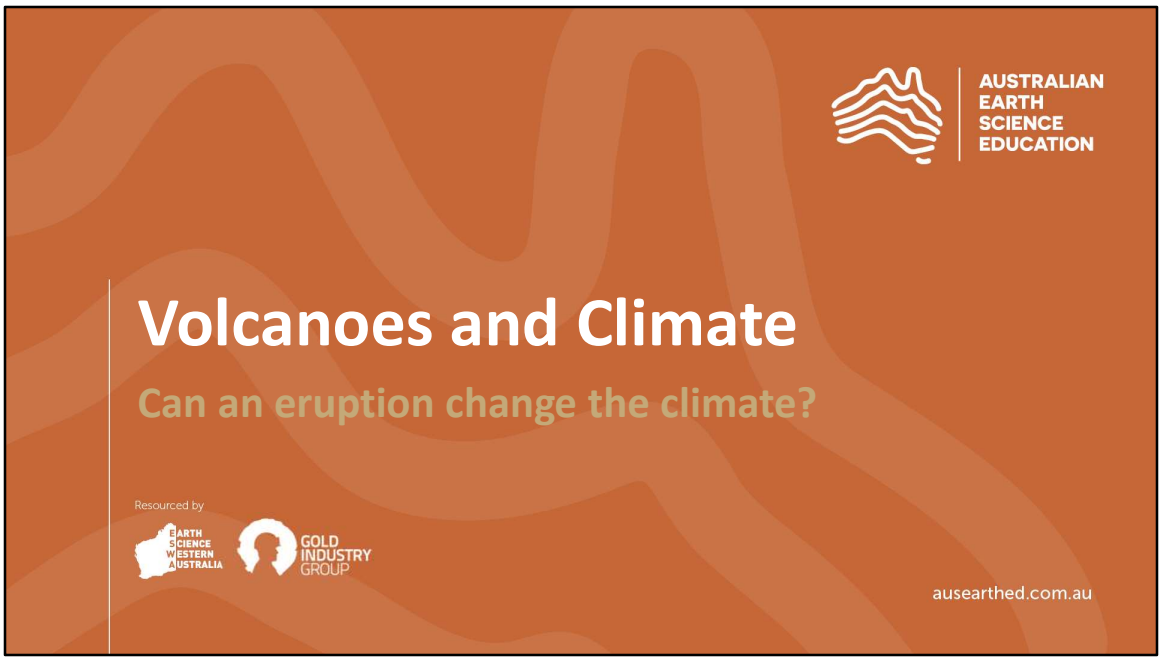

The NSW syllabus asks students to analyse the effects of a major volcanic eruption on climate – both warming and cooling. As we will see, only one of these happens as a result of normal volcanic eruptions.

How can a volcano affect climate?

- Greenhouse gases
  - water vapour
  - carbon dioxide
- Sulfur dioxide

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There are two possible ways for a volcano to affect climate and both are due to gas emissions release during eruptions.

Volcanic gases include greenhouse gases that can cause warming (water vapour and carbon dioxide). They also have sulfur dioxide that can cause cooling, if ejected into the stratosphere.

Will GHGs cause warming?

- Water falls quickly as rain

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Although water vapour is the most plentiful greenhouse gas, we do not worry about it. Water quickly enters and leaves the atmosphere through the water cycle. After a volcanic eruption, fine ash particles encourage droplet formation and make rain more likely.

Will GHGs cause warming?

- Water falls quickly as rain
- Carbon dioxide dissolves in ocean

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Carbon dioxide is highly soluble and generally dissolves in the ocean – our greatest carbon sink. However, some remains in the atmosphere.

Carbon dioxide in perspective

- Kilauea
  - Erupting since 1980s
  - Average 3 Mt/y of CO_2
- Fossil fuel burning
  - Average 33 000 Mt/y CO_2

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Even if all of the carbon dioxide emitted by a volcano remained in the atmosphere, it is about one tenth of the carbon dioxide produced by burning fossil fuels. Normal volcanic eruptions in the past have not caused warming and this continues to be the case. Note Mt = Mega tonne (1 000 000 tonnes)

Large Igneous Provinces (LIPs) are different. These massive pulses of volcanic activity are associated with major rifting and are unlike any single volcanic eruption on the planet. See the AusEarthEd resources about LIPs and climate to learn more.

Will sulfur dioxide cause cooling?

- Troposphere: “vog”

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In the lower atmosphere, sulfur dioxide interacts with sunlight, oxygen, water and dust to form “vog” (volcanic smog). This acidic smog is eventually washed out of the air as acidic rain. This leads to acidic soils in volcanic areas. It causes breathing distress, but has no climate effects.

Will sulfur dioxide cause cooling?

- Troposphere: “vog”
- Stratosphere: sulfur aerosols

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If sulfur dioxide is ejected into the stratosphere, the effect is different. Sulfur dioxide reacts with water and oxygen to form sulfuric acid aerosol droplets that block some of the incoming solar radiation (from reaching the troposphere) and can disperse globally due to winds. These aerosols cause cooling for up to four years. They eventually consolidate into larger droplets and fall into the troposphere, eventually reaching the surface as acid rain

Reference:
Ospipov S, Stenchikov G, Tsigaridis K, et al. (2020). The role of the SO_2 radiative effect in sustaining the volcanic winter and soothing the Toba impact on climate. *JGR Atmospheres* **125**(2) Open Access: https://doi.org/10.1029/2019JD031726

USGS (n.d.). Volcanoes can affect climate. https://www.usgs.gov/natural-hazards/volcano-hazards/volcanoes-can-affect-climate

Explosive eruptions lead to cooling

- Aerosols blasted high into stratosphere
- Linger up to 4 years
- Absorb infrared in the stratosphere heating it up
- Surface cooling due to less infrared

Pinatubo eruption (D Harlow 1991, public domain)

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Explosive eruptions eject sulfur dioxide high into the stratosphere, where it forms sulfate aerosols that linger for years. The 1991 eruption of Mt Pinatubo ejected an estimated 20 Mt of sulfur dioxide more than 20 km into the atmosphere.

Sulfate aerosols in the stratosphere reflect visible light and absorb infrared radiation. This heats the stratosphere, but cools the troposphere, as infrared does not reach the troposphere and surface.

Reference:
Stenchikov GL, Kirchner I, Robock A, etal. (1998). Radiative forcing from the 1991 Mount Pinatubo volcanic eruption. *Journal of Geophysical Research* **103**(D12): 13 837 – 13 857. https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/98JD00693

Wolfe J (2020). Volcanoes and climate change. https://earthdata.nasa.gov/learn/sensing-our-planet/volcanoes-and-climate-change

Effect of volcanic cooling

- 1991 Pinatubo
  - Overall drop of 0.5°C for 15 months
  - Changed rainfall – 1992 drought
- 1815 Tambora
  - Overall drop of 3°C
  - "Year Without a Summer" in 1816

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The 1991 eruption of Mt Pinatubo caused a global average temperature drop of 0.3 – 0.7°C. Some areas experienced slightly warmer temperatures, while others were much cooler. This effect lasted 15 months. There were also changes in rainfall because the troposphere was cooler, so held less water vapour. Less rain fell over land, leading to drought in 1992.

The 1815 eruption of Indonesia's Mt Tambora was the largest eruption in recorded history. The 3° C temperature drop and reduced visible light caused food shortages due to reduced plant growth. Spectacular sunrises and sunsets were observed globally and the summer was very gloomy.

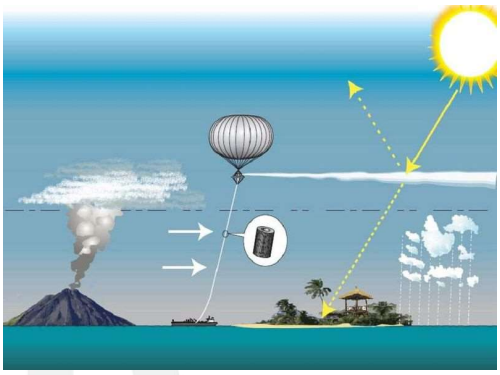
References:

Trenberth KE, Dai A (2007). Effects of Mount Pinatubo volcanic eruption on the hydrological cycle as an analog of geoengineering. *Geophysical Research Letters* **34**(15). https://doi.org/10.1029/2007GL030524

UCAR Center for Science Education (n.d.). Mount Tambra and the Year Without a Summer. https://scied.ucar.edu/learning-zone/how-climate-works/mount-tambora-and-year-without-summer

Aerosol geoengineering

- Could change global climate for short periods
- May buy time
- Serious consequences



SPICE geoengineering project (Hughhunt 2011, Creative Commons 3.0)

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We know that stratospheric aerosols can cool the globe because of past volcanic eruptions. This has been proposed as an emergency measure to combat global warming. However, the examples of drought and food shortage from volcanic cooling events serve as a cautionary tale.

Learn more about geoengineering in our AusEarthEd Geoengineering resources under the Climate Change section at https://ausearthed.com.au/nsw/earth-enviro-science/


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