A shift toward aridity

Westerly winds and other forces could make drought-prone regions even drier

By Stephanie Doster and Dan Ferguson

On February 28, 2008, the Climate Assessment for the Southwest (CLIMAS) program hosted a small, informal roundtable with several climate scientists from The University of Arizona. The discussion focused on how a poleward shift in the westerly winds over the northern hemisphere may influence the climate of the Southwest. The following article is based on the roundtable discussion.

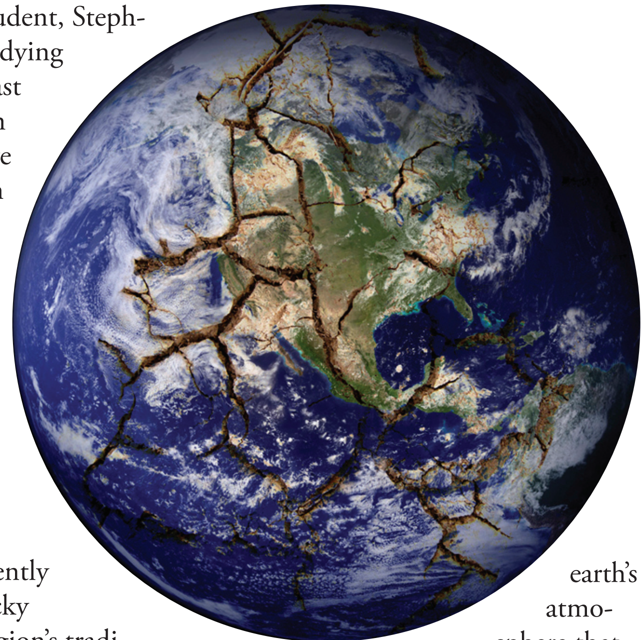
It's been in newspapers, on television, and in radio reports: greenhouse gas emissions from tailpipes and factories are very likely the culprits in global warming, and that in this era of accelerated climate change, the Southwest should brace for drier conditions in the coming decades. But beyond global warming, what are the forces that would drive this shift toward less precipitation?

The answer likely lies in the westerly winds, said Joellen Russell, a climate modeler and assistant professor of geosciences at The University of Arizona (UA).

Recent studies suggest that the westerly winds that blow over the mid latitudes in both the northern and southern hemispheres are shifting toward the poles. The poleward migration of the westerly winds, often referred to as the jet stream, will potentially alter, and perhaps already is changing, winter precipitation patterns in the southwestern United States.

"In the southern hemisphere, there's a very clear signal that over the last thirty to forty years we've seen about a four to six degree shift poleward of the westerly winds in the winter," Russell said. "In the northern hemisphere the shift has not been quite as distinct, in the sense that we've had a slightly weaker shift."

Russell and her graduate student, Stephanie McAfee, have been studying the climate records of the last thirty years in the American West. They believe they have spotted a significant shift in the winter-time location of the jet stream that's influenced the amount of precipitation in the Southwest.



The shift is important to the Southwest, Russell said, because it could change the winter storm track so that the jet stream more consistently flows north around the Rocky Mountains, bringing the region's traditional share of precipitation instead to northern areas of the country. Winter rain and snow make up most of the total precipitation received in Arizona and New Mexico annually, so any large scale change in the winter storm track has the potential to directly affect precipitation totals in the region. It remains unclear how these trends in large-scale atmospheric circulation patterns may influence the summer monsoon season in the Southwest because different forces cause the heavy summer rains.

"When the jet comes in towards the Rockies [during the winter], it has to make a decision whether the storms will break north around the northern edge or break south around the southern edge. We [in the Southwest] like it when they break south, because that means we get rain," Russell said.

The mechanisms for this jet stream shift are not fully understood, but two potential drivers are tied to manmade impacts on the global climate system. A strong body of scientific literature suggests that the depletion of ozone in the stratosphere is causing stratospheric cooling. The stratosphere is a thin layer of the earth's atmosphere that sits above the troposphere, the lowest layer of the earth's atmosphere. Stratospheric cooling is driven by anthropogenic depletion of ozone in the stratosphere.

"That ozone is a gas in the stratosphere that absorbs incoming shortwave radiation from the sun. …Because it's absorbing that radiation, there's heating. So if we reduce the amount of ozone [in the stratosphere], you get less heating," said Jonathan Overpeck, a UA geosciences professor and director of UA Institute for the Study of Planet Earth.

At the same time the stratosphere is cooling from ozone depletion, tropospheric ozone, a greenhouse gas, is building up, trapping more heat and keeping it from escaping to the upper atmosphere, Overpeck said.

Scientists have seen a 0.6 to 0.8 degree Celsius change in the troposphere, where it's warming; the polar stratosphere has cooled almost seven degrees in the Antarctic, Russell said.

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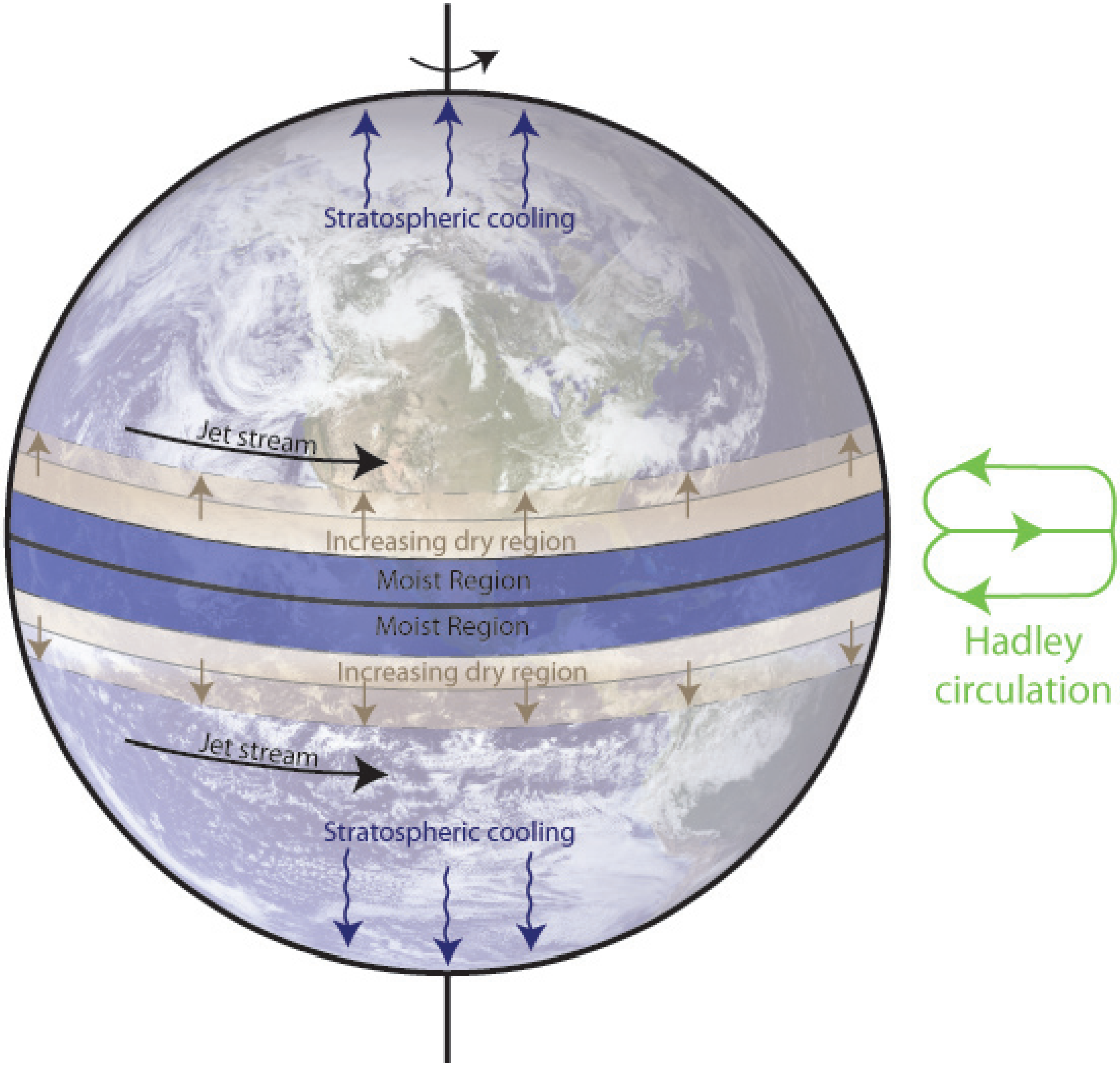

Figure 1. Cooling of the stratosphere from ozone depletion high in the atmosphere and expansion of the Hadley cell from warming oceans are impacting the winter time tracks of the westerly winds over both hemispheres. This change could expand the world's deserts, meaning a potentially drier southwestern United States.

A cooler stratosphere and a warmer troposphere could shift the westerly winds over both the northern and southern hemispheres, in part, because of the polar vortex, that very fast wind that spins around each pole during winter, when the equator-to-pole thermal gradient is steepest.

An increase in the thermal gradient, or change in temperature across a distance, has a direct effect on atmospheric winds. In this case, the increased thermal gradient that results from a cooler stratosphere and a warmer troposphere leads to a poleward pull of the jet streams.

The other mechanism that may be linked to a poleward shift of the jet streams over both hemispheres is the expansion of the Hadley cell, an atmospheric circulation pattern that exerts a strong influence over the climate of the tropics and subtropics.

"The Hadley cell is that convective cell on the equator, where you have warm water creating convection, which then

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rains out and creates our lovely rain forests in the tropics," Russell said. Most of the world's deserts, including the Sonoran Desert, exist just beyond that point, at around 30 degrees north and south latitude.

"Because we're trapping more radiation with carbon dioxide, we're warming the tropical oceans, which are then [generating] more convection," Russell said.

Models indicate that increased convection appears to be expanding the Hadley cell, which could mean an expansion of the world's deserts (Figure 1).

"We don't quite know yet whether it's because those dry areas are expanding, or because of something different in the hydrologic cycle associated with the tropical shift," Russell said.

While still an area of active research, it appears that the expansion of the tropics may push the jet stream, and the cooling of the stratosphere due to the ozone holes may pull it, Russell said.

"They're both happening. We can't attribute one way or the other, because we can't distinguish between the impacts," Russell said. "All [the global climate] models agree on very little, but they all agree that the winds are moving poleward in both hemispheres. If you've got a small shift because of the warming in the troposphere, but you've got a big shift because of the ozone loss in the stratosphere, it kind of doesn't matter [which mechanism is dominant], because they both work together."

One uncertainty is how the shifts in the jet stream interact with existing natural variability in the climate system, like El Niño Southern Oscillation and the Pacific Decadal Oscillation, said Chris Castro, UA assistant professor of atmospheric sciences. He added that temperature also will play a role in a more arid southwestern United States.

"There has been a trend toward an increase in snow melt happening earlier. If you look, for example, at Climate Prediction Center forecasts, you can consistently see this bull's eye of above-average temperature anomalies in the Southwest—and this is accounted for nearly entirely by long term temperature trends," Castro said. "Water managers in the western U.S. make most of their planning decisions based on spring snowpack, and this has been decreasing, on average, over the last twenty years or so."

From a water management perspective, warming temperatures—and increased evaporation rates—also create more demand for water, noted Julia Cole, geosciences professor.

Castro agreed, adding that the caveat to water demand in Arizona, at least from an urban water usage perspective, is the onset date of the monsoon. A very recent study by Jeremy Weiss, a UA geosciences researcher, has shown that during recent years, temperatures are higher in the weeks just before the onset of the monsoon, specifically the early to late June period, Castro said.

"That's the trend, but then what controls exactly when the transition period occurs and whether the monsoon is early or late? That's modulated by the natural variability in the climate system. How does that change with global warming? We don't know. What happens during these very climatologically different periods? The pre-monsoon period, and during the monsoon itself?" Castro said. "We really need to adopt the perspective of how climate change is affecting these very climatologically different periods and interacting with natural climate variability. That kind of information will be of much greater relevance to local stakeholders, rather than just describing the mean change for the entire summer."

One trend southwesterners are likely to see, Castro said, is more intense precipitation events, which can lead to flooding and runoff. This has already been occurring over the U.S. during the warm season and during the monsoon in Arizona, according to Castro.

"This means that, in a warming world, Arizona's seasons are becoming even more extreme. The period before the monsoon is getting hotter and drier, but once the monsoon rains come they are more intense. The summer of 2006, the sixth wettest in Tucson, is a very good example," Castro said.

Although not discussed in the roundtable, another player in aridity could be dust, Overpeck said. If increased amounts of the tiny heat-absorbing particles, kicked up by the activities of a growing population and drier conditions, settle on mountain snowpack, the snow would melt earlier in the spring. That would spiral into a positive feedback loop of yet more dust and aridity, Overpeck said.

But regardless of what the models reveal about future climate conditions, Overpeck said, there is one wild card that can throw off even the best climate projections: natural variability. It is unknown how natural variability is interacting with global warming.

"There's a lot of variation in the climate system," Overpeck said. "We could have winters like this winter, which have more than average precipitation."

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