

Global Climate Change - Final Exam Topics Overview - 2011

Chapter 12 - Last Glacial Maximum

greatest extent of northern hemisphere ice sheets was ~21,000 yrs ago

insolation was rising, was nearly what it is today

but more ice than today because of lag time in ice dynamics

glacial max climate - colder & drier

extensive loess deposits

expansion of active regions of sand dune development

North Atlantic much colder (ice rafted debris farther south than today)

models indicate split jet stream around Laurentide ice sheet

glacial era lakes in S.W. North America

displaced vegetation belts

expanded Antarctic sea ice

how much cooler were the tropics? (important b/c tells sensitivity to greenhouse gases)

contradictory evidence from sea surface temp studies & tropical glaciers

perhaps middle ground is right: ~3 °C cooler

Chapter 13 - Climate During and Since the Last Deglaciation

carbon dating terminal moraines shows retreat of Laurentide ice sheet between

21,000 yrs (max) and 6,000 yrs (essentially gone)

changing volume of ice tracked by sea level studies (Barbados corals)

changing melt-rate seen in sea level curve & meltwater pulses in Gulf of Mexico

Younger Dryas pause in melting - temporary return to cold

recognized in Greenland, N.Atlantic, & Europe

not a global event

very rapid climate change

result of changes in N.Atlantic circulation?

could it happen today?

Insolation Max, 10,000 yr ago, Laurentide ice sheet still large but thin

strong summer monsoons in north Africa and Asia

Warm Max, 6,000 yrs ago, Laurentide ice sheet gone

north African lakes full

climate cooling last 6,000 yrs

decreased melting, some glacial and sea ice advance, southward shift of tree line

northern hemisphere summer insolation near a minimum today

why don't glaciers start to expand?

Chapter 14 - Millennial Oscillations of Climate

oscillations in Greenland $\delta^{18}\text{O}$ record

ice rafting (Heinrich) events in N.Atlantic

oscillations of N.Atlantic polar foraminifera populations

Europe: oscillations in soil clay & tree pollen (in sync?)

Antarctica also - but Greenland-Antarctica out of sync(?)

millennial oscillations quasi-periodic (no real cyclic behavior)

possible causes?

solar variability - not likely

greenhouse gas forcing - unclear

ice sheet instability

bipolar seasaw

ocean circulation changes in flow of heat

between northern & southern hemisphere

climate oscillations reduced or absent during interglacials

suggests that ice sheet dynamics is a leading cause

could alter ocean circulation, formation of North Atlantic Deep Water

Chapter 15 - Humans and Preindustrial Climate

Noah's flood?

Black Sea flooded from sea level rise from melting glaciers

CO₂ & CH₄ have been rising at a point in the current interglacial when they were falling in previous interglacials

coincides approximately with the rise of agriculture

flooded rice paddy cultivation - produces methane

clearing of forests for farmland - returns CO₂ to atmosphere

climate modeling suggests some glacial ice should be returning if not for the above

Chapter 16 - Climate Change During the Last 1000 years

Medieval Warm Period, Little Ice Age, modern warmth: how widespread?

evidence for Little Ice Age

expanding snow fields in arctic Canada during Little Ice Age (lichen evidence)

formation of sea ice around Iceland during Little Ice Age

$\delta^{18}\text{O}$ from alpine glaciers in Peru & Tibet

tree ring studies from around the arctic/subarctic and Mongolia

tropical Pacific & Indian Ocean corals indicate cooler 19th century

Little Ice Age not seen

Greenland and Antarctic ice $\delta^{18}\text{O}$

Tasmania tree rings

multi-proxy studies

borehole temperature studies

proposed causes of climate change A.D. 1000 - 1850 & beyond

orbital forcing - probably not

bipolar seasaw - not enough data

solar variability - no more than 10%

explosive volcanic eruptions - part of the story

greenhouse gas forcing - bubonic plague & Native American pandemic

Chapter 17 - Climate Changes Since the 1800s

instrumental record

difficulties: increasing heat island effect, changing measurement type

surface temperature rose ~ 0.7 °C in 20th century

deep ocean temp rose ~ 0.06 °C since late 1940s

melting ice & arctic warming

98% of all mountain glaciers melting

decreasing snow cover

Alaskan growing season increasing

arctic sea ice receding in summer

Greenland ice sheet volume decreasing near edges

rising sea level

difficulties: must first account for tectonics & isostatic rebound

sea level has risen ~ 20 cm since the 1880s (~ 17 cm in 20th century)

mostly due to thermal expansion of oceans, melting of alpine glaciers

a little from melting in Greenland (+/- Antarctica)

rate of sea level rise increasing: ~ 1.7 mm/yr (early 90s) to ~ 3 mm/yr (1995-2005)

complications to measuring temperature and sea level trends

ENSO, Pacific Decadal Oscillation, North Atlantic Oscillation

Chapter 18 - Causes of Warming Over the Last 125 Years

solar variability probably causes no more than 0.1 °C of the 0.7 °C temperature rise

there doesn't appear to be a decrease in volcanoes (and their 1-2 year cooling)

this warming coincides with rise of CO_2 & CH_4 well above glacial-interglacial range

although not all CO_2 emitted is in atmosphere: some in oceans and biomass

CFCs, tropospheric ozone, N_2O , and black carbon aerosols also help to warm climate

organic aerosols (brown haze) absorb insolation at 2-3 km, shading the surface

and masking atmospheric warming

sulfate aerosols reflect sunlight helping to counter some of the warming

tropical deforestation releases CO_2 resulting in additional warming

but increased albedo of deforested land results in small cooling effect

CO_2 concentration has risen $\sim 35\%$

all greenhouse gases combined result in CO_2 equivalent rise of $\sim 60\%$

as a result, the greenhouse effect is now 1.8% stronger

doubling CO_2 should result in ~ 1.25 °C (0.5 - 5 °C range) global mean temperature rise

positive (increased humidity, melting snow & ice)

negative feedbacks (increased cloudiness)

resulting equilibrium global mean temperature rise should be ~ 2.5 °C

depending on sensitivity of climate to CO_2

checking data from ancient climates (glacial max, Cretaceous Greenhouse)

suggests that climate is at the more sensitive end of the range

the recorded 0.7 °C 20th century temperature rise is less than expected due to

its not at equilibrium yet (watch the lags!)

aerosols and tropical deforestation have increased Earth's albedo

both natural and anthropogenic forcing must be incorporated to reasonably account for the pattern 20th century climate change

Conclusion: humans are responsible for the larger part of 20th century warming

Chapter 19 - Future Climatic Change

population is rising

with hard work we may cap peak CO₂ at 450 ppm

scientific aim (considering political and social difficulties)

more likely we will reach double preindustrial levels (~560 ppm) or greater

business as usual approach will bring us to ~4 times CO₂ (>>1000 ppm)

in all likelihood we will reach CO₂ levels not seen since the early Cenozoic

modeling (Hansen) indicates that no polar ice caps existed before CO₂ levels dropped

below 450 ppm; Hansen proposes that we should keep CO₂ below 350 ppm long-

term to prevent continued melting of polar ice caps (and resulting sea level rise)

though the Greenland and Antarctic ice sheets will take thousands of years to melt
current estimates of temperature rise by 2100 are ~1.5 °C to 6 °C

depending on the pace of CO₂ emissions

temperature rise in polar regions will be much more than average

positive feedbacks: melting ice-decreasing albedo-more absorption of insolation

arctic warming & melting of permafrost, arctic wetlands will produce methane

precipitation will increase at high latitude (warmer air holds more moisture)

precipitation may decrease at midlatitudes (as subtropical deserts expand)

warming sea surface temperature will result in increasing hurricane power

(combination of hurricane number, intensity, duration - but not all 3 at once)

sea level will probably rise more than 0.2-0.6 m (IPCC), 0.7-3.0 m (USGPRP)

neither estimate includes changing ice sheet dynamics, faster ice flow from

Greenland and Antarctic ice sheets [or feedbacks from warming of Arctic]

ocean acidification (pH reduction) will continue causing problems for organisms with

calcium carbonate skeletons (coral, foraminifera, calcareous nanoplankton)

Mitigation Strategies

CO₂ cap and trade

regulate short-lived atmospheric components (quicker and cheaper for partial solution)

improved coal combustion: to get more energy and less CO₂ per ton of coal

investment by government and industry is required to develop the technologies

conventional coal energy is very inefficient and polluting

but coal is cheap and very plentiful & will continue to be an important energy source

carbon capture and sequestration

technology exists to capture CO₂ in smokestacks

can be improved to decrease energy required from 25-30% to 15-20% of the overall

heat generated by burning the fuel

methods also exist to remove CO₂ directly from the air

CO₂ can be pumped into deep porous/permeable formations under land or oceans

pipeline network (like our natural gas pipelines) needed to deliver CO₂

CO₂ can be used to help pump oil and natural gas out of deep reservoirs

CO₂ may gradually leak out of some reservoirs but at the very least the method

will help give us valuable time to change our energy economy
Some pilot projects are already running, others are being built or planned
investment by government and industry is required to develop the technologies

alternative energy

- alternative heat sources: nuclear, solar thermal, biofuels
- alternative turning power: hydroelectric, wind, tidal, ocean currents
- alternative electron source: photovoltaic

very small government investment in research and development
prices (now high) come down with increased development