DOE/SC-ARM-15-012

Southern Great Plains Ice Nuclei Characterization Experiment Final Campaign Summary

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Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Executive Summary

The first ever ice nucleating particle (INP) measurements to be collected at the Southern Great Plains site were made during a period from late April to June 2014, as a trial for possible longer-term measurements at the site. These measurements will also be used to lay the foundation for understanding and parameterizing (for cloud resolving modeling) the sources of these climatically important aerosols as well as to augment the existing database containing this knowledge. Siting the measurements during the spring was intended to capture INP sources in or to this region from plant, soil, dust transported over long distances, biomass burning, and pollution aerosols at a time when they may influence warm-season convective clouds and precipitation. Data have been archived of real-time measurements of INP number concentrations as a function of processing conditions (temperature and relative humidity) during 18 days of sampling that spanned two distinctly different weather situations: a warm, dry and windy period with regional dust and biomass burning influences in early May, and a cooler period of frequent precipitation during early June. Precipitation delayed winter wheat harvesting, preventing intended sampling during that perturbation on atmospheric aerosols. INP concentrations were highest and most variable at all temperatures in the dry period, where we attribute the INP activity primarily to soil dust emissions. Additional offline INP analyses are underway to extend the characterization of INP to cover the entire mixed phase cloud regime from -5°C to -35°C during the full study. Initial comparisons between methods on four days show good agreement and excellent future promise. The additional offline immersion freezing data will be archived as soon as completed under separate funding. Analyses of additional specialized studies for specific attribution of INP to biological and smoke sources are continuing via the National Science Foundation and National Aeronautics and Space Administration funding that helped support instrumentation used for the measurements described herein. Aerosol Observing System aerosol data will be vital to the interpretation and parameterization of results as part of analyses for publications in preparation.

Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement
ASR	Atmospheric Systems Research
CFDC	Continuous flow diffusion chamber
CSU	Colorado State University
DOE	Department of Energy
INPs	Ice nucleating particles
IS	Ice spectrometer
NASA	National Aeronautics and Space Administration
NSF	National Science Foundation
SGP	Southern Great Plains
SP-2	Single particle soot photometer (Droplet Measurement Technologies)
WIBS-4A	Wideband Integrated Bioaerosol Sensor Model 4A (Droplet Measurement Technologies)

Contents

Figures

1.0 Background

Ice nucleating particles (INPs) are required to trigger the formation of the first ice crystals in the mixed phase (liquid and ice) regions of clouds, thereby impacting the transfer of solar and thermal energy through and precipitation formation processes in many clouds. Advances in quantifying the number concentrations of INPs in different weather and aerosol scenarios has direct application, via parameterization development, to improving the representation of mixed phase clouds in regional and global climate models. This is the clearest relevance of this research to DOE-ARM objectives and the DOE-ASR science plan.

Varied natural and human-caused sources of INPs remain poorly quantified and their impact on clouds and climate therefore remain relatively unconstrained. Soils of all types and plant surfaces are sources for INPs that are produced when those surfaces are perturbed, such as by rain, wind or fire (Garcia et al. 2012; Prenni et al. 2013). Deserts are known as strong global sources of ice nuclei of mineral origin. Plants are reservoirs of special highly effective biological INPs (certain bacterial and fungal spores), and the action of these and other microorganisms within soils works to create a distinct population of dominant organic INPs that we have identified in agricultural soils (Tobo et al. 2014). Further, the combustion of plant matter in fires releases black carbon and other particles that are potential INPs. All of these influences are present at the DOE Southern Great Plains site in the spring season.

The Southern Great Plains (SGP) Ice Nuclei Characterization Experiment (SINCE) was shaped around the desire to sample aerosols active as INPs during a period when wheat and grass fields are harvested, and sometimes subsequently burned, and when long-range smoke and dust sometimes reaches it. The work plan centered around collecting a comprehensive suite of daily measurements of INP number concentrations at the SGP instrument lab (including elevated sample inlets) via two methods: the Colorado State University (CSU) continuous flow diffusion chamber (CFDC), which has been used for real-time measurements in campaigns over more than 20 years (DeMott et al. 2010); and collections of filter samples for offline INP analysis of the immersion freezing activity of particles in liquid using the CSU ice spectrometer (IS) instrument (Hill et al. 2014). These measurements were supported by other measurements of aerosol properties via site instrumentation at SGP (aerosol sampling and remote sensing), and other instrumentation we brought to the site, including a WIBS-4A instrument for measuring fluorescing biological particle concentrations, an SP-2 for measuring black carbon aerosol concentrations, and an aerosol concentrator for use ahead of the CFDC to improve INP measurement statistics. Measurements were made during two specific periods in spring 2014, from April 29 to May 8, and from June 3 to June 8, the latter of which was specifically targeted to coincide with an expected harvest period, although rain ultimately prevented harvesting at that time. Such measurements have never been conducted at the SGP site, despite their clear relevance to a variety of campaigns held at or around the site with objectives focused around precipitation, such as the MC3E campaign[1]. Aerosol impacts on convective precipitation are the focus of a current DOE-ASR-funded project entitled "Aerosol Indirect Effects on the Anvil Characteristics, Cold Pool Forcing, Stratiform-Convective Precipitation Partitioning and Latent Heating of Mesoscale Convective Systems," with Professor Susan van den Heever as PI. Dr. DeMott is a co-investigator on that proposal, and hence will apply the SINCE data set toward these other DOE-funded

[1] For more information, please visit http://campaign.arm.gov/mc3e/

studies. Finally, these first measurements at the SGP site set the stage for longer-term observations of INP at SGP, a near-term objective of the DOE-ASR ice nucleation working group, to which Dr. DeMott belongs.

Participants were Dr. Paul DeMott (Senior Research Scientist, PI), Dr. Thomas Hill (Research Scientist, Co-PI), and Drs. Ezra Levin and Kaitlyn Suski, both postdoctoral scientists in the Department of Atmospheric Science at CSU. DOE-ARM funding supported shipping and site support for SINCE. Data collected also was in support of separate National Aeronautics and Space Administration (NASA) and National Science Foundation (NSF)-funded studies, which supported costs for deploying instruments, as well as those of lodging, personnel support, and salary.

NASA funding supported measurements to constrain the numbers of black carbon-containing INPs in the atmosphere, especially those released from biomass combustion. The SGP deployment specifically supported atmospheric testing of a novel method to identify INP of black-carbon origin by pre-filtering aerosols with a single particle soot photometer (SP2) prior to measurement of ice nucleation properties with the CFDC on some days. Our experience from laboratory studies (Levin et al. 2014) and field studies of prescribed and wildfires (McCluskey et al. 2014) has been that biomass burning produces particles active as INP, including black carbon particles, but agricultural burning has yet to be sampled. We also wished to evaluate the possibility that heat-stable organic INP from the fertile soils (Tobo et al. 2014) may also be released when crop stubble is burned in place in fields.

NSF studies supporting investigations of INP sources and emissions from arable soils are also probing the production of biological INPs from soil and plant-surface microorganisms and plant tissues. Soil samples were collected for subsequent dispersion in laboratory studies and comparison to ambient measurements. Wheat fields were targeted specifically for bio-INP releases because of the high numbers of bacterial INPs we have found on wheat (Hill et al. 2014) that are likely only released in large numbers during harvest perturbation (Garcia et al. 2012).

An additional collaborator for this study is Dr. Patric Seifert of the Institute for Tropospheric Research in Leipzig, Germany, who is utilizing our collected data to test and validate methods being developed for remote retrieval of INP number concentration (Seifert et al. 2011; Mamouri and Ansmann 2015).

2.0 Notable Events or Highlights

The sampling periods exhibited a strong contrast in aerosol scenarios. Early May included a dry period punctuated by episodic wind release of soils, overlain by a likely episode of long-range biomass burning aerosol transport. Early June was a more humid and rainy period. The data from these contrasting periods will be useful for constraining expected INP in different scenarios at SGP. The dry and dusty period was especially useful for the remote retrieval study with collaborator Seifert.

We did experience some difficulties with sustaining a constant aerosol particle concentration factor with our aerosol concentrator, which was a remnant problem (now solved) caused by deposits and corrosion following a previous campaign. This limited the efficiency of concentration or concentrator factor for particles >500 nm to values of 10-20 instead expected values of 100. The WIBS-4A instrument was delayed in delivery for our NSF studies and consequently was only available for the June deployment. A final problem was the frequent traffic on dirt roads during the dry May period, which had “spike” effects on our real-time INP measurements.

3.0 Lessons Learned

Several lessons were learned from which we can grow this research. Since we were unable to sample a harvest period at SGP, we now understand that it is not possible to pin our deployment to explicit dates if we are to conduct such sampling. Other scheduled studies prevented such flexibility in spring 2014. A longer single deployment through the spring period would be useful. As mentioned above, we did experience difficulty with our aerosol particle concentrator and have since identified the location prone to accumulation of deposits and learned that this instrument should be cleaned nearly daily in dusty conditions such as observed at SGP in early May. To provide additional flexibility in sampling over harvest regions, we believe that we should also be prepared to bring our mobile laboratory for future sampling at and near the SGP site. This might also help with road dust contamination near the main laboratory.

4.0 Results

Strong INP variability exists for varied time scales at SGP: Figure 1 shows a summary of interval (5-10 minute) CFDC measurements of INP number concentration (per liter) on all days sampled during SINCE. For simplicity of interpretation, the CFDC was operated at a nominal 105% RH to emphasize condensation and immersion freezing nucleation (DeMott et al. 2015). As air temperatures warmed during the dry period in early May, INP number concentrations increased. During the more humid period in early June, which was also punctuated by higher precipitation, INP number concentrations were lower overall, though retaining variability, especially around times of rain events (see Figure 3).

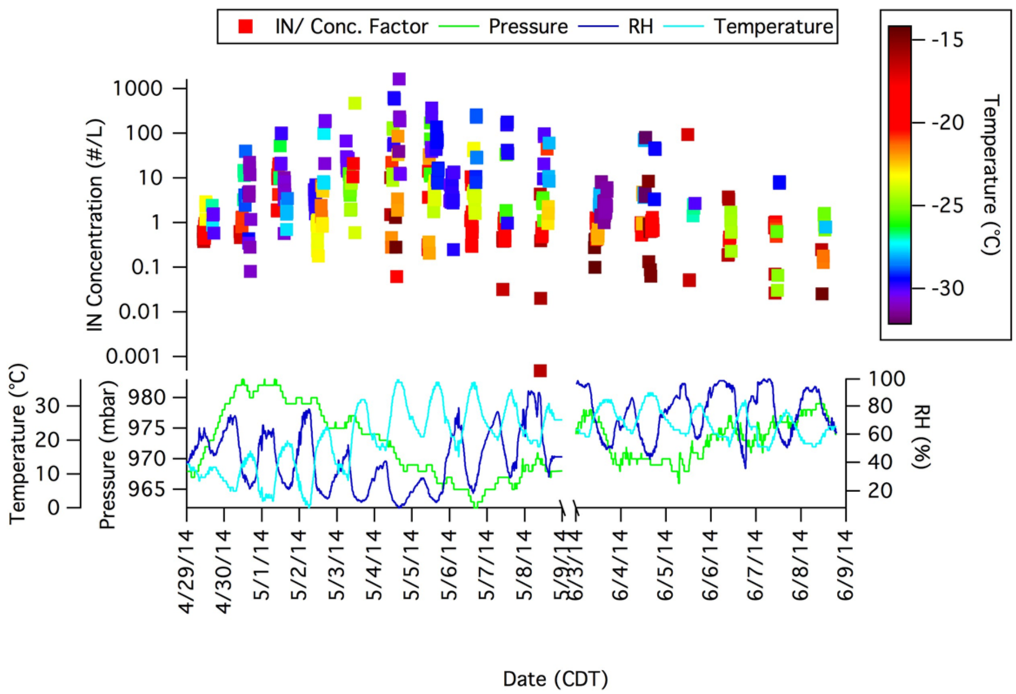

Figure 1. INP concentrations measured during two distinct sampling periods at SGP during spring 2014 (note the division in the middle of the plot), color coded by CFDC processing temperature. CFDC relative humidity was nominally 105% during the entire study. Also plotted are ambient temperature, pressure, and relative humidity during the sampling periods.

The variability noted in Figure 1 is also evident when data are plotted as temperature spectra of INP number concentrations, and segregated by date, as in Figure 2. The brief and episodic occurrences of higher INP concentrations are most evident during the dry early May period, although a few still occurred in June.

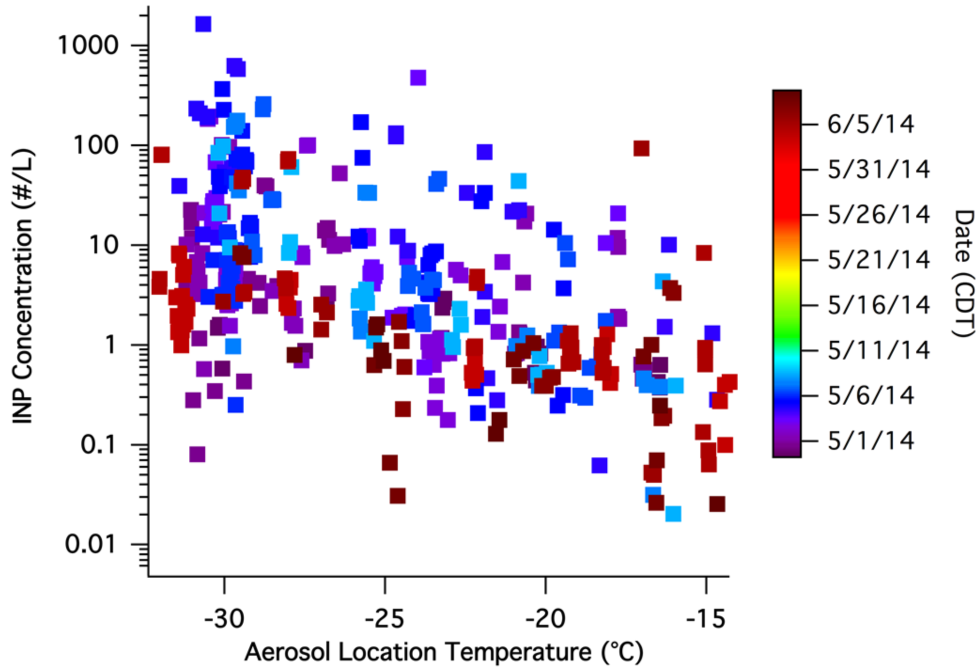

Figure 2. Temperature spectra of CFDC INP number concentrations by date for the entire project period.

Direct comparisons of CFDC and IS data for different daily sampling periods through the study are shown in Figure 3. These data represent some of the first ever direct intercomparisons of these two complementary methods for assessing full-spectrum natural INP data. Consistency between methods is mostly excellent, considering the difficulty in comparing measurements made at a certain time and certain temperature (progressing warmer to colder during a sampling period) with the CFDC, and measurements integrated over the whole sampling period with the IS. Larger sample volume and longer time interval filters do not capture the often <15 minute periods of elevated INP concentration values, but allow for extending the average immersion freezing INP number concentrations to much warmer (i.e., minimally supercooled) temperatures. We note that for higher INP number concentrations below -20°C, where soil dusts have their strongest ice nucleation activity, the filter samples also capture the strongest rise in INP activity. A hump in INP activity, such as is often associated with biological INP at temperatures warmer than -20°C, is only resolved by the IS filter method, due to the larger sample volumes used.

Short periodic variances in INP captured in CFDC data have a few sources. The events during days in early May are likely associated with soil dust releases in higher winds. During the wetter period in early June, which generally showed lower INP activity, high INP excursions were noted during short periods following brief, intense convective rain events, as indicated in the Figure 3 panel for June 5.

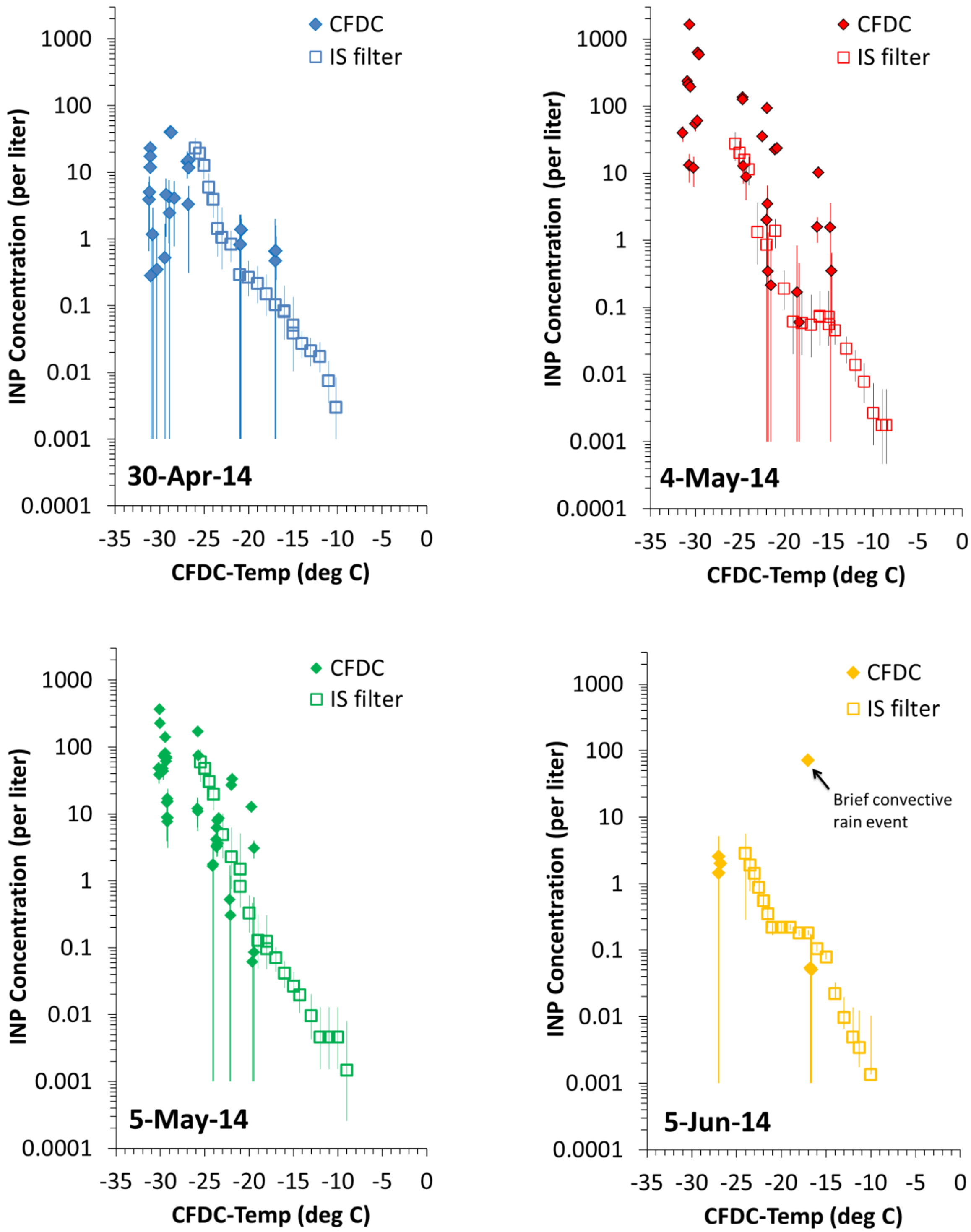

Figure 3. Temperature spectra of INP number concentrations for four selected sampling periods of 4-6 hours, three in the first phase and one in the second phase of the study. CFDC 5-20 minute samples and IS filters processed for the entire sampling period on each day are distinguished. Uncertainties representing 95% confidence limits for the IS data and twice the Poisson sampling error for CFDC data are shown as vertical bars in the figure.

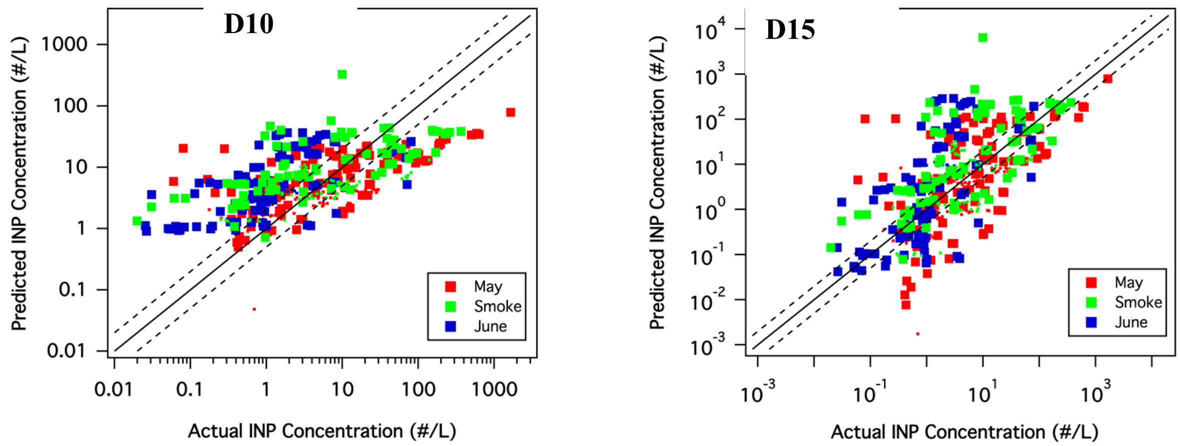

Figure 4. Relation between INP number concentrations (at standard temperature and pressure) and values predicted based on the concentrations of all particles larger than 500 nm, assuming these particles are representative of average free tropospheric INP (left panel, D10: DeMott et al., 2010) or are specifically mineral dusts (right panel, D15: DeMott et al. 2015).

Some initial exploration of the suitability of existing parameterizations to describe the data was done. Figure 4 shows that the overall data set does not well fit the DeMott et al. (2010) parameterization for global average INP (left panel: D10), while it does align with assumption of a mineral dust composition (right panel: D15), albeit with much scatter. Thus, the INPs in the region appear similar to mineral dust, but with a great deal of unexplained variability that warrants exploring. Different periods also show some distinct behaviors of INPs. A period identified as with smoke influence on the basis of SP-2 and AMS data in early May is seen to be little distinguished from the rest of this period, except to emphasize some over-prediction of both parameterizations in comparison to the INP data, consistent with current understanding of smoke contributions to INP in dusty regions discussed by McCluskey et al. (2014).

Related NSF and NASA studies: Measurements made in conjunction with the studies at SGP included testing of collected soil samples in the laboratory and testing of the refractory black carbon (rBC) contributions to INP from ambient air. Soil INPs were found to have a strong basis in an organic component, much as found by Tobo et al. (2014) for soils in Wyoming. Subsequent sampling in Kansas in October 2014 confirmed the presence of such INP in air, using a real-time heating tube system that could be deployed to SGP in future campaigns. Little contribution of long-range transported rBC INP in smoke periods was noted, at least under the elevated INP in dry weather period in early May.

Further analyses are planned, and will likely include other data obtained in this geographical region (Kansas, including crop harvesting) during Fall 2014 and measurements planned for 2015 that are expected to include sampling during wheat and other crop harvesting events. Additional measurements will be made under NSF funding, and publications will include data obtained with both NSF and DOE funding. Collaborator Seifert also obtained first remote retrievals of aerosol properties for correlation to INP data during the SGP deployment, and this will serve as the basis for an additional publication. CFDC data were archived in the ARM Data Archive. IS data will be archived once analyses of SINCE samples are completed under NSF funding (expected by spring 2015).

Future research opportunities include obtaining an annual cycle of INP measurements (at least IS data), additional potential intensive observation periods to include real-time measurements such as the CFDC, and the possibility of an SGP-based aerosol-cloud interactions (cloud condensation nuclei and INP) field campaign.

5.0 Public Outreach

No public outreach was performed on this short study.

6.0 Publications

6.1 Journal Articles/Manuscripts

None submitted at the time this report was published.

6.2 Meeting Abstracts/Presentations/Posters

DeMott PJ, KJ Suski, EJT Levin, TCJ Hill, SC van den Heever, and SM Kreidenweis.2014. “Ice Nucleating Particles at SGP and in the U.S. High Plains.” *DOE-ASR Fall 2014 Working Group Meetings*, November 19, 2014, Potomac, Maryland. Presentation.

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