# Moving Toward a Conceptual Design for Moderating Global Warming with Polar Shielding

M. C. MacCracken[1], Ho-Jeong Shin[2,3], Ken Caldeira[2], and George A. Ban-Weiss[2,4]

1. Climate Institute, 900 17th St. NW, Suite 700, Washington, DC 20006, USA (mmaccrac@comcast.net)
2. Carnegie Institution for Science, Dept of Global Ecology, 260 Panama Street, Stanford, CA 94305, USA (kcaldeira@carnegie.stanford.edu)
3. Supercomputing Center, Dept of Application & Support, Korea Institute of Science and Technology Information, Daejeon, KOREA (hjshin@kisti.re.kr)
4. Lawrence Berkeley National Laboratory, Berkeley CA USA (georgebw@gmail.com)

## Model Selection and Simulations

- We have used the NCAR CAM3.1 atmospheric model, coupled to a slab ocean model (so the response of the oceans is limited to thermodynamic processes), to study the potential for offsetting changes in climate due to the rising atmospheric concentration of $CO_2$. This is the same model as was used in Caldeira and Wood (2008).
- A doubling of the atmospheric $CO_2$ concentration from 280 ppm to 560 ppm leads to a global average warming of 2.23°C and a significant reduction in polar sea ice.
- Simulations have been carried out to examine the potential for reductions in solar radiation over various regions of the Earth to offset the warming and changes in precipitation from a $CO_2$ doubling, both within the particular regions and over the rest of the Earth. Solar insolation is set at 1366 W/m$^2$.
- The reductions in solar radiation have been imposed over the following regions:

| Domain of Solar Reduction | Working Name of Simulation | Percent Solar Reduction in Domain | Solar Flux Reduction in Domain (W/m²) | Solar Flux Reduction over Globe (W/m²) |
|---|---|---|---|---|
| Global | Gp2 | -1.8% | -4.14 | -4.14 |
| North of 51°N | N51p6 | -6.0% | -6.86 | -0.77 |
| North of 61°N | N61p10 | -10.0% | -9.05 | -0.57 |
| North of 71°N | N71p25 | -25.0% | -19.07 | -0.52 |
| South of 51°S | S51p6 | -6.0% | -6.70 | -0.75 |
| South of 61°S | S61p10 | -10.0% | -8.41 | -0.53 |
| South of 71°S | S71p25 | -25.0% | -15.59 | -0.43 |
| Poleward of 51° | NS51p6 | -6.0% | -6.78 | -1.51 |
| Poleward of 61° | NS61p10 | -10.0% | -8.73 | -1.09 |
| Poleward of 71° | NS71p25 | -25.0% | -17.33 | -0.94 |

**Key to the Maps:** The top row shows the changes due to 2x$CO_2$ as compared with 1x$CO_2$ and the effects of a globally uniform reduction in insolation of 1.8% compared to 2x$CO_2$ and to 1x$CO_2$. 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. Hatching shows the areas with statistically significant changes at the 95% confidence level. Units are in W m$^{-2}$ or Kelvins.

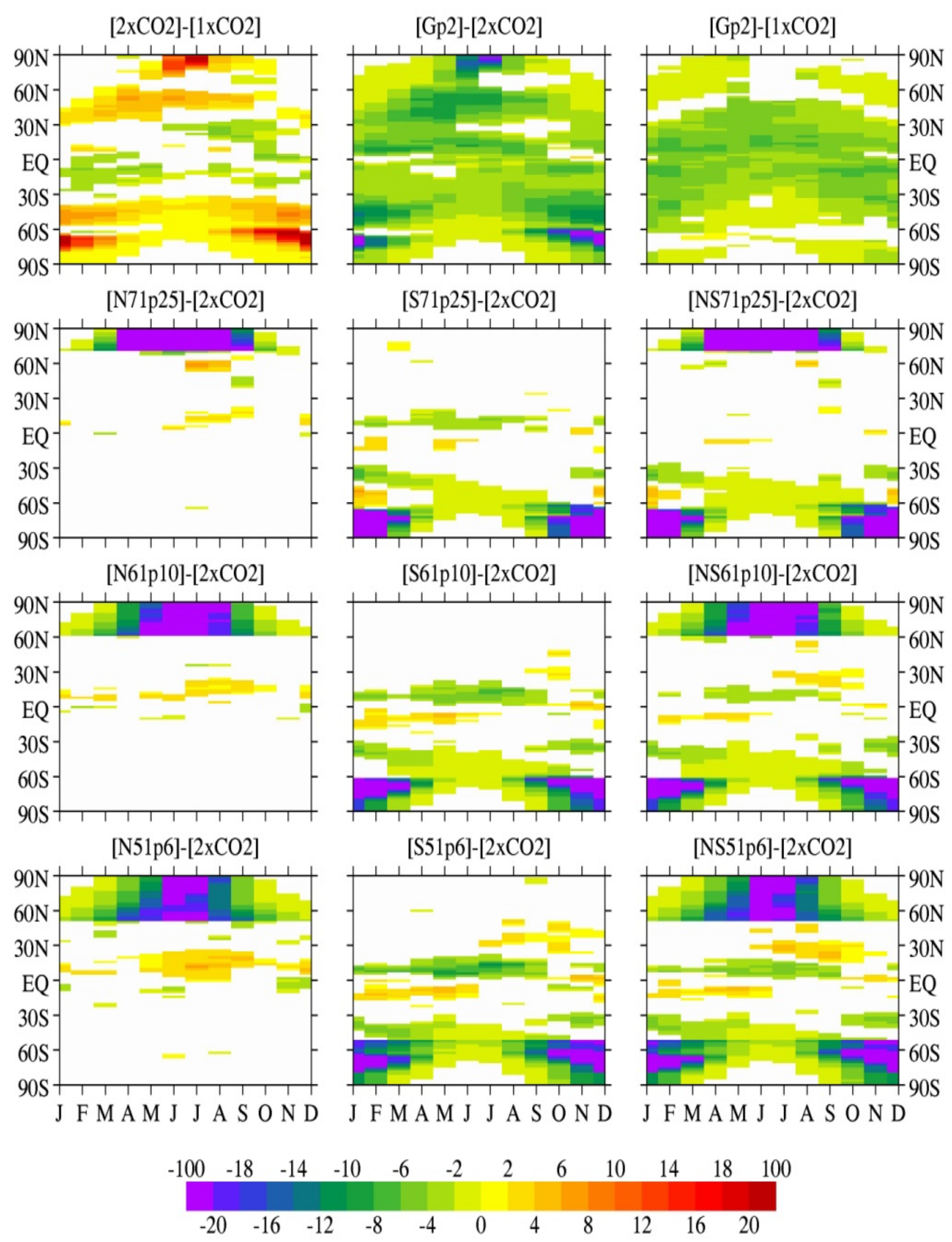


**Figure 1**: Annual cycle of changes in net downward solar radiation at the top of the atmosphere (TOA) due to the reductions in TOA insolation as compared with the changes resulting from a $CO_2$ doubling. Changes in high latitudes during polar summer are due to imposed reduction in solar radiation; changes elsewhere generally represent changes due to changes in cloud cover. In low latitudes the main change is due to a shift in the ITCZ.

## Summary

•Model simulations have been carried out using the NCAR CAM3.1 to study the climatic response to global and polar reductions in solar radiation, extending the work of Caldeira and Wood (2008).

•Reducing solar radiation incident on Earth's polar regions was able to limit cooling in the high latitudes where the reductions in solar radiation were imposed.

•Both the northern and southern polar shielding simulations also tended to cool middle and lower latitude regions by drawing additional heat to the poles from these regions.

•When the reductions in solar radiation were simultaneously imposed on both polar regions, the temperature increases in both polar regions were nearly fully offset, and the $CO_2$-induced increase in temperature over mid-latitude land areas were roughly halved.

•For the polar perturbations, as found for the Northern Hemisphere simulation by Caldeira and Wood (2008), the precipitation increases in high latitudes caused by the doubling of the $CO_2$ concentration were only modestly reduced.

•At lower latitudes, the northern polar region shielding simulation did not significantly alter the southward shift of the ITCZ precipitation caused by the $CO_2$ doubling, whereas the southern polar shielding appeared to push the ITCZ northward, thus tending to moderate its shift due to the $CO_2$ increase.

•Carried out together, especially when the polar interventions were applied poleward of 61º latitude, the interventions tended to generally moderate the precipitation changes induced by the $CO_2$ doubling, although not erasing some of the regional continental dryings that have been projected.

•Recognizing the important shortcomings of counterbalancing human-induced climate change via an increase in the global stratospheric sulfate layer, polar perturbations appear capable of exerting a significant moderation of $CO_2$-induced warming with potentially fewer adverse impacts.

•While achieving the required levels of solar radiation reduction in high latitudes would require enhancing the stratospheric or tropospheric sulfate layer and/or taking actions to promote cloud or surface brightening, the solar reduction need only be effected during the few sunlit months.

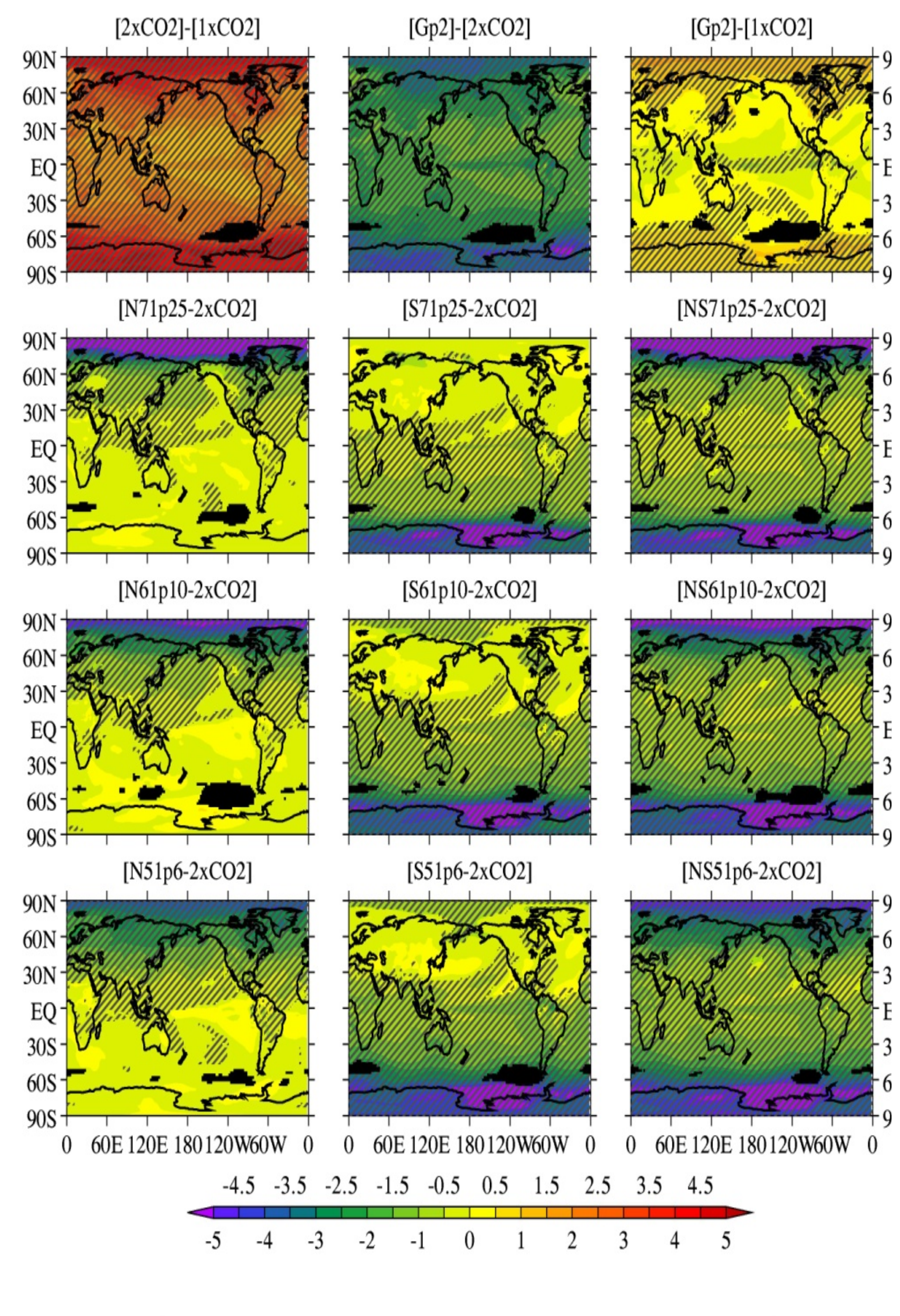


**Figure 2**: Changes in climatological annual-mean surface air temperature (K) in response to specified reductions in TOA solar insolation as compared to the equilibrium climate for a $CO_2$ doubling. Note that the global solar reduction of -1.8% roughly offsets the full warming from a $CO_2$ doubling (upper right). For the polar reductions in solar radiation, the reduction in temperature nearly totally offsets the warming in high latitudes, but there is also an offset extending into middle and low latitudes. For reductions in both polar regions, the offset is large and statistically significant over the entire globe.

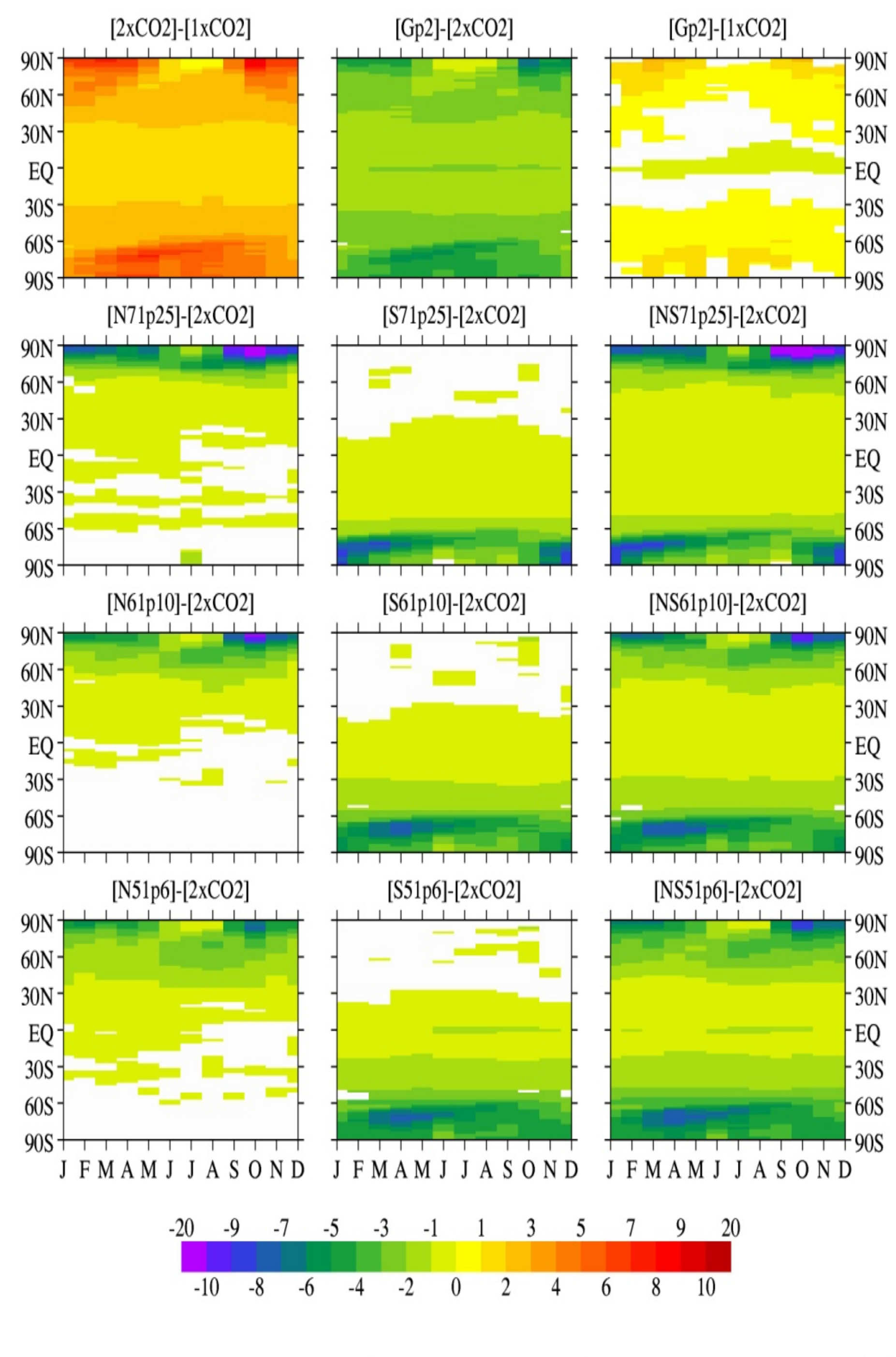


**Figure 3**: Annual cycle of changes in surface air temperature (K) due to reduction in top-of-atmosphere (TOA) insolation as compared to the equilibrium climate for a $CO_2$ doubling. Note that the global solar reduction of -1.8% roughly offsets the global average warming from 2X$CO_2$, but that some solar warming remains in high latitudes, as does the shift of the ITCZ (upper right). For all of the polar reductions, the seasonal cycle is very small even though the flux changes at particular latitudes are strongly seasonal, suggesting that atmospheric circulation and climate feedbacks tend to spread the effects across seasons.

## Polar Amplification of Climate Sensitivity

•Reductions of solar radiation in polar regions lead to reductions in temperature in the region, as well as extending out to middle and even low latitudes.

•The effectiveness of reductions in solar radiation (i.e., the climate sensitivity) is greater in high latitudes than for the globe as a whole. This is presumably because of the particularly strong influence of polar solar reductions on ice-albedo feedback and because the fraction of trapped IR radiation from a $CO_2$ doubling is higher in high latitudes where the solar intervention is imposed (see table).

•The regional climate sensitivity is greater in the Southern Hemisphere than in the Northern Hemisphere because solar reductions and consequent cooling of the Southern Ocean can lead to quite large extensions of sea ice that induce large surface cooling in the region.

•Reductions in solar radiation in a polar region lead to a shift of the ITCZ away from that hemisphere during its winter, enabling greater heat extraction from tropical waters. Appropriately balanced reductions in solar radiation in both hemispheres would thus seem to have the potential to adjust the ITCZ shift.

| Domain of Solar Reduction | Working Name of Simulation | Global Warming Remaining after Solar Reduction (2xCO2=2.23°C) | Global Climate Sensitivity (K/Wm⁻²) | Climate Sensitivity in the Domain (K/Wm⁻²) |
|---|---|---|---|---|
| Global | Gp2 | 0.20 | 0.49 | 0.49 |
| North of 51°N | N51p6 | 1.70 | 0.69 | 1.45 |
| North of 61°N | N61p10 | 1.84 | 0.69 | 1.91 |
| North of 71°N | N71p25 | 1.84 | 0.76 | 1.77 |
| South of 51°S | S51p6 | 1.18 | 1.41 | 1.77 |
| South of 61°S | S61p10 | 1.36 | 1.65 | 4.27 |
| South of 71°S | S71p25 | 1.60 | 1.49 | 1.05 |
| Poleward of 51° | NS51p6 | 0.68 | 1.03 | 1.53 |
| Poleward of 61° | NS61p10 | 0.98 | 1.14 | 2.51 |
| Poleward of 71° | NS71p25 | 1.21 | 1.08 | 1.28 |

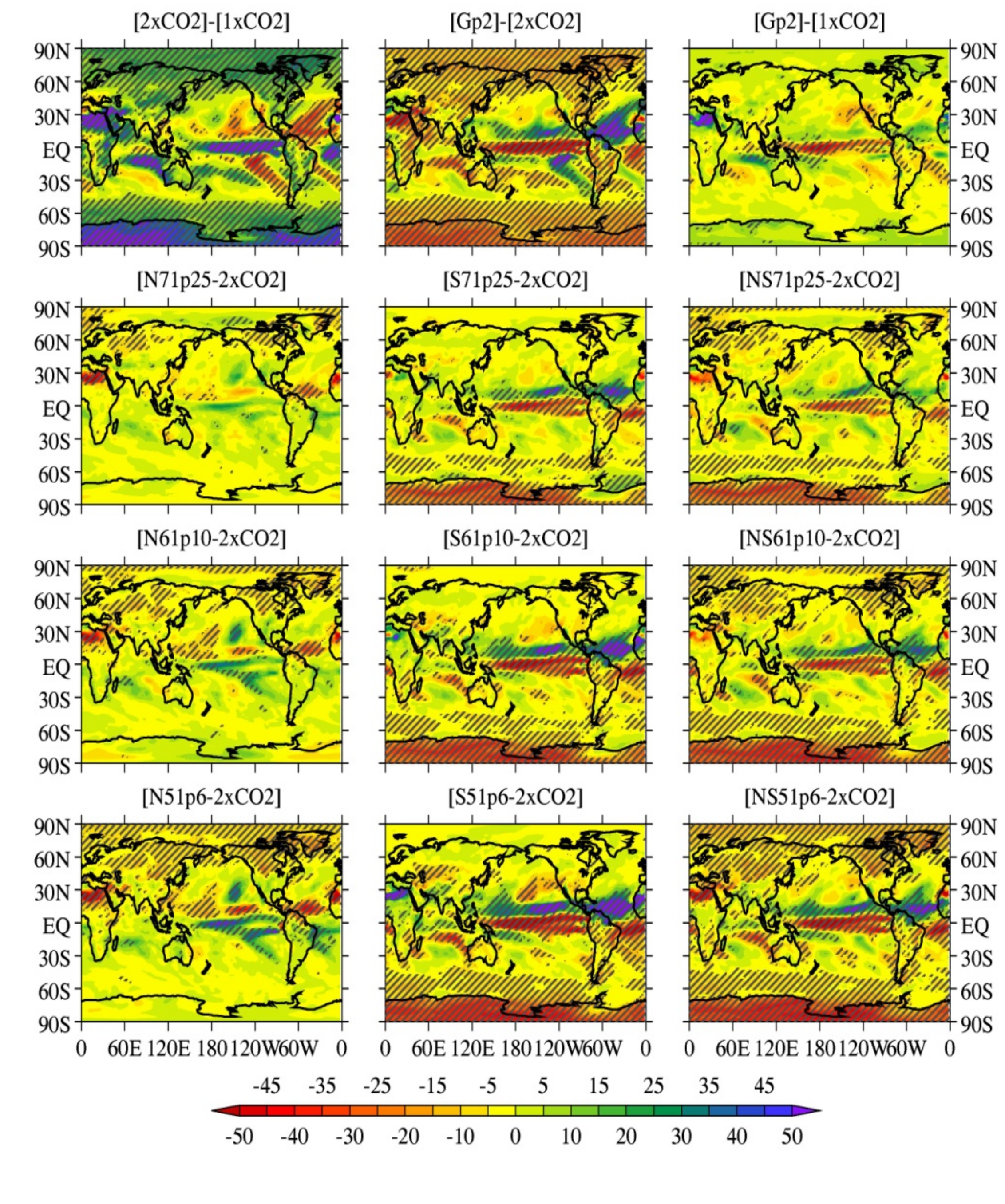


**Figure 4**: Changes in climatological annual-mean total precipitation rate (%) due to specified reductions in TOA solar insolation as compared to the precipitation in a simulation for an equilibrium climate for a $CO_2$ doubling. Note that, except for causing an apparent shift in the ITCZ, the polar reductions in solar radiation do not significantly offset in changes in precipitation caused by a $CO_2$ doubling. This is to be expected because the solar radiation reaching the surface is not reduced in non-polar latitudes as a result of the polar interventions. Note that for the global reduction in solar radiation (top row middle), the reductions in precipitation are roughly global and the remaining precipitation changes from 1X$CO_2$ are small, except for the ITCZ changes (upper right).