Rising temperatures bump up risk of wildfires

Global warming adds firefighting challenges in both forest and desert

by Melanie Lenart

The Grand One looks doomed. The world's largest recorded saguaro, it stood its ground on a hillside near Phoenix while last year's Cave Creek Complex fire raced through on knee-high grasses and, worse, lingered in nearby shrubs. Now yellow lines radiate up several of its roughly dozen arms as the magnitude of the event sinks in (Figure 1).

It may soon join the list of casualties from wildfire—a list expected to grow longer with the days of summer as the southwestern climate continues to warm. The input of greenhouse gases mainly from burning oil, coal, and gas has temperatures on the upswing around the globe, including the southwestern United States.

The ancient saguaro looks worse than it did even a few months before, range and watershed specialist Carol Engle said on a day in late March. Now she has doubts about whether it will pull through, as she and many others had been hoping. She pointed out splits where insects could penetrate its massive trunk, larger than a refrigerator at the base. Between the trunk and an arm, bubbles of black char look like a belated attempt to form protective bark. Or, to use Engle's analogy, like a marshmallow that's toasted for too long.

Singed during a record Arizona fire year that burned more than 700,000 acres in 2005, The Grand One could serve as a poster illustration about how wildfires could worsen with global warming and related changes. 2005 nearly tied 1998's record for world's warmest year since instrumental records became relatively reliable in the late nineteenth century. While the fire raged, Phoenix set its own record lows for humidity and highs for temperatures.

When it's hot

Climbing temperatures are expected to bring more raging infernos, in desert, grasslands, and forests alike—and the homes constructed among them. The 47,000 acre forest fire around Los Alamos, New Mexico ruined about 260 homes and required the evacuation of about 20,000 people in 2000. The 468,000 acre Rodeo-Chediski forest fire in northern Arizona destroyed about 400 homes and forced 30,000 people to evacuate in 2002.

In both cases, high temperature extremes in the three months leading up to the fire ranked right up there with low precipitation extremes (Table 1).

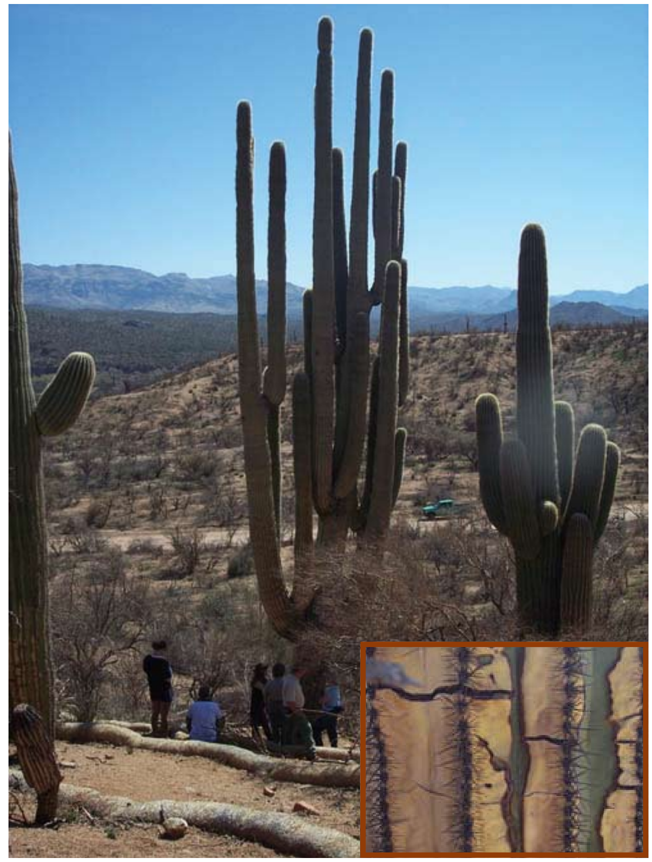

Figure 1. The world's largest recorded saguaro was damaged last year during a fire near Phoenix, Arizona. The lower righthand inset shows a close up of the fire damage. Source: Stephanie Doster, Institute for the Study of Planet Earth

Firefighters managed to shield homes in the Scottsdale area of Phoenix from the 248,000 acre Cave Creek Complex fire, which torched about two-thirds of the 50,000 acres of Sonoran Desert that burned in 2005. This important ecosystem features the saguaro cactuses (*Carnegiea giganetea*) exclusive to the southwestern United States and northern Mexico.

Some researchers suspect warming temperatures and an early spring are aiding and abetting the invasive grasses that helped carry last year's fires into saguaro territory (*Southwest Climate Outlook*, April 2005). Although native grasses and wildflowers can also carry fire following rainy winters, their clumpy, uneven cover proves less efficient at carrying fire than an even, continuous cover of monocultural grasses.

After wet winters like 2005, even normal southwestern temperatures in May and June soon convert invasive and native grasses alike into what firefighters call "fine fuels"—dried-out stalks that feed a surface fire.

Tonto National Forest fire manager Gary Daniel provided an example of how temperatures affect fine fuels, referring to his work on prescribed burns. If grasses remain moist after the cool of evening, he and his crew had an easy solution: "We just let the sun beat on it a little more, let the ambient air temperature dry out, and we're ready," Daniel recalled. "An hour in full sunlight would have a tendency to dry that grass out."

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Forest drying

In the forest, it takes about 40 hot, dry days (roughly a thousand hours) to convert fallen branches on the forest floor into flammable material that will magnify a fire's heat—perhaps enough to ignite live saplings. These saplings, in turn, can become ladders to lift the flames into the crowns of established trees. Branches and logs from three to six inches in diameter are the "thousand-hour fuels" that firefighters worry about when gauging forest fire danger and evaluating whether a surface fire might transform into a crown fire.

Woody materials are likely to remain dry longer as the climate warms, Timothy Brown of the Desert Research Institute in Nevada and colleagues projected, based on the expected impact of warmer temperatures and their influence on relative humidity (*Climatic Change*, January 2004). Their modeling experiment focused on forests, comparing conditions for two decades through 1996 to those projected for two decades through 2089 using a global warming scenario.

"The key thing was an increase in the number of days of high fire danger," Brown said. "We basically found throughout the West that the number of days increased by about two to three weeks."

In another analysis, of 11 western states, New Mexico and Arizona were among the most sensitive to temperature effects on the annual "area-burned"—the amount of land crossed by fire in a given year. U.S. Forest Service researcher Donald McKenzie and colleagues found higher temperatures led to a "sharp increase" in area-burned in the historical record, using data for the years 1916 through 2002 (*Conservation Biology*, August 2004). New Mexico's annual area-burned fluctuates with spring temperatures in particular, the analysis by McKenzie and colleagues showed.

Similarly, research by The University of Arizona's Michael Crimmins and Andrew Comrie found low-elevation fires in southern Arizona increased during warm springs when they followed wet winters (*International Journal of Wildland Fire*, 2004).

The results fit the pattern for the Southwest fire season to start during the dry days of May and June and end within weeks of the summer's monsoon season arrival, usually in July. It also sparks concern for those anticipating the continuation of global warming, as spring temperatures in New Mexico and Arizona are rising as are temperatures in other seasons (Figure 2).

It's the heat *and* humidity

Temperature has an established link with fire danger on several fronts. Fires light more readily when the sun is beating down and raising daily temperatures. Lightning bolts fly more often with higher temperatures, too, providing more opportunities for fire ignitions. And fires can spin out of control more easily when overlying air is warm, especially in the absence of cool nights that help the fire to "lay down."

Fire event	Temperature rank (highest)	Precipitation rank (lowest)	State
Los Alamos (2000)	2	1	New Mexico
Rodeo-Chediski (2002)	4	3	Arizona
Hayman (2002)	12	2	Colorado
Biscuit (2002)	17	15	Oregon

Table 1. While seasonal precipitation tended to rank among the lowest during three months leading up to major western fires, temperatures tended to rank among the highest. Climate records go back to 1895. Source: Data from Western Regional Climate Center.

Some of these factors combined in 2005 in the Phoenix-area Cave Creek Complex fire, the union of several lightning-started fires. Local daytime temperatures in the "hundred and teens" and relative humidity levels that dipped as low as 2 percent turned the grass-invaded desert into a sea of flames, reported Jeff Whitney, a natural resource manager who helped battle the blaze. Even at night, relative humidity only rose to about 9 percent, well within the 20 percent range that firefighters peg as dangerous.

"We've usually got a better opportunity to work on suppressing the fire at night," Whitney said. "But we didn't have those conditions during the Cave Creek Complex—it burned through the night."

Air temperature wields an important effect on relative humidity. Hot air can hold more moisture than cool air, which is partly why higher daytime temperatures are linked to higher evaporation rates. Conversely, when air cools during the night, its relative humidity increases, sometimes to the point of saturation. If the air drops down to the "dewpoint temperature" some of the moisture it contains will condense into dew, fog, or some other form of precipitation.

Whether moisture condenses or not, higher relative humidity levels reduce fire danger, Daniel noted.

"In the evening, temperatures will go down and the humidity levels will start to increase again. We call it a recovery. If we have not much of a recovery at all at night, we can have active burning during the night and this can also make it worse the next day," he said.

Both global warming and the urban heat island effect tend to boost nighttime temperatures more than daytime temperatures. That's because greenhouse

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gases and concrete both absorb solar radiation. After a long day of solar heating, they release some of the energy they've collected as infrared radiation—i.e., heat. This is most noticeable at night, once the sun's direct rays are out of the picture.

Hot air

Warm air tends to be more "unstable" than cool air in a meteorological sense, too, explained Charles Maxwell, fire weather program manager for the Southwest Coordination Center.

"If you have warmer surface temperatures, the atmosphere is more unstable. That's more conducive to strong convection and to blow-up fires" like the Rodeo-Chediski, Maxwell said. "Instead of having a fire driven by the wind and environment, the fire becomes a lot more powerful and controls the environment and dictates the weather. It's very similar to a thunderstorm, the way it works," Maxwell said.

A warm surface, whether caused by a fire or a mountainside baking in the hot summer sun, will lift air parcels up into the atmosphere. A fire tends to do so faster, which adds to the instability. The ascent of these air parcels leaves a void that surrounding air quickly moves to fill. These winds further fan the flames.

As with thunderstorms, the air parcels uplifted by fires often become clouds as they rise and cool. These clouds, known as pyrocumulus, contain moisture they extracted from fuel, soil, and especially living trees, Maxwell noted.

Alex McCord, a longtime Arizona Division of Emergency Management hazards officer, elaborated on this, noting that combustion also contributes moisture by converting stored carbohydrates in trees back into carbon dioxide and water.

"Even if it's bone dry, there's moisture in the wood," McCord said. When this

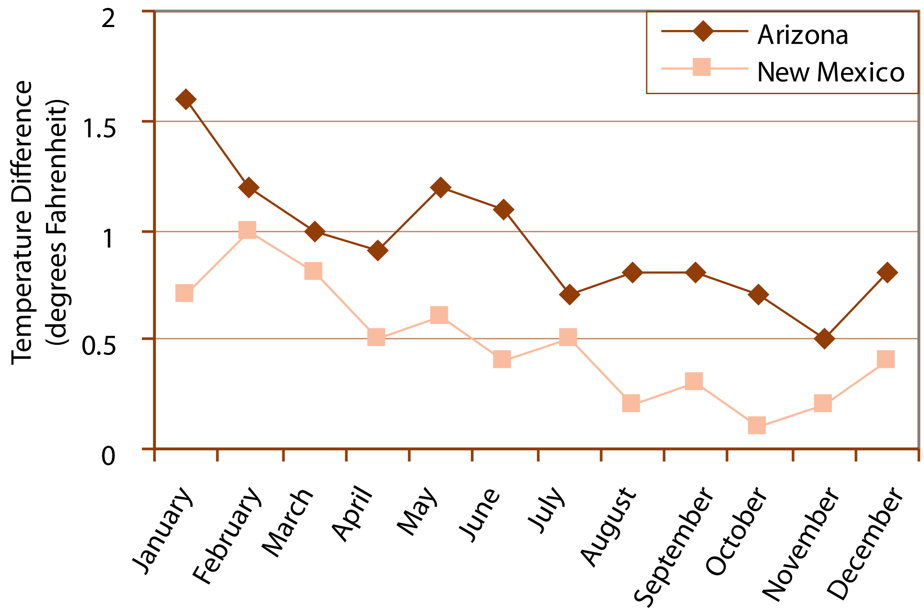

Figure 2. The difference between Arizona and New Mexico's average monthly temperatures in the past five years (2000–2005) compared to the full record (1895–2005) is shown above. The difference was most pronounced in winter and spring. Data: Western Regional Climate Center.

wood "blows up" into the clouds, it can form raindrops. "It used to be wood but now it's rain," he added.

Like the updrafts that helped form the clouds, downdrafts can accompany pyrocumulus rainfall. These sudden, erratic winds further vex firefighters by spreading flames in unpredictable directions.

Warmer air also tends to increase the incidence of lightning, which causes about 80 percent of the fire starts in the West. However, lightning strikes remain relatively unpredictable despite their importance in igniting western wildfires.

The fuel factor

Seasonally, fire danger fluctuates with the moisture condition of grasses and downed wood, respectively known as fine and heavy fuels in firefighter parlance. At longer time scales, explosive growth of saplings makes southwestern forests more prone to large-scale crown fires (*Southwest Climate Outlook*, February 2005).

"A lot of our landscapes are primed," as Whitney observed. Like many fire managers and historians, he noted that ongoing efforts to smother most blazes as upstarts means the ones that do manage to mature generally have loads of material to fuel their flames. Nationwide, only about an eighth of the acreage that would naturally burn each year typically escapes suppression efforts, according to an analysis by U.S. Forest Service researcher Ron Neilson and others.

The bark beetles and drought that killed millions of pines in recent years appear to have contributed to reducing fire risk—at least temporarily—by reducing the amount of flammable foliage in the forest. At an August 2005 water summit in Flagstaff, Northern Arizona University researcher Neil Cobb reported that the ponderosa and pinyon that had succumbed to bark beetles in 2003 and 2004 retained only about 13 percent of their needles, on average.

"If you don't have a canopy—all you have is dead sticks sitting up there—you probably decrease the risk of catastrophic crown fires," Cobb told

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the group. However, once the beetle-killed trees start falling to the ground, their wood will join the thousand-hour fuels that can potentially ignite future conflagrations.

Management efforts to thin forest stands or clear out invasive grasses can reduce fire danger locally. Tree-thinning projects in forests in Arizona's White Mountains and Flagstaff reduce fire hazards in sections of pine forest. Not surprisingly, efforts focus on areas where forests border communities.

However, climate variability and change also influences fuel build-up to an extent that makes it difficult for people to reduce fire danger on the regional scale without allowing a return to the natural fire regime. Global warming is likely to increase climate variability, with larger swings from wet to dry and back again. Some project global warming will increase the magnitude of events associated with El Niño and La Niña (*Southwest Climate Outlook*, January 2006).

Records compiled from historic observations, tree rings, and charcoal deposits all indicate large climate swings boost the potential for severe fires in highland forests. Wet periods encourage abundant growth in forests—many small trees pop up to celebrate the moisture. This increases the risk of stand-level drought during dry periods that follow, with a multitude of tree stems drawing from the same pool, like too many straws in a drink.

Back in the desert

In lowland systems like grasslands and desert, wildflowers and grasses tend to flourish following above-average winter rainfall, which typically coincides with El Niño events, U.S. Geological Survey researcher Janice Bowers has found (*Southwest Climate Outlook*, September 2005). Ironically, this often increases fire danger because grasses soon dry out to become fuel loads.

Evidence indicates some invasive grasses can load conditions even more than native grasses. For instance, the invasive buffelgrass yields a longer-lasting fuel than many native grasses. Buffelgrass is sensitive to winter lows, so the warmer temperatures that come with global warming may be encouraging its spread.

Another invasive grass, red brome, appears to gain a stronger foothold based on an aspect of global warming— higher carbon dioxide levels. Rising atmospheric carbon dioxide levels account for about 60 percent of the modern warming. They also tend to boost plant growth, favoring some plants more than others.

In one experiment considering the effect of futuristic carbon dioxide levels, red brome grew 50 percent bigger and more dense on average than three native grasses found in the Sonoran Desert (*Nature*, November 2000). Atmospheric carbon dioxide levels in the experiment were roughly double the pre-industrial level of 280 parts per million, while today's levels are about one-third higher than pre-industrial levels.

An invasion of red brome helped carry fire into the desert areas torched by the Cave Creek Complex fire last year. During a March visit to a 30-degree slope that tapers down to the Verde River, the desert area touched by the fire was sprouting flowers again.

From afar, the classic Sonoran Desert landscape looked less damaged than the charred oak scrub nearby. But up close, many of the cactuses looked scarred. Past experience indicates that many of the saguaros straddling this steep slope could take another five years before they realize they're dead, researchers indicate.

Research on the effects of fires in saguaro territory remains limited, so it's unclear exactly what it would take to bring this system down. However, fire has a well-documented role in promoting grasslands over woody plants like juniper and mesquite (*Southwest Climate Outlook*, February 2006). Saguaros are also woody plants, as their ribbed remains on the desert floor indicate.

Some vegetation models of global warming effects predict grasslands will encroach upon major expanses of southwestern desert, given an increase in precipitation as well as temperature. For instance, in one climate change scenario considered by the Mapped Atmosphere-Plant-Soil System project, a rise in average temperature of 12 degree Fahrenheit with an increase of average precipitation of 22 percent in the model led to grasslands taking over deserts in most of southern Arizona and some of southern New Mexico (*Pacific Northwest Research Station Science Update*, January 2004).

The Sonoran Desert may be starting to head in that direction already, if 2005 is any indication of what warmer temperatures will bring during wet years. With help from invasive grasses, wildfires can fly across low-elevation grasslands and even deserts, as during this record-setting year in Arizona. Meanwhile, warmer temperatures during dry years can help set the high-elevation forests ablaze. Dense thickets of saplings can feed the conflagrations, as in the Rodeo-Chediski and Los Alamos fires.

Management efforts to defuse forests through thinning projects and protect deserts by weeding grasses and shrubs around saguaros can help. But unless there's a quantum leap in the number of acres treated through such efforts, southwesterners should brace themselves for longer, potentially severe fire seasons in years to come as the climate continues to warm.

Melanie Lenart is a postdoctoral research associate with the Climate Assessment for the Southwest (CLIMAS). The SWCO feature article archive can be accessed at the following link: http://www.ispe.arizona.edu/climas/forecasts/swarticles.html