Geoengineering

EES 3310/5310

Global Climate Change

Jonathan Gilligan

Class #36: Monday, April 18 2022

Geoengineering

Scope of Problem

- After 10,000 years:
  - High-level nuclear waste: about 0.03% of excess radioactivity remains
  - CO_2: about 25% remains in atmosphere (for release of 4,000–5,000 GTC)
- Consequences uncertain
  - Possible catastrophic consequences lasting thousands of years
  - Experts think “business as usual” has high probability (>50%) of tipping point to disaster
- Eliminating fossil fuels quickly looks very challenging, expensive

Comparing imperfect solutions

- Mitigation:
  - Cut emissions
  - Geoengineering
- Adaptation
  - Manageable, unmanageable, and unmanaged systems
- Do nothing

“We have three options:
mitigation, adaptation, and suffering.”
— Prof. Lonnie Thompson

Defining Geoengineering

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- Scale and Intent
  - Intent without scale: *ornamental gardening*
  - Scale without intent: *pollution, global warming*
  - **Scale with intent: geoengineering**

Basic Concepts

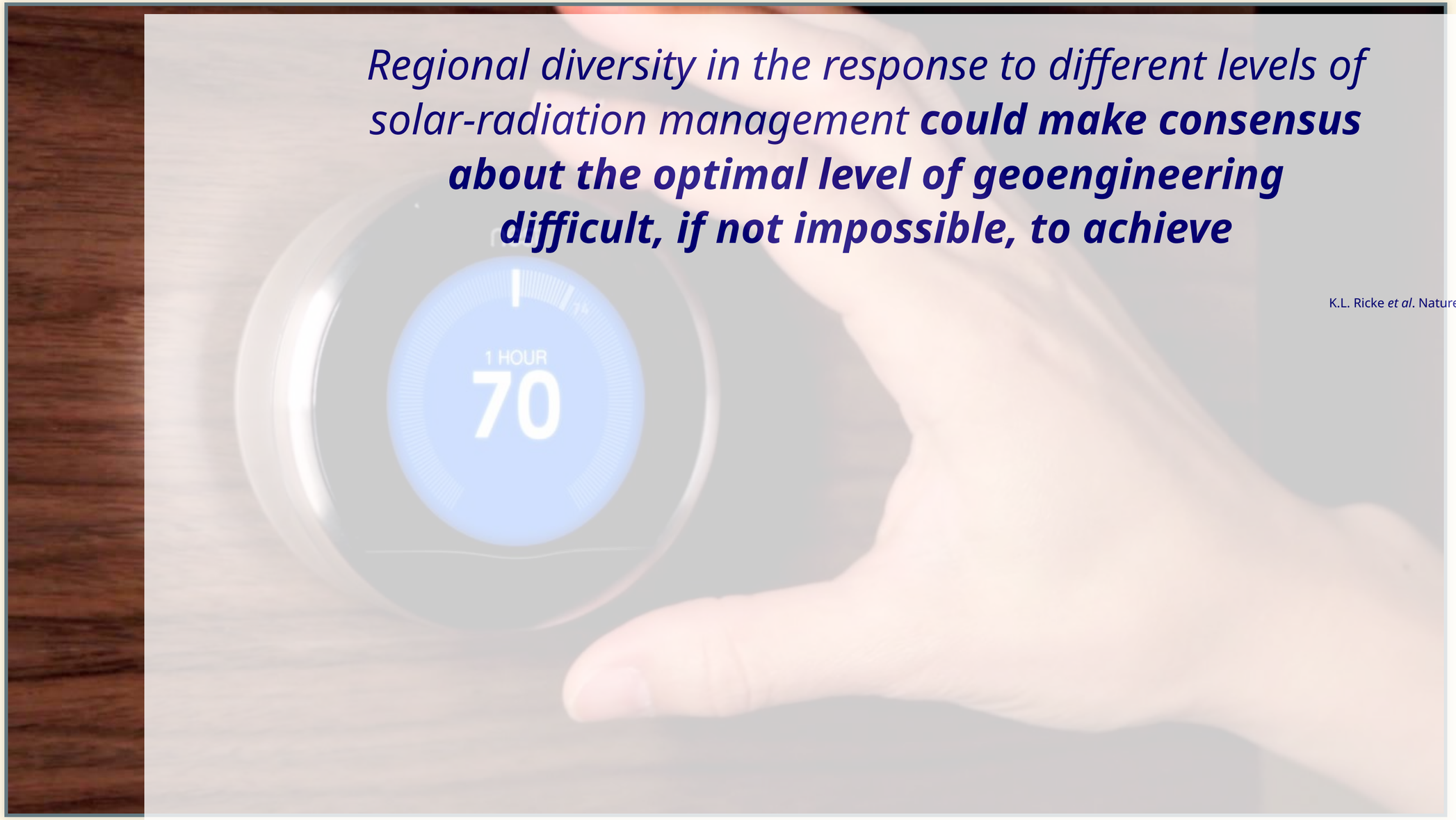
- Technological fix
- Geoengineering:
  - Albedo engineering
    - Pielke: Doesn’t work as technological fix
    - Nordhaus:
      - Reflecting 2% of sunlight cancels doubling CO_2
      - Costs 1-10% as much as reducing emissions
      - “Fire truck” vs. “Fire insurance”
      - “Salvage therapy”
  - Air capture of CO_2
    - Pielke: Worth considering
  - Nordhaus:
    - All geoengineering poses a moral hazard problem

Criteria for Technological Fix

1. Cause-effect relationship
   - Can it work in theory?
2. Assessable effects
   - Can we tell whether it’s working?
3. Established technological base
   - Research and development needs somewhere to start
   - Beginning from scratch takes too long to be useful.
   - Focus on incremental improvements
   - Don’t bet on big breakthroughs


SPL

Who Controls the Thermostat?

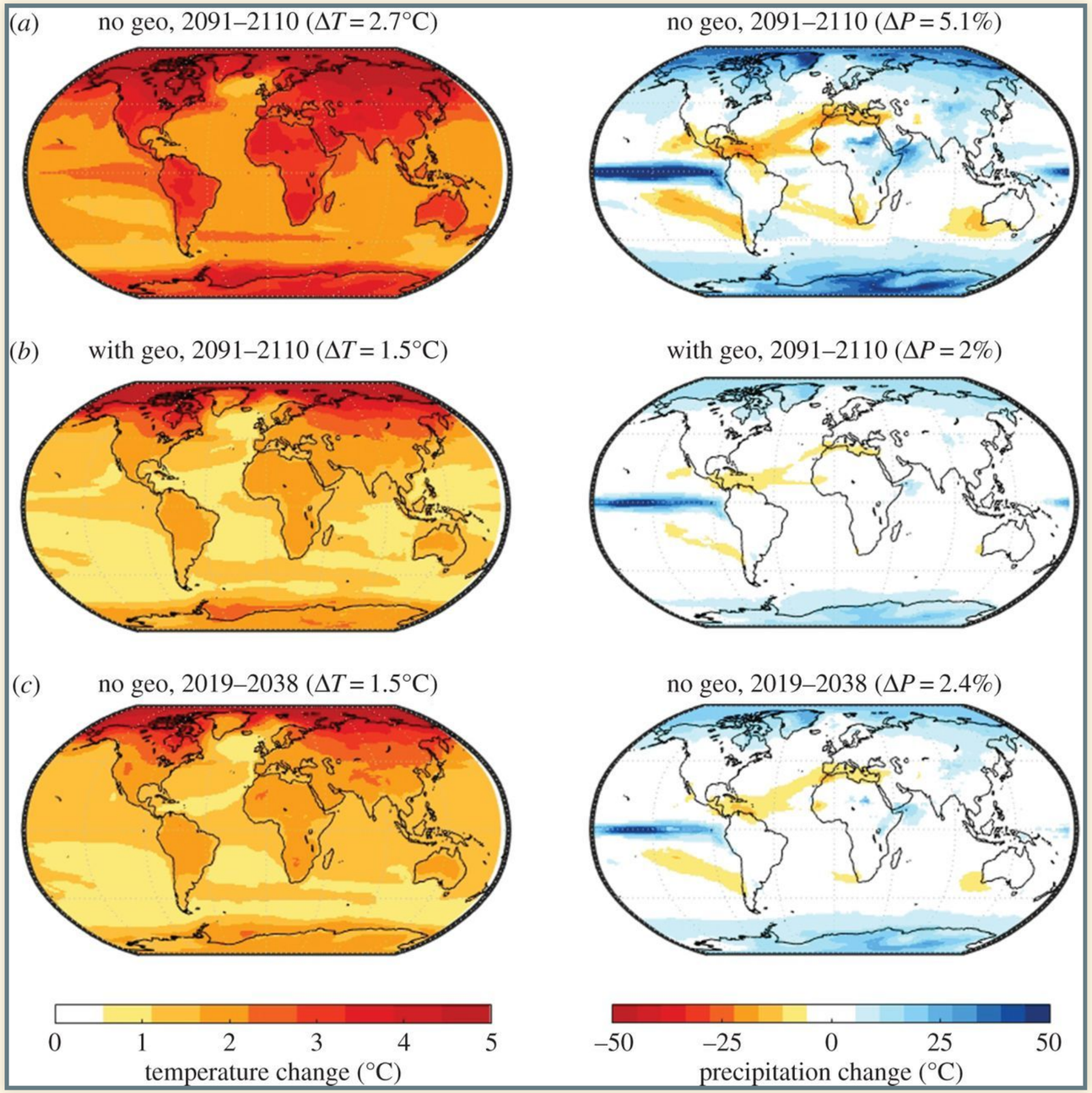


Regional diversity in the response to different levels of solar-radiation management ***could make consensus about the optimal level of geoengineering difficult, if not impossible, to achieve***

K.L. Ricke *et al*. Nature Geosci. **3**, 537 (2010).

It’s not just about global average temperature

- Can geoengineering manage all parts of the planet at once?
- Can we manage both temperature and precipitation?
- What about other effects of CO_2?
  - Ocean acidification?
- However…
  - It looks likely that it could reduce the harm from climate change.
    - Can’t return planet to pre-industrial climate, but:
      - Can probably *reduce changes* in both temperature and precipitation
      - Can probably *reduce changes* across the whole planet
      - The same climate models we use to study climate change say SRM should work



D.G. MacMartin, K.L. Ricke, and D.W. Keith, Phil. Trans Roy. Soc. A **376**, 20160454 (2018). doi:10.1098/rsta.2016.0454

Who’s responsible for unintended consequences?

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Geoengineering Litigation

THE LEGAL ASPECTS OF RAI

Since the first successful ex
laboratories of the General
1946, the artificial precipita
has become a reality. The m
such experiments involves t
milar cooling materials.

HARVARD LAW REVIEW

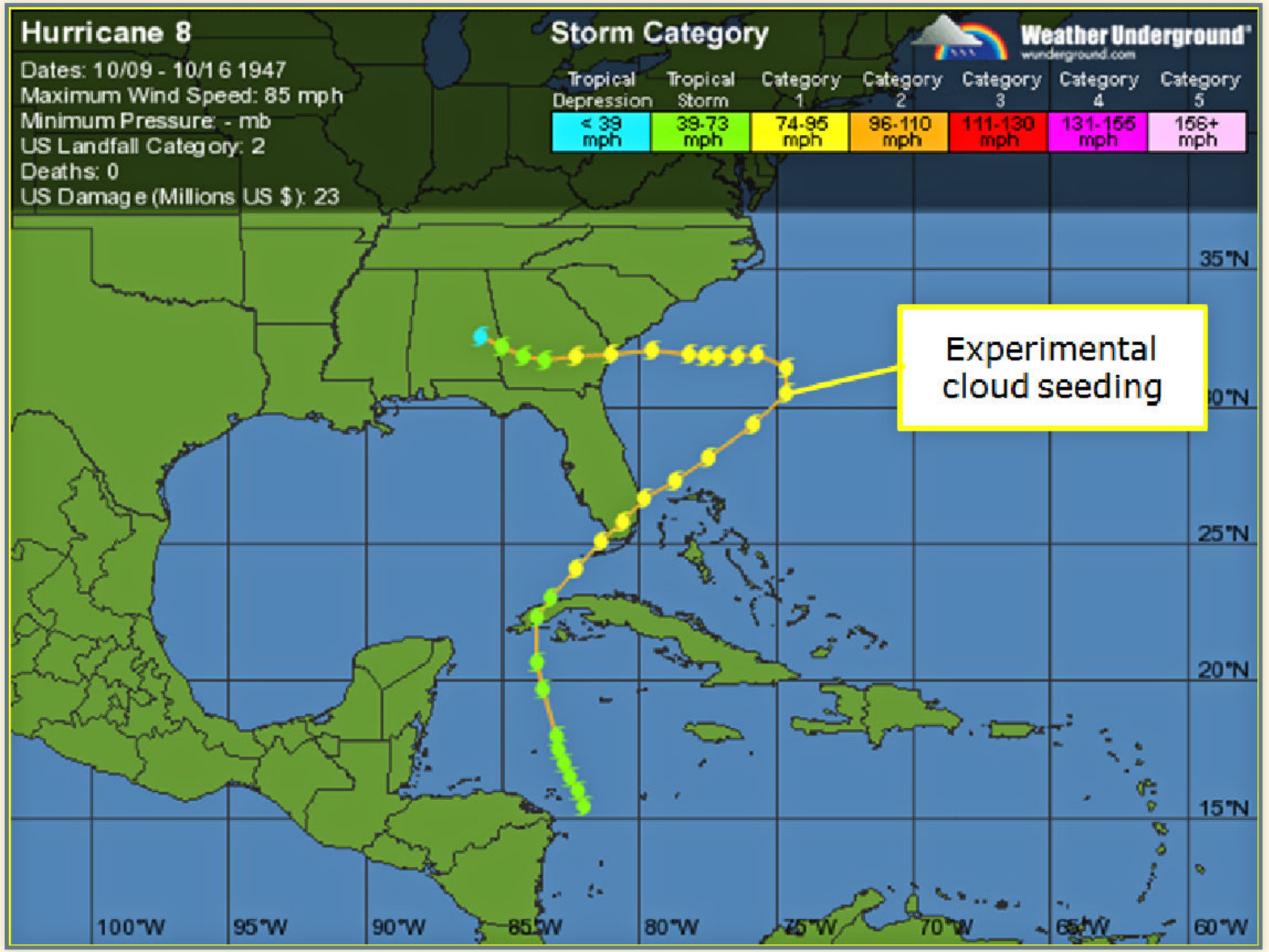
Property— Property Rights Incident to Ownership of Land—Cloud Seeding Infringes Property Rights of Subadjacent Landowners — *Southwest Weather Research, Inc., v. Rounsville (Tex. Civ. Appl. 1958)*

73 Harvard L. R. 790 (19

LEGAL REMEDIES FOR "CLO
ACTIVITIES"

The important question of l
seeding" has been decided
level for the first time. The c
Southwest Weather Research,
added significance in that it
landowner's rights in the ra
land and circumscribes the

Hurricane #8, Oct. 1947



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In North Carolina, hurricanes did what scientists could not: Convince Republicans that climate change is real

“I always thought climate change was a bunch of nonsense, but now I really do think it is happening,” said [Margie] White, a 65-year-old Trump supporter.

Washington Post, Oct. 18, 2018

Yes, Climate Change Made Harvey and Irma Worse

… the consensus among scientists is that the effects of climate change … made these torms far more destructive.

CNN, Sept. 19, 2017

Are Tornadoes More Powerful Due to Climate Change?

AccuWeather, June 15, 2012

Links between More Extreme Weather and Climate Change

… the key thing, then is that all of the weather that is occurring, all of the storms are occurring in an environment that is simply different than it used to be.

NPR Science Friday, Apr. 5, 2012

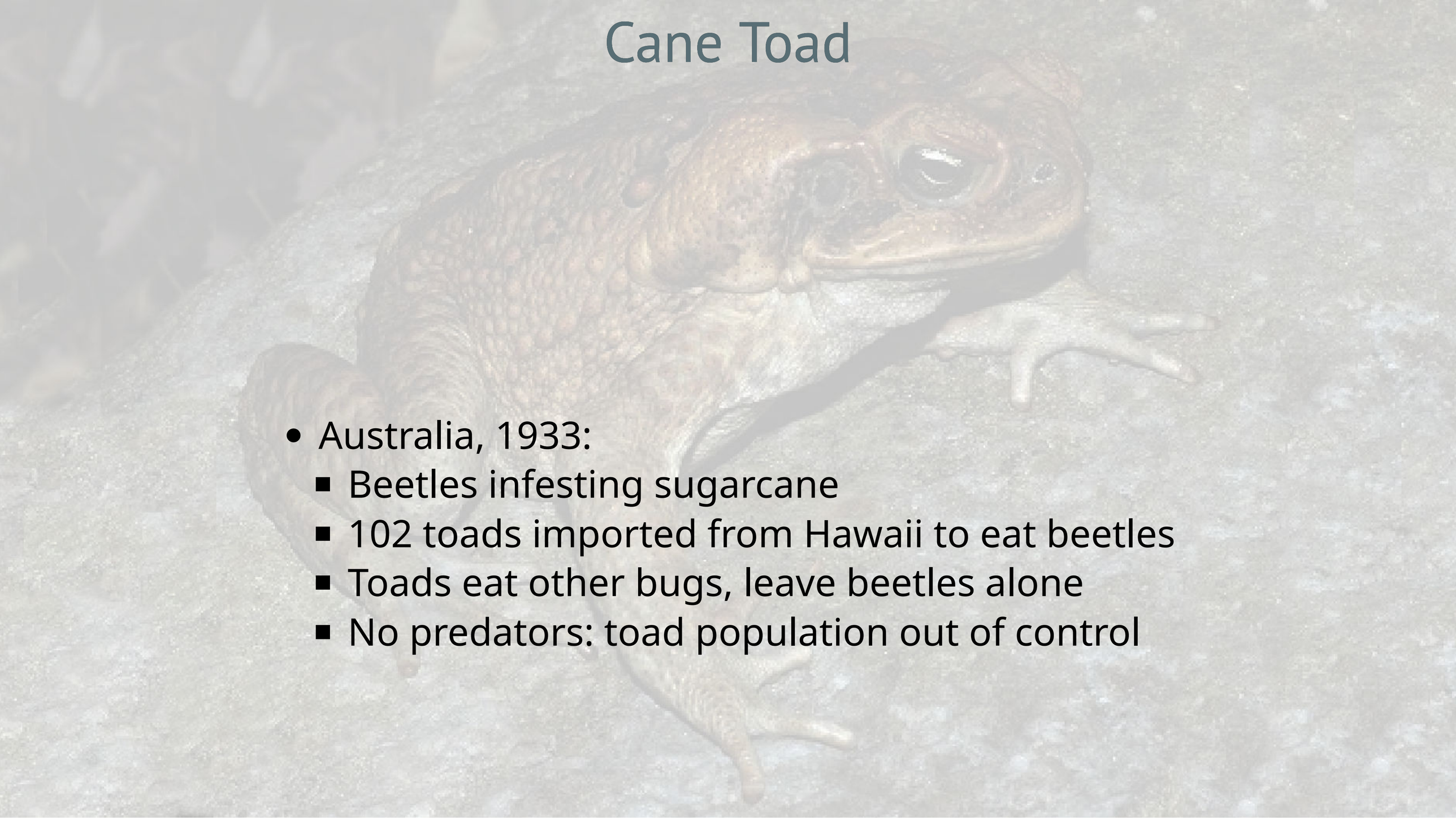
Colorado Flooding: Did Climate Change Play A Role in Recent Disaster?

Huffington Post, Sept. 14, 2013

- **Most scientific reviews on link between climate change and extreme weather are inconclusive**
- **But public, media jump to conclusions**
- **Will they also blame geoengineering?**

–>

Cane Toad

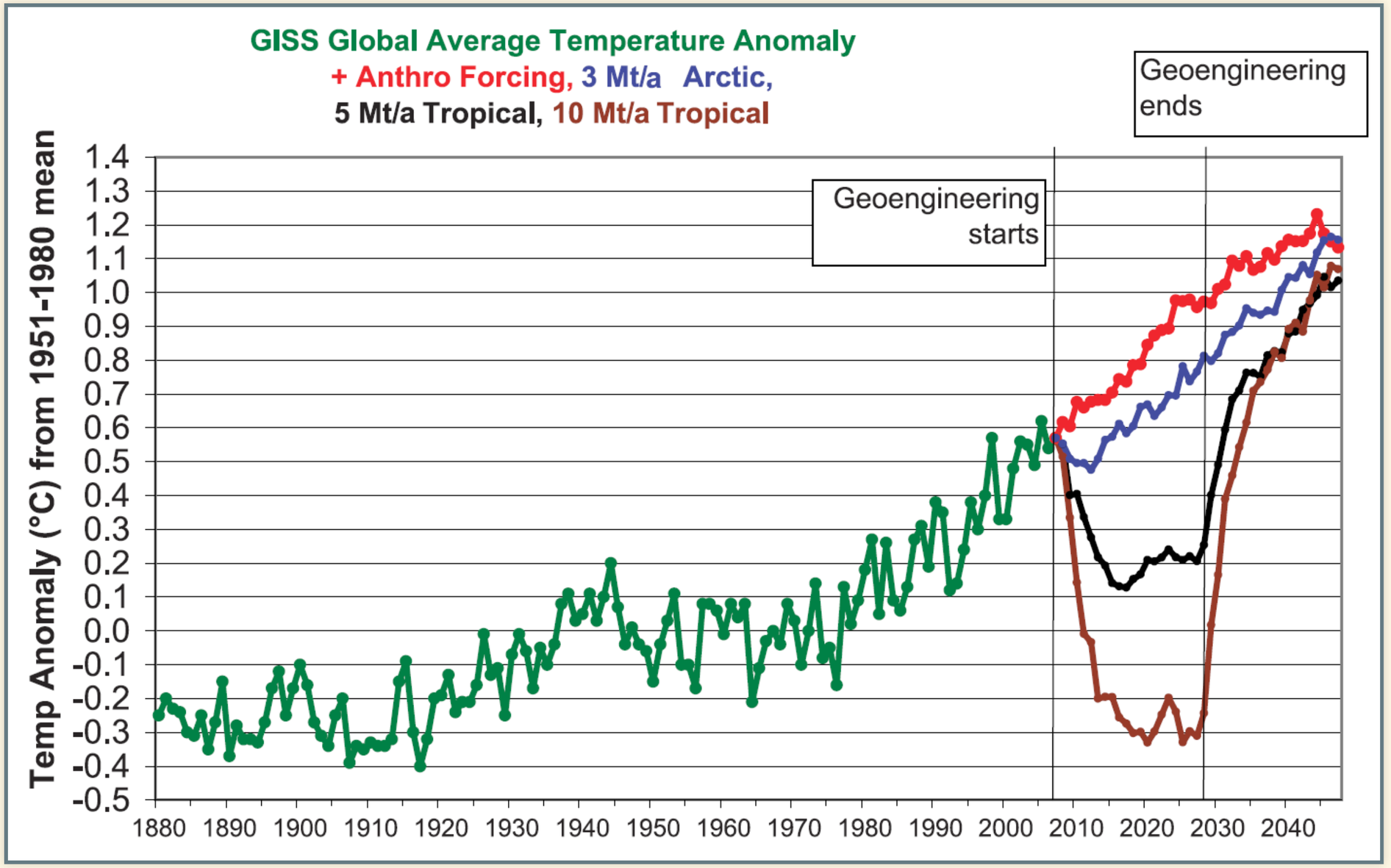


- Australia, 1933:
  - Beetles infesting sugarcane
  - 102 toads imported from Hawaii to eat beetles
  - Toads eat other bugs, leave beetles alone
  - No predators: toad population out of control

Kudzu

- **USA, 1930s–1950s:**
  - Government encourages farmers in Southeastern U.S. to plant **kudzu** to prevent erosion
  - Spread rapidly and widely
  - Now infests 8,000–12,000 square m
  - Controlling infestation costs $500 million per year

Maintenance


GISS Global Average Temperature Anomaly
+ Anthro Forcing, 3 Mt/a Arctic,
5 Mt/a Tropical, 10 Mt/a Tropical
Geoengineering ends
Geoengineering starts
Temp Anomaly (°C) from 1951-1980 mean
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020 2030 2040

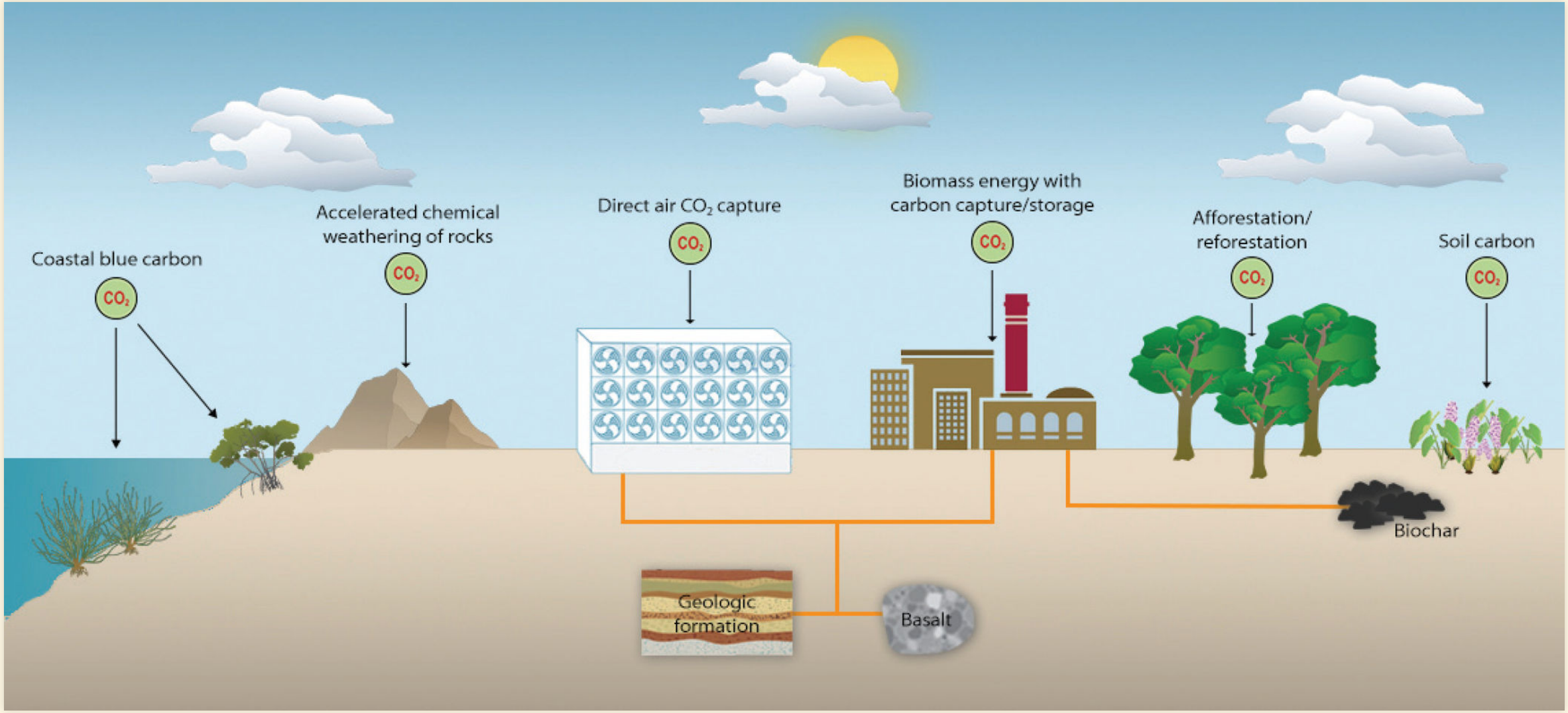
Albedo Control as Technological Fix

Albedo Control as Technological Fix

1. Cause-Effect Relationship?
   - Mismatched changes: incoming shortwave vs. outgoing longwave
   - Feedbacks
   - Temperature vs. precipitation
   - Geographic distribution
   - Ocean acidification
2. Assessable Effects?
   - No way to test it on small scale
   - No way to assess unintended consequences
3. Established Technological Base?
   - No “practice earth” for testing
   - Can’t build it incrementally

Air-capture of CO_2

Technologies



National Research Council, *Negative Emissions Technologies and Reliable Sequestration*, (2019)

Forests and Soil

Potential capture/storage rates (GT CO_2 per year)

Technology	Cost	US	Global
Forest Growth	Low	0.15	1.0
Forest Management	Low	0.10	1.5
Agriculture/Soils	Low to Med	0.25	3.0
Total		0.50	5.5

National Research Council, *Negative Emissions Technologies and Reliable Sequestration*, (2019)

Direct Air-Capture ("Artificial Trees")

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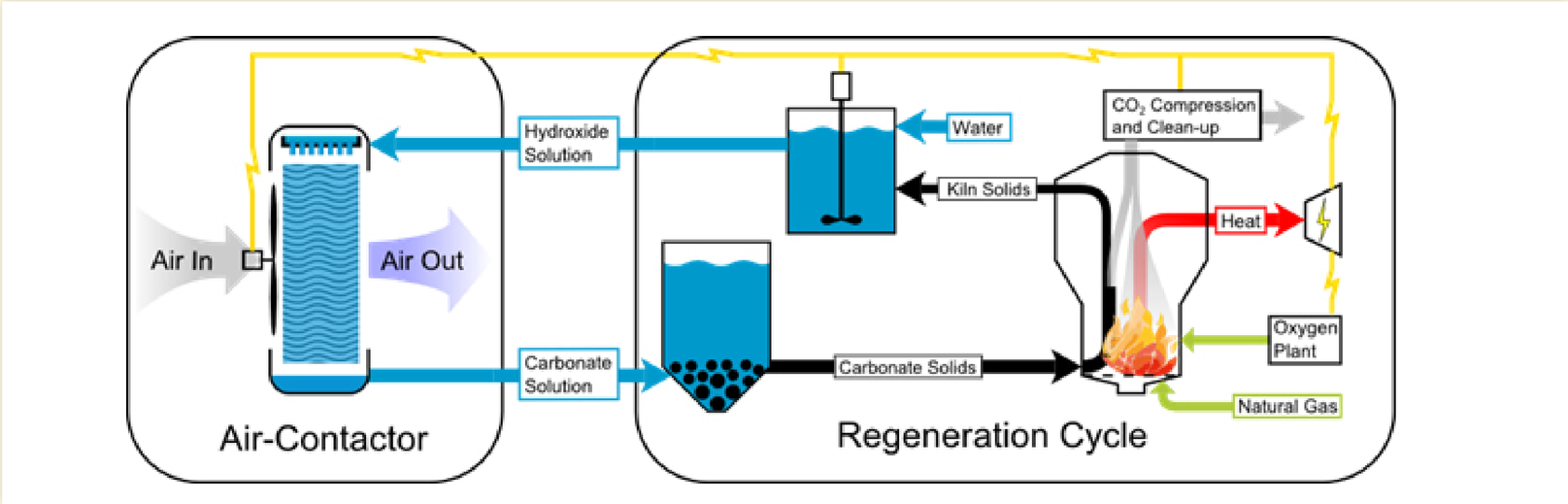

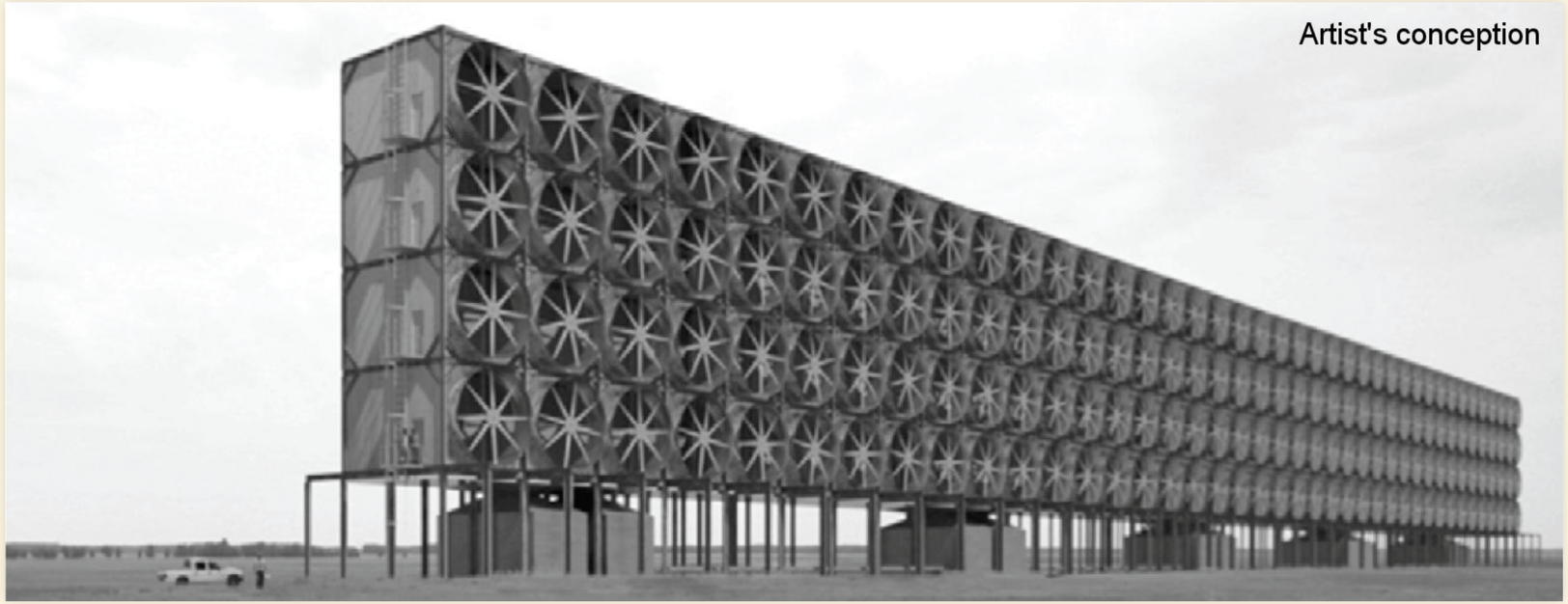

National Research Council, *Negative Emissions Technologies and Reliable Sequestration*, (2019)

Feasibiliity of Direct Air-Capture

- Possible in principle
- Hasn’t been tried on large scale
- Very expensive
  - National Academy Estimates: $90–600/ton

Bioenergy with Carbon Capture and Storage (BECCS)

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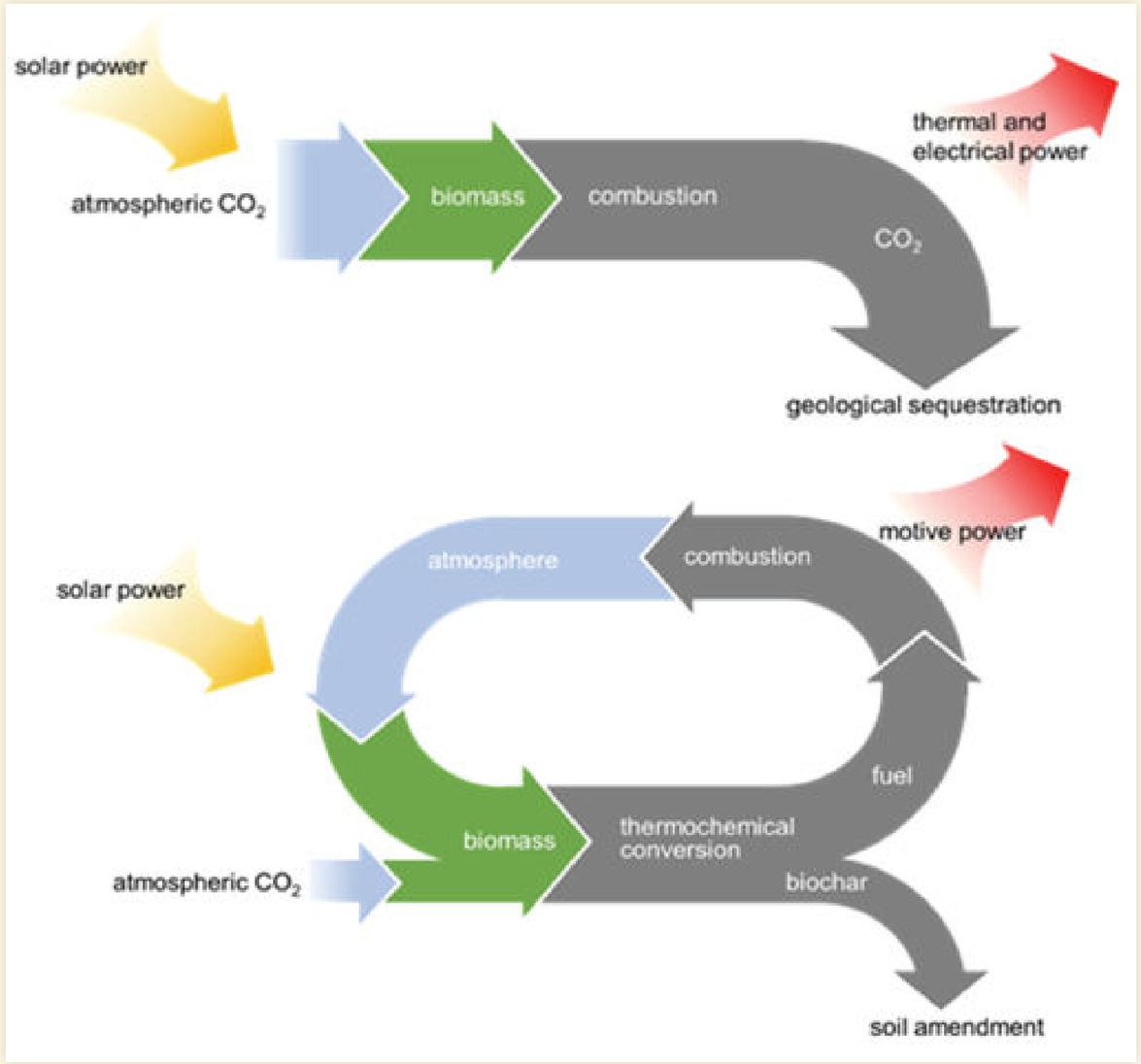

National Research Council, *Negative Emissions Technologies and Reliable Sequestration*, (2019)

Bioenergy with Carbon Capture and Storage (BECCS)

- Biomass production for fuel is already in wide use
- Carbon capture is not currently used, but would be three times as energy-efficient as direct air capture.
- Estimated costs:
  - For power plants: $70/ton
  - For vehicles: $40–130/ton
- Concerns about impact of converting so much land to energy production.

Feasibility of Air Capture

Cost of Air Capture

- Cost to capture all human emission:
  - At \$140/metric ton CO_2:
    - \$6–8 trillion: 10–15% of world GDP
  - At \$27/metric ton CO_2:
    - \$1.2–1.5 trillion: 2–3% of world GDP
- Is it worth it?
  - Stern: “If mitigation costs 1% of world GDP by 2100 … this is equivalent to growth rate dropping from 2.50% to 2.49%”
  - GDP in 2100 would still be 950% greater than today.

Air-Capture as Technological Fix

Pielke's assessment:

1. Cause-Effect Relationship?
   - Yes: Removing CO_2 would cancel adding CO_2
2. Assessable Effects?
   - Yes: We can measure CO_2 concentrations (almost 70 years experience)
3. Established technological base?
   - Laboratory projects to build on
   - Challenge is scaling up
4. What's missing?
   - Where to store CO_2 after we capture it?

Scaling Up

An apparatus the size of a semi trailer could remove a ton of carbon dioxide per day, or 365 tons a year.

The world's cars, planes, refineries, and power plants now produce about thirty six billion tons of CO_2 annually, so ...

... if you built a hundred million trailer-size units you could actually keep up with current emissions.

— Elizabeth Kolbert, The New Yorker, 20 Nov. 2017

Current Thinking

Recent Scholarship

Negative-emission technologies are not an insurance policy, but rather an unjust and high-stakes gamble. There is a real risk they will be unable to deliver on the scale of their promise.

The promise of … negative-emission technologies is more politically appealing than … rapid and deep mitigation now.

If we rely on [negative-emission technologies] and they are … unsuccessful at removing CO_2 from the atmosphere at the levels assumed, society will be locked into a high-temperature pathway.

— K. Anderson & G. Peters, Science **354**, 182 (14 Oct., 2016)

Context

The IPCC considered more than 1000 possible [emissions] scenarios.

Of these, only 116 limit warming to below [2°C], and of these 108 involve negative emissions.

In many below-two-degree scenarios, the quantity of negative emissions … reaches the same order of magnitude as the "positive" emissions being produced today.

— E. Kolbert, The New Yorker, 20 Nov. 2017

National Research Council Report (2019)

Negative emissions technologies are best viewed as a component of the mitigation portfolio, rather than a way to decrease atmospheric concentrations of carbon dioxide only after anthropogenic emissions have been eliminated.

Comparing Imperfect Solutions

- Mitigation
  - Cut emissions
  - Geoengineering
- Adaptation
- Do nothing

“We have three options:
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