An approach to designing a national climate service

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Climate variability and change are considerably important for a wide range of human activities and natural ecosystems. Climate science has made major advances during the last two decades, yet climate information is neither routinely useful for nor used in planning. What is needed is a mechanism, a national climate service (NCS), to connect climate science to decision-relevant questions and support building capacity to anticipate, plan for, and adapt to climate fluctuations. This article contributes to the national debate for an NCS by describing the rationale for building an NCS, the functions and services it would provide, and how it should be designed and evaluated. The NCS is most effectively achieved as a federal interagency partnership with critically important participation by regional climate centers, state climatologists, the emerging National Integrated Drought Information System, and the National Oceanic and Atmospheric Administration (NOAA) Regional Integrated Sciences Assessment (RISA) teams in a sustained relationship with a wide variety of stakeholders. Because the NCS is a service, and because evidence indicates that the regional spatial scale is most important for delivering climate services, given subnational geographical/geophysical complexity, attention is focused on lessons learned from the University of Washington Climate Impacts Group's 10 years of experience, the first of the NOAA RISA teams.

Pacific Northwest climate | regional integrated sciences and assessments

The last 20 years have seen exciting advancements in climate science, from seasonal forecasting to understanding anthropogenic climate change. Equally exciting is the growing awareness in scientific and resource management communities of the opportunities and challenges presented by these scientific advancements. Capturing the full potential of this increasing synergism between the producers and users of climate information, however, requires more than can be provided by existing institutional arrangements. What is needed is a sustained mechanism for promoting science to support decision-relevant questions, translating new climate information into relevant decision environments, and building regional and national capacity to anticipate, plan for, and adapt to climate variability and change. What is needed is a national climate service (NCS).

An NCS identifies, produces, and delivers authoritative and timely information about climate variations and trends and their impacts on built and natural systems on regional, national, and global space scales. This information informs and is informed by decision making, risk management, and resource management concerns for a wide variety of public and private users acting on regional, national, and international scales. Such a service does not yet exist in the United States despite the need having been recognized more than 20 years ago [informal discussions within the National Oceanic and Atmospheric Administration (NOAA) about creating a national climate service began in the early 1980s]. However, designing and implementing a climate service can no longer be debated casually. Natural climate variations bring increasingly costly impacts, and research repeatedly indicates that it is cheaper to prepare for climate events that have negative consequences than to react to the consequences of those events (1).

This article enhances the national discussion on an NCS by posing and answering five questions. (*i*) Why build an NCS? (*ii*) What is an NCS? (*iii*) What functions and services should an NCS provide? (*iv*) How should an NCS be designed? (*v*) How should an NCS be evaluated? The article uses the decade-long (1995–2005) experience of the Climate Impacts Group (CIG) at the University of Washington to provide insight into the design and function of an NCS and to highlight the effectiveness of regionally based production and delivery of climate information. In this article, "climate information" includes statistical descriptions of climate; "climate forecasts" are forecasts of the future state of the atmosphere and oceans (derived primarily from the evolving state of the tropical Pacific); and "climate scenarios" are long-term (multidecadal) projections of future climate based on predictions of greenhouse gas concentrations. "Climate variability" refers to natural seasonal to decadal variations in climate, whereas "climate change" refers to human-induced changes in climate as a result of increasing greenhouse gas concentrations.

Why Build an NCS? Weather and climate are clearly important for human activities and natural ecosystems. Between 1980 and 2005, the United States saw 66 extreme weather and climate events costing at least $1 billion each, with total inflation adjusted losses of >$500 billion.† The trend in actual damages has been increasing steeply, largely because of increasing human exposure, with a single storm, Hurricane Katrina (2005), causing >$100 billion in costs/damages and >1,200 fatalities (2, †).

Climate forecasts create opportunities for society to prepare, potentially reducing the costs of climate-related events. The impacts of the 1997–1998 El Niño on the U.S., predicted with 6 months' notice as a result of improved climate observations and other forecasting advances, cost the U.S. an estimated $4.2–4.5 billion (1998 dollars) and 189 lives. An estimated 850 lives were saved and $19.6–19.9 billion in economic gains realized, however. Although many factors contributed to these benefits (e.g., a milder winter, record construction levels), the lead time provided by the forecast is credited for reducing El Niño-related losses in California, where major steps were taken to prepare for an increased risk of flooding, and reducing heating costs to consumers as utilities used the forecasts to delay purchase of natural gas and heating oil rather than sign higher-priced early-season contracts (1).

Despite the increasing predictability of climate, information on predicted climate and climate impacts is not typically used well. Every empirical study conducted to date has shown that climate forecasts are not used to their full potential (3–7). Similarly, few

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Abbreviations: NCS, national climate service; NOAA, National Oceanic and Atmospheric Administration; RISA, Regional Integrated Sciences and Assessments; CIG, Climate Impacts Group; NWS, National Weather Service; ENSO, El Niño/Southern Oscillation; PDO, Pacific Decadal Oscillation; NIDIS, National Integrated Drought Information System; RCC, Regional Climate Center; PNW, Pacific Northwest.

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†Lott, N., Ross, T., American Meteorological Society 86th Annual Meeting, January 28–February 3, 2006, Atlanta, GA.

See accompanying Profile on page 19613.

entities are preparing for projected impacts of climate change. To be sure, progress remains to be made with respect to understanding the earth's climate system, predicting climate variations, and projecting climate change. However, increasing societal resilience to climate variability and change is not just about increasing information; it is also about building capacity, overcoming institutional barriers, and stimulating social learning at the level of managerial and operating agencies. In short, increasing societal resilience to climate impacts requires: (*i*) understanding climate trends and variations as well as possible, (*ii*) understanding the impacts of climate on human and non-human systems, (*iii*) providing decision-relevant tools based on that information, and (*iv*) increasing society's capacity to act on that information. The institution that would provide these services is an NCS.

What Is an NCS, and Why Do We Need One? An NCS identifies, produces, and delivers authoritative and timely information about climate variations and trends and their impacts on built and natural systems on regional, national, and global space scales. This information informs and is informed by decision-making, risk management, and resource management concerns for a variety of public and private users acting on regional, national, and international scales. The stakeholders (and the constituency for an NCS) include public and private individuals and organizations at federal, state, and local levels within the U.S. with sensitivity to and need for climate-related information.

A climate service should be national foremost, because every part of the country is affected by climate variability and change, although the type and intensity of impacts often vary regionally. An NCS, therefore, exists to serve national needs related to enhancing economic growth, managing risk and protecting life and property, and promoting environmental stewardship, *inter alia* (8). Over time, as has occurred after the establishment and maturation of the NOAA's National Weather Service (NWS), we can expect opportunities for the private sector to use government data and products to craft a wide range of products that meet the special needs of private-sector users. Secondly, an NCS is needed to provide an overarching and coordinated approach for managing climate observation systems and producing and disseminating information on climate impacts to stakeholders at the federal, state, and local levels.

Not all aspects of a climate service must be national in scale, however. The true strength of the NCS concept is the regional focus of the service. Experience has shown that connections between climate scientists and stakeholders are most effective at the local, regional, statewide, and multistate scales at which the stakeholders operate (5, 9–11). It is also clear, as is shown in *Evolution of the CIG as a Regional Resource in the PNW*, that partnerships between long-lasting regional research and assessment teams such as the NOAA's RISA teams and groups of stakeholders lead to increased utility of decision tools and climate forecasts.

Functional Elements of an NCS. Conceptually, an NCS is a three-legged stool consisting of observations, modeling, and research nested in global, national, and regional scales with a user-centric orientation (Fig. 1). The first leg is a climate observing system adequate for documenting, understanding, and predicting changes in the global climate system (atmosphere, ocean, land, and cryosphere). Although some components of the global observing system exist, the current system is considered "seriously deficient" with respect to the spatial coverage and data quality needed to manage the impacts of climate change.[‡] Furthermore, because the global

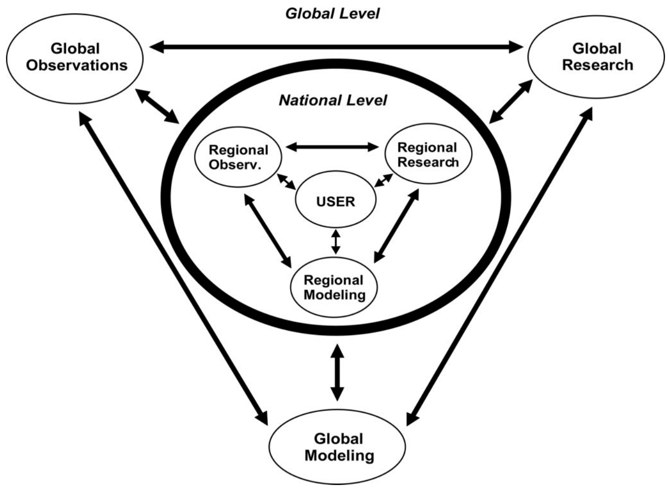

Fig. 1. Functional elements and relationships of an NCS.

observing system is the sum total of national systems that contribute to it, its maintenance and operation depends on widely divergent levels of funding. The global climate-observing system must not only satisfy the principles of climate observation laid out by the Global Climate Observing System[§] in support of the overall regime for monitoring long-term climate trends, as defined by the Framework Convention on Climate Change, but also monitor for assessing and predicting seasonal to interannual variability [e.g., the El Niño/Southern Oscillation (ENSO)] and decoding decadal variability [e.g., the Pacific Decadal Oscillation (PDO)], which are functions currently not included in the Framework Convention on Climate Change scope.

Current U.S. observational capacity, which is primarily national and administered by federal agencies, is highly fragmented, with different systems having been established at different times by different organizations for different reasons, all without cross-calibration. This fragmentation leads to gaps in observations in space and time as well as in parameters measured (12). Major observing systems include the NOAA's NWS cooperative network for weather observations, the Federal Aviation Administration's Automated Surface Observing System, the U.S. Geological Survey's Stream Gauge Network, and the U.S. Department of Agriculture's Snowpack Telemetry and Remote Automated Weather Stations networks. No structure exists to shape the development of a comprehensive, cohesive whole from these disparate parts. An NCS would provide the overarching structure to address these deficiencies, enhance the effectiveness of the global observing system, and expand the limits of what we can currently know and forecast about climate. The observations are by far the most expensive component of the NCS, yet are essential.

The second leg of an NCS is modeling to support routine global climate analysis and regional modeling on the spatial scales needed by stakeholders and climate impacts researchers. Global coupled climate models are needed to assimilate disparate global climate data and produce a routine (at least monthly) global analysis of the climate system; this forms the data and model basis for global predictions, the basis for a consistent and orderly growth of the climate record, and for the large-scale boundary conditions for modeling downscaled information. Decision makers typically need quantitative information for a specific location or area (13). For example, the CIG has often been asked to provide analysis to support decisions made at the spatial scale of a county or smaller,

[‡]Global Climate Observing System (2003) *The Second Report on the Adequacy of the Global Observing Systems for Climate in support of the UNFCCC* (World Meteorological Organization TD No. 1143).

[§]Global Climate Observing System (2004) *Implementation plan for the Global Observing System for Climate in Support of the UNFCCC* (World Meteorological Organization TD No. 1219).

which is significantly less than the resolution of global models. This discrepancy is important for the regional component of an NCS, which must downscale global/national observations and modeling to address problems faced at and by the regional spatial scale.

The third leg of an NCS is research. On the global scale, research is needed to improve the models and the data assimilation schemes used in global and regional modeling. Research should also represent an optimal melding of what stakeholders need for managing resources and what scientists view as necessary for developing a deeper understanding of the coupled climate/resource systems. However, national- or global-scale research is often difficult for a stakeholder to apply directly to location-specific decisions. The research component of an NCS would allow stakeholders to work more actively with climate scientists on decision-relevant research; consequently, the NCS should have the authority and the funds required to issue requests for proposals for the research needed to succeed in its mission.

Fig. 1 reflects the structural and organizational imperatives of an NCS. The purpose of the system is to provide useful information and products to society by combining observations, models and modeling, research, forecasts, and a wide variety of decision tools on the indicated space scales to build understanding and capacity and to increase resilience to climate variability and change. To accomplish this, an NCS must have a user-centric orientation in which stakeholders are seen as a continuously involved constituency. Salient and authoritative information must flow to the user from observations, modeling, and research on the space and time scales determined by user needs. It should be emphasized that every specific user need that requires climate information will require all of the elements indicated in Fig. 1.

The arrows in Fig. 1 indicate not only scientific flows between the elements of the global, national, and regional infrastructures, but also the flow of appetite. The user must be able to place reasonable demands on the global, national, and regional infrastructure (either directly or indirectly) and have some means of knowing that this appetite can be satisfied. The climate service is a service, after all. The organizational imperative corresponding to this flow of appetite is crucial to the balanced workings of an NCS. The lines of authority and organization must be such that any imbalance or inadequacy in infrastructure, whether regional or global, that affects the quality or utility of the information demanded by and delivered to the user can be redressed in a reasonable amount of time. This need for direct lines of authority and the need to maintain the complex infrastructure illustrated by Fig. 1 are the bases for our call for a centralized form of management at the national scale, as is described in *What Functions and Services Should an NCS Perform?*

What Functions and Services Should an NCS Perform? The principal functions and services of an NCS are listed in Tables 1 and 2. In this context, "functions" refer to the general operating objectives of the NCS system as a whole. "Services" refer to the general tasks that the national and regional NCS components provide to NCS stakeholders. The first function of an NCS is integrating global, national, and regional observations infrastructure to produce information and assessments useful to stakeholders. The NCS becomes the primary U.S. agency involved in designing and maintaining the global observational system and participating in global-scale assessments. The NCS also negotiates with other governments operating within the Framework Convention on Climate Change regime. At the national scale, the NCS would assist in coordinating the upgrade, expansion, and/or optimization of existing and future observation networks. This point is key: new modeling and analytical techniques permit very sophisticated methods of determining the optimal placement and instrumentation for multiple objectives for a given cost and may permit the retirement of some existing observations and the establishment of much-needed new observations (14, 15).

The second function of an NCS is modeling at all scales with emphasis on regional-scale products that can be used to support stakeholder decisions. This function includes developing forecasting models for hydrologic variables (e.g., runoff, water supply, flood risk, drought risk), fisheries, and forest-fire risk.

The third function consists of performing basic and applied research on climate dynamics and impacts with a focus on understanding and explaining interactions among climate, society, and natural resources; identifying important climate-related vulnerabilities and opportunities; and furthering the development of climate forecasts and regional-scale climate-based resource forecasts. Much of this research, particularly research that is related to projections of future conditions, will be based on modeling driven by the set of applications and potential applications identified by stakeholders and/or researchers. This research differs from traditional standalone climate research in that research within the NCS addresses and is motivated by specific user needs. For example, the extensive and persistent drought in the western U.S. has led many water managers to ask why it is happening, how long it will continue, and whether it is related to global warming. All of these questions have motivated very good research.

The fourth function is creating and maintaining an operational delivery system for new products and/or or facilitating transition of new products for delivery by parties outside of the NCS and

Table 1. NCS functions

1. Integrate global, national, and regional observations infrastructure to produce information and assessments of use to stakeholders and researchers
2. Develop models for decision support
3. Perform basic and applied research on climate dynamics and impacts relevant to stakeholder interests
4. Create and maintain an operational delivery system and facilitate transition of new climate applications products to NCS member agencies
5. Develop and maintain a dialog among research teams, member agencies, and stakeholders for developing information relevant for planning and decision making
6. Identify climate-related vulnerabilities and build national capacity to increase resilience
7. Represent regional and national climate issues and concerns in regional and national policy arenas and facilitate regional–national communications on NCS needs and performance
8. Outreach to stakeholder groups

Table 2. NCS services at the national and regional level

1. Serve as a clearinghouse and technical access point to stakeholders for regionally and nationally relevant information on climate, climate impacts, and adaptation; developing comprehensive databases of information relevant to specific regional and national stakeholder needs
2. Provide education on climate impacts, vulnerabilities, and application of climate information in decision-making
3. Design decision-support tools that facilitate use of climate information in stakeholders' near-term operations and long-term planning
4. Provide user access to climate and climate impacts experts for technical assistance in use of climate information and to inform the climate forecast community of their information needs
5. Provide researcher, modeler, and observations experts access to users to help guide direction of research, modeling, and observation activities
6. Propose and evaluate adaptation strategies for climate variability and change

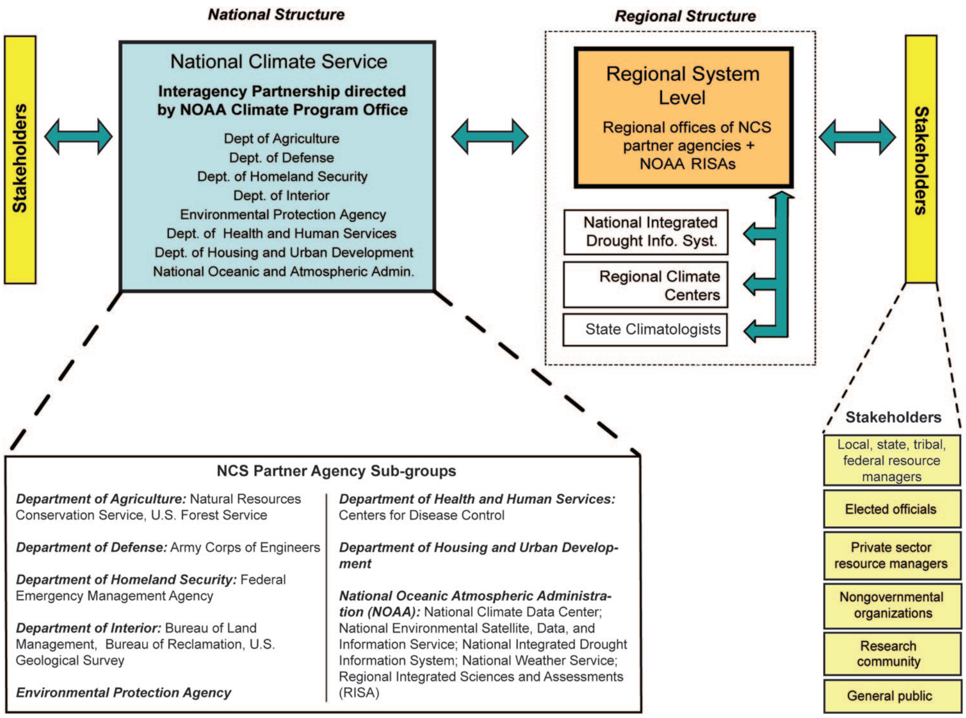

Fig. 2. Representation of an NCS.

its partner agencies. These products include climate-change scenarios, climate and resource forecasts, decision tools, and planning resources, such as information that identifies shifts in patterns of variability and their implications for water demand and reservoir management or forest-fire management.

The fifth function is developing and maintaining a continuing dialogue among research teams, member agencies, and stakeholders focusing on development and delivery of information useful for planning and decision-making. The sixth function is identifying climate-related vulnerabilities and building national capacity to increase resilience to climate impacts. This function includes providing projections of climate change and drought that are useful to those concerned not only about impacts but also the design of structures, facilities, and other long-term planning objectives. This function also includes preparing national integrated impacts and vulnerability assessments.

The seventh function is representing regional and national climate issues and concerns in policy arenas, such as the development of a national drought policy or changes in Federal policies regarding flood insurance and coastal hazards. The eighth and final function is outreach. Outreach to stakeholder groups provides valuable opportunities for feedback on research products, decision-support products, and other information needs. Outreach also facilitates building relationships with potential NCS service users and enhances learning about climate, climate impacts, and use of climate information by stakeholders.

How Should an NCS Be Designed? The proposed structure is a nationally distributed system with institutional partnerships operating at the national and regional scales (Fig. 2). This structure draws on existing capacity and expertise but configures the components to create a structure that can achieve the integrated objectives of an NCS in a way that no single agency could do alone. The NCS must be implemented as an interagency partnership, given the distribution of interests and capabilities across Federal agencies and the distribution of stakeholders across public and private sectors in the 50 states. This partnership must be authorized and funded by Congress to provide both the authority and incentives needed to facilitate such a partnership at the national and regional levels. Over time, interagency coordination at the federal and regional levels will in turn induce greater degrees of coordination between the partner agencies at the state level.

The principal roles of the national office are to (*i*) combine the observation, research, and modeling activities of multiple agencies into a coherent whole; (*ii*) secure financial resources to support the work of the NCS at national and regional levels; (*iii*) participate in negotiating, designing, and implementing a global observing system and global-scale assessments; and (*iv*) participate in international and bilateral negotiations, coordination arrangements, and consultations on climate matters. The NCS should be directed by the Director of NOAA's Climate Program Office, because many components of the NCS (e.g., observations and research) are currently administered by that office.

The regional level provides the critical regional link to stakeholders for the NCS. Knowledge of regional systems and decision processes combines with expertise in observations, research, and modeling at all scales (global to the regional) to produce climate information and products designed to fit the specific needs of local decision makers. The regional-level is where most of the services are actually delivered. The regional level member agencies, which are partners with NOAA and each other at national and regional scales, work collaboratively with each other, the RISAs, public and private sector stakeholders, and the national offices of the National Environmental Satellite, Data, and Information Services, the NWS Climate Prediction Center, and the forthcoming National Integrated Drought Information System (NIDIS).

The Regional Climate Centers (RCCs) and state climatologists should also play a key role in the NCS. Economies of scale related to data archiving and the existing connection of RCCs to region-specific needs and perspectives would make the RCCs a valuable resource for the observational component of the NCS. State climatologists also have a valued connection to stakeholders that would be useful to the NCS. Formerly part of the NWS, state climatologists are now supported to varying degrees (mostly at very small levels) by the respective states. They are often faculty members at land-grant universities with ties to the agriculture and water-user communities. Through their close association with state agencies and other stakeholders, state climatologists are historically very responsive to user needs and have developed innovative new services as a result. The South Carolina State Climatology Office, for example, has developed a tool that allows users to obtain drought information over various geographic scales, including county, watershed, or groups of watersheds. State climatologists are also in many cases deeply involved in advising governors and communicating with news media in times of drought. Two RISA programs include state climatologists in a prominent role: the CIG and the Southeast Climate Consortium (with the state climatologists for Washington and Florida, respectively).

Programmatically, the RCCs already have a well defined role and fit easily into an NCS, but systematically entraining the state climatologists across the nation will require some thought and effort. Both the American Association of State Climatologists (AASC) and the NCDC, which currently provides some assistance to state climatologists individually and through the AASC, would need to be involved on behalf of state climatologists in NCS design.

Fig. 2 represents an initial design for an NCS. The system will evolve over time, and the internal organizational subculture of NOAA will likely play a large part in its evolution. We can foresee one path such an evolution would take. The Climate Program Office is a research unit within the NOAA's Office of Oceanic and Atmospheric Research. But it is expected that the NCS will facilitate a steady stream of innovations that will be transferred to operations, which means that the NCS must also be able to control its own operations like the NWS controls theirs. Eventually, therefore, the NCS will have to be spun off from the Office of Oceanic and Atmospheric Research because the latter is not an operational unit.

How Should the NCS Be Evaluated? The system should be periodically evaluated on four criteria. The first criterion judges the degree of collaboration between regional research teams and the regional offices of NCS member agencies, between the regional research teams and the national data centers and observations system, and between the NCS and regional stakeholders. The critical parameter of collaboration is the establishment of partnerships among and between researchers, modelers, and users and how well those partnerships function. The second criterion judges performance on the quality and relevance of regional research efforts to stakeholders and researchers. Judging relevance always involves asking the users. The third criterion judges performance on the relevance and quality of decision support and of decision tools. The fourth criterion calls for periodic detailed and systematic investigations to document evidence of the impact of the system on regional planning and decision-making by user communities.

The NIDIS as a First Step Toward an NCS. An early demonstration of the national-scale concept of an NCS is found in the emerging NIDIS program.[¶] NIDIS looks to develop a drought information system, which will help stakeholders assess the impacts and risks of drought, and decision support tools for preparing for and mitigating drought impacts. Major support for NIDIS emerged in the Western Governors' Association (WGA), an organization whose members govern the country's most drought-prone regions (including the West and the Great Plains). The WGA's support for NIDIS was a response to the ad hoc manner in which the U.S. manages drought. This diffuse approach stands in sharp contrast to the clear national system that exists for managing other climate-related events such as floods and hurricanes.[¶] The WGA decried the absence of a national drought policy and the lack of a coordinated, integrated drought monitoring and forecasting system. To remedy these deficiencies, the WGA has proposed the following objectives for NIDIS to Congress.

1. Improving and expanding the national drought indicators database by combining physical/hydrological with socioeconomic and environmental impacts data.
2. Facilitating integration and interpretation of data "with easily accessible and understandable tools, which provide timely and useful information to decision makers and the general public."
3. Seeking to establish a "comprehensive national drought policy, including improving drought monitoring and forecasting (NIDIS), coordinating and integrating governmental programs, establishing reliable funding for drought preparedness and response activities, and facilitating state-based drought preparedness and mitigation programs."[¶]

The Governors also specifically recommended that NOAA be designated the lead agency for NIDIS.

The emerging NIDIS program is a first step toward demonstrating the national-scale concept of an NCS for several reasons. First, NIDIS is intended to be a fully integrated system linking together observations, modeling, and research for predicting drought events. Second, the integrated system will be matched with specific operational managers (e.g., the Natural Resources Conservation Service), who in turn are linked to a wide range of stakeholders in drought-prone regions of the U.S. Third, the information and decision tools provided by NIDIS will be linked to planning at Federal, regional, and state levels to increase adaptive capacity and resilience to drought. The fundamental design of NIDIS is centered on the nature, type, quality, and utility of information that it must provide. NIDIS is therefore a good example of the need to consider design, implementation, evaluation, and enhancement of observing systems in relation to the function of an information service (E. Shea, personal communication). NIDIS would become a component of the NCS with a specifically defined task and role related only to drought.

Working from the Global to the Regional: The RISA Program and the Experience of the University of Washington's CIG. The case for a regionally distributed design as the basis for the NCS derives from the experiences of the NOAA's Regional Integrated Sciences and Assessments (RISA) teams. The NOAA's RISA program supports research on climate-sensitive sectors (e.g., water resources, fisheries, wildfire, agriculture, human health, and coasts) relevant to the concerns of decision makers and policy planners at a regional level, with the aim of increasing regional resilience to climate fluctuations. The RISA program consists of teams in the following regions: California, the Carolinas, Colorado, New England, the Pacific Northwest (PNW), the Southeast U.S., the Southwest U.S., and the Pacific Islands. A ninth RISA is scheduled to begin in Alaska in 2007. The teams are primarily university-based but may also draw on researchers from government research facilities, nonprofit organizations, and private-sector entities.

A graphical representation of RISA's role in bridging the climate research and resource management communities is shown in Fig. 3. RISAs function as producers and providers of region-specific, climate-based resource forecasts for regional stakeholders. This work is made possible by research on how climate, natural systems, and human socioeconomic systems and institutions interact to determine a region's sensitivity, adaptability, and vulnerability to climate fluctuations. Links to stakeholders are created through a wide variety of outreach activities

[¶]Western Governors Association (2004) *Creating a Drought Early Warning System for the 21st Century: The National Integrated Drought Information System* (Western Governors Association, Denver, CO).

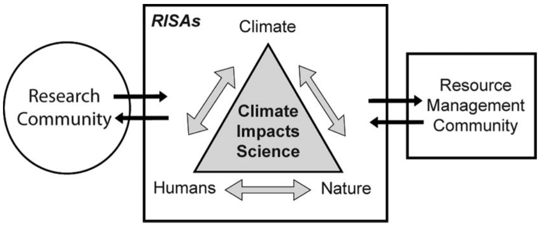

Fig. 3. RISAs bridge the research and resource management communities.

reaching appropriate individuals and authoritative decision makers at all levels.

The experience of RISA shows that each regional team evolves in its own context, in which building trust over time with repeated contacts is critical, as is finding ways to expand stakeholder awareness and understanding of the ways in which regional climate dynamics shape the variation in the resources they manage and the activities in which they engage. There are no general recipes that would work well in all contexts, but there are lessons to be learned from each other that can be adapted and transferred to good effect. Thus, the emphasis is on the evolutionary development of the teams as they are connected to regional stakeholders, and evolution does not occur in a straight line.

The CIG. How then does the regional system work with respect to the NCS functions and services listed in Tables 1 and 2? The answer to this question lies in the origins of the RISA program and the work of the CIG from 1995 to 2005. By the mid-1990s, the NOAA's Office of Global Programs (now the Climate Program Office) was seeking a strong integrative research and assessment role with continuous interaction between researchers and users for the purpose of developing prototype products and interpreting climate forecasts for likely impacts. The Office of Global Programs was the catalyst, providing leadership for the national observation system, research investments within the NOAA National Laboratories and in the universities, and in the design and coordination of regional developments. When it implemented these initiatives in connection with the U.S. Global Change Research Program, the Office of Global Programs emphasized supporting pilot applications and the development of a process for creating a national delivery system for climate information (16).

The CIG was established in July 1995 as the first RISA team. As a pilot, the CIG was designed to be a voyage of discovery with the objective of increasing regional resilience to climate variability and change particularly through development of new seasonal/interannual resource forecast capabilities based on an improved understanding of ENSO dynamics. Research at the CIG focuses geographically on the U.S. PNW (defined as Washington, Oregon, Idaho, and the Columbia River Basin). The region includes several key natural and managed systems with sensitivity to climate. The impacts associated with population growth add to current and future management challenges. Recognizing this, research at the CIG has focused on four climate-sensitive economic sectors: hydrology/water resources, forest ecosystems, the coastal zone, and aquatic ecosystems. Plans for adding human health and irrigated agriculture have not been realized to date because of budget limitations.

We envision our work as an inverted triangle, the base of which is research to support adaptation. The results of this research provide the foundation for the other vertices of the triangle, decision support and outreach. Decision-support tools, listed in Table 3, are designed to facilitate use of climate information in operations and planning. Outreach is designed to develop and maintain ongoing relationships with the stakeholder community. Table 4 shows a list of key stakeholders as of 2005. Investment in outreach should not be overlooked. By educating our stakeholders about ENSO, PDO, paleoclimate, and climate change, we create a demand for information about climate and implications for resource management that previously did not exist. CIG outreach activities include workshops, presentations, an on-line newsletter, web-site development and maintenance, and graduate-level courses at the University of Washington.

The CIG has made several major contributions to regional climate impacts science during the past decade. These include the following.

Table 3. CIG contributions to decision support in the PNW

Climate variability
Monthly climate outlook
Long-lead (1-year) seasonal streamflow forecasts based on ENSO/PDO
Long-lead (1-year) seasonal marine survival forecasts for Oregon coastal coho salmon
Mid-term (6-month) municipal reservoir forecasts
Near-term (7- to 14-day) extreme weather risk forecasts
Climate change
Climate change temperature, precipitation, snowpack, and streamflow scenarios
Climate change streamflow scenarios for water-supply planning
Client-based research consultancies (e.g., climate-change impacts on municipal water supplies)
Optimization models for evaluating climate-change impacts on streamflow management
Technical assistance to watershed planning

Table 4. Key stakeholders for the CIG

Federal level
Bonneville Power Administration
NOAA Fisheries Service
NOAA River Forecast Center
U.S. Army Corps of Engineers
U.S. Bureau of Reclamation
U.S. Congress
U.S. Environmental Protection Agency
U.S. Fish and Wildlife Service
U.S. Geologic Survey
USDA Natural Resource Conservation Service
State/tribal level
Alaska Department of Fish and Game
California, Oregon, and Idaho Departments of Water Resources
Washington Department of Ecology
Washington Department of Fish and Wildlife
Washington, Oregon, and Idaho Governor's Offices
Washington, Oregon, and Idaho State Legislatures
Columbia River Inter-Tribal Fish Commission
Northwest Indian Fisheries Commission
Local level
Central Puget Sound Water Suppliers' Forum
City of Tualatin, OR
King County, WA
Washington State watershed planning units
Portland Water Bureau
Puget Sound Clean Air Agency
Seattle City Light
Seattle Public Utilities
BC Hydro (Canada)
National Wildlife Federation
Northwest Power and Conservation Council
News media

- Defining the PDO. The CIG demonstrated a solid connection between interdecadal variations in North Pacific climate and the abundance of salmon and other marine species in the PNW and Alaska, and in so doing named and defined the PDO. The PDO is now recognized internationally as a major climate driver with wide-scale impacts on natural resources in the western U.S., Canada, and eastern Russia (17, 18).
- Identifying ENSO and PDO impacts on the PNW winter climate and key natural resources. The CIG characterized PNW climate variability, including the association of warm-dry and cool-wet winters with warm and cool phases of ENSO and PDO, and the links between several other large-scale climate modes (e.g., Pacific North America pattern and the Arctic Oscillation) and extreme weather events such as windstorms, cold-air outbreaks, and snow. The CIG demonstrated how ENSO, PDO, and other aspects of climate influence key PNW natural resources (including snowpack, streamflow, flooding, and droughts), forest productivity and risk of forest fire, salmon returns, and quality of coastal and near-shore habitat (9, 19–21).
- Identifying 20th century trends in PNW temperature, precipitation, and snowpack. The CIG analyzed 20th century trends in PNW temperature, precipitation, and snow water equivalent (an important indicator for predicting summer water supplies). Annually averaged PNW temperature increased more than the global average during the 20th century, precipitation showed no clear signal, and regional snow water equivalent decreased significantly (up to 60% at some locations) since 1950 (22–25).
- Defining and evaluating the potential impacts of global climate change on PNW climate and resources. CIG research on the impacts of climate change on the PNW projects significant challenges in the decades ahead for the region's water resources, salmon, forests, and coasts as a result of human-caused global warming. These include increased risk of winter flooding and summer drought; salmon mortality in freshwater habitats; forest fires; changes in Puget Sound ecosystem structure and function; and coastal erosion and flooding (9, 26, 27).
- Identifying barriers to the effective use of climate information and characteristics of adaptive institutions. Elite surveys with PNW natural resource managers have revealed that barriers to the use of climate forecasts include lack of knowledge on the part of forecast users, problems with the forecasts themselves, and institutional barriers to use of forecasts (5).

Evolution of the CIG as a Regional Resource in the PNW. Evolutionary development is highly interactive and often serendipitous. At the beginning, the CIG worked to identify and quantify the relationships between global climate phenomena and regional hydrologic processes using the historical record. The results of these analyses were applied to explaining variations on PNW water resources systems. Interaction with stakeholders led the CIG to develop general hydrologic forecasting techniques and specific applications of hydrologic forecasts for PNW water resources management. But the application of these forecasts to operations was not straightforward, given the importance of institutional factors that determine vulnerability to climate variability and barriers to the use of climate forecasts. Only after this work was done was it possible to integrate the understanding of the physical dynamics of climate variability with advances in hydrologic forecasting, modeling of climate change effects, and understanding of the institutional vulnerabilities to climate variability and change in a comprehensive fashion (28).

As time passed, the CIG saw that learning within the stakeholder community develops in an evolutionary way, punctuated by sharp transitions in response to external events. The 1997–1998 El Niño, the strongest of the 20th century, was a high-profile event that we could use to illustrate regional vulnerabilities to climate fluctuations and how climate impacts are amplified when ENSO and PDO are simultaneously in warm or cool phases. We also learned from this event that media coverage could give our activities a significant boost during periods when climate issues were highly salient. The event proved to be a wonderful opportunity to teach and learn about responding to climate variability and to attempt to decrease vulnerability to extreme events.

The emphasis on serving the specific needs of regional stakeholders is a key objective of the RISA program. Serving such needs includes not only publication of peer-reviewed research but development of decision support tools designed to help decision makers apply climate information. The CIG has made many innovative contributions to decision support in the PNW (Table 3). These tools are a direct result of the CIG's growing understanding of the region's sensitivity to climate, the predictability of these impacts, and the expressed needs of stakeholder for managing critical resources.

This brief sketch of how the RISAs operate, as seen through the lens of one of the regional teams, demonstrates that not only the RISAs but the NCS as a whole clearly fit into the category of knowledge–action systems as defined by a workshop of the National Research Council:

> These systems are generally viewed as organized efforts to harness science and technology in support of social goals. In general [such systems] encompass the set of relationships, actors, institutions, and organizations that set priorities, mobilize funds, do the R&D, review publications/promotions, facilitate practical application and reinvention, and provide evaluative feedback on performance. Such systems are not generally designed from scratch, but rather evolve through time as a result of multiple and only partially integrated interventions (29).

Effective systems for linking knowledge and action must produce information that is seen to be salient, credible, and legitimate. Collaborative problem definition is "user driven, but reflect[s] input from the scientific (producer) community on what is feasible" (29).

Conclusions

Developing the institutional capacity to provide climate services is a very large undertaking and is neither quick nor easy. The NCS requires comprehensive and interlinked global, national, and regional observing systems, a comprehensive climate model, and a largely distributed research and application capability. These components create the three-legged stool for the ultimate objective: producing climate-based resource information that is not only useful but also used in planning and decision-making. Achieving this objective also requires developing integrated research and outreach teams at the regional scale for sustained, long-term innovation and communication with a wide variety of stakeholders; defining, in a collaborative process with stakeholders, the types of climate information that are most useful for individual applications; producing specific, mutually defined products; and building trust with stakeholders over time.

The NCS is essential for developing national capacity to understand and manage the impacts of climate variability at a time when observations clearly indicate that human-generated climate change is also under way. The NCS would be achieved most effectively as a Federal interagency partnership with critically important participation by regional climate centers and state climatologists, by NIDIS at the mega-regional level, and by the RISA teams. Collaboration and coordination are essential in this respect. The regional scale is clearly the most effective for integrating research and decision support with stakeholder needs, but because the organization is crafted from existing components that do not now fit together, they can and must be made to fit. NIDIS may well evolve into more of a broker than the RISAs, operating at the mega-region level. The RCCs can evolve into units that focus primarily on the production of decision tools, to which the RISAs transition their innovations and go on to the invention of others.

All of this we know, but major challenges stand in the way of achieving these objectives. The issue of achieving comprehensive, effective global, national, and regional observing systems is perhaps the greatest difficulty, because it seriously limits what the scientific community can do and is greatly affected by the other challenges. Additional challenges include issues of institutional arrangements affecting agencies, jurisdictions, budgets, and Congressional priorities.

Can we do better at national and regional levels within the U. S. at fusing the bits and pieces of a climate service into a comprehensive whole? Certainly, because we have the technical capacity and the knowledge to do so. So far, either we have not demonstrated the will to do so, or we have not recognized the real need to do so in the face of a changing climate. The challenge lies in changing the existing organizational infrastructure to produce an integrated observing system with an information system catering to research and decision-making interests at the national level and designing a carefully crafted series of regional systems from what currently exists. The stumbling blocks are organizational inertia and the competition for programs, budget, and turf and very low Congressional funding allocation priorities. The latter can be changed given salient prodding by Nature. The former can be changed only if Congress clearly specifies changes in system design, in the authority structure, and in providing the resources to achieve change to act as incentives to change in the desired direction. What we need is a large influx of guided interagency collaboration and integration under effective Congressional oversight. The present article is intended to facilitate a national dialogue leading to recognition of the need to change.

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