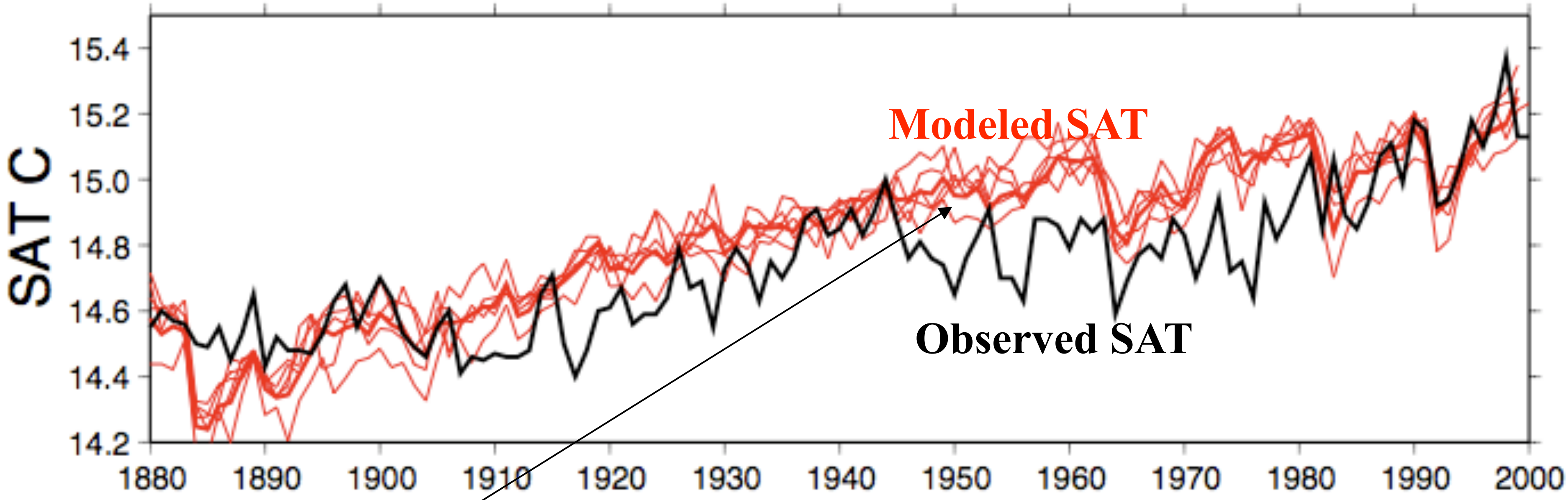
TOA forcing changes



STD model (no IE yet) global Surface Air Temperature (SAT)

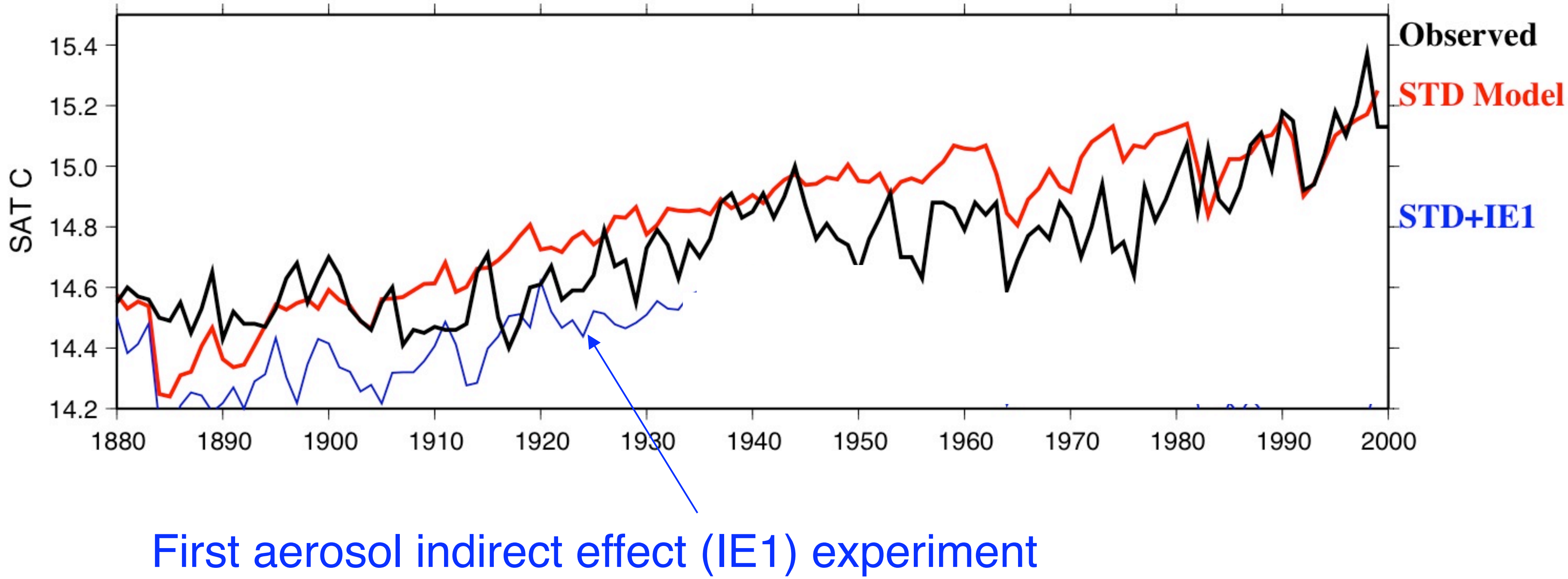
STD warms the right amount, without the indirect effect.

Note: Hansen et al. 2007 needed $-1 Wm^{-2}$

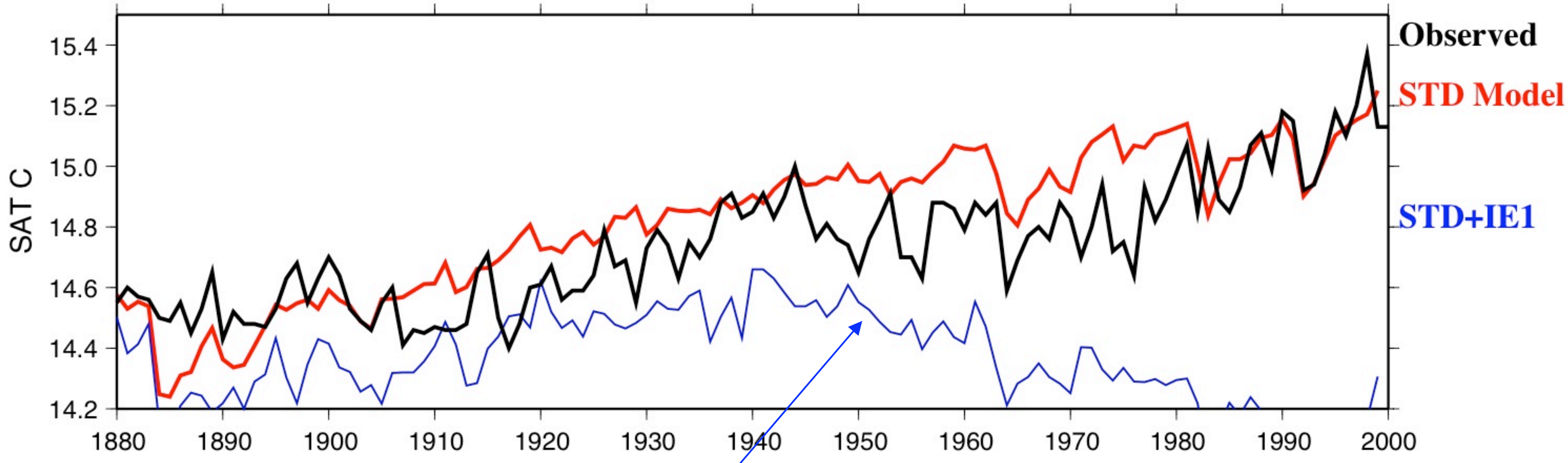


But model is too warm mid-century, so maybe IE can help this. Put in IE from our Q-flux model experiments…

First try: IE model Surface Air Temperature trend



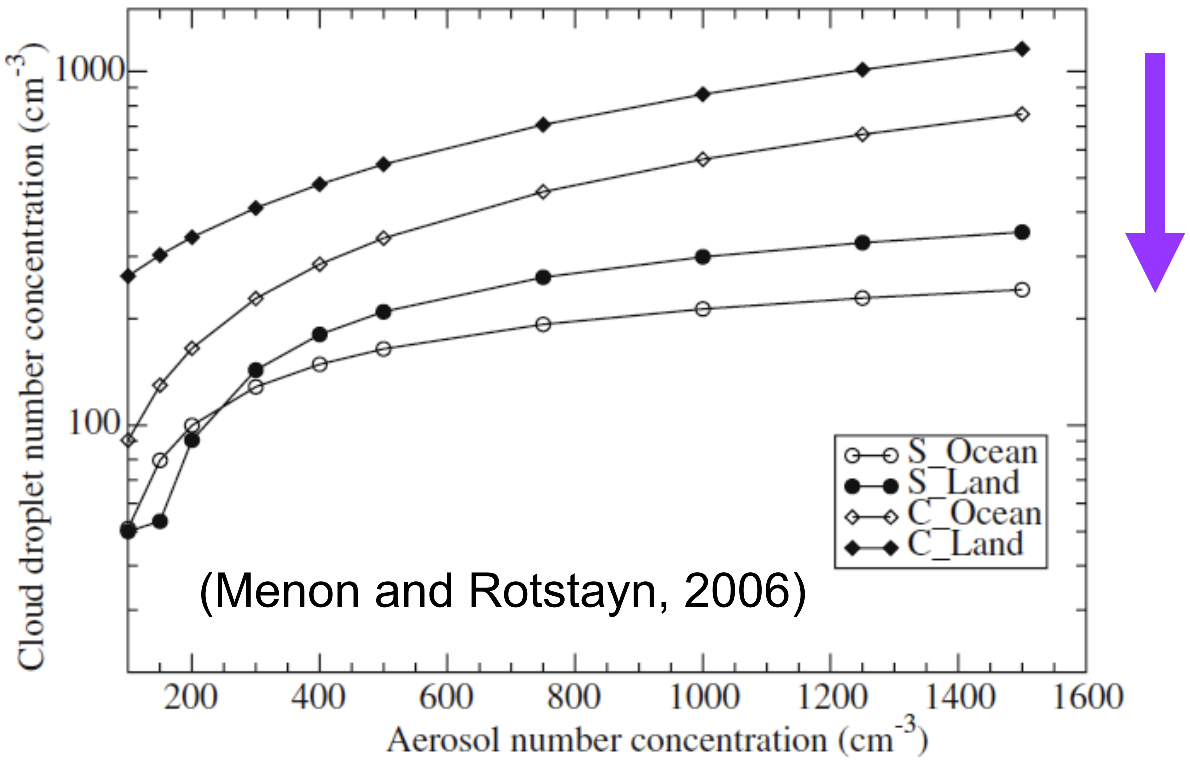
First try: IE model Surface Air Temperature trend



First aerosol indirect effect (IE1) experiment Failed!

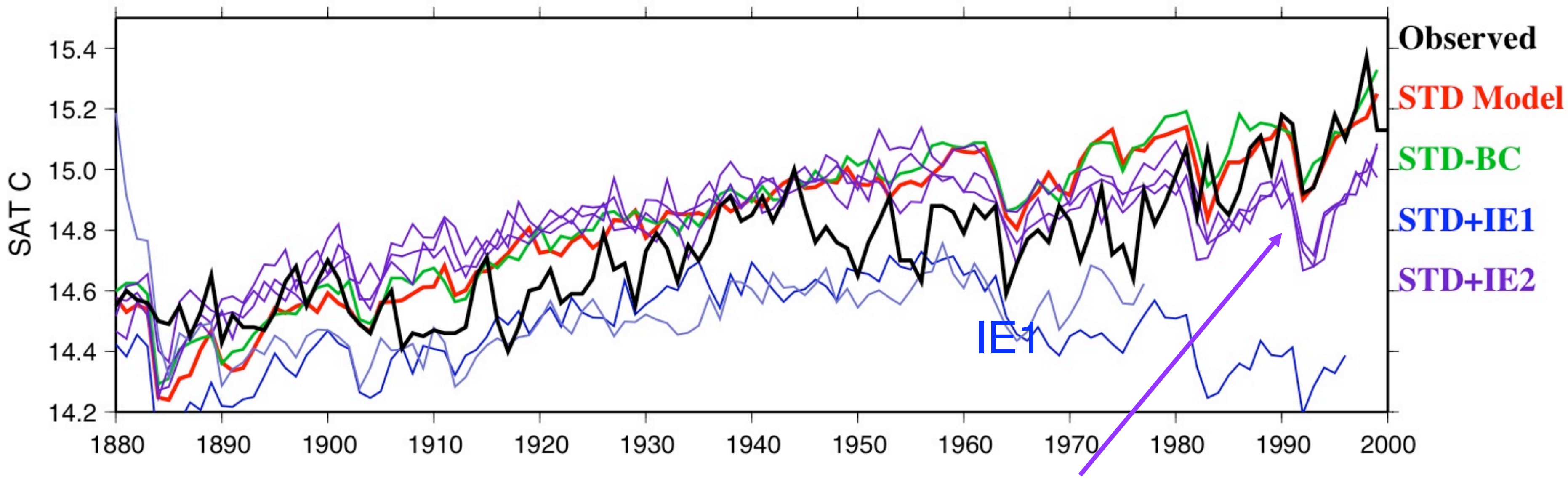
1. Qflux had 0.8°C cooling, certainly more than we need.
2. Also the cloud forcing is stronger in the transient run…

IE2: weaker indirect effect



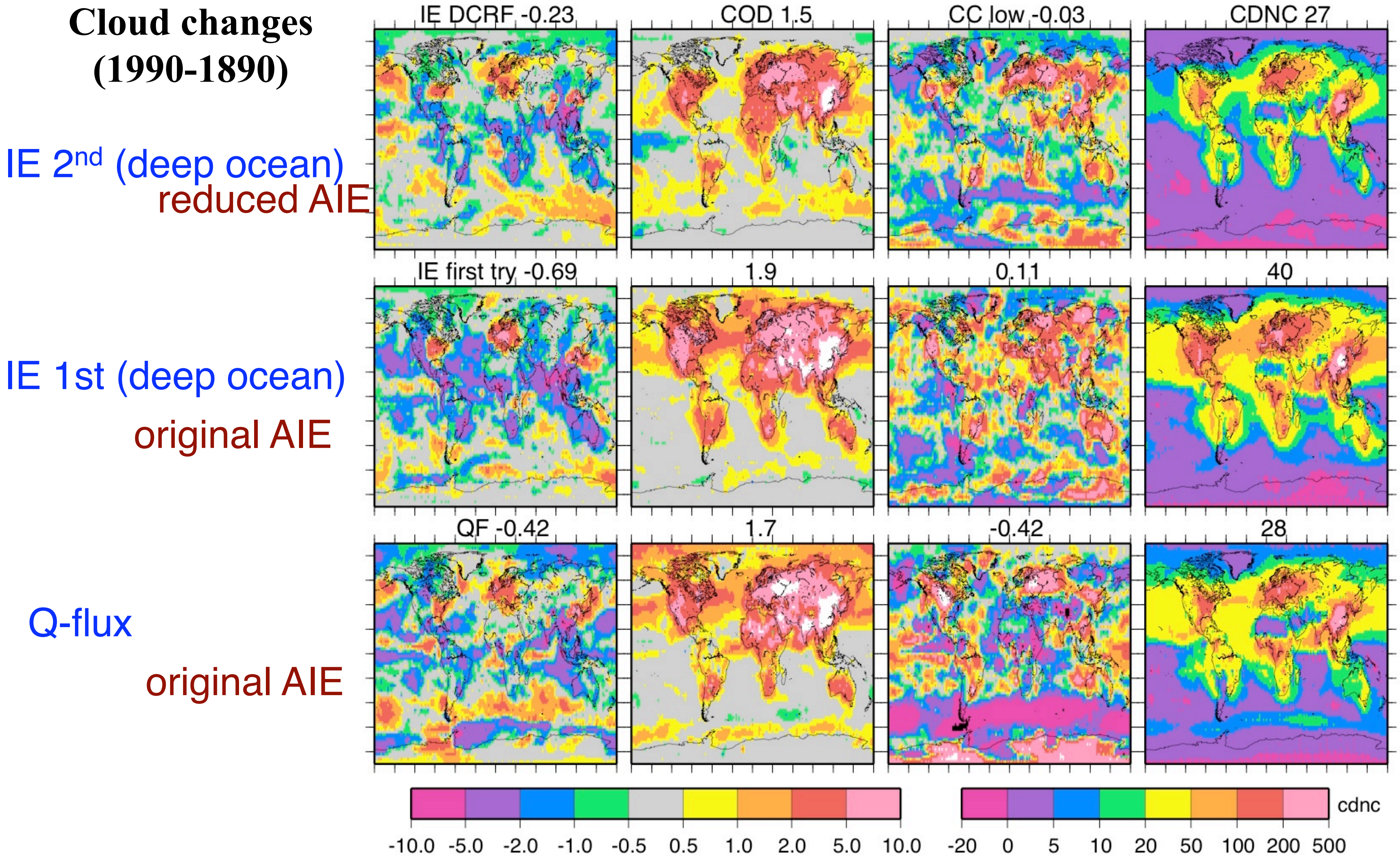
IE2: weaker sulfate dependence (justification: maybe ½ of sulfate is condensed on other particles)

STD, IE trend in Surface Air Temperature



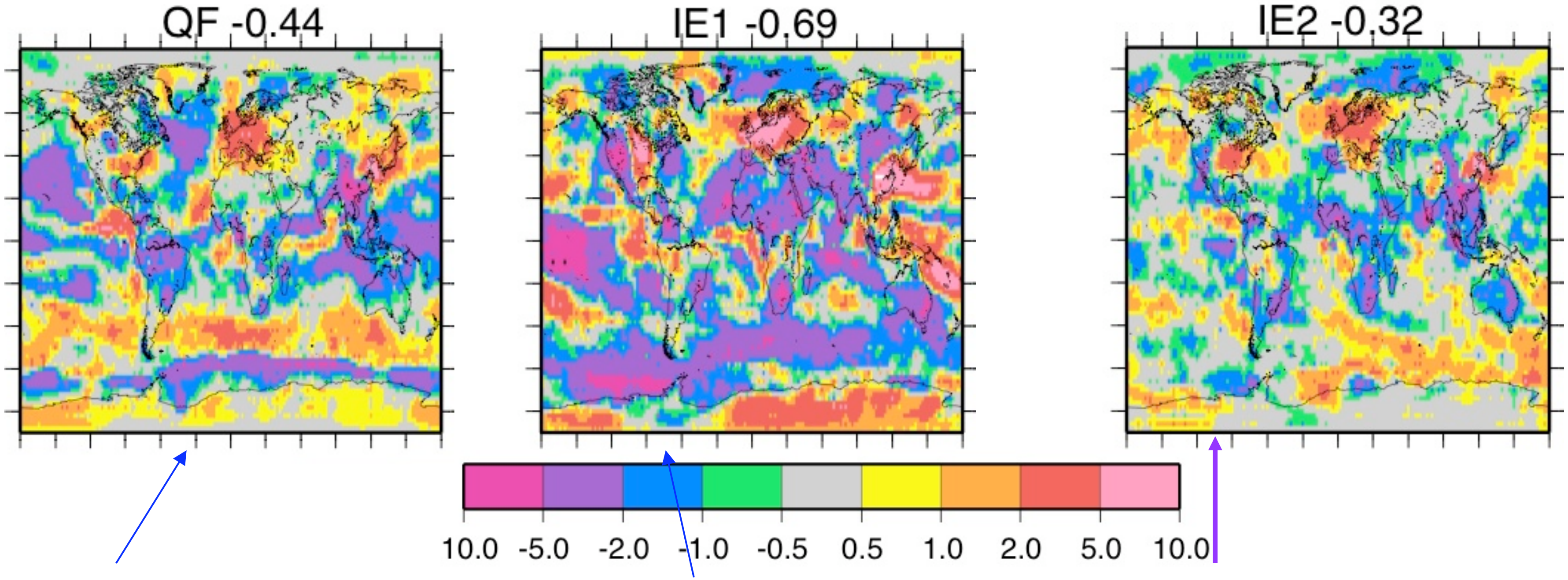
IE2 better but still cool near the end

Cloud changes (1990-1890)



The deep ocean (used for transient) has stronger cloud cooling response to the indirect effect compared to the Q-Flux slab ocean.

Cloud forcing change (1990-1890) for Q-flux, IE1 and IE2



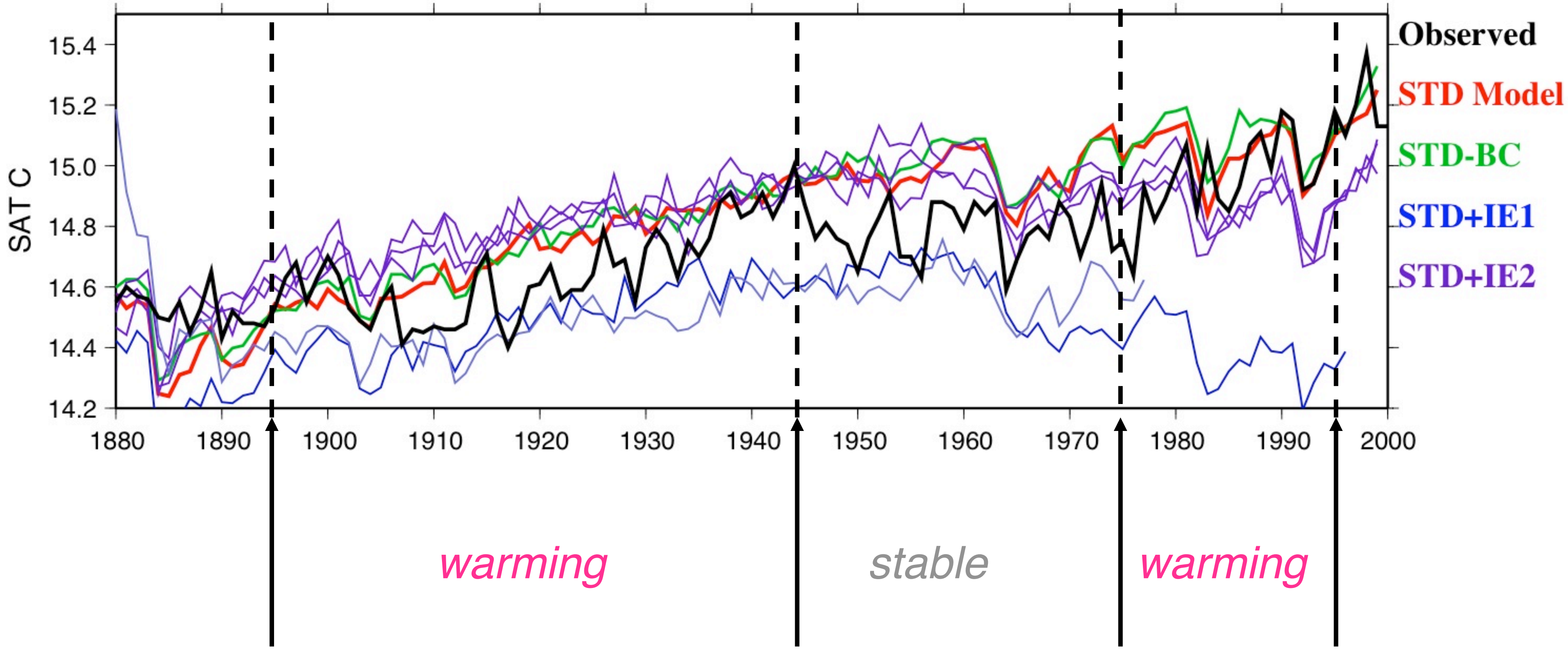
Qflux

IE1

IE2: Decreased sulfate effect on CDNC gives smaller cloud forcing change, more like Q-flux.

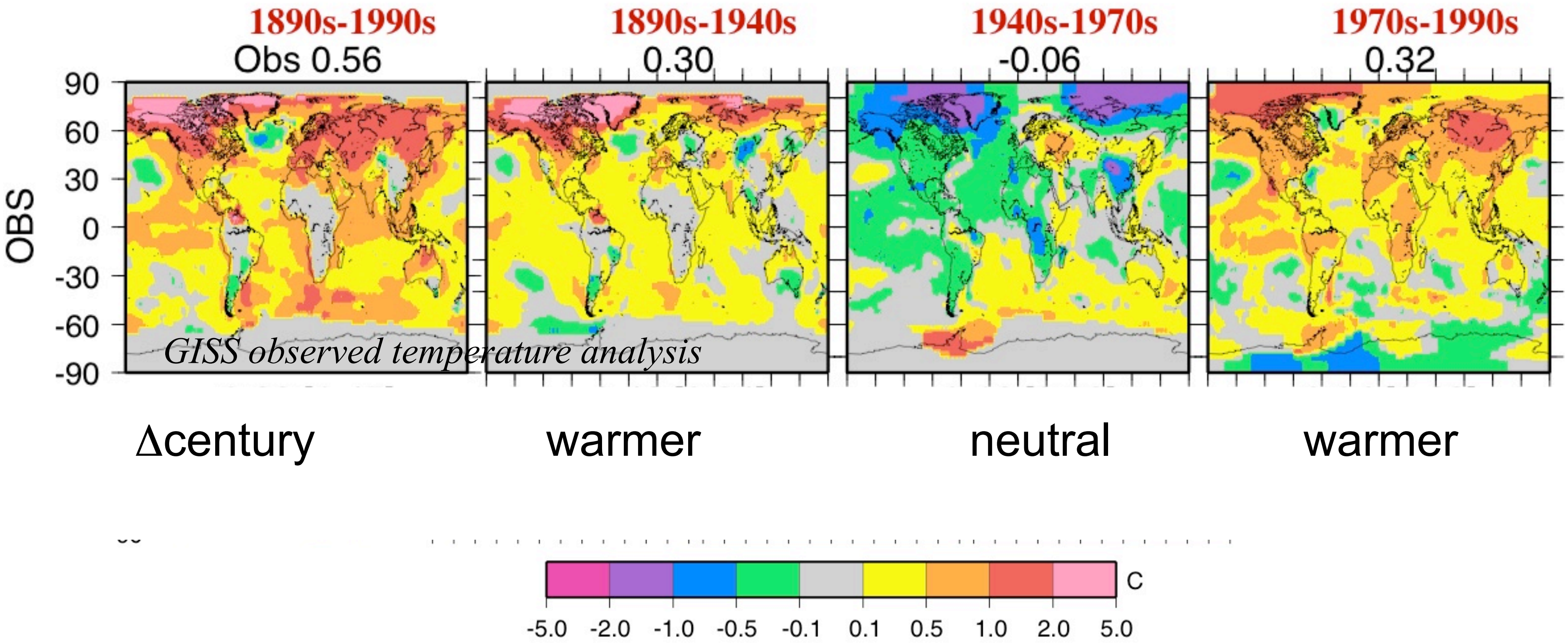
We show results now for IE2

Surface Air Temperature trends

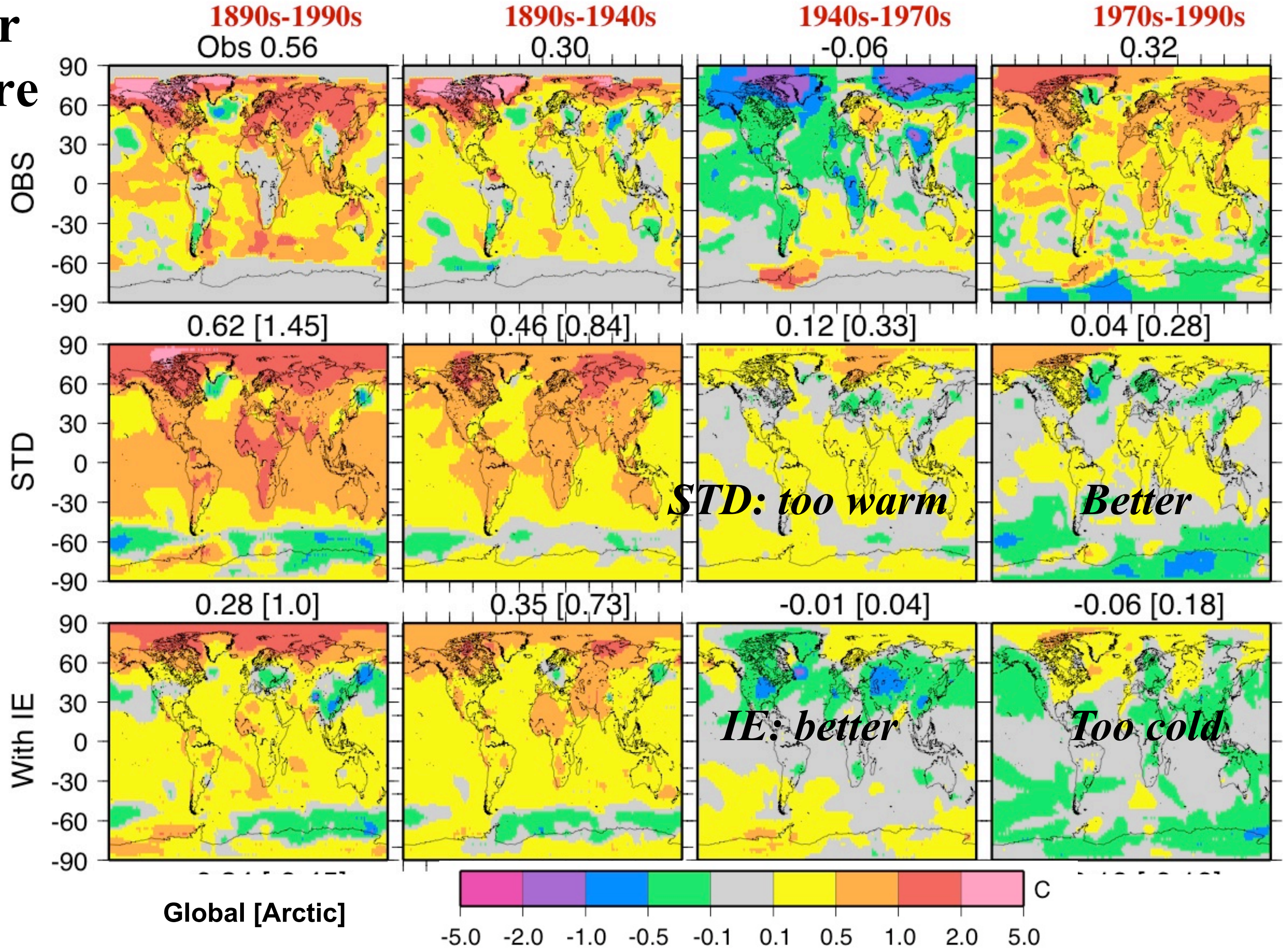


What are IE effects on climate during these periods?

Observed Surface Air Temperature (SAT) changes

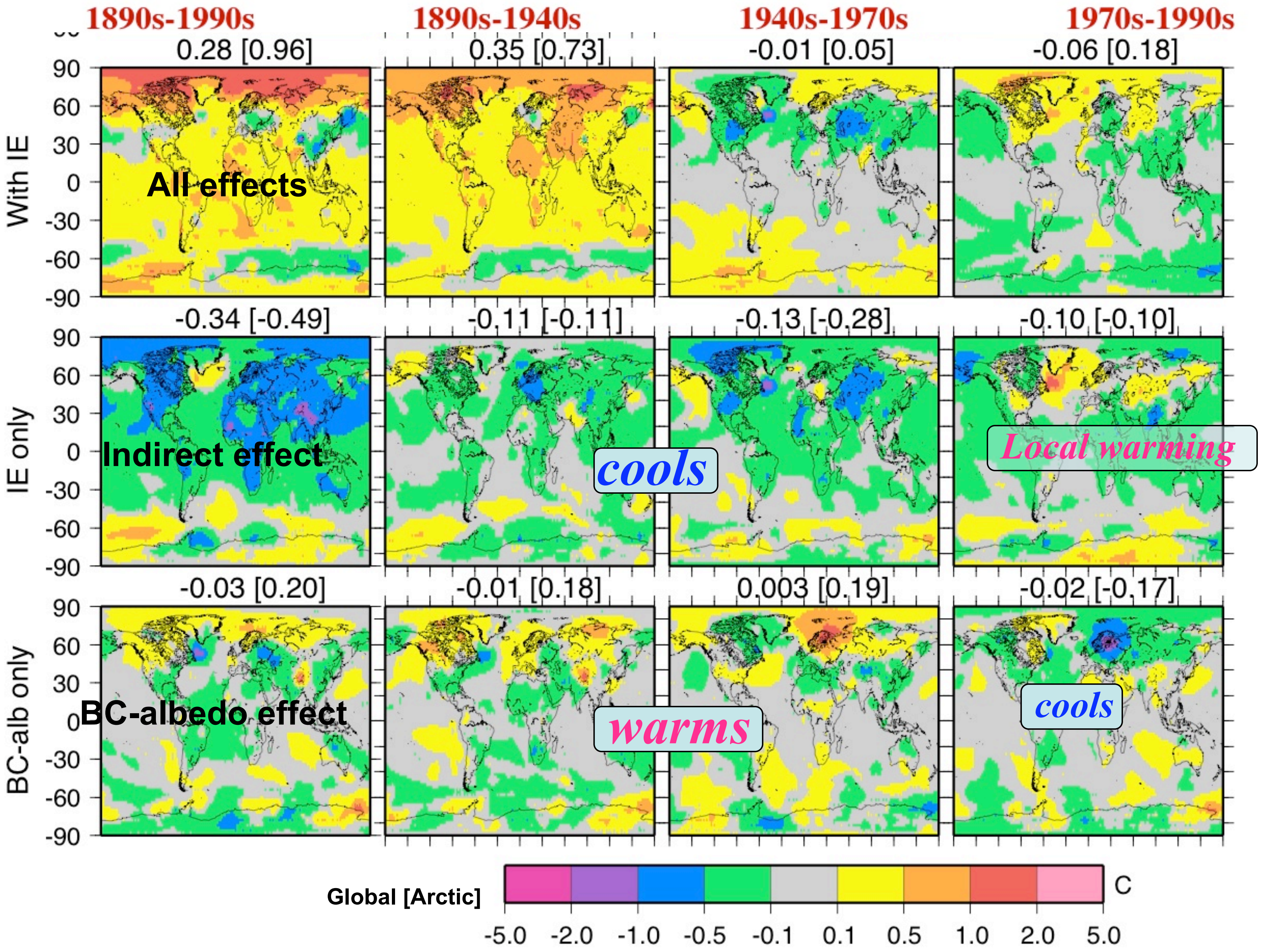


Surface Air Temperature (SAT) changes

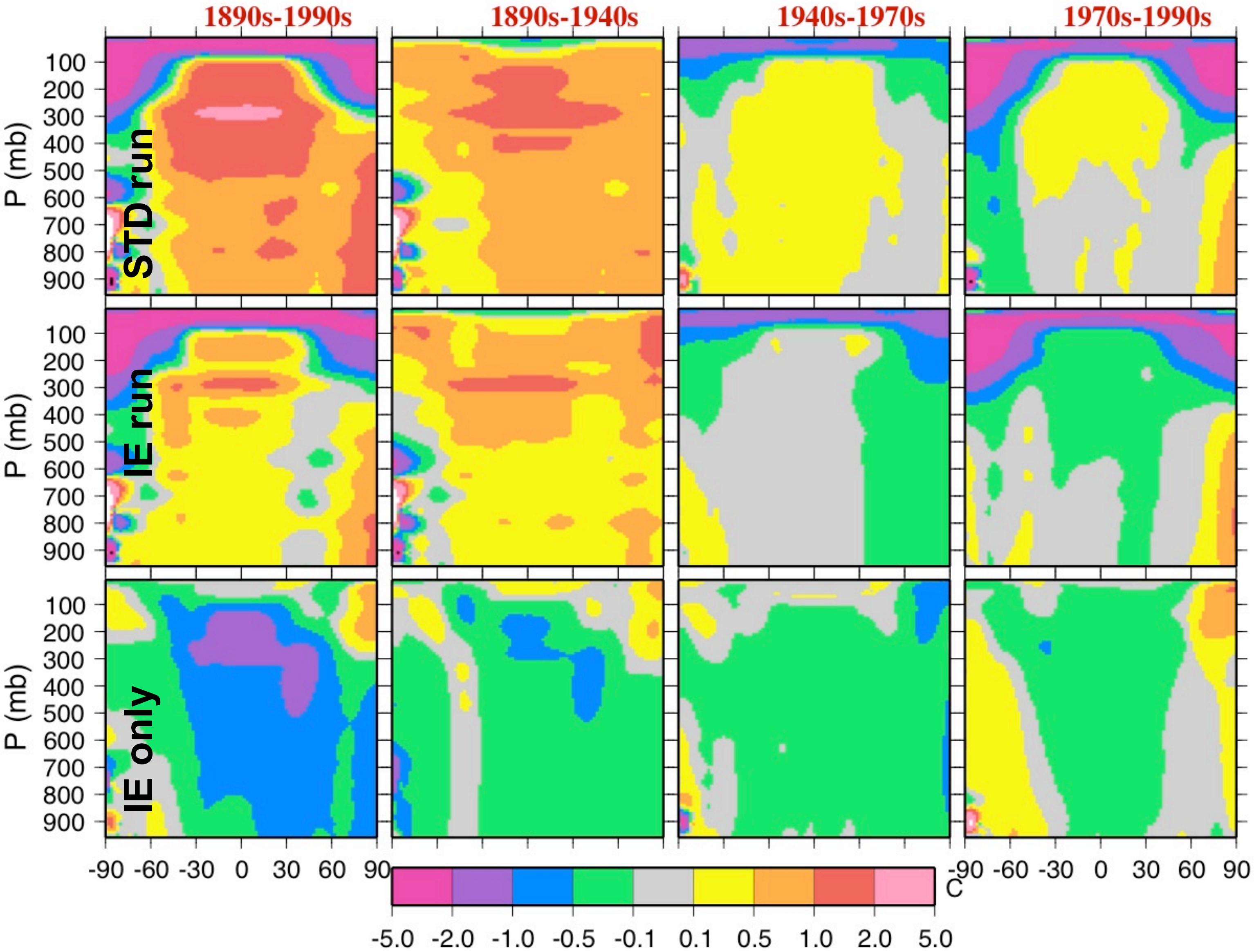


First part of century, the IE run does better than the STD run. But both are too cold near the end.

Aerosol effects on Surface Air Temperature (SAT) changes



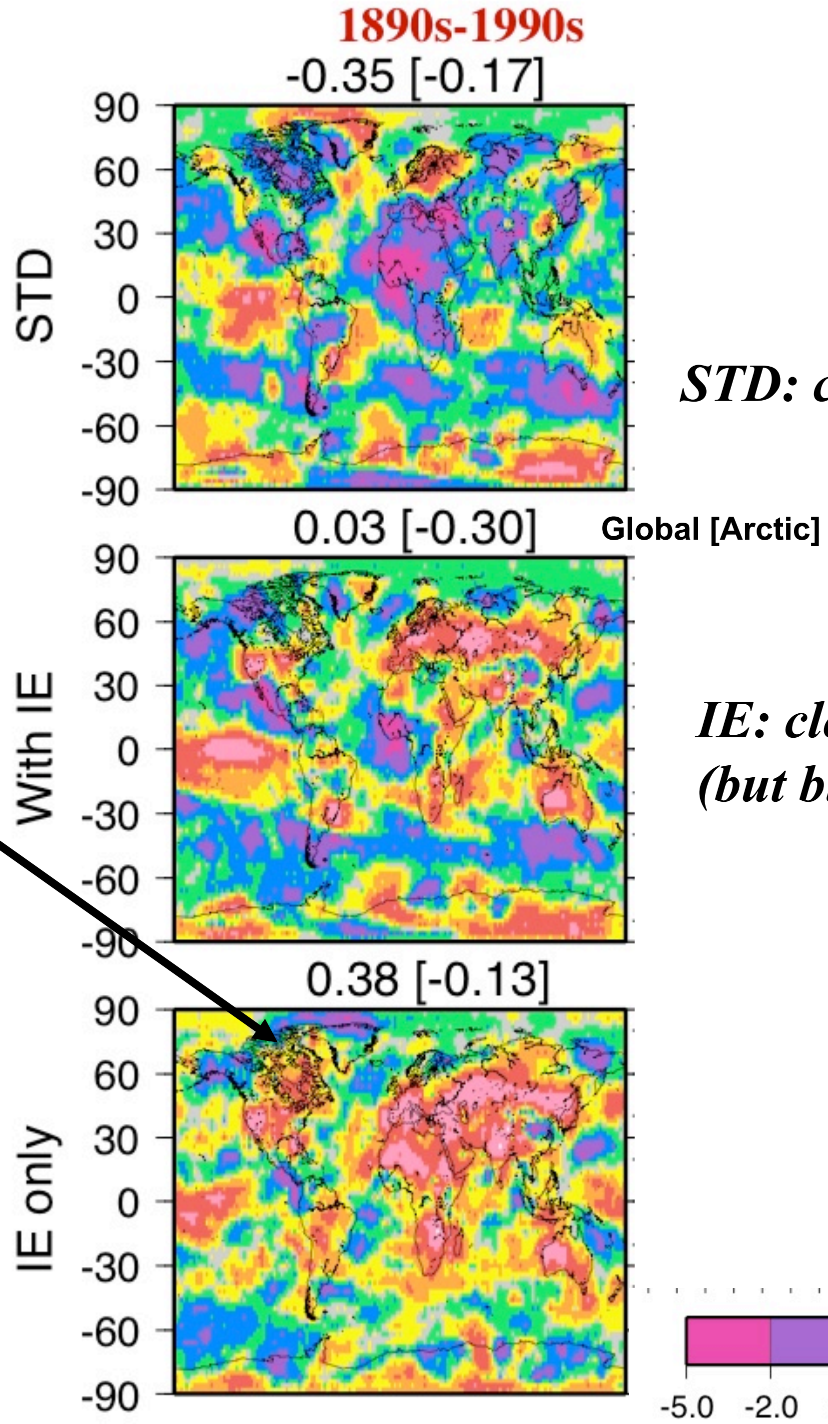
Indirect effect improves vertical temperature gradient



AR4 models have stronger upper tropical tropospheric warming than surface.
Radiosonde trends upper troposphere should warm same as surface, not more.
IE reduces upper tropical tropospheric warming.

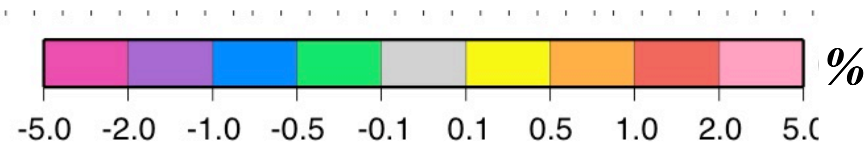
Model cloud changes changes, STD vs IE

IE clouds increase over continents compared with STD



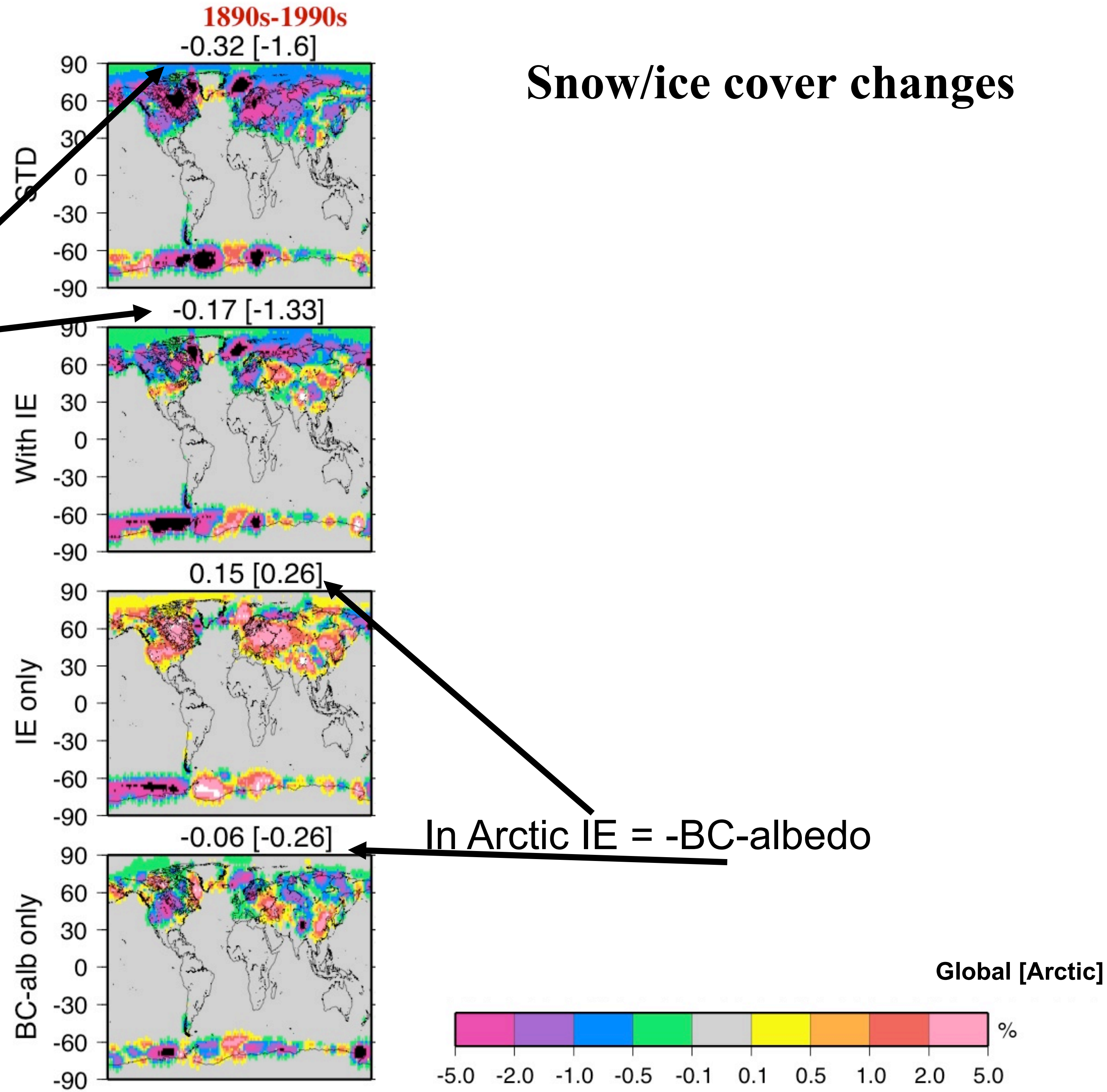
STD: cloud cover decreases

IE: cloud cover increases slightly, (but bigger loss in the Arctic)



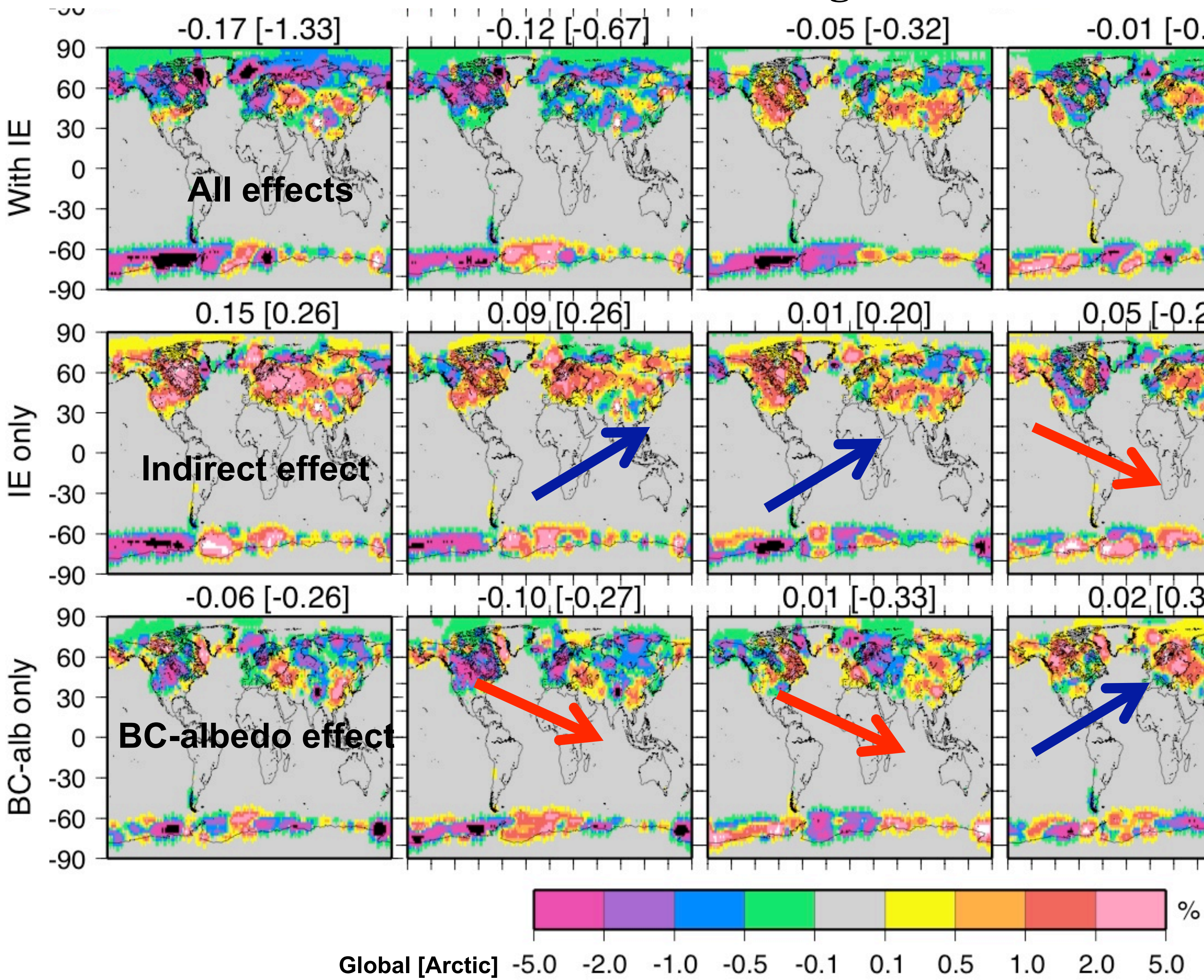
Snow/ice cover changes

IE reduces snow/ice loss by 1/2 globally.



In Arctic IE = -BC-albedo

Model snow/ice cover changes



STD: “Mitigation” Sensitivity studies 1970-2000

Starting in 1970 we branch off 3 cases from STD and run to 2000:

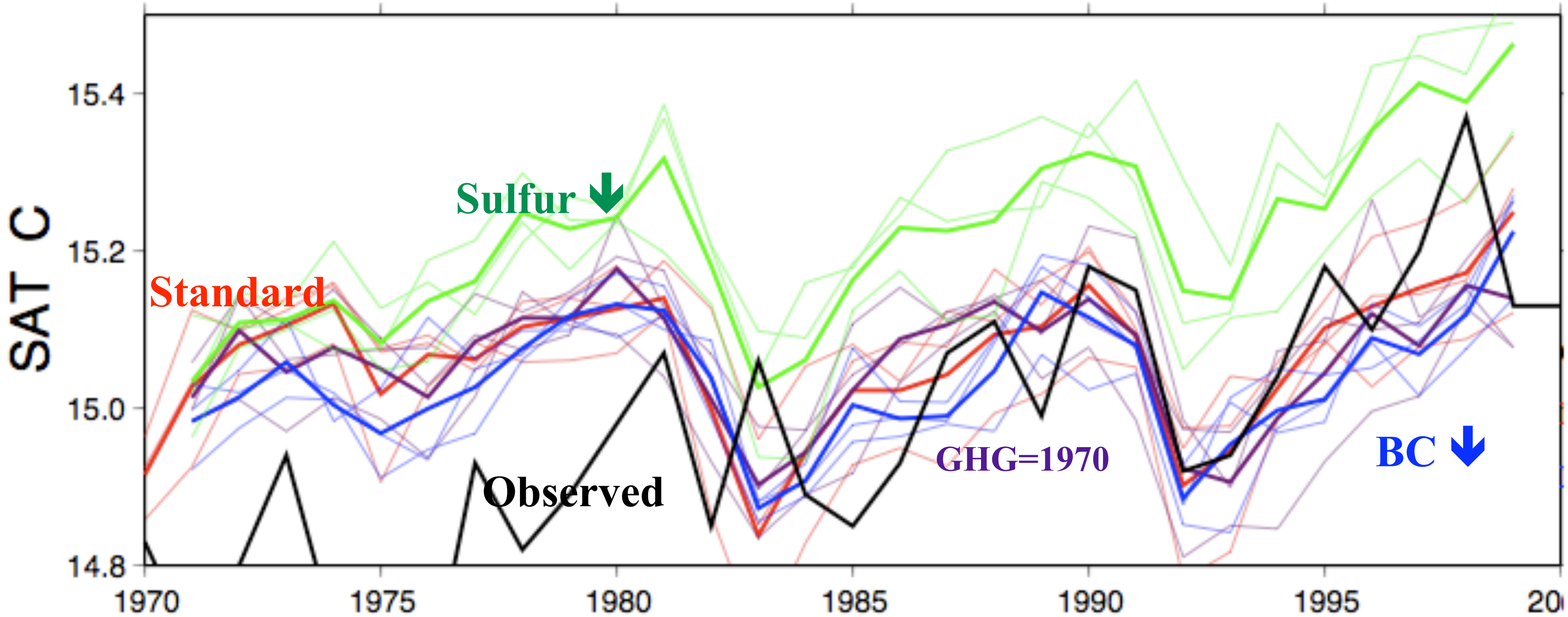
1. **BC fossil fuel, biofuel = 0; biomass burning BC, OC emissions are 1890** (-0.3 W/m2)

2. **Pollution sulfur = 0** (+0.4 W/m2)

3. **Long-lived GHG concentrations remain at 1970 levels** (-1 W/m2)

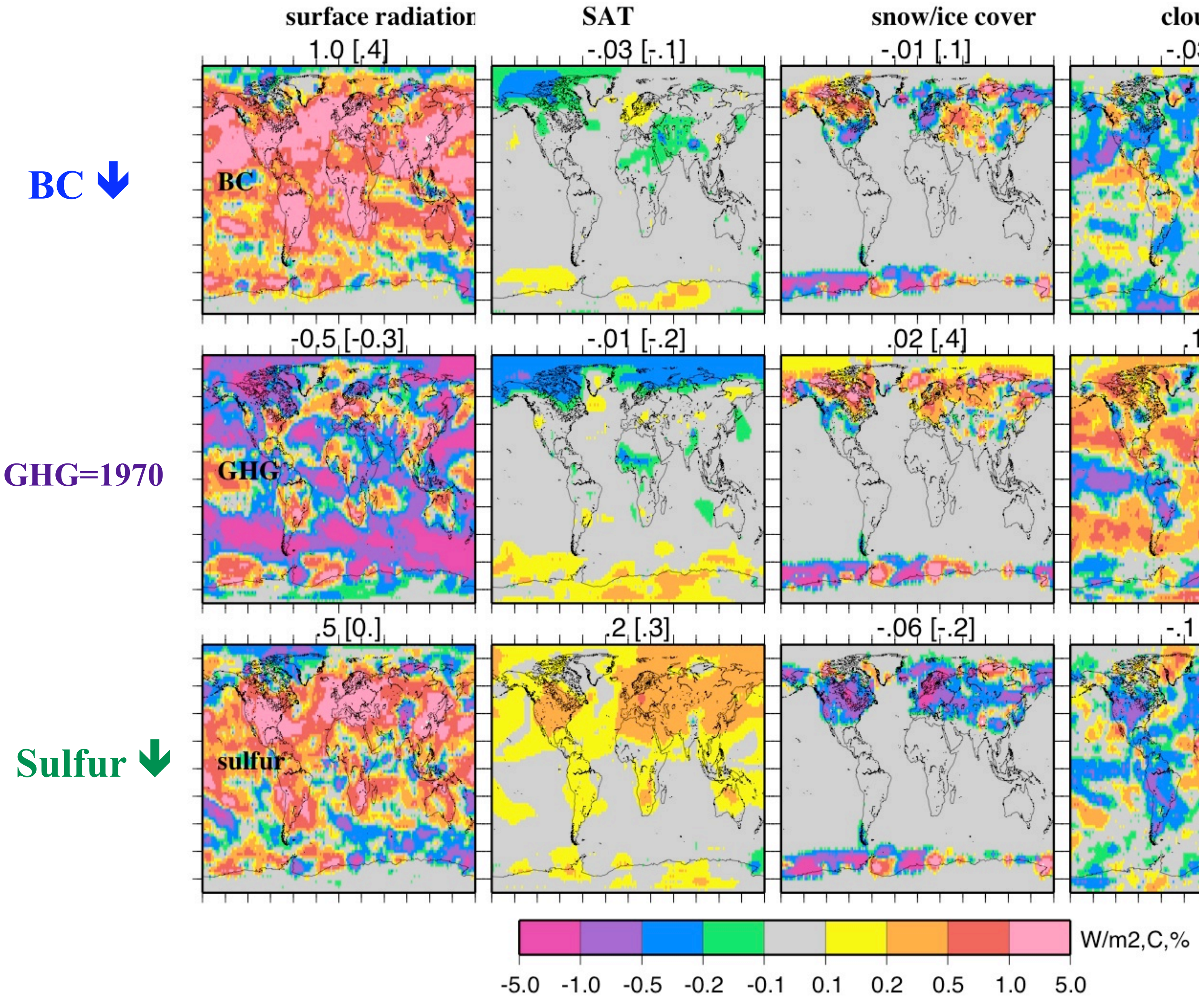
(ensembles of 3 each are performed)

Global Surface Air Temperature Trend



Sulfur reduction, "unmasking": much warmer
BC, GHG reductions, only small cooling

Climate changes for mitigation experiments



Conclusions

1. BC, BC-albedo are important warmers and snow/ice melters especially up to 1950s. However later in the century reduced BC emissions from Europe, North America contribute to high latitude cooling. Over century BC-albedo effect caused 20% of Arctic snow/ice loss.

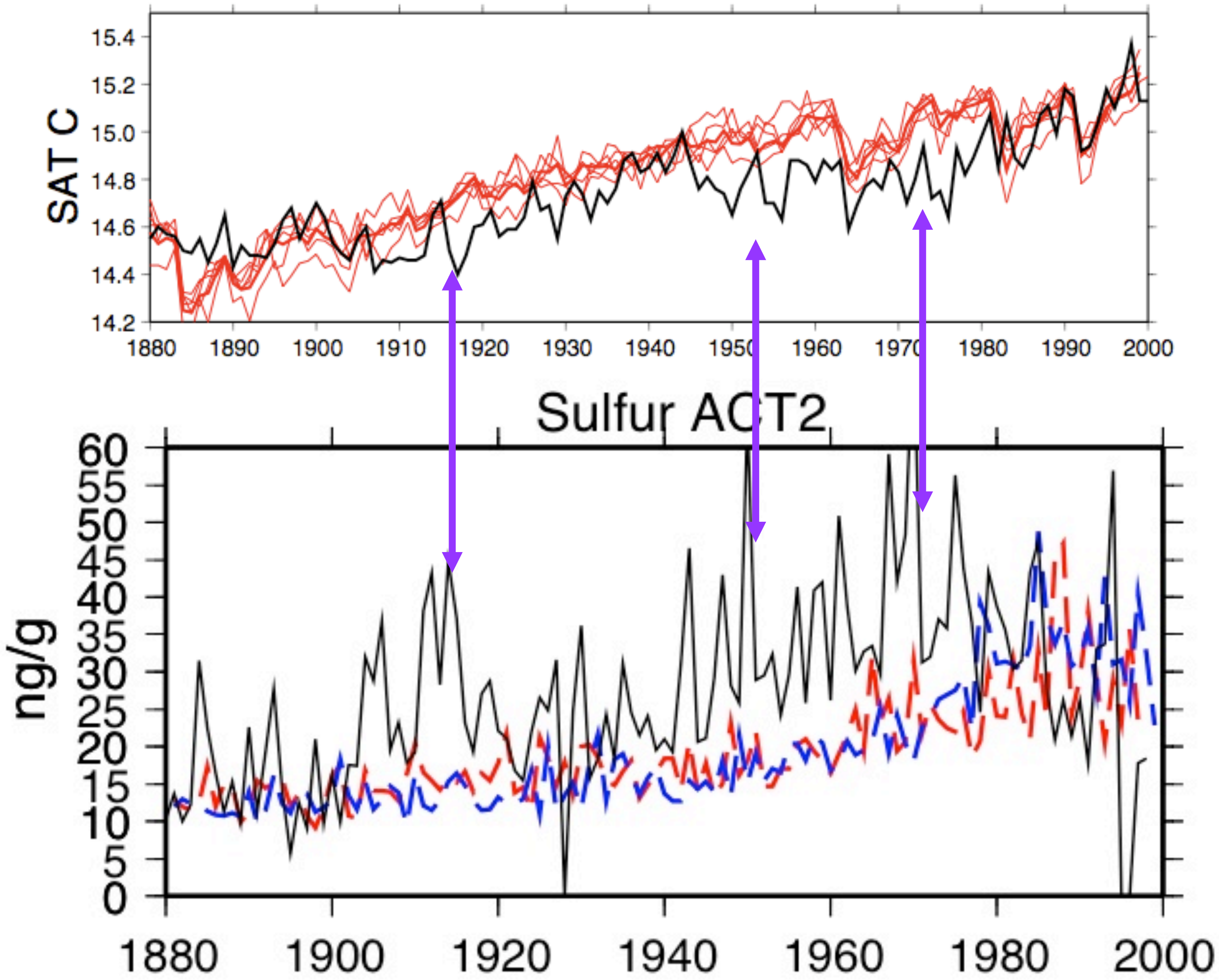
2. Sulfate and the indirect effect caused strong dimming and cooling from 1940s to 1980s, and maybe too much cooling late in century. Some decline in sulfur from Europe contributes to warming ("unmasking") in final decades.

3. Our sulfur emissions are possibly to blame for failure to warm at end of century, since we jumped from EDGAR-HYDE (1890 to 1980) to EDGAR32 (1990 and 2000). Smith et al. (2004) has better shape (AR5 emissions).

Conclusions

STD model, observed global SAT trends

Model, observed sulfur ice core trends



Conclusions

4. The IE cloud forcing is stronger in the transient deep-ocean simulations than it was in Qflux simulations. We weakened the indirect effect using a pseudo-microphysical justification. We will repeat these experiments using our aerosol microphysical scheme (MATRIX).

Transient climate is a good test (challenge) for the indirect effect!

5. Tropospheric ozone seems to be the strongest positive short-lived forcer in the Arctic during the last half of the century.

6. "Mitigation": Reduction of sulfur causes strong warming, while reduction of BC or stabilization of GHG has small (short-term) impact. This may be due to thermal inertia in the system - it is hard to turn the climate around. GHG stabilization seems a more effective cooler than BC reduction because it enhances cloud cover (in our model).


Thanks!