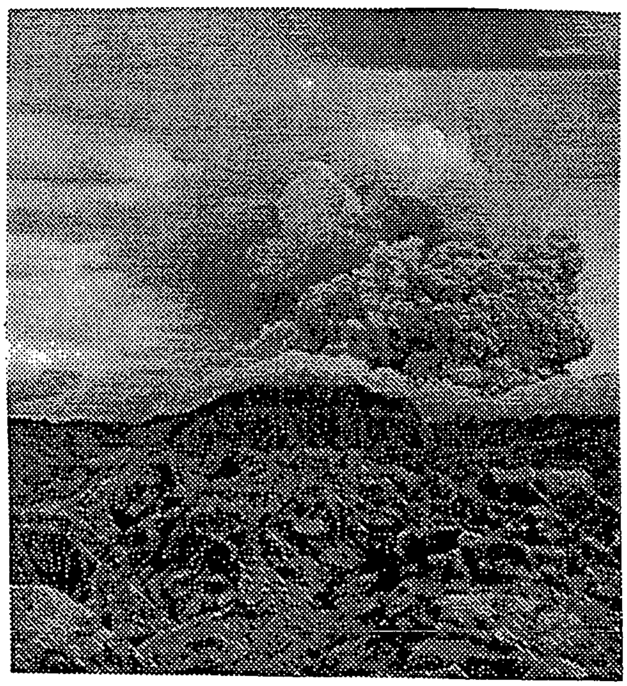
Teaching Activity: Volcanoes and Climate Change

Introduction: Visitors to certain regions in North America and Europe in the summer of 1783 would have noticed an unusual "dry fog" or haze" in the air. They would have also noticed that the next winter (1783-84) was unusually cold. Suggestions were made by scientists that these unusual weather conditions were the result of volcanic activity. In later years, as investigations into volcanic activity became more comprehensive, it was discovered that Laki volcano in Iceland had erupted in early 1783.

Scientists studying volcanic eruptions and their relationship to climate, have noticed many short-term climate changes associated with volcanic activity:

- **1816** - Europe and many other parts of the Northern Hemisphere experienced what was called the "Year Without a Summer" as the result of an unusually cool summer and exceptionally cold winter. One year before, a very powerful eruption had occurred on Mt. Tambora in Indonesia.
- **1883**- following the eruption of Krakatau in Indonesia, strange colors and halos around the sun and moon were observed along with vivid sunrises and sunsets. Krakatau was considered one of the most explosive eruptions in history at that time, and had serious global consequences: a loss of between 20-30 % of the direct solar radiation normally reaching the Earth for three years following this event.
- **1982** - the eruption of El Chichon in Mexico;
- **1991**- Mt. Pinatubo in the Phillipines in 1991, gave climatologists strong evidence of the impact that volcanic activity has on global climate. Both these eruptions ejected huge amounts of dust, ash, carbon dioxide and sulfur dioxide high into the atmosphere.



Volcanic eruptions, of the types shown here, can cause short term cooling of the climate. If the climate were in a warming trend at the time of the eruption, the effects of the eruption could be a slowing of the process, with no cooling effect detectable. Once the ejected ash and volcanic dusts are thrown out into the atmosphere, upper level winds and global pressure systems circulate the material around the globe. Volcanic aerosols, particularly sulfuric acid, block incoming solar radiation and can reduce global surface temperatures for 2-4 years following the eruption.

Volcanic eruptions of the types mentioned above, can cause short term cooling of the climate. If the climate were in a warming trend at the time of the eruption, the effects of the eruption could be a slowing of the process, with no cooling effect detectable. Once the ejected volcanic dusts and ash are thrown out into the atmosphere, upper level winds and global pressure systems circulate the material around the globe. Volcanic aerosols, particularly sulfur dioxide, block incoming solar radiation and can reduce global surface temperatures for between 2-4 years following the event.

Objectives:

- Students will locate major volcanoes around the world using latitude and longitude (Activity A);
- Students will explain how the latitudinal location of volcanic activity may affect global climate conditions (Activity A);
- Students will use the **Volcanic Explosivity Index (V.E.I.)** to predict the potential of a volcanic eruption to affect global climate (Activity A);
- Students will examine the dispersal of aerosols throughout the atmosphere after a volcanic eruption (Activity B)

Important Terms: Aerosols, wind currents, latitude, longitude, sulfur dioxide, stratosphere, troposphere, climatologist, carbon dioxide, lava;

Activity A: Where and when have recent volcanic eruptions occurred?

Background: Volcanic eruptions are not all the same. They differ in the quantities of dust and ash they produce; some just produce lava. As a result, not every volcanic eruption produces significant global climate changes. Some of the significant characteristics needed for an eruption to affect global climate include the latitude of the volcano, the season of the year of the eruption, the height of the eruptions and the type and quantity of gases produced.

Materials: A large wall map of the world, a blank 8.5 x11" map of the world with latitude and longitude lines , library resources of computer data base for information on volcanic eruptions, or the data list at the end of this activity.

Procedure:

1) Using Table 1 and the blank 8.5 x 11" map of the world, have students locate each volcano by its latitude and longitude as listed in the table.

Location	Elev. (m)	Lat.	Long.	Date	V.E.I.
Krakatau, Indonesia	0813	6.1S	105.42E	08 1883	6
Pelee,West Indies	1397	14.8 N	61.17 W	05 1902	4
Santa Maria,Guatemala	3772	14.8 N	91.55W	10 1902	6
Ksudach, Kamchatka	1079	51.8 N	157.52 E	03 1907	5
Katmai, Alaska	0841	58.3 N	155.16 W	06 1912	6
Katla, Iceland	1363	63.6 N	19.03 W	10 1918	4
Komaga-take, Japan	1140	42.7 N	140.68 E	06 1929	4
Agung, Indonesia	3142	8.3 S	115.51 E	03 1963	4
Taal, Philippines	0400	14.0 N	121.00 E	09 1965	5
Mt. St. Helens, U. S. A.	2549	46.2 N	122.18 W	05 1980	5
El Chichon, Mexico	1060	17.3 N	93.2 W	03 1982	5

Table 1. - Data from eleven major explosive volcanic eruptions.

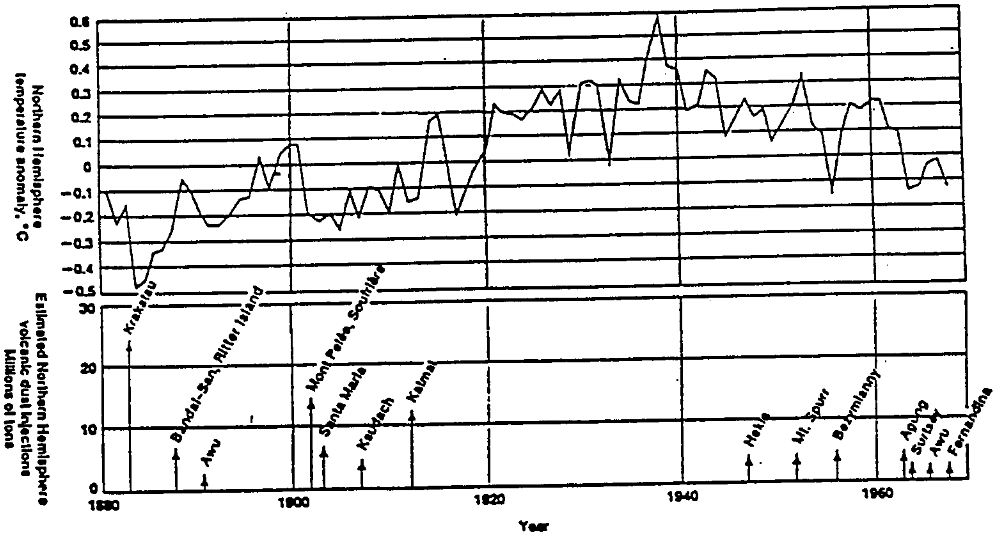
(NOTE: **The volcanoes listed in Table 1 were selected at random. The intent is to give an even distribution of V.E.I. between the values of 4 and 6)**

2) Have students label each volcano with its name, elevation above sea, and the date of the eruption.

3) Direct students to the world map.
   - Ask if they notice any difference in the amount of volcanic activity recorded in the Northern Hemisphere as opposed to that in the Southern Hemisphere.
   - What possible explanations do they have for this observation?

4) Climatologists have theorized that only low latitudinal volcanic eruptions between 20 * N and 20 * S, can significantly affect global climate conditions.
   - Ask students to hypothesize a possible basis for this theory.

Another significant variable affecting the impact of an eruption on climate change is the power of the volcanic eruption and the direction of the blast. Some eruptions are extremely explosive and can inject material high into the stratosphere. Volcanologists have developed a **Volcanic Explosivity Index (V.E.I.)** to compare eruptions. Volcanoes are rated from 0 to 8, where 0 is the least explosive and 8 the most explosive.



Graph of average temperature variations after major volcanic eruptions. (Source: Oliver, *Journal of Applied Meteorology,* 1976.)

5) Have students arrange the data provided in Table 1 in a different way.
   - Sort the volcanoes by their V.E.I.;
   - Arrange them by latitude and determine if a correlation exists;
   - Sort the volcanoes by their V.E.I.;
   - Arrange by longitude and investigate for any correlation
   - Sort the volcanoes by the V.E.I.;
   - Arrange by data and examine any correlation;

6) Continue this process until all of the variables have been examined in relation to each other.

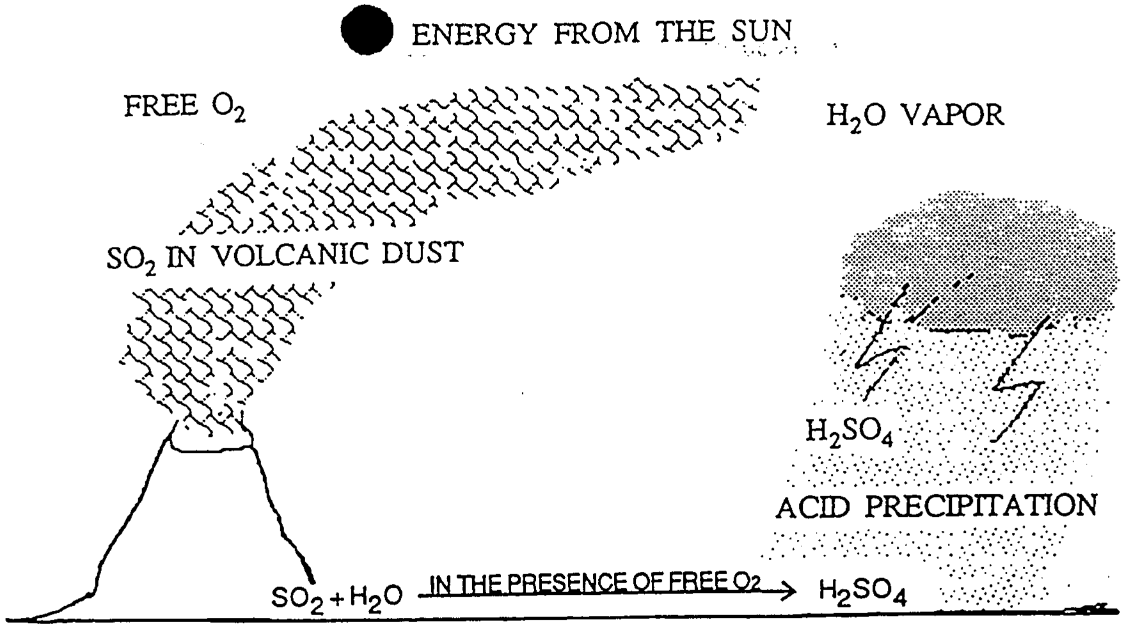
7) Using the information compiled from Table 1, students should determine which volcanoes have the greatest effect on global surface temperatures.
8) Many climatologists have criticized the V.E.I. because it does not accurately assess some of the important aspects of a volcanic eruption. Have students determine (considering global change) what characteristics of an eruption the V.E..I. does not take into account.

Activity B: How are aerosols dispersed through the atmosphere after a volcanic eruption?

Background: When Mt. Pinatubo erupted in the early summer of 1991, it sent clouds of smoke, ash, sulfur dioxide, and water into the atmosphere. Most of the heavier ash settled to Earth within the first several weeks. BY mid-August, however, satellite measurements showed that a band of sulfuric acid droplets in the stratosphere had spread around the Earth on both sides of the equator. Sulfuric acid is formed when sulfur dioxide, a gas, combines with water. IN this case, the tiny sulfuric acid droplets are called *aerosols*. Aerosol particles that travel around the Earth in the stratosphere are less likely to fall to Earth and therefore, remain aloft for a longer period of time than particles in the troposphere.

The larger aerosol particles will settle out of the atmosphere within about three years. The smaller particles can remain suspended for decades. Some computer models of atmospheric chemistry suggest that a huge increase in sulfuric acid aerosols could contribute to the thinning of the ozone layer, as well as affecting the Earth's temperature. Since more light from the Sun is reflected back into space by the increased amount of aerosol particles ion the stratosphere, the Earth's lower atmosphere is likely to cool. This cooling effect will complicate efforts to determine whether or not there is a net global warming due to the enhanced greenhouse effect.

Atmospheric scientists at the National Oceanic and Atmospheric Administration (NOAA) are studying the effects of Mt. Pinatubo's eruption using *lidar,* a type of radar that uses pulses of laser light instead of pulses of radio waves. The short pulse of light bounces off particles, molecules, and even insects in the atmosphere. Some of the scattered light returns to its source. Measuring the amount of time it takes for the scattered laser light to return allows us to calculate the distance to the object (in this case, aerosols). The light that returns to the source is called "***backscatter***". The amount of backscatter indicates the amount of sulfuric acid aerosols in the atmosphere.



A diagrammatic representation of the chemical process that occurs when SO_2 is oxidized (in the presence of free O_2) and combines with H_2O vapor to produce H_2SO_4. Energy for this chemical process comes from the sun.

Materials: Activity Sheet, ruler, pencil, and colored pencils;

Procedure: Instruct students to complete the following:

1) Number the horizontal axis of the graph from zero to 3600, by 100s.
2) Number the vertical axis, from zero to 30, by ones.
3) Using the data provided, plot the data points corresponding to the units of backscatter for each time period.
   - Connect the points with a smooth line.
   - Use a different colored pencil for each time period.
4) Draw a horizontal dashed line across the graph at 10 km.
   - Label the area beneath the line "Troposphere".
5) Draw a horizontal dashed line across the graph at 11 km.
   - Label the area beneath the line "Tropopause".
   - Label the upper part of the graph "Stratosphere".
6) Print a title at the top of the graph.
7) Place a color coded legend on your graph in the space provided.
8) Complete the questions in the ***Analysis*** and the activity in the ***Conclusions*** section.

Student Activity Sheet: Volcanoes and Climate Change

Background: Volcanic eruptions are not all the same. They differ in the quantities of dust and ash they produce; some just produce lava. As a result, not every volcanic eruption produces significant global climate changes. Some of the significant characteristics needed for an eruption to affect global climate include the latitude of the volcano, the season of the year of the eruption, the height of the eruptions and the type and quantity of gases produced.

When major volcanic eruptions occur, large clouds of smoke, ash, sulfur dioxide and water into the atmosphere. While most of the heavier materials settle to the Earth within the first several weeks; the lighter droplets of sulfuric acid remain in the atmosphere and spread around the globe on both sides of the equator. The tiny droplets are called ***aerosols***. They create problems for the stratospheric ozone layer, as well as affecting the Earth's average temperature.

Atmospheric scientists study the effects of volcanic eruptions using a type of radar called ***lidar***. Lidar uses pulses of laser light rather than radio waves. The laser light bounces off particles and molecules in the atmosphere and eventually returns to its source. The light that returns to the source is called ***backscatter*** and indicates the amount of sulfuric acid aerosols in the atmosphere.

Important Terms: Aerosols, wind currents, latitude, longitude, sulfur dioxide, stratosphere, troposphere, climatologist, carbon dioxide, lava, backscatter, lidar;

Materials: Student Activity Sheets, paper/pencil, colored pencils, ruler;

Procedure:

Activity A:

1. Using Table 1 and the blank world map, locate each volcano listed by its latitude and longitude as listed on the table.

Location	Elev. (m)	Lat.	Long.	Date	V.E.I.
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Table 1. - Data from eleven major explosive volcanic eruptions.

2. Label each volcano with its name, elevation above sea level and the date of the eruption.
3. Look carefully at the world map. Discuss the following questions with the class.
    - Do you see any difference in the amount of volcanic activity in the Northern Hemisphere as opposed to the Southern Hemisphere?
    - What possible explanation can you arrive at for this observation.

4. Climatologists have a theory that only volcanoes in the low latitudes of the globe (between 20 degrees north or south of the equator) can affect climate conditions significantly.
    - Develop a hypothesis of your own in support of this theory.

5. Using the information in Table 1, arrange the data in the following way:
    - Sort the volcanoes by their V.E.I.
    - Arrange them by latitude and determine if a correlation exists.
    - Sort the volcanoes by their V.E.I.
    - Arrange them by longitude and determine if a correlation exists.
    - Sort the volcanoes by their V.E.I.
    - Arrange by date and examine any correlation.

6. Continue this process until you have examined all of the variables in relation to each other.

7. Using the information from Table 1, determine which volcanoes have then greatest effect on global surface temperatures.

8. Many climatologists do not think that the V.E.I. assesses the important aspects of a volcanic eruption.
    - Determine (considering global change) from the data provided, what characteristics of an eruption the V.E.I. does not take into account.

Activity B: How are aerosols dispersed through the atmosphere after a volcanic eruption?

Procedure:

1. Number the horizontal axis of the graph from zero to 3600, by 100s.
2. Number the vertical axis, from zero to 30, by ones.
3. Using the data provided, plot the data points corresponding to the units of backscatter for each time period.
    - Connect the dots with a smooth line.

- Use a different colored pencil for each time period.

4. Draw a horizontal dashed line across the graph at 10 km.
    - Label the area beneath the line "Troposphere".
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    - Label the upper part of the graph "Stratosphere".
6. Print a title at the top of the graph.
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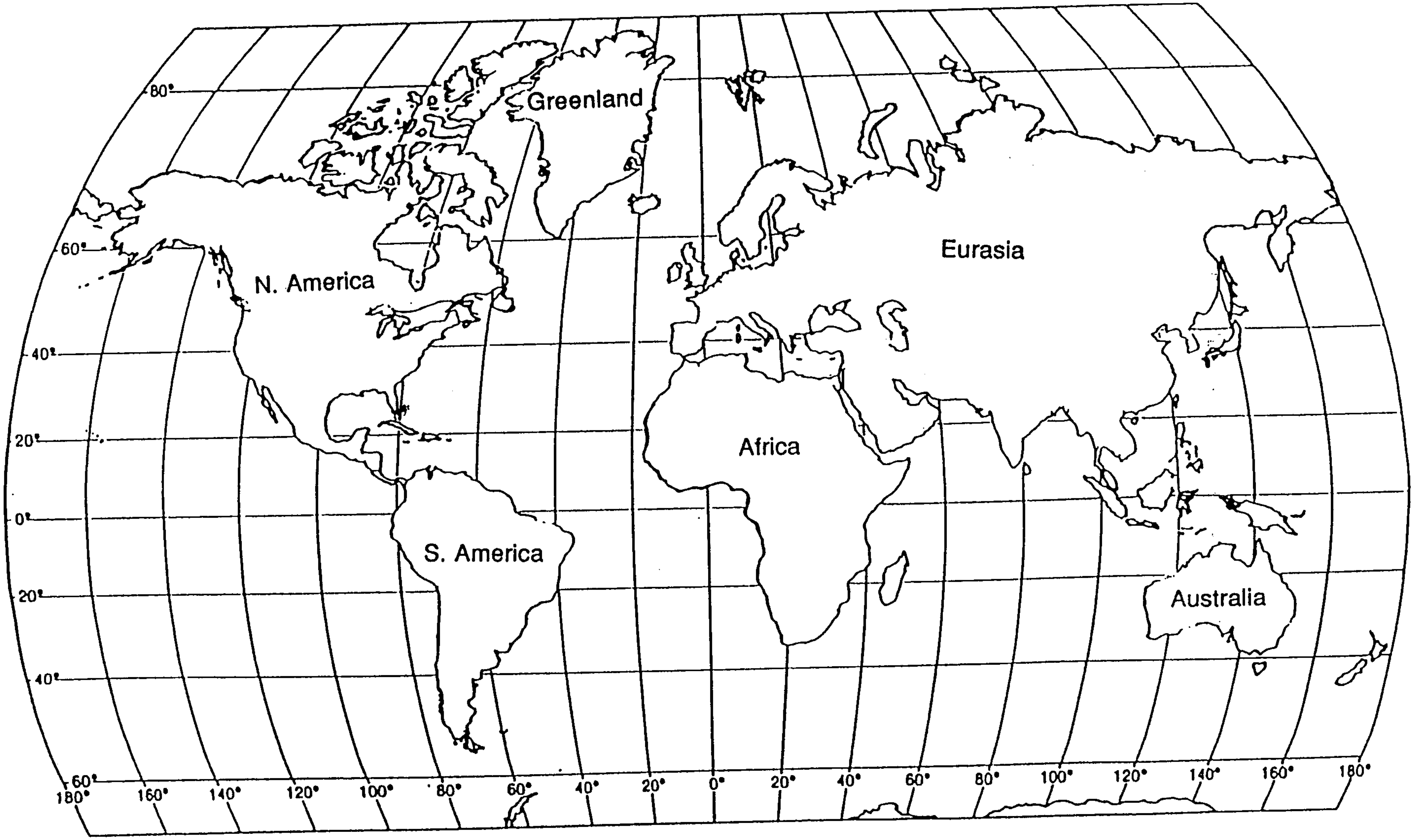
8. Complete the questions in the ***Analysis*** section and the activity in the ***Conclusions*** section.



Greenland
N. America
Eurasia
Africa
S. America
Australia
80°
60°
40°
20°
0°
20°
40°
60°
180°
160°
140°
120°
100°
80°
60°
40°
20°
0°
20°
40°
60°
80°
100°
120°
140°
160°
180°

Data:

These data tables are a shortened version of the data collected at the National Oceanic and Atmospheric Administration (NOAA), Wave Propagation Laboratory, Boulder, Colorado.

January - June 1991

Altitude (km)	Backscatter
4.0	2970
5.5	893
7.0	170
8.5	95
10.0	225
11.5	119
13.0 and above	*

*For this period, since the amount of backscatter at 13 km and above is too small to measure, it can be plotted as zero.

August 1991

Altitude (km)	Backscatter
4.0	18900
5.5	3100
7.0	333
8.5	130
10.0	97
11.5	101
13.0	272
14.5	636
16.0	971
17.5	482
19.0	217
20.5	340
22.0	116
23.5	38

October 1991

Altitude (km)	Backscatter
4.0	10900
5.5	505
7.0	129
8.5	120
10.0	176
11.5	339
13.0	506
14.5	864
16.0	1020
17.5	975
19.0	901
20.5	830
22.0	416
23.5	150

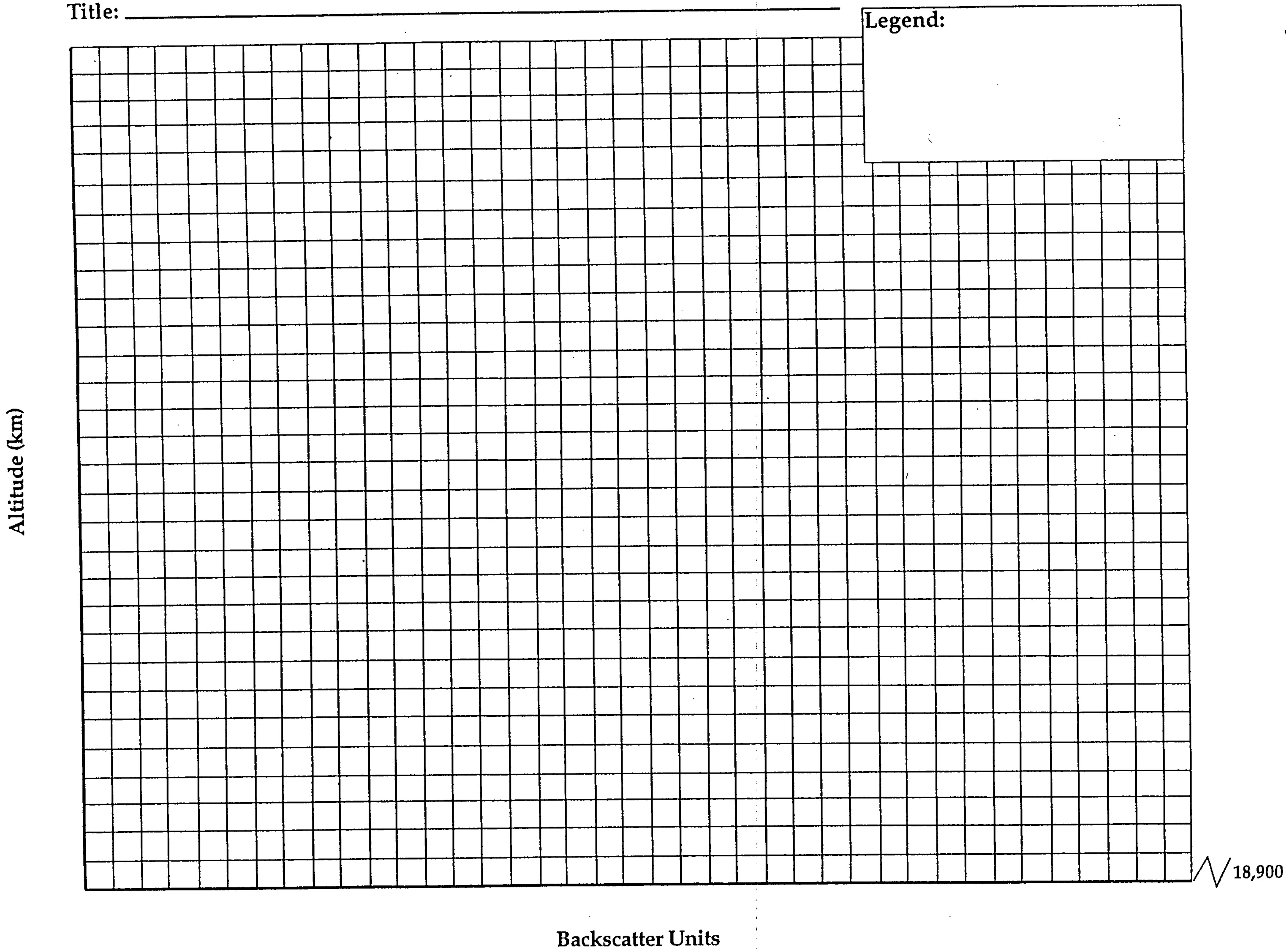
January 1992

Altitude (km)	Backscatter
4.0	201
5.5	44
7.0	34
8.5	42
10.0	63
11.5	250
13.0	425
14.5	485
16.0	682
17.5	1140
19.0	1790
20.5	1340
22.0	215
23.5	151
25.0	88
26.5	57
28.0	43

March 1992

Altitude (km)	Backscatter
4.0	9650
5.5	3580
7.0	1100
8.5	426
10.0	412
11.5	845
13.0	972
14.5	999
16.0	1180
17.5	1420
19.0	1660
20.5	1230
22.0	395
23.5	136
25.0	35
26.5	16
28.0	11

Title: ____________________



Analysis:

1) What gas combines with water from a volcanic eruption to form sulfuric acid?

   ____

2) At what altitude above the troposphere, is the most backscatter from aerosols located? ______________________

3) What layer of the Earth's atmosphere above 10 km has the most aerosol backscatter? ______________________

4) From January to August 1991 what happened to the amount of backscatter above an altitude of 10 km? Why?

   ____

5) What is the maximum (highest) amount of backscatter in the stratosphere for August 1991? For January 1992? ______________________

6) In what layer of the Earth's atmosphere, above the troposphere, is the largest amount of backscatter located for January 1992 and March 1992?

   ____

7) Between August 1991 and January 1992, what change in altitude, above the troposphere occurred for the maximum amount of backscatter?

   ____

8) Why is the change in altitude significant for the maximum amount of backscatter between August 1991 and January 1992?

   ____

9) Why does the maximum amount of backscatter occur in January 1992, when the eruption of Mt. Pinatubo occurred in June 1991, <u>six months earlier</u>? (Hint: Think about our location on the globe compared to Mt. Pinatubo.)

8) What is the change in altitude significant for the maximum amount of backscatter between August 1991 and January 1992?

Conclusion:

- Review the problem stated for **Part B** and write your conclusions here.