Geoengineering Research and Governance

July 31, 2009
WAAS Symposium on Geoengineering

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CIGI The Centre for International Governance Innovation
Centre pour l'innovation dans la gouvernance internationale

IIASA International Institute for Applied Systems Analysis
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Outline of Talk

- Framing the discussion: Two core questions for geoeng governance
  - *Governance of what?* (*focus on the science*)
  - *Governance by whom?* (*focus on the geopolitical and socio-political*)
- How will geoengineering governance “emergence”?
  - Potential “uses” for geoengineering
  - Two scenarios
    - A fast emergency
    - Long term development
  - *In between, with uncertainty…*

Governance of what?

- Two axes to consider:
  1. From research to long-term use
  2. Type of "geoengineering" technology

Novim

Climate Engineering Responses to Climate Emergencies

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July 29, 2009

Santa Barbara, California

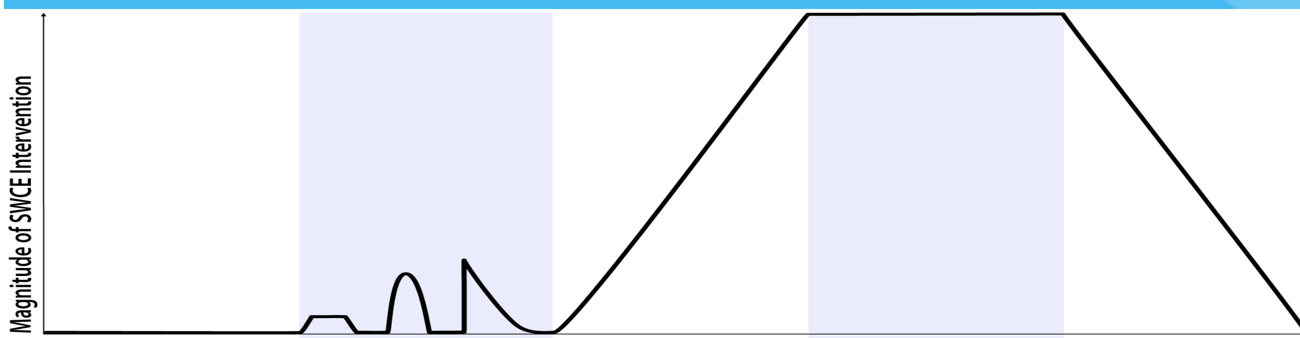
Core Components

1. Summary of current science on stratospheric aerosols
2. Decade-long scientific research agenda to "develop" stratospheric aerosols as an "emergency response"

Available at:
http://arxiv.org/pdf/0907.5140

Phases of RD&D… M&D

From Novim Report on Climate Engineering



Phase I
Non-Invasive Research

Objective Utilize existing understanding of climate system to evaluate SWCE concepts

Components
- Laboratory experiments
- Computer modeling
- Analogue case studies

Important Characteristics
- No direct climatic impacts or associated risks
- Limited learning potential without some iterative empirical testing (Phase II research)
- Existing evaluations of SWCE concepts are Phase I research (*see Boxes 2.1.1.2 and 2.1.1.3*)

Phase II
Field Experiments

Objective Develop understanding of potential SWCE concepts through limited scale intervention experiments

Components
- SWCE interventions limited in duration, magnitude and/or spatial range
- Climatic impact monitoring

Associated Issues
- Climatic impacts and associated risks increase with scale of field test (though not necessarily increasing proportionally)
- Signal-to-noise limits associated with natural variability and temporal/-spatial delays in climatic responses constrain potential learning from field-tests (*see Section 3.2 for discussion*)
- Empirical data from tests could iteratively improve Phase I research

Phase III
Monitored Deployment

Objective Achieve a desired state of the climate system

Components
- Deployment of a full-scale SWCE intervention (possible ramp-up timescale between gradual and immediate)
- Climatic impact monitoring
- Development of a control-system for the SWCE intervention system (based on monitored climate parameters)

Associated Issues
- Increasing climatic impacts and risks with increasing SWCE intervention scale (though not necessarily increasing proportionally)
- Gradual deployment could be similar to Phase II research, allowing time for testing iterative improvement of Phase I research

Phase IV
Steady-State Intervention

Objective Maintenance of a desired state of the climate system

Components
- Maintenance and improvement a full-scale SWCE intervention
- Climatic impact monitoring
- Improvement of the SWCE intervention control-system

Associated Issues
- Long-term SWCE could generate cumulative climate impacts and risks unobserved in field-tests (Phase II) or initial deployment (Phase III)
- Increasing atmospheric GHG concentrations will have a separate impact on the climate system that must be incorporated into any intervention control-system

Phase V
Disengagement

Motivations for Intentional Disengagement
- Reduction in need due to successful achievement of intervention target (e.g. mitigation reduces GHG levels and SWCE to prevent warming no longer required)
- Discovery of harmful side effects of the intervention

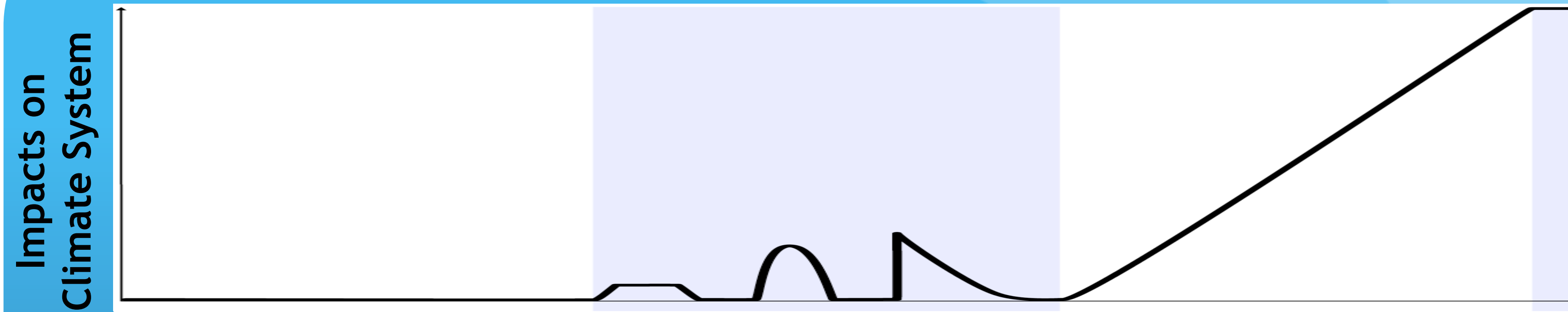
Possible Causes of Unintentional Disengagement
- Technical or socio-political system failure
- Counter-climate engineering or countermeasures

Associated Issues
- Potential for climatic parameter rebound effects
- Severity of climate parameter rebound will increase with intervention scale and disengagement rate

The pharmaceutical analogy

- Preclinical trials (lab work and modelling)
- Clinical testing (field tests, low-level global experiments)
- Clinical use ramped and monitored deployment
- Disengagement strategy

Phases of Geoengineering Research



Phase I
Non-Intervention Research

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Governance of what?

- Two axes to consider:

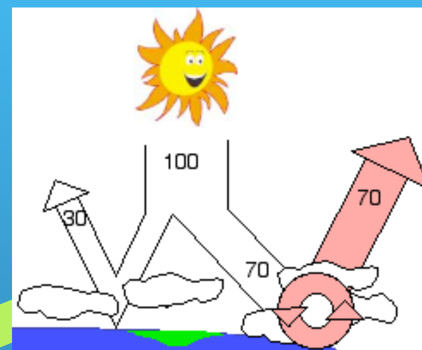
1. From research to long-term use (when?)
   a) *Lab/Computer Research* → Already happening
   b) *Field-testing* → Some happening, more called for
   c) *Deployment "Trigger"* → ???years to decades???
   d) *Management & Tuning* → ???
   e) *Disengagement* → ???
2. Type of "geoengineering" technology

Governance of what?

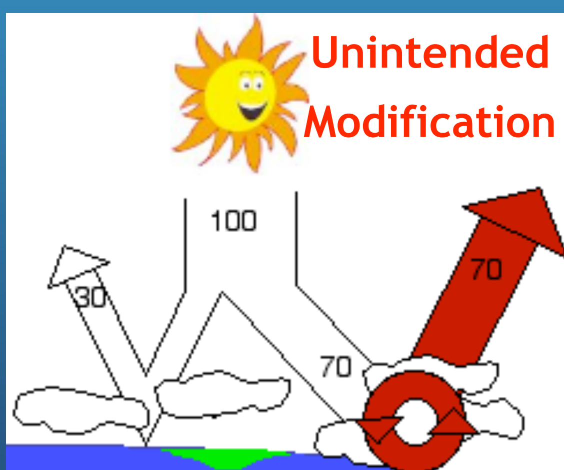
- Two axes to consider:
  1. From research to long-term use (issues?)
     a) *Lab/Computer Research* → Transparency, Accessibility
     b) *Field-testing* → Required Scale & Impact, Vulnerability, Risks
     c) *Deployment "Trigger"* → Moral Hazard, Defining "Emergency"
     d) *Management & Tuning* → Defining the "ideal" climate
     e) *Disengagement*
  2. Type of "geoengineering" technology

The Global Energy Balance and Types of Geoengineering

Three ways to change the climate:



To **warm** the Earth add CO_2 and other GHGs.

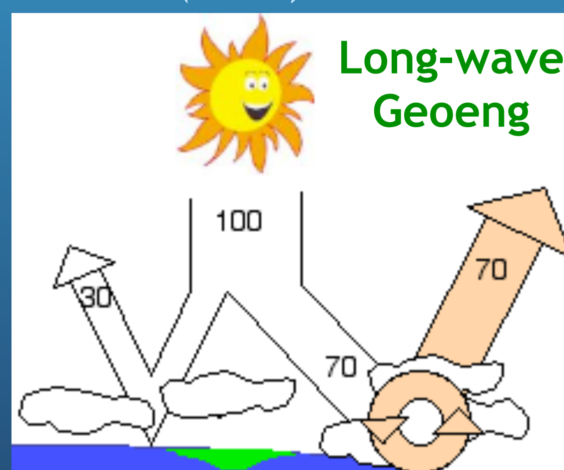


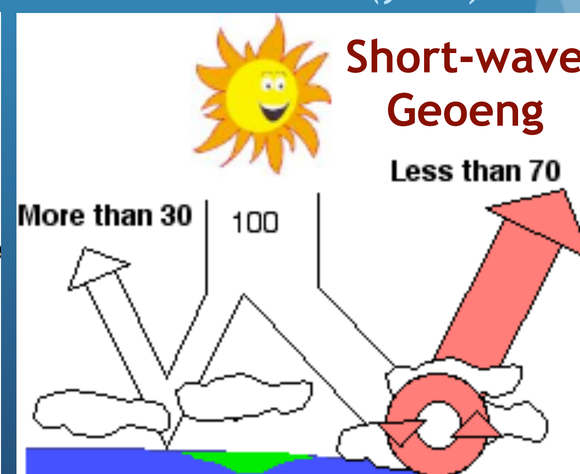
To <u>cool</u> the earth either:

Remove CO_2 and other GHGs (slow).

OR

Increase albedo just a little bit (fast).

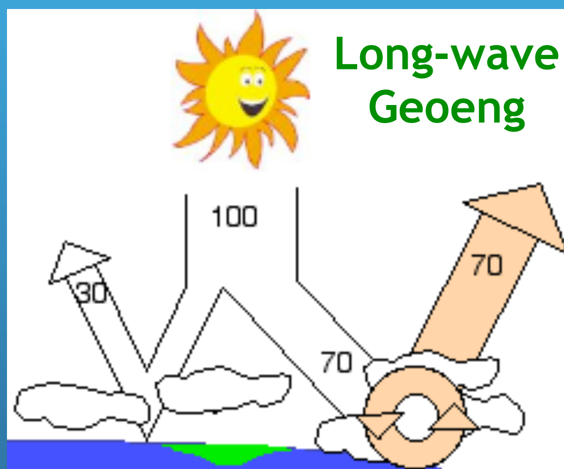




The Global Energy Balance and Types of Geoengineering

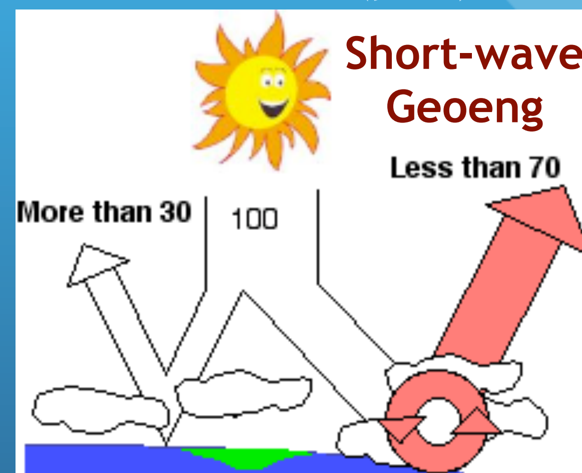
Potentially "Practical" Technologies

Remove CO_2 and other GHGs (slow).



"Carbon Management"
- Ocean Fertilization
- "Direct Carbon Capture"

Increase albedo just a little bit (fast).

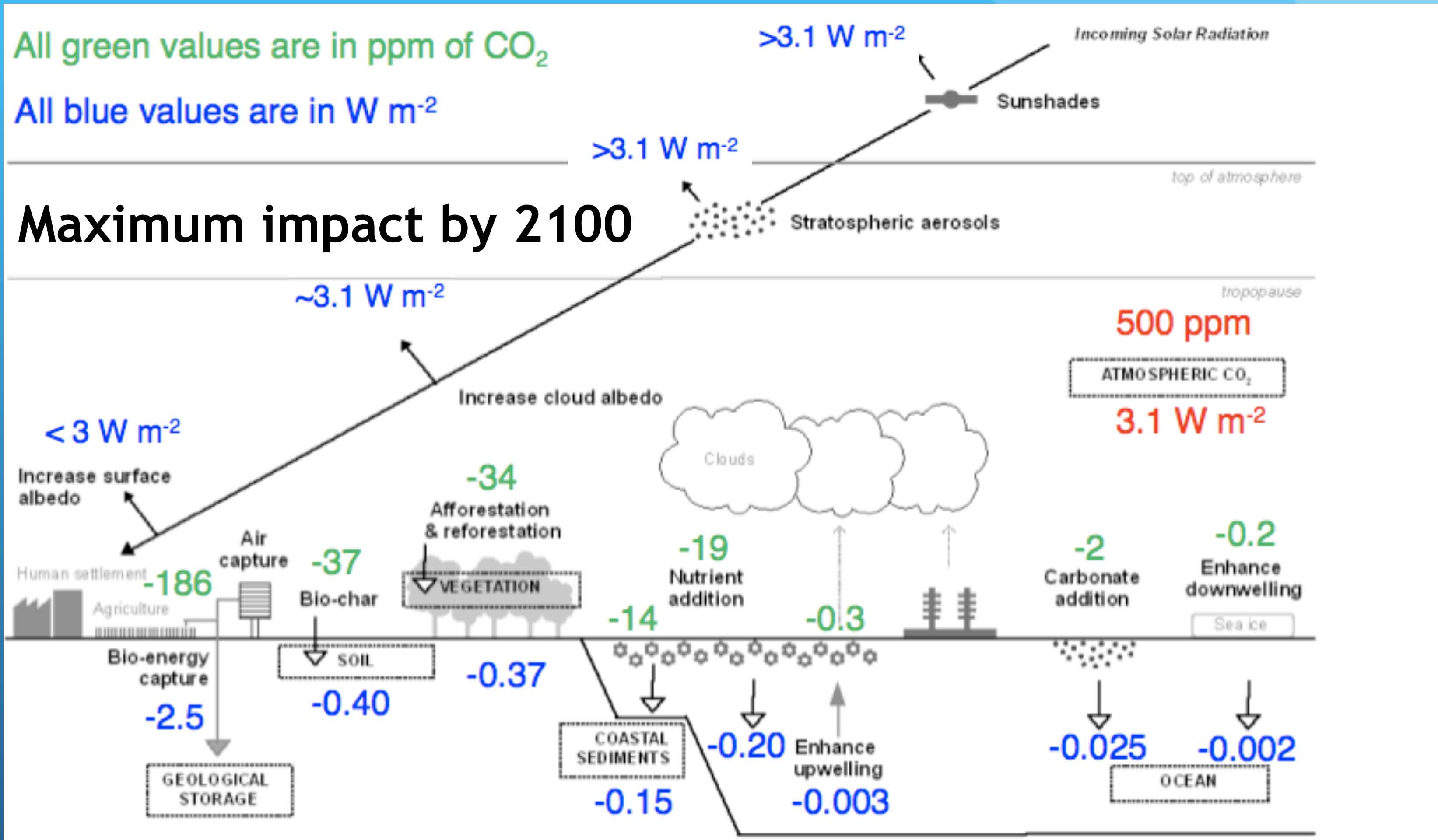


"Solar Radiation Management"
- Stratospheric aerosols
- Cloud Whitening
- Surface brightening

Comparing the Options

- **Focus on three critical parameters:**
  1. **Ability to “counteract” GHG-induced climate change**
  2. **Technical Feasibility and Costs**
  3. **Timescale (*and total potential magnitude*) of Impact**

Comparing the Options



Lenton & Vaughan (2009) *Atmospheric Chemistry and Physics Discussions* 9: 2559-

Comparing the Options

- **Focus on three critical parameters:**
  1. Ability to "counteract" GHG-induced climate change
  2. Technical Feasibility and Costs
  3. Timescale (*and total potential magnitude*) of Impact

Parameter	(1) Counteract GHG Climate Change	(2) Technical Costs & Feasibility	(3) Timescale of Reasonable Climatic Impact
Long-Wave Geoeng	GOOD	UNCERTAIN	LONG (Decades)
Short-Wave Geoeng	NOT PERFECT (details uncertain)	Appears FEASIBLE with LOW COST (*for Stratospheric Aerosols*)	SHORT (*~1yr from deployment*)

Governance of what?

- Two axes to consider:
  1. From research to long-term use (impact of type)
     a) *Lab/Computer Research*
     b) *Field-testing* → Very different scales of testing
     c) *Deployment "Trigger"* → Time scale of impact matters
     d) *Management & Tuning* → "Sensitivity" of system to tuning
     e) *Disengagement* → Different danger of "rebound"
  2. Type of "geoengineering" technology
     a) *Carbon Management*
     b) *Solar Radiation Management*

Governance of what?

- Two axes to consider:
  1. From research to long-term use
  2. Type of “geoengineering” technology

- Key points:
  - *Governance discussions of near-term research are necessary… and (mostly) not yet happening*
  - *Understanding the needed scientific research agenda is critical for clarifying the governance questions*

From Novim Report on
Climate Engineering

A Comprehensive Stratospheric Aerosol Research Agenda

- **Engineering Stream** – *How to do it*.
  - What aerosols? What lofting and dispersion? What spatial, temporal, altitudinal distribution?
- **Climate Science Stream** – *Understanding it*.
  - Could proposed interventions produce desirable outcomes across all regions and timescales?
  - How much of GHG-induced climatic change could they offset?
  - What unintended climatic impacts could they produce?
- **Climate Monitoring Stream** – *Tracking our understanding*.
  - What climate variables do we need to monitor before/during intervention?

A nominal research agenda for stratospheric aerosols

From Novim Report on Climate Engineering

Detailed Timeline

Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 | Year 9 | Year 10

Focal Timeline for Centrally Coordinated Research Program

- **Option Design and Evaluation** (Years 1–4)
- **Downselection and Non-Intervention Testing** (Years 3–7)
- **Control System Design, Development and Evaluation** (Years 4–10)
- **Potential Field Testing** (Years 5–10)

Component Project Timelines for Centrally Coordinated Research Program

Intervention Design, Laboratory Experiments and Testing
- E1 Aerosol Precursor Materials and Dispersion Methods
- E3 Stratospheric Lofting System Development
- E4 Aerosol Radiative, Chemical and Environmental Interactions
- CM1 Monitoring Systems Evaluation and Design

SWCE Exploratory Computer Modeling
- E2 Stratospheric Aerosol Transport Dynamics
- CS1 Climate Parameters Potentially Sensitive to SWCE
- CS2 Response Function Mapping

Case Study Evaluations
- CS1 Climate Parameter Sensitivities
- CS2 Transient Response Function Evaluation
- CS3 Examination of Social/Ecological Impacts
- CM2 Existing Climate Monitoring Capabilities and Historic Background/Calibration Data

Non-Intervention Field-Tests
- E2 Inert Tracer Particle Tracking
- E3 Lofting System Prototype Tests (no aerosol dispersion)

Monitoring System Deployment and Testing
- CS1/2/3 Natural and Unintentional Anthropogenic Experiment Monitoring
- CM1 Monitoring System Assembly, Deployment and Testing
- CM3 Collection of Background/Calibration Data

Targeted Computer Modelling (Experiment/Intervention Specific)
- E2 Stratospheric Aerosol Transport Dynamics
- CS2 Response Function Mapping for Select Intervention Designs
- CS3 Social/Ecological Impact Sensitivity Analyses
- E2,CS2,CM1/2/3 Control System Design and Modeling

Potential Field Testing
- E1 Stratospheric Aerosol/Precursor Material Dispersion
- E2 Stratospheric Aerosol Transport Dynamics
- E3 Lofting System Demonstration
- E4 Environmental/Ecological Interactions
- CS2 Climate Parameter Response Function Observations
- CM1/2 Testing of Monitoring System Capabilities

Legend

Engineering Questions = E

Climate Science Questions = CS

Climate Monitoring Questions = CM

Phase I Research

Phase II Research

(E) Engineering Stream

(E1) What are the possible and optimal materials and dispersion methods to facilitate stratospheric loading with aerosols of appropriate size and composition?

(E2) To what minimal altitudes must (and optimal altitudes should) the materials be lofted at different latitudes? How do the lofting altitude, location, and temporal sequencing of aerosol injection determine the temporal and spatial distribution of aerosols in the stratosphere around the globe?

(E3) What are the possible and optimal lofting methods given different mass (or volume), altitudinal, and spatial injection requirements?

(E4) What are the radiative impacts and environmental interactions of the engineered aerosol?

(CS) Climate Science Stream

(CS1) What are the climate parameters that a stratospheric aerosol SWCE intervention could have a significant impact on?

(CS2) What are the response functions for these important climate parameters, particularly defined in terms to the control variables for stratospheric aerosol interventions?

(CS3) What are risk sensitivities of societal and ecological systems to these important climate parameters?

(CM) Climate Monitoring Stream

(CM1) What monitoring capabilities are required to confidently assess the most important climatic impacts of a stratospheric aerosol SWCE intervention?

(CM2) What monitoring capabilities presently exist that fulfil these requirements, and what new capabilities are needed? On what timeline can these tools be developed and deployed?

(CM3) How far in advance of an SWCE intervention (or field test) do these monitoring capacities need to be operational to provide the necessary calibration/background data?

Governance of what?

- Two axes to consider:
  1. From research to long-term use
  2. Type of “geoengineering” technology

- Key points:
  - *Governance discussions of near-term research are necessary… and (mostly) not yet happening*
  - *Understanding the needed scientific research agenda is critical for clarifying the governance questions*
  - *Two “types of geoengineering” have some similarities… but also a lot of differences*

Governance by whom?

- Different "Lenses" through which to consider the "governance of what" questions above:
  1. Unitary Rational Actor
  2. "Black Box" Nation States (realism)
  3. New International Actors (IGOs, NGOs, corporate)
  4. Civil Societies

Stages of RD&D:

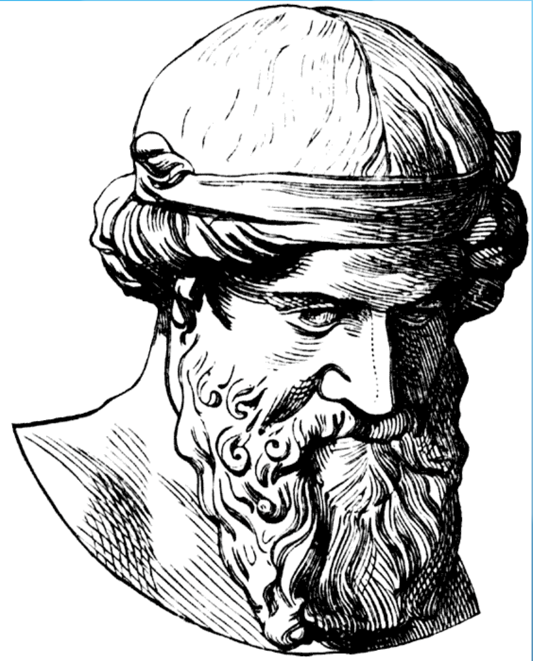
(1) lab (2) field-testing (3) deployment (4) management (5) disengagement

Geoeng Types:

Carbon Management versus Solar Radiation Management

Governance by whom?

- Unitary Rational Actor
  - The “should” questions
    - Decision in the face of *very* large scientific uncertainty
    - Questions about humanity’s relationship with nature (ethical and religious)



Plato: The Philosopher King

Stages of RD&D:

(1) lab (2) field-testing (3) deployment (4) management (5) disengagement

Geoeng Types:

Carbon Management versus Solar Radiation Management

Governance by whom?

- Nation States
  - The "interests" questions
    - How can/will interests be defined in the face of scientific uncertainty?
    - Raises issues of control, equity, responsibility, liability
    - The "spoiler" problem (*not tragedy of the commons)*

Stages of RD&D:

(1) lab (2) field-testing (3) deployment (4) management (5) disengagement

Geoeng Types:

Carbon Management versus Solar Radiation Management

Governance by whom?

- One new International Actor: <u>*The Scientific Community*</u>
  - Can the scientific community self-regulate research?
  - Raises issues of accessibility and accountability

Stages of RD&D:

(1) lab (2) field-testing (3) deployment (4) management (5) disengagement

Geoeng Types:

Carbon Management versus Solar Radiation Management

Governance by whom?

- The perspectives:
  1. Unitary Rational Actor
  2. "Black Box" Nation States (realism)
  3. New International Actors (IGOs, NGOs, corporate, *scientific community*)
  4. Civil Societies

- Complexity increases at each level…
  - *At what "level" should decisions be made?*
    - *Time scale of "democracy" versus "technocracy"*
  - *What role can/should international organizations and/or agreements/treaties play in facilitating governance?*

Stages of RD&D:

(1) lab (2) field-testing (3) deployment (4) management (5) disengagement

Geoeng Types:

Carbon Management versus Solar Radiation Management

How will governance emerge?

- The potential "uses" of geoengineering
  - *What the various actors could care about…*
- Two scenarios
  - A fast emergency
  - Long term development
- *In between, with uncertainty…*

Different "uses" for geoengingeering

- Four *very basic* categories of "uses" (*or objectives*) for geoengeering:
  - (1) Response to a "climate emergency"
  - (2) Buy time for mitigation
    - *Objective: Keep global average temperature rise below X˚C (say X=2˚C)—or an equivalent measure for precipitation changes (or other variable)*
  - (3) Buy time for adaptation
    - *Objective: Keep the rate of temperature rise (or precipitation change, or storm intensity/frequency increase) slow enough to allow "smooth" adaptation of human and ecological systems*
  - (4) Climate Control

What interests would drive various actors to various "goals"/"uses"?

(1) Rational actor (2) Nation States (3) New Int'l Actors (4) Civil Society

How will governance emerge?

- The potential "uses" of geoengineering
- Two scenarios
  - A fast emergency
  - Long term development
- *In between, with uncertainty…*

Climate "Emergencies"
Feedbacks & Tipping Points

We cannot rule out the possibility that the planet is so "twitchy" that small increases in CO2 concentration produce havoc, via myriad feedbacks. Moreover, the probability distribution of adverse impacts has a "fat tail." – R. Socolow

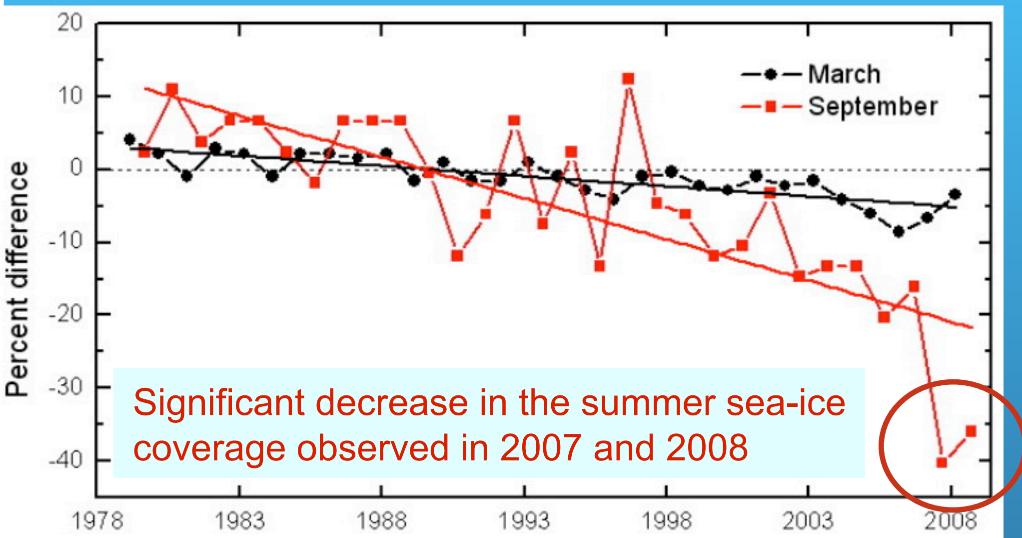
- Disappearance of the Artic ice (ice-albedo feedback)
- Methane outgassing of the permafrost
- Accelerated melting of ice sheets
- Shifting patterns of storms, floods, drought, heat

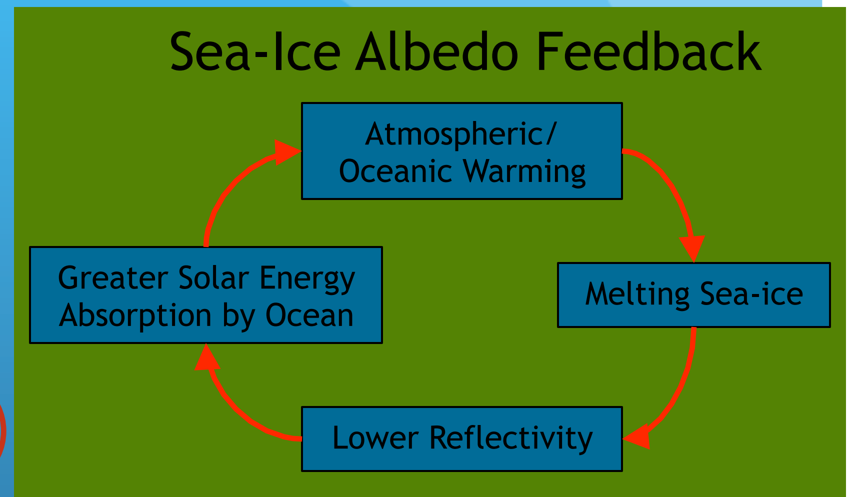
Rapid and undesirable changes are possible… *and potentially irreversible*

Tipping element	Feature of system, F (direction of change)	Control parameter(s), ρ	Critical value(s),† ρ_{crit}	Global warming†‡	Transition timescale,† T	Key impacts
Arctic summer sea-ice	Areal extent (−)	Local ΔT_{air}, ocean heat transport	Unidentified§	+0.5–2°C	≈10 yr (rapid)	Amplified warming, ecosystem change
Greenland ice sheet (GIS)	Ice volume (−)	Local ΔT_{air}	+≈3°C	+1–2°C	>300 yr (slow)	Sea level +2–7 m
West Antarctic ice sheet (WAIS)	Ice volume (−)	Local ΔT_{air}, or less ΔT_{ocean}	+≈5–8°C	+3–5°C	>300 yr (slow)	Sea level +5 m
Atlantic thermohaline circulation (THC)	Overturning (−)	Freshwater input to N Atlantic	+0.1–0.5 Sv	+3–5°C	≈100 yr (gradual)	Regional cooling, sea level, ITCZ shift
El Niño–Southern Oscillation (ENSO)	Amplitude (+)	Thermocline depth, sharpness in EEP	Unidentified§	+3–6°C	≈100 yr (gradual)	Drought in SE Asia and elsewhere
Indian summer monsoon (ISM)	Rainfall (−)	Planetary albedo over India	0.5	N/A	≈1 yr (rapid)	Drought, decreased carrying capacity
Sahara/Sahel and West African monsoon (WAM)	Vegetation fraction (+)	Precipitation	100 mm/yr	+3–5°C	≈10 yr (rapid)	Increased carrying capacity
Amazon rainforest	Tree fraction (−)	Precipitation, dry season length	1,100 mm/yr	+3–4°C	≈50 yr (gradual)	Biodiversity loss, decreased rainfall
Boreal forest	Tree fraction (−)	Local ΔT_{air}	+≈7°C	+3–5°C	≈50 yr (gradual)	Biome switch
Antarctic Bottom Water (AABW)*	Formation (−)	Precipitation–Evaporation	+100 mm/yr	Unclear¶	≈100 yr (gradual)	Ocean circulation, carbon storage
Tundra*	Tree fraction (+)	Growing degree days above zero	Missing‖	—	≈100 yr (gradual)	Amplified warming, biome switch
Permafrost*	Volume (−)	$\Delta T_{permafrost}$	Missing‖	—	<100 yr (gradual)	CH_4 and CO_2 release
Marine methane hydrates*	Hydrate volume (−)	$\Delta T_{sediment}$	Unidentified§	Unclear¶	10^3 to 10^5 yr ($>T_E$)	Amplified global warming
Ocean anoxia*	Ocean anoxia (+)	Phosphorus input to ocean	+≈20%	Unclear¶	≈10^4 yr ($>T_E$)	Marine mass extinction
Arctic ozone*	Column depth (−)	Polar stratospheric cloud formation	195 K	Unclear¶	<1 yr (rapid)	Increased UV at surface

Lenton et al. (2008, *PNAS*)

Near-term? Climate Feedbacks & Tipping Points
Recent Sea-ice Loss… and Implications???





Coupled feedbacks that could be triggered…

Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss

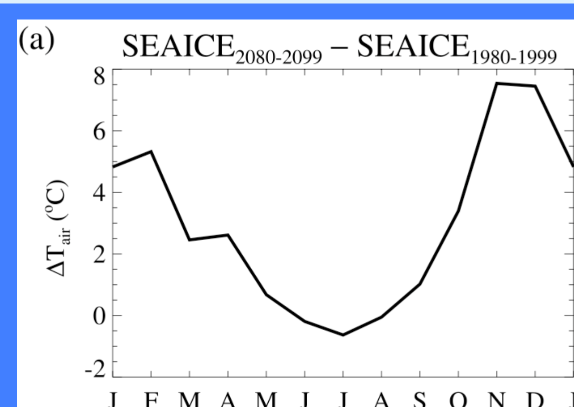
David M. Lawrence,[1] Andrew G. Slater,[2] Robert A. Tomas,[1] Marika M. Holland,[1] and Clara Deser[1]

GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L11506, doi:10.1029/2008GL033985, 2008

Recent radical shifts of atmospheric circulations and rapid changes in Arctic climate system

Xiangdong Zhang,[1] Asgeir Sorteberg,[2] Jing Zhang,[3] Rüdiger Gerdes,[4] and Josefino C. Comiso[5]

GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L22701, doi:10.1029/2008GL035607, 2008



Fast "Emergency Poll"

- When would you "pull the trigger"???
  - 2012: Permafrost outgassing during summer/fall months increases CO2e concentrations by ~0.5ppm
  - 2013: Outgassing increases CO2e by 1ppm
  - 2014: Outgassing increases CO2e by <2ppm

What interests would drive the actors in this scenarios?

(1) Rational actor (2) Nation States (3) New Int'l Actors (4) Civil Society

At which Stages of Research:

(1) lab (2) field-testing (3) deployment (4) management (5) disengagement

For which types of geoengineering:

Carbon Management versus Solar Radiation Management

Far from the only emergency scenario… *but geoeng might not be useful for most!!!*

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Marine methane hydrates*	Hydrate volume (−)	$\Delta T_{sediment}$	Unidentified§	Unclear¶	10^3 to 10^5 yr (>T_E)	Amplified global warming
Ocean anoxia*	Ocean anoxia (+)	Phosphorus input to ocean	+≈20%	Unclear¶	≈10^4 yr (>T_E)	Marine mass extinction
Arctic ozone*	Column depth (−)	Polar stratospheric cloud formation	195 K	Unclear¶	<1 yr (rapid)	Increased UV at surface

Lenton et al. (2008, *PNAS*)

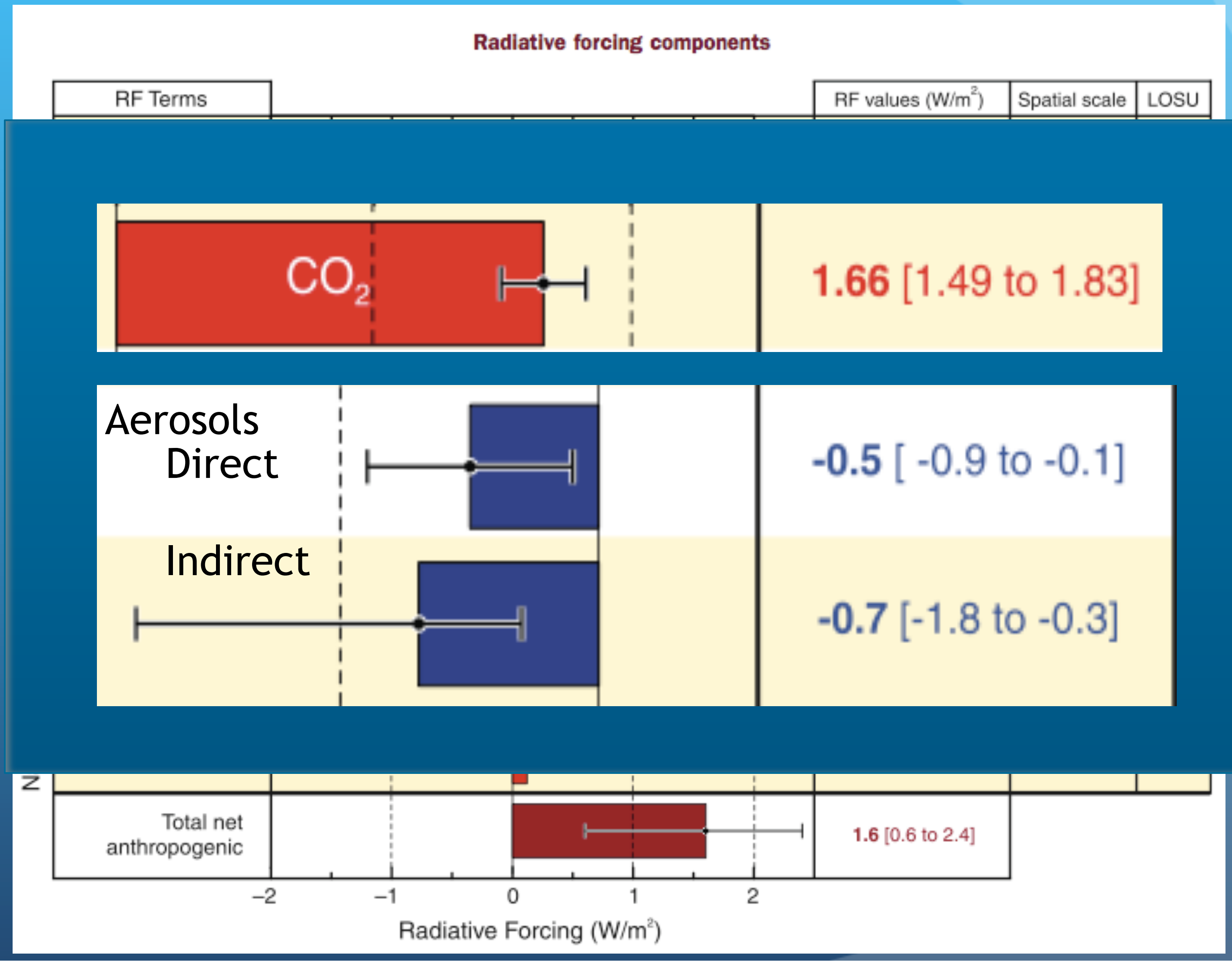
How will governance emerge?

- The potential “uses” of geoengineering
- Two scenarios
  - A fast emergency
  - Long term development
- *In between, with uncertainty…*

Committed Climate Change and Rapid Mitigation

- Currently around 170ppm CO_2-***equivalent*** and ~0.7°C above preindustrial…
- But how much of the "committed warming" have we seen?

Committed Climate Change and Rapid Mitigation



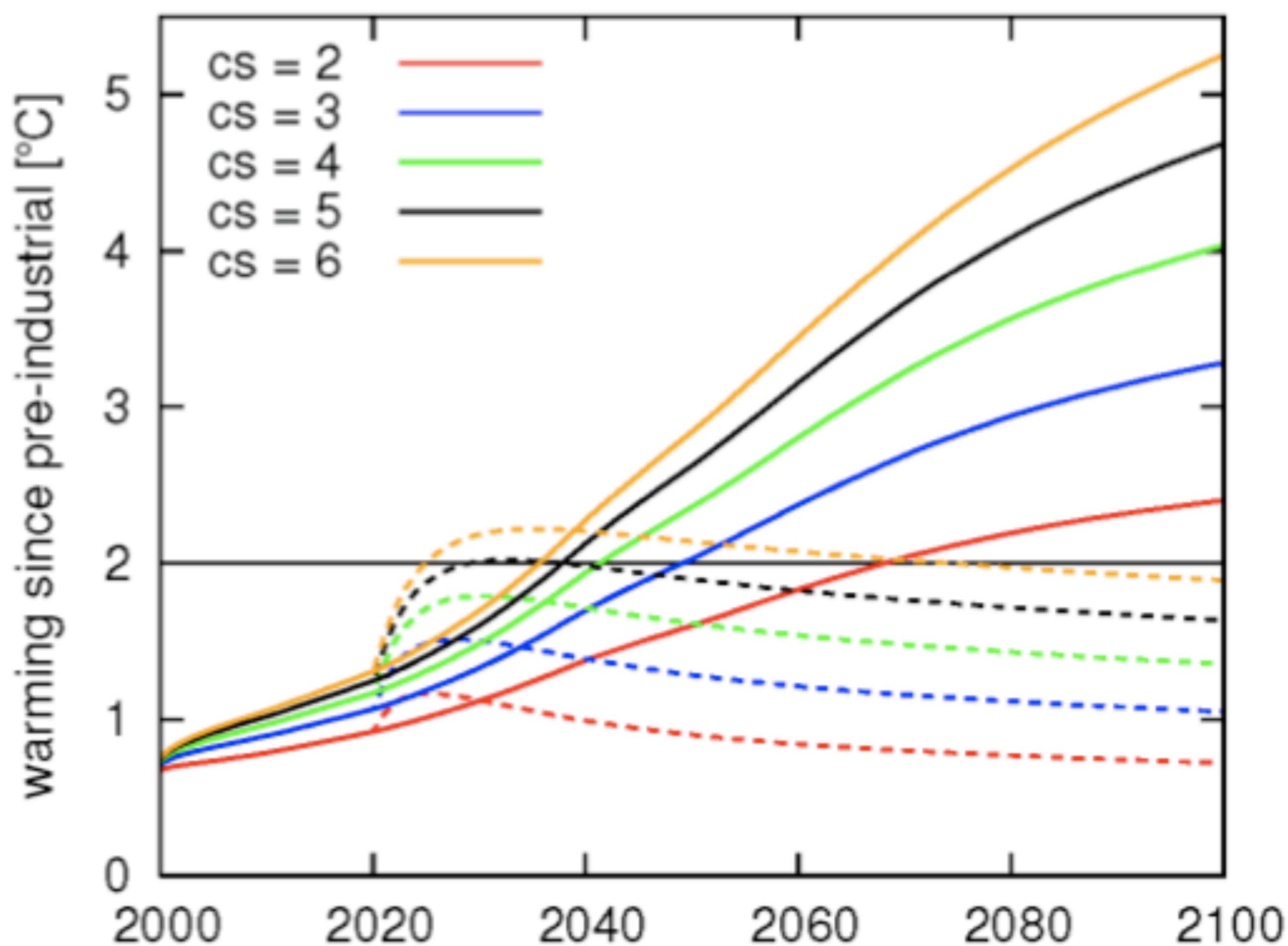
Committed Climate Change and Rapid Mitigation

- Currently around 170ppm CO_2-*equivalent* and ~0.7°C above preindustrial…
- But how much of the "committed warming" have we seen?
- Potentially NOT MUCH of the committed warming…
- The Case of Rapid Mitigation:
  - Would remove aerosols *much* faster than CO_2…
  - Would reveal our "committed change" and thereby our "real" climate sensitivity…
  - But if we are on the "high" end of the uncertainty (*high aerosol forcing, and therefore high climate sensitivity*)…
  - Fast mitigation could *accelerate* the near-term rate of warming!!!

Committed Climate Change and Rapid Mitigation

- Curr … bove prei…
- But … en?
- Pote…
- The…
  - W…
  - W … eal" cl…
  - Bu … *erosol fo…*
  - Fa… ne…

If we shut off emissions TODAY…



Raddatz and Tanaka (submitted)

Long term Development Poll

- What stages of research should be undertaken when to provide “insurance” against uncertainty in committed climate change?
  - Laboratory and computational research?
  - Field-testing this decade?
  - Gradual deployment this decade?

What interests would drive the actors in this scenario?

(1) Rational actor (2) Nation States (3) New Int’l Actors (4) Civil Society

At which Stages of Research:

(1) lab (2) field-testing (3) deployment (4) management (5) disengagement

For which types of geoengineering:

Carbon Management versus Solar Radiation Management

How will governance emerge?

- The potential “uses” of geoengineering
- Two scenarios
  - A fast emergency
  - Long term development
- *In between, with uncertainty…*
  - *High uncertainty about even probability of future scenarios*
  - *“Multi-use” potential of geoeng technologies*
  - *Multi-actors with varied motivations*

This is the environment in which governance must be developed.

Review

- Framing the discussion: Two core questions for geoeng governance
  - Governance of what? (*focus on the science*)
  - Governance by whom? (*focus on the geopolitical and socio-political*)

- How will geoengineering governance "emergence"?
  - Potential "uses" of geoengineering
  - Two scenarios
    - A fast emergency
    - Long term development
  - *In between, with uncertainty…*

Thank you

Questions/Comments/
Discussion