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Technical Memorandum No. 86-68210-2016-10

Evaluating the Relevance, Credibility, and Applicability of CMIP5 Climate Projections for Water Resources and Environmental Planning

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

September 2016

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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1. Introduction

Water resources planning and management often focus on reducing the impacts of hydrologic variability and extremes such as droughts and floods. To meet these objectives, water resources planning studies routinely consider hydrologic variability and extremes on timescales ranging from days to decades. Because weather and climate are two primary drivers of hydrologic variability on a continuous time-scale, these studies also consider—implicitly or explicitly—variability and extremes in precipitation, temperature, and other climate variables that impact hydrologic conditions and water supplies and demands.

Water resources planning has traditionally relied on historical observations as the basis for characterizing the likely range of future climate and hydrologic conditions. Similarly, historical observations, in combination with assumptions regarding future population and economic growth, served as the basis for projecting future water supplies and demands. A vast amount of research over the past two decades, however, has demonstrated that climate change is altering, and will continue to alter, climate and hydrology across the globe. This research suggests that historical observations are not sufficient to characterize the potential range of climate and hydrologic conditions over future decades. In response, numerous federal and state agencies have adopted guidelines, directives, and mandates that require consideration of climate change in long-term water resources and environmental planning.

Significant progress has been made in developing technical methods to incorporate climate projections into analyses of hydrologic variability and extremes, and numerous studies have been carried out to assess impacts and vulnerability of water resources systems to projected climate change. These studies have helped to build awareness about the potential impacts of climate change and to begin quantifying the risks of climate change in the context of water resources management. With the evolution of agency directives and mandates regarding consideration of climate change, water resources planners and managers are now required to consider climate projections in developing and conducting technical analyses to support major decisions. In other words, consideration of climate change is no longer limited to research studies and sensitivity analyses—it is now a required element of many planning studies that directly support major decisions ranging from infrastructure investments to development of long-term operating plans.

As the use of climate projection information evolves from relatively simple standalone impact and vulnerability assessments into high-profile decision-support studies, planners and managers require a consistent framework for selecting climate projection information to support specific investment and management decisions. To this end, the U.S. Department of the Interior Bureau of Reclamation (Reclamation) recently collaborated with the U.S. Army Corps of Engineers (USACE) and the National Oceanic and Atmospheric Administration (NOAA) to develop a conceptual framework for selecting climate projection information. The overall objective of this collaborative project was to demonstrate and evaluate this conceptual framework by applying the framework to select climate projection information for a hypothetical planning study.

This report summarizes the conceptual framework developed by Reclamation, USACE, and NOAA and documents research activities carried out as part of this collaborative project. Chapter 2 summarizes the conceptual framework developed by Reclamation, USACE, and NOAA, referred to here as the Climate Projection Applicability Framework (Applicability Framework). The objectives of this study are detailed in Chapter 3, and the methods used to achieve the study objectives are summarized in Chapter 4. Study results are presented in Chapter 5. Conclusions from the pilot workshop are discussed in Chapter 6.

2. Overview of the Climate Projection Applicability Framework

Reclamation, USACE, and NOAA recently developed the Climate Projection Applicability Framework (Applicability Framework) to guide water resources and environmental planners in selecting climate projection information for use in technical and planning studies to support major decisions, including decisions regarding infrastructure investment and development of long-term operating plans. The Applicability Framework is a conceptual framework based on three core elements or considerations, summarized below and illustrated in Figure 1:

1. Identify climate aspects that are relevant to the study situation;
2. Evaluate credibility of climate projections with respect to relevant climate aspects;
3. Determine which aspects of climate projections are applicable to the study situation based on consideration of relevance and credibility.

It should be noted that the Applicability Framework has not been formally adopted by Reclamation, USACE, or NOAA. However, the three core elements of the Applicability Framework form the underlying basis of guidance recently developed by Reclamation for incorporating climate change information into water resources planning studies (see Reclamation 2014).

As used in the Applicability Framework, the term climate aspect refers to a specific feature of the climate system. Climate aspects are defined by a given climate variable at a specified spatial and temporal domain and resolution—e.g., total wintertime precipitation over a watershed of interest or monthly average daily maximum temperature at a specific location. The term climate projection refers to quantitative projections of future climate conditions. Climate projections are typically developed by using global climate models (GCMs) to simulate climate conditions under specified future emissions scenarios. Climate projections also include GCM-based projections that have been statistically or dynamically downscaled to finer spatial resolution.

The first component of the Applicability Framework involves identifying the climate aspects that are relevant to a given decision, where a climate aspect is considered relevant if a change in that aspect is likely to affect the decision outcome(s). The relevance of a given climate aspect will depend on the study situation. For example, decisions regarding investments in local flood reduction such as the design and construction of a new levee system are likely to be sensitive to precipitation characteristics on shorter timescales, including the intensity, duration, and frequency characteristics of precipitation at timescales from one hour to several days. By contrast, decisions regarding management of regional water supply or investments in ecological restoration may be most sensitive to characteristics of precipitation and temperature variability on seasonal to interannual timescales. Relevance can be assessed quantitatively through sensitivity analysis, for example, by using rainfall-runoff model or water resources planning model to simulate sensitivity to changes in climate-related inputs. Where the necessary data or tools are not available to carry out a quantitative sensitivity analysis, relevant climate aspects may be assessed analytically or qualitatively by planners, managers, and technical specialists.

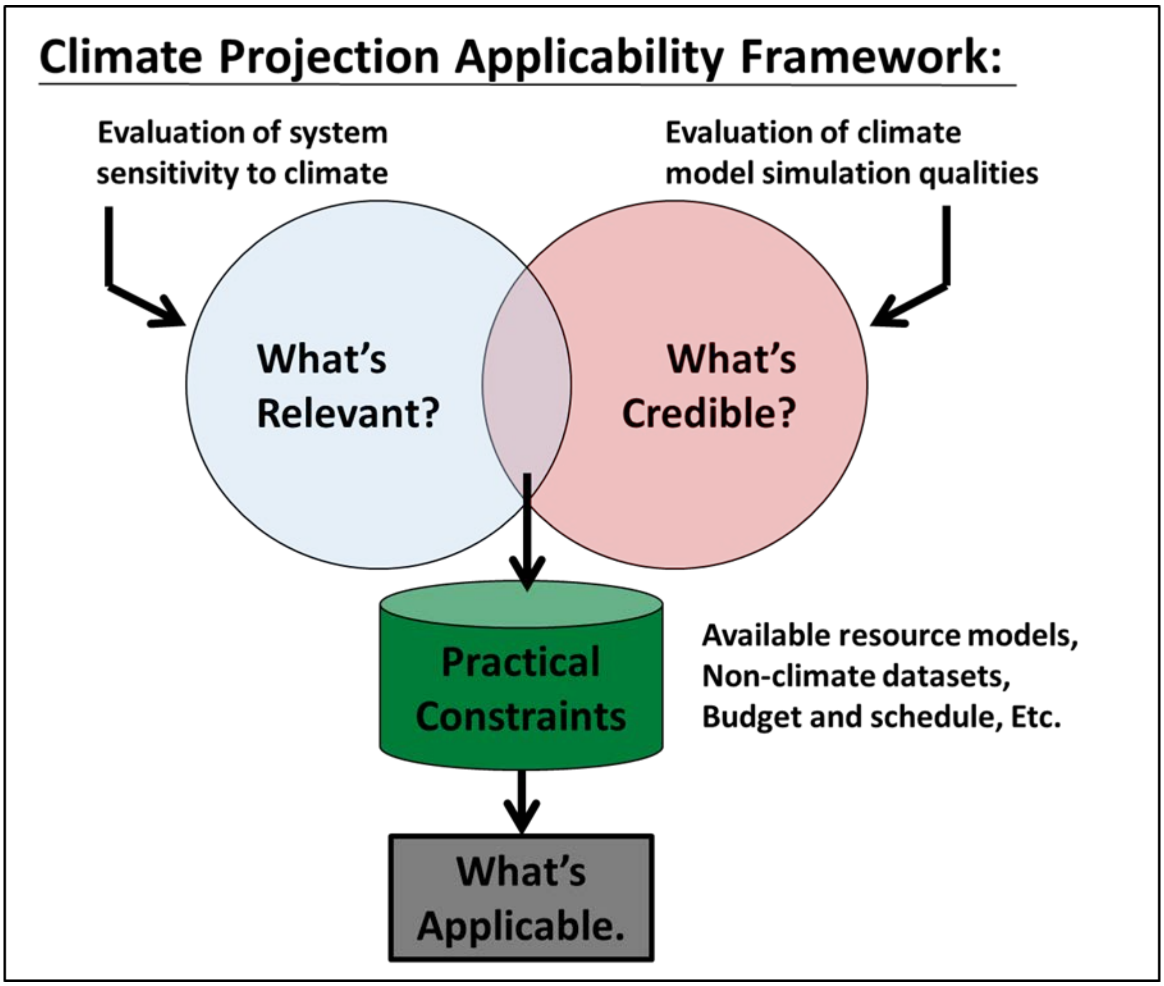

Figure 1.—Schematic illustration of the Climate Projection Applicability Framework

The second element of the Applicability Framework involves evaluating the credibility of available climate projections with respect to climate aspects of interest. In the context of the Applicability Framework, the term credibility refers to the perceived skill of a given climate projection in representing a given climate aspect under current conditions and the change in that aspect in response to anthropogenic forcings, including greenhouse gas and aerosol emissions, land cover change, and other factors. Similar to relevance, the credibility of a given climate projection will depend on the study situation and the climate aspects most relevant to the decision being considered. For example, climate projections based directly on outputs from a GCM often reproduce observed climate variability and trends quite well at larger (e.g., continental) spatial scales and longer (e.g., seasonal) timescales, while exhibiting significant biases at smaller (e.g., watershed) spatial scales and shorter (e.g., daily) timescales. GCM-based projections may therefore be judged as credible for use in a study to support national and international policy decisions and simultaneously judged as not credible for use in a study to support long-term planning decisions for a local water agency.

Credibility is, to some extent, subjective as it requires assessing the "trustworthiness" of climate projections for use in decision making. In general, credibility is assessed by evaluating how well the method or model used to produce a given climate projection is able to reproduce observed climate. In the case of GCM-based projections, credibility is often assessed by comparing GCM simulations of 20th century climate to historical observations. Assessing credibility may also include consideration of the theoretical basis of a given model or method used to develop a given climate projection, as well as how that theoretical basis is implemented in that model or method. However, it is important to note that climate projections cannot be directly evaluated against observations, as projections by definition apply to future conditions and observations of the future obviously are not yet available. As a result, substantial judgement is involved in assessing the credibility of climate projections based on evaluation over a historical period.

The third and final element of the Applicability Framework involves selecting the climate projections—or climate aspects thereof—that are applicable to the decision at hand. In the context of the Applicability Framework, the term applicable represents the intersection of relevance and credibility. In other words, a climate projection is considered applicable where assumptions regarding future climate are likely to affect the study outcome(s) (relevance criteria) and where climate projections are considered sufficiently trustworthy to support the decision at hand (credibility criteria). A key concept underlying the Applicability Framework is that study teams should prioritize study resources to incorporate climate projections (or aspects thereof) into their analysis where they are most relevant and most credible, while devoting fewer study resources to incorporating climate projections that are judged to be less relevant and/or less credible. As illustrated in Figure 1, in addition to considering relevance and credibility, judgement regarding the applicability of climate projections must also consider the overall study context, including the available resource models and non-climate datasets as well as the realities of study budget and schedule.

3. Study Purpose, Objectives, and Tasks

Reclamation, USACE, and NOAA prepared a Collaborative Project Summary to define the study purpose and objectives, key tasks, and roles and responsibilities of each agency prior to initiating the study. The Collaborative Project Summary is included as Appendix 1 of this report.

As defined in the Collaborative Project Summary, the purpose of this study is to address the following critical questions related to selection of climate projection information for use in water resources and environmental planning studies and assessments:

Question 1: *How good are the model projection results from CMIP5 for water resources and environmental planning applications?*

a. *What is the broadband of performance characteristics collectively relevant for these various applications?* This broadband should encompass the primary climate state variables and derivatives, spatial and temporal scales, and measures of skill and fidelity that are relevant for water resources and environmental planning applications.

b. *What are the components of a framework that structures this broadband of performance characteristics to support subsequent discussions on the applicability of CMIP5 projections in planning and assessment situations?* This framework should allow for various types of CMIP5 GCM output, including bias-corrected and spatially downscaled translations of this output. There will be some overlap between state variables projected by GCMs and extended from observations, but also some unique to each information type.

Question 2: *How applicable are the CMIP model projections for water resources and environmental planning applications?*

a. *How do we develop a general framework to judge information applicability that flexibly addresses unique aspects of a local planning and assessment situation?* Unique aspects of a local management situation include the management objectives, management actions being considered, assessments necessary to support a decision among these actions, and climate aspects that are relevant to the assessments.

b. *How do we determine relevant climate aspects within this framework?*

c. *How do we evaluate the credibility (trustworthiness of projection information on these relevant climate aspects, leveraging the broadband performance characteristics framework developed under Question 1?*

As stated in Chapter 1, the overall objective in addressing these questions was to demonstrate and evaluate the Climate Projection Applicability Framework by applying the framework to select climate projection information for a hypothetical planning study. The Collaborative Project Summary outlines four tasks to achieve this objective:

Task 1: Conduct Broadband Quality Evaluation of CMIP5 Historical Simulations

Task 2: Conduct Water Resources System Sensitivity Analysis for a Selected System

Task 3: Develop Online Resource to Serve CMIP5 Broadband Quality Evaluation Results

Task 4: Conduct Pilot Workshop to Implement and Evaluate the Applicability Framework

The specific objectives of each task are defined in the Collaborative Project Summary and summarized below in Table 1. Tasks 1 and 3 were led by NOAA with support from the Cooperative Institute for Research in Environmental Science, a partnership of NOAA and the University of Colorado Boulder. Tasks 2 and 4 were led by Reclamation. USACE participated in scoping, review, and discussion of all tasks.

Table 1.—Summary of Study Tasks and Objectives

Task	Lead Agency	Task Name and Objective(s)
1	NOAA / CIRES	*Broadband Evaluation of CMIP5 Historical Simulations* • Identify menu of performance characteristics (evaluation metrics) collectively relevant to various water resources and environmental planning applications • Identify components of a framework that structure the broadband of performance characteristics to support subsequent discussion of credibility and applicability in planning and assessment situations • Compute performance characteristics (evaluate metrics) to evaluate CMIP5 climate model performance in simulating historical climate and trends at regional to local scales
2	Reclamation	*Water Resources System Sensitivity Analysis* • Select a water resource system for pilot implementation of Applicability Framework (pilot to focus on hypothetical planning situation) • Develop a framework for identifying “more relevant” climate aspects in water resources planning and assessment situations • Carry out water resources system sensitivity analysis to evaluate system to support discussion of relevance and applicability in planning and assessment situations
3	NOAA / CIRES	*Online Resource to Serve CMIP5 Evaluation Results* • Design and develop a web-portal to serve evaluate results from Task 1 and permits users to flexibly query results that are relevant to their specific decision context
4	Reclamation	*Pilot Workshop* • Organize pilot workgroup consisting of planners and climate change technical specialists from Reclamation region responsible for water resources system selected in Task 2 • Work with pilot workgroup to develop a judgement process to assess the applicability of climate projections given results from broadband evaluation (Tasks 1 and 3) and sensitivity analysis (Task 2) • Conduct pilot workshop to implement Applicability Framework for hypothetical planning situation(s) • Obtain feedback from workgroup regarding utility and challenges of Applicability Framework

4. Study Methods

Reclamation, USACE, and NOAA collaborated to outline the overall approach used in this study to demonstrate and evaluate the Applicability Framework, including the primary elements of the four study tasks summarized above in Chapter 3. Tasks were then carried out largely independently: NOAA carried out Tasks 1 and 3, with interim review and feedback from Reclamation and USACE; Reclamation carried out Tasks 2 and 4, with interim review and feedback from USACE and NOAA.

The technical methods used by NOAA to implement Tasks 1 and 3 are detailed in Scott et al. (2016) and summarized below in Sections 4.1 and 4.3, respectively. The technical methods used by Reclamation to implement Tasks 2 and 4 are detailed below in Sections 4.2 and 4.4, respectively.

4.1 Task 1: Broadband Evaluation of CMIP5 Historical Simulations

Task 1 focuses on evaluating how well the CMIP5 climate models simulate historical climate and trends over the 20th century. Task 1 was led by NOAA and is documented by Scott et al. (2016). As part of Task 1, Reclamation and USACE worked with NOAA to identify a suite of climate aspects[1] that are potentially relevant to a broad range of water resources and environmental planning situations, along with a corresponding suite of metrics to quantify and characterize these climate aspects. NOAA then applied these climate metrics to observational datasets and CMIP5 model simulations of the 20th century. The results support evaluation of CMIP5 model performance in simulating observed historical climate and trends. As discussed in Chapter 2, evaluation results with respect to CMIP5 simulation of 20th century climate may also serve as a basis for assessing the credibility of CMIP5 projections of 21st century climate change, as climate projections cannot be directly evaluated against observations.

A menu of performance characteristics, also referred to as evaluation metrics, was identified in Task 1 based on a matrix of four elements: climate variable, statistic (metric), season, and period of interest. The options that were considered in Task 1 for each of these elements are listed in Table 2. Individual performance

[1] As defined in Chapter 2, as used in this report, the term *climate aspect* refers to a specific feature of the climate system defined by a given climate variable at a specified spatial and temporal domain and resolution—e.g., total wintertime precipitation over a watershed of interest or monthly average daily maximum temperature at a specific location.

characteristics were developed for each unique combination across the four elements—e.g., mean precipitation for season December-January-February for reference period 1911-2005, or linear trend in daily maximum air temperature for season June-July-August for reference period 1956-2005.

Table 2.—Elements of Climate Performance Metrics Considered in Task 1

Climate Variables:	Statistics (Metrics):	Seasons:	Reference Periods:
• precipitation • daily mean temperature • daily maximum temperature • daily minimum temperature • sea surface temperature	• mean • median • standard deviation • 10th percentile • 90th percentile • linear trend • lag-1 autocorrelation	• Jan-Feb-Mar • Feb-Mar-Apr • Mar-Apr-May • Apr-May-Jun • May-Jun-Jul • Jun-Jul-Aug • Jul-Aug-Sep • Aug-Sep-Oct • Sep-Oct-Nov • Oct-Nov-Dec • Nov-Dec-Jan • Dec-Jan-Feb • annual	• 1901-1950 • 1956-2005 • 1979-2008 • 1911-2005

Two groups of climate data were used in Task 1: simulation results from the CMIP5 20th century simulations (see Taylor et al. 2012), and a suite of gridded datasets of observed 20th century climate (see Table 3). Simulation results were obtained from the CMIP5 Multi-Model Dataset (PCMDI 2015). The CMIP5 Multi-Model Dataset includes results from global climate model (GCM) simulations of 20th century climate and projections of the 21st century climate from a total of 61 GCMs from 27 modeling centers representing 15 different countries (PCMDI 2015). Task 1 considers a total of 37 models from the CMIP5 Multi-Model Dataset; the remaining models were not considered due to missing data for one or more of the climate variables, emissions scenarios, and/or time periods considered. Observational datasets used for evaluation of simulation results are listed below. Observational datasets were selected based on their spatial and temporal coverage and resolution, and also on their common usage within the climate science community.

Table 3.—Observational Datasets Used by NOAA Climate Change Web Portal

Climate Variables:	Dataset Name	Primary Reference
Precipitation	Global Precipitation Climatology Centre (Version 5)	Rudolf et al. (2011)
Daily mean temperature	University of Delaware (Version 3.01)	Wilmott and Matsuura (2001)
Daily maximum temperature	Global Historical Climatology Network	Menne et al. (2012)
Daily minimum temperature	Global Historical Climatology Network	Menne et al. (2012)
Sea surface temperature	Hadley Centre Sea Surface Temperature (HadISST2)	Rayner et al. (2006)

The four primary climate variables considered in Task 1—precipitation, daily mean temperature, daily maximum temperature, and daily minimum temperature—were selected by Reclamation, USACE, and NOAA based on a common understanding of the primary climate variables that impact local and regional hydrologic conditions, including water supplies and demands. The fifth climate variable considered—sea surface temperature (SST)—was selected because of its important role in local hydroclimate variability through large-scale ocean-atmosphere teleconnections such as the El Niño-Southern Oscillation, which impacts climate and hydrologic variability across much of the globe.

Seven statistics (metrics) were used to characterize each climate variable. The mean and median characterize the central tendency of a given climate variable over selected period of time, whereas the standard deviation characterizes the range of variability (dispersion) of that variable over a selected period (a small standard deviation indicates that values are generally close to the mean, whereas a large standard deviation indicates that values deviate from the mean over a wide range). The 10th and 90th percentiles are commonly used as threshold values for identifying the lower and upper extreme values of a given climate variable, respectively, and the linear trend characterizes whether a given variable has increased or decreased over a given time period. Lastly, the lag-1 autocorrelation characterizes the extent to which fluctuations in a given variable persist from season-to-season or year-to-year: higher autocorrelation indicates that a positive fluctuation (e.g., above average precipitation) will tend to persist over multiple seasons, whereas a lower autocorrelation indicates that a positive fluctuation will generally be short-lived.

Each combination of climate variable and statistic can be applied to any given location, temporal resolution (e.g., daily, monthly, seasonal, or annual), and time period. For this study, gridded observational datasets and CMIP5 climate model results were regridded from their respective native grid resolutions to a common grid of 1.0˚ latitude by 1.0˚longitude. Metrics were then computed on a grid cell by grid cell basis. Metrics were computed on annual and seasonal timescales, where seasons are defined as consecutive three-month periods. This study considers twelve overlapping seasons: January-February-March (JFM), February-March-April (FMA), March-April-May (MAM), and so on. Metrics were not computed on monthly or daily timescales due to the significant increase in computational resources required, as well as the lack of comprehensive daily model results for some simulations in the CMIP5 Multi-Model Dataset. Finally, metrics were computed for four historical reference periods (see Table 2), where reference periods were selected based on data availability and common current practice within the climate science community.

4.2 Task 2: Water Resources System Sensitivity Analysis

Task 2 focuses on developing and implementing a framework for evaluating the *relevance* of climate aspects to a given study or decision situation. Task 2 was led by Reclamation, with interim review and feedback from USACE and NOAA. As defined above in Chapter 2, in the context of the Applicability Framework, a climate aspect is considered relevant to a given situation if a change in that aspect is likely to affect the study or decision outcome(s). The study team developed a sensitivity-based approach to assessing the relevance of climate aspects to a given situation, as detailed below.

4.2.1 Overview of Sensitivity-Based Approach

The study team selected a sensitivity-based approach to identifying relevant climate aspects in the context of a specific planning or decision situation. Sensitivity analyses have long been used to evaluate how a given system will respond to changes in system inputs, parameters, boundary conditions, and other factors that affect system performance. Sensitivity analyses are commonly used to evaluate the sensitivity of both natural hydrologic systems (e.g., a watershed) and managed water resources systems (e.g., a water supply or flood control system) to changes in climate, land use, and other stressors (Jain and Singh 2003, Loucks et al. 2005). Quantitative sensitivity analyses are typically carried out using a numerical model of the hydrologic and/or water resources system of interest—e.g., a rainfall-runoff model, groundwater model, or integrated hydrologic model of a given watershed or a water resources planning or operations model of a given water resources system.

The sensitivity-based approach to identifying relevant climate aspects involves simulating the behavior of the water resources system of interest under a range of perturbed climate conditions and assessing the system response to those perturbations. In this context, the term *system response* refers to the change in a performance metric for the system of interest. Performance metrics vary between different water resources systems. For water supply systems, performance metrics often include measures related to the quantity and/or reliability of water deliveries. Performance metrics may also include measures related to operational targets for surface water storage, water quality, hydropower generation, and environmental conditions (e.g., instream flow targets). Under the Applicability Framework, climate perturbations that result in greater changes in system performance are considered more relevant, whereas climate changes that have a smaller impact on system performance are considered less relevant.

The sensitivity-based approach developed and implemented in this task consists of five steps:

- Identify a water resources system of interest
- Identify broad spectrum of potentially relevant climate aspects
- Develop idealized climate scenarios
- Develop modified inputs to water resources system model of the selected system of interest
- Simulate system performance under idealized climate scenarios

Each of these steps is described below.

4.2.2 Identify Water Resources System of Interest

Reclamation worked with USACE and NOAA to identify a water resources system to use as a pilot case study for the Applicability Framework. The study team considered several criteria, including: managed water resources system with climate-sensitive operations; existing management/operations model that responds to changes in climate and non-climate inputs (i.e., limited use of fixed inputs, such as closure terms and loss factors, that do not respond dynamically to input changes) and supports batch capabilities; and management team willing and interested in participating in pilot workgroup. In addition to these criteria, Reclamation focused on systems operated to meet multiple objectives, including water supply management, flood control, and ecosystem protection or restoration.

Based on these criteria, the study team selected the combined Central Valley Project and State Water Project (CVP/SWP) system in California. The coordinated operations of the CVP (Reclamation) and SWP (California

Department of Water Resources; DWR) serve multiple purposes of water conservation, flood control, power generation, recreation, and streamflow and water quality protection. Both projects include major storage facilities in Northern California that store winter and spring runoff from the Sierra Nevada Mountains, as well as from the southern Cascade Range to the upper Sacramento River basin and from the Trinity Alps to the Trinity River basin (Figure 2). Reservoir releases from CVP and SWP reservoirs in northern California provide water for irrigation in the Sacramento Valley. Reservoir releases also flow through the Sacramento-San Joaquin Delta and are exported by CVP and SWP pumping plants, which supply the Delta Mendota Canal and the California Aqueduct, respectively. Delta exports serve agricultural and urban needs in the western San Joaquin Valley and the central and south coast regions of the California. The scale and complexity of the combined projects, the unique nature of their shared legal and regulatory requirements, their operations' effects on environmental resources, and their role in the statewide and national economy all indicate that the CVP/SWP system meets the needs of this study.

Reclamation and California DWR have developed a water resources planning model for the CVP/SWP system referred to as CalSim. CalSim simulates system operations—including reservoir storage and releases, surface water deliveries and return flows, and groundwater pumping—for a multi-year period using a monthly time step. CalSim assumes that facilities, land use, water supply contracts, and regulatory requirements are consistent over the simulation period. CalSim's standard input dataset was developed from historical climate and streamflow records, with adjustments for the influence of land use changes over time. Primary climate and hydrology inputs include inflows to system reservoirs, surface runoff entering the stream network below system reservoirs, and agricultural and urban water demands. Primary outputs include simulated reservoir storage and releases, streamflows, and CVP/SWP deliveries, including north of the Delta and via south Delta exports. Outputs are commonly post-processed to analyze system delivery reliability as well as reliability in meeting flow and water quality criteria.

Figure 2.—Overview of Central Valley Project (CVP) and State Water Project (SWP) storage and conveyance facilities. Federally-owned CVP facilities are shown in purple; state-owned SWP facilities are shown in orange; and major locally-owned facilities are shown in green. CVP and SWP facilities are operated in coordination by Reclamation and California DWR under the Coordinated Operations Agreement of 1986.

CalSim uses the Water Resources Integrated Modeling System (WRIMS) modeling environment developed and maintained by California DWR. WRIMS uses a mixed integer linear programming solver to determine optimal CVP/SWP operations at each monthly time step based on a large set of constraints, including physical constraints, contract obligations, and regulatory criteria. The first CalSim model was developed by California DWR in 2000; this model replicated and ultimately replaced DWR's previous planning model. CalSim-II was developed jointly by Reclamation and DWR. CalSim-II was initially released in 2002 and has undergone continual evolution to address planning study needs. CalSim3 was also developed jointly by Reclamation and DWR. The two main improvements of CalSim3 compared to CalSim-II are a consistent, high-resolution, land-use based approach for all modeled demands that is able to adapt to climate inputs, and the incorporation of a spatially discrete groundwater module capable of simulating groundwater heads and stream-groundwater interaction. This study uses the latest version of CalSim3 available at the time the study was initiated, Version191, to evaluate changes in CVP/SWP operations in under a broad range of climate scenarios, including changes in reservoir levels, streamflows, surface water deliveries, and other performance metrics.

4.2.3 Identify Broad Spectrum of Potentially Relevant Climate Aspects

Reclamation, USACE, and NOAA identified a broad spectrum of climate aspects that have the potential to impact to CVP/SWP operations and performance based on their potential effects on the hydrologic processes that control runoff and water supplies and demands. The initial list of climate aspects spanned a broad range of climate variables, spatial and temporal scales, and statistical characteristics (e.g., mean, variability, autocorrelation and frequency characteristics, etc). A subset of climate aspects was then selected for analysis based on the climate variables and timescales relevant to CalSim3 (climate aspects not relevant to model inputs were excluded) and available climate projections (climate aspects for which downscaled climate projections are not readily available were excluded). The subset of climate aspects selected for detailed analysis ultimately focus on important characteristics of precipitation and temperature at seasonal to interannual timescales, including seasonal and annual means, variability, and autocorrelation.

4.2.4 Develop Idealized Climate Scenarios

In order to evaluate system sensitivity to the selected climate aspects, a suite of idealized climate scenarios was developed. Each scenario was developed by perturbing a specific aspect of observed historical climate—for example, by perturbing the mean of summer precipitation or standard deviation of winter temperature. Time series of observed historical climate were first decomposed into three components: a monthly climatology (annual cycle), monthly standard deviation, and a monthly time series of standardized anomalies. Idealized climate scenarios were then developed by perturbing one or more components of the decomposed time series for one or more season. The resulting climate scenarios were subsequently used as inputs to hydrologic, water demand, and water resources system models to evaluate CVP/SWP sensitivity to changes in specific aspects of climate.

Time series of observed historical climate were decomposed based on Equation 1:

$$X_{ym} = \bar{X}_m + \left(\sigma_m \cdot {}' \;\; {}_{ym}\right) \qquad (1)$$

Where:

X_{ym} = Observed value of climate variable X for month *m* of year *y* (e.g., monthly precipitation in January of 1985 or monthly average daily maximum air temperature in July of 2000)

$\bar{X}_m$ = Climatological mean of observed climate variable X for month *m* (e.g., average January precipitation or average July temperature over a specified reference period)

σ_m = Standard deviation of observed climate variable X for month *m* (e.g., standard deviation of January precipitation or standard deviation of July temperature over a specified reference period)

${}' \;\; {}_{ym}$ = Standardized monthly anomaly (also referred to as normalized deviation) of observed climate variable X for month *m* of year *y*, defined according to Equation 2:

$$X'_{ym} = \frac{X_{ym} - \bar{X}_m}{\sigma_m} \qquad (2)$$

Scenarios representing perturbations in the mean and/or variability of a given climate variable were then developed by applying perturbation factors to the climatological and time-varying terms of Equation 1. Perturbations were applied to the climatological term as multiplicative factors for precipitation (Equation 3) and as additive factors for temperature variables (Equation 4). Perturbations were applied to the time-varying term as multiplicative factors for all variables.

$$\tilde{X}_{ym} = a_{im} \cdot (\bar{X}_m) + c_{im} \cdot \left(\sigma_m \cdot {}' \;\; {}_{ym}\right) \qquad (3)$$

$$\tilde{X}_{ym} = (b_{im} + \bar{X}_m) + c_{im} \cdot \left(\sigma_m \cdot {}' \;\; {}_{ym}\right) \qquad (4)$$

Where:

$\tilde{X}_{ym}$ = Perturbed (scenario) value of climate variable X for month *m* of year *y*

a_{im} = Multiplicative perturbation factor applied to climatological mean of variable *X* for scenario *i* and month *m*

b_{im} = Additive perturbation factor applied to climatological mean of variable *X* for scenario *i* and month *m*

c_{im} = Multiplicative perturbation factor applied to time-varying component of variable *X* for scenario *i* and month *m*

Scenarios representing perturbations in the autocorrelation of a given climate variable were developed by replacing the time series of standardized monthly anomalies ($'\ \ _{ym}$) derived from the observational dataset with a stochastically generated sequence of standardized monthly anomalies with the desired autocorrelation characteristics.

Whereas perturbations were applied to time series of observed monthly climate, the hydrologic and water demand models used in this study require daily climate inputs. Idealized climate scenarios were temporally disaggregated to a daily time step by preserving the daily sequencing of precipitation and temperature fluctuations from the observational dataset. For any given month, monthly precipitation was distributed across days of the month based on the fraction of observed monthly precipitation that occurred on each day of the month (Equation 5). Similarly, monthly temperature was disaggregated across days of the month based on the observed difference between daily and monthly temperature for that day (Equation 6).

$$\tilde{P}_{d|ym} = \tilde{P}_{ym} \cdot \left(\frac{P_{d|ym}}{P_{ym}}\right) \tag{5}$$

$$\tilde{T}_{d|ym} = \tilde{T}_{ym} \cdot \left(T_{d|ym} - T_{ym}\right) \tag{6}$$

Where:

$\tilde{P}_{d|ym}$ = Perturbed (scenario) daily precipitation for day *d* of month *m* of year *y*

$\tilde{P}_{ym}$ = Perturbed (scenario) monthly precipitation for month *m* of year *y* (Calculated from Equation 3)

$P_{d|ym}$ = Observed daily precipitation for day *d* of month *m* of year *y*

P_{ym} = Observed monthly precipitation for month *m* of year *y*

$\tilde{T}_{d|ym}$ = Perturbed (scenario) daily temperature for day *d* of month *m* of year *y*

$\tilde{T}_{ym}$ = Perturbed (scenario) monthly temperature for month *m* of year *y* (Calculated from Equation 4)

$T_{d|ym}$ = Observed daily temperature for day *d* of month *m* of year *y*

T_{ym} = Observed monthly temperature for month *m* of year *y*

A total of 80 idealized precipitation scenarios and 70 idealized temperature scenarios were developed for the system sensitivity analysis. Scenarios were developed by perturbing the mean or standard deviation for one of four seasons (December-January-February (DJF); March-April-May (MAM); June-July-August (JJA); or September-October-November (SON)) or for all seasons (annual). For precipitation, 50 scenarios were developed by perturbing seasonal mean precipitation (10 perturbation factors applied to each of 4 seasons and to all months of the year) and an additional 30 scenarios were developed by perturbing seasonal standard deviations (6 perturbation factors applied to each of four seasons and to all months). Similarly, 40 temperature scenarios were developed by perturbing seasonal mean temperature (8 perturbation factors applied to each of four seasons and to all months) and 30 scenarios were developed by perturbing standard deviations (6 perturbation factors applied to each of four seasons and to all months). Perturbation factors applied to the mean and standard deviation of precipitation are listed in Table 4, and perturbation factors applied to the mean and standard deviation of temperature are listed in Table 5. This study did not consider scenarios consisting of joint perturbations to the mean and standard deviation of either variable.

Table 4.—Perturbation Factors for Idealized Precipitation Scenarios

Perturbation Factors Applied to Means for Target Season	Perturbation Factors Applied to Standard Deviations for Target Season
–0.25 (decrease mean by 25%)	–0.20 (decrease standard deviation by 20%)
–0.20	–0.10
–0.15	–0.05
–0.10	+0.05
–0.05	+0.10
+0.05	+0.20 (increase standard deviation by 20%)
+0.10	
+0.15	
+0.20	
+0.25 (increase mean by 25%)	

Table 5.—Perturbation Factors for Idealized Temperature Scenarios

Perturbation Factors Applied to Means for Target Season		Perturbation Factors Applied to Standard Deviations for Target Season	
–10.0 ˚C	(decrease mean by 10.0 ˚C)	–0.20	(decrease standard deviation by 20%)
–7.5 ˚C		–0.10	
–5.0 ˚C		–0.05	
–2.5 ˚C		+0.05	
+2.5 ˚C		+0.10	
+5.0 ˚C		+0.20	(increase standard deviation by 20%)
+7.5 ˚C			
+10.0 ˚C	(increase mean by 10.0 ˚C)		

4.2.5 Develop Modified Inputs to CalSim3

CVP/SWP system performance was evaluated under each idealized climate scenario by using CalSim3 to simulate system operations under each scenario. In order to simulate CVP/SWP system operations under a given scenario, all climate-related inputs were modified to be consistent with that scenario.

Inputs to CalSim3 can be divided into three broad groups: rim inputs, valley inputs, and index inputs. Rim inputs represent climate and hydrologic conditions in the watersheds that surround the Central Valley—i.e., the so called "rim watersheds" of the Central Valley. Rim inputs consist of inflows to CVP/SWP reservoirs, most of which are located in the foothills surrounding the Central Valley, along with reservoir precipitation and evaporation rates. Valley inputs represent the hydrologic and climate conditions in the Central Valley, including water demands throughout the valley. Valley inputs include irrigation demands in the form of applied water demand (also referred to as farm delivery requirement); deep percolation and tailwater from irrigation; storm runoff occurring within the Central Valley; urban water demands (including landscape irrigation); and urban wastewater effluent. Finally, index inputs represent forecasted inflows for individual watersheds (e.g., American, Feather, and Sacramento river streamflow forecasts), forecasted water runoff across multiple basins (e.g., Eight River Index, which represents unimpaired runoff from eight major tributaries in the Sacramento and San Joaquin river basins), and water year types for various sub-basins and tributaries. Water supply and demand indices are used in determining annual operating criteria for various portions of the CVP/SWP system. For example, indices representing water year type are used to determine CVP allocations to contractors and environmental flow targets at certain locations.

Rim inputs for each scenario were developed by using the Variable Infiltration Capacity (VIC) macro-scale hydrology model (Liang et al. 1994) to simulate the change in runoff at each inflow location and the change in open-water evaporation at each reservoir location between historical climate and each idealized climate scenario, and then applying the simulated changes CalSim3's default (historical) inputs. Valley inputs for each scenario were developed by modifying the climate-related inputs to CalSimHydro, a pre-processing tool developed by California DWR to calculate valley inputs, and then using CalSimHydro to generate perturbed valley inputs. CalSim3's default (historical) index inputs were derived largely from historical streamflow records. Index inputs for each scenario were therefore calculated based on simulated changes in runoff and the relationship between streamflow and index values for the CalSim3's baseline index inputs.

The methods used to develop rim, valley, and index inputs for idealized climate scenarios are summarized below, followed by a brief description of the workflow used to carry out the large number of CalSim3 simulations for this study.

Rim Inputs

Figure 3 shows a schematic illustration of the process used to develop perturbed rim inputs for each idealized climate scenario. First, the gridded historical climate dataset of Maurer et al. (2002) was obtained for the study area. For each climate scenario, an idealized perturbation was applied to the historical dataset as described above. The VIC model was then used to simulate hydrologic conditions in the rim watersheds that provide inflows to Central Valley tributaries and CVP/SWP reservoirs. VIC inputs include daily precipitation, maximum and minimum air temperature, and wind speed; precipitation and temperature inputs were perturbed according to each idealized scenario, whereas historical wind inputs were used for all simulations. Quantile-based change factors were developed for each rim input variable based on the difference between simulations driven with historical climate (no perturbation applied) and perturbed climate (Wood et al. 2002). Lastly, change factors were applied to the original (historical) CalSim3.0 inputs. The resulting perturbed CalSim3 inputs reflect the simulated hydrologic response to a given idealized climate scenario while preserving the overall sequencing of wet and dry spells from the original CalSim3.0 inputs.

Valley Inputs

The process used to develop perturbed valley inputs for idealized climate scenarios is generally similar to that used for rim inflows, as illustrated schematically in Figure 4. Valley inputs are generated by CalSimHydro, a pre-processing tool developed by California DWR to calculate agricultural and urban water demands in the Central Valley. In addition to calculating irrigation and urban water demands, CalSimHydro simulates the water balance at the land surface for specified Water Budget Areas (WBA) and Demand Units (DU) within the Central Valley, including deep percolation and tailwater runoff from irrigation as well as storm runoff within the valley. CalSimHydro inputs include daily precipitation, monthly pan evaporation (E_{pan}), monthly reference evapotranspiration (ET_o), and monthly crop evapotranspiration (ET_c) for 23 different crops grown in the Central Valley. For each idealized climate scenario, the idealized perturbation was applied to all climate-related inputs to CalSimHydro. CalSimHydro was then used to calculate valley inputs under a given scenario. In contrast to the quantile mapping approach used to develop rim inputs, valley inputs are taken directly from CalSimHydro without additional processing.

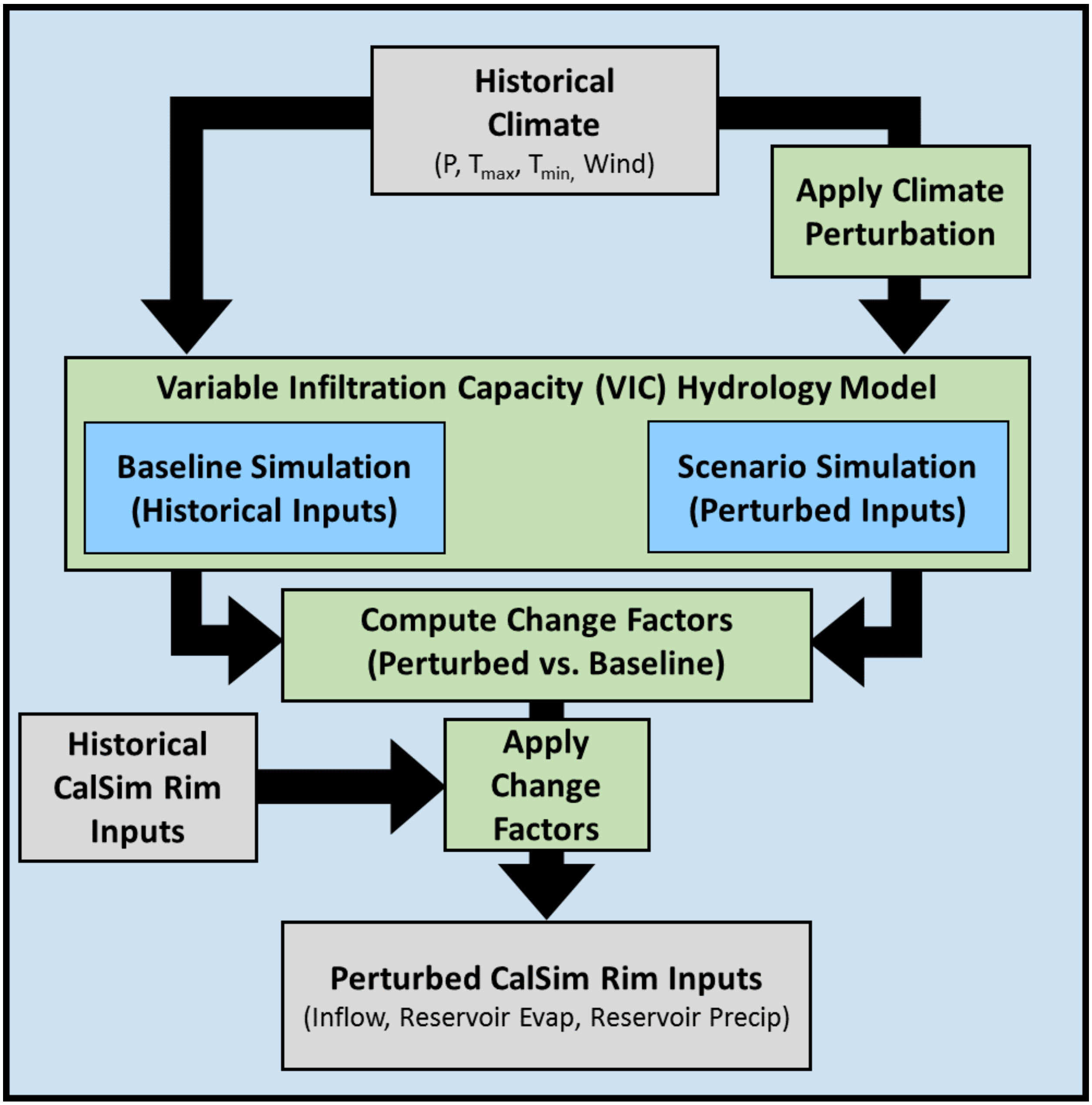

Figure 3.—Overview of process used to develop perturbed CalSim3 rim inputs corresponding to an idealized climate scenario.

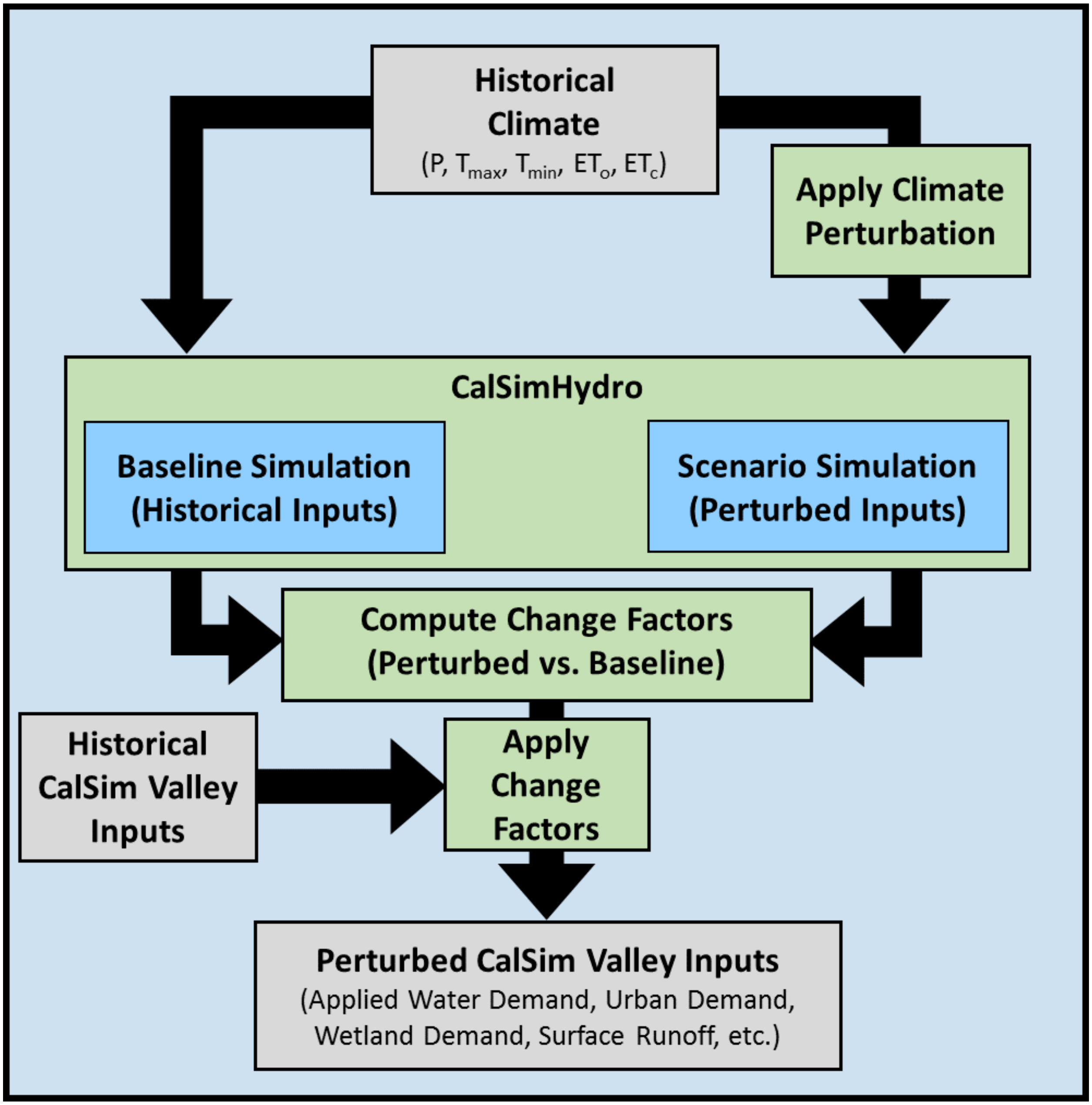

Figure 4: Overview of process used to develop perturbed CalSim3 valley inputs corresponding to an idealized climate scenario.

Index Inputs

The majority of index inputs were developed largely from historical streamflow records. For these index inputs, perturbed indices corresponding to each scenario were developed by multiplying the default index value for a given time step by ratio of simulated runoff under perturbed climate to historical climate for that time step. The streamflow data used to calculate a given index may vary between months. Indices of forecasted runoff, for example, represent forecasted inflows from the current month through the end of the current water year. As a result, the time period represented by the index ranges from 8 months for the February index value (February through September) to just one month for the September index value (September only). For each streamflow-based index, perturbed index values were calculated for each time step by multiplying the default index value by a scaling factor. For each index and time step, the scaling factor was calculated as the ratio of streamflow simulated using the VIC hydrology model under perturbed versus historical climate for the locations and time period represented by the default index value.

Indices representing water year types under each climate scenario were developed based on the streamflow thresholds use to develop water year type indices for the default CalSim3 inputs. Water year types are used to characterize water availability for a given year and corresponding allocation or operating criteria for that year. Indices of water year type range from 1 to 5 corresponding to Critical Year, Dry Year, Below Normal Year, Above Normal Year, and Wet Year. Indices for each climate scenario were developed based on perturbed streamflows for that scenario and water year type thresholds derived from the default index values.

4.2.6 Simulate System Performance under Idealized Climate Scenarios

Sensitivity of the CVP/SWP system to climate perturbations was assessed by using CalSim3.0 to simulate system performance with perturbed rim and index inputs, valley inputs, or all inputs. Rim and index inputs were perturbed together as these inputs both relate to runoff and streamflow from the mountainous headwaters surrounding the Central Valley into the CVP/SWP system. These inputs are thus sensitive to climate conditions in the rim watersheds. Valley inputs, by contrast, represent water supplies and demands within the Central Valley itself and are therefore sensitive to climate conditions in the valley. Inputs representing conditions in the rim watersheds and the Central Valley were perturbed separately in order to assess the relative sensitivity to climate change between the major supply areas (rim watersheds) and demand areas (Central Valley).

Perturbed input files were prepared for all rim, index, and valley input variables for all idealized scenarios considered in this study. A suite of perturbation simulations was then developed by combining idealized climate scenarios with different sets of input variables representing rim and index inputs, valley inputs, or all inputs. A relational database was constructed to manage the suite of perturbation simulations, and a control script was developed to automate carrying out the large number of simulations. The control script carried out the following tasks:

1. Select simulation from database
2. Read simulation parameters
3. Prepare simulation inputs
4. Run CalSim3 calibration procedure (discussed below)
5. Run CalSim3 simulation
6. Archive simulation results
7. Repeat procedure

Once a simulation is selected from the database, the control script reads a set parameters that define the idealized climate scenario for the simulation as well as the inputs that will be perturbed for the simulation (e.g., rim and index inputs, valley inputs, or both). The script then generates the perturbed inputs and prepares the CalSim3 input file. Perturbed rim inputs are read from pre-processed input files developed from VIC simulation results, whereas index inputs are calculated by the control script based on default and perturbed streamflow inputs. If the simulation includes perturbed valley inputs, the control script prepares and runs CalSimHydro and copies the resulting input variables from the CalSimHydro output file to the CalSim3 input file.

After preparing all CalSim3 inputs a given simulation, the control script runs the CalSim3 calibration procedure. Unlike traditional calibration procedures which determine values of physical and operational parameters, the CalSim3 calibration procedure determines the relationship between system-wide water supplies and demands. Water supplies are represented by a Water Supply Index (WSI), which is calculated as the sum of reservoir storage in selected reservoirs and forecasted inflows at selected locations. Water demands are represented by a Demand Index (DI), which represents the sum of water available to meet target deliveries and carryover storage. The calibration procedure develops a linear relationship between WSI and DI (i.e., the WSI-DI Curve) based on calculated WSI and simulated deliveries and carryover storage. The resulting WSI-DI Curve is then used by CalSim3 to estimate the amount of water available for delivery and carryover storage, which in turn is used to determine CVP and SWP allocations.

Following the calibration procedure, the control script runs CalSim3 to simulate the CVP/SWP system operations under the selected simulation parameters, archives the CalSim3 results, and restarts the process to launch the next simulation. A separate set of scripts was developed to post-process the results of each CalSim3 simulation, including calculating relevant statistics to characterize system performance across multiple operating objectives and calculating system sensitivities as the change in system performance under a given set of simulation parameters relative to the baseline simulation (i.e., the difference in system performance relative to results from CalSim3 using default inputs).

Lastly, a set of scripts was developed to visualize system sensitivity results by plotting changes in selected performance metrics as a function of changes in climate, including performance metrics related to CVP delivery volume and reliability, average and end-of-year storage in CVP reservoirs, and streamflow at selected locations. The graphics generated by the post-processing scripts were intended to support assessment of climate relevance in the context of CVP/SWP system performance. The performance metrics selected for the pilot workshop are summarized in Table 6, along with the names CalSim3 output variables corresponding to each metric. It should be noted that the performance metrics selected for the pilot workshop represent a small subset of the large number of performance metrics considered in actual CVP/SWP planning and operations.

Table 6.—CVP/SWP Performance Metrics and Corresponding CalSim3 Variables

Performance Metric	CalSim3 Variable
Reservoir Storage	
Oroville Reservoir	S_OROVL
Shasta Reservoir	S_SHSTA
Trinity Reservoir	S_TRNTY
Streamflow	
American River below Natomas Dam – MIF[1]	C_NTOMA_MIF
Clear Creek below Whiskeytown Dam – MIF[1]	C_WKYTN_MIF
Feather River at Power Canal Diversion to Thermalito Forebay – MIF[1]	C_FTR068_MIF
Feather River at Sunset Pumps – MIF[1]	C_FTR039_MIF
Sacramento River below Keswick Dam – MIF[1]	C_KSWCK_MIF
Sacramento River at Red Bluff Diversion Dam	C_SAC240
Sacramento River at State Ranch Bend	C_SAC097
Sacramento River at Fremont Weir	C_SAC083
Sacramento River at Hood, CA	C_SAC041
Sacramento River at Confluence of Yolo Bypass and Lindsay-Barker Slough	C_SAC017
Sacramento River at Sacramento-San Joaquin Confluence – MIF[1]	C_SAC000_MIF
Sacramento River at Sacramento-San Joaquin Confluence – ADD[2]	C_SAC000_ADD
Trinity River below Lewiston Dam – MIF[1]	C_LWSTN_MIF
Project Deliveries	
CVP Total Deliveries	DEL_CVP_TOTAL
SWP Total Deliveries	DEL_SWP_TOTAL

[1] Minimum Instream Flow – Contribution of total streamflow that contributes to meeting the minimum instream flow requirement at a specific location
[2] Additional Flow – Streamflow at a specific location exclusive of MIF (total streamflow minus MIF)

4.3 Task 3: Online Resource to Serve CMIP5 Broadband Evaluation Results

Task 3 focuses on designing and developing web portal to serve evaluate results from Task 1 and permits users to flexibly query results that are relevant to their specific decision context. Task 3 was led by NOAA and documented by Scott et al. (2016). NOAA worked with Reclamation and USACE to design the Climate

Change Web Portal (http://www.esrl.noaa.gov/psd/ipcc/) as a tool to support evaluation and interpretation of model results from the CMIP5 Multi-Model Dataset by planners, resource managers, and stakeholders as well as technical specialists. The web portal supports evaluation and interpretation of model results by providing graphical results of comparisons between model simulations of the 20th century and historical observations based on evaluation metrics considered in Task 1 (see Section 4.1). The web portal also allows users to investigate projected climate changes over the 21st century and to compare projected changes to simulated historical averages and model biases.

In order to allow users to quickly display model outputs and evaluation metrics, model output was pre-processed using a combination of software tools, including Javascript, Python, and NCAR's Command Language (NCL). As a first step, output from CMIP5 models were interpolated from each model's native grid resolution, which vary substantially across models, to a common resolution of 1.0˚ latitude by 1.0˚ longitude. Statistics for different climate metrics were then computed on the common grid as described in Section 4.1. A series of menus was developed to allow users to select a combination of seven attributes for spatially-distributed evaluation results (i.e., results presented as a map) or five attributes for spatially-aggregated evaluation results (i.e., results presented as a time series). The attributes of spatially-distributed and spatially-aggregated results are summarized in Tables 7 and 8, respectively. The web portal creates and displays graphical results based on the combination of attributes selected by the user. The Climate Change Web Portal provides evaluation results in graphical format only.

Table 7.—Attributes of Spatially-Distributed Evaluation Results

Attribute	Description
Model	Model for which results will be displayed (individual model or average of all models)
Experiment	Emissions scenario for which results will be displayed (RCP 4.5 or RCP 8.5)
Field	Climate field for which results will be displayed (Air Temperature, Precipitation, Sea Surface Temperature, Daily Maximum Temperature, or Daily Minimum Temperature)
Statistic	Statistical metric to be displayed (mean, median, standard deviation, 10^{th} percentile, 90^{th} percentile, linear trend, lag-1 autocorrelation)
Season	Season over which statistic will be computed (entire year [all months], Jan-Feb-Mar, Feb-Mar-Apr, Mar-Apr-May, Apr-May-Jun, etc.)
20^{th} Century Period	Time period over which statistic will be computed for comparison of observed and simulated historical climate (1911-2005, 1901-1950, 1956-2005, 1979-2008)
21^{st} Century Period	Time period over which statistic will be computed for comparison of simulated historical and simulated future climate (2006-2100, 2006-2050, 2050-2099, 2010-2039, 2040-2069, 2070-2099)
Region	Region over which results will be displayed (options include global, 16 defined regions, or custom region selected by the user via map interface)

Table 8.—Attributes of Spatially-Aggregated (Timeseries) Evaluation Results

Attribute	Description
Model	Model for which results will be displayed (individual model or average of all models)
Experiment	Emissions scenario for which results will be displayed (RCP 4.5 or RCP 8.5)
Field	Climate field for which results will be displayed (Air Temperature, Precipitation, Daily Maximum Temperature, or Daily Minimum Temperature)
Season	Season over which statistic will be computed (entire year [all months], Jan-Feb-Mar, Feb-Mar-Apr, Mar-Apr-May, Apr-May-Jun, etc.)
Time Average	Time period over which running averages of mean values and anomalies (relative to 1901-2005 climate) will be calculated (5 years, 10 years, 20 years, 30 years).
Region	Region over which spatial averages will be calculated, based on 21 water resources regions of the United States defined by USGS (Seaber et al. 1987).

4.4 Task 4: Pilot Workgroup and Workshop

Task 4 focuses on demonstrating the Climate Projection Applicability Framework through a pilot workshop and obtaining feedback from workshop participants regarding the utility and challenges of the Applicability Framework as the basis for determining what climate projection information to consider in water resources and environmental planning and decision making. Task 4 was led by Reclamation, with input on workshop design and content from NOAA and USACE. NOAA also supported Task 4 by leading one of three pre-workshop webinars, which introduced the Climate Change Web Portal to workshop participants.

Task 4 is the capstone of this collaborative effort. The task focuses on a pilot workshop in which teams of planners and technical specialists consider scoping the climate change portion of feasibility studies for two hypothetical projects related to CVP infrastructure and operations. Selected planners and technical specialists from Reclamation's Mid-Pacific Region were invited to participate in the workgroup. Participants attended a series of three webinars, followed by a full-day in-person workshop. The first webinar introduced the conceptual basis and core elements of the Climate Projection Applicability Framework. The second webinar focused on evaluating the credibility of global climate models and discussed NOAA's Climate Change Web Portal. The third webinar focused on evaluating the relevance of climate projections (or various aspects of climate projections) to a given decision and discussed the CVP/SWP sensitivity analysis carried out in Task 2. Slides from each webinar are included in Appendix 2 of this report.

A full-day in-person workshop was held following the third webinar. The workshop was held at the headquarters of the Mid-Pacific Region, located in Sacramento, California. The workshop included a brief presentation recapping the key themes of the three webinars and introducing the workshop. Workshop participants were then divided into two scoping teams. Each team was assigned a hypothetical project and asked to outline a scope for detailed technical analysis of the proposed project alternatives, focusing on how to select and incorporate climate projections into the analysis. Each team was provided with a summary of the proposed project and alternatives. One hypothetical project involved raising the height of Shasta Dam to increase storage in Shasta Reservoir; the other involved designing a modification to Fremont Weir for the purpose of restoring and improving salmonid habitat and fish passage in the Yolo Bypass. Scoping teams were also provided two packets of information—one consisting of climate model evaluation results obtained from the NOAA Climate Change Web Portal, and one consisting of CVP/SWP sensitivity results from the sensitivity analysis carried out in Task 2. All materials provided to workshop participants are included in Appendix 3 of this report.

In order to structure each team's scoping discussion, workshop participants were asked to answer a series of scoping questions identified in Reclamation's Technical Guidance for Incorporating Climate Change Information into Water Resources Planning Studies (Reclamation 2014). These questions are consistent with the Climate Projection Applicability Framework, with the first three questions focused on *relevance* of climate to the study decision and the latter three questions focused on *credibility* (also referred to as *reliability*) of climate projections with respect to their specific study objectives. The questions addressed by each scoping team are included in Appendix 3 of this report.

Scoping teams were given time to review and discuss the materials provided and to answer the six scoping questions. Each team then presented a brief summary of their answers to the six scoping questions and discussed how they considered the evaluation results and sensitivity results in answering each question. The workgroup then provided feedback regarding the overall utility and challenges of using the Applicability Framework in selecting and incorporating climate projection information into water resources and environmental planning, management, and decision making.

5. Results

Reclamation organized a workgroup to pilot the Applicability Framework in selecting climate projections for water resources and environmental planning studies and provide feedback on the utility and challenges of the proposed framework. As summarized in Section 4.4, the workgroup participated in a series of three webinars introducing the overall concept and core elements of the Climate Projection Applicability Framework. The workgroup subsequently participated in a full-day in-person workshop where they used the Applicability Framework to outline the scope for a detailed technical analysis of proposed project alternatives for two hypothetical projects related to the Central Valley Project.

This chapter presents results from the pilot workgroup. Climate model evaluation results developed for the workgroup are detailed in Section 5.1 and CVP/SWP system sensitivity results developed for the workgroup are detailed in Section 5.2. Results of the pilot workshop are discussed in Section 5.3.

5.1 Evaluation of CMIP5 Climate Projections (Tasks 1 & 3)

The pilot workgroup used the Climate Change Web Portal developed by NOAA as the basis for assessing the credibility of climate projections in the context of the two hypothetical projects considered in the workshop (see Section 4.4 and Appendices 3.3 and 3.4 for description of hypothetical projects considered by the workgroup). Evaluation results from the web portal were used to assess the performance of CMIP5 climate models in simulating observed historical climate and trends over the Central Valley and surrounding watersheds. As summarized in Section 4.3, the portal provides graphical results from a comparison of observed 20th century climate conditions and 20th century climate conditions simulated by the CMIP5 climate models. The workgroup was provided with a set of 20 evaluation plots downloaded from the web portal; these evaluation plots are provided in Appendix 3.5. Workgroup members were also given an opportunity to use the web portal to explore additional evaluation results.

Selected evaluation plots for spatially-distributed seasonal temperature and precipitation from the Climate Change Web Portal are shown in Figures 5-8. Evaluation results show substantial differences in the spatial patterns of seasonal mean temperature over California for spring (March-April-May, MAM; Figure 5) and summer (June-July-August, JJA; Figure 6). As shown in Figure 5, for example, spatial patterns of simulated MAM temperatures are rather smooth and generally follow latitudinal gradients (upper right panel of Figure 5), whereas spatial patterns of observed MAM temperatures are more variable and reflect the influence of mountainous terrain in eastern California and western Nevada (upper left panel of Figure 5). Evaluation results show moderate differences in the spatial patterns of seasonal mean temperature for summer (JJA; upper panels of Figure 6). The lower left panels of Figures 5 and 6 show the seasonal biases in air temperature (i.e., the difference between observed and simulated seasonal means) for MAM and JJA, respectively. While the spatial patterns of positive and negative biases are generally similar for both seasons, negative biases are slightly larger in JJA while positive biases are larger in MAM. Evaluation results for fall (September-October-November; SON) and (December-January-February, DJF) are provided in Appendix 3.5; results for SON and DJF generally consistent with results for MAM and JJA.

Evaluation results show that, on average, CMIP5 climate models exhibit biases in seasonal mean air temperature over California ranging from approximately -3.5˚C to +3.5˚C in all seasons, with positive biases typically occurring along the coast and negative biases typically occurring in the Central Valley and southeastern portions of the state. Biases are smallest over the California Coastal Ranges along the coast and the Sierra Nevada and Cascade Mountains in the northern and eastern portions of the state.

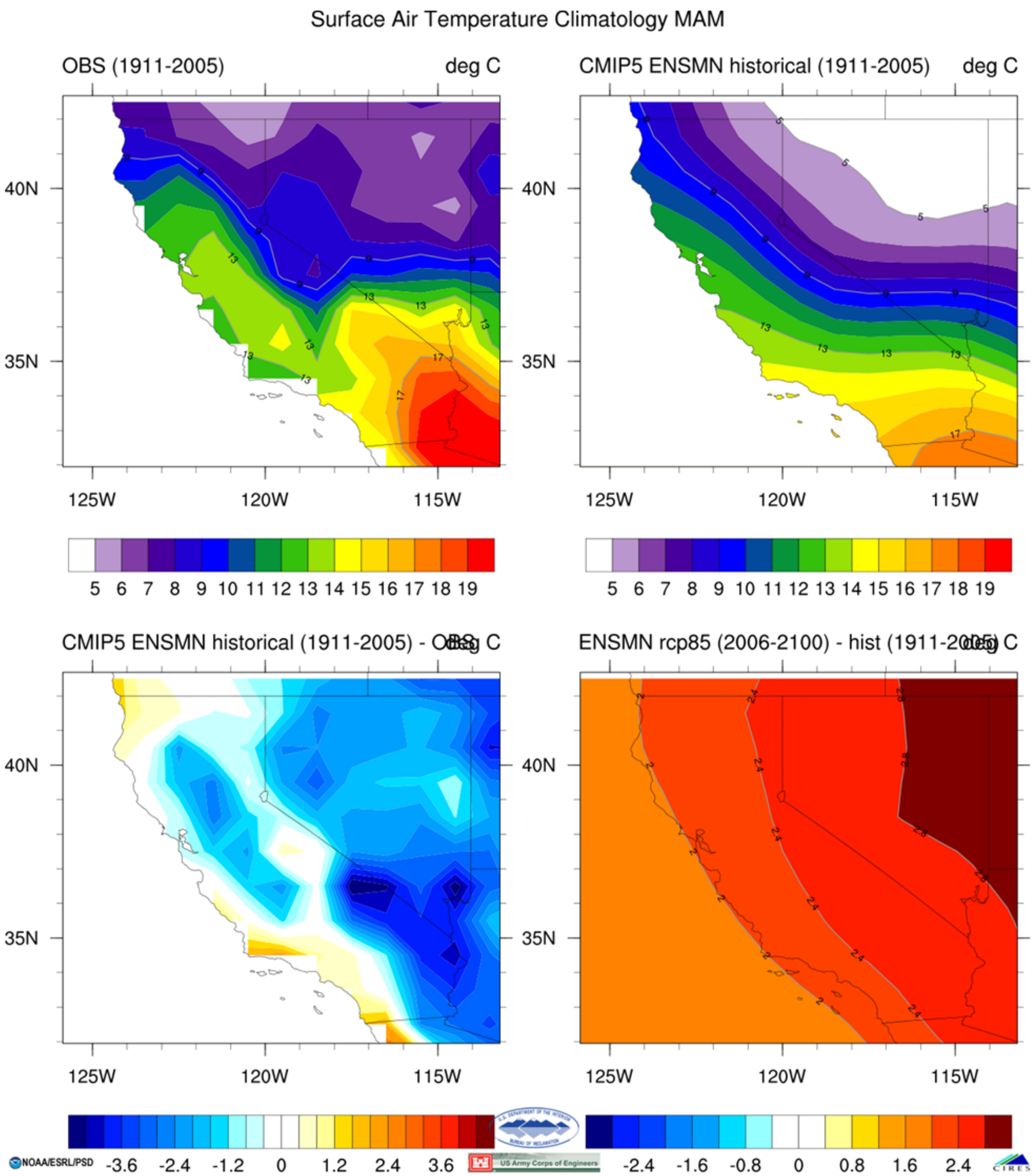

Figure 5.—Sample evaluation plot from NOAA's Climate Change Web Portal for spatially distributed (map) results. Evaluation plot shows the observed seasonal mean air temperature for March-April-May (MAM) over the period 1911-2005 [upper left]; the simulated seasonal mean air temperature averaged over all CMIP5 climate models for MAM over the period 1911-2005 [upper right]; the difference between observed and simulated seasonal mean air temperature for MAM [lower left]; and the projected change in seasonal mean air temperature between the periods 1911-2005 and 2006-2100, averaged over all CMIP5 climate models, for MAM under the RCP 8.5 scenario [lower right].

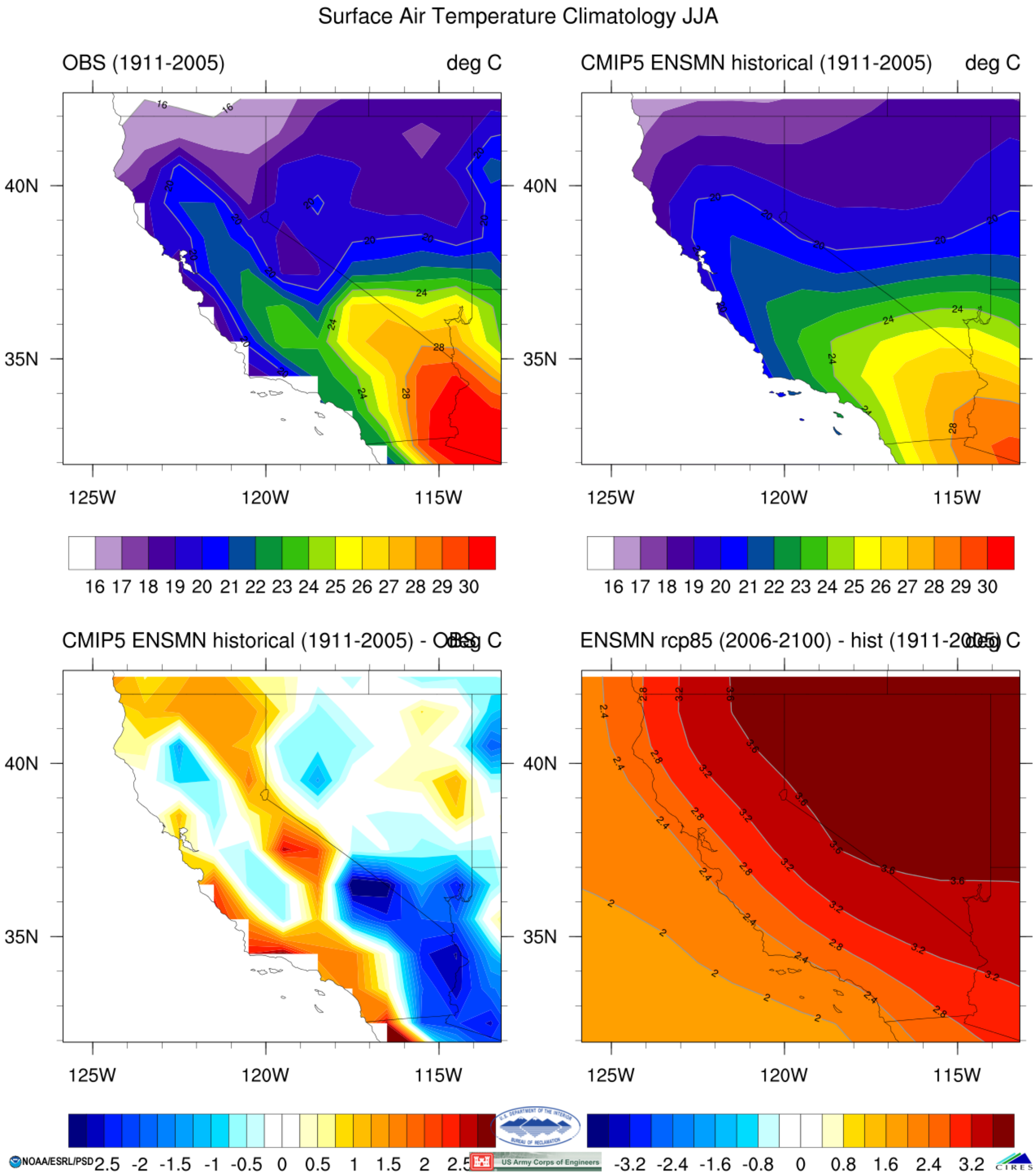

Figure 6.—Sample evaluation plot from NOAA's Climate Change Web Portal for spatially distributed (map) results. Evaluation plot shows the observed seasonal mean air temperature for June-July-August (JJA) over the period 1911-2005 [upper left]; the simulated seasonal mean air temperature averaged over all CMIP5 climate models for JJA over the period 1911-2005 [upper right]; the difference between observed and simulated seasonal mean air temperature for JJA [lower left]; and the projected change in seasonal mean air temperature between the periods 1911-2005 and 2006-2100, averaged over all CMIP5 climate models, for JJA under the RCP 8.5 scenario [lower right].

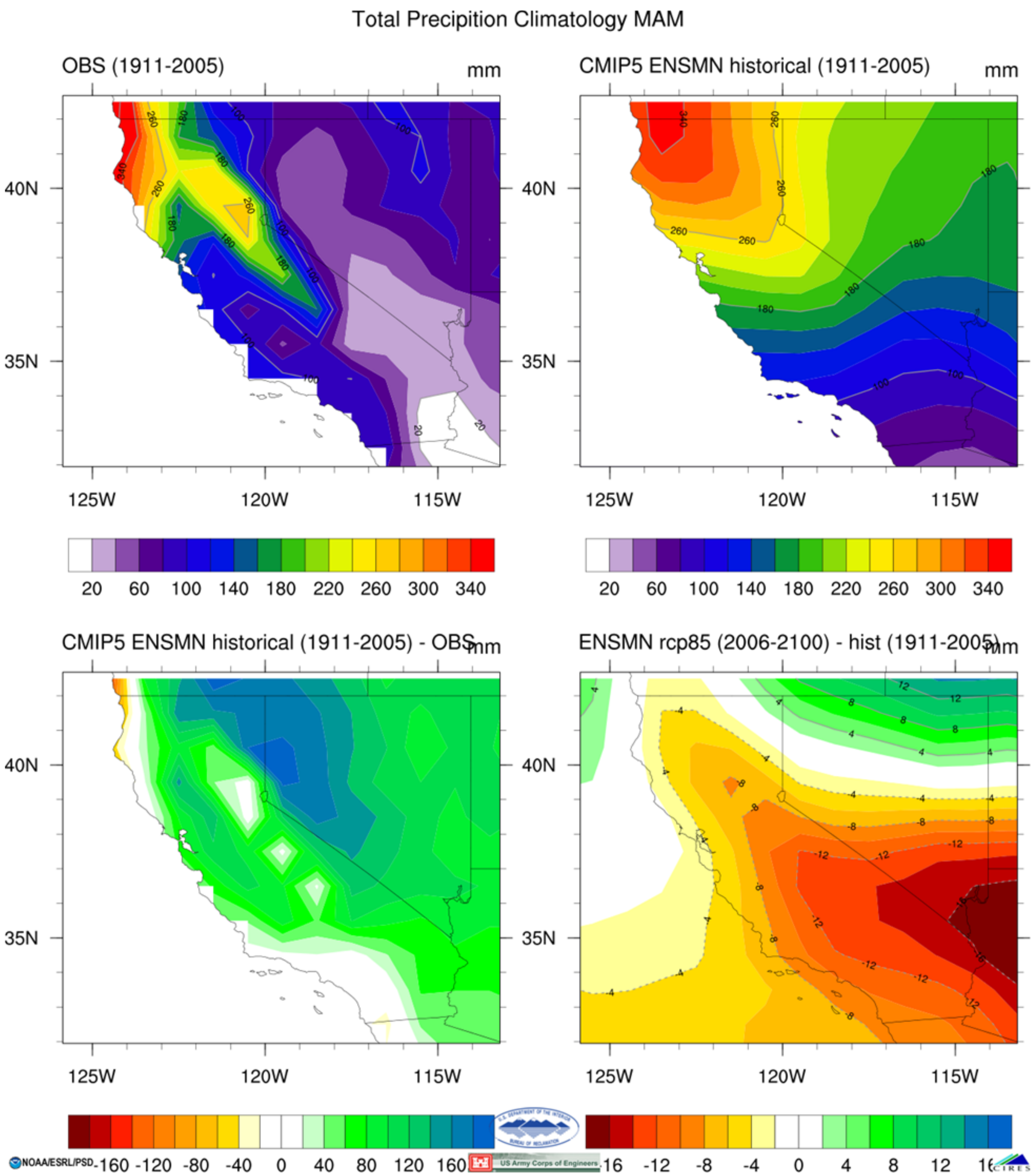

Figure 7.—Sample evaluation plot from NOAA's Climate Change Web Portal for spatially distributed (map) results. Evaluation plot shows the observed seasonal mean precipitation for March-April-May (MAM) over the period 1911-2005 [upper left]; the simulated seasonal mean precipitation averaged over all CMIP5 climate models for MAM over the period 1911-2005 [upper right]; the difference between observed and simulated seasonal mean precipitation for MAM [lower left]; and the projected change in seasonal mean precipitation between the periods 1911-2005 and 2006-2100, averaged over all CMIP5 climate models, for MAM under the RCP 8.5 scenario [lower right].

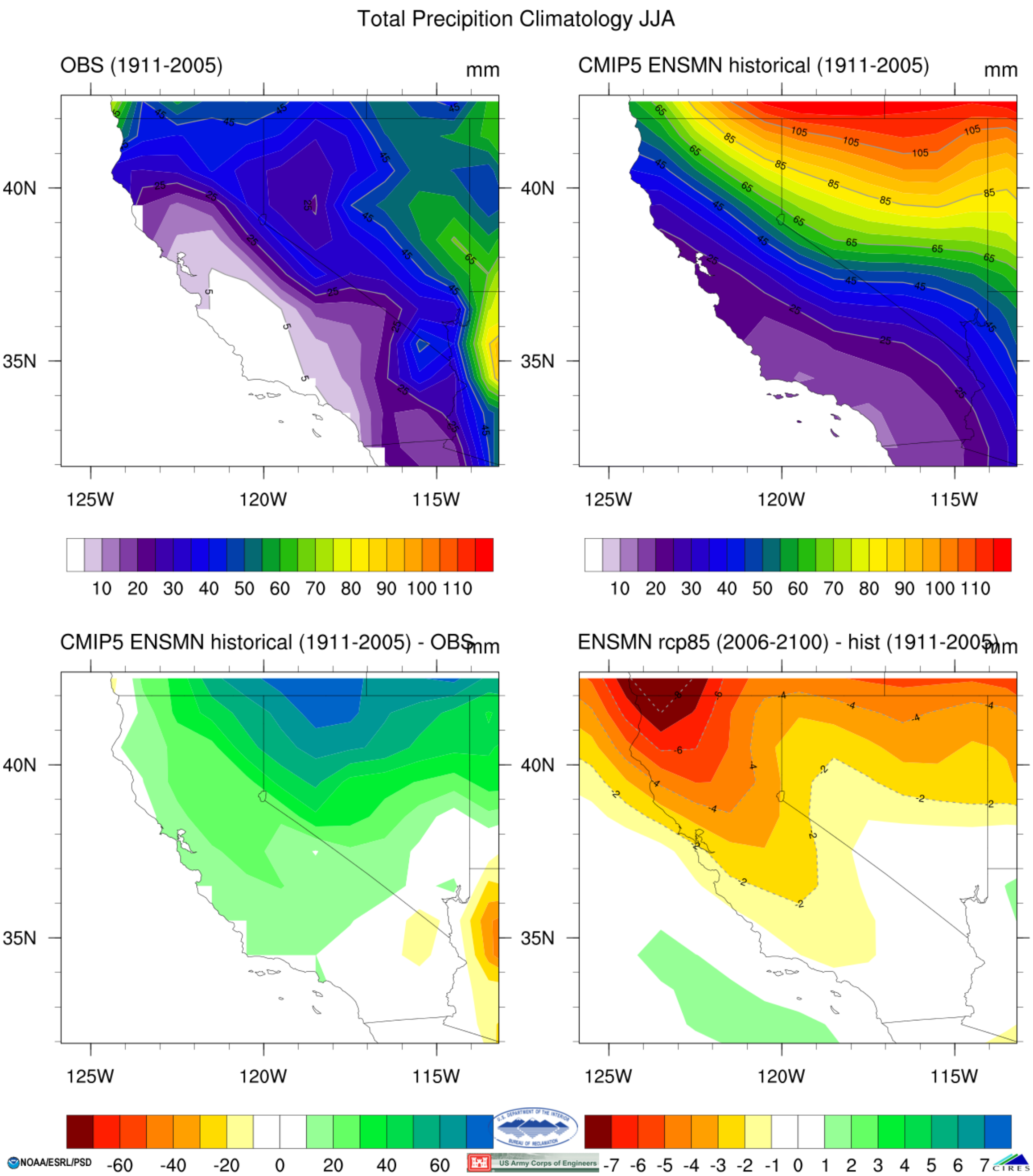

Figure 8.—Sample evaluation plot from NOAA's Climate Change Web Portal for spatially distributed (map) results. Evaluation plot shows the observed seasonal mean precipitation for June-July-August (JJA) over the period 1911-2005 [upper left]; the simulated seasonal mean precipitation averaged over all CMIP5 climate models for JJA over the period 1911-2005 [upper right]; the difference between observed and simulated seasonal mean precipitation for JJA [lower left]; and the projected change in seasonal mean precipitation between the periods 1911-2005 and 2006-2100, averaged over all CMIP5 climate models, for JJA under the RCP 8.5 scenario [lower right].

Evaluation results similarly show substantial differences in the spatial pattern of seasonal and annual mean precipitation over California for all season, as illustrated by comparing the upper left and upper right panels of Figure 7 for MAM and Figure 8 for JJA. Evaluation plots also show substantial biases in seasonal mean precipitation throughout much of the state and for all seasons, as shown in the lower left panel of Figures 7 and 8. Biases are greatest over the northeastern California and the northern Central Valley, with biases in springtime (MAM) precipitation approaching 180 mm over northern California. Biases are generally small along the Coastal Ranges and over the arid southeastern portion of the state. Biases are also generally small over the Sierra Nevada Mountains in eastern-central California.

Selected evaluation plots for spatially-aggregated (time series) annual temperature and precipitation from the Climate Change Web Portal Evaluation are shown in Figures 9-10. Plots show time series of non-bias-corrected (left panel) and bias-corrected (right panel) annual precipitation and temperature over a rectangular region centered over California and encompassing portions of Nevada, southern Oregon, southern Idaho, and western Arizona. A 30-year running average was applied to annual values prior to plotting. Evaluation results show that the distribution of 20^{th} century temperatures simulated by CMIP5 climate models is centered on observed historical temperatures, and that simulated temperatures exhibit similar trends over the 20^{th} century compared to observed trends (Figure 9). The range of simulated temperatures, however, is quite large, with 20% of CMIP5 climate models exhibiting biases greater than +/- 1.0˚C (Figure 9, left panel). Bias correction reduces this range significantly (Figure 9, right panel).

As shown in Figure 10, evaluation results for precipitation reveal much larger differences between simulated and observed 20^{th} century precipitation. This is consistent with numerous previous studies that demonstrate generally low skill among global climate models in simulating the overall magnitude of precipitation means and the spatial and temporal characteristics of precipitation variability. Without bias correction, more than 80% of CMIP5 climate models produce annual average precipitation that is substantially higher than observed (Figure 10, left panel). In addition, simulations do not reflect the observed trend in precipitation over the 20^{th} century. Bias correction significantly reduces discrepancies between simulated and observed average annual precipitation (Figure 10, right panel). However, bias correction does not reduce discrepancies between simulated and observed trends over the 20^{th} century.

A broad range of additional evaluation results are available through the Climate Change Web Portal, including results for different climate fields, statistical metrics, and time periods. The region for which results are shown can also be customized to any rectangular area; the size of the region selected, however, is limited by the spatial resolution of the evaluation analysis (1.0˚ latitude by 1.0˚ longitude grid resolution). In general, the evaluation results available through the

Climate Change Web Portal are consistent with previous studies showing that global climate models have higher skill in simulating temperature compared to precipitation, higher skill in simulating mean values and long-term trends compared to the magnitude and timescale of variability (e.g., standard deviation and lag-1 autocorrelation), and higher skill at larger spatial and temporal scales compared to smaller scales.

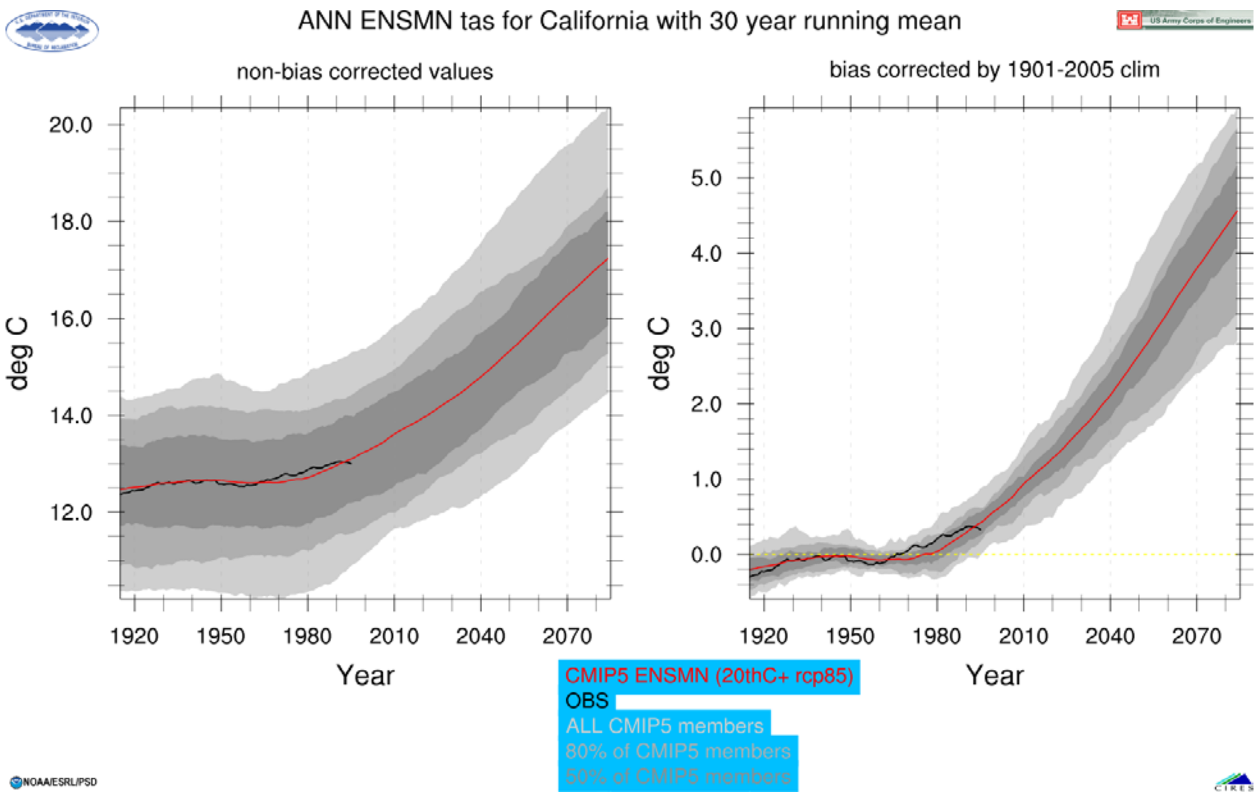

Figure 9.—Sample evaluation plot from NOAA's Climate Change Web Portal for spatially aggregated (time series) results. Evaluation plot shows the observed, regionally-averaged, annual mean air temperature over the period 1911-2000 [black line] and the simulated, regionally-averaged, annual mean air temperature averaged over all CMIP5 climate models [red line]. Gray shading indicates the range of simulated, regionally-averaged, annual mean air temperature for individual CMIP5 models [light gray shading is range across all CMIP5 models; medium gray shading is range across 80% of models (10th to 90th percentiles); and dark gray shading is range across 50% of models (25th to 75th percentiles)]. The left panel shows simulation results without bias correction and the right panel shows results after bias correction.

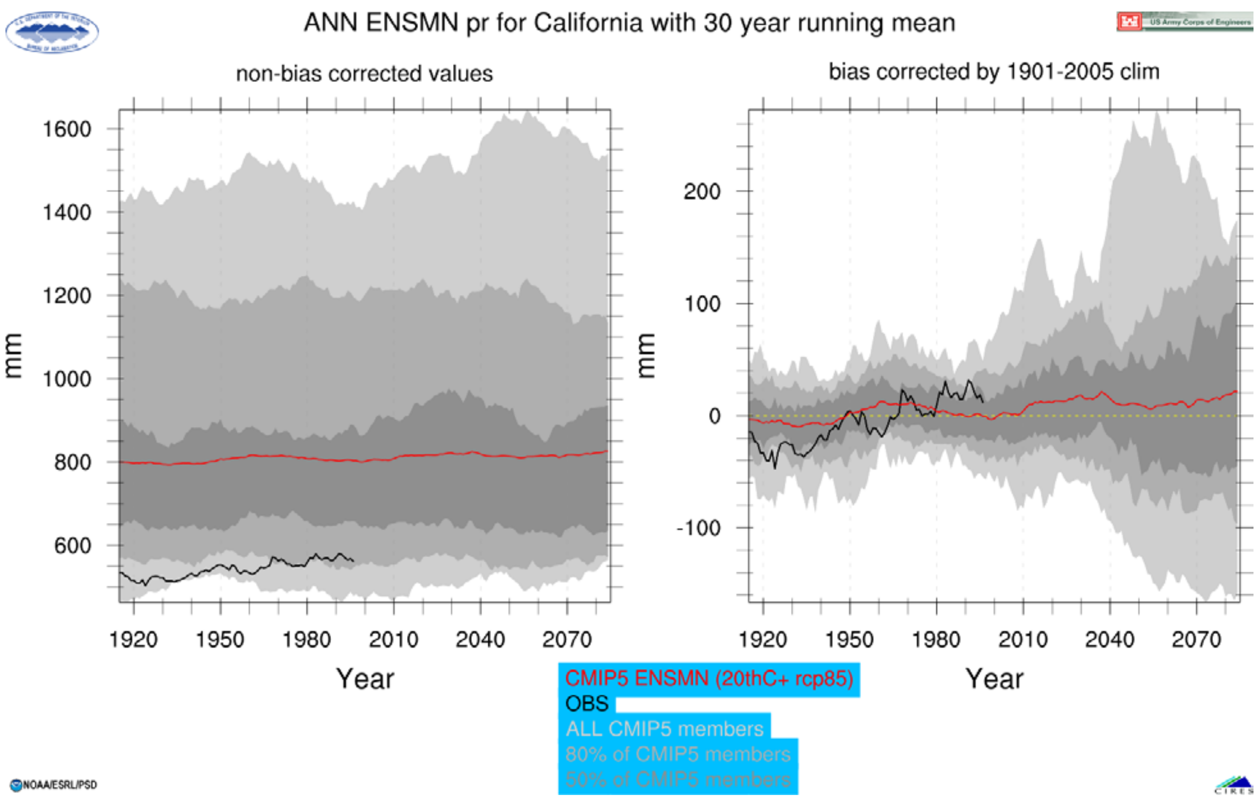

Figure 10.—Sample evaluation plot from NOAA's Climate Change Web Portal for spatially aggregated (time series) results. Evaluation plot shows the observed, regionally-averaged, annual precipitation over the period 1911-2000 [black line] and the simulated, regionally-averaged, annual precipitation averaged over all CMIP5 climate models [red line]. Gray shading indicates the range of simulated, regionally-averaged, annual precipitation for individual CMIP5 models [light gray shading is range across all CMIP5 models; medium gray shading is range across 80% of models (10th to 90th percentiles); and dark gray shading is range across 50% of models (25th to 75th percentiles)]. The left panel shows simulation results without bias correction and the right panel shows results after bias correction.

5.2 Evaluation of CVP/SWP System Sensitivity to Climate Perturbations (Task 2)

The CVP/SWP system sensitivity analysis was carried out by Reclamation as the basis for considering the relevance of climate variability and change in the context of the two hypothetical projects considered in the pilot workshop. Each workgroup scoping team was provided with a handout containing eight plots illustrating the sensitivity of key CVP/SWP performance metrics to changes in precipitation or temperature; sensitivity plots are provided in Appendix 3.6. Performance metrics included average storage in selected reservoirs, average annual flow at selected stream locations, and average annual surface water deliveries to CVP contractors (see Table 6 in Section 4.2).

Selected sensitivity plots are shown in Figures 11-14. Figure 11 shows the sensitivity of annual mean reservoir storage in Shasta Reservoir (upper row) and Trinity Reservoir (lower row) to changes in mean temperature (individual panels within each row) and mean precipitation (bar-and-whisker plots within each panel), where changes in precipitation and temperature are applied to all months of the year. Each panel corresponds to a specified change in temperature: the left panel shows results for historical (baseline) temperatures; left-center panel for 2.5˚C increase from baseline; right-center panel for 5.0˚C increase from baseline; and right panel for 7.5˚C increase from baseline. Within each panel, individual bar-and-whisker plots show distribution of differences in annual mean reservoir storage between the baseline simulation and the simulation under perturbed temperature and precipitation conditions. Each box-and-whiskers plot shows the sensitivity of average annual storage to changes in precipitation for a given change in temperature; comparison across panels then shows the influence of temperature changes on average annual storage.

For both Shasta and Trinity reservoirs, if temperature remains at baseline conditions, a decrease in precipitation results in a decrease in average annual storage and an increase in precipitation results in an increase in average annual storage (left panels in Figure 11). Increases in temperature result in decreases in average storage, as shown by comparing panels across each row of Figure 11. A 25% increase in precipitation without any change in temperature results in a median increase in annual reservoir storage of approximately 10% (Figure 11, left panels, right most bar-and-whiskers plot). By contrast, under a 25% increase in precipitation combined with a 7.5˚C increase in temperature, the median change in annual storage is negligible (Figure 11, right panels, right most bar-and-whiskers plot). This occurs because the increase in precipitation is offset by the increase in temperature and corresponding increase in irrigation demand.

Similar to Figure 11, Figure 12 shows the sensitivity of annual total CVP deliveries and annual streamflow in the Sacramento River at Fremont Weir, above the Yolo Bypass, to changes in mean temperature (individual panels) and mean precipitation (bar-and-whiskers plots within each panel). Results show that CVP deliveries (upper row of panels in Figure 12) are sensitive to changes in precipitation, with greater sensitivity to decreases in precipitation compared to increases. Similar to reservoir storage, decreased precipitation results in decreased total CVP deliveries, with decreases exacerbated by warming temperatures. Increased precipitation results in increased deliveries under baseline temperatures. However, increases in deliveries become smaller as temperature is increased because temperature-driven changes in the timing of runoff (earlier snow melt) means that some of the increased precipitation is not captured by reservoirs and therefore not available for delivery during peak irrigation season. Annual streamflow at Fremont Weir exhibits similar sensitivity to changes in precipitation and temperature, though increases in temperature do not offset increases in precipitation to the same degree as they do for total CVP deliveries.

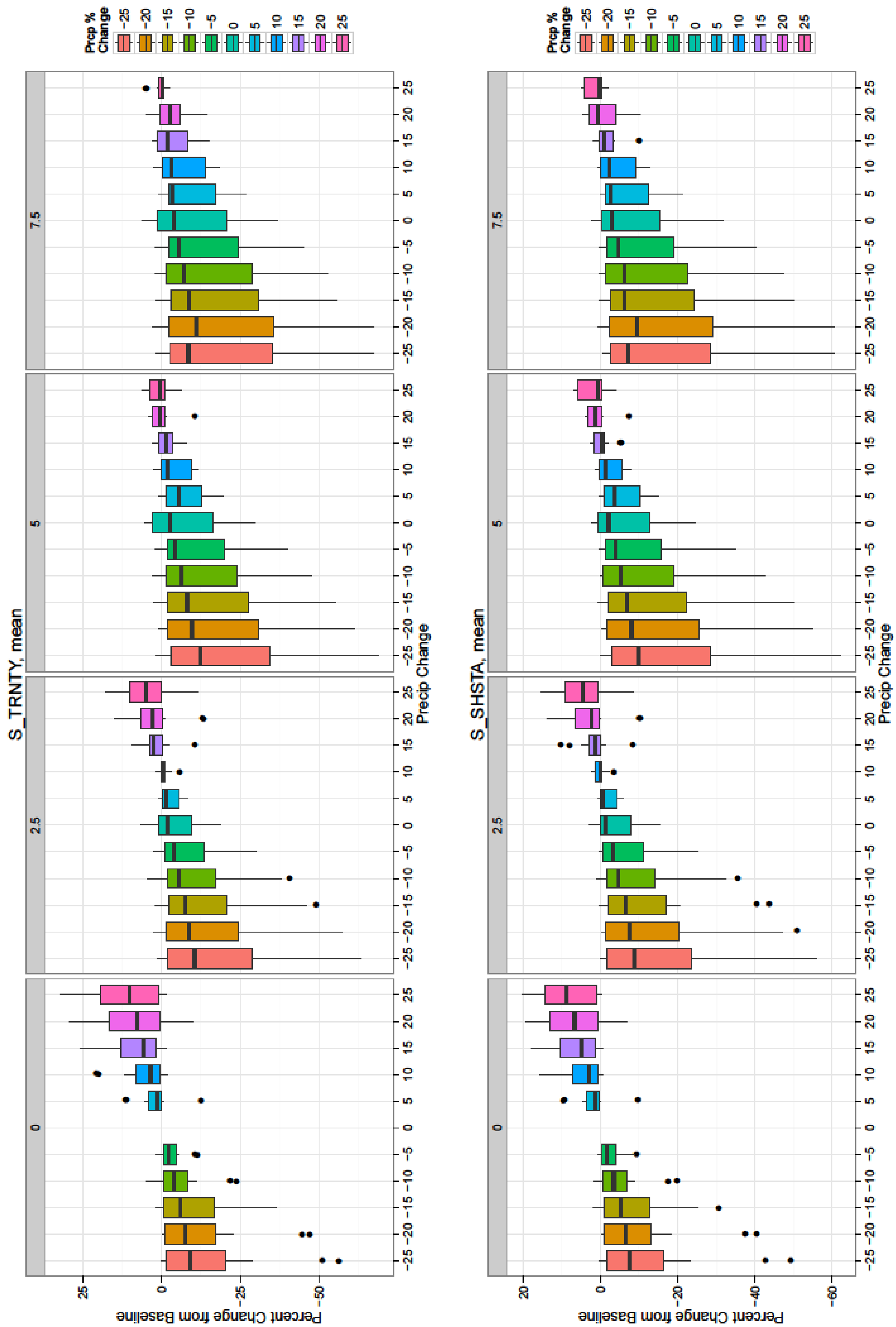

Figure 11.—Sample results from CVP/SWP system sensitivity analysis using CalSim3. Figure shows sensitivity of annual mean reservoir storage in Shasta Reservoir (upper row) and Trinity Reservoir (lower row) to joint changes in precipitation and temperature. See discussion in text.

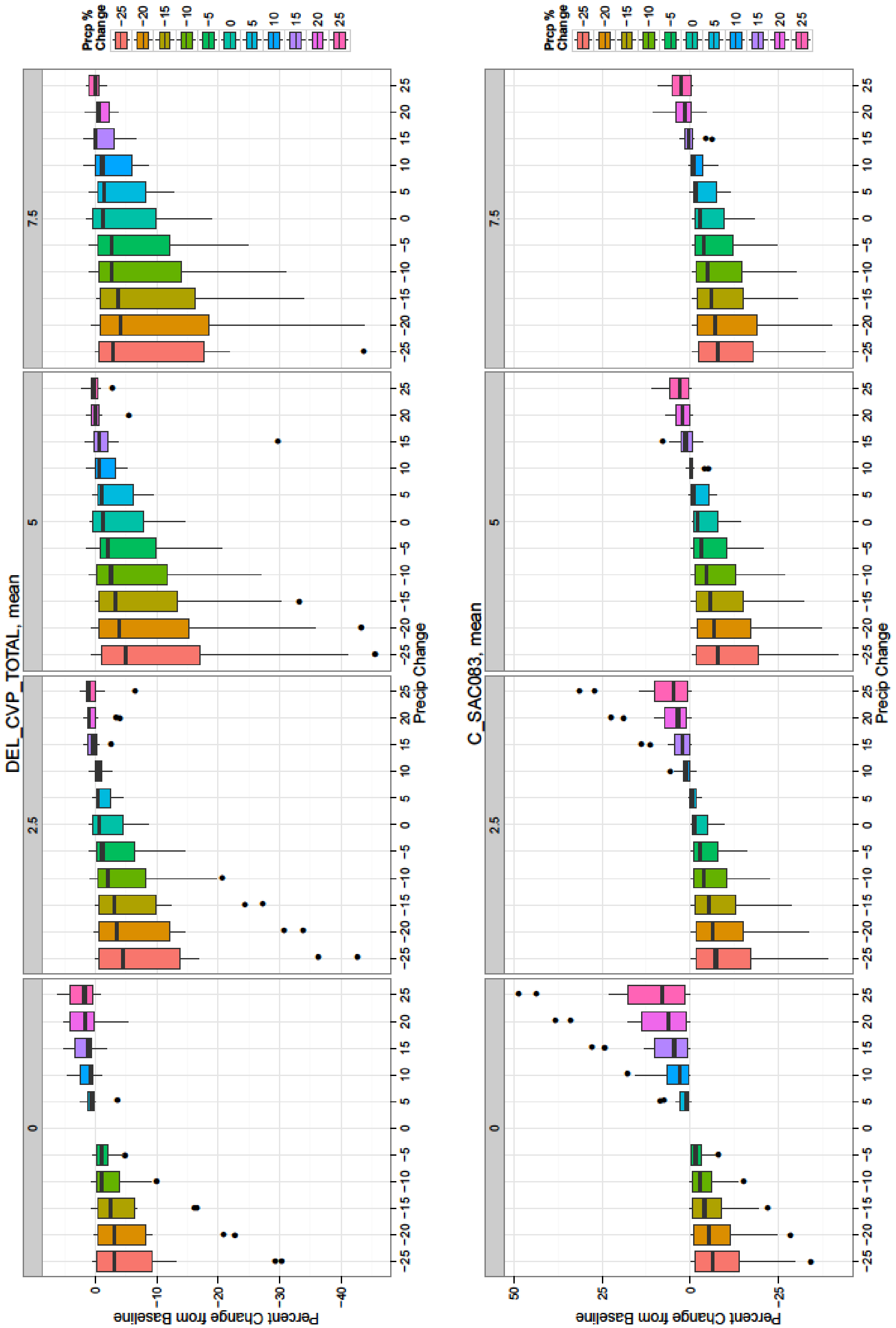

Figure 12.—Sample results from CVP/SWP system sensitivity analysis using CalSim3. Figure shows sensitivity of annual total CVP deliveries (upper row) and annual mean streamflow in the Sacramento River at Fremont Weir (lower row) to joint changes in precipitation and temperature. See discussion in text.

Figures 13 and 14 show sensitivities of Sacramento River streamflows at various locations to changes in the mean and standard deviation of seasonal and annual precipitation, respectively. In general, changes in mean precipitation result in corresponding changes in streamflow: increased mean precipitation results in increased mean streamflow, and decreased mean precipitation results in decreased mean streamflow. However, the magnitude of the streamflow change is generally greater than the magnitude of the precipitation change. For example, a 25% increase in mean precipitation across all months results in a 90% increase in streamflow at the confluence of the Sacramento and San Joaquin rivers (Figure 13, top left panel, black line) whereas a 25% decrease in mean precipitation across all months results in a 30% to 50% decrease in streamflow at most streamflow locations (Figure 13, all panels, black line). The magnitude of streamflow response to changes in precipitation varies between seasons, with larger response to changes in wetter seasons (DJF and MAM) and smaller response to changes in drier seasons (JJA and SON).

It should be noted that CalSim3 represents total streamflow in the Sacramento River at the confluence of the Sacramento and San Joaquin rivers as two separate components: flow that contributes to the required minimum instream flow, and flow that exceeds the required minimum instream flow. Meeting minimum instream flow requirements is an important performance metric for CVP/SWP system operations (see Table 6 in Section 4.2). As shown in the top center panel of Figure 13, the portion of total streamflow at the confluence of the Sacramento and San Joaquin rivers that contributes to minimum instream flow is largely insensitive to changes in precipitation. This is because the required minimum instream flow is largely insensitive to climate and runoff conditions within the basin; only the small portion of the minimum instream flow requirement related to maintaining water quality in the Sacramento-San Joaquin Delta depends on hydrologic conditions within the Sacramento River basin. The general lack of sensitivity to changes in precipitation and temperature thus indicates that minimum instream flow requirements are met under all of the climate scenarios considered.

As shown in Figure 14, streamflow response to changes in the standard deviation of precipitation—i.e., the magnitude of interannual variability relative to the mean—is more complicated than the response to changes in mean precipitation. Decreasing the interannual variability of precipitation results in decreased streamflow in the lower portion of the Sacramento River basin, including at the confluence of the Sacramento and San Joaquin rivers (Figure 14, top left panel) and Fremont Weir (Figure 14 top right panel). Further upstream, decreased precipitation variability results in increased streamflows, particularly when variability is decreased in winter (DJF) or for all seasons (Figure 14, bottom panels). Increased precipitation variability results in increased streamflow in lower portions of the basin (Figure 14, top left and top right panels), whereas increased variability has little impact on average streamflows further upstream (Figure 14, bottom panels).

Figure 14 illustrates the CVP/SWP system's complex response to changes in precipitation variability. In the upper portion of the Sacramento River basin, upstream of major storage reservoirs and diversions, increased precipitation variability (with no change in mean precipitation) increases the variability of runoff and unregulated streamflow (not shown). Reservoirs act to dampen this increase in variability by storing excess flow during periods of high runoff and releasing water from storage during periods of low runoff. System response downstream of major reservoirs thus depends on the storage capacity and operating rules of system reservoirs. The larger the system's reservoir storage, the more likely it is that excess streamflow will be captured during periods of high runoff and released during periods of low runoff, resulting in little change in reservoir releases, streamflow, and project deliveries downstream of reservoirs. The smaller the system's reservoir storage, the less likely it is that all excess streamflow will be captured and that high runoff periods will result in reservoir spills or excess releases for flood control. If these reservoir spills are not usable by project water users, the water is not diverted and continues downstream. If the system's reservoir capacity is insufficient to capture all excess runoff during high flow periods, storage may be insufficient to meet water demands during low runoff periods.

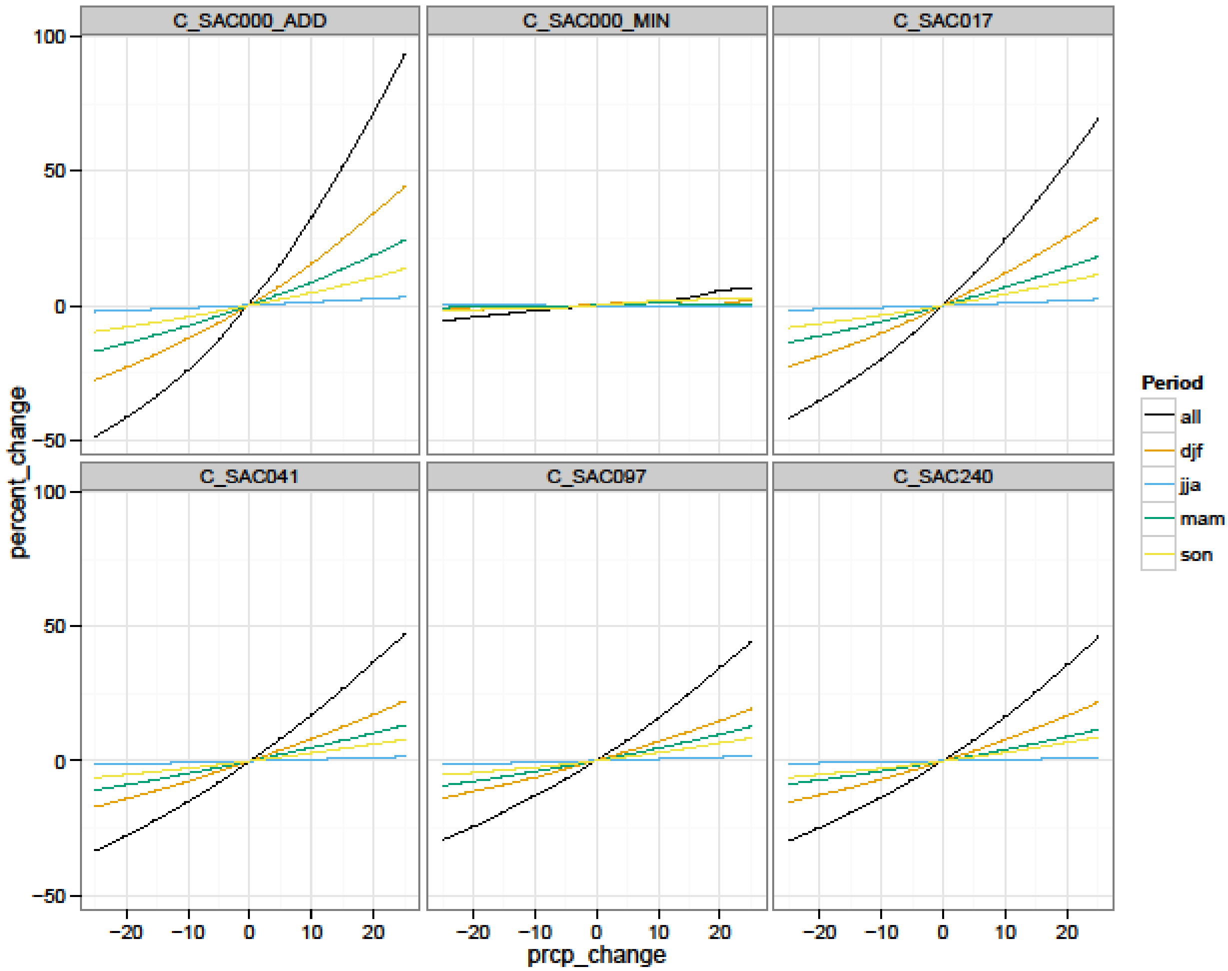

Figure 13.—Sample results from CVP/SWP system sensitivity analysis using CalSim3.0. Percent change in average annual streamflow (ordinate) as a function of percent change in mean seasonal or annual precipitation (abscissa) at five locations on the Sacramento River, including: Confluence of Sacramento and San Joaquin rivers, flow above required minimum instream flow (C_SAC000_ADD; top left); confluence of Sacramento and San Joaquin rivers, flow to meet required minimum instream flow (C_SAC000_MIF; top center); Sacramento River at Fremont Weir (C_SAC017); Sacramento River at Hood, California (C_SAC041); Sacramento River at State Ranch Bend Pumping Plant (C_SAC097); and Sacramento River at Red Bluff Diversion Dam (C_SAC240). Lines on each panel differ according to the season over which precipitation was perturbed (orange for DJF; blue for JJA; green for MAM; yellow for SON; and black for all months).

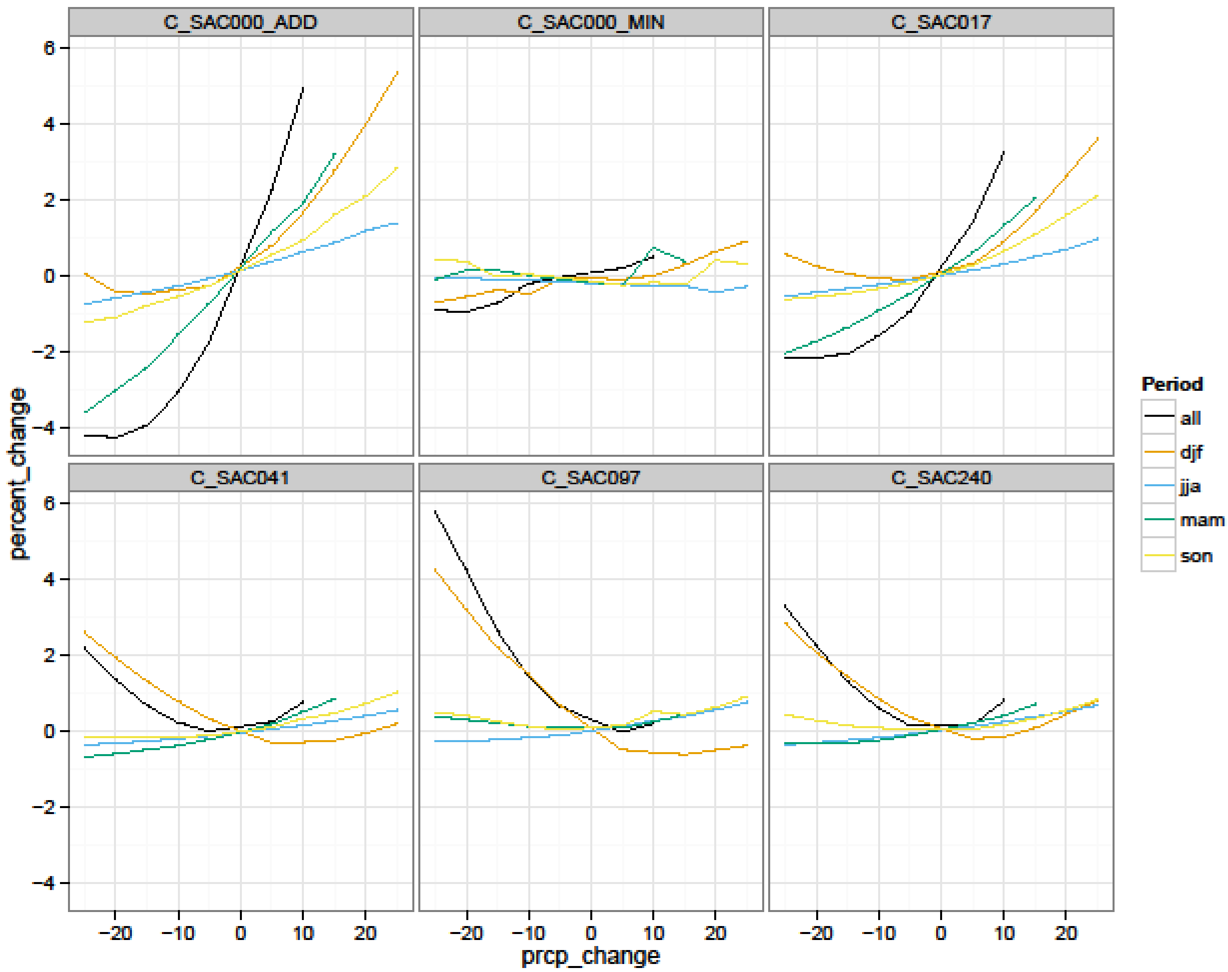

Figure 14.—Sample results from CVP/SWP system sensitivity analysis using CalSim3.0. Percent change in average annual streamflow (ordinate) as a function of percent change in standard deviation of seasonal or annual precipitation (abscissa) at five locations on the Sacramento River, including: Confluence of Sacramento and San Joaquin rivers, flow above required minimum instream flow (C_SAC000_ADD; top left); confluence of Sacramento and San Joaquin rivers, flow to meet required minimum instream flow (C_SAC000_MIF; top center); Sacramento River at Fremont Weir (C_SAC017); Sacramento River at Hood, California (C_SAC041); Sacramento River at State Ranch Bend Pumping Plant (C_SAC097); and Sacramento River at Red Bluff Diversion Dam (C_SAC240). Lines on each panel differ according to the season over which precipitation was perturbed (orange for DJF; blue for JJA; green for MAM; yellow for SON; and black for all months).

5.3 Assessing Credibility, Relevance, and Applicability (Task 4)

As discussed in Section 4.4, a workgroup was organized to pilot the Applicability Framework and provide feedback regarding the utility and challenges of the framework in the broader context of water resources and environmental planning. The workgroup, which consisted of selected planners, resource managers, and technical specialists from Reclamation's Mid-Pacific Region, was divided into two scoping teams. Each team was assigned a hypothetical project and asked to outline a scope for detailed technical analysis of the proposed project alternatives, focusing on how to select and incorporate climate projections into the analysis. The first hypothetical project involved raising the height of Shasta Dam to increase the storage capacity of Shasta Reservoir; the other involved designing a modification to Fremont Weir on the Sacramento River for the purpose of increasing overflows from the Sacramento River to Yolo Bypass for the purpose of restoring and improving salmonid habitat and fish passage in the Yolo Bypass.

Teams were provided with selected results from the evaluation of CMIP5 climate models (Tasks 1 and 3) and the CVP/SWP system sensitivity analysis (Task 2) as the basis for judging the credibility and relevance of climate projections to their study. In order to structure scoping discussions, teams were asked to answer six scoping questions relating to the credibility and relevance of climate projections in the context of water resources and environmental planning (see Reclamation 2014). Results of the pilot workgroup include responses to the six scoping questions provided, feedback from workgroup participants regarding the evaluation and sensitivity results, and feedback from workgroup participants regarding Applicability Framework in general. Each of these results is summarized below.

5.3.1 Responses to Scoping Questions

Each scoping team's responses to the six scoping questions relating to credibility and relevance of climate projections are summarized below.

Scoping Question 1.1:

How can climate uncertainties affect study decisions?
Scoping Question 1.1 focuses on identifying the hydroclimate drivers and climate uncertainties that may affect study outcomes and subsequent decisions. This scoping question was accompanied by two prompting questions:

- What hydrologic and climate variables and/or processes are likely to affect project infrastructure and operations?

- What is the time period and geographical extent of the likely impacts of climate change on project infrastructure and operations? What uncertainties should be considered regarding future hydroclimatic conditions over this period and extent?

The scoping team considering the proposed raising of Shasta Dam (Shasta Team) and the team considering the proposed modification of Fremont Weir (Fremont Team) both identified a wide range of hydrologic and climate drivers relevant to their respective projects. Both teams identified runoff and streamflow throughout the Sacramento River basin as the primary hydrologic driver of CVP/SWP operations. Runoff and streamflow in the San Joaquin River basin were also identified as important due to the coordination of CVP/SWP operations across both basins. The Shasta Team focused primarily on the timing and volume of streamflow, whereas the Fremont Team identified short-term runoff and flood characteristics as important hydrologic drivers with respect to their project. The Fremont Team also identified groundwater conditions as an important hydrologic driver due to the influence of groundwater/surface-water interactions on streamflow in portions of the Central Valley.

With respect to climate drivers, both teams identified the amount, timing, and form of precipitation (i.e., rain vs. snow) in the rim watersheds that supply CVP and SWP reservoirs as a primary climate driver due to the influence of precipitation on runoff and streamflow, and the subsequent impacts of runoff and streamflow on overall system supply and operations. Both teams also identified air temperature in the rim watersheds as a primary climate driver due to the effects of temperature on precipitation form and on the magnitude of snow accumulation and timing of snowmelt, all of which affect the timing, and to a lesser extent the volume, of runoff and streamflow. Effects of air temperature on water demands for agriculture and urban landscaping were also identified as an important consideration, as well as the relationship between air temperature, water temperature, and water quality and aquatic habitat. The Shasta Team also identified the relationship between temperature and sea level as an important consideration stemming from CVP and SWP operating criteria related to salinity in the Sacramento-San Joaquin Delta.

Scoping Question 1.2:

What measures of system performance are expected to influence study decisions? Scoping Question 1.2 focuses on identifying the performance measures that will be used to evaluate the need for and benefits of a proposed project. As used here, *performance measures* refer to quantitative metrics or qualitative criteria that characterize the performance of the CVP/SWP system with respect to project objectives. Performance measures may apply to the CVP/SWP system as a whole or to a specific portion of the system. Similar to Scoping Question 1.1, this scoping question was accompanied by two prompting questions:

- What measures can be used to evaluate and compare system performance with respect to primary and secondary operating objectives?
- How will system performance measures be computed and used to evaluate and compare alternatives?

The Shasta Team identified a broad range of well-established performance measures for the CVP/SWP system, including measures related to the volume and reliability of surface water deliveries and reliability of meeting environmental and water quality targets related to stream flow, stream temperature, and salinity. The Shasta Team also identified hydropower generation and recreation as important performance measures. The Fremont Team identified a narrower range of metrics specifically related to their hypothetical project, which involves modifying Fremont Weir to increase the amount of flood flow reaching Yolo Bypass. Metrics identified by the Fremont Team include the flow rate entering Yolo Bypass and the inundated area of Yolo Bypass, along with inundation characteristics such as inundation frequency, depth, duration, and timing.

With respect to how system performance measures will be computed and used to evaluate and compare alternatives, the Shasta Team focused on the use of existing tools, including CalSim (CVP/SWP system planning model), HEC-5Q (stream temperature model), SalMod (anadromous fisheries model), DSM-II (hydrodynamnic and water quality model of Sacramento-San Joaquin Delta), and Plexus (hydropower model). The team noted, however, that several of the existing models may require substantial updates in order to accurately represent system operations and performance under altered climate and hydrologic conditions. In addition to updating input datasets, including inputs representing time-varying hydrologic and climate conditions, several of these models incorporate simplified representations of environmental regulations and related operating criteria that were developed based on historical streamflow volume and timing. Representation of some operating criteria may therefore need to be revised to more accurately simulate CVP and SWP coordinated operations under climate change.

The Fremont Team identified a similar set of existing tools for use in evaluating and comparing alternatives. More specifically, the team determined that an operations model such as CalSim would be required to simulate overall system operations, with results from the CalSim model used to develop inputs for subsequent simulations with hydrodynamic, fisheries, and economic models. A fine-resolution hydrodynamic model would ultimately be required to compute system performance measures related to inundation of Yolo Bypass under each alternative, with a well-calibrated fisheries model required to estimate potential benefits to fish populations.

Scoping Question 1.3:

What types of climate change influence system performance the most?
Scoping Question 1.3 focuses on identifying the aspects of climate change that are likely to have the greatest impact on system performance and are thus the most relevant to the study at hand. This question was again accompanied by two prompting questions:

- Which of the system performance measures identified above are most likely to be sensitive to changes in climate?

- What types of climate projection information (and corresponding hydrologic projection information) are needed to represent the impacts of climate change on system performance when evaluating and comparing proposed alternatives?

The Shasta Team identified a broad range of performance measures related to water supply and delivery reliability most likely to be sensitive to changes in climate, including CVP and SWP deliveries north of the Sacramento-San Juaquin Delta (i.e., deliveries in the Sacramento River basin) as well as deliveries south of the Delta (i.e., deliveries in the San Joaquin River basin and southern California, including Delta exports). The Shasta team also identified performance metrics related to stream temperature as likely to be impacted by climate change. With respect to the types of information needed to represent impacts of climate change on system performance, the team identified projections of precipitation and temperature as the highest priority. The team determined that downscaled and bias corrected GCM-based projections of precipitation and temperature are most likely the best source of climate projection information, in conjunction with hydrologic modeling to develop corresponding projections of future runoff (including runoff timing and volume) and future water demands (including irrigation demands and for agriculture and urban landscaping). The Shasta Team also identified projections of sea level rise as important for evaluating future system performance due to CVP/SWP operating criteria related to flow and salinity in the Sacramento-San Joaquin Delta.

The Fremont Team identified performance measures related to streamflow in the Sacramento River, with one team member emphasizing the sensitivity of winter and spring streamflows. The Fremont Team identified variability in winter precipitation, including characteristics of heavy precipitation events, and corresponding variability in streamflow and heavy runoff events as important climate drivers of the primary performance metrics related to their hypothetical project. The team determined that performance measures were likely to be sensitive to changes in both precipitation and temperature, with greater sensitivity to changes in the volume and form of winter precipitation. As a result, the team identified projections of future precipitation and temperature as the primary types of climate projection information needed to represent impacts of climate change when evaluating proposed alternatives for their project.

It should be noted that both scoping teams considered the sensitivity results from Task 2 in identifying the hydroclimatic drivers and types of climate changes that are most likely to affect their study. However, both teams also relied heavily on prior understanding of the CVP/SWP system and its operations. As discussed further in Section 5.3.4 below, both study teams felt that results of the sensitivity analysis using CalSim3 were informative, but were not sufficient in and of themselves to fully assess the relevance of climate conditions to their respective hypothetical projects.

Scoping Question 2.1:

What types of regional future climate and hydrology datasets are available?
Scoping Question 2.1 prompts each scoping team to identify existing resources that provide information on future climate and hydrologic conditions, including climate projection datasets and existing projections of future hydrology. Scoping Question 2.1 was accompanied by two prompting questions:

- What types of projected climate and hydrologic information are available?
- Does the available projection information include the relevant climate and hydrologic variables, spatial and temporal scale(s), and future period(s) relevant to the proposed alternatives?

Both scoping teams indicated that they were aware of a large number of existing resources for climate and hydrologic projections, including the CMIP5 Multi-Model Dataset of GCM-based climate projections, multiple datasets of downscaled and bias corrected GCM projections, and multiple datasets of hydrologic projections developed from downscaled and bias corrected GCM projections. Both teams also identified several recent studies as providing relevant climate projection information, including the California Water Plan Update 2013, the Sacramento and San Joaquin Basins Climate Impact Assessment (ongoing at time of workshop), the Sacramento – San Joaquin Rivers Basin Study (ongoing at time of workshop), and various water resources management plans developed under California's Integrated Regional Water Management (IRWM) program. Both teams also noted that the scientific community is continually updating existing climate projection information and developing new resources to evaluate climate change and its impacts on water supplies and demands.
With respect to available projection information including the variables, scales, and periods relevant to the proposed alternatives, the Shasta Team responded that existing datasets of downscaled and bias corrected climate projections largely

meet the needs of their study. The team also felt that downscaled hydrology projections were available for reservoir inflows to CVP and SWP reservoirs and for major tributaries to the Central Valley. However, the Shasta Team identified spatial and temporal resolution as potential limitations of existing datasets. The team noted that while CalSim operates on a monthly time step, climate and hydrologic information at daily resolution, and at finer spatial resolution than currently available, would be potentially relevant to their analysis. The team also noted that climate projections are generally available for precipitation and temperature variables, but are not available for other variables that are likely to affect water demands in the Central Valley, including humidity and wind speed.

The Fremont Team generally agreed that existing datasets of downscaled and bias corrected climate projections largely met the needs of their study as well, noting that several existing datasets provide bias corrected and downscaled projections at daily temporal resolution. The study team identified the spatial resolution of hydrology projections as the primary limitation of existing information in the context of their study. The Fremont Team also identified the temporal resolution of CalSim as a major limitation to their study. While climate and hydrologic projections are available at daily temporal resolution, CalSim's monthly time step limits the degree to which these projections can be represented in the context of CVP/SWP operations relevant to the proposed modification of Fremont Weir.

Scoping Question 2.2:

Which future climate and hydrology changes are projected well for the study objectives?

Scoping Question 2.2 focuses on assessing the skill—and ultimately the credibility—of available climate and hydrology projections in the context of a given study. This question was accompanied by two prompting questions:

- How well do the climate projections reproduce observed records of temperature and precipitation? What biases are present?
- Which model outputs are sufficient to represent future climate assumptions in support of key study decisions?

Based on the selected evaluation results from the Climate Change Web Portal provided during the workshop, both scoping teams identified positive biases in seasonal and annual precipitation as a major concern (e.g., see Figures 7, 8, and 10 in Section 5.1). Both scoping teams noted that biases are greatest over the Central Valley and smallest over the Sierra Nevada Mountains in eastern central California. The Stasta Team noted that while relatively low biases over mountain regions bode well for simulation of snowpack, runoff, and inflow to CVP and SWP reservoirs, significant biases over the Central Valley bode poorly for simulation of soil moisture and irrigation demands. The Fremont Team further noted that the bias in precipitation is larger than the projected change in precipitation (e.g., as shown by comparing the lower left and lower right panels of Figures 7-8 in Section 5.1).

Both the Shasta and Fremont teams found that CMIP5 models exhibit generally lower biases in simulating temperature compared to precipitation. Based on spatially-aggregated (time series) figures, both teams noted that the CMIP5 models generally capture observed magnitudes and trends in seasonal and annual mean temperature over the study region, despite moderate biases for some seasons. However, both teams also noted that CMIP5 models exhibit compensating biases between high-elevation and low-elevation portions of the region, with the models generally exhibiting positive biases (too warm) over the Sierra Nevada and Cascade mountain ranges and negative biases (too cool) over the Central Valley. Warm biases over the mountains may affect projections of snow accumulation and melt processes, whereas cool biases over the Central Valley are likely to affect projections of irrigation demand. Technical specialists noted that the spatial pattern of GCM biases appears related to coarse resolution of GCMs and their inability to resolve the complex topography of the Central Valley and surrounding watersheds.

Based on the evaluation results available through NOAA's Climate Change Web Portal, both study teams questioned whether CMIP5 climate models exhibited sufficient skill in simulating both temperature and precipitation to be considered credible in the context of their study. In general, both teams determined that the CMIP5 GCMs are moderately credible in simulating temperature, with generally low credibility in simulating precipitation over the region of interest. However, both teams noted that several bias correction techniques are available reduce the systematic biases exhibited by GCMs. In addition, one participant on the Fremont Team noted that climate models did not need to exactly reproduce observed historical climate conditions, but simply needed to provide reasonable projections of the likely range of changes in future climate.

Scoping Question 2.3:

What future climate or hydrology assumptions should still be based on historical records?

Scoping Question 2.3 prompts each scoping team to consider what climate aspects should be represented in their study based on climate projections and what should be based on historical observations. This question was accompanied by two prompting questions:

- Which climate model timescales (if any) are appropriate to use? Do climate models provide the necessary credibility at these spatial and temporal scales?

- What additional information is being provided by model output versus historical records?

Both scoping teams struggled to confidently answer Scoping Question 2.3 based on the evaluation results provided by the Climate Change Web Portal. In particular, both teams were interested in characteristics of GCM-simulated precipitation and temperature at daily and monthly timescales in addition to seasonal and annual timescales. Scoping teams were also unclear regarding how to interpret this scoping question in cases where evaluation results show low bias in one season and high bias in another—in this case, are results considered reliable or unreliable at the seasonal timescale? With respect to spatial scale, both scoping teams noted that the spatial resolution of most GCMs is too coarse for GCM-based climate projections to be applied directly in water resources and environmental planning and management. As a result, downscaling is generally required in order to use GCM-based projections to evaluate impacts on surface water and groundwater hydrology and water supplies and demands. Scoping teams were therefore unclear regarding how to interpret spatially-distributed (map) results, given the coarse resolution of GCM outputs relative to the region of interest—namely the Sacramento and San Joaquin river basins and areas of southern California that receive water from the SWP—and the significant variation in topography, climate, and hydrology within this region. Given these uncertainties, both scoping teams relied largely on prior experience and understanding regarding GCM skill and biases across various timescales.

The Fremont Team felt, based on prior experience and understanding, that CMIP5 climate models—with appropriate downscaling and bias correction—were sufficiently credible at the larger spatial and temporal scales that affect the CVP/SWP system as a whole. However, even after downscaling and bias correction, the team felt that climate models were not sufficiently credible at the finer spatial and temporal sales specifically relevant to short-term, localized storms that contribute to high streamflow events in the lower reaches of the Sacramento River near Fremont Weir. To this end, the Fremont Team responded that projected climate trends at monthly, seasonal, and annual timescales were likely to be credible, while projected changes in climate characteristics at smaller spatial scales and shorter timescales were likely to be less credible. Based largely on prior experience and understanding, the Shasta Team similarly responded that GCM projections were most credible at monthly and longer timescales, and that climate characteristics at shorter timescales should still be based on historical records.

5.3.2 Workgroup Feedback: CMIP5 Evaluation and Web Portal

Both scoping teams provided detailed feedback regarding the evaluation results available through the Climate Change Web Portal, as well as the menu options, format, and presentation of evaluation results within the portal. The majority of workshop participants felt that the portal was a useful tool for gaining a general understanding of the magnitude and distribution of GCM biases, similarities and differences between observed and simulated regional (spatially-aggregated) averages and trends, and projected changes in seasonal and annual precipitation and temperature. Several participants commented that the portal was likely to be good resource for planners, stakeholders, decision makers, and others without technical expertise in climate science to explore climate model results and to gain a first-order understanding of climate model capabilities.

Workgroup members also noted several limitations of the web portal from the perspective of climate scientists, hydrologists, engineers, and other technical specialists who likely require a more detailed understanding of GCM capabilities and limitations. Comments fell under four general themes, summarized below:

- **Temporal Resolution**:
  Evaluation results at seasonal and annual timescales do not allow for consideration of GCM credibility with respect to climate variability at shorter timescales, including many types of extreme events. Climate and hydrologic extremes such as flood events and extreme heat events often occur on timescales ranging from hours to weeks. These extreme events have the potential to significantly impact human and environmental systems.

- **Spatial Resolution**:
  While some water resources and environmental planning situations involve spatial scales of on the order of 1000 kilometers or more—e.g., planning studies involving major river basins—many involve spatial scales on the order of 100 kilometers or less. Spatially-distributed (map) evaluation results are presented at a relatively coarse spatial resolution of 1.0˚ latitude by 1.0˚ longitude, which was sometimes difficult to interpret even at the scale of the CVP/SWP system, which is larger than most water resources systems. While the spatial resolution of evaluation results is consistent with the scale of CMIP5 climate models, the relatively coarse spatial resolution limits the utility of the web portal for planning situations that involve smaller spatial scales.

- **Graphical Format**:
  The web portal provides evaluation results in graphical format only. Technical specialists from the workgroup commented that graphical results are difficult to interpret quantitatively. In addition, the graphical format made it difficult to interpret the relative skill of individual climate models and to identify models that perform better or worse than others. Workgroup participants felt that providing evaluation results in

tabular format for spatially-aggregated results and/or at a specific location would facilitate quantitative interpretation of evaluation results.

- **Datasets Considered**:
  Several workgroup participants noted that a significant amount of scientific literature has shown that GCM-based climate projections are not directly applicable to climate change impact and adaptation studies due to their coarse spatial resolution and model biases. As a result, planning studies typically rely on downscaled and bias corrected climate projections. Workgroup participants were uncertain how evaluation results based on un-processed (raw) GCM outputs apply to the types of bias corrected and downscaled GCM outputs typically used in planning studies.

Overall, workgroup participants indicated that the Climate Change Web Portal was a useful tool for exploring climate model capabilities and biases, but that it did not provide evaluation results at the spatial and temporal resolution and quantitative format required to fully assess what aspects of climate projections are credible in the context of a given study. Workgroup participants felt that more detailed consideration of available climate projections, including bias corrected and downscaled projections, would typically be required in order to support decisions regarding the credibility of climate projection information for use in a given study.

5.3.3 Workgroup Feedback: Sensitivity Analysis

During the workshop, both scoping teams were provided with the same set of sensitivity results, which are provided in Appendix 3.6 of this report. Scoping teams were also given an opportunity to review additional sensitivity plots on a laptop computer during the workshop. Sensitivity plots were provided in several different formats, each of which uses a different approach to illustrating the sensitivity of CVP/SWP system performance to changes in various aspects of precipitation and/or temperature. Both scoping teams generally found sensitivity plots for a single variable or climate aspect easy to interpret. Plots that represent sensitivity to multiple variables or aspects required additional discussion before the scoping teams were confident in their interpretation of the information displayed in the plots. Both teams suggested that additional instruction regarding interpretation of sensitivity plots would be helpful, along with a written summary providing narrative discussion system sensitivities.

The scoping team that considered a hypothetical project to raise Shasta Dam felt that the sensitivity analysis using CalSim3 provided important and useful information regarding the sensitivity of CVP/SWP system performance to changes in climate. The use of idealized climate scenarios, in which specific climate aspects were systematically and incrementally perturbed over a wide range, provided new insights with respect to the types or aspects of climate change that are most likely to impact various system performance metrics. The Shasta Team felt that the sensitivity results provided important context for considering climate change in the context of their hypothetical project.

The Fremont Team, by contrast, felt that the CalSim3 sensitivity analysis did not provide sufficient information to consider the relevance of climate drivers in the context of their project. The hypothetical modification to Fremont Weir would reduce the stream stage at which overflow occurs from the Sacramento River to Yolo Bypass, potentially allowing for greater frequency, duration, and magnitude of overflow events. CalSim3 sensitivity results include changes in streamflow at Fremont Weir in response to the idealized climate perturbations considered here. CalSim3's monthly time step, however, does not provide detailed information regarding the high flow events that typically result in overflow from the Sacramento River to Fremont Weir. While the frequency, duration, and magnitude of overflow events is likely to be correlated with monthly mean streamflow, the processes that drive high-flow events and the resulting overflow events often occur on hourly to daily timescales. The Fremont Team thus felt that CalSim3 does not provide sufficient representation of Fremont Weir and Yolo Bypass to accurately represent climate-related sensitivities relevant to their hypothetical project, and that additional hydraulic and/or hydrodynamic modeling would be required.

5.3.4 Workgroup Feedback: Climate Projection Applicability Framework

After completing their scoping tasks and discussion, workgroup participants provided feedback on the overall concept of the Climate Project Applicability Framework. Participants also discussed potential pros and cons of using the framework in the context of water resources and environmental planning.

Participants understood the concepts of *credibility*, *relevance*, and *applicability* as used in the Applicability Framework. Participants also felt that the concepts underlying the Applicability Framework, as discussed in Chapter 2 and illustrated in Figure 1, were readily understood by both planners and technical specialists and provided an intuitive approach to considering what climate projection information to include in a given study. Moreover, the majority of participants agreed that the Applicability Framework fit reasonably well with the broader context of water resources and environmental planning, in which planners, technical specialists, and decision makers routinely must determine what information is sufficiently credible and relevant to support major decisions.

Regarding the credibility component of the applicability framework, workgroup participants felt that evaluation results available through NOAA's Climate Change Web Portal provided useful information regarding climate model skill; however, as discussed above, technical specialists felt that additional analysis would likely be required to assess climate model credibility in the context of a specific planning study. While the Climate Change Web Portal is likely not sufficient in and of itself to support assessment of credibility, participants noted that study teams were likely to have sufficient data and tools available to evaluate the skill of climate models in simulating observed historical climate conditions and trends in the context of a specific study.

As noted above, technical specialists identified potentially significant limitations with respect to the climate model evaluation results provided through the Climate Change Web Portal, including their spatial and temporal resolution, their graphical format, and their focus on "raw" GCM outputs. Most notably, technical specialists questioned how bias correction and downscaling of climate projections fits into the credibility component of the Applicability Framework. Evaluation carried out for the Climate Change Web Portal focuses on "raw" GCM simulations and projections. By contrast, the vast majority of water resources and environmental planning studies rely on bias corrected and downscaled climate projections. Workgroup participants were uncertain as to whether bias correction eliminated the need to consider the credibility of "raw" GCM-based projections. Participants suggested that additional guidance should be provided regarding consideration of bias corrected and/or downscaled climate projections, including the use of downscaling techniques that effectively combine climate attributes from GCM-based projections with climate attributes from historical observations.

While workgroup participants agreed that assessing model credibility was an important consideration, they also raised a number of general questions and concerns regarding the credibility component of the Applicability Framework. Technical specialists from both scoping teams noted that skill in simulating past conditions does not necessarily represent skill in predicting future conditions. Technical specialists referred to recent studies that suggest model performance in simulating historical weather and climate is not a clear indicator of model credibility in projecting future climate change (Reifen and Toumi 2009, Knutti et al. 2010, IPCC 2013). For example, Knutti et al. (2010) found that projected changes in temperature over the 21st century do not "seem to depend in an obvious way on the simulated pattern of current temperature." Assessing the credibility of climate projections based on model evaluation over the 20th century thus requires a "leap of faith"—i.e., requires the assumption that retrospective skill is indicative of predictive skill. As discussed in the scientific literature, this assumption may not be valid.

Technical specialists also noted that the skill of any given climate model varies by region, variable, and timescale (Gleckler et al. 2008, Brekke et al. 2008, IPCC

2013). As noted by IPCC (2013), “some models perform better than others for certain climate variables, but no individual model clearly emerges as the ‘best’ overall.” For example, a model may simulate historical climate means, variability, and trends very well over one region and very poorly over another, or may simulate temperature quite well over a region of interest while simulating precipitation quite poorly over the same region. In the case of model skill varying by region, evaluation results may result in substantially different climate projection information being selected for studies over different regions. If a study consider a large geographic region, model skill may vary significantly across the study area, leading to potential challenges in assessing credibility in the context of the overall study area.

In the case of model skill varying by climate variable, different models may be identified as credible for different variables—e.g., one subset of models may be identified as credible with respect to precipitation, and an entirely different subset may be identified as credible with respect to temperature. This could again lead to potential challenges in assessing the overall credibility of climate projections. Alternatively, situations could arise where projections of one variable are identified as credible whereas other variables are identified as not credible—e.g., evaluation results indicate that projections of temperature are credible whereas projections of precipitation are not credible. Planners and technical specialists felt that it would be difficult to justify using climate projections of one climate variable while relying solely on historical data for another. Planners felt this situation would raise concerns because it has not been widely used in previous decision support studies to date, and because it could be difficult to interpret study results based partially on historical climate and partially on climate projections. Technical specialists, on the other hand, noted that this situation could result in a disconnect between climate variables, which could, in turn, result in unrealistic climate situations. For example, precipitation and temperature are often correlated, with a tendency for warmer temperatures during drier periods and cooler temperatures during wetter periods. If a study were based on a combination of historical and projected climate conditions for different variables, care would be required to preserve the relationship between climate variables.

Regarding the relevance component of the Applicability Framework, workgroup participants noted that sensitivity analyses are commonly used to assess system response to changes in system inputs and/or system parameters, as well as identify and assess uncertainties in simulating and predicting system performance. Participants agreed that sensitivity analyses were therefore an appropriate approach to assessing relevance in the context of the Applicability Framework.

Technical specialists noted, however, that conducting a climate sensitivity analysis along the lines of the sensitivity analysis carried out in Task 2 of this project is likely to require a significant amount of time and effort, and thus significant cost. Sensitivity analysis also require an appropriate model of the system of interest. In particular, technical specialists noted that traditional approaches to modeling water resources systems often incorporate highly simplified representation of important physical processes, such as groundwater/surface-water interactions and stream depletions. It may be difficult to assess the sensitivity of these processes, and related sensitivity of system performance, to changes in climate due to their simplified representation. Technical specialists thus felt that in order for the Applicability Framework to be adopted as formal framework, agencies would need to develop detailed guidance regarding the model features required to assess relevance.

In addition to the issue of model adequacy, planners and technical specialists raised a number of questions regarding how study teams would develop climate scenarios for climate sensitivity analyses, as well as how these scenarios would be translated into perturbed model inputs. Questions include how study teams will identify potentially relevant climate variables and aspects; how they will determine the method and magnitude by which to perturb the selected variables and attributes; and what type of interim models and methods would be required to develop corresponding model inputs. Workgroup participants also questioned whether it was more appropriate to consider idealized climate scenarios, similar to the scenarios used in this study, or to use scenarios developed from actual climate projections. Similar to concerns regarding model adequacy, participants felt that detailed guidance would be required before agencies could formally adopt the Applicability Framework.

Regarding the applicability component of the Applicability Framework, workgroup participants raised a number of questions regarding interpretation of credibility and relevance information—i.e., results of climate model evaluation and sensitivity analysis—including interpretation of results independently as well as jointly. Important questions include:

- What level of skill is considered *credible*—e.g., are there specific threshold values for different skill metrics that are considered “good enough” for a model to be credible?

- What level of sensitivity is considered *relevant*—e.g., are there specific threshold values for change in a given system performance metric in response to change in a given climate variable that are considered “sensitive enough” for the climate variable or aspect to be relevant?

- How do study teams interpret conflicting results between credibility and relevance—e.g., what happens when a system is highly sensitive to a given climate variable or attribute (high relevance), but climate models exhibit poor skill in simulating that variable or attribute (low credibility)?

With respect to the question of what level of skill is considered credible, one workgroup participant expressed concern that setting the credibility threshold too high could be used to justify excluding climate change from some studies. Climate projections are known to exhibit substantial limitations and biases, particularly with respect to simulating climate conditions at the finer spatial and temporal scales that are important to water resources and environmental planning. Workgroup participants felt that these limitations and biases could be interpreted as indicating that climate projections are not credible and therefore should not be used to support planning and decision making. Clear guidance would therefore be required to ensure that study teams do not associate known biases and limitations with general lack of credibility and subsequently dismiss climate projections outright.

Workgroup members also raised concerns regarding whether the Applicability Framework incorporates appropriate consideration of uncertainties in future climate change. Characterizing the range of uncertainty in projected climate is an important component of climate change impact and adaptation studies. The approaches used to consider climate change in many previous water resources and environmental planning studies have often focused on evaluating future conditions under a broad range of projected climate conditions. However, the Applicability Framework does not explicitly address the issue of climate projection uncertainty.

Lastly, workgroup members raised concerns regarding when and how to consider practical constraints in assessing the overall applicability of climate projection information in the context of a given study. As illustrated schematically in Figure 1, practical constraints include the availability and limitations of resource models, including hydrologic and water resources system models; availability and uncertainties of non-climate datasets and inputs; and considerations related to the study budget and schedule. Workgroup members were uncertain as to how these factors should be considered relative to climate projection credibility and relevance. For example, if climate projections are identified as both credible and relevant, to what extent is it appropriate to limit consideration of climate change based on budget and schedule constraints.

6. Summary and Conclusions

Water resources and environmental planning involves scoping, conducting, and interpreting detailed analyses of how natural and managed systems, ranging from watersheds and ecosystems to large-scale reservoir and conveyance systems, perform under current conditions and under projected future conditions. Many of these systems are strongly influenced by weather and climate conditions, including effects of weather and climate on water supplies and demands as well as on species habitat and other environmental factors. A vast amount of research over the past two decades has demonstrated that climate change is altering, and will continue to alter, climate and hydrology across the globe. These changes in climate and hydrology are likely to have significant impacts on water resources and environmental systems.

Numerous federal and state agencies have recently adopted guidelines, directives, and mandates that require consideration of climate change in long-term water resources and environmental planning. As a result, study teams now require a consistent framework for selecting and incorporating climate projection information to support specific investment and management decisions. This study used a workgroup approach and hypothetical scoping exercises to demonstrate and evaluate the Climate Projection Applicability Framework (Applicability Framework), a conceptual framework developed by Reclamation, USACE, and NOAA for selecting climate projection information for use in water resources and environmental planning.

Workgroup participants provided detailed feedback regarding the three core elements of the Applicability Framework: assessing the *credibility* of climate projections, the *relevance* of climate to the system of interest, and the *applicability* of climate projection information to the study objectives. The Applicability Framework is discussed in Chapter 2, and feedback from workgroup participants is detailed in Section 5.3 of this report.

Workgroup participants found that the Applicability Framework provides a logical and consistent approach to selecting climate projection information for use in individual planning studies. Participants also noted that the Applicability Framework is consistent with the overall process of water resources and environmental planning by federal agencies. However, workgroup participants identified a number of questions and potential challenges in implementing the Applicability Framework across a broad range of water resources and environmental planning contexts. Participants suggested that in order to fully adopt and implement the Applicability Framework, detailed guidance would be required to address several important issues. Guidance needs are summarized below.

Guidance Needs: Assessment of Climate Projection *Credibility*:

- Guidance regarding the types of climate projections that should be considered in assessing credibility: Should credibility be based on evaluation of "raw" GCM projections, or should credibility be based on bias corrected and/or downscaled climate projections? With respect to bias corrected climate projections, how should bias correction be considered when identifying climate attributes and metrics for the evaluation?

- Guidance regarding identification of appropriate metrics for evaluating climate projections in the context of a given study: What climate attributes have the potential to influence study objectives and outcomes and thus warrant consideration in assessing credibility, and what spatial and temporal scales are appropriate for evaluating climate projections? In the context of the Applicability Framework, should assessment of climate projection credibility be guided by the assessment of climate relevance?

- Guidance regarding how to interpret conflicting evaluation results: How should study teams interpret evaluation results that suggest climate projections are credible for some climate variables but not others, or over some regions and time scales but not others, etc?

Guidance Needs: Assessment of Climate Projection *Relevance*:

- Guidance regarding methods to assess relevance: Is a quantitative sensitivity analysis required to assess relevance, or can relevance qualitatively based on understanding of the system of interest?

- Guidance regarding identifying climate aspects to consider in assessing relevance: How should study teams determine what climate variables, attributes, characteristics, time scales, and spatial scales to consider in assessing relevance?

- Guidance regarding climate scenarios used in sensitivity-based assessment of relevance: Should climate scenarios used in sensitivity analyses be based on idealized perturbations (as used in this study) or based directly on climate projections?

- Guidance regarding modeling tools for use in sensitivity-based assessment of relevance: What features and capabilities are required for a model (or models) to be used in a sensitivity analysis to support assessment of climate projection relevance?

Guidance Needs: Assessment of Climate Projection *Applicability*:

- Guidance regarding the level of agreement between climate models and observations (i.e., what level of skill) is considered credible: For a given evaluation metric, is there a threshold above which climate models are considered highly credibility, a range within which models are considered to have an acceptable level of credibility, and a threshold below which climate models are considered not credible?

- Guidance regarding the level of sensitivity of a given hydrologic, water resources, or environmental system that is considered relevant: For a given system and performance metric, is there a sensitivity threshold above which climate drivers are considered highly relevant, a range within which climate drivers are moderately relevant, and threshold below which climate drivers are considered not relevant?

- Guidance regarding joint interpretation of credibility and relevance: How do study teams assess applicability in cases where a system is identified as being highly sensitive to a given climate variable or attribute (high relevance), but climate models exhibit poor skill in simulating that variable or attribute (low credibility)?

- Guidance regarding consideration of practical constraints: How do study teams consider practical constraints—e.g., availability of resource models, availability of non-climate data, and study schedule and budget constraints—relative to the credibility and relevance of climate projections?

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APPENDIX 1

Collaborative Project Summary

COLLABORATIVE PROJECT SUMMARY: Evaluating the Relevance, Trustworthiness, and Applicability of CMIP5 Climate Projections for Water Resources and Environmental Planning

Overview

Water managers need knowledge of the relevance, trustworthiness, and applicability of climate projection information to support decision-making at the scale of their applications. This requirement occurs as new global climate projections are being released through the World Climate Research Programme's Coupled Model Intercomparison Project Phase 5 (WCRP CMIP5) effort, presenting new opportunities and challenges for the climate change adaptation community.

This project involves an interagency collaboration to evaluate new CMIP5 projections for use in water and environmental resources planning contexts. The overarching goal is to develop and demonstrate a framework for evaluating CMIP5 information for credibility and applicability in these contexts, focusing on climate variables and impacts scales relevant to water and environmental resources management. Outcomes will inform discussion of information credibility which is emerging as a challenging issue when rationalizing adaptation investments or decisions to delay investment. In addition to considering CMIP5 21st century projection information, the framework will be developed to support evaluation of CMIP5 decadal predictability experiment simulations and reconcile those simulations with 21st century projections.

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Budget Summary

The following information includes total costs for each funding agency (see table at end of this summary). Bureau of Reclamation costs support internal staff participation and direct contribution to CIRES (see CIRES-Reclamation Project Work Plan); USACE costs support internal staff participation and direct contribution to NOAA (see NOAA-USACE Project Work Plan); NOAA costs support internal staff participation.

Funding Agency	Bureau of Reclamation	USACE	NOAA
Estimated Budget – FY12	$111,400	$120,000	$68,307
Estimated Budget – FY13	$252,140	$234,000	$70,947
Two-Year Total	$363,540	$354,000	$139,254

CIRES-Reclamation Project Work Plan Information

Cooperative Agreement No. __R11AC81334______________________________

CIRES Proposal #: ____

Project Work Plan #: __BOR3____________________________________

Revision #: ____

Period of Performance: __September 2012 – March 2014________________

Project Summary Acceptance

Reclamation

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Signature

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Printed Name / Date

USACE

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Signature

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Printed Name / Date

NOAA

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Signature

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Printed Name / Date

CIRES

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Signature

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Printed Name / Date

Work plan

1. Background

Water resources managers have long faced the challenge of understanding how best to use climate projection information when assessing climate change vulnerabilities, risks, and adaptation needs. As agency directives and programmatic mandates evolve (e.g., new Feasibility Study directives and standards under development at Reclamation[1], the USACE Climate Change Adaptation Policy Statement[2], NOAA's lead role in Action 8 under Priorities for Managing Freshwater Resources in a Changing Climate[3], and the requirements from the Council on Environmental Quality for all Federal agencies to write plans for climate change adaptation[4]) this challenge has evolved, also, to the point that managers will soon be making judgments about which aspects of climate projection information are *trustworthy*[5] and *applicable* with respect to their given long-range decision-making and investment decisions for water resources infrastructure, or in the establishment of long-range water and environmental management criteria.

This challenge builds on progress made in understanding how to technically incorporate climate projection information into such decision-support assessments. As the conversation moves from simple standalone impacts and vulnerability assessments meant to build awareness about climate impacts without influencing decisions to assessments requiring decision-support information, managers are going to require sharper understanding of the elements of climate projection information that are *trustworthy* on the climate aspects *relevant* to their decision situation in order to help them arrive at a judgment on which portions of projection information are *applicable* to their decision-making. In addition, agencies are going to require resources that facilitate a consistent approach to thinking through this issue, understanding that the approach will need to be flexible relative to different water resources and environmental planning contexts (varying by agency office, geography, system, etc.).

Applicability ultimately is a matter of judgment. It stems from the evaluation of three questions linked to the intended application in a short causal chain:

1. What climate aspects are relevant in my study situation? (i.e., aspects having the attribute of variable, domain and resolution; domain and resolution being specified in space and time)
2. What information is available to characterize those future climate aspects relevant to the study? (e.g., paleoclimate proxies, instrumental records, climate projections (native-scale or downscaled))
3. How trustworthy is that information on the climate aspects relevant to my situation? (e.g., skill of climate models used to generate climate projections, reliability of projections, appropriateness of

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[1] Draft Reclamation Manual Directive and Standard CMP 09-02, *Water and Related Resources Feasibility Studies*, Public comment period for this draft release ends on April 25, 2012. Draft available at: http://www.usbr.gov/recman/drafts/cmp09-02webdraft.pdf

[2] http://corpsclimate.us.

[3] "National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate", prepared for the Interagency Climate Change Adaptation Task Force, October 2011, Action 8 "Publish guidance on the use of modeled projections for water resource applications."

[4]"Implementing Instructions for Federal Agency Adaptation Planning" 4 March 2011. http://www.**whitehouse**.gov/administration/eop/**ceq**/initiatives/**adaptation**

[5] Reliable and sufficiently robust to be used in resource management policy, planning and decision making.

bias-correction and downscaling methods, uncertainties of paleoclimate proxies and modern observations)

With respect to question (1) above, relevant climate aspects depend on the study situation. For example, local flood damage reduction investments may be sensitive to future estimates of intense and short-duration storms, spurring interest in the credibility of projected daily precipitation at a spatial scale of 10^1 km. In contrast, regional water supply or ecological restoration investments may be sensitive to future estimates of hydrologic variability over a large watershed with considerable natural or built water storage. For these situations, interest may be focused on the credibility of projected annual hydroclimate (temperature, precipitation, and runoff) and associated variability at a spatial scale of 10^2 to 10^3 km.

With respect to questions (2) and (3), considerable research has been carried out on CMIP3 20th century historical simulations to assess the relative skill of global climate models (GCMs) based on how well each model simulates various aspects of 20th century climate relative to observations (Reichler and Kim 2008, Gleckler et al. 2008, Brekke et al. 2008, Walsh et al. 2008, Pierce et al. 2009, Santer et al. 2009, Dominguez et al. 2010, Mote and Salathe 2010). While each of these studies offers a way to evaluate and rank GCMs, each of these studies exhibits critical limitations with respect to water resources applications:

- Previous analyses have focused on a limited set of climate aspects and locations, and not the myriad aspects (variables, domains, resolutions) meaningful to water resource and environmental management situations throughout the U.S.
- Previous analyses generally focus on GCM native-scale raw performance as a means to judge a GCM's suitability for informing an impacts assessment without recognizing that GCM output is typically subjected to some form of bias-correction and/or spatiotemporal downscaling prior to use in water resources applications, which can significantly affect GCM performance assessment.
- Previous analyses often focus on GCM native-scale raw performance in terms of simulating historical climatological (or period-climate) aspects, and do not consider model skill in simulating regional- and local-scale historical climate trends in response to changes in global climate forcing.
- Previous analyses do not address whether GCM performance with respect to historical climate is an appropriate indicator of a given GCM's skill or reliability in simulating climate change in response to natural and anthropogenic forcings; similarly, previous analyses do not provide clear evidence that ranking or weighting GCMs is beneficial for subsequent water resources applications, compared to using all available GCMs with equal weighting. Previous studies also lack a quantitative method for separating the components of climate trends caused by anthropogenic forcing from those resulting from natural low-frequency variability inherent to the global climate system.
- Lastly, previous analyses do not address whether GCMs, with or without bias-correction and downscaling, provide information of sufficient quality for application in local-scale water resources investments.

Addressing any of the first three limitations would yield significant benefit by creating a "broadband" information resource to help the national community of water resources managers answer the questions of climate projection trustworthiness. Moreover, assessing the applicability of GCM-derived climate change information to water resources and environmental management decisions will provide insight into how uncertainties in the assessment, weighting, and ranking of GCMs impacts users' perception of the trustworthiness and relevance of climate change information for climate change risk assessments and mitigation studies at local and basin scales.

Finally, even as managers are confronted with the question of what is applicable from *available* climate projections (CMIP3[6]), there is the additional requirement of understanding what will be applicable in the *next generation* of climate projections (CMIP5[7]). CMIP5 (Taylor et al. 2010) addresses many more science questions than CMIP3, and, as a result, its suite of results is more complex than CMIP3. Prominent new features include:

- New types of greenhouse gas emissions scenarios; i.e., the Representative Concentration Pathways (RCPs) expressed as radiative forcing on climate[8].
- Multiple types of climate models, including CMIP3-like models that simulate climate only, new earth system models (ESMs) that simulate coupled carbon cycle and climate to reveal carbon cycle-feedbacks/controls on climate, and new atmosphere-only GCMs applied at high spatial resolution – in a manner like that of post-processed dynamical downscaling resolutions applied to CMIP3.
- Multiple types of initialization, including the CMIP3-style where initializations of historical or future century simulations are not constrained by observations, and a new type where initialization is constrained by observations and used to set up decade-long simulations that may then be concatenated to characterize climate from late 20th century to early 21st century.

2. Purpose

This work proposed here addresses the following questions:

I. *How good are the model projection results from CMIP5 for water resources and environmental planning applications?*
   a. *What is the broadband of performance characteristics collectively relevant for these various applications?* This broadband should encompass the primary climate state variables and derivatives, spatial and temporal scales, and measures of skill and fidelity that are relevant for water resources and environmental planning applications.
   b. *What are the components of a framework that structures this broadband of performance characteristics to support subsequent discussions on the applicability of CMIP5 projections in planning and assessment situations?* This framework should allow for various types of CMIP5 GCM output, including bias-corrected and spatially downscaled translations of this output. There will be some overlap between state variables projected by GCMs and extended from observations, but also some unique to each information type.

II. *How applicable are the CMIP model projections for water resources and environmental planning applications?*

[6] World Climate Research Programme (WCRP) Coupled Model Intercomparison Project – Phase 3: http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php
[7] WCRP Coupled Model Intercomparison Project – Phase 5: http://cmip-pcmdi.llnl.gov/cmip5/
[8] Details of RCPs provided at: http://www.iiasa.ac.at/Research/ENE/IAMC/rcp.html

a. *How do we develop a general framework to judge information applicability that flexibly addresses unique aspects of a local planning and assessment situation?* Unique aspects of a local management situation include the management objectives, management actions being considered, assessments necessary to support a decision among these actions, and climate aspects that are relevant to the assessments.
b. *How do we determine relevant climate aspects within this framework?*
c. *How do we evaluate the trustworthiness of projection information on these relevant climate aspects, leveraging the broadband performance characteristics framework developed under Question I?*

Relevance to CCAWWG User Needs

This research relates to several user needs discussed in the Reclamation/USACE "LTdoc" ("Addressing Climate Change in Long-Term Water Resources Planning and Management: User Needs for Improving Tools and Information", available at: http://www.usbr.gov/climate/userneeds/). In particular, it relates to the following needs under Area 3: Make Decisions About How to Use the Climate Change Information (http://www.usbr.gov/research/climate/long-term/N3-use.html):

- 3.02 Understanding how to interpret future variability in climate projections and relevance to operating constraints on shorter- to longer-term time scales (from daily to multidecadal).
- 3.03 Basis for culling or weighting climate projections (if at all) when deciding which projections to use in planning.
- 3.04 Guidance on how to appropriately relate planning assumptions to either Period-Change or Time-Developing aspects of climate projections when deciding how to use projections in planning.
- 3.05 Guidance on how to jointly utilize the longer-term climate variability from observed records, paleoclimate, and projected climate information when portraying drought and surplus possibilities in planning.
- 3.06 Method and basis for estimating extreme meteorological event possibilities, deterministically or probabilistically, in a changing climate.

It also relates to needs under Area 2: Obtain Climate Change Information (http://www.usbr.gov/research/climate/long-term/N2-information.html)

- 2.03- Information on the strengths and weaknesses of downscaled data and the downscaling methodologies used to develop these data (including both statistical and dynamical methods and associated approaches for climate model bias-correction).

3. Tasks

The work proposed under this effort begins to address Reclamation and USACE needs associated with "Types of situations where we need to determine Applicability" relative to "Types of CMIP5 Information Available" as shown on **Figure 1**. The work plan involves the following seven tasks.

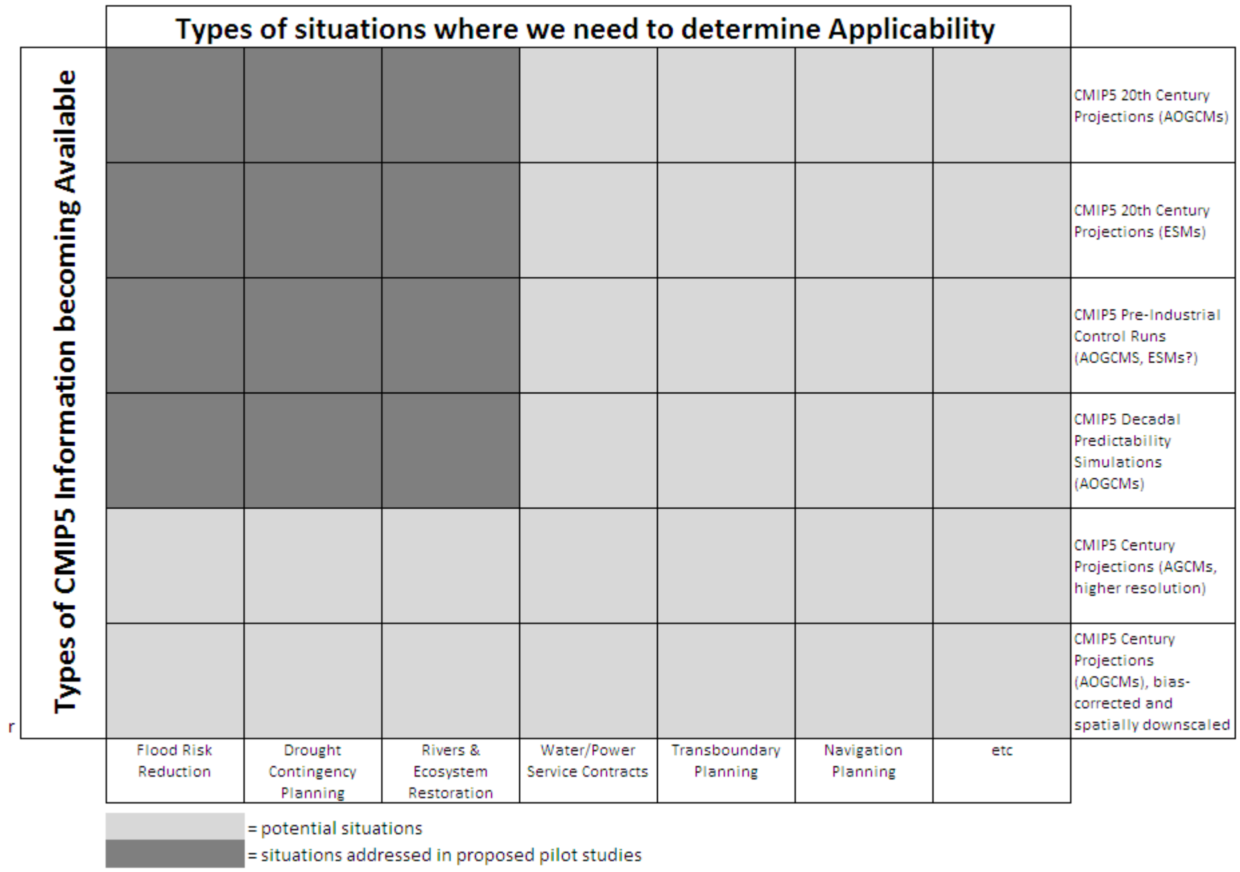

Figure 1. Matrix of Needs – Situations versus Available Information.

Task 1: Applicability Pilots Preliminary Activity #1 - Conduct a Broadband Quality Evaluation of CMIP5 Historical Simulations

- CIRES to work with Reclamation and USACE to identify performance characteristics that are collectively relevant for various water resources and environmental planning applications.
  - Develop menus relevant to Reclamation water supply management at big-basin and monthly to decadal scales.
  - Develop menus relevant to USACE flood risk at local to regional and daily to monthly scales.
- CIRES to work with Reclamation and USACE to identify the components of a framework that structures this broadband of performance characteristics to support subsequent discussions on the applicability of CMIP5 projections in planning and assessment situations.
- CIRES to evaluate model runs and variables from the CMIP5 repository in order to assess climate model performance in simulating historical regional to local climate trends. CIRES to conduct performance evaluations on CMIP5 simulations within the broadband framework identified above, including pre-industrial control simulations as well as historical simulations forced by

estimated historical climate forcing, simulated by atmosphere-only GCMs (AGCMs, to aid in diagnosing regional climate variability and trends), atmosphere-ocean GCMs (AOGCMs), and Earth System Models (ESMs).

- CIRES to diagnose characteristics of monthly and short-term extreme precipitation events in CMIP5, including analysis of interannual variability and trends. Comparisons will be made between historical observations and 20th Century simulations, and amongst model projections.
- CIRES to develop improved indicators of extremes that can be used at the spatial and temporal scales resolved in global climate models and that allow for direct comparisons between models and observations. New indices will be guided by user needs and/or developed to take advantage of large-scale processes that the GCM's do well, such as convective available potential energy (CAPE) and convective inhibition (CIN), measures of atmospheric stability, which influence heavy precipitation during summer in mid-latitudes.
- As part of the evaluation, CIRES to select historical reference data and conduct evaluation at the GCM scales. Evaluation may be carried out at GCM native scale, or models may be regridded to a common grid conducive with the native scales of CMIP5 AOGCMs.
- CIRES to focus initial analysis on monthly metrics that will feed forward to Task 3, building the web-interface to serve monthly results. While Task 3 is being implemented with monthly results, CIRES will conduct evaluation of daily metrics and prepare daily results to serve through the web-interface.

<u>Task 2: Applicability Pilots Preliminary Activity #2 – Conduct Water Resources System Sensitivity Analyses to Identify Relevant Climate Metrics</u>

- Reclamation and USACE to respectively lead two pilot sensitivity studies:
    - (Reclamation) water supply management for a selected basin in the Western U.S, preferably in a basin where flood risk reduction is also a requirement and involves interaction with USACE.
    - (USACE) flood vulnerability assessment and/or ecosystem management assessment in a selected basin in the U.S.
- CIRES to provide assistance in two case studies, in the form of helping to interpret observed and simulated climate information and helping to develop the sensitivity analysis framework.
- Reclamation and USACE to work with CIRES and pilot workgroups to develop a framework for identifying "more relevant" climate metrics in water resources assessment situations, where metrics are defined by specific variable, domain, resolution, and statistical measure.
- Relevant climate metrics to be identified based on management sensitivity to changes in various climate metrics. Management simulations will be carried out to explore sensitivities of key performance measures to changes in various types of climate and non-climate inputs, where key performance measures are simulation results that directly support decisions by quantifying the extent to which system-specific operating objectives are met. Sensitivity will be evaluated by perturbing individual or selected groups of climate and non-climate input variables multiple times and quantifying the corresponding change in performance metrics.
- Reclamation to carry out related uncertainties inventory, tiered from Reclamation pilot study and building on the models, data, and integration assembled for the sensitivity analysis. The uncertainties inventory will differ from the sensitivity analysis (above) in that it will evaluate how

key performance measures respond to joint changes in model inputs, rather than changes in individual inputs. Combination of sensitivity analysis and uncertainties inventory will help to apportion output uncertainty to relative contributions of input uncertainty. Revealing most influential input uncertainties – climate or otherwise - in the context of combined uncertainties yields two benefits: (a) bolster communication of key uncertainties in assessment situations, and (b) inform research strategy to reduce output uncertainty by focusing on the most influential inputs.

- Reclamation and USACE to select pilot water resources systems that are conducive to sensitivity and uncertainty analyses. Selection criteria include: pilot system with climate-sensitive operations; existing management/operations model that responds to changes in climate and non-climate inputs (i.e., limited fixed inputs, such as closure terms, that do not respond dynamically to input changes) and supports batch capabilities; and management team willing and interested in participating in pilot workgroup.
- Reclamation and USACE to consider effects of weighting or ranking GCMs based on historical evaluation (Task 1) on distribution of key performance metrics.

<u>Task 3: Applicability Pilots Preliminary Activity #3 - Develop Online Resource to Serve CMIP5 Broadband Quality Evaluation Results to Support User Assessment Trustworthiness and Applicability of CMIP5 Climate Models</u>

- CIRES to design and develop a web-portal that serves evaluation results from Task 1 and permits users to flexibly query results that are relevant to their specific decision context (e.g., climate variable, geographic domain, spatial and temporal scales, statistical measures, etc.). Example capabilities of the web portal may include:
  - Permit Reclamation users to evaluate results by (a) simulation, by model or by model ensemble, (b) sub-basin to large-basin spatial scale, and (c) monthly to decadal statistic.
  - Permit USACE users to evaluate results by (a) simulation, by model or by model ensemble, (b) local to regional spatial scale, and (c) daily to monthly statistic.
  - Permit users to evaluate results by comparing model-simulated extremes and large-scale factors that influence extremes to their observational counterparts.
- CIRES to consider different approaches to data visualization, including dynamic user-driven web-based data analysis tools as well as gridded (2D) and timeseries plotting capabilities.
- Online resource to permit users to define a regular latitude-longitude region and/or input a shape-file defining an evaluation region, and to permit users both visualize evaluation results and download values from selected observational datasets, model, and evaluation metrics.
- Online resource to be developed in an expandable format to allow addition of additional model simulations, observational datasets, or statistical metrics if desired in the future.

<u>Task 4: Applicability Pilots</u>

- Reclamation and USACE to lead respective applicability pilots. Agencies will work with pilot workgroups to develop a judgment process to assess the applicability of projected climate information given results from the broadband evaluation of CMIP5 historical climate simulations (Tasks 1 and 3) and water resources system sensitivity analyses (Task 2).

  - (Reclamation) water supply management for a selected basin in the Western U.S, preferably in a basin where flood risk reduction is also a requirement and involves interaction with USACE.
  - (USACE) flood vulnerability assessment and/or ecosystem management assessment in a selected basin in the U.S.
- CIRES to assist during pilot workshops by helping to interpret observed and simulated climate information and interpret CMIP5 historical simulation performance evaluation, which could include weighting and/or culling model simulations. CIRES to develop process diagnostics tailored to the pilot situations, focusing on relevant climate aspects identified in Task 2.

<u>Task 5: Scope Evaluation of Effect of Spatial Downscaling on CMIP5 Historical Simulations</u>

- CIRES to develop scope to evaluate effects of dynamical and non-dynamical downscaling schemes on climate metrics computed from CMIP5 historical simulations. Scope to consider variety of dynamical and non-dynamical downscaling methods, including methods with and without bias correction; scope to focus on downscaling applied to longer-term CMIP5 historical simulations (Task 1) and subsequent effects on climate metrics relevant to applicability pilots (Tasks 1 and 2).
- Scope to leverage developments from the NOAA National Climate Projections Pilot framework for assessing strengths, weaknesses, and appropriate application of climate projection downscaling efforts, as well as leverage lessons learned from downscaling efforts of Regional Climate Prediction.net.

<u>Task 6: Networking, Outreach, and Dissemination of Results</u>:

- CIRES, working with USACE and Reclamation, to host quarterly meetings with interested research groups (e.g., NOAA ESRL, NOAA NCPP, NOAA RISAs, NCAR, DOI Climate Science Centers, USGS National Climate Change and Wildlife Science Center). Meetings will be designed to share project progress and hear about related activities from participating groups.
- CIRES, Reclamation, and USACE to network with science community directly involved with evaluation of CMIP5 simulations to track various approaches, metrics, and decision support products being developed by the community.
- CIRES, Reclamation, and USACE to network with water resources and environmental decision makers, including decision makers within the agencies as well as state and local partners, to track ongoing developments in the use of climate projection information in water resources and environmental planning.
- CIRES, Reclamation, and USACE to document project results in technical reports, peer-reviewed journal articles, and conference presentations.

4. Anticipated Task Schedule

- Task 1: Applicability Pilots Preliminary Activity #1 - Conduct a Broadband Quality Evaluation of CMIP5 Historical Simulations. Sub-tasks include downloading model output, developing observational datasets for model evaluation, and identifying and computing climate metrics relevant to Reclamation and USACE decision makers: September 2012-February 2013

- Task 2: Applicability Pilots Preliminary Activity #2 – Conduct Water Resources System Sensitivity Analyses to Identify Relevant Climate Metrics. Sub-tasks include identifying of water resources systems to be studied, developing pilot workgroup, compiling climate- and non-climate input datasets and pre-processing tools, developing perturbation strategy, and conducting sensitivity analysis and uncertainties inventory: September 2012-February 2013

- Task 3: Applicability Pilots Preliminary Activity #3 - Develop Online Resource to Serve CMIP5 Broadband Quality Evaluation Results to Support User Assessment of Trustworthiness and Applicability. Sub-tasks include developing online web-portal, including user-driven visualization and analysis tools and supporting datasets (developed under Task 1): initial web-portal: October-December 2012; expanded web-portal: January-September 2013

- Task 4: Applicability Pilots. Sub-tasks include preliminary correspondence with workgroups (to begin under Task 2), preparing and carrying out workshop, and developing judgment process to guide water resources and environmental planners in assessing applicability of projected climate information: February-September 2013

- Task 5: Scope Evaluation of CMIP5 Historical Simulations to consider the effect of Spatial Downscaling. Sub-tasks include selectioning CMIP5 GCM simulations/projections for consideration; identifying downscaling methods for consideration, including regional climate models and statistical methods with and without bias correction; identifying primary climate metrics to be considered; and coping specific study tasks: July-December 2013

- Task 6: Networking, Outreach, and Dissemination of Results: August 2013-March 2014

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Project Title: Evaluating the Relevance, Trustworthiness, and Applicability of CMIP5 Climate Projections for Water Resources and Environmental Planning

		Production Center [1]	Reclamation	USACE	NOAA		CIRES
		Source of Support [1]	Reclamation (IKS)	USACE (IKS)	NOAA IKS (cost-share) [2,3]	USACE (DC to NOAA) [3]	Reclamation (DC to CIRES) [3]
Task 1	Applicability Pilots Preliminary Activity #1 - Conduct a Broadband Quality Evaluation of CMIP5 Historical Century Simulations	*FY12*	3,040	-	27,929	63,013	63,013
		FY13	-	-	20,517	36,563	36,563
Task 2	Applicability Pilots Preliminary Activity #2 – Conduct Water Resources Systems Analyses to identify Relevant Climate Metrics	*FY12*	3,800	20,000	16,789	20,692	20,692
		FY13	52,540	45,000	11,555	10,176	10,176
Task 3	Applicability Pilots Preliminary Activity #3 - Develop Online Resource to serve Broadband Quality Evaluation results from Task 1	*FY12*	1,520	-	21,089	13,795	13,795
		FY13	5,212	-	13,273	28,754	28,754
Task 4	Applicability Pilots	*FY12*	3,040	-	-	-	-
		FY13	69,590	65,000	15,281	13,507	13,507
Task 5	Scope Evaluation of CMIP5 Historical Simulations to consider the effect of Spatial Downscaling	*FY12*	-	-	-	-	-
		FY13	8,480	5,000	4,274	3,500	3,500
Task 6	Networking, Outreach, and Dissemination of Results	*FY12*	-	-	2,500	2,500	2,500
		FY13	16,318	19,000	6,047	7,500	7,500
		FY12 Subtotal	11,400	20,000	68,307	100,000	100,000
		FY13 Subtotal	152,140	134,000	70,947	100,000	100,000
		Two-Year Subtotal	163,540	154,000	139,254	200,000	200,000

Totals (IKS+DC)	Reclamation	USACE	NOAA
FY12	111,400	120,000	68,307
FY13	252,140	234,000	70,947
Two-Year Total per Agency/Program [3]	363,540	354,000	139,254
Two-Year GRAND TOTAL	**856,794**		

Notes:

[1] IKS = In-Kind Service, DC = Direct Contribution, Reclamation = U.S. Department of the Interior's Bureau of Reclamation, NOAA = National

[2] NOAA's cost-share involves leveraging their Earth System Research Laboratory (ESRL) funding to help support this effort, where funding

[3] Reclamation and USACE cost-shares are dependent on annual funding, and are therefore subject to change. Likewise, NOAA ESRL's cost-

APPENDIX 2

Slides from Workgroup Webinars

APPENDIX 2.1

Webinar 1: Incorporating Climate Projections into Water Resources and Environmental Planning

RECLAMATION
Managing Water in the West

Assessing Applicability of CMIP5 Climate Projections for Water Resources and Environmental Planning:

Webinar 1: Incorporating Climate Projections Into Water Resources & Environmental Planning

---

Ian Ferguson (USBR, TSC)
Cameron Bracken (USBR, TSC)
Levi Brekke (USBR, Research Office)
Jamie Scott (NOAA CIRES)
Michael Alexander (NOAA ESRL)
Jeff Arnold (USACE)

U.S. Department of the Interior
Bureau of Reclamation

Preview:

- Recent changes to Feasibility Study D&S directly link analysis of **climate change** to **investment decisions**
- Reclamation, NOAA and USACE are partnering to **develop a framework** to guide evaluation of climate projection **relevance, reliability, and applicability** in context of water resources and environmental planning
- We need **your help** to evaluate and improve this framework

Objectives of Webinar 1:

- **Frame the Question**
  How should study teams choose between available climate change information and methods in water resources planning studies?

- **Introduce the Proposed Framework**
  Selection of climate change information and methods based on assessment of information reliability, relevance, and applicability

- **Start the Dialogue**
  Pilot workshop to gather feedback – what aspects of the framework are useful, what need to be revised, and what should be removed?

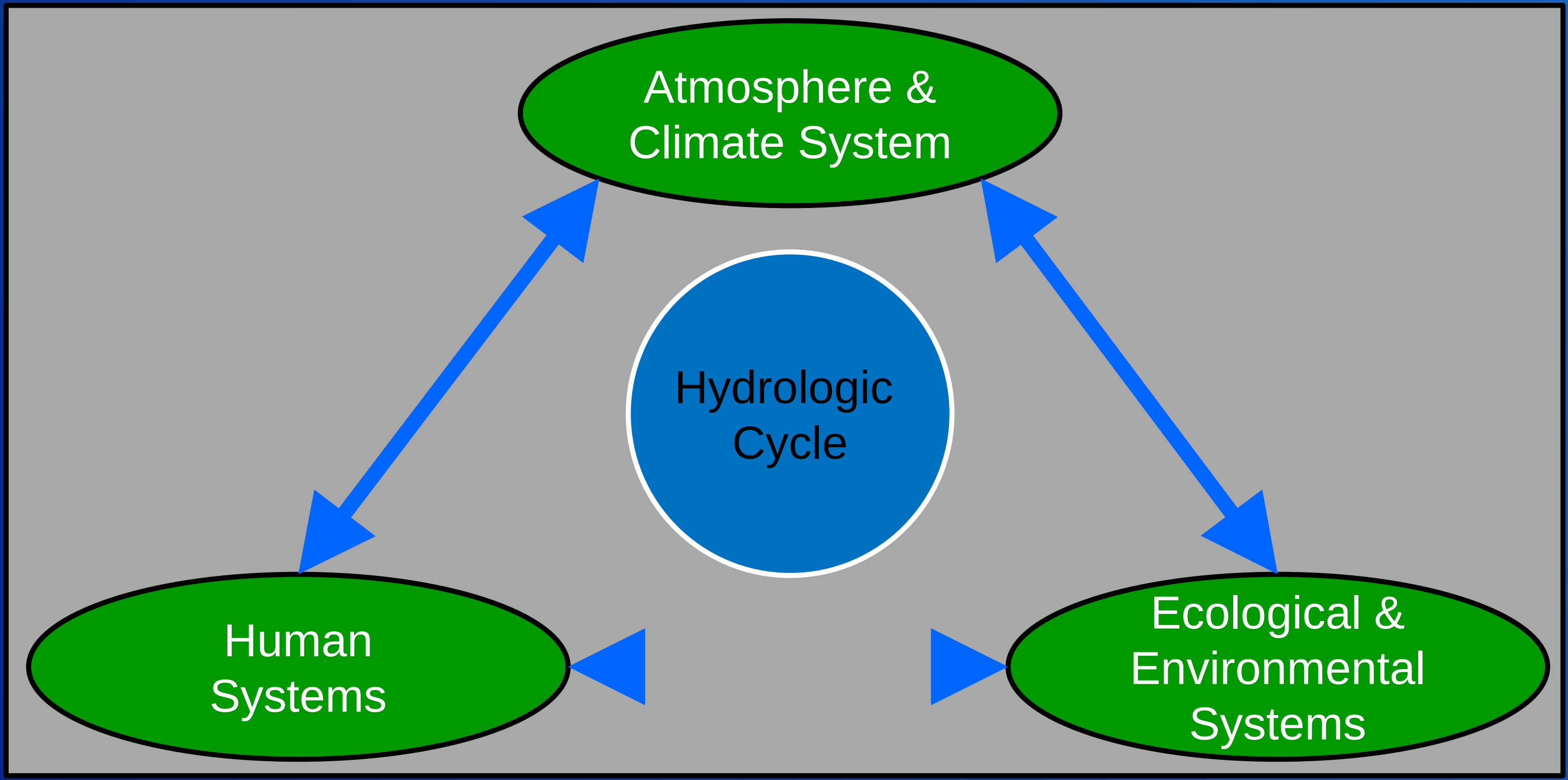
Outline:

- **Background & Motivation**
  Science, Policy, and Practical Questions
- **Applicability Framework**
  Combining Reliability and Relevance to Assess Applicability
- **Pilot Workshop**
  Mock Scoping Session to Evaluate the Applicability Framework

Background & Motivation:

- **Prior to SECURE Water Act (2009)**

  Climate change recognized as important planning consideration



Background & Motivation:

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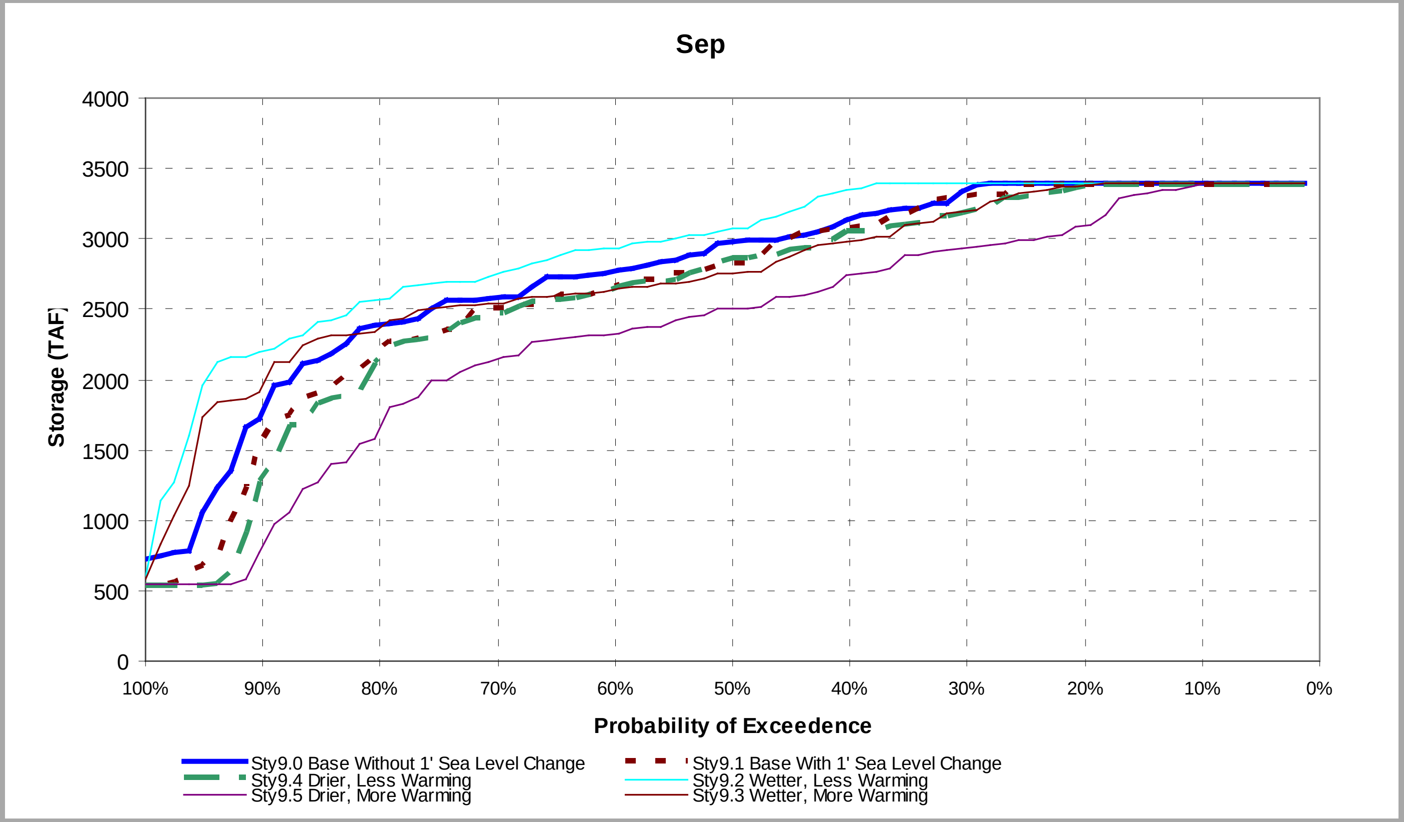
  Climate change recognized as important planning consideration

CVP/SWP Operations Criteria and Plan (OCAP) Biological Assessment



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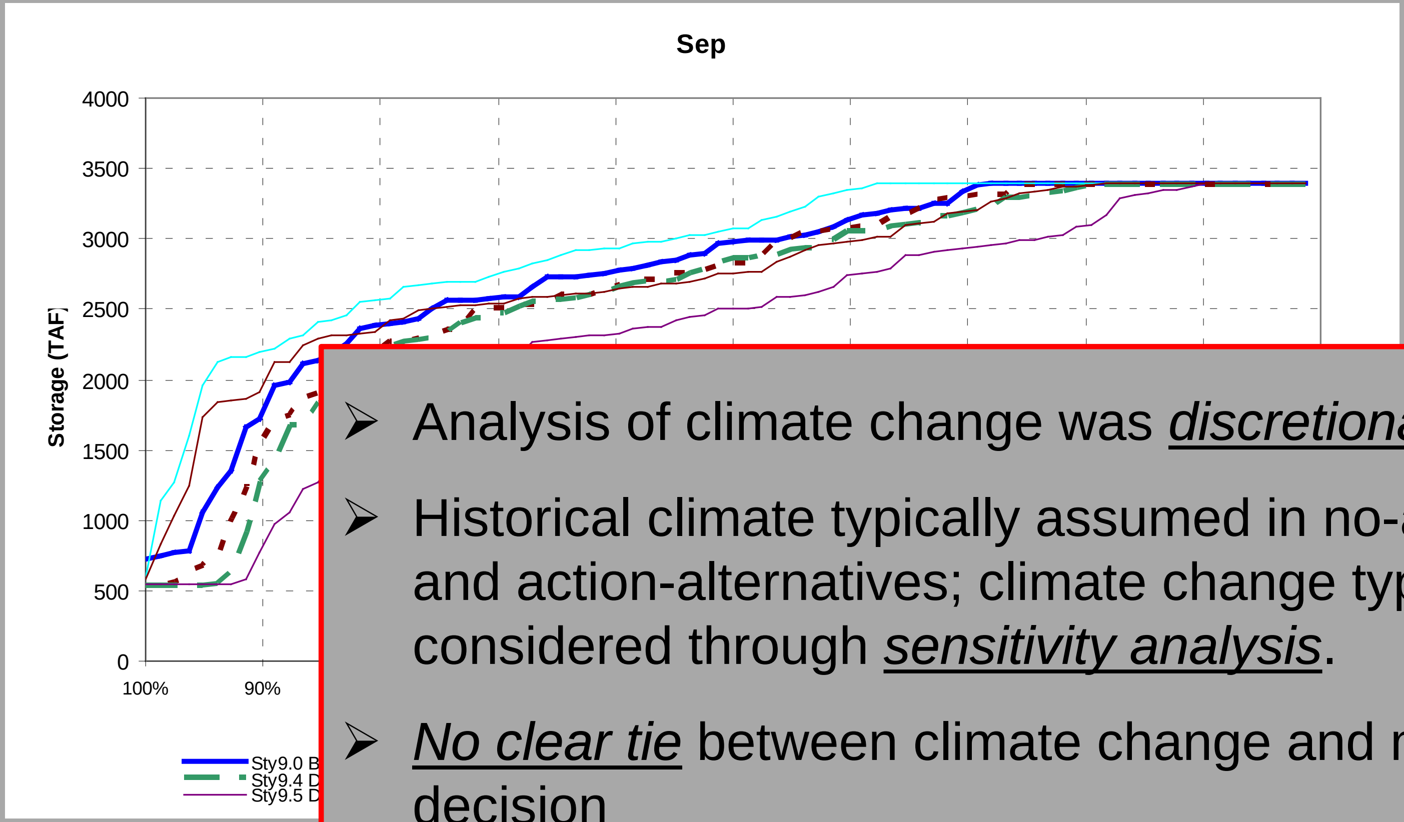


- ➢ Analysis of climate change was *__discretionary__*
- ➢ Historical climate typically assumed in no-action and action-alternatives; climate change typically considered through *__sensitivity analysis__*.
- ➢ *__No clear tie__* between climate change and major decision

Background & Motivation:

- **SECURE Water Act**

  Authorized direct consideration of climate change risks and development of climate change adaptation and mitigation strategies

SECURE Water Act (Section 9503)

(a) IN GENERAL. — The Secretary shall establish a climate change adaptation program —

(1) to coordinate with the Administrator and other appropriate agencies to assess each effect of, and risk resulting from, global climate change with respect to the quantity of water resources located in a service area; and

(2) to ensure, to the maximum extent possible, that strategies are developed at watershed and aquifer system scales to address potential water shortages, conflicts, and other impacts to water users located at, and the environment of, each service area.

RECLAMATION

Background & Motivation:

- **SECURE Water Act**

  Authorized direct consideration of climate change risks and development of climate change adaptation and mitigation strategies

SECURE
Feasibility Studies

- ➢ Detailed analysis of climate change risks, evaluation of adaptation/mitigation alternatives
- ➢ Support planning and decision making
- ➢ Applies only to studies conducted *under SECURE programs*

Background & Motivation:

- **Feasibility Study D&S (CMP-09-02)**

  Requires consideration of climate change in development of feasibility study without-plan future condition

Reclamation D&S CMP-09-02:

" The potential impacts of climate change will be considered when developing projections of environmental conditions, water supply and demand, and operational conditions at existing facilities as part of the without-plan future condition. Climate change impacts will be further analyzed, as appropriate, as part of the feasibility study when the following conditions are true:

(i) there is a reasonable likelihood of significant variation in hydroclimatic conditions over the planning horizon, between alternatives, or both; and

(ii) available regional models have been down-scaled to a resolution adequate for the study area, or can be produced within reasonable time and cost constraints."

RECLAMATION

Background & Motivation:

- **Feasibility Study D&S (CMP-09-02)**

  Requires consideration of climate change in development of feasibility study without-plan future condition

Reclamation D&S CMP-09-02:

" Plans will be compared in accordance with the P&Gs and will include a comparison of responses and adaptability of the project to the uncertainties of climate changes previously identified in the without-plan scenario. The comparison of alternatives is part of the NEPA alternatives analysis. The plan that reasonably maximizes net public benefits will be identified.."

Background & Motivation:

- **Feasibility Study D&S (CMP-09-02)**

  Requires consideration of climate change in development of feasibility study without-plan future condition

Game Changer:

Then:

Use of climate change was at the **discretion** of individual study teams

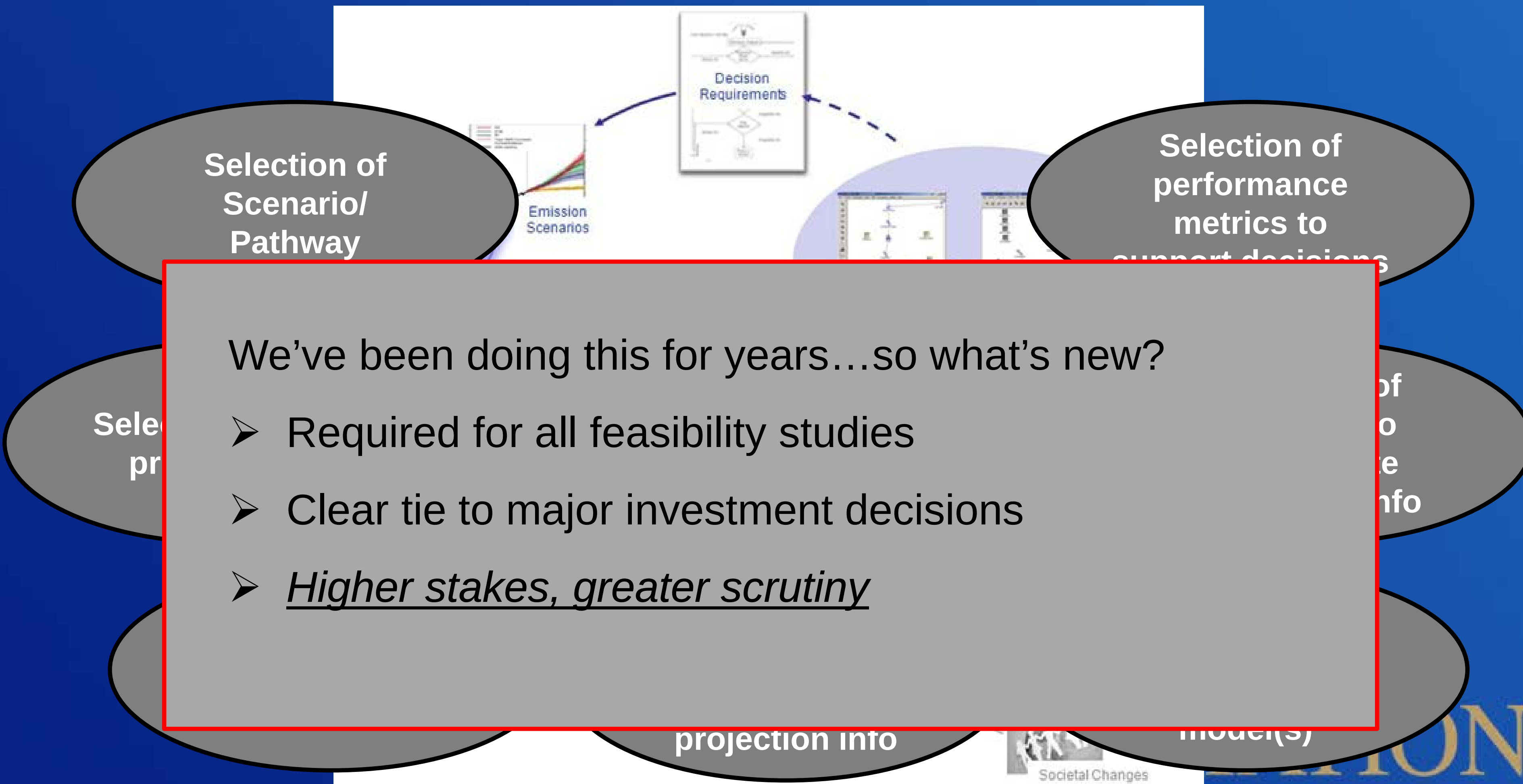
Now:

Consideration of climate change is **required** for **all feasibility studies**

Background & Motivation:

- **Practical Questions**

  How should study teams determine what climate change information to use and how to use it?

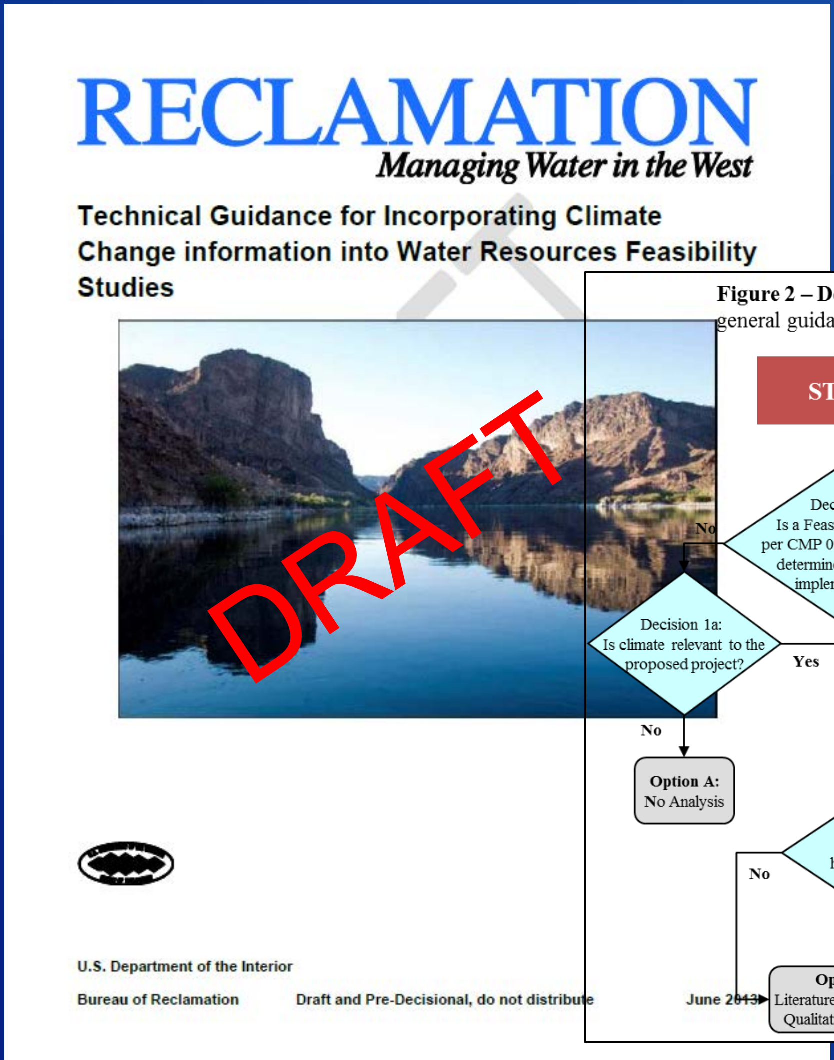


We've been doing this for years…so what's new?

- ➢ Required for all feasibility studies
- ➢ Clear tie to major investment decisions
- ➢ *<u>Higher stakes, greater scrutiny</u>*

Background & Motivation:

- **SECURE Feasibility Guidance**



RECLAMATION

Managing Water in the West

Technical Guidance for Incorporating Climate Change information into Water Resources Feasibility Studies

DRAFT

U.S. Department of the Interior

Bureau of Reclamation Draft and Pre-Decisional, do not distribute June 2013

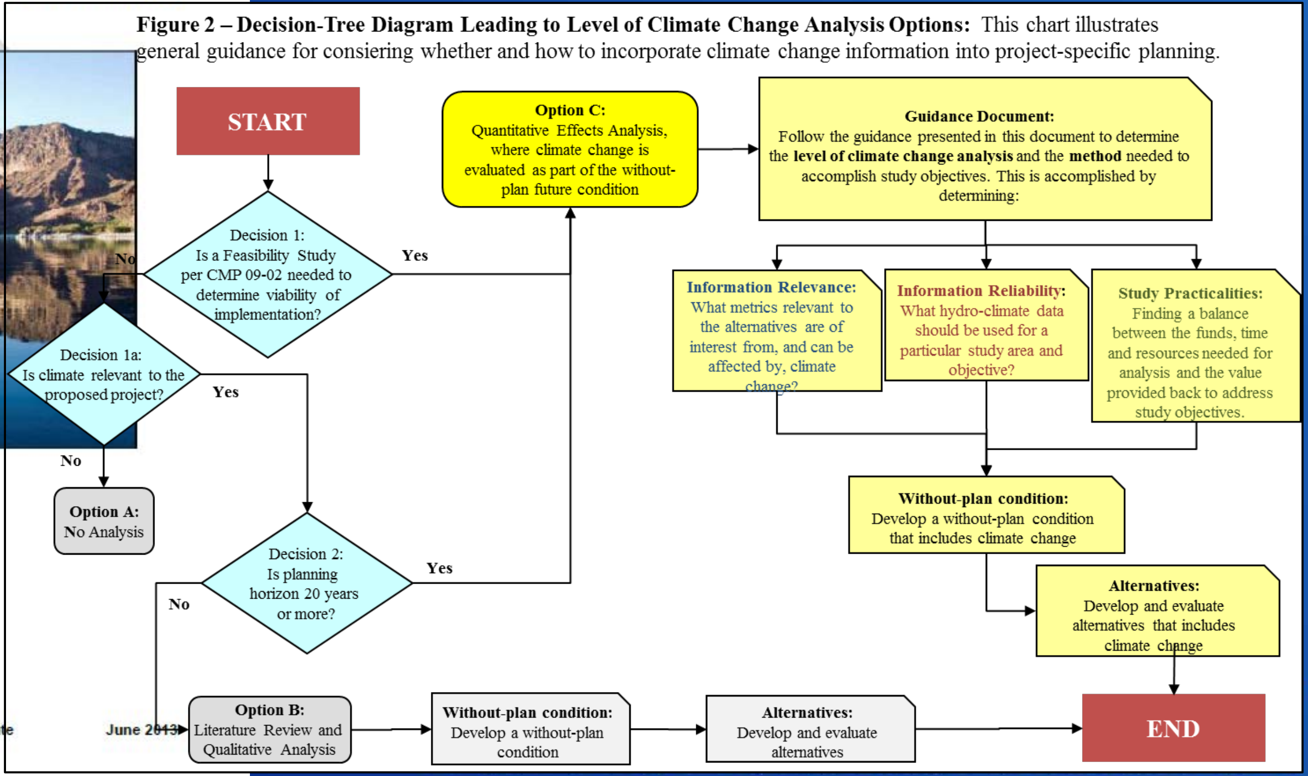


Figure 2 – Decision-Tree Diagram Leading to Level of Climate Change Analysis Options: This chart illustrates general guidance for consiering whether and how to incorporate climate change information into project-specific planning.

Background & Motivation:

- **Applicability Framework & Pilot Project**
  - Develop framework for implementing scoping process outlined in draft guidance
  - Demonstrate framework in context of hypothetical scoping situation
  - Gather feedback to evaluate and improve framework

RECLAMATION

Questions?

RECLAMATION

Outline:

- **Background & Motivation**

  Science, Policy, and Practical Questions

- **Applicability Framework**

  Combining Reliability and Relevance to Assess Applicability

- **Pilot Workshop**

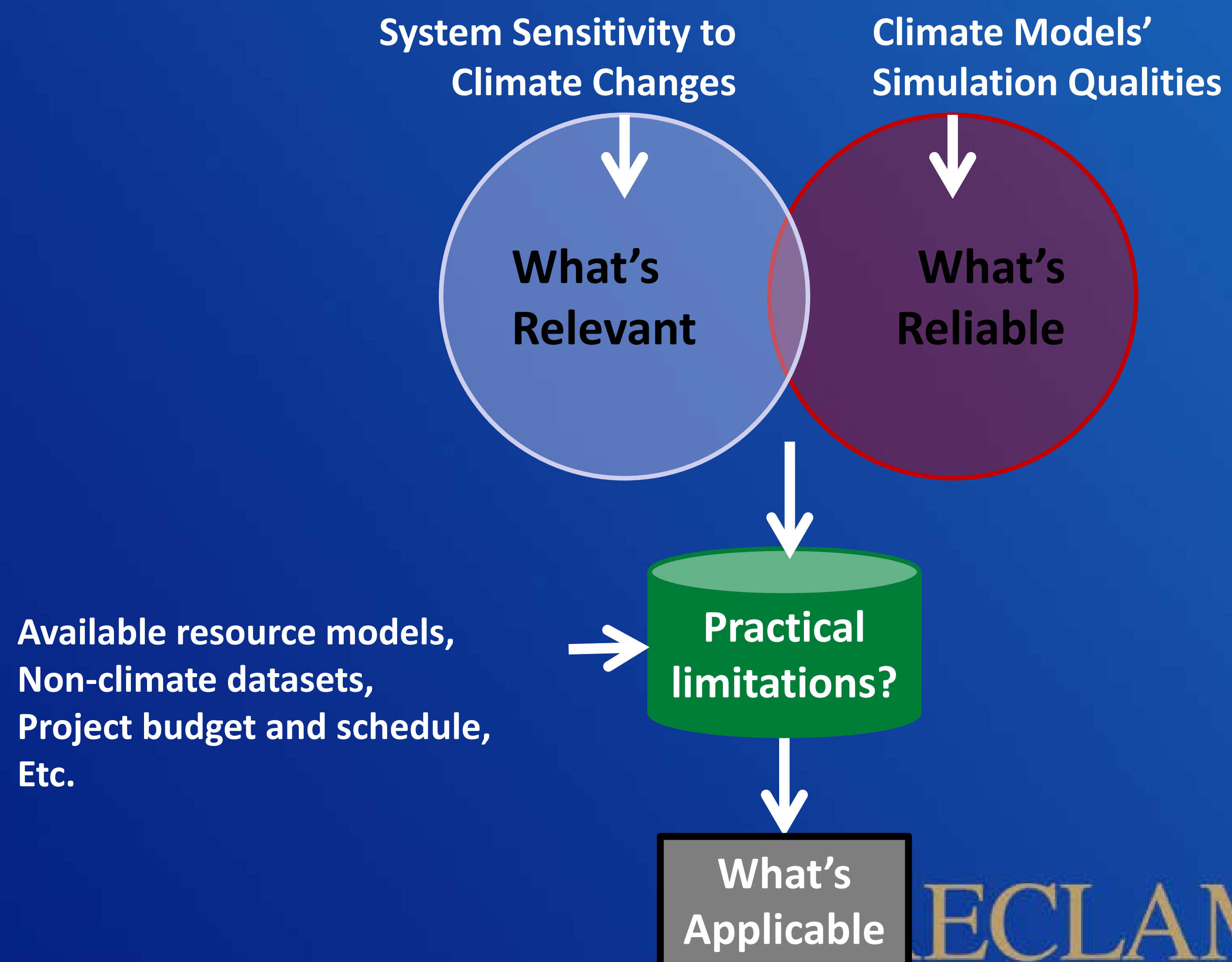
  Mock Scoping Session to Evaluate the Applicability Framework

Applicability Framework:

- How to select climate change information and methods for a specific study?

Applicability Framework:

- Proposed Framework

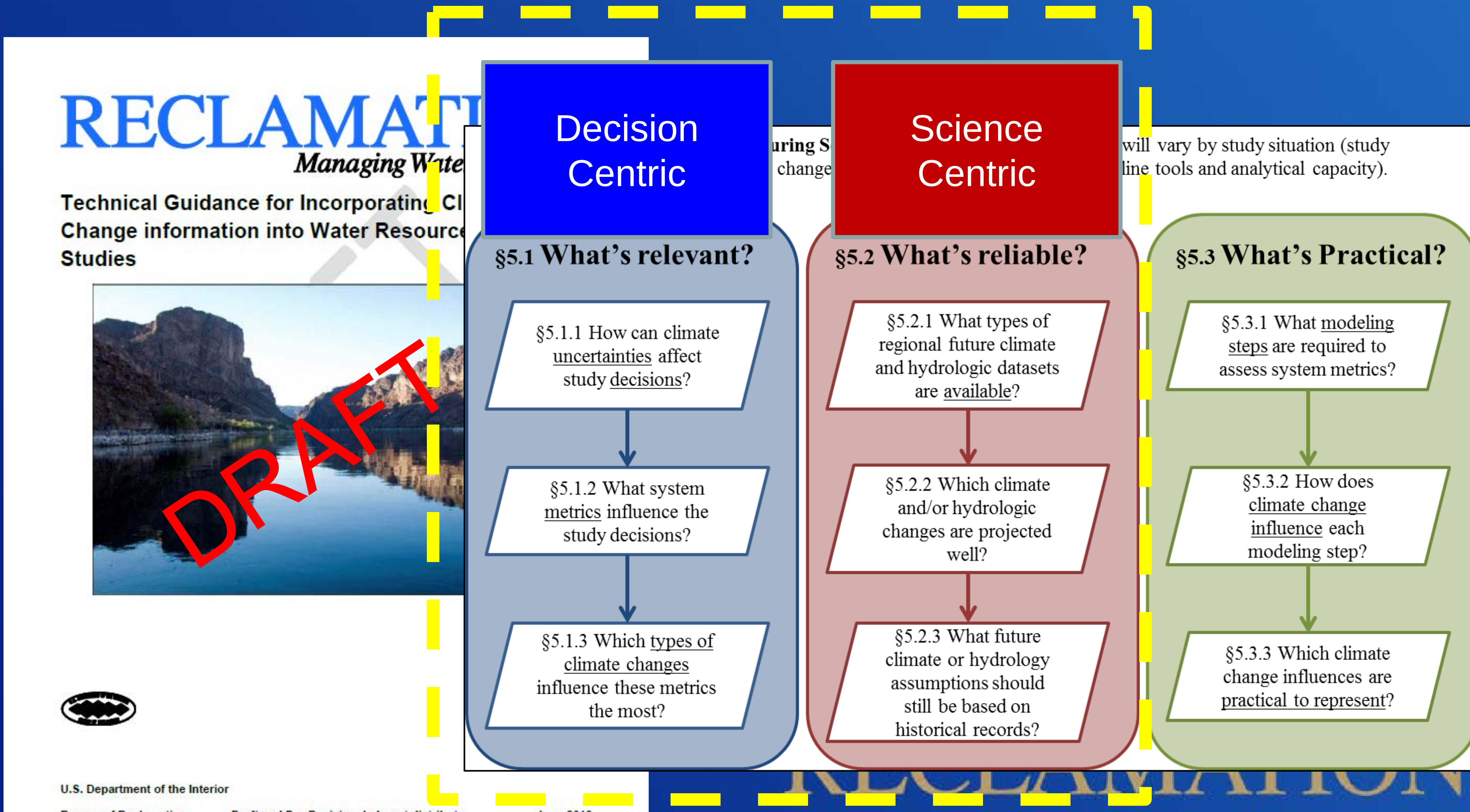


RECLAMATION

Applicability Framework:

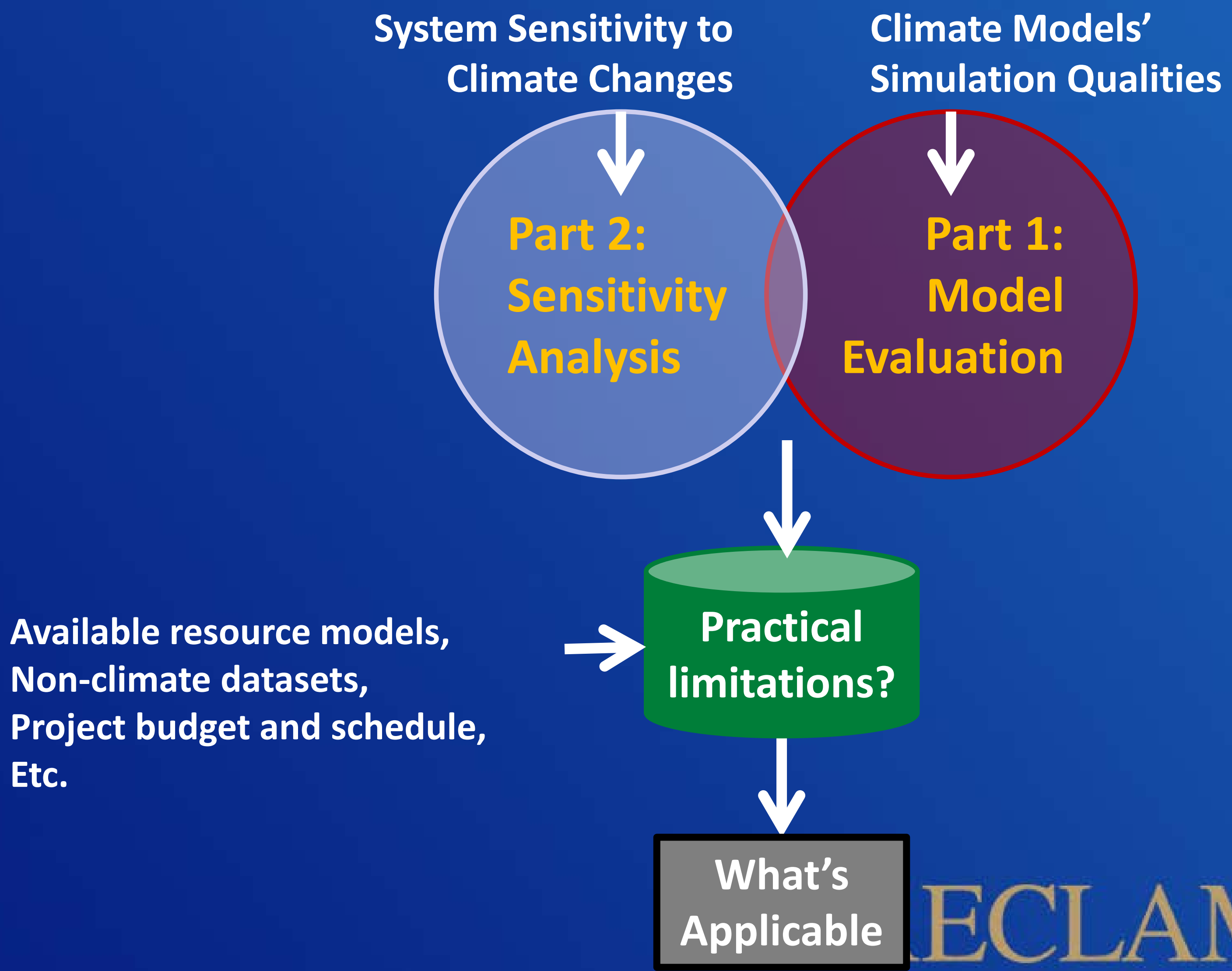
- **SECURE Feasibility Guidance**

Focus of our Applicability Workshop



Applicability Framework:

- Proposed Framework



RECLAMATION

Applicability Framework:

- **Part 1: Reliability**

  What do climate models do well and what do they do poorly – i.e., Which aspects of climate projections are **reliable** or **credible** enough to support major decisions?

Climate Variables –
- Temperature
- Precipitation
- Wind speed
- Net radiation

Aspects of Variability –
- Mean
- Variance
- Autocorrelation / frequency distribution

Timescales –
- Daily
- Monthly
- Seasonal
- Annual

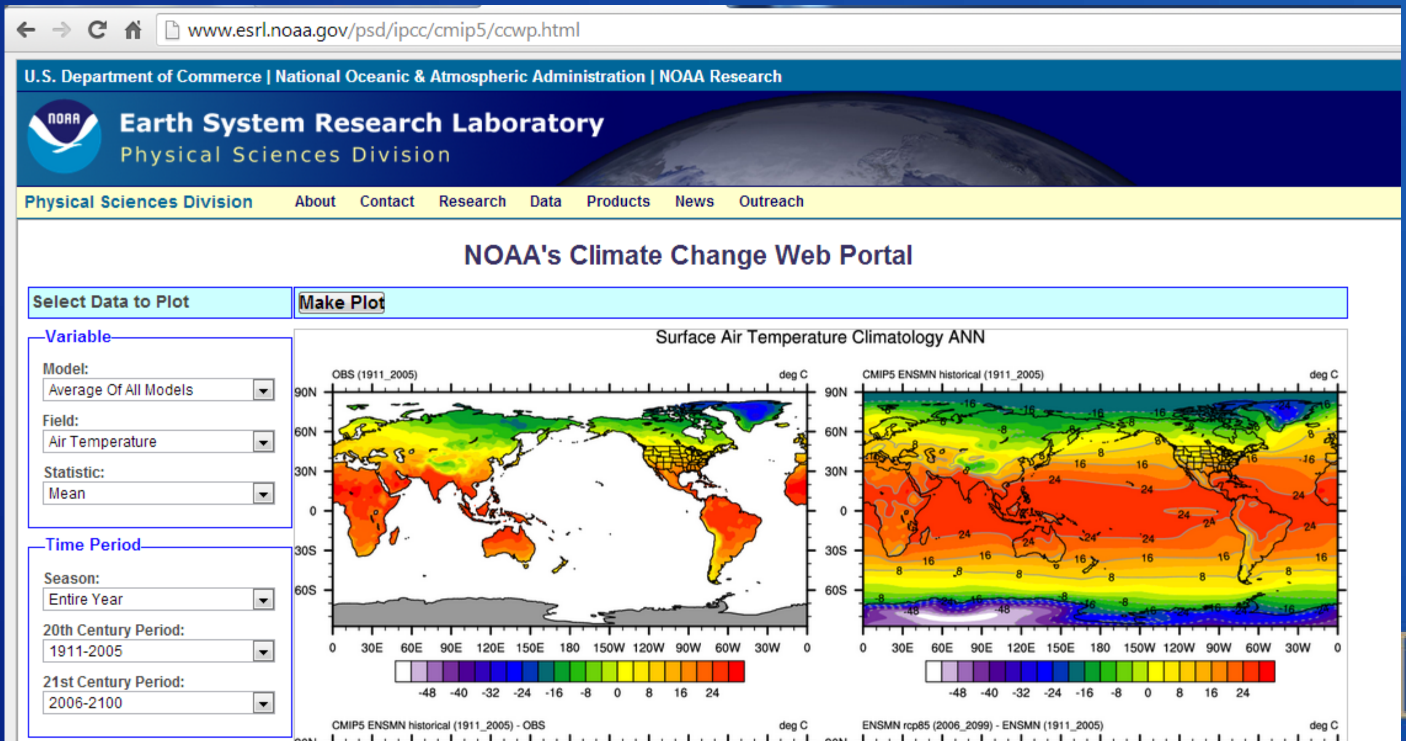
Domain / Spatial Scale –
- Local
- Basin
- Regional
- Continental

Applicability Framework:

- **Part 1: Reliability**

  What do climate models do well and what do they do poorly – i.e., Which aspects of climate projections are **reliable** or **credible** enough to support major decisions?

  → Broadband evaluation of CMIP5 global climate models
  www.esrl.noaa.gov/psd/ipcc/cmip5/ccwp.html

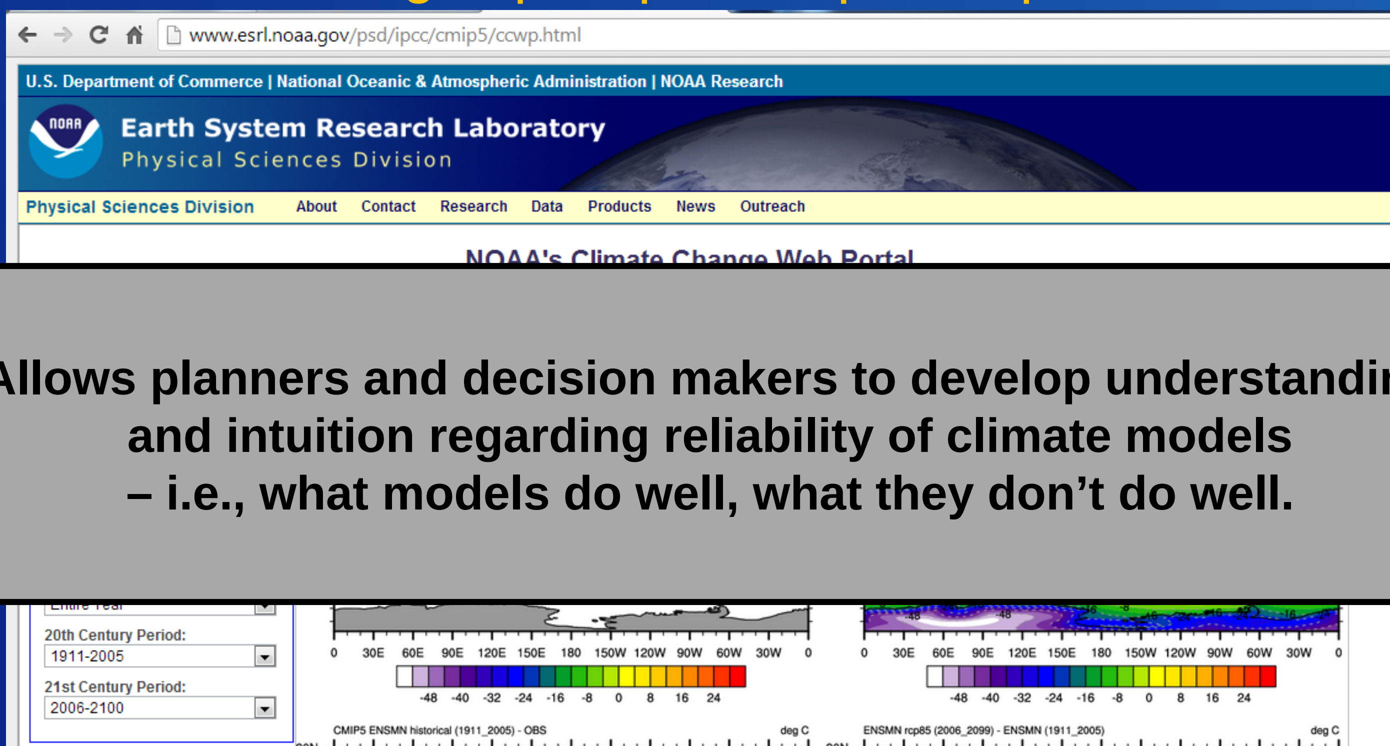


Applicability Framework:

- **Part 1: Reliability**

  What do climate models do well and what do they do poorly – i.e., Which aspects of climate projections are **<u>reliable</u>** or **<u>credible</u>** enough to support major decisions?

  → Broadband evaluation of CMIP5 global climate models
  www.esrl.noaa.gov/psd/ipcc/cmip5/ccwp.html

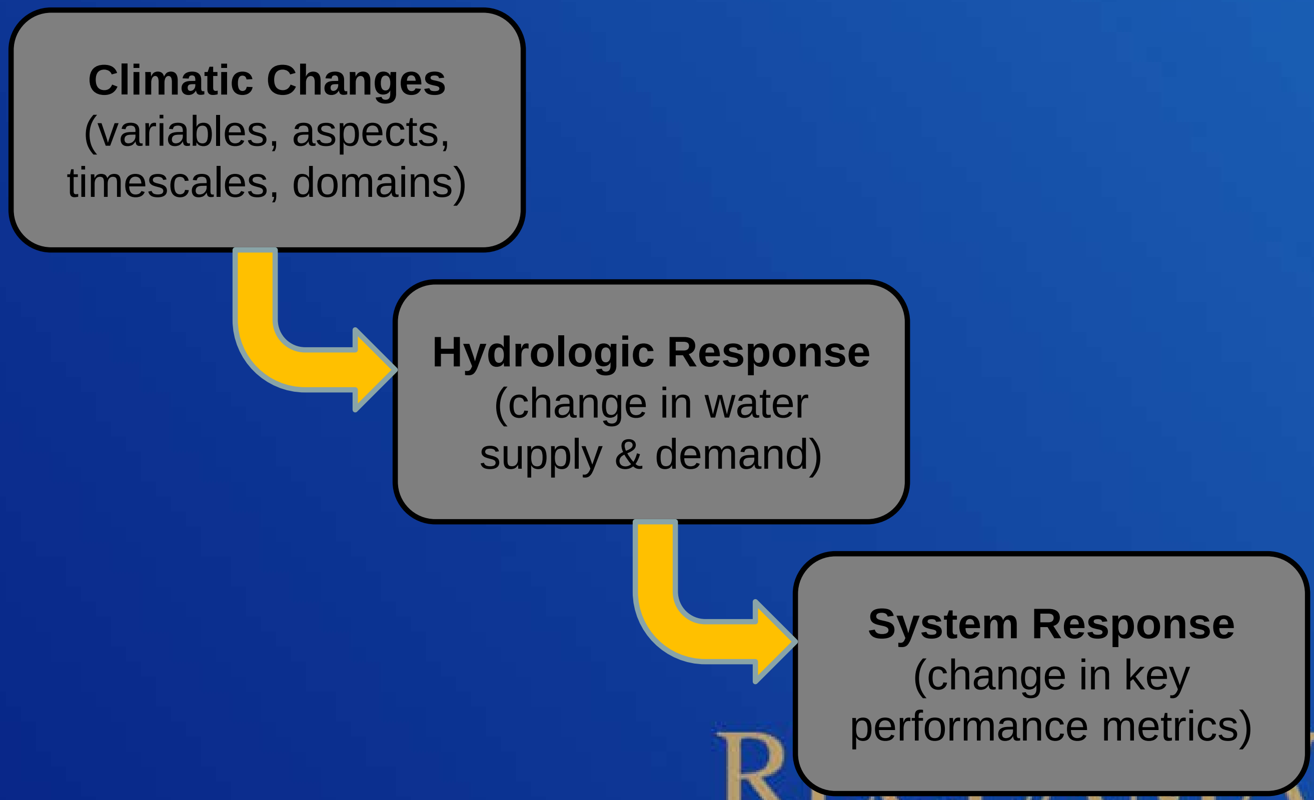


Allows planners and decision makers to develop understanding and intuition regarding reliability of climate models – i.e., what models do well, what they don't do well.

Applicability Framework:

- **Part 2: Relevance**

  What types of climate changes affect system performance – i.e., which aspects of climate change are **relevant** to water resources planning and decisions?

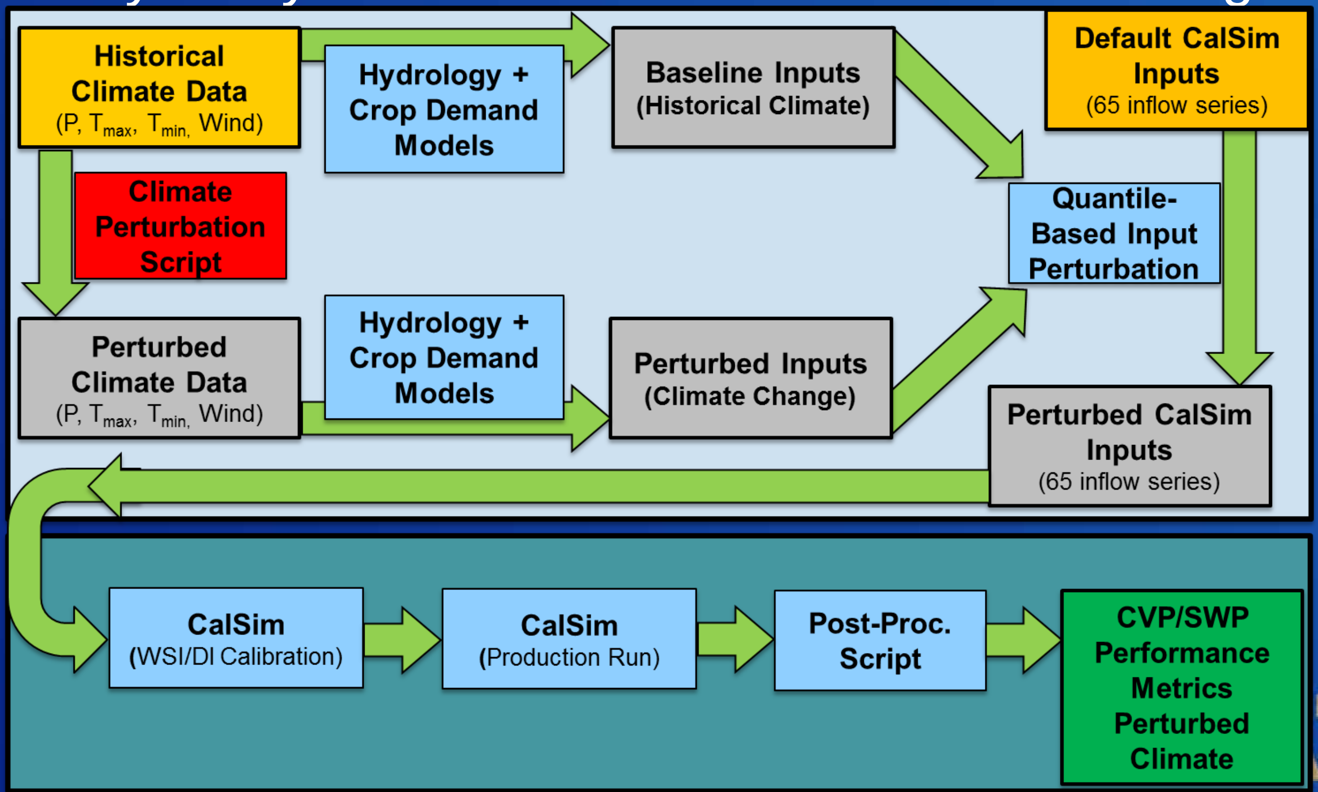


Applicability Framework:

- **Part 2: Relevance**

  What types of climate changes affect system performance – i.e., which aspects of climate change are **relevant** to water resources planning and decisions?

  → Sensitivity analysis of Sacramento River Basin using CALSIM-3.0



Applicability Framework:

- **Part 2: Relevance**

  What types of climate changes affect system performance – i.e., which aspects of climate change are **relevant** to water resources planning and decisions?

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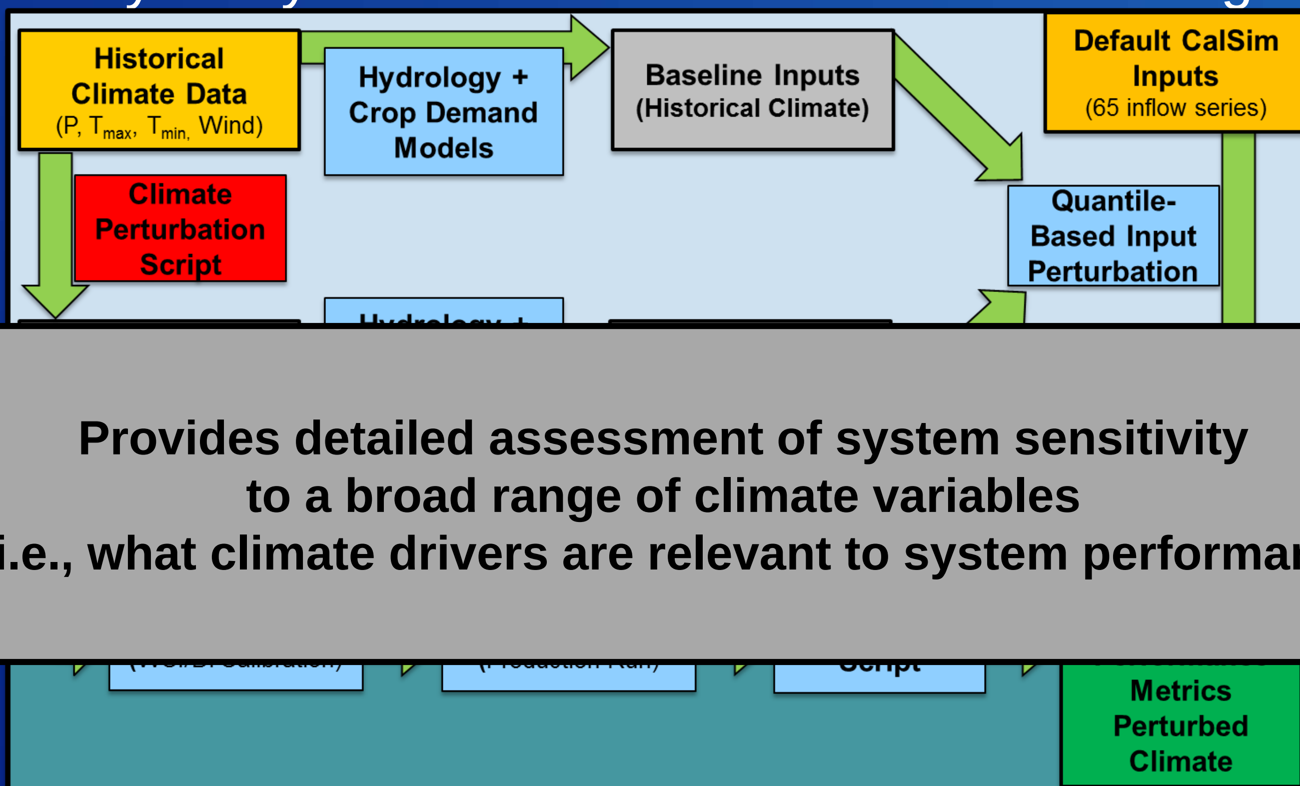

Provides detailed assessment of system sensitivity to a broad range of climate variables – i.e., what climate drivers are relevant to system performance

Applicability Framework:

- **Fundamental Premise**

  When choosing climate projection information and methods, study teams should focus on climate information that is both reliable and relevant, and thus applicable to a given study or decision

Questions?

Outline:

- **Background & Motivation**
  Science, Policy, and Practical Questions
- **Applicability Framework**
  Combining Reliability and Relevance to Assess Applicability
- **Pilot Workshop**
  Mock Scoping Session to Evaluate the Applicability Framework

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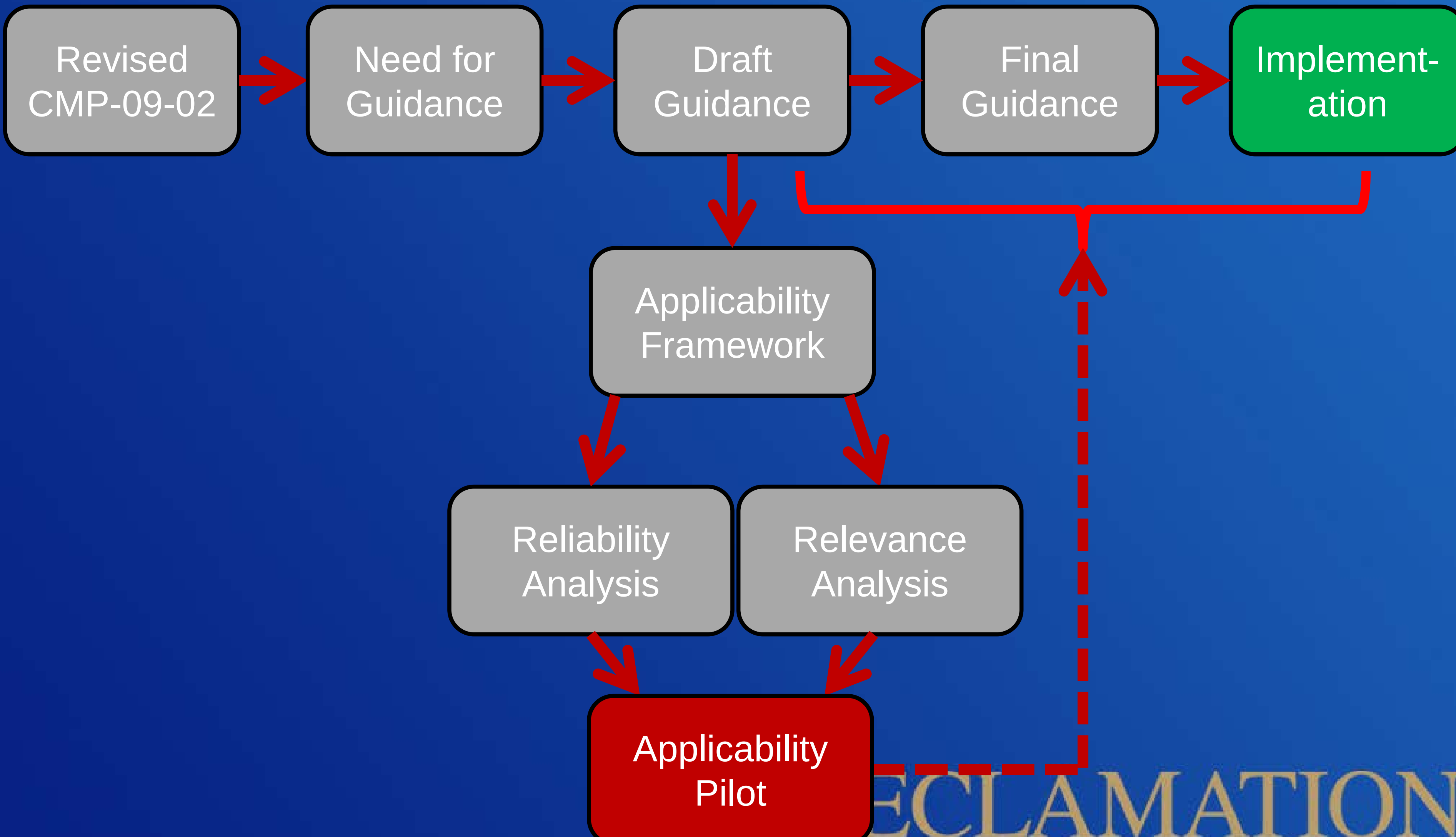
Pilot Workshop:

- **We need your help!**



Pilot Workshop:

- **We need your help!**

  Reclamation partnered with NOAA and USACE to develop and demonstrate applicability framework

  - Collaborators developed conceptual framework
  - NOAA lead broad-band evaluation of CMIP5 global climate models, development of online evaluation portal
  - Reclamation lead sensitivity analysis of Sacramento River CVP/SWP system to wide array of climate changes

  Now we need your feedback on the strengths and weaknesses of the framework.

Pilot Workshop:

- **We need your help!**

Webinar 1	Incorporating Climate Change into Water Resources and Environmental Planning ***July 23, 10:00am (Pacific)***
Webinar 2	Assessing Applicability of Climate Projection Information, Part 1: Evaluating Reliability ***July 30, 3:00pm (Pacific)***
Webinar 3	Assessing Applicability of Climate Projection Information, Part 2: Evaluating Relevance ***August 6, 11:00am (Pacific)***
Workshop	CMIP5 Applicability Pilot Workshop ***August 13, 11:00am (Pacific)*** *(TENTATIVE DATE)*

Pilot Workshop:

- **We need your help!**

  Workshop Format

  - **Three scoping teams**
    - 1-3 planners / scoping managers
    - 1 technical specialist – water operations / system sensitivity
    - 1 technical specialist – climate change / climate model evaluation
    - 1 note taker
  - **Three hypothetical projects**
    - New storage facility
    - Implementation of new operating criteria under a restoration program
    - Renewal of a long-term water service contract
  - **Mock scoping session**
    Each group will use the applicability framework to scope climate change portion of a feasibility study for one of the three mock projects
  - **Discussion**
    Each group describe their scoping experience, including which aspects of the proposed framework worked well and which did not.

Pilot Workshop:

- **We need your help!**

Workshop Schedule

- 8:30 – 9:00 Introduce workshop and participants, define goals
- 9:00 – 9:30 Recap applicability framework within context of planning process
- 9:30 – 9:45 Break
- 9:45 – 10:15 Discuss details of mock scoping assignment
- 10:15 – 12:00 Breakout Groups – scoping session 1: evaluating reliability
- 12:00 – 1:00 Lunch
- 1:00 – 2:30 Breakout Groups – scoping session 1: evaluating relevance
- 2:30 – 2:45 Break
- 2:45 – 3:30 Scoping Results – group presentations
- 3:30 – 4:30 Group discussion – gather feedback

Pilot Workshop:

- **We need your help!**

  We are looking for your feedback …

  - Are the purpose and general concept of the proposed framework sufficiently clear?
  - Was the evaluation information provided clear?
    Is the NOAA climate change portal useful for understanding model strengths/weaknesses and assessing reliability?
  - Was the sensitivity information provided clear?
    Are the sensitivity results useful for understanding system drivers and assessing relevance?
  - Is the proposed framework compatible with existing scoping process?
  - Etc…

RECLAMATION

Questions?

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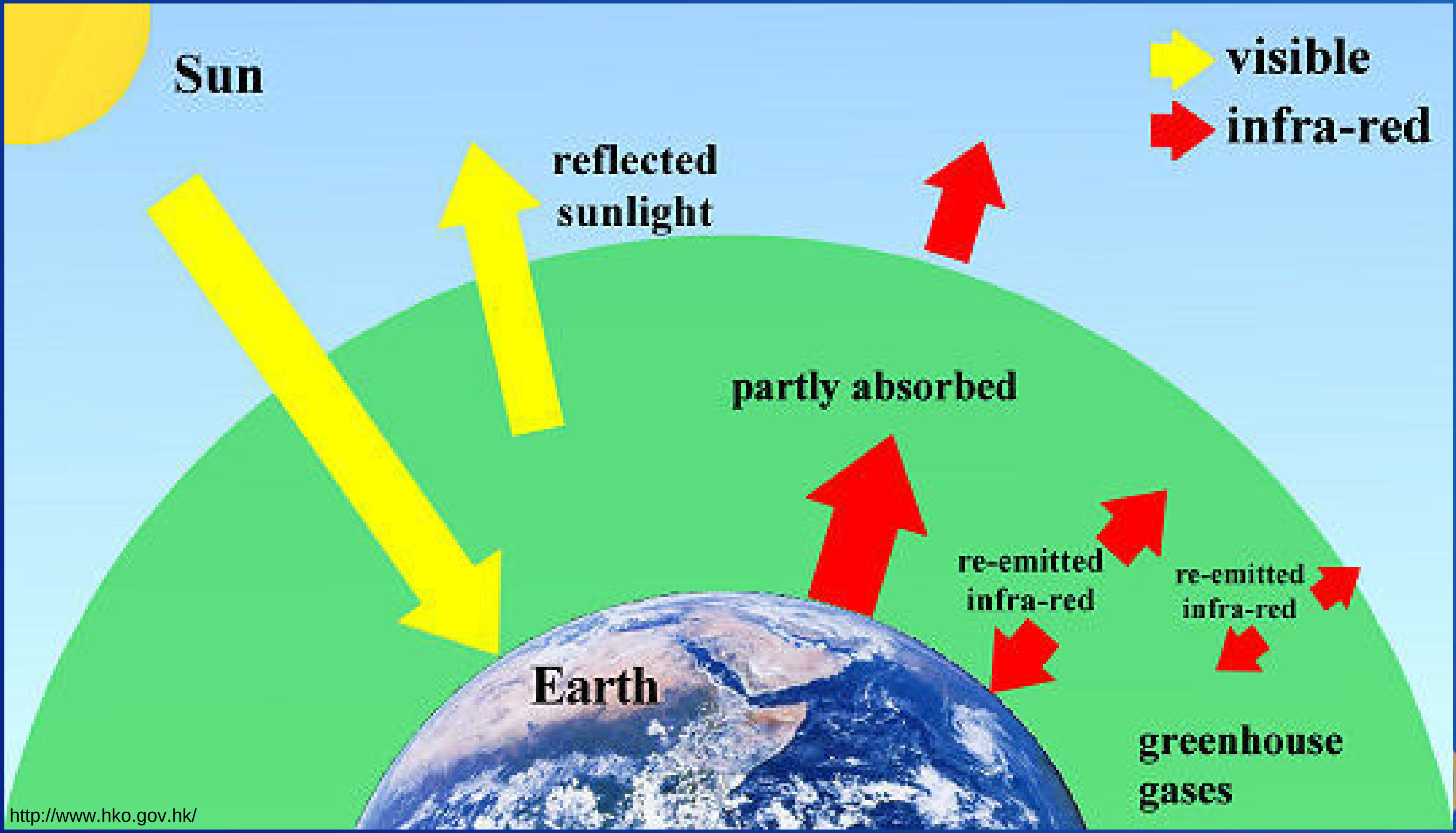
Background & Motivation:

- **Science**

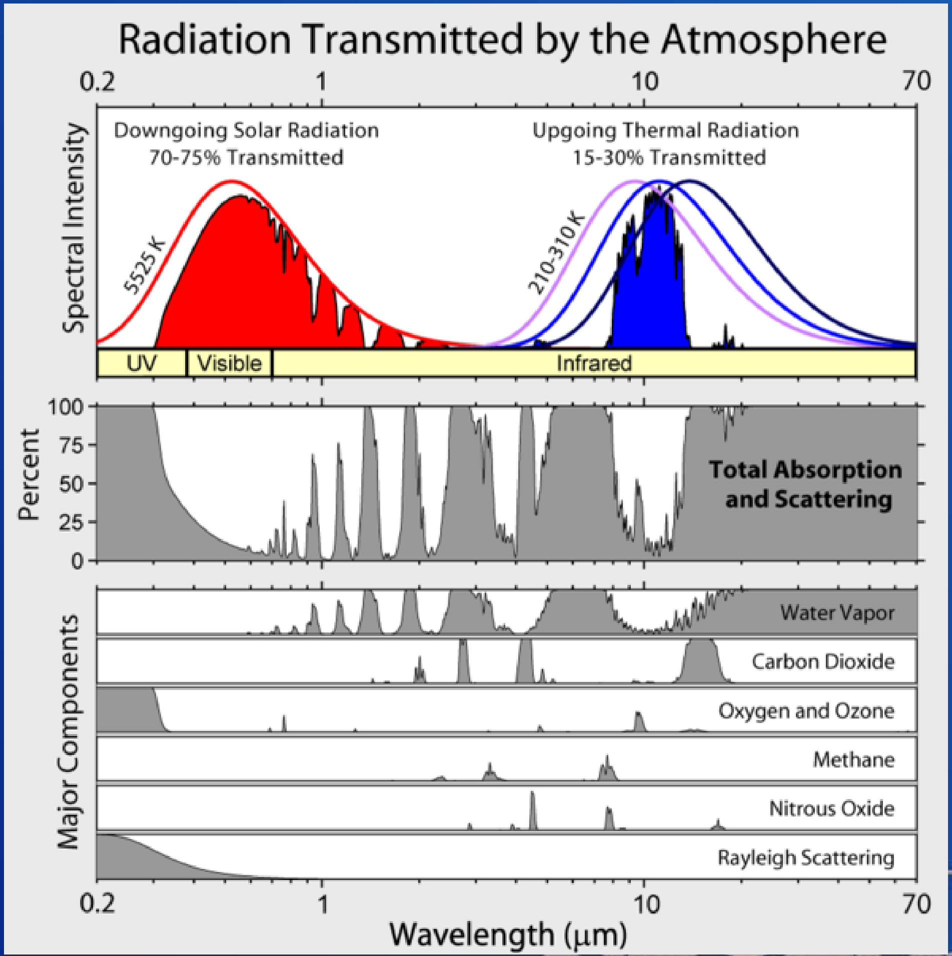
  Fact: The greenhouse effect increases the available energy in the earth system



Background & Motivation:

- **Science**

  Fact: Carbon Dioxide, Methane, Nitrous Oxide, and Ozone are major greenhouse gasses.



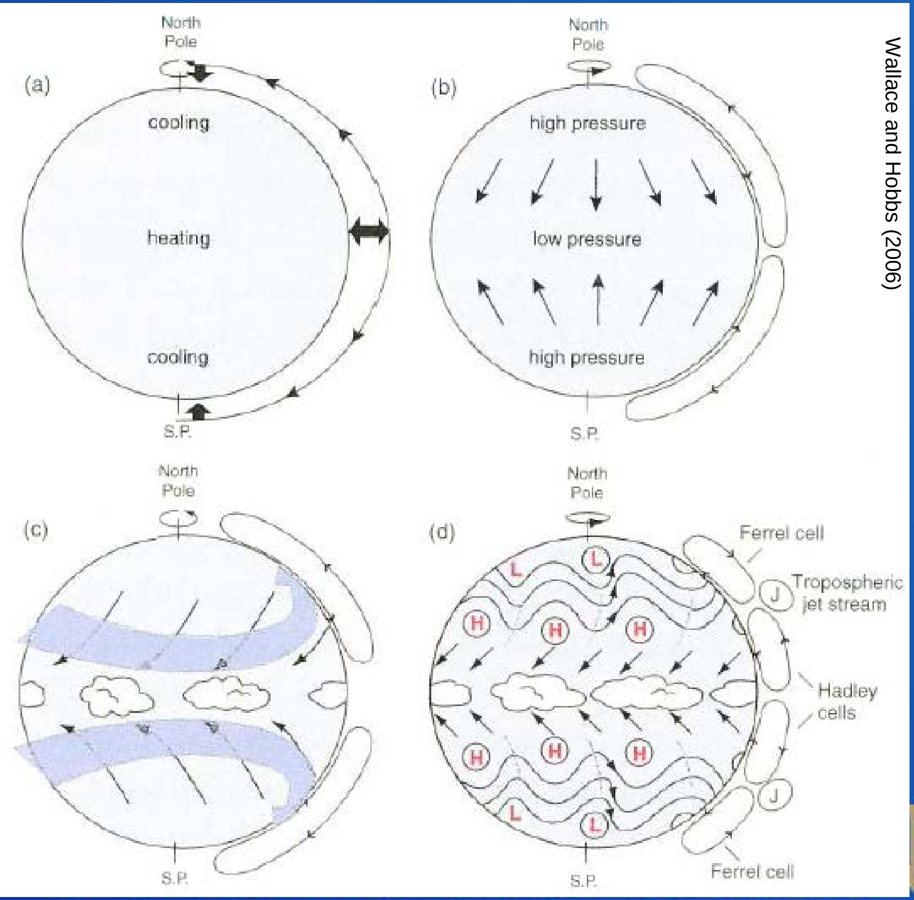
Background & Motivation:

- **Science**

Theory: Increasing greenhouse gas concentrations will increase the greenhouse effect, thus increasing the energy in the system and altering the system state and/or dynamics

Simple Example:

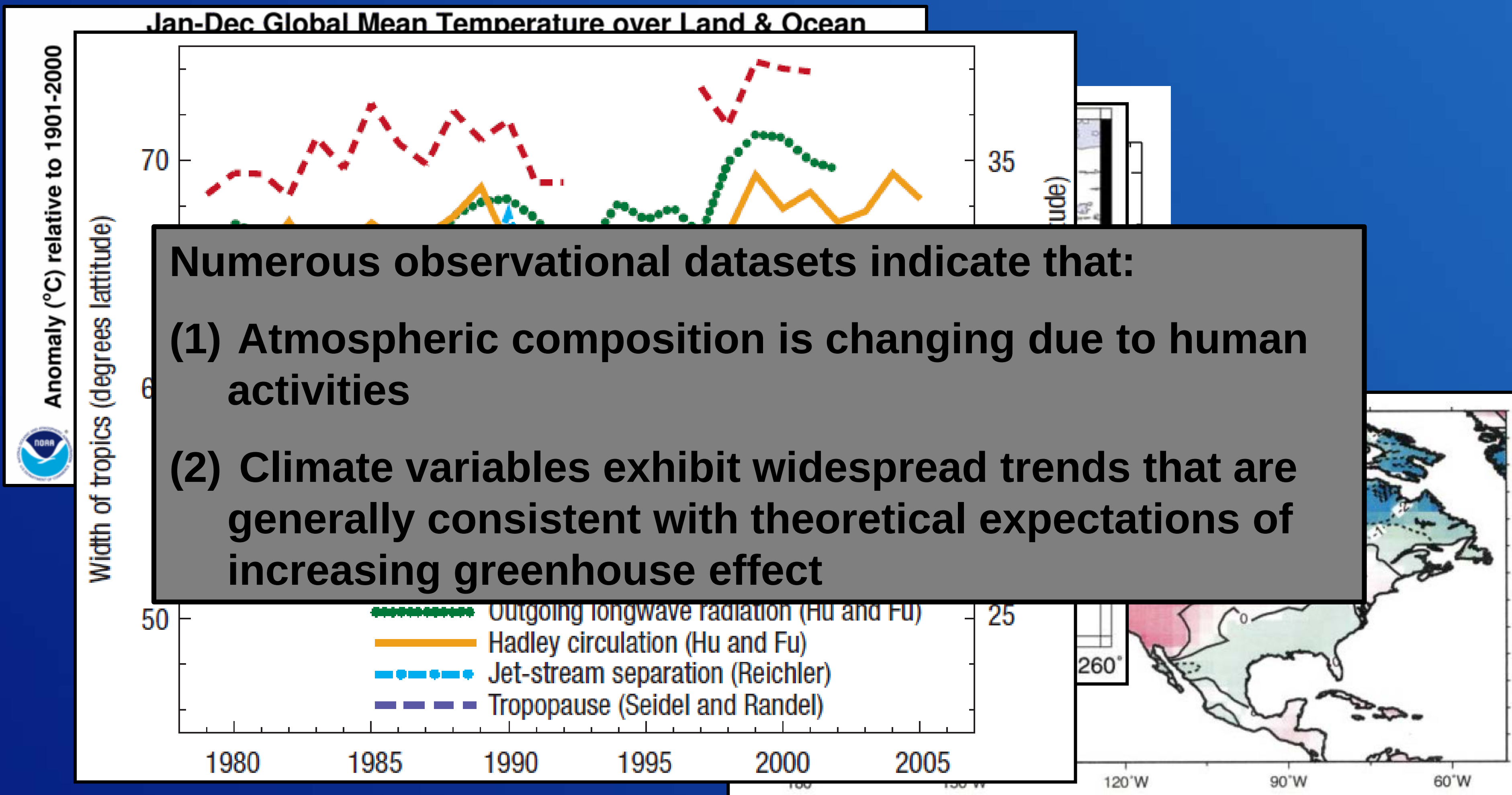
General circulation of a uniform atmosphere over a uniform surface



Background & Motivation:

- **Science**

  Evidence: Analysis of Historical Trends (observations)



Numerous observational datasets indicate that:

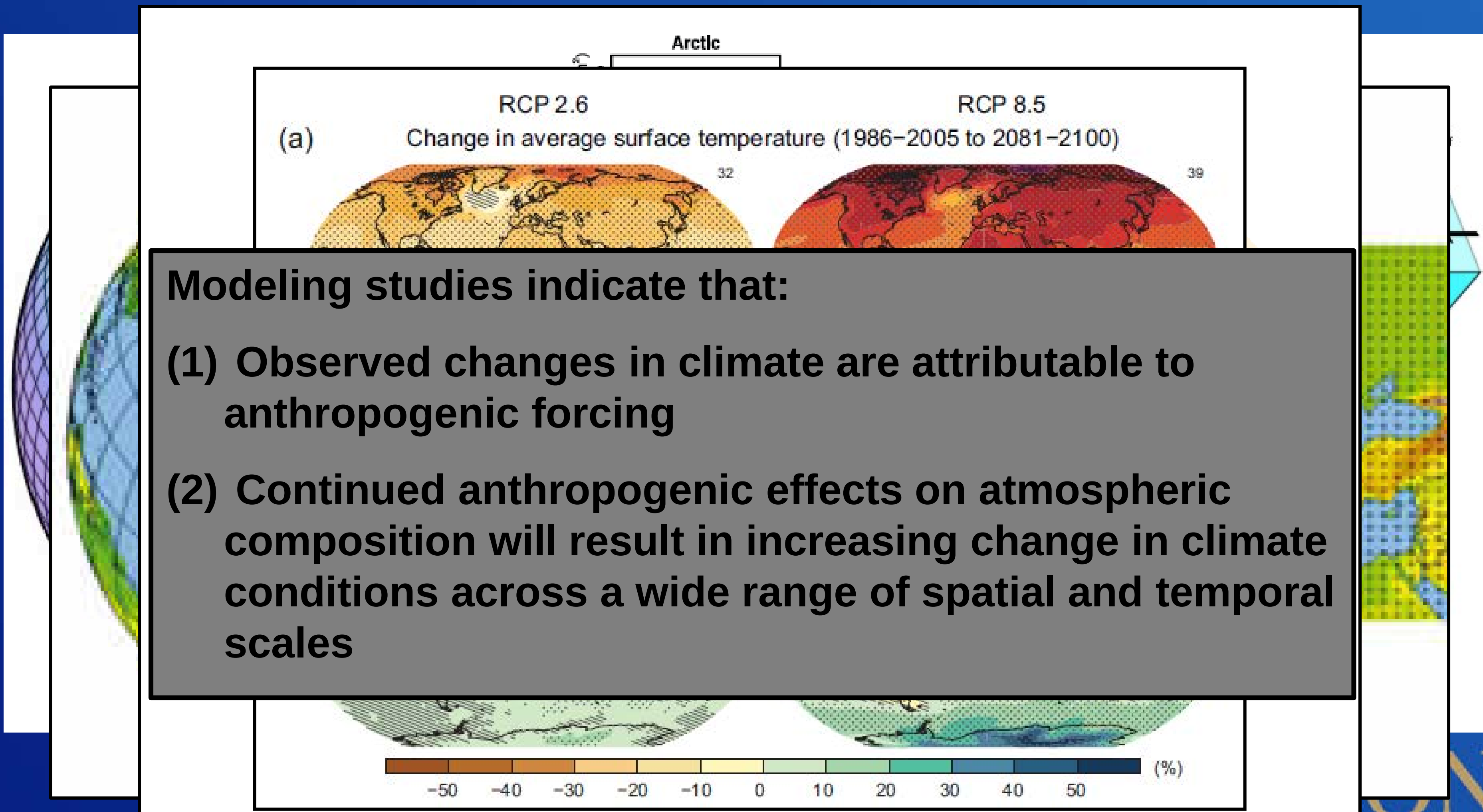
(1) Atmospheric composition is changing due to human activities

(2) Climate variables exhibit widespread trends that are generally consistent with theoretical expectations of increasing greenhouse effect

Background & Motivation:

- **Science**

  Evidence: Attribution and projection (models)



Modeling studies indicate that:

(1) Observed changes in climate are attributable to anthropogenic forcing

(2) Continued anthropogenic effects on atmospheric composition will result in increasing change in climate conditions across a wide range of spatial and temporal scales

Applicability Framework:

- **How to select climate change information and methods for a specific study?**

Science

1. What do we think we know about future climate conditions?

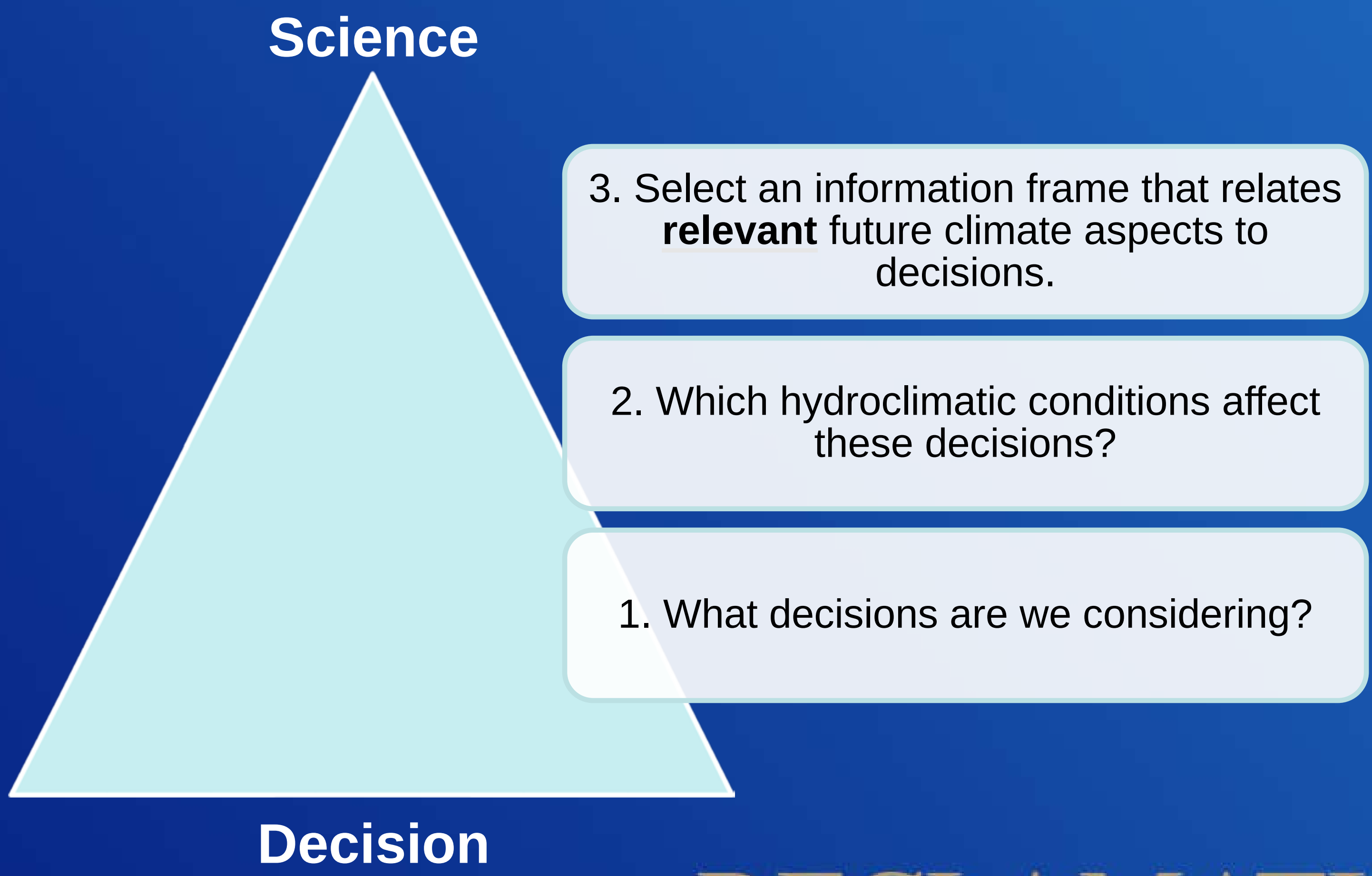
2. Which climate information do we feel comfortable about relating to our decisions?

3. Select an information frame that relates **reliable** future climate aspects to decisions

Decision

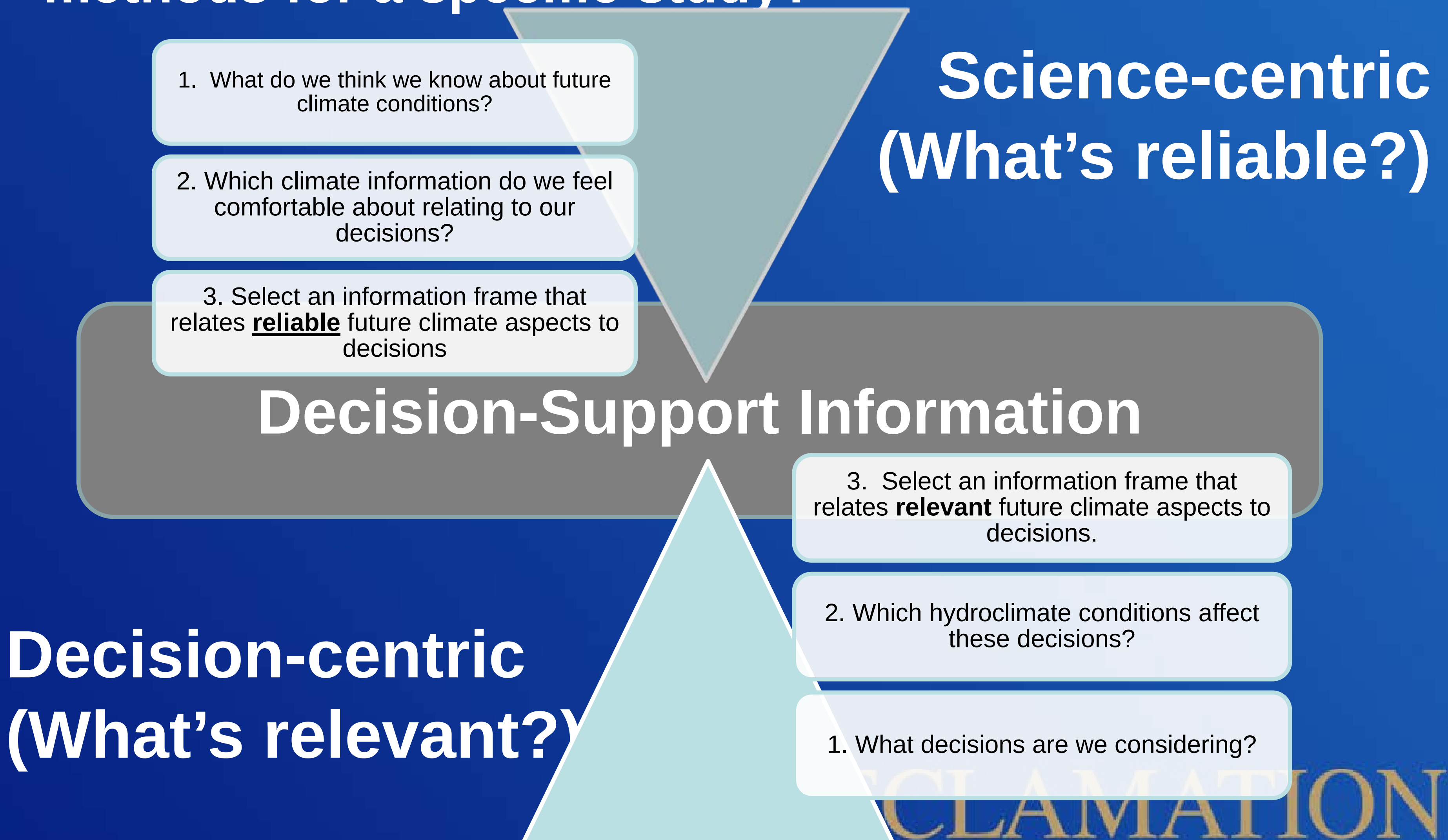
Applicability Framework:

- **How to select climate change information and methods for a specific study?**



Applicability Framework:

- **How to select climate change information and methods for a specific study?**



APPENDIX 2.2

Webinar 2: Assessing Applicability of Climate Projection Information, Part 1: Evaluating Credibility

RECLAMATION
Managing Water in the West

Assessing Applicability of CMIP5 Climate Projections for Water Resources and Environmental Planning:

Webinar 2: Assessing Applicability of Climate Projection Information, Part 1: Evaluating Credibility

Ian Ferguson (USBR, TSC)
Cameron Bracken (USBR, TSC)
Levi Brekke (USBR, Research Office)
Jamie Scott (NOAA CIRES)
Michael Alexander (NOAA ESRL)
Jeff Arnold (USACE)

U.S. Department of the Interior
Bureau of Reclamation

Objectives of Webinar 2:

- **What is CMIP5?**
  Overview of GCMs, how we use them, and the role of CMIP5
- **NOAA Climate Change Web Portal**
  Brief summary of data, methods, and options built into the portal
- **Assessing Reliability**
  Using the portal to assess reliability of climate projection information

Outline:

- **Recap of Webinar 1**
- **What is CMIP5?**
  Coupled Model Intercomparison Project
- **Climate Change Web Portal**
  Features and functionality
- **Assessing Reliability**
  Using the web portal to gain intuition about climate models

Webinar 1 Recap:

- Recent changes to Feasibility Study D&S directly link analysis of **climate change** to **investment decisions**
- Reclamation, NOAA and USACE are partnering to **develop a framework** to guide evaluation of climate projection **relevance, reliability, and applicability** in context of water resources and environmental planning
- We need **your help** to evaluate and improve this framework

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Webinar 1 Recap:

- **SECURE Feasibility Guidance**

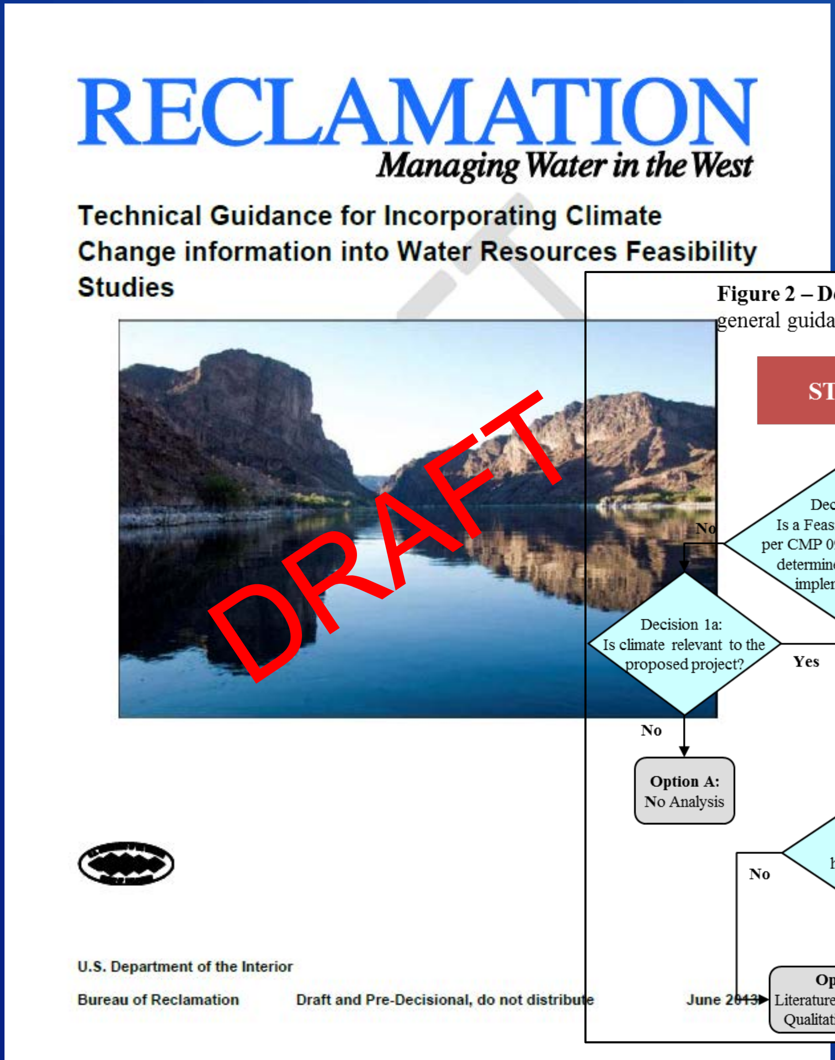
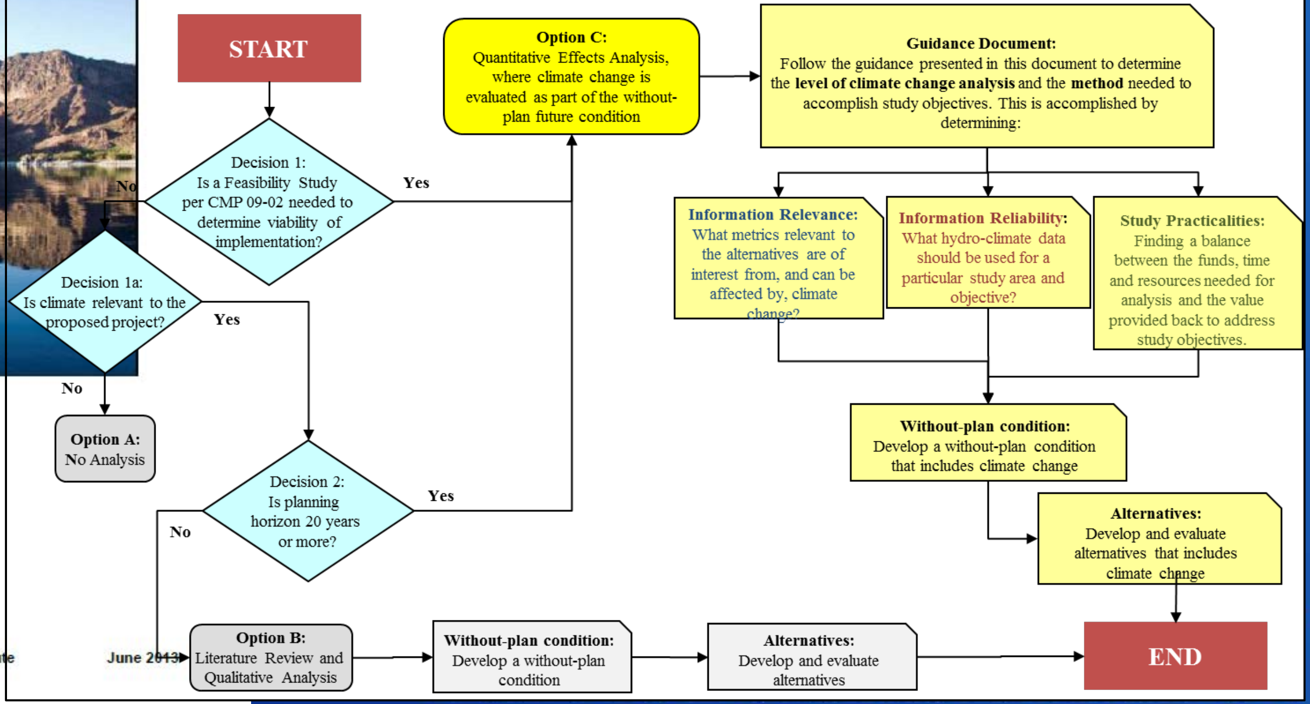
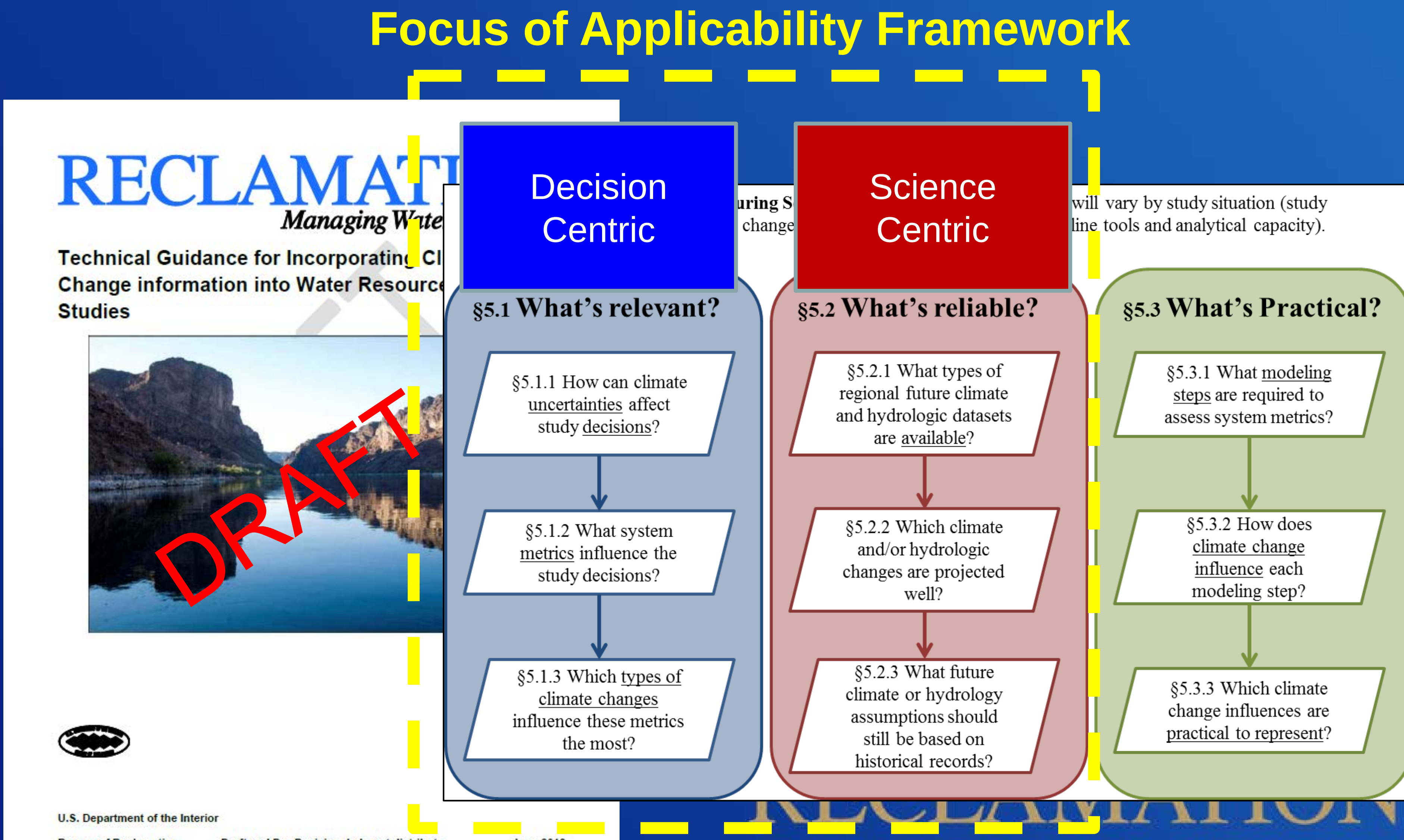


Figure 2 – Decision-Tree Diagram Leading to Level of Climate Change Analysis Options: This chart illustrates general guidance for consiering whether and how to incorporate climate change information into project-specific planning.



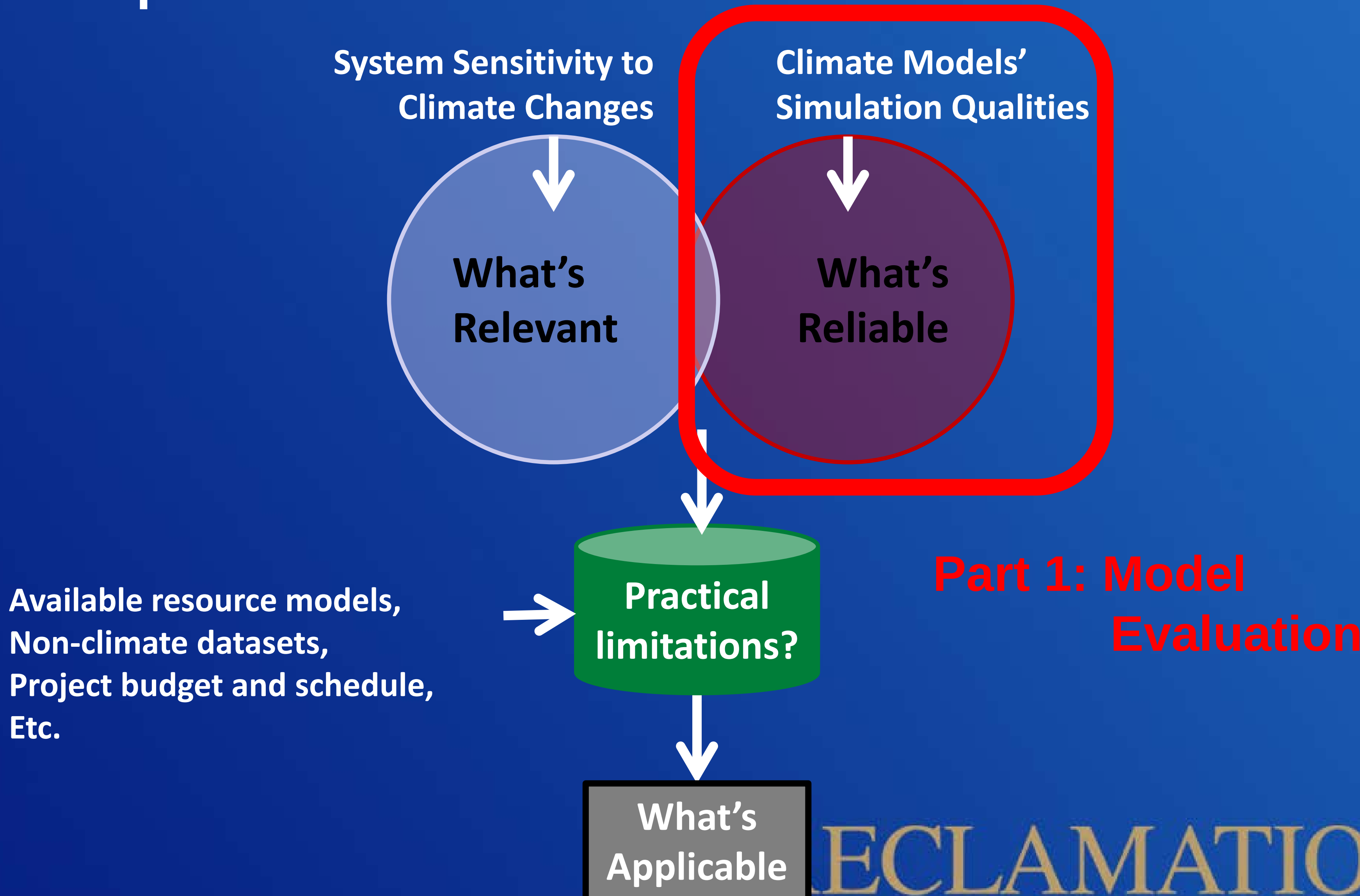
Webinar 1 Recap:

- SECURE Feasibility Guidance



Webinar 1 Recap:

- **Proposed Framework**



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Questions?

RECLAMATION

Outline:

- Objectives of Webinar 2

- **What is CMIP5?**

  Coupled Model Intercomparison Project

- **Climate Change Web Portal**

  Features and functionality

- **Assessing Reliability**

  Using the web portal to gain intuition about climate models

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What is CMIP5?

- **Coupled Model Intercomparison Project – Phase 5**

  "Established … as a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models [GCMs]…"

  - Enable diverse community of scientists to analyze GCMs in a systematic fashion
  - Support diagnosis, validation, intercomparison, documentation, and model improvement

What is CMIP5?

- **What are Global Climate Models (GCMs)?**

  Numerical models developed to simulate physics of the atmosphere, ocean and land surface that together make up the global climate system

What is CMIP5?

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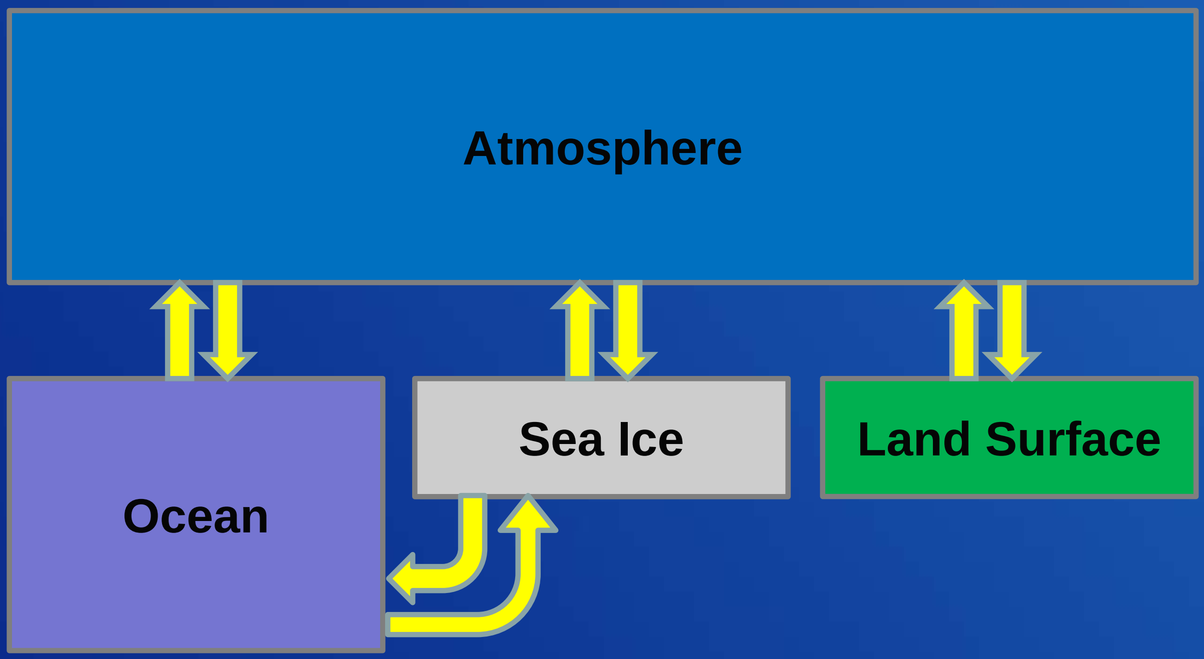
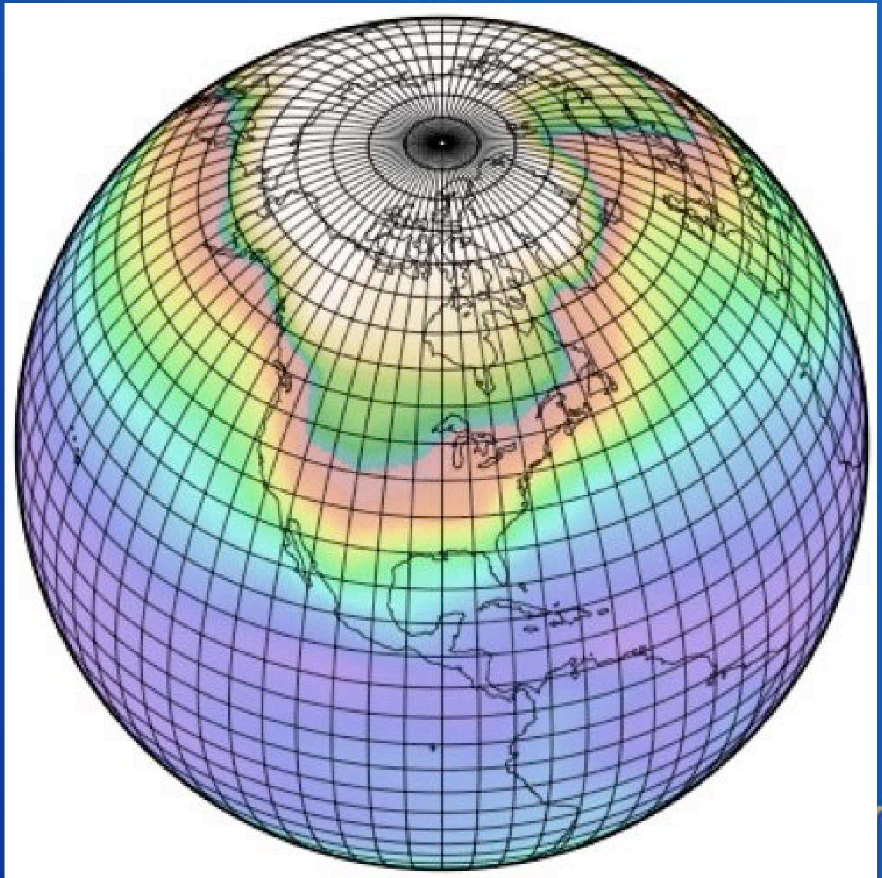


What is CMIP5?

- **What are Global Climate Models (GCMs)?**

  Numerical models developed to simulate physics of the atmosphere, ocean and land surface that together make up the global climate system

- Key Features:
  - ➢ Discrete representation of the real world
  - ➢ Spatial scales typically ~1°
  - ➢ Temporal scale typically ~3 hr
  - ➢ Global extent



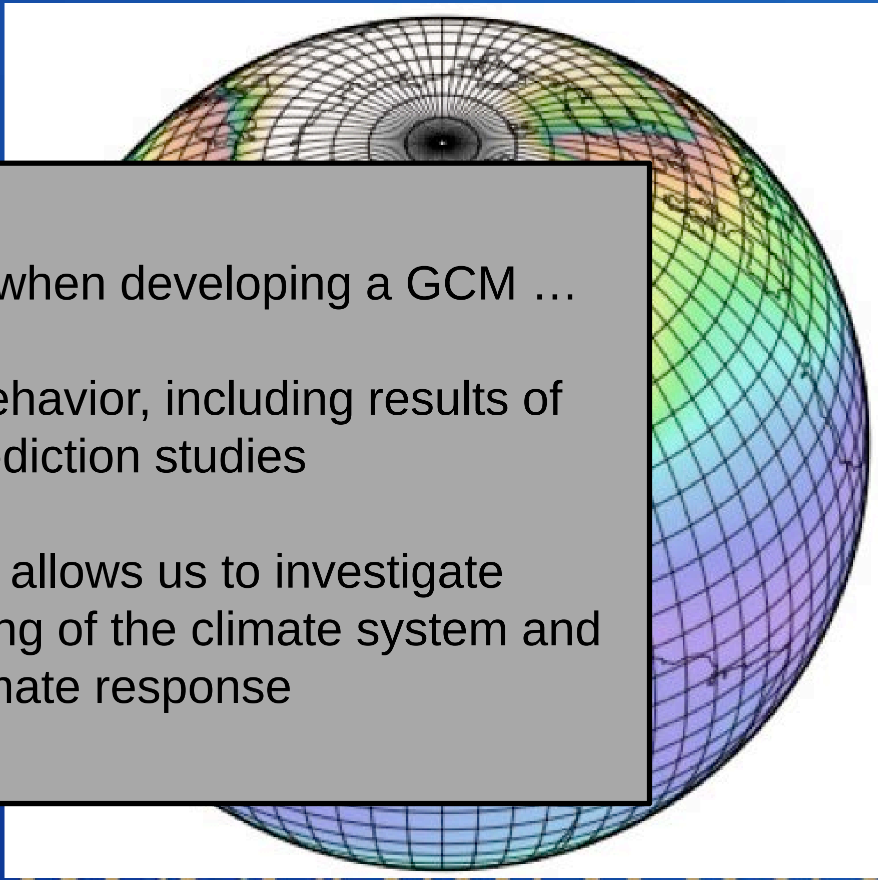
What is CMIP5?

- **Why do we use GCMs?**
  - ***Attribution*** –
    Explain physical processes responsible for observed behavior
  - ***Prediction*** –
    Predict response of climate system to external factors

What is CMIP5?

- **Why do we need so many GCMs?**

- GCMs Approximate Real World…
  – Larg
    equa
  – Num
  – Para
    proc
  – Spat
  – Tem



Modelers make many choices when developing a GCM …

These choices affect model behavior, including results of attribution and prediction studies

Analysis of multiple models allows us to investigate uncertainties in our understanding of the climate system and predictions of climate response

What is CMIP5?

- **Coupled Model Intercomparison Project – Phase 5**

  (1) Developed Standard Set of Model Simulations:
  - Evaluate how well models simulate the recent climate
  - Provide projections of future climate change
  - Understand key factors responsible for differences in model projections

  (2) Developed Standard Set of Data Protocols:
  - Facilitate sharing and comparison of model results
  - Serve time-aggregated model results to scientific community for broad range of analyses

What is CMIP5?

- **Coupled Model Intercomparison Project – Phase 5**

  Standard Set of Model Simulations:
  - Historical simulations: 1911-2005
  - Future simulations: 2006-2100

Climatic Change (2011) 109:5–31 25

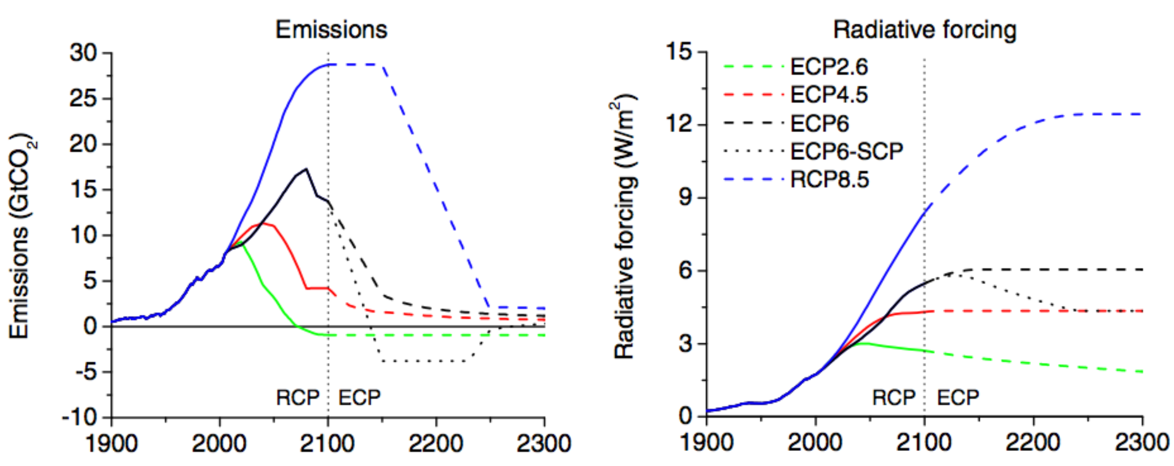
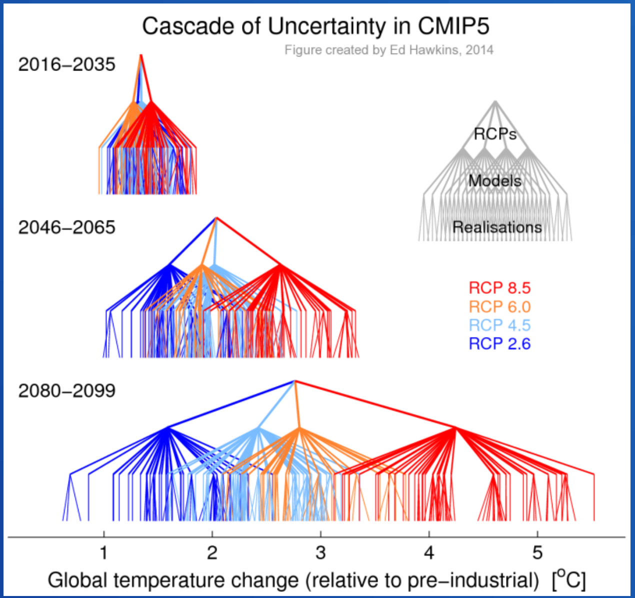


Fig. 11 Extension of the RCPs (radiative forcing and associated CO_2 emissions). ECP is extended concentration pathway. The SCP6to4.5 (supplementary concentration pathway) shows an alternative extension for RCP6 (see main text) (Meinshausen et al. 2011b)



RECLAMATION

Questions?

Outline:

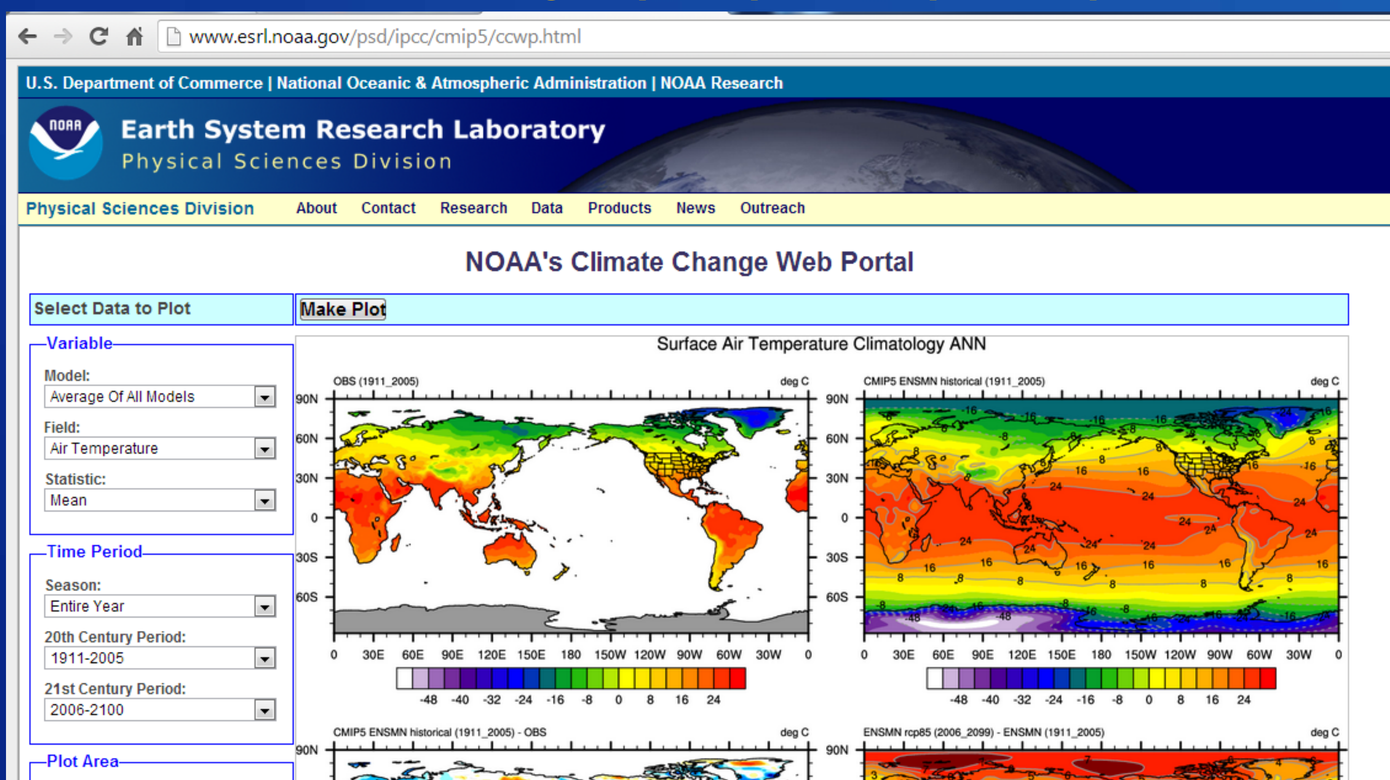
- **Objectives of Webinar 2**
- **What is CMIP5?**
  Coupled Model Intercomparison Project
- **Climate Change Web Portal**
  Features and functionality
- **Assessing Reliability**
  Using the web portal to gain intuition about climate models

NOAA Climate Change Portal:

- **Purpose**

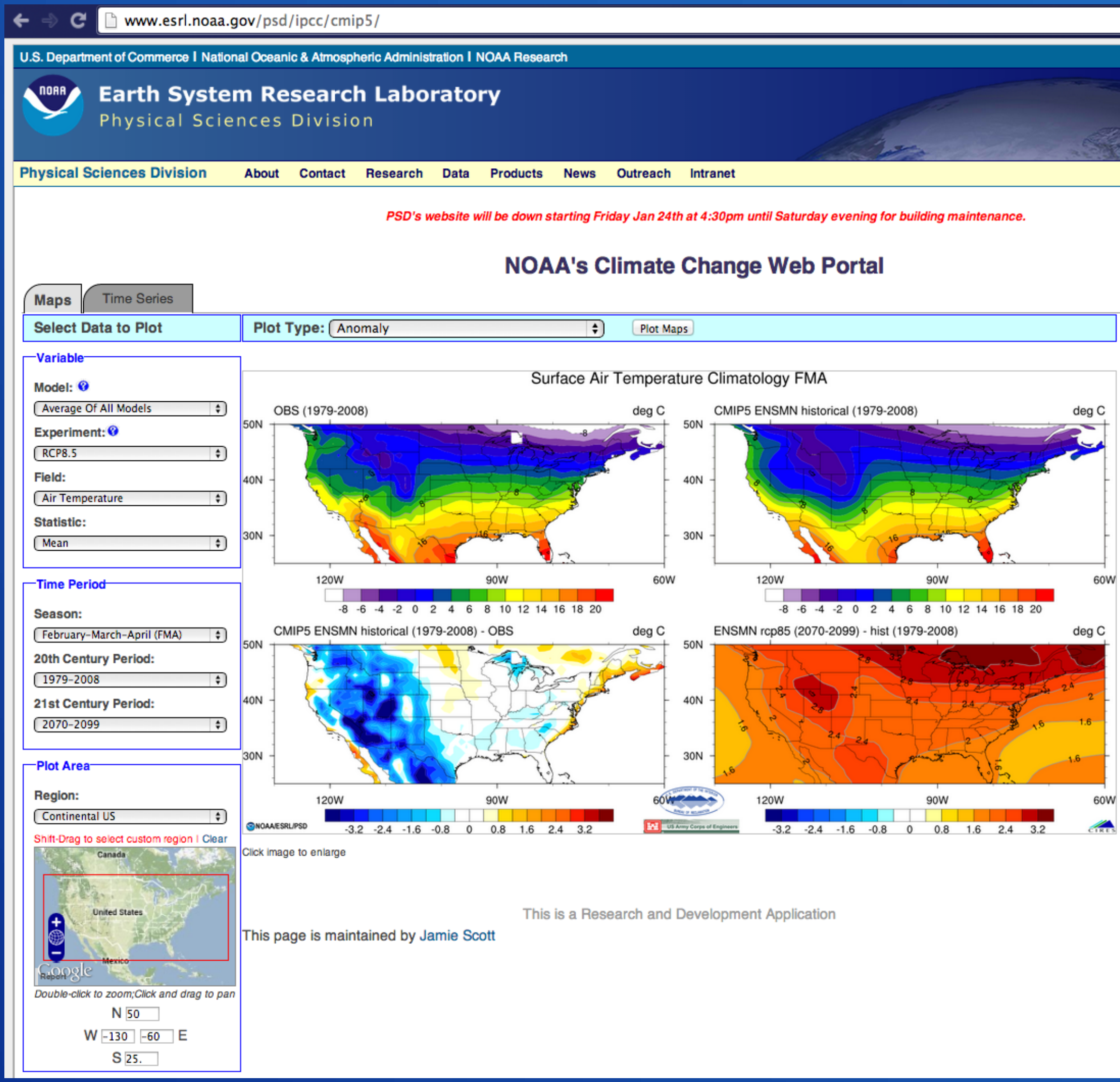
  Facilitate evaluation of climate model reliability based on evaluation of climate models relative to observed 20th century climate

www.esrl.noaa.gov/psd/ipcc/cmip5/ccwp.html



Climate Change Web Portal:

- Quickly compare CMIP5 historical simulations to observations
- Explore models, variables, climate metrics and seasons.
- Explore emissions/ concentration pathways
- Choose pre-defined regions or create custom regions



NOAA Climate Change Portal:

- **Data**

Variables:

- Air Temperature (daily average, T_{max}, T_{min})
- Precipitation
- Sea Surface Temperature (SST)

Observations:

- Publically-available gridded datasets for each variable

Simulations:

- 37 models used for precipitation and daily average temperature
- 28 models used for T_{max}, T_{min}, and SST

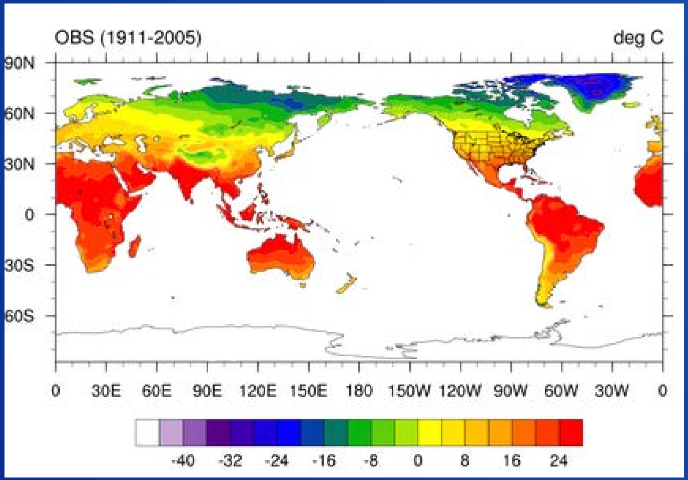
Timescales:

- Seasonal averages (all 3-month seasons)
- Annual averages

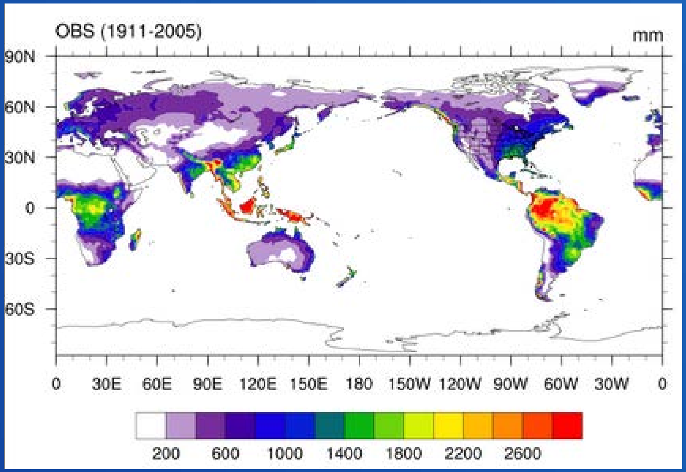
NOAA Climate Change Portal:

- **Data: Extent of Observational Datasets**

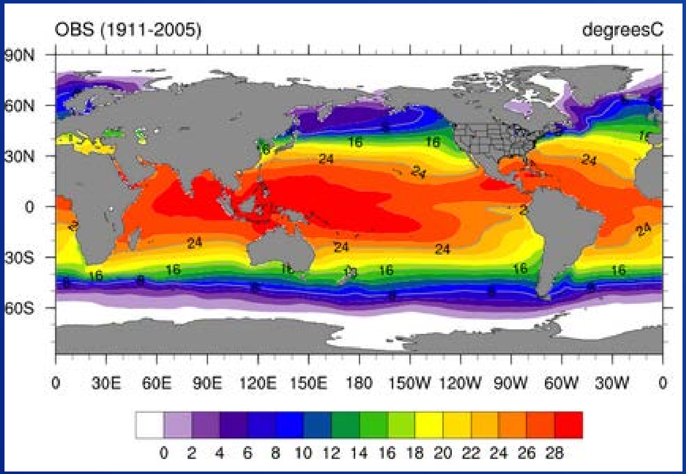
Air Temp



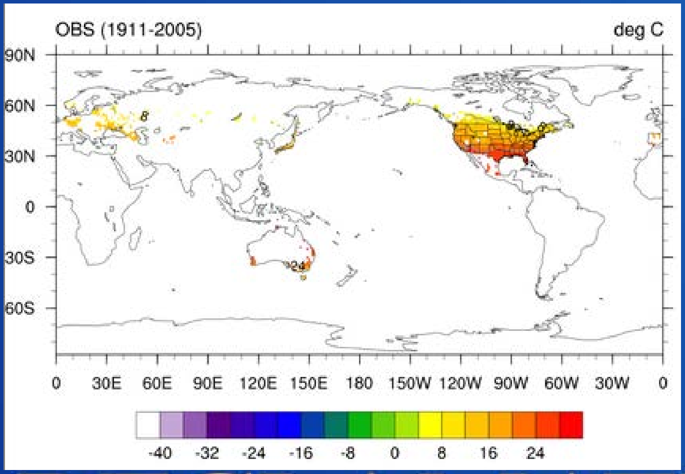
Precip



SST



Tmax/Tmin



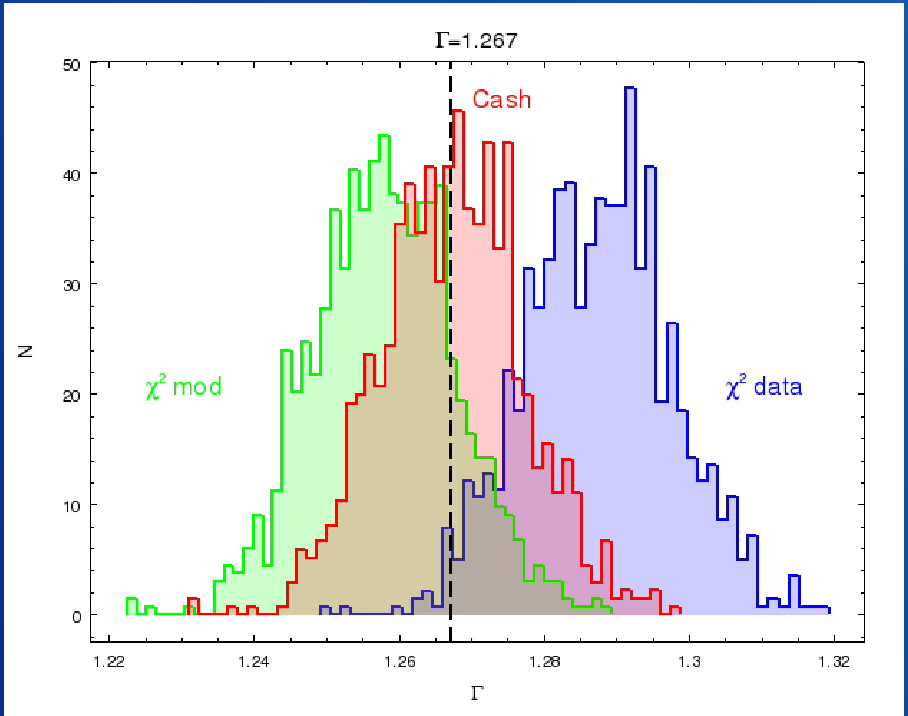
RECLAMATION

NOAA Climate Change Portal:

- **Primary Components of Portal:**

  Bias

  Difference between modeled and observed value of a selected metric



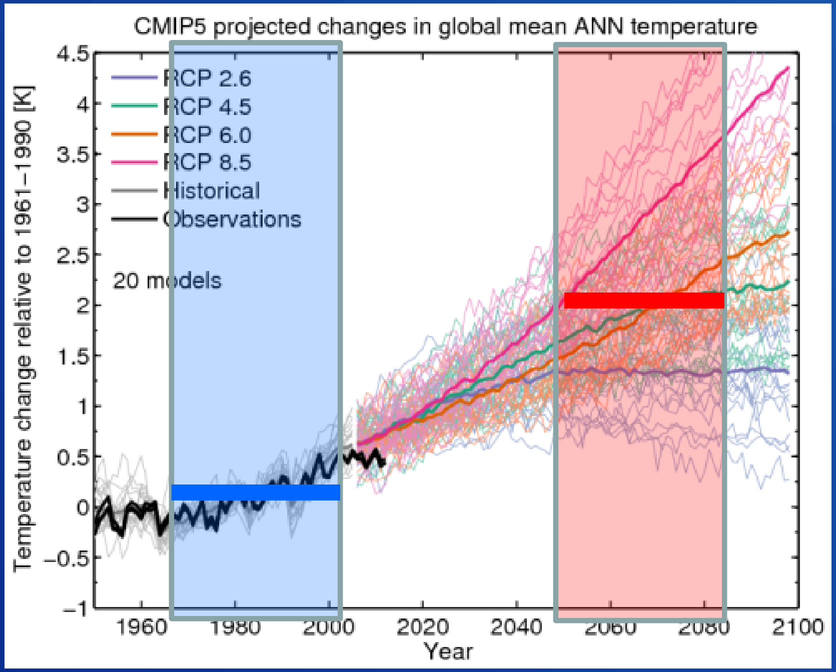
RECLAMATION

NOAA Climate Change Portal:

- **Primary Components of Portal:**

  Future Change

  Projected change in the value of a given metric between selected historical and future time periods



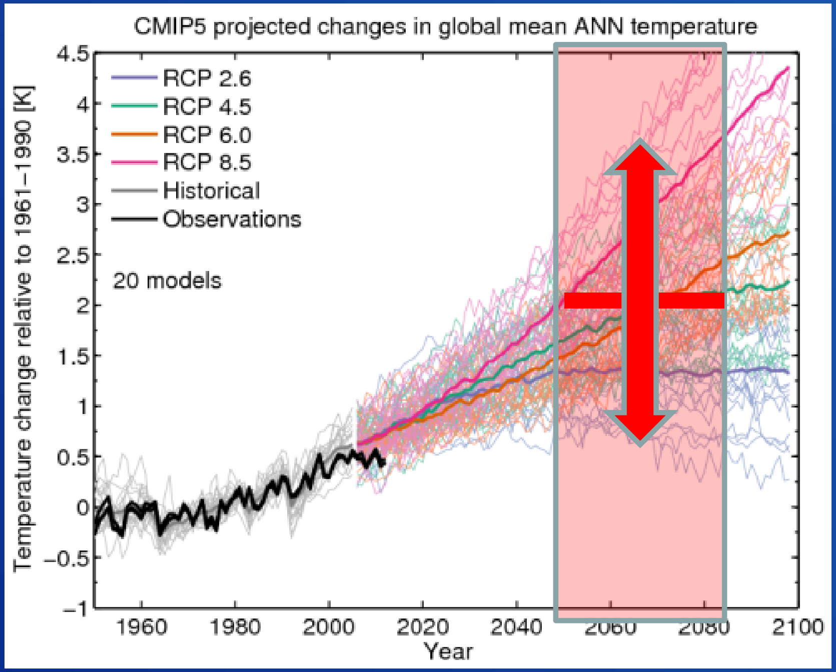
RECLAMATION

NOAA Climate Change Portal:

- **Primary Components of Portal:**

  Model Agreement

  Uncertainty between different model projections or between different emissions/concentration pathways



RECLAMATION

Questions?

Outline:

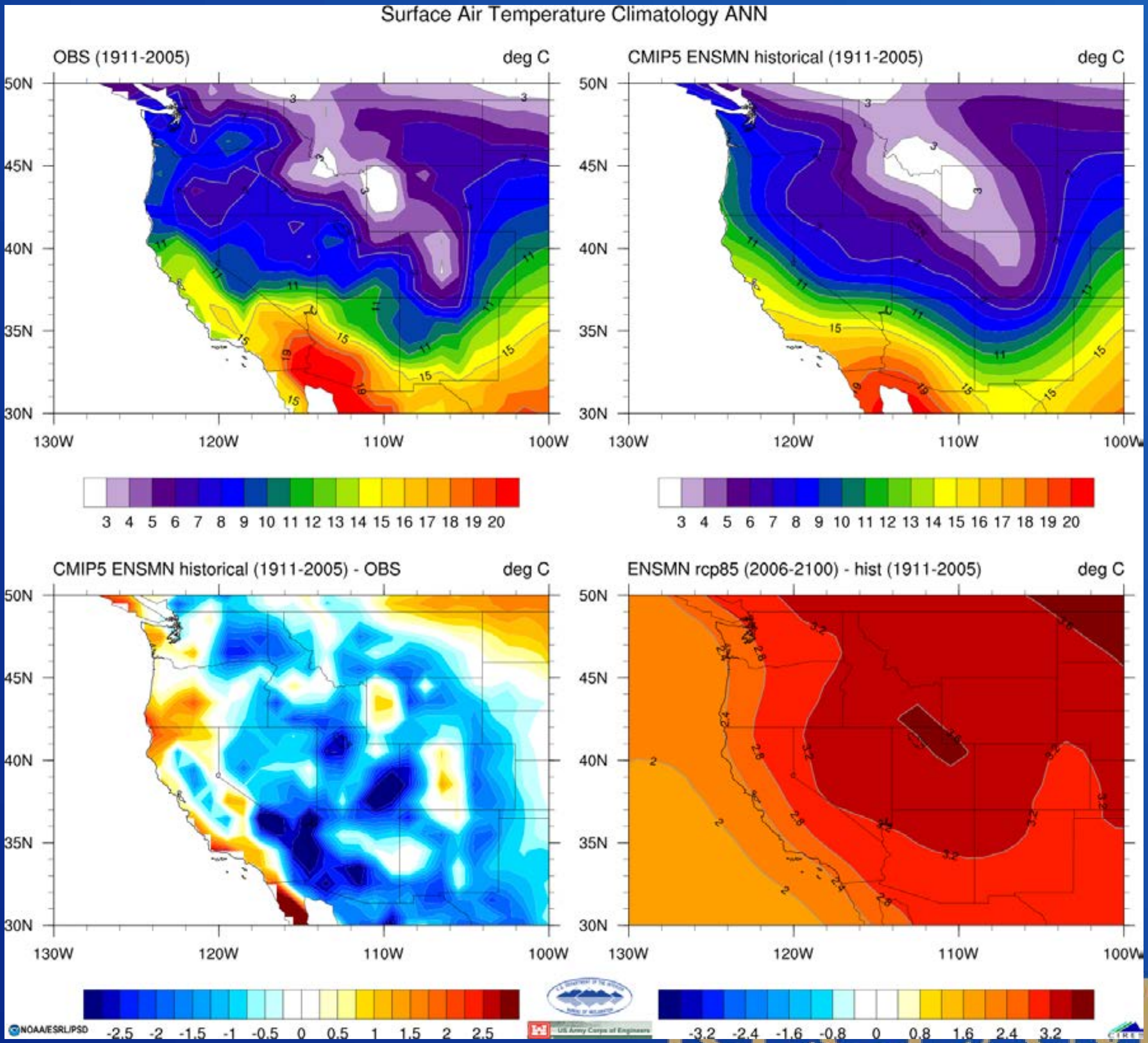
- **Objectives of Webinar 2**
- **What is CMIP5?**
  Coupled Model Intercomparison Project
- **Climate Change Web Portal**
  Features and functionality
- **Assessing Reliability**
  Using the web portal to gain intuition about climate models

Assessing Reliability:

- **Maps – Air Temperature:**

Observations

Model Results driven with historical data



Bias (Model-Observed)

Future Change (Projections – Historical)

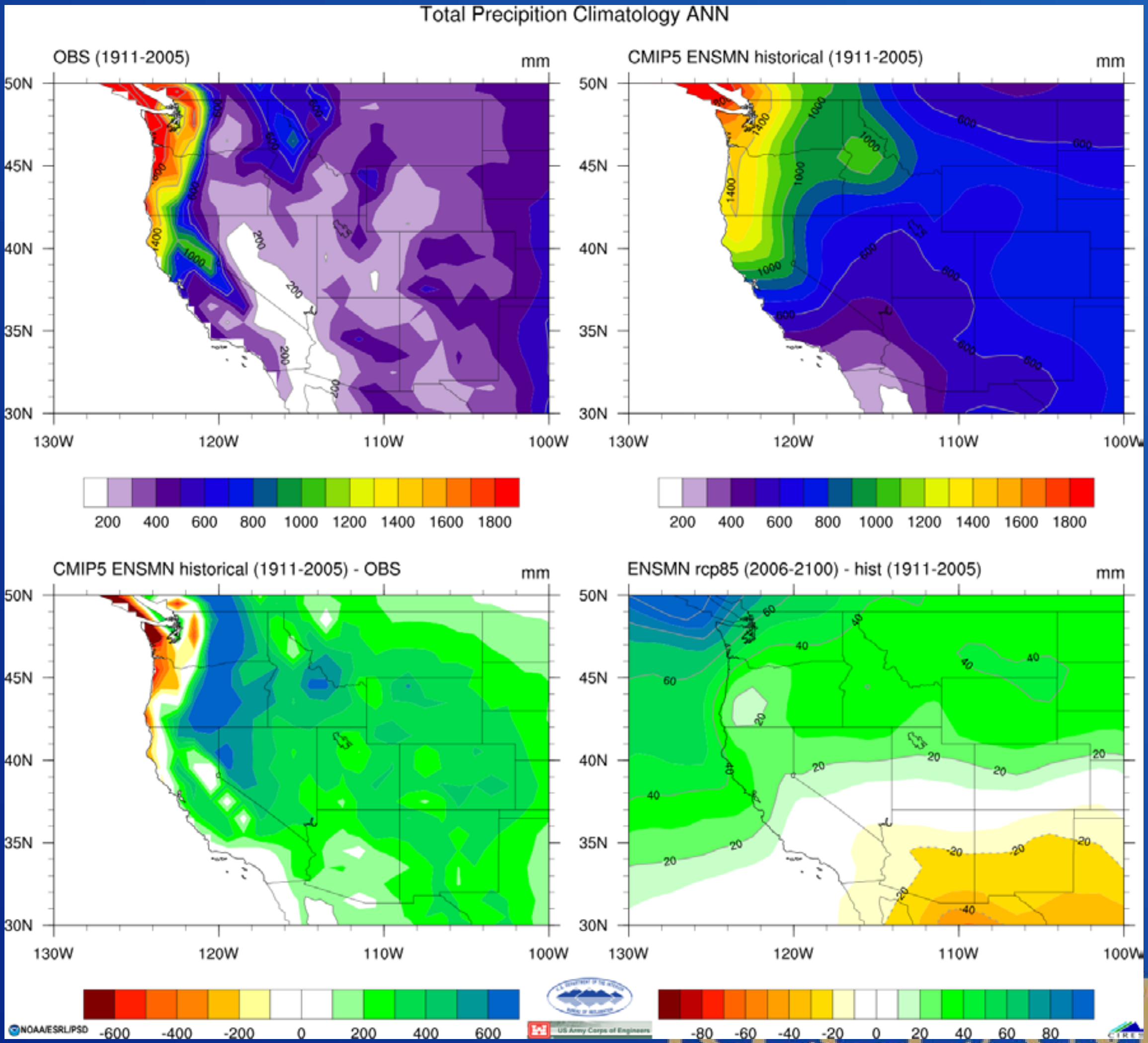
RECLAMATION

Assessing Reliability:

- **Maps – Precipitation:**

Observations

Model Results driven with historical data



Bias (Model-Observed)

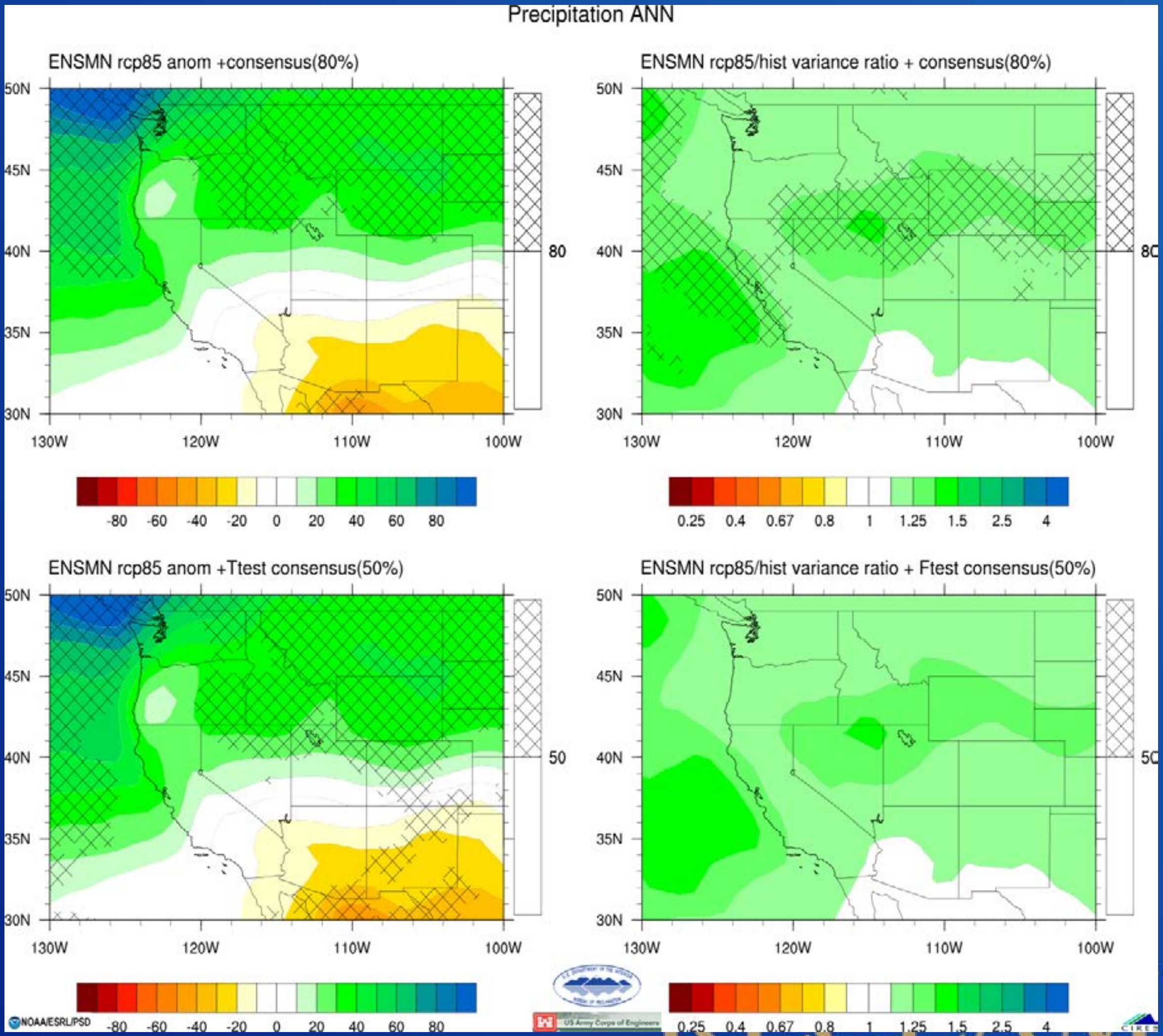
Future Change (Projections – Historical)

Assessing Reliability:

- **Maps – Precipitation with Significance Metrics**

Model Consensus: Change in Mean

T-test significance



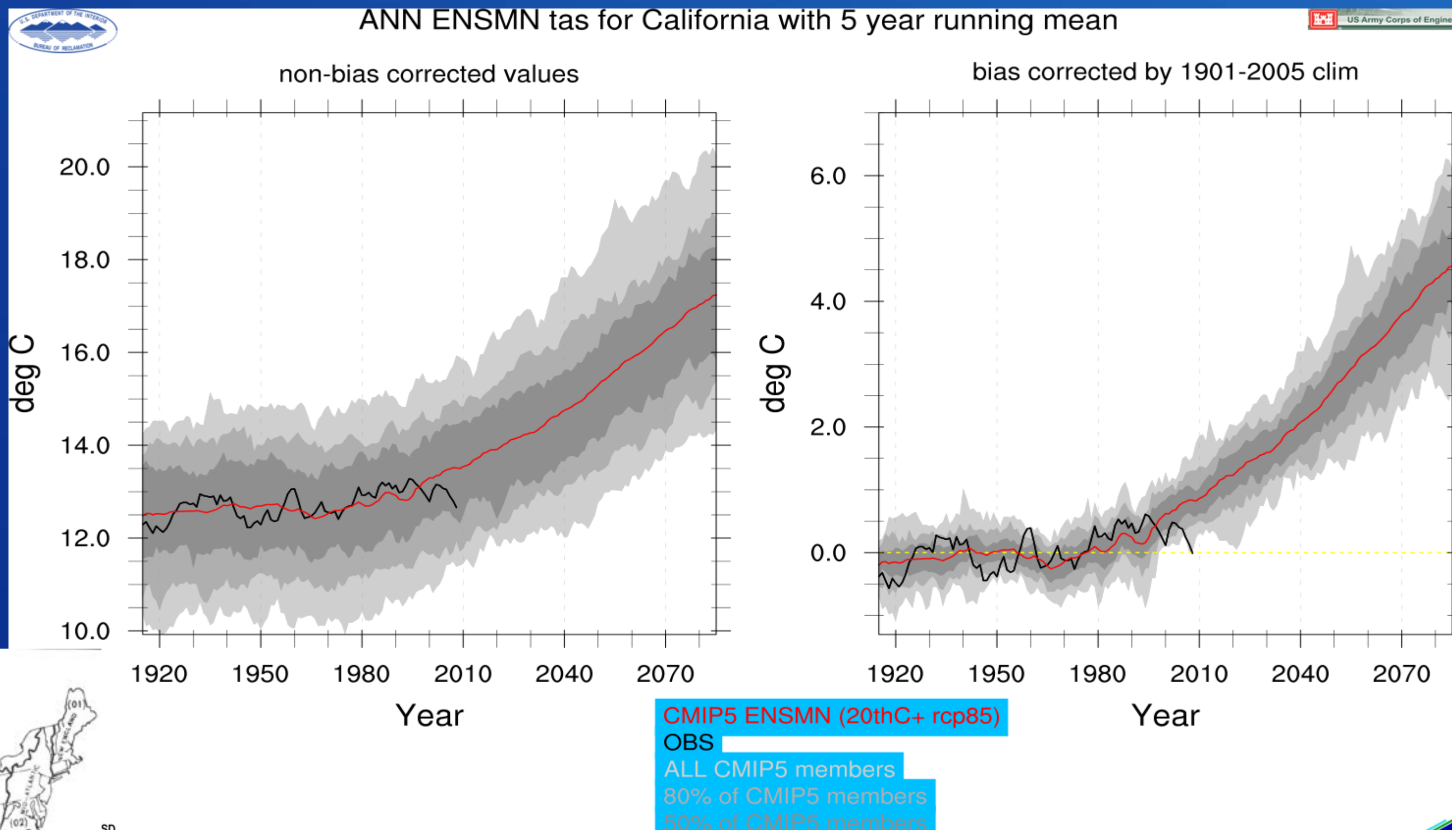
Model Consensus: Change in Variance?

F-test significance

RECLAMATION

Assessing Reliability:

- **Time Series – Temperature**

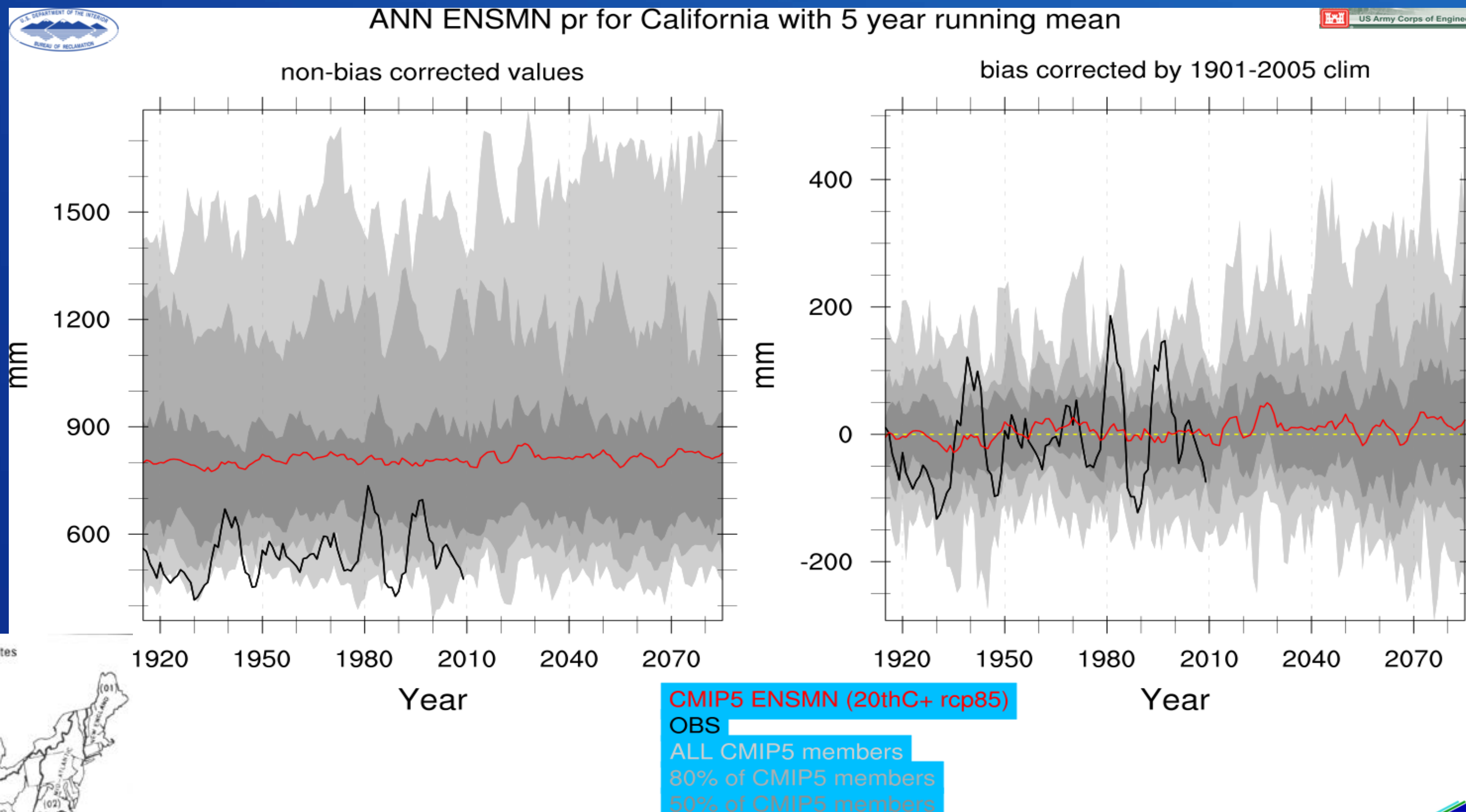


Strong agreement in warming trend

RECLAMATION

Assessing Reliability:

- **Time Series – Precipitation**

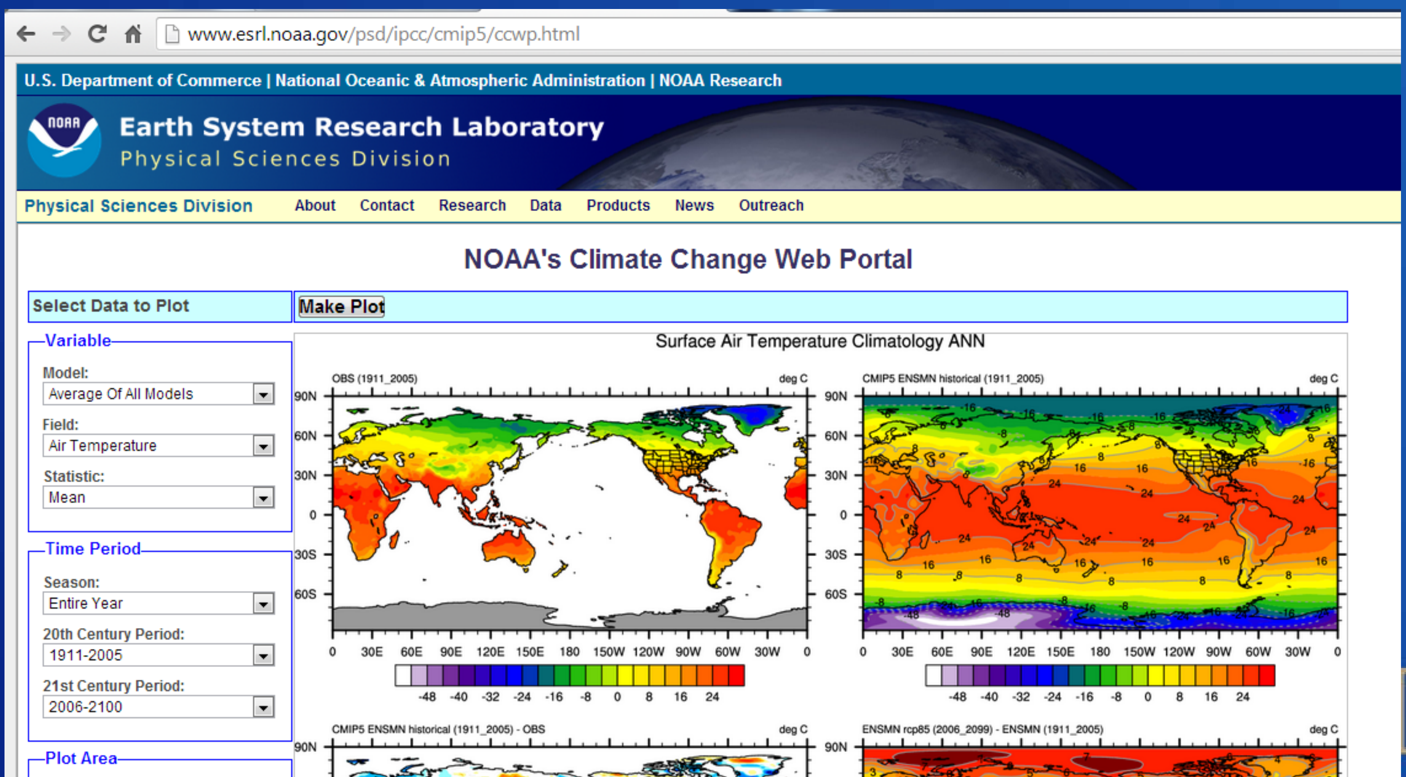


Story for precipitation is less clear

RECLAMATION

Questions?

www.esrl.noaa.gov/psd/ipcc/cmip5/ccwp.html



Availability:

- **We need your help!**

Webinar 1	Incorporating Climate Change into Water Resources and Environmental Planning ***July 23, 10:00am (Pacific)***
Webinar 2	Assessing Applicability of Climate Projection Information, Part 1: Evaluating Reliability ***July 30, 3:00pm (Pacific)***
Webinar 3	Assessing Applicability of Climate Projection Information, Part 2: Evaluating Relevance ***August 6, 11:00am (Pacific)***
Workshop	CMIP5 Applicability Pilot Workshop ***August 13, 11:00am (Pacific)*** *(TENTATIVE DATE)*

RECLAMATION

APPENDIX 2.3

Webinar 3: Assessing Applicability of Climate Projection Information,
Part 2: Evaluating Relevance

RECLAMATION
Managing Water in the West

Assessing Applicability of CMIP5 Climate Projections for Water Resources and Environmental Planning:

Webinar 3: Assessing Applicability of Climate Projection Information, Part 2: Evaluating Relevance

Ian Ferguson (USBR, TSC)
Cameron Bracken (USBR, TSC)
Levi Brekke (USBR, Research Office)
Jamie Scott (NOAA CIRES)
Michael Alexander (NOAA ESRL)
Jeff Arnold (USACE)

U.S. Department of the Interior
Bureau of Reclamation

Outline:

- Recap of Webinars 1 and 2
- Objectives of Webinar 3
- Overview of Sensitivity Analysis and Addressing Relevance

Webinar 1 Summary:

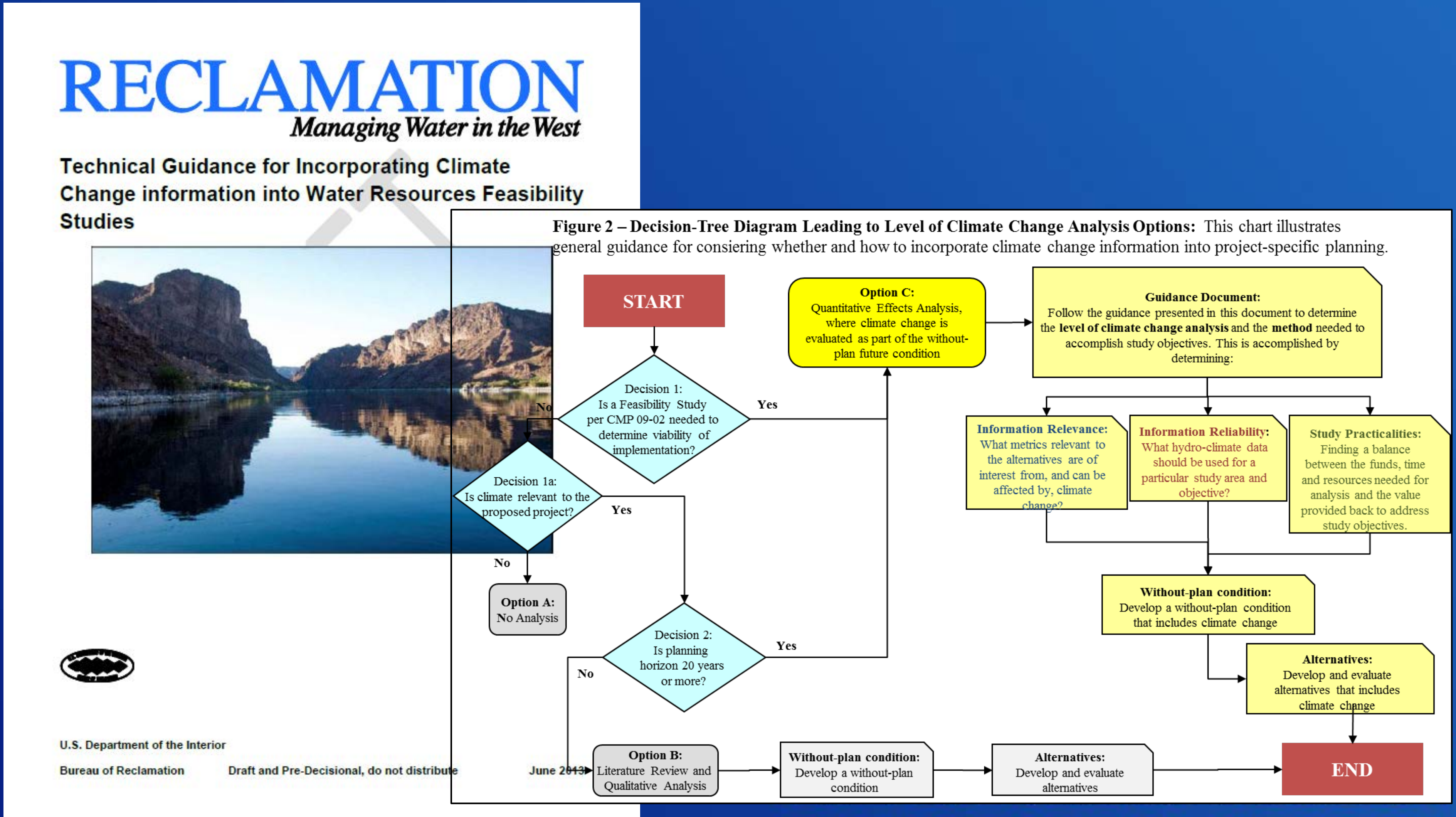
- We have **many methods** for assessing climate change implications for water/environmental management.

- **Recent planning drivers** push us to consider data and method selection from the view of **information applicability**.

- Reclamation, NOAA and USACE are partnering to **develop a framework** to guide evaluation of climate projection **relevance, reliability, and applicability** in context of water resources and environmental planning.

Webinar 1 Recap:

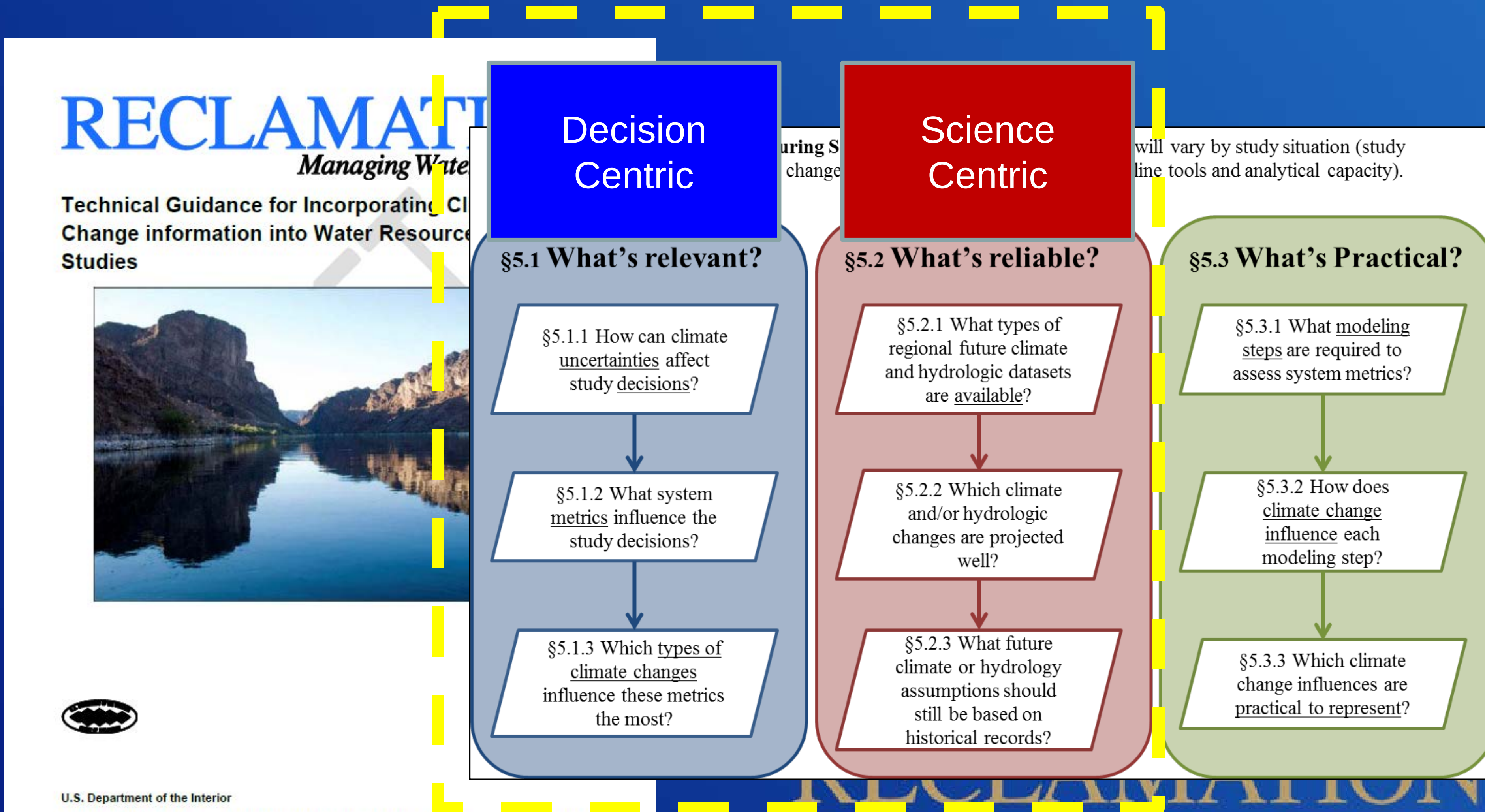
- **SECURE Feasibility Guidance**



Webinar 1 Recap:

- **SECURE Feasibility Guidance**

Focus of Applicability Framework

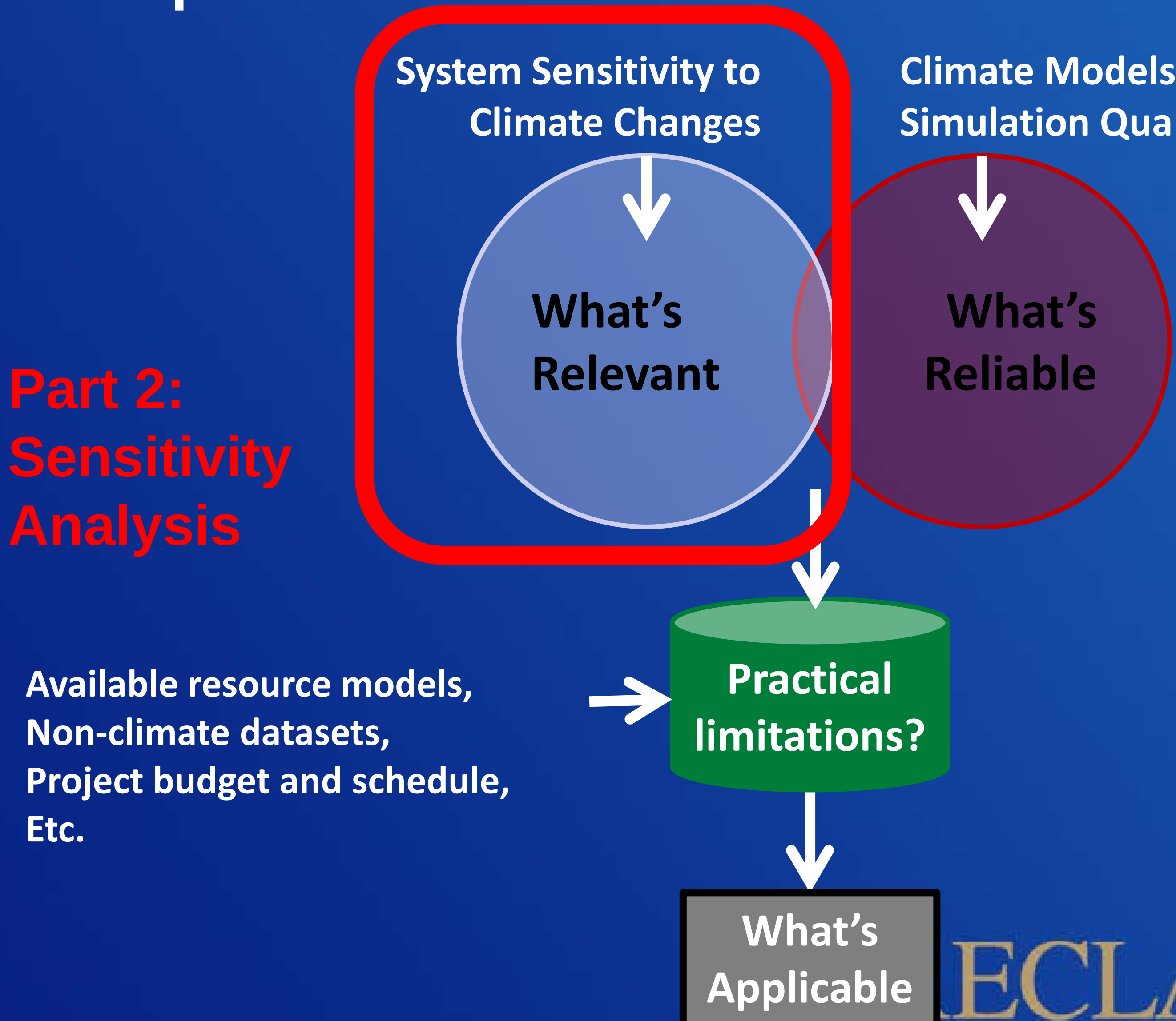


Webinar 2 Summary:

- The Coupled Model Intercomparison Project version 5 (CMIP5) is a valuable dataset for assessing potential climate change impacts.
- The Climate Change Web Portal (developed by NOAA) is a tool for summarizing and visualizing CMIP5 data.
- Using the web portal is a tool for assessing reliability of climate models (what they do well and what they don’t)

Applicability Framework:

- Proposed Framework



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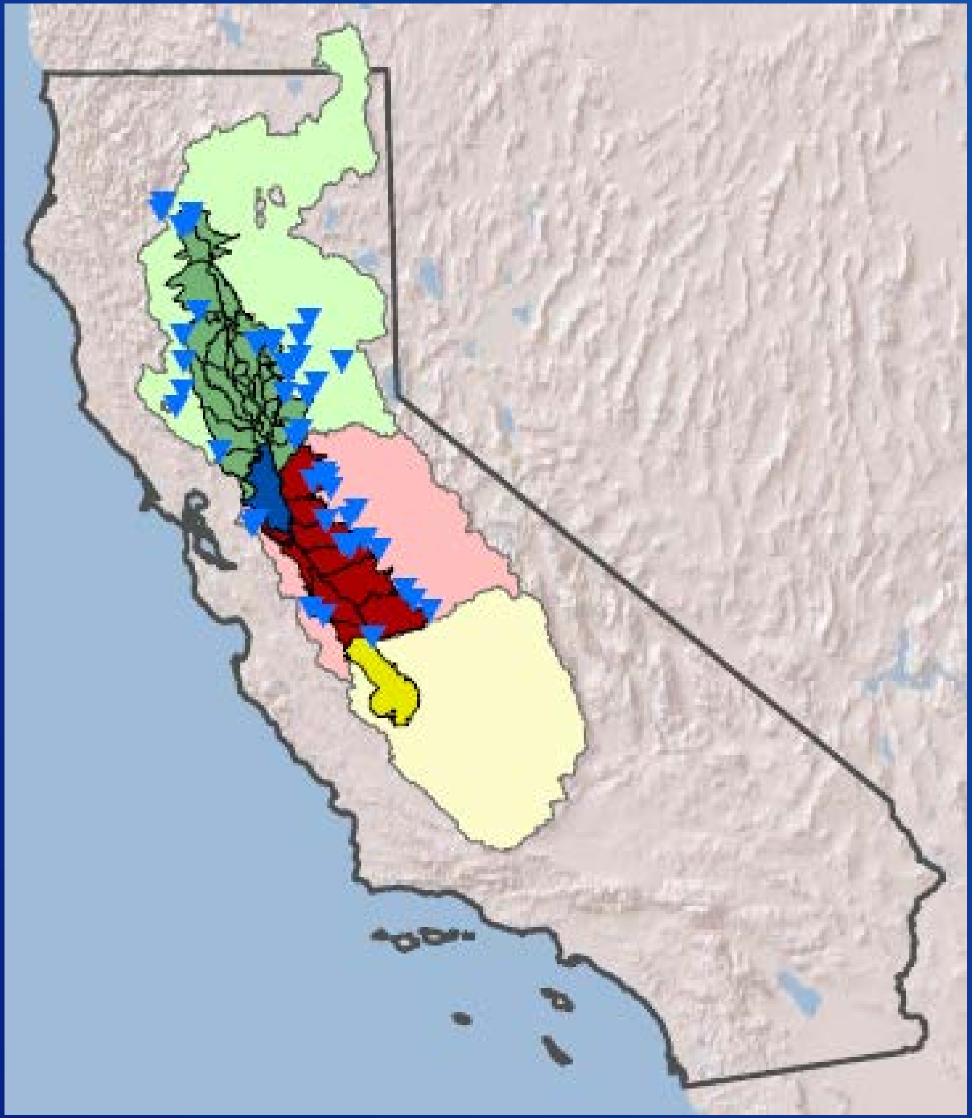
Pilot Study:

Central Valley Project + State Water Project



Sacramento River (green)
- 27,500 mi^2
- 22 MAF

San Joaquin River (red)
- 15,600 mi^2
- 4.5 MAF

Tulare Basin (yellow)
- 16,200 mi^2
- Flow to SJR only in flood
- Avg ~ 142 TAF
- Max ~ 2.37 MAF

Part 2: Relevance

Sensitivity analysis of CVP-SWP system to broad range of climate perturbations

CalSim3.0

Model Nodes	
Storage Nodes	~45
Demand Nodes	~250
Conveyance Nodes	~725
Miscellaneous	~75
Total	**>1100**

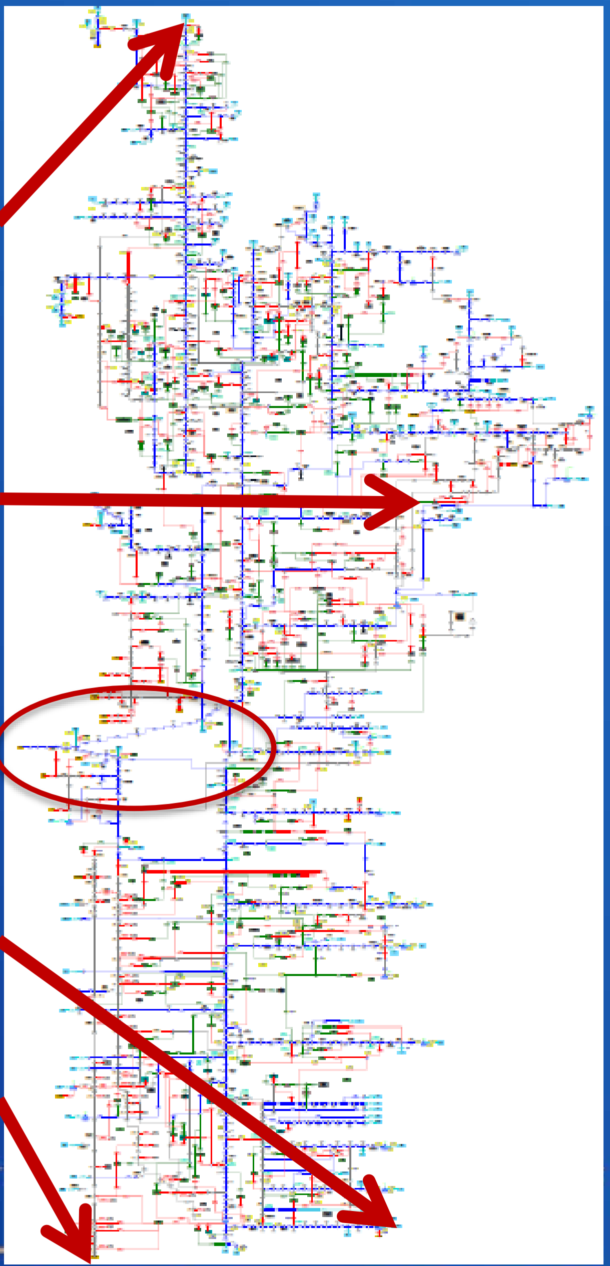
Lake Shasta

Folsom Lake

Delta

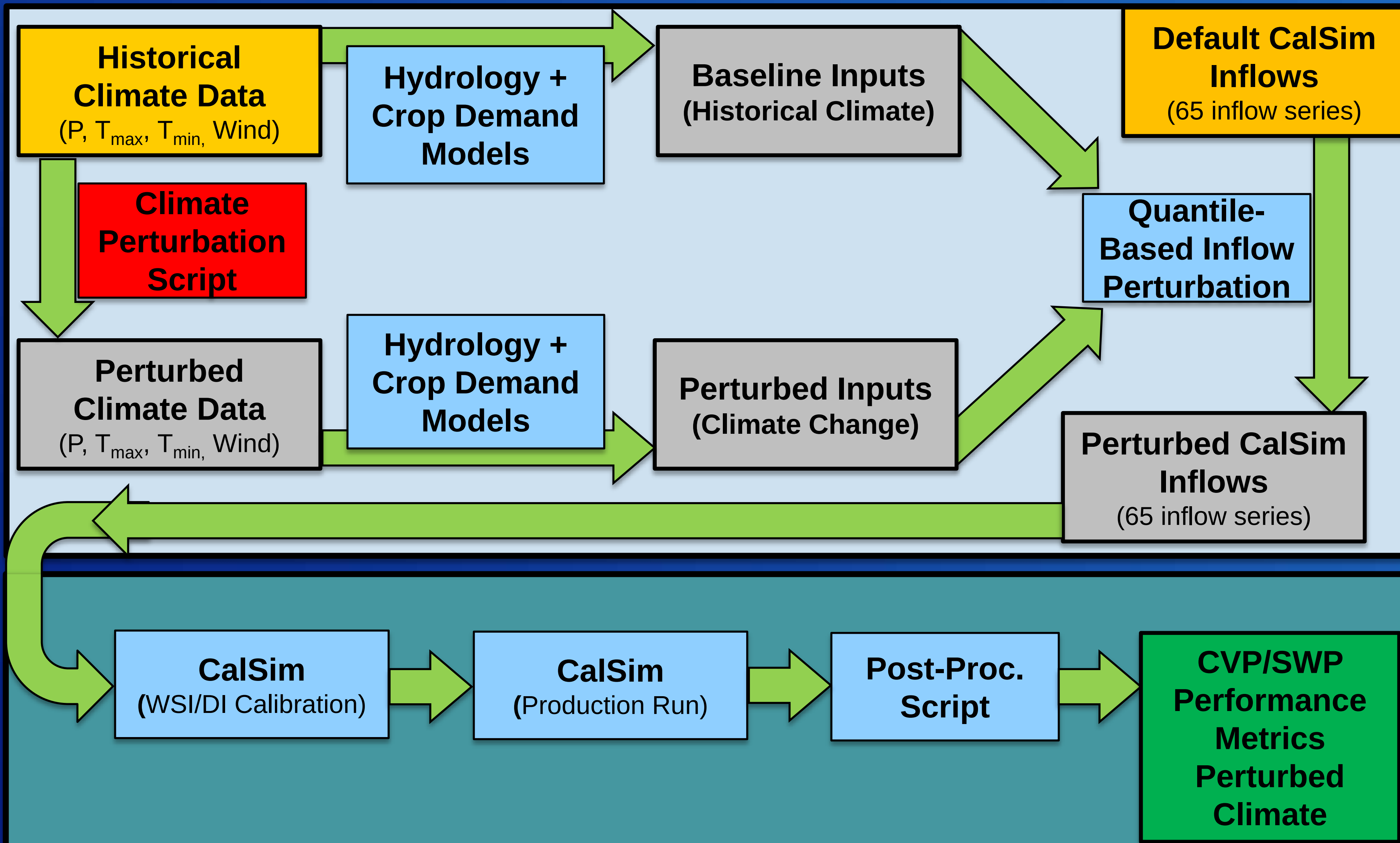
Millerton Lake

California Aqueduct to SoCal



Part 2: Relevance

- **Sensitivity Analysis Workflow**



Part 2: Relevance

- **Climate Perturbation Approach**

➢ Systematic, idealized perturbation of historical precipitation and temperature

Variable decomposed into mean, standard deviation, and standardized anomaly…

$$\Pi_{ym} = \left(\overline{\Pi}_m\right) + \left(\sigma_{\Pi_m} \cdot \Pi'_{ym}\right)$$

Perturbation applied to mean and/or variance for selected months of the year…

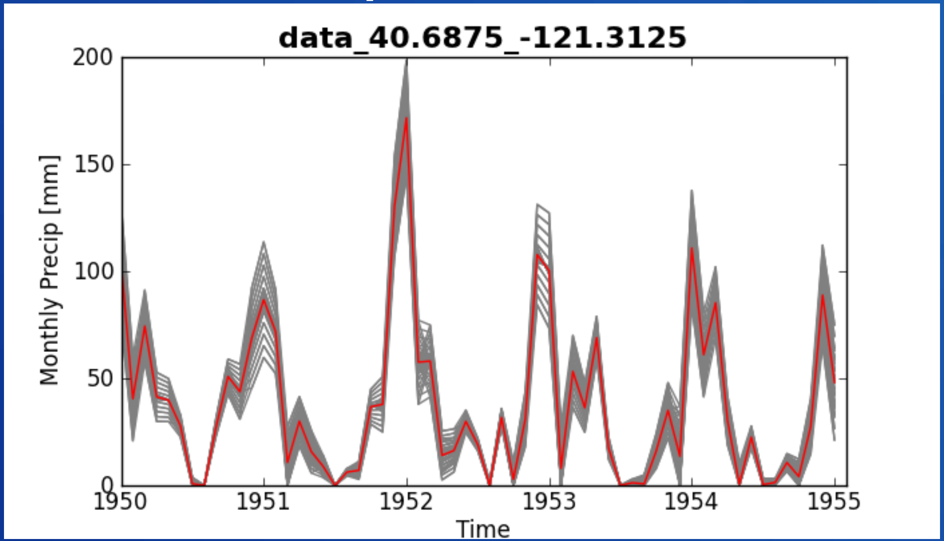
$$\Pi_{ym}^{perturb} = a_m\left(\overline{\Pi}_m\right) + b_m\left(\sigma_{\Pi_m} \cdot \Pi'_{ym}\right)$$

Part 2: Relevance

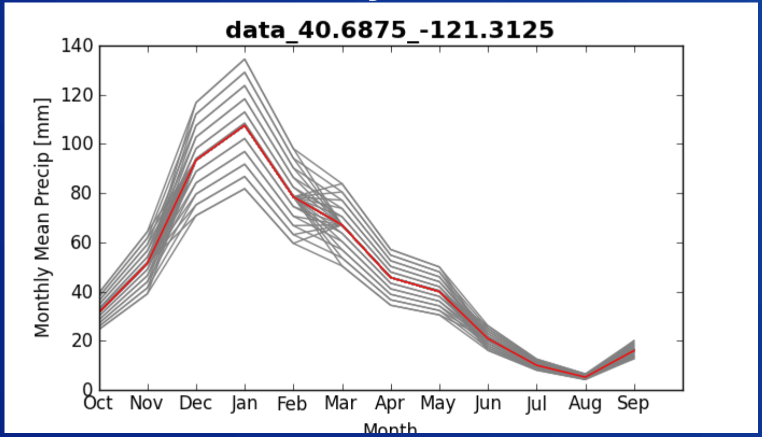
Perturbed Climate Inputs…

<u>Example</u>: Perturbed precipitation inputs

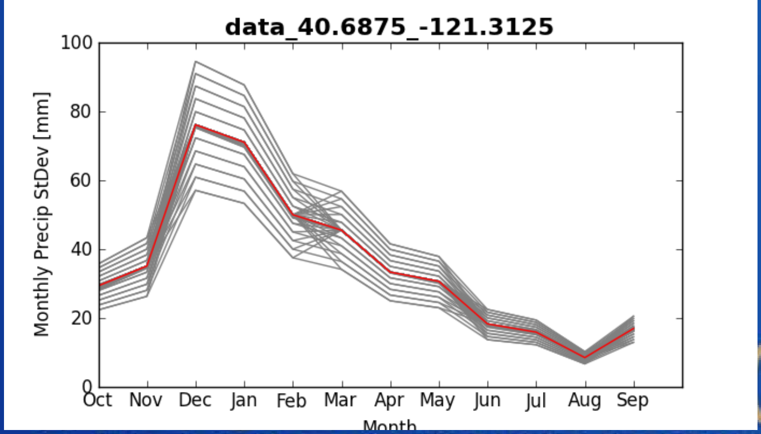
Sample Time Slice



Monthly Means



Monthly Standard Deviations

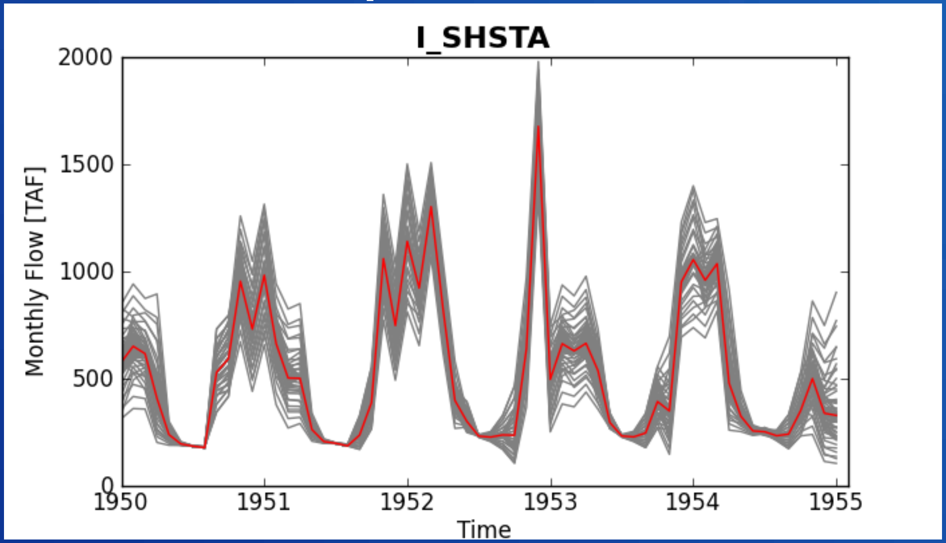


Part 2: Relevance

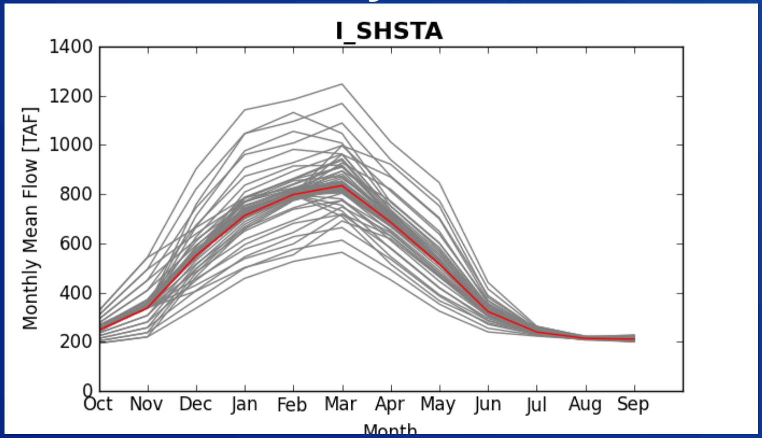
Perturbed CalSim Inflows…

<u>Example</u>: Corresponding perturbed inflows to Lake Shasta

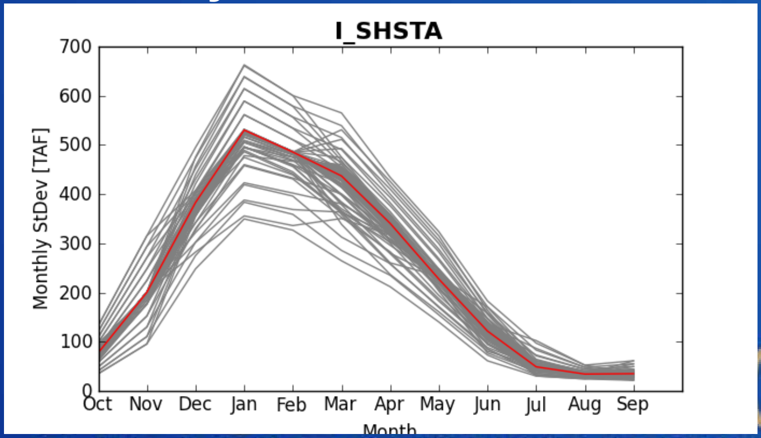
Sample Time Slice



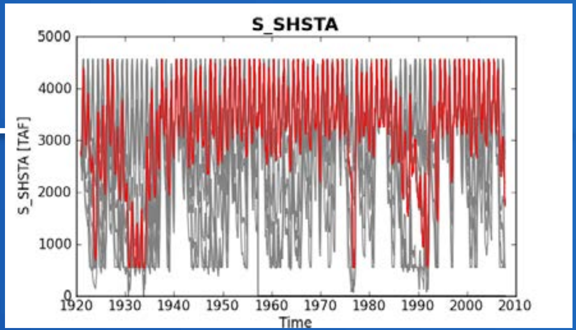
Monthly Means



Monthly Standard Deviations



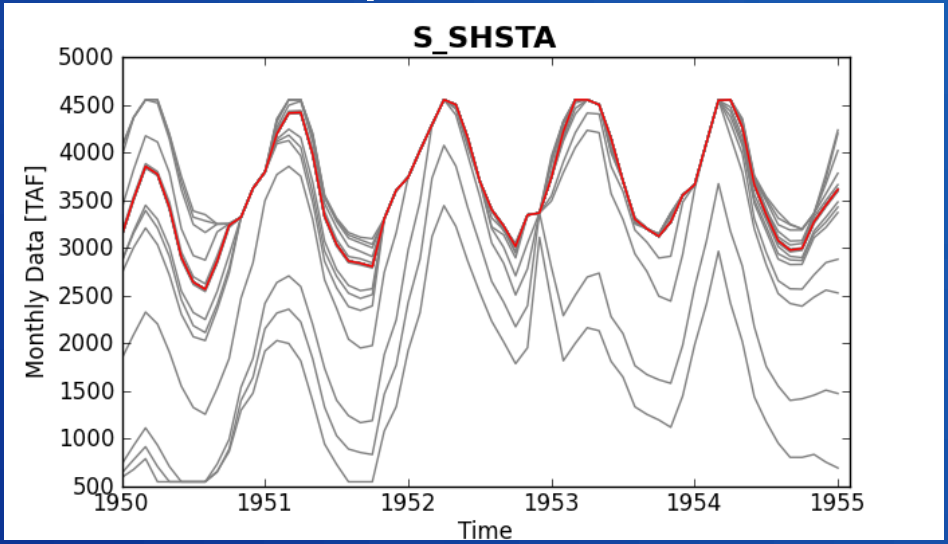
Part 2: Relevance



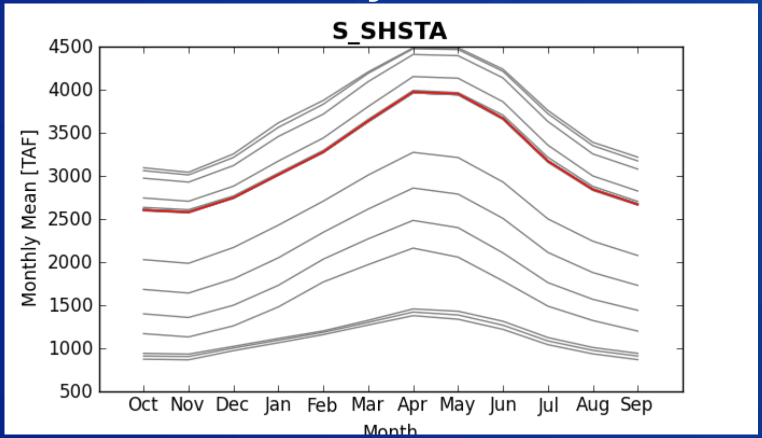
CalSim Perturbation Results…

<u>Example</u>: Corresponding Lake Shasta storage and releases

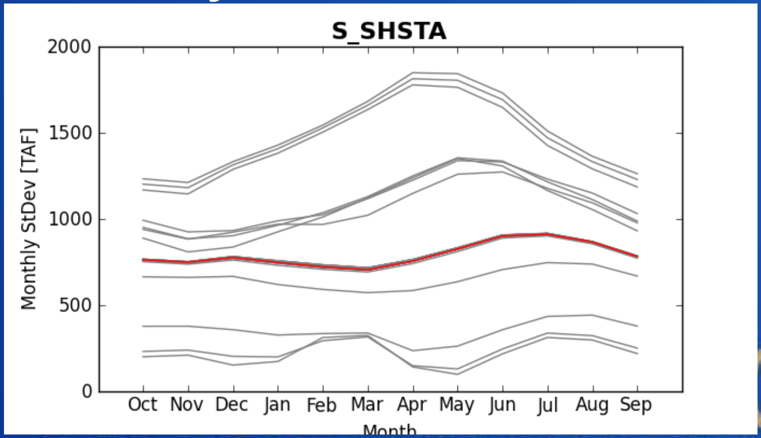
Sample Time Slice



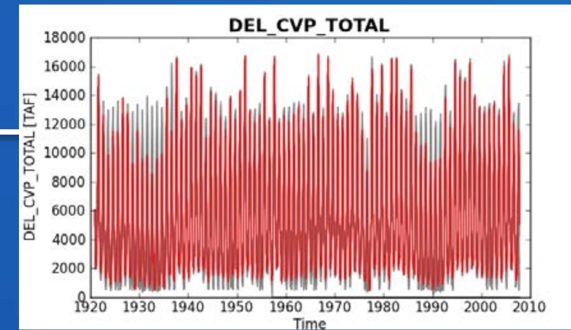
Monthly Means



Monthly Standard Deviations



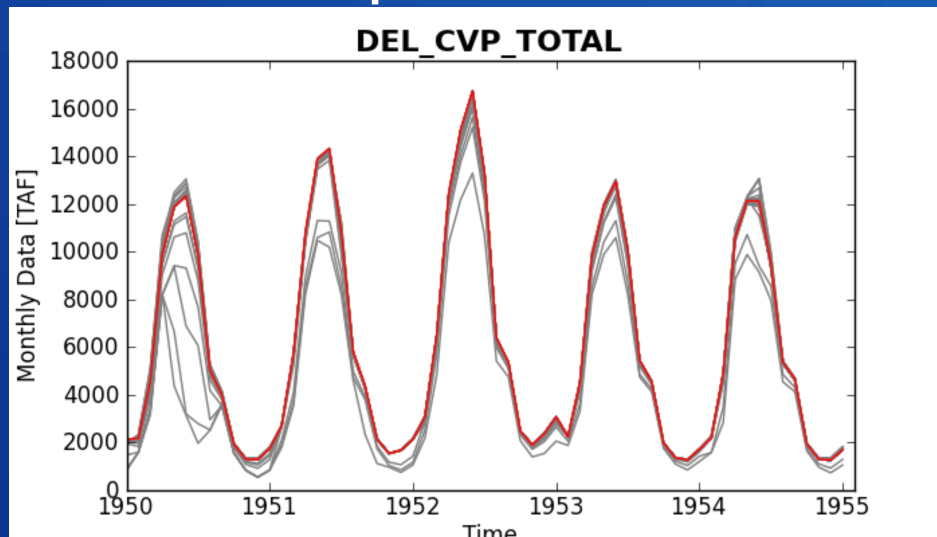
Part 2: Relevance



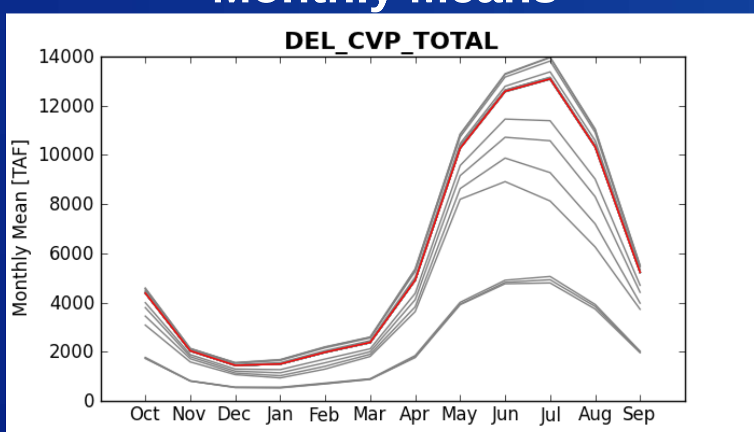
CalSim Perturbation Results…

Example:
Corresponding Total CVP Deliveries

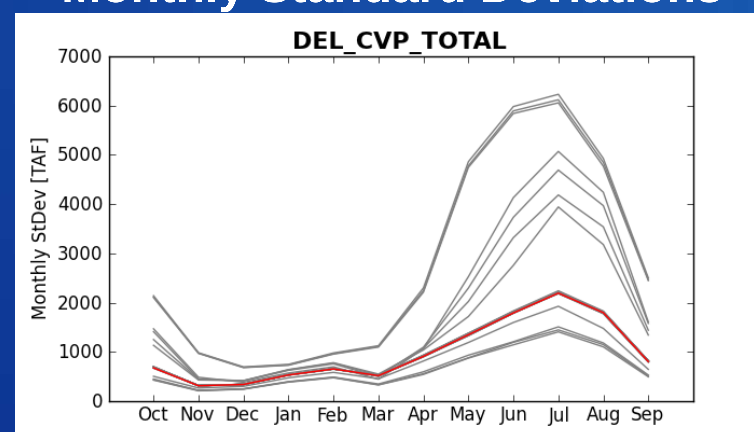
Sample Time Slice



Monthly Means



Monthly Standard Deviations



Part 2: Relevance

List of input types that get perturbed:

- applied water (i.e., ag demands) [AW]
- urban demand [UD]
- surface runoff [SR]
- deep percolation [DP]
- tailwater [TW]
- wastewater effluent [WW]
- inflows [I] -- includes river indices
- delta accretions/depletions
- reservoir evap rates

List of input types that does NOT get perturbed:

- closure terms
- reuse factors
- demand patterns
  operational targets (minimum flow targets, minimum groundwater pumping, storage targets, B2 triggers)
- spills / returns (applies to SAC pre-op inputs)
- salinity (applies to CS-II code @ SJR)
- tile drain flows (applies to CS-II code @ SJR)
- baseflows (applies to CS-II code @ SJR)
- groundwater returns (applies to CS-II code @ SJR)

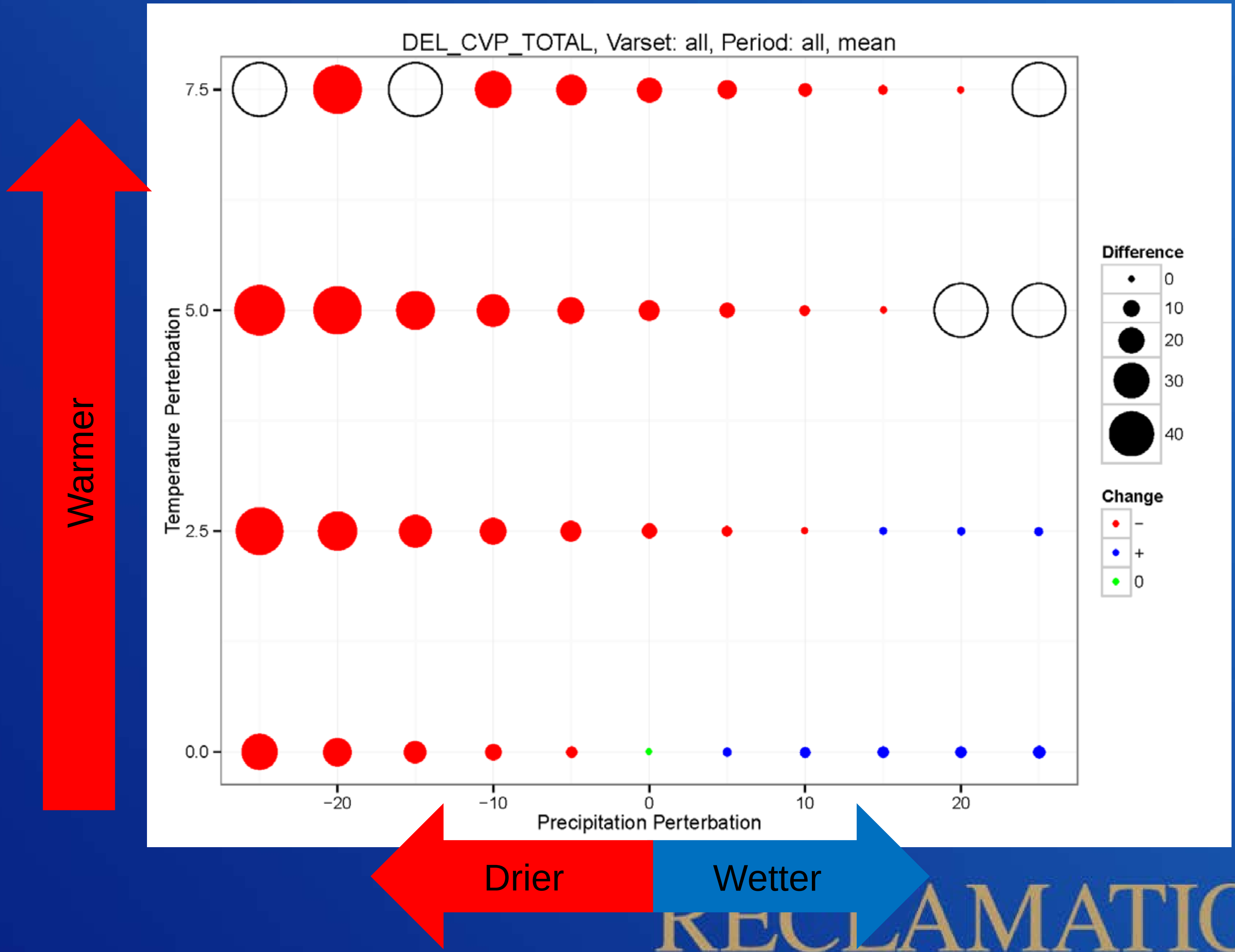
Part 2: Relevance

Climate Perturbations

- Current Perturbations:

Precipitation		T_{avg}	
DJF:	Increase mean 5-25% Decrease mean 5-25% Increase variance 5-25% Decrease variance 5-25%	DJF:	Increase mean 1°, 2.5°, 5°, 7.5°, 10° Decrease mean 1°, 2.5°, 5°, 7.5°, 10° Increase variance 5-25% Decrease variance 5-25%
MAM:	Increase mean 5-25% Decrease mean 5-25% Increase variance 5-25% Decrease variance 5-25%	MAM:	Increase mean 1°, 2.5°, 5°, 7.5°, 10° Decrease mean 1°, 2.5°, 5°, 7.5°, 10° Increase variance 5-25% Decrease variance 5-25%
JJA:	Increase mean 5-25% Decrease mean 5-25% Increase variance 5-25% Decrease variance 5-25%	JJA:	Increase mean 1°, 2.5°, 5°, 7.5°, 10° Decrease mean 1°, 2.5°, 5°, 7.5°, 10° Increase variance 5-25% Decrease variance 5-25%
SON:	Increase mean 5-25% Decrease mean 5-25% Increase variance 5-25% Decrease variance 5-25%	SON:	Increase mean 1°, 2.5°, 5°, 7.5°, 10° Decrease mean 5-25% Increase variance 5-25% Decrease variance 5-25%
All:	Increase mean 5-25% Decrease mean 5-25% Increase variance 5-25% Decrease variance 5-25%	All:	Increase mean 1°, 2.5°, 5°, 7.5°, 10° Decrease mean 5-25% Increase variance 5-25% Decrease variance 5-25%

Part 2: Relevance



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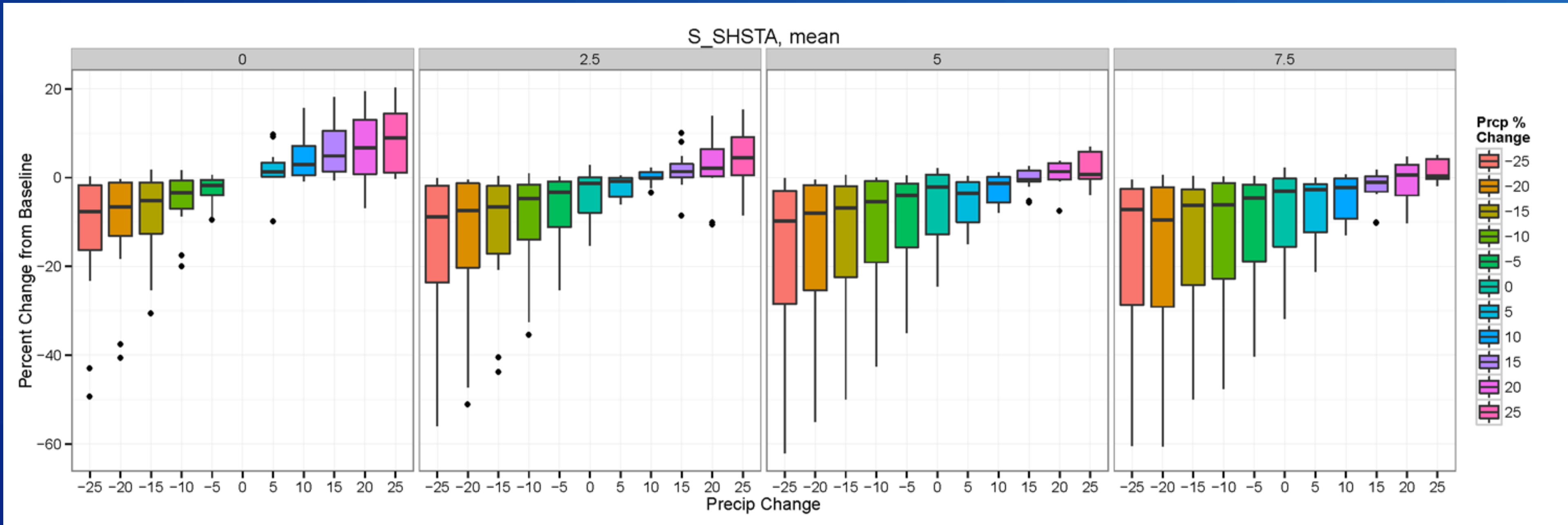
Part 2: Relevance

Shasta Storage



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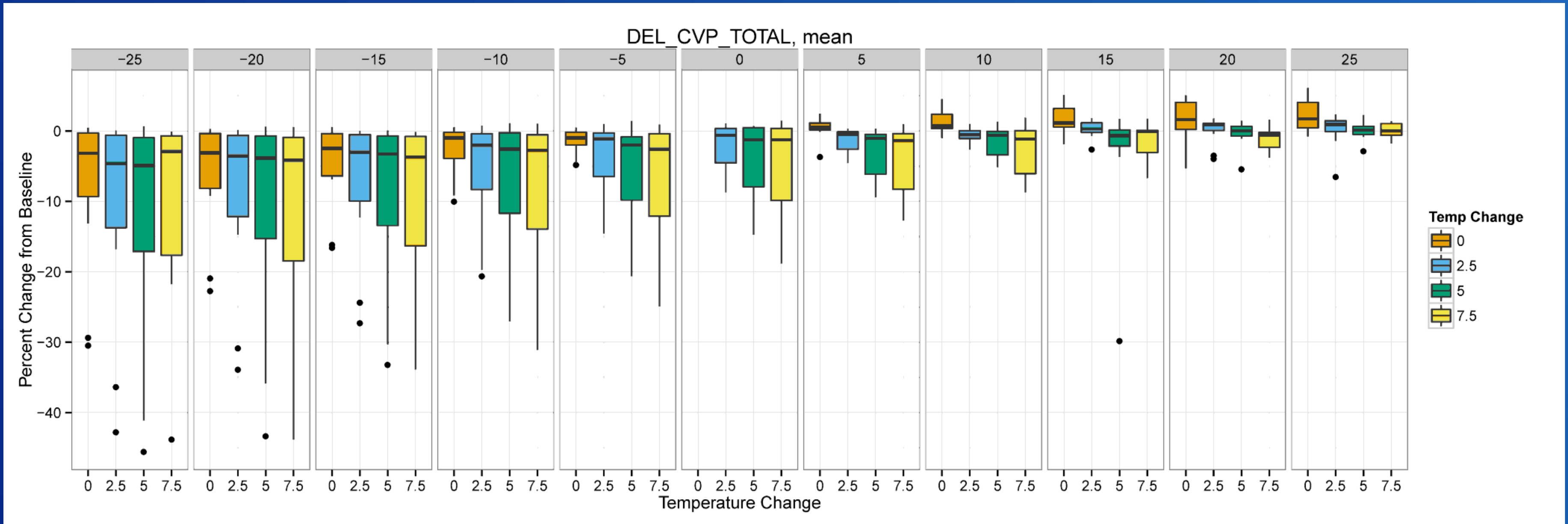
Part 2: Relevance

CVP total delivery



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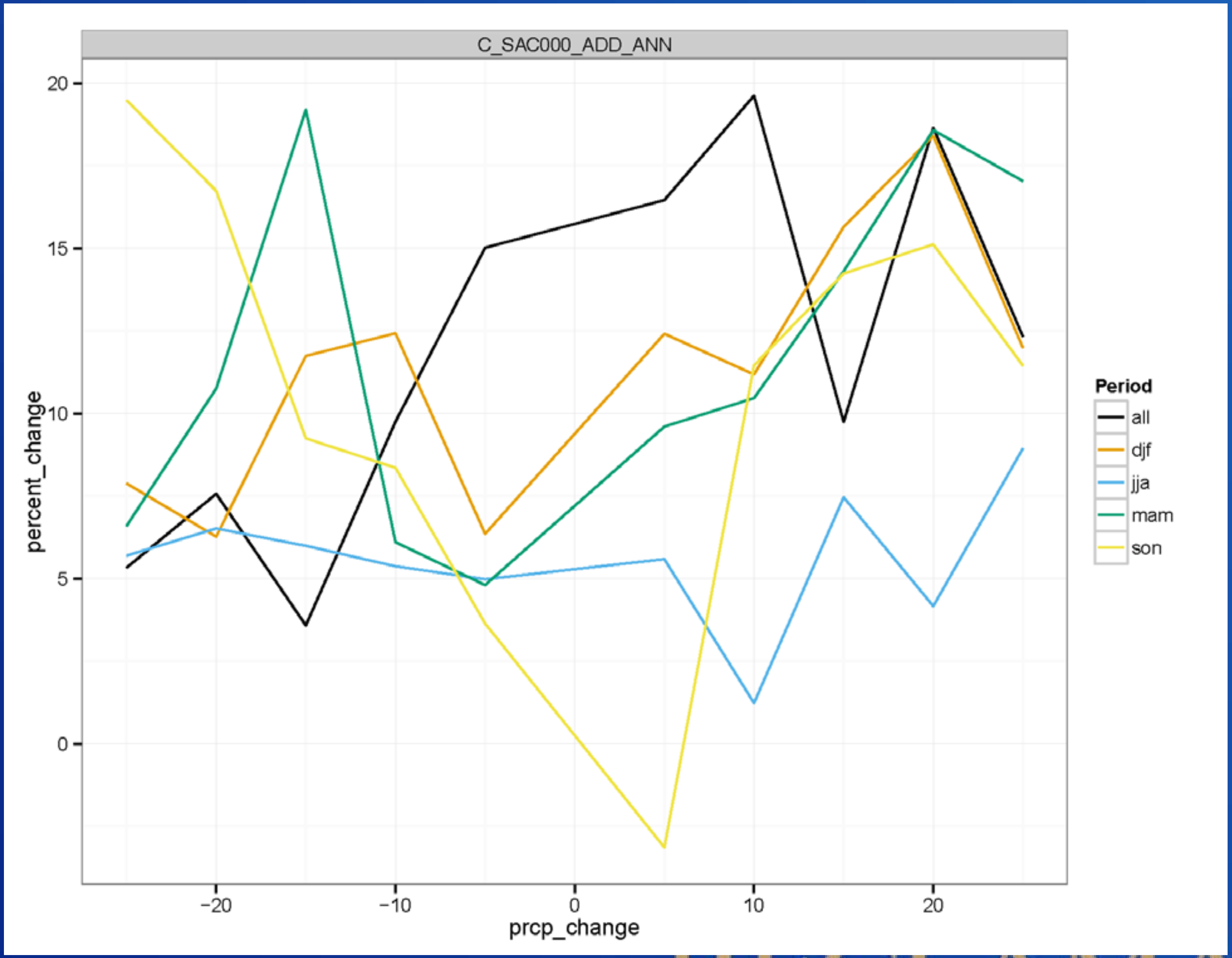
Part 2: Relevance

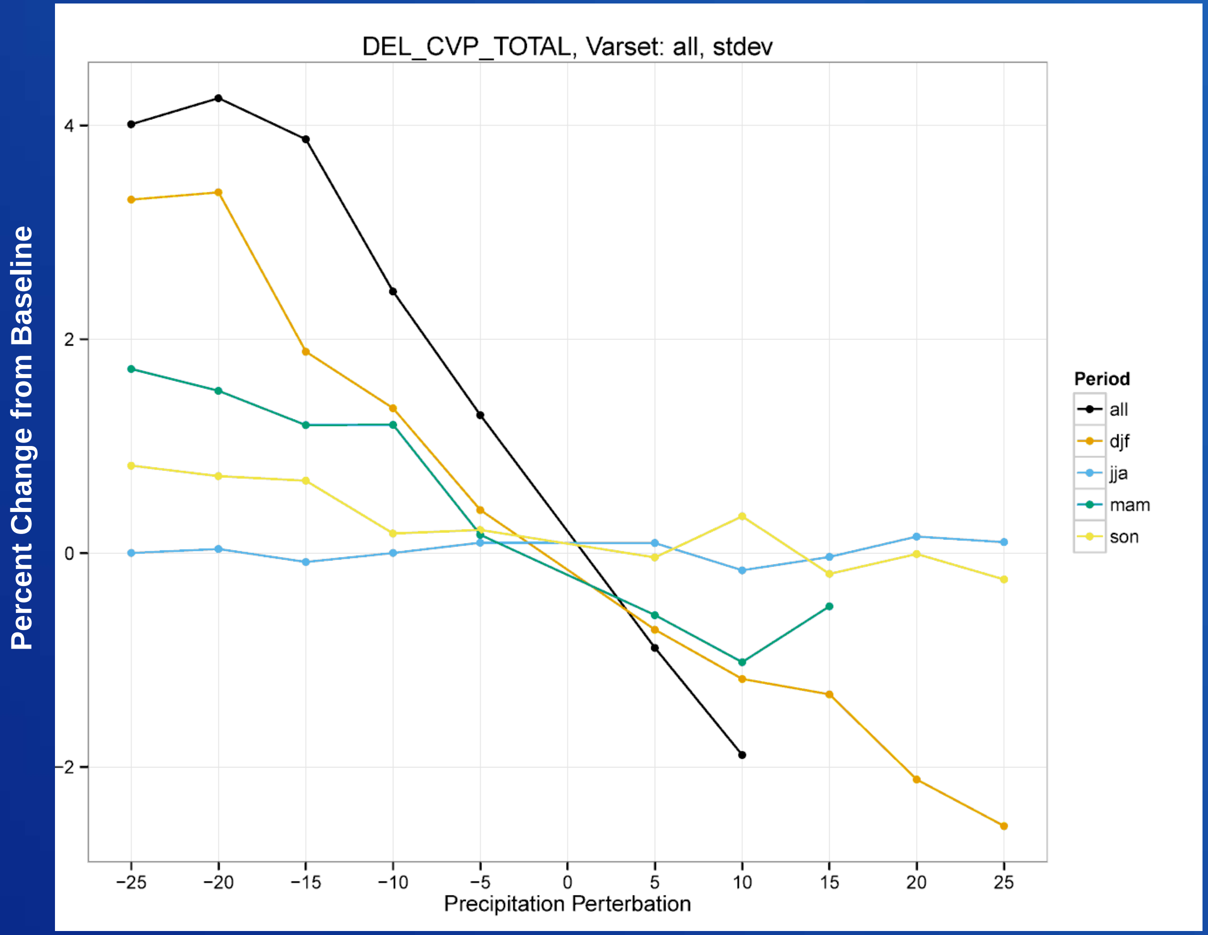
Instream Flow, Nonlinear response



RECLAMATION

Part 2: Relevance

CVP delivery, change in standard dev



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Conclusions

- Relevance addresses decision centric component of incorporating climate change information
- Looks at climate change in terms of system metrics that influence decisions
- Sensitivity analysis is a tool for identifying influential system metrics

Pilot Workshop

Now scheduled for Wednesday Oct 22.

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APPENDIX 3

Workshop Materials

APPENDIX 3.1

Workshop Description

CMIP5 Applicability Project Pilot Workshop

Purpose

Recent changes in agency directives and programmatic mandates require consideration of climate change in federal water resources and environmental planning and management. As a result, planners and managers are now required to make judgments regarding which aspects of climate projection information are applicable to a given decision, such as a decision to invest in new infrastructure or modify operating criteria.

Reclamation is partnering with NOAA, USACE, and CU Boulder/CIRES to develop and demonstrate a framework for evaluating the applicability of climate projection information for water resources and environmental planning, focusing on relevant climate variables and impacts scales. This collaborative effort proposes on a two-pronged framework for assessing applicability of projection information that considers, on the one hand, the reliability of global climate models based on evaluation of model performance over the 20th century and, on the other hand, the relevance of climate drivers based on analysis of system sensitivity to changes in climate drivers.

The capstone of this collaborative effort is a pilot workshop in which teams of planners and technical specialists will scope feasibility studies for mock projects related to the Central Valley Project (CVP) in California. The pilot workshop will provide valuable feedback to Reclamation researchers, planners, and policy makers to improve the proposed framework and develop guidance for evaluating and selecting climate projection information for application to water resources and environmental planning.

Format

The pilot workshop will consist of three one-hour webinars followed by a full-day in-person workshop. Webinars will introduce the proposed two-prong approach for assessing the applicability of climate projection information and provide a foundation for the workshop. Webinar 1 will introduce the proposed two-pronged framework and how it fits into the federal planning process; webinar 2 will focus on reliability component of the framework, illustrated using a climate model evaluation web portal developed by NOAA/CIRES; and webinar 3 will focus on the relevance component of the framework, illustrated using a detailed sensitivity analysis of CVP operations under a broad range of climate conditions.

The workshop will focus on mock scoping for hypothetical projects related to the CVP. Three mock scoping projects have been identified that encompass a wide range feasibility studies: (a) development of a new storage facility, (b) implementation of new operating criteria under a restoration program, and (c) renewal of a long-term water service contract. Three teams will participate, each focusing on one mock project. Each team will utilize the climate model evaluation web portal and CVP sensitivity results developed under this collaborative project to inform development of a mock scope for climate change analysis and provide feedback regarding the utility of this information in assessing the applicability of climate projection information during the mock scoping process.

Participants

The pilot workshop will be held in Reclamation's Mid-Pacific Regional Office in Sacramento, California. Participants in the pilot workshop will consist of planners, study managers, and technical specialists from Reclamation's Mid-Pacific Region and partner agencies in California. Study participants will be sought who have interest and experience in scoping, conducting, and managing water resources and environmental planning studies in the context of climate change. Scoping teams (detailed below) will be identified and selected by Mid-Pacific planning division leadership team.

Contacts:

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Ian Ferguson, PhD, PE
Technical Service Center
Phone: 303-445-2513
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Jamie Scott
NOAA/CIRES
Phone: 303-497-6257
Email: James.D.Scott@noaa.gov

Pilot Workshop Details:

Scoping Teams:

- 1-3 Planners / Scoping Managers
- 1 Technical Specialist – water operations / system sensitivity
- 1 Technical Specialist – climate change / climate model evaluation
- 1 Note Taker

Draft Agenda:

Webinar 1 *(one hour)*:
Incorporating Climate Projection Information in Water Resources and Environmental Planning

- Overview of climate change considerations for water resources and environmental planning
- Introduction to proposed climate projection information applicability framework
- Introduction to draft guidance on consideration of climate change in Reclamation feasibility studies
- Overview of mock projects considered in pilot workshop

Webinar 2 *(one hour)*:
Assessing Applicability of Climate Projection Information, Part 1: Evaluating Credibility

- Introduction to concept of credibility
- Overview of climate models and climate projection methods
- Introduction to NOAA climate model evaluation web portal
- Climate model evaluation results for selected regions

Webinar 3 *(one hour)*:
Assessing Applicability of Climate Projection Information, Part 2: Evaluating Relevance

- Introduction to concept of relevance
- Overview of CVP sensitivity analysis
- Sensitivity analysis results for selected CVP performance criteria

Workshop *(one day)*:

- **8:30-9:00** Introduce workshop and participants, define goals
- **9:00-9:30** Recap proposed applicability framework within the context of broader planning process
- **9:30-9:45** Break
- **9:45-10:15** Discuss details of mock scoping assignment
- **10:15-12:00** Breakout Groups – Scoping Session 1: evaluating credibility
- **12:00-1:00** Lunch
- **1:00-2:30** Breakout Groups – Scoping Session 2: evaluating relevance
- **2:30-2:45** Break
- **2:45-3:30** Scoping Results – each group presents results, discusses utility of evaluation and sensitivity results
- **3:30-4:30** Group Discussion – gather feedback

APPENDIX 3.2

Workshop Slides

RECLAMATION

Managing Water in the West

Assessing Applicability of CMIP5 Climate Projections for Water Resources and Environmental Planning:

Pilot Workshop

Ian Ferguson (USBR, TSC)
Cameron Bracken (USBR, TSC)
Nancy Parker (USBR, TSC)

U.S. Department of the Interior
Bureau of Reclamation

Agenda:

- **8:30 - 9:00** Introduce workshop and participants, define goals
- **9:00 - 9:45** Recap proposed applicability framework within the context of broader planning process
- **9:45 - 10:00** Break
- **10:00 - 10:30** Discuss details of mock scoping assignment
- **10:30 - 12:00** Breakout Groups – Session 1: evaluating credibility
- **12:00 - 1:00** Lunch
- **1:00 - 2:30** Breakout Groups – Session 2: evaluating relevance
- **2:30 - 2:45** Break
- **2:45 - 3:30** Scoping Results – presents results, discusses utility of evaluation and sensitivity results
- **3:30 - 4:30** Group Discussion – gather feedback

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Introductions – Workshop:

Overview:

- Recent changes to Feasibility Study D&S directly link analysis of **climate change** to **investment decisions**

- Reclamation, NOAA and USACE are partnering to **develop a framework** to guide evaluation of climate projection **relevance, reliability, and applicability** in context of water resources and environmental planning

- We need **your help** to evaluate and improve this framework

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Introductions – Workshop:

Objectives:

- Introduce proposed framework for assessing climate change information for use in planning studies
- Test drive framework via mock scoping session
- Gather feedback

Introductions – Participants:

- Name
- Position / Title
- Experience scoping planning studies
- Experience scoping climate change analyses

Agenda:

- **8:30 - 9:00** Introduce workshop and participants, define goals
- **9:00 - 9:45** Recap proposed applicability framework
- **9:45 – 10:00** Break
- **10:00- 10:30** Discuss details of mock scoping assignment
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- **2:45 - 3:30** Scoping Results – presents results, discusses utility of evaluation and sensitivity results
- **3:30 - 4:30** Group Discussion – gather feedback

Recap – Outline:

- **Background & Motivation**

  Science, policy, and practice

- **Applicability Framework**

  Combining *reliability* and *relevance* to assess applicability

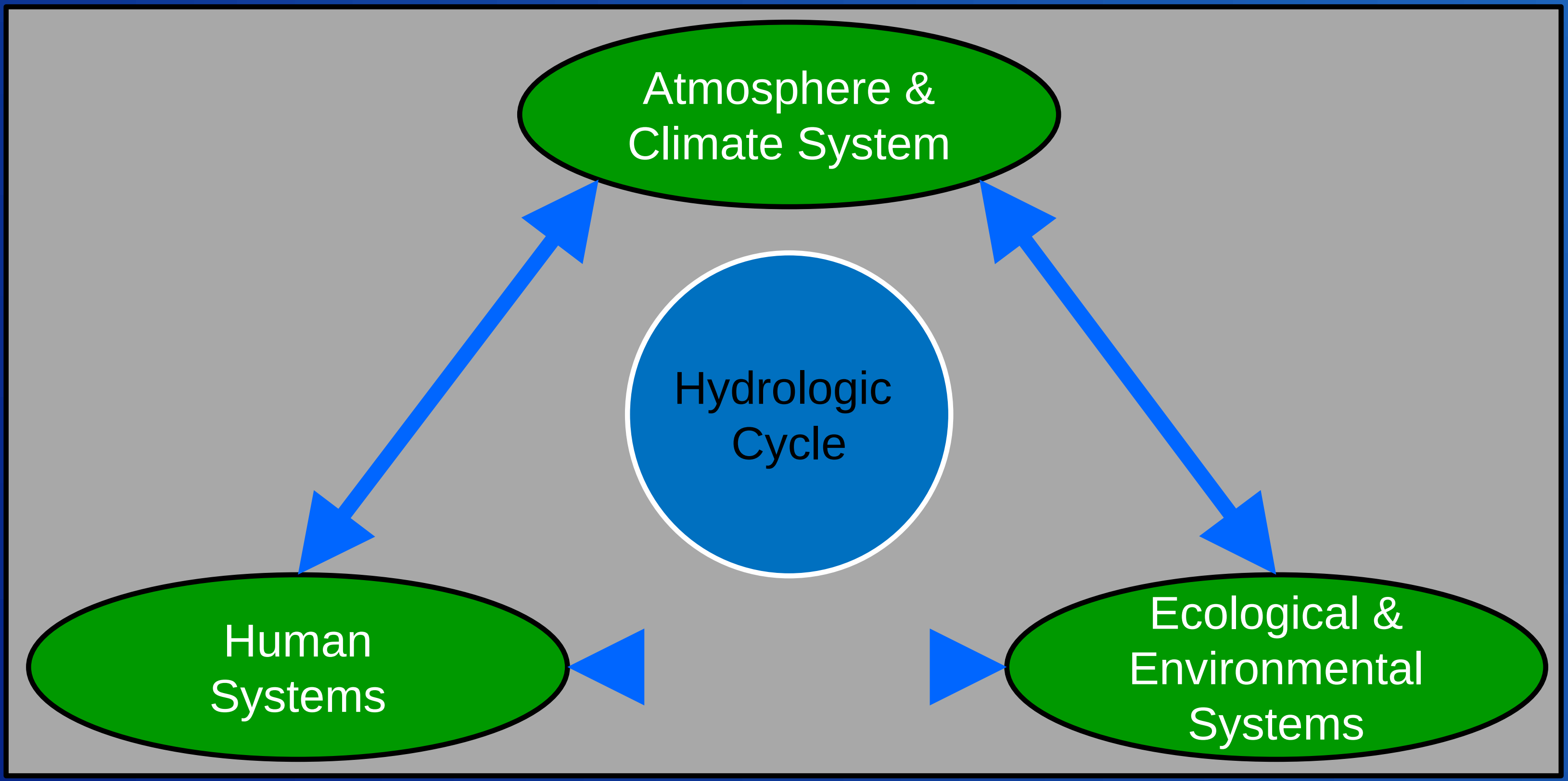
- **Pilot Workshop**

  Testing and evaluating the framework through mock scoping exercise

Recap – Background & Motivation:

- **Prior to SECURE Water Act (2009)**

  Climate change recognized as important planning consideration



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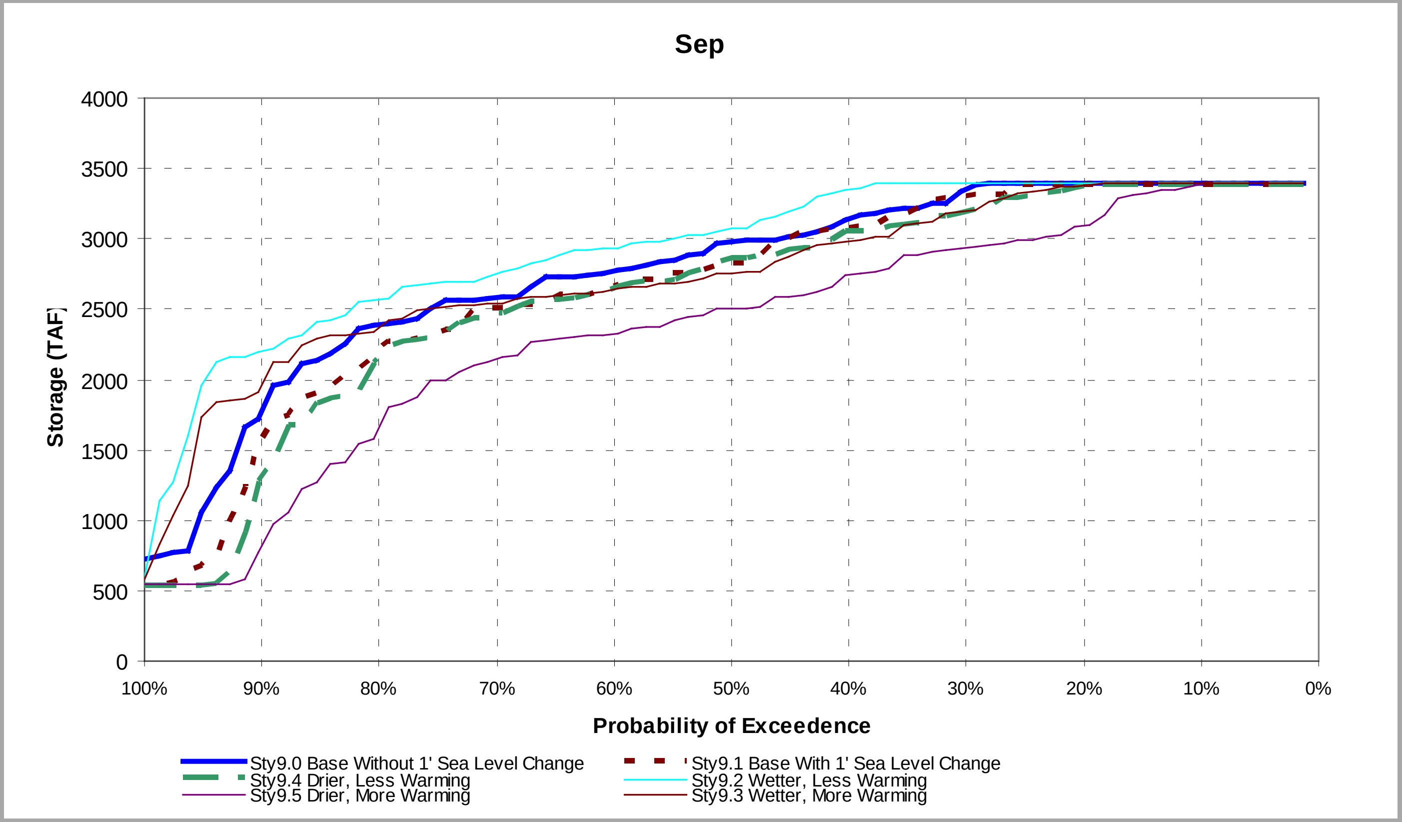
Recap – Background & Motivation:

- **Prior to SECURE Water Act (2009)**

  Climate change recognized as important planning consideration

CVP/SWP Operations Criteria and Plan (OCAP) Biological Assessment



RECLAMATION

Recap – Background & Motivation:

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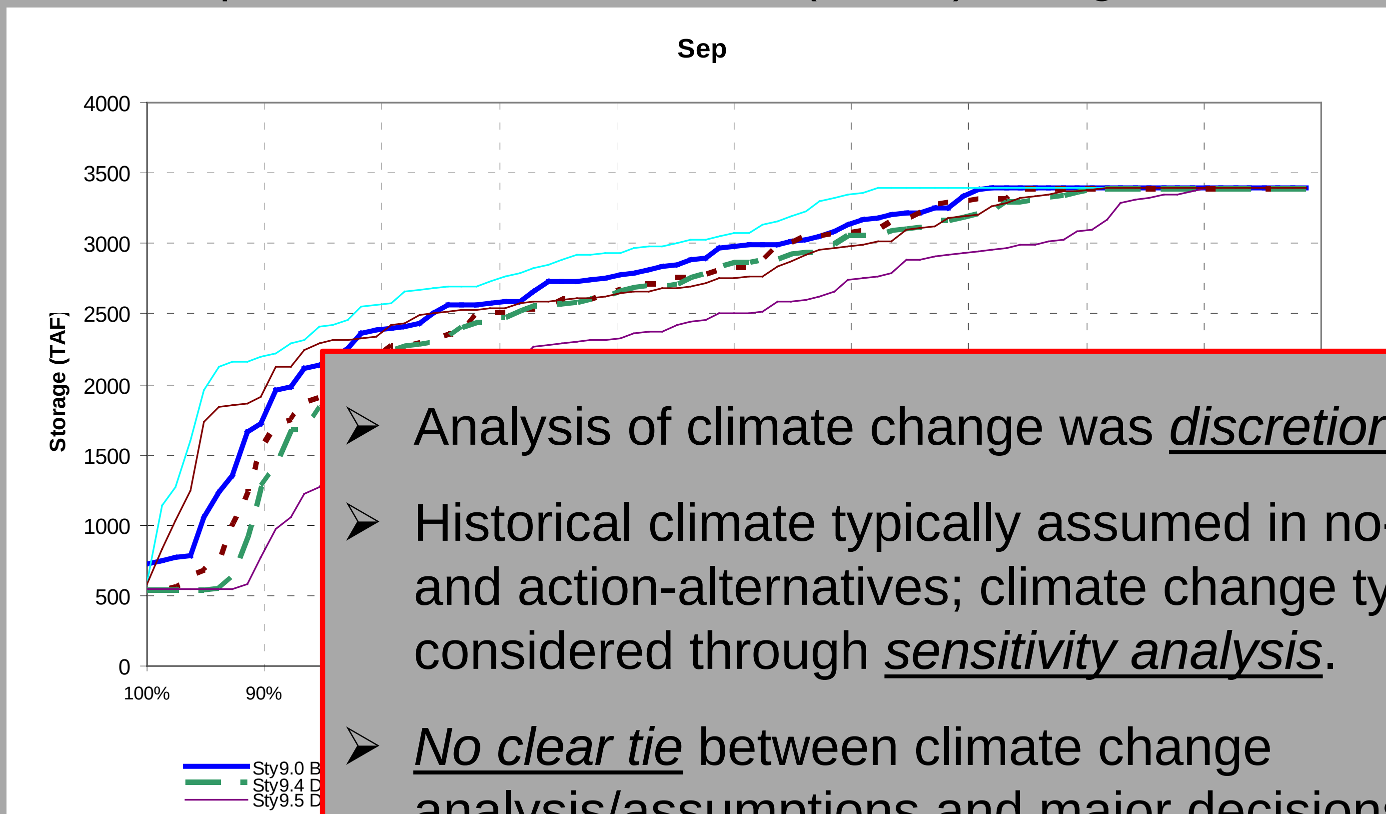
CVP/SWP Operations Criteria and Plan (OCAP) Biological Assessment



- ➢ Analysis of climate change was *discretionary*
- ➢ Historical climate typically assumed in no-action and action-alternatives; climate change typically considered through *sensitivity analysis*.
- ➢ *No clear tie* between climate change analysis/assumptions and major decisions

Recap – Background & Motivation:

- **SECURE Water Act**

  Authorized direct consideration of climate change risks and development of climate change adaptation and mitigation strategies

SECURE Water Act (Section 9503)

(a) IN GENERAL. — The Secretary shall establish a climate change adaptation program —

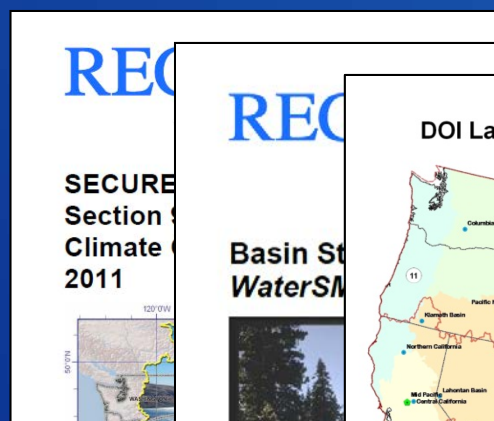
(1) to coordinate with the Administrator and other appropriate agencies to assess each effect of, and risk resulting from, global climate change with respect to the quantity of water resources located in a service area; and

(2) to ensure, to the maximum extent possible, that strategies are developed at watershed and aquifer system scales to address potential water shortages, conflicts, and other impacts to water users located at, and the environment of, each service area.

Recap – Background & Motivation:

- **SECURE Water Act**

  Authorized direct consideration of climate change risks and development of climate change adaptation and mitigation strategies



SECURE
Feasibility Studies

- ➢ Detailed analysis of climate change risks, evaluation of adaptation/mitigation alternatives
- ➢ Support planning and decision making
- ➢ Applies only to studies conducted *<u>under SECURE programs</u>*

Recap – Background & Motivation:

- **Feasibility Study D&S (CMP-09-02)**

  Requires consideration of climate change in development of feasibility study without-plan future condition

Reclamation D&S CMP-09-02:

" The potential impacts of climate change will be considered when developing projections of environmental conditions, water supply and demand, and operational conditions at existing facilities as part of the without-plan future condition. Climate change impacts will be further analyzed, as appropriate, as part of the feasibility study when the following conditions are true:

(i) there is a reasonable likelihood of significant variation in hydroclimatic conditions over the planning horizon, between alternatives, or both; and

(ii) available regional models have been down-scaled to a resolution adequate for the study area, or can be produced within reasonable time and cost constraints."

Recap – Background & Motivation:

- **Feasibility Study D&S (CMP-09-02)**

  Requires consideration of climate change in development of feasibility study without-plan future condition

Reclamation D&S CMP-09-02:

" Plans will be compared in accordance with the P&Gs and will include a comparison of responses and adaptability of the project to the uncertainties of climate changes previously identified in the without-plan scenario. The comparison of alternatives is part of the NEPA alternatives analysis. The plan that reasonably maximizes net public benefits will be identified.."

Recap – Background & Motivation:

- **Feasibility Study D&S (CMP-09-02)**

  Requires consideration of climate change in development of feasibility study without-plan future condition

Game Changer:

Then:

Use of climate change was at the **discretion** of individual study teams

Now:

Consideration of climate change is **required** for **all feasibility studies**

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Questions?

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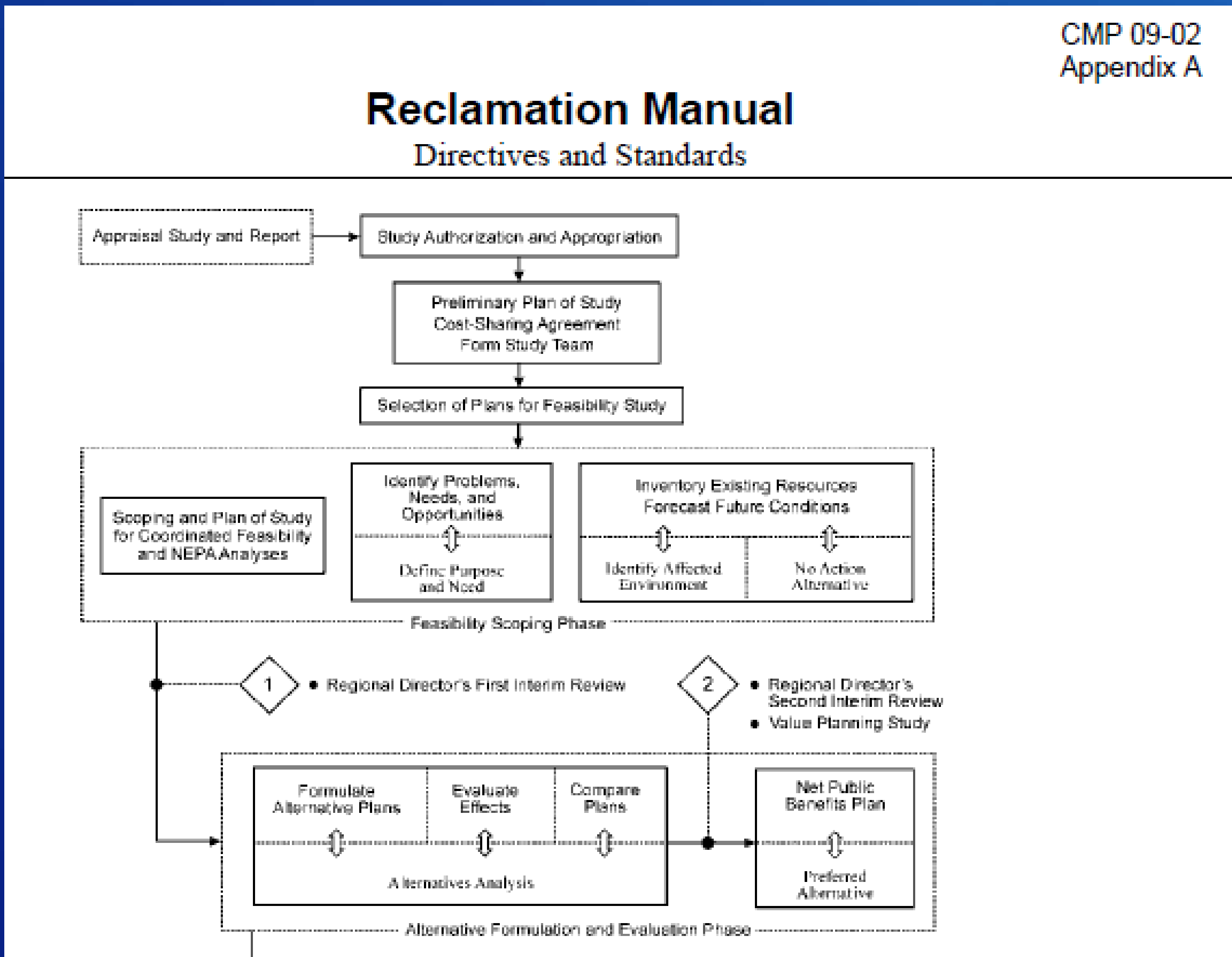
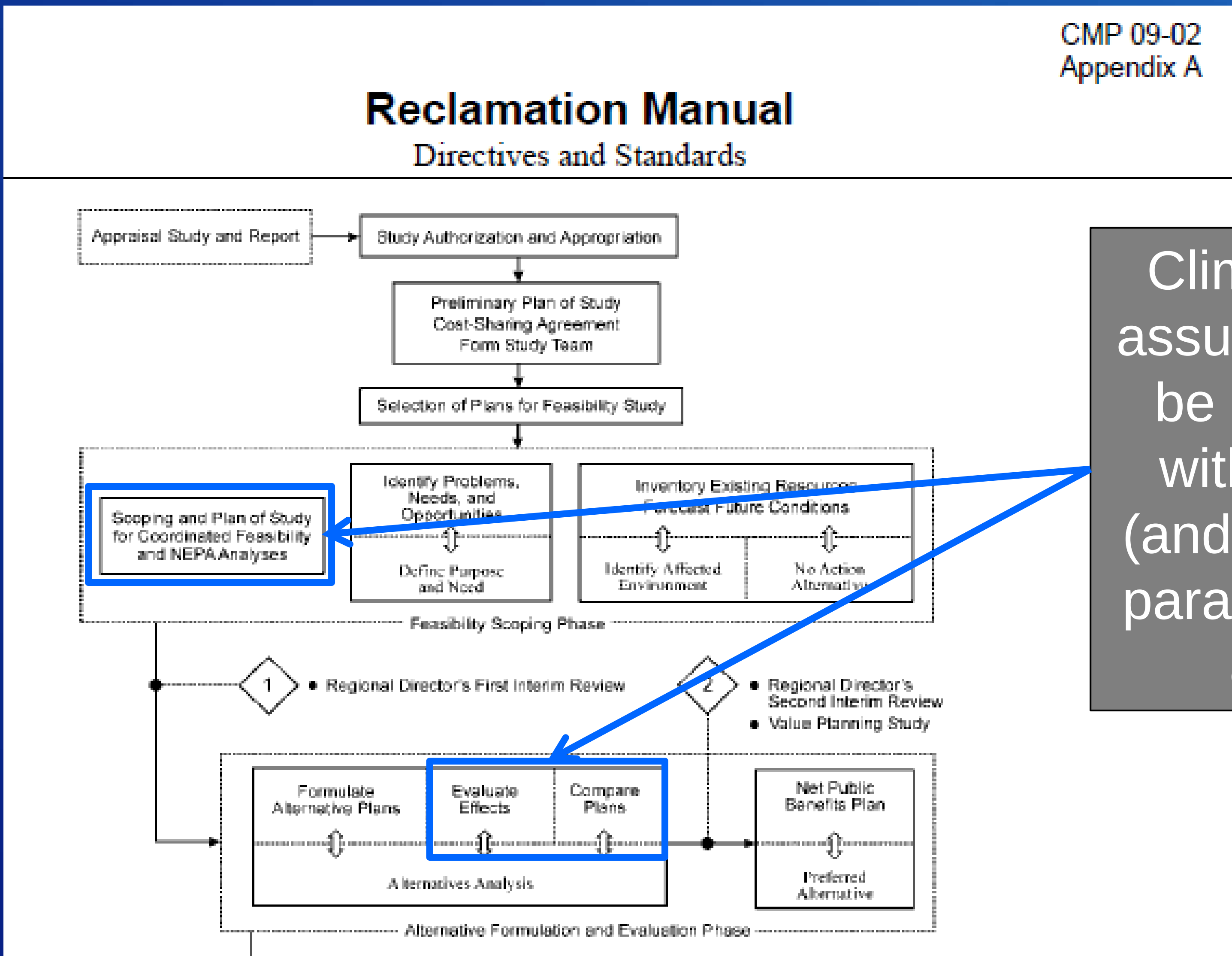
Recap – Background & Motivation:

- **From Policy to Practice**



Recap – Background & Motivation:

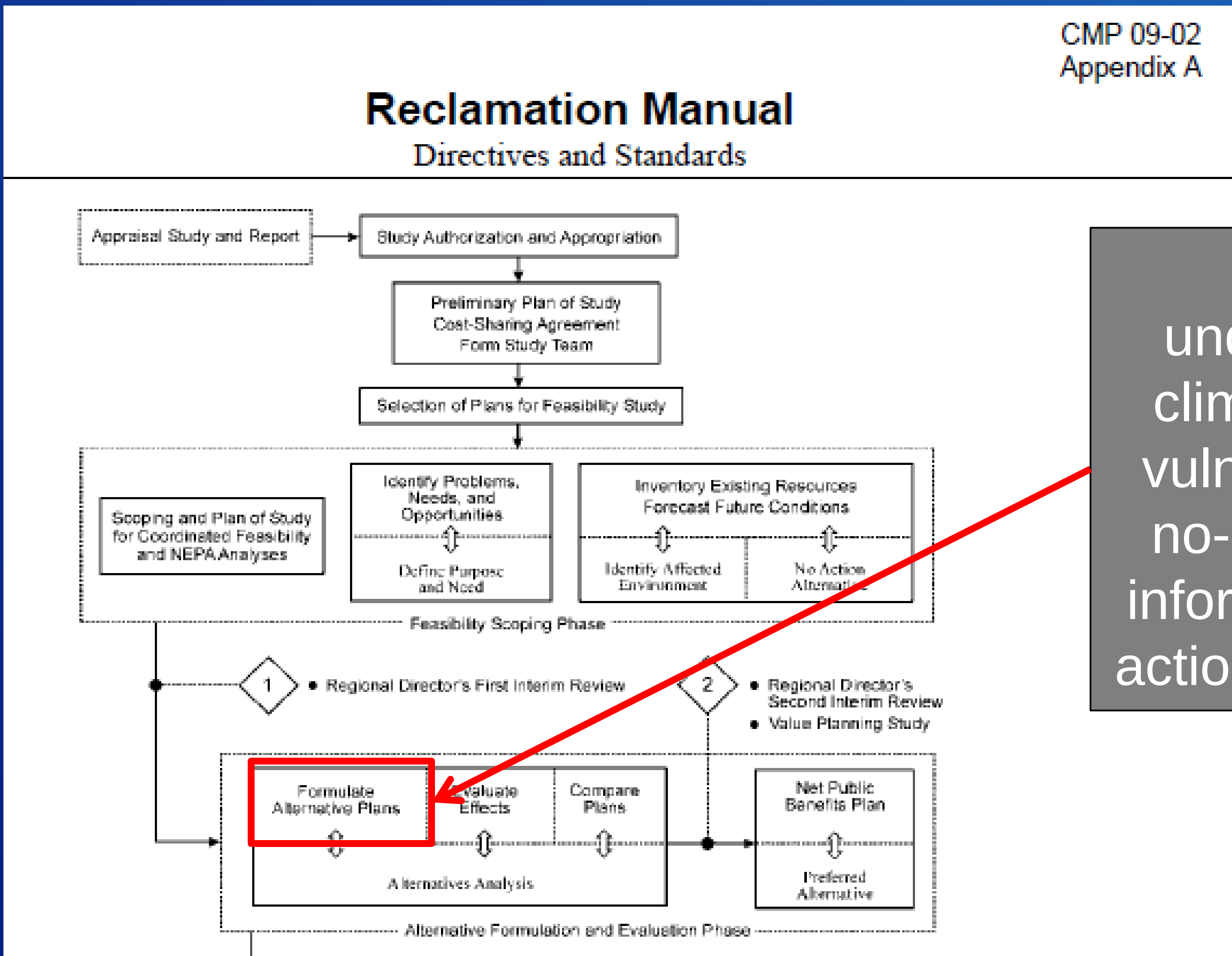
- **From Policy to Practice**



Climate change assumptions must be in the future without-project (and potentially in parallel sensitivity analysis)

Recap – Background & Motivation:

- **From Policy to Practice**

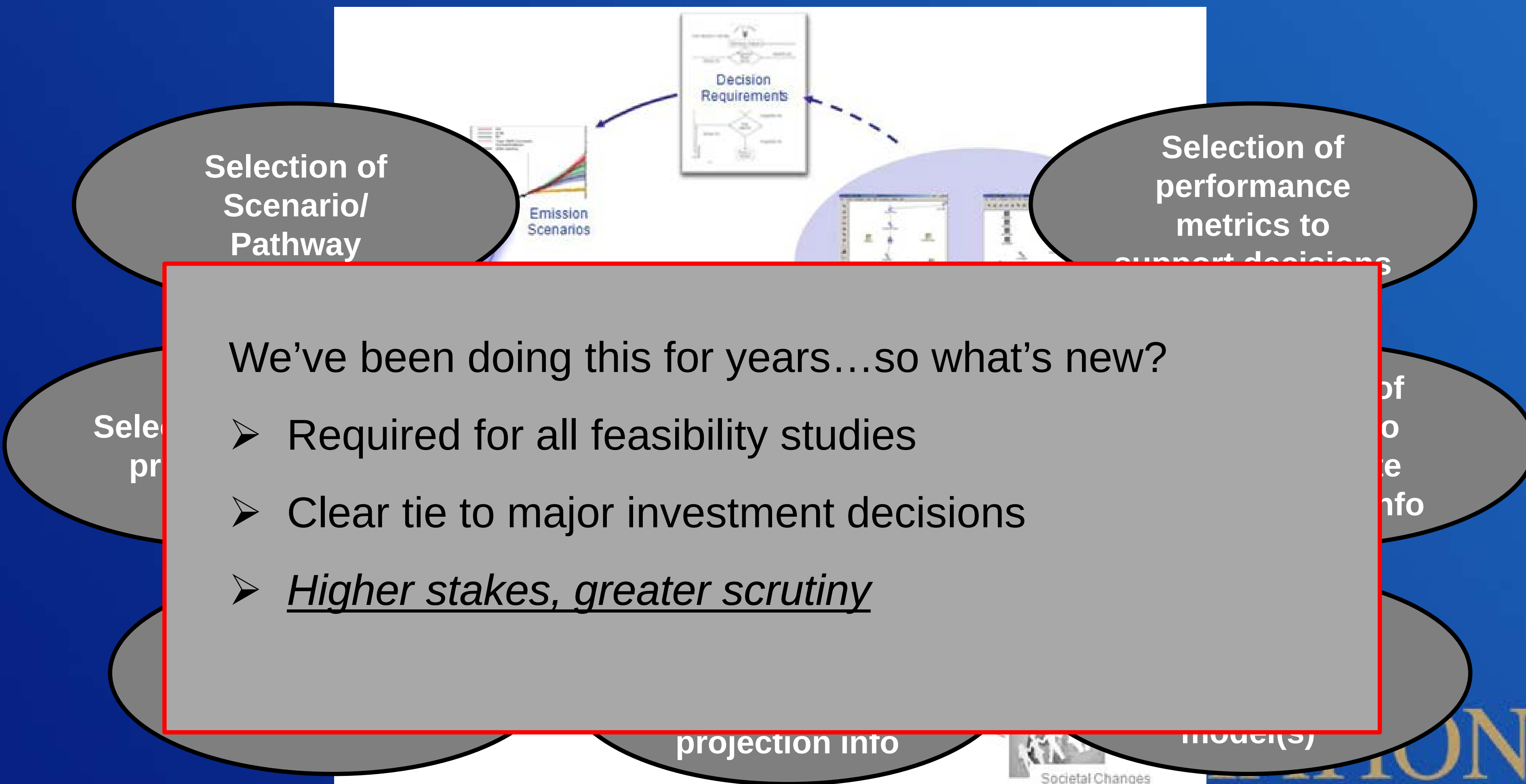


…and understanding climate change vulnerabilities in no-action could inform shaping of action-alternatives

Recap – Applicability Framework:

- **Scoping Challenge**

  How should study teams determine what climate change information to use and how to use it?

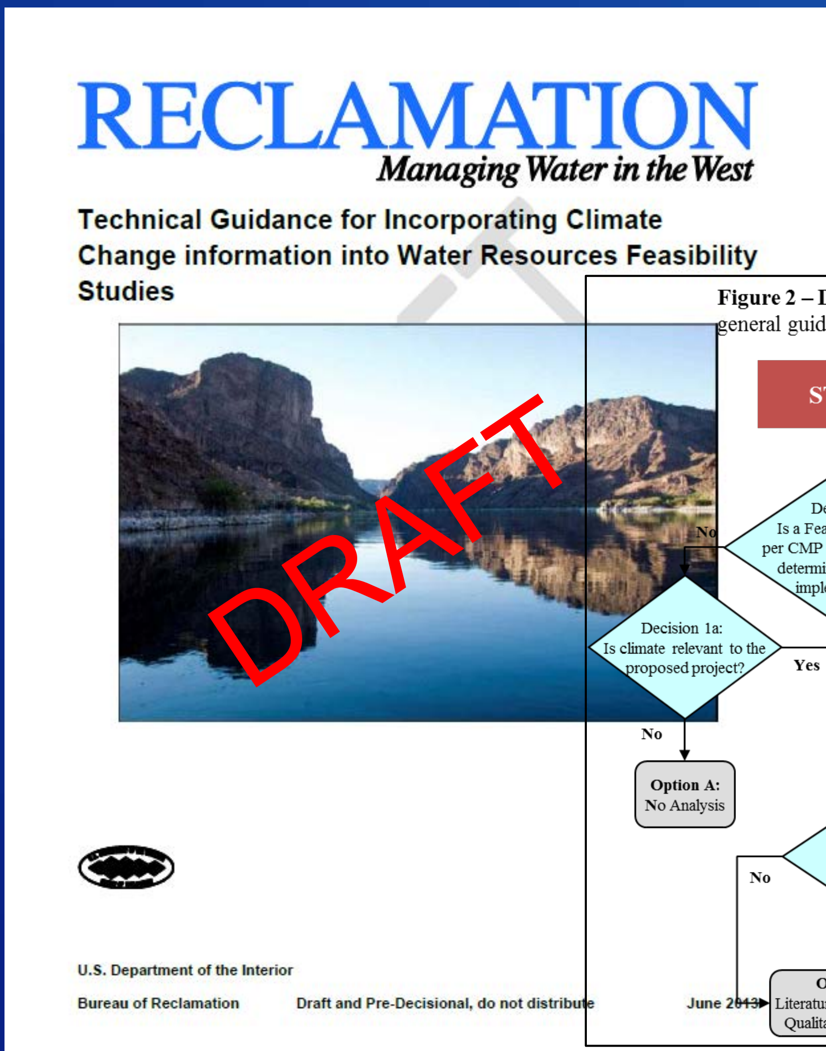


We've been doing this for years…so what's new?

- ➢ Required for all feasibility studies
- ➢ Clear tie to major investment decisions
- ➢ *Higher stakes, greater scrutiny*

Recap – Background & Motivation:

- Technical Guidance


RECLAMATION
Managing Water in the West

Technical Guidance for Incorporating Climate Change information into Water Resources Feasibility Studies

DRAFT

U.S. Department of the Interior

Bureau of Reclamation Draft and Pre-Decisional, do not distribute June 2013

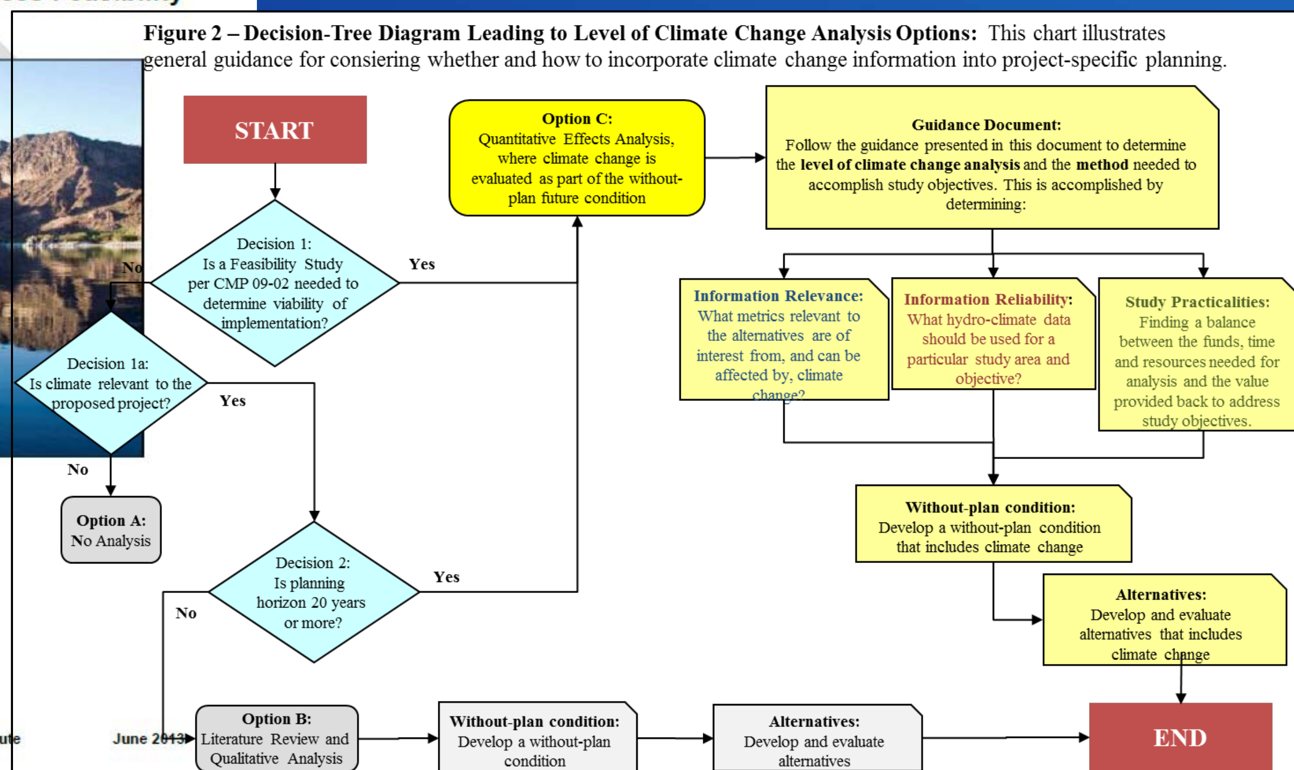
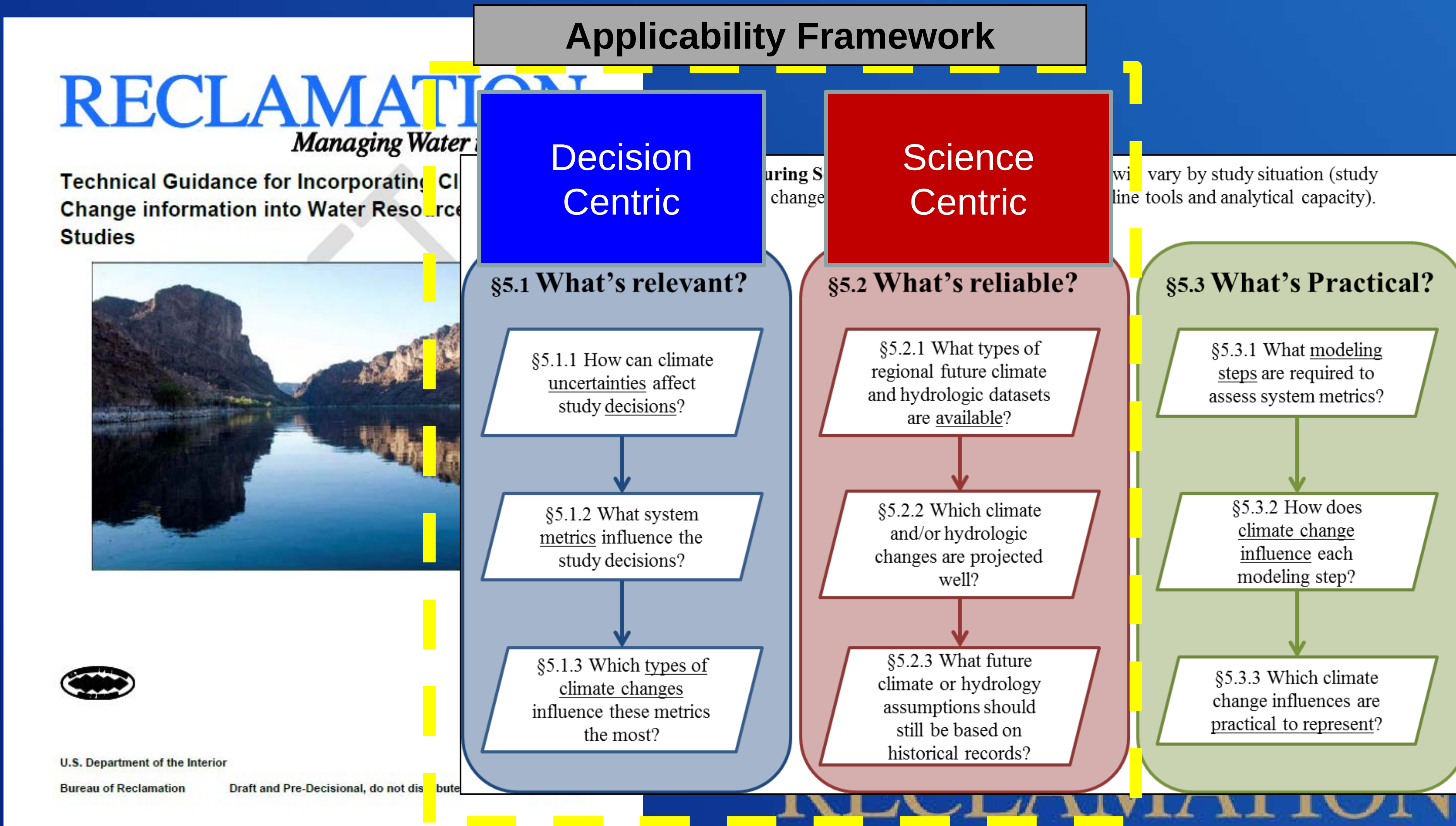


Figure 2 – Decision-Tree Diagram Leading to Level of Climate Change Analysis Options: This chart illustrates general guidance for consiering whether and how to incorporate climate change information into project-specific planning.

Recap – Background & Motivation:

- Technical Guidance



Recap – Background & Motivation:

- **Applicability Framework**

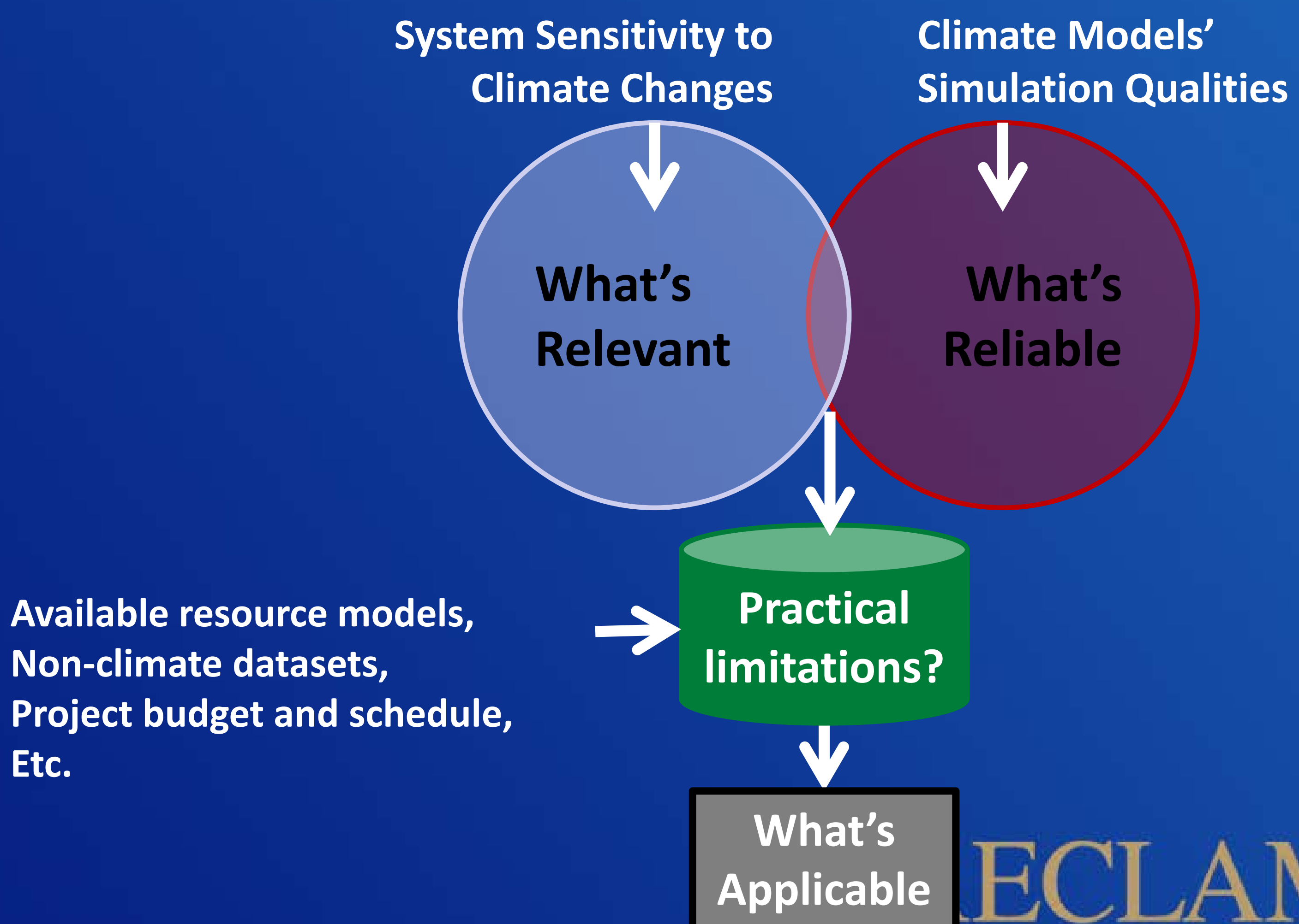
  Framework for implementing scoping process outlined in technical guidance document

  - Refine conceptual approach for assessing climate change information for use in planning studies
  - Define information basis for answering guidance questions
  - Facilitate consistent application of guidance and documentation of scoping choices across Reclamation planning studies

Questions?

Recap – Applicability Framework:

- How to select climate change information and methods for a specific study?



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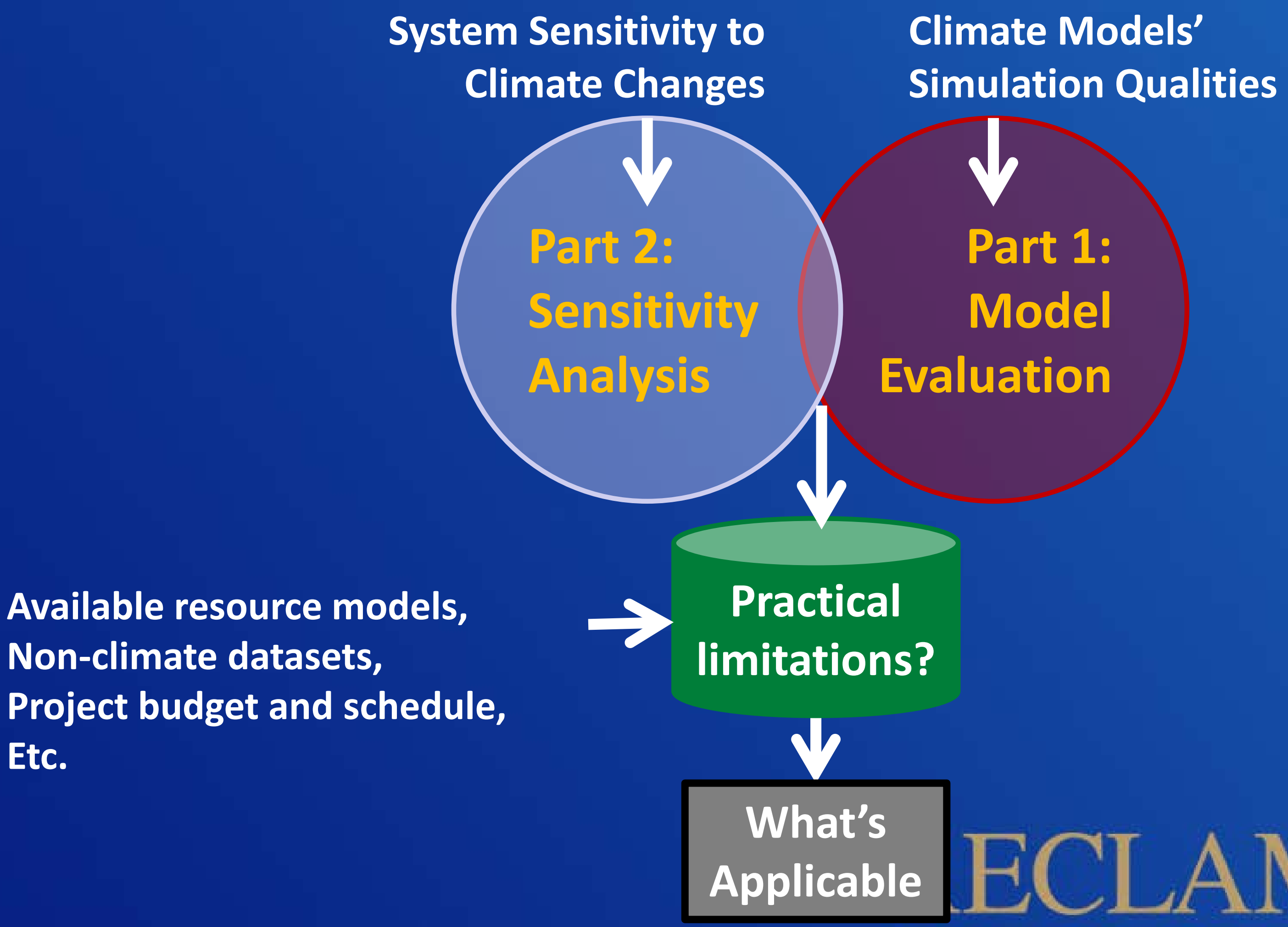

Recap – Applicability Framework:

- **Part 1: Reliability**

  What do climate models do well and what do they do poorly – i.e., Which aspects of climate projections are **reliable** or **credible** enough to support major decisions?

RECLAMATION

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- **Part 1: Reliability**

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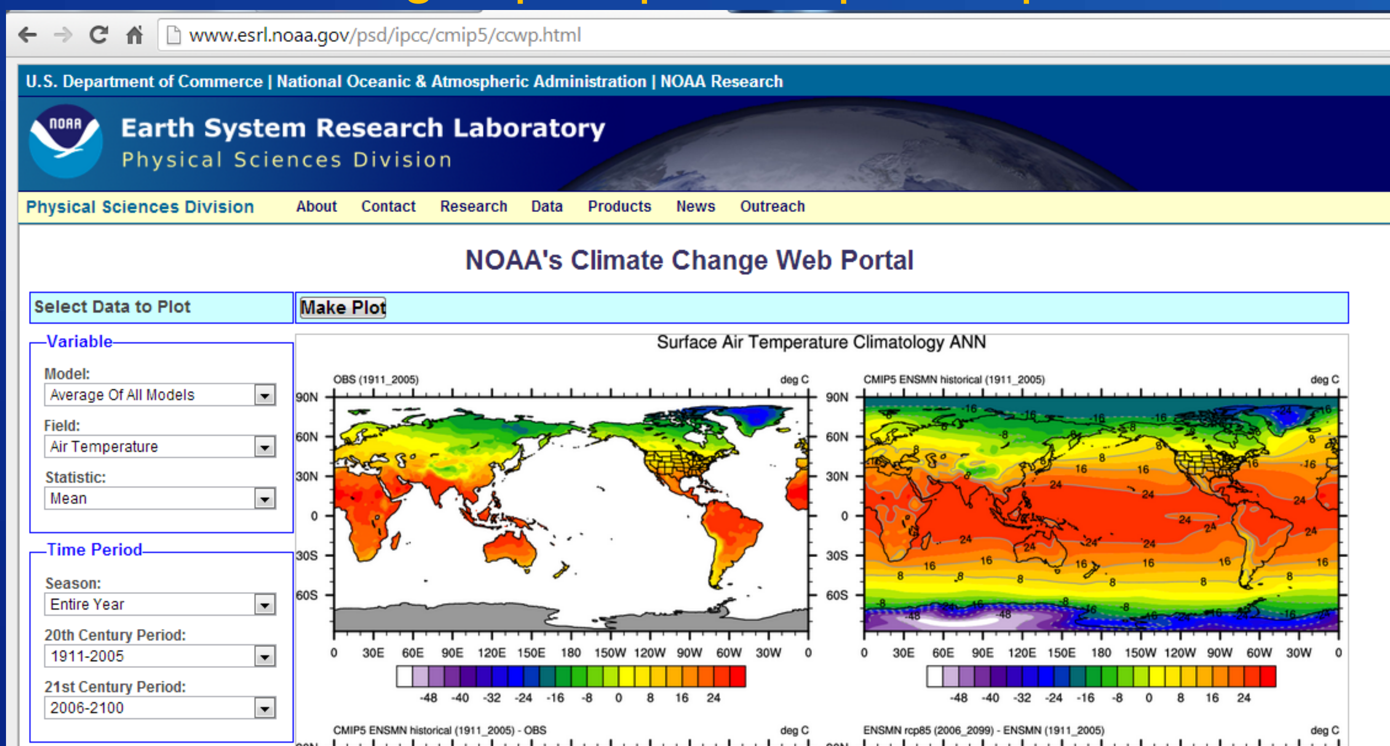
  → Broadband evaluation of CMIP5 global climate models

  www.esrl.noaa.gov/psd/ipcc/cmip5/ccwp.html



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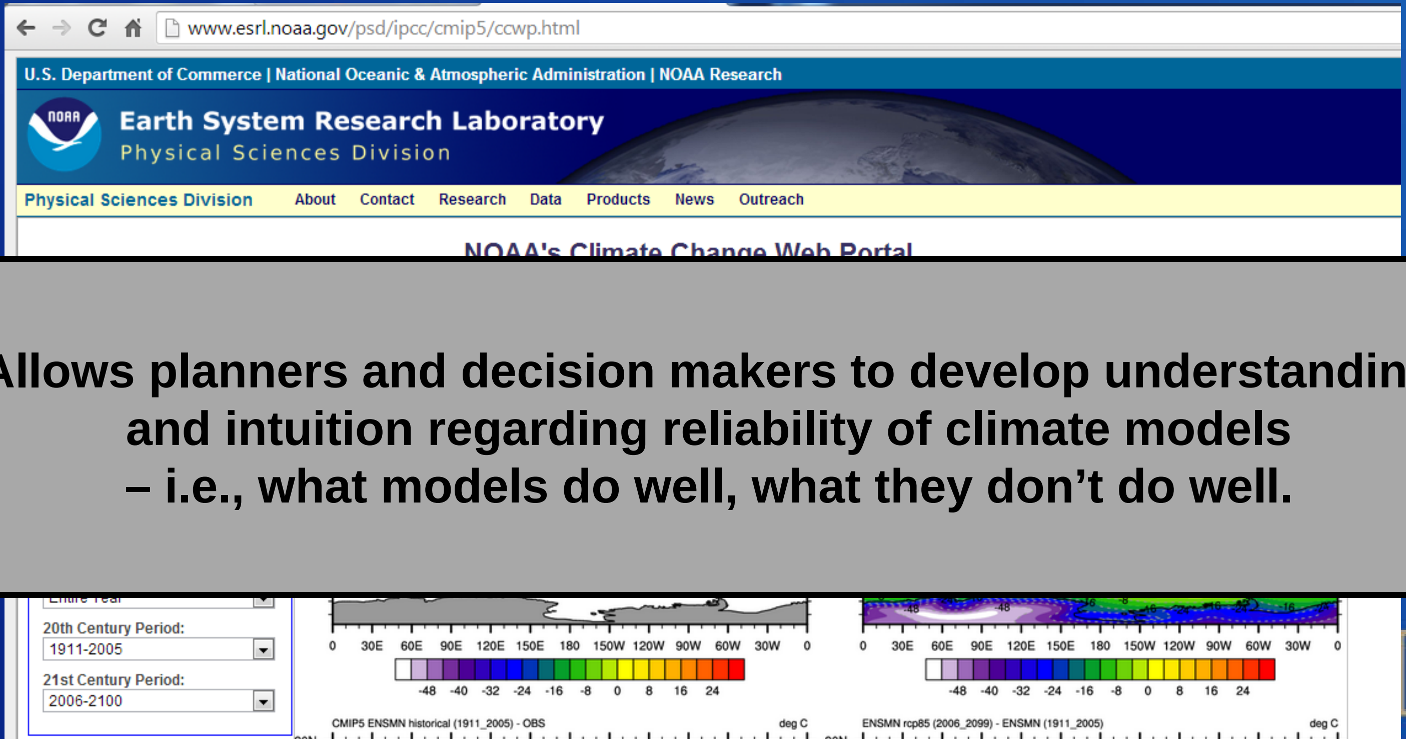
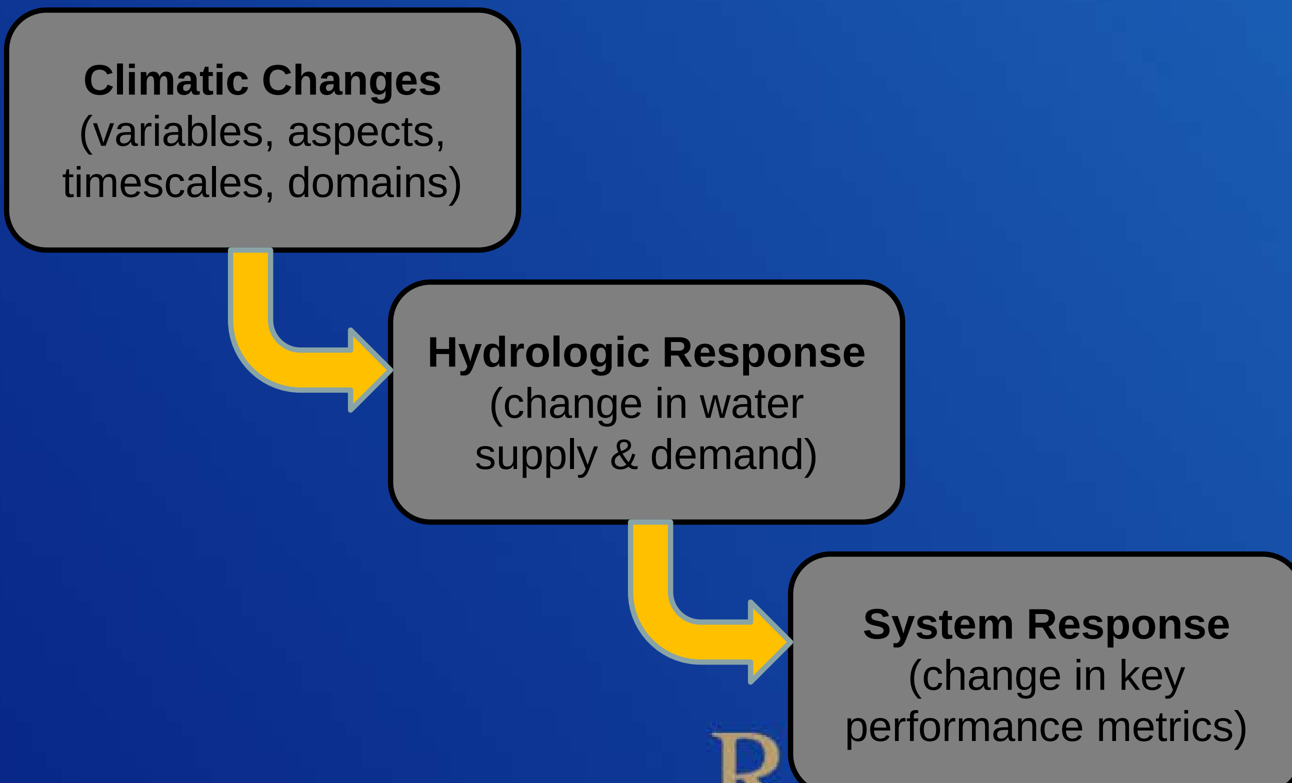


Allows planners and decision makers to develop understanding and intuition regarding reliability of climate models – i.e., what models do well, what they don't do well.

Recap – Applicability Framework:

- **Part 2: Relevance**

  What types of climate changes affect system performance – i.e., which aspects of climate change are <u>**relevant**</u> to water resources planning and decisions?



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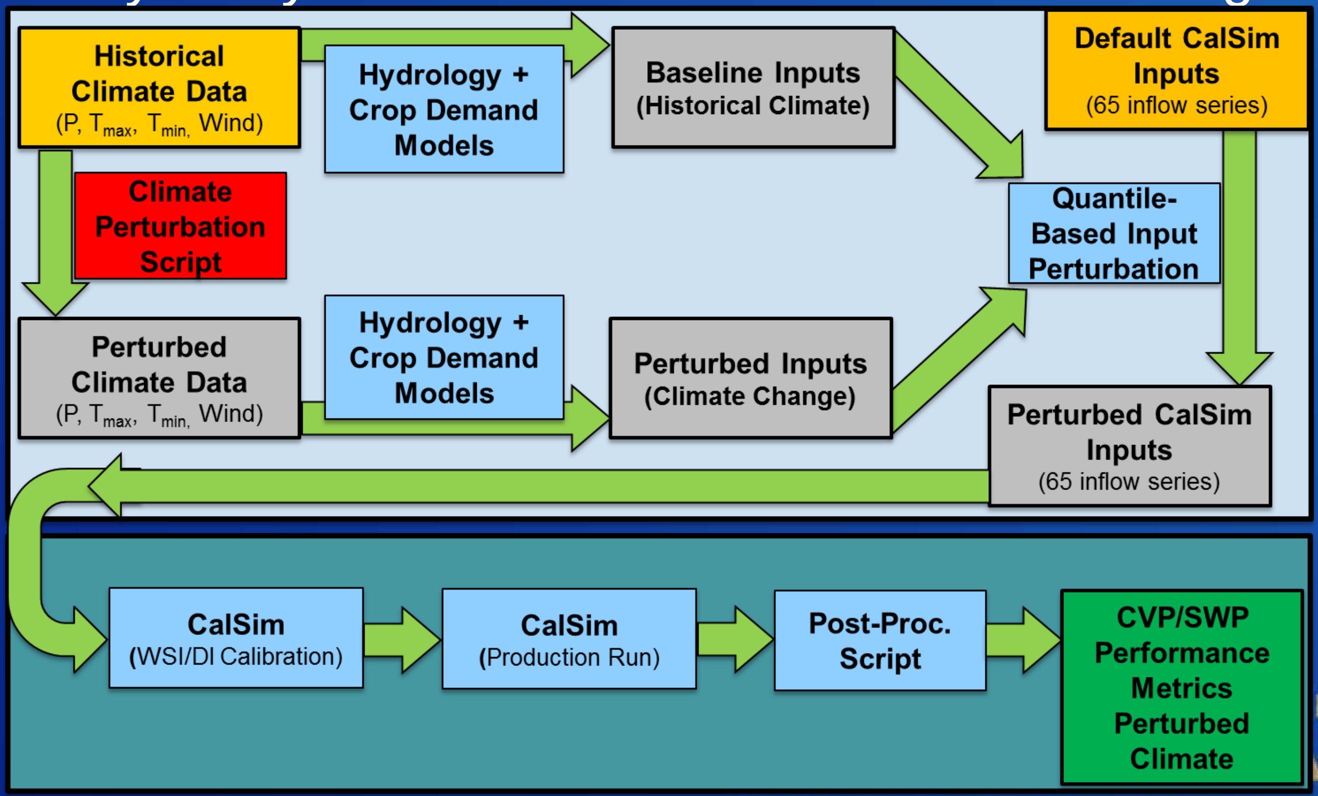
  What types of climate changes affect system performance – i.e., which aspects of climate change are **relevant** to water resources planning and decisions?

  → Sensitivity analysis of Sacramento River Basin using CALSIM-3.0



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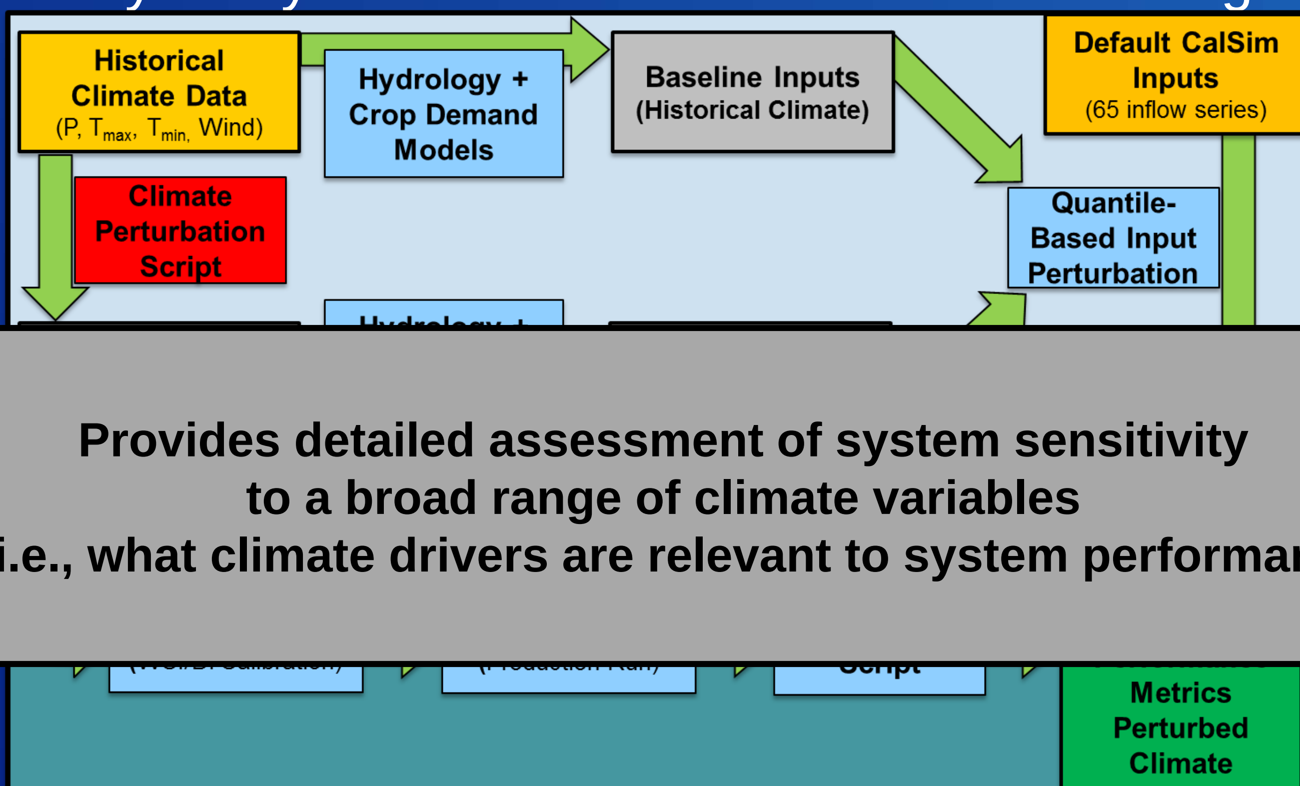


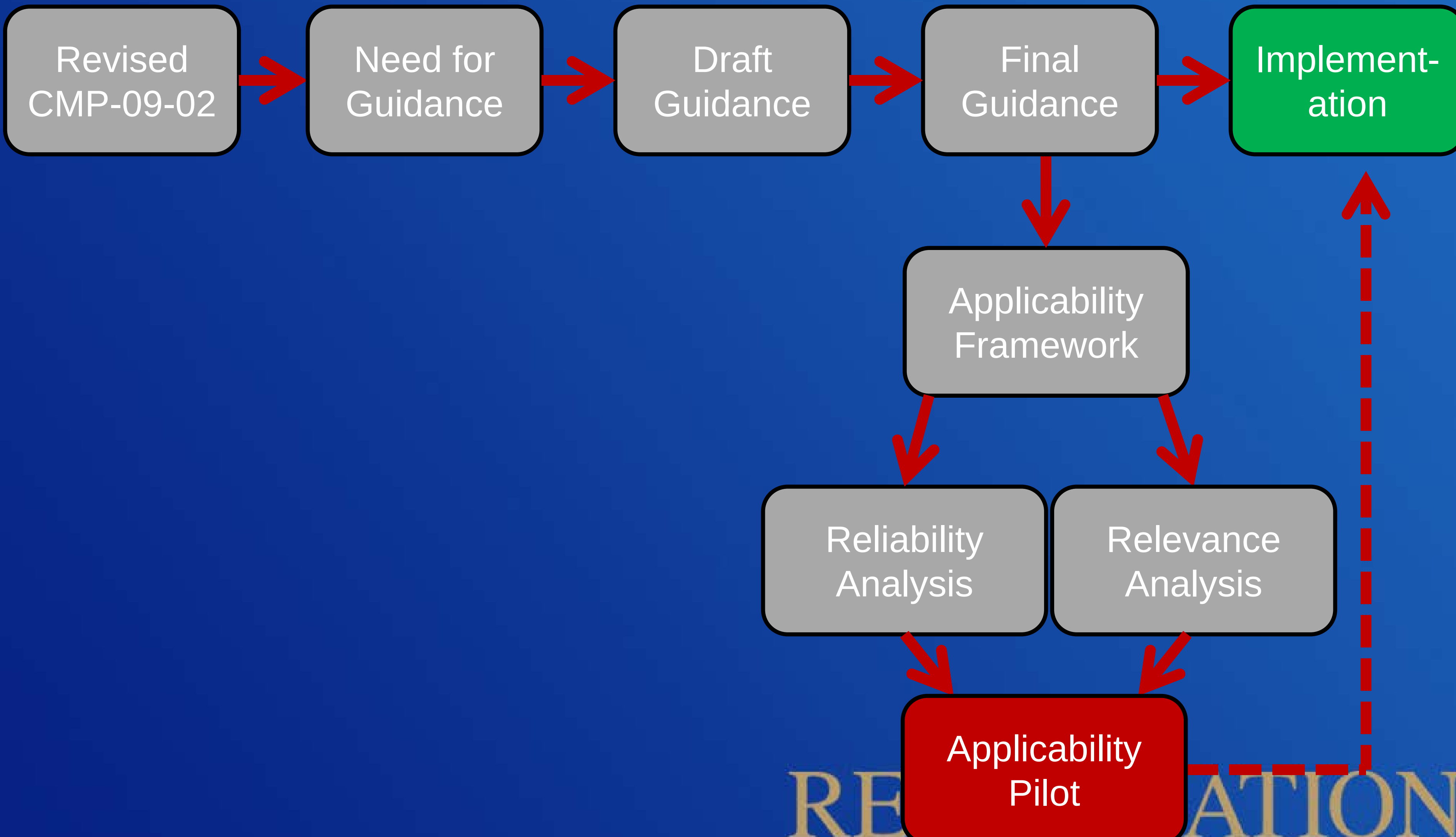
Provides detailed assessment of system sensitivity to a broad range of climate variables – i.e., what climate drivers are relevant to system performance

Questions?

RECLAMATION

Pilot Workshop:

- **We need your help!**



Pilot Workshop:

- **We need your help!**
  - Collaborators developed conceptual framework
  - NOAA lead broad-band evaluation of CMIP5 global climate models, development of online evaluation portal
  - Reclamation lead sensitivity analysis of Sacramento River CVP/SWP system to wide array of climate changes

Now we need your feedback on the strengths and weaknesses of the framework and related information.

Pilot Workshop:

- **We need your help!**

Workshop Format

- **Scoping teams**
  - Planners / scoping managers
  - Technical specialist – water operations / system sensitivity
  - Technical specialist – climate change / climate model evaluation
- **Hypothetical projects**
  - New storage facility
  - New restoration project/program
- **Mock scoping session**

  Each group will use the applicability framework to scope climate change portion of a feasibility study for one of the mock projects
- **Discussion**

  Each group describe their scoping experience, including which aspects of the proposed framework worked well and which did not.

RECLAMATION

Pilot Workshop:

- **We need your help!**

  We are looking for your feedback …

  - Are the purpose and general concept of the proposed framework sufficiently clear?
  - Was the evaluation information provided clear?
    Is the NOAA climate change portal useful for understanding model strengths/weaknesses and assessing reliability?
  - Was the sensitivity information provided clear?
    Are the sensitivity results useful for understanding system drivers and assessing relevance?
  - Is the proposed framework compatible with existing scoping process?
  - Etc…

RECLAMATION

Questions?

RECLAMATION

Agenda:

- **8:30 - 9:00** Introduce workshop and participants, define goals
- **9:00 - 9:45** Recap proposed applicability framework
- **9:45 – 10:00** Break
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RECLAMATION

Mock Scoping Session:

- **Scoping Assignment**
  - ➢ Review project descriptions
  - ➢ Answer scoping questions
  - ➢ Document information needs and other considerations during scoping process
  - ➢ Provide feedback on applicability framework as tool or approach to facilitate implementing scoping process outlined in guidance

Focus on Applicability Framework

- Consider sensitivity results when answering relevance questions
- Consider evaluation results when answering reliability questions
- Consider overall information needs throughout scoping process

Mock Scoping Session:

- **Project 1: Shasta Reservoir Enlargement**

<u>Purpose</u>:

Improve operational flexibility of the Delta watershed system through modifying the existing Shasta Dam and Reservoir to meet specified primary and secondary project objectives.

<u>Primary Objectives</u>:

- Increase the survival of anadromous fish populations in the Sacramento River, primarily upstream from Red Bluff Pumping Plant (RBPP)
- Increase water supply and water supply reliability for agricultural, M&I, and environmental purposes to help meet current and future water demands, with a focus on enlarging Shasta Dam and Reservoir

Mock Scoping Session:

- **Project 2: Yolo Bypass Habitat Restoration**

Purpose:

Restore floodplain rearing habitat for juvenile salmonids in the Yolo Bypass by providing floodplain connectivity that will result in improved physical habitat conditions, including sustaining water quality and forage necessary to support juvenile salmonid growth and mobility.

Primary Objectives:

- Restore floodplain fisheries rearing habitat in the Yolo Bypass for juvenile Sacramento River winter-run Chinook salmon, Central Valley spring-run Chinook salmon and Central Valley steelhead (inundation)
- Reduce migratory delays and fish mortality at Fremont Weir and other structures in the Yolo Bypass (fish passage)

Mock Scoping Session:

- **Scoping Teams**

Project 1: Storage Expansion	Project 2: Habitat Restoration
• • • •	• • • •

Mock Scoping Session:

- Questions?

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RECLAMATION

APPENDIX 3.3

Hypothetical Project Summary – Shasta Resize Feasibility Study (Handout)

Shasta Resize Feasibility Study

Project Purpose

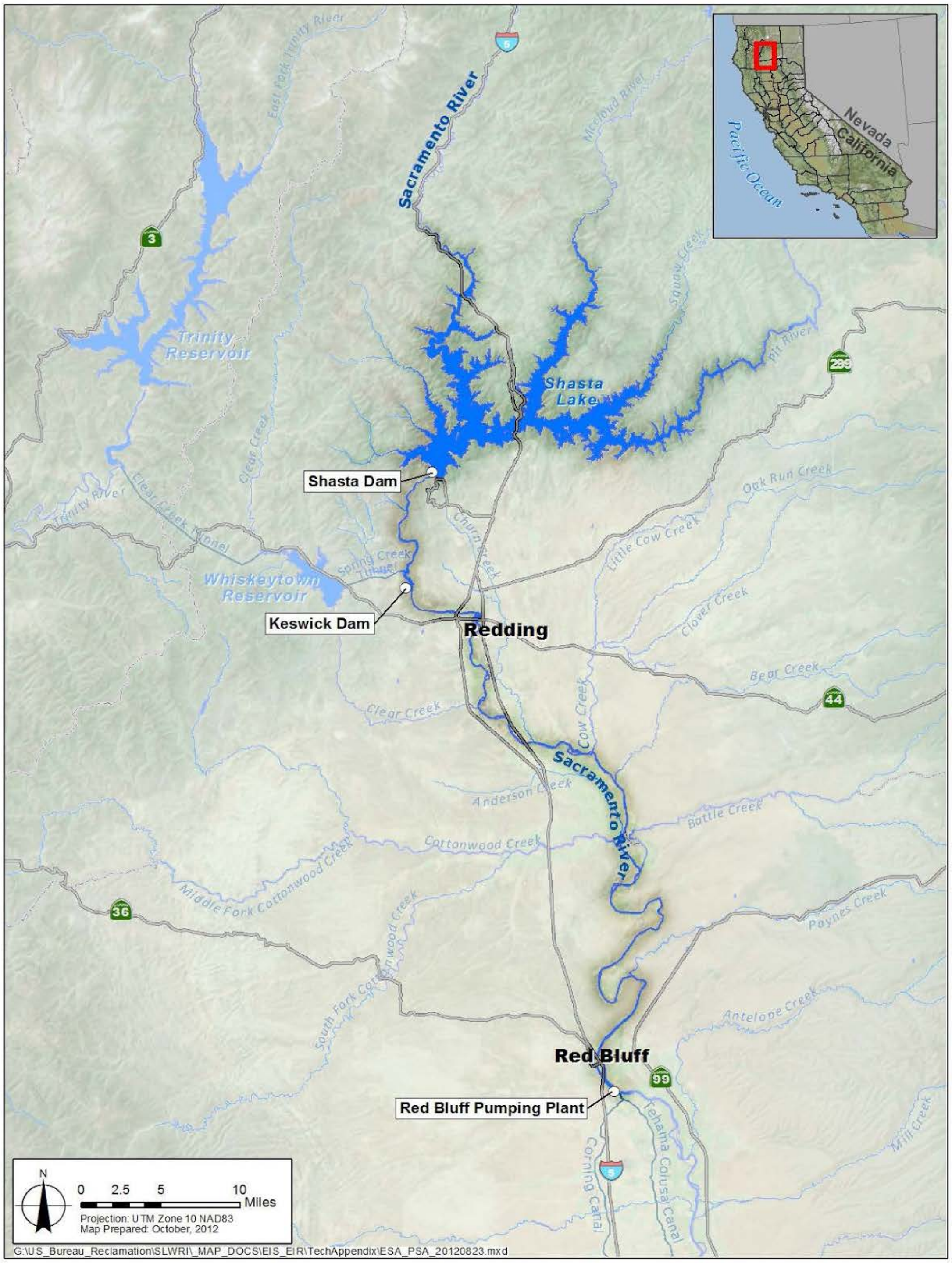
The purpose of the proposed action is to improve operational flexibility of the Delta watershed system through modifying the existing Shasta Dam and Reservoir to meet specified primary and secondary project objectives.

Primary Project Objectives

- Increase the survival of anadromous fish populations in the Sacramento River, primarily upstream from Red Bluff Pumping Plant (RBPP)
- Increase water supply and water supply reliability for agricultural, M&I, and environmental purposes to help meet current and future water demands, with a focus on enlarging Shasta Dam and Reservoir

Secondary Project Objectives

- Conserve, restore, and enhance ecosystem resources in the Shasta Lake area and along the upper Sacramento River
- Reduce flood damage along the Sacramento River
- Develop additional hydropower generation capabilities at Shasta Dam
- Maintain and increase recreation opportunities at Shasta Lake
- Maintain or improve water quality conditions in the Sacramento River downstream from Shasta Dam and in the Delta


Sacramento River
Shasta Lake
Trinity Reservoir
Whiskeytown Reservoir
Shasta Dam
Keswick Dam
Redding
Red Bluff
Red Bluff Pumping Plant
Clear Creek
Cow Creek
Little Cow Creek
Oak Run Creek
Clover Creek
Bear Creek
Churn Creek
Anderson Creek
Battle Creek
Cottonwood Creek
Middle Fork Cottonwood Creek
South Fork Cottonwood Creek
Paynes Creek
Antelope Creek
Mill Creek
Pit River
Mccloud River
Squaw Creek
Trinity River
East Fork Trinity River
Clear Creek Tunnel
Spring Creek Tunnel
Corning Canal
Tehama Colusa Canal
Pacific Ocean
Nevada
California
0 2.5 5 10 Miles
Projection: UTM Zone 10 NAD83
Map Prepared: October, 2012
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System Overview

Infrastructure and Facilities:
Shasta Dam is a curved, gravity-type, concrete structure that rises 533 feet above the streambed with a total height above the foundation of 602 feet. The dam has a crest width of about 41 feet and a length of 3,460 feet. Shasta Reservoir has a storage capacity of 4,550,000 acre-feet, and water surface area at full pool of 29,600 acres. Maximum seasonal flood management storage space in Shasta Reservoir is 1.3 million acre-feet (MAF). Releases from Shasta Dam can be made through the powerplant, over the spillway, or through the river outlets. The powerplant has a maximum release capacity of nearly 20,000 cubic feet per second (cfs), the river outlets can release a maximum of 81,800 cfs at full pool, and the maximum release over the drum-gated spillway is 186,000 cfs.

Operations:
Releases from Shasta Dam are often made for flood management purposes. Releases for flood management occur either in the fall, beginning in early October, to reach the prescribed vacant flood space, or to evacuate space during or after a storm event to maintain the prescribed vacant flood space in the reservoir. During a storm event, releases for flood management occur either over the spillway during large events or through river outlets for smaller events. Between 1950 and 2006, flows over the spillway occurred in 12 years, or in 21 percent of years. During the same time interval, releases for flood management (either for seasonal space evacuation or during a flood event, and including spills over the spillway) occurred in about 37 years, or nearly 70 percent of the years.

Historically, the largest flood events along the upper Sacramento River have been from heavy rainfall, with a relatively smaller component of the flows coming from snowmelt in the upper basin. Flood management operations at Shasta Dam include forecasting runoff into Shasta Lake as well as runoff of unregulated creek systems downstream from Keswick Dam. A critical component of upper Sacramento River flood operations is the forecast of local runoff entering the Sacramento River between Keswick Dam and Bend Bridge near Red Bluff.

Flood Management Space Requirements Shasta Reservoir capacity is 4,552 TAF, with a maximum objective release capacity of 79,000 cfs. The end-of-September storage target for Shasta Reservoir is 1,900 TAF, except in the driest 10 percent of water years, to conserve sufficient cold water for meeting temperature criteria for the winter-run Chinook incubation period (summer to early fall). Storage levels are lowest by October to provide sufficient flood protection and capture capacity during the following wet months. The storage target gradually increases from October to full pool in May. Storage is then withdrawn for high water demand (i.e., municipal, agricultural, fishery, and water quality uses) during summer.

A storage space of up to 1,300 TAF below a full pool is also kept available for flood management purposes in the reservoir in accordance with the Shasta Dam and Lake Flood Control Diagram as prescribed by USACE (USACE 1977; see Exhibit B in the Hydrology, Hydraulics, and Water Management Technical Report). Under the diagram, flood management storage space increases from zero on October 1 to 1,300 MAF on December 1, and is maintained until December 23. From December 23 to June 15, the required flood management space varies according to parameters based on the accumulation of seasonal inflow. This variable space allows for the storage of water for conservation purposes, unless it is required for flood management based on basin wetness parameters and the level of seasonal inflow. Daily flood management operation consists of determining the required flood storage space reservation, and scheduling releases in accordance with flood operations criteria.

Description of Alternatives

Consistent with NEPA and the P&Gs, the plan formulation process for the Shasta Lake Water Resources Investigation was divided into multiple phases. Through this process, five comprehensive plans (i.e., action alternatives) were formulated in addition to a No-Action Alternative. Each of the five comprehensive plans includes enlarging Shasta Dam and Reservoir and a variety of management measures to address, in varying degrees, all of the project objectives. All of the comprehensive plans include eight common management measures:

- Enlarge Shasta Lake cold-water pool – All action alternatives would involve enlarging the cold-water pool by raising Shasta Dam to enlarge Shasta Reservoir.
- Modify the temperature control device (TCD) – Minimum modifications to the TCD under all action alternatives would include raising the existing structure and modifying the shutter control.
- Increase conservation storage – All action alternatives would increase the conservation storage in Shasta Reservoir by raising Shasta Dam.
- Reduce water demand – All action alternatives would include an additional water conservation program for new water supplies created by the project to augment current water use efficiency practices.
- Modify flood operations – Enlarging Shasta Reservoir would require adjustment of the existing flood operation guidelines, or rule curves, to reflect physical modifications, such as an increase in dam/spillway elevation; the rule curves would be revised with the goal of reducing flood damage and enhancing other objectives to the extent possible.
- Modify hydropower facilities – Enlarging Shasta Dam would require various modifications to the dam’s existing hydropower facilities to enable their continued efficient use.
- Maintain and increase recreation opportunities – Recreation is important to the Shasta Lake region; therefore, existing recreation opportunities would be maintained and/or increased under all action alternatives.
- Maintain or improve water quality – All action alternatives would maintain and potentially improve water quality by increasing Delta outflow during drought years and reducing

salinity during critical periods, and may also provide additional operational flexibility for responses to Delta emergencies.

Modeling

CalSim-II

CalSim-II is the application of the Water Resources Integrated Modeling System software to the CVP/SWP. This application was jointly developed by Reclamation and DWR for planning studies relating to CVP/SWP operations. The primary purpose of CalSim-II is to evaluate the water supply reliability of the CVP and SWP at current or future levels of development (e.g., 2005, 2030), with and without various assumed future facilities, and with different modes of facility operations. Geographically, the model covers the drainage basin of the Delta, and CVP/SWP exports to the Bay Area, San Joaquin Valley, Central Coast, and Southern California. CalSim-II typically simulates system operations for an 82-year period using a monthly time step. The model assumes that facilities, land use, water supply contracts, and regulatory requirements are constant over this period, representing a fixed level of development (e.g., 2005, 2030). The historical flow record of October 1921 to September 2003, adjusted for the influences of land use changes and upstream flow regulation, is used to represent the possible range of water supply conditions. Major Central Valley rivers, reservoirs, and CVP/SWP facilities are represented by a network of arcs and nodes. CalSim-II uses a mass balance approach to route water through this network. Simulated flows are mean flows for the month; reservoir storage volumes correspond to end-of-month storage.

CalSim-II models a complex and extensive set of regulatory standards and operations criteria. (Descriptions of both are contained in Chapter 2 of the Modeling Appendix.) The hydrologic analysis for this DEIS used SLWRI 2012 Benchmark Version CalSim-II model, which is the best available hydrological modeling tools, to approximate the changes in storage, flow, salinity, and reservoir system reoperation associated with the SLWRI alternatives. Although CalSim-II is the best available tool for simulating system-wide operations, the model also contains simplifying assumptions in its representation of the real system.

The monthly CalSim-II model results are useful for comparative purposes. It is important to differentiate between “absolute” or “predictive” modeling applications and “comparative” applications. In “absolute” applications, the model is run once to predict a future outcome and errors or assumptions in formulation, system representation, data, operational criteria, etc., all contribute to total error or uncertainty in model results. In “comparative” applications, the model is run twice, once to represent a base condition (No-Action Alternative) and a second time with a specific change (project) to assess the change in the outcome because of the input change. In this mode (the mode used for this DEIS), the difference between the two simulations is of principal importance. Potential errors or uncertainties that exist in the “no-project” simulation are also present in the “project” simulation such that their impacts are reduced when assessing the change in outcomes. The SLWRI analysis is a comparative analysis.

DSM2

DSM2 is a branched 1-dimensional model for simulation of hydrodynamics, water quality, and particle tracking in a network of riverine or estuarine channels (DWR 2002). The hydrodynamic module can simulate channel stage, flow, and water velocity. The water quality module can simulate the movement of both conservative and nonconservative constituents. The model is used by DWR to perform operational and planning studies of the Delta.

Impact analyses for planning studies of the Delta are typically performed for an 82-year period (1922 to 2003). In model simulations, EC is typically used as a surrogate for salinity. Results from CalSim-II are used to define Delta boundary inflows. CalSim-II-derived boundary inflows include the Sacramento River flow at Hood, San Joaquin River flow at Vernalis, inflow from the Yolo Bypass, and inflow from the eastside streams. In addition, Net Delta Outflow from CalSim-II is used to calculate the salinity boundary at Martinez.

APPENDIX 3.4

Hypothetical Project Summary – Shasta Resize Feasibility Study (Handout)

Yolo Bypass Salmonid Habitat Restoration and Fish Passage Study

Project Purpose

The purpose of the proposed action is to restore floodplain rearing habitat for juvenile Sacramento River winter-run Chinook salmon, Central Valley spring-run Chinook salmon, and California Central Valley steelhead in the Yolo Bypass by providing floodplain connectivity that will result in improved physical habitat conditions, including sustaining water quality and forage necessary to support juvenile salmonid growth and mobility.

Primary Project Objectives

- Restore floodplain fisheries rearing habitat in the Yolo Bypass for juvenile Sacramento River winter-run Chinook salmon, Central Valley spring-run Chinook salmon and Central Valley steelhead (inundation)
- Reduce migratory delays and fish mortality at Fremont Weir and other structures in the Yolo Bypass (fish passage)

Secondary Project Objectives

- Seek alternatives that are flood-neutral or which improve flood protection
- Maintain a sustainable balance for all significant uses of the Yolo Bypass (agriculture, waterfowl, education)

System Overview

Yolo Bypass:
The Sacramento River Flood Control Project was designed to offer protection from storm events in the watershed that cannot be contained within the Sacramento River levee system. A system of weirs and flood relief structures was developed to route excess flows into adjacent basins, eventually conveying flood waters back to the Sacramento River near Rio Vista. The Yolo Bypass is the southernmost feature in the system.

The Yolo Bypass is a designated floodway that encompasses approximately 60,000 acres in eastern Yolo County between the cities of Davis and Sacramento. Yolo bypass consists of both public and private lands, and all properties within the bypass are subject to a flood easement that allows the state to flood the land for public safety and ecological benefit. Land uses include designated wildlife refuges, but most of the area is managed as agricultural land, supporting crops in drier years and after flood waters have receded in wet years.

The bypass has been identified by several State and federal entities as a potential site for habitat restoration to ease pressure on and increase benefits to threatened and endangered fish species. Alternatives for providing seasonal floodplain rearing habitat through increased control of flows over and through the Fremont Weir are being studied.

Infrastructure and Facilities:
Overflow waters from the Sacramento River, Sutter Bypass, and Feature River are directed into Yolo Bypass by the Fremont Weir. The weir is a passive structure built in 1924. The weir stands approximately seven feet high relative to the river bed and is approximately one mile in length. During periods of high flow, water overtopping the weir spills into the Yolo Bypass, reducing flow down the Sacramento River.

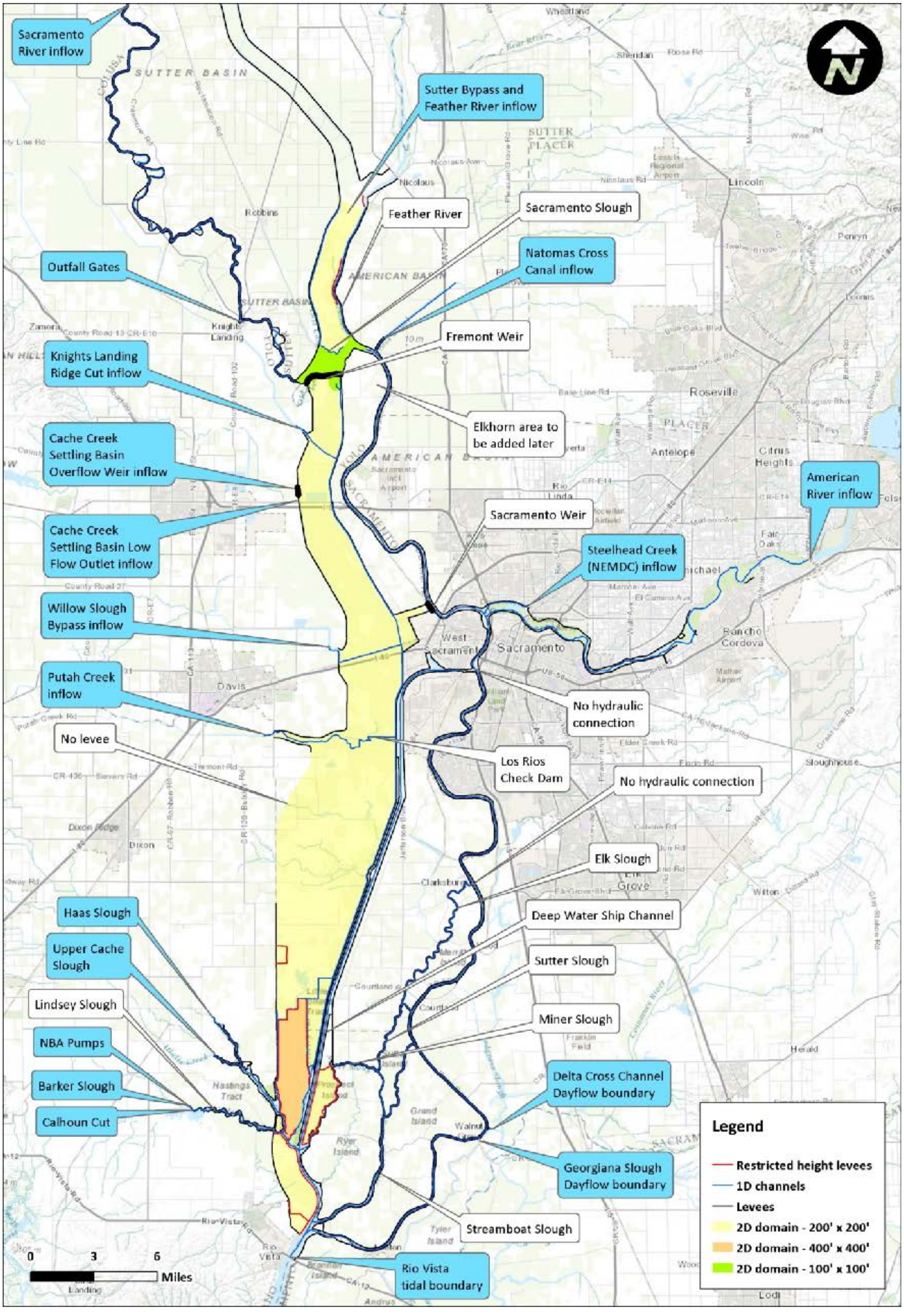
Operations:
Fremont Weir was designed to allow overtopping during periods of high flow; as a passive structure, the weir is not actively operated. Fremont Weir has historically been overtopped at some level in about 70% of years, with the timing, frequency, and duration of inundation in the Yolo Bypass dependent on contributing flow levels in the Sacramento River.

Description of Proposed Alternatives:
Reclamation and DWR are considering several alternatives for meeting the project purpose of restoring floodplain habitat in the Yolo Bypass. Each alternative involves modification of the existing Fremont Weir by constructing one or more notches to allow flow from the Sacramento River into Yolo Bypass under lower flows than the current weir design. Alternatives differ in the location, elevation, and width of the proposed notch in Fremont Weir; as a result, the timing, frequency, and duration of inundation of the Yolo Bypass differ between alternatives. Under all alternatives, Fremont Weir will remain a passive flow control structure with a design capacity of 6,000 cfs. Proposed alternatives include:

- Small east-side Fremont Weir Notch
- Medium east-side Fremont Weir Notch
- Large east-side Fremont Weir Notch
- Levee notch east of Fremont Weir
- Levee notch west of Freemont Weir

Analytical and Modeling Tools:
TUFLOW, developed by BMT-WBM, was chosen as it scored high in the HMAT rankings and meets the stringent requirements for the project. The approach selected was to use a single hydraulic model to evaluate benefits and impacts both within the bypass and for the larger region. The model includes simulation of existing and proposed alternatives during 16 water years, which includes the months of October through May. TUFLOW is able to meet the challenges of large computational domains and long simulation times by using a combination of 1D channels and multiple grids of varying resolution and an efficient finite-difference solver.

TUFLOW supports all the necessary features of the project such as multiple scenario management, computing flows using weir equations automatically when appropriate, and support for hydraulic structures including operational controls.

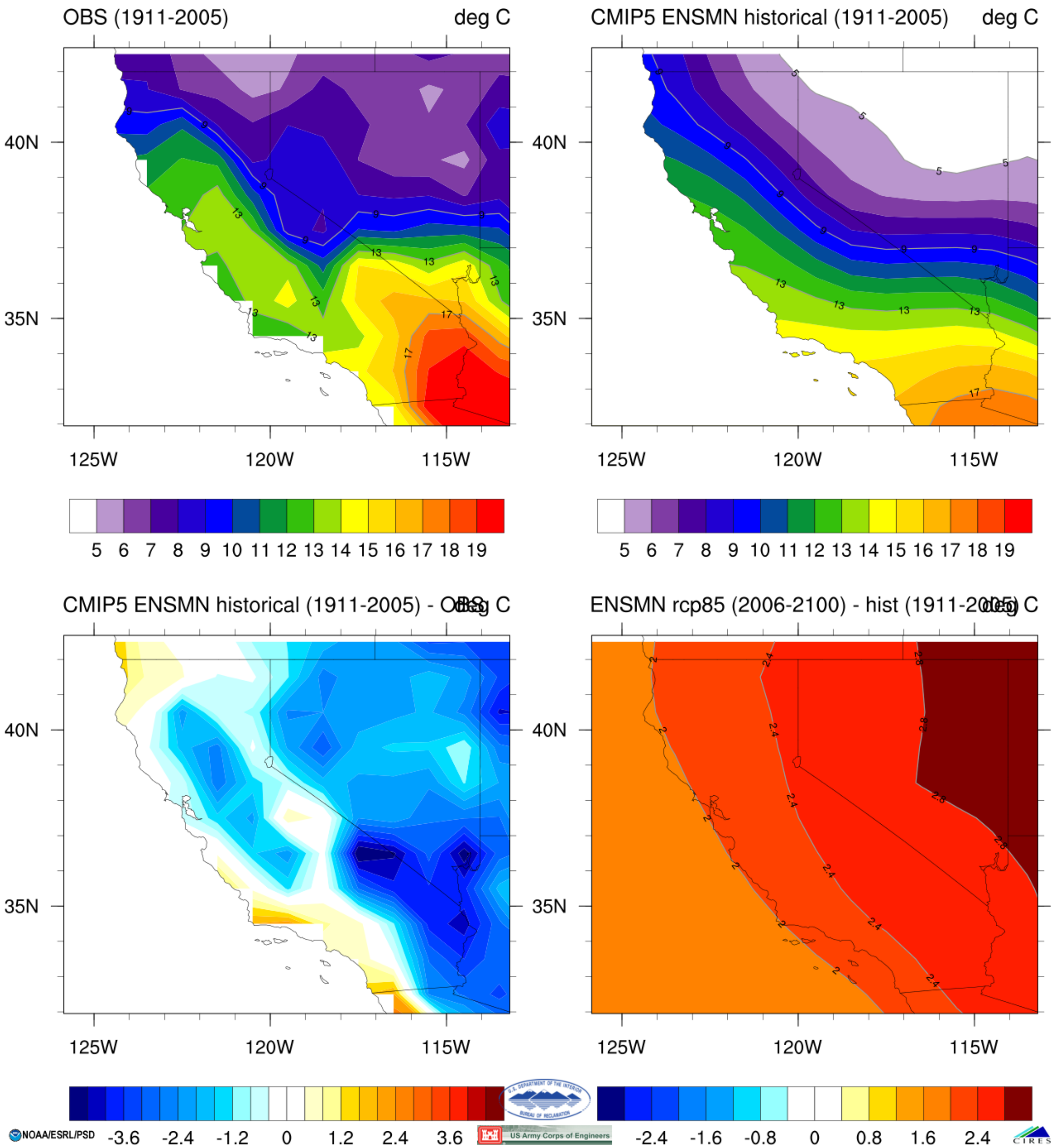


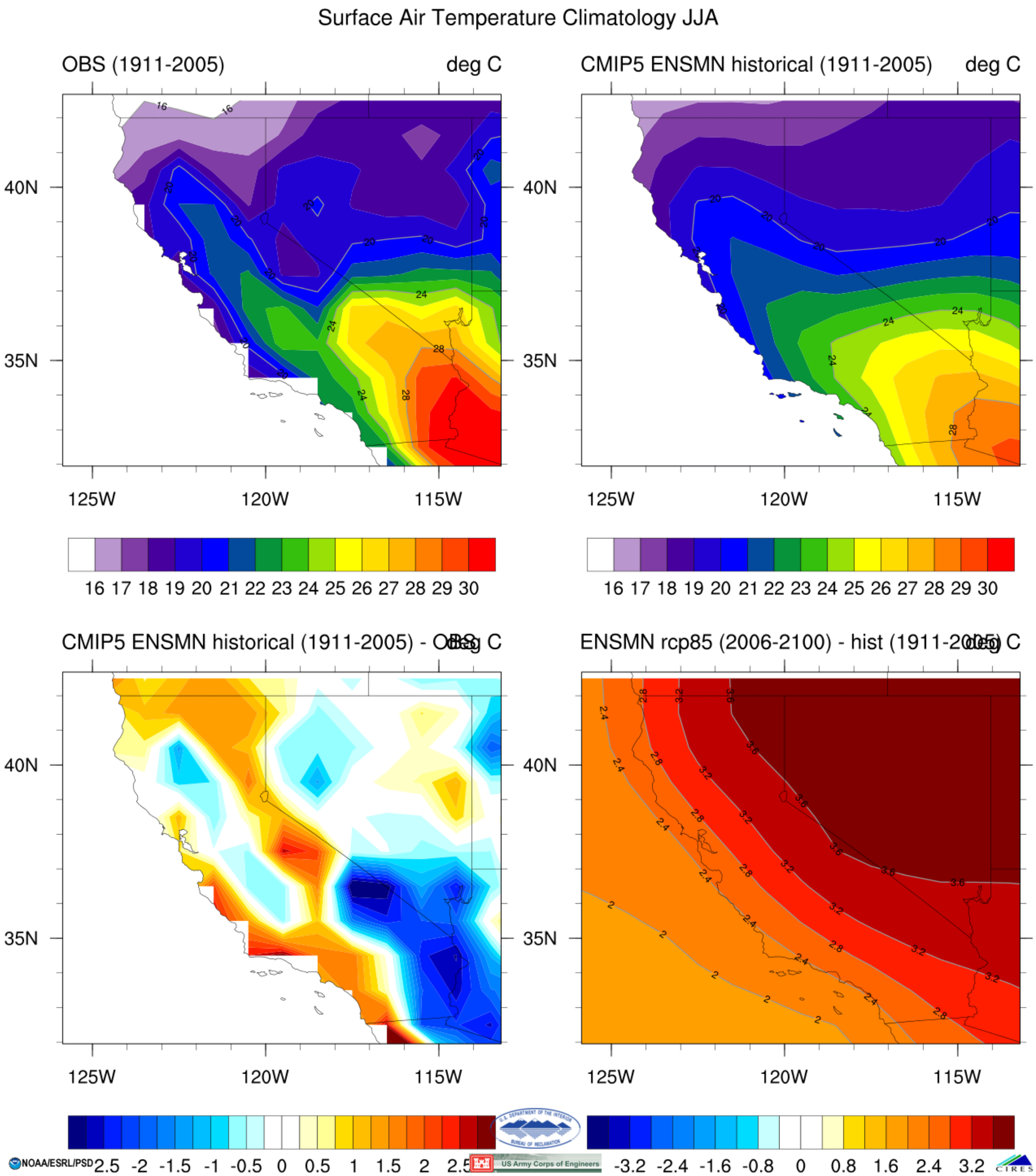
Sacramento River inflow
Sutter Bypass and Feather River inflow
Feather River
Sacramento Slough
Natomas Cross Canal inflow
Outfall Gates
Fremont Weir
Knights Landing Ridge Cut inflow
Elkhorn area to be added later
Cache Creek Settling Basin Overflow Weir inflow
Sacramento Weir
American River inflow
Cache Creek Settling Basin Low Flow Outlet inflow
Steelhead Creek (NEMDC) inflow
Willow Slough Bypass inflow
Putah Creek inflow
No hydraulic connection
No levee
Los Rios Check Dam
No hydraulic connection
Elk Slough
Haas Slough
Deep Water Ship Channel
Upper Cache Slough
Sutter Slough
Lindsey Slough
Miner Slough
NBA Pumps
Delta Cross Channel Dayflow boundary
Barker Slough
Calhoun Cut
Georgiana Slough Dayflow boundary
Streamboat Slough
Rio Vista tidal boundary
0 3 6
Miles
Legend
Restricted height levees
1D channels
Levees
2D domain - 200' x 200'
2D domain - 400' x 400'
2D domain - 100' x 100'

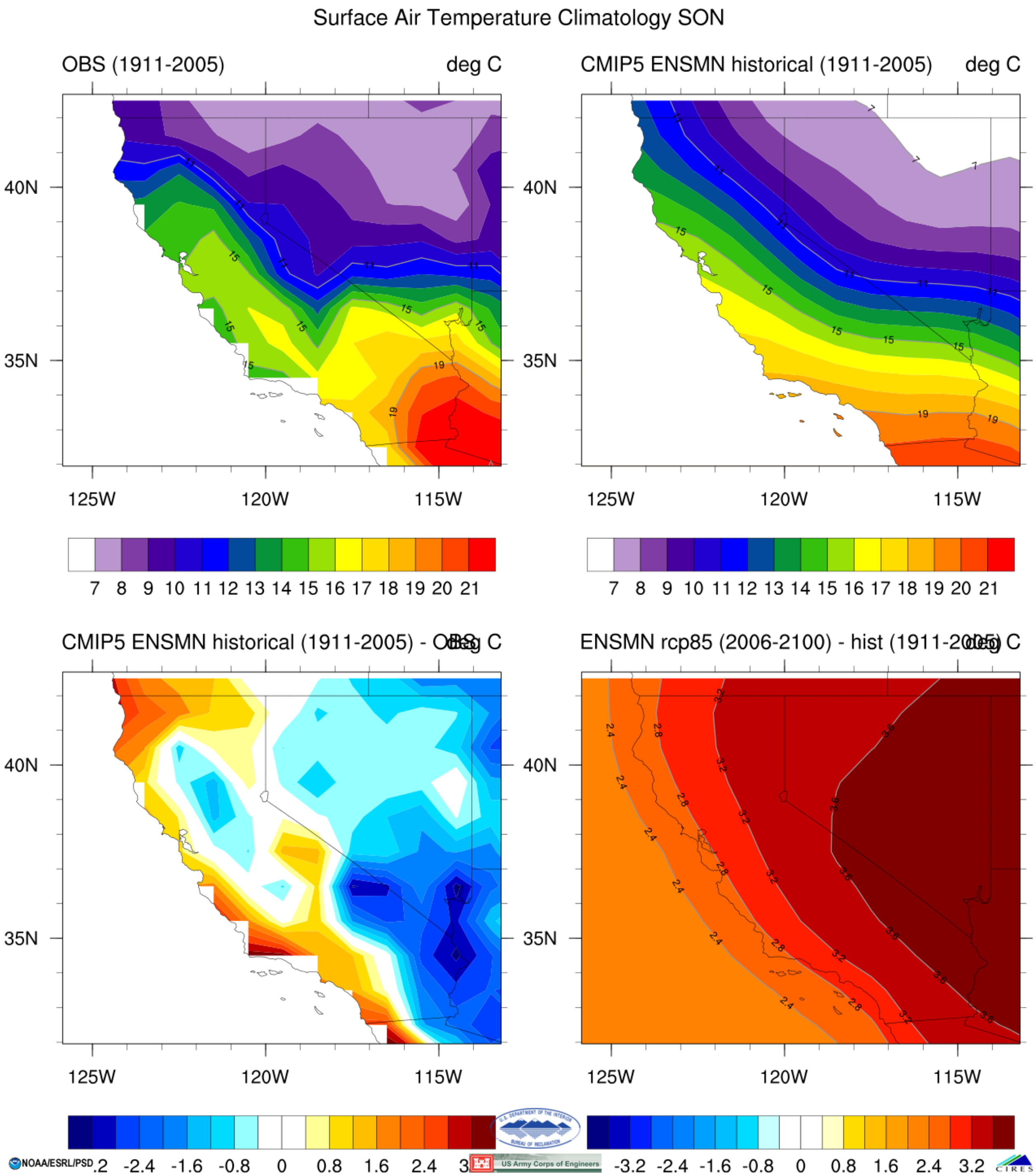
APPENDIX 3.5

Selected Results from CMIP5 Model Evaluation (Handout)

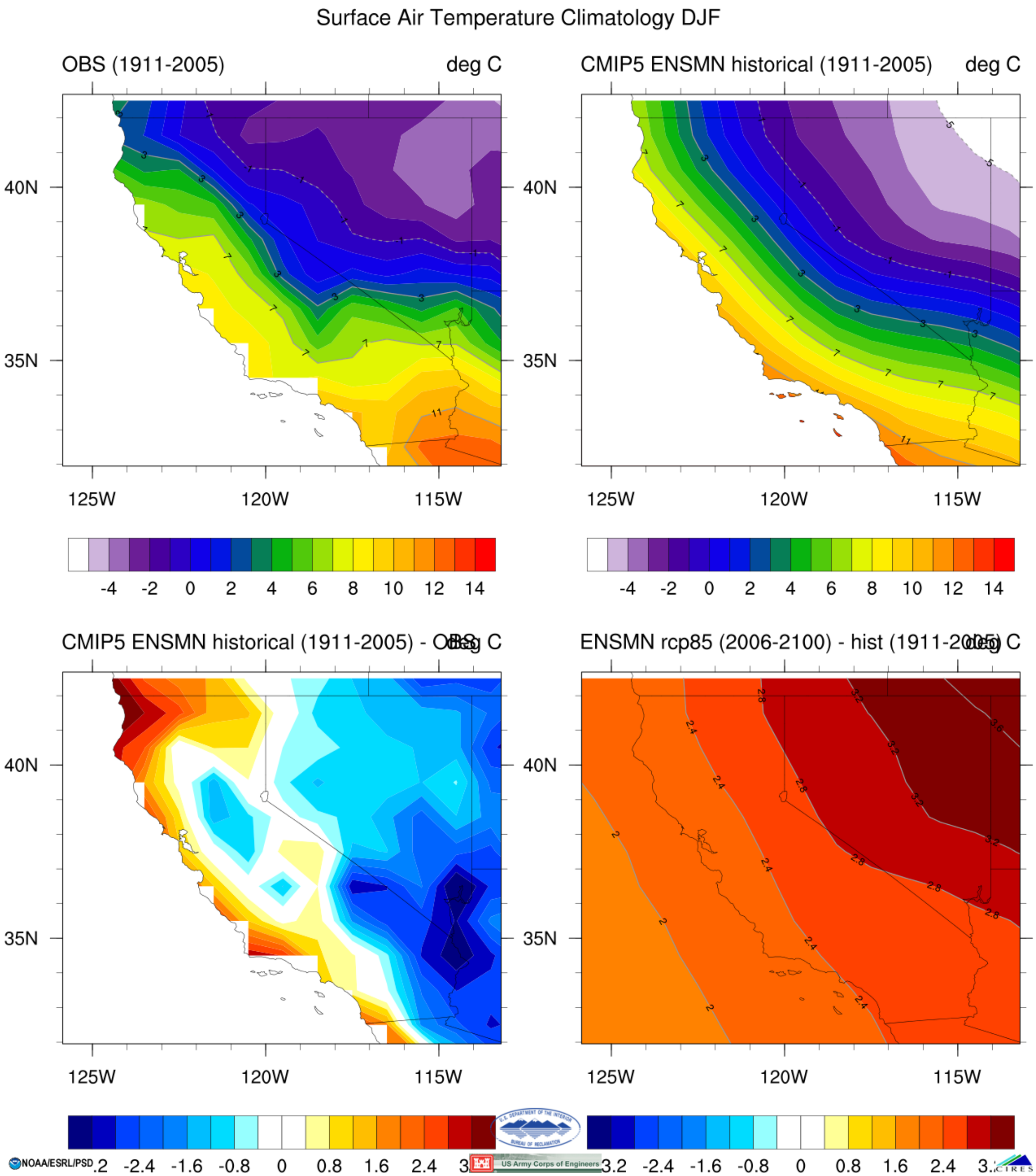
Surface Air Temperature Climatology MAM

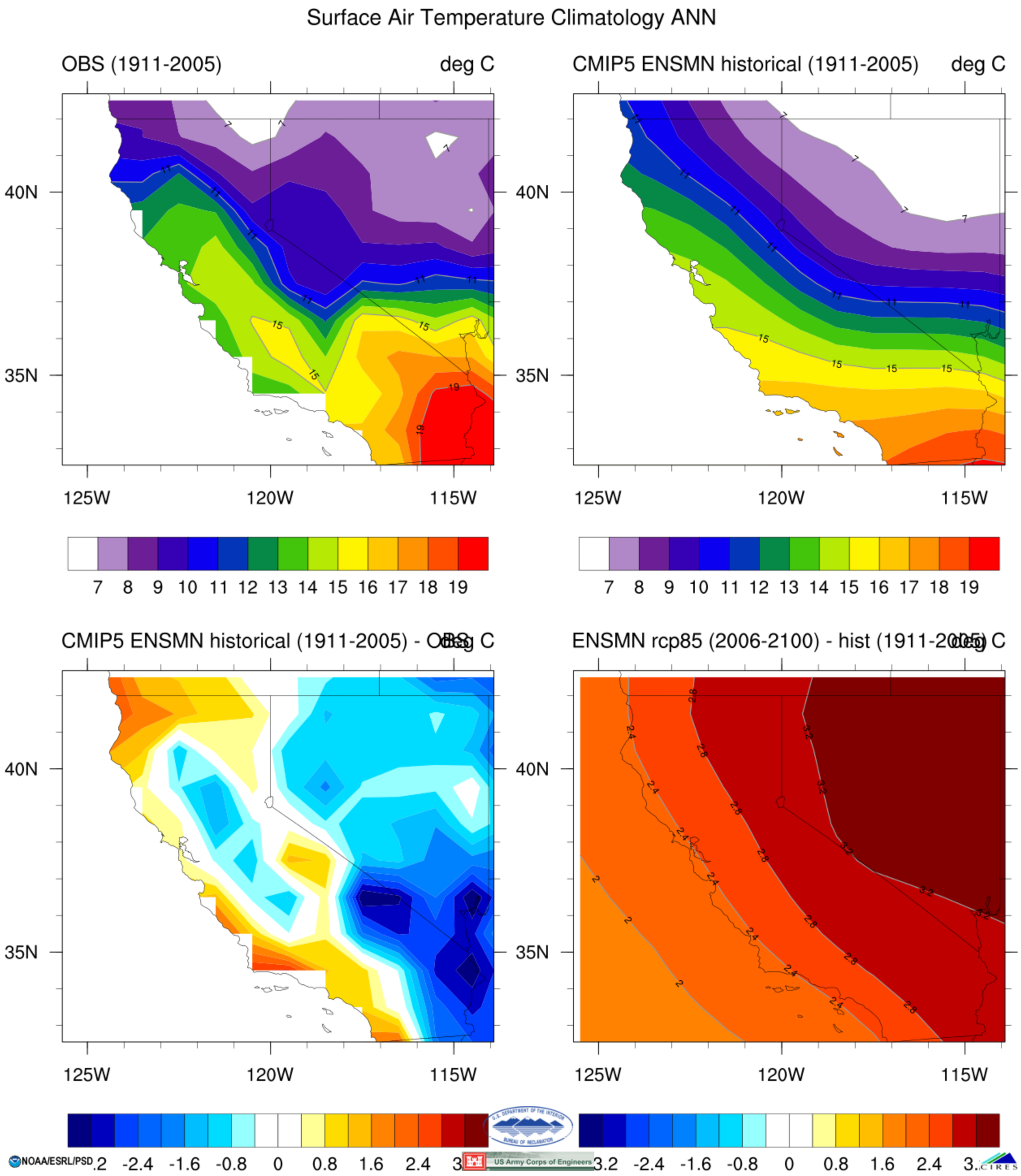


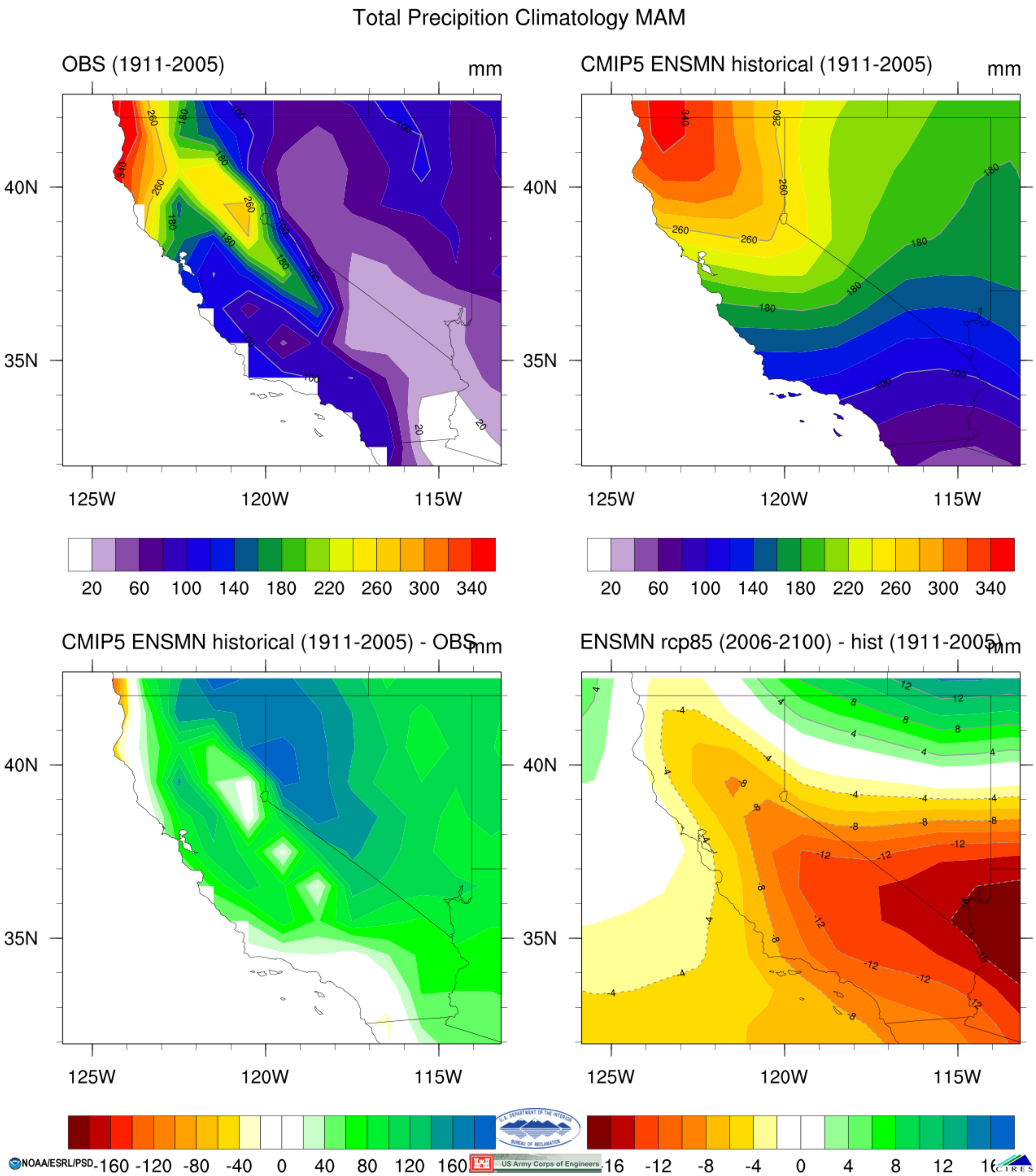

Surface Air Temperature Climatology JJA
OBS (1911-2005)
deg C
CMIP5 ENSMN historical (1911-2005)
deg C
40N
35N
125W
120W
115W
16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
CMIP5 ENSMN historical (1911-2005) - OBS
deg C
ENSMN rcp85 (2006-2100) - hist (1911-2005)
deg C
-2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5
-3.2 -2.4 -1.6 -0.8 0 0.8 1.6 2.4 3.2
NOAA/ESRL/PSD
US Army Corps of Engineers
CIRES



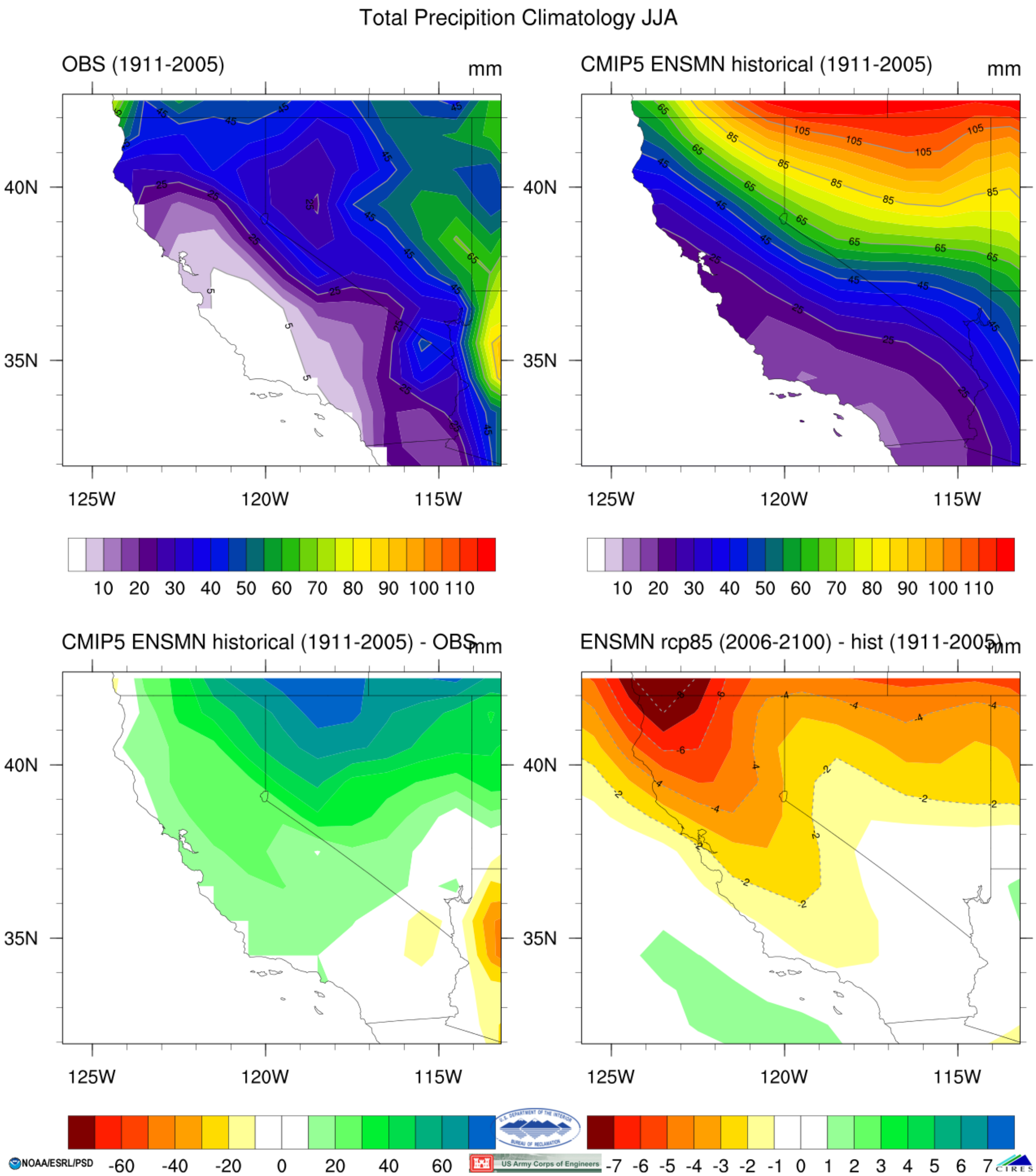
Surface Air Temperature Climatology SON
OBS (1911-2005)
deg C
CMIP5 ENSMN historical (1911-2005)
deg C
40N
35N
125W
120W
115W
7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
CMIP5 ENSMN historical (1911-2005) - OBS
deg C
ENSMN rcp85 (2006-2100) - hist (1911-2005)
deg C
-2.4 -1.6 -0.8 0 0.8 1.6 2.4
-3.2 -2.4 -1.6 -0.8 0 0.8 1.6 2.4 3.2
NOAA/ESRL/PSD
US Army Corps of Engineers

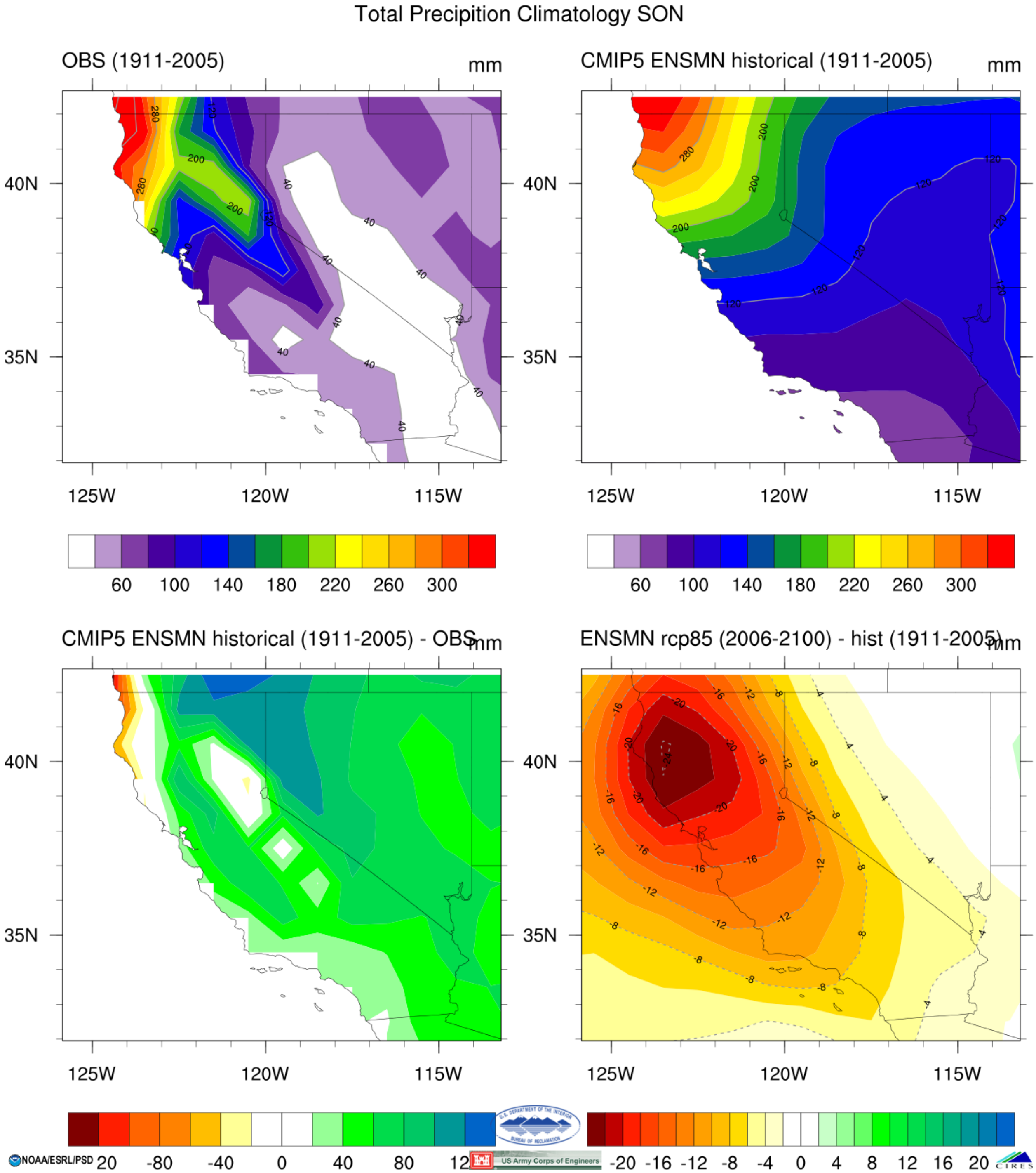

Surface Air Temperature Climatology DJF
OBS (1911-2005)
deg C
CMIP5 ENSMN historical (1911-2005)
deg C
CMIP5 ENSMN historical (1911-2005) - OBS
deg C
ENSMN rcp85 (2006-2100) - hist (1911-2005)
deg C
40N
35N
125W
120W
115W
-4 -2 0 2 4 6 8 10 12 14
-2.4 -1.6 -0.8 0 0.8 1.6 2.4
NOAA/ESRL/PSD
US Army Corps of Engineers
CIRES


Surface Air Temperature Climatology ANN
OBS (1911-2005)
deg C
CMIP5 ENSMN historical (1911-2005)
deg C
CMIP5 ENSMN historical (1911-2005) - OBS
deg C
ENSMN rcp85 (2006-2100) - hist (1911-2005)
deg C
40N
35N
125W
120W
115W
7 8 9 10 11 12 13 14 15 16 17 18 19
-2.4 -1.6 -0.8 0 0.8 1.6 2.4
NOAA/ESRL/PSD
US Army Corps of Engineers
CIRES



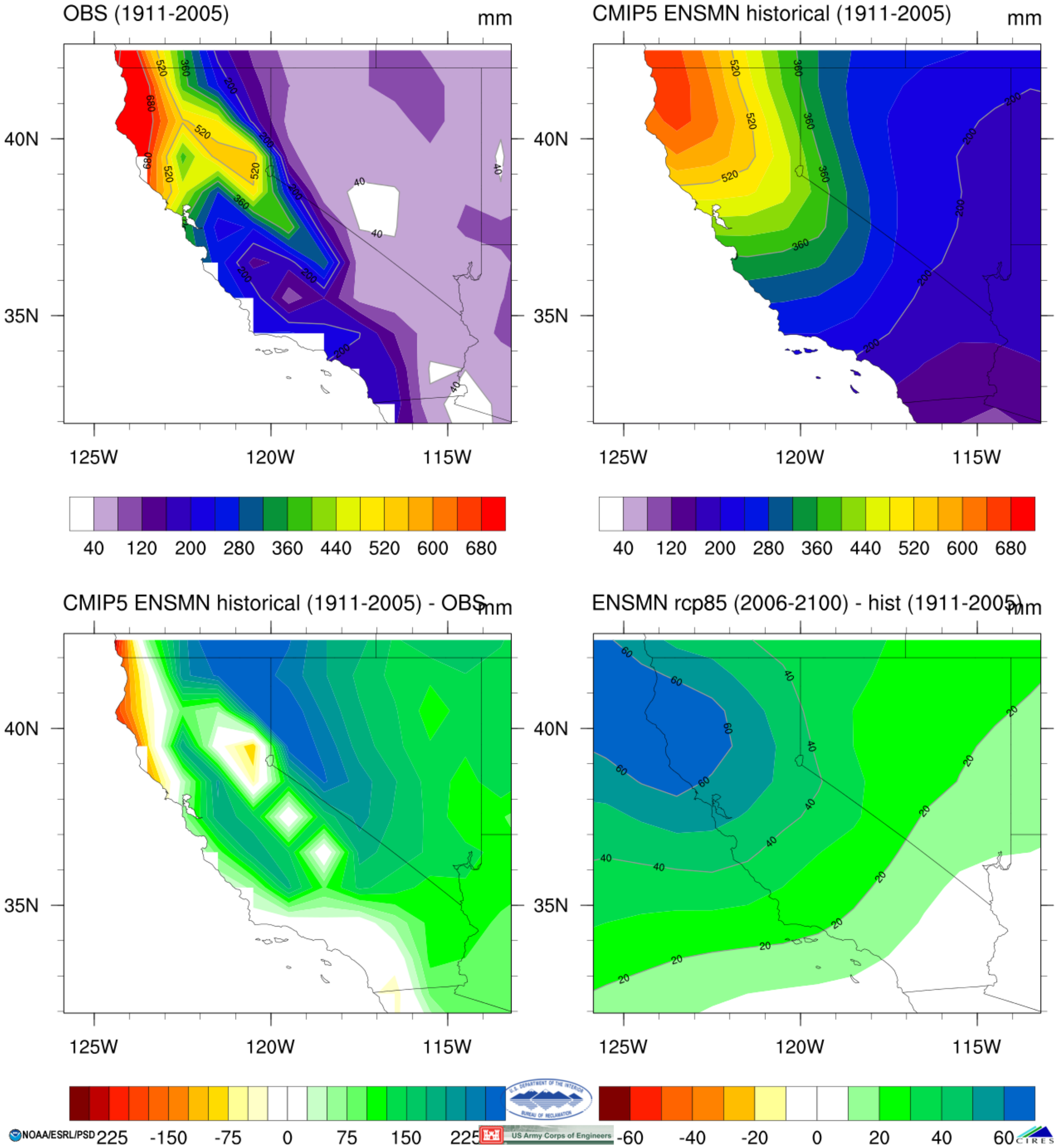
Total Precipition Climatology MAM
OBS (1911-2005)
mm
CMIP5 ENSMN historical (1911-2005)
mm
20 60 100 140 180 220 260 300 340
CMIP5 ENSMN historical (1911-2005) - OBS
mm
ENSMN rcp85 (2006-2100) - hist (1911-2005)
mm
40N
35N
125W 120W 115W
-160 -120 -80 -40 0 40 80 120 160
-16 -12 -8 -4 0 4 8 12 16
NOAA/ESRL/PSD
US Army Corps of Engineers
CIRES

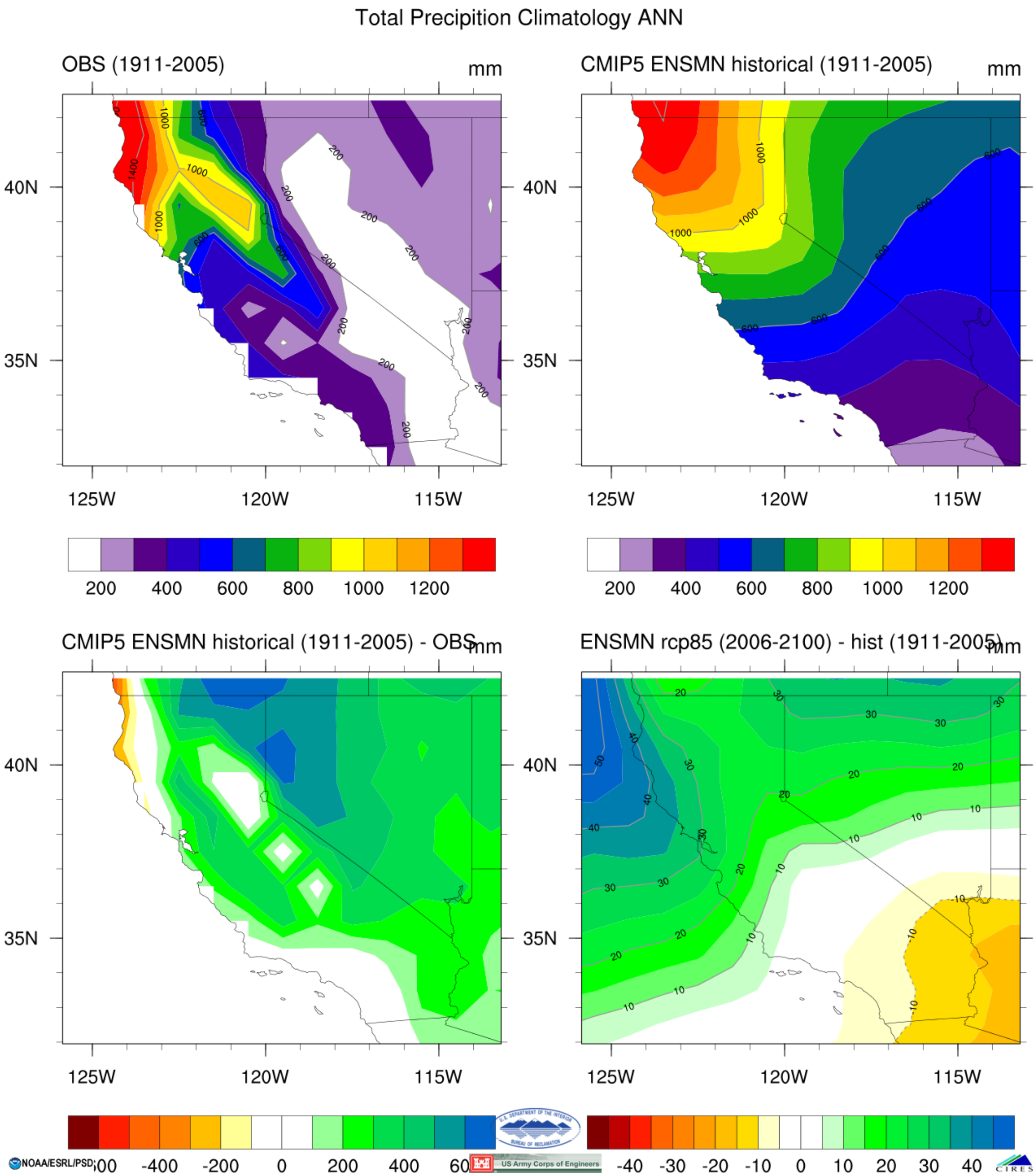

Total Precipition Climatology JJA
OBS (1911-2005)
CMIP5 ENSMN historical (1911-2005)
CMIP5 ENSMN historical (1911-2005) - OBS
ENSMN rcp85 (2006-2100) - hist (1911-2005)
mm
40N
35N
125W
120W
115W
10 20 30 40 50 60 70 80 90 100 110
-60 -40 -20 0 20 40 60
-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
NOAA/ESRL/PSD
US Army Corps of Engineers
CIRES



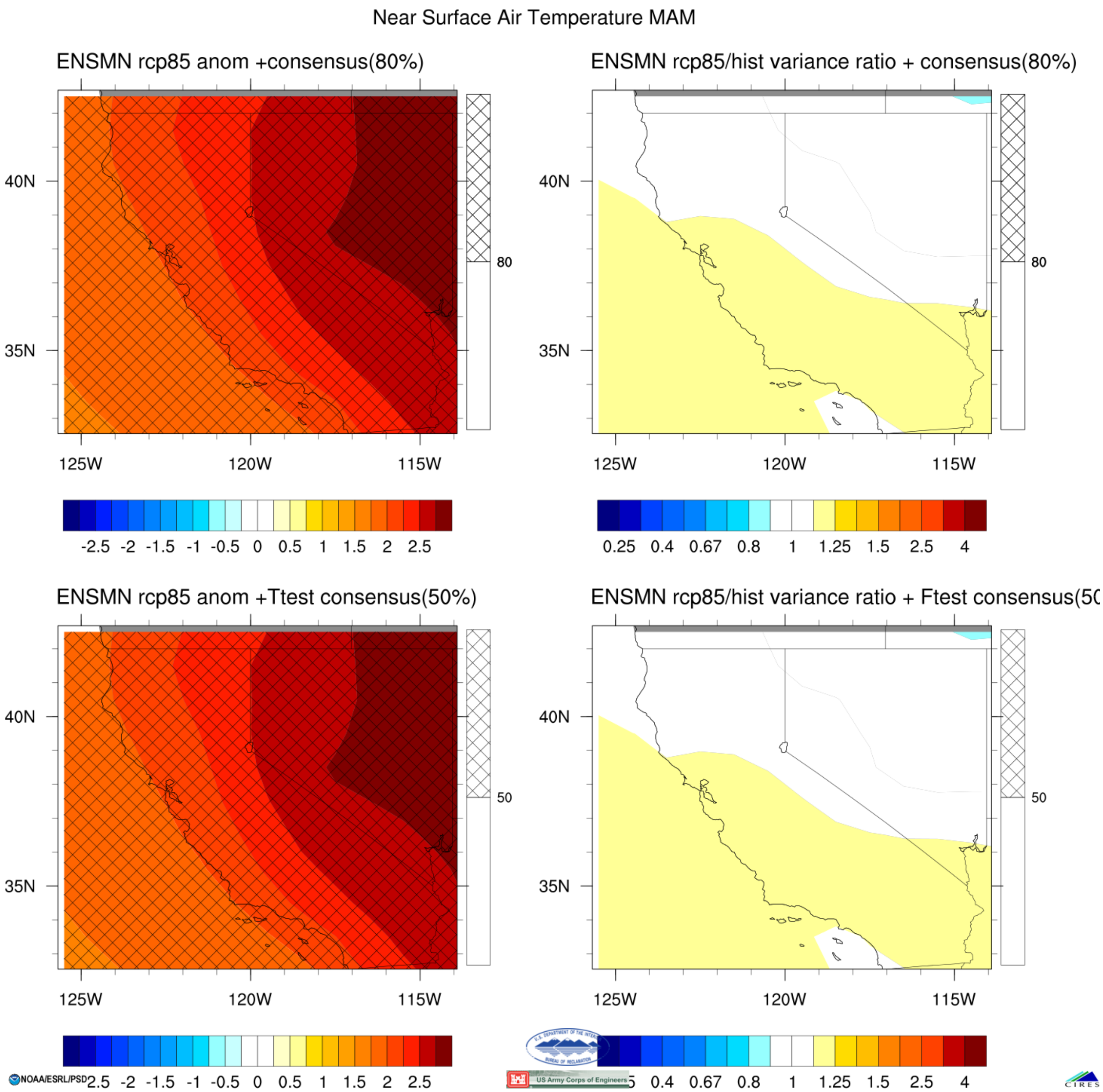
Total Precipition Climatology SON
OBS (1911-2005)
mm
CMIP5 ENSMN historical (1911-2005)
mm
CMIP5 ENSMN historical (1911-2005) - OBS
mm
ENSMN rcp85 (2006-2100) - hist (1911-2005)
mm
40N
35N
125W
120W
115W
60 100 140 180 220 260 300
20 -80 -40 0 40 80 12
-20 -16 -12 -8 -4 0 4 8 12 16 20
NOAA/ESRL/PSD
US Army Corps of Engineers
CIRES

Total Precipition Climatology DJF



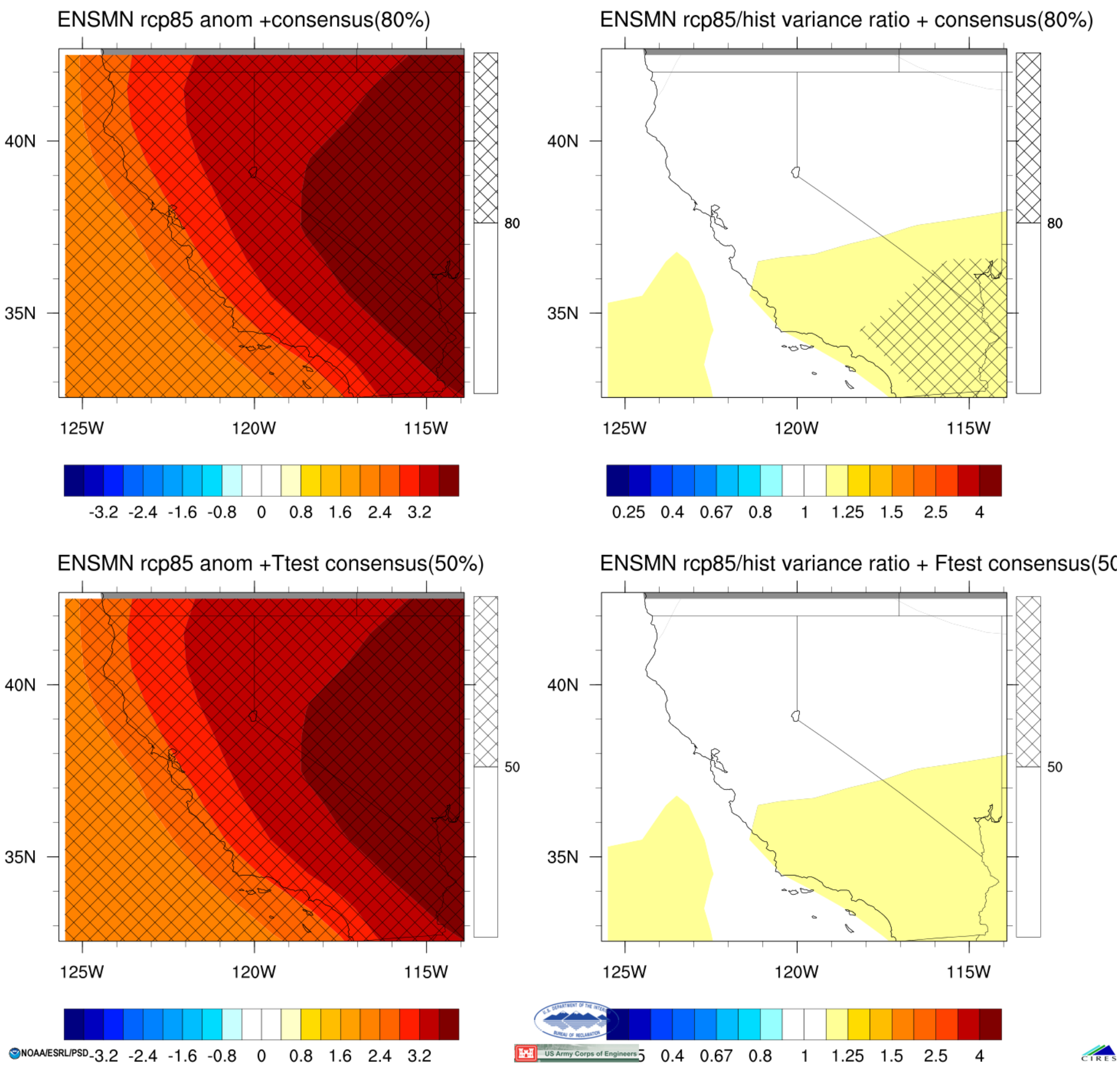


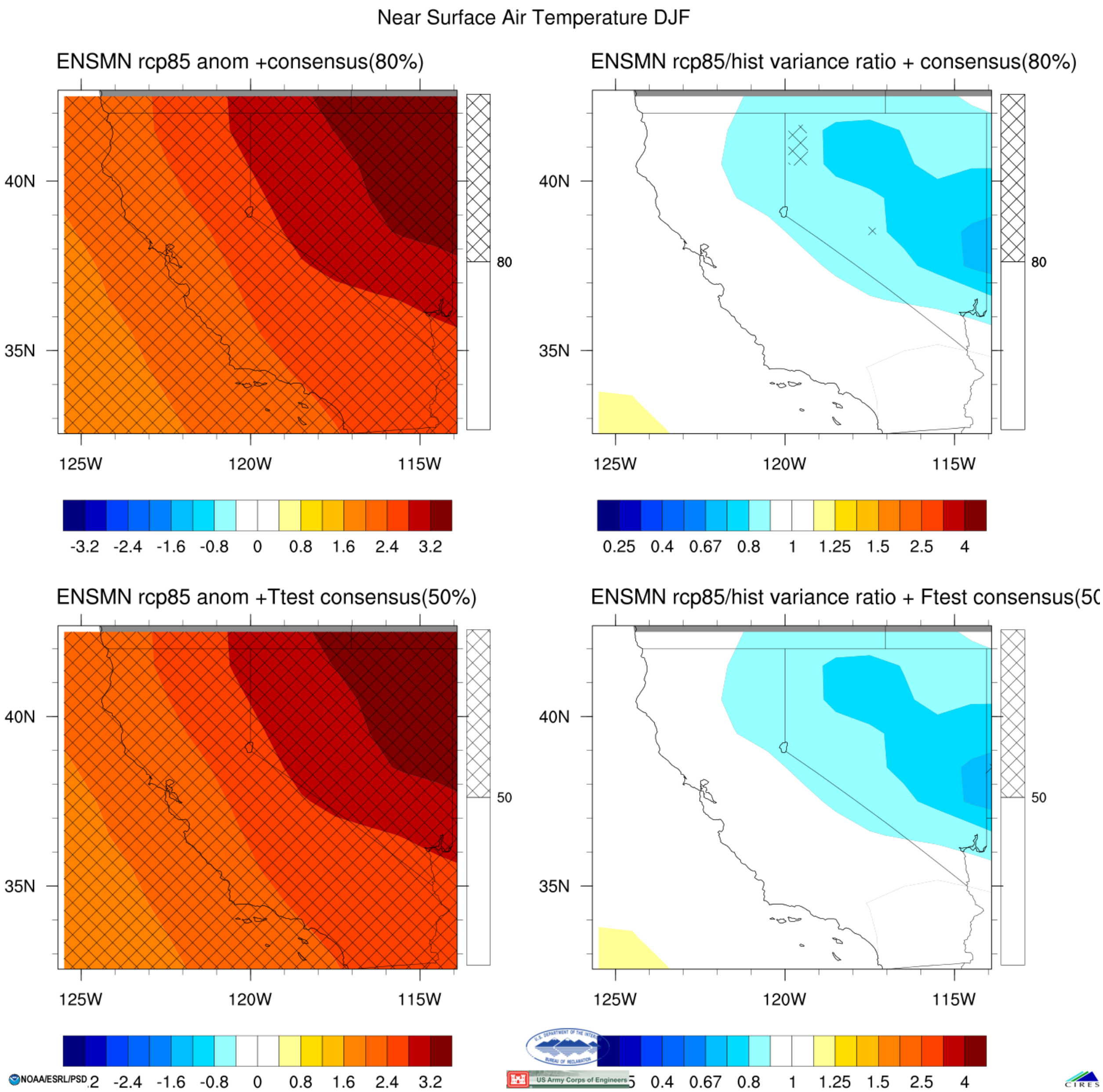
Total Precipition Climatology ANN
OBS (1911-2005)
mm
CMIP5 ENSMN historical (1911-2005)
mm
CMIP5 ENSMN historical (1911-2005) - OBS
mm
ENSMN rcp85 (2006-2100) - hist (1911-2005)
mm
125W
120W
115W
40N
35N
200
400
600
800
1000
1200
-400
-200
0
200
400
-40
-30
-20
-10
0
10
20
30
40
NOAA/ESRL/PSD
US Army Corps of Engineers
CIRES



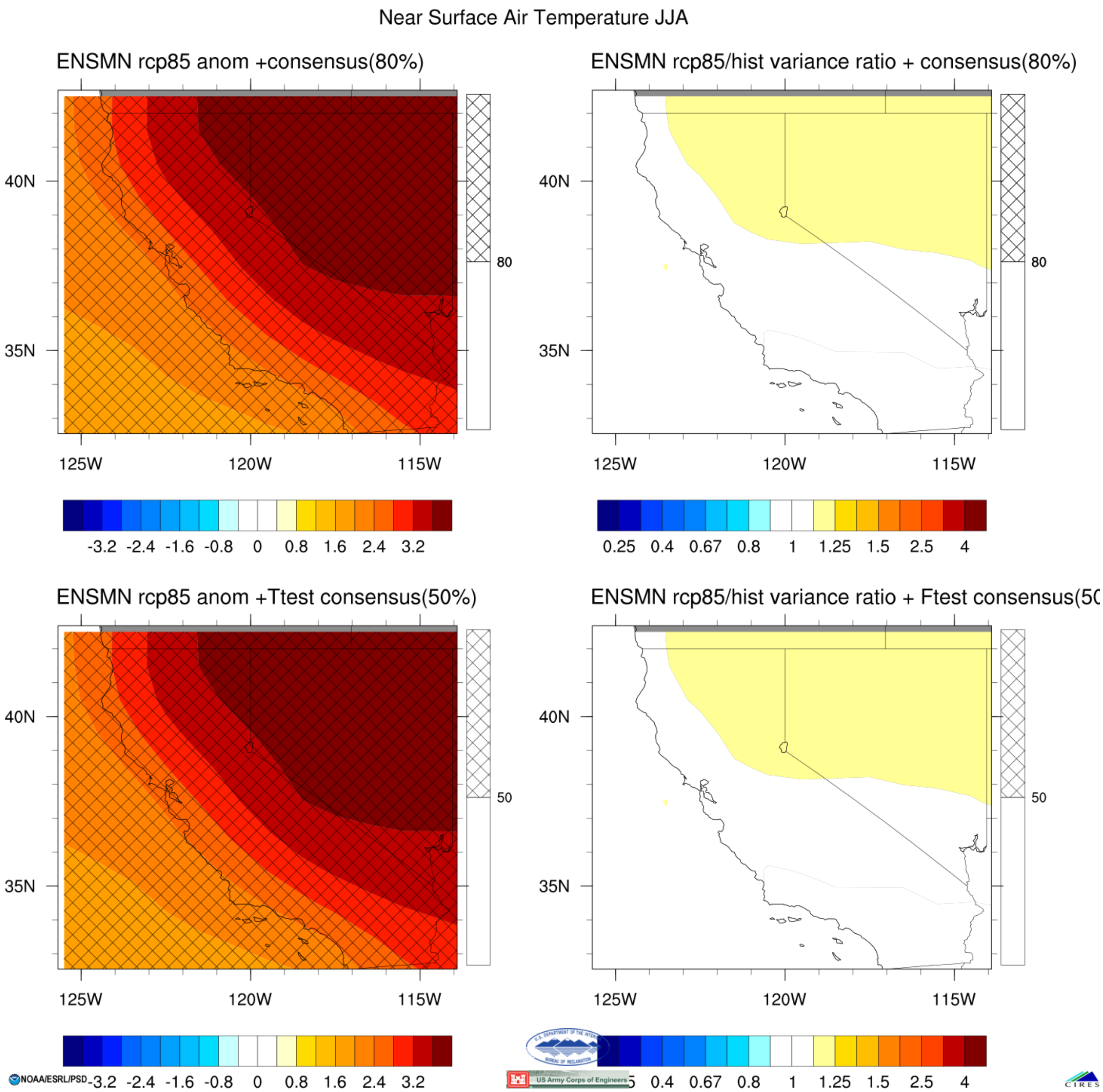
Near Surface Air Temperature MAM
ENSMN rcp85 anom +consensus(80%)
ENSMN rcp85/hist variance ratio + consensus(80%)
ENSMN rcp85 anom +Ttest consensus(50%)
ENSMN rcp85/hist variance ratio + Ftest consensus(5(
40N
35N
125W
120W
115W
80
50
-2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5
0.25 0.4 0.67 0.8 1 1.25 1.5 2.5 4
NOAA/ESRL/PSD
US Army Corps of Engineers
CIRES

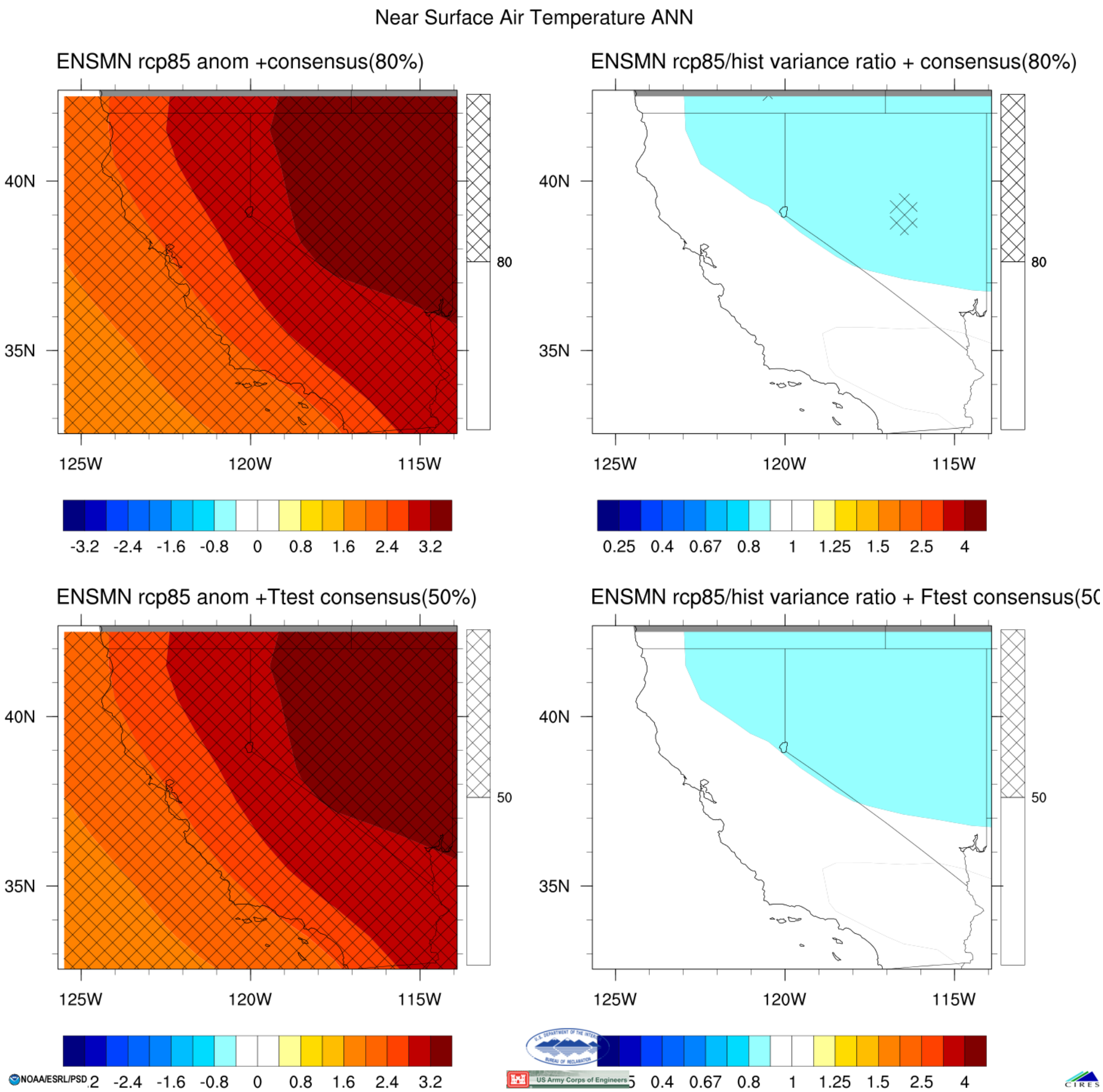
Near Surface Air Temperature SON

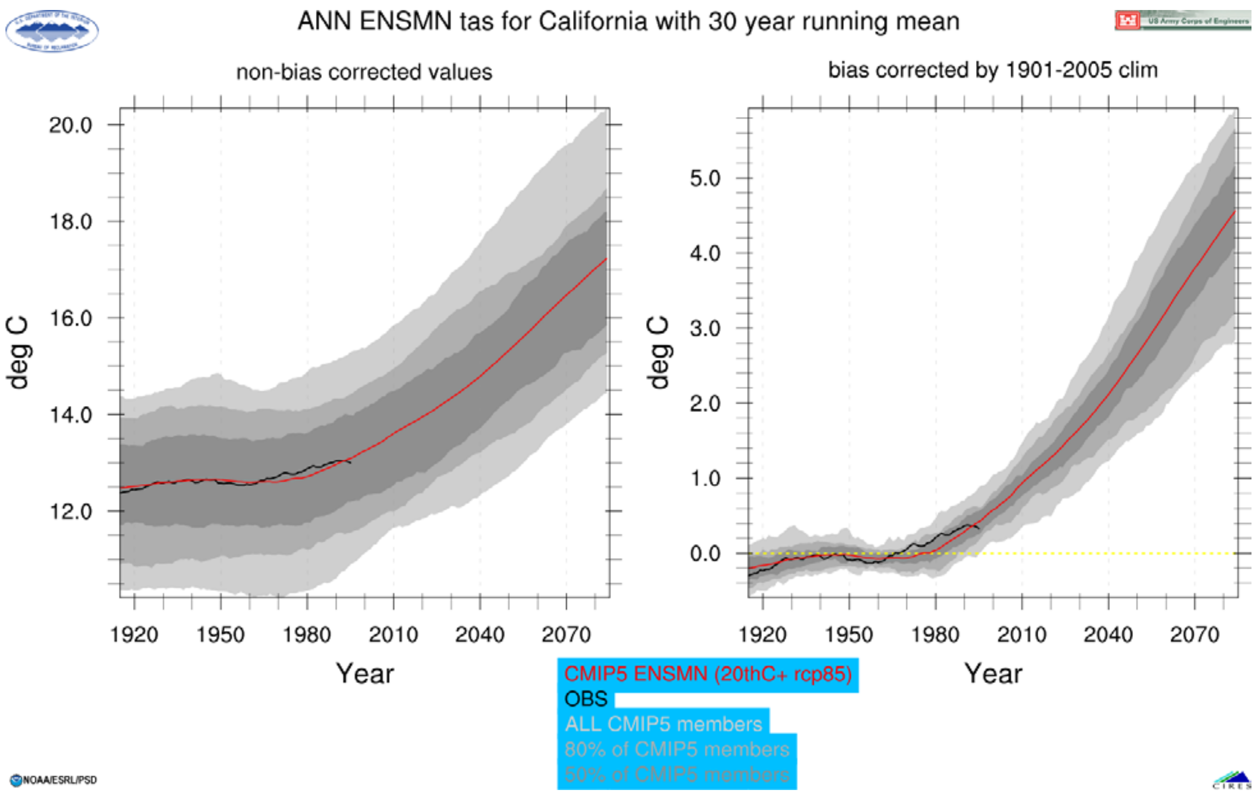


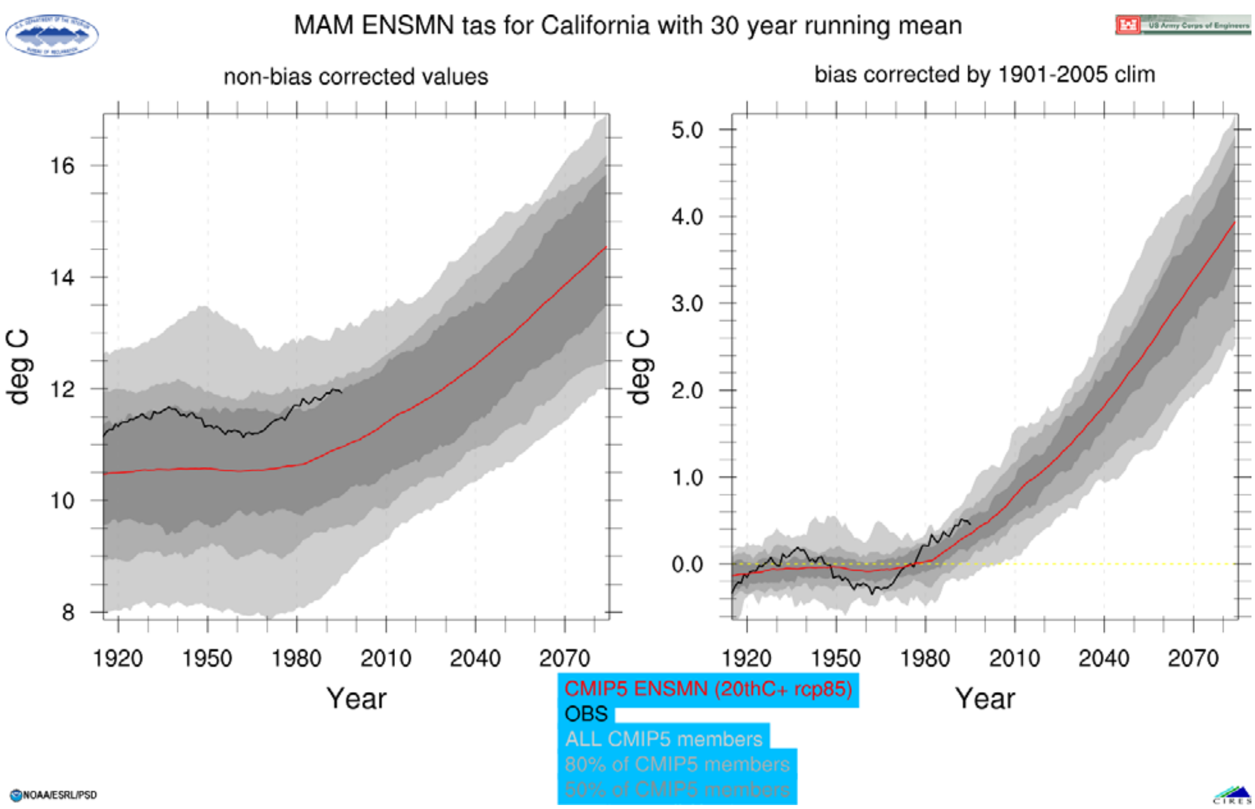


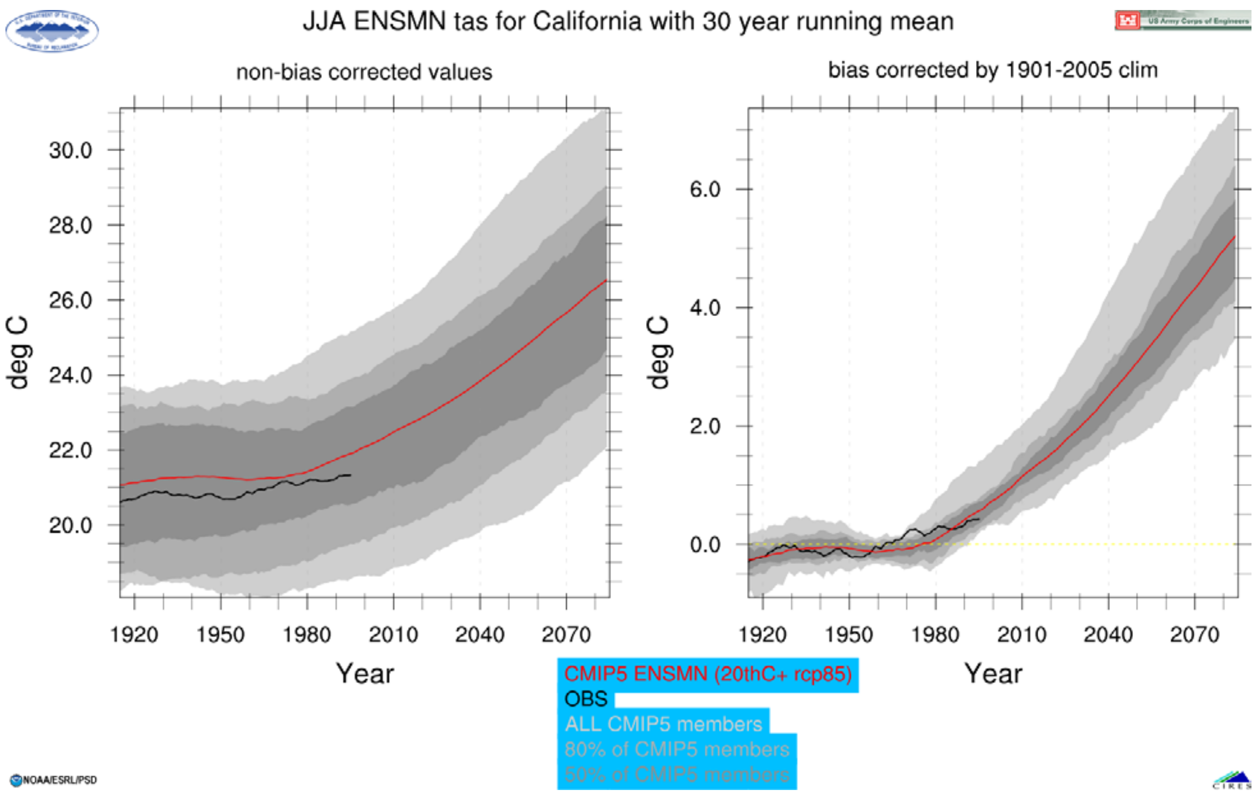
Near Surface Air Temperature DJF
ENSMN rcp85 anom +consensus(80%)
ENSMN rcp85/hist variance ratio + consensus(80%)
40N
35N
125W
120W
115W
80
-3.2 -2.4 -1.6 -0.8 0 0.8 1.6 2.4 3.2
0.25 0.4 0.67 0.8 1 1.25 1.5 2.5 4
ENSMN rcp85 anom +Ttest consensus(50%)
ENSMN rcp85/hist variance ratio + Ftest consensus(5(
50
NOAA/ESRL/PSD
US Army Corps of Engineers

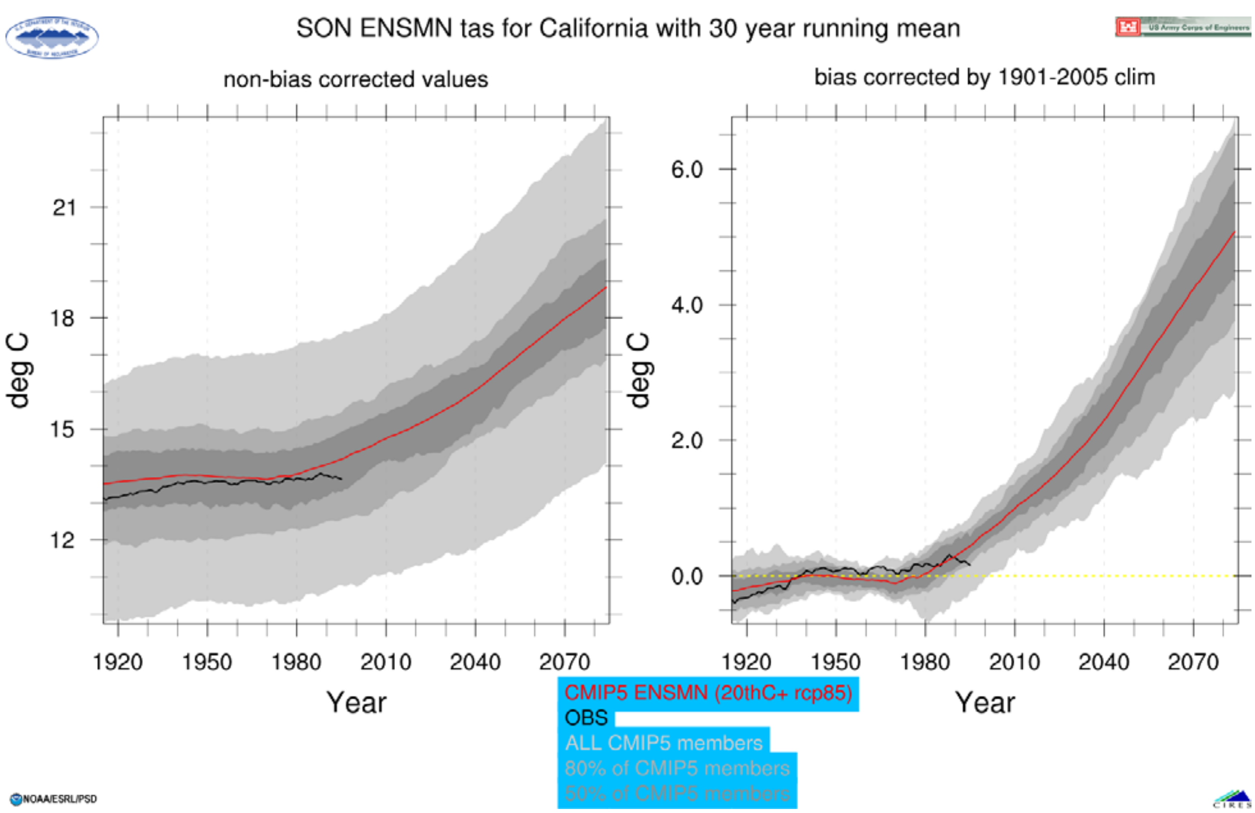

Near Surface Air Temperature JJA
ENSMN rcp85 anom +consensus(80%)
ENSMN rcp85/hist variance ratio + consensus(80%)
ENSMN rcp85 anom +Ttest consensus(50%)
ENSMN rcp85/hist variance ratio + Ftest consensus(5(
40N
35N
125W
120W
115W
80
50
-3.2 -2.4 -1.6 -0.8 0 0.8 1.6 2.4 3.2
0.25 0.4 0.67 0.8 1 1.25 1.5 2.5 4
NOAA/ESRL/PSD
US Army Corps of Engineers
CIRES

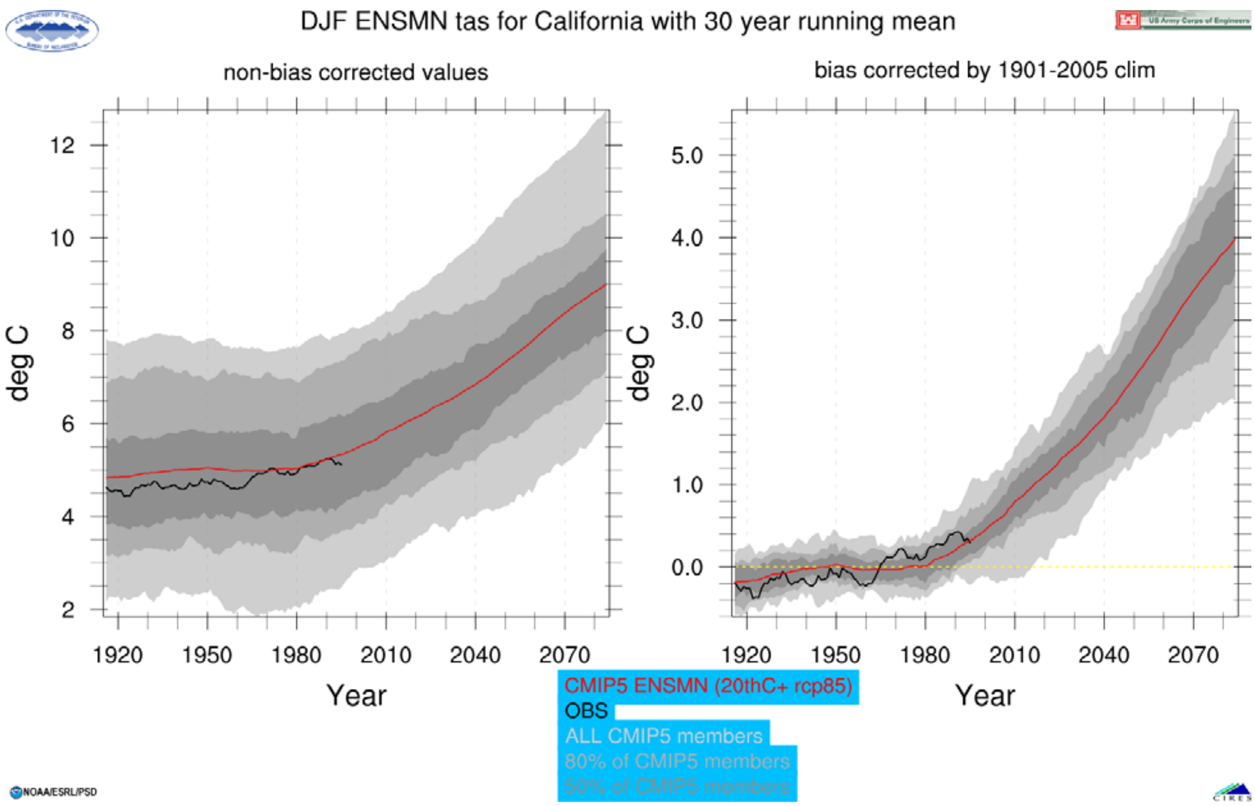

Near Surface Air Temperature ANN
ENSMN rcp85 anom +consensus(80%)
ENSMN rcp85/hist variance ratio + consensus(80%)
ENSMN rcp85 anom +Ttest consensus(50%)
ENSMN rcp85/hist variance ratio + Ftest consensus(5(
40N
35N
125W
120W
115W
80
50
-3.2 -2.4 -1.6 -0.8 0 0.8 1.6 2.4 3.2
0.25 0.4 0.67 0.8 1 1.25 1.5 2.5 4
NOAA/ESRL/PSD
US Army Corps of Engineers
CIRES

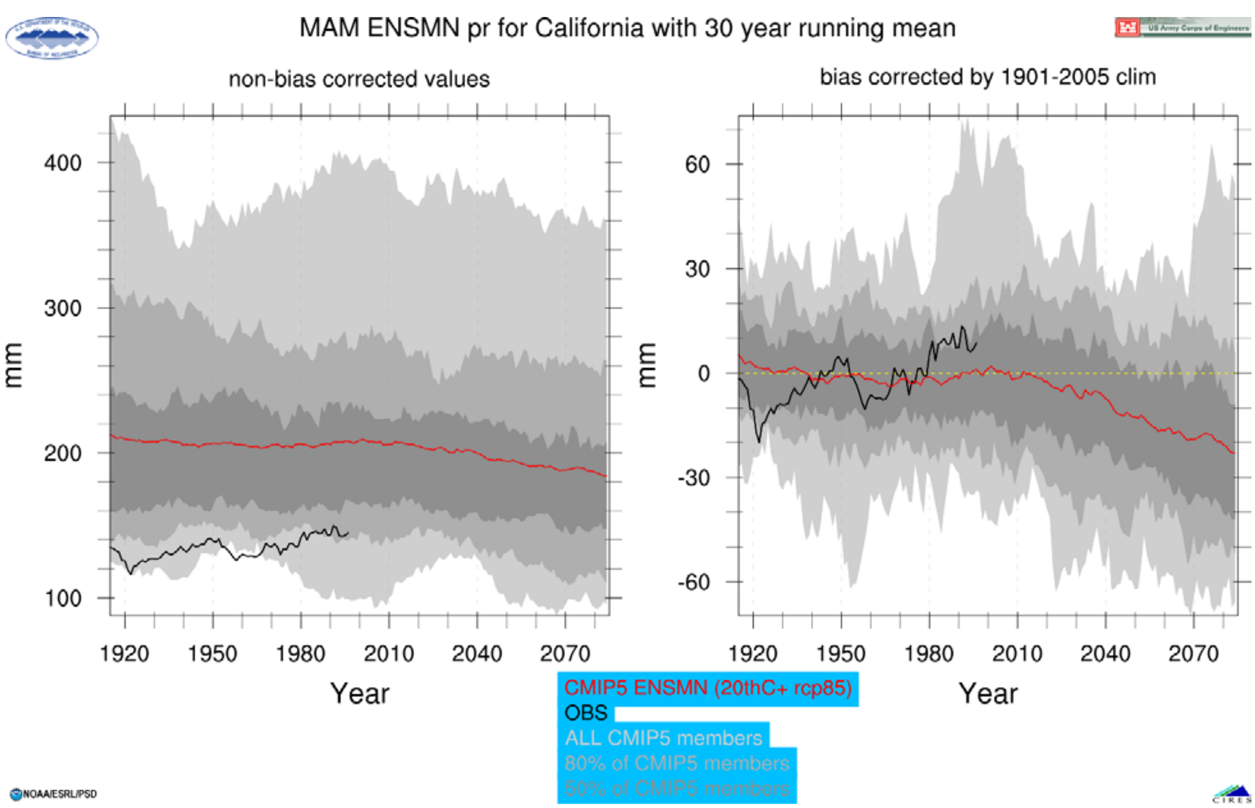

ANN ENSMN tas for California with 30 year running mean
non-bias corrected values
bias corrected by 1901-2005 clim
deg C
20.0
18.0
16.0
14.0
12.0
5.0
4.0
3.0
2.0
1.0
0.0
1920
1950
1980
2010
2040
2070
Year
CMIP5 ENSMN (20thC+ rcp85)
OBS
ALL CMIP5 members
80% of CMIP5 members
50% of CMIP5 members
NOAA/ESRL/PSD

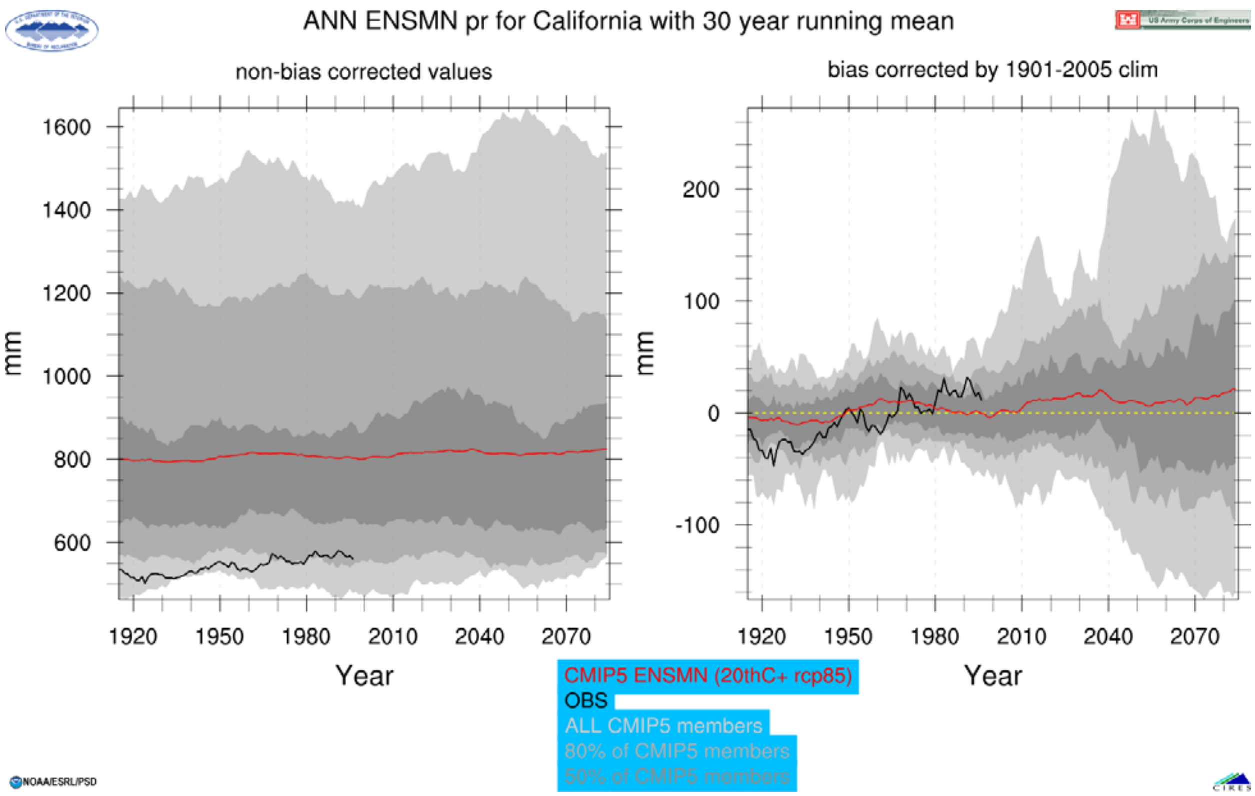

MAM ENSMN tas for California with 30 year running mean
non-bias corrected values
bias corrected by 1901-2005 clim
deg C
16
14
12
10
8
5.0
4.0
3.0
2.0
1.0
0.0
1920
1950
1980
2010
2040
2070
Year
CMIP5 ENSMN (20thC+ rcp85)
OBS
ALL CMIP5 members
80% of CMIP5 members
50% of CMIP5 members
NOAA/ESRL/PSD

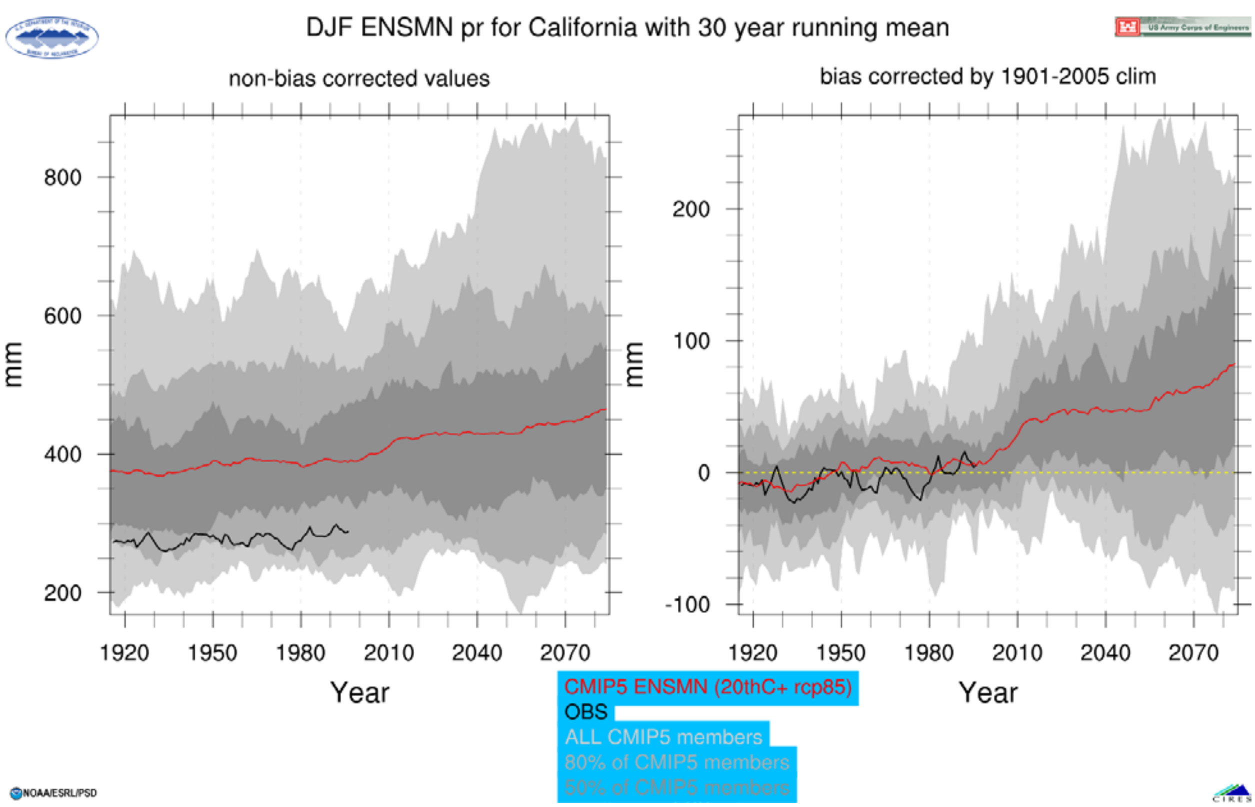

JJA ENSMN tas for California with 30 year running mean
non-bias corrected values
bias corrected by 1901-2005 clim
deg C
Year
CMIP5 ENSMN (20thC+ rcp85)
OBS
ALL CMIP5 members
80% of CMIP5 members
50% of CMIP5 members
NOAA/ESRL/PSD

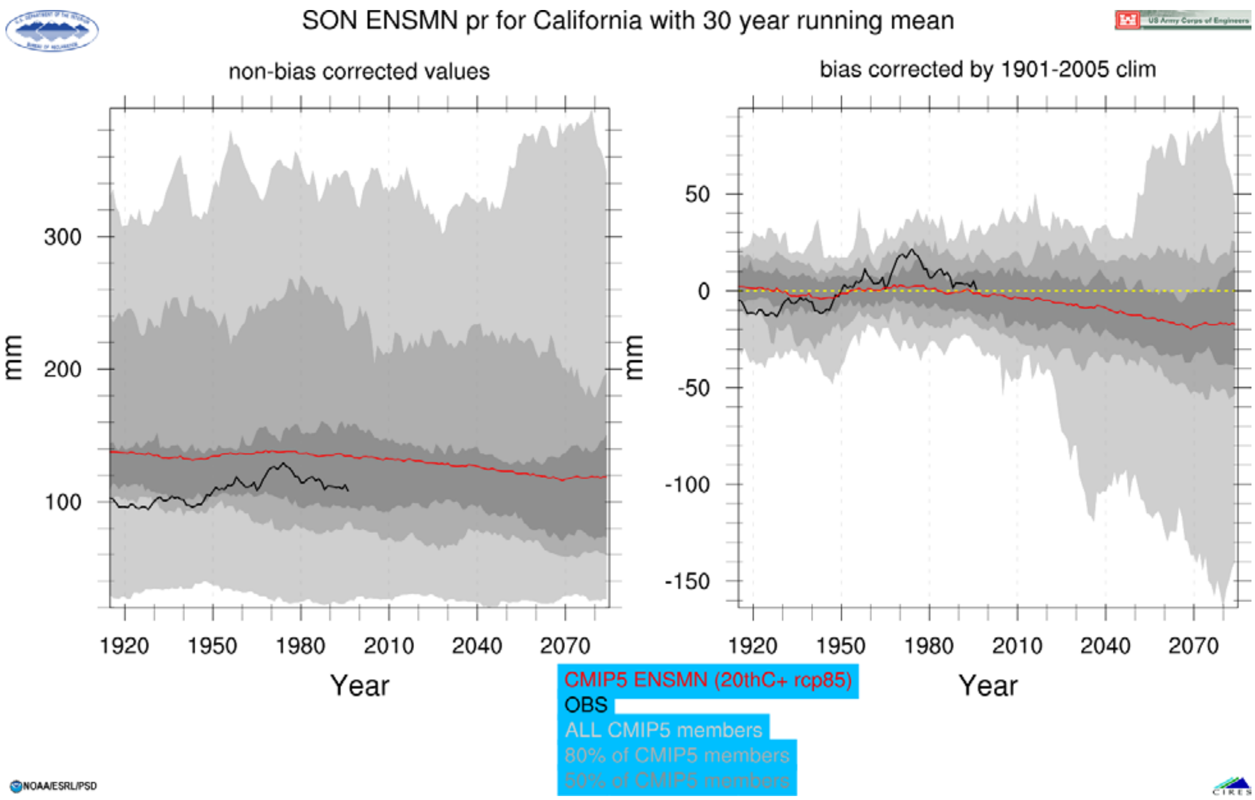

SON ENSMN tas for California with 30 year running mean
non-bias corrected values
bias corrected by 1901-2005 clim
deg C
Year
CMIP5 ENSMN (20thC+ rcp85)
OBS
ALL CMIP5 members
80% of CMIP5 members
50% of CMIP5 members
NOAA/ESRL/PSD

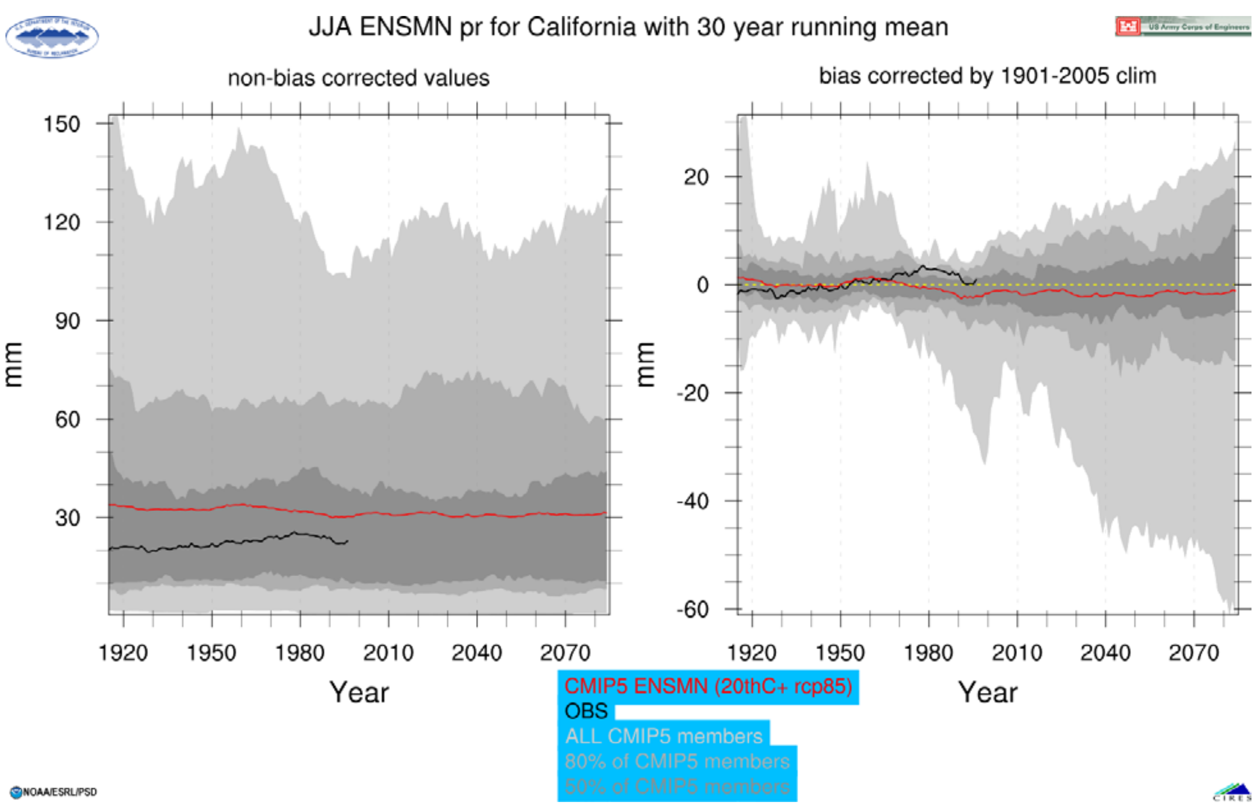

DJF ENSMN tas for California with 30 year running mean
non-bias corrected values
bias corrected by 1901-2005 clim
deg C
Year
CMIP5 ENSMN (20thC+ rcp85)
OBS
ALL CMIP5 members
80% of CMIP5 members
50% of CMIP5 members
NOAA/ESRL/PSD


MAM ENSMN pr for California with 30 year running mean
non-bias corrected values
bias corrected by 1901-2005 clim
mm
Year
CMIP5 ENSMN (20thC+ rcp85)
OBS
ALL CMIP5 members
80% of CMIP5 members
50% of CMIP5 members
NOAA/ESRL/PSD


ANN ENSMN pr for California with 30 year running mean
non-bias corrected values
bias corrected by 1901-2005 clim
mm
Year
1920
1950
1980
2010
2040
2070
1600
1400
1200
1000
800
600
200
100
0
-100
CMIP5 ENSMN (20thC+ rcp85)
OBS
ALL CMIP5 members
80% of CMIP5 members
50% of CMIP5 members
NOAA/ESRL/PSD


DJF ENSMN pr for California with 30 year running mean
non-bias corrected values
bias corrected by 1901-2005 clim
mm
Year
1920
1950
1980
2010
2040
2070
800
600
400
200
100
0
-100
CMIP5 ENSMN (20thC+ rcp85)
OBS
ALL CMIP5 members
80% of CMIP5 members
50% of CMIP5 members
NOAA/ESRL/PSD


SON ENSMN pr for California with 30 year running mean
non-bias corrected values
bias corrected by 1901-2005 clim
mm
300
200
100
50
0
-50
-100
-150
1920
1950
1980
2010
2040
2070
Year
CMIP5 ENSMN (20thC+ rcp85)
OBS
ALL CMIP5 members
80% of CMIP5 members
50% of CMIP5 members
NOAA/ESRL/PSD


JJA ENSMN pr for California with 30 year running mean
non-bias corrected values
bias corrected by 1901-2005 clim
mm
150
120
90
60
30
20
0
-20
-40
-60
1920
1950
1980
2010
2040
2070
Year
CMIP5 ENSMN (20thC+ rcp85)
OBS
ALL CMIP5 members
80% of CMIP5 members
50% of CMIP5 members
NOAA/ESRL/PSD

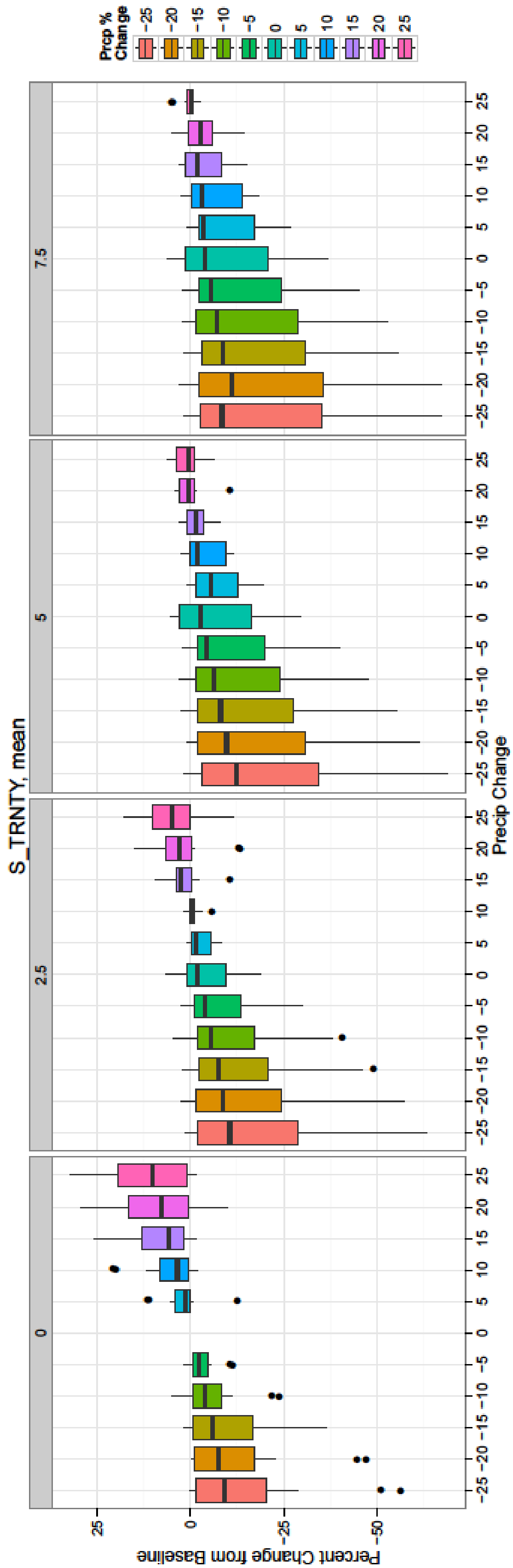
APPENDIX 3.6

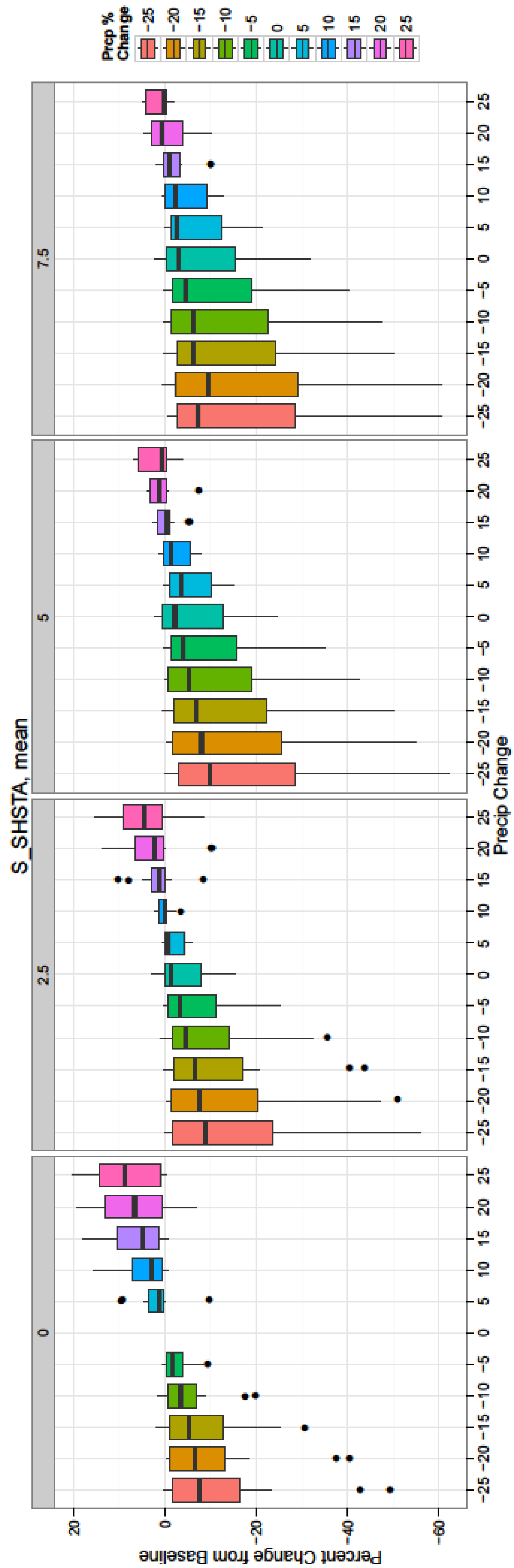
Selected Results from CVP/SWP System Sensitivity Analysis
(Handout)

Nodename cheat sheet

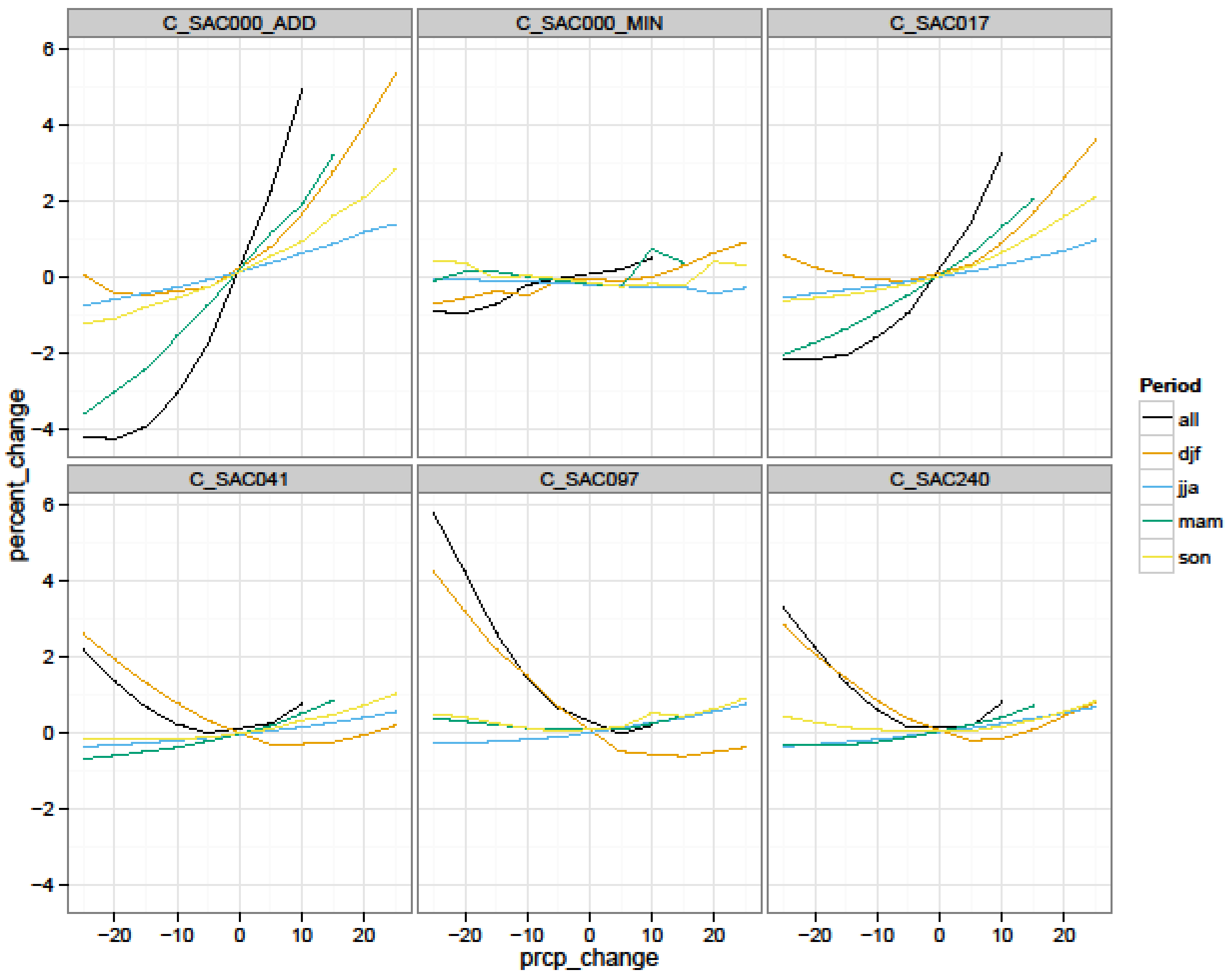
Calsim Nodename	River	Description
D418		Jones Pumping Plant
D419		Clifton Court Forebay
DEL_CVP		CVP Delivery
DEL_SWP		SWP Delivery
FOLSM	American River	Folsom Lake Dam. Diversion point for San Juan (Sidney N. Peterson) and City of Roseville WTPs upstream of USGS Gage - 11446220. C2VSIM/CalSim2 Node.
FTR039	Feather River	Sunset Pumps
FTR068	Feather River	Power Canal Diversion to Thermalito Forebay. C2VSIM/CalSim2 Node near Gage - 11406825
KSWCK	Sacramento River	Keswick Dam
LWSTN	Trinity River	Lewiston Dam near Clear Creek Tunnel diversion from Lewiston Lake. CalSim2 Node
NTOMA	American River	Lake Natoma and diversion point for Folsom South Canal. C2VSIM/CalSim2 Node.
OMR014	Old River/Middle River(simulated)	Sum of gages: Old River at Bacon Island/Middle River at Middle River
OROVL	Feather River	Lake Oroville
SAC000	San Joaquin River	Sacramento/San Joaquin confluence
SAC017	Sacramento River	Yolo Bypass/Lindsey-Barker Slough confluence??
SAC030	Sacramento River	Delta Cross Channel diversion
SAC041	Sacramento River	C2VSIM Node at Hood. DWR 'SRD" gage at Hood. USGS11447810 at MP38.8
SAC097	Sacramento River	C2VSIM Node (State Ranch Bend Pump Station)
SAC240	Sacramento River	Red Bluff Diversion Dam to TCC and CCL near USGS Gage - 11378930
SHSTA	Sacramento River	Shasta Dam. Also represents historic flows from Sacramento River at Kennett. USGS11369500/DWRA2160
WKYTN	Clear Creek	Whiskeytown Dam

Mean difference from baseline for joint changes in precipitation and temperature

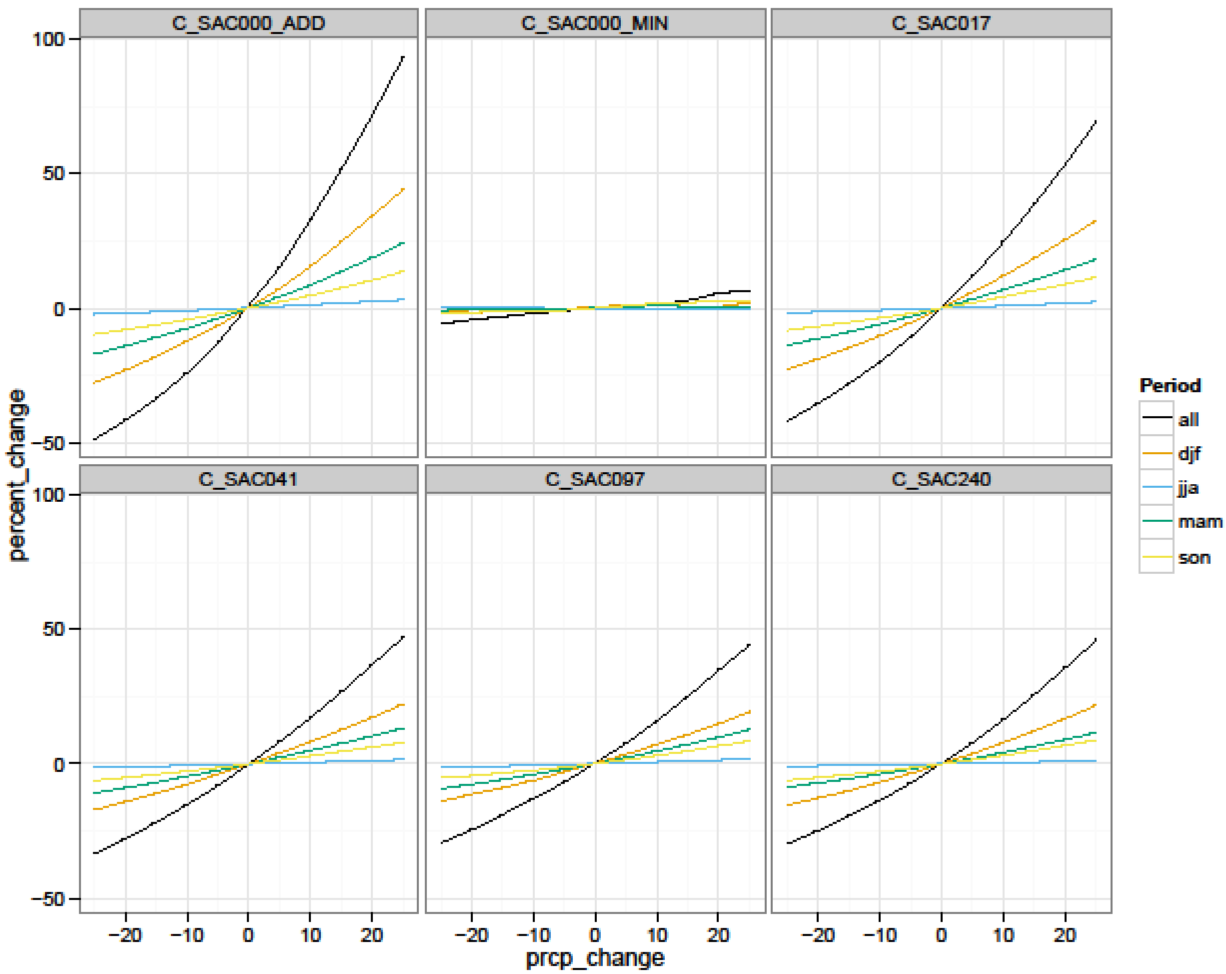




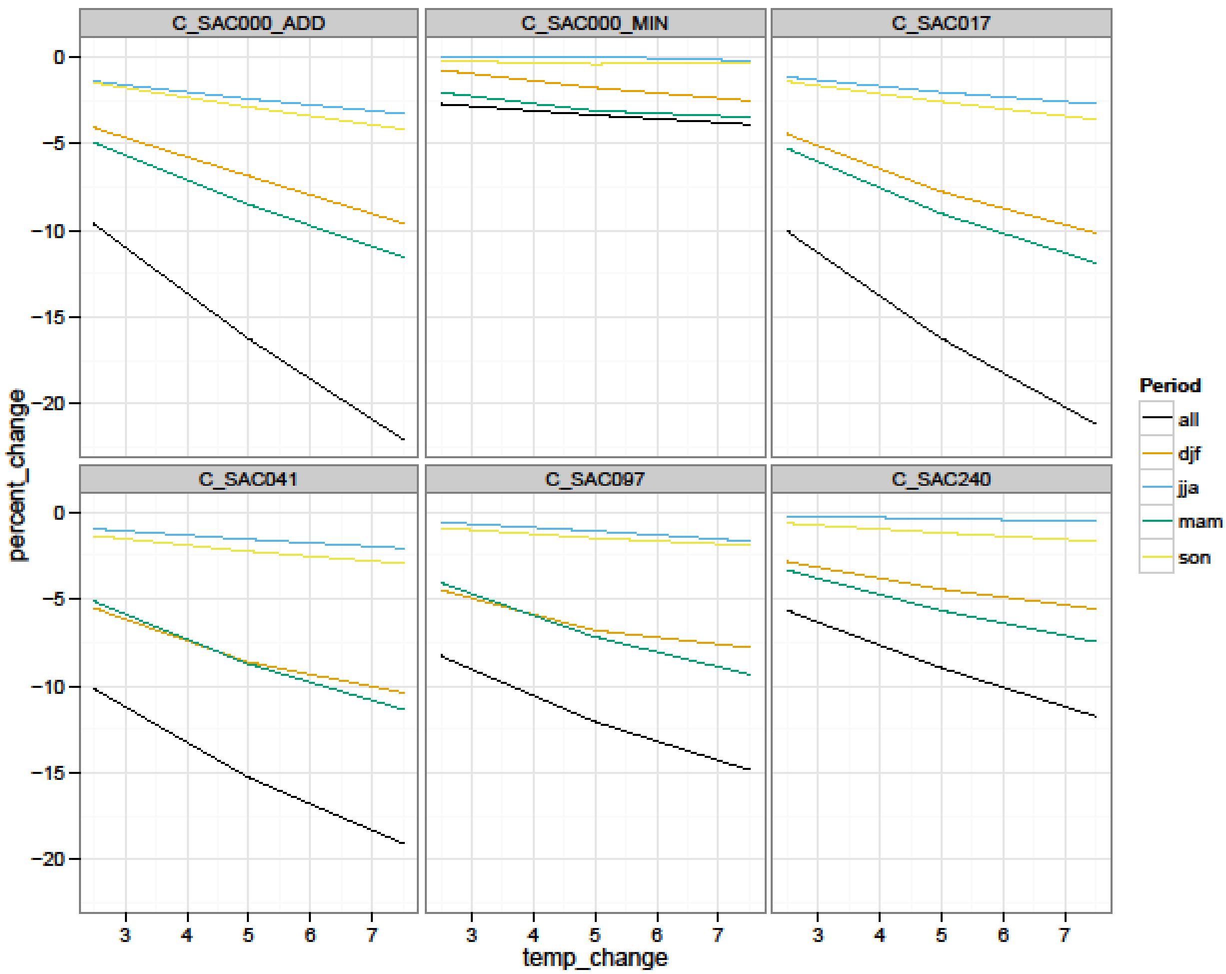
Percent change from baseline for channel flow, for a range of changes to precipitation standard deviation, no temperature change



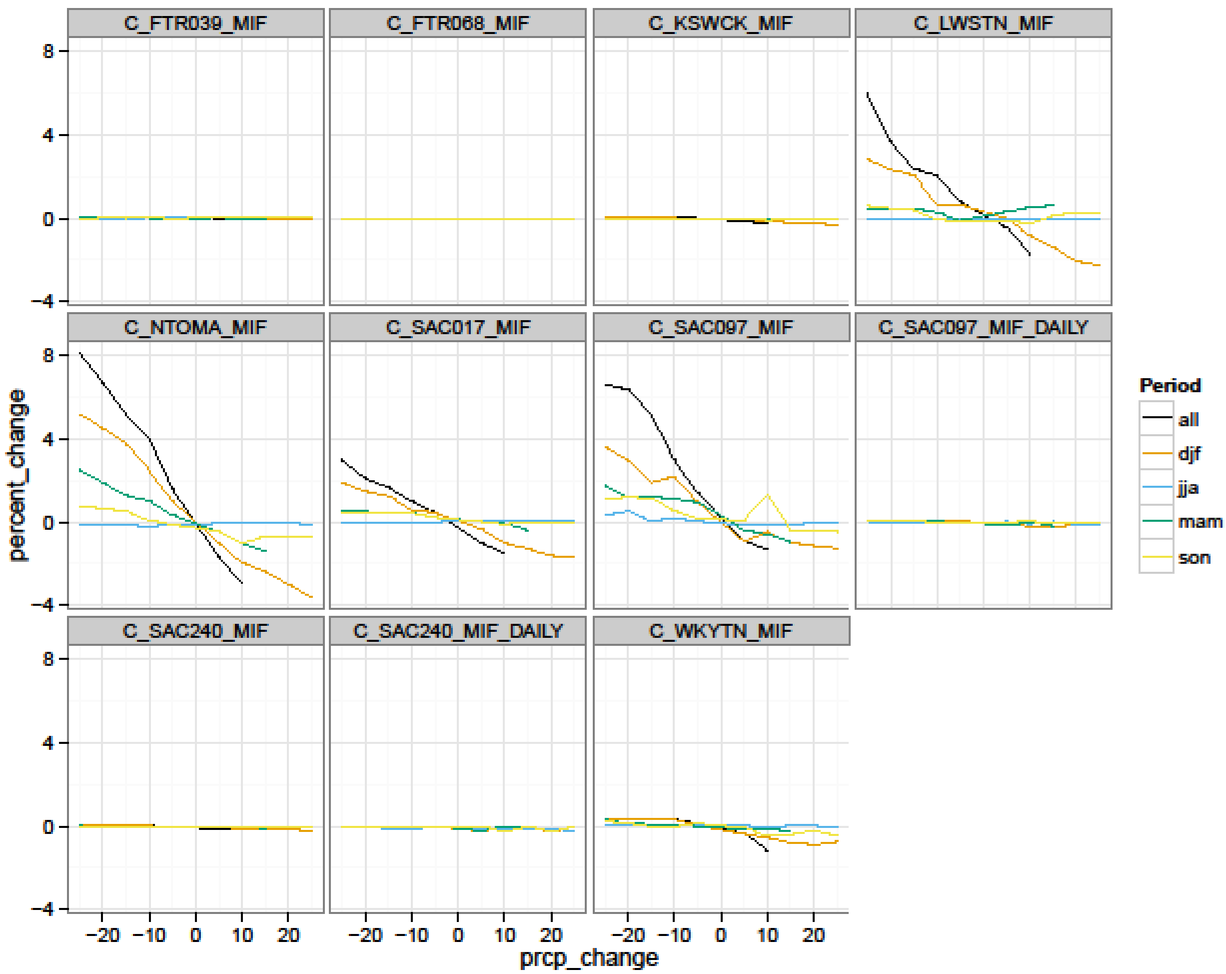
Percent change from baseline for channel flow, for a range of precipitation changes, no temperature change



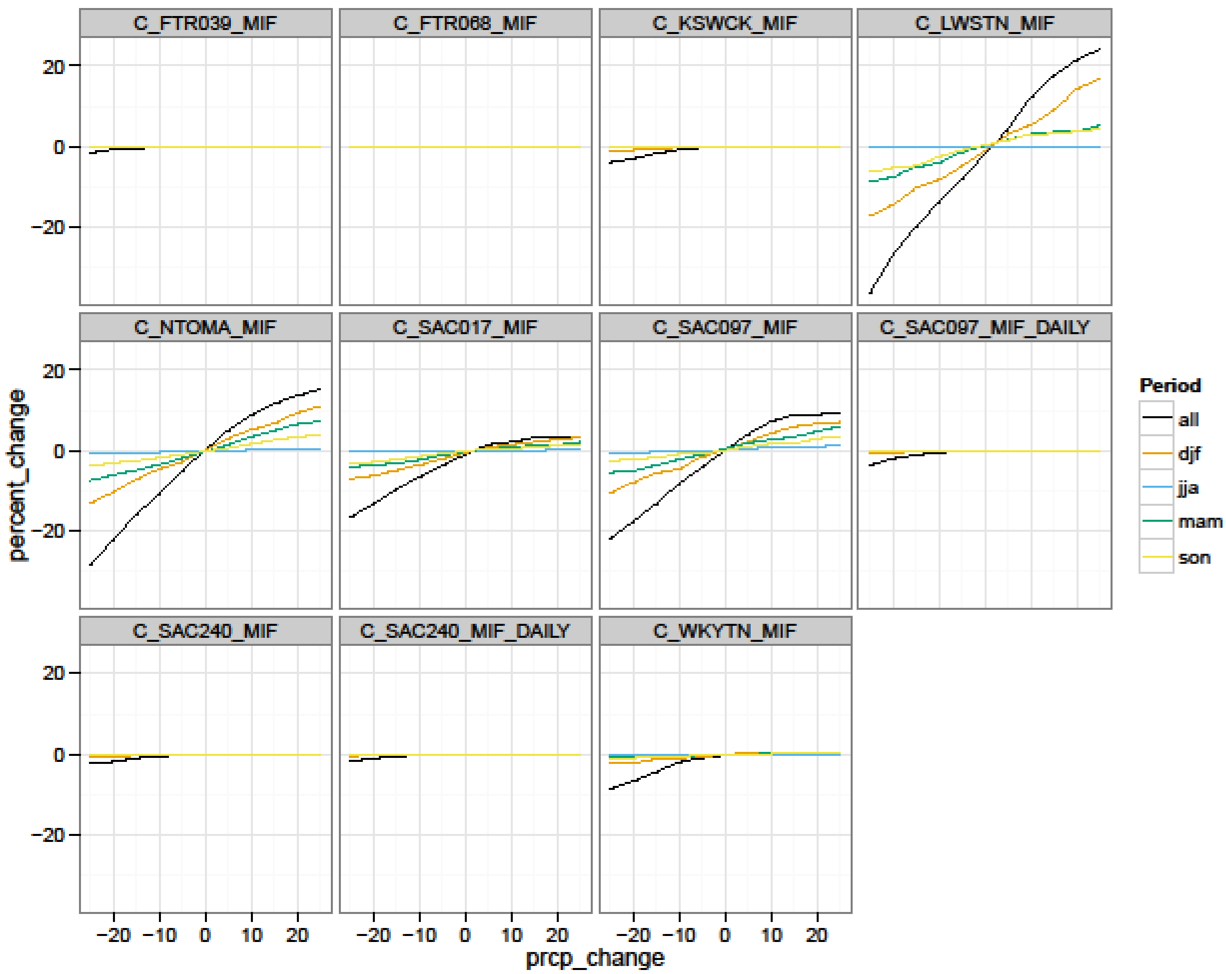
Percent change from baseline for channel flow, for a range of temperature changes, no precipitation change



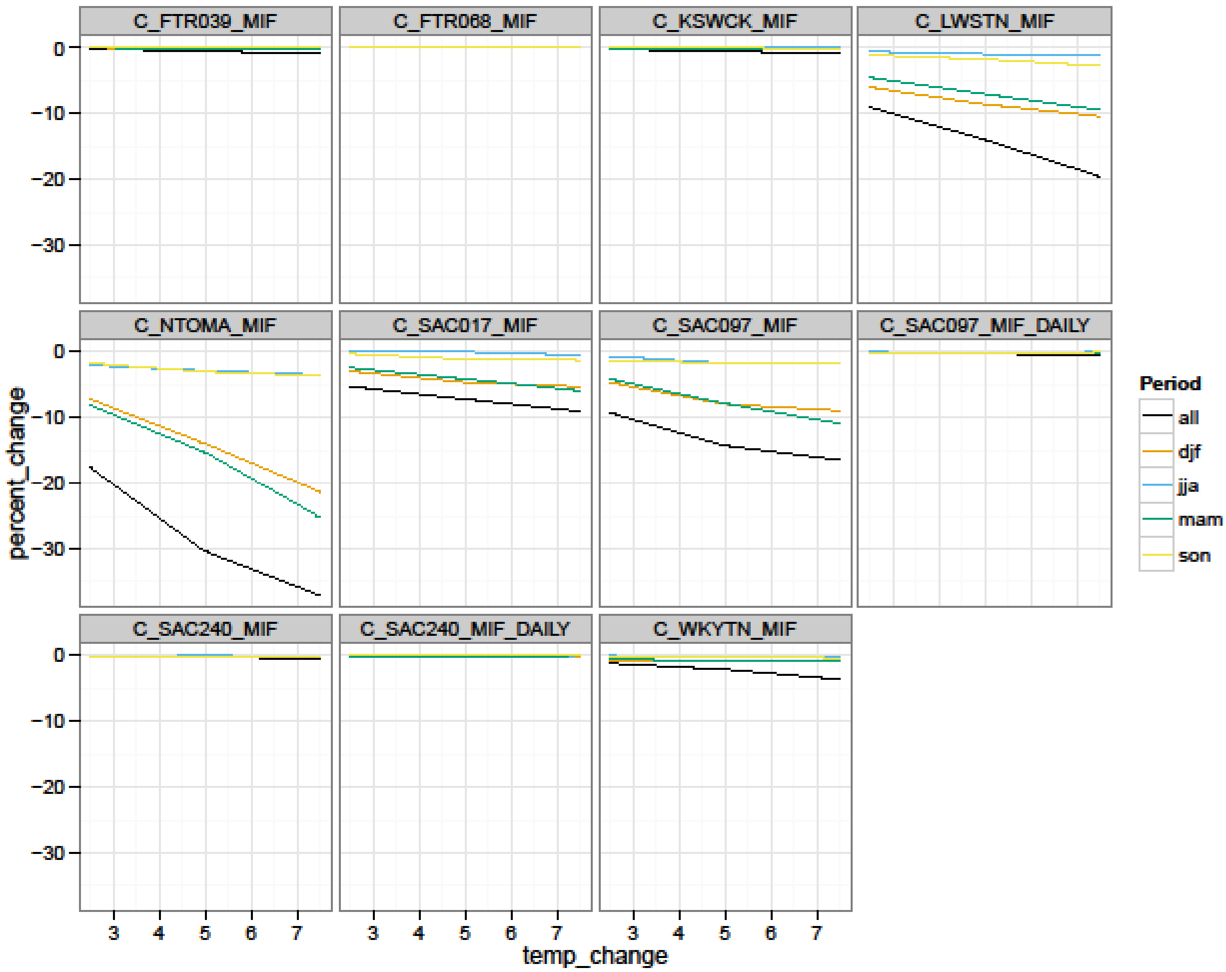
Percent change from baseline for channel flow, for a range of precipitation changes, no temperature change



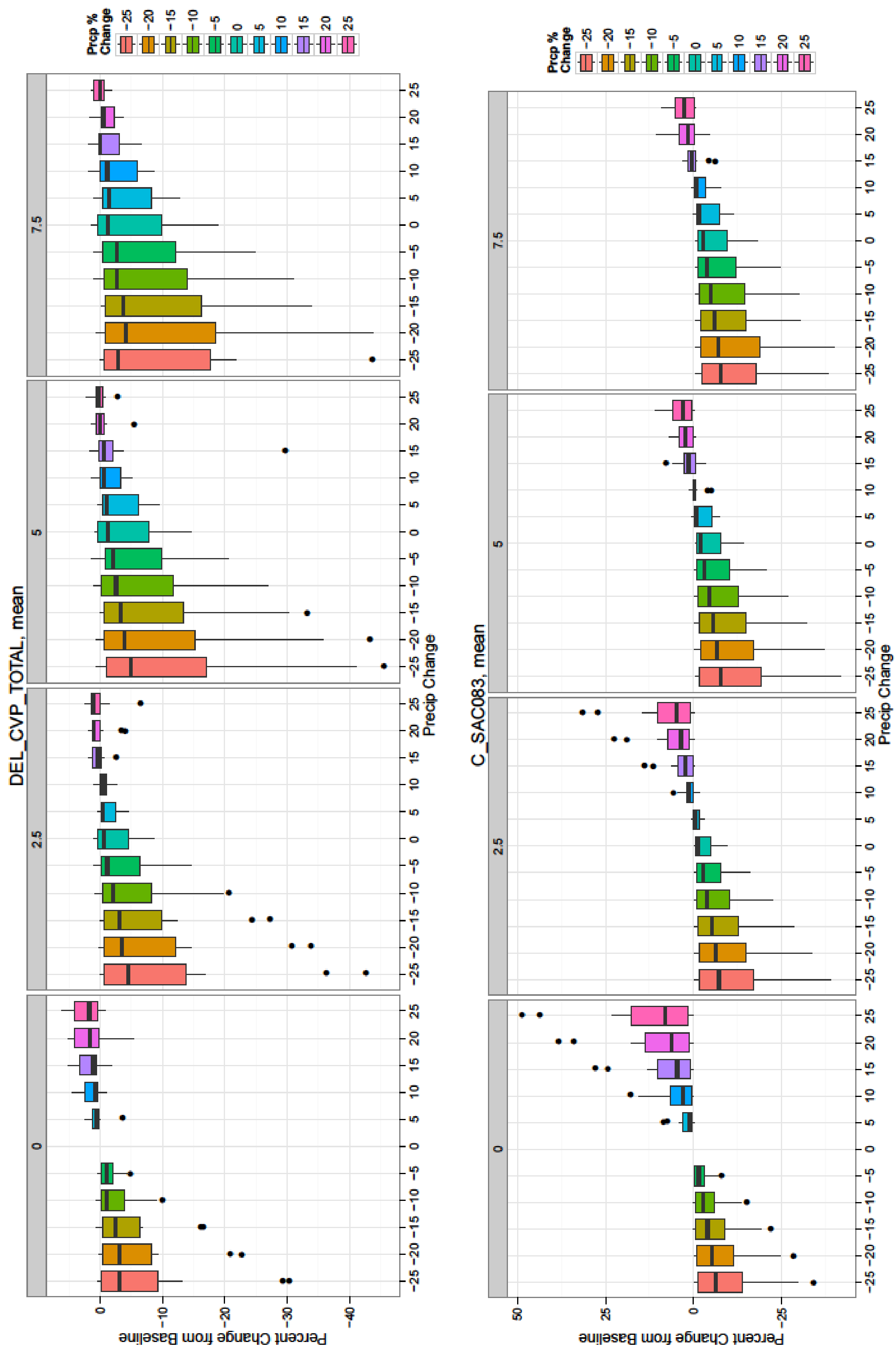
Percent change from baseline for channel flow, for a range of precipitation changes, no temperature change



Percent change from baseline for channel flow, for a range of temperature changes, no precipitation change



CVP total delivery and channel flow below confluence of the Feather River and the Sacramento River



APPENDIX 3.7

Scoping Questions (Handout)

Briefly describe the primary infrastructure, operating objectives, and hydroclimate drivers relevant to the proposed project:

- **Infrastructure**
  What are the primary infrastructure and facilities that are directly or indirectly affected by the proposed project?

- **Operating Objectives**
  What are the primary and secondary operating objectives of the infrastructure and facilities listed above?

Scoping Question 1.1:
How can climate uncertainties affect study decisions?

- **Hydroclimate Drivers**
  What hydrologic and climatic variables and/or processes are likely to affect project infrastructure and operations?

- **Climate Uncertainties**
  What is the time period and geographical extent of the likely impacts of climate change on project infrastructure and operations? What uncertainties should be considered regarding future hydroclimatic conditions over this period and extent?

Scoping Question 1.2:
What measures of system performance are expected to influence study decisions?

- **Performance Measures**
  What measures can be used to evaluate and compare system performance with respect to primary and secondary operating objectives?

- **Influence on Decisions**
  How will system performance measures be computed and used to evaluate and compare alternatives?

Scoping Question 1.3:
What types of climate change influence system performance the most?

- **Connecting Hydroclimate Drivers and System Performance**
  Which of the system performance measures identified above are most likely to be sensitive to changes in climate?

- **Relevant Climate Projection Information**
  What types of climate projection information (and corresponding hydrologic projection information) are needed to represent the impacts of climate change on system performance when evaluating and comparing proposed alternatives.

Scoping Question 2.1:
What types of regional future climate and hydrology datasets are available?

- **Available resources**
  What types of projected climate and hydrology information are available?

- **Methodological choices and information relevance**
  Does the available projection information include the relevant climate and hydrologic variables, spatial and temporal scale(s), and future period(s) relevant to the proposed alternatives?

Scoping Question 2.2:
Which future climate and hydrology changes are projected well for study objectives?

- **Climate model verification and bias**
  How well do the climate projections reproduce observed records of temperature and precipitation? What biases are present?

- **Judgement of available outputs**
  Which model outputs are sufficient to represent future climate assumptions in support of key study decisions?

Scoping Question 2.3:
What future climate or hydrology assumptions should still be based on historical records?

- **Spatial and temporal scales**
  Which climate model time scales (if any) are appropriate to use? Do climate models provide the necessary reliability at these spatial and temporal scales?

- **Judgement of reliability**
  What additional information is being provided by model output versus historical records?