Climate Projections FAQ

Amy E. Daniels, James F. Morrison, Linda A. Joyce,
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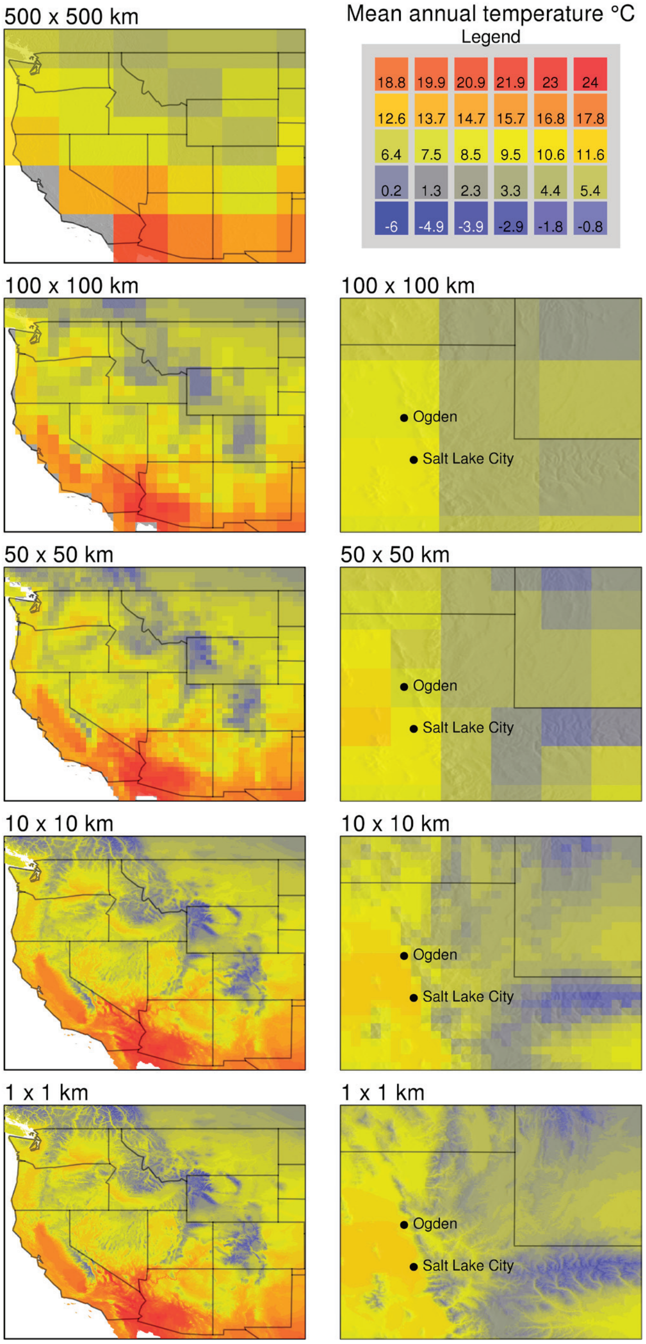

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Abstract

Climate scenarios offer one way to identify and examine the land management challenges posed by climate change. Selecting projections, however, requires careful consideration of the natural resources under study, and where and how they are sensitive to climate. Selection also depends on the robustness of different projections for the resources and geographic area of interest, and possibly on what climate projections are available for a region. Rather than a misguided attempt to identify the "most accurate" climate scenario, managers are strongly encouraged to explore variability through the use of multiple climate scenarios. Considering a range of possible future climates facilitates the identification of management strategies to help ensure resilience of natural resource systems across a broad set of potential conditions. Downscaling climate projections increases the spatial resolution of climate information and can make projections more relevant to natural resource managers by allowing decision-makers to better visualize what these different futures imply locally and regionally. The following series of questions describes key concepts that end-users of climate projection products should understand to appropriately interpret downscaled climate projections, including various sources of uncertainty. The selection used for each component of a downscaled climate projection has implications for interpreting the resulting climate scenario. Understanding the merits and limitations of the downscaling method employed is also important since downscaling approaches vary in their dependence on observed data availability, computational requirements, and in resultant uncertainty owed to biases of the method or the spatial scale of the downscaling.

Keywords: climate change, climate projections, downscaling, general circulation models, vulnerability assessment

Cover: *Mean annual temperature (1961-1990) presented at different resolutions: 500 km (311 mi) typical of a GCM grid cell; 50 km (31 mi) typical of RCM grids; and 10 km (6 mi) and 1 km (0.6 mi), which represents some GCM downscaled outputs.*

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Foreword

The Forest Service is now engaged in an agency-wide effort to respond to climate change. As laid out in the *National Roadmap for Responding to Climate Change*, the Forest Service is assessing current risks, vulnerabilities, policies, and gaps in knowledge; engaging internal and external partners in seeking solutions; and managing for resilience in coupled human and natural systems through adaptation, mitigation, and sustainable consumption strategies. Each of the national forests and grasslands is involved in this effort, with support from Research Stations, Regional Offices, and National Programs.

Understanding current climate variability, as well as the range of plausible climate futures, is a cornerstone to this effort. The implications of climate change at local and regional scales are complex. Not only mean temperature, but changes in temperature extremes, length of growing season, plant moisture stress, and extreme events such as wind and heavy rainfall factor in to stress on resources and must be considered in developing adaptive strategies.

Responding effectively to climate change requires us to use the best available science to anticipate expected changes, and understand what they mean to resources and management alternatives. As Chief Tidwell has reminded us, “sound climate science is the foundation for an effective management response.” Using science to help us deal with change is not new to us. We are a science-based organization. The science behind climate change projections, however, is new to many of us, as is the exercise of scenario planning. Climate projections are typically developed at broad scales using a number of alternative general circulation models, driven by various socioeconomic scenarios. The output may then be “downscaled” to finer spatial resolution, using a variety of techniques, to develop more location-specific information. It is our hope that you will find this document helpful as you navigate this complex arena and develop or select projections that will be most useful in assessing vulnerability of the resources you manage and in crafting prudent management responses.

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Preface

In the spring of 2010, the Forest Service Washington Office of Research & Development began to catalogue and organize metadata for all downscaled climate projection data holdings and uses within the Forest Service. The agency has over 140 datasets across 15 different groups. There is relatively little coordination or communication regarding dataset use and application. This effort highlighted considerable confusion about both the availability and use of downscaled climate projections. It also underscored the importance of beginning a coordinated national dialogue, as well as the need for educational guidance about climate projections applicable to multiple purposes. A team was formed in March 2011 to assess the availability and applicability of downscaled climate projections for Forest Service research and land management use. This document is an output from that assessment.

Our main objective is to develop a shared understanding within the Forest Service of what climate projections are, their strengths and limitations, and to provide some guidance regarding how climate projections might be used for climate change impact analyses by Forest Service units and partner organizations. Decision-makers within the Forest Service should ask certain questions about the data and methods used to develop projected climate change maps and other decision-support products. This document intends to highlight and explain the key concepts that end-users of climate projection products should understand in order to appropriately interpret them. Recommending particular climate projections for specific regions, questions, or applications is beyond our scope. Such prescriptive guidance must be developed on a case-by-case basis. However, we reference a number of regional climate research centers that may prove helpful in this regard.

This document is intended for a general Forest Service audience including planners, resource specialists, researchers, and line officers. We have organized the questions into three categories based on the anticipated degree of relevance for different sub-audiences. Because the intended audience is so broad, the text may not be ideally suited for any one group—likely being too technical in some places and too general in others. We strongly encourage readers to not only peruse the entire document for perspective, but to explore the many links and references made throughout for more information.

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Acronyms

AR4	IPCC Fourth Assessment Report
BCSD	Bias-corrected Statistical Downscaling
GCM	General Circulation Model
GHG	Greenhouse Gas
IAM	Integrated Assessment Model
IPCC	Intergovernmental Panel on Climate Change
RCM	Regional Climate Model
TAR	IPCC Third Assessment Report

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General Forest Service Questions

1. Why should the Forest Service begin a coordinated dialogue about the use of climate projections?

Every time the Forest Service makes a natural resource management decision, e.g., deciding to plant a specific species from a specific seed source, or identifying priority restoration actions and locations, assumptions about future climate conditions are made. Often, the assumed or implicit climate scenario holds that conditions of the past century will continue through this century. Yet, this assumption is widely considered to be very unlikely given the projected changes in climate.

Climate change vulnerability assessments and adaptation planning are greatly assisted by evaluating a range of plausible climate futures. These futures are represented through climate projections that are based on thoughtfully chosen management objectives and the social, ecological, and economic impacts and risk. Climate projections are valuable for considering the direction and magnitude of potential changes and prioritizing locations for adaptation actions. However, developing—or selecting from already-developed—climate projections involves many decisions. It requires transparent documentation of climate projection components, and clear communication of uncertainties, among other criteria for judicious use. Downscaling coarse climate projections to finer spatial resolution is increasingly used to better align the scale of projections with the scale of land management processes and decisions. This adds yet another dimension of complexity to impact assessments and a further need for a coordinated national dialogue in the Forest Service, and with its partners, regarding the opportunities and limitations of using such projections.

Currently no published agency guidance is available to assist Forest Service units in determining the climate projection parameters, downscaling methods, and data sources that best meet their needs. Guidance would help ensure scientific credibility and appropriate use of climate projections within the Forest Service. A coordinated dialogue would allow the Forest Service to more effectively engage in on-going discussions with partners using climate projections for landscape-level vulnerability assessments. Also, a systematic, agency-wide framework for accessing, applying, and managing downscaled climate projection data would improve the efficiency and consistency of agency investments while enhancing opportunities for long-term partnerships with research institutions, other agencies, and contractors. (**back**)

2. How might climate change projections be used in management, decision-making, and planning processes?

Many management decisions in the Forest Service, such as identifying priority restoration actions and locations, are made using historical conditions as a reference. Changing climate may cause significant ecosystem changes regardless of management actions to direct the change. Using a historical reference in such cases reduces our ability to meet both the agency's mission and stakeholders' expectations. Climate scenarios offer a reasonable way to identify and examine the challenges posed by climate change; they provide a meaningful, tangible framework for considering management actions against a range of potential climate futures. Downscaling climate projections to a spatial resolution relevant to Forest Service management units allows decision-makers to better visualize what these different futures imply locally and regionally.

Rather than impossibly attempting to identify the "most accurate" climate scenario, it is better to explore the maximum possible range of projected variability through the use of multiple climate scenarios. This approach promotes system resilience for a range of possible future conditions. Managers are encouraged to work with scientists and stakeholders to construct a climate scenario-planning framework in a thoughtful way that (a) brackets the upper and lower ends of the range of projected variability for a particular variable (e.g., temperature) or process of interest and (b) facilitates at least pairwise or multiple comparisons holding all but one climate projection component constant (e.g., constant emissions scenario and downscaling technique for multiple general circulation models (GCMs), or multiple emissions scenarios for a single GCM with a consistent downscaling approach). This facilitates identifying sources and ranges of variability in the model outputs, as well as exploring implications of various management options.

Adaptive management and scenario planning present complementary frameworks for decision-making in the face of uncertainty. By considering the management options that are appropriate for a number of different scenarios, the Forest Service may begin to identify "no regret" strategies that facilitate ecosystem resilience for desired functions and services. Adaptation strategies that hedge against impacts common to a range of possible future conditions are more robust than traditional prescriptive management for a single outcome. By explicitly naming assumptions and desired management outcomes, and including monitoring regimes designed to track ecosystem trajectories, adaptive management provides a roadmap to navigate the many contingencies represented by a suite of future scenarios. Note that the spatial and temporal resolution of even the downscaled GCM data may, however, still be too coarse a resolution to accurately forecast the probability or frequency of extreme events (e.g. flooding and ice storms). (**back**)

3. What are the components of a climate projection?

Most climate change impact assessments rely on climate projections developed through coordinated international modeling efforts that have supported the Intergovernmental Panel on Climate Change's (IPCC) role in assessing the science of climate change. This process entails a number of components and decision points in developing or using a given climate projection, each of which is represented as a box or oval in fig. 1. First, socioeconomic storylines are modeled to predict emissions that result from different assumptions about population growth, energy

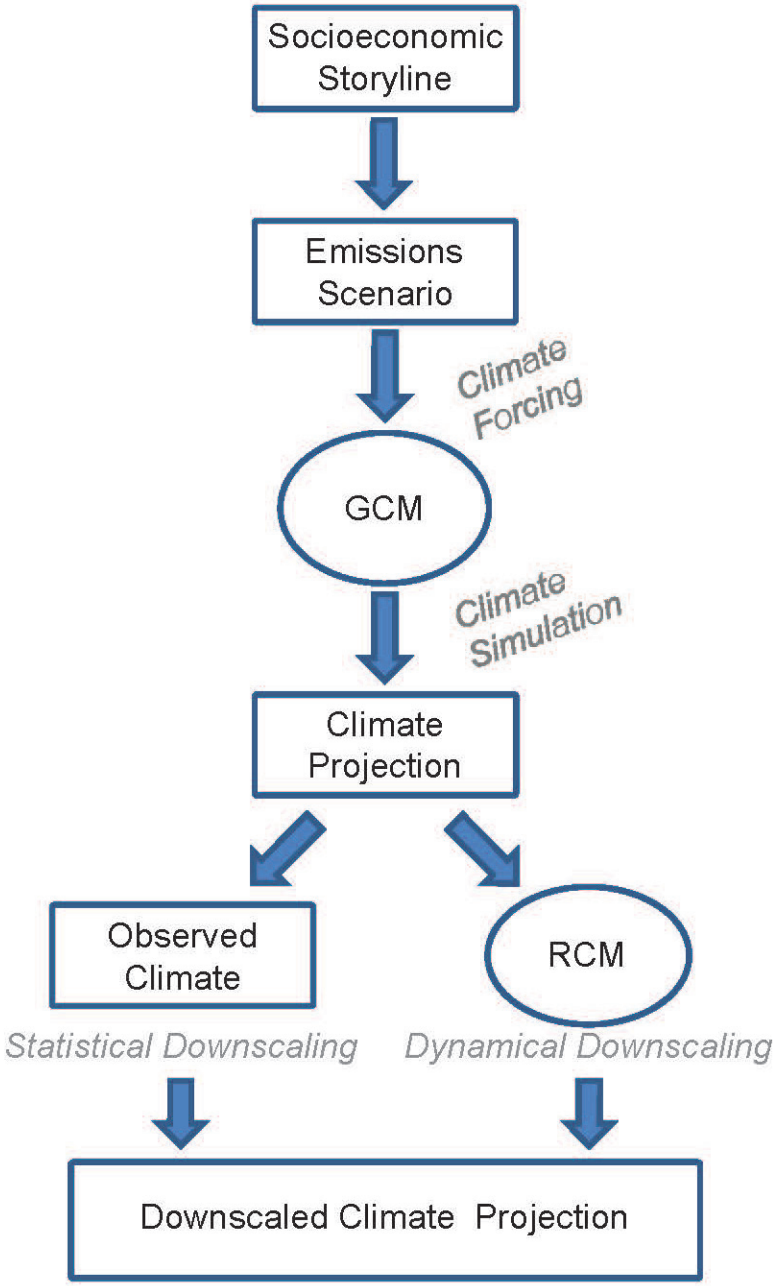

Figure 1—Conceptual illustration of the components and decision points associated with developing a climate projection, as per the IPCC process. Acronyms: GCM (general circulation model), RCM (regional climate model)

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use, etc. Each resulting emissions scenario yields a particular trajectory of atmospheric concentrations of greenhouse gases (e.g., carbon dioxide) that make up important climate-driving forces. IPCC emissions scenarios have been broadly used by modeling centers around the world in the last decade (see Nakicenovic and others 2000 for details of emissions scenarios used for the last two IPCC assessments, TAR and AR4). Using these standardized, global emissions scenarios as drivers of GCMs has facilitated comparisons among the models' responses to these future emissions (Le Treut and others 2007). Yet note that emissions scenarios are all considered equally likely (i.e., there is no built-in or implicit assumptions about which path global development will take).

The next component of a climate projection is the general circulation model (fig. 2). The last IPCC assessment (AR4) rigorously reviewed the latest versions of twenty-three different GCMs (Meehl and others 2007). All have been studied and characterized in terms of their sensitivity to factors that drive climate, including atmospheric chemical composition and other physical parameters. The number of

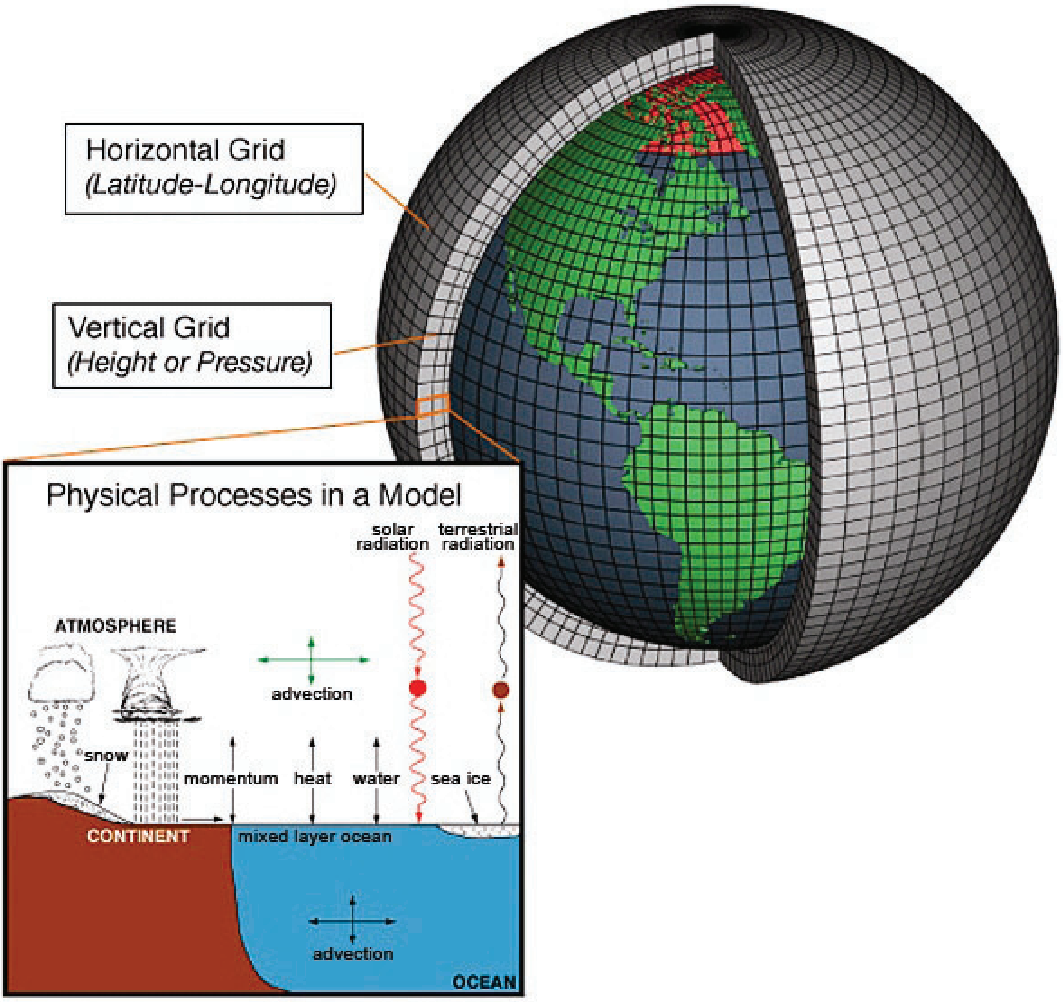

Figure 2—Schematic of a general circulation model (GCM) illustrating the horizontal and vertical dimensions of the model grid. Physical processes occurring within grid boxes are shown in the inset and are represented in the model through parameterization (source: NOAA 2008).

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possible parameter settings, emissions scenario and GCM pairings creates a significant number of alternative climate projections for exploring a range of potential climate futures. Output from GCMs includes many climate variables for both historical and future time periods for each cell in a grid that covers the globe. These direct GCM outputs can be used to derive additional climate variables. Finally, coarse GCM projections can also be downscaled to finer resolution, as discussed at length in questions below. This entails further decisions on downscaling techniques and baseline (observed) climatology.

Though not explored in detail here, other approaches (i.e. independent of the described IPCC process) may be used to explore the potential impacts of climate change on ecosystems. For example, a constructed suite of hypothetical temperature or precipitation surfaces may be input to an ecosystem process model to explore the range of outcomes associated with changes in climate variables on some process of interest (e.g., net primary productivity or wildland fire behavior). (**back**)

4. What is the rationale for using downscaled data?

GCMs are the principal source of future climate projections. They are designed to evaluate the behavior of the global climate system and are relatively effective at simulating global climate characteristics like global temperature and broad circulation patterns. The coarse spatial resolution of GCMs used in AR4 ranges from 76 to 350 mi on a grid cell side at the equator (i.e. 5776 to 122,500 mi^2). Each modeled grid cell is homogenous—i.e., GCM output for a given variable is uniform within the cell). Yet spatial patterns of regional climate are far more heterogeneous than suggested by GCM output. The coarse spatial resolution severely limits the direct application of GCM output in regional and sub-regional analyses and decision-making. This limitation is particularly problematic in areas with diverse topography, land cover and drainage patterns, such as mountainous regions or by large lakes (e.g., Great Lakes). For example, projections of precipitation, snow dynamics, and runoff at the native GCM resolution are of limited use for evaluating regional and sub-regional hydrologic impacts. In contrast, the typical range of spatial resolutions achieved through downscaling is from 1/16 degree (≈ 3.5 mi over U.S. latitudes) to 1/2 degree (≈ 30 mi over the U.S. latitudes), typically constrained by the availability of observational data or the gridding model used to spatially interpolate such data. With temporal downscaling, climate projections in the form of monthly averages may be downscaled to daily outputs. Increasing spatial resolution increases land surface heterogeneity. For example, mean annual temperature is resolved with much greater detail with smaller grid cell sizes (**fig. 3**).

Downscaling GCM-derived climate projections adds additional decisions, computational steps, and modeling assumptions. Downscaled results are, at best, only as realistic as the GCM's ability to simulate climate dynamics of interest for a given scenario of driving forces. If wisely developed and used to address appropriate

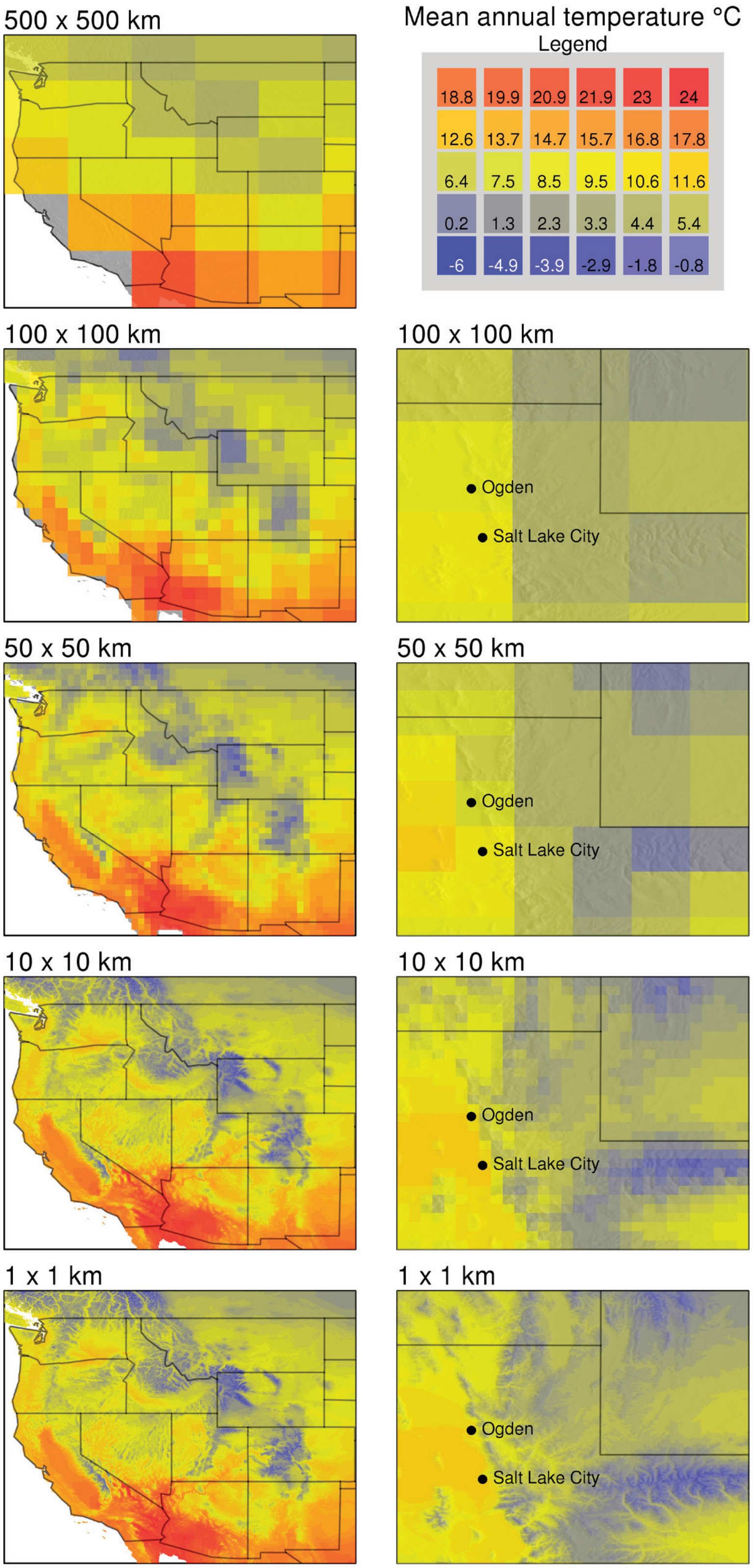

Figure 3—Mean annual temperature (1961-1990) presented at different resolutions: 500 km (311 mi) typical of a GCM grid cell; 50 km (31 mi) typical of RCM grids; and 10 km (6 mi) and 1 km (0.6 mi), which represents some GCM downscaled outputs.

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climate change impact questions, downscaled climate projections allow for more detailed representations of potential changes associated with a particular climate scenario. Also, downscaled data are often better suited as inputs for ecosystem models and other important analyses compared with the unaltered spatial resolutions of GCM output, particularly regional and sub-regional impact analyses, vulnerability assessments, and adaptation planning. (**back**)

5. What are the main approaches for downscaling climate data from coarse-scale GCM output?

There are two broad classes of methods for downscaling GCM simulations to finer spatial scales: statistical and dynamical.

- Statistical methods range from relatively simple to sophisticated. The simplest is the delta or change factor approach. Techniques in this approach may be as simple as applying average GCM-projected change from some future period (e.g., 2030-2040 monthly mean) to a finer-resolution interpolated grid of observed values from some baseline period (e.g., 1971-2000). The most common implementation of the delta method incorporates only changes in mean monthly temperature and precipitation and does not include daily data, even though these change factors may be applied to daily observed values. Another statistical downscaling method widely used in the United States known as the "bias-corrected spatial-disaggregation" (BCSD) approach. BCSD combines a bias-correction step that uses a quantile mapping technique, with a simple "disaggregation" of the broad scale changes to the downscaled grid to produce daily time series over the simulated period. Yet other statistical methods rely on coarse GCM outputs (e.g., atmospheric pressure fields) as statistical predictors of local climate variables (e.g., precipitation). A statistical method with increasing application is the "weather typing" approach based on spatial pattern matching with daily meteorological fields from a large library of observed meteorological patterns. Common to most statistical downscaling methods are spatial interpolation algorithms that transform unevenly distributed point data for observed climate into spatially-continuous surfaces.
- Dynamical downscaling uses a regional climate model (RCM) embedded within a GCM to simulate regional climates. RCMs are physical process models with much finer spatial resolution than GCMs, typically ranging from 7.5 mi to 31 mi. As a result, RCMs effectively simulate the regional and subregional effects of topography, land cover, diurnal cycle, lake effects, and regional circulation patterns too fine for GCMs to resolve. For example, they better capture elevation-dependent precipitation patterns, and the effects of snow-albedo feedback on local temperatures (Salathé and others 2008). (**back**)

6. How, where, and why is the Forest Service using downscaled climate projections?

The Forest Service uses downscaled climate projections for both research and planning. At the national scale, the 2010 RPA Assessment uses a scenario approach to evaluate the future of natural resources on all ownerships of forest and rangelands over the next 50 years in relation to drivers of change such as climate change, population growth, and economic development as mandated by the Resources Planning Act of 1974. Regionally, Forest Service Regions 1 and 6 (see **Appendix A** for map of Forest Service regions) are using downscaled climate and hydrologic scenarios to conduct climate vulnerability assessments. Forest Service Region 9 used downscaled data from the *Wisconsin Initiative on Climate Change Impacts* (WICCI) to evaluate key forest ecosystem vulnerabilities to climate change for the Chequamegon-Nicolet National Forest and surrounding landscape (see Swanston and others 2011). Specifically, this vulnerability analysis modeled climate change effects on tree species dominance and habitat suitability.

At the level of National Forests & Grasslands, downscaled climate scenarios have been used in the Watershed Vulnerability Assessment pilots on 11 units across the United States. Downscaled projections are also used to model tree species distributions under a range of anticipated climate futures through species envelope models in the northeastern part of the United States (Iverson and others 2010), and to better understand in situ forest dynamics like species composition and size through the tool Climate-FVS (Crookston and others 2010). TACCIMO is a web-based decision support tool for forest planning applications throughout the United States that relies on a relational database framework to integrate four kinds of inputs, including downscaled climate projections, to generate customized reports for assessing climate change impacts at the National Forest, state, and county scales. In some cases, the Forest Service is also directly engaged in developing downscaled data or in contracting its development for particular purposes (in contrast with downloading data already downscaled by others). Downscaled climate projections for the 2010 RPA Assessment were developed in cooperation with the Canadian Forest Service (projections from three emissions scenarios by three GCMs, downscaled using a delta method to 1/12 degree resolution, see Coulson and others 2010). Forest Service Regions 1 and 6, together with the Pacific-Northwest Research Station, contracted the Climate Impacts Group at the University of Washington to analyze a suite of future climate projections and assembled an ensemble of climate models best-suited to simulate the regional climate system. They selected two models whose results bracketed the upper and lower bounds of variability projected by the ensemble. Finally, they downscaled projections from the ensemble and the two bracketing models to 1/16 degree using a delta method and used the projections in hydrologic simulations to analyze potential future hydrologic changes (Littell and others 2011).

As of spring 2011 Forest Service units collectively hold over 140 downscaled climate projections that vary by emissions scenario, by GCM, by geographic coverage, and by available climate variables (**Appendix D**). Some of these data were expressly downscaled by and/or for the agency, while others were accessed from one of the many online repositories mentioned in this FAQ. Forest Service uses these data in a number of research and management contexts. See **Appendix B** for research publications using downscaled climate projections. (**back**)

7. How reliable are GCM-based climate projections?

The IPCC concluded that GCMs provide a credible range of quantitative estimates of future climate change, particularly at global and continental scales and over long time periods (Randall and others 2007). Extensive, rigorous multi-model intercomparisons underpin this conclusion. Over the many generations of climate models and across a range of emissions scenarios, models unanimously and unambiguously project warming over the next 2 decades in response to increasing atmospheric GHG concentrations.

The scientific credibility of climate models and resulting projections hinges on several lines of evidence. First, climate models are consistent with well-understood physical processes and physical laws (e.g., conservation of energy and Newton's laws of motion). Second, current-generation climate models demonstrate a significant and increasing ability to simulate recent and past climate dynamics (e.g., Reichler and Kim 2008). Third, extensive comparisons of multiple models reveal that over the past 2 decades different models have converged toward similar results (Reichler and Kim 2008). GCM projections include uncertainties and they represent some climate elements better than others. For example, confidence in the projections of temperatures is greater than for precipitation projections. As with all models, interpreting and applying results appropriately entails understanding models' strengths and limitations. (**back**)

8. What are the main sources of uncertainty associated with climate projections?

Uncertainty is the degree to which a value is unknown either from a lack of information, disagreement about what is known, or because the value may be unknowable (IPCC 2007). Climate projections, partly by design, embody a number of uncertainties. Sources include uncertainties about future emissions as driven by socioeconomic processes and influenced by currently unpredictable policy choices, variability internal to a given GCM's simulation of weather and climate, variability across GCMs related to parameterization and other model characteristics, and uncertainty or error in observed climate data used in downscaling GCM output. The relative contributions of these different sources of uncertainty varies by output variable, by how far out into the future the projection is carried, by the geographic extent of the analysis, and by latitude (Hawkins and Sutton 2009).

Some sources of uncertainty are quantifiable, particularly as climate observation networks improve. Others are not, such as what the cumulative global GHG emissions from human activity will be in 2050 or 2100. Nonetheless, uncertainty is not the same as incorrect information, nor does it mean we know too little to act. The suite of GCMs from AR4 reproduce the range of measured changes in temperature over the 20th century (fig. 4), illustrating that GCM-based climate projections for given future emissions scenarios are reliable. Decisions are routinely made in the context of military operations, monetary policy or financial investments—to name a few examples—where levels of uncertainty often exceed those of climate projections (Mabey and others 2011). Finally, uncertainty associated with climate projections is tempered by the fact that there is very little scientific confidence that average climate conditions of the last century will persist into the future (see next question). (back)

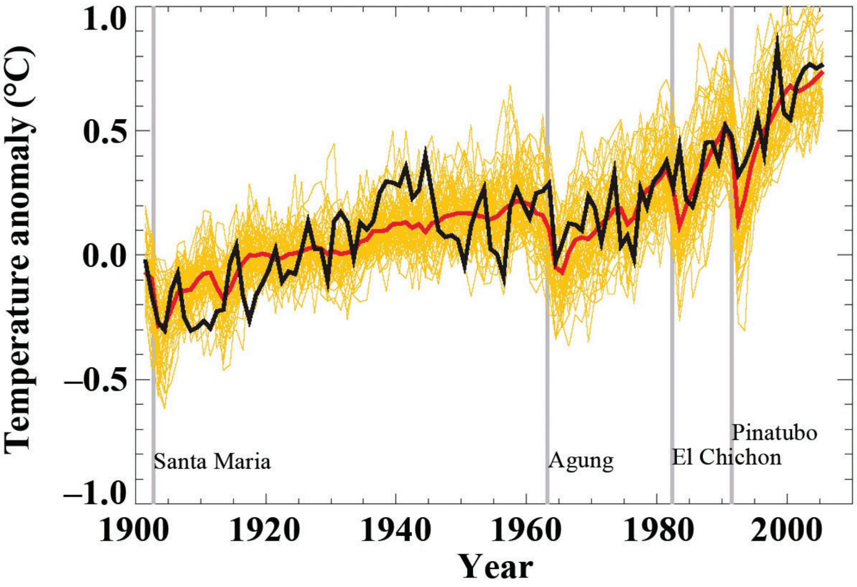

Figure 4—Global near-surface mean temperature anomalies (relative to the 1901 to 1950 mean) observed for the 20th century (black) and that simulated by fourteen different GCMs driven by natural and anthropogenic factors (yellow). The simulated mean is shown in red. Key volcanic eruptions are identified with vertical lines (gray) and labeled accordingly (source: AR4 WG1 Ch 8 p. 600).

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9. What are the robust findings with respect to future climate projections?

Global GHG emissions will continue to grow, given current policies. For the next two decades, a range of climate scenarios projects 0.2 °C warming per decade (IPCC 2007a, b) and time series of annual average temperature for North America show substantial warming since the middle of the 20th century (Shein 2006). With continued warming, the fraction of GHGs remaining in the atmosphere increases.

Even if emissions were stabilized, warming and sea level rise would continue for centuries owing to time lags in climate system feedbacks and also because once greenhouse gases are emitted, they remain in the atmosphere for decades to centuries (Solomon and others 2009).

Projected changes for which the AR4 concluded with high or very high confidence include the following.

- Warming is expected to be greatest over land and at high northern latitudes.
- Precipitation is likely to increase at high latitudes but decrease for subtropical land regions.
- Area covered by snow and sea ice will contract, while the thaw depth of permafrost increases for many regions.
- Semi-arid and dry regions, particularly at mid-latitudes, will experience decreased water availability due to changes in precipitation, evapotranspiration and snow-melt dynamics.
- At high latitudes and in the tropics, precipitation is likely to increase.
- Changing patterns of wind, precipitation, and temperature are anticipated with projected poleward shifts of extra-tropical storm tracks.

Building on these climate science findings, the IPCC (2007a) concludes that some ecosystems, sectors, and regions are likely to be especially affected. These include the ecosystems of the tundra, boreal forest, mountains, Mediterranean-type ecosystems, mangroves, salt marshes, coral reefs, and sea-ice biomes. Additional areas that are likely to be affected include low-lying coasts, water resources in some dry regions at mid-latitudes and in the dry tropics, and areas dependent upon snow and ice melt. Increased frequencies and intensities of extreme weather events—like heat waves and heavy precipitation—are likely to increase the impacts. (**back**)

Management Questions

10. What are the advantages and disadvantages of downscaling GCM projections? Do these vary by downscaling approach?

Downscaling the output of GCMs aids with visualizing and understanding potential climate futures in relation to local and regional landscapes. Different downscaling techniques present unique advantages and disadvantages as outlined in **Table 1**. (**back**, also see question 15)

11. Is downscaled data always better for my application?

Downscaling climate projections from the coarse resolution of GCM outputs certainly has its advantages (see questions 2, 4, 5). Finer scale climate scenarios may greatly facilitate a meaningful dialogue about management options under different sets of future conditions by allowing managers to visualize those conditions in relation to landscape features relevant to their unit and region.

Table 1—Advantages and disadvantages of different approaches of downscaling climate projections to finer resolution (from Benestad and others 2008; Fowler and others 2007; Mearns and others 2003; and Wilby and others 2004). (back)

	Advantages	Disadvantages
Statistical (including delta)	Techniques range from exceptionally simple to more elaborate, and are flexible enough to tailor models for specific purposes. Computationally cheap, allowing for consideration of many different emissions scenarios and GCM pairings. The same method can be applied across regions or entire globe. This can facilitate comparisons across applications or case studies. Relies on observed climate as a basis for deriving future climate projections. Can locate and assess the strength of coupled patterns among climate parameters, allowing for analysis of historical data as well as results from dynamical downscaling.	Relies on statistically sufficient density of observed data that may be unavailable for many areas or variables. Assumes that change factors and model bias remain constant over time and space, and that coarse-to-fine-scale climate relationships under future conditions will remain the same as modeled. The simplest methods may only provide projections at monthly resolution. Cannot account for feedbacks in regional climate systems that change as climate changes.
Dynamical	Based on consistent, physical relationships and resolves atmospheric and surface processes occurring at sub-GCM-grid scale. May better capture changes in inter-annual and inter-decadal variability, and in the magnitude and frequency of extreme events. May be set up to capture regional climate feedbacks by allowing interaction between regional processes and the overlaying GCM-scale circulation for the area modeled. Models climate system dynamics that are physically plausible but not necessarily part of historical/observed record. If using a dynamic land surface, can model impacts to regional climate driven by regional landscape changes resulting from natural processes, anthropogenic activities, or even climate change adaptation itself (e.g. vegetation change).	Computational requirements are often prohibitively intensive. Requires high-temporal resolution (e.g., 6-hourly) GCM output as input to regional model, which is not always archived for GCM model runs. Due to computational demands, typically RCMs are driven by only 1 or 2 GCM/emission scenario simulations, possibly under-sampling the range of likely future global climates. Limited number of regional climate models available with no model results available for many parts of the globe at present. May require further downscaling for some purposes. If using static surface vegetation conditions to interact with overlying atmosphere does not capture regional landscape changes interaction with climate.

Nonetheless, the finer resolution of downscaled data may inappropriately convey greater certainty or "accuracy" than the original, coarse GCM outputs, even though GCMs are optimized to simulate climate processes at their native resolution (Wilby and others 2004). Downscaling methods may actually add uncertainty and error that is difficult to quantify.

Some researchers have explored tradeoffs in error created in the downscaling process versus GCM uncertainties at native resolutions (Klausmeyer and Shaw 2009), demonstrating that it differs by climate variable and that further research is needed to understand scale-dependencies.[1] For many applications, knowing the sign of change (e.g., increase versus decrease in temperature) is enough to identify the potential impacts (e.g., increased heat stress, increased evaporative demand) and to define the range of possible management contingencies in the systems of interest.

Finally, in some locations (e.g., flat terrain over large areas) observed spatial variability is small for some variables, like air temperature. Downscaling data for these regions significantly increases the computational time and data storage demands of climate projections used in some ecosystem assessments without any appreciable increase in the utility of projected impacts. (**back**)

12. Where can I find guidance and information on climate projections available for my region?

Regional assessments of projected climatic trends and impacts are rapidly proliferating throughout the United States. One component of these assessments is a review of regional climate projections and the rationale for selecting the specific climate projections used in the assessment. This discussion may help National Forest units determine which climate projections are appropriate for their area. Leading sources include NOAA-funded Regional Impact and Science Assessment ("RISA") groups. Also, some states have funded climate impact assessments through universities. More recently, Department of the Interior bureaus have initiated numerous regional assessments, and Landscape Conservation Cooperatives, that are compiling information on regional climate projections and impacts. In 2009, the U.S. Global Change Research Program completed a National Assessment of Climate Change Impacts that included regional information on projected climate changes and from 2004-2009 released a number of synthesis and assessment products. Another periodic national climate assessment is underway currently. Nearly all of these impact assessment programs are sources of climate projection information for individual regions. Scientists from Forest Service Research Stations are a valuable resource

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[1] "Understanding scale-dependencies" refers to understanding the way in which the scale (both the spatial and/or temporal resolution and the total extent of area or time period examined) affects our understanding of the process or value in question.

for advice on acquiring and using regional climate projection data (see Appendices B and D). **Appendix C** details a number of regional climate impacts assessments that may inform planning and management decisions within Forest Service units. (**back**, also see question 17)

13. If more GCMs project a similar result for a given emissions scenario, does that indicate greater certainty and/or less error about the model's outcome?

In some respects convergence in projected outcomes across different climate models (holding the emissions scenario constant) may indicate a more refined and accurate representation of the underlying physical processes of the climate system. Confidence has increased through the advancing generations of GCMs as different modeling groups produce accurate simulations of observed climate processes and coarse circulation patterns. Indeed, the degree of model spread (the range of projected values across GCMs) is often assumed to provide some estimate of confidence for a particular climate system component or region of the world (Knutti 2008). However, models may share similar biases because of the way they are developed (Pirtle and others 2010) and, for good reason, since all are based on firmly rooted knowledge like conservation laws. Model independence across GCMs increases for components of the climate system where there is yet no consensus on the best approach, such as representation of cloud behavior in GCMs (IPCC 2001). An outlier scenario across a number of climate projections may be equally as likely or more likely than those representing central tendencies, because it may include processes or feedbacks not modeled in other GCMs. Excluding particular models for the purpose of understanding how their exclusion affects the range of climate projections is useful. In contrast, the indiscriminate exclusion of outlying climate values could negatively impact management's preparedness for extreme events and outcomes, which is a key goal in the context of land management. (**back**)

14. What can I expect from the next generation of climate modeling work? Is it better to wait for the next generation of climate scenarios or begin to assess impacts with scenarios available at present?

Climate projections for past IPCC assessments were based on "what if" emissions scenarios to explore how the climate system might respond in the long term given different assumptions about global development (see question 2). One component of the next IPCC assessment, however, will include climate *predictions* out to 2030, as opposed to *projections*. Given that the greenhouse gases driving near-term climate change over the next 2 decades have already been released into the atmosphere, these predictions will use the current climate as a starting point to assess the actual climate system changes. Despite that this near-term "predictive" component of the next assessment may sound more certain, results are unlikely to narrow the range of projected climate changes. In fact, uncertainty may increase as on-going GCM refinements improve the representation of ecological processes and include many more feedbacks that past model versions simply omitted.

Climate change is occurring now and decision makers need not wait for output from the next generation of climate models (likely available in 2013) to begin adaptation and mitigation planning. The magnitude of climate change and the resulting impacts on ecosystems present major challenges that will require creativity and ingenuity to address. While relevant new information and data are being produced continuously, very little of the information generated in the past decade or so has been shown to be irrelevant (Randall and others 2007). As with most resource-management issues, analysts and decision makers must proceed without perfect knowledge or unequivocal confidence in available information about future conditions regardless of what generation of modeling their climate projections are based on (see question 7). (**back**)

Research Questions

15. What are the implicit assumptions of statistical downscaling? Of dynamical downscaling?

Numerous assumptions are embedded in statistical downscaling, depending on the specific method. The delta method assumes changes in long-term averages can be applied uniformly to all events. For example, a GCM projection of +0.5 degrees in average March temperatures over a defined time period is applied to every observed March temperature in the baseline period by the same +0.5 degrees. Statistical downscaling assumes that GCMs provide a realistic simulation of predictor variables (in accordance with assumed socioeconomic driving forces for a given projection) and that a tight relationship exists between broad-scale predictors (e.g., atmospheric pressure fields) and the finer-scale climate variables they predict (e.g., precipitation). Statistical downscaling methods, using transfer functions based on comparison of local observations and GCM-scale simulations for the same historic period (e.g, 1971-2000), assume these relationships will remain the same over time. Numerous assumptions are also embedded in the various interpolation methods (not detailed here).

Current methods of dynamical downscaling assume that large-scale atmospheric circulation drives fine-scale events within the RCM by specifying the variables at the boundaries of the RCM spatial domain to be those from a GCM. This approach is referred to as boundary forcing. Another assumption of the dynamical approach is that the many physical and empirical model parameters developed or tuned under current climate conditions will remain valid for the future climate. (**back**, also see question 10)

16. How do I select a downscaled climate dataset, from which climate model(s) and driven by which emissions scenarios?

Global simulation results from a suite of 23 GCMs used in the AR4 are archived and accessible online[2] (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php). These GCMs have been well-vetted in the scientific literature and share many basic features in how they characterize physical relationships of the climate system. However, models differ in many key respects including climate sensitivity (i.e. a model's response to doubled atmospheric CO_2); parameterization of sub-grid scale process (e.g., cloud formation and dissipation); treatment of land surface processes; and spatial resolution. Data archived for AR4 models include simulations of 20th century climate, and select emissions scenarios (typically A1B, A2, and B1).

There is no single "best" downscaled dataset for all applications across regions or even within a single region. Exploring the greatest possible range of projected climate change is highly advisable in order to increase the range of impacts considered in planning for the future. Yet, in practice, analyzing results from every possible combination of climate model and emissions scenario would be time-consuming, expensive, and unwieldy (**fig. 5**). So a range of approaches have been used to select subsets of climate projections that maximize the range of projections to the extent practical, depending on the questions addressed in impacts studies.

In selecting models, many analysts consider a GCM's ability to simulate 20th century climatic conditions for the region of interest (e.g., multi-year averages, trends and seasonal patterns in precipitation and temperature). Research demonstrates some GCMs are better than others in replicating 20th century conditions of particular regions (Cai and others 2009). The most appropriate GCMs for the Pacific Northwest are different from those for the Southeast. And although a model's ability to simulate the past is no guarantee of its ability to simulate the future, particularly at finer scales, this nonetheless serves as one criterion for distinguishing the relative performance of climate models. Also, impact analysts may consider how results from individual GCMs for the climate variable of interest compare with a multi-model ensemble mean.

A number of impact studies have based their analyses on a subset of projections that were chosen to bracket the full suite's projected temperature and precipitation ranges (CWCB 2010), or use a multi-model mean with two or more bracketing GCMs where both approaches attempt to encompass a substantial portion of the range of results for the climate variable of interest among all available GCMs (Littell and others 2011). While a bracketing approach is helpful in exposing and considering some of the uncertainty inherent in GCM simulations, simplifying

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[2] For some GCMs, multiple simulations of the same conditions—known as individual "realizations"—are available. The different "realizations" are useful for examining the natural internal climate variability represented in the model.

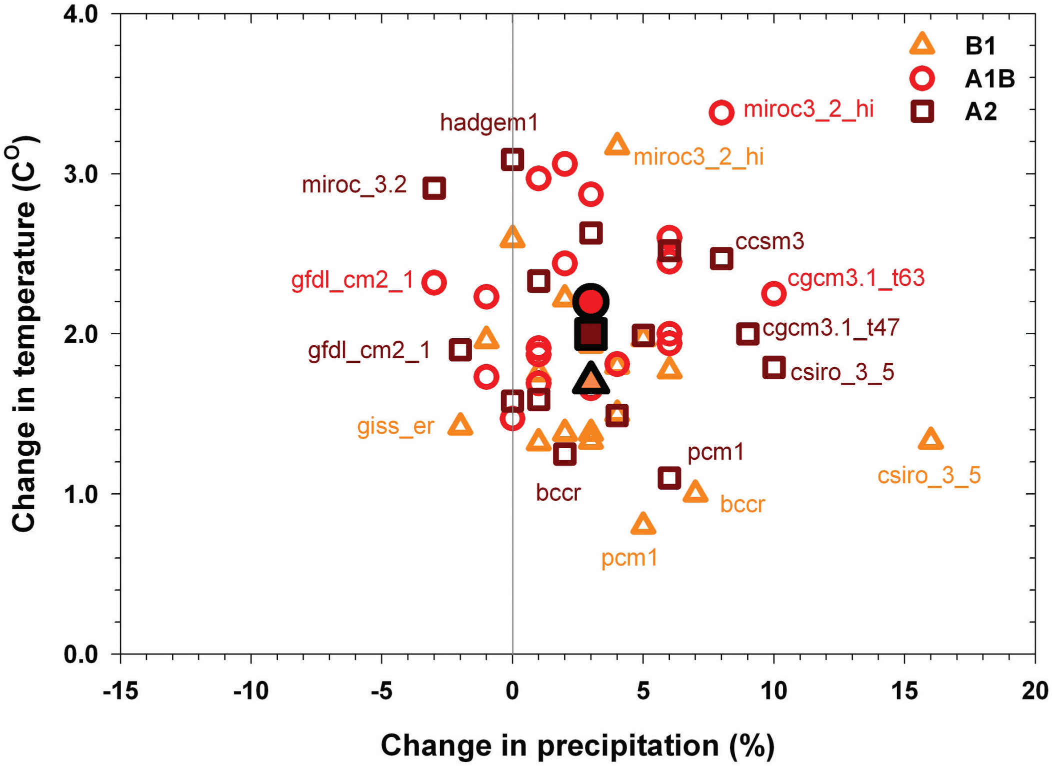

Figure 5—Scatterplot of change in annual average temperature (°C) and precipitation (%) projected by different GCMs for the 2040s (2030-2059) in the Upper Missouri River Basin. Triangles represent GCM simulations of the B1 emissions scenario; circles = A1B; and squares = A2. Large bold symbols represent multi-model averages for each emissions scenario (source: Littell and other 2011).

Back

the characterization of individual model projections as strictly "hot," "dry," etc. is difficult for large regions and particularly for different seasons in the same region. While the multi-model ensemble is suggested as the most-optimal approach for some applications (Pierce and others 2009), the assumption that a suite of different models provides statistically independent information evenly distributed around the true state may not be valid (Pennell and Reichler 2010).

Impact analysts also face choices regarding which emissions scenarios to include in their analyses. The differences in cumulative emissions across different emissions scenarios do not begin to generate significant differences in projected climate until mid-century. So for questions focused on projected changes over the next three to four decades, the choice of emissions scenarios to consider is less important than the choice of GCMs when interested in the climate part of the projections alone (as opposed to also using demographic projections and other components of emissions scenarios for separate impact models as done in the 2010 RPA Assessment, (USFS 2012)). After mid-century, cumulative emissions from different scenarios and their respective influences on climate begin to diverge. As a result, for longer-term analyses (e.g., out to 2100), emissions scenario selection becomes a more important consideration in selecting and interpreting climate scenarios. In sum, when evaluating which GCMs and emissions scenarios to use in developing a climate projection for regional impact analyses, it is helpful to consider the relative importance of mid-century and late-century projections to the decisions being made. (**back**)

17. Where can I access output from model runs of different GCMs, particularly downscaled data?

Data from global simulations produced as part of IPCC 4th Assessment Report are available online from the Coupled Model Intercomparison Project of the World Climate Research Program, known as "CMIP3" data archive (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php). This archive containing native-resolution GCM data, is intended to support research and advanced analyses, and is unlikely to be particularly useful to resource managers.

- Santa Clara University and the U.S. Bureau of Reclamation (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html), in partnership with U.S. DOE Lawrence Livermore National Laboratory, has developed a public-access archive of statistically downscaled climate projections. The online archive includes downscaled versions of 112 climate projections, included in the CMIP3 multi-model dataset mentioned above. The BCSD downscaling has been applied to support multiple climate change impacts assessments on water resources in the western United States. Each downscaled projection dataset includes monthly temperature and precipitation, for 1950-2099, at 1/8 degree spatial resolution, covering the contiguous United States. Conveniently formatted data are freely available at their website, which includes functions to support customized data requests (e.g., by variable, time period, geographic region). The site also includes data documentation, limitations, and a tutorial to orient new users.

- The Nature Conservancy, in collaboration with the University of Washington and the University of Southern Mississippi, has created the Climate Wizard, (http://www.climatewizard.org/) which enables technical and non-technical audiences to easily access online estimates of changes in average temperature and precipitation. The climate projections for the United States are the same as produced by the Santa Clara/Bureau of Reclamation website above, but provide some enhanced abilities for viewing and analyzing data, navigating the database, and downloading climate data into ArcGIS.

- The CASCaDE Project (http://cascade.wr.usgs.gov/data/Task1-climate/index.shtm) of the USGS maintains a website serving statistically downscaled data, using a constructed analogues method, minimum and maximum temperature, plus precipitation data over the conterminous United States.

The website provides access to gridded historical data, simulations from two GCMs (GFDL CM2.1 and PCM1) driven by two emissions scenarios (B1 and A2), downscaled to a 7.5 mi grid using the constructed analog method.

- The Climate Impacts Group at the University of Washington provides downscaled data from a number of AR4 GCMs via three different downscaling methods (hybrid delta, transient BCSD, and delta method) for two emissions scenarios (A1B and B1) for the Pacific Northwest region. A description of the available datasets and variables can be found on the Climate Impacts Group website (http://www.hydro.washington.edu/2860/new_users/).

- The Rocky Mountain Research Station Forest Sciences Laboratory (http://forest.moscowfsl.wsu.edu/climate) in Moscow, Idaho, maintains delta method downscaled climate data covering all of North America. The website generates custom gridded or point-based estimates of monthly average, minimum, and maximum temperature, plus precipitation for the climate normal period of 1961-1990 and for three future 10-year periods: 2030, 2060, and 2090 according to the projections of these TAR-generation GCM/scenario combinations: CGCM3 from the Canadian Center for Climate Modeling and Analysis, scenarios A1B, A2, and B1; HadCM3 is from the Hadley Center scenarios A2 and B2; GFDL CM2.1 is from the Geophysical Fluid Dynamics Laboratory, scenarios A2 and B1. No explicit grid resolution is associated with the data as they are based on spline surface techniques.

- The North American Regional Climate Change Assessment Program (http://www.narccap.ucar.edu/index.html) makes available dynamically downscaled data covering the conterminous United States and most of Canada at 50 km resolution for multiple pairings of RCMs and GCMs driven by the A2 emissions scenario. Climate is projected for a mid-range future time period (2041-2070) and compared to a current period of 1971 to 2000.

In addition, to these global and national online databases, regional or state level databases are also accessible online, including the following.

- The Scenarios Network for Alaska Planning (SNAP) maintains an online repository of downscaled climate projections covering Alaska. Datasets include projected changes in average monthly temperature and total precipitation, snow-water equivalent, and other derived data. Data sets are provided for five GCMs each driven by three emissions scenarios (B1, A1B, and A2), and a multi-model ensemble. The projections are statistically downscaled to a 1.2 mi grid using the basic delta method with bias correction.

- Northeast Climate Change Impact Assessment climate data website (http://www.northeastclimatedata.org/welcome_home.php?userID=38) contains downscaled climate projection data from three GCMs, each run with two emissions scenarios (A1FI and B1), and two downscaling methods (1/8 degree gridded data produced via BCSD), and "city-level" downscaled data for six large cities in the Northeast based on simple regression analysis.

- The State of Idaho also has an online repository of downscaled climate projection data for the western United States downscaled via modified BCSD approach and with a spatial resolution of 2.5 mi (http://inside.uidaho.edu/index.html).

- The RPA Scenarios used in the 2010 RPA Assessment used nine projection scenarios (A1B, A2 and B2 emissions scenarios, each for three GCMs) and a set of historical climate data available at the county or 1/12 degree scale.

The resources listed above are not comprehensive. Several of the Department of Interior's Landscape Conservation Cooperatives and their Climate Science Centers are actively pursuing development of additional web services for delivering downscaled climate data for some areas of the United States. Climate modeling centers in the United States (e.g., Geophysical Fluid Dynamics Laboratory and the National Center for Atmospheric Research) and around the world provide free access to data generated by their GCMs. (**back**, also see question 12)

18. Where can I find further guidance on developing or using downscaled climate projections for my research?

A number of climate change adaptation guidebooks include sections addressing the use of climate models and derived data for climate change impact analyses (e.g., Barsugli and others 2009; Peterson and others 2011; Ray and others 2008; Stein and others 2011). These guidebooks provide a very approachable starting point for exploring how downscaled climate projections might be useful for your research. More detailed and technical guidance is available on the use of climate scenarios produced through dynamical modeling (Mearns and others 2003) and also for statistically downscaled climate projections (Wilby and others 2004). They review the nuances of different techniques within the two different approaches, along with detailed explanations of their respective assumptions, strengths, and limitations. These guidelines also consider the degree of value that is added through finer-resolution climate data for different goals and contexts. Pierce and others (2009) address the question of selecting a GCM for regional climate change studies, concluding the superiority of multi-model ensemble means over any single GCM for many types of regional applications. Knutti and others (2010) discuss the challenges of interpreting ensemble means, and Pennell and Reichler (2010) raise questions about the effective number of GCMs within the ensemble. Yet, clearly using more than one climate projection is absolutely vital for capturing a range of plausible futures.

The spatial scale (resolution and extent), geographic location (particularly latitude), and temporal domain (near-term versus long-term) are all important factors to explicitly consider as related to your research questions in order to find and interpret guidance on the use of climate projections. You might first consider the sensitivity of your research target—the system, species, or process of interest—to changes in mean climate conditions and to increasing climate variability. Has a particular climate variable, such as relative humidity, been identified as influential with respect to your research target? This step may help identify the climate variables and the most relevant driving forces that are most important for your study. Driving forces may include different demographic, land use, energy supply or macroeconomic assumptions evaluated by different emissions scenarios.

Unless you are developing your own climate projections (i.e. selecting the GCM, emissions scenario, downscaling methods, etc.) you may be either aided or constrained by the climate projections already available for your region of interest. Availability of a downscaled variable at a particular temporal resolution key to the analysis at hand (e.g., daily temperature maximum) may play a key role in the selection of climate projections for practical reasons alone. The climate variables, and their derivatives, vary by downscaled dataset. Downscaled climate variables with high temporal resolution may be scarce. The database underlying the summary chart of downscaled climate data holdings within the Forest Service in **Appendix D** may assist you in locating readily available downscaled climate projections appropriate for your criteria. Also, regional climate research centers (see question 12) may publish relevant evaluations of the skill-level of different GCMs in simulating observed climate features for your study area. (**back**)

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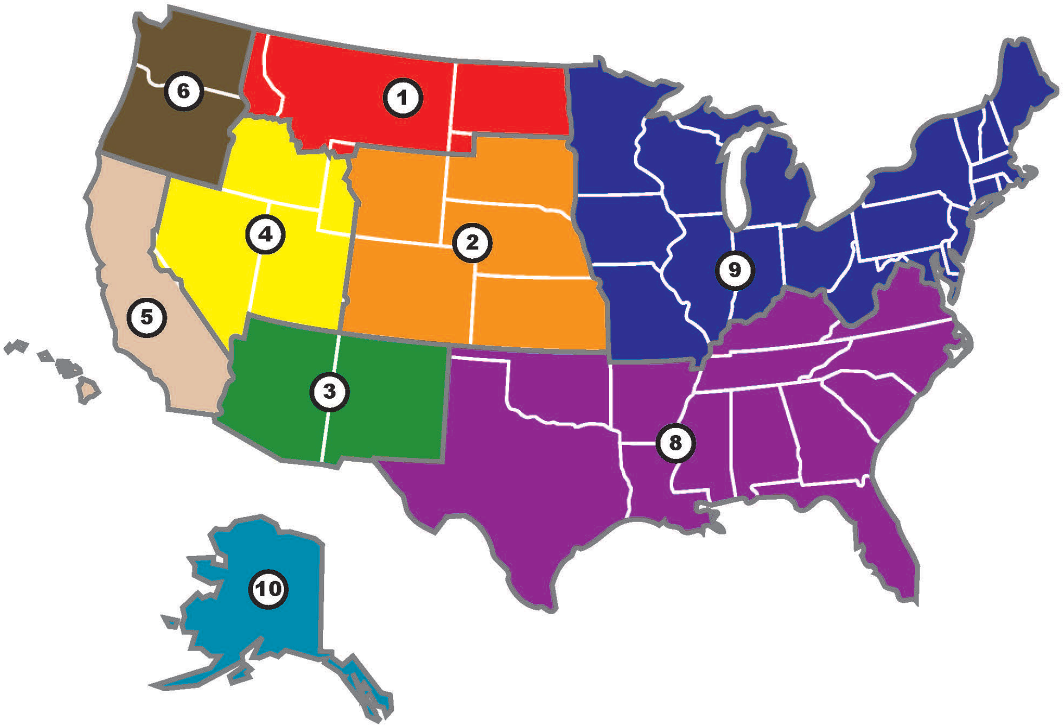
Appendix A: USDA Forest Service Regions. (back)



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Appendix C—Regional assessments using climate projection information (back)

Assessment	Year	Spatial Domain	Spatial Resolution	Statistical Downscaling Method	Regional Climate Model	# of GCMs/ Emissions Scenarios	Multi-model ensemble
NE Climate Impacts Assessment/ Climate Change and Massachusetts Fish and Wildlife	2006/ 2010	8 States NE U.S.	1/8° (~6.5mi)	BCSD	CMM5	3/2	N
Climate Change in Colorado	2008	36-42°N – 110-101°W	1/8° (~7mi)	Delta	N	22/1	Y (22 CMIP3 models)
California Climate Scenarios	2007	California	1/8° (~7mi)	BCSD	N	3/2	N
Wisconsin's Changing Climate	2011	Wisconsin	5mi		N	14/3	Y
Lake Tahoe Basin Assessment	2010	Lake Tahoe Basin	1/8° (~7mi)	Constructed Analogs	N	1/2	N
Climate Change in Prince George	2009	North-central British Columbia	28 mi & GCM scale	N	CRCM4	1/1, 22/3	N
Chequamegon-Nicolet National Forest Ecosystem Vulnerability Assessment and Synthesis	In prep.	Northern Wisconsin	1/10 GCM scale	N	N	general climate 3/2 (tree species distribution model)	N
Evaluating Sustainability of Projected Water Demands Under Future Climate Change Scenarios	2010	Contiguous US	1/8° (~7mi)	BCSD	N	16/1	Y
Connecting Alaska Landscapes into the Future	2010	Alaska	1.2 mi	Delta	N	5/3	N
Washington Climate Change Impact Assessment	2010	Washington/ Columbia Basin	1/16° (~3.5mi)	Delta & BCSD-modified	(see below)	20/2	Y
Washington Climate Change Impact Assessment	2010	Washington/ Columbia Basin	22.4 mi & 12.4 mi	(see above)	CCSM3-WRF and ECHAM5-WRF	2/1	N

Appendix D Part I. (back)

Other USFS Downscaled GCM Data

by Model + Emissions Scenario (updated 2/28/11)

Group	Model	Equilibrium Sensitivity (°C)[2]	Emissions Scenarios[3]					Downscaled Runs	
			B1	B2	A1B	A2	A1FI	total per GCM	national only per GCM
Pre-AR4 Models	CSIRO_MK2	n/a		US				1	1
	HadCM3	n/a		US				1	1
	CCMA_CGCM2	n/a		US				1	1
	INGV_ECHAM4	n/a			HI			1	0
Ensemble	10 Model Ensemble Mean*	n/a			PNW & N.Rockies(3)			3	0
Unpublished Sensitivity	CSIRO_MK3.5	n/a	US		US(2)	US(2)		5	5
	GISS_AOM	n/a			HI			1	0
	CNRM_CM3	n/a	US		US	US		3	3
	BCCR_BCM2.0	n/a			PNW & N.Rockies			1	0
		Scenario Total	2	3	9	3		17	
		National Total	2	3	3	3			11

Increasing Cum. Emissions →

*(BCCR_BCM2.0, CNRM_CM3, CSIRO_MK3.5, MPI_ECHAM5, ECHO_G, UKMO_HADCM3, UKMO_HADGEM1, MIROC3.2_HIRES, MIROC3.2_MEDRES, NCAR_PCM1)

Appendix D Part II. (back)

USFS Downscaled GCM Data (AR4 or later)

by Model + Emissions Scenario (updated 2/28/11)

Increasing Climate Sensitivity

Model Sensitivity[1]	Model	Equilibrium Sensitivity (°C)[2]	Emissions Scenarios[3]					Downscaled Runs	
			B1	B2	A1B	A2	A1FI	total per GCM	national only per GCM
high	UKMO_HADGEM1	4.4			HI			1	0
	IPSL_CM4	4.4			HI			1	0
	MIROC3.2_HIRES	4.3			HI			1	0
	MIROC3.2_MEDRES	4	Global, US (3), OR/WA		Global, US(4), HI, OR/WA, PNW&N.Rocks	Global, US(4), OR/WA		19	11
medium	CCMA_CGCM3.1_T47	3.4	US(3)		US(4), HI	US(4), 4Corners		13	11
	ECHAM5	3.4			PNW&N.Rocks			1	0
	CCMA_CGCM3.1_T63	3.4	US		US, HI	US		4	3
	GFDL_CM2.1	3.4	US, E.US	US	US, HI	US(2), PNW& N.Rocks, 4Corners	E. US	10	5
	MPI_ECHAM5	3.4			HI			1	0
	UKMO_HADCM3	3.3	Global, US(5), E.US, OR/WA		Global, US (4), PNW&N.Rocks, HI, OR/WA	US(4), PNW&N.Rck 4Corners, OR/WA	E. US	24	13
	MIUB_ECHO_G	3.2			HI			1	0
	MRI_CGCM2.3.2	3.2	US		US, HI	US		4	3
	CSIRO_MK3.0	3.1	Global, US, OR/WA		Global, US, HI, OR/WA	Global, US, OR/WA		10	3
	GFDL_CM2.0	2.9	US (2)		US (3), HI	US(2)		8	7
	NCAR_CCSM3	2.7	US(2)		US (3), PNW& N.Rocks, HI	US(2), S.US, PNW& N.Rocks, 4Corners(2)		13	7
	GISS_ER	2.7	US		US, HI	US		4	3
	GISS_EH	2.7			HI			1	0
low	IAP_FGOALS_G1.0	2.3			HI			1	0
	NCAR_PCM1	2.1	US		US	US	E. US	4	3
	INM_CM3.0	2.1	US		US, HI	US		4	3
Not included here: Ensembles; Runs from GCMs without published climate sensitivities (BCCR_BCM2.0, GISS_AOM, CCMA_CGCM3); TAR vintage models.		Scenario Total	30	1	53	38	3	125	
		National Total	22	1	25	24	0		72

Increasing Cum. Emissions →

B1: high GDP; low pop. growth, peaking mid-century then declining; development emphasizing service & info economy; emphasizes global sustainability solution

B2: medium GDP; intermediate economic dev.; continuously increasing pop. yet lower than A2; local/regional solutions for environmental protection & social equity

A1B: v. high GDP; rapid economic growth; pop. peaking mid-century then declining; economic convergence, diminished diffs in per capita income; balanced energy sources

A1FI: v. high GDP; rapid econom growth, pop. peaking mid-century hen declining; economic convergence; diminished diffs in per capita income; fossil-fuel intensive system

A2: medium GDP; heterogenous world w/ regional economic development; continuously increasing pop. (higher than B2); slow technological change

[1] Model sensitivity classified as follows: <2.7° = low, 2.7-3.4° = medium, >3.4° = high

[2] IPCC Working Group I, Fourth Assessment Report http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html p. 631

[3] Scenario cumulative emissions classification: IPCC Working Group III, 2000. SRES p. 244

Cum. Emissions Classification by 2100* (projected range increase°C)**

B1: <516 ppm (1.1-2.9)

B2: 516-681 ppm (1.4-3.8)

A1B: 681-845 ppm (1.7-4.4)

A1FI: (not available from Figure 5-1 p. 244)(2.4-6.4)

A2: >845 ppm (2.0-5.4)

*class that the marker scenario for each family falls in (source: SRES, I converted from GtC to ppm); **source: IPCC AR4 WG1 SPM

Appendix E: Glossary of Key Terms.

accuracy Back

A measure of how close a quantity is to its actual, true value. In relation to future climate projections, it is typically inappropriate to discuss the "accuracy" of climate projections as used for IPCC assessments to date. This is because the emissions scenarios that drive such projections vary in their assumptions about socioeconomic development; are not assigned a degree of likelihood; and by-design, are intended to explore how climate might vary along different development storylines.

climate change impacts assessment Back

A process to identify and evaluate the effects of climate change on natural and human systems, as well as the product(s) from that process (adapted from Savonis and others 2008).

climate change impacts Back

The effects of climate change on coupled natural and human systems (adapted from Savonis and others 2008).

climate projection Back

A quantified response of the climate system, based on GCM simulations, to a particular scenario of climate driving forces. *Projections* are distinguished from *predictions* in this context since the former are designed to explore "what if" scenarios as opposed to intending to predict actual values for the future climate.

climate (change) scenario Back

A plausible and often simplified representation of the future climate, based on an internally consistent set of known principles about the climate system and a given set of assumptions about climate driving forces. A 'climate change scenario' is the difference between a climate scenario and the current climate (adapted from USFS 2011).

emissions scenario Back

A plausible representation of the future emissions of radiatively active substances in the atmosphere, like greenhouse gases and aerosols. These scenarios are based on coherent and internally consistent assumptions about driving forces such as demographic and socioeconomic development, technological change, etc. To date, the IPCC has developed two sets of emissions scenarios: the IS92, used for the Second Assessment, and the SRES scenarios used for the TAR and AR4. GCM-based climate simulations for the AR5 will be based on "representative concentration pathways" (RCPs). Trajectories of emissions concentrations will drive the models without regard to the societal and natural forces that result in those emissions. In parallel, scenarios will be developed to see what socioeconomic development paths result in emissions concentrations corresponding to RCPs.

ensemble Back

A group of parallel model simulations used for *climate projections*. Variation of the results across the GCMs in an ensemble is one approach to estimating uncertainty. Ensembles composed of a number of simulations from the same GCM but with different starting conditions characterize the uncertainty owed to internal climate variability. Ensembles composed of many different GCMs characterize uncertainty associated with GCM differences.

extreme event Back

An event such as a flood or drought 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. Extreme weather events include floods and droughts (adapted from Christensen and others 2007).

general circulation model (GCM) Back

A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, and their interactions and feedback processes. The climate system can be represented by models of varying complexity. Coupled atmosphere/ocean/sea-ice general circulation models (GCM, also known as AOGCMs) provide a comprehensive representation of the climate system (adapted from Savonis and others 2008).

parameterization Back

Accounts for processes occurring at a finer-scale than a given climate model's grid cell size can represent. Parameterizations are based on empirical relationships and are applied universally to all grid cells. Parameterization schemes are improved by running GCMs many times where everything is held constant except small tweaks in the parameter settings (adapted from Barsugli et al. 2009).

regional climate model (RCM) Back

A model covering typically a continent, or a subregion thereof, capable of resolving fine-scale climate processes and effects of land use, topography, etc. In dynamical downscaling, climate variables from a GCM are input at the spatial boundaries of an RCM (adapted from Christensen and others 2007).

uncertainty Back

An expression of the degree to which a value (e.g., the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. Uncertainty arises from many sources—from quantifiable errors in the data, to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can be represented by quantitative measures (e.g., a range of values calculated by various GCMs) or by qualitative statements (e.g., reflecting the judgment of a team of experts) (adapted from USFS 2011).

vulnerability Back

The degree to which a system, species or resource is susceptible to, and unable to cope with, adverse effects of stressors, including climate variability and extremes. Vulnerability to climate change is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (adapted from USFS 2011).

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