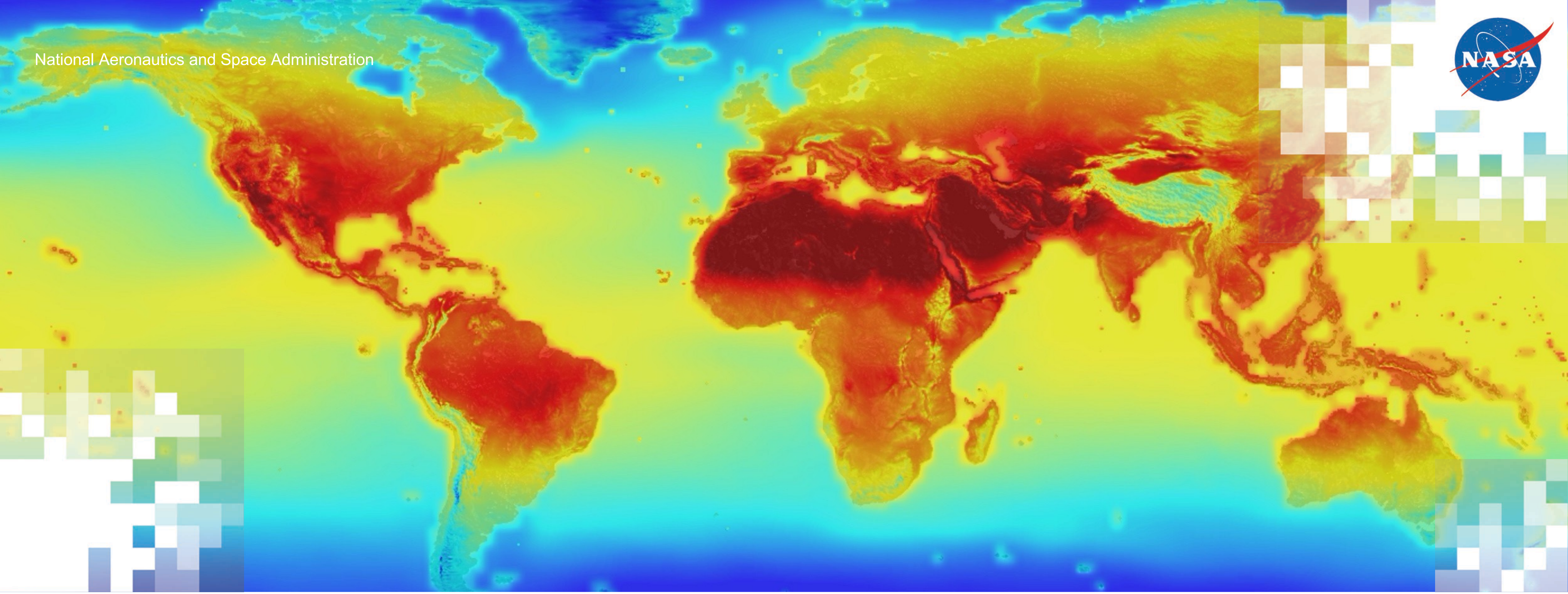


Climate Change Monitoring and Impacts Using Remote Sensing and Modeled Data

Sean McCartney & Amita Mehta

Sep 29, 2021

Training Objectives

After participating in the 2-part training, attendees will be able to:

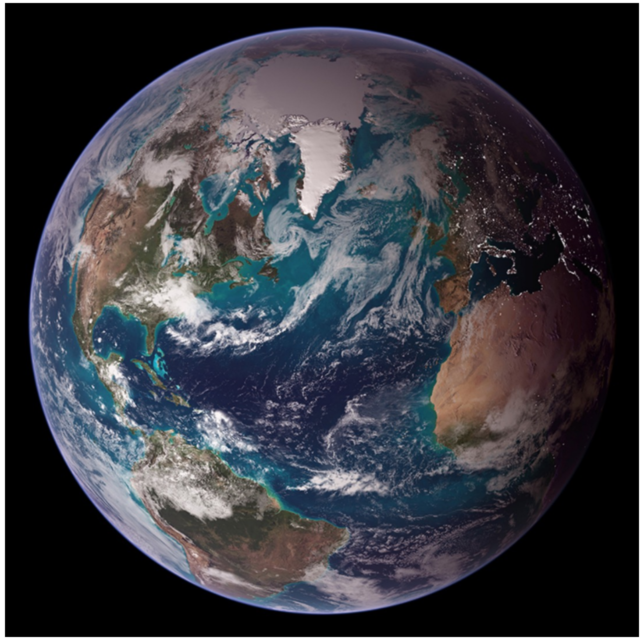
- Explain the difference between weather and climate
- Summarize the evidence and causes behind climate change
- Identify how Earth observations are used in climate change assessment
- Recognize the main components relevant to climate change decision making
- Summarize different types of climate information across time scales
- Discuss how models can be used for climate change adaptation planning

Prerequisites

- Fundamentals of Remote Sensing, Session 1
- https://appliedsciences.nasa.gov/join-mission/training/english/arset-fundamentals-remote-sensing

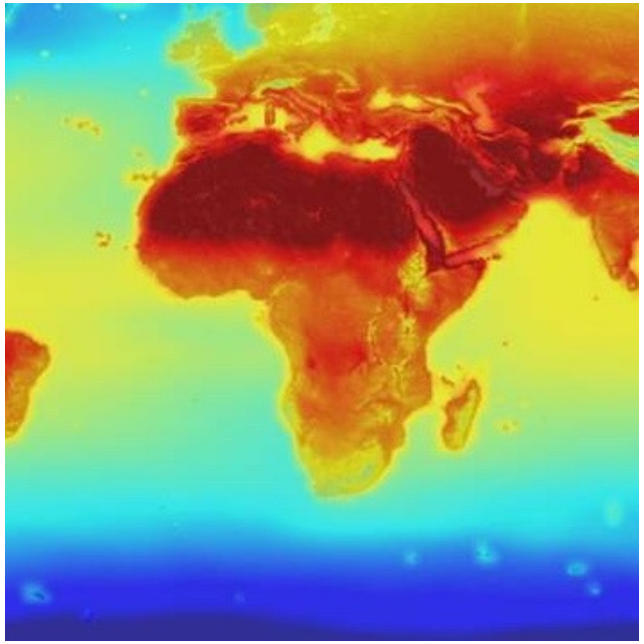
Training Outline

Part 1: Climate Change Monitoring & Impacts Using Remote Sensing and Modeled Data



September 29, 2021

Part 2: Climate Change Future Scenarios, Impact Forecasting, and Adaptation



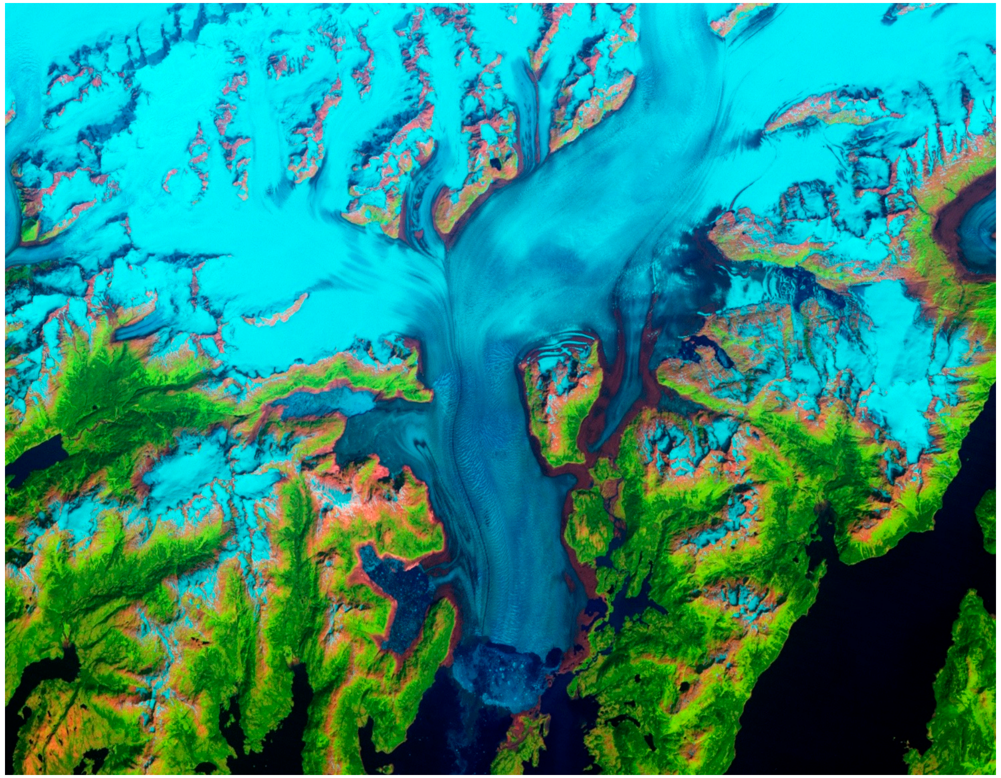
October 6, 2021

Homework and Certificate

- One homework assignment:
  - Answers must be submitted via Google Form, accessed from the ARSET website.
  - Homework will be made available on October 6, 2021.
  - Due date for homework: October 20, 2021.
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Outline for Part 1

- About ARSET
- Overview of climate change
- The role of Earth observations in climate change assessment
- Monitoring climate change impacts using NASA data
- Main components relevant to climate change decision making



The Columbia Glacier descending into an inlet in southeastern Alaska (USA). Credit: NASA

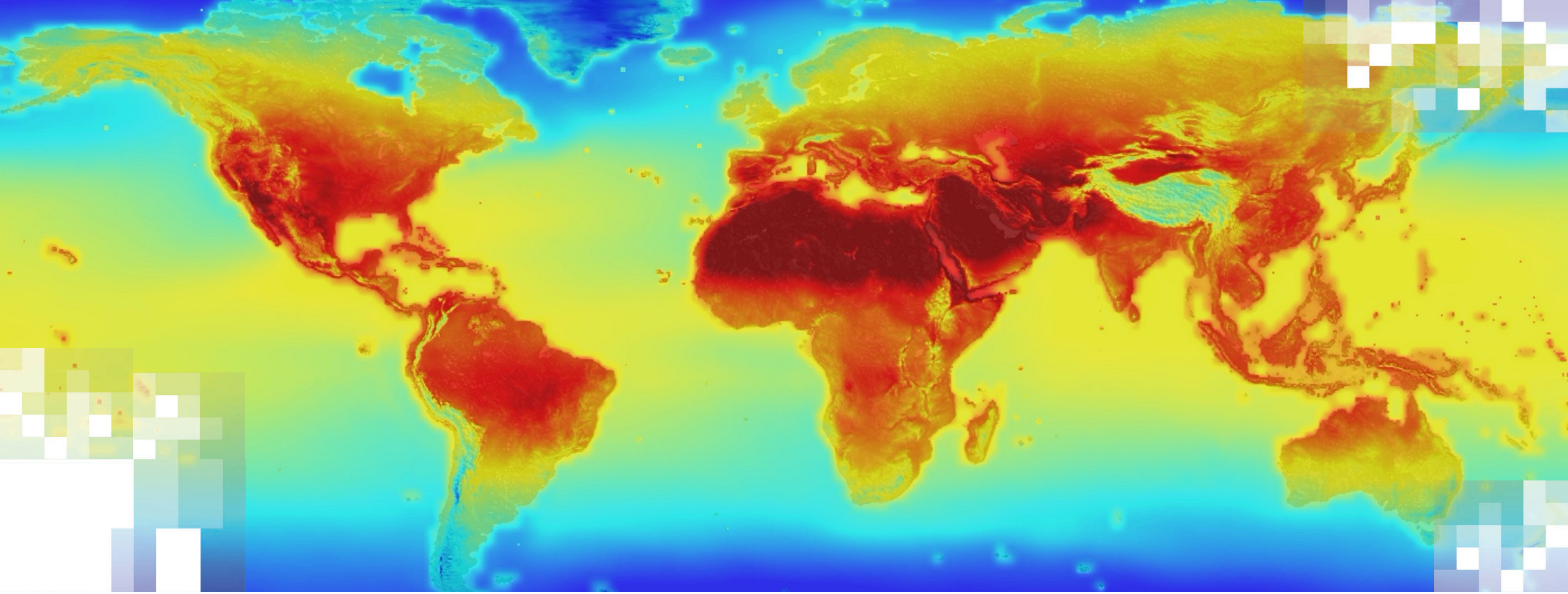
About ARSET

- *ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.*
- Our trainings are:
  - Online and *in-person
  - Open to anyone
  - Live, instructor-led or self-guided
  - Tailored to those with a range of experience in remote sensing, from **introductory** to **advanced**

*ARSET is not currently offering in-person trainings due to the COVID-19 pandemic.

- ARSET offers trainings for:
  - Disasters
  - Health & Air Quality
  - Land Management
  - Water Resources

For more information, visit appliedsciences.nasa.gov/arset



Overview of Climate Change

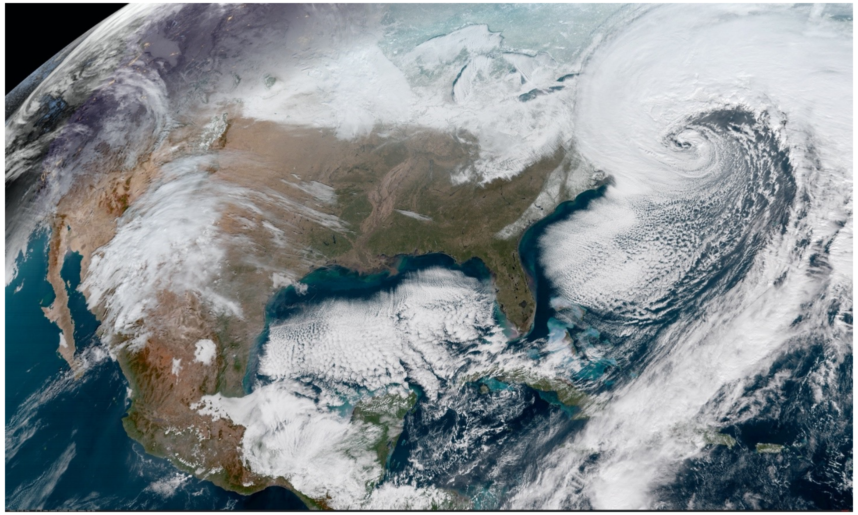
Overview: Weather, Global Warming, and Climate Change

- The terms "weather" and "climate" are sometimes confused, though they refer to events with broadly different spatial and temporal scales.
- Similarly, the terms “climate change” and “global warming” are often used interchangeably but have distinct meanings.

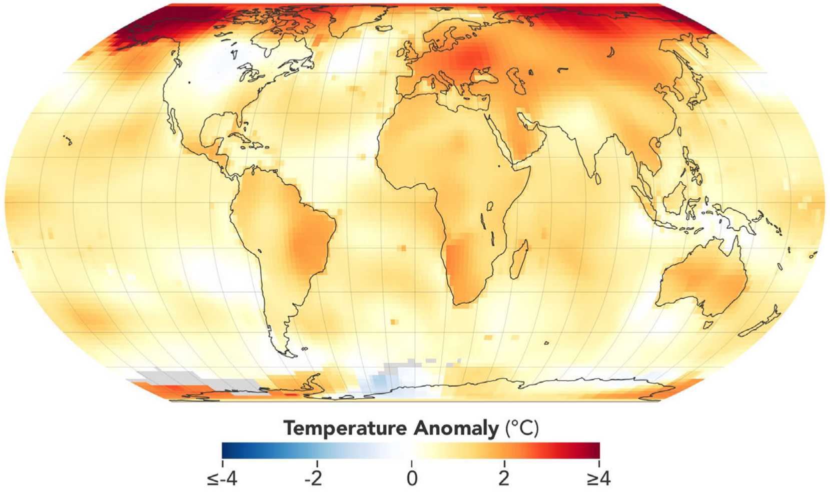
Credit: Pixabay

Overview: Weather, Global Warming, and Climate Change

- **Weather** refers to atmospheric conditions that occur locally over short periods of time—from minutes to hours, days to weeks. Familiar examples include rain, snow, clouds, winds, or thunderstorms.
- **Climate**, on the other hand, refers to the long-term regional or global average of temperature, humidity, and rainfall patterns over a period of time, often 30+ years.



Credit: NOAA



Credits: NASA/Josh Stevens

Overview: Weather, Global Warming, and Climate Change

- **Global warming** is the monotonic, long-term heating of Earth's climate system observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth's atmosphere.

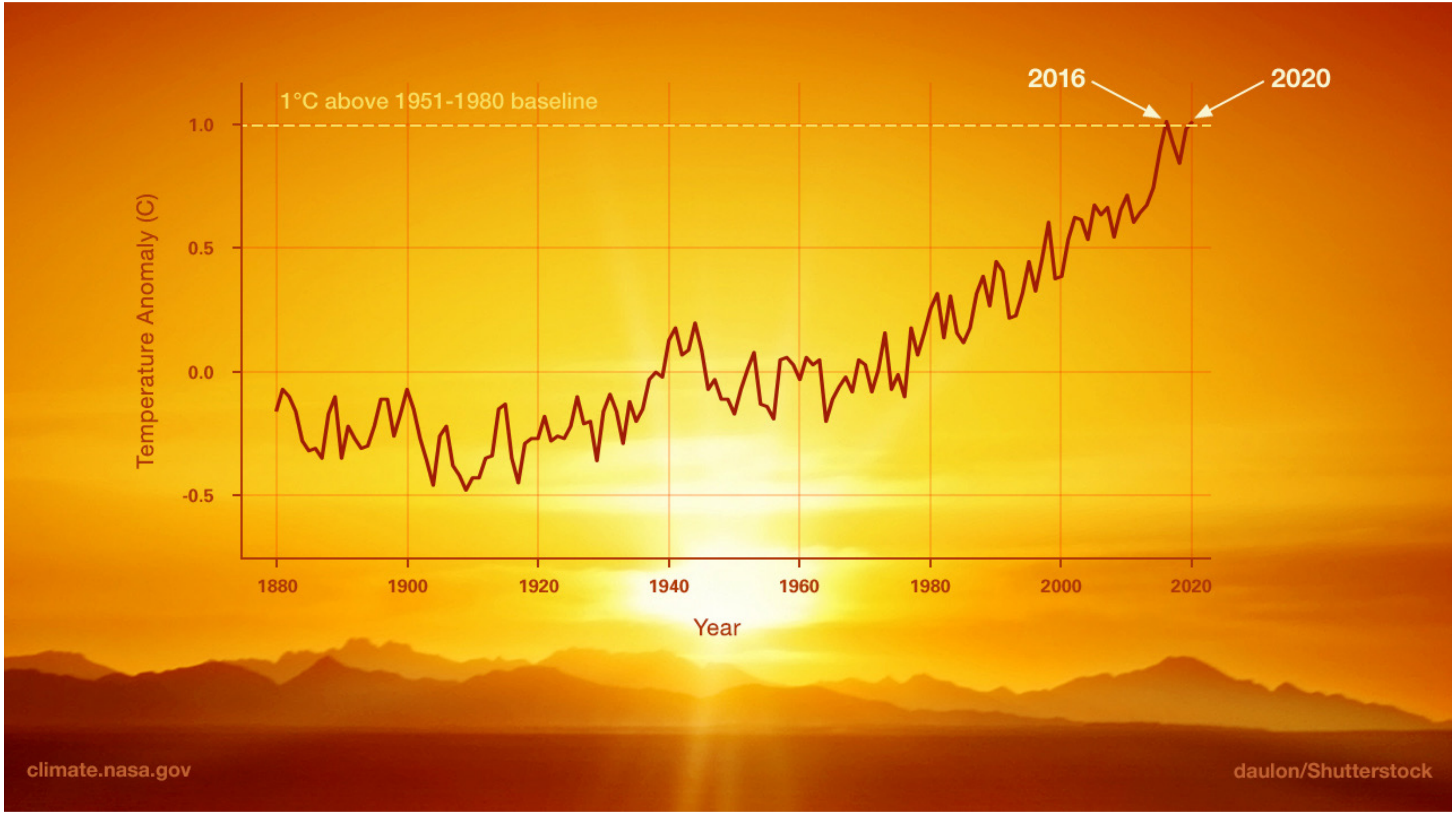
- **Climate change** is a long-term change (30+ years) in the **average** weather patterns that have come to define Earth's local, regional, and global climates. It encompasses global warming, but refers to the broader range of changes that are happening to our planet, including shrinking mountain glaciers; accelerating ice melt in Greenland, Antarctica, and the Arctic; rising sea levels; shifts in phenology; ocean acidification; coral bleaching; and extreme weather.

Overview: Climate Change

- **Natural processes** can contribute to climate change, including internal variability (e.g., cyclical ocean patterns like El Niño and La Niña) and external forcings (e.g., volcanic activity, changes in the Sun's energy output, variations in Earth's orbit).
- Changes observed in Earth's climate since the early 20th century are partly driven by **human activities**, particularly fossil fuel burning and deforestation, which increases heat-trapping greenhouse gas levels in Earth's atmosphere, raising Earth's average surface temperature.

Credit: Tony Webster

Overview: Climate Change

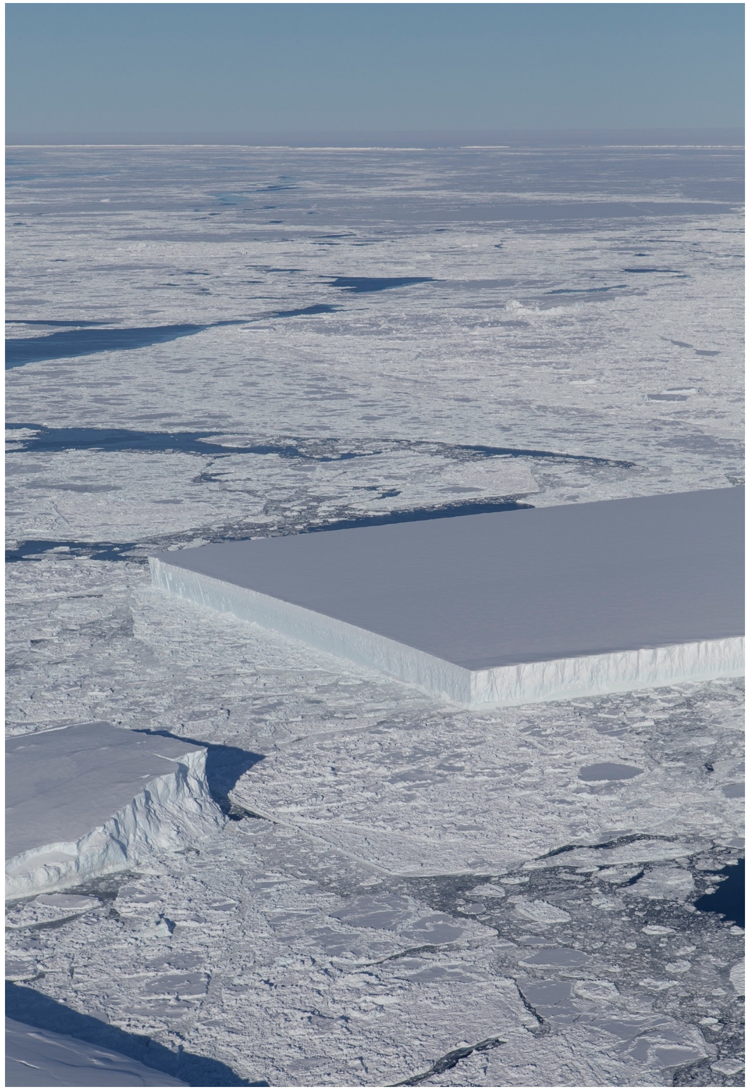


Graph illustrating the change in global surface temperature relative to 1951-1980 average temperatures, with the year 2020 tying with 2016 for warmest on record (Source: NASA's Goddard Institute for Space Studies).
Credit: NASA/JPL-Caltech

Overview: Climate Change

- Earth's climate has changed continuously throughout its history.
- In the last 650,000 years, there have been seven cycles of glacial advance and retreat, with the abrupt end of the last ice age about 11,700 years ago, marking the beginning of the modern climate era—and of human civilization.
- The current warming trend is of particular significance because has been accelerated by human activity since the mid-20th century.

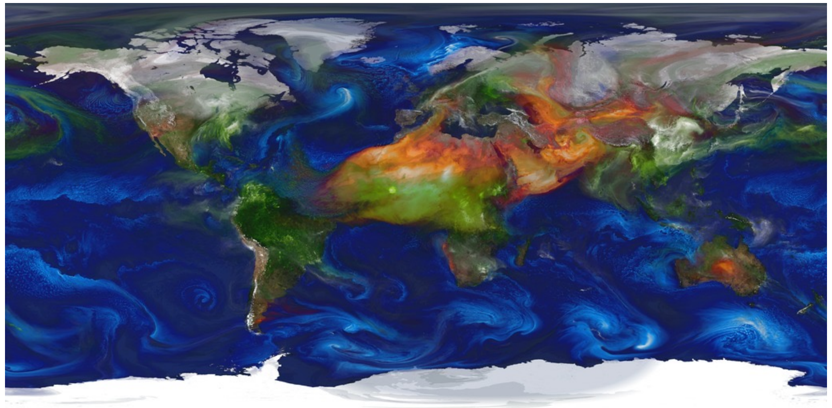
https://climate.nasa.gov/evidence/



Credits: NASA/Jeremy Harbeck

Overview: Climate Change

- Climate scientists separate factors that affect climate change into three categories: forcings, feedbacks, and tipping points.
- **Forcings:** The initial drivers of climate
  - Solar Irradiance
  - Greenhouse Gas Emissions
  - Aerosols, Dust, Smoke, and Soot



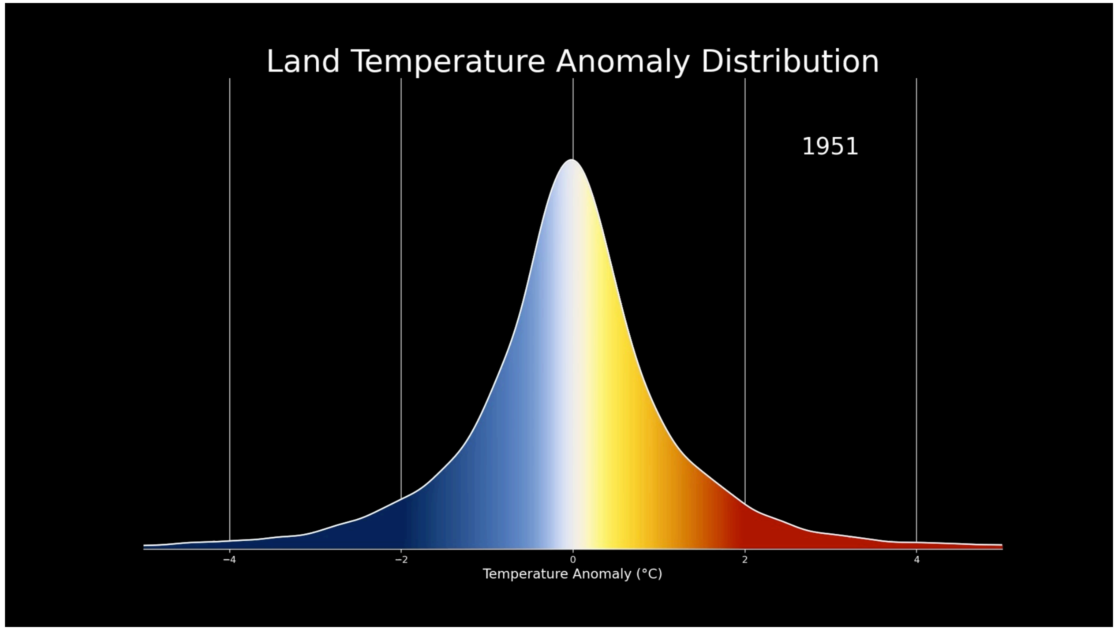
GEOS-5 Aerosols Simulation
Credit: NASA's Goddard Space Flight Center/Global Modeling and Assimilation Office

- **Feedbacks:** Processes that can either amplify or diminish the effects of climate forcings.
  - Clouds
  - Precipitation
  - Greening of the Forests
  - Ice Albedo
- **Climate Tipping Points:** When Earth's climate abruptly moves between relatively stable states.
  - Ocean Circulation
  - Ice Loss
  - Rapid Release of Methane

https://climate.nasa.gov/nasa_science/science/

Overview: Climate Change

- The planet's average surface temperature has risen about 1.18 degrees Celsius (2.12 degrees Fahrenheit) since the late 19th century, a change driven largely by **increased greenhouse gas emissions** into the atmosphere.
- Observed increases in well-mixed greenhouse gas concentrations since around 1750 are unequivocally caused by human activities (IPCC, 2021).
- Most of the warming has occurred in the past 40 years, with the seven most recent years being the warmest.



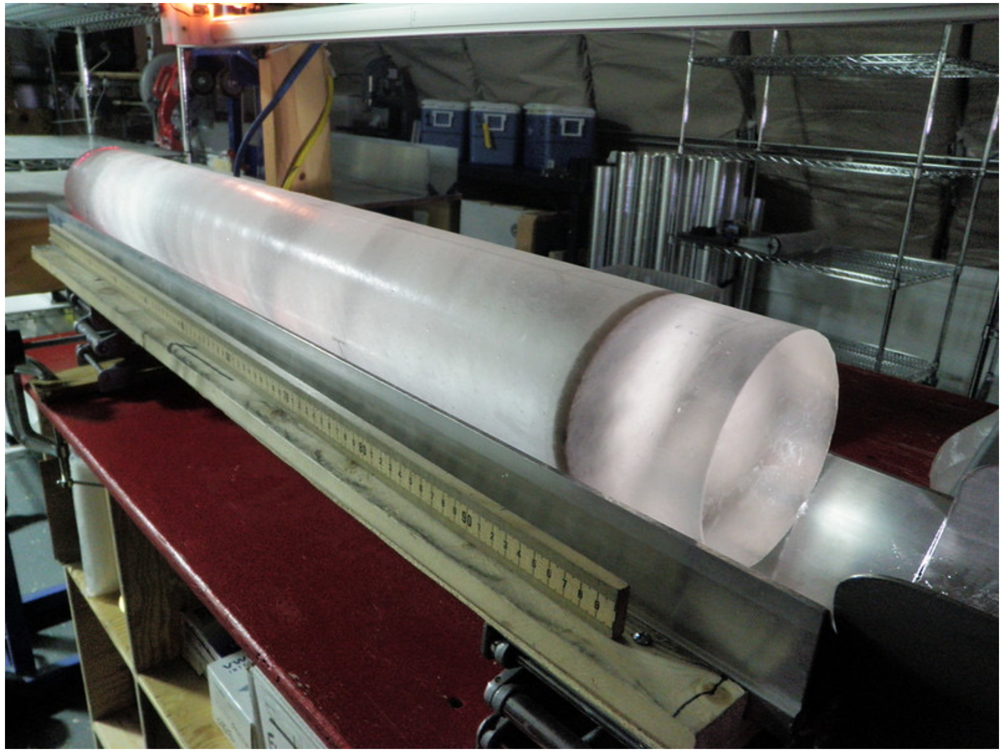
This visualization shows how the distribution of land temperature anomalies has varied over time. As the planet has warmed, we see the peak of the distribution shifting to the right. The distribution of temperatures broadens as well. This broadening is most likely due to differential regional warming rather than increased temperature variability at any given location.
Credit: NASA's Scientific Visualization Studio

NASA Global Climate Change : https://climate.nasa.gov/evidence/

NASA Goddard Institute for Space Studies: https://data.giss.nasa.gov/gistemp/

Overview: Climate Change

- **Ice cores** tell scientists about the temperature, precipitation, and atmospheric composition of Earth's paleoclimate.
- Proportions of different **oxygen** and **hydrogen isotopes** provide information about ancient temperatures, and the air trapped in tiny bubbles can be analyzed to determine the level of atmospheric gases such as carbon dioxide.
- The oldest ice cores, from East Antarctica, provide an **800,000-year-old record** of Earth's climate.



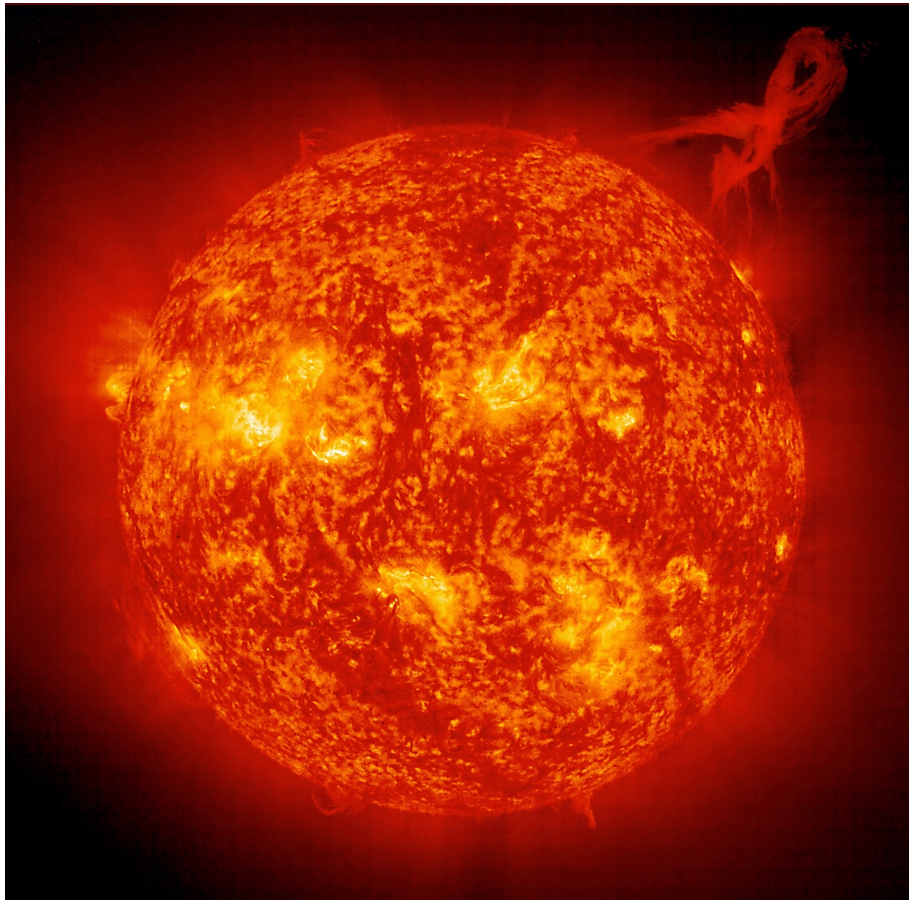
A volcanic ash layer in the WAIS Divide ice core. Volcanic markers like these were used in the new study to synchronize ice cores from across Antarctica. Credit: Heidi Roop & Oregon State University

NOAA NCEI: https://www.ncdc.noaa.gov/news/picture-climate-what-can-we-learn-ice

NASA Global Climate Change: https://climate.nasa.gov/news/2616/core-questions-an-introduction-to-ice-cores/

Overview: The Sun's Impact on Climate

- The Sun can influence Earth's climate, but it isn't responsible for the warming trend we've seen over the past half century.
- Subtle changes in Earth's orbit around the Sun are responsible for the comings and goings of the ice ages, but the warming we've seen in recent decades is too rapid to be linked to changes in Earth's orbit or caused by solar activity.



Credit: NASA

https://climate.nasa.gov/faq/14/is-the-sun-causing-global-warming/

Overview: The Sun’s Impact on Climate

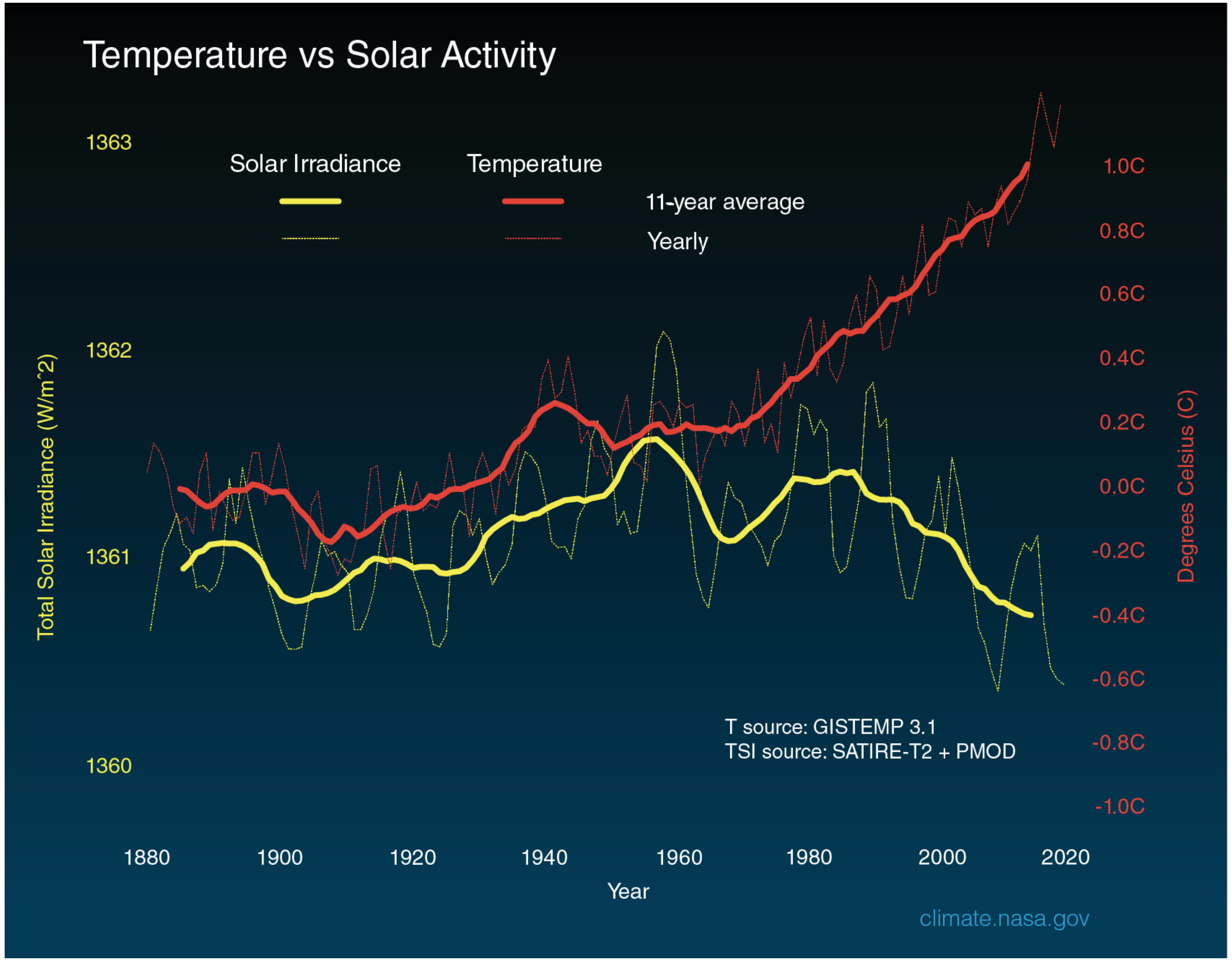
- Since 1978, scientists have been tracking the amount of solar energy reaching the top of the atmosphere using satellite sensors, and there has been no upward trend in the amount of solar energy reaching our planet.
- If the Sun were responsible for global warming, we would expect to see warming throughout all layers of the atmosphere. What we observe is warming at the surface and cooling in the stratosphere. This is consistent with warming caused by a buildup of heat-trapping gases near Earth's surface.

https://climate.nasa.gov/faq/14/is-the-sun-causing-global-warming/

Overview: The Sun's Impact on Climate

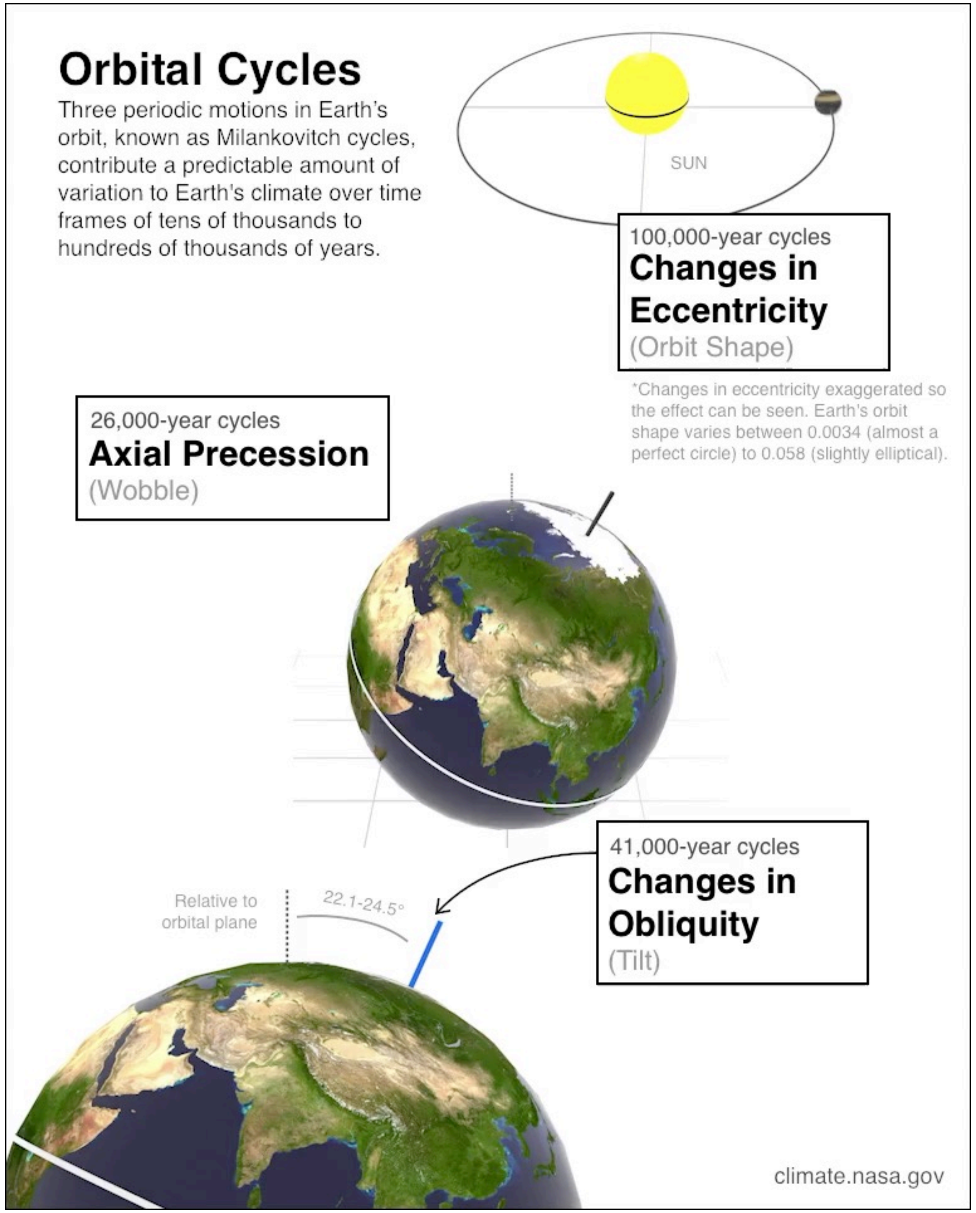
The graph on the right compares global surface temperature changes (red line) and the Sun's energy received by Earth (yellow line) in watts (units of energy) per square meter since 1880. The lighter/thinner lines show the yearly levels, while the heavier/thicker lines show the 11-year average variations related to sunspot cycles.

The amount of solar energy Earth receives has followed the Sun's natural 11-year cycle with no net increase since the 1950s. Over the same period, global temperature has risen markedly. It is therefore **extremely unlikely** that the Sun has caused the observed global temperature warming trend over the past half-century.



Overview: Milankovitch Cycles

- Milankovitch cycles include the shape of Earth's orbit (its **eccentricity**), the direction that Earth's spin axis is pointed (its **precession**), and the angle that Earth's axis is tilted with respect to Earth's orbital plane (its **obliquity**).
- These cycles affect the amount of sunlight – and therefore, energy – that Earth absorbs from the Sun. They provide a strong framework for understanding ***long-term*** changes in Earth's climate, including the beginning and end of Ice Ages throughout Earth's history.



Credit: NASA/JPL-Caltech

https://climate.nasa.gov/blog/2949/why-milankovitch-orbital-cycles-cant-explain-earths-current-warming/

Overview: Milankovitch Cycles

- Milankovitch cycles can't explain all climate change that's occurred over the past 2.5 million years. And more importantly, they cannot account for the current period of rapid warming Earth has experienced since the pre-Industrial period.
- Milankovitch cycles operate on long time scales, ranging from tens of thousands to hundreds of thousands of years.
- Earth's current warming has taken place over time scales of decades to centuries.
- Milankovitch cycles are just one factor that may contribute to climate change, both past and present.
- If there were no human influences on climate, scientists say Earth's current orbital position within the Milankovitch cycles predict that our planet should be cooling, not warming.

https://climate.nasa.gov/blog/2949/why-milankovitch-orbital-cycles-cant-explain-earths-current-warming/

Overview: Volcanic Eruptions and Climate

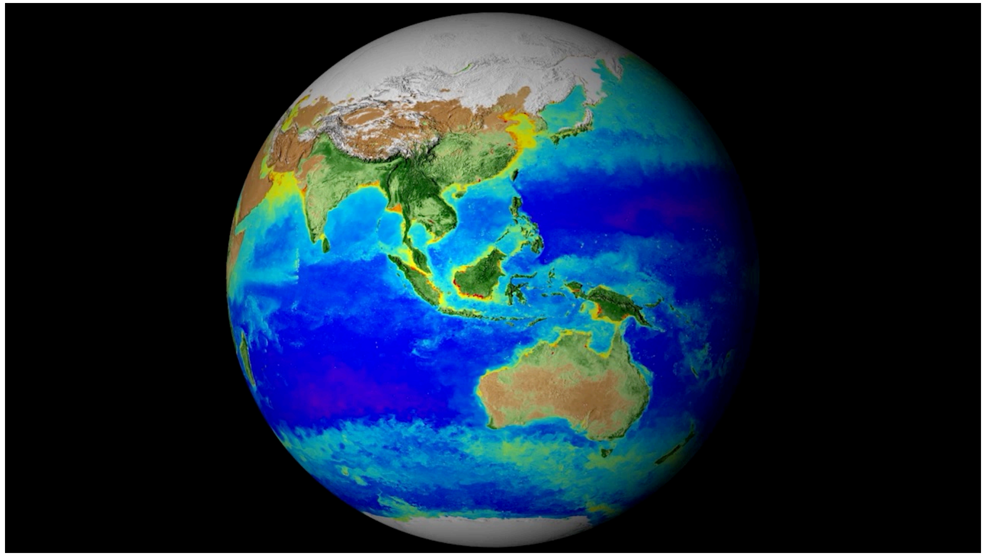
- Gases and dust particles thrown into the atmosphere during **volcanic eruptions** have influences on hemispheric and global climate over the short term.
- Particles and gases spewed from volcanoes **cool the planet** by shading incoming solar radiation. The cooling effect can last for months or years.
- Overall, volcanoes release about 1% of the equivalent amount of CO_2 released by human activities.
- By comparison, human activities emit a Mount St. Helens eruption of CO_2 every 2.5 hours and a Mount Pinatubo eruption of CO_2 twice daily (NASA Global Climate Change).

https://scied.ucar.edu/learning-zone/how-climate-works/how-volcanoes-influence-climate

Eruption of Mount Pinatubo, Philippines, 1991
Credit: U.S. National Archives

Life Depends On, is Shaped By, and Affects Climate

- Throughout geologic history, life has affected the climate system and vice versa.
- Life—including microbes, plants, and animals—is a major driver of the global carbon cycle and can influence global climate by modifying the chemical makeup of the atmosphere.
- Changes in climate conditions can affect the health and function of ecosystems and the survival of entire species.



Data visualization showing 20 years of Earth's biosphere data on ocean and land. Credit: NASA Goddard Space Flight Center

Greenhouse Gases

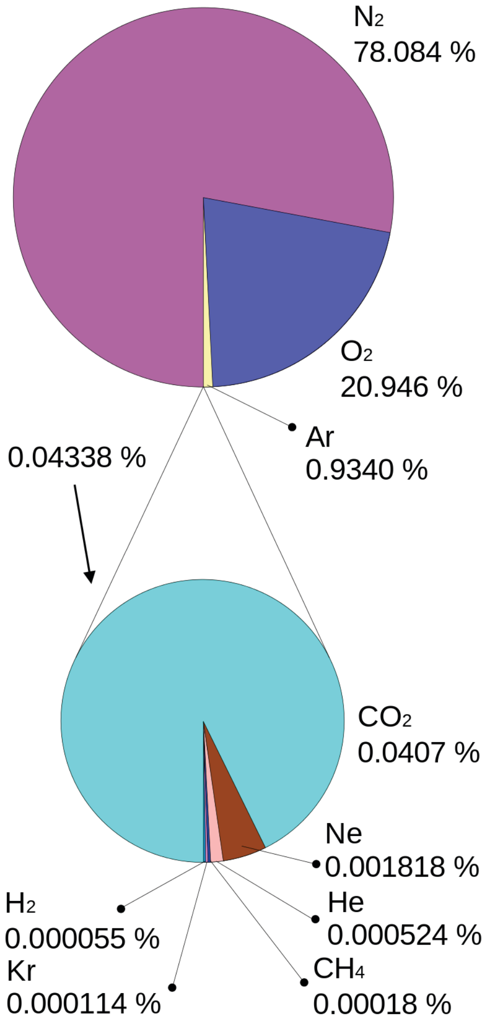
- Most of the energy that reaches Earth's surface is short wave (UV, visible, and infrared), which warms the surface and is radiated back toward space in long-wave infrared.
- **Greenhouse gases** – such as water vapor, carbon dioxide, and methane – occur naturally in small amounts and **absorb and release heat energy** more efficiently than abundant atmospheric gases like nitrogen and oxygen.

A simplified animation of the greenhouse effect. Credit: NASA/JPL-Caltech

https://www.climate.gov/teaching/essential-principles-climate-literacy/teaching-essential-principle-2-climate-regulated

Greenhouse Gases

- Unlike nitrogen or oxygen, which make up most of our atmosphere, greenhouse gases (water vapor, carbon dioxide, methane, nitrous oxide, and fluorinated gases) absorb thermal infrared energy (heat) and release it gradually over time to space and some portion back to the surface.
- Without this natural greenhouse effect, Earth's average annual temperature would be below freezing instead of close to 15.5°C (60°F).
- The abundance of carbon in the atmosphere is **reduced** through seafloor accumulation of marine sediments and accumulation of plant biomass (photosynthesis) and is **increased** through deforestation and burning of fossil fuels.

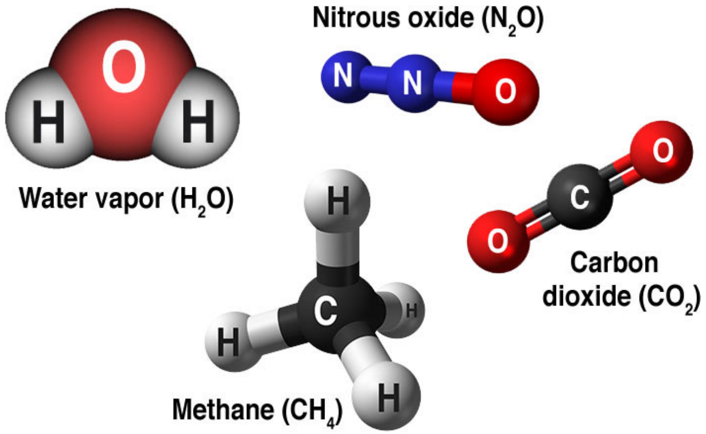


Composition of Earth's atmosphere by molecular count, excluding water vapor. Lower pie represents trace gases that together compose about 0.043391% of the atmosphere. Credit: [Mysid]

Greenhouse Gases

Water Vapor (H_2O)

- The most abundant greenhouse gas in the atmosphere.
- As the temperature of the atmosphere rises, more water is evaporated from ground storage (rivers, oceans, reservoirs, and soil). Because the air is warmer, the absolute humidity can be higher (in essence, the air is able to 'hold' more water when it's warmer), leading to more water vapor in the atmosphere.
- Changes in its concentration are considered to be a result of the warming of the atmosphere rather than a direct result of industrialization and are an important positive climate feedback.

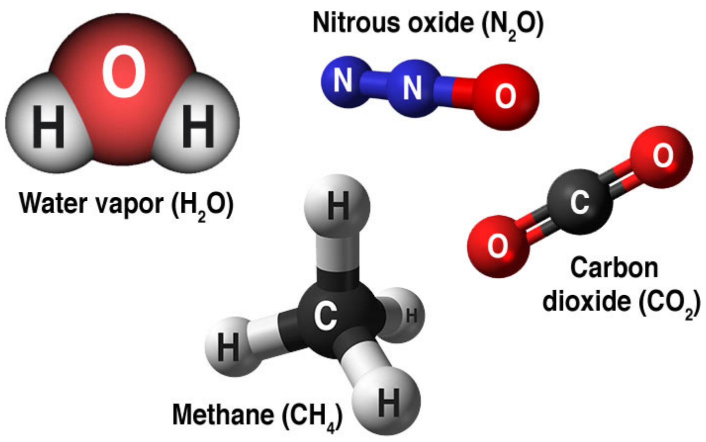


Credit: NOAA NCEI

Greenhouse Gases

Carbon Dioxide (CO_2)

- The natural production and absorption of carbon dioxide is achieved through the terrestrial biosphere and the ocean.
- Humankind has altered the natural carbon cycle by burning coal, oil, natural gas, and wood, and since the industrial revolution began in the mid 1700s, each of these activities has increased in scale and distribution.
- Prior to the industrial revolution, CO_2 concentrations were fairly stable at 280 parts per million (ppm). In May 2021, the monthly average was 419 ppm, an increase of approximately 49 percent.

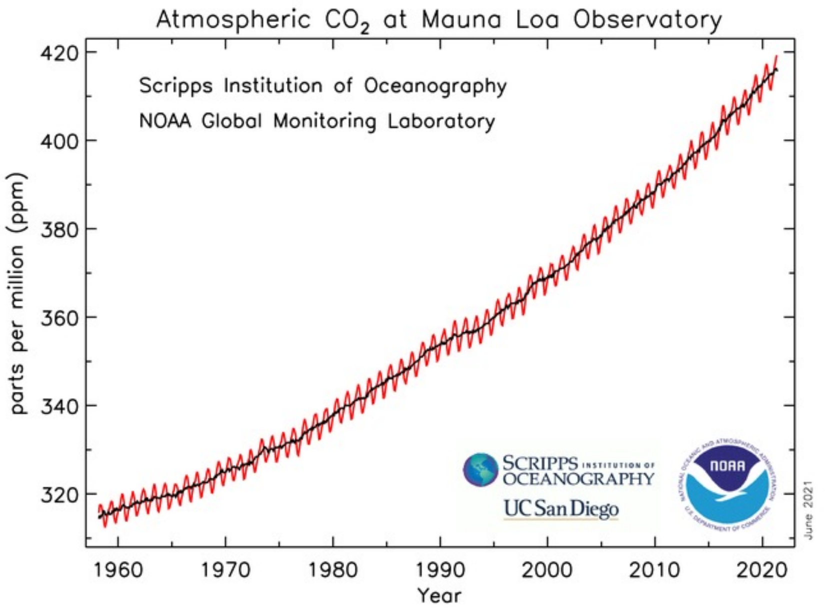


Credit: NOAA NCEI

Greenhouse Gases

The Keeling Curve

- The highest monthly mean CO_2 value of the year occurs in May, just before plants in the northern hemisphere start to remove large amounts of CO_2 from the atmosphere during the growing season.
- In the northern fall, winter, and early spring, plants and soils give off CO_2, causing levels to rise through May.
- Charles David Keeling was the first to observe this seasonal rise and fall in CO_2 levels every year, a dynamic which is now known as the **Keeling Curve**.
- Keeling was also the first to recognize that despite the seasonal fluctuation, CO_2 levels were rising every year.



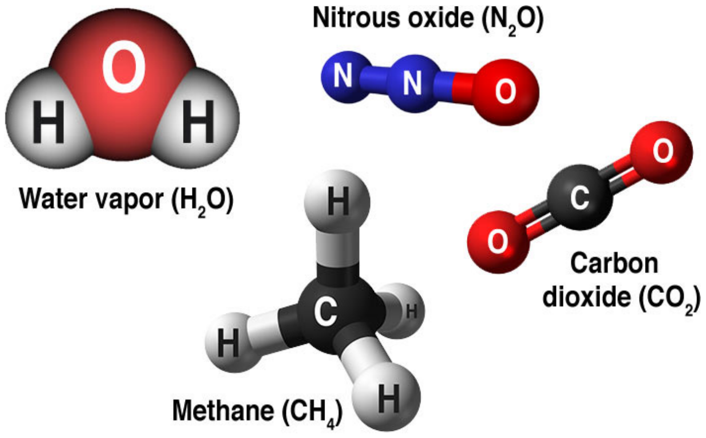
This graph depicts the upward trajectory of carbon dioxide in the atmosphere as measured at the Mauna Loa Atmospheric Baseline Observatory by NOAA and the Scripps Institution of Oceanography. The annual fluctuation is known as the Keeling Curve. Credit: NOAA Global Monitoring Laboratory

Credit: NOAA

Greenhouse Gases

Methane (CH_4)

- Methane is an extremely effective absorber of radiation, though its atmospheric concentration is less than CO_2 and its lifetime in the atmosphere is brief (10-12 years).
- Methane has both natural and anthropogenic sources.
- It is released as part of the biological processes in low-oxygen environments, such as in swamplands or in rice production (at the roots of the plants).
- Over the last 50 years, human activities such as growing rice, raising cattle, using natural gas, and mining coal have added to the atmospheric concentration of methane.

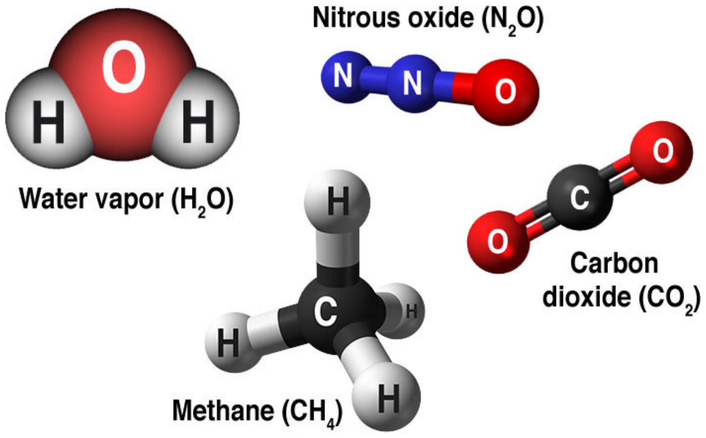


Credit: [NOAA NCEI]

Greenhouse Gases

Nitrous Oxide (N_2O)

- Concentrations of nitrous oxide began to rise at the beginning of the industrial revolution and are understood to be produced by microbial processes in soil and water, including those reactions which occur in fertilizer containing nitrogen.
- The use of these fertilizers has increased over the last century.
- In addition to agricultural sources for the gas, some industrial processes (fossil fuel-fired power plants, nylon production, nitric acid production, and vehicle emissions) also contribute to its atmospheric load.

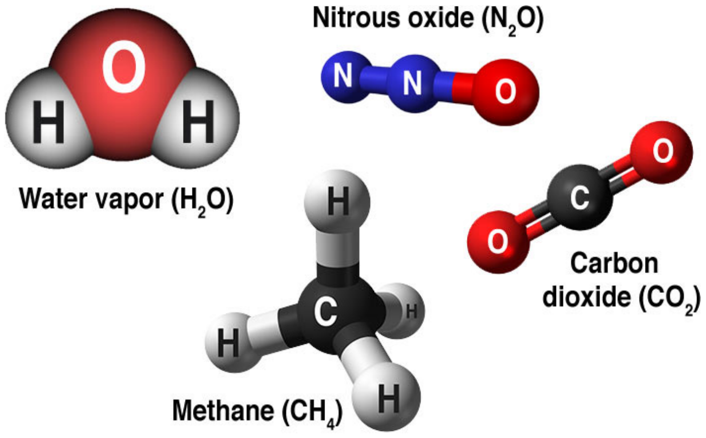


Credit: NOAA NCEI

Greenhouse Gases

Chlorofluorocarbons (CFCs)

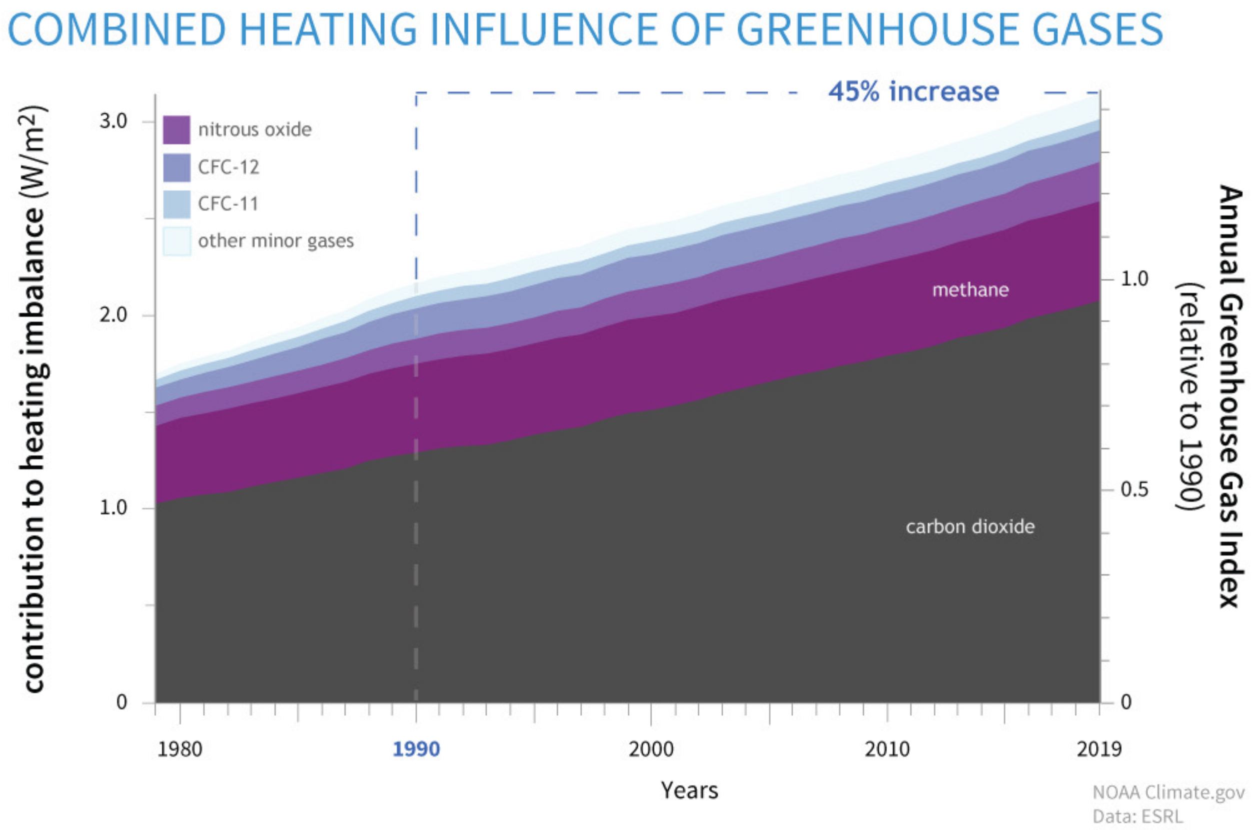
- Chlorofluorocarbons (CFCs) have no natural source, but were entirely synthesized for such diverse uses as refrigerants, aerosol propellants, and cleaning solvents.
- Due to the discovery that they can destroy stratospheric ozone, a global effort to halt their production was undertaken and was extremely successful.
- Their long atmospheric lifetimes determine that some concentration of the CFCs will remain in the atmosphere for over 100 years.
- Since they are also greenhouse gas they are of concern, along with such other long-lived synthesized gases.



Credit: NOAA NCEI

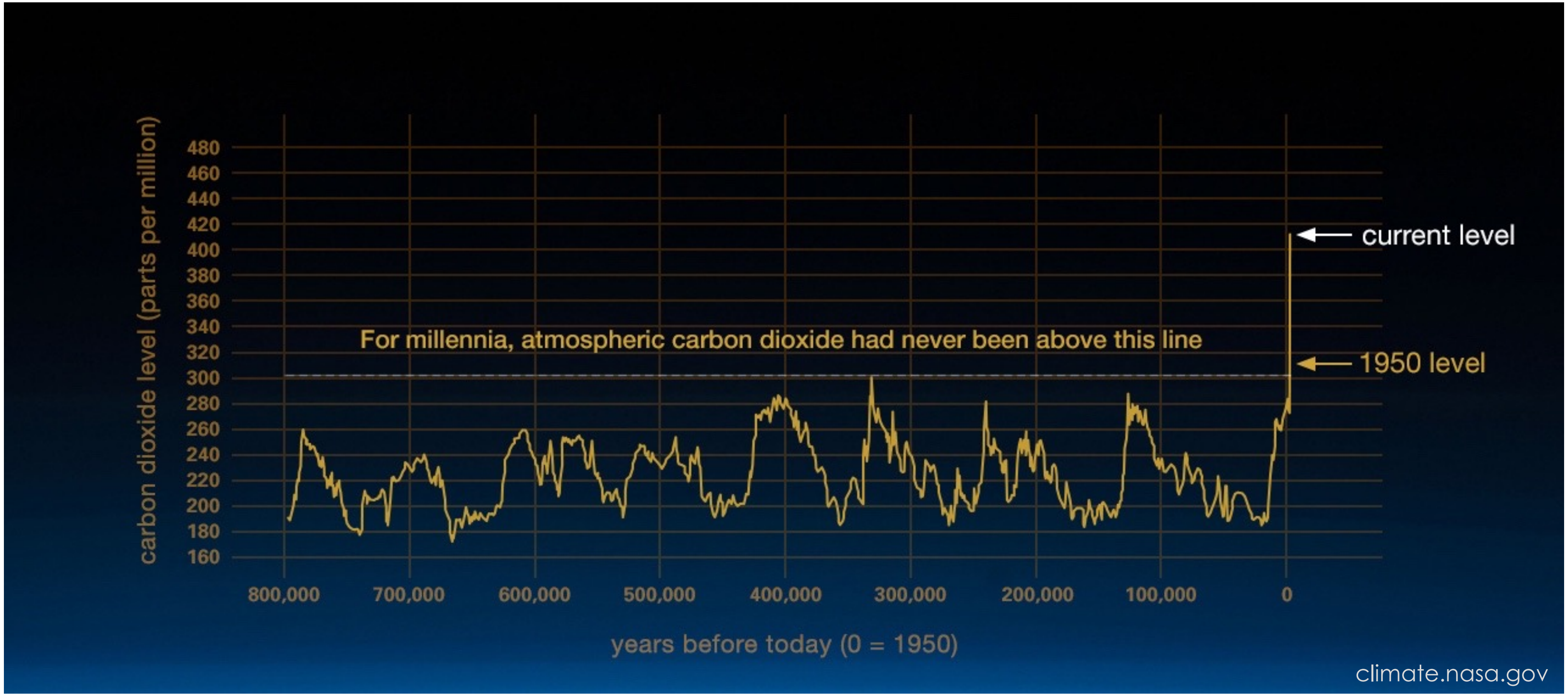
Why Carbon Dioxide Matters

- Carbon dioxide is the most important of Earth's long-lived greenhouse gases.
- Carbon dioxide absorbs less heat per molecule than the greenhouse gases methane or nitrous oxide, but it's more abundant and stays in the atmosphere longer (300 to 1,000 years).
- Increases in atmospheric carbon dioxide are responsible for about two-thirds of the total energy imbalance that is causing Earth's temperature to rise.



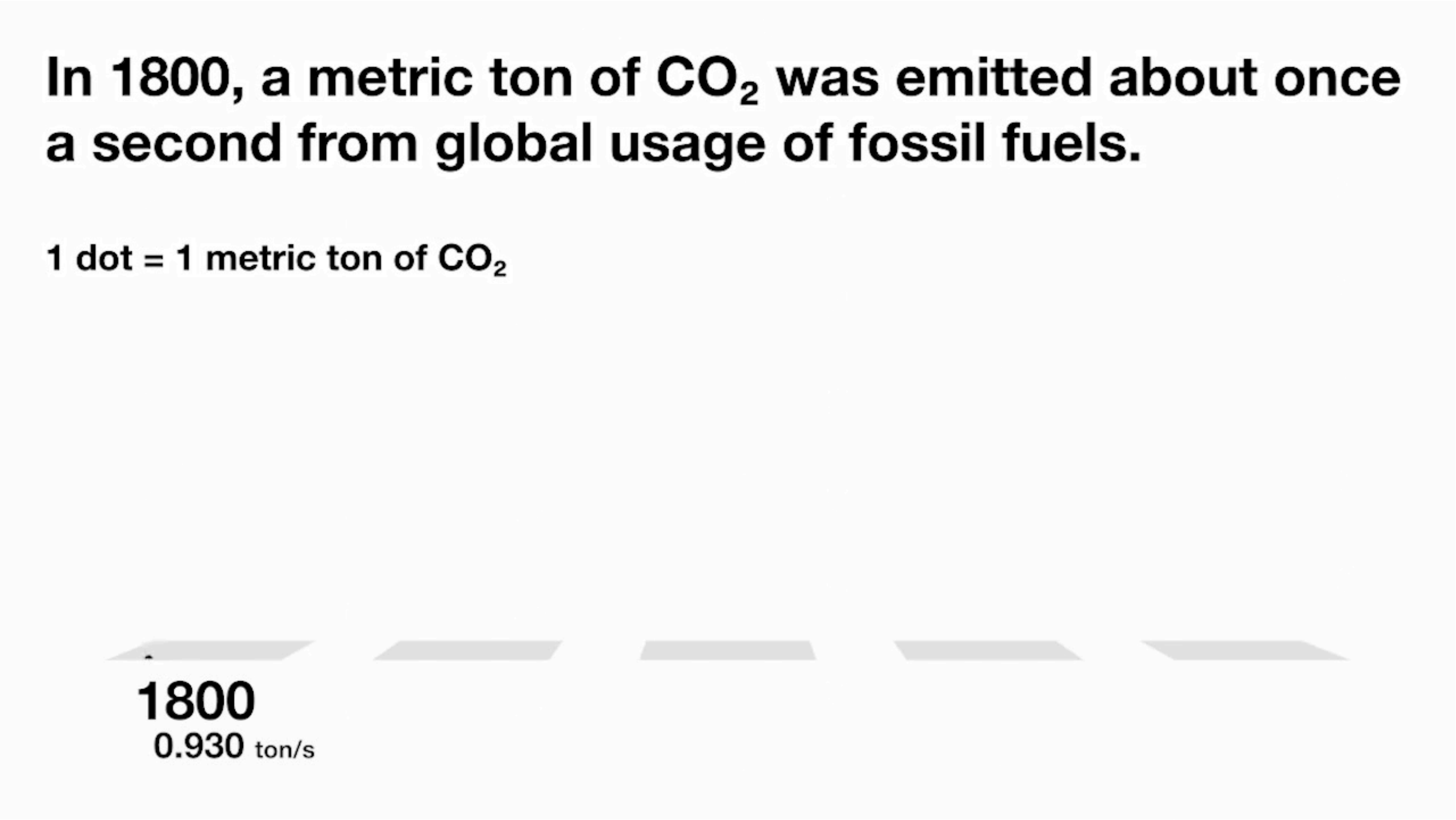
This graph shows the heating imbalance in watts per square meter relative to the year 1750 caused by all major human-produced greenhouse gases: carbon dioxide, methane, nitrous oxide, chlorofluorocarbons 11 and 12, and a group of 15 other minor contributors. Today's atmosphere absorbs about 3 extra watts of incoming solar energy over each square meter of Earth's surface. According to NOAA's Annual Greenhouse Gas Index (right axis) the combined heating influence of all major greenhouse gases has increased by 43% relative to 1990. Credit: NOAA Climate.gov, based on data from NOAA ESRL.

Atmospheric CO_2 Levels Over the Past Millenia



This graph, based on the comparison of atmospheric samples contained in ice cores and more recent direct measurements, provides evidence that atmospheric CO_2 has increased since the Industrial Revolution.
Credit: Luthi, D., et al.. 2008; Etheridge, D.M., et al. 2010; Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO_2 record.

Atmospheric CO_2 Levels Over the Past Two Centuries



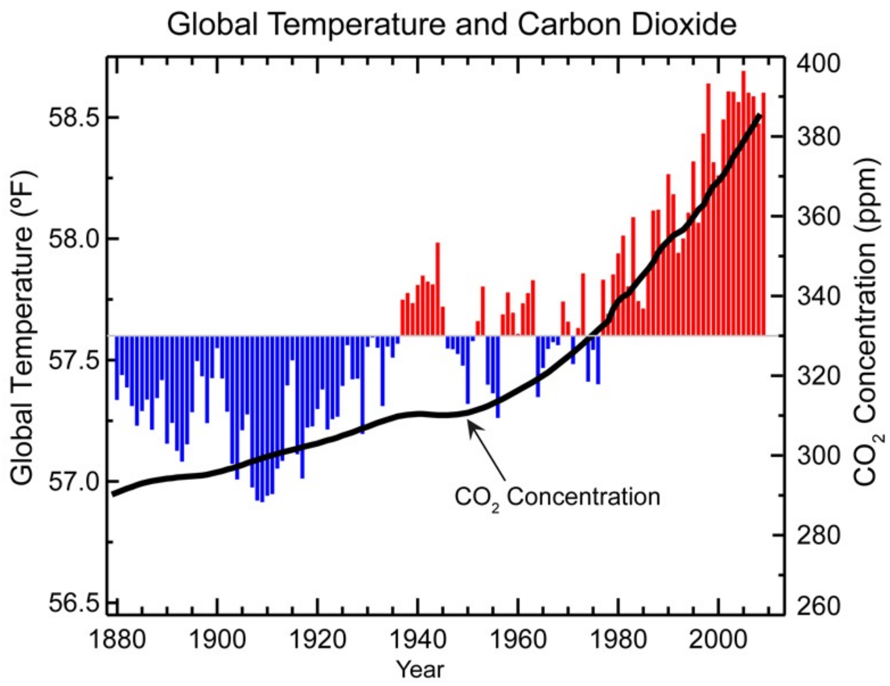
The amount of carbon dioxide released due to burning fossil fuels has been increasing since the start of the Industrial Revolution in the mid-18th century. In 1900, almost 2 billion metric tons of CO_2 were released due to fossil fuel usage. The Carbon Dioxide Information Analysis Center (CDIAC) shows that over 35 billion metric tons of CO_2 were released in 2014. Credit: CDIAC and NASA Global Climate Change.

Evidence of Rapid Climate Change

- **Global Temperature Rise** – The planet's average surface temperature has risen roughly 1.18 degrees Celsius (2.12 degrees Fahrenheit) since the late 19th century.
- The global surface temperature is based on air temperature data over land and sea-surface temperatures observed from ships, buoys, and satellites.
- Notably, the 20 warmest years have all occurred since 1981, and the 10 warmest have all occurred in the past 12 years.

https://www.ncdc.noaa.gov/monitoring-references/faq/indicators.php#warming-climate

https://climate.nasa.gov/evidence/



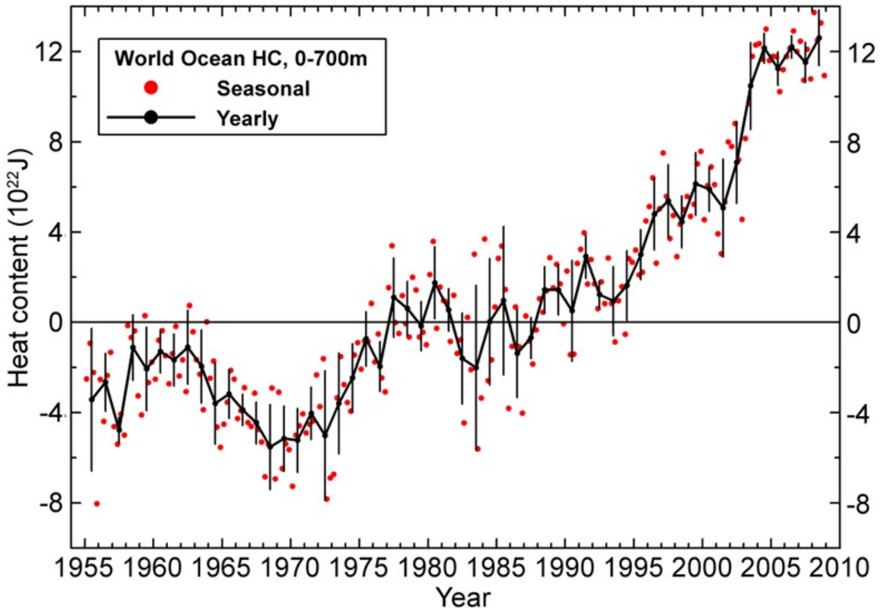
Global annual average temperature measured over land and oceans. Red bars indicate temperatures above and blue bars indicate temperatures below the 1901-2000 average temperature. The black line shows atmospheric carbon dioxide concentration in parts per million (ppm). Credit: NOAA

Evidence of Rapid Climate Change

- **Warming Ocean** – The top 100 meters (328 feet) of ocean show warming of more than 0.33 degrees Celsius (0.6 degrees Fahrenheit) since 1969.
- While ocean heat content varies significantly from place to place and from year-to-year (result of changing ocean currents and natural variability), there is a strong trend of reliable measurements.
- Increasing heat content in the ocean is also consistent with sea level rise, which is occurring mostly as a result of thermal expansion of the ocean water as it warms.

https://www.ncdc.noaa.gov/monitoring-references/faq/indicators.php#warming-climate

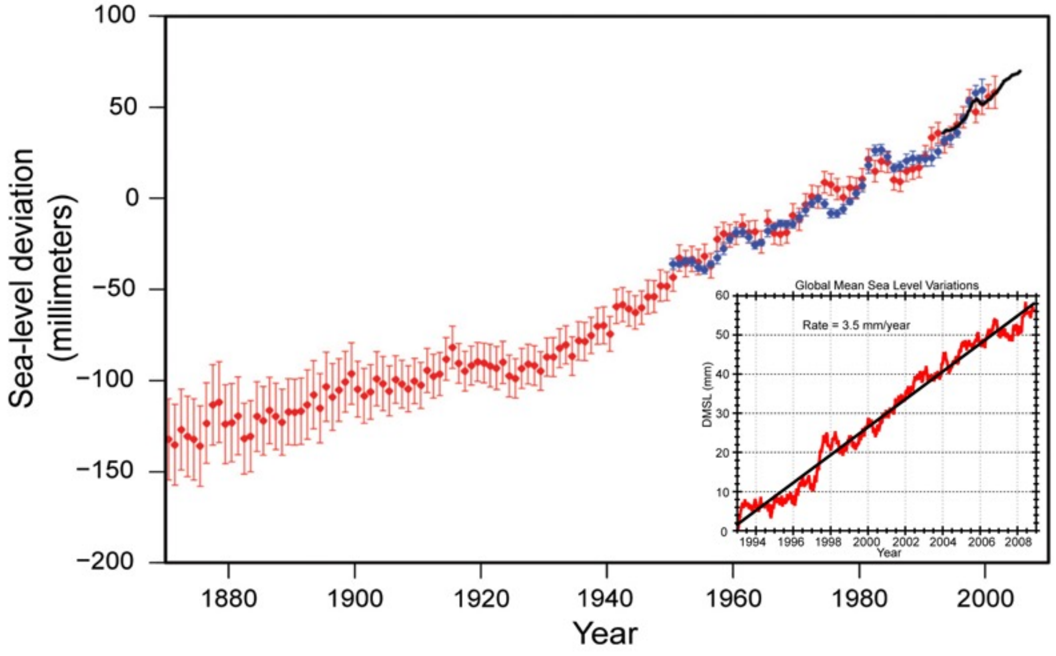
https://climate.nasa.gov/evidence/



Time series of seasonal (red dots) and annual average (black line) of global upper ocean heat content for the 0-700m layer since 1955.
Credit: NOAA

Evidence of Rapid Climate Change

- **Sea Level Rise** – Heating of the climate system has caused global mean sea level rise through ice melt on land and thermal expansion from ocean warming. Thermal expansion explained 50% of sea level rise during 1971– 2018, while ice loss from glaciers contributed 22%, ice sheets 20%, and changes in land water storage 8% (IPCC, 2021).
- Global sea level rose about 20 centimeters (8 inches) in the last century. The rate in the last two decades, however, is nearly double that of the last century.

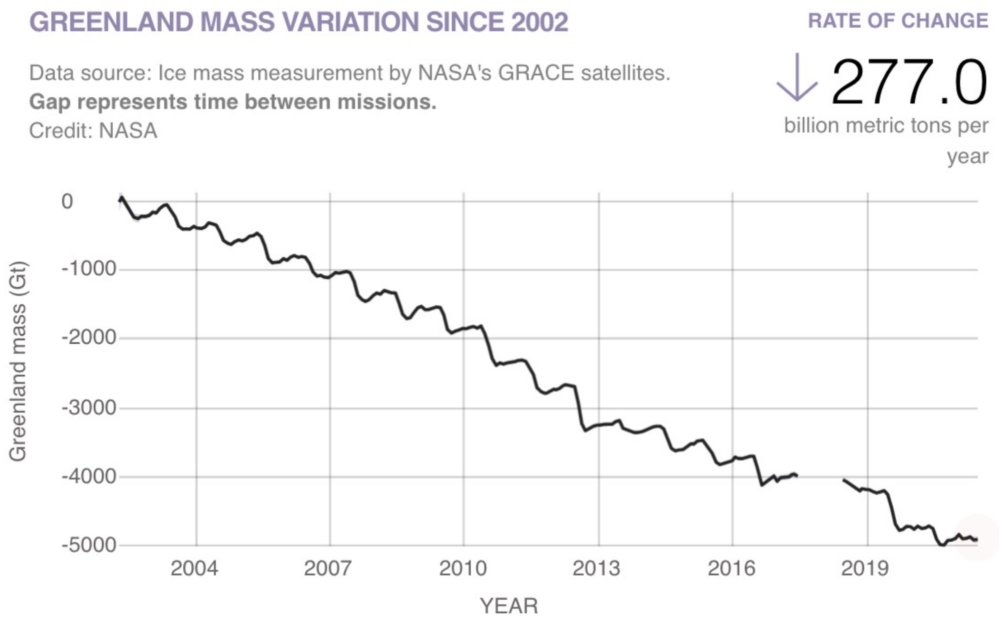


Annual averages of global sea level. Red: Sea-level since 1870; Blue: Tide gauge data; Black: Based on satellite observations. The inset shows global mean sea level rise since 1993 - a period over which sea level rise has accelerated. Credit: NOAA

https://climate.nasa.gov/evidence/

Evidence of Rapid Climate Change

- **Shrinking Ice Sheets** – Observations of ice sheets losing mass are consistent with trends in small glaciers as well as warming trends in global temperatures during this period.
- Ultimately, as ice sheets shrink, the water they add to the ocean raises sea level around the world.
- Melting of Greenland and Antarctica's ice sheets accounted for about one third of observed global sea level rise between 2006 and 2015 (IPCC, 2019).

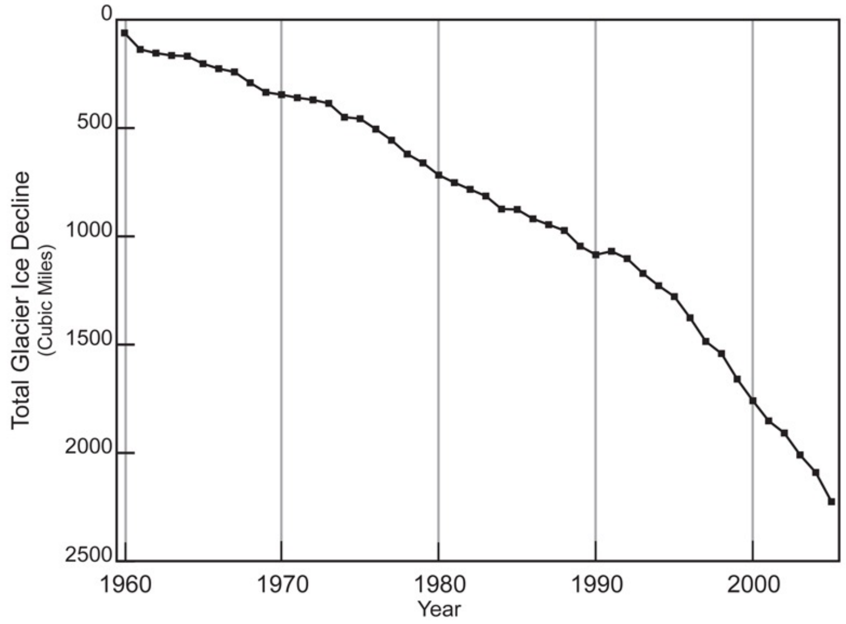


https://www.epa.gov/climate-indicators/climate-change-indicators-ice-sheets

https://climate.nasa.gov/vital-signs/ice-sheets/

Evidence of Rapid Climate Change

- **Glacial Retreat** – Warming temperatures lead to the melting of glaciers and ice sheets.
- Glaciers have been retreating worldwide for at least the last century; the rate of retreat has increased in the past decade.
- Only a few glaciers are advancing (in locations that were well below freezing, and where increased precipitation has outpaced melting).
- The progressive disappearance of glaciers has implications not only for a rising global sea level, but also for water supplies in certain regions of Asia and South America.



Cumulative decline (in cubic miles) in glacier ice worldwide. Credit: NOAA

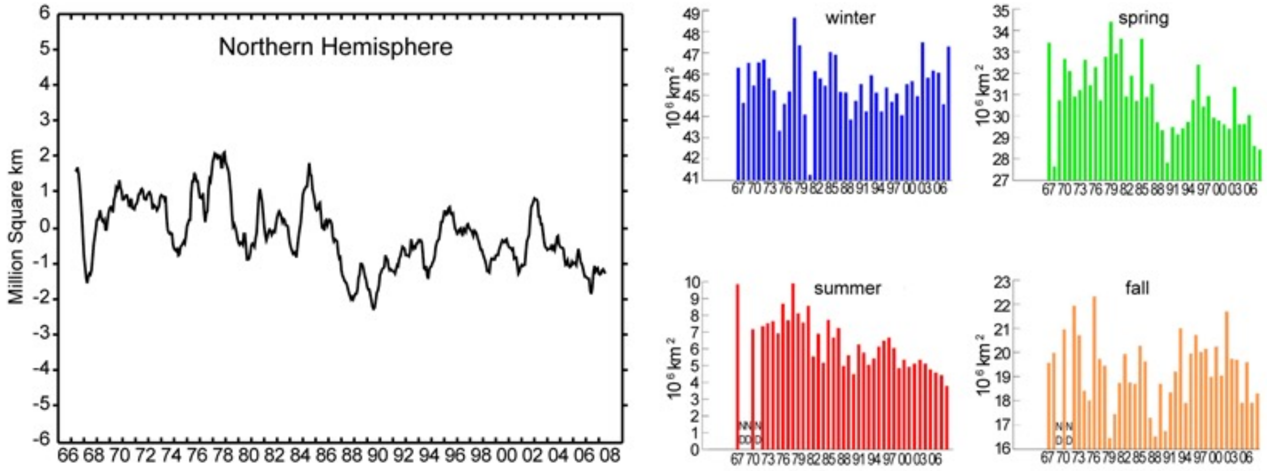
https://www.epa.gov/climate-indicators/climate-change-indicators-ice-sheets

https://climate.nasa.gov/evidence/

Evidence of Rapid Climate Change

https://www.ncdc.noaa.gov/monitoring-references/faq/indicators.php#warming-climate

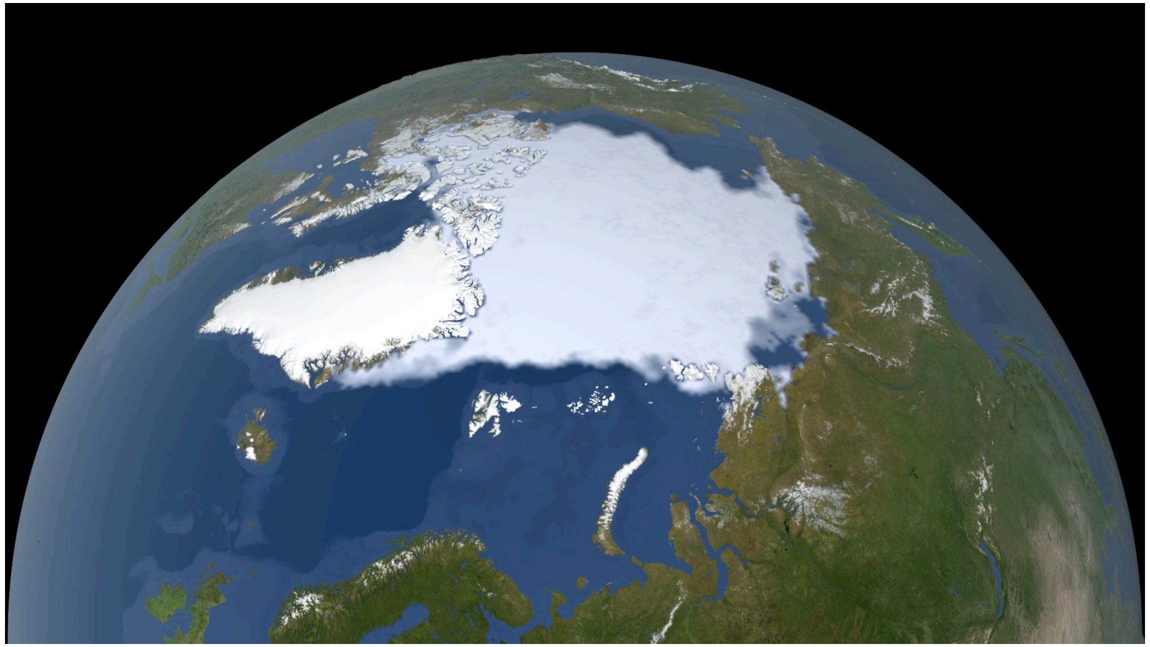
- **Decreased Snow Cover** – Satellite observations reveal that the amount of spring snow cover in the Northern Hemisphere has decreased over the past five decades and the snow is melting earlier.
- This pattern is consistent with warmer global temperatures.
- Some of the largest declines have been observed in the spring and summer months.



Average of monthly snow cover extent anomalies over Northern Hemisphere lands (including Greenland) since Nov 1966. Right: Seasonal snow cover extent over Northern Hemisphere lands since winter 1966-67. Calculated from NOAA snow maps. From BAMS State of the Climate in 2009 report.

Evidence of Rapid Climate Change

- **Declining Arctic Sea Ice** – Both the extent and thickness of Arctic sea ice has declined rapidly over the last several decades.
- Arctic sea ice reaches its minimum each September.
- September Arctic sea ice is now declining at a rate of 13.1 percent per decade, relative to the 1981 to 2010 average.



The animated time series shows the annual Arctic sea ice minimum since 1979, based on satellite observations. The 2012 sea ice extent is the lowest in the satellite record. Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio

https://climate.nasa.gov/vital-signs/arctic-sea-ice/

Evidence of Rapid Climate Change

- **Extreme Weather Events** – It is virtually certain that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with high confidence that human-induced climate change is the main driver of these changes (IPCC, 2021).
- The frequency and intensity of heavy precipitation events have both increased since the 1950s over most land area for which observational data are sufficient for trend analysis (high confidence), and human-induced climate change is likely the main driver (IPCC, 2021).
- It is likely that the global proportion of major (Category 3–5) tropical cyclone occurrence has increased over the last four decades, and the latitude where tropical cyclones in the western North Pacific reach their peak intensity has shifted northward (IPCC, 2021).

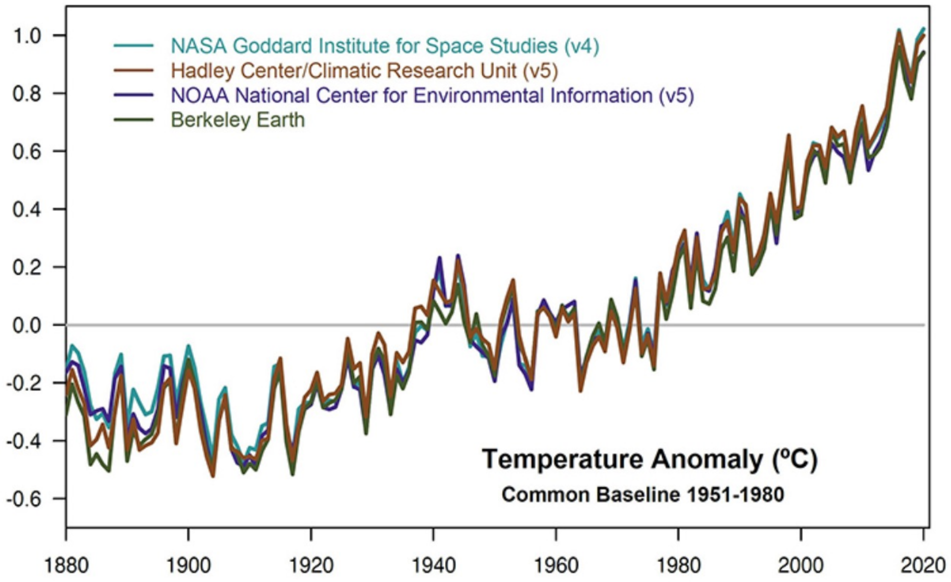
Evidence of Rapid Climate Change

- **Ocean Acidification** – The ocean absorbs about 30% of the carbon dioxide that is released in the atmosphere, where it dissolves into the ocean and reacts with water molecules, producing carbonic acid and lowering the ocean's pH.
- Since the start of the Industrial Revolution, the pH of the ocean's surface waters has dropped from 8.21 to 8.10. This drop in pH is called ocean acidification.
- A drop of 0.1 may not seem like a lot, but the pH scale is logarithmic; a 1-unit drop in pH means a tenfold increase in acidity. A change of 0.1 means a roughly 30% increase in acidity.
- Increasing acidity interferes with the ability of marine life to extract calcium from the water to build their shells and skeletons.

https://climate.nasa.gov/evidence/

Scientific Consensus

- NOAA, NASA, the National Science Foundation, the National Research Council, and the U.S. Environmental Protection Agency have all published reports and fact sheets stating that Earth is warming mainly due to the increase in human-produced heat-trapping gases.
- Multiple studies published in peer-reviewed scientific journals show that 97 percent or more of actively publishing climate scientists agree: Climate-warming trends over the past century are extremely likely due to human activities. In addition, most of the leading scientific organizations worldwide have issued public statements endorsing this position.

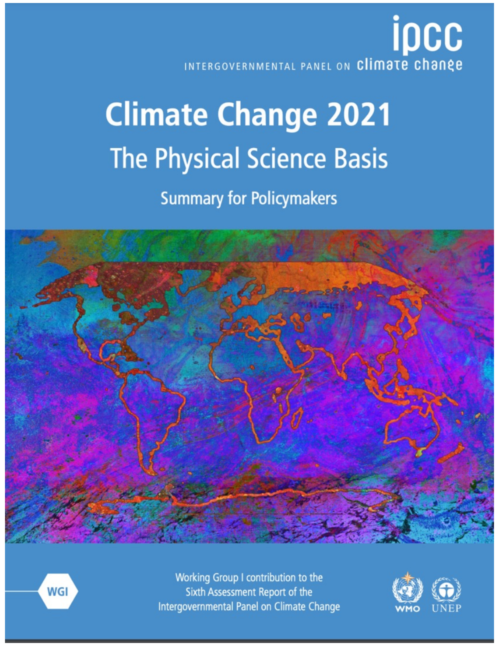


Temperature data showing rapid warming in the past few decades, the latest data going up to 2020. The 10 warmest years in the 141-year record have occurred since 2005, with the seven most recent years being the warmest. Credit: NASA's Goddard Institute for Space Studies.

https://climate.nasa.gov/scientific-consensus/

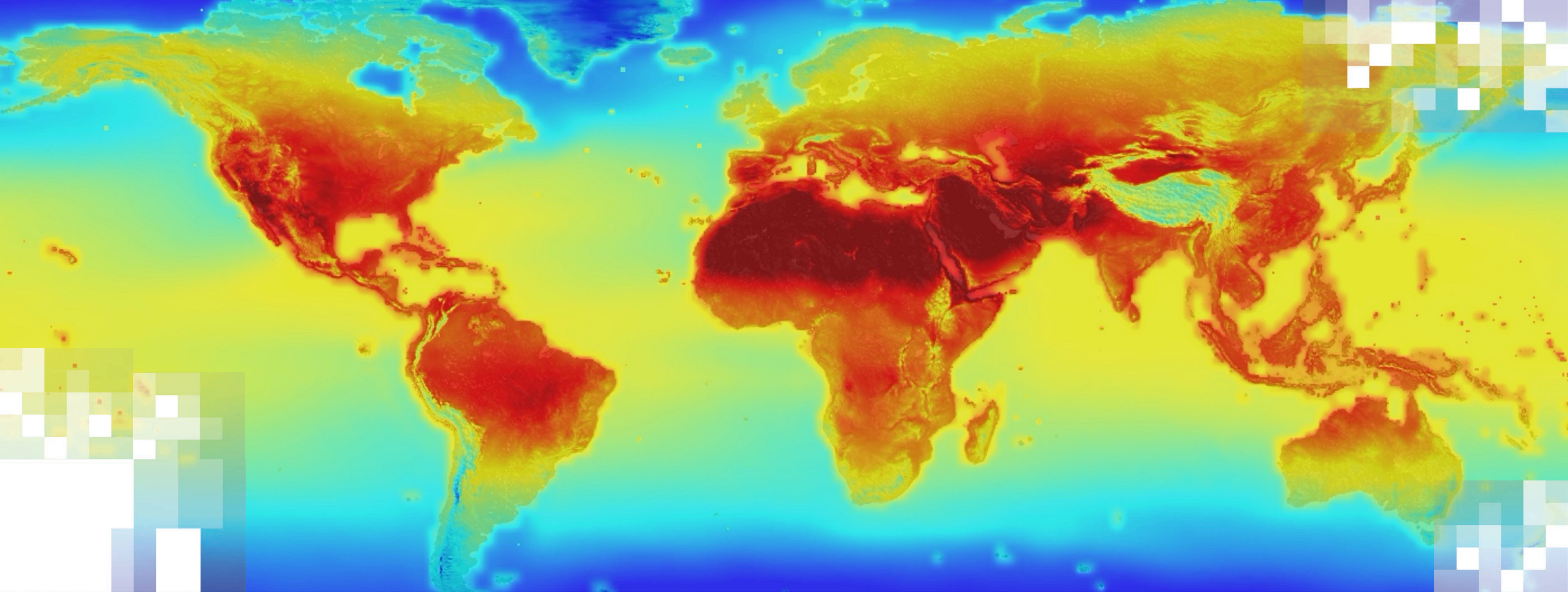
Intergovernmental Panel on Climate Change (IPCC)

- One of the most definitive assessments of global climate science come from the Intergovernmental Panel on Climate Change (IPCC).
- Founded by the United Nations in 1988, the IPCC releases periodic reports, and each major release includes three volumes: one on the science, one on impacts, and one on mitigation.
- Each volume is authored by a separate team of international experts, who reviews, evaluates, and summarizes relevant research published since the prior report.
- Hundreds of leading experts in the different areas covered by IPCC reports volunteer their time and expertise as Coordinating Lead Authors and Lead Authors to produce these assessments.



IPCC AR6, 2021: Summary for Policymakers.

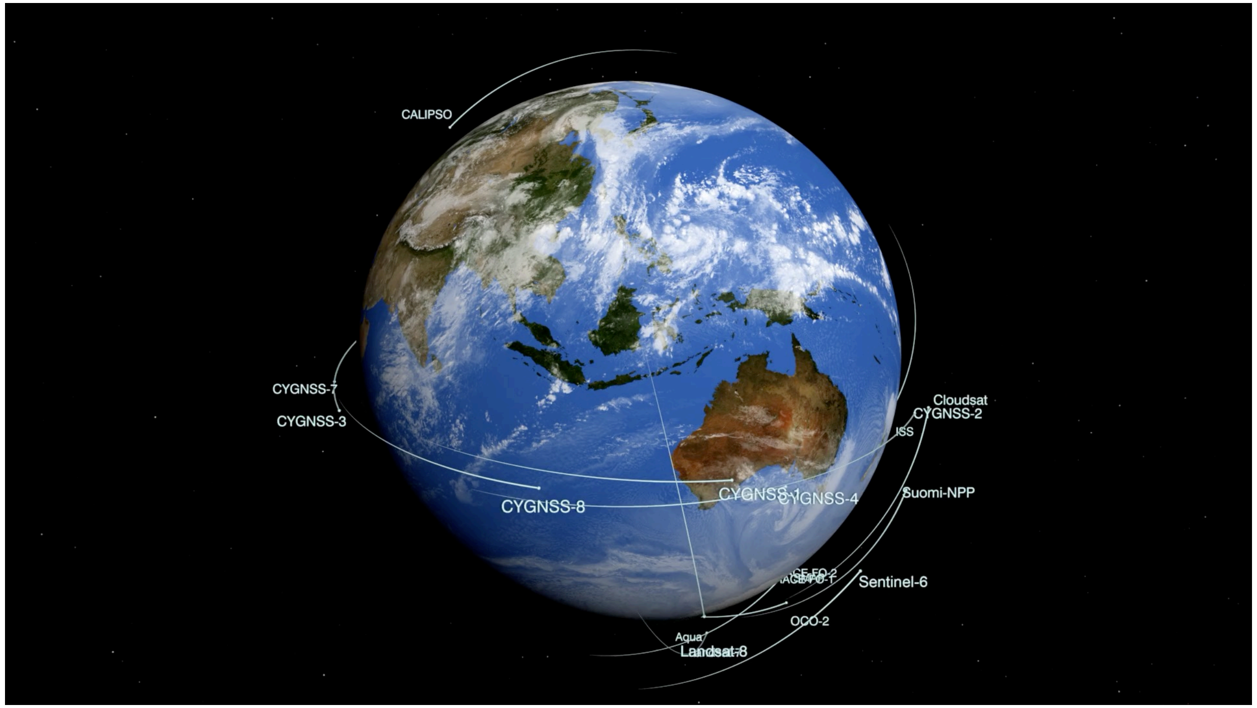
https://climate.nasa.gov/scientific-consensus/



The Role of Earth Observations in Climate Change Assessment

Role of Earth Observations in Climate Change Assessment

- NASA Earth observing satellites observe changes across the entire planet, from the atmosphere, biosphere, hydrosphere, cryosphere, and lithosphere.
- They provide consistent, timely, global, accurate measurements, from the tropics to the polar regions.
- NASA conducts a program of breakthrough research on climate science, enhancing the ability of the international scientific community to advance globally-integrated Earth system science.



NASA’s Earth Observing Fleet (2021). Credit: [NASA's Scientific Visualization Studio]

[https://climate.nasa.gov/nasa_science/history/]

NASA Missions for Climate

Aura

- NASA's Aura mission obtains measurements of ozone, aerosols, and key gases to gain insights into the chemistry of our atmosphere.
- The U.S. Environmental Protection Agency monitors six criteria pollutants to make air quality forecasts. The Aura spacecraft monitors five of the six pollutants: ozone (O_3), carbon monoxide (CO), aerosols, nitrogen dioxide (NO_2), and sulfur dioxide (SO_2).

https://aura.gsfc.nasa.gov/index.html

Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO)

- CALIPSO is a joint NASA/French (Centre National d'Etudes Spatiales [CNES]) mission. Observations from spaceborne lidar, combined with passive imagery, will lead to improved understanding of the role aerosols and clouds play in regulating the Earth's climate (also included in slide 52).

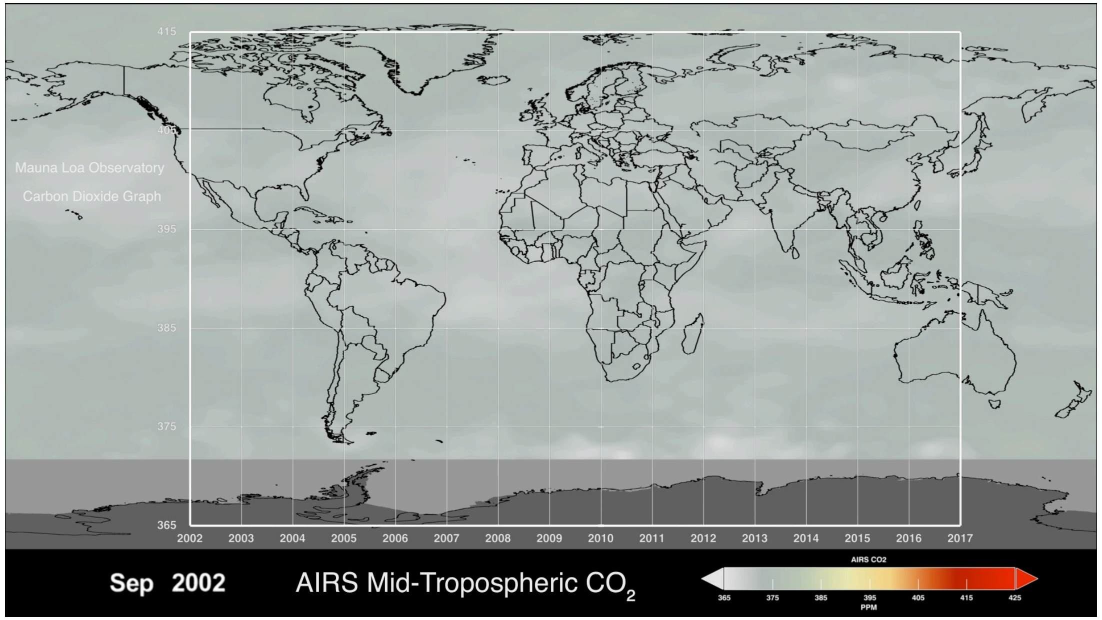
https://www-calipso.larc.nasa.gov/

NASA Missions for Climate

Aqua

- The **AIRS** instrument is the most advanced water vapor sensor ever built (60% of the greenhouse effect of the global atmosphere comes from water vapor). It observes trace gases in the atmosphere, such as ozone, carbon monoxide, carbon dioxide, and methane.
  https://airs.jpl.nasa.gov/mission/overview/

- The **AMSR** instrument measured geophysical parameters including precipitation, oceanic water vapor, cloud water, near-surface wind speed, sea surface temperature, soil moisture, snow cover, and sea ice parameters.
  https://earthdata.nasa.gov/eosdis/sips/amsr-sips



Visualization of the global distribution and variation of the concentration of mid-tropospheric carbon dioxide observed by the Atmospheric Infrared Sounder (AIRS) on the NASA Aqua spacecraft. For comparison, it is overlain by a graph of the seasonal variation and interannual increase of carbon dioxide observed at the Mauna Loa, Hawaii observatory.
Credit: NASA's Scientific Visualization Studio

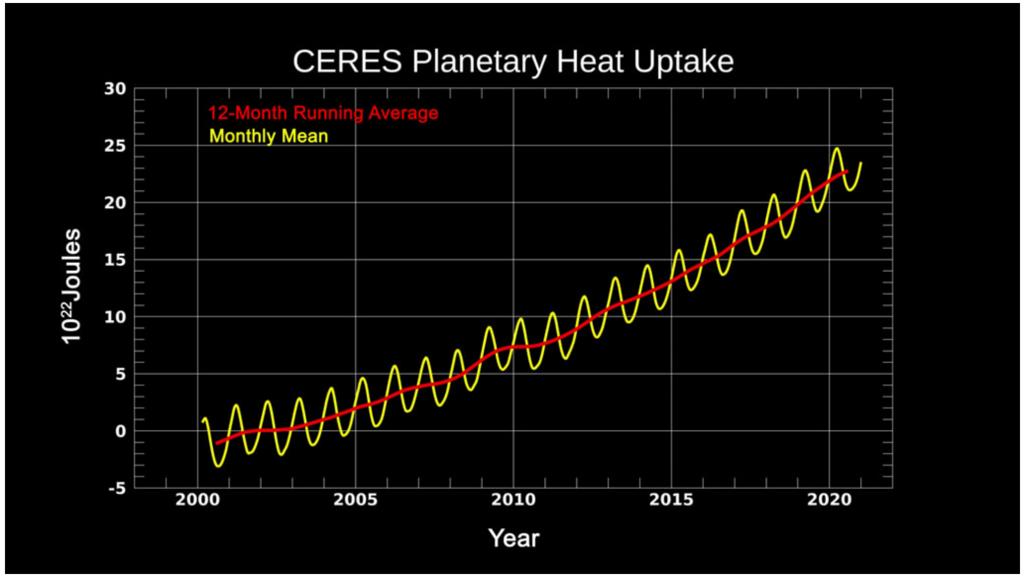
NASA Missions for Climate

Aqua

- The Clouds and Earth's Radiant Energy System (**CERES**) instrument measures both solar-reflected and Earth-emitted radiation from the top of the atmosphere to the Earth's surface providing measurements of the spatial and temporal distribution of Earth's radiation budget.
- Increases in greenhouse gases trap emitted thermal radiation from the surface and reduce how much is lost to space, resulting in a net surplus of energy into the Earth system.

https://www.nasa.gov/centers/langley/news/factsheets/ceres_aqua.html

- There are currently six CERES instruments on NASA and NOAA satellites.



A plotted view of planetary heat uptake since the beginning of the CERES data record showing an oscillating, monthly mean (yellow) and twelve-month running average (red line). These data show how much energy is added (absorbed) by Earth during the CERES period. Credit: NASA's Scientific Visualization Studio

NASA Missions for Climate

Aqua

- The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, with its sweeping 2,330-km-wide viewing swath, observes every point on the planet every 1-2 days in 36 discrete spectral bands.
- This wide spatial coverage enables MODIS, together with MISR and CERES, to help scientists determine the impact of clouds and aerosols on the Earth's energy budget.
- MODIS also measures the properties of aerosols that enter the atmosphere from anthropogenic sources like pollution and biomass burning and natural sources like dust storms, volcanic eruptions, and forest fires.

https://terra.nasa.gov/about/terra-instruments/modis

- MODIS helps scientists determine the amount of water vapor in a column of the atmosphere and the vertical distribution of temperature and water vapor—measurements crucial to understanding Earth's climate system.
- MODIS is ideal for monitoring large-scale changes in the biosphere that are yielding new insights into the workings of the global carbon cycle.
- Coupled with the sensor's surface temperature measurements, MODIS' measurements of the biosphere are helping scientists track the sources and sinks of carbon dioxide in response to climate changes.
- Together with SNPP VIIRS it will provide 20+ years of aerosol information (climate forcing), and surface temperature trend (impact).

NASA Missions for Climate

CloudSat

- CloudSat is studying clouds in detail to better characterize the role they play in regulating Earth's climate.
- CloudSat is providing the first direct, global survey of the vertical structure and overlap of cloud systems and their liquid- and ice-water contents.
- Data returned should lead to improved cloud representations in atmospheric models, helping improve the accuracy of weather forecasts and climate predictions made using these models.

https://cloudsat.atmos.colostate.edu/home

Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO)

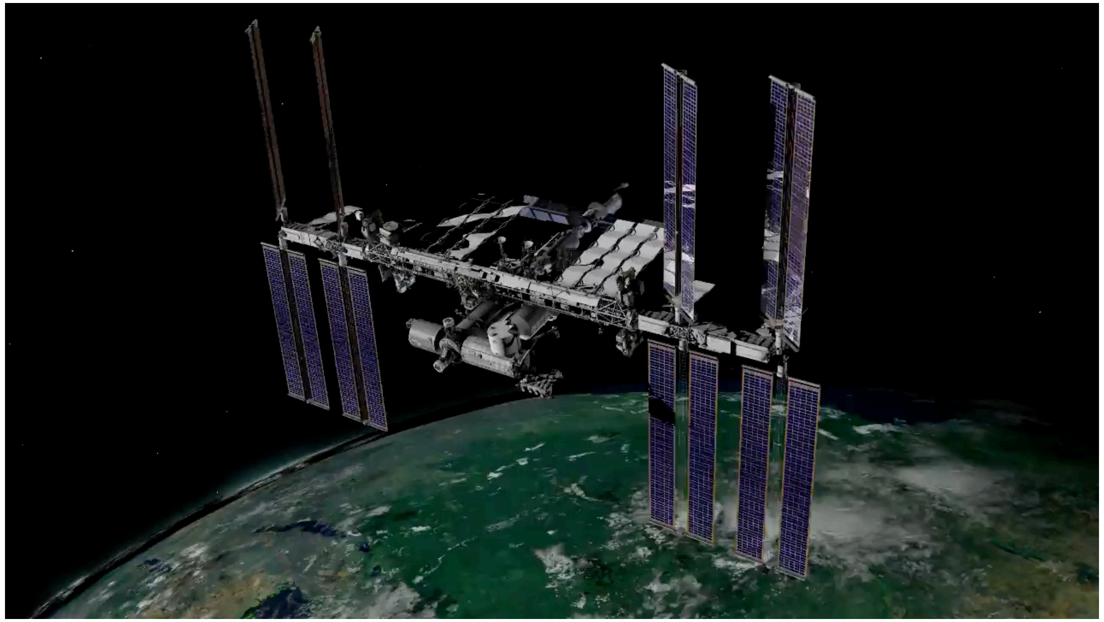
- CALIPSO is a joint NASA/French (CNES) mission. Observations from spaceborne LiDAR, combined with passive imagery, help us understand the role aerosols and clouds play in regulating the Earth's climate.
- CloudSat and CALIPSO were designed to complement each other in the 1990s. They launched together on the same rocket in 2006 and are in the same "C-train" orbit.

https://www-calipso.larc.nasa.gov/

NASA Missions for Climate

Global Ecosystem Dynamics Investigation (GEDI)

- Installed on the International Space Station (ISS), GEDI produces high-resolution laser ranging observations of the 3D structure of the Earth.
- GEDI laser altimetry observations provide unprecedented measurements of the Earth's surface, coastal waters, and **temperate glaciers**.
- GEDI observes wasting sub-polar land ice, including the high mountain Asia and Patagonia glaciers and ice caps, which contribute to sea level rise.



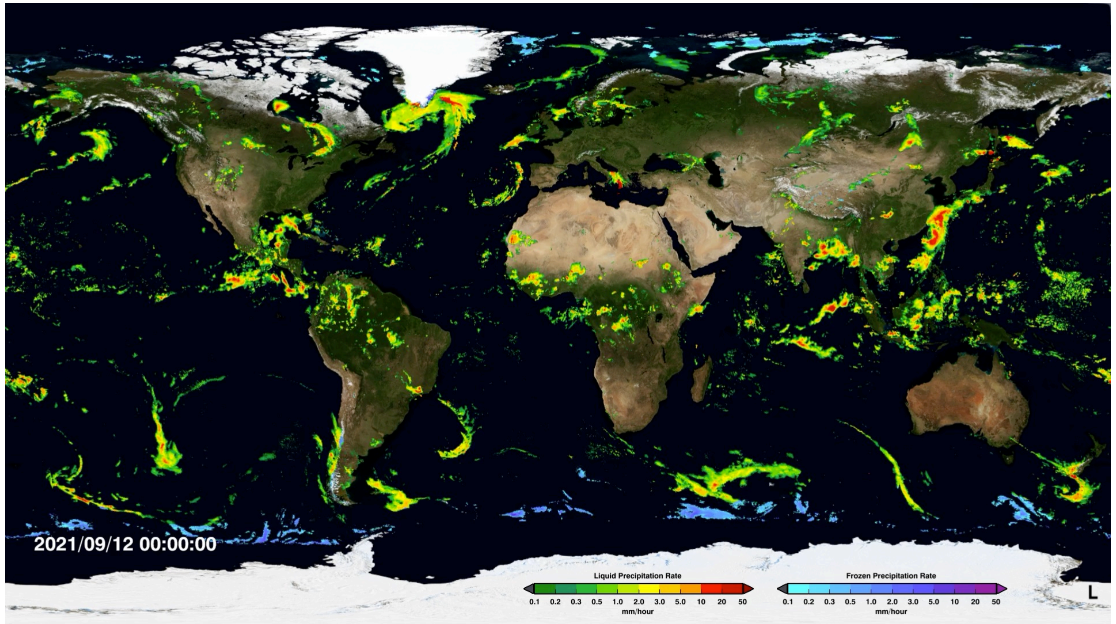
Animation of the Global Ecosystem Dynamics Investigation (GEDI) instrument, as installed on the ISS. GEDI will provide answers to how deforestation has contributed to atmospheric CO2 concentrations, how much carbon forests will absorb in the future, and how habitat degradation will affect global biodiversity.
Credit: NASA's Goddard Space Flight Center

https://gedi.umd.edu/

NASA Missions for Climate

Global Precipitation Measurement Mission (GPM)

- The GPM mission is an international partnership co-led by NASA and JAXA.
- GPM Core Observatory collects data with a constellation of additional satellites that together provide next-generation global observations of precipitation from space.
- The mission improves climate prediction through progress in quantifying space-time variability.
- Part of NASA's Precipitation Measurement Mission (PMM), together with TRMM, which has collected rain and snowfall data from space for 20 years.



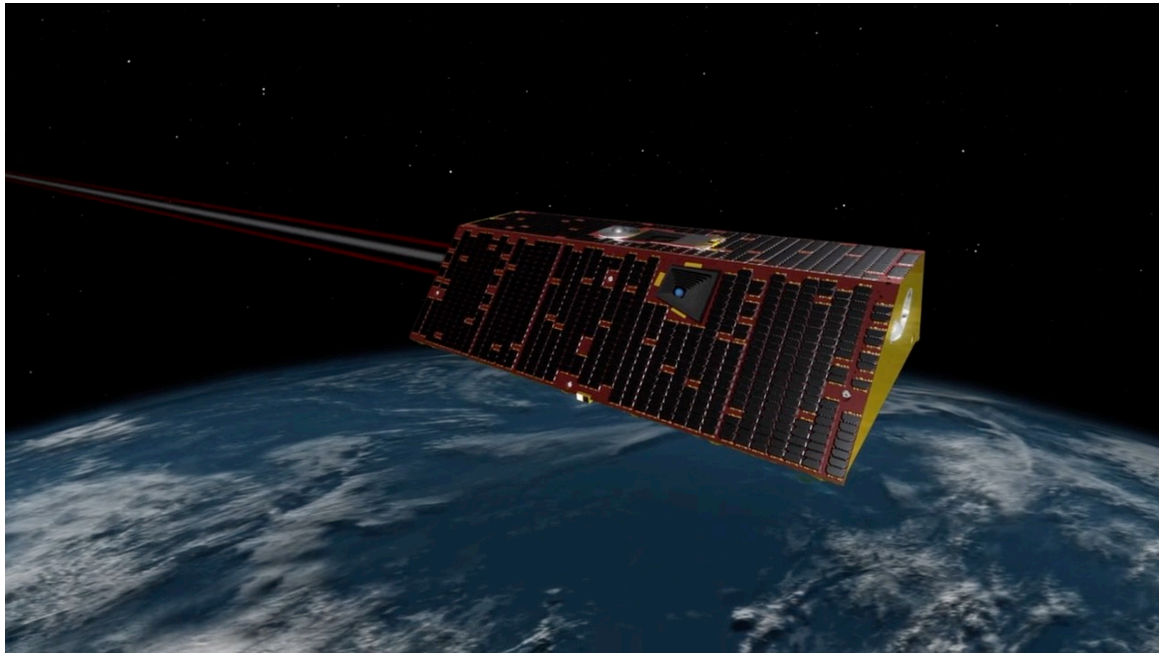
Seven-day visualization of the Integrated Multi-satellitE Retrievals for GPM (IMERG) algorithm, which combines information from the GPM satellite constellation to estimate precipitation over the majority of the Earth's surface. Being able to compare past and present data, researchers are better informed to make climate and weather models more accurate. Credit: [NASA's Scientific Visualization Studio]

https://gpm.nasa.gov/missions/GPM

NASA Missions for Climate

Gravity Recovery and Climate Experiment (GRACE) Follow-On (GRACE-FO)

- GRACE and GRACE-FO track Earth's water movement to monitor changes in underground water storage, the amount of water in large lakes and rivers, soil moisture, ice sheets and glaciers, and sea level.
- These discoveries provide a unique view of Earth's climate and have far-reaching benefits to society and the world's population.
- For more information, refer to the training: https://appliedsciences.nasa.gov/join-mission/training/english/arset-groundwater-monitoring-using-observations-nasas-gravity



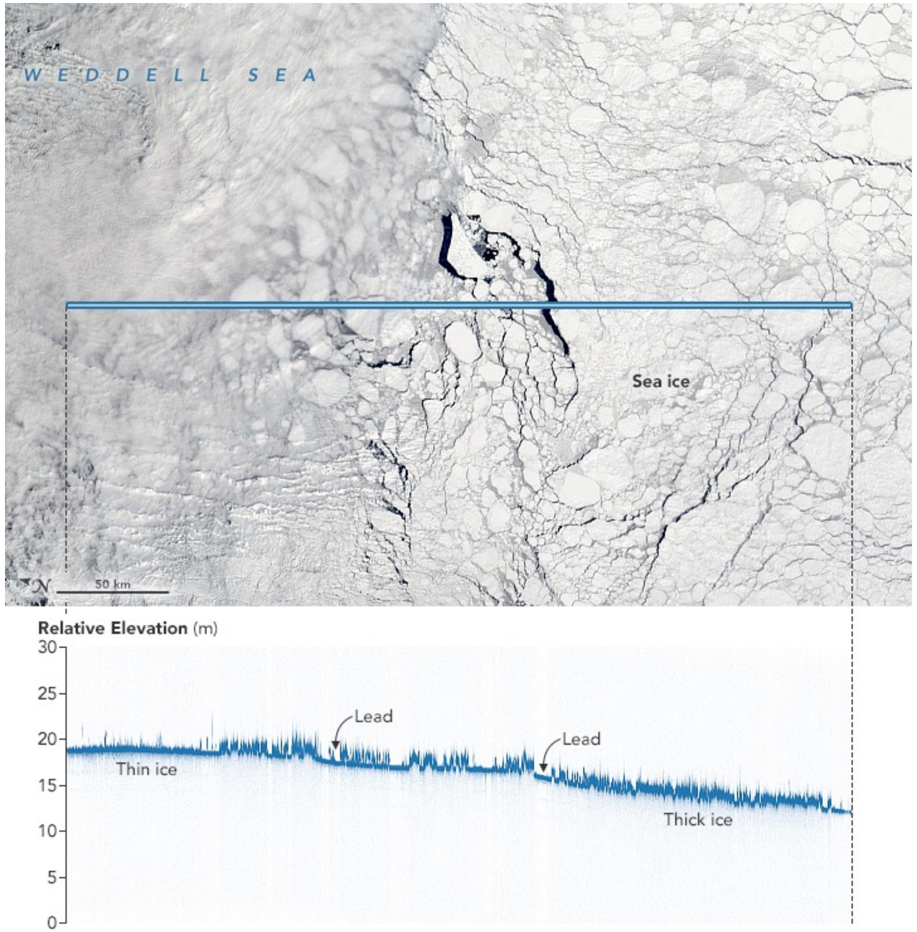
Visualization of how GRACE-FO twin satellites follow each other in orbit, separated by about 137 miles (220 km). They constantly send microwave signals to each other to measure the distance between them. As the pair circles the Earth, areas of slightly stronger gravity (greater mass concentration) pull on the satellites. This information from the satellites is used to construct monthly maps of the Earth's average gravity field, offering details of how mass, in most cases water, is moving around the planet.
Credit: NASA's Scientific Visualization Studio

https://gracefo.jpl.nasa.gov/

NASA Missions for Climate

Ice, Cloud, and land Elevation Satellite-2 (ICESat-2)

- ICESat-2 carries a laser altimeter (ATLAS) that allows scientists to measure the elevation of ice sheets, glaciers, and sea ice.
- The mission will help scientists investigate how the Earth's cryosphere is changing in a warming climate.
- The mission has four science objectives:
  - Measure melting ice sheets and investigate how this effects sea level rise
  - Measure and investigate changes in the mass of ice sheets and glaciers
  - Estimate and study sea ice thickness
  - Measure the height of vegetation in forests and other ecosystems worldwide



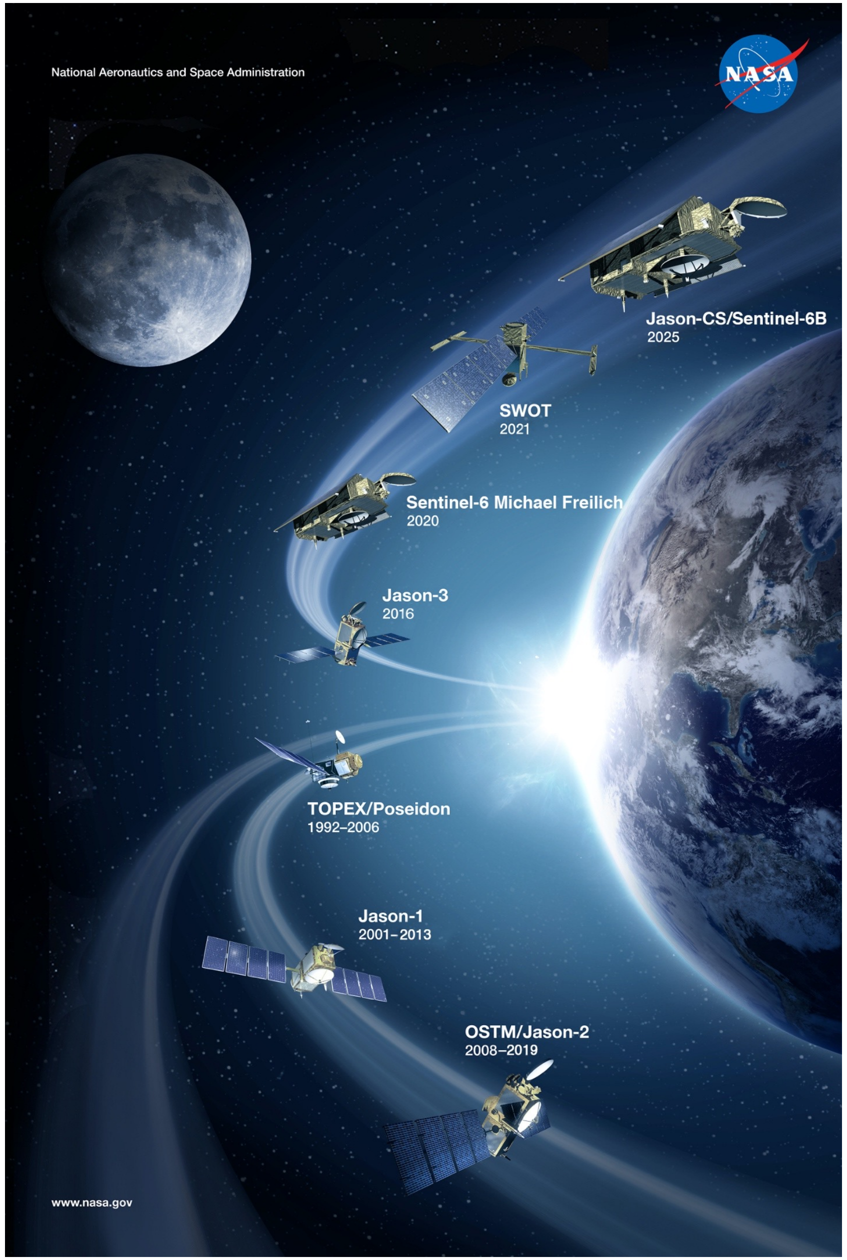
Elevation measurement acquired by ICESat-2 on October 17, 2018, showing the height of the sea ice along an orbital path over the Weddell Sea. For reference, the orbital path is laid over a natural-color image acquired by MODIS on the same day. Credit: Joshua Stevens, using ICESat-2 data courtesy of Kaitlin Harbeck, NASA Goddard Space Flight Center.

https://icesat-2.gsfc.nasa.gov/

NASA Missions for Climate

Jason-3

- Jason-3 is the fourth mission in a U.S.-European series of satellite missions that measure the height of the ocean's surface using radar altimetry going back to 1992.
- The measurements provide scientists with critical information about circulation patterns in the ocean and both global and regional changes in sea level and the climate implications of a warming world.
- For nearly three decades, satellite altimeters have provided a precise, continuous record of global sea level with excellent spatial and temporal resolution.



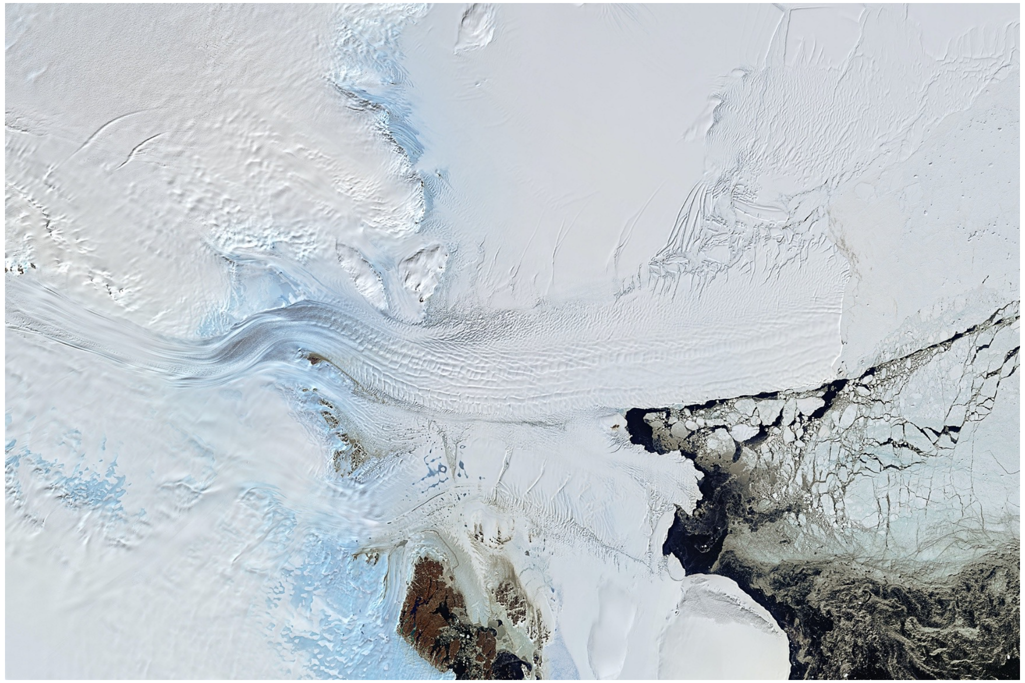
Past, present, and future NASA altimetry missions.
Credit: NASA

https://sealevel.jpl.nasa.gov/missions/jason-3/summary/

NASA Missions for Climate

Landsat 7, 8, and 9

- A joint NASA/USGS mission
- The data from Landsat spacecraft constitute the longest record of coastal regions, polar ice, islands, and continental areas as seen from space.
- The missions characterize and monitor land-cover use and change over time for global climate research, polar studies, and the impacts of natural events as well as human activities on Earth's surface.



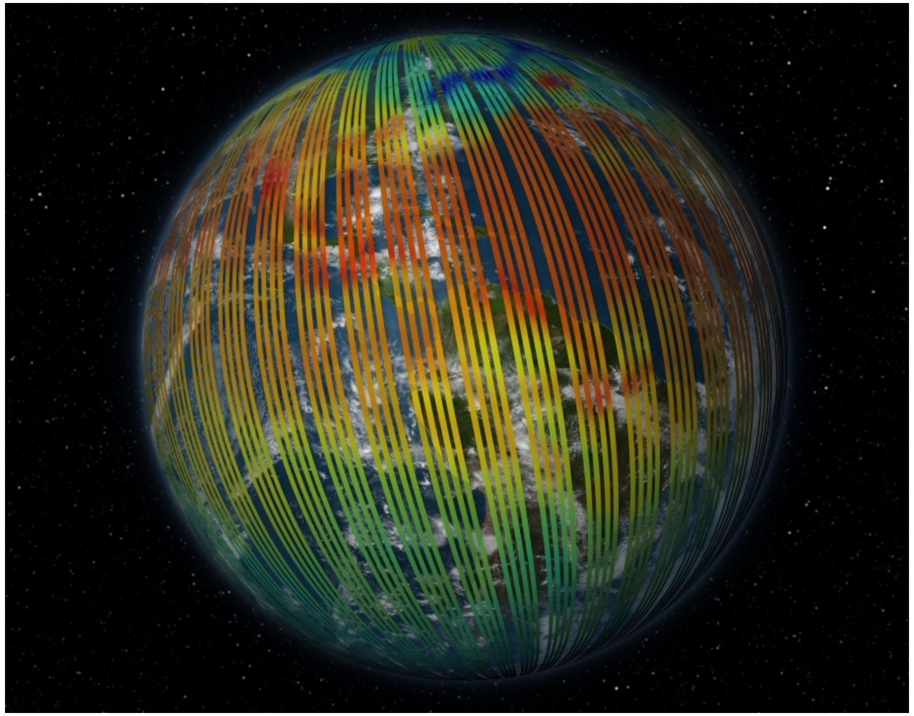
Mosaic of cloud-free images acquired by Landsat 8 from February 26-28, 2020, of the Denman Glacier (Antarctica).
Credit: USGS, NASA Earth Observatory

https://landsat.gsfc.nasa.gov/

NASA Missions for Climate

Orbiting Carbon Observatory (OCO)-2

- OCO-2 is collecting space-based global measurements of atmospheric CO_2 with the precision, resolution, and coverage needed to characterize sources and sinks on regional scales.
- OCO-2 will be able to quantify CO_2 variability over the seasonal cycles year after year.
- This enhanced understanding is essential for improving predictions of future atmospheric CO_2 increases and their impact on Earth's climate.



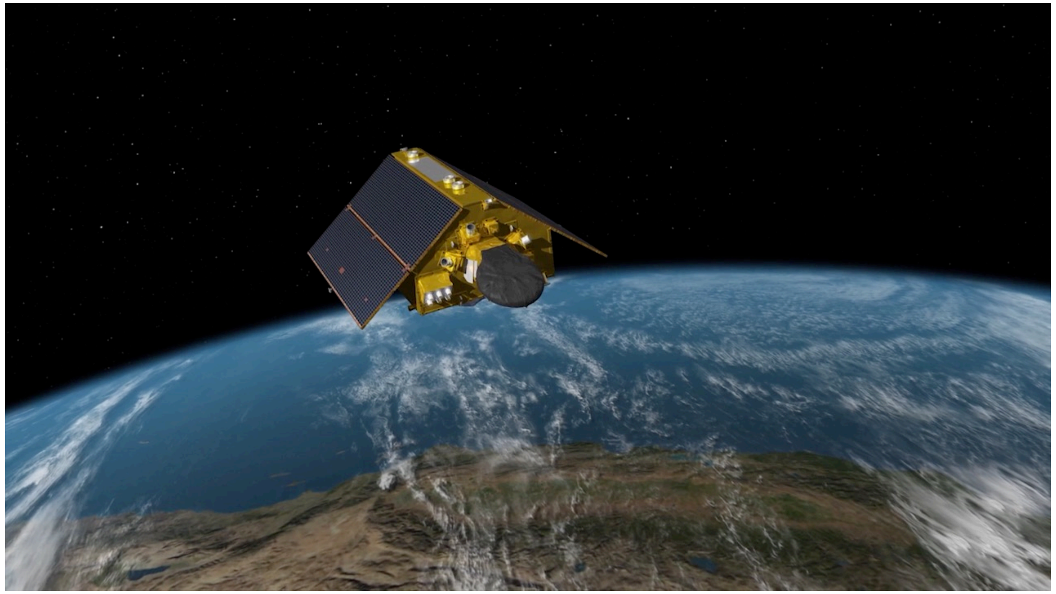
The OCO-2 satellite will produce a global map of carbon dioxide every 16 days (233 orbits), allowing scientists to locate ground sources and monitor how levels worldwide are changing over time. Credit: NASA's Goddard Space Flight Center, image courtesy of NASA/JPL-Caltech

https://ocov2.jpl.nasa.gov/

NASA Missions for Climate

Sentinel-6 Michael Freilich

- A joint U.S.-European effort to collect the most accurate data yet on sea level and how it changes over time.
- The mission consists of two identical satellites that will be launched five years apart (Sentinel-6 Michael Freilich launched on Nov. 21, 2020).
- Both satellites use a radar altimeter to measure sea level down to the centimeter for more than 90% of the world's oceans. The data they collect will add to a long-term dataset that began with a joint U.S.-French effort called TOPEX/Poseidon in 1992.



Visualization of Sentinel-6 Michael Freilich collecting radar altimetry data over the Earth's oceans to monitor sea level down to the centimeter and how it changes over time. Credit: NASA's Scientific Visualization Studio

https://www.nasa.gov/sentinel-6

NASA Missions for Climate

Soil Moisture Active Passive (SMAP)

- The SMAP mission measures the amount of water in the surface soil everywhere on Earth.
- SMAP will produce global maps of soil moisture and scientists will use these to help improve our understanding of how water, energy, and carbon fluxes maintain our climate and environment.
- Soil moisture information is key to understanding the flows of water and heat energy between the surface and atmosphere that impact weather and climate.

Animation of SMAP launching and collecting data. SMAP produces global maps of soil moisture every 2-3 days.
Credit: NASA/Jet Propulsion Laboratory

https://smap.jpl.nasa.gov/

NASA Missions for Climate

Suomi National Polar-orbiting Partnership (Suomi-NPP)

- Suomi-NPP represents the gateway to the creation of a U.S. climate monitoring system, collecting both climate and operational weather data and continuing data records that are critical for global climate change science.
- The mission maintains a global record of atmospheric, land surface, and sea surface temperatures critical to understanding the long-term dynamics of climate change.
- Monitors changes to Earth's sea ice, land ice, and glaciers to track the pace of climate change.

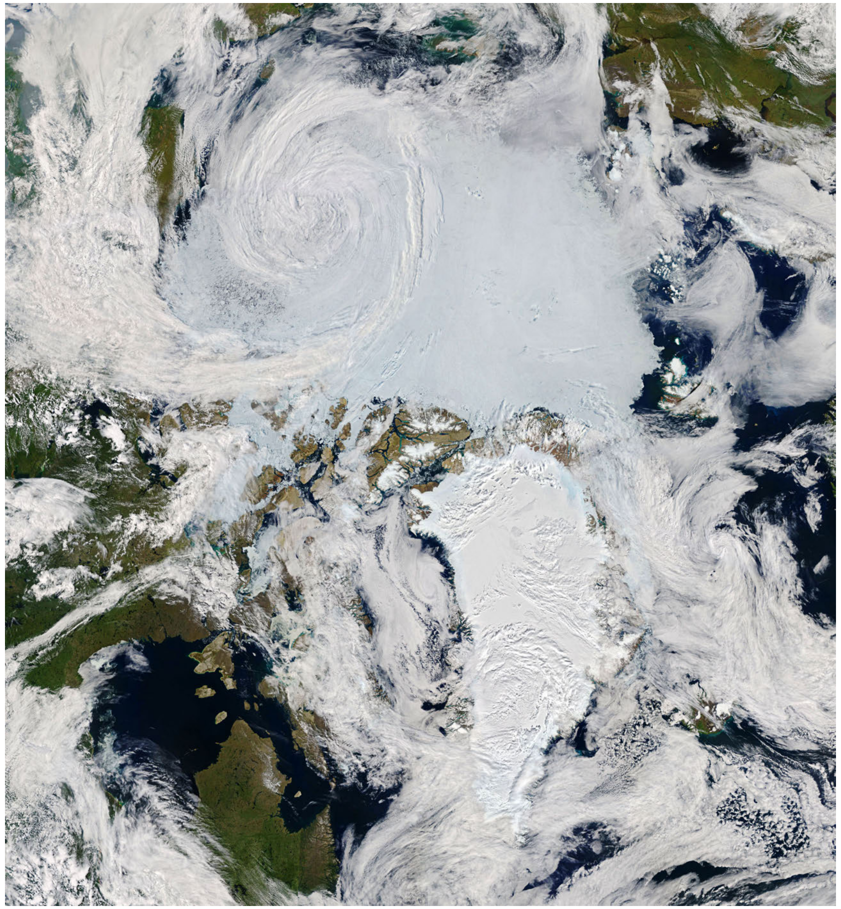
Composite image of North and South America at night assembled from data acquired by the Suomi-NPP satellite in April and October 2012. The new data was mapped over existing Blue Marble imagery of Earth to provide a realistic view of the planet. Credit: NASA

https://www.nasa.gov/mission_pages/NPP/main/index.html

NASA Missions for Climate

Terra

- The Terra satellite is the flagship of NASA's Earth Observing System (EOS), providing global data on the state of the atmosphere, land, and oceans, and their interactions with solar radiation and with one another.
- Terra's five instruments provide important climate measurements that record how Earth's energy budget—the amount of energy flowing through the Earth system from the Sun—is changing.
- The satellite launched on December 18, 1999, and has provided near-global coverage every 1-2 days for 21 years.



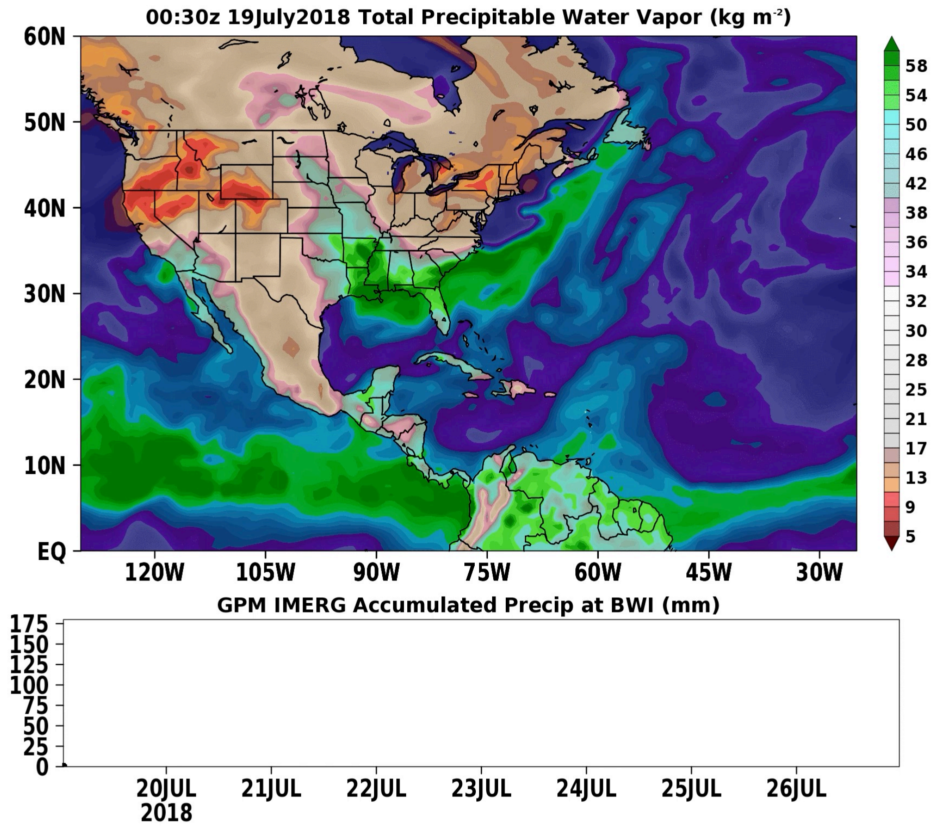
An atmospheric low-pressure system over the Arctic Ocean, captured on July 28, 2020 by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra and Aqua satellites. Credit: NASA

https://terra.nasa.gov/

Modeled Data for Proxy Observations

Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2)

- The Global Modeling and Assimilation Office (GMAO) is a NASA organization that uses computer models and data assimilation techniques to enhance NASA's program of Earth observations.
- MERRA-2 is the first long-term, global reanalysis to assimilate space-based observations of aerosols and represent their interactions with other physical processes in the climate system.
- MERRA-2 provides data beginning in 1980 and runs a few weeks behind real time.



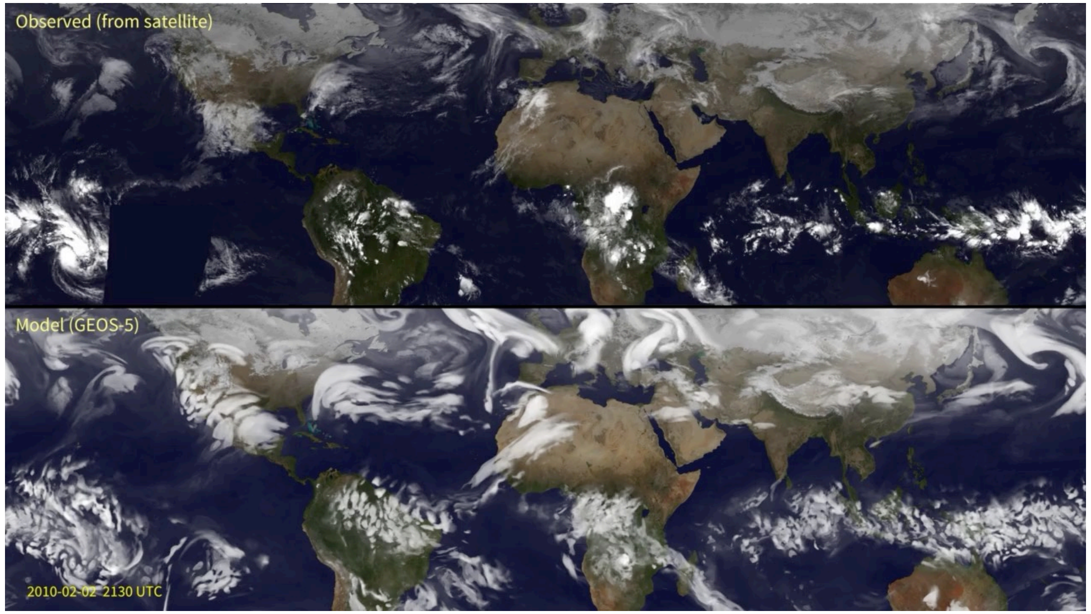
Beginning on July 21, 2018, an atmospheric river positioned itself over the region, resulting in record daily rainfall totals and extensive flash flood warnings as the entire months' worth of precipitation fell in a matter of days. This rainfall event was clearly captured by GMAO's MERRA-2. Throughout the multi-day precipitation event, a sub-tropical high-pressure system was present over the Atlantic Ocean and a digging trough extended south into the Gulf of Mexico and north to the east coast. Both features helped guide the transport of water vapor into the Maryland area, as evident in the animation. Credit: NASA GMAO

https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/

Modeled Data for Proxy Observations

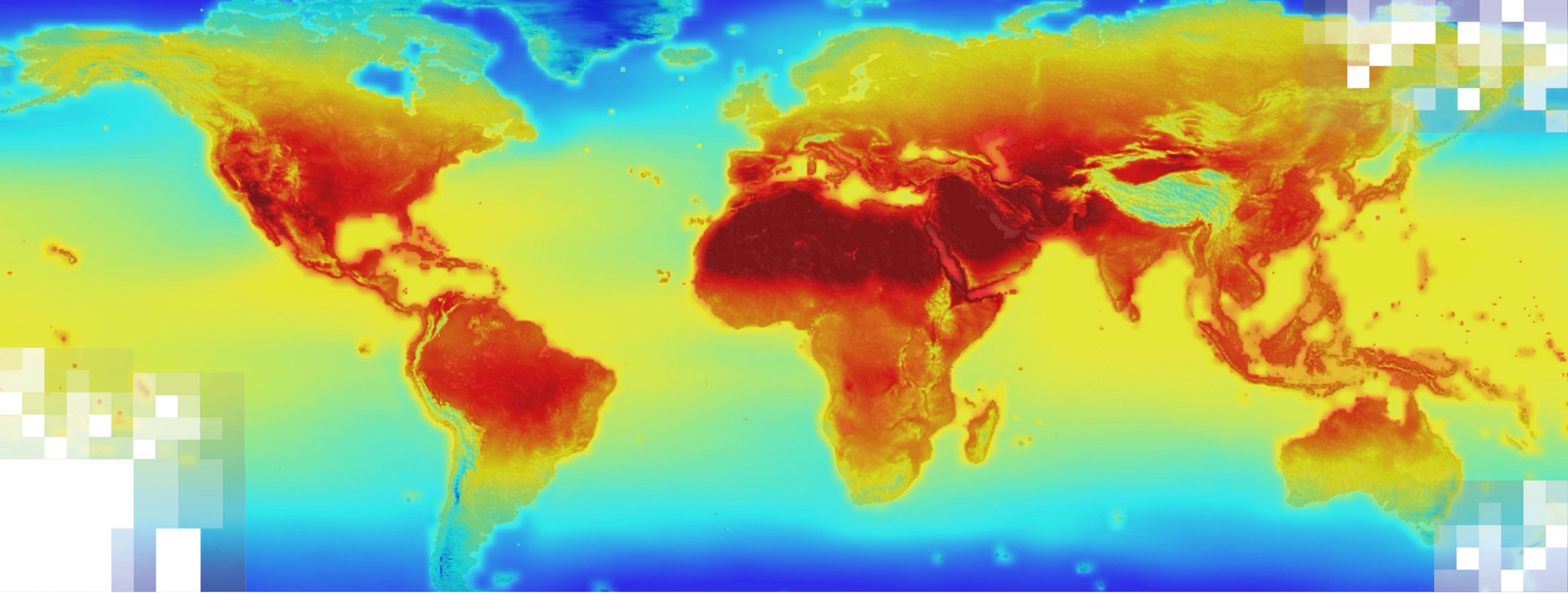
Goddard Earth Observing System (GEOS)

- The GEOS family of models is used by the GMAO for applications across a wide range of spatial scales, from kilometers to many tens of kilometers.
- GMAO's work with GEOS spans a large range of space and time scales, and the modular structure of the models encompasses the representation of dynamical, physical, chemical, and biological processes which are chosen according to the application.



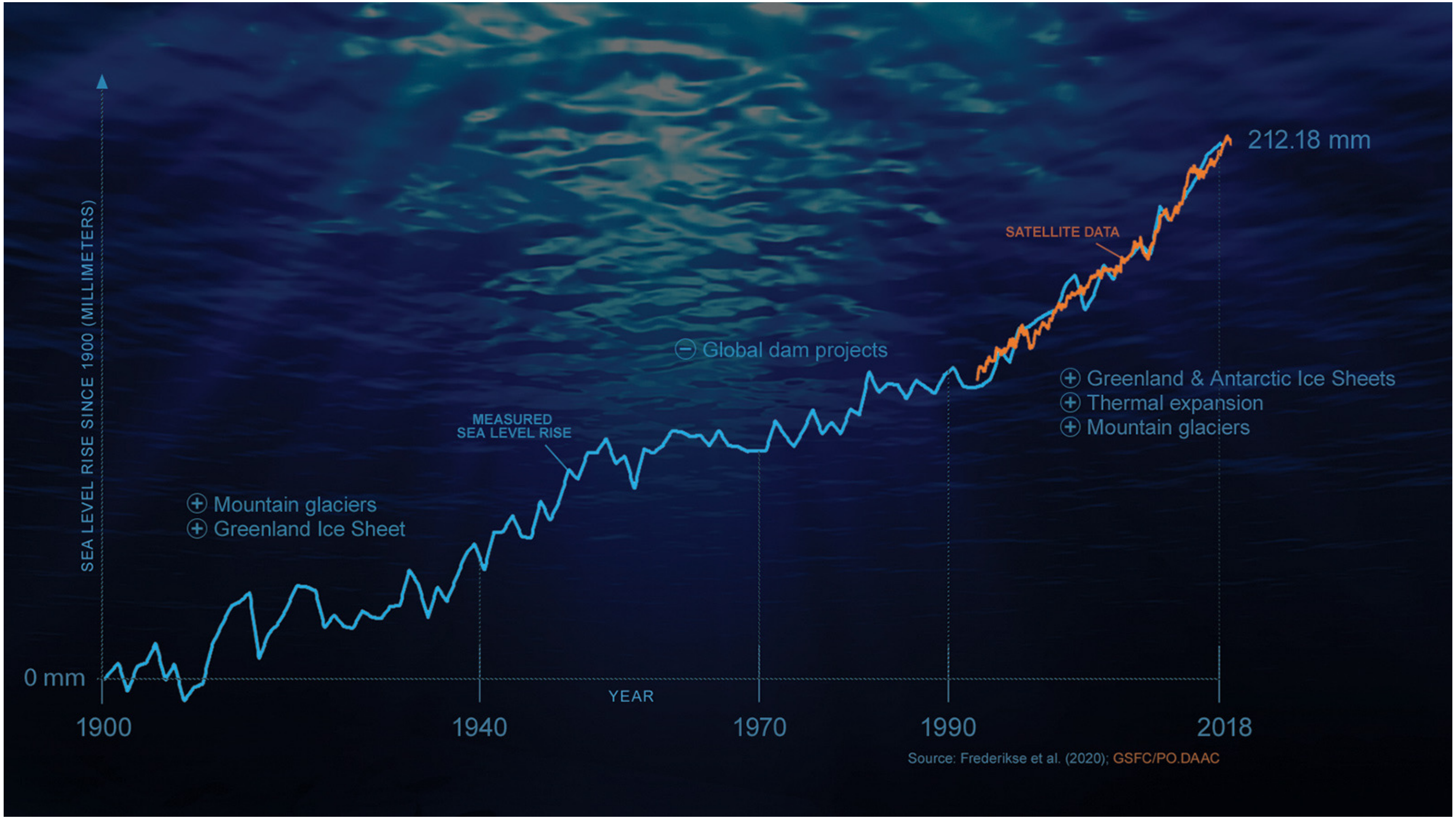
This animation compares data taken by several geostationary weather satellites, including the Geostationary Operational Environmental Satellites (GOES), and the Goddard Earth Observing System Model, Version 5 (GEOS-5). GEOS-5 is an assimilation model that starts from observations taken by satellites such as GOES and then builds a forecast for some days into the future. The period of time shown here is during February 2010, which brought record snowfall to the east coast of the United States. Credit: NASA Goddard Space Flight Center

https://gmao.gsfc.nasa.gov/GEOS_systems/



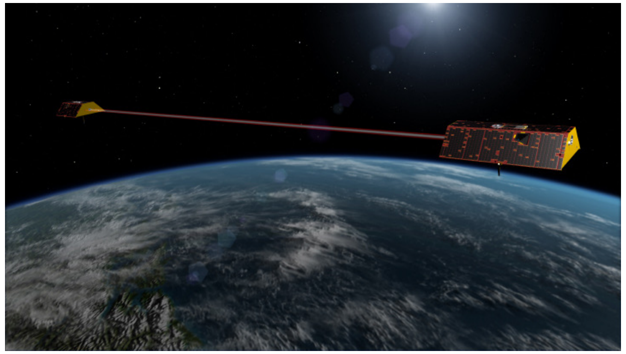
Monitoring Climate Change Impacts Using NASA Data

Global Mean Sea Level



Why is sea level rising globally?

Ice (GRACE-FO)



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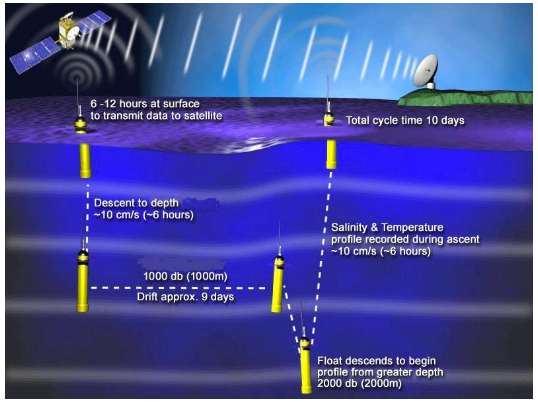
Thermal Expansion (Argo)



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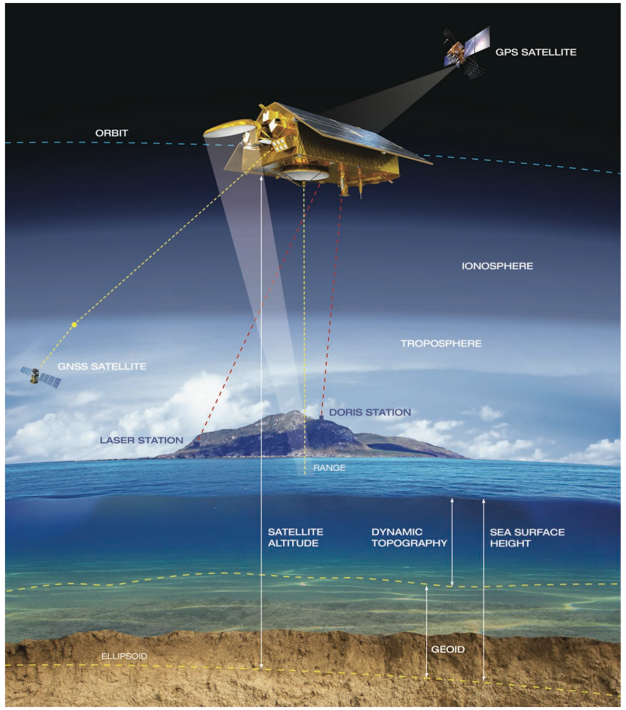
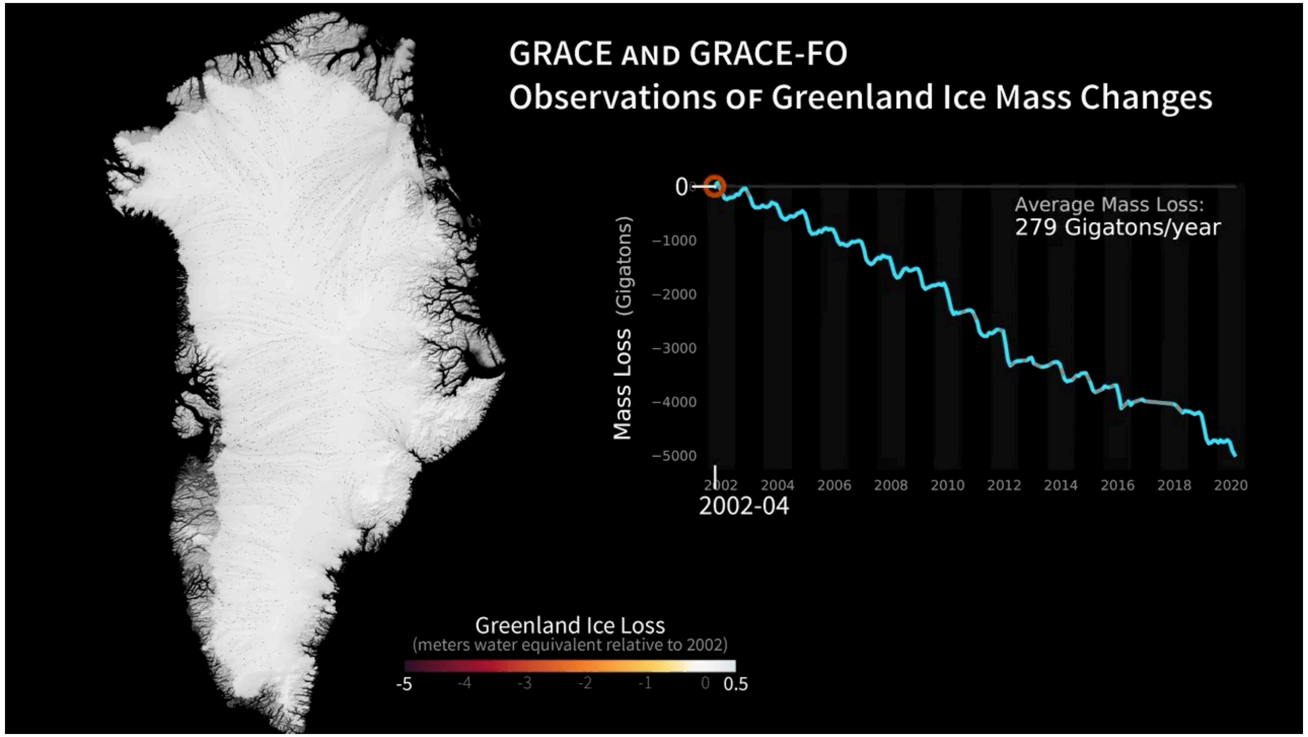
Total Sea Level (Altimetry)



GRACE and GRACE-FO

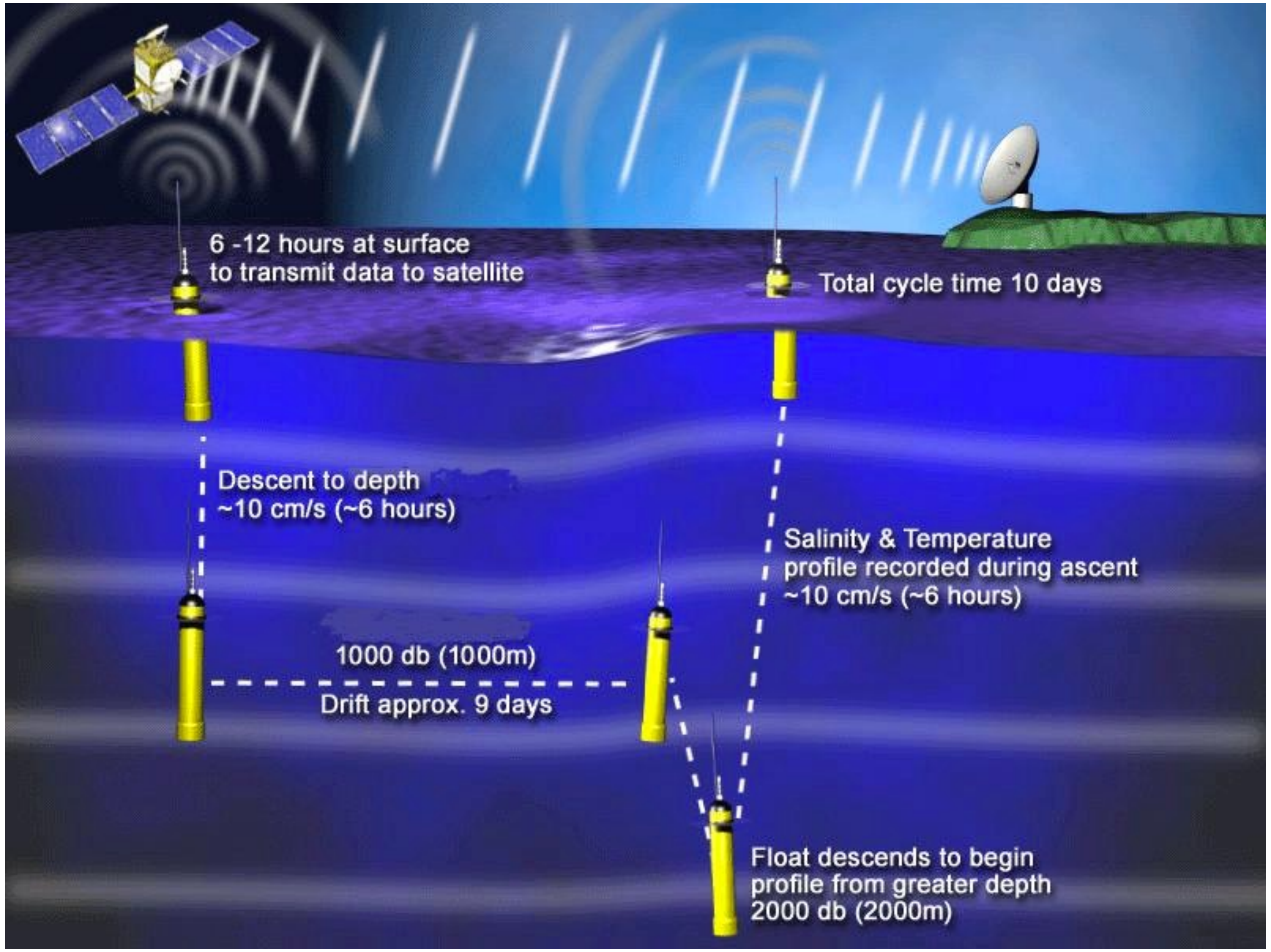
- Gravity Recovery & Climate Experiment (GRACE; 2002-2016) and GRACE Follow-On (GRACE-FO; 2018-pres.) measure gravity changes on Earth.
  - These satellites can tell us how much ice is being lost across Earth's ice sheets and glaciers (e.g., Greenland & Antarctica)
  - They also tell us about the movement of water on Earth.



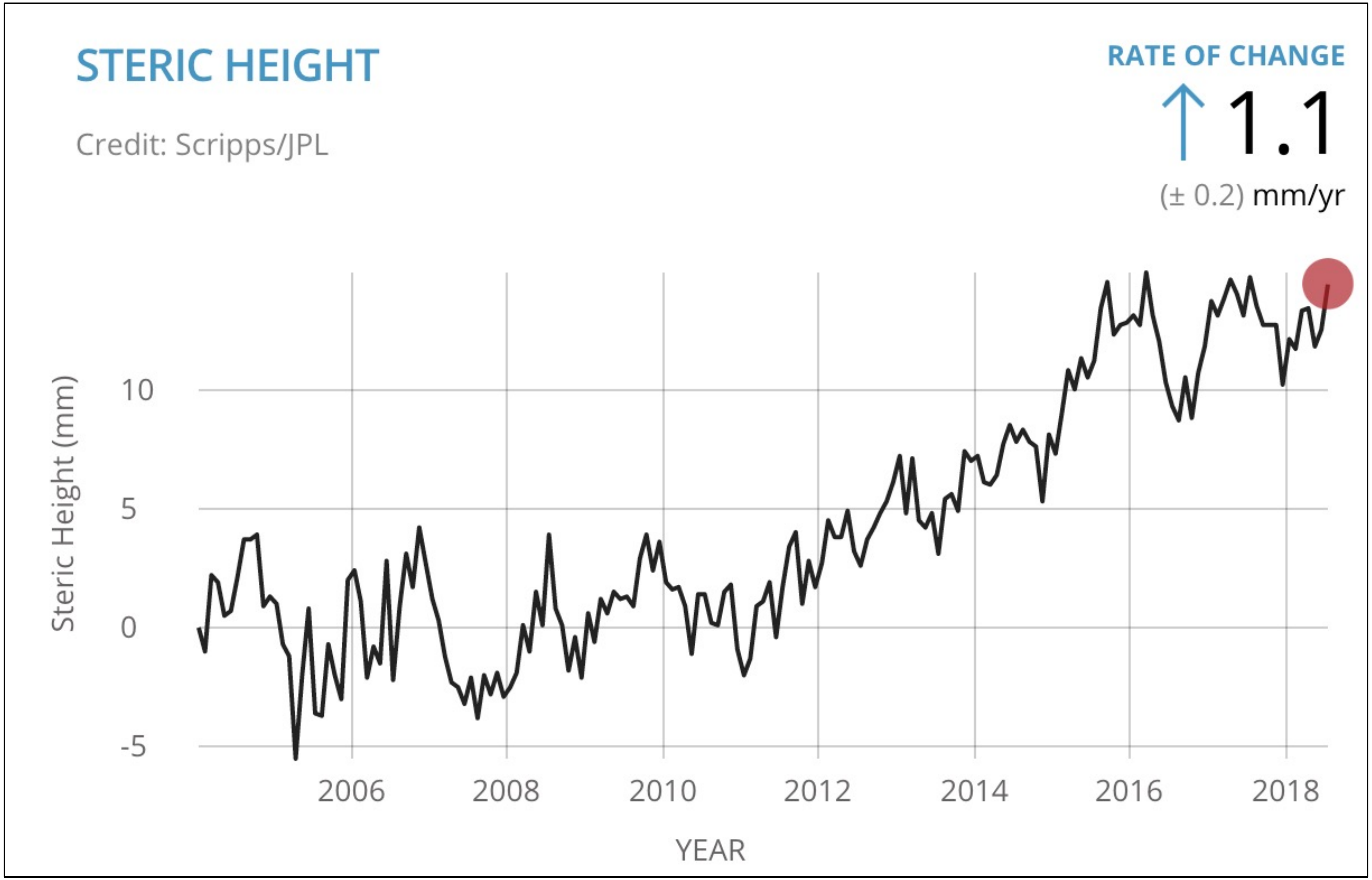
The mass of the Greenland ice sheet has rapidly declined in the last several years due to surface melting and iceberg calving. Research based on observations from the GRACE satellites (2002-2017) and GRACE-FO (since 2018) indicates that between 2002 and 2020, Greenland shed approximately 280 gigatons of ice per year, causing global sea level to rise by 0.8 millimeters (0.03 inches) per year. Credit: NASA and JPL/Caltech

Argo Profiling Floats

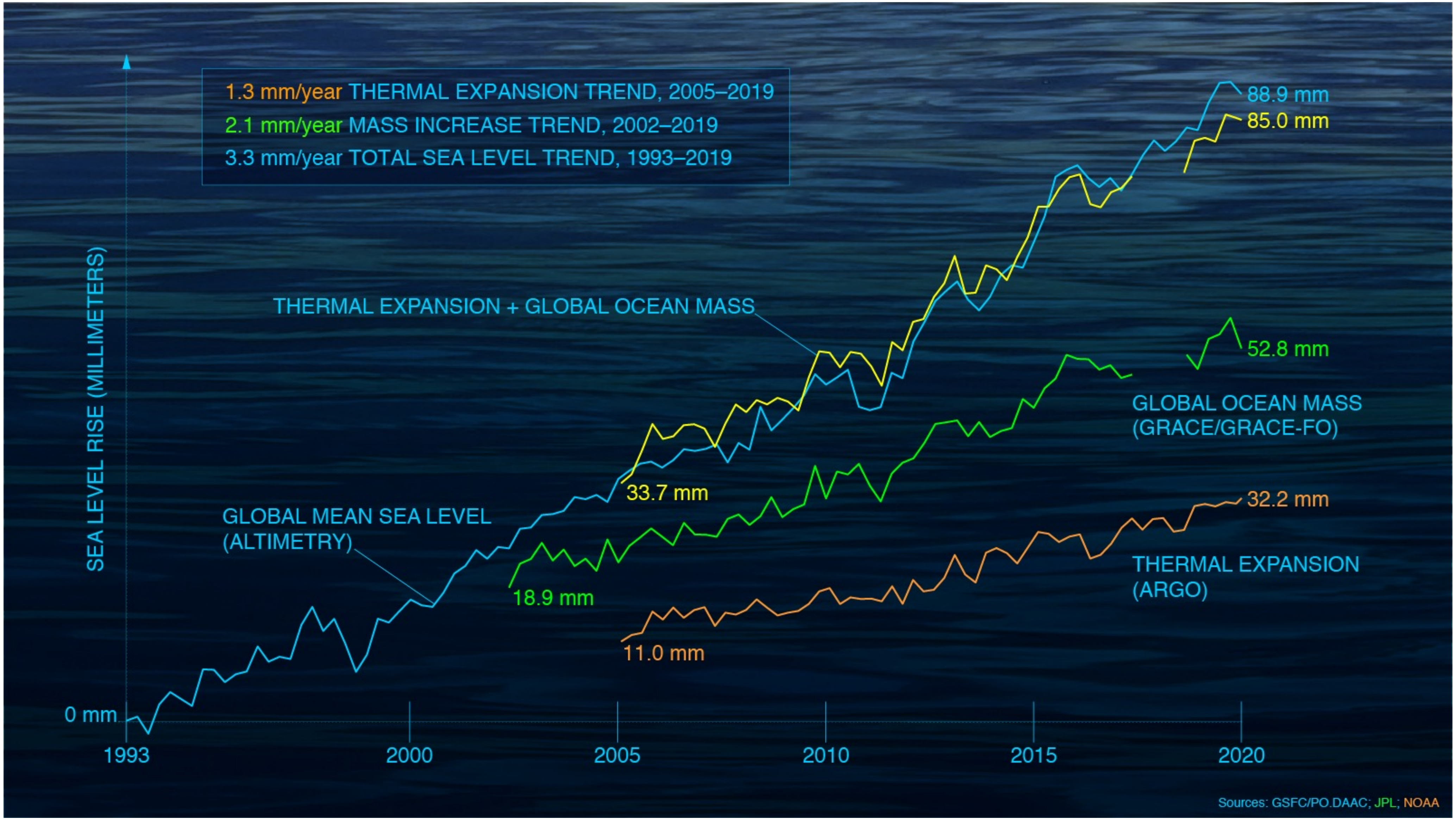
- Since ~2005, Argo profiling floats have been measuring the temperature and salinity of the ocean from 0 to 2000 m below the surface.
- From these measurements we can estimate the impact of thermal expansion on sea level rise.



Sea Level Change from Thermal Expansion



Closing the Sea Level "Budget"



Regional Sea Level Change

- Sea level changes on a wide range of spatial and temporal scales.
- The ocean does not behave like a bathtub.
- Contributions to the pattern of regional sea level change include:
  - Natural variability signals like El Niño - Southern Oscillation and North Atlantic Oscillation.
  - Ice-sheet “fingerprints”.

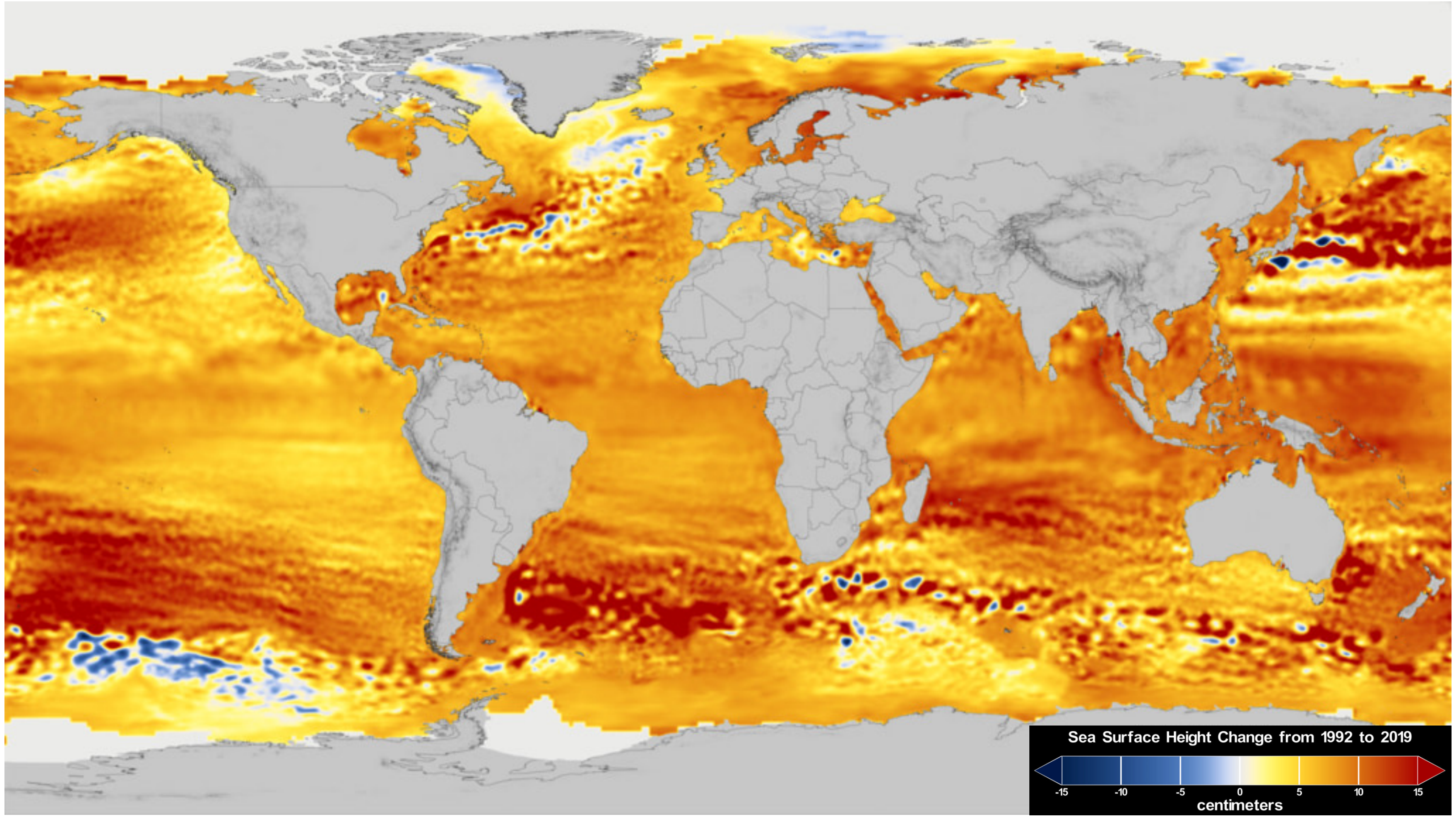


Image showing sea surface height changes from 1992 to 2019 in cm using satellite altimetry data.
Credit: NASA GSFC Visualization Studio

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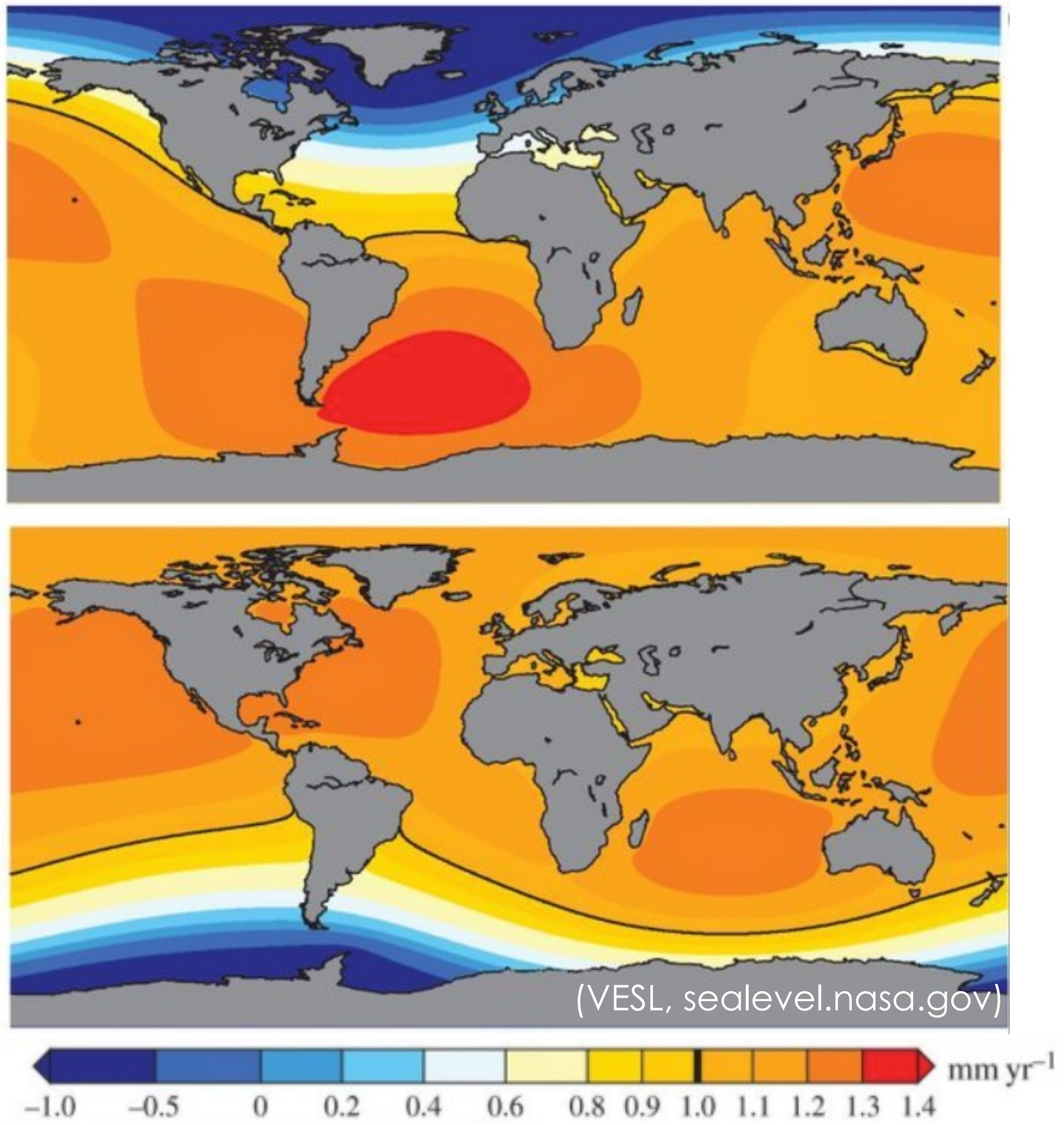

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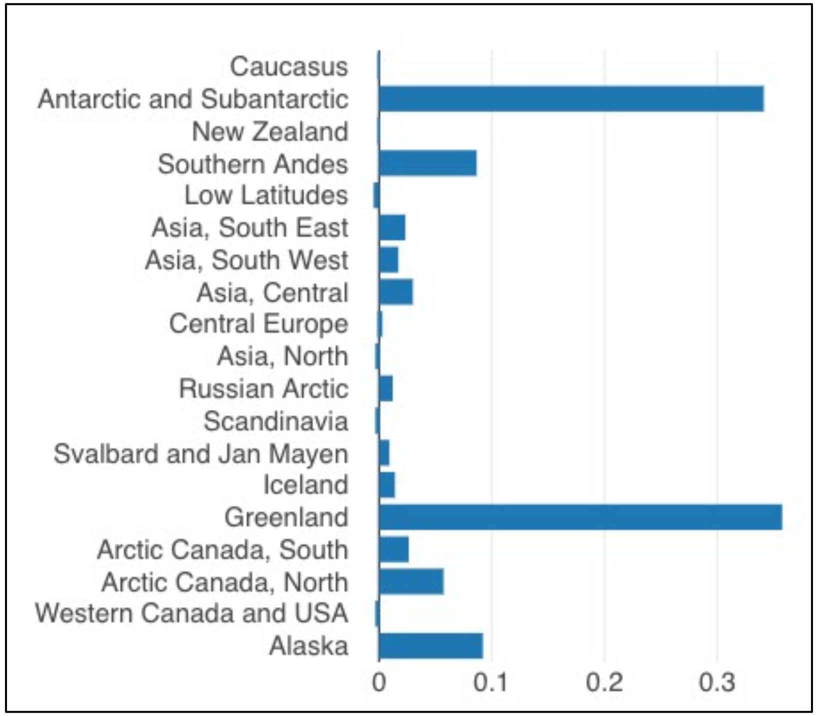
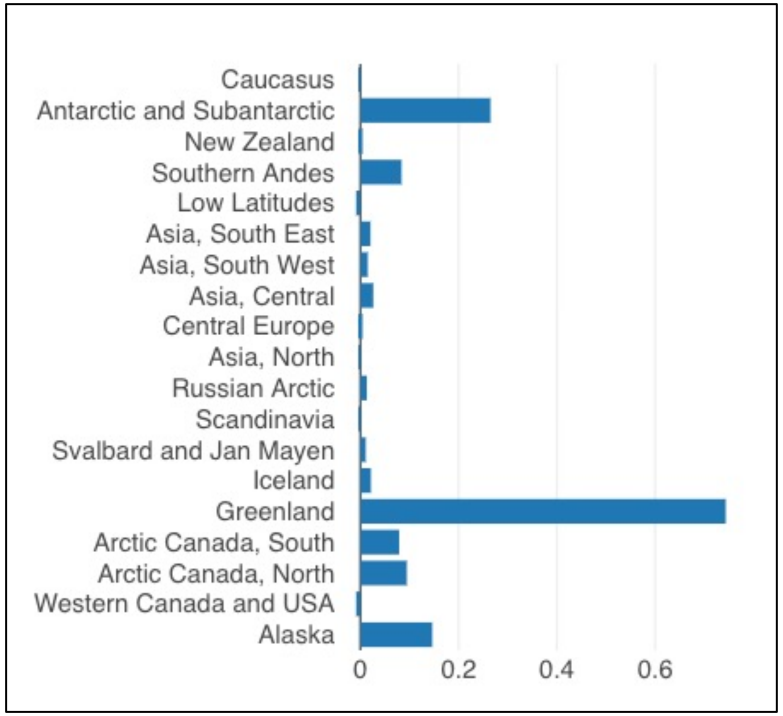
New York City: 1.06 mm/yr



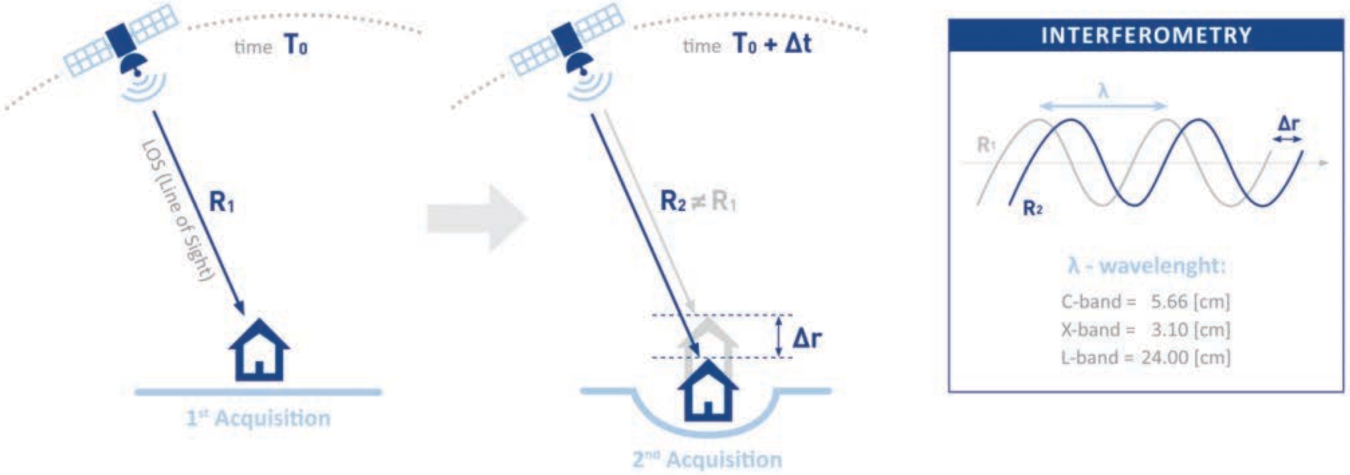
Sydney: 1.50 mm/yr



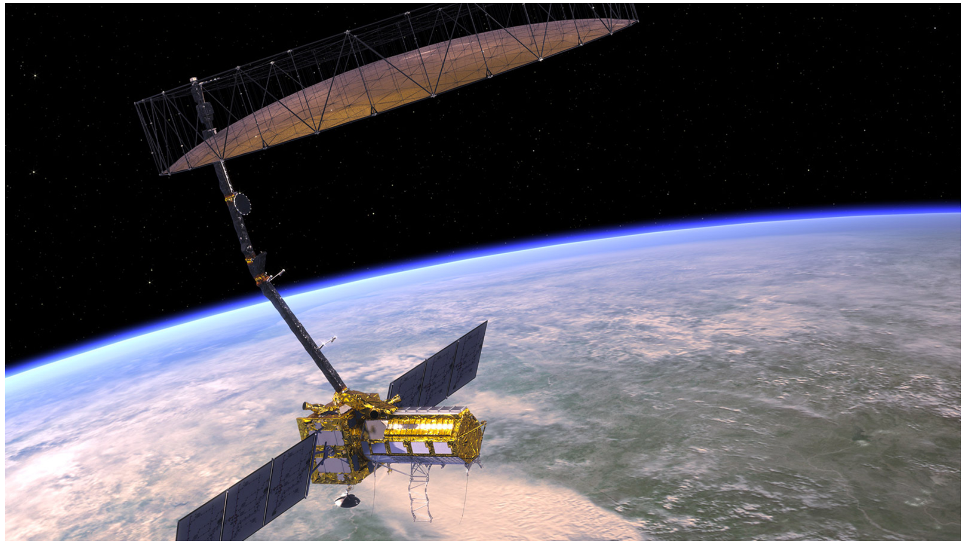
Credit: VESL, sealevel.nasa.gov

Coastal Subsidence

- In addition to the ocean rising, many coastal regions around the world are sinking. This contributes to a rise in *relative sea level*.
  - Groundwater withdrawal, glacial isostatic adjustments, and tectonics.
- Interferometric Synthetic Aperture Radar Analysis (InSAR) can be used to estimate this movement of land at high spatial resolutions.
  - Satellite measures change from one pass to another over the same location.



Credit: https://site.tre-altamira.com/



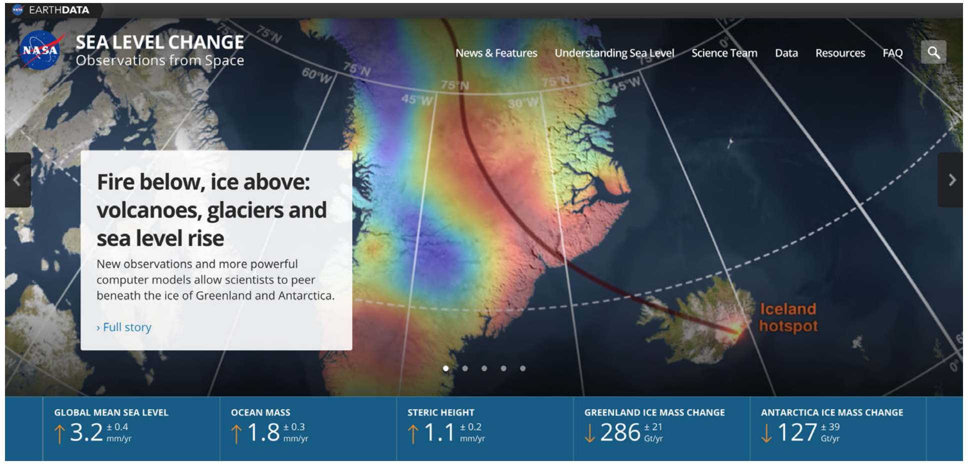
https://nisar.jpl.nasa.gov/

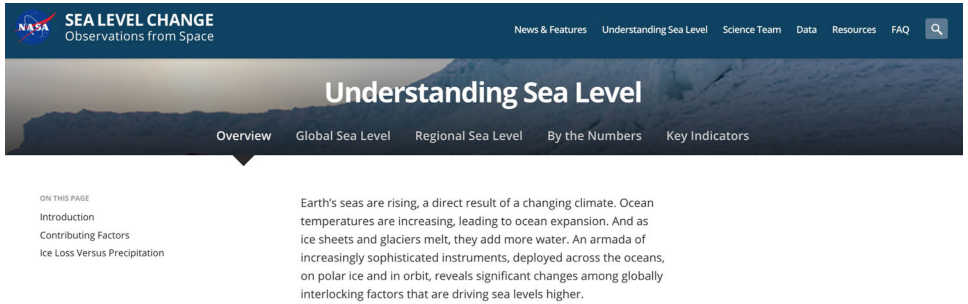
NASA Sea Level Change Team

- Satellites will play a critical role in monitoring these processes and provide important information to decision-makers and planners.
  - What can NASA do to provide “useful” information?
- To meet this challenge, NASA created the **NASA Sea Level Change Team** (N-SLCT) in 2014.
  - sealevel.nasa.gov was created as part of this effort.
  - 70+ scientists from government and academia.

Two Goals:

- Science: Provide improved forecasts of sea level across a range of timescales.
- Outreach: Connect with practitioners and stakeholders to define and provide ‘useful’ sea-level information.

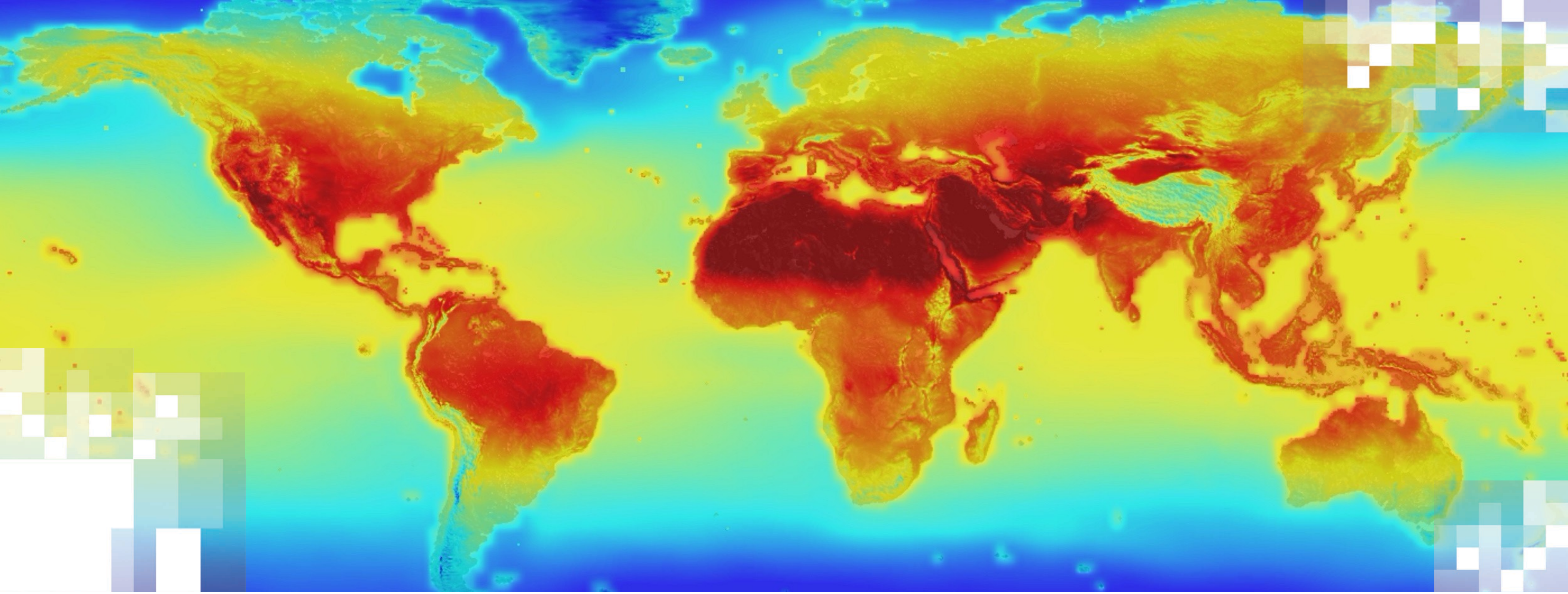




Satellite and Integrated Products

- A full list of data tools on NASA sea level portal can be found here: https://sealevel.nasa.gov/data/tools.
- As a demonstration of how these tools and data can be combined to understand past, present, and future sea level, refer to the links below:

1. Data Analysis Tool: https://sealevel.nasa.gov/data_tools/1
2. Virtual Earth System Laboratory: https://sealevel.nasa.gov/data_tools/2
3. Sea Level Evaluation and Assessment Tool: https://sealevel.nasa.gov/data_tools/16
4. IPCC AR6 Sea Level Projection Tool: https://sealevel.nasa.gov/data_tools/17
5. Flooding Days Projection Tool: https://sealevel.nasa.gov/data_tools/15



Climate Change Decision Making

Responding to Climate Change

- NASA is a world leader in climate studies and Earth science. While its role is not to set climate policy or prescribe particular responses or solutions to climate change, its purview does include providing the robust scientific data needed to understand climate change.
- NASA then makes this information available to the global community – the public, policy- and decision-makers, and scientific and planning agencies around the world.

Responding to Climate Change

- Climate change is one of the most complex issues facing us today. It involves many dimensions – science, economics, society, politics, and moral and ethical questions – and is a global problem, felt on local scales, that will be around for decades and centuries to come.
- Carbon dioxide, the heat-trapping greenhouse gas that has driven recent global warming, lingers in the atmosphere for hundreds of years, and the planet (especially the oceans) takes a while to respond to warming.
- Even if we stopped emitting all greenhouse gases today, global warming and climate change will continue to affect future generations.
- In this way, humanity is "committed" to some level of climate change.

Credit: NASA Global Climate Change

https://climate.nasa.gov/solutions/adaptation-mitigation/

Responding to Climate Change

- Despite increasing awareness of climate change, our emissions of greenhouse gases relentlessly continue to rise.
- In 2013, the daily level of carbon dioxide in the atmosphere surpassed **400 parts per million** (ppm) for the first time in human history. The last time levels were that high was about three to five million years ago, during the Pliocene Epoch.
- Because we are already committed to some level of climate change, responding to climate change involves a two-pronged approach:
  1. Reducing emissions of and stabilizing the levels of heat-trapping greenhouse gases in the atmosphere **(“mitigation”)**;
  2. Adapting to the climate change already in the pipeline **(“adaptation”)**.

https://climate.nasa.gov/solutions/adaptation-mitigation/

Responding to Climate Change

- **Mitigation** – Reducing climate change involves reducing the flow of heat-trapping greenhouse gases into the atmosphere, either by reducing sources of these gases (for example, the burning of fossil fuels) or enhancing the "sinks" that accumulate and store these gases (i.e., oceans, forests, and soil).
- **Adaptation** – Adapting to life in a changing climate involves adjusting to actual or expected future climate. The goal is to reduce our vulnerability to the harmful effects of climate change (like sea-level encroachment, more intense extreme weather events, or food insecurity).

https://climate.nasa.gov/solutions/adaptation-mitigation/

Responding to Climate Change

- NASA, with its eyes on the Earth and wealth of knowledge on the Earth's climate system and its components, is one of the world's experts in climate science.
- NASA makes detailed climate data available to the global community – the public, policy- and decision-makers, and scientific and planning agencies around the world.
- Started in 2010, NASA's Carbon Monitoring System (CMS) is a forward-looking initiative established under direction of the U.S. government. The CMS is improving the monitoring of global carbon stocks and fluxes.
- NASA's related Megacities Carbon Project is focused on the problem of accurately measuring and monitoring greenhouse-gas emissions from the world's biggest cities. About three-quarters of fossil-fuel carbon dioxide emissions come from about 2 percent of the land surface – namely the cities and the power plants that feed them.
- Although NASA's main focus is not on energy-technology research and development, work is being done around the agency and with/by various partners and collaborators to find viable alternative sources of energy to power our needs. These sources of energy include the wind, waves, the Sun, and biofuels.

https://climate.nasa.gov/solutions/adaptation-mitigation/

Responding to Climate Change

Earth System Observatory

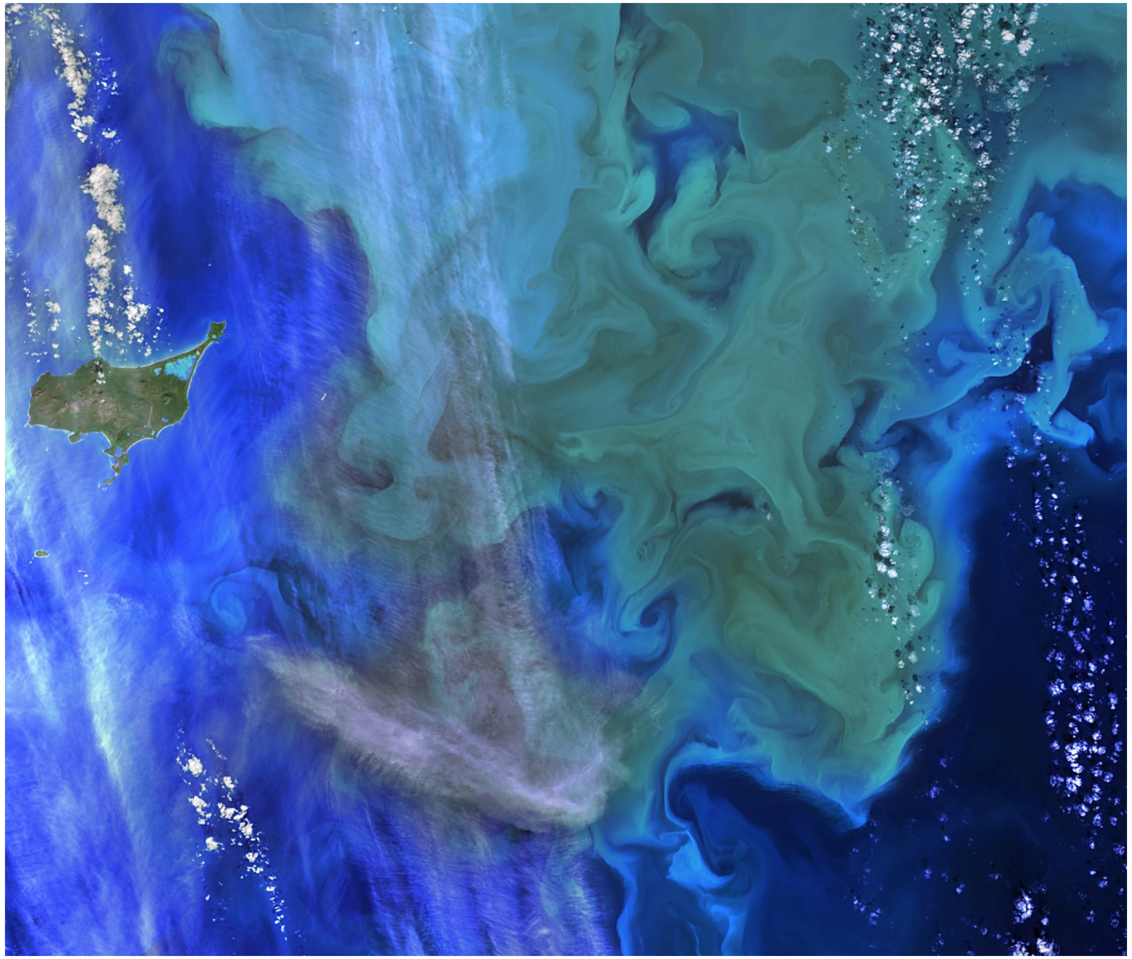
- NASA's new Earth System Observatory will design a new set of Earth-focused missions to provide key information to guide efforts related to climate change, disaster mitigation, fighting forest fires, and improving real-time agricultural processes.
- With the Earth System Observatory, each satellite will be uniquely designed to complement the others, working in tandem to create a 3D, holistic view of Earth, from bedrock to atmosphere.
- Areas of focus for the observatory include:
  – Aerosols
  – Cloud, Convection, and Precipitation
  – Mass Change
  – Surface Biology and Geology
  – Surface Deformation and Change

https://www.nasa.gov/press-release/new-nasa-earth-system-observatory-to-help-address-mitigate-climate-change

Responding to Climate Change – Earth System Observatory

Questions

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.



Credit: USGS

Contacts

- Trainers:
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  - Amita Mehta: amita.v.mehta@nasa.gov
- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-introduction-nasa-resources-climate-change-applications
- ARSET Website:
  - https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

APPLIED REMOTE SENSING TRAINING PROGRAM

TRAIN - EMPOWER - ADVANCE

Thank You!

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