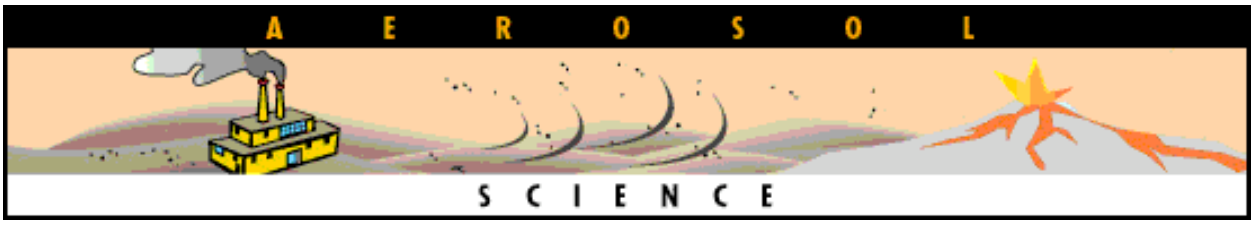


***Recommended Age:***
Intermediate Level (Grade 6-8); Secondary Level (Grade 9-12)

***Guiding Question:***
*What effects do volcanic eruptions have on the Earth's climate, and how can we tell?*

***Concepts:***
Volcanic eruptions release small particles (aerosols) into the atmosphere, which are thought to reflect incoming solar radiation (thus cooling the climate).

**Principles:**
1. There are different types and sizes of volcanic eruptions.
2. Certain large eruptions are thought to release enough aerosols in the form of SO2 (sulfur dioxide) to cool the climate. Aerosol clouds from such eruptions can be detected from orbiting satellites.
3. There are many factors which influence climate, and a large volcanic eruption does not automatically mean that a cooler year will follow.

**Facts:**
1. Past eruptions can be given a general magnitude rating, based on factors such as the height of the aerosol cloud and the total volume of material released during the eruption. This rating is called the Volcano Explosivity Index (VEI). Eruptions are given a number from 0 (the smallest or least explosive) to 8 (the largest). Eruptions with a rating of 6 or higher are rare.
2. The eruption of Mt. Pinatubo (1991) volcano is thought to rate 6 on a VEI. The average global temperature in 1992 was approximately 0.28 degrees Celsius cooler than the average temperature for 1991.
3. The 1902 eruption of Mt. Pelee in Martinique had a VEI of 4 or 5.
4. The volcanic eruption of Tambora in Indonesia in 1813, with a VEI of 7, is suspected to have caused the "year without a summer" whereby killing frosts destroyed crops and caused famine.
5. Average temperatures world wide the year after the 1982 volcanic eruption of El Chichon, Mexico (VEI of 5) were actually 0.22 deg. C *warmer* than they were for the year of the eruption.
6. NASA's Total Ozone Mapping Spectrometer (TOMS) instrument detected the Mt. Pinatubo aerosol cloud from space. Other eruptions have been similarly detected by satellites.
7. The Stratospheric Aerosol and Gas Experiment (SAGE) contains a three generation project (SAGE I, II, and III) focusing on the collection of data about aerosols in the stratosphere. SAGE I ran for 3 years, starting in 1979. The SAGE II instrument measures the amount of ozone and other trace gases in the atmosphere by measuring the amount of sunlight that comes through the atmosphere at different altitudes. The SAGE II instrument was launched in 1984. Three flights of the SAGE III instrument are currently planned including a flight aboard a Russian Meteor-3M platform in mind-1999 and the International Space Station in 2002. The third flight has not been identified.

**Skills:**
1. Calculating an average (mean)
2. Graphing
3. Cause and effect relationship
4. Interpreting data and drawing conclusions

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**Applicable National Standards (Science, Level 9-12):**
- Standard A, "Understanding about scientific inquiry," items 3-4
- Standard D, "Energy in the earth system," item 4
- Standard F, "Natural and human-induced hazards," item 4
- Standard G, "Nature of scientific knowledge," item 2

**Preparation Materials:**
1. Data sets
2. Graph paper
3. Calculator(s)
4. Aerosols trading cards
5. Internet access can be used for an optional research component (see "Extension Ideas").
6. Glossary

**Room Preparation:**
None in particular. If you wish to allow students to work in cooperative groups, the room can be arranged accordingly.

**Safety Precautions:**
None particular to this activity.

**Procedures and Activity Prelab discussion:**
1. Introduce basic principles and ideas.
2. Ask:
   (1) What do you think happens to the temperature of the Earth if something blocks incoming solar radiation?
   (2) Do you think all volcanic eruptions can cause this to happen?
   (3) How can we find out?
3. All measurements given in this activity are estimates only. Make sure that students understand the difference between "facts" and educated guesses!

**Activity & Discussion:**
**NOTE: The teacher should review the information on page 1 of this activity before class.**
1. DATA and CALCULATIONS:
   * Students should fill in the data tables provided, using calculators if desired.
2. GRAPHING THE DATA:
   * A graph of the data should be constructed, with the independent variable (VEI) on the "x" axis and the dependent variable (change in temperature following the eruption) on the "y" axis. The y axis can be labeled in intervals of 0.1 to 0.2 degrees Celsius. If the graphic skills of your students are weak, you may choose to lead the creation of the class graph, on the chalkboard.
3. DISCUSSION I:
   * Ask, "Are there any obvious trends to be seen, looking at the graph as is? Can a conclusion be formed?" (No--the graph will look like a mess at this point--that's OK).

4. GRAPHING THE MEANS:
   * Lead the class in calculating the means on the Labsheet,
   * On the same graph for part 2, plot the *mean* temperature change vs. the VEI (students should use a separate color for this, if possible).
5. DISCUSSION II:
   * Ask,"Now is there any trend?" (On average, the greater the VEI, the more likely there is to be a temperature drop for the following year).
   * "Can a conclusion be formed now?" (Even though a trend is shown, lead students to understand that the results are somewhat ambiguous, and THERE IS NOT ENOUGH DATA TO FORM A DEFINITE CONCLUSION. The best one can do with it is to say, "On average, it looks as if bigger eruptions might lead to cooler temperatures, but we *can't be sure*.")

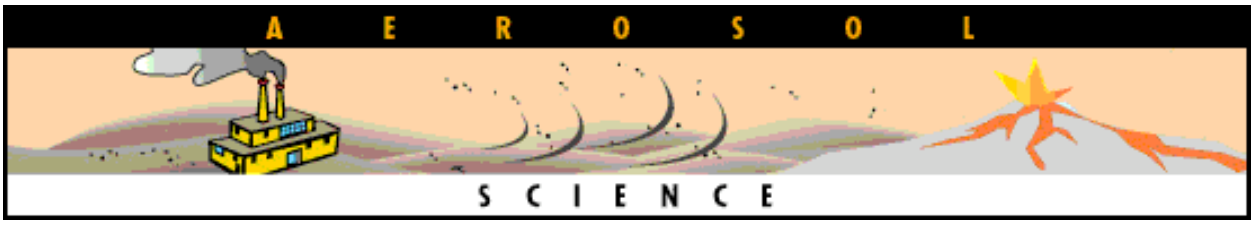
6. EXTENSION:
   * Explain that the 1902 eruption of Mt. Pelee (port city of St. Pierre on the island of Martinique) killed an estimated 29,025 people and had a VEI of 4 or 5. The 1991 eruption of Mt. Pinatubo, Philippines, had a VEI of 6 and killed an estimated 800 people. Each student should be required to provide one explanation of how this might be possible. (Alternatively, allow groups of students to create lists of possibilities).

   * In summary, it should be clear that it is NOT possible to correlate VEI with **fatalities**, because of the range of other factors (population density, proximity to site of eruption with global cooling), and one must realize that there are a range of factors which influence temperature, and may make results difficult to interpret. The use of satellites by NASA to collect data may help to resolve this question with more certainty.

**Closing:**
Ask again, "Do volcanoes definitely affect the climate?

**Evaluation:**

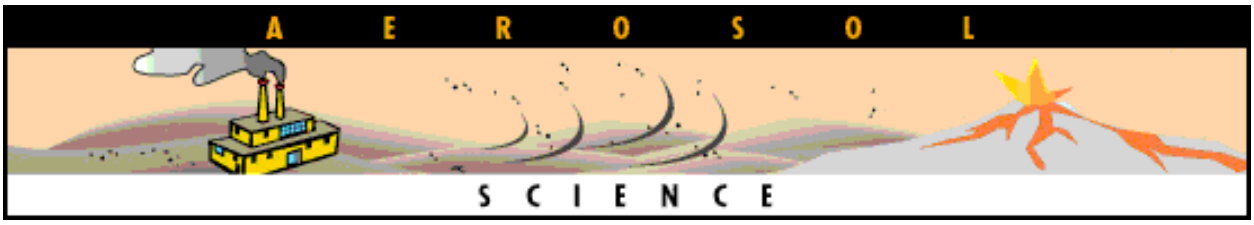
1. Check Volcano and Means Calculations Data Tables
2. Check AEROSOL SCIENCE GRAPH.
3. Check answers to SUMMARY QUESTIONS.




**VOLCANO DATA TABLE:**

| Volcano | Location | VEI* | Year | Avg.Temp (Celsius) That Year** | Avg.Temp (Celsius) This Year** | Change in Temp. (next year-eruption year) |
|---|---|---|---|---|---|---|
| Krakatoa | Indonesia | 6 | 1883 | 14.60 | 14.35 | |
| Torawera | New Zealand | 5 | 1886 | 14.60 | 14.48 | |
| Santa Maria | Guatemala | 6 | 1902 | 14.75 | 14.64 | |
| Ksudach | Russia | 5 | 1907 | 14.57 | 14.70 | |
| Katmei | USA | 6 | 1911 | 14.71 | 14.72 | |
| Novarupta | Alaska | 6 | 1912 | 14.72 | 14.77 | |
| Cerro Azul | Chile | 5 | 1932 | 15.02 | 14.87 | |
| Paracutin | Mexico | 5 | 1943 | 15.03 | 15.11 | |
| Benzymi-anny | Russia | 5 | 1955 | 14.94 | 14.83 | |
| Mauna Loa | Hawaii | 4 | 1976 | 14.79 | 15.16 | |
| St. Helens | USA | 5 | 1980 | 15.28 | 15.39 | |
| El Chichon | Mexico | 5 | 1982 | 15.07 | 15.29 | |
| Kilauea | Hawaii | 4 | 1983 | 15.29 | 15.11 | |
| Nevado del Ruiz | Columbia S.America | 3 | 1986 | 15.16 | 15.32 | |
| Pinatubo | Philippines | 6 | 1991 | 15.41 | 15.13 | |

* From Volcano World
** From The United Nations Environment Program




**MEAN CALCULATIONS:**

| VEI* | Positive Temp. Changes (°C) | Negative Temp. Changes (°C) | TOTAL | MEAN (Total Divided by Number of Items) |
|---|---|---|---|---|
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |

**SUMMARY QUESTIONS:**

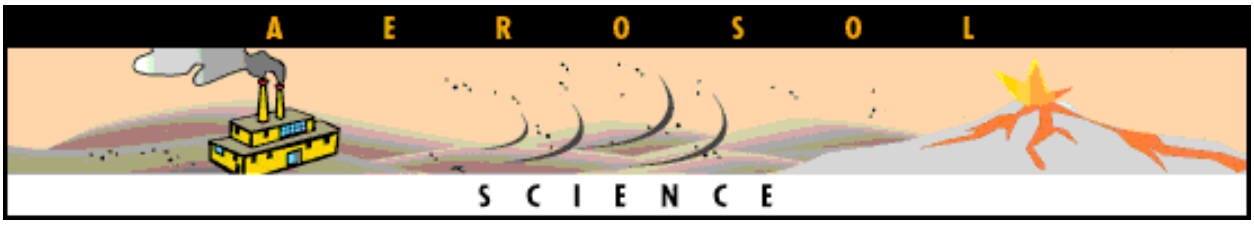
1. Which VEI values showed an average *increase* in temperature for the year after the eruption?

2. Which VEI values showed an average *decrease* in temperature for the year after the eruption?

3. What might this indicate about whether volcanic eruptions can cause the climate to cool?

Do all eruptions cause the climate to cool? Or only certain categories? Explain.

4. Write a paragraph summarizing what you have learned and how you know this: "Do volcanoes definitely affect the climate?




# AEROSOL SCIENCE GLOSSARY

**Aerosols** Tiny particles suspended in the atmosphere, liquid or solid matter. Incoming solar energy can be absorbed or reflected by aerosols.

**Atmosphere** The envelope of gases surrounding the Earth and bound to it by the Earth's gravitational attraction.

**Atmospheric Haze** A fine dust or light vapor causing the lack of transparency of the air.

**Biomass Burning** The burning of the world's forests, grasslands, and agricultural lands following the harvest for land clearing, land conversion, and natural burning resulting from lightning-induced fires.

**Desert Dust** Common source of aerosols. Dust comprises minerals and absorbs sunlight as well as scatters it. Through absorption of sunlight, the dust particles warm the layer of the atmosphere where they reside. This warmer air is believed to inhibit the formation of storm clouds.

**Cinder Cone Volcano** A type of volcano built from particles of congealed lava ejected from a single vent. This is the simplest type of volcano. Most cinder cones have a bowl-shaped crater at the summit, and rarely rise more that a thousand feet or so above their surroundings.

**Climate** The average or expected weather conditions in a particular region and season.

**Composite Volcano** A type of volcano built by the accumulation of materials erupted through the conduit, which increases in size as lava, cinder, and ash are added to its slopes.

**Human-made Aerosols** A large portion is composed of smoke from burning tropical forests, but the major component comes in the form of sulfate aerosols created by the burning of coal and oil. The concentration of aerosols is highest in the northern hemisphere where industrial activity is centered.

**Emission** To throw or give off or out.

**International Space Station (ISS)** Not simply a satellite, but rather an entire orbiting space station. The International Space Station (ISS) is being built in segments which will be launched separately and assembled in orbit.

**Mauna Loa** Mauna Loa is the largest volcano on Earth. It makes up half of the area of the Island of Hawaii. Mauna Loa began to form nearly a million years ago.

**Mt. Pinatubo** Volcano in the Philippines; the large eruption of Pinatubo in 1991 is thought to have temporarily cooled the Earth's climate by about 0.5 degrees Celsius. Aerosols from this eruption were detected by orbiting satellites.

**Photometer** An instrument used for measuring luminous intensity, illumination or brightness.

**Ozone** A molecule made up of three atoms of oxygen. In the *stratosphere*, ozone occurs naturally and provides a protective layer shielding the Earth from ultraviolet radiation, and the subsequently harmful health effects on humans and the environment. In the *troposphere*, ozone is a chemical oxidant and a major component of smog. Ozone is an effective greenhouse gas especially in the middle and upper *troposphere* and lower *stratosphere*.

**SAGE I** Stratospheric Aerosol and Gas Experiment. Three generation project focusing on the collection of aerosols data in the **stratosphere.** SAGE I collected data for 3 years, starting in 1979.

**SAGE II** The SAGE II instrument measures the amount of ozone and other trace gases in the atmosphere by measuring the amount of sunlight that comes through the atmosphere at different altitudes.
SAGE II instrument was launched in 1984 and has collected data for 15 years.
**SAGE III** Three flights of the SAGE III instrument are currently planned including a flight aboard a Russian Meteor-3M platform in late-1999 and the International Space Station in 2002. The third flight has not been identified.

**Shield Volcano** A type of volcano built almost entirely of fluid lava flow. This volcano has a dome-like, warrior's shield shape. The largest shield volcano is Mauna Loa. It makes half of the area of the Island of Hawaii and began to form nearly a million years ago.

**Stratosphere** The second layer of the atmosphere, starting at about 15 km (9 miles) above the Earth's surface and extending to a height of about 50 km (30 miles).

**Sulfur Dioxide ($SO_2$)** A heavy toxic gas that is easily condensed to a colorless liquid and is a major air pollutant. Certain large volcanic eruptions are thought to release enough aerosols in the form on SO2 (sulfur dioxide) to cool the climate.

**Tambora** Indonesian volcano; its huge eruption in 1815 is thought to have caused the "Year Without a Summer," during which severe frosts killed crops and caused widespread famine.

**TERRA** The launch of EOS AM-1 will comprehensively monitor the solar radiation, the atmosphere, the oceans, and the Earth's continents from a single-based platform. The EOS AM-1 satellite is the flagship of NASA's Earth Science Enterprise. It will be the first EOS platform and will provide global data on the state of the atmosphere, land, and oceans.

**Total Ozone Mapping Spectrometer (TOMS)** TOMS instruments aboard Nimbus-7 and Meteor-3M provide global measurements of total column ozone on a daily basis, observes environmentally important areas such as the Antarctic ozone hole, and observe sulfur dioxide resulting from volcanic eruptions. TOMS also detected the Mt. Pinatubo aerosol cloud from space.

**Tropics** Either of two parallels of terrestrial latitude at a distance of about 23 1/2 degrees north or south of the equator where the sun is directly overhead when it reaches its most northerly or southerly point in the sky.

**Tropopause** The boundary between the troposphere and the stratosphere.

**Troposphere** The lowest atmospheric layer, between the Earth's surface and the tropopause. The troposphere is the region of most interest to meteorologists because the Earth's weather occurs in this atmospheric layer.

**Volcanic Explosivity Index** An eruption magnitude scale called the Volcanic Explosivity Index or VEI is used to measure how big an eruption is.
Volume of products, eruption cloud height and qualitative observations are used to determine the explosivity value. The scale ranges from 0 (small non-explosive eruptions) to 7 (large explosive eruptions).

**Volcanic Aerosols** Aerosols are released during volcanic eruptions, notably sulfur dioxide (SO2). Once formed, these aerosols stay in the stratosphere for several years. They reflect sunlight, reducing the amount of energy reaching the lower atmosphere and the Earth's surface, cooling them.