Effects of Climate Change

AOSC / CHEM 433 & AOSC 633

Ross Salawitch & Walt Tribett

Class Web Site: http://www.atmos.umd.edu/~rjs/class/spr2019

Today:

- **Climate Feedback**
- **Consequences of Climate Change**
- **Last year's first exam**

Bonus Lecture

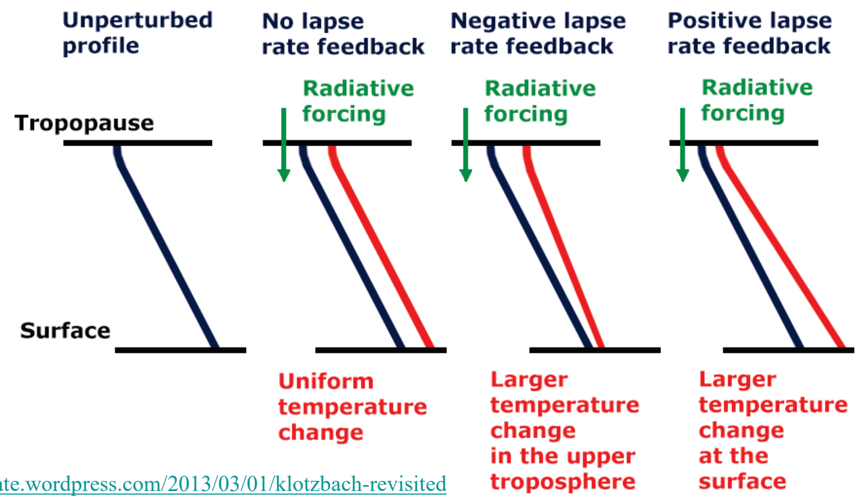
28 February 2019

Announcements

- Problem Set #2:
  - ***Late penalty***: No late penalty since some of the material helpful for completion will be covered in class today. We'll review on Monday, March 4, 5 pm, ATL 2428. To receive credit, your solutions must be turned in prior to the start of the review.
  - We'll return graded solutions on March 4 for anyone who turns in completed solutions this Friday by 9 pm. On Friday, can either hand solutions to Ross (ATL 2403), Walt (ATL 4100), or place under Ross's door.
  - Please work with version of P Set #2 updated on 25 Feb

- First exam is **Tues, 5 Mar** in class:
  - Closed book, no calculator or e-device
  - Will focus on concepts rather than calculations
  - New exams every year; we will review prior exam in class today
  - **We'll start when the clock strikes 2 pm and end at 3:15 pm**
    Students who arrive a few minutes late will be allowed a few minutes extra time, so that everyone has 75 minutes.

Lapse Rate Feedback



https://ourchangingclimate.wordpress.com/2013/03/01/klotzbach-revisited

- Photons emitted in UT can escape to space more easily than photons emitted near surface
- If UT warms more than surface, bulk atmospheric emissivity increases

UT :upper troposphere   Emissivity: efficiency in which thermal energy is radiated

- GCMs indicate water vapor & lapse rate feedbacks are intricately linked, with the former almost certainly being positive (in response to rising GHGs), the latter almost certainly being negative, and the sum probably being positive
- Definition of the empirical lapse rate feedback is marred by controversy, having to do with how to properly interpret UT data from various Microwave Sounding Unit (MSU) instruments

Houghton’s Notation

Climate feedback comparisons

Climate feedbacks affect the *sensitivity* of the climate in terms of the temperature change ΔT_s at the surface that occurs for a given change ΔQ in the amount of net radiation entering the top of the troposphere (known as the radiative forcing[15]). ΔQ and ΔT_s are related by a *feedback parameter f* (units $\mathrm{Wm^{-2}\ K^{-1}}$) according to

$$\Delta Q = f \Delta T_s$$

If nothing changes other than the temperature (see Figure 2.8), f is just the basic temperature feedback parameter $f_0 = 3.2\ \mathrm{W\ m^{-2}\ K^{-1}}$ (i.e. the change in radiation at the top of the troposphere that leads to a 1°C change at the surface).

However, as we have seen other changes occur that result in feedbacks. The total feedback parameter f allows all the feedbacks to be added together:

$$f = f_0 + f_1 + f_2 + f_3 + \ldots$$

Estimates of the feedback parameters for the main feedbacks from different climate models are:[16]

Water vapour (including lapse rate feedback – see Note 13)	-1.2 ± 0.5
Cloud	-0.6 ± 0.7
Ice albedo	-0.3 ± 0.3
Total feedback parameter (sum of f_0 and the three above[17])	1.1 ± 0.7

Note that with this total feedback parameter the amplification factor is about 2.9 and the resulting climate sensitivity to doubled carbon dioxide a little over 3°C.

$$f_{HOUGHTON} = f_o + f_{WV} + F_{CLOUD} + F_{ICE\ ALBEDO} = 3.2 - (1.2 + 0.6 + 0.3)\ \mathrm{W\ m^{-2}\ K^{-1}} = 3.2 - 2.1\ \mathrm{W\ m^{-2}} = 1.1\ \mathrm{W\ m^{-2}\ K^{-1}}$$

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Total feedback parameter (sum of f_0 and the three above[17])	1.1 ± 0.7

Note that with this total feedback parameter the amplification factor is about 2.9 and the resulting climate sensitivity to doubled carbon dioxide a little over 3°C.

His ΔQ is our ΔRF

Therefore, without feedbacks, he has:

$$\Delta T = 1/(3.2\ \mathrm{W\,m^{-2}\,K^{-1}}) \times \Delta RF = 0.31\ \mathrm{K/(W\,m^{-2})} \times \Delta RF$$

Lecture 04:

Above equation can be re-arranged to yield:

$$\Delta T \approx \frac{1}{4\,\sigma\,T^3}\,\Delta F$$

So: $$\lambda = \frac{1}{4\,\sigma\,T^3}$$

If we plug in value of Boltzmann's constant and global mean T at which Earth radiates to space, we find $\lambda_{BB} \approx 0.3$ K / (W m^{-2})

Here: BB refers to Black Body

Houghton's Notation

Climate feedback comparisons

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Total feedback parameter (sum of f_0 and the three above[17])	1.1 ± 0.7

Note that with this total feedback parameter the amplification factor is about 2.9 and the resulting climate sensitivity to doubled carbon dioxide a little over 3°C.

His ΔQ is our ΔRF

Therefore, with feedbacks, he has:

$$\Delta T = 1/(1.1\ \mathrm{W\,m^{-2}\,K^{-1}}) \times \Delta RF = 0.91\ \mathrm{K/(W\,m^{-2})} \times \Delta RF$$

Lecture 04:

In our terminology:

$\lambda_{ACTUAL} = \lambda_{BB}\,(1 + f_{TOTAL})$

where f_{TOTAL} is the magnitude of total climate feedback

Since 0.91/0.31 = 2.9, Houghton's numbers on page 113 implies f_{TOTAL} = 1.9

Houghton's Notation

Table 5.1 Estimates of global average temperature changes under different assumptions about changes in greenhouse gases and clouds

Greenhouse gases	Clouds	Change (in °C) from current average global surface temperature of 15°C
As now	As now	0
None	As now	−32
None	None	−21
As now	None	4
As now	As now but +3% high cloud	0.3
As now	As now but +3% low cloud	−1.0
Doubled CO_2 concentration otherwise as now	As now (no additional cloud feedback)	1.2
Doubled CO_2 concentration + best estimate of feedbacks	Cloud feedback included	3

Here, we have:

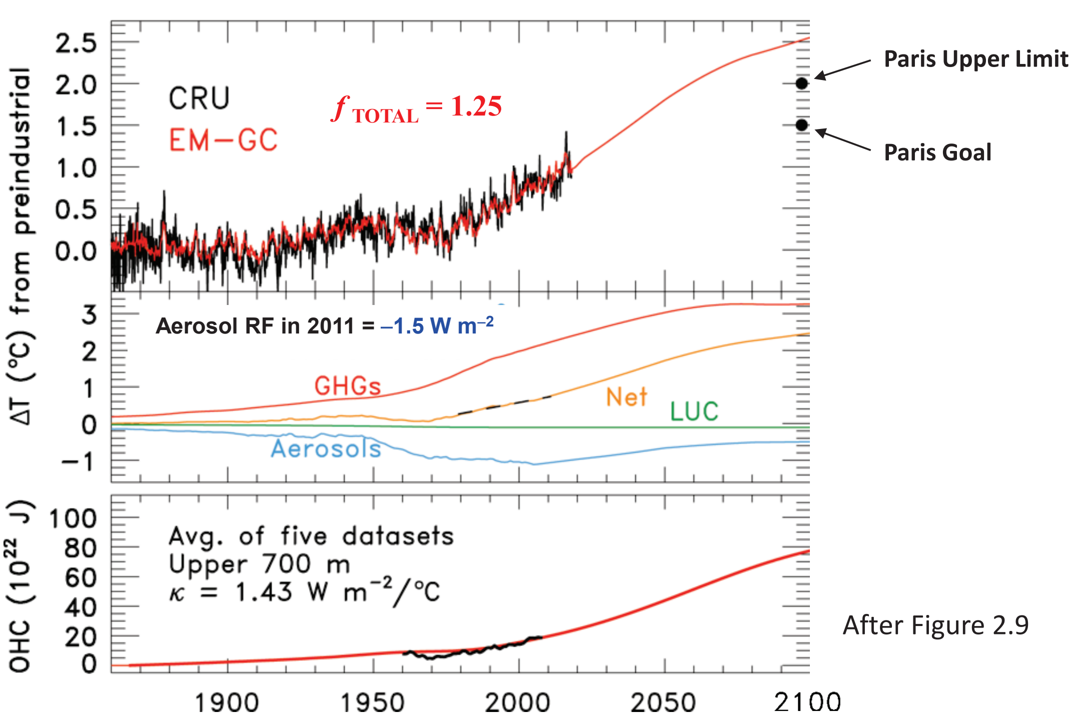
$\Delta T^{2\times CO2}$ = 0.31 K/(W m $^{-2}$) × (5.35 ln (2)) W m $^{-2}$ = 1.149 K

$\Delta T^{2\times CO2+Feebacks}$ = 3 K, which implies:

$\Delta T^{2\times CO2+Feebacks}$ = 0.31×2.5 K/(W m $^{-2}$) ΔRF = 0.775 K/(W m $^{-2}$) ΔRF

- or- f_{TOTAL} = 1.5

EM-GC Forecast for RCP 4.5 GHG scenario



After Figure 2.9

We assume that whatever value of climate feedback is inferred from the climate record will persist into the future. For Aerosol RF in 2011 of −1.5 W m $^{-2}$ & assuming best estimate for H_2O and Lapse Rate feedback is correct, this simulation implies sum of other feedbacks (clouds, surface albedo) must be ***strongly positive***.

Negative Feedback

Initial Action:
Humans Release CO_2

→

Initial Response:
$T_{SURFACE}$ rises

↓

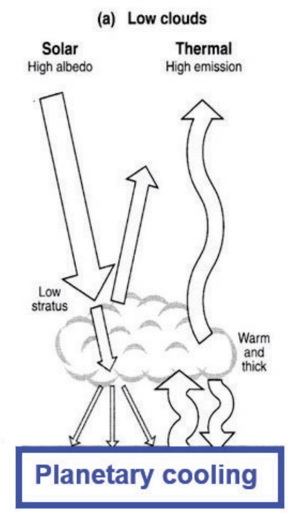
Then:
Low Altitude clouds become ***more*** prevalent

↓

Consequence:
More solar radiation reflected

↓

Feedback:
⇨ $T_{SURFACE}$ declines: *negative* feedback



Positive Feedback

Initial Action:
Humans Release CO_2

→

Initial Response:
$T_{SURFACE}$ rises

↓

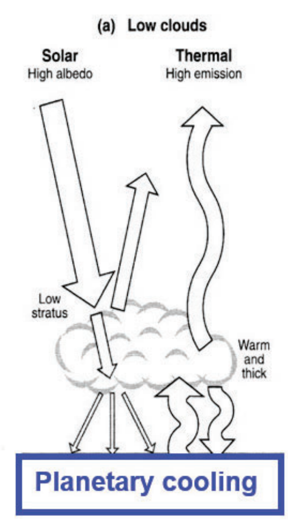
Then:
Low Altitude clouds become ***less*** prevalent

↓

Consequence:
Less solar radiation reflected

↓

Feedback:
⇨ $T_{SURFACE}$ rises: *positive* feedback



Consequences of Climate Change

1. **Rising sea-level threatens many populated coastal regions, including Maryland**

2. **Desert are expanding and permafrost is melting, threatening agriculture, Arctic habitat, water supply to populated regions**

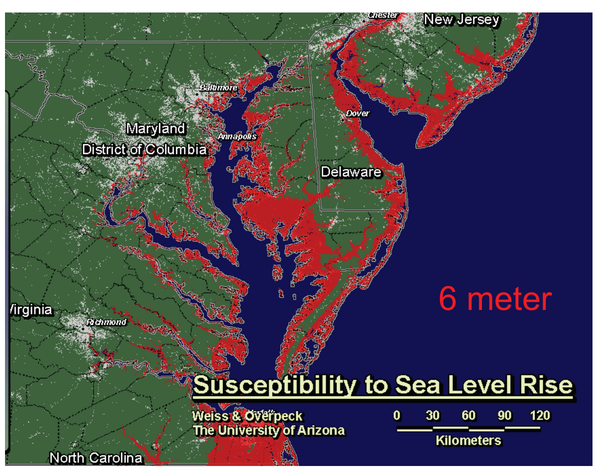
3. **World is becoming more "tropical", including poleward migration of ecosystems, weather patterns, and tropical diseases**

4. **Hurricane intensity is increasing, affecting populations that reside in coastal regions**

5. **Ocean is becoming increasingly acidic, threatening vast portions of the ocean ecosystem**

Consequences of Climate Change

1. **Rising sea-level threatens many populated coastal regions, including Maryland**

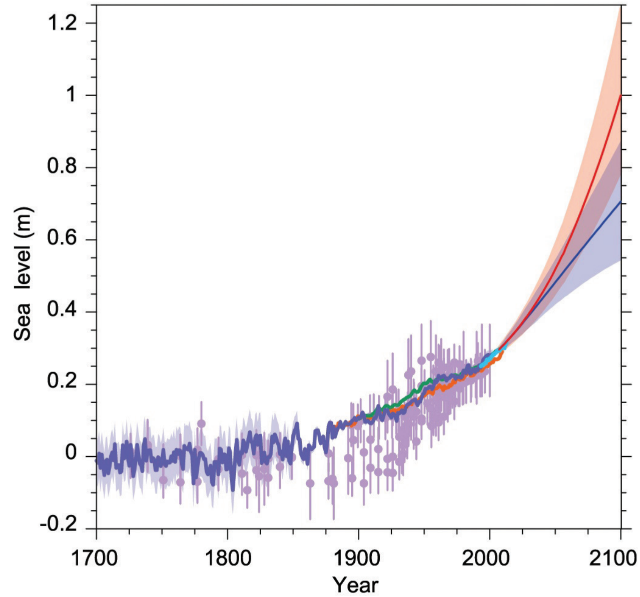


Maryland:

- **more coastline than California !**
- **more susceptible to sea level rise than all but 2 other states**

Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland

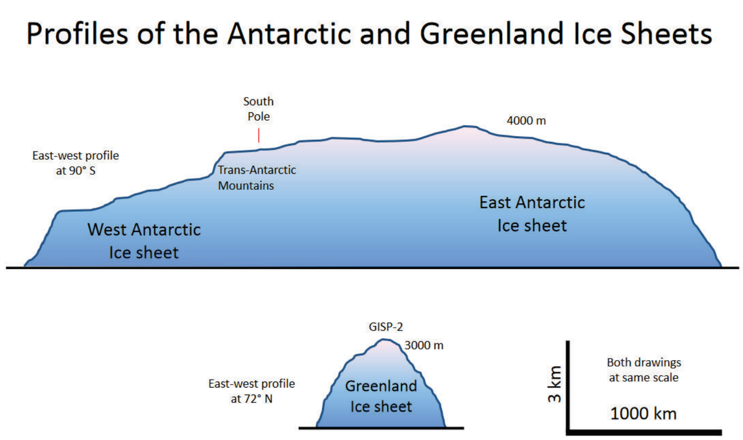


Compilation of paleo sea level data (purple), tide gauge data (blue, red and green), altimeter data (light blue) and central estimates and likely ranges for projections of global mean sea level rise from the combination of CMIP5 and process-based models for RCP2.6 (blue) and RCP8.5 (red) scenarios, all relative to pre-industrial values.

IPCC (2013)

Volume of Antarctic Ice Sheet ~26.5×10^6 km^3 and volume of cubic Greenland Ice Sheet ~2.85×10^6 km^3

https://en.wikipedia.org/wiki/Antarctic_ice_sheet & https://en.wikipedia.org/wiki/Greenland_ice_sheet

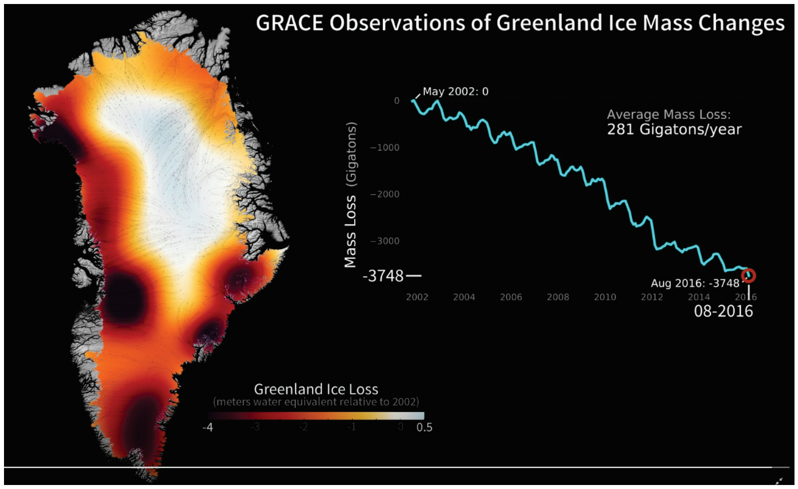


https://web.viu.ca/earle/geol305/The%20Greenland%20Ice%20Sheet.pdf

Radius of Earth = 6371 km; Surface area of Earth = 510×10^6 km^2
70% of earth, or 357×10^6 km^2 is covered by water.

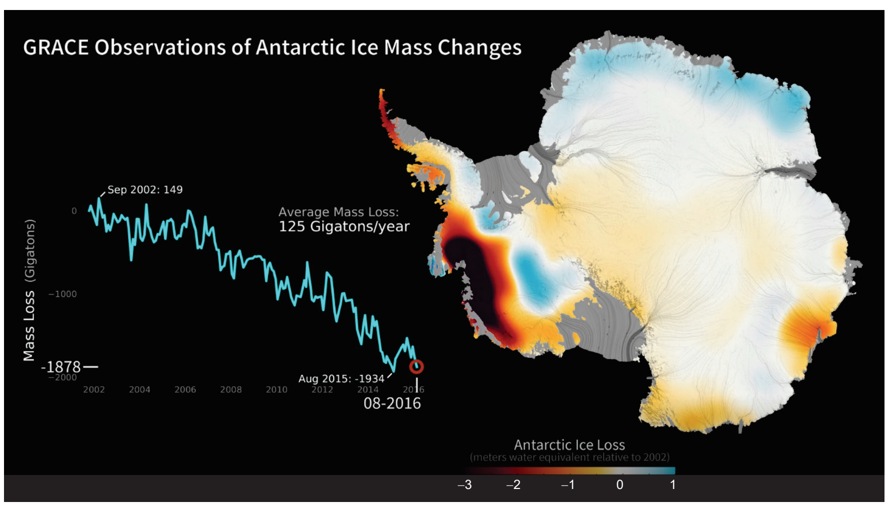
The complete collapse of Greenland would lead to sea-level rise of
2.85×10^6 km^3 / 357×10^6 km^2 = 8 meters according to these numbers.
Since more area would be covered by water following the collapse,
the actual rise in sea level is closer to 7 meters … or 23 feet!

HONR 229L: Climate Change: Science, Economics, and Governance



Observations obtained by the NASA Gravity Recovery and Climate Experiment (GRACE) showed loss of ~280 gigatons of ice per year from Greenland, causing global sea level to rise by a total of 0.4 inches between 2002 and 2016 (or 0.03 inches per year)

https://gracefo.jpl.nasa.gov/resources/33/greenland-ice-loss-2002-2016



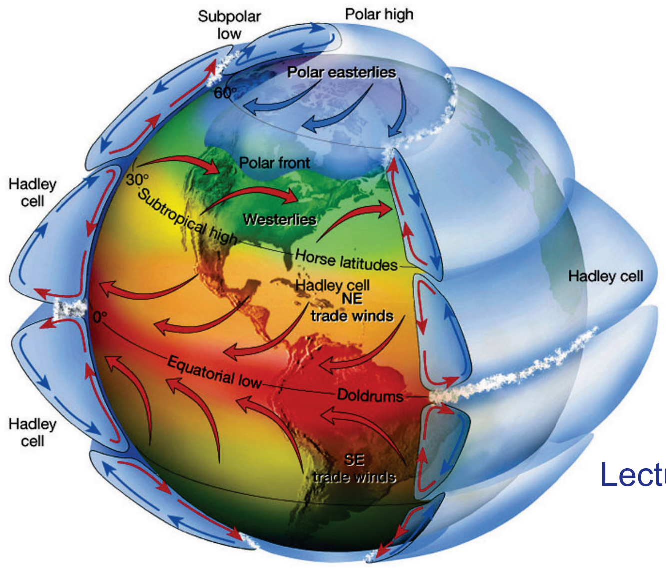
Observations obtained by the NASA Gravity Recovery and Climate Experiment (GRACE) showed loss of ~125 gigatons of ice per year from Antarctica, causing global sea level to rise by a total of 0.18 inches between 2002 and 2016 (or 0.014 inches per year)

https://grace.jpl.nasa.gov/resources/31/antarctic-ice-loss-2002-2016

Consequences of Climate Change

2. **Desert are expanding and permafrost is melting, threatening agriculture, Arctic habitat, water supply to populated regions**
3. **World is becoming more "tropical", including poleward migration of ecosystems, weather patterns, and tropical diseases**

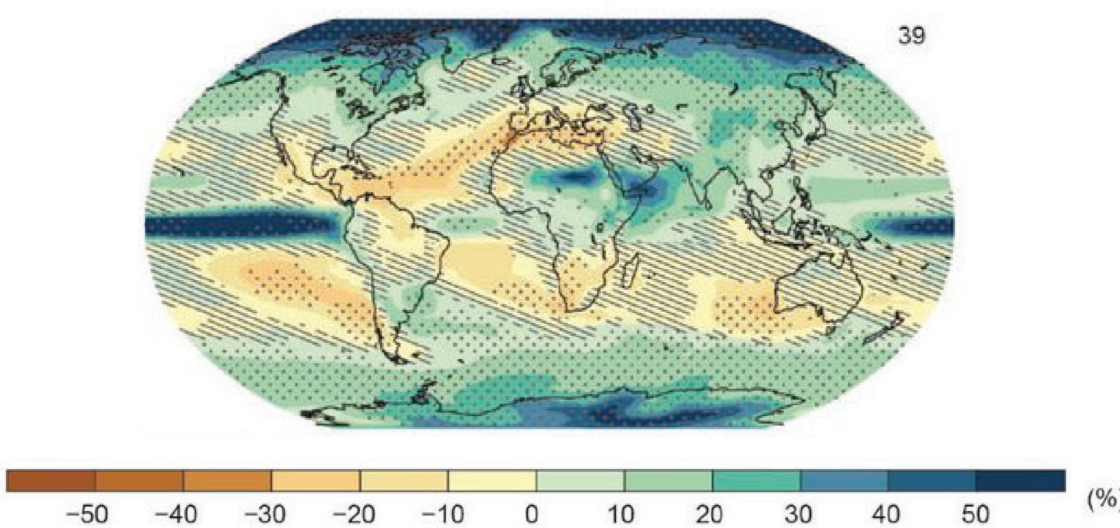
Ferrel Circulation (Modern View)



Lecture 3

Connection to Climate Change

Spatial Distribution of Precipitation Changes, 2081 −2100 relative to 1986−2005

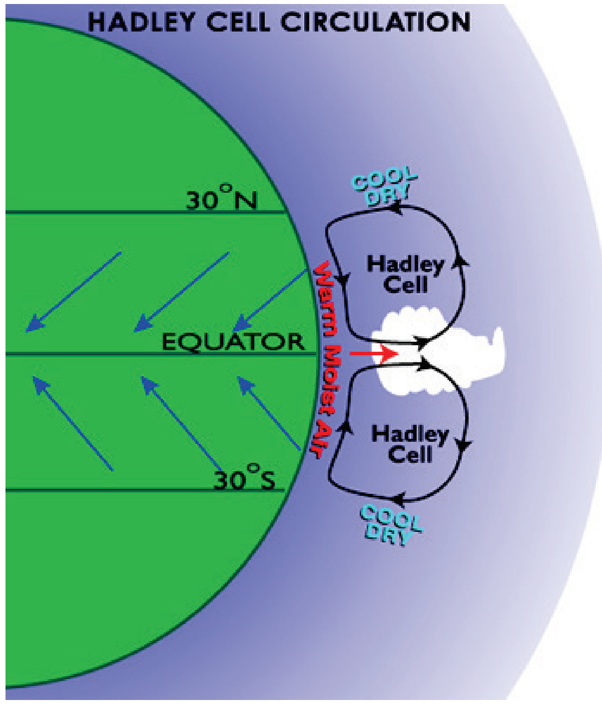


Climate model projections, RCP 8.5 (aggressive growth of GHGs)

https://www.cnbc.com/2017/08/28/the-stunning-images-from-record-setting-flooding-in-houston-texas.html

IPCC 2013

Connection to Climate Change
WWDD: Wet-gets-Wetter, Dry-gets-Drier (WWDD) paradigm



http://www.windows2universe.org/vocals/images/HadleyCell_small.jpg

Recent papers linking fires to climate change

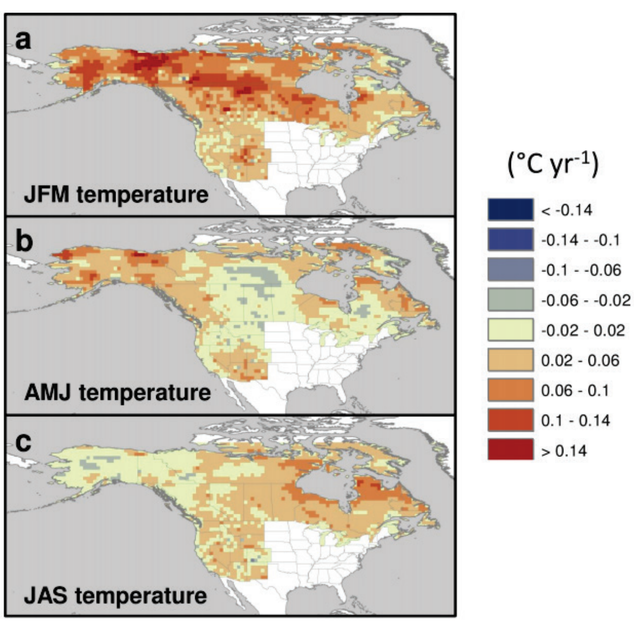
RESEARCH ARTICLE

Direct and indirect climate controls predict heterogeneous early-mid 21st century wildfire burned area across western and boreal North America

Thomas Kitzberger[1] *, Donald A. Falk[2,3], Anthony L. Westerling[4], Thomas W. Swetnam[2]

1 Laboratorio Ecotono, CONICET–INIBIOMA, Universidad Nacional del Comahue, Quintral, Bariloche, Argentina, 2 University of Arizona, Laboratory of Tree-Ring Research, Tucson, AZ, United States of America, 3 University of Arizona, School of Natural Resources and the Environment, Environment and Natural Resources Building, Tucson, AZ, United States of America, 4 Sierra Nevada Research Institute, University of California, Merced, California, United States of America

* kitzberger@comahue-conicet.gob.ar



Trends in temperature for:
(a) Winter (JFM)
(b) spring (AMJ)
(c) summer (JAS)
over the 1972–2006 time period

Recent papers linking fires to climate change

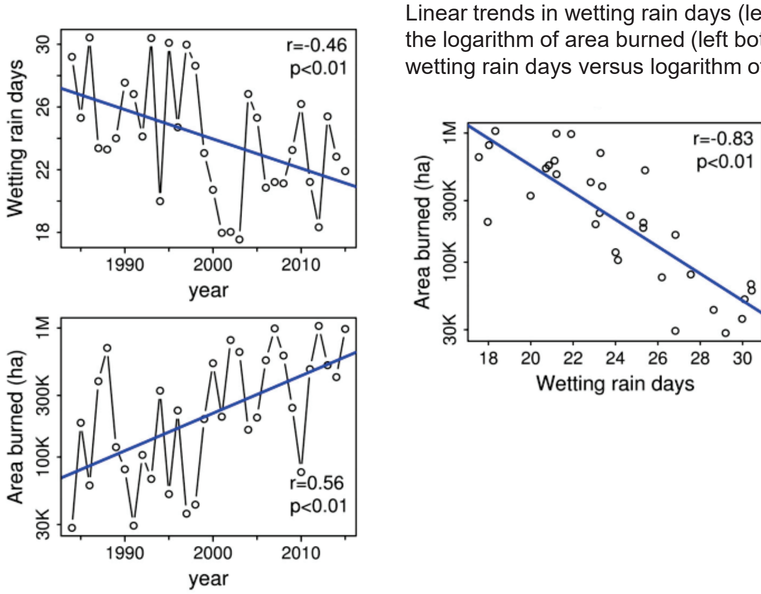

PNAS

Decreasing fire season precipitation increased recent western US forest wildfire activity

Zachary A. Holden[a,1], Alan Swanson[b], Charles H. Luce[c], W. Matt Jolly[d], Marco Maneta[e], Jared W. Oyler[f], Dyer A. Warren[b], Russell Parsons[d], and David Affleck[g]

[a]US Forest Service Region 1, Missoula, MT 59807; [b]School of Public and Community Health Sciences, University of Montana, Missoula, MT 59812; [c]US Forest Service Aquatic Science Laboratory, Rocky Mountain Research Station, Boise, ID 83702; [d]US Forest Service, Fire Sciences Laboratory, Rocky Mountain Research Station, Missoula, MT 59808; [e]Department of Geosciences, University of Montana, Missoula, MT 59812; [f]Earth and Environmental Systems Institute, Pennsylvania State University, University Park, PA 16802; and [g]Department of Forestry and Conservation, University of Montana, Missoula, MT 59812

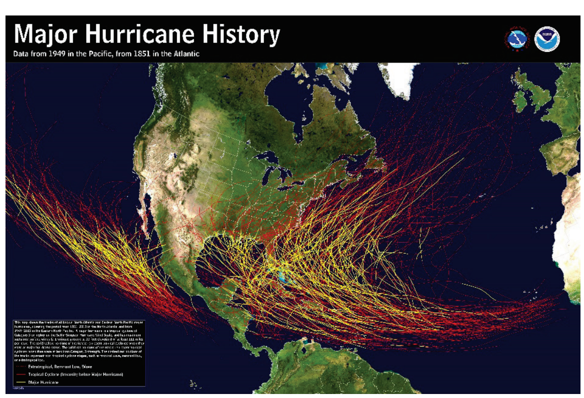
Linear trends in wetting rain days (left top), the logarithm of area burned (left bottom), and wetting rain days versus logarithm of area burned (right)



Consequences of Climate Change

4. Hurricane intensity is increasing, affecting populations that reside in coastal regions

- Projection of the effect of global warming on hurricanes requires conducting calculations on a ~20-km grid ("serious supercomputer")
- Some simulation project that at end of century, rising GHGs will lead to:
  - a) ~ 30% decrease in annual mean occurrence number of tropical cyclones, due to larger increases in T at 250 mbar than at surface, which causes a more stable atmosphere
  - b) increase in maximum surface winds of the tropical cyclones that do occur:
    - i.e., ***hurricanes less frequent but more powerful*** Oouchi *et al.*, *Journal Meteor. Soc. Japan*, 2006
- Confounding factor:



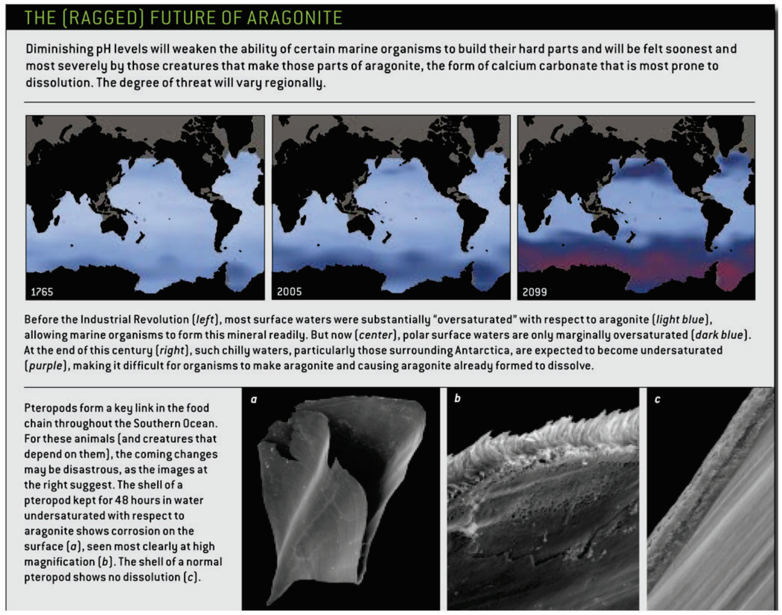
http://www.c2es.org/science-impacts/extreme-weather/hurricanes

Consequences of Climate Change

5. Ocean is becoming increasingly acidic, threatening vast portions of the ocean ecosystem

Future ocean uptake of atmospheric CO_2 will lead to ***ocean acidification***

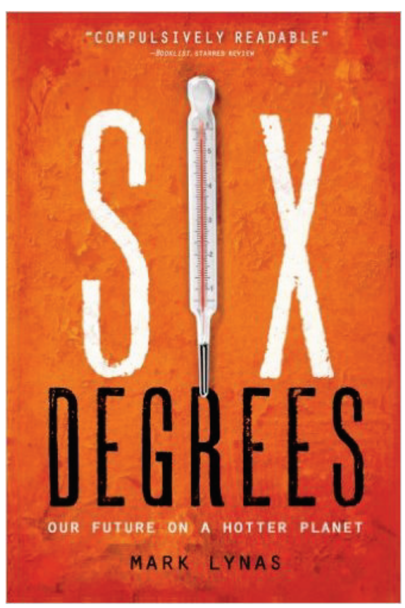
Bad news for ocean dwelling organisms that precipitate shells (basic materials)



Doney, The Dangers of Ocean Acidification, *Scientific American*, March, 2006

Possible Impacts of Climate Change

- **1°C (already committed to this)**
  - Loss of glacial waters in Africa & Asia, with regional declines in food production
  - Tropical islands such as Tuvalu, ***Kiribati***, Marshall Islands, and Maldives severely threatened

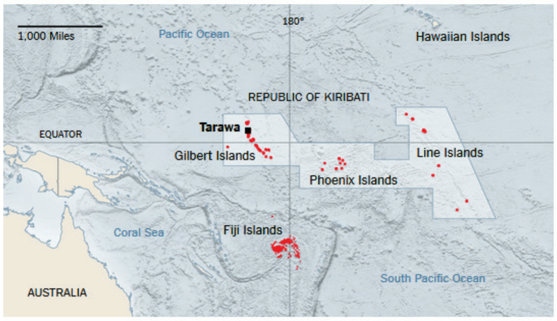


Book: https://www.amazon.com/Six-Degrees-Future-Hotter-Planet

Summary: http://www.sustainablewoodstock.co.uk/onetwo%20degrees%20summary.pdf

Kiribati: Population 118,000 as of 2018

- Undergoing intrusion of salt water into freshwater supplies
- Some farmers unable to grow food because of saltwater intrusion



High tide keeps getting higher on the islands of the Republic of Kiribati – 33 coral atolls in the Pacific Ocean that rest only a few feet above sea level. In Kiribati culture, Nareau the Creator scattered stones to the north and south to create this mosaic of coral and rock. But, today, the effects of climate change are closing in and there's no higher land to move to. Even as the atolls shrink, Kiribati's population grows. The country is experiencing *baki-aba*: **"land hunger"**. ***In 2014, Kiribati president, Anote Tong purchased 20 square km on Vanua Levu, a Fiji island making this the first international land purchase intended for climate refugees***.

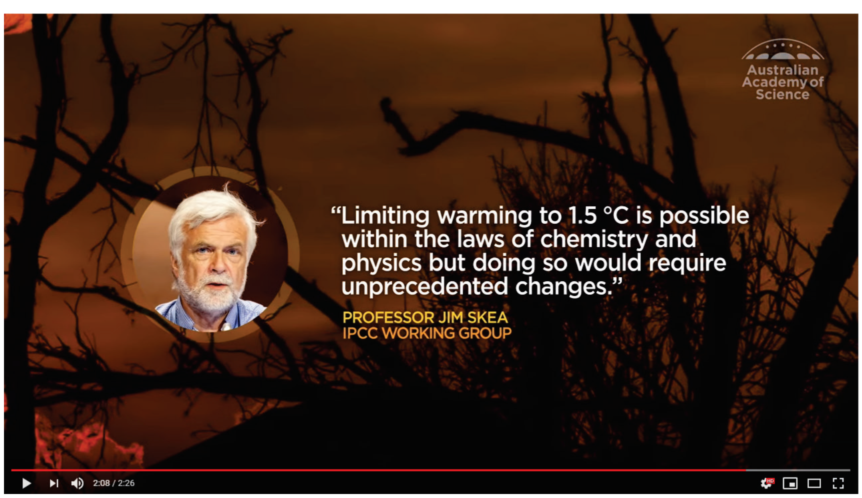
For Kiribati, adapting to climate change might mean relocating entirely.

Pacific islanders' identities are very much tied to their ancestral land, the physical islands on which they live. Migration may mean a national and cultural loss, especially when most traditions are preserved orally.

https://www.nytimes.com/2016/07/03/world/asia/climate-change-kiribati.html
https://thewire.in/culture/kiribati-migration-climate-change

Possible Impacts of Climate Change

- **1°C (already committed to this)**
  - Loss of glacial waters in Africa & Asia, with regional declines in food production
  - Tropical islands such as Tuvalu, Kiribati, Marshall Islands, and Maldives severely threatened
- **2°C (Paris Climate Agreement Upper Limit)**
  - Polar bear habitat under severe threat
  - Glacial melt rate doubles; disappearance of glaciers will create water shortages in places such as India, Peru, Ecuador, and Bolivia
  - Stability of Greenland ice sheet threatened



https://www.youtube.com/watch?time_continue=19&v=Yvkm9t7xRF4

Possible Impacts of Climate Change

- **3°C (occurs in ~2050 according to IPCC climate models using RCP 8.5)**
  - 80% of Arctic sea ice melted
  - Loss of Himalayan glaciers threaten water supply of Pakistan & China's hydro-electric industry
  - Indian monsoon, essential to 60% or world's population, more variable and possibly fails on a persistent basis
  - Many plant species become extinct if they can not adapt, an ecological catastrophe but also another source of atmospheric carbon
- **4°C (occurs in ~2080 according to IPCC climate models using RCP 8.5)**
  - Mass displacement of populations from places such as Bangladesh, Egypt, etc
  - Major flooding in Mumbai, Shanghai, Boston, New York, London, etc
  - Australia supports little to no agriculture
  - Stability of Antarctic ice sheet threatened
- **5°C (possibly end of this century)**
  - Stability of all of world's ice sheets threatened, leading to drastic change in coast line geography
  - Risk of methane release from hydrates, a strong positive feedback that is considered one of several tipping points
  - Possible massive decline in supportable, global population
- **6°C (next century)**
  - Sea level rise could be 20 meters (65 feet!)
  - Dystopian world

Six Degrees: Our Future on a Hotter Planet by Mark Lynas