United States
Department of
Agriculture

Forest
Service

**Southwestern
Region**

May 2010

Southwestern Region Climate Change Trends and Forest Planning

A Guide for Addressing Climate Change in Forest Plan Revisions for Southwestern National Forests and National Grasslands

Southwestern Region Climate Change Trends and Forest Planning

Prepared for:

USDA Forest Service
Southwestern Region
333 Broadway SE
Albuquerque, New Mexico 87102

Submitted by:

Southwestern Region Climate Change and Forest Planning Work Group

Name	Unit	Resource Specialty	Comment
Richard Periman	RO – Planning	Regional Social Science	Team Leader
Christine Dawe	RO – Planning	Regional Planning Specialist	
Bryce Rickel	RO – Wildlife	Biology	
Amy Unthank	RO – Wildlife	Biology	
Champe Green	Cibola NF	Planner	
Roy Jemison	RO – Watershed	Hydrology	
Kurt Nelson	Carson NF	Planner	
Brian Kent	RMRS	Decision Sci/ Human Uses	RMRS Rep

Other Contributors

Jack Triepke	RO – Planning	Regional Ecologist / Air Prog. Mgr.
Ernest W. Taylor	RO – Wildlife	Biology / Budget Coordinator
Yolynda Begay	RO – Planning	Social Science

Contents

Introduction

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.

Former Forest Service Chief Abigail R. Kimball has characterized the agency's response to the challenges presented by climate change as "one of the most urgent tasks facing the Forest Service." In October of 2008, the Forest Service released the Strategic Framework for Responding to Climate Change[1], which outlines seven key goals for sustaining forest and grassland resources under a changing climate. Policy outlined in this framework requires that climate change be incorporated as appropriate, into Forest Service policies, program guidance, and communications, including Land Management Plans (LMPs). One outcome of this direction, was that in January of 2009, the Washington Office, Ecosystem Management Coordination (EMC) Staff issued national direction for addressing climate change in plan revision in the paper *Climate Change Considerations in Land Management Plan Revisions*.

Further direction specific to Forest Plan Revision in the Southwestern Region is needed to clarify this national direction. Section One of this document provides guidance on how to incorporate climate change into land management plans given the uncertain nature of this issue. Section Two contains a review of climate change literature, specifically focused on the needs of Forest Plan Revision in the Southwest Region. Section Three outlines potential climate change strategies for Southwestern Region National Forests. This summary is based on the most current science and knowledge of potential climate change impacts in the Southwestern United States, and will be the basis of our approach in meeting the requirement to incorporate climate change into land management planning.

Individual forests and grasslands should draw upon the regional climate change literature review (Section Two of this document), which discusses current scientific information and any available local climate change information. This review 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. Next, the review provides a short, forest plan revision-oriented, synthesis of climate change literature. This review focuses on how climate change might be currently influencing, and in the future may impact ecological and socioeconomic systems.

[1] See http://www.fs.fed.us/climatechange/documents/strategic-framework-climate-change-1-0.pdf

Section One: Guidance on Climate Change and Land Management Plans

This section outlines both how to use the literature review in Section Two and the appropriate places in plans to consider climate change information given the current state of knowledge. This section includes guidance on how to address climate change in land management planning documents in the following areas:

Current conditions and trends
Desired conditions or goals
Monitoring, and
Decision documentation.

Current Conditions and Trends

One of the first steps in the plan revision process is a planning unit evaluation of the current conditions and trends followed by identification of need for change in the plan. This includes discussion of current and projected climate conditions and trends. Individual forests and grasslands should draw upon syntheses and assessments of scientific information from other Regions and FS Research Stations and other organizations and agencies relevant to climate change for land management planning. Climate Assessments are likely to be at scales broader than the forest planning unit.

The primary consideration for evaluating climate change is how it is likely to modify social, economic, and ecological conditions on the planning unit.

Current conditions and trends should discuss risks, vulnerabilities, and potential ecological changes that could result from climate change. Focus on potential climate change impacts that are most likely to affect ecological systems, goods, and services. Evaluation of climate change impacts may lead to recognition that some current conditions may be difficult to maintain in the future.

Identify ecosystems that are most at risk due to climate change. One example may be aquatic ecosystems potentially impacted by changes in water availability and seasonal timing, changes in temperature. Identify vulnerable ecosystem components as appropriate, such as cold-water fisheries aquatic biota, grassland plant diversity, or alpine characteristics.

Goals and Desired Conditions

Information from the evaluation of current conditions and trends should be used to develop social, economic, and ecological goals and desired conditions that reflect potential impacts while considering climate change. Focus on describing components that provide system resiliency[2] to these potential impacts.

Integrate climate change as appropriate, rather than developing stand-alone desired conditions for climate change. An example is, "The composition, structure, and function of vegetative conditions (PNVT) are resilient to the frequency, extent, and severity of disturbances and components that may provide resiliency to climate variability are maintained." Consider the influence of climate change related to threatened, endangered and other relevant species.
Based on climate projections, the following should also be considered when developing goals and desired conditions for the planning unit.

- Forest productivity
- Threatened, and endangered, and sensitive species
- Forest insects and disease
- Wildfire risks
- Shifts in major vegetation types for the Southwest
- Weather-related stresses on human communities (temperature, air quality)
- Increased extreme weather related forest disturbances (floods, drought, wind-throw)
- Water stresses (ground water, run-off, and timing), aquatic biota
- Outdoor recreation (swimming, boating, skiing)
- Impacts of green energy technology and development on NFS lands as a consequence of mitigating fossil fuel combustion emissions, and increased energy demands due to climate change (transmission lines, wind energy turbines, solar collectors).

Monitoring

It is not recommended that planning units create a completely new initiative or program of work solely for monitoring climate change. However, consider appropriate adjustments to the monitoring program that will improve understanding of the relationships between key plan components and climate change. For example, while collecting information on aquatic conditions pertinent to aquatic species, information about water temperatures and water flows associated with climate change may provide relevant information to understanding the condition and trends of these species and their habitats.
The plan monitoring program should address the three basic climate change conditions influencing ecosystems, goods, and services: 1) water, 2) air temperature, and 3) timing of water delivery. Monitoring results may be useful for describing variability within ecosystem condition and trends observed over a prescribed evaluation period. In turn, this information may assist the planning unit to periodically re-evaluate effects of climate change.

[2] The concept of resilience within an ecosystem is the subject of much debate. For the purposes of this document, the term resilience is used to infer the capacity of a system to absorb disturbance and reorganize while undergoing change so as to retain essentially the same function, structure, identity, and feedbacks. From: Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig. 2004. Resilience, adaptability and transformability in social–ecological systems. Ecology and Society 9(2): http://www.ecologyandsociety.org/vol9/iss2/art5/

Decision Document Guidance

Discuss how the plan responds to pertinent aspects of climate change in the rationale section of the decision documents. Summarize the potential changes to social, economic, and ecological systems within the planning unit(s) that are most at risk from climate change. Examples of ecosystems, characteristics, and species most at risk may include: fire adapted vegetation, native aquatic species, and other endemic species. Examples of socioeconomic systems at risk of change may include: wildland-urban-interface values at risk from uncharacteristic fires, ranching operations, winter recreation, and personal use products industries. Discuss use of the Southwestern Region climate change planning literature review in Section Two of this document as a summary of the best available science, which documents specifically those broad–scale climate change patterns and trends that may impact National Forests in the Southwestern Region.

Discuss adaptive management as a response to the anticipated climate change effects that are pertinent to the unit. Consider long-term effects, but also describe steps that could be taken during the life of the plan to mitigate climate change impacts.
Consider including the following statements in the relevant section of decision document[3]:

"The current climate change effects models do not incorporate all of the potential effects or their interactions that are relevant to land management planning. Most are appropriately applied at much broader spatial scales—continental, even hemispheric—but not at the planning unit or regional scale. However, the influence of climate change was considered in developing plan components."

The decision document should clearly articulate how climate change was considered in the land management planning process, specifically relative to the current conditions and trends, development of goals, desired conditions, and in the monitoring sections of the plan record.

3. See Washington Office technical guide "Climate Change Considerations in Land Management Plan Revisions" (01/13/09).

Section Two: Southwestern Region Climate Change Trends and Forest Planning

Overview and Background

This section contains a description of the climate patterns and trends in the Southwestern United States followed by description of how current climate models and predictions may generally affect those climate patterns in the near future. Then, a short, forest plan revision-oriented, synthesis of climate change literature is provided. 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 in the future impact 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 Southwestern Forests and Grasslands are managed. Specifically, this section summarizes current and future climate trends, at the Regional and if possible the Forest level, possible effects of climate change on ecosystems, water abundance and quality, biodiversity and wildlife species, economic conditions, and social conditions in the Southwest, and a characterization of limitations and uncertainties inherent in projected future climate scenarios. Finally, this document discusses possible management issues that should be considered during forest plan revision.

A broad variety of sources was reviewed in this summary. Numerous national and regional synthesis documents, including those compiled by the U.S. Climate Change Science Program, were utilized. Review included, for example, the Synthesis and Assessment Products (SAP) 4.3-- *The Effects of Climate on Agriculture, Land Resources, Water Resources, and Biodiversity* (CCSP 2008a), and SAP 4.4-- *Preliminary Review of Adaptive Options for Climate-Sensitive Ecosystems and Resources* (CCSP 2008b). Other large syntheses reviewed included the U.S. Global Change Research Program (USGCRP) report, *Global Climate Change Impacts in the United States* 2009 (Karl et al. 2009), *Climate Change 2007: The Physical Basis* (IPCC 2007), and USGCRP report, P*reparing for a Changing Climate: The Potential Consequences of Climate Variability and Change-Southwest 2000* (Sprigg et al. 2000). In addition, a number of regional internet resources were utilized, including: Climate Assessment for the Southwest (CLIMAS), The Southwest Climate Change Network, The Western Regional Climate Center, the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT), The Nature Conservancy Climate Wizard tool, and the U.S. Forest Service Climate Change Resource Center (web pages provided in the references cited section). State and local government climate change resources were also reviewed. Finally, peer reviewed climate change literature, at more regional and localized scales were reviewed to include up-to-date climate modeling and a better understanding of possible impacts on specific resources. All of the sources used are based on peer reviewed documents, or on synthesis documents which were themselves based on an extensive peer reviewed literature.

Climate in the American Southwest

What is Climate?

Climate may be defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years. The classical 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. In contrast, weather describes the daily conditions (individual storms) or conditions over several days (a week of record-breaking temperatures), to those lasting less than two weeks[4]. Natural climate variability refers to variations due to natural internal processes in the climate system or natural external forcing, 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, the chemical composition and dynamics of the atmosphere, and the 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, land-use change, animal husbandry, and fertilized and irrigated agriculture lead to increases in greenhouse gases (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 as a result of human activities since 1750, and now far exceed pre-industrial values (IPCC 2007).

Southwest Climate Influences

While many factors influence climate in the Southwest during a particular year or season, predictable patterns hold across the years and decades to define the region's climate.

- The overall aridity relates to a global circulation pattern known as Hadley circulation, which creates a semi-permanent 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.

The climate of the southwestern United States 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, while 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 (Sheppard et al. 2002).

[4] 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).

To a large degree, a quasi-permanent subtropical high-pressure ridge over the region 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[5]. 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 outhwestern 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), which 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, has a well developed teleconnection[6] with the Southwest, usually resulting in wet winters. La Niña, the opposite oceanic case of El Niño, usually results in 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 climate of the Southwest apart from the rest of the United States is the North American Monsoon, which, in the U.S., is most noticeable in Arizona and New Mexico. Up to 50% of the annual rainfall of Arizona and New Mexico occurs as monsoonal storms from July through September (Sheppard et al. 2002).

Future Climate of the Southwest

Currently there appears to be broad agreement among climate modelers that the Southwestern U.S.is experiencing a drying tend that will continue well into the latter part of 21st century (IPCC 2007; Seager et al. 2007). While the ensemble[7] scenario used by Seager et al. 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 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 within a time frame of years to decades. According to recent multi-model ensemblescenarios, the slight warming trend observed in the last 100 years in the Southwest may continue into the next century, with the greatest warming to occur during winter. These climate models depict temperatures

[5] Hadley circulation is a circulation pattern that dominates the tropical atmosphere, with rising motion near the equator, poleward flow 10-15 kilometers above the surface, descending motion in the subtropics, and equatorward flow near the surface. This circulation is intimately related to the trade winds, tropical rainbelts, subtropical deserts and the jet streams.

[6] 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 Southwest United States involves large-scale changes in climatic conditions that are linked to increased winter rainfall.

[7] Multi-Model 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).

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). Southern areas of the Great Plains (i.e., Kiowa-Rita Blanca and Black Kettle National Grasslands) are projected to experience increased temperatures, similar to the Southwest (Karl et al. 2009).

> **Climate Change**
> Based on Multi-Model ensemble climate models, by the end of the century, the Southwest is likely to experience:
> - Temperatures increases of 5 to 8 degrees Fahrenheit.
> - An increase in the number of extremely hot days, with summer heat waves lasting two weeks or longer.
> - Warmer winters and reduced snowpack, and a later monsoonal season.
> - A 5 percent drop in precipitation in most of Arizona and New Mexico; possible 10 percent drop in southern Arizona.
> - An increase in extreme flood events following an overall increase in tropical storms.

The number of extremely hot days is also projected to rise during the first 100 years of the 21st century. By the end of the century, parts of the Southwest are projected to face summer heat waves lasting two weeks longer than those 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 1961–1985. 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).

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. Shorter winters, and less snowpack, also affect the timing of natural cycles such as plant blooming and peak river-flows. 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 F 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 complex in the Southwest, due to added complexities such as topography and monsoonal timing. When comparing climate model simulations of climate 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 drop 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 decline could be in store for the southern half of Arizona, while northeastern New Mexico is projected to remain roughly stable, based on these 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). Southern areas of the Great Plains (i.e., Kiowa, Rita Blanca, and Black Kettle National Grasslands) are projected to experience decreased precipitation, similar to the Southwest (Arizona and New Mexico) (Karl et al. 2009).
In another study, researchers using a multi-model ensemble of 19 models, projected an increase in aridity for the American Southwest. Their study defined the Southwest as the land area stretching from east to west, from Houston to San Francisco and north-south from Denver to Monterrey, Mexico. Only two 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 river flows occur when the reservoirs are at full capacity, increasing the probability of flashfloods (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 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 empower a remnant tropical storm (Guido 2008).

Discussion

The state of knowledge needed to address climate change at the National Forest scale is still evolving. Because none of the current climate models, including multi-model ensembles, adequately resolves important topographic variations (mountain ranges) and phenomena 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 National Forest scale. This limits regional and forest-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 (Lenart 2008). These model improvements also may provide researchers the information they need to downscale results to the local level of National Forest. 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 multi-model ensemble climate projections to spatial resolutions between 1 and 12km (Enquist and Gori 2008). In another effort, scientists used statistical downscaling of multi-model ensemble to consider how Colorado River streamflow might alter with climate (Christensen and Lettenmaier 2007).

Climate modeling is a developing science

- Newer multi-model ensembles are "better than the sum of their parts," and are used increasingly for projection 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, have a high potential to improve localized climate projections.
- As yet, no reliable climate models at the Forest-scale.

On a more local scale, paleoenvironmental studies of changing southwestern climate 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.

Southwestern Climate Change and 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, we set the stage of this 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 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 Colorado River flow. 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 trade-offs 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 2000 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 1999. This event is the most severe western drought of the last 110 years, and is being 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 the water resource. In the Forest Service’s Southwest Region, 13 municipal watersheds in New Mexico and 19 municipal watersheds in Arizona are located on National Forest administered lands. Additionally, the locations of most snow pack and upland reservoirs are on National Forests in the Southwest (Smith et al. 2001, State of New Mexico 2005). Some studies predict water shortages and lack of storage capabilities to meet seasonally changing river flow, 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 user of water in the Southwest, there has been a decreased 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 on-going trend and could affect future agricultural uses. Without upland reservoirs and watersheds, often managed by the Forest Service, alternative water sources, water delivery systems, and infrastructure support for agriculture would need to be developed (Lenart 2007).

Flashflooding, 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 one-year drought on record, water demand may exceed supply by 68 percent. In the five-year scenario modeled after the worst drought in the historical record, water demand in Arizona could exceed supply by 67 percent, and in the ten-year scenario, demand may exceed supply by 59 percent (Lenart 2007). In the Southwest, intense debate will likely continue over water allocation. Add to this 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 is likely to 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, as well as 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

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).

Climate and Southwestern Ecosystems

- Projected decreases in precipitation, reduced snowpack, and overall water availability.
- Increased risk from wildfire, insects and disease, invasive species.
- Potential decrease in ecosystem productivity from water limitations and increased heat.
- Potential impacts to alpine, riparian, wetland, sky Island, and aquatic habitats.

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 National Forest management strategies:

---

[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 higher surface albedo and has a warming effect (positive feedback) (IPCC 2007).

- 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).
- 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).
- Species ranges and demographics are expected to be highly unstable as the climate shifts (Millar et al. 2007:30).

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

- More extreme disturbance events, including wildfires and intense rain and flashfoods and wind events (Swetnam et al. 1999).
- Greater vulnerability to invasive species, including insects, plants, fungi, and vertebrates (Joyce et al 2007).
- 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 tree species to the more northern portions of their existing range (Clark 1998).
- Potential decreases in overall forest productivity due to reduced precipitation (USDA 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. 2007, Millar et al. 2007).
- Effects on biodiversity, pressure on wildlife populations, distribution, viability, and migration patterns, because of increasing temperatures, water shortages, and changing ecological conditions.

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. Decreasing water availability will accelerate the stresses experienced in forests, which typically involve some combination of multi-year 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, and abundance of forest species, and carbon sequestration. Many Southwestern ecosystems contain water-limited vegetation today.. Vegetation productivit in the Southwest may decrease further 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. Pinyon-juniper woodlands, a key Southwestern vegetation type, are clearly waterlimited systems, and pinyon-juniper ecotones are sensitive to feedbacks from environmental fluctuations and existing canopy structure that may provide tree a buffer against drought. However, severe multi-year droughts periodically cause dieback of pinyon pines, which may overwhelm local buffering. 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 pinyon 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 pinyon pines to re-establish. There continues to be no easy way to precisely 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 disturbances having the greatest impact on forests include: insects, diseases, introduced species, fires, droughts, inland storms caused by hurricanes, flashflooding, landslides, windstorms, and ice storms. Climate variability and changes can alter the frequency, intensity, timing, and spatial extent of these disturbances. Many potential consequences of future climate change are expected to be buffered by the resilience of forests to natural climatic variation. However, an extensive body of literature suggests that new disturbance regimes under climate change are likely to result in significant perturbations to U.S. forests, with lasting ecological and socioeconomic impacts (Joyce et al. 2001).

Wildfire

Historically, wildfires have been a recurring disturbance in conifer forests, pinyon-juniper woodlands, chaparral shrublands, and grassland ecosystems of the Southwest. An analysis of trends in wildfire and climate in the western United States from, 1974–2004, 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, with suppression costs of more than $1 billion per year from 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. If temperatures increase, precipitation decreases, and overall drought conditions become more common, fire frequency and severity may be exacerbated. 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-Chediski fires in northern Arizona 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 Disease

Insects and pathogens are significant disturbances to forest ecosystems in the United States, costing $1.5 billion 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. 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 in the late 1800s and early 1900s, 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 may favor the spread of invasive exotic grasses into arid lands where the native vegetation is too sparse to carry a fire. When these areas burn, they typically convert to non-native monocultures and the native vegetation is lost (Ryan et al. 2008). The Southwest suffers from many types of invasive species outbreaks, including plants (buffelgrass, cheatgrass, saltcedar, and red brome), animals (bullfrogs, cowbirds, quagga mussels, and crayfish). Invasive plants can alter landscapes by overtaking native species, facilitating fire outbreaks, and altering the food supply for herbivorous animals and insects. Buffelgrass was introduced to the region for cattle feed in the mid-1900s, but has since traveled from ranchlands into the desert ecosystem. Subsequently, these grasses have increased fuel loads in the Sonoran Desert, a region where native plants are not adapted to frequent fires. Buffelgrass-induced fires tend to burn faster, for longer periods, at high temperatures, and cause more plant and animal deaths than fires involving only native plants. After a fire, buffelgrass seeds sprout quickly, often within a few days, while many native desert plants, like saguaro cactus or palo verde trees, take months to years to re-establish themselves (Owen 2008).

Specific Habitats

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 are therefore important when considering the potential impacts of climate change on ecosystems managed by The National Forests in the Southwest.

Alpine

Alpine habitat is 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, alpine and subalpine habitats, and the variety of species dependent upon them, are likely to be greatly reduced in the conterminous U.S. alpine ecosystems are projected to all but disappear from the western mountains, and perhaps overtaken by encroaching forests (Joyce et al. 2001). Increasing temperatures and shifting precipitation patterns will drive declines in high-elevation ecosystems such as alpine forests and tundra because alpine and subalpine plants are isolated on high mountains (Horikawa et al. 2009, Karl et al. 2009).

Upward shifts of plants in the alpine ecotones of mountains have been increasing in North America. Some researchers have reported the upward shifts in alpine vegetation due to climate. Assessing the vulnerability of species and locations in alpine zones to climate change is an important issue for their conservation (Horikawa et al. 2009), and for the wildlife species that depend on alpine habitats. Alpine 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[9] 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 in the National Forests in the Southwestern Region; approximately 69% (461 species, 15 amphibian, 252 birds, 153 mammals, and 41 reptiles) of terrestrial vertebrates inhabit riparian areas at sometime during the year. Research predicts that as climate changes, water inputs are expected to decline due to reduced precipitation, consequently reducing water in riparian zones. Water losses are also likely to increase due to elevated evapotranspiration rates at higher temperatures and greater run-off 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 a small fraction of arid lands, they provide critical habitat for arid land vertebrates, migratory birds, and 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 Playas

Climate change is likely to affect native plant and animal species by altering key habitats such as the wetland ecosystems known as prairie potholes or playa lakes (Karl et al. 2009). Playa lakes create unique microclimates that support diverse wildlife and plant communities. A playa can lie 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 frogs, toads, clam shrimp, and aquatic plants. The playas provide a perfect habitat for migrating birds to feed, mate, and raise their young (Karl et al. 2009).

Sky Islands

Mountainous "sky islands" of southeastern Arizona are made up of forested ranges separated by expanses of desert and grassland plains, are among the most diverse ecosystems in the world because of their great topographic complexity and unique location at the meeting point of several major desert and forest biological provinces. “Sky islands” refers to a particular area vs. the other habitats that essentially refer to life zones of the southwest (including those of sky islands). The patterns described here for sky islands are

[9] Phenology is the study of periodic plant and animal life cycle events, and how these are influenced by seasonal and interannual variations in climate.

applicable to many areas of the southwest. The sky islands are particularly vulnerable to fragmentation, which may exacerbate the effects of climate change. These mountain ranges are isolated from each other by intervening valleys of grassland or desert. The valleys of these basins act as barriers to the movement of certain woodland and forest species. Species, such as mountain lions and black bears, depend on movement corridors between mountain islands to maintain genetic diversity and population size. The region is a blend of tropical and temperate, harboring well over half the bird species of North America, 29 bat species, over 3,000 species of plants, and 104 species of mammals, a diversity exceeding anywhere else in the U.S. Climate change poses a unique threat to sky islands. Temperature increases of as little as a few degrees could push sky island habitats to higher elevations, reducing their area and potentially causing local extinction of endemic taxa and divergent populations harboring unique genetic and phenotypic diversity. Sky islands in the Southwest and Mexico are already being affected by climate change, with increases in drought, fire, and outbreaks of invasive insects. Although these resilient systems have endured large-scale shifts in climate during and since the last ice age, the pace of human-induced climate change may represent an insurmountable challenge for sky islands, with potentially devastating consequences to their biodiversity and evolutionary potential (Sky Island 2007).

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 useless some efforts to reintroduce species into their historic range (Millar et al. 2007). For cool and cold-water species a nearly 50% reduction in thermal habitat is projected with scenarios of increased water temperatures (Eaton and Scheller 1996). Predicted impacts to aquatic ecosystems include altered seasonal discharge 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 Meka-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 foraging 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. We have 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 non-natives add to the complexity of managing and adapting to climate change.

Plant and animal species

The Southwestern Region includes a high degree of biodiversity and an unusually large number of plant and animal species that are endemic (found nowhere else). The Regional Forester’s Sensitive Species list identifies over 215 species, including highly endemic or restricted salamanders, shrews, and freshwater springsnails. The majority of the sensitive species are mammals (70) including two species of pika, followed by birds (41 species), snails (38 species), insects (21 species), fish (16 species), reptiles (16 species), amphibians (11 species), and clams (3 species). The number of plant species on the Regional Forester's Sensitive Species list is 167, the majority of which occur only on one National Forest, with over 50% of the sensitive plants occurring on the Coronado National Forest.

We can expect 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 phonological 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 National Forests 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 feedbacks among weather, land use, land cover, hydrology, fire, and stresses from invasive 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, such as the pika (Ochotona princeps), with habitat in talus slopes of alpine and sub-alpine areas the Santa Fe and Carson National Forests, are at great risk of being extirpated since they may not be able to adapt to habitat changes. Other species such as endemic squirrels that depend on high elevation forest habitat on the Lincoln NF and the Coronado NF are also at extreme risk with potential loss of habitat.

It already appears that some species are unable to disperse or adapt fast enough to keep up with the high rates of climate change. Endemic salamanders, such as the Jemez Mountain salamander (Plethoodon neomexicanus) are an example of a species subject to this type of risk. 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 habitat. This may occur through a decrease in available water, changes in vegetation type through 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).

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, 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 (Sinett 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 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 and general 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 2000:335). 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. As of the latest American Communities Survey (U.S. Census 2006), Arizona’s population was 6,056,817. The total increase for Arizona between 1980 and 2006 has been 123 percent. In New Mexico, the percent change in total population between 1980 and 2006 shows a 47 percent increase. Some counties in both states have seen population increases of between 300 and 500 percent (U.S. Census 2006, Sammis 2001, Farber et al. 2002, Gonzalez 2005). 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 United States, 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 river flow, winter air temperature, and snow pack between 1950 and 1999 are human-induced. The study predicts water shortages, lack of storage capabilities to meet seasonally changing river flow, transfers of water from agriculture to urban uses, and other critical impacts (Barnett et al. 2008:1082). 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. However, climate change could have long-term impacts on many of the amenities, goods, and services from forests, including 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. Agricultural, urban, and suburban areas are expanding into forestland. This expansion of human influences into the rural landscape alters disturbance 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).

Socioeconomic Impact

- Climate impacts are exacerbated by increasing populations in the region.
- Limitations in water supplies could affect most social systems and economic sectors.
- Potential impacts to alpine, riparian, wetland, sky Island, and aquatic habitats.
- Ranching, recreation, wood products, urban expansion, health, and energy, may be affected by changing climate.

Livestock Grazing

Livestock grazing is one of the key economic uses occurring on southwestern National Forests. Ranching is a key agricultural, economic, and social activity throughout the rural Southwest. It is a dominant land-use in both Arizona and New Mexico, and its success depends on the natural vegetation accessible to grazing animals. Rangelands[10] not only support livestock grazing and ranching, but also provide crucial habitat for wildlife. As the majority of rangelands in the region are not irrigated, any variability in

[10] Rangelands are lands that support livestock grazing and ranching, and can be comprised of several different ecosystems.

precipitation and temperature can directly affect rangeland plant production and wildlife habitat. Changes in climate may affect the vitality and productivity of rangeland plants, and thus the overall conditions of both wildlife habitat and range conditions. It is possible that higher temperatures and decreased precipitation depicted for the next century will also decrease forage production and lengthen the growing and grazing season for ranching, while flashfloods and increased risk of animal disease can adversely affect the industry (Joyce et al. 2001). Coupled with poor forage conditions, there may be a general scarcity of water for cattle. For a pasture to be available for grazing, it not only has to have sufficient nutritious vegetation, but also it must have adequate water supplies. Some ranchers rely on well water, but often ranchers use dirt tanks to capture summer monsoon rainfall and use this water for their cattle over the winter. During the recent droughts, these dirt tanks dried prematurely, making many pastures useless for cattle even though forage was still available (Conley et al. 1999). Ranching is in a vulnerable position, especially when viewed against a backdrop of changing climate, economic structure, urban expansion, increasing population, fluctuating market conditions, and environmental protection measures (Sprigg et al. 2000).

Recreational Value

Climate change affects forest and range 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. Forests provide many recreational opportunities including hiking, camping, hunting, bird watching, skiing, autumn leaf tours, and water-related activities such as fishing, boating, and swimming. 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 skiing. Ski 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). In areas of marginal annual snow pack, the inability to maintain downhill skiing may result in the closure of some ski areas.

Urban and suburban expansion into forests and rangelands are 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 (Langner 2007). As temperatures increase in lowland, urban areas, recreation may increase in mountainous areas, where cooler temperatures will attract people to higher elevations, with National Forests possibly becoming refugia from increasingly hot summers (Irland et al. 2001).

Wood and Paper 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, 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 National Forests may actually increase the overall availability of small-diameter timber and related wood products (Joyce et al. 2001).

Multiple socioeconomic impacts often follow 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. Perceived enhanced fire risk and views about montane aesthetics following beetle-cause mortality have an influence on public views of insect outbreaks, which could drive future public policy (Ryan et al. 2008). Wood supply will no doubt vary by forest and ecosystem (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, 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 inter-annual 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 American Southwest, there is clear seasonal variation in mortality; death rates during the winter season are 10-25% higher than those 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 and Githeko 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 United States, making disease surveillance increasingly difficult (Sprigg et al. 2000).

Urban Areas

Already setting a nationwide pace for growth, urban expansion in the Southwest is expected to continue in the coming century. Growing population centers will be vulnerable to climate-influenced natural hazards. Overall decreases in precipitation, but increases in severe weather events and flashfloods depicted in future climate scenarios could lead to property loss, and contribute to premature decay of sewage systems, pipelines, roadways, and other urban infrastructure. Rising temperatures will add to the energy demand for cooling, intensify the urban heat island effect, and reduce air quality within the region's urban areas (Sprigg 2000). Additionally, we need to remember that as temperature increases and large urban areas become less hospitable, there may indeed be a slowing or reduction in the number of people moving to Southwestern cities. Until such reversals in in-migration into the Southwest become evident, population growth, increased forest use, wildland-urban interface, and higher demand for water and other resources will likely continue to place increased demand on National Forests' resources.

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 National Forests through growing need for new energy corridors, wind and solar energy sites, and other special use-related requirements.

Key Climate Change Factors for Southwestern Region National Forests

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, and (5) increased use of 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 Southwestern Region National Forests and affect desired conditions in the revised Forest Plans 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, and non-native invasive species.
Projected increase in demand for deceasing upland water supplies, and
Projected increase in National Forest socioeconomic uses and demands.

These disturbance factors and the potential impacts on desired conditions for Forests in the Southwestern Region are described below.

Increased Extreme Weather Events

Climate change likely will increase flashfloods, making the region's growing population more susceptible to loss of life and property. While the Southwest 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 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 infrastructure such as trails, facilities, and roads; and loss of recreation opportunities. Disturbances that exceed the historic range of natural variation can change the makeup, structure, and function of watersheds and some vegetation types, could affect a number of desired conditions. Heavy rains and higher flood levels can affect maintenance and structural integrity of built infrastructure and slow progress toward improvements. Flooding is a natural and beneficial disturbance in many aquatic systems. However, damage to aquatic systems from flashflood-caused erosion, downed trees, and inundation from flooding can change streamside habitats, affect aquatic life, and impact proper functioning of stream channels. These disturbances could create challenges in the ability of a Forest to achieving Plan objectives for aquatic habitat restoration. Overall, increasing weather-related disturbances can divert limited Forest staff and funding to recovery efforts for extended periods and delay progress toward desired conditions, or require reconsideration 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 forest management and fire suppression practices have changed the dynamics of fire on the landscape within the Southwestern Region’s National Forests, resulting in greater fuel-loads and risk of wildfire. A combination of fire suppression and Federal land-management agencies in the West routinely exceed expenditures of over $1 billion per year for wildfire suppression. Since about the mid-1970s, the total acreage of area burned and the severity of wildfires in pine and mixed-conifer forest have increased.

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-Chediski fires in Arizona were both started by humans and combined to burn nearly half a million acres, the largest fire on record in Arizona (Joyce et al 2008).

Outbreaks of Insects, Diseases, and Non-Native 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 non-native 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.

Desired conditions for healthy forests include resilience to dramatic changes caused by abiotic and biotic stressors and mortality agents (pine beetle), and a balanced supply of essential resources (light, moisture, nutrients, growing space). Insects and diseases typically invade in cycles followed by periods of relative inactivity. Non-native invasive species, such as Buffelgrass and Saltcedar, 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

In the Forest Service's Southwest Region, 13 municipal watersheds in New Mexico, and 19 municipal watersheds in Arizona are located on National Forest administered lands. Additionally, the locations of most snow-pack and upland reservoirs are on National Forests in the Southwest. In many western mountain ranges, less precipitation is falling as snow, and spring melting is occurring earlier in the year. The Colorado River, Rio Grande, and several other southwestern rivers have streamflows that appear to be peaking earlier in the year, suggesting that the 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 trade-offs 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 2006, Arizona's population was 6,056,817. The total increase for Arizona between 1980 and 2006 has been 123 percent. In New Mexico, the percent change in total population between 1980 and 2006 shows a 47 percent increase. The combination of population growth and climate change will likely exacerbate climatic effects, putting even greater pressure on water, forest, and other resources. Climate change could have long-term impacts on many of the amenities, goods, and services from forests, including 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. Climate, combined with increasing regional population also will likely increase demand for water-related recreation opportunities on the National Forests, as residents of urban areas seek relief from rising temperatures.

Section Three: Potential Climate Change Strategies for Southwestern Region National Forests

The potential management approaches described below relate to the five projected, key climate change factors that are most likely to be a potential concern for Southwestern Region National Forests in moving toward the desired conditions in the Forest Plan (extreme weather events, wildfire risks, insects, diseases, and invasive species, water use and demand, and increase in socioeconomic demands). These 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 strategies which follow 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 National Forests 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 can be addressed through five 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,
5. Monitor climate change influences.

These management strategies should be considered as suggestions and a place to begin addressing climate change while revising forest plans. They are broad and general in scope, and are not meant to be prescriptive. Once size does not fit all. You may wish to use these as a basis from which to build forest-specific strategies. Conversely, when developing forest-specific strategies, keep in mind that the climate change science is evolving and adding to our body of knowledge, which in turn can result in changes in recommended management approaches to climate change. With this in mind, try to keep your overall strategies general and not overly specific.

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 management practices such as buffers, filter strips, broad-based dips, and piling slash down slope of skid trails and along streams, can help mitigate increased erosion conditions. Trails close to streams may need to be relocated further away from stream channels as part of improving and maintaining the recreation trails system and reducing 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 historic conditions. New recreation sites, such as campgrounds, ski areas, and other facilities should be located well away from potential flashflood areas.

Reduce Vulnerability by Maintaining and Restoring Resilient Native Ecosystems

Managing ecosystems under uncertainty necessitates flexible and adaptive approaches that are reversible, are implemented in incremental steps, and which allow for new information and learning, and that can be modified with changing circumstances (Millar et al. 2007). Southwestern 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 southwestern systems have a built-in resilience. Restoring and maintaining resilience in forest and grassland ecosystems should be part of the basic elements of Forest-wide desired conditions. Risks of increased wildfire, outbreaks of insects and disease, and invasive species, represent ongoing, broad-scale management challenges. 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 catastrophic fire, forest insect or disease pandemics) 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[11] or resilience identified by Millar and others (2007), the following may be useful for planning:

- Manage for asynchrony[12], promoting diversity
- Promote connected landscapes
- Reset significantly disrupted animal and plant communities

Prescribed fires are 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. Prescribed burning is also a management strategy that will be important for maintaining desired habitats in a changing climate with more natural disturbances. With projections of storms that are more frequent, and other more extreme weather events, plus the potential for increased stresses from forest pests in a warmer, drier climate, continued prescribed burning will continue to be an important management strategy for the future.

Although current programs and guidance are already in place to limit introduction of non-native species, treat invasive species, and control insects and diseases, these efforts are likely to become more critical to maintaining desired conditions for healthy forests under a changing climate. Due to the fragmented land ownership patterns, success in reducing forest pests requires going beyond National Forest boundaries, and continued collaboration with partners will be needed. In addition, management practices (such as thinning for age class diversity) that sustain healthy forests and provide adequate nutrients, soil productivity, and hydrologic function promote resilience and reduce opportunities for disturbance and damage.

For wildlife and plant species, that are dependent on forest ecosystems, planning may want to address:

Fragmentation

Conservation strategies should consider preservation and restoration of large, unfragmented areas, (Robinson et al. 1995) and avoid creating small patches.

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, and through which species can readily move (Taylor et al., 1993, Millar et al. 2007). Connectivity has two components, structural and biological connectivity and biological components. 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).

---

[11] Resistance – The capacity of an organism or a system to withstand the effects of an environmental agent.
[12] Asynchrony, in the general meaning, is the state of not being synchronized. In this usage, asynchrony refers the promotion of diversity by managing for a range of conditions, occurring at different times, within a given ecosystem.

Riparian

Riparian areas, respective uplands, and watersheds need to be protected from degradation, be enhanced where possible, and maintained in order to maintain proper hydrologic functions.

Maintain Biodiversity

If the above recommendations are implemented, biodiversity will be maintained as much as possible as climate change occurs.

Increase Water Conservation and Plan for Reductions in Upland Water Supplies

In the Southwest Region, mountain snowpack and the headwaters of river systems are located on National Forest lands. 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 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 watersheds in New Mexico and Arizona are dependent on these upland sources. In many western mountain ranges, 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. 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, water for fire-fighting, recreational uses, and aquatic habitats.
- Assess and maintain infrastructure that could be affected by flooding (dams, bridges, roads, culverts).
- Review current status of state and regional water plans, forest and watershed health plan, integrated regional water planning (IRWP) paradigm,
- Plan for extreme events, e.g., flooding and/or drought.

Anticipate Increase Forest Recreation Use, Utilize Markets and Demand for Small-Diameter Wood and Biomass for Restoration, Renewable Energy, and Carbon Sequestration

The use of southwestern National Forests 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 ski areas.

Salvaging and converting biomass into boards and other wood products can help reduce carbon loss from fire, as a byproduct of forest restoration. Another consideration may be to use biomass that cannot be converted to wood products (such as from clearing roads and trails) for bioenergy production. Bioenergy production would be carbon neutral and could not only replace the use of fossil fuels in generators, but 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 planning units create a completely new initiative or program of work solely for monitoring climate change. However, consider appropriate adjustments to the monitoring program that will improve understanding of the relationships of key plan components and climate change. As Forests review their existing and potential research natural areas (RNAs), monitoring of climate change affects on specific ecosystems may be part of the research goals considered when building the RNA establishment record.

References Cited

Adams, H. D., M. Guardiola-Claramontea, et al. (2009). "Temperature Sensitivity of Drought-Induced Tree Mortality Portends Increased Regional Die-Off Under Global Change-Type Drought." Proceedings of the National Academy of Sciences **106**(17): 7063-7066.

Allen, C. D. and D. D. Breshears (1998). "Drought-Induced Shift of a Forest-Woodland Ecotone: Rapid Landscape Response To climate Variation." Proceedings of the National Academy of Sciences **95**(25): 14839-14842.

Archer, S. R. and K. I. Predick (2008). "Climate Change and Ecosystems of the Southwestern United States." Rangelands(June 2008): 23-28.

Aublet, J.-F., M. Festa-Bianchet, et al. (2009). "Temperature constraints on foraging behaviour of male Alpine ibex (Capra ibex) in summer." Oecologia 2009 **159**(1): 237-247.

Barnett, T. P., D. W. Pierce, et al. (2008). "Human-Induced Changes in the Hydrology of the Western United States." Science **319**: 1080-1083.

Biro, P. A., J. R. Post, et al. (2007). "Mechanisms of Climate-Induced Mortality of Fish Populations in Whole-Lake Experiments." Proceedings of the National Academy of Sciences **104**(23): 9715-9719.

Brooks, C. P. (2003). "A scalar analysis of landscape connectivity." Oikos **102**: 466-439.

CCSP (2008a). The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. P. Backlund, A. Janetos, D. Schimelet al. Washington, D.C., U.S. Environmental Protection Agency**:** 362.

CCSP (2008b). Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. S. H. Julius, J. M. West, J. S. Baronet al. Washington, D.C., U.S. Environmental Protection Agency**:** 873.

CCSP (2008c). Reanalysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change. A Report by U.S. Climate Change Science Program and the Subcommittee on Global Change Research. R. Dole, M. Hoerling and S. Siegfried. Asheville, NC, National Oceanic and Atmospheric Administration, National Climatic Data Center**:** 156.

CCSP (2008d). Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. A Report by U.S. Climate Change Science Program and the Subcommittee on Global Change Research. T. R. Karl, G. A. Meehl, C. D. Milleret al. Washington, D.C., Department of Commerce, NOAA's National Climate Data Center,**:** 164.

Christensen, N. and D. P. Lettenmaier (2006). "A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River basin." Hydrology and Earth System Sciences **3**: 3727-3770.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, (2007). Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University. Press, Cambridge, United Kingdom and New York, NY, USA.

Clark, J. S. (1998). "Why trees migrate so fast: confronting theory with dispersal biology and the Paleorecord." The American Naturalist **152**(2--August): 204-224.

Conley, J., H. Eakin, et al. (1999). CLIMAS Ranching Case Study: Year 1. Tucson, AZ, Institute for the Study of the Planet Earth, Arizona State University.

Dale, V. H., L. A. Joyce, et al. (2001). "Climate Change and Forest Disturbances." BioScience **51**(9): 723-734.

Dean, J. S. (2000). Complexity Theory and Sociocultural Change in the American Southwest. The Way the Wind Blows: Climate, History, and Human Action. R. J. McIntosh, Joseph A. Tainter, Susan Keech McIntosh. New York, Columbia University Press**:** 89-118.

Eaton, J. G. and R. M. Scheller (1996). "Effects of Climate Warming on Fish Thermal Habitat in Streams of the United States." Limnology and Oceanography **41**(5, Freshwater Ecosystems and Climate Change in North America): 1109-1115.

Eisen, R. J. and et al. (2007). "A Spatial Model of Shared Risk For Plague and Hantavirus Pulmonary Syndrome in the Southwestern United States." American Journal of Tropical Medicine and Hygiene **77**: 999-1004.

Enquist, C. and D. Gori (2008). Implications of Recent Climate Change on Conservation Priorities in New Mexico. A Climate Change Vulnerability Assessment for Biodiversity in New Mexico, Part 1, The Nature Conservancy and Wildlife Conservation Society.

Farber, S. C., R. Costanza, et al. (2002). "Economic and Ecological Concepts for Valuing Ecosystem Services." Ecological Economics **41**: 375-392.

Guido, Zack. (2008). Southwest Climate Change Network. http://www.southwestclimatechange.org/impacts/land/fire

Gonzalez, G. A. (2005). "Urban sprawl, global warming and the limits of ecological modernisation." Environmental Politics **14**(3): 344-362.

Herweijer, C., R. Searger, et al. (2007). "North American Droughts of the Last Millennium from a Gridded Network of Tree-Ring Data." Journal of Climate **20**: 1353-1376.

Hoegh-Guldberg, O., L. Hughes, et al. (2008). "Assisted Colonization and Rapid Climate Change." Science **321**(no. 5887): 345-346.

Horikawa, M., T. Ikutaro, et al. (2009). "Assessing the Potential Impacts of Climate Change on the Alpine Habitat Suitability of Japanese Stone Pine (Pinus pumila) Export." Landscape Ecology **24**: 115-128.

Hughes, M. K. and H. F. Diaz (2008). "Climate variability and change in the drylands of Western North America." Global and Planetary Change **35**: 111-118.

Hulin, V., V. Delmas, et al. (2009). "Temperature-depenedent sex determination and global change: are some species at greater risk?" Oecologia **160**(3): 493-506.

Inouye, D. W. (2008). "Effects of Climate Change on Phenology, Frost Damage, and Floral Abundance of Montane Wildflowers." Ecology **89**(2): 353-362.

Institute of the Environment. (2007). "Climate Assessment for the Southwest." from http://www.climas.arizona.edu.

Institute of the Environment and Climate Assessment for the Southwest. (2009). "Southwest Climate Change Network." from http://www.southwestclimatechange.org/climate/southwest.

IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Quin, M. Manninget al. Cambridge, United Kingdom, Cambridge University Press**:** 996.

Irland, L. C., D. Adams, et al. (2001). "Assessing Socioeconomic Impacts of Climate Change on US Forests, Wood-Product Markets, and Forest Recreation." BioScience **51**(9): 753-764.

Joyce, L., J. Aber, et al. (2001). Potential Consequences of Climate Variability and Change for the Forests of the United States. National Assessment Synthesis Team Climate Change Impacts on the United States: The potential Consequences of Climate Variability and Change, Report for the U.S. Global Change Research Program. Cambridge, UK, Cambridge University Press**:** 489-522.

Joyce, L., R. Haynes, et al., Eds. (2007). Bringing climate change into natural resource management: proceedings. Gen. Tech. Rep. PNW-GTR-706. Portland, OR, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Joyce, L. A. and R. Birdsey (2000). The impact of climate change on America's forests Gen. Tech. Rep. RMRS-GTR-59. Fort Collins, CO**:** 133

Joyce, L. A., G. M. Blate, et al. (2008). National Forests. Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources. S. H. Julius, J. M. West, J. S. Baronet al. Washington, D.C., U.S. Climate Change Science Program and the Subcommittee on Global Change Resarch**:** 3-1 to 3-127.

Karl, T. R., J. A. Melillo, et al. (2009). Global Climate Change Impacts in the United States. United Kingdom and New York, NY, Cambridge University Press.

Lawler, J., S. L. Shafer, et al. (2009). "Projected climate-induced faunal change in the Western Hemisphere." Ecology **90**(3): 588-597.

Lenart, M. (2007). Global Warming in the Southwest: Projections, Observations, and Impacts. Climate Assessment for the Southwest. Tucson, AZ, University of Arizona, Institute for the Study of Planet Earth**:** 88.

Lenart, M. (2008). Climate of the Southwest. Tucson, AZ, Southwest Climate Change Network, University of Arizona.

Lomolino, M. V. and D. R. Perault (2007). "Body size variation of mammals in a fragmented, temperate rainforest." Conservation Biology **21**(4): 1059-1069.

Maurer, E. P. and H. G. Hidalgo (2008). "Utility of daily vs. monthly large-scale climate data: an intercomparison of two statistical downscaling methods." Hydrology and Earth System Science **12**: 551-563.

McMichael, A. and A. Githeko (2001). Chapter 9: Human Health. Climate Change 2001: Impacts, Adaptation, and Vulnerability, Working Group II Contribution to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, Cambridge University Press.

Meko, D. M., C. A. Woodhouse, et al. (2007). "Medieval drought in the upper Colorado River Basin." Geophysical Research Letters **34**: 1-5.

Millar, C. I., N. L. Stephenson, et al. (2007). "Climate Change and Forests of the Future: Managing in the Face of Uncertainty." Ecological Applications **17**(8): 2145-2151.

Owen, G. (2008). Impacts: Invasive Species. Tucson, AZ, Southwest Climate Change Network, University of Arizona.

Robinson, S. F., F. R. Thompson III, et al. (1995). "Regional Forest Fragmentation and the Nesting Success of Migratory Birds." Science **267**(1): 1987-1990.

Rosenzweig, C., G. Casassa, et al. (2007). Assessment of Observed Changes and Responses in Natural and Managed Systems. Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M. L. Parry, O. F. Canziani, J. P. Palutikofet al. Cambridge, UK, Cambridge University Press.

Ryan, M., S. Archer, et al. (2008). Land Resources. The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity. Washington, D.C., U.S. Climate Change Science Program and the Subcommittee on Global Change Research**:** 362.

Sammis, T. (2001). Current, Past, and Future Climate of New Mexico. New Mexico Climate. Las Cruces, NM. , New Mexico State University's Climate Center, Office of the State Climatologist, Department of Agronomy and Horticulture, College of Agricultural and Home Economics, Agricultural Experiment Station**:** 1-4.

Schmidt-Nielsen, K. (1997). Animal Physiology: Adaptation and Environment. Cambridge, UK, Cambridge University Press.

Seager, R., R. Burgman, et al. (2008). "Tropical Pacific Forcing of North American Medieval Megadroughts: Testing the Concept with an Atmosphere Model Forced by Coral-Reconstructed SSTs." Journal of Climate **21**: 6175-6190.

Seager, R., M. Ting, et al. (2007). "Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America." Science **316**(5828): 1181-1184.

Sheppard, P. R., A. C. Comrie, et al. (2002). "The climate of the US Southwest." Climate Research **21**(3): 219-238.

Sinett, T. S., R. T. Holmes, et al. (2000). "Impacts of a Global Climate Cycle on Population Dynamics of a Migratory Songbird." Science **288**: 2040-2042.

Sky Island Alliance (2007). "Restoring Connections: Climate Change." Newsletter of the Sky Island Alliance **10**(2): 1-15.

Smith, J. B., R. Richels, et al. (2001). The Potential Consequences of Climate Variability and Change: The Western United States. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. Report for the US Global Change Research Program. N. A. S. Team. Cambridge, UK, Cambridge University Press**:** 219-245.

Sprigg, W. A., T. Hinkley, et al. (2000). Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change: Southwest. A Report of the Southwest Regional Assessment Group. U. o. A. The Institute for the Study of Planet Earth. Tucson, AZ, US Global Change Research Program**:** 66.

State of New Mexico (2005). Potential Effects of Climate Change on New Mexico. Agency Technical Work Group.

Swetnam, T. W., C. D. Allen, et al. (1999). "Applied Historical Ecology: Using the Past to Manage for the Future." Ecological Applications **9**(4): 1189-1206.

Swetnam, T. W. and J. L. Betancourt (1997). "Mesoscale Disturbance and Ecological Response to Decadal Climatic Variability in the American Southwest." Journal of Climate **11**: 3128-3147.

Tainter, J. A. (2000). Global Change, History, and Sustainability. The Way the Wind Blows: Climate, History, and Human Action. R. J. McIntosh, J. A. Tainter and S. K. McIntosh. New York, Columbia University Press: 331-356.

Taylor, P. D., L. Fahrig, et al. (1993). "Connectivity is a vital element of landscape structure." Oikos **68**: 571-573.

The Nature Conservancy, The University of Washington, et al. (2007). "Climate Wizard." from http://www.climatewizard.org/index.html.

Trouet, V., J. Esper, et al. (2009). "Persistent Positive North Atlantic Oscillation Mode Dominated the Medieval Climate Anomaly." Science **324**: 78-80.

United States Census Bureau. (2006). United States Census, 2000. U.S. Dept. of Commerce. http://www.census.gov/

United States Census Bureau. (2006). American Communities Survey Data. http://www.census.gov/

USDA Forest Service (2005). Monitoring for Sustainability. Fort Collins, CO., US Department of Agriculture, Forest Service, Inventory and Monitoring Institute, **2005:** 2.

USDA Forest Service. (2008). "The Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT)." from www.fs.fed.us/psw/cirmount/.

USDA Forest Service. (2010). "Climate Change Resource Center." from http://www.fs.fed.us/ccrc/.

Westerling, A. L., H. G. Hildalgo, et al. (2006). "Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity." Science **313**: 940-943.

Whitlock, C. (2008). Turning Up the Heat... On a Bubbling Cauldron of Forest Threats. Compass, USDA Forest Service, Southern Research Station.

Williams, J. E. and J. M. Carter (2009). "Managing Native Trout Past Peak Water." Southwest Hydrology **8**(2): 26-34.

Specific Web Pages:

Climate Assessment for the Southwest (CLIMAS)
http://www.climas.arizona.edu/
Climate Wizard Web Page
Climate Wizard
IPCC
IPCC - Intergovernmental Panel on Climate Change
Past Global Change Web Page
PAGES - Past Global Changes
Pew Center on Global Climate Change
Homepage | Pew Center on Global Climate Change: The Pew Center on Global Climate Change
The Southwest Climate Change Network
http://www.southwestclimatechange.org/climate/southwest
The Western Regional Climate Center
http://www.wrcc.dri.edu/
The Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT)
http://www.fs.fed.us/psw/cirmount/
The Nature Conservancy Climate Wizard
http://www.climatewizard.org/
USGCRP-US Global Change Research Program
US Global Change Research Program
U.S. Forest Service Climate Change Resource Center
http://www.fs.fed.us/ccrc/

Climate Change Glossary

The following terms have been gathered by Forest Service researchers from numerous sources including NOAA, 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 mm precipitation per year.

Atmosphere: The gaseous envelop surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1% volume mixingratio) and oxygen (20.9% volume mixing ratio), together with a number of trace gases, such as argon (0.93% volume mixingratio), helium, and radiatively active greenhouse gases such as carbon dioxide (0.035% volume mixing ratio) and ozone. In addition, the atmosphere contains water vapor, whose amount is highly variable but typically 1% 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 (CO2): A naturally occurring gas, and also a by¬product 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 (CO2) 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 atmospheric carbon dioxide concentration.

Climate: Climate in a narrow sense is usually defined as the "average weather" or more rigorously as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, 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 forcings, 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 anyone 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 towards more complex models with active chemistry and biology. Climate models are applied, as a research tool, to study and simulate the climate, but also for operational purposes, including monthly, seasonal, and interannual climate predictions.

Drought: There is no definitive definition of drought based on measurable processes; 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, is a warmwater current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. This oceanic event is associated with a fluctuation of theintertropical 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 10th or 90th 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: Greenhouse gases are those 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 (SF6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

Radiative Forcing: The term radiative forcing refers to 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/m2).

Rangeland: Unimproved grasslands, shrublands, savannahs, and tundra.

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).

Rapid climate change: The non¬linearity 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 non¬linear system.

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 Southwest United States 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 two weeks.