Guide to the Science of Climate Change in the 21st Century

Chapter 12
Climate Change – Natural Forces

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12.0 Climate Change – Natural Forces

12.1 Introduction

Earth's climate is constantly being *forced* to change by a variety of natural occurring phenomena that directly or indirectly affect the energy budget.

The IPCC distinguishes radiative forcing caused by anthropogenic and natural forcing as described in https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf . Natural occurring phenomena affecting Earth's climate include:

- Tectonic processes resulting in movement of continents.
- Increase or decrease in intensity of solar radiation from the Sun.
- Changes in Earth's orbit and orientation to the Sun.
- Volcanic activity.

These interact with Earth's climate system as shown in Figure 12.1.

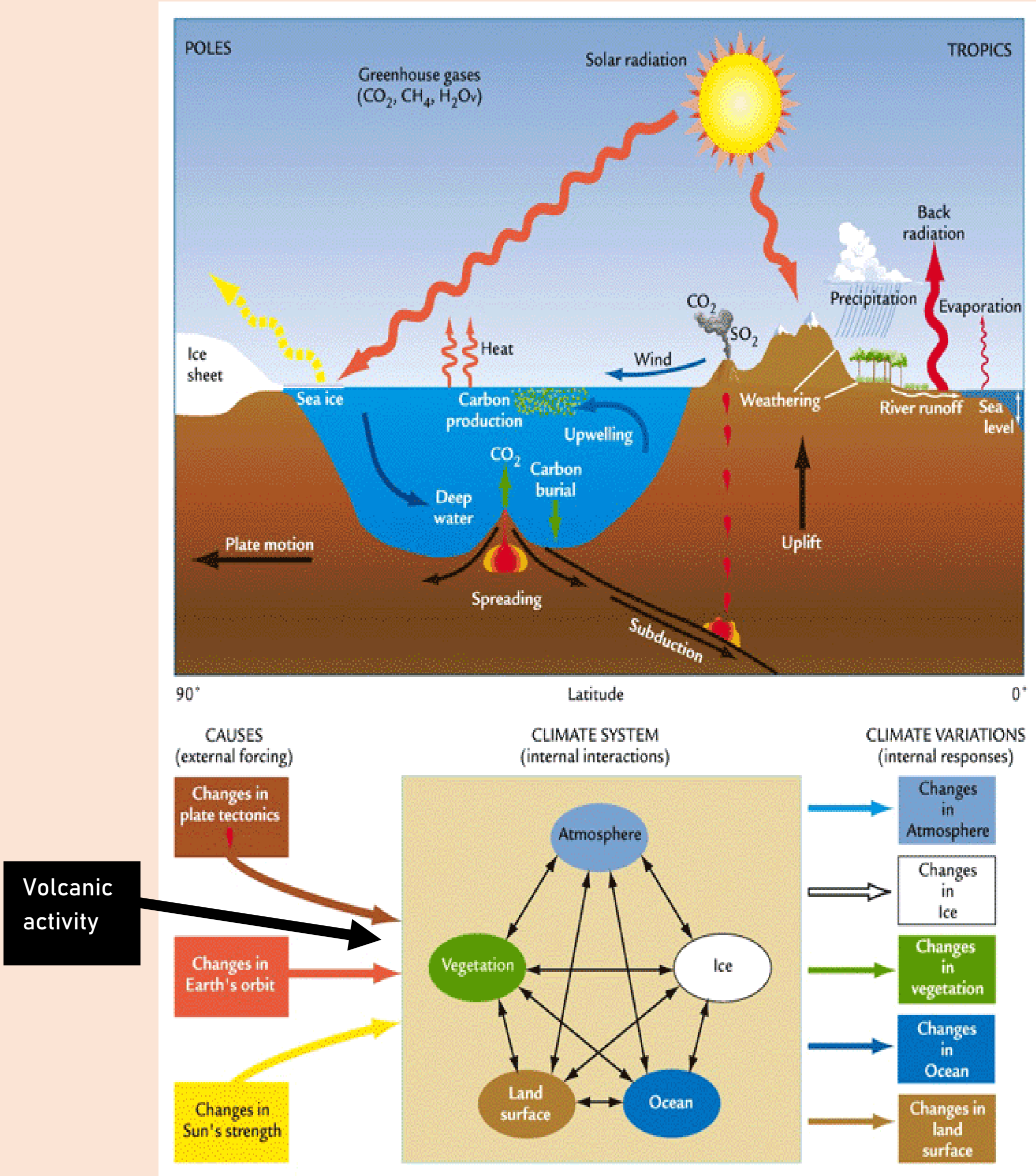


Figure 12.1 Earth climate system.

12.2 Tectonic activity

Tectonic processes that influence climate system variability include plate motion, changes in continental geography, mountain building and erosion, the production and subduction of seafloor crust, and related changes in bio-geo-chemical cycles, particularly the carbon cycle https://education.nationalgeographic.org/resource/crust/ .

Figure 12.2 shows a segment of Earth from its center, the core, to its outer surface, the lithosphere and crust. The lighter crust floats on the lithosphere. As shown in Figure 12.3 there are two types of crust, the ocean crust and the continental crust which is much thicker.

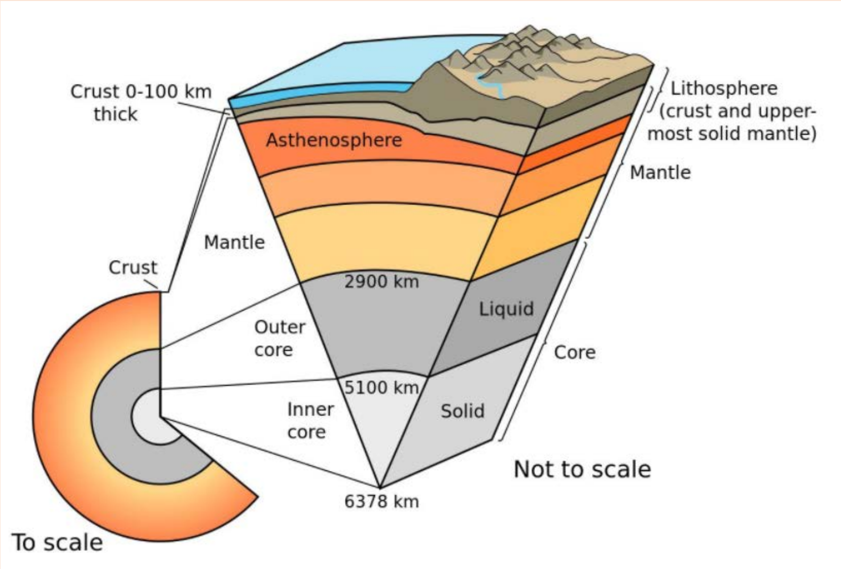


Figure 12.2 A segment of Earth from its center, the core, to its outer surface consisting of the lithosphere and the crust https://education.nationalgeographic.org/resource/crust/ .

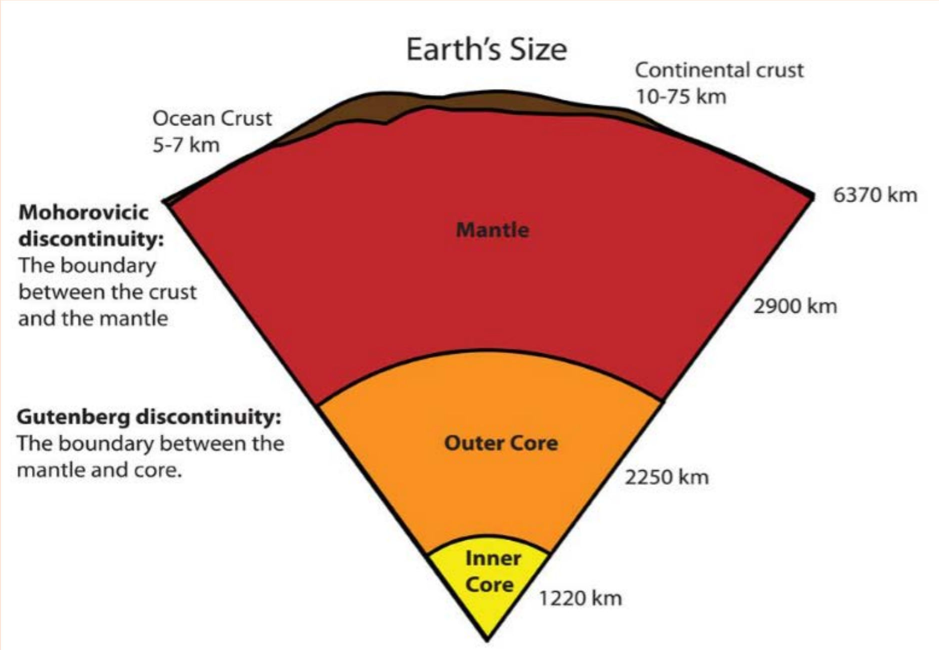


Figure 12.3 Note the Earth's crust consists of the ocean crust and the much thicker continental crust https://education.nationalgeographic.org/resource/crust/ .

The Earth's crust and lithosphere are divided into portions known as plates that move more-or-less independently of each other. The crust and lithosphere below it move together. Figure 12.4 illustrates the plates as they exist today. Note that a plate might include both ocean and continental types of crust.

Approximately 240 million years BP (before present) the plates were orientated to form a single continental mass or continent known as Pangaea as shown in Figure 12.5 and the top illustration in Figure 12.6. As a result of plate movement, (known as tectonic drift), the continental masses separated to ultimately form present day continents. The plates continue to move. The Himalayas continue to be forced upwards – Mount Everest gains four mm per year.

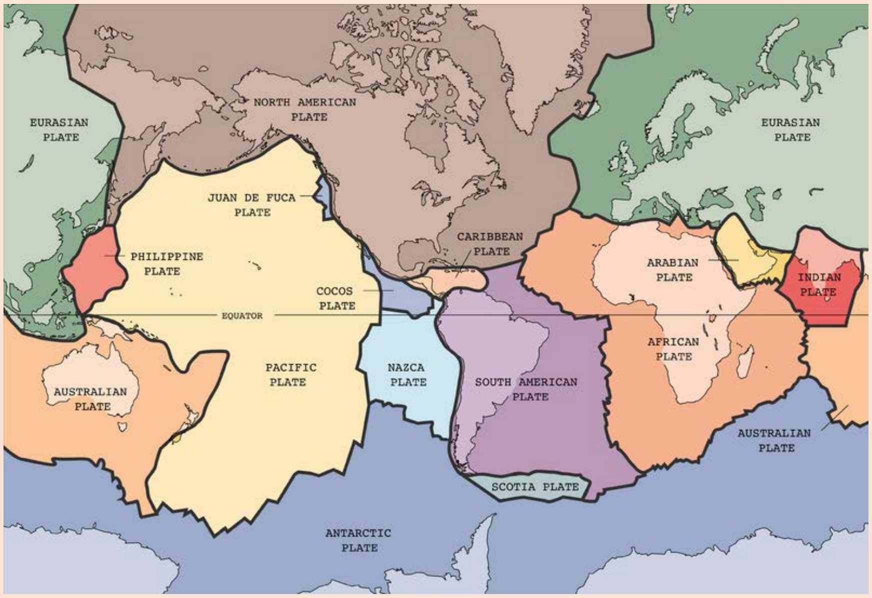


Figure 12.4 Plates as they exist today.

Figure 12.5 Earth supercontinent, Pangaea, 240 million years or more.

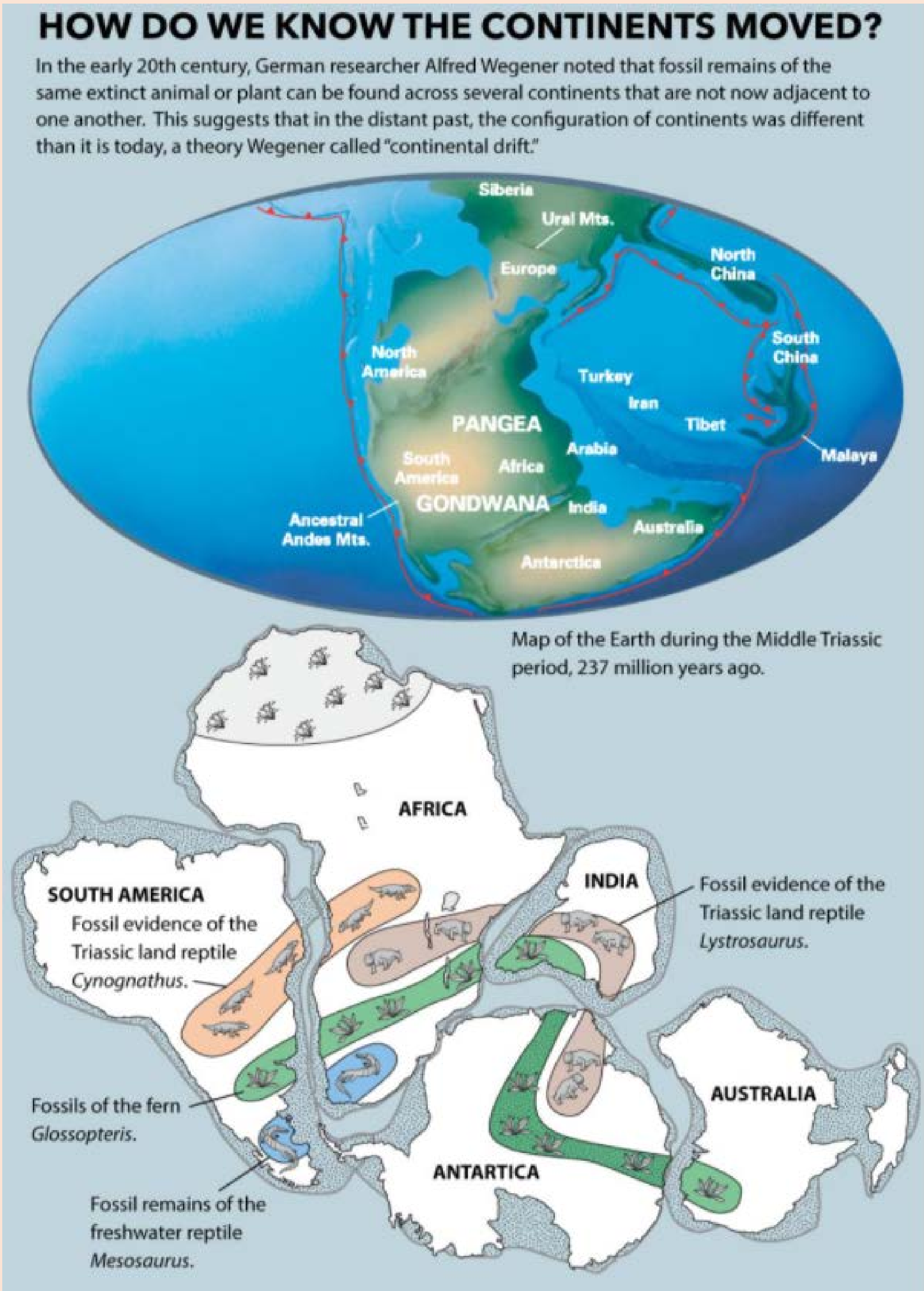


Figure 12.6 Continental drift.

In the process of moving the various plates collide with each other https://oceanservice.noaa.gov/facts/tectonics.html . One of the plates may be thrust vertically to form mountains as shown in Figure 12.7. The subducting process may also result in volcanic activity as illustrated in Figure 12.8. This is illustrated in greater detail in Figure 12.9. As the subducting ocean crust and associated lithosphere sink the result may be local uplift of the resisting plate and/ or the lighter subducting crust may melt. The mixed lighter molten rock, magma, moves upward, breaks through the overlying lithosphere and crust to spill out over the surface to form a volcano https://volcanoes.usgs.gov/vsc/file_mngr/file-139/This_Dynamic_Planet-Teaching_Companion_Packet.pdf . The occurrence of this process around the Pacific Ocean is illustrated in Figure 12.10 and is known as the 'Ring of Fire' named after the volcanoes that are formed as a consequence plate collision.

Volcanos may form from plumes of magma flowing directly from the mantle. This is shown in Figure 12.7 and 12.8. Volcanoes resulting from plate movement around the Pacific are shown in Figure 12.9 where many of largest eruptions in the past 10,000 years have occurred.

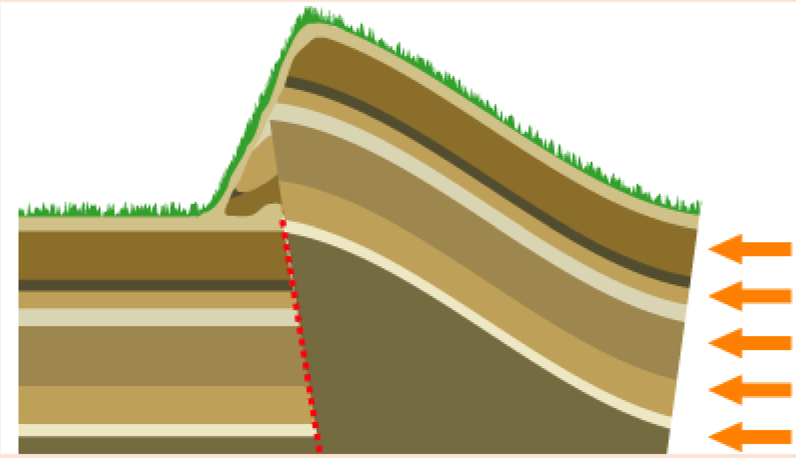


Figure 12.7 Thrust and reverse fault movement resulting in mountain formation.

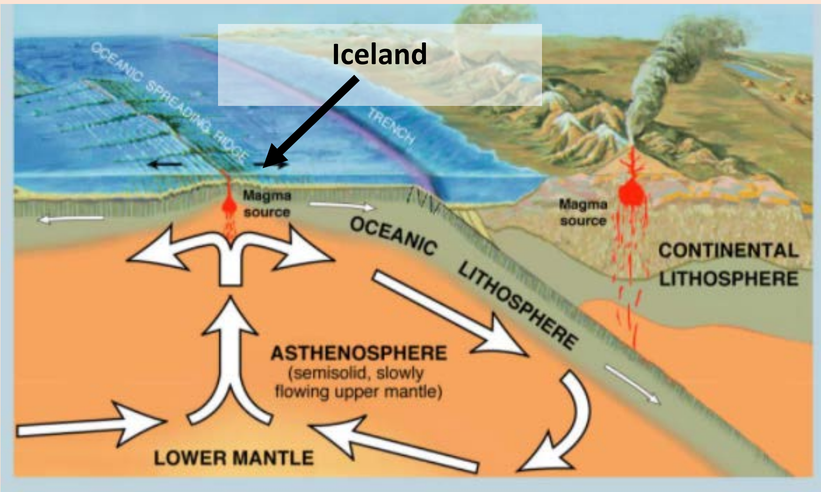


Figure 12.8 Subduction.

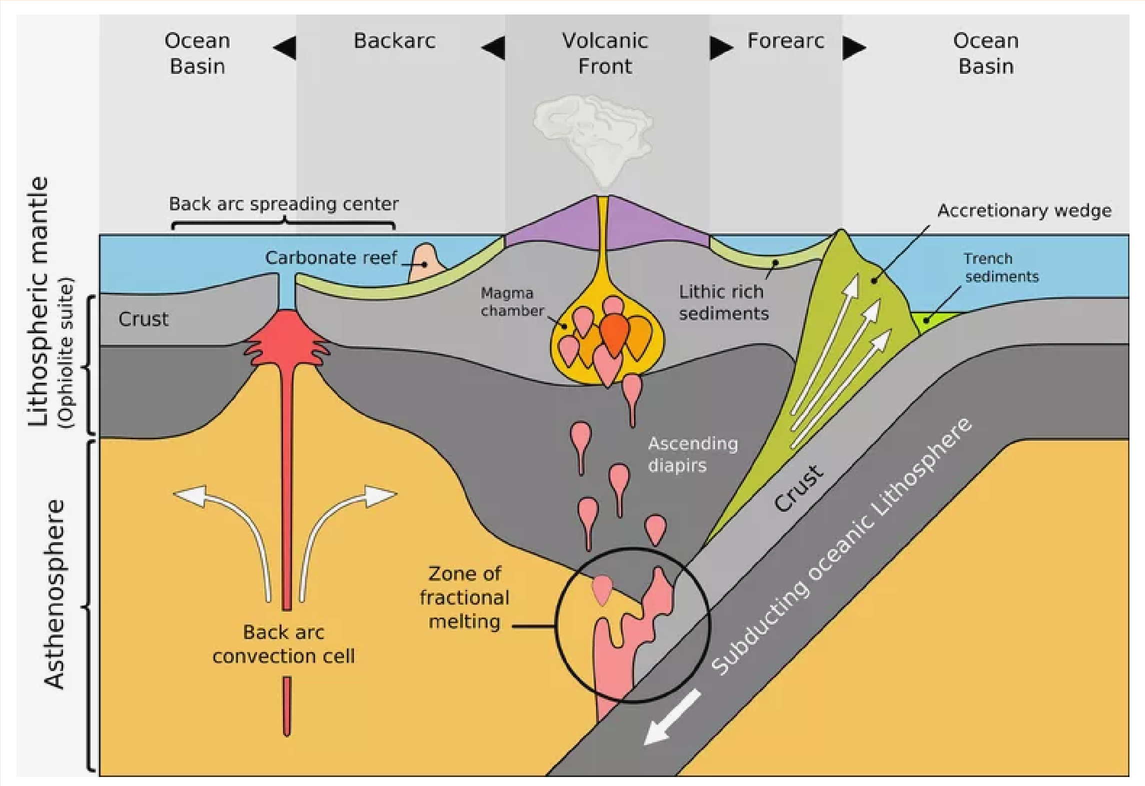


Figure 12.9 Movement of magma within the Earth's crust.

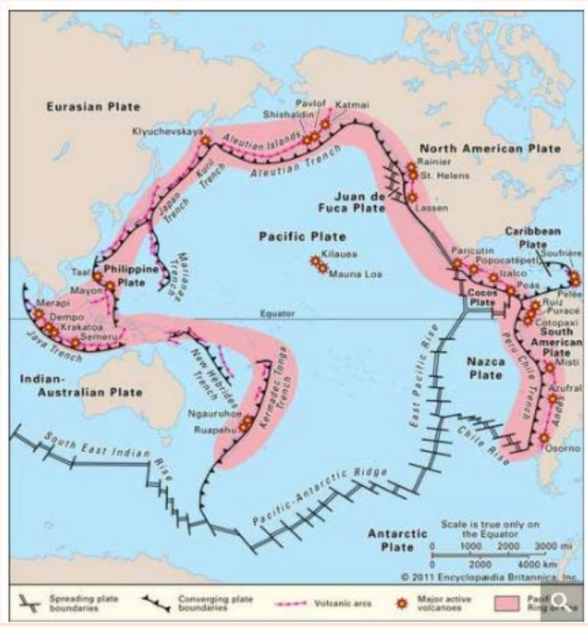


Figure 12.10 Ring of fire. Volcanic activity on the Pacific Rim https://oceanservice.noaa.gov/facts/tectonics.html , https://en.wikipedia.org/wiki/Ring_of_Fire , and https://www.britannica.com/place/Ring-of-Fire .

Hawaiian Islands are formed as a result of ‘hot spots’ in the lithosphere and movement of the Pacific Plate as shown in Figure 12.10. Magma will periodically flow upwards, at the same location on the mantle, and penetrate the lithosphere wherever it may have moved. A new volcano results when the magma flows upwards to form a new island.

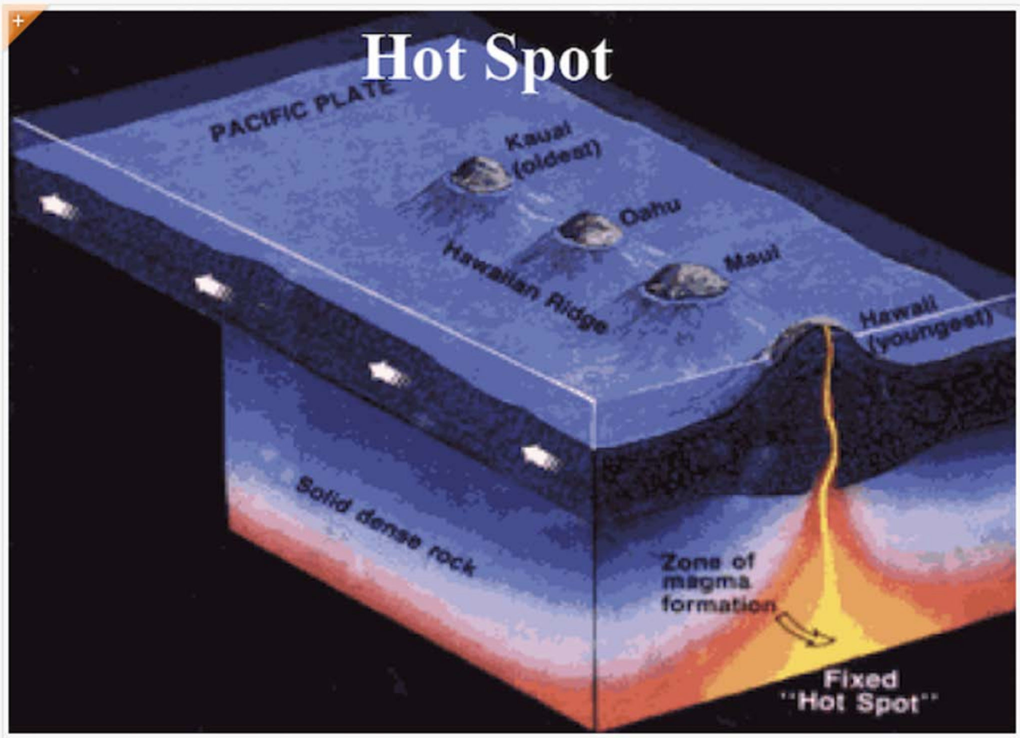


Fig. 8. Hot spot formation.
Image courtesy of the original SEA content

Figure 12.11 Hawaiian Islands – result of hots spots in the lithosphere and movement of the Pacific Plate, https://manoa.hawaii.edu/sealearning/grade-4/earth-and-space-science/exploring-plate-tectonics .

Another phenomenon is related to the melting of the Greenland and Antarctic ice sheets. As they formed the weight of the ice caused the underlying land mass to sink into the crust. As they melt and the water drains into the surrounding ocean the underlying land masses rise in a process known as isostatic rebound (also called continental rebound, post-glacial rebound or isostatic adjustment). Land masses once covered by kilometers thick layers of ice during the last ice age are still rebounding even though the ice essentially disappeared twelve thousand years ago https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter13_FINAL.pdf .

Tectonic processes impact ocean currents, atmospheric circulation, and volcanic activity. Ocean circulation will be affected by the spatial relationships of the continents to each other but the changes can be expected to be very gradual occurring over many millions of years similar to mountain building processes that will affect atmospheric circulation. By comparison volcanic activity occurs continuously and can have immediate effect and for this reason is treated separately.

12.3 Solar radiation, sunspots and cosmic radiation

Solar radiation reaching the Earth has been discussed quite extensively in Chapter 4. Solar irradiance is the power per unit area, Watts per square metre (Wm^{-2}) of solar radiant energy reaching the Earth as observed at the top of the atmosphere or earth's surface. The measure of solar irradiance received over a period of time of energy per unit area, Joules per square metre (Jm^{-2}), is known as solar radiant energy per square metre, solar irradiation, solar insolation or insolation, https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch1s1-4-3.html , https://en.wikipedia.org/wiki/Solar_irradiance , and https://www.sciencedirect.com/topics/earth-and-planetary-sciences/insolation .

Solar irradiance varies over a ten to twelve-year period. Each period is called a solar cycle https://spaceplace.nasa.gov/solar-cycles/en/ , https://en.wikipedia.org/wiki/Solar_cycle , https://scied.ucar.edu/sunspot-cycle#:~:text=The%2011%2Dyear%20sunspot%20cycle,northern%20and%20southern%20hemispheres%20switch . The variations in strength of solar irradiance over each cycle are in the order of 0.05% to 0.1% https://www.pnas.org/doi/10.1073/pnas.1118965109 . These small variations in solar irradiance, on a daily and annual basis, are shown in Figure 12.12. In the absence of anthropogenic forcing these variations have been shown to be significant and insignificant when anthropogenic forcing is present (industrial era) https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf .

The solar cycle is observed by variations in the Sun's magnetic activity and on the surface of the Sun by the presence of sunspots and solar flares. Sunspots are colder areas of the Sun's surface and are observed as shown in Figure 12.13 and are of particular interest because they were once considered to have an association with the forcing of climate change.

At the beginning, midway and end of a solar cycle there are the least number of sunspots, known as a solar minimum (least amount of solar activity) and one- quarter and three-quarter way into the cycle there are the most sunspots, known as the solar maximums (most amount of solar activity). Figure 12.13 illustrates sun spots on the surface of the Sun compared to the size of the Earth. Figure 12.14 illustrates the difference between a solar maximum and a solar minimum.

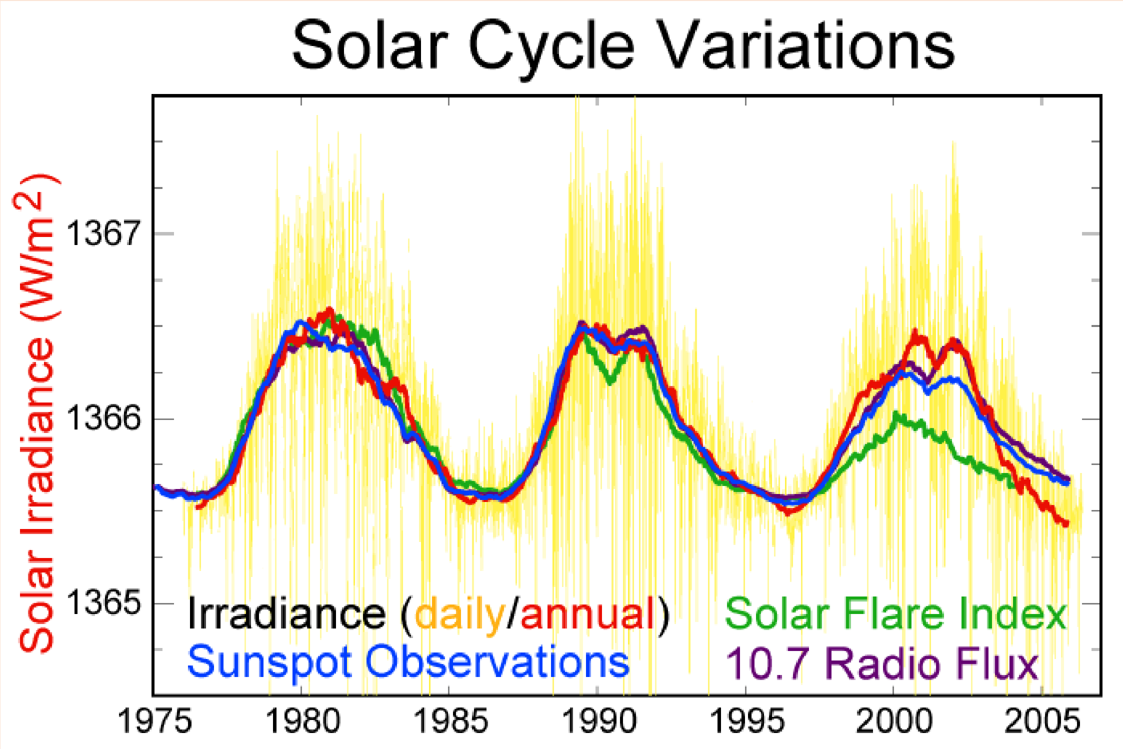


Figure 12.12 Solar cycle variations – daily and annual.

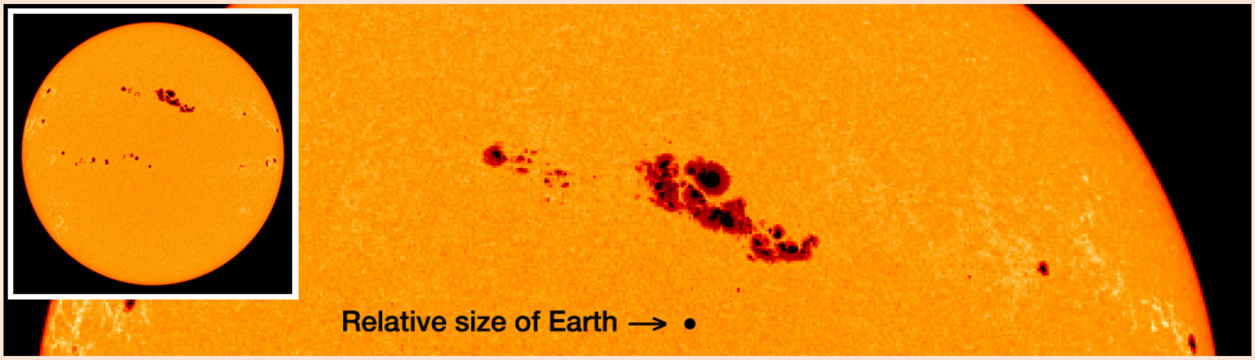


Figure 12.13 Sunspots on surface of the sun.

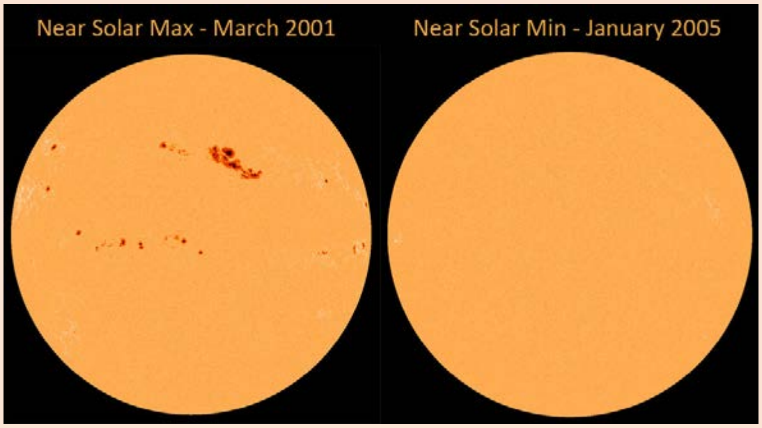


Figure 12.14 Difference between a solar maximum and a solar minimum.

Solar flares appear as bright flashes of light on the Sun as shown in Figure 12.15. NASA, https://hesperia.gsfc.nasa.gov/rhessi3/mission/science/the-impact-of-flares/index.html#:~:text=The%20x%2Drays%20from%20flares,atmosphere%2C%20causing%20it%20to%20expand , describes solar flares and their impact as follows: 'Solar flares produce high energy particles and radiation that are dangerous to living organisms. However, on the surface of the Earth, we are well protected from the effects of solar flares by the Earth's magnetic field and atmosphere. The most dangerous emissions from flares are energetic charged particles (primarily high-energy protons) and electromagnetic radiation (primarily x-rays).
The x-rays from flares are stopped by our atmosphere well above the Earth's surface. They do disturb the Earth's ionosphere, however, which in turn disturbs radio communications. Along with energetic ultraviolet radiation, they heat the Earth's outer atmosphere, causing it to expand. This increases the drag on Earth-orbiting satellites, reducing their lifetime in orbit. Also, both intense radio emission from flares and changes in the atmosphere can degrade satellite communications, for example the precision of Global Positioning System (GPS) measurements can be degraded.'

They go on to explain the phenomenon of coronal mass ejections or CMEs as follows:
'The most serious effects on human activity occur during major geomagnetic storms. It is now understood that the major geomagnetic storms are induced by coronal mass ejections (CMEs) which are frequently associated with flares. Like flares, CMEs are more frequent during the active phase of the Sun's approximately 11-year cycle. The exact relationship between flares and CMEs is still not well understood, as flares seem to trigger CMEs but sometimes CMEs are observed without any flares!
Coronal mass ejections are more likely to have a significant effect on our activities than flares because they carry more material into a larger volume of interplanetary space, increasing the likelihood that they will interact with the Earth. While a flare alone produces high-energy

particles near the Sun, some of which escape into interplanetary space, a CME drives a shock wave which can continuously produce energetic particles as it propagates through interplanetary space. When a CME reaches the Earth, its impact disturbs the Earth's magnetosphere, setting off a geomagnetic storm. A CME typically takes 3 to 5 days to reach the Earth after it leaves the Sun therefore observing the associated solar flare or the ejection of CMEs from the Sun provides an early warning of geomagnetic storms.'

The manner with which the Earth's magnetic field protects Earth from solar activity is shown in Figure 12.16. The interaction of radiation from solar flares and CMEs in particular is the Aurora Borealis and Aurora Australis.

Cosmic radiation includes all high-energy charged particles, x-rays and gamma rays produced in space regardless of source.

Fluctuations in the Sun's magnetic field inversely affect the amount of cosmic radiation reaching the Earth – the greater the activity and stronger the magnetic field, the less cosmic radiation reaches the Earth.

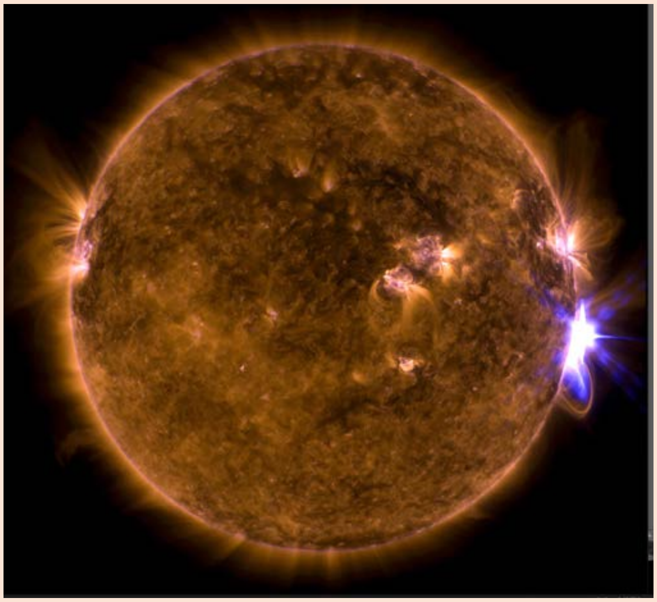


Figure 12.15 Solar flares https://hesperia.gsfc.nasa.gov/rhessi3/mission/science/the-impact-of-flares/index.html#:~:text=The%20x%2Drays%20from%20flares,atmosphere%2C%20causing%20it%20to%20expand

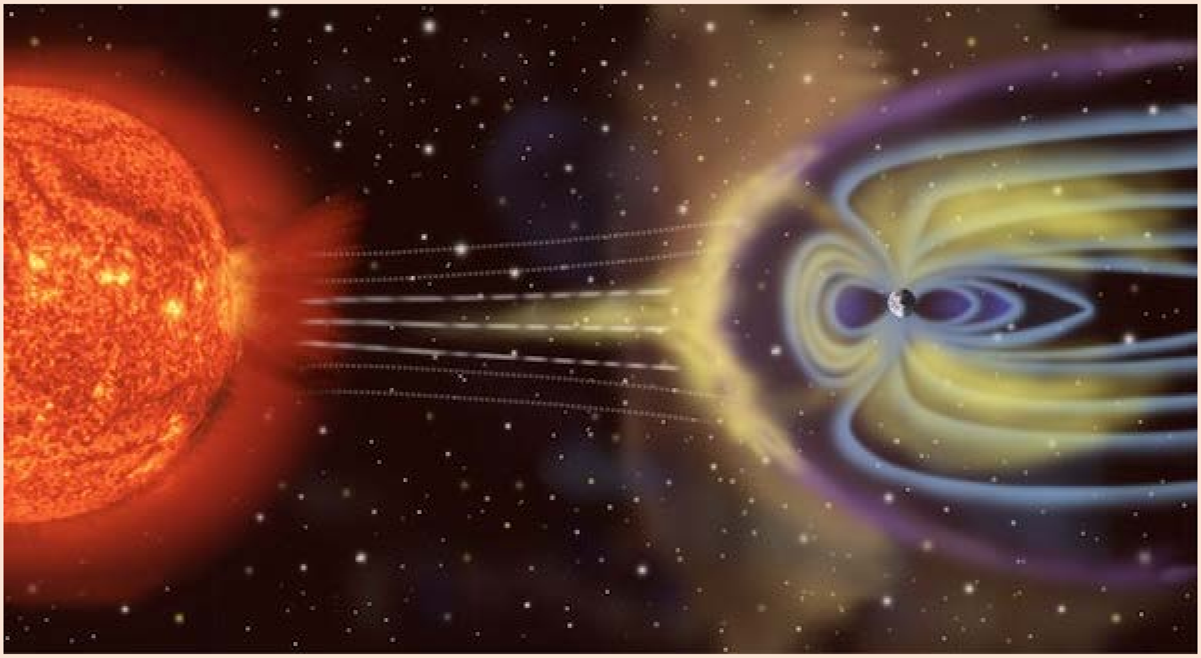


Figure 12.16 Earth's magnetic field protects Earth from solar activity, https://hesperia.gsfc.nasa.gov/rhessi3/mission/science/the-impact-of-flares/index.html#:~:text=The%20x%2Drays%20from%20flares,atmosphere%2C%20causing%20it%20to%20expand.

Because the occurrence and number of sunspots are directly correlated to the solar cycle and the Sun's magnetic field their presence can be correlated to amount of cosmic radiation reaching the Earth – in particular its atmosphere. It had been hypothesized that because cosmic radiation can induce aerosol formation that this must lead to increased cloud formation and global cooling. The sequence of steps were the production of aerosols, growth of aerosols, and the production of water particles that result in cloud formation and reflection of solar radiation. The European Organization for Nuclear Research, CERN, has demonstrated that cosmic radiation can induce aerosol formation. However, several investigations have disproved the hypothesis that aerosol production would lead to significant increases in cloud cover that would result in global cooling https://skepticalscience.com/cosmic-rays-and-global-warming-advanced.htm

The NOAA explains the impact of the solar cycle on global warming, https://www.climate.gov/news-features/understanding-climate/climate-change-incoming-sunlight#:~:text=During%20strong%20solar%20cycles%2C%20the,0.1%20degrees%20Celsius%20or%20less. , as follows:
'If the Sun were to intensify its energy output, then, yes, it would warm our world. Indeed, sunspot data indicate there was a small increase in the amount of incoming sunlight between

the late 1800s and the mid-1900s that experts estimate contributed to *at most* up to 0.1°C of the 1.0°C (1.8°F) of warming observed since the pre-industrial era. However, there has been no significant net change in the Sun's energy output from the late 1970s to the present, which is when we have observed the most rapid global warming.

A second reason that scientists have ruled out a significant role for the Sun in global warming is that if the Sun's energy output had intensified, we would expect all layers of Earth's atmosphere to have warmed. But we don't see that. Rather, satellites and observations from weather balloons show warming in the lower atmosphere (troposphere) and cooling in the upper stratosphere (stratosphere)—which is exactly what we would expect to see as a result of increasing greenhouse gases trapping heat in the lower atmosphere. Scientists regard this piece of evidence as one of several "smoking guns" linking today's global warming to human-emitted, heat-trapping gases.'

A significant affect of solar activity, sunspots in particular and the increase and decrease is emission of cosmic rays, is the production of cosmogenic isotopes, carbon-14 found in tree rings, and beryllium-10 found in ice cores, which have allowed the reconstruction of solar activity back thousands of years (9,000 or so). C14 measurements in tree rings allow for accurate dating of other biologic material containing carbon.

12.4 Milankovitch Cycles – changes in Earth's orbit and orientation to the Sun.

Perhaps the most important of the natural forces affecting Earth's climate are the Milankovitch Cycles named after the Serbian geophysicist and astronomer Milutin Milankovitch https://en.wikipedia.org/wiki/Milankovitch_cycles , https://skepticalscience.com/Milankovitch.html , and https://www.researchgate.net/publication/238956033_Astronomical_theory_of_climate_change . He hypothesized that variations in Earth's orbit known as eccentricity, the axial tilt of the Earth known as obliquity, and rotation of the axial tilt known as precession resulted in cyclical variation in how solar radiation was received by the Earth and that these variations could be used to explain the periodic formation and disappearance of the ice ages. Figures 12.17, 12.18 and 12.19 illustrate eccentricity, axial tilt and precession. Note that were a few other investigators who had made similar hypothesis but were unable to demonstrate the validity of their ideas because of the lack evidence of the occurrence and timing of ice age phenomena. This information only became available toward the end of the nineteenth century.

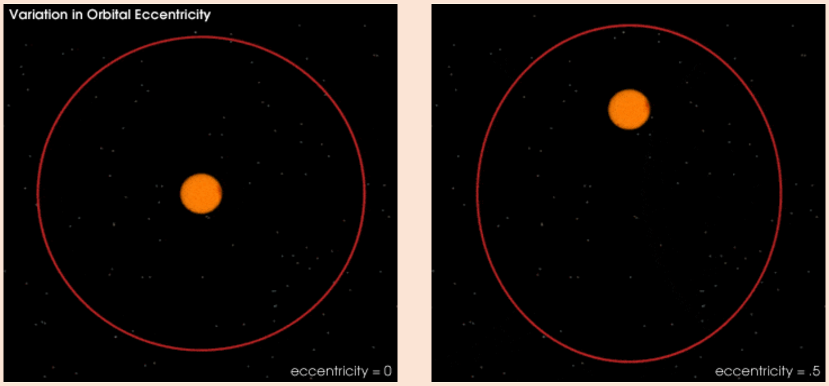


Figure 12.17 Variation of Earth’s orbit around the Sun – eccentricity.

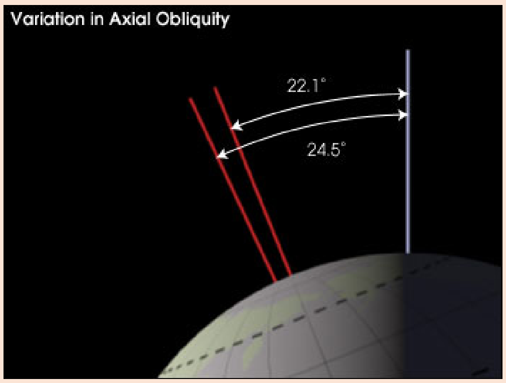


Figure 12.18 Variation of the tilt of the Earth’s axis of rotation – axial tilt or obliquity.

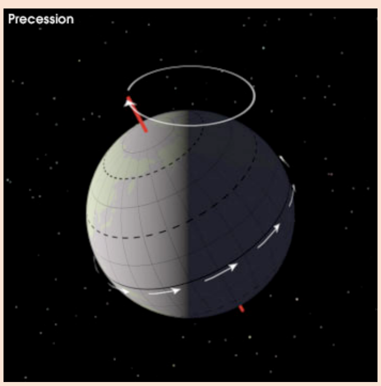


Figure 12.19 Variation of Earth’s rotational axis – precession.

There are two other cycles, rotation of Earth’s orbit around the Sun in the same plane known as apsidal precession and the movement of the inclination of Earth’s orbit around the sun, up and down, known as orbital inclination. These are shown in Figures 12.20 and 12.21. Neither have any significant impact on solar energy flux at the Earth.

Figure 12.22 illustrates each of the Milankovitch cycles and the duration of their cycles.

Figure 12.23 illustrates how variations in Earth’s orbit resulting from the Milankovitch cycles affect solar energy flux at high latitude and how this compares to the ice core .

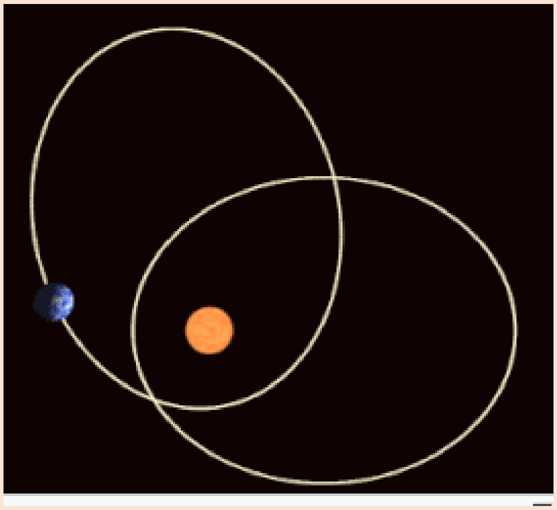


Figure 12.20 Rotation of Earth's orbit around the sun – apsidal precession.

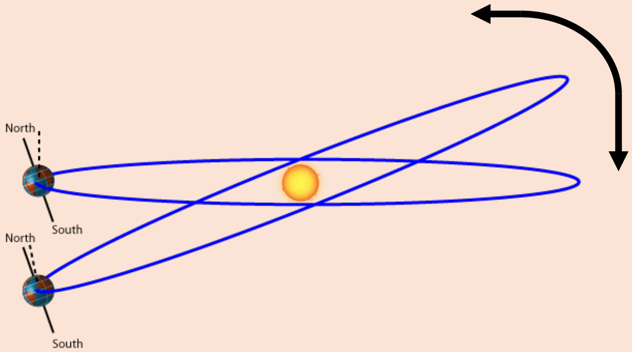


Figure 12.21 Back and forth tilt of the plane of Earth's orbit around the Sun relative to a reference plane – orbital oscillation.

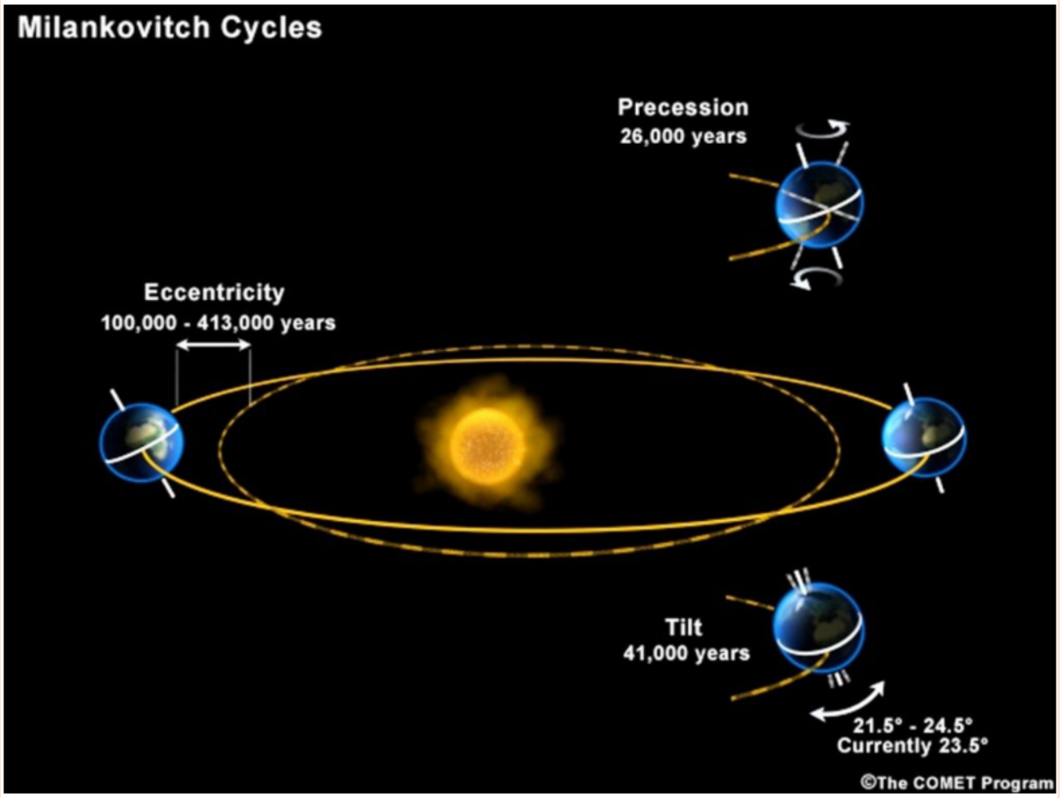


Illustration of the three Milankovitch cycles from the COMET Program at the University Center for Atmospheric Research.

Figure 12.22 Milankovitch Cycles https://www.carbonbrief.org/explainer-how-the-rise-and-fall-of-co2-levels-influenced-the-ice-ages/

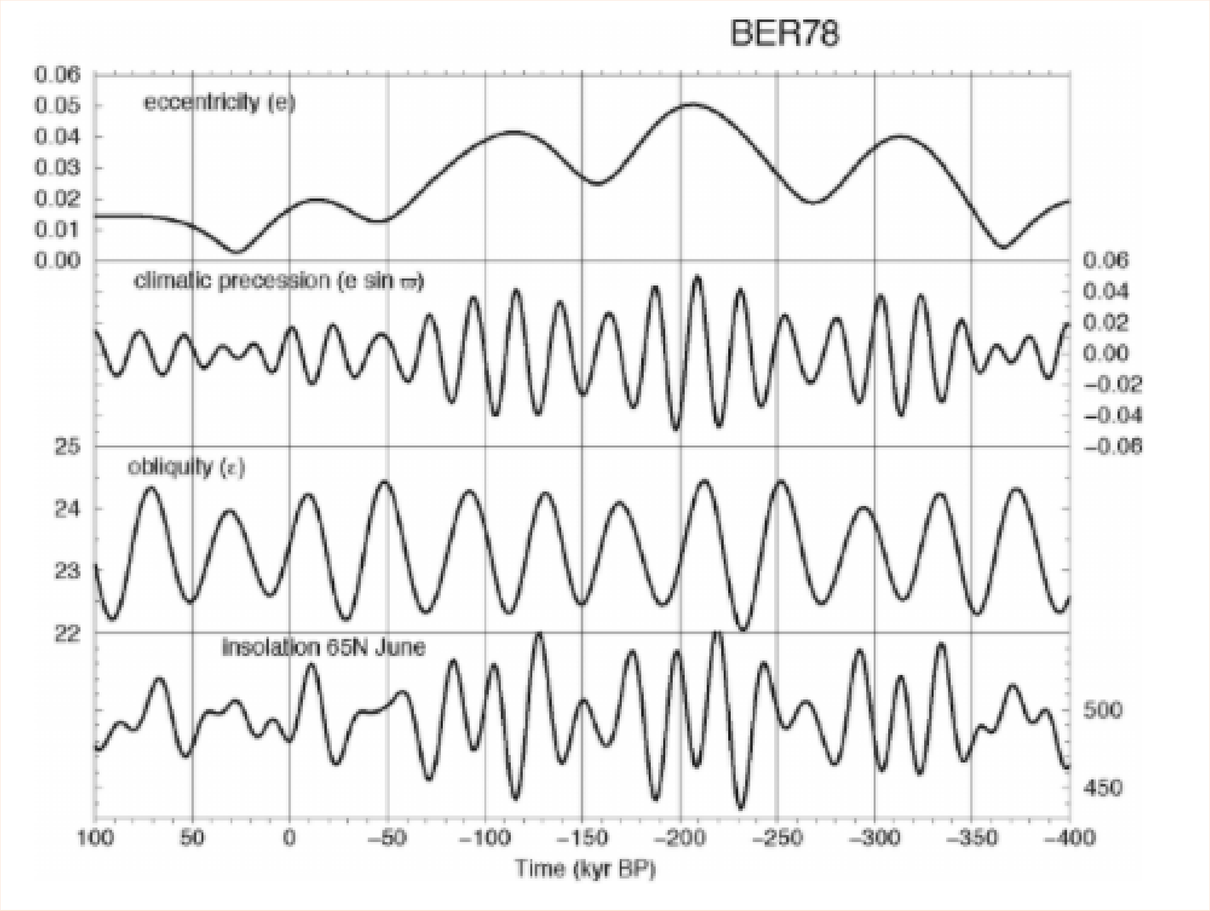


Figure 12.23 Berger astronomical model of orbital variability, past, present and future.

An excellent discussion on the relationship between the Milankovitch cycles and CO2 concentration in the atmosphere may be found in https://www.carbonbrief.org/explainer-how-the-rise-and-fall-of-co2-levels-influenced-the-ice-ages/ and https://phys.org/news/2019-10-antarctic-sea-ice-key-triggering.html . The Milankovitch cycles, during cooling phase, result in atmospheric cooling and increased sea ice. The oceans are able to contain greater amounts of CO2 resulting in a decrease of CO2 in the atmosphere – a positive feedback resulting in more cooling. The opposite phenomenon occurs when the Milankovitch cycles enter a warming phase.

12.5 Volcanic activity

Volcanic activity occurs as a result of tectonic processes as discussed in 12.1. It frequently results in the ejection of molten rock, ash and gas from below the Earth's crust as illustrated in

Figure 12.24.   The impact may be local or global as did the eruption of Mt. Pinatubo in the Philippines shown in Figure 12.25.   NASA estimates that the maximum effect of the five largest volcanoes over the past century is less than 0.2 degrees cooling globally and 0.4 degrees regionally https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch9s9-3-3-2.html . Volcanoes produce approximately 1% of the carbon dioxide produced by human activity. Aerosols may persist up to two years or longer in the northern hemisphere which can result in greater areas of snow and ice cover and regional cooling https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch8s8-7-2-3.html , https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-7-2.html . The stratosphere may warm several degrees which in turn may strengthen the polar vortex in the northern hemisphere and the polar jet stream resulting in warmer winters. The ozone layer may also be depleted because of the presence of chlorine and other CFCs similar to those produced by human activity https://scied.ucar.edu/learning-zone/how-climate-works/how-volcanoes-influence-climate and https://scied.ucar.edu/learning-zone/how-climate-works/how-volcanoes-influence-climate , https://www.earthdata.nasa.gov/learn/sensing-our-planet/volcanoes-and-climate-change , http://climate.envsci.rutgers.edu/pdf/ROG2000.pdf , https://www.carbonbrief.org/in-brief-how-much-do-volcanoes-influence-the-climate/ .

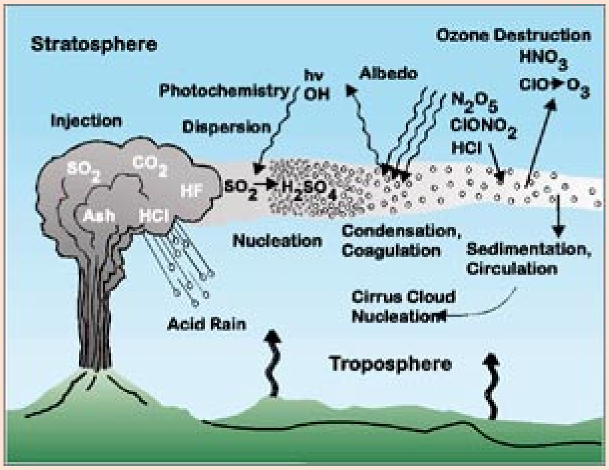


Figure 12.24 Volcanic eruption releasing ash and a variety of aerosols and gases

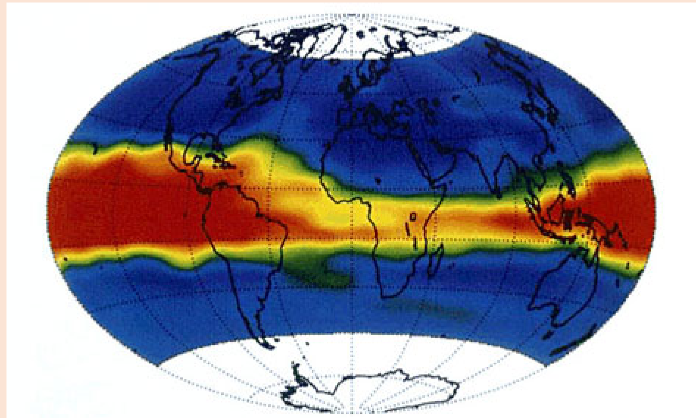


Figure 12.25 Mt. Pinatubo and global circulation of ash https://pubs.usgs.gov/fs/1997/fs113-97/ and https://earthobservatory.nasa.gov/images/1510/global-effects-of-mount-pinatubo

Figure 12.26 illustrates the significant volcanic activity since 1870. The greater the optical depth the more aerosols ejected into the atmosphere. Figure 12.27 shows the most recent volcanic eruptions and how their effects have dissipated with time.

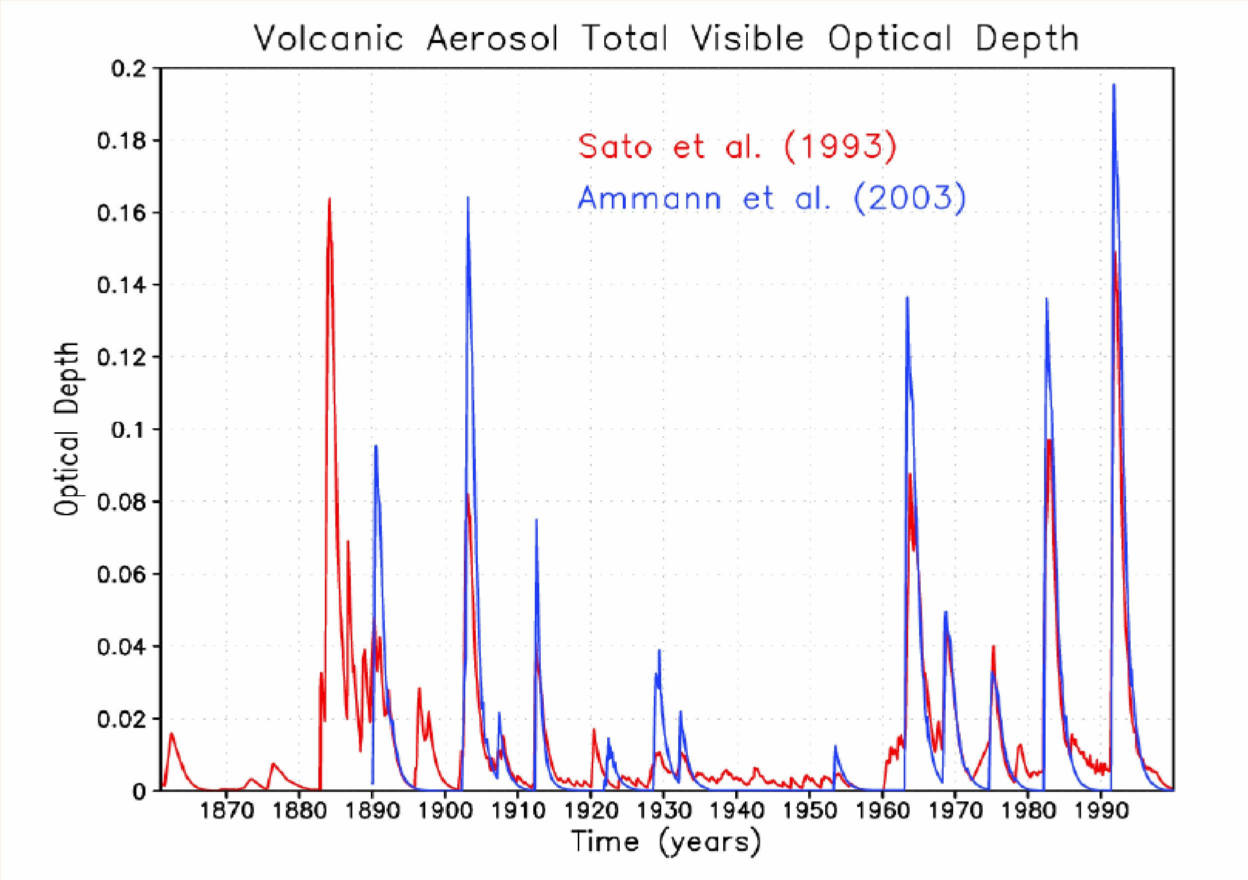


Figure 12.26 Volcanic eruptions since 1870.

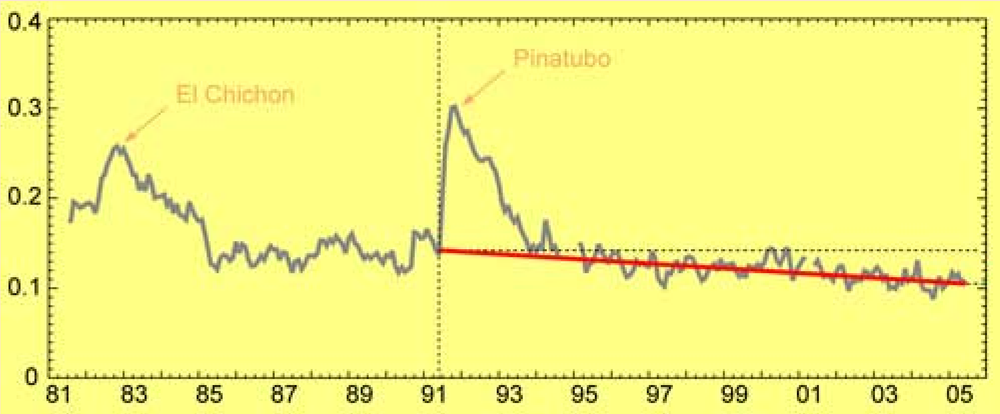


Figure 12.27 Sun-blocking aerosols around the world since the 1991 eruption of Mount Pinatubo according to satellite estimates. NASA

12.6 Global dimming

Global dimming is caused by forest fire, pollution, contrails and dust storms https://en.wikipedia.org/wiki/Global_dimming . The effect is the same as volcanic activity as described 12.4. Global dimming caused by contrails as shown in Figure 12.28 be more significant than the GHG emissions from the jet plane engines. Global dimming due to forest fires is shown in Figures 12.29 and 12.30. Global dimming due to pollution is shown in Figure 12.31. The effect of dust storms is shown in Figure 12.32.

Figure 12.28 Contrails 2001 https://www.science.org/content/article/aviation-s-dirty-secret-airplane-contrails-are-surprisingly-potent-cause-global-warming .

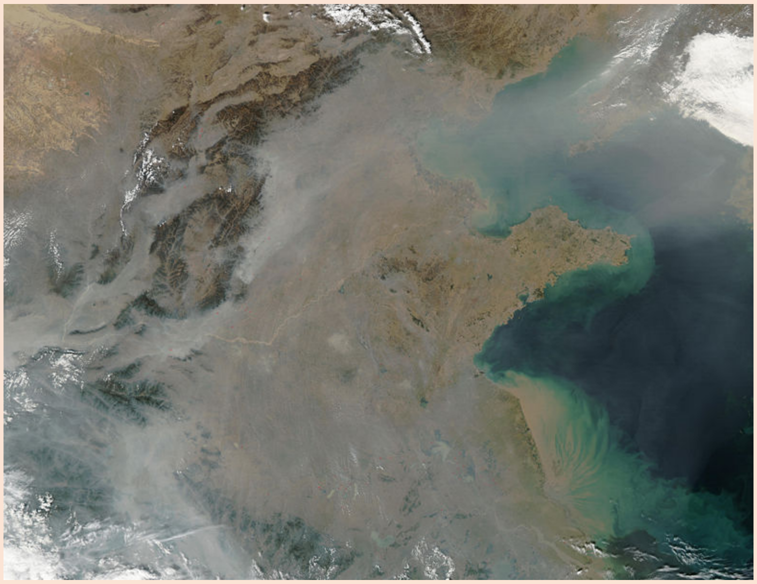
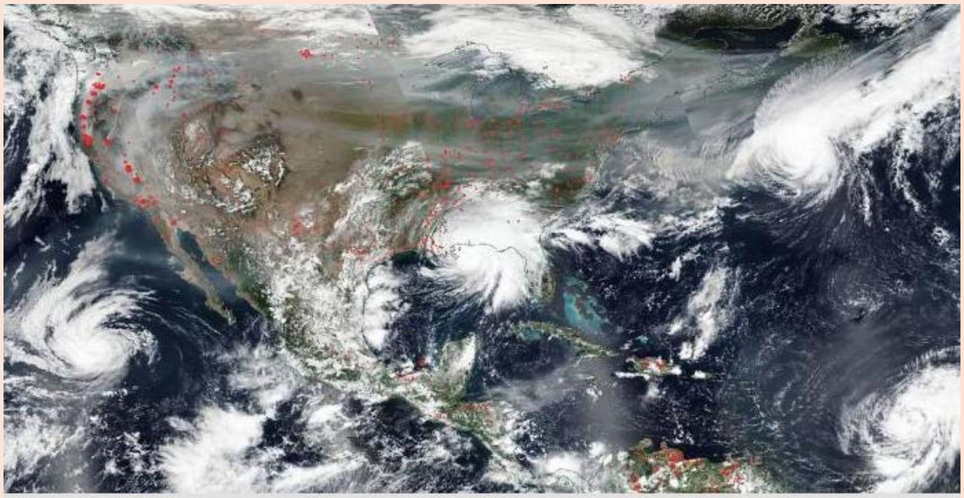


Figure 12.29 Forest fires – eastern China.



NASA's Aqua satellite captured this true-color image of the United States on Sep. 15, 2020, showing the fires in the West, the smoke from those fires drifting over the country, several hurricanes converging from different angles, and Hurricane Sally making landfall. Credit: NASA

Figure 12.30 Forest fires 2020 – western United States, NASA.

Figure 12.31 Pollution - Golden Gate Bridge – San Francisco.

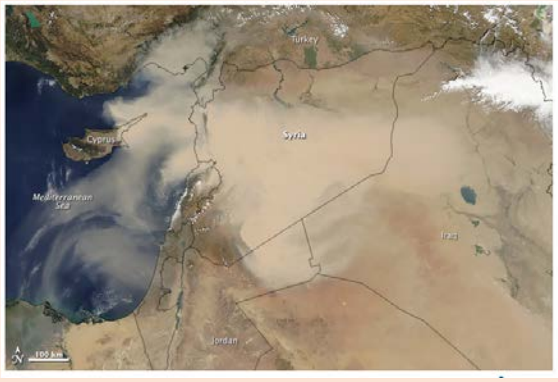


Figure 12.32 Dust storm sweeping across the Middle East – NASA https://earth servatory.nasa.gov/images/86571/dust-storm-sweeps-across-middle-east .

12.7 Information support

Key web sites:

1. Solar variability and the total solar irradiance. https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch1s1-4-3.html

2. Sea level change. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter13_FINAL.pdf

3. Anthropogenic and natural radiative forcing. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf

4. Solar irradiance. https://en.wikipedia.org/wiki/Solar_irradiance

5. Insolation. https://www.sciencedirect.com/topics/earth-and-planetary-sciences/insolation

6. Solar cycle. https://en.wikipedia.org/wiki/Solar_cycle

7. Solar cycle. https://spaceplace.nasa.gov/solar-cycles/en/

8. Sunspot cycle. https://scied.ucar.edu/sunspot-cycle#:~:text=The%2011%2Dyear%20sunspot%20cycle,northern%20and%20southern%20hemispheres%20switch.

9. Solar flares, coronal mass ejections or CMEs, NASA. https://hesperia.gsfc.nasa.gov/rhessi3/mission/science/the-impact-of-flares/index.html#:~:text=The%20x%2Drays%20from%20flares,atmosphere%2C%20causing%20it%20to%20expand.

10. Cosmic radiation and solar activity from ice cores and tree rings. https://www.pnas.org/content/109/16/5967

11. Cosmic rays and global warming. https://skepticalscience.com/cosmic-rays-and-global-warming-advanced.htm

12. Impact of the solar cycle on global warming, NOAA. https://www.climate.gov/news-features/understanding-climate/climate-change-incoming-sunlight#:~:text=During%20strong%20solar%20cycles%2C%20the,0.1%20degrees%20Celsius%20or%20less. ,

13. Milankovitch cycles. https://en.wikipedia.org/wiki/Milankovitch_cycles

14. Milankovitch cycles. https://www.skepticalscience.com/Milankovitch.html

15. Astronomical theory of climate change. https://www.researchgate.net/publication/238956033_Astronomical_theory_of_climate_change

16. Volcanoes, explained. https://www.nationalgeographic.com/environment/natural-disasters/volcanoes/#close

17. Ring of fire. https://en.wikipedia.org/wiki/Ring_of_Fire

18. Ring of fire. https://www.britannica.com/place/Ring-of-Fire

17. Tectonic shift. https://oceanservice.noaa.gov/facts/tectonics.html

18. Plate tectonics. https://volcanoes.usgs.gov/vsc/file_mngr/file-139/This_Dynamic_Planet-Teaching_Companion_Packet.pdf

19. Earth's crust. https://www.nationalgeographic.org/encyclopedia/crust/#:~:text=1%2F12-,%E2%80%9CCrust%E2%80%9D%20describes%20the%20outermost%20shell%20of%20a%20terrestrial%20planet.,of%20solid%20rocks%20and%20minerals .

20. Eruption of Mount Pinatubo, Philippines. https://pubs.usgs.gov/fs/1997/fs113-97/

21. Global effects of Mount Pinatubo. https://earthobservatory.nasa.gov/images/1510/global-effects-of-mount-pinatubo

22. How volcanoes influence climate. https://scied.ucar.edu/shortcontent/how-volcanoes-influence-climate

23. Volcano hazards. https://www.usgs.gov/natural-hazards/volcano-hazards/volcanic-gases

24. Anthropogenic and natural radiative forcing. http://www.climatechange2013.org/images/report/WG1AR5_Chapter08_FINAL.pdf

25. Volcanoes and climate change. https://earthdata.nasa.gov/learn/sensing-our-planet/volcanoes-and-climate-change

26. Volcanic eruptions and climate. http://climate.envsci.rutgers.edu/pdf/ROG2000.pdf

27. Volcanoes. https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch8s8-7-2-3.html

28. Explosive volcanic activity. https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-7-2.html

29. Role of volcanism and solar irradiance. https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch9s9-3-3-2.html

30. How much do volcanoes influence the climate? https://www.carbonbrief.org/in-brief-how-much-do-volcanoes-influence-the-climate

32. Global dimming. https://en.wikipedia.org/wiki/Global_dimming

33. Contrails. https://www.sciencemag.org/news/2019/06/aviation-s-dirty-secret-airplane-contrails-are-surprisingly-potent-cause-global-warming

34. Dust storm sweeps across Middle East. https://earthobservatory.nasa.gov/images/86571/dust-storm-sweeps-across-middle-east

35. CO2 ice ages, https://phys.org/news/2019-10-antarctic-sea-ice-key-triggering.html and https://www.carbonbrief.org/explainer-how-the-rise-and-fall-of-co2-levels-influenced-the-ice-ages/ .