International Environmental Modelling and Software Society (iEMSs)
2012 International Congress on Environmental Modelling and Software
Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany
R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.)
http://www.iemss.org/society/index.php/iemss-2012-proceedings

Strategies and Tactics for the Design of Hydroclimatic Decision Support Tools

Holly C. Hartmann[1]
[1]*Arid Lands Information Center, School of Natural Resources and Environment, University of Arizona, Tucson, Arizona USA*
[1]*holly.hartmann@arizona.edu*

Abstract: The U.S. national investment in remote sensing systems, supercomputers, hydroclimatic research, and scientist education has produced significant advances in hydroclimatic monitoring, understanding, and predictive capabilities. However, realization of socio-economic benefits from those investments remains incomplete, for many reasons. Experience within the Climate Assessment for the Southwest (CLIMAS) has clarified commonalities across sectors and stakeholders on which to base systemic advancement of hydroclimatic decision support tools. Case studies of six very different tools, developed through CLIMAS activities and emphasizing human factors in the use of environmental information, are used to illustrate user-centric strategies and tactics for developing effective decision support tools. The case studies include a forecast evaluation tool, an information portfolio management system, a hydrologic alert system, tools for drought analysis of paleoclimatological flow reconstructions, a tool for customizing probabilistic forecasts, and a guided compendium of tools for considering climate change in water planning and management. Our design framework reflects that because decisions are made through the integration of knowledge and wisdom, with the latter more complex, diverse, and changeable than can be practically programmed in traditional computerized decision support tools, knowledge development is the most appropriate level for systemically providing hydroclimatic information in support of the broadest range of decisions in an equitable manner. The case studies highlight that effective decision support tools need to, and can, accommodate the unique needs of decision makers, including the specific mix of multiple products required to support their decisions, matching the level of information certainty and forecast skill with realistic decision requirements, supporting varying technical sophistication, and reflecting users' varying roles within decision making processes.

***Keywords**:* Decision support tools, climate services, information systems, decision support

1 INTRODUCTION

The U.S. national investment in remote sensing systems, supercomputers, hydroclimatic research, and scientist education has produced significant advances in monitoring, understanding, and predictive capabilities. However, realization of socio-economic benefits from those investments remains incomplete [National Research Council, 2005, 2006, 2009, 2010]; recurrent themes include disappointment in the extent to which improvements in hydroclimatic science from large-scale research programs have affected resource management policies and practices, calls for research to become user-inspired or "stakeholder driven", and calls for more relevant information and forecasts, more usable products, and more effective decision support.

The challenge is complex and daunting, with an entire nation of stakeholders affected by or managing issues at many temporal and spatial scales, including reservoir operations, drought management, groundwater well-field management, ecosystem and agriculture management, and infrastructure integrity, among others. Temporal scales range from minutes to days, seasonal to interannual, and decadal to centuries. Potentially relevant information about the past includes records covering decades to about one century, with paleoclimatological indicators extending back centuries to millennia; information about the future ranges from forecasts from weeks to over one year, and climate change projections extending out about one century.

1.1 RISA Program and CLIMAS

The U.S. National Oceanic and Atmospheric Administration's (NOAA) Regional Integrated Sciences and Assessments (RISA) program was created in 1995 to improve the ability of stakeholders to anticipate and respond to climate variability and change [Whitely Binder et al., 2009]. Goals for the multi-state regional teams include (1) innovate and assess regionally relevant climate research and decision support products, (2) improve climate literacy and adaptive capacity, (3) inform policy, (4) pursue collaborations to enhance the development and use of climate information, (5) better use non-NOAA capabilities to support climate assessments and adaptation, and (6) transition RISA research products, tools, and services to sustainable operations [Whitely Binder et al., 2009]. RISAs work closely with resource managers, policy planners, nongovernmental organizations, communities, and the private sector to assess regionally important climate-sensitive issues such as water resource management, drought, agriculture, ecosystems, and public health [Parris et al., 2010].

As the second RISA project, begun in 1998, the Climate Assessment for the Southwest (CLIMAS) was created to "undertake research on the nature, causes, and consequences of climate change and variability in the Southwestern United States with the goal of providing improved information to regional decision makers and resource managers" [Bales et al., 1997]. Input from stakeholders, solicited in varied ways, shapes the project's research agendas, activities, and resultant products. Efforts focus on the resource-intensive cultivation of relationships with stakeholders, developing in-depth understanding of decision contexts and needs for climate and ancillary products, as well as effective means for supporting access to and use of information.

2 DECISION SUPPORT CHALLENGES

2.1 Stakeholder Perspectives

CLIMAS interactions clarified commonalities across sectors and stakeholders that have guided efforts to systemically advance hydroclimatic decision support tools. These perspective emerged early within CLIMAS [Hartmann, 2001] and, with some exceptions, have remained relevant even as stakeholder climate literacy has improved. Perspectives commonly encountered, regardless of sector or role in regional decision making, include (1) the lack of distinction between weather and climate phenomena, (2) uninformed or mistaken interpretation of forecast products, (3) information usage is limited by uncertainty, especially the lack of demonstrated forecast skill, and (4) confusion over multiple scenario studies. Perspectives encountered among many, but not all stakeholders include difficulties (5) discerning between "good" and "bad" products[1], (6) comparing forecasts to historical conditions, and (7) conceptually connecting information from different contexts, i.e., "connecting the dots". However, stakeholders have a variety of unique needs; the variation can be as great within a sector as across different

[1] For example, some users pay for commercial products which, while graphically more attractive, are incorrect translations of government products.

sectors. These unique needs include (8) the roles of climate information in decision making, (9) the specific variables, regions (location and scale), calendar schedules for impacts and decision lead times, and sensitivity to forecast error or information uncertainty, and (10) their technical sophistication in working with statistics and probability distributions.

2.2 National Perspectives

From a national perspective, the development of experimental climate services (e.g., briefings, collaborative risk assessments), products, and tools is concerned with the overall hydroclimatic science enterprise, as well as regional and individual stakeholder needs. These larger-scale goals include fostering public support for hydroclimatic research, scaling regional advances in climate products and tools to national coverage, sustaining research products and tools after initial development, and changing decision processes. The strategies for achieving the goals, however, depend on how objectives are framed. An objective of economic efficiency suggests focusing efforts on meeting the needs of high-value clients, e.g., within the energy or high-value agriculture sectors, and creating products and tools customized for transfer to specific end users. An objective of large-scale impact on decisions suggests working with policy and regulatory agencies, and focusing efforts on analysis of policy and management alternatives that can pass muster under contention, whereby traditional peer-reviewed science products are important. An objective of equity suggests focusing on affected stakeholders as well as agencies. This objective is arguably the most challenging, due to the diversity of stakeholder decision settings and technical capacities. The challenge is to create flexible information products and tools that can accommodate unique user needs, transferable across regions, sectors, and decision contexts, and scalable to make practical research-to-operations transfer.

3 CASE STUDIES

Case studies of six very different decision support tools emerging from CLIMAS activities and emphasizing human factors in the use of environmental information are used to illustrate user-centric strategies and tactics for developing effective decision support tools. They have emerged from stakeholder engagement occurring between 1998 and 2011. They differ in the stakeholders that inspired the tool development, the complexity of the application, and admittedly, the effectiveness of the individual projects.

3.1 Forecast Evaluation Tool

The Forecast Evaluation Tool (FET) is an interactive web application (http://fet.hwr.arizona.edu/ForecastEvaluationTool/) that allows users to (1) study tutorials about seasonal climate outlooks and test their forecast interpretation skills, (2) efficiently monitor the time evolution of the climate forecasts and subsequent observations, (3) place forecasts in the context of recent and historical observations, and (4) evaluate forecast performance for the regions, seasons, forecast lead times and performance criteria relevant to a decision maker’s specific situation. Components of the application were designed by stakeholders in a workshop setting [Hartmann, 2001]. Webtool graphical products and interfaces were iteratively vetted by stakeholders for relevance and ease of understanding. Although the stakeholders originally engaged were in the Southwest, the FET was designed to apply nationally. Additional forecasts were incorporated at the request of the National Weather Service (NWS). The FET has been incorporated into formal professional development training for climate services practitioners.

3.2 Paleo Toolkit

A pair of webtools, collectively considered part of an evolving Paleo Toolkit, allows users to place current droughts into long-term, paleoclimatological context. The

Drought Sequence Analysis Tool allows drought sequences of streamflows from instrumental records to be visually compared to analog sequences from tree-ring reconstructions of streamflow over several centuries, allowing users to explore how observed multi-year droughts have differed in their year-to-year evolution from those occurring before flows were recorded. The Variability in the Gage Record Tool allows streamflows from instrumental records to be visually compared to the frequency distribution of reconstructed paleoclimatological streamflows, allowing users to explore how unusual observed droughts are compared to their frequency of occurrence over several centuries. Both tools emerged out of engagement of CLIMAS researchers with water resources stakeholders based in the Southwest, beginning with extension of an interface from the FET, and using iterative review and adjustment via a series of workshops. The tools were designed to accommodate any watershed for which paleostreamflow reconstructions are available via a contextually supportive web resource for tree-ring reconstructions, TreeFlow (http://treeflow.info), where the tools were integrated as "Analysis Tools".

3.3 Dynamic Probability of Exceedance Tool

The NWS has long provided maps for their probabilistic seasonal climate outlooks for temperature and precipitation, depicting only probabilities associated with tercile classes. Supplemental probability of exceedance (POE) outlooks that depict the seasonal outlooks as cumulative density functions allow users to identify probabilities for temperature or precipitation thresholds and intervals not limited by the tercile classes. However, as static diagrams festooned with substantial ancillary information, the POE outlooks have proved nearly intractable for users to interpret. The Dynamic POE (http://www.ua-alic.com/DynamicPOE/) is an interactive simplified version that survey- and interview-testing indicated had higher comprehension [Hartmann, 2007; Hartmann et al., 2011a]. It allows users to customize the depiction of forecast distributions, and to extract outlooks for specific thresholds or intervals identified on the basis of the variable or the probability. The tool provides simple statements about the customized outlooks, including comparisons to the climatological reference period. The tool was developed using collaborative software development processes to ensure ease of transition from research to NWS operations, although even that effort has experienced difficulty in final transfer of code.

3.4 Climate Information Delivery and Decision Support System (CLIDDSS)

CLIDDSS (http://cliddss.arid.arizona.edu/) was designed to meet three needs of information intermediaries rather than end users [Hartmann et al., 2008]. The first need is for efficient access and updating of products and analysis results from the diverse distributed network of websites; CLIDDSS allows users to interact with those diverse websites and save access information for products within those sites, in the form of portfolios of information products, enabling efficient automated retrieval of the products or analysis results. The second need is for dynamic generation of newsletters and reports, which are proven effective means for helping stakeholders conceptually link diverse information products and concepts. Using CLIDDSS, an information intermediary (e.g., an extension agent, consulting firm, or non-governmental organization) can create hardcopy reports containing a collection of data and analysis products, whereby each report component (e.g., a climate forecast) includes required standard supporting information required by the provider (e.g., the source agency and contact, standard interpretation guidance), and can also include the intermediary's customized interpretation of the material (e.g., a localized interpretation). The intermediary can then store the PDF report in a project folder to save or be accessed by designated users, and also print it as hardcopy for use in situations where Internet access is impractical (e.g., at rural meetings). Self-organizing groups can co-manage shared information portfolios and contribute to joint reports. The third need is for feedback to the research and operations communities. CLIDDSS has extensive session tracking, which can identify which products are included in portfolios and reports most frequently, during which times of the year, or by specific user communities. This knowledge can help prioritize additional product development and information delivery system enhancements, as well as guide climate services regarding which user communities to engage about future product or system developments they would find most useful. CLIDDSS has had relatively little user engagement since initial identification of needs.

3.5 Automated Hydrologic Threshold Alert System (AHTAS)

AHTAS (http://ahtas.arid.arizona.edu) uses the concept of "PUSH" technology to notify people and organizations about user-specified conditions, for any type of data that is routinely available via web servers. AHTAS continually checks conditions measured by other organizations and compares them to pre-determined thresholds (e.g., minimum streamflows, maximum rates of change in river stage). Alerts are sent out by email or cell phone text messages, providing details about the basis for the alert, conditions prior to the alert event, and links to external data sources. Alert-initiated web-forms summarize conditions leading to the notifications and provide opportunities for groups to enter their commentary about the event and impacts; web-forms are archived to periodically assess the thresholds and events. Based on CLIMAS success with other tools, AHTAS was requested by Northwest stakeholders but was implemented as a single system supporting many individual projects. Project teams develop their unique database of threshold equations for specified hydrologic variables and location, their alert messages, and alert notification lists, which can be maintained by designated members of their groups, including modification of threshold equations, station lists, alert messages, and alert notification lists. AHTAS proved to be a useful tool for "connecting the dots" between real-time monitoring and historical information, learning among users within a project, and efficiently extending to other contexts [Hartmann et al., 2005].

3.6 Carpe Diem West Academy

The Carpe Diem West Academy (http://carpediemwestacademy.org) is organized around an interactive compendium of externally developed tools, training resources, and best practices for water resources practitioners dealing with uncertainties posed by climate change [Hartmann et al., 2011b]. Tools are evaluated using criteria about relevance, legitimacy and credibility, usability, and connection and communication; training is evaluated based on scientific accuracy, teaching effectiveness, each of use and technical quality. Shared learning is supported through engaging webinars addressing specific questions of planners and managers. The compendium also is useful for identifying gaps where additional tools, methods, or professional development training are needed. The Academy was initiated through a series of meetings with relatively advanced water resources utilities, but now serves a network of over 800 practitioners across the U.S. West, as well as an increasing network of tool developers.

4 STRATEGIES AND TACTICS

4.1 Design Framework

Each of the case study tools emerged from a design emphasis on equity rather than economic efficiency or policy impact. The design framework used to guide development of each case study tool reflects a continuum linking data, information, knowledge, and wisdom that has been applied in many fields [Rowley, 2007], but highlighted for climate application by Meinke et al. [2001]. Because decisions are made through the integration of knowledge and wisdom[2], with the latter more complex, diverse, and changeable than can be practically programmed in

[2] An emergency manager has knowledge that strong El Nino conditions increase large-river flooding likelihood in the U.S. Southwest, but uses wisdom to decide whether to proactively clear a vegetated flood channel under community scrutiny, or wait to exploit an event for a permit-free response [Pagano et al., 2002].

traditional computerized decision support tools, knowledge development was considered the most appropriate level for systemically providing hydroclimatic information in support of the broadest range of decisions in an equitable manner. Key framework elements emphasize (1) equity of physical and conceptual access, (2) knowledge development rather than information delivery[3], (3) facilitation of climate service intermediaries as a way to scale application of tools by or for stakeholders, (4) eventually serving a broader mix of sectors, regions, and decision contexts than reflected in the necessarily limited mix of stakeholders engaged in a research setting, and (5) planning for eventual transfer from research to operations.

4.2 Design Strategies

Strategies concern issues that encompass an entire tool lifespan, are difficult to reverse, cover a wide scope affecting many functional areas, and are aimed at realizing the framework elements. In every case study, tool concepts were developed, not by asking stakeholders their perceived needs, but by translating deep understanding of their challenges into an application design[4]. Methods used included semi-structured interviews, focus group discussions, and workshops that explored a variety of stakeholder perspectives about how climate affects their operations, their decision calendar, the role of specific climatic and non-climatic variables and conditions in their decision making, important past hydroclimatic events, and their use of historical and forecast information, among other topics.

Application designs focused, from the start, on generalizable and customizable interfaces, analyses, communication, and support capacity. Ideas for tools typically emerged from engagement with stakeholders having greater capacity for entrainment of hydroclimatic science, with interface design and additional functionalities based on requirements of less experienced stakeholders for effective engagement. Applications were designed to be supported for at least several years to provide some confidence for stakeholders that their engagement would lead to more than a short-lived prototype.

While prototypes of even static interface or graphical mock-ups may be used to engage stakeholders while applications are in development, backend software has been designed to be delivered as a commercial quality product. Stakeholders were increasingly reluctant to engage with only experimental prototypes produced by researchers lacking commitment to the continued existence of the tools.

Within a tool, depth of coverage on a specific topic (e.g., forecast evaluation, alert system, tool compendium) was emphasized more than breadth across different topics. Each tool serves a specific purpose that can apply across decision contexts, rather than trying to be an encompassing portal. Each tool provides for a high-level of user customization of interaction or exploration within the application; generic products are the anti-thesis of the design strategy exemplified by the case studies.

Backend software is designed to be of commercial "turnkey" quality that could be transferred to any operating system or database, meets coding standards, and enables efficient code maintenance. Sharing code across tools has been a design strategy, although it has been difficult to implement; more practical has been extension of foundational code from one application (e.g., the FET) to another (e.g., the PaleoToolKit). Actual transfer of code to operational entities remains challenging, due mostly to agency capacity limitations; even the Dynamic POE,

[3] Information delivery is providing climate outlook as a cumulative distribution function for probability of exceedance, from which many statements can be made. Knowledge development enables users to understand that a high probability statement will require a wide range of possible conditions, while a narrow range of possible conditions will require accepting a lower probability of occurrence.

[4] Stakeholders were unable to suggest how to measure forecast skill, but had differing sensitivity to forecast failure (e.g., surprise, false alarms), leading to using multiple evaluation criteria within the FET [Hartmann et al., 2002].

developed in collaboration with the NWS has been inordinately delayed by slow evolution of agency policies and procedures.

4.3 Design Tactics

Tactics concern efforts are shorter in nature, easier to change, have a more narrow scope affecting few functionalities, and focus on means rather than ends. Based on the case studies, a key design tactic consists of providing a clear structure, including numbering each interface step, for how to move through the application; the FET, PaleoToolKit, and the Dynamic POE each have clearly indicated steps to complete tasks. Initial designs benefit from a series of mockups, refinement from a graphical designer, and further refinement based on usability assessments. Frequent usability assessments [Krug, 2006], whereby observers track the movements and thinking of a small number of participants asked to complete specific tasks, are indispensable for resolving development group conflicts over design issues, allowing foundational code development to proceed.

Field surveys leading to the FET and Dynamic POE confirmed that information is, itself, insufficient for stakeholders, with confusion and tentativeness about interpretation of basic probability and statistical principles dominating interface design flaws [Hartmann, 2007]. Applications need explicit presentation of basic principles related to the use of probabilities applied to single values rather than ranges, mean vs. median as a measure of central tendency, total probability to bound probability shifts, and shifting climatological reference periods. Language matters. Use of statistical terms that have different non-statistical meanings foster misinterpretation, especially the use of “normal” in any form, and the use of “most likely” as a minimum error estimate.

The FET and Academy experiences highlight that outreach using tools, e.g., in workshops or professional development training, is an effective tactic to continue engagement to identify usage issues, refine design, and identify additionally desired functionality. Outreach for the FET led directly to development of the Paleo Toolkit and the Dynamic POE, illustrating advancement of stakeholder dialogue and knowledge development to include more complex concepts and information.

5 CONCLUSIONS AND RECOMMENDATIONS

The case studies highlight that stakeholder engagement, focused on understanding challenges in using hydroclimatic information, can inform the development of climate products and decision support tools that can serve a wider variety of users than involved in initial research and development efforts. Rather than trying to create “one stop shops” or centralized portals for specific stakeholders or sectors, these tools have smaller scope that allows them to connect with other decision contexts (e.g., use of the FET by financial firms, energy companies, construction companies). The design strategies have resulted in tools that can accommodate the unique needs of decision makers, including the specific mix of multiple products required to support their decisions, matching the level of information certainty and forecast skill with realistic decision requirements, supporting varying technical sophistication, and reflecting users’ varying roles within decision making processes. The variety of tools examined here emerged from recognition of broad user needs for knowledge development and information management, combined with exploiting evolving technologies that enabled ‘live’ file formats and products, customized products, efficient information management tools.

ACKNOWLEDGMENTS

The author stresses that these projects could not proceed without the essential contributions of the software developers involved in the case studies, including Ellen Lay, Damian Hammond, Sundarajan Srinivasan, and Dominic Martinez. Also critical to these projects are collaborators within the NWS, CLIMAS, and stakeholder groups. Work was funded by a variety of NOAA projects, including DG133W07SE3974, NA07OAR4320382, and NA07OAR4310004.

REFERENCES

Bales, R., D. Liverman, and B. Morehouse, Integrated assessment as a step toward reducing climate vulnerability in the southwestern United States, *Bulletin of the American Meteorological Association*, 85(5), 1727-1734, 2004.

Hartmann, H., Stakeholder driven research in a hydroclimatic context, Ph.D. thesis, University of Arizona, Tucson, 2001.

Hartmann, H., T. Pagano, S. Sorooshian, and R. Bales, Confidence builders: evaluating seasonal climate forecasts from user perspectives, Bulletin of the American Meteorological Society 83(5):683-698, 2002.

Hartmann, H. and R. Hartmann, An automated hydrologic threshold alert system for the North Umpqua River Basin, Oregon, presented at Annual Meeting, American Water Resources Association, Seattle, Washington, November 7-10, 2005.

Hartmann, H., Misinterpretation of probabilistic seasonal climate outlooks by resource management professionals, presented at 35th Conference on Broadcast Meteorology, American Meteorological Society, San Antonio, Texas, January 15-18, 2007.

Hartmann, H. and E. Lay, CLIDDSS: a decision support tool for climate services, presented at Informal Seminar, East-West Center and NOAA Integrated Data and Environmental Applications (IDEA) Center, Honolulu, Hawaii, December 9-11, 2008.

Hartmann, H., E. O'Lenic, D. Hammond, S. Marquardt, M. Charles, D. Unger, and S. Srinivasan, CLIMAS-CPC collaborative development of an interactive web tool for 3-month outlooks, presented at 36th Annual Climate Diagnostics Workshop, Ft. Worth, Texas, October 3-5, 2011a.

Hartmann, H., and K. Morino, An organized toolbox: choosing the appropriate tools and methods to support climate change adaptation, Conference on Climate Adaptation, presented at American Meteorological Society, Asheville, North Carolina, July 18-22, 2011b.

Krug, S., Don't Make Me Think: Common Sense Approach to Web Usability, New Riders Publishing, 201 pp., Berkeley, California, 2006.

Meinke, H., W. Baethgen, P. Carberry, M. Donatelli, G. Hammer, R. Selvaraju, C. Stöckle, Increasing profits and reducing risks in crop production using participatory systems simulation approaches. Agricultural Systems, 70, 493-513, 2001.

National Research Council, *Decision Making for the Environment.* National Academy Press, 281 pp., Washington, D.C., 2005.

National Research Council, *Completing the Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts.* National Academy Press, 124 pp., Washington, D.C., 2006.

National Research Council, *Informing Decisions in a Changing Climate.* National Academy Press, 188 pp., Washington, D.C., 2009.

National Research Council, *Informing an Effective Response to Climate Change.* National Academy Press, 325 pp., Washington, D.C., 2010.

Parris, A., C. Simpson, and S. Abdelrahim, *RISA Workshop Report: Looking Ahead to Climate Science, Assessment, and Adaptation.* National Oceanic and Atmospheric Administration, 26 pp., Washington, D.C., 2011.

Pagano, T., H. Hartmann, and S. Sorooshian, Use of climate forecasts for water management: Arizona and the 1997-98 El Niño, Journal of the American Water Resources Association 37(5):1139-1152, 2001.

Rowley, J., The wisdom hierarchy: representations of the DIKW hierarchy, Journal of Information Science, 33(2), 163-180, 2007.

Whitely Binder L., H. Campbell, G. Carbone, M. Finucane, G. Garfin, H. Hartmann, K. Ingram, D. Kenney, N. Lewis, C. Simpson, S. Trainor, B. Udall, and R. Webb, *RISA 2020.* University of Colorado, 25 pp., Boulder, CO, 2009.