Climate Change in Mountainous Regions

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Learning Objectives

- After this class you should:
  - Have a basic understanding of recent global and regional climate trends and their drivers
  - Recognize the significance of climate change for mountainous regions
  - Be able to distinguish between climate variability and change and how they affect and complicate the interpretation of long-term trends and weather events
  - Have a basic understanding of how future climate change will affect snow over the western US and Utah

Discussion

What aspects of our understanding of climate change do we know with medium or high confidence?
In what areas do we still have large uncertainties?

Recent Global Climate Trends

Recent Temperature Trends

Global Land and Ocean Temperature Anomalies, January–December

“Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.”
– IPCC (2013)

A Longer View

Anomalies relative to 1881–1980 mean

"The mean NH temperature of the last 30 or 50 years very likely exceeded any previous 30- or 50-year mean during the past 800 years...Confidence is lower in this finding prior to 1200, because the evidence is less reliable and there are fewer independent lines of evidence."
– IPCC (2013)
**An Even Longer View**

GISP2 Ice Core Temperature and Accumulation Data

**Arctic Sea Ice**


**Arctic vs. Antarctica**

*Source: [www.grid.unep.ch/glaciers/pdfs/glaciers.pdf](http://www.grid.unep.ch/glaciers/pdfs/glaciers.pdf), USGS*

**Land Ice (Antarctica/Greenland)**

365 Gigatones = 1 mm sea level rise

*Source: [nsidc.org](http://nsidc.org)*

**Greenland Mass Balance**

"The total 2000–2008 mass loss is equally split between surface processes (runoff and precipitation) and ice dynamics. Without the moderating effects of increased snowfall and refreezing, post-1996 Greenland ice sheet mass losses would have been 100% higher."

*Source: van den Broeke (2009, Science)*

**Glaciers**


**South Cascade Glacier, WA**
Glaciers


Sea Level Rise

Rise since 1870 = 195 mm (7.5 inches)
Current rate = 3.3 mm/yr = 1.3 in/decade

Attribution of Recent Climate Change

Contributors (1993–2010)*
- Ocean Thermal Expansion = 1.1 mm/yr
- Glacial Mass Loss = 76 mm/yr
- Greenland Ice Sheet = .33 mm/yr
- Antarctic Ice Sheet = .27 mm/yr
- Land Water Storage = .38 mm/yr

*Middle of estimate range noted

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Greenhouse Gas Concentrations

- CO2 more than 35% higher than pre-industrial
  - Half of increase since mid 1970s
  - Very likely exceeds highest natural concentrations over at least the last several hundred thousand years
- Increases in other greenhouse gases too

Source: Forster et al. (2007), https://www.esrl.noaa.gov/gmd/ccgg/trends/
Known Climate Forcings

Climate Model Sensitivity

Climate Fingerprinting

Recent Estimates

Key Remaining Uncertainties

- Aerosol-radiation and aerosol-cloud-radiation interactions
- Future climate forcings
  - Trajectory of anthropogenic forcings like GHG concentrations, aerosols, dust, etc.
- Sensitivity of climate to those forcings (still a wide range of possible outcomes)
- Regional climate and impacts
- Shifts in weather and climate extremes
  - Water is often the agent that delivers climate change impacts
Climate Change in Mountainous Regions

Discussion

What makes mountains important for the study of climate change and its impacts?
What are some of the possible consequences of climate change in mountainous regions?

Significance of Mountains

- Mountains are unique areas for detecting climate change and assessing climate-related impacts
  - Vegetation, snow, ice, and hydrology vary rapidly with elevation and over short distances
  - Mountains have high biodiversity with large ecosystem gradients (ecotones)
  - Mountains are often climate and ecosystem islands compared to the surrounding plains

Source: Beniston (2003)

Significance of Mountains

- Mountains cover about 25% of continental surfaces
  - Mountains, Hills, and Plateaus cover 46%
- 26% of world’s population lives in mountains or their foothills
- 40% of world’s population lives in watersheds originating in mountainous regions
- Mountain-based resources indirectly provide sustenance for over half the world’s population


Significance of Mountains

- Mountains are important sources of water, energy, minerals, forest and agricultural products and areas of recreation. They are storehouses of biological diversity, home to endangered species and an essential part of the global ecosystem.

- UN (1992)

Source: Beniston (2003)

Specific Areas of Concern

- Water, snow, and ice
  - Amount, timing, and seasonality of precipitation and snowfall
  - Depth and duration of the seasonal snowpack
  - Changes in “permanent” snow and ice
  - Amount, timing and seasonality of runoff
  - Extreme events and hazards such as floods, landslides, avalanches, etc.

- Vegetation, forests, and biodiversity
  - Vulnerability to climate-change thresholds
  - Impacts to natural and human-managed ecosystems and agriculture

- Health
  - Shifts in vector-borne diseases (e.g., Malaria)

- Tourism
  - Skiing, hiking, etc.

Source: Beniston (2003)
How do you think climate change will affect the aforementioned areas of concern in the western US?

How will changes vary regionally and with aspect and elevation?

US Temperature Trends


Note: Based largely on low-elevation stations & doesn’t capture the small-scale variability

Utah

Western Snowpack Trends

SWE/P
Fraction of winter precipitation retained in the snowpack on April 1st

Source: Pierce et al. (2008)

Western Streamflow Trends

“Immediate forcings for the spatially coherent parts of the year-to-year fluctuations and longer-term trends of streamflow timing have been higher winter and spring temperatures. Although these temperature changes are partly controlled by the Pacific decadal oscillation (PDO), a separate and significant part of the variance is associated with a springtime-warming trend that spans the PDO phases.”

– Stewart et al. (2005)
Weather/Climate Variability vs. Change

"Weather is mood, climate is personality"
– Marshall Shepherd

Source: https://news.uga.edu

A Tale of Two Seasons

WY2015: West

““This is the New Normal”
- CA Gov. Jerry Brown

Source: NRCS

WY2017: West

“This drought emergency is over, but the next drought could be around the corner. Conservation must remain a way of life.”
- CA Gov. Jerry Brown

Source: NRCS

Discussion

What is the new normal?

The Future
Future Projections

Wintertime Temperature Change

Source: IAMC RCP Database, Steenburgh (2014, adapted from Knutti and Sedlacek 2012)

Wintertime Precipitation Change

Source: Steenburgh (2014, adapted from Diffenbaugh and Giorgi 2012), Court Strong

Discussion

What do you think this means for the future of snow and skiing in the west?

Snowfall Vulnerability

Vulnerability greatest @ lower elevations
Upper elevations less vulnerable (but not immune)

Downscaled Projections

Source: Steenburgh (2014), adapted from Jones (2010)
**Summary**

- Warming of the climate system is unequivocal
- Multiple lines of evidence support the conclusion that most (perhaps all) of the recent warming is human caused
- Future warming depends on future emissions and other human influences and the sensitivity of the climate system
- Impacts on mountainous regions vary regionally and with elevations and extend to people in non-mountainous regions
- The competitive advantages of high elevation resorts will likely increase in time due to the uneven loss of snow and snowpack with altitude

**References**