

## Chapter 6

### The ARM Southern Great Plains (SGP) Site

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#### 1. Introduction

At its very core, the Atmospheric Radiation Measurement (ARM) Program's objective was to make a wide range of atmospheric measurements that would support the science needed to improve the treatment of clouds and atmospheric radiation in global climate models (e.g., Stokes and Schwartz 1994; Ackerman and Stokes 2003; Ellingson et al. 2016, chapter 1; Stokes 2016, chapter 2). Early ARM planning indicated that this ambitious objective would require the establishment of several comprehensive measurement facilities in key climate regions across the globe (Cress and Sisterson 2016, chapter 5). Further, it was clear that one of those facilities should be placed in a mid-continental, midlatitude location in the Northern Hemisphere, because of the importance of those extensive areas

for the functioning of the global climate system and ultimately for society through crucial agricultural production and water resources (U.S. Department of Energy 1991).

The necessity for ARM to have its first and most comprehensive measurement site in a midlatitude and mid-continent location had a strong meteorological basis. Such locations were considered to experience the broadest range of cloud and atmospheric state conditions because of their rich variety of migratory disturbances and air masses along with strong diurnal and annual cycles of surface and atmospheric conditions. The obvious choice of the central United States in the above context stemmed from its quasi-uniform surface conditions and avoidance of terrain complications, along with its logistical simplicity that involved ease of access, proximity to sources and routes of supply, and availability of troubleshooting expertise (Barr and Sisterson 2000).

The Southern Great Plains (SGP) site went from an idealized concept to reality in a very short period of time in the 1990s. This chapter describes the site, some of the people who made it happen, the logistics of building up the physical site, and some of the more unique scientific studies that have been made with the SGP observations.

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Dr. Fred Luther was one of the motivating forces that led ultimately to the establishment of the ARM Program (Ellingson et al. 2016, chapter 1; Cress and Sisterson 2016, chapter 5), and as such the SGP site was dedicated in Luther's name in 1992. The dedication plaque reads "During his all-too-short career, Dr. Luther made many outstanding contributions to the field of atmospheric research, particularly to furthering the understanding of atmospheric radiation and its interactions with clouds, aerosols, and gases. Talented individuals, researchers, and scientists join here to promote man's understanding of the physical processes that make his environment." This is a succinct statement of the purpose of the SGP site (and all of the ARM sites).

## 2. Site selection

### a. Southern Great Plains locale

Initially, three "similar but different" candidate locales were identified in the central United States (appendix A; U.S. Department of Energy 1990): 1) a Midwest locale that included Illinois, Indiana, western Ohio, northeastern Missouri, and eastern Iowa; 2) a southern Great Plains locale that initially spanned northern Texas, Oklahoma, Kansas, and eastern Colorado; and 3) a northern Great Plains locale that extended across Kansas, Nebraska, North and South Dakota, and the eastern halves of Wyoming and Montana. A preliminary assessment favored the Midwest locale because of its greater range of surface energy fluxes and pollutant aerosol variation that can influence cloud optical properties. Crucial logistical issues in the Midwest locale arose that diminished its attractiveness. These issues included the use of airspace for aircraft and balloons, operation of lidar (some non-eye-safe) systems, and access to appropriate radio transmission frequencies for operations and communications. Furthermore, the scientific advantage for the Midwest locale over the other two locales was small. There was a clear recognition of advantages in shifting the selection to either the northern or southern Great Plains related to superior logistics and potential synergisms with other programs or facilities that were or ultimately would be in place. The SGP was chosen because of its considerably greater potential for synergism.

There were several synergistic opportunities that led the ARM Program to favor the SGP site. Briefly summarized, these included the following:

- The National Oceanic and Atmospheric Administration (NOAA) Wind Profiler Demonstration Network (WPDN; Smith and Benjamin 1993; Barth et al. 1994; Ralph et al. 1995) would provide profiles of wind direction and speed to altitudes through the depth of the troposphere with a temporal resolution of 15 min

at sites located in the central part of the country, with its densest cluster in Oklahoma and Kansas.

- The Oklahoma Mesonet (Brock et al. 1995) was beginning to install its then 109-station network of instruments to provide continuous temperature, wind speed and direction, pressure, humidity, and other meteorological data for long-term climate studies across the state of Oklahoma, and could potentially be used to augment ARM data for a higher density of surface measurements.
- The developing National Weather Service (NWS) Weather Surveillance Radar (WSR-88D) Doppler radar network and its proposed facilities (Crum and Alberty 1993), which had radars located in a manner that would provide almost complete areal coverage over the SGP locale.
- The Tropical Rainfall Measuring Mission (TRMM; Simpson et al. 1996) satellite would be a valuable source of remote sensing data on clouds and precipitation. Because the satellite's orbit was designed for tropical systems, it was in a 35° inclination orbit, which means it was able to collect data between 35° south and 35° north. Thus, its orbit would permit data acquisition over a significant amount of the SGP site (Kummerow et al. 1998).
- The First ISCCP Regional Experiment (FIRE) program had conducted a field campaign in southeastern Kansas (Coffeyville) in the late 1980s to study cloud radiation feedback in cirrus clouds (FIRE-Cirrus) that provided invaluable insights and background for ARM instrumentation and facilities (Ackerman et al. 1990).
- Project Storm-Scale Operational and Research Meteorology (STORM)-Fronts Experimental Systems Test (STORM-FEST) was planning a field campaign in the spring of 1992 to study mesoscale convective complexes in the Southern Great Plains during the spring thunderstorm season, providing an early opportunity for collaboration (Szoke et al. 1994).
- A GEWEX Global Continental-Scale International Project (GCIP) was planned for 1994 and was expected to take advantage of the STORM deployment in Oklahoma and Kansas as well as watershed studies in Oklahoma (Lawford 1999).

The SGP was given the highest priority as the first ARM site and received the earliest development support from the ARM Program. This decision was driven primarily for the ease of access to the site (relative to the other sites being considered for the ARM Program in the tropics and Arctic). Furthermore, the high density of the vertical atmospheric structure data from the WPDN and the high density of surface characterization sites from the Oklahoma Mesonet were extremely attractive.

In addition to the synergistic value of collaborating with other research programs and the ease of access, there were

two additional significant considerations related to the SGP locale, namely airspace and National Environmental Policy Act (NEPA) constraints. A primary concern was the potential for airspace restrictions over potential sites; although routine aircraft measurements initially would be cost prohibitive, short-term intensive operations periods or field campaigns were likely to use aircraft. Limitations of the airspace for scientific missions at all altitudes would be a critical factor for selecting specific site locations. Over much of the SGP locale, Vance Air Force Base had a restricted airspace for pilot training. As would be learned, Vance managed their airspace by dividing their controlled airspace into specified blocks. After tentative siting of the SGP Central Facility (CF), discussions with Vance resulted in an agreement to allow the airspace block over the site to be used by ARM aircraft (and to “flight-follow” them) during ARM field campaigns as long as it did not interfere with the Vance training mission. There would be occasions when Vance would need to preclude ARM use of the airspace, but that impact could be almost entirely mitigated by timely planning. This cooperation would turn out to be a major advantage for the SGP site.

The other major consideration for locale selection was the potential for limitations imposed by NEPA requirements. For example, there were specific guidelines not only regarding wetlands and historical sites, but also the impact of sound, light, and instrument frequency on local residents and communities that had to be evaluated. The physical layout and remoteness of the SGP location made addressing the NEPA requirements easier than would have been possible at the other candidate U.S. midlatitude sites.

### *b. The Cloud and Radiation Testbed*

As discussed in [Cress and Sisterson \(2016, chapter 5\)](#), the SGP was selected as the first Cloud and Radiation Testbed (CART) locale. Once the SGP locale was chosen, the actual physical location of the SGP site facilities needed to be identified. In late 1991, Sumner Barr and Doug Sisterson completed an exhaustive study that was officially published much later ([Barr and Sisterson 2000](#)), which identified specific measurement locations, potential ARM Program collaborations, and airspace limitations within the SGP locale.

The primary mission of the SGP site was to meet the data needs of the instantaneous radiative flux (IRF; [Mlawer and Turner 2016, chapter 14](#)) and single-column model (SCM; [Zhang et al. 2016, chapter 24](#)) measurement strategies described in [Stokes \(2016, chapter 2\)](#). The IRF approach required the collection of data at and above the CF on the vertical distribution of radiation and radiatively active constituents of the atmosphere, and on the radiative properties of the lower boundary ([Table 6-1](#)). To that end, vertical profiles and integrated measures of temperature and water vapor

were to be observed at regular intervals with traditional balloon-borne sounding systems, and continuously with state-of-the-science remote sensing systems (microwave radiometer, radar acoustic sounding system, Raman lidar). Cloud cover was to be quantified continuously by contemporary remote sensing systems (day-night whole sky imager, laser ceilometer, and a micropulse lidar system). Profiles of cloud microphysical properties would be derived from the millimeter-wave cloud radar (MMCR) and lidar systems. Components of the surface radiation budget were monitored continuously, in both a broadband manner (with traditional instrumentation) and with spectrally resolved state-of-the-science instruments. Satellite and aircraft (during field campaigns) platforms provided additional information on the vertical distribution of radiation. The near-surface aerosol content of the atmosphere was sampled by an optical particle counter, integrating nephelometers, an optical absorption system, and cloud condensation nuclei counters. Ozone was monitored continuously at the ground level, with vertical profiles obtained during field campaigns. The CF was designed to serve as the figurative center of the SGP site domain and was, in short, the location for the vertically pointing or “soda-straw”-type measurements through the depth of the atmosphere.

The SCM data requirements were another matter altogether. The general approach to SGP data collection for the ARM SCM research effort was through the network of facilities, providing routine data, arrayed over the grid cell area ([Fig. 6-1](#)). However, significant amounts of data were needed from field campaigns designed to support the estimation of large-scale vertical motion and temperature and moisture tendencies due to horizontal advection ([appendix B](#); [U.S. Department of Energy 1996](#); [Zhang et al. 2016, chapter 24](#)). In particular, the SGP SCM data were intended to permit investigation of a wide range of site-specific questions:

- What processes control the formation, evolution, and dissipation of cloud systems?
- What relative roles do the advection of air mass properties and variation in surface characteristics play in cloud development?
- How do these roles vary with season and short-term climatic regime?
- What aspects of cloud development are controlled by the low-level jet, the moisture return flow from the Gulf of Mexico during winter and early spring, the development of mesoscale convective complexes, and frontal passages?
- What are the effects on radiative fluxes of regional northwest-to-southeast gradients of elevation, soil type, vegetation, temperature, and precipitation?
- How important for atmospheric energy transport processes are seasonally varying distributions of aerosols

TABLE 6-1. An abridged timeline of major events at the SGP site.

Time	Event
May 1992	First (borrowed) instrument (a surface meteorological station) deployed at the CF
By Jul 1993	Surface meteorology and radiation and fluxes, 915-MHz radar wind profiler and RASS, 60-m tower meteorology, AERI-00, microwave radiometer, and 60-m tower all operational. Radiosondes are being launched 3 per day Monday through Friday at the CF. Surface meteorology and fluxes instruments operational at 7 EFs
By Dec 1993	Aerosol observing system, 50-MHz radar wind-profiler and RASS, whole-sky imager, and ceilometer installed at CF. Surface radiation installed at the above EFs, and additional EFs installed. Microwave radiometers and radiosonde systems installed at the 3 of the 4 BFs, with 1 sonde per day at the BFs Monday through Friday
Apr 1994	Remote cloud sensing IOP
By Dec 1994	SORTI and MPL installed at CF. All 22 EFs were operational by now. The BFs and CF were launching 4 sondes per day at 0000, 0600, 1200, and 1800 UTC Monday through Friday
Jul–Oct 1995	First SCM IOP conducted, Surface Energy Exchange intensive observing period (IOP), UAV IOP, ARESE-I IOP
By Dec 1995	Radiometer calibration facility operational. New BF at Purcell (BF6) installed. Radiosonde launches at the BFs reduced to 1 per day Monday through Friday. AERI-01 replaced the AERI-00
Aug–Sep 1996	Raman lidar installed, Boundary Layer Experiment IOP, Water Vapor IOP, UAV IOP
By Dec 1996	CIMEL sunphotometer installed, MMCR installed, surface water and temperature sensors (SWATS) installed at most EFs, and radar wind profilers with RASS installed at three IFs
Sep 1997	Mega-IOP (combination of a cloud, water vapor, aerosol, SCM, and UAV IOPs)
Apr 1998	AERIs installed at all 4 BFs
Mar 2000	Cloud IOP, ARESE-II IOP
Sep 2000	ARM-FIRE Water Vapor Experiment
By Dec 2002	Routine launching of radiosondes at BFs stopped
Mar 2003	Aerosol IOP; Cloud IOP; AERIs removed from all four BFs
By May 2006	Whole-sky imager and 50-MHz radar wind profiler decommissioned
By Dec 2009	All observations stopped at the BFs; EFs relocated to make SGP footprint smaller
By Mar 2011	Most ARRA procured instruments (e.g., scanning cloud radar, scanning precipitation radar, Doppler lidar) operational at the SGP
Jun 2011	Mid-Continental Convective Cloud Experiment (MC3E) IOP
Mar 2016	New BFs deployed

and particulates that could emanate regionally from oil refineries and wheat field burning?

Against these requirements, six Intermediate Facilities (IFs, sometimes called “Auxiliary Facilities” in older ARM documentation) were intended to provide three-dimensional mapping of the atmosphere above the CF from about 10 km away. The network of approximately 25 Extended Facilities (EFs) was designed to obtain a distribution of surface meteorological, broadband radiometric, and surface flux variables across the extent of the site domain. The EFs were to be situated in a weighted distribution according to land use rather than a simple geometric pattern. To the greatest extent possible, EF sites were to be augmented by Oklahoma Mesonet measurement sites, which were to be nearly identical in instrumentation. Finally, the four Boundary Facilities (BFs) were to be placed approximately 200 km away from the CF on the sides of the SGP domain to establish the general large-scale motion of the atmosphere passing into and out of the domain—in short, the advection terms. Instruments at the BFs were to provide profiles of the atmospheric state. One EF was to be collocated at each BF, unless an Oklahoma Mesonet site was located within 5 km of the BF.

### 3. Evolution of the SGP site

The SGP site experienced three distinct phases in its evolution:

- 1) The establishment of the site, which took several years as new instruments from the Instrument Development Program (Stokes 2016, chapter 2) took time to mature and be deployed.
- 2) A mature phase that was marked by a reorganization of the infrastructure in the late 1990s and becoming a National Scientific User Facility in 2004.
- 3) A large reconfiguration of the SGP that resulted from input from scientists through a series of DOE-sponsored workshops.

#### a. Establishment of the SGP site

The SGP site was deployed slowly over time due to a wide range of programmatic issues associated with identifying instruments, arranging land leases, establishing the infrastructure at each of the facilities, and (primarily) budget. The first SGP instrument was installed at the CF on 13 May 1992 using a borrowed portable automated meteorological (PAM) station from the National Center for Atmospheric Research



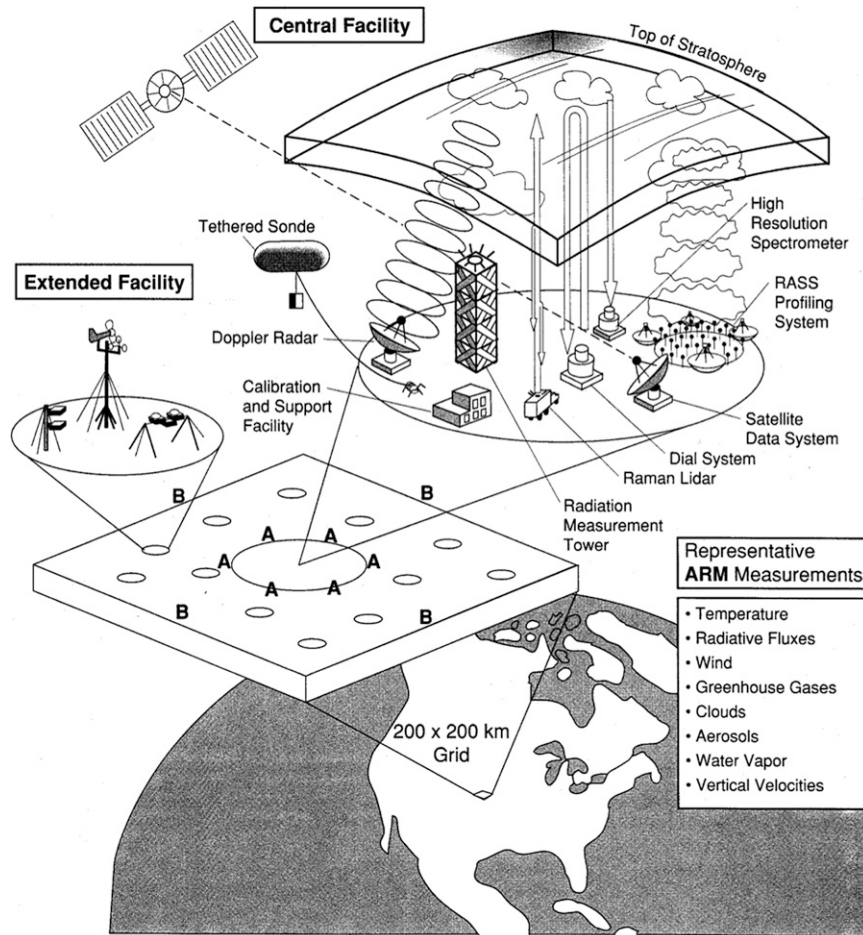


FIG. 6-1. Conceptual implementation design circa 1992 for the 1 Central, 6 Auxiliary, 25 Extended, and 4 Boundary Facilities for the SGP CART Site (after Barr and Sisterson 2000).

(Stokes 2016, chapter 2), and the CF was not deemed to be “complete” until the MMCR (Kollias et al. 2016, chapter 17) was installed in 1996. The four BF, which were critical for providing observations of the advective tendencies over the domain for the SCM experiment (Zhang et al. 2016, chapter 24), were installed between 1993 and 1995, although the Atmospheric Emitted Radiance Interferometers (AERIs; Turner et al. 2016b, chapter 13) were not deployed at these facilities until 1998. Ultimately, 23 EFs (including one at the CF) were established, with the last being installed in 1995. Three IFs were established by 1996. At that time, the SGP site was considered complete and spanned nearly 90 000 km<sup>2</sup> across south-central Kansas and central Oklahoma.

However, before any instruments could be deployed, there were many tasks that needed to be completed first, and these tasks consumed an immense amount of time and energy. The first and most critical phase of establishing the SGP site was the completion and approval of an

Environmental Assessment (EA) that was required by NEPA. The assessment had to identify all instrument locations a priori so that their physical locations could be screened for approval. Figure 6-2 shows the first detailed map of where the SGP facilities were to be located. This assessment was required not only by DOE, but also by the states of Oklahoma and Kansas. No work could begin on the implementation of the SGP site until a “finding of no significant impact” was issued. Furthermore, landowner permissions needed to be obtained before the EA would be approved. As part of this process, the impacts of instrument noise, frequency, and location, as well as impacts from possible aircraft overflights, all had to be documented. Items that needed to be presented in the EA included impacts to wildlife due to instrument towers and guy cables, the amount of soil disrupted by buildings, shelters, pathways, and pads, and more. During the early 1990s, large EAs typically took 12–24 months for approval, but the EA for the SGP established an unofficial record of

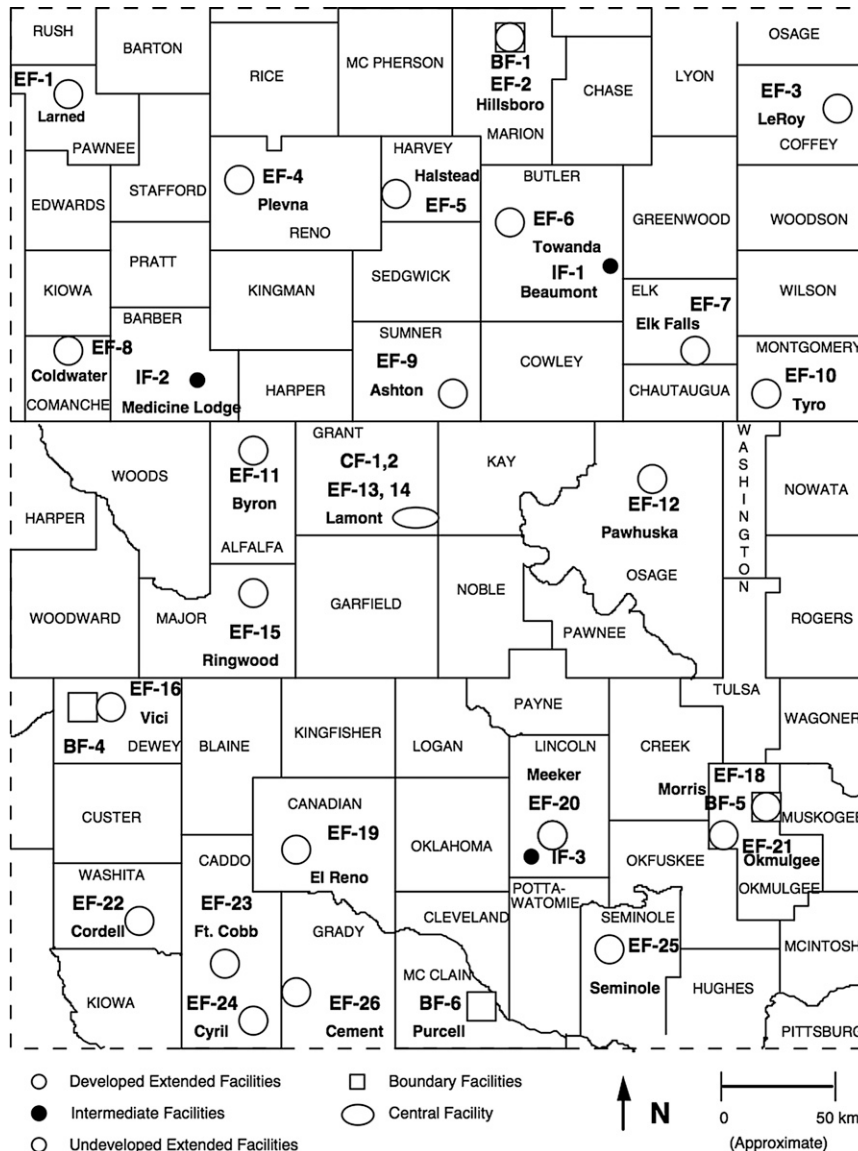


FIG. 6-2. Proposed locations of the SGP Central, Extended, and Auxiliary (name later changed to Intermediate) Facilities circa 1992 (after Barr and Sisterson 2000).

just 108 days between submission and when the permission to proceed was given.

As discussed above, the physical locations for each of the sites needed to be identified before the EA could proceed. So during the summer of 1990, Doug Sisterson and Peter Lunn, who was the DOE ARM Program Manager at the time, spent a week driving in Oklahoma to attend community town hall meetings in the area determined to be the best location for the CF. Meetings were set up with local residents to inform them about the ARM Program and its potential for local residents. Lunn made it clear that ARM was looking for a community that would be receptive to scientific instruments

and the scientists, as well as jobs for local residents. He and Sisterson met local residents in churches, taverns, and city halls. They met people who discussed how the government had come in to “help” them before, in one instance regarding establishing potential nuclear waste disposal sites in south central Kansas in the early 1970s. Therefore, trying to sell the DOE Atmospheric “Radiation” Measurement Program ended up being a challenge, but this challenge was overcome by describing the establishment of ARM as a “sunshine” study. Lunn was gifted at addressing the widely diverse and outspoken local residents, and his honesty and patience won over nearly every person that attended the meetings.

Meanwhile, Jack Shannon from Argonne National Laboratory was asked to help identify locations for all of the Central, Intermediate, Extended, and Boundary Facilities and to contact the landowners to start the conversation about arranging leases for these facilities. Jack was an atmospheric scientist and modeler, but most importantly, was born and raised in Oklahoma, attended the University of Oklahoma, and “spoke Oklahoman.” Jack spent considerable time driving around Oklahoma and Kansas, knocking on doors to find agreeable landowners. Most of his leads were identified during his frequent stops at local Farm Bureau offices; they were instrumental in identifying farmers who were 1) in need of financial assistance, 2) well-known and respected in their local communities, and 3) willing to host scientific instruments and scientists for weather-related research.

Doug Sisterson negotiated the lease for the 160-acre CF (Fig. 6-3) with Vicki and Stan Schulein over a home-cooked, family dinner in their home and officially signed it in May 1992, only days before the first instrument was scheduled to be deployed.

One unique physical aspect of the location of the CF was that it had a hollowed-out shale pit, which was surrounded by a berm on a couple of sides. This was very important as the Program was going to deploy radar wind profilers (RWPs) with radio acoustic sounding system (RASS) units. The RWPs are able to provide profiles of wind, but when the RASS units were activated, the radars tracked the propagating speed of the sound wave, thereby providing a direct measurement of the virtual temperature profile. Two frequencies were envisioned: one at 915 MHz, which was suitable for low-altitude profiling, and one at 50 MHz for profiling in the middle-to-upper troposphere. These sound waves emitted by the two units sounded like a high-pitched whistle and a deeper warbling, respectively. As part of the EA, the Program needed to ensure that these acoustical instruments did not irritate or harm humans or animals. By placing the RWPs and their RASS units in this depression, the Program was able to meet the EA requirements.<sup>1</sup>

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<sup>1</sup> A public demonstration was required to satisfy the EA. On the day of the event, one of the local farmers came up to the crew that was setting up for the test and wanted to know the exact time the RASS test would start. Then he went down to the pasture where his cattle were feeding. The crew started the test, and the farmer came up about 20 minutes later and asked when the test was starting again. The crew pointed to the RASS, which was warbling away, and the farmer asked if that was all it was? The crew said yes, it would do that for about 10 min every hour or so. He remarked that farm tractors were louder than that. And the cattle never looked up once.

The observational goal of the CF was to provide the most comprehensive view of the overlying state of the atmosphere from surface to tropopause in the world. It needed to be staffed daily and have offices, storage space, and facilities for instrument calibration and repair and to house the site data computer system. The goal was to staff the facility not with on-site Ph.D. researchers, but with local personnel who had a basic skill set that, after training, documentation, and oversight, would enable them to become skilled technicians. It was envisioned that the on-site technicians would learn both by experience and with guidance from Instrument Mentors (Cress and Sisterson 2016, chapter 5), who were to be on site as needed. The technical staff would service CF instruments daily and would visit all other facilities once every two weeks. Part-time staff were hired at the BFs to conduct routine radiosonde launches, and more frequently when those facilities were launching balloons in support of field campaigns. This model proved to be an effective approach both scientifically and economically. Hiring and training people from the local community exceeded expectations and the SGP site became seen as a welcomed neighbor. The on-site SGP staff grew as site activity grew. By 2010 the site employed about 30 staff, making it the third largest employer in Grant County, Oklahoma.

The distribution of the EFs in the original idealized ARM planning illustrations indicated a uniform geometric pattern. In reality, it was determined that the distribution of these sites would be better sited scientifically if they were distributed by land use category. The primary land use classification throughout the SGP area was agriculture and pasture with a small portion characterized as forest. In addition, a significant northwest-to-southeast gradient in both temperature and precipitation (lower to higher) further impacted siting decisions (Fig. 6-4).

The instrumentation at the IFs was envisioned to include scanning instruments (e.g., atmospheric radars), instruments with a wide field of view (e.g., whole-sky imagers), or instruments that would provide a wider view of the atmospheric state in the vicinity of the CF. In 1996, 915-MHz radar wind profilers with RASS units were installed at the IFs to provide wind and virtual temperature profiles as well as boundary layer height measurements around the CF. The continuous measurements coupled with the detailed CF radiosonde information increased the view of the atmospheric state from “soda straw” to a 4D view on the order of 15–30 km.

Instrumentation at the BFs was initially limited to a balloon-borne sounding system, a ceilometer, and a microwave radiometer; however, these facilities were



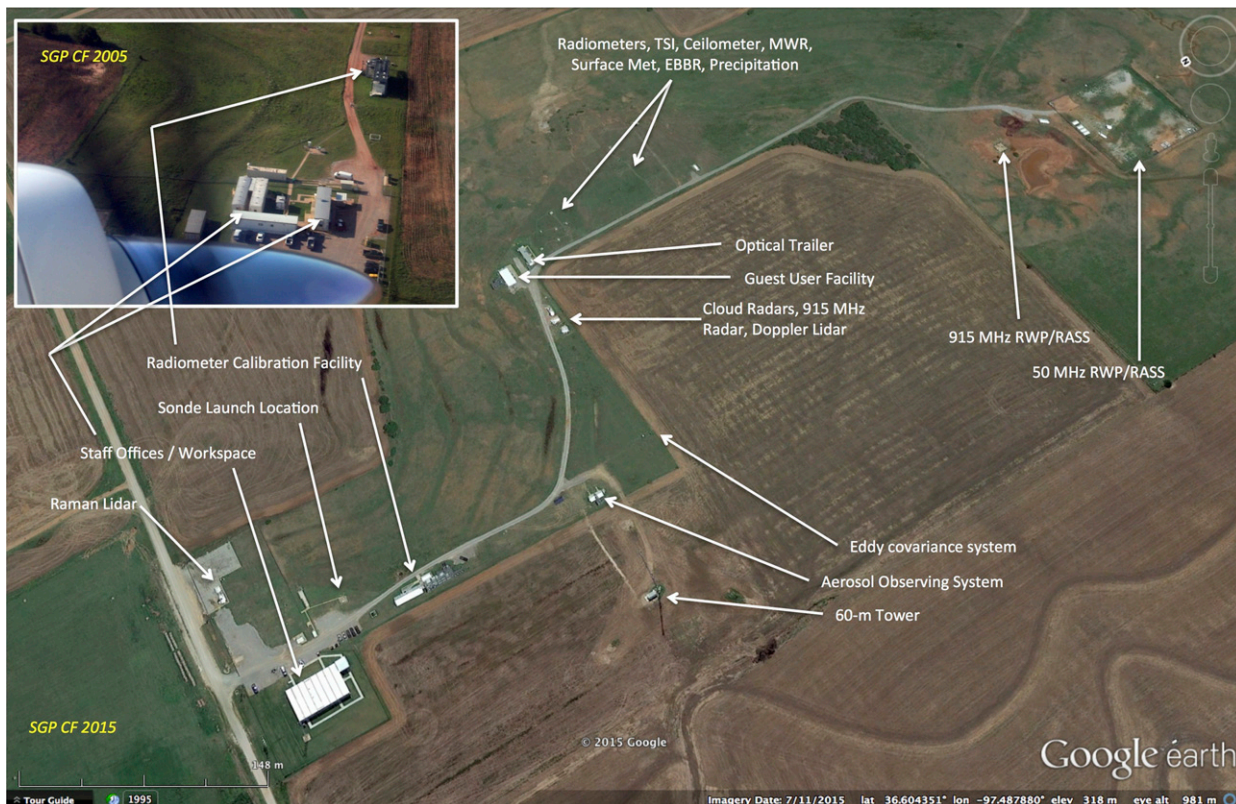


FIG. 6-3. Photo of the SGP CF in 2015 with the locations of some of the observing systems indicated. North is to the lower left. The 915- and 50-MHz radar wind profiler (RWP) and RASS locations on the upper right of the image are no longer used; the 50-MHz system was retired and the 915-MHz system was moved next to the cloud radars. The inset photo, taken in 2002, shows the mobile homes that were used for the primary working spaces for the SGP staff. (Photo from Google Earth, downloaded December 2015. Inset photo courtesy of the ARM Program).

later augmented with AERI systems. These instruments provided for wind, temperature, and water vapor profiles on which to base estimations of the lateral fluxes of moisture and energy into and out of the SGP domain, along with the divergence and tendencies of atmospheric properties for that volume; these observations were required by the SCM measurement strategy.

Site personnel and scientific oversight were identified quickly. Doug Sisterson was selected as the SGP Site Manager in late 1990. Jim Teske, a retired Operations Manager for the NOAA WPDN, and David Breedlove, who provided technical support for the WPDN, became the first on-site staff at the SGP site and were based at the CF. Teske's communication and configuration management skills, commitment to safety, knowledge of instrumentation, and experience as a U.S. Navy officer contributed significantly to the early success of the SGP site in his role as On-Site Operations Manager. Together, Teske, Breedlove, and Sisterson identified other local talent to join the SGP operations team to maintain and operate the site.

One of the really impactful activities at the SGP site was the early implementation of a safety program. During site implementation, the smallest of incidents could have caused a shutdown or, worse, crippled the deployment with ripple effects to other parts of ARM. Monte Brandner of Argonne National Laboratory not only provided oversight for the overall construction of the SGP, but also implemented a Continuous Quality Improvement Program that mandated inspections of instruments and facilities to evaluate the adequacy of the communications equipment, site structures, and procedures being used by the SGP operations team. These activities helped reveal potential issues before they became problems and really illustrated the benefits of an integrated safety management effort for a field program, especially for a long-term program like ARM.

The ARM Program was established to do science, and there was a genuine desire to keep scientists integrated with the operations that were occurring at each of the sites. Scientific oversight of the SGP site was established in 1992 when Peter Lamb at the University



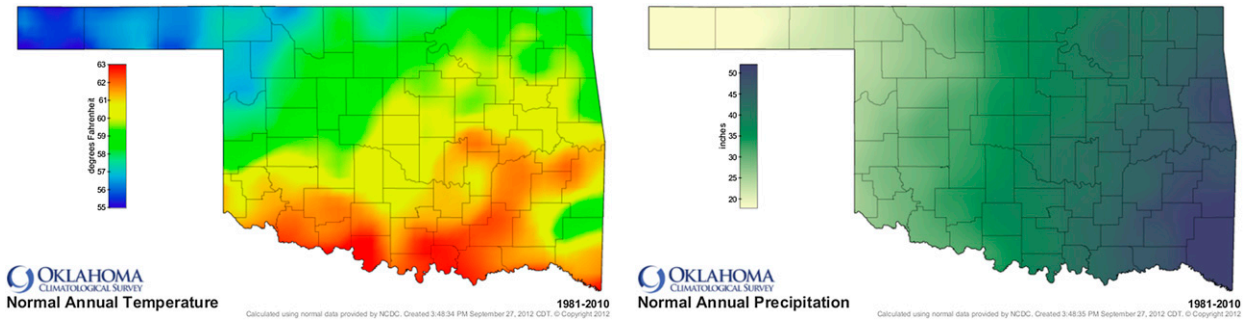


FIG. 6-4. Annual mean values of the (left) air temperature ( $^{\circ}\text{F}$ ) at 2-m height and (right) precipitation (in.) from 1981 to 2010. Images courtesy of the Oklahoma Climatological Survey.

of Oklahoma, which is located about 100 miles south of the CF, was selected to serve as the SGP Site Scientist. Pete Lamb's Site Scientist Team and the Site Manager wrote a Site Scientific Mission Plan every six months from 1993 through 1999 (Schneider et al. 1993a,b; 1994a,b; Splitt et al. 1995; Pepler et al. 1996a,b; 1997a,b; 1998a,b; 1999a,b; 2000) that detailed priorities for scientific activities, summarized scientific goals, described new instrumentation, outlined field campaigns, and listed upcoming expectations for the next six months. These reports<sup>2</sup> are rich with the details of the development of the SGP site and are available through the ARM Program website.<sup>3</sup>

The deployment of instruments at the SGP site was not done at once, but was phased over many years with the site being considered fully instrumented by late 1996 by Tom Ackerman (who was the second ARM Chief Scientist). Table 6-1 provides an abridged timeline of the development of the infrastructure and deployment of instruments at SGP, as well as some of the more significant IOPs. The slow deployment of instruments to the SGP site was due in a large degree to the time it took for the Instrument Development Program (IDP; Stokes 2016, chapter 2; Cress and Sisterson 2016, chapter 5) to provide the robust, hardened instruments needed for ARM's operational paradigm. Almost all of ARM's IDP instruments were initially deployed and evaluated at the SGP. These IDP instruments provided truly unique (especially in the mid-1990s) measurements for

atmospheric science, and are now an important part of the core instruments seen at almost every ARM site. These instruments include the AERI (Turner et al. 2016b, chapter 13), the world's first automated Raman lidar (Turner et al. 2016a, chapter 18), the multifilter rotating shadowband radiometer (Michalsky and Long 2016, chapter 16), the micropulse lidar (Campbell et al. 2002), and the millimeter cloud radar (Kollias et al. 2016, chapter 17). Each time that a major IDP instrument was deployed initially at the SGP site, an IOP was conducted to bring other similar research-grade instruments to the SGP to help evaluate the abilities of the new IDP-developed instrument. The instrument intercomparison effort was a large component of many of the IOPs that occurred at the SGP before 2000. However, today the focus has largely changed, wherein instrument developers bring newly developed instruments to the SGP in order to characterize them relative to the operational (and well understood) ARM instruments.

#### *b. The mature SGP site*

By the late 1990s, it was clear that ARM was entering a new phase. The various sites were largely established (with the exception of the TWP site at Darwin, which was to be installed in 2003; Long et al. 2016, chapter 7) and ARM no longer was faced with a hurried need to field instrumentation and race to meet short-fuse deadlines. DOE instigated a formal review of the ARM Infrastructure in mid-1999, and this review would result in an internal reorganization of the Program's infrastructure (Cress and Sisterson 2016, chapter 5).

This reorganization shifted the ARM Program to a longer-term operational paradigm involving a more formalized infrastructure to ensure overall Program efficiencies. Steps were taken to make the various ARM sites and facilities more uniform in both instrument operations and procedures used to process, document, and handle the data. An ARM Operations Manager for all sites was established, and Doug Sisterson assumed

<sup>2</sup>These reports every 6 months were no longer required by ARM Program management after mid-2000, and hence the reports were no longer produced.

<sup>3</sup>Many of the early reports published by the ARM Program were produced only in hardcopy. Most of these have since been re-scanned into PDF format and placed upon the ARM web page, and can be found using the search engine on the "publications" tab of the ARM web page <http://www.arm.gov>. However, any ARM report can be retrieved by sending an e-mail message to [info@arm.gov](mailto:info@arm.gov).

this role. James Liljegren, who was the original mentor for the microwave radiometers in the Program and heavily involved in many of the initial SGP activities, replaced Sisterson to become the second SGP Site Program Manager; he held this role until 2005. During this time, Liljegren's main focus was to formalize the processes that dealt with configuration management (such as storing spare instruments and components, arranging for localized instrument repairs, improving procedures for instrument calibrations, and developing better defined roles and procedures for Instrument Mentors and on-site technical support and their interactions), improved operational efficiencies particularly regarding support for field campaigns, and tighter budgeting for leaner economic times. One significant improvement made at the SGP during Liljegren's tenure was the construction of the building with a stable observation deck to support guest scientists and their instruments during IOPs; this facility was used heavily during the 2003 Aerosol IOP (McComiskey and Ferrare 2016, chapter 21).

In 2004, Jim Teske retired as the SGP on-site Operations Manager and was succeeded by Dan Rusk, who assumed the role through 2011. John Schatz, who had been the full-time on-site SGP Safety Officer since 1993, became the third on-site Manager to date. However, the core operations and engineering staff at the SGP site have remained relatively constant over the decades. This stability has benefitted the Program tremendously, because the SGP staff have developed incredible expertise with the various ARM instruments and have developed a different set of skills that complements those of the instrument mentors nicely.

In 2004, the infrastructure component of the ARM Program was designated a DOE Biological and Environmental Research (BER) Scientific User Facility and became known as the ARM Climate Research Facility (ACRF; Ackerman et al. 2016, chapter 3). From the mission statement, the ACRF "provides the climate research community with strategically located in situ and remote sensing observatories designed to improve the understanding and representation, in climate and earth system models, of clouds and aerosols as well as their interactions and coupling with the Earth's surface." The SGP was the flagship of ACRF and continues to be one of the key sites for long-term measurements of radiative fluxes, cloud and aerosol properties, and related atmospheric properties. This change, along with the relatively easy access by the scientific community to the SGP due to its location in the center of the United States, has resulted in a large number of small IOPs conducted at the SGP site that have focused on a huge range of topics (see [www.arm.gov/campaigns/table](http://www.arm.gov/campaigns/table) for a full listing of IOPs conducted at each ARM site).

After about a decade of operations at the SGP, the cost of operating aging instruments was starting to increase. In addition, there was a strong desire by the ARM scientific community to continue to add new instruments to the SGP site that would keep ARM at the forefront of climate observations. Therefore, ARM formed the instrument "Sunset Committee" that was charged with evaluating the scientific utility against the operational demands of various instruments to determine if any of the current ARM instruments could be retired, thereby providing funding that could be used for other instruments. This determination proved to be a rather difficult and emotional task since researchers were used to the data from instruments they knew well (including their quirks) and retiring (or "sunsetting") of instruments was a new concept that was hard to embrace. Ultimately, a few instruments were retired (listed in Table 6-1), but the impact on the operational budget was relatively minimal.

In late 2005, Brad Orr became the third SGP Site Manager and was focused primarily on how the site could be nimbly reconfigured as climate models and research needs evolved. For instance, one question was "Could the SGP footprint be changed to reduce the coarse EF site spacing of the original grid with a finer spacing over an area of  $150 \times 150$  km?" The horizontal resolution of climate models is continuously improving, with typical model grid sizes now smaller than the original size of the SGP domain. The finer resolution of the models required finer resolution of the data inside to domain to identify inhomogeneities across the domain. Furthermore, the original horizontal extent of the SGP required staff to drive many hundreds of miles in order to maintain the full complement of EFs across the domain, which resulted in increased costs to maintain all of these facilities. Thus there was a desire to reduce the size of the domain from a programmatic point of view to save money and effort, but only if this would not have a negative impact on the science.

In an iterative relationship typical to many of ARM's scientific endeavors, a conversation was begun between the SCM community, and in particular Shaocheng Xie, who was the translator supporting that community [see Ackerman et al. (2016, chapter 3) for a description of a "translator"], to see if an optimal reduced-sized SGP footprint could be found. Xie performed a set of variational analyses (Zhang et al. 2016, chapter 24) using data from different subsets of EF locations to determine an optimal array of site locations. Based on Xie's runs, a new SGP footprint was conceived in 2006 and approved in 2007, although the reconfigured site array would take 24 months to complete. As part of this restructuring, the BFs were decommissioned in 2009, and several of the

original EFs in Oklahoma that were farthest from the CF were retired although the EFs in Kansas were maintained. Much of the instrumentation from those sites was used to populate the new denser array of new EFs that were closer to the CF.

### *c. Renewed growth at the SGP site*

In 2007 and 2008, the DOE Program Managers held workshops to obtain community input on scientific problems that ARM should be pursuing and recommendations for new ARM instrumentation and new locales that were needed to address these problems (Ackerman et al. 2016, chapter 3). The timing of these workshops was fortuitous as the American Recovery and Reinvestment Act (ARRA) came into being in 2009 to help improve the U.S. economy after the recession of 2008. However, ARRA desired “shovel-ready” projects in order to jump-start the economy, and the workshop reports (along with input from the ARM scientists that was accumulated through the yearly ARM Science Team Meetings) provided DOE Management the ability to present a cohesive plan on how to greatly upgrade the ACRF to address some pressing scientific problems. As a result, the U.S. Department of Energy’s Office of Science allocated \$60 million from ARRA to the ARM Climate Research Facility. These funds were distributed across the ARM infrastructure, allowing all of the sites to acquire new instruments, improvements to the computational and physical infrastructure, and more.

At the CF, two of the changes were very noticeable (Fig. 6-3). The first was the construction of a modular building at the CF to house the site’s staff. The original buildings used by site staff were single-wide mobile homes that were deployed in 1992; mobile homes were used because at the time the ARM Program was considered a 10-yr program and the site would be decommissioned afterward. However, by 2009 these mobile homes were in very poor shape and more space was required to support the staff needed for the increased instrument complement that would soon be at the site. The new building provided much needed space and comfort, as the mobile trailers were hot in the summer and cold in the winter!

The second obvious change at the CF was the deployment of the scanning dual-frequency cloud radar. Before installation of this radar, virtually all of the instruments at the ARM sites appeared to the untrained visitor to just sit there with the exception of the radiometers on solar trackers or with shadowbands or the anemometers that measure wind speed. The scanning cloud radar gave visitors something to look at while they were at the site.

The ARRA funds also allowed ARM to transition from a constrained soda-straw perspective to a more three-dimensional perspective (Mather and Voyles 2013). The scanning cloud radars allowed the Program to get statistics on the spatial distribution of the clouds, instead of having to rely on the frozen turbulence assumption to convert the high-temporal-resolution zenith observations to spatial statistics. Additionally, four new scanning precipitation radars that operate at longer wavelengths (10 cm and 3 cm) were deployed at the IFs around the CF, providing for the first time spatial measurements of precipitation and allowing dual and triple Doppler retrievals of the horizontal wind field to be derived. Last but not least, ARRA also enabled ARM to greatly improve its ability to measure the size distribution and composition of aerosols at the site, thereby enabling a wide range of research to investigate new aerosol particle formation and growth processes and better understand how aerosols can evolve into cloud condensation nuclei. These new instruments have greatly expanded the science from ARM observations, and were an important component of the process-level research that is at the core of the Atmospheric System Research (ASR) Program that began in 2010 (Mather et al. 2016, chapter 4).

There have also been some changes in the leadership of the SGP site. In 2012, Doug Sisterson resumed overall oversight of the SGP site again, working closely with John Schatz to continue the implementation of the new instruments that started with ARRA. He continued in this role until 2014, when Nicki Hickmon assumed the SGP Site Manager role.

In a sense, the end of the first 20 years of the ARM Program at the SGP is similar to when the ARM Program was just starting the SGP by implementing state-of-the-art instruments and new facilities intended to attack an ever-widening scope of scientific questions. Many of the current challenges are to develop improved methods to operate and calibrate these new instruments, process and distribute the voluminous data that comes from them, and improve the scientific utility of the Program by merging together data from both original and new ARM instruments.

## **4. Scientific contributions**

Between 1992 and 2010, many different scientific and engineering studies had been conducted using data from the SGP site. The topics include characterizing IDP and other instruments; evaluating different water vapor measurements and developing a more accurate water vapor product; improving clear-sky radiative transfer models; investigating different ways to construct an

objective analysis from ARM observations that could be used to drive SCM models; deriving statistics on cloud overlap; characterizing the absorption of shortwave radiation by aerosols and clouds; developing new aerosol and cloud property retrieval algorithms; evaluating cloud and precipitation microphysical parameterizations in SCMs; improving understanding of land surface properties and the impact on the atmosphere above; and much more. These topics are covered in detail in chapters 13 through 27 of this monograph. Instead of trying to summarize all of the scientific advancements made using data from the SGP site, we focus here on one unique aspect of the SGP: its multidecadal record of continuous observations.

One of the motivations of the ARM Program was to provide a dataset that captured all of the major modes of variability in the atmosphere, including diurnal, synoptic, seasonal, and yearly variations. The ARM Program instruments have done exactly this, and several studies have looked at how various geophysical variables have evolved over multiyear periods. These studies include the development of a decade-long dataset that can be used to drive SCM and cloud-resolving models (Xie et al. 2004), a climatology of cirrus and the relationship with atmospheric state (Mace et al. 2006), an analysis of the vertical structure of cloud occurrence and overlap (Mace and Benson 2008), determination of a significant increase in the all-sky downwelling shortwave radiation over the central United States (Long et al. 2009), the variation of aerosol optical depth and Angstrom exponent (Michalsky et al. 2010), the variability in the vertical profile of aerosol scattering and absorption properties (Andrews et al. 2011), a climatology and trend analysis of the downwelling spectral infrared radiation (Turner and Gero 2011; Gero and Turner 2011), and an observational analysis of the surface radiative forcing by carbon dioxide (Feldman et al. 2015). These studies are interesting in their own right, but also provide the foundation for detailed case studies because the conditions of the case study can be placed into perspective with the longer-term climatology.

## 5. Summary

The SGP site has been the observational centerpiece and anchor of the ARM Program since 1992. It represents the scientifically required midlatitude, mid-continental observing facility. It was selected over two other U.S. locales that were similarly attractive from a weather/climate regime standpoint, but the ultimate choice of the SGP site was made due to its substantially greater potential for synergy with other developing state and federal observational networks and research programs.

Entering its third decade, the mission of the SGP site remains the same—to provide a continuous multivariable observationally based dataset that can be used to understand atmospheric processes and to evaluate and improve how these processes are represented in climate models. The transition to a National Scientific User Facility in the mid-2000s enlarged the users to include scientists that were outside the ARM Program and placed new demands on the operational aspects of the site. The merging of the DOE's Atmospheric Sciences Program with the ARM Scientific Program to create the new Atmospheric System Research (ASR) Program together with the Recovery Act funding in the late 2000s resulted in an expanded site, with new instruments to focus on quantifying aerosol processes and the spatial variability of clouds and precipitation (Mather and Voyles 2013). The SGP provides perhaps the most complete and comprehensive set of observations of any of the large-scale atmospheric observatories located around the world.

In 2016, the SGP will transform again by installing new BFs, albeit much closer to the CF than they were before, to support routine high-resolution modeling based on data from the SGP site (U.S. Department of Energy 2014; Table 6-1). This expansion keeps the SGP site and its increasing capabilities at the forefront of the effort to provide the long-term multivariable datasets needed for climate system model improvements. The SGP will continue to evolve to provide the data necessary to address emerging issues of the scientific community. That was its origin, and that is its role.

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