Appendix A. Climate Change Trends and Apache-Sitgreaves NFs Land Management Planning

Overview and Background

Climate scientists agree that the Earth is undergoing a warming trend, and that human-caused elevations in atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases (GHGs) are among the causes of global temperature increases. The observed concentrations of these greenhouse gases are projected to increase. Climate change may intensify the risk of ecosystem change for terrestrial and aquatic systems, affecting ecosystem structure, function, and productivity.

This section contains a description of the climate patterns and trends in the Southwestern United States followed by a description of how current climate models and predictions may generally affect those climate patterns in the near future. Then, a short, land management plan revision oriented synthesis of climate change literature follows. This review of current climate change related scientific literature for the Southwestern United States focuses on how climate change might be currently influencing—and may impact in the future—ecological and socioeconomic systems. The intent of the review is to examine those areas of climate change research that may have an impact on how the Apache-Sitgreaves NFs is managed. Specifically, this section summarizes current and future climate trends at the regional and, if possible, the forests level. Possible effects of climate change on ecosystems are discussed regarding water abundance and quality, biodiversity and wildlife species, economic and social conditions in the Southwest, and a description of limitations and uncertainties inherent in projected future climate scenarios. Finally, this document discusses possible management issues that should be considered during land management planning.

Climate in the American Southwest and the Apache-Sitgreaves NFs

What is Climate?

Climate may be defined as the "average weather," or more rigorously, as the statistical description of weather in terms of the mean and variability of relevant quantities (e.g., temperature, precipitation, wind) over a period ranging from months to thousands or millions of years. The standard period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the statistical description of the state or condition of the climate system[1]. In contrast, weather describes the daily conditions (individual storms) or conditions over several days (e.g., a week of record-breaking temperatures), to those lasting less than 2 weeks[2]. Natural

[1] According to the World Meteorological Organization, the climate system is a highly complex arrangement consisting of five major components: the atmosphere, hydrosphere, cryosphere, and land surface and biosphere, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions and solar variations and human-induced influences such as the changing composition of atmosphere and land use changes.

[2] The glossary of climate terms used in this report is drawn from "A Glossary of Terms" used in the "Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report" (IPCC, 2007).

climate variability refers to variations due to natural internal processes (internal variability) in the climate system or natural external forcing (external variability), in the mean state and other statistics of the climate on all spatial and temporal scales beyond that of individual weather events (IPCC, 2007). Climate and climate variability are determined by the amount of incoming solar radiation, chemical composition, dynamics of the atmosphere, and surface characteristics of the Earth. The circulation of the atmosphere and oceans influences the transfer of heat and moisture around the planet and, thus, strongly influences climate patterns and their variability in space and time. Much of the current climate change literature states that human activities, such as fossil fuel burning, industrial activities, changes in land use, animal husbandry, and fertilized and irrigated agriculture, lead to increases in GHGs, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These increased GHGs contribute to the greenhouse effect and cause the surface temperature of the Earth to increase. Global atmospheric concentrations of CO_2, CH_4, and N_2O have increased markedly because of human activities since 1750, and they now far exceed preindustrial levels (IPCC, 2007).

The climate of the Southwest U.S. is often referred to as dry and hot; however, it is very complex. While low deserts of the Southwest experience heat and drying winds in the early summer, forested mountain areas and plateaus may experience cold and drifting snow during winter. Climate variability is the norm within this region, as temperature and precipitation fluctuate on time scales ranging from seasons to centuries. Monsoon thunderstorms in July and August are often accompanied by flash flooding. From fall to spring, the weather can be warm with clear skies. The Southwest also experiences periods of short- and long-term drought. Indeed, severe regional floods or droughts have affected both indigenous and modern civilizations on time scales ranging from single growing seasons to multiple years, even decades (Hughes et al., 2002).

To a large degree, a quasi-permanent subtropical high-pressure ridge over the Southwest leads to the characteristically low annual precipitation, clear skies, and year-round warm weather over much of the region. This high-pressure ridge is created through Hadley circulation[3]. Where the descending branch of Hadley circulation comes down, it tends to create a zone of atmospheric high pressure that makes it difficult for clouds to form. Much of the Southwest U.S. lies in the subtropical zone, where warm, dry air is flowing back down to Earth following its rain-inducing rise in the tropics. Descending air in the subtropics relates to an ongoing global pattern known as Hadley circulation.

In addition, the Southwest is located between the mid-latitude and subtropical atmospheric circulation regimes. This positioning, relative to shifts in these atmospheric patterns, is the main reason for the region's climatic variability. El Niño (also known as the El Niño Southern Oscillation or ENSO) is an increase in sea surface temperature of the eastern equatorial Pacific Ocean with an associated shift of the active center of atmospheric convection from the western to the central equatorial Pacific. ENSO has a well-developed teleconnection[4] with the Southwest, usually resulting in wet winters. La Niña, the opposite oceanic case of El Niño, usually results in

[3] Hadley circulation is a flow pattern that dominates the tropical atmosphere, beginning with warm, moist air rising near the equator, poleward movement 6 to 9 miles above the surface, descending motion in the subtropics, and equatorward movement near the surface. This circulation is intimately related to the trade winds, tropical rainbelts, subtropical deserts, and jet streams.

[4] Teleconnections: Atmospheric interactions between widely separated regions that have been identified through statistical correlations (in space and time). For example, the El Niño teleconnection with the southwestern U.S. involves large-scale changes in climatic conditions that are linked to increased winter rainfall.

dry winters for the Southwest. Another important oceanic influence on winter climate of the Southwest is a feature called the Pacific Decadal Oscillation (PDO), which has been defined as temporal variation in sea surface temperatures for most of the northern Pacific Ocean. The major feature that sets the climate of the Southwest apart from the rest of the U.S. is the North American Monsoon which, in the U.S., is most noticeable in Arizona and New Mexico. Up to 50 percent of the annual rainfall of Arizona and New Mexico occurs as monsoonal storms from July through September (Hughes et al., 2002).

In summary, while many factors influence climate in the Southwest during a particular year or season, the region's overall climate is defined by predictable weather patterns that occur across the years and decades to define the region's climate. The region's overall aridity relates to a global circulation pattern known as Hadley circulation, which creates a semipermanent high-pressure zone over the Southwest. Relatively high temperatures with dynamic daily swings define this geographic region. Mountains and other differences in elevation affect local climate patterns. The North American Monsoon works to bring moisture from the tropics into the region during the summer months.

Future Climate of the Southwest and the Apache-Sitgreaves NFs

Currently, there appears to be broad agreement among climate modelers that the Southwest U.S. is experiencing a drying trend that will continue well into the latter part of the 21st century (IPCC, 2007; Seager et al., 2007). While the ensemble[5] scenario used by Seager et al. (2007) included two models with predictions of increased precipitation, the researchers concluded that the overall balance between precipitation and evaporation would still likely result in an overall decrease in available moisture. Regional drying and warming trends have occurred twice during the 20th century (1930s Dust Bowl and the 1950s Southwest Drought), and they were severe during what is known as the Medieval Climate Anomaly, an interval of warm, dry conditions with regional variability from A.D. 900 to 1350 (Hughes and Diaz, 2008; Herweijer et al., 2007). The current drought conditions may very well become the new climatology of the American Southwest, including the Apache-Sitgreaves NFs, within a timeframe of years to decades. According to recent multimodel ensemble scenarios, the slight warming trend observed in the last 100 years in the Southwest may continue, with the greatest warming to occur during winter. These climate models depict temperatures rising approximately 5 to 8 degrees Fahrenheit by the end of the century (IPCC, 2007). This trend would increase pressures on the region's already limited water supplies, as well as increase energy demand, alter fire regimes and ecosystems, create risks for human health, and affect agriculture (Sprigg, 2000).

The number of extremely hot days is also projected to rise during the 21st century. By the end of the century, parts of the Southwest, including the Apache-Sitgreaves NFs, are projected to face summer heat waves lasting 2 weeks longer than have been occurring in recent decades. Some climate model downscaling results also suggest a fivefold increase in unusually hot days by the end of the century, compared to 1961 to 1985. In effect, the high temperatures that formerly occurred on only the hottest 5 percent of days could become the norm for a quarter of the year—100 days or more—in much of the Southwest (IPCC, 2007).

[5] Multimodel ensembles: Researchers have found that the average of numerous available climate models—sometimes called the ensemble mean—almost always weigh in with more accuracy than any one model. This technique often uses 18 to 20 different coupled global circulation models and combines the output from each to produce and ensemble output (CCSP, 2008c).

Observations based on measurements from weather stations indicate that the temperature rise projected for the future is on par with the rate of increase much of the Southwest has already registered in recent decades, particularly since the mid-1970s. Since 1976, the average annual temperature increased by 2.5 degrees Fahrenheit in Arizona and 1.8 degrees Fahrenheit in New Mexico. The recent temperature increase is unusual, even in the context of records dating back more than 1,200 years that were compiled from tree rings and other natural archives of temperature for the northern hemisphere (Trouet et al., 2009; Hughes and Diaz 2008; Herweijer et al., 2007; Meko et al., 2007).

Warmer winter temperatures in the Southwest have serious implications for snow cover, an important natural reservoir of water in the West. In a study conducted on two watersheds in central Arizona (one watershed is partially located on the Apache-Sitgreaves NFs), Svoma (2009) found that between water years 1934 and 2007, average snowpack elevation levels have increased with a decrease in snow amounts. In his study, he directly correlated this with increasing temperatures. Shorter winters and less snowpack also affect the timing of natural cycles such as plant dormancy and blooming and peak riverflows. Throughout the West, the number of days in the frost-free season, which varies by location, has been increasing more rapidly than in the East (Lenart, 2007). Summer temperatures have also climbed, especially since the mid-1970s. Maximum temperatures regularly reach above 100 degrees Fahrenheit daily for weeks on end in many southwestern cities (Lenart, 2007). The temperature rise alone has some predictable effects on aridity in the region. For instance, higher temperatures increase evaporation rates. Higher temperatures and a drier landscape increase wildfire hazard and put extra stress on ecosystems (Lenart, 2007).

Precipitation changes remain much more difficult to predict than temperature, because precipitation is more variable and operates on a smaller scale. Predicting future precipitation is difficult in the Southwest, due to added complexities such as topography and monsoonal timing. When comparing climate model simulations to what actually occurred, researchers found the results roughly matched 50 to 60 percent of the time for precipitation. This compares to about 95 percent of the time for temperature (Lenart, 2007).

However, precipitation is projected to decline by 5 percent by 2100 for much of Arizona and New Mexico, based on modeling results from an ensemble of 18 general circulation models. A 10 percent decrease could be in store for the southern half of Arizona; while northeastern New Mexico is projected to remain roughly stable, based on these same estimates. Such a decrease in precipitation could have a more serious impact than the numbers suggest. The decrease of water draining from the landscape into rivers and reservoirs typically can be double or triple the proportional reductions in rainfall amounts, especially when combined with higher temperatures (Christensen and Lettenmaier, 2006).

In another study, researchers using a multimodel ensemble of 19 models projected an increase in aridity for the Southwest. Their study defined the Southwest as the land area stretching from east to west, from Houston to San Francisco and north to south from Denver to Monterrey, Mexico; this area includes the Apache-Sitgreaves NFs. Only 2 of the 19 climate models evaluated suggested a potential decrease in aridity for the southwestern quadrant of the country (Seager et al., 2007).

Snowpack measurements suggest that rising temperatures are melting winter snow progressively earlier in the year and causing streamflows to deliver water to reservoirs and water users in greater quantities earlier in the spring season. Historically, snowmelt has occurred at the same time communities' ramp up their water consumption, which has drained reservoirs as they fill. When streamflows become elevated earlier in the year, however, reservoirs fill more quickly. Earlier future streamflows will likely increase the chance that spikes in riverflows occur when the reservoirs are at full capacity, increasing the probability of flash floods (Guido, 2008).

Average air temperatures are rising, and it is likely that continued warming will accentuate the temperature difference between the Southwest and the tropical Pacific Ocean, enhancing the strength of the westerly winds that carry moist air from the tropics into the Southwest during the monsoon. This scenario may increase the monsoon's intensity or its duration, or both, in which case, floods will occur with greater frequency (Guido, 2008).

While the region is expected to dry out, it is also likely to see larger, more destructive flooding. Along with storms in general, hurricanes and other tropical cyclones are projected to become more intense overall. Arizona and New Mexico typically receive 10 percent or more of their annual precipitation from storms that begin as tropical cyclones in the Pacific Ocean. In fact, some of the largest floods in the Southwest have occurred when a remnant tropical storm hit a frontal storm from the north or northwest, providing energy to intensify a remnant tropical storm (Guido, 2008).

In summary, based on multimodel ensemble climate models, by the end of the 21st century, the Southwest is likely to experience the following conditions: temperature increases of 5 to 8 degrees Fahrenheit; an increase in the number of extremely hot days, with summer heat waves lasting 2 weeks or more, accompanied by warmer winters with a reduced snowpack, and a later monsoonal season; a 5 percent drop in precipitation throughout most of Arizona, including the Apache-Sitgreaves NFs, and possibly a 10 percent drop in southern Arizona; and an increase in extreme flood events following an overall increase in tropical storms.

Discussion

The state of knowledge needed to address climate change at the Apache-Sitgreaves NFs scale is still evolving. Because none of the current climate models, including multimodel ensembles, adequately resolve important topographic variations (e.g., mountain ranges versus valleys) and occurrences such as ENSO (El Niño) or the North American Monsoon, their results are imprecise and the subject of continuing research. However, these models do reproduce much of the underlying features of the Earth's climate, and their basic structure has been proven under countless experiments and forecasts of the weather systems from which climate is usually described. Therefore, these models remain a credible means of estimating potential future climate scenarios. Most global climate models are not yet precise enough to apply to land management at the ecoregional or Apache-Sitgreaves NFs scale. This limits, to some degree, regional and Apache-Sitgreaves NFs specific analysis of potential effects from climate change. Additionally, industrial society during the past 200 years has likely placed unprecedented pressures on ecosystems, increasing the unpredictable quality of future environmental change (Millar et al., 2007).

Improvement in regional-level models has increased with refinement of global climate modeling techniques. As climate model resolution increased to about 4,000 square miles per grid square, regional models may eventually be considered reliable at resolutions of about 350 square miles, which is nearly double the area of Albuquerque, New Mexico (Lenart, 2008). These model improvements also may provide researchers the information they need to downscale results to the local level of national forests. Research efforts in this area have been successful in capturing fine-scale details of historical climate, suggesting that regional methods can add value for assessments of the impacts of climate change projections (Maurer and Hidalgo, 2008). Researchers at The Nature Conservancy are currently downscaling multimodel ensemble climate projections to spatial resolutions between roughly ½ and 7½ miles (Enquist and Gori, 2008). In another effort, scientists used statistical downscaling of multimodel ensemble to consider how Colorado River streamflow might alter with climate (Christensen and Lettenmaier, 2006). In the future, this same approach could have application for streams that headwater on the Apache-Sitgreaves NFs (e.g., Blue River, Black River).

Paleoenvironmental studies of changing climate in the Southwest may provide at least a limited historical ecological context for ecosystem variability and climate change. Such studies can provide a limited range of knowledge about past climate change, strengthening or weakening El Niño or La Niña events, patterns of precipitation, drought severity, and changes in vegetation patterns (Swetnam and Betancourt, 1997; Swetnam et al., 1999). A recurrent trend in the literature suggests that predicting the future effects of climate change and subsequent challenges to land management in the Southwest remains inexact and will require a combination of approaches.

In summary, climate modeling is a developing science. Newer multimodel ensembles are “better than the sum of their parts” and are used increasingly for projecting climate change in the Southwest. Downscaling techniques, including statistical downscaling, dynamical downscaling, and sensitivity analysis, are improving. Regional modeling, which incorporates jet stream activity, tropical storm and monsoon tracking, and regional elevation effects, has a high potential to improve localized climate projections. However, this general regional-level modeling still relates to the Apache-Sitgreaves NFs.

Southwestern Climate Change and Apache-Sitgreaves NFs Ecosystems

Water and Climate Change

Changes in water distribution, timing of precipitation, availability, storage, watershed management, and human water uses may present some of the most important challenges of climate change and national forest management in the Southwest. Terrestrial and aquatic ecosystems and all human socioeconomic systems in the Southwest depend on water. In this section, the stage is set for the review of climate change by briefly discussing water in the Southwest, its overall importance to ecological and socioeconomic systems, and the possible impacts to this resource by potential changes in climate.

The prospect of future droughts becoming more severe because of global warming is a significant concern, especially because the Southwest continues to lead the Nation in population growth. Recent warming in some areas of the Southwest is occurring at a rate that is among the most rapid in the Nation (Seager et al., 2007), significantly higher than the global average in some areas. This is driving declines in spring snowpack and riverflows. Further water cycle changes are projected which, when combined with increasing temperatures, signal a serious water supply challenge in the decades and centuries ahead. Water supplies are projected to become increasingly scarce, demanding tradeoffs among competing uses, and potentially leading to conflict.

Climate change, with both wet periods and droughts, has been a part of southwestern climate for millennia. The droughts of the last 110 years pale in comparison to some of the decades-long “megadroughts” that the region has experienced over the last 2,000 years (Seager et al., 2008). During the closing decades of the 1500s, for example, major droughts gripped areas of the Southwest. As of 2009, much of the Southwest remains in a drought that began about 1998, with 2002, the driest water year on record for many parts of Arizona[6] (McPhee et al., 2004), including the Apache-Sitgreaves NFs. This event is the most severe western drought of the last 110 years and was exacerbated by record warming. Projections for this century point to an increasing probability of drought for the region, made more probable by warming temperatures. The most likely future for the Southwest is a substantially drier one. Combined with the historical record of severe droughts and the current uncertainty regarding the exact causes and drivers of these past events, the Southwest must be prepared for droughts that could potentially result from multiple causes. The combined effects of natural climate variability and human induced climate change could result in a challenging combination of water shortages for the region (Karl et al., 2009).

Development in the Southwest has been primarily dependent upon technology to deliver water resources. The locations of most snowpack and upland reservoirs are on national forests in the Southwest (Smith et al., 2001; State of New Mexico, 2005). There are an estimated 3,771 surface acres of perennial lakes and ponds within the Apache-Sitgreaves NFs (Forest Service, 2008). The Apache-Sitgreaves NFs also contain many of the headwater streams for the Little Colorado, Salt, and Upper Gila River Basins. The Apache-Sitgreaves NFs receive a large portion of Arizona’s annual snowpack. Current estimated water yields from the Apache-Sitgreaves NFs are roughly 384,650 acre-feet per year (Forest Service, 2008), the majority going to the greater Phoenix metropolitan area. Some studies predict water shortages and lack of storage capabilities to meet seasonally changing riverflow and transfers of water from agriculture to urban uses, as critical climate-related impacts to water availability (Barnett et al., 2008).

While agriculture remains the greatest water user in the Southwest, there has been a decrease in the amount of water used by agriculture, as Arizona’s and New Mexico’s booming populations demand more water for municipal and other uses and irrigation technologies improve; this has been an ongoing trend and could affect future agricultural uses. Without upland reservoirs and watersheds important to Arizona’s largest metropolitan center (e.g., Little Colorado, Salt, and Upper Gila River Basins) managed by the Apache-Sitgreaves NFs, alternative water sources, water delivery systems, and infrastructure support for agriculture would need to be developed (Lenart, 2007).

Flash flooding, occurring after extended drought, may increase the number and severity of floods; and accelerate rates of soil erosion. The timing and extent of storm-related precipitation will play a key role in determining the degree to which people and the environment are affected (Swetnam and Betancourt, 1997; Swetnam et al.,1999; Lenart, 2007). In a drought of the magnitude of the worst 1-year drought on record, water demand may exceed supply by 68 percent. According to National Weather Service data, over the last 110 years, portions of the Apache-Sitgreaves NFs experienced below average precipitation 1 out of every 2 years and drought[7] 1 out of every 6. In the 5-year scenario modeled after the worst drought in the historical record, water demand in

[6] Drought impacts in 2002 included extensive wildfires, water supply emergencies, vegetation and wildlife mortality, and economic losses in the ranching, agriculture, and tourism sectors.

[7] The Society for Range Management defines drought as 75 percent or less of the average yearly rainfall.

Arizona could exceed supply by 67 percent, and in the 10-year scenario, demand may exceed supply by 59 percent (Lenart, 2007). In the Southwest, intense debate will likely continue over water allocation. Add to the mix a highly variable climate, over time and occurring on a large, landscape scale, and the situation becomes even more conflict prone (Lenart, 2007).

In the realm of human health, a sequence of rain-drought-rain can trigger outbreaks of Hantavirus, and there is evidence linking unusually wet seasons with an increase in reported cases of valley fever. In both instances, the distribution of precipitation over time and space are important factors.

The potential for flooding is very likely to increase because of earlier and more rapid melting of the snowpack, with more intense precipitation. Even if total precipitation increases substantially, snowpack will likely be reduced because of higher overall temperatures. However, it is possible that more precipitation would also create additional water supplies, reduce demand, and ease some of the competition among competing uses (Joyce et al., 2001; Smith, et al., 2001).

In contrast, a drier climate is very likely to decrease water supplies and increase demand for such uses as agriculture, recreation, aquatic habitat, and power, thus increasing competition for decreasing supplies (Joyce et al., 2001). Overall, these trends would increase pressures on the already limited water supplies in the Southwest, increase energy demand, alter fire regimes and ecosystems, create risks for human health, and affect agriculture in the region (Swetnam and Betancourt, 1997; Sprigg et al., 2000).

Climate Change and Potential Ecosystem Impacts on the Apache-Sitgreaves NFs

Natural ecosystems are regulated by climate, and climate is to some degree determined by natural ecosystems. Long term or short term climate variability may cause shifts in the structure, composition, and functioning of ecosystems, particularly in the fragile boundaries of the semiarid regions. These areas already contain plants, insects, and animals highly specialized and adapted to the landscape. A changing climate of wetter, warmer winters, and overall temperature increases, would alter their range, type, and number throughout the Southwest. Responding differently to shifts in climate, the somewhat tenuous balance among ecosystem components will also change. As phenology is altered, the overall effects among interacting species are difficult to predict, particularly given the rate of climate change and the ability of symbionts to adapt. As the health of the ecosystem is a function of water availability, temperature, carbon dioxide, and many other factors, it is difficult to determine accurately the extent, type, and magnitude of ecosystem change under future climate scenarios. Yet, should vegetation cover and moisture exchanging properties of the land change, important local and regional climate characteristics such as albedo[8], humidity, wind, and temperature will also change with potential compounding effects to vegetation (Sprigg et al., 2000).

[8] Albedo is the reflectance of a surface. Absorbed solar radiation warms the Earth’s surface, whereas, reflected radiation does not. Albedo is one component of this energy feedback. Different land covers have varied albedo. Thus, land use change can influence albedo and whether a land surface has a warming or cooling effect. For example, snow has a very high albedo and, thus, has a cooling effect (negative feedback). Melting of snow or coverage of snow with vegetation or black carbon (from air pollution) results in a lower surface albedo and has a warming effect (positive feedback) (IPCC, 2007).

Current research shows that climate is much more variable than is commonly understood and that this is expressed in nested temporal and spatial scales. Millar et al. (2007) provide an elegant summation of natural climatic variables and its implications for forest managers. These are three key points from that research which should be considered in Apache-Sitgreaves NFs management strategies:

1. The past record clearly shows that ecological conditions change constantly in response to climate. Plant and animal species will shift even in the absence of human influence (Millar et al., 2007).
2. Wet/dry oscillations associated with ocean-atmosphere patterns have driven regional and continental scale fire patterns for centuries. These patterns provide a basis for fire forecasting tools (Westerling et al., 2006).
3. Species ranges and demographics are expected to be highly unstable as the climate shifts (Millar et al., 2007).

Climate may influence the distribution and abundance of plant and animal species through changes in resource availability, reproduction, and survivorship. The potential ecological implications of climate change trends in the Southwest indicate:

- More extreme natural ecological process events, including wildfires, intense rain, flash foods, and wind events (Swetnam et al.,1999).
- Greater vulnerability to invasive species, including insects, plants, fungi, and vertebrates (Joyce et al., 2006).
- Long-term shifts in vegetation patterns (Westerling et al., 2006; Millar et al., 2007).
- Cold-tolerant vegetation moving upslope or disappearing in some areas; migration of some plant species to the more northern portions of their existing range (Clark, 1998).
- Potential decreases in overall forest productivity due to reduced precipitation (Forest Service, 2005).
- Shifts in the timing of snowmelt (already observed) in the American West, which, along with increases in summer temperatures, have serious implications for the survival of fish species and may challenge efforts to reintroduce species into their historic range (Joyce et al., 2006; Millar et al., 2007).
- Effects on biodiversity, pressure on wildlife populations, distribution, viability, movement and migration patterns because of increasing temperatures, water shortages, and changing ecological conditions.
- Effects on phenology and changes in the date of flowering and associated pollination and food-chain disruptions (Guido, 2008).

In summary, expected changes to Southwest and Apache-Sitgreaves NFs ecosystems due to climate change include the following: projected decreases in precipitation, including reduced snowpack and overall water availability; increased risk from wildfire, insects and disease, and invasive species; and potential decreases in ecosystem productivity from water limitations and increased temperature. In addition, potential impacts to riparian, wetland, and aquatic habitats and the species that depend on them are other concerns.

Vegetation Changes

A warmer climate in the Southwest is expected to affect ecosystems by altering the biotic and abiotic stresses that influence and affect the vigor of ecosystems, leading to increased extent and severity of disturbances on the Apache-Sitgreaves NFs. As an example, the results of modeling efforts by Ironside et al. (2010) between five different climate scenarios showed only the San Francisco Peaks and the highest elevations of the Apache-Sitgreaves NFs as having the only suitable climate for ponderosa pine (*Pinus ponderosa* C. Lawson) sustainability in Arizona over the 21st century. Decreasing water availability and higher temperatures will accelerate the stresses experienced in forests, woodlands, grasslands, chaparral, and riparian communities, which typically involve some combination of multiyear drought, insects, and fire. As has occurred in the past, increases in fire disturbance superimposed on ecosystems, with increased stress from drought and insects, may have significant effects on growth, regeneration, long-term distribution, abundance of forest species, and carbon sequestration.

Many Apache-Sitgreaves NFs ecosystems contain water-limited vegetation today (e.g., semi-desert grassland, Madrean pine-oak woodland, chaparral). Vegetation productivity on the Apache-Sitgreaves NFs may decrease with warming temperatures, as increasingly negative water balances constrain photosynthesis, although this may be partially offset if CO_2 fertilization significantly increases water use efficiency in plants. Piñon-juniper woodlands, a key Apache-Sitgreaves NFs PNVT, are clearly water limited systems, and piñon-juniper ecotones are sensitive to feedbacks from environmental fluctuations and existing canopy structure that may provide trees a buffer against drought. However, severe multiyear droughts periodically cause dieback of piñon pines, which may overwhelm local buffering. Since the early 1900s, the size and severity of the recent drought and piñon ips beetle (*Ips confusus*) related dieoff is unprecedented for the White Mountains and Coconino Plateau (Lynch et al., 2008), where the Apache-Sitgreaves NFs is located.

Interdecadal climate variability strongly affects interior dry ecosystems, causing considerable growth during wet periods. This growth increases the evaporative demand, setting up the ecosystem for dieback during the ensuing dry period (Swetnam and Betancourt, 1997). The current dieback is historically unprecedented in its combination of fire suppression, low precipitation, and high temperatures. Increased drought stress via warmer climate is the predisposing factor, and piñon pine mortality and fuel accumulations are inciting factors. Ecosystem change may arise from large scale, severe fires that lead to colonization of invasive species, which further compromises the ability of piñon pines to reestablish. There continues to be no easy way to predict these changes at the forest planning scale, although the science community is working on single national forest scale models that will assist forest managers in forecasting vegetation trends under different climate scenarios (Joyce et al., 2008).

Temperature increases are a predisposing factor causing often lethal stresses on forest ecosystems of western North America, acting both directly through increasingly negative water balances and indirectly through increased frequency, severity, and extent of disturbances—chiefly fire and insect outbreaks. Human development of the West has resulted in habitat fragmentation, creation of migration barriers such as dams, and introduction of invasive species. The combination of development, presence of invasive species, complex topography, and climate change is likely to lead to a loss of biodiversity in the region. However, some species may migrate to higher altitudes in mountainous areas. It is also possible that some ecosystems, such as alpine ecosystems, would virtually disappear from the region (Joyce et al., 2008).

Natural ecological processes having the greatest impact on the Apache-Sitgreaves NFs include: insects, diseases, fires, droughts, inland storms caused by hurricanes, flash flooding, windstorms, ice storms, and the introduction of nonnative species. Climate variability and changes can alter the frequency, intensity, timing, and spatial extent of these natural events. Many potential consequences of future climate change are expected to be buffered by the resilience of Apache-Sitgreaves NFs plant and animal communities to natural climatic variation. However, an extensive body of literature suggests that new disturbance regimes under climate change are likely to result in significant disturbances to U.S. forests, with lasting ecological and socioeconomic impacts (Joyce et al., 2001).

Wildfire

Historically, wildfires have been recurring natural ecological processes in conifer forests, piñon-juniper woodlands, chaparral, and grassland ecosystems of the Apache-Sitgreaves NFs. An analysis of trends in wildfire and climate in the western United States from 1974 to 2004 shows that both the frequency of large wildfires and fire season length increased substantially after 1985 (Westerling et al., 2006). These changes were closely linked with advances in the timing of spring snowmelt and increases in spring and summer air temperatures. Earlier spring snowmelt probably contributed to greater wildfire frequency in at least two ways: by extending the period during which ignitions could potentially occur, and by reducing water availability to ecosystems in mid-summer before the arrival of the summer monsoons, thus enhancing drying of vegetation and surface fuels (Westerling et al., 2006). These trends of increased fire size correspond with the increased cost of fire suppression.

In recent years, areas of western forests have been increasingly impacted by wildfires, burning homes and wildlands, and suppression costs have totaled more than $1 billion per year for Federal land management agencies. Since about the mid-1970s, the total acreage of areas burned and the severity of wildfires in pine and mixed-conifer forests have increased. Fire frequency and severity may be exacerbated if temperatures increase, precipitation decreases, and overall drought conditions become more common. In addition, continued population growth will likely cause greater human-started fires, since humans start nearly half of the fires in the Southwest. In 2002, for example, the Rodeo and Chediski Fires on the Fort Apache Indian Reservation and Apache-Sitgreaves NFs were both started by humans and combined to burn nearly half a million acres, becoming the largest fire on record in Arizona (Joyce et al., 2008).

Insects and Pathogens

Insects and pathogens are significant natural occurring ecological processes within forest ecosystems in the U.S., costing 1.5 billion dollars annually (Dale et al., 2001). Extensive reviews of the effects of climate change on insects and pathogens have reported many cases where climate change has affected and/or will affect forest insect species range and abundance, as witnessed in the Southwest. Climate also affects insect populations indirectly through effects on hosts. Insect and pathogen populations have responded to variability in climate and changing forest character (especially to changing structure and species composition) on the Apache-Sitgreaves NFs (Lynch et al., 2010). Drought stress, resulting from decreased precipitation and/or warming, reduces the ability of a tree to mount a defense against insect attack, though this stress may also cause some host species to become more palatable to some types of insects. Fire suppression and large areas of susceptible trees, a legacy from logging, may also play a role (Ryan et al., 2008).

Invasive Species

Disturbance may reset and rejuvenate some ecosystems in some cases and cause enduring change in others. For example, climate change may favor the spread of invasive, nonnative grasses into arid lands where the native vegetation is too sparse to carry a fire. When these areas burn, they typically convert to nonnative monocultures and the native vegetation is lost (Ryan et al., 2008). The Apache-Sitgreaves NFs suffer from many types of invasive species outbreaks, including plants (e.g., yellow star-thistle, musk thistle, cheatgrass, saltcedar, weeping lovegrass) and animals (e.g., brown-headed cowbird, crayfish). Collectively, 58 nonnative invasive plant species currently infest roughly 30,000 acres on the Apache-Sitgreaves NFs (Forest Service, 2008). Invasive plants can alter landscapes by overtaking native species, facilitating fire outbreaks, and altering the food supply for herbivorous animals and insects. For example, weeping lovegrass was introduced to the region for cattle feed and erosion control in the mid-1900s, but it has since moved from ranchlands and roadways into the forest, woodland, and grassland communities on the Apache-Sitgreaves NFs. Subsequently, this grass has displaced native species.

Specific Habitats on the Apache-Sitgreaves NFs

Our knowledge of possible climate change impacts on specific vegetation types remains limited. However, projected and observed climate change effects are being studied at the broad scale habitat level throughout the Southwest. The mild nature of climate gradients among lower life zones of the Southwest and protracted ecotonal bands make woodland plant communities particularly vulnerable (Allen and Breshears, 1998; Adams et al., 2009). Many of the region’s plant and animal species are associated with these key habitats, and they are, therefore, important when considering the potential impacts of climate change on ecosystems managed by the Forest Service in the Southwest.

Subalpine

Subalpine habitats are very susceptible to climate change in the Southwest, given its limited extent and marginal existence. Analyses of the results of ecological models when driven by different climate scenarios indicate changes in the location and area of potential habitats for many tree species and plant communities. For example, subalpine habitats found on the Apache-Sitgreaves NFs, and the variety of species dependent upon them, are likely to be greatly reduced. In some areas of the contiguous U.S., subalpine ecosystems are projected to all but disappear from western mountains (Joyce et al., 2001). On the Apache-Sitgreaves NFs, subalpine habitat is projected to be replaced by ponderosa pine (Ironside et al., 2010). Increasing temperatures and shifting precipitation patterns will drive declines in high elevation ecosystems such as subalpine and grasslands plants are isolated on high mountains (Lenihan et al., 2008).

Upward shifts in elevation of plants in the subalpine ecotones of mountains have been increasing in North America. Some researchers have reported the upward shifts in elevation in subalpine vegetation due to climate. Assessing the vulnerability of species and locations in subalpine zones to climate change is an important issue for their conservation (Lenihan et al., 2008) and for the wildlife species that depend on alpine habitats. Subalpine species are at higher risk of extinction as suitable habitats rapidly disappear from mountaintops (Christensen et al., 2007). Some wildlife may be reliant upon melting of the snowpack to set phenological clocks (Inouye, 2008), and the warm summer temperatures may force a reduction in daytime foraging for large herbivores, whose tolerance for heat is lower than for species adapted to warmer weather (Aublet et al., 2009).

Riparian

Riparian habitats are very important for wildlife on the Apache-Sitgreaves NFs; approximately 511 wildlife and fish species (32 fish, 13 amphibian, 324 birds, 105 mammals, 36 reptiles) (Vander Lee et al., 2006), as well as an unknown number of invertebrate and plant species, inhabit or use riparian areas at some time during their life. Research predicts that as climate changes, water inputs are expected to decline due to reduced precipitation and, subsequently, reduced water in riparian zones. Water losses are also likely to increase due to elevated evapotranspiration rates at higher temperatures and greater runoff losses associated with increased frequencies of high intensity convectional storms. Urban expansion will also increase human demand for water and further reduce water availability for wildland ecosystems. Decreased water availability will affect riverine and riparian ecosystem function, due to modifications in geomorphological processes and an overall reduction in the availability of moisture to plant communities. Although these areas comprise less than 1 percent of Apache-Sitgreaves NFs lands, they provide critical habitat for vertebrates, invertebrates, migratory birds, and other riparian-dependent species. Reduced water inputs will cause riparian ecosystems to contract in size. Furthermore, lowered water availability will stress riparian plants and increase the ecosystem susceptibility to invasion by nonnative plants, such as salt cedar and Russian olive, which in turn will disrupt the natural wildlife community (Archer and Predick, 2008).

Wetlands and Cienegas

Climate change is likely to affect native plant and animal species by altering key habitats such as the wetland/cienega, fen, and bog ecosystems (Karl et al., 2009). There are roughly 11,825 acres of wetland/cienega riparian areas on the Apache-Sitgreaves NFs (Forest Service, 2008). Wetlands/cienegas create unique habitats and microclimates that support diverse wildlife and plant communities. Wetlands/cienegas can exist with little or no water for long periods, or have several wet/dry cycles each year. When it rains, what appeared to be only a few clumps of short, dry grasses just a few days earlier suddenly teems with aquatic plants and animals. Wetlands/cienegas provide a perfect habitat for migrating birds to feed, mate, and raise their young (Karl et al., 2009). Wetlands/cienegas also serve as natural wastewater purification systems. Wetlands/cienegas perform two important functions in relation to climate. They have mitigation effects through their ability to sink carbon, and they have adaptation effects through their ability to store and regulate waterflows. Due to their ability to store and slowly release water, properly functioning wetlands/cienegas are imperative in periods of extreme droughts.

Aquatic Systems

There are already observed shifts in the timing of snowmelt in the American West which, along with increases in summer air temperatures, have serious implications for the survival of fish species and may render some efforts useless to reintroduce species into their historic range (Millar et al., 2007). Of the 14 native fish species found on the Apache-Sitgreaves NFs, 7 are currently protected under the Endangered Species Act (Forest Service, 2008). For cool and cold-water species, a nearly 50 percent reduction in thermal habitat is projected with scenarios of increased water temperatures (Eaton and Scheller, 1996). Predicted impacts to aquatic ecosystems include altered seasonal high flow events, increases in drought severity during summer flows, and increasing temperatures in small streams and tributaries that further limit habitat during seasonal flows (Williams and Carter, 2009).

The fundamental physiological components of growth and metabolism are strongly affected by temperature (Schmidt-Nielsen, 1997). For fishes, this implies that populations highly adapted to local climates that experience increases in temperatures in excess of their optimum values for growth will reduce consumption rates and increase metabolic rates; this results in decreased growth. Fish increase feeding rates to compensate for poor growing conditions caused by increased temperature, which can lead to greater visibility and encounter rates with predators. Trout in whole lake experiments had lower survival at temperatures above optimum, and those populations with the highest temperatures and lowest food abundance experienced the lowest survival. The prediction is for an increasing frequency of poor or failed year classes where fish cannot escape the warmer conditions. Research, so far, reflects a basic understanding of the impacts of climate warming on individuals but not on the outcomes at the population levels (Biro et al., 2007). Current stresses on native aquatic species, including heat-tolerant nonnatives add to the complexity of managing and adapting to climate change.

Plant and Animal Species

The Nature Conservancy (Vander Lee et al., 2006) produced a list of 511 known and potential vertebrate species on the Apache-Sitgreaves NFs, accounting for 14 native fish, 18 nonnative fish, 13 amphibian, 36 reptile, 324 bird, and 105 mammal species. In addition, there are roughly 2,500 plant species found on the forests and potentially several thousand invertebrate species. The White Mountains harbor several endemic species that are found primarily or exclusively on the forests. Twenty-one invertebrates have been found only in the White Mountains (Stevens, 2007), while five small mammals and one fish are found primarily in the White Mountains (AZGFD, 2007; Hoffmeister 1986; NatureServe Web site 2007, 2008, 2009). Another three mammal species found in the White Mountains are more widespread, but they occur only within Arizona (AZGFD, 2007).

Research suggests large changes in the structure and species composition of plant communities due to the warming air temperatures and altered hydrological cycles. Many of the region’s plant, animal, and insect species depend on precise phenological events based on climatic conditions for migration, flowering, and timing for foraging and reproductive activities. Climate thus influences their distribution and abundance through changes in resource availability, fecundity, and survivorship. It is currently unknown how many species will successfully adapt to changing conditions. The ability of plant and animal species to migrate under climate change is strongly influenced by their dispersal abilities and by disturbances to the landscape. Land use changes and habitat alterations around the Apache-Sitgreaves NFs will add to the challenge of plant and animal species adapting to climate change. Within an ecological context, wildlife and plant responses to climate change in the region are highly dependent on interaction between weather, land use, land cover, hydrology, fire, and stresses from invasive, nonnative species.

Distribution

Many studies of species support the predictions of systematic shifts in distribution related to climate change, often via species specific physiological thresholds of temperature and precipitation tolerance. Temperature is likely to be the main driver for different species, including possible shifts in a coordinated and systematic manner throughout broad regions (Rosenzweig et al., 2007). Species at the upper elevations are at greater risk of being extirpated since they may not be able to adapt to habitat changes. Other species such as White Mountains water penny beetle (*Psephenus montanus*), New Mexico meadow jumping mouse (*Zapus hudsonius luteus*), or

Three Forks springsnail (*Pyrgulopsis trivialis*) are also at risk with potential loss of habitat due to their limited distribution and occurrences, or they are unable to disperse or adapt fast enough to keep up with the high rates of climate change. Such organisms face increased risk of extinction (Hoegh-Guldberg et al., 2008). In many instances, the impacts of range shifts will go far beyond the mere addition or subtraction of a species to or from a system. Some range shifts will have cascading effects on community structure and the functioning of ecosystems (Lawler et al., 2009).

Habitat Quality

Climate change may cause a host of physical consequences to the ecosystems, which may in turn affect the quality of plant and animal habitats. This may occur through a decrease in available water, changes in vegetation type through decline in vigor, severe drought or fire, or through changes in hydrology. Large areas of forest that were once suitable habitat for some species of wildlife may no longer be suitable, potentially leading to significant changes in species due to loss of needed habitat components (Karl et al., 2009). In their current state, 9 of the 14 major PNVTs on the Apache-Sitgreaves NFs are already at risk to their sustainability (Forest Service, 2008) without even factoring in potential effects of climate change.

Behavior and Biology

The timing of seasonal activities of plants and animals is perhaps the simplest process in which to track changes in the response of species to climate change. Observed phenological events include leaf unfolding, flowering, fruit ripening, leaf coloring, leaf fall of plants, bird migration, chorusing of amphibians, and appearance/emergence of insects (Rosenzweig et al., 2007).

Large herbivores, such as pronghorn, inhabiting highly seasonal temperate environments are subject to drastic daily and seasonal changes in environmental quality. During summer, they must acquire sufficient resources for growth and reproduction and to survive the following winter. Foraging behavior in summer is thus vitally important. Higher temperatures may reduce the daily activities of large herbivores. This may affect foraging, growth, reproduction, and overall health of animals. They may experience hardship during the winter and may not reproduce as successfully (Aublet et al., 2009). In reptiles and amphibians, increased temperatures, and changing precipitation could negatively affect reproduction, for many of the same reasons as with fish (Hulin et al., 2009). Impacts are also possible to the migration and dispersal routes of many species, including migratory songbirds, which are already of concern due to declines in abundance (Sillett et al., 2000).

Fragmentation and Isolation

The effects of fragmentation likely range across the full spectrum of biological diversity, from altering behavior of individuals, their genetics, and the demographic characteristics of populations, which can fundamentally change the structure and function of ecological communities (Lomolino and Perault, 2007). Climate change may contribute to further fragmentation of habitat and to creating barriers to migration. Fragmentation and barriers are likely to impede elevational and/or northward migration of many species, resulting in decreases in their total range. Habitat loss and fragmentation may also influence shifts in a species distribution. Empirical evidence shows that the natural reaction of species to climate change is to redistribute to more favorable habitats. However, this redistribution may be hampered by fragmentation by simply isolating suitable areas for colonization and preventing species movements, which may contribute to their extinction (Rosenzweig et al., 2007).

Southwestern Climate Change and Socioeconomic Effects

This review of the literature found few substantive studies of the possible social and economic effects that climate change might cause or exacerbate in the Southwest. Most climate related socioeconomic studies are either heavily theoretical, or too broad to apply specifically to the region. Over thousands of years, societies in the Southwest have faced climate change repeatedly—some successfully, some not so successfully (Dean, 2000). It is often difficult to "draw a conceptual line between climate change and other kinds of environmental transformations: both affect human societies by changing the availability of resources" (Tainter, 2000). How societies adapt to climate change is fundamentally dependant on how they approach problem solving (Tainter, 2000). However, some of the more general social and economic projections can help to inform us about climate change effects on the region.

Population distribution, economic activity, quality of life, and many other human values are influenced by changes in natural environments. Populations in Arizona and New Mexico are growing at unprecedented rates. The combination of population growth and climate change will likely exacerbate climatic effects, putting even greater pressure on water, forest, and other resources. Additionally, pressures put upon agriculture and other climate-sensitive occupations in neighboring Mexico may increase an already large migration of people into the southwestern U.S., making disease surveillance increasingly difficult (Sprigg et al., 2000; Smith et al., 2001). While this is the current demographic trend in the Southwest, if conditions become too hot and dry, there may very well be a decrease in the number of people moving to the region.

Recent research in the Southwest shows that up to 60 percent of the climate related trends of riverflow, winter air temperature, and snowpack between 1950 and 1999 are human induced. The study predicts water shortages, lack of storage capabilities to meet seasonally changing riverflow, transfers of water from agriculture to urban uses, and other critical impacts (Barnett et al., 2008). The region's economy will likely continue to grow in the future. Increases in service-oriented sectors as well as the expanding high-tech industry may bring more jobs and employment opportunities for the growing population. Significant changes due to population pressures include the following: decreased forest cover; increased construction; additional Federal and State parks, wilderness areas, and wildlife refuges; more land utilized for national defense and industry; expanded urban areas; and decreased pasture and rangelands (Joyce and Birdsey, 2000).

Forests significantly enhance the environment in which people live, work, and play. Population levels, economic growth, and personal preferences influence the value that is placed on forests and, consequently, the resources demanded from forests. Changes caused by human use of forests could exceed impacts from climate change. According to the Forest Service (2009), the majority of recreation visitors on the Apache-Sitgreaves NFs come from the Phoenix and Tucson metropolitan areas. According to National Visitor Use Monitoring data, the Apache-Sitgreaves NFs received nearly 2 million visits during 2001, 70 percent of those visitors came from Maricopa (Phoenix) and Pima (Tucson) Counties. Many Arizonans consider access to public lands a major contributor to the quality of life. Many southwestern forests as well as the Apache-Sitgreaves NFs are experiencing very high recreational use while urban expansion is decreasing the amount of available open space. Climate change could have long-term impacts on many of the amenities, goods, and services from forests including: recreational opportunities; productivity of locally harvested plants such as berries or ferns; local economics through land use shifts from forest to other uses; forest real estate values; and tree cover and composition in urban areas and associated benefits and costs. Private agricultural, urban, and suburban areas are expanding and affecting Forest Service management. This expansion of human influences into the rural landscape alters natural ecological process patterns associated with fire, flooding, landslides, and native and introduced species. These land use changes are very likely to interact with and potentially exacerbate stresses on forests associated with climate change (Joyce and Birdsey, 2000).

Livestock Grazing

Livestock grazing is one of the management activities occurring on the Apache-Sitgreaves NFs. Ranching is a social, cultural, and agricultural activity throughout the rural Southwest. It is a major land use in both Arizona and New Mexico, and its success depends on the natural vegetation accessible to grazing animals. The Apache-Sitgreaves NFs provide forage for livestock grazing, but they also provide crucial habitat for wildlife. Lands grazed on the Apache-Sitgreaves NFs are not irrigated and any variability in precipitation and temperature directly affects forage plant production and wildlife habitat. Changes in climate may affect the vigor and productivity of forage plants and, thus, the overall conditions of both wildlife habitat and ecological conditions. It is possible that higher temperatures and decreased precipitation described for the next century will also decrease forage production and shorten the growing and grazing season; while flash floods and increased risk of animal disease can adversely affect the livestock industry (Joyce et al., 2001) dependent upon the Apache-Sitgreaves NFs' forage resources.

Coupled with poor forage conditions, there may be a general scarcity of water for livestock. For a pasture to be available for grazing, it not only has to have sufficient nutritious vegetation but adequate water availability as well. Some allotments/pastures rely on wells and developed springs, but many often utilize dirt tanks to capture snowmelt and monsoon rainfall and use this water for livestock. During recent droughts, many dirt tanks on the Apache-Sitgreaves NFs dried up, making many pastures unusable for cattle even though forage may have been available. Ranching is in a vulnerable position, especially when viewed against a backdrop of changing climate, economic structure, urban expansion, increasing population, fluctuating market conditions, resource availability (Sprigg et al., 2000), and changing public policies.

Recreational Value

Climate change affects national forest ecosystems and the relationships people have with those places. Population distribution, economic activity, quality of life, and many other human values are influenced by changes in natural environments. The Apache-Sitgreaves NFs provide many recreational opportunities including hiking, camping, hunting, bird watching, skiing, autumn leaf tours, and water-related activities such as fishing and boating. These activities provide income and employment in every forested region of the U.S. Outdoor recreation opportunities are likely to change, with resulting changes in public expectations and seasonality of use. Higher temperatures are very likely to result in a longer season for summer activities such as backpacking, but a shorter season for winter activities such as dog-sledding, cross-country skiing, and snowshoeing. Areas at low elevations and in more southern parts of the region are very likely to be at particular risk from a shortening of the snow season and rising snowlines (Joyce et al., 2001; Svoma 2009). In areas of marginal annual snowpack, the inability to maintain cross-country skiing may result in the closure of some ski areas.

Urban and suburban expansion into undeveloped lands is likely to shift in response to climate change. Population shifts may cause new resource related human conflicts, and create unforeseen impacts on already stressed urbanized ecosystems. As temperatures increase in lowland, urban areas, recreation is expected to increase on the Apache-Sitgreaves NFs (Forest Service, 2009), where cooler temperatures will attract people to higher elevations, with the forests becoming more of a refuge from increasingly hot summers (Irland et al., 2001).

Wood Products

Changes in climate and the consequent impacts on forests will very likely change market incentives for investment in biomass technology and in wood conservation techniques. The market for wood products in the U.S. is highly dependent on the area and species composition of forests, supplies of wood, technological change in production and use, availability of wood substitutes, demand for wood products, and international competition. Rising atmospheric CO_2 will increase forest productivity and carbon storage in forests if sufficient water and nutrients are available. Any increased carbon storage will be primarily in live trees. However, in the Southwest and Apache-Sitgreaves NFs, as discussed above, overall production may be limited by a decrease in available water. While increases in wildfire may decrease some available wood supply, treatment of wildland-urban interface and restoration of the fire-adapted ecosystems in southwestern and Apache-Sitgreaves NFs may actually increase the overall availability of small diameter timber and related wood products (Joyce et al., 2001).

Multiple socioeconomic impacts often follow drought and severe insect outbreaks. Timber production, manufacturing, and markets may not be able to take advantage of vast numbers of killed trees, and beetle-killed timber has several disadvantages from a manufacturing perspective. In addition, when insect outbreaks occur, the public often perceives this as an increased fire risk and as detrimental to the aesthetics of montane areas (Ryan et al., 2008). These factors could drive future public policy. Furthermore, wood supplies will no doubt vary by forest and woodland type (Sprigg et al., 2000; Joyce et al., 2001).

Health

Future climate scenarios will undoubtedly amplify current climatically driven human health concerns, with potential increased risk of dengue fever[9], encephalitis, and other diseases associated with warmer climes, and the northern movement of disease vectors, such as malaria-carrying mosquitoes. Diseases such as valley fever and Hantavirus pulmonary syndrome are endemic in the Southwest. The incidence of Hantavirus has been linked to seasonal and interannual patterns of rainfall (Eisen et al., 2007). Research strongly suggests that valley fever is connected to the sequence and pattern of precipitation and wind. Future climate scenarios will undoubtedly amplify current climatically driven human health concerns. Projected temperature increases are anticipated to create greater numbers of heat-induced illnesses, reduced air quality, and increased cases of respiratory illness due to the presence and persistence of dust and allergens. Conversely, in many temperate areas—which include the Southwest—there is clear seasonal variation in mortality; death rates during the winter season are 10 to 25 percent higher

[9] Dengue fever is a virus-based disease spread by mosquitoes.

than in the summer. Several studies cited by the IPCC indicate that decreases in winter mortality may be greater than increases in summer mortality under climate change (McMichael et al., 2001). The geographical range of disease-bearing vectors such as the mosquito would expand under the model scenarios for the 21st century (Liverman and Merideth, 2002). Pressures put upon agriculture and other climate-sensitive occupations in neighboring Mexico may increase an already large migration of people into the southwestern U.S., making disease surveillance increasingly difficult (Sprigg et al., 2000). This is of interest to the Apache-Sitgreaves NFs and surrounding communities because the majority of forest users are from Maricopa and Pima Counties. Increased visitor use could be the vector necessary to spread any number of these health issues.

Energy

Higher air temperatures may increase the overall demand for energy within the region's urban areas, and this increasing energy demand could affect the Southwest's current socioeconomic environment (Sprigg et al., 2000; Smith et al., 2001). Electricity supports human activity and offers the possibility of economic growth. For much of the region, water delivery systems rely on electricity for pumping groundwater and for directing water throughout the system. Urban and agricultural uses of energy driven water resources are essential in the region's current socioeconomic environment. During the warmest summer months, energy demands increase with the use of energy intensive air-cooling systems. Given population projections for the region, a greater number of electricity generating plants will be needed to handle the demands that follow. Climate warming contributes to increased energy demands and evaporative loss from reservoirs. All reasonable scenarios of future climate variability must be considered when anticipating the costly measures necessary to provide dependable, safe, and reasonable supplies of energy (Sprigg et al., 2000). Increasing energy demand and the ensuing demand for alternative energy will likely impact the Apache-Sitgreaves NFs through growing need for new energy corridors, requests for wind and solar energy sites, and other special use related requirements, as well as the current and ongoing demand for biomass supplies to existing electrical cogeneration plants.

Key Climate Change Factors for the Apache-Sitgreaves NFs

Based on current projections, the primary regional-level effects of climate change most likely to occur in the Southwest include: (1) warmer temperatures, (2) decreasing precipitation, (3) decreased water availability with increased demand, (4) increased extreme disturbance events (natural and human caused), and (5) increased use of the national forests for relief from increased temperatures.

Based on current climate model projections and research, the climate change factors that appear most likely to affect the Southwestern Region and Apache-Sitgreaves NFs and affect desired conditions in the revised land management plan are ecological, weather-related disturbances, and socioeconomic demands, as described:

- Projected increase in frequency of extreme weather events (intense storms);
- Projected increase in wildfire risks;
- Projected increase in outbreaks of insects, diseases beyond endemic levels, and nonnative invasive species;

- Projected increase in demand for decreasing upland water supplies; and
- Projected increase in national forest socioeconomic uses and demands.

These natural ecological processes and human-caused disturbance factors and the potential impacts on desired conditions for the national forests in the Southwestern Region and the Apache-Sitgreaves NFs are described below.

Increased Extreme Weather Events

Climate change likely will increase flash floods, making the region's growing population more susceptible to loss of life and property. While the Southwest and Apache-Sitgreaves NFs is expected to become warmer and drier, it is likely to experience more flooding. This relates in part to the fact that warm air holds more moisture than cooler air. The frequency of floods is also influenced by the rate of snowmelt in the winter and spring, the character of the summer monsoon, and the incidence of tropical hurricanes and storms in the autumn.

Hurricanes and other tropical cyclones are projected to become more intense in the future. Since Arizona and New Mexico typically receive 10 percent or more of their annual precipitation from tropical storms, it is likely that this change will also increase flooding. In Arizona and New Mexico, floods killed 57 people between 1995 and 2006; while hundreds of others have needed swift water rescues. The economic price tag is also high, costing Arizona, New Mexico, Colorado, and Utah approximately 5 billion dollars between 1972 and 2006. A potential increase in extreme storms, floods, heat waves, and droughts may present challenges for achieving desired conditions.

Impacts from extreme weather events could include changes in the composition and diversity of desired ecosystems; destruction of habitat; timber loss; increasing damage to the forests' infrastructure such as trails, facilities, and roads; and loss of recreation opportunities. Natural ecological process events that exceed the historic range of natural variation can change the makeup, structure, and function of vegetation types and watersheds, and could affect a number of desired conditions. Heavy rains and higher flood levels can affect maintenance and structural integrity of forest infrastructure and slow progress toward improvements. Flooding is a natural and beneficial process in many aquatic systems. However, damage to aquatic systems from flash flood-caused erosion, downed trees, and inundation from flooding can change streamside habitats, affect aquatic life, and impact proper function of stream channels. These processes could create challenges in the ability of a national forest to achieving plan objectives for aquatic habitat restoration. Overall, increasing weather-related disturbances can divert limited Apache-Sitgreaves NFs staff and funding to recovery efforts for extended periods and delay progress toward desired conditions, or it may require reevaluation of desired conditions, to allow for a more dynamic resilience.

Wildfire

Wildfire is another climate-related impact to ecosystems in the Southwest. Historically, wildfires have played an important role in the vitality of fire-adapted ecosystems. Past management and fire suppression practices have changed the dynamics of fire on the landscape within the Apache-Sitgreaves NFs, resulting in greater fuel loads and risk of wildfire. Fire suppression activities in the West, including those conducted by Federal land management agencies, routinely exceed expenditures of 1 billion dollars per year. Since about the mid-1970s, the total acreage area burned and the severity of wildfires in pine and mixed-conifer forests have increased on the Apache-Sitgreaves NFs.

Fire frequency and severity will likely increase as temperatures rise and precipitation decreases. Population growth in the Southwest may also lead to greater numbers of human started wildfires. The 2002 Rodeo and Chediski Fires on the Fort Apache Indian Reservation and Apache-Sitgreaves NFs were both started by humans and combined to burn nearly half a million acres (Joyce et al., 2008).

Outbreaks of Insects, Diseases, and Nonnative Invasive Species

Disturbances associated with climate change can have secondary impacts indirectly caused by wildfire and climate-related extremes. Increased variation in temperature and moisture can cause stress and increase the susceptibility of forest ecosystems to invasions by insects, diseases, and nonnative species. New environmental conditions can lead to a different mix of species and tend to be favorable to plants and animals that can adapt their biological functions or are aggressive in colonizing new territories (Whitlock, 2008). However, changes in adaptability may be too slow given the predicted rate of change. Species that are already broadly adapted may become more prevalent and species with narrow adaptability may become less prevalent. Disturbance factors that create more vulnerability in native ecosystems or require extensive controls to maintain the status quo are likely to affect desired conditions for healthy and diverse forests.

According to Lynch et al. (2010), insect and pathogen populations have responded to changing forest character on the Apache-Sitgreaves NFs (especially to changing structure and species composition) and variability in climate. They reported that contemporary outbreaks differ from pre-1950s regimes in that Ips bark beetle species became more significant than Dendroctonus species in ponderosa pine compared to the beginning of the 20th century when the reverse was once the case. Damage to white fir has increased; dwarf mistletoe incidence and infection severity have increased in ponderosa pine, Douglas-fir, and spruce; and the cumulative effects of several biotic and abiotic agents, which individually are seldom fatal, is causing significant, widespread mortality and decline in aspen. They go on to state that damage in the piñon-juniper and spruce-fir PNVTs is unprecedented in the historic record, in terms of both the severity of damage and in the identity and variety of insects causing damage in the spruce-fir forest. Lynch et al. (2010) also found that coniferous species are replacing aspen in extensive areas and aspen die-off and decline caused by a suite of biotic and abiotic factors has intensified the loss of this species. Extensive areas of damaged piñon-juniper are becoming juniper woodlands or grasslands. The potential for catastrophic insect outbreaks and pathogen-related mortality continues, especially during drought periods. There is also an enduring threat of new exotic insects and pathogens establishing. Contemporary trends have enough differences from historic trends to anticipate altered ecosystem processes in the future.

Desired conditions for healthy vegetation communities on the Apache-Sitgreaves NFs include resilience to dramatic changes caused by abiotic and biotic stressors and mortality agents (e.g., pine beetles), and a balanced supply of essential resources (e.g., light, moisture, nutrients, growing space). Insects and diseases typically invade in cycles followed by periods of relative inactivity. Nonnative invasive species, such as cheatgrass and salt cedar, are expected to continue to increase in numbers and extent. Vulnerabilities to forest threats from an environment that may be much different from the historic range of natural variability is an active area of research, and includes developing new management approaches for changing conditions.

Diminishing Water Resources

As stated previously, locations of most snowpack and upland reservoirs are on national forests in the Southwest and on the Apache-Sitgreaves NFs specifically. In many western mountain ranges, less precipitation is falling as snow and spring melting is occurring earlier in the year. The Colorado, Rio Grande, and several other southwestern rivers have streamflows that appear to be peaking earlier in the year, suggesting that spring temperatures in these regions are warmer than in the past, causing snow to melt earlier. Water supplies are projected to become increasingly scarce, calling for tradeoffs among competing uses, potentially leading to conflict. Without upland reservoirs and watersheds, many managed by the Forest Service, elaborate water delivery systems and other infrastructure support, agriculture, urbanization, and other development could be severely constrained. In the Southwest, intense debate will likely continue over resource allocation and conservation of available supplies.

Climate Related Socioeconomic Demand

Populations in Arizona and New Mexico are growing at an unprecedented rate. As of the latest American Communities Survey (2009), Arizona’s population was 6,595,778. The total increase for Arizona between 1980 and 2009 has been over 123 percent. New Mexico’s current population of 2,009,671 represents a percent change of over 47 percent between 1980 and 2009. Currently, over 5 million people live within a 5-hour drive of the Apache-Sitgreaves NFs. The combination of population growth and climate change will likely exacerbate climatic effects, such as increasing visitor use which will put even greater pressure or demand on water, recreational opportunities, and other resources on the Apache-Sitgreaves NFs. Climate change could have long-term impacts on many of the amenities, goods, and services from the Apache-Sitgreaves NFs. These include productivity of locally harvested plants such as berries or mushrooms, wildlife, local economics through land use shifts from forest to other uses, forest real estate values, and tree cover and composition in urban areas and associated benefits and costs. Climate, combined with increasing regional population, also will likely increase demand for water-related recreation opportunities on the Apache-Sitgreaves NFs, as residents of urban areas seek relief from rising temperatures. The number of human-caused fire and wildlife-human conflicts will likely increase as well.

Potential Climate Change Strategies for the Apache-Sitgreaves NFs

The five potential management strategies described below relate to the five projected, key climate change factors that are most likely to be a potential concern for the Southwestern Region and the Apache-Sitgreaves NFs in moving toward the desired conditions in the revised land management plan. These are extreme weather events; wildfire and human-caused risks; insects, diseases, and invasive species; water use and demand; and increase in socioeconomic demands. These management strategies focus on ways to incorporate changes from disturbances into managed forests and enhance ecosystem resilience.

In developing strategies for managing future changes, the range of possible approaches could be quite broad, but the management strategies listed below are focused on recommendations from recent research studies, including the U.S. Climate Change Science Program, SAP 4.4 (CCSP, 2008b), which are appropriate for the Southwestern Region and the Apache-Sitgreaves NFs and balance effectiveness, feasibility, and available resources. Although some strategies contain new ideas, most of these management options include practices that are already in effect, can serve multiple needs, and may just need to be adjusted or expanded to respond to climate changes during the next 5 to 15 years. Using an adaptive management approach will allow national forest managers to adopt and adjust strategies as new information is available, conditions change, and staff and resources are available.

The key climate change factors are addressed directly or indirectly through the Apache-Sitgreaves NFs desired conditions, objectives, and management strategies:

1. Enhance adaptation by anticipating and planning for disturbances from intense storms;
2. Reduce vulnerability by maintaining and restoring resilient native ecosystems;
3. Increase water conservation and plan for reductions in upland water supplies;
4. Anticipate increase in forest recreation use, utilize markets and demand for small-diameter wood and biomass for restoration, renewable energy, and carbon sequestration; and
5. Monitor climate change influences.

Enhance Adaptation by Anticipating and Planning for Disturbances from Intense Storms

Although occurrences of storms and other disturbances cannot be precisely predicted and are often beneficial types of disturbance, anticipatory planning may predict impacts and have adaptive guidelines in place to protect sensitive areas. Areas such as riparian zones, endangered species habitats, and special areas may require different approaches for reducing disturbances or recovering from damaging events. Management responses from previous events can provide guidance for similar situations and take advantage of prior learning experiences. Planning prior to disruptions can take advantage of disturbances when they eventually occur to convert vegetation to more resilient and desirable ecosystems and reduce assessment and response time while ensuring that sensitive resources requiring special responses are protected.

With the projected increase in extreme weather events, management practices for reducing soil erosion may be even more critical in the future. For example, standard soil erosion best management practices such as buffers filter strips, broad-based dips, and piling slash downslope of skid trails and along streams, can help mitigate increased erosion conditions. Roads and trails close to streams may be closed, removed, revegetated, or relocated away from stream channels to reduce impacts to aquatic ecosystems and water quality. In another example, appropriately sized culverts at stream crossings should consider projections for future runoff in a changing climate as well as reference conditions. New recreation sites, such as campgrounds, cross-country ski areas, and other facilities should be located well away from potential flash flood areas.

Reduce Vulnerability by Maintaining and Restoring Resilient Native Ecosystems

Managing ecosystems under uncertainty necessitates flexible and adaptive approaches that are reversible, implemented in incremental steps, allow for new information and learning, and can be modified with changing circumstances (Millar et al., 2007). Apache-Sitgreaves NFs ecosystems have evolved under a long and complex history of climate variability and change. Taking into consideration the number of mega-droughts and other climate-related variation through time, these plant and animal communities have a built-in resilience. Restoring and maintaining resilience in forest, woodland, chaparral, grassland, and riparian ecosystems are part of the basic elements of forestwide desired conditions, objectives, and management approaches. Risks of increased wildfire, outbreaks of insects and disease, invasive species, and loss of habitat represent ongoing, broad-scale challenges to management of the Apache-Sitgreaves NFs. These issues are nothing new. However, climate change has the potential to increase or augment the impacts of these ecosystem risks.

Restoring and maintaining resilience will likely improve the potential for ecosystems to retain or return to desired conditions after being influenced by climate change related impacts and variability. Managing for resistance (e.g., maintenance thinning to prevent uncharacteristic fire, forest insect or disease epidemics) or resilience (e.g., noxious weed control), both traditional sustainability themes, offer common ground and present opportunities for meaningful response to climate change. Of the themes of resistance[10] or resilience identified by Millar et al. (2007), the following may be useful for planning:

- Manage for asynchrony[11], which promotes diversity
- Promote connected landscapes
- Restore significantly disrupted animal and plant communities

Prescribed fire (i.e., planned ignition) is a current management tool that can serve multiple purposes, from sustaining desired conditions for fire-adapted ecosystems and sustaining habitat for threatened and endangered species to reducing fuel loads. It is also a management strategy that will be important for maintaining desired habitats in a changing climate with more natural disturbances. With projections for more frequent storms and other extreme weather events, plus the potential for increased stresses from forest pests in a warmer, drier climate, planned and unplanned ignition burning will continue to be an important management strategy for the future.

Although current programs and guidance are already in place to limit the introduction of nonnative species, treat invasive species, and manage insects and diseases, these efforts are likely to become more critical to maintaining desired conditions for healthy plant and animal communities under a changing climate. Due to the relationship of land ownership patterns, success in reducing forest pests requires going beyond Apache-Sitgreaves NFs' boundaries by continuing to collaborate with partners. In addition, management practices (e.g., thinning for age class diversity and structure, reclaiming and restoring native grasslands) that sustain healthy plant and animal communities and provide adequate nutrients, soil productivity, and hydrologic function promote resilience and reduce opportunities for disturbance and damage.

For Wildlife and Plant Species Dependent on Forest Ecosystems

Fragmentation

Apache-Sitgreaves NFs' desired conditions, objectives, and management approaches address preservation, establishment, and restoration of large, unfragmented areas of wildlife habitat.

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[10] Resistance is the capacity of an organism or a system to withstand the disruptive effects of an environmental agent.

[11] Asynchrony, in the general meaning, is the state of not being synchronized. In this usage, asynchrony refers to the promotion of diversity by managing for a range of conditions, occurring at different times, within a given ecosystem.

Large, interconnected blocks of habitat support a wide array of species and allow for genetic and behavioral interactions that are lacking with the creation of small patches (Robinson et al., 1995).

Promote Connectivity

Landscape connectivity is the degree to which the landscape facilitates or impedes movement of a species among habitats required for its persistence with few physical or biotic impediments to migration (Taylor et al., 1993; Millar et al., 2007). Connectivity has two components: structural and biological connectivity. Structural connectivity, the spatial structure of a landscape, can be described from map elements. Biological connectivity is the response of individuals to the scale of landscape features (Brooks, 2003). Promoting connectivity in landscapes with flexible management goals that can be modified as conditions change may assist species to respond naturally to changing climates. Desired goals include reducing fragmentation and planning at large landscape scales to maximize habitat connectivity (Millar et al., 2007). Apache-Sitgreaves NFs' desired conditions, objectives, and management approaches address the importance and need for connectivity for both terrestrial and aquatic habitats.

Riparian Areas

Apache-Sitgreaves NFs' desired conditions, objectives, and management approaches address riparian areas, respective uplands, and watersheds by emphasizing protection from degradation, enhancement where possible, and maintenance of proper hydrologic functions. The forests also recognize that riparian areas provide important habitat connectivity for terrestrial and aquatic species.

Maintain Biodiversity

By implementing the Apache-Sitgreaves NFs' desired conditions, objectives and management approaches, and the above recommendations, biodiversity will be maintained as much as possible as climate change occurs.

Increase Water Conservation and Plan for Reductions in Upland Water Supplies

As mentioned earlier, a major portion of Arizona's snowpack and the headwaters of several river systems are located on the Apache-Sitgreaves NFs. Aquatic and riparian ecosystems may be negatively impacted by increasing temperatures and reduced precipitation. Too much water arriving at once, in the form of severe storm events, also has the capacity to affect these water dependent ecosystems. Water amount, availability, distribution, and allocation, for a variety of ecological, wildlife, and aquatic species, as well as for human uses, needs to be considered in planning.

Municipal water supplies of Arizona are dependent on these upland sources. In many western mountain ranges, the Apache-Sitgreaves NFs included, less precipitation is falling as snow, and spring melting is occurring earlier in the year. These water sources and associated water rights have always been important and contentious areas of concern for public land managers in the Southwest and Apache-Sitgreaves NFs. With climate change, planning for water quantity and quality may become even more important. To address such concerns, planners may wish to consider some of the following measures:

- Determine the water rights status of water resources for range, wildlife, public drinking systems, firefighting, recreational uses, and aquatic habitats;
- Assess and maintain infrastructure that could be affected by flooding (e.g., dams, bridges, roads, culverts);
- Review current status of State and regional water plans, forest and watershed health plan, integrated regional water planning efforts; and
- Plan for extreme events (e.g., flooding and/or drought).

Anticipate Increased Forest Recreation Use, Markets and Demand for Wood and Biomass, Renewable Energy, and Carbon Sequestration

The use of Apache-Sitgreaves NFs as havens from summer heat and for water-related recreation continues to grow with population increases throughout the region. Planning for recreation should take into account the possible expansion of demand as temperatures increase and precipitation decreases because of climate change. This may affect recreation facilities—like campgrounds and boating facilities—as well as access to lakes, rivers, and other water features. Analysis of both potential snowfall and future winter temperature changes may need to be conducted for consideration of additions to, or new construction, of cross-country skiing and other snow-based recreation activities.

Salvaging and converting biomass into boards, firewood, and other wood products (as a byproduct of forest restoration) can help reduce carbon loss from fire. Another consideration may be to use biomass that cannot be converted to wood products (such as from clearing roads and trails) for the continuation of bioenergy production. Bioenergy production can be carbon neutral and could replace the use of fossil fuels in generators; mobile generation facilities could also provide power to schools, hospitals, command centers, and other immediate needs.

Monitor Climate Change Influences

It is not recommended that the Apache-Sitgreaves NFs create a completely new initiative or program of work solely for monitoring climate change. However, consideration of appropriate adjustments to the monitoring program to improve understanding of the relationships of key plan components and climate change may be needed. As the Apache-Sitgreaves NFs review their existing and potential research natural areas (RNAs), monitoring of climate change effects on specific ecosystems should be part of the research goals considered when building the RNA establishment record.

Climate Change Glossary

The following terms have been gathered by Forest Service researchers from numerous sources including the National Oceanic and Atmospheric Administration (NOAA), Intergovernmental Panel on Climate Change (IPCC), and others. Included are the most commonly referred to terms in climate change literature and news media. This is only a partial list of terms associated with climate change. See other NOAA or IPCC documents for full glossaries associated with this topic.

Anthropogenic: Resulting from or produced by human beings.

Anthropogenic emissions: Emissions of greenhouse gases, greenhouse gas precursors, and aerosols associated with human activities. These include burning of fossil fuels for energy, deforestation, and land use changes that result in net increase in emissions.

Arid regions: Ecosystems with less than 250 millimeters precipitation per year.

Atmosphere: The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1 percent volume mixing ratio) and oxygen (20.9 percent volume mixing ratio), together with a number of trace gases, such as argon (0.93 percent volume mixing ratio), helium, and radiatively active greenhouse gases such as carbon dioxide (0.035 percent volume mixing ratio) and ozone. In addition, the atmosphere contains water vapor, whose amount is highly variable but typically 1 percent volume mixing ratio. The atmosphere also contains clouds and aerosols.

Biodiversity: The numbers and relative abundances of different genes (genetic diversity), species, and ecosystems (communities) in a particular area.

Carbon dioxide (CO_2): A naturally occurring gas, and also a byproduct of burning fossil fuels and biomass, as well as land use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and, therefore, has a Global Warming Potential of 1.

Carbon dioxide (CO_2) fertilization: The enhancement of the growth of plants as a result of increased atmospheric carbon dioxide concentration. Depending on their mechanism of photosynthesis, certain types of plants are more sensitive to changes in the atmospheric carbon dioxide concentration.

Climate: Climate may be defined as the "average weather," or more rigorously, as the statistical description of weather in terms of the mean and variability of relevant quantities (e.g., temperature, precipitation, wind) over a period ranging from months to thousands or millions of years. The standard period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the statistical description of the state or condition of the climate system.

Climate change: Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines "climate change" as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between "climate change" attributable to human activities altering the atmospheric composition, and "climate variability" attributable to natural causes. See also climate variability.

Climate feedback: An interaction mechanism between processes in the climate system is called a climate feedback, when the result of an initial process triggers changes in a second process that in turn influences the initial one. A positive feedback intensifies the original process, and a negative feedback reduces it.

Climate model (hierarchy): A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. The climate system can be represented by models of varying complexity—that is, for any one component or combination of components a "hierarchy" of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical, or biological processes are explicitly represented, or the level at which empirical parametrizations are involved. Coupled atmosphere/ocean/sea-ice general circulation models (AOGCMs) provide a comprehensive representation of the climate system. There is an evolution toward more complex models with active chemistry and biology. Climate models are applied, as a research tool, to study and simulate the climate, but they are also for operational purposes including monthly, seasonal, and interannual climate predictions.

Drought: There is no definitive definition of drought based on measurable processes. Instead, scientists evaluate precipitation, temperature, and soil moisture data for the present and recent past to determine drought status. Very generally, it refers to a period of time when precipitation levels are low, impacting agriculture, water supply, and wildfire hazard.

El Niño: In its original sense, El Niño is warm water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. This oceanic event is associated with a fluctuation of the intertropical surface pressure pattern and circulation in the Indian and Pacific Oceans, called the Southern Oscillation. This coupled atmosphere-ocean phenomenon is collectively known as El Niño Southern Oscillation or ENSO. During an El Niño event, the prevailing trade winds weaken and the equatorial countercurrent strengthens, causing warm surface waters in the Indonesian area to flow eastward to overlie the cold waters of the Peru Current. This event has great impact on the wind, sea surface temperature, and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world. The opposite of an El Niño event is called La Niña.

Extreme weather event: An extreme weather event is an event that is rare within its statistical reference distribution at a particular place. Definitions of "rare" vary, but an extreme weather event would normally be as rare as or rarer than the 10^{th} or 90^{th} percentile. By definition, the characteristics of what is called extreme weather may vary from place to place. An extreme climate event is an average of a number of weather events over a certain period of time, an average, which is itself extreme (e.g., rainfall over a season).

Greenhouse effect: Greenhouse gases effectively absorb infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus, greenhouse gases trap heat within the surface-troposphere system. This is called the "natural greenhouse effect." Atmospheric radiation is strongly coupled to the temperature of the level at which it is emitted. In the troposphere, the temperature generally decreases with height. Effectively, infrared radiation emitted to space originates from an altitude with a temperature of, on average, -19 °C, in balance with the net incoming solar radiation, whereas the Earth's surface is kept at a much higher temperature of, on average, +14 °C. An increase in the concentration of greenhouse gases leads to an increased infrared opacity of the atmosphere and, therefore, to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing, an imbalance that can only be compensated for by an increase of the temperature of the surface-troposphere system. This is the “enhanced greenhouse effect.”

Greenhouse gas (GHG): Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth’s surface, the atmosphere, and clouds. This property causes the greenhouse effect. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth’s atmosphere. Moreover, there are a number of entirely human made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine-containing substances, dealt with under the Montreal Protocol. Besides CO_2, N_2O, and CH_4, the Kyoto Protocol deals with the greenhouse gases sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

Radiative forcing: Changes in the energy balance of the Earth atmosphere system in response to a change in factors such as greenhouse gases, land use change, or solar radiation. The climate system inherently attempts to balance incoming (e.g., light) and outgoing (e.g., heat) radiation. Positive radiative forcings increase the temperature of the lower atmosphere, which in turn increases temperatures at the Earth’s surface. Negative radiative forcings cool the lower atmosphere. Radiative forcing is most commonly measured in units of watts per square meter (W/m^2).

Rangeland: Undeveloped land that is suitable for use by wildlife and domestic ungulates.

Rapid climate change: The nonlinearity of the climate system may lead to rapid climate change, sometimes called abrupt events or even surprises. Some such abrupt events may be imaginable, such as a dramatic reorganization of the thermohaline circulation, rapid deglaciation, or massive melting of permafrost leading to fast changes in the carbon cycle. Others may be truly unexpected, as a consequence of a strong, rapidly changing, forcing of a nonlinear system.

Regeneration: The renewal of a stand of trees through either natural means (seeded onsite or adjacent stands or deposited by wind, birds, or animals) or artificial means (by planting seedlings or direct seeding).

Teleconnections: Atmospheric interactions between widely separated regions that have been identified through statistical correlations (in space and time). For example, the El Niño teleconnection with the southwestern U.S. involves large-scale changes in climatic conditions that are linked to increased winter rainfall.

Weather: Describes the daily conditions (individual storms) or conditions over several days (week of record-breaking temperatures) to those lasting less than 2 weeks.

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