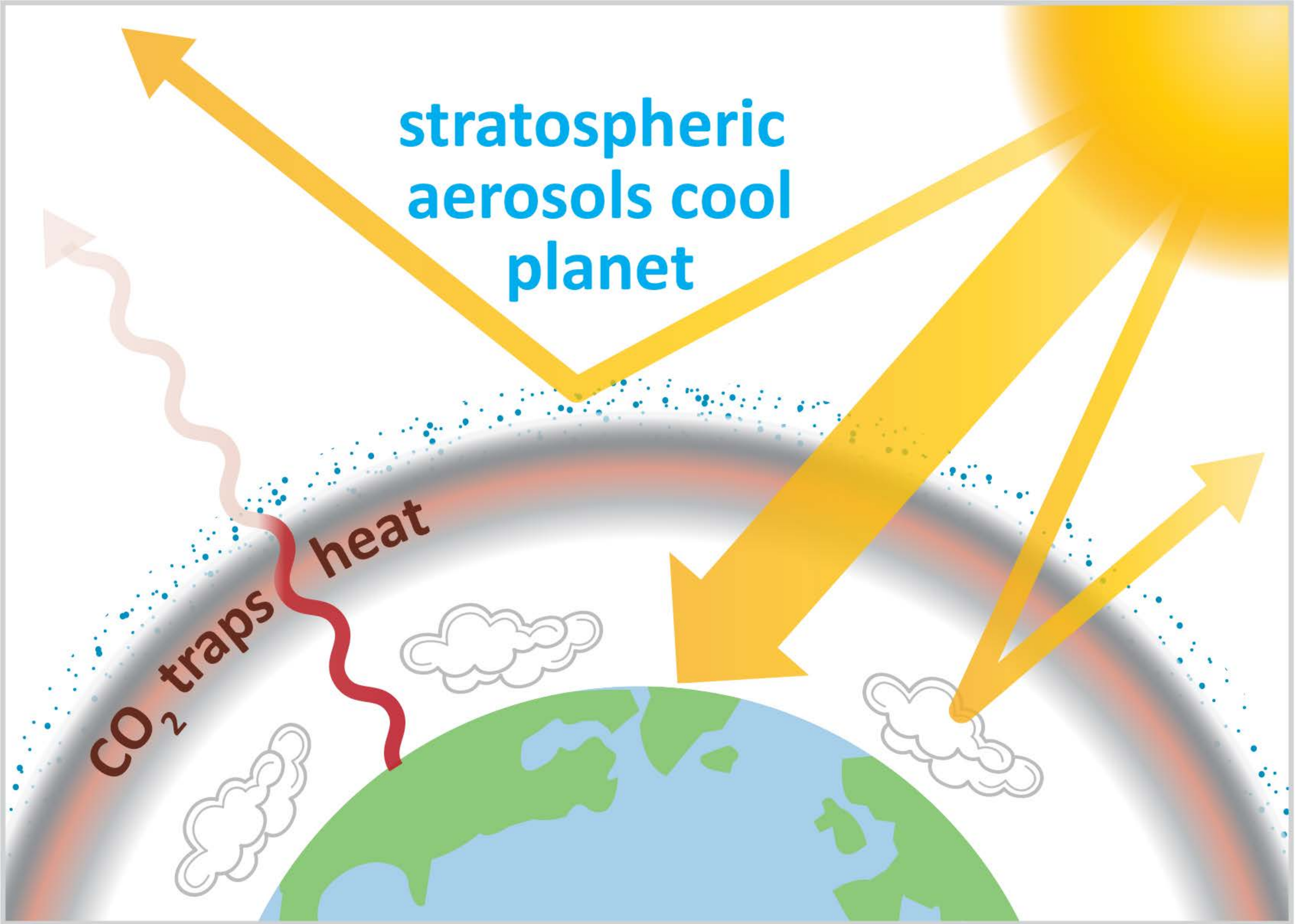
stratospheric aerosols cool planet
CO_2 traps heat

Method	Confidence that substantial global ΔRF (e.g. > 3 Wm^{-2}) is achievable	Advantage	Disadvantage
Strat sulfates	Very high: Current technologies can likely be adapted to loft materials and disperse SO_2 and relevant scales	Similarity to volcanic sulfate gives empirical basis for estimating efficacy and risks	Hard to adjust zonal distribution; ozone loss; stratospheric heating
Other strat aerosol	Moderate: depends on aerosol, lofting similar to sulfate but aerosol dispersal much more uncertain	Some solid aerosols may have less strat heating and minimal ozone loss	Hard to adjust zonal distribution; higher uncertainty than sulfates
Marine clouds	Uncertain: observations support wide range of CCN impact on albedo; significant work on development of spray systems, but no system-level analysis of cost of deployment	Ability to make local alterations of albedo; ability to albedo modulate on short timescales.	Only applicable on marine stratus covering ~10% of earth means RF inherently patchy; fast timescale rases termination risk
Cirrus	Uncertain: deep uncertainty about fraction of cirrus strongly depended on homogeneous nucleation; no studies of dispersal technologies nor system studies examining diffusion off CCN and link to flight profiles	Works on LW more than SW so could provide better compensation than "perfect" strat or space-based scatters; better RF uniformity that MCB	More ability to adjust zonal distribution that strat aerosols, perhaps less meridional adjustability.
Space based	Low physical uncertainty, but deep technological uncertainties about cost and feasibility	Possibility of near "perfect" alteration of solar constant. Spectral tailoring may be easier	Some methods (e.g. L1 point) would not allow zonal or meridional tailoring of RF

Wake Smith's study

Scenario: 0.1 Mt/year ramping to 1 Mt/year in 10 years, delivery to 20 km (66 kft)

Info gathered from: Boeing, Airbus, Gulfstream, Bombardier, Northrup, Lockheed, Pratt & Whitney, Virgin Orbit, The Spaceship Company (another Virgin affiliate), Scaled Composites, Worldview, Near Space Corporation, and NASA in respect of its ER2, Global Hawk, and WB57 research aircraft

Findings:

- No existing or readily modified aircraft works. Aurora study was wrong about reengined biz jets, max is ~53 kft.
- Aircraft design: un-swept wings; four engines at least; small dia fuselage 25 – 35 metric ton payload, capable of level flight at 66 kft
- Development costs (both aircraft and airline): ˜ $2.5 billion
- Operational costs (aggregate) for years 1 – 5: ˜ $3.5 billion
- Total costs through year 5 (ie, required capitalization): ˜ $6 billion
- Cost per injected ton for first decade: ˜ $2,000

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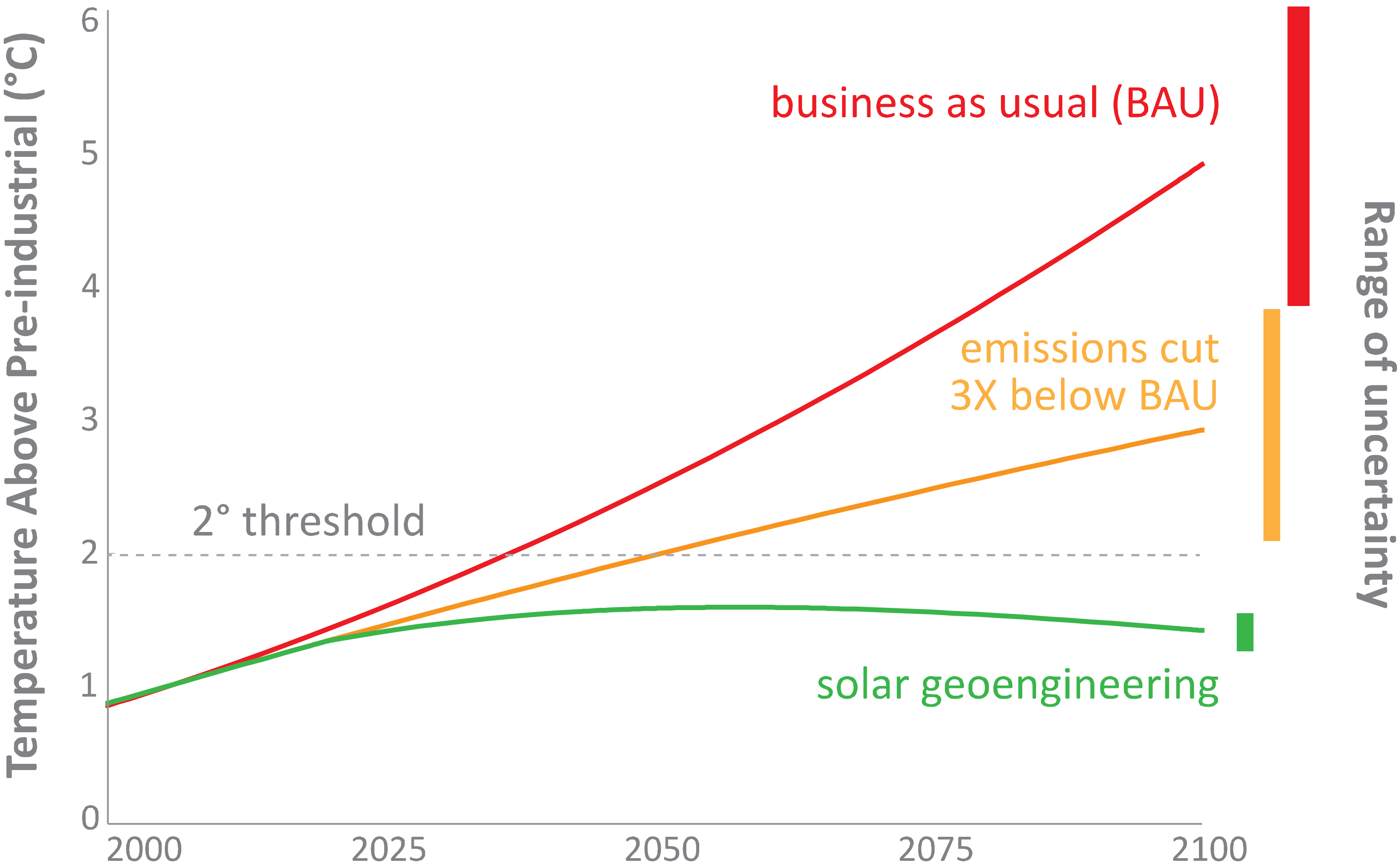
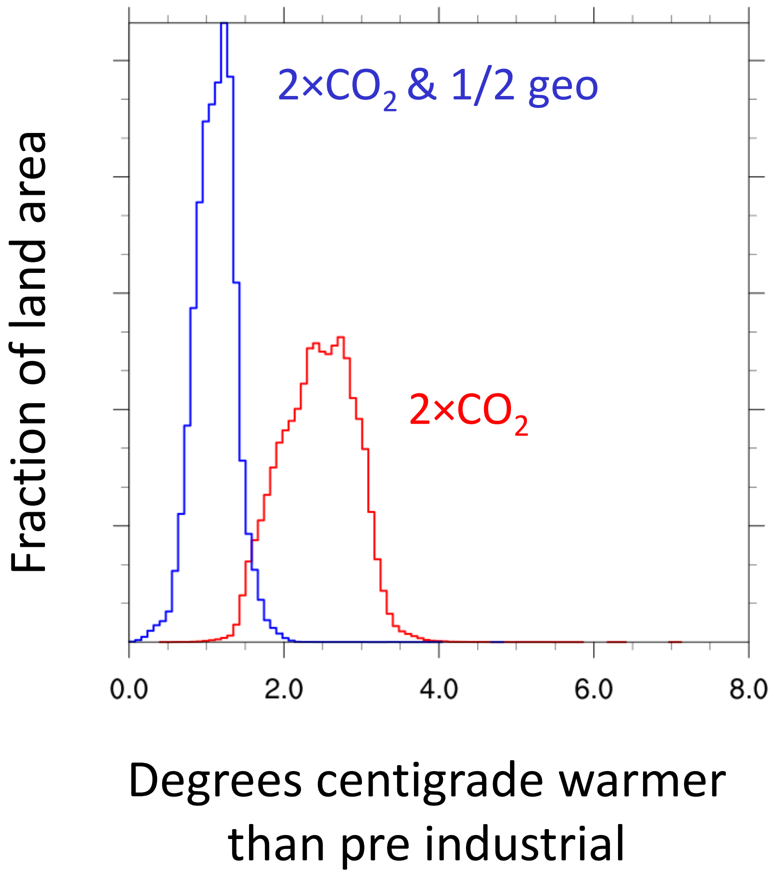

Temperature Above Pre-industrial (°C)
6
5
4
3
2
1
0
2000
2025
2050
2075
2100
business as usual (BAU)
emissions cut
3X below BAU
2° threshold
solar geoengineering
Range of uncertainty

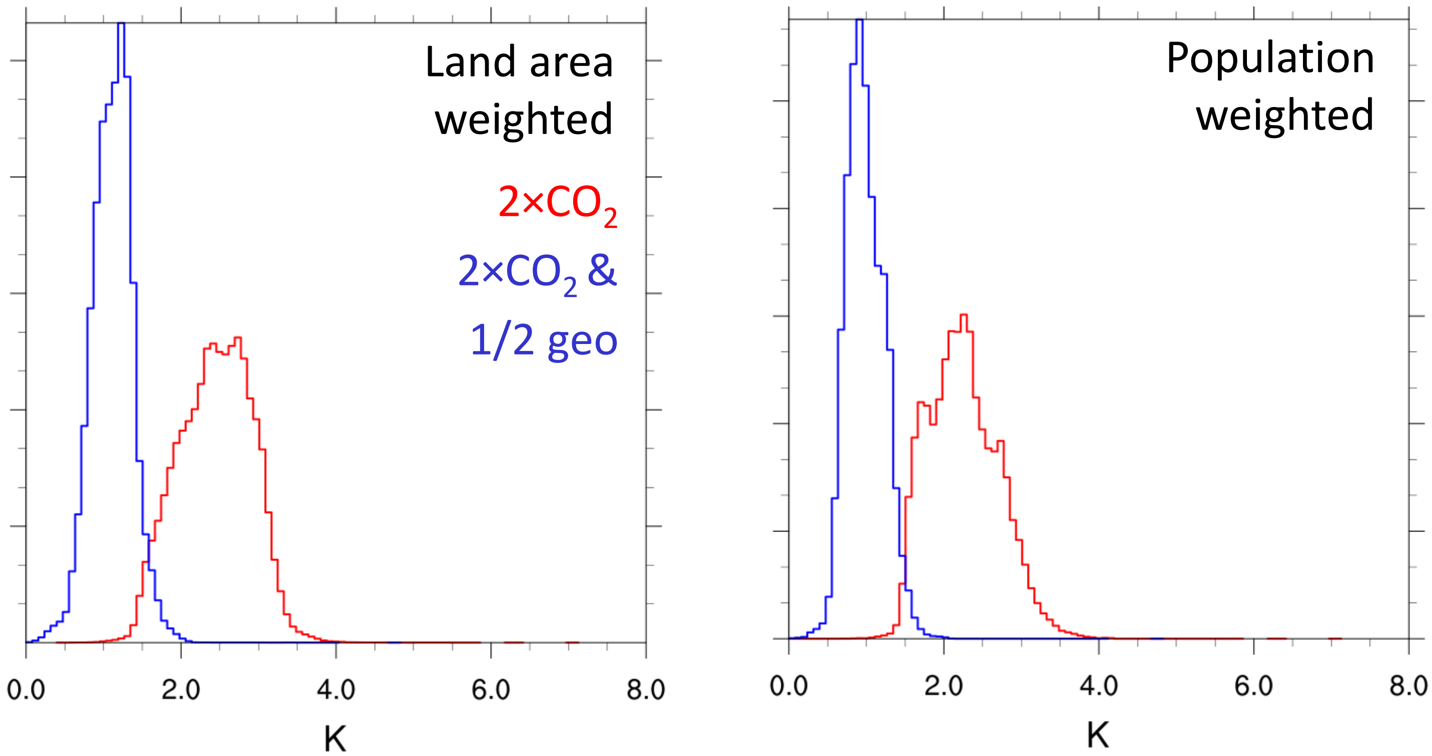
Annual maximum temperatures



Annual maximum temperatures

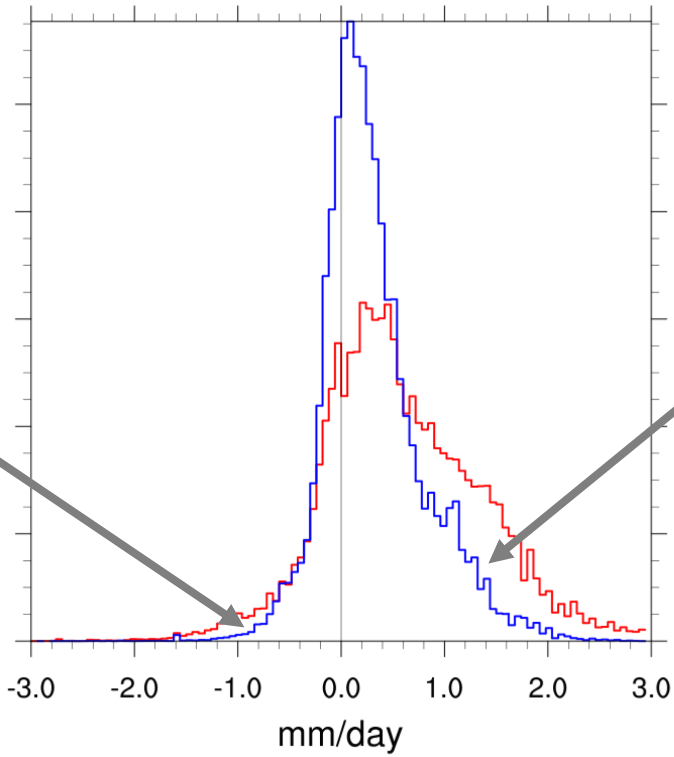
If better defined as
closer to pre-industrial

Better = 100%
Worse = 0%
Don't Know = 0%



Annual max 5-day precipitation from GFDL HiFLOR, thanks to Gabriel Vecchi at Princeton University, Larry Horowitz and Jie He at GFDL and Peter Irvine at Harvard University

Extreme precipitation



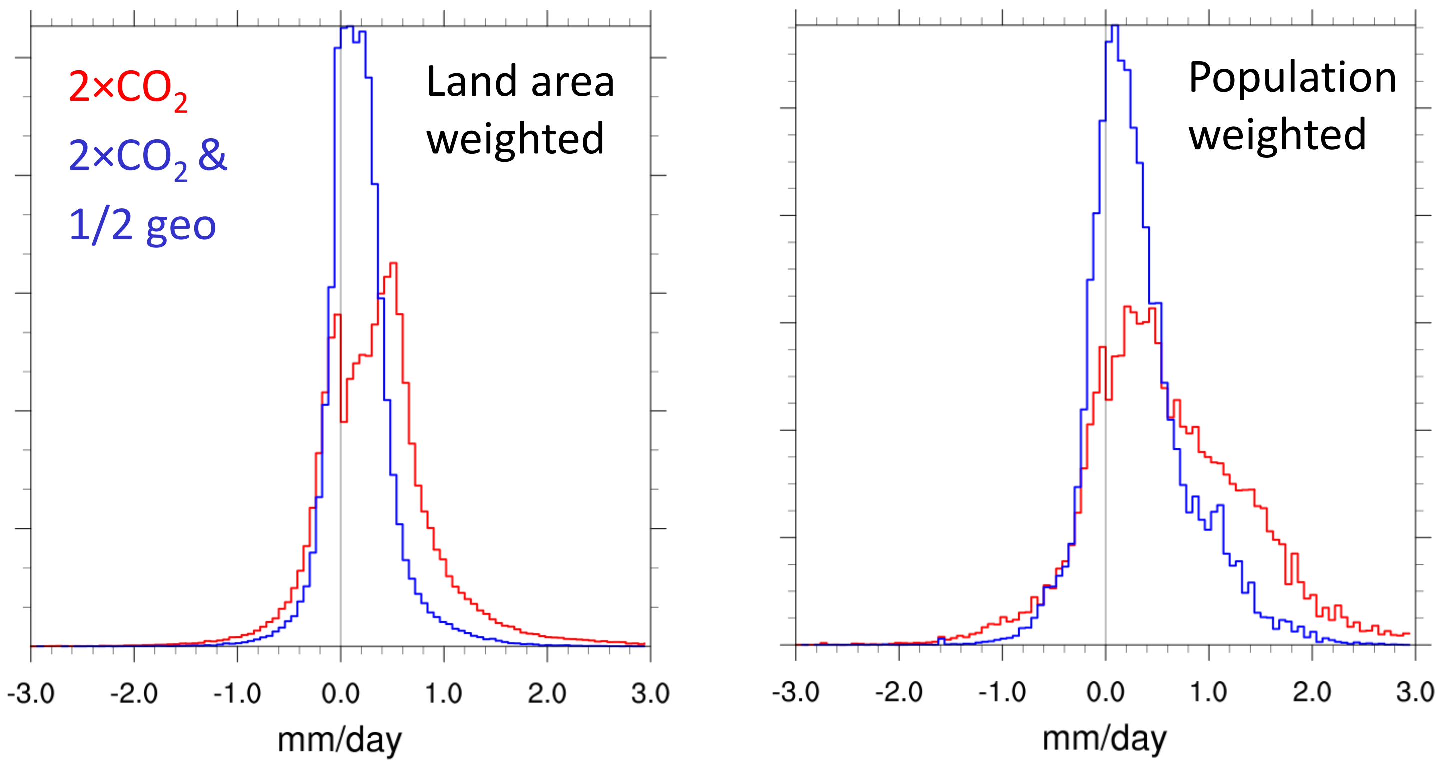
Significant reduction in ***decreases*** in precipitation

Big reduction in ***increases*** in precipitation

Extreme precipitation

If better defined as
closer to pre-industrial

Better = 45%
Worse = 1%
Don't Know = 54%



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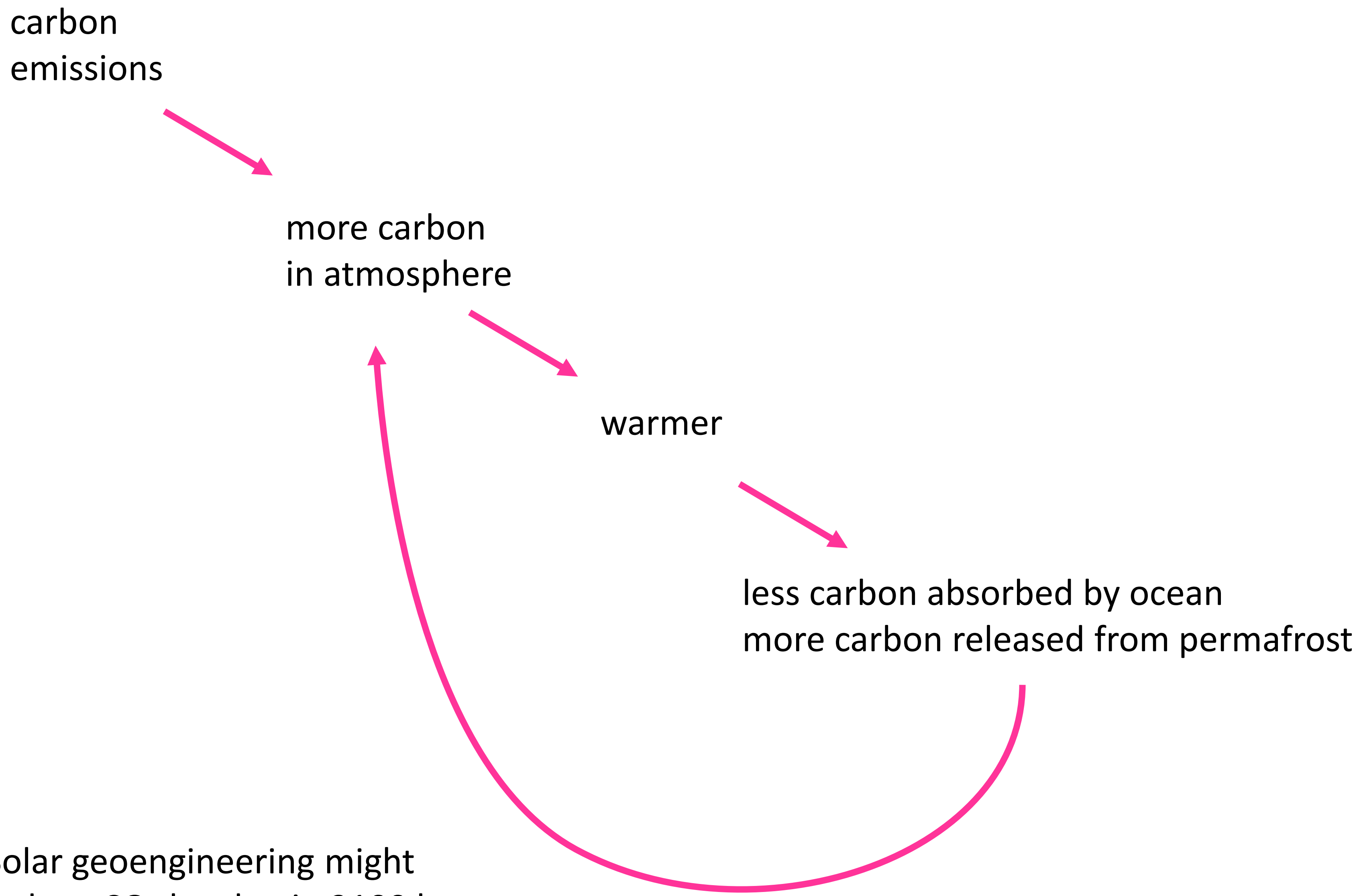
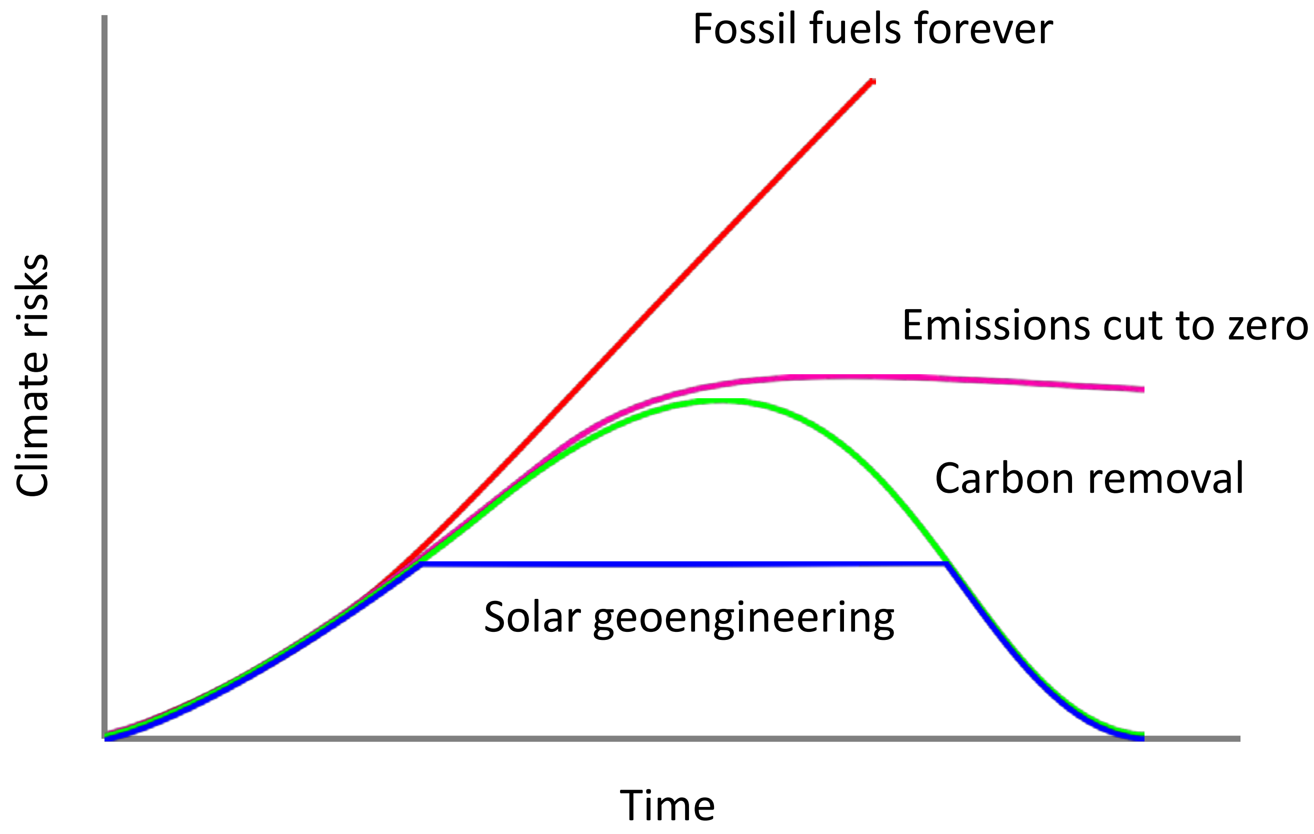
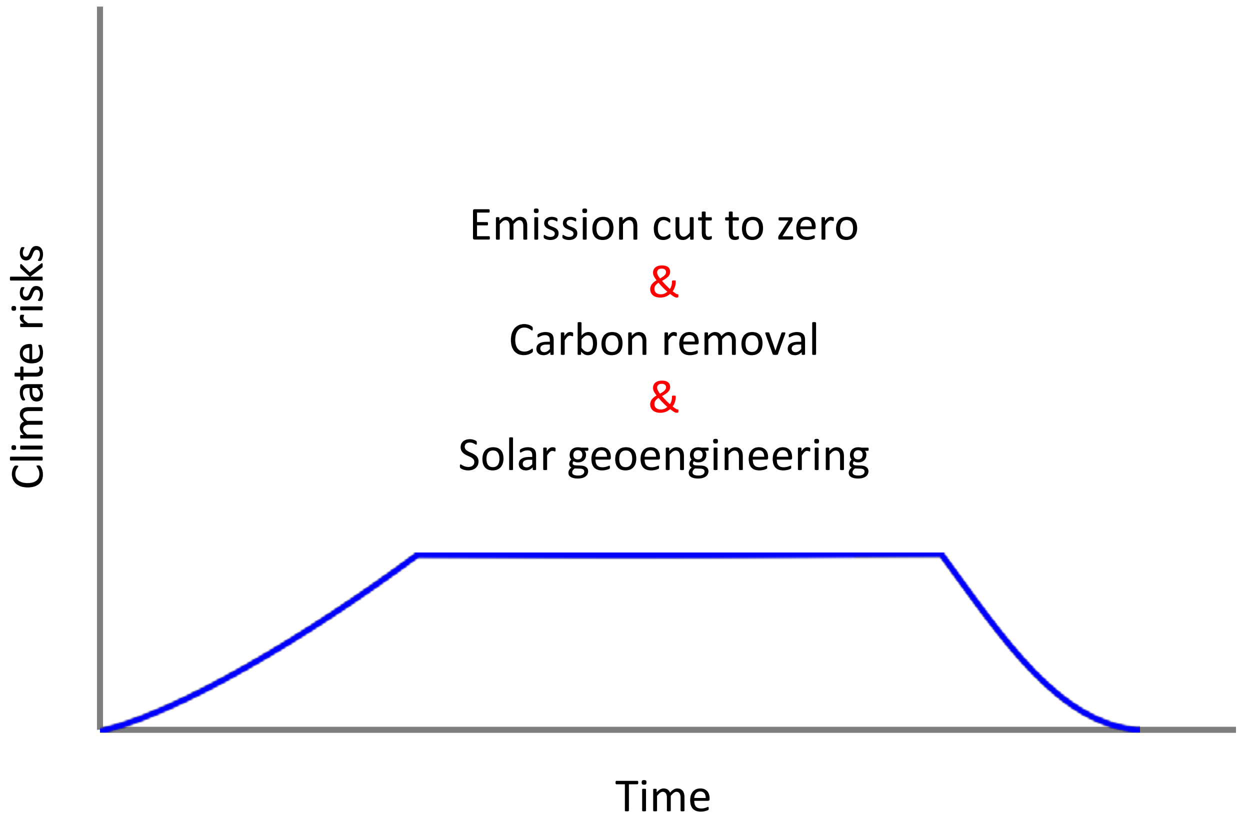


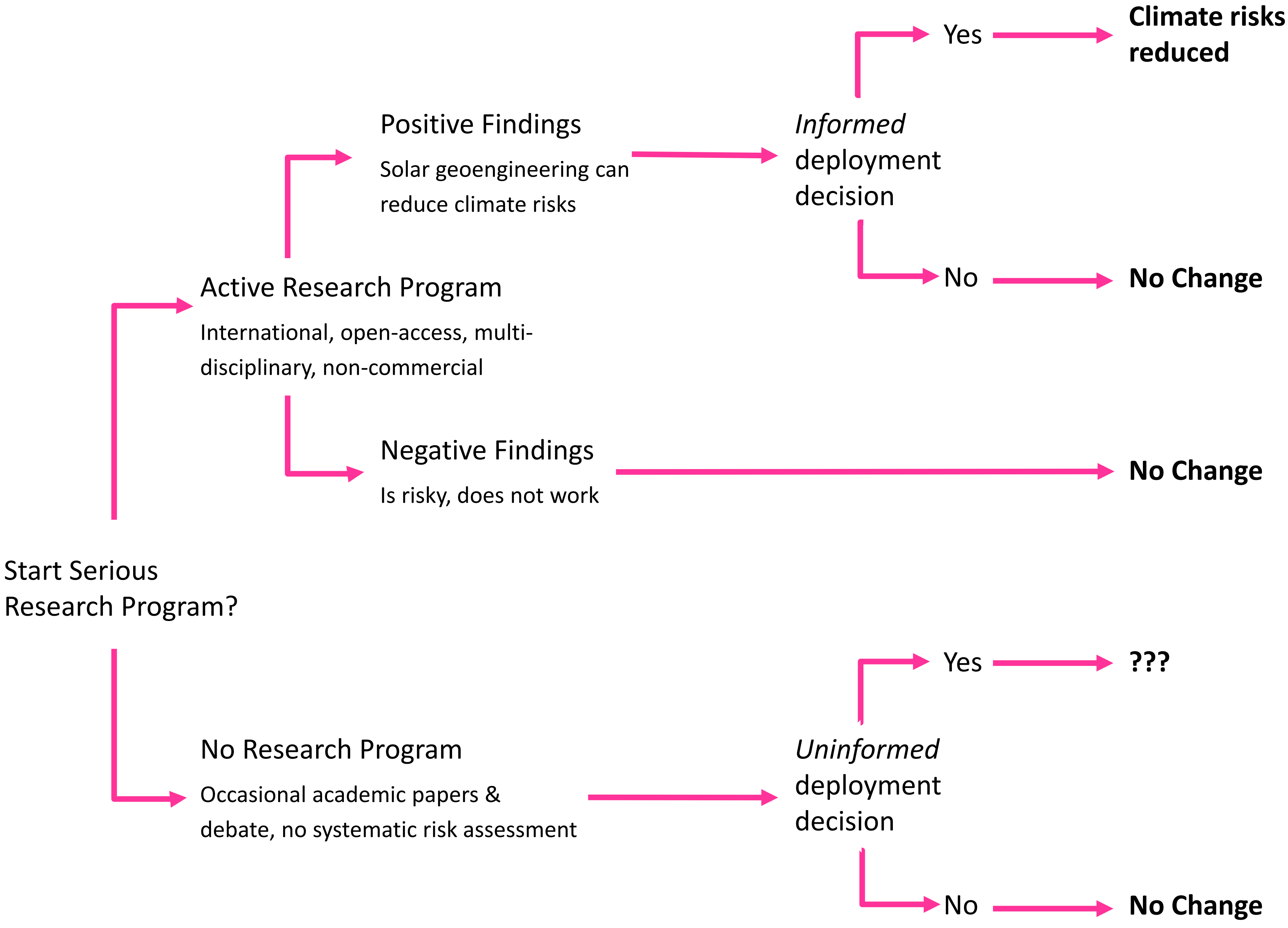
Carbon cycle feedbacks

Solar geoengineering might reduce CO_2 burden in 2100 by 5-25% at a cost of <0.5 \$/tCO_2

Solar geoengineering reduces atmospheric carbon burden, Keith, Wagner, and Zabel, *Nature Climate Change,* 2017


Fossil fuels forever
Emissions cut to zero
Carbon removal
Solar geoengineering
Climate risks
Time


Climate risks
Emission cut to zero
&
Carbon removal
&
Solar geoengineering
Time



Start Serious
Research Program?
Active Research Program
International, open-access, multi-disciplinary, non-commercial
Positive Findings
Solar geoengineering can reduce climate risks
Informed deployment decision
Yes
Climate risks reduced
No
No Change
Negative Findings
Is risky, does not work
No Change
No Research Program
Occasional academic papers & debate, no systematic risk assessment
Uninformed deployment decision
Yes
???
No
No Change

Harvard’s Solar Geoengineering Research Program (SGRP)

A Harvard-wide interdisciplinary program housed in Harvard’s Center for the Environment

Three broad research tracks:

- Advancing science and technology
- Assessing efficacy and risks
- Governance and social implications

Program governed by an advisory committee composed of Peter Huybers, David Keith (Faculty Director), Dan Schrag, Elsie Sunderland, Dustin Tingley, and Gernot Wagner (Executive Director)

Funding target: $10 to $20 million program over 5 to 7 years

Opportunities: graduate and post-doctoral fellowships, faculty research grants, and a residency program to support visiting scholars working with members of the Harvard community

geoengineering.environment.harvard.edu