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ATMOSPHERIC RADIATION MEASUREMENT
CLIMATE RESEARCH FACILITY

Decadal Vision Progress Report

Implementation Plans and Status for the Next Generation ARM Facility

June 2016

ARM
CLIMATE RESEARCH FACILITY

U.S. DEPARTMENT OF ENERGY | Office of Science

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Decadal Vision Progress Report Implementation Plans and Status for the Next Generation ARM Facility

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Acronyms and Abbreviations

AERI	atmospheric emitted radiance interferometer
AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement Climate Research Facility
ASR	Atmospheric System Research
ASSIST	Atmospheric Sounder Spectrometer for Infrared Spectral Technology
CIRES	Cooperative Institute for Research in Environmental Sciences
3DVar	3-dimensional variational analysis
DL	Doppler lidar
DOE	U.S. Department of Energy
ECMWF	European Center for Medium-Range Weather Forecasting
ERASMUS	Evaluation of Routine Atmospheric Sounding Measurements using Unmanned Systems
FNL	Final Data produced by the National Centers for Environmental Prediction
GSI	Gridpoint Statistical Interpolation
HRRR	High-Resolution Rapid Refresh
HSRL	high-spectral-resolution lidar
Hybrid-EnKF	hybrid ensemble Kalman filter
ICARUS	Inaugural Campaigns for ARM Research using Unmanned Systems
LASSO	LES ARM Symbiotic Simulation and Observation
LES	large-eddy simulation
MS-DA	Multiscale Data Assimilation
MWR3C	3-channel microwave radiometer
NOAA	National Oceanic and Atmospheric Administration
NSA	North Slope of Alaska, an ARM megasite
PNNL	Pacific Northwest National Laboratory
POPS	printed optical particle spectrometer
RL	ARM Raman Lidar
SAM	System for Atmospheric Modeling
SGP	Southern Great Plains, an ARM megasite
STaMP	soil temperature and moisture profile
TBS	Tethered Balloon Systems
UAS	Unmanned Aerial Systems
WRF	Weather Research and Forecasting

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1.0 Background

The reconfiguration of the ARM facility, formally initiated in early 2014, is geared toward implementing the Next Generation of the ARM Facility, which will more tightly link ARM measurements and atmospheric models. The strategy is outlined in the ARM Climate Research Facility Decadal Vision (DOE 2014a). The strategy includes the implementation of a high-resolution model, initially at the Southern Great Plains (SGP) site, and enhancements at the SGP and North Slope of Alaska (NSA) sites to provide additional observations to support modeling and process studies. Enhancements at the SGP site focus on ground-based instruments while enhancements at the NSA make use of Unmanned Aerial Systems (UAS) and Tethered Balloon Systems (TBS). It is also recognized that new data tools and data products will need to be developed to take full advantage of these improvements. This document provides an update on the status of these ARM facility enhancements, beginning with the measurement enhancements at the SGP and NSA, followed by a discussion of the modeling project including associated data-processing activities.

2.0 Enhancements to the ARM Southern Great Plains site

The first implementation of the combined observation/modeling framework will be at the SGP site. This site offers the most extensive measurement capabilities and so is ideal for developing this capability. Initially, the focus will be on shallow convection. The strategy to focus on shallow convection emerged from the SGP modeling workshop (DOE 2014b) with the intent of starting with a relatively simple problem in which the domain of interest could largely be captured by a large-eddy simulation (LES) model. This emphasis also builds on a recent growing interest in land-atmosphere interactions within the DOE Atmospheric System Research (ASR) community. Activities are underway to have this framework operational in mid-2017. The initial focus of this framework will be on shallow convection as described in the Decadal Vision document; it is expected that future efforts will target other phenomena.

The primary enhancements of the SGP site are designed to support the development of a continuous forcing data set for use with modeling. At the SGP modeling workshop (DOE 2014b), a particularly high priority was identified to implement a network of boundary-layer profiling sites that provide profiles of temperature, water vapor, and winds as lateral boundary conditions for the modeling domain. SGP has installed profiling modules at four Extended Facilities to provide these measurement in addition to the measurements normally obtained at an Extended Facility site (http://www.arm.gov/sites/sgp/E). The profiling modules consist of the following instruments:

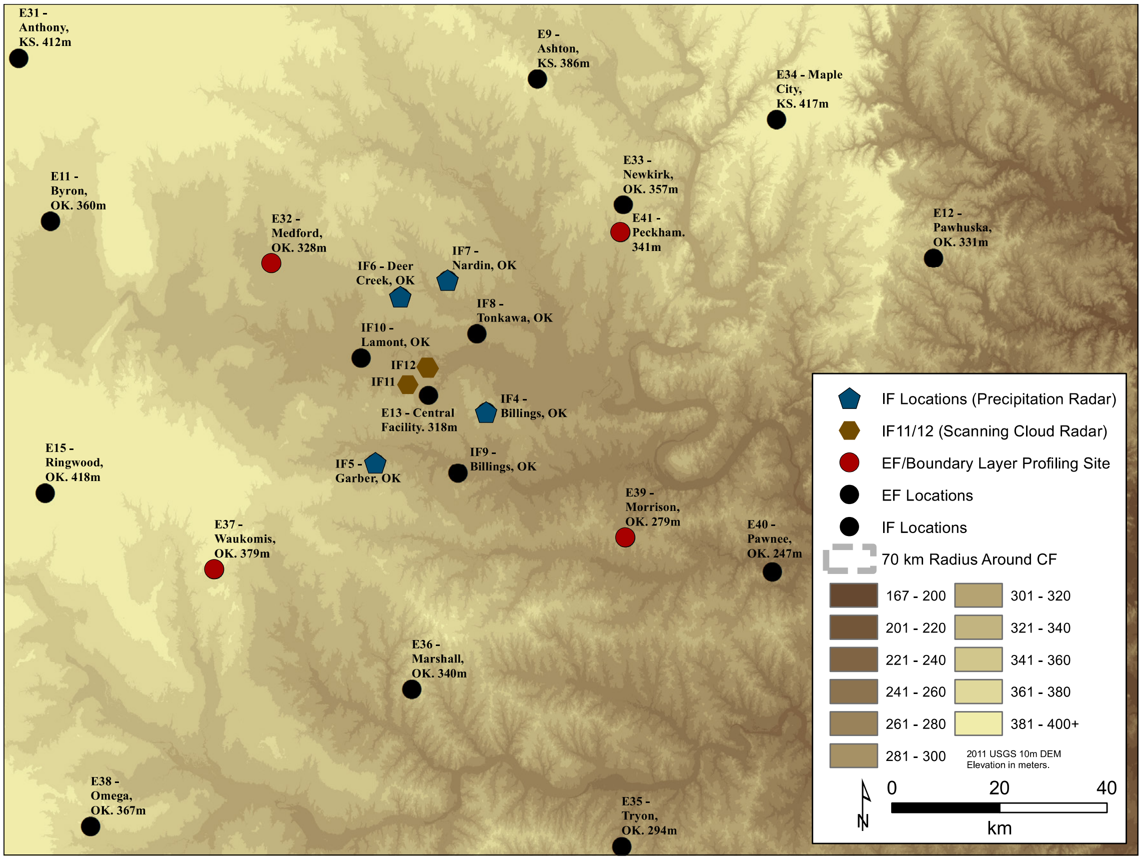

Figure 1. Network of SGP sites. New sites include the boundary-layer profiling sites and the Scanning radars at two new extended facilities (planned for summer 2016).

- Atmospheric Emitted Radiance Interferometer (AERI) or Atmospheric Sounder Spectrometer for Infrared Spectral Technology (ASSIST) (http://www.arm.gov/instruments/aeri or http://www.arm.gov/instruments/assist)
- 3-channel Microwave radiometer (MWR3C) (http://www.arm.gov/instruments/mwr3c)
- Doppler Lidar (DL) (http://www.arm.gov/instruments/dl)

The AERI or ASSIST will be used to derive vertical profiles of temperature and humidity in the boundary layer on a continuous basis using an optimal estimation technique (Turner and Löhnert 2014). Wind profiles will be provided by the Doppler lidar, which will also provide vertical profiles of vertical motion for evaluation. The microwave radiometer has been included to provide information about variability of water vapor in the total column as well as measurements of liquid water path for model validation. The infrastructure for these boundary-layer profiling sites has been installed along with most of the instruments.

The only remaining instrument to be installed is the ASSIST, which is scheduled for installation in July 2016.

Also important are improved measurements of soil moisture throughout the SGP domain. Accurate soil moisture measurements are expected to be important for land-atmosphere interactions that impact shallow convection. Responding to community concerns about the existing soil moisture measurements, which did not perform well under dry soil conditions (DOE 2014b), ARM recently deployed a new array of soil temperature and moisture profile (STaMP) measurements. The new STaMP sensors will provide a better representation of soil moisture over the broad range of this parameter experienced at the SGP.

Aerosol measurements are being enhanced by upgrading the surface aerosol observing system to be consistent with recommendations from the DOE Atmospheric System Research Aerosol Lifecycle Working group and by exploring a method for obtaining aerosol extinction profiles using a three-wavelength lidar technique (Mueller et al. 2015, Mueller et al. 2014). Obtaining vertical profiles of aerosol properties has long been expressed as a need of the DOE aerosol community. To test the lidar technique, a two-channel High-Spectral Resolution Lidar (HSRL) (http://www.arm.gov/instruments/hsrl) was deployed next to the ARM Raman lidar (RL) (http://www.arm.gov/instruments/rl) during the summer of 2015. Those data are being analyzed now to evaluate the potential of a three-wavelength ground-based retrieval. Precipitation measurements are also being improved to provide better and more consistent measurements across all the ARM sites, including the SGP.

To assist in the detection of the small droplets prevalent in shallow continental clouds, the deployment of multiple pairs of high-resolution cameras is also being investigated to apply stereo photogrammetry to mapping the 3-dimensional cloud field (Oktem et al. 2014). Work is underway to develop these photogrammetry systems. Development of cloud products from the stereo camera network are planned to follow once data collection has begun.

3.0 Use of Unmanned Aerial Systems and Tethered Balloon Systems at Oliktok, Alaska

On the North Slope of Alaska, following input from the community obtained during two workshops (Ivey et al. 2013, DOE 2015), the strategy for collecting spatial information about the arctic environment is to use Unmanned Aerial Systems (UAS) and Tethered Balloon Systems (TBS) in conjunction with the third ARM Mobile Facility (AMF3) ground-based instruments at Oliktok. These platforms are expected to provide spatial information about surface radiation and heat fluxes along with vertical profiles of the basic atmospheric state (temperature, humidity, horizontal wind) as well as turbulence, aerosol properties, and cloud properties. In 2016, ARM is ramping up efforts to develop these measurement capabilities at Oliktok through a series of deployments between April and October. These activities include the second phase of the ERASMUS (Evaluation of Routine Atmospheric Sounding Measurements using Unmanned Systems; de Boer et al. 2016) field campaign and an internal ARM activity dubbed ICARUS (Inaugural Campaigns for ARM Research using Unmanned Systems).

The first phase of ERASMUS was held in 2015 and made use of small DataHawk2 UAS to measure profiles of temperature and humidity. The second phase of ERASMUS was held in April 2016, again using the DataHawk2 UAS, but also making use of the Pilatus, configured to carry a Vaisala RS-92 radiosonde package, and a subset of: an SPN-1 shortwave radiometer, a CGR-4 longwave radiometer, and a POPS (Printed Optical Particle Spectrometer) aerosol spectrometer. The two phases of ERASMUS were each set up to be a few weeks long and the experiment was designed to address questions related to the vertical structure of temperature, humidity, and aerosols.

While ERASMUS was a field campaign led by external investigators (principally from University of Colorado—Boulder and the Cooperative Institute for Research in Environmental Sciences (CIRES), ICARUS is the first foray into routine UAS and TBS operations by ARM, using ARM instruments and measurement platforms and processing of measurements using ARM processing conventions. The small Datahawk2 UAS will be flown by pilots from Pacific Northwest National Laboratory (PNNL) and a contract pilot from the University of Alaska—Fairbanks while the TBS will be operated principally by ARM staff based at Sandia National Laboratories. ICARUS is configured as a series of short (few weeks) measurement periods from April through October. While it is not possible to deploy UAS and TBS continuously due to logistical constraints, the repeat deployments will allow sampling of a broad range of conditions at the site. At least initially, this sampling will be restricted to sunlit portion of the year due to the significant challenges associated with operating in the dark and extreme cold of the northern Alaska winter. The UAS platform is once again the small Datahawk2 while the TBS is capable of carrying significantly heavier payloads. Initially, the TBS will focus on the basic atmospheric state, but the plan is to add later the POPS and eventually a turbulence package and a cloud particle imager for the final flights in October. It is currently envisioned that a similar series of measurement periods will be carried out in 2017 and subsequent years.

Small UAS and TBS provide the means to sample the environment immediately surrounding the ARM site but ARM also plans to deploy a much more capable mid-size UAS that will provide the opportunity to carry significantly larger payloads far from the Oliktok site. ARM is in the process of purchasing a NASC Tiger Shark UAS that will provide the capability of carrying payloads of up to 100 pounds, to an altitude of up to 15,000 feet for periods of up to 12 hours. This mid-size UAS combined will provide the capability of sampling aerosol, and eventually cloud properties, along with radiation and a variety of atmospheric state parameters, well out over the Arctic Ocean, thus providing greater context for the ARM measurements.

4.0 The LES ARM Symbiotic Simulation and Observation (LASSO) Project

The 2014 SGP modeling workshop (DOE 2014b) raised many questions about the modeling strategy that should be implemented at the SGP, including which model to use, over what domain, with what resolution, and with what frequency. A recommendation from the workshop was to address these questions and initiate the development of the modeling framework through a pilot project. That recommendation has been followed and the LASSO model implementation project is now midway through its two-year duration. The LASSO implementation plan is described in detail in Gustafson and Vogelmann (2015) and additional information about the project including how to get involved can be found on the LASSO web site: http://www.arm.gov/science/themes/lasso. This section is meant to provide a short summary and status of this work. The LASSO project is quite broad and seeks to implement the workflow described in Figure 1. Described here are several core components specific to the modeling portion of the workflow: development of the model forcing, selection and implementation of the model, organizing the model output, and computational requirements.

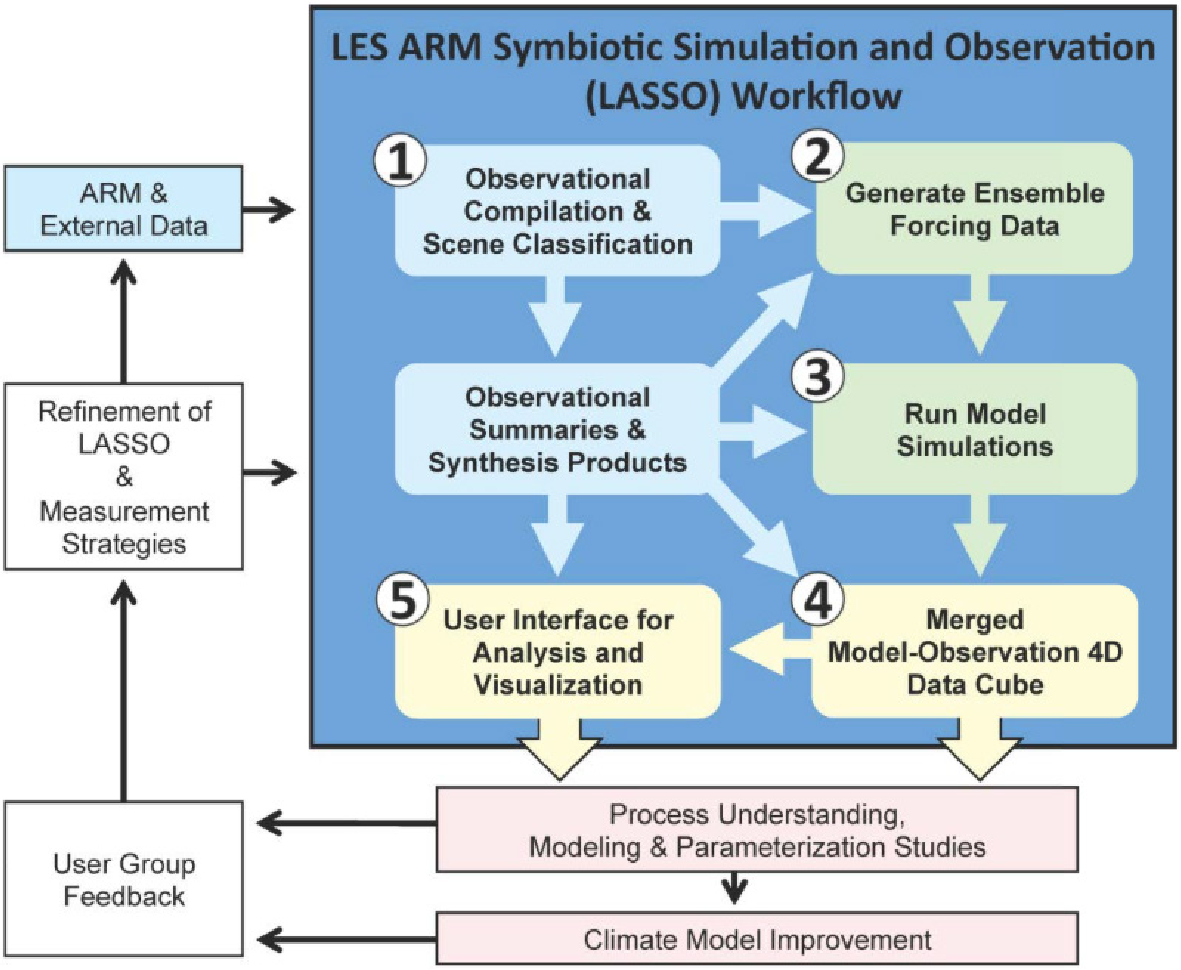

Figure 2. Workflow linking ARM observations and high-resolution model simulations (Gustafson and Vogelmann, 2015).

4.1 Continuous Forcing Data Sets

The purpose of the boundary-layer profiling sites, as well as the enhancements to the soil moisture and precipitation measurements, is to provide continuous measurements that can be used to better define the background atmospheric state for developing the forcing data sets required to initialize and force the LES model. The LASSO project will produce multiple forcing data sets to be used for generating LES ensembles for the SGP region. Along with their use within the LASSO project, these forcing data sets will also be made available to the broader research community for use in their own modeling studies. Three types of forcing have been proposed for evaluation. Others will be evaluated as availability and time permit. Samples of these data sets are being developed for review by ARM staff and the science community. Each forcing selected for ongoing simulations will need to be set up as a separate ARM product for operations after the pilot project. At a minimum, the forcing data sets will be required for any days simulated by the LASSO workflow, though there has been interest in generating these data sets continuously. Discussion will be needed to determine if the forcing data sets should be generated for all days as an added resource for researchers.

The first forcing to be configured is the ARM variational analysis product (http://www.arm.gov/data/eval/29). This is a well-known and frequently used product by the ARM community. For use in LASSO, production of the current ARM product will need to be automated for ingesting into the LES model. Ultimately, automating LASSO in a timely manner will require receiving the variational analysis product within several weeks of real time.

The second forcing will be based on ECMWF (European Center for Medium-Range Weather Forecasting) analyses. This involves taking the gridded ECMWF analyses and converting them into an LES forcing. Prototype scripts have been developed to do this work. Additional work needs to be done to confirm the accuracy of the method, as the ECMWF model has changed since the scripts were developed.

The third forcing is based on Multiscale Data Assimilation (MS-DA) (Li et al, 2013). This basically involves conducting weather hindcasts with the WRF (Weather Research and Forecasting) model using the MS-DA algorithm, and then processing the gridded hindcasts into LES forcing data sets. Initial configurations of MS-DA will use the Gridpoint Statistical Interpolation (GSI) program with a 3-D variational analysis (3DVar) methodology. Once this is evaluated, additional testing will be done with a hybrid ensemble Kalman filter (Hybrid-EnKF) methodology. Testing will be done with different background fields as inputs to MS-DA, such as the FNL (Final) analyses, HRRR (High-Resolution Rapid Refresh), and ECMWF. Data from ARM that will be ingested include radiosondes, the new boundary-layer profiles retrieved at the boundary facilities, and wind profiles from the radar wind profilers at the intermediate facilities. Other data ingested includes satellite information and the standard National Oceanic and Atmospheric Administration (NOAA) operational observation data. Because the new boundary-layer profiles are not yet available, initial testing will be done using profiles from the Central Facility. The ultimate goal is to ingest the boundary facility and intermediate facility data and to use the Central Facility data for model evaluation.

4.2 Model Implementation

The LASSO project is testing two LES models, WRF and SAM (System for Atmospheric Modeling), for conducting routine LES runs at SGP. Work is underway to develop a series of test simulations to evaluate these two options. Elements of this work include configuring the models, comparison of the models to identify pros and cons of each, and developing the software needed to automate running the models. Configuring the models will involve evaluating appropriate physics choices, domain size, grid spacing, boundary-condition methodology, and forcing data sets to be used on an ongoing basis. This will be done using a series of test simulations that compare results for a number of cases to determine optimal choices.

The pilot project will next develop the steps that need to be automated to run the models. This will involve working with ARM software developers to provide them with the knowledge they need to automate the modeling process within the ARM computer ecosystem. The code will be designed to work both on ARM's computers and at other DOE computing facilities, which will both assist with the model testing and provide a means for LASSO users to reproduce the LASSO simulations and variants of them as necessary to further their research.

4.3 Data Bundles

A central goal of the LASSO project and, more broadly, the planned ARM observation/modeling framework, is to more closely link ARM observations with models and the modeling community. The LASSO project is in the process of designing "data bundles" that provide integrated access to model output and observations. The data bundles will consist of observations, large-eddy simulation (LES) model output, processed values (such as from instrument simulators applied to both observations and model output), metrics, diagnostics, and quicklook plots.

The data bundles must provide ease of data discovery, access, and usage. Addressing each of these three areas will minimize barriers for users to use the LES model output and combine it with ARM's extensive observations to achieve their scientific goals. The data bundles will be organized around selected days where LES simulations will be performed, but, in theory, could be extended to work with observational data from non-simulated days.

The process for determining details surrounding the data bundles will require involving a wide range of ARM staff and community members. The overall design and contents will originate within the LASSO project team (using the LASSO funding) in consultation with relevant ARM staff to ensure achievability. The LASSO team will propose the initial implementation based on several to-be-determined use scenarios and with initial beta users. Feedback will be solicited from ARM and ASR researchers to further refine the bundle design.

4.4 Data Discovery

Beyond the design of the data bundles are the means for efficient data discovery and access. The bundles will include metrics that users may search on to find cases that meet their scientific needs. Accessing these metrics involves modifying or replacing the data discovery tool, which currently only allows for variable type searches, with the ability to search on values of the variables. Near-term work is to address this need using pre-computed metrics and quicklook plots. More advanced options are needed to enable users with an interactive ability to examine the data bundles not only within a simulated case but also across different cases for the variables of interest. Exploratory work is being conducted on a NoSQL approach to determine what aspects of the needs it can address. Finally, there are discussions about how to provide users limited access to the data for processing at the DMF to find their cases of interest before ordering the data for downloading from the archive.

4.5 Operating Mode and Computational Requirements

As with UAS operations, operation of the ARM LES model is being characterized as "routine". The specification of what is meant by "routine" in this case is also under discussion; however, it is anticipated that, at least initially, the model will be run for a set of cases that meet target criteria – perhaps 30-60 days over the course of a year. While not continuous, this would represent a significant increase in simulated cases in comparison to the typical mode of running models for a few special cases.

As with the frequency of the simulations, details of the LES configuration are also under discussion. The WRF and SAM models are both being evaluated. The domain size is anticipated to be on the order of 20 km horizontally with a horizontal resolution of 100 m. It is further expected that on the order of 15 ensemble members will be run for each simulation.

These parameters will be reviewed over the coming year, but it is clear that the computational requirements of this modeling system will be significant. For the configuration described above, it is estimated that a computer cluster with on the order of 5,000 – 10,000 cores will be required. ARM is in the process of exploring options for this computational system, which it is anticipated will be set up at the ARM Data Center at Oak Ridge National Laboratory.

5.0 The Next Phase of the ARM Observation/Modeling Framework

The current LASSO pilot study is intended to develop the workflow that will implement routine model simulations at the SGP and support the integration of model output with ARM observations as noted in previous sections. At the end of the pilot study, this framework will be transitioned to an operational state. The nature of that operational state, including the questions raised at the original SGP workshop such as how often the model will be run and with what configuration, will be worked out through development activities and conversations with the science community over the next year. Once the framework is transitioned to the operational state, the model will be run within the ARM infrastructure, much like advanced data products are currently processed and data will be made available through the mechanisms that are being developed now through the pilot project. It is also likely that the framework will continue to be refined once this transition occurs.

As noted previously, the LASSO modeling framework is being developed first for application to shallow convection at the SGP but it is expected that, once the framework has been developed, it will be applied to other meteorological regimes, such as deep convection, and at other ARM sites. The current plan is to next apply the LASSO framework to the North Slope of Alaska region where the Barrow and Oliktok sites constitute a second distributed megasite; however, this plan needs to be assessed with consideration to scientific impact and implementation constraints. A recent NSA workshop (DOE 2015) included discussion of possible modeling strategies in that region; however, the NSA will present a number of new challenges for the application of routine modeling and it is expected that over the coming year, there will be discussions between ARM and the science community regarding what site and meteorological regime represent the best next step for ARM routine modeling.

6.0 For Additional Information

In addition to the referenced background material, additional information related to the activities described in this document can be obtained by contacting the following individuals.

For general information, contact:

Jim Mather, ARM Technical Director (Jim.Mather@pnnl.gov)

or

www@arm.gov (questions will be routed appropriately)

For questions about development at the SGP, contact:

Nicki Hickmon, SGP site manager (nhickmon@anl.gov)

For questions about UAS activities including the Datahawk and the Tiger Shark, contact:

Beat Schmid, ARM Aerial Facility manager (beat.schmid@pnnl.gov)

For questions about TBS activities, contact:

Mark Ivey, Manager for the NSA and Oliktok site (mdivey@sandia.gov)

For questions about LASSO including the model configuration and supporting data sets, contact:

Bill Gustafson, LASSO principle investigator (william.gustafson@pnnl.gov)

or Andy Vogelmann, LASSO co-investigator (vogelmann@bnl.gov)

And for questions about ARM computing capabilities, contact:

Giri Prakash, ARM Data Services manager (palanisamyg@ornl.gov)

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