Earth’s Climate:
Old Problems, New Thoughts

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Roadmap for the evening

1. Background & long-term perspective
2. Potential solution
3. Other factors
The bottom

- Lower Emissions Scenario, 2080-2099

- Higher Emissions Scenario, 2080-2099

- Recent Past, 1961-1979

Number of days over 100° F

climatecommunication.org
Global Climate Change
A geologist’s perspective

- Earth’s energy budget
  Heat-trapping gases influence Earth’s energy budget
- Paleoclimate
- Climate change today
Global Climate Change
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INCOMING ENERGY

OUTGOING ENERGY

Earth's energy budget

Heating-trapping gases:

- Outgoing infrared radiation: 239.9
- Reflected by surface: 22.9
- Emitted by surface: 398.2
- Reflected by clouds & atmosphere: 77.0
- Absorbed by surface: 163.3
- Absorbed by atmosphere: 358.2
- Latent heat (change of state)

All values are fluxes in Wm⁻² and are average values based on ten years of data.

Data from:
- Trenberth et al., BAMS, 2009

nasa.gov
CARBON DIOXIDE (CO$_2$)
CONCENTRATION IN ATMOSPHERE: 0.04%
50% OF TRAPPED HEAT

METHANE (CH$_4$)
CONCENTRATION IN ATMOSPHERE: 0.00018%
20% OF TRAPPED HEAT
Questions about Earth’s energy budget?
Global Climate Change
A geologist’s perspective

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Paleoclimatologists Study Past Climate
ICE CORES: MEASUREMENTS OF FOSSIL AIR

Research.gov; Petit et al. 1999
ICE CORES: MEASUREMENTS OF FOSSIL AIR

WHICH CAME FIRST, INCREASES OF HEAT-TRAPPING GASES OR WARMING?

research.gov; Petit et al. 1999
HEAT-TRAPPING GASES!

Antarctic Temp.

Global Temp.

Age (thousands of years before present)
Questions about past climate?
Global Climate Change
A geologist’s perspective

• Earth’s energy budget

• Heat-trapping gases influence Earth’s energy budget

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• Climate change today
HEAT-TRAPPING GASES TODAY: A GEOLOGIST’S PERSPECTIVE

Where do these heat-trapping gases come from?

Petit et al. 1999
Brayton Point coal-fired power plant, Fall River, MA
HEAT-TRAPPING GASES TODAY: A GEOLOGIST’S PERSPECTIVE

When was the last time that heat-trapping gas concentrations were so high?

Petit et al. 1999
Ellesmere Island today…
Ellesmere Island during the Eocene (50 million years ago)...
HOW DOES THIS IMPACT CLIMATE HERE?

Spring 2010 floods in Rhode Island

October 2011 snowstorm

Massachusetts climate ‘migration’
SO WHAT CAN WE DO?

Multi-model projections of surface warming

We have a choice!!

Temperature relative to today (°F)

-1.8
-0.0
1.8
3.6
5.4
7.2
9.0
10.8

Year

1900
2000
2100

A2
A1B
B1
Year 2000 Constant Concentrations
20th century

Higher Emissions Scenario®, 2080-2099

Lower Emissions Scenario®, 2080-2099

IPCC, 2007; climatemunication.org
References cited


Shakun JD, et al. (2012) Global warming preceded by increasing carbon dioxide concentrations during the last deglaciation. *Nature* 484: 49-55.

Most data are publicly available at http://www.ncdc.noaa.gov/paleo
Reducing CO$_2$ Emissions
By Pumping Them Underground

Sujit S. Datta, Harvard University
Possible Approaches

- Sunlight
- Infrared heat
Possible Approaches

1) Long term: Minimize CO₂ production (“clean” energy)
Possible Approaches

1) Long term: Minimize CO$_2$ production ("clean" energy)

2) Medium-long term: geoengineer the Earth
Possible Approaches

1) **Long term**: Minimize CO$_2$ production ("clean" energy)

2) **Medium-long term**: geoengineer the Earth
Possible Approaches

1) Long term: Minimize CO₂ production ("clean" energy)

2) Medium-long term: geoengineer the Earth

3) Short term: Reduce emission of produced CO₂
Outline for this Segment

• Storing CO$_2$ underground: Why would you dream of such a thing?

• Ways in which CO$_2$ can be stored

• Current state of the art
Geological Storage: Not That New

~1km

Can store gas/fluid for millions of years

Moore, State Geological Survey (1920)

Geological Storage: Not That New

Can store gas/fluid for millions of years

Moore, State Geological Survey (1920)

Cnudde et al., Geosphere (2011)

Geological Storage: Not That New

~1km

Cnudde et al., Geosphere (2011)

Can store gas/fluid for millions of years


Caprock

Moore, State Geological Survey (1920)
CO$_2$ Sequestration

1-3km
What Happens To The CO$_2$?

Szulczewski et al., PNAS (2012)
What Happens To The CO$_2$?

Szulczewski et al., PNAS (2012)

Datta et al. (2012);
Bickle Nature Geo. (2009)
What Happens To The CO$_2$?

Szulczewski et al., *PNAS* (2012)

Datta et al. (2012); Bickle *Nature Geo.* (2009)

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Datta et al. (2012); Bickle Nature Geo. (2009)

Ennis-King and Paterson, SPE J. (2005)
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First Case: Sleipner, North Sea
First Case: Sleipner, North Sea

- 1996-present: 1 million tonnes/year (~300,000 cars)
- >100 billion tonnes capacity
- No evidence of leaks: seismic monitoring
Storage Capacity

- US > 160 billion tonnes
- World > 1 trillion tonnes
- This could stabilize our emissions for ~100 years

Dooley et al., JGCRI (2006); Szulczewski et al., PNAS (2012)
Points To Consider

- Safety and stability: pressure control, leak monitoring

Statoil, Veritas, BP

(≈1km underground)

Increasing depth

Statoil, Veritas, BP
Points To Consider

- Safety and stability: pressure control, leak monitoring
- Economics: capture to injection = $45-170/tonne

Statoil, Veritas, BP

(~1km underground)

Increasing depth
Points To Consider

- Safety and stability: pressure control, leak monitoring
- Economics: capture to injection = $45-170/tonne
- Energy use: can be 25% of a plant’s output!
Overview

• Greenhouse gas emissions can drive climate change

• Some of these emissions can be stored underground

• But this isn’t the whole story! Dust…
Droughts – the ‘creeping disaster’ and desert dust

Atreyee Bhattacharya

Outline for the talk

1. Desert dust as tracers of climate change
2. Dust as drivers of climate change.

A case study in North African Sahel
World map of Köppen-Geiger climate classification

DATA SOURCE: GHCN v2.0 station data
Temperature (N = 4,844) and Precipitation (N = 12,396)

PERIOD OF RECORD: All available
MIN LENGTH: ≥30 for each month.
RESOLUTION: 0.1 degree lat/long

Contact: Murray C. Peel (mpeel@unimelb.edu.au) for further information
Higher Emissions Scenario, 2080-2099

Times Magazine
Dry farm lands in southern Australia

Dry lake beds in southwestern China
Data from Mitchell et al, 2005
Russell and Johnson, 2007
Regional meteorology modulates dust emission
What causes droughts in the Sahel?

Ocean temperatures!!

Bhattacharya et al, 2012
Cape Verde

Mukhopadhyay and Kreycik, 2008
Corals as novel dust archives

Barnard et al., Nature 1974
Dark Ages | Medieval climate anomaly | Little Ice Age | Sahel Drought

Russell and Johnson, 2007

Age (AD)
Ocean circulation

Ice sheet extent

Salinity

Atmospheric dust
Dust transport from North Africa (illustration adapted from Garrison et al., 2003)
Cools the ocean temperatures which can sustain droughts.
Natural causes
- Ocean temperatures
- Land temperatures
- Rain belt movement

Anthropogenic Impact
- Land degradation
- Overgrazing
- Loss of forest canopy
Conclusions

Heat trapping gases in the atmosphere has increased beyond anything natural over the last 400,000 years

Migration of weather patterns and more severe weathers

Dust in the atmosphere is a tracer for past droughts BUT can also have prolonged the late 20th century Sahel Drought.

Geo engineering techniques may help although they are still cost prohibitive
Dust bowl of the 1930’s
Acknowledgements

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