Stratospheric Geoengineering with Black Carbon Aerosols

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Abstract

We used ModelE2, a general circulation model developed by the NASA Goddard Institute for Space Studies, to simulate the sensitivity of stratospheric geoengineering with black carbon aerosols to aerosol size and altitude of injection. All ensembles (Table 1) are ten-year simulations with three ensemble members involving injection of 1 Tg of black carbon aerosols per year into the stratosphere, simulated with fixed sea surface temperatures and sea ice. This causes variable surface air temperature effects over land, with globally averaged cooling by ~0.8°C if small particles are used, ~0.4°C if a high altitude of injection is used, or negligible cooling if a larger particle size (0.08 or 0.15 μm) in the lower stratosphere is used. In some cases, there are large annually averaged regional cooling effects, sometimes up to 7°C. The aerosols cause significant stratospheric heating, often exceeding 40°C, resulting in stratospheric ozone loss for many of the cases. Ozone increases in the tropics due to lower penetration of UV radiation are not enough to compensate for the loss. This heating causes circulation changes, creating an Arctic ozone hole, with losses exceeding 50% in multiple experiments. The Antarctic ozone hole shows some recovery, as the stratospheric heating makes the Antarctic spring too warm to sustain polar stratospheric clouds. Because of the large impacts on ozone, geoengineering with black carbon aerosols likely presents too many risks to be considered as a practical way of addressing global warming.

Experiment Design

Experiment	Description	Particle Radius (μm)	Altitude of Injection (mb)
Con	Control run (constant year 2000 conditions)		
Def	Default	0.08	100-150
HA	High Altitude	0.08	20-57
SmR	Small Radius	0.03	100-150
LgR	Large Radius	0.15	100-150
HALgR	High Altitude + Large Radius	0.15	20-57

Table 1. Description of the experiments in this study. All geoengineering simulations involved injection of 1 Tg of black carbon aerosols per year into the tropical stratosphere.

Black Carbon Mass Distribution

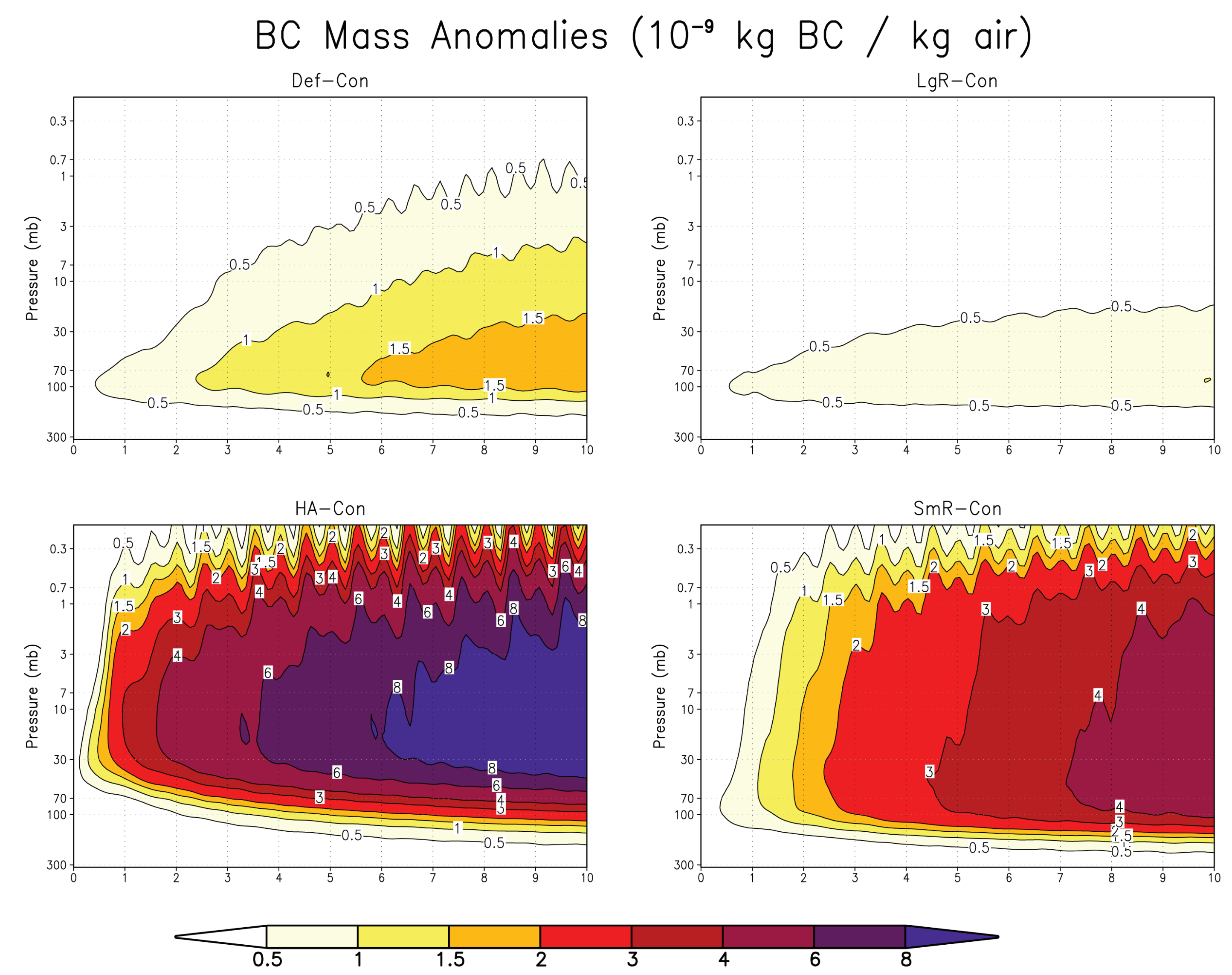

Figure 1. Black carbon aerosols generally remain concentrated near the altitude of injection, but they are also heated by the sun and self-loft [e.g., *Pueschel et al.*, 2000]. In some cases, aerosols are found near the model top (80 km).

Table 2. *e*-folding lifetimes of black carbon aerosols in each of the experiments, calculated by a mass balance equation.

Experiment	e-folding lifetime (years)
Def	1.40
HA	4.26
SmR	3.77
LgR	0.75
HALgR	3.31

Ozone Loss

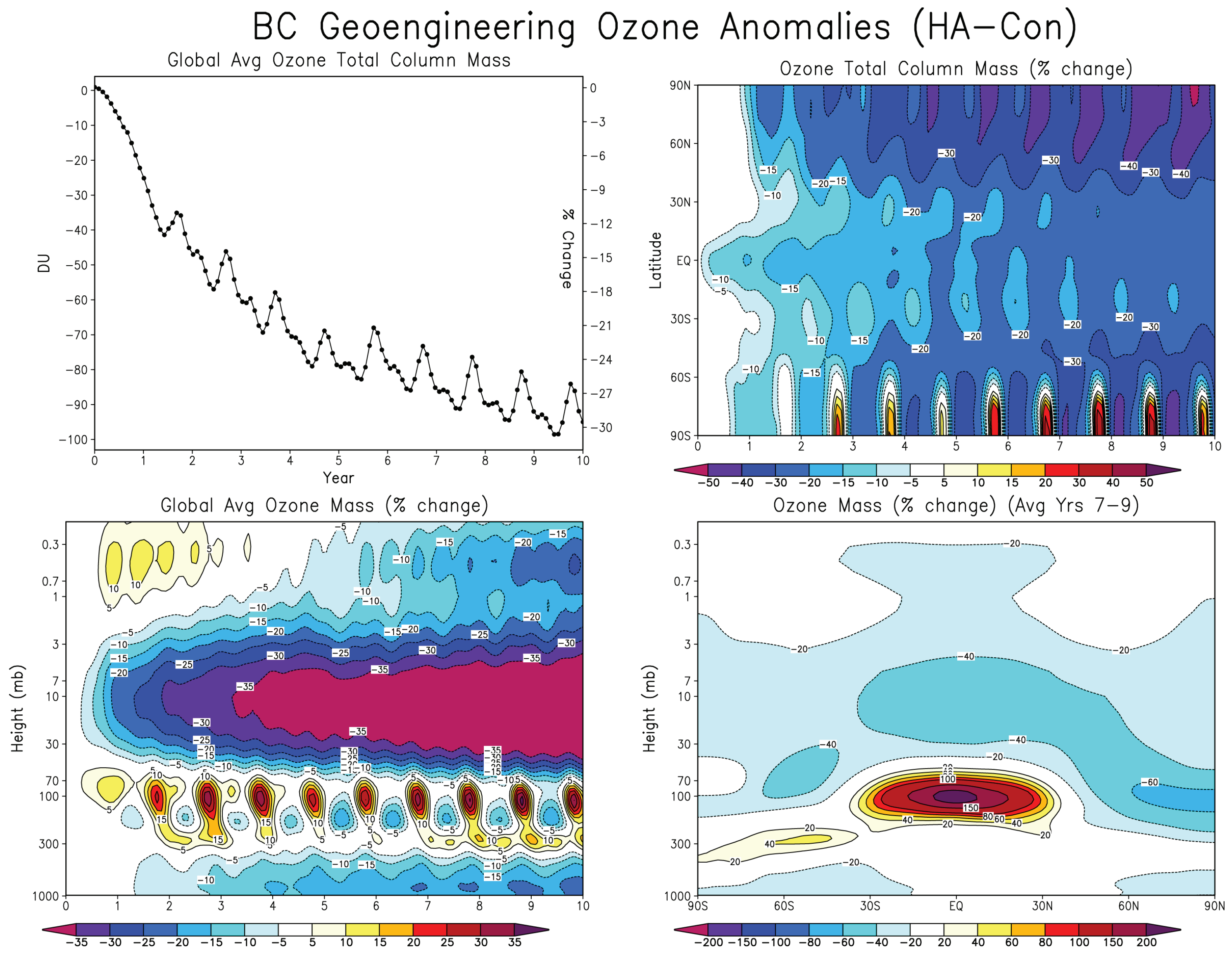

Figure 4. Ozone anomalies for the HA experiment. Lower altitude ozone recovery in the tropics is due to lower penetration of UV light and consequent photodissociation of oxygen. Antarctic ozone recovery in the austral spring is from stratospheric heating; the warmer temperatures prevent formation of polar stratospheric clouds.

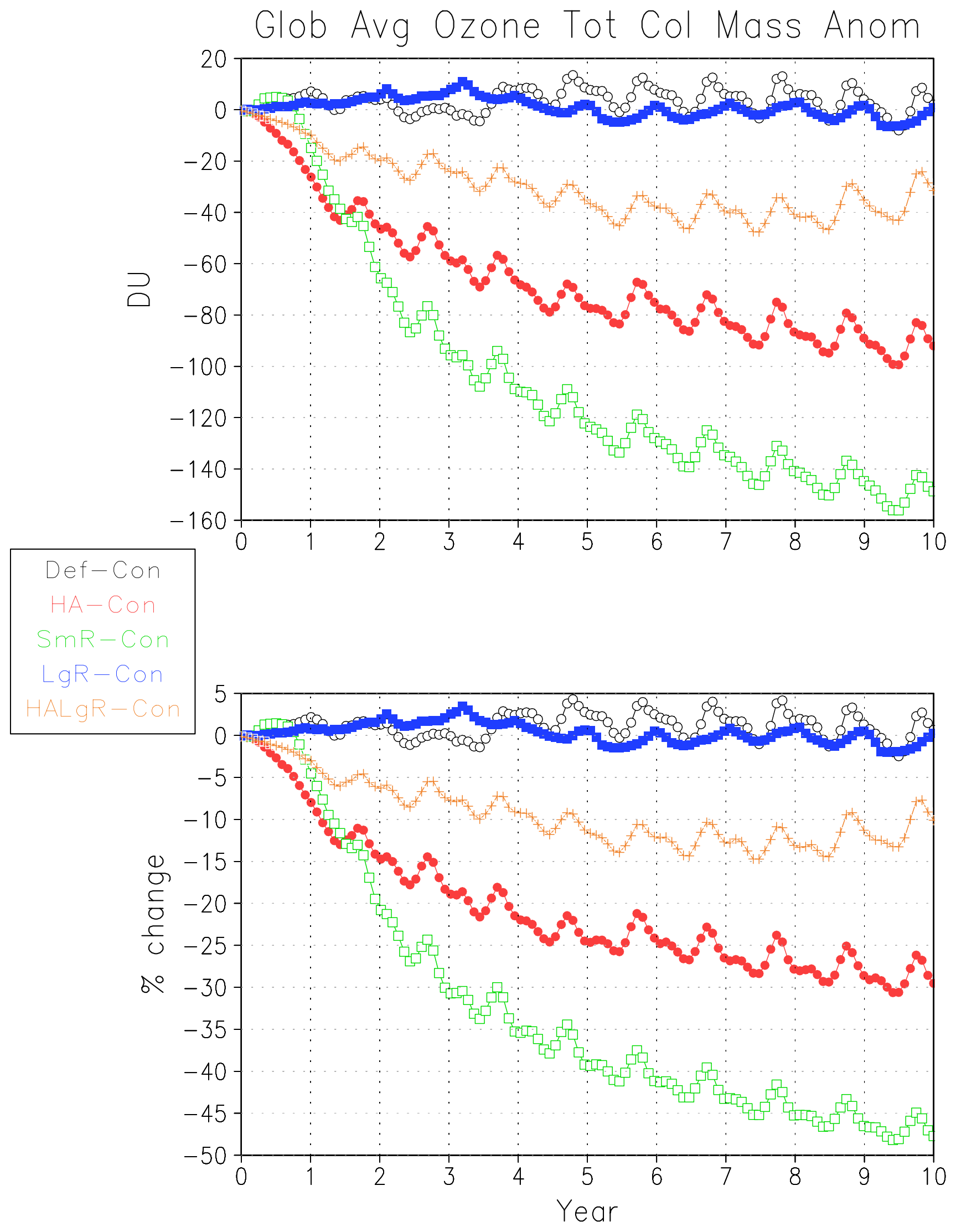

Figure 5. Globally averaged total column ozone loss for each experiment, in terms of Dobson Units (DU) and percent loss. Most of the ozone loss is a direct consequence of stratospheric heating [e.g., *Solomon*, 1999].

Temperature Anomalies

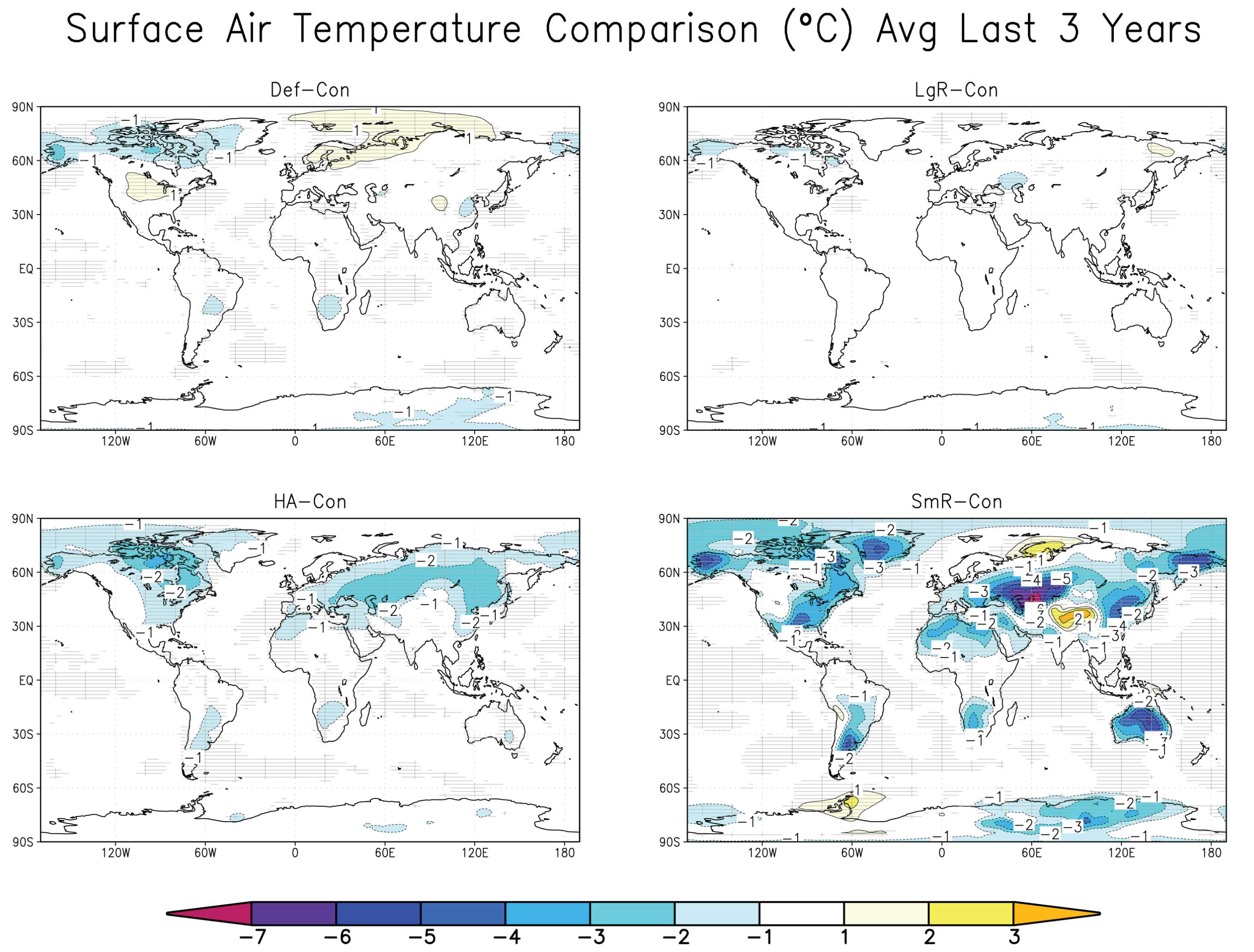

Figure 2. Surface cooling for four geoengineering ensembles, averaged over the last three years of simulations. Globally averaged values in the last year are 0.4°C for HA-Con, 0.8°C for SmR-Con, and negligible (within the range of variability of the control ensemble) for the other two. The simulations were conducted with fixed sea surface temperatures, so there are few anomalies over the oceans.

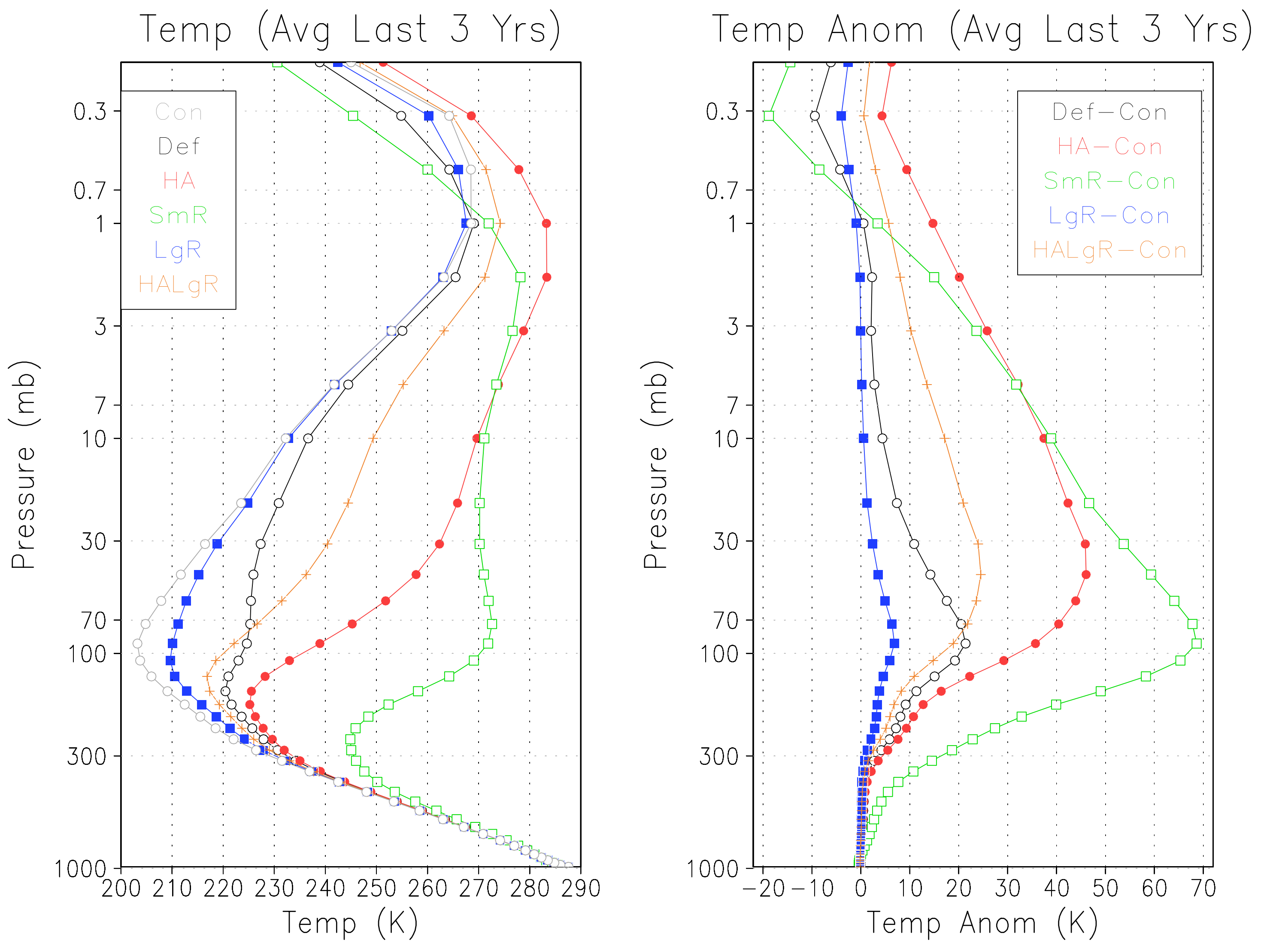

Figure 3. Temperature profiles and anomalies for each of the geoengineering experiments. Stratospheric heating has a strong dependence upon the aerosol parameters (radius and injection height). Heating modifies circulation patterns, forcing a positive mode of the Arctic Oscillation and strengthening the polar jets.

Conclusions

The surface cooling and degree of side effects of geoengineering strongly depend upon the aerosol size and altitude of injection. The impacts of the resulting changes in stratospheric dynamics and ozone loss need to be studied in much more careful detail. This study should be repeated with a dynamic ocean to determine impacts on the hydrologic cycle and cryosphere, including the "dirty snow" effect in which black carbon deposited on fresh snow can reduce the albedo. The amount of cooling and radiation perturbations suggest an excessive amount of black carbon aerosols was used, in some cases by several orders of magnitude.

Acknowledgments

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References

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