THE VOLC

The 14,411-foot-high peak of Mount Rainier looms over downtown Seattle. A 1994 National Academy of Sciences report said, “A major volcanic eruption or debris flow [from Rainer] could kill thousands of residents and cripple the economy of the Pacific Northwest.” Prevailing winds from the west could carry ash from such an eruption across the United States, disrupting air travel.

CANO-

Climate Connection

by Jack Williams

During the chilly, wet summer of 1816, a group of people gathered together on Lake Geneva in Switzerland to spend a summer holiday. They included the poets George Gordon Byron, also known as Lord Byron, and Percy Bysshe Shelley, as well as Shelley's fiancé, Mary Wollstonecraft Godwin; Mary's stepsister, Claire Clairmont; and Bryon's physician, John William Polidori. The weather that summer—in what would eventually become known as the Year Without a Summer—was unrelentingly grim.

"At first," Mary recalled, "we spent our pleasant hours on the lake or wandering on its shores. But it proved a wet, ungenial summer and incessant rain often confined us for days to the house." The group passed the rainy, gloomy days reading and discussing German ghost stories. During one of these conversations, Byron suggested that each of them write a ghost story and, "his proposition was acceded to."

DARLENE SHIELDS

The result of this suggestion was one of the most well known horror stories in modern literature. Mary's short story about a character named Dr. Victor Frankenstein, who creates a monster that he brings to life, was ultimately expanded into a novel, which was published in 1818 as *Frankenstein, or The Modern Prometheus*.

Polidori, meanwhile, used the opportunity to write a short story that he called "The Vampyre," which Christopher John Frayling, a British professor of popular culture, describes as "the first story successfully to fuse the disparate elements of vampirism into a coherent literary genre."

More than a century and a half later, on the evening of June 24, 1982, the passengers and crew aboard British Airways Flight 9, a Boeing 747 cruising 37,000 feet above Indonesia, experienced an eerie event worthy of inclusion in one of Shelley's or Polidori's stories.

The jet was cruising through smooth air when the pilots saw pinpricks of white light on the windshield. They recognized the pinpricks as St. Elmo's fire—a harmless, electrical glow that sometimes forms on airplanes when they fly into a cloud with an electrical charge, such as in or near thunderstorms. But the airplane's weather radar had not shown any thunderstorms in the area. At the same time, blue smoke with a sulfuric odor was coming through the plane's air vents. Those who looked out the windows saw an eerie white light around the airplane, and the engines appeared to be on fire. Then one engine surged and stopped. Within minutes, the other three engines stopped.

Although many onboard the aircraft assumed they were doomed, the pilots ultimately were able to restart three engines after the aircraft had glided down to an altitude of 13,000 feet, and the smoke and strange lights began to fade away. Flight 9 landed safely in Jakarta, Indonesia.

What connection can these two seemingly disparate events—the gloomy, dark summer that inspired two famous horror stories and the terror aboard an airplane in 1982—possibly have to each other? The answer, in a word: volcanoes.

The Volcano-Weather Link

While most people might not immediately connect volcanic eruptions with weather effects, there are, in fact, both immediate and longer-term meteorological consequences related to eruptions, and both were at play in the scenarios described above.

Climate scientists who have studied the meteorological patterns during the Year Without a Summer generally agree that the unusually cool weather

US GEOLOGICAL SURVEY PHOTO BY LYN TOPINKA

What is left of Mount St. Helens after the 1980 eruption is reflected in Spirit Lake on May 19, 1982.

U.S. GEOLOGICAL SURVEY PHOTO BY ROBERT KRIMMEL

Black and white photo shows the May 18, 1980 eruption of Mount St. Helens in Washington. Mount Adams is in the background on the right.

in the northeastern United States, eastern Canada, and Europe was the result of the eruption of the Indonesian volcano Mount Tambora in April 1815, following eruptions of three other large volcanoes in the tropics beginning in 1812.

Scientists now know that these volcanoes, especially Tambora—the largest volcanic eruption in the last 10,000 years—had spewed large amounts of sulfur dioxide into the air, which combined with water vapor to create a sulfuric acid mist of tiny particles (aerosols) that blocked up to 1 or 2 percent of the solar energy that normally reaches the earth for months following the eruption. This might not sound like much, but as scientists confirmed after late twentieth century eruptions, it's enough to upset global weather.

Meanwhile, the eerie events aboard British Airways Flight 9 demonstrate the immediate consequences that can confound the satellites and radars that help pilots avoid meteorological dangers.

The problems on Flight 9 occurred when the airplane flew into a cloud of volcanic ash from the violent eruption of Mount Galunggung in Indonesia. This eruption began in early May of 1982 and continued for 9 months with a series of relatively small blasts compared to Tambora. During this time, the volcano didn't send enough sulfur dioxide high enough in the sky to have any measurable global effects. But, the volcano's ash did stop the 747's engines.

Ash that comes from volcanoes is not the soft, fluffy material that's left when a campfire goes out. Instead, it is pulverized rock, which can be harder than steel and has sharp edges. In addition to being abrasive, volcanic ash conducts electricity, which accounts for the stunning display of St. Elmo's fire. The engine shutdown is explained by the fact that

> "[a] Boeing 747 experienced an eerie event worthy of inclusion in one of Shelley's or Polidori's stories"

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Huge eruptions often cause vivid sunsets around the world, such as this one in Hong Kong a year after Mount Pinatubo erupted in the Philippines in 1991.

a jet engine's heat melts volcanic ash that flows into it. The melted ash then fuses as a kind of dirty glass onto the internal engine parts, causing the engine to lose power and stop. Fortunately when the engine stops, it cools, making the ash deposits brittle. Repeated attempts to restart the engine can break off enough material for the engine to finally begin running again.

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Volcanic Ash Dunes of Tarvurvur, Rabaul, Papua New Guinea.

But why didn't the pilots know about the ash cloud ahead of time so they could avoid flying through it? Weather radars are designed to locate water droplets and ice crystals, but volcanic ash particles are too small for them to detect. If a pilot sees a volcanic eruption, the huge cloud of ash can easily be avoided, but eruptions can occur at night, and darkness obscures the pilot's vision. Moreover, clouds can hide a volcanic eruption from above, which means pilots or weather satellites are not likely to see it. Finally, volcanic ash can mix with ordinary clouds without changing their appearance, meaning a pilot might not even know he or she is flying into an ash-laden cloud.

Three weeks after the Flight 9 incident, a Singapore Airlines 747 flew into ash from the same volcano with similar results. Fortunately, as with Flight 9, the pilots managed to restart the engines in time to make a safe landing. But the two incidents brought the dangers of flying through volcanic ash to the attention of the world and highlighted the shortcomings of observational instruments' in detecting ash clouds.

The Galunggung volcano encounters and other less dramatic incidents, as well as the growing number of flights over volcanically active areas, including the busy route from North America across the northern Pacific to Asia, helped prompt NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) to begin supplying the Federal Aviation Administration (FAA) with global volcanic ash information in 1987. In 1995, the International Civil Aviation Organization established today's international system of Volcanic Ash Advisory Centers.

These centers include the NOAA Volcanic Ash Advisory Center (VAAC) in Camp Springs, Maryland; the Anchorage, Alaska, VAAC; and seven similar centers in other nations that keep a continuous eye on the earth's volcanoes. Infrared satellite sensors that detect various infrared frequencies are the primary tools used by these centers, because the sensors see the different infrared frequencies emitted by ice crystals at the tops of most clouds, as well as by volcanic ash.

> "[a] pilot might not even know he or she is flying into an ash-laden cloud"

Delving Deeper into the Science

In the early nineteenth century, no one had any explanation for bad weather, except possibly an angry god. The first scientific hypotheses about what caused the Year Without a Summer were developed in the early twentieth century. These studies and work in following years made a convincing case for a link between volcanoes and climate, but they failed to answer one important question: Why wasn't the cooling uniform around the globe, at least in areas with volcanic material overhead?

From the early twentieth century until the late 1960s, most scientists talked of "volcanic ash" or "dust" as affecting global climate, but some were beginning to argue that sulfuric acid aerosols, not ash or dust, were probably blocking sunlight. Such aerosols both absorb some solar energy and reflect some back into space. Absorption warms the stratosphere, while the reduced solar energy reaching the surface cools the lower layer of atmosphere, the troposphere.

When the Agung volcano in Indonesia erupted in March 1963, scientists had the technology to confirm that the aerosols that formed from sulfur, not ash or dust, cool the globe after a large eruption. The cataclysmic eruption of Mount St. Helens in southern Washington on May 18, 1980, helped support that conclusion and showed why some large volcanoes have little effect on global climate. Some of Mount St. Helens' ash circled the globe and stayed in the stratosphere for years, but the volcano didn't eject enough sulfur into the stratosphere above most clouds to block sunlight around the world.

Rain and snow quickly wash sulfur from the lower atmosphere, which falls as acid precipitation.

FLUXFOTO/ISTOCKPHOTO

When a plane files through clouds of volcanic ash, the jet engine's heat can melt the ash that flows into it, fusing onto the internal engine parts and causing the engine to lose power and stop.

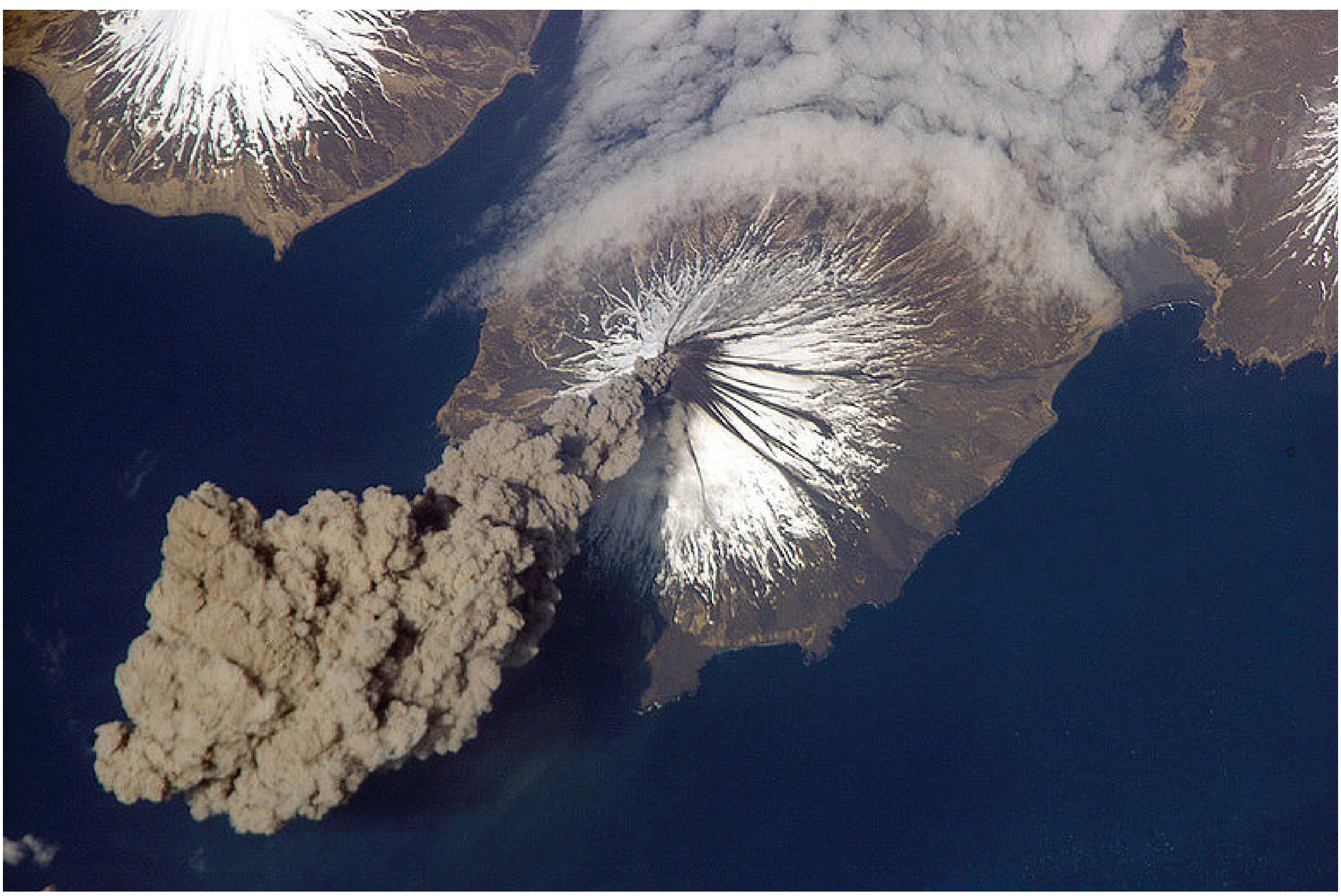
The largest volcanic event in the twentieth century—the 1912 eruption of the Katmai volcano on the Alaska Peninsula approximately 300 miles southwest of Anchorage—likewise had little impact on the climate. While Katmai ejected large amounts of sulfur, the volcano is so far north that the aerosols stayed in the north where there is less solar energy to absorb and reflect. Thus the global effects were weaker than for a tropical volcano.

In contrast, the June 1991 eruption of Mount Pinatubo in the Philippines, the century's second-largest eruption, created enough haze to cool the global atmosphere by an average of almost 1°F. In its 2007 report, the Intergovernmental Panel on Climate Change called Pinatubo the "best-documented explosive volcanic event to date," adding that the "growth and decay of aerosols resulting from this eruption have provided a basis for modeling (the effects) due to explosive volcanoes."

> "[t]he airplane flew into a cloud of volcanic ash from the violent eruption of Mount Galunggung"

Pinatubo modeling studies helped untangle some of the complex effects of big volcanic eruptions, including one answer for the big question of why some areas don't cool. Proving an exception to the general global cooling that occurred for two years after the Pinatubo eruption, parts of the polar and middle latitudes in the Northern Hemisphere had warmer-than-average winters in the following 2 years. Researchers concluded that the aerosols had affected the Arctic Oscillation, a seesaw pattern that influences weather around the Northern Hemisphere.

The Arctic Oscillation has a positive phase that includes stronger-than-average west-to-east winds roughly around the latitude of Moscow, Belfast, and Ketchikan, Alaska. These winds tend to make winters warmer than average by pulling in warm air from the oceans to North America and Eurasia and blocking frigid air from moving south. During the oscillation's negative



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Mount Cleveland in Alaska eruption in July 2006. Photographed by astronaut Jeffrey N. Williams from the International Space Station.

Monitoring Volcanoes

Soon after the next Pinatubo-size eruption spews sulfur high into the air, meteorologists should be able to predict the odds of warmer, cooler, or average temperatures for different parts of the earth during the coming months thanks to the extensive studies of the effects of past eruptions.

However, volcanologists can't predict where this eruption will be and whether it will occur tomorrow or 50 years from now. Fortunately, scientists can closely monitor volcanoes that threaten large numbers of people, such as those of the Cascade Range in Washington, Oregon, in northern California, and in Alaska. The U.S. Geological Survey says that its close monitoring of instruments that track escaping gases and ground movements on and near volcanoes means in most instances there will be time to warn people who live nearby and airline pilots when there is an increased risk of an eruption.

The United States has been expanding its volcano-monitoring network to the more than 30 volcanoes in Alaska's Aleutian island chain, which endanger few people on the ground, but which are a potential threat to the many airplanes that fly over this region each day. One goal is to be able to notify the Anchorage Volcanic Ash Advisory Center within 5 minutes of the beginning of an eruption.

In nations that can't afford extensive volcano monitoring, eruptions still occur without warning, threatening both people who live near the volcanoes and those flying overhead. For many volcanoes around the world, the first news of an eruption comes from the pilots of an airplane who have inadvertently flown into an ash cloud.

Today, unlike in the 1980s, most pilots who fly over volcanoes have been trained on how to quickly recognize and react to an encounter with volcanic ash.

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The June 12, 1991 eruption column from Mount Pinatubo seen from Clark Air Base. Warnings from volcano experts had prompted the U.S. Air Force to evacuate everyone from the base by this time. Extensive volcanic ash damage to the base led the United States to speed up plans to turn it over to the Philippines, which it did in November 1992.

phase, with its weaker winds in this belt, more outbreaks of frigid air move south over North America and into Europe. In brief, the scientists concluded that the heating and cooling of different parts of the atmosphere by the Pinatubo aerosols had changed air-pressure patterns in ways that strengthened the Arctic Oscillation's positive phase.

Because several studies have confirmed that large volcanoes cool the earth naturally, some people are arguing for large amounts of sulfur dioxide to be injected into the stratosphere to offset the general warming of earth caused by the greenhouse gases that humans are adding to the air. Many atmospheric scientists have grave doubts about this and other proposals for using "geoengineering" to offset climate change. As the American Meteorological Society said in a statement issued in July 2009: "Indeed, geoengineering must be viewed with caution, because manipulating the Earth system has considerable potential to trigger adverse and unpredictable consequences."

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