Chapter 16 Study Guide and Case Studies: Long- and Short-term Climate Variations

Key Concepts

- Natural external drivers for climate change include asteroid impacts, change in solar output, changes in Earth's orbital parameters.
- Natural internal drivers for climate change include changes in atmosphere and ocean chemistry, ocean circulation, volcanism and plate tectonics in general
- The main constituents of Earth's atmosphere are Nitrogen (78.08%) and Oxygen (20.95%). Argon contributes with another 0.93%. The remaining 0.043% comes from other compounds where carbon dioxide with 0.040% provides the largest contribution.
- Greenhouse gases, including water vapor, are transparent to visible light but block infrared (heat). They trap the heat in Earth's atmosphere. Earth's surface temperature is 15ºC (or 59ºF). Without greenhouse gases, Earth's surface would be 33ºC (59ºF) cooler.
- There is almost 200 times more carbon dioxide in the atmosphere than methane. But because of methane's greater ability to trap heat, methane's contribution to the greenhouse is 16% (compared to 60% from carbon dioxide). The remaining contributions come from nitrous oxides, tropospheric ozone and chloroflourocarbons (CFCs).
- CFCs are exclusively anthropogenic and contribute with 11% to the greenhouse, and so is contributor #3.
- CFCs also destroy the protective ozone layer in the stratosphere (ozone hole).
- Radiative forcing is the difference of radiant energy received by Earth and energy radiated back to space. It is a measure to evaluate the contribution of a compound to warming (positive forcing) and cooling (negative forcing).
- Greenhouse gases have positive radiative forcing
- H_2O has positive or negative forcing, depending on the phase it is in; as water vapor, it warms the atmosphere, while as clouds it cools it
- aerosols have positive or negative forcing, depending on where in the atmosphere they occur (positive in the lower atmosphere; negative in the upper atmosphere)
- feedback mechanisms cause changes in reaction to a process. Positive feedback enhances a process while negative feedback counteracts it
- ice sheet melting in a warming climate have a positive feedback as a result of reduction in albedo. Methane release in a warming climate enhances the greenhouse and so is a positive feedback.
- A warming climate leads to more evaporation and cloud formation, which cools the planet, providing a negative feedback. During warming, ice sheets melt and

fresh water provides a lid on the global ocean heat conveyor thereby contributing to cooling (negative feedback).

- Earth's early atmosphere contained much more carbon dioxide than today. But the Sun's output was also lower.
- Long-term climate changes on the order of millions of years are caused by plate tectonics and changes in solar output. Climate indicators on this time scale are provided by rock profiles and the fossils they contain, i.e. stratigraphic indicators or other markers in the rocks (e.g. glacial striation).
- A proxy is the observation of one parameter (e.g. tree rings) to infer another parameter (e.g. past climate or temperature)
- Past long-term cold periods include the Carboniferous and early Permian (320-270 Mio yrs ago) when many of Earth's coal deposits formed. Past long-term warm periods include the mid-Triassic (240-220 Mio yrs ago) and the late Jurassic through Cretaceous (170-65 Mio yrs ago) when dinosaurs lived on Earth.
- Sea level changes with climate but long-term changes can also be caused by plate tectonics.
- Climate changes on the order of tens to hundreds of thousands of years are mainly caused by changes in Earth's orbital parameters (Milankovitch cycles). Climate indicators come primarily from ice cores and lake sediments but also from coral rings and pollen compositions in sediments.
- The ice age cycle of the last 2 million years coincides with the Milankovitch cycles. The last ice age lasted from about 100,000 to 18,000 years ago.
- The Milankovitch cycles are a composite resulting from changes in three parameters: eccentricity of Earth's orbit around the Sun, the tilt of Earth's rotation axis (obliquity) and the precession of Earth's rotation axis about the normal of the orbital plane
- Positive feedback mechanisms cause a saw-tooth pattern in the warming/cooling cycle, with rapid warming at the end of an ice age, and slow cooling into the next ice age.
- Climate changes on the scale of 10s to 100s of years can still be drawn from natural proxies, such as pollen counts in sediments, tree rings. But human written, pictorial and oral records provide clues to recent past climate.
- Possible natural causes of climate change in this time scale are volcanic eruptions, changes in ocean currents, decadal oscillations in the Pacific and Atlantic, interactions between oceans, atmosphere and ice sheets, El Niño/La Niña cycle, changes in solar output (e.g. 11-year sunspot cycle)
- The warm climate at time of the Fertile Crescent in Asia Minor could have been due to increased solar output.
- The Maunder Minimum (a loss of 0.25% of solar output and a 50-year absence of sunspots) may have caused the "Little Ice Age" (1400-1850)
- The cooler first half of the 20th century (prior to 1950s) coincides with a drop in solar activity/sunspots
- A 1-2 years hiatus of global warming in the early 1990s followed the VEI 6 eruption of Mt. Pinatubo, Philippines that injected massive amounts of aerosols into the upper atmosphere.

Key Terms

- Natural climate variations
- Anthropogenic climate change
- Solar output
- Ocean circulation
- Greenhouse gases
- Chloroflourocarbons (CFCs)
- Radiative forcing
- Aerosols
- Climate feedback mechanisms
- Plate tectonics
- Climate indicators
- proxies
- Stratigraphic indicators
- Glacial striation
- Sea level changes
- Coal deposits
- Era of the dinosaur
- Milankovitch cycles
- Ice cores
- Lake sediments
- Coral rings/oxygen isotopes
- Climate saw-tooth pattern
- Decadal oscillations
- El Niño/La Niña
- Fertile Crescent
- Maunder Minimum
- Little Ice Age

Questions for Review

1. What are the natural external drivers of climate change on Earth?
2. What are the natural internal drivers of climate change on Earth?
3. Discuss the main constituents of Earth's atmosphere.
4. Discuss the amount of Earth's major greenhouse gases and their relative contribution to greenhouse warming.
5. Discuss the special role of CFCs.
6. What is radiative forcing? Provide examples.
7. Describe the climate feedback mechanism. Provide examples for positive and negative climate feedbacks.
8. Describe the dual function of H_2O as driver of climate feedback.
9. Describe the dual function of aerosols as driver of climate feedback.
10. What are possible causes of climate change on the scale of millions of years?
11. How do Earth scientists piece together climate on such time scales?

12. What is a proxy? Given an example.

13. What are possible causes of climate change on the scale of tens to hundreds of thousands of years?

14. What causes the recent ice age cycle (last 2 million years)?

15. How do Earth scientists piece together climate on such time scales?

16. Is the coming and going of ice ages symmetric in terms of cooling and warming?

17. What are possible causes of climate change on the scale of tens to hundreds of years?

18. How do Earth scientists piece together climate on such time scales?

19. What is the possible cause of the 'Little Ice Age'?

Case Studies

Case Study 1: Rapidly Shrinking Arctic Sea Ice

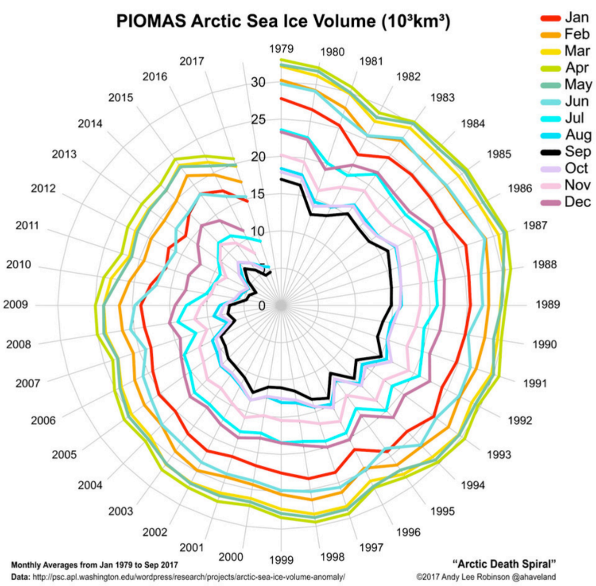

Figure 16.C1 Monthly averages from 1979 – 2017 of Arctic Sea Ice Volume. Data source vie the Polar Science Center (University of Washington). (source: Andy Lee Robinson, Wikipedia)

The devastation of peat fires of recent years, with a significant human-impact component in both effect but also cause, is dramatically illustrated by the **2010 wildfires in Russia**. After record-high temperatures during an oppressive heat wave and drought-conditions in early summer, several hundred wildfires, including many peat fires, broke out in late July. Smoke from the fires produced heavy smog (a mix of smoke and fog) that blanketed large urban regions (Figs. 10.C1, 10.C2). Within a few days, the smog in Moscow was so thick that flights had to be diverted to other airports. By noon on 7 August, the carbon monoxide level there reached 6.6 times the normal level, and particulate matter 2.2 times the normal level. An estimated 56,000 people perished from the effects of the smog and heat wave. The bogs surrounding Moscow had been drained in the 1960s for agricultural use and peat mining to generate energy. In 2002 already, a series of hard-to-extinguish peat fires led the government to recognize that some peat fields should be re-waters to prevent wildfires. And the areas not re-watered by 2010 were exactly those that burned. In the aftermath, there also had been extensive debate about who was responsible to extinguish the fires, the central government or local authorities, after the Russian State Fire Service was abolished in 2007. Some criticize that current fire fighting companies chose not to fight forest fires in order to stay profitable.

Case Study 1: Rapidly Shrinking Arctic Sea Ice

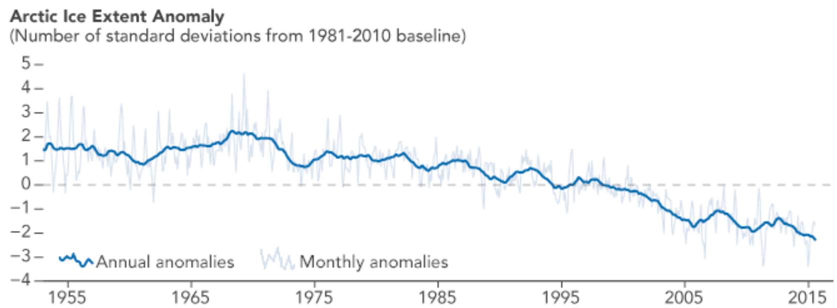

Figure 16.C1 Anomalies in Arctic sea ice. (source: NASA, Wikipedia)

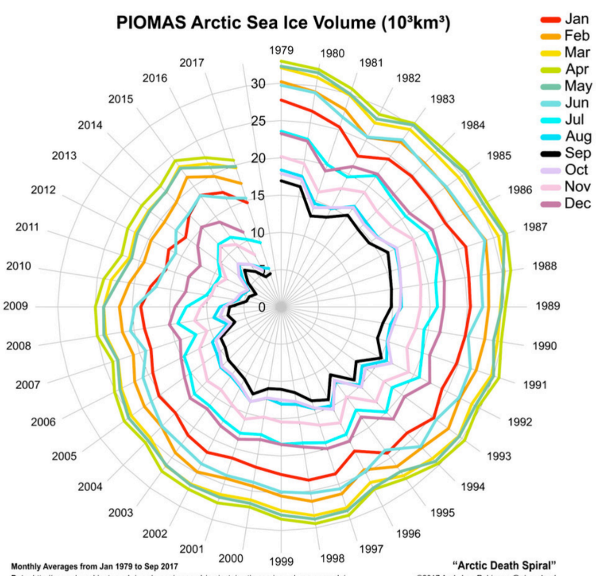

Figure 16.C2 Monthly averages from 1979 – 2017 of Arctic Sea Ice Volume. Data source vie the Polar Science Center (University of Washington). (source: Andy Lee Robinson, Wikipedia)

Since about 1970, sea ice in the Arctic Ocean has been melting faster during summer than it re-freezes during the winter. Consequently, the total Arctic sea ice volume has shrunk, and the shrinking has accelerated since about 2000. The 2007 IPCC report predicted that warming in the Arctic would be more than elsewhere on the planet, but their models did not suggest that the loss of sea ice would be this quick (Figs. 16.C1). September is usually the month with the smallest extent in sea ice. But in 2012, the ice volume was only about 28% of that at the same time in 1979. On the other hand, sea ice has the largest extent in April, but in 2017, the ice volume was only 62% of that in 1979 at the same time.

The loss of high-latitude sea ice is troubling because ice melt accelerated the warming through a positive climate feedback. In a warming climate, the melt of sea ice reduces the albedo and more sunlight is retained by the atmosphere and oceans, which ultimately warm. The region is found to be at its warmest in at least 4000 years and the Arctic-wide melt season has lengthened at a rate of 5 days per decade (from 1979 to 2013). During the summer of 2019, lightning was observed for the first time ever, and Greenland and Scandinavia have experienced devastating wildfires in the last few years.

Case Study 2: The Little Ice Age

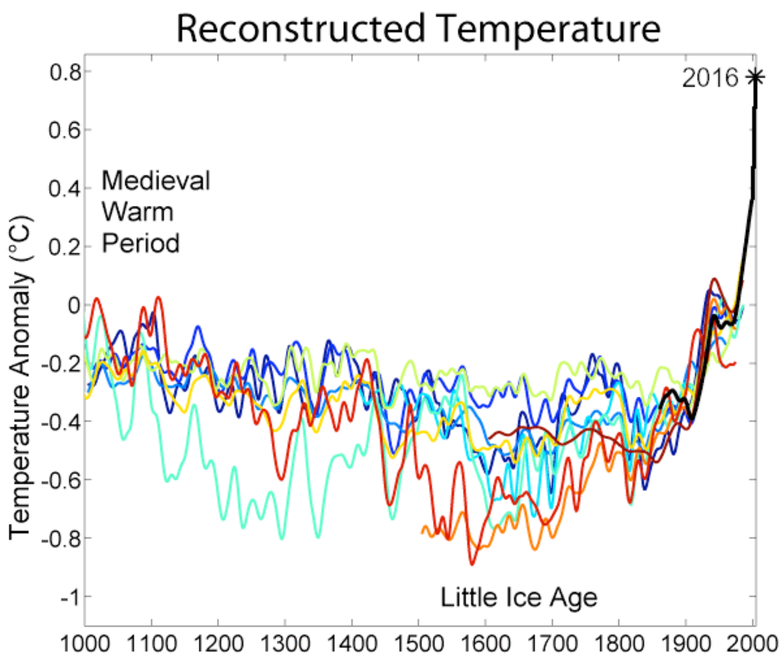

Figure 16.C3 Reconstructed Temperature of the last millennium (with respect to the 1950-1980 reference period). Lower-than-average temperatures from 1400 to 1850 mark the 'Little Ice Age'. Different colors mark 10 different published reconstructions of mean temperature change (with the most recent once in redder colors). An instrumental history is shown in black. Earlier temperatures are estimated through proxies (such as tree rings). (source: Wikipedia)

Figure 16.C4 Winter landscape with iceskaters in Holland (ca 1608, Hendrick Avercamp). (source: Wikipedia)

The Little Ice Age was a period of relatively cold climate between about 1400 and 1850. It followed the Medieval Warm Period during which Greenland was found to be 'green' and ice cover was less than today (Fig. 16.C3). Paintings and stories tell about frozen rivers and lakes in Europe and North America that no longer freeze today (Fig. 16.C4). The NASA Earth Observatory notes that the Little Ice Age had three particularly cold intervals around 1650, 1770 and 1850, all separated by slight warming. Whether this was a more regional event in the northern hemisphere or a global event is still subject to research.

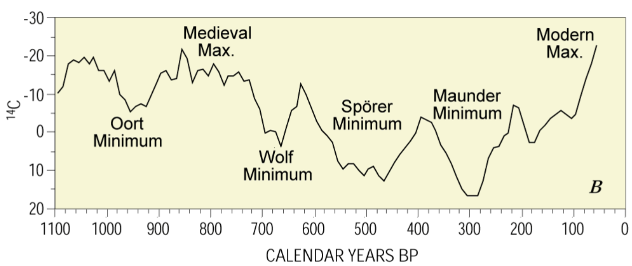

Figure 16.C5 Changes in Carbon-14 concentrations in Earth's atmosphere, which serves as a long term proxy for solar activity. (source: USGS, Wikipedia)

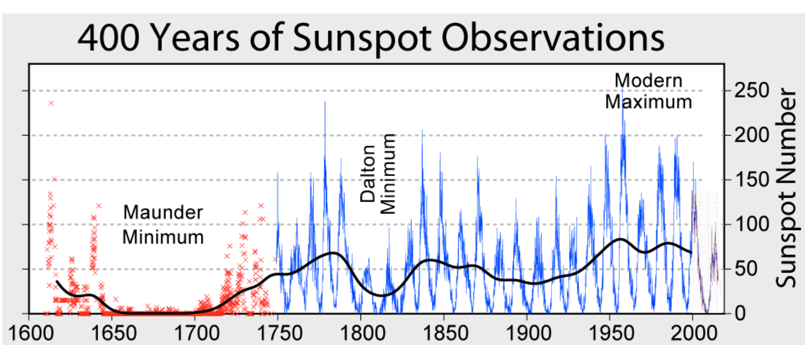

Figure 16.C6 The Maunder Minimum in a 400-year history of sunspot numbers. The sunspot cycle has a period of 11 years and follows that waxing and waning of solar activity (black line). (source: Wikipedia)

Several causes for the Little Ice Age have been suggested. External causes could come from cyclical lows in solar radiation and tiny variations in the tilt of Earth's rotation axis. In this case, the event should have had a global impact. Low CO2 concentrations in Antarctic ice cores from 1600 to 1800 to below 280 ppm support this idea. Radiocarbon record indicate that solar activity was dropping into the Maunder Minimum in the early 1700s (Fig. 16.C5), where sunspot activity was also low (Fig. 16.C6).

Other, internal causes have also been discussed, including changes in volcanic activity and ocean circulation and decreases (and activity) in human populations (e.g. as consequence of repeated Black-Death pandemics). For example, a large, VEI 7 eruption of the Tambora, Indonesia volcano in 1815 caused subsequent global cooling, harvest failure and famine in Europe. In 1783, the eruption of the Laki fissure in Iceland sent massive amount of sulfuric dioxide and hydrofluoric acid aerosols into the atmosphere, causing cooling and poisoning the ground. The eruption triggered a famine and ultimately killed half of Iceland's lifestock and a quarter of its population. Several other large eruptions occurred during the Little Ice Age.

Case Study 3: The Younger Dryas

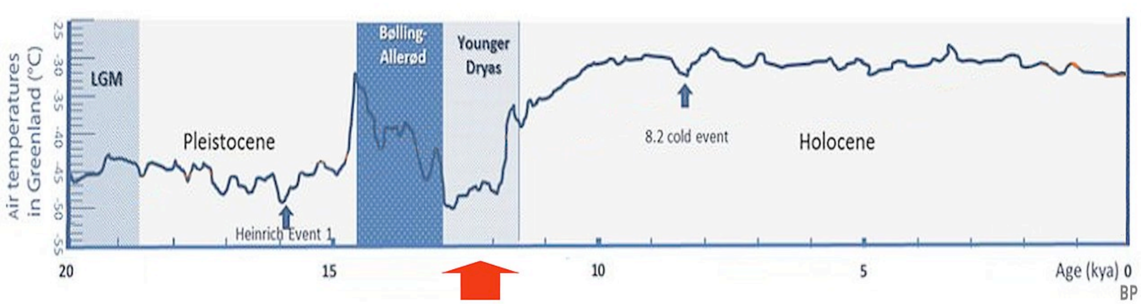

Figure 16.C7 Temperature during the Post-Glacial period, after the Last Glacial Maximum (LGM). The Younger Dryas shows very low temperatures, even below the LGM. While the decline was moderate during the preceding 1000 years, the decline was rapid at the onset of the Younger Dryas. (source: Wikipedia)

The Younger Dryas (12,9000-11,700 BP) marks a period after the last ice age ended (c. 14,000 years ago) in which Earth's climate turned rapidly back into that of an ice age (Fig. 16.C7). Pollen counts indicate that the Younger Dryas was a period in which vegetation of a warmer climate was replaced by cold-climate plants. While temperatures drop slowly going into an ice age, the drop at the onset of the Younger Dryas was rapid, a matter of a few decades. Observations are well-defined in western Europe and Greenland, cooling in tropical North American may have started a few centuries before, and observations in South America show a less well-defined onset but a sharp ending.

The Younger Dryas is thought to have been caused by a weakening of the Atlantic meridional overturning circulation that transports warmed water from equatorial regions toward the North Pole. But the ultimate cause has not been identified definitively. Some argue that an increasing influx of cold freshwater from North America to the Atlantic cause the weakening of the overturn, but that would mean that there was preceding significant warming causing glaciers and ice shields to melt. However, other causes are under discussion. Evidence for one or several asteroid or comet impact craters from has been found along the perimeter of Greenland. Finds of impact-related melt-glass material in sediments in Pennsylvania, South Carolina and Syria dating to ca. 13,000 BP appear to support this idea. Another hypothesis is based on volcanic eruptions. The Laacher See volcano in western Germany erupted explosively (estimated VEI 6) near the beginning of the Younger Dryas.