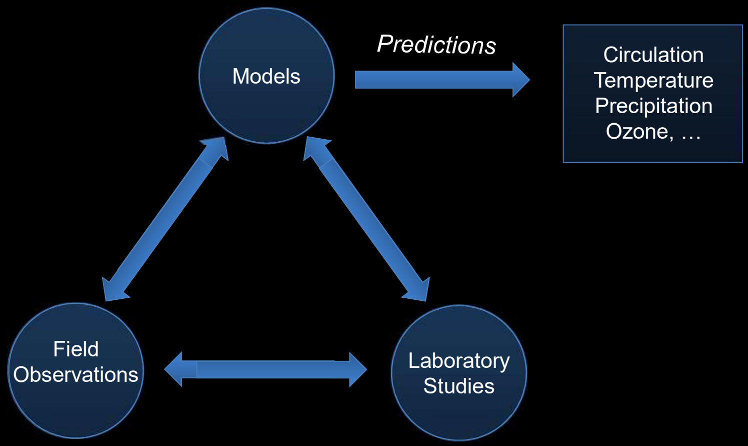
Stratospheric solar geoengineering research: the need for laboratory and outdoor experiments

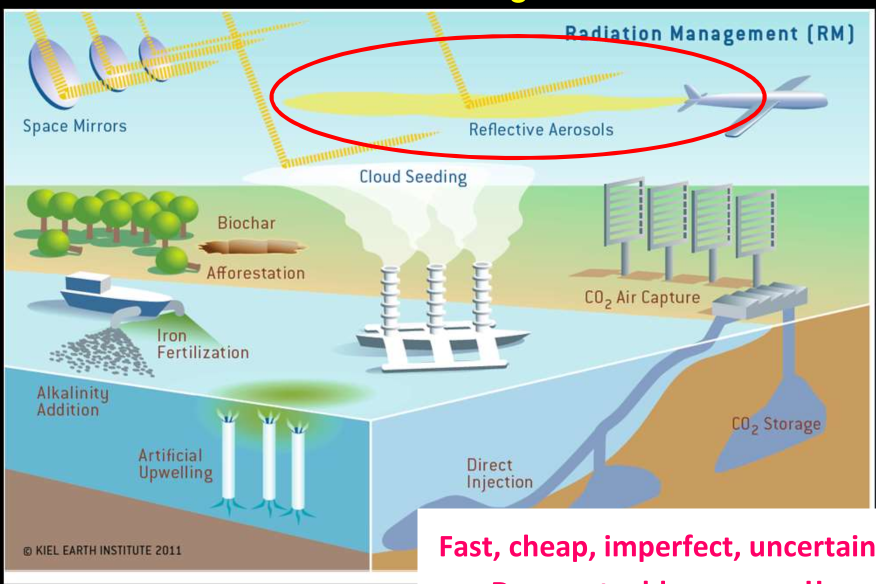


Frank Keutsch, Harvard University

June 10-11 2019, Academia Brasileira De Ci□ncias

1

Radiation Management



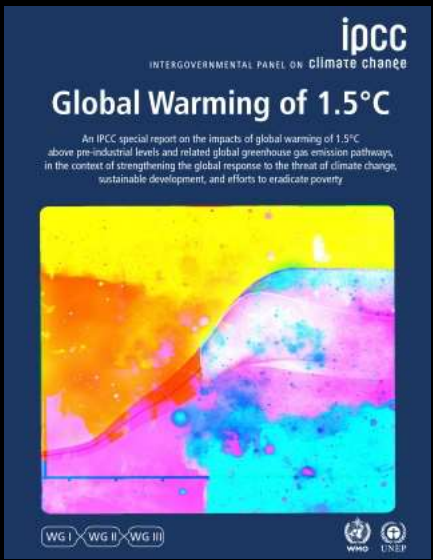
Fast, cheap, imperfect, uncertain

Does not address cause!!

2

2

Intergovernmental Panel on Climate Change 1.5ºC Special Report



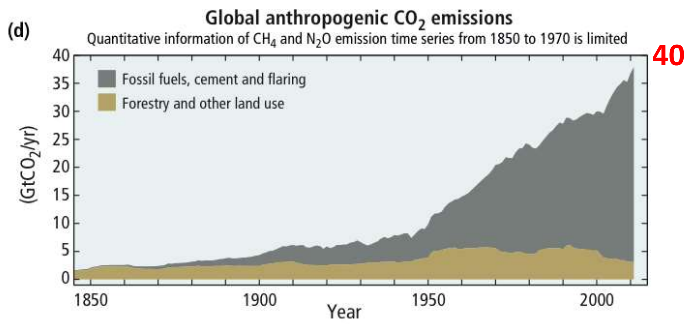
Halve CO_2 Emissions by 2030 compared to 2010

CO_2 neutral by 2050

3

3

A Rapidly Changing World: CO_2 Emissions



Global:	**5.0 t CO_2 / capita / year (2014)**
US:	**16.5 t CO_2 / capita / year**
Germany:	**8.9 t CO_2 / capita / year**
China:	**7.5 t CO_2 / capita / year**
Argentina:	**4.7 t CO_2 / capita / year**
Brazil:	**2.6 t CO_2 / capita / year**
Colombia:	**1.8 t CO_2 / capita / year**

Adapted from IPCC 2013 WGI_AR5_FigSPM-4; https://data.worldbank.org/indicator/EN.ATM.CO2E.PC?year_high_desc=true

4

4

The Problem With 1.5 and 2°C

Cumulative CO_2 emissions from 1870 in $GtCO_2$		
Net anthropogenic warming [a]	<1.5°C	
Fraction of simulations meeting goal [b]	66%	50%
Complex models, RCP scenarios only [c]	2250	2250
Cumulative CO_2 emissions from 2011 in $GtCO_2$		
Complex models, RCP scenarios only [c]	400	550

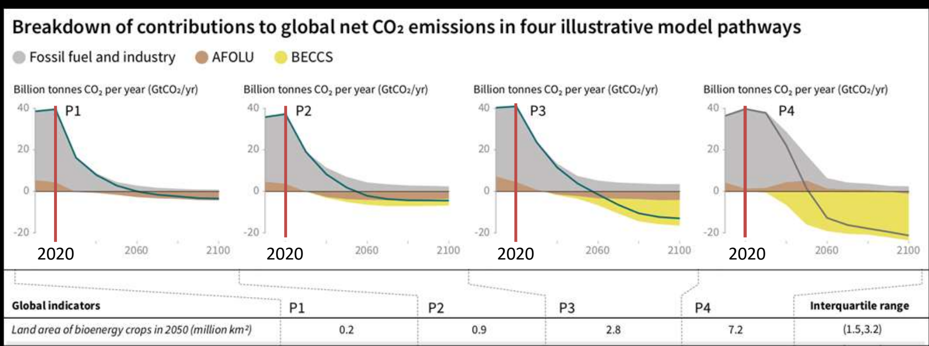
Implies emissions have to be **zero in ~ 2022** for 66% chance of staying below 1.5 °C!

Adapted from Table 2.2 IPCC AR5

5

5

IPCC Models: BECCS Land Use



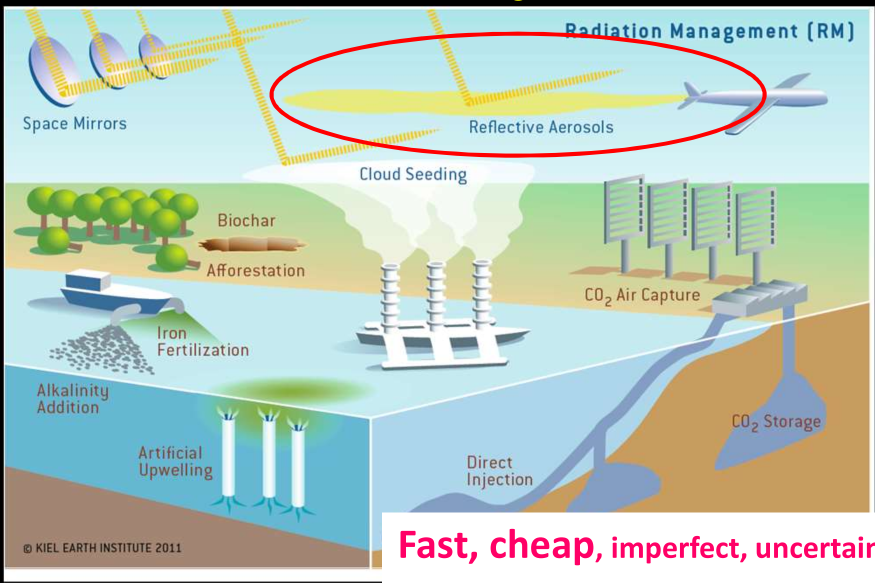
Land use 2050 **Ecuador** **Nigeria** **India** **Australia**

Adapted from IPCC 1.5C Report

6

6

Radiation Management



Fast, cheap, imperfect, uncertain

Does not address cause!!

7

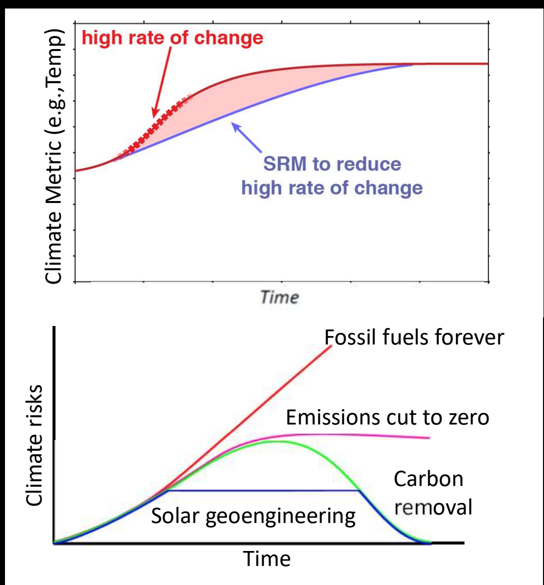
7

1.5 and 2°C: Possible solar radiation management (SRM) approaches

Risk: related to *rate of change, extreme events,* and *tipping points*

Mitigation efforts unable to reduce risk of change in the short term (?)

SRM to reduce high rate of change and "peak shaving" to reduce risk

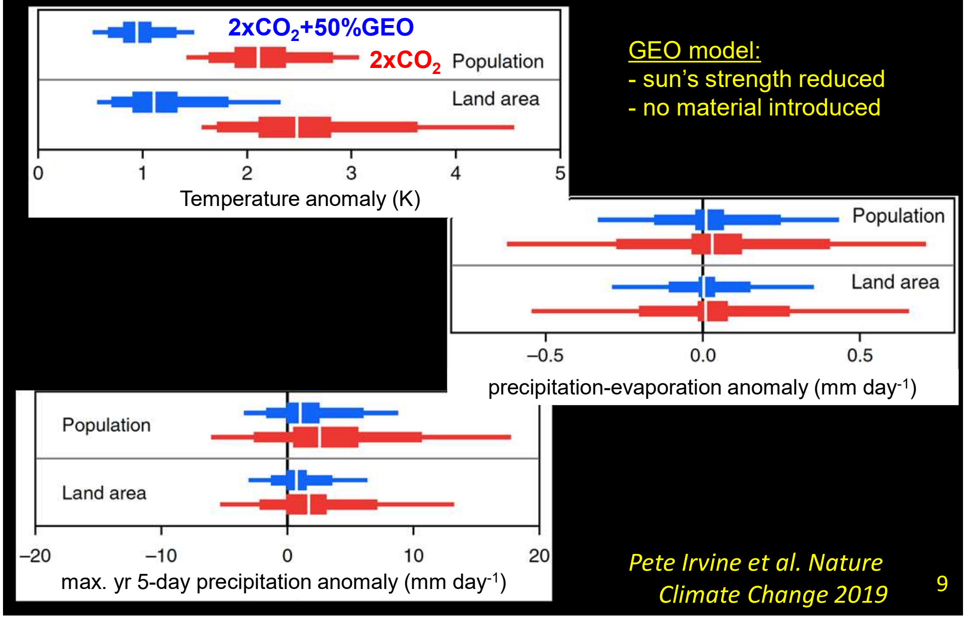


SRM at best supplement to mitigation, never solution

8

8

Temperature and Hydrological Cycle: Better or worse off in 50% SRM scenario?



GEO model:
- sun's strength reduced
- no material introduced

Pete Irvine et al. Nature Climate Change 2019

9

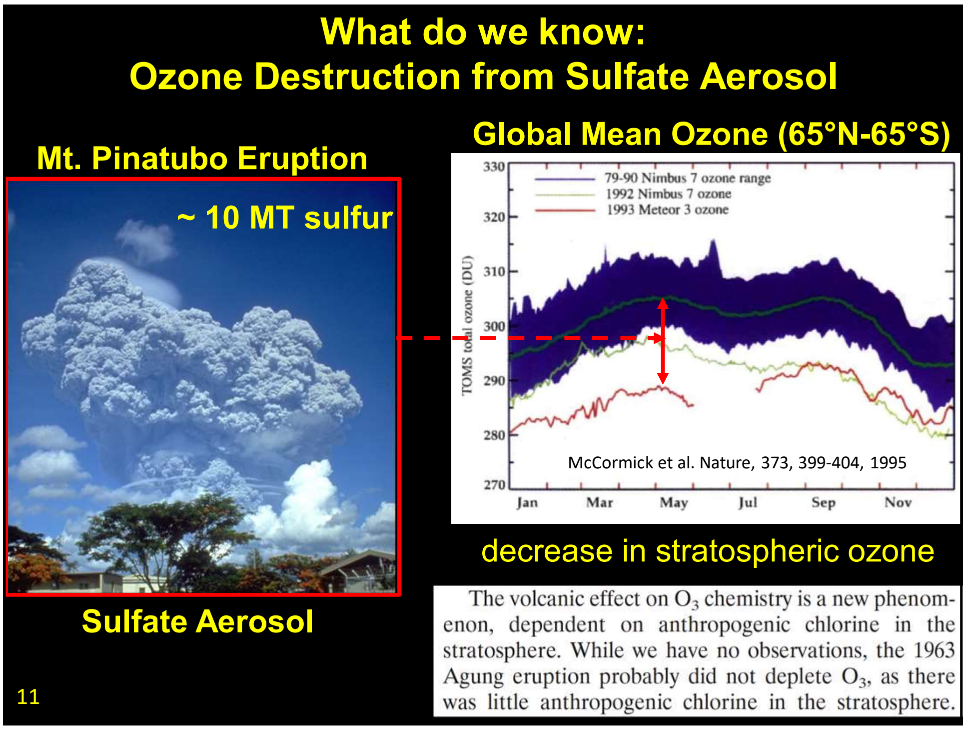
9

Geoengineering via Stratospheric Aerosol Injection

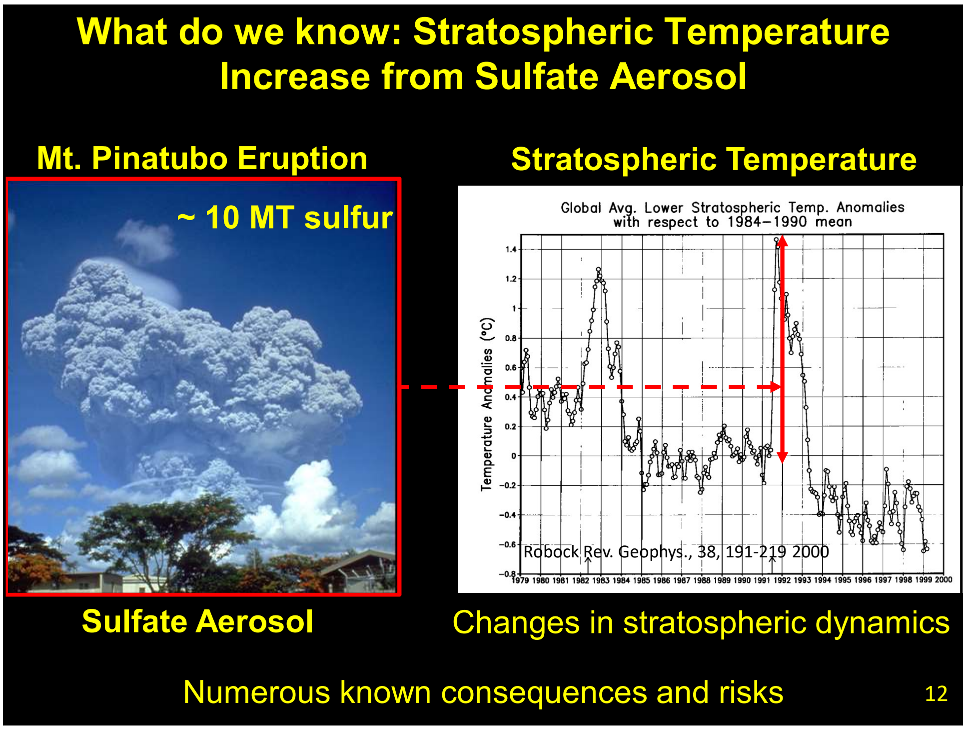
- Only addresses symptoms, not cause
- Entails numerous new and poorly understood risks (research needs!)
- Prospect of geoengineering could be viewed as an "insurance policy" promoting high risk behavior and curb voluntary efforts to reduce carbon emissions, even increase
- Resources moved away from mitigation and adaptation?
- Starting larger and larger scale experiments "slips" into deployment?
- Who controls scale of geoengineering, different nations will have different goals?
- May be viewed as only fast method to counter impacts of climate change!

10

10

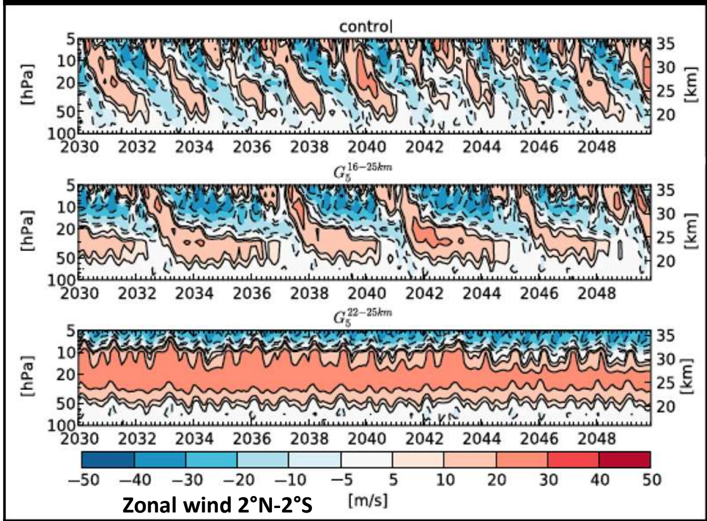

What do we know:
Ozone Destruction from Sulfate Aerosol
Mt. Pinatubo Eruption
~ 10 MT sulfur
Sulfate Aerosol
Global Mean Ozone (65°N-65°S)
79-90 Nimbus 7 ozone range
1992 Nimbus 7 ozone
1993 Meteor 3 ozone
TOMS total ozone (DU)
330
320
310
300
290
280
270
Jan
Mar
May
Jul
Sep
Nov
McCormick et al. Nature, 373, 399-404, 1995
decrease in stratospheric ozone
The volcanic effect on O_3 chemistry is a new phenomenon, dependent on anthropogenic chlorine in the stratosphere. While we have no observations, the 1963 Agung eruption probably did not deplete O_3, as there was little anthropogenic chlorine in the stratosphere.
11

11


What do we know: Stratospheric Temperature
Increase from Sulfate Aerosol
Mt. Pinatubo Eruption
~ 10 MT sulfur
Sulfate Aerosol
Stratospheric Temperature
Global Avg. Lower Stratospheric Temp. Anomalies
with respect to 1984–1990 mean
Temperature Anomalies (°C)
Robock Rev. Geophys., 38, 191-219 2000
Changes in stratospheric dynamics
Numerous known consequences and risks
12

12

Sulfate Stratospheric Geoengineering: Stratospheric Heating



Control

Injection 16-25 km
2.5 Mt S/year

Injection 22-25 km
2.5 Mt S/year
-3W/m²

- Stratospheric dynamics clearly affected

Aquila et al. *GRL* 2014

13

13

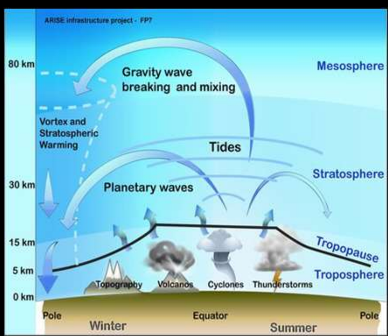
Stratospheric Geoengineering Science Needs: Background Stratospheric Dynamics Representation of Stratospheric Aerosols in Models

SPARC themes (https://www.sparc-climate.org/activities/**)**

- Atmospheric Dynamics and Predictability
- Chemistry and Climate
- Long-term Records for Climate Understanding

SPARC activities

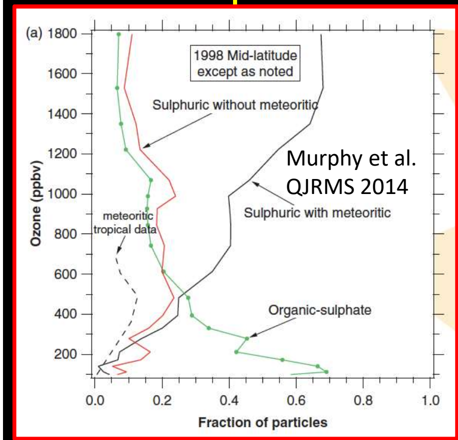
- Composition Trends and Variability in the Upper Troposphere and Lower Stratosphere (OCTV-UTLS)
- Stratospheric sulfur (SSiRC)
- Dynamical variability (DynVar)
- Fine-scale Processes (FISAPS)



14

Stratospheric Geoengineering Science Needs: Understanding "Non-Geo" Stratospheric Aerosol

What is Stratospheric Aerosol?



Stratospheric Sulfur Budget?

- in-situ observations: 3.6×10^{-3} MT S from SO_2
- MIPAS satellite/SOCOL model: 51×10^{-3} MT S from SO_2
- Total S (SO_2+OCS+DMS+sulfate): 43 - 181 $\times 10^{-3}$ MT S

What is source of sulfur?

Rollins et al. GRL 2017

- pure sulfate aerosol never dominates!
- 30-40% of nonvolcanic aerosol optical depth from organics
- 20% of forcing from direct aerosol effect from stratosphere

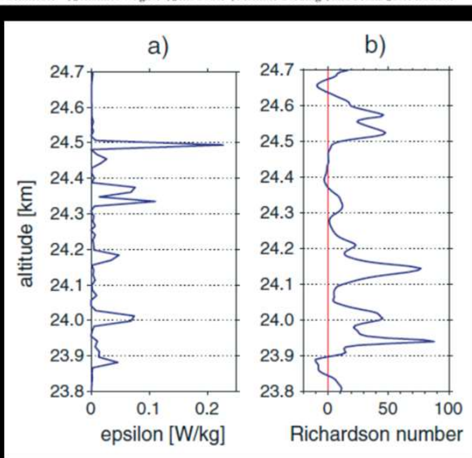
Yu et al. GRL 2016

15

Stratospheric Geoengineering Science Needs: Background Stratospheric Dynamics Representation of Stratospheric Aerosols in Models

Case study of wave breaking with high-resolution turbulence measurements with LITOS and WRF simulations

Andreas Schneider[1,a], Johannes Wagner[2], Jens Söder[1], Michael Gerding[1], and Franz-Josef Lübken[1]

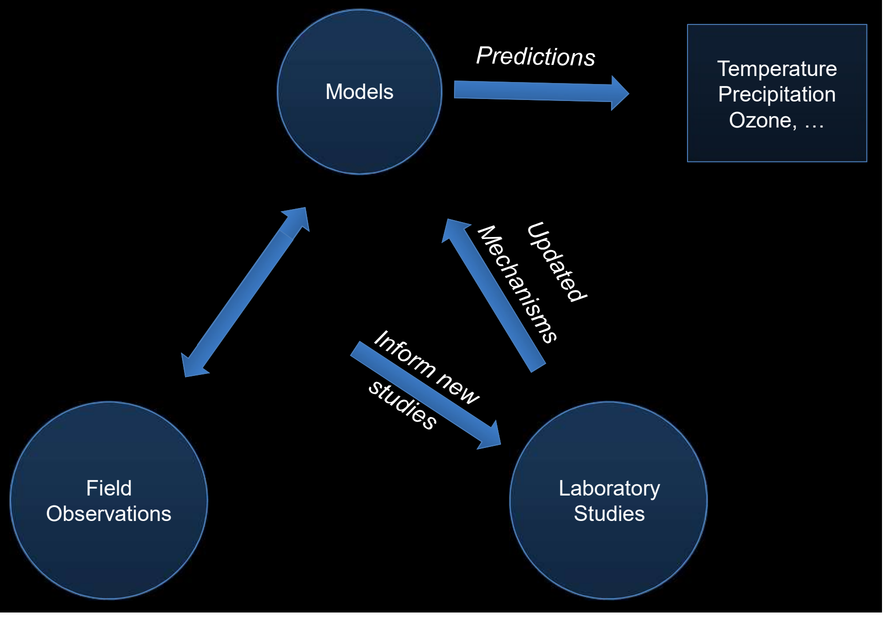


<u>LITOS balloon study:</u>
anemometer measurements show current models of turbulence cannot explain observed stratospheric turbulence

Schneider et al. ACP 17, 7941 2017

16

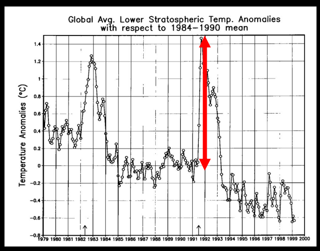
Experiment/Observation/Model Approach



17

Quantifying/Reducing Risks:
Better Materials Than Sulfate Aerosol?

Stratospheric Temperature



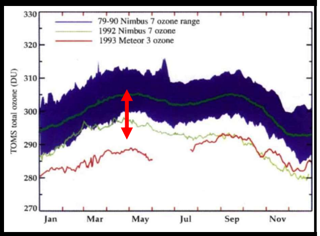
Sulfate Aerosol:

Sulfuric Acid

Water (?)

Physical and Chemical properties of H_2O and H_2SO_4 determine impacts

Ozone



Search for "better" materials:
non-acidic, no light absorption, …

Impacts on stratosphere, troposphere (cirrus, ozone, particulate matter, meteorology), diffuse versus direct radiation, surface (ecosystems, human health)…

18

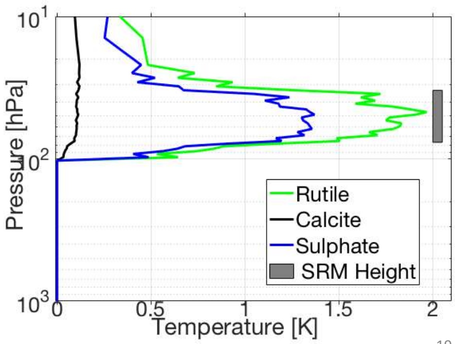
Solution: Reactive Aerosol with Potential for "Control" of Stratospheric Ozone?

Calcite ($CaCO_3$, limestone):

common in the environment, non-toxic

near-ideal optical properties

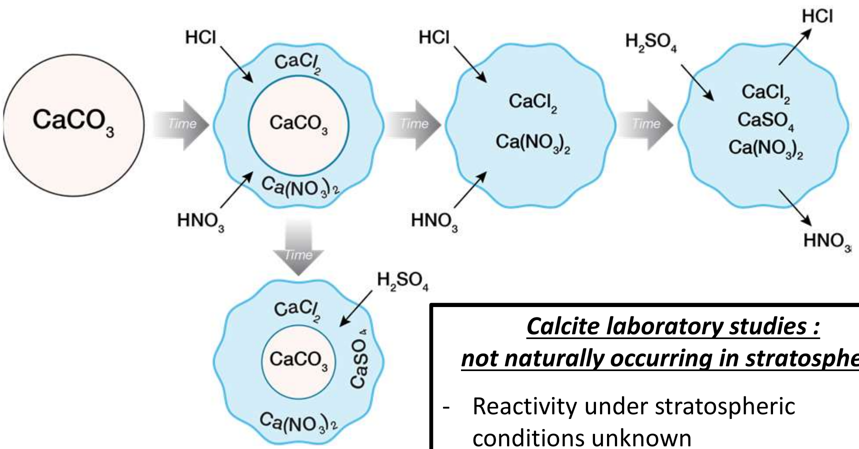
Alkaline → neutralizes acids, potential "control" of halogen and NOx cycle



19

19

Calcite: A Reactive SRM Aerosol with Potential for "Control" of Stratospheric Ozone



Calcite laboratory studies :
not naturally occurring in stratosphere

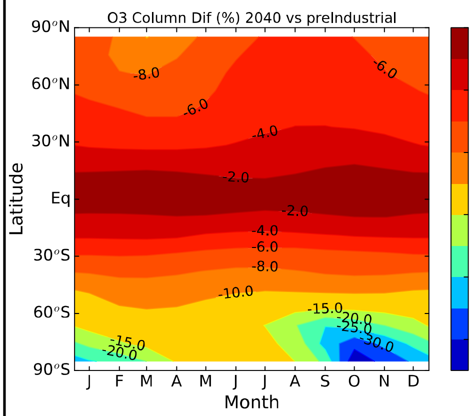
- Reactivity under stratospheric conditions unknown
- Reaction rates for chlorine activation (and N_2O_5 hydrolysis) unknown
- Chemical considerations promising

20

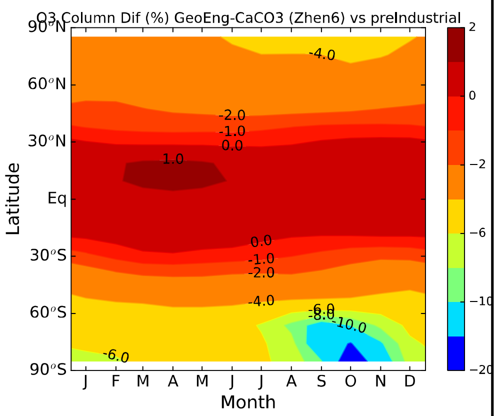
20

O_3 Column Change 2040 vs preindustrial AER-2D

Without Geo

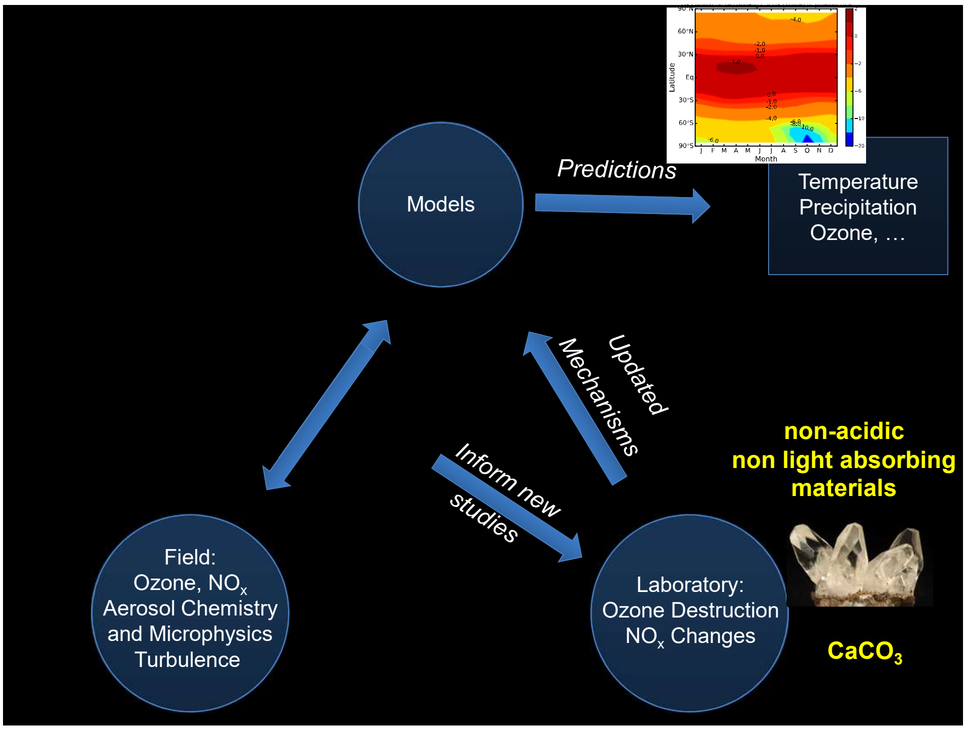


With Geo 5.6 Tg/yr



Polar stratospheric loud surface area vs preindustrial:
2040 (no Geo): +40%; 2040 (with Geo): -30%

21



22

Stratospheric Controlled Perturbation Experiment (SCoPEx) Goals

Improve understanding of solar geoengineering's efficacy and some risks

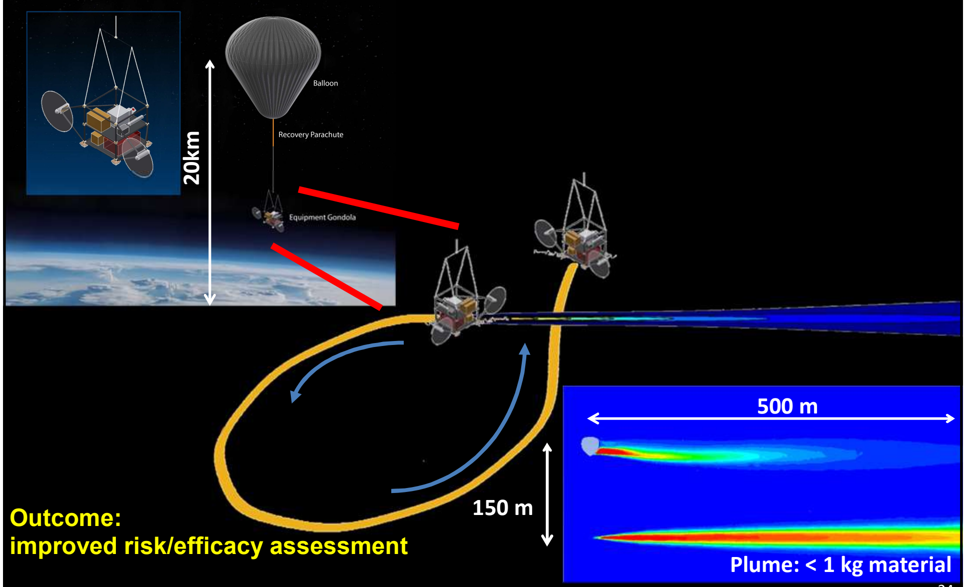
Contribute to development of methods that improve efficacy and reduce some risks.

Exemplify good governance that can serve as useful template for future solar geoengineering field experiments.

https://projects.iq.harvard.edu/keutschgroup/scopex-governance

23

Small Scale Stratospheric Controlled Perturbation Experiment (SCoPEx) Goals



For comparison: 737 flight 1-2 kg S or 3-6 kg sulfuric acid / 1000km flight

24

24

Stratospheric Controlled Perturbation Experiment (SCoPEx)

Quantify risks: quantitative measurements of aerosol micro-physics and atmospheric chemistry to improve large-scale models used for predicting risks and efficacy of solar geoengineering

Specific objectives:

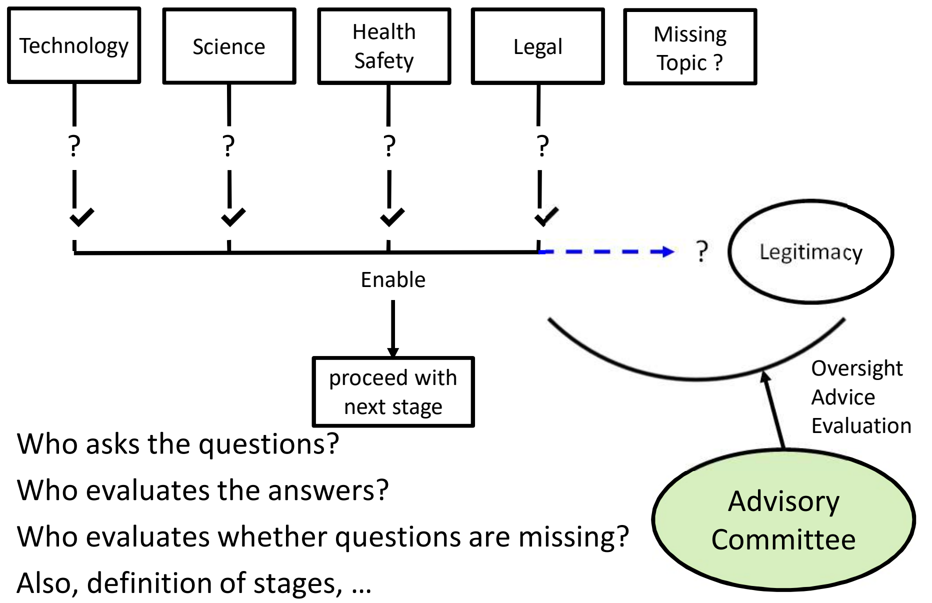
- Develop and test a propelled balloon that creates and monitors region of perturbed chemistry in the stratosphere.
- Test ability to generate and observe regions with perturbed aerosols and chemical constituents.
- Test models of small scale stratospheric mixing.
- Test predictions of chemical response to $CaCO_3$ aerosol.
- Test models of chlorine activation (ozone destruction) by aerosols under mid-latitude conditions.

Objectives overlap with SPARC FISAPS and SSiRC

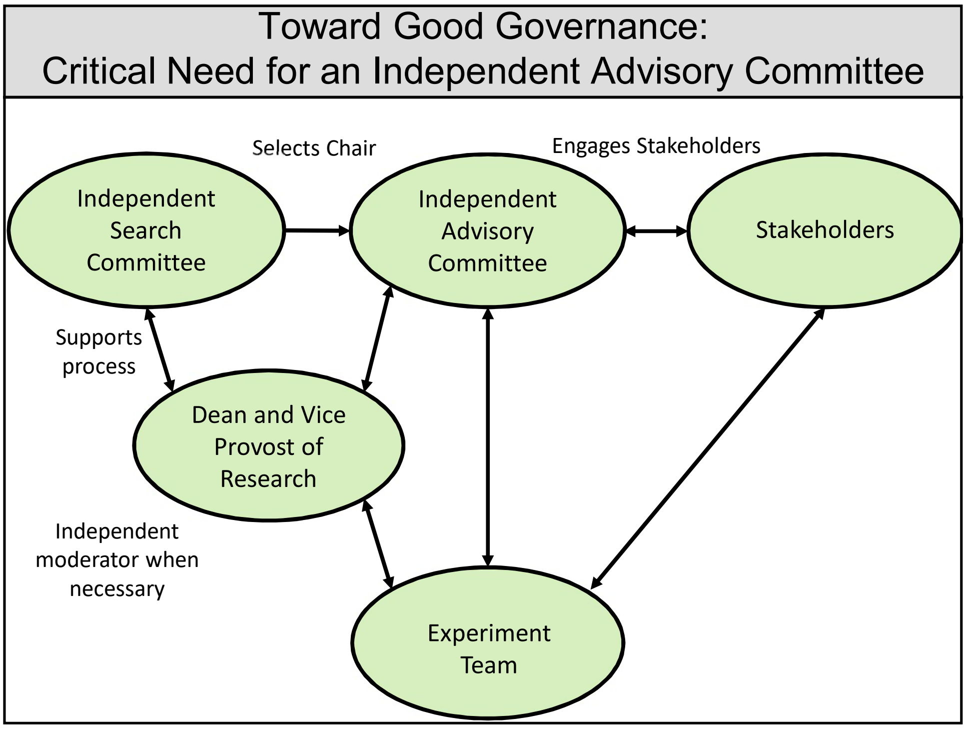
25

25

Toward Good Governance: Critical Need for an Independent Advisory Committee



26


Toward Good Governance:
Critical Need for an Independent Advisory Committee
Selects Chair
Engages Stakeholders
Independent Search Committee
Independent Advisory Committee
Stakeholders
Supports process
Dean and Vice Provost of Research
Independent moderator when necessary
Experiment Team

27


An Interdisciplinary Harvard Research Program
28

28

29