THE MAN WHO SMELLS FORESTS

Chemist Allen Goldstein has spent his career tracking elusive compounds emitted by trees. **Erik Vance** joined him for a tour of the woods.

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Standing almost 20 metres above the forest floor on a scaffolding tower in the Sierra Nevada, Allen Goldstein looks over the spiky tops of a young ponderosa pine forest. At ground level, the air is warm, still and rich with the sweet smell of pine and cedar. But above the forest, a stiff breeze from the west causes the tower to sway disconcertingly.

Goldstein inhales deeply before explaining the forest's daily chemical rhythm. At sunrise, the trees start pumping out a complex mix of volatile organic compounds (VOCs), such as pine-scented terpenes. By mid-morning, the westerly breeze adds a dose of the VOC isoprene from oak woodlands about 30 kilometres away. Then, as the sun reaches its peak in the sky, pollution from California's Central Valley makes its way up into the mountains.

A chemist at the University of California, Berkeley, Goldstein specializes in interpreting the scents of the forest. He has built his career on finding and characterizing some of the more elusive airborne chemicals in nature. For 10 years at this site near the University of California's Blodgett Forest Research Station (see map), he and his team have described more than a dozen plant-released compounds that no one had previously measured or, in some cases, even known existed in the atmosphere.

Working at the tops of the trees with ever more sensitive detectors, he has found that forests play a crucial part in the chemistry of aerosol particles and with pollutants such as ozone. His discoveries may help to fill in confounding gaps in atmospheric science, such as how VOCs from plants affect air quality and how they influence climate.

"Where Allen has really made his mark is in new ways of making measurements — basically seeing things that you have never seen before," says atmospheric scientist Inez Fung, a colleague at Berkeley.

Goldstein, now in his mid-forties, has broad shoulders, a quick smile, and an unpretentious demeanour. He is popular with students and easily becomes animated when talking chemistry. He is also popular with faculty members, although this might have something to do with his hobby as a winemaker. Fung says that recent vintages are "getting better" — other colleagues rave about them.

Goldstein came to Berkeley in 1996 from Harvard University, where he developed one of the first devices that could track VOCs from plants continuously throughout the day. Testing his device in Berkeley, it was sensitive enough to pick up the morning spike in airborne caffeine from nearby cafes, as well as traces of marijuana.

But Goldstein was not interested in tracking people's vices. His focus was the many types of VOCs emitted by forests. Estimates suggest that the vast majority, perhaps up to 90%, of Earth's VOC output comes from vegetation[1], a fact infamously alluded to by US president Ronald Reagan, when he said that forests pollute more than cars.

Goldstein scowls when asked about that statement, in part because it conflates natural emissions with car exhaust and also because journalists always ask about it. But in a way, Reagan's muddled formulation captures Goldstein's primary interest: the relationship between human pollution and plant emissions.

Goldstein often says he went into chemistry not purely for science, but to make a tangible difference to society (he originally planned on being a lawyer). "I've always tried to pick scientific problems that were interesting and challenging," he says, "but also had relevance to how we manage the world around us."

THE GOLDEN (AND HAZY) STATE

Allen Goldstein has run experiments near the Blodgett Forest Research Station for the past decade.

Spare the pores

The term VOC is a bit of a chemical catch-all, encompassing everything from exhaust fumes and the stench of solvents to the bouquet of Goldstein's wines. Some VOCs are highly reactive, existing in nature for just moments. Others float around for years.

At the Sierra Nevada research site, they were a solution to a mystery. When ozone pollution from more populous regions to the west blows into the forest, a significant fraction of it seems to disappear. For years, scientists thought almost all of this missing ozone went into trees through pores in their leaves called stomata, where it could cause damage. But in his first Blodgett readings in the late 1990s Goldstein quickly discovered that in the summer the trees absorbed at most only a third of the missing ozone[2].

E. VANCE

A. GOLDSTEIN

High and mighty: Allen Goldstein works in the treetops of California's Sierra Nevada.

The key, he learned, was that when temperatures increased, more ozone went missing. To Goldstein, this implicated VOCs because warmer weather causes plants to release more VOCs (which is why forests smell more pungent on hot days). He found that some of these VOCs react in seconds, quickly stripping oxygen atoms from ozone[3]. The now oxygen-rich molecules get heavier and stickier, forming aerosols that can create haze over a forest.

Joost de Gouw, an atmospheric chemist with the National Oceanic and Atmospheric Administration in Boulder, Colorado, says that Goldstein's work linking VOCs and these aerosols was a crucial breakthrough[4]. "He was one of the first to start thinking about VOCs and organic aerosols as a whole," says de Gouw, leading to what he calls the provocative idea "that the sources of organic aerosol are much [larger] than we think".

Of the 1.3 billion tonnes of VOCs released by humans and plants every year, conservative estimates say as little as 12 million become aerosol particles[4]. But Goldstein estimates that 150–200 million tonnes end up converted into aerosol. "That creates quite a chemical soup that we are not keeping track of," he says.

Furthermore, many of these compounds are good at hiding. For example, estragole (methyl chavicol), a liquorice-like aromatic found in aniseed, is a semi-volatile compound — at room temperature it could be either a gas or a particle. This unpredictability means that Goldstein has to make one detector able to detect the compound in either state. It also means that the stuff is prone to sticking to the inside of tubes before it can be measured. Once Goldstein and his students worked out how to detect it, they found that it is fairly common in the air around ponderosa pines. Near his site, Goldstein picks a few needles from a ponderosa, crushes them between his fingers, and sniffs. Sure enough, there is an unmistakable hint of aniseed.

"Goldstein's more recent wine vintages are getting better."

Planetary power

Now Goldstein is starting to look at the global picture. Atmospheric modellers say that, on the planetary scale, the climatic impacts of aerosols from plants are unknown. Such aerosols may exert a cooling effect, but scientists know little about the strength of that cooling and how it might change in the future.

Understanding what is happening is crucial, says de Gouw. "If models don't have the right emissions going into them, then they don't have the right chemistry and they don't have the right products coming out of them."

It is difficult to tell how much of the aerosol blanket over a given region comes from plants, and estimates vary widely[5]. Fung, Goldstein and their colleagues looked at aerosols that spike in the southeastern United States during hot summer days. The aerosols could not be explained by man-made sources alone and indicate, just as in Blodgett Forest, that plants are responsible for a large fraction. These aerosols in the southeast block enough sunlight that they cool the region, the researchers reported this month[6].

Although much of his work during the past decade has focused on the Blodgett site, Goldstein is getting ready to say goodbye. This summer, he will conduct his last field campaign there and then will box up his towers and shut down the site. When he first came there, Goldstein was a young professor. Now he is head of his department and well respected in his field. Looking around at the well-used equipment shacks, he seems a little sad.

"It's time to move on," he says. "I am moving out of the mountains and into the valley." By this he means he is moving from crisp mountain air to some of the worst air quality in the country. Arvin, a small Central Valley town near which Goldstein might soon set up a tower, exceeds federal ozone levels for a record one-fifth of the year. Goldstein will be looking at the emissions in the Central Valley, hoping to learn where they come from and how to minimize them.

It is one of several projects he is starting that might ask uncomfortable questions of the state's farmers. In many regions, VOCs from plants react with nitrogen pollution to form ozone and Goldstein wonders how much of the ozone in the Central Valley is due to the almonds, pistachios, oranges, lemons and grapes grown in the area.

These are the questions Goldstein ponders as he inspects cables in preparation for the summer experiments at Blodgett. He says the chemistry of trees and the chemistry of man are linked in ways that scientists are only beginning to understand. But there's no time to dwell on this topic today. He has to get out of the forest, down the hill, and back through the Central Valley before the traffic hits. ■

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