Vog plume rising from Kīlauea Volcano.
Photograph by M. Poland, November 13, 2008, USGS HVO.

Pohina I Ka Uahi:
Atmospheric Pollution and Global Warming

Steven Businger & Sara daSilva
businger@hawaii.edu, scouto@hawaii.edu
Kapōmaikaʻi Stone & Iasona Ellinwood
pomaistone@gmail.com, jasonke@hawaii.edu
Pauline W. U. Chinn, chinn@hawaii.edu
University of Hawaiʻi at Mānoa

Title: Atmospheric Pollution and Global Warming, *Pohina I Ka Uahi* (Hazy with Smoke)
Grades: 6-8, modifiable for 3-5, 9-12
Time: 2 - 10 hours

STANDARDS: EARTH AND SPACE SCIENCE (ESS)

ESS2D: Weather and Climate
Weather varies day to day and seasonally; it is the condition of the atmosphere at a given place and time. The ocean absorbs and stores large amounts of energy from the sun and releases it slowly, moderating and stabilizing global climates. Sunlight heats the land more rapidly. Heat energy is redistributed through ocean currents and atmospheric circulation, winds. Greenhouse gases absorb and retain the energy radiated from land and ocean surfaces, regulating temperatures and keep Earth habitable.

ESS3C: Human Impacts On Earth Systems
Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of many other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. Typically, as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise (A Framework for K-12 Science Education, NRC, 2012).

ESS3D: Global Climate Change
Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise in Earth's mean surface temperature (global warming). Reducing human vulnerability to whatever climate changes do occur depend on the understanding of

climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior and on applying that knowledge wisely in decisions and activities (*ibid*).

Hawai'i Content & Performance Standards III, Grade 7, 8
(http://165.248.30.40/hcpsv3/pdf/ScienceEarthSpaceScience6335.pdf)

Strand	**The Scientific Process**
Standard 1: The Scientific Process: SCIENTIFIC INVESTIGATION: Discover, invent, and investigate using the skills necessary to engage in the scientific process	
Topic: Scientific Inquiry	**Benchmark SC.8.1.1** Determine the link(s) between evidence and the conclusion(s) of an investigation **Benchmark SC.8.1.2** Communicate the significant components of the experimental design and results of a scientific investigation
Standard 2: The Scientific Process: NATURE OF SCIENCE: Understand that science, technology, and society are interrelated	
Topic: Science, Technology, and Society	**Benchmark SC.8.2.1** Describe significant relationships among society, science, and technology and how one impacts the other
Strand	**Physical, Earth, and Space Sciences**
Standard 8: Physical, Earth, and Space Sciences: EARTH AND SPACE SCIENCE: Understand the Earth and its processes, the solar system, and the universe and its contents	
Topic: Forces that Shape the Earth	**Benchmark SC.8.8.4** Explain how the sun is the major source of energy influencing climate and weather on Earth.
Strand	**Life and Environmental Sciences**
Standard 3: Life and Environmental Sciences: ORGANISMS AND THE ENVIRONMENT: Understand the unity, diversity, and interrelationships of organisms, including their relationship to cycles of matter and energy in the environment	

Topic: Interdependence	**Benchmark SC.7.3.3** Explain how biotic and abiotic factors affect the carrying capacity and sustainability of an ecosystem

To the Teacher: Connections to Place & Culture(s)

How do Earth's surface processes and human activities affect each other? Humans depend on all of the planet's systems for a variety of resources, some of which are renewable or replaceable and some of which are not. Humans have become one of the most significant agents of change in Earth's surface systems. In particular, it has been shown that climate change—which could have large consequences for all of Earth's surface systems, including the biosphere—is driven not only by natural effects but also by human activities. Sustaining the biosphere will require detailed knowledge and modeling of the factors that affect climate, coupled with the responsible management of natural resources (excerpted from A Framework for K-12 Science Education, NRC, 2012).

An example of humanity's effect on the environment can be found in an article printed in *Ka Lahui Hawaii* on March 1, 1877, simply entitled "Ka Ua" ["The Rain"].
No ke aha keia nele i ka ua? Ua olelo ka poe naauao, o na ululaau nui oia ka mea nana e ume mai i na ao ua maluna o ka aina. Ua ike ia no hoi ma na aina kahiko e like me Aigaputa a me kekahi mau wahi e ae, i ka wa i neoneo ai ka aina i na ululaau o ka uuku ihola no ia o ka ua, a maloo iho la na kahawai. Aka ma na wahi i hooulu hou ia i na ululaau ua hoi hou mai ka ua ma ia mau wahi. Ua maa no hoi ka poe kamaaina o Maui i ka ike ana aku i na kuaua o Koolau e nihi hele mai ana maluna o na ululaau o Haleakala a mawaho mai o Makawao o ka nalowale ae la no ia o ka ua, aohe hele loa aku i na aina panoa o kula. Me he mea la, e hooiaio mai ana keia, o na ululaau nui kekahi mea e kokua ana i ka aina ma ka ume ana mai i na ao ua.

[Why has there been a lack of water? The wise ones have said, it is the great forests that attract the rain clouds upon the land. It has been seen in the ancient lands, like Egypt, and several other places, when the land was barren with no forests, the rain decreases and the rivers dry up. However, in the places where they reforested, the rain returns to those places. The natives of Maui are accustomed to the Koʻolau showers creeping atop the forests of Haleakalā and outside of Makawao, and then the rain disappears, it does not reach the barren plains. It is as if this is proving that large forests aid the land by attracting rain clouds.]

This writer uses observation and the principle of the rain following the forest to examine the causes of drought, pointing to the negative impact of deforestation and the positive solution of reforestation, and thus illustrating the ways in which humanity can effect the environment.

Atmospheric Pollution

Air pollution is elevated levels of harmful gases and/or aerosols that threaten the health of the Earth's flora and fauna (plants, animals, and people). The source of air pollution can be natural (forest fires, volcanic emissions like those from Kīlauea, wind born dust, etc.) or through human activities (burning of fossil fuels, industrial emissions, etc.). By far the majority of air pollution is released into the atmosphere at the Earth's surface. In the absence of winds and upward mixing, pollution can rapidly accumulate, especially in urban areas, leading to pollution episodes. The term "smog," a combination of the words smoke and fog, was coined to describe such events. Cold, stable air drains into basins and valleys from adjacent higher terrain,

especially during the longer nights of winter, reducing air circulation in these regions. In December 1952, a particularly bad smog episode in London claimed the lives of over 4000 people. Since that time legislation, such as the Clean Air Act in the U.S., has reduced air pollution.

A major pollutant of city air is carbon monoxide (CO), a colorless, odorless gas emitted by incomplete combustion of fuels to carbon dioxide (CO_2) by internal combustion engines (primarily cars and trucks). Carbon monoxide is a toxic gas that is actively taken up by oxygen carrying molecules leading to poisoning, even death at high concentrations. There has been about a 40% decrease in carbon monoxide in the U.S. since 1970, due to stricter air quality standards and use of emission-control equipment (http://en.wikipedia.org/wiki/Carbon_monoxide_poisoning).

Rain and cloud water has become more acidic as a result of the burning of fossil fuels that contain sulfur dioxide (SO_2) and nitrous oxides (NO_X). These pollutants recombine with oxygen molecules in cloud droplets to form sulfuric and nitric acids. These newly formed acids are flushed from the atmosphere through precipitation in the form of rain, snow, sleet, or fog. The highest concentration of acid is found in cloud water that has not yet been diluted. In mountainous regions, such as the Appalachian Mountains, acid fogs have weakened many trees, making them susceptible to drought, disease, and insect infestation. In Hawai‘i, the largest source of sulfuric acid is from SO_2 emissions from Kīlauea Volcano (Fig. 1). The distribution of acid rain in Hawai‘i is related to the dispersion of pollution by the winds. On days with prevailing trade winds the pollution is greatest across the southern end of the Island on Hawai‘i and along the Kona Coast, where the daily sea breeze brings vog onshore along with afternoon clouds and showers. On days with southerly (Kona) or southeasterly winds, other areas of the Island of Hawai‘i and the outer islands are subject to elevated levels of sulfuric acid from vog. On Maui the upland area along the western slope of Haleakalā is subject to elevated concentrations of vog with the flow of Kona or southeasterly winds.

The effects and range of Kīlauea's vog can be seen in several reports that appeared in the Hawaiian language newspapers. This article that appeared in *Ka Nupepa Kuokoa* on February 5, 1881, reports on the appearance of vog in Hilo:

Ua uu ia ae ke kulanakauhale o Hilo a pouli i ka uahi o ka luapele, a ke hao la hoi ka makani i ke kuehu i ka lepo, pela mai nei ka leka a J M Pea.

[The city of Hilo was soaked, and darkened by the smoke of the volcano, and the wind is stirring up dust clouds, according to the recent letter from J M Pea.]

From Hilo we turn to Maui, where vog was reported in the *Kuokoa* on October 24, 1868:

POHINA I KA UAHI—Ina la hope o ka pule i hala, ua lohe pono mai makou mai a Asa Hopu Esq., mai o Hana, ua uhi paapuia kela wahi e ka uahi o ka wahine o ka lua. Haalele aku nei no ia, ke poluluhi no na huna uahi ma ka lewa lani. He hana nui hoi kau e ka wahine o ka lua.

[HAZY WITH SMOKE—In the final days of the past week, we heard from Asa Hopu Esq., from Hāna, that place was completely covered by the smoke of the woman of the pit. Then it left, but bits of smoke make the sky overcast. You are working hard, o woman of the pit.]

And onwards from Maui, we find vog covering O‘ahu, in an article that was printed in *Ke Au Okoa* on August 29, 1872:

Ma na la hope o kela pule iho nei, ua uhi'a o Oahu nei e ka pohina uahi a Pele, he hoailona e hoike mai ana ua ho-a hou ke ahi a ka wahine o ka lua. Ma na hoike ana a kekahi mau moku i ku mai nei, ua ike ia ka pohina uahi ma ka moana no kekahi mau haneri mile elua a keu ka mamao mai Hawaii aku.

[In the final days of last week, O‘ahu was covered by the hazy smoke of Pele, a sign showing that the fire of the woman of the pit has again ignited. In the reports of several ships that arrived, the hazy smoke was seen over the ocean over two hundred miles away from Hawai‘i.]

Not only had the vog spread across the Hawaiian Islands, but it was also observed over the ocean over two hundred miles away! And while these reports are from the 19th century, this is still happening today.

A primary constituent of contemporary urban smog episodes is ozone (O_3), a poisonous substance that irritates the eyes and respiratory system, and retards plant growth. In the lower atmosphere ozone forms in a chemical reaction that involves nitrogen dioxide (NO_2) and molecular oxygen (O_2) in the presence of ultraviolet light from the sun (thus the term photochemical smog). Ozone concentrations in the lower atmosphere tend to display a daily afternoon maximum and early morning minimum.

Ironically, ozone that occurs naturally in the stratosphere absorbs high-energy ultraviolet light in the upper atmosphere, thus blocking these harmful rays from reaching the Earth’s surface. A decrease in the concentrations of stratospheric ozone globally (Fig. 2) due to a complex chemical interaction involving chlorofluorocarbons (CFC) that depletes stratospheric ozone has raised concerns of increased incidence of skin cancer and crop damage.

Atmospheric pollution in the form of greenhouse gasses (e.g., CO_2) is one of the results of reliance upon burning of non-renewable fossil fuels--coal, oil. Observations show that global warming is occurring as a result of the release of greenhouse gases when burning fossil fuels. In time global average temperature will continue to increase, while droughts, heat waves, wildfires, and flood events will become more frequent. Air pollution affects not only the atmosphere and the weather of the islands but also the ocean. It is important to remember and consider the ways that atmosphere and ocean (hydrosphere) are a coupled system and that a change in one will generate changes in the other.

The Clean Air Act and its amendments address mainly urban pollution and acid rain and include strategies for controlling high ozone levels in the lower atmosphere. It also offers protection of the stratospheric ozone layer by including provisions for recycling CFCs and calling for a ban on the production of CFCs. Currently, greenhouse gas emissions remain relatively unregulated,

however, in 2007 the US Supreme Court ruled that rising carbon dioxide concentrations in the atmosphere pose a sufficient threat to society that the EPA must regulate CO_2 emissions.

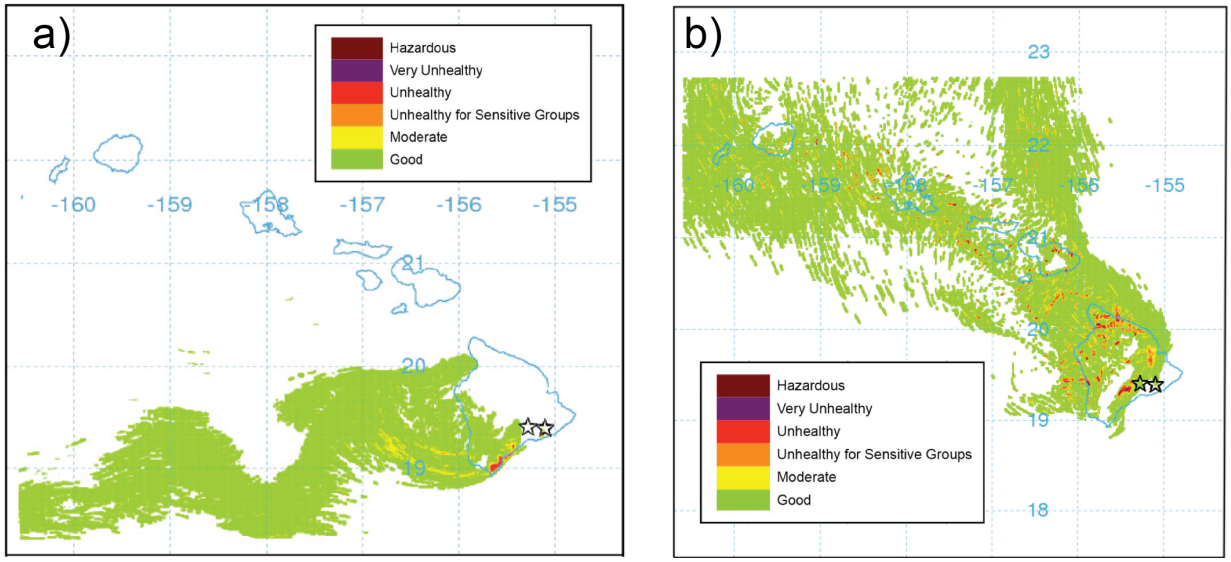

Figure 1 Distribution of vog (sulfate aerosol) from Kīlauea Volcano under conditions of a) prevailing trade winds and b) Kona winds.

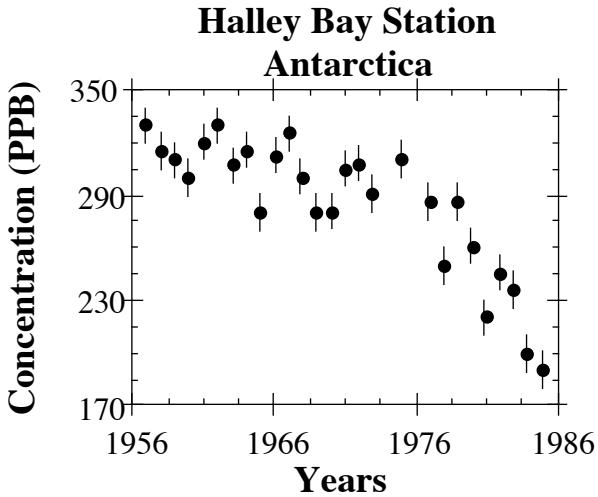

Figure 2 Ozone concentration in parts per billion (PPB) for Halley Bay, Antarctica.

INSTRUCTIONAL ACTIVITIES

1. **Engage**:

- What are sources of air pollution in your community?
- Can you identify several of your everyday activities that lead to air pollution?
- What can you to reduce the emission of pollutant gases?

2. **Explore:**

- Do Lab 1 to explore how much your car contributes to air pollution.
- See Lab. 4, Part II. What patterns appear in data from Earth, Mars, Venus, and Mercury?
- Mauna Loa is the site of the world's longest record of monitoring CO_2 levels. (See http://www.esrl.noaa.gov/gmd/ccgg/trends/) What is the trend? What are some reasons for it?

3. **Explain:**

- Hawai'i burns imported oil and coal to generate electricity. How do fossil fuels contribute to acid rain and global warming?
- How does Hawaiian newspaper article 1 relating human impact on water resources guide us on ways to avoid drought from reduced rainfall due to global warming?
- Read Hawaiian newspaper articles 2-4. Explain how you know if trade winds or kona winds were blowing when the articles were written.

4. **Elaborate/Extend**

- Study your family's electricity or gasoline bills. Develop a project to reduce your own or your family's reliance on fossil fuels.
- Develop a project to reduce levels of CO_2 in your community.

5. **Evaluate**

Teacher's perspective:

- What aspects of the lesson engaged students' interest and curiosity?
- What parts of the lesson did students learn easily, what caused difficulty?
- What could be done to improve the lesson?

Student's perspective:

- What was the most important knowledge I gained from this lesson?
- I would like to learn more about this topic:
- What are some ways I can apply what I learned from this lesson?

LAB 1: AUTOMOBILES AND AIR POLLUTION

Standard 1: Scientific Inquiry, SC8.1.1, SC8.1.2

Standard 2: Science, Technology, and Society, SC8.2.1

For many high school students, one of the first signs of adulthood is being able to operate an automobile. But along with this wonderful freedom comes much responsibility. In Driver's Education classes you learn a great deal about traffic safety, but what is the environmental impact of operating an automobile? How much does your automobile contribute to our air pollution problems (Fig. 3)?

In the introduction a number of serious pollution problems directly related to the exhaust and operation of motor vehicles were mentioned. To summarize here, automobile exhaust contributes to global warming through the emission of carbon dioxide; to acid rain and smog through the emission of nitrous oxides, carbon monoxide, carbon dioxide and unburned hydrocarbons; and to stratospheric ozone depletion through leakage of chlorofluorocarbons from air conditioning units.

ACTIVITY: Analyze Impacts of Driving and of Pollution Control Devices

PROCEDURE: Adult assistance may be needed.

1. Fit a clean white sweat sock snugly over the cool tailpipe of a car, using a broad rubber band to keep it in place. Then turn on the ignition and let the car run for three minutes. Turn off the engine and carefully remove the sock. Inspect the sock for particulate matter.
2. Repeat the instructions in 1) with a second clean sock and a car lacking emission control devices (pre-1975). If your car has no pollution control devices, choose a second car that does for this part. Again inspect the sock for particulate matter and compare your observations.
3. Compute your annual fuel consumption by completing the following calculations.

a) _____ Number of miles driven per week (Mainland average = 200)

b) _____ Estimated fuel mileage of your car (average = 20 mpg)

c) _____ Divide line a by line b. This is weekly fuel consumption in gallons.

d) _____ Multiply line c by 52. This is annual fuel consumption in gallons.

Gasoline is actually a very complex mixture of chemicals that when burned releases another complex mixture of gases. The table below shows the pounds of air pollutants per gallon. For each pollutant in the data table below, use your annual fuel consumption figure (line d) to calculate your annual release of pollutants from your automobile.

Data Table

POLLUTANT	POUNDS PER GAL	X	ANNUAL GALLONS (line d)	=	MY ANNUAL RELEASE (in lbs)
CO_2	20.000	X		=	
NO_2	0.110	X		=	
CO	2.300	X		=	
Hydrocarbons	0.200	X		=	
Aldehydes	0.004	X		=	
Particulates	0.012	X		=	
Organic acids	0.004	X		=	
SO_2	0.009	X		=	
TOTAL	22.639	X	_____	=	_____

QUESTIONS:

1. Describe the difference between the appearances of the two socks. Estimate the percentage decrease in the particulate pollution from the pre-1975 car to the newer car.

2. Compare the socks in your class. Is there a pattern in the appearance of the socks on the basis of the age of the cars, their fuel efficiency, etc.?

3. Based on your calculations above, is your contribution to air pollution significant?

4. In 2009 there were 254 million registered passenger vehicles in the United States. What would be the total amount of air pollution from automobiles if everyone drove like you?

5. Describe four ways in which you could reduce your automobile air pollution.
   a.
   b.
   c.
   d.

6. Do you know anyone driving an electric car? How would you estimate the fuel efficiency of such a vehicle, when plugged into an electric outlet that is fed by the local electric company?

Figure 3 Photochemical smog over Los Angeles primarily due to exhaust from automobiles.

LAB 2: MEASURING pH: ACIDIC, NEUTRAL, BASIC SOLUTIONS

Standard 3: Life and Environmental Sciences, Interdependence, SC7.3.3

We have all heard the term "acid rain," but do we really understand what it is and how it affects the environment? To understand acid rain it is necessary to understand the pH scale. The pH scale was developed in 1909 by a Danish biochemist. The pH scale measures the number of hydrogen ions in an aqueous solution and determines the acidity or alkalinity of a solution. Values on this scale range from 0 to 14. A solution with a pH of 7 is neutral; acidic solutions have pH values below 7 and basic solutions have pH values above 7. The pH scale is logarithmic, which means that a change in pH by one number actually represents a change by a tenfold. For example, a solution with a pH of 5 is ten times more acidic than a solution with a pH of 6 and one hundred times more acidic than a solution with a pH of 7.

Very few substances are neutral (have a pH of 7). Distilled water is considered neutral. Background rainwater falling from clean air is not neutral; it has a pH value of 5.6. This is a result of the presence of carbon dioxide in the atmosphere and the formation of carbonic acid in cloud water. Acid rain is defined as a solution with a pH less than that of background rainwater. Typically, pH values for acid rain range from 4.0 to 4.6. However cloud water with a pH as low as 2.3 has been observed in fogs in the Appalachian Mountains. Similarly low pH values have also been measured in cloud along the slopes of Mauna Loa as a result of sulfuric acid that is a by product of emissions of sulfur dioxide gas from Kīlauea Volcano.

ACTIVITY: Investigate the pH of Various Acids And Bases

MATERIALS:

§ aspirin
§ sugar
§ vitamin C
§ baking soda
§ salt
§ soap
§ tea
§ crushed coral bits
§ milk- fresh
§ milk- sour
§ white vinegar
§ rainwater
§ orange/lemon/apple juice
§ clear, colorless soda
§ distilled water
§ pH paper
§ small cups
§ stirring rod
§ tweezers

PROCEDURE:

1. Add one teaspoon of each solid to one-quarter cup of distilled water and stir until dissolved.

Add one tablet to one-quarter cup of water.

2. Use tweezers to dip the pH paper into each solution. Do not re-use the pH paper.
3. Determine the pH of each solution based upon the color scale. Record your observations and results in the table provided. Label each substance as an acid, a base, or neutral.

QUESTIONS:

1. Which solution was the most acidic? Basic?
2. What would happen to the pH value if you dilute the liquid solutions with distilled water?
3. What would happen to pH of a solution if the solids do not dissolve in water?
4. What would happen to the pH of a solution if it were left uncovered for a weekend?
5. Why are the lowest values of pH observed in cloud water rather than in rainwater?
6. What are the consequences of #5 to forests in Hawaii and elsewhere growing at altitudes where cloud water condenses on them?

Data Table

Substance	pH Value	Acid or Base	Observations
Aspirin			
Sugar			
Cocoa			
Indigestion Tablets			
Salt			
Soap			
Tea/ Coffee			
Milk- fresh			
Milk-Sour			
Vinegar			
Rain water			
Juice			
Soda			

LAB 3: MONITORING ACID RAIN

Standard 3: Life and Environmental Sciences, Interdependence, SC7.3.3

The acidity of rain water depends upon a combination of naturally occurring acids in the atmosphere and acids that are the result of man made pollutants introduced into the atmosphere from a variety of sources. Three types of acid commonly found in rainwater include carbonic acid, nitric acid, and sulfuric acid. The concentration of carbonic acid depends upon the presence of carbon dioxide; and gives rainwater its natural background acidity (pH = 5.6). Sulfuric and nitric acids are the products of sulfur dioxides and nitric oxides introduced into the atmosphere by industrial power plants (and Kīlauea Volcano in Hawai‘i) and motor vehicles, respectively. *Check the local pH index, if one is available for the area.*

ACTIVITY: TAKE PH MEASUREMENTS OF RAIN UNDER FIELD CONDITIONS

OBJECTIVES: The goals of this activity are to learn how to take pH measurements of rain under field conditions, and to gain knowledge of the variation in acid rain episodes, analyze the human and natural (Kīlauea Volcano) impacts on the environment, and become aware that the degree of accuracy of measurements has to be taken into account when results are interpreted.

MATERIALS:

§ pencil, greenhouse type

§ 2 pocket type, student thermometers, single or double scale

§ heavy duty, 1 m^2 plastic tarp

§ 500 mL, plastic graduated cylinder

§ plastic rain gauge to measure up to 15 cm. of rain

§ 10+ pH sticks, wide range (permanent type, ColorpHast)

§ 18+pH sticks, narrow range (permanent type, ColorpHast)

§ storage bag/vial to store used, dry pH papers, (color is permanent)

§ waterproof plastic case

§ plastic laminated pH Colorchart, wide range

§ plastic laminated pH Colorchart, narrow range

§ map of expedition area

PROCEDURE:

1. Before or at the first hint of rain, spread the 1 m^2 plastic tarp on the ground, in an open area away from trees, and anchor it.
2. Position the rain collecting graduated cylinder so that it catches rainwater run-off from the tarp. This will require some ingenuity and you may have to rearrange your anchors. Keep tarp clean.
3. Place the rain gauge in the same general area as the tarp.
4. At intervals throughout the storm, collect water samples and record the sample data.
5. Record the following information on a copy of the General Data Sheet that follows:
   A. Record name or names or members in observation group
   B. Date sample taken.
   C. Describe the rain sample site location and vegetation. Provide as much detail as you can.
   D. Record actual location with map coordinates or attach a map to the Data Sheet with the sample site location clearly marked.
   E. Note the duration of rainfall. Time Began, Time Stopped, and Total Time of Precipitation.
   F. Describe the cloud type if you can or describe sky conditions: completely overcast, thunderstorms, passing showers, etc., or use a word description of your own. You can check it against a weather guide when you return home.
6. If it rains long enough, attempt to collect at least three samples during the rainstorm's duration. Record the following data for each sample in the Data Table:
   G. Time sample taken.
   H. Rain intensity - i.e., downpour, light, medium, heavy, mist, etc.
   I. Wind direction.
   J. Wind speed: estimate with Beaufort scale, Lesson 3 Weather Maps and Hazardous storms
   K. Air temperature.
   L. Amount of rainfall accumulated per sample (Rain Gauge).
   M. Determine and record the pH. Use the wide range pH paper, which gives the pH to within one pH unit (Record). Obtain a more accurate pH reading by using the appropriate narrow range pH paper. Take three readings and record them on the Data Sheet.
   N. Determine and record the overall pH of the entire rainfall by testing the rainwater collected in the rain gauge during the rain. Record.
   O. Record total accumulation (Rain Gauge).
   P. Dry the used pH papers, label them with the sample number, and place them in the used pH storage vial. Do not discard used pH papers, pack them out.

GENERAL DATA **NAME**_____

1. Date Sample Taken _____

2. Site Description

3. Map Location:

   Coordinates _____

   (Or attach map with location marked)

4. Rainfall Duration:

Time Rain Began _____

Time Rain Stopped _____

Total Time of Precipitation _____

5. Cloud Description/Sky Conditions _____

6. pH of Total Accumulation _____

7. Total Rain Accumulation (run-off) _____ cm.

8. Total Rainfall (measured in rain gauge) _____ cm.

Data Table

Sample #	1	2	3	4	5
1. Time Sample Taken					
2. Rain Intensity					
3. Wind Direction					
4. Wind Speed					
5. Air Temperature					
6. Sample Accumulation					
7. pH of Sample					
a. Wide Range					
b. Narrow Range					
Trial 1					
Trial 2					
Trial 3					
8. Local pH Index (if available)					

QUESTIONS:

1. How did the acidity of the samples vary with location and wind direction. Can the observations be explained in the context of the location of pollution sources in the area? In Hawai‘i, how did the presence of vog affect the pH measurements?

2. How did the acidity of the samples vary with the time the sample was taken; early or late in the day, early or late in the rain event. Can these differences be explained in the context of diurnal variations in pollution or the impact of precipitation on the quality of the air?

3. Investigate the effects of soot/particulates from a gas engine's exhaust, placed on fabrics and moistened with distilled water.

5. How do the leaves of a plant react to the application acids of varying pH? Examine the tensile properties of yarn exposed to acid solutions of varying pH.

GLOBAL WARMING

The global climate of the Earth is largely determined by the balance between available (not counting that reflected back to space by clouds and the surface) incoming short wave (visible) solar radiation and outgoing long wave (infrared) radiation emitted to space by the Earth and atmosphere. Climate change depends upon changes that affect this radiation balance. Such changes can be separated into several categories:

1. Changes that affect the reflectivity of the Earth-atmosphere system for incoming short wave radiation:
   i) changes in cloud cover (strong radiator in infrared and strong reflector in visible)
   ii) changes in snow cover (strong radiator in infrared and strong reflector in visible)
   iii) changes in the surface characteristics, e.g., deforestation, overgrazing, urbanization
   iv) changes in aerosols, e.g., smoke, ash
2. Changes in the composition of the atmosphere affecting outgoing long wave radiation:
   i) changes in radiatively active gases (e.g., water vapor, CO_2, methane, chlorofluorocarbons, etc.)
   ii) changes in aerosols, e.g., smoke, ash
3. Astronomical changes affecting incoming solar radiation:
   i) celestial mechanics of Earth's orbit
   ii) solar aging
   iii) changes in the concentration of intergalactic dust
   iv) asteroid impact

The complexity of the climate system is evident in the above outline and our knowledge of the complex interactions between the atmosphere, ocean, cryosphere (ice) and biosphere (plant/animal) systems is incomplete. Our ability to adequately observe the global climate is also insufficient. NASA's Mission to planet Earth and NOAA's Global Change Program include efforts to address these pressing issues.

Concern for global warming stems from the observed increase in gases such as carbon dioxide and methane, which inhibit outgoing long wave radiation (Fig. 4). Records of temperature and carbon dioxide concentration derived from glacier ice cores show a strong relationship between these two. Observations show that the troposphere is warming, the stratosphere cooling, and ocean surface temperatures are rising, leading to more intense storm systems and wider swings in local climate, including enhanced droughts and flood events. Melting of ice sheets and warming of ocean temperatures produce sea level rise, with obvious implication for coastal areas. See Global Climate Change Indicators at http://www.ncdc.noaa.gov/indicators/.

Thinking Ahead

According to a NASA blueprint, we can decrease CO_2 emissions over the next 30 years by 40% by doing the following five things:

1. Increase auto fuel efficiency by 30% (promote electric cars as a superior technology).

2. Use compact fluorescent bulbs

3. Produce more efficient motors

4. Apply tougher standards for refrigerators and dishwashers

5. Develop alternative renewable energy sources (e.g., wind and solar)

While human activity (burning of fossil fuels, agricultural activity, etc.) has increased the concentration of carbon dioxide and other radiatively active gases in the atmosphere during this century, it has simultaneously increased the burden of aerosol, decreasing the amount of sunlight reaching the Earth's surface. Recent research has shown that areas where the aerosol input to the atmosphere is greatest have experienced cooler surface temperatures regionally. As governments act to reduce health-harmful aerosols, global warming will accelerate. Important strategies to control global warming include:

- Stabilize world population
- Initiate a no-coal world energy strategy
- Vastly enhance renewable energy dependence
- Institute strong energy conservation
- Develop treaties strongly controlling greenhouse gases
- Initiate CO_2 sequestration
- Discover counter-greenhouse technologies

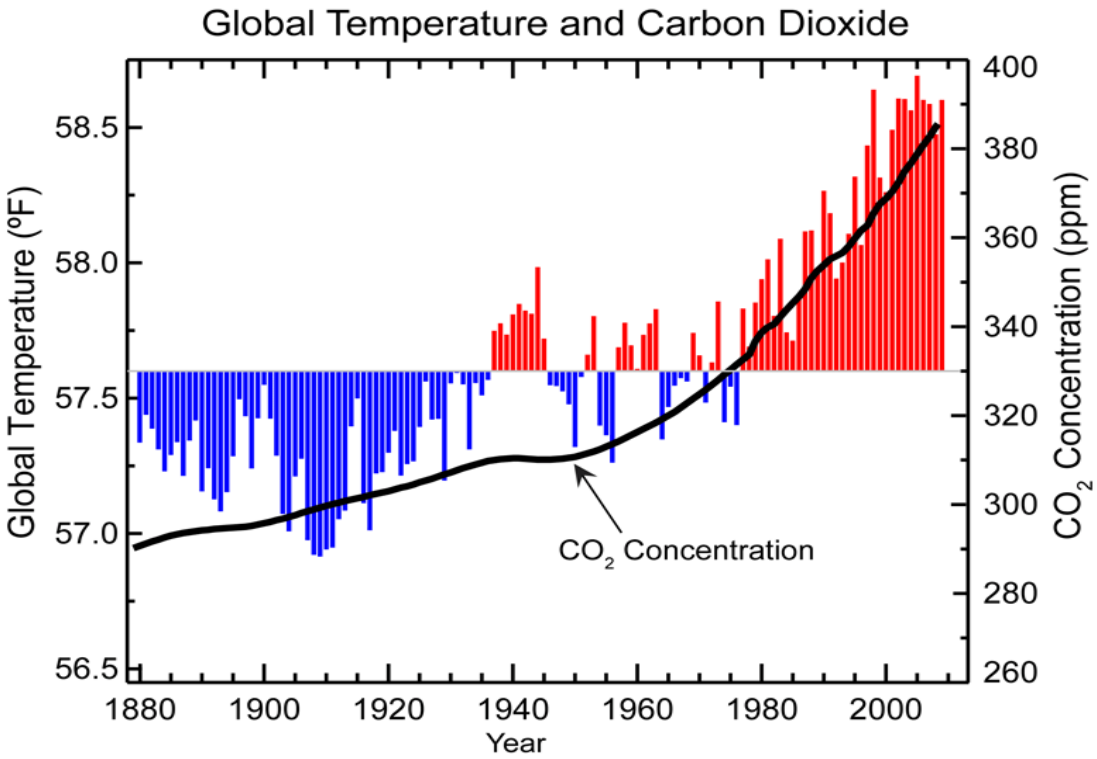

Figure 4 Graph showing the increase of CO_2 and the observed global average temperature from 1880 through 2009 (source NASA).

LAB 4: THE ATMOSPHERE EFFECT AND GLOBAL WARMING

Standard 8: Forces that shape the Earth, SC8.8.4

When visible light passes through large windows of a greenhouse, it is largely absorbed after striking objects within (and in the case of plants results in photosynthesis). These objects heat up and in turn conduct heat into the air of the greenhouse as *sensible heat* (heat you can *sense* with a thermometer). The glass or Plexiglas windows prevent the mounting sensible heat inside the greenhouse from escaping and mixing with cooler outside air and the building stays warm even on cold sunny days. Unlike a greenhouse, the atmosphere does not have a barrier that limits mixing of the air, such as the glass in a greenhouse, thus the term "greenhouse warming" when applied to the atmosphere is actually a misnomer.

How does the atmosphere work? Recall that light is emitted by all objects in wavelengths and energies that depend on the temperature of the object. As the Earth's surface is warmed by sunlight, it emits increasing amounts of infrared radiation, radiation with a longer wavelength than sunlight. Several gases in the atmosphere absorb and reradiate this energy back to the surface and are mislabeled "greenhouse gases." Examples include water vapor (H_2O), carbon dioxide (CO_2), and methane (CH_2). Water vapor is the most important greenhouse gas in the Earth's atmosphere. The latter two gases are now increasing daily because of exhaust from cars and burning fossil fuels such as coal and natural gas. At present, the atmosphere traps only a small part of the infrared radiation that is emitted into the air at the surface of Earth. As the amounts of carbon dioxide and methane increase, the Earth will become gradually warmer as the atmosphere absorbs and reradiates more and more of the infrared radiation that would otherwise have passed directly out to space.

The temperature here on Earth depends upon several factors -- seasons, latitude, altitude, proximity to oceans, and prevailing weather patterns. Some think the temperature on our closest planet "neighbors" is simply a result of that planet's distance from the sun. In part two, we see there is another important factor.

ACTIVITY PART I. What Occurs in a Greenhouse on Earth?

OBJECTIVE: The objective is to observe and to investigate the processes that occur in a greenhouse and compare them to those that take place in the Earth's atmosphere. Part two of this activity will compare and contrast the environments of the other terrestrial (Earth-like) planets in our solar system with each other and Earth.

MATERIALS:

For the class:	**For each student or group of students:**
§ one large bag of potting soil	§ two thermometers
§ one box of plastic wrap	§ one rubber band
§ hole punch	§ two large disposable plastic cups

PROCEDURE:

1. Use the hole punch to make a hole big enough for a thermometer to be inserted about an inch from the top of each plastic cup.
2. Fill each cup with dirt until the soil is about one inch below the hole just made.
3. Insert a thermometer through each hole so that the bulb is about one inch above the dirt and centered in the middle of the cup. **Caution: Do not force the thermometer through the hole. If it will not go, punch a bigger hole.**
4. Turn the thermometer so that it can be read.
5. Cover one cup with plastic wrap, and leave the other cup uncovered. Secure the plastic wrap on the cup with a rubber band as shown below in Fig. 5.
6. On a sunny day, take the two cups outside at the beginning of the class period, and place them where they will not be disturbed. Stabilize the thermometers so they will not move.
7. Record the initial temperature on each thermometer in the Data Table below.
8. Record temperatures every 5 minutes for 30 minutes.
9. Make a graph for the temperatures in each cup on the same sheet of graph paper. Graph the temperatures on the vertical scale and the time on the horizontal scale. Designate each line as being for the covered cup or the uncovered cup.

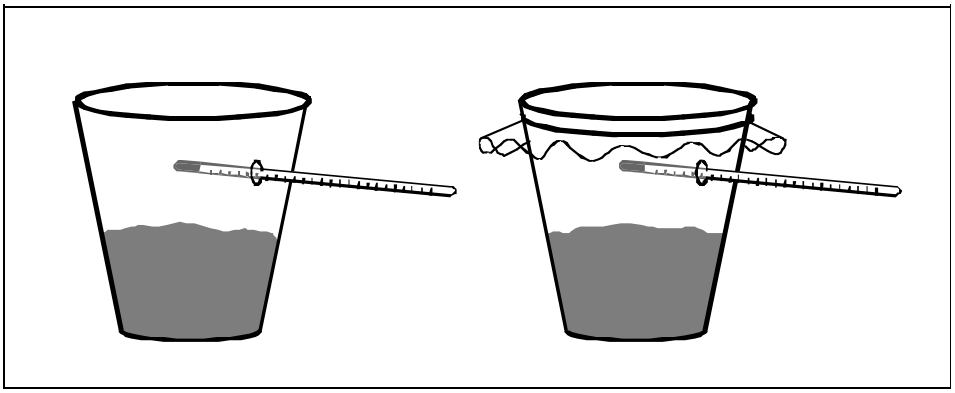

Figure 5 Schematic diagram

QUESTIONS:

1. Describe what happened to the temperature in each cup.

2. Given that infrared radiation will pass freely through the plastic wrap over the top of the cup, what is making the temperature rise more rapidly in the covered cup?

3. In a glass greenhouse the infrared rays emitted within are trapped to some extent by the glass, not so in a Plexiglas greenhouse, yet the latter still stays warm. What does this tell you about the importance of the infrared radiation in keeping a greenhouse warm?

4. In the absence of other factors, what will be the result for global surface air temperatures if

greenhouse gases continue to increase?

5. Extra credit: What factors may help offset global warming?

6. Extra credit: Potting soil tends to be moist. How might the results of this experiment been different if dry soil or sand had been used instead? (See the introduction for a hint.)

Data Table

	COVERED CUP	UNCOVERED CUP
0 min.	°	°
5 min.	°	°
10 min.	°	°
15 min.	°	°
20 min.	°	°
25 min.	°	°
30 min.	°	°

ACTIVITY PART III: Exploring the radiation balance and temperature in car

Objective

Investigate the thermal equilibrium temperature of a dashboard exposed to direct sunlight and one not exposed to direct sunlight and the resulting impact on the compartment air temperature of an automobile.

MATERIALS:

§ Infrared pyrometer – to measure the radiation temperature of objects

§ Thermometer – to measure sensible heat in the air

PROCEDURE:

1. Unlock you car, which is parked in the shade (parking garage works well for this) and make air temperature measurements in the compartment using a standard thermometer. Take IR temperature measurements inside the car (seats, ceiling, dash).

2. Move your car into a sunny parking spot with the windshield facing the sun and windows closed.
   Place a sunshade to cover half of the windshield.
   Place a standard thermometer on each half of the dashboard.

3. Take readings for each instrument at the start and at 15-minute intervals for one hour. Include a separate column for reading the IR temperature through the windshield.

LAB WRITEUP: Include the following in your separate lab write-up.

1. Use Matlab or Excel to plot the data collected as a time series. Comment on the curves that result.

2. How would the results of this experiment differ if all the windows of the car were fully open. Is the IR temperature of the dash different when measured through the windshield? Is your car serving as a greenhouse? Explain why the greenhouse effect is a misnomer for the way in which the atmosphere works.

3. Why would car manufacturers insist on manufacturing nearly black car dashes that absorb the maximum solar radiation?

4. Upon driving away in your sun-heated car, estimate the total radiant emittance (W m^{-2}) emanating from your car's dashboard, given it hottest measured surface temperature (hint: you

will need to estimate the surface area of the dash). How does this figure compare to the total radiant emittance using the temperature of the dash taken in the garage?

5. Mr. Barnes is building a stone house with a concrete floor (read large thermal mass) in the mountains of Vermont (read cold) and although the house will have rural charm, he wants to install an economical and most comfortable heating system. You have been contracted to come up with the best design. Describe its components (real basic), energy source, and most importantly explain why your system will provide the most comfortable environment for Mr. Barnes to grade homework sets in (hint: why ask this question as part of this lab?).

ACTIVITY PART III: Is There a Greenhouse Effect on Other Planets?

Examine the four terrestrial (Earth-like) planets -- Mercury, Venus, Mars and Earth. Please review the data in Table 4.1 then answer the questions that follow.

Table 4.1 Temperature range and atmospheric composition for Mercury, Venus, Mars and Earth.

Planet	Distance from Sun (X1,000,000 Km)	Lowest Temp (˚C)	Highest Temp (˚C)	Temp Range (˚C)	Atmosphere
Mercury	58	-173	427	600	None
Venus	107	430	480	50	CO_2
Earth	149	-73	50	123	N_2, O_2
Mars	223	-125	-60	65	CO_2

QUESTIONS:

1. Which planet has the coldest nighttime temperatures? Explain?

2. Which planet has the highest daytime temperature? Explain?

3. Which planet has the largest temperature range? Explain?

4. Which planet has the smallest temperature range? Explain?

5. What two factors do Venus and Mars have in common?

   a.

   b.

6. From the data above, what do you think the effect of a high CO_2 atmosphere is on temperatures observed?

7. What do you think would happen to the Earth's daily temperature cycle if we suddenly lost our atmosphere?

9. What do you think would happen to the Earth's global climate if the percentage of CO_2 in the Earth's atmosphere were to double over the next 30 years?

RESOURCES:

1. Businger, S. (2006). *Eye to the Sky: Exploring Our Atmosphere*, Novus Publishing.
2. Hawaii Content and Performance Standards III Database. Hawaii State Department of Education. Retrieved June 6, 2012 from http://165.248.30.40/hcpsv3/index.jsp.
3. Ka Nupepa Kuokoa. (1881). 5 February.
4. Ka Ua. (1877). Ka Lahui Hawaii. 1 March
5. Ke Au Okoa. (1872). 29 August.
6. National Research Council (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Retrieved July 5, 2012 from http://www.nap.edu/catalog.php?record_id=13165.
7. Pohina I Ka Uahi. (1868). Ka Nupepa Kuokoa. 24 October.

Article 1: *Ka Lahui Hawaii.* 1 March 1877, pg. 2

KA NUPEPA KA LAHUI HAWAII.

HONOLULU, MARAKI 1, 1877.

Ka Ua.

"Ka na i haule mai
Ma koonei kihapai,
Ka mea ia e ulu ai
Na mea kanu nei.

Ma ka po o ka Poakahi iho nei a me ke ao o ka Poalua, he mau kuaua nui kai haule mai maluna o ka moku aina o Oahu nei. Ua ma-u ka aina; a me he mea la ua ma-u pu me na manao kuea o ka poe hakaka no na wai ma na kuauna kaika o kakou; a na pohala ae ka manao maule o ka poe mahiai. Aole poina ia makou na hoolo ua nui o na kau i hala ae. He nui loa ka ua iloko o ia mau makahiki. Ua hoopiha ia na kiowai a me na punawai, a me na kahawai o na kuahiwi. Piha ka aina i ka wai ia wa. Na na kuaua nui o ka hooilo i hoolawa i ka wai no na mahina ua ole o ke kau. Iloko o keia mau makahiki iho nei, ua like ole ka nui o ka na me na wa mamua.

No ke aha keia nele i ka na? Ua olelo ka poe naauao, o na ululaau nui oia ka mea nana e ume mai i na ao na maluna o ka aina. Ua ike ia no hoi ma na aina kahiko e like me Aigupita a me kekahi mau wahi e ae, i ka wa i neonao ai ka aina i na ululaau o ka uuku iho la no ia o ka ua, a maloo iho la na kahawai. Aka ma na wahi i hooulu hou ia i na ululaau ua hoi hou mai ka na ma ia mau wahi. Ua maa no hoi ka poe kamaaina o Maui i ka ike ana aku i na kuaua o Koolau e nihi hele mai ana maluna o na ululaau o Haleakala a mawaho mai o Makawao o ka malowale ae la no ia o ka ua, aohe hele loa aku i na aina panoa o kula. Me he mea la, e hooiaio mai ana keia, o na ululaau nui kekahi mea e kokua ana i ka aina ma ka ume ana mai i na ao na.

Ina he mea hiki ke hooulu ia na laau a paapu maluna o na aina panoa o kakou, he pomaikai nui ia no na mea a pau. He mea ulu hikiwawe ka laau kiawe ma na aina maloo, e like me na aina o Kona nei, Oahu. Ina e kanu ia ke kiawe mai Pawaa aku a hiki i ka Lae o Makapuu; a mai Kapalama aku a hiki i Waianae; Mai Lahaina aku a hiki i na pali o Aalaloloa, a me Kanaalaea, Honuaula; a mai Kawaihae aku a hiki i Kona Hema, iloko iho no paha o na makahiki he iwakalua e ike ia ai ka waiwai nui o keia mau ululaau—he wahie, he lanahu, a he ai na na holoholona, a he mea e ma-u ai na aina e pili ana.

Ua mahalo makou i ka lawelawe ana o ke aupuni e hookaawale i na holoholona mai ka aina aku o Nuuanu. He pono e hookapu loa ia kela awawa, aole e ae ia na holoholona hoopau nahelehele e hele wale malaila. E kapu loa ia wahi no na mea ulu, no na manu a me na dia paha. Pehea no hoi ke hookaawale ia kau wahi ma ke ano he Park, a e kapaia o Kamehameha Pa, a i ole ia o Kaahumanu Pa?

Article 1 Translation: *Ka Lahui Hawaii.* 1 March 1877, pg. 2

The Newspaper *Ka Lahui Hawaii.*
Honolulu, March 1, 1877.
The Rain.

"The rain that fell
On this garden here,
Is the thing that caused
These plants to grow.

Last Monday night until Tuesday morning, some large showers fell upon this island of Oʻahu. The land was soaked; and it was as if the profane thoughts of those fighting for water on the banks of our taro patches were also dampened; and the dispirited thoughts of the farmers revived. We have not forgotten the great, rainy winters of seasons passed. The rains were great in those years. The springs and pools were filled, as well as the rivers of the uplands. The land was filled with water at that time. It was the great showers of winter that supplied the water for the rainless months of summer. Within these past years, that amount of rain has not been the same as before.

Why has there been a lack of water? The wise ones have said, it is the great forests that attract the rain clouds upon the land. It has been seen in the ancient lands, like Egypt, and several other places, when the land was barren with no forests, the rain decreases and the rivers dry up. However, in the places where they reforested, the rain returns to those places. The natives of Maui are accustomed to the Koʻolau showers creeping atop the forests of Haleakalā and outside of Makawao, and then the rain disappears, it does not reach the barren plains. It is as if this is proving that large forests are a thing aiding the land by attracting rain clouds.

If trees can be grown until they cover our barren lands, that is a great blessing for all of us. The kiawe tree grows quickly on dry lands, like here in Kona, Oʻahu. If kiawe was planted from Pāwaʻa to Makapuʻu point; and from Kapālama to Waiʻanae; from Lahaina to the cliffs of ʻAʻalaloloa, and Kamalaoa, Honuaʻula; and from Kawaihae to Kona Hema, within perhaps twenty years great prosperity will be seen from these forests. They can be firewood, charcoal, food for animals, and it will moisten the adjacent areas.

We appreciate the government undertaking to remove the animals from the land of Nuʻuanu. That valley needs to be off limits, so that animals that destroy the forest are not allowed to just wander there. That is a very sacred place because of the plants, the birds, and maybe even the deer. How about making that place a Park? and call it Kamehameha Park, or Kaʻahumanu Park?

Article 2: *Ka Nupepa Kuokoa*. 5 February 1881, pg. 3

Ua uu ia ae ke kulanakauhale o Hilo a poulu i ka uahi o ka luapele, a ke hao la hoi ka makani i ke kuehu i ka lepo, pela mai nei ka leka a J M Pea.

Article 2 Translation: *Ka Nupepa Kuokoa*. 5 February 1881, pg. 3

The city of Hilo was soaked, and darkened by the smoke of the volcano, and the wind is stirring up dust clouds, according to the recent letter from J M Pea.

Article 3: *Ka Nupepa Kuokoa*. 24 October 1868, pg. 3

Maui.

POHINA I KA UAHI.—Ina la hope o ka pule i hala, ua lohe pono mai makou mai a Asa Hopu Esq., mai o Hana, ua uhi paapuia keia wahi e ka uahi o ka wahine o ka lua. Haalele aku nei no ia, ke poluluhi la no na kuna uahi ma ka lewa lani. He hana nui hoi kau e ka wahine o ka lua.

Article 3 Translation: *Ka Nupepa Kuokoa*. 24 October 1868, pg. 3

Maui.

HAZY WITH SMOKE.—In the final days of the past week, we heard from Asa Hopu Esq., from Hāna, that place was completely covered by the smoke of the woman of the pit. Then it left, but bits of smoke make the sky overcast. You are working hard, o woman of the pit.

Article 4: *Ke Au Okoa*. 29 August 1872, pg. 2

Ma na la hope o kela pule iho nei, ua uhi'a o Oahu nei e ka pohina uahi a Pele, he hoailona e hoike mai ana ua hoa hou ke ahi a ka wahine o ka lua. Ma na hoike ana a kekahi mau moku i ku mai nei, na ike ia ka pohina uahi ma ka moana no kekahi mau haneri mile elua a keu ka mamao mai Hawaii aku.

Article 4 Translation: *Ke Au Okoa*. 29 August 1872, pg. 2

In the final days of last week, O‘ahu was covered by the hazy smoke of Pele, a sign showing that the fire of the woman of the pit has again ignited. In the reports of several ships that arrived, the hazy smoke was seen over the ocean over two hundred miles away from Hawai‘i.