APES CHAPTER 19 NOTES (MRS. BAUCK): GLOBAL CHANGE

MODULE 62: Global Climate Change and the Greenhouse Effect

I. Global Change: climate change and global warming

A. Weather

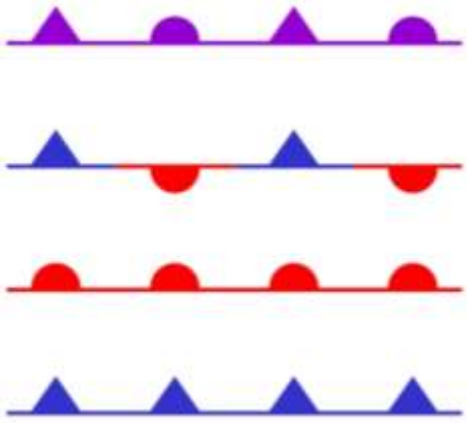
1) *weather—daily variations* in temperature, precipitation, wind, pressure, etc.
2) *climate—long-term weather patterns* of an area (tropical, polar, middle-latitude climates)
3) *convection currents*: warm air rises, cooler air sinks
4) *meteorology*—the study of the atmosphere and its changes
5) *air masses—large bodies of air with the same temperature and moisture*
   a) *maritime polar*—(mP)—*moist* and *cool* air mass
   b) *maritime tropical*—(mT)—*moist* and *warm* air mass
   c) *continental polar*—(cP)—*dry* and *cool* air mass
   d) *continental tropical*—(cT)—*dry* and *warm* air mass
   e) *continental arctic*—(cA)—very *dry* and *cold* Arctic air mass
6) *fronts—air mass boundaries*
   1) regions of change
   2) can be *cold, warm, stationary, or occluded*

OCCLUDED

STATIONARY

WARM

COLD



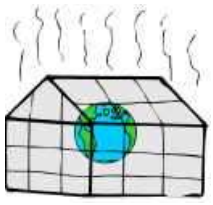
Source: Donegal Weather Channel

7) *monsoons*—climatic systems anywhere in which the moisture increases dramatically in the warm season
8) *jet stream*—current of fast moving air found in the upper levels of the atmosphere

B. Global climate change *** Fig. 62.1***

1) **global change**—*changes in the biological, physical, and chemical properties of Earth*
2) **global climate change**—*changes in average climate* (long-term weather patterns over years or decades)
3) **global warming**—*trends of temperature increase of land masses, atmosphere, and bodies of water on Earth*

II. Solar radiation and the Greenhouse Effect



- *human-made* = **anthropogenic**
- *from biological processes* = **biogenic**
- *from geochemical activity* = **geogenic**

1) warming processes
   a) **Greenhouse effect**—heating up of Earth's atmosphere (1827)
      - **infrared radiation or IR** *is absorbed by the surface and radiated out from the ground as heat*
      - *IR is absorbed and radiated back by greenhouse gases and is trapped in the troposphere*
      - **greenhouse gases** *(GHG)*—any gases contributing to this
   b) Sun-Earth heating system—visible light and some UV incoming
   c) **greenhouse warming potential**—how much a molecule can contribute to global warming over a period of 100 yrs, compared to a CO_2 molecule
2) cooling processes
   1) **planetary albedo**—*reflection of solar radiation from low-level clouds back into space*
      (high-level clouds contribute to the greenhouse effect)
   2) *volcanism*—contributes particulates and aerosols
   3) *anthropogenic (human-made) sulfate* $(SO_4)^{2-}$ *aerosols*

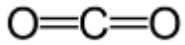
III. Greenhouse Gases (GHG)

A. summary of important GHG

CO_2	H_2O	CH_4	N_2O	O_3	CFCs

B. *Carbon Dioxide* (CO_2): Major Greenhouse Gas

1) *causes of increased atmospheric* CO_2



   a) *combustion of fossil fuels* increases atmospheric CO_2
   b) *deforestation* and *removal of other vegetation* reduces absorption of CO_2 for photosynthesis from atmosphere

2) *Review of the CARBON CYCLE*

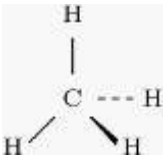
- C in CO_2 in atmosphere and in water is moved to C in glucose by **PHOTOSYNTHESIS** by producers. **$6CO_2 + 6H_2O$ + energy → $C_6H_{12}O_6 + 6O_2$**
- C in glucose is moved to C in CO_2 by **CELL RESPIRATION:** **$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy**
- C in glucose is moved to C in organic molecules by synthesis reactions in living things.
- C in organic molecules is moved to C in CO_2 by combustion.
- C in organic molecules in organisms is moved to C in fossil fuels over millions of years by pressure, heat, and bacterial action.
- C in limestone ($CaCO_3$) is released slowly to C in CO_2 when exposed to oxygen and/or water.
- *Largest reservoir of carbon: sedimentary rocks (limestone)*
- *Second largest reservoir of carbon: top 300 m of ocean (dissolved* CO_2*), living things in ocean.*
- In water:
  $CO_2 + H_2O \rightarrow HCO_3^-$ (bicarbonate ions) + CO_3^{2-} (carbonate ions)

$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$ (calcium carbonate) in shells/skeletons of aquatic organisms
$CaCO_3 \rightarrow$ buried, long period of time, pressure $\rightarrow$ limestone

C. *water vapor: H_2O (g) – most common GHG*

From NOAA.gov (National Oceanic and Atmospheric Administration): "*Water vapor is the most abundant greenhouse gas in the atmosphere*… However, changes in its concentration is also considered to be a result of *climate feedbacks related to the warming of the atmosphere rather than a direct result of industrialization*. The feedback loop in which water is involved is critically important to projecting future climate change, but as yet is still fairly poorly measured and understood."

D. *methane: CH_4*



1) the simplest *hydrocarbon (structure containing H and C)*
2) "lifetime" in the atmosphere is relatively brief (10-12 years)
3) *sources of methane*
   a) *fermentation—cell respiration by partial breakdown of glucose*
   b) *"swamp gas" in wetlands*
   c) *livestock*
   d) *landfills*
   e) *natural gas production*
   f) *manure*
   g) *coal mining*
   h) *paddy rice farming*
   i) *covered vented landfill emissions*
   j) *newer style fully vented septic systems*

E. *nitrous oxide (AKA dinitrogen monoxide): N_2O*

$$N \equiv N^+ - O^- \quad \text{and} \quad N^- = N^+ = O$$

1) N_2O is a resonance structure ("flipping" of bonds)
2) sources of nitrous oxide
   a) agriculture
   b) combustion of biomass
   c) combustion of fossil fuels (lower conc.)
   d) anaerobic denitrification
   e) acts as a greenhouse gas and contributes to ozone depletion

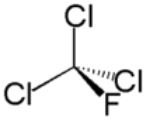
F. *CFCs and other halocarbons (halons)* – anthropogenic emissions only

1) **CFC = chlorofluorocarbon** *(hydrocarbon halogenated specifically with Cl and F)*
2) 10,000 times more efficient than CO_2 in absorbing IR radiation
3) *uses: refrigerants, industrial solvents, fire suppressants*
4) *types of CFCs*

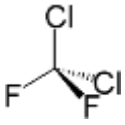
- *CCl_3F: trichlorofluoromethane, CFC-11, Freon-11, or R-11*
- *CCl_2F_2: dichlorodifluoromethane, CFC-12, Freon-12, or R-12*
- *CCl_4: carbon tetrachloride or tetrachloromethane*
- *CCl_2FCClF_2: 1,1,2-Trichloro-1,2,2-trifluoroethane, CFC-113, F-113, R-113*

5) *hydrochlorofluorocarbons (HCFCs):*

- *$CHClF_2$: chlorodifluoromethane, difluoromonochloromethane, HCFC-22, Freon-22, Halocarbon R22, or R-22*

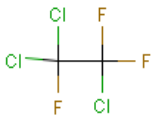


CFC-11

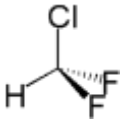


CFC-12

CCl_4



CFC-113



HCFC-22

G. other gases from noaa.gov (National Oceanic and Atmospheric Administration)

1) *carbon monoxide (CO)*

"Carbon monoxide (CO) is not considered a direct greenhouse gas, mostly because it does not absorb terrestrial thermal IR energy strongly enough. However, CO is able to modulate the production of methane and tropospheric ozone."

2) *Volatile Organic Compounds (VOCs)*

"Volatile Organic Compounds (VOCs) also have a small direct impact as greenhouse gases, as well being involved in chemical processes which modulate ozone production. VOCs include non-methane hydrocarbons (NMHC), and oxygenated NMHCs (eg. alcohols and organic acids), and their largest source is natural emissions from vegetation. However, there are some anthropogenic sources such as vehicle emissions, fuel production and biomass burning. Though measurement of VOCs is extremely difficult, it is expected that most anthropogenic emissions of these compounds have increased in recent decades."

3) long-lived synthesized gases
   a) CF_4 (carbon tetrafluoride)
   b) SF_6 (sulfur hexafluoride)
   c) SF_5CF_3 (trifluoromethyl sulfur pentafluoride)
   d) perfluorocarbons (PFCs; fluorinated hydrocarbons)

IV. Sources of Greenhouse Gases

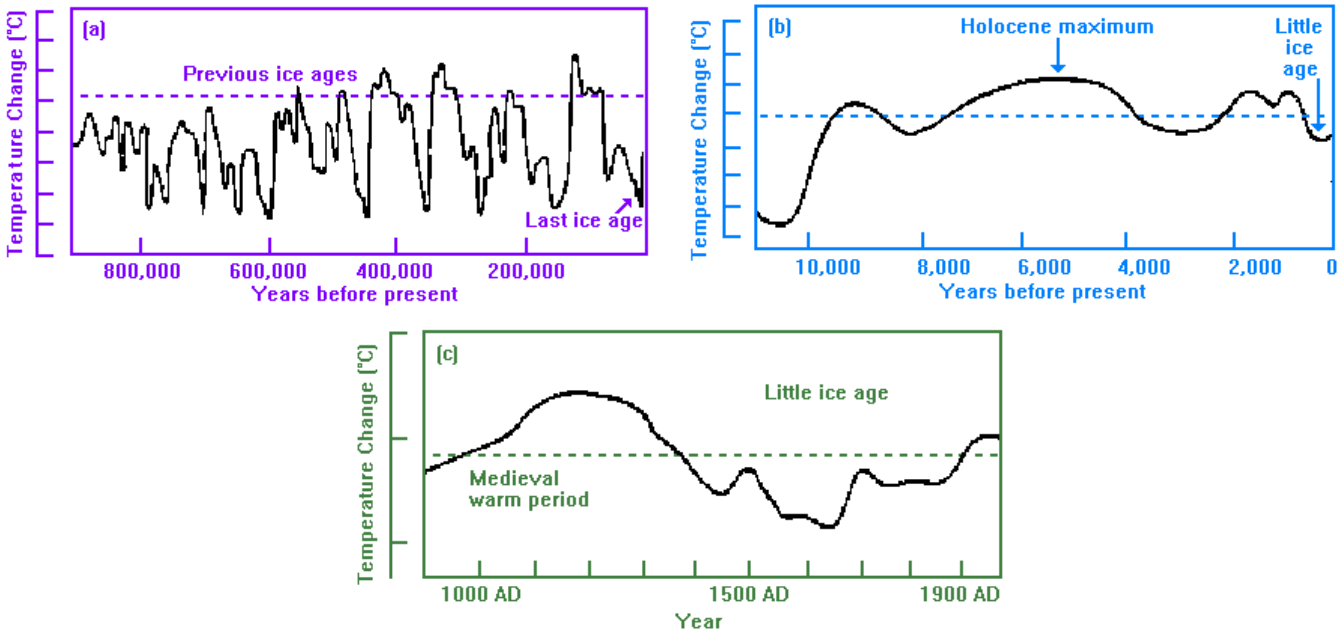
A. natural sources
   1) volcanic eruptions—H_2O, CO_2, SO_2, CO
   2) decomposition/digestion—CO_2, CH_4
   3) denitrification—N_2O
   4) evaporation/evapotranspiration—H_2O

B. anthropogenic sources
   1) fossil fuel combustion—CO_2, CO, SO_2, NO_2
   2) agriculture—CH_4 from livestock, CO_2, CH_4
   3) deforestation—less CO_2 removed, CH_4, N_2O
   4) landfills—CH_4
   5) industry—CFCs/HCFCs

MODULE 63: The Evidence for Global Warming

I. Climate

A. Climates in the Past from nasa.gov:



1) **Milankovitch cycles**—*time periods of oscillations*
2) CO_2 concentrations have been increasing for the past 60+ years
3) How do we know about past climate?
    1) "The *geological record* of carved mountain valleys, scratched bedrock, and glacial debris and moraines gives evidence of the past several million years.
    2) *Cores* have been removed from the *ice* at Vostok Station in Antarctica. The longest cores are about 2000 meters, sampling layers of ice deposited as early as 160,000 years ago. *The ice trapped bubbles of air when it froze. The ratio of oxygen isotopes in this air indicates the average air temperature at the time the bubble was trapped in ice. The bubbles also trap atmospheric greenhouse gases that can be measured.*
    3) *Tree rings* provide a record of the weather back 3,000 years in some cases, and hundreds of years in many areas.
    4) *Fossil plants and the distribution of pollen* show that vegetation has changed, consistent with changing climate.
    5) The *historical record* speaks to us for some 2,000 years and there have been real quantitative measurements since about 1850.
    6) Pollen from plants, buried in shallow deposits of earth, indicate the distribution of vegetation since the last glaciation, about 20,000 years ago."

3) **Ice Ages**—"*intervals of time when large areas of the surface of the earth are covered with ice sheets (large continental glaciers)*
from http://www.museum.state.il.us/exhibits/ice_ages/when_ice_ages.html

a) *describes long, generally cool intervals of Earth history (tens to hundreds of millions of years) during which glaciers advanced and receded*
b) *shorter time periods (tens of thousands of years) during which glaciers were near their maximum extent ('glaciations')*
c) the term 'Ice Age' is sometimes used to refer to the last major glaciation that occurred in North America and Eurasia. When used in this way, the first letters of both words are often capitalized."

Four Geologic Times of Glaciations

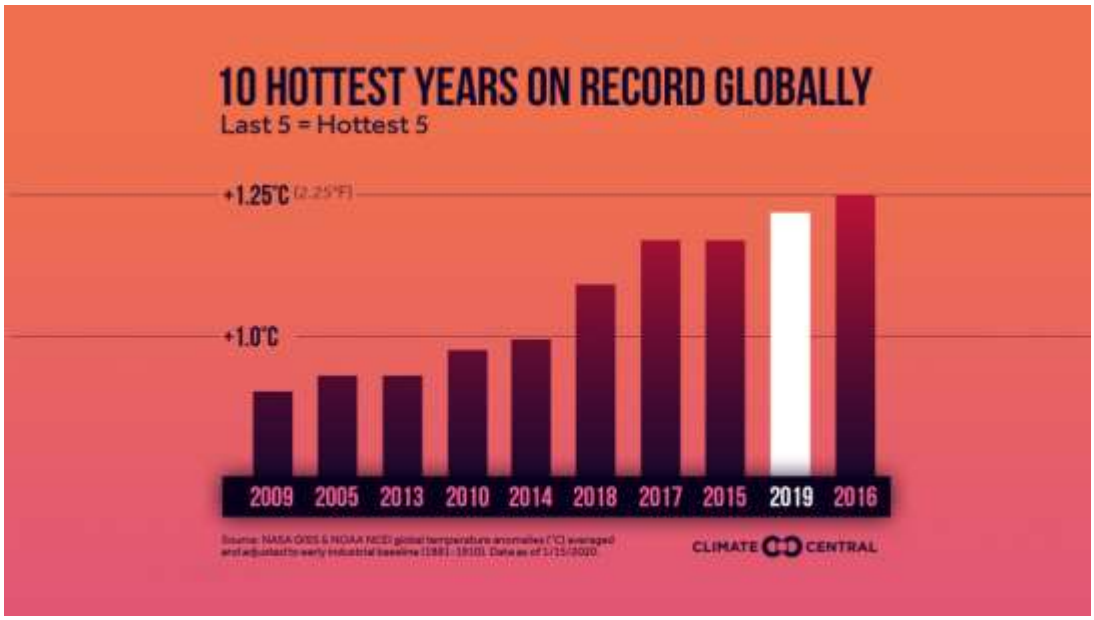
B. Data and Actions on Climate Change

1) **IPCC** from http://www.ipcc.ch

"**Intergovernmental Panel on Climate Change (IPCC)** *was established in 1988 by two United Nations organizations, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess the 'risk of human-induced climate change*'."

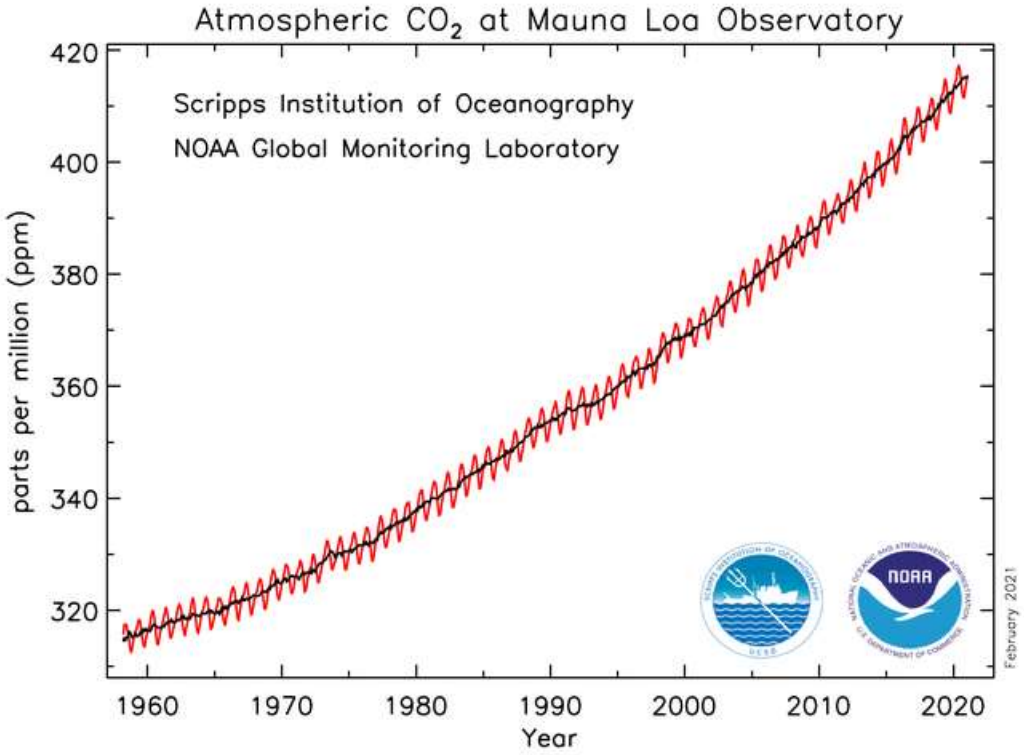
a) The IPCC has three working groups (WGs) and a task force
   - WGI: Scientific aspects of climate
   - WGII: Vulnerability, consequences, and options
   - WGIII: Limitation and mitigation options
   - Task Force: National Greenhouse Gas Inventories Program
b) 3000+ scientists, reports researched and written by hundreds of experts
c) Assessment Reports (AR) done periodically
d) summaries of past recent reports:

- Carbon dioxide, methane, and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values.
- The primary source of the increase in carbon dioxide is fossil fuel use, but land-use changes also make a contribution.
- The primary source of the increase in methane is very likely to be a combination of human agricultural activities and fossil fuel use.
- Warming in the last 100 years has caused about a 0.8 °C (1.4 °F) increase in global average temperature.
- Average Arctic temperatures increased at almost twice the global average rate in the past 100 years.
- It is likely that greenhouse gases would have caused more warming than we have observed if not for the cooling effects of volcanic and human-caused aerosols.
- Average Northern Hemisphere temperatures during the second half of the 20th century were very likely higher than during any other 50-year period in the last 500 years and likely the highest in at least the past 1300 years (a time near the beginning of the Little Ice Age).
- Mountain glaciers and snow cover have declined on average in both hemispheres.
- Losses from the land-based ice sheets of Greenland and Antarctica have very likely (> 90%) contributed to sea level rise.
- Ocean warming causes seawater to expand, which contributes to sea level rising.



Source: https://www.climatecentral.org/gallery/graphics/top-10-warmest-years-on-record

2) Keeling's Mauna Loa data:
   a) **(CO_2 levels) α (fossil fuel combustion + deforestation)**
   b) oscillations due to seasonal changes (deciduous trees and algae action)
   c) https://www.esrl.noaa.gov/gmd/ccgg/trends/



3) CO_2 emissions differ among nations
   a) highest CO_2 emissions: *China*, *U.S.*, India, Russia, Japan
   b) highest per capita CO_2: *U.S.*, Australia, Saudi Arabia, Canada, Taiwan

C. Ocean and Atmosphere

1) oceans' importance

From MIT: "Understanding the circulation and CO_2 biogeochemistry of the oceans is key to our ability to predict and assess the future evolution of climate."

a) *role in hydrologic cycle*
b) *regulation of heat and moisture*
c) *ocean currents move heat as well as water (convection currents, horizontal currents)*
d) *oceanic physical and biogeochemical processes are major regulators of natural atmospheric carbon dioxide (as well as being an important sink of fossil fuel CO_2)*
e) *high specific heat of water (4.184 J/g°C): heats up and cools downs slowly* (see specific heat practice problems)

II. Scientists' Estimation of Global Temperatures and GHG

A. How do we know about past climate? (quotes from NASA) – from p. 5

1) changing species composition – implications of ocean temperatures from sediment fossil foraminifera analysis
2) fossil plants and pollen distribution
3) geologic record of effects from running water and glaciation
4) ice core gas analysis
5) tree rings
6) historical record

B. Global temperature increase: GHG vs. increased solar radiation?

IPCC conclusion: most of the global average temperature increase is because of increased anthropogenic GHG emissions.

C. Global Climate Models (GCM)

https://www.giss.nasa.gov/projects/gcm/
http://ipcc-data.org/guidelines/pages/gcm_guide.html
from http://climate.calcommons.org/lists/general-circulation-models

"*A Global Climate Model (GCM), also known as a general circulation model, is a mathematical model of the circulation of the Earth's atmosphere and ocean.* Atmospheric and oceanic GCMs are key components of global climate models along with sea ice and land-surface components. *GCMs and global climate models are widely applied for weather forecasting, understanding the climate, and projecting climate change.* The first general circulation climate model that combined both oceanic and atmospheric processes was originally created in the 1960s at the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey (NOAA). Scientists were for the first time able to understand how the ocean and atmosphere interacted with each other to influence climate. The model still stands today as a breakthrough of enormous importance for climate science and weather forecasting. Since then, *additional GCMs have been developed based on the integration of a variety of fluid dynamical, chemical, and sometimes biological equations*."

III. Feedback Loops and Climate Change

A. Positive feedback loops (not good)

1) defrosting tundra permafrost
   a) pools of standing oxygen-deficient water form
   b) anaerobic decomposition of organic matter produces CH_4
2) increased aerobic breakdown of soil components releases CO_2
3) remember synergistic effects occur

B. Negative feedback loops (good)

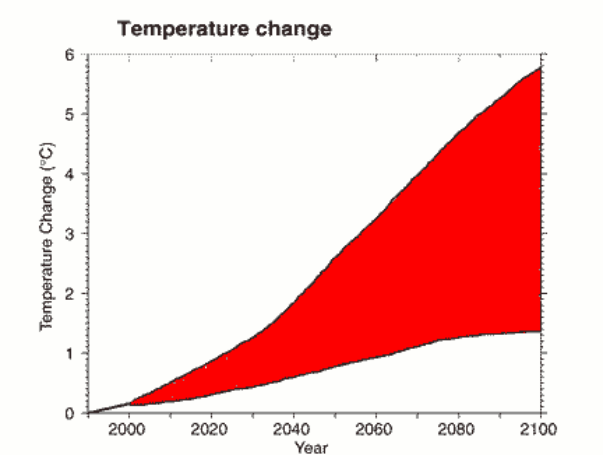
1) stimulation of plant growth with increased CO_2
2) increased oceanic absorption of CO_2 (good to get it out of the atmosphere but this contributes to **ocean acidification**) **$CO_2 + H_2O \rightarrow H_2CO_3$**
3) remember synergistic effects occur

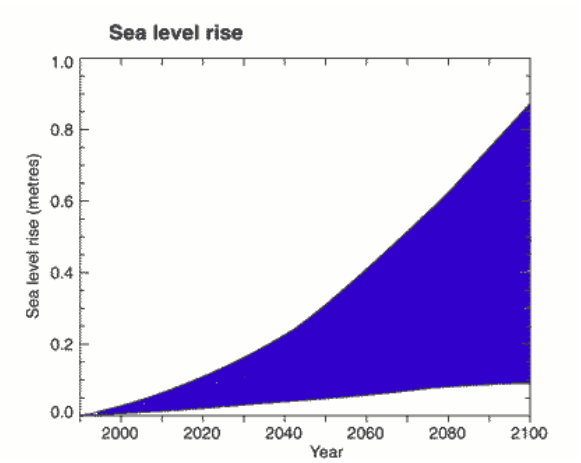
MODULE 64: The Consequences of Global Climate Change

I. Global impacts of warming

A. impacts of continued warming on abiotic factors

1) *polar ice melting* – Artic, Antarctica, Greenland
   National Snow and Ice Data Center http://nsidc.org/arcticseaicenews/
2) *glaciers and ice fields melting* faster than can be replenished
3) *permafrost melting*
4) *regional climate changes*
   a) affect agriculture
   b) affect rainfall and droughts
   c) affect oceanic circulation
   d) more exaggerated effects seen in the poles than at the equator
5) *weather changes*
   a) more intense El Niño events
   b) warmer and wetter European winters
   c) increased yearly U.S. rainfall; increased heavy storms
6) *rising sea level*
   a) *~ 2 mm/year*
   b) thermal expansion





Source: EPA

B. impacts of continued warming on biotic factors
Changes observed in…
1) time of plant germination and flowering
2) time of terrestrial animal migration
3) time of bird migration
4) time and duration of animal hibernation
5) time of insect hatching
6) geographic ranges of species
7) coral reefs (bleaching)

II. Predicted Effects of Future Warming *** TABLE 64.1***
A. heat waves and cold spells
B. altered precipitation patterns
C. increased intensity of storms
D. ocean's thermohaline circulation (THC) disruption
E. human population issues
1) possible relocation to other areas; SES issues
2) disease vectors affected by climate change
3) other economic issues

III. International Treaties
A. **United Nations Framework Convention on Climate Change** https://unfccc.int/ **(UNFCCC)** – document signed at the UNCED (United Nations Conference on Environment And Development) conference in Rio in 1992
B. **Paris Agreement**
C. U.S. withdraw in 2017 and rejoined in 2021

https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement

"In Paris, on 12 December 2015, Parties to the UNFCCC reached a landmark agreement to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low carbon future. The Paris Agreement builds upon the Convention and – for the first time – brings all nations into a common cause to undertake take ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so… *The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.* Additionally, the agreement aims to increase the ability of countries to deal with the impacts of climate change, and at making finance flows consistent with a low GHG emissions and climate-resilient pathway."

6/1/17

The Paris Agreement remains a historic treaty signed by 195 Parties and ratified by 146" (now more) "countries plus the European Union. Therefore it cannot be renegotiated based on the request of a single Party.

The Paris Agreement is aimed at reducing risk to economies and lives everywhere, while building the foundation for a more prosperous, secure and sustainable world. It enjoys profound credibility, as it was forged by all nations and is supported by a growing wave of business, investors, cities, states, regions and citizens. We are committed to continue working with all governments and partners in their efforts to fast forward climate action at global and national levels."

IV. **Kyoto Protocol** (December 1997)

A. background info.

From http://unfccc.int/kyoto_protocol/items/2830.php :

"The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change (FCCC). The major feature of the Kyoto Protocol is that it sets binding targets for industrialized countries and the European community for reducing greenhouse gas (GHG) emissions. These targets amount to an average of 5% against 1990 levels over the five-year period 2008-2012. The major distinction between the Protocol and the Convention is that while the Convention *encouraged* industrialized countries to stabilize GHG emissions, the Protocol *commits* them to do so."

B. based on the **Precautionary Principle**

Precautionary Principle: *Rio Declaration, 1992, Principle 15*

"In order to protect the environment, the Precautionary Approach shall be widely applied by States according to their capabilities. *Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*."

- *Taking precautionary action before scientific certainty of cause and effect*
- Setting goals
- Seeking out and evaluating alternatives
- Shifting burdens of proof
- Developing more democratic, thorough decision-making criteria/methods

C. gases targeted:

1) *carbon dioxide (CO_2)*
2) *methane (CH_4)*
3) *nitrous oxide (N_2O)*
4) *hydrofluorocarbons (HFCs)*
5) *perfluorocarbons (PFCs)*
6) *sulfur hexafluoride (SF_6)*

D. implementation http://unfccc.int/kyoto_protocol/items/2830.php

1) **carbon sequestration**—removing CO_2 from the atmosphere to decrease its effects as a GHG
2) countries must meet their targets primarily through national measures
3) restrict companies, etc. emitting the most pollutants
4) reduce emissions from vehicles
5) promote and use renewable, alternative energy sources
6) three market-based mechanisms to assist in other ways:
   a) *emissions trading – the 'carbon market'*
   b) *clean development mechanism* (CDM)

... "allows a country to implement an emission-reduction project in developing countries, which can earn saleable *certified emission reduction (CER) credits*, each equivalent to one ton of CO_2 counted towards meeting Kyoto targets"

   c) *joint implementation* (JI)

... "allows a country to implement an emission-reduction or emission-removal project in other countries, which can earn saleable *emission reduction units (ERUs)*, each equivalent to one ton of CO_2 counted towards meeting Kyoto targets"

E. An updated Kyoto protocol
   1) U.S., Canada, Russia, and Japan will not sign a new agreement. They object that developing countries are not required to make targeted emission cuts.
   2) http://www.breakingnews.com/topic/kyoto-protocol
   "Almost 200 nations extended a weak U.N. plan for fighting global warming until 2020, averting a new setback to two decades of U.N. efforts that have failed to halt rising world greenhouse gas emissions. The extension of the Kyoto Protocol keeps it alive as the only legally binding plan for combating global warming, even though it will cover developed nations whose share of world greenhouse gas emissions is less than 15 percent."

F. role of the U.S.
   1) The U.S. signed but never ratified the original Protocol. The signature alone was merely symbolic, as the Kyoto Protocol was non-binding on the United States unless ratified.
   2) The America's Climate Security Act of 2007, the "Cap and Trade Bill," was proposed for greater U.S. alignment with the Kyoto goals.

V. Response to Climate Change

A. Responses
   1) **adaptation**—prepare for the changes and protect ourselves
      a) Less Developed Countries Fund

https://www.un.org/ldcportal/least-developed-countries-fund-ldcf/

"The Least Developed Countries Fund (LDCF) was established under the UN Framework Convention on Climate Change (UNFCCC) to assist LDCs to carry out the preparation and implementation of national adaptation programmes of action (NAPAs). It is operated by the Global Environment Facility (GEF)."

      b) Special Climate Change Fund

https://unfccc.int/topics/climate-finance/resources/reports-of-the-special-climate-change-fund

"The Special Climate Change Fund (SCCF) was established under the Convention in 2001 to finance projects relating to: adaptation; technology transfer and capacity building; energy, transport, industry, agriculture, forestry and waste management; and economic diversification. This fund should complement other funding mechanisms for the implementation of the Convention."

      c) new research by U.N. committees
      d) general poverty reduction and sustainable development

   2) **mitigation**—take action to reduce GHG emissions
      a) **Intergovernmental Panel on Climate Change (IPCC)**
      b) **United Nations Framework Convention on Climate Change (FCCC)**
      c) United States Global Change Research Program (USGCRP) -- http://www.globalchange.gov/

B. Developments – What can be done?
   1) *CO_2 cap: Limit fossil fuel use in industry and transportation*
   2) *Promote safe, regulated nuclear power use*
   3) *Combat deforestation; promote reforestation projects*
   4) *Tighten building codes for energy efficiency*
   5) *Improve mass transit system*
   6) *Invest in renewable energy technology*

C. skepticism—why do anything at all?
   1) **precautionary principle** (see p. 11)
   2) **polluter pays principle** (polluters should pay for the damage they cause)
   3) **equity principle** (the affluent should be concerned about the disadvantaged)