Engineering the Climate with Polar-only Solar Radiation Management

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Cooling from Polar Interventions

- Polar interventions are more effective on a per Watt basis than an intervention with uniform global coverage (see table). This is the case because the polar interventions especially activate ice-albedo feedback, are concentrated over only a few months, and primarily affect regions with unusually large temperature changes. This suggests that full global interventions with aerosol loadings that are not uniform in latitude and season merit investigation.
- Polar interventions of the size studied returned sea ice extent to levels typical of conditions with the baseline CO_2 concentration.

Domain of Solar Reduction	Working Name of Simulation	Percent Solar Reduction in Domain	Global Warming Remaining after Solar Reduction (2xCO2=2.23°C)	Relative per-W Effectiveness of the Polar Intervention
Global	Gp2	-1.8%	0.20	1.00
North of 51°N	N51p6	-6.0%	1.70	2.96
North of 61°N	N61p10	-10.0%	1.84	3.90
North of 71°N	N71p25	-25.0%	1.84	3.61
South of 51°S	S51p6	-6.0%	1.18	3.61
South of 61°S	S61p10	-10.0%	1.36	8.71
South of 71°S	S71p25	-25.0%	1.60	2.14
Poleward of 51°	NS51p6	-6.0%	0.68	3.12
Poleward of 61°	NS61p10	-10.0%	0.98	5.12
Poleward of 71°	NS71p25	-25.0%	1.21	2.16

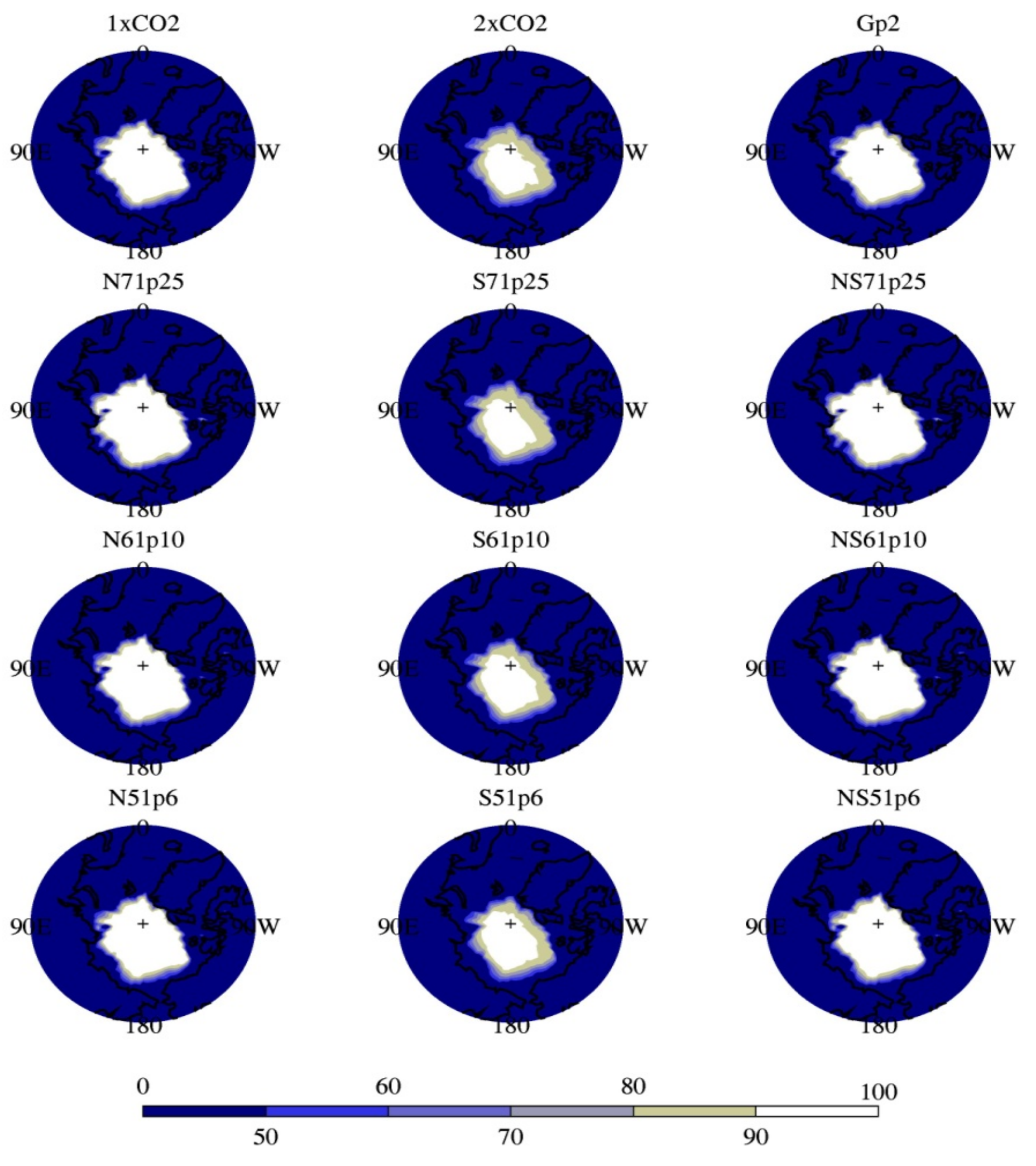

Figure 1: Climatological mean sea ice fraction in the Arctic during June-July-August .The top three maps show the ice extent for 1xCO2, 2xCO2, and for a global intervention reducing solar radiation by 1.8%. The nine lower maps show the results for interventions in the polar regions of the Northern (left column), Southern (center), and both (right) hemispheres. The second, third, and fourth rows show results for reductions in solar radiation extending from the pole to 71, 61, and 51 degrees latitude, respectively. Note that the Antarctic intervention has virtually no effect on Arctic sea ice. Units are percentage.

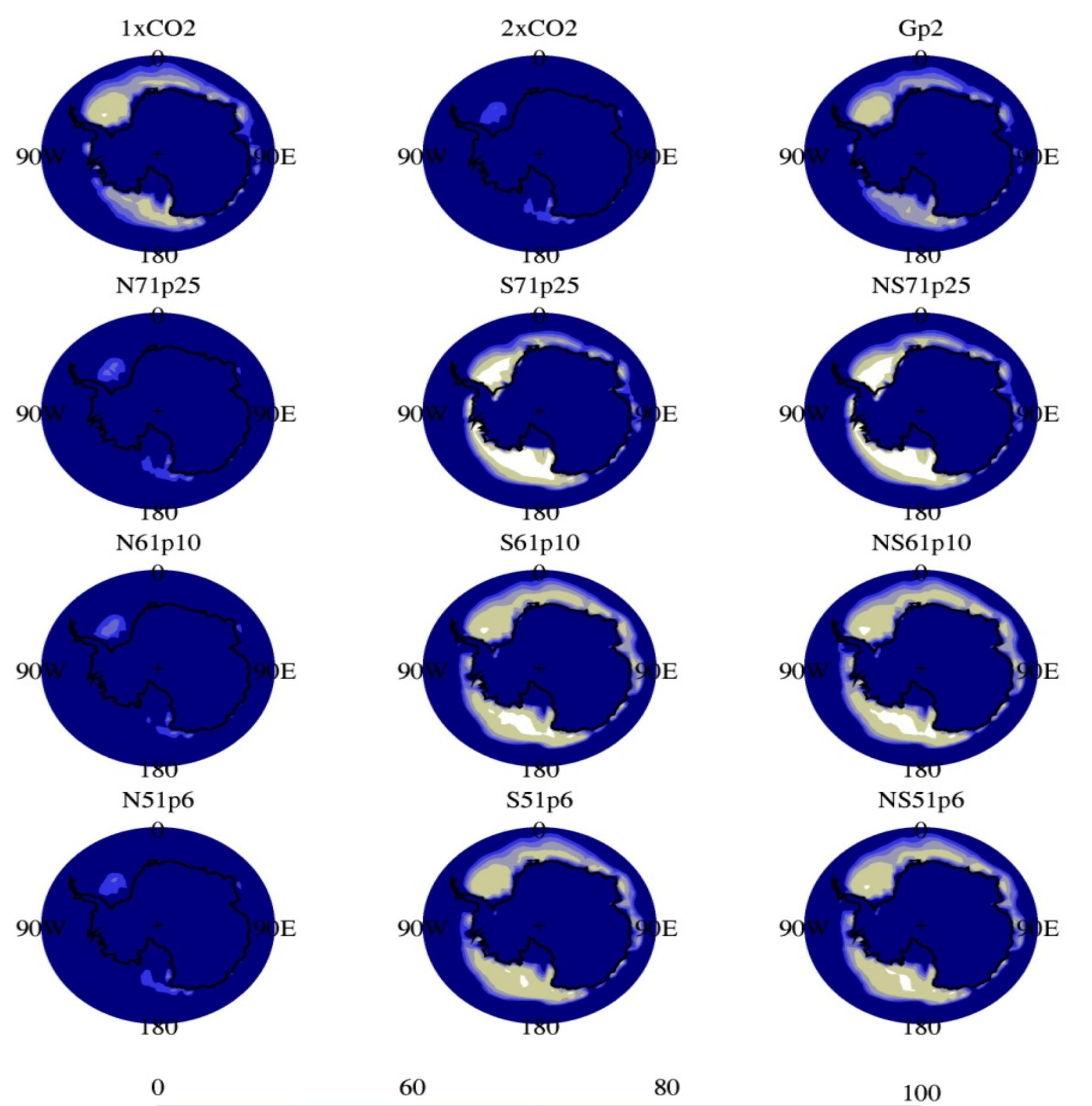

Figure 2: Climatological mean sea ice fraction in the Antarctic during December-January-February. Distribution of maps as for Figure 1. Note that the Arctic interventions have virtually no effect on the extent of Antarctic sea ice.

Summary

- Reducing incoming solar radiation has the potential to counter-balance the warming influence of the additional infrared radiation that is trapped by the human-caused increases in the concentrations of of CO_2 and other greenhouse gases. Model simulations indicate that globally uniform reductions in solar radiation equivalent to the increase in infrared radiation would largely return the seasonal and geographic patterns of temperature and precipitation, as well as the global averages, to near their undisturbed distributions.
- Limiting incoming global solar radiation (i.e., global-SRM) by increasing the global stratospheric loading of sulfate aerosols, basically imitating an ongoing sequence of major low-latitude volcanic eruptions, appears to be the most cost-effective approach. Associated with the reductions in temperature and precipitation, however, would be significant conversion of direct radiation to diffuse radiation, a possible weakening of the hydrological cycle and summer monsoons, and a possible slowing of the recovery of the stratospheric ozone layer.
- We have conducted simulations with the NCAR CAM3.1 model to explore the potential for an alternative approach that would only reduce incoming solar radiation over the polar regions during the sunlit seasons. Simulations were conducted reducing solar radiation separately over each polar region and over the two polar regions together (see accompanying poster for more information on the model results).
- The model results indicate that the large temperature increases in high latitudes can be largely offset. Interestingly, the increases in high-latitude precipitation associated with global warming would not be reduced, suggesting that a side effect of polar-SRM would be increased snowfall, thus tending to also offset the glacial loss from global warming. In that implementation would be only during the primary sunlit months, the likelihood of slowing the recovery of polar stratospheric ozone would likely be low.
- Cooling the high latitudes pulls energy from lower latitudes, spreading their cooling influence to mid- and even low latitudes. To provide access to the needed energy, the ITCZ shifts away from the wintertime pole. While significant in the simulations for solar reductions made in only one polar region, the shifts are reduced when polar-SRM is imposed in both polar regions. Fine tuning of latitudinal extents and amounts of solar reduction would seem likely to allow adjustments to minimize or intentionally adjust the changes in low-latitude precipitation that would result.
- While achieving the required levels of solar radiation reduction in polar regions would require a significant sulfate loading, the aerosol layer need only be present for the sunlit months, so the polar injections could be into either the lower stratosphere or the upper troposphere. This would likely reduce the spreading of sulfate to low and mid-latitudes, where the hydrological cycle and monsoon might be affected. Cloud or surface brightening, if used, would also only need to be seasonally induced.
- Overall, the model simulations suggest that, if the magnitude of the solar radiation reduction could be achieved, polar-SRM could lead to a significant reduction in warming in the polar regions as well as in mid- and low latitudes without a number of the unintended adverse consequences of global-SRM. Note that actual implementation might well be gradual rather than sudden, seeking to maintain a near-present climate.
- Because the amount of solar radiation reaching the surface in mid- and low latitudes is not reduced, the global hydrologic cycle remains roughly consistent with the increased intensity in the warmed world, with the snowfall increase in high latitudes likely being viewed as beneficial because this would slow loss of ice mass in high latitudes. Whether the failure of polar-SRM to limit the intensification of the hydrologic cycle in low latitudes, where it apparently adds to the tendency to more intense precipitation in low- and mid latitudes, would be viewed as beneficial or harmful merits further examination.

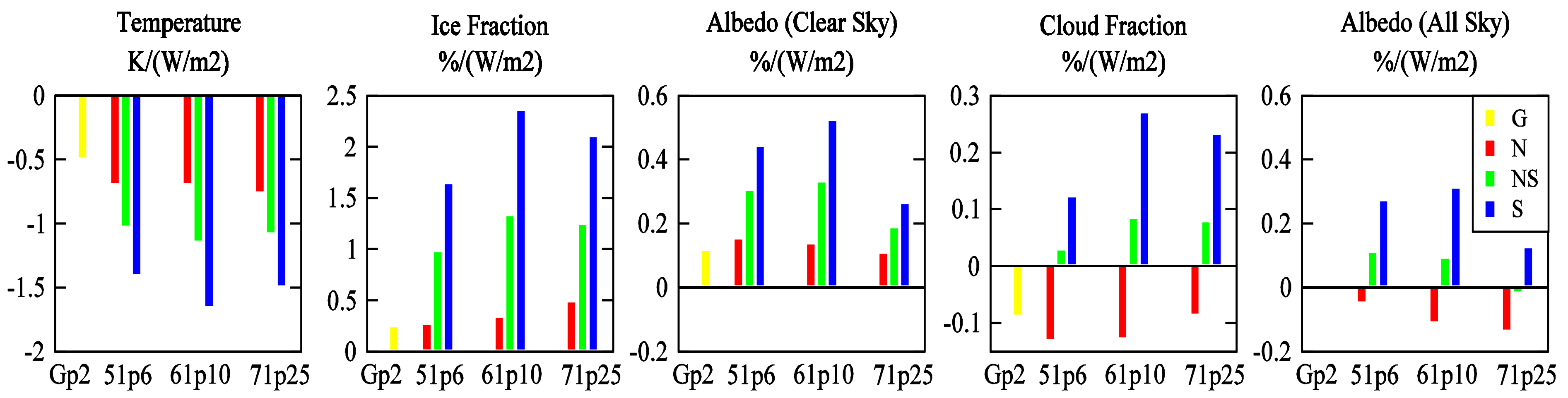

Figure 3: Global mean changes in surface air temperature, ice fraction, TOA albedo over clear skies, cloud fraction, and TOA albedo over all skies, **with each being normalized by dividing by the reduction in solar radiative forcing averaged over the entire globe**. The yellow bars represent the results from the globally uniform reduction in solar insolation (G), the red bars from the northern high-latitude insolation reduction (N), the blue bars from the southern high-latitude insolation reduction (S), and the green bars from northern and southern high-latitude insolation reduction (NS). For the three high-latitude reduction cases, incident solar radiation at the TOA was reduced by 6% poleward of 51 degrees, 10% poleward of 61 degrees, and 25% poleward of 71 degrees.

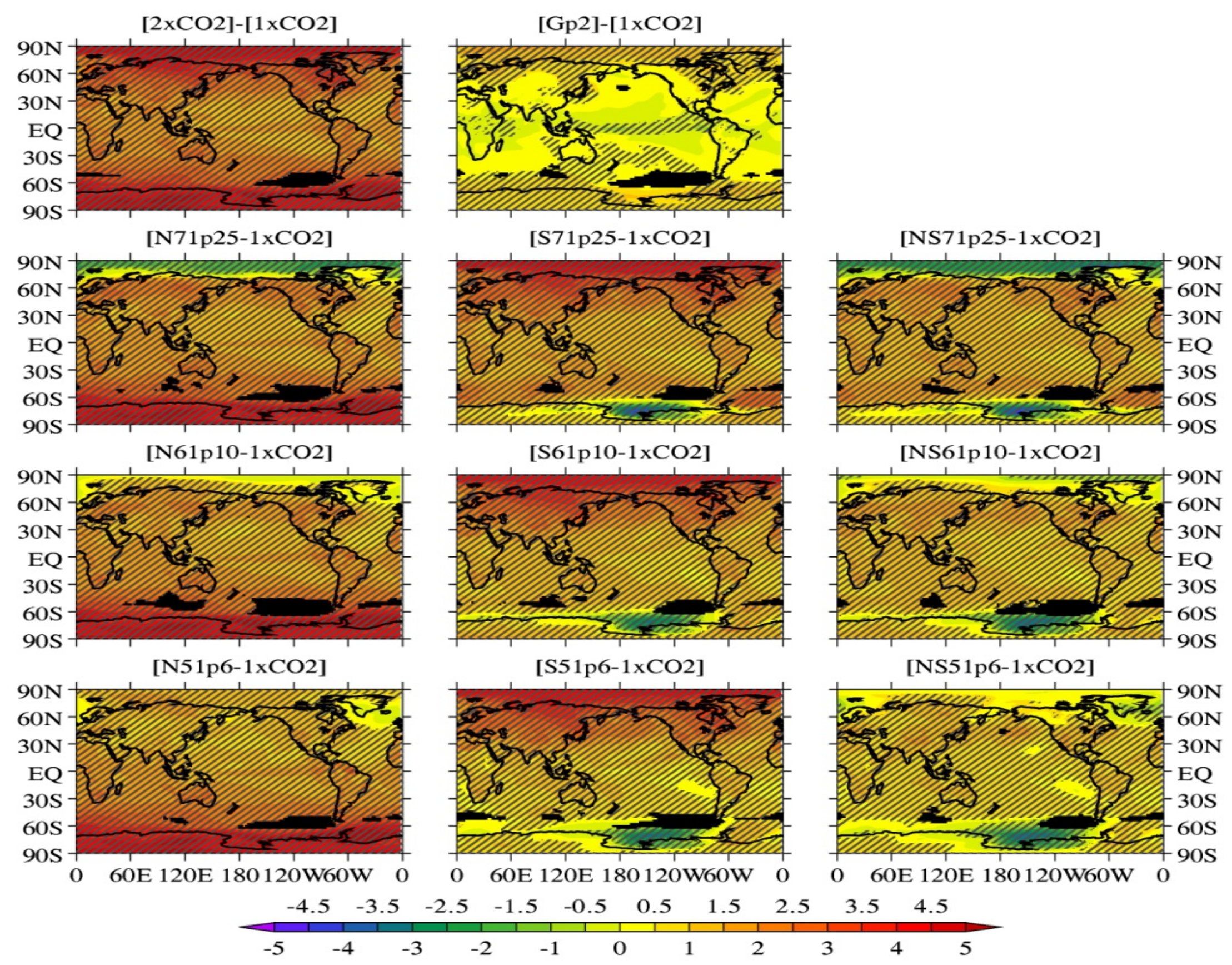

Figure 4: Annual-mean changes in surface air temperature (K) from the 1XCO2 baseline after imposing both a doubling of the atmospheric CO_2 concentration (2xCO2) and the indicated reductions in top-of-the-atmosphere (TOA) solar insolation, with the hatching indicating areas where the changes are statistically significant at a 95% confidence level. Note that the individual polar interventions tend to limit warming in their hemisphere, and that the interventions in both polar regions have significant influences at all latitudes.

Key to the Maps: The top row shows the changes for CO_2 doubling as compared with $1xCO_2$ (left column) and the changes after imposing both a CO_2 doubling and the global intervention (center). The nine lower maps show the results for interventions in the polar regions of the Northern (left), Southern (center), and both (right) hemispheres. The second, third, and fourth rows show results for reductions in solar radiation extending from the pole to 71, 61, and 51 degrees latitude, respectively. Hatching shows the areas with statistically significant changes at the 95% confidence level.

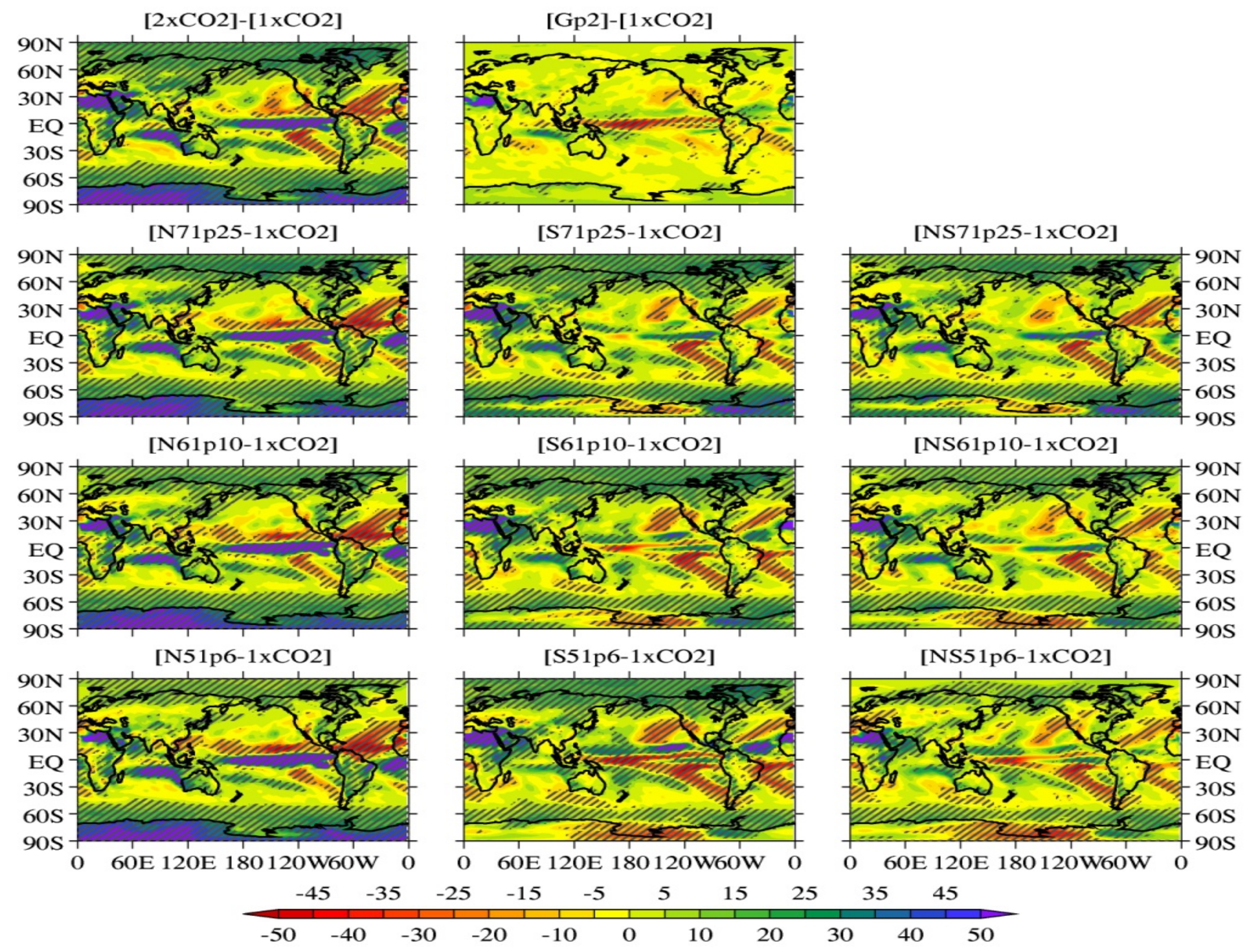

Figure 5: Annual-mean percentage changes in surface precipitation rate from the 1XCO2 baseline after imposing both a doubling of the atmospheric CO_2 concentration (2xCO2) and the indicated reductions in TOA solar insolation in polar regions, with the hatching indicating areas where the changes are statistically significant at a 95% confidence level.

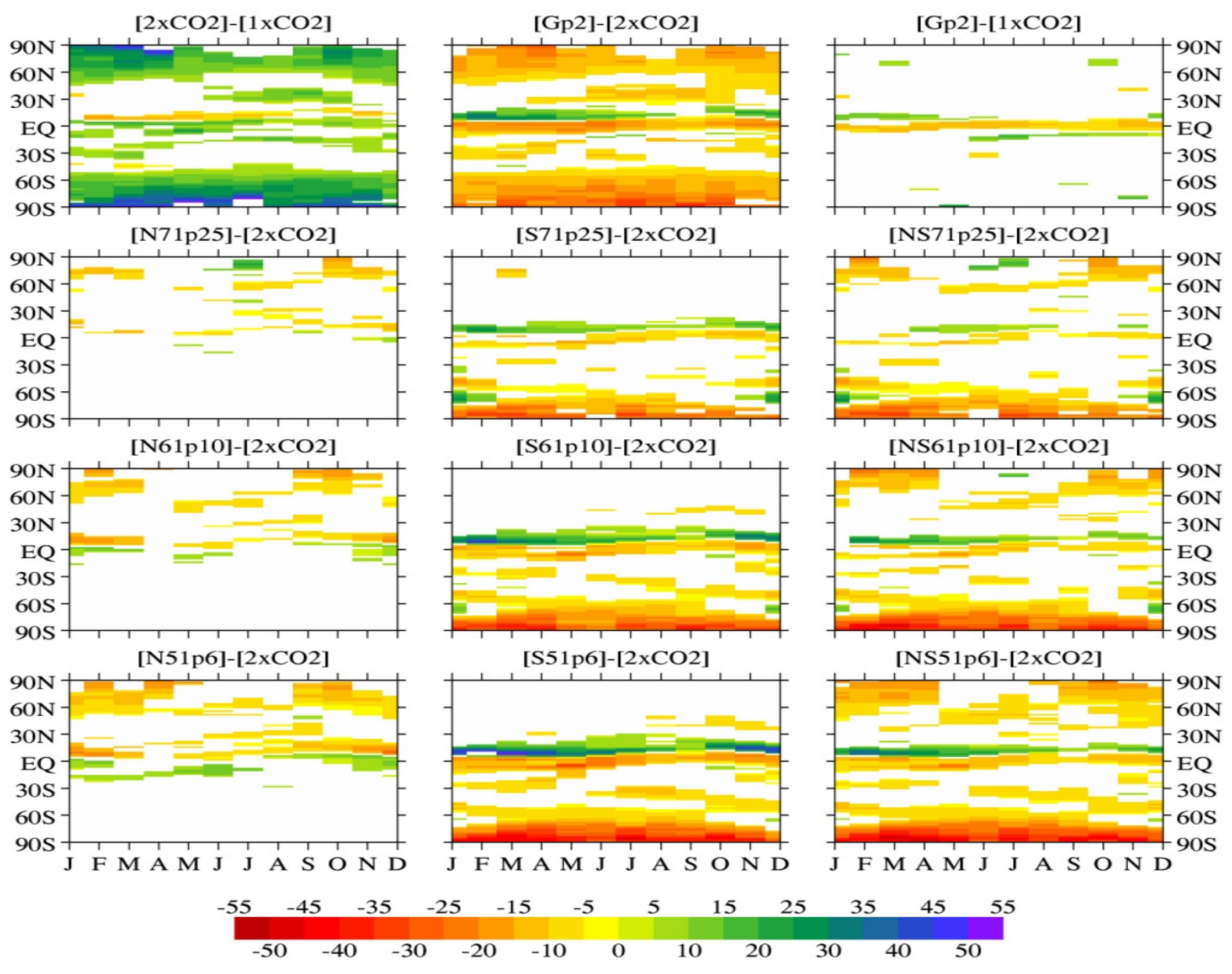

Figure 6: Annual cycle of percentage changes in total precipitation rate at the surface due to reductions in TOA insolation as compared with 2xCO2. The change for the 2xCO2 case and the effect of a globally uniform reduction in insolation of 1.8% as compared with 1xCO2 case are shown in the upper left and right corners as a reference. Only the areas with statistically significant changes at the 95% confidence level are shown in color. Note that the Arctic interventions do not significantly reduce the increase in Arctic precipitation caused by the CO_2 doubling, whereas the Antarctic intervention has a much more significant effect.