Chapter 10

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Durango
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G. of California
California
Gulf of Mexico
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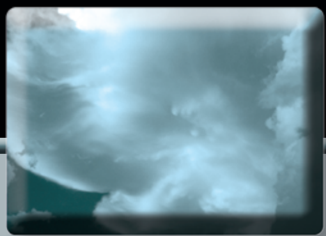


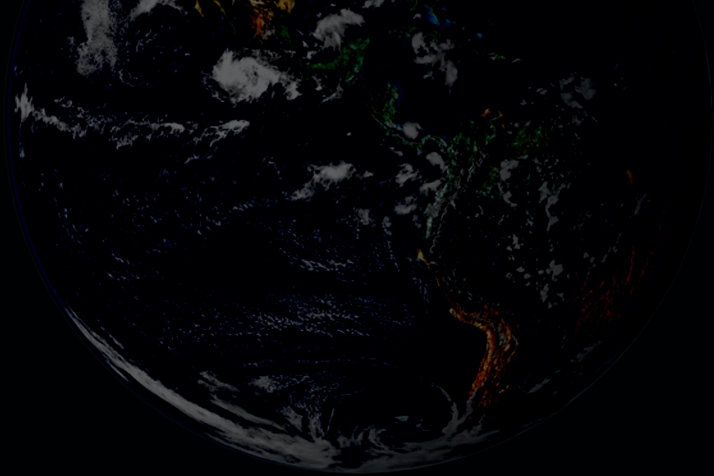
Chapter 10

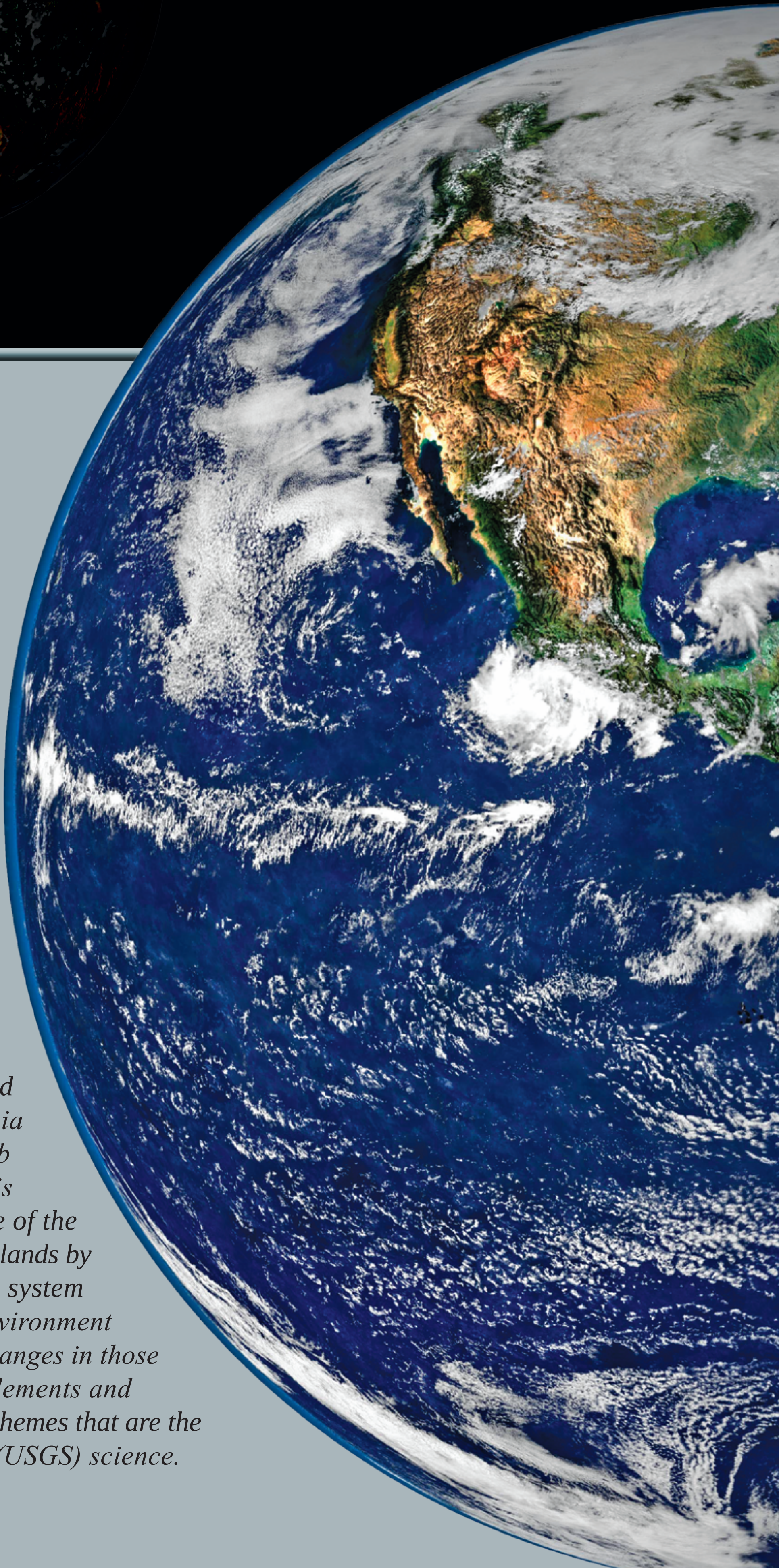
The Borderlands and Climate Change

By Joan Fitzpatrick, Floyd Gray, Russell Dubiel, Jeff Langman, J. Bruce Moring, Laura M. Norman, William R. Page, and Jean W. Parcher

Introduction

The prediction of global climate change in response to both natural forces and human activity is one of the defining issues of our times. The unprecedented observational capacity of modern earth-orbiting satellites coupled with the development of robust computational representations (models) of the Earth's weather and climate systems afford us the opportunity to observe and investigate how these systems work now, how they have worked in the past, and how they will work in the future when forced in specific ways. In the most recent report on global climate change by the Intergovernmental Panel on Climate Change (IPCC; Solomon and others, 2007), analyses using multiple climate models support recent observations that the Earth's climate is changing in response to a combination of natural and human-induced causes. These changes will be significant in the United States–Mexican border region, where the process of climate change affects all of the Borderlands challenge themes discussed in the preceding chapters. The dual possibilities of both significantly-changed climate and increasing variability in climate make it challenging to take full measure of the potential effects because the Borderlands already experience a high degree of interannual variability and climatological extremes.





The populations of the Borderlands are growing quickly and are potentially vulnerable to the projected effects of both increased climate variability and overall climate change. Water planners have only recently begun to acknowledge the substantial risks implied by natural long-term climate variability (Cook and others, 2004), and individual States are now beginning to study the potential effects of a changing climate on their infrastructure and economies (for example, California Coastal Commission, 2001; Jacob and others, 2007). The goal of this chapter is to show the importance of the climate change issue to the Borderlands by discussing elements of the climate system that influence the Borderlands environment now, discussing the anticipated changes in those elements, and connecting those elements and changes with the seven challenge themes that are the focus of U.S. Geological Survey (USGS) science.

Climatological Setting of the Borderlands

General Setting

The climate of the Borderlands ranges from temperate to extreme and includes some of the driest and hottest parts of North America (fig. 10–1). The region spans approximately 20 degrees of longitude and 9 degrees of latitude, from about 25°N. to 34°N., and includes over 1,829 meters (m) (6,000 feet [ft]) of elevation change. Climatologically, the Borderlands span the convergence of two Northern Hemisphere atmospheric circulation cells near lat 30°N. This atmospheric convergence creates a generally dry, warm climate with clear skies and enhanced evaporation. The convergence shifts north in the summer and south in the winter, creating seasonal climate variability. Further variability in the region is caused by the shifting positions and strength of these cells relative to each other and their interaction with topography and elevation (Sheppard and others, 1999).

Other climate phenomena, some of which are periodic (for example, the El Niño–Southern Oscillation cycle, the Pacific Decadal Oscillation cycle, and the North American monsoon), also contribute to seasonal variability; for example, northeastern and tropical Pacific sea-surface temperature anomalies have been shown to correlate with precipitation (Schubert and others, 2004; McCabe and others, 2004).

Fence along the United States–Mexican border at Tijuana, Baja California

The seasonal distribution of precipitation in the Borderlands is determined primarily by its proximity to moisture from both the Pacific Ocean and the Gulf of Mexico. Summer precipitation can have its origin in moisture from the Pacific Ocean, the Gulf of Mexico, or even the Gulf of California; winter precipitation, however, is generally derived from Pacific frontal systems moving eastward across the region (D'Arrigo and Jacoby, 1992). Average annual precipitation ranges from less than 12.7 centimeters per year (cm/yr) (5 inches per year [in/yr]) in the low, dry areas north of the Gulf of California (subarea 2) to more than 50.8 cm/yr (20 in/yr) in the Gulf Coast region near Brownsville, Texas (subarea 8) (fig. 10–2, bottom). Average monthly temperatures across the Borderlands range from midsummer daytime highs in excess of 40.6°C (105°F) in rain-shadowed, low-elevation locations such as El Centro in the Imperial Valley of California (-12 m [-39 ft]; subarea 1) or Yuma, Arizona (34 m [112 ft]; subarea 2), to average midwinter low temperatures near freezing in high-altitude locations such as Nogales, Sonora (1,178 m [3,865 ft]; subarea 3), or El Paso, Texas (1,158 m [3,800 ft]; subarea 5) (fig. 10–2, top). Both temperature and precipitation patterns and timing are strongly influenced by local topography and elevation, by proximity to moisture sources, and by the interaction of these factors with regional climate phenomena on the synoptic scale over seasonal, annual, and decadal periods, and longer.

Kemp's Ridley sea turtle (*Lepidochelys kempii*) on Padre Island, Texas

Queen Isabella Causeway at Laguna Madre, Texas

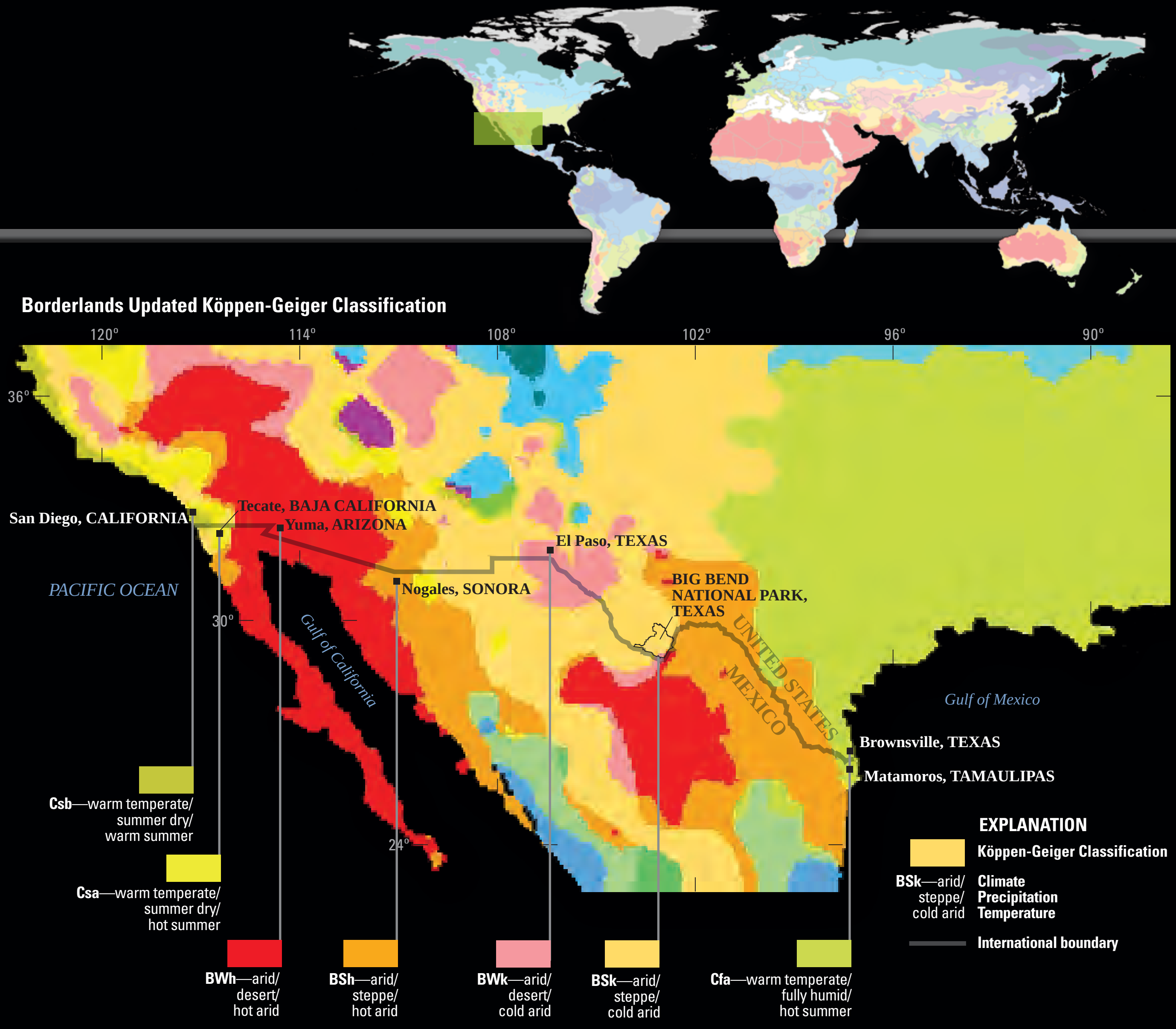
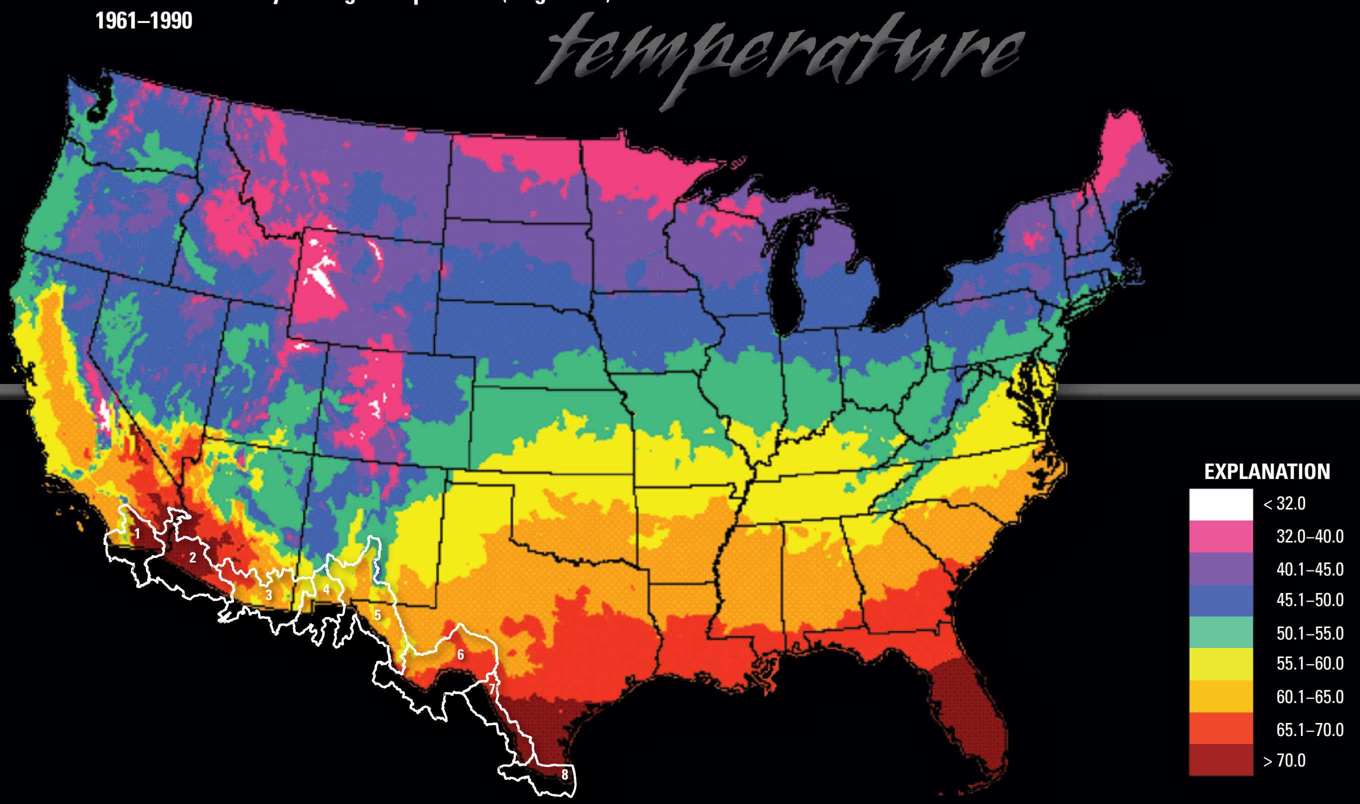


Figure 10–1. Updated Köppen-Geiger climate classification for the Borderlands, based on long-term monthly temperature and precipitation records. Data from Kottek and others (2006); modified from Peel and others (2007).

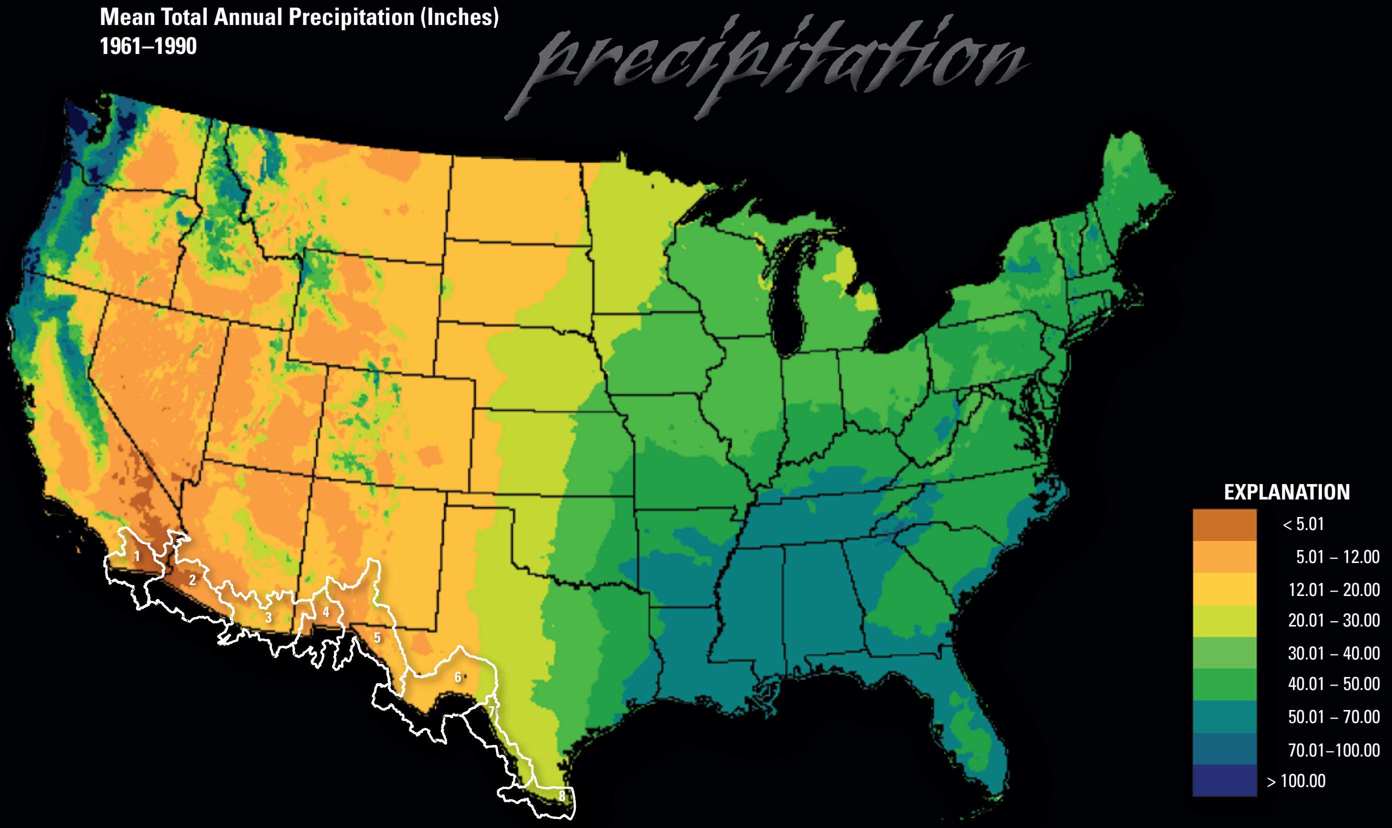
In general, much of the Borderlands is characterized by climate extremes and intense weather. Hot, dry summer days can be punctuated by short-lived, intense thunderstorms that produce fully half the average annual precipitation in a few days, washing out roads and bridges and damaging structures in flash floods. Infrequent winter storm systems on the Pacific side that pull tropical moisture into the central Borderlands can be unexpectedly intense as well, dropping 7.6–12.7 cm (3–5 in) in equally short times (Tucson Weather Forecast Office, 2006). Tropical cyclones (on the Pacific side) and hurricanes (on the Gulf side) can reach well inland after striking coastal areas, and longer-lived, pervasive conditions such as decadal or even multidecadal drought with significant effects on society are not uncommon (deMenocal, 2001).

Figure 10–2 (facing page). Annual mean daily average temperature (top) and mean total annual precipitation (bottom) for the conterminous United States for the period 1961–1990. The United States–Mexican border region includes areas with both the lowest mean annual precipitation in the United States and Mexico and highest mean annual temperatures in the United States. Data from the National Oceanic and Atmospheric Administration–National Climate Data Center; *http://cdo.ncdc.noaa.gov/cgi-bin/climaps/climaps.pl.*

Annual Mean Daily Average Temperature (Degrees F)
1961–1990



Mean Total Annual Precipitation (Inches)
1961–1990



Timing and Delivery of Moisture in the Borderlands

Peak precipitation occurs at different times in different parts of the Borderlands, depending on the proximity to moisture sources and seasonal movement of moisture in the area. At the western end of the Borderlands (subarea 1), the San Diego–Tijuana sister city area (California–Baja California) receives most of its annual precipitation during the winter months, typically with 85 percent of rainfall occurring from November through March, unlike the rest of the Borderlands, which typically see peak precipitation between May and October. In northwestern Mexico (exclusive of the Baja California peninsula), southern Arizona, and southwestern New Mexico (subareas 2–4), peak annual precipitation occurs in midsummer in association with the North American monsoon (Adams and Comrie, 1997). Northern Chihuahua, southeastern New Mexico, and the Trans-Pecos area of Texas (subareas 5–6) also experience precipitation maxima during the summer, but this moisture is due primarily to intense, periodic summertime convective thunderstorm activity and not necessarily to moisture arriving from the south in association with monsoonal flow. The Borderlands east of the Trans-Pecos area (subarea 7) experience a bimodal precipitation pattern with maxima in both spring and autumn, though the annual maximum in these areas typically occurs in September. At the far eastern end of the Borderlands, from the Brownsville-Matamoros sister city area (Texas-Tamaulipas) inland (subarea 8), autumn delivery of precipitation includes the contribution of late-season hurricanes and tropical storms, which historically have produced some of the heaviest interior rainfalls in Texas history (Carr, 1967). The remnants of tropical cyclones originating in the eastern Pacific Ocean can also penetrate into the west-central Borderlands, bringing late summer precipitation as far inland as northern New Mexico (Corbosiero and others, 2009).

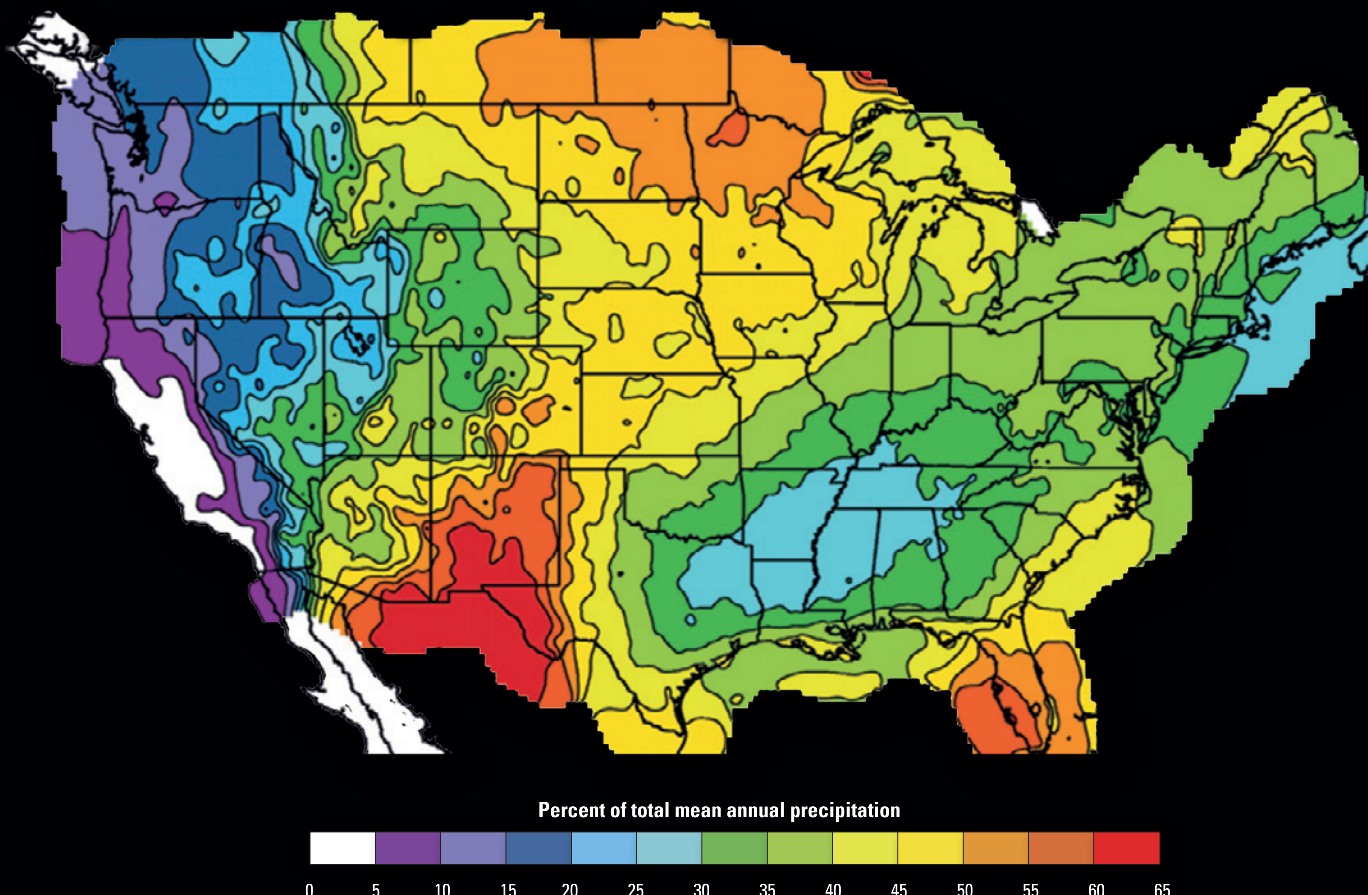


Figure 10–3. Percentage of yearly precipitation contributed during the warm season (mid-June through mid-October), averaged over the period 1958–2003. The central and eastern areas of the Borderlands are very dependent on precipitation received during this time of the year, most of which is attributable to the North American monsoon phenomenon. The far western Borderlands, however, receive most of its precipitation during the cool season. Modified from Corbosiero and others (2009).

Although peak precipitation typically occurs during summer and early autumn over most of the Borderlands (fig. 10–3), wintertime precipitation can contribute over 50 percent of the total mean annual precipitation in some areas as well. The importance of wintertime precipitation should not be underestimated. Winter precipitation arrives as soaking rains that move through the Borderlands over several days. Because evaporation is low at this time of year, the rain recharges groundwater aquifer systems, especially along mountain fronts. Especially wet winters during El Niño years can provide significant recovery to these aquifer systems (Poole, 2005) and can be heavy enough to produce wintertime streamflow and reservoir levels that exceed those observed during summer months (Magaña and Conde, 2000).

Important Contributors to Borderlands Climate

Variability in climate and seasonal activity for a given area along the border is influenced by factors such as land elevation and proximity to moisture, as described above. It is also affected by the state of periodic and seasonal climate regimes. For the Borderlands, those influential regimes are the North American monsoon and tropical cyclones, the El Nino–Southern Oscillation cycle, and the Pacific Decadal Oscillation cycle; they are discussed in more detail below. Any future changes to the climate state that modify these phenomena will also potentially modify precipitation, temperature, and the timing and variability of seasonal weather in the Borderlands and thus will affect several aspects of life there. For example, variability in warm-season precipitation, influenced primarily by the North American monsoon and tropical cyclones, will affect agriculture and ecosystems management, integrated water management, and human health (National Oceanic and Atmospheric Administration, 2009).

North American Monsoon and Tropical Cyclones

In the central western Borderlands (subareas 2–4), the hot, dry weather of early summer is relieved in July when the wind shifts from west-southwest to east-southeast, bringing thunderstorms generated by the North American monsoon system. The North American monsoon circulation pattern develops over northwestern Mexico in late May and early June as intensifying sunlight heats dry inland areas. The hot rising air over Mexico's Sierra Madre Occidental and Central Plateau pulls moisture in laterally from the eastern Pacific Ocean, the Gulf of Mexico, and the Gulf of California, which leads to daily thunderstorms over the Sierra Madre Occidental from late June through mid-July. By mid-July, this atmospheric flow is well established over northwest Mexico and expands into southern Arizona and southwestern New Mexico. There, it delivers moisture in the form of intermittent, sometimes intense thunderstorms through mid-August, when solar heating begins to decline (National Oceanic and Atmospheric Administration, 2009). From late August through September, the monsoon season comes to an end as the monsoonal flow gradually becomes disrupted by cooling surface temperatures and a return to southwesterly winds.

View of the Sierra Madre Occidental in Hostotipaquillo, Jalisco, Mexico

Monsoon over El Cajon, California

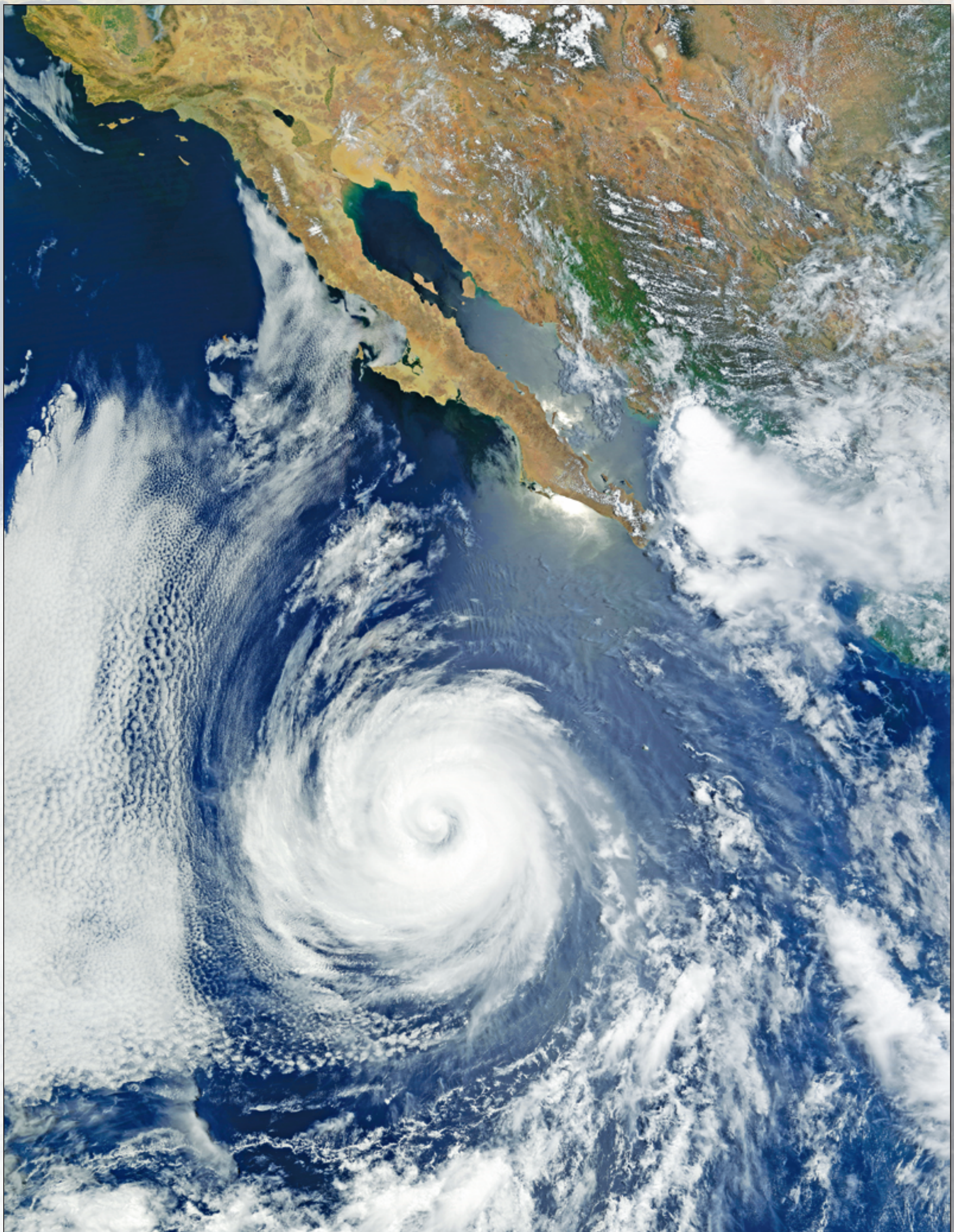
Monsoonal thunderstorm activity accounts for more than half the total annual precipitation in most of the core monsoonal area—northern Sonora, southern Arizona, and southwestern New Mexico—with the largest amounts of precipitation occurring in northwestern Mexico (fig. 10–3) (Douglas and others, 1993; Adams and Comrie, 1997). The timing and strength of monsoonal flow, however, vary greatly from one year to the next, and the relation of the North American monsoon to other atmospheric circulation regimes over the eastern Pacific Ocean and North America is not yet well understood. In addition, the localized interaction of monsoonal circulation with the varied topography and summertime vertical convection conditions in the Borderlands creates additional complexity when modeling this phenomenon (Adams and Comrie, 1997). As a result, research into the onset, development, and evolution of the monsoon is ongoing and extensive (see, for example, North American Monsoon Experiment Science Working Group, 2004; Vera and others, 2006).

In the eastern Borderlands (subareas 5–8), late summer precipitation comes primarily from Atlantic hurricanes. Recent work by Corbosiero and others (2009) has also shown that remnants of eastern Pacific hurricanes and cyclones can contribute significant moisture to this area in late summer, with contributions increasing from less than 5 percent of total summer rainfall in New Mexico to more than 20 percent in southern California and northern Baja California, with individual storms accounting for as much as 95 percent in some locations.

El Niño–Southern Oscillation Cycle

The El Niño–Southern Oscillation (ENSO) cycle is a periodic climate phenomenon originating in the equatorial Pacific Ocean. It is a significant factor in the climate variability of the Borderlands, as well as most of North America. In the Borderlands, El Niño years typically correlate with increased winter precipitation and cool temperatures, while La Niña years correlate with decreased winter/spring precipitation and variable temperatures (Ropelewski and Halpert, 1986; Andrade and Sellers, 1988; Cavazos and Hastenrath, 1990; D'Aleo, 2002; Magaña and others, 2003). In the past, El Niño events typically occurred every 3–4 years (Barry and Chorley, 1998; Sheppard and others, 1999), but recent observations suggest that while El Niño and La Niña episodes prior to 1976/1977 occurred in approximately equal proportion, El Niño episodes since that time have occurred twice as often as La Niña episodes (Trenberth, 1997). The cause of this shift is not yet understood.

The ENSO cycle has been proposed as the primary interannual modulator of precipitation in the Borderlands (Magaña and Conde, 2000). In parts of the Borderlands, winter (December–March) precipitation in an El Niño year can exceed 180 percent of normal, leading to an increased incidence of winter flooding. In the summer following an El Niño winter, the shift in climate from extremely wet to extremely dry has been observed to correlate with an increased incidence of wildland fires (Swetnam and Betancourt, 1998; Kitzberger and others, 2001). In contrast, the cooler La Niña phase of the ENSO cycle is associated with a general drying over the southern United States during winter and spring. For example, the 1998–2002 drought coincided with a protracted La Niña phase that may have been reinforced by a concurrent shift of the Pacific Decadal Oscillation cycle (see p. 246) to its cool phase (Hoerling and Kumar, 2003).



Hurricane Douglas, south of Baja California, July 23, 2002. For more information on this image, see *http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=9989*.

Pacific Decadal Oscillation Cycle

The Pacific Decadal Oscillation (PDO) cycle is another Pacific-based quasi-periodic climate phenomenon that has a demonstrable influence over climate in the Borderlands. With a period lasting 20–30 years, the PDO cycle has been described as a long-lived ENSO-like pattern of Pacific sea-surface temperature variability (Zhang, and others, 1997), but the focus of the effects on sea-surface temperatures is in the North Pacific Ocean rather than in the tropical region.

Climate conditions associated with the PDO cycle are broadly similar to conditions associated with the ENSO cycle. During the positive index or warm phase of the PDO cycle, sea-surface temperatures are warmer than average in the Pacific Ocean near the North American coast and are contrastingly cooler than average in the central North Pacific Ocean. The current PDO phase, which began in 1977, correlates with enhanced winter precipitation over the southwestern United States and northwestern Mexico, similar to the effects of the El Niño phase. The negative or cool phase of the PDO cycle has the opposite distribution and correlates with effects similar to La Niña conditions.

The relation between ENSO and PDO is a matter of ongoing research (for example, whether the PDO cycle is independent of the ENSO cycle or a response to it; see Shakun and Shaman, 2009), but it has been noted that PDO phases can influence the effects of coinciding ENSO phases. Some studies indicate that the timing of relative phases of the long-cycle PDO and the short-cycle ENSO are important in determining the overall intensity of El Niño and La Niña conditions (Gershunov and others, 1999; McCabe and Dettinger, 1999) and that some of the historically wettest and driest conditions in parts of the Borderlands have developed during periods when the related phases of the two phenomena coincided (Liles, 2002). Thus, El Niño phases of ENSO can be enhanced during the warm phase of PDO and La Niña phases can be enhanced during the cool phase of PDO.

At this time, the underlying cause of the PDO cycle is not well understood and it is not yet possible to predict its behavior with any confidence since its long cycle time has provided observational records over only a few cycles. Some recent observations suggest that the PDO phase changed from warm to cool (enhancing La Niña) with the end of the 1997/1998 El Niño episode (Greene, 2002; Peterson and Schwing, 2003). Other observations suggest that because recent anomalies in sea level and sea-surface temperature in the North Pacific Ocean do not fit the PDO concept, consideration of this single indicator alone yields an incomplete characterization of North Pacific climate (Bond and others, 2003).

Projections for Climate Change in the Borderlands

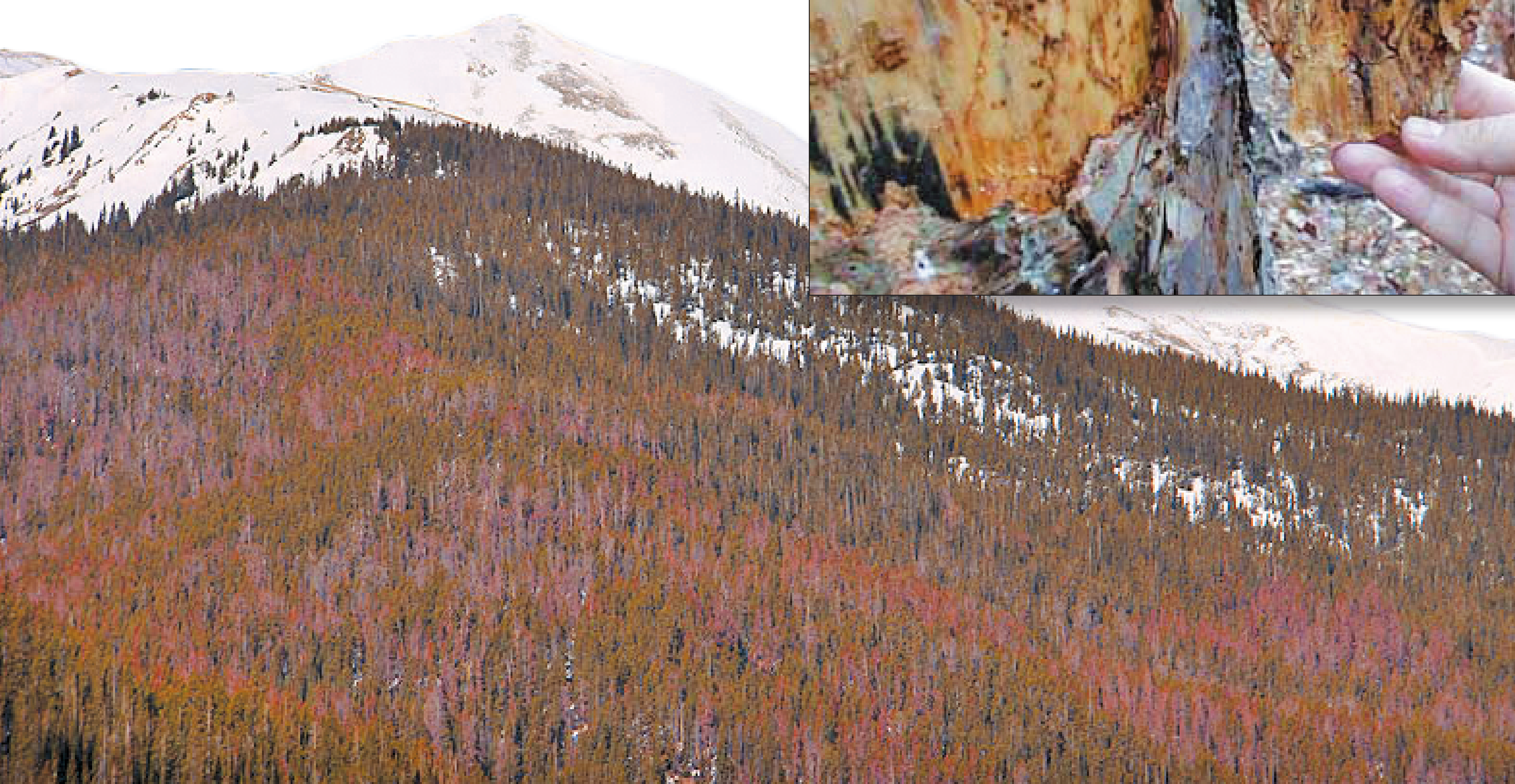
Observed Current Trends

Since the late 1970s, the western United States has experienced climatological changes that, based on climate models, are unlikely the result of natural climate variability alone (for example, Barnett and others, 2008; Das and others, 2009):

- a 1°C and 2°C (1.8°F and 3.6°F) increase in mean annual temperatures at lower and higher elevations, respectively (Diaz and Eischeid, 2007);
- an increase in the elevation at which it rains rather than snows (Knowles and others, 2006);
- a reduction in snowpack (Mote and others, 2005) and an advance in the onset of snowmelt and snowmelt-driven streamflow (Stewart and others, 2005);
- an advance of 8–10 days in the onset of spring averaged over the West (Cayan and others, 2001) and an associated increase in the frequency of large fires (Westerling and others, 2006); and
- an increase in tree mortality that may have resulted from pine or bark beetle (*Dendroctonus* spp.) infestations associated with longer and hotter growing seasons during a severe drought (Breshears and others, 2005; Raffa and others, 2008).

Some additional effects suggested by climate models (discussed on the following pages) include increased incidence of droughts, floods, and heat waves.

Mountain pine beetle (*Dendroctonus ponderosae*)



Farmer and sons walking through a dust storm in Cimarron County, Oklahoma, 1936

Ranch manager near Paso Robles, California, inspects drought-parched soil, 1976

Global Ensemble Projections and Regional Effects

Projections from ensemble climate model simulations, reported on by the IPCC (Solomon and others, 2007), indicate that it is "very likely"[1] North America will warm more than the global mean during the 21st century. Temperatures are projected to increase in the southwestern United States and northern Mexico by 3–4°C (5.4–7.2°F) by the end of the century (fig. 10–4, top row). Similar projections for precipitation indicate a general drying most significant in the winter and an overall drop in precipitation below the 1980–1999 average by as much as 30 percent (fig. 10–4, middle row).

Multiple global circulation model (GCM) studies are in fundamental agreement that a primary result of global warming will be an expansion of tropical atmospheric circulation and a northward shift of mid-latitude stormtracks (for example, Kushner and others, 2001; Yin, 2005; Frierson and others, 2007; Lu and others, 2007). This expansion and shift may already be in progress (Fu and others, 2006), and it has been identified as a significant contributor to southwestern drought (Seager and others, 2007). Other studies indicate that this shift should be accompanied by a decrease in the number of cyclones (low pressure systems) and an increase in their intensity (for example, Lambert, 1995; Fyfe, 2003). McCabe and others (2001) conclude that this decreased incidence and intensification of low-pressure systems is already observable during in the latter half of the 20th century.

Model results also indicate that it is a decrease in wintertime precipitation (fig. 10–4, middle row) that will be the primary cause of a transition to a sustained drier climate in the Southwest (Seager and others, 2007). A decrease in winter precipitation has significant implications for future groundwater supplies in the Borderlands because many of its aquifers are recharged through winter precipitation. Models of the change in mean annual precipitation minus evaporation (P-E) reach values of 0.1 millimeter (mm) per day (0.0039 in/day) by the middle of the 21st century; for comparison, the 1930s Dust Bowl measured 0.09 mm/day (0.0035 in/day), and the 1950s drought in the Southwest measured 0.13 mm/day (0.0051 in/day). A quarter of GCMs indicate that P-E drying, and thus decreases in winter precipitation, may already be in progress.

[1] For an explanation of IPCC uncertainty vocabulary, refer to "Treatment of Uncertainties in the Working Group I Assessment," Box TS.1 of Solomon and others (2007, p. 22).

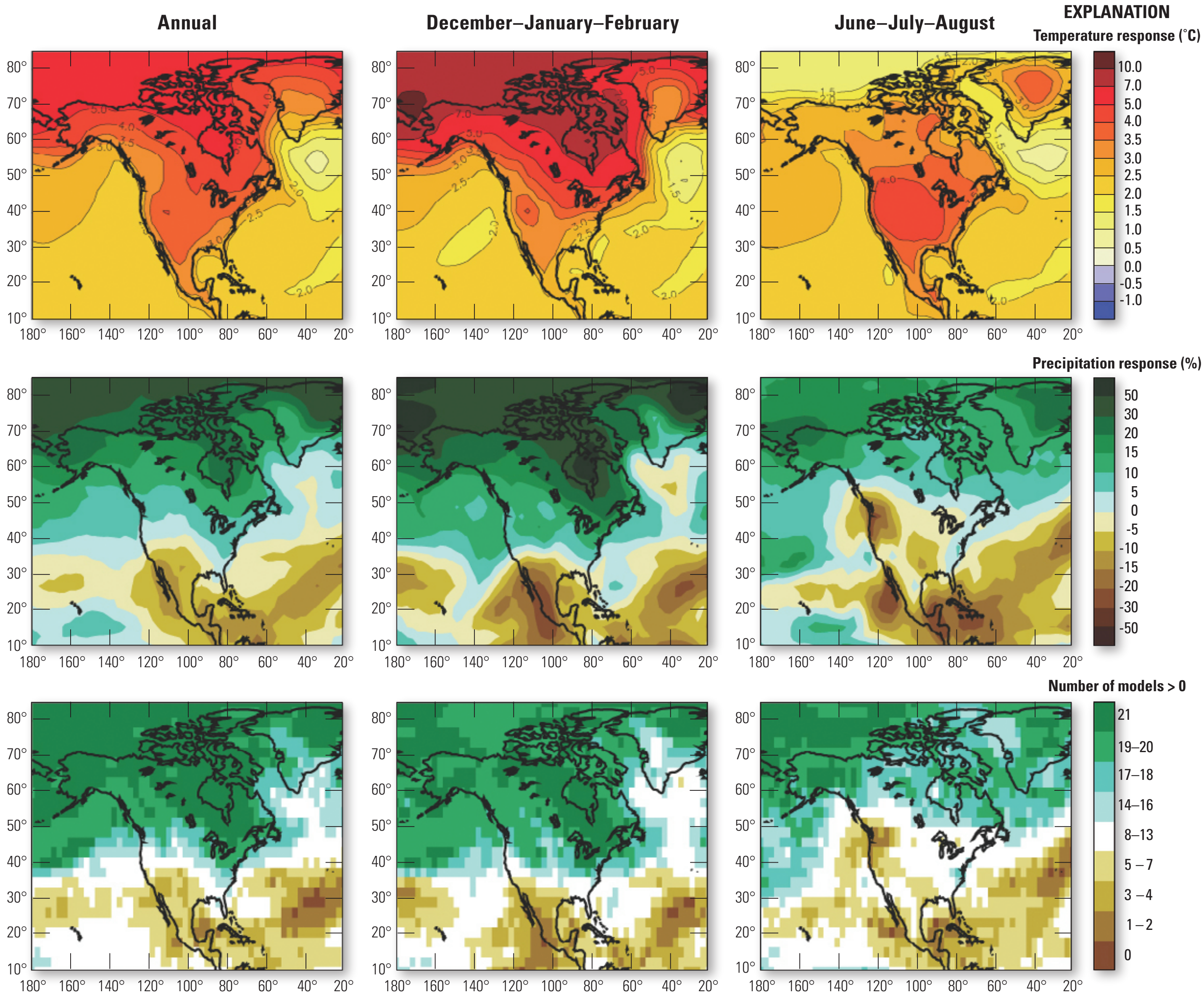


Figure 10–4. Projected changes in temperature (top row) and precipitation (middle row) over North America, from the average of the period 1980–1999 to the average of the period 2080–2099. Changes shown are for annual mean, mean for December–February (winter), and mean for June–August (summer). Note the projected changes in summer temperature (upper right) and winter precipitation (lower middle). Modified from Solomon and others (2007, fig. 11.12); data from the MMD-A1B simulations, averaged over 21 models.

The anticipated northward shift in mid-latitude stormtracks may also be responsible for changes in early spring precipitation patterns. A study by McAfee and Russell (2008) indicates that such a northward shift would result in an earlier annual onset of warm-season atmospheric circulation patterns. The early arrival of spring weather would have potentially strong effects on hydrological and biological systems in the region. This effect could already be in progress; it has been observed over much of the western United States since the late 1970s (Cayan and others, 2001).

Taken together, these projections point to the potential for a “new normal” condition of Borderlands climate, which includes an increase in overall climate variability, overall intensification of the hydrological cycle, increase in aridity primarily due to wintertime moisture deficit, increase in precipitation variability with a likelihood of fewer but more intense frontal storms, early onset of springtime conditions, decrease in snowpack, and increase in summertime mean temperatures. In addition to these baseline projections, the behaviors of the North American monsoon, the ENSO cycle, and the PDO cycle must also be considered, but projections for their fates in a changing climate remain unclear at this time.

For more information on mesoscale model data available through the Internet, see the North American Regional Climate Change Assessment Program (http://www.narccap.ucar.edu/).

Sensitivity studies for the Colorado River basin are important to the western Borderlands because the river supplies most of the area's water supply. Future warming could lead to a decreased supply. For more information, see McCabe and Wolock (2007) and Barnett and Pierce (2009).

Mesoscale Climate Projections

At 15-kilometer (km) (9.3-mile [mi]) resolution, GCMs are primarily useful for global and hemispheric scales, capturing interactions between ocean, atmosphere, and idealized landmasses. While GCM results set the overall global context for climate change, regional climate models (RCMs) on the mesoscale show the interaction of landscapes with climate processes at a more localized scale (5–10 km [3.1–6.2 mi]). The mesoscale in the Borderlands is detailed to the level of deserts, mountain ranges, and coastal plains and uplands, so models on this scale will be the most informative and will support effective regional planning (Christensen and others, 2007).

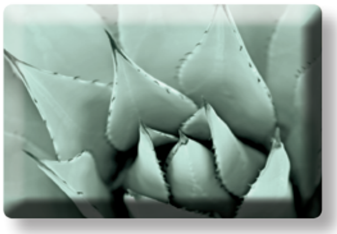
Regional climate modeling is an emerging research area, so there are a variety of approaches to predict the future of climate at the scale of the Borderlands. Different approaches sometimes produce different results, and there may be circumstances in which the application of one particular approach yields more robust results than others. Though much has been written on model validation for regional climate modeling, there is little focus on mesoscale projections for the Borderlands. Some programs make their mesoscale model data available on the Internet, but research that applies this information to the Borderlands has only recently begun to appear in the literature.

The use of ensemble modeling to help provide level-of-confidence evaluation for a regional climate model is not yet a mature practice; at the time of this writing only a few regional studies use this approach (see Rinke and others, 2006; Sanchez-Gomez and others, 2009). For example, Hoerling and others (2009) recently attempted to reconcile the results of several publications on the effect of global warming on modeled runoff in the Colorado River basin (Christensen and others, 2004; Milly and others, 2005; Hoerling and Eischeid, 2007). The different approaches taken in each of the studies yielded a wide range of results—a reduction in flow from 5 to 45 percent by 2050—but they all show a similar sensitivity of streamflow to changes in precipitation—a 2:1 ratio of percent change in flow to percent change in precipitation.

Recent ensemble model results for precipitation change under IPCC low and high greenhouse gas emissions scenarios downscaled to the western Borderlands indicate the potential for a reduction in precipitation greater than 12 percent (relative to 1961–1990); it would begin in southern California and northern Baja California and move east by the middle of the century (Cavazos, 2009). Other studies that focus on potential changes in the distribution of plants and animals in Mexico project significant species turnover and disruptions in the ecology (for example, Villers-Ruiz and Trejo-Vazquez, 1998; Peterson and others, 2002).

climate and the borderlands challenge themes

Previous chapters in this report have identified the challenges of the Borderlands in the areas of ecology, water resources, the environment and human health, human activity, energy and mineral resources, natural hazards, and border security. The present climate and the projected changes discussed thus far will potentially affect elements of each of these challenge themes. Some of the most significant potential effects of climate change are discussed on the following pages.



Challenge Theme 1—Ecological Resources

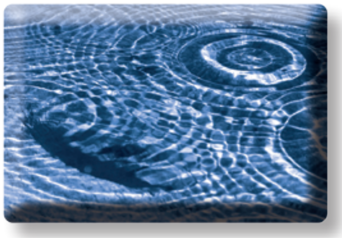
Climate change in the Borderlands will have profound influences on the biota of the region, both spatially and temporally. Rates of aridification are predicted to increase, desert temperatures are predicted to rise as much as 3–4°C (5.4–7.2°F) (Solomon and others, 2007), and desert rainfall is predicted to decrease as much as 10–20 percent by 2071–2100 (United Nations Environmental Programme, 2007). The Sonoran and Chihuahuan Deserts have the highest richness of plant species of any desert region on Earth, and desert biota is adapted to extreme fluctuations in daily temperature and seasonal rainfall, but some species may not be able to adapt to such extreme rates of change.

In addition to overall trends, long-term or short-term climate variability can cause shifts in the structure, composition, and functioning of ecosystems, particularly in the fragile boundaries of the semiarid regions. The plants, insects, and animals of the Borderlands are highly specialized and adapted to the landscape, but a changing climate of wetter, warmer winters and overall temperature increases will alter their range, type, and number throughout the Southwest. For the Sonoran Desert, this trajectory of climate change may lead to contraction of the desert boundary in the southeast and expansion in the north (Weiss and Overpeck, 2005). A trend of warmer winters and springs and fewer instances of freezing temperatures could change the distribution of plant species and consequently the boundaries and overall size of the Sonoran Desert.

The health of an ecosystem is a function of many factors—water availability, temperature, carbon dioxide, etc.—so it is difficult to determine accurately the extent, type, and magnitude of ecosystem change under future climate scenarios without more highly resolved regional modeling efforts. Further, because the various components of ecosystems respond differently to shifts in climate, the overall tenuous balance among them can also change. For example, should vegetation cover and the moisture-exchanging properties of the land change, important local and regional climate characteristics such as albedo (reflectivity of the land), humidity, wind, and temperature will also change. Rangeland ecosystems support ranching and provide crucial habitat for wildlife in the Borderlands, and they comprise the largest area of grazing and ranching land in both Arizona and New Mexico, but the health and maintenance of these rangelands are climate dependent. Because changes in climate can affect the vitality and productivity of plants within this ecosystem, changes in climate can affect the overall success of both wildlife and ranching in the region.

Increased levels of carbon dioxide (CO_2) and warming temperatures can accelerate invasions by nonnative, flammable grasses that are currently the biggest threat to desert ecosystems. Enrichment of CO_2 will favor increased spread and productivity of red brome (*Bromus rubens*) and other winter annuals unless climate change decreases winter precipitation in the region. After a particularly wet winter in 2005, these annual grasses fueled extensive fires in the Sonoran Desert (approx. 250,000 acres [101,175 hectares] in the Cave Creek fire north of Phoenix) and the Mojave Desert (approx. 750,000 acres [303,525 hectares] east of Las Vegas). Warmer winters will push African buffelgrass (*Pennisetum ciliare* or *Cenchrus ciliaris*), which is sensitive to frost, upslope and to the north. Buffelgrass was planted to feed cattle in Texas and Sonora and to control erosion in southern Arizona, but it now threatens to become a major fire and ecological risk along the border from southern Texas to southern Arizona.

Climate itself can also contribute to wildfire risk. Historically, wildfires have played an important role in the vitality of the forest ecosystem, but the amount of land area burned per year by wildfires has steadily increased since the 1960s. Because of fire suppression measures used by management agencies, fuel loads waiting to burn have increased over time. Alternating wet and dry conditions over seasonal time scales or longer encourage vegetation growth—this biomass subsequently dries, and additional fuel reserves are created. The projected warming in the Southwest and sequences of wet and dry periods optimal for fuel production will increase fire hazard potential. This process already occurs when wet El Niño phases are followed by dry La Niña phases (Swetnam and Betancourt, 1998; Kitzberger and others, 2001).



Challenge Theme 2—Water Availability and Quality

From California to Texas, the dominant climate along the border is semiarid to arid and is characterized by low precipitation, low groundwater recharge, and frequent drought conditions. The general inadequacy of the water supply has been and likely will continue to be stressed by projected increases in aridity, and the current demands on hydrologic resources will intensify with population increases and the predicted increase in drought conditions and alteration of precipitation patterns (Solomon and others, 2007). The strains on the supply would be felt by agriculture, industry, and municipalities. Studies of the effects of climate change in the southwestern United States have concluded that regional drying will occur as global temperature increases (Seager and others, 2007), and it is predicted that rainfall will be more variable with increased frequency of both large precipitation events and longer droughts. Increased evapotranspiration will occur with rising temperatures and will further strain surface-water resources. For example, with increased evapotranspiration and a decline in surface-water flow, irrigated agriculture will become increasingly dependent on groundwater that is already being mined in many areas to supply growing urban populations. The probable outcomes of all of these predicted changes will be less aquifer recharge, decreased baseflow in streams, more catastrophic flooding, and greater erosion (Lenart and others, 2004; Serrat-Capdevila and others, 2007).

Because a substantial part of the water used in the Borderlands is derived from snowmelt runoff from the Sierra Nevada and the Rocky Mountains, the alteration of climate in these areas will also affect the hydrologic resources of the Borderlands. Snowmelt runoff from the Rocky Mountains produces substantial flows in the Colorado River and the Rio Grande, which in turn provide recharge to adjacent aquifers. Increased temperatures will influence the mix of rain and snow, the persistence of the snowpack, and the timing of snowmelt runoff, which already has begun to arrive earlier than historical norms (Cayan and others, 2001; Stewart and others, 2005). These changes in snowmelt runoff mean potentially larger winter floods but less runoff captured in reservoirs in the Sierra Nevada and Rocky Mountains. Further, the increased temperatures could also result in decreased recharge, especially in areas where snowmelt is the dominant source of recharge (Dettinger and Earman, 2007).

The Rio Grande in August 2012 near Los Lunas, New Mexico, south of Albuquerque. Prolonged drought and irrigation demands upstream have left the riverbed here dry and the riparian vegetation stressed.

Previous changes in climate and the drying up of water resources have caused population shifts and dwelling abandonment in the past. For more information, see Polyak and Asmerom (2001).

An example of the effects of drought on water resources—Lake Mead, Nevada, in July 1983 (top) and July 2009 (bottom)

Challenge Theme 3—Environment and Human Health

According to future climate scenarios, climate change could amplify human health issues driven by climate, such as disease transmission, air and water quality, and heat-induced illnesses (Gamble, 2008). Many communities are capable of preparing and adapting to these changes and thus minimizing human suffering, but the economically and socially disadvantaged populations found disproportionally along the United States–Mexican border are more vulnerable to the predicted negative effects of climate change (Liverman and Merideth, 2002).

Diseases such as Valley Fever, hantavirus pulmonary syndrome (Eisen and others, 2007), West Nile virus (Kilpatrick and others, 2008), and dengue fever are predicted to be more common in the Borderlands as temperature increases and seasonal and interannual patterns of rainfall change. Human disease issues may also be influenced by changes in animal migratory patterns, invasions of new species, and stress-induced development of diseases in wild and domesticated animals.

Water quality can be expected to deteriorate as drought conditions concentrate waterborne contaminants and nutrients. Increased eutrophication and temperatures may also result in the expansion of blooms of harmful, often toxic, algae. The severity of flooding is predicted to increase, furthering the already extant health risks of seasonal extreme flooding along much of the border, where infrastructure is inadequate to control storm runoff and prevent the mingling of wastewaters with potable sources (Liverman and Merideth, 2002).

Poor air quality is also a major health concern along the United States–Mexican border, largely a result of emissions from idling trucks at border crossings (Good Neighbor Environmental Board, 2006) and airborne particulate matter, or dust (U.S. Environmental Protection Agency, 2009). In addition to organic contaminants released by the combustion of fossil fuels, dust can also diminish air quality and affect health. Health risks from dust include the inhalation of very small particles—particulate matter less than 10 micrometers in diameter (PM10) can penetrate into deep lung tissue—of mineral dust, pathogens (such as the fungal spores that cause Valley Fever), allergens, and toxic heavy metals and metalloids (such as lead and arsenic, respectively). Dust concentration, frequency of emission, and dust composition can all cause health problems and are susceptible to changing climate and human disturbances (some of which are responses to changing climate). Drying soil caused by changes in climatic conditions leads to greater emission of mineral dust from desert landscapes (Brazel and Nickling, 1987; Urban and others, 2009). The drying of lakes and wetlands by natural processes or human activities (water diversion and groundwater extraction) commonly leads to soil salinization, which can release salt dusts enriched in toxic metals (Gill and others, 2002; Breit and others, 2009). Satellite images commonly capture enormous dust plumes from saline settings in northern Chihuahua extending into southern New Mexico and Texas and beyond (fig. 10–5). These saline settings make up one of the largest dust sources in North America. Incidence of Valley Fever has been related primarily to winter precipitation and temperature that preceded infection by a year or more (Kolivras and Comrie, 2003). Because warm and dry conditions influence dust emission, increasing temperatures and decreasing precipitation of the Borderlands will increase dust emissions and as a result will increase associated health risks.

Colony of harmful algae
Gloeotrichia echirulata

Dust storm in Phoenix, Arizona

Drying soil can occur under several conditions over several time periods—a drought of a few seasons to a few years, the cool phase of the PDO cycle over a few decades, or widespread and long-term drying due to increasing temperatures. For more information on climatic causes of drying soil, see Seager and others (2007).

dust storms

Figure 10–5 (facing page). Satellite image of a dust storm carrying particulates from northern Chihuahua into southeastern New Mexico and the Trans-Pecos area of Texas (right). In the background, a dust storm moves through Lubbock, Texas, north of subarea 6. Increased incidence of dust events such as these has the potential to increase health risks from pathogens and environmental contaminants on both sides of the border.


NEW MEXICO
ARIZONA
TEXAS
UNITED STATES
MEXICO
SONORA
CHIHUAHUA
COAHUILA


CALIFORNIA
ARIZONA
NEW MEXICO
TEXAS
PACIFIC OCEAN
Gulf of California
3
4
5
6
BAJA
CALIFORNIA
SONORA
CHIHUAHUA
COAHUILA
Gulf of Mexico
NUEVO
LEÓN
TAMAULIPAS

Challenge Theme 4—People in the Borderlands

Especially along the United States–Mexican border, there is a strong relation between human activities and environmental stressors in which both aspects perform in a reactionary circle. Issues that function in this circle include policy actions, human population and urban growth, land-use change, environmental justice, ecosystem services, sustainable development, cultural resources, and environmental health, which includes health risks to border families such as exposure to air pollution, dust, drinking water contaminants, pesticides, and other toxic chemicals. Climate change model projections have indicated that areas of the southwestern United States and northern Mexico are the most persistently susceptible to change (Seager and others, 2007; Diffenbaugh and others, 2008).

According to Seager and others (2007), climate changes caused by human action will affect hydroclimate in the arid regions of southwestern North America and will have implications for the allocation of water resources and regional development. Decisionmakers and water resource managers must cooperate to assess their shared resources and understand how management of these resources will affect the health of humans and ecosystems. Extant factors to consider include urban development, background contamination from mineral deposits, irrigation, and sewage effluent, but global climate change can also combine with these issues to potentially alter the stability of the fragile systems in the Borderlands (Seager and others, 2007; Diffenbaugh and others, 2008; Norman and others, 2008, 2009). The direct and indirect effects of implementing policy not only can lead to unforeseen changes in agricultural, municipal, and industrial demand for water, but also could increase climate vulnerability (Norman and others, 2010). It is necessary to understand these interactions in order to assess how projected climate changes will affect a given watershed.

Abandoned United Verde Mine and Little Daisy Hotel dormitory for miners, Jerome, Arizona

Urban sprawl of San Diego, California

Challenge Theme 5—Energy and Mineral Resources

Mining in the Borderlands, whether for minerals (copper) or energy (coal), is a net consumer of water and energy resources. Mining processes cannot proceed efficiently when low rainfall produces too little water, and either water shortages or influxes of water in excess of storage capacity can lead to process interruptions and additional costs. Both increased aridification and precipitation variability are increasingly likely with the projected temperature increase and the related intensification of the hydrological cycle, so it follows that economic stresses on Borderlands mining operations could also increase. An increase in threatened and endangered species could also affect the minerals and energy sectors; as habitats are lost to change climate, land once leased for mining could become environmentally protected (see Bureau of Land Management, 2009). Given the water needs of mining operations, decreasing water resources could lead to public pressure to terminate mining leases on public lands in order to lessen the competition for already limited resources (for example, Michaels, 2001).

Mining in the Borderlands has also left a legacy of waste rock and mine tailings that contain toxic metals such as arsenic, lead, and cadmium. These mine tailings, which are barren or have minimal stabilizing vegetation, are vulnerable to wind and water erosion. Intensification of the hydrologic cycle associated with climate change may result in increased transport of these metals over significant distances to ecosystems previously too far away to be affected.

Projected changes in storm intensity and sea level can affect the ability of traditional energy sources to meet demands. Encroaching sea level and intensified storm surge activity directly threaten coastal oil and gas well pads and pipelines and, through potential saline and fresh groundwater flooding, indirectly threaten subsurface oil and gas reservoirs. In addition, the critical infrastructure for petroleum refineries for gasoline will become increasingly prone to damage from intensified cyclonic activity, as was the case when Hurricane Katrina disrupted the economy of not just the Texas coast but the entire country.

Despite the negative effects of predicted climate change on the energy sector, it may provide new economic benefits in energy resource development for parts of the Borderlands. In the search for renewable energy resources that do not emit CO_2, people are focusing on the Borderlands as a potential source for solar- and wind-based energy (fig. 10–6) (Western Governors' Association, 2009). Areas with a high percentage of clear-sky days (more than 90 percent in some locations) or a class 3 wind zone categorization (average annual wind speed of 5.1–5.6 meters per second [m/s] [16.7–18.4 ft/s]) and the potential for large-scale utility development (1,500 megawatts or more) of renewable energy facilities and transmission infrastructure make the Borderlands ideal for the generation of solar and wind energy.

Most of the alternatives proposed to alleviate greenhouse gas emissions—solar power, wind turbine arrays, and electric cars—will create a significant increase in the demand for copper. Domestic supplies of copper are largely produced in the Borderlands, primarily in Arizona and Sonora. Climate change may also lead to a return to preexisting and established extractive energy sources such as coal, oil, and gas for heating and electric power generation and for gasoline and diesel transportation needs. Exploitation of preexisting infrastructure for the exploration, production, and supply of hydrocarbon resources for fuel has an economic advantage over developing new nonrenewable energy sources in the short term.

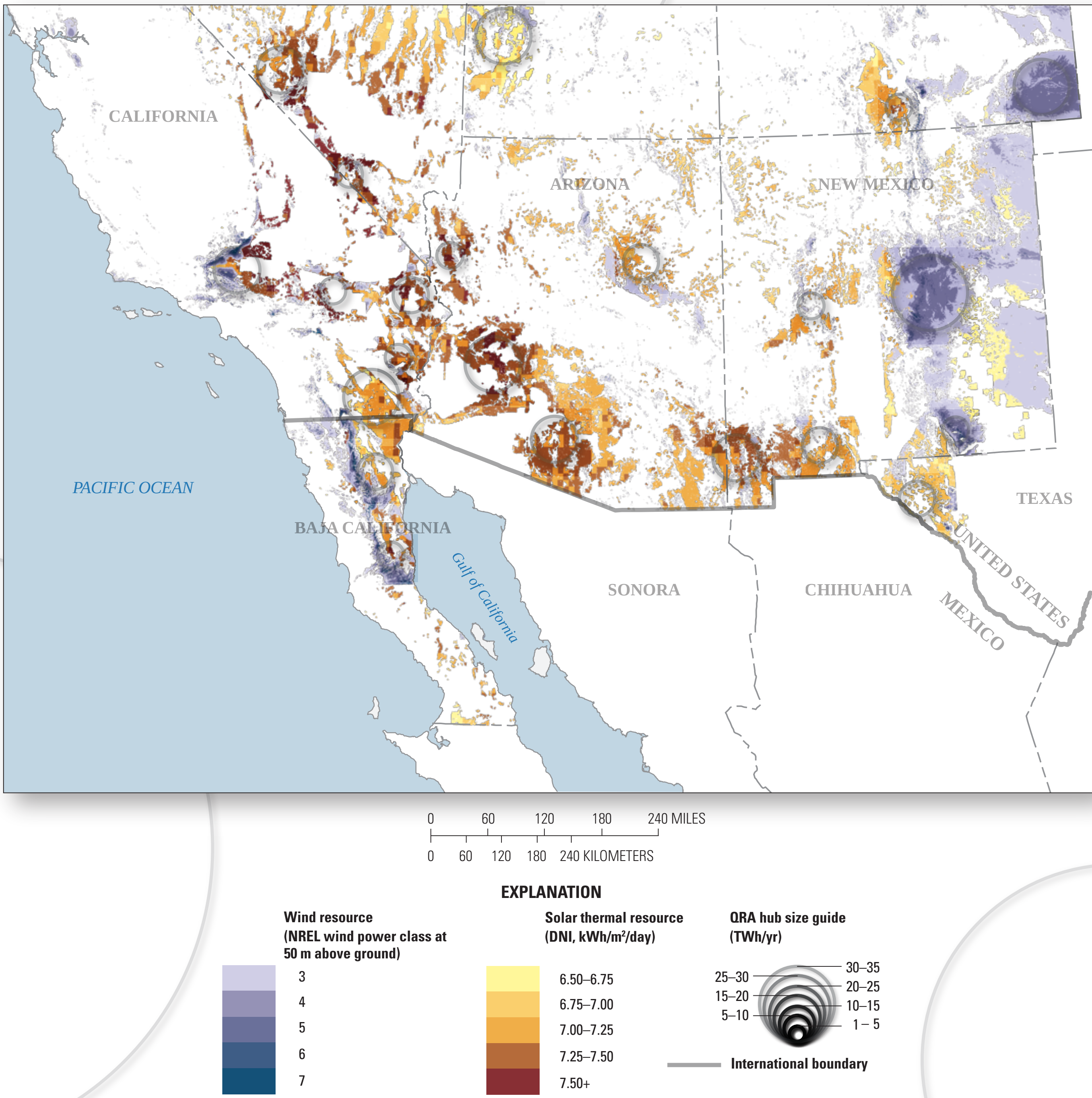
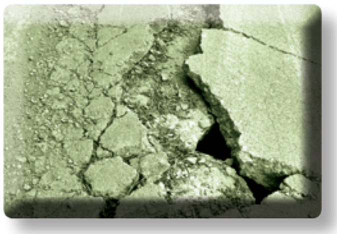


Figure 10–6. Potential areas for renewable energy development (solar and wind) in the western United States–Mexican border region as identified by the Western Governors' Association in collaboration with the U.S. Department of Energy. Data from Western Governors' Association (2009). [NREL, National Renewable Energy Laboratory; DNI, direct normal insulation; QRA, qualified resource area; m, meter; kWh/m^2/day, kilowatthour per square meter per day; TWh/yr, terawatthour (1,000 gigawatthours) per year].



Challenge Theme 6—Natural Hazards

Increased incidence of drought—the single most imminent climate-related threat to the Borderlands—will have far-reaching adverse effects on agriculture, water availability and quality, energy production, and health. Droughts occurring over the last 110 years have challenged existing populations, yet the longer term history of most of the Borderlands indicates past occurrences of even more extensive droughts than those occurring in this recent past (Woodhouse and Overpeck, 1998). Model projections indicate that the cause of increasingly dry conditions will be fundamentally different from those seen in the instrumental record. Severe multiyear droughts over the western United States during both the recent and long-term past have been attributed, via GCM studies, to variations in sea-surface temperatures in the tropical Pacific Ocean, but future (and possibly current) aridification is attributed to increasing moisture divergence and changes in atmospheric circulation cells that include overall expansion of subtropical dry zones (Seager and others, 2007). Thus, the periodic occurrence of dry conditions associated with the La Niña phase of the ENSO cycle will be superimposed on an increasingly dry base state.

Despite increasing aridification over much of the Borderlands, seasonal episodic flooding is predicted to increase primarily as a consequence of increased intensity of precipitation events and decreased natural flood-buffering capacity (Karl and others, 2009). Events such as the devastating floods of 2006 in the El Paso–Ciudad Juárez sister city area (Texas-Chihuahua) and southern Arizona (see chapter 8) are likely to become more frequent.

Since the 1960s, the amount of land burned by wildfires each year in the United States has steadily increased in part because of increasing fuel accumulation resulting from fire suppression practices. As previously discussed, increasing aridification and alternating wet and dry conditions over longer time periods in the Borderlands will increase the availability of fuel and enhance wildfire risk (Swetnam and Betancourt, 1998; Brown and others, 2004). Increased incidence of wildfire poses a compounded threat because burned areas are highly vulnerable to potential flooding, landslides, debris flows, and rapid erosion due to vegetation loss (Kirkham and others, 2000; Cannon, 2001).

Sea-level rise is a heretofore unfamiliar hazard in the Borderlands. There is strong evidence that global sea level is currently rising at an increased rate after a 1,900-year period of little change. During the 20th century, globally-averaged sea level rose at a rate of about 1.7 mm/yr (0.067 in/yr), and it has risen at a rate of about 3 mm/yr (0.118 in/yr) since 1993 (Bindoff and others, 2007), but it is not a globally uniform phenomenon. Coastal areas of the Borderlands, especially the Gulf Coast and the Colorado River delta, will be vulnerable to the consequences of rising sea level in a warming world (Martinez-Gutierrez and others, 2008; Weiss and Overpeck, 2009). Increasing global temperatures cause sea-level rise through the thermal expansion of warming ocean water and melting of land-based glacier ice (Bindoff and others, 2007); modest IPCC projections predict a sea-level rise of 0.21–0.48 m (0.69–1.57 ft) by the end of the century, but these are acknowledged to be unrealistically low estimates.

Hazards associated with sea-level rise are not confined to the immediate threat of periodic inundation—they also include increased coastal erosion, enhanced storm surges in association with cyclonic activity, and saltwater incursion of coastal aquifers. Potential outcomes of these hazards will be strongest on the Gulf Coast segment of the Borderlands, where sensitive ecosystems associated with Padre Island and Laguna Madre are at risk, as are infrastructures associated with the Gulf Intracoastal Waterway and oil refining activities. In the Gulf of California, the primary risk associated with rising sea level is the migration and loss of habitat for the area’s diverse flora and fauna, especially in the Colorado River delta environs.

Challenge Theme 7—Border Security and Environmental Protection

Climate change does not respect borders, nor are the effects of climate change distributed equally. Population growth and intensified water demand related to socioeconomic changes and climate uncertainties such as droughts and floods greatly increase the vulnerability of populations on both sides of the border. For the Borderlands, monitoring environmental and socioeconomic effects of climate change, mitigating the consequences, and responding to extreme weather events require open sharing of environmental, demographic, and economic data to allow decisionmakers to develop short- and long-term strategies. Differences in economic development between the United States and Mexico, coupled with the projected increase in the risk and vulnerability of populations at the lower end of the economic scale, have the potential to increase migration of climate affected refugees into the United States.

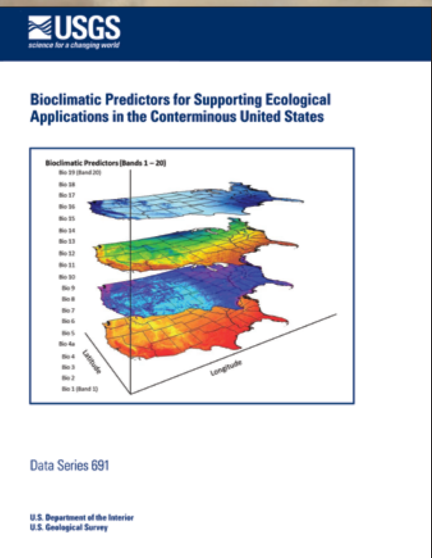
Satellite image of El Paso, Texas (top), and Ciudad Juárez, Chihuahua (bottom). For more information on this image, see *http://earthobservatory.nasa.gov/IOTD/view.php?id=4206*.

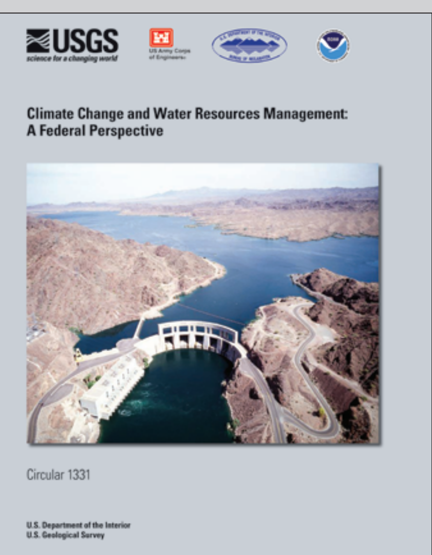
(Above) Damage from the 2006 floods and mudslides in El Paso, Texas

(Left) Water from a flash flood flowing along the border fence and through the port of entry at Organ Pipe Cactus National Monument, Arizona, and Sonoyta, Sonora, July 2008

Scientific alliance between United States and Mexican Federal agencies is needed to develop common scientific standards for sharing environmental data and developing environmental indicators, to monitor environmental consequences of climate change, and to develop mitigation plans for both the United States–Mexican border region specifically and North America in general. For example, at the current population, per capita water availability in the Rio Grande watershed is estimated to be 1,467 cubic meters (m^3) (387,581.4 gallons [gal]) per person per year, which is between the acceptable limit (1,700 m^3 [449,140 gal] per person per year) and the water scarcity limit (1,000 m^3 [264,200 gal] per person per year) (as calculated by the Swedish hydrologist Malin Falkemark; Patino, 2005). Climate change and increased population will force both Federal and local governments to search for innovative solutions to manage scarce water resources, and providing both United States and Mexican scientists with the data and modeling tools to develop binational solutions is the first step to develop these alternative solutions. Several federally funded binational information and research collaborations are currently laying the groundwork for improved water management of the Rio Grande watershed, such as the USGS Border Environmental Health Initiative and United States–Mexico Border Geographic Information System, the Transboundary Aquifer Assessment Program, and the Physical Assessment Project for the Rio Grande watershed.

When a hazard strikes the Borderlands, damage to either country affects the other, in both economic and societal ways. During the August 2006 monsoon activity, 35.1 cm (13.8 in) of rain fell over the El Paso–Ciudad Juárez sister city area in a 2-week period. During the storm, several earthen dams in the Sierra de Juárez were in danger of collapsing; because of the steep topography, the flood waters had the potential to inundate downtown El Paso. Analysis of the changes to the urban landscape, such as increased development of unplanned communities on the margins of Ciudad Juárez, coupled with peak surface runoff of surface waters, almost resulted in critical economic loss for El Paso. The sharing of technologically sophisticated mapping tools, such as light detection and ranging (LIDAR) imaging, and risk and vulnerability methodology, such as the Community Vulnerability Assessment Tool (CVAT), is critical for analyzing and mitigating the risks of flood hazards on both sides of the border (see chapter 8).



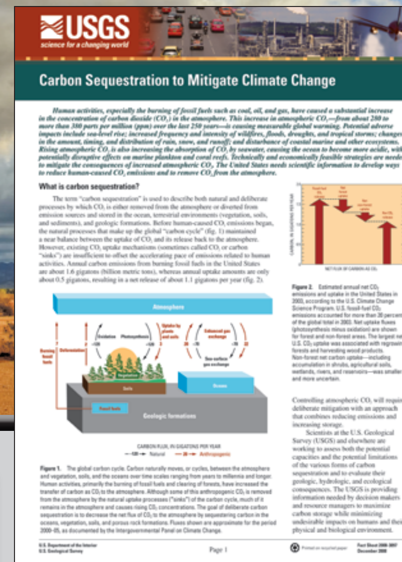


USGS Capabilities

Identifying and understanding the connections between multiple causes and effects are especially important in decisions that require anticipating the interactive effects of changes in climate and changes in resource management. The USGS occupies a strong position in the United States climate science community. The observation and research networks maintained by the USGS allow research scientists to monitor and interpret the interactions of climate change with ongoing changes in land, water, and biological resources. The multidisciplinary scientific expertise of the USGS—spanning geology, biology, hydrology, and geography—enables the USGS to deliver to the managers of the Nation's lands, waters, and ecosystems uniquely integrated information, predictive scenarios, and technological tools for response to climate change. These capabilities will become a major component in government response to the emerging need for information about interdependent resource effects of climate change.

Multidisciplinary Research

The USGS conducts research and monitoring efforts to identify and understand critical interdependencies between climate, land use, and management decisions in the response of natural resources including water, energy, and ecosystems. Challenging research efforts such as those focusing on the effects of the El Niño phenomenon on Southwest regional streamflow, lake levels, and landslide potential have broad implications for climate change monitoring and response. The El Niño phenomenon is perhaps the best-studied example of a global climate change, having coherent influences that arise from recognized physical origins, and it is also of a scale that is comparable to much of the greenhouse change projected in climate-model experiments, both spatially and in terms of the magnitude of temperature deviations. The ways in which water and land resources are managed and maintained in the presence of ENSO-like variability provide snapshots of the kinds of responses that might be necessary in a warming world (Reynolds and others, 1997; see also Arnow and Stephens, 1990; Cayan and Webb, 1992; Glantz, 1996; Wieczorek, 1996).


USGS
science for a changing world

Carbon Sequestration to Mitigate Climate Change

Human activities, especially the burning of fossil fuels such as coal, oil, and gas, have caused a substantial increase in the concentration of carbon dioxide (CO_2) in the atmosphere. This increase in atmospheric CO_2—from about 280 to more than 380 parts per million (ppm) over the last 250 years—is causing measurable global warming. Potential adverse impacts include sea-level rise; increased frequency and intensity of wildfires, floods, droughts, and tropical storms; changes in the amount, timing, and distribution of rain, snow, and runoff; and disturbance of coastal marine and other ecosystems. Rising atmospheric CO_2 is also increasing the absorption of CO_2 by seawater, causing the ocean to become more acidic, with potentially disruptive effects on marine plankton and coral reefs. Technically and economically feasible strategies are needed to mitigate the consequences of increased atmospheric CO_2. The United States needs scientific information to develop ways to reduce human-caused CO_2 emissions and to remove CO_2 from the atmosphere.

What is carbon sequestration?

The term "carbon sequestration" is used to describe both natural and deliberate processes by which CO_2 is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments (vegetation, soils, and sediments), and geologic formations. Before human-caused CO_2 emissions began, the natural processes that make up the global "carbon cycle" (fig. 1) maintained a near balance between the uptake of CO_2 and its release back to the atmosphere. However, existing CO_2 uptake mechanisms (sometimes called CO_2 or carbon "sinks") are insufficient to offset the accelerating pace of emissions related to human activities. Annual carbon emissions from burning fossil fuels in the United States are about 1.6 gigatons (billion metric tons), whereas annual uptake amounts are only about 0.5 gigatons, resulting in a net release of about 1.1 gigatons per year (fig. 2).

Figure 1. The global carbon cycle. Carbon naturally moves, or cycles, between the atmosphere and vegetation, soils, and the oceans over time scales ranging from years to millennia and longer. Human activities, primarily the burning of fossil fuels and clearing of forests, have increased the transfer of carbon as CO_2 to the atmosphere. Although some of this anthropogenic CO_2 is removed from the atmosphere by the natural uptake processes ("sinks") of the carbon cycle, much of it remains in the atmosphere and causes rising CO_2 concentrations. The goal of deliberate carbon sequestration is to decrease the net flux of CO_2 to the atmosphere by sequestering carbon in the oceans, vegetation, soils, and porous rock formations. Fluxes shown are approximate for the period 2000–05, as documented by the Intergovernmental Panel on Climate Change.

Figure 2. Estimated annual net CO_2 emissions and uptake in the United States in 2003, according to the U.S. Climate Change Science Program. U.S. fossil-fuel CO_2 emissions accounted for more than 20 percent of the global total in 2003. Net uptake fluxes (photosynthesis minus oxidation) are shown for forest and non-forest areas. The largest net U.S. CO_2 uptake was associated with regrowing forests and harvesting wood products. Non-forest net carbon uptake—including accumulation in shrubs, agricultural soils, wetlands, rivers, and reservoirs—was smaller and more uncertain.

Controlling atmospheric CO_2 will require deliberate mitigation with an approach that combines reducing emissions and increasing storage.

Scientists at the U.S. Geological Survey (USGS) and elsewhere are working to assess both the potential capacities and the potential limitations of the various forms of carbon sequestration and to evaluate their geologic, hydrologic, and ecological consequences. The USGS is providing information needed by decision makers and resource managers to maximize carbon storage while minimizing undesirable impacts on humans and their physical and biological environment.

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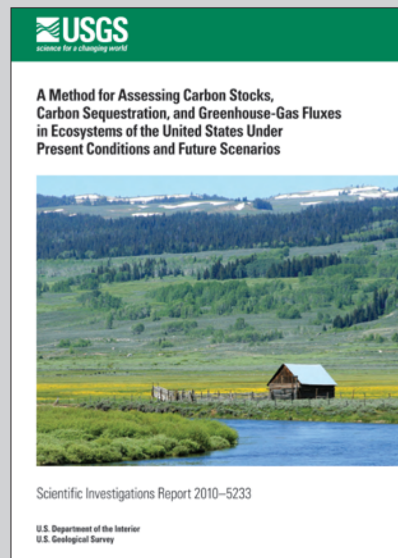
December 2008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science for a changing world

A Method for Assessing Carbon Stocks, Carbon Sequestration, and Greenhouse-Gas Fluxes in Ecosystems of the United States Under Present Conditions and Future Scenarios

Scientific Investigations Report 2010–5233

U.S. Department of the Interior
U.S. Geological Survey

Red-winged Blackbird
(*Agelaius phoeniceus*)

floods

The USGS also researches the interactions among climate, land-use change, human-caused disturbances on ecosystems and their biota, natural hazards and their effects, water availability and quality, and exposure of humans and biota to disease. This research can identify thresholds of environmental change and address the social and ecological risks associated with crossing these thresholds. In order to evaluate the potential effects of climate change on the Borderlands, the regional climate change projections should be scaled down to something approaching the county scale. These climate change projections can then be used to produce products such as aridity index maps (calculated as the ratio of average annual precipitation to potential evapotranspiration) for the Borderlands to help identify where water resources and natural habitat will be stressed in different climate change projections.

To address the issue of rising levels of carbon dioxide (CO_2), the USGS studies geologic options for storing CO_2 in depleted oil and gas reservoirs, deep coal seams, and saline formations. The USGS methodology to assess the Nation's resources for geologic carbon sequestration estimates storage resource potential as volume of pore space into which CO_2 can be injected and retained for tens of thousands of years, and it can be applied uniformly to geologic formations across the United States. The storage resources are accessible through present-day geological and engineering knowledge and technology. No economic factors are used in the estimation of the volume of storage resource. For more information on the USGS and geologic carbon sequestration, see *http://energy.usgs.gov/HealthEnvironment/EnergyProductionUse/GeologicCO2Sequestration.aspx*.

drought

Product Development

The USGS provides high-resolution spatial climate and ecosystem model results for public lands and for use by land managers. We are developing a public-access delivery system for integrated geospatial data that can be used to delineate ecosystems and evaluate effects. We also develop predictive and adaptive tools and strategies for managers to use to reduce the risks of hazards as well as increase the potential for hydrologic and ecological systems to be self-sustaining and resilient to climate change and related disturbances.

References cited in this are listed in chapter 12.