7.3 REGIONAL KNOWLEDGE TRANSFERS: COPING WITH DROUGHT THROUGH COLLABORATION

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1. INTRODUCTION

Drought is a slow onset climate-related hazard with a natural hazard component (lack of precipitation or water) and a social vulnerability component (e.g., preparedness, robustness of economy, infrastructure, laws and policies). The United States suffers billions of dollars in losses each year, due to drought. Nevertheless, the nation lacks a national drought plan. In 2006, the President and Congress took one small step toward a remedy for this situation, by passing the National Integrated Drought Information System Act of 2006 (Public Law 109-430) (NIDIS, 2006). The goal of NIDIS is to improve the nation's capacity to proactively manage drought-related risks, by providing affected communities with the best available information and tools to assess drought impacts and to improve the nation's ability to better prepare for and mitigate the effects of drought. Two of the key objectives stated in the NIDIS implementation plan include (a), creating a drought early warning system capable of providing accurate, timely, and integrated information on drought conditions and risks at spatial scales relevant to facilitate proactive decisions and (b) providing interactive early warning information delivery systems for easily comprehensible and standardized products (such as, databases, maps, forecasts, etc.) (NIDIS Implementation Team, 2007).

Beginning in August, 2007, to support the NIDIS effort, the NOAA Regional Integrated Sciences and Assessments program funded several projects to enhance stakeholder access to drought decision support resources. Two of the projects seek to demonstrate the transferability, scalability and expandability of region-specific decision support tools. . The projects include the transfer of the Southeast Climate Consortium's (SECC) *AgroClimate* tool (Fraisse et al., 2006) to New Mexico, the Carolinas Integrated Sciences and Assessments' (CISA) Dynamic Drought Index Tool (Carbone et al., 2008) to Arizona and New Mexico, and the Arizona Cooperative Extension/Climate

Assessment for the Southwest's (CLIMAS) Arizona Droughtwatch impact reporting system (Garfin, 2006) to the Carolinas. This paper provides a progress report on the two related projects, and the implications for NIDIS in terms of public sector technology transfer, regional stakeholder needs and decision support preferences in the agriculture, natural resources and water management sectors, and enhancements to decision support tools for effective use by stakeholders.

2. DECISION SUPPORT TOOL BACKGROUND

Since 2000, southwestern states have exhibited a variety of drought impacts, including over 2.6 million acres of Arizona and New Mexico conifers damaged from a combination of severe drought stress and enhanced insect pest outbreaks (USDA Forest Service 2004; Breshears et al. 2005), substantial increases in acres burned in the Colorado River Basin states (Westerling et al., 2006), loss of habitat for native freshwater fish (e.g. the Rio Grande silvery minnow) and declines in some endangered fauna (Bright and Hervert, 2005), water restrictions in small cities, such as Santa Fe, NM and Flagstaff, AZ, water shortages in vulnerable rural regions and on tribal lands, and substantial livestock losses. Particularly sensitive to drought is the rapidly growing population of the southwestern United States, which demands water from the relatively arid Colorado River Basin and overallocated Colorado River. Since 2000, prolonged declines in Colorado River reservoir storage have sensitized regional water managers to the increasingly likely possibility of drought-related shortages (McCabe and Wolock 2007; Garrick et al., 2008). Regional cities and states have engaged in unprecedented drought planning, and the seven Colorado River Basin states developed the first-ever shortage criteria for reservoir operations (USDOI, 2007).

Agriculture accounts for one third of New Mexico's economy. During the drought that began in 1995, irrigators along the lower Rio Grande suffered cutbacks in irrigation allocations. In 2003, for example, Elephant Butte Irrigation District irrigators received only 15% of their allocations; deepening wells to supplement surface water supplies can cost up to $10,000 per well. Moreover, small farmers in northern New Mexico (Embudo-Alcalde region), dependent on local surface water supplies called *acequias*, are exceedingly vulnerable to interannual climate variations, in addition to multi-year drought. Residents of these rural New Mexico communities count on local small-farm agriculture for food, as some 16% of New Mexicans do not always have access to enough food to meet their basic needs.

Given the aforementioned concerns, both Arizona and New Mexico have enhanced their drought planning and monitoring efforts. New Mexico's first drought plan, completed in 1999, required revision in 2003, as aspects of monitoring and implementation of mitigation and response measures lagged drought impacts during 2000-2002. Arizona developed its first drought preparedness plan in 2004, in reaction to severe drought impacts in 2002. Despite the fact that drought monitoring committees in both states meet monthly to update drought status reports and alerts, funding has been lacking for improving the display of drought information and the ability to put this information into decision contexts germane to regional stakeholders. Concomitantly, the demand for much information, by county, state, federal and private land and resource managers has increased. Making forecast and historical climate information matter to stakeholders is not simply a matter of making web fools available, but requires careful understanding of decision contexts, and iterative development in consultation (and partnership) with the end users of the information (Hartmann et al., 2002; Bales et al., 2004). The following paragraphs describe the climate and drought decision support tools in the pair of NOAA-funded projects described above.

AgroClimate (formerly known as *AgClimate*) is a web-based climate decision support system developed by the SECC in partnership with Cooperative Extension. Information available in *AgroClimate* includes information on climate variability and forecasts combined with risk management tools and information for selected crops, forestry, pasture, and livestock. *AgroClimate* is unique as a climate based suite of decision support tools for the United States, based on strong shifts in regional climate due to the El Niño–Southern Oscillation (ENSO). Fortunately, New Mexico climate is determined, in part, by a moderate-to-strong ENSO signal, which can help agriculturalists anticipate variations in precipitation and evapotranspiration.

CISA's Dynamic Drought Index Tool (DDIT) accommodates decision makers who must consider drought different physical and political units and in the context of state and local ordinances. The tool was born out of a combination of crisis management during an extreme event (1998-2002 drought), and a regulatory requirement for multiyear Federal Energy Regulatory Commission (FERC) dam relicensing negotiations. Assessment of the tool in the Carolinas (via informal feedback and a structured survey of drought task force members), revealed a need to redesign its entry level to accommodate both users looking for quick access to a preferred set of outputs, and more sophisticated users desiring advanced capabilities, and to better express uncertainties associated with station and interpolated data.

Drought mapping tools have advanced more quickly than our ability to monitor drought impacts. Impact and vulnerability information – important to judging the societal and economic implications of drought, corroborating state drought status, and differentiating impacts within watersheds – are almost completely lacking nationwide (WGA, 2004). A collaborative at the University of Arizona, in consultation with the National Drought Mitigation Center (NDMC), has developed a system for reporting a wide variety of drought impacts. Based on stakeholder recommendations, these partners are improving the drought impacts reporting system (AZ DroughtWatch) interface. The improved interface will use Google Earth technology and will have the capability to record impacts, display impact history (map and graph format), and provide contributors with a full suite of data and metadata. The Carolinas also need such drought impact information as water scarcity becomes increasingly relevant, especially during a significant recurrence of severe drought during the last year. Part of our overall effort to enhance drought management capabilities in both regions will be to transfer the drought impact reporting system to the Carolinas. The contrast provided between the Carolinas, Arizona and New Mexico, will inform our understanding of regional differentiation of drought impacts.

The Climate Information Delivery and Decision Support System (CLIDDSS) helps information intermediaries (e.g., extension agents) and decision makers "connect the dots" among a variety of information products from diverse, distributed sources. CLIDDSS lets individuals or groups create and manage customized information portfolios and the production of commercial quality PDF reports containing both provider-controlled content (e.g., forecast images, descriptions, and contacts) and intermediary-controlled value-added content (e.g., application-based interpretive comments). CLIDDSS also provides rich tracking of product usage (e.g., which products users are linking together) to inform both research and operational climate services.

3. PROJECT METHODS AND APPROACHES

3.1 AgroClimate New Mexico

The concept of implementing the SECC's *AgroClimate* decision support tool in New Mexico grew out of (1) stakeholder demand for more useable and useful climate information to inform agricultural operations decisions and (2) interactions among outreach-oriented individuals from the CLIMAS and SECC RISA programs. Recognizing that many complexities would be involved in transferring a decision-support tool between two climatically dissimilar regions, the CLIMAS-SECC team used an incremental approach to implementing the tool in New Mexico. Initial implementation was limited to the *AgroClimate* Climate Risk module, which provides probabilistic and historical climate information on a monthly time scale, at the county level. Variables include precipitation, average minimum and maximum temperatures, and extreme minimum and maximum temperatures. Tools requiring extensive research on the relationships between local climate, crop yields, and economics will be added at a later time. Online and written surveys, focus groups, and interviews were used to identify stakeholder needs and research priorities, and to garner initial feedback from New Mexico stakeholders about *AgroClimate*.

The CLIMAS-SECC team adopted SECC's model for *AgroClimate* tool development and deployment, which is based on years of research, outreach, and ongoing development (Fraisse et al. 2006; Breuer et al. 2008). A cornerstone of SECC's method is collaboration with cooperative extension services, in order to provide local agricultural expertise and to ensure that the information provided in the decision-support system was relevant to end users. New Mexico State University's (NMSU) Cooperative Extension Service water, agronomy, and dairy specialists directly participated in project implementation. The team divided into technical and social science working groups that met monthly through teleconferences. The technical team developed the climatic database, implemented the SECC *AgroClimate* code, developed the web site (following NMSU institutional requirements), and incorporated initial usability feedback from end users; the technical team is now linking the final product to the CLIDDSS system.

The social science team worked with NMSU cooperative extension to identify potential early adopters of *AgroClimate*. The team developed online and written survey instruments, and focus group and interview protocols (e.g., Roncoli et al. 2006) for garnering feedback from stakeholders. Feedback from surveys, workshops and interviews were used to guide the project team on changes to AgroClimate to improve usability in the Southwest, and to identify priorities for implementing additional components and research.

3.2 DDIT and AZ DroughtWatch

The concept of implementing CISA's Dynamic Drought Index Tool in the Southwest grew out of (a) needs expressed by stakeholders for easier access to data and information to represent drought status at scales more relevant to decision-making, and (b) an interest in demonstrating the transferability and scalability of the DDIT as a pilot project for NIDIS regional drought early warning systems. The DDIT project team adopted a three-part implementation strategy that included (a) garnering stakeholder feedback on DDIT usefulness and usability in the Southwest, (b) expanding DDIT source code, to facilitate shared programming and implementation at a central repository or cooperating operational institution, and (c) garnering feedback on revised website usability once changes had been implemented. The team's social science members worked with Arizona's Statewide Drought Program to identify stakeholders from a variety of decision making contexts, in order to evaluate changes that would need to be made for making DDIT usable in the Southwest.

The CLIMAS-CISA team built on CISA's experience in working with stakeholders in the Southeast (Carbone et al., 2008), and initial feedback from Southeast stakeholders on usability and interface improvements. The project team met at least monthly by teleconference, with several intensive work periods, in order to address key technical issues, identify technical priorities, and assign programming tasks. The team divided into technical and social science working groups, and employed a social science team member to document the technology and knowledge transfer processes. The technical team developed a climate, hydrology and spatial information databases, augmented the existing DDIT website, and incorporated initial usability feedback from end users. The technical team is now linking the final product to the CLIDDSS system. The social science working group developed written survey instruments and focus group protocols for garnering feedback from stakeholders. Feedback from two focus groups were used to guide the project team on changes to the DDIT to improve usability in the Southwest, and to identify priorities for implementing additional components.

A subset of the team is working on implementation of the Arizona drought impact reporting system (AZ DroughtWatch), which suffered delays, due to a complete product redesign associated with a project to implement local drought impact reporting, as part of the state drought plan. The team approach involves working closely with the drought councils and State Climatologists in South and North Carolina, in order to garner feedbacks about changes necessary to implement local drought impacts reporting as an operational complement to climate and hydrologic monitoring in the Carolinas. The social science team is developing survey and focus group protocols for demonstrations of the beta version of AZ DroughtWatch to the state drought councils.

4. STAKEHOLDER INTERACTIONS: RESULTS

4.1 AgroClimate

Stakeholder interactions followed a four-part process, as follows: (a) surveys with Cooperative Extension personnel, (b) SECC *AgroClimate* demonstration workshops and discussions, (c) NM *AgroClimate* prototype demonstration workshop and interviews with growers, (d) website usability testing. Thus far, the team has completed steps a-c.

Stakeholder assessment began with the administration of an online climate needs assessment survey to all agricultural related New Mexico State University Extension agents and specialists, in order to determine (a) which products they were using and how often they accessed those products, (b) difficulties and challenges they encountered when accessing or using data, (c) their preferred format and delivery method for data, and (d) any new products that they would like to see offered. This survey had 21 respondents and included individuals from all three of New Mexico's Extension Districts (Southwest, Northern, and Eastern) whose clientele included, but were not limited to, livestock producers, orchard and viticulture growers, vegetable farmers, horticulture, and water managers.

Over half (57%) of the survey respondents had over 10 years experience in the Cooperative Extension Service, and all but one considered themselves to be somewhat or very knowledgeable about weather and climate. All respondents agreed or strongly agreed that their clientele were interested in using climate information, but thought that the majority (84%) would need assistance with interpretation. No clear preference was given for a preferred format (i.e., graphs, tables, text, decision-support tools). However 76% wanted to receive information via e-mail and from accessing websites. Respondents indicated that they would most like to see the following products: crop yield forecasts (61%), growing degree days (57%), plant moisture stress (70%), cattle heat stress index (59%), probabilities of occurrence (55%), and crop and range management tools (55% and 67%, respectively).

In the months following the needs assessment survey, we convened three workshops (one in each Extension district) to demonstrate the SECC *AgroClimate* website to stakeholders and to elicit feedback on the website and determine whether the stakeholders thought the tool would be a valuable addition to their decision-making process. We gave particular emphasis to identifying which features might need to be changed to accommodate *AgroClimate* users in New Mexico, and to determine priorities for the incorporation of future tools and information. Participants at the first workshop represented only agricultural Extension agents, while participants at the latter two workshops represented Cooperative Extension agents and specialists, agricultural researchers, and producers. The format for the three workshops varied slightly. At the first workshop (December 2007; Albuquerque), team members demonstrated features of the SECC *AgroClimate* website and then gave participants time to examine the website on their own. The workshop concluded with guided discussion to gather feedback. At the latter two workshops (March 2008; Roswell and Las Cruces), participants completed a written survey at the beginning of the workshop to garner background information about their knowledge of climate (in particular, ENSO) and their perceptions about climate and weather forecasts. Team members demonstrated features of the SECC *AgroClimate* website and then presented sample images from a New Mexico *AgroClimate* prototype for users to examine, in order to provide local context that would make the information more tangible to participants.

Participants' response to the *AgroClimate* tool ranged from resistance to very positive responses. Resistance was due to the following:

- Concerns about county level estimates providing effective information for decision-making, given the extreme topographic variability in New Mexico
- Information would not be updated frequently enough to be useful
- Websites frequently contain too much information that was not very useful
- Their decisions relied on information at weather time scales, not climate time scales
- Concerns about the *AgroClimate* website providing management advice

Nevertheless, participants suggested that AgroClimate could provide valuable information, such as: visualization of historical climate data (Last 5-years), ENSO-derived chances of seasonal temperature and precipitation anomalies, and ability to track the success of ENSO-derived "forecasts" (in contrast to reliance on *The Farmers Almanac*).

Key concerns for participants at the March 2008 workshops included:

- Temperatures at planting time (if a cool spring is forecasted, then planting could be delayed)
- Conditions during harvest time (heavy rain could prevent harvest)
- Freeze risk
- Damaging wind episodes
- Precipitation and temperatures when fungicides are applied
- Precipitation and fertilizer application (more nitrogen needed if conditions are wet)
- Chill accumulation hours for orchard crops
- Evapotranspiration and soil temperatures for cotton
- Hail damage risk
- Livestock forage and needs for supplemental feed

One extension agent remarked that even a 10% shift in the odds for precipitation would be valuable information, and that knowing that the information provided by *AgroClimate* is based on historical data, rather than guessing, would improve his confidence in using the product.

After the technical team completed a prototype New Mexico *AgroClimate* website, featuring the climate risk tool, we convened five focus group discussions and conducted interviews with eight growers in June and July, 2008. We designed our protocols to (a) elicit feedback on the New Mexico climate risk tool, (b) learn about growers' decision contexts, (c) determine the potential and ascertain priorities for implementing additional *AgroClimate* tools, and (d) determine priorities for future research. We interviewed orchard crop growers, vegetable growers, alfalfa, crop consultants, and ranchers in central, southern, and eastern New Mexico.

Climate related factors of concern to all growers include: pests, disease, planting dates, freeze risk, growing degree days, wind, hail, relative humidity, and scheduling farm labor. Wind is a particular concern in southern and eastern New Mexico where, in addition to enhanced evapotranspiration and plant desiccation, abrasion by dust-laden winds and saltation are key concerns, especially during the spring months. Thus, studies of ENSO –based probabilities of episodes of stronger than average winds or enhanced dust transport could be of use to these growers.

Most New Mexico growers use irrigation from surface and groundwater. In the Middle Rio Grande Conservancy District, water supply was not a major concern for irrigators, due to high priority water rights and allocations sufficient enough to weather even the exceedingly dry run of years in the late 1990s and early 2000s. In the Carlsbad Irrigation District, along the Pecos River, irrigators have fixed 5-year allotments; advanced knowledge of increased chances for winter and spring wetness or dryness could help growers better assess irrigation decisions and risk. ENSO-related changes in total precipitation could also affect supplemental groundwater irrigation decisions, when pumping costs are also factored in. Relative humidity is a chief concern for all growers, and may be more important than precipitation, especially for irrigators with limited allotments. Corn growers, in particular, are affected by soil moisture; some of the growers interviewed suggested that ENSO-based precipitation and temperature information (GDDs) could inform decision regarding which varieties of corn to plant.

Row crop growers were especially concerned with temperatures during late winter and early spring, as these influence planting dates. Temperature directly affects growing degree days and decisions regarding fertilizer application for row croppers. GDDs were mentioned as especially useful for corn and cotton. Freeze risk was unanimously of concern to growers; for row crop, alfalfa, and orchard growers, late spring frosts could destroy a year's crops. Research by the SECC indicates that ENSO. Neutral years show the brightest frost lists; preliminary research for Southeastern Arizona indicates a plight shift in the chances of late spring temperatures below 32°F and 28°F during La Niña years, due to occasional storms tracking southeastward and pulling cold air across the region, in their wake. Fall frosts are critical for pecan growers, because a hard frost is essential for splitting shells; harvest does not commerce until shells have split. Knowledge of increased chances of late fall frosts could influence labor management decisions, as growers would retain labor for additional weeks, if a late frost was likely.

Ranchers, previously noted as the most climate sensitive agriculture sector in the Southwest (Eakin and Conley, 2002; Vasquez-Leon et al., 2003) were keenly interested in the AgroClimate climate risk tool. In east-central New Mexico, there are two types of operations: cow-calf (which rely upon steady stock, and produce stock for others) and calfer (which purchase calves on an annual basis, and raise them for market). Ranchers in this area rely heavily on native grass forage; dry winters reduce native forage and cow-calf operations must decide whether to purchase hay, which is expensive, or cull stock. Advance knowledge of a dry winter half-year could influence calfer decisions on whether or not to purchase calves that year. If local alfalfa growers are also affected by a dry year, then the entire region can be severely affected. Ranchers noted the value of well coordinated data and information provided by AgroClimate ("one-stop shopping"). They also suggested enhanced value for AgroClimate, if remotely sensed vegetation information could be incorporated.

The agriculture conservationist that we interviewed envisioned many potential uses for AgroClimate information, including (a) the monthly report to growers, (b) state drought working group reports, (c) planting decisions (particularly with regard to planting short season crops), and (d) dissemination of seasonal information to resource conservation districts. The conservationist's priorities for importing additional SECC AgroClimate tools included the irrigation scheduler and the yield risk tool. The latter, be suggested, might help reduce uncertainty at the start of the growing season.

Participants throughout the course of our field investigations made the following suggestions to improve the usefulness and usability of AgroClimate:

Usability:

- Current ENSO phase information and explanations: make them easy to access, region-specific, and simple. The ENSO information should include related impacts; users need to know: What does this phase mean for me?
- Stakeholders recommended only lowercase letters in the website URL; during the demonstration, most people typed in the address with all lower case and thought the website wasn't working when their browsers showed error messages.
- The website must be "back compatible" with older versions of browsers; approximately 30-50% of farmers in Guadalupe County have internet access, but might not all have up-to-date machines or browsers.

- Metadata must be accessible from all pages: data source, data description (including interpolation methods), period for which average is calculated. Other metadata: ENSO years, by phase.
- Guide book on how to use website and interpret information; animated or slide show.

Usefulness:

- In order to improve the usefulness of NM AgroClimate decision support website, participants recommended further tailoring, in order to accommodate county-specific characteristics of agriculture. For example, variations in agricultural practices, such as ranching versus irrigated agriculture, and in crop type (annuals vs. perennials) suggest different default settings, tools, and navigation. In Guadalupe County, settings might be it tailored to ranchers' needs and interests, and in Bernalillo County focused on annual crop farmers.
- Most participants in northern New Mexico like the idea of one-stop shopping. Most of the data used in AgroClimate is available on other websites, but stakeholders suggested that they could save substantial investments of time, if data and information was (a) served from a single website, or (b) if a single website contained region- and sector-specific links. Water and land managers, in particular, expressed this point of view.
- Links to information about current ENSO phase, including information about regional and local ENSO impacts.
- Show multiple graphs at once, in order to facilitate comparisons between phases.
- Ability to show current (this year's) data versus ENSO phase averages. Also, ability to contrast user's data with ENSO phase averages.
- Show current data (or user's data) in Last 5 Years tab.
- Links to forecasts on other time scales: 8-10 day; daily, weekly.
- Develop displays for variables such as relative humidity, wind speed and direction.

The June-July focus group and interview participants recommended the following climate-related diagnostic and forecast research priorities: pests and diseases; wind speeds and windstorm episodes; multi-year water supply forecasts; seasonal frost forecasts; water quality; weeds; and crop consumptive water use prediction for weekly or bi-weekly periods.

4.2 Dynamic Drought Index Tool

We convened two focus groups (n=14), to demonstrate the DDIT to a diverse group of Arizona stakeholders and to elicit feedback on characteristics of the DDIT website, which may need to be changed to accommodate DDIT users in the Southwest. These included clarity of procedure to generate output, need for additional map layers and information, terminology, needs for additional analytical tools, etc. Participants represented cooperative extension, universities, federal and tribal natural resource management agencies, state environmental quality and water management agencies, and county and city water management and emergency preparedness agencies. At the outset of the workshop, participants completed a survey to garner background information about their management and decision contexts, use of drought and climate information in decision-making, and professional training. All features of the DDIT were then demonstrated, followed by a hands-on exercise during which the focus group participants examined the website, in pairs. Participants reconvened for a guided discussion. All stakeholder feedback was recorded by the research team.

Participants' chief concerns included ecosystem health, streamflow, surface water and groundwater supplies, water quality and wildlife management. Most participants had worked for their organizations for more than five years, and were involved in gathering, analyzing, and providing information to others, as well as making decisions. Fifty percent had training in hydrology; however only two had training in climatology or meteorology. Only one participant was limited by communications technology or infrastructure; however, inadequate staffing and organizational issues (e.g., inter-departmental communication) limited the use of climate information in their organizations. Only two participants reported that available information was not specific enough to use. Most participants currently used the standardized precipitation index (McKee et al., 1995); participants all used a variety of other indices in their drought management efforts.

Participants stakeholders found DDIT to be a powerful and relatively easy to understand decision-making tool. All mentioned that it would help them in their work, specifically for impact analyses (e.g. for endangered species), public service announcements, water resource decisions, and to justify management actions (such as policy or drought declarations). Participants expressed enthusiasm for the ability to custom blend drought indices, one of the most sophisticated capabilities of the DDIT. They noted that the DDIT may be too overwhelming for some users, such as small water providers; therefore, the recommended sets of default options for non-expert users. Participants made many recommendations for improvements to the DDIT and to enhance its usability in the Southwest; we categorized these improvements as interface enhancements, data and data management enhancements, and ancillary changes to improve comprehension and the overall usability. Improvements most relevant to NIDIS and technology or knowledge transfer, include:

- Interface. Ability to compare multiple maps or graphs on one screen. Ability to retain user preferences. Ability to add user-generated labels and notes. Rollover capabilities to provide map information, such as river and mountain names. Ability to import custom coverages.
- Data. New parameters, such as snow and groundwater. A wide variety of spatial boundaries, in addition to the default climate division, county, and state boundaries; for example, physiographic regions, so classifications, state trust lands, township and range, ecosystem types, tribal land holdings, federal lands, resource conservation districts Arizona active management areas, and others. Seasonal climate and stream flow forecasts for map overlay.
- Ancillary. More explicit communication of units of measurement. Step by step tutorial or guidebook. Ability to measure distances. Glossary. Functionality for downloading GIS shapefiles or to export DDIT maps into desktop GIS.

5. TECHNOLOGY TRANSFER

One key focus of these projects is an assessment of lessons learned about transferring technologies within the public sector, a topic about which there is far less written than technology transfer within or to the private sector. Our projects involve transferring web-based tools that have been designed to meet the needs of stakeholders within specific geographic regions. In order to transfer these tools to other regions requires adapting the tools to new assumptions regarding the spatial homogeneity of hydroclimatology, as well as new challenges with regard to the length of records, data continuity, and international borders. In addition, our projects require scaling the software, in order to handle an increase in the amount of visitors to the websites, and scaling the applications to include new types of data and new functions. We have divided our assessment of technology transfer challenges into three topics: data, programming, and communication.

5.1 Data.

All climatologists are familiar with standard data challenges, including data homogeneity, handling missing data, length of record, and other quality assurance concerns. The AgroClimate tool estimates probabilities of parameters exceeding thresholds (e.g., 1 inch of precipitation during the month of August) during three ENSO phases (La Nina, Neutral, El Nino); in order to ensure robust probability distributions, given the relatively few occurrences of individual ENSO phases during the period of record, AgroClimate uses statistical bootstrapping. Moreover, AgroClimate provides county-level estimates of climate parameters for the Southeast, by assigning a single station to each county; this method is robust for most of the Southeast, where topography is relatively homogeneous and counties are relatively small. In order to adapt AgroClimate for use in the Southwest, we needed to address several concerns, such as: station records that are often 50% shorter than records in the Southeast, fewer stations per unit area, higher percentages of missing data, sharp topographic contrasts, and larger county sizes. For the DDIT, we also needed to handle data issues associated with the international border between the United States and Mexico, in order to provide robust spatial estimates of parameters in the border region.

For AgroClimate, we adopted *Westmap* county-level estimates of precipitation and monthly average temperature parameters; *Westmap* uses spatial estimates from PRISM (Daly et al., 2002) for the period 1895-present. PRISM estimates are serially complete, account for topography and other potential spatial inhomogeneities (e.g., rainshadows), and have received rigorous quality control. However, for extreme monthly maximum and minimum temperatures, we needed to use station data, which requires an additional database, additional quality control, less certainty in bootstrapped probability distributions, given the short record lengths. In addition, we cannot assign single stations to counties, given the dramatic elevation changes and associated climatic phenomena (e.g., cold air drainages) in New Mexico.

For DDIT, additional climate data challenges included the integration of Mexican data, in the data sparse northern border with the United States. Consequently, we needed to merge gridded data estimates for the border region (e.g., NOAA's Unified Precipitation Dataset) with station data in the U.S. For DDIT to be fully useful in the Southwest, we will also need to incorporate snow data, which are less of a concern in the Southeast. Transferring DDIT also required the team to use new types of geographic units, such as National Parks and Tribal Lands, for the computation of spatial estimates of drought indices; considerations included: For how small a region can we provide credible estimates of spatially interpolated drought indices? Moreover, we found that the needed GIS data for many land units that stakeholders identified as useful (e.g., Natural Resources Conservation Districts, State Lands, Game and Fish Management Regions) were not located in a central archive, as is the case with NCDC or USGS climate and streamflow data.

5.2 Programming.

In a previous era, a single scientist (or group) developed databases, analytical tools, and the code for an application; for others to adopt the application merely required transferring the code, and perhaps the database. Now, developing a web-based decision support tool requires a wide array of specialties, including expertise in climatology, GIS, database management, web interface design, and software development. Coordinating these activities requires a technology translator, who has sufficient knowledge of all of these skills, plus the ability to communicate clearly with climatologists and other scientists. As mentioned earlier, these projects require scaling software to handle additional users, and region-specific applications. Considerations include:

- Supporting an order of magnitude more users, while guaranteeing speed, robustness and stability of the web tool;
- Multiple programming languages, and developing facility in working with new languages;
- Open-source versus proprietary coding;
- Maintenance of the tool (i.e, updating data, and maintaining accuracy and stability of code), which is frequently the most expensive part of the software life cycle;
- Portability – Can the tool be deployed on multiple operating systems? Does running the tool require proprietary software and for how long will companies support their software? Is the application mirrored?
- Code management and oversight – How can multiple developers simultaneously work on the code? How will multiple institutions implement code error corrections and updates?
- Resources – Do programming teams, usually located in specific university departments, have sufficient technical expertise (e.g., GIS, IT, design)?

A time-honored approach to some of these issues is to port the code for the application to the cooperating institution, and "let 'em have at it." This means that each copy is customized and maintained to work for its local user base. Such an approach is practical, if the developer does not intend to improve the code or see improvements implemented in all of the multiple versions. In addition, some web tools require commercial software to implement certain functions (e.g., Java-based charting packages); in order to keep up-to-date with improvements in the commercial software code often requires the purchase of annual support agreements for updates of the source code. Thus, sharing new functionalities or software updates is complicated when maintaining multiple copies of code between different institutions, and it requires equivalent programming expertise at all institutions.

The technical teams for our projects have converged upon a similar solution, well articulated by the DDIT developers, to maintain a single copy of the source code, housed at a cooperating institution with the operational and technical capacity for adding users and maintaining industry-standard hardware and software. In the case of DDIT, the Northeast Regional Climate Center has agreed to house the code, provided that we use their revision control system (more about revision control, below); for AgroClimate, the Southeast Climate Consortium is investigating housing code at the University of Florida; for AZ DroughtWatch, we are initially using code-transfer, but as resources become available, we are likely to adopt the single source code/multiple developers model. The single source code/multiple developers model allows flexibility for individual regions to tailor their tools to region-specific contexts and concerns, and to develop web interfaces unique to institutional branding and regional user requirements – at the same time that all developers and institutions can leverage resources for error corrections, proprietary code updates, innovations to improve response times, and so on. In order to implement the source code/multiple developers model requires management oversight through a revision control system – software that tracks code changes and allows multiple developers to modify the code simultaneously. Developers must also use the same code documentation standards.

5.3 Communication.

In order to effect the aforementioned technology transfers required a large investment in communication. Teams met monthly or more frequently via teleconference and videoconference. The first barrier to overcome was developing a common understanding of the product development process and software life cycle. This process required further time for scientists and technical staff to clarify needs, standards, and tasks. In order to facilitate the process of adapting the DDIT for requests from Arizona users, for example, meant the development of a "requirements document," that explicitly stated desired functionality, administration, browsing capabilities, search capabilities, metadata protocols, user registration, and public versus administrative website features. The teams also needed time to overcome language barriers related to technical specialties, programming languages, and data types. To paraphrase Eveland (1986), technology transfer is an appreciation of the role that language plays in how people and groups understand new things. Regular communication and technical team leadership by a single tech transfer generalist who had familiarity with product life cycles, and experience in managing projects vastly improved the capability of our teams to progress.

5.4 Recommendations

Such considerations may not seem germane to applied climatologists; however, with the increasing trend toward deployment of user-friendly web-based applications, we believe that the following recommendations are worthy of consideration for improved regional climate services and for sharing innovations across regions and in support of national programs, such as NIDIS.

- Schedule regular meetings, using online video/teleconferencing.
- Assign a tech transfer manager, with knowledge of various specialties and ability to communicate clearly with academics and researchers, with authority to coordinate and lead decision making process.
- Develop a requirements document to clarify needs and implementation. This involves setting up a customer-producer relationship between team scientists and team technologists/product developers.
- Use shared code via a revision control system. In addition to facilitating product scaling and ease of maintenance, this provides an opportunity for groups to work in a collaborative fashion and to innovate more rapidly.
- Involve users in product development, in order to clarify team goals, identify common and unique needs of regions, and create knowledge by jointly exploring the full potential of a new system. Mutual understanding can push the technical system and the work process to new heights of performance, and users will be more receptive to new tools if they contribute to its design (Leonard-Barton and Sinha, 1993).
- Developing products with potential national use in mind, makes the process easier for developers and for porting products to NIDIS. While this requires more effort in initial design, scaling down to accommodate regional needs ultimately requires fewer resources. Organized leveraging of technical transfer expertise (e.g., through an agency or national coordinating center, such as the ESIP Federation) would decrease the time and effort required to deploy new products throughout the country.

6. CONCLUDING REMARKS

The Southeast-Southwest regional decision support technology transfer projects mentioned in this paper are nearing completion for the first phases of development. Insights garnered through engagement with stakeholders revealed some differences in regional requirements, such as definitions of useful land management regions for evaluating drought, and needs to address spatial heterogeneity of climate in the Southwest. In general, the project teams benefitted from cross-regional dialogues and collaboration, which facilitated communication of important improvements to the original decision support tools, enhanced innovative thinking, and forced teams to clarify technology process and requirements (and thus allowed for ease of future technology transfer to other regions or to the NIDIS drought portal). Insights garnered from stakeholder interactions led to the following priorities for continuation of these projects: (a) addition of snow, groundwater, and vegetation health data, (b) improvement of interfaces to allow multiple graphs, tables, and maps to be viewed simultaneously, (c) research into climate-agriculture relationships in the Southwest related to insects, disease, wind, and crop yields, (d) expansion of extension and outreach activities to facilitate product use, feedback, and decision discussion (Nelson et al., 2002), in addition to decision support. Most of the DDIT interface enhancements have been completed, and the NM AgroClimate website climate risk tool is available to users. Future work to complete these one-year projects includes integration of CLIDDSS tools, completion of AZ DroughtWatch transfer, completion of DDIT interface enhancements, incorporation of growing degree day and chill accumulation unit tools into NM AgroClimate, implementation of single source code and revision control system for AgroClimate, and formally testing the usability of revised versions of these web-based tools.

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