The North Atlantic Climate Response to Stratospheric Sulfate Geoengineering

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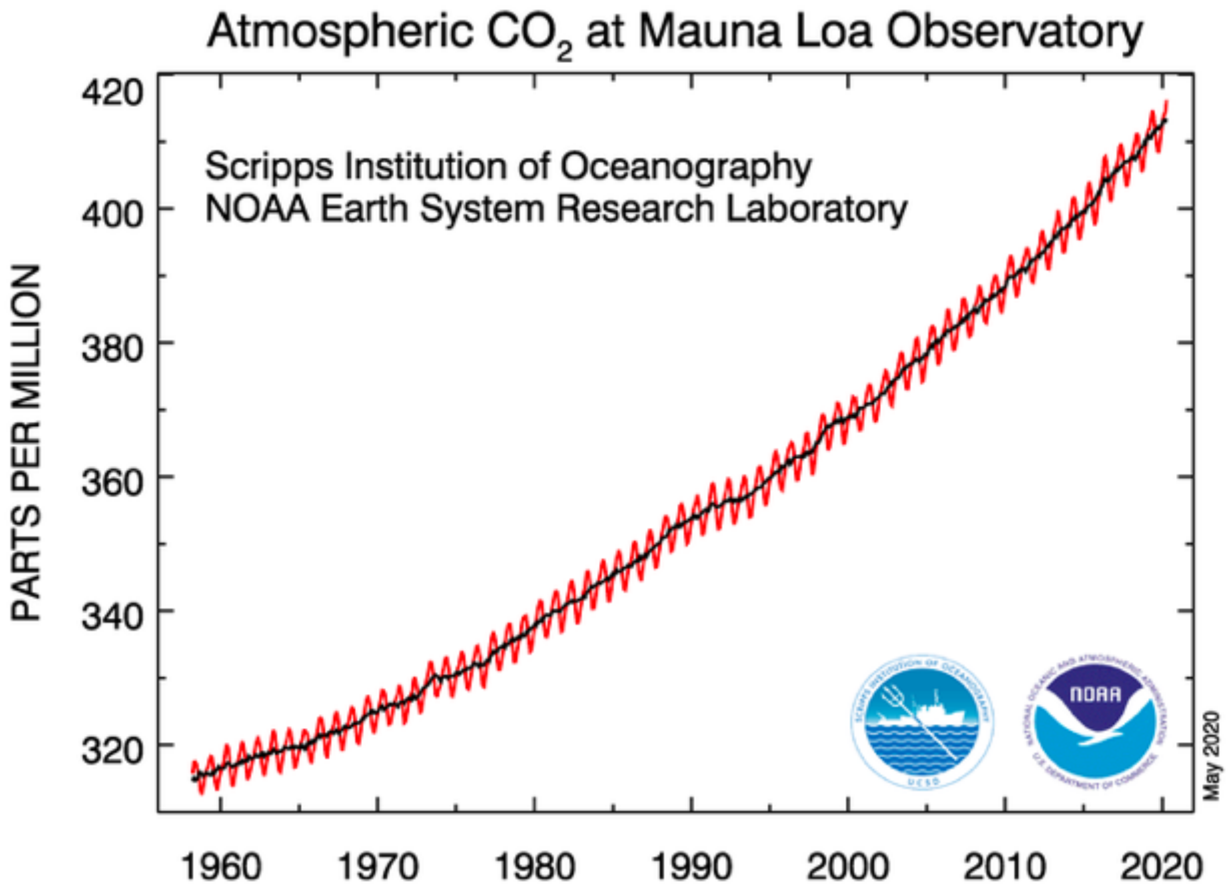
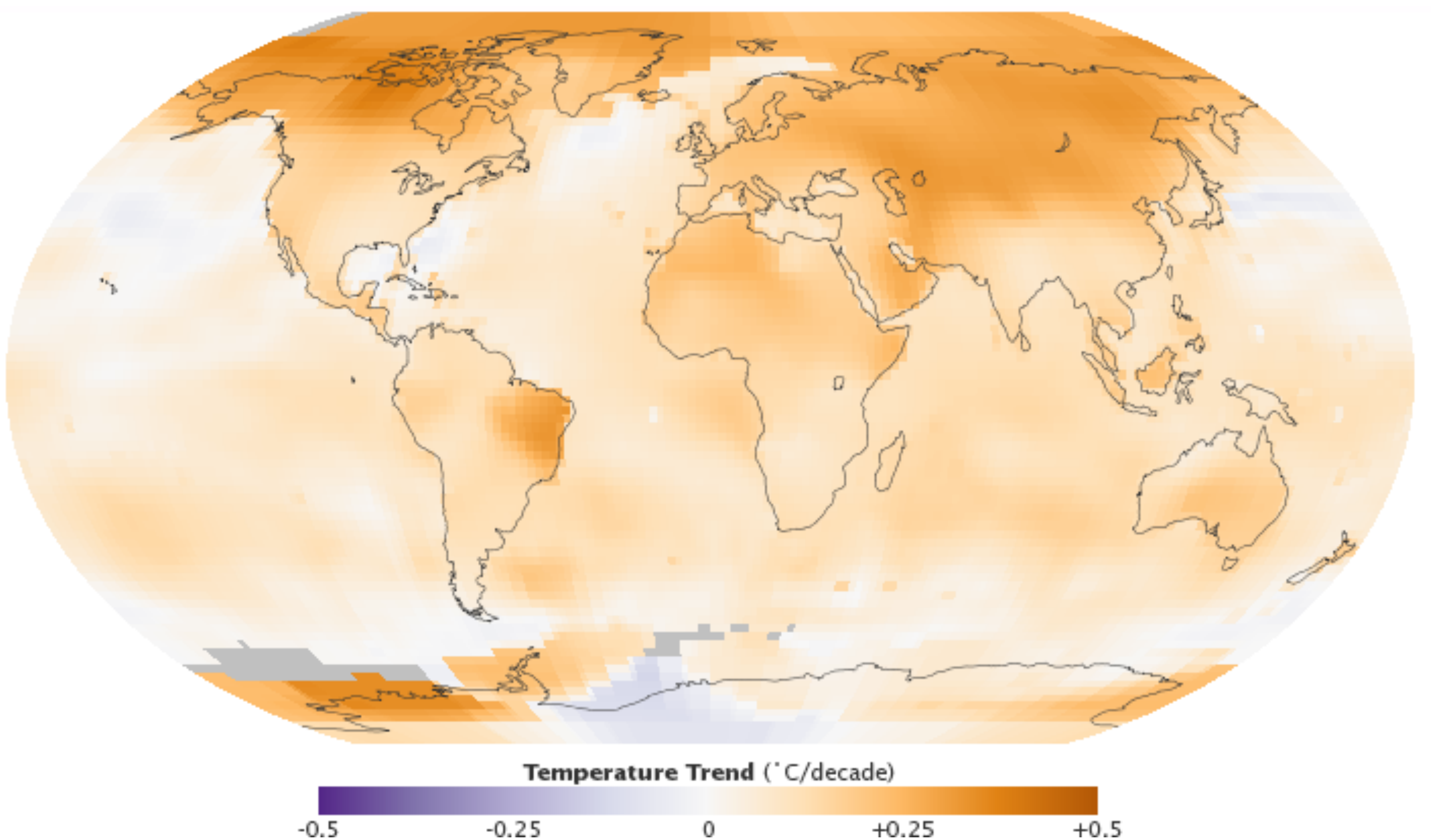
The "Keeling Curve"

Carbon dioxide has **increased about 45%** since preindustrial times . . .

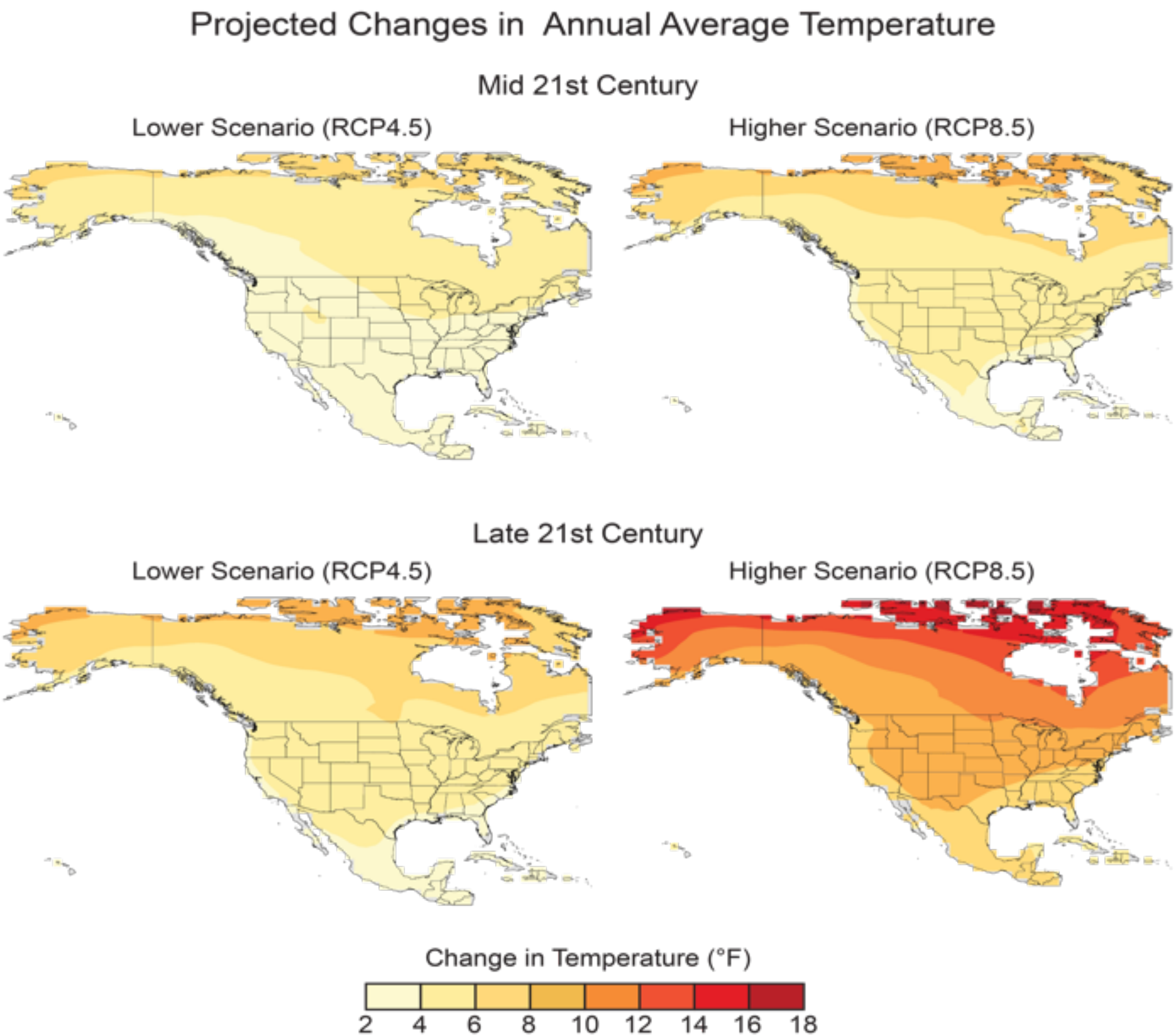


According to the law of conservation of energy, the trapped greenhouse energy must warm Earth

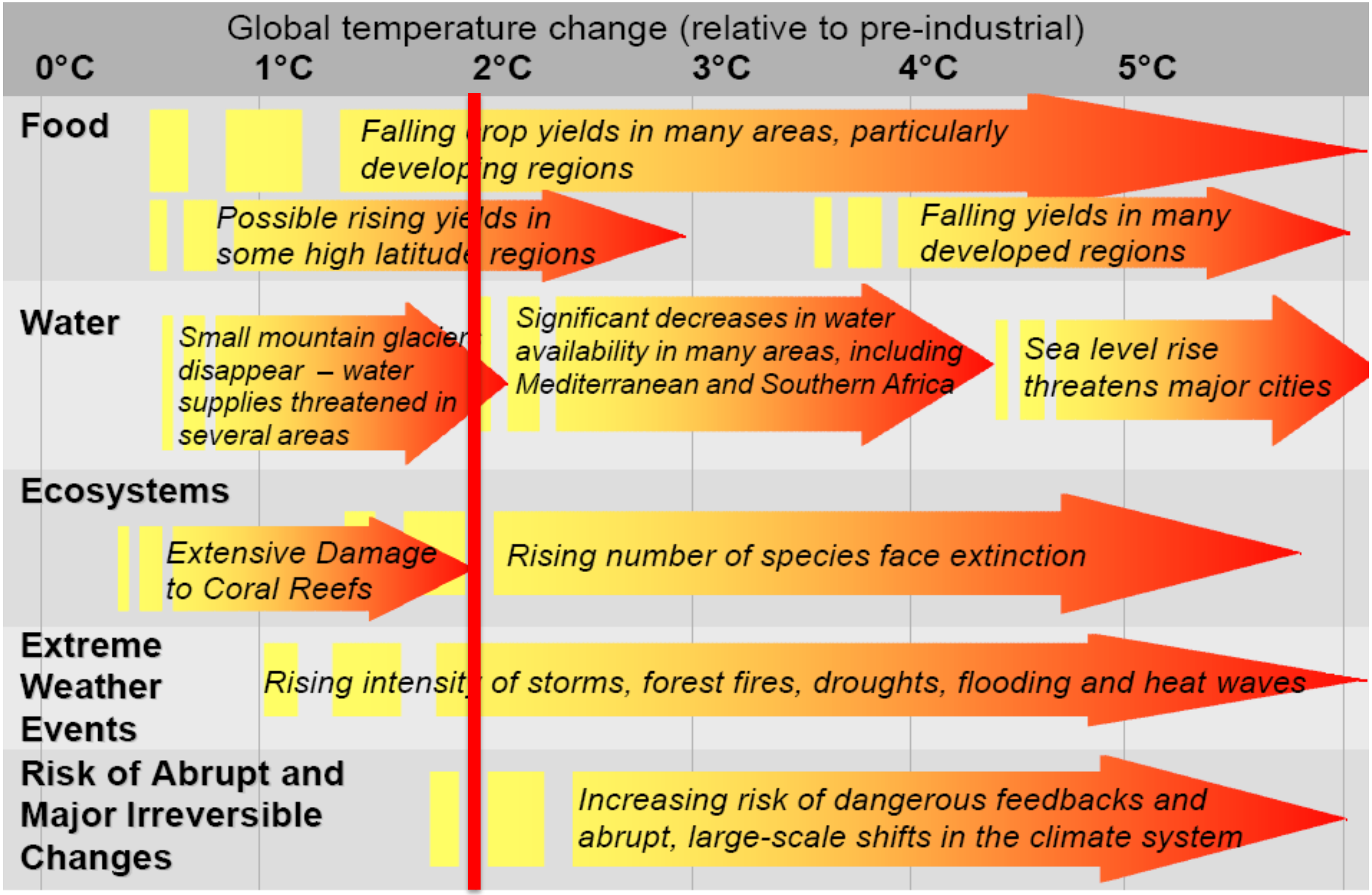
Observed trend in surface temperature since 1950



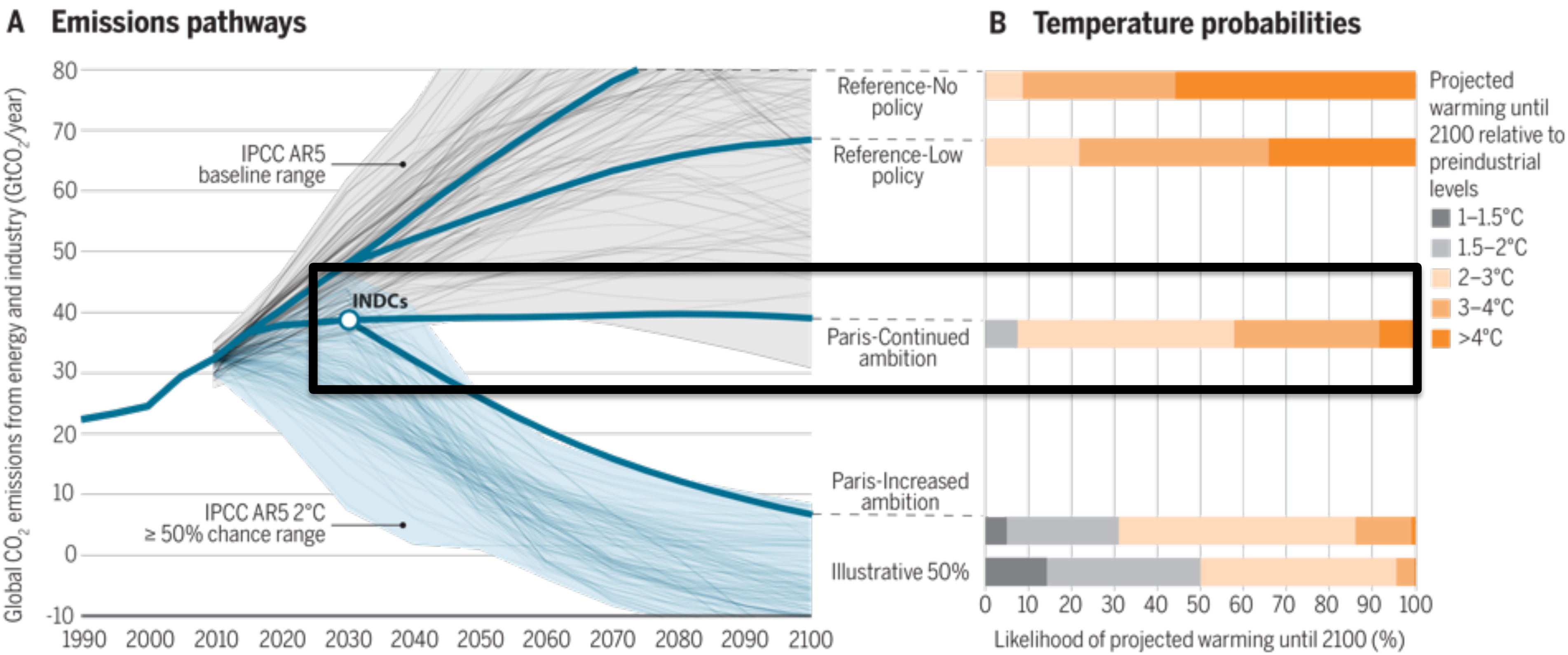
US National Climate Assessment



Projected Impacts of Climate Change

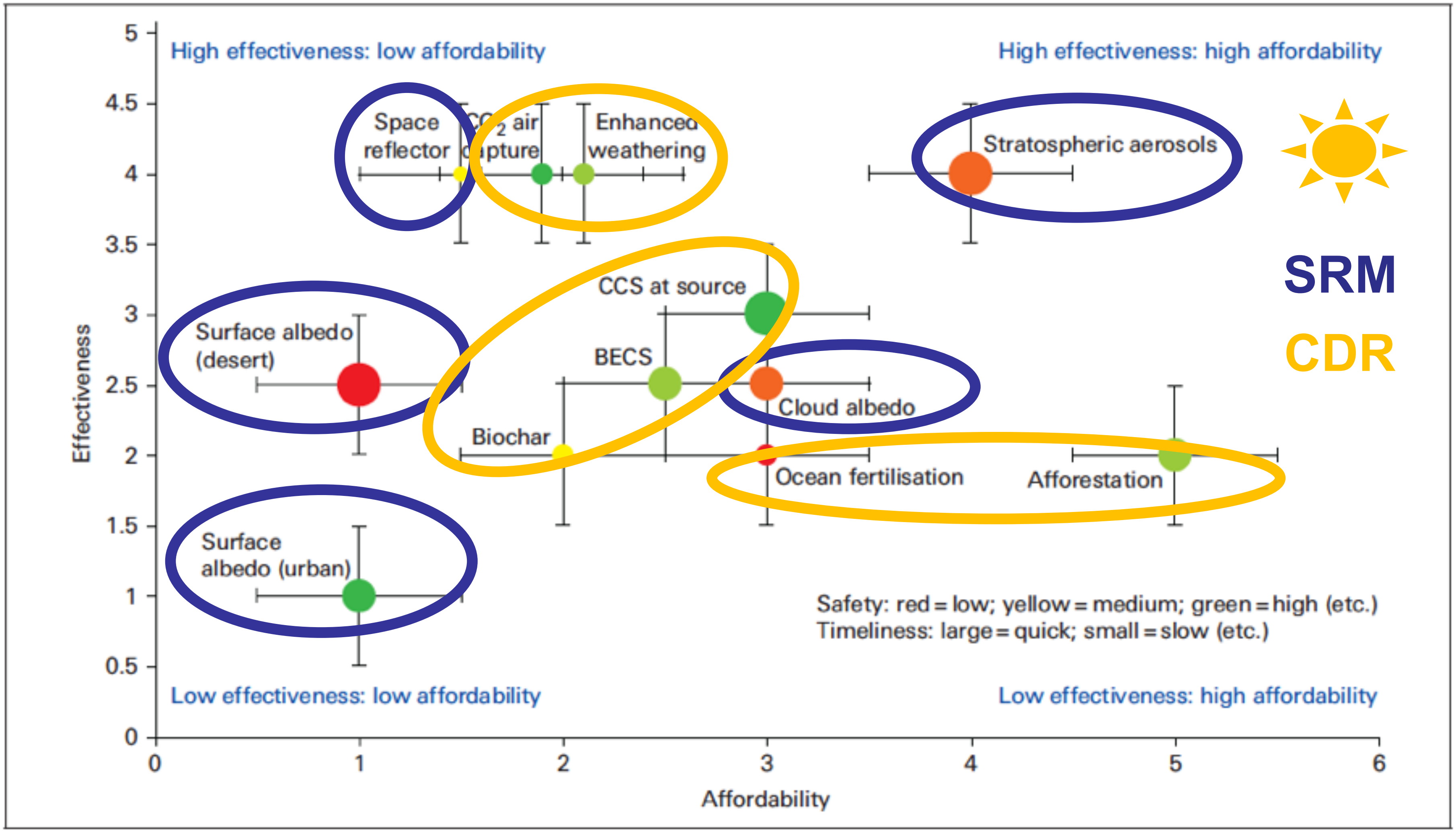


Global CO2 emissions and probabilistic temperature outcomes of government announcements associated with the lead up to the Paris climate conference



INDCs refer to Intended Nationally Determined Contributions which is the term used for the governments' announced actions in the lead up to Paris

Evaluation of Climate Intervention Techniques



Royal Meteorological Society Report (2009)

Our Objective

- Explore and understand the potential impacts of stratospheric aerosol geoengineering over the North Atlantic sector, including changes to weather and climate regimes, as well as impacts on sea ice, ocean and land.

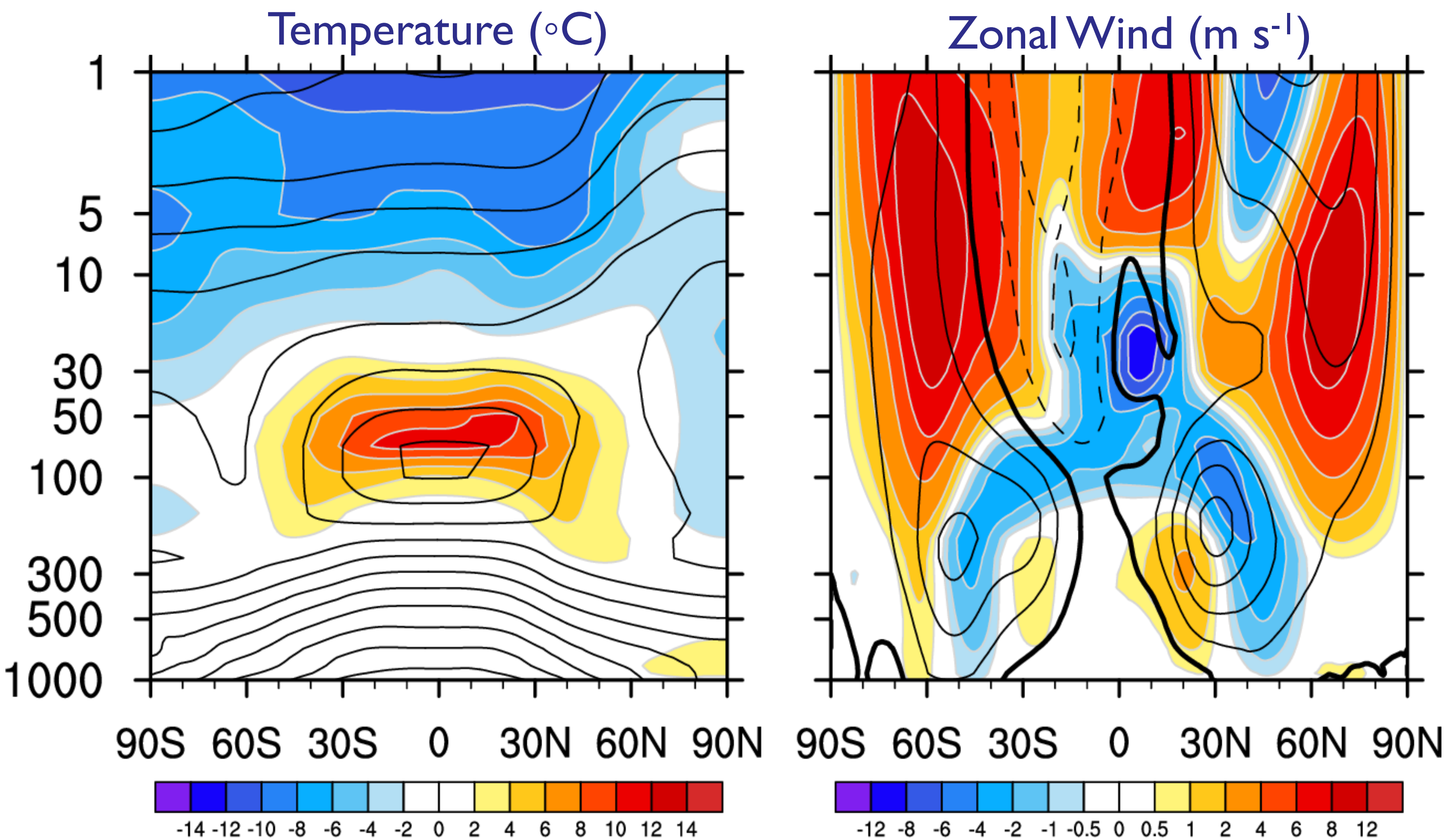
Primary Tool

NCAR NSF

- Stratospheric Aerosol Geoengineering Large Ensemble Project (GLENS)
  - Community Earth System Model with Whole Atmosphere Community Climate Model as its atmospheric component (CESMv1-WACCM; Mills et al. 2017)
  - Utilize feedback-control strategy optimizing annual injections of SO_2 at four different locations in stratosphere
  - Sulfur injections using the feedback-control algorithm were applied to each of 20 ensemble members separately and continued until 2099 (Tilmes et al. 2018)
  - **Climate Goals** – maintain global mean surface temperature, interhemispheric and equator-to-pole surface temperature gradients at 2020 values under RCP8.5
  - We illustrate impacts by differencing the geoengineered climate at the end of this century (2080-2099) from the present-day simulated climate (2010-2029)

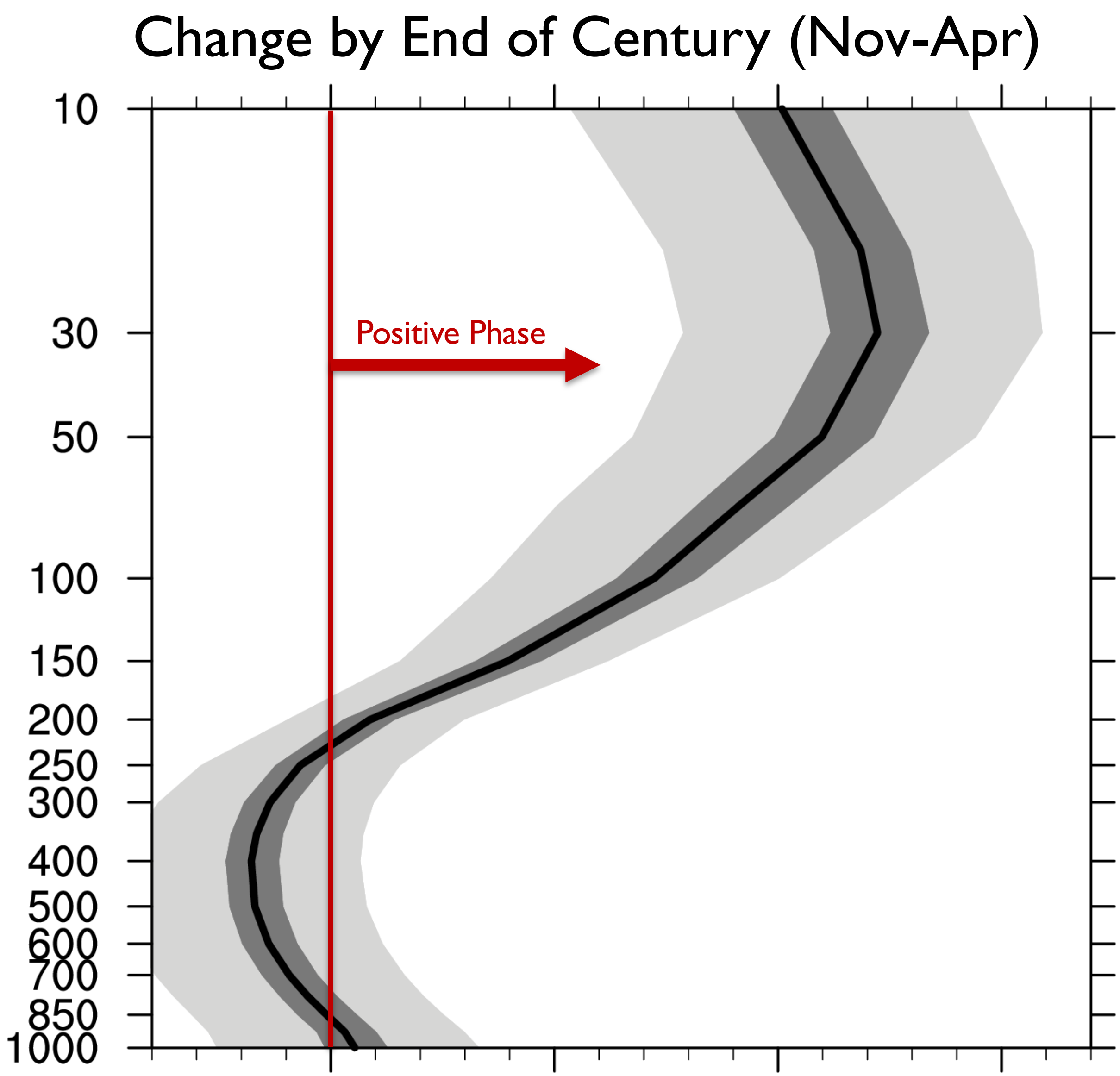
GLENS: Ensemble Mean Changes by End of Century

Extended Boreal Winter (Nov-Apr)



See also Richter et al. (2017) and Tilmes et al. (2018)

Northern Annular Mode (NAM) Index

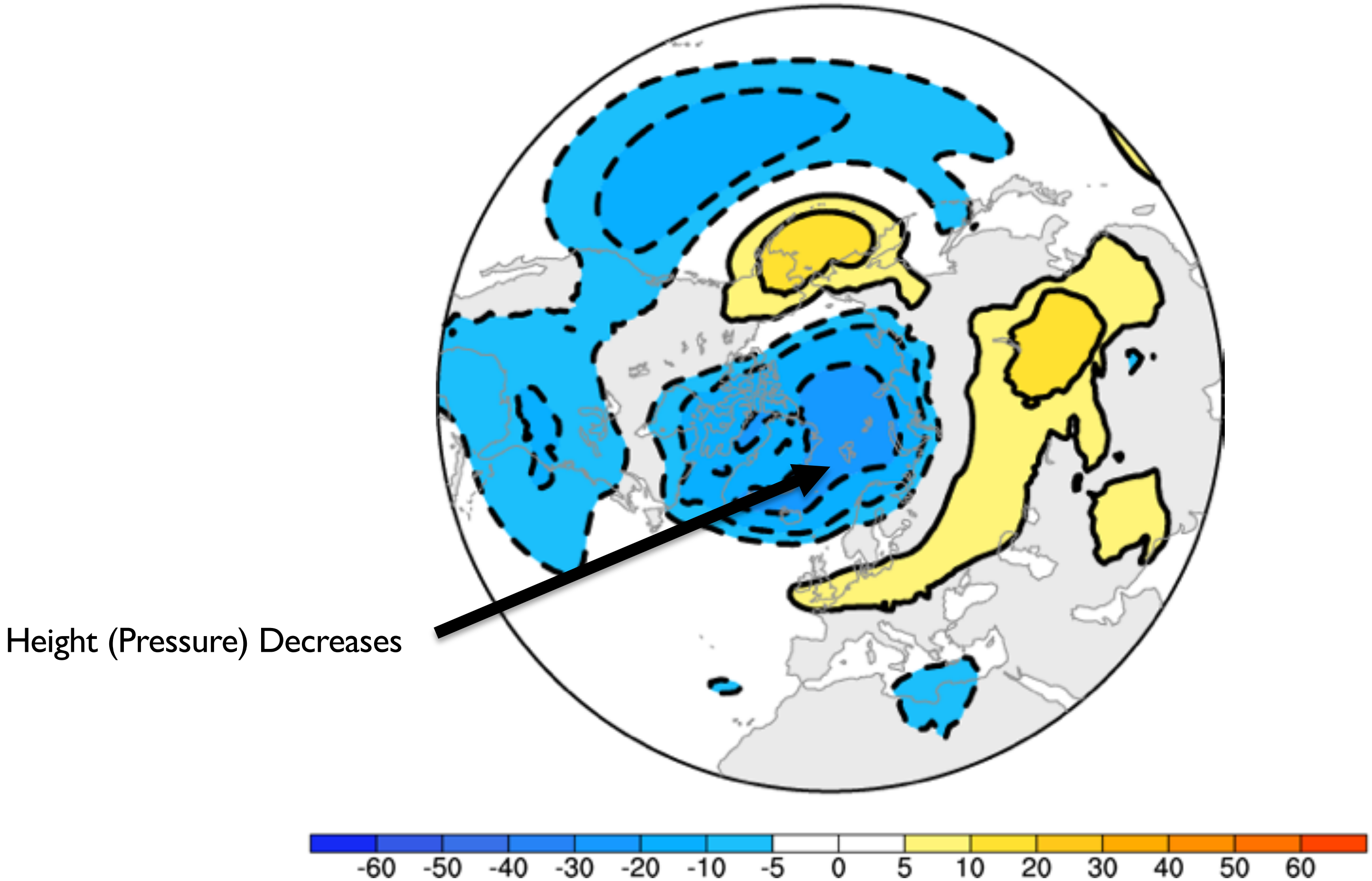


Antara Banerjee, Amy Butler, Lorenzo Polvani and Alan Robock (GRL, in prep)

Surface Climate Impact

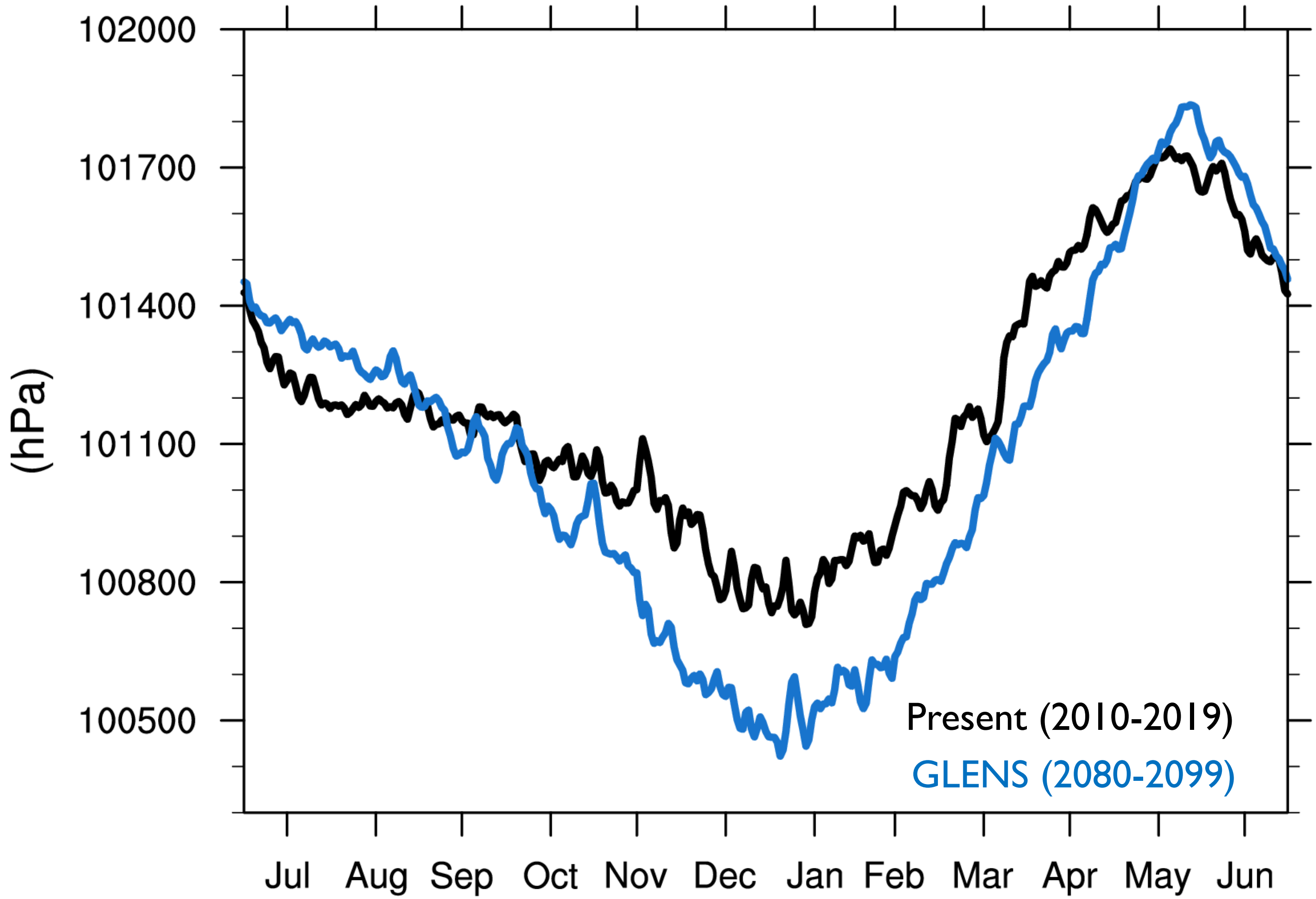
Change by End of Century (Nov-Apr)

1000 hPa Height (m)



Subpolar North Atlantic

Daily SLP



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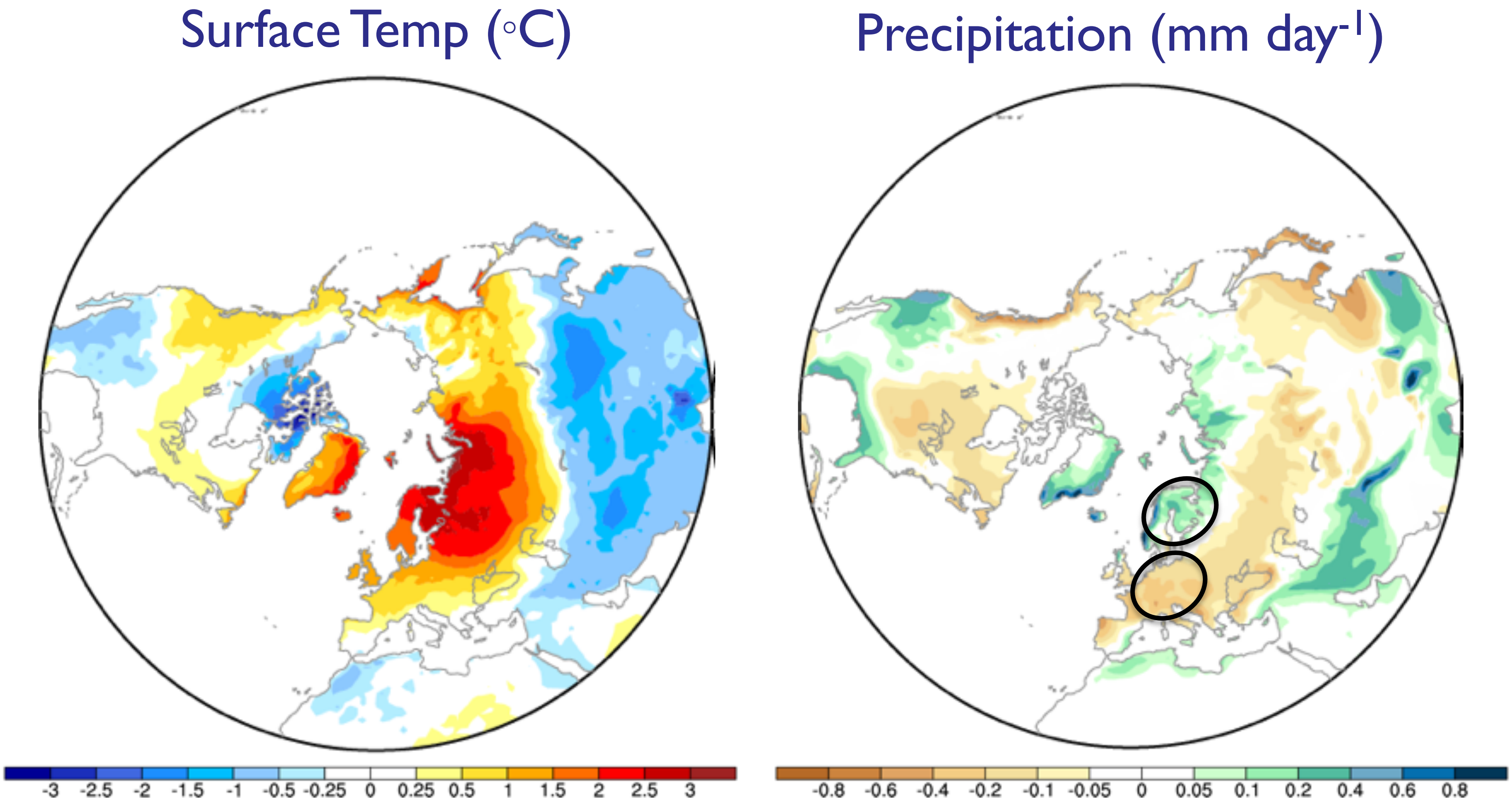
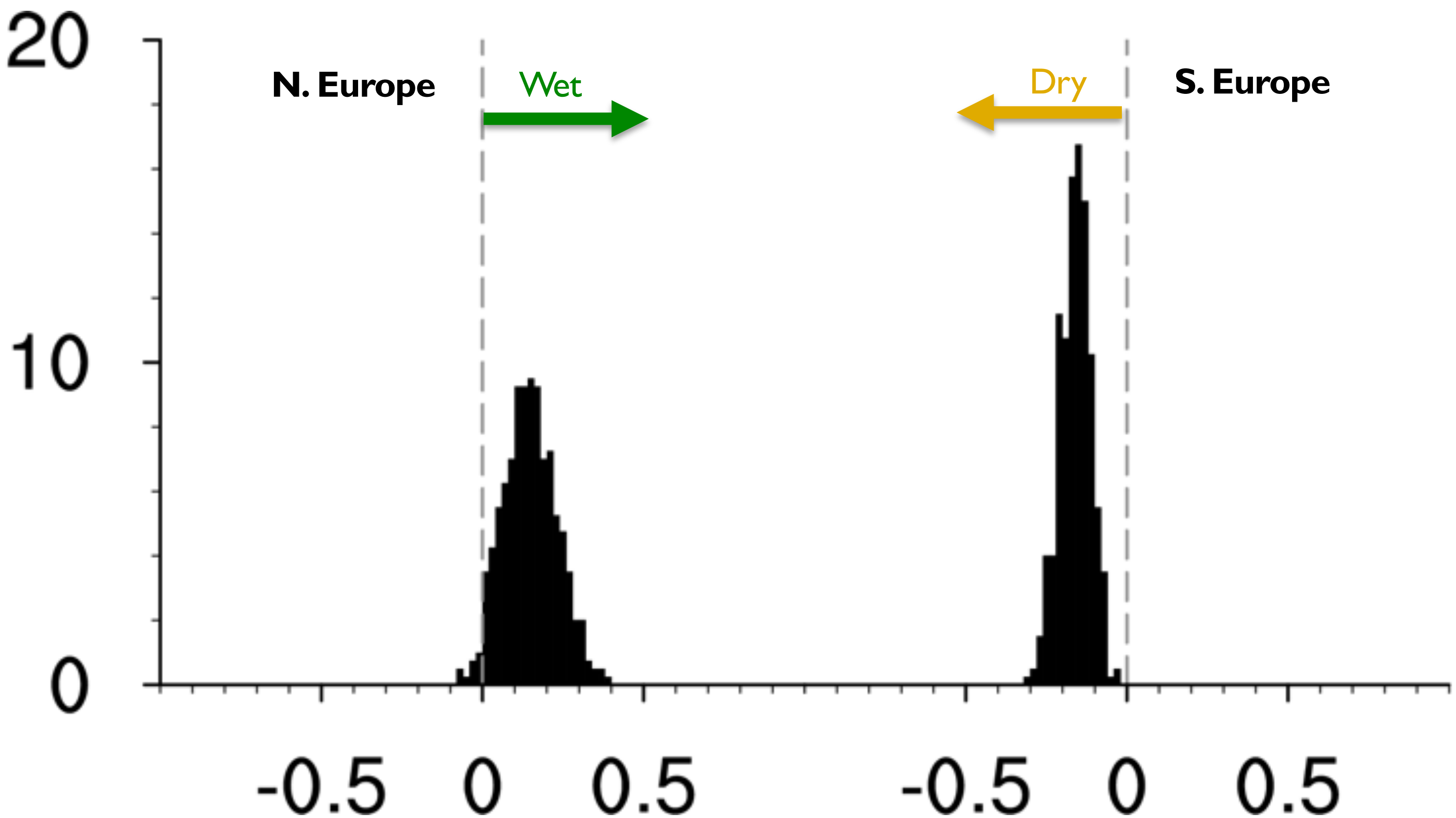


Surface Climate Impact

Change by End of Century (Nov-Apr)

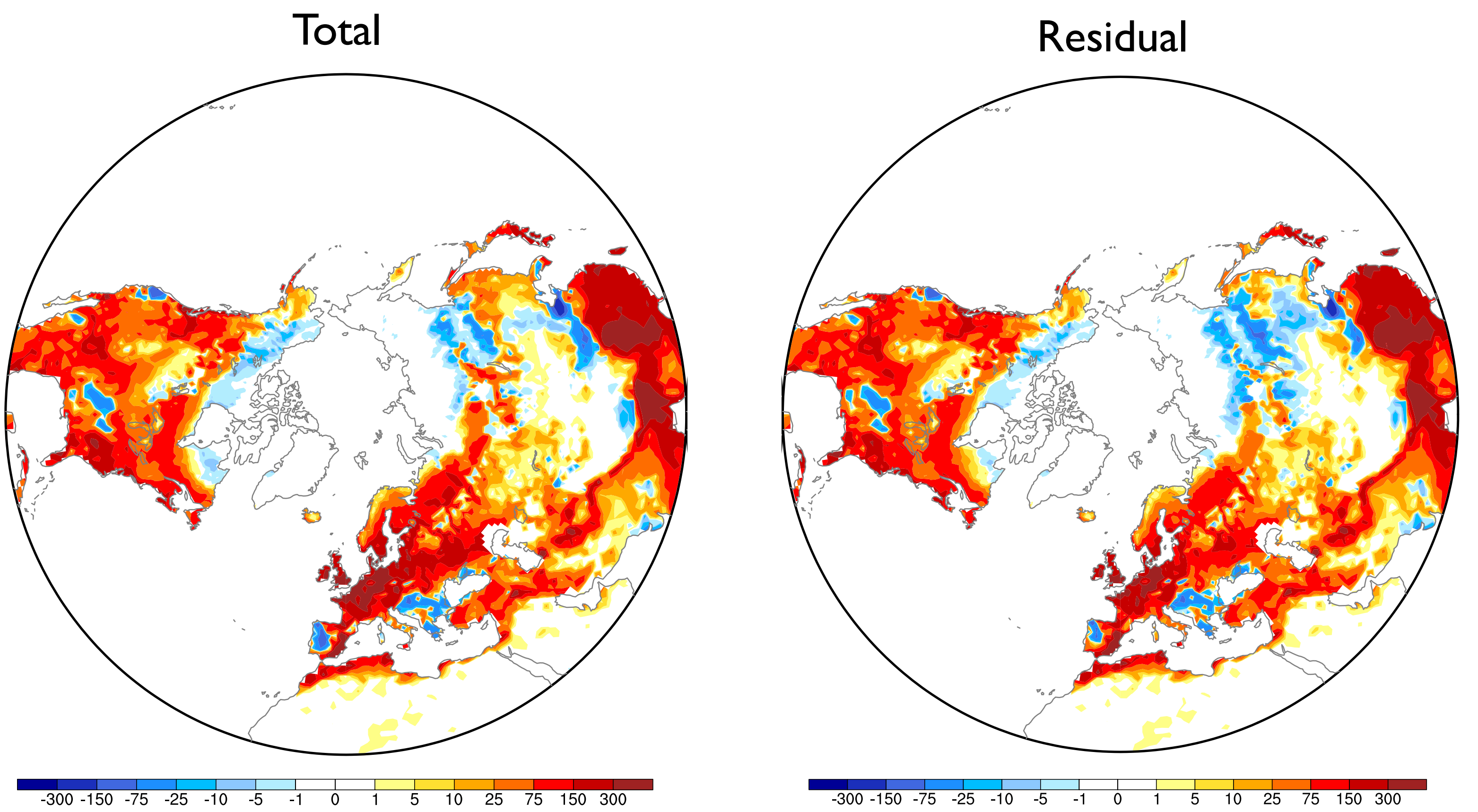
Precipitation (mm day^{-1})



Terrestrial Ecosystem Impact

Change by End of Century (Mar-Apr)

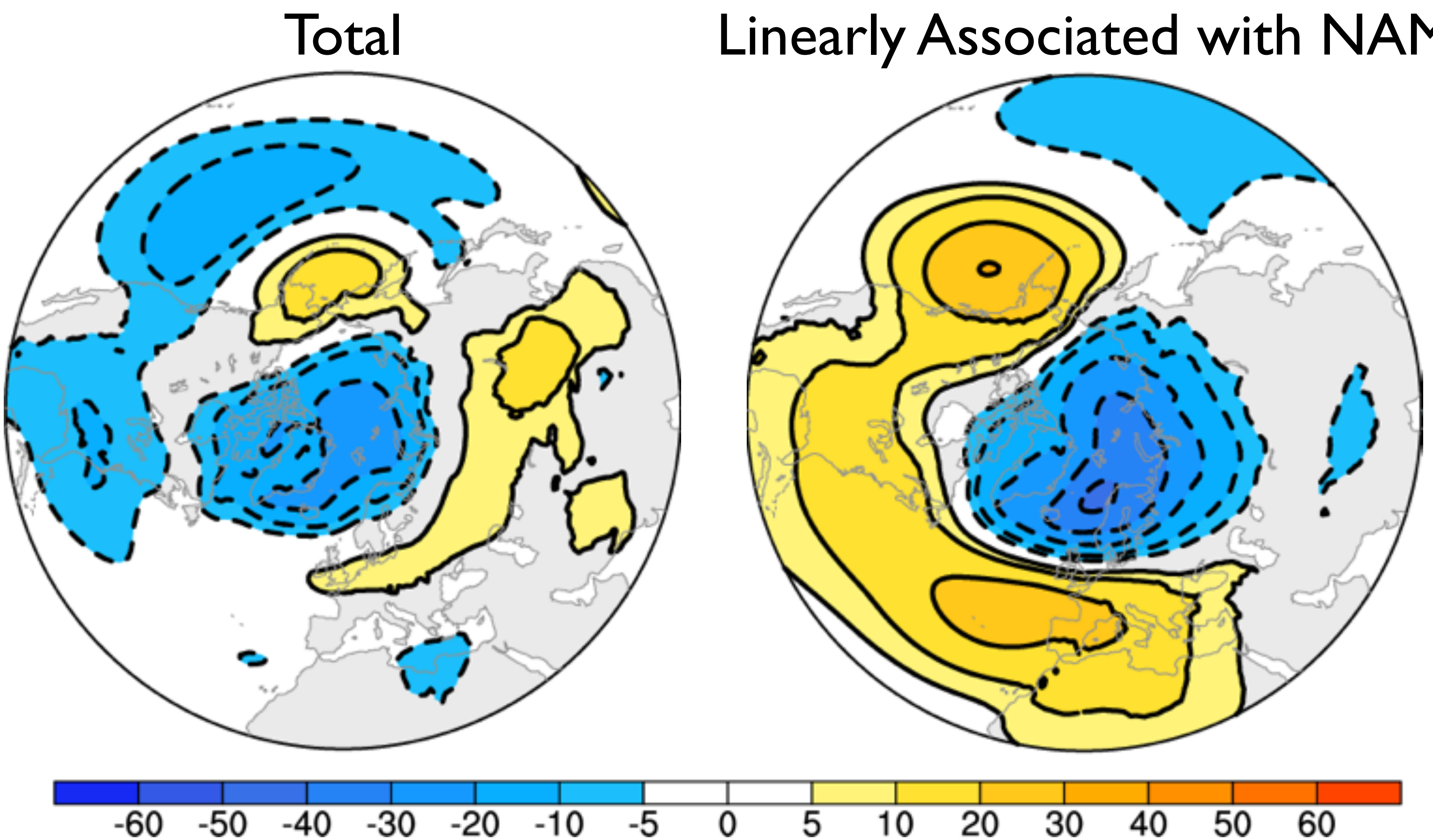
Net Primary Production (g C m^{-2} yr^{-1})



Surface Climate Impact

Change by End of Century (Nov-Apr)

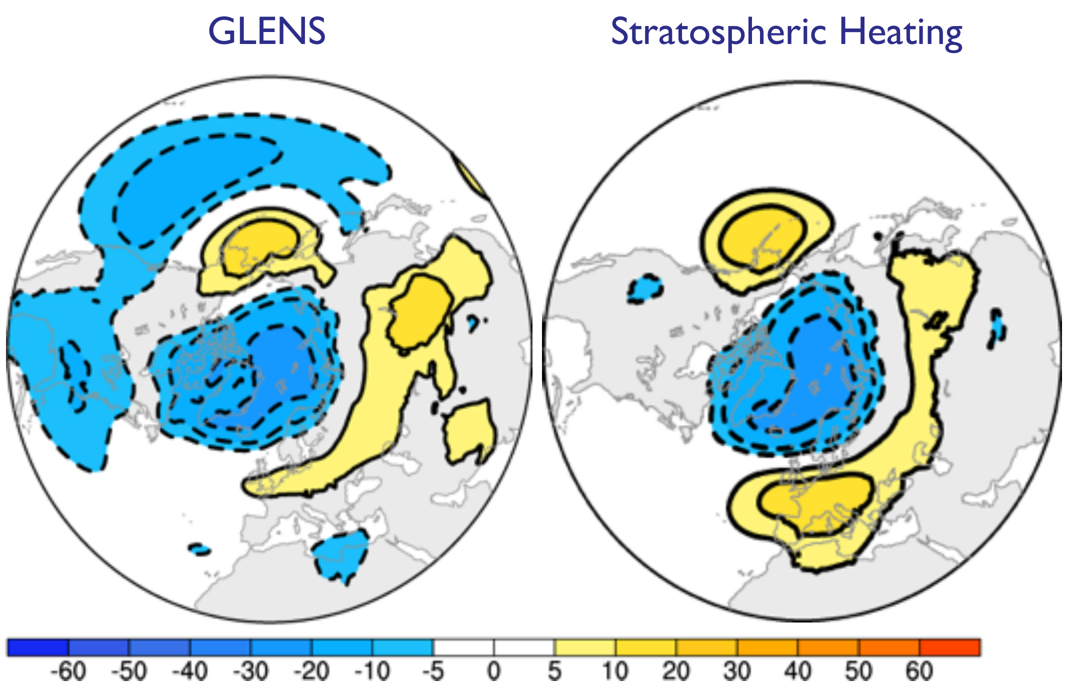
1000 hPa Height (m)



Dynamical Response to Stratospheric Heating

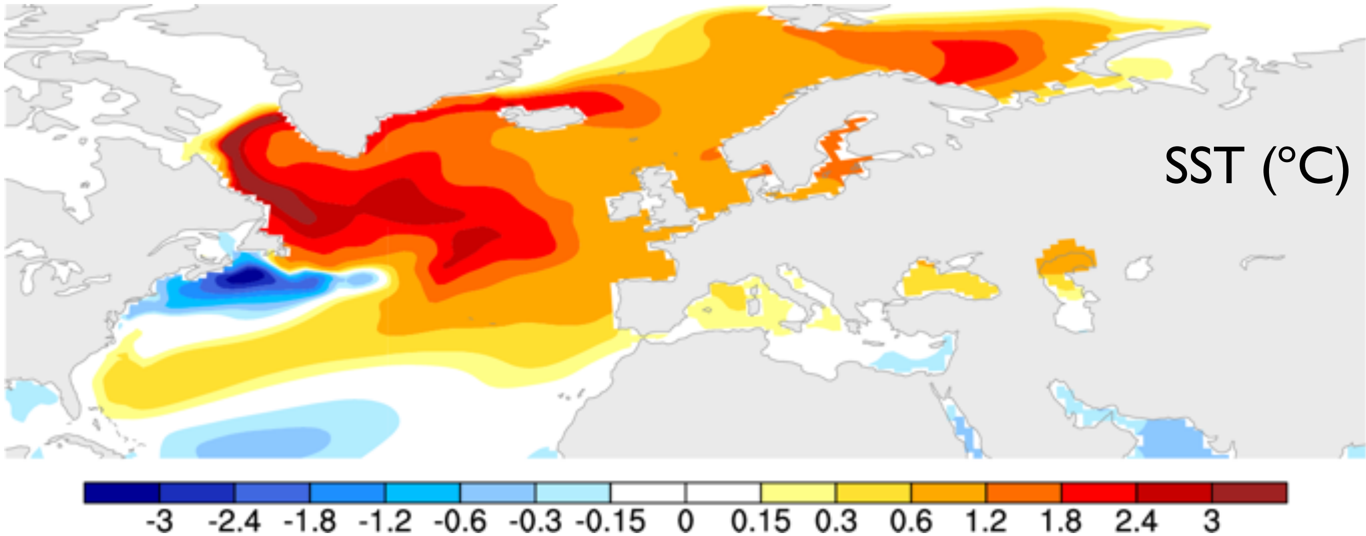
- Isla Simpson performed additional stratospheric heating experiments with the same CESMv1-WACCM version as GLENS
- In these, a zonally symmetric, seasonally varying temperature tendency is added to the prognostic equation for temperature to mimic the additional heating caused by the sulfate aerosols in GLENS.
- 80 14-month ensemble members, initialized from present-day CTRL dates. See Simpson et al. (2019) for details.

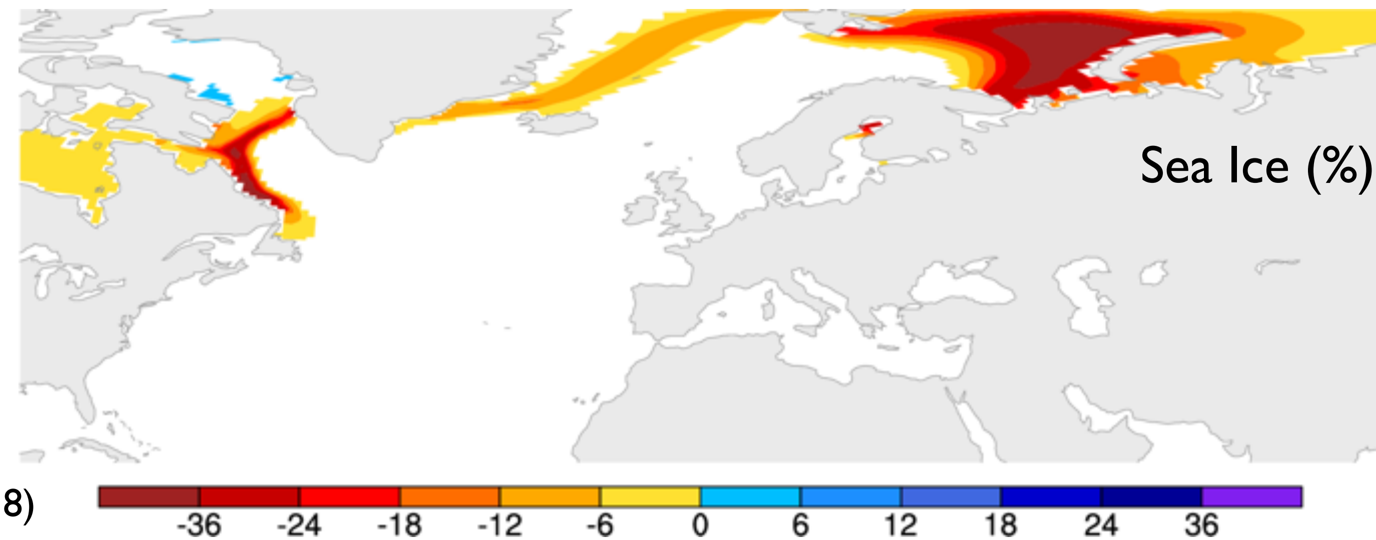
1000 hPa Height (m)



GLENS: End of Century SST Warming and Sea Ice Loss

(Nov-Apr)



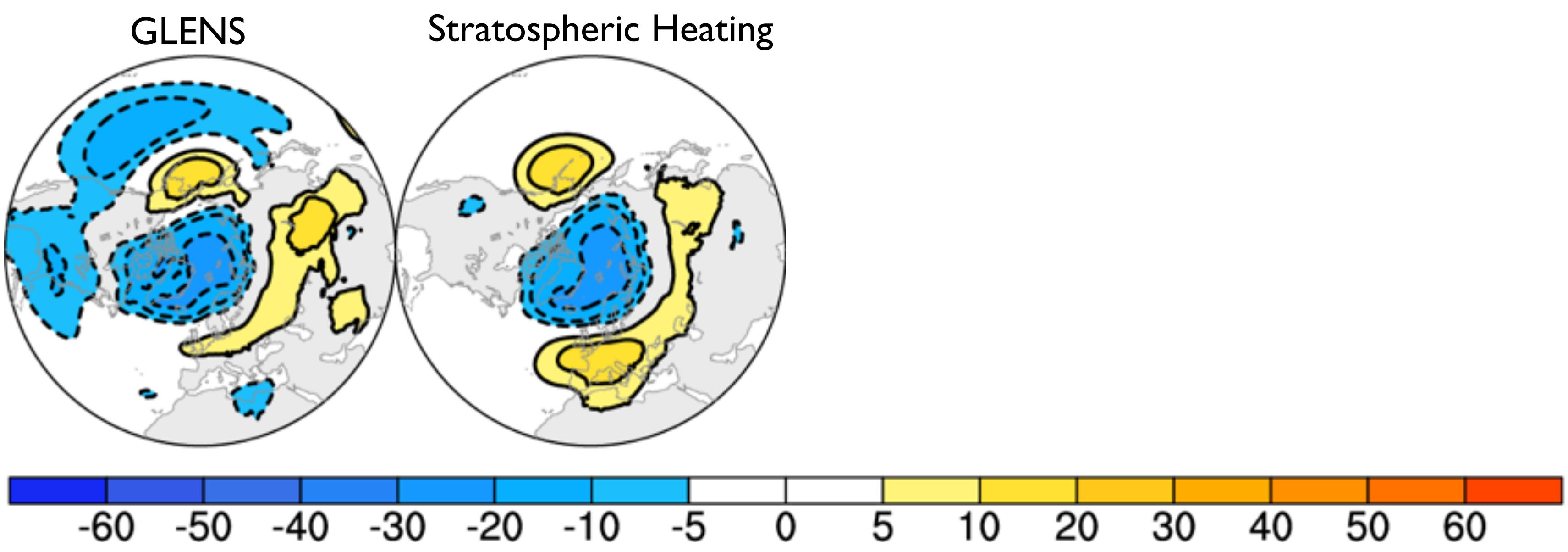


Fasullo et al. (2018)

Dynamical Response to SST and Sea Ice Changes

- Prescribed ocean CESM experiments with radiative forcing from 2000
- 100 CTRL simulations with SST/SIC from RCP 8.5 (2010-2029)
- 100 perturbation simulations with SST/SIC from GLENS (2080-2099)
- Each simulation is 14 months from 1 September; first 2 months discarded

1000 hPa Height (m) (Nov-Apr)



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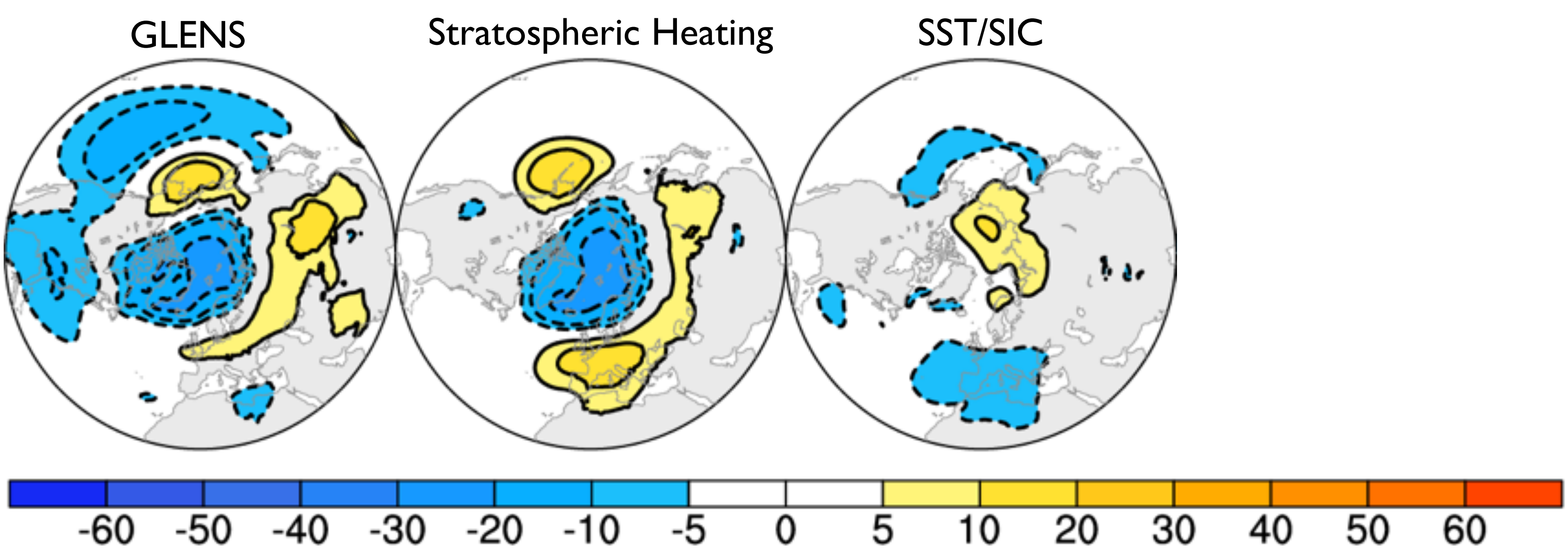

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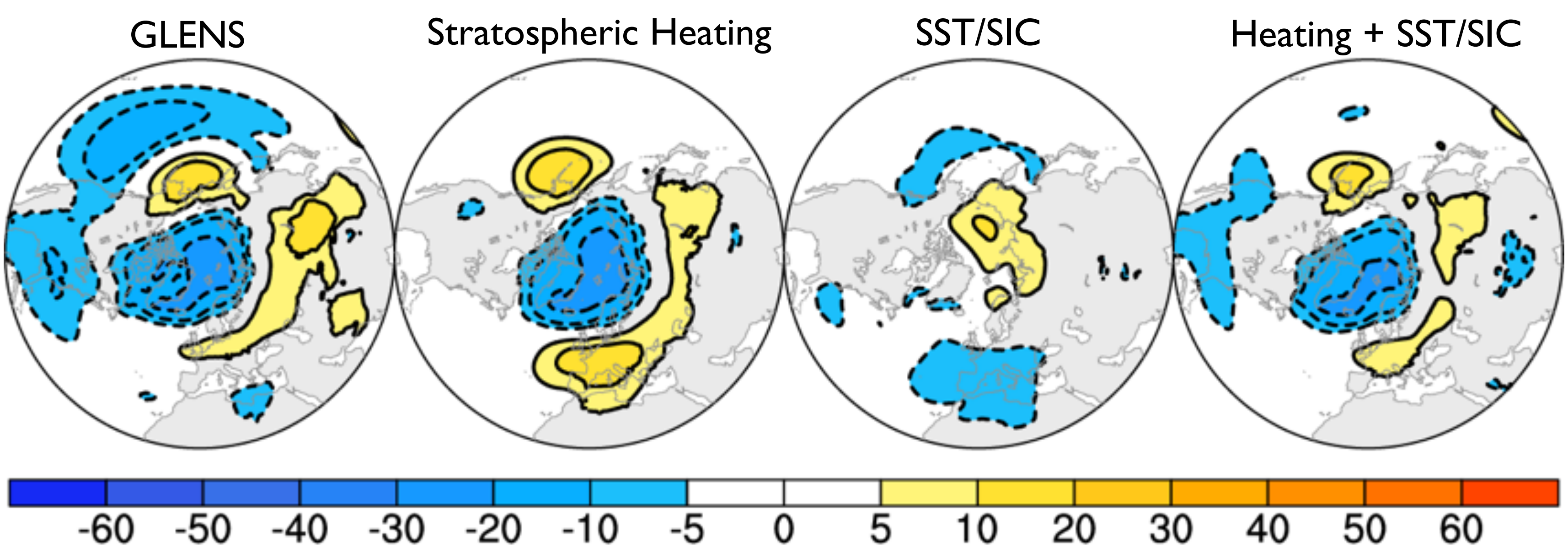

Some Thoughts and Early Findings …

- While it is an imperative to significantly reduce emissions of GHG, the enormous risks that climate change poses now and over the coming decades means it is important to research potential geoengineering approaches
- Before employing solar geoengineering, it is critical that the potential impacts of any given approach are understood to the fullest extent possible.
- While globally-averaged precipitation will decrease with stratospheric aerosol injection (Simpson et al. 2018), regionally, there is no such constraint
- Over Europe and Eurasia, stratospheric heating caused by stratospheric aerosol injection produces a stronger polar vortex, which lowers Arctic sea level pressure and shifts the zonal wind over the North Atlantic
- These circulation changes produce widespread warming with robust wetting over northern Europe and drying over southern Europe
- North Atlantic SST warming and sea ice loss also appear to produce a dynamical response, which impacts of the details of the regional surface temperature, precipitation and terrestrial ecosystem changes