6.1 CLIMATE SCIENCE AND SERVICES: SOME LESSONS FROM CLIMAS

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1. INTRODUCTION

The Climate Assessment for the Southwest (CLIMAS) is one of several Regional Integrated Science and Assessment (RISA) projects established in recent years in the United States. These RISAs have begun to blur the division between climate science and society, through the production of "usable" knowledge from interaction between scientists, policymakers and the public. Climate scientists, like many other members of the science community, have typically had difficulty involving users (a.k.a. stakeholders) in the process of knowledge creation in efforts to gain broader support for their research enterprise. One critical aspect has been their inability to reconcile the needs of users with the state of their science. We address this issue by describing the way basic and applied climate science have been integrated with user needs in the "end-to-end" RISA model by CLIMAS. First, we discuss how the interdisciplinary CLIMAS team works with users to identify common research objectives. Next, these objectives are placed in a framework that summarizes the basic character of the research and its relation to users. We then highlight these interactions by examining specific examples of climate research sub-projects driven by users' needs. We draw from our interactions with users in different areas such as water and wildland fire management, public health, farming and ranching. Finally, we discuss lessons learned and highlight how the concept of usable science can be expanded into a critical component of the climate science enterprise with the establishment of a new national climate services program.

1.1 Background

The climate science community is increasingly challenged by the need to connect the creation of basic knowledge with users. Many influential studies on the use of knowledge-based information in policymaking have focused on the dichotomy between science produced for policy ("applied" or "mission-driven") and science grounded on research alone ("basic" or "pure"). More recently, scholars have become increasingly interested in a third approach in which the division between science and society is bridged and "usable" knowledge is co-produced in the context of everyday interaction between scientists, policy and decision-makers and the public. Yet, the science community has had difficulty involving users in the process of knowledge creation in an effort to gain broader support for the research enterprise. One critical constraint has been the inability of scientists to define usable knowledge in a way that reconciles the needs of users with the state of their science.

In 1990, the United States Congress defined "usable knowledge" for global change research in terms of the need for "an 'information management strategy' that would, in part, 'combine and interpret data from various sources to produce information readily usable by policy makers attempting to formulate effective strategies for preventing, mitigating and adapting to the effects of global change" (Pielke 1995). While this approach has been critical in dealing with broad climate related issues such as global warming, it has neglected the pressing needs of local level users. Thus, we define usable knowledge "as one that can be incorporated in decision-making processes of all stakeholders with the goal of improving on their previous situation. In addition, usable knowledge presupposes a concerted effort from knowledge producers to "package" information as readily as possible for stakeholder consumption (Lemos and Morehouse 2003). At the same time, there has been a rapid increase in the understanding of seasonal to interannual climate variability and how local users can benefit from it. To respond to this opportunity a group of universities have teamed up with NOAA to engage in a fundamental new form of usable, or user-driven, climate science.

The NOAA-university partnership has resulted in a number of Regional Integrated Science and Assessment (RISA) initiatives, one of which is the University of Arizona based CLIMAS (Climate Impact Assessment for the Southwest) program. The organizing framework of CLIMAS works from a foundation of social science research (e.g., ethnographic analysis using surveys and interviews, institutional and policy analysis, etc.) and direct stakeholder (user) linkages, which in turn drive formulation of the natural science and outreach agendas. This type of integration involves development of end-to-end understanding of how global, synoptic and local scale climate conditions and processes generate regional-scale social and natural impacts and responses. In CLIMAS, this includes efforts to involve stakeholders in all phases of the research process, integration across scales ranging from the global to the local, and identification of essential factors comprising the multiple stressors that members of the region must take into account when making decisions.

1.2 Climate impact analysis and integrated assessment

The broad field of applied climate studies dates back several centuries, climate being central to agriculture as well as many other important human

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activities. The established literature on climate impact analysis as a specific area of study dates back several decades. Until recently, and with a few exceptions, large regional or national cross-sectoral analyses of climate impacts have focused on impacts of climate *change*, rather than seasonal to decadal *variability*. These studies also were 'climate-centric' and top-down in their approach. There have been very few climate impact studies of this kind that explicitly employ social and natural science to identify and answer user-driven research questions at interannual time scales.

The value of stakeholder involvement and engagement in the creation of knowledge in general and, in climate impact research in particular, is well-established in the literature (Scott et al. 1999, Caswill and Shove 2000, Gibbons et al. 1994, Agrawala et al. 2001, Hartmann et al. 2002) Yet, there is no established theory or practice of "how to do it" in the social or natural sciences. In order to narrow this gap, in this paper, we synthesize and communicate what we have learned from several years of experience interacting with stakeholders to define a framework and process to carry out user-driven climate variability impact and assessment. Hence, the goal of this paper is to describe how CLIMAS integrates basic climate science and stakeholder interests by adopting an iterative model of regional assessment research. Such model is defined by four basic conditions: interdisciplinarity, close interaction with stakeholders, production of usable knowledge, and the existence of a synergistic relationship between knowledge production and stakeholders' needs through which each process is adapted and transformed (Lemos and Morehouse, 2003). First, we discuss how the CLIMAS team works with users to identify common research objectives, and how the team achieves interdisciplinary integration. Next, these objectives are placed in a framework that summarizes the basic character of the research and its relation to users. We then highlight these interactions by examining specific examples of climate research sub-projects driven by users' needs. We draw from our interactions with users in different areas such as water and wildland fire management, public health, farming and ranching. Finally, we discuss lessons learned and highlight how the concept of usable science can be expanded into a critical component of the climate science enterprise.

2. STRATEGIES FOR INTERDISCIPLINARY USER-DRIVEN RESEARCH

2.1 Working with users

Stakeholder-driven climate science is not just a new term for applied climatology. In fact, this process is less user-driven *per se* and is more accurately described as a relationship, in which climate scientists and users communicate with each other in an ongoing and iterative way. The underlying concept is that regular interaction with a stakeholder group will not only identify the kind of information needed, the preferable formats and levels of complexity for its delivery, etc., but also that this exchange of ideas will sometimes lead to new research questions that otherwise might not have been asked. Because they are involved in the process, user communities will encourage work on these kinds of problems as well as more conventional basic research questions resulting from the overall process. Consequently, one clear measure of success for such a relationship is real advocacy for support of the climate science, *by users*. Clearly this model of (federally funded) climate science with the inclusion of the user as a cornerstone in the process differs from the typical knowledge-driven model of past decades.

In the context of CLIMAS, these user groups vary by size, function, and topic. Depending on the problem, they might include policymakers, resource managers, or groups of individuals such as ranchers or farmers. What are the best ways to get information flowing and to initiate and develop relationships between users and climate scientists? While the simple pairing of climate scientists with potential users may be appropriate in limited situations, in many circumstances, the complexities of the social and physical settings in which users function require a far more sophisticated analysis. Social scientists have the necessary theoretical background and research methods to address exactly these kinds of problems, for example using interviews, surveys, and other ethnographic techniques to elucidate user needs and preferences, and subsequently to analyze and identify institutional opportunities and constraints, information flows, decision-making, and science-policy interfaces.

Within CLIMAS we have evolved some practical ways to develop relationships with users, as individuals or groups or both. For larger user groups or for users with a broad background that represent a geographic area or sector (e.g., farmers and ranchers in a valley, or fire managers across a region), a team of anthropologists within the project use rapid ethnographic assessment methods to appraise the needs and concerns of users while simultaneously informing them of CLIMAS' activities. Other user interactions may involve presentations followed by question and answer sessions at meetings (e.g., Cattlemen's Association), or CLIMAS staff may convene a workshop or series of workshops to bring together a range of users (e.g., the Southwest Fire and Climate Workshops that bring together field operations and agency-level fire managers with climate specialists). At individual or group meetings with users, CLIMAS team members may make use of specially developed newsletters, brief printed summaries, longer white papers, or more formal presentations by staff or climate researchers to convey climate information. For small groups of more technically specialized stakeholders (e.g., dam managers or disease ecologists), informal meetings and presentations may be used instead.

Whatever their form, these interactions constitute a mutual learning process. Initially, users learn the state of the science and which aspects of their climate information needs may or may not be achievable, while researchers learn, in very specific ways, the strengths and weaknesses of users' current climate information as well as their particular needs. The outcome is a jointly defined set of desired usable-science "products" that, depending on the context, may range from retailored existing knowledge to new basic research. Iteration of this process during the months and years that follow leads to refinement and further development of usable-science products. The nature of these products may be quite straightforward and tangible, such as reformatted and synthesized climate forecasts, or a decision support tool. Yet, the nature of other products may be more assessment oriented, such as an examination of interagency use and decision-making involving climate information, or a broader policy analysis of a climate-related resource.

2.2 Research interdisciplinarity and integration

Interdisciplinary research is easy to talk about, but a lot harder to really do well. Truly interdisciplinary work, especially between the natural and social sciences, is very hard to achieve because of the fundamentally different paradigms used and questions asked. Moreover, many of the institutional arrangements guiding work within universities and research organizations are not conducive to promote interdisciplinary work. Indeed, the presence or lack of institutional support for interdisciplinary research plays a critical role in the ability of projects such as climate assessments to achieve interdisciplinarity. Thus it is not surprising that, rather than being interdisciplinary, many such projects are, at best, multidisciplinary in that cooperation consists of working on the common theme but under different disciplinary perspectives. In this sense, one critical advantage of CLIMAS is its location within the Institute for the Study of Planet Earth (ISPE), a research unit that supports and facilitates the integration of knowledge within the University structure.

We therefore provide some brief comments on natural and social science integration here because it is fundamental to integrated assessment within CLIMAS. An important part of achieving interdisciplinarity is for each of the disciplinary groups to learn how the other thinks, a non-trivial and continuous process. We illustrate this with an example. An early hurdle to overcome was a perception by natural scientists that the social scientists were involved in the project to do user surveys ("market research"). Natural scientists initially tended to see the technology transfer of their work to users as a simple matter of presenting useful results or models, a process that could be advantageously improved with some knowledge of their users' needs. It took some time and many interactions for natural scientists to understand that, while surveys or interviews may form part of the social science research process, social scientists have research agendas of their own which transcend the applicability or "packaging" of natural science-generated knowledge for potential users. For example, while carrying out research, social scientists were interested in understanding how different formal and informal institutional environments affect stakeholders' decision-making and response to climate and climate information; how climate variability affect stakeholders' vulnerability and capacity to adapt and cope with possible climate change, how issues of communication, access and equity affect stakeholders' willingness to use climate information, how social science can contribute to improve the interface between science and policymaking–to mention a few of the research themes within CLIMAS. In addition, and not less importantly, social scientists were interested in contributing to the scholarship on the social studies of science, by examining how the relationship between natural and social scientists within the scope of CLIMAS shapes and is re-shaped by their interaction.

Other interdisciplinary interactions did not necessarily require mutual understanding as nuanced as this. A case in point involves communication of technical information to a less-specialized audience. We found that the successful transfer of science results requires attention to appropriate cartographic visualization as well as "lay" interpretation to put results in more readily understandable verbal form. An example from CLIMAS work (Hartmann et al. 2002) is the need to educate users (and many climatologists!) on the correct and incorrect interpretation of probability terciles in climate forecasts (Figure 1). Hence, through interaction with both social scientists in the project and stakeholders in the field, new approaches to communication of forecasts were developed which strived to enhance access to the information.

The common thread among the above examples is the interest of social scientists in the *processes* of human interaction related to climate science, be they related to decision-making, communication, or policy processes. Achieving this kind of synthesis is a challenging goal. If realized, it can lead to better-informed science (natural and social) and improved access to and use of information on the part of users. Thus, to work well together and to do high-quality integrated work, both groups of researchers need to have complementary intellectual stakes in the project, and to understand the reciprocal benefits of each other's deeper intellectual engagement.

While we do not claim to have solved all the problems of interdisciplinary integration, we have indeed achieved some real understanding and collaboration between the natural and social sciences within CLIMAS. In order to achieve this level of integration, we have implemented a few practical management and communication strategies, some of which are less commonly found in more conventional multi-investigator research projects. The CLIMAS project is made up of faculty members, postdoctoral associates, extension agents, graduate students, and undergraduates from a variety of disciplines including anthropology, political science, geosciences, geography, and hydrology. The project is structured around a symbiotic relationship between a "core office," which manages the project and connects users with researchers, and a range of topical research groups that are each led by one or more faculty principal investigators. The core office coordinates communication within the project and with users. Vehicles for communication include regular meetings of the whole CLIMAS team and between various parts thereof, as appropriate, for issues ranging from strategic planning to topical research updates

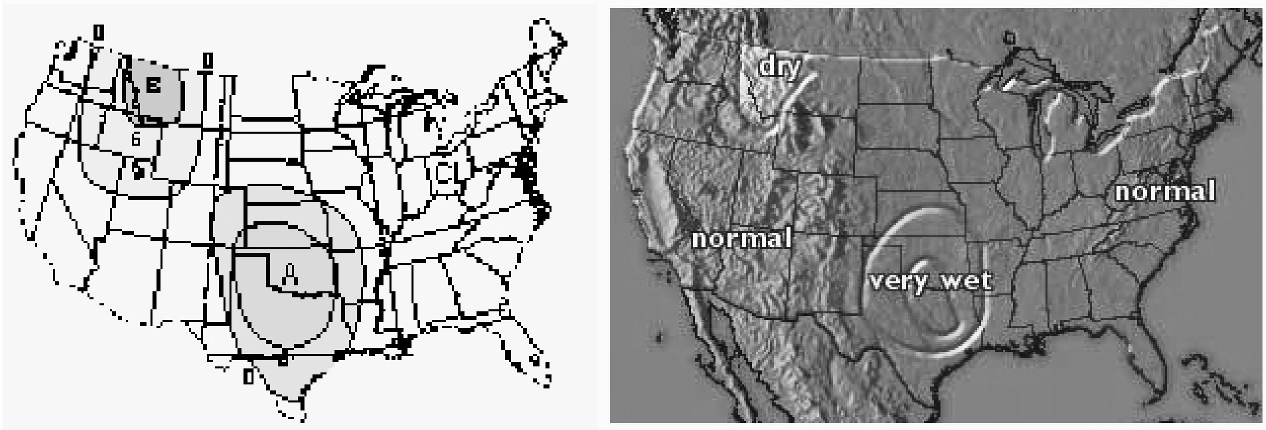

Figure 1: Example of the graphical and verbal misinterpretation of technical information, in this case a climate forecast map from the Climate Prediction Center (left) and an incorrect private-sector version of it (right). Original maps were in color. The correct interpretation of the map at left is that Oklahoma has a 5% greater chance of being in the wettest tercile (i.e., 38% chance of wet, 33% chance of normal, 28% chance of dry), and that climatology (CL) over the Midwest means "no forecast skill" or "complete uncertainty" rather than normal conditions.

within the project, and from workshops to ongoing web-based services for users. We have found it advantageous to co-locate the project manager and core office staff, many of the postdoctoral associates, and some graduate assistants in the same set of offices. This arrangement enables frequent communication and encourages intellectual and practical integration between those doing much of the day-to-day work on the project.

3. ANALYTICAL DIMENSIONS OF USER-DRIVEN CLIMATE SCIENCE

Since its inception, CLIMAS has been designed to respond to user needs in a flexible manner. Whereas some users were identified at the beginning through user surveys, others were recognized based on preexisting relationships between researchers and users, or in response to a particular climatic event. In developing such relationships for over five years, CLIMAS has thus been able to engage, with varying degrees of success, a significant and diverse range of user communities across the U.S. Southwest.

User-driven climate science and service require a spectrum of research activities and user interaction. We have identified at least two important analytical dimensions covering all interactions between researchers and users: the degree of new knowledge creation and the type of stakeholder. The first dimension encompasses both social science and natural science research. As we mentioned above, social science research is essential not only to identify users' needs but also to increase our understanding of how climate information is incorporated into decision-making processes. Natural science research involves the creation of new user-driven knowledge as well as the repackaging of existing knowledge to meet user needs. Within CLIMAS, therefore, all user-driven climate science (social and natural) falls along a gradient ranging from new knowledge creation on one extreme to repackaging of existing knowledge on the other.

The second dimension of researcher-user interaction reflects the fact that climate science must also address a wide spectrum of users. Within CLIMAS, these users range from individual small-scale stakeholders such as ranchers, farmers, and the general public to institutional stakeholders such as water and wildfire managers and public health officials. Depending on the precise science and service involved, and largely independent of topical area, the gradient of users therefore ranges from fewer, more-technically specialized stakeholders to many less-specialized stakeholders. These two fundamental dimensions are shown in Figure 2, which also illustrates the positions of some selected sub-projects from the CLIMAS program.

Many projects within CLIMAS, and similarly to those in user-driven climate science and services more broadly, fall roughly along the diagonal in Figure 2. New basic or applied research tends to be carried out with a small group of specialized users (i.e., the lower left of Figure 2), and repackaged information tends to be employed in situations where user groups are large (i.e., the upper right of Figure 2). Our diagnostic studies of North American monsoon variability and our climate-health research on valley fever outbreaks are examples of the former, with user groups of up to 10 individuals. Our work on climatic aspects of urban water use and planning across southern Arizona (Morehouse 2000a, Morehouse et al. 2000) involved a combination of current knowledge with new research and a moderately-sized group of water managers from urban areas in the region. The user groups for our climate-wildfire and ranching projects are relatively large (50-100, and even more at some meetings), and the relevant information focuses more on education, outreach and extension and less on the generation of new knowledge from research (Morehouse 2000b).

Yet, user attributes and information are not always correlated. Figure 2 shows two examples of CLIMAS sub-projects with different combinations of characteristics on the two dimensions. Our streamflow forecasting project brought existing climate science to a small specialized group of river forecasters to update an older generation of models to account for climate variability. In contrast, the fine-scale climate mapping project provides data to many varied kinds of users, but new applied research was required to develop the data products (Brown and Comrie 2002).

4. EXAMPLES OF USER-DRIVEN CLIMATE RESEARCH

In this section, we present four case studies to exemplify the conceptual points we make in the sections above. For each case, we describe the nature of the interdisciplinary and user relationships, outline the climate science and service activity involved, and briefly summarize the results and outcomes of the case. The four cases are indicated in boldface on Figure 2.

4.1. Climate information and wildfire decision-making in the U.S. Southwest

Recent work has demonstrated links between

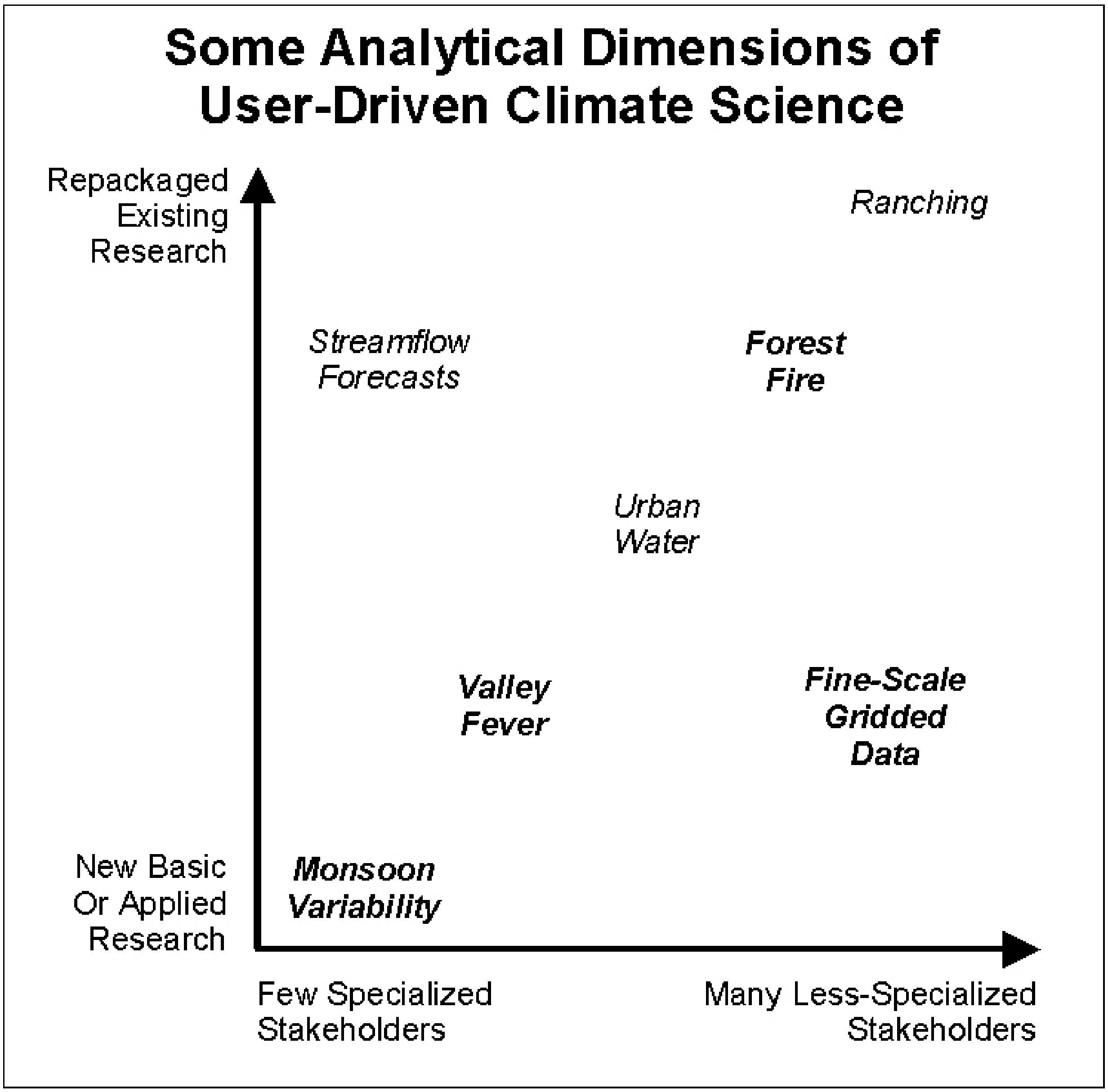

Figure 2: Two dimensions of CLIMAS user-driven climate science interactions: type of users and nature of knowledge. Approximate locations of some example sub-projects are shown. Many of these span a range on each dimension. The four examples in boldface are detailed in section 4 of the text.

interannual to decadal-scale climate variability and the incidence of wildland fire in the U.S. Southwest that have potential predictive power of enormous practical significance. Knowledge of climate variability has not, however, played a major role in the planning of forest management, or, more specifically, of fire management. Fire meteorology is, on the other hand, considered as an integral part of procedures for responding to and managing the control of forest fire.

We therefore initiated a series of workshops designed to facilitate dialogue between climatologists and fire-decision managers and to improve the use of climate information in wildfire decision-making. The managers were drawn not only from the national level, but from the regional level too (and hence the location of this case in Figure 2). The workshops have provided valuable insights into how to ensure that wildfire managers not only receive the climate information they need, as well as when and where they need it, but also that they have the basic knowledge needed to appropriately interpret and use the information provided. By "climate information" we mean not only forecasts on useful time scales, but also records of past conditions for the region in particular, and information on the links between large-scale circulation processes and conditions and events relevant to wildland fire. In short, the workshops were designed to help bring the benefits of state-of-the-art climatology to wildfire managers. These workshops have also served to help us learn how best to bring existing science effectively to a body of users with motivation to receive it, and to establish channels through which their voice can be heard in the planning of new research.

Work with paleorecords of both past fire and past climate in the U.S. Southwest has shown that, over the last 400 years, extensive wildfire occurrences in the mixed conifer forests of the region tended to follow a sequence of one or more wet 'El Niño' winters followed by one or more dry 'La Niña' winters (Swetnam and Betancourt, 1990, 1992, 1998; Swetnam and Baisan, 1996; Grissino-Mayer and Swetnam, 2000). This observation is consistent with the known roles of fine fuel quantity and condition in Southwestern forest fires. A wet winter in 1997-1998 was followed by a dry winter season in 1998-1999, and, by late summer 1999, a further dry winter was forecast for 1999-2000, threatening to complete the historical pattern of wet and dry winters followed by a regional fire year.

It was in this anticipatory context that we held the first of the workshops: "The implications of 'La Niña' and 'El Niño' for Fire Management" in February 2000. The catastrophic fire season of summer 2000 followed, setting the context for the other two workshops: "Fire and Climate 2001" (February 2001) and "Fire and Climate in the Southwest 2001" (March 2001). Pre- and post-workshop surveys were conducted for these last two workshops. The surveys of fire and land use managers, researchers and decision makers were used to assess: 1) their use of and their perception of the usefulness of climate forecasts; 2) how they changed their management tactics, resource allocation, and training based on the availability of climate forecasts, 3) dissemination of information during the fire season; 4) fire-climate research initiatives, and 5) their major concerns and needs. A different questionnaire was used with climate/weather research and forecast professionals, focusing on: 1) degree of interaction with the fire community; 2) fire-climate research initiatives; 3) feedback from the fire community regarding research and forecast products, and 4) their major concerns and needs. We also conducted evaluation surveys for each of the workshops.

The workshops and surveys yielded much valuable information. For example, although most respondents used climate forecasts for long-term planning activities, such as resource allocation, risk assessment, support planning and long-range fire behavior prediction, they were rarely used in the determination of preparedness levels, community education and fire prevention. They also brought to light changes in fire management preparation tactics that will need to be changed in order to make good use of climate information, and a strong statement that "a low rate of incorrect forecasts is more important than a high rate of correct forecasts."

4.2. Improving knowledge and predictive capabilities for climate and health

Valley fever (coccidioidomycosis) is caused by inhaling the spores of a soil-dwelling fungus (*Coccidioides immitis*) that is endemic to the deserts of the Southwest. The life cycle of *C. immitis* is such that fungal growth responds to various sequences of moisture and temperature conditions, including a period of drying when the spores can become airborne. This regional disease has national importance in that 6,000 to 8,000 severe cases occur in the United States each year; 50 to 100 of those who contract the disease die, and overall treatment costs amount to some $60 million per year.

Valley fever was selected as a critical and understudied, climate-sensitive disease for the U.S. Southwest. In fact, our review of the literature (Kolivras et al. 2001) and subsequent research (Kolivras and Comrie 2003) was the first work explicitly examining climate and valley fever relationships since the 1950s. Because so little is understood about these relationships, this project contains a fairly high degree of new research into climate-valley fever relationships. It therefore involves somewhat fewer, moderately specialized stakeholders with respect to the dimensions of user-driven climate science in Figure 2. Toward this end, we linked up with a stakeholder group made up of environmental and health researchers and professionals. Interactions among the group have been facilitated by the University of Arizona's Valley Fever Center for Excellence (VFCE), who strongly encouraged our work in this area.

The actual forms of interactions with the users have included workshop-style meetings and discussions two or three times per year, and more frequent small group and individual contacts between the climate science and health user groups. Our interactions with stakeholders/users identified that the primary need was for better fundamental understanding of climate-coccidioidomycosis relationships. We therefore set out to provide improved basic knowledge, which we were able to augment with an experimental disease incidence forecast model.

For many climatically influenced diseases, there is a paucity of continuous, high quality incidence data. Time series of disease data, relative to climate data, are even more fraught with biases, errors, changes in reporting requirements, lack of metadata, etc. Most climate-sensitive diseases are mediated by further environmental factors for which there are usually no suitable time-series and very limited data. These factors include complex ecological information such as vector population dynamics (e.g., mosquitoes for encephalitis and dengue fever, or rodents for hantavirus). In the case of valley fever, there are poor-quality time series of incidence data for humans with the severe form of the disease. There are no useful data on *C. immitis* itself because of the current unavailability of methods for prompt and reliable identification of spores in the soil or air. Thus, our work involved close collaboration with doctors, public health officials, fungal specialists and soil scientists in our group of users in order to make appropriate operating assumptions and to perform valid analyses on the available data.

Our study (Kolivras and Comrie 2003) revealed that antecedent temperature and precipitation in different seasons are important predictors of incidence. We identified sequences and amounts of precipitation and temperature controlling disease incidence and variability. These results were used in the selection of candidate variables for multivariate predictive modeling, which was designed to predict deviation from mean incidence based on past, current, and forecast climate conditions. Winter temperature and precipitation variables were included in the models more frequently than variables for other seasons, and most variables were time-lagged one year or more prior to the month being predicted. Model accuracy was generally moderate, and months with high incidence can be predicted more accurately than months with low incidence. In this case the exploratory model and related data analyses provided stakeholders with an improved understanding of climate-health relationships and a limited ability to anticipate aspects of future disease variability where none existed before.

4.3. Diagnostics and potential predictability of the North American monsoon

The climate of the Southwest is one of the most variable and extreme in the nation. In addition, control of the winter and summer half-years is by atmospheric circulations that are relatively independent of one another. The mid-latitude westerly circulation governs the region's winter climate and transmits ENSO-related variability therein. The North American monsoon and related subtropical and tropical circulations control the summer climate, and its variability is far more complex and less well understood. Numerous recent studies have examined the complex controls on variability of the North American monsoon system, highlighting features such as the role of sea surface temperatures, antecedent land surface conditions, and mesoscale dynamics along the Gulf of California and the Sierra Madre Occidental (e.g., Adams and Comrie 1997, Higgins and Shi 2000, Gutzler 2000, Mo and Paegle 2000).

These and other monsoon papers, as well as a broader review of the climate of the Southwest by CLIMAS colleagues (Sheppard et al. 2002), have highlighted the importance of improving the state of knowledge regarding the North American monsoon system and its role in summer climate variability over our region. CLIMAS stakeholder surveys in southern Arizona have indicated that there is a large user demand for better seasonal monsoon forecasts (need cite!), but current climate forecasts have little to no skill predicting summer climate conditions. Therefore, we initiated a set of diagnostic analyses into the nature and causes of monsoon-related variability for the American Southwest. Our foci were on intraseasonal variability of daily monsoon precipitation, and the identification of potential seasonal precipitation predictability for broader use by the climate community in experimental forecasts. This work complements broader monsoon research initiatives within the planned North American Monsoon Experiment (NAME).

With respect to the research dimensions in Figure 2, this work strongly emphasized the development of new knowledge. The nature of stakeholder interactions is in two stages. The research was initially driven by stakeholder requests and researcher's own perceptions of priorities, but the immediate use of the knowledge is by climate forecast scientists. It is only in the longer term that the benefits of improved monsoon precipitation forecasts will be felt by the broad range of stakeholders.

For the diagnostic studies of intraseasonal variability, we used a nonlinear classification technique (neural network-based self organizing maps) to investigate the evolution of the monsoon in southeast Arizona during the 1980-1993 period (Cavazos *et al*. 2002). The technique successfully captures the evolution of the monsoon, the mature phase of which we found to be strongly linked to an intraseasonal mid-tropospheric wave-like anomalous height pattern over the Pacific-North American sector. This intraseasonal pattern is characterized by the largest amounts of mid-tropospheric moisture over the southwest; it is also the most common mode during the mature phase and the second wettest. In contrast, the wettest monsoon mode shows weak mid-tropospheric height anomalies over North America, but also the largest amounts of mid-tropospheric specific humidity over Arizona and New Mexico at daily time scales that may be linked to tropical forcing (Cavazos *et al*. 2002).

For the identification of potential predictive information, we used several winter and spring sea surface temperature (SST) indices from the Pacific and Atlantic Basins and winter and spring precipitation as predictors of all-Arizona July-August-September precipitation. We used linear regression and artificial neural networks to test their predictive skills. A P-mode principal components analysis was applied to all 11 predictors of monsoon precipitation to determine the best set of predictors. We found 3 major predictor variables: winter or spring SST indices from the North Pacific/Baja California and North Atlantic Ocean, and winter precipitation. The neural networks produced better results, indicating that antecedent winter and spring conditions in the surrounding oceans and on the land-surface seem to modulate monsoon precipitation. In the past, the majority of the seasonal forecasts have given too much weight to tropical SSTs associated with ENSO conditions as compared to SSTs in the Atlantic basin. Our results indicate that both the North Atlantic and the North Pacific SST conditions need to be considered to achieve improved seasonal forecast of monsoon precipitation over Arizona.

4.4. Developing fine-scale gridded climate data

The results of CLIMAS stakeholder surveys indicated a large unmet need for historical climate data at a fine spatial scale (~1 km). Many aspects of the CLIMAS project, including both social science and natural science components, can profit from such a data set, as can a very broad range of climatological research and climate impact studies in the region. This spatial scale is considerably finer than the scale of the observing network, and there are many non-trivial issues involved in creating the desired data. Yet, the complex terrain and spatially variable climate of the Southwest make it a useful test bed to develop spatial models for this task. Our goal was to develop a methodology that could ultimately be used to produce several gridded datasets for the region, and which was sufficiently flexible that we could apply it to various timescales in the instrumental record as well as to paleoclimatic timescales. While this work has similarities to other approaches (e.g., PRISM), the particularly fine scale and the need to articulate this work with CLIMAS paleoclimate researchers led us to develop our own tailored scheme.

Regarding the dimensions of the users and the research in Figure 2, there is a very large range of stakeholders who need climate data at better spatial resolutions than the observing network. Although some of these might be advanced users, many are less-specialized and simply need such data for a wide range of activities. Development of the data sets required a moderate to large degree of new and largely applied study. Thus, this case occupies a position off the diagonal to the lower right in Figure 2 reflecting many users and new research.

Using a Digital Elevation Model (DEM) and the cooperative climate station network for Arizona, New Mexico and surrounding areas, we developed an initial set of multivariate regression models of winter temperature and precipitation. The winter season was selected as the initial study period because of the crucial role precipitation plays in the recharge of dams, aquifers, and reservoirs, and for overlap with a paleoclimate sub-project that deals with winter-biased moisture. There are several established techniques for interpolating and mapping climate data to finer spatial scales, including inverse-distance weighting (IDW) and kriging. These approaches are problematic if the spatial distribution of the station data does not adequately resolve elevated terrain, which is the case in the Southwest. A simple alternative is to use "smart interpolation" (Willmott and Matsuura 1995, Willmott and Robeson 1995), or to implement a more complex regression methodology using digital elevation data to perform fine-scale spatial modeling of terrain effects (Daly et al. 1994, Carbone and Bramante 1995, Dodson and Marks 1997, Agnew and Palutikof 2000). In theory, the regression residuals represent precipitation with terrain effects removed, so the residuals can be interpolated before adding the terrain component back in to create a final surface. To provide better estimates of the spatial distribution of seasonal and annual precipitation across the study area, we therefore created regression models based on latitude, longitude, and a variety of terrain data (Brown and Comrie 2002). Terrain variables created as regression inputs included elevation, slope, and several transformed measures of aspect.

We have completed production of the gridded datasets for the historical record from 1960 (this is as far back as station densities will reasonably allow) through the present, for each core winter season (DJFM). This work is ongoing and will likely cover monthly-level data soon. Ultimately, we will make available a suite of gridded climate data via a graphical web interface, whereby users can specify particular pixels or areas and view animated maps or time series, or download localized modeled data for temperature, precipitation and other variables.

5. CONCLUDING DISCUSSION

This paper has attempted to synthesize and communicate some of the lessons we have learned doing integrated climate science. We have several years of experience interacting with stakeholders, and have drawn from this sufficient background to define a framework and a set of processes that we use to carry out user-driven climate variability impact and assessment. The paper has outlined how CLIMAS integrates basic climate science and stakeholder interests by adopting an iterative model of regional assessment research.

In this paper we have also identified 2 dimensions of user-driven science and services, and we have illustrated these dimensions using four examples of climate science projects that were directly driven by stakeholder interaction and needs. They have varying characteristics in terms of stakeholder type as well as the degree of basic to applied research employed.

At one level, each of these examples is not especially different from many other individual climate applications. Yet, the inclusion of well-grounded applications that generate basic and applied knowledge as part of the larger (federal or large agency-funded) climate science enterprise marks a fundamental change in how such science is carried out. Users can now be directly connected to the formulation and practice of "big science." This bottom-up link is a new paradigm for major climate science initiatives, with basic and applied science connected to the users of that knowledge (end-to-end) far better than under the older top-down approach. To express this concept in terms meaningful to politicians, taxpayers can have a far more direct link to how their tax dollars are spent on science that is tangible and directly useful.

It is worth emphasizing that this model of user-driven science works to the advantage of basic research. Under the older model, science carried out under the top-down structure was routinely criticized as esoteric and unconnected to practical issues. By connecting the public and stakeholders to with scientists, a range of science and services will emerge that are more likely to bolster support for increased science funding.

Lessons learned in the CLIMAS initiative have the potential to inform a range of other activities in and beyond the climate sciences. A wide range of user demand for climate knowledge remains to be addressed in the U.S. Southwest, and there will be significant economies of scale as CLIMAS and its partners meet this demand. The same holds true in meeting user needs in other regions in and outside the United States, and the CLIMAS experience also provides compelling evidence that climate knowledge must be created and used in a broader interdisciplinary “multiple-stress” framework that includes for example, ecological, socioeconomic, institutional, and cultural knowledge. A critical aspect of use-inspired climate research is interdisciplinary education and capacity building, as well as new level of scientific flexibility and responsiveness. The CLIMAS lessons highlight the need for sustainable “end-to-end” interaction between all the players in the science and user communities that is both continual and iterative. Finally, the CLIMAS lessons can inform the establishment of a new national climate services program – a program that is urgently needed to sustain the science-user partnerships that have been developed by CLIMAS and other regionally-integrated science and assessment activities.

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