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New Mexico's Changing Climate

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The past several years of severe drought in New Mexico have undermined the perception that we exist within a static climate regime and have intensified the need to understand shifts in climate over broader time scales. From agriculture, forestry, and water management to tourism and development, the effects of both short-term climate variability and long-term climate change are felt at multiple levels. A deeper grasp of fundamental climatic processes can potentially enable us to predict changes in climate over time and to respond with appropriate policies and planning. In New Mexico, as elsewhere, the continuing development of a multi-dimensional science of climate change is crucial to the future viability of resources and communities.

NEW MEXICO'S CLIMATIC SETTING

"Climate is what you expect, while weather is what you get." While the fundamental processes responsible for weather are the same everywhere, climate involves the average variations in weather from place to place. For example, an individual thunderstorm occurring in New Mexico, Alabama, or Argentina is caused by the same essential atmospheric processes, but the average frequency and seasonal variability of thunderstorms in each place are considerably different. Climatological "normal" conditions for a particular place and time of year are defined officially as a 30-year average of weather (most often described in terms of temperature and precipitation), measured over the most recent three decades.

Climate is determined by fixed or slowly varying factors called boundary conditions, which modulate weather. The primary factor is the intensity of sunlight, determined by the brightness of the sun, Earth's orbital geometry, and latitude. Locations in tropical latitudes receive a steady stream of high intensity sunlight year-round; polar latitudes actually receive slightly more sunlight than the tropics in summer, yet virtually no sunlight at all in winter. In addition to the sun's radiation, Earth's surface receives infrared radiation from the atmosphere above. The intensity of infrared radiation received at the surface is determined by cloud cover, humidity, and the atmospheric concentrations of

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infrared-absorbing trace gases (greenhouse gases such as carbon dioxide).

Other climatic boundary conditions vary depending on longitude. Such longitudinally varying conditions include the distribution of oceans and continents, continental topography, and land surface cover. If our planet were a featureless sphere, then its climate would depend only on the distribution of sunlight, and would therefore be the same at each point along a latitude circle. This is obviously not the case. For example, Albuquerque and Los Angeles are at nearly the same latitude, but their climates are markedly different: unlike Albuquerque, Los Angeles rarely experiences subfreezing temperatures and receives most of its precipitation in winter rather than summer. The climate of Los Angeles is considerably moderated by its proximity to the Pacific Ocean, whereas Albuquerque's climate owes a great deal to its elevation above sea level, its distance from any ocean, and the presence of major mountain barriers in all directions. If we can understand the relationship between the boundary conditions and local temperature and precipitation, then we have a greater capacity to predict the shifts in climate that may accompany known or predicted changes in those boundary conditions.

NEW MEXICO'S CLIMATE TODAY

The statewide annual average temperature for 1961-1990 was 53.1°F (but that average is rising: the 1971-2000 average was almost 53.5°F). New Mexico's temperature is considerably cooler than states at the same latitude to the east, because of the high average elevation of the state and the absence of the moderating effects of oceans in winter. Temperature within the state decreases from south to north, due primarily to the gradient in the intensity of sunlight. If a temperature map were superimposed on that pattern, it would show the low-lying Rio Grande valley as a tongue of warm temperature extending northward into the center of the state amidst cooler temperatures in high elevation regions such as the Colorado Plateau and the Sacramento and Sangre de Cristo ranges.

Albuquerque is located at a latitude of 35°, within a latitude zone that encompasses many of the world's deserts (between about 25°-35° in either hemisphere). This zone owes its arid character to a global circulation system called the Hadley Cell, which generates a belt of subsiding air that tends to suppress clouds and precipitation at these latitudes. In addition to this global circulation, New Mexico's remoteness from oceanic moisture sources acts to keep our climate dry. The lack of humidity has a particularly pronounced cooling effect on nighttime temperatures, because heat stored in surface soil rapidly radiates away to space during the night. Precipitation increases across the eastern half of the state, where humid air from the Gulf of Mexico penetrates more often, particularly in springtime.

Moisture and precipitation enter the state from a variety of directions depending on the season. In winter, most precipitation is carried in by eastward moving frontal systems originating over the Pacific Ocean. In an average winter, the majority of these storms track to our north, dumping more snow in Colorado than in New Mexico. Winter snow pack at high elevations is particularly important for water resources statewide, because snowmelt provides a very effective means for recharging ground water and filling reservoirs. In summer, humid low-level winds from the south, part of the so-called North American monsoon system, bring thunderstorms that can produce spotty but locally copious precipitation, making summer the wettest season for most of New Mexico.

SHORT-TERM CLIMATE VARIABILITY

"Average weather" can vary systematically from year to year within a 30-year climate period. Such interannual variability in climate is associated principally with changes in ocean temperatures that modulate storm tracks and moisture transport for entire seasons or years. Slow variations in ocean temperature and currents, especially in the Pacific Ocean, are a major cause of wintertime climate variability across North America.

The El Niño cycle is the best known and best understood example of the ocean's effect on climate variability. El Niño is an enormous tongue of anomalously warm Pacific Ocean surface water extending along the equator westward from the South American coast. The mirror-image cold phase is known as La Niña. El Niño pulls the North Pacific atmospheric jet stream, and the storm track associated with it, southward and eastward so that more winter storms that would normally pass to our north generate precipitation over New Mexico instead (as happened in early 1983, 1987, and 1992). La Niña has the opposite effect, pushing the jet stream northward and leaving New Mexico drier than normal (as in 1971, 1974, and 1989). The El Niño–La Niña cycle is not periodic, but extreme warm and cold phases each tend to occur several years per decade, reaching maximum amplitude in the Northern Hemisphere's winter season.

Recent research suggests that longer, multi-decadal fluctuations in the North Pacific Ocean also affect precipitation across southwest North America, perhaps helping to explain long-term drought and wet spells throughout the Southwest. North Pacific Ocean temperatures seem to vary more slowly than tropical El Niño-related anomalies. This Pacific Decadal Oscillation (PDO) tends to modulate the effects of El Niño, such that in its negative phase the effects of La Niña are amplified and the effects of El Niño are suppressed, whereas in the PDO's positive phase the opposite modulation occurs. The PDO was in a negative phase during the 1950s, when persistent drought plagued New Mexico, then abruptly flipped to a positive phase in 1977, heralding the wet decades of the 1980s and 1990s. Teasing out the association between decadal climate variability across the Southwest and slower, multi-decadal oceanic cycles in the Pacific Ocean (and perhaps the Atlantic as well) is a very active area of research.

LONG-TERM CLIMATE CHANGE

Forming a backdrop to New Mexico's short-term climate variability are constant climatic shifts that occur over longer time scales. Over the past several decades the statewide average temperature has been on a fairly steady and rapid rise, with every year since 1992 being warmer than the 1971-2000 "climatological average" value of 53.5°F, with no cooling trend in sight. On the other hand, the early years of the twentieth century, as well as the 1960s and early 1970s, were generally somewhat cooler than this average value. The current warming trend is observed across much of the world, consistent with the prevailing hypothesis (supported by a large body of climate model research) that such warming can be attributed to worldwide increases in greenhouse gases. However, because natural and man-made climate changes are now occurring simultaneously in unprecedented ways, we cannot confidently extrapolate past variability into the future. An improved comprehension of the fundamental processes that govern the climate system is thus central to our ability to understand and predict future changes in climate.

While the significance of the current warming trend in climate should not be understated, projected twenty-first century climate changes are nonetheless modest compared to some changes that have occurred in the distant past. During the last ice age, which maximized some 15,000-20,000 years ago, abundant geological evidence indicates that huge ice sheets covered much of North America to the north and east of New Mexico. That event was merely the latest in a long series of ice age cycles that characterize climate over the last two million years. These ice age cycles are thought to be caused by decreases in the tilt of Earth's rotational axis that turn Northern Hemisphere summers cold and make seasons less pronounced. As ice sheets grow, less sunlight is absorbed by Earth's surface (due to the highly reflective nature of ice), and cold conditions are amplified. Bubbles of air trapped in ice cores show that atmospheric CO_2 concentration declined dramatically during the last ice age, decreasing the greenhouse effect and thereby depressing temperature still further.

Although New Mexico itself was not covered with ice 20,000 years ago, the climate here was still much cooler than at present. Geologists have found evidence of small glaciers in the Sangre de Cristo Mountains of northern New Mexico, which are currently unglaciated. Further south, large lakebeds, such as the Estancia Basin east of the Manzano Mountains, now exist as dry basins, providing distinct evidence of a very different climate regime. Layers in lake bed sediment cores, called varves, contain pollen grains, magnetized minerals, and tiny fossils that can be analyzed to determine the temperature of the lake and how long ago the sediment layer was laid down.

The wet climate that once supported large lakes in this now-arid land also generated the huge ground water reservoirs that currently provide us with much of our water supply. Geochemical evidence suggests that much of the well water we now tap seeped into the ground during the last ice age. The implication is that we are rapidly "mining" ground water from aquifers that filled up thousands of years ago, and our extraction of this water vastly exceeds the recharge taking place under current, more arid climatic conditions. Thus, ground water in New Mexico, like oil, is effectively a nonrenewable resource on human timescales.

New evidence of decade-scale climate variability during the past 1000 years has recently come to light through examination of annual growth rings in ancient trees, a proxy indicator of climate developed in the early twentieth century. The distinct sequence of good and bad growth years in the trees creates an excellent "fingerprint" that allows archeologists and geologists to determine when trees were cut or died, providing an invaluable source of precise dating for many scientific studies.

One of the major results of recent tree ring analysis is the discovery of Southwestern "drought cycles" on sub-century time scales. The tree ring record shows that intermittent severe droughts have been a recurring feature of New Mexico's climate, with an apparent 50 to100 year return period for such droughts. The cause of this time scale for drought recurrence is not known, but it may be related to poorly understood changes in global ocean temperature patterns. Furthermore, the terrible 1950s drought does not appear in the tree ring record to be extraordinary in terms of either duration or severity—just another "normal" feature of southwestern climate variability! The lessons for New Mexico are clear: the most recent few decades represent unusually wet conditions, and we need to anticipate future droughts at least as severe as the 1950s episode. Fifty years later, it is quite possible that we are experiencing the next such drought right now, and climate histories like the tree ring record indicate that our current drought could easily persist for several more years.

Climate variability and change exert profound influences on agriculture, natural ecosystems, wildfires, tourism, and water resources in New Mexico. Our vulnerability to climatic anomalies has been highlighted during the past few years of drought. The prospect of skillful climate forecasting, which was inconceivable just a few decades ago, could provide a useful management tool for policy makers and the public for reducing our vulnerability. However, current skill in climate forecasting is very limited. Achieving a better forecasting capability will require a more thorough understanding of how and why climate has changed in the past, and an improved database for monitoring today's climate. Geologists, atmospheric scientists, and computer science experts are collaborating to make this happen.