Earth 2402: Climate Change: An Earth Science Perspective
Quizzes: drop lowest mark, only 9 quizzes count - 15 %
Midterm: Saturday **May 29** 1 to 3 pm - 30 %
Final: 55 %

Early Civilizations

- man's awareness can be traced back to early civilizations
- transmitted through myth and legend
- "fertile crescent" - Holocene interglacial, 5000 to 6000 years before pleistocene
- there were three cool intervals which characterize holocene
- earliest records **Egypt**
    - inscriptions recording the early levels of the Nile flood as early as 3000 B.C.
    - from the tomb of Ankhtifi - earliest known famine (around 2180 - 2130) in upper egypt
    - from the prophecy of Neferty composed between 2000 and 1950 B.C. - told of egypt becoming arid and dry, river empty, no wind
- biblical report in book of moses, talked of seven years of abundance and seven lean years
    - joseph - stored food for lean years
- other records of droughts and floods found in various texts
- commonest account are those like the great flood of Noah's Arc
- flooding also in Babylon, where inscriptions are found
- example at Ur, show flood layer from before 3000 B.C.
- some sea level change due to more rainfall, other related to eustatic rise of world sea level which drowned costal regions
    - **eustatic:** global sea level changes due to water added or removed
- during cooling periods, highest change in water levels
- weather driven by difference in temperature between poles, greater the difference, more extreme weather
- Maldives: sea level risen many times in the past 4000 years, even more so than water level now
- Norse legend of Ragnarok - records the doom of the gods and end of the world accompanied with a long and dreadful winter - three snowy winters with no summer
- Edda - recounts that wars raged over the earth and wolves attacked, but then a new world arose
- records the end of an old way or life when climate became colder in the early Iron Age
- Indian legend recounts a flood for 12 years that marks the end of the world
    - indian concept of successive ages of world points to continual renewal followed by destruction and renewal once more
- aristotle wrote about climate change in critical matter (384 - 322 BC)
    - same parts of earth are not always moist of dry, but change according as rivers come into existence or dry up
    - we much suppose the changes follow some order of cycle

        - aristotle gestures to the earth - felt that knowledge is through observation and experience
        - Plato theories that ideas are passed to us through gods
- Pliny the Elder
        - beech tree did not thrive, it was too hot
- reports indicate that in Roman Empire, the European climate was much warmer, recovering from a colder period
        - by the late 4th century AD, it may have been warmer than it is now
- China: studied evidence of pattern of cultivation in china during dynasties, and determined climate had led been warmer than now
- European civilization - there are written records of change in the environment
        - in the first century (AD 870 - 930), there was no record of ice
        - but when monks found the same waters in 6th to 8th century, there was significant ice
        - the Little Ice Age progressed Iceland and many costal areas were blocked by ice
- scientific view in nineteenth century - climate was constant
        - this approach was at variance with earlier generations
        - idea of constant climate abandoned at face of significant climate change during 1900-1950

Medieval Warm Episodes
- Medieval Warm Episode, around 1000 AD, warmth moved around the world at different times, affecting different areas of the world at different times
- CO_2 has increased in the last hundred years, but temperature has been changing all the time
- oxygen 18 isotope records indicate a warm period between 600 - 1100 AD

The Little Ice Age
- Little Ice Age began there around 1200 AD
- by AD 1250, the Kinds Mirror tells us that in East Greenland ice was formidable
- by AD 1342, the old sailing route used to reach Greenland had been abandoned because of an increase in ice
- by 1492, the situation has worsened - difficult to get to Greenland and Iceland
- at beginning of 13th and 14 century, famine began to form, bad harvest - led to Black Plague (much worse due to weakened population)
- East Europe experienced the harshest climate, because its continental and no waters affecting climate
- climate would change from one year to another - characteristic of cooling climate
- some summers would be rainy, other would be filled with drought
- weather calamities - people ate people, animals ate people
- whole globe cooler during this period
- more ice on land and sea since the last glaciation
- last from about 1250 to 1870
- during the famine and little ice age, men much shorter in Europe

- 1812 - Napoleon marched on Russia, Russia destroyed Moscow food source and Napoleon had to retreat. 95 % of his men died, starvation, disease, frostbite. “Napoleon syndrome” - groups to focus reasoning on their own interest
- documents in little ice age that glaciers advancing in the Alps
- earliest documentation is advance of Vernagt Glacier in 13th century
- glacier advances in swiss alps in 1280 - coincide with advance of Arctic Sea Ice off east Greenland
- glaciers then advanced again in 16th century - advancing glaciers crossed main valley bottoms and forms ice dammed lakes
- Allalin glacier in Switzerland blocked the Saas valley in 1589 - formed a lake which drained in a flood and had disastrous results - this lake existed until the 19th century, and caused many floods like this
- Grindelwald Glacier - advance in 13th century - still stand or retreat until 1500’s - coverage today is similar to AD 900 - 1200. In 1588, destroyed houses by advancing - stayed and then advanced again in 1703 - came down the valley even more. Another retreat, and then another advance that lasted until the 19th century.
- Conditions in iceland had eased between 1500 and 1550 and attempts were made to contact old Greenland colony - reacher Greenland, but colony had completely died ou
- Glaciers wipe out food sources - no more wheat, now sheep farming
- temperatures declined 1.5 - 2 degrees during the ice age
- the upland parishes in Scotland were also hit - nursing women found dead on public roads
- During little ice age, growing grain above 200 m elevation became impossible in Scandinavia, Scotland and Northern England
- crop failures were common - famine, wars, rebellion
- severe weather of some years led cultivators to decisions that indicated a dawning of awareness of climate change
- orange and mandarin cultivation were abandoned in china after cold waves
- France wine growing was shifted to South of France
- North America has less evidence
    - ancestors of modern northern Cree forced to abandon corn near Winnipeg in 1500
    - geological evidence of expansion of icecap on Baffin Island and other North regions
    - European settlers in North America are full of bitter winters
- polynesians colonized all major islands groups in the pacific islands 2000 years ago
    - shortly after the start of the Little Ice age, inter-island travel in ocean going canoes nearly ceased
    - coastal villages were abandoned in favour of hilltop settlements
    - increased storms from El Nino was a major factor is discouraging travel
    - change in water temperature and lower sea level impacted coastal fish populations and moving away from the coast
- climate of Europe turned toward greater warmth soon after the beginning of the 18th century
- temperatures were observed by thermometers and entered into observation books

- health and population statistics in Europe and Iceland positively registered the effect of the warmer decades
- 18th century was a more cheerful social and political mood in the 17th century
- puritan opposition was temporarily overcome in 1733-1734 to permit a new years ball in the Town House
- recorded that “first wheat was grown” - memories were short as wheat was grown in 1500’s
- average temperatures remained high through the 18th century until about 1810
- climate variations of 18th century affected society in many ways - there was a renewed built up of ice around the coasts of Iceland in late 18th century
    - population declined 25 % from famine, 1784 Danish government considered evacuation
- colder climates in 18th and 19th century had an impact on fashion - colder weather led to introduction of warmer women’s underwear - end to daring fashions after the Frensh Revolution - “aid of north wind to enforce the return to modesty”

Modern Times
- In Canada
    - early in 19th century - North American prairies received far more rain than now
    - canada west too cool to grow wheat crops
    - settlers in 1840’s found cornucopia
- conditions from 1930’s onward - researchers to appreciate climate variability
    - the drought of 1930 affected much nor North America (and Great Depression) create “dustbowl” and uprooted millions of people
    - highest temperature ever (45oC at Midale Sask)
- quaternary ice age (last 2 billions years) has consisted of 22 glacials, each followed by a brief interglacial

Hudson’s Bay Company Records of Canadian Climate
- Began in 1670’s
- recorded wind direction temperature changes and precipitation beginning in 1700’s
- brought the first thermometers as early as 1768
- functioning following medieval warm period
- fur trade was happening during the little ice age
- spanish armada storm was 1588 - severe storms with cold air moving south
- warming since 1680
- tree rings represent more precipitation than climate
- co2 can also affect tree rings, as well as insects
- settlement in northern newfoundland - see the landing site of the vikings in the medieval warm period
- 1683 - thames frozen over, carriages and fayre on the thames - thames froze during the reign of Queen Elizabeth I
- sulphur from volcanic eruption in 1815 - covered earth and created a year with no summer - 1816

- John Ray - medical surgeon with HBC - kept records and mapped much of Canadian Arctic Coast - told the truth about the clear evidence of cannibalism of Franklin expedition
- Canvas boat dipped in rubber to float on arctic ice - still had open water during this time
- relative homogeneity - if looking at regional climate change or global climate change
    - can have temperature or weather change that doesn't fit global pattern

Climate of Solar System

- three zones:
    - inner: earth, mars, mercury, venus (dense silicates)
    - middle: asteroid belt (bodies rich in carbonaceous material)
    - outer: jupiter and beyond (comprised of ice, hydrogen, helium)
- comets: chunks of ice and dust
    - orbit the sun as the planets do but in more exaggerated elongated paths
- **Venus**
    - 224.7 days in a year
    - 243 days in a day
    - most similar to Earth in distance and size
    - most unusual and fearsome environments
    - dense CO_2 plus sulphuric acid clouds
    - lower atmosphere stable
    - higher atmosphere - dynamic
    - venus has less water no oceans
    - on Earth CO_2 dissolves into oceans, not accumulated into atmosphere
    - on Venus, no oceans, CO_2 in atmosphere
    - no plate tectonics
    - CO_2 is more dense, air pressure is higher
    - shrouded with featureless, yellow white clouds
    - filled with sulphuric gas, falls as rain
- **Mars**
    - year 687 days
    - day: 24 hours, 37 min
    - rusting of iron bearing minerals causes red colour
    - not much solar energy by Sun
    - Mars is a cold planet, can reach 20oC during care, but colder, -140oC at night
    - summer winds whip up dust devils that can cover whole hemisphere
    - CO_2 and water vapour freezes in cold mornings into fog banks and dry ice
    - season storm pile up cause large sand dunes around north polar cap
    - clouds on mars localized and can cover entire regions but not entire planet
    - air temperatures are so cold, puffy and wispy clouds by water vapour and CO_2 vapour
    - Olympus Mons - largest Volcano - base would cover New Brunswick
    - dominates an entire hemisphere of Mars
    - water once flowed across surface
    - air pressure of only 3 mb

    - used to rain a lot - shallow oceans existed
    - geothermal heating from volcanoes melts ice causing floods
    - global warming 4 times faster than earth
    - impact structures on channel surfaces suggest that some water was free (for extended periods of time) on the surface sometime between 100 million and 3 billion years ago
- **Titan (Jupiter's Moon)**
    - revolution 224.7 days
    - thick yellowish clouds and haze
    - pressures at 1.6 times earth - composed of nitrogen
    - atmosphere the most the earth
    - however, much colder, around -180oC
    - nitrogen, methane, ethane, acetylene, ethylene, hydrogen cyanide
    - UV radiation in atmosphere produces octane resulting in frozen gasoline showers
    - at surface, methane may exist as ice or snow
    - maybe evaporating gas from methane ocean might replenish methane in atmosphere destroyed by UV rays
- **Europa**
    - revolution, 3.6 days
    - slightly smaller than our own moon
    - possible water oceans, heated by tidal flexing
    - on surface, shallow valleys
    - lack of craters, surface is not as old as other parts of solar system
    - surface is mostly frozen water
    - water is warmed by solar flexing

Reading the Rock Records

- rocks are fossils in Grand Canyon
- clams that are in "intertidal zone" add a thin calcareous layer to their shell, meaning there are two thin layers in the clams for the two different parts of the day - can tell how long the year was
    - growth slows and stops during winter, which shows the number of days in the year by counting the layers
    - clams show that earths rotation has slowed due to earth's rotation
- corals respond to the sun with a growth layer for each day
    - one siderial month is the time is takes for the moon to go around the earth once (28 days)
    - thickness of layer varies with season and lunar month - time from new moon to new moon (moon is in same position relative from earth to sun)
    - length of year can be inferred for the recent past
- earth expresses itself in many ways - analysis of modern sedimentary rocks allow us to interpret the record
- **facies**: reflection of original environment in a rock
    - sandstone may be result of beach or river facies
    - coal represents a swamp facies

    - limestone composed of coral and shell debris formed in warm-shallow sea facies
- **hiatus**: interval of time for which a record no longer exists, whether due to erosion or not
    - common for parts of a rock sequence to be missing
    - geologic formation called - unconformity
    - limestones may dissolve
- **stratigraphy**: branch of geology, studies rock layers and layering
    - used in the study of sedimentary and layered volcanic rocks

Geological Laws

1. Law of Superposition
- formulated by Nicolaus Steno
- edge of a sequence of sedimentary rocks or lava flow decreases upwards; each bed being younger than the one underneath

2. Law of Initial Horizontality
- most sediments have been planted in a flat surface

3. Law of Lateral Continuity
- sediments initially were a continuous layer

4. Law of Cross Cutting Relations
- if a bed is transversed by a dyke or fault, the dyke or fault is newer

Fossils as Relative Dating Tools
- fossils can be used to place an outcrop in its proper place on the geologic time scale
- some fossils exist during eras and then die off
- not all fossils good for correlation, some species have limited defined environment that is not useful for relative dating
- characteristics of good index fossils
    - wide distribution
    - abundant
    - must preserve well
    - short range (evolved and became extinct rapidly)

Bob Carter Video
- looking at last 16000 years, slight warming
- last 10000 years slightly cooling
- 2000 years still cooling
- 200 years still cooling
- for the last 20 years, there has been increasing in temperature
- last three warm periods were warmer than the current warm period
- cold periods between the warm periods
- most of the time its cold periods and not warm periods, unlikely that it will get warmer and warmer
- rate of change is less now than it was in the last 5000 years

Age of the Earth

- James Hutton - famous Scottish geologist thought that the Earth was very old
- Darwin's theory of evolution indicated that Earth needed to be quite old
- discovery of radioactivity in later years permitted precise age determinators for past
- in 1654 James Ussher - Ireland - based on scriptures said that Creation - 4004 BC
- Vice Chancellor of Cambridge - 9 am Oct 26 4004 BC
- eventually could not be 6000 years
- in 1749, French Naturalist de Buffon - 75,000 years
- Kelvin estimated that earth was 20-30 million years based on uniformitarianism (mirror of past - gradually changing over time)
    - ball molten lava to cool
- irish chemist assumed that ocean had no sald - reasoned that 90 million years to be as salty as today
    - if used his method today, 260,000 years

Carbon Information
- carbon dioxide is not carbon
    - carbon is: basic element that forms thousands of compounds - some poison, some beneficial - all life based on carbon
    - natural pure carbon - graphite, diamonds, soot
- carbon dioxide - natural odorless gas - naturally occurring
    - oceans, volcanoes, rotting vegetation, plant respiration, combustion
    - essential to plant photosynthesis and to life
    - not a pollutant
    - at less than 180 ppm, life is marginal
- CO2 rises = more growth
    - higher CO2 allows for more growth in dryer regions

Radiometric Dating
- discovery of radioactivity - allowed mechanism for earth to remain hot
    - convection of earth additional heat
- better estimate for age of earth
    - determine that earth was 400 million to 2 billion
    - since refined - now 4.6 billion years
- principles behind dating rocks with radioactive elements is simple
    - number of protons controls chemical behavior
    - number of neutrons varies giving rise to isotopes
    - sum of neutrons and protons is mass number
- oxygen isotopes are stable and are not used for radioactive dating
- carbon-14 is the only radioactive - decays to nitrogen-14
- rate of decay - half life : time for half the number of atoms present to decay to daughter plus radiation (constant)
- can put dates and ages on samples
- half lives can vary - 4.5 billion for uranium-238, 1600 years for radium
- 14C is the unstable isotope of carbon and is created in the upper atmosphere
    - cosmic rays collide with atom producing energetic neutron
    - neutron collides with nitrogen

- radioactive 14C is made
    - reaction with oxygen
    - co2 molecule produced with 14C
    - absorbed in plants - water
    - 14C in organic material eventually decays to 14N
- radiocarbon decays back to 14N as soon as it appears
- living organisms maintain equilibrium with the reservoir in the atmosphere or ocean until they die
    - 14C begins to decay as soon as it hits body
    - level of 14C same as in atmosphere
    - when die, fraction of 14C begins to reduce - no new 14C coming in
- conditions that must be met
    - rock must be impermeable
    - parent or daughter isotopes cannot be gained or lost except by radioactive decay
    - metamorphic rocks must be avoided as the radioactive clock will be reset
- isotope age data subject that are not easily spotted
- statistical errors, repeat measurements give different values
    - age of 100 +- 6 million years - 2/3 of measurements will fall between 94-106 my
- latest cenozoic boundary dates known to within 100 000 years
- uncertainty increases to 0.5 million in paleocene
- uncertainty increases as we get older
- radioactive decay - exclusively igneous rocks
    - use igneous intrusions
    - causes problems with long sedimentary sequences with no lava flows
- many igneous rocks become magnetized parallel to earth's magnetic field as they cool
    - shifts every 700,000
    - variable - irregular
- Sr can be used - comes off surface with weathering
    - if you measure - you can decide water weathering or not
    - work has been done to calculate ratio
    - analysis of fossils from different times and dates by other means provided a standard curve of the changing Sr
    - Sr enters calcareous skeletons and shells with the radio of seawater at that time

Assessing Paleo-Climate Data
- accurate widespread temperature records only available for a century
- increased in accuracy with computers and satellites
- climatic data from a single year cannot be meaningful to much of anything
- other proxies
    - dendrichonology
        - trees ad a growth ring each season
        - rings are of variable width depending on growing conditions
        - provide accurate estimate of long term climate conditions
    - crop production records (wheat and grapes)

- even in the middle ages scrupulous records were kepy on planting and harvest dates and frosts
- alpine glacial advances and retreats
  - relative position of massive glaciers is a concern of europeans
  - subject of paintings
- oxygen-18 and oxygen-16
  - 1/500 O is O-18 (2 extra neutrons)
  - O-18 is heavier, if water contains O-18, heavier
    - O-16 evaporates faster than water with O-18
    - interglacial - rains onto land, and river brings it back
    - glacial - O-16 into ice and snow, leaves only O-18 in water
      - animals build shells from the water - have more O-18
- assessing paleo-climate data
  - annual layers of ice form in many polar ice sheets
  - these layers can be counted in some deep drill cores to as far back as several hundred thousand years

Lecture 6: Video 1

- glacier is a large mass of ice that moves (flows) due to gravity moving on it
- ice came from snow which has recrystalized into ice
- glaciers are dependent on the ocean to keep them active
- water from seas evaporates and moves into atmosphere, water freezes as snow and falls
- if more snow accumulates than melts, beginning of glacier
- glaciers can even be found at equator
- high elevations (3 - 4 miles above sea level) in warmer climates

Lecture 6: Video 2

- around 18 000 years ago, massive glaciers locked 1/3 of land
- rivers of ice gouged through mountains,
- temperatures began to rice, glaciers retreated, exposing a changed landscape
- glacier is created when snow falls faster than melts, snow accumulates weight and crystalizes into ice
- glaciers move less than 3 cm a day
- bottom layer moves slower than top, strain cracks the ice, created crevases in the top
- still 1/10 of earth has glaciers

Glaciations and the Ice Age

- not until 1830's when a swiss Louis Agassiz - hypothesized that we were living in glacial age
  - took years to convince piers
  - evidence in swiss alps
- until 1970's believed that 4 of 5 glacial periods separated by interglacials
- now we understand more than 33 have occurred
- more O18 than O16 in a glacial period
- Holocene period - interglacial period that has been broken off as a separate unit
- glaciations began in the northern hemisphere about 3 million years ago

- Antarctica has had glaciations for about 15 millions years
- glacial - cool period in ice age
- interglacial - warm period in ice age
- cold house period (tens of millions of years of colder temperature)
- hot house period (tens of millions of years of warmer temperature)

Isotopes and the Fossil Record
- carbon-14 is radioactive - decays
- oxygen-18 and oxygen-16 are not radioactive, do not decay
- oxygen isotopes are how we recognize glacial and interglacials from ocean sediment
- discovered how many using fossil shells of marine organisms
    - analyze them using oxygen isotopes
- at some point during Cretaceous period - there was no ice on the earth (hot house period)
- 500 million year records shows two major ice ages (Ice Houses (50 - 100 million years))
- sequence of ice age
    - **Ice House, Ice Age, Glacial, Little Ice Age**
- ice ages began millions and millions of years ago
- quaternary glaciation record is displayed in oxygen isotope record of ocean sediment
    - sharp transitions from cold to warm states delimit global oxygen isotope stage time boundaries
    - defined as TERMINATION
- glacial cycles have changed with time
- early glacials and interglacials were roughly equal length, about 40 to 50 thousand years
- around 1 million years ago, glacials became fewer and longer - now about 100, 000 years
    - interglacials shorter
- world at height of last glaciation indicates what climate change is capable of
- ice cover was extensive over much of North America and Europe and through southern hemisphere from 25,000 to 17,000 years ago
    - ice dome was 3 km high covered much of Canada
    - high period was in Hudson's Bay
    - patchy periods - no ice cover in Yukon, Siberia (not much precipitation)
    - separate ice dome in Europe

World Beyond the Ice
- in the last glacial - 4o million cubic km of ice
    - sough of ice margin were fast treeless plains
    - forest grew not to far south from that
    - glacial stops advancing if there is not enough source material ro push it
    - advance into areas that are quite warm, but if advancing faster than melting, can move far south as the northern US
    - as long as ice kept building in north, kept moving south (even if warmer) because glaciers flow

- ice sheet - ice mass covered an area of >50, 000 km2
- ice cap - ice mass that covers less than 50,000 m2 of land
- ice shelf - thick (100 - 1000m, sea ice is much thinner) floating platforms of ice that forms when glacier or ice sheet flows to coastline and onto ocean surface
- icecap over Antarctica was not much larger during ice age than now, as ice would break off into icebergs
    - surge from icebergs falling off the ice cap could destroy boats
- deep ocean surrounding continent prevented expansion
    - any glacial advances were calved off as icebergs
    - southern hemisphere was protected from the antarctic ice

The Ice Age
- microfossils tell us that during summer about 18 thousand years ago,
    - ocean frozen from greenland to UK
    - pack ice extended from carolinas to spain
    - gulf stream flowed directly form florida to azores
    - summer ocean temperature off carolina and spain did not exceed 10oC
- cannot tell this by land, because glaciers destroy old glacier information that passed over
    - one glacier rides across and obliterates other glacier debris
- icebergs break off in ice ages, as bergs drift, they drop evidence into ocean
    - different sedimentary layers that build up with each ice age
- there layers are not eroded away by next glacier
- in 1988, Harmut Heinrich identified six sedimentary layers rich with debris in North Atlantic
    - events accompanied changes in climate
    - Heinrichs events occurred when North Atlantic was coldest
    - represent great armadas of melting icebergs
    - changes in north pacific ocean were minor compared to atlantic
    - equatorial ocean was much cooler than now
    - Haiti, Indonesia and California were similar to now
- large climate swings at high and mid latitudes had impact on tropics and subtropics
    - equatorial regions were wetter
    - lake levels in east africa and middle east were higher
    - sahara was lush
- because warm areas were compressed toward the equator, rains that fall in midlatitudes (Mediterranean) fell at lower latitudes (norther sahara)
- in western north america, large high over the icecap deflected winter pacific storms southward - rains that fall from BC fell in California
- North America was lushly forested with lots of lakes - now gone
- most of world was drier
- cooler ocean meant reduced evaporation
- low evaporation meant lower precipitation
- cooling on land most pronounced at higher latitudes
- continental climate records derived largely from study of plant pollen
    - pollen abundant and resistant to decay

- accumulates at datable layers in lakes and ponds
    - plants sensitive to change in environment - precise record of climate change
- during glacial maxima
    - boreal forest of birch pine, hemlock and spruce grey south of tundra
    - temperate deciduous forest of eastern north america retreated to florida and gulf coast

Amazon Jungle in Amazonia: Professor Patterson
- cooler climate and less precipitation decreased area covered by tropical rain forests in South America, central america, central africa india and south east asia
- little patches of rainforest with mostly Savannah
- mountain trees and plants supplanted much of tropical rain forest
- lungs of planet - calcareous diatoms in ocean
- ecosystems of Amazonian rainforest are traditionally depicted as fragile
    - only been established for 6-7000 years
    - in pleistocene - tropical Amazonian rainforest has only existed for brief intervals during interglacials
- during a glaciation, the rainforest retreat into small areas, expanding quickly when conditions become favorable again

Pleistocene Glaciation: Levels of Land and Sea
- water was drawn from sea to build icecaps
    - sea level changes significantly altered coastline - declined
    - melting glaciers resulting in flooded coastal plaints
    - ice buildups resulted in exposed continental shelves
    - **eustatic sea level change** - global sea level changes due to water added or removed
    - **isostatic sea level change** - sea level changes that are due to the ground rising or falling
- ice less dense then crust - but ice very thick
    - depression of crust underneath
    - significant impact of depression of land
    - leads to relative sea level change due to loading and unloading of weight
- Hudson bay was formed in depression continental crust formerly at centre of an ice sheet
    - has been rebounding since ice retreated
    - will by dry in a few thousand years
    - probably in time for it to be the centre of the new ice sheet
- if remaining ice on greenland and Antarctica were to melt, the sea would rise 70 m - but this rebounding would take thousands of thousands of years
    - last glacial removed 100 - 150 m of water removed
    - more sever glacials can remove up to 160 m off
- glaciation induced rise of trop in sea estimated by
    - calculating ice volume from known area and thickness of icecaps
    - extent of terminal moraines - ice thickness, a critical parameter, is difficult to determine

- during the glacial - there was an exposure of continental shelf
    - covered with ice, however some areas were dry land - North Sea in England
    - some settlements that used to be above land, that are now underwater
- able to walk to Australia
- sea level dropped 115 m during this Ice Age
- isostatic sea level makes changes difficult to tell
- oxygen isotopes indicate water removed during glacial maximum equivalent to 165 m of sea level change
    - only see about 115 m change due to isostatic events
    - more water than deepest submerged shores suggest

Glaciers Come and Go
- Last interglacial
    - Eemian (North America)
    - Sagamon (Europe
    - isotope change (temperature change) 5e
        - arrived 131, 000 before present
        - lasted until about 114,000 before present
    - followed by two cooler intervals separated by slight warmings
    - climate warmer and more humid (holocene max)
    - average temperatures were 1-2 degress warmer
    - lions and elephants roamed England
    - Hippo's inhabited the thames
    - West Antarctic icesheets had melted
    - sea level was 2 m higher
    - perhaps equivalent to where greenhouse warming might take us
    - Greenland ice-core data indicates that Eemian climate was not stable
    - warmth interrupted several times by cold spells lasting from 70 - 700 years
    - temperatures in North Atlantic may have dropped by up to 10oC
- first major glaciation
    - began at stage 4e (75, 000 years before present)
    - forests vanished from mid latitudes and replaced by tundra and steppe
    - ice thickened at rate of 20-60 cm/year
    - ice sheets advanced at fast rates - up to 1km/year
- milder conditions by stage 3e
- full blown glaciation began 25, 000 years ago
    - stage 2e
    - full blown around 18,000 years ago
    - icecaps were probably not at their greatest extent most of the time
    - icecap over antarctica was not much larger during glaciation than it is now
- only 1000 years after reaching peak advance - the ice sheets began to retreat
    - speed ranged from 100's to more than 1000 m/year
    - ice sheets began to withdraw and took thousands of years to clear
- Holocene (stage 1) interglacial began 10,000 years ago
    - climate not as warm as as Eemian
    - holocene maximum - temperature reached at about 5000-6000 years ago

    - three cool intervals characterize Holocene
- levels of land and sea
    - at height of last glaciation - considerable amount of continental shelves exposed
    - upon deglaciation - sea level rose slowly at first then rose 24 meters in 1000 years about 12,000 years ago
    - return to cold during 10-11,000 years ago slowed sea level rise
    - rapid sea level rise again 8000 years ago - when sea level was 25 m below todays level
    - sea level has continued to rise slowly and hasn't stopped yet
    - claimes that Maldives sea level is rising too fast - however data shows that sea level was higher in the 70's, and the island still survived
    - sea level varies because water is soaked up into ice
    - between 16,000 and 9,000 years ago, shoreline of Gulf of Mexico retreated landward more than 3 m per years
    - west Antarctic ice sheet has been melting since last glacial maximum - retreat not caused by humans (began before humans existed)

Life Returns
- animals and plants quickly move north to fill the void
- white spruce - move in quickly to replace snow and ice
- some plants that move in quicker are grasses
- Dr. Ball - tree line advanced up to 200 km in some areas as climate warmed
- factors that influence speed of advancing vegetation
    - **ecological inertia**
        - ability of a plant community to persist in a partical area despite climate gradually becoming less suitable
        - often would take fire to clear ecological space
    - **photoperiodism**
        - genetic programming of plants to bloom when there is an appropriate numbers of hours and day and night
- northward migration of marine organisms
    - waters warming
    - changes in ocean currents

Lecture 7: Video 1
- cooling wiped out the entire population
- when vikings first landed on Greenland - super fertile
- Sun - true external driver of Earth's system energy
- Sun's magnetism has affect on the earth, when sun spot activity is compared - radiation from sun seems to contribute to radiation and climate on earth
- temperature leads CO_2 in last 600 years
    - warmer earth has more fertile soil, which allows more plant life, equals better CO_2 cycles
    - if you warm surface of ocean - CO_2 diffuses out of the ocean

Cold Periods

Name	Duration (Years)	Temp (oC) drop from average	Hypothesized Cause
Ice House	Tens of Millions	7+	Entering Galactic arms
Ice Age	Millions	5+	Continental positions
Glacials	Tens of Thousands	3++	Orbital Parameters (Milankovich)
Little Ice Age	Centuries	1 - 2	Solar Variability

Causes of Climate Change

Movement through the Milky Way Galaxy

- in early 2000's - University of Ottawa professor won award and spent money gathering fossilized sea shells around the world
    - looked at 018 to 016 and figure out warm and cold periods
    - figured out the temperature changes in tropical oceans (sin like waves)
- on other side of world - professor in Jerusulum
    - cosmic rays seemed to act in a similar way (sin like waves)
- pieces in galaxy move in and out of galactic arms
- go around galaxy every 200, 000, 000 years
- galaxy is like a wheel - areas of greater density in the arms of the galaxy than outside the arms
    - more material in arms = new stars make supernovas
- **galactic cosmic rays**
    - high energy particles
    - pieces of atoms, neutrons, protons
    - originate from supernovas
- looking at iron isotopes - see change of galactic cosmic rays
- as we go through galactic arms - more cosmic rays
- when galactic cosmic rays come into atmospheres - hit aerosols and they pick up electric charges
    - the aerosols then are able to hold water and create more low lying clouds
- clouds are a net cooling agent - temperature lowers

Plate Tectonics

- earth has 12 major plates and several minor plates that are constantly moving
    - the fastest plate moves at 15 cm/year
    - the slowest plates move less than 2.5 cm/year
- as continents drift - climate changes

- deep narrow passage control abyssal flow - control temperature
- continental drift controls gateways
- even minor tectonic events can have a profound influence on circulation
- if there is equatorial currents flow around entire planet - earth's oceans warmer
- earth is water and wetter
- throughout mesozoic there was no circumpolar - good equatorial
- when circumpolar current exists - antarctica becomes cooler and isolated
- when oceans were able to circulate around the equator - temperatures much warmer
- fossil forest found in US states of Georgia are similar to those found in Northern Canada
- when continents move - currents change and climates change
- Tethies ocean - circum-equitorial currents
- during Cenezoic era, continental drift caused two major changes in ocean circulation
    - gradual change to ice-house conditions
    - opening of antartic curcumpolar seway 25-35 MYA
    - closure of Isthmus of Panama
- at Eocene/Oligocene boundary, surface water suddenly cooler
    - triggered 4-5 degree temperature drop at abyssal depth
    - first of several drops
    - caused major extinctions of bottom dwellers
    - cold water covered antarctic shelf and glaciation began
    - northern hemisphere was less affected
    - low latitude surface waters not affected
    - this was around 35 MYA
- Oligocene: supply of warm water to high latitude further diminished at Thethys ocean closed
    - drake passage opened and thus began antarctic ice cap
    - arctic ocean began to form as north america and eurasia moved northward
    - although not as cold as Antarctica, arctic sea ice began to form
    - sea level dropped as antarctic was built in glacier
    - rise in 18O in benthic microfossils
    - marked transition from hot house to ice house world
    - coincides with transition from circumequatorial to circumpolar ocean circulation
- world also changed from submerged to emergent continents
    - prairies covered in oceans, as sea level drop, prairies unveiled
    - emergence and drift of continents led to greater seasonal changes
    - climates at high latitudes became more severe
- production of cold antarctic water accelerated resulting in bull blown antarctic bottom water
    - why was antarctic ice sheet formation delayed for 15 MY beyond the time when it started to become glaciated?
    - greenland-iceland-faeroes ridge continued to sink during interval, interfered with natural flow of water - began to sink and allowed north atlantic deep water to travel the entire ocean range and pop up - warm water caused snow fall
- miocene - delay in antarctic icecap formation result of lack of precipitation rather than lack of cold (teleconnection)

    - temperatures fluctuated, cooling at about 6 MY
    - sea levels dropped, more ice in antarctic
    - Mediterranean became isolated and evaporated locking up salt - Messinian Salinity Crisis (late miocene)
    - straights of Gibraltar is only 14km across, and closed off entirely at this point
    - major source of salt was gone, oceans became deficient in salt - higher freezing point, sea ice is pushed farther south
    - 4.5 MYA, a rise of sea level and a relaxation of plate movement, waters fell over the Gibraltar waterfall to fill Mediterrenean sea
    - as moved through miocene, greater contrast in temperature between equator and poles
    - colder oceans resulted in less global rainfall
    - dry conditions lured some forest dwelling primates out of the trees and into the savannah
    - contributed to bipedal locomotion and eventual evolution of homo sapiens
- Pliocene - world warmed briefly during this time
    - icecaps began finally to appear in Northern hemisphere 3 MYA
    - development indicated by aprupt shift in oxygen isotope ratios and ice rattled cobbles in marine sediments
    - cobbles dropped by glaciers and found in the interior continental region
    - northern glaciation linked to closure of Panamanian Isthmus
    - closure pushed warm gulf stream further north
    - increased water water which brought more moisture to high latitude which facilitated growth of ice cap development
    - need a source of water to increase glaciers

Orogenesis (Mountain Building)
- mountain and high plateas have a profound influence on climate
- rain falls on upwind flank and rain shadows develop on downwind flank
- in South America, the Andes intercept moisture brought by trade wings with dense forests on eastern sloped and desert on the western slope - Atacama desert goes right up to the ocean, cold desert (hasn’t rain for 4 centuries)
- infleunce of mountains and high plateaus reaches high into the stratosphere
    - late cenozoic time of massive mountain building
    - colorado plateau and tibetan plateau had a huge effect on climate in the area
    - monsoon winds are seasonally reversed and driven by temperature differences between land and sea, blow toward heart of continent in summer, blow toward sea in winter
    - heat capacity of water is much higher than capacity of air
    - indian government - while the observed monsoon rainfall at the all-indian level does not show any significant trend, regional monsoon variations have been recorded

Orbital Parameters

- equinox happens at two specific moments in time, when the centre of the sun is vertically above the earths equator (night and day are equal length) - March 20/21 and Sept 22/23
- amount of polar radiation striking the Earth depends on relative position of Earth and Sun
- natural variations in orbital parameters impact the climate of the planet
- orbital fluctuations set conditions for the cooler and warmer periods of glacial-interglacial stages
- Mutilin Milankovich (1920) first proposed that glacial interglacial cycles were controlled by amount of radiation received from the sun
    - argued that periods were initiated by three orbital parameters
        - eccentricity
        - axial tilt (obliquity)
        - time of perihelion
    - acting independently of each other, the three factors change the amount and distribution of sun's energy over planetary surface at regular intervals

1. Orbital Eccentricity Change
- move in ellipses, when we are at perihelion, our earth is tilted from sun (winter), meaning that our winters are less sever, when we are at our aphelion, our summers are less severe
- extremes a little moderated by tilt in northern hemisphere
- moderated by oceans in southern hemisphere
- eccentricity is a measure of the shae of the earths orbit around the sun
- the orbit changes from elliptical to circular around ever 100 thousand years
- earth orbit varies from 0.005, nearly circular, to quite elliptical at 0.06
- it is now 0.0174, which is a 3 % difference in the distance to the sun at perihelion and aphelion, this causes a 7% variation in the amount of solar energy received at the top of the atmosphere
- as eccentricity rises, the variation in solar energy receieved between the perihelion and aphelion
- when the difference is at its highest, there is a 20% change

2. Axis Tilt Changes
- when a higher tilt, more seasonal changes
- poles receive less sunlight when tilt is deceased and more when incresed
- 41000 year cycle
- tilt, or roll moves between 24.5 and 22.1 degrees
- when the tilt is high, there is more variation between summer and winter seasons in mid and high latitudes. winters tend to be colder and summers warmer
    - colder winters = less snow in high latitudes
    - warmer summers = more snow and ice melt
    - net effect is that there is an extensive retreat in the polar latitudes (neglecting other contributing factors)
- when tilt is lower, there is less variation between summer and winter seasons
    - warmer winters = more snow
    - cooler summers = not as much melt

- net effect is that there is a build up of glaciers

3. Axis Direction Changes

- as earth rotates on hits axis, it wobbles like a spinning top with a cycle of about 26,000 years

- during the past 2.6 MY, the 41,000 obliquity cycle dominated earth part with resultant glaciations and interglacials about the same length
- more recently, the eccentricity has dominated, resulting in very long glacials and not as long interglacials
- computer models and historic evidence suggests that Milankovich cycles exert greatest influence when troughs and peaks of the tree cycles all coincide
- variations in earth's movements, resulting changes in solar energy flux at high latitude, and the observed glacial cycles (caused by the changes in the earths movements)

Planetary Albedo

- percentage of incident solar radiation of all wavelengths reflected
- an ideal white body had an albedo of 100% and an ideal black body 0%
- reflectivity of earths affects heat budged of planet
- albedo contributed to by: aerosols, clouds, ice, water, land, surface plants
- differences in surface characteristics of planet affect radiations reflected from earth's surface back to space
- ice and clean snow surfaces have high alberdos, most solar radiation is reflected. larger area covered by ice sheets, cooler the planet
- oceans, and plants have low albedo and absorb most of radiation striking them
- increases in areas of ocean and vegetation lead to decrease in planetary albedo and warmer Earth

Aerosols

- small airborne particles
- natural aerosols are from volcanoes, wildfires, wind blown dust, land/ocean emissions of biologically produced gas and sea salt sprays
- the greater the amount of aerosols in atmosphere, the greater the amount of solar radiation reflected back into space
- aerosols generally cause a cooling effect
- satellite image shows distribution of sulphur dioxide and dust from volcano plume, caused global cooling

Urban Heat Island Effect

- different urban surfaces have different albedo values
- surface temperatures of urban structures can be 20 degrees higher than the ambient air temperatures, forming heat islands
- since the 1970's, Atlanta GA has undergone massive urbanization forming a heat island
- starting to change colour of buildings and less asphalt to decrease temperature in cities
- Atlanta make its own weather - induces development of thunderstorm

- by 2025, 80 percent of the world will live in urban cities, this can cause many more heat islands
- planting vegetation and using light coloured building can help to prevent these heat islands

Greenhouse Effect
- without the natural greenhouse effect, the earth would have an average annual temperature would be -18degrees, instead of the present value of 15
- thus, the natural greenhouse effect contributes a warming of 33 degrees, making life possible on this planet
- most of this warming is from water vapour (clouds) in the atmosphere
- a small amount of warming is due to carbon dioxide and other gases
- by comparison, the atmosphere of mars (96% of its atmosphere is carbon dioxide) has an average temperature of -56
- atmospheric greenhouse gases comprise less than 0.1 % of the air
- they are necessary gases to maintain an equitable climate on earth
- the greenhouse effect has an important influence on the climate of the Earth
- temperature of Earth is maintained by a balance between flux of incoming radiation and amount of outgoing infrared radiation to space
- CO_2 has an impact on the earths climate, but not nearly as much as they claimed in the IPCC report
- distribution of radiation at top of atmosphere depends on
    - geometry of globe, its rotation, and its elliptical orbit around the sun
    - on entering the earth's atmosphere solar radiation is absorbed and scattered
- Earth's annual and global mean energy balance
    - absorbed radiation - added to heat budged of planet
    - scattered radiation - returned to space
    - some radiation absorbed by ozone in stratosphere causing warming
- without clouds, only 10% of incoming radiation would be reflected, with clouds 30% radiation reflected
- low level strata clouds and storm clouds cool more than they warm (low cooling clouds that are caused by galactic rays)
- high level icy clouds warm more than they cool
- thick stratocumulus clouds reflect sunlight and cool the surface
- thin cirrus clouds allow energy to pass through and warm the surface
- overall clouds globally exert cooling influence on planet
    - add to heat budget of planet
- aerosols and sulphates in the air generally reflect energy back toto space and cause cooling
- depending on surface albedo, a certain portion of solar energy is reflected
- emitted energy from surface mainly in form of infared radiation and convection
- "trapping" of radiation from surface causes natural greenhouse effect and makes planet habitable
- global ambient temperature would be 33o cooler than it is without the greenhouse effect
- relative importance of major human-produced greenhouse gases to warming

- CO_2 is the most important followed by methane, CFC's
- heat loss from the surface without infrared absorbing gases
    - half energy from fluid dynamics, have radiation
- anthropogenic causes may result in increasing greenhouse effect and warming Earth
- host of factors may be contributing to warming - release of greenhouse gases
    - burning of fossil fuels
    - deforestation
    - agriculture and industrial practices
    - release of man made CFC's still in parts of the developing world
- greenhouse warming could heat up the earth above ambient temperature for several hundred ears
    - left on its own, it could delay the onset of the next glaciation
    - climate change under current cold house could be very quick
    - development of super interglacial might delay onset of next glacial interval
- difficult for researchers to differentiate natural climate change signlas from anthropogenically generated climate change signals
    - analogous to trying to decipher an encrypted radio message when you don't know the carrier wave
    - critical information for planners

Methane
- CH_3 - natural gas - effective greenhouse gas
- atmospheric concentration (1.78 ppm in 2008)
- 20 times as effective as CO_2 at trapping infrared radiation (heat)
- produced by the decay of plant material by anaerobic bacteria in stomachs of cows, sheep, guts of termites, wet soils of swamps and rice paddies
- methane has been accumulated in the atmosphere at about 1% annually

Nitrous Oxide
- naturally occurring gas that is produced by microbial activity in the soilds and the ocean
- also from combustion of fossil fuels
- biomass burning
- production of fertilizers
- contributes to an enhanced greenhouse effect
- 310 times more of an impact than CO_2

Halocarbons
- clorine, fluorine, bromine, or iodine
- subset of these are chlorofluorocarbons
    - human creation - industrial origin
    - responsible for stratospheric ozone depletion
    - less abundant in atmosphere, but 10,000 times as an impact than CO_2

Ozone
- natural source of O_3 are

    - electrical storms
    - decomposing plants
    - forest fires
- although toxic, O_3 is important in the stratosphere as it blocks out harmful UV rays
- tropospheric ozone concentrations may have increased
- pollutant in many urban areas - including Ottawa

Water Vapour
- H_2O is the principal greenhouse gas, although it varies considerably
- water cycle is very complex
- typically responsible for 85 percent of greenhouse event
- amount of water vapour determines the makeup of clouds
- water vapour is pretty stable, not increase

Carbon DIoxide
- natural carbon cycle involves movement of carbon through reservoirs in lithosphere, hydrosphere, atmosphere and biosphere
- cycle has gone on through geologic time
- co_2 in atmosphere has varied significantly over time, much higher in distant past than now
- 450 MYA, very high CO_2 levels
- sometimes there was high CO_2 and high temp, sometimes low CO_2 and high temp
- Vostok
    - look at air bubbles trapped in ice
- CO_2 rises after temperature rises
    - confirms that CO_2 is not the force that drives climate system during deglaciation
    - similarity between CO_2 and Vostok temp support than CO_2 may be controlled by something else
    - during past 400,000 temperature rose 800 years before CO_2
- during Eemian interglacial 135,000 years ago, CO_2 concentrations were around 280 ppmv
- during the last glacial maximum, CO_2 concentrations were around 180 ppmv
- during the Holocene interglacial CO_2 concentrations have varied from 200-300 ppmv, now towards 400 ppmv

Sun as a Driver of Climate Change and Marine Productivity in the Pacific
- Effingham Inlet
    - core description
        - core length = 123 cm
        - top 23 cm laminated
        - rest of core is earthquake stump later
    - cronology constrained by
        - valve (shell) countint
        - major 1946 earthquake
        - ^{137}Cs and ^{210}Pb dating
    - time series shows correlation with sun spot cycles

        - 11 year Schwabe cycle
        - 75-90 year Gleissberg cycle
        - 200-500 year Suess cycle
        - 1100-1500 year Bond cycle
    - 3500 years before present phase, frequency of herring and anchovy data

Solar / Celestial Factors that Affect Climate

1. Sun

- the suns energy is known to fluctuate periodically
- in 1612, during the sumer months Galileo looked at the sun through a telescope and discovered sunspots
    - move over the suns surface
    - sunspots are dark and relatively cooler (3000-4000 K) areas on the surface
    - larger than the earth
    - in 1843, Heinrich Schwabe found sunspots to have an 11 year cycle
    - they originate at high latitudes and drift towards the equator
    - the peak activity corresponds to high latitudesolar flares that form geomagnetic storms that can impact the Earth
- the suns corona is 300 times hotter than the surface
    - eruptive events in the region can disrupt high tech systems on earth
- during sunspot maxima, radiation emissions from Sun's poles are at a max providing more heat for the Earth
- total daily solar energy received is around 1360 W/m
    - suns output varies by (1.4W/m2) through 11 year solar cycle
    - insufficient on own to cause significant climate variability and observed 0.6-0.8 degree warming since the little ice age

2. Clouds

- evolution of cloud modeling: computer forecast have changed over recent years from a net warming to a net cooling of the planet
- Cloud climate forcing results of opposite effects
    - heating by clouds (positive forcing)
    - cooling by clouds (negative forcing)

3. Galactic Cosmic Rays

- one supernova per second in universe
- high energy particles
- pieces of atoms
    - neutrons
    - protons
    - originate in galactic supernova
- whispy blue lines are galactic cosmic rays in Cassiopeia A supernova remnant
- earth cools when we enter galactic arms as cosmic ray flux increases
    - temperature is not correlated with CO_2 over geologic time frames
    - temperature is not correlated with
    - correlation between sunspot cycle, galactic cosmic rays and global cloudiness

    - 15% variation in cosmic ray penetration between solar maximum and minimum casuses 1.7% variation in low cloud formation
    - 1.7% variation in low cloud formation equals 1.3 W/m2 in surface warming
    - 85% of IPCC estimate for effect of all CO_2 since beginning of industrial revolution = 1.4 W/m2
- ion-aerosol near-cloud mechanism
- highly charged aerosols develop at cloud boundaries which migrate within clouds enhancing ice crystal formation
    - 1.7% variation in low cloud formation between solar maximum and minimum
- cosmic rays have caralytic effect on nucleation of cloud droplets
- cosmic rays continually bombard solar system
- celestial climate amplifier
- cosmic ray intensity varies by factor of 3-4 on decadal to millennial scale
- cosmic rays in the geologic record
    - energy output from cosmis rays only one-billionth of solar radiation
    - dominant source of penetrating ionizing particle radiation
    - cosmic rays generate light radioisotopes of 14C and 10Be
    - time series of sunspot number reconstructed from 10Be concentration in ice cores from Antactica and Greenland
    - temporal lag of 14C with respect to sunspot number is due to long attenuation time of 14C
    - changes in 10Be concentration in one Greenland ice core,
    - decrease in 10Be since 1900 reflects a decrease in cosmic ray flux over this period
    - the reason is that solar magnetic flux has increased by almost a factor of 2 since 1900 for reasons that are not fully understood
    - since 1900, the 10Be concentration has decreased, which indicates that the cosmic ray flux has decreased about 10% over this period
    - decrease in cosmic ray flux led to a decreased in cloudiness
    - resulting decrease in cloudiness would have caused an increase in global mean temperature of about 0.6 C, equivalent to a radiative forcing of about 1.4 W/m2

4. Sun, UV, Radiation
- greenhouse gas create ozone which blocks UV radiation
- 0.4% increase in solar shortwave UV radiation under solar maximum conditions
- influences: ozone concentration, radiative heating, zonal circulation
- increased rate of penetration of circulation anomalies from stratosphere to troposphere under solar maximum conditions
- influences planetary waves
- increased rate of penetration of jet stream from stratosphere to troposphere under solar maximum conditions
- correlation between sunspot cycle and location of Aleutian low and north pacific high
- efffingham climate and diatom production interconnection
    - sunspot cycle, celestial / solar modulation ->
    - cloud formation / circulation anomalies ->
    - displacement of jet stream in troposphere and stratosphere ->

    - NPH/AL move ->
    - Enhanced upwelling increases nutrients and diatom production
- as solar irreadiance increases and decrases, so does the flow of the Mississippi river
- sun more active now than in the last 8000 years
- the next cycle, cycle 25 is said to be the weakest in centuries
- record low crawl, normally 1 m/s, now 0.75 m in N and 0.35 m in S
- serious concern in agricultural sector
- projected temperature decline of 2C would halve production from 22 – 10 million tons of wheat

Ocean and Atmosphere

Origin of Atmosphere
- earth is about 4.6 billion years old
- little atmosphere early on because most of the original very light gas envelope (H/He) escaped into space due to high heat off of planet, proximity to the sun and low surface gravity
- volcanoes expelled gases and formed the new (2nd) atmosphere
    - composed mostly of CO_2 and water vapour
- clouds reflected 60%, they also trap energy
- water began accumulated in liquid form about 4.0 bya, forming the earliest terrestrial oceans
- volume of earths mantle is 10 to the 27 cm3 (avg density of 4.5 g/cm3)
    - total mass for mantle is 4.5 x 10 to the 27 g
    - water of oceans has a mass of 1.4 x 10 to the 24 g
    - mantle would have only had to lose 0.031% of mass as H_2O to produce oceans
- alternate source of earths ocean water is comet like balls of ice
    - measure about 9 m in diameter
    - enter atmosphere at a rate of 20/sec
    - at the observed rate of occurance, earth would recieve 0.0025 mm of water per year
    - four billion years of these would give enough water to fill the oceans
- primary crystalline rocks were weathered and eroded
    - high concentrations of carbonic acid resulting from CO_2 and H_2O molecules in the atmosphere aided the weathering
    - various inorganic compounds were also washed into the new oceans
- absent in the early atmosphere was free oxygen
- oceans became salty from addition of the Cl^- ion
    - $2Na + Cl_2 \rightarrow 2NaCl$
- first fossil life - bacteria like forms (3.8BYA)
    - these forms must have been heterotrophs, which depend on external food supply
    - autotrophs eventually evolved
- photosynthesizing autotrophs appeared 2.3 BYA (stromatolites)
    - $6H_2O + 6CO_2 + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6O_2$
    - water + carbon dioxide + sunlight --> sugar + oxygen

- single celled plants appeared 2.1 BYA
    - coincided with appearance of significant amount of oxygen in atmosphere
- by 1.8 BYA, oxygen levels reached 10% of present levels
    - appearance of life impacted almost all aspects of further physical evolution of Earth
- more solar energy absorbed than radiated bac into space between 35N and 40S

Atmospheric Anatomy
- if it were not for atmospheric and ocean circulation redistributing the heat, the low latitude areas would bake and high latitude areas would freeze
- greater heating of atmosphere over equator causes air to decrease in density and rise
- this air cools by expansion, and water vapour condenses and falls as precipitation in equatorial zone
- after losing moisture, this now dry air mass descends in the subtropical regions (-30 latitude) of Northern and Southern hemispheres
- as descending air approaches Earth's surface, it is warmed by compression
- it moves away from the tropics, toward either the equator or higher latitudes
- a high pressure belt develops in subtropics because of this dense air
- between subtropical high pressure belts, lies an equatorial low pressure belt (Intertropical Convergence Zone (ITCZ)
- as Earth rotates on axis, objects on Earth's surface travel at very different speeds depending on their latitudes
- air mass moves with same speed as the surface under it
- so winds have an extra component of velocity, the tangential velocity, to add to any north or south-ward velocity
- objects on earths surface veer to right in N. Hemisphere and to left in S. Hemisphere
- Trade winds blow out of northeast (in N. Hemisphere), because as the air mass moves south from the subtropical region near 30Nlatitude, it is also moving with the rotating Earth in the easterly direction at about 1400 km/h (land which it is travelling faster)
- trade winds blow in both hemispheres, out of the southern hemisphere because, as the air mass moves north from the subtropical region, it is also moving with the rotating Earth in the easterly direction at about 1400 km/h
- returning air to equator veers right in the Northern hemisphere and left in the southern
- air moving from subtropical high pressure belts toward equatorial low pressure belt forms the trade winds
- air that descends in subtropical regions at higher latitudes forms the westerly wind belts, or westerlies
    - a westerly wind air mass moves from 30 latitude in a northernly direction to 60 latitude
    - this mass also is moving in an easterly direction at 1400 km/h, which is faster than the land mass over which it travels and so it veers east
    - these masses rise over dense, cold air moving away from polar high pressure caps at sub polar low pressure belts
- air moving away from poles produces polar easterly wind belts, or easterlies
- air that rises at 60 latitude cools, releases precipitation in these regions, and descends in polar or sub tropic regions

- severe storms are common when cold polar air masses interact with warm tropical air masses
- idealized latitudinal patterns significantly altered by uneven distribution of land and ocean over Earth's surface and the tilt of Earth's axis of rotation
- Eastward movements of air masses is brought about by movement of jet stream
- easterly moving air mass centered at about 10 km above midlatitude
- jet stream path usually follows a wavy path and may cause unusual weather by pulling a polar air mass far south or a tropical air mass far north

Oceanic Anatomy
- more or less stable climatic difference is maintained between the polar and tropical regions though
- open ocean divided into climatic regions run east to west
- temperature and salinity waters determined by
    - solar radiation
    - rate of evaporation
    - precipitation
- ocean basins divided into three regions
    - continental margins (extend from shore to shelf break)
    - continental slope (steep averaging about 4o)
    - deep sea basins (>4000 m, slopes less than 1:1000)
- in ocean absorption of visible light is greater for longer wavelength colours
    - in ocean, shorted wavelength portion of the visible spectrum transmitted to depth
- green colour characteristic of more productive ocean areas in the north is due to higher concentrations of dissolved organic matter scattering the longer light wavelengths
- currents are driven by energy from the sun
    - circulation of these massive currents is either
        - wind-driven
        - thermohaline (density gradient created by surface heat, salinity changes)
    - wind driven circulation set in motion by moving air masses
        - confined primarily to horizontal movements in upper waters of the ocean
        - plays roll in transporting excess heat from tropics to higher latitudes
        - due to coreolis effect and deflection along continental margins, currents move away from equator as warm boundary currents
- motion is caused by dominant surface feature of each major ocean basins; the subtropical gyres
    - gyres rotate clockwise in Northern hemisphere and counterclockwise in southern hemisphere
- in atlantic ocean surface and subsurface currents form conveyor belt that exchanges water in polar regions
- interaction of atmospheric and oceanic circulation form a global conveyor belt
- teleconnections between components mean variations developed in one region can have global consequences

- teleconnections: climate anomalies being related to each other at large distances; a set of recognized conditions that are linked to, or controlled by, forcing conditions a great distance away

El Nino / La Nina: The Southern Oscillation

- 1899, Famine strikes india when monsoons fall
    - British director general of observatories in India, sets out to understand phenomenon
    - goal is to predict monsoons so that famine can be averted
    - collected weather records from all over the globe
    - established room full of “computers” (people with pen and paper), to calculate the correlation of all these records
    - identified connections between weather / climate pattern in remote parts of the world
    - never succeeded in predicting - **still can’t**
- he did note that
    - when atmospheric pressure unusually high in western equatorial pacific, it tended to be unusally low in southeastern tropical pacific, and vice versa
    - this seesaw between pressure - Southern Oscillation
        - oscillation in air pressure between the tropial eastern and western pacific ocean waters

at the same time

- fisherman in coastal peru were noticing an annual influx of warm water would temporarily result in reduced catches
    - took this time off to repair nets
    - around christmas time
    - El Nino (the male child)
- during nortmal years, nutriends brought to the surface by cold Peru undercurrent support a rich concentration of fish
- Peruvian coast is characterized by low surface temperatures and high concentrations of nutriends, making high biological productivity
- trade winds push warm surface water westward where it piles up, raising the sea level by 40 m
    - change direction every few years
    - warm surface waters accumulated in the west moving eastward, pooling in central Pacific and beginning El Nino (oct - nov)
    - warm waters reach the pacific coast in december and suppress upwelling of cold water - every 2 to 7 years
    - fresh fish die without the nutrient rich water and fishing industry collapses
    - on land; crops grow and animals graze in regions inhospitable to agriculture
    - down floes - floods accompany rainfall
    - marine food chain is disrupted and marine mammals and seabirds starve
        - Nov 1982, all 17 million nesting birds on Kritimati Island had abandoned nestings
- plays havoc with world weather via teleconnections
    - worsening drought in Sahel

        - weakens Indian monsoon
- El Nino pushes mid-latitude storms poleward
- causes drought in central North America
    - dec, 1997 - drought and high temperatures in Alberta triggered massive wildfires that destroyed livestock and homes
- 1997-1998 Early El Nino effects included
    - fall 1997 - drought and high temperatures trigger fires in Australia
    - fall 1997 - cyclones pounded Mexican Pacific coast
    - an intense ice storm enveloped the northeaster United States and eastern Canada during the week of Jan 5 1998
        - successive belts of freezing rain over the course of several days caused extensive damage to trees and powerlines
        - storm heralded the world of century caused extensive power outages
        - 40% of electricity delivered infrastructure destroyed in southern Quebec and easter Ontario
        - at peak, outages with more than 3 million customers
        - state of emergency was declared throughout the region - 16000 federal troops brought in to clean up
        - power was not restored for some people for up to four weeks
        - storm damage caused the single largest natural distaster in Canada
        - 27 deaths - car accidents, CO poisoning, hypothermia
        - clean up - 2 billion
    - typically impacts of El Nino on North America and Atlantic Basin
        - Hurricanes: below normal number of hurricanes
        - Monsoons: a drier than normal North American Monsoon
        - Drought: a drier than normal fall and winter in northwestern north america
        - Wintertime Storms: a wetter than normal winter in the gulf coast states and in central and southern CA
        - Warmer Temperatures: a warmer than normal late fall and winter in northern great prairies and upper midwest
    - in highly weather sensitive energy sector
        - households and business save on heating costs
        - energy production and distribution suffered from reduced sales
- geologically record
    - modern gulf of california is a very deep young ocean
    - many contained basins are characterized by anoxic conditions caused by poor circulation
    - lack of benthic biological activity in theses basins permit preservation of laminar deposits when plankton fall
    - these deposits often record a very highly detailed record of paleoceanographic change, including fossil evidence of ancient el Nino
    - analysis of microfossils from these deposits laid down in the miocene and younger rocks of california reveal that the el Nino cycle did not exist until the onset of much cooler global conditions in the Pleistocene
    - dendrochronological analysis also provides record of El Nino

- in north america, detailed records of the terrestrial effects of El Nino are available for the last 5000 years.
- modern El Nino began at the termination of Holocene Hypithermal about 5000 years BP
- 453 moderate to strong El Nino's detected in lake on Galapagos islands
- intensity increases during Cold Intervals - Iron Ice Cold Period and little Ice Age

Pacific Decadal Oscillation
- long-lived El Nino- like pattern of Pacific climate variability
- two climate oscillations have similar spatial climate fingerprints but behave very differently in time
- cause not known
- coined in 199 while researching connections between Alaska salmon and pacific climate
- lasts for 20-30 years, EN last 6 to 18 months
- PFD most visible in North Pacific / North American sector

North Atlantic Oscillation
- seesaw in winter climate now known as North Atlantic Oscillation
- index is difference of sea-level pressure between Iceland and Azores

Denis Lachelle
- during Pleistocene, large ice sheet covered most of Canada
- ancient permafrost layer on mars
- Pleistocene ice sheet still shown in Barnes ice cap
    - laurentide ice sheet
    -

Climate Models
- three D General Circulation Models provide most complete numerical representations and simulations of climate system available
- ocean models constructed like atmospheric models
    - lower boundary is stepped ocean floor
    - upper boundary is atmosphere
- typical output data from ocean GCM experiments are ocean temperature, salinity, and sea ice extent
- ocean models are at a more primitive stage of development than atmospheric models
    - know less about ocean circulation
    - foundation of bottom waters
- assume that:
    - at every stage in development of model necessary to make assumptions - perhaps hundreds of them
    - might or might not be considered reasonable by others in the field, but rapidly become hidden
    - some larger models of recent times deal with interactions of variables whose nature is very poorly understood by todays science

- testibility
    - models are useless unless they can be tested against reality
    - if model gives reasonably accurate predictions on simple system there are grounds for believing it may be accurate in other circumstances
    - unfortunately truism lost in enthusiasm of new computer modelling age
- mismatch between real geologic data and climate output from the model is common
    - important factors may be missing
    - model may not adequately simulate parts of climatic system
    - geologic data used for comparison with model output may have been misinterpreted
- principals of forecasting
    - 139 principals are used to summarize knowledge about forecasting. They cover formulated a problem, obtaining information about it, selecting and applying methods, evaluating methods, using forecasts. Each principle is described along with its purpose, the conditions under which it is relevant, and the strength and sources of evidence
    - IPCC approach violated 72 principles of forecasting
- critique of climate models
    - have so far not been validated
    - models have not been successful in simulating the past - consequently, they do not offer a reliable basis for predicting the future
    - there is insufficient knowledge of the role of water (~85 of the greenhouse effect)
    - models do not adequately characterize clouds, water vapour, aerosols, ocean currents and solar effects
    - the role of the sun has been underestimated
    - insufficient amount has been take of the progressive uptake of CO_2 by plants and the equally progressive growth of vegetation
    - consequently, the CO_2 concentration will increase less than expected
    - growth of vegetation as such is very valuable for mankind

Dr. Tad : Guest Lecture

- three types of wave motion
    - **a.** longitudal waves (sound waves)
        - **i.** as wave moves, particles also move in same direction
    - **b.** vertical transverse waves (light waves)
        - **ii.** as wave moves horizontal, particles move up and down
    - **c.** horizontally transverse waves
        - **iii.** as wave moves horizontal, particles moves north and south
- three types of natural hazards
    - **a.** permanent
        - climate change, tides
    - **b.** evanescent
        - slow and gradual
        - no clear beginning and end

- sea level rise, drought

c. Episodic
- fast occuring
- short duration

- permanent hazards
    - tides, wind waves, climate change
    - tides occur due to the imbalance between the gravitational forces of the moon and sun on the earth and the centrifugal forces due to Earth's rotation on its axis once in 24 hours
    - wind waves are permanent, although their amplitudes vary in time and in space
    - climate change has been occurring continuously for the past 280 million years
    - climate change will continue to happen for the next however many years
    - the maximum coastal inundation on Earth is due to tides, however since it is a regular feature, humans have already factored this into account in planning their coastal activities
    - for permanent hazards, no warning systems, rather routine prediction
- evanescent
    - droughts, sea level rise
    - these are slow and gradual and there is no beginning of end
    - difficult to set up warning systems
    - various parameters defining these hazards can be monitored in real time
- episodic
    - earthquakes, tsunamis, landslides, submarine land slides, volcanic eruptions, tropical cyclones, extra tropical cycles, meso-scale weather systems, storm surges, river floods, flash floors, snow avalanches, rogue waves, tornadoes, thunderstorms
    - early warning systems exist
- why are there tides
    - gravitational attraction between the moon and earth and between sun and earth
    - other planets in our solar system are too far from earth to exert any significant gravitational attraction
    - imbalance between gravitational attraction and centrifugal force, gives rise to tidal attraction or force
- tidal force
    - inversely propotional to the cube of the distance between the moon and the earth
    - moon is on average 224000 miles from the earth
    - sun is 93 million miles away
    - even though sun if bigger, moon is closer
    - semidiurnal, diurnal

Tsunami's

- sources of tsunami generation
    - submarine earthquakes
    - submarine volcanic explosions
    - submarine landslides

    - nuclear explosions
    - chemical and munitions explosions
    - asteroid strikes the ocean
    - decomposition of gas hydrates
    - large scale sudden release of water from the continent that were stored in ice - marginal lakes
- inundation distance and run-up height
    - debris brought onshore by the tsunami and caught in bushes indicate the height of the tsunami
    - survey topographic profiles and to measure heights of water marks above sea level
    - interactions with the locals
- amplification of tsunami in shallow water
- direction of tsunami signal
    - tide gauge
    - ocean bottom pressure sensors
    - pressure fluctuations int he lower troposphere
    - ionosphere
- characteristics of Kallakadal in Kerala India
    - occurs mostly during pre monsoon season and sometimes during post monsoon
    - continues for a few days
    - inundates the low lying coast
    - during high tide the run up, water level can reach as much as 3.4 m above maximum water level
    - the associated wave characeteristics are typical of swells with moderate heights (2-3 m) and long period (15 sec)
    - occurrence is more often along the southern Kerala coast
- wave - current interaction
    - when a wave interacts with a current travelling in the same direction as wave propagation, wave amplitude reduces while the wavelength increases
    - when a wave encounters an incoming current, the wave amplitude increases while its wavelength decreases

Do World Scientists really Agree that our Emissions of CO2 are causing a global warming crisis?

- 1945 - UN formed to ensure military and economic security
- 1972 - United Nations Environment Programme (UNEP) formed
- 1985 - International workshop on climate change in Austria
    - conclude that significant climate change is probable, and that a global climate convention should be adopted
- 1988 - unusually hot summer
    - convined it was “getting warmer” - due to humans
- 1988 - WMO and UNEP established Intergovernmental Panel on Climate Change (IPCC)
- 1988 - Toronto - World Conference on the Changing Atmosphere

    - global CO_2 emission reductions of 20% by 2005
- 1988 - UN resolution is approved characterizing climate as a “common concern of mankind”
- 1990 - IPCC releases first assessment report on global climate
    - concludes global temperatures could increase by 0.3 if CO_2 emissions not reduced
- 1992 - UN framework convention on climate change signed at the earth summit in brazil
    - recognizes that reducing emissions by 2000 would be bennificial
- 1992 - UN framework convention on climate change ratified at the earth summit in brazil
- 1994 - berlin mandate - committing signatories to negotiations to extend and strengthen commitments under UNFCCC
- 1995 - IPCC’s second report
    - finds that GHG concentrations have continued to rise, climate has changed over the past century and is expected to change in the future
    - balance of evidence suggests a discernible influence of humans
    - chapter 8 controversy - erode credibility
- 1997 - Kyoto protocol
    - gives binding targets to UNFCC
    - 1/5 worlds population has GHG restrictions - does not apply manditory reductions to rapidly developing nations
- 2001 - IPCC’s third assessment
- 2002 - canada ratifies kyoto
    - does not meet targets eventually
- 2005 - Russia ratifies kyoto
- 2006 - An Inconvient Truth comes out
- 2007 - AIT released on DVD and shown in schools
- 2007 - fourth IPCC report
    - “greenhouse gas forcing has very likely caused most of the observed global warming over the last 50 years”
- 2009 - 15th UNFCC conference
    - copenhagen accord
    - 17% reduction of greenhouse gas emissions by 2020

IPCC

- three working groups
- WG 1 - assesses available scientific information on climate change - its causes and future forecasts
- WG 2 - assesses impacts of climate change
- WG 3 - formulates response strategies
- working groups composed of UN nominees, mainly government employees, or recipients of government finance, who generally agree with the UN’s position

The Popular Opinion

- humanity is causing a climate crisis, and all serious scientists agree

- claimed evidence
    - 2500 scientists from UN's IPCC
    - joint statements from science bodies
    - individual scientists
- a report released by the UN IPCC
    - humans very likely to have caused climate change
- "scientific integrity is not determined by a show of hands" - Tim Ball
- "many experiments may prove me right, but it only takes one to prove me wrong" Einstein