THE NEXT ONE HUNDRED YEARS

SHAPING THE FATE OF OUR LIVING EARTH

JONATHAN WEINER

BESTSELLING AUTHOR OF PLANET EARTH
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For Aaron and Benjamin

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From the cosmic point of view, what is happening is catastrophically abrupt. In geological perspective, the collective exhalations of human industry will look like a single eruption, a sharp spike in the air. The petroleum geologist M. King Hubbert was the first to chart the modern age in this way, and the spike is sometimes referred to as the Hubbert blip:

![Image of a spike]

But from the point of view of mortal scientists, and the man and woman on the street, standing somewhere on the rising side of the Hubbert blip, everything to do with the greenhouse effect has seemed to be happening in extreme slow-motion. That may be the ultimate reason that it has taken us all so long to begin to worry about it. Even those who believed it was happening thought it was happening slowly. People lived in its shadow as comfortably as they live in the city of Hilo, under the volcano Mauna Loa.

We don’t respond to processes. We respond to events. It takes an eruption or an earthquake or a weird belch from a poisonous lake in Cameroon or the collapse of an ice sheet to rivet our attention. I once read of a teacher who illustrated this point with a frog. First the teacher dropped the frog into a beaker of hot water. The frog jumped right out. Then the teacher put the frog in a beaker of cool water, and turned on a Bunsen burner. The frog kept swimming in the beaker and it boiled to death.

For one hundred years the build-up of the gas and the rise in global temperatures have been too gradual to catch our attention. Its pace affected even the manner of Keeling’s discovery, the one real Eureka in this century. Our image of the way a scientific discovery should take place dates from ancient Syracuse. Archimedes, the Greek mathematician, discovered a law of physics while musing in his bathtub. According to legend, Archimedes ran naked through the streets shouting, "Eureka! I have found it!"

In Victorian England a banknote engraver named George Smith spent years searching the cuneiform tablets in the British Museum, looking for confirmation of the Biblical story of Noah and the Ark. One
day Smith was handed a freshly cleaned tablet. The cuneiform inscription was a fragment of a Babylonian narrative of a World Flood. "Setting the tablet on the table," a colleague records, "he jumped up and rushed about the room in a great state of excitement, and, to the astonishment of those present, began to undress himself!"

Archimedes’ echo.

I have asked many people who were close to Keeling’s project in the early days about the Eureka moment. I talked to the Swiss ice-expert Oeschger in Bern. Oeschger had worked at Scripps when Keeling was just getting started. "I knew Keeling very well in ’58," Oeschger told me. "We played together. He plays piano and I the violin. I think he was very early aware that he did something important." Although they had stayed in touch ever since, and although Keeling recently had spent a year in Oeschger’s lab, Oeschger told me he knew of no Eureka moment.

John Chin is a technician at the Mauna Loa Observatory. He and the other technicians on the volcano kept Keeling’s gas analyzers running. They changed the graph paper, and each week they sent the tracings to Keeling. Sometimes the technicians used an ordinary ruler to line up the charts and look for a rise or fall in the tracings. "I was here in ’60. In ’60, we already saw the increase," Chin says. "... Maybe Keeling got very excited. But we just went, ‘More work.’ We got to measure more often.”

In his office at the University of California at San Diego, I asked Revelle about the Eureka moment.

"I don’t remember that. It’s an interesting point," Revelle said. "But I really don’t think it was a sudden flash of insight. Just an accumulation of evidence. That’s the nature of the monitoring process. You’ve got to monitor it for long enough so that you get above the noise level. And the noise level here had been quite high... Anyhow it wasn’t a problem that many people thought about..."

At Scripps, in an office on the same hall where Keeling put together his first gas analyzers, I asked him if he remembered the moment when he first realized that his global carbon-dioxide network was picking up a rise in the gas. "I can tell you that," Keeling said, promisingly, and he rummaged around in his files. There was a long silence. "I don’t know why it’s not there, but it’s not there." At last he produced a paper. "Tellus, June, 1960," Keeling pronounced, and read aloud: "Where the data extend beyond one year, averages for the second year are higher than for the first year.”
"But when did it hit you?" I asked him. "What was the atmosphere like in this laboratory when you knew?"

Keeling remembered no particular moment of joy, dismay, or reflection. "I didn't have time. I was just up to my ears trying to keep this experimental program going. It was all kinds of logistics, and communicating, repairing. . . . It was such an enormous effort to keep that program going. I almost decided to quit measurements at the end of '63."

I visited Saul Price at his office in the U.S. National Weather Service in Honolulu. Unlike Chin, Price is trained as a research meteorologist. And unlike Keeling and Revelle, Price spent many nights on the volcano in the early days. He watched the gas analyzers trace out what became some of the first points on the Keeling curve. "Earth-watchers generally don't get to shout Eureka," said Price. "Generally what happens is that somebody writes a paper as soon as he dares, and says, look, this is how things are. Then you can say Eureka!—but not too loudly. Because how do you know that after two dots, or three dots, or four dots, the thing isn't going to turn around again? What constitutes a trend? You might say two dots, for two years, at least. Only after quite a while—maybe ten years—you're sure you're dealing with something real and authentic now. In spite of tremendous variability in the sources and sinks all over the world, in the atmosphere, the biosphere, the hydrosphere, the net effect is still showing up year by year by year. Finally you say to yourself, 'My goodness.'"

The road to the Mauna Loa Observatory climbs first between two giants, Mauna Loa and Mauna Kea, the Long Mountain and the White Mountain and then, at the twenty-seven mile marker, turns south to ascend Mauna Loa. These volcanoes are so young and their slopes so gradual that the convicts from Kulani Prison Camp who built the road had little need for switchbacks. According to local legend, they bulldozed through the rubble straight toward the summit, and when the money ran out, there they built the Mauna Loa Observatory. Because the mountain is so smooth, one does not have to change gears to drive higher than the summits of some Alps. The grade of the road is like the grade of the global warming—you hardly know you are climbing until you are almost there. Suddenly you feel as though you have left Hawaii. You are 3,400 meters above sea level. The Sun is harsh, the
air is thin and cold, the sky a dark and astronomical blue, and the view, wider than from the Jungfrau, is an endless wasteland of black frozen lava, like a giant heap of cinders, receding on all sides nearly as far as the eye can see. (Far, far below you can see the rain forests of Hilo and the palm beaches of Kona.)

Some visitors to the Mauna Loa Observatory need oxygen. Many feel nauseous. It impresses us at such moments of need how thin the atmosphere really is. You can drive almost halfway out of it in an hour in a jeep. You can fly all of the way out in a few minutes in a rocket. On his first flight in outer space an East German astronaut looked out the window and for the first time in his life he saw the curving line of the planet's horizon. "It was accentuated by a thin seam of dark blue light—our atmosphere," Ulf Merbold wrote afterward. "Obviously this was not the ocean of air I had been told it was so many times in my life. I was terrified by its fragile appearance."

The road ends at the Mauna Loa Observatory's main building, a small plain box of cinderblock with a roof of corrugated aluminum. Around it, bulbous white plastic shapes sprout from the basalt like a Martian flora and fauna—instruments to measure ozone and to watch the Sun. There are also nephelometers, hygrometers, maximum-minimum thermometers. Instruments to measure dust particles, water vapor, extremes of temperature. Most of the scientists who watch the planet through these robot instruments live many thousands of miles away and many thousands of feet below. The observatory's staff scientists and technicians tend the robot garden from day to day.

On my visit, John Chin (who has now spent a quarter of a century on the volcano) led me across the black rubble on bare wood-plank walkways. I asked him if he ever worries now about the trend in Keeling's curve. He told me that he sleeps well at night. "Sometimes I look at it and I say, 'Well . . .'" He enjoyed explaining the purpose of the new monitors around the observatory, each of them the best of its kind. Each year another dangerous gas is added to the watch: methane, CFCs, sulfur dioxide, carbon monoxide. A final exam question at York University once asked: "List six unknown substances that will be found to harm the ozone layer." When those six substances are discovered, sensors will be invented for them and Chin will help to install these in the black rubble on Mauna Loa.

One squat, unpainted wooden platform near the main building holds particle-monitors belonging to the atmospheric chemist William Zoller.
The pumps suck in air greedily—fifty liters a minute. Each year, Zoller can tell when plowing starts in China. In Japan they call it “Yellow Dust.” Zoller calls it “Gobi Dust.”

Standing among these prodigies of environmental sensitivity are an outhouse and a green tank. The tank holds 1,000 gallons of extra water for the technicians who run the observatory. “We won’t drink it—we don’t know what’s in the bottom,” Chin said, without irony. “We use it to wash our hands.”

And rising above the rest is the tower. It is by far the tallest structure on Mauna Loa, erected by the National Oceanic and Atmospheric Administration: an open-frame vertical Jungle-Gym of aluminum pipes with flights of aluminum steps zig-zagging into the sky. The purest air in the world is sucked down through an aluminum straw at the top of the tower, 120 feet above the observatory, and drawn down to the carbon-dioxide detectors that are housed below in the main building, including the ancient black-box detector that Keeling purchased during the I.G.Y. and has never allowed anyone to replace.

“He’s a very careful man,” Chin said. “Very particular in his research. It’s got to be so-so. Don’t just change anything—even an intake line—without a lot of intercomparisons.”

Lately there had been dozens of phone calls about the new tower. Keeling wanted Chin to flush each new intake line with lots of fresh air before hooking it up to his gas analyzers. “I am flushing and flushing day and night—until I pick up the phone and say, ‘Is it OK to change tubes?’ I think people call him a super-careful man. He was born with it.”

Keeling had just given Chin permission to connect a piece of aluminum tubing from the new tower to the carbon-dioxide detectors. Now Keeling wanted to know exactly how long it took a sample of air entering the valves to reach the main building, and to be recorded there on the scrolls of computer paper. Chin proposed an experiment.

The sun was getting lower in the sky by the time I started climbing the steps of the tower, but it still stung the back of my neck. (According to the UV radiometer, the ultraviolet light is much stronger at the top of the volcano than at the bottom—there is so much less atmosphere to block it.) I started out too fast and ran out of breath about ten feet up. On the neighbor volcano, Mauna Kea, astronomers often drive up to the observatories for a few nights’ work and then faint on the floor of the telescope room. “I lose ten percent of my mental circuitry up here,” a technician had told me when we were driving up the
road to the observatory. "You'll be surprised. You won't remember much of your visit here. And you won't be able to read your notes."

I sat down for a moment on the steps of the tower and scribbled in my notebook until I caught my breath. That page is an accidental imitation of free verse.

Strenuous to walk—
   breath comes loud—
   hear it loud in
   ears as if I were
   a diver—
   long slow pants—

The first intake valve was thirty feet up, mounted outside the railing. To reach it, I had to straddle the aluminum banister and lean way out over the volcano. I puffed into the valve as if testing a microphone. Since the average human breath contains thousands of parts per million of carbon dioxide, even a puff a few inches away from the valve should make a big impression down in the main building. I climbed to the valve at sixty feet, and puffed into that one. Then eighty feet.

The air was so clean and transparent that from the top of the tower the observatory below looked like a tinkertoy affair—a model train set without many pieces. The road rolled down the slope of the volcano with no perceptible diminution of clarity. The eye of an eagle might have counted a thousand utility poles running down the Mauna Loa Road through the spilled desert of lava. Away across the valley the white astronomical domes on Mauna Kea were lit pink at the summit in alpenglow. From one of those white observatory domes an astronomer recently sighted the farthest known galaxy in the universe.

"Hey!" yelled John Chin. "Do one more time!"

"OK! When I lower my arm I've done it!"

"OK!" Chin stood in the shade of the aluminum shed, watching me and his stopwatch. I exhaled into the intake pipe, leaning out over the aluminum rail to give it a good blast, and lowered my left arm. Chin darted back into the main building.

It was strange being alone up there. All around there was almost nothing but lithosphere, black newborn lithosphere, as far as the eye could see. Overhead was the blue pennant, the old blue friend, and on the horizon was less than half of the sphere of fire. It was one of the most abstract landscapes I had ever seen. It felt like Mars. Several
spheres were missing from the scene, and I was, for the moment, the sole representative of my species and of the biosphere. In a sort of schematic diagram of our situation on the planet, molecules of carbon dioxide, which did not care if they arose from the lithosphere, the atmosphere, the biosphere, or the human sphere, kept flying down the aluminum hole whether I intended them to or not. I scribbled some wild notes—"I am part of the experiment"—that I can decipher but won't print.

In the main building, Chin clicked his stopwatch. A breath had taken one minute and 50 seconds to travel down 300 feet of new aluminum tubing and make Keeling's old gadget jump. "Not bad—that's good!" Chin cried out.

Then Chin whooped. "Dr. Keeling will be mad! Dr. Keeling will say, not too much horsing around!"

Future generations may wonder how we lived so long under the volcano without doing anything. The fact is that we did not know what the volcano meant. Scientists were slow to warn us and we were slow to hear them. At the time I climbed the tower I had been writing about Earth science for several years. I had been gathering material for this book for one year. I had spent one week in Keeling's laboratories, and many weeks in many others. Strange to confess: but the subject of global change was still just so much hearsay and doomsday until I climbed the tower. At that moment it all came together for me: that carbon dioxide is building up, and that each of us is responsible. At that moment it finally dawned on me that the greenhouse effect might be real.

A few weeks later an envelope from Chin arrived in my mailbox. It contained a page of printout. The Mauna Loa record; one piece of it.

"Aloha!" Chin wrote. "Your breath—about 378 ppm CO₂."