THE YEAR WITHOUT SUMMER: 1816

AND THE VOLCANO THAT DARKENED THE WORLD AND CHANGED HISTORY

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To Janet and Emma

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1.

THE VOLCANO

JUST BEFORE SUNSET on April 5, 1815, a massive explosion shook the volcanic island of Sumbawa the Indonesian archipelago. For two hours, a stream of lava erupted from Mount Tambora, the highe peak in the region, sending a plume of ash eighteen miles into the sky.

More than eight hundred miles away, Thomas Stamford Raffles, the lieutenant-governor of Jav heard the blast at his residence and assumed it came from cannon firing in the distance. Other Britis authorities on the island made the same mistake. Fearing a neighboring village was under attack, th commander of the city of Djogjokarta, in central Java, dispatched troops to repel the invader Officials along the coast interpreted the sounds as signals from a ship in distress, and launched rescu boats to look for survivors.

At Makassar on the southwestern tip of Sulawesi, 240 miles northeast of Tambora, the command of the *Benares*, a cruiser of the British East India Company, reported “a firing of cannon” on April The explosions appeared to come from the south; as they continued, “the reports seemed to approa much nearer, and sounded like heavy guns occasionally, with slighter reports between.” Assuming th pirates were in the area, the *Benares* put to sea and spent the next three days scouring nearby islan for any signs of trouble, but found nothing. Nearly five hundred miles farther to the east, the Britis resident on the island of Ternate heard “several very distinct reports like heavy cannon,” and se another cruiser, the *Teignmouth*, to investigate. It, too, returned empty-handed.

British authorities might have been excused for assuming that the threatening sounds came fro potential enemies rather than the earth itself. They were not yet accustomed to the frequent volcan eruptions that plagued the Indonesian islands. Britain had gained control of Java and the surroundi islands less than four years earlier, when British troops overwhelmed a vastly outnumbered band French defenders who themselves had held Java for only a short time, having taken it from the Dut when France conquered the Netherlands in 1794. By the spring of 1815, neither the government London nor the British East India Company was entirely certain that they wanted to keep the islan since the expense of administering and defending it had outweighed the commercial benefits thus far

Responsibility for British policy on the scene lay squarely with Raffles himself. The son of a ship captain, Raffles—who actually was born at sea, off the coast of Jamaica—dreamt of a Britis maritime empire throughout South Asia, an “Eastern insular Empire” that would provide new marke for English cotton and woolen textiles, and a profitable supply of coffee and sugar for Europe. It w

Raffles who had persuaded the governor general of India, Lord Minto, to seize Java in the first plac
Raffles also hoped to use Java as an avenue to improve relations with Japan, which he viewed as rising Asiatic power. Meanwhile, heeding Minto’s advice to “do as much good as we can” whi governing Java, Raffles reformed the colonial administration of the island, limiting the powers of t great landowners over their tenants and ameliorating the worst abuses of slavery while banning t importation of slaves under fourteen years of age.

But Raffles’ interests in the region extended beyond politics and commerce. After years of stud he was sufficiently fluent in the Malay language to conduct discussions directly with local chieftai He regularly employed botanists and zoologists to obtain—at his own expense—specimens of loc flora and wildlife, some of which he had preserved in spirit and shipped back to Britain. In h capacity as president of the Batavian Society, dedicated to the study of Java’s natural history, Raffl frequently toured the island and recorded his observations of geological phenomena. Several wee before Mount Tambora erupted, Raffles became the first European to ascend a nearby mounta known as Gunong Gede; by using thermometers to measure the difference in temperature between t base and the peak, Raffles and his companions determined that they had climbed at least sev thousand feet. “We had a most extensive prospect from the summit,” he subsequently wrote to friend. “The islands all round were quite distinct and we traced the sea beyond the southernmost poi of Sumatra; the surf on the south coast was visible to the naked eye.”

So Raffles’ scientific curiosity was piqued when the cannonlike explosions from the southea continued throughout the night of April 5 and into the morning hours. Shortly after dawn, a light ra of ash provided evidence that a volcano somewhere in the region had erupted. Few suspected Mou Tambora. It was generally believed that Tambora was extinct, although natives living in the neare village had reported rumblings from deep inside the mountain during the past year. Besides, few o Java believed that such powerful sounds could have come from a volcano several hundred miles awa As Raffles subsequently noted, “the sound appeared to be so close, that in each district it seemed ne at hand, and was generally attributed to an eruption either from the mountains Merapi, Klut, Bromo.”

As a fog of ash drifted across Java, the sun faded; the warm, humid air grew stifling, a everything seemed unnaturally still. The oppressive pressure, Raffles noted, “seemed to forbode earthquake.” Over the next several days, however, the explosions gradually subsided. Volcanic as continued to fall, but in diminishing quantities. Relieved, Raffles returned to his routi administrative duties.

* * *

FAR from Tambora and the island of Java, a different sort of shock greeted the rulers and citizens Europe in April 1815: Napoléon had returned to Paris.

The Emperor had spent the past year ruling the island of Elba, a rocky, desolate piece of real esta of no discernible strategic importance off the coast of Italy. Sixteen miles long and only seven mil across at its widest point, Elba in the early nineteenth century was home mainly to goats, desert ruins, a variety of vines and scraggly shrubs on arid hillsides, and approximately twelve thousan impoverished peasants with a well-deserved reputation for being "extremely irritable" and "almo universally ignorant." Its primary natural resource was rocks. One French observer who visited Ell shortly before Napoléon's arrival warned that the island's unremittingly inhospitable topography w likely to "fatigue the senses and impart sensations of sorrow to the soul."

Napoléon had been consigned to Elba by the victorious allied coalition of Britain, Prussia, Austri and Russia shortly after abdicating the French throne on April 6, 1814. (Perhaps as an ironic jest, the allowed him to retain the title of "Emperor.") But the Allied statesmen who gathered at Vienna to so out the consequences of nearly two decades of war neglected to provide a jailer, or even an effectiv network of informants to keep them apprised of Napoléon's movements. Encouraged by press repor of widespread popular disaffection with the restored Bourbon monarchy in Paris, Napoléon decid that his former subjects would welcome him back. And so on February 25, 1815, accompanied b slightly more than a thousand troops, forty horses, and four cannon, Napoléon sailed away from Ell unopposed.

Six days later he landed at Golfe Juan, about a mile west of Cannes. "Frenchmen! In my exile have heard your complaints and your wishes," he exclaimed. "I have arrived in spite of every obstacl and every danger." Napoléon marched north rapidly, opposition crumbling as his entourage expand at every town. "Taking towns at his liking and crowns at his leisure / From Elba to Lyons and Paris h goes," crowed Lord Byron, who admired Napoléon and fancied himself an English counterpart of th Eagle. Although many of Napoléon's former subjects—particularly his troops—greeted hi enthusiastically, others responded more warily. Their caution reflected the heavy costs of Napoléon previous quest for glory: more than 900,000 French soldiers dead, and a depleted national treasu now saddled with millions of francs of reparations due the Allies. Napoléon attempted to allay the anxieties by publicly disavowing any new imperial ambitions. "I want less to be sovereign of France he told the people of Grenoble, "than the first of her citizens."

News of Napoléon's flight reached Vienna on March 7. Stunned, the Allied representatives decid within hours to send troops to oppose Napoléon, but they also embargoed the news from France f several days until they were prepared to make a public statement. Several days later, they joint declared that by reappearing in France, Napoléon had proved himself "an enemy and disturber of th peace of the world," and that together, "the sovereigns of Europe would be ready to give the King France and the French nation the assistance necessary to restore peace."

King Louis XVIII would need all the help he could get. Twenty-two years after the execution of h brother, Louis XVI, few Frenchmen outside of a die-hard circle of royalists desired to return to th days of a pre-Revolutionary monarchy. Too much land belonging to the king, the aristocracy, and th church had been dispensed to too many members of the Third Estate to turn back the clock. Nor had year of life under the restored Bourbon dynasty endeared King Louis to his subjects. Facing a immense national debt which he inherited from Napoléon, Louis' ministers found it necessary to slas the army budget, cancelling contracts for military supplies and throwing nearly three hundre thousand soldiers out of work. The government also reduced spending on public construction projec while maintaining an oppressive array of taxes. As unemployment rose along with the price of brea hungry citizens in Channel ports rioted against the shipment of grain to Britain. "We are really goin on very badly," wrote one government official, "and we must do better if we do not wish to peris completely."

Louis himself engendered little personal loyalty, or even respect; a British bishop once said that th French king was "a man fit only to cook his own capons." Fifty-eight years old and so gross overweight that he could not sit on a horse, Louis abhorred hard work and delegated authority wi alacrity. Despite a modest measure of charm in private conversations, Louis never developed compelling public presence. Certainly he paled in comparison with the charismatic former empero As Napoléon hastened towards the capital in March, covering two hundred miles in six days, Lou grew increasingly anxious. Ominous strains of the incendiary *Marseillaise* rang through Paris street royal troops deserted en masse and went over to Napoléon; and newspaper editorials likened th situation to the eve of the Terror, when nobles and monarchists were slaughtered. Recognizing that, one writer put it, "the Parisians love for their King has so died down that barely a spark remains Louis decided on the evening of March 18 to flee Paris.

Three days later, Napoléon entered the city without a shot being fired. By the first week of Apri however, it was clear that the weary and impoverished French public lacked any appetite for ambitiou schemes to restore the glory of the empire. Napoléon's proposals for new taxes to fund a revitalize army met with widespread opposition. Visible signs of disaffection appeared; rallies in support of th emperor's return clashed with demonstrations demanding his ouster. To bolster his defenses again the Allied assault he knew was coming, Napoléon issued orders on April 8 for a general mobilizatio of the French nation. Meanwhile, he assured the sovereigns of Europe (whom he formally referred as "my brothers") that he wanted nothing more than "the maintenance of an honourable peace."

But more than anything else, France—and the rest of Europe—desperately needed a breathin space. A year earlier, the Marquis de Caulaincourt had written that "the need for rest was s universally felt through every class of society, and in the army, that peace at any price had become th ruling passion of the day." Napoléon's return from Elba only deepened the prevailing exhaustio "Our objective is to make sure that our children have years of peace," noted the Austrian general Ka Schwarzenberg, "and that the world has some repose. The Emperor Napoléon had shown all to plainly of late that he desires neither of these things."

* * *

AROUND seven o'clock on the evening of April 10, Mount Tambora erupted once again, this time f more violently. Three columns of flaming lava shot into the air, meeting briefly at their peak in wh one eyewitness termed “a troubled confused manner.” Almost immediately the entire mounta appeared to be consumed by liquid fire, a fountain of ash, water, and molten rock shooting in ever direction. Pumice stones—some walnut-sized but others twice the size of a man’s fist—rained dow upon the village of Sanggar, nineteen miles away. After an hour, so much ash and dust had been hurl into the atmosphere that darkness hid the fiery mountaintop from view.

As the ash clouds thickened, hot lava racing down the mountain slope heated the air above it thousands of degrees. The air quickly rose, leaving behind a vacuum into which cooler air rushed fro all directions. The resulting whirlwind tore up trees by the roots and swept up men, cattle, and horse Virtually every house in Sanggar was flattened. The village of Tambora, closer to the volcan vanished under a flood of pumice. Cascading lava slammed into the ocean, destroying all aquatic li in its path, and creating tsunamis nearly fifteen feet high which swept away everything within the reach. Violent explosions from the reaction of lava with cold seawater threw even greater quantities ash into the atmosphere, and created vast fields of pumice stones along the shoreline. These field some of which were three miles wide, were light enough to float; they drifted out to sea where the were driven west by the prevailing winds and ocean currents. Like giant icebergs, the pumice fiel remained a hazard to ships for years after the eruption. The British ship *Fairlie* encountered one in t South Indian Ocean in October 1815, more than 2,000 miles west-southwest of Tambora. The cre initially mistook the ash for seaweed, but when they approached they were shocked “to find [composed of] burnt cinders, evidently volcanic. The sea was covered with it during the next tw days.” As there was no land for hundreds of miles (and evidently being unable to believe that t pumice could have traveled that far) the crew attributed the field to an underwater eruption unknown location.

At ten o’clock the magma columns—which now consisted almost entirely of molten rock and as most of the water having boiled away and evaporated—collapsed under their own weight. T eruption destroyed the top three thousand feet of the volcano, blasting it into the air in pieces, leavi behind only a large crater three miles wide and half a mile deep, as though the mountain had bee struck by a meteor. Propelled by the force of the eruption, gray and black particles of ash, dust, a soot rose high into the atmosphere, some as high as twenty-five miles above the crumbling peak of t mountain, where the winds began to spread them in all directions. As they moved away from t eruption, the largest, heaviest particles lost their momentum first and began to fall back towards t ground. This gave the ash cloud the shape of a mushroom or an umbrella, with the still-erupti Tambora as the fiery shaft. The lightest particles in the cloud, however, retained their momentum a remained high in the air; some even continued to rise.

By eleven o’clock, the whirlwind had subsided. Only then did the explosions commence. At Bim on the northeast coast of Sumbawa about forty miles east of Tambora, the British resident reporte that the blasts sounded like “a heavy mortar fired close to his ear.” A rain of ash poured down upo the villages, heavy enough to crush the roofs of houses, including the resident's, rendering the uninhabitable. Waves surged in from the sea, flooding houses a foot deep and ripping fishing boa from their moorings in the harbor, tossing them high up onto the shore. In place of dawn, there w only darkness.

On board the *Benares*, still moored at Makassar, sailors heard the explosions—far louder than tho o f the previous eruption—throughout the night. "Towards morning the reports were in quic succession," noted the ship's commander, "and sometimes like three or four guns fired together, an so heavy, that they shook the ship, as they did the houses in the fort." As soon as a semblance of dav broke, the cruiser again set sail southward, to determine the cause of the blasts.

But the sky troubled the *Benares*'s captain. "By this time," he noted, "which was about eight A.M., was very apparent that some extraordinary occurrence had taken place. The face of the heavens to th southward and westward had assumed the most dismal and lowering aspect, and it was much dark than when the sun rose." What appeared to be a heavy squall on the horizon quickly took on a dark re glow, spreading across the sky. "By ten it was so dark that I could scarcely discern the ship from th shore, though not a mile distant." Ash began to fall on the decks of the *Benares*. An hour later, nearl the entire sky was blotted out.

By this time, Tambora's umbrella ash cloud extended for more than three hundred miles at i widest point. As the cloud spread, the heavier clumps of ash within it drifted to the ground, but the re remained aloft. "The ashes now began to fall in showers," the ship's captain wrote, "and th appearance altogether was truly awful and alarming." By noon, the darkness was complete, and th rain of ash—which one sailor described as a tasteless "perfect impalpable powder or dust" that gav off a vaguely burnt odor—covered every surface on the ship. "The darkness was so profour throughout the remainder of the day," continued the commander, "that I never saw any thing equal t it in the darkest night; it was impossible to see your hand when held up close to the eye." As continued to fall throughout the evening; despite the captain's efforts to cover the deck with awning the particles piled as much as a foot high on many surfaces. At six o'clock the following mornin there was still no sign of the sun, but the accumulated weight of the ash—which one officer estimate at several tons—forced the crew to begin tossing the powder overboard. Finally by noon on April 12, faint light broke through, and the captain was struck by the thought that the *Benares* resembl nothing more than a giant calcified pumice stone. For the next three days, however, he noted that "th atmosphere still continued very thick and dusky from the ashes that remained suspended, the rays the sun scarce able to penetrate through it, with little or no wind the whole time."

A Malaysian ship from Timor sailing through the region also found itself in "utter darkness" o April 11. As it passed by Tambora, the commander saw that the lower part of the mountain was still flames. Landing farther down the coast to search for fresh water, he found the ground "covered wi ashes to the depth of three feet," and many of the inhabitants dead. When the ship departed on a stron westward current, it had to zigzag through a mass of cinders floating on the sea, more than a foot thic and several miles across.

On the island of Sumatra, over a thousand miles west of Tambora, local chieftains heard th explosions on the morning of April 11. Fearing a conflict had broken out between rival villages, the hurried down to Fort Marlborough, the British encampment in Bengkulu. Other tribal chieftains o Sumatra and the neighboring islands also assumed the sounds presaged some sort of invasion, b once they received reassurance on that score, they ascribed the explosions to supernatural causes. “O chiefs here,” reported an official at Fort Marlborough, “decided that it was only a contest between J (the very devil), with some of his awkward squad, and the manes of their departed ancestors, who ha passed their period of probation in the mountains, and were in progress towards paradise.”

At Gresik on eastern Java, natives decided that the blasts were the “supernatural artillery” of th venerated South Java Sea spirit queen Nyai Loroh Kidul, fired to celebrate the marriage of one of h children; the ash was “the dregs of her ammunition.” If so, her ammunition made most of April 1 utterly dark in the village. When the British resident in Gresik awoke that morning, he had th impression that he had slept through a very long night. Reading his watch by lamplight, he discovere that it was 8:30 A.M., and pitch-black outside from the cloud of ashes descending. He breakfasted b candlelight at 11:00 and thought he could see a faint glimmering of light, but at 5 P.M. he still cou “neither read nor write without candle.” In the nearby village of Sumenep, ash fell about two inch thick, and “the trees also were loaded with it.”

A tsunami reached eastern Java around midnight on April 10–11, and tremors struck the centr region of the island eighteen hours after the eruption. Between two and three in the afternoon of Apr 11, a European observer in the village of Surakarta (Solo) noticed “a tremulous motion of the eart distinctly indicated by the tremor of large window frames; another comparatively violent explosio occurred late in the afternoon.… The atmosphere appeared to be loaded with a thick vapour: the Su was rarely visible, and only at short intervals appearing very obscurely behind a semitranspare substance.” Surakarta remained in darkness for much of the following day, as well. Raffles, to reported that even at a distance of eight hundred miles, “showers of ashes covered the houses, th streets, and the fields, to the depth of several inches; and amid this darkness explosions were heard intervals, like the report of artillery or the noise of distant thunder.”

Twenty-four hours after Tambora erupted, the ash cloud had expanded to cover an are approximately the size of Australia. Air temperatures in the region plunged dramatically, perhaps much as twenty degrees Fahrenheit. Then a light southeasterly breeze sprang up, and over the ne several days most of the ash cloud drifted over the islands west and northwest of Tambora. By th time the cloud finally departed, villages within twenty miles of the volcano were covered with as nearly forty inches thick; those a hundred miles away found eight to ten inches of ash on the ground.

Even a small quantity of ash could devastate plants and wildlife. One district that received abo one-and-a-quarter inch of ash discovered that its crops were “completely beaten down and covered b it.” Dead fish floated on the surfaces of ponds, and scores of small birds lay dead on the ground.

By the time the volcano finally subsided, Tambora had released an estimated one hundred cub kilometers of molten rock as ash and pumice—enough to cover a square area one hundred miles c each side to a depth of almost twelve feet—making it the largest known volcanic eruption in the pa 2,000 years. Geologists measure eruptions by the Volcanic Explosivity Index, which uses whol numbers from 0 to 8 to rate the relative amount of ash, dust, and sulphur a volcano throws into tl atmosphere. Like the Richter Scale for earthquakes, each step along the Explosivity Index is equal to tenfold increase in the magnitude of the eruption. Tambora merits an Index score of 7, making tl eruption approximately one thousand times more powerful than the Icelandic volcano Eyjafjallajöku which disrupted trans-Atlantic air travel in 2010 but rated only a 4; one hundred times stronger tha Mount St. Helens (a 5); and ten times more powerful than Krakatoa (a 6). Only four other eruptions the last hundred centuries have reached a score of 7. Modern scientists identify and measure pa eruptions using layers of volcanic debris found in ice cores, lake sediments, and other undisturbe soils. Each eruption has a distinct chemical signature that, along with conventional methods of carbo dating, can be used to associate each layer of volcanic material with a particular eruption.

Volcano	Location	Year of eruption	Volcanic Explosivity Index
Vesuvius	Italy	79	5
Huaynaputina	Peru	1600	6
Tambora	Indonesia	1815	7
Krakatoa	Indonesia	1883	6
Santa Maria	Guatemala	1902	6
Mount St. Helens	Washington, USA	1980	5
Pinatubo	Philippines	1991	6
Eyjafjallajökull	Iceland	2010	4

(Source for table: Smithsonian Museum of Natural History; http://www.volcano.si.edu/world/largeeruptions.cfm)

It was also by far the deadliest eruption in recorded history. As soon as the volcano quieted, Raffl ordered the British residents to make a survey of their districts to ascertain the extent of the damag The reports that reached him detailed a horrific picture.

Before the eruption, more than twelve thousand natives lived in the immediate vicinity of Tambor They never had a chance to escape. Nearly all of them died within the first twenty-four hours, most from ash falls and pyroclastic flows—rapidly moving streams of partially liquefied rock ar superheated gas at temperatures up to 1,000 degrees, hot enough to melt glass. Carbonized remains villagers caught unaware were buried beneath the lava; fewer than one hundred people survived. "Tl trees and herbage of every description, along the whole of the north and west sides of the peninsula reported one British official, "have been completely destroyed." Another found that in the are surrounding Mount Tambora, "the cattle and inhabitants were nearly all of them destroyed … ar those who survived were in such a state of deplorable starvation, that they would unavoidably sha the same fate.” One village had sunk entirely, its former site now covered by more than three fathom (eighteen feet) of water. And the Raja of Sanggar confirmed that “the whole of his country w entirely desolate, and the crops destroyed.” The survivors of his village were living on coconuts, b even the supply of that food was nearly exhausted.

On April 19, the *Benares* reached Bima. The coastline was barely recognizable; what had been on of the most beautiful and regular harbors in Asia now was an obstacle course, littered with masses black pumice stone, tree trunks burnt and splintered as if by lightning, and the prows of previous sunken ships which the ocean had thrown onto land. The village had only a small supply of rice stave off starvation. When the *Benares* departed several days later, it sailed past Mount Tambor which had been one of the highest peaks in the archipelago, often used by sailors as a landmar Clouds of smoke and ash still obscured the volcano’s peak. Even at a distance of six miles, sailo could see patches of lava steaming along the mountainside.

A heavy rainstorm on April 17 had left the air cleaner and cooler, and probably saved a substanti number of lives on the more distant islands as the rain washed the ash off crops and provided fres drinking water to help stem an incipient epidemic of fever. But nothing could save those closer Tambora. Over the following month, thousands more perished—some from severe respirato infections from the ash that remained in the atmosphere in the aftermath of the eruption, others fro violent diarrhoeal disease, the result of drinking water contaminated with acidic ash. The same dead ash poisoned crops, especially the vital rice fields, raising the death toll higher. Horses and catt perished by the hundreds, mainly from a lack of forage. Lieutenant Owen Phillips, dispatched b Raffles to investigate conditions and provide an emergency supply of rice to the inhabitants, arrived Bima several weeks after the eruption and reported that “the extreme misery to which the inhabitan have been reduced is shocking to behold. There were still on the road side the remains of sever corpses, and the marks of where many others had been interred: the villages almost entirely desert and the houses fallen down, the surviving inhabitants having dispersed in search of food.” In th nearby village of Dompo, residents were reduced to eating stalks of papaya and plantain, and the head of palm. Even the Raja of Sanggar lost a daughter to hunger.

In the end, perhaps another seventy to eighty thousand people died from starvation or disea caused by the eruption, bringing the death toll to nearly ninety thousand in Indonesia alone. No oth volcanic explosion in history has come close to wreaking disaster of that magnitude.

And yet there would be more casualties from Tambora. In addition to millions of tons of ash, th force of the eruption threw 55 million tons of sulfur-dioxide gas more than twenty miles into the a into the stratosphere. There, the sulfur dioxide rapidly combined with readily available hydroxide g —which, in liquid form, is commonly known as hydrogen peroxide—to form more than 100 millio tons of sulfuric acid. The sulfuric acid condensed into minute droplets—each two hundred times fin than the width of a human hair—that could easily remain suspended in the air as an aerosol cloud. Th strong stratospheric jet streams quickly accelerated the particles to a velocity of about sixty miles p hour, blowing primarily in an east-to-west direction. The sheer power of the jet stream allowed th aerosol cloud to circumnavigate Earth in two weeks; but the cloud did not remain coherent.

Variations in the wind speed and the weight of the particles caused some parts of the cloud to trav faster or slower than others, and so the cloud spread as it moved around Earth, until it covered th equator with an almost imperceptible veil of dust and sulfurous particles. It also began to spread nor and south, albeit far more slowly. While it took only two weeks for the aerosol cloud to cover th globe at the equator, it was likely more than two months before it reached the North and South Poles.

Rather than a slow, steady broadening of the equatorial cloud into the Northern and Southe Hemispheres, the cloud expanded in fits and starts. As some pieces of the cloud were blown awa from the equator, they were quickly caught up in the dominant stratospheric jet streams—which May blow east to west in the Northern Hemisphere, and west to east in the Southern Hemisphere. Th cloud soon began to resemble streamers or filaments, with small portions regularly pushed off th equator and into the middle latitudes in each hemisphere. Eventually, these filaments coalesced into single, coherent cloud that covered Earth.

And there they remained. Had the aerosol cloud ascended only into the lowest part of th atmosphere, the troposphere, where clouds form, rain would soon have cleansed the ash from the ai But in the more stable stratosphere, conditions mitigate against the formation of clouds of wat droplets. The coldest air already is at the bottom of the stratosphere, with warmer air above it, so a rarely rises from the troposphere into the stratosphere. With no rising plumes of warm air to carr moisture into the stratosphere, clouds almost never form; the stratosphere is drier than most desert With no clouds, there could be no rain to wash away the stratospheric aerosol veil. Only the slo action of gravity and the occasional circulation of air between the stratosphere and the tropospher could drag the droplets back to the earth. And so the extraordinarily fine sulfur particles fro Tambora that reached the stratosphere remained suspended in the air for years, freely transporte around the globe by the winds. By the winter of 1815–16, the nearly invisible veil of ash covered th globe, reflecting sunlight, cooling temperatures, and wreaking havoc on weather patterns.

2.

PORTENTS

“The country has all the appearance of the middle of winter…”

FROM TERAMO IN central Italy, near the Adriatic coast, came reports in late December 1815 of “th heaviest snow ever known in that country.” According to one account, over a six-hour period “ greater quantity of snow [fell] than has been known in the memory of man.” More astonishing was th nature of the precipitation. The snow “was of a red and yellow color … [which] excited great fear an apprehension in the people.” Believing that “something extraordinary has taken place in the air,” th local residents organized religious processions to placate God; in the meantime, provincial authoriti summoned a professor of physical science from Parma (who was also a Jesuit priest) to study th phenomenon. For the rest of the winter, the Abruzzo region remained cold, with significantly mo snow and freezing rain than usual.

Several weeks later, an intense blizzard raged across northeastern Hungary for two days. The sno reportedly covered houses to the rooftops, and killed more than ten thousand sheep and hundreds oxen. Despite the magnitude of the storm, news accounts focused primarily on the fact that “the sno was not white, but brown or flesh colored.” April brought reports of another colored snowfall in Ital this time around the Tonale Pass, in the Italian Alps: “It was brick red and left an earthy powder, ver light and impalpable, unctuous to the touch … [with an] astringent taste.” The colored snow almo certainly was the result of ice droplets forming with ash particles from Tambora as their nuclei. Th deepest clouds associated with severe storms occasionally are able to reach into the stratospher which is consistent with the colored snow falling in particularly extreme weather events. Over th course of months—and, in this case, years—gravity also slowly dragged the stratospheric sulf particles into the upper reaches of the troposphere, where the particles could more easily form th centers of ice crystals.

No contemporary accounts appear to have made the connection between the phenomenon colored snow in Italy and Hungary and the eruption of Mount Tambora nearly halfway around th world, although reports of Tambora had reached London by the end of 1815, and a few amate scientists—most famously Benjamin Franklin—had previously essayed a connection betwe volcanic eruptions and unusual atmospheric conditions. Following the eight-month-long eruption Laki in southern Iceland in June 1783, Europe and North America experienced highly unusu weather, including a persistent dry haze during the summer and an extremely cold and snowy wint that killed thousands of people across Europe. Although Franklin, who was living in Europe at th time, acknowledged in a 1784 lecture to the Manchester Literary and Philosophical Association th "the cause of this universal fog is not yet ascertained," he suggested that it may have been "the va quantity of smoke, long continuing, to issue during the summer [from Laki] … which smoke might l spread by various winds, over the northern part of the world." And the frigid temperatures, l proposed, probably resulted from this fog blocking the rays of the sun, thereby reducing the amount solar energy that reached Earth.

Throughout the winter of 1815–16, the spreading aerosol cloud from Mount Tambora had bee doing precisely that: cooling global temperatures by reflecting and scattering sunlight. Although th cloud reflected only one half to one percent of the incoming energy, it reduced the Norther Hemisphere average temperature in 1816 by about three degrees Fahrenheit. This seemingly sma cooling had a considerable impact on global weather patterns, with devastating consequences f agriculture on both sides of the Atlantic. Ironically, however, the effects of Tambora's aerosol clou could have been far worse if the eruption had been slightly weaker. While immense in size and scop Tambora's aerosol cloud was not particularly efficient at reflecting sunlight. Stronger volcan eruptions tend to eject more sulfur dioxide into the stratosphere than weaker eruptions, which leads more sulfuric acid droplets within the same volume of atmospheric gases. A greater number o droplets increases the chance that droplets will meet and collide, forming larger droplets that will l removed more quickly from the stratosphere by gravity. A single, larger droplet also has less tota surface area than two smaller droplets, and so is less effective at scattering sunlight. There is therefo a balance to be struck between eruptions that are too weak to penetrate into the stratosphere—and s produce small, short-lived cooling—and eruptions that produce large, less effective sulfuric ac droplets. By measuring the remnants of Tambora's aerosol cloud in ice cores and lake sediment modern scientists have determined that the climatic consequences—while undoubtedly devastating- could have been far worse if the particles had been roughly half their size.

Unlike the sudden drop in temperatures in the Indonesian archipelago that occurred immediate after the eruption of Mount Tambora, the planet-wide cooling was a gradual process that took up to year to be fully realized. While air temperatures can, and frequently do, change rapidly in response variations in solar energy, soil and ocean temperatures adjust much more slowly. The land and se possess considerable capacity to store heat, while the atmosphere has practically no storage. When th atmosphere is cooler than the land and sea, heat will flow from these reservoirs back into the air; b since the air cannot store heat for long, much of this is soon lost to space. If, on the other hand, th atmosphere is warmer, some of that excess heat will be stored in soil and water until a balance reached. This process may be seen clearly in summer: The warmest weather often occurs not in Jun when the sun is strongest, but in August, when the ocean and land have warmed.

As Tambora's stratospheric aerosol cloud began to cool temperatures by subtly reducing th

amount of solar energy reaching the earth, the land and oceans would have resisted this cooling b
transferring stored heat into the atmosphere, and cooling themselves as a result. By early 1816, th
land, ocean, and atmosphere were shifting toward a new balance of energies, largely as a result of th
solar-dimming effect of the aerosol cloud. The adjustment cooled first air, then land, and finally ocea
temperatures across the globe. Using information from tree rings—the width of each ring is related
the growing conditions (mostly temperature and precipitation) that year—climatologists hav
determined that 1816 was the second-coldest year in the Northern Hemisphere since 1400, surpass
only by 1601, following the eruption of Huaynaputina in Peru. Even as the aerosol began to settle o
of the atmosphere through gravity, it would take years for land and ocean temperatures to return
normal. And so 1817 was the fifth coldest, 1818 the twenty-second coldest, and 1819 the twenty-nin
coldest year in the Northern Hemisphere since 1400.

In the meantime, the aerosol cloud had produced other noticeable optical phenomena, most notab
a series of spectacular red, purple, and orange sunsets in London in the summer and autumn of 181
Observers noted repeatedly that "the sky exhibited in places a fire," with "crimson cirri" [hig
altitude cirrus clouds, composed of fine ice particles] and "much redness in the twilight." "Th
evening twilight has been generally coloured of late," wrote one contemporary, "and at times streake
with converging shadows, the origin of which could not be traced to clouds intercepting the light." O
several particularly unsettled September nights, the storm clouds continued to glow various shades
red for half an hour after sunset.

Sunsets typically appear yellow, orange, or red because atmospheric gases scatter blue light mo
effectively than other colors, skewing the visible-light spectrum toward red. The effect is even mo
pronounced when the sun is low on the horizon, since its light must pass through a thicker layer of th
atmosphere to reach the ground, resulting in less blue and more red light.

Stratospheric ash, dust, and soot particles from volcanic eruptions—or from pollution or fires-
enhance this atmospheric scattering effect, leading to brilliant red sunsets. After the sun passes belo
the horizon and light no longer reaches the surface, some sunlight still passes through the upp
portions of the atmosphere. Aerosol veils reflect this sunlight toward Earth, giving the colorf
postsunset glows reported in London. So exceptional were these sunsets that Londoners commented o
them repeatedly in letters, journals, and newspaper articles, which suggests that they likely we
caused by the Tambora aerosol cloud rather than the heavy industrial pollution that habitual
afflicted the city during that era. In fact, scientists have taken advantage of this effect by using th
amount of red in contemporary paintings of sunsets to estimate the intensity of volcanic eruption
Several Greek scientists, led by C. S. Zerefos, digitally measured the amount of red—relative to oth
primary colors—in more than 550 samples of landscape art by 181 artists from the sixteenth throug
the nineteenth centuries to produce estimates of the amount of volcanic ash in the air at various time
Paintings from the years following the Tambora eruption used the most red paint; those after Krakat
came a close second.

* * *

Americans greeted the year 1816 with confidence and optimism. They had recently concluded tw and a half years of war with Great Britain, arguably the strongest and certainly the wealthiest nation the world, and the conflict had ended essentially in a draw. Admittedly the British had captured ar partially burned the nation's capital, forcing President Madison and his wife, Dolley, to flee for the lives, accompanied by several wagons full of White House valuables and Cabinet papers stuffed in trunks. But American troops led by General Andrew Jackson had ended the fighting on such a positiv note with their overwhelming victory over a numerically superior force of British regulars at Ne Orleans in January 1815, that many Americans believed they had actually won the War of 1812.

European events since that time offered hope that the United States could look forward to a lo period of peace, undisturbed by events abroad. On June 18, 1815, British and Prussian troo commanded by the Duke of Wellington and Marshal Blucher dealt a crushing defeat to Napoléon army outside the Belgian town of Waterloo. The outcome had hung in the balance for most of the da Wellington later acknowledged that the battle had been "the nearest run thing you ever saw in yo life." It had been exactly a hundred days since Napoléon had entered Paris in triumph. This time, t Allied statesmen at Vienna gave the British government sole authority to choose the site of t Eagle's exile—it selected the remote island of Saint Helena, in the South Atlantic—and so responsibility for keeping him there. With Napoléon removed from the scene, it seemed unlikely th the United States would be drawn into European affairs anytime in the near future. "We are, happil at peace with all the world," exulted one Massachusetts congressman, "and there are no indicatio which threaten soon to disturb this tranquility."

Everything in the United States appeared to be expanding. Since 1789, the nation had added fi new states and five territories. By European standards, the United States's population was growing an astonishing rate. In 1815, there were nearly 8.5 million Americans, twice as many as there had bee only twenty-five years earlier. Immigration—primarily from northern and western Europe- contributed to this prolific growth, but most of the increase came from Americans who married you and had large families; on average, American women in the early nineteenth century had betwe seven and eight live births. It was also a very young population: 85 percent of the population w under the age of forty, including nearly all of the leaders of Congress.

Slightly more than 80 percent of Americans were white, and in a nation where land was cheap b labor scarce, the vast majority of white adults—more than 80 percent—made their living subsistence farmers. Most American farmers spent only a portion of their working hours tending the crops, however, doubling as coopers, or tanners, or blacksmiths, or shoemakers. Wives and childre frequently carded wool or spun linen in the evenings after spending their days in the fields. Far families produced enough goods for their own needs, and sold the rest. "Go into the interior of t country," wrote Albert Gallatin, former secretary of the treasury, "and you will scarcely find a farm who is not, in some degree, a trader. In a grazing part of the country, you will find them buying ar selling cattle; in other parts you will find them distillers, tanners, or brick-makers."

Fewer than seven percent of Americans lived in cities, the largest of which were New York ar Philadelphia, but neither even remotely approached the size of London or Manchester. Nearly all o the nation's towns were located on the East Coast, relying on commerce for their prosperity. Mo municipalities lacked any public sewer or water system, which meant that garbage, dead animals, ar human waste routinely accumulated in the streets.

Manufacturing remained relatively primitive. Beyond the products of farm families, most of th goods offered for sale were fashioned by mechanics working by hand, either in a small shop or home. Transportation was even less advanced. Goods and passengers rarely traveled very far ov land; American roads were notoriously poor, many no more than narrow, bumpy, overgrown trails th turned into quagmires when it rained. (Travelers told stories of horses actually drowning in the pit and wagons sinking slowly out of sight.) It cost as much to send a ton of goods thirty miles from a ocean port inland as it did to ship it three thousand miles across the Atlantic. And progress was slow; traveler who set out by carriage from Boston in April would not arrive in Charleston, South Carolin until July. In 1802, Congress had authorized the construction of the National Road across th Appalachians, but fourteen years later the road had not yet crossed the Ohio River. Hence merchan and farmers continued to rely on river systems to move goods in the interior.

Yet significant improvements lay close at hand. Steamboats, dismissed as "floating smokestack by skeptical observers when Samuel Fulton's prototype made its debut on the Hudson River in 180 were slowly gaining popularity, especially on the Western rivers. And Governor DeWitt Clinton o New York had begun to elicit legislative support for the construction of a canal (derided by his criti as "Clinton's Big Ditch" or "the Governor's Gutter") that would stretch across the state for 340 mil from Albany to Buffalo, through thick forests and disease-ridden swamps, connecting the Hudso River with the Great Lakes.

Manufacturing was poised to expand as well. When the recent war temporarily deprived America consumers of British goods, New England merchants and entrepreneurs provided financial backing f scores of small-scale domestic textile "manufactories" that produced a total of $24 million worth cotton goods and provided employment to nearly a hundred thousand men, women, and childre Americans produced an additional $19 million worth of woolen goods in 1815, and the Bosto Manufacturing Company, headed by Frances Cabot Lowell, had recently completed the nation's fir integrated textile factory along the Charles River in Waltham, Massachusetts.

In the aftermath of war, a new spirit of nationalism swept over the United States. For the pa twenty-five years, the nation had been riven by deep divisions over domestic issues—primari Alexander Hamilton's economic proposals—and the war in Europe. The disagreements produced th first two political parties in the United States: the Federalists, led by Hamilton and John Adams, wh were horrified at the disorder and excesses of the French Revolution; and the Democrati Republicans, who shared Thomas Jefferson's dislike of a strong central government, and Madison distrust of Great Britain.

Lately, however, many Republicans had come to accept much of the Federalist domestic agenda; powerful central government seemed less threatening if they controlled it, as they had since 180 (Madison, however, had grown no more fond of Britain since the king's troops burned the President Mansion in Washington; in early 1816 Madison was living in a private dwelling on the corner of Ne York Avenue and 18th Street known as the "Octagon House," while workmen repaired and repainte the mansion, this time with white rather than gray paint.) Moderate Federalists who could recognize lost cause were deserting to the opposition in increasing numbers. And a series of costly missteps b the dwindling band of hard-core Federalist stalwarts—including vocal opposition to the war effort ar a thinly veiled threat by New England political leaders in December 1814 to secede—destroyed ar hopes the Federalists may have entertained to regain power on the national level.

Partisan rancor thus subsided, although it did not entirely disappear when the Fourteenth Congre concluded its regular session in the spring of 1816. Legislators spent much of their time debatir economic issues. In early April, Congress approved the first protective tariff in the nation's histor Several weeks later, legislators voted to establish a second Bank of the United States, to provide uniform, stable currency and a source of credit for business ventures.

Yet there remained many congressmen and voters, especially from rural areas, who distrusted th power of a central bank independent of popular control. These same critics demanded that the feder government cut taxes now that the war had ended. Since military expenditures during the war had se the federal debt soaring to nearly $124 million, Congress hesitated to slash taxes and decrease revenu too rapidly. It did repeal all duties on domestic manufactures, but it retained several other min taxes, including those on carriages and postage. Administration officials estimated that the nev higher tariff rates would bring in at least $25 million per year, which they claimed would be sufficie to pay the government's routine civil and military expenses, fund annual increases in the size of th navy (which had proven woefully inadequate during the recent hostilities), and pay off the remainir debt in about twelve years.

Before Congress adjourned, it also voted itself a pay raise. Since the first Congress convened 1790, legislators had received six dollars per diem in lieu of a regular salary. Although the cost o living had increased by at least 75 percent over the past twenty-six years, their remuneration had n changed. Hence congressmen felt justified in approving the Compensation Act, which granted them a annual salary of $1,500. Few realized at that time that this measure would destroy many member political careers.

As lawmakers departed Washington at the end of April, they congratulated themselves o accomplishing their tasks in an unusual display of good feelings. "Among the most auspiciou appearances of the times, is the obliteration of party spirit," declared a Southern representative. "N question at the present session of congress has been discussed or determined on the ground of party.. Let us then cherish these feelings; let us emulate each other only in serving our country with the mo zeal, and the more fidelity."

* * *

On April 29, Americans noticed a large, irregular spot on the surface of the sun when they glanc skyward. One observer compared it to "a spider, having parts extending from the main body," whi another claimed that "its general appearance is not unlike that of a cluster of islands … surrounded b a belt of rocks." A representative of the National Mathematical Academy in Philadelphia estimat the length of the spot at just under 40,000 miles, with a breadth of nearly 3,000 miles. It lay just nor of the center of the sun's surface, and its stationary nature over the course of a week led a group American astronomers to dismiss their initial hypothesis that it might simply have been the plan Mercury moving across the face of the sun. Instead, they decided it was probably a wandering com pulled in by the sun's gravitational force.

In its May 1816 issue, the *North American Review* cited the theories of Sir Frederick Willia Herschel, a British astronomer, who argued that the spots were "chasms in the [sun's] atmospher occasioned by ascending currents of gaseous fuel." Since there appeared to be "a variable emission light and heat, intimately connected with the appearance and disappearance of spots," Hersch theorized that "seasons of uncommon heat and cold, of fertility and barrenness, so far as they depe upon the supply of heat, are to be traced not so much to accidental causes near at hand, as to t inconstancy of the fountain." (Herschel, a legendary figure in the history of astronomy, mad numerous important discoveries, including Uranus and its two moons, but also believed the sun w inhabited, along with all the other planets and stars. He speculated that the sun's surface was actual cool enough to support life; only the outer solar atmosphere was hot.)

Others suggested that the sunspots were volcanoes on the surface of the sun, or "burning mountai of immense size; so that when the eruption is nearly ended and the smoke dissipated, the fierce flam are exposed, and appear as luminous spots." Yet another explanation proposed the spots to be "a ki of excavation of the luminous fluid supposed to envelope [sic] the opake [sic] and solid body of t sun." Even those who supported this concept found it difficult to imagine how any gap within a liqu could remain unfilled; one contributor to the *Gentleman's Magazine* in Britain likened it to "no less miracle than the passage of the Israelites through the Red Sea." Perhaps, suggested a writer in t *Baltimore American*, "the Sun has cast forth several immense bodies, and … there is a danger of o of them coming in contact with our little tiney [sic] globe, when, in the horrible crash, we m experience another deluge, or suffer a terrible conflagration!"

No one in 1816 understood that sunspots are formed by variations in the strength of the magnet field that surrounds the sun. Occasionally, a portion of the magnetic field grows strong enough that t field coils back on itself and punctures the surface of the sun, a process which inhibits the fusi reactions that produce solar energy. This in turn reduces the temperature of the sun's surface at t point of the puncture. Since the brightness of the sun's surface is proportional to its temperature, t sunspots appear darker than the rest of the sun.

Scientists in Europe and the United States had regularly recorded sunspot activity with telescop since the early seventeenth century, when several astronomers, including Galileo, first observed ther Most of the earliest sunspot observations were taken during the period now known as the Maund Minimum—named for the English scientist Edward Maunder—that extended from 1645–1717, whe sunspot activity was at an unusually low level. The near disappearance of sunspots in the 165 puzzled astronomers, as did their sudden reemergence in the second decade of the eighteenth century

While individual sunspots occur almost randomly, the total number of spots follows a fair predictable eleven-year cycle (a cycle that was discovered in 1844). But sunspot activity also vari over much longer periods of time which are less predictable and less regular than the short-term cycl The eruption of Tambora coincided with another minimum in sunspot activity—the Dalton Minimu of 1790–1830. The Dalton Minimum was shorter and less intense than the Maunder Minimum, but still resulted in a notable decrease in sunspot activity; hence the surprise exhibited by the appearan of a large sunspot in April 1816.

According to one contemporary account, no sunspots of this magnitude had been witnessed in th United States since 1779. Moreover, observers could stare at the spot without the usual protection shaded glasses, because the atmosphere lately had been filled with a curious thick haze—“a fine dust reported a Virginia newspaper, “very injurious to respiration.” “It had nothing of the nature of a hum fog,” noted an American physician. “It was like that smoking vapour which overspread Europe abo thirty years ago.” And while sunspots typically are visible to the naked eye only when the sun is bare above the horizon, when the atmosphere has scattered much of the sunlight, this spot could be se throughout much of the day. In fact, the aerosol haze from Tambora may have lengthened by as muc as five times the usual window for viewing sunspots after sunrise and before sunset.

Since most Americans had never witnessed the sunspots that routinely move across the face of th sun, this highly visible spot—much larger than usual—generated more apprehension than the haz Some feared it was an omen of impending apocalypse, a “calamitous sign in heaven,” or a warnin that “the sun may, in time … become wholly incrusted” with spots, “so as to plunge us at once into th unutterable darkness that characterized the primitive chaos.” Others predicted the huge spot wou weaken the sun’s rays and permanently cool Earth’s atmosphere. While the editors of the *Nor American Review* dismissed such speculation, they did admit that “the observation … that the light the sun is less brilliant and dazzling than usual, is unquestionably well founded. We have remarked different times during the present season, on days when the sky was perfectly clear, that there was degree of feebleness and dimness in the Sun’s rays, not unlike the effect produced by a parti eclipse.”

Yet the first four months of 1816 were not noticeably colder than normal in the Eastern Unite States. In New England, the winter had been one of the mildest in a decade, with significantly le snow than usual. “The winter was open,” noted Noah Webster in his diary at Amherst, Massachusett

“A snow in January, which was sufficient for sledding, was swept away in a few days. The ground w uncovered most of the winter.” Judging by the measurements of several amateur meteorologists Northeastern colleges, January’s temperatures appeared to have been slightly above normal, with warming trend at the end of the month. In Maine, the days were so pleasant “that most perso allowed their fires to go out and did not burn wood except for cooking.” Similarly, the *Connectic Courant* reported that “January was mild—so much so as to render fires almost needless in sitti rooms.” (Thomas Jefferson, on the other hand, wrote to a friend from his retreat at Monticello, ju west of Charlottesville, Virginia, shortly after New Year’s Day that he was “shivering and shrinking body from the cold we now experience.”)

February brought generally mild temperatures with only a few snowstorms. “The first of Mar was very warm,” noted Adino Brackett, a farmer and schoolteacher in Lancaster, New Hampshi “and almost all the snow went off.” The weather then turned clear and cold for several weeks, but t month ended with another warm spell and a rare appearance of early spring thunderstorms in t Northeast. There had been sharp cold snaps along the East Coast in mid-March, however, including bout of sleet in Richmond, Virginia, that left fruit trees covered in icicles. As winter departed, the fir week of April was slightly warmer than usual in New England, with very little precipitation.

Although it appears counterintuitive, the stratospheric aerosol cloud from Tambora was part responsible for both the mild winter of 1815–16 in North America and the stormy conditions acro central Europe. The aerosol cloud not only scattered sunlight, preventing it from reaching Earth surface, it also absorbed some of the incoming energy, reradiating it as heat. This warmed t stratosphere immediately above the cloud. If the aerosol cloud had warmed the stratosphere even around the globe, its effect would have been minimal. In the depths of winter, however, the hig northern latitudes are plunged into continual darkness for several months. Without sunlight to abso the aerosol cloud could not heat the Arctic stratosphere; yet it continued to heat the stratosphere in t sunlit middle and lower latitudes.

A strong, cyclonic vortex forms near the North and South poles each winter. Strong west-to-ea winds surround the vortex and expand to cover much of the high latitudes. These winds are created the difference in winter temperatures between the sunlit middle and perpetually dark high latitude Air always flows from warmer temperatures toward colder ones, but Earth’s rotation turns the air o its path, towards the right in the Northern Hemisphere and the left in the Southern, to produce wester winds. These westerly winds prevent cold, polar air from moving into the middle latitudes. When t vortex is particularly strong, lower atmospheric pressures exist near the pole; higher pressures a found in the middle latitudes; and the westerly winds provide an effective barrier. Should the vort weaken, the pressure rises near the poles and falls in the middle latitudes, leading to freque outbreaks of polar air. In the Northern Hemisphere, scientists have defined the North Atlant Oscillation index to describe this seesaw of pressures between the poles and the middle latitudes, wi a high index associated with a strong vortex.

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