Climate in the Future
AOSC 200
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Class Web Site: http://www.atmos.umd.edu/~tcanty/aosc200

Topics for today:

Evidence of a changing climate
Possible issues associated with a changing climate

Lecture 28
Dec 5 2019

Increase in temperature is correlated with increase in GHGs (and population)

http://www.parisbeaconofhope.org/index.htm
Land use change

Converting forests to land for agriculture may decrease radiative forcing (cooling). Albedo increases as snow on the ground is more reflective than snow on trees.


Aerosol: Direct Climate Effect

Aerosols are often brighter than the surface and reflect incoming solar radiation. This leads to cooling.
Aerosol: Direct Climate Effect

Some aerosols are darker and lead to regional warming. May explain retreat of Himalayan glaciers.


Aerosol: Direct Climate Effect

Dark aerosols on snow will decrease albedo and lead to increased absorption of solar energy and snow melt.

http://earthobservatory.nasa.gov/Features/Aerosols/page3.php
Aerosol: Indirect Climate Effect

Aerosols = cloud condensation nuclei

Clean air: clouds made of fewer, larger drops. Cloud is darker

Dirty air: clouds made of many smaller drops. Cloud is brighter

Influences on Climate

To try and predict future climate, we need to understand past climate

Understanding past climate allows us to separate natural changes in climate from human-made (anthropogenic)

Need to understand how changing climate can lead to further changes (feedback mechanisms)
Climate Feedback

A climate feedback mechanism is a climate response to an initial change

*Positive Feedback*: amplifies the initial change

*Negative Feedback*: diminishes the initial change

Feedback mechanisms are one of the big “unknowns” in climate research

Understanding climate feedbacks vital to predicting climate trends.

Ice-Albedo Feedback

A rise in temperature, caused by increasing greenhouse gases like CO$_2$, will cause a further increase in temperature

How will this affect ice?
### Ice-Albedo Feedback

**Initial Action:** Humans Release CO₂

**Initial Response:** $T_{\text{SURFACE}}$ and $T_{\text{OCEAN}}$ Rise

**Secondary Response:** Ice Melts

**Consequence:** Albedo Falls

**Response to Consequence:** $T_{\text{SURFACE}}$ Increases

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2. Albedos of selected surfaces on Earth:

<table>
<thead>
<tr>
<th>Surface</th>
<th>Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>snow</td>
<td>0.7 ± 0.2</td>
</tr>
<tr>
<td>sand</td>
<td>0.25 ± 0.05</td>
</tr>
<tr>
<td>grasslands</td>
<td>0.23 ± 0.03</td>
</tr>
<tr>
<td>bare soil</td>
<td>0.2 ± 0.05</td>
</tr>
<tr>
<td>forest</td>
<td>0.15 ± 0.1</td>
</tr>
</tbody>
</table>
| water (highly dependent on surface roughness and incident angle of sunlight) | 0.2 ± 0.6


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### Water Vapor Feedback

A rise in temperature caused by increasing greenhouse gases, like CO₂, will cause an increase in temperature.

How will this affect H₂O vapor?

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Saturation vapor pressure

Relative Humidity (%)

0 10 20 30 40 50 60 70 80 90 100

0 -16 -12 -8 -4 0 4 8 12 16 20 24 28

Vapor Pressure (mb)

Temperature (°C)
**Water Vapor Feedback**

Initial Action: Humans Release CO₂

Initial Response: $T_{\text{SURFACE}}$ rises

Secondary Response: Surface water evaporates

Consequence: Increased water vapor

Response to Consequence: \( \Rightarrow T_{\text{SURFACE}} \) Increases

**CO₂ Feedback: Plants**

Initial Action: Humans Release CO₂

Initial Response: $T_{\text{SURFACE}}$ rises

Secondary Response: Increased plant growth due to more CO₂

Consequence: CO₂ decreases

Response to Consequence: \( \Rightarrow T_{\text{SURFACE}} \) decreases

This is a negative feedback

Cloud Feedback

Increased temperatures can increase the amount of water vapor which, in turn, can lead to an increase in clouds

How will clouds affect temperatures?

This one’s tricky?

Clouds can either lead to more warming or more cooling

Cloud feedback is one of the largest uncertainties in climate science
Climate Change

What is Climate Change?

“Any systematic change in the long-term statistics of climate elements (such as temperature, pressure, or winds) sustained over several decades or longer.”

http://glossary.ametsoc.org/wiki/Climate_change

We’ve focused on temperature.

Are there other indications of a changing climate?
Evidence that climate is changing?

Numerous data sets indicate long term changes in the Earth system.

Increase in Energy in Oceans since 1970

All data normalized to 0 in 1993
0 to 700 m depth

Gouretski & Reseghetti, 2010
Giese & Ray, 2011
Ishii & Kimoto, 2009

Balmaseda et al., 2013
Levitus et al., 2012
Church et al., 2011
Atlantic Tropical Storms

Since the 1950’s, the amount of energy (power dissipation) in tropical storms has been closely correlated with Atlantic Ocean temperature.

http://www.nature.com/nclimate/journal/v2/n7/full/nclimate1452.html?WT.ec_id=NCLIMATE-201207

Arctic Sea Ice Loss

(http://www.nsidc.org/arcticseaicenews/)
Arctic Sea Ice Loss

Average Monthly Arctic Sea Ice Extent
October 1979 - 2019

Sea ice steadily decreasing

Greenland is melting...

Total Annual Melt Area

https://nsidc.org/arcticseaicenews/

https://nsidc.org/greenland-today/
Greenland is melting...faster

The great Greenland meltdown

By Eli Kintisch | Feb. 23, 2017, 8:00 AM

From a helicopter clattering over Greenland’s interior on a bright July day, the ice sheet below tells a tale of disintegration. Long, roughly parallel cracks score the surface, formed by water and pressure; impossibly blue lakes of meltwater fill depressions; and veiny networks of azure streams meander west, flowing to the edge of the ice sheet and eventually out to sea.


Glacial Retreat
Pedersen Muir and Riggs Glaciers

2004

1941

Pedersen Muir and Riggs Glaciers

50°00'0"W

0  2  4  8  12  16  20 km

1941
Shrinking glaciers are indicated in red
Blue represents the glaciers that are increasing

This figure shows the number of glaciers that are growing in blue and the number of glaciers that are shrinking in red.

If temperatures are warming, how can some glaciers be growing? Warmer air carries more moisture. As long as temperatures are cold enough, this can fall as snow and cause some glaciers to grow.

Movement of the Sub-tropical Jet

From 1979–2010, the subtropical jet moved poleward by:

- 3.7° in the Northern Hemisphere
- 6.5° in the Southern Hemisphere

The tropics are expanding.

Storms that follow the path of the jet stream will move poleward as well.

Hudson, ACP, 2012
Warmer temperatures promote the spread of warm climate diseases.

- **Dengue Fever** (Maurens and Fauci, *JAMA*, 2008)
  - fever, severe muscle and joint pain, may last week or more
  - Affect millions each year
  - Carried by mosquito, currently at Texas/Mexico border

- **Chikungunya Fever**
  - Symptoms similar to dengue fever, pain persists for weeks-months
  - Higher rates of death than dengue fever
  - Carried by mosquito, first cases in Italy, 2007 came from Africa

- **Zika Virus**
  - fever, rash, joint pain, or conjunctivitis (red eyes)
  - Usually mild with symptoms lasting for several days to a week
  - Remains in the blood of an infected person for about a week
  - Infection during pregnancy can cause microcephaly and other severe brain defects

Cold temperatures kill off the mosquito species that carry these diseases.

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**Poleward shift in the Tropics can impact human health**

- Limiting global-mean temperature increase to 1.5–2 °C could reduce the incidence and spatial spread of dengue fever in Latin America

_Felipe J. Colón-González, Ian Harris, Timothy J. Osborn, Christine Steiner São Bernardo, Carlos A. Peres, Paul R. Hunter, and Iain R. Lake_

*PNAS* May 29, 2018. 201718945; published ahead of print May 29, 2018. [https://doi.org/10.1073/pnas.1718945115](https://doi.org/10.1073/pnas.1718945115)

Edited by B. L. Turner, Arizona State University, Tempe, AZ, and approved April 27, 2018 (received for review October 30, 2017)
Have temperatures in other parts of the atmosphere exhibited changes?

The Sun provides the energy that warms the planet.

The rise in surface temperature must be caused by more heat at the surface.

Some people say that increasing solar output is causing the rise in surface temperature.

If this is the case then the entire atmosphere should be warming.

Is this the case?

Are extreme weather events getting more frequent?

Weather-related loss events in the U.S. 1980 - 2014

Number of events

Weather related events have increased

- Meteorological events (tropical storm, extratropical storm, convective storm, local storm)
- Hydrological events (flood, mass movement)
- Climatological events (extreme temperature, drought, forest fire)
In the United States, the number of extreme precipitation events has increased

![Observed U.S. Trend in Heavy Precipitation](http://nca2014.globalchange.gov/highlights/report-findings/extreme-weather#intro-section)

Heavy rainfall events in Europe are increasing

![Heavy rainfall events have increased by 20% over Europe since 1960](https://www.climate-lab-book.ac.uk/author/ehawkins/)
Globally, severe weather has increased

Some regions of the world have experienced a greater increase in severe weather events

What drives food production?

Food security: the supply of food and people’s access to it.

Food security is driven by climate and non-climate factors and all must be accounted for.

Too much rain or not enough will affect crop yields

Crop yields have been increasing due to better farming practices but nature can play a negative role at times.

http://www3.epa.gov/climatechange/impacts/agriculture.html#impactscrops

Less frost means a longer growing season but …

The number of frost free days has been increasing

http://www.globalchange.gov/browse/indicators/indicator-frost-free-season
...warmer temperatures can harm crop yields

http://www.globalchange.gov/browse/multimedia/crop-yields-decline-under-higher-temperatures

As ocean waters warm, species move northward to stay in waters that are more comfortable for them.

This means that species more accustomed to warmer waters will move into the area.

http://www.globalchange.gov/browse/multimedia/fisheries-shifting-north
Future Predictions

Model prediction (red) without human activity

Natural Variations
Future Predictions

Fig 11.25, IPCC 2013
Future Predictions: Corrected

In some areas, human activity plays a larger role than in other areas

Hurricane prediction is very difficult. It is expected that ocean waters will warm. It is also expected that wind shear will increase.

In Today’s World, 90% of major hurricanes are category 3 or 4.

Computer climate models that simulate a world where CO₂ is 220% greater than today and these results indicate over 90% of hurricanes will be category 4 or 5 but there will be fewer hurricanes overall.
How can melting ice sheets affect sea level?

http://www.coastalreview.org/2013/06/rising-seas-come-with-rising-co2/

The predictions are that dry areas will get drier and wet areas will get wetter

CHANGE IN PRECIPITATION BY END OF 21st CENTURY
inches of liquid water per year

as projected by NOAA/GFDL CM2.1

https://www.gfdl.noaa.gov/will-the-wet-get-wetter-and-the-dry-drier/#movies
The predictions are that dry areas will get drier and wet areas will get wetter.

https://www.gfdl.noaa.gov/will-the-wet-get-wetter-and-the-dry-drier/#movies

15 years of satellite observations (GRACE) indicate this is happening now.

Rodell et al., Nature 2018

https://www.nature.com/articles/s41586-018-0123-1#Fig1
Analysis:

- Climate has warmed and most likely will continue to
- Recent warming due to human activity
- Warmer temperatures will affect weather
- Prediction is more extreme events; will cost more $$$, risk more lives
- Yes, it can still snow (all you need is below 32°F)

- *But*...climate models seem to be warming too quickly
- If correct, this gives us more time to fix the problem