

# SOLAR GEOENGINEERING: KUN EN FIKS IDÉ ELLER PARISAVTALENS PLAN C?

Dr. Helene Muri  
helene.muri@ntnu.no



Industrial Ecology Programme

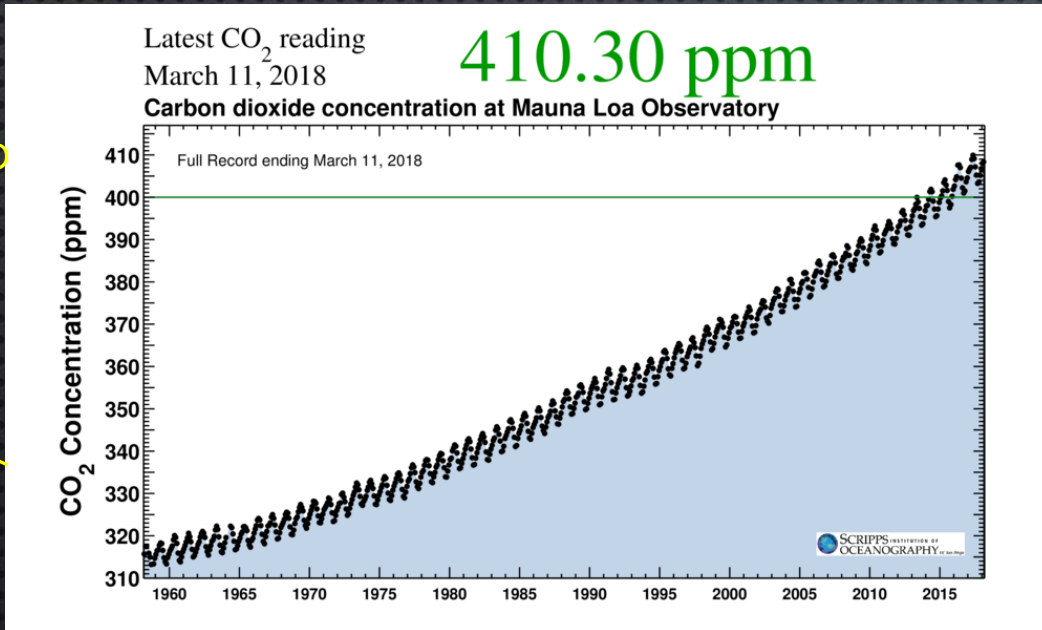


# OUTLINE

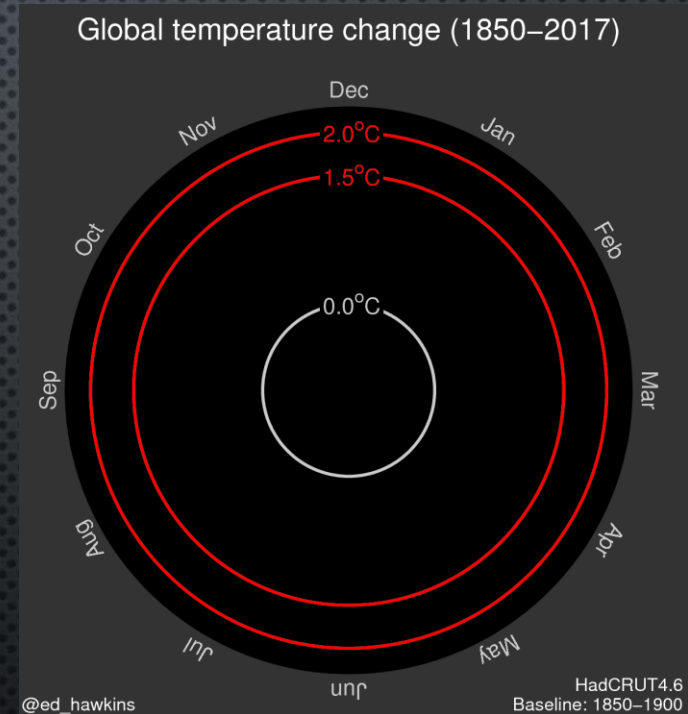
- STATUS PÅ GLOBAL OPPVARMING
- PARIS AVTALEN
- DEFINISJON AV GEOENGINEERING
- OVERSIKT OVER GEOENGINEERING METODER:
  - KARBONFANGST OG FJERNING
  - SOLAR GEOENGINEERING
- ÅPNE SPØRSMÅL
- OPPSUMMERING

# GLOBAL WARMING

Note: y-scale changes

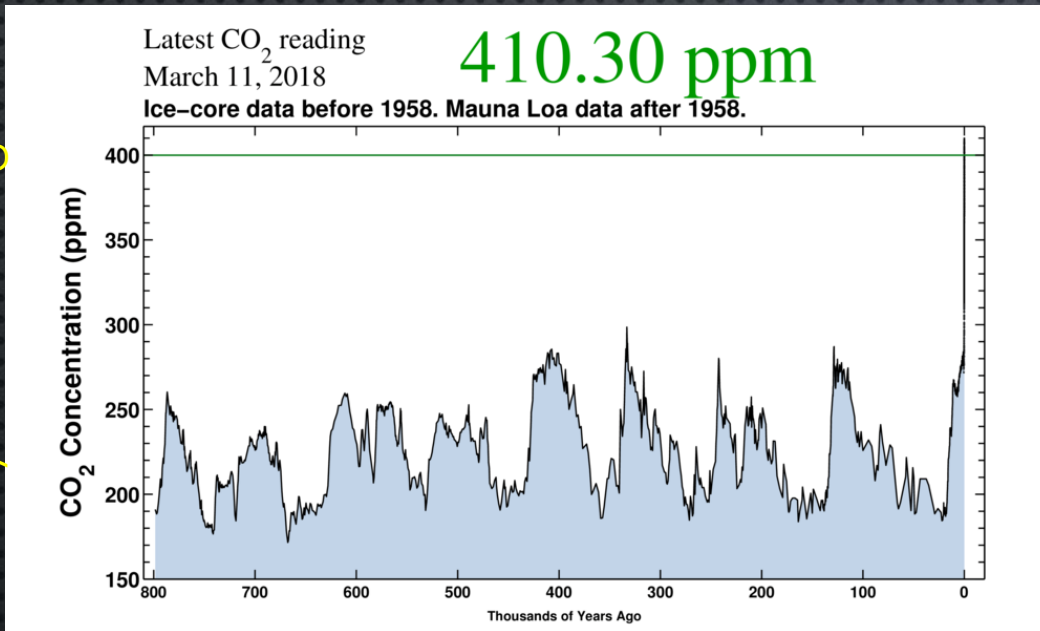


<https://scripps.ucsd.edu/programs/keelingcurve/>

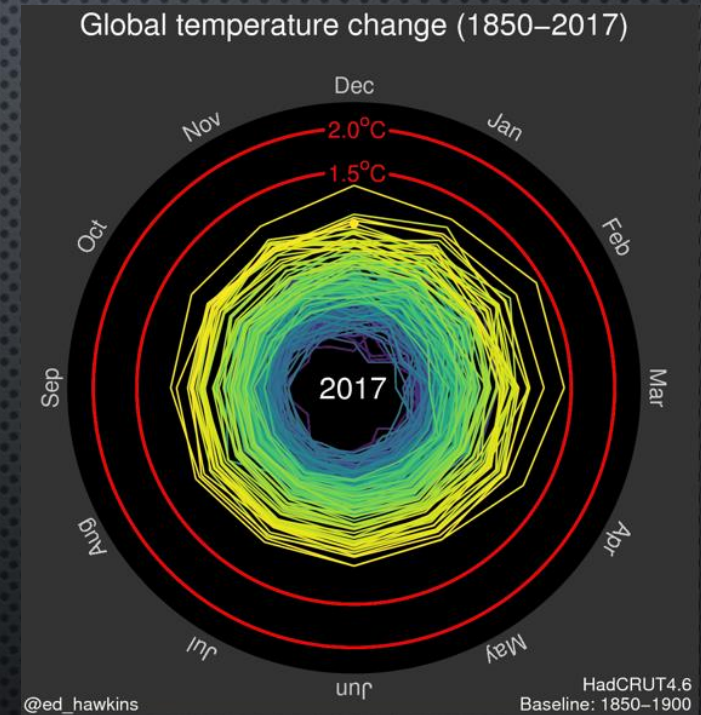


# GLOBAL OPPVARMING

Note: y-scale changes



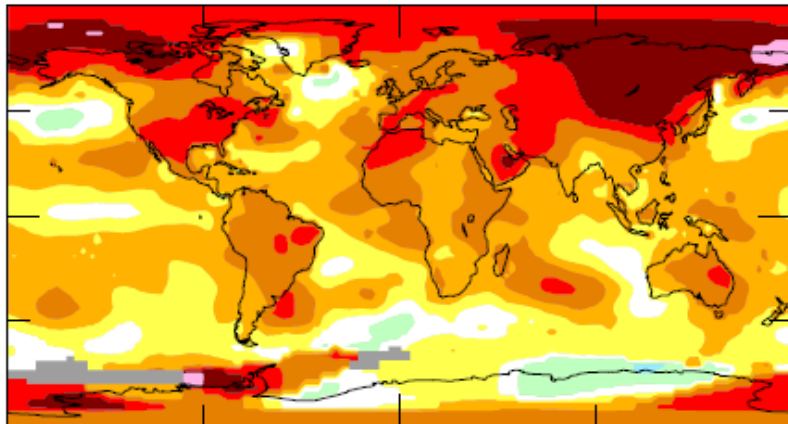
<https://scripps.ucsd.edu/programs/keelingcurve/>



# January-November Mean Surface Temperature Anomaly (°C)

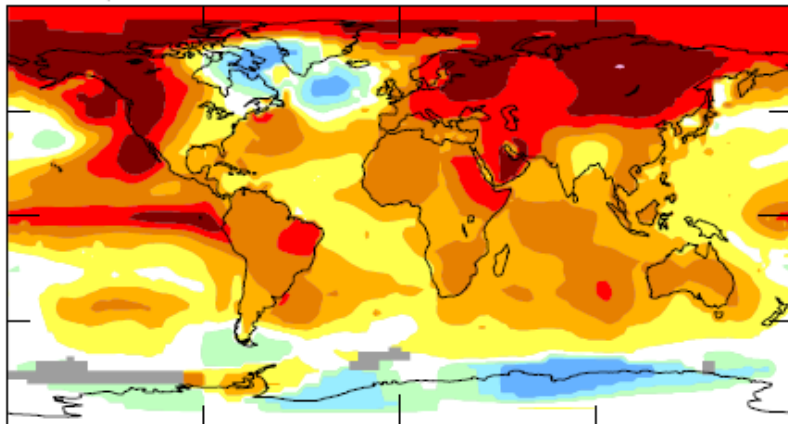
2<sup>nd</sup> warmest 2017

0.90



2015, 3<sup>rd</sup> warmest

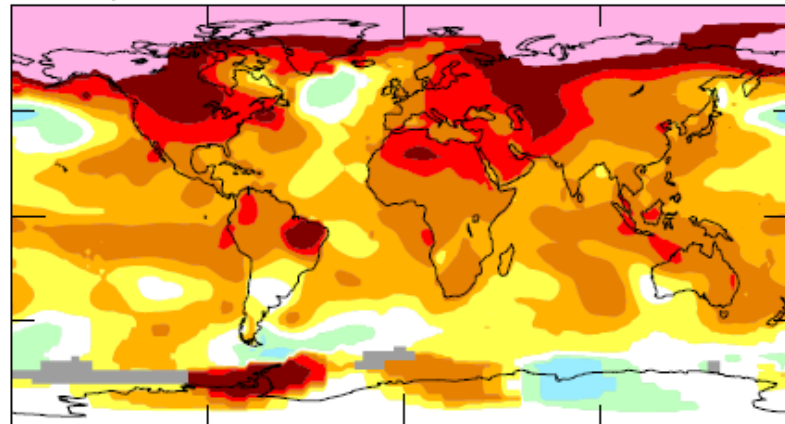
0.84



-2.1 -2 -1.5 -1 -0.6 -0.2 .2 .6 1 1.5 2 3 3.6

2016, the warmest

1.01



-2.1 -2 -1.5 -1 -0.6 -0.2 .2 .6 1 1.5 2 3 4.8

Spesielt rask oppvarming på våre breddegrader.

Base Period: 1951-1980

# Parisavtalen

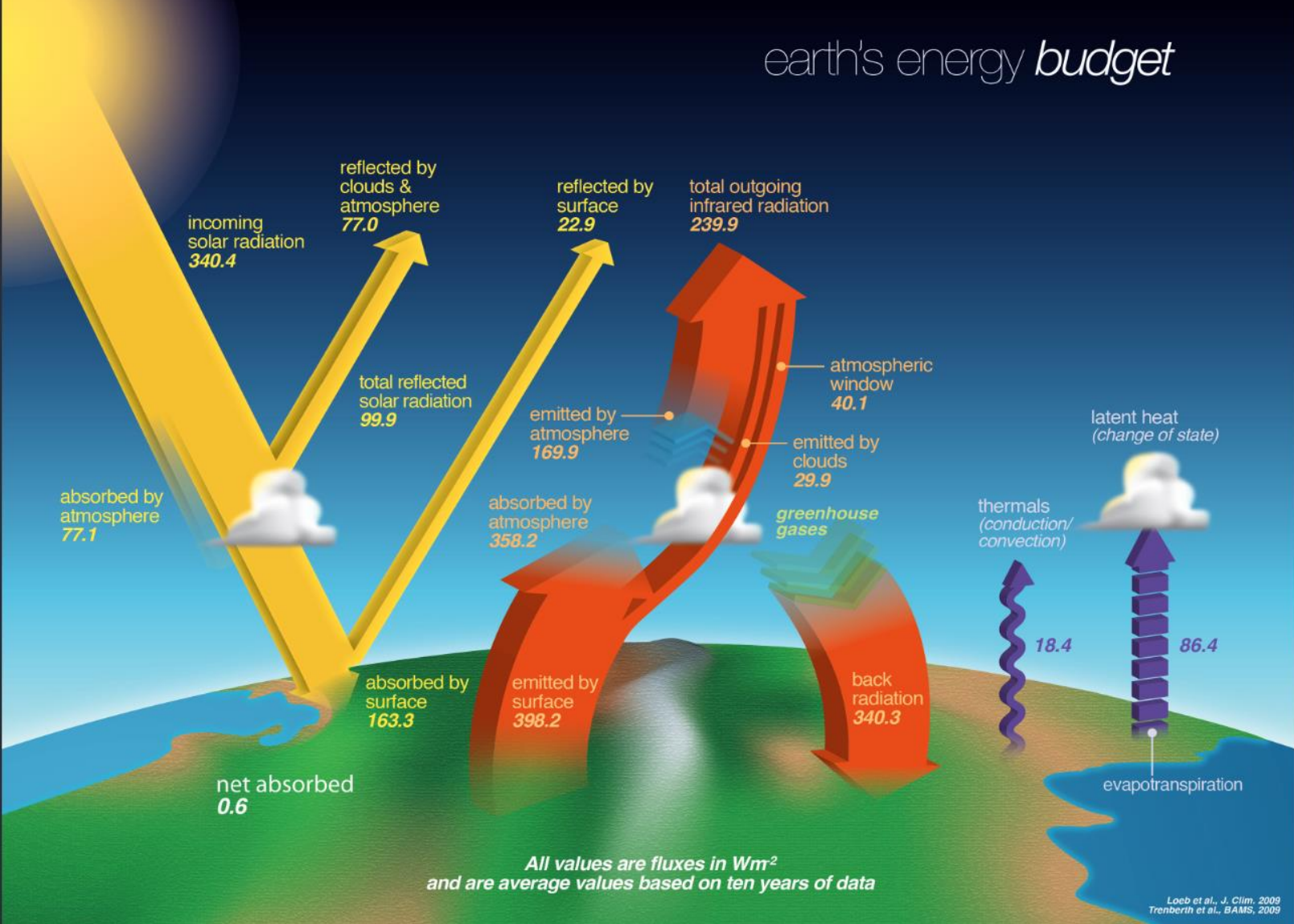
(a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;



## GEOENGINEERING DEFINISJON

“Deliberate large-scale modification of the climate system”.

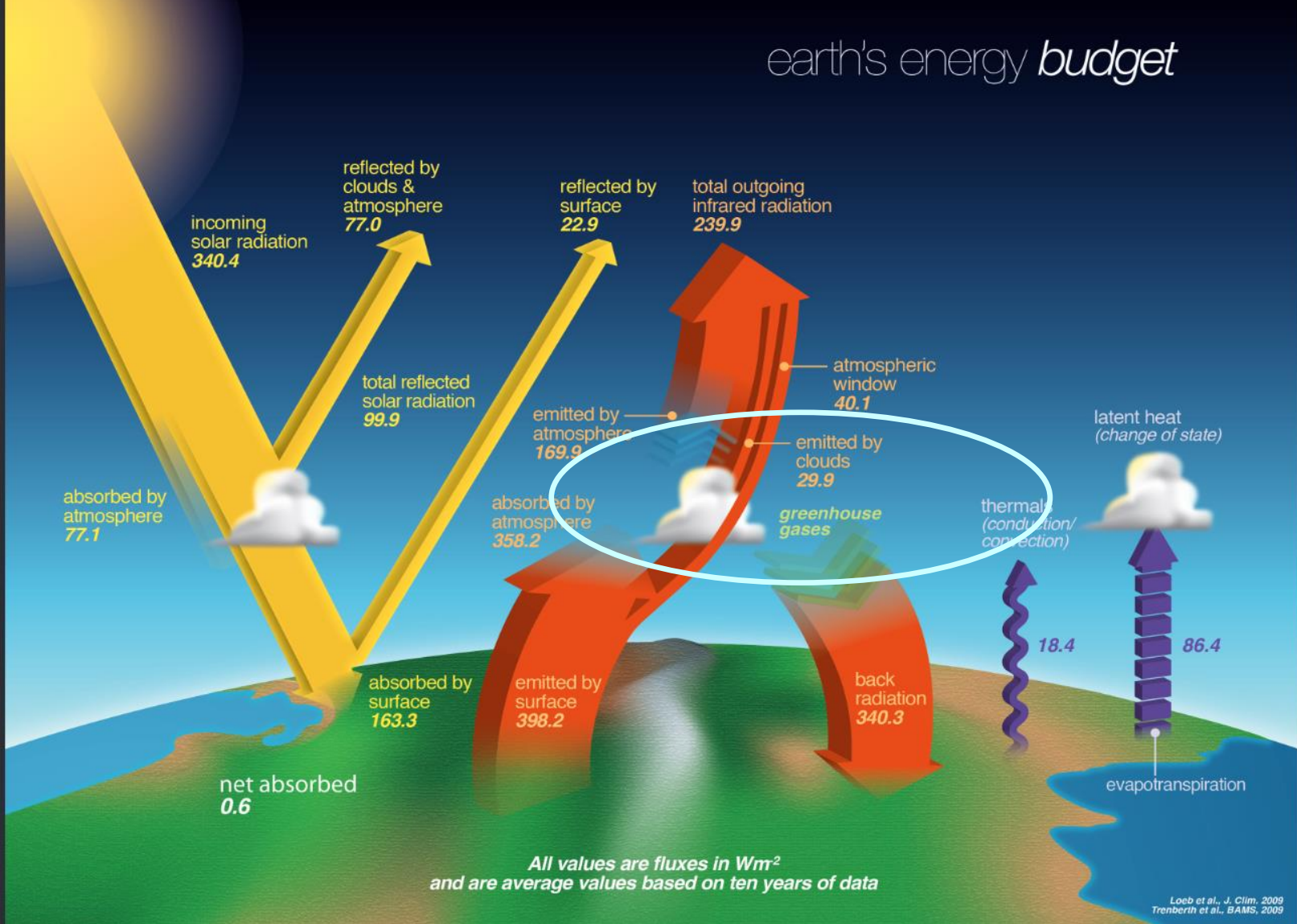
# earth's energy budget



Loeb et al., J. Clim. 2009  
Trenberth et al., BAMS, 2009

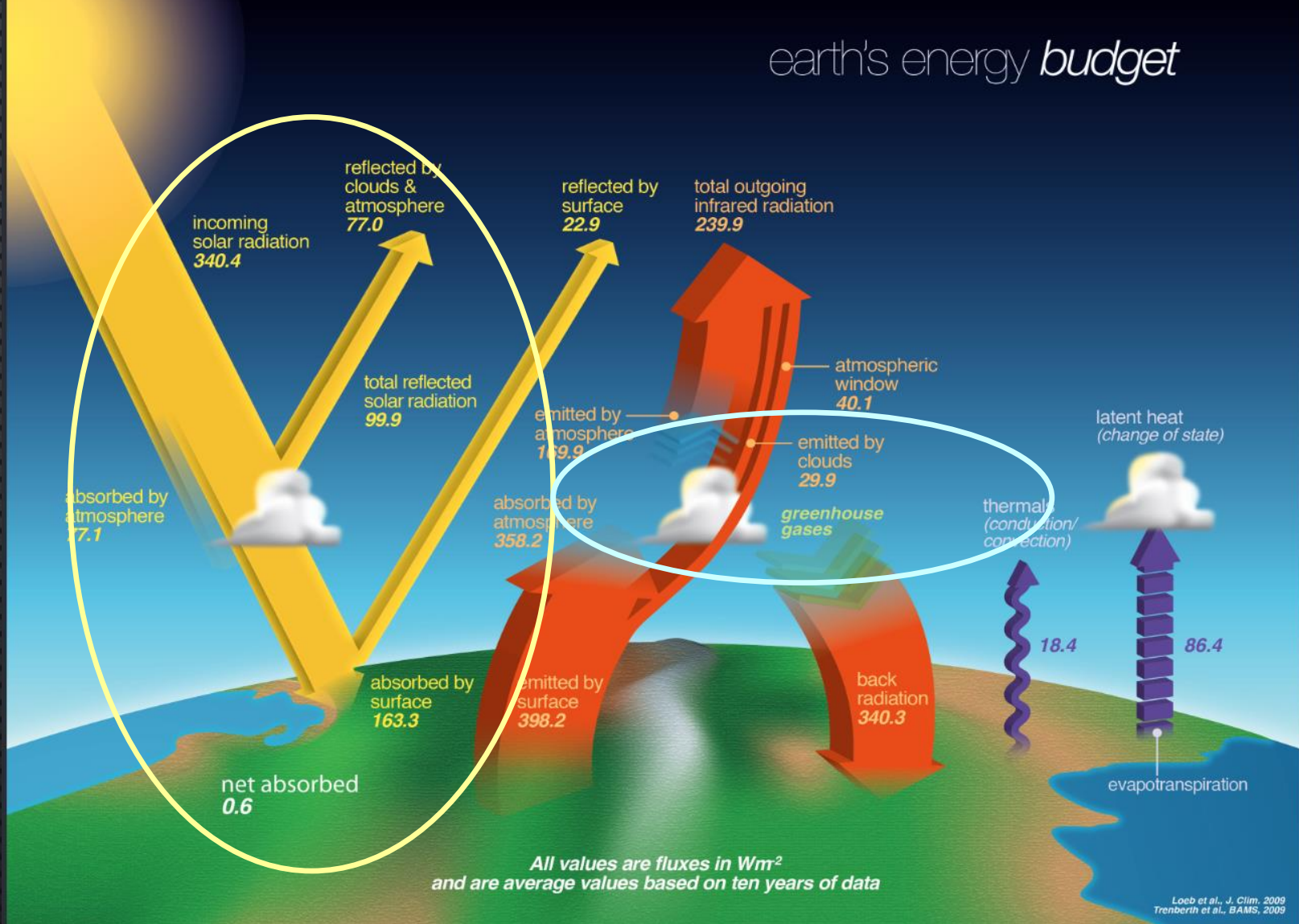


earth's energy budget



CDR: carbon dioxide removal – acts on the longwave (terrestrial) contribution to the energy balance

earth's energy budget



Solar geoengineering – most act on the shortwave (solar) contribution to the energy balance

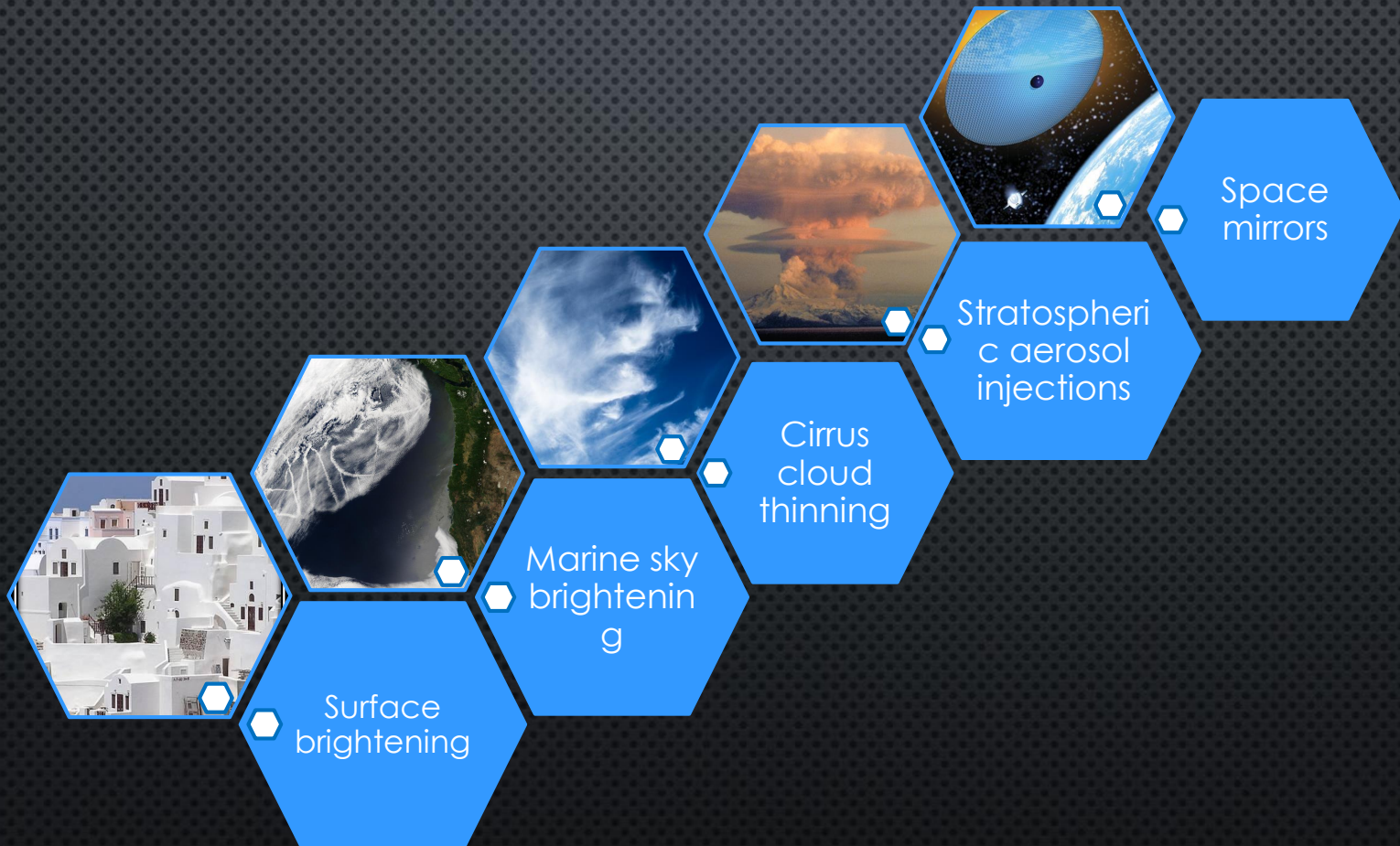
CDR: carbon dioxide removal – acts on the longwave (terrestrial) contribution to the energy balance

# IDEAS FOR CARBON DIOXIDE REMOVAL (CDR)

## Land Interventions



# IDEAS FOR SOLAR GEOENGINEERING



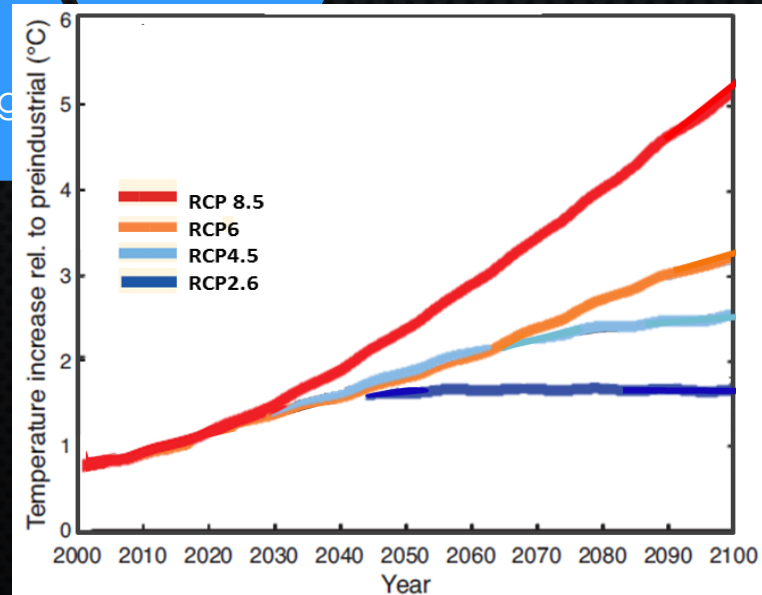
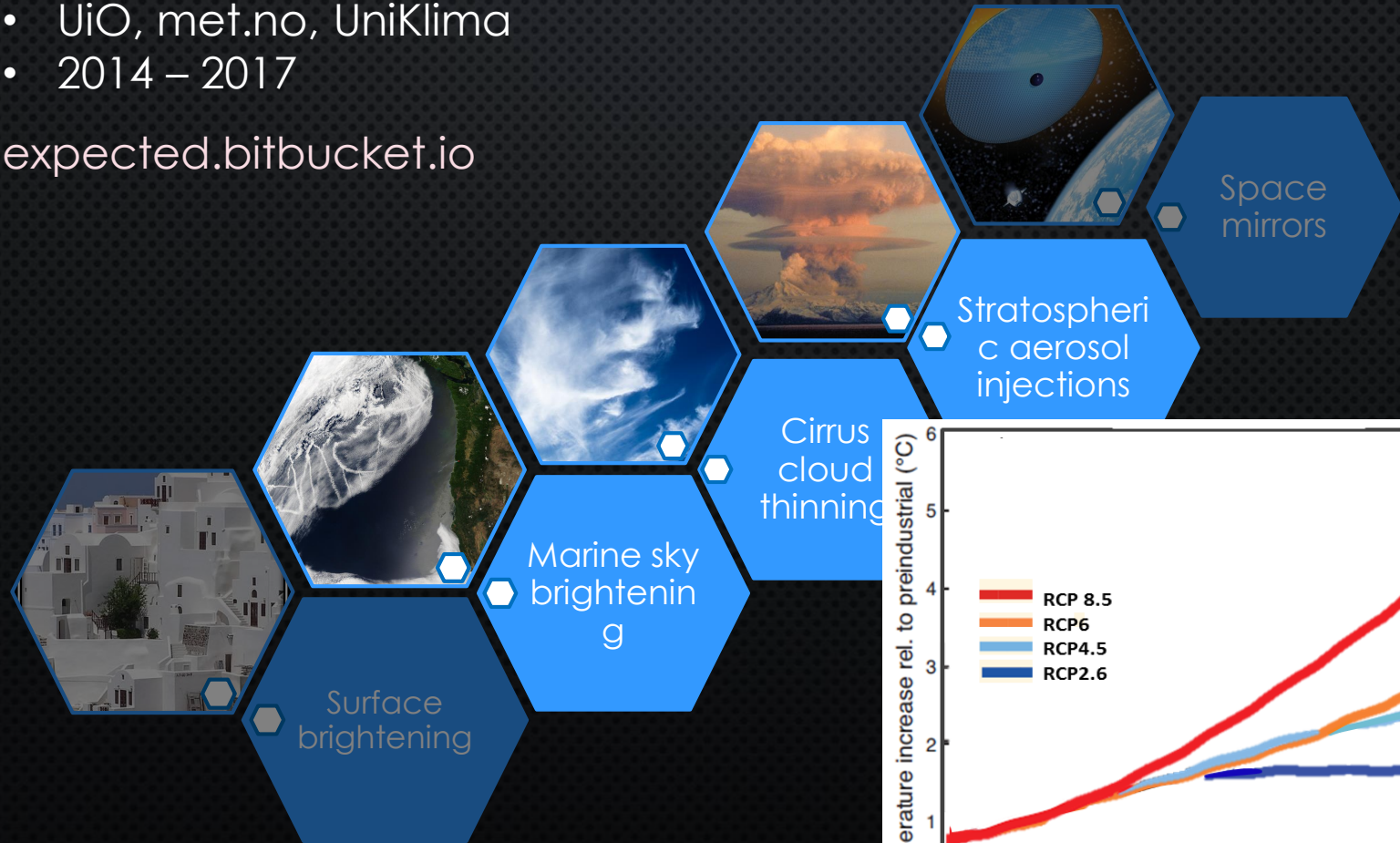
# IDEAS FOR SOLAR GEOENGINEERING

## EXPECT prosjektet

- NFR
- UiO, met.no, UniKlima
- 2014 – 2017

[expected.bitbucket.io](http://expected.bitbucket.io)

Avkjøling av et høy-utslipps scenario til et mellom-utslipps scenario med geoengineering.





### Journal of Climate

#### **Climate response to aerosol geoengineering: a multi-method comparison.**

Helene Muri<sup>1,2</sup>, Jerry Tjiputra<sup>3</sup>, Odd Helge Otterå<sup>3</sup>, Muralidhar Adakudlu<sup>3</sup>, Siv K. Lauvset<sup>3</sup>, Alf Grini<sup>4</sup>, Michael Schulz<sup>4</sup>, Ulrike Niemeier<sup>5</sup>, and Jón Egill Kristjánsson<sup>1</sup>

<sup>1</sup> University of Oslo, Department of Geosciences, Section for Meteorology and Oceanography, Oslo, Norway

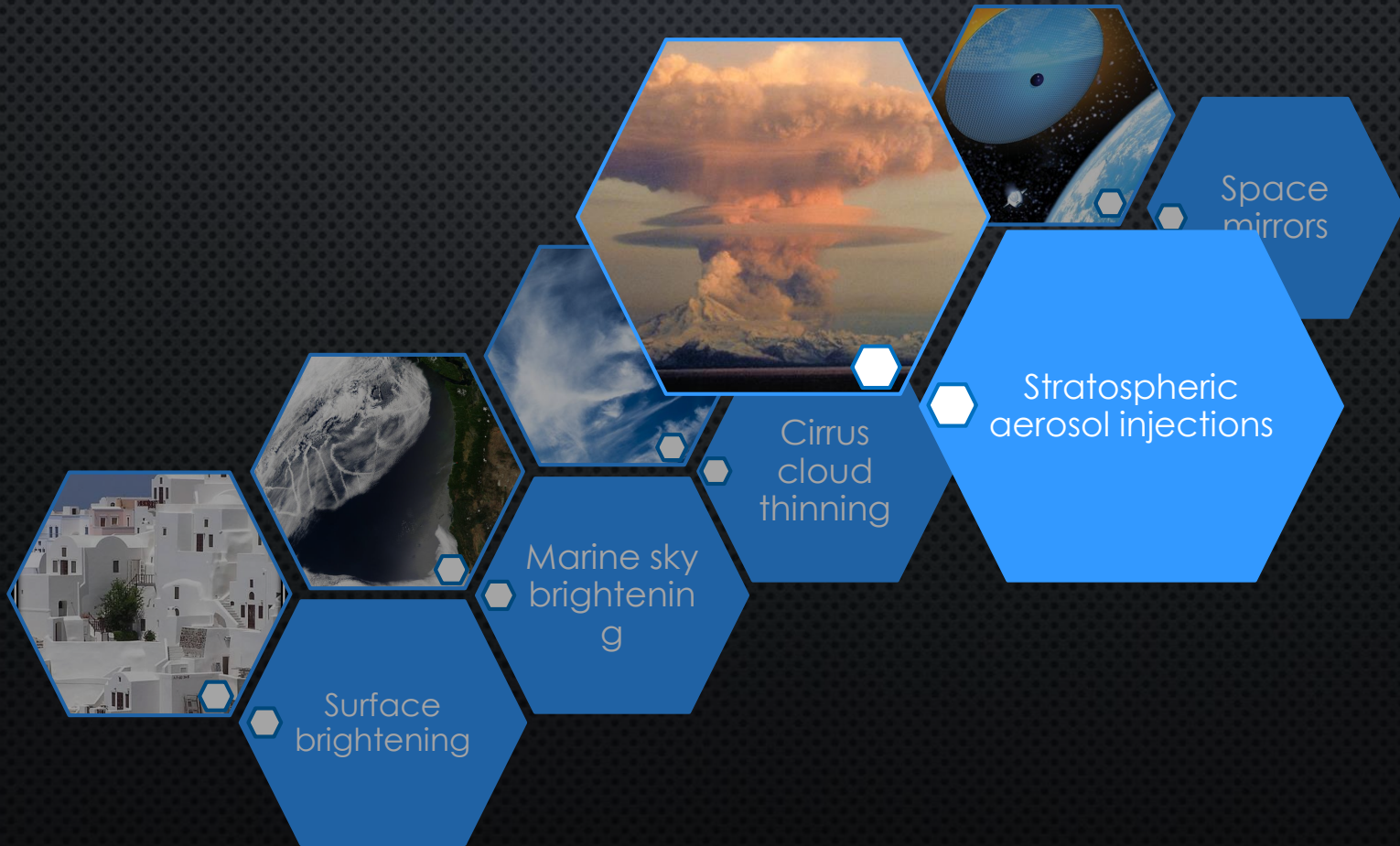
<sup>2</sup> Norwegian University of Science and Technology, Department of Energy and Process Engineering, Industrial Ecology Program, Trondheim, Norway

<sup>3</sup> Uni Research Climate, Bjerknes Centre for Climate Research, Bergen, Norway

<sup>4</sup> Meteorological Institute, Oslo, Norway

<sup>5</sup> Max Planck Institute for Meteorology, Hamburg, Germany

# Ideas for Solar Geoengineering



Concept: 'mimic' volcanic eruptions by injecting reflective aerosol particles (or their precursors) into the lower stratosphere.



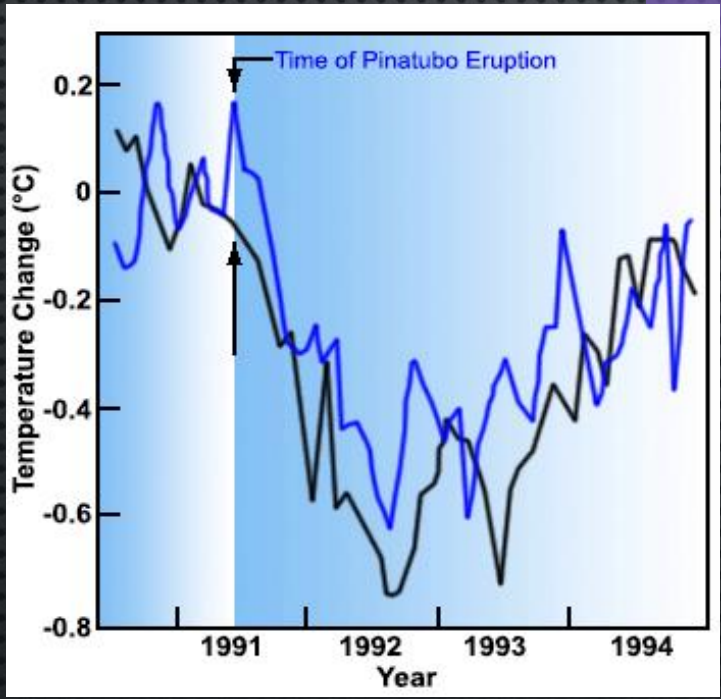
Stratospheric  
aerosol injections

The particles would scatter and reflect solar radiation, increasing the planetary reflectivity, and cool the climate.

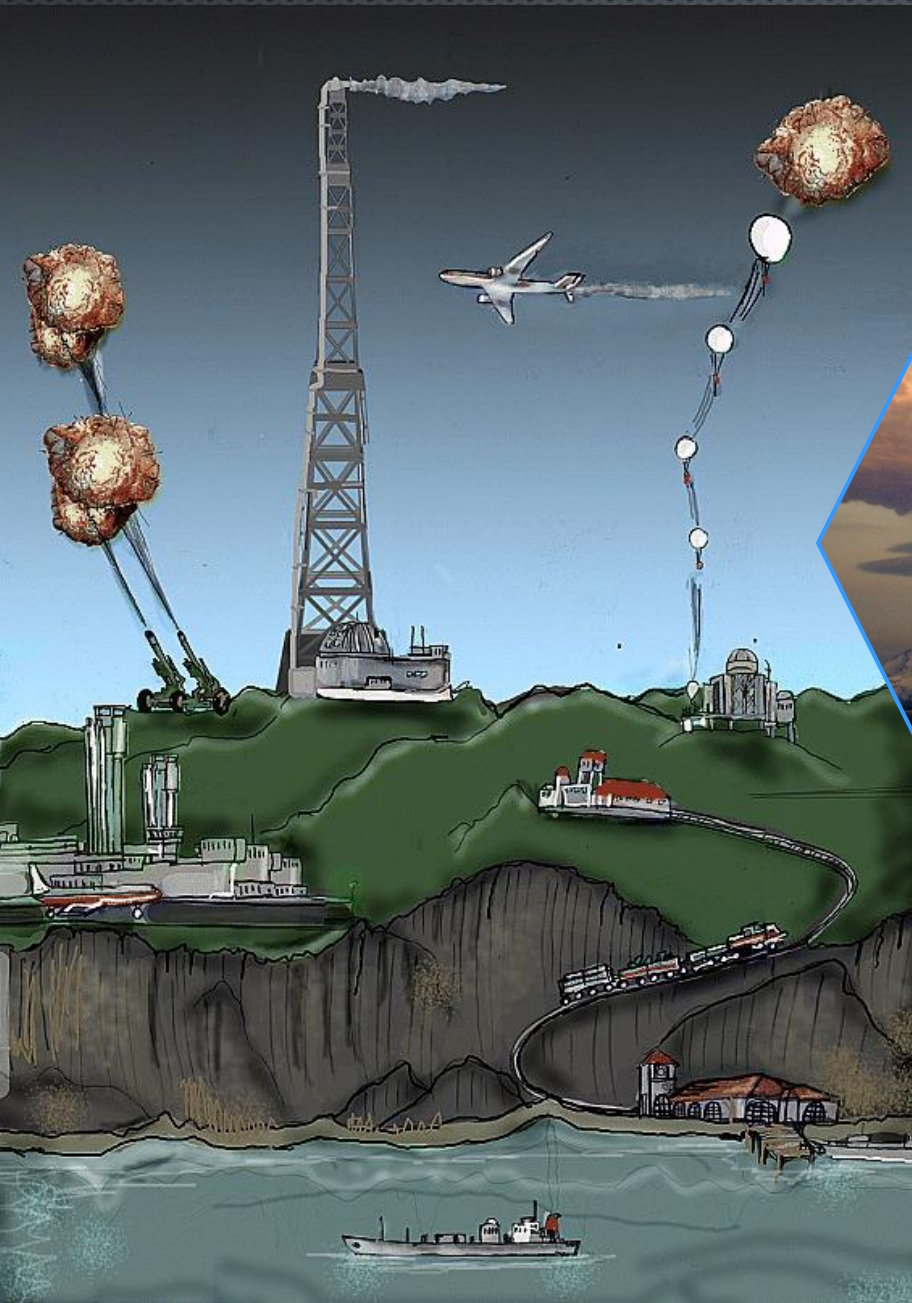


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(After Hansen et al., 93)

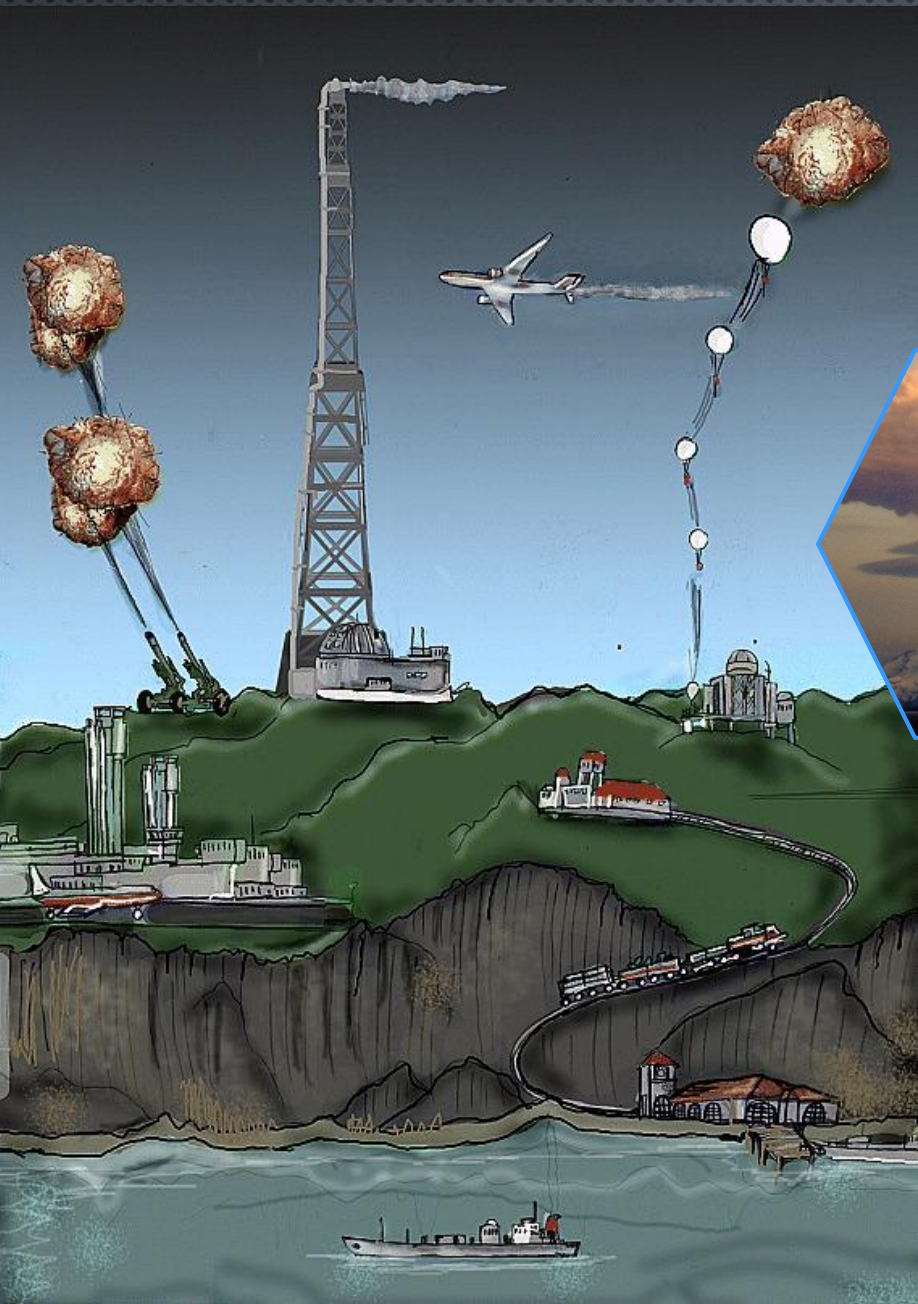


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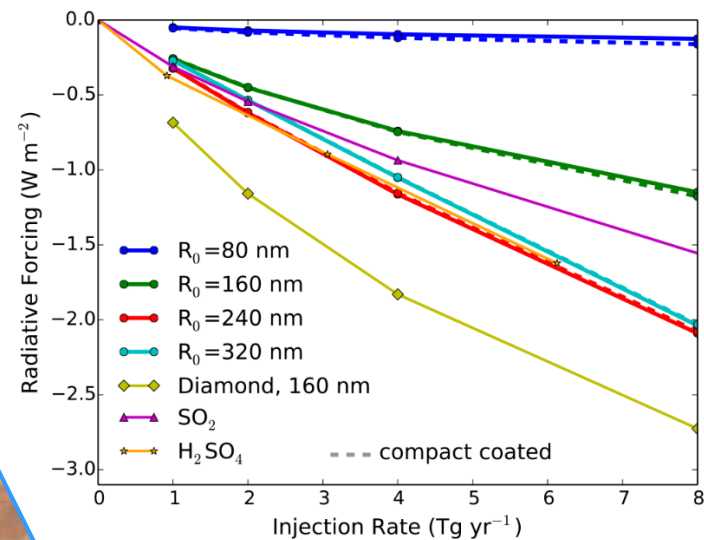


Stratospheric aerosol injections

(Robock et al., 2009. Drawing by Brain West)



(Robock et al., 2009. Drawing by Brain West)

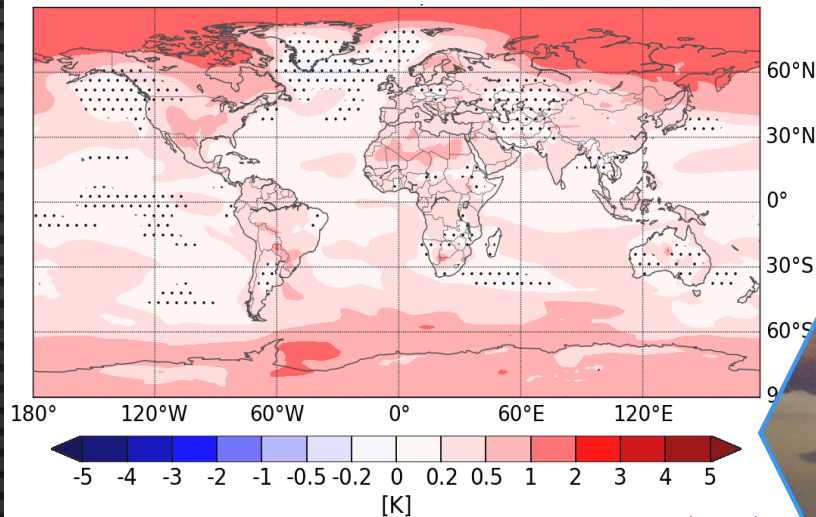


(Weisenstein et al., 2015)

Stratospheric  
aerosol injections

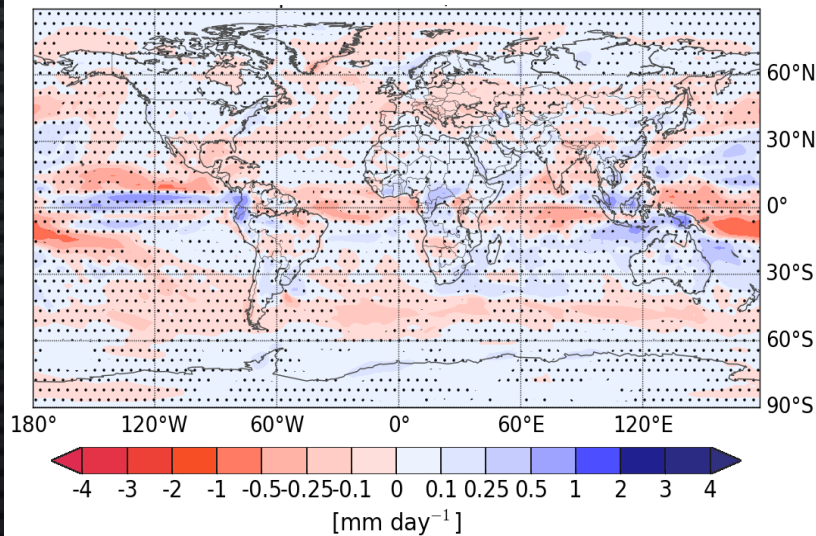
Temperaturer:  
resterende varme ved  
høye breddegrader

RCP8.5SAI - RCP4.5



(0.321)

RCP8.5SAI - RCP4.5



Stratospheric  
aerosol injections

2060 - 2090

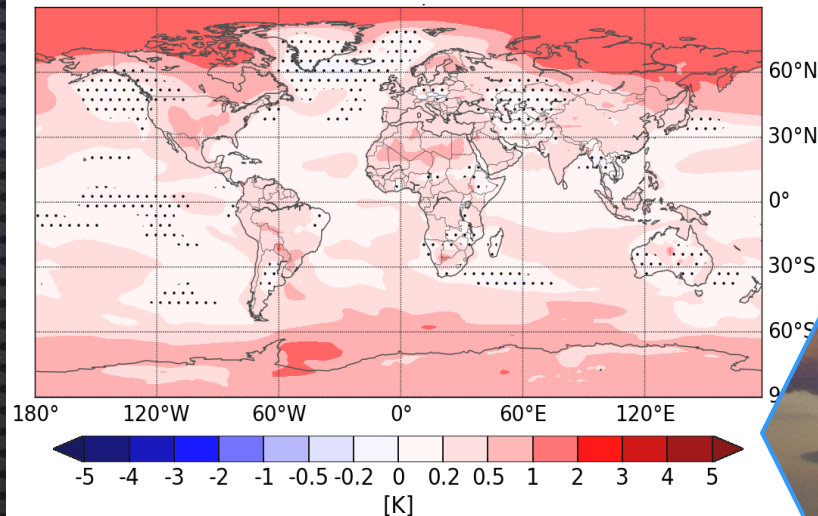


Non-significant values

(Muri et al., 2018, J Clim)

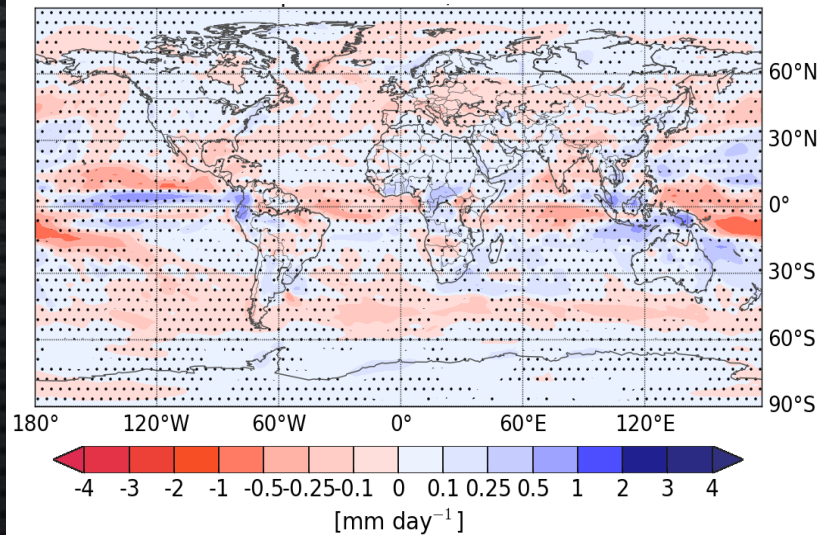
Temperaturer:  
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RCP8.5SAI - RCP4.5



(0.321)

RCP8.5SAI - RCP4.5



Stratospheric  
aerosol injections

Hydrologisk syklus: P-E  
Mindre nedbør globalt – men  
også mindre fordamping ->  
små endringer.

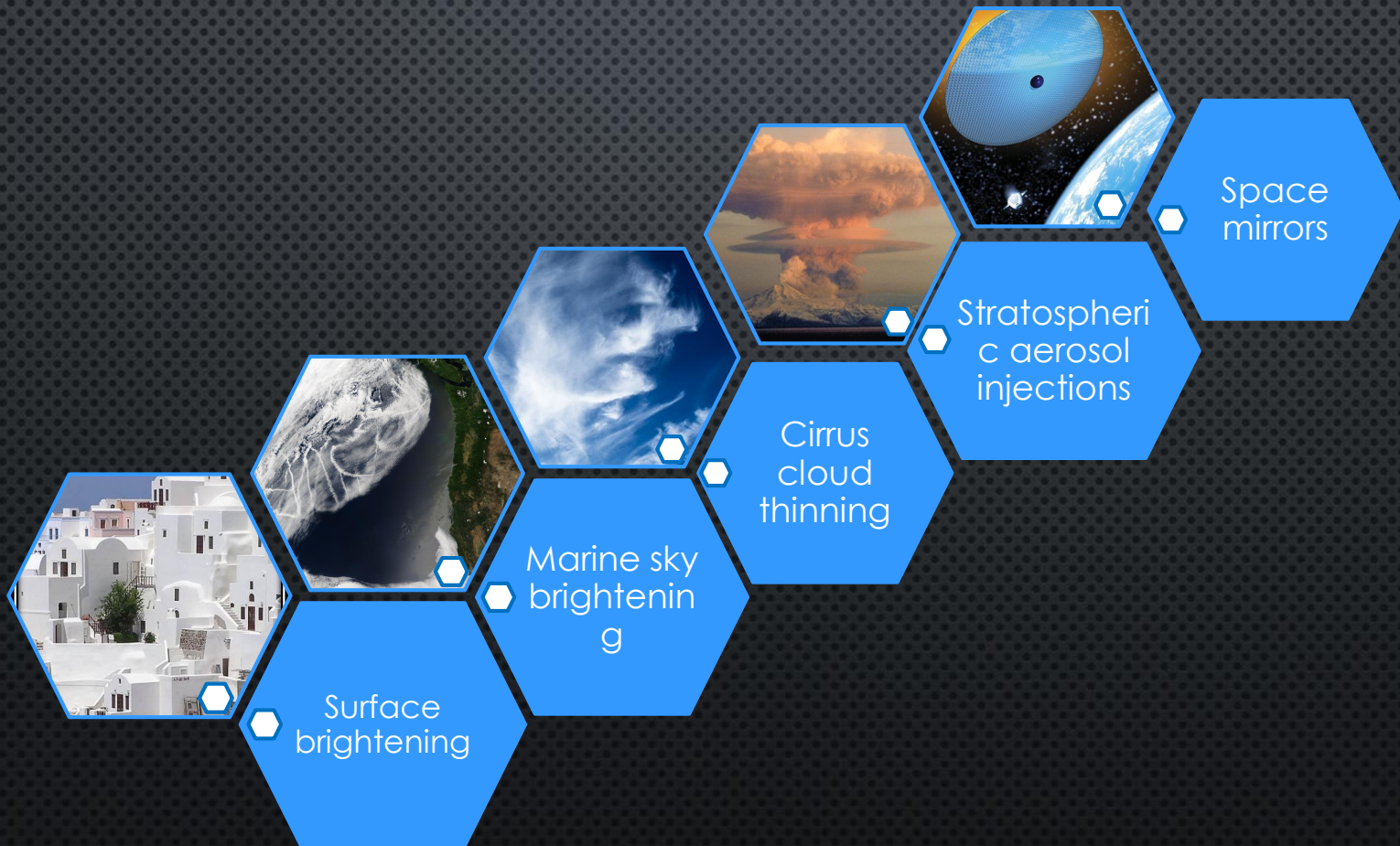
2060 - 2090



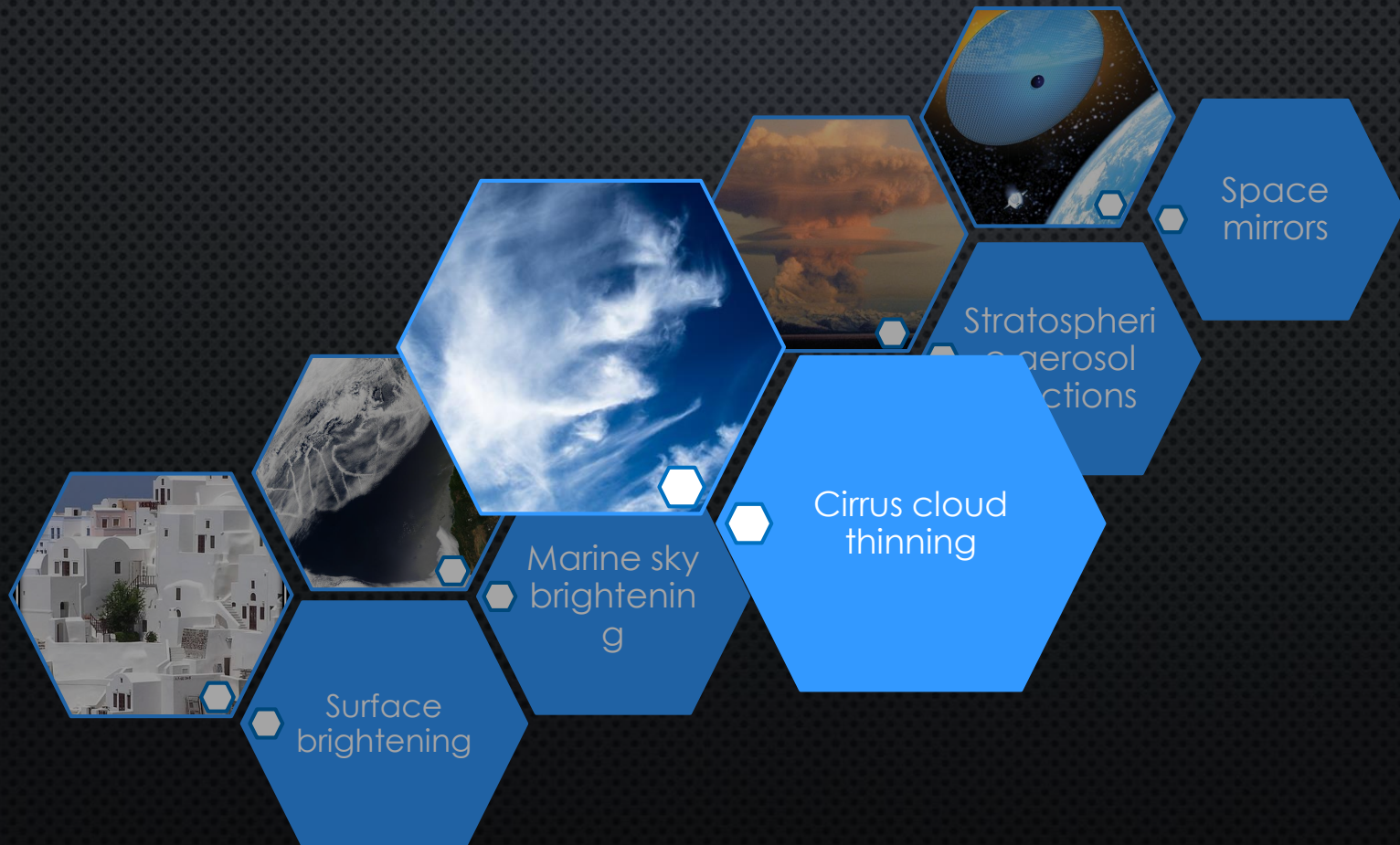
Non-significant values

(Muri et al., 2018, J Clim)

# Ideas for Solar Geoengineering

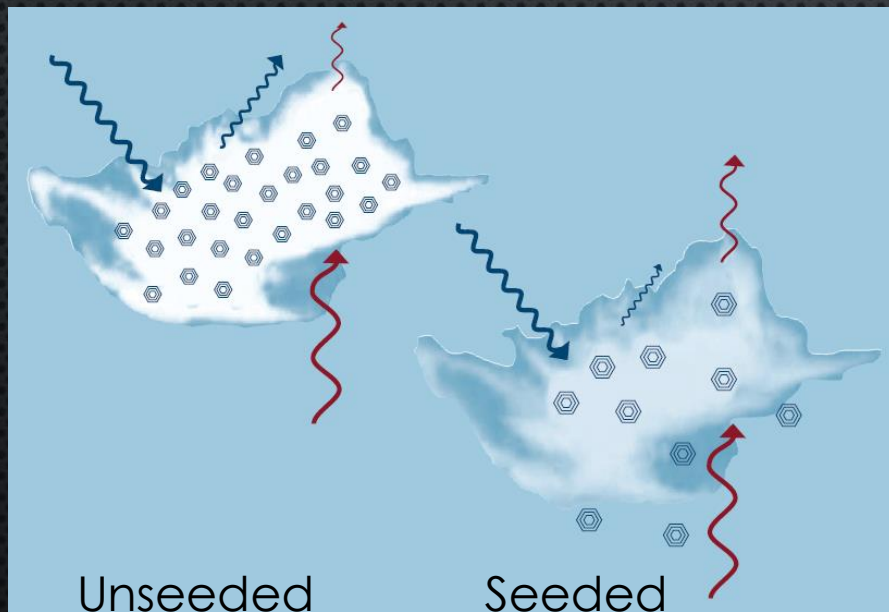


# Ideas for Solar Geoengineering



# Concept: deplete high level, heat trapping ice clouds.

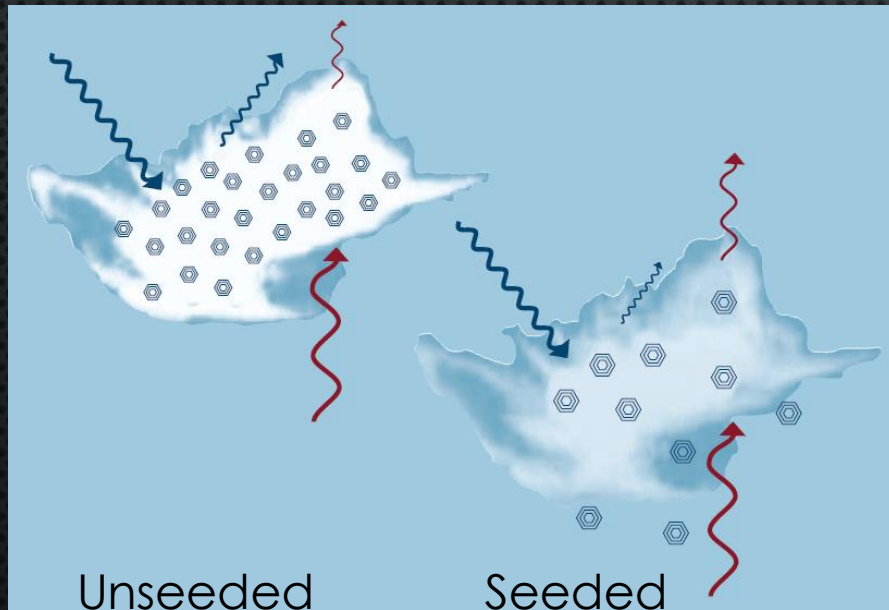
- Seed the clouds with very effective ice nuclei.
- Grow large ice crystals that fall out of clouds.
- Release more **LW** radiation.





# Concept: deplete high level, heat trapping ice clouds.

- Seed the clouds with very effective ice nuclei.
- Grow large ice crystals that fall out of clouds.
- Release more **LW** radiation.



(After Storelvmo, Muri, et al., 2013)



Cirrus cloud thinning

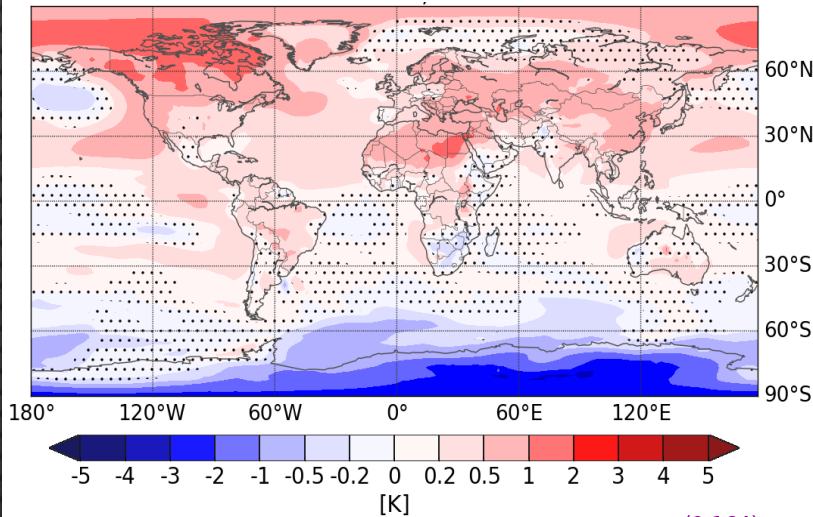


(Credit: Kevin Clifford/Drone America)

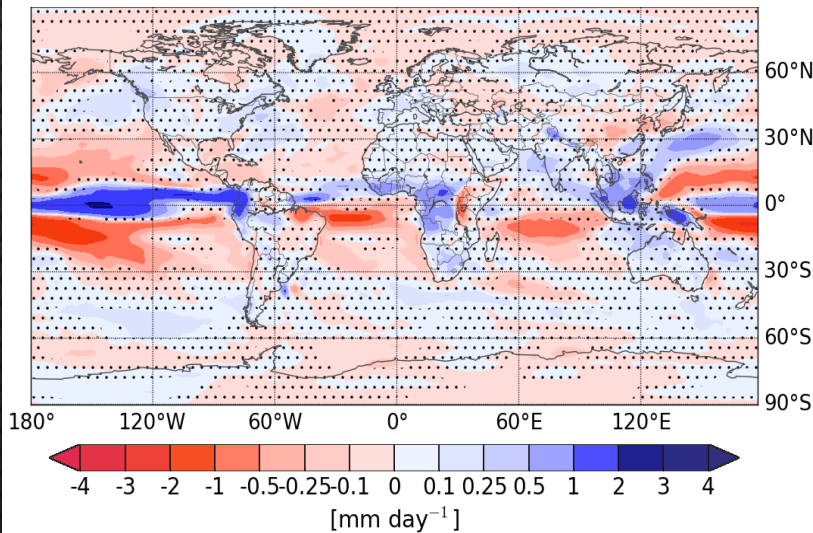


# Temperaturrespons avhengig av dekke av isskyer og hvor de er.

RCP8.5CCT - RCP4.5



(0.164)



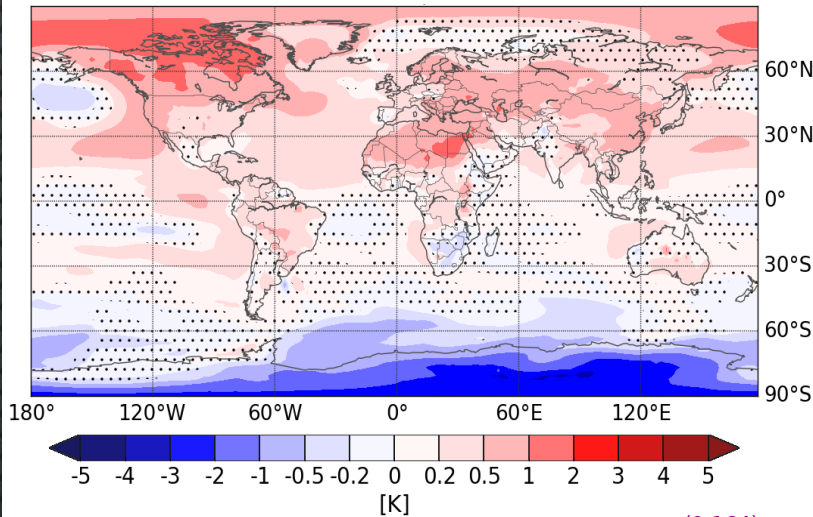
Non-significant values  
2060 - 2090

(Muri et al., 2018, J Clim)

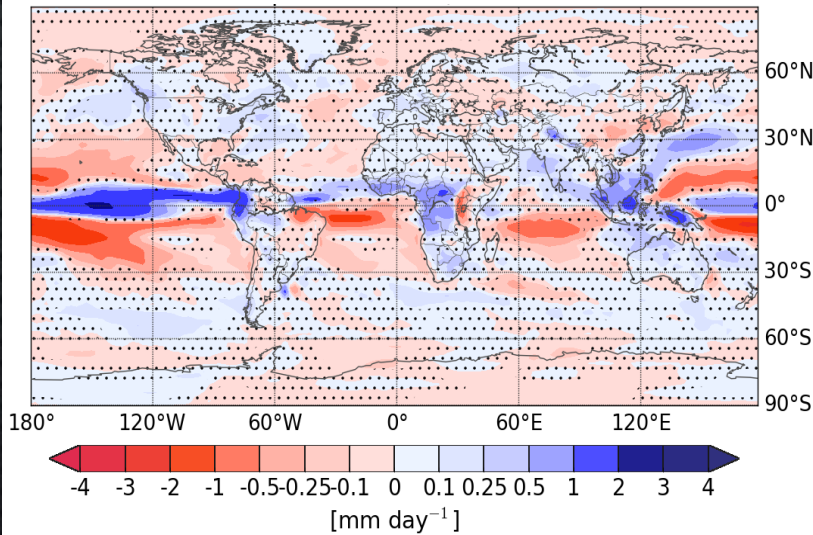


Temperaturrespons  
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isskyer og hvor de er.

RCP8.5CCT - RCP4.5



(0.164)



Non-significant values  
2060 - 2090

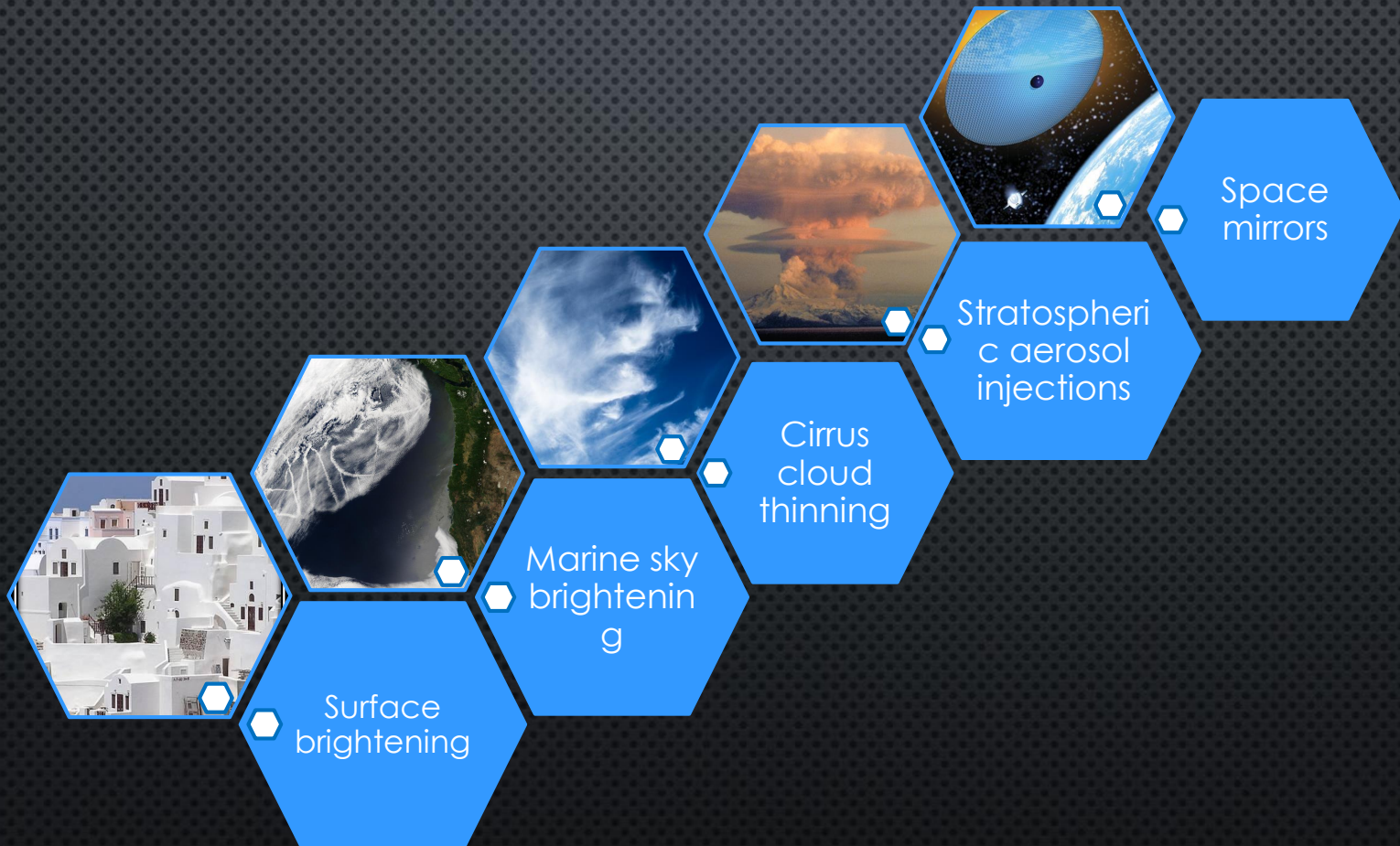
(Muri et al., 2018, J Clim)



Cirrus cloud  
thinning

Mer intens hydrologisk syklus.  
Spesielt over land.

# Ideas for Solar Geoengineering

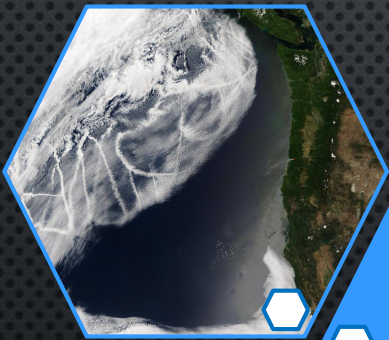
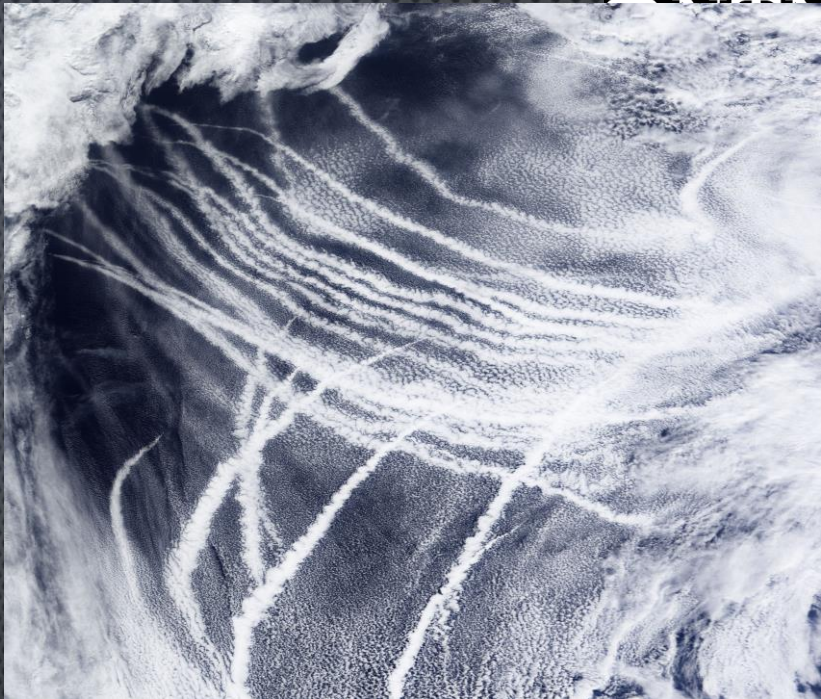


# Ideas for Solar Geoengineering

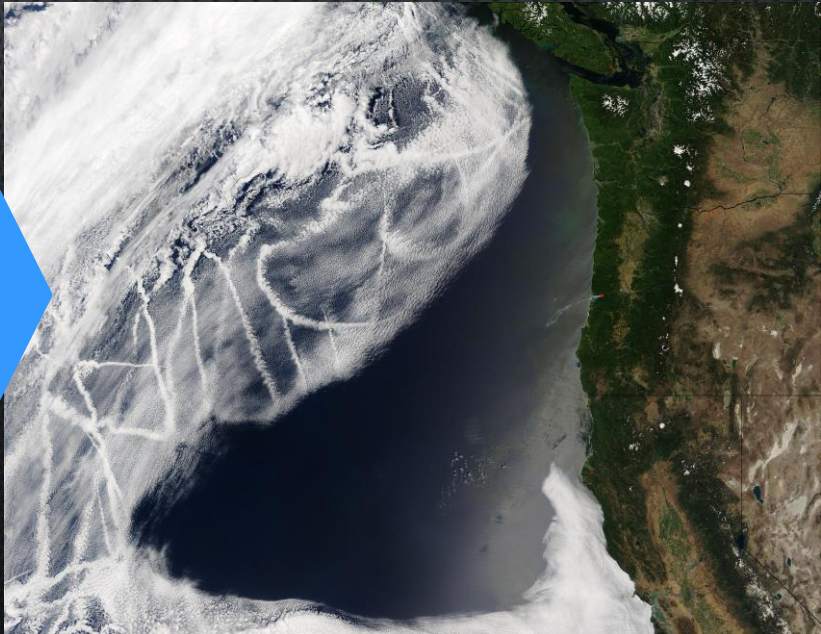


Concept: brighten clouds to reflect more sunlight.

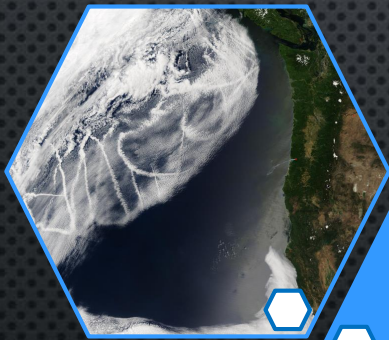
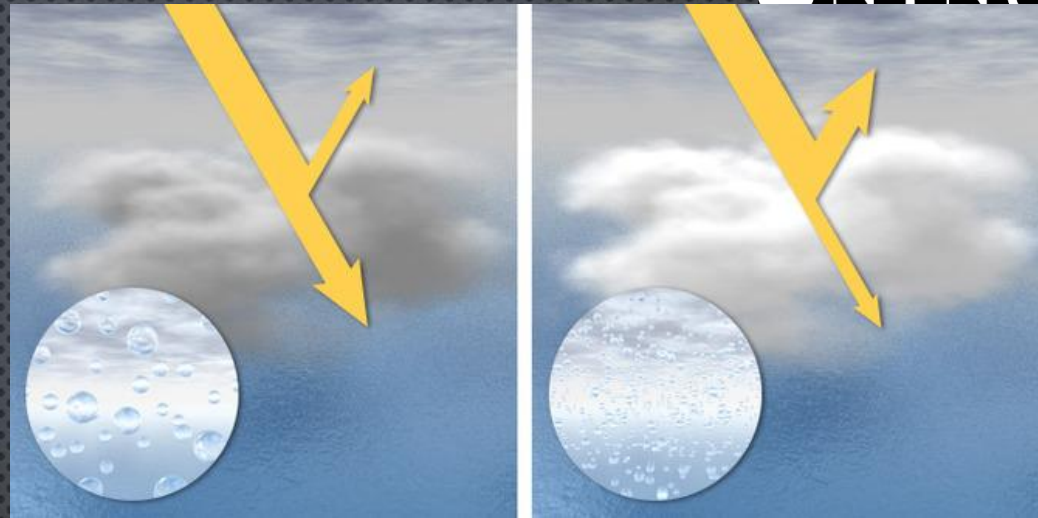
Ship tracks analogy



Marine sky brightening

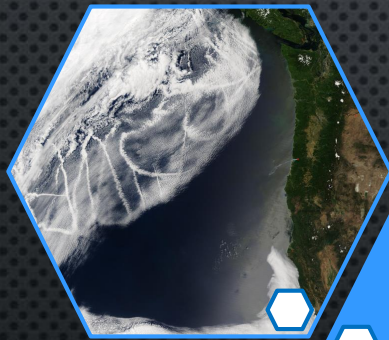
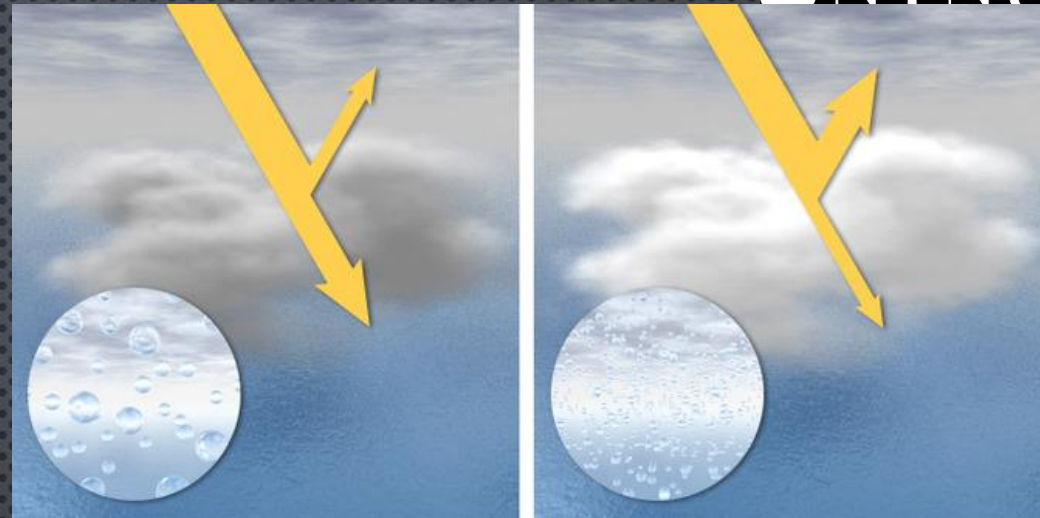


- Spray sea water.
- Sea salt aerosols can act as cloud condensation nuclei to make clouds denser.
- Aerosols also directly reflective.

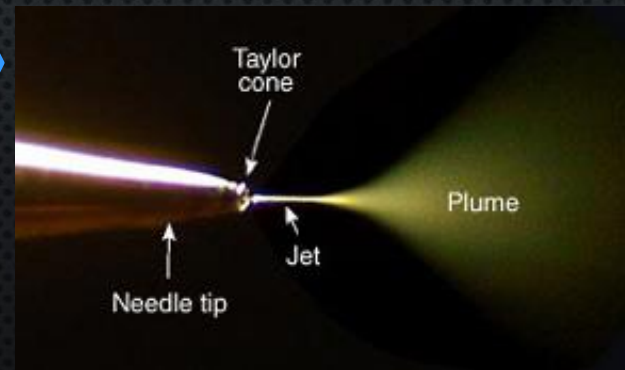


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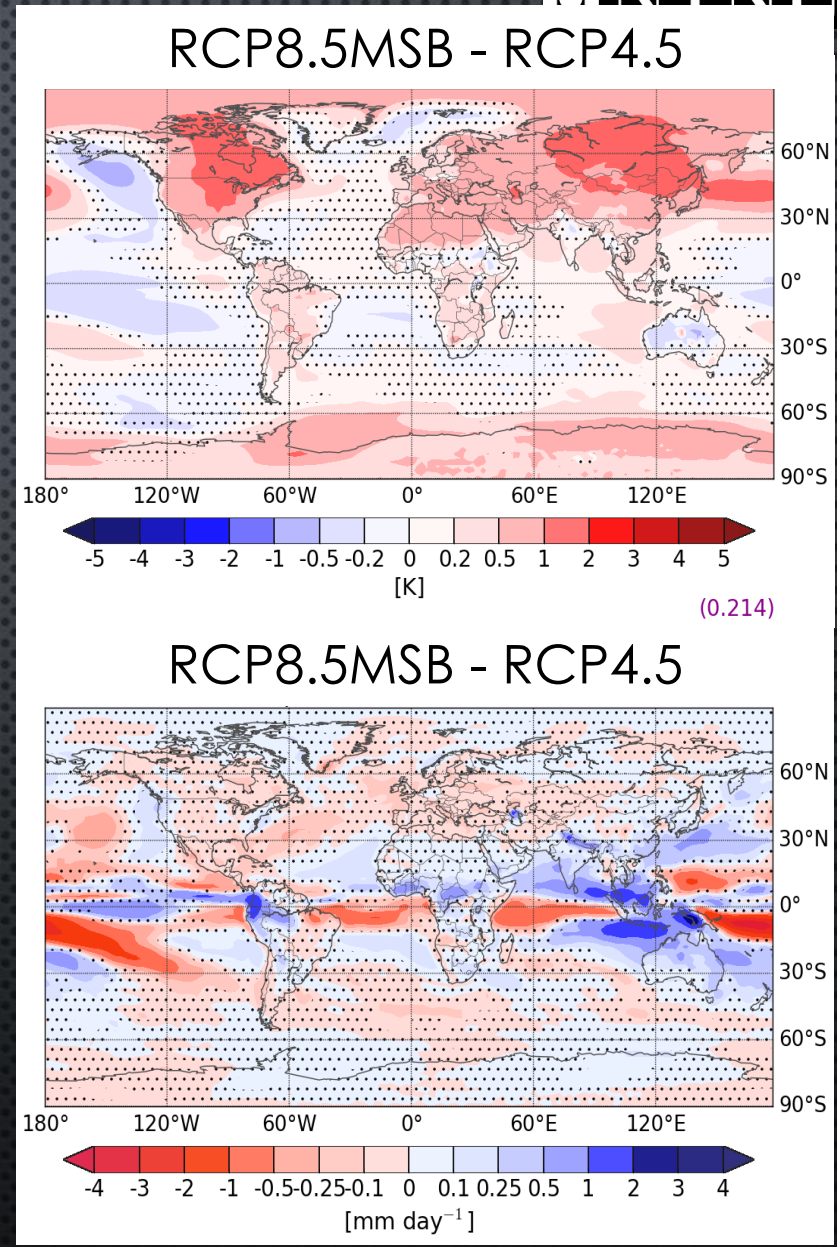


Marine sky brightening





Sterkere avkjøling over havet p.g.a. regionalt pådriv.



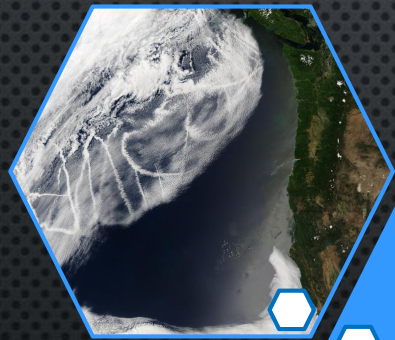
(0.214)

2060 - 2090 [Dotted box] Non-significant values

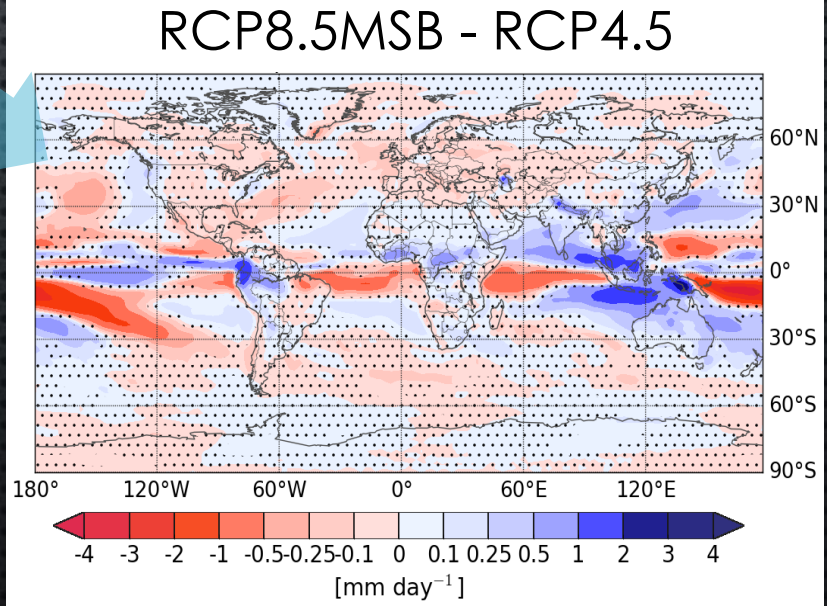
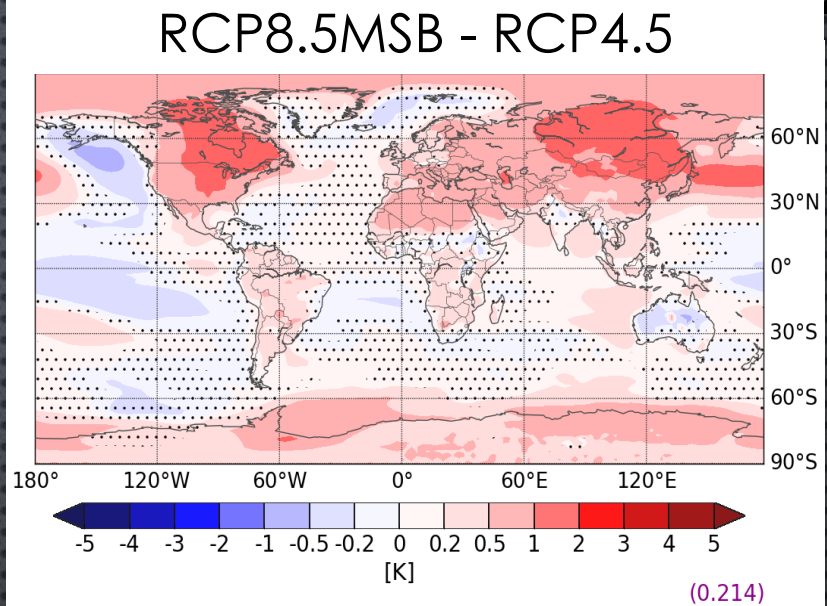
(Muri et al., 2018, J Clim)

Sterkere avkjøling over havet p.g.a. regionalt pådriv.

Endrede nedbørsfelt med økt intensitet over land.



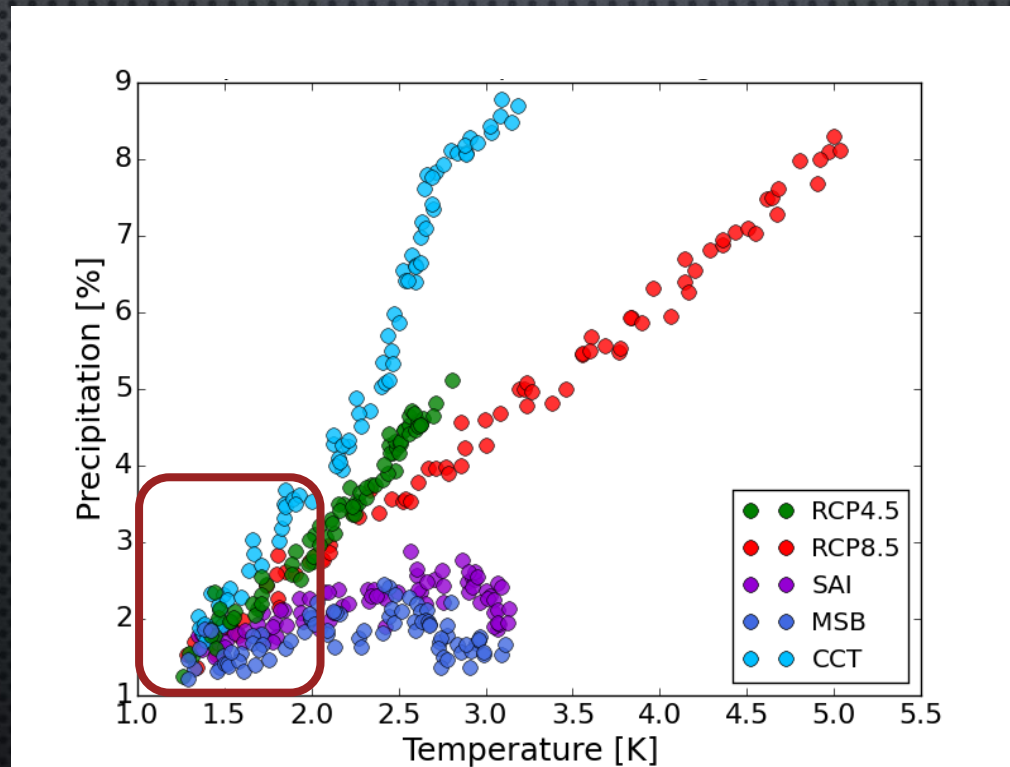
Marine sky brightening



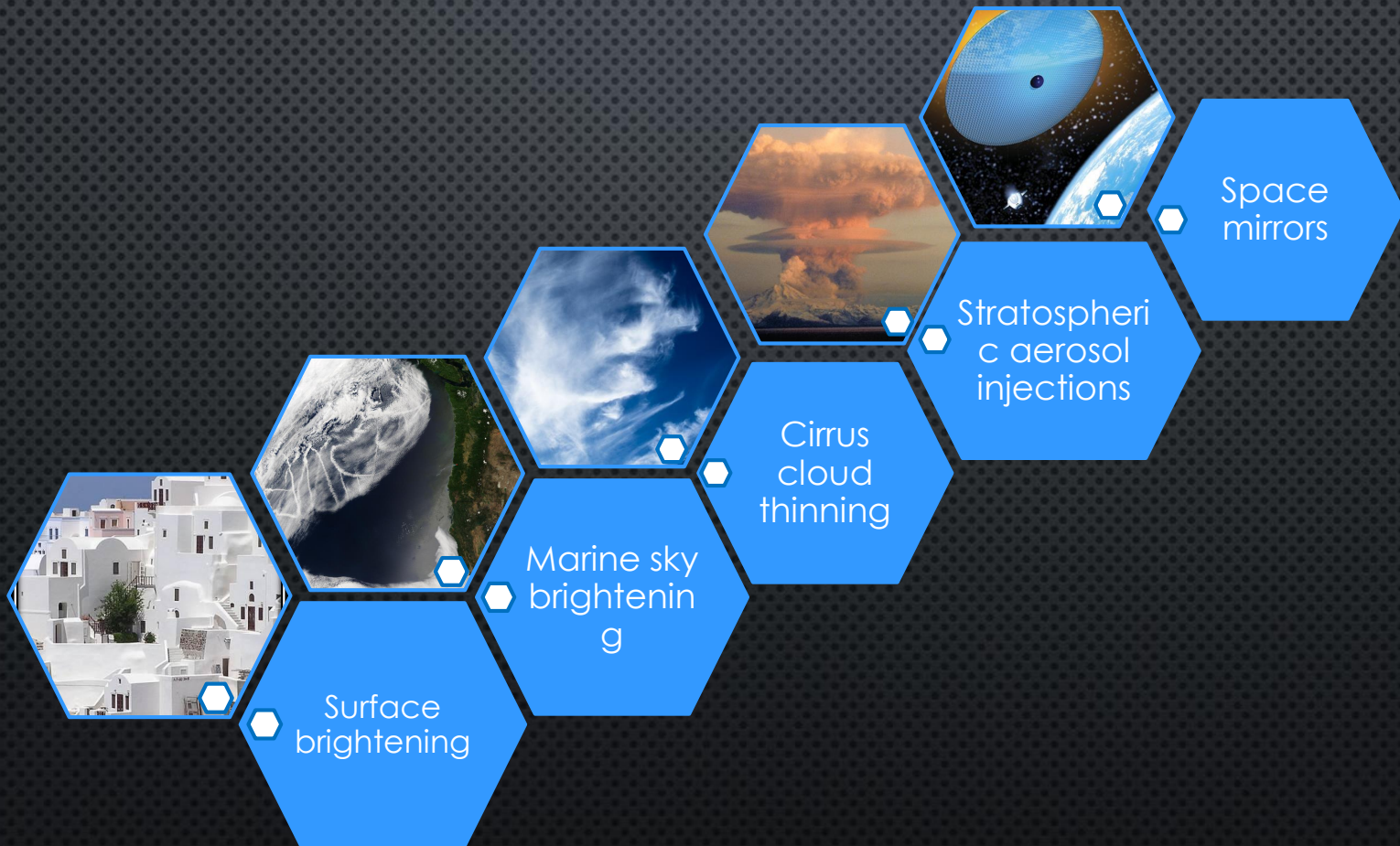
2060 - 2090    [Dotted Box] Non-significant values

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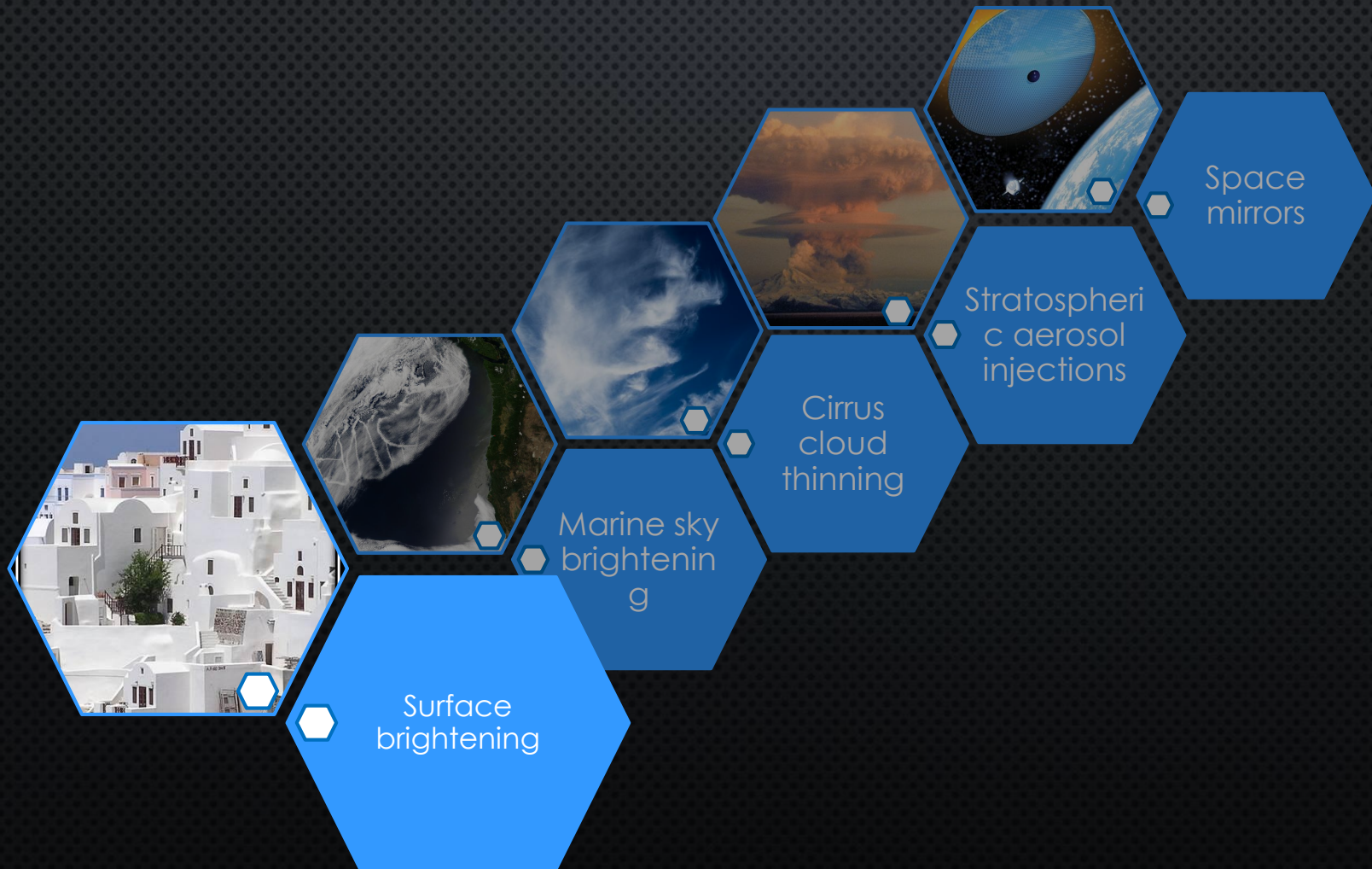
# TEMPERATURE VS PRECIPITATION CHANGE FROM THE PRE-INDUSTRIAL



# IDEAS FOR SOLAR GEOENGINEERING



# IDEAS FOR SOLAR GEOENGINEERING

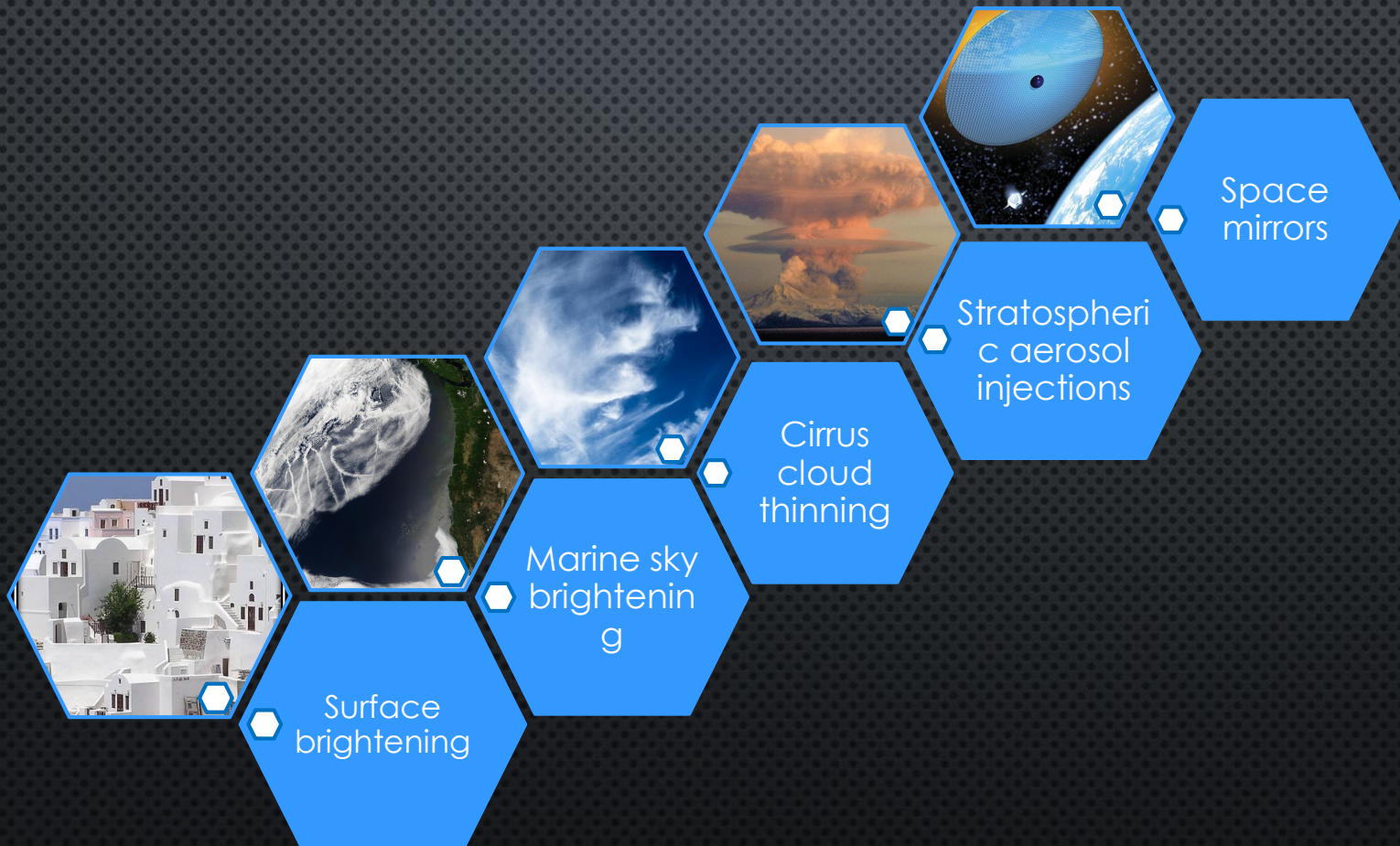




Surface brightening



# IDEAS FOR SOLAR GEOENGINEERING

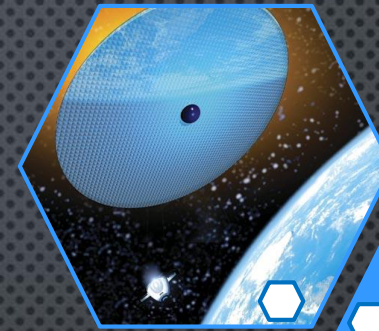


# IDEAS FOR SOLAR GEOENGINEERING



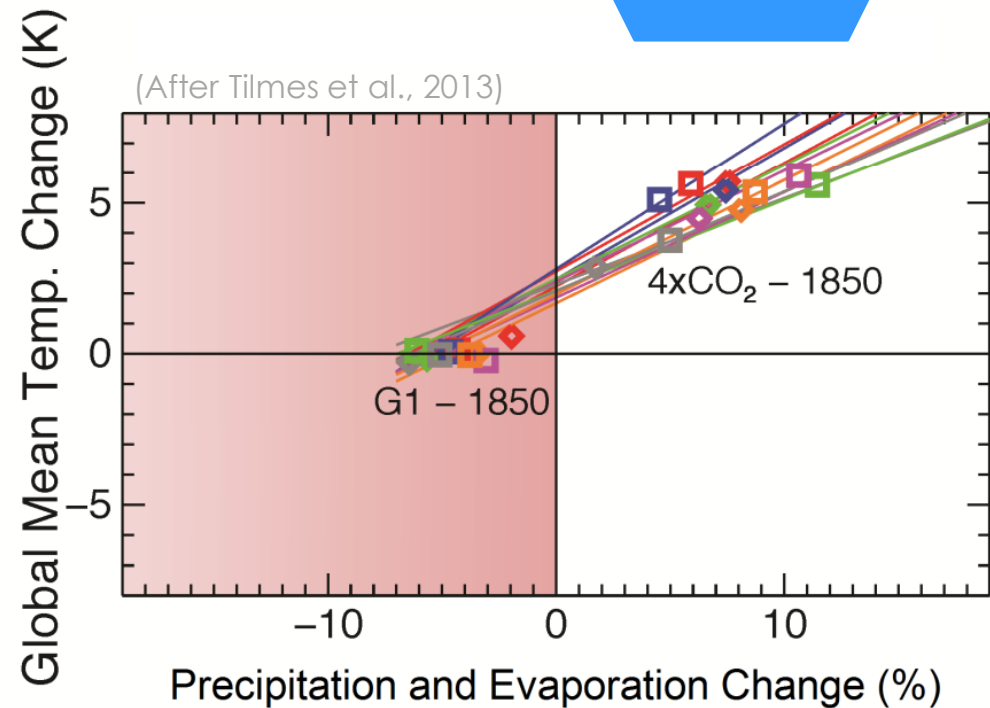


Concept: Place mirrors in space to reflect sunlight before reaching Earth.

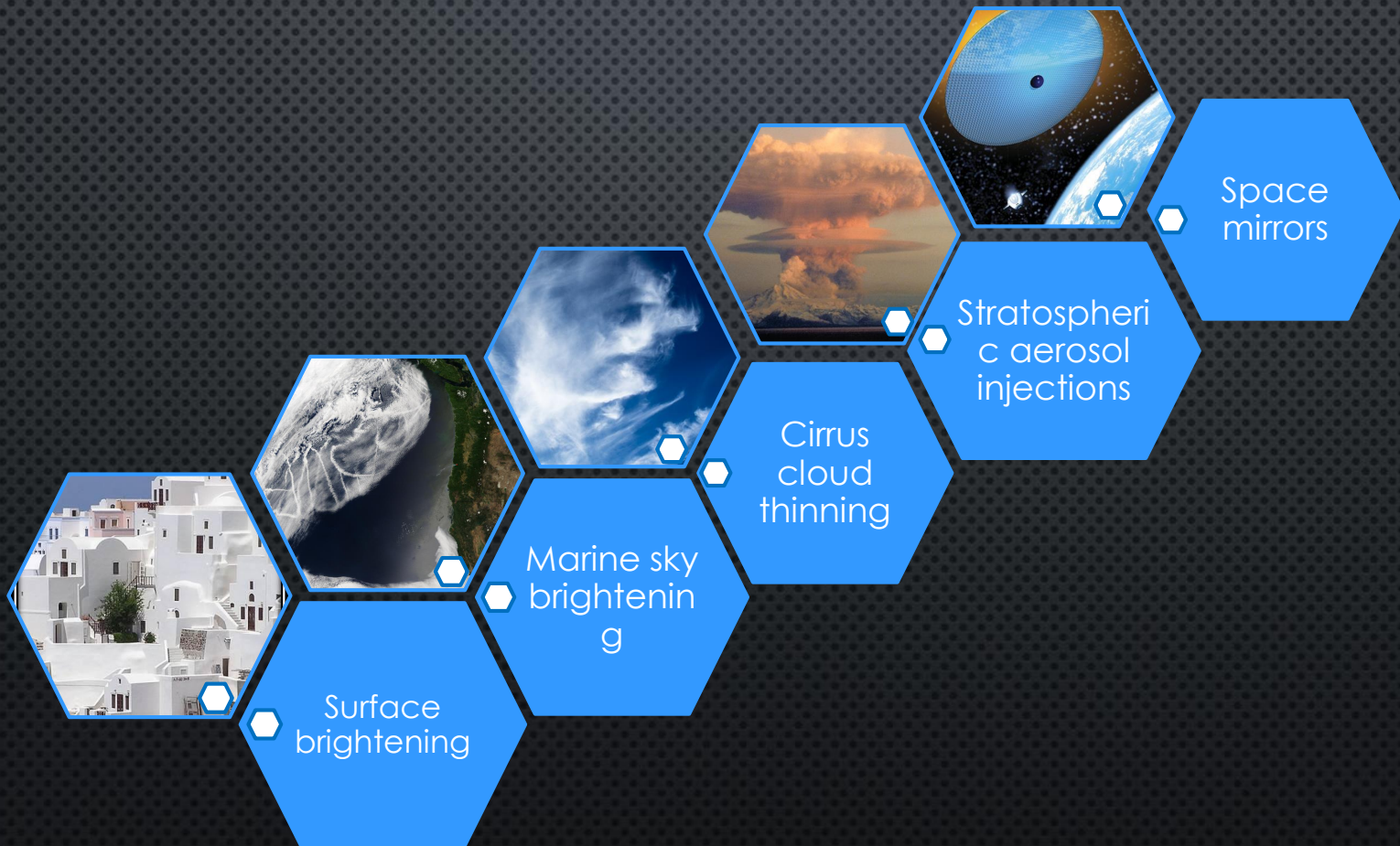


Space mirrors

- \*Astronomical\* deployment costs.
- Modelling can reveal fundamentals of solar geoengineering types like SAI.

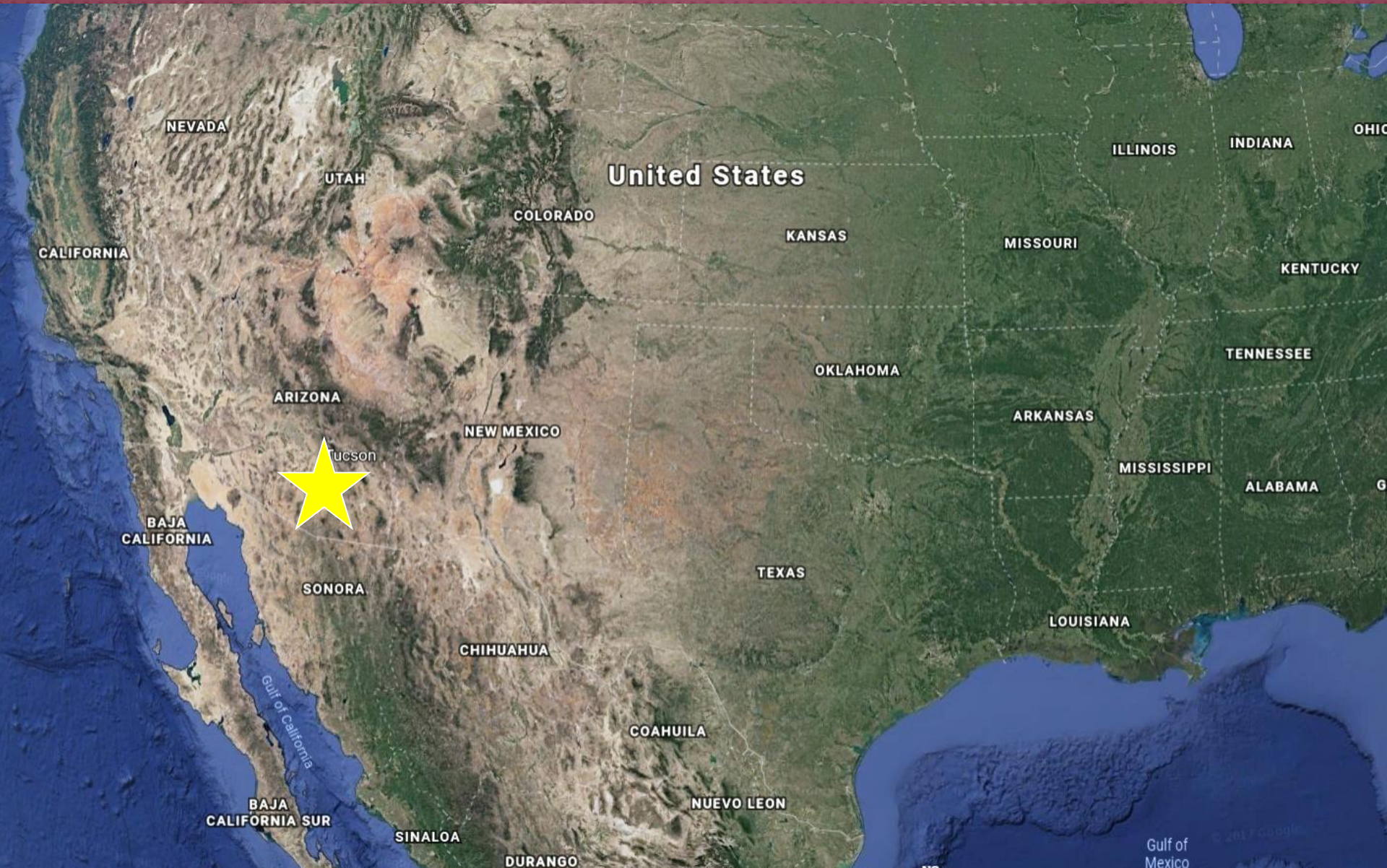


# IDEAS FOR SOLAR GEOENGINEERING



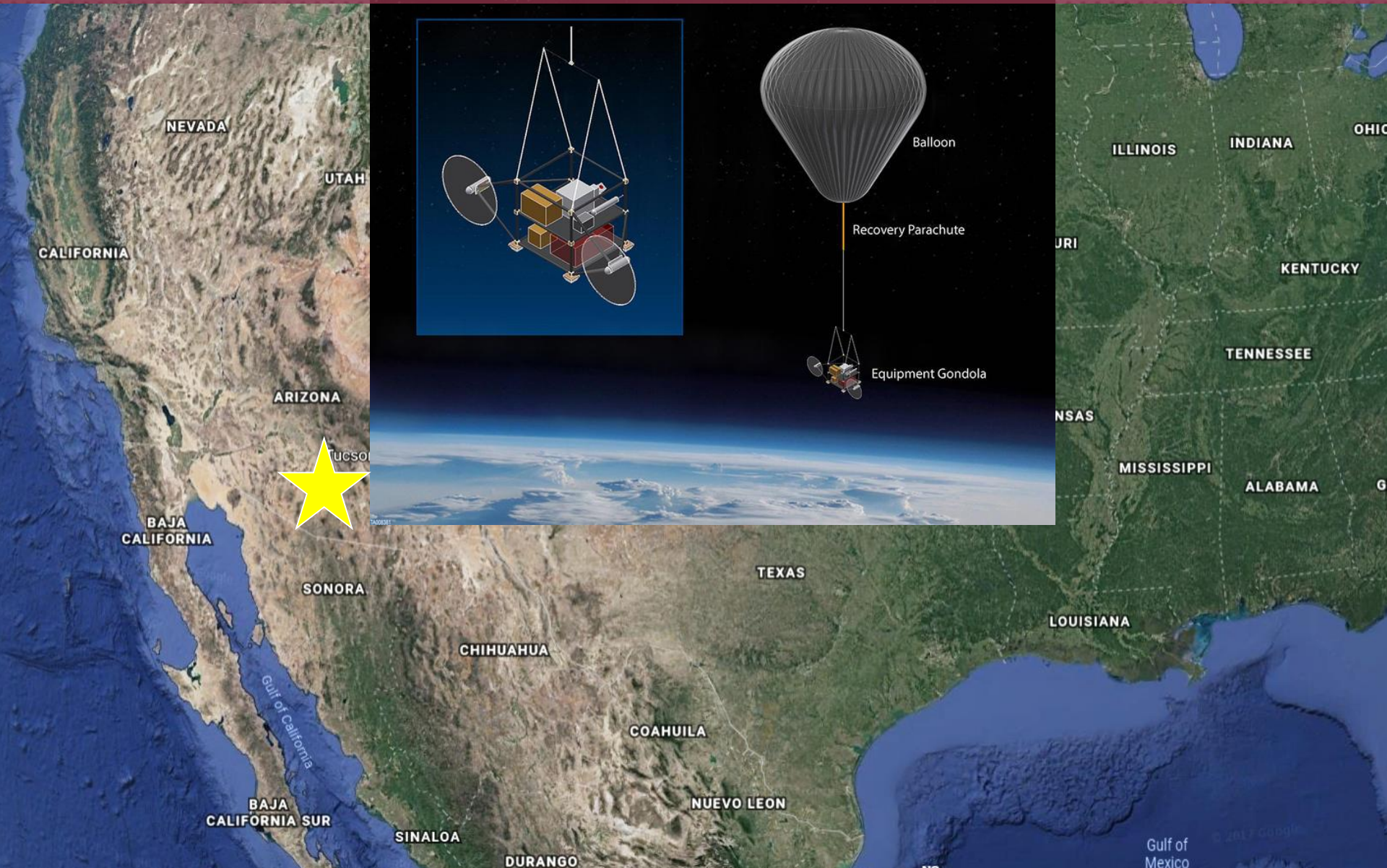
# UTENDØRSTESTING | 2018

## Stratospheric Controlled Perturbation Experiment (SCoPEX)



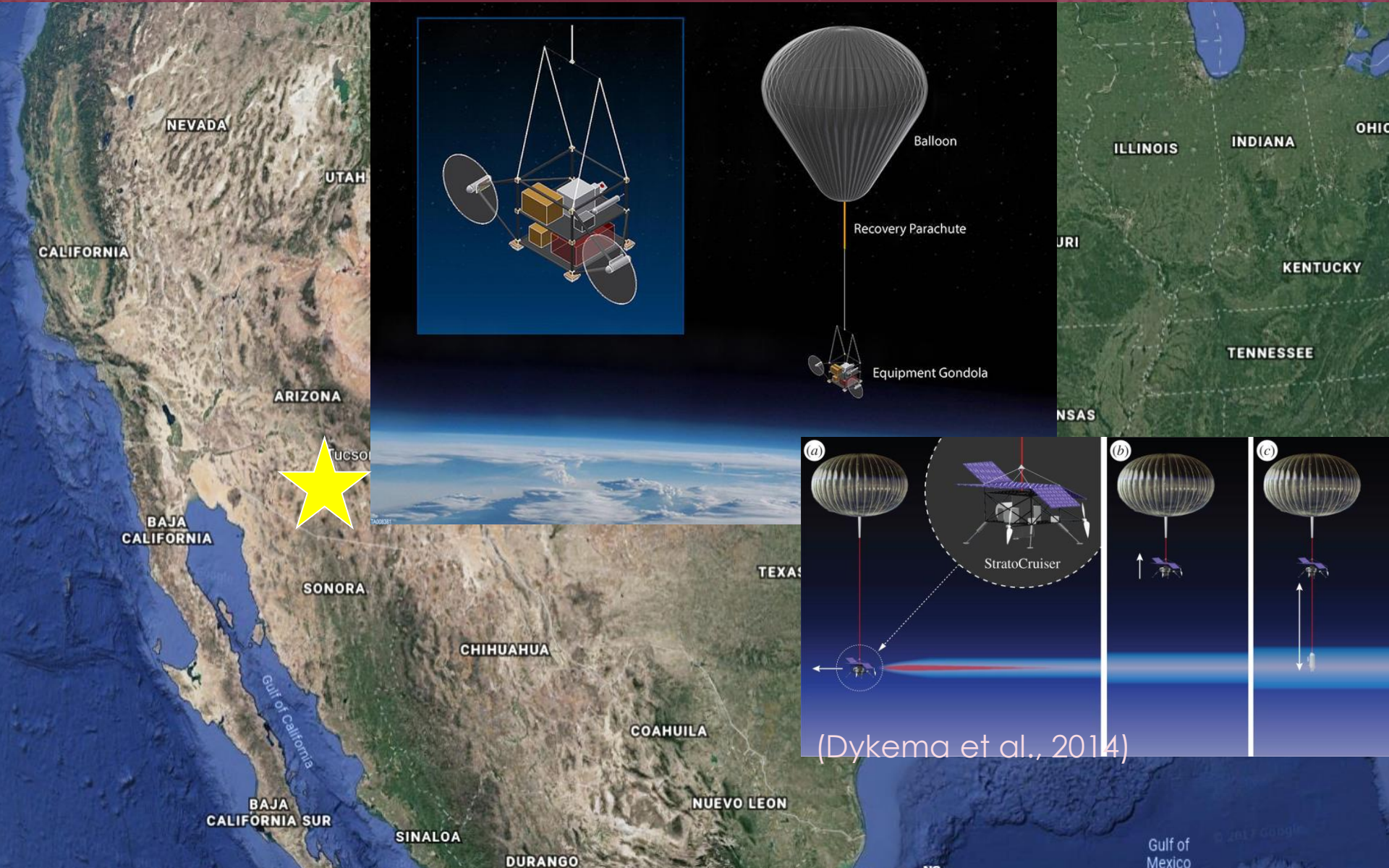
# UTENDØRSTESTING | 2018

## Stratospheric Controlled Perturbation Experiment (SCoPEX)



# UTENDØRSTESTING I 2018

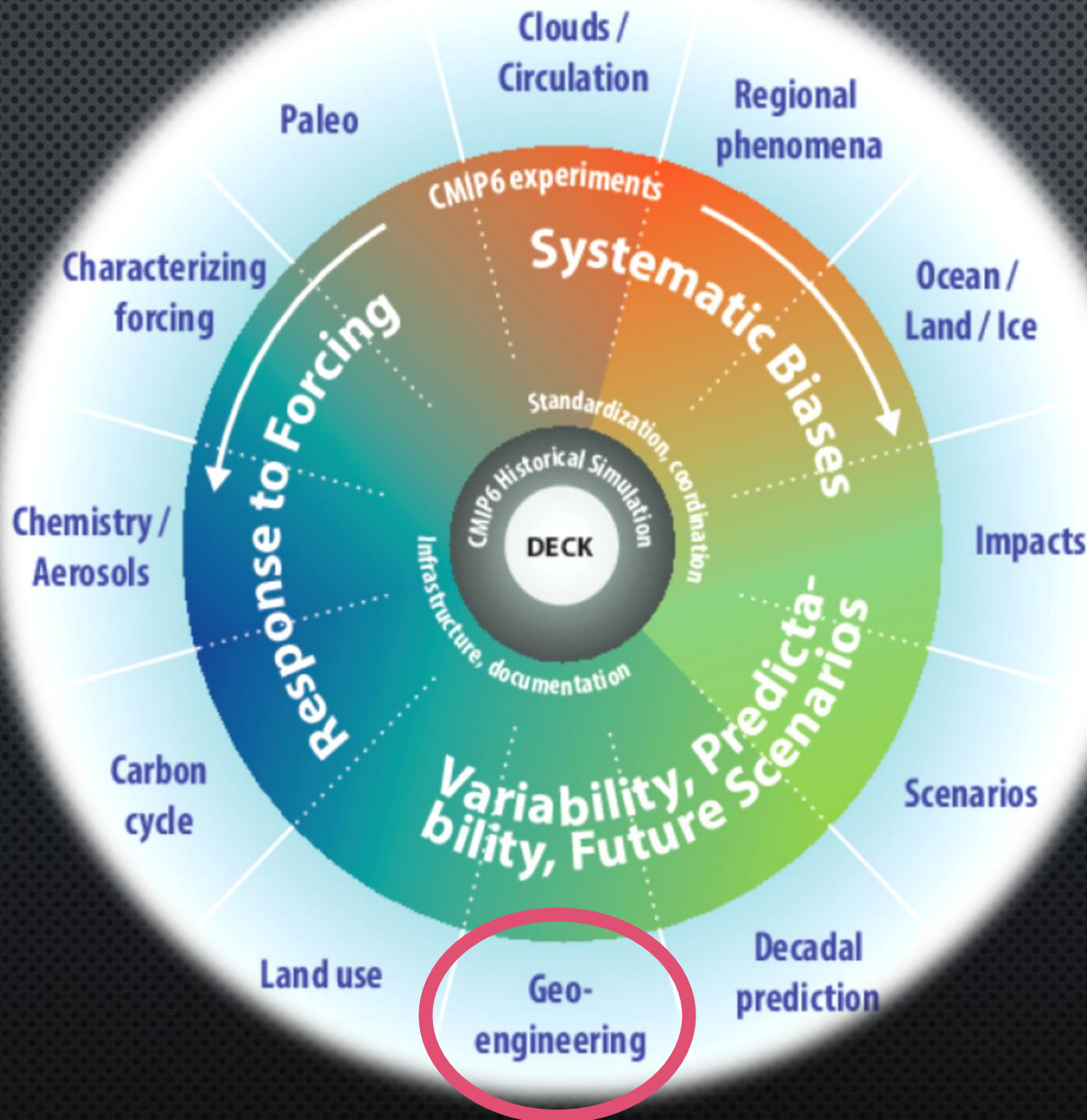
## Stratospheric Controlled Perturbation Experiment (SCoPEX)



TIL ETTERTANKE: UTENDØRSAKTIVITETER HAR EN  
TENDENS TIL Å BLI MESSY ...



([superpants.net/gameshows.html](http://superpants.net/gameshows.html))



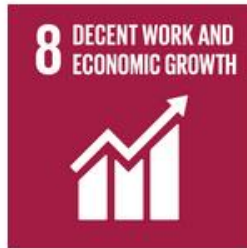
# Åpne Spørsmål

- UNCERTAIN CLIMATE *IMPACTS* (IPCC WG2).
- WHO SETS THE THERMOSTAT?
- IS IT TOO SOON TO FIELD TEST?
- DON'T WE NEED GOVERNANCE TO CATCH UP FIRST?
- WHAT ROLE FOR *COUNTER-GEOENGINEERING*?
- WHAT WOULD A GEOENGINEERING COALITION LOOK LIKE?
  - INTER-AGENCY OR CROSS-COUNTRY?
- HOW WOULD ONE DEFINE «SUCCESS»?
  - OF TESTING?
  - OF DEPLOYMENT?
- WHAT KIND OF «SAFETY NET» PREVENTING SUDDEN TERMINATION?
- BLAME GAME ...?
  - WINNERS AND LOSERS.
- MORAL HAZARD – REDUCED DRIVE FOR MITIGATION.
- MORAL AUTHORITY – DO WE HAVE THE RIGHT TO DO THIS?
- + + + ...





# SUSTAINABLE DEVELOPMENT GOALS



# Solar geoengineering

- Kan oppnå avkjøling raskt.
- Flere grader mulig.
- Tar seg av “symptomene”, men ikke “sykdommen”.
- Dermed ikke noe substitutt for utslippskutt.
- Klimabivirkninger sannsynlige, men usikre.
- ikke velutviklet nok teknologisk,
- kan ikke regnes som en del av klimaløsningen (ennå).
- Evaluering i neste syklus av FNs klimapanels rapporter (SR15, AR6).



Final report of the FP7 CSA project EuTRACE  
European Transdisciplinary Assessment of Climate Engineering

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## The European Transdisciplinary Assessment of Climate Engineering (EuTRACE)

Removing Greenhouse Gases from the  
Atmosphere and Reflecting Sunlight  
away from Earth

Editors: Stefan Schäfer, Mark Lawrence, Harald Stelzer,  
Wanda Born, Sean Low

**EuTRACE rapporten:**  
<http://www.eutrace.org/>

## Mer informasjon:



@HeleneMuri

[helene.muri@ntnu.no](mailto:helene.muri@ntnu.no)

**CEC14/CEC17:**  
<http://www.ce-conference.org/>

**EXPECT prosjektet:**  
<http://exepected.bitbucket.io>