Indicators of Climate Changes

Introduction to the lecture

- Indicators of climate change lecture provide an overview on the indicators that preserve the evidence of global climate change.
- This lecture focuses on the question that how do we know global climate change.
- This lecture discusses the evidence for rapid climate change i.e. global temperature, ocean acidification, warming ocean, sea level rise, extreme events, declining arctic sea ice, glacial retreat and decreased snow cover.

Aim and Learning outcomes

- The aim is to deepen students understanding of climate change indicators.
- On completion of lecture “Indicators of climate change” students will be able to:
  - Understand the indicators of climate change.
  - Know how global climate is changing and factors that control the global climate change.

Indicators of Climate Changes

Climate Change: How Do We Know?

- Earth's climate has changed throughout history.
- Just 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.
- Most of these climate changes are attributed to very small variations in Earth’s orbit that change the amount of solar energy our planet receives.

Climate Change: How Do We Know?

- The current warming trend is of particular significance because most of it is extremely likely (greater than 95% probability) to be the result of human activity since the mid-20th century (IPCC, 2003).
- Earth-orbiting satellites and other technological advances have enabled scientists to see the big picture, collecting many different types of information about our planet and its climate on a global scale. This body of data, collected over many years, reveals the signals of a changing climate.

Climate Change: How Do We Know?

- The heat-trapping nature of carbon dioxide and other gases was demonstrated in the mid-19th century (Fourier, 1824). Their ability to affect the transfer of infrared energy through the atmosphere is the scientific basis of many instruments flown by NASA. There is no question that increased levels of greenhouse gases must cause Earth to warm in response.
- Ice cores drawn from Greenland, Antarctica, and tropical mountain glaciers show that Earth's climate responds to changes in greenhouse gas levels

Climate Change: How Do We Know?

- Ancient evidence can also be found in tree rings, ocean sediments, coral reefs, and layers of sedimentary rocks. This ancient, or paleoclimate, evidence reveals that current warming is occurring roughly ten times faster than the average rate of ice-age-recovery warming.
- Gaffney, O. & Steffen, W., 2017 stated that Carbon dioxide from human activity is increasing more than 250 times faster than it did from natural sources after the last Ice Age.

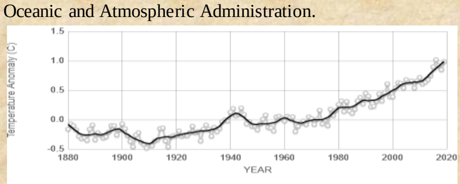
The evidence for rapid climate change is compelling

- **Global Temperature Rise**
- **Ocean Acidification**
- **Warming Ocean**
- **Sea Level Rise**
- **Extreme Events**
- **Declining Arctic Sea Ice**
- **Shrinking Ice Sheets**
- **Glacial Retreat**
- **Decreased Snow Cover**

Global Temperature Rise

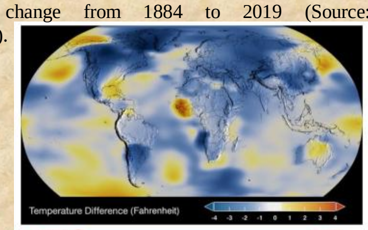
- The planet's average surface temperature has risen about 2.05 degrees Fahrenheit (1.14 degrees Celsius) since the late 19th century, a change driven largely by increased carbon dioxide and other human-made emissions into the atmosphere (NOAA, 2020).
- Most of the warming occurred in the past 40 years, with the six warmest years on record taking place since 2014. Not only was 2016 the warmest year on record, but eight months out of that year — from January through September, with the exception of June — were the warmest on record for those respective months (NASA, 2019).

This graph illustrates the change in global surface temperature relative to 1951-1980 average temperatures. Nineteen of the 20 warmest years all have occurred since 2001, with the exception of 1998. The year 2016 ranks as the warmest on record (source: NASA/GISS). This research is broadly consistent with similar constructions prepared by the Climatic Research Unit and the National Oceanic and Atmospheric Administration.



The time series below shows the five-year average variation of global surface temperatures. Dark blue indicates areas cooler than average. Dark red indicates areas warmer than average.

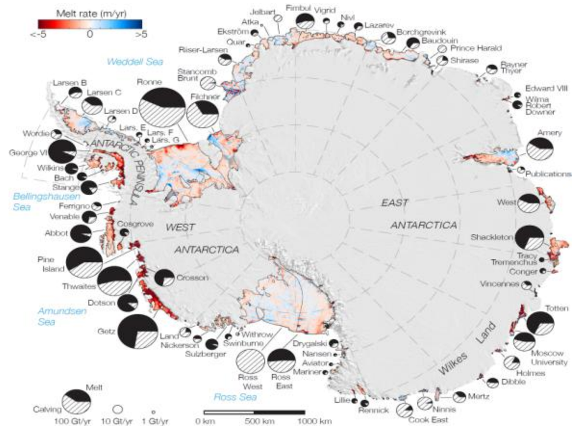
The "Global Temperature" figure on shows global temperature change from 1884 to 2019 (Source: NASA/GISS).



Warming Ocean

- The ocean has absorbed much of this increased heat, with the top 100 meters (about 328 feet) of ocean showing warming of more than 0.6 degrees Fahrenheit (0.33 degrees Celsius) since 1969 (Levitus *et al.*, 2017). Earth stores 90% of the extra energy in the ocean.
- **Warming ocean causing most Antarctic ice shelf mass loss**

This photo shows the ice front of Venable Ice Shelf, West Antarctica, in October 2008.



- Rates of basal melt of Antarctic ice shelves (melting of the shelves from underneath) overlaid on a 2009 mosaic of Antarctica created from data from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard NASA's Terra and Aqua spacecraft.
- Red shades denote melt rates of less than 5 meters (16.4 feet) per year (freezing conditions), while blue shades represent melt rates of greater than 5 meters (16.4 feet) per year (melting conditions).
- The perimeters of the ice shelves in 2007-2008, excluding ice rises and ice islands, are shown by thin black lines.
- Each circular graph is proportional in area to the total ice mass loss measured from each ice shelf, in gigatons per year, with the proportion of ice lost due to the calving of icebergs denoted by hatched lines and the proportion due to basal melting denoted in black (Image credit: NASA/JPL-Caltech/UC Irvine/Columbia University).

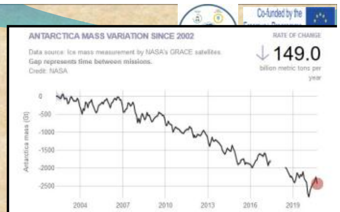
Shrinking Ice Sheets

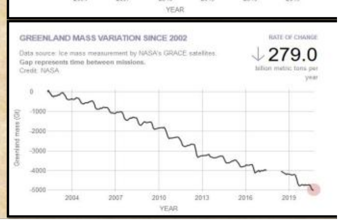
- The Greenland and Antarctic ice sheets have decreased in mass. Data from NASA's Gravity Recovery and Climate Experiment show Greenland lost an average of 279 billion tons of ice per year between 1993 and 2019, while Antarctica lost about 148 billion tons of ice per year (Velicogna, I. et al., 2020).

Image: Flowing meltwater from the Greenland ice sheet

Data from NASA's GRACE and GRACE Follow-On satellites show that the land ice sheets in both Antarctica (upper chart) and Greenland (lower chart) have been losing mass since 2002. The GRACE mission concluded science operations in June 2017.

GRACE Follow-On began data collection in June 2018 and is now continuing the mass change data record for both ice sheets. This data record includes the latest data processing improvements and is continually updated as more data are collected (with a lag of up to two months).





Glacial Retreat

- Glaciers are retreating almost everywhere around the world — including in the Alps, Himalayas, Andes, Rockies, Alaska, and Africa (National Snow and Ice Data Center & World Glacier Monitoring Service)

Image: The disappearing snowcap of Mount Kilimanjaro, from space.

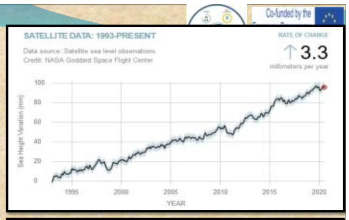
Decreased Snow Cover

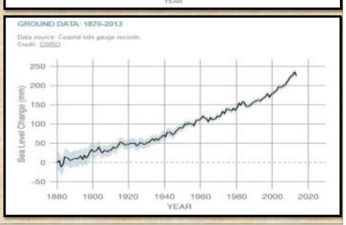
- According to Robinson, D. A. *et al.*, 2014, Satellite observations reveal that the amount of spring snow cover in the Northern Hemisphere has decreased over the past five decades and the snow is melting earlier.

Sea Level Rise

- Global sea level rose about 8 inches (20 centimeters) in the last century. The rate in the last two decades, however, is nearly double that of the last century and accelerating slightly every year (Nerem, *et al.*, 2018).

Image: Republic of Maldives: Vulnerable to sea level rise





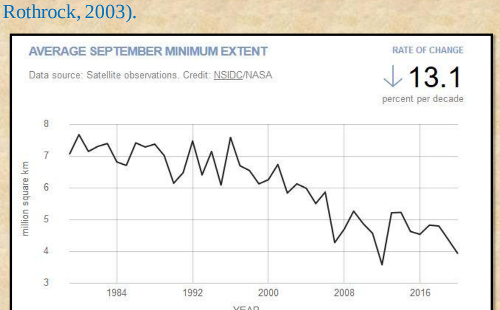
Sea level rise is caused primarily by two factors related to global warming: the added water from melting ice sheets and glaciers and the expansion of seawater as it warms. The first graph tracks the change in sea level since 1993 as observed by satellites.

The second graph, derived from coastal tide gauge data, shows how much sea level changed from about 1870 to 2013.

Declining Arctic Sea Ice

- 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. This graph shows the average monthly Arctic sea ice extent each September since 1979, derived from satellite observations.
- The animated time series below 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.

Both the extent and thickness of Arctic sea ice has declined rapidly over the last several decades (PIOMAS, Zhang and Rothrock, 2003).



Extreme Events

- Some extreme weather and climate events have increased in recent decades, and new and stronger evidence confirms that some of these increases are related to human activities.
- As the world has warmed, that warming has triggered many other changes to the Earth's climate. Changes in extreme weather and climate events, such as heat waves, natural hazards like floods, hurricanes, cyclones and droughts, are the primary way that most people experience climate change.
- Human-induced climate change has already increased the number and strength of some of these extreme events. Over the last 50 years, most of the countries has seen increases in prolonged periods of excessively high temperatures, heavy downpours, and in some regions, severe floods, hurricanes, cyclones and droughts etc.

Carbon Brief's (2017) analysis reveals:

- 69% of the 355 extreme weather events and trends included in the map were found to be made more likely or more severe by human-caused climate change.
- 9% of events or trends were made less likely or less severe by climate change, meaning 78% of all events experienced some human impact. The remaining 22% of events and trends showed no discernible human influence or were inconclusive.
- Heatwaves account for 47% of such events, while droughts and heavy rainfall or floods each make up 15%.
- Of the 125 attribution studies that have looked at extreme heat around the world, 93% found that climate change made the event or trend more likely or more severe.
- For the 68 studies looking at rainfall or flooding, 54% found human activity had made the event more likely or more severe. For the 61 drought events studied, it's 61%.

- The events and trends shown on the previous map are covered by 308 individual scientific papers or rapid studies. Where a single study covers multiple events or locations, these have been separated out.
- Combining the evidence over the past 20 years, the literature is heavily dominated by studies of extreme heat (35%), rainfall or flooding (19%) and drought (17%). Together, these make up more than two-thirds of all published studies (72%).
- As the chart below shows, the number of events studied each year has grown substantially over the past decade.

Number of attribution studies by extreme weather event type and year. Note: the total number of events dipped in 2017 because the Bulletin of the American Meteorological Society special report for that year was published in early 2018 rather than late 2017. Chart by Carbon Brief using Highcharts.

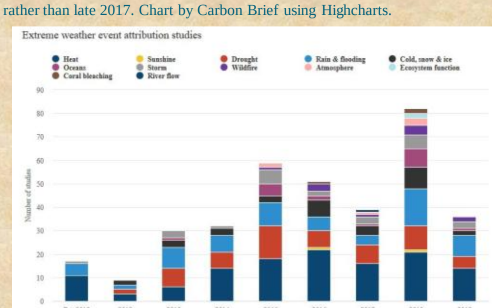
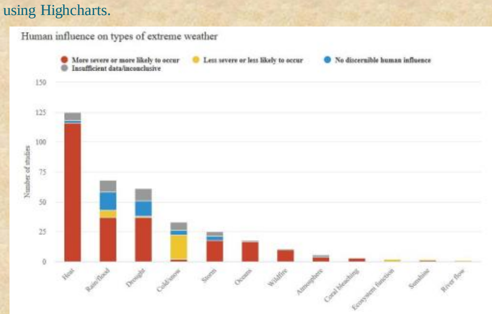
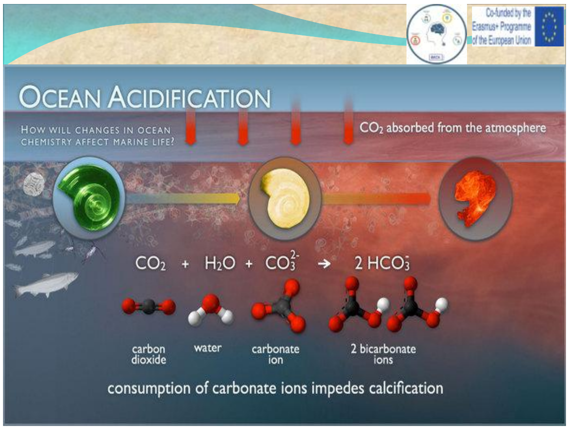


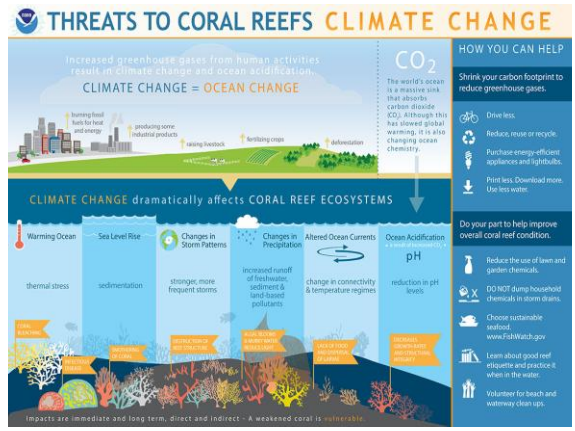
Chart shows the number of studies for each type of extreme event that fall within each category of human influence: More severe/likely (red), less severe/likely (yellow), no influence (blue) and inconclusive (grey). Chart by Carbon Brief using Highcharts.



Ocean Acidification

- Since the beginning of the Industrial Revolution, the acidity of surface ocean waters has increased by about 30% (NOAA report, 2016). This increase is the result of humans emitting more carbon dioxide into the atmosphere and hence more being absorbed into the ocean. The ocean has absorbed between 20% and 30% of total anthropogenic carbon dioxide emissions in recent decades (7.2 to 10.8 billion metric tons per year) (C. L. Sabine et.al., 2014).





- Climate change is the greatest global threat to coral reef ecosystems. Scientific evidence now clearly indicates that the Earth's atmosphere and ocean are warming, and that these changes are primarily due to greenhouse gases derived from human activities.
- As temperatures rise, mass coral bleaching events and infectious disease outbreaks are becoming more frequent. Additionally, carbon dioxide absorbed into the ocean from the atmosphere has already begun to reduce calcification rates in reef-building and reef-associated organisms by altering seawater chemistry through decreases in pH. This process is called ocean acidification.
- Climate change will affect coral reef ecosystems, through sea level rise, changes to the frequency and intensity of tropical storms, and altered ocean circulation patterns. When combined, all of these impacts dramatically alter ecosystem function, as well as the goods and services coral reef ecosystems provide to people around the globe.

Scientific evidence for warming of the climate system is unequivocal.

- Intergovernmental Panel on Climate Change

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