Today I Learned About Clouds

Description:

How do clouds form? How are clouds affected by (and affect) climate change? Students create a cloud in the classroom, and then investigate climate models and real-time cloud observation data.

Skills & Objectives

SWBAT

- Explain that clouds need a nucleus around which to form.
- Understand that climate models can predict future climate patterns, but that factors such as carbon emissions make specific predictions uncertain.
- Describe observed and predicted changes in precipitation in the continental US.

Skills

- Map reading
- Observation

Students Should Already Know That

- Weather and climate systems are large and complex.

Standards Alignment:
HS-ESS2-2 Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.
HS-ESS3-5 Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth's systems.

Disciplinary Core Ideas:
ESS2.A Earth Materials and Systems
ESS2.D Weather and Climate
ESS3.C Human Impacts on Earth Systems
ESS3.D Global Climate Change

Today I Learned About Clouds

How To Use These Activities:

Pages with the circular "TILclimate Guide for Educators" logo and dark band across the top are intended for educators. Simpler pages without the dark band across the top are meant for students.

Each of the included activities is designed to be used as a standalone, in sequence, or integrated within other curriculum needs. A detailed table of contents, on the next page, explains what students will do in each activity.

A Note About Printing

All student pages are designed to be printable in grayscale. Larger versions of the maps on pages 3 and 4 are included, which could be projected or printed to share in color.

The worksheets do not leave space for students to answer questions. Students may answer these questions in whatever form is the norm for your classroom – a notebook, online form, or something else. This allows you, the teacher, to define what you consider a complete answer.

Representative Concentration Pathways (RCPs)

On page 3, students are introduced to the *Representative Concentration Pathways* RCP8.5, RCP4.5, and RCP2.6. These terms refer to modeled *radiative forcing* (heat) in watts per square meter. For more on radiative forcing, read the MIT Climate Explainer at https://climate.mit.edu/explainers/radiative-forcing.

Podcasts in the Classroom: Throughout these Guides for Educators, we invite students to think about how they would share their learning with family and friends. One way to do this is to encourage your students to create their own podcasts - they're shareable, creative, and have multiple options for embedded assessment. We would love to hear any podcasts or see any other projects you or your students create! Email us at tilclimate@mit.edu, Tweet us @tilclimate, or tag us on Facebook @climateMIT.

Today I Learned About Clouds

Detailed Table of Contents

Materials for Cloud in a Bottle Demonstration

- A clear container with a flat top, such as a large lab flask, empty jar, or vase.
- Warm (not boiling) water
- Ice
- A metal pie plate or similar flat-bottomed metal surface
- A stirrer
- A match

https://www.jpl.nasa.gov/edu/learn/project/make-a-cloud-in-a-bottle/

Today I Learned About Clouds

Particulate Matter, Clouds, and Climate Models

This Educator Guide includes a hands-on activity, reading materials, and two map-based investigations. Educators may pick and choose among the pieces of the Guide, as suits their class needs.

Parts of this Guide may align with the following topics:

- Physical science: Cloud formation, atmospheric chemistry
- History/social science: Debates about geoengineering
- ELA/nonfiction: Understanding and communicating complex science topics

MIT Resources

We recommend the following as resources for your own better understanding of climate change or as depth for student investigations. Specific sections are listed below:

- Climate Science, Risk & Solutions, an interactive introduction to the basics of climate change. https://climateprimer.mit.edu/
    - Chapter 02 The greenhouse effect and us
    - Chapter 06 Predicting climate
    - Chapter 09 How long can we wait to act?
    - Chapter 10 What can we do?

- MIT Climate Portal Explainers are one-page articles describing a variety of climate topics. https://climate.mit.edu/explainers
    - Climate Models
    - Greenhouse Gases
    - Wildfires
    - Radiative Forcing
    - The National Climate Assessment

Today I Learned About Clouds

Wrap-Up Discussion Questions

- What are some ways that human actions increase the amount of particulate matter (PM) in the atmosphere?
- What are some factors that affect cloud formation, size, and precipitation? How are these factors affected by a warming planet and human actions?
- Did any of the observed or predicted precipitation patterns surprise you? What have you observed?
- Why is it important for climate modelers to include carbon emissions predictions?
- Why is it important to model different emissions scenarios?
- In the episode, Professor Cziczo says, “Uncertainty is not a call for inaction.” What do you think he meant by that?

Climate Solutions

Climate solutions can be thought of as falling into four categories outlined below. Across all categories, solutions at the community, state or federal level are generally more impactful than individual actions. For example, policies that increase the nuclear, solar and wind mix in the electric grid are generally more effective at reducing climate pollution than asking homeowners to install solar panels. For more on talking about climate change in the classroom, see “How to Use This Guide”.

- **Energy Shift**
  How do decision-makers make the switch from carbon-producing energy to carbon-neutral and carbon-negative energy?
- **Energy Efficiency**
  What products and technologies exist to increase energy efficiency, especially in heating and cooling buildings?
- **Adaptation**
  How can cities and towns adapt to the impacts of climate change?
- **Talk About It**
  Talking about climate change with friends and family can feel overwhelming. What is one thing you have learned that you could share to start a conversation?

What solutions are the most exciting in your classes? We would love to hear from you or your students! Images, video, or audio of student projects or questions are always welcome. Email us at tilclimate@mit.edu, Tweet us @tilclimate, or tag us on Facebook @climateMIT.

Today I Learned About Clouds

"[Clouds] don't just sort of form out of water vapor. They actually condense [around] a little particle. And so, as we as humans put more and more particles into the atmosphere, we're making more and more sites on which clouds form."
Professor Dan Cziczo, MIT Center for Global Change Science
TILclimate podcast: Today I Learned About Clouds

Make a Cloud in a Bottle

Follow the instructions from NASA's Jet Propulsion Laboratory to create a cloud in your classroom. You will need:

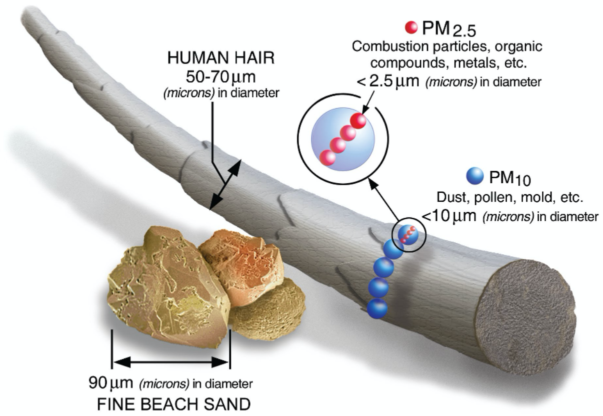
- A clear container with a flat top
- Warm water
- Ice
- A metal pie plate or similar
- A stirrer
- A match

https://www.jpl.nasa.gov/edu/learn/project/make-a-cloud-in-a-bottle/

Particulate Matter

In the demonstration, the smoke from the match gave the water vapor a nucleus around which to form. Clouds form around *particulate matter* (PM.) PM can be large enough to see with the naked eye (dust, dirt, soot, or smoke) or so tiny it can only be detected with an electron microscope.

The most dangerous articulate matter for human health is classified as PM_{10} and $PM_{2.5}$. These are particles small enough to be inhaled into the lungs. The numbers indicate the size of the particles in micrometers (microns or µm.)



Visit https://www.airnow.gov/ to check air quality in your area and to learn how to protect yourself and loved ones from harmful air pollutants.

Depending on the source, size, and location of PM, along with many other factors, clouds may form around these particles. Modeling exactly which kinds of particles have which kinds of effects on cloud formation is a delicate and complex science. Understanding these relationships helps scientists model the impacts of air pollution on clouds, precipitation, storms, and drought.

Cloud and jar images from Pixabay. Particulate matter diagram from EPA.gov

ENVIRONMENTAL SOLUTIONS INITIATIVE

Today I Learned About Clouds

"The truth of the matter is that we … have (for over a hundred years now) understood the impact the greenhouses gases are going to have around the planet…. [We] are highly certain that the temperature of the planet has risen and will continue to rise. The amount that is rises is very secondary to the fact that it is rising. Uncertainty is not a call for inaction."

Professor Dan Cziczo, MIT Center for Global Change Science

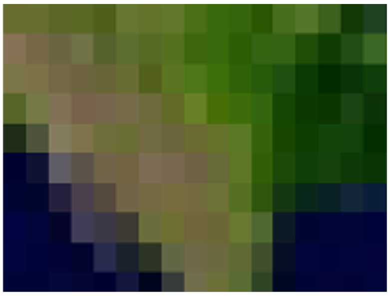
TILclimate podcast: Today I Learned About Clouds

Climate Models and Uncertainty

Climate scientists use computer models to predict what the climate of the future will look like. Predicting precipitation (rain, snow, and drought) changes is particularly difficult because smaller-scale weather patterns such as rainstorms are extremely complex. As Professor Cziczo explains in the episode, cloud modeling is challenging for many reasons.

The computer programs used for climate modeling can run to millions of lines of code. The supercomputers needed to run these huge programs can be the size of a tennis court[1]. (For comparison, the average smartphone app has fewer than 50,000 lines of code.)





When developing the code for a model, scientists must consider the level of detail. Higher levels of detail give more exact results but make the model more complicated. Complicated models take longer to run and use more computing power. The left image is high-resolution and shows a lot of detail. Since a model would have to run multiple calculations for each color dot, the lower-resolution image in the middle would take less computing power, and the right-hand image even less.

Some models work on large scales, such as the whole planet. These computer programs use less detail and model at the level of countries or regions. Since clouds are smaller than countries, they are not "seen" by these models. "Downscaled" models show changes at smaller scales (cities to states) which can help inform how to include phenomena like clouds, mountains, lakes, and valleys.

1 Climate Brief, How do climate models work? https://www.carbonbrief.org/qa-how-do-climate-models-work
Images from https://climate.mit.edu/explainers/climate-models

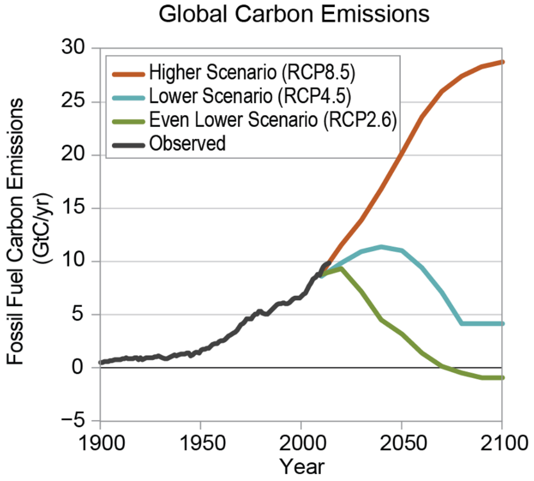
Today I Learned About Clouds

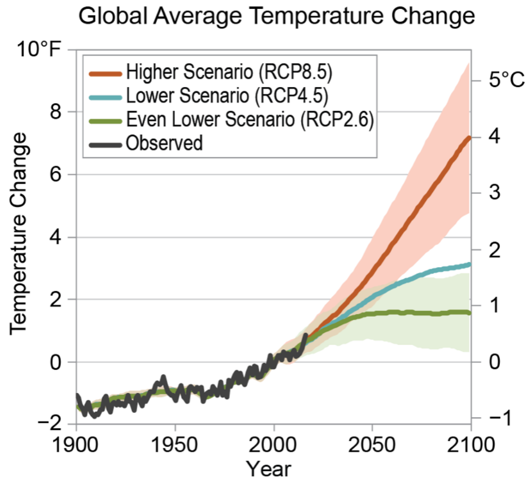
Representative Concentration Pathways

Climate models must also include possible changes in carbon dioxide (CO_2) emissions. As we burn fossil fuels like coal, oil, and natural gas and cut down forests, we release CO_2 into the atmosphere. In the atmosphere, CO_2 and other gases act like a blanket, trapping heat. This trapped heat is warming our Earth, ocean, and air and causing dramatic changes in weather and climate.

National and international scientific organizations use a series of *Representative Concentration Pathways* (RCPs) to model different possible futures. Each pathway is based on a different story about the future of heat-trapping gas emissions through 2100.

RCP8.5 is called the 'high emissions scenario' – a future in which CO_2 emissions continue to rise at high levels. This scenario does not reflect changes that are already happening in how we generate electricity or power vehicles, and it leaves out new technologies like carbon capture. In the short term (through 2050) RCP8.5 is useful because it models the effects of current and past CO_2 emissions.





https://nca2018.globalchange.gov/chapter/2/

RCP4.5 is a middle scenario in which CO_2 emissions peak around 2040 and then decline, leading to about 85% lower emissions by 2100. This is often considered the most likely scenario, as it has the potential to meet international agreements, such as the Paris Accord.

A more dramatic cut (RCP2.6) would have had CO_2 emissions peak in 2020 and reach zero by 2100.[1] This extreme low-emissions scenario depends heavily on technology, forests, and the ocean removing CO_2 from the atmosphere.

Climate models show us that a future with fewer emissions looks very different from a future with high emissions. There is no question that a higher emissions scenario includes more extreme weather, sea level rise, and other climate impacts than a lower emissions scenario. Climate modelers use multiple scenarios to see the range of possibilities. Decision-makers use multiple scenarios to plan for the future.

1 National Climate Assessment 2018, Chapter 1 https://nca2018.globalchange.gov/chapter/1/

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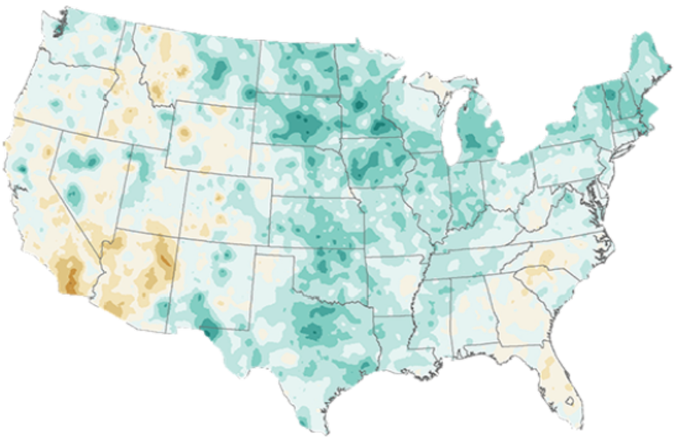
"One of those complicated factors that we're sort of trying to tease out right now is where are we going to see less rainfall? Where are we going to see more rainfall? Where are we going to see more snowfall? Where are we going to see less snowfall and so on."

Professor Dan Cziczo, MIT Center for Global Change Science

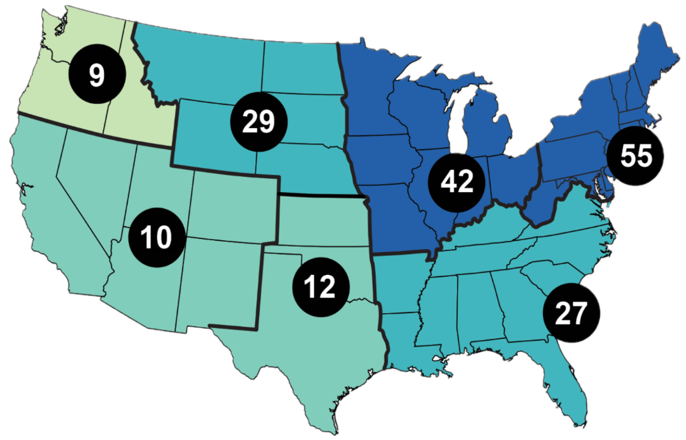
TILclimate podcast: Today I Learned About Clouds



Observed Change in
Total Annual Precipitation 1901-2018

-20 | -10 | 0 | +10 | +20

Percent Change



Observed Change in Total Annual Precipitation
Falling in the Heaviest 1% of Events, 1958-2016

0-9 | 10-19 | 20-29 | 30-39 | >40

Percent Change

Precipitation Observations

Some people think of climate change as something that will happen in the future, but human-caused climate change is already happening. Climate scientists observe and model current variations as well as predict future changes. In fact, modelers often use current observations to check that their models are accurate.

Across the continental US, some areas are experiencing as much as 20% less precipitation each year thanin the early 1900s, while others are receiving as much as 20% more. The patterns of how that precipitation falls are changing, as well.

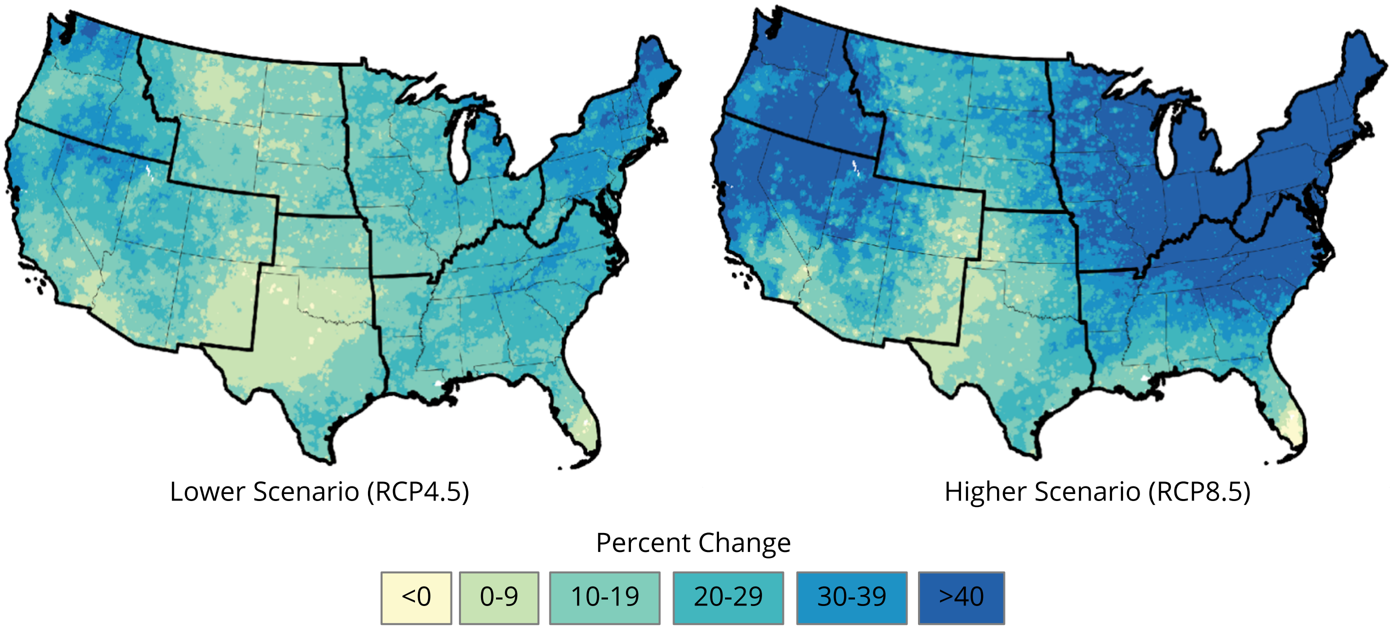
One pattern climate scientists have observed is that large storms (the top 1% of storms in each year) are tending to include more precipitation (rain, snow, etc.) This means that, whether the total amount of precipitation is going up or down, more of it comes all at once in big storms.

Look at the maps above from the National Climate Assessment. Across the continental US, every region is experiencing higher amounts of precipitation in big storms. In the Northwest, this is a relatively small increase of 9% since 1958. In the Northeast, large storms are dumping 55% more water!

All images from the National Climate Assessment, Chapter 2 https://nca2018.globalchange.gov/chapter/2/

Today I Learned About Clouds

Projected Change in Total Annual Precipitation
Falling in the Heaviest 1% of Events by Late 21st Century



Precipitation Predictions

By 2100, the heavy-storm pattern is expected to continue. However, how it continues is determined by which emissions scenario is included in the model: RCP4.5, where heat-trapping gas emissions peak in 2040; or RCP8.5, where they continue to rise.

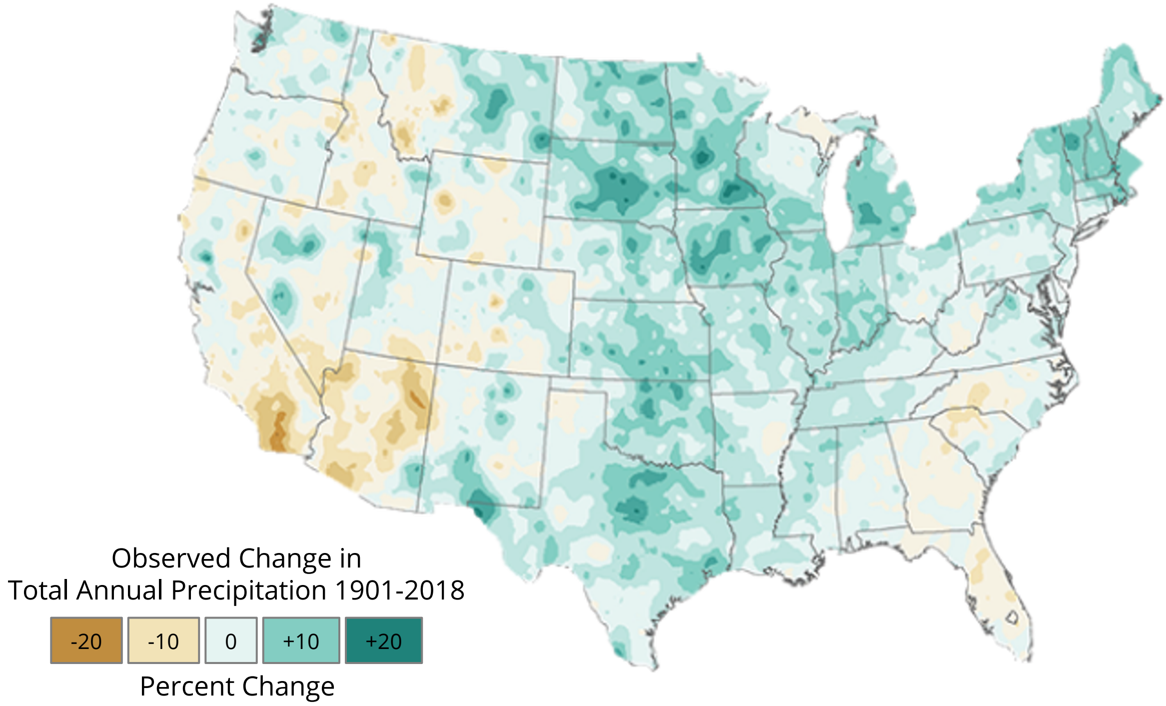
Questions

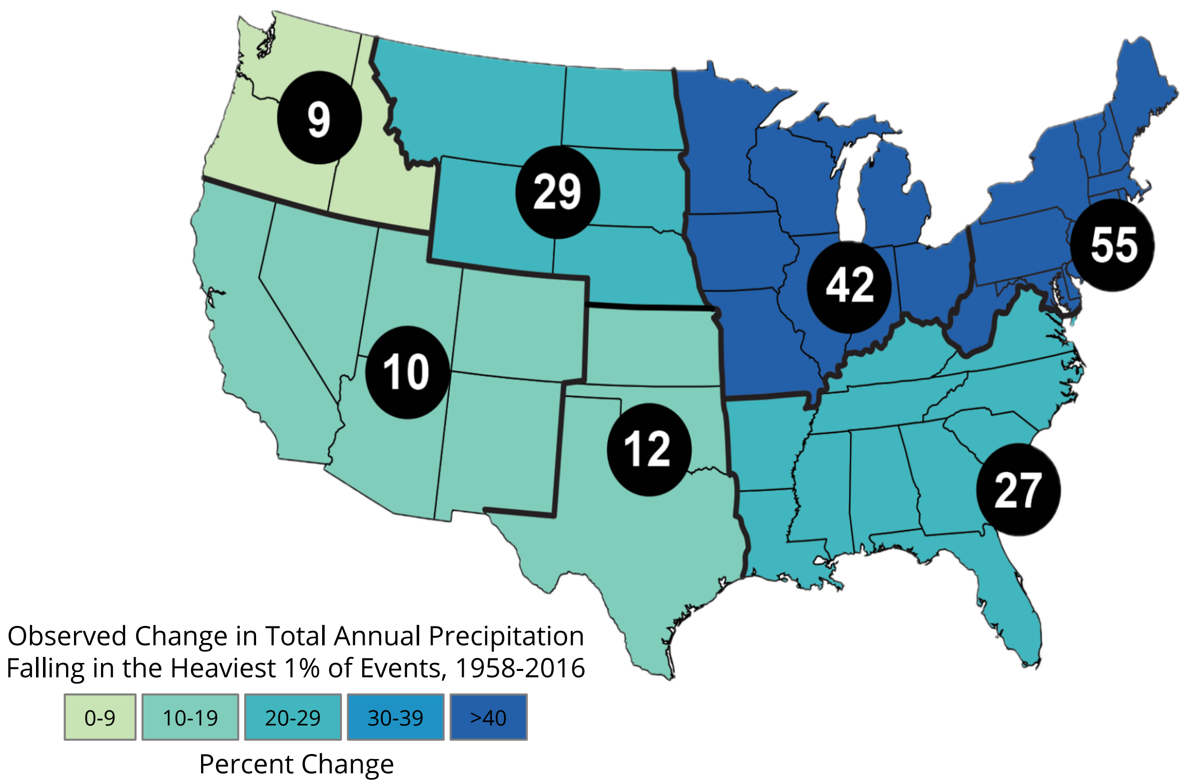
1. Look at the graphs on the previous page. How has overall precipitation and/or precipitation in major storms changed in your region? Have you observed this pattern yourself?
2. Predict how this pattern of heavier precipitation in large storms might affect flooding, farm irrigation, and drought.
3. What is the prediction for your region under the two emissions scenarios? Remember that these maps model precipitation in big storms, not overall amount of rain or snow.
4. Describe the similarities and differences between the two prediction maps.

Read more: https://nca2018.globalchange.gov/chapter/2#key-message-6

All images from the National Climate Assessment, Chapter 2 https://nca2018.globalchange.gov/chapter/2/

Today I Learned About Clouds

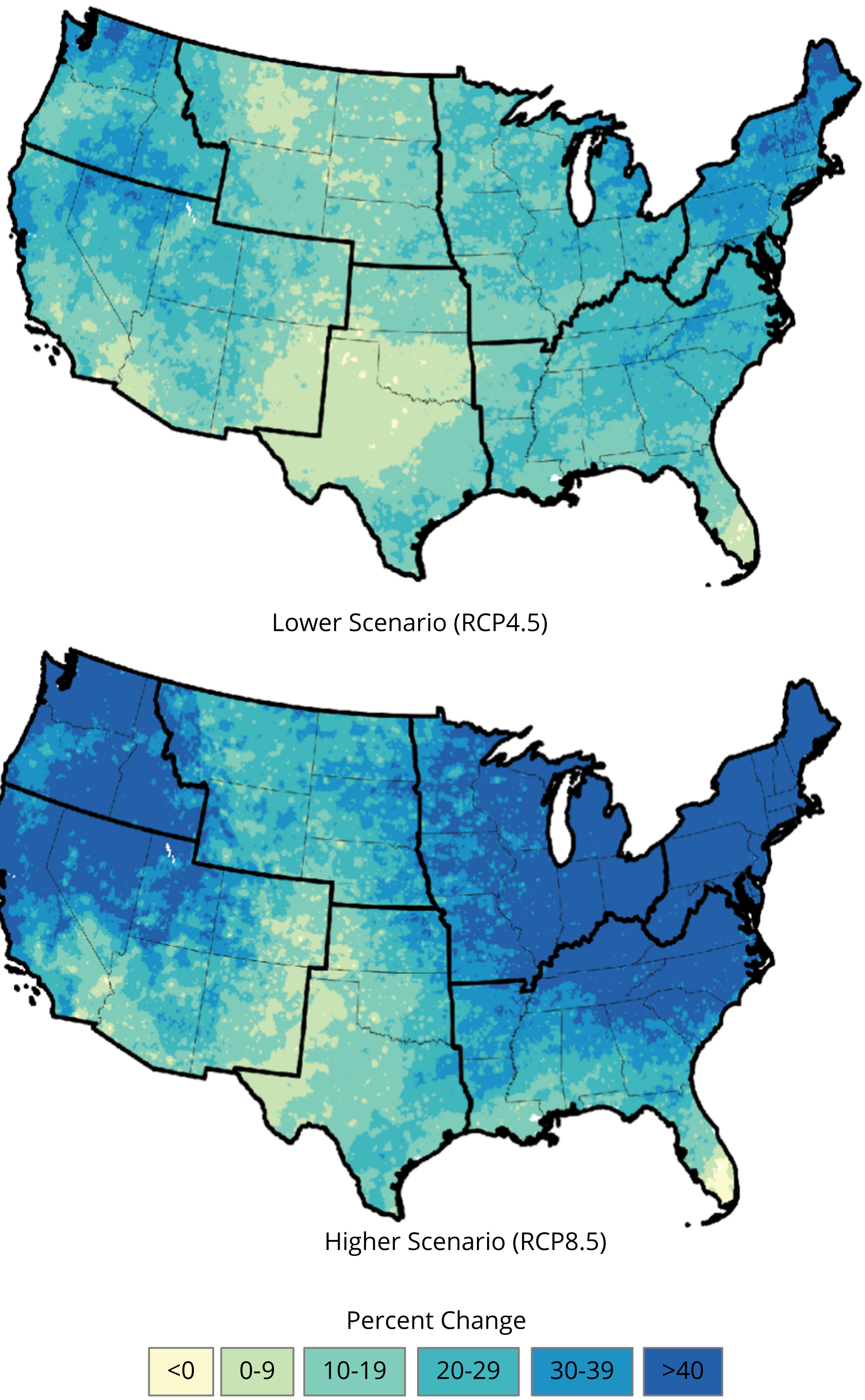




All images from the National Climate Assessment, Chapter 2 https://nca2018.globalchange.gov/chapter/2/

Today I Learned About Clouds

Projected Change in Total Annual Precipitation
Falling in the Heaviest 1% of Events by Late 21st Century



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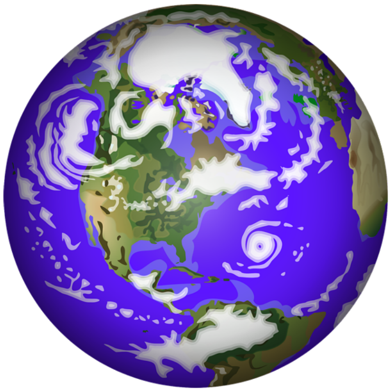
Today I Learned About Clouds



Questions

Clouds

1. What are some ways clouds can be impacted by particulate matter (PM)?
2. What are some other factors that affect cloud formation, size, and precipitation? How are these factors affected by a warming planet?

Read more: https://news.mit.edu/2013/cirrus-clouds-mineral-dust-0509

Climate Models

3. In your own words, explain the difference between the three Representative Carbon Pathways (RCP2.6, RCP4.5, and RCP8.5) in terms of carbon emissions. (Use the graph on page 2 to help.)
4. Why is it important for climate modelers to include carbon emissions predictions?
5. Why is it important to model different emissions scenarios?

Read more: https://climate.mit.edu/explainers/climate-models

What other questions do you have about clouds, particulate matter, precipitation, or climate models? How might you investigate some of these questions?

Image from Pixabay

Today I Learned About Clouds

"We do two types of studies. One is we make clouds and the other one is that we find clouds."
Professor Dan Cziczo, MIT Center for Global Change Science
TILclimate podcast: Today I Learned About Clouds

See Clouds Around the Globe

1. Visit https://earth.nullschool.net/ * (this website can work on any device, but was designed for use on a touchscreen such as a smartphone or tablet)
2. Click the word **Earth** in the bottom left-hand corner.
3. Select the following:
   - Control: Now
   - Mode: Air
   - Animate: Wind
   - Height: Sfc (Surface)
   - Overlay: TCW (Total Cloud Water)
   - Projection: O (Orthographic)

Observe
What patterns do you notice in clouds around the world?

Predict
What patterns would you expect at different times of year?

4. In the **Control** line, click the calendar icon and choose a recent date when your area experienced a storm.

Observe
What does a storm look like? Change **Overlay** settings to see how this storm is visible in wind, temperature, relative humidity, etc.

5. In the **Control** line, reset to Now. Change **Overlay** back to TCW to remember where the current clouds are, and then to 3HPA to see precipitation over the past three hours.

Analyze
Do all parts of a cloud system produce precipitation? (TCW shows you where the cloud was, and 3HPA shows where it rained or snowed.)

Extend
What other questions could you investigate using this tool?

*This model is intended for demonstration and educational purposes and is not meant to be a fully-accurate climate model. It was designed to be simple enough to run on a smartphone, and so must be less complex than a scientific model.

Today I Learned About Clouds

"The environment around us is always this complex mixture of natural particles and human-made particles... As humans, what we've actually done is we've unintentionally increased the amount of these natural particles in the world.

Professor Dan Cziczo, MIT Center for Global Change Science

TILclimate podcast: Today I Learned About Clouds

See Particulates Around the Globe

1. Visit https://earth.nullschool.net/
2. Click the word **Earth** in the bottom left-hand corner.
3. Select the following:
   - Control: Now
   - Mode: Particulates
   - Animate: Wind
   - Overlay: $PM_{2.5}$
   - Projection: O (Orthographic)

Observe

Where are the highest concentrations of particulates right now?

4. Change the **Overlay** to see different kinds of air particulates.

DUex: Sunlight blocked due to dust in the atmosphere.

PM_1, $PM_{2.5}$, PM_{10}: Concentration of particulate matter under 1, 2.5, or 10 microns in size.

SO_4ex: Sunlight blocked due to sulfate in the atmosphere.

Analyze

What do you think is causing these different particulate concentrations?

Investigate

Option 1: Choose one location with high particulate concentrations. Research what might be causing these observations.

Option 2: Choose one category of particulate. Research what the impacts of that particulate are in the atmosphere.

Extend

What other questions could you investigate using this tool?

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"We do two types of studies. One is we make clouds and the other one is that we find clouds."
Professor Dan Cziczo, MIT Center for Global Change Science
TILclimate podcast: Today I Learned About Clouds

Community Science: Help Find Clouds

Community science (also often called citizen science) projects invite everyday people to help collect or analyze data. While some kinds of data need specialized training, there are many projects that just need time – and lots of eyes and brains! By involving communities in science, scientists benefit from more eyes and brains on their projects, and communities benefit from involvement in the science.

Scientists at NASA need help better understanding the effects of clouds on Earth's climate. Satellite images can show clouds from above, but human observers are best at identifying the specific type and amount of cloud cover from below.

Get Started with NASA GLOBE Cloud Gaze

1. Visit https://www.zooniverse.org/projects/nasaglobe/nasa-globe-cloud-gaze (Optional: Create a free account on Zooniverse to participate in other projects and get notifications about projects you have helped.)
2. Read about the two projects, **Cloud Cover** and **What Do You See** and choose the project that most appeals to you.
3. Click the button for your chosen project.
4. Read/watch the brief tutorial.
5. Start helping!

Cloud Cover asks community scientists to look at photographs of the sky, and rate cloud cover on a scale from "few" to "overcast."

What Do You See asks community scientists to identify cloud types from a glossary of examples provided.