Volcanoes

• ~60 volcanoes erupt each year worldwide
• 2-3 volcanoes erupt each year in Alaska
• Kilauea (Hawaii) erupted continuously since 1983

• Volcanoes differ greatly in style of eruption and associated hazards
• Densely populated countries in volcanically active areas especially vulnerable
**Select Historic Volcanic Eruptions**

### Table 6.1 Selected Historic Volcanic Events

<table>
<thead>
<tr>
<th>Volcano or City</th>
<th>Year</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vesuvius, Italy</td>
<td>A.D. 79</td>
<td>Destroyed Pompeii and killed 16,000 people. City was buried by volcanic activity and rediscovered in 1595.</td>
</tr>
<tr>
<td>Skaptar Jokull, Iceland</td>
<td>1783</td>
<td>Killed 10,000 people (many died from famine) and most of the island’s livestock. Also killed some crops as far away as Scotland.</td>
</tr>
<tr>
<td>Tambora, Indonesia</td>
<td>1815</td>
<td>Global cooling; produced “year without a summer.”</td>
</tr>
<tr>
<td>Krakatoa, Indonesia</td>
<td>1883</td>
<td>Tremendous explosion; 36,000 deaths from tsunami.</td>
</tr>
<tr>
<td>Mount Pelée, Martinique</td>
<td>1902</td>
<td>Ash flow killed 30,000 people in a matter of minutes.</td>
</tr>
<tr>
<td>La Soufrière, St. Vincent</td>
<td>1902</td>
<td>Killed 2000 people and caused the extinction of the Carib Indians.</td>
</tr>
<tr>
<td>Mount Lamington, Papua New Guinea</td>
<td>1951</td>
<td>Killed 6000 people.</td>
</tr>
<tr>
<td>Villarica, Chile</td>
<td>1963–64</td>
<td>Forced 30,000 people to evacuate their homes.</td>
</tr>
<tr>
<td>Mount Helgafell, Heimaey Island, Iceland</td>
<td>1973</td>
<td>Forced 5200 people to evacuate their homes.</td>
</tr>
<tr>
<td>Mount St. Helens, Washington, USA</td>
<td>1980</td>
<td>Debris avalanche, lateral blast, and mudflows killed 54 people, destroyed more than 100 homes.</td>
</tr>
<tr>
<td>Nevado del Ruiz, Colombia</td>
<td>1985</td>
<td>Eruption generated mudflows that killed at least 22,000 people.</td>
</tr>
<tr>
<td>Mount Unzen, Japan</td>
<td>1991</td>
<td>Ash flows and other activity killed 41 people and burned more than 125 homes. More than 10,000 people evacuated.</td>
</tr>
<tr>
<td>Mount Pinatubo, Philippines</td>
<td>1991</td>
<td>Tremendous explosions, ash flows, and mudflows combined with a typhoon killed more than 300 people; several thousand people evacuated.</td>
</tr>
<tr>
<td>Montserrat, Caribbean</td>
<td>1995</td>
<td>Explosive eruptions, pyroclastic flows; south side of island evacuated, including capital city of Plymouth; several hundred homes destroyed.</td>
</tr>
</tbody>
</table>


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### Deadliest Historic Volcanic Eruptions

<table>
<thead>
<tr>
<th>Deaths</th>
<th>Volcano, Location</th>
<th>When</th>
<th>Major Cause of Death</th>
</tr>
</thead>
<tbody>
<tr>
<td>92,000</td>
<td>Tambora, Indonesia</td>
<td>1815</td>
<td>Starvation</td>
</tr>
<tr>
<td>36,417</td>
<td>Krakatau, Indonesia</td>
<td>1883</td>
<td>Tsunami</td>
</tr>
<tr>
<td>29,025</td>
<td>Mt. Pelee, Martinique</td>
<td>1902</td>
<td>Ash flows</td>
</tr>
<tr>
<td>25,000</td>
<td>Ruiz, Colombia</td>
<td>1985</td>
<td>Mudflows</td>
</tr>
<tr>
<td>14,300</td>
<td>Unzen, Japan</td>
<td>1792</td>
<td>Volcano collapse, tsunami</td>
</tr>
<tr>
<td>9,350</td>
<td>Laki, Iceland</td>
<td>1783</td>
<td>Starvation</td>
</tr>
<tr>
<td>5,110</td>
<td>Kelut, Indonesia</td>
<td>1919</td>
<td>Mudflows</td>
</tr>
<tr>
<td>4,011</td>
<td>Galunggung, Indonesia</td>
<td>1882</td>
<td>Mudflows</td>
</tr>
<tr>
<td>3,500</td>
<td>Vesuvius, Italy</td>
<td>1631</td>
<td>Mudflows, lava flows</td>
</tr>
<tr>
<td>3,360</td>
<td>Vesuvius, Italy</td>
<td>79</td>
<td>Ash flows and falls</td>
</tr>
<tr>
<td>2,957</td>
<td>Papandayan, Indonesia</td>
<td>1772</td>
<td>Ash flows</td>
</tr>
<tr>
<td>2,942</td>
<td>Lamington, Papua N.G.</td>
<td>1951</td>
<td>Ash flows</td>
</tr>
<tr>
<td>2,000</td>
<td>El Chichon, Mexico</td>
<td>1982</td>
<td>Ash flows</td>
</tr>
<tr>
<td>1,680</td>
<td>Soufriere, St Vincent</td>
<td>1902</td>
<td>Ash flows</td>
</tr>
<tr>
<td>1,475</td>
<td>Oshima, Japan</td>
<td>1741</td>
<td>Tsunami</td>
</tr>
<tr>
<td>1,377</td>
<td>Asama, Japan</td>
<td>1783</td>
<td>Ash flows, mudflows</td>
</tr>
<tr>
<td>1,335</td>
<td>Taal, Philippines</td>
<td>1911</td>
<td>Ash flows</td>
</tr>
<tr>
<td>1,200</td>
<td>Mayon, Philippines</td>
<td>1814</td>
<td>Mudflows</td>
</tr>
<tr>
<td>1,184</td>
<td>Agung, Indonesia</td>
<td>1963</td>
<td>Ash flows</td>
</tr>
<tr>
<td>1,000</td>
<td>Cotopaxi, Ecuador</td>
<td>1877</td>
<td>Mudflows</td>
</tr>
<tr>
<td>800</td>
<td>Pinatubo, Philippines</td>
<td>1991</td>
<td>Roof collapses and disease</td>
</tr>
<tr>
<td>700</td>
<td>Komagatake, Japan</td>
<td>1640</td>
<td>Tsunami</td>
</tr>
<tr>
<td>700</td>
<td>Ruiz, Colombia</td>
<td>1845</td>
<td>Mudflows</td>
</tr>
<tr>
<td>500</td>
<td>Hibok-Hibok, Philippines</td>
<td>1951</td>
<td>Ash flows</td>
</tr>
<tr>
<td>1000s</td>
<td>Santorini, Greece</td>
<td>1650 BC</td>
<td>Ash flows, tsunami?</td>
</tr>
</tbody>
</table>
Volcanism and Plate Boundaries

Volcanism directly related to plate tectonics

Volcanoes located at plate boundaries or over hot spots
Volcanoes of the United States

Over 40 different volcanoes have erupted in Alaska over last 100 years (subduction zone)

Volcanoes also mark the Cascade subduction zone

Hot spots include Yellowstone and Hawaii
Each type of volcano has a characteristic style of activity determined by composition, viscosity, and dissolved gas content of its magma

- **Viscosity**: liquid’s resistance to flow determined by silica content (composition) and temperature

- Non-explosive eruptions: low viscosity and low dissolved gas contents (basaltic magma)

- Explosive eruptions: high viscosity and high dissolved gas contents (andesitic and rhyolitic magma)
Shield Volcanoes

- Gently sloping, very broad volcanoes built up over time by successive lava flows
- Characterized by gentle eruption of fluid basaltic lava that is low in silica and rich in Fe and Mg

Mauna Loa
Hawaii
Composite Volcanoes

- Stratovolcanoes: steep sided, conical shaped
- Characterized by alternating periods of explosive activity and intermediate viscosity (andesitic) lava flows
- Composed of alternating layers of pyroclastic (air–fall) deposits and lava flows

Mt. Hood
Oregon
Volcanic Domes

- Highly viscous rhyolitic magma with high silica content
- Builds very steep sided dome prone to collapse
- Activity mostly explosive

Lassen Peak
California
Cinder Cones

- Frothy ejection of basaltic magma with high gas content
- Steep, conical hill of volcanic fragments that accumulate around and downwind from the vent.
- The rock fragments, called cinders or scoria, are glassy and contain numerous gas bubbles "frozen" into place as magma exploded into the air and then cooled quickly.

Sunset Crater
Arizona
### TABLE 6.2 Types of Volcanoes

<table>
<thead>
<tr>
<th>Volcano Type</th>
<th>Shape</th>
<th>Silica Content of Magma</th>
<th>Viscosity</th>
<th>Rock Type Formed</th>
<th>Eruption Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shield volcano</td>
<td>Gentle arch, or shield shape, with shallow slopes; built up of many lava flows</td>
<td>Low</td>
<td>Low</td>
<td>Basalt</td>
<td>Lava flows, tephra ejections</td>
<td>Mauna Loa, Hawaii Figure 6.5</td>
</tr>
<tr>
<td>Composite volcano, or stratovolcano</td>
<td>Cone-shaped; steep sides; built up of alternating layers of lava flows and pyroclastic deposits</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Andesite</td>
<td>Combination of lava flows and explosive activity</td>
<td>Mt. Fuji, Japan Figure 6.7</td>
</tr>
<tr>
<td>Volcanic dome</td>
<td>Dome shaped</td>
<td>High</td>
<td>High</td>
<td>Rhyolite</td>
<td>Highly explosive</td>
<td>Mt. Lassen, USA Figure 6.8</td>
</tr>
<tr>
<td>Cinder cone</td>
<td>Cone shaped; steep sides; often with summit crater</td>
<td>Low</td>
<td>Low</td>
<td>Basalt</td>
<td>Tephra (mostly ash) ejection</td>
<td>Springerville, AZ Figure 6.9</td>
</tr>
</tbody>
</table>

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Volcanic Vents

Vents: openings from which lava is erupted
- May be roughly circular openings (craters) or elongated cracks (fissures or rifts)

South Sister summit crater, Oregon

Laki fissure row, Iceland
Volcanic Calderas

Calderas: large circular depressions produced by rapid, often explosive ejection of magma and subsequent collapse

Crater Lake Caldera, Oregon
Calderas from when a large amount of magma is erupted over a short time. The upper portion of the volcano is left unsupported and collapses into the empty magma chamber.
Caldera forming eruptions eject huge amounts of magma catastrophically

Recent caldera forming eruptions, though large, pale compared to eruptions in the Pleistocene

Holocene calderas with eruptive volumes >25 km³
- Tambora (Indonesia) 1815: 50 km³
- Kuwae (Tropical Pacific) ~1453: 40 km³
- Santorini (Thera) Greece ~3600 BP: 30 km³
- Mazama (Crater Lake) 6845 BP: 60 km³

Select Pleistocene Calderas
- Toba (Indonesia) 74,000 BP: 3500 km³
- Yellowstone Caldera 600,000 BP: 1000 km³
- Yellowstone Caldera 2.1 million years ago: 2500 km³
Volcanic Calderas

The Toba caldera, Sumatra, Indonesia, site of the second largest volcanic eruption ever discovered. The caldera is partly filled by Lake Toba. The flat area in the distance are pyroclastic deposits from the eruption.
Three major caldera systems are found in North America: Long Valley, California; Valles, New Mexico, and Yellowstone, Wyoming.

Long Valley caldera formed 700,000 years ago with the eruption of 600 km$^3$ of magma to produce the caldera and its deposit, the Bishop Tuff.

Eruptions have occurred as recently as 250 years ago at Mono Lake along a fissure extending through the western part of the caldera.

Harmonic tremors (earthquake swarms, up to a magnitude of 5-6) occurred in the early 1980’s, indicating magma movement is still occurring.
Volcanic Calderas

Shaded relief map of Long Valley Caldera
About 170 acres of trees have been killed on Mammoth Mountain since 1990 by high concentrations of carbon dioxide gas in the soil.

The gas may be coming directly from magma that intruded beneath Mammoth Mountain during an earthquake swarm in 1989 or may be exsolved from limestone-rich rocks beneath Mammoth Mountain that were heated (contact metamorphism) by the hot magma.
Three caldera-forming eruptions have occurred at Yellowstone in the last two million years. The oldest event produced the Huckleberry Ridge Tuff, approximately 2,100,000 years ago. The second event occurred 1,300,000 years ago resulting in the Mesa Falls Tuff. The most recent cataclysmic explosion occurred a mere 600,000 years ago, producing the Lava Creek Tuff. The Yellowstone system is still active. Old Faithful and other geysers and hot springs indicate magma is still present beneath the caldera floor.
Volcanic Calderas
Volcanic Hazards

• Lava Flows
• Pyroclastic flows
• Ash Fall
• Lahars
• Poisonous gases
• Climate Change
Lava flows: From the vent of a crater or along a line of fissure, often basaltic composition

Two types of basaltic lava flows:
- Pahoehoe: Less viscous, higher temp, with a smooth ropy surface texture
- Aa: More viscous, lower temp, with a blocky surface texture
Lava Flows

Pahoehoe lava flow from Kilauea destroying houses
Controlling a Lava Flow

Heimaey, Iceland, 1973

Lava flow threatened to close off harbor vital to town’s existence as Iceland’s most important fishing port.
Water was used to slow the advance of the lava.

Some homes were saved.

More importantly, the flow was slowed enough to keep it from closing off the harbor.
Pyroclastic Flows

- Mixtures of hot rock, ash, and gases that sweep down sides of a volcano at high speeds
- Move as fast as 100 km/hr with temperatures of several hundred degrees Celsius
- Produced by explosive eruptions or when a dome or thick lava flow collapses down a steep slope
- Most pyroclastic flows consist of two parts: a basal flow of coarse fragments that moves along the ground, and a turbulent cloud of ash that rises into the air
- Ash may fall from this cloud over a wide area downwind from the pyroclastic flow
Pyroclastic flows descend the south-eastern flank of Mayon Volcano, Philippines during its 1984 eruption. Photograph by C.G. Newhall
Effects of Pyroclastic Flows

Destroy structures by direct impact
El Chichon, Mexico, 1982

Bury sites under hot volcanic debris
Pinatubo, Philippines, 1991
Effects of Pyroclastic Flows

- Rapidly melt snow and ice to produce lahars
  Redoubt, Alaska, 1989

- Burn trees, crops, and buildings
  Soufriere, Montserrat, 1997
Effects of Pyroclastic Flows

Results are deadly if a pyroclastic flow sweeps through a populated area

Mt. Pelée, Martinique, Caribbean
May 8, 1092

Pyroclastic flow generated by collapse of lava dome destroyed town of St. Pierre

29,000 killed
2 survivors
Ash Fall

- Can cover thousands of square kilometers
- Destroy crops and vegetation
- Contaminate surface water with ash and volcanic acids
- Weight of ash can cause structural damage and roof collapse, especially when wet
- Health hazards, lung and eye irritation
- Damage to jet engines
Poisonous Gases

• Volcanoes emit various gases including $\text{H}_2\text{O}$, $\text{CO}_2$, $\text{CO}$, $\text{SO}_2$, $\text{H}_2\text{S}$, $\text{HF}$, $\text{HCl}$, $\text{HBr}$
• In high concentrations dangerous to people, plants, and animals
• Acids can produce acid rain or settle out with ash, poisoning soils and pasture
• 1783 eruption of Laki, Iceland killed 90% of livestock in Iceland by fluoride poisoning, causing famine
Poisonous Gases

• Very rarely, CO2/CO emitted from volcanoes in high enough concentrations to kill people by asphyxiation
• Sudden overturn of Lake Nyos, Cameroon, partially occupying a volcanic caldera, released dense cloud of gas that settled in nearby villages, killing 2000
Lahars

- Rapidly flowing mixture of rock debris and water that originates on the slopes of a volcano
- Also referred to as volcanic mudflows or debris flows
- Caused by rapid melting of snow and ice by pyroclastic flows, intense rainfall on loose volcanic rock deposits, breakout of a lake dammed by volcanic deposits, and as a consequence of debris avalanches
- Topographically channeled down river valleys at high speed and for long distances away from volcano
Lahars

Explosive eruption of Nevado del Ruiz, Columbia September 1985 produced pyroclastic flows that melted about 10% of volcano’s ice cover.

Resulting lahars gained volume as the swept down river channels, incorporating additional loose material.

Traveled more than 100 km from volcano, destroying low-lying towns and killing 23,000.
Lahars

Volcanoes of the PNW have generated large debris flows in past

5000 year old Osceola mudflow from Mt. Rainier traveled 85 km downslope and left deposits up to 150 m thick
Hundreds of thousands now live in path of future lahars

Hazard map generated from topographic data showing areas inundated by lahars of different volumes

Risk of lahars extends much farther from volcano than pyroclastic or lava flows
Mount St. Helens, 1980

Typifies many of the volcanic hazards just discussed

- Activity began in March 1980 with seismic activity and small explosions as groundwater contacted hot rock
- By May 1, a bulge on the north flank of the mountain could be clearly observed growing 1.5 per day
- Magnitude 5.0 earthquake on May 18 triggered flank failure involving the entire bulge area
- Slide displaced water in Spirit Lake and traveled 18 km down the Toutle River
Mount St. Helens, 1980

- Release of pressure triggered laterally directed blast
  blast flattened trees over 600 square kilometer area
- Mudflows caused by the debris avalanche and by
  rapid glacier and snow melt traveled 100 km down
  Toutle and Cowlitz  Rivers to the Columbia
- Vertical eruption column of juvenile material
  developed to height of 18 km
- As portions of column lost buoyancy and collapsed,
  pyroclastic flows generated
- Ash fall covered eastern Washington, northern Idaho,
  and central Montana
Mt. St. Helens Before 1980
Mt. St. Helens in 1982
Lateral Blasts

Laterally directed blasts like MSH 1980 are also called Bezymianny type eruptions after a Kamchatkan volcano whose 1956 eruption was triggered by flank failure.

Bezymianny in 1957

Bezymianny in late 1980s

Note growing lava dome has nearly filled the 1956 crater.
Deposits of the 1980 Eruption

(a)

- Debris-avalanche deposits
- Down-timber zone
- Scorch zone
- Pyroclastic flow deposit
- Mudflow deposits, scoured areas

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Ash Fall from 1980 Eruption

Approximate area covered by at least 5 mm of ash

Path of ash cloud — May 18, 19, 20, 1980

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Katmai, Alaska 1912
Katmai, Alaska 1912

Novarupta rhyolite lava dome

source vent of the 1912 eruption
Katmai, Alaska 1912

Novarupta with Trident in background
Katmai, Alaska 1912

Valley of Ten Thousand Smokes ignimbrite deposit
Katmai, Alaska 1912

Compensatory caldera collapse at Mt. Katmai

10 km away
Predicting Volcanic Activity

- Monitoring seismic activity: shallow earthquake swarms indicate movement of magma

- Geophysical monitoring: movement of hot material changes thermal, magnetic and hydrologic conditions

- Topographic monitoring: Tilting and bulging of ground surface

- Change in amount of volcanic gas emission

- Geologic history of a volcano: mapping and dating volcanic deposits
Uplift centered 3 km west of South Sister, Oregon, indicates accumulation of magma beneath the surface.
Volcanoes and Climate

Pinatubo
Philippines
June 12, 1991

(Aherns, 2001)
1991 Eruption of Pinatubo

• June 15–16, 1991
• Killed 350 people, mostly when roofs collapsed under weight of wet ash
• Nearly 1-ft depth of ash covered buildings over a 40-km radius
• Huge cloud of ash and gas 400 km wide extending to 40 km elevation
• Injected 15 megatons (15 x 10^12 g) of sulfur dioxide gas into the stratosphere where it was circulated globally and affected climate
Volcanoes and Climate

SO₂ plume from Pinatubo three months after the eruption

(Aherns, 2001)
Volcanoes and Climate

(Aherns, 2001)
Volcanoes and Climate

Mean Annual temperature at New Haven, CT 1790-1983

From Stommel and Stommel, 1979, Scientific American 240, 176-186.
Volcanoes and Climate

Tambora, Indonesia
1816: The Year Without a Summer
Volcanoes and Climate

From Self et al., 1981, J. Volcanology and Geothermal Res. 11, 41-60
Volcanoes and Climate

<table>
<thead>
<tr>
<th>Eruption</th>
<th>Year</th>
<th>Magma Erupted (km³)</th>
<th>Stratospheric Aerosol (Mt)</th>
<th>Petrologic Estimate (Mt) H₂SO₄</th>
<th>HCl</th>
<th>N.H. ΔT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tambora (8°S)</td>
<td>1815</td>
<td>50</td>
<td>150</td>
<td>52</td>
<td>220</td>
<td>-0.4 to -0.7</td>
</tr>
<tr>
<td>Krakatau (6°S)</td>
<td>1883</td>
<td>10</td>
<td>30-38</td>
<td>55</td>
<td>2.9</td>
<td>3.8</td>
</tr>
<tr>
<td>Santa Maria (15°N)</td>
<td>1902</td>
<td>9</td>
<td>22</td>
<td>&lt;20</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Katmai (58°N)</td>
<td>1912</td>
<td>15</td>
<td>0</td>
<td>&lt;30</td>
<td>12.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Agung (8°S)</td>
<td>1963</td>
<td>0.6</td>
<td>30</td>
<td>20</td>
<td>2.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Mount St. Helens (46°N)</td>
<td>1980</td>
<td>0.35</td>
<td>0</td>
<td>--</td>
<td>0.08</td>
<td>0.04</td>
</tr>
<tr>
<td>El Chichón (17°N)</td>
<td>1982</td>
<td>0.3-0.35</td>
<td>&lt;8</td>
<td>12</td>
<td>0.07*</td>
<td>--</td>
</tr>
<tr>
<td>Pinatubo (15°N)</td>
<td>1991</td>
<td>5(±1)</td>
<td>20-30</td>
<td>~0.3*</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Table 1. A comparison of some notable modern volcanic eruptions illustrates the pitfalls of trying to extrapolate from relatively small modern eruptions to super-eruptions of the past. Tambora, for example, expelled over 150 times as much magma as El Chichón, yet the amount of stratospheric aerosols they produced differs only by a factor of ten and surface temperature
Volcanoes and Climate

Figure 2. Physical and chemical processes of volcanic interactions with the atmosphere. The eruption injects water vapor (H$_2$O), sulfur dioxide (SO$_2$), hydrochloric acid (HCl), and mineral ash into the stratosphere. HCl can dissolve in water and rain out of the atmosphere. SO$_2$ remains gaseous and is eventually converted to sulfuric acid (H$_2$SO$_4$), which condenses in a mist of fine particles. These sulfate aerosols reflect the Sun’s radiation, cooling the troposphere; they also absorb the Earth’s heat, warming the stratosphere. The aerosols also hasten ozone destruction by altering chlorine and nitrogen chemical species in the stratosphere. As the aerosols settle down into the upper troposphere, they may serve as nuclei for cirrus clouds, further affecting the Earth’s radiation balance. (Courtesy Richard Turco, University of California at Los Angeles)
Volcanoes and Climate

For an excellent summary of climatic effect of volcanic eruptions, see Robock, Reviews of Geophysics

Volcanoes affect climate by

• Direct blocking of solar radiation by volcanic ash

• Reflection of solar radiation by sulfate aerosols produced by oxidation of SO2 gas

• Volcanic ash settles out of the atmosphere fairly quickly, limiting its effects

• Can produce daytime cooling while ash is overhead
Volcanoes and Climate

Surface temperature changes following the Mount St. Helens eruption

Arrow marks time of plume arrival
Volcanoes and Climate

Sulfate aerosols also washed out of the troposphere relatively quickly (few weeks)

Sulfate aerosols in stratosphere can remain aloft for several years after an eruption

Stratospheric circulation spreads volcanic aerosols globally in the case of tropical eruptions and throughout hemisphere of origin in the case of mid to high latitude eruptions
Volcanoes and Climate

Change in atmospheric transmission following the El Chichon (1982) and Pinatubo (1991) eruptions
Volcanoes and Climate

Ice cores provide records of volcanic aerosol loading prior to direct instrumental measurement.
Volcanic eruptions result in tropospheric cooling but stratospheric warming by increasing stratospheric absorption of infrared radiation.
Volcanoes and Climate

Stratospheric warming forces a change in tropospheric circulation, producing a characteristic pattern of winter warming following a major volcanic eruption.
Volcanoes and Climate

Stratospheric aerosol heating increases equator-pole temperature gradient

Strengthens polar vortex, resulting in larger amplitude jet stream pattern

This allows warmer air to move northward in the troposphere beneath ridges
Volcanoes and Climate

Because polar vortex is much stronger in winter, meridional amplification is a winter-time phenomenon.

Direct radiative forcing dominates in summer and throughout the year at tropical latitudes.

Net result is summer cooling but winter warming in certain regions.
Volcanoes and Climate

Stratospheric aerosols (lifetime ≈ 1-3 years)

H₂S → H₂SO₄
SO₂ → H₂SO₄
CO₂, N₂, H₂O

Absorption (near IR)

Heterogeneous → Less O₃ depletion
Solar Heating

NET HEATING

Backscatter

More Reflected Solar Flux

IR Heating absorption (IR)

Less Upward IR Flux

Emission

Emission

Less Total Solar Flux

NET COOLING

Reduced Direct Flux

Enhanced Diffuse Flux

XR Effects on citrus clouds

More Downward IR Flux

Explosive

Quiescent

Net Cooling
Climatic impact of individual eruption depends on:

- Size of eruption
- Height of eruption column
- Sulfur content of magma
- Latitude of eruption
- Season
- Circulation patterns at time of eruption
- General state of climate system