Climate Services: the RISA Experience

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Executive Summary

NOAA's Regional Integrated Sciences and Assessments (RISA) program consists of nine teams focused on different climatically-sensitive regions of the United States. These teams have developed innovative *place-based, stakeholder-driven research*, *partnership,* and *services* programs over the past decade, and in doing so, have created an effective demonstration-scale climate service for parts of the nation. The experiences of the RISA programs, along with their successful development of decision support tools and other products, indicate that the following key elements will be critical to an effective National Climate Service (NCS):

1. An NCS must be *stakeholder (user) – driven*, and accountable to stakeholders
2. An NCS must be based on *sustained regional interactions* with stakeholders
3. An NCS must include efforts to improve *climate literacy*, particularly at the regional scale
4. *Multi-faceted assessment* as an ongoing, iterative process, is essential to an NCS
5. An NCS must recognize that stakeholder decisions need climate information in a *interdisciplinary context that is much broader than just climate*
6. An NCS must be based on effective *interagency partnership* – no agency is equipped to do it all
7. Implementation of an NCS must be *national, but the primary focus must be regional, where decisions are made*
8. NCS capability must span a range of space and time scales, including *both climate variability and climate change*
9. An NCS design should be *flexible and evolutionary, and be built around effective federal-university partnership*
10. NCS success requires that an effective regional, national and international *climate science enterprise, including ongoing observations, model simulations and diagnostics,* exists to support it

Prepared with the collaboration of RISA partners, this document reviews literature in support of the RISA approach, and provides several examples of RISA efforts that illustrate these ten key elements, focusing on water resource, wildfire, and agriculture. Moreover, during the past 10 years, droughts in the western and the southeastern U.S. have illustrated the value and utility of RISA teams in diagnosing and predicting droughts, and in designing drought mitigation and preparedness plans. Such efforts arise from the interdisciplinary and collaborative nature of the RISAs, and provide a template for an NCS. Scaling up the RISA experience into an NCS poses organizational challenges, but offers numerous important lessons, as well as the promise of success.

1. Introduction

Climate services are intended to provide the use-inspired climate science needed to support decision-making in society, particularly as it relates to anticipating, planning for, and dealing with climate variability and climate change. Owing to steady progress in climate science and vigorous growth in public demand for actionable climate information, the motivation for rapid expansion of climate services has never been greater. Climate information includes paleoclimate (reconstruction of past climate from proxies like tree rings); statistics about means and extremes from instrumental data and interpretations thereof; seasonal climate forecasts; projections of global and regional climate change; and much more. Climate services are already provided in various forms by the NOAA Regional Integrated Sciences and Assessments (RISA) program through its nine regional groups, by regional climate centers, private consultants, state climatologists, the National Weather Service, and others. This document describes the experiences of the RISA program for input as the nation contemplates the design and implementation of a National Climate Service (NCS).

Basic research in climate dynamics, as well as efforts to observe and predict the Earth system have paid immense dividends in improved weather forecasts, seasonal climate predictions, and responses of global climate to external forcing like greenhouse gases or volcanic eruptions. Climate services connect these advances to specific decision environments, much the way the National Weather Service implements new research in an operational, decision-relevant setting. A fundamental aspect of this connection is a responsiveness to users' needs. It is this responsiveness that is at the heart of the RISA success in understanding how climate information is interpreted and used by a wide range of stakeholder decision-makers.

The RISA program supports integrated, place-based research across a range of social, natural, and physical science disciplines to expand decision-makers' options in the face of climate change and variability at the regional level. RISA teams are comprised of researchers from the physical, natural, and social sciences as well as the fields of economics, geography, engineering and law who work together and partner with stakeholders in a region to determine how climate impacts key resources and how climate information and tools could aid in decision-making and planning for those stakeholders. It opens new conduits for the flow of information and documents innovative practices for providing services that can lead to improvement across the whole climate services enterprise. The significant RISA success in meeting user needs illustrates the power of regional stakeholder-driven interdisciplinary climate research as a complement to the more operational, national-scale support provided by federal agencies such as NOAA.

In this document we briefly review some relevant history of climate services, describe key elements of climate services, provide examples based on the RISA experience, and offer some thoughts about implementing an NCS as informed by the RISA experience.

2. RISA Teams and Background Literature

The network of RISA teams (Figure 1) represents a significant body of experience and knowledge about climate services needs. Each RISA developed independently and defined its own approaches to meeting stakeholder demand. Since the first RISA was established in the Pacific Northwest in 1995, the network has expanded to nine teams, each of which has long-term relationships with users of climate information from a wide variety of sectors, levels of government, and regions. RISAs work closely with these users to identify and address needs including climate literacy, fundamental use-inspired and applied research, and development of decision-support tools.

A critical element of the regional focus is the intense, sustained contact with users that is necessary to uncover, assess and refine the ways in which climate services can best meet user needs. These efforts often break new ground as they respond to the research and support needs of regional user groups. Some specific RISA efforts have also delved more deeply into cross-scale issues examining a local situation, a sector, or multi-jurisdictional area within a regional context. The efforts have generated many lessons on climate needs, as well as best practices in effective development and delivery of services. RISAs have also had success in the development and transfer of information prototypes, applications, service innovation, and research methodologies. With time, RISAs have also begun to collaborate more regularly with each other, as well as other regional climate science partners.

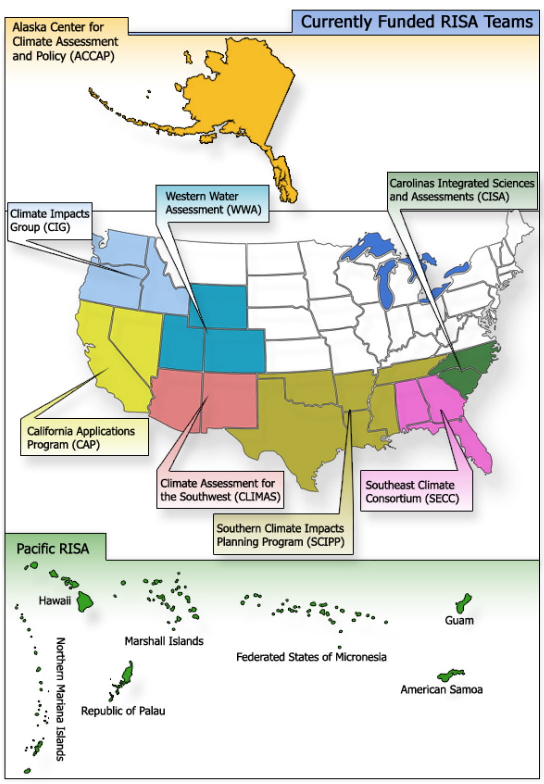

Figure 1. The geographic coverage of the nine RISA teams.

A steady drumbeat of published statements has stressed the need for a coordinated approach to climate services. In 2001 the National Research Council issued a report called *A Climate Services Vision: first steps toward the future* (NRC, 2001). The report highlighted that the societal value of climate information is dependent upon many factors, including the:

- strength and nature of linkages between climate, weather, and human activities;
- nature of uncertainties associated with forecasts;
- accessibility of credible and useful climate information by decision-makers;
- ability of users and providers to identify each other's needs and limitations; and
- ability of users to respond to useful information.

According to the NRC report, addressing these factors requires research, data stewardship, product development, and education programs.

The NRC report also outlines five "guiding principles" for the development of a new climate services effort:

(1). The activities and elements of climate services should be **user-centric** - the user community is diverse, with a wide range of space and time scales needed. Users are becoming increasingly diverse and knowledgeable, with a commensurate increase in specialized needs. In order to address these needs, evaluation, mutual information, and feedback are needed to improve communication and accessibility of information.

(2). If a climate service function is to improve and succeed, it should be supported by **active research**, and research is needed not just on the fundamentals of climate variability and change, but also on diffusion of knowledge and information. This requires mission-oriented research with active mechanisms to transfer knowledge from research to useful products.

(3). Advanced information (including predictions) should be provided on a **variety of space and time scales**, and in the context of the historical record, in order to understand natural variability and climate change. Predictions should be accompanied by analysis of probabilities, limitations, and uncertainties. The causes and character of natural variability should be described. Continuous, accurate, and reliable historical climate observations are needed at diverse locales, and products need to be provided for scales from local to global.

(4). The climate services knowledge base requires **active stewardship**: observations must be reliable, freely exchanged, and accessible. This requires open and free exchange of data, combining observations into useful, multipurpose records, and assuring synergism between observations, theories, and models. All of this should be driven by a "robust and easily accessible delivery system."

(5). Climate services require **active and well-defined participation by government, business, and academe**. Each of these players has important roles in providing climate services. The government should be motivated by "public goods and services", which they describe as non-rival and non-exclusive. These are products that are of a general nature, not for individuals or individual commercial operations. Government should also take the lead role in maintaining the official climate records. The private sector should use the data to meet basic and applied research needs of its users. Academic research organizations should focus on their central mission of research, education, and outreach. Sometimes this may include research data and analysis and product development in partnership with industry or government towards meeting these goals.

The NRC recommendations were presented in three sections: (1) promoting more effective use of the nation's weather and climate observation systems; (2) improving the capability to serve the climate information needs of the nation; and (3) interdisciplinary studies and capabilities needed to address societal needs. Recommendations 1 and 2 of the NRC report focus primarily upon the infrastructure and provision of routine services. While the RISAs contribute to these goals, their most notable successes occur in recommendation 3, which can be elaborated as:

- develop regional enterprises designed to expand the nature and scope of climate services;
- increase support for interdisciplinary climate studies, applications, and education;
- foster climate policy education; and
- enhance the understanding of climate through public education.

The report describes a service system that "should strive to meet the needs of a user community at least as diverse and complex as the climate system itself, ranging from the international community to individual users, and involving both the public and private sectors. Central to the scope of a climate service is the need to embrace wide ranges of time and space scales because decision-making occurs on all scales from local to global and from weeks to centuries."

Since 2001, several reports have highlighted the critical role that RISAs provide through their research and service. A 2003 forum of the American Meteorological Society focused on "Improving Responses to Climate Predictions," emphasized the need for more "science integrators" (Greenfield and Fisher, 2003). Finding 5 of the forum states that "climate information is most effectively developed and applied through **partnerships between climate information providers and decision makers**." The report also notes the importance of evaluation of risks and benefits as a factor encouraging use of climate forecasts.

Miles et al. (2006) provided a perspective on climate services linking the international aspects of climate monitoring, research and modeling to regional applications of climate information. Based in large part on the success of the Climate Impacts Group (the Northwest RISA), they stressed that regional organizations were a key component in successful delivery of climate services within the context of an NCS.

In a review of the Climate Change Science program, the *National Research Council* (2007) noted that "discovery science and understanding of the climate system are proceeding well, but **use of that knowledge to support decision making and to manage risks and opportunities of climate change is proceeding slowly**." The report emphasized the smaller spatial scales at which decisions are made and the need for improved understanding of the impact of climate changes on human well-being and vulnerabilities. The review called for stronger connections with social science researchers and a more comprehensive and balanced research program, including human dimensions, economics, adaptation, and mitigation. The report again highlights RISA as a positive example: "NOAA's Regional Integrated Sciences and Assessments program has been effective in communicating research results to stakeholders in particular sectors … or regions, but this program is small and has limited reach. Building and maintaining relationships with stakeholders is not easy and requires more resources in the CCSP Office and participating agencies than are currently available. Yet a well-developed list of stakeholders, target audiences, and their needs is essential for educating the public and informing decision making with scientifically-based CCSP products."

In 2007, the Western Governors' Association and Western States Water Council suggested that **improving relationships between state agencies, academia and federal climate science agencies** was the most critical action on improving state and regional response to climate variability and change (CDWR, 2007). RISA was again highlighted as a "successful step to a bridging effort between the research community and practitioners" and they recommended that the program be expanded.

The maturation and expansion of the RISA Program has contributed to the body of knowledge about how climate information is conveyed, received, and utilized by key stakeholder groups. These findings should be used to construct improvements in the products and services provided by federal agencies and state climate office services. Within the NOAA Climate Program Office, programs such as Transition of Research Applications to Climate Services and the Sector Applications Research Program have supported research geared toward better understanding of how stakeholders use climate information. These studies are often at a regional, state or local level, allowing each study to capitalize upon unique circumstances to the area. For example, the RISA-served areas of the country with a strong response to El Niño-Southern Oscillation (ENSO), namely the Pacific Islands, Northwest, California, Southwest, and Southeast, can make use of seasonal predictions; whereas for the parts of the country with lower seasonal predictability, the utility of seasonal forecasts may be low.

A common theme in these reports is that rapid growth in demand for climate services have converged with growth in knowledge of climate and of human interactions, and with technological advances including communication networks, to pave the way for a **transformation of climate services**. They envision the emergence of a broader, organized, and sustained climate service that addresses multiple environmental challenges.

3. Essential Elements of a National Climate Service

Drawing on collaboration and shared experiences, the RISA teams have summarized our reflections on the essential elements of a National Climate Service (Table 1). These include elements that are essential when working with user groups, as well as implications for institutional design.

Table 1. Essential Elements of an **NCS**

1. An NCS must be *stakeholder (user) – driven*, and accountable to stakeholders
2. An NCS must be based on *sustained regional interactions* with stakeholders
3. An NCS must include efforts to improve *climate literacy*, particularly at the regional scale
4. *Multi-faceted assessment* as an ongoing, iterative process, is essential to an NCS
5. An NCS must recognize that stakeholder decisions need climate information in a *interdisciplinary context that is much broader than just climate*
6. An NCS must be based on effective *interagency partnership* – no agency is equipped to do it all
7. Implementation of an NCS must be *national, but the primary focus must be regional, where decisions are made*
8. NCS capability must span a range of space and time scales, including *both climate variability and climate change*
9. NCS design should be *flexible and evolutionary, and be built around effective federal-university partnership*
10. NCS success requires that an effective larger *national (and international) climate science enterprise* exists to support it

3.1 A stakeholder-driven perspective

A national climate service must prioritize stakeholder needs and support services based on their *usefulness* in addressing those needs. Critical climate services need to vary among regions depending on vulnerabilities and how planning and policy decisions consider local climate conditions such as drought, wildfire, snowpack depth, ice storms, storm frequency, the likelihood of heatwaves, or the impact of ocean temperatures on fisheries. The climate science enterprise currently addresses these issues, but as the NRC report Decision Making for the Environment (2005:26) points out, approaches to framing research questions and data analysis often mean that, "when science is gathered to inform environmental decisions, it is often not the right science." A user-centric approach, which is more likely to gather the "right science," affects the design of research, models, and observation systems to support fundamental use-inspired and applied research, and extends to new communication and operations standards. The timeliness of information availability is also critical to its utility - decision calendars vary by region, and climate services will need to be timed to provide the best information at most useful times.

3.2 Sustained, ongoing regional interactions with users

From El Niño events in the 1980s, to global climate change today, stakeholder interest in climate science has grown rapidly. In order to provide relevant information, RISAs have demonstrated that users and scientists committed to innovation in this area must make a sustained commitment to learning from each other about climate science and about the equally complex sectoral decision needs – the processes, vulnerabilities, goals, constraints, calendars, and capabilities – that influence the value, utility, and availability of climate information. Stakeholders are seeking trusted sources to help them understand a new set of issues characterized by rapidly evolving science, uncertainties, and highly politicized controversies. Ongoing engagement is necessary to build and maintain the credibility required of a national climate service, and to respond flexibly to rapidly evolving stakeholder needs and capabilities.

Implicit in making climate services stakeholder-driven, and based on sustained stakeholder partnerships, is the fact that the enterprise must be inherently regional in nature. National entities cannot succeed without strong regional presence and partnership. The RISA success has been built on the regional strengths of universities and their well-established ability to partner in a sustained way in their regions, and to do so in a way that cuts across disciplinary, agency, and sectoral boundaries. In addition, university-based programs are often able to leverage the well-developed outreach networks of other university-based organizations such as the Cooperative Extension Service, the Marine Advisory Program, and Sea Grant.

3.3 Broad efforts to improve climate literacy

Many decision-makers are already hearing and heeding calls to use climate information as part of accountability and disclosure from regulators, constituents, or clients. For decision-makers to use climate information in an effective manner, they often must have at least a rudimentary understanding of the strengths, limits, and availability of good climate information and services. For example, seasonal forecasts are often expressed as shifts in probabilities, whereas users often reduce these forecasts to the simpler notion of "above average." Many users are in the early stages of learning about general climate issues, whereas others are interested in more sophisticated treatment of topics related to specific professional or occasionally personal interests. RISA experiences indicate that both sophisticated and casual users of climate information want to relate general processes (e.g., global warming or El Niño) to local/regional experience, expectations, and concerns, and vice versa. When users understand the statistical and physical reasoning of climate sciences, and how to evaluate the plausibility of an explanation or the validity of a seasonal forecast, they can make better use of climate information. They can also be a more active partner in driving the needed science and services. One of the most effective ways to improve society's resilience to climate variability and change is through greater climate literacy.

3.4 Assessment as an multi-faceted, ongoing, and iterative process

Several types of assessment are integral to successful climate services. At one end of the spectrum, climate services must assess – at regular intervals - the state of the climate system, the state of climate understanding, and the range of potential climate impacts, risks and vulnerabilities that might occur. This is akin to the assessment approach employed by the Intergovernmental Panel on Climate Change. In addition, advances in climate science and the changing dynamics of socioeconomic systems require that the needs of stakeholder decision-makers also be assessed in an ongoing, iterative manner, just as the effectiveness of all climate service methodologies and activities must be routinely assessed and improved. These latter types of assessment are best implemented via social science research.

Growing populations, shifting economic sectors, greater reliance on new energy sources, changing demands on water and on other critical resources, are but a few of the trends that will alter the character of known vulnerabilities and stakeholder needs. Changing patterns of threats and hazards, and emerging issues like re-engineering California's San Francisco Bay and Delta system, ocean dead-zones and acidification, will require regular investigation of patterns of risk and vulnerability to inform decision-making (Healy, Dettinger and Norgard 2008; Dettinger and Culberson 2008). For all of these reasons, assessment must be addressed as an iterative process, and all aspects of the climate service enterprise must learn from these assessments. Ongoing assessments at regional scales will improve conditions and decision-making at those scales while also, in composite, providing a better grounding for decisions, adaptation and mitigation by the Nation as a whole.

3.5 Stakeholder decisions need climate information and much more

Decisions that could benefit from climate information typically also have inputs from other types of environmental and societal information. National climate services must address critical interfaces of climate variability and change with societal decision-making and adaptation across scales and sectors. For example, coastal communities concerned about projections of sea level rise and variability in frequency and intensity of storms, also need to worry about municipal bond ratings, availability of insurance, and impacts of local coastal erosion processes. Water utilities evaluating strategies for dealing with projected changes in drought frequency, intensity, and duration, must make their decisions in the context of aging infrastructure, projections of population growth and demand, the efficacy of water conservation strategies, future energy requirements, ecological constraints and the flexibility of regulatory frameworks. To meet these interdisciplinary needs, an NCS must provide services that are useful in the context of socioeconomic and environmental decision-making – e.g., decision support tools – that in turn requires developing both (a) much closer interactions between climate science and other intellectual disciplines and (b) closer coordination of climate information with socioeconomic and environmental impact models.

3.6 Interagency partnership is essential

The capacity to address the broad scope of activities and goals affected by climate is distributed across federal, tribal, state and local agencies where experienced staff, tools, and skill sets as well as a deep understanding of the policies, procedures, and regulations have been developed over decades. In particular, *a federal-level interagency partnership* is needed to ensure that climate services support the integration of appropriate climate information with non-climatic information, and also enable users to make decisions in cross-agency jurisdictional frameworks. Specialized insights into sectoral capacity, key institutional challenges, major regulatory issues, research needs, critical uncertainties, and potential interactions among climate, social, economic, and ecological systems is critical to successful adaption involving multiple complex systems and avoiding maladaptive choices and unexpected consequences.

3.7 Implementation must be national in scope, but regional in focus

Ultimately, an NCS should be capable of providing both regionally specialized products and equivalent quality services to all parts of the country. Brief consideration of the contrasts among the Pacific Islands, the small, highly variable New England states, the arid, rapidly growing Southwest, and the climatically vast state of Alaska highlights the formidable scale of the task. The distinctive regional character of environmental and climate processes and science challenges, as well as regional-distinct vulnerabilities, decision-making processes, adaptation issues, and the value of close engagement with stakeholders, all indicate that many of those services will be most effectively designed and delivered through a regional focus. To achieve equity in coverage, many regional issues will require regionally-explicit approaches to meet specific observation and research needs, or to assess the complex interactions of human and natural systems in a place.

Regional texture in predominant issues, climate-sensitive sectors, policy context, and dominant climate processes require regionally specific information, not just higher spatial resolution. National implementation of a regionally focused climate service can ensure that shared regional needs (e.g., large-scale observing systems, modeling and basic research on continental to global-scale processes) are addressed in an efficient manner, and that lessons learned in one region can benefit another. A national scope also addresses the interconnectedness of climate-sensitive sectors in which information about drought, crop productivity, or snowfall in another region can be as important as local information: for example, energy supply in California is closely related to snowpack (and hence hydropower production) in the Northwest. Agricultural production in one region can often be optimized when coordinated nationally. In order to meet demands for climate services for national-scale needs, regional findings must be intercomparable and amenable to national-scale compilations, thus requiring national scale equivalency of quality and, to some extent, methods.

3.8 Capability must span a range of space and time scales

Decision contexts often require information on a range of timescales in one location, for example, water supply planning can integrate timescales from 1 to 40 years, or longer. The demand for climate services will continue to come from nested spatial and temporal scales in which each of the levels plays a role in increasing overall societal resilience, so the products of an NCS must be able to span these scales. Notably, RISAs have repeatedly identified decadal scale variability as an area of unexpected and, to date, under-addressed importance to stakeholders as they plan, scope, and design long-term infrastructure investments and adaptations to climate variations and change.

A successful climate service must also cover both climate variability on seasonal to centennial time-scales, as well as climate change. Decision-makers often need information and support that integrates across both near-term and long-term decision scales. Ideally, climate services also integrate seamlessly with weather. In the real world, all variations in the environment, whether natural or human caused, have to be dealt with.

3.9 Program design should be flexible and evolutionary – universities are key

Climate service is a relatively young endeavor that requires greater capacity in new areas to address dynamic areas of knowledge and rapidly expanding – and changing - user needs. In just the past decade, stakeholder needs have grown much more sophisticated and have expanded from a focus on seasonal forecasts to an integrated interest in climate change projections, paleoclimate, and interdecadal outlooks. Recent droughts, wildfires, levee failures, and insect outbreaks have prompted calls to understand the nature of these threats and to inform strategies to increase social, economic, and ecological resilience. Many such climate-related events have limited public issue-attention cycles and "windows of opportunity" when constituents, victims, and policy makers are focused on addressing an event or issue. An NCS will need to continually prepare, anticipate, evolve, and then be quick on its feet to be judged successful in meeting those periods of intense, focused demand. Successful climate services must maintain the ability to translate and apply new science and to anticipate and fulfill evolving research and information needs. Effective climate services must be able to learn and change.

Table 2. Key Climate Service Capabilities Provided by Universities

1. A majority of the nation's climate science expertise, including expertise on regional climate dynamics and influences;
2. A tradition of trusted regional stakeholder partnerships (especially at land- and sea-grant institutions);
3. The needed interdisciplinary expertise - (e.g., climate science, social science, ecosystem science, policy, law, and economics);
4. The social science capability needed for needs, performance and other assessment;
5. Proven ability to work simultaneously with multiple federal, tribal, state and local agency partners;
6. A flexible project workforce that can shift rapidly as stakeholder needs evolve;
7. The best framework for educating and training stakeholders and the next generation workforce, and;
8. Proven entrepreneurship, development of new climate observations, technology-transfer, and private sector partnership capacity.

The RISA program has proven the merits of using innovative and strong federal-university partnerships to develop and provide climate services. Table 2 highlights some of the key capabilities that universities provide, and the RISAs have demonstrated how universities are uniquely able to understand regional issues, build and maintain regional science and stakeholder partnerships, provide the needed interdisciplinary contexts, rapidly shift foci in response to new stakeholder need, educate, and work with private-sector partners. RISAs have also shown how university teams are ideally configured for interdisciplinary research, for developing prototype service methodologies and products, and for working with operational organizations (e.g., federal agencies) to transition these services into operations. Universities also have a long tradition of working with federal partners to develop national-scale observing, modeling, and research programs.

3.10 Climate services rely on a larger climate science enterprise

In designing and implementing a national climate service, there may be an inclination to include all climate science activities under the rubric of climate services. Certainly, climate services rely on quality observations, modeling, and research, much of which requires vastly more resources than any NCS effort can provide on its own. Regionally-focused observation, research, and modeling efforts may be sensibly included within climate services (and at universities), but where to draw the line between an NCS and national or global climate science that supports the NCS? Should global satellite observation programs be included? The modernization of the Historical Climate Network? The USGS stream gauge network? Global climate model intercomparison efforts? The importance of all of these examples goes beyond just regional climate service, and design of an NCS needs to include mechanisms for determining what is within or outside the NCS institutionally and financially. At the same time, it is critical that mechanisms be developed that allow the climate service to influence other elements of the national climate-science enterprise to ensure it is responsive to stakeholders and useful to the Nation. Separating an NCS from other climate science activities recognizes the importance of these other activities, and allows NCS champions to identify and advocate for the whole breadth of climate science.

4. RISA Experiences in Climate Service

Some examples of climate services developed by RISAs illustrate the ten essential elements just discussed. These examples are not intended to be a comprehensive catalogue of each RISA's activities, nor do they reflect the level of accomplishment of each individual RISA. Although the examples below emphasize the work of the mature RISAs, it is worth highlighting that the "new" RISAs (i.e., ACCAP in Alaska, and SCIPP in the South-central US) also provide illustrations of the ten essential elements. The examples cover some of the research topics that span several of the RISAs - water, agriculture, and wildfire – that collectively serve to illustrate the ten key elements enumerated in the previous section.

4.1 Water

Most RISAs have a significant focus on water because of its deep connections to other societal and environmental needs, like agriculture, energy, aquatic ecosystems, wildfire, and human health. Stakeholders with significant interest in water have been at the forefront of adoption of new applications of climate science, owing in part to their extensive computational and technical capacity.

Early successes resulted from applying seasonal forecasts to water supply. As early as 1997 Seattle Public Utilities and several other stakeholders began paying attention to seasonal forecasts, and even applying them internally, in partnership with CIG (northwest RISA). CIG also issues annual ENSO-based seasonal hydrologic forecasts (Hamlet et al., 2002) that are now closely watched by public and private entities alike. Likewise, Pacific island water resource managers used ENSO forecasts to determine how to plan for water system conservation, with assistance from the Pacific RISA.

Drought cuts across sectors in ways that no other natural environmental hazard does, because water is fundamental to municipal water supplies, public health, fire, agriculture and food production, ecosystems, energy production, and more (Wilhite and Buchanan-Smith, 2005). Thanks in part to unusually prevalent western and southeastern U.S. droughts since 1999, several RISAs have had the opportunity to engage in drought planning, monitoring, and post-drought analysis. CLIMAS (southwest RISA) worked with state agencies in Arizona to construct the Arizona Drought Preparedness Plan. In the Carolinas, RISA scientists developed a regional drought monitoring tool used to determine and monitor low-flow triggers for Federal Energy Regulatory Commission dam relicensing processes (Carbone et al., 2007). This tool has been transferred across RISAs to New Mexico and Arizona and funding through the NOAA TRACS program is supporting its transfer to the NOAA Northeast Regional Climate Center where it will become operational for 18 east coast states in 2010. RISA scientists and regional and municipal water managers in the West led to infusion of NOAA paleoclimatology program analyses and data into water resources planning and the adoption of new modeling methods for evaluating the sensitivity of water supply to drought (Woodhouse and Lukas, 2006). CIG researchers also found strikingly different institutional responses in Oregon and Idaho to the 2001 drought. RISAs worked over several years with Western Governors' Association to develop the framework for the National Integrated Drought Information System, and the newest RISA (SCIPP, the south-central RISA) has a major focus on drought.

Vigorous efforts by RISA scientists to educate stakeholders about the emerging science of climate change have convinced many public agencies and businesses that climate change may pose significant challenges to future water supply. Indeed, work by RISA scientists and others show that many of the expected changes are already detectable (e.g., Barnett et al. 2008). Using fine regional scale observations, global climate model simulations, downscaling technique, and a set of hydrologic models, RISA scientists have projected future streamflows on scales from the small watersheds supplying urban needs, to the large basins of the Colorado and Columbia Rivers. Such projections are now routinely being used in long-range planning and assessments by municipal and state governments in partnership with RISAs in California, Colorado, and Washington. A multi-RISA project, "Reconciling Projections of Future Colorado River Stream Flow," compares different modeling approaches to see how well these methods can reproduce recent flows, as part of a larger cross-RISA effort to help western U.S stakeholders deal with drought and climate change.

For water resources planning, western RISAs have worked for a number of years with the U.S. Bureau of Reclamation and related agencies to understand uses of climate information and respond to these needs. Early efforts included studies of the Salt River Project in Arizona, as well as the Aspinall Unit in Colorado (e.g., Ray, 2004). When the Bureau of Reclamation began considering climate change, their personnel were already well acquainted with RISA scientists and turned to them for information. As a result of a process including WWA (intermountain west RISA), CAP (California RISA), and CIG, long term climate variability, risk of extended drought, and climate change were included in the National Environmental Policy Act process for contending with shortage on the Colorado River.

The Carolinas RISA is integrating its work on drought and hydrology with coastal water resources issues through a partnership with North and South Carolina Sea Grant Extension. New research initiatives are supporting planning for salinity intrusion in major coastal rivers and climate outreach capacities have been strengthened by the creation of a coastal climate extension specialist position.

4.2 Agriculture

The SECC (southeast RISA) has demonstrated a successful regional approach for climate services for the agricultural and water sectors with most of the essential elements of climate services presented in this document. With multiagency funding and input from farmers, Extension Agents, and foresters, the SECC developed a climate risk management decision support system (http://AgroClimate.org). This system was transitioned to the Cooperative Extension Services, which now operates it and provides educational programs and climate information to all counties in four SE states. The success of this research-to-operational program has also been demonstrated through financial support provided by the USDA and by other states adapting AgroClimate for their agricultural stakeholders. For example the most recent support from USDA translated AgroClimate into Spanish to serve farmers who would otherwise not be able to make use of this information. Now that this system is in use, the RISA is developing similar climate information and decision support systems for water resources managers and coastal resource users. The SECC is focusing much of its research to develop information to address needs expressed by a wide range of stakeholders, working with Extension to reach county and city managers, water managers, coastal resource managers, land developers, public utilities, and other sectors. Many of the new demands for local and regional climate services are for information options for responding to climate change.

Using integrated climate and social science research, CLIMAS is investigating the prospects for improved use of climate information by ranchers in the Southwest. CIG is using a crop model to evaluate impacts of climate change on key crops in Washington State.

4.3 Wildfire

Wildland fires cost the United States over $1 billion annually and their severity is determined by several factors including climate, vegetation and human behavior, on timescales from weeks to decades. Successful climate services supporting wildland fire management and prediction require multi-agency coordination and multidisciplinary perspectives. In anticipation of sustained dry conditions, CLIMAS, CAP, and SECC convened a ground-breaking 2000 workshop to bring together climate scientists and fire management stakeholders (Morehouse, 2000). After first hearing that the fire management community did not see an obvious need for climate information, a spirited discussion stimulated interest in using historical ENSO information and climate forecasts in pre-season fire prediction. Scientific knowledge was too new for operational implementation at first, so the RISA program facilitated sustained science-management exchanges, which led to identification of early adopters, potential agency partners, and better understanding of the insertion points for climate information in fire management decision-making (Corringham et al., 2008).

In 2003, CLIMAS, the National Interagency Coordination Center's Predictive Services Group, and the Program for Climate, Ecosystem, and Fire Applications (a contributor to the CAP RISA) began developing pre-season fire potential climate outlooks for the conterminous United States and Alaska through a decision support process called the National Seasonal Assessment Workshops (NSAW) (Garfin et al., 2003). Over the years this process has improved understanding of climate forecasts and forecast evaluation, and facilitated connections between NOAA science and operational entities and the fire community. RISA involvement and partnership has catalyzed change in (a) operational use of climate forecasts by this stakeholder community, and (b) climate-fire integrated research and prediction (Brown and Kolden, 2007).

The pre-season outlooks are used by the National Multi-Agency Coordinating Group in firefighting resource allocation decisions, including pre-positioning of resources, personnel planning, prescribed and wildland fire use decision-making, and fire mitigation (park closures and fire bans). Outlooks are now routinely used to brief the Secretary of Agriculture and have been successfully transferred to operations.

CAP, CIG, CLIMAS, and ACCAP (Alaska's RISA) have contributed substantially to climate-fire research, particularly on the subject of climate change. CIG research demonstrated that in most western states, a substantial portion of the interannual variability and long-term trends in area burned can be explained by considering summer climate (McKenzie et al., 2004). Collaborative CAP and CLIMAS research elaborated the mechanisms, focusing on spring snowpack and on fire season length and other fire parameters (Westerling et al., 2006). CIG research further distinguished climate-fire relationships for different eco-regions (Littell et al. 2008). ACCAP researchers recently developed a fire forcasting tool for use by agencies in firefighting asset management. These results have been of great interest to forest ecosystem managers, insurance companies, timber companies, and others.

4.4 Reflection on key elements

In the examples just given, a central theme is the focus on user needs as the driving force, as well as on assessment and partnership as mechanisms to identify and fulfill need. In many cases the scientists took the lead in contacting stakeholders and educating them about emerging climate science, and piqued the institutional curiosity of the stakeholders. Two examples are the fire season outlooks and the use of climate model projections by municipal utilities. Growing interaction provides both the climate scientists and the stakeholders with insights regarding new products, for example the fire season outlooks that could be developed and used. Social science research also proved essential in stakeholder needs assessment.

Another theme is the success of cross-institutional interagency interactions. The wildfire example was explicitly multi-agency, and it was a multi-agency institution that ultimately made climate an integral part of their operational efforts. The fire season outlooks include USFS; an array of NOAA entities, including CPC, ESRL, and NWS; IRI, Scripps ECPC, Regional Climate Centers, and the CLIMAS, CAP, WWA, ACCAP, and SECC RISAs.

Moreover, SECC has forged a successful partnership with USDA and with the state climatologists of its three constituent states, Florida, Georgia, and Alabama. CIG annual workshops on water resources outlooks likewise involve USDA, NRCS, the NOAA River Forecast Center, and a close partnership with Idaho Department of Water Resources. Operational forecasts of coho salmon returns were developed in a collaboration between

CIG and NOAA fisheries scientists (Lawson et al. 2004), and because the collaboration included agency scientists the result was both usable and influential. These partnerships, and many others, provide RISA teams with the broad expertise – and best practices - needed to carry out their mission of meeting stakeholder needs.

Several of the RISA programs have developed effective and productive relationships with Native American (CLIMAS, WWA), Native Alaskan (ACCAP) and indigenous Pacific Island (Pacific RISA) peoples, tribes, and tribal organizations. These RISAs are developing adaptation strategies that have the cultural context critical to tribes and incorporate traditional, indigenous knowledge.

Other partnerships extend internationally. The Pacific RISA emerged as a demand for climate research and policy from stakeholders established by the Pacific ENSO Applications Climate Center, which serves the US client jurisdictions of American Samoa, Federated States of Micronesia, Guam, Hawaii, Northern Mariana Islands, Marshall Islands, and Palau. Partnerships extend across the Pacific to the Fiji Met Service, New Zealand's National Institute for Water and Atmospheric Research, Australia's Bureau of Meteorology, and Pacific regional environmental and disaster management organizations. These partnerships ensure value and consistency of climate information, and the network establishes the Pacific Climate Information System (PaCIS), a regional climate services example.

CLIMAS in the southwest and CIG and ACCAP in the Northwest also have partnerships in Mexico and Canada respectively. Climatic, hydrologic, and ecological issues cross the border and cannot be solved without recognizing that fact. CIG has partnered with Canadian organizations like the Columbia Basin Trust as it grapples with climate change, and helped train hydrologists at the University of Victoria's Pacific Climate Information Consortium. One of CLIMAS' regular stakeholder publications, the bilingual monthly "*Border Climate Summary/Resumen del Clima de la Frontera*" is co-produced with colleagues in Mexico. CAP, along with many other university, state, federal and NGO partners, is centrally involved in an ongoing biennial assessment of California's vulnerability and adaptive capacity to climate change. The California experience has demonstrated that, when defined goals are set, the State Government and research community is able to collaborate across disciplinary lines to produce useful analyses and syntheses. This effort produced scenarios-based climate evaluations in 2006 and in 2009 (Cayan et al. 2008; Franco et al. 2008; State of California 2009).

Placing climate information in the stakeholders' interdisciplinary decision context is also critical. WWA is working with a number of municipal and other large-scale water providers who are trying to understand the sensitivity of their systems and supply to climate change, but the looming issue is how population growth and land use change will affect the equation. Fluctuations in salmon populations in the Northwest are best understood as climatically driven within the context of a long decline in salmon habitat extent and quality.

The examples given above are but a small subset of the climate services developed by the RISAs that would not have been possible without the inherently regional understanding, approach and presence of the university-based RISAs. Education, training, and literacy-building was also integral, as was the production of a steady flow of graduate students and post-doctoral researchers trained to do stakeholder-driven, interdisciplinary climate research – many now work in other regions, have helped spawn new RISAs, or work in government agencies. Clearly, both climate variability and change are needed foci, and for example, many stakeholders originally focused on climate variability and skeptical of climate change, are now actively working on climate-change adaptation strategies.

Lastly, much of the regional RISA success in supporting stakeholders would have been impossible with out federal agency partners, particularly in NOAA, but in other agencies as well. The RISA program has successfully transferred a number of programs to their federal operational partners, and the national science enterprise (e.g., the Climate Change Science Program and the U.S. Global Change

Research Program) is integral to RISA success at the regional level.

5. Implementation Advice

Implementing a vision for national climate services will require careful deliberation including all major federal and non-federal partners, and we can do no more here than offer some thoughts based on the RISA experience. Primary issues to be addressed include governance structure, funding, and defining roles for federal agencies and non-federal partners in a way that recognizes their respective missions, strengths, and limitations.

Many RISAs were involved in the first US National Assessment, a large climate-focused interagency effort whose strengths and weaknesses have been discussed elsewhere (Morgan et al. 2005). The National Assessment included 5 sectorally focused activities, 17 regionally focused activities, and one focused on native peoples and homelands. Among the lessons are (1) each regionally or sectorally focused activity had a lead federal agency as a partner and funder, which ensured an uncluttered reporting structure on the team level; (2) perhaps the biggest strength was that regional teams almost all had strong participation by stakeholders; (3) sustained funding is required to sustain interactions with stakeholders; and (4) the Assessment needed "a budgeting mechanism which would allow greater freedom in allocating resources across various assessment activities" (Morgan et al. 2005).

We note several other considerations of the federal context for an NCS. Though still in its early stages, the National Integrated Drought Information System (NIDIS) provides a working example of a multi-agency partnership intended to connect climate science to decision-makers. Another federal context for the development of climate services is the reexamination of the US Global Change Research Act of 1990 and the Climate Change Science Program. The National Weather Service some years ago designated a "climate focal point" at each weather forecast office, someone to discuss seasonal forecasts. These must be augmented by experts in climate dynamics, global change, water resources, and so on, at other federal and non-federal institutions to build a climate service.

Clearly the governance structure and funding must be designed so that participants – particularly the regional decision-makers in society - are the primary drivers of climate services enterprise, and so that the whole is greater than the sum of its parts. This means ensuring that each federal agency has sufficient new funding, working authority, and intellectual motivation to engage in climate service activities that relate to its central mission, and to collaborate with other federal agencies and other partners. It also means that mechanisms be established so that regional stakeholders have a real say in setting funding priorities for all aspects of the climate services enterprise.

The pre-eminence of NOAA in climate research, observations, and prediction, and the differences between the role of a climate service and the primary tasks of the other agencies lend weight to the argument that NOAA should play a lead role overall, although certainly other agencies should appropriately play a lead role on specific topic areas. For example, the USFS should clearly take the lead on forest management and planning in order to manage the massive land-cover transformations that are sure to be a part of world that is undergoing climate change.

Another RISA lesson is that longer-term funding mechanisms ensure that regional partners, for example at universities, can entrain and sustain the stakeholder partnerships that are needed for success. The current NOAA model works well, with extended period grants (i.e., 5 year once a RISA is mature and proven) competed at five-year intervals for each region.

Some RISAs are working examples of multi-agency partnerships as well, with funding and participation by USGS, USFS, USDA and others. University-based scientists, agency scientists, and agency managers collaborate on researching and developing new climate knowledge with clear applications in mind, and host frequent workshops to extend the connections to other partners, as discussed in some of the examples above. Some RISA participants have joint university – agency appointments, formally bridging the two institutional environments and ensuring better communication of research results to others within the agency. In the province of Quebec, a RISA-like entity called Ouranos takes such partnership one step further: personnel from several universities, one federal agency, the provincial hydropower company, and several provincial ministries interact daily because they all work together in the Ouranos office. Another example of successful regional multi-agency partnerships involves the co-location of NOAA Sacramento Weather Forecast Office and California Nevada River Forecast Center with the California Department of Water Resources' Hydrology, Flood Operations Office, and the State Climatologist. Federal and state staff work side-by-side to produce daily river forecasts, issue flood bulletins, water supply forecasts, and to share and exchange data. The added benefit to users comes from the regional integration of various sources of observations, forecasts, and expertise to produce internally consistent information.

Governance of a climate service should probably include a cabinet-level council, led by the Secretary of Commerce, to ensure agency cooperation and coordination at the highest level. A second, working-level council involving all participating federal agencies and key non-federal partners would oversee the climate services efforts in greater detail. Participation by non-federal partners would be crucial, since much of the on-the-ground connection to decision-makers happens in the RISAs, the regional climate centers, state climatologists, and private sector experts.

Finally, we note that the Climate Working Group of NOAA's Science Advisory Board recommended considering four structural options for a national climate service:

1. Create a national climate service federation that would determine how to deliver climate services to the nation

2. Create a non-profit corporation with federal sponsorship

3. Create a national climate service with NOAA as the lead agency with specifically defined partners, and

4. Expand and improve weather services into weather and climate services within NOAA.

An assessment of these four options is underway by NOAA and its partners.

6. Conclusions and outlook

The RISA teams have successfully built knowledge-action networks to provide useful climate information, connecting the climate research enterprise with real-life situations where the outputs of that enterprise can materially improve the lives of Americans. These successes have required very modest investment and have had large payback to the nation.

The RISA teams also see huge gaps that a mature and well-designed NCS could fill. One obvious gap is purely geographic: only about half the land area of the nation is actually served by RISAs. Another gap is the fact that when a product or decision support tool is developed through RISA research, there is generally no obvious mechanism to provide a transition to an operational environment, as was done with the fire season outlooks.

Three emerging issues need the kind of effort that only an NCS could provide. In all three of these cases, basic research can be connected to stakeholder needs through RISA efforts and/or a national-scale sectoral research program – that is, the stakeholder demand already exists. The first is the need for vigorous research on *decadal-scale predictions* with a goal of providing outlooks with skill demonstrated from hindcasts and with uncertainties properly characterized; such outlooks would help fill an oft-stated need of stakeholders. These predictions would be useful for a variety of decisions, but are not yet produced either by the seasonal forecasting entities like the National Centers for Environmental Prediction (NCEP) nor by the climate change simulations of IPCC.

The second emerging issue concerns *sea level rise*, which is already a great concern for coastal communities from Alaska to the Pacific Islands to the Carolinas. Stakeholders want probabilistic guidance about sea level rise on a very fine spatial scale, overlaid on planned or existing infrastructure, beach slopes, inland estuaries, wetlands, and river deltas. Meeting these demands will require a concerted effort among ice sheet researchers, coastal oceanographers, wetlands scientists, and social scientists, to name a few. As a stopgap, a few RISAs have attempted to provide such guidance (e.g., Cayan et al. 2007; Mote et al. 2008) but without the full complement of needed expertise.

The third is a crosscutting issue, the issue of *climate adaptation*. Vigorous research in social sciences including economics, policy, and law, are needed in conjunction with climate and natural science research to provide tools and processes for building adaptive capacity, especially at the local to regional level. A significant step in this direction was the creation of a *Guidebook for local, regional, and state governments* (Snover et al. 2007), a joint effort of CIG and staff from King County (which includes Seattle), Washington, and all the RISAs are already in jeopardy of being overwhelmed by stakeholder demand for help in adapting to climate change (in addition to climate variability). Adaptation science and application must also be an integral part of the decision-making currently underway on alternative energy deployment and climate change mitigation – for example, regional adaption needs for land and water resources should be factored in as early as possible, and before costly mistakes are made.

The RISA experience also highlights the central role that universities must play in an NCS. Universities have a tradition of trusted regional stakeholder partnerships, as well as the interdisciplinary expertise – including social science, ecosystem science, law, and economics – required to meet stakeholder climate-related needs. Universities have a proven ability to build and sustain interagency partnerships. Universities excel in most forms of education and training. Universities also have proven innovation, entrepreneurship, technology transfer and capability for partnership with the private sector.

RISAs have become a resource in their respective regions for dealing with climate variability and change in practical ways. When drought or climate change or sea level rise became a central issue for Bureau of Reclamation, US Fish and Wildlife Service, US Forest Service, and state governments in Alaska, Colorado, Washington, Idaho, California, Florida, the Carolinas and elsewhere, these stakeholders turned to RISAs for technical, intellectual, and policy assistance.

A well-funded, carefully designed, and properly governed NCS will meet the rapidly growing needs for applied climate information, drawing together partners from federal agencies, academic partners, private sector, state climatologists, and other experts. The experiences in the RISA program offer many useful lessons in the design of an NCS.

7. References Cited

Barnett, T.P., D.W. Pierce, H.G. Hidalgo, C. Bonfils, B.D. Santer, T. Das, G. Bala, A. W. Wood, T. Nozawa, A. A. Mirin, D. R. Cayan, and M. D. Dettinger, 2008: Combining a regional hydrologic and global climate model implies that human-caused CO2 emissions have already greatly changed river flows and snow pack in the western United States. Science **319** (5866), 1080. [DOI: 10.1126/science.1152538]

Brown, T. and C. Kolden, 2007. The Science of Fire: New technologies at the Desert Research Institute make a difference in wildland fire management. *Wildland Firefighter* **9**: 28-29.

California Department of Water Resources, 2007: *Proceedings of the May 2007 Climate Change Research Needs Workshop.* Sacramento, CA: California Department of Water Resources.

California Department of Energy 2009: DRAFT 2009 Climate Action Team Biennial Report to the Governor and Legislature http://www.energy.ca.gov/2009publications/CAT-1000-2009-003/CAT-1000-2009-003-D.PDF

Carbone, G.J., J. Rhee, H. Mizzell, and R. Boyles, 2008. A regional-scale drought monitor for the Carolinas. *Bull. Amer. Meteorol. Soc.* **89**(1): 20-28.

Cayan, D.R., P.D. Bromirski, K. Hayhoe, M. Tyree, M.D. Dettiinger, and R.E. Flick, 2007: Climate change projections of sea level extremes along the California coast. *Climatic Change,* 10.1007/s10584-007-9376-7.

Cayan, D.R., A.L. Luers, G. Franco, M. Hanemann, B. Croes and E. Vine, 2008: Overview of the California climate change scenarios project. *Climatic Change*, **87**, (Suppl 1):S1-S6, doi:10.1007/s10584-007-9352-2.

Corringham, T., A. L. Westerling and B. Morehouse, 2008: Exploring Use of Climate Information in Wildland Fire Management: A Decision Calendar Study. *Journal of Forestry*, **106**(2):71-77.

Dettinger, M.D., and S. Culberson, 2008: Internalizing climate change - Scientific resource management and the climate change challenges. San Francisco Estuary and Watershed Science, **6**(2), Article 6

Franco, G., D. Cayan, A. Luers, M. Hanemann and B. Croes, 2008: Linking climate change science with policy in California. *Climatic Change*, **87**, (Suppl 1):S7-S20, doi:10.1007/s10584-007-9359-8.Garfin, GM, Wordell T, Brown T, Ochoa R, and Morehouse B. 2003. *National Seasonal Assessment Workshop Final Report,* February 25-28, 2003, Mesa Arizona. Tucson, AZ: Institute for the Study of Planet Earth, Univ. of Arizona, 24 pp.

Greenfield, R.S. and G.M. Fisher, 2003. Improving Responses to Climate Predictions: An Introduction. *Bull. Amer. Meteorol. Soc.* **84**(12): 1685-1685.

Hamlet, A.F., D. Huppert, and D.P. Lettenmaier. 2002. Economic value of long-lead streamflow forecasts for Columbia River hydropower. *ASCE Journal of Water Resources Planning and Management* **128**(2): 91-101.

Healey, M., M. Dettinger and R. Norgaard, 2008: State of the science for the Bay-Delta system - Summary for policymakers and the public: CALFED Science Program Report, 19p.

McKenzie, D., Z. Gedalof, D. Peterson, and P. Mote, 2004: Climatic Change, Wildfire, and Conservation. *Conservation Biology* **18**(4): 890-902.

Miles. E.L., A.K. Snover, L.C. Whitely Binder, E.S. Sarachik, P.W. Mote, and N. Mantua, 2006: An approach to designing a national climate service. *Proceedings of the National Academy of Sciences*, 103, 19616-19623.

Morehouse, B., 2000. *The Implications of La Niña and El Niño for Fire Management*. Tucson, AZ: Institute for the Study of Planet Earth, The University of Arizona, 45 pp.

Morgan, M.G., R. Cantor, W.C. Clark, A. Fisher, H.D. Jacoby, A.C. Janetos, A.P. Kinzig, J. Melillo, R.B. Street, and T.J. Wilbanks, 2005: Learning from the U.S. National Assessment of Climate Change Impacts. *Environ. Sci. Technol., 39,* 23, 9023–9032, 10.1021/ es050865i

Mote, P.W., A. Petersen, S. Reeder, H. Shipman, and L.C. Whitely Binder, 2008. *Sea Level Rise Scenarios for Washington State.* Report prepared by the Climate Impacts Group, University of Washington, Seattle, and the Washington Department of Ecology.

National Research Council, 2001. *A Climate Services Vision*. Washington, DC: National Academy Press. 96 pp.

National Research Council, 2005. Decision Making for the Environment. Washington, DC: National Academy Press. 296 pp.

Ray, A.J. 2004, *Linking climate to multi-purpose reservoir management: Adaptive capacity and needs for climate information in the Gunnison Basin, Colorado.* Dissertation, University of Colorado Dept of Geography, 328 pp.

Snover, A.K., L.C. Whitely Binder, J. Lopez, E. Willmott, J.E. Kay, D. Howell, and J. Simmonds. 2007. *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments.* In association with and published by ICLEI - Local Governments for Sustainability, Oakland, CA.

Wilhite, D. A. and M. Buchanan-Smith, 2005. Drought as hazard: understanding the natural and social context. In D.A. Wilhite (ed.), *Drought and Water Crises: Science, Technology, and Management Issues.* Boca Raton, Taylor and Francis, pp. 3-29.

Woodhouse, C. A. and J. J. Lukas, 2006. "Drought, tree rings, and water resource management." *Canadian Water Resources Journal* **31**: 297-310.