TOWARD REGIONAL CLIMATE SERVICES

The Role of NOAA's Regional Climate Centers

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A comprehensive national climate services strategy requires the infrastructure, operational services, and applied research activities that have characterized the Regional Climate Center Program since its inception.

Over the 25-yr history of the Regional Climate Center (RCC) program, the central goals of the 1978 Climate Program Act that initiated the program have remained at the core of the centers' mission. However, the methods, infrastructure, tools, and collaborations that define the program have evolved and the demand for and sophistication of climate service requests has increased. Unlike the program's partners whose focus is on the collection and archival of climate data, integrated research, and addressing state-specific climate inquiries, the RCCs fill the following three operational niches in national climate services:

- provision and development of sector-specific and value-added data products and services;
- establishment of robust and efficient computer-based infrastructure for providing climate information; and
- seamless integration and storage of non–National Oceanic and Atmospheric Administration (NOAA) climate data with traditional NOAA data sources.

These roles mirror the five major guiding principles for climate services outlined by the National Research Council (NRC 2001). Collectively, the RCC program mission is rooted in i) user-centric services, ii) active research, iii) a range of space and time scales, iv) active data stewardship, and v) effective partnership.

With the renewed interest in climate services that is characterized by current NOAA priorities (NOAA 2008) and pending congressional (U.S. Congress 2009) and state (e.g., New York State Governor's Office 2008) legislation, it is informative and useful to summarize the history, motivations, and lessons of the RCC program, particularly as they relate to these guiding principles. The socioeconomic and environmental impacts of climate change and variability have provided a new impetus for reexamination of how the United States or any nation should structure its climate service activities. The experience of the RCC program and its rich partnerships offer valuable insights concerning growth through better integration among existing providers, identification of service gaps not addressed by RCCs or other climate service agencies, and enhanced efficiency through incorporation of activities and technical infrastructure already in place within the RCC program. As decision-maker concerns expand to impacts and potential adaptations to changing climate conditions, it is important to ground these changes with the temporal and spatial variations evident in the historical records and build on existing climate-based decision tools.

History. The RCC program dates to the National Climate Program Act of 1978. Early on, Stan Changnon, an instrumental leader in the establishment of the RCC program, recognized the necessity of a regional, place-based approach if climate services were ever to achieve their true potential for the nation (Redmond 2004). In this legislation, a number of program elements were laid out, including a provision for intergovernmental climate-related studies and services including participation by universities, the private sector, and others concerned with applied research and advisory services. Regional service functions were further specified, including i) analyses of climatic effects on agricultural production, water resources, energy needs, and other critical sectors of the economy; ii) atmospheric data collection and monitoring on a statewide and regional basis; iii) advice to state, regional, and local government agencies regarding climate-related issues; iv) provision of information to users within the states regarding climate and climatic effects; and v) sharing of information with the Department of Commerce regarding the needs of entities within the states for climate-related services, information, and data.

Based on this legislation, several demonstration projects were proposed in 1981, within NOAA. The first of these were awarded to the Illinois State Water Survey and Cornell University in 1982, and it set the foundations for the current Midwestern (MRCC) and Northeast Regional Climate Centers (NRCC). The beginnings of the third center followed shortly thereafter at the University of Nebraska–Lincoln, focusing on irrigation scheduling and also the assessment of the impacts of climate change on agriculture. This was the first real mention of climate change in the context of the RCC program. The Western Regional Climate Center (WRCC) at the Desert Research Institute in Reno, Nevada, was the first formally designated RCC, in 1986. It would take several years before the existing six-center program was complete, with the creation of the Southern Regional Climate Center (SRCC) at Louisiana State University and the Southeast Regional Climate Center (SERCC) within the South Carolina Department of Natural Resources in 1990. Following a national competitive contract process, the SERCC moved to its current home at the University of North Carolina at Chapel Hill in 2007.

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PARTNERSHIPS. The RCC program provides operational capacity in all 50 states through collaboration with other regional and federal entities (Fig. 1). The RCC program is managed by the NOAA/National Climatic Data Center (NCDC) and forms an integral part of its data operations and climate services. Likewise, the program is integrated into the NOAA/National Weather Service (NWS) Climate Services Division (CSD) and collaborates with the American Association of State Climatologists (AASC), NOAA cooperative institutes and research programs such as the Regional Integrated Sciences and Assessments (RISA), numerous state and federal agencies, private industries, and individuals.

Each center delivers a comprehensive suite of climate services at national, regional, state, and local levels. The success of the program is based on the provision of jointly developed products, services, and capabilities that enhance the delivery and usefulness of climate information. These collaborative efforts form a framework for data stewardship; climate services; climate assessment; and applied research geared toward helping individuals, communities, government agencies, and industries make informed decisions that need climate input. Although each center addresses an array of unique regional interests and agencies, collectively the six centers form an integrated national program, sharing infrastructure, resources, and intellectual talent and collaborating, where appropriate, across regional and sector boundaries.

The longevity of the RCC program has allowed for the development of trust-based relationships between the centers, their federal and state partners, and decision makers from various economic sectors.

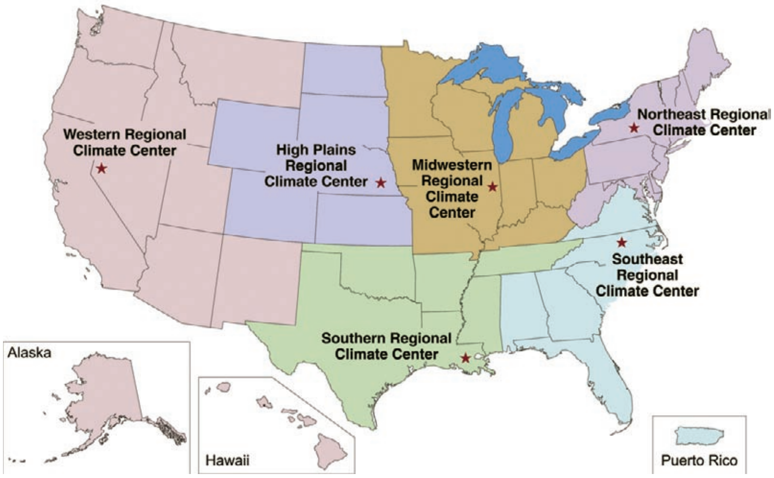


Fig. 1. Regions served by the RCC program.

The clientele for RCC information spans a vast range, encompassing NOAA and other federal agencies, governmental units, companies, organizations, and individuals (Fig. 2). RCC experience has reiterated early lessons that the user–provider relationship is an actively evolving two-way street. Decision makers receive the data and information they need in a format, time frame, and manner that is most useful for their application, whereas the RCCs capitalize on the feedback received from users of climate information to develop robust and efficient data delivery systems, drive applied research projects, and synthesize the climate-related phenomena that impact specific sectors within their regions. The distinction and the crossover of RCC, RISA, and AASC climate service programs should be more widely understood to avoid duplication of activities; to clarify the unique roles that these programs have in providing climate services on regional, state, and local levels; and to highlight synergistic partnerships.

RCC–RISA. The RCC and RISA programs play complementary mutually supportive roles, both necessary ingredients of a robust suite of climate service activities serving the nation. As such, there are ample opportunities for collaboration and associated needs for coordination. The RCCs tend to emphasize the ongoing delivery of climate services as a quasioperational activity. The RISAs were primarily developed as research entities, with a primary emphasis on learning. The RISAs concentrate on the acquisition of knowledge about the user and their decision environment and how these affect the use of climate information. Many RISAs are also engaged in assessing climate vulnerability to support adaptation. This may include modeling and impact studies as well as research to improve understanding of user needs.

The clientele of the RCCs covers essentially all sectors of society; the RISAs deliberately cover only selected sectors at any one time (e.g., water resources management, range management, agriculture). The RCCs emphasize breadth with isolated pockets of depth, whereas the RISAs emphasize depth of understanding with less focus on breadth across all sectors at any one time. The RISAs gain understanding of how specific sectors work and report this knowledge in the research literature and then move on to other sectors in succession; RCCs maintain relatively constant contact with their wide user base. Early on, S. Changnon (1993, personal communication) described this RCC role as being akin to "milkmen," having an established clientele that relies on a routine service. However, in addition, RCCs also function as "firefighters," maintaining the tools and being nimble enough to respond to climate-related decisions that

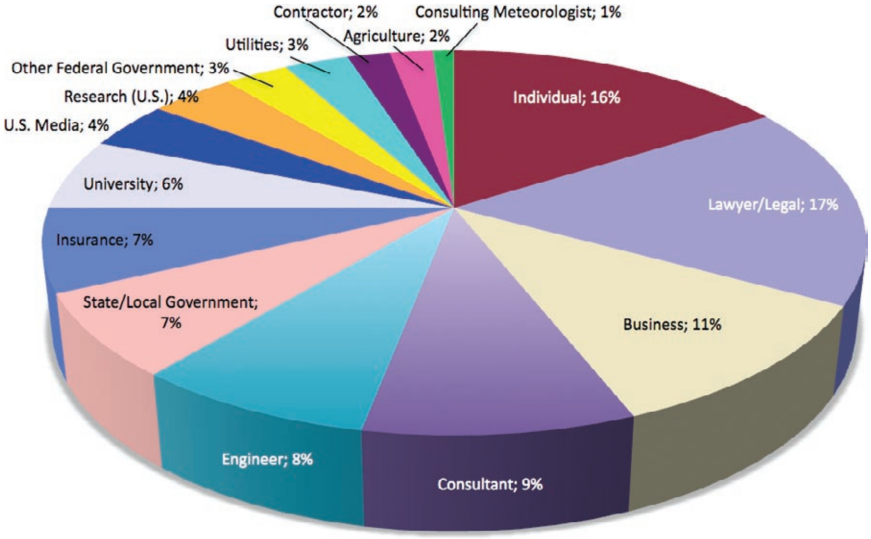


Fig. 2. Pie chart of RCC program users by sector.

may arise unexpectedly. In this crucial climate services role, there is a clear distinction between the RCCs and the RISAs.

The RCCs stand to benefit significantly from the knowledge of how users think and work that is derived from RISA activities, and the RISAs depend on the data, tools, and infrastructure that RCCs provide as a necessary ingredient of their research agenda. The RISAs may occasionally build research tools that are deemed suitable for long-term operationalization, and the RCCs can assist in the transition process to an operational environment. Thus, the missions of the RCC and RISA programs are distinct but heavily interwoven, and four of the six RCCs have members directly involved with a RISA. As elsewhere in climate services, long-term trust and engagement are integral to successful working relationships between these two programs. In effect, the RCC and RISA programs, which have separately and in concert demonstrated considerable benefit to climate services, should view themselves as stakeholders in each other. This special relationship has already shown its power through a variety of long-standing interactions and successes and needs to be given proper attention in any formulation of national climate services.

RCC–AASC. The AASC provides services at a state level; they are generally authorized by state entities and hence are a source of climate expertise to state government. Like the RISAs, they also serve roles that are complementary to the RCCs but have their distinctions. Historically, all but one of the RCCs evolved from state climate programs. This has led to more organized and formal interactions between the two programs. The RCCs often provide the basic climate products and infrastructure that are needed by state climatologists to assess local climate anomalies, respond to the media, or support requests from state government or other state-specific users. Conversely, AASC members have themselves become sources of data for the RCCs as local and state data networks have proliferated and the use of these data in regional and national climate monitoring has become more widespread.

The AASC typically emphasizes breadth in their services, fielding information requests from an array of users; albeit, in some cases, particularly in states with large agriculture economies, the services provided by an office may be more sector focused. Regardless, these types of local interactions are key to the provision of climate services at a national scale, because they enable direct interaction with local stakeholders. Such interactions and more importantly the development of trust-based working relationships become more difficult when climate service providers are at a regional or national level.

The AASC also provides a critical linkage to state government. In the past as well as currently, this tie was an important mechanism for guiding state responses to drought, severe storms (e.g., hurricanes), flooding, etc. Increasingly, states have begun to develop action plans in anticipation of climate change impacts and as guides for implementing adaptation (and mitigation) options. There are clear roles for the AASC in this area scientifically, through knowledge of relevant nonclimatological issues and in leveraging established state government stakeholder relationships. Such roles are and should continue to be strengthened by the availability of RCC data infrastructure, decision tools, and experience as well as the application of RISA-based knowledge about specific users, their decision environment, and how these affect the use of climate information.

USER-CENTRIC DATA PRODUCTS.

The RCCs of the early 1990s emphasized responsiveness to user requests, at that time mostly received by telephone. Consultants, engineers, agriculturalists, lawyers, and energy firms routinely contacted RCCs with requests such as, how many times did the temperature in Chicago exceed 90°F last year? In response to repeated similar requests, early versions of RCC software facilitated rapid extraction of this type of information from data files to serve customers' needs. Such queries have often motivated research projects (e.g., DeGaetano et al. 2000).

Through the 1990s, with the proliferation of the Internet and computer technology, the RCCs pooled their in-house climate analysis software, creating online systems that allowed data users to make such requests directly by logging into RCC computers. This led to the need for a system that could provide identical output for stations located throughout the country, derived from identical datasets using identical assumptions about numeric rounding, missing data tolerances, statistical methodologies, etc.

These systems continued to evolve into their present form. In addition to the online climate access systems operated and maintained by individual RCCs, systems developed and operated by RCCs collectively provide specialized access to climate data products for NWS Weather Forecast Offices (WFOs), the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), and the AASC. Figure 3 shows the interface to an additional system developed for the NWS to provide access to a limited number of climate data products via each WFO Web site. This

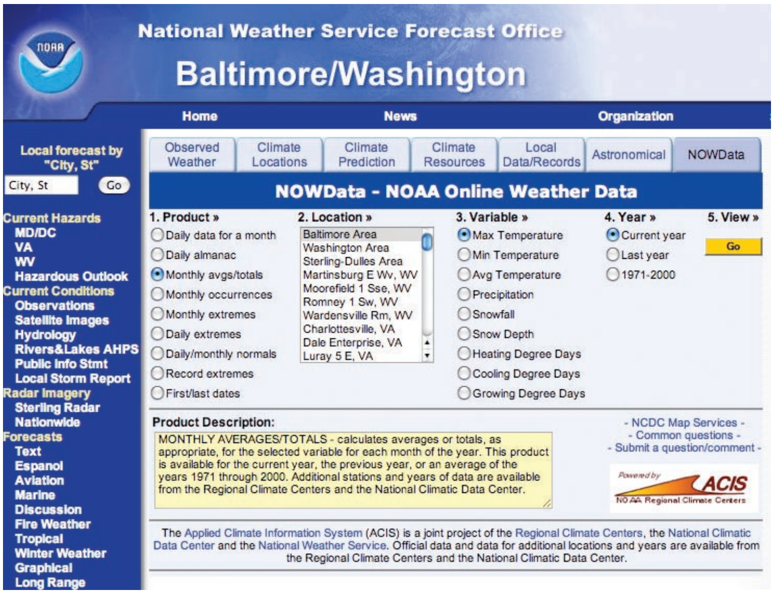
NOAA Online Weather Data (NOWData) system answers more than 70,000 such climate data inquires each month. One of the major advantages of NOWData is that it saves the local NWS offices valuable staff time answering questions and looking up data.

Decision tools. Increasingly, RCC data systems have also matured to provide direct links between climate data and an array of models and tools of utility to different sectors. These tools highlight the regional emphasis of the centers and focus on important regionally specific issues. Users should not be expected to be aware of inevitable artificial administrative boundaries. By utilizing shared data and computer infrastructure, software can be adapted to or simply run for any part of the country. These tools can best be illustrated through two selected regional examples.

Northeast: Precision nitrogen management. In the Northeast, the proximity of agricultural land to water supply systems and coastal ecosystems often raises environmental concerns. Of particular importance is the leaching of nitrogen fertilizer into surface and ground water systems as well as estuaries, such as the Chesapeake Bay. Like many agricultural practices, application rates for nitrogen fertilizers have been based on average climatological conditions related to crop development rates and rainfall. In specific years, these average application rates can be either insufficient for optimal crop (primarily maize) yields or excessive, contributing to nitrogen runoff to water supplies. In addition to the adverse economic and environmental consequences of these nonoptimal application rates, there is increasing political pressure to reduce and regulate the amount of nitrogen entering waterways.

To address these issues, NRCC scientists and programmers have worked with agronomists, crop consultants, and river basin coalitions to link real-time climatological data from the NRCC database with soil nitrogen and crop growth models. Given the strong dependence of the optimal application rates on precipitation, the climatological data used by the model represent a blend of station data and daily radar-estimated precipitation totals (DeGaetano and Wilks 2009). Likewise, temperature data are also interpolated from station values using a technique that relies on daily Rapid Update Cycle (RUC) model initializations (DeGaetano and Belcher 2007). Based on these data, the model computes a recommended nitrogen application rate specific to the field location and antecedent climate conditions (Fig. 4). In dry years, the application of additional nitrogen is of little benefit to yield, because sufficient nitrogen reserves are likely to exist in the soil, increasing the potential for excess nitrogen to run off into water systems. Timing is also of critical importance to the determination of application rates. Once the crop enters its active growth phase (a function of antecedent temperature conditions), uptake of nitrogen by plants limits the potential for runoff. Application prior to this stage, particularly in wet years, increases the potential for excessive nitrogen runoff and hence crop nitrogen deficiencies. This may necessitate additional application and hence increased cost to assure an optimal yield.

Midwest: West Nile Virus risk model. In response to concern over the spread of West Nile Virus (WNV), the MRCC sought to monitor disease transmission risk based on climate. Two temperature-based climate models were developed to help predict the date when the population of the *Culex pipiens* mosquito, which is largely responsible for the transmission WNV to humans, becomes dominant in the summer (Kunkel et al. 2006). These models were developed in partnership with entomologists from the Illinois Natural History Survey. MRCC staff continue to improve the model with the goal of developing a decision support



1. Product »
○ Daily data for a month
○ Daily almanac
● Monthly avgs/totals
○ Monthly occurrences
○ Monthly extremes
○ Daily extremes
○ Daily/monthly normals
○ Record extremes
○ First/last dates

2. Location »
Baltimore Area
Washington Area
Sterling-Dulles Area
Martinsburg E Wv, WV
Moorefield 1 Sse, WV
Romney 1 Sw, WV
Wardensville Rm, WV
Charlottesville, VA
Dale Enterprise, VA
Luray 5 E, VA

3. Variable »
● Max Temperature
○ Min Temperature
○ Avg Temperature
○ Precipitation
○ Snowfall
○ Snow Depth
○ Heating Degree Days
○ Cooling Degree Days
○ Growing Degree Days

4. Year »
● Current year
○ Last year
○ 1971-2000

5. View »
Go

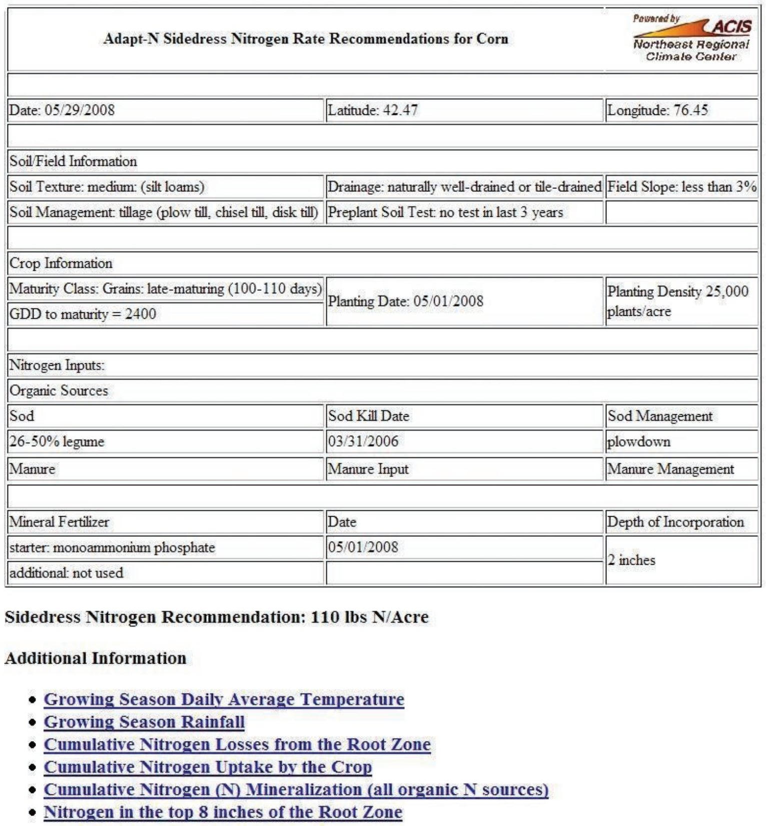
Product Description:
MONTHLY AVERAGES/TOTALS - calculates averages or totals, as appropriate, for the selected variable for each month of the year. This product is available for the current year, the previous year, or an average of the years 1971 through 2000. Additional stations and years of data are available from the Regional Climate Centers and the National Climatic Data Center.

The Applied Climate Information System (ACIS) is a joint project of the Regional Climate Centers, the National Climatic Data Center and the National Weather Service. Official data and data for additional locations and years are available from the Regional Climate Centers and the National Climatic Data Center.

Fig. 3. Interface to NOWData, allowing the general public to request climate information generated by the RCC program from each NWS Forecast Office Web site.

tool for mosquito control and abatement. Prior to the 2009 season, modifications were made to the model to utilize NWS model output statistics (MOS) temperature forecasts as the "first guess" for temperatures 10 days from the current date instead of climatology. The models were run for 2001–09, and it was found that the use of the MOS data increased the forecast lead time of the projected crossover date (to *Culex pipiens* becoming the dominant species) by an average of 4.5 days. MRCC staff will be engaging the Illinois Mosquito and Vector Control Association as the next step in developing a decision support tool that may eventually be able to be expanded to other areas of the country.

Leveraging applied research. These examples also highlight the role of applied research at the RCCs. Each RCC is located at a Research I university. Thus, the research programs of the directors with professorial responsibilities as well as the research conducted within the departments and colleges that house the centers often relate directly to the mission of the centers. Since 2006, more than 50 peer-reviewed publications have been authored by RCC scientists.



Adapt-N Sidedress Nitrogen Rate Recommendations for Corn		Powered by ACIS Northeast Regional Climate Center
Date: 05/29/2008	Latitude: 42.47	Longitude: 76.45
Soil/Field Information		
Soil Texture: medium: (silt loams)	Drainage: naturally well-drained or tile-drained	Field Slope: less than 3%
Soil Management: tillage (plow till, chisel till, disk till)	Preplant Soil Test: no test in last 3 years	
Crop Information		
Maturity Class: Grains: late-maturing (100-110 days) GDD to maturity = 2400	Planting Date: 05/01/2008	Planting Density 25,000 plants/acre
Nitrogen Inputs:		
Organic Sources		
Sod	Sod Kill Date	Sod Management
26-50% legume	03/31/2006	plowdown
Manure	Manure Input	Manure Management
Mineral Fertilizer	Date	Depth of Incorporation
starter: monoammonium phosphate	05/01/2008	2 inches
additional: not used		

Sidedress Nitrogen Recommendation: 110 lbs N/Acre

Additional Information

- Growing Season Daily Average Temperature
- Growing Season Rainfall
- Cumulative Nitrogen Losses from the Root Zone
- Cumulative Nitrogen Uptake by the Crop
- Cumulative Nitrogen (N) Mineralization (all organic N sources)
- Nitrogen in the top 8 inches of the Root Zone

Fig. 4. Precision Nitrogen Management model output page showing table with summary of model inputs, nitrogen application rate recommendation, and links to additional climatological and agronomic output.

Also RCC efforts to publish in sector-specific journals foster cross-disciplinary collaboration and expose the RCC to relevant sectors and fields outside of the atmospheric sciences. For example, work on WNV at the MRCC has appeared in the *American Journal of Tropical Medicine and Hygiene* (Kunkel et al. 2006).

CLIMATE DATA. At a regional level, the RCCs complement the climate data services provided at the national scale by their partner NCDC. Quality controlled surface-based observations obtained from NCDC are an important source for many RCC data products and tools. Data from the NOAA/Cooperative Observer Program (COOP), Climate Reference Network (CRN), and other hourly networks (including all major airports) are stored on RCC servers to facilitate the generation of climate data products.

Synchronization. Considerable effort has allowed the highest level of synchronization between RCC and NCDC data sources to ensure that consistent information is provided by both sources. Likewise, automated synchronization of data files among the six RCCs ensures both consistency in source data and redundancy between the centers. Although the six centers operate autonomously, this standardization among the centers allows each center to provide backup capabilities to its sister centers, limiting downtime in both online and offline data services. For instance, users of NOWData are routed through an offsite private broker. The broker directs information requests to one of the available RCC servers. This server may be in a region different from where the request originates depending on server availability, volume, or network traffic.

Standard products are also synchronized. For instance, maps available from the Applied Climate Information System (ACIS; http://rcc-acis.org) are generated daily to incorporate new or edited data values that have become available since the original creation of the product. All six centers cooperate to produce daily updates of several thousand climate anomaly maps for the nation, regions, and states. These maps, made available at the High Plains RCC (HPRCC) as a joint RCC activity, are heavily used for a variety of purposes, including the weekly U.S. Drought Monitor (Svoboda et al. 2002).

The existence of multiple slightly different versions of major databases leads to problems for some applications. Even minor inconsistencies in climate elements, such as monthly degree-day accumulation, can have considerable financial impacts (Zeng 2000). Similarly, subtle differences may alter the actions by data users. For instance, different environmental regulations can take effect when daily rainfall exceeds a legislated limit, triggering different actions for rainfall differences as small as 0.0254 cm (0.01 in). Partnership between the RCCs, NCDC, and NWS CSD has all but eliminated this problem, as individual unsynchronized databases at each local weather service forecast office have been replaced by the fully synchronized NCDC–RCC databases.

Major non-NOAA federal observing systems also exist and are particularly prevalent in the West. Some agencies, such as the National Park Service (NPS), and the multiple resource management agencies at the National Interagency Fire Center (NIFC) have teamed with the WRCC to help manage data and observation networks. Other agencies, such as the NRCS, have turned to the RCC to help manage their own data and integrate these with standard NOAA datasets. Others are relying on RCC expertise and advice to guide their observational activities. Efforts to work with state climate offices on data storage and access are also under way.

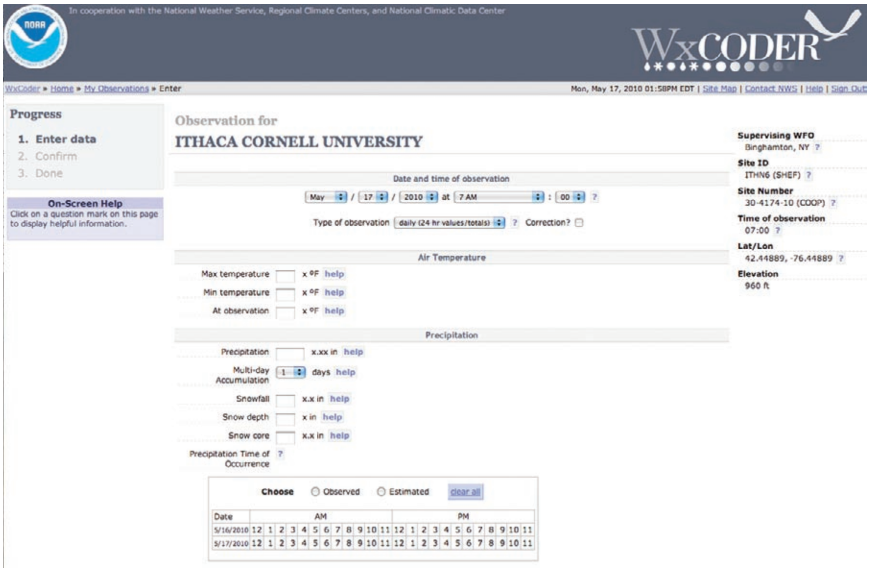
Synchronization has also been driven by private industries such as the media. Differences in daily temperature and precipitation records reported by national media outlets and federal, regional, and state sources have been problematic and confusing to users for certain applications. These discrepancies arose from differences in the quality control applied to different datasets and inconsistencies in the periods of record used to compute records. In association with users from the media, the NWS and NCDC, a standardized set of temperature and precipitation records spanning the multiple stations that define metropolitan media markets was developed by the RCCs. These "threaded" data records, suitable for informal usage but not for climate research, are maintained, updated, and disseminated by the RCCs and used in most broadcast markets.

Stewardship. Related to this effort, the SRCC developed Datzilla, a tool maintained by the RCCs to identify and correct discrepancies among data records. Often, discrepancies in the data used by local weather service offices and state climatologists arose because a particular extreme was flagged as suspect in one database and not the other. Even when these differences were identified, a means of evaluating the cause of the difference and establishing the proper value was not available. Standardization has allowed such problems to be rectified. This not only facilitates the use of synchronous data but also provides a means of rigorous quality control for the most extreme values in the national climate archive. Equally important, it instills a sense of ownership of the data among providers, despite a centralized data portal.

The RCCs have become sources of real-time climate data, allowing the monitoring of national and regional climate conditions and rapid identification of extremes while filling a gap in temporal data coverage that in the past was devoid of information. At multiple times during the day, the RCCs ingest data from electronic federal, state, and regional data feeds. Starting in 2007, the centers have also served as a collection point for daily manual observations by COOP observers. The WRCC has upgraded a system developed by the NWS, now called WeatherCoder III (WxCoderIII), as the primary means of daily data entry by these observers (Fig. 5), with 2,360 stations using this interface in October 2009. The HPRCC currently serves as a failover point if problems occur. Upon entry, the manual data are propagated nationwide to NOAA agencies and the other RCCs, providing immediate synchronization of data resources. The system can be adapted to other manual observations. WeatherCoder III also represents the first step in a sequence that will result in a "paperless" COOP, with 28.5% of the network in this status as of October 2009.

Initial quality screening is incorporated into the WeatherCoder III software, providing a means for immediate feedback to the observer. These simple "at source" expedients have helped to greatly reduce the number of COOP errors, many of which can now be caught or flagged immediately while the observer is interacting. Supplemental screening is then conducted prior to the incorporation of these data into the RCC database using an array of techniques. These are primarily applied to real-time data feeds and data that do not become a part of the NCDC archive.

QUALITY CONTROL. Values failing this preliminary screening are evaluated on a daily basis by RCC staff. Based on the spatial distribution of flagged data, knowledge of the ambient meteorological conditions, recent radar imagery, and local knowledge from NWS forecasters and state climatologists, these suspect observations are either accepted as "locally verified" or rejected as erroneous and flagged as such by ACIS.



In cooperation with the National Weather Service, Regional Climate Centers, and National Climatic Data Center

WxCoder » Home » My Observations » Enter

Mon, May 17, 2010 01:58PM EDT | Site Map | Contact NWS | Help | Sign Out

Progress

1. Enter data
2. Confirm
3. Done

On-Screen Help
Click on a question mark on this page to display helpful information.

Observation for
ITHACA CORNELL UNIVERSITY

Date and time of observation
May / 17 / 2010 at 7 AM : 00 ?
Type of observation daily (24 hr values/totals) ? Correction? ☐

Air Temperature
Max temperature x °F help
Min temperature x °F help
At observation x °F help

Precipitation
Precipitation x.xx in help
Multi-day Accumulation 1 days help
Snowfall x.x in help
Snow depth x in help
Snow core x.x in help
Precipitation Time of Occurrence ?

Choose ○ Observed ○ Estimated clear all

Date	AM												PM											
5/16/2010	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
5/17/2010	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11

Supervising WFO
Binghamton, NY ?
Site ID
ITHN6 (SHEF) ?
Site Number
30-4174-10 (COOP) ?
Time of observation
07:00 ?
Lat/Lon
42.44889, -76.44889 ?
Elevation
960 ft

Fig. 5. Interface to WxCoderIII maintained by the WRCC. Access to WxCoder III (http://wxcoder.org/wxcoder/) is limited to Cooperative Network Weather Observers.

This system is designed to ensure that erroneous values do not appear in this initial data stream while also minimizing the potential that valid extremes are excluded as erroneous. This initial data screening is ultimately overridden by more comprehensive quality control of the data by NCDC to ensure synchrony at national and regional levels. However, a system is under development to share the outcomes of this manual screening with NCDC and possibly "protect" certain data values deemed valid by the RCC screening process. This is a critical component in assessing the occurrence of extreme events. NCDC is moving to a new approach of quality control (Durre et al. 2008) designed to minimize errors introduced by flaws in the quality control process itself.

Integration. The RCC databases are unique in their ability to allow integration of NOAA data with that from other non-NOAA networks. This integration is a key component of RCC capabilities in monitoring and climate decision support as it enables RCC analysis software to generate standardized products from multiple data sources. Similarly with regard to monitoring, the availability of stations from different networks enhances data density and improves the ability to capture fine spatial scale details that otherwise may not have been apparent using NOAA data alone. Maps such as that shown in Fig. 6 are used extensively by agencies such as the National Drought Mitigation Center (NDMC), the USDA NRCS, and the NWS in their climate and drought monitoring operations. Similar regional graphics are often created in response to one-time requests related to specific regional events such as rainfall, snowfall, and freeze/frost occurrence. These are often used by the Federal Emergency Management Agency (FEMA) and state and regional emergency management organizations.

Currently, the RCC data structure includes observations from the COOP, CRN, and Automated Surface Observing Network as well as data from the Automated Weather Data Network (AWDN) in the High Plains and Network for Environment and Weather Awareness (NEWA) in New York and New England. Data from the USDA Snowpack Telemetry (SNOTEL) and Community Collaborative Rain, Hail & Snow (CoCoRaHS) networks will be added to the data stream in 2010. Plans to add data from the Oklahoma Mesonet are also being discussed. In addition, the RCCs maintain an archive of Remote Automated Weather Station (RAWS) data for the western United States and a large number of smaller networks.

Climate tools. Integrating data sources also allows specialized decision tools to be run using both user-supported and NOAA data. For instance, the majority of the nation's irrigated corn (71%) and soybeans (more than 20%) are grown within the region served by HPRCC. Water for surface flood irrigation is often provided on a predetermined schedule, but sprinkler irrigation is more amenable to flexible scheduling responsive to recent and ongoing weather conditions. The effective use of irrigation eliminates under- or overirrigation while maintaining crop yields, reducing erosion, preventing groundwater contamination, and promoting water-use efficiency.

The use of climate information to estimate crop water usage allows an irrigator to delay irrigation as long as possible but to provide moisture before any stress begins. A regional network is now used for this purpose. The AWDN presently consists of 200 stations deployed and operated by the states in the High Plains region and surrounding states, with infrastructure and data maintained by HPRCC. The benefit-to-cost ratio for this network in the six-state region of the HPRCC (irrigation costs avoided divided by weather station operating costs) has been shown to be 195 to 1 if only one irrigation is saved per season. Clearly, the cooperation between state climatologists, university extension services, and the HPRCC has been a success story for water users in the region. Other agricultural uses for this network include crop choice, planting date, seeding rates, pest treatments, and fertilizer plans.

Any number of networks can be added to the database. The data structures are flexible and modular, facilitating the incorporation of data sources, provided they are associated with sufficient metadata and transmit reliable observations. All data management and ingest efforts require operational resources, and stations and networks deemed not suitable for applications or lacking sufficient documentation are routinely excluded. Data from private, regional, and state networks are occasionally proprietary. In such cases, the data structures can allow specific users to have access to all individual data values from one of these networks, whereas general users are not provided with access to this subset of stations. However, the data from all networks could be used in blended products, such a regional map of precipitation departure. Priorities specific to data quality can also be set, giving the highest-quality NCDC data preference in default analyses.

COMPUTER INFRASTRUCTURE. The ACIS is at the heart of the RCCs' ability to transform data into information. The modular design of ACIS allows flexibility in developing climate information products. Existing components provide a foundation to expediently address new or evolving information needs. Common data storage protocols allow the seamless integration of data from an array of datasets and observation networks. Integrated quality control techniques and coupled metadata servers complete the framework that enables ACIS to serve a wide array of climate information needs.

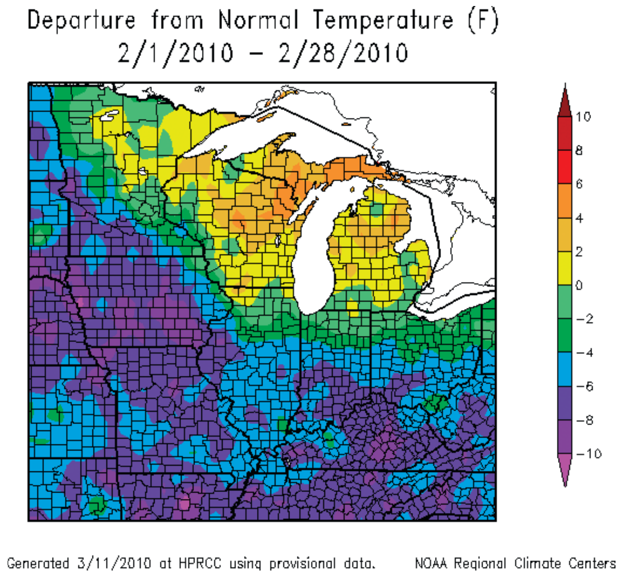


Fig. 6. Example of a temperature departure from normal map generated by ACIS for the midwestern region, showing unusually cold winter conditions. (A suite of ACIS maps is available at www.hprcc.unl.edu/maps/current/.)

Much of ACIS consists of behind-the-scenes software and database structure that provides efficient and reliable access to RCC data products. Only the interfaces to ACIS provide users with a tangible connection to the system, which is by intent essentially invisible to the user. This interface exists in three forms. Perhaps the most visible are the Web interfaces, such as NOWData, where users can access data products by submitting information describing the necessary data parameters. In general, all ACIS products require users to specify a product type, location, variable, and date or time range (Fig. 3).

The Web interfaces provide a user-friendly means of supplying this information to ACIS and likewise provide visually appealing methods of displaying the climate product. However, in many cases they limit the usefulness of ACIS. The Web services interface provides an intermediate level of access to ACIS. This interface is intended for more sophisticated users. It is a particularly useful interface for other climate service providers (e.g., state climatologists) to use the functionality of ACIS in developing their own applications or Web sites or for generating multiple ACIS products (e.g., data summaries for multiple stations). Through the Web service calls, ACIS products can be generated from the command line of a Web browser or from calls incorporated within user-developed software. Such calls return comma-separated output files, allowing users the flexibility to format the product to suit their needs. This interface was recently used by Northrop Grumman Corp. to develop a prototype Global Earth Observing System of Systems (GEOSS) decision tool (Lowther et al. 2009).

A VISION FOR THE FUTURE OF CLIMATE SERVICES. The future holds many opportunities for the RCC program and its partners as providers of climate data, information, research, weather and climate forecasts, and climate projections; particularly in light of recent advances in modeling, remote sensing, the proliferation of specialized state and regional observing systems, increased reliance on sustainability and environmental justice, and the realization that future decisions will be complicated by the nonstationarity of climate conditions. To meet these challenges, the RCCs envision a future that draws upon their accrued expertise, familiarity with user communities, and collaborations with NOAA agencies and programs, other federal agencies, nongovernmental organizations, state climatologists, and private industry. Undoubtedly, the future role of climate services will need to respond to the growing demand for information related to climate change and variability from all levels of government, the business world, and society in general. Because these concerns encompass scales that are most often regional to local, the RCCs are poised to continue providing sector-relevant climate information at the "right" scale for a large range of practical issues. Broadly, the RCCs' vision for their role in climate services can be described by the following four strategic goals:

- lead in the emerging area of operational environmental data management;
- engage with existing and new climate service partners to understand, characterize, and reduce risk associated with climate-related decisions;
- define and implement innovative trust-based and place-based approaches to regional and local climate services in partnership with entities such as the RISAs and state climatologists; and
- provide scientifically sound climate data products that span historical and future time frames and solve climate-related problems that are identified through coordination with relevant stakeholders and partners in the assessment process.

To achieve these broad goals, we envision a system that catalyzes existing regional applied research, data collection, operational product dissemination, and outreach. This is the key to innovation, because it eliminates inefficiencies, allows several groups to take ownership of deliverables, precludes the use of substandard or outdated analyses by individual groups, and allows the depth of expertise of each partner to contribute to the breadth necessary for effective climate services. Such a system allows the specialized expertise of one partner to be tapped by the collective partnership. This is particularly important when dealing with sector-specific issues and models, economic or social science aspects, strategies for effective communication and decision making, or implementation of computer technology enhancements.

Data management. Recent strategic enhancements to ACIS are one example of the RCCs commitment to defining climate services in the twenty-first century through environmental data management. Advances in Web services offer the opportunity for RCCs to operationally link an array of climate data sources and products with tools developed through research and system design efforts at state climate offices, RISAs, and other partner organizations. This would allow, for example, federal, state, and private partners to develop their own customized Web interfaces that are based on RCC-maintained software and databases. The modular design of ACIS can be exploited through the sharing of software modules, contributed, evaluated, and adapted by partners. Data summaries and products generated by these routines and made available via ACIS would serve customized interfaces adapted to suit specific user and provider needs.

As an example of such an infrastructure, the increasing frequency of drought in the southeastern United States during the last few years has increased the demand for water-related information at SERCC and at state climate offices throughout the region. In close cooperation with SERCC and local water managers, the Carolinas RISA developed a set of tools so that the managers could analyze the past and current drought situation in a way that fosters their decision-making tasks (Carbone et al. 2008). This RCC-RISA partnership provides the infrastructure, data feeds, and interfaces that allow up-to-date, day-by-day analyses whenever required; leverages the collective strengths of the partners; and revolutionizes the way in which research is transitioned to operations. Too often, research code is left to languish, because it is not developed for the speed and memory efficiencies required for operational use.

Although tailored to the Southeast, the system is currently being expanded to encompass the whole of the East Coast and, increasingly, some western states. Without a standardized infrastructure for climate data analyses, mapping, time-series analyses, etc., such an expansion would be cumbersome.

Regional and local climate services are already transitioning from a dependence on one or two national datasets to a demand for location-specific data from an expanding set of data sources, increasingly of regional or local origin. To remain ahead of this trend, the RCCs have expanded their database capabilities to become regional repositories of in situ meteorological datasets from state, local, and non-NOAA federal sources while maintaining their role of providing standardized products based on NCDC daily datasets. Working with these partners, the RCCs anticipate development of novel hybrid datasets that combine the veracity of quality federal, state, and local in situ observations with the enhanced spatial density of data provided by remote sensing platforms and output from meteorological and climatological models. The RCCs do not intend to duplicate existing archives of these gridded datasets but rather, by concentrating on station-based surface observations, provide tools and climate products that are rooted in such unique blended datasets and make these data products readily available to users in both public and private sectors. NRCC and MRCC high-resolution degree-day data recently were used to guide state and federal responses to the discovery of the invasive pest the emerald ash borer in New York.

Engaging climate service partners and users. Data infrastructure is necessary for the RCCs to excel in the area of environmental data management; however, it is not the sole component. To be successful, the RCCs are prepared to leverage their positions within major research universities to conduct applied research, link sector-specific models to dynamic climate data, and formulate the climate databases necessary for users to take advantage of the expanding suite of data, climatological model output, and research results that end users typically find inaccessible or cumbersome to access. In this role, we expect to capitalize on colleagues in disparate disciplines, the latest innovations in database and software design, and research in risk communication and conveying uncertainty that will emerge from closer collaboration with the RISA program. Likewise, the location of many RCCs and state climate offices at land-grant universities provides a ready-made mechanism for transitioning research to operations and to an academic system that expects and rewards this type of outreach. Such an environment facilitates the collaboration of physical and social scientists that is required to develop and provide useful and relevant environmental data management and climate decision tools.

Innovative local climate services. One of the strongest assets of the current RCC, RISA, and AASC programs is their connection to a diverse array of stakeholders representing numerous economic sectors, private businesses, nongovernment organizations, and state and local governments. Existing RCC partnerships, particularly with the Cooperative Extension System, provide a conduit to climate data users in every U.S. county. It is our plan to expand upon these existing connections, providing a system of stakeholder engagement that extends from the local level to the states, through the regions to the national level. These connections will provide a mechanism by which climate service gaps can be identified. They also provide a springboard for quantifying the value of climate services and a network by which products and information can be disseminated to the local level.

Traditionally, this model has been very effective, as static climate data products and publications were often developed and disseminated via such collaboration. As we progress in the twenty-first century, the RCCs view a new model of dynamic decision tools that replaces the static, primarily mean-based tools of the past. To facilitate this needed paradigm shift, the RCCs plan to exploit the sector-based ties and expertise provided by their land-grant colleagues, RISAs, and the state climatologists.

Climate change assessment and adaptation. Moreover, the RCCs are poised to work with their established stakeholders to begin to answer requests for new types of information that rely not solely on the historical climate record but also on projections of the climate conditions into the future. RCC climatologists are already fielding such requests. Adaptation activities for future climate change will be based in large part on understanding how climate currently impacts various sectors and how these sectors utilize climate data and information in their decision making and planning. Regional-level workshops hosted by RCCs have already begun to elucidate the types of products, information, and tools that specific stakeholders need to address the challenges of climate change. Conducting such regional workshops directly addresses key recommendations regarding the understanding of climate change impacts, educating decision makers, and building adaptive capacity (Karl et al. 2009).

Most if not all of the data, tools, and products currently provided by the RCCs can be used or modified to support climate change assessment and adaptation activities. For example, a current crop yield model could be used to plan for adaptation to climate change, providing outcomes for different scenarios of temperature, precipitation, and other climate-related inputs into the model. Adaptation strategies may call for modifications to existing infrastructure, whereas for others a risk management approach may be the best way to deal with climate change. These decisions need to be made based on the available data and with knowledge of the uncertainty about future climate change. The stakeholder-driven development that fostered the evolution of the RCCs has proven to be the foundation of regional climate services and will continue to be critical as we face the challenges of climate change. Adaptation and assessment will be most effective when stakeholders are engaged, priorities are established, and implementation is monitored and reviewed. The RCCs work hand in hand with stakeholders to provide the climate data and information important to their needs.

CONCLUDING THOUGHTS. A rich 25-yr history has allowed the local to regional climate services provided by the RCCs to evolve into an efficient, stakeholder-driven, nimble, and technologically advanced program. This experience provides support for several of the key features cited for effective climate services at the national level, including partnerships across public, private, and academic sectors (Dutton 2002); the sharing of technology and innovation and their ultimate transition to operations (Miles et al. 2006); stakeholder-driven development (NRC 2001); and the provision of decision tools (Miles et al. 2006).

By teaming with state climatologists, RISAs, federal and state agencies, and private partners, the RCC program is poised to respond to user demands for more sophisticated and expanded climate services. Addressing the climate challenges of the twenty-first century requires the infrastructure, outreach, applied research, and operational services that have characterized the RCCs since their inception.

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