Nuclear winter simulations with CESM-WACCM/CARMA

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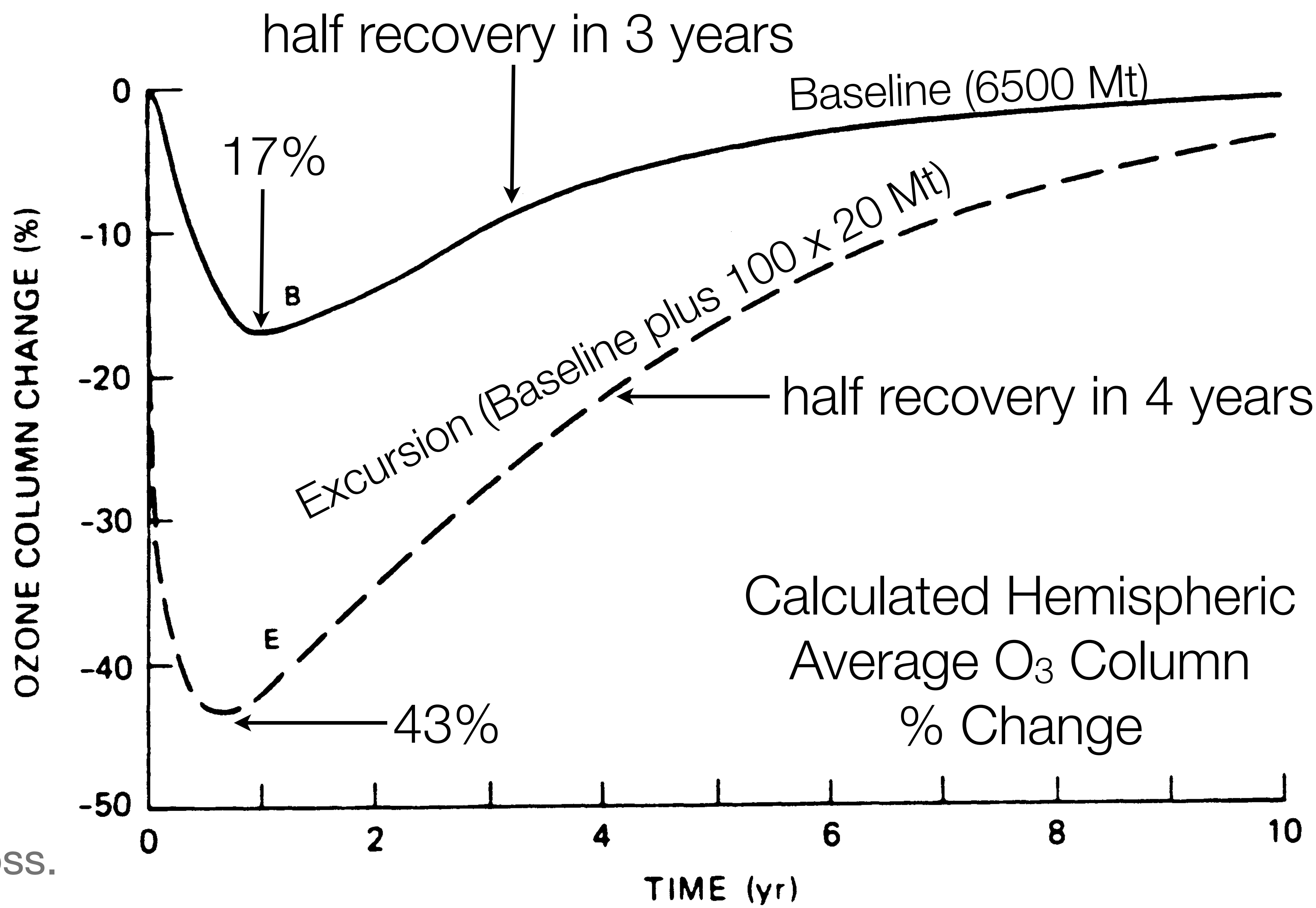
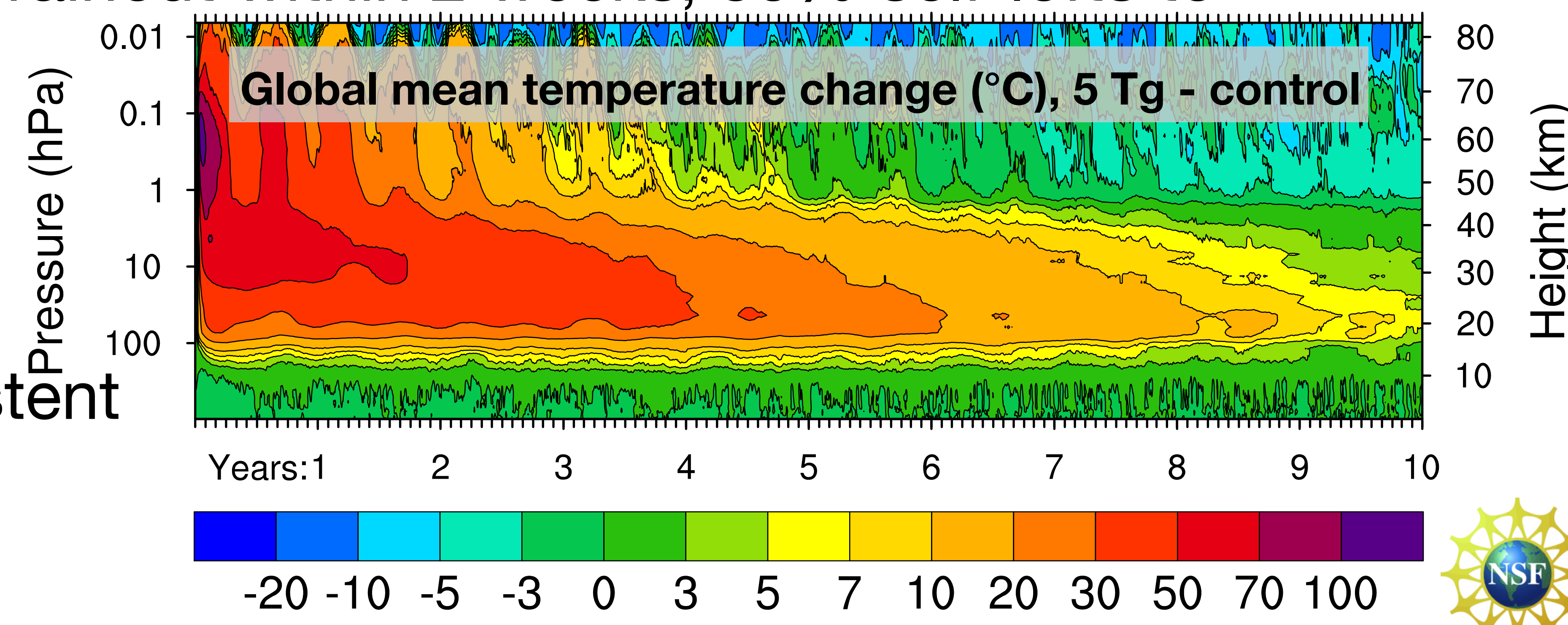
National Research Council, 1985: *The Effects on the Atmosphere of a Major Nuclear Exchange*

- NRC's 1985 calculations were based on NO_x production by shock waves and fireballs lofted into the stratosphere from thermonuclear explosions in a full-scale US-USSR war.
- NO_x in the stratosphere catalyzes ozone loss.
- Models could not adequately represent the rise of smoke plumes at that time.



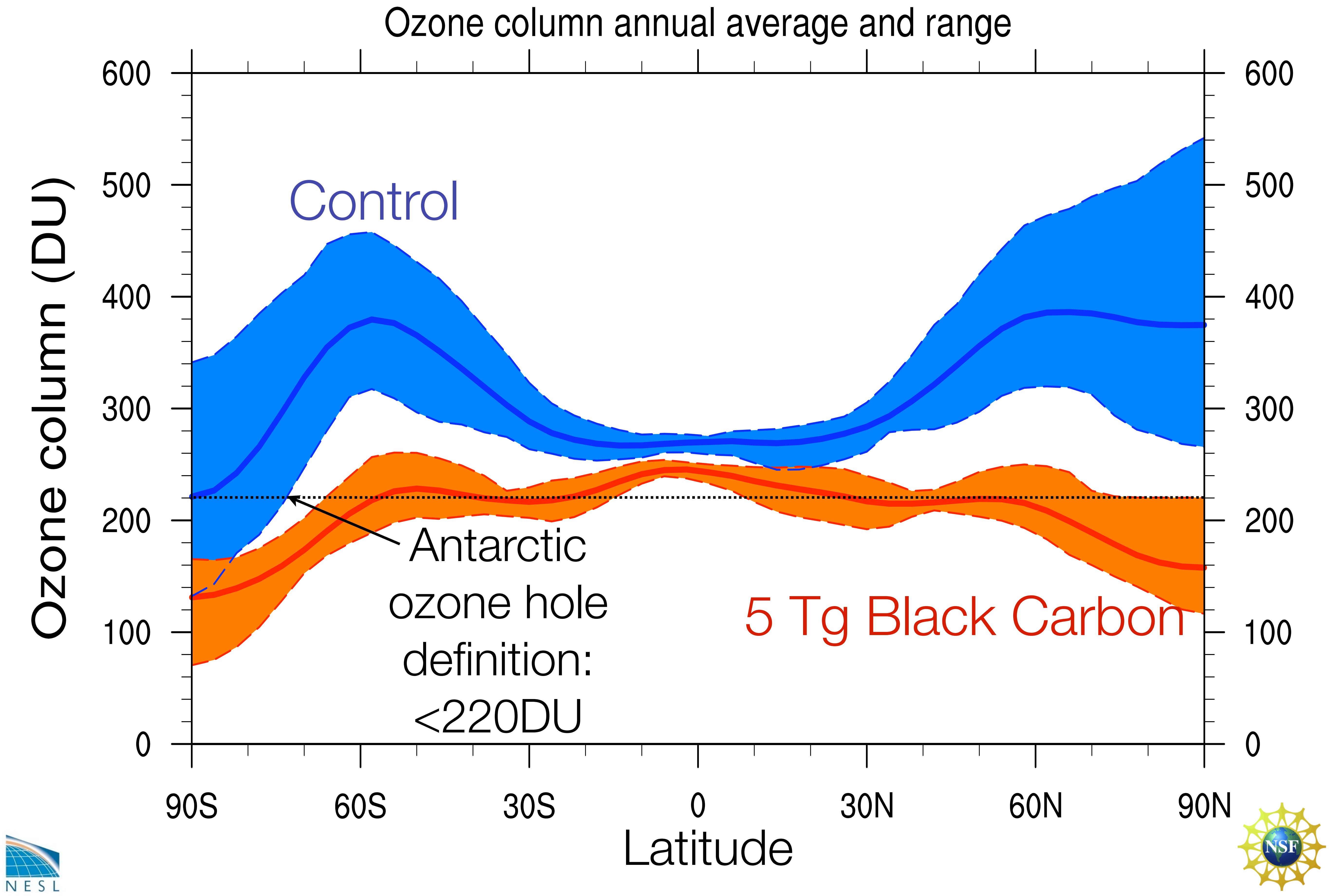
Massive global ozone loss predicted following regional nuclear conflict (Mills *et al.*, PNAS, 2008)

- 100 x 15-kt weapons detonated in the sub-tropics, 30°N, 70°E
- Urban firestorms would loft up to 5 Tg black carbon (BC) smoke into upper troposphere after initial rainout (Toon *et al.*, 2006)
- 10-year runs with WACCM3/CARMA at 4°x5°
  - 5 Tg of BC, 150-300 hPa in one column
  - control run without BC radiative feedback
- 20% removed by rainout within 2 weeks, 80% self-lofts to stratosphere
- BC absorbs sunlight, heating the stratosphere by 30-100K, consistent with Robock et al. (ACP, 2007)

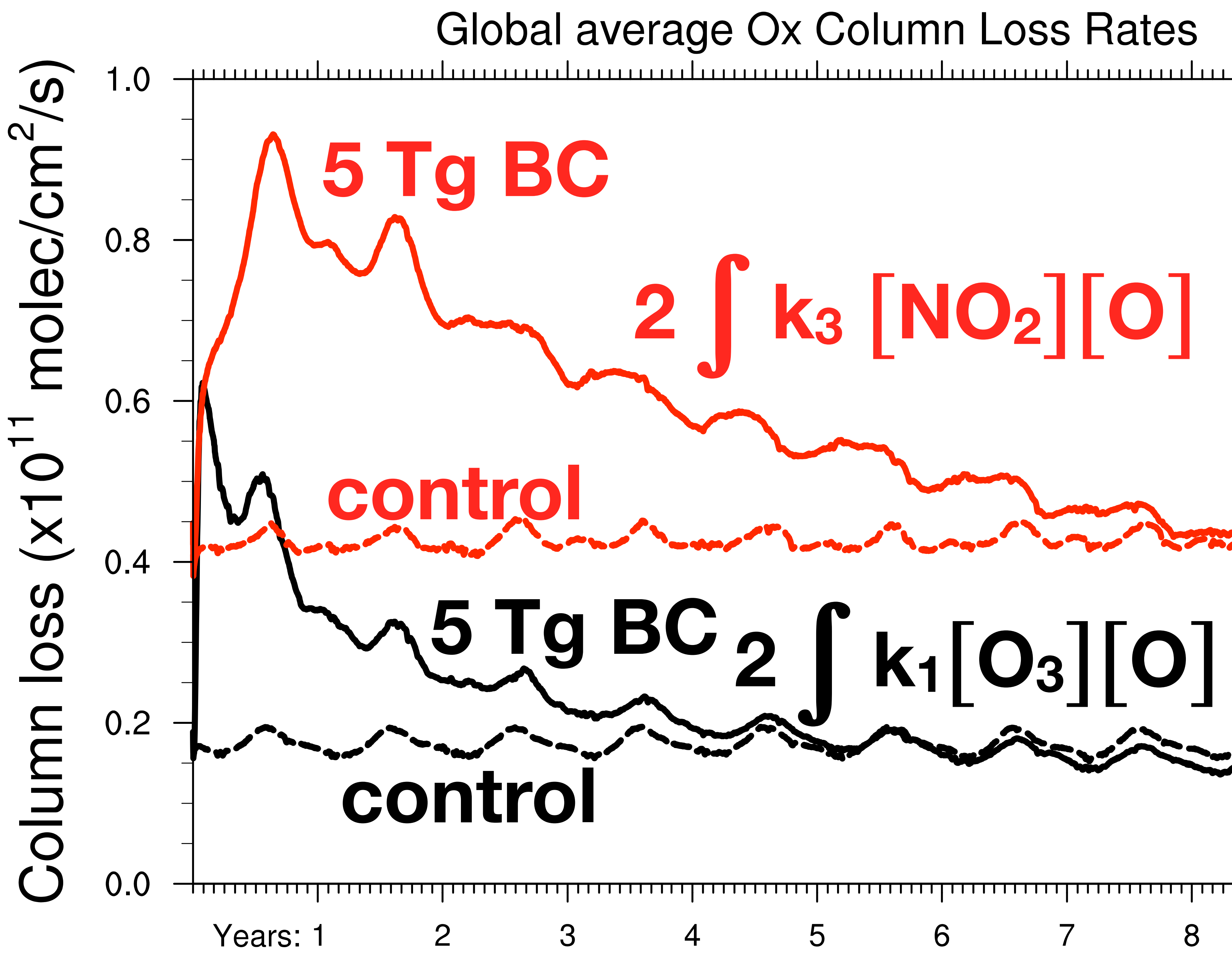


NESL

WACCM Whole Atmosphere Community Climate Model



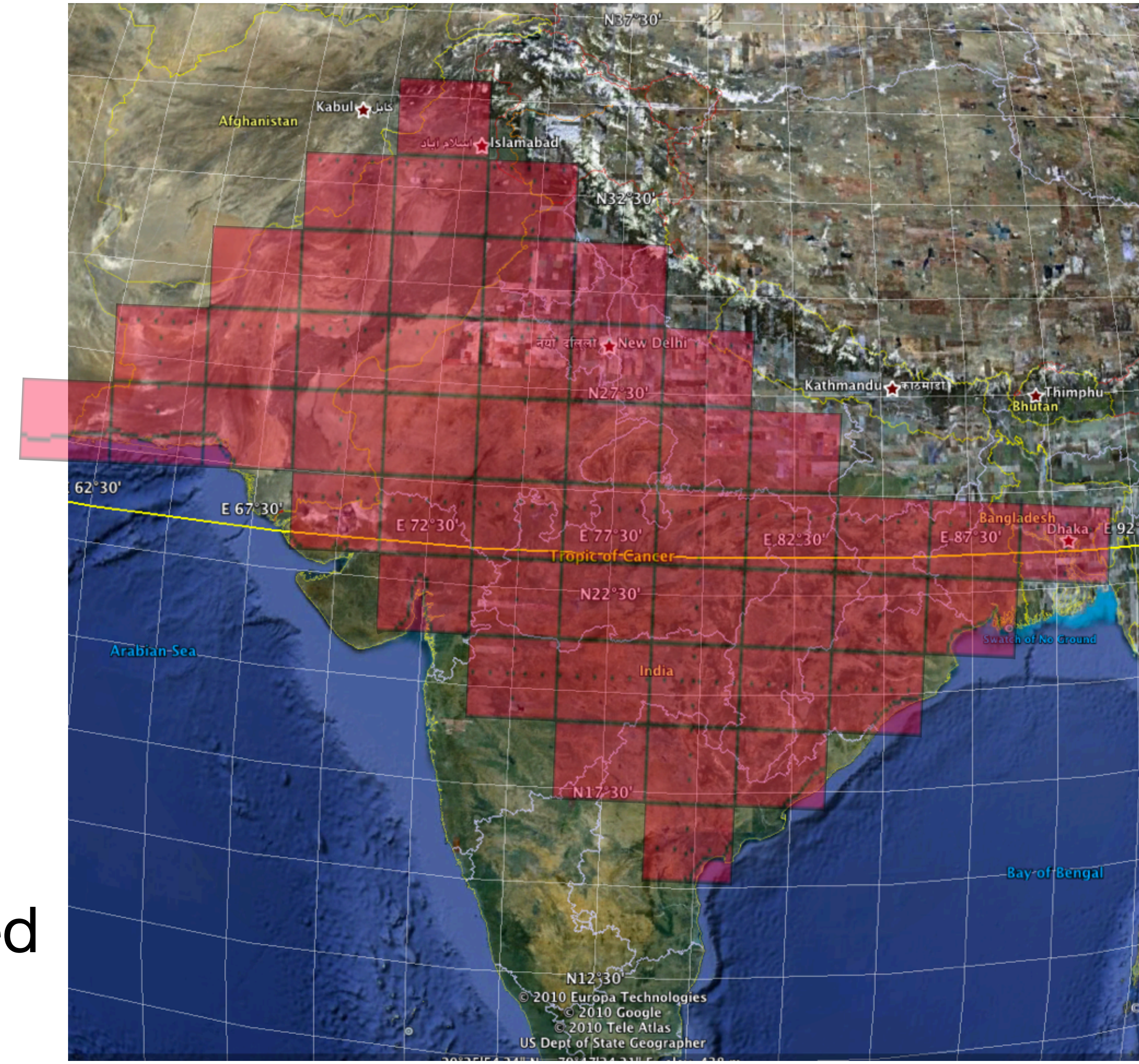
Ozone Loss Mechanisms



1. smoke rises to the top of the stratosphere producing stronger and longer-lasting heating
2. two temperature-sensitive ozone loss reactions accelerate
3. the rise of the smoke plume perturbs N_2O, which leads to enhanced NO_x production
4. radiative effects reduce the stratospheric circulation, so smoke and NOx stays in the stratosphere longer

New Regional Nuclear War Simulation

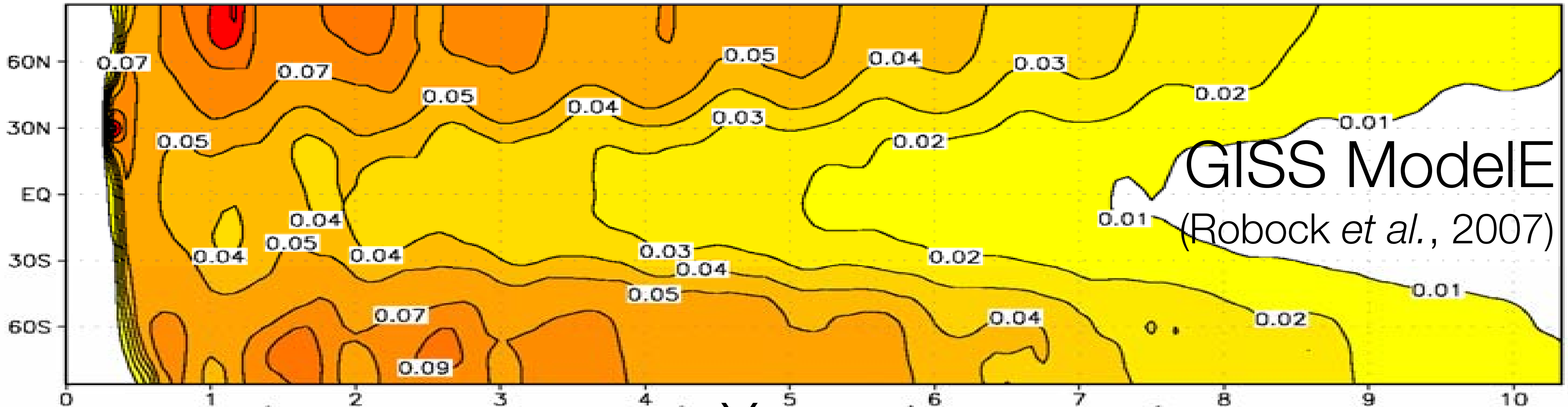
- CESM1/WACCM4-CARMA: coupled to full ocean, land, sea ice and land ice models
- 1.9° lat x 2.5° lon resolution
- BC initialized in 50 columns on Jan 1, 2013, 150-300 hPa, uniform mmr
- Wet and dry deposition passed to surface models
- 10-year ensembles: 3 experiment, 3 control runs based on CMIP5 RCP4.5

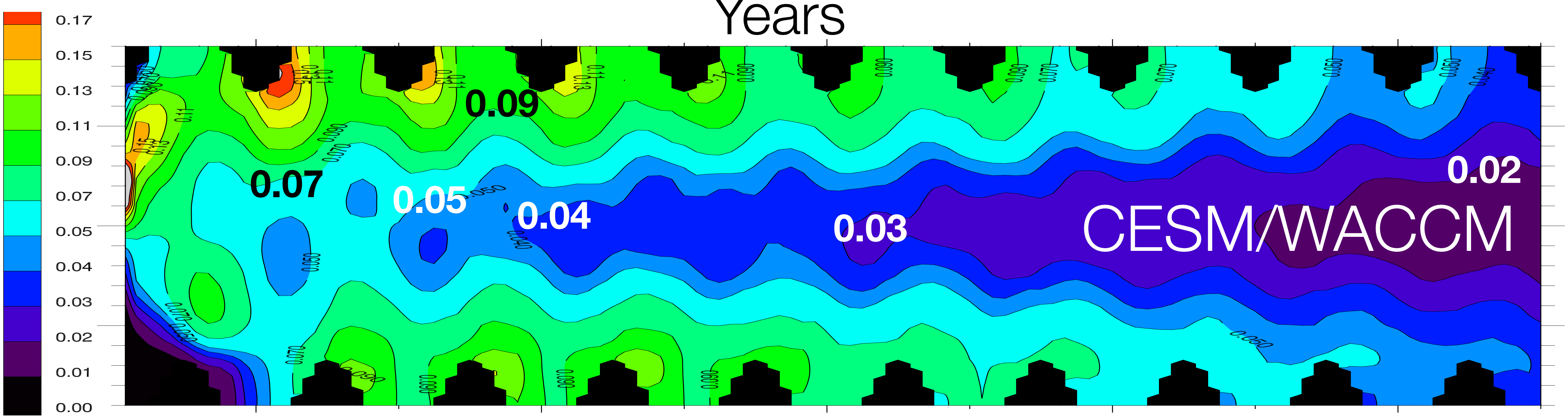


CESM-CARMA model setup

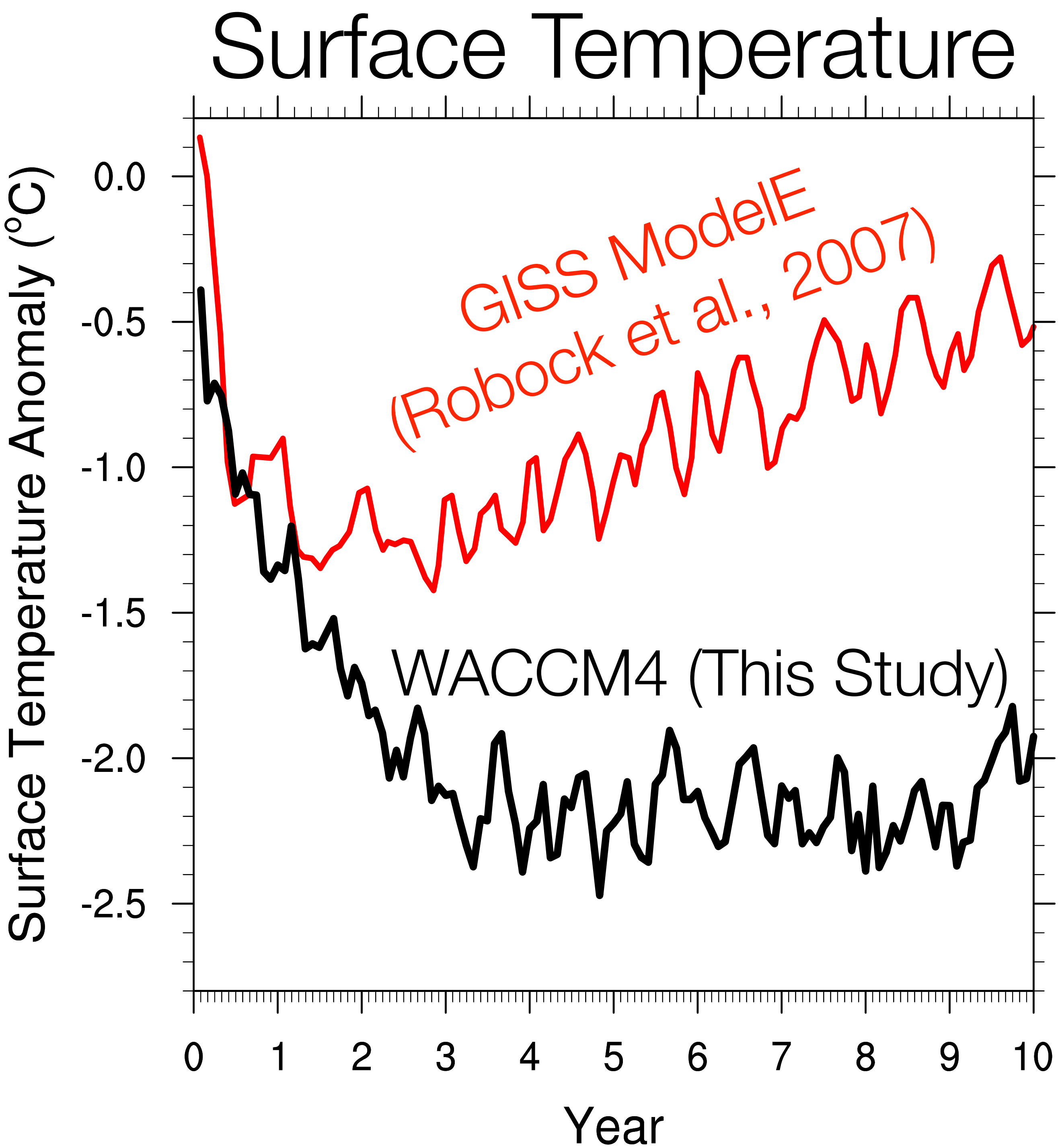
- CARMA3.0 (Bardeen) is joining the CAM developer trunk this month (Feb 2012)
- science model bc_strat (Mills):
  - single 0.1μm bin
  - mass added to hydrophobic black carbon (BCPHO) in CAMRT
- Building CESM-CARMA:
  - create_newcase -compset BRCP45WCN ...
  - edit env_conf.xml
  - add ” –carma <model>” to the CAM_CONFIG_OPTS tag: <entry id="CAM_CONFIG_OPTS" value=”...-carma bc_strat" />
- Run 3 ensemble members by either:
  - varying ICs using CMIP5 ensemble of ICs for Jan 1, 2013
  - creating new realizations by offsetting atm and ocean by 1 day

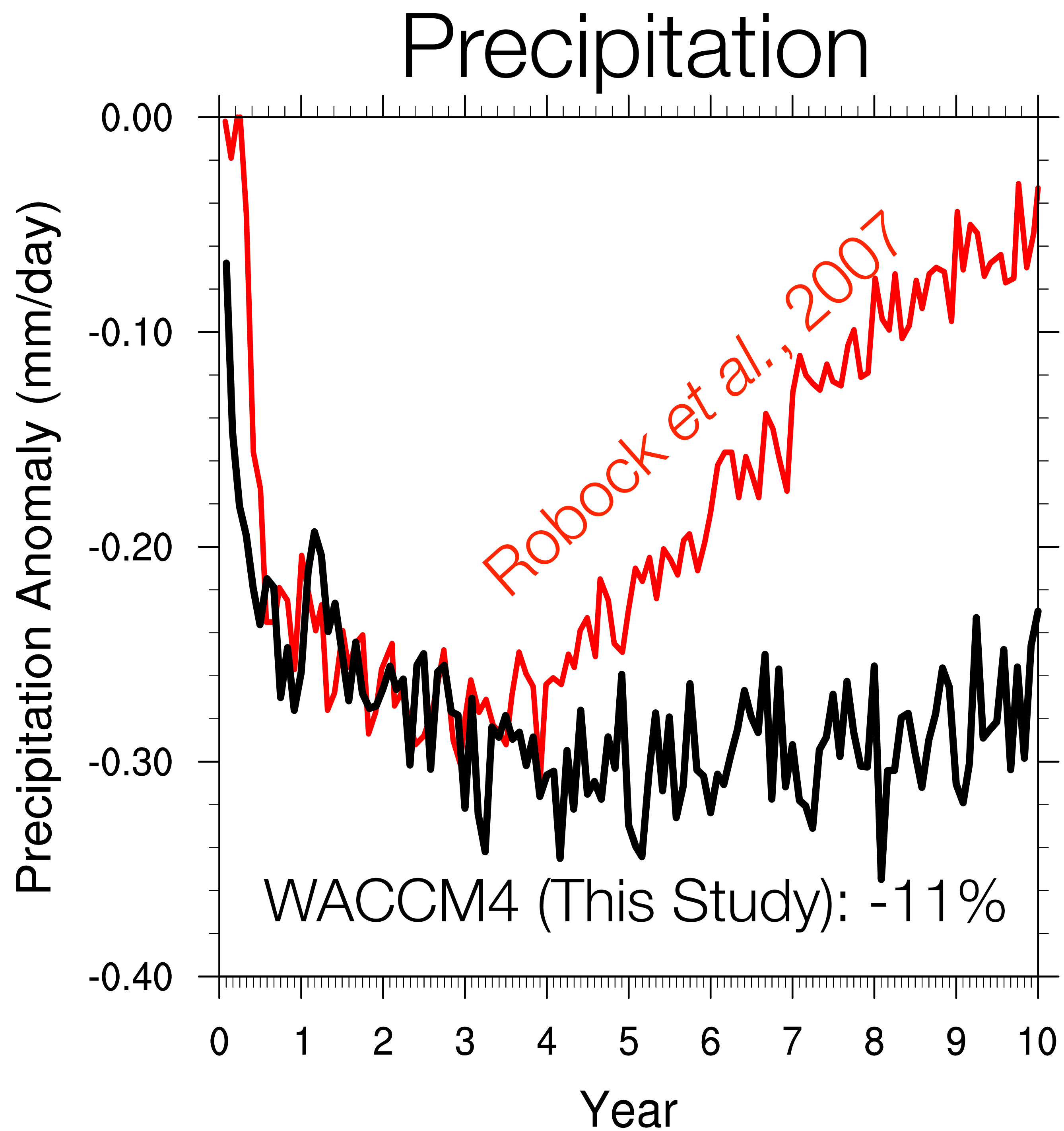
Column-integrated optical depths





Globally Averaged Anomalies





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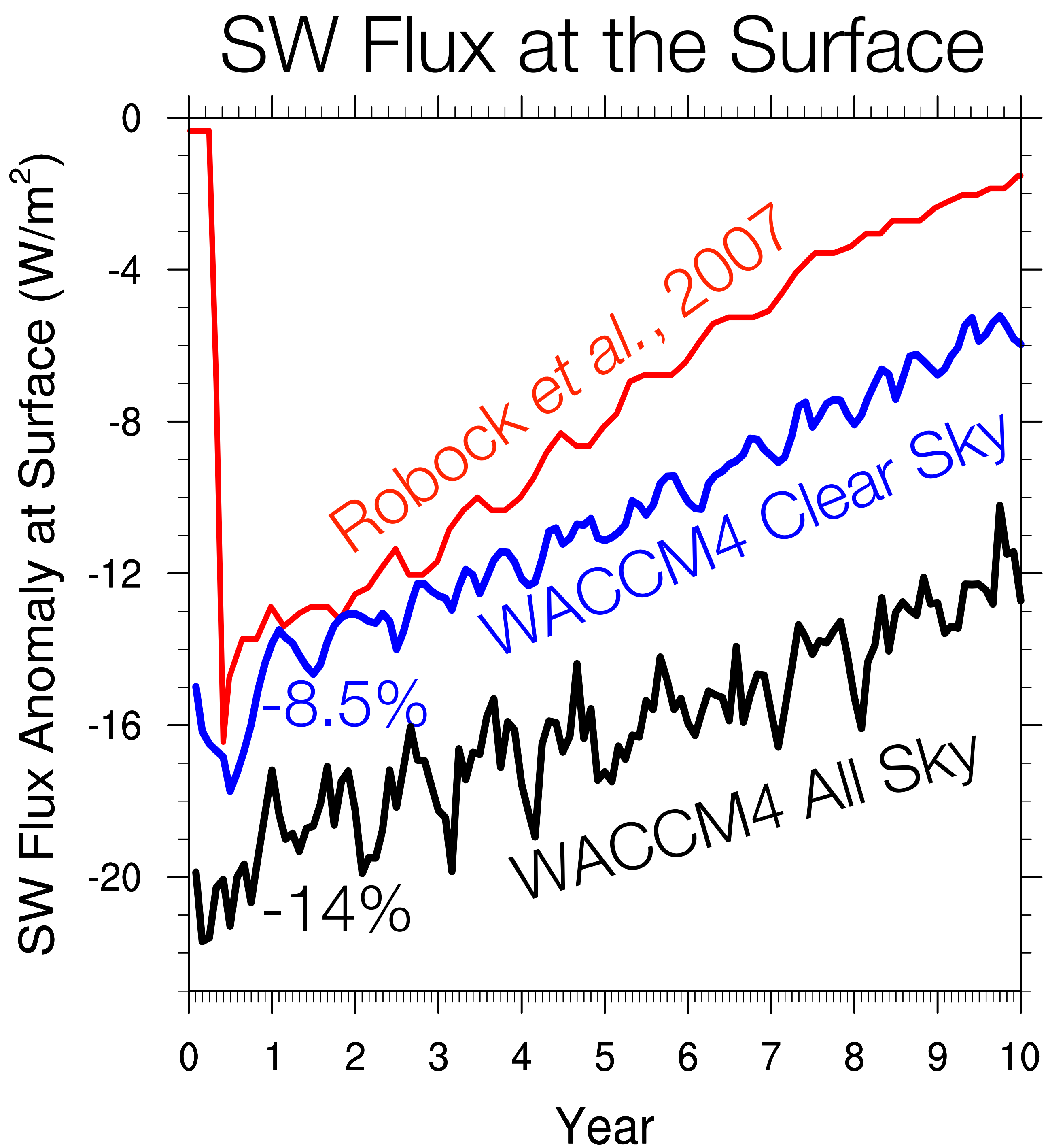
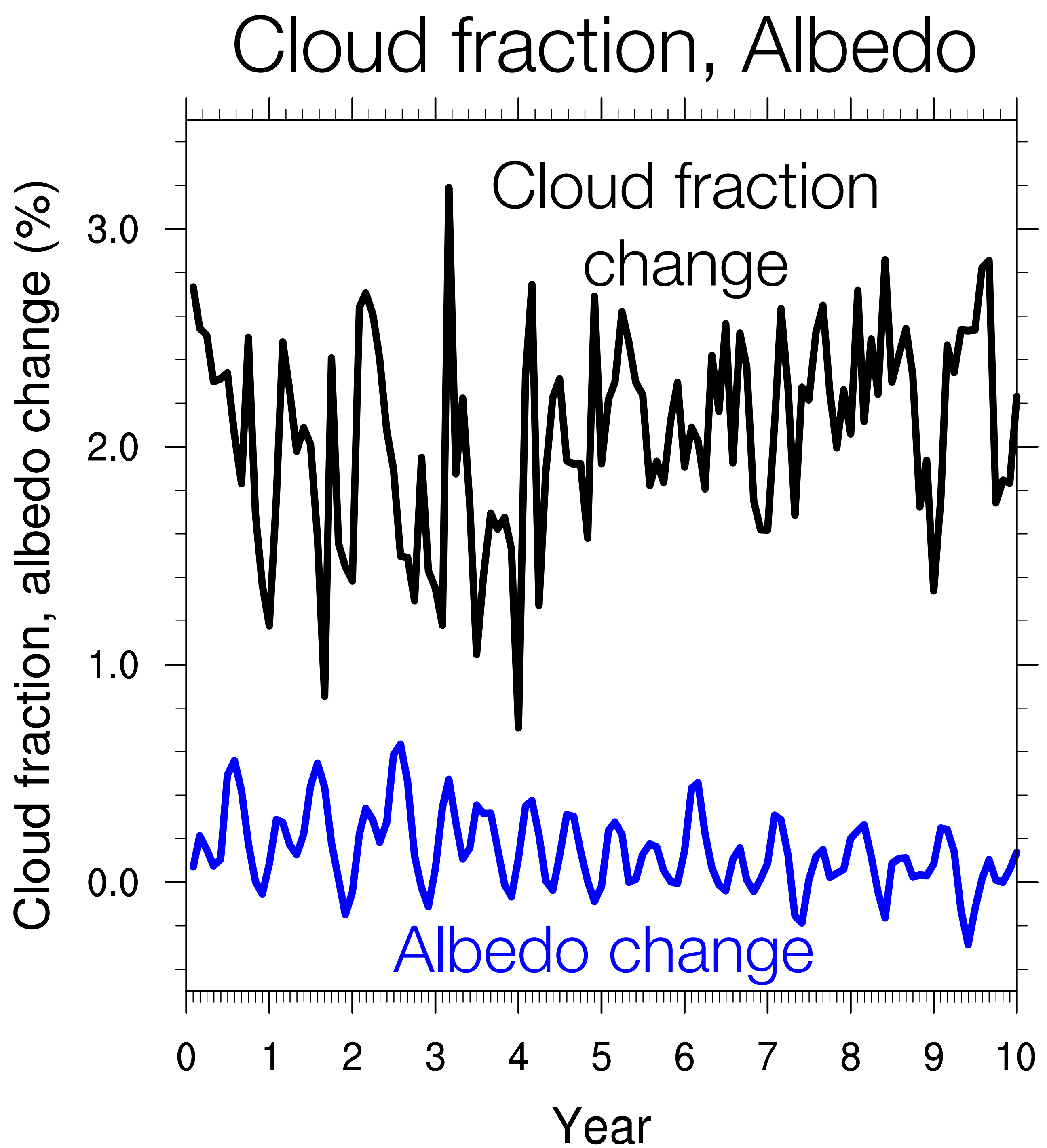
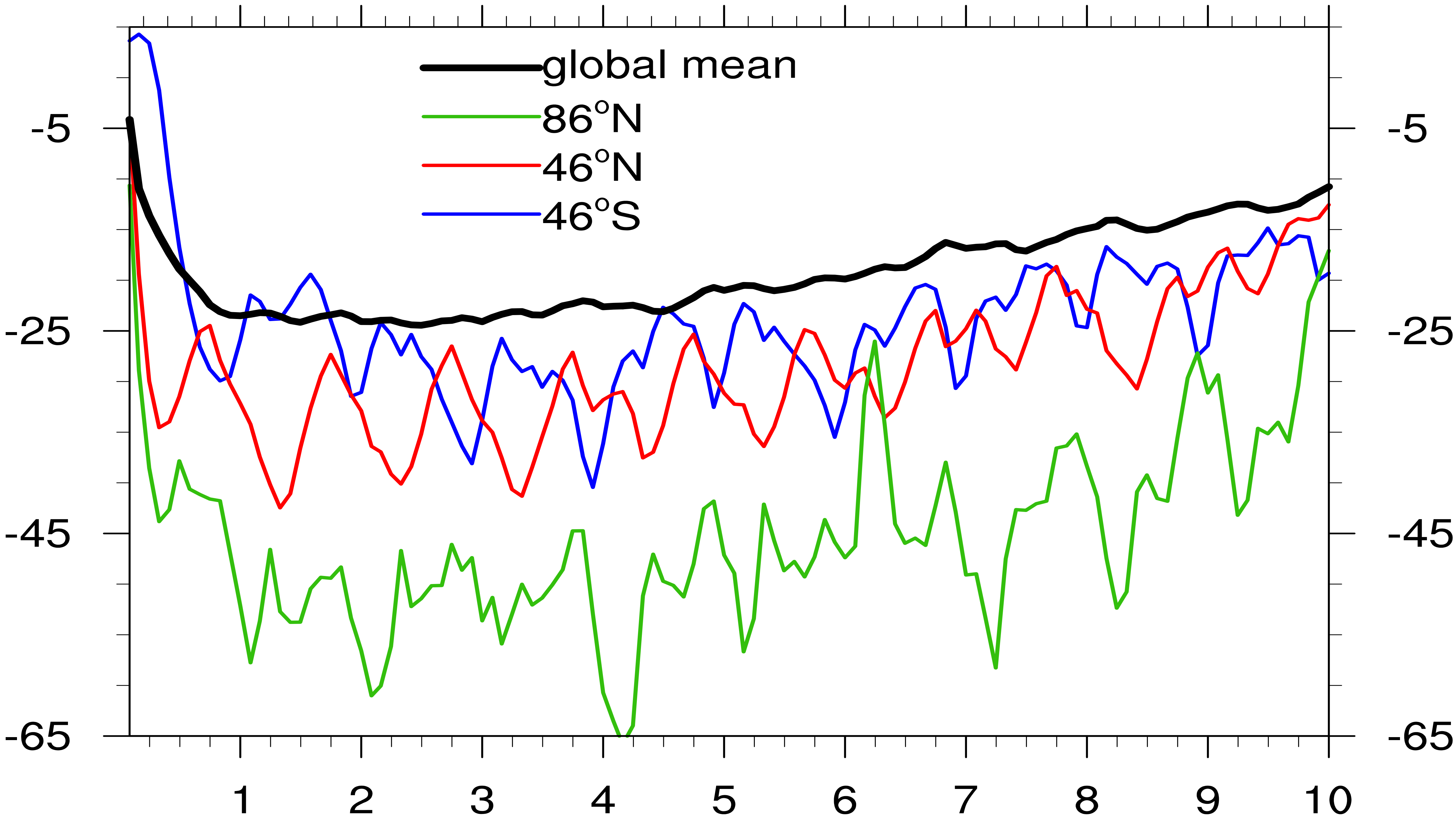
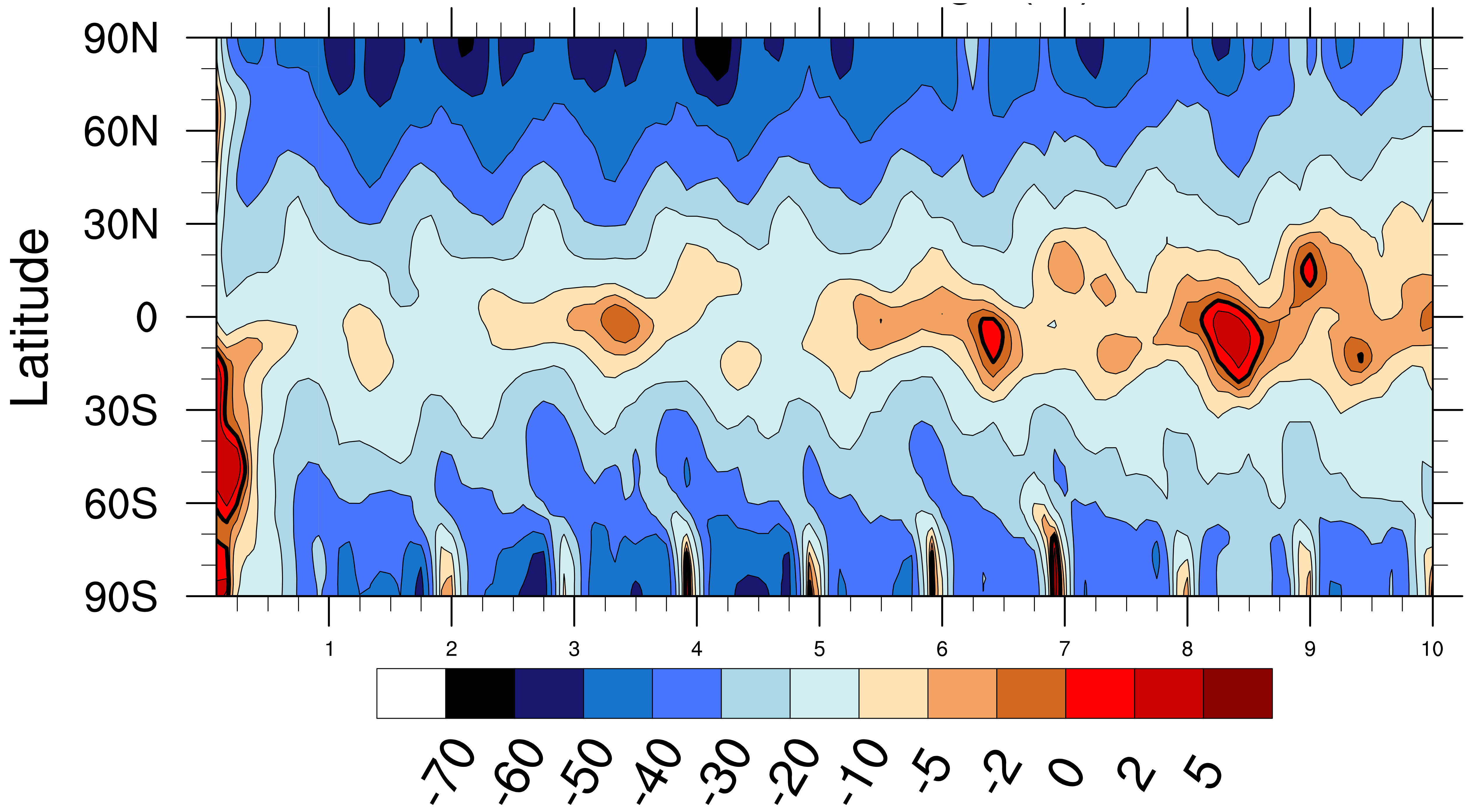




Column ozone loss (%)



Column ozone loss (%)



UV Index

From *Global Solar UV Index: A Practical Guide*, WHO, 2002.

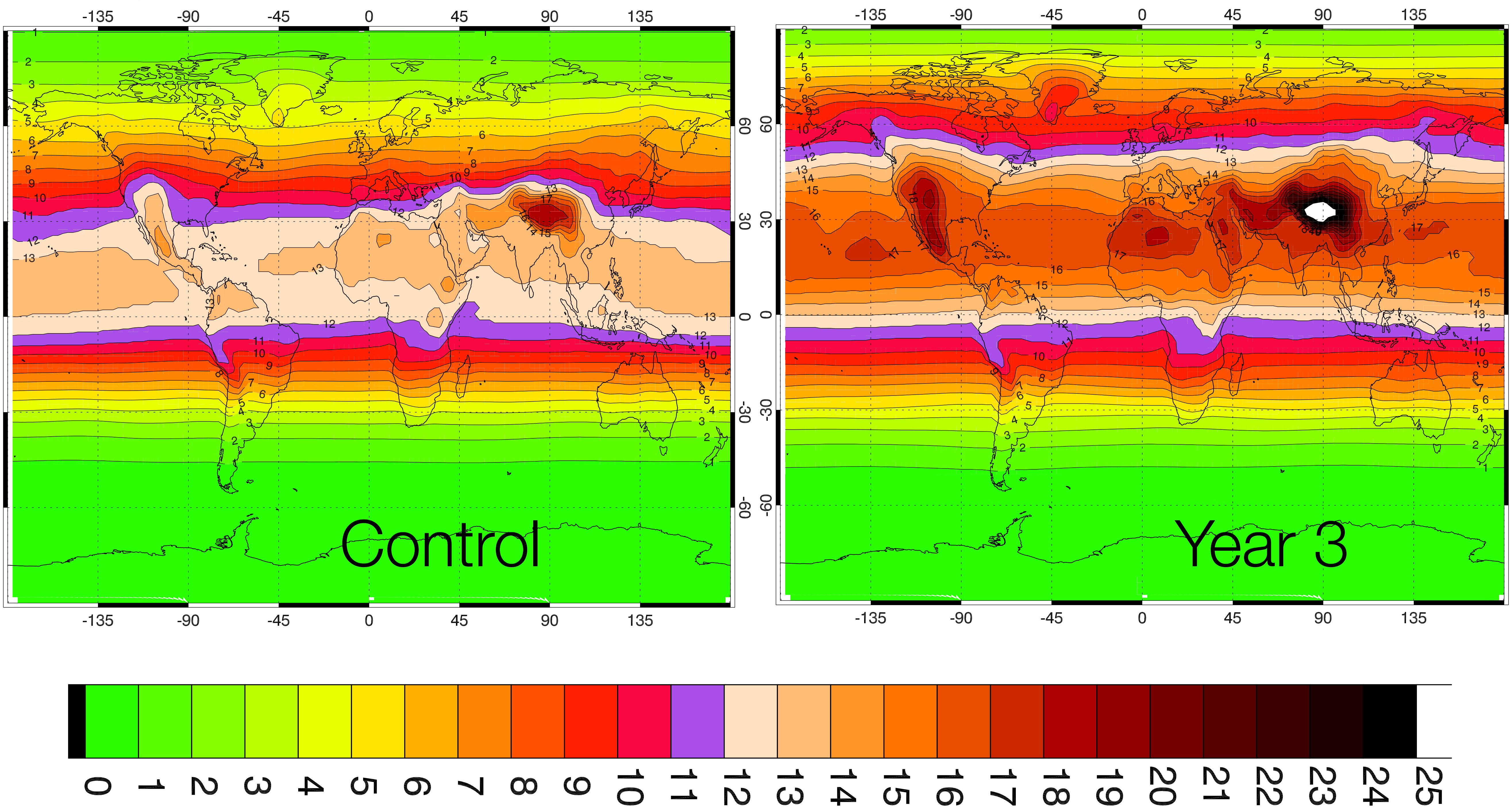
The Global Solar UVI is formulated using the International Commission on Illumination (CIE) reference action spectrum for UV-induced erythema on the human skin. It is a measure of the UV radiation that is relevant to and defined for a horizontal surface. The UVI is a unitless quantity defined by the formula:

$$I_{UV} = k_{er} \cdot \int_{250\,\mathrm{nm}}^{400\,\mathrm{nm}} E_{\lambda} \cdot s_{er}(\lambda)\,d\lambda$$

UV INDEX 1, 2	UV INDEX 3, 4, 5, 6, 7	UV INDEX 8, 9, 10, 11+
NO PROTECTION REQUIRED	**PROTECTION REQUIRED**	**EXTRA PROTECTION**
You can safely stay outside!	Seek shade during midday hours! Slip on a shirt, slop on sunscreen and slap on a hat!	Avoid being outside during midday hours! Make sure you seek shade! Shirt, sunscreen and hat are a must!

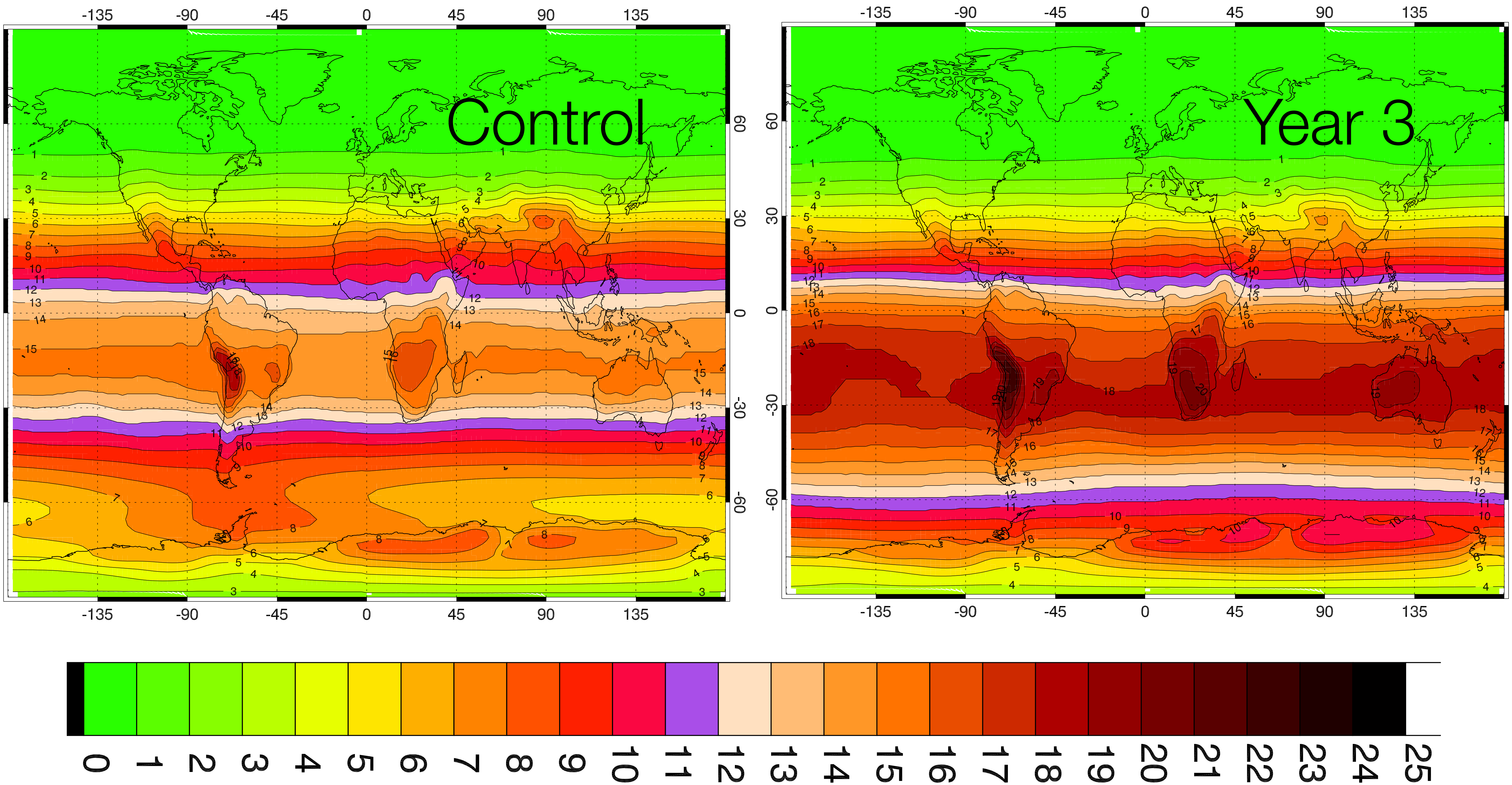
UV Indices, June, including BC attenuation

noon, cloud-free conditions



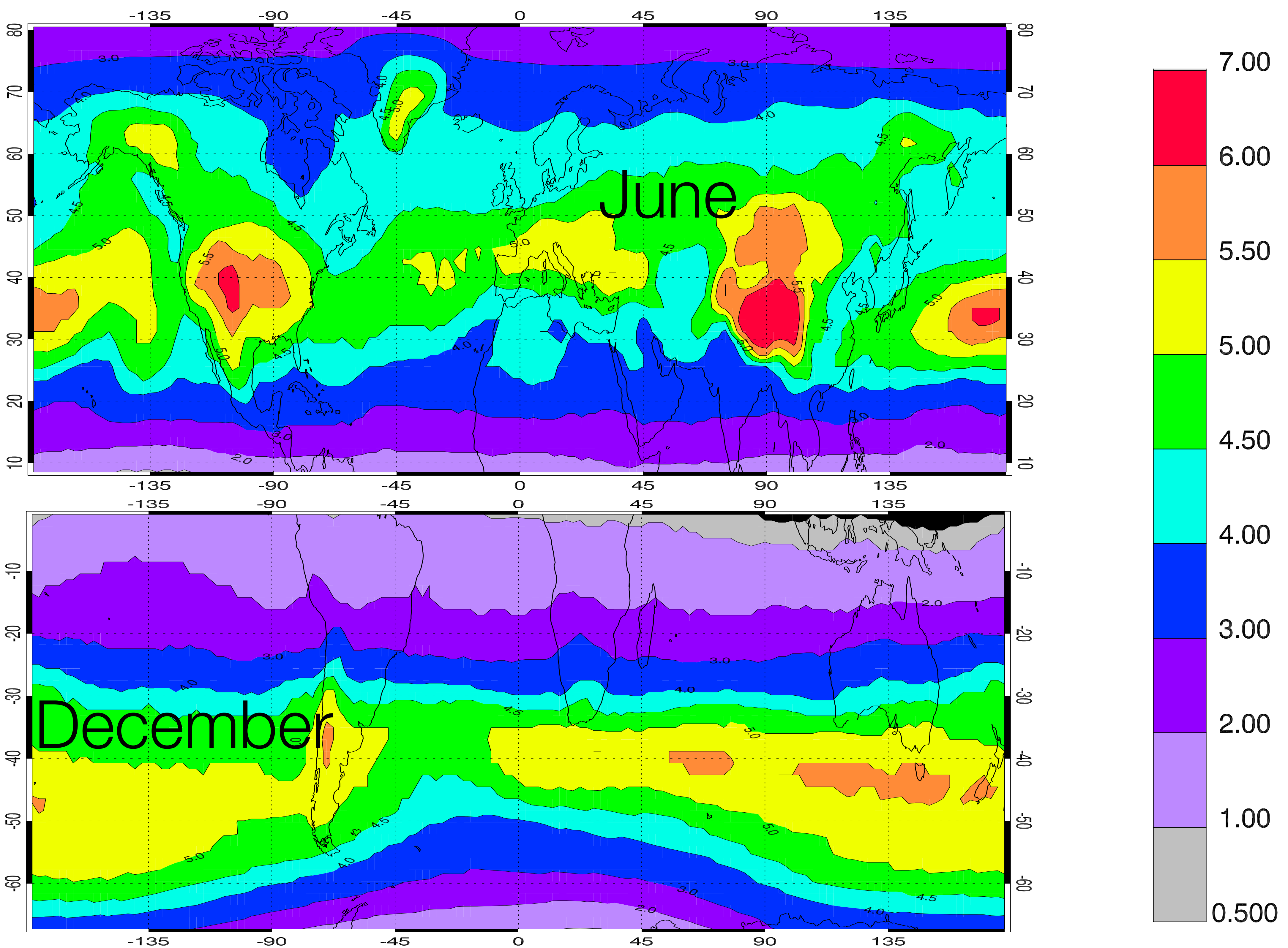
UV Indices, December, including BC attenuation

noon, cloud-free conditions

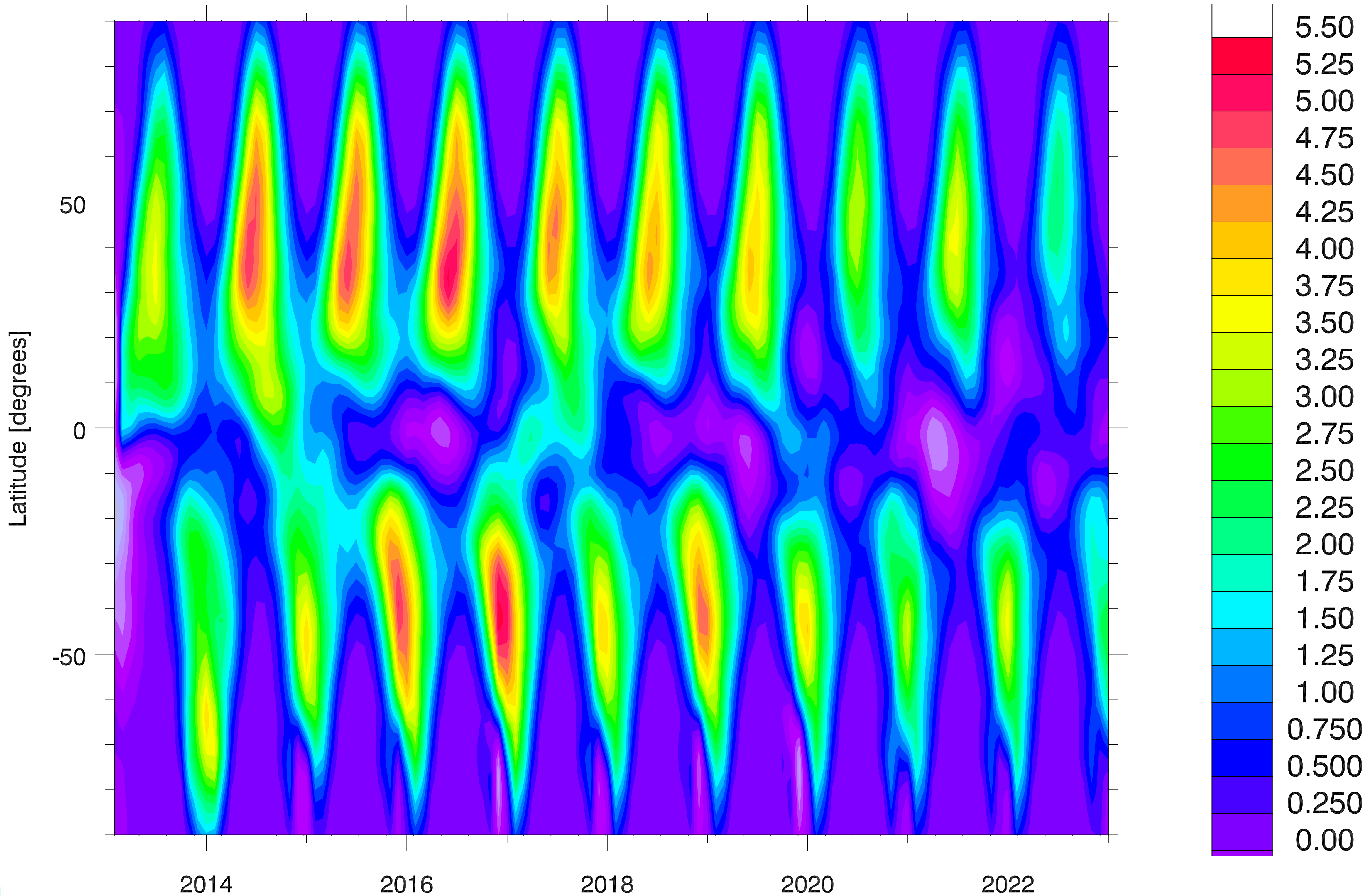


WACCM Whole Atmosphere Community Climate Model

UV Index changes, year 3



Zonal mean changes in UV Index over 10 years



Consequences of Severe Ozone Depletion

E. Pierazzo *et al*. (2010)

- Flora:
  - "recorded general effects of increased UV-B exposure include plant height reduction, decreased shoot mass, and reduction in foliage area (Caldwell *et al.*, 2003)."
  - "During extended increased UV-B exposure, not all DNA damage may be fully repaired; as a result, damage may accumulate over time and carry-over to following plant generations, affecting the genetic stability of plants by increasing the frequency of mutations (e.g., Walbot, 1999)."
  - "changes in the susceptibility of plants to attack by insects and pathogens and changes in competitive balance of plants and nutrient cycling (e.g., Mpoloka, 2008)."
  - "may also affect important soil surface processes, such as nitrogen fixation by cyanobacteria (Solheim et al., 2002)."
- Sea life:
  - "Over 30% of the world's animal protein for human consumption comes from the sea, mostly in the form of finfish, shellfish and seaweed, and particularly in the developing countries, this percentage can be significantly higher (Hader et al., 1995)."
  - "Increased UV-B levels associated with Antarctic ozone hole levels have been shown to inhibit phytophankton activity in the upper ocean layer (Smith et al., 1992)."
  - "Hader et al. (1995) estimated that a 16% ozone depletion could result in a 5% loss in phytoplankton, which, based on estimates of Nixon (1988), could cause a reduction in fishery and aquaculture yields of about 7% and a loss of about 7 million tons of fish per year."
  - "Solar UV-B radiation has also been found to cause damage to early developmental stages of fish, shrimp, crab and other animals. The most severe effects are decreased reproductive capacity and impaired larval development (USEPA, 1987)."

Conclusions

- A regional nuclear exchange of 100 15-kt weapons (<0.1% of the yield of nuclear weapons that currently exist) would produce unprecedented low ozone columns over populated areas in conjunction with the coldest surface temperatures experienced in the last 1000 years, and would likely result in a global nuclear famine.
- Global average column losses exceeding 20% would persist for at least 3.5 years, with mid-latitude losses of 30-40%, and polar losses up to 70%.
- The primary chemical loss is from NO_x. Temperatures increase the rate of reaction in the NO_x-catalyzed cycle, and dynamical disruptions redistribute N_2O, the source of stratospheric NO_x.
- Previous studies, done in the 1980s, showing smaller ozone losses for much larger nuclear exchanges did not adequately represent the rise of the smoke plume into the stratosphere and consequent temperature increase.
- Massive increases in UV would reach the surface over 10 years, with little attenuation from the black carbon.