Homework

HW6 (emissions): due today

HW7 (forcings): due Thursday

HW8 (feedbacks): opened today

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Extra Homework for Thursday 2/24

Find, print, read and understand the following article:

Xu, Y., V. Ramanathan and D. G. Victor (2018): Global warming will happen faster than we think, *Nature*, **564**, 31.

Be able to answer some quiz question on this article.

Devastating wildfires ravaged California last month.

Global warming will happen faster than we think

Three trends will combine to hasten it, warn **Yangyang Xu**, **Veerabhadran Ramanathan** and **David G. Victor**.

Prepare for the "new abnormal". That was what California Governor Jerry Brown told reporters last month, commenting on the deadly wildfires that have plagued the state this year. He's right. California's latest crisis builds on years of record-breaking droughts and heatwaves. The rest of the world, too, has had more than its fair share of extreme weather in 2018. The *Lancet* Countdown on health and climate change announced last week that 157 million more people were exposed to heatwave events in 2017, compared with 2000.

Such environmental disasters will only intensify. Governments, rightly, want to know what to do. Yet the climate-science community is struggling to offer useful answers.

In October, the Intergovernmental Panel on Climate Change (IPCC) released a report setting out why we must stop global warming at 1.5 °C above pre-industrial levels, and how to do so[1]. It is grim reading. If the planet warms by 2 °C — the widely touted temperature limit in the 2015 Paris climate agreement — twice as many people will face water scarcity than if warming is limited to 1.5 °C. That extra warming will also expose more than 1.5 billion people to deadly heat extremes, and hundreds of millions of individuals to vector-borne diseases such as malaria, among other harms.

But the latest IPCC special report underplays another alarming fact: global warming is accelerating. Three trends — rising emissions, declining air pollution and natural climate cycles — will combine over the next 20 years to make climate change faster and more furious than anticipated. In our view, there's a good chance that we could breach the 1.5 °C level by 2030, not by 2040 as projected

2018

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ATMOS 1020 Climate Change

8. Climate Feedbacks

Thomas Reichler, Dept. of Atmospheric Sciences, February 22, 2022

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Outline

- Climate feedbacks
  - things that change in response to a climate forcing
    - ice/snow
      - ice melts when it gets hotter: classic example of feedback
    - water vapor
    - clouds
- Why is there uncertainty in climate forecasts?

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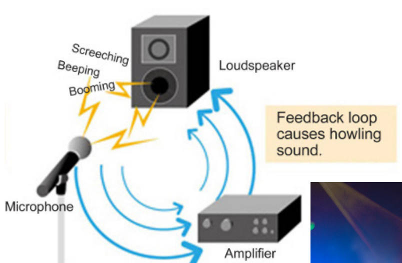
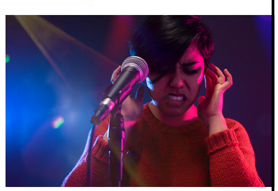
What is a Feedback?





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Forcings vs. Feedbacks

- Forcings
  - things that have a **direct** impact on temperatures
  - e.g., aerosols that block out the sun
- Feedbacks
  - things that have an **indirect** impact on temperatures
  - first they respond to an initial forcing because temperature changes
  - then in turn they affect temperature too!
  - depending on their sign, feedbacks can **amplify or diminish** the initial forcing

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Climate Feedbacks

- Things that change when climate gets warmer or colder and then create additional temperature change
- Feedbacks are of critical importance in determining temperature response to forcings
  - **positive feedbacks** are things that **amplify** the response to an initial forcing
  - **negative feedbacks** are things that **reduce** the response to an initial forcing
- What are the main climate feedbacks? And are they positive or negative?
- We'll discuss
  1. water vapor feedback
  2. ice-albedo feedback
  3. cloud feedbacks
  4. lapse rate feedback

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Water Vapor Feedback

- This is the most important feedback
- It is **positive**
- Why?
- Remember, **water vapor is the #1 greenhouse gas**!
- Because **warmer air can "hold" more moisture**

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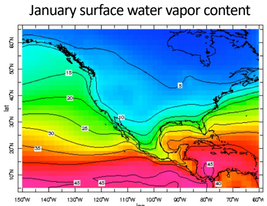
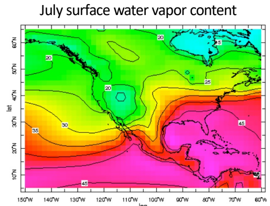
Water Vapor Content

- Winters are much drier than summers
- Simply because cold temperatures means small water vapor content

January surface water vapor content



July surface water vapor content



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Water Vapor Feedback

- Basic idea:
  - a warmer climate means more water vapor
    - if temperatures increase by 3°C there will be 20% more humidity
  - water vapor is a strong greenhouse gas
  - greenhouse effect will increase
  - even more warming
- Forcing → warming → more water vapor → stronger greenhouse effect → even more warming

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Water Vapor Feedback

- Observations show evidence for a **strong positive feedback**, as expected from theory
  - observed water vapor increases/decreases right along with natural swings in global temperatures (e.g., from ENSO)

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Ice Albedo Feedback

Can you think of a feedback involving ice/snow?

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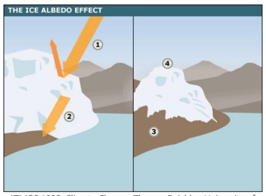
Ice Albedo Feedback

- Forcing → warming → sea ice melts → dark open ocean visible → more solar energy absorbed → more warming
- Similar feedback is present for snow, revealing darker land surfaces below (snow albedo feedback)
- This feedback is most effective when temperatures are at the freezing point



1. Light colored ice reflects back the Sun's energy efficiently
2. Exposed land is darker and absorbs more energy
3. As the ice melts from global warming, more land is exposed. This absorbs more heat
4. Melting more ice

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Cloud Feedbacks

- Like greenhouse gases, the water droplets and ice crystals of clouds very efficiently **trap longwave radiation**
- Clouds might change due to global warming
  - amount, type, structure, position of clouds
  - this may change the climate effect of clouds, which is a feedback
- But this feedbacks is quite uncertain
- Partially because clouds have **two** important, competing **climate effects**
  - albedo effect: cools
  - greenhouse effect: warms
- **High** thin clouds **warm** b/c greenhouse effect
- **Low** thick clouds **cool** b/c albedo effect

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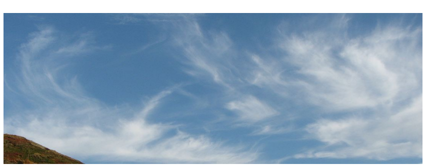
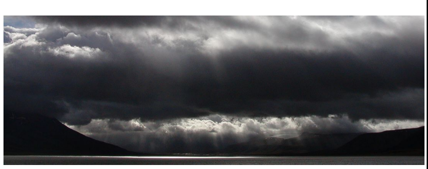
High vs. Low Clouds

- High clouds (cirrus)



- Low clouds (strato-cumulus)



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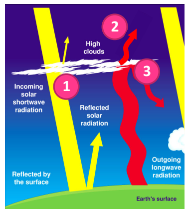
Climate Effects From High Clouds

High clouds have a **warming** effect:

1) high clouds are usually **thin** → reflect little incoming shortwave radiation; not much albedo effect
2) high altitude → **cold** → little upward emission of longwave radiation
3) **greenhouse effect** by trapping longwave radiation from below; more energy is absorbed than emitted → **warming**; some longwave radiation is also sent to the surface



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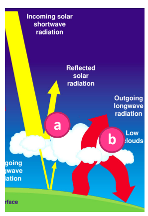
Climate Effects From Low Clouds

Low clouds have a **cooling** effect:

a) Low clouds are usually **thick** → reflect much incoming shortwave radiation → **cooling**
b) low altitude → **warm** → large up- and downward emission of longwave radiation → net **no greenhouse effect**



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Cloud Feedbacks

- It is unclear how clouds change in a warming world
  - more low clouds could lead to less warming
  - however, roughly equally likely, less low clouds could lead to significantly more warming …
- Thus, the **sign and magnitude** of the cloud feedback is **uncertain**
- This represents one of the **biggest uncertainties** in predicting future climate

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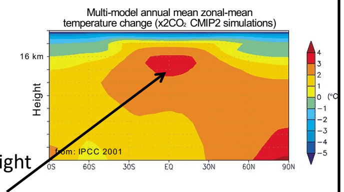
Lapse Rate Feedback

- One of the few feedbacks known to be **negative**
  - most other feedbacks are positive
- Lapse rate: rate at which temperatures cool with height
- **Upper troposphere warms faster** than lower atmosphere in climate models
- Upper troposphere is where longwave radiation to space comes from → **more cooling**



- Forcing → pronounced upper atmosphere warming → more radiation out to space → reduced warming

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Climate Sensitivity

= how much temperature change for a given forcing

- Depending on the nature of climate, a forcing $\boldsymbol{F}$ can lead to a small or large temperature change
- Mathematically:

$$\boldsymbol{\Delta T = \lambda \cdot F}$$

Δ = common symbol indicating the change in a quantity

ΔT = change in temperature (in degrees C)

F = forcing, AKA: radiative forcing (in W/m^2)

λ = **climate sensitivity**
the larger, the more warming for a given forcing

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Feedbacks and Climate Sensitivity

- Lots of **positive feedbacks** means **large** $\boldsymbol{\lambda}$
  - a strong amplification of the initial forcing, and thus a **very sensitive** climate
- Lots of **negative feedbacks** means **small** $\boldsymbol{\lambda}$

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Feedbacks and Climate Sensitivity

- Climate models predict that expected warming is approximately **double** that expected with no feedbacks
- Warming response to doubling CO_2 (we'll likely get to this around 2050) with no feedbacks: ~1.5°C
- $\Delta T = \lambda F \rightarrow \lambda = \Delta T / F$
  - radiative forcing from doubling CO_2: F = 4 Wm^{-2}
  - $\lambda_{without\ feedbacks}$ = 1.5 / 4 ~ 0.4
- Climate models predict ~3°C average response to warming with all feedbacks acting
  - $\lambda_{with\ feedbacks}$ = 3 / 4 ~ 0.8
  - climate sensitivity doubles due to feedbacks
- There's some uncertainty in the feedbacks though

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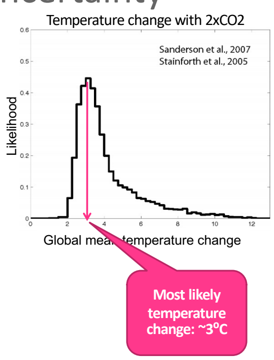
Feedback Uncertainty

- Since most feedbacks are positive and additive, high climate sensitivity is hard to rule out
- Graphic from 6,000 simulations randomly changing model parameters
- Very high temperature changes (e.g., 8°C) are less likely, but not impossible
- But small temperature changes (e.g., 1°C) are essentially impossible



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Summary

- Feedbacks
  - water vapor feedback is positive
  - ice-albedo feedback is positive
  - cloud feedback is highly uncertain
    - remember: forcing strength from the aerosol effect is another key uncertainty
  - lapse rate feedback is negative
- High sensitivity climates are hard to rule out

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- A model demonstrating the positive and negative feedbacks to initial changes to the climate system - produced by Andrew de Freitas for his "atmospheres" exhibition at Window Contemporary Art space, July 2008

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