BASICS OF CLIMATE CHANGE

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THE CLIMATE UMBRELLA

Climate Variability
Climate "Normals"
Climate Extremes
Climate Change
WEATHER VS. CLIMATE
WEATHER VS. CLIMATE

Weather – *state of the atmosphere* with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness; **short-term**

Climate – *statistical collection of weather conditions* at a place over a period of years; **long-term**

“Climate is what you expect. Weather is what you get.”
CLIMATE VARIABILITY VS. CHANGE

Random variability

Periodic variability

Trend with periodic variability

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REALLY LONG-TERM CLIMATE CHANGE

Shape of Earth’s orbit changes over ~100,000 yrs

Wobble (precession) of Earth on its axis changes over ~22,000 yrs

Tilt of Earth’s axis changes over ~41,000 yrs
NATURAL CAUSES OF CLIMATE CHANGE

External factors: (1) luminosity of sun (amount of incoming radiation), (2) Earth’s orbital mechanics (tilt, precession, orbit shape) & (3) comet, meteorite, or asteroid impact event

Internal factors: (1) plate tectonics (location of land, weathering), (2) ocean temperatures & currents, & (3) natural changes in atmospheric composition
TEMPERATURE VS. LUMINOSITY OF SUN

Sun’s energy output has been decreasing over past few decades

Energy from the sun cycles with sunspot activity (~11 yrs)
**KEY POINTS**

No single weather event (e.g., early autumn blizzard, December heat wave, landfalling hurricane) is a sign of climate change, but a higher frequency of certain events or trend toward higher intensity events may be.

There are natural drivers to climate change, but they typically occur over 1000s to 100,000s of years. Faster changes, like those that occur with volcanic eruptions, usually last only a few years and are part of climate variability, not climate change.
“Since NCA3 [Third National Climate Assessment], stronger evidence has emerged for continuing, rapid, human-caused warming of the global atmosphere and ocean. This report concludes that ‘it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century. For the warming over the last century, there is no convincing alternative explanation supported by the extent of the observational evidence.’” – Climate Science Special Report
4TH NATIONAL CLIMATE ASSESSMENT (2018)
WHY ARE IPCC REPORTS IMPORTANT?

IPCC = Intergovernmental Panel on Climate Change

Rigorous & transparent review process focusing on climate change, its impacts, and our ability to adapt and mitigate

Main assessment reports summarize almost 10,000 peer-reviewed scientific papers in both an easy-to-read format (for policymakers) & in a detailed manner (for researchers)

Policy relevant but not policy prescriptive
REASONS FOR CONCERN

Aggregate impacts & damages

Risks of large-scale discontinuities & disruptions

Uneven distribution of climate change impacts

Risks of extreme weather events

Risks to unique & threatened systems

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Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

Impacts and risks associated with the Reasons for Concern (RFCs)

- **RFC1**: Unique and threatened systems
- **RFC2**: Extreme weather events
- **RFC3**: Distribution of impacts
- **RFC4**: Global aggregate impacts
- **RFC5**: Large scale singular events

**Purple** indicates very high risks of severe impacts/risks and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.

**Red** indicates severe and widespread impacts/risks.

**Yellow** indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.

**White** indicates that no impacts are detectable and attributable to climate change.

**Confidence level for transition:**
- L = Low
- M = Medium
- H = High
- VH = Very high

**Source:** IPCC Special Report on Global Warming of 1.5°C (October 2018)
The Intergovernmental Panel on Climate Change (IPCC) reports and the National Climate Assessment (NCA) are the two best sources for expert assessments of climate change worldwide and across the United States.

Available at:

http://www.ipcc.ch (IPCC)

http://www.globalchange.gov (NCA)
The Greenhouse Effect

Some solar radiation is reflected by the Earth and the atmosphere.

Some of the infrared radiation passes through the atmosphere. Some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth’s surface and the lower atmosphere.

Most radiation is absorbed by the Earth’s surface and warms it.

Infrared radiation is emitted by the Earth’s surface.
**Natural Greenhouse Effect**

More heat escapes into space

**Human Enhanced Greenhouse Effect**

Less heat escapes into space

- CO₂
- CH₄
- N₂O

Solar Radiation

Less re-emitted heat

Atmosphere

Solar Radiation

More re-emitted heat

Atmosphere
WE’VE KNOWN THIS FACT FOR 160 YEARS

“The atmosphere admits of the entrance of the solar heat, but checks its exit; and the result is a tendency to accumulate heat at the surface of the planet.” — John Tyndall, 1859

“Doubling of CO₂ would raise surface temperature by 5-6°C, or 9-11°F, above pre-industrial temperatures.” — Svante Arrhenius, 1896
KEY POINT

Greenhouse gases are necessary for Earth to be livable, but adding too much into the atmosphere will disrupt the long-term energy balance, increasing the thermal energy in the atmosphere.
Greenhouse gases selectively absorb infrared energy & convert it to heat energy to warm troposphere (surface to 12 miles)

Ozone selectively absorbs ultraviolet energy & converts it to heat energy to warm stratosphere (13 to 30 miles above surface)
ANTARCTIC OZONE HOLE (2018 & PAST)

Data from NASA's Aura satellite

Note: No data were acquired during the 1995 season

Data from NASA's Aura satellite
IMPACT OF MONTREAL PROTOCOL

Effective chlorine & Montreal Protocol

Source: CSIRO Marine and Atmosphere Research

NASA says ozone hole stabilizing but won't fully recover until 2070

December 12, 2013 | by Tony Barboza

The hole in the ozone layer is stabilizing but will take until about 2070 to fully recover, according to new research by NASA scientists.

The assessment comes more than two decades after the Montreal Protocol, the international treaty that banned chlorofluorocarbons and other compounds that deplete the ozone layer, which shields the planet from harmful ultraviolet rays.
KEY POINTS

The **ozone holes** at the North and South Poles are **NOT** related to climate change!!

Because of international cooperation, the **ozone layer is healing** and projected to **recover by 2070**
GLOBAL CARBON DIOXIDE BUDGET


CO₂ flux (Gt CO₂/yr)

-40 -30 -20 -10 0 10 20 30 40

1880 1900 1920 1940 1960 1980 2000 15

Fossil fuels and industry
Land-use change
Land sink
Atmosphere
Ocean sink

Global carbon dioxide budget (gigatones of carbon dioxide per year)
2006-2015

Fossil fuels & Industry
34.1 ± 1.7

Atmospheric growth
16.4 ± 6.4

Land-use change
3.5 ± 1.8

Land sink
11.5 ± 3.1

Ocean sink
9.7 ± 1.8

Geological reservoirs

Data: CDIAC/NOAA–ESRL/GCP
GREENHOUSE GASES INCREASING

Significant increases in carbon dioxide, methane, & nitrous oxide observed since the industrial revolution

Changes in Greenhouse Gases from Ice-Core and Modern Data

© 2012 Pearson Education, Inc.
Charles Keeling first measured CO\textsubscript{2} at the Mauna Loa Observatory, leading the scientific community to notice the human contribution to the greenhouse effect.
Largest contributor is CO$_2$ from fossil fuel use.
KEY POINT

Greenhouse gases have been increasing at an abnormally fast rate, primarily as a result of human activity (i.e., fossil fuel use, deforestation, agriculture, etc.). Our oceans and ecosystems cannot absorb CO$_2$ quickly enough to keep up. Except for water vapor, these greenhouse gases are long-lived and will remain in our atmosphere for decades.
TECHNIQUES TO OBSERVE THE CLIMATE
OBSERVATIONAL EVIDENCE FOR A WARMING CLIMATE

(a) Northern Hemisphere spring snow cover

(b) Arctic summer sea ice extent

(c) Change in global average upper ocean heat content

(d) Global average sea level change

IPCC AR5
Globally, the past three decades have been successively warmer, on average, than the prior decades. Multi-decadal warming is superimposed on decadal and interannual variability from natural climate patterns.
CLIMATE CHANGE IMPACTS ARE REGIONAL

For example, surface temperature changes are not uniform

Surface Temperature Change

Change in Temperature (°F)

Annual Temperature

Winter Temperature

Summer Temperature

NCA4, Vol 1

NCA4, Vol 1
REGIONAL CHANGES HAVE CAUSES
CLIMATE CHANGE IMPACTS ARE REGIONAL

Precipitation & sea-level rise changes are not uniform

Annual Precipitation

Winter Precipitation

Spring Precipitation

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RAPID DECLINE OF ARCTIC SEA ICE

Annual Arctic Sea Ice Minimum Area

Millions km²

MOUNTAIN GLACIAL RETREAT

Okpilak Glacier 1907

Okpilak Glacier 2004

National Snow and Ice Data Center
AS OCEANS ABSORB CO$_2$, THEY BECOME MORE ACIDIC

NCA 2014; modified from Feely et al. 2009
WARMING OCEANS BLEACH CORALS

Coral reefs endangered by bleaching in global event, researchers say

By Adam Voynovich, CNN
Updated 1:06 PM ET, Thu October 6, 2016

NOAA CRW 5-km Night-Only HotSpot Year-to-date Maximum 08 Oct 2016

NOAA
WARMER WATER + MELTING GLACIERS = SEA-LEVEL RISE

In AK, land is rising because of glacial retreat.

In LA, land is sinking faster because of compaction & increased erosion.
MANY OTHER CLIMATE CHANGE-RELATED CHANGES
KEY POINTS

Historical observations demonstrate rapid (decadal) climate changes in surface temperature, sea ice, mountain glaciers, sea level, and other parts of our climate system.

These changes are all consistent with a warming planet resulting from increased greenhouse gases.

The changes are not consistent with long-term natural variations in our climate.
GLOBAL CLIMATE MODEL (GCM)

Models based on physical laws and statistical representations of observations

Provides reasonable description of physical changes, not detailed predictions
REAL VS. COMPUTED CLIMATE

Multi-Satellite Image Animation

Global Climate Model Simulation
Using computer models from 20 climate modeling groups worldwide, global climate models that include both natural forcing and forcing from human activities best relate to the actual observations.
Several scenarios are used to depict how greenhouse gas (GHG) emissions may change in the future.

**RCP 8.5** – GHG emissions continue to increase (“business as usual”)

**RCP 6** – GHG emissions stabilized around 2100 using various technologies & reduction strategies

**RCP 4.5** – similar to RCP 6 but with a lower stabilization target

**RCP 2.6** – a “peak-and-decline” scenario where GHG emissions are reduced significantly over time
PROJECTED CHANGES IN AVERAGE ANNUAL TEMPERATURE

Lower Scenario (RCP4.5)  

Higher Scenario (RCP8.5)

Projections for the late 21st century relative to 1976–2005

Change in Temperature (°F)

2  4  6  8  10  12  14  16  18

NCA4, Vol 1

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PROJECTED CHANGES IN SEASONAL PRECIPITATION

Projections for the late 21st century relative to 1976–2005

NCA4, Vol 1
KEY POINTS

General trends over time and large-scale regional patterns can be projected using numerical climate models.

These climate models have satisfactorily depicted changes in the past.

Model results depicting future changes in temperatures are more certain than results depicting future changes in precipitation.
“DOWNSCALING” THE GCM OUTPUT

**What is downscaling?** – a method to use “low resolution” global climate model output (e.g., 100-500 km grid) & obtain “high resolution” (e.g., 10-50 km grid) climate projections
WHY DOWNSCALE?

Climate scientists downscale GCM data to help answer stakeholders’ questions about how the climate will change in their location (i.e., impact assessments) & better represent local climates.

- Mountain climates
- Coastal climates
- Urban-rural climates
ENSEMBLE APPROACH TO DOWNSCALING

Each gray line represents multiple scenarios

Each dotted line represents multiple GCMs & scenarios
ENSEMBLE APPROACH TO DOWNSCALING

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Questions?