Geoengineering: Plan B Remedy for Global Warming

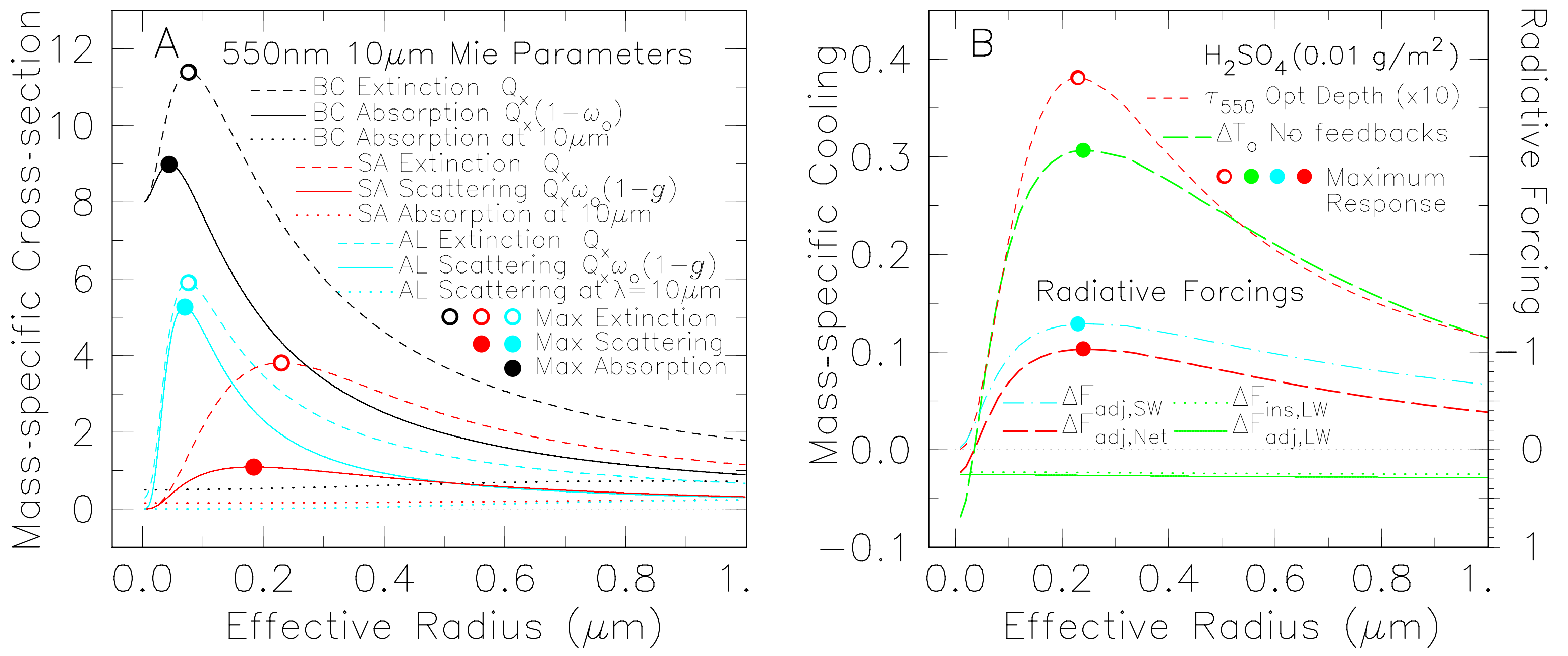
Andrew A. Lacis

NASA Goddard Institute for Space Studies

Abstract

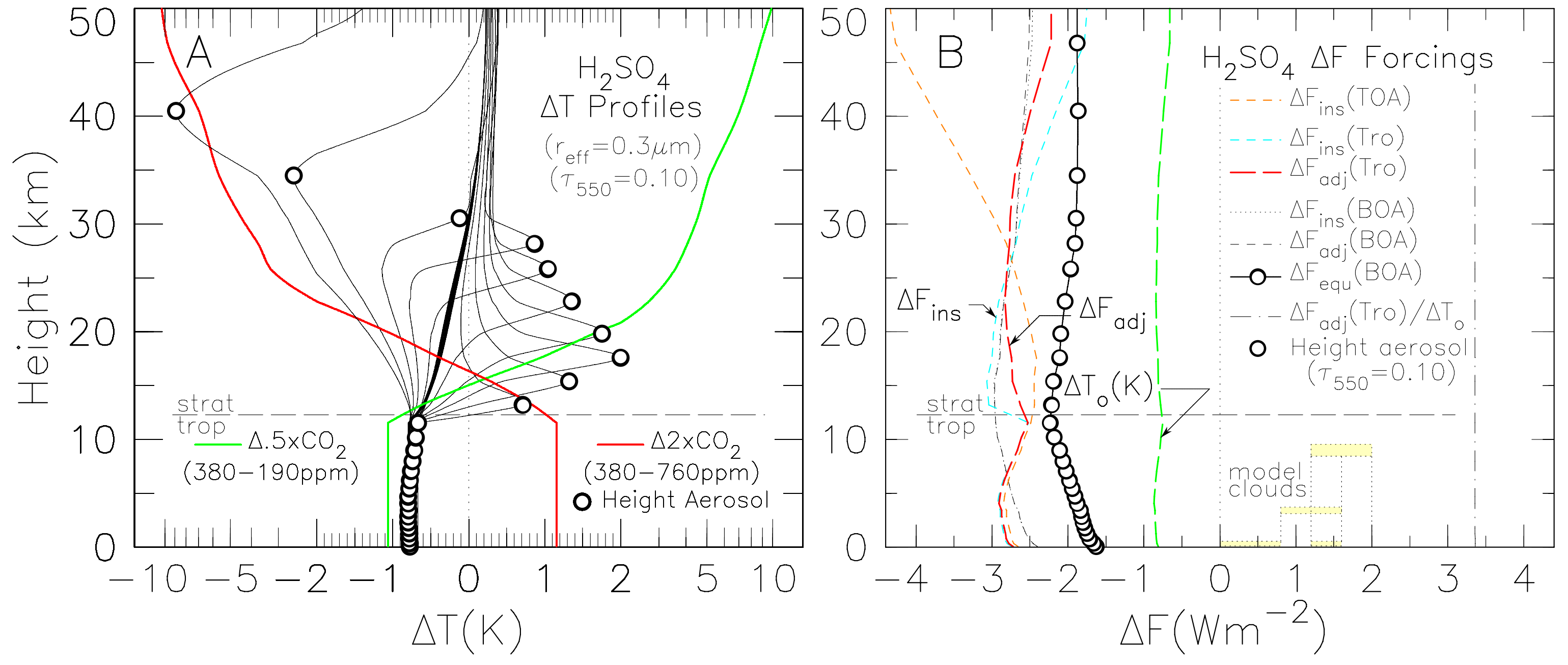
Accelerated melting of Greenland ice is a clear indication that consequences of global warming are real and impending. The underlying causes of global warming are well enough understood, but the necessary reduction of greenhouse gases to prevent irreversible climate change is unlikely to happen before the point of no return is reached. To reverse the impending sea level rise, geoengineering countermeasures may be required to counter the current global energy imbalance due to global warming. Of the many proposed remedies, deploying aerosols within the stratosphere offers realistic prospects. Sulfur injections in the lower stratosphere would have the cooling effect of naturally occurring volcanic aerosols. Soot at 40-50 km would be more efficient in cooling the ground surface, but at the cost of heating up the middle atmosphere. Should serious action ever be taken to combat global warming, then all options, including reduction of the greenhouse gases, will need to be fully considered and evaluated for their feasibility, environmental impact, and economic cost. Geoengineering countermeasures are clearly not a cure for the global warming problem, but they may buy time while atmospheric greenhouse gases are brought under control into a sustainable long-term equilibrium.

Mie Scattering Constraints



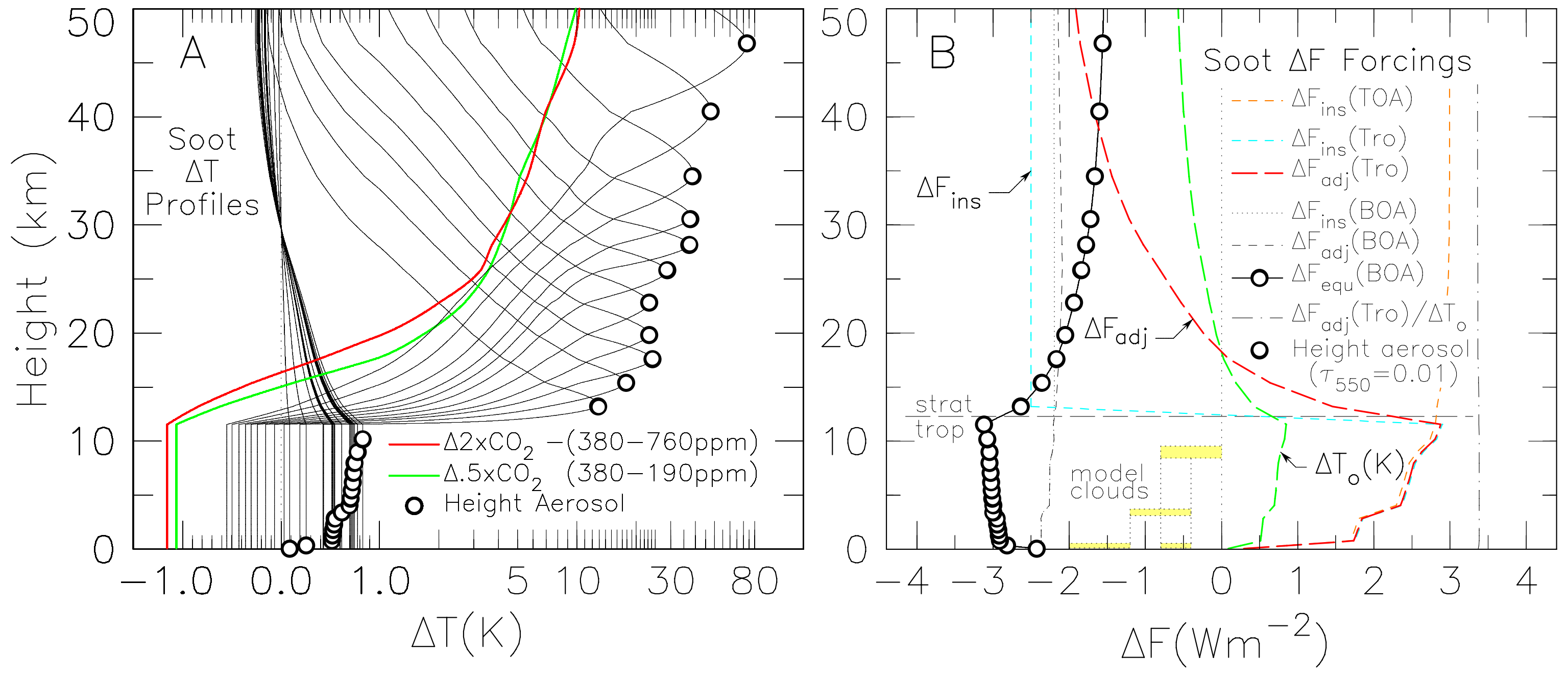
Mass-specific cross-sections (m2/g) at 550 nm and 10 μm for black carbon (BC), sulfuric acid (SA), aluminum (AL) aerosols (A), and mass-specific cooling for SA aerosol for mass density of 0.01 g/m2 (B) as functions of aerosol size. Dashed lines are Mie extinction efficiency factors Qx. BC absorption cross-section is solid black. Solid red and blue lines depict effective scattering cross-sections of SA and AL aerosols. Black and red dotted lines are BC and SA absorption cross-sections at 10 μm. Blue dotted line is AL scattering at 10 μm. In panel B, dashed red line is SA optical depth (x10) with maximum τ= 0.038 at *reff* = 0.23 μm for mass density 0.01 g/m2. Long-dash green line depicts no-feedback surface temperature (cooling) change (ΔTo = -0.31 K at *r* = 0.24 μm). Radiative forcings use right hand scale. The long-dash red line depicts adjusted forcing (ΔFadj = -1.03 W/m2 at r*eff*=0.24 μm) with solar only (SW) component (ΔFadj = -1.24 W/m2 at *reff* = 0.24 μm) given by dot-dash cyan line. Dashed and solid green lines are LW instantaneous and adjusted forcings. The circles represent peak values.

Sulfuric Acid Aerosol



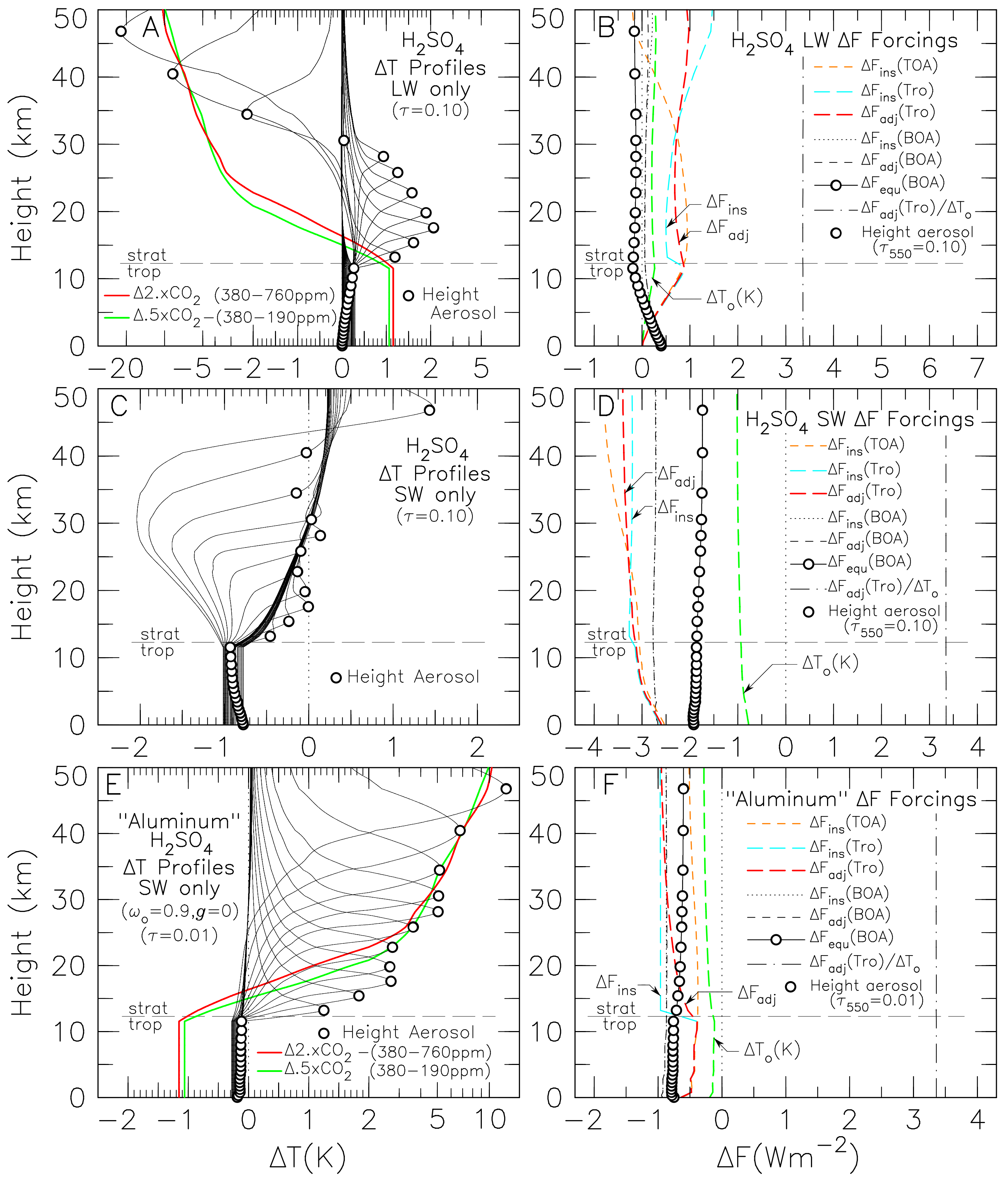
Atmospheric heating and cooling profiles (A) and radiative forcings (B) for sulfuric acid (H2SO4) aerosol for optical depth τ= 0.10 at 550 nm as functions of aerosol height (indicated by open circles). ΔT scale is linear from -2.0 to 2.0, logarithmic otherwise. ΔT temperature changes for 2xCO2 (red line) and 0.5xCO2 (green line), are included for comparison. Long-dash green line in B depicts no-feedback surface temperature change ΔTo. Long-dash red line depicts adjusted radiative forcing ΔFadj. Blue dot-dash line is instantaneous forcing ΔFins, while orange dashed line depicts instantaneous flux change at TOA. Dotted, dashed and solid black lines are instantaneous, adjusted, and equilibrium flux changes at BOA, respectively. Double dot-dash line is ratio of adjusted forcing divided by surface temperature change ΔTo. Schematically illustrated at the bottom in ΔT interval 0 to 4 is the model cloud structure (0.5, 0.2, 0.1, 0.1, 0.1 for clear-sky, and low, middle, high, and overlapped clouds, respectively). The strat/trop demarcation is the point where the convective energy transport ceases, and above which the atmosphere is in radiative equilibrium in 1-D RCM calculations.

Black Carbon (Soot) Aerosol



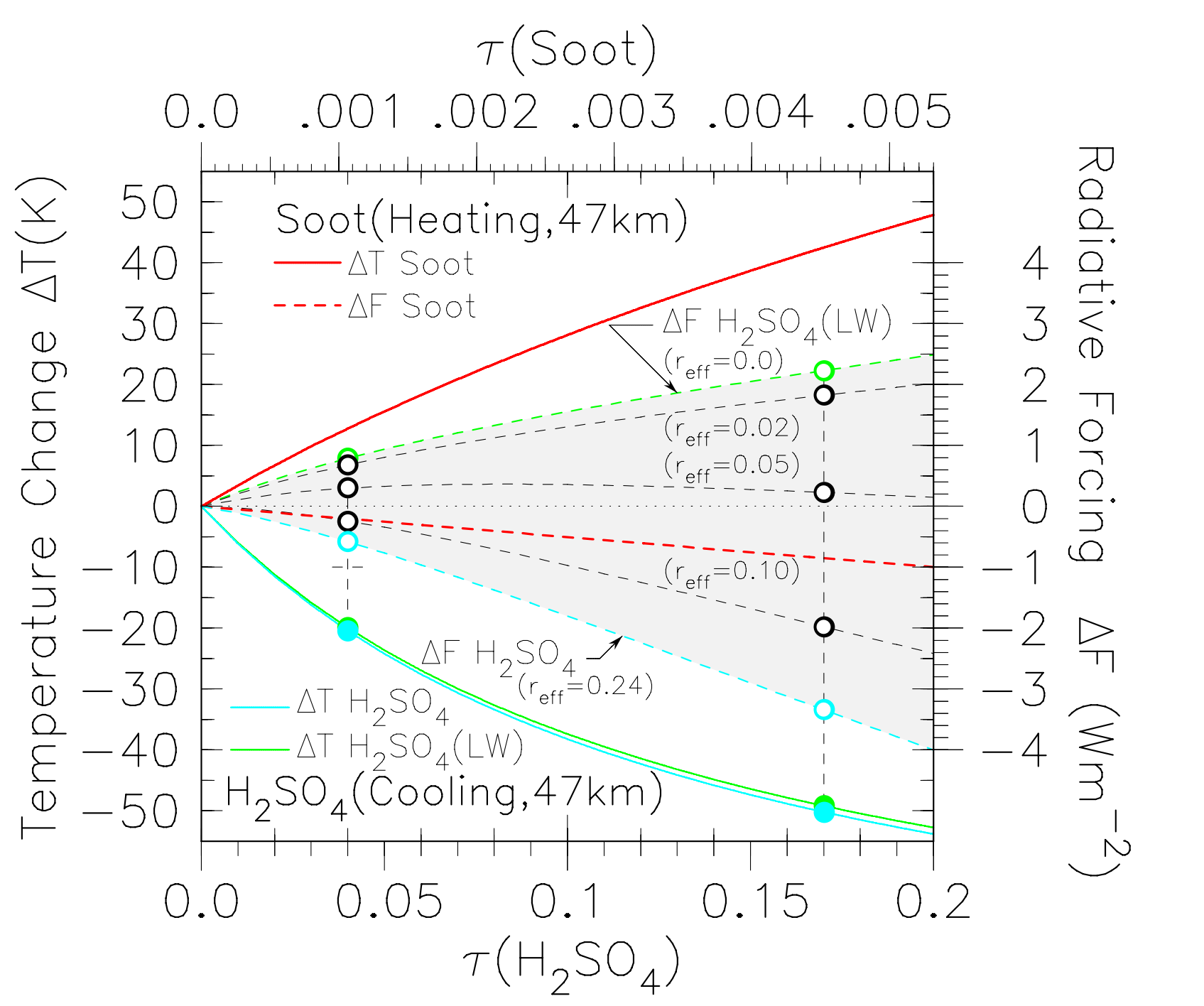
Temperature change profiles (A) and radiative forcings (B) for soot of optical depth τ= 0.01 as functions of height. The height of aerosol layers is indicated by the open circles. ΔT scale is linear from -1.0 to 1.0, otherwise logarithmic. For comparison, the reference temperature response for doubled CO2 is plotted as a negative change of temperature. The radiative parameters are the same as described for Sulfuric Acid. Strongly absorbing aerosols like soot are effective in cooling the ground surface if placed at high altitude (above 40-50 km altitude). Such particles can be made arbitrarily small to increase their atmospheric residence time, and not lose their radiative efficiency.

SW and LW Components

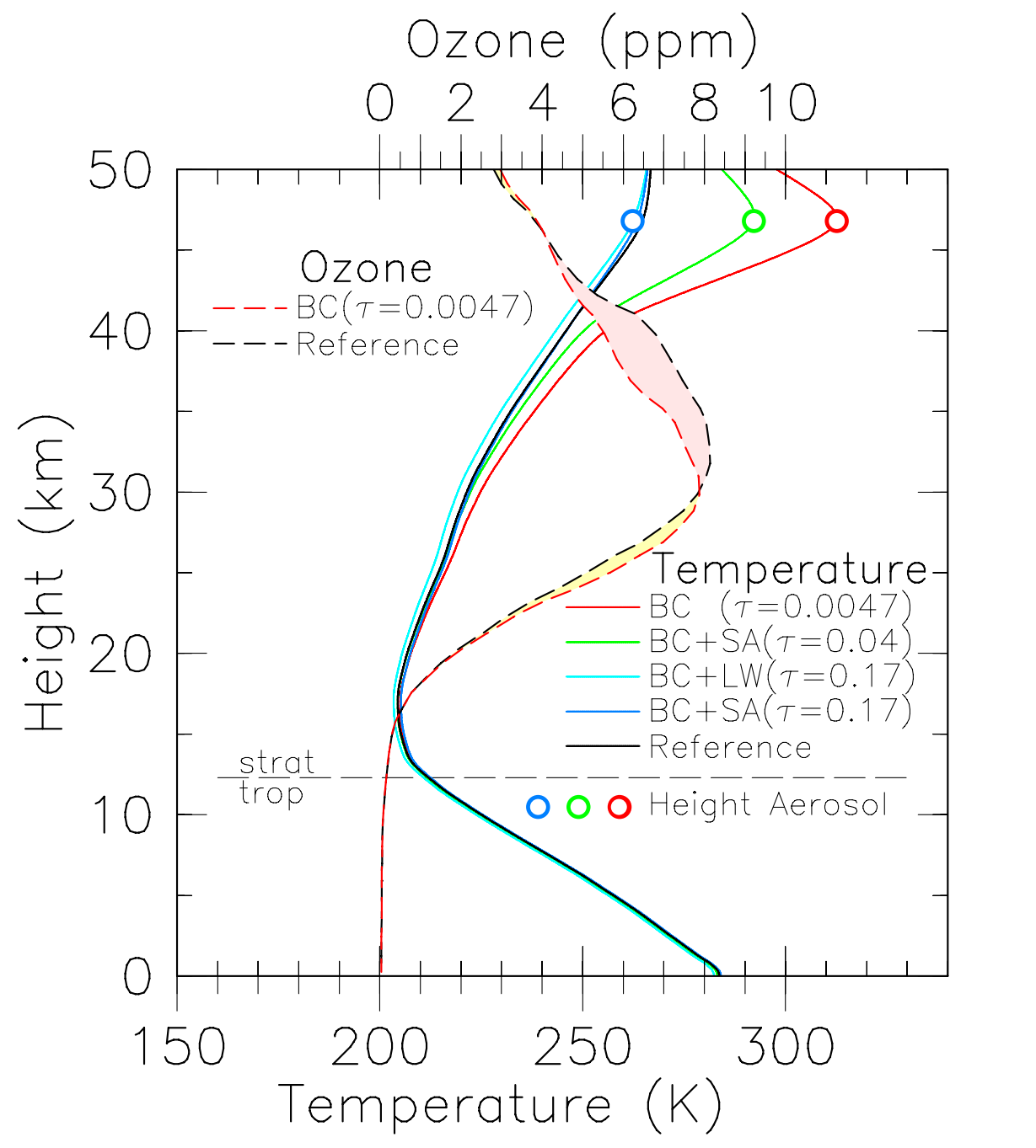


Temperature change profiles (A,C,E) and radiative forcings (B,D,F) for sulfuric acid aerosol. Parameters are as given above, except that panels A and B are for the LW H2SO4 component and panels C and D are asymmetry parameter *g* set to zero, and the single scattering albedo limited not to exceed 0.9, to represent scattering properties of aluminum aerosol. For reference, profiles of temperature change for 0.5xCO2 (red line) and 2.0xCO2 (green line) are plotted as negative values in A and E, respectively. Long-dash red lines depict adjusted radiative forcing ΔFadj. Blue dot-dash lines are instantaneous forcing ΔFins, while orange dashed lines depict instantaneous flux change at TOA. Dotted, dashed and solid black lines are instantaneous, adjusted, and equilibrium flux changes at BOA, respectively. Double dot-dash lines give the ratio of adjusted forcing ΔFadj divided by surface temperature change ΔTo. Compared to purely scattering aerosols, metallic aerosols, such as aluminum, unnecessarily heat up the stratosphere for the same surface cooling.

Sample Results and Collateral Effects

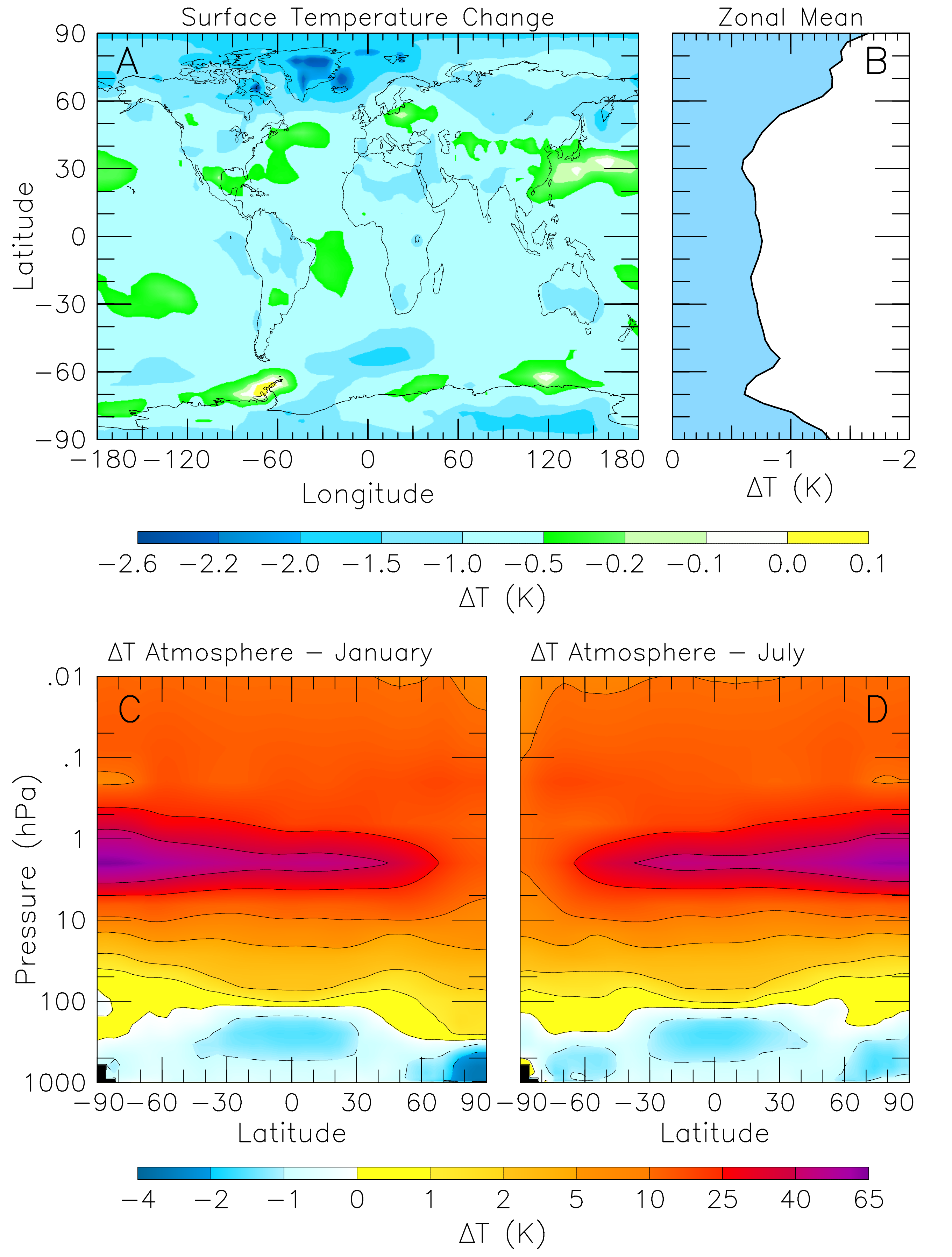


Heating by soot and cooling by H2SO4 aerosols at 44-50 km. The solid red line depicts stratospheric heating by soot alone (top and left scales), while the dashed red line depicts the cooling by soot at ground level (right scale). H2SO4 aerosol (bottom scale) is added with the full amount of the 1 nm soot (τ= 0.0047) already in place. Shaded area depicts range of radiative forcings due to H2SO4 aerosol with changing particle size. Solid blue and green lines show stratospheric cooling by H2SO4. The open and solid circles depict the range of surface radiative forcing and local stratospheric cooling for nominal H2SO4 aerosol optical depths of 0.04 and 0.17, respectively.



The impact of stratospheric heating by soot deployed at 44-50 km on atmospheric ozone. Soot optical depth is τ= 0.0047. The open circles depict temperature profiles mitigated by nominal H2SO4 optical depths τ= 0.04 (green) and τ= 0.17 (blue). Ozone increases (yellow) and decreases (pink) with respect to reference ozone are for the maximum soot-alone (red line) heating. Remarkablely, the vertically integrated change in atmospheric ozone column is very close to zero.

GCM Simulation of Soot Aerosol at 40-50 km Altitude



Equilibrium surface temperature change for years 21-30 of 30-year experiment minus control simulations using GISS modelE GCM with 65 m q-flux ocean for τ = 0.005 of soot aerosol uniformly deployed at 1-2 hPa (A). Corresponding zonal mean surface temperature change (B). Change in zonally averaged monthly-mean atmospheric temperatures for January (C) and July (D) conditions. There is strong stratospheric heating by nearly 65 K in the summer polar regions at the 1-2 hPa level. As expected, there is polar amplification by a factor of 2 of the surface temperature change due to the applied radiative forcing of the soot aerosol. Thee is a small region of statistically insignificant surface warming over the Antarctic Peninsula. Perhaps it is a fortuitous coincidence, the maximum surface cooling by about 2.5 K is seen to occur over Greenland, just where it is need most. Stratospheric sulfate forcings produces similar patterns of polar surface cooling.