“Solar” Geoengineering:

Reflecting Sunlight to Cool the Climate

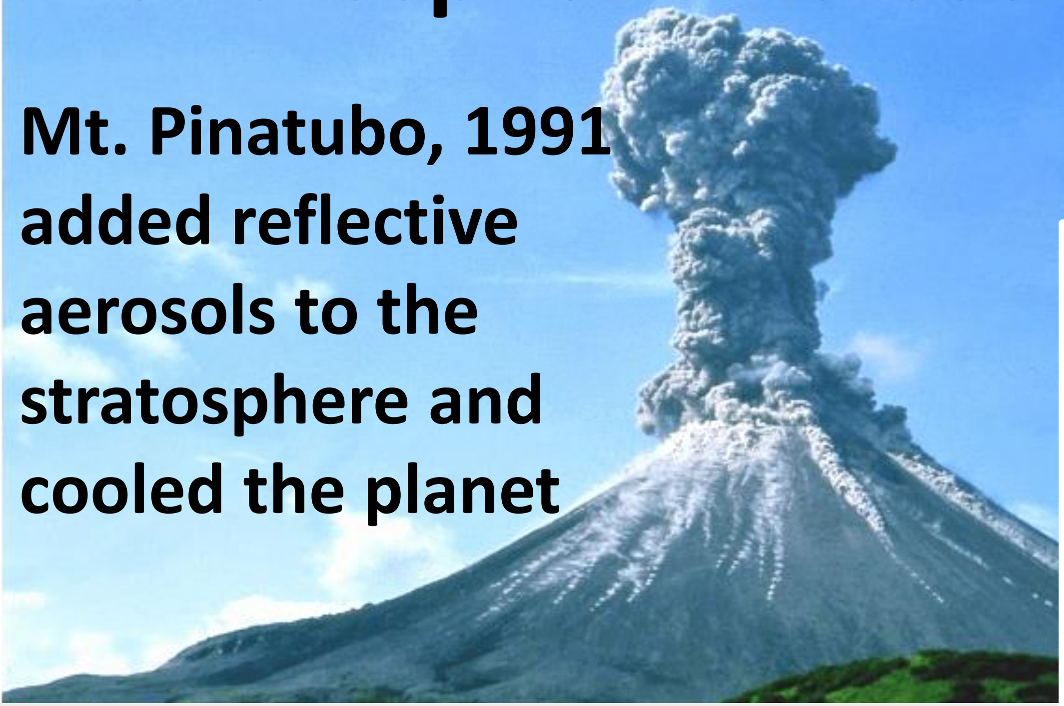
What role might it play in an overall climate strategy?

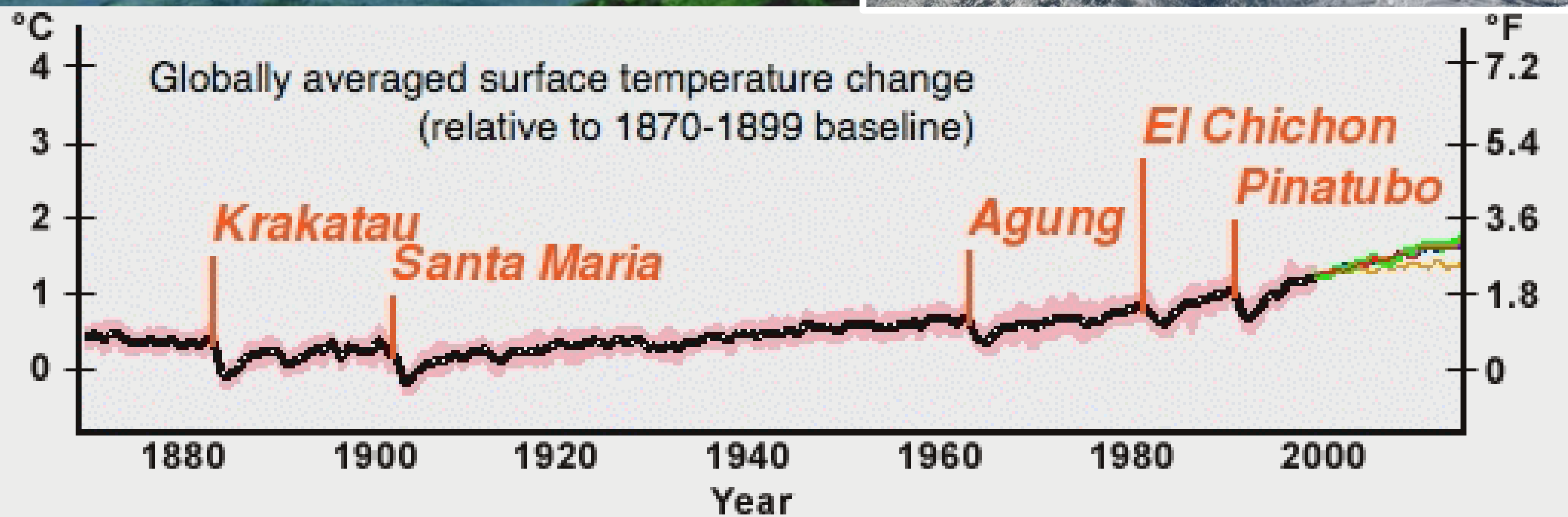
Douglas MacMartin

Mechanical and Aerospace Engineering, Cornell University

Computing + Mathematical Sciences, California Institute of Technology

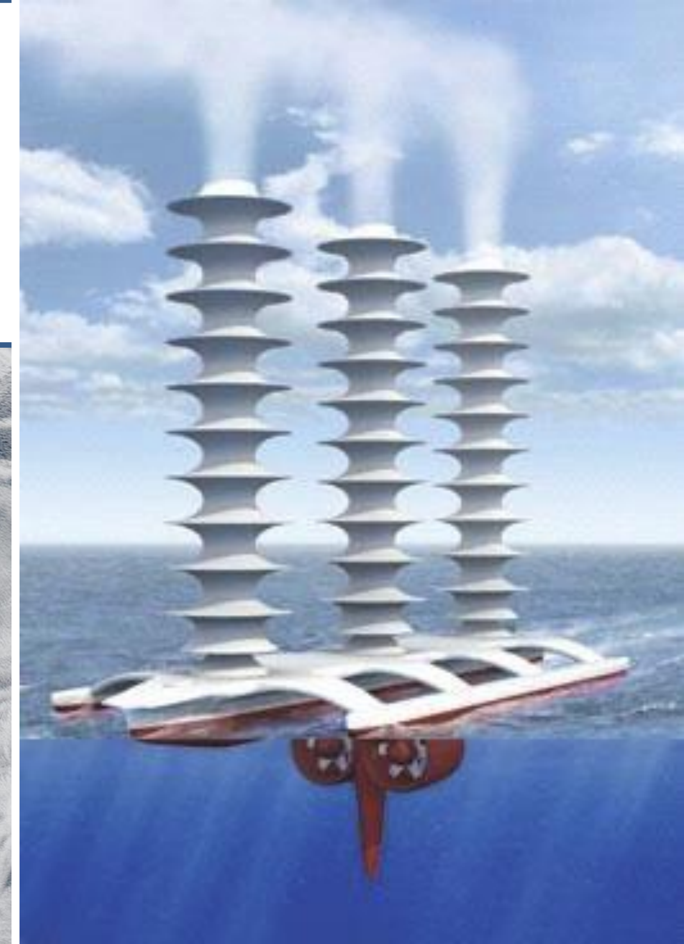
Stratospheric Aerosol Injection





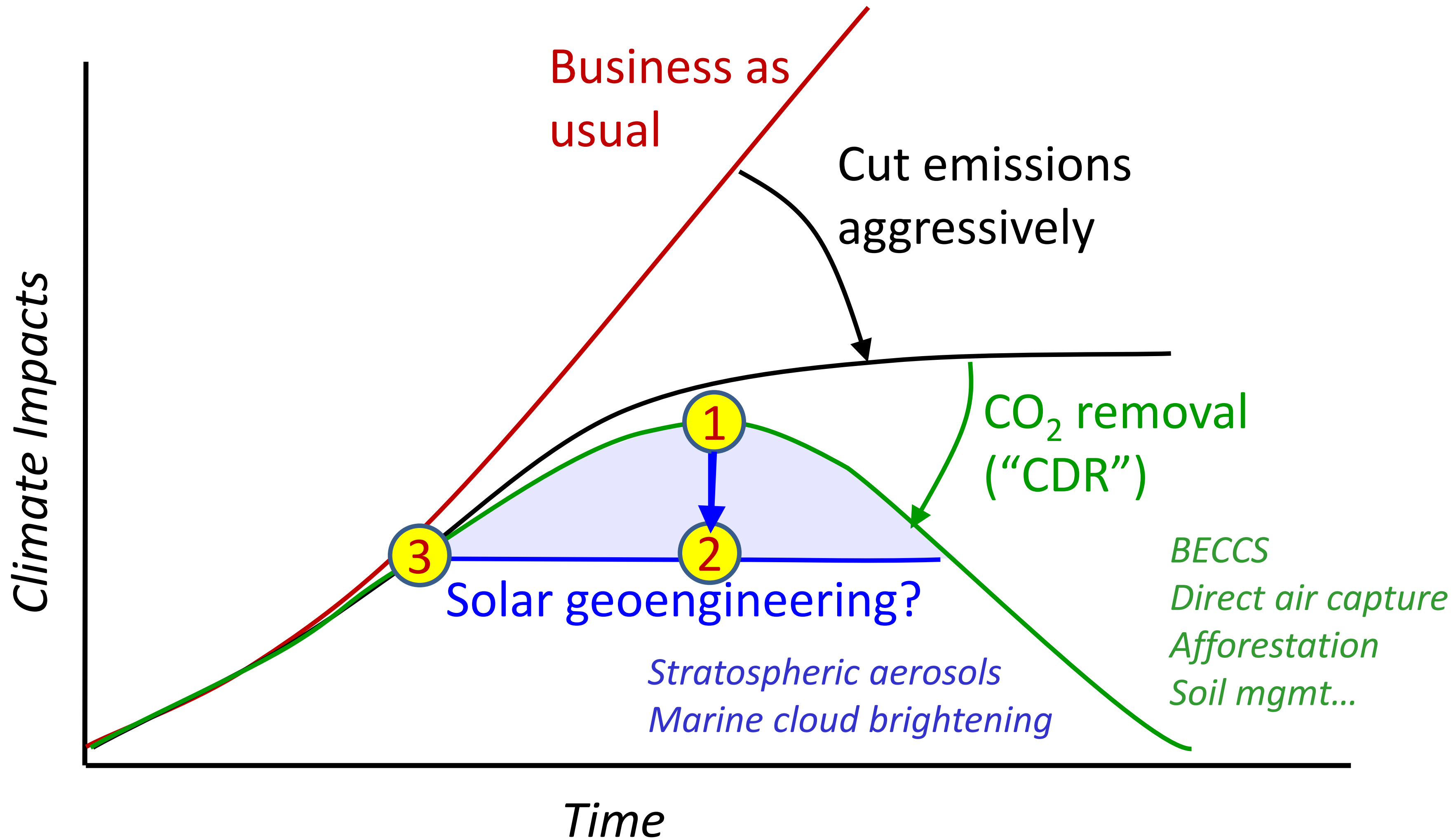
Marine Cloud Brightening

Ship tracks due to aerosols

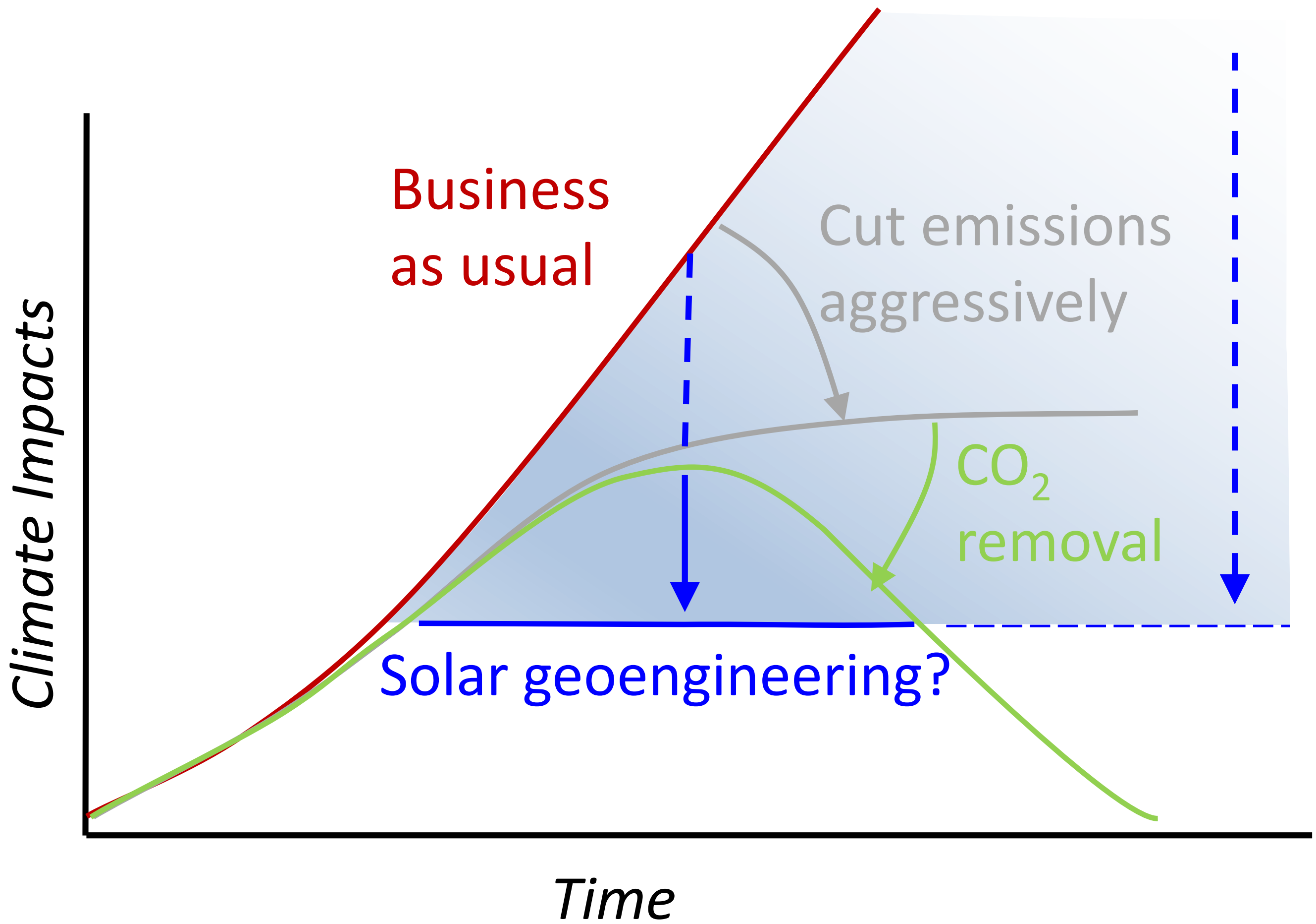


- Use ships to spray salt-water into low clouds
- More uncertain
- Doesn't work everywhere

What is the (possible) role for geoengineering?



NOT a substitute for mitigation

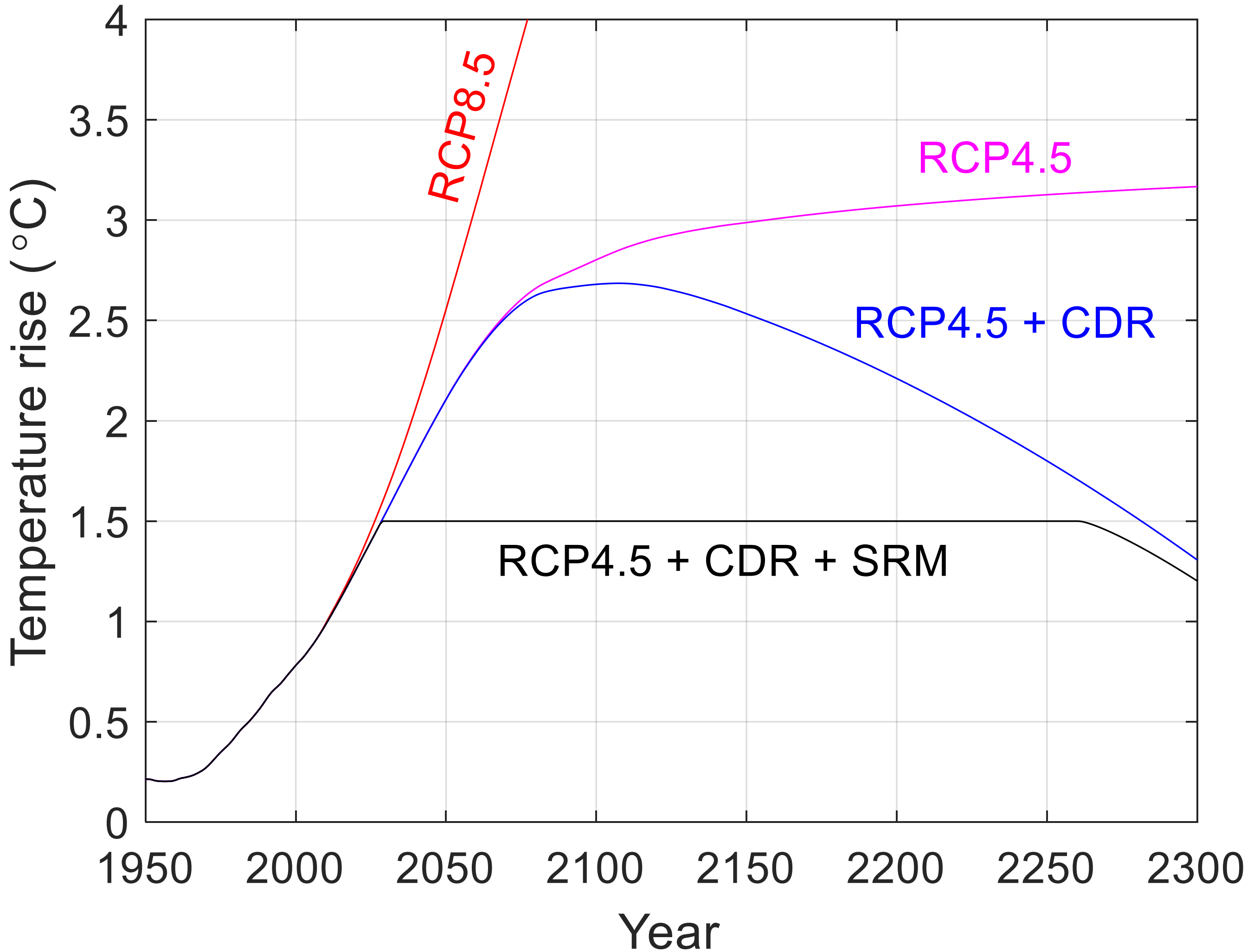


- Would require high forcing
  - Risks scale with amount
- Would require practically indefinite commitment
- Doesn't address all impacts of climate change
  - E.g. ocean acidification

A specific scenario…

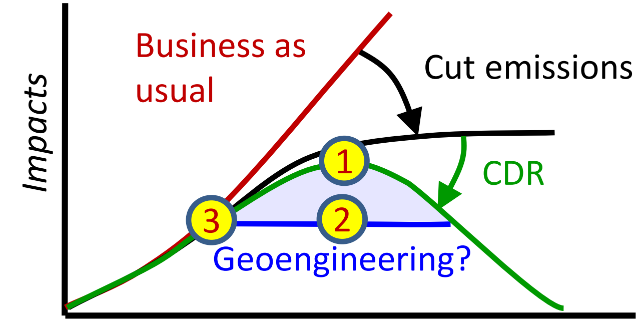
- "CDR" level is chosen to reduce CO_2 at 1ppm per year
  - Of order 15 Gt per year

- Temperature overshoots are measured in centuries



MacMartin, Ricke, Keith,
Phil. Trans. Royal Soc. A 2018

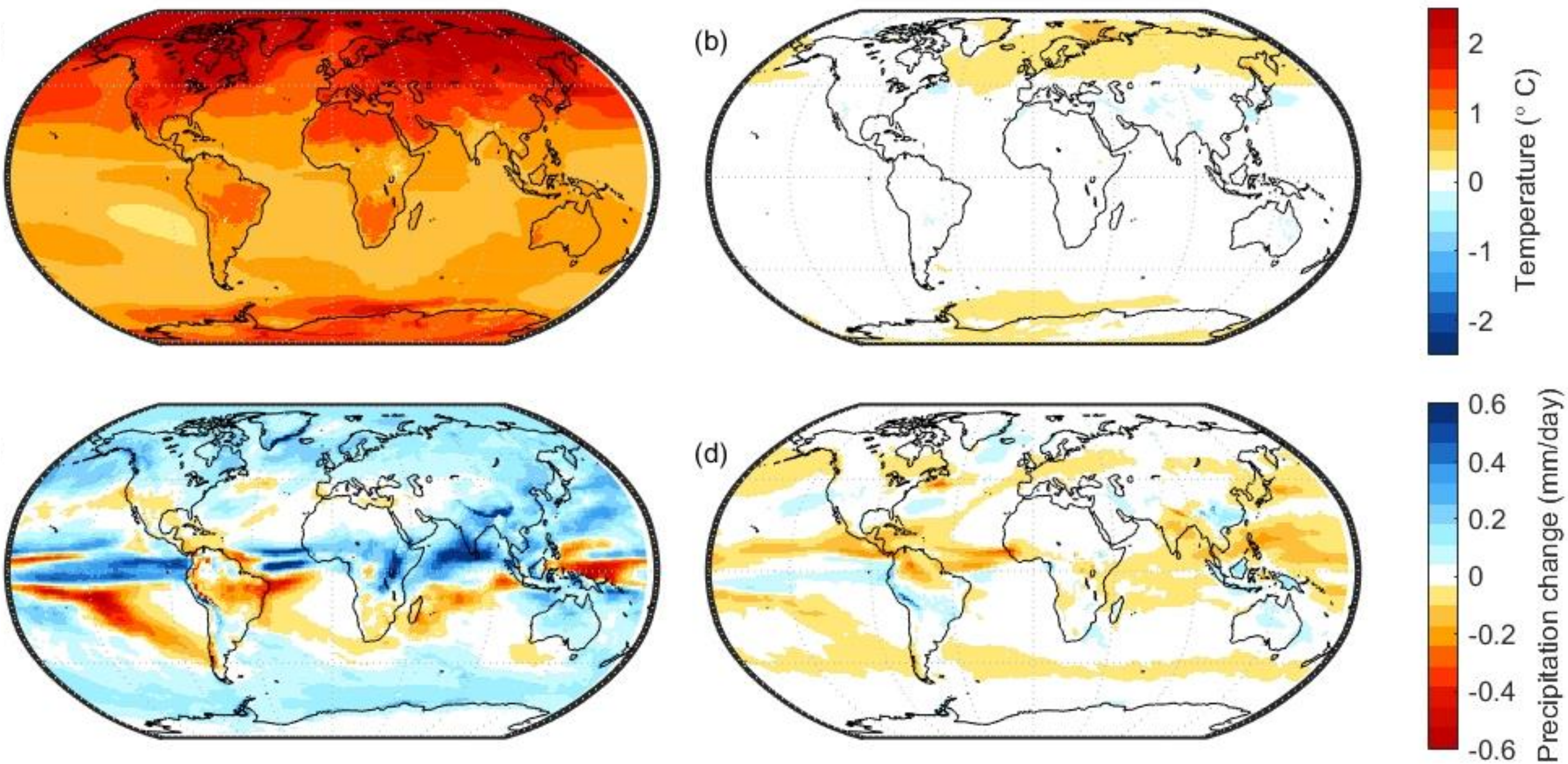
Simulations with stratospheric aerosols



1° warming from CO_2 | 1° warming offset by 1° cooling

Temperature

Precipitation



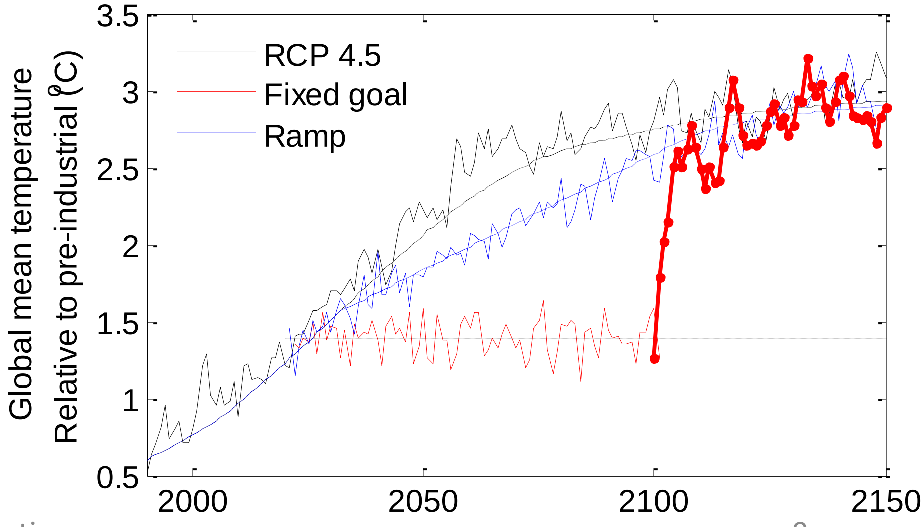
MacMartin et al, *submitted*

Key Observations for Solar geoengineering

- A limited deployment *in addition to mitigation* might reduce many climate risks and avoid tipping points
  - Ideally (if used at all) as part of an integrated strategy
- We don't know enough today to make an informed decision
  - My guess is we need ~20 years
  - Research needs to address impacts to most vulnerable
  - Research will likely require *small* outdoor experiments
  - There will always be uncertainty; this will always be a difficult tradeoff
- There are both physical climate risks and societal risks associated with solar geoengineering

Stratospheric Aerosol Geoengineering: What we know

- It would cool the planet (everywhere), and quickly
  - Reduces many climate impacts but not all, e.g. ocean acidification
- Reduces precipitation *changes* in most (not all) places
- Reduces stratospheric ozone if sulfate aerosols are used before ~2040s
- Reversible (stop injecting, effect stops after a few years)
- Relatively cheap: could have an effect for a few $B
  - *Direct* cost not relevant factor in deployment decisions
  - Dominant "cost" might be liability?



Stratospheric Aerosol Geoengineering: What don't we know?

- What size distribution of aerosol particles are created?
- Effect on stratospheric dynamics and heating, atmospheric chemistry
- What is the effect on cirrus clouds? (A positive or negative feedback?)
- Regional precipitation response remains uncertain (ditto for CO_2)
- Effect on ecosystems? Impacts?
- The ana…
- …goals?
- …well can we design the system given uncertainty, nonlinearity, and variability?
- What are the limits to how well we can know the system?
- Societal response:
  - Would people emit more CO_2?
  - Would people blame everything on the deployment?
  - How might this be governed, how would amount be adjusted over time?

This will take a LOT of research

"Forcing"

"Response" & impacts

Strategic

Societal Feedbacks

Backup

Physical-Science Research

- Research to date extremely limited
  - By a few academics mostly in US, Europe, and China

- What are the impacts of a (responsible) deployment strategy?
  - Evaluate impacts on ecosystems, agriculture, etc.
  - In every country of the world
  - Need to ensure that the right questions are being asked

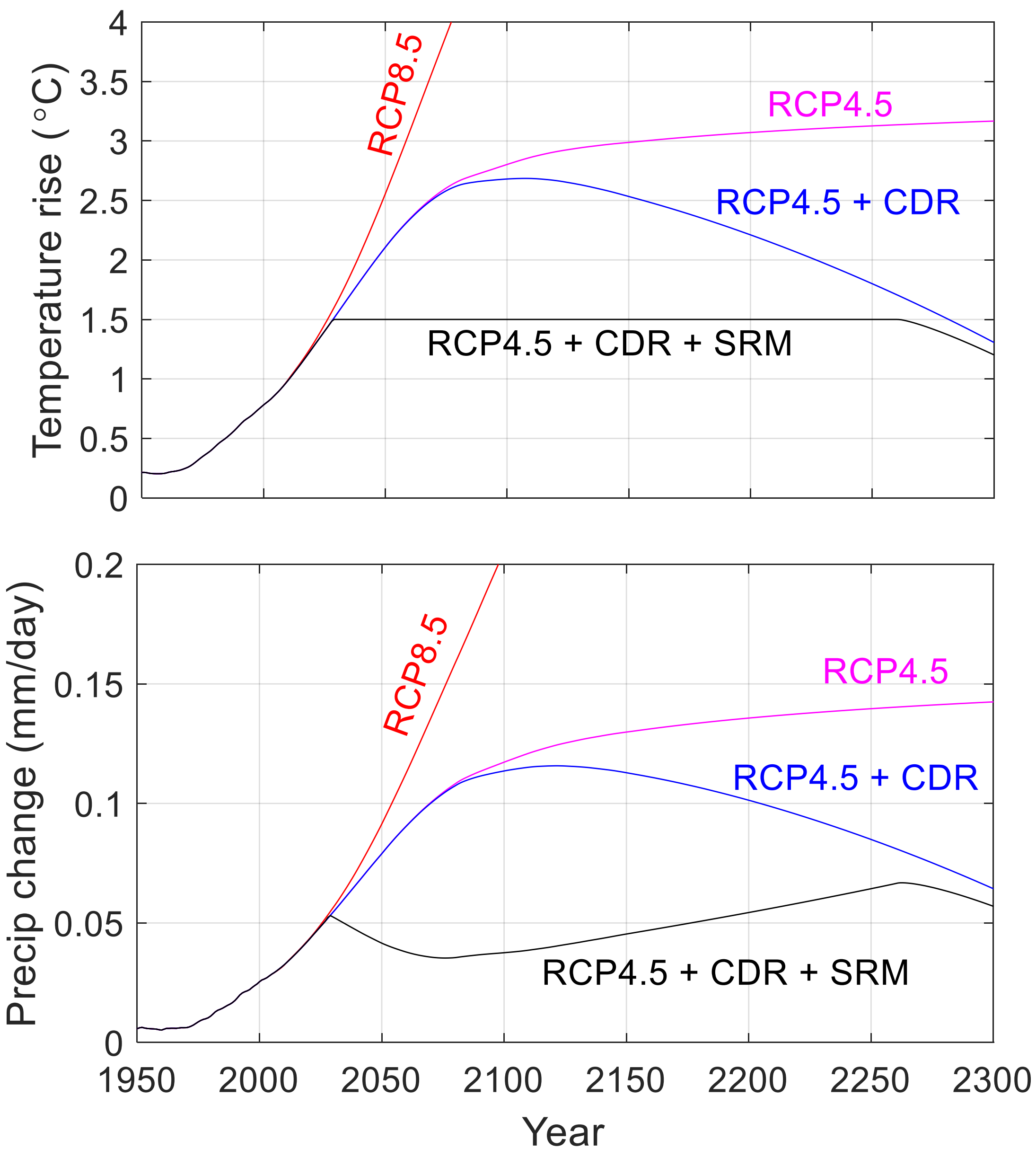
- How confident are we?
  - What is the range of possible outcomes?
  - Reducing uncertainty is likely to require some *small-scale* outdoor experimentation

Big Questions

- How confident do we need to be?
  - Some uncertainty will not be resolvable
- Who gets to decide?
  - Everyone is affected
- What happens if some places are harmed?
  - Or are perceived to be harmed?
- How do you manage deployment for centuries?
  - Without any interruption…
- How do you ensure that this isn't taken as an excuse not to mitigate?

Not all variables respond the same way

- Solar geoengineering would overcompensate global mean precipitation
- Other variables like ocean pH would hardly be affected



Summary

Context:

- Mitigation is necessary, it probably won't be sufficient to avoid serious risks
  - 2°C target requires
    - extremely aggressive reductions in emissions, combined with
    - negative emissions (or CO_2 removal)
  - 1.5°C is much harder than 2°C
  - Current INDC commitments are more likely to lead to ~3°C

A strategic approach for managing climate change

- Developing capability for CO_2 removal is essential
- It is plausible that an additional, limited deployment of solar geoengineering could reduce aggregate climate risks
  - Not enough is known today to make informed decisions
  - Raises challenging issues in ethics, governance, etc.

Extremes of heat and precipitation

- **Effective at reducing temperatures in general and therefore extreme heat events**

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE
10.1002/2013JD020648

Special Section:
The Geoengineering Model Intercomparison Project (GeoMIP)

A multimodel examination of climate extremes in an idealized geoengineering experiment

Charles L. Curry[1], Jana Sillmann[1,2], David Bronaugh[3], Kari Alterskjaer[2], Jason N. S. Cole[4], Duoying Ji[5], Ben Kravitz[6], Jón Egill Kristjánsson[2], John C. Moore[5], Helene Muri[2], Ulrike Niemeier[7], Alan Robock[8], Simone Tilmes[9], and Shuting Yang[10]

Sea level rise

- **Projected that SRM could significantly slow (but not stop) rising sea levels**

PNAS

Efficacy of geoengineering to limit 21st century sea-level rise

J. C. Moore[a,b,c,1], S. Jevrejeva[d], and A. Grinsted[e]

[a]College of Global Change and Earth System Science, Beijing Normal University, China; [b]Arctic Centre, University of Lapland, PL122, 96100 Rovaniemi, Finland; [c]Thule Institute, University of Oulu, PL3000, 90014 Oulun Yliopisto, Finland; [d]National Oceanography Centre, Joseph Proudman Building, 6 Brownlow Street, Liverpool L3 5DA, United Kingdom; and [e]Centre for Ice and Climate, Niels Bohr Institute,University of Copenhagen, Copenhagen, Denmark

Edited by Robert E. Dickinson, University of Texas, Austin, TX, and approved July 15, 2010 (received for review June 12, 2010)

Geoengineering has been proposed as a feasible way of mitigating anthropogenic climate change, especially increasing global temperatures in the 21st century. The two main geoengineering

and financially reasonable—in so far as any geoengineering project may be thought of as feasible. Here we present simulations of 21st century global sea level resulting from both geoengineered

Effects on plant life and agriculture

- **Many factors, many variables, much more research necessary**

nature climate change
LETTERS
PUBLISHED ONLINE: 22 JANUARY 2012 | DOI: 10.1038/NCLIMATE1373

Crop yields in a geoengineered climate

J. Pongratz[1]*, D. B. Lobell[2], L. Cao[1] and K. Caldeira[1]

AGU PUBLICATIONS
JGR
Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE
10.1002/2013JD020630

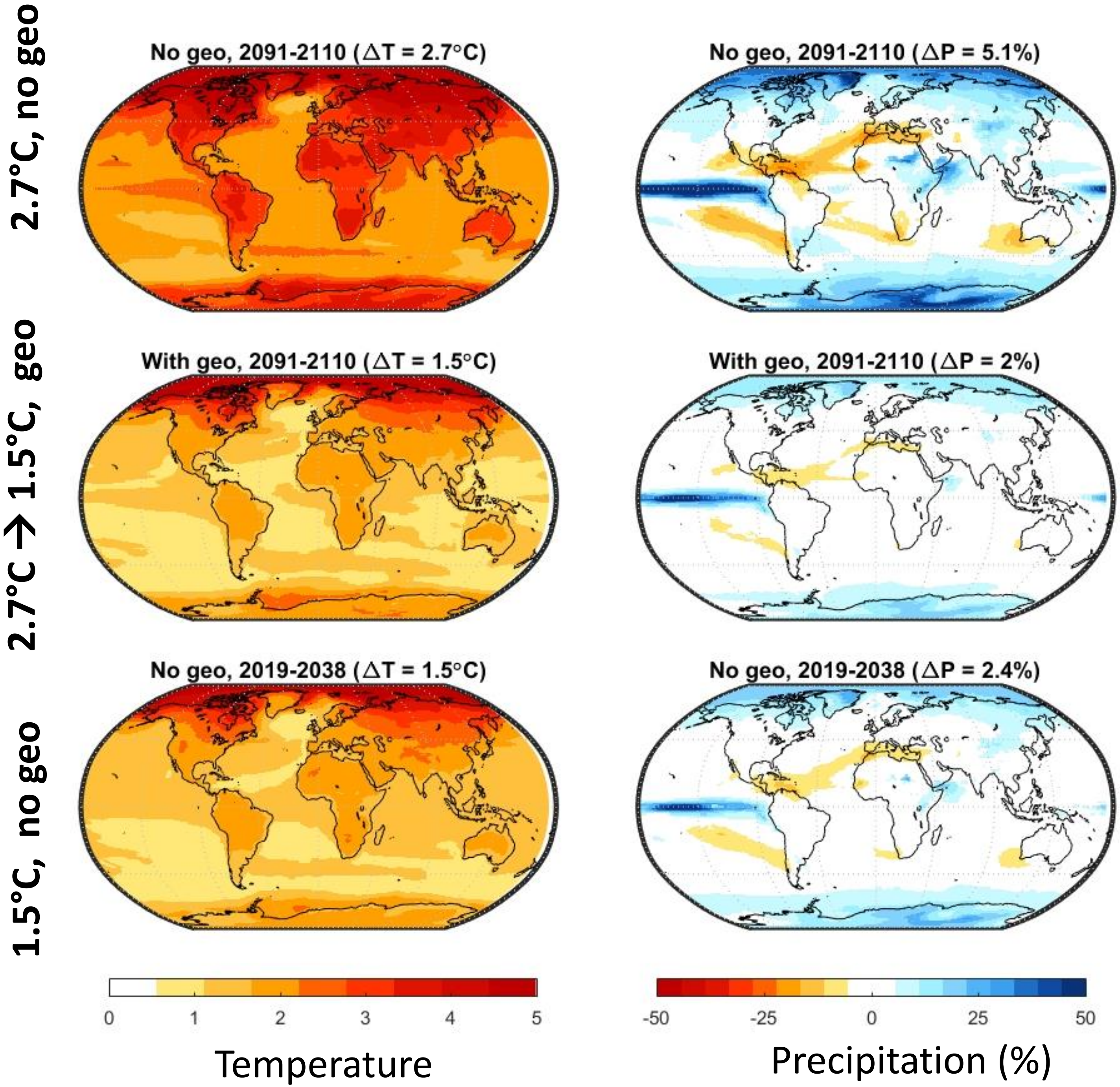
Special Section:
The Geoengineering Model Intercomparison Project (GeoMIP)

Solar radiation management impacts on agriculture in China: A case study in the Geoengineering Model Intercomparison Project (GeoMIP)

Lili Xia[1], Alan Robock[1], Jason Cole[2], Charles L. Curry[3], Duoying Ji[4], Andy Jones[5], Ben Kravitz[6], John C. Moore[4], Helene Muri[7], Ulrike Niemeier[8], Balwinder Singh[6], Simone Tilmes[9], Shingo Watanabe[10], and Jin-Ho Yoon[6]

Median over 12 models:

- Temperature is reduced everywhere
- Precipitation changes are reduced in most places
- Median hides model uncertainty!
- Solar reduction; not same as stratospheric aerosols



Options

CO_2-removal

- BECCS (bio-energy with carbon capture and sequestration)
- Direct air capture (DAC)
- Afforestation/reforestation
- Carbon-smart soil management
- Enhanced mineral weathering
- Ocean iron fertilization??

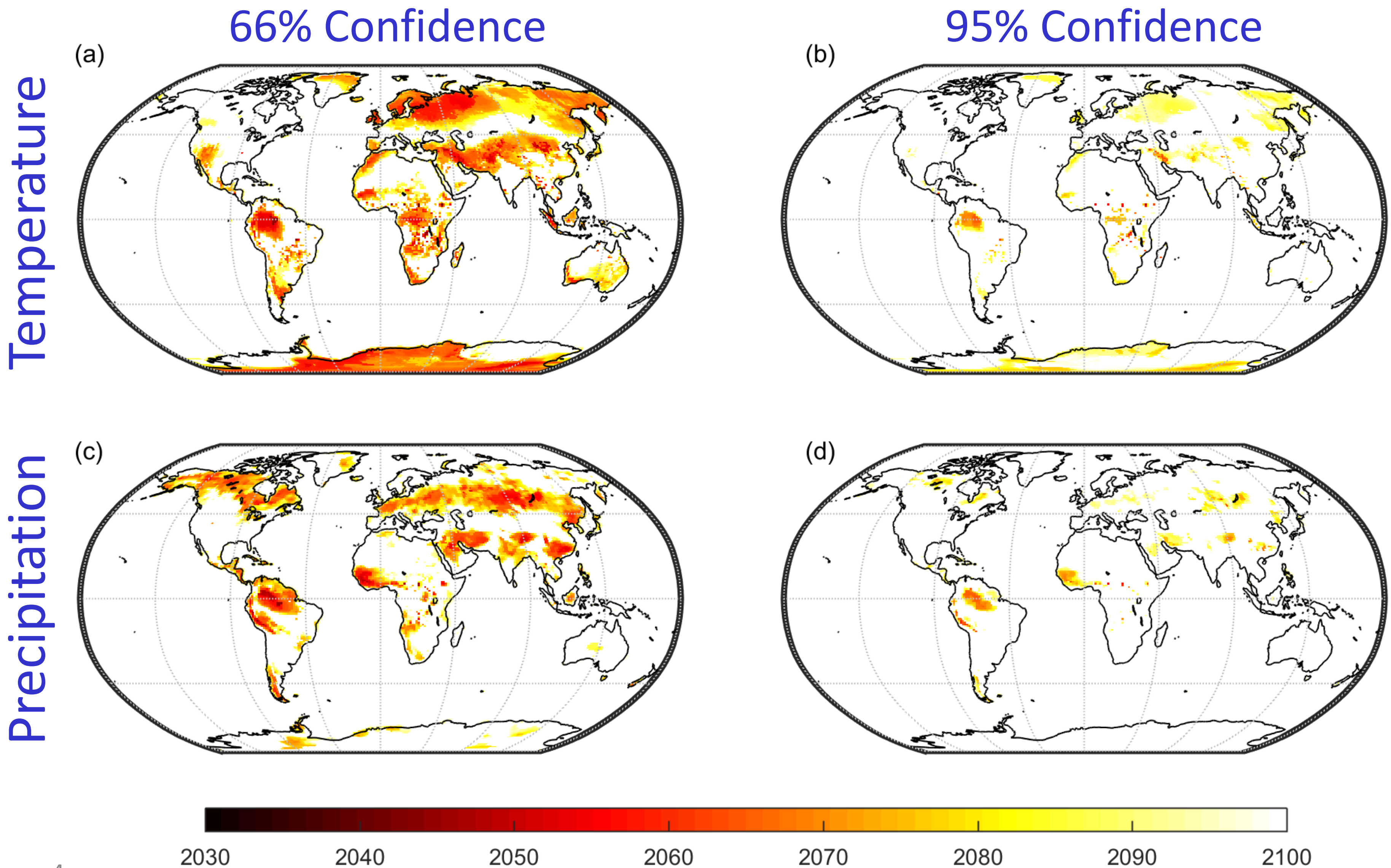
- Typically either expensive or hard to do at sufficient scale
- Low climate risk but potentially significant local issues if deployed at scale

Solar geoengineering

- Stratospheric aerosols
  - Guaranteed to "work", relatively straightforward to implement
- Marine cloud brightening
  - Cloud aerosol interactions
- Cirrus cloud thinning??
- Ocean albedo, land albedo,…

- Cools quickly
- Doesn't affect the climate the same way as increased CO_2
- Novel risks, both climate and socio-political

Detection: Moderate Scenario (1.5°C with RCP4.5)



MacMartin et al, submitted