

Climate Studies

introduction to climate science

Chapter 1

Earth's Climate as a Dynamic System

Essential Questions

- How is climate defined?
- What is a system?
- Why is climate a unique and complex system?
- What comprises the climate system?
- What role do humans play in the climate system?
- How are humans affecting climate?
- How are humans affected by changes in this system?

Introduction

- The Earth is a finite and fragile resource
- Earth's climate can be studied using the systems approach
- **Climate** – state of a complex system consisting of five major components, the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the interactions amongst them
- A **system** is an arbitrary portion of the universe with fixed or movable boundaries which may contain matter, energy or both

- The climate system evolves over time due to its own internal dynamics and due to external forcings like volcanic eruptions, solar variations and because of human actions that change the atmosphere and the terrain due to land use
- Balanced incoming and outgoing radiation cause a stable global climate
- Unbalanced incoming and outgoing radiation cause a climate shift according to the gain or loss of energy
- Current evidence shows the Earth is not in a global radiative equilibrium
 - The system is gaining energy
 - Climate change is taking place

- Earth's climate system establishes the environmental conditions and sets boundaries for weather
- Climate is dynamic
 - It has changed in the past
 - Will change again in the future



- Changes in climate occur on different scales and vary in magnitude and direction
 - Natural cycles
 - Human actions
- Consequences grow in number and intensity based upon past and current human actions

Climate and Society

The importance of climate studies for human endeavors

- Climate is variable, but is changing at an unprecedented rate due to the burning of fossil fuels
- Human activities link humans to the Earth's natural systems making climate change more complex
- **Mitigation** - actions that reduce sources of gases which contribute to the warming of the climate system and enhance the mechanisms that remove them from the atmosphere
- Gases that contribute to the warming of the climate system are known as **greenhouse gases**

- **Adaptation** is the adjustment in natural or human systems to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities
- Climate change heightens the vulnerabilities of societies and ecosystems
- Impact is both global and local
 - Economic interdependence enhances the global component

Climate and Society

Human Vulnerability to Climate

- **Climate Variability**

- Change in average state of the climate on all spatial and temporal scales separate from singular weather events
- Occurs with or without human actions

- **Climate Change**

- a change in the state of the climate system, identified by changes in the average conditions and the variability of its properties, which persists for an extended period, typically decades or longer, due to natural or anthropogenic processes and forcings

- **Climate Vulnerability**

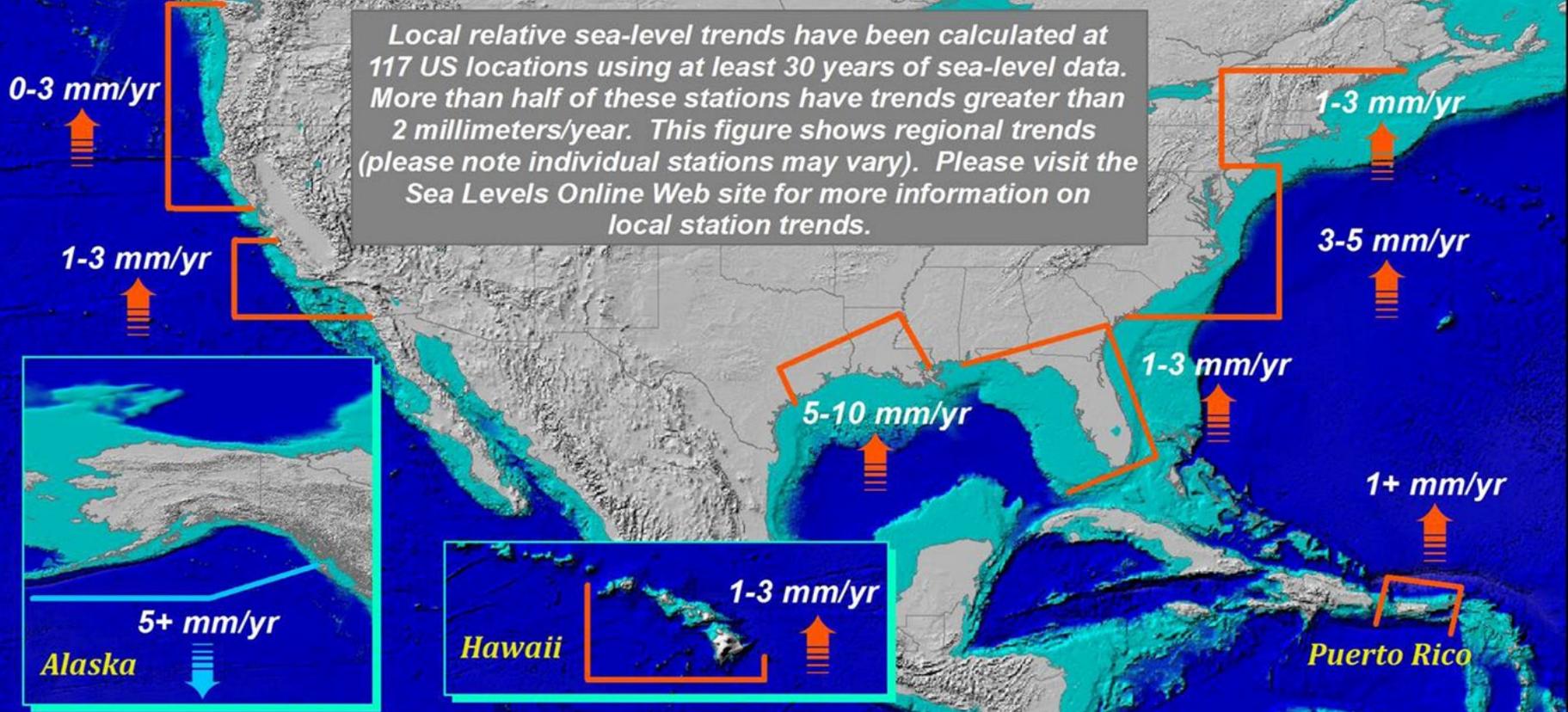
- Degree to which physical, biological, and socio-economic systems are susceptible to, or incapable of coping with, adverse impacts of a variation in climate
- Storms such as Katrina and Sandy have proven that modern society is not shielded from climate-induced social degradation



LONG TERM RELATIVE SEA LEVEL TRENDS FOR THE UNITED STATES

NOAA Sea Levels Online: www.tidesandcurrents.noaa.gov/sltrends/sltrends.html

Local relative sea-level trends have been calculated at 117 US locations using at least 30 years of sea-level data. More than half of these stations have trends greater than 2 millimeters/year. This figure shows regional trends (please note individual stations may vary). Please visit the Sea Levels Online Web site for more information on local station trends.



Pacific Island Territories (not shown): 0-3 mm/yr

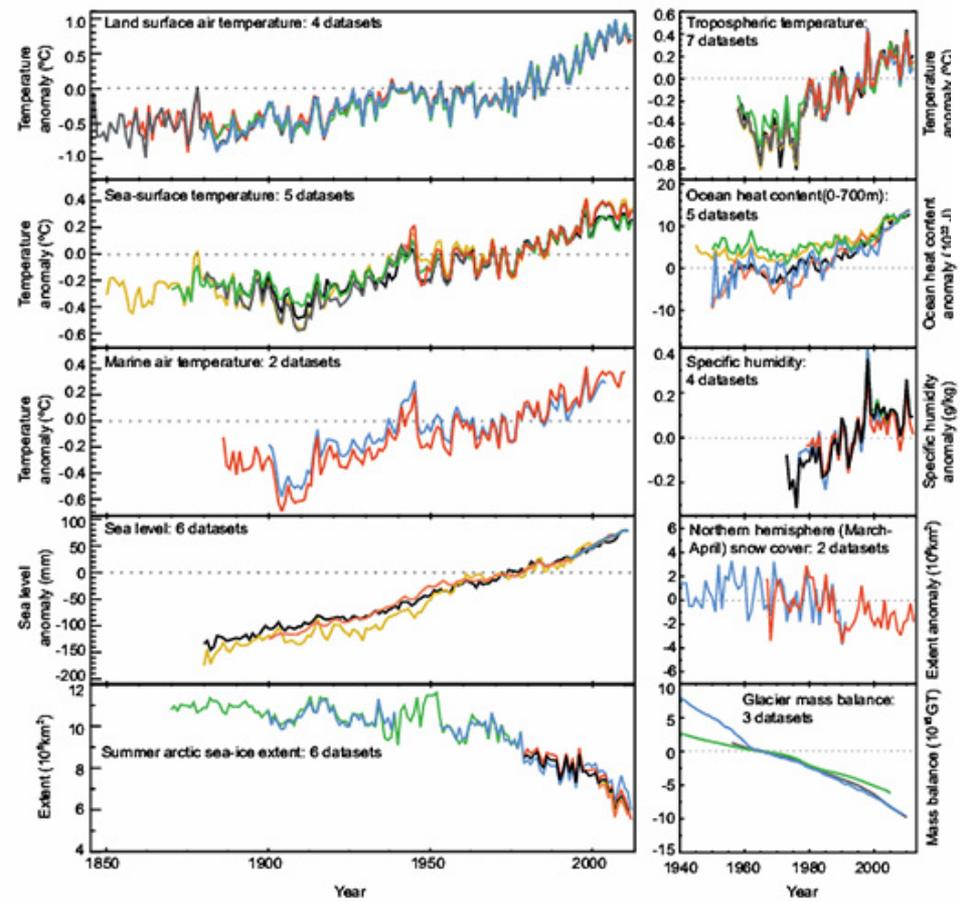
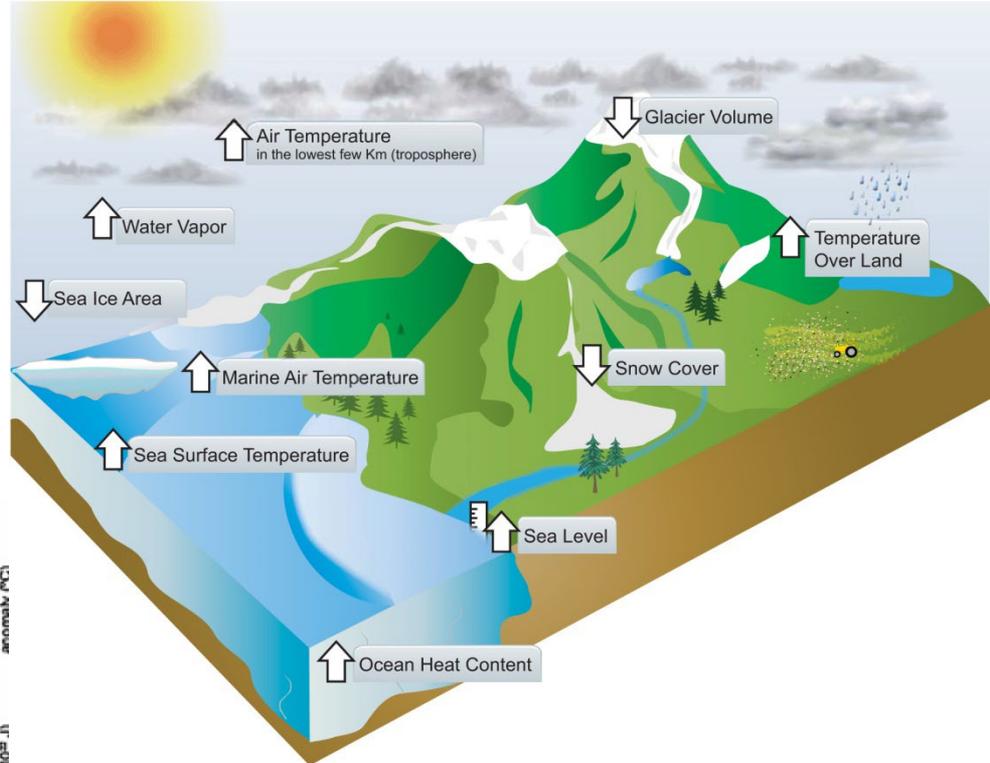
- **Sustainability**

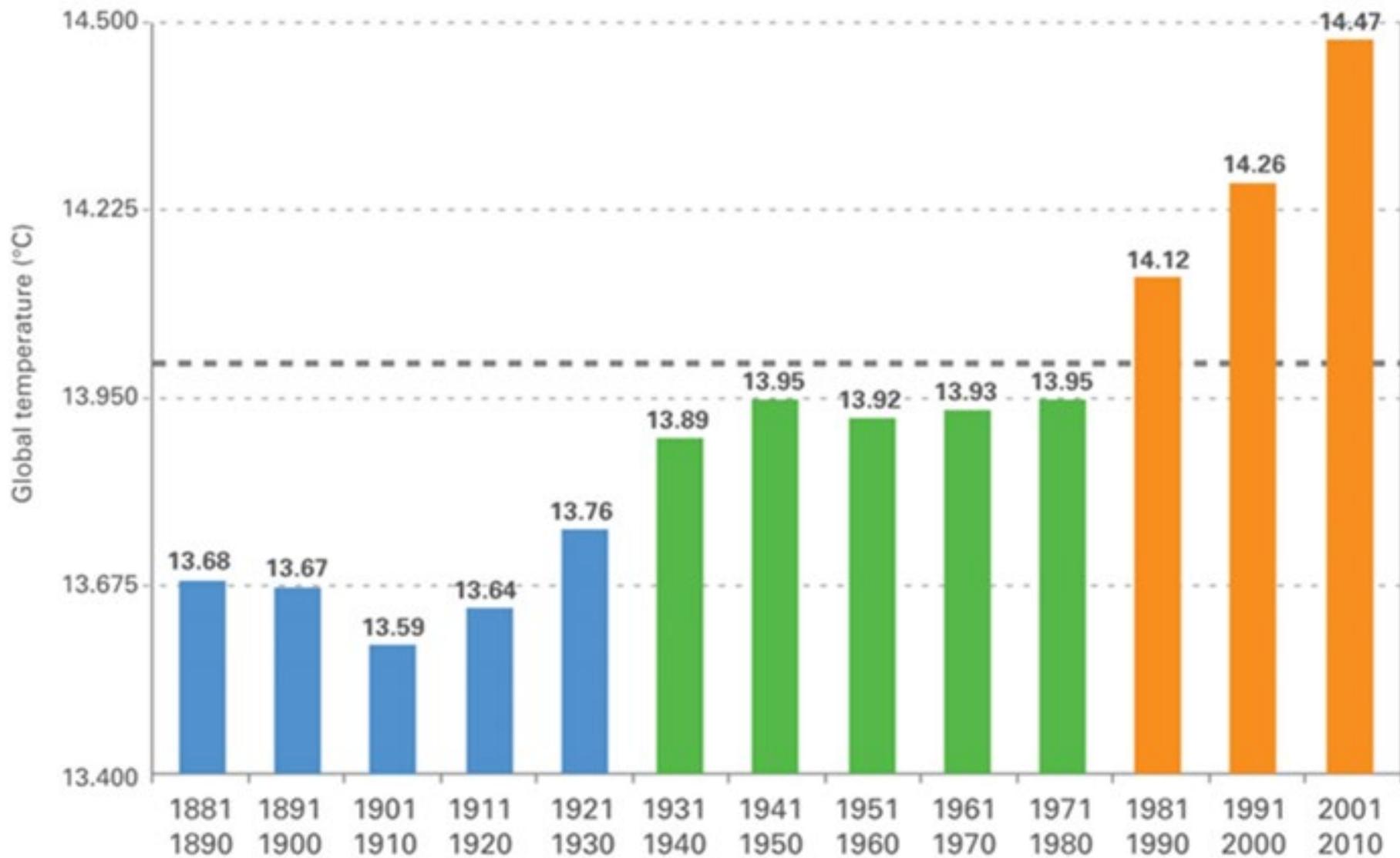
- Capacity to meet the needs of the present without compromising the ability of future generations to meet their own needs
- Balancing mitigation attempts with economic impacts can cause resistance

Importance of the Climate System

A Changing Climate

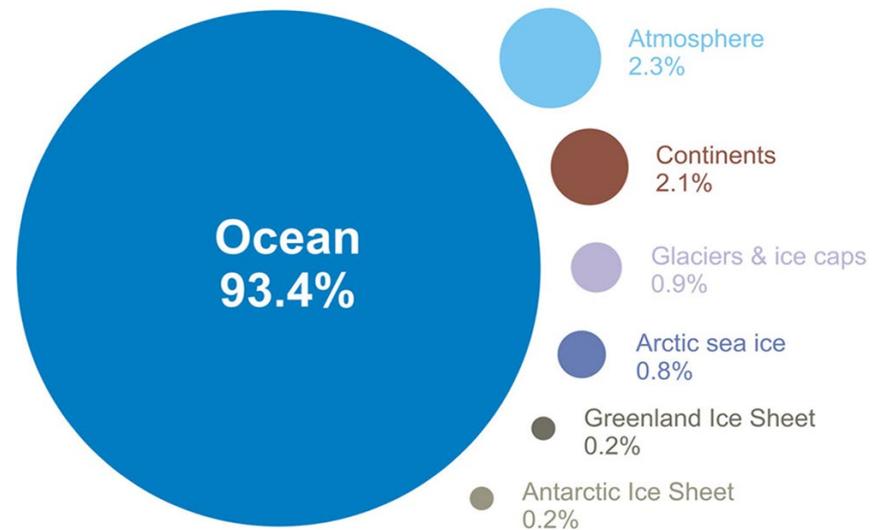
- Each of the last three decades has been warmer at the surface than any preceding decade since 1850





- Ocean is warming more than any other location
 - Much of this energy is likely stored in the deep ocean

Where is global warming going?

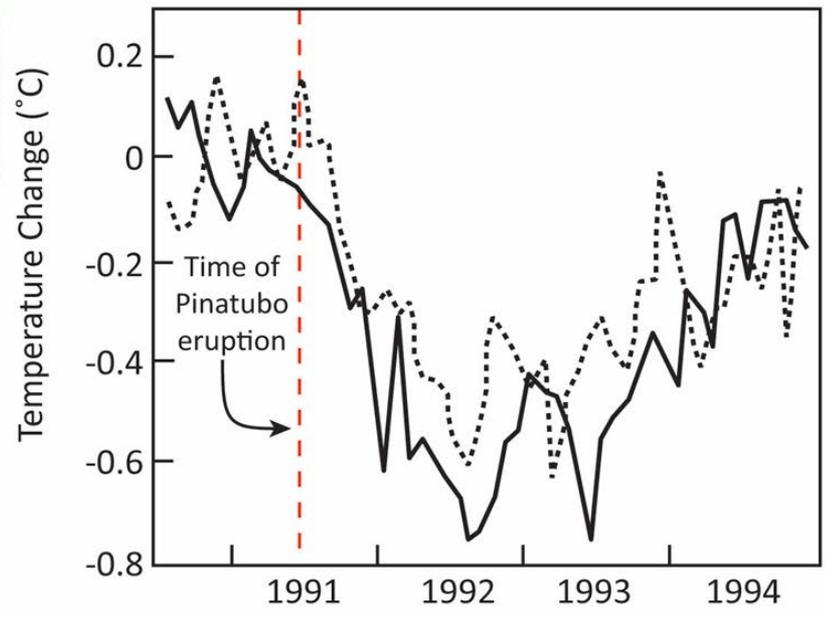


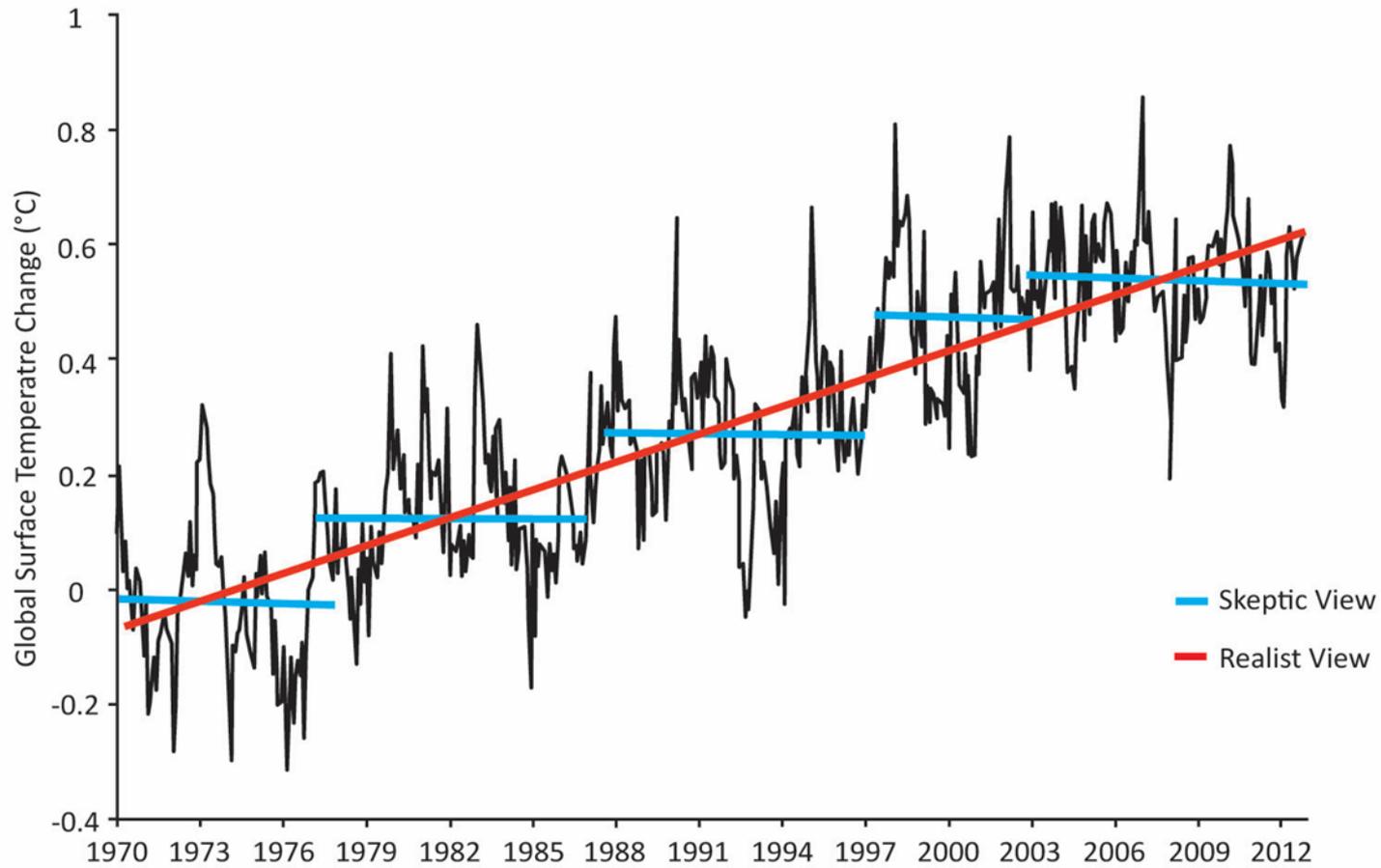
- Plant and animal species also react to changes in climate
- **Ecosystem** - a collection of living organisms within the non-living substances they depend on or near the surface of the Earth
 - Changes in the climate affect ecosystems in many ways
 - Significant ecosystem disturbance signals a change in the climate system

Importance of the Climate System

Climate Variability vs. Climate Change

- Variability relates to natural fluctuations on a smaller time scale
- Range of variation and change are a response to the interactions of many mechanisms
- Differentiating between the two is done by matching causes to a forcing agent





Importance of the Climate System

Assessing Credible Climate Information

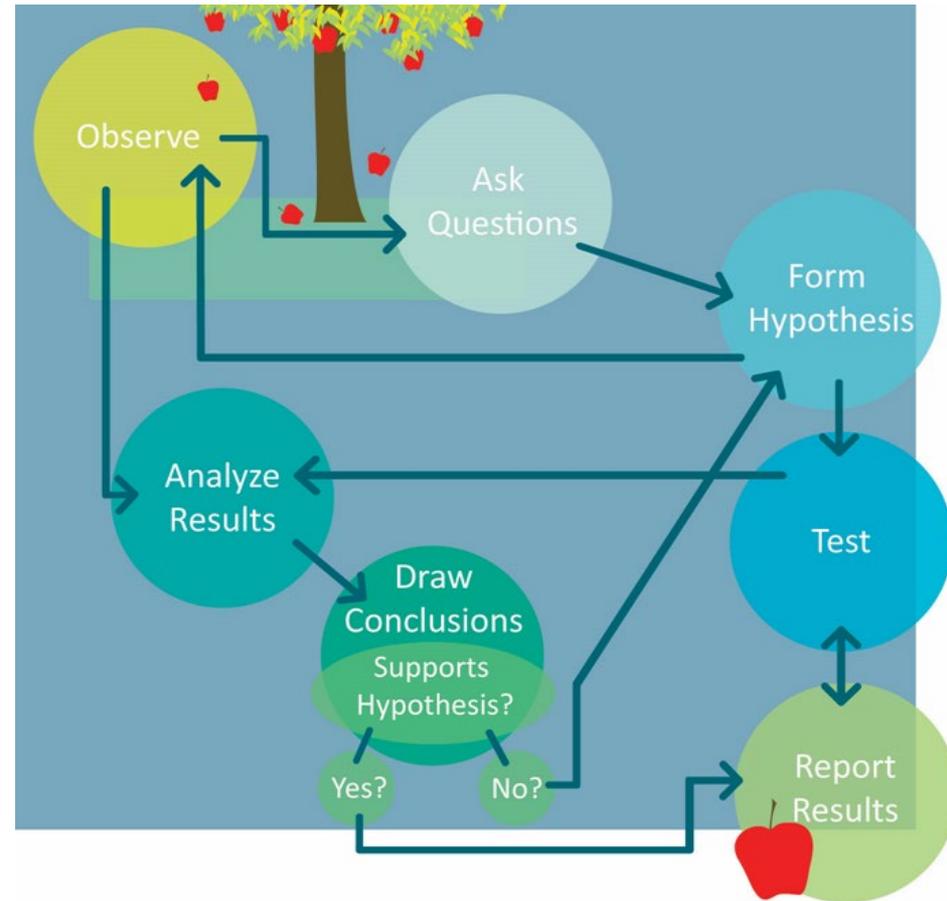
- **Peer Review Process** – the objective, professional evaluation of scientific studies and published papers
 - Ensures that data and findings are accurate and accurately reported
 - Ensures a high level of credibility and quality

Current Climate Paradigm

- Climate change first reported in the 1980s
- In order to understand, we must look at all components, sub-systems and interactions.
- **Climatology** - the scientific discipline that investigates Earth's climate system, focusing on how it functions, what drives its changes, and how it varies in both space and time
 - Both empirical and theoretical
- **Climate science** – the scientific discipline generally focusing more on the physical processes on Earth that can affect or force climate to change

Current Climate Paradigm

- **Scientific Method** - a process entailing systematic observation, measurement and experimentation, and the formation, testing and modification of hypotheses
 - Used as a template for scientific investigations



Current Climate Paradigm

Modes by which Climate is defined

- Climate is more encompassing and enduring than weather
- Atmosphere is a continuum with energy and mass being exchanged constantly
- Use weather variables and observations over long periods of time to get a glimpse at climate

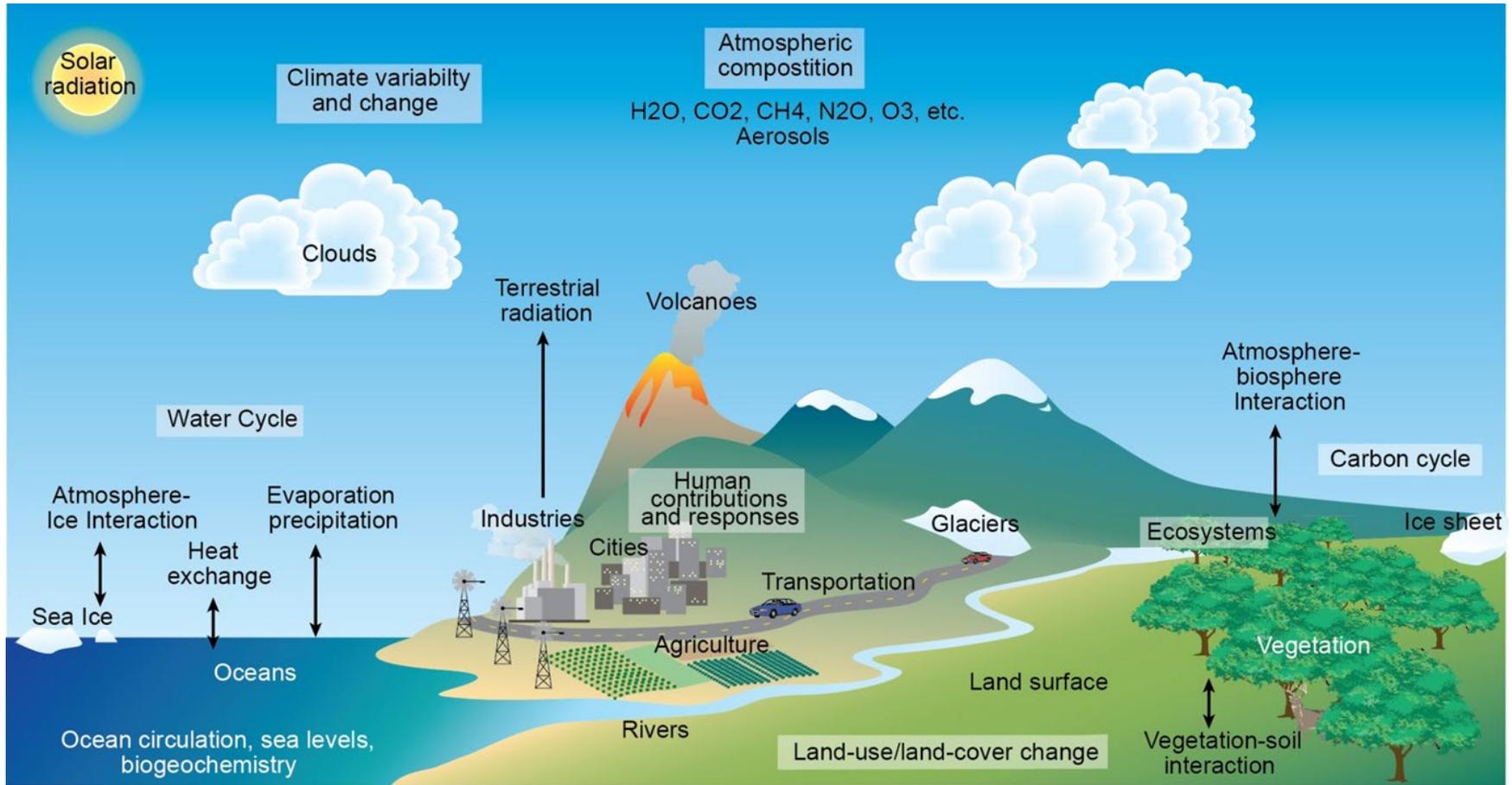
Current Climate Paradigm

Climate System

- Climatologists look at each of the sub-systems to pose hypotheses about how it will operate in the future
- **Open System** – a system that exchanges both energy and mass with its environment
- **Closed System** – a system that exchanges energy but not mass with its environment

Currently Climate Paradigm

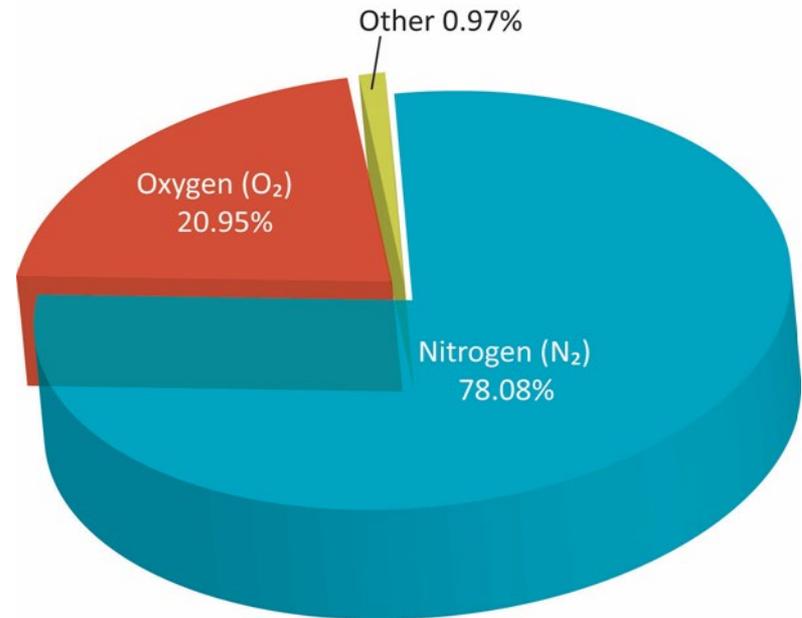
Atmosphere



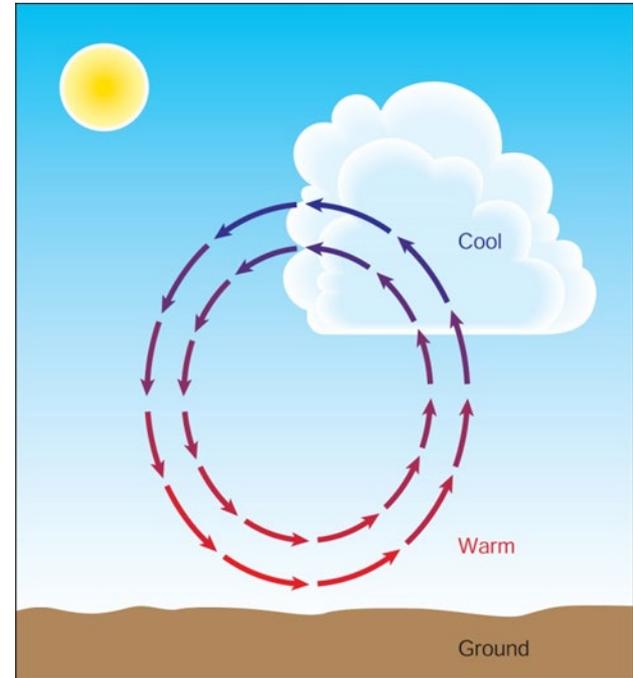
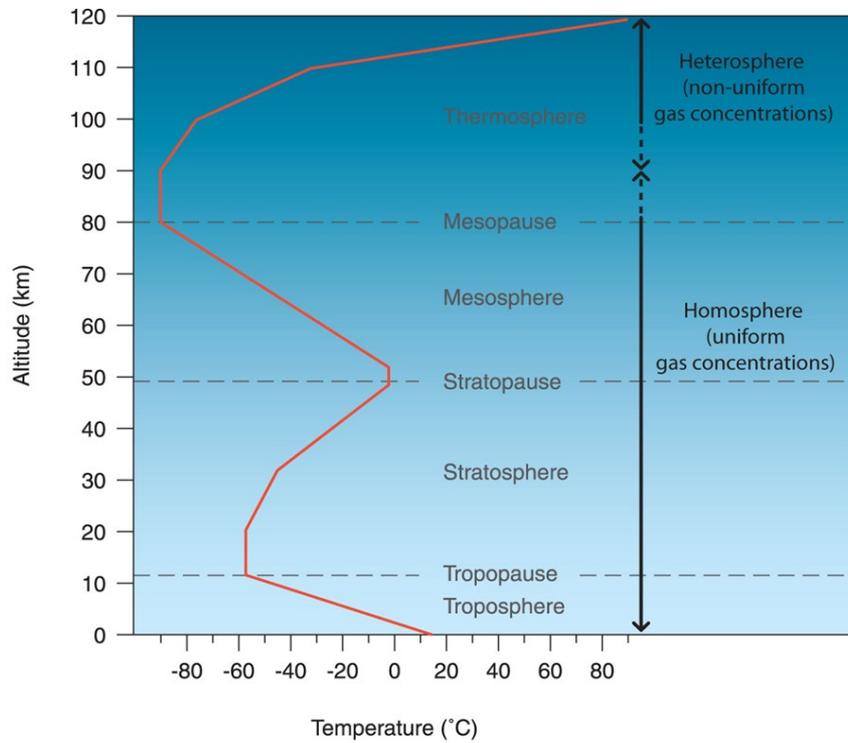
Current Climate Paradigm

Atmosphere

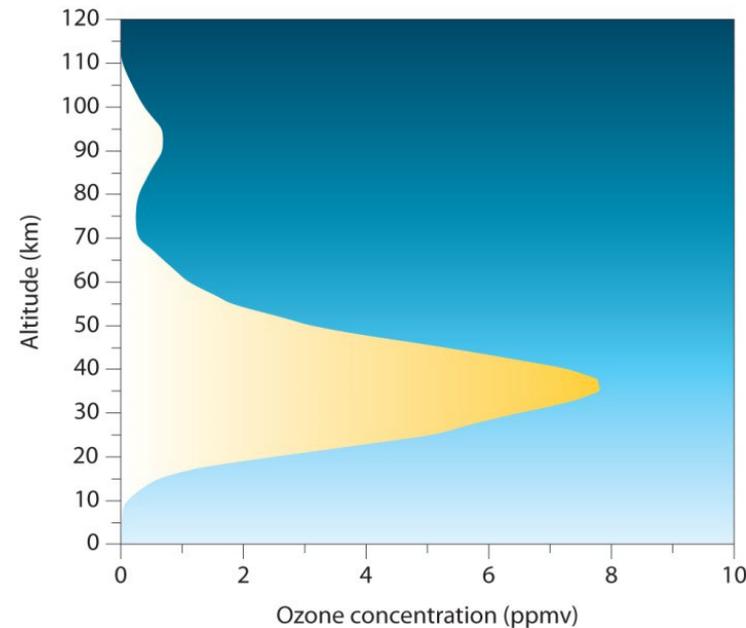
- Free-flowing, well-mixed envelope of gases at the interface of Earth and space
- Necessary for survival of life on Earth
- Mainly nitrogen, oxygen and water vapor
- Also includes **trace gases**
 - atmospheric gases with much smaller concentrations, often making up less than a hundredth or thousandth percent of the atmosphere, yet still have a significant impact on the climate system



- Typically studied by its temperature profile
- Can be broken into layers based upon the lapse rate (change in temperature with height)
- The **troposphere** interacts with other spheres and sub-systems as it is the lowest layer of the atmosphere

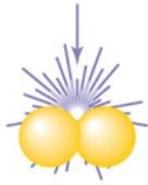


- **Ozone** alters the thermal profile 20-30km above the surface
 - A variant of oxygen, ozone is a triatomic molecule, consisting of *three* oxygen atoms rather than two in the most common form of oxygen, and highly concentrated in the stratosphere
 - Serves as a protective barrier against UV Radiation

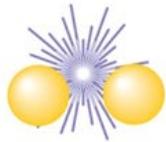


- **Stratosphere** – the second lowest layer of the atmosphere, with a major temperature inversion and an underlying isothermal layer (the ozone shield)
- **Mesosphere** – the second highest layer of the atmosphere
- **Thermosphere** – the highest layer of the atmosphere, with a temperature inversion, where gases absorb highly energetic solar radiation

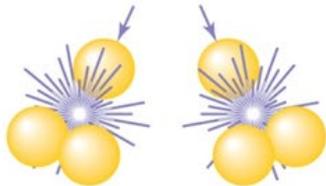
OZONE PRODUCTION



High energy ultraviolet radiation strikes an oxygen molecule...



...and causes it to split into two free oxygen atoms.



The free oxygen atoms collide with molecules of oxygen...

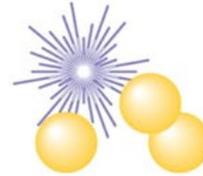


To form ozone molecules.

OZONE DESTRUCTION



Ozone absorbs a range of ultraviolet radiation...



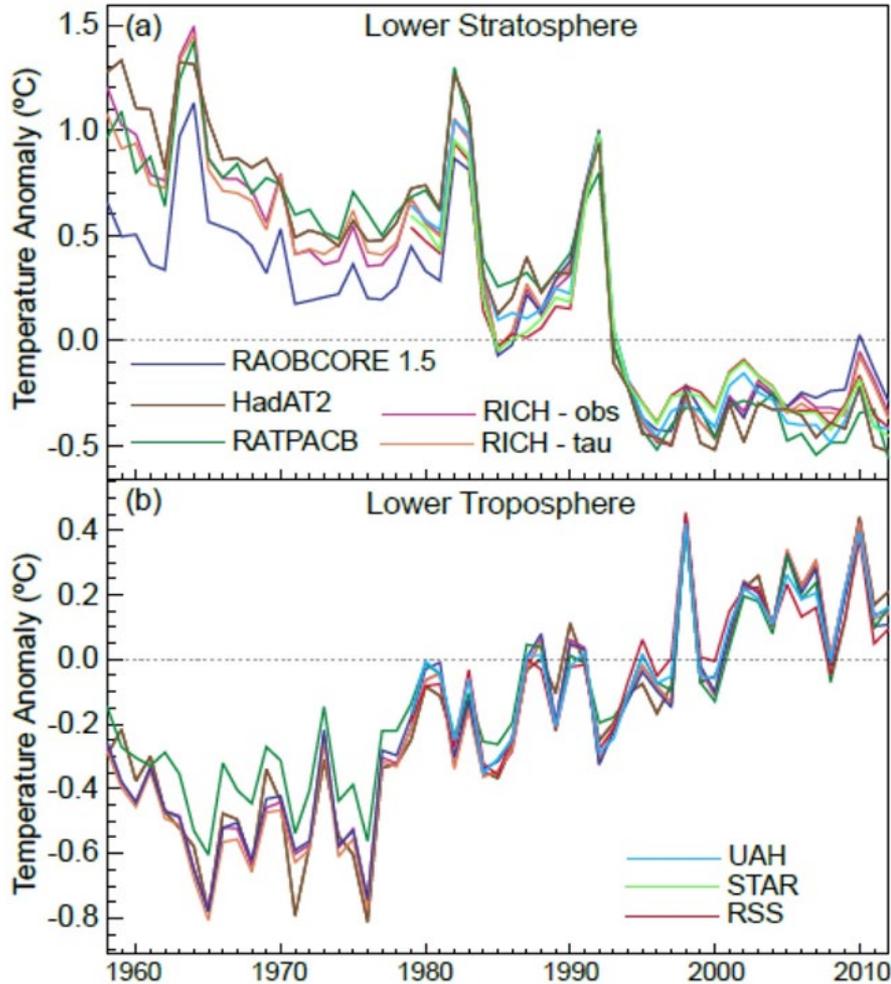
...splitting the molecule into one free oxygen atom and one molecule of ordinary oxygen.



The free oxygen atom then can collide with an ozone molecule...



To form two molecules of oxygen.



- Warming in one layer can cause cooling in another, as is shown in the figure to the right.
- As the troposphere warms, the stratosphere cools.

Current Climate Paradigm

Hydrosphere

- **Hydrosphere** – includes all water, in all forms on, under and over Earth's surface
- Water covers more than two-thirds of the planet
 - Occurs naturally in all three states of matter
 - Changes in state can have a dramatic impact on climate
 - 96.5% of water is in the ocean
 - 68% of remaining freshwater is ice
 - Remainder of freshwater is in groundwater, lakes, etc.

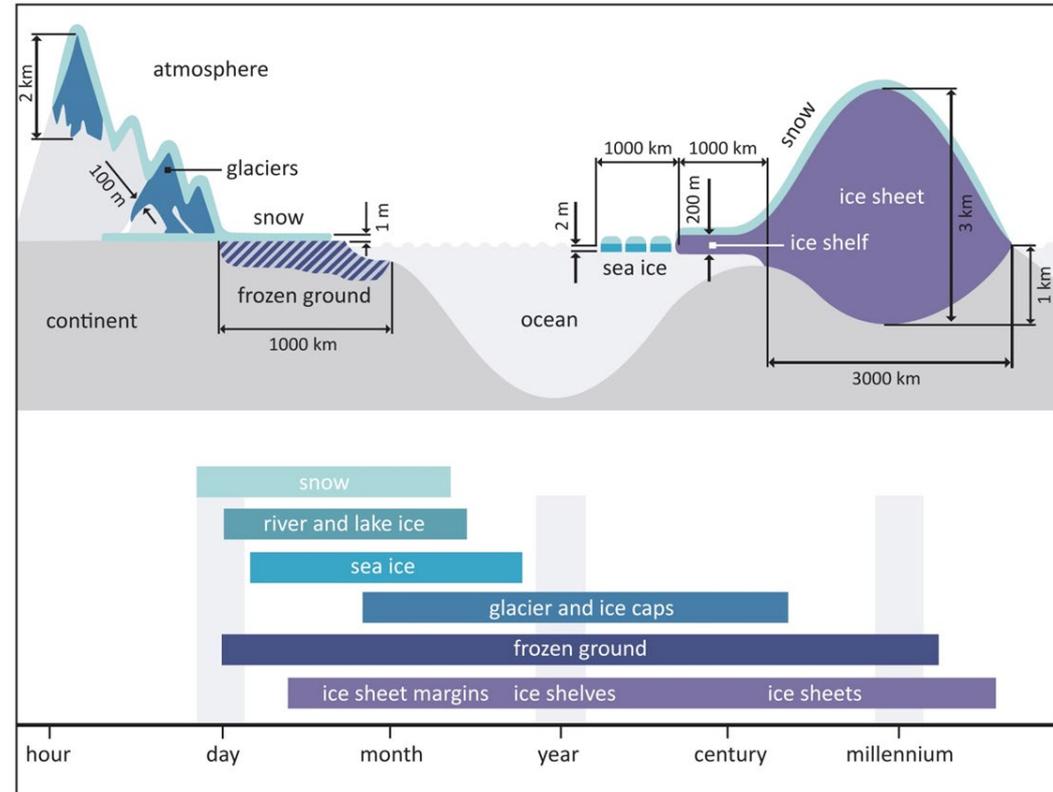
Current Climate Paradigm

Hydrosphere

Reservoir	Volume (1000 km ³)	% of Total Water	% of Fresh Water
Oceans, seas and bays	1,338,000	96.5	—
Ice caps, glaciers and permanent snow	24,064	1.74	68.7
Groundwater	23,400	1.7	—
<i>Fresh</i>	10,530	0.76	30.1
<i>Saline</i>	12,870	0.94	—
Soil Moisture	16.5	0.001	0.05
Ground ice and permafrost	300	0.022	0.86
Lakes	176.4	0.013	—
<i>Fresh</i>	91.0	0.007	0.26
<i>Saline</i>	85.4	0.006	—
Atmosphere	12.9	0.001	0.04
Swamp water	11.47	0.0008	0.03
Rivers	2.12	0.0002	0.006
Biological water	1.12	0.0001	0.003
TOTAL	1,385,984	100.0	100.0

- Less than 1% of water exists in the vapor phase
- Hydrosphere is a closed system, but is dynamic
 - Movement is caused by changes in temperature and salinity

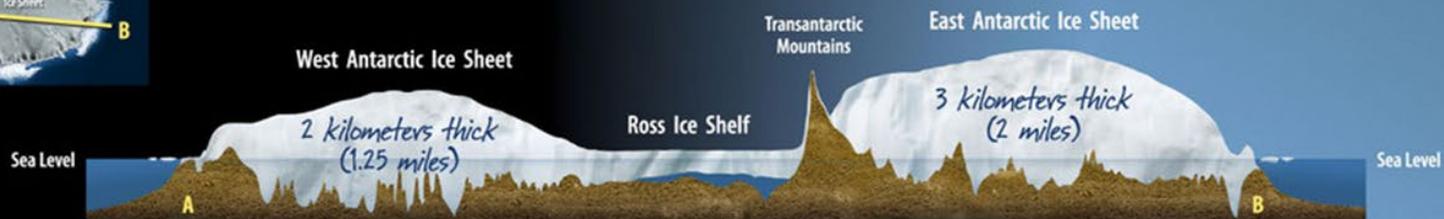
- **Cryosphere** - portion of the hydrosphere in solid form
- Most ice is found in the polar regions
- East Antarctic Ice Sheet seems to be unaffected, however, it is believed wind direction is helping to save this ice sheet from melting



- Continued warming will cause melting of the ice sheet and decrease in glacial volumes
- 23% of the Northern Hemisphere is covered in ice during the winter months
- Annual cycles of snow and ice are monitored because they serve as a signal for climate change
 - Volume as well as physical properties including albedo are measured



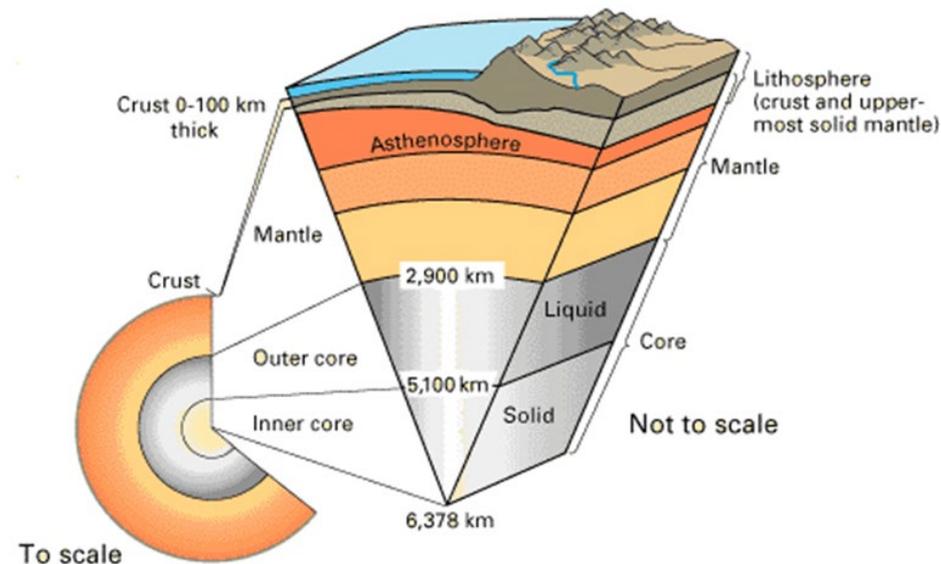
Cross Section of Antarctica's Ice Sheets



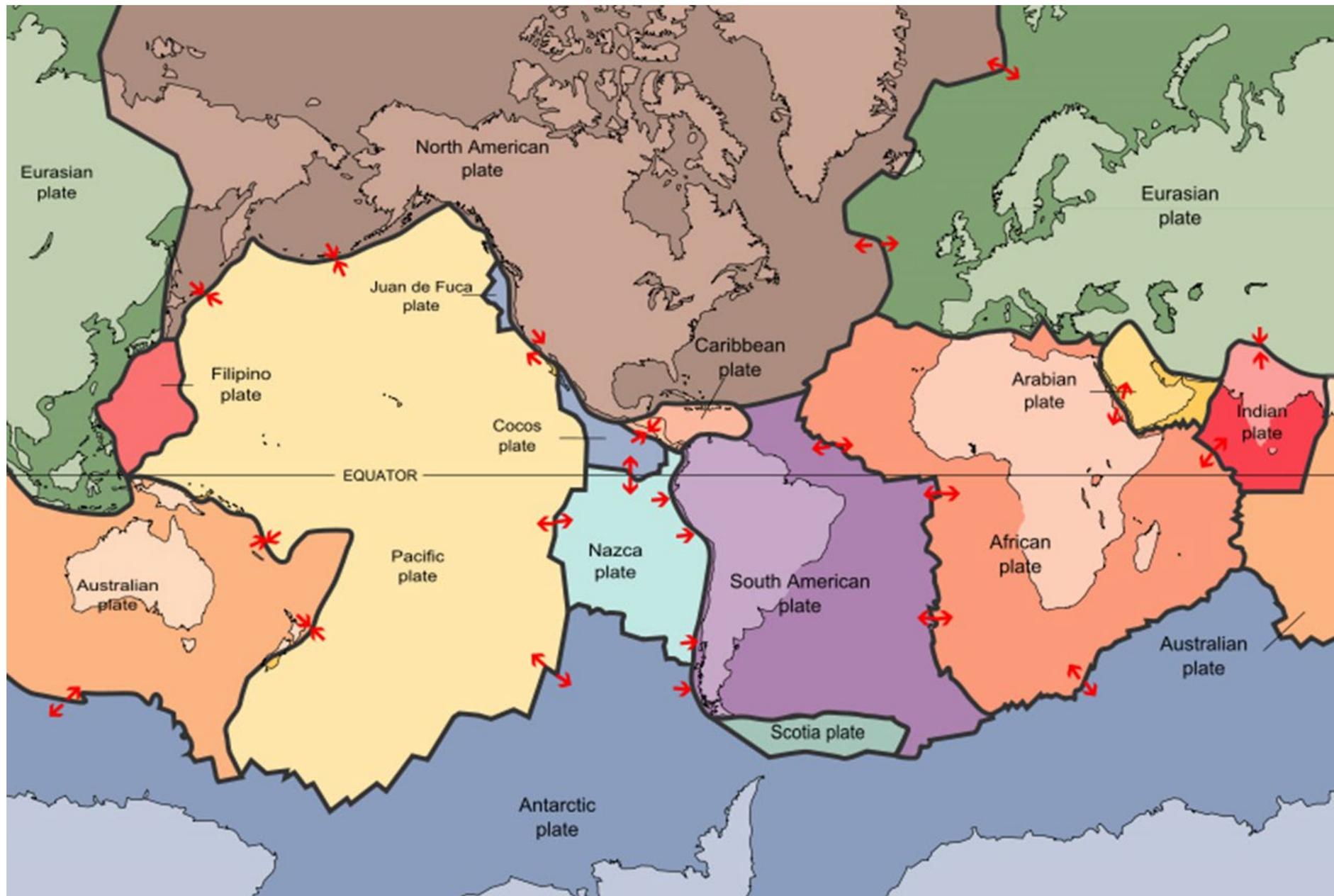
Current Climate Paradigm

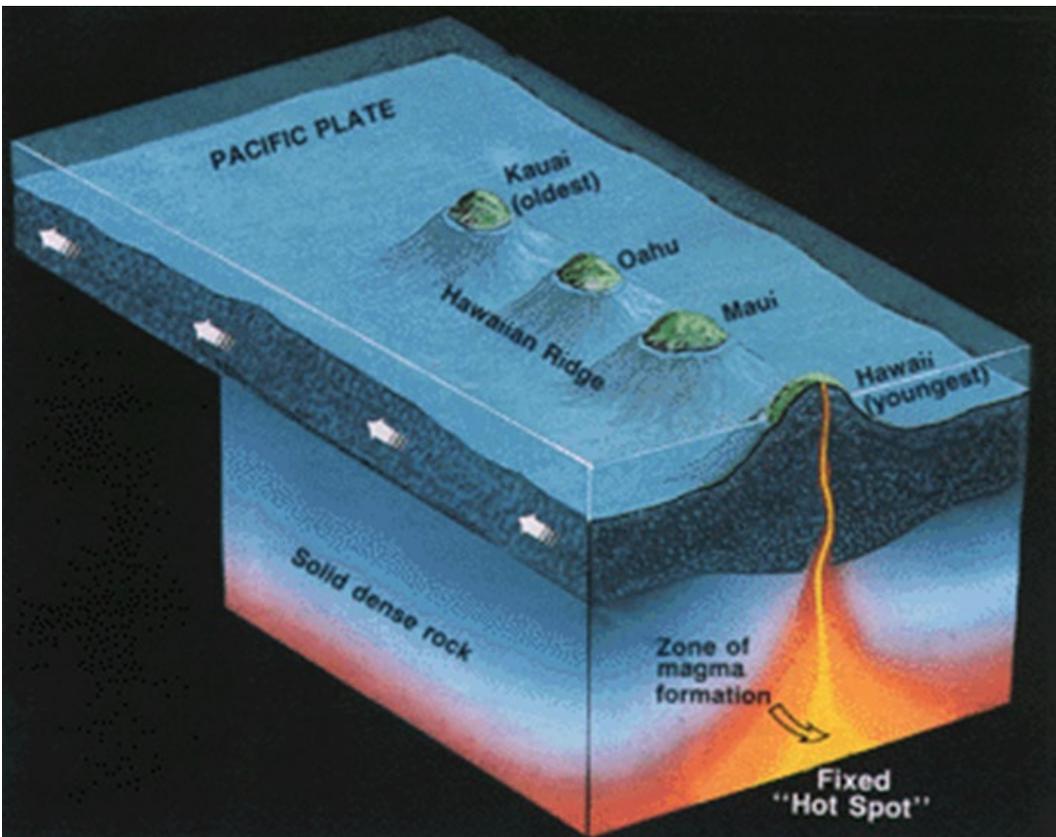
Lithosphere

- **Lithosphere** - relatively cool, crusty, outer layer encompassing Earth's surface to the deeper, hotter portions where rocks become more elastic and melt (called the upper mantle)

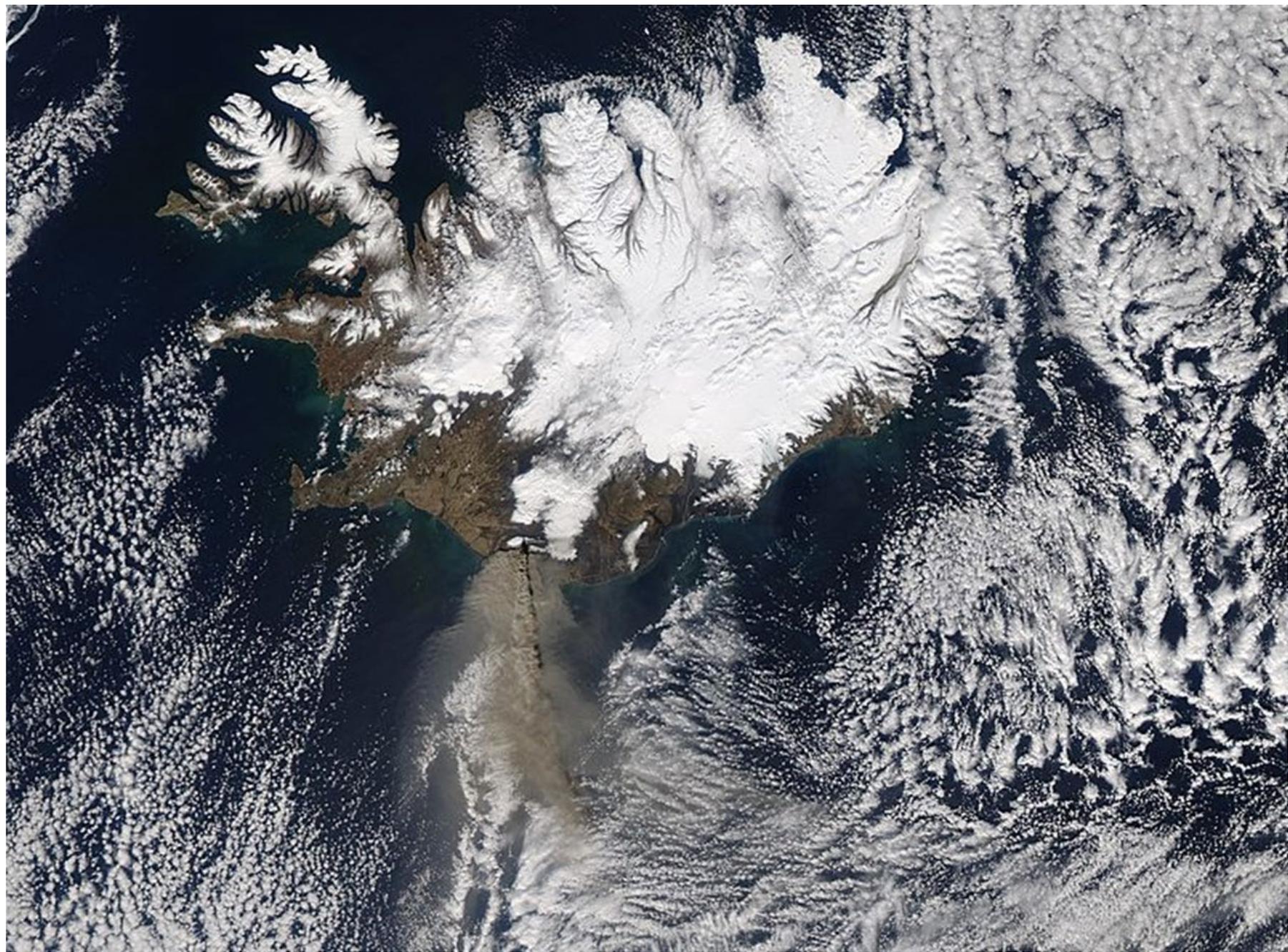


- Crust is thinnest under the oceans and thickest under continents
- Houses a great abundance of resources, many of which are used as fuels
- **Asthenosphere** – layers of rock below the lithosphere that bend more like a fluid and adjust to stress through plastic-like deformations
- Lithosphere is broken into large plates, which move over the period of millions of years



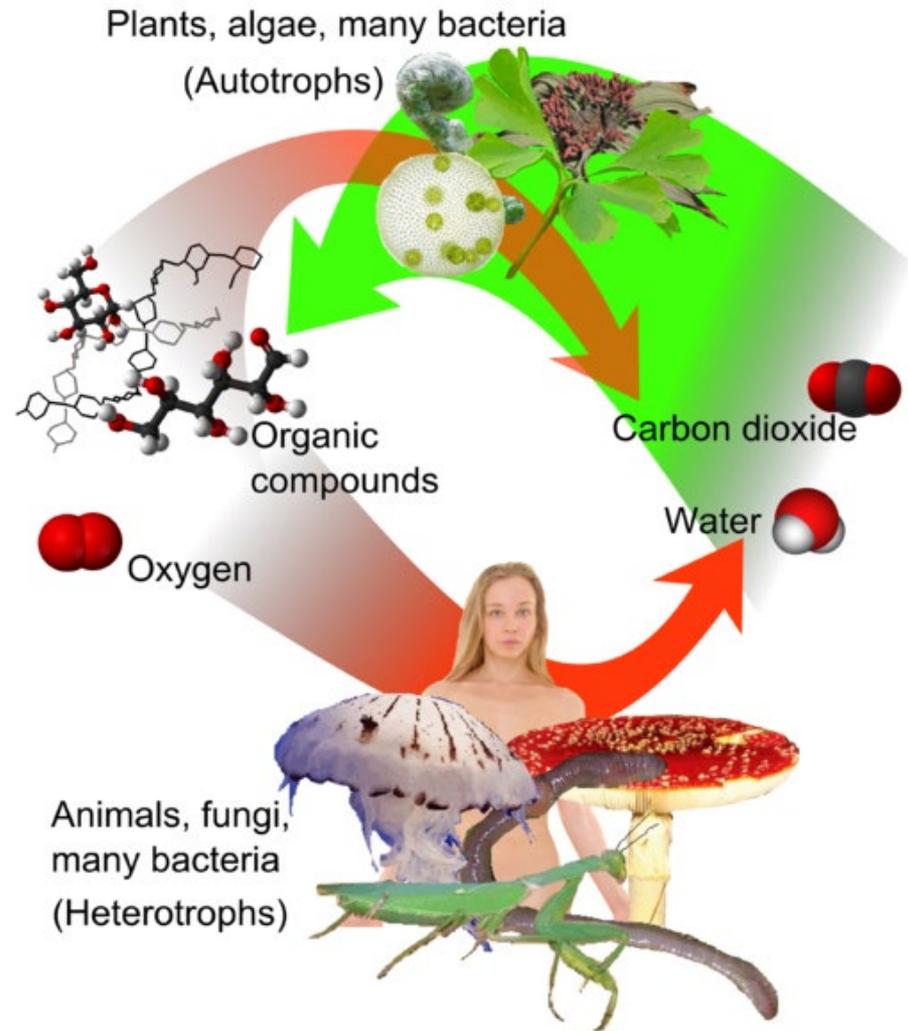


- Volcanic activity can occur on the plate boundaries or at hot spots
- A hot spot occurs when super heated materials rise in plumes from below
- A hot spot can coincide with a plate boundary, as is the case in Iceland



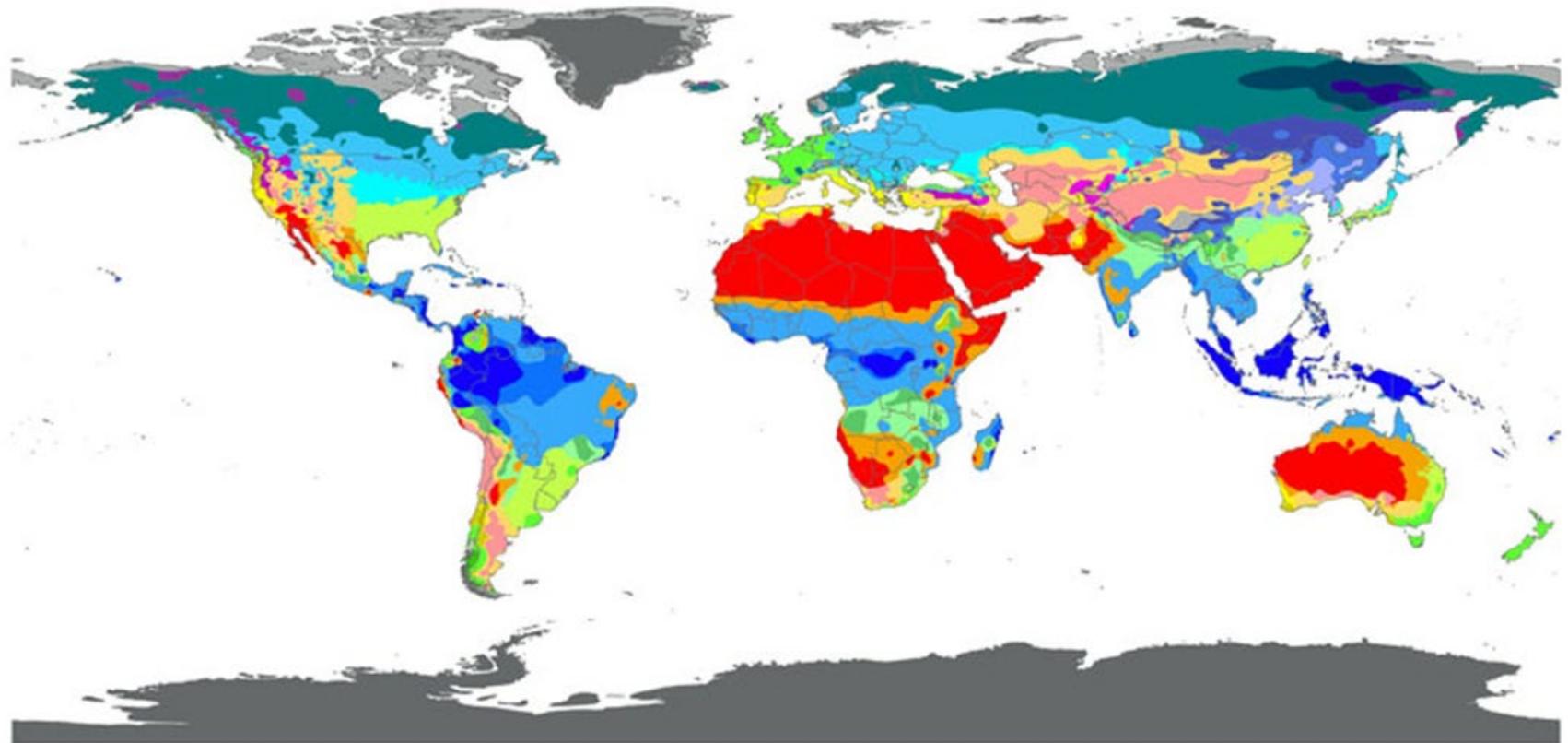
- **Pedosphere** - portion of the lithosphere at its upper-most extent, which forms the world's soils
- Includes all organisms in the soils
- Water flows through cracks and permeates deep into the lithosphere
- Freeze-thaw cycle can trap greenhouse gases

- **Biosphere** - integrates all living beings and their relationships with the lithosphere, hydrosphere, cryosphere and atmosphere
- Collection of all ecosystems worldwide
- Every part of Earth supports life of some sort
- Can be broken into producers, consumers and decomposers
 - Relationship between these is known as a food chain
 - **Food web** consists of all the food chains in a single ecosystem



- Köppen recognized the climatic influence on ecosystems
- Developed a climate scheme based upon native vegetation in the area
 - Vegetation is a sign of temperature and precipitation patterns in the area

World map of Köppen-Geiger climate classification



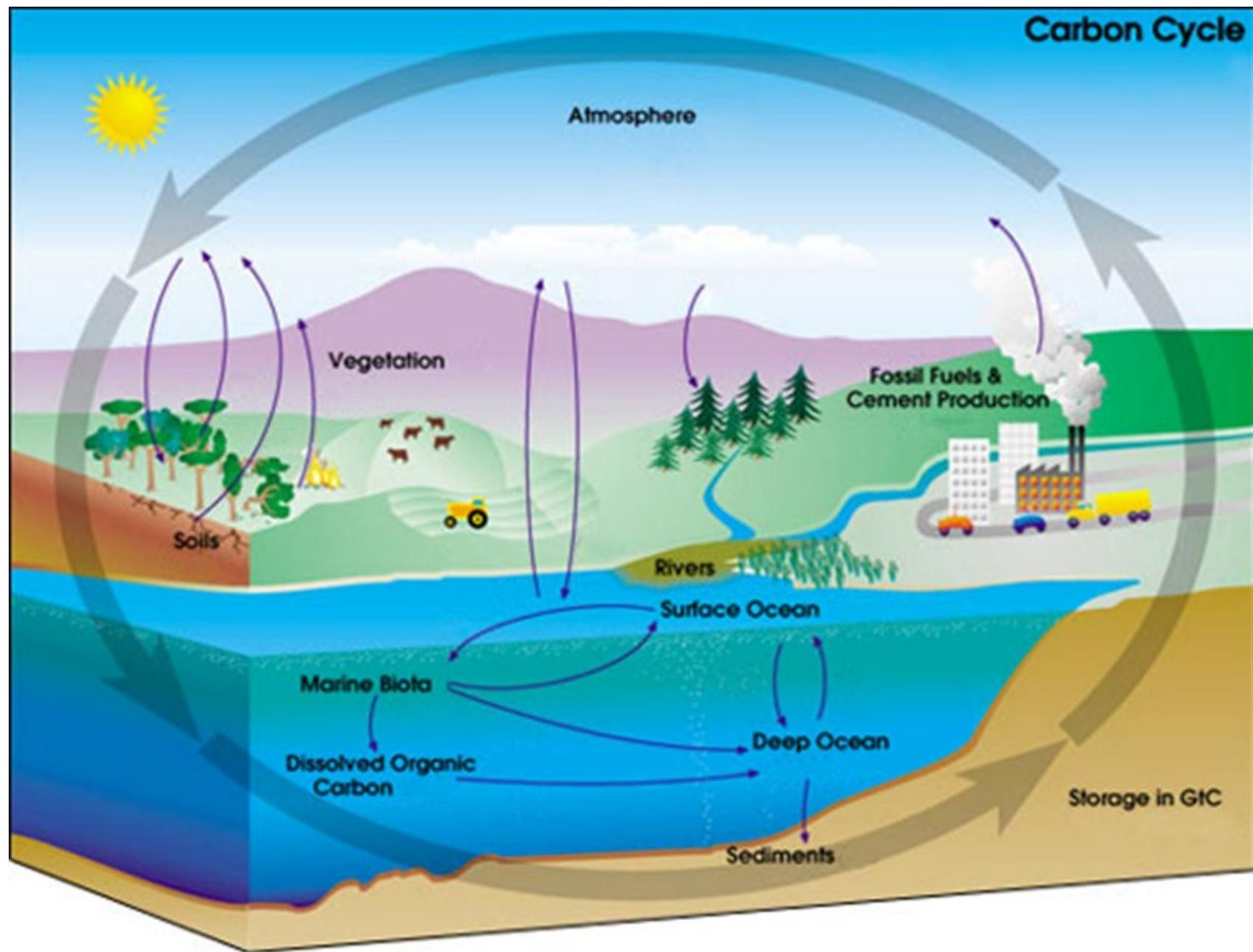
 Af	 BWh	 Csa	 Cwa	 Cfa	 Dsa	 Dwa	 Dfa	 ET
 Am	 BWk	 Csb	 Cwb	 Cfb	 Dsb	 Dwb	 Dfb	 EF
 Aw	 BSh	 Cwc	 Cfc	 Dsc	 Dwc	 Dfc		
 BSk				 Dsd	 Dwd	 Dfd		

Current Climate Paradigm

Carbon Cycle

- Carbon ties all subsystems together
- Chemically or physically transformed between spheres due to the law of conservation of matter
- **Carbon cycle** - carbon moving through living entities (bio), non-living entities like rocks (geo) in the form of a myriad of compounds (chemical), it is part of a *biogeochemical cycle*

Carbon Cycle

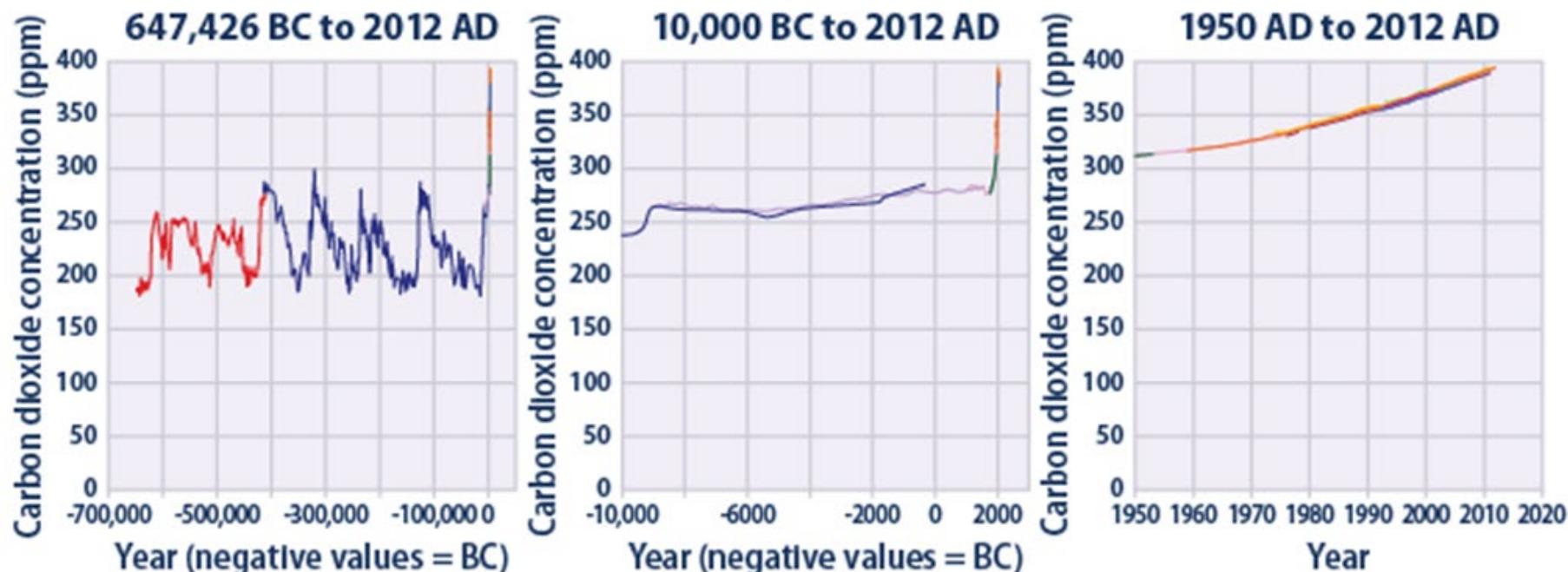


Current Climate Paradigm

Carbon Cycle

- **Conservation of matter** – matter can be neither created nor destroyed, but can change in chemical or physical form
- Mass deposition made during carboniferous period, which are released through the burning of fossil fuels
 - Adds carbon dioxide to atmosphere at greater rates
- **Fossil fuels** – coal, oil and natural gas that formed from the layering and compression of organic sediment

Global Atmospheric Concentrations of Carbon Dioxide Over Time



Data source: Compilation of 12 underlying datasets. See www.epa.gov/climatechange/science/indicators/ghg/ghg-concentrations.html for specific information.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climatechange/indicators.

Big Ideas

- Earth's climate system is comprised of the atmosphere, hydrosphere, cryosphere, biosphere and pedosphere.
- Climate is the journey of the Sun's energy received on Earth as it is deflected, stored, transformed, put to work, and eventually emitted back to space.
- Climate is variable, and is changing at an unprecedented rate.

Big Ideas

- Human activities play a key role in climate change, and connect humans to our natural environment.
- Through scientific study, we are able to see our influence on climate, and take actions to mitigate and adapt.
- Our understanding of the climate system is incomplete, but still speaks to the need for a dialog between scientists and the broader community to prepare and implement adaptation and mitigation strategies.

Key Terms

System

Climate

Mitigation

Greenhouse Gases

Climate Variability

Climatic Vulnerability

Climate Change

Ecosystem

Sustainability

Peer Review Process

Climatology

Scientific Method

Open and Closed Systems

Trace Gases

Troposphere

Ozone

Stratosphere

Mesosphere

Thermosphere

Temperature gradient

Hydrosphere

Cryosphere

Feedbacks (positive and negative)

Lithosphere

Asthenosphere

Pedosphere

Biosphere

Food Web

Carbon Cycle

Fossil Fuels