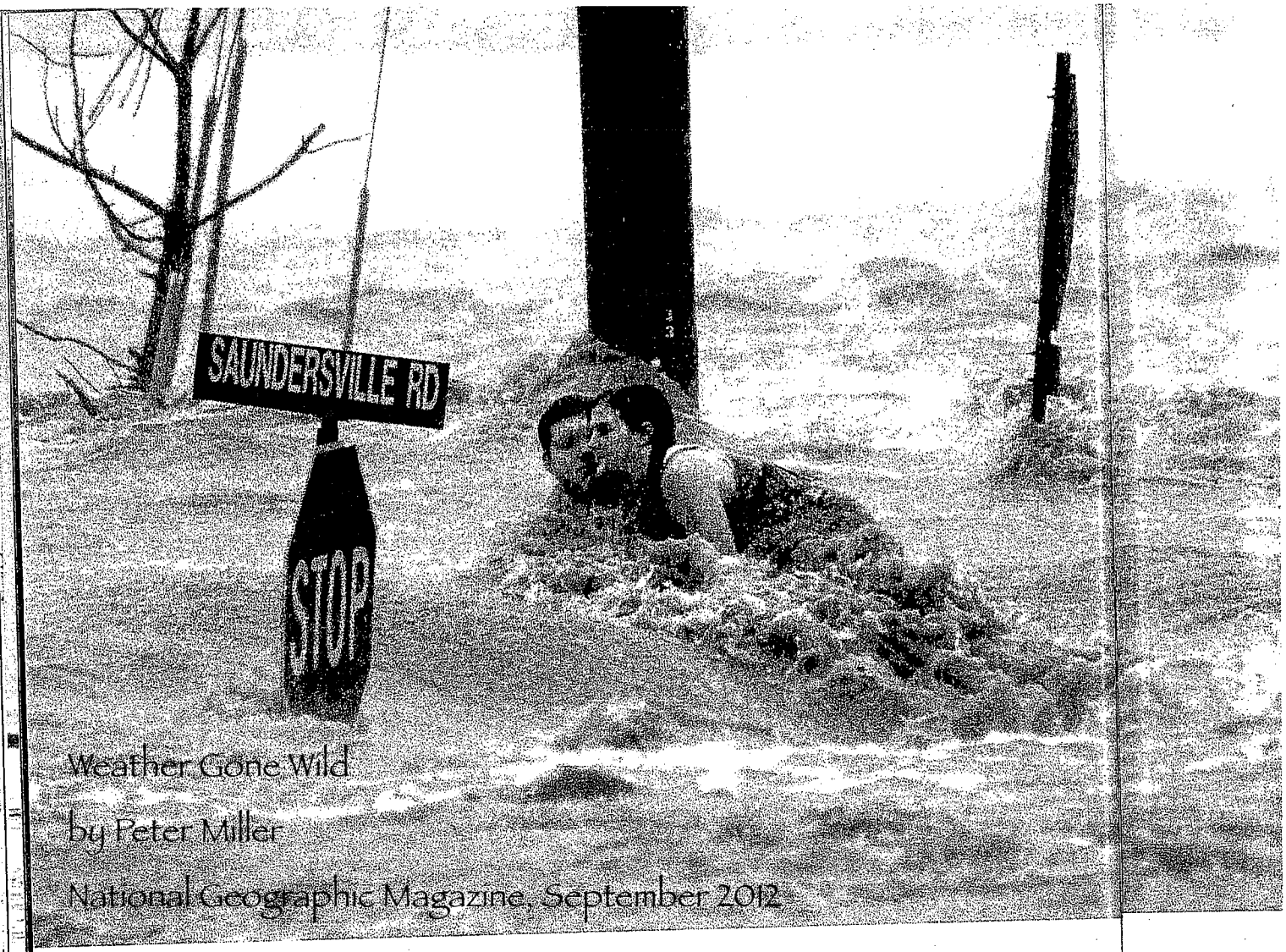


Weather Gone Wild

by Peter Miller

National Geographic Magazine, September 2012

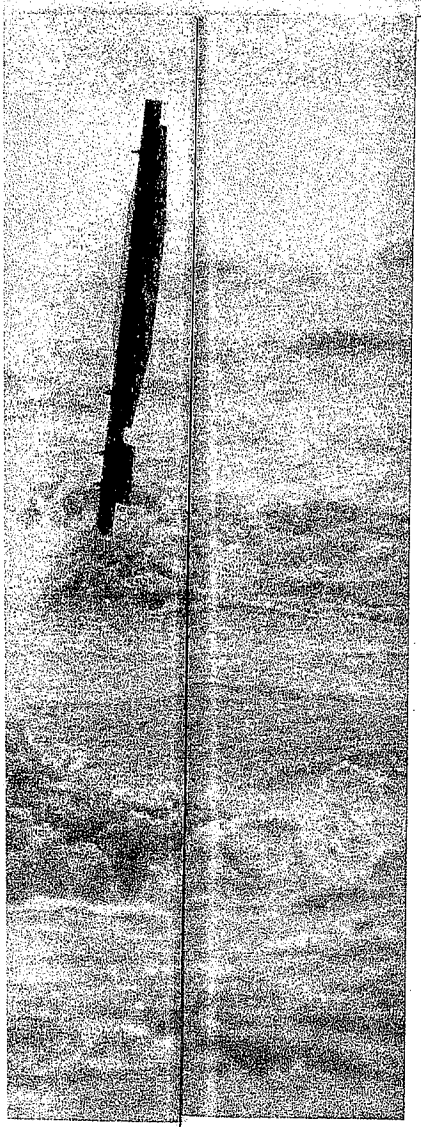
THE WEEKEND FORECAST FOR NASHVILLE, TENNESSEE, CALLED FOR TWO TO FOUR INCHES OF RAIN.

But by the afternoon of Saturday, May 1, 2010, parts of the city had seen more than six inches, and the rain was still coming down in sheets.

Mayor Karl Dean was in the city's Emergency Communications Center monitoring the first reports of flash flooding when something on a TV screen caught his eye. It was a live shot of cars and trucks on Interstate 24 being swamped by a tributary of the Cumberland River southeast of the city. Floating past them in the slow lane was a 40-foot-long portable building from the Lighthouse Christian School.

"We've got a building running into cars," the TV anchorman was saying.

Dean had been in the "war room" for hours. But when he saw the



TENNESSEE *Jamey Howell and Andrea Silvia had just heard that church was canceled when the flood submerged their Jeep near Nashville on May 2, 2010. The teenagers clung to the roof rack for more than an hour and then—as their parents watched helplessly—let go. A mile downstream they struggled onto a riverbank, alive.*
RICK MURRAY

building floating down the highway, he says, "it became very clear to me what an extreme situation we had on our hands." Soon 911 calls were coming in from every part of the city. Police, fire, and rescue teams were dispatched in boats. One crew in a skiff headed out to I-24 to pluck the driver of an 18-wheeler from the chest-high water. Other teams pulled families off rooftops and workers from flooded warehouses. Still, 11 people died in the city that weekend.

This was a new kind of storm for Nashville. "It came down harder than I've ever seen it rain here," says Brad Paisley, the country singer, who owns a farm outside town. "You know how when you're in a mall and it's coming down in sheets, and you think, I'll give it five minutes, and when it lets up I'll run to my car? Well, imagine that it didn't let up until the next day."

Over at NewsChannel 5, the local CBS station, meteorologist Charlie Neese could see where the weather was coming from. The jet stream had gotten stuck over the city, and one thunderstorm after another was sucking up warm, humid air from the Gulf of Mexico, rumbling hundreds of miles northeast, and dumping the water on Nashville. While Neese and his colleagues were broadcasting from a second-floor studio, the first-floor newsroom was being swamped by backed-up sewers. "Water was shooting up through the toilets," Neese says.

The Cumberland River, which winds through the heart of Nashville, started rising Saturday morning. At Ingram Barge Company, David Edgin, a former towboat captain, had more than seven boats and 70 barges out on the waterway. As the rain continued to pound down, he called the U.S. Army Corps of Engineers to get its forecast of how high the river would rise. "It's blowing up our models," the duty officer said. "We've never seen anything like this." Edgin ordered all of Ingram's boats to tie up at safe locations along the riverbank. It turned out to be a smart move.

By Saturday night the Cumberland had risen at least 15 feet, to 35 feet, and the corps was predicting it would crest at 42. But the rain didn't stop Sunday, and the river didn't crest until Monday—at 52 feet, 12 feet above flood stage. Spilling into downtown streets, the flood caused some two billion dollars in damage.

When the sun came out on Monday morning, parts of Nashville had seen more than 13 inches of rain—about twice the previous record of 6.6 inches set during Hurricane Frederic in 1979. Pete Fisher, manager of the Grand Ole Opry, needed a canoe to get into the famous theater, which is on the riverfront northeast of the city. He and audio engineer Tommy Hensley paddled across a parking lot and through a side door. "We basically just floated into the theater," Fisher says. "It was pitch black, and we shined a light on the stage. If you'd been sitting in the front row, you'd have had seven feet of water over your head."

In warehouses along the river, the flood had submerged millions of dollars' worth of

equipment, including components for a 36-by-60-foot video screen that had been assembled for Brad Paisley's upcoming concert tour, which was set to begin in less than three weeks. "Every amp, every guitar I'm used to, was destroyed," Paisley says. "I felt powerless in a way I've never felt before with weather."

The experience changed him. "Here in Nashville our weather is manageable, normally," he says. "But since that flood, I've never once taken normalcy for granted."

THERE'S BEEN A CHANGE in the weather. Extreme events like the Nashville flood—described by officials as a once-in-a-millennium occurrence—are happening more frequently than they used to. A month before Nashville, torrential downpours dumped 11 inches of rain on Rio de Janeiro in 24 hours, triggering mud slides that buried hundreds. About three months after Nashville, record rains in Pakistan caused flooding that affected more than 20 million people. In late 2011 floods in Thailand submerged hundreds of factories near Bangkok, creating a worldwide shortage of computer hard drives.

And it's not just heavy rains that are making headlines. During the past decade we've also seen severe droughts in places like Texas, Australia, and Russia, as well as in East Africa, where tens of thousands have taken refuge in camps. Deadly heat waves have hit Europe, and record numbers of tornadoes have ripped across the United States. Losses from such events helped push the cost of weather disasters in 2011 to an estimated $150 billion worldwide, a roughly 25 percent jump from the previous year. In the U.S. last year a record 14 events caused a billion dollars or more of damage each, far exceeding the previous record of nine such disasters in 2008.

What's going on? Are these extreme events signals of a dangerous, human-made shift in Earth's climate? Or are we just going through a natural stretch of bad luck?

The short answer is: probably both. The primary forces driving recent disasters have been natural climate cycles, especially El Niño and La Niña. Scientists have learned a lot during the past few decades about how that strange seesaw in the equatorial Pacific affects weather worldwide. During an El Niño a giant pool of warm water that normally sits in the central Pacific surges east all the way to South America; during a La Niña it shrinks and retreats into the western Pacific. Heat and water vapor coming off the warm pool generate thunderstorms so powerful and towering that their influence extends out of the tropics to the jet streams that blow across the middle latitudes. As the warm pool shifts back and forth along the Equator, the wavy paths of the jet streams shift north and south—which changes the tracks that storms follow across the continents. An El Niño tends to push drenching storms over the southern U.S. and Peru while visiting drought and fire on Australia. In a La Niña the rains flood Australia and fail in the American Southwest and Texas—and in even more distant places like East Africa.

ARE WE SEEING A DANGEROUS SHIFT IN CLIMATE? OR JUST A NATURAL STRETCH OF BAD LUCK?

Those outcomes aren't mechanical and invariable; the atmosphere and ocean are chaotic fluids, and other oscillations influence the weather at a given time and place. The tropical Pacific is especially influential, though, because it pumps so much heat and water vapor into the atmosphere. Extreme El Niños or La Niñas thus set the stage for extreme events elsewhere.

But natural cycles can't by themselves explain the recent streak of record-breaking disasters.

Senior Editor Peter Miller wrote the January cover story on the scientific study of twins.

Something else is happening too: The Earth is steadily getting warmer, with significantly more moisture in the atmosphere. Decades of observations from the summit of Mauna Loa in Hawaii, as well as from thousands of other weather stations, satellites, ships, buoys, deep-ocean probes, and balloons, show that a long-term buildup of greenhouse gases in the atmosphere is trapping heat and warming up the land, oceans, and atmosphere. Although some places, notably the Arctic, are warming faster than others, the average surface temperature worldwide has risen nearly one degree Fahrenheit in the past four decades. In 2010 it reached 58.12°F, tying the record set in 2005.

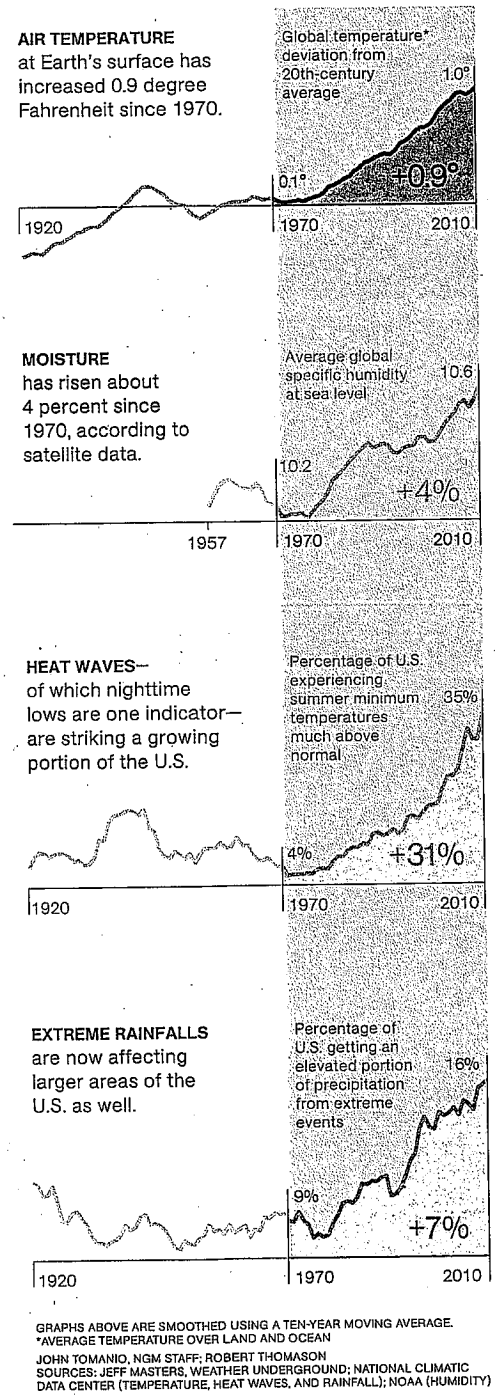
As the oceans warm, they're giving off more water vapor. "Everybody knows that if you turn up the fire on your stove, you evaporate the water in a pot more rapidly," says Jay Gulledge, senior scientist at the Center for Climate and Energy Solutions (C2ES), a think tank in Arlington, Virginia. During the past 25 years satellites have measured a 4 percent average rise in water vapor in the air column. The more water vapor, the greater the potential for intense rainfalls.

By the end of the century the average world temperature could rise anywhere from three to eight degrees Fahrenheit—depending in part on how much carbon we emit between now and then. Scientists expect the weather to change substantially. Basic circulation patterns will move toward the Poles, just as some plants and animals are doing as they flee (or take advantage of) the expanding heat. The tropical rain belt is already widening, climatologists report. The subtropical dry zones are being pushed poleward, into regions such as the American Southwest, southern Australia, and southern Europe, making these regions increasingly susceptible to prolonged and intense droughts. Beyond the subtropics, in the midlatitudes, including the lower 48 of the United States, storm tracks are moving poleward too—a long-term trend superimposed on the year-to-year fluctuations triggered by La Niña or El Niño.

One of the biggest wild cards in our weather future is the Arctic Ocean, which has lost 40

WHY SO WILD?

The atmosphere is getting warmer and wetter. Those two trends, which are clear in data averaged globally and annually, are increasing the chances of heat waves, heavy rains, and perhaps other extreme weather.



GRAPHS ABOVE ARE SMOOTHED USING A TEN-YEAR MOVING AVERAGE.
*AVERAGE TEMPERATURE OVER LAND AND OCEAN

JOHN TOMANIO, NGM STAFF; ROBERT THOMASON
SOURCES: JEFF MASTERS, WEATHER UNDERGROUND; NATIONAL CLIMATIC DATA CENTER (TEMPERATURE, HEAT WAVES, AND RAINFALL); NOAA (HUMIDITY)

percent of its summer sea ice since the 1980s. Autumn temperatures over what is now open ocean have risen 3.6 to 9°F, as the dark water absorbs sunlight that the ice once bounced back into space. New evidence suggests that warming is altering the polar jet stream, adding lazy north-south meanders to its path around the planet—which might help to explain why North America was so warm last winter and Europe so cold. Meandering farther north than normal into Canada, the jet stream brought warm air with it; dipping far south over Europe, it delivered frigid winds and snow to that region. In the winter of 2010-11 it was eastern North America that got heavy snow. Because the meanders move around every year, the extreme weather may too.

When it comes to individual storms, scientists are even less certain what effect global warming might have. In theory extra water vapor in the atmosphere should pump heat into big storms such as hurricanes and typhoons, adding buoyancy that causes them to grow in size and power. Some models have predicted that global warming could increase the average strength of hurricanes and typhoons by 2 to 11 percent by 2100. But the jury's still out on whether any increase has occurred yet. And the same models that predict bigger hurricanes also say we could get fewer of them in the future.

The picture is murkiest with tornadoes. A hotter, wetter atmosphere should promote more severe thunderstorms, but it might also reduce the wind shear needed for those storms to spawn twisters. More tornadoes are being reported in the U.S., but there are more people looking for them with better instruments—and there's been no documented increase in the past half century in the number of severe tornadoes. The spring of 2011 was one of the worst tornado seasons in U.S. history, with monster twisters roaring through Tuscaloosa, Alabama, and Joplin, Missouri. But scientists don't yet have the data or the theoretical understanding to say whether global warming was to blame.

In the case of some weather extremes, though, the connection is pretty clear. The warmer the atmosphere, the more potential for record-breaking heat waves. In the U.S. high-temperature records are being set these days twice as often as low-temperature ones; around the world 19 countries set national records in 2010.

As moisture in the atmosphere has increased, rainfall has intensified. The amount of rain falling in intense downpours—the heaviest one percent of rain events—has increased by nearly 20 percent during the past century in the U.S. "You're getting more rain from a given storm now than you would have 30 or 40 years ago," says Gerald Meehl, a senior scientist at the National Center for Atmospheric Research in Boulder, Colorado. Global warming, he says, has changed the odds for extreme weather.

THE AMOUNT OF RAIN FALLING IN THE HEAVIEST DOWNPOURS HAS INCREASED NEARLY 20 PERCENT

"Picture a baseball player on steroids," Meehl goes on. "This baseball player steps up to the plate and hits a home run. It's impossible to say if he hit that home run because of the steroids, or whether he would have hit it anyway. The drugs just made it more likely."

It's the same with the weather, Meehl says. Greenhouse gases are the steroids of the climate system. "By adding just a little bit more carbon dioxide to the climate, it makes things a little bit warmer and shifts the odds toward these more extreme events," he says. "What was once a rare event will become less rare."

NOBODY HAS LIVED THROUGH more weather on steroids lately than Texans. The 1,049 residents of Robert Lee, a West Texas town of ranchers,

oil workers, retirees, and small business owners, spent much of 2011 watching their water supply dry up. The E. V. Spence Reservoir, like many lakes in the region, lost more than 99 percent of its water.

"If we don't get some additional runoff soon, there will be no more water coming out of the faucets," Mayor John Jacobs said last winter. "As in nothing. It's getting serious." In January the town began construction of a 12-mile pipeline to Bronte, a community that has wells in addition to a reservoir. Completed in March, the pipeline was still being tested in early May. "We feel like we're going to get it done in time," Jacobs said. "But it's going to be just under the wire. Living in West Texas is not for the weak at heart."

Less rain fell on Texas from October 2010 to September 2011 than in any other 12-month period since record keeping began in 1895. The whole state suffered, but West Texas was already close to the edge. All across the region farmers, ranchers, and municipalities were feeling the damage. (See "The New Dust Bowl," page 56.) In many places water levels dropped below well pumps, causing the motors to burn out. "A lot of wells are going dry," said Clark Abel, a well driller in San Angelo. "Our phone's been ringing off the hook. It's overwhelming."

The drought withered grazing lands too, forcing some ranches to ship their livestock to greener pastures up north. In a kind of modern cattle drive, ranch hands from the Four Sixes Ranch near Guthrie and from its Dixon Creek operation in the Texas Panhandle drove more than 4,000 head of Angus crossbreeds onto double-decker trucks to transport them to leased lands from Nebraska to northern Montana.

The last time the Four Sixes attempted such a thing, said general manager Joe Leathers, was more than a century ago, when the ranch moved herds to what was then the Indian Territory of Oklahoma. This drought was worse. By last July the ranch had run out of tank water—drinking water in dirt ponds for cattle. "The long and the short of it is that nobody has ever faced anything like this before," Leathers said.

"This has been the most severe one-year drought we've ever had," said state climatologist John Nielsen-Gammon. (A drought in the 1950s took six years to get as bad.) On top of that, Texans sweated last year through the hottest summer in memory. Dallas residents saw the mercury climb to 100°F or higher on 71 days.

There's no mystery about the main cause, Nielsen-Gammon said: It was La Niña, which pushed storm tracks farther north over the U.S., reducing rainfall throughout the South, from Arizona to the Carolinas. "We just happened to be right in the center of it," he said.

But global warming aggravated the situation, making an already bad heat wave even worse. "Under normal conditions a lot of the sun's energy gets used to evaporate water from the soil or from plants," Nielsen-Gammon explained. "But when there's no water to evaporate, all that energy goes into heating the ground and consequently heating the air. Given how little rain we had, we probably would have had record warmth in Texas in 2011 even without climate change. But climate change added an additional degree or so of heat to it."

That extra degree of heat was like an extra shot of gasoline on the state's forests: By increasing evaporation, it made them even drier. In a drought, said Nielsen-Gammon, "every little increase in severity makes a big difference." Texas in 2011 experienced the worst wildfire season on record. Taken together, the fires blackened an area larger than Connecticut—nearly twice as much acreage as in the previous worst year.

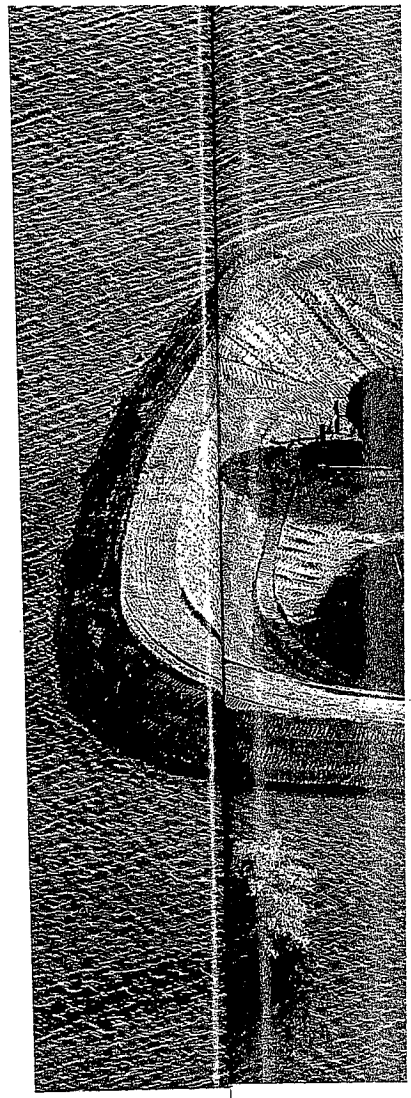
One of the costliest fires started last September just outside Bastrop State Park, southeast of Austin, where the loblolly pines were as dry and brittle as kindling. Fanned by strong winds, the blaze raced south through suburban neighborhoods in what firefighters call long "streets" of fire. It consumed 1,685 houses but occasionally spared others nearby, leaving residents shaking their heads.

When Paige and Ray Shelton returned to inspect their property adjacent to the state forest, they found their bungalow still standing, but the sawmill that Ray operated with his brother, Bo, was reduced to ashes and Paige's pottery studio

was burned to the ground. As Paige picked through the wreckage, Ray made a beeline for the chicken coop, hoping to spare his wife the sorrow of cleaning up all the burned carcasses. Trees all around the coop were charred black.

"Well, guess what?" Ray said later. "As I came around the corner, the rooster stuck his head out and crowed. I couldn't believe it. I almost fell over backwards."

The fire had come within an inch of the coop, but for some reason the red cedar walls hadn't ignited, and somehow the birds had avoided the intense heat and smoke—a small miracle in the midst of great loss. All five hens had survived too, along with 18 doves Paige was raising. "They were singing up a storm," Ray said.



MISSISSIPPI *Fortified by a levee, a house near Vicksburg survives a Yazoo River flood in May 2011. Snowmelt and intense rains—eight times as much rainfall as usual in parts of the Mississippi River watershed—triggered floods that caused three to four billion dollars in damages.*

SCOTT OLSON, GETTY IMAGES

THE RISING COST and frequency of natural disasters can be blamed only partly on the weather. Disasters are also on the rise because more people are located in harm's way. In states like Texas, Arizona, and California the buildup of neighborhoods in former woodlands has exposed more properties to wildfires, just as coastal development in states like Florida, North Carolina, and Maryland has exposed expensive beach houses and hotels to hurricanes and other storms. At the same time, the rapid growth of megacities in developing countries in Asia and Africa has made millions more vulnerable to heat waves and floods. Instead of defending themselves against climate change, many communities appear to be leading with their chin.

"Something has gone wrong," says climatologist Michael Oppenheimer of Princeton University, who helped write a recent report on extreme weather for the Intergovernmental Panel on Climate Change. "To put it bluntly, we're doing a lousy job keeping up with disasters."

The economic significance of this hasn't been lost on the insurance industry. Insured losses from natural disasters in the U.S. last year totaled nearly $36 billion, 50 percent higher than the average during the previous decade. "Whether it's the 'new normal' or not, the industry sees a pattern of losses that's extraordinary," says Frank Nutter of the Reinsurance Association of America. "The past is not prologue to the type of weather we're about to see."

In Florida, where hurricanes, wildfires, and drought pose enormous risks to insurers, several national firms have stopped writing new policies altogether or pulled back in other ways. They're afraid of another disaster like Hurricane Andrew in 1992, which cost the industry an estimated $25 billion. To fill the gap, small companies have sprung up across the state, and in 2002 the state government created the Citizens Property Insurance Corporation, which has become Florida's largest provider of homeowner's insurance. Whether this new system has the resources to survive a big storm isn't clear yet, Nutter says. "It's an untested experiment. They haven't had a major hurricane there since 2005."

Meanwhile some governments have taken small but important steps to better prepare for

extreme weather. An exceptional heat wave in Europe in 2003 took at least 35,000 lives; a later analysis found that climate change had doubled the odds of such a disaster. Afterward French cities set up air-conditioned shelters and identified older people who would need transportation to the shelters. When another heat wave hit France in 2006, the death rate was two-thirds lower.

Similarly, after a tropical storm killed as many as 500,000 people in Bangladesh in 1970, the government there developed an early warning system and built basic concrete shelters for evacuated families. When cyclones hit today, the death count stays in the thousands.

Weather disasters are like heart attacks, says Jay Gulledge. "When your doctor advises you about how to avoid a heart attack, he doesn't say, Well, you need to exercise, but it's OK to keep smoking," he says. The smart approach to extreme weather is to attack all the risk factors, by designing crops that can survive drought, buildings that can resist floods and high winds, policies that discourage people from building in dangerous places—and of course, by cutting greenhouse gas emissions.

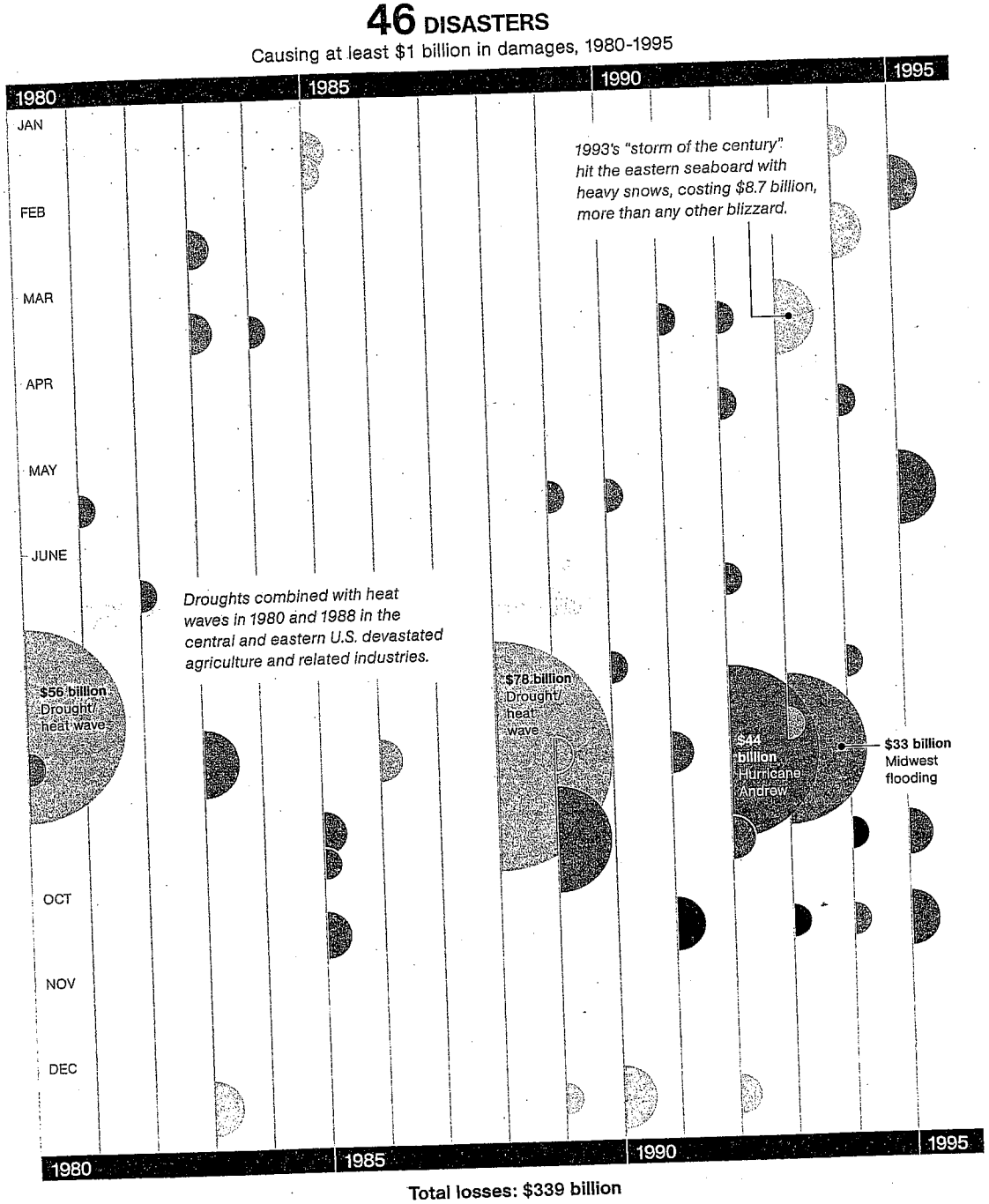
"We know that warming of the Earth's surface is putting more moisture in the atmosphere. We've measured it. The satellites see it," Gulledge says. So the chances for extreme weather are going nowhere but up.

We need to face that reality, Oppenheimer says, and do the things we know can save lives and money. "We don't have to just stand there and take it." □

Educational Note National Geographic has free educational resources about weather for students, teachers, and families at *natgeoed.org/weather.*

BILLION-DOLLAR WEATHER

A chart of the most costly U.S. weather disasters shows nearly twice as many billion-dollar events since 1996 as in 1980-1995. The main reason: More people are living on higher-value properties in vulnerable places, such as coasts. But as the atmosphere warms, scientists expect destructive weather itself to become more common.

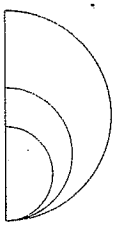


*ALL DOLLAR AMOUNTS ADJUSTED TO MARCH 2012 DOLLARS

JOHN TOMANIO, NGM STAFF. SOURCES: ADAM SMITH, NATIONAL CLIMATIC DATA CENTER; JEFF MASTERS, WEATHER UNDERGROUND; NATIONAL CLIMATIC DATA CENTER

ALL U.S. WEATHER DISASTERS from 1980 to 2011 that caused at least one billion dollars* in damages are plotted by month and year; the size of each half circle represents the cost of the disaster. The ten most costly events are labeled.

COST OF DISASTER

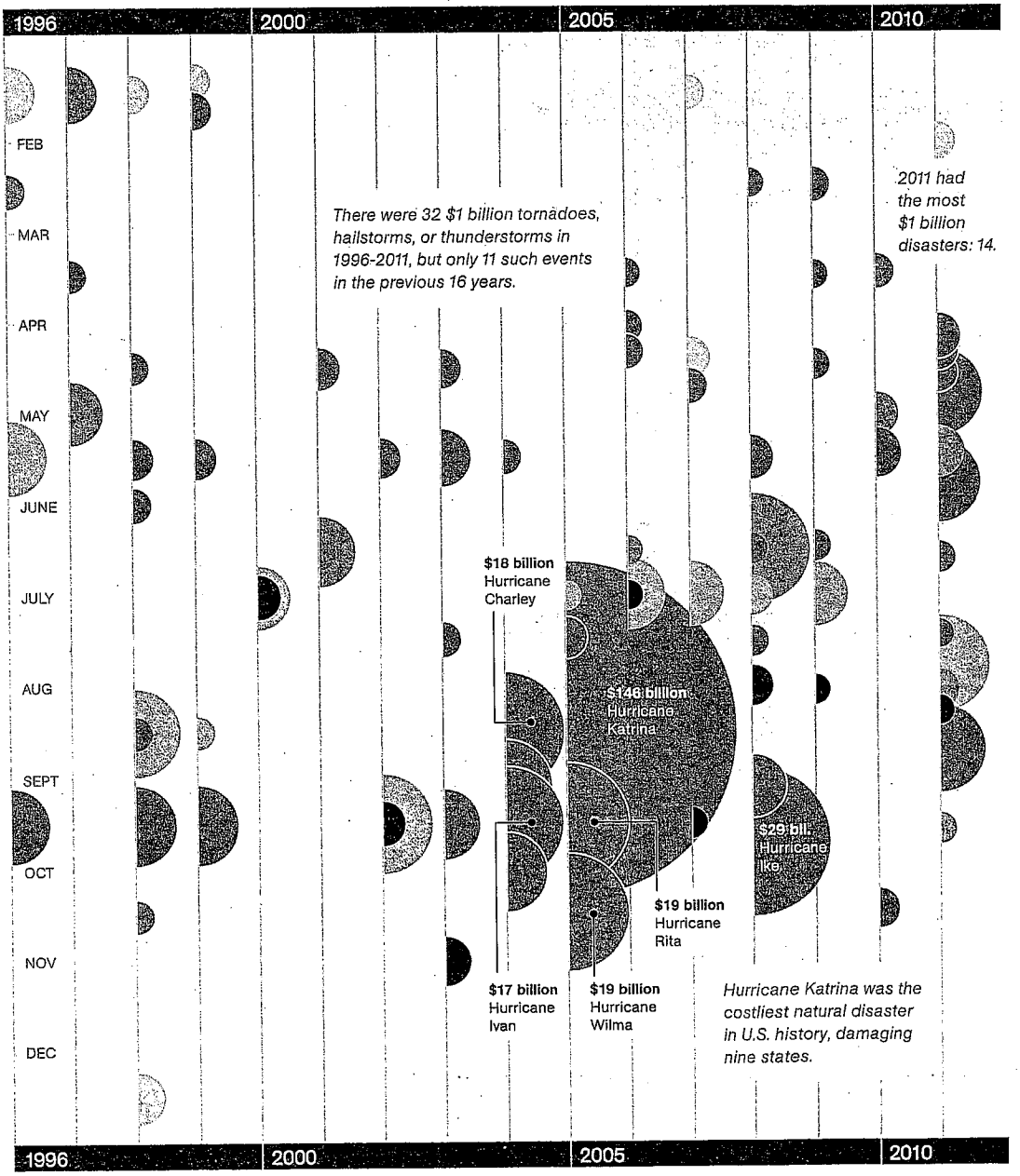


DISASTER TYPE

- Drought/heat wave
- Wildfire
- Flood
- Hurricane
- Tornado/hailstorm/thunderstorm
- Blizzard/ice storm/freeze

87 DISASTERS

Causing at least $1 billion in damages, 1996-2011



Total losses: $541 billion