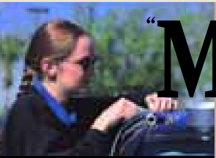
A Dome Of Our Own



Graduate student Cori Matyas attches the intake for the mobile CO_2 sampling equipment.

John C. Phillips photo

"MOST FUTURE CLIMATE PREDICTIONS are based on mathematical models," explains Craig Idso, a post-doctoral climatology researcher at Arizona State University. "You can't just double the CO2 concentration and see what happens in the real world. We don't have the technology to do that." Computer models are hardly perfect. They can't account for every single variable that affects climate. But they've been the only way to study the dynamics of CO2 in the atmosphere. Until now.

In 1998, Idso discovered that Phoenix lies under a carbon dioxide "dome," with peak values as much as 50 percent higher than the global average.

"CO_2 concentrations in central Phoenix are currently 500-600 parts per million. That's what it will be globally in 50 years. So it allows a natural lab experiment to take place," says Idso.

Add to this the fact that Phoenix has an urban "heat island." Afternoon temperatures are 3 to 5 degrees Celsius (5 to 9 degrees Fahrenheit) above surrounding areas. Together, more CO_2 and hotter temperatures add up to a pretty good example of what most cities will experience in the future.

"People are running around saying we'll double carbon dioxide sometime in the next century," says ASU climatologist Robert Balling. "What we're saying is that we've already come close to doing it in Phoenix. You don't have to wait around."

Balling heads up a multidisciplinary research team studying the relationship between carbon dioxide, humans, and the environment. The project is based on a pilot study that Idso conducted as a field exam while he was a doctoral student at ASU. His committee members asked him to characterize variations in CO_2 levels over time and space in Phoenix.

Idso had two weeks to complete the study. He spent hours driving along transects through the city, stopping every mile to take air samples using medical syringes. Since ASU didn't have gas analyzers at the time, Idso borrowed equipment from the U.S. Water Conservation Lab, where he painstakingly input samples from syringe after syringe. Idso's efforts paid off with more than a degree, however.

"After he did the field exam we realized that his results were amazing," Balling says. "They showed a tremendous dome of carbon dioxide in Phoenix. This really had never been observed before in any city."

In fact, few similar studies even exist. Those that do show only minor increases of CO_2 over urban areas. In central Phoenix, afternoon CO2 values are as much as 105 ppm over the global mean, compared to about 5 ppm in Cincinnati and Vancouver.

"It looks like everything comes together in Phoenix to produce this carbon dioxide dome," says Balling.

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CRAIG IDSO

For one thing, the desert has little vegetation, which absorbs CO_2. Phoenix residents drive a lot, emitting CO_2 from their vehicle tailpipes as they go. Finally, Phoenix has little wind compared to other cities.

"If you go to Chicago and emit carbon dioxide, the stuff's down in Gary and South Bend before you know it," Balling says.

Based on Idso's results, Balling and his colleagues submitted a grant proposal to the National Science Foundation's Urban Research Initiative program. The program seeks projects that interface the built-up urban environment, the natural environment, and human activity. The carbon dioxide dome seemed like a perfect example of such interaction. The team received $500,000 to study the dynamics of urban CO_2 over three years.

"This is the Cadillac. This is the [grant] you dream of. Half a million dollars from the National Science Foundation. I'd advise everybody to get one!" laughs Balling.

The project consists of three phases. Phase one, now complete, involves collection of primary data. During phase two, researchers will describe the relationships between CO2 and related variables. Phase three will merge the findings into a more integrated model and develop future scenarios based on growth predictions for the area.

Pulling Data Out Of Thin Air The first step was to create a comprehensive picture of the CO_2 dome by measuring it over time and space. "We're just going to measure this thing until we can't think of what more to measure," says Balling.

Idso's pilot study provided a starting point. Following his original transect routes, the ASU scientist and a group of students crisscrossed the Phoenix metropolitan area measuring CO_2 concentrations in the air. Each of the four routes begins and ends outside the CO_2 dome, cutting through the heart of Phoenix along the way.

This time, however, Idso had his own infrared gas analyzers, or IRGAs. The shoebox-sized devices take in air samples and analyze their CO_2 content using an infrared beam. By duct-taping the intake tube to the top of his car, Idso samples the air without even stopping.

The team took transect measurements once every two weeks from July 1999 through January 2000. They drove the transects at 5 a.m. and 2 p.m. They also took measurements twice daily from January 2-16. This allowed them to observe CO_2 fluctuations throughout the week.

Two permanent sites in Tempe have monitored CO_2 levels continuously since October 1, 1999. Now that the transect data is complete, IRGAs will be allocated to create three more continuous sites—in the towns of Peoria, Chandler, and Gilbert.

Idso's team has taken measurements from an airplane. Soaring over the city in a Piper Warrior, researchers recorded CO_2 concentrations up to 6,000 feet above the ground.

To date, the results support Idso's earlier findings of a pronounced CO_2 dome. In the heart of Phoenix, CO_2 levels can reach 555 ppm, compared to 370 ppm on the outskirts. In fact, CO_2 levels in the city never dip below 400 ppm. A secondary peak in the dome occurs over Mesa, Arizona's third largest city.

Where does it come from?

There are many sources. Anything that burns fossil fuels, like cars and power plants, will produce CO_2. Cement production also releases the gas. Decomposing materials produce CO_2, so landfills may be a big contributor. And vegetation puts out CO_2 at night. Even people are a source, because we all exhale CO_2.

"You're producing carbon dioxide right now, never forget it," says Balling. "We have plans sometime in the next year or so to go out in Sun Devil Stadium just to measure the carbon dioxide dome around that stadium when 70,000 ASU football fans are out there screaming and yelling. It probably goes way up."

Phoenix's CO_2 dome is nearly 50 percent stronger in mid-winter than it is in the summer. Nights are longer, and air close to the surface is strongly layered at different temperature levels during the winter. The team also found that lower values occur on weekends compared to weekdays due to a decrease in commuting on weekends.

On a daily level, pre-dawn CO_2 concentrations are significantly higher than mid-afternoon values. ASU ecologist Jeff Klopatek explains two likely causes for this difference.

"We tend to have inversions at night. The CO_2, which is heavier, tends to settle in," Klopatek says. "During the day, because we have convection heating, we think the CO_2 may just be rising with the warmer air. It could also be a function of vegetation. In most natural ecosystems the CO_2 level is going to be a lot lower during the day. Plants are using it as fuel during the process of photosynthesis."

Wind, which picks up during the day, scatters CO_2 as well. This also contributes to the drop in concentration.

The airplane readings show that CO_2 decreases as you get higher in the atmosphere. Idso explains, "The surface is the source. It's like a smokestack. Right near the smokestack you can see higher concentrations of smoke, but it dissipates as you go up."

John C. Phillips photo

Vegetation: Cause and Effect Vegetation is one of the trickiest pieces of the CO_2 puzzle. It affects the CO_2 dome but is affected by it as well. At night, plants contribute CO_2 to the atmosphere through a process called transpiration. But during the day, plants take in CO_2 for photosynthesis.

ASU plant biologist Tad Day is studying the relationship between plants and the CO_2 dome.

"There's been a lot of past research done on the effects of elevated CO_2 on photosynthesis and plant growth," he says. "But nearly all of this work has been done using a constant elevated level of CO_2. Some of those studies found that photosynthesis and growth are improved under elevated CO_2. However, with other plants and other systems it appears that the plants can't take advantage of the elevated CO_2 because other nutrients become limiting," says Day.

This study is quite different from previous research because the CO_2 levels are not constant in a real-world situation.

Day is studying four land-use types: turf outside the dome, turf inside the dome, desert remnant outside the dome, and desert remnant inside the dome. He measures ambient CO_2, plant intake and output of CO_2, temperature, visible light, wind speed, and wind direction.

To date, Day has found that there is a wider daily range of CO_2 levels over turf than over desert areas. Over turf, nightly spikes are higher while daily lows are lower than those above the desert. "This makes sense because turf vegetation draws in much more CO_2 per ground surface area [during the day]," says Day.

Day is also looking at stomata, the tiny pores on leaves that take in CO_2 and release water vapor. In previous lab studies, plants grown under elevated CO_2 levels produced fewer stomata per square inch. As a result, plants in higher CO_2 environments release less water vapor, and require less water overall. Such plants might also take in fewer air pollutants, reducing the damage that these pollutants cause.

Jeff Klopatek digs deeper into the vegetation issue, studying belowground and soil contribution to the CO_2 dome.

"If you take a look at most ecosystems, about 80 to 90 percent of the CO_2 in the system is being emitted from the soil," he says.

Soil respiration comes from root and fungal activity and from the decomposition of organic matter. Klopatek is comparing these belowground sources of CO_2 across Phoenix, especially in landfills.

"We anticipate that they're significant sources," he says. "Lots of organic matter is buried in the landfills. Once it starts decomposing, it starts releasing carbon dioxide."

Human Interest Human activities are at the heart of Phoenix's CO_2 dome. It's easy to see that CO_2 concentrations spike over the densest parts of the city. Teasing out which activities influence the dome and to what extent is more difficult.

Patricia Gober is a social geographer who gathers information about human activities in the Phoenix area. She compiles data on traffic patterns, population, land use and employment from a variety of local and national sources, including offices right here at ASU.

"This project has gotten groups of people together that haven't worked together before. Social scientists aren't going to be able to understand complex environmental systems themselves. Neither are ecologists or climatologists," says Gober.

"The climatologists are mostly interested in local meteorological effects. The ecologists are interested in plant effect. I am interested in human activity."

Tim Hogan is also interested in human activity. As director of ASU's Center for Business Research, Hogan provides information on man-made sources of CO_2.

"We've done literature review on what the sources of CO_2 are. If you generate one kilowatt of electricity with natural gas, how much CO_2 would that put out? That kind of thing," he explains.

Hogan and his colleagues also locate these sources in Phoenix. They find out just how many kilowatts of electricity the power plants are producing, or how many miles people are driving, to learn how much CO_2 is being generated.

"We have the information historically and currently on an aggregate basis of how many cars there are, how many miles they drive each year, etc. Our job is to come up with aggregate measurements of how much CO_2 has been generated over time and how it correlates to major sources like traffic, home heating, and power plants," he says.

"CO_2 levels are definitely influenced by the vegetation but they are also affecting the vegetation as well. I'm trying to tease out the significance of that."

TAD DAY

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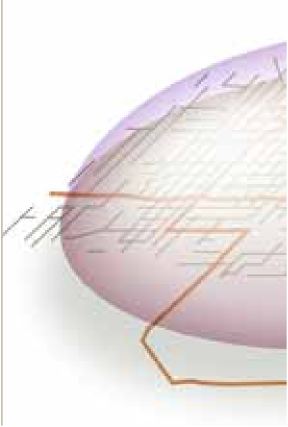
Map of Craig Idso's transect routes through the Phoenix metropolitan area.



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Hogan also looks at how these values vary over time. Using future growth estimates for the Phoenix area, he helps predict how the CO_2 dome will change, and how it will affect the entire Valley of the Sun.

Putting It All Together Gober and geographer Elizabeth Wentz combine the human data with information from Idso's team and the plant biologists. They use Geographic Information System software to try and identify patterns among the masses of information.

"GIS is essentially compiling map data in a computerized environment so that analysis can take place. The idea is that you can then look at spatial patterns and spatial relationships within a computerized environment," explains Wentz.

The geographers also need to look at changes over time as well as space. This temporal aspect poses a challenge for GIS mapping.

"One of the research limitations of GIS is looking at spatial processes and including the temporal element. How do things change over time? Most of the representations of spatial data in a GIS are very static, very much like a map," explains Wentz.

She is working to enhance GIS software to mesh spatial and temporal data more easily.

"GIS is a tool. But I'm not just interested in applying the tool. I'm interested in expanding the technology and trying to get GIS to do something that it currently doesn't do," Wentz says.

Her task is difficult because data that are collected with frequency, like climate data, usually aren't collected in many locations. The reverse is also true: data collected over a wide area aren't usually collected with great frequency.

"Here's where that spatial-temporal problem comes in," explains Wentz. "We know that the traffic volume fluctuates, but I only have average weekly traffic, so I can't say, 'here's morning traffic, here's midafternoon traffic, here's night traffic.' I don't have that kind of data."

Joe Fernando is also working to model the GIS data being collected. Instead of using GIS to map the information, he is using a three-dimensional numerical model that demonstrates GIS flow patterns in the Phoenix area.

Fernando is the director of ASU's Environmental Fluid Dynamics program in the College of Engineering. Fluid dynamics is the study of all things that flow, like air and water. Fernando's three-dimensional animations will show how variables like wind, temperature, and land cover affect the movement of GIS in the air—both vertically and horizontally.

"Whatever CO_2 is coming in and getting out has been included," he says. "We look at how this CO_2 goes back and forth,"

Like Wentz, Fernando also struggles with gaps in the data.

"The biggest problem we have now is lack of measurements. For example, we need a good idea of how much CO_2 is coming out of the freeways," he explains. "We don't have good values for how it changes during the day. Right now we have to hypothesize a certain amount. We make an educated guess."

Even so, the models provide a useful look at where CO_2 goes once released from its sources.

"The models are very good at telling us where things are moving in general," Fernando says.

The animations and the GIS data will bring us closer to answering some of the daunting questions about carbon dioxide. To what extent do human activities impact CO_2 levels? What effect does vegetation have, and how is it affected? How and why do CO_2 concentrations vary throughout the day, the week, or the year? How will the CO_2 dome change over time if the city continues to grow at its breakneck pace?

"There are all these linkages," says Balling. "To fully understand carbon dioxide, we're going to all work together as a grand team and see if we can pull something out of all this information."

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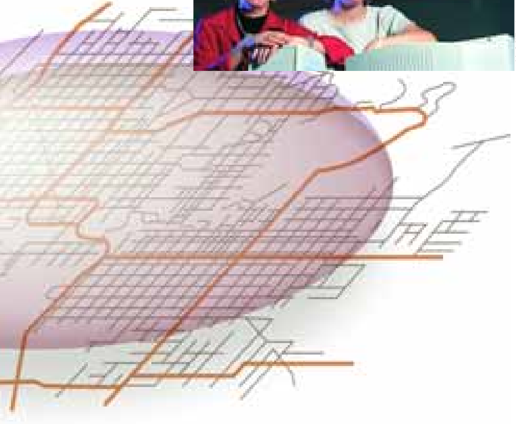
> PAT GOBER


Pat Gober and Elizabeth Wentz

John C. Phillips photo



Carbon dioxide research is funded by the National Science Foundation. For more information, contact Robert Balling, Ph.D., ASU Office of Climatology, 480.965.3560. Send e-mail to robert.balling@asu.edu