An Overview of Solar Radiation Management: Approaches to Cool a Warming Planet

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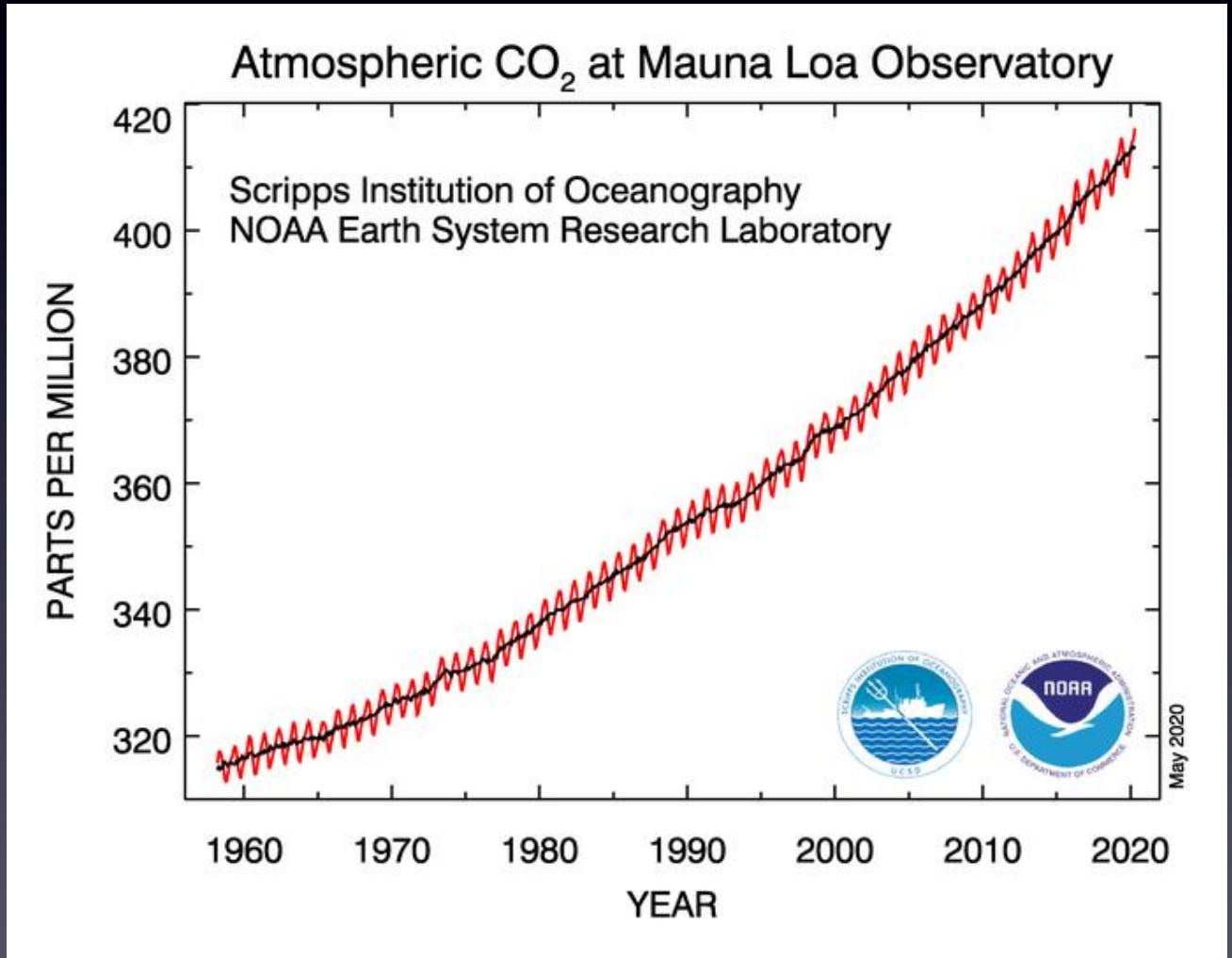
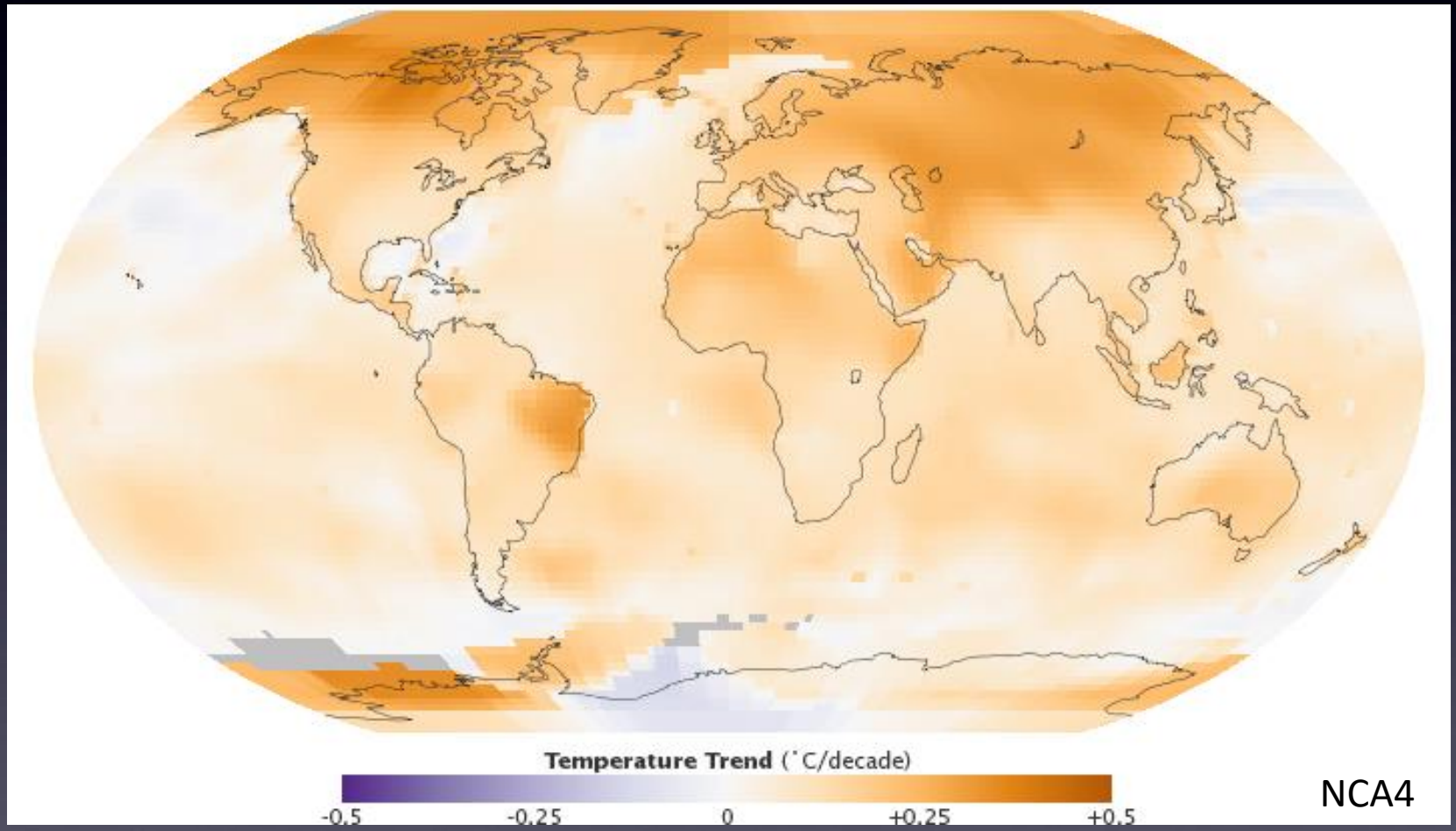
The “Keeling Curve”

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



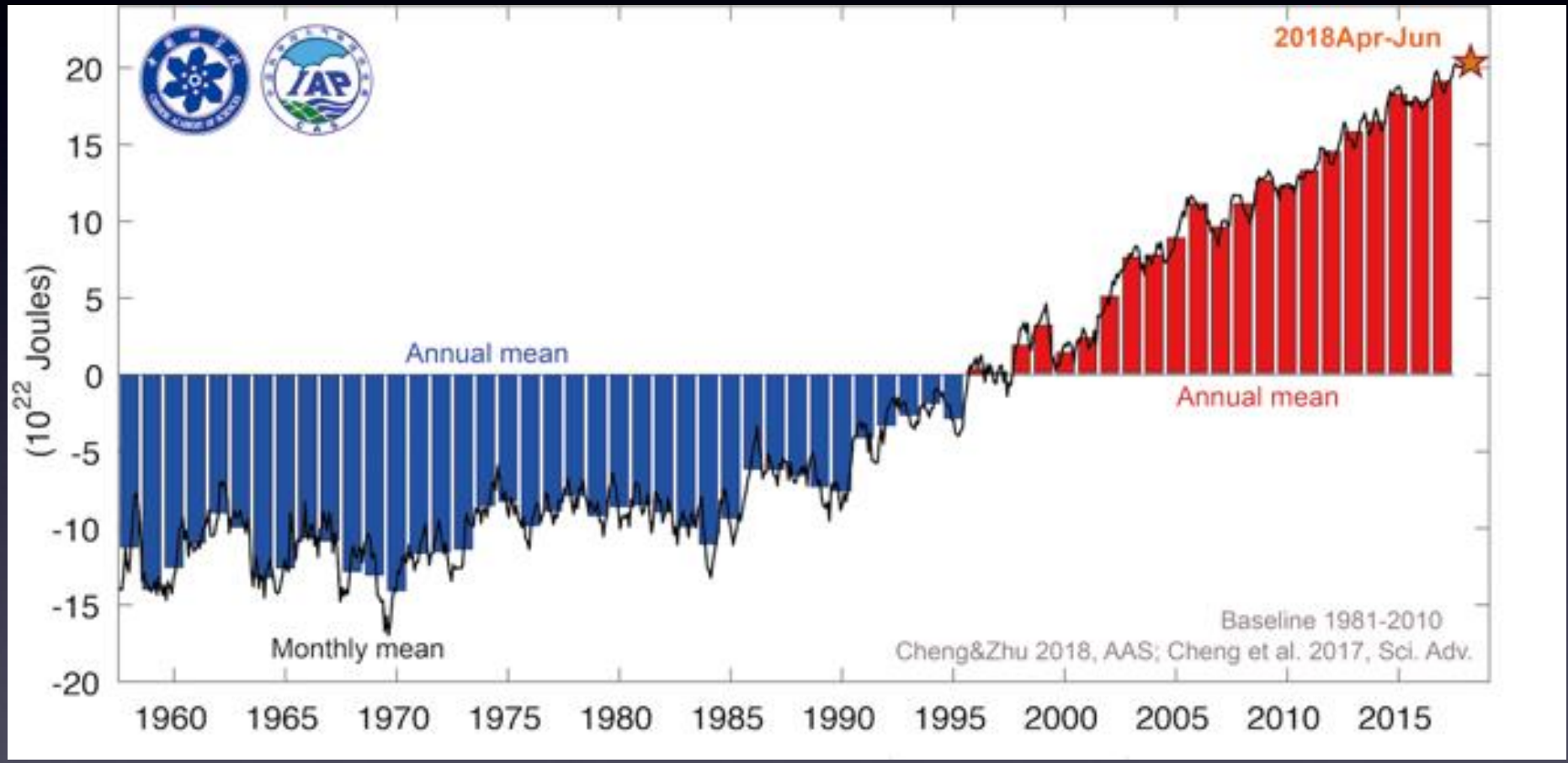
According to the law of conservation of energy, the trapped greenhouse energy must warm Earth

Observed trend in surface temperature since 1950

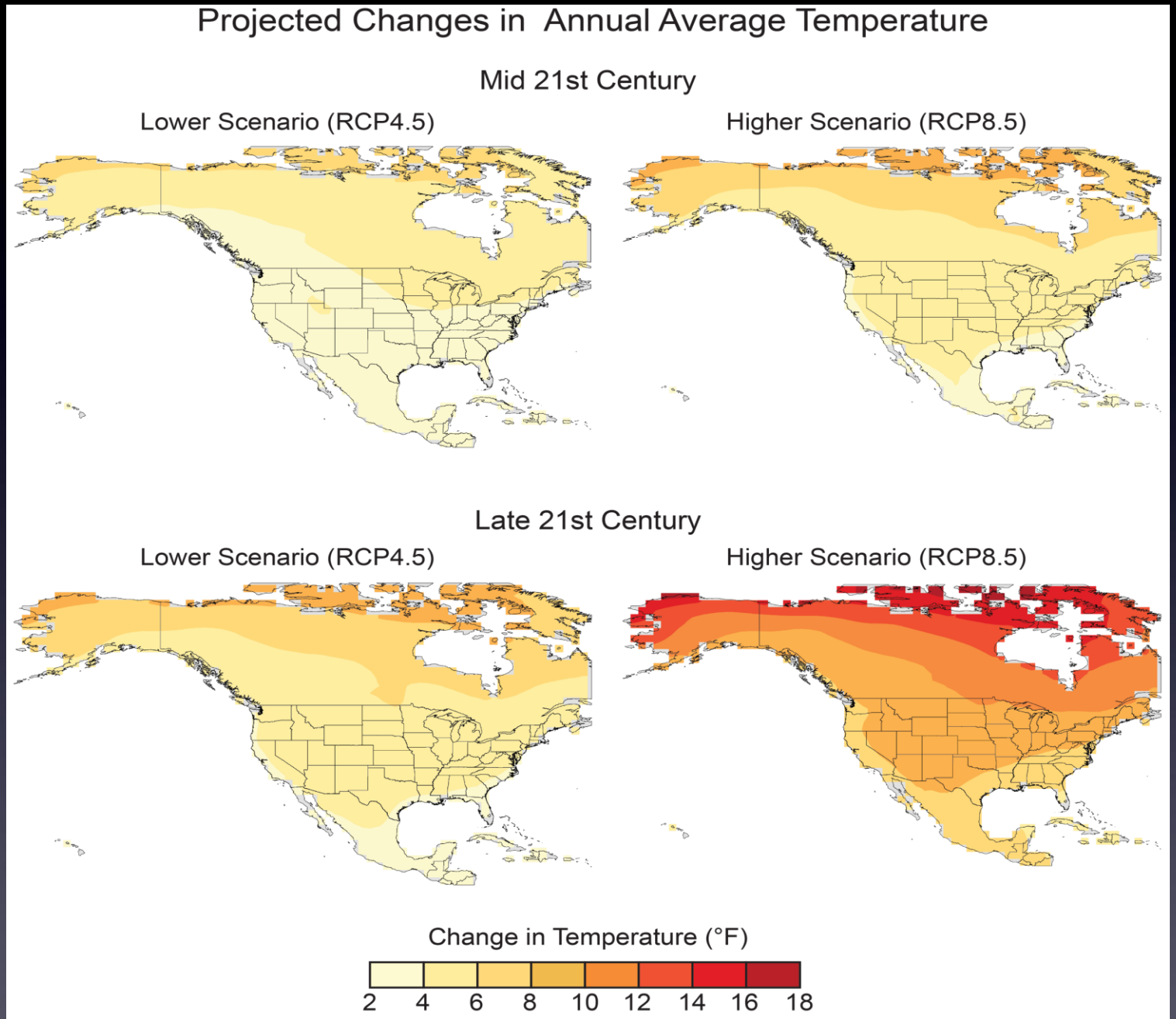


NCA4

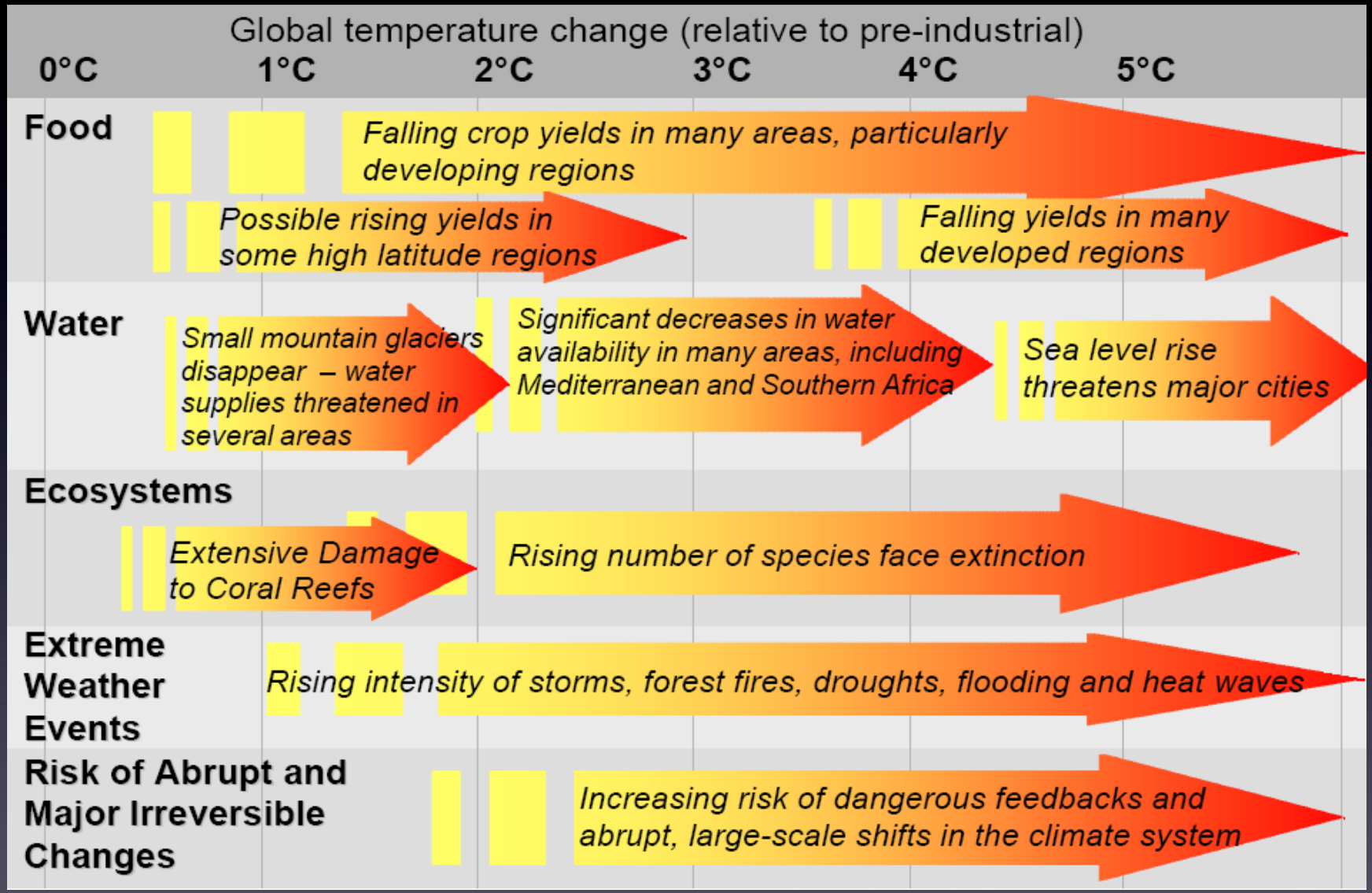
Global Ocean Heat Content (0-2000 m)



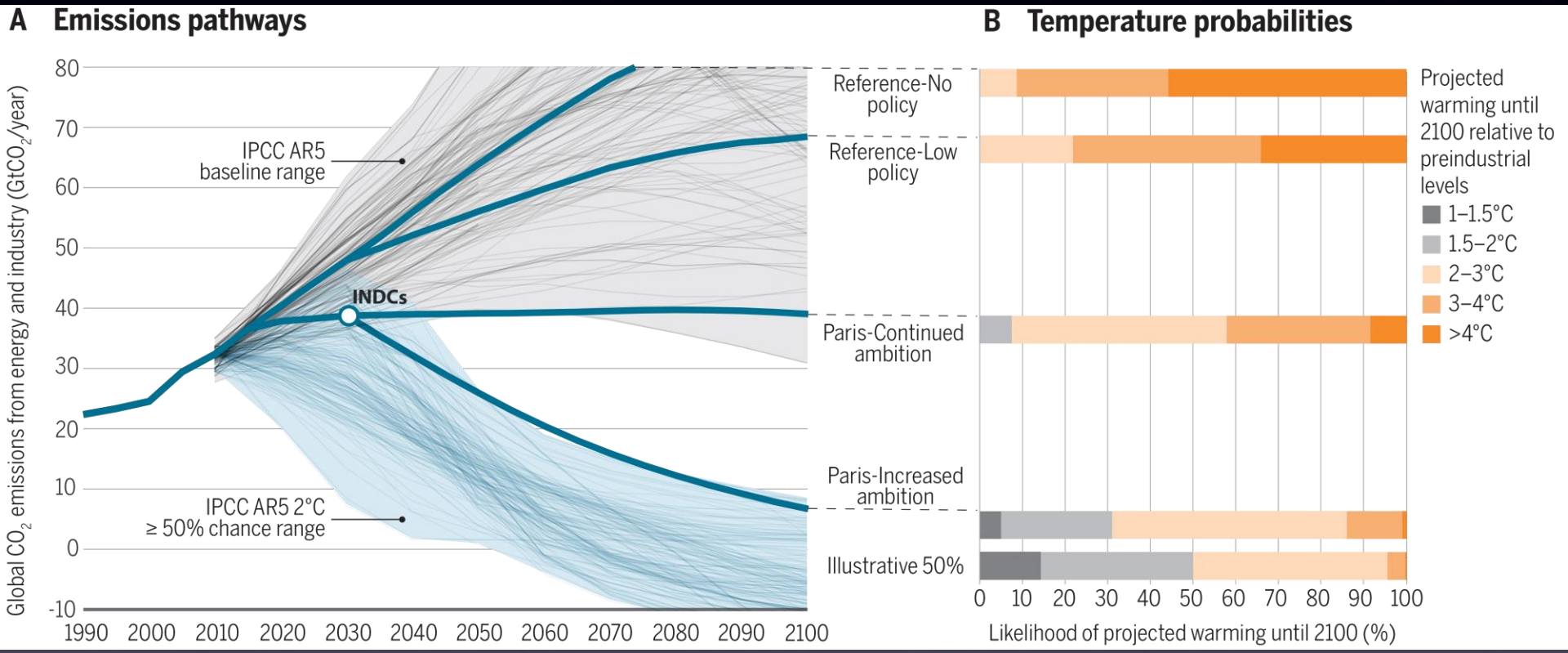
US National Climate Assessment



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

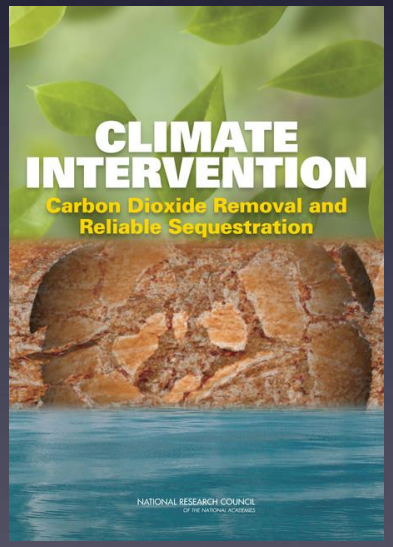


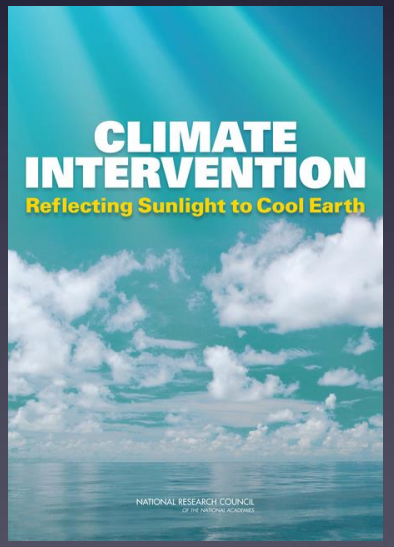
INDCs refer to Intended Nationally Determined Contributions which is the term used for the governments' announced actions in the lead up to Paris.

Climate Intervention

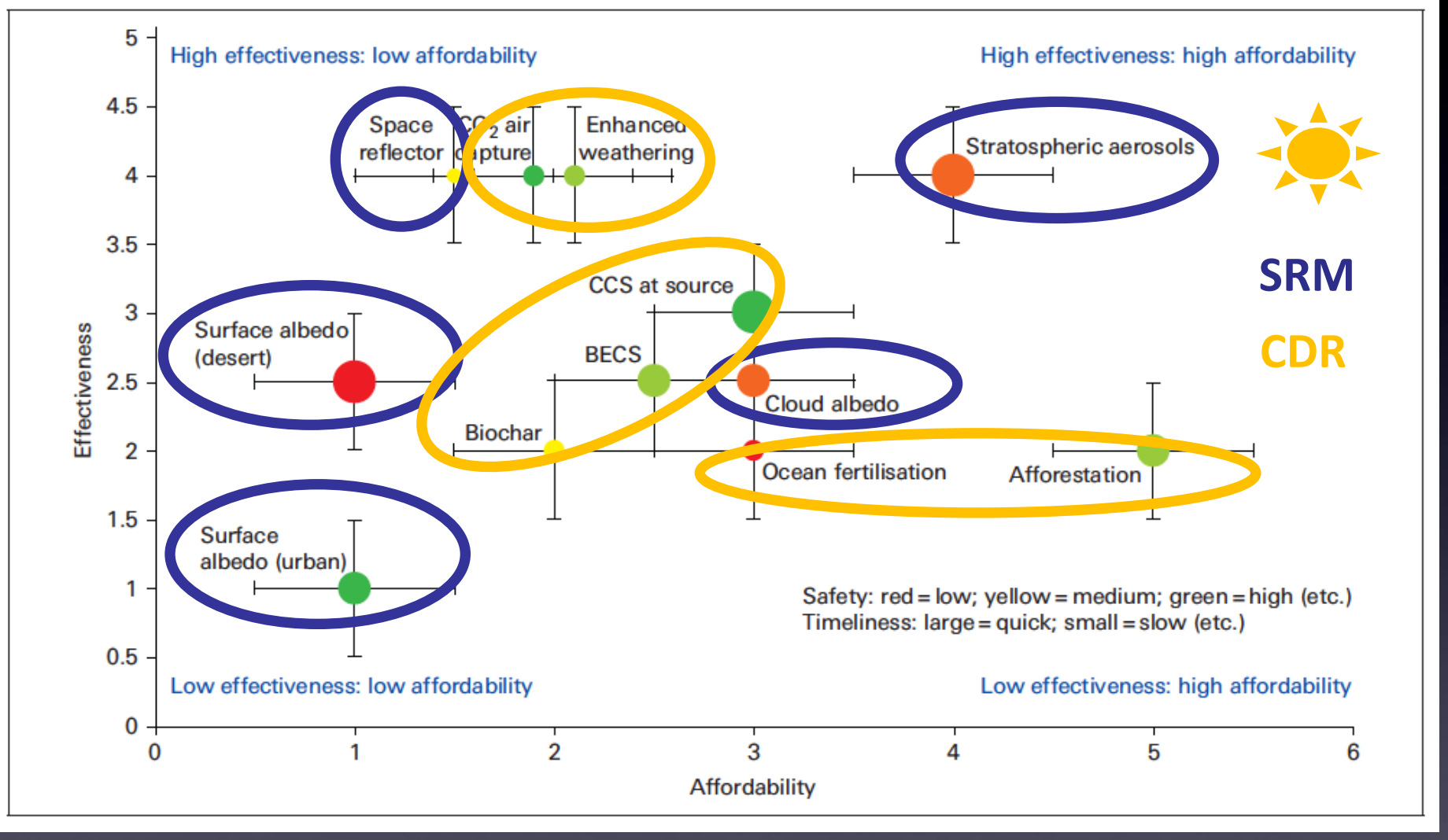
Potential Role of Climate Intervention in Mitigation Strategies

- Limiting the global mean temperature increase through emissions reductions or adapting to the impacts of a greater-than 2°C (3.6°F) warmer world is severely challenging.
- Consequently, is it important to explore additional measures designed to reduce climate change impacts through other actions
- These are often referred to as geoengineering or climate intervention (CI) actions – both Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM).
- NRC (2015):
  - CDR: "the removal and long-term sequestration of CO_2 from the atmosphere in order to reduce global warming"
  - SRM: Even though it is not a **SOLUTION** to anthropogenic climate change, much **MORE RESEARCH IS NEEDED** to understand feasibility and especially impacts

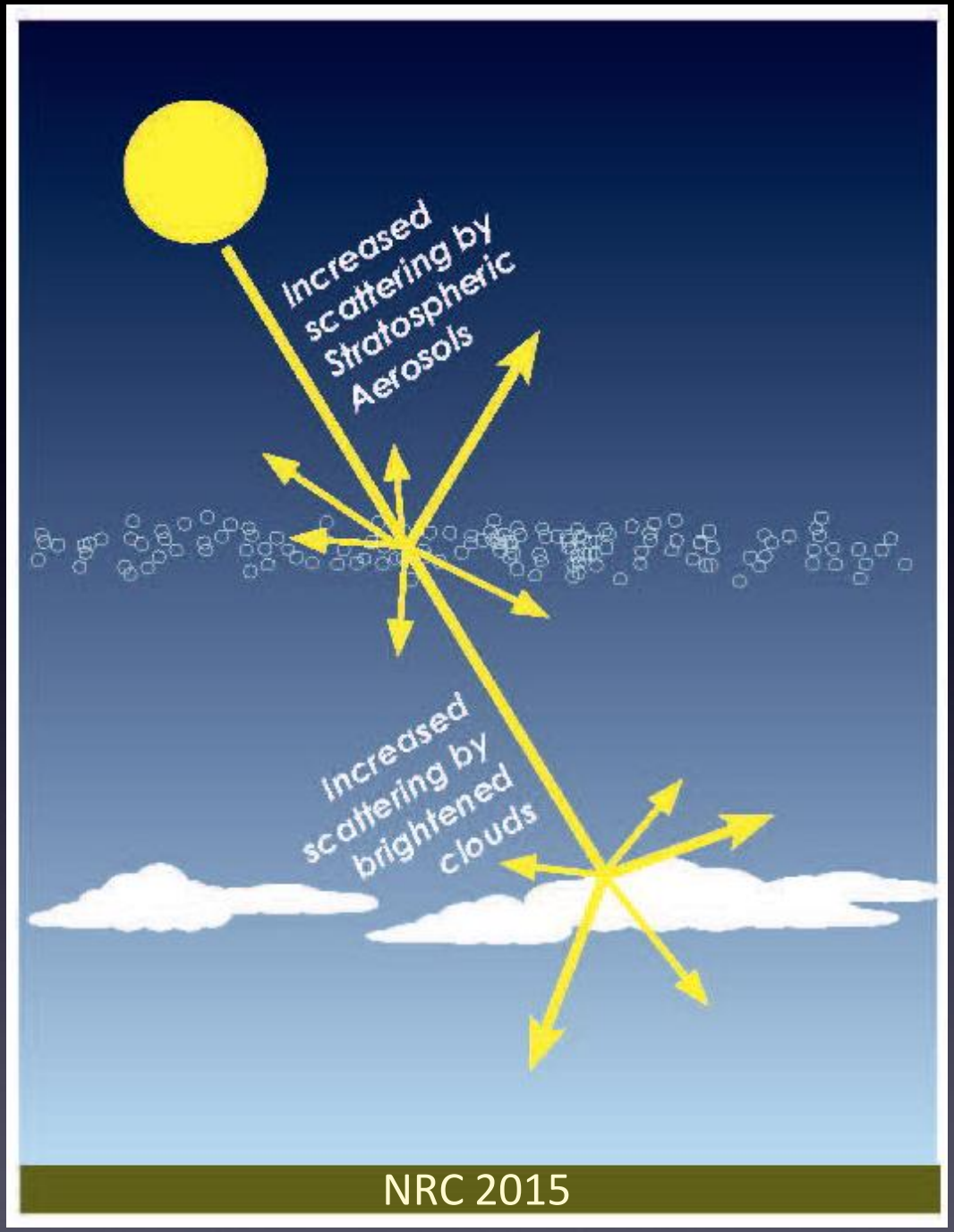




Evaluation of Climate Intervention Techniques



Royal Meteorological Society Report (2009)


Increased scattering by Stratospheric Aerosols
Increased scattering by brightened clouds
NRC 2015

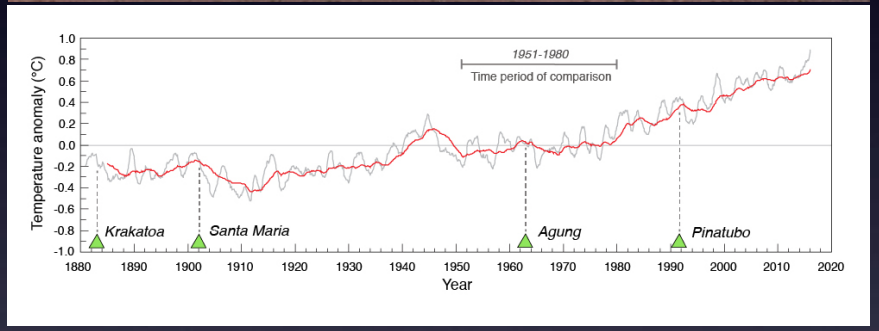
Marine Cloud Brightening (MCB)

- Idea is to cool Earth by increasing reflecting of clouds over the oceans
- An analog is “ship tracks”
- Adding aerosols – perhaps by spraying a fine mist of salt water – would produce more water droplets, brightening the clouds

- Details of cloud-aerosol interactions are not well understood, however, so it is currently unclear where and when cloud albedo could be modified and by how much
- Sarah Doherty: key questions on potential efficacy of MCB

Stratospheric Aerosol Injection (SAI)

- The most studied and perhaps best understood of proposed SRM approaches
- Large volcanic eruptions add SO_2 to stratosphere, where it oxidizes and forms sulfate aerosols that reflect sunlight back to space



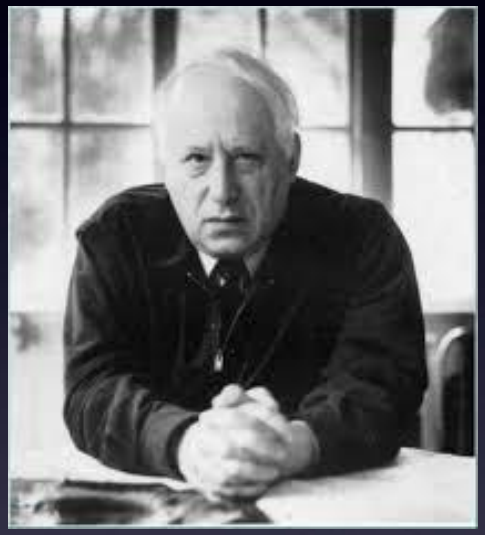
- Global distribution of aerosols can result in pronounced global cooling (0.3-0.5ºC) that lasts for 12-18 months
- A similar effect could be achieved deliberately by injecting SO_2, sulfate particles, or solid particles such as calcite
- Jean-Francois Lamarque: modeling stratospheric aerosols

Could we do the same?

… by pumping SO2 high into the atmosphere

- The idea was first proposed by Soviet climatologist **Mikhail Budyko**

1970s

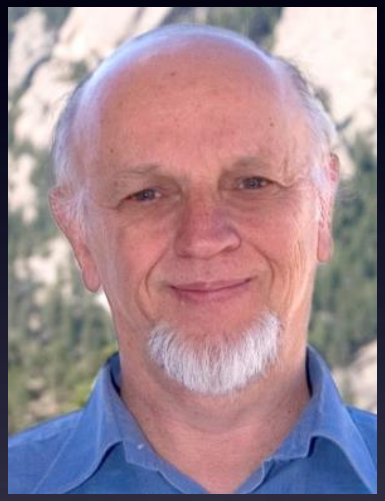


1980s

Wally Broecker

2000s

Paul Crutzen



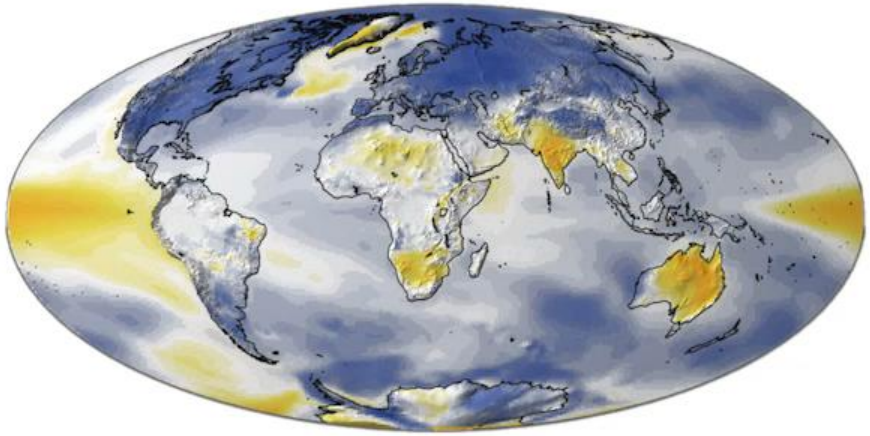
Tom Wigley

Crutzen's "Escape Route" essay in 2008 motivated by his belief that political attempts to limit man-made greenhouse gases are so lacking that a radical contingency plan is needed

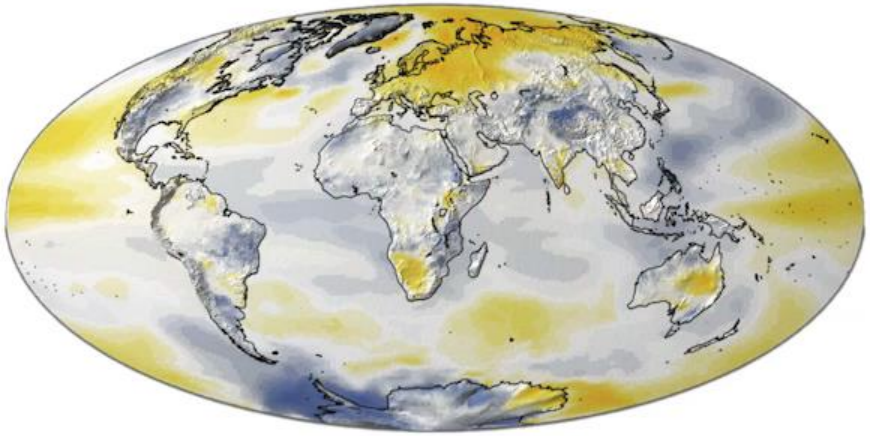
Geoengineering Large Ensemble (GLENS)

http://www.cesm.ucar.edu/projects/community-projects/GLENS/

Surface Temperature Anomaly

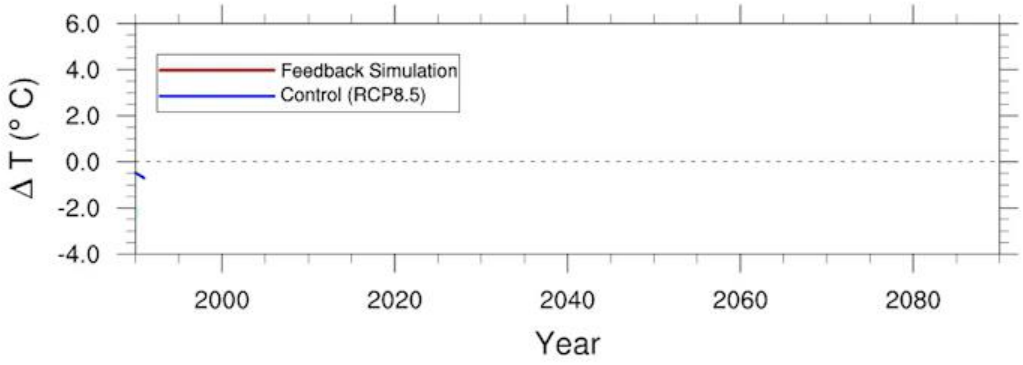


RCP8.5



Feedback Simulation

Feb 1990

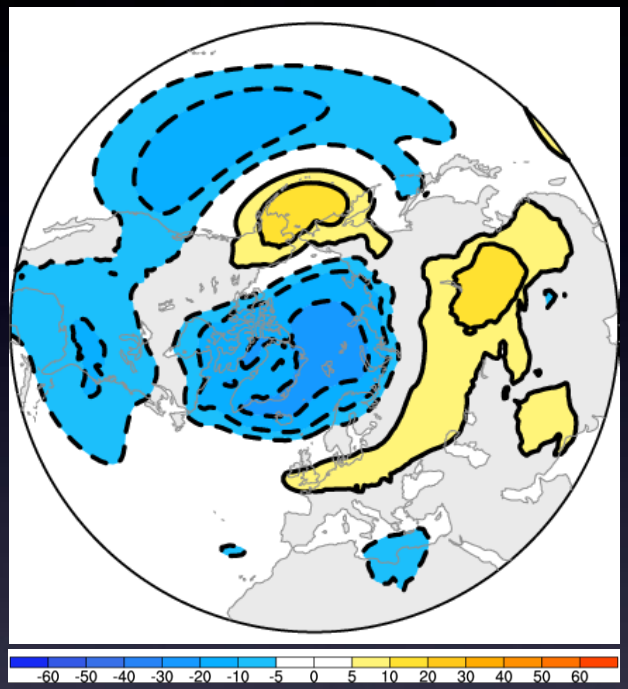


Aerosol Covered Earth

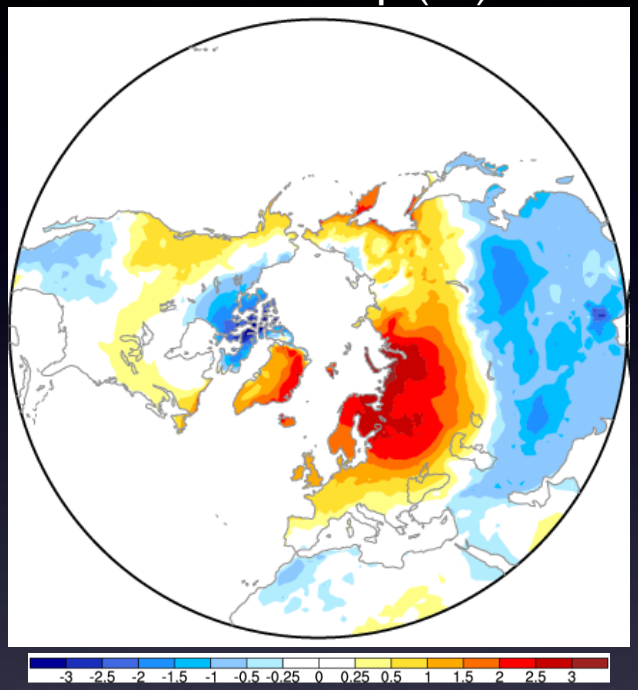
Surface Climate Impact

Change by End of Century (Nov-Apr)

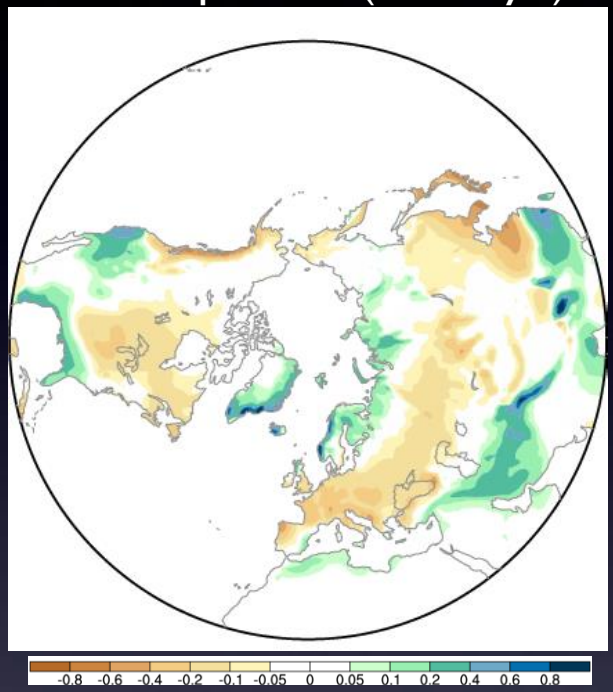
1000 hPa Height (m)



Surface Temp (◦C)



Precipitation (mm day^{-1})



- Critical that potential impacts of any given SRM approach be understood the fullest extent possible to a hypothetical deployment, not only for physical climate but also for ecosystems, human health, etc.
- The climate response will depend on the specific method and spatial distribution of forcing

Solar Radiation Management

Some Concluding Thoughts

- Over the past 20 years, stratospheric aerosol injection and marine cloud-brightening ideas have been tested in modern climate models (Jim Haywood, next)
- Results from idealized scenarios across a broad spectrum of models yield broadly consistent results on the cooling effects of SRM
- Changes in the hydrological cycle are more complex and harder to summarize

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- Although there are consistencies across models, modeling uncertainties make it difficult to provide reliable, quantitative statements about relative risks, consequences, and benefits of SRM globally, let alone benefits and risks to specific regions
- Also, while SRM can reduce global-mean T to a target level, the resulting climate will be different in a number of important ways from a low carbon, natural albedo climate

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- Nevertheless, while SRM is not a substitute for mitigation, it could provide options to help stabilize natural systems and protect the safety of people worldwide and locally
- Also, there are a number of hypothetical but plausible scenarios in which deployment of albedo modification might be considered; e.g. a climate emergency or limited deployment as part of a portfolio of actions to reduce the risks of climate change

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- NRC 2015: More research is needed to understand feasibility and especially impacts

Thank you

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