The Late Summer Monsoon

I used to dread the Fourth of July in Tucson. Actually I enjoyed the fireworks and the lightning storms that often debut here on the same night. Unfortunately the concussive overture drums in three months of that weather: broiling, wet air that makes my skin itch; humidity which disables my evaporative cooler; dust storms, slamming rains, floods and sultry days. But no more complaints—bring on the monsoon! The rewards make the problems worth while: grand light shows, evenings of cool breezes, and the welcome scent of wet creosote across the desert.

The word monsoon comes from the Arabic monsoon, meaning an alternating seasonal wind that moves in summer from sea to land, in winter from land to sea. Continents in winter are colder than the sea, so the cold, heavy air of the land rolls down to the sea. In summer, the land warms before the sea and the pattern reverses. Warm continental air rises, and a sea breeze rushes inland to fill the partial vacuum created by rising air.

In the desert Southwest in winter, wind reversal is weak and does not affect the entire area, but in summer the Sonoran Desert experiences a strong onshore wind in classic monsoon style. In late summer, this invading sea breeze brings evaporated oceanic moisture into the Sonoran Desert, and rain results. So, in proper usage, the word monsoon refers to the wind pattern, not to the rain itself. Technically, we have a monsoon here whether it rains or not. But the monsoon usually does bring rainstorms, and we can legitimately call these "monsoon storms."

To put our monsoon in perspective, it helps to understand why much of the North American Southwest is a desert. The reasons: we’re in a rain shadow, we’re in a high pressure zone, and the major storm tracks pass us by.

Rain shadow—a cause of deserts and a descriptive term once you understand it. Imagine a parcel of moist air moving inland from the sea. As the air rises to get over mountain ranges, it expands (less pressure up there), and this cools it. Cooler air holds less moisture than warmer air, so the rising air releases moisture. Clouds form, and rain falls on the windward side of the mountains. By the time the air has crossed several ranges, as it must to get to Tucson, the moisture has been wrung out of it. As mountains block the light of the evening sun, they also block the rain, casting a rain shadow toward the east. We are in the dry shadow.

High pressure means, simply, that there is more air above us than in other regions. At Earth’s equator, hot air rises continuously (on average). Eventually the air can’t rise any more, so it spreads out and moves north and south. At about our Sonoran Desert latitude, 30 degrees north, the air has cooled and become denser, so it sinks in huge clockwise whirls. High pressure results from the increased amount of air above us, as equatorial heat continues to pump air up to our latitude. But here is the key: our descending air warms up from increasing pressure as it descends, and warmer air can hold more moisture than cooler air. If it withholds its moisture, no precipitation falls here, so the climate remains arid.

The world’s storm tracks are the jet streams. In southwestern North America, these usually are weak and they pass north or south of the Sonoran Desert, so fewer storms come our way. During the dry months of May and June, the storm tracks are far north of Arizona.

Tucson’s moisture comes in two cycles, late summer and winter. About half of the total falls in winter. (Of
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course, rainfall varies considerably in different parts of the desert and from year to year. Where does this moisture originate, and how is it delivered?

Coincidentally, while there are three main reasons it is dry here, there are also three main sources of our moisture: winter storms, chubascos, and monsoons.

Our winter storms come to us across the mountains and valleys of California, down from the north Pacific. They are broad frontal systems that can affect most of our desert at one time. Despite rain shadow, the fronts contain sufficient moisture to retain some of it for the Sonoran Desert even after passing over hundreds of miles of mountainous terrain. The rains are gentle but soaking.

Chubascos are tropical cyclones that occur in late summer or fall, usually September or October, overlapping the monsoon. They originate off the west coast of Mexico south of Baja California. Blown by the easterly trade winds, the storms move northwest, following the Pacific coast of Baja. Crossing an invisible boundary into the mid-latitudes, the storms come under the influence of westerly winds and they turn inland.

Finding a way through Baja mountain passes, the chubascos wade across the upper Gulf of California, which lies steaming at 80°F. They pick up additional energy from the warm waters and crash into the Sonoran Desert near Yuma, Arizona. Yes, Yuma, the driest city in the United States.

At several per decade, chubascos are relatively uncommon; they probably contribute only a small percentage of the desert's total moisture. However, they can be the wettest storms of the year, dropping over six inches of rain in areas that may receive less than half that as an annual average.

Sonoran Desert monsoon storms are memorable. Out of a clear indigo sky, a puffy white cloud appears. It is cumulus, from the Latin word for heap. For a couple of hours the cloud grows at an astonishing rate until it fills half the sky, lower layers translucent gray, lightning within, at the top a shining white anvil of ice crystals: everything is ready now. The wind comes first, in front of the rain.

Downdrafts within the storm spread out when they hit the ground, blowing up sixty mile per hour gust fronts. From the evolving cumulonimbus (a "raining heap") come the first lashing raindrops, obscured by amber dust clouds.

The gusts pick your hat off and pin a few tumbleweeds against the fence. A crackling flash is followed instantly by cannon fire; the drenching rain is on you. There is barely time to enjoy the coolness and the clean-washed air—the rain lasts only part of an hour. Then the storm trundles out across the desert, filling arroyos and wetting the hot creosote, which now releases its perfume. The storm dissipates as it goes. Out where the sun is still shining you can see brooms of rain, called virga, evaporating before they reach the ground.

Our monsoon moisture originates as evaporation from the Gulf of California. Winds bring the moisture from there, swirling around so they reach the Sonoran Desert as southeast winds. Thunderstorms build and wring the moisture from the air. These monsoon thunderstorms are driven by heat acting on humid air. The heat comes from two sources.

The first source is the summer sun. As the sun heats the desert, humid air columns (thermals) three to five miles in diameter begin to rise; by midday these form into thunderstorms. The thermals are separated by much broader areas of slowly descending cooler air, which is why the thunderheads are so widely scattered. The sun's heat energy has set up a vertically circulating system, called convection, analogous to water boiling in a pot. As air heats up, its molecules gain energy and vibrate faster and faster, bumping and pushing against the air molecules around them. This causes the air to expand. Since expanded air contains fewer molecules in a given volume, the warm air parcel weighs less than it did while cool. And because it weighs less, it rises. As it rises, the air begins to cool due to the lower pressure higher in the atmosphere. Although the air is cooling as it rises, it is still warmer than the surrounding air, so it retains its buoyancy.

Finally, at about 17,000 feet, thunderstorm air gets so cold that raindrops freeze into hailstones. Condensing moisture forms into snow. Soon the growing cloud towers
40,000 feet or more, and the whole top of it contains a raging snowstorm. Meanwhile we broil at ground level. Next time you see a monsoon thunderhead, look up and try to imagine that. Of course, by the time snow and hail reach the ground, they have melted and become raindrops.

The second source of heat is the condensation of rain and snow from the rising thermal. You know that it takes heat energy to boil water and turn it to steam. Perhaps surprisingly, that same heat energy is released when the steam condenses back into water. Every large raindrop that forms releases about 500 calories of heat to the surrounding air! This really gets the storm going. All that heat makes the air rise even more, which cools it and causes even more condensation.

This heats the air again, and so on until the storm runs out of moisture. That takes only a couple of hours for most monsoon storms. If you have read this part carefully, you will have more questions than answers. May I suggest Skywatch: The Western Weather Guide, 1987, by Richard Keen or Weather Proverbs, 1992, by George Freier.

Until recently, our monsoon moisture was thought to originate in the Gulf of Mexico, under the sway of the Bermuda high pressure system. The Bermuda High does kick its moisture westward. But many meteorologists now feel certain that the Gulf of Mexico moisture rarely or never makes it over the 6,500-foot Mexican Sierra Madre into the Sonoran Desert.

In 1974, John Hales, Jr. of the National Weather Service postulated that our monsoon moisture comes from the Pacific Ocean off the coast of Baja via the Gulf of California. Other workers corroborated his findings, but many writers ignored the new data. However, Michael Douglas of the National Severe Storms Laboratory, and others, now present compelling evidence that our moisture has an eastern Pacific and Gulf of California origin. The evidence is that the greatest monsoon cloud cover and precipitation occur on the west side of the Sierra Madre. Satellite imagery shows that maximum monsoon-style clouds form on the west slopes of the Mexican sierra, not the east. Also, the July onset of the monsoon is most pronounced in the west. These data are all in keeping with a Pacific and Gulf of California moisture source for our monsoon.

In summary, there are three steps to delivering monsoon moisture to the Sonoran Desert. First, the warm waters of the Pacific and the Gulf of California evaporate. Next, southeast winds bring the moisture to our desert. Finally, heat-driven convective monsoon thunderstorms wring the moisture out of the air and drop it on the desert.

Monsoon moisture originates through evaporation from the Pacific and the tepid water of the Gulf of California. Late summer winds carry the moist air northward into the heart of the Sonoran Desert. Some of these winds occur in rapid pulses called "gulf surges." These are the classic monsoon winds.

Once the air has moved into the Sonoran Desert of Arizona, there must be some way of removing its moisture to provide rain to this dry land. Otherwise the moist air would eventually go elsewhere, leaving our desert dry. In fact, that's what happens on many a sultry monsoon day, when a few clouds may form but rain refuses to come.

Moisture is wrung from humid air when it rises. Often this happens in "mountain islands," where air is forced to move up, causing cooling to the dewpoint. Rains may be brief, but cool downwinds can flow down the mountainside, lifting moist foothills air like a spatula under a pancake. As this new air rises and cools, a new storm can develop, bringing more rain and another downdraft. In this manner, a series of successive thunderstorms can migrate off the mountain and into the surrounding desert.