Should we do Geoengineering Research?

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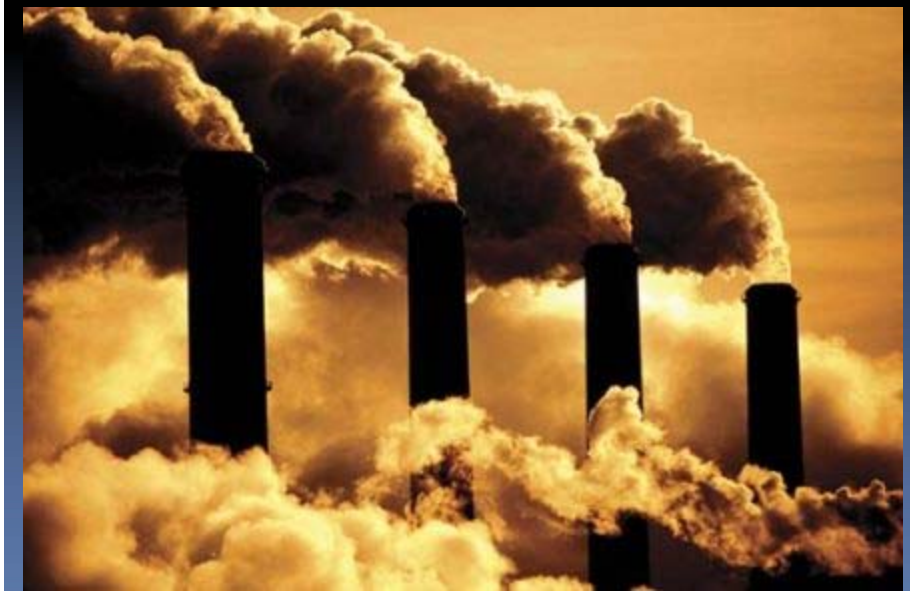
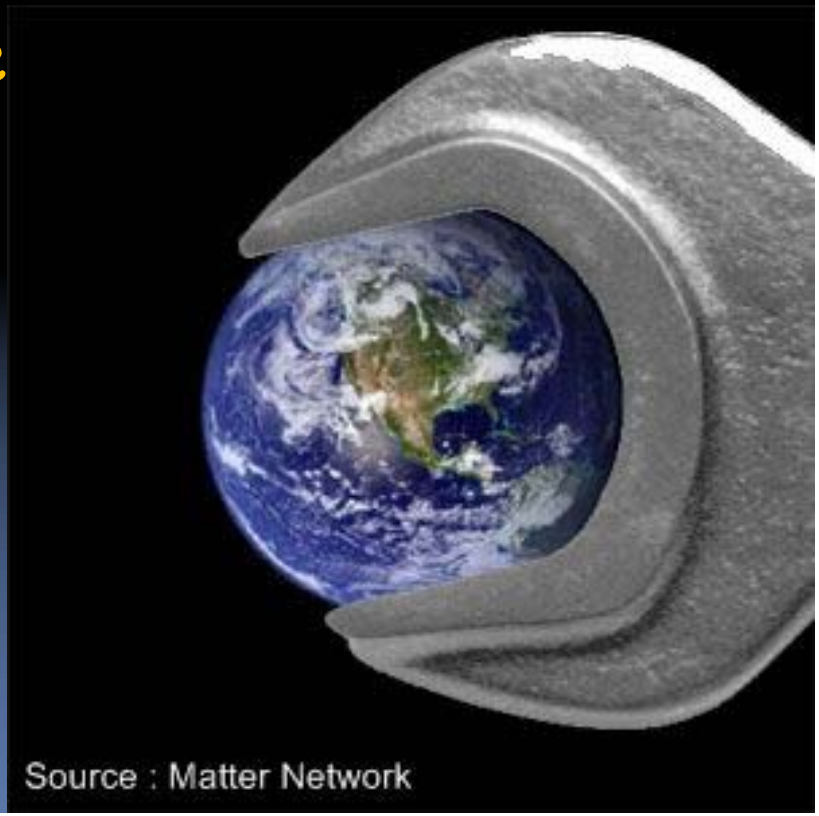




Context

What should we do if we cannot reduce fossil fuel emissions or climate change becomes unmanageable and there is a planetary emergency?

Should geoengineering be considered?

What is geoengineering?

It is the "Intentional" "Large-scale" manipulation of the climate system.

Geoengineering schemes are broadly categorized into Solar Radiation Management (SRM) and Carbon Dioxide Removal (CDR) geoengineering schemes.

SRM

CDR

SRM and CDR

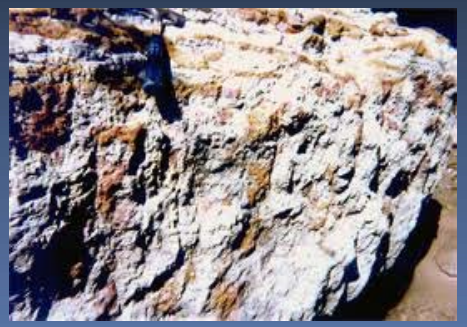
SRM: Reduction of solar absorption (~2% to counter 2xCO2) by the planet to balance the increase in long wave absorption

CDR: Methods that accelerate the *removal* of atmospheric CO2

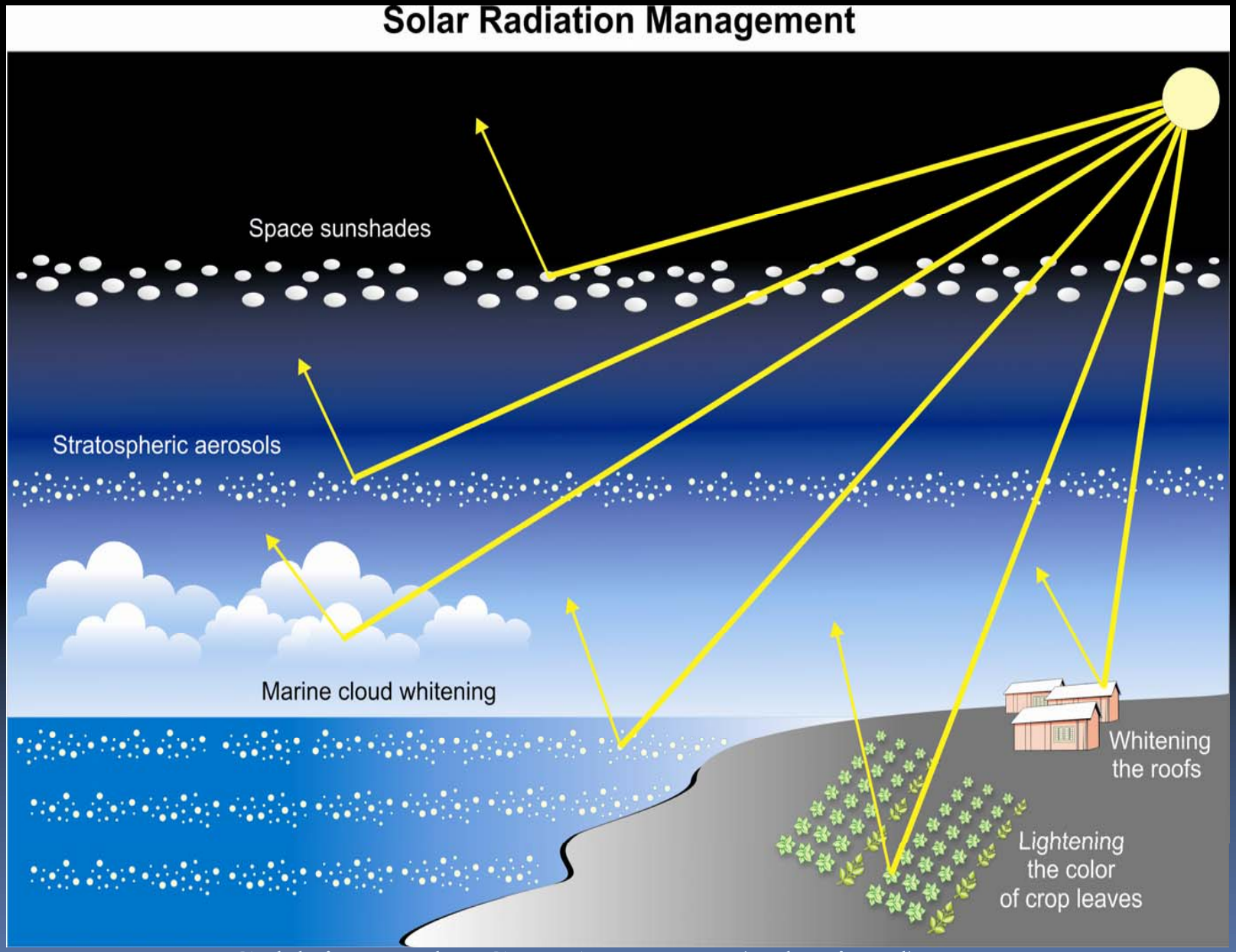
Natural Analogs for SRM and CDR

SRM: Volcanoes

CDR: Biological uptake by plants over land and oceans and chemical weathering of rocks

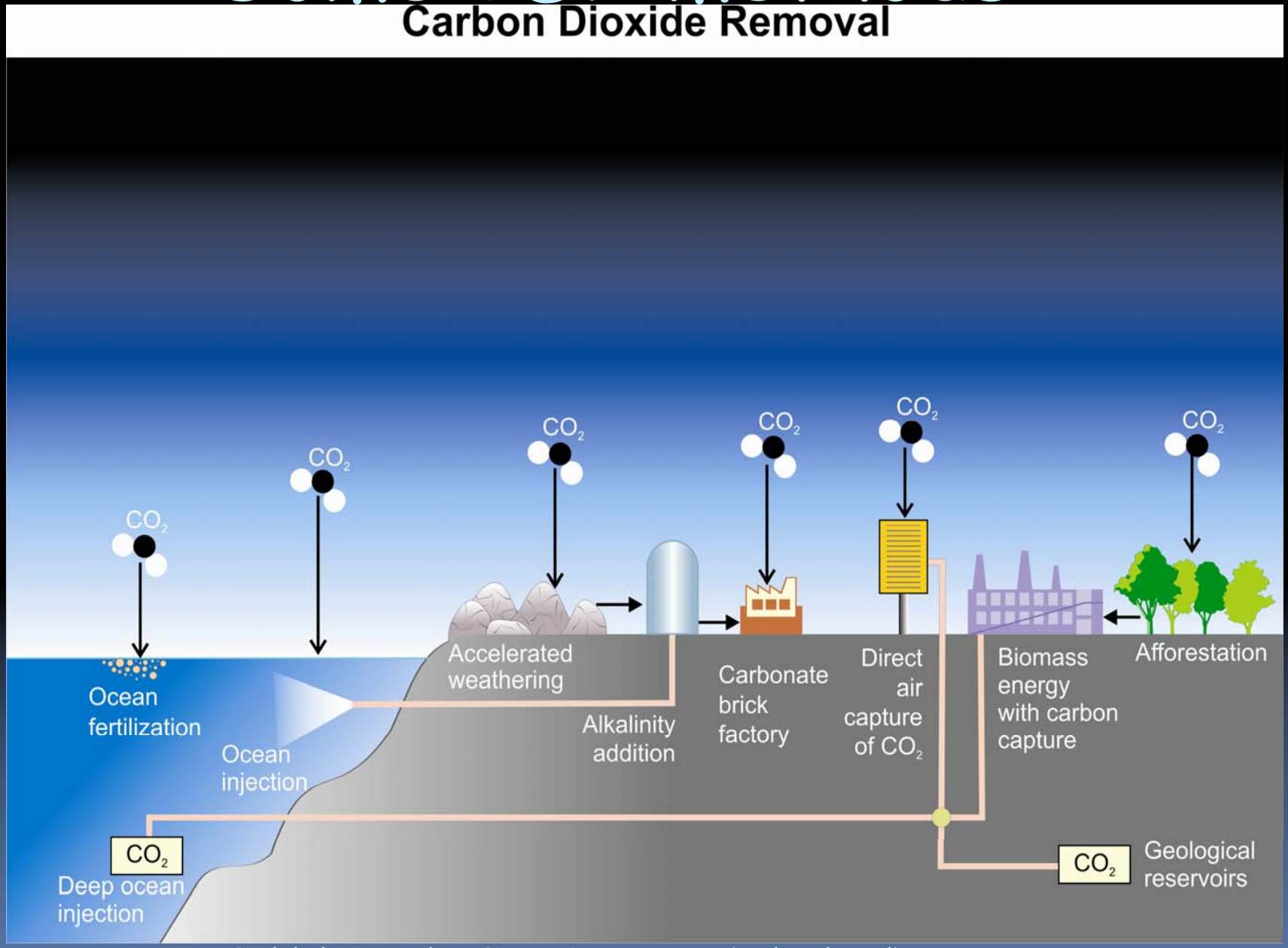


Some SRM methods



Caldeira, Bala, Cao, Ann Rev. (submitted)

Some CDR methods

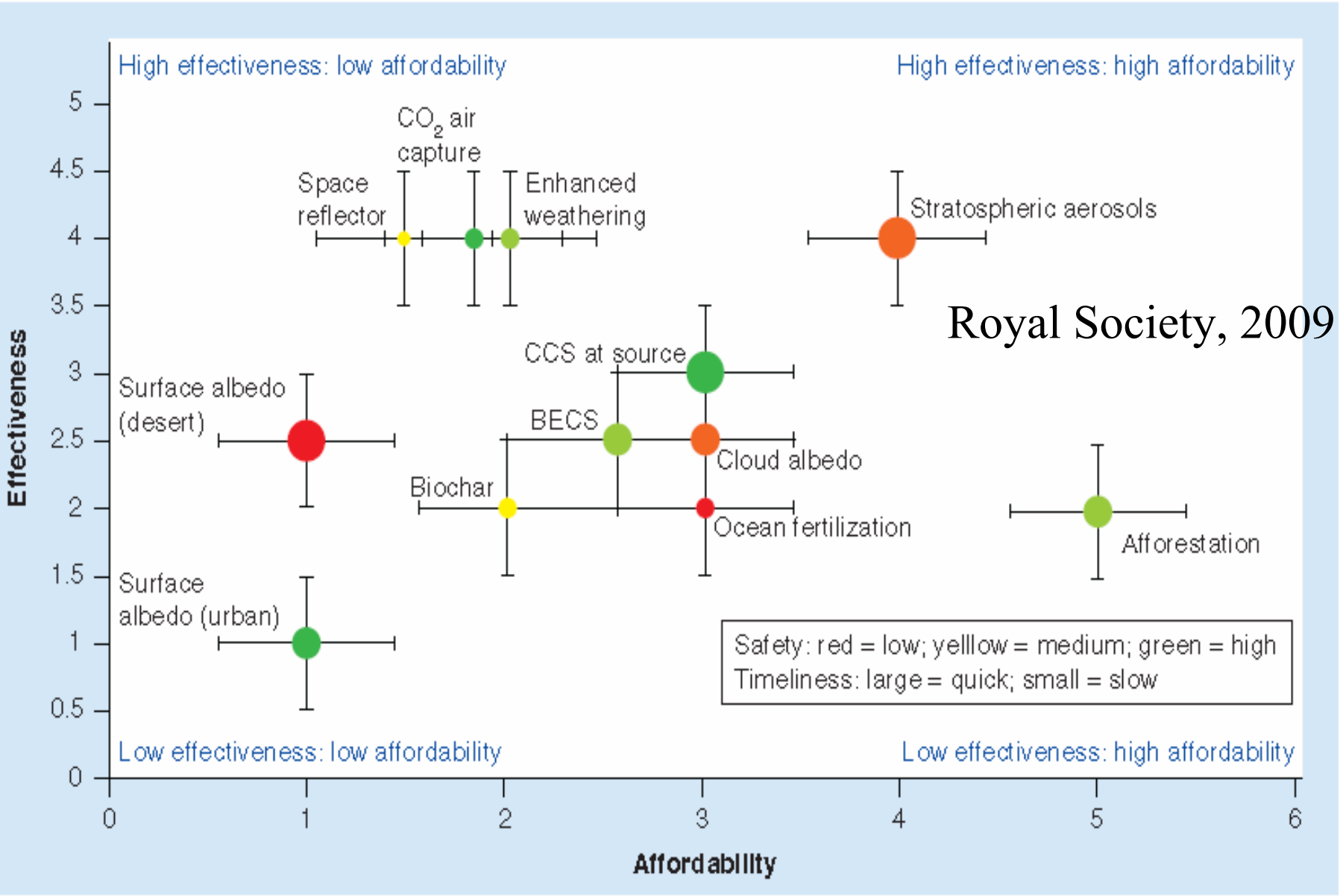


Caldeira, Bala, Cao, Ann Rev. (submitted)

Pros and Cons

SRM	CDR
Acts on the effects of climate change	Acts on the root cause of climate change
Can rapidly reduce global warming	Slow and will take long time
Ocean acidification not addressed	Ocean acidification addressed
Termination problem	Less risky
Some are Cheap	Current costs are high

Affordability



Royal Society, 2009

The trigger for recent debate on geoengineering

Karin Jackson, U.S. Air Force

Mount Pinatubo erupting on June 12, 1991, as seen from Clark Air Force base eight miles away

Nobel Laureate Paul Crutzen's paper in Climatic Change (2006)

Advocates artificial injection of sulfate aerosols into the stratosphere

Explosion of research papers on geoengineering

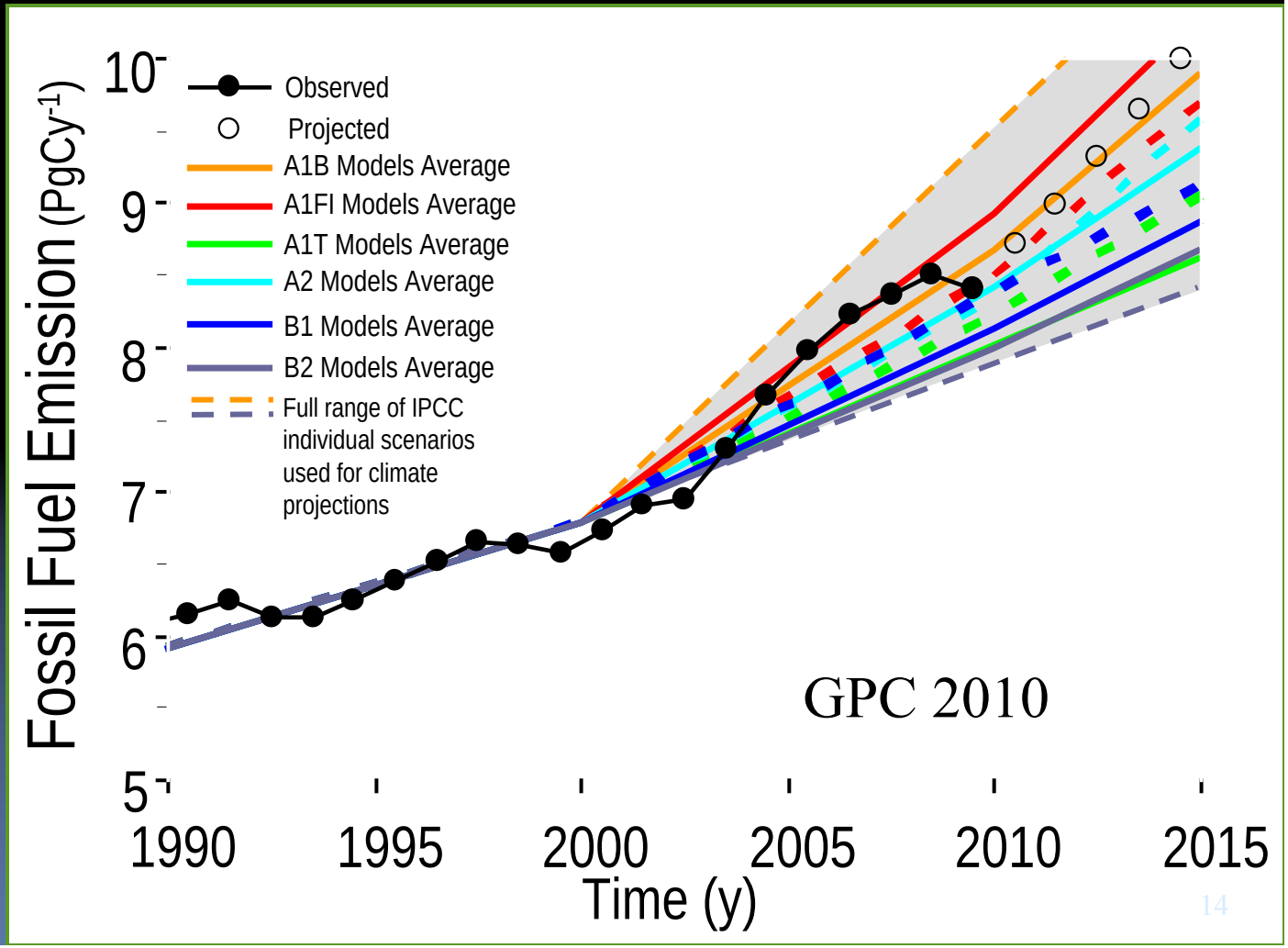
What is the urgent need for geoengineering research ?

It is important to understand whether potential intervention options are available in case of potent feedbacks or collapse of some components of the climate system

What is the urgent need for geoengineering research ?

1. CO2 emission reductions are not happening

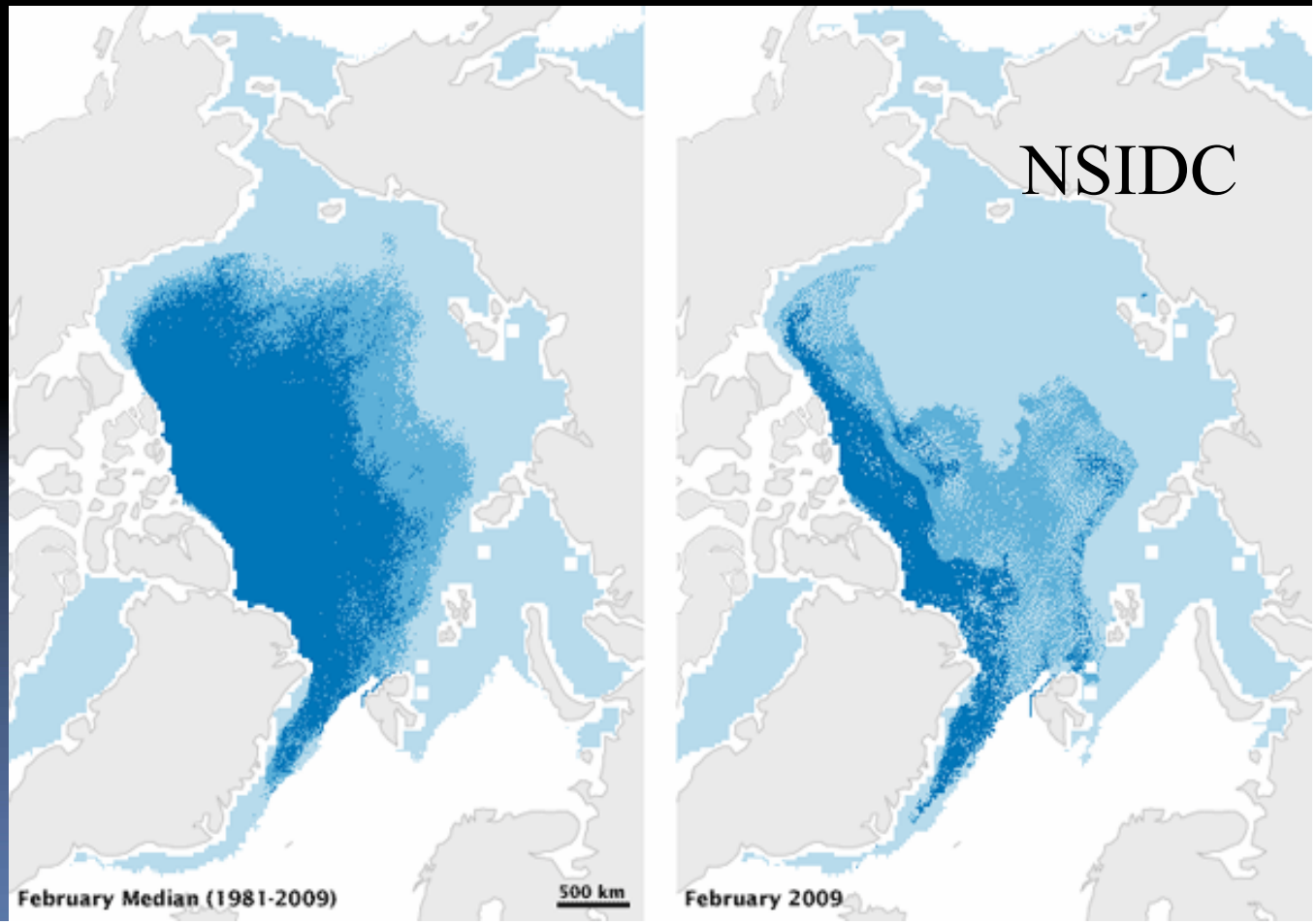
Fossil fuel emissions are now about 40 % higher than in 1990



What is the urgent need for geoengineering research ?

2. Permanent Ice in Arctic is disappearing

Ice older than 2 years accounted for less than 10 % in 2009

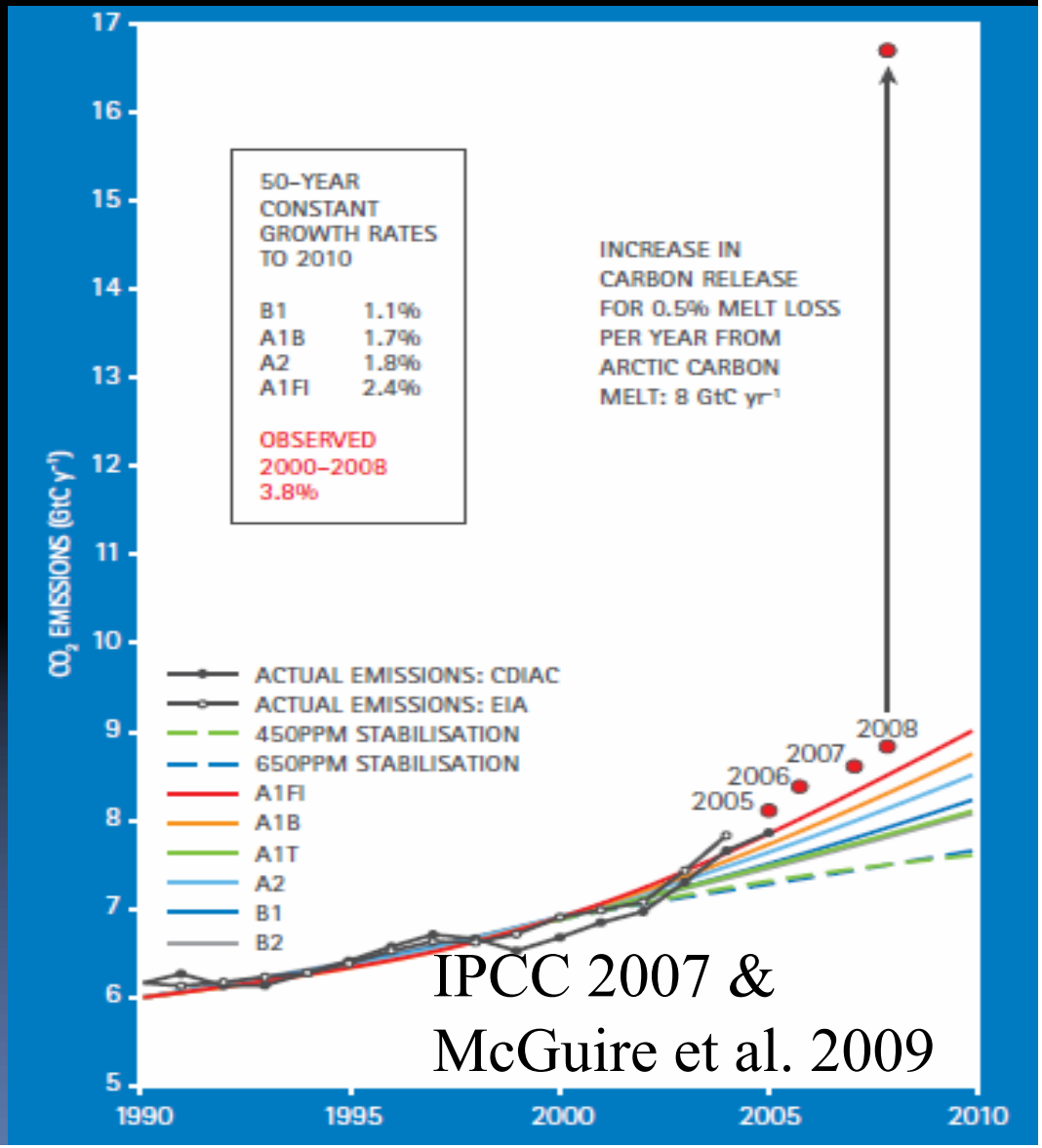


What is the urgent need for geoengineering research ?

3. Massive release of Permafrost carbon is possible

Soils in Alaska and Siberia hold about 2000 Gt-C carbon

A catastrophic release of CO2 and CH4?



IPCC 2007 &
McGuire et al. 2009

What is the urgent need for geoengineering research ?

4. Tipping points in the climate system?

Our knowledge of ice sheet break up is not complete

Melting of Greenland and West Antarctic ice sheets could raise the sea level by 14 meters

What is the urgent need for geoengineering research ?

5. Threat to food and water supply?

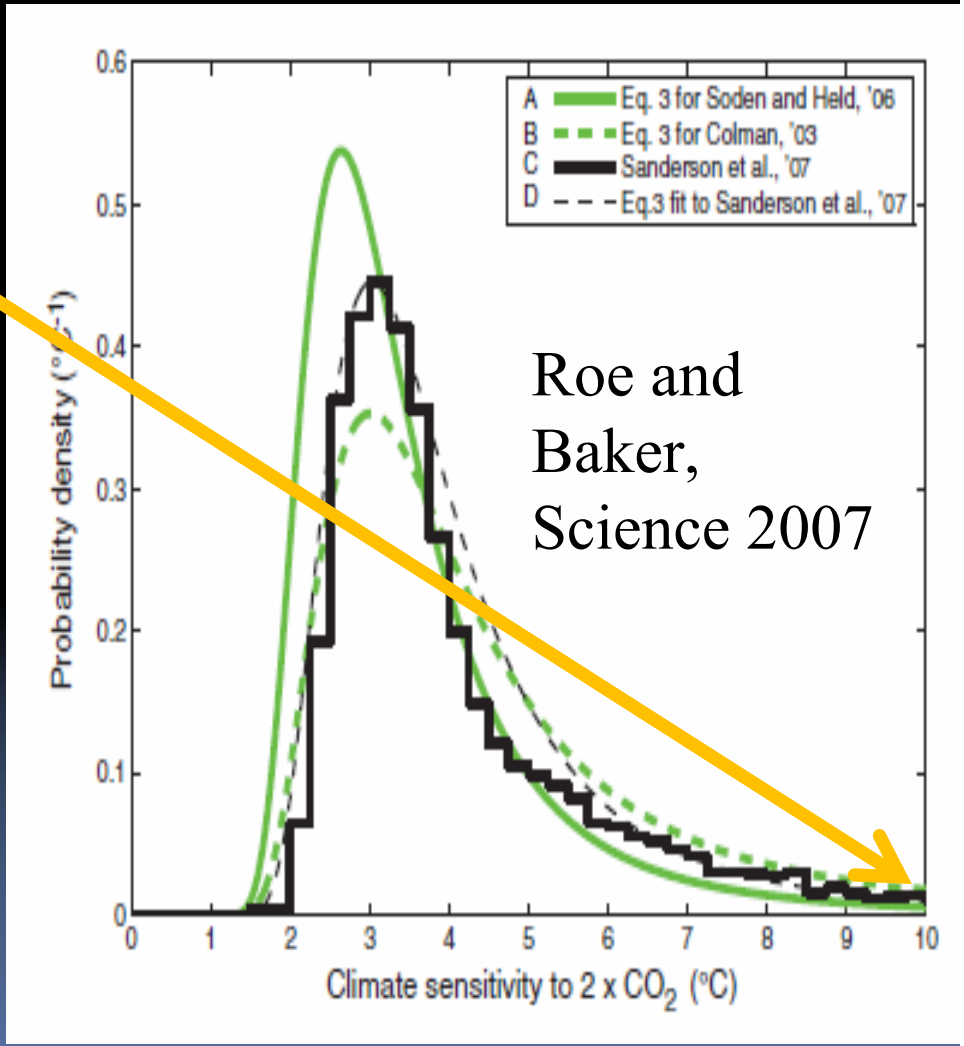
What if food and water supply decline rapidly in some regions because of climate change?

What is the option?

What is the urgent need for geoengineering research ?

6. Higher climate response is a distinct possibility

Small uncertainty in feedback can be highly amplified to yield large climate response



Roe and Baker, Science 2007

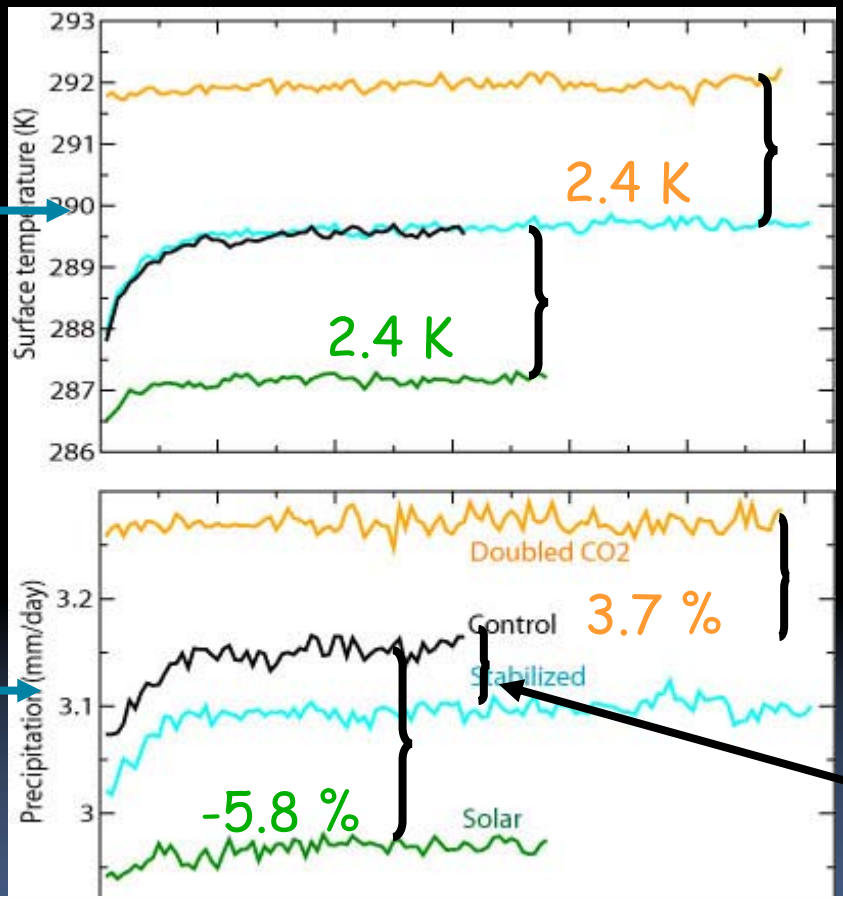
Science

- Global mean temperature and precipitation changes can not be simultaneously mitigated by SRM
- Marine cloud albedo enhancement could increase runoff over land
- Land albedo enhancement could lead to drier continents
- Removal of CO_2 of will lead to precipitation increase
- Climate benefits of afforestation depend on location
- "Rebound effect" in CDR methods

1. Temperature change is mitigated but precipitation is not

Global mean temperature change

Global mean precipitation change



Impact of geoengineering schemes on the global hydrological cycle

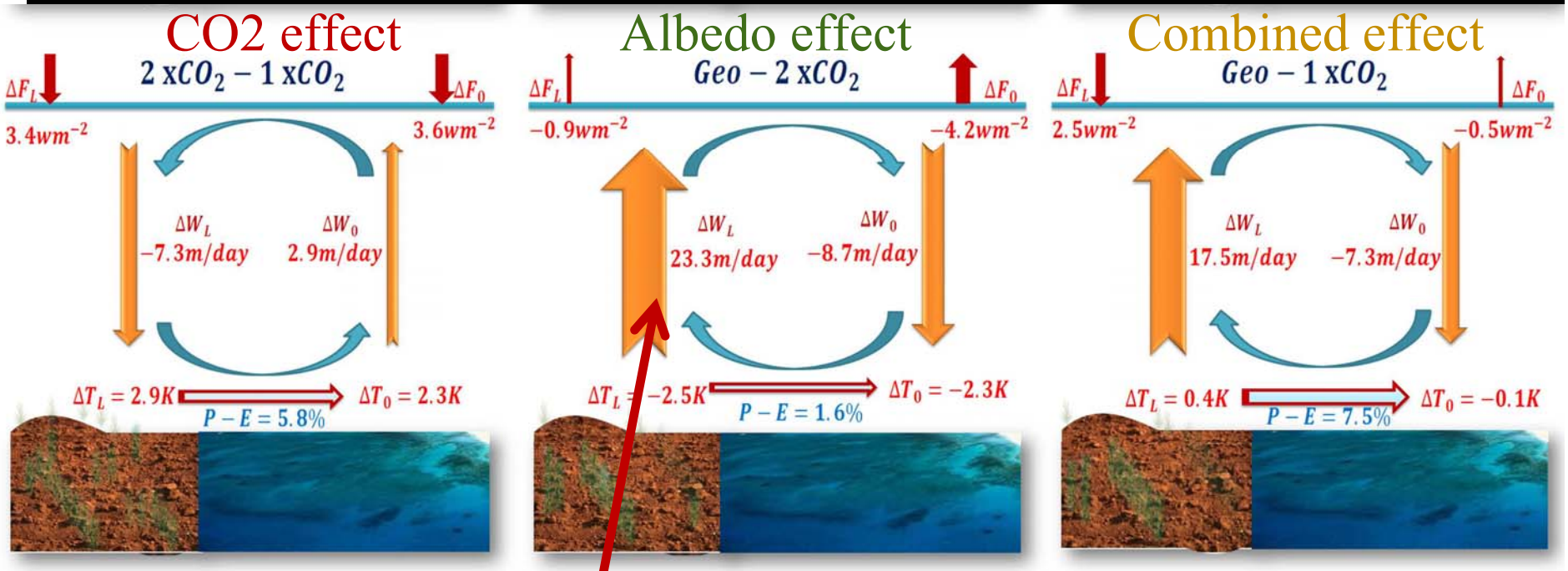
PNAS 2008

G. Bala*, P. B. Duffy, and K. E. Taylor

Atmosphere, Earth, and Energy Division, Lawrence Livermore National Laboratory, Livermore, CA 94550

Edited by Robert E. Dickinson, Georgia Institute of Technology, Atlanta, GA, and approved March 12, 2008 (received for review December 12, 2007)

2. Marine cloud albedo increase could lead to increased runoff



Heterogeneous forcing leads to enhanced global monsoon

Caveat: idealized study

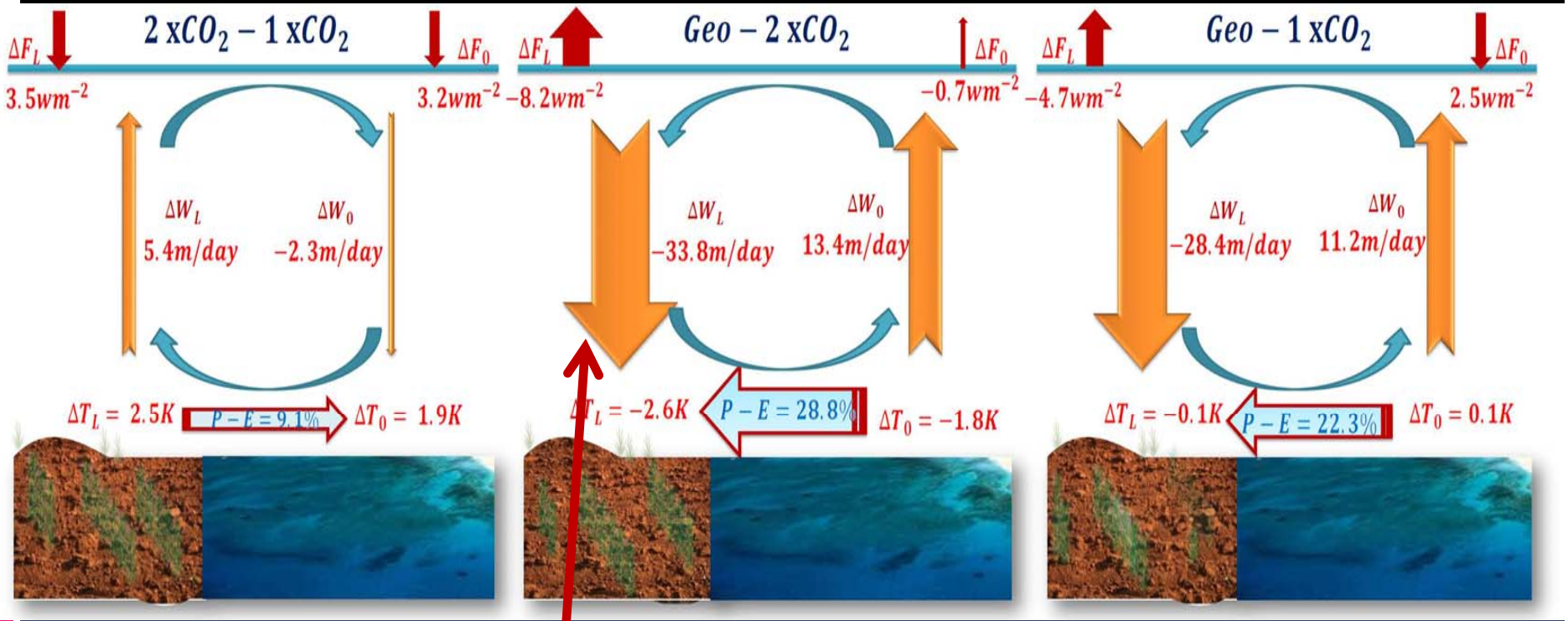
Clim Dyn
DOI 10.1007/s00382-010-0868-1

Climate Dynamics 2010

Albedo enhancement of marine clouds to counteract global warming: impacts on the hydrological cycle

G. Bala · Ken Caldeira · Rama Nemani · Long Cao · George Ban-Weiss · Ho-Jeong Shin

3. Land albedo increase could lead to drier continents



Heterogeneous forcing leads to weakened global monsoon

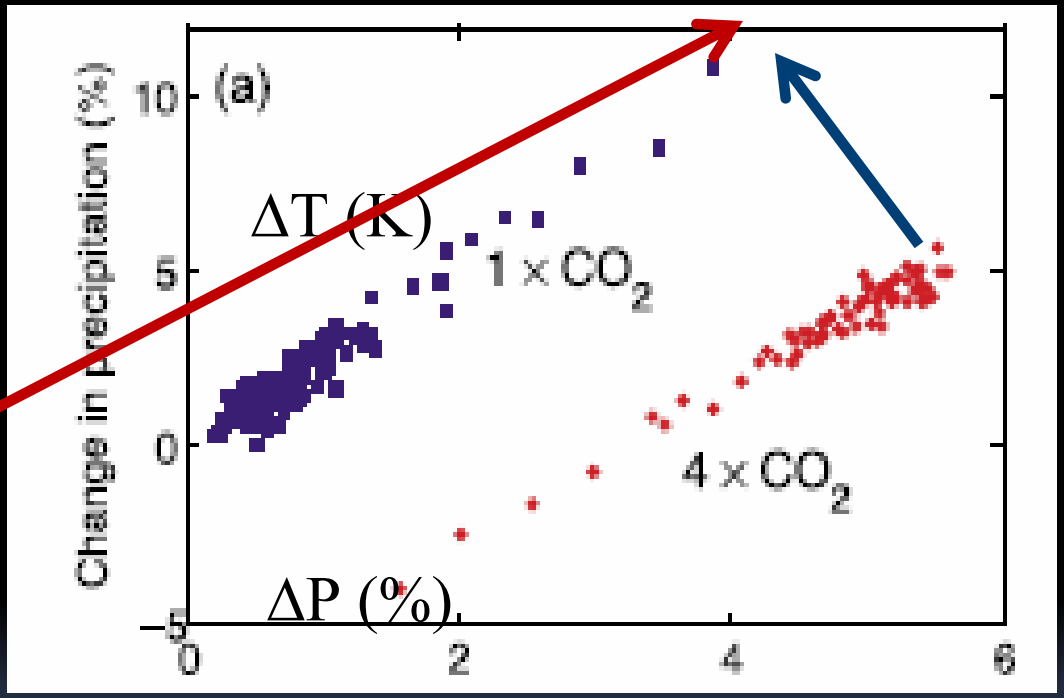
Caveat: idealized study

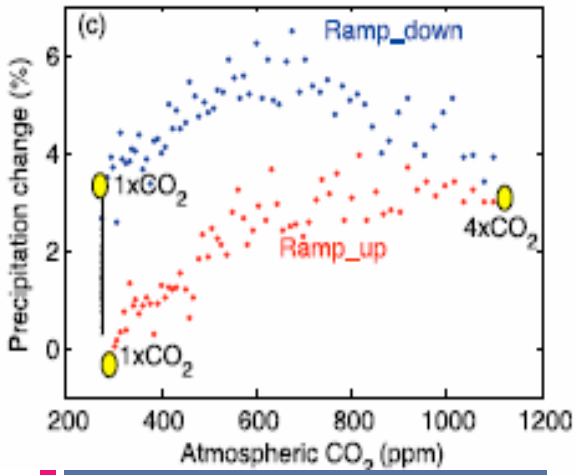
Bala and Nag, Climate Dynamics 2011

(Submitted)

4. Removal of CO2 could accelerate global water cycle

Instantaneous removal of CO2 leads to a jump in precipitation by about 5 %





GEOPHYSICAL RESEARCH LETTERS, VOL. 38, L06703, doi:10.1029/2011GL046713, 2011

GRL 2011

Why is there a short-term increase in global precipitation in response to diminished CO_2 forcing?

Long Cao,[1] Govindasamy Bala,[2,3] and Ken Caldeira[1]

5. Location is important for afforestation (CDR) programs

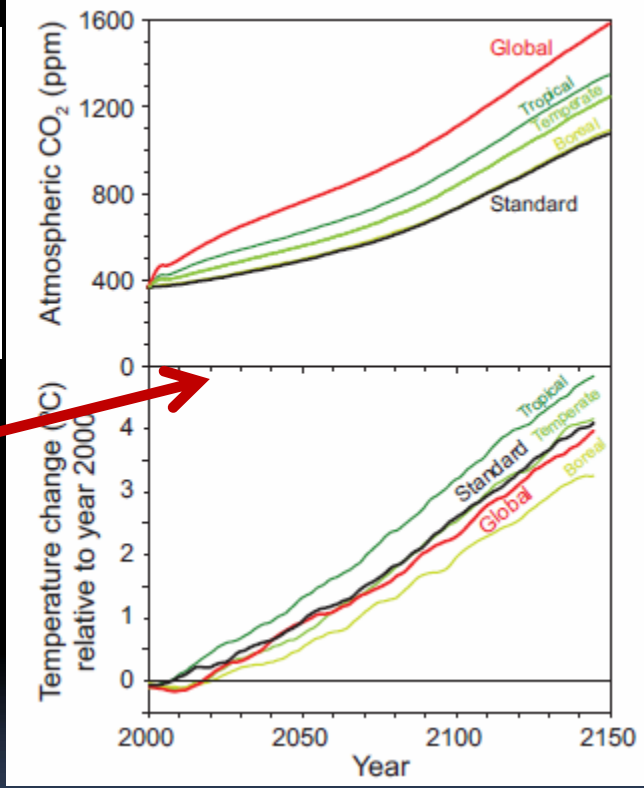
Combined climate and carbon-cycle effects of large-scale deforestation

PNAS 2007

G. Bala*†, K. Caldeira‡, M. Wickett*, T. J. Phillips*, D. B. Lobell*, C. Delire§, and A. Mirin*

*Energy and Environment Directorate, Lawrence Livermore National Laboratory, Livermore, CA 94550; ‡Department of Global Ecology, Carnegie Institution, Stanford, CA 94305; and §Université Montpellier II, 34095 Montpellier cedex 5, France

Tropical afforestation may lead to cooling but boreal afforestation could accelerate global warming



LETTERS
PUBLISHED ONLINE: 19 JUNE 2011 | DOI: 10.1038/NGEO1182
nature geoscience

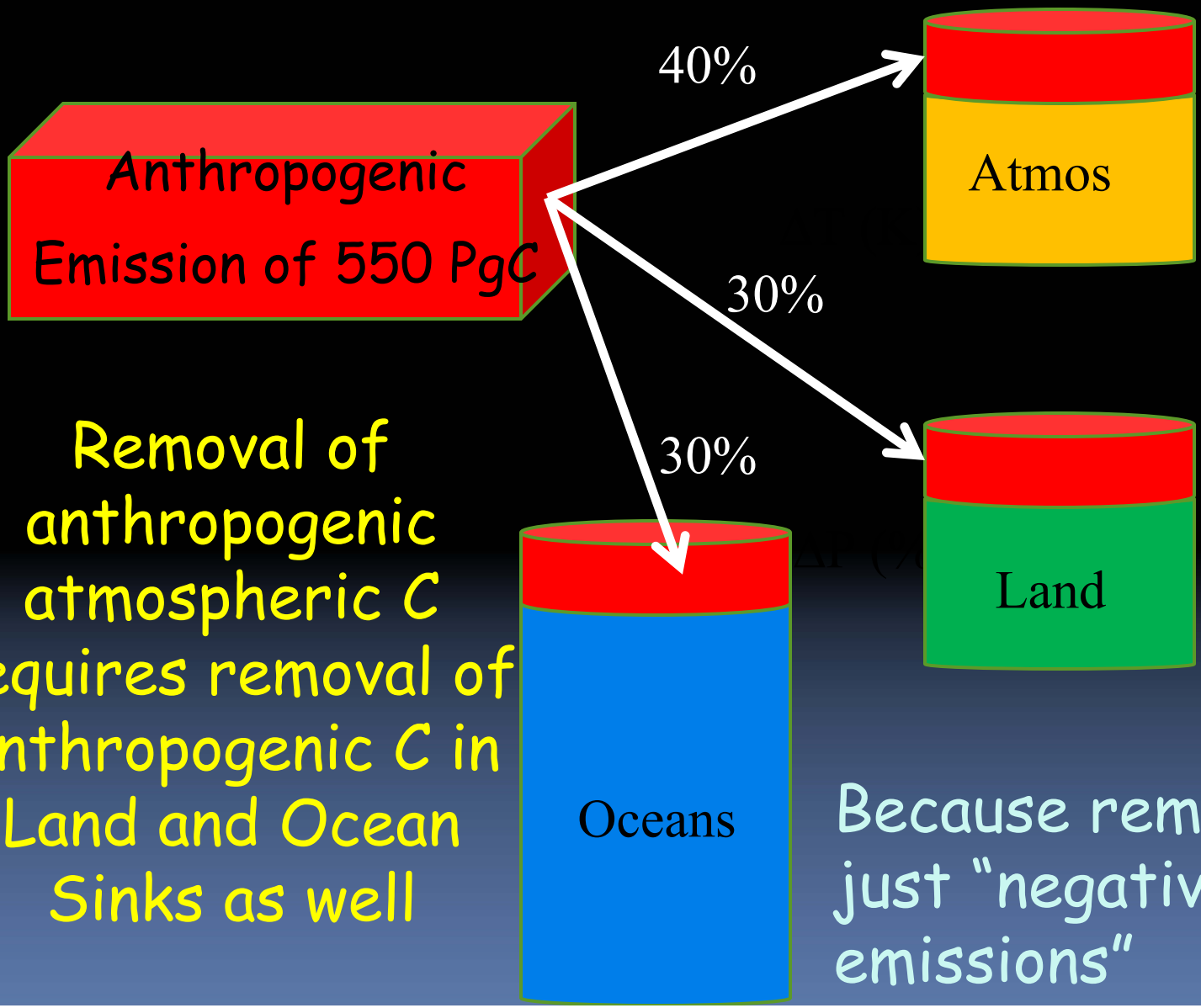
Small temperature benefits provided by realistic afforestation efforts

2011

Vivek K. Arora[1]* and Alvaro Montenegro[2]

Warming reductions per unit afforested area in tropical areas is 3 times higher than in mid- and high latitudes

6. The "rebound effect"



Removal of anthropogenic atmospheric C requires removal of anthropogenic C in Land and Ocean Sinks as well

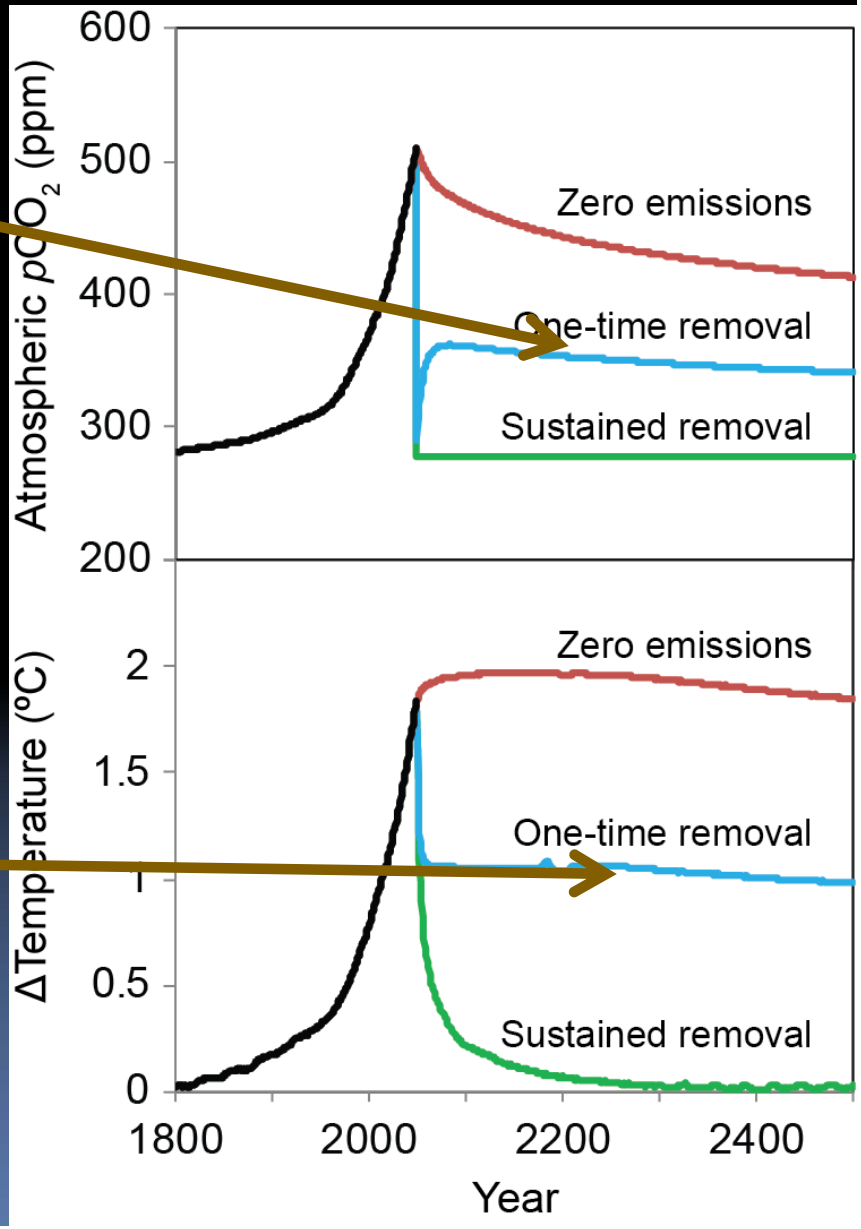
Because removal is just "negative emissions"

6. The "rebound effect"

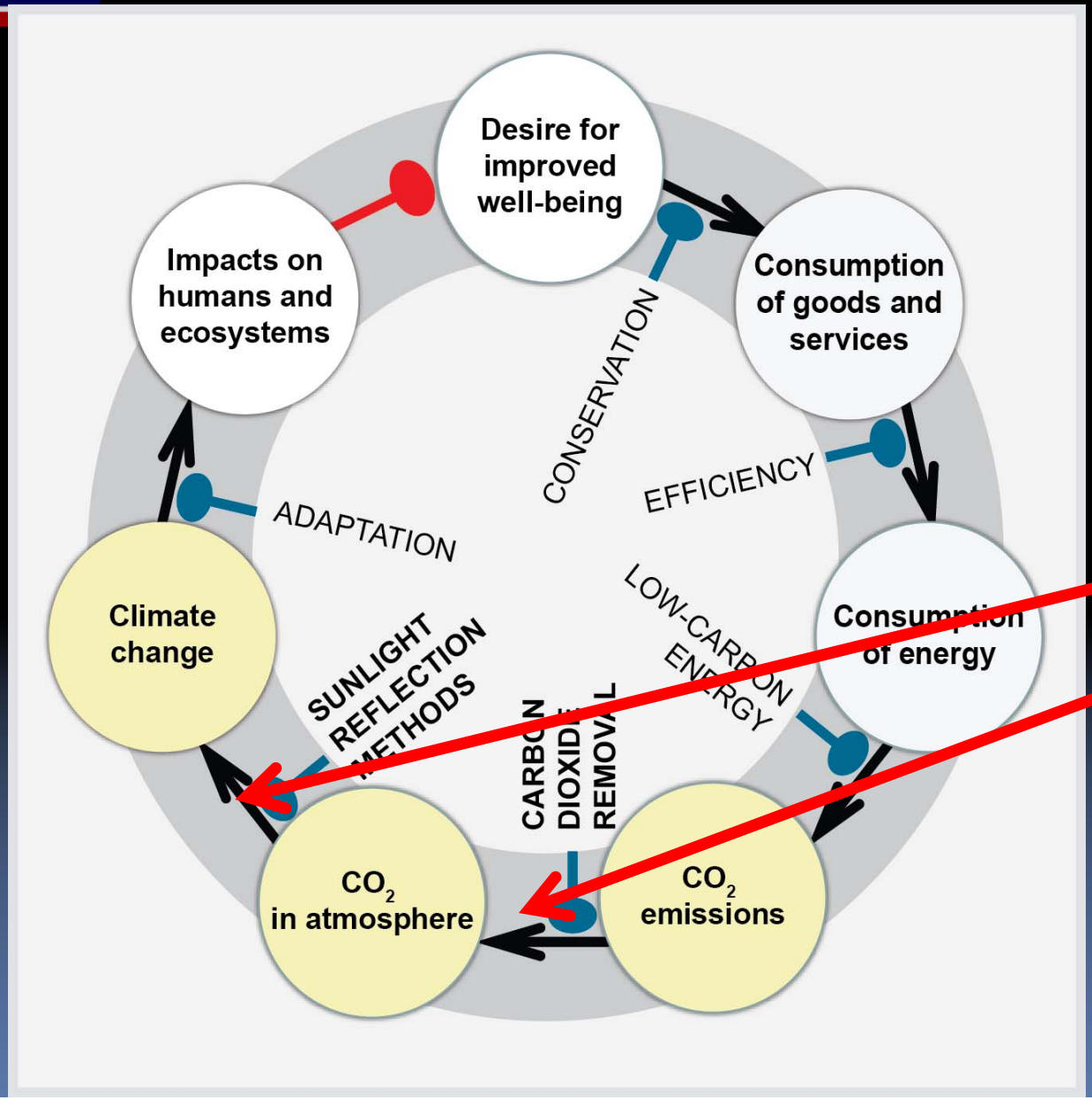
Removal of all anthropogenic atmospheric CO2 effectively removes only half

1 degree warming remaining after the removal of all atmospheric anthropogenic C

Cao and Caldeira 2010



Take Home Message



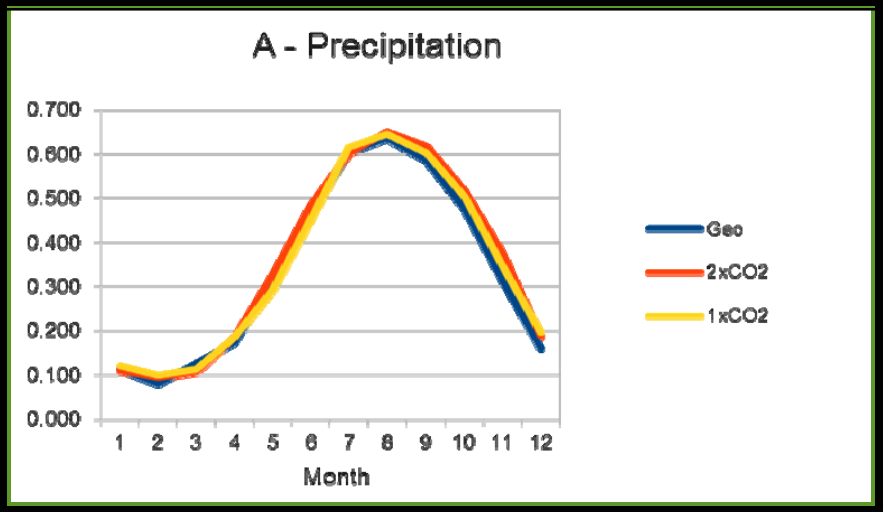
There are multiple ways to weaken the links in this chain.

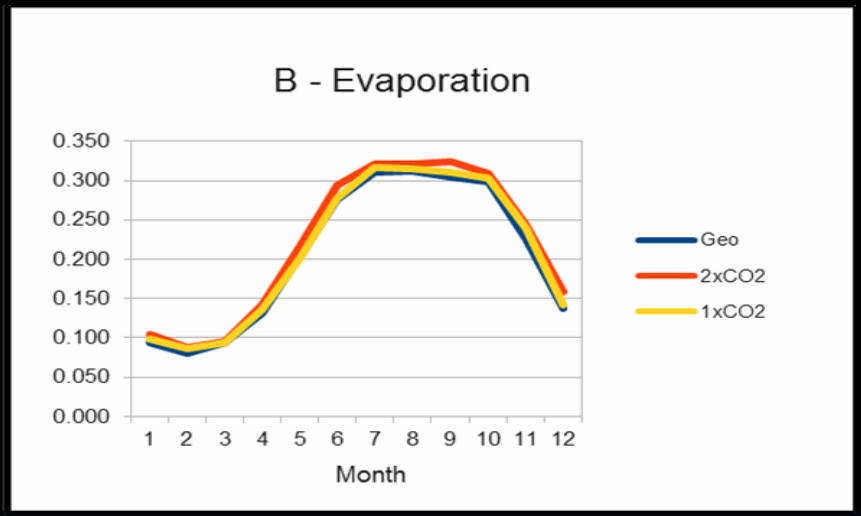
SRM and CDR are really some mitigation measures

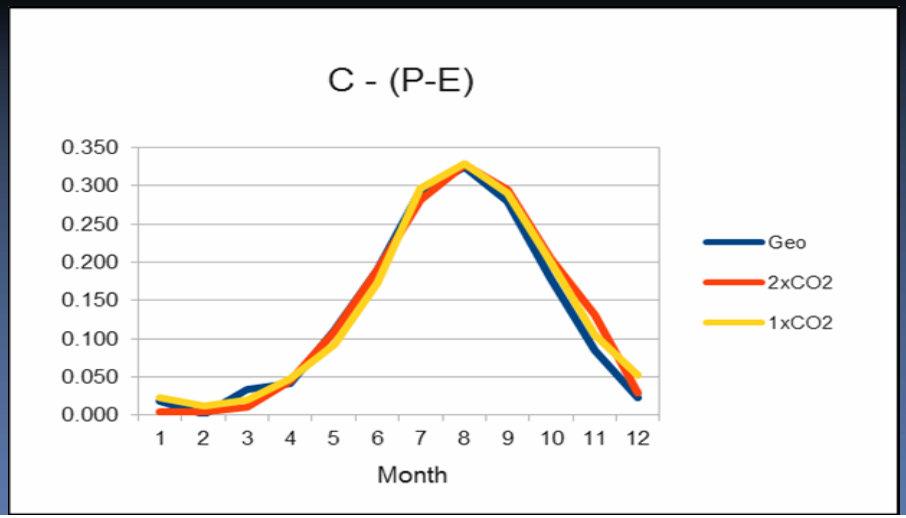
Take Home Message :

Prevention (Early emission reduction) is Better than **Cure** (Geoengineering)

Effect on India – Uniform solar reduction







Effect on India – Marine cloud albedo enhancement