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ARM Support for the Plains Elevated Convection at Night (AS-PECAN) Field Campaign Report

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Executive Summary

The Plains Elevated Convection at Night (PECAN) field campaign was a large multi-agency/multi-institutional experiment that targeted nighttime convection events in the central plains of the United States in order to better understand a range of processes that lead to the initiation and upscale growth of deep convection. Both weather and climate models struggle to properly represent the timing and intensity of precipitation in the central United States in their simulations. These models must be able to represent the interactions between the nocturnal stable boundary layer (SBL), the nocturnal low-level jet (LLJ), and a reservoir of convectively available potential energy (CAPE) that frequently exists above the SBL. Furthermore, a large fraction of the nocturnal precipitation is due to the organization of mesoscale convective systems (MCSs). In particular, there were four research foci for the PECAN campaign:

- The initiation of elevated nocturnal convection focus seeks to elucidate the mesoscale environmental characteristics and processes that lead to convection initiation (CI) and provide baseline data on the early evolution of mesoscale convective clusters.
- The dynamics and internal structure and microphysics of nocturnal MCSs focus will investigate the transition from surface-based to elevated storm structure, the interaction of cold pools generated by MCSs with the nocturnal stable boundary layer, and how the organization and evolution of elevated convection is influenced by the SBL and the vertical profile of wind and stability above the LLJ.
- The bores and wave-like disturbances focus seeks to advance knowledge of the initiation of bore disturbances by convection, how the vertical profile of stability and winds modulate bore structure, the role of these disturbances in the initiation, maintenance, and organization of deep convection, and their impact on the LLJ and SBL.
- The LLJ focus seeks to understand the processes that influence the spatial and temporal evolution of the LLJ, how it affects the SBL, and the interaction between the LLJ and atmospheric boundaries in the development of CI.

AS-PECAN, which was supported by the U.S. Department of Energy (DOE), was a critical component of the observational strategy of PECAN. AS-PECAN provided five Atmospheric Emitted Radiance Interferometers (AERIs) that were deployed at PECAN Integrated Sounding Array (PISA) sites. The AERIs were an integral component of the fixed PISA array, providing temperature and water vapor profiles continuously during the 1.5-month campaign (1 June-16 July 2015).

Acronyms and Abbreviations

AERI	Atmospheric Emitted Radiance Interferometer
AMS	American Meteorological Society
ARM	Atmospheric Radiation Measurement Climate Research Facility
CAPE	convectively available potential energy
CDT	Central Daylight Time
CF	Central Facility
CI	convective initiation
DLPROF	Doppler Leader Profiles, an ARM Value-Added Product
DOE	U.S. Department of Energy
EOL	Earth Orbiting Laboratory
HSRL	High Spectral Resolution Lidar
LLJ	low-level jet
LT	local time
MCS	mesoscale convective system
MC3E	Mid-Latitude Continental Convective Cloud Experiment
MHz	megahertz
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NSSL	National Severe Storms Laboratory
NWP	Numerical Weather Prediction
PECAN	Plains Elevated Convection at Night
PISA	PECAN Integrated Sounding Array
PPI	plane parallel indicator
SBL	stable boundary layer
SGP	Southern Great Plains
UFO	unofficial field operation
UTC	Coordinated Universal Time
VAD	velocity azimuth display

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1.0 Background

The Plains Elevated Convection at Night (PECAN) experiment (1 June-16 July 2015) is a large field campaign that was supported by the National Science Foundation (NSF) with contributions from the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and DOE. The overarching goal of the PECAN experiment is to improve the understanding and simulation of the processes that initiate and maintain convection and convective precipitation at night over the central portion of the U.S. Great Plains. These goals are important since a large fraction of the yearly precipitation in the Great Plains comes from nocturnal convection, and because nocturnal MCSs may unleash flashfloods and other severe weather. The convection initiation and upscale growth mechanisms are fundamentally different at night than during the day. Nocturnal convection in the Great Plains is most often decoupled from the ground and is thus forced by other phenomena, such as a stable lower boundary layer, propagating bores, and low-level jets, which are uniquely nocturnal. There is a relative lack of understanding how these disturbances initiate and maintain nocturnal convection. This lack of understanding greatly hampers the ability of numerical weather and climate models to simulate nocturnal convection well, which leads to significant uncertainties in predicting the onset, location, frequency, and intensity of convective cloud systems and associated weather hazards over the Great Plains.

The PECAN experiment was held over a large domain that encompasses most of western and central Kansas, northern Oklahoma, and southern Nebraska. A unique component of the PECAN observational strategy is the concept of the PECAN Integrated Sounding Array (PISA). Each PISA had remote-sensing instruments that were able to profile temperature, humidity, and winds throughout the boundary layer and lower troposphere at high time resolution (~5-min). PISAs also had collocated radiosonde systems that provided detailed profile information at lower temporal resolution but at higher vertical resolution at all levels up to the lower stratosphere.

There were six fixed PISAs in the domain and four mobile PISAs; the latter were relocated for each Intensive Operational Period (IOP) to augment the domain where convection was anticipated to occur. The DOE Atmospheric Radiation Measurement (ARM) Climate Research Facility's Southern Great Plains (SGP) Central Facility (CF) served as the fixed PISA in the southeastern cornerstone of the PECAN domain. A large number of instruments from the NSF Lower Atmospheric Observing Facility pool, university investigators, a private company, and from other agencies such as NOAA and NASA were used to instrument the other PISA sites. The detailed characterization of the thermodynamic and kinematic evolution of the boundary layer across the experimental domain greatly enhanced the rest of the observational data sets, which included fixed and mobile 3D scanning precipitation radars at frequencies ranging from X- to S-band, mobile mesonet systems, clear-air and storm-penetrating aircraft, and mobile radiosonde launching systems.

The ARM Facility supported PECAN by providing five Atmospheric Emitted Radiance Interferometers (AERIs), which were deployed at the fixed PISAs in the domain. These instruments, together with the AERI at the SGP CF, provided a uniform and consistent thermodynamic data set across domain, which will greatly improve the ability of data assimilation schemes and other analysis techniques to characterize the thermodynamic environment and its evolution before and during these nocturnal events. Many recent studies have indicated that the lack of a spatial array of high-temporal-resolution thermodynamic profiles in the lower troposphere has been the limiting factor in understanding the processes at work in

preconvective and convective situations, especially at night when the lower troposphere is ill-represented by the surface station network, on account of a stable boundary layer (SBL). Furthermore, the ARM Facility also provided a radiosonde station and consumables that were used at one of the other fixed PISAs (fixed PISA #6 at Hesston, Kansas), thereby allowing all of the fixed PISAs to have radiosonde capability. The ARM Facility also provided a surface met station for fixed PISA #6, and a Doppler lidar that was used in mobile PISA #3. The vast array of sensitive radar and lidar profilers at the CF (e.g., Raman lidar, Doppler lidar, 915 MHz wind profilers, etc.) will be used to investigate nocturnal convection when the convection occurs near that site. The full PISA data set will become public domain on 16 July 2016 from the National Center for Atmospheric Research (NCAR) Earth Observing Laboratory (EOL). It will serve for many years as a leading mesoscale-profiling network data set for data assimilation and prediction studies by DOE scientists and others. It greatly augments the data set collected during the Mid-Latitude Continental Convective Cloud Experiment (MC3E), which focused on diurnal convection over the SGP.

2.0 Notable Events or Highlights

The PECAN experiment was designed to focus on events, and as a consequence a large fraction of the observational capability was mobile (i.e., mobile radars and mesonets, aircraft, mobile PISAs). A typical day started with a forecast briefing at noon local time (LT), wherein the lead scientists for each of the four foci (MCS, bores, elevated CI, and LLJ) were briefed on what sort of weather might be expected that evening and night. The lead scientists then conferred with their colleagues to decide whether to propose a mission that evening or not. A more detailed weather briefing occurred at 3 pm LT using output from more recent Numerical Weather Prediction (NWP) forecasts. After this briefing, the lead scientists and the PECAN chief scientist (note that the actual people holding these positions typically rotated weekly) would make a decision on what sort of mission would be conducted during this IOP, where it would be conducted, and the start time. This information would be passed to both the mobile and fixed observational teams via coordinators. The lead scientist for the topic area chosen would be elevated to the mission scientist for that IOP. The mission scientist would work closely with the observational coordinators, the real-time weather forecaster team, and others to conduct the IOP in a safe manner. At the end of the IOP, the mission scientist and the observational coordinators would write up reports for the IOP, which were often presented to the group the next day, and can be found at http://catalog.eol.ucar.edu/pecan/tools/missions.

An IOP involved on the order of 100 participants, distributed over a large region, including at the Operations Center in Hays, Kansas, at flight facilities in Great Bend and Salina, Kansas, and in the air, at the fixed PISA sites, plus a distributed array of mobile PISA, mobile radar, mobile sounding, and mobile mesonet units in the region of interest. The logistics of field deployment, communication, and effective coordination involved much advanced planning and new technologies, such as the real-time display of the location of all mobile units and aircraft, mapped on top of radar imagery with very little latency.

Ultimately, PECAN conducted 13 MCS IOPs, 4 LLJ IOPs, 5 bore IOPs, 5 CI IOPs, and 3 IOPs that were classified as a joint CI-LLJ experiment. A brief summary of each, extracted from the website above, is provided in Table 1. Even though IOPs by design assumed an observational strategy specific to the science objective at hand (e.g., MCSs), multiple objectives often were accomplished (e.g., bores often were observed and sampled on MCS missions) by the nature of the interdependencies of MCSs, LLJs,

bores, and CI events, and also because prediction of the behavior of mesoscale convection even at short times scales (6-12 hours) is still in its infancy—a key motivator for PECAN, as discussed above. There were also 12 "unofficial field operations" (UFO) days, wherein the mobile fleet was not required to participate but could if they desired. Most of the time this involved collecting some additional data in or around Ellis, Kansas (i.e., just outside Hays, Kansas, which served as the base of operations for PECAN).

Due to the complexity of this experiment and the number of IOPs, data (especially from the mobile platforms such as the aircraft and the mobile radars) are still being processed and quality controlled, and hence there have been few significant analyses performed as of the time of this report. Given the large number of participants, the large number of NSF grants in support of PECAN (11, some of which were collaborative), and the field campaign success (which has led to several follow-on proposals, currently pending, mostly focused on modeling aspects), we are confident that the PECAN field campaign will lead to numerous publications.

Table 1. A short summary of each PECAN IOP and UFO.

IOP	Mission Type	Start Date/Time (UTC)	Notes
IOP1	**N/A**	2015-06-02 01:00	Shake-out dry run to test communications, scanning strategies, and deployment logistics. Deployment IP was Colby, Kansas, and was patterned after an MCS-A mission.
IOP2	**LLJ**	2015-06-03 00:00	A strong LLJ developed with all MPs along the same latitude as S-Pol. Radial velocities started to increase at DDC/S-Pol ~0100 Coordinated Universal Time (UTC) and the LLJ continued to strengthen and by 0300 UTC it also covered a larger spatial area. All PISAs released 0000, 0130, 0300, and 0430 UTC sondes and the FPs also released at 0600 UTC. The King Air had two flights with saw tooth legs along the track.
IOP3	**MCS**	2015-06-04 00:00	An unsuccessful MCS-A mission with the IP being Salina and deployment around Clay Center, Kansas. RaXPOL replaced DOW6 as part of the hexagon. FP soundings started at 00 UTC and were conducted every 90 minutes to 0600. Hourly soundings from MGAUS starting at 0130 UTC. The King Air flight was scrubbed as it became clear convection would not form an MCS in region. A good case for examining a partial failure of numerical guidance.
IOP4	**Bore**	2015-06-05 00:00	Several bores were generated overnight. The mobile radar and sounding array observed a very weak and diffuse bore/gravity current over northern Kansas. A strong bore event emanated from strong convective cluster over the Hays-Ellis region around midnight. The King Air flew through the bore experiencing strong updraft and turbulence. The bore generated new convection in SW Kansas. Excellent observations from mobile mesonet/soundings and Fixed PISA sondes show a pronounced bore.
IOP5	**Bore**	2015-06-06 00:00	Bore mission declared after LLJ mission scrubbed at 5pm Central Daylight Time (CDT). More challenging than IOP4. Expectation of E-W oriented outflow boundary in west-central to north-central Kansas from high res models. Consequently anticipated inflow from LLJ needed for bore ducting was greatly diminished as the orientation of the outflow was nearly parallel to the orientation of the LLJ. Limited duration mission conducted of a weak, shallow bore in area of Colby, Kansas, and west of Ness City. Nice shallow undular feature observed by SMART-R2 radar and King Air lidar. Bore did not generate new convection.
UFO1	**Bore**	2015-06-07	A UFO Bore mission was conducted during the evening of the down day.

IOP	Mission Type	Start Date/Time (UTC)	Notes
			Instruments collected data from the parking lot at Fort Hays State University as a bore passed through Hays. The feature began as a boundary moved out of convection near Goodland, Kansas, at 03 UTC and moved SE. The feature moved over FP3 at 0430UTC. A pronounced wave response was noted on the 449 megahertz (MHz) profiler at FP3. The wave reached S-Pol at 0500 UTC.
IOP6	CI	2015-06-08 0200 UTC	A CI mission over a spread-out region primarily SW of S=Pol. Soundings at 03 and 06 UTC. The King Air took off at 02 UTC and flew racetracks across the boundaries. While most of the mobile radars were spread out, there was a dense array in St. John, Kansas. A bore initiated new convection at 0340 UTC ~100km south of S-Pol. The bore passed over MP3 at Cimarron. MM observed 8mb pressure rise across bore and then CI formed over that location.
IOP7	LLJ	2015-06-10 0000 UTC	A LLJ mission centered on S-Pol near McCracken, Kansas, that produced a nice data set of remarkably pure baroclinically-generated LLJ over a shallow slope. MP and FP released soundings at 0000, 0130, 0300, 0600, and 0900 (FP only) UTC, except FP3 with soundings every 30 min from 0000 to 0430 and 0600/0900. King Air conducted two flights. The jet was late developing across most of KS. Flow was diffluent with a principal axis running through PECAN domain. The jet was quite shallow with peak winds generally 200m AGL. Peak jet winds from the later soundings and the DOWs were 16-18m/s after 0600 UTC.
IOP8	MCS	2015-06-11 00:00	A successful MCS-A mission. Several convective "fingers" developed in the inflow region and merged with convection that developed along the surging outflow from the main MCS. Several of these bands moved through the mobile array. Later an extensive stratiform region as sampled with evidence of an incipient MCV forming at it traversed the mobile radar network. The King Air encountered strong turbulence and diverted to an emergency landing in Salina, Kansas. A good case for examining several wake-like bands of elevated convection.
IOP9	MCS	2015-06-12 00:00	An MCS mission around DDC. A messy, non-textbook upscale-growth, but data collected on both a small-scale bowing segment and a larger-scale, more classic linear MCS with rear inflow that passed through the array. FPs conducted 00/03/06 sondes, MP and FP2 every 90 minutes from 00 UTC. MG/MM conducted ambient and cold pool soundings and transects. MPs collected data of a northward-moving outflow early on and then in a precipitation-free region for "ambient" observations. S-Pol operated from 0400-0745UTC.
UFO2	CI	2015-06-14 04:00	A surprise CI UFO mission conducted in Hays and FPs during a down day. The official forecast was for low CI probability due to warm air advection as a stronger LLJ from Oklahoma moved NE. CI occurred over Hays and FP2 as several instruments were operating (including SPARC and S-Pol). CI started aloft around S-Pol at ~04UTC with NW-SE bands around the radar. Instruments showed some stronger/deeper updrafts and deepening moisture leading up to CI. There was also CI near Wichita, Kansas.
IOP10	MCS	2015-06-15 00:00	An MCS mission located near Sawyer, Kansas. Sonde releases: FPs (except FP4) 01/04 UTC, MPs 01/0230/04 UTC. King Air took off at 0200 UTC. Six mobile radars participated, although there were delays with setup of three of them. Mobile soundings/mesonets sampled most of the evening. Initial target system at Alva, Oklahoma, fell apart before setup, so targeted convection developing along the boundary to the north. While not a classic MCS, good data was collected on back-building convection above a weak

IOP	Mission Type	Start Date/Time (UTC)	Notes
			cold pool as well as a CI event along colliding boundaries.
IOP11	MCS	2015-06-17 00:00	A successful long-duration data collection on upscale growth and MCS genesis and early evolution near McCook, Nebraska. Sondes were released by the FPs at 00/03/06 UTC and the MPs every 60 minutes (except in heavy precipitation). The King Air flew the inflow over the hexagon. The P-3 had success later in the mission at the system transitioned to LL/TS with at least one spiral over MIPS and MAX/NOXP dual Doppler. Seven mobile radars were scanning. The MGs moved to MP1 location and released every 15 minutes with MP1 just west of McCook. The MMs made several E-W and N-S transects through the system. There was also retrieval of bore data by S-Pol, FP5 and TWOLF in western Kansas.
UFO3	AET/CI	2015-06-19 01:30	A monitoring-type UFO around Hays to test the UFO concept and look for surprise CI on a day where the official PECAN forecast was for no CI in the PECAN domain. Soundings were released by CLAMPS and CSWR. A boundary of unknown origin moved through the domain toward the SW at 00 UTC. Some wave-like features in S-Pol at 05 UTC and a cyclonic circulation. Just a few clouds were present. There was CI over DDC at 0600 UTC and a stronger N-S line of storms formed in the Oklahoma/Texas panhandle.
IOP12	LLJ	2015-06-20 00:00	An LLJ mission centered near S-Pol. Some stations continued collection beyond 0930 UTC. FP soundings were taken at 0000/0130/0300/0430/0600/0900 UTC with additional soundings released at FP3. DOWS and SMART-Rs were synched with S-Pol for dual-Doppler analysis. MPs and CSWR MM and pods were also used. A strong (25m/s) LLJ developed as forecast, the instruments worked well, and a successful data set was collected.
UFO4	MCS	2015-06-20 01:00	A very strong MCS moved across SD producing severe winds across the state. The P-3 flew three pseudo-dual Doppler legs, two directly across the rear inflow jet when it had winds of 80kts. Also, four spirals (ascent or descent) were performed through the rear inflow jet and two were done in adjacent stratiform areas. The initial convective mode around 02 UTC was supercells which eventually merged with a convective line that developed to their west. During these early stages there was extensive lightning in the "stratiform" region. Finally by 0700-0830 the system developed a classic bow-echo shape with an intense rear inflow jet.
UFO5	Bore	2015-06-20 06:30	A large MCS developed in western South Dakota producing lots of wind damage. The deep cold pool, deep SBL, and strong LLJ supported bore formation and ducting. A long-lived bore wave train was sampled in 18 flight legs. The waves were rather smooth, undular, sometimes with breaking on the northern side. Moderate turbulence was encountered on the first intercept at 0746z; otherwise turbulence was light.
UFO6	AET/CI	2015-06-20 22:00	A UFO mission around Hays examining the afternoon-evening transition of the boundary layer and potential elevated CI. Surface-based CI occurred just south of the boundary near MIPS at 2317 UTC. The cold front made it nearly to S-Pol at 0110 UTC. The boundary was complicated as it intersected rolls and cellular convection, evolving into a non-linear feature with undulations and segments. Another linear feature moved SE past S-Pol at 0130 UTC. MIPS measured sustained 4m/s updrafts as the boundary passed over. FP3 release a sounding north of the boundary at 03 UTC. RaXPol observed striking NE/SW wave-like structures. No elevated CI was observed.
IOP13	LLJ	2015-06-21	LLJ mission with the core in central Kansas, centered near S-Pol. IOP ran

IOP	Mission Type	Start Date/Time (UTC)	Notes
		23:00	from 2300Z – 0930Z, with the first sonde launch at 0000Z. When possible, observations were collected at 2300Z or earlier to sample the state of the CBL before the onset of LLJ and to capture the evening transition. From the Chief-Scientist summary: *A strong LLJ developed as forecast and we were able to collect a good set of data during the IOP. Peak winds of about 30 m/s were observed with the core of the jet occurring within the IOP domain. Compared to the jet observed on Friday 06/20 (IOP12), the development of the jet core followed a more classic picture with the evolution starting soon after sunset and strengthening of the jet throughout the night. The core of the LLJ was also better defined. Although we had some issues with some of the radars and data sets still need to be carefully evaluated, preliminary results suggest that most instruments worked well and a successful data set was collected. Below we show some initial and preliminary results.*
IOP14	**CI-LLJ**	2015-06-24 01:30	Joint CI-LLJ mission in SE Nebraska. Several interesting structures in the elevated convection and wave features in the boundary layer and evolution of the LLJ were observed within the PECAN domain.
IOP15	**MCS**	2015-06-24 23:00	MCS mission over Eastern Iowa and Western Illinois. From Chief-Scientist Summary: • *Strong MCS with very heavy rainfall, but with only marginally severe surface winds in clearly elevated convective environment* • *Small segment producing severe winds moved directly through the radar "hexagon"* • *High-frequency soundings both ahead and behind the MCS* • *Interesting surface wind features observed by mobile mesonets*
IOP16	**Bore**	2015-06-26 00:00	Bore Mission over Western Kansas. From the Chief-Scientist Summary: • *Atmospheric bores dominated this nocturnal environment. Over 7 different bores present.* • *If no bores had occurred in the domain, 2, possibly 3, MCSs may not have generated.* • *The bores lifted stable air, at times intact, 1-2km. Consistent with some cases from MAPR data during IHOP.* • *Objectives met:* ◦ *Possible capture of gust front-bore generation. Many individual pieces.* ◦ *Horizontal extent of bore potentially captured as it overran the N-S oriented network*
UFO7	**AET/CI**	2015-06-29 22:00	From the Chief-Scientist summary: *A beautiful north-south gust front propagated over S-Pol at 0015 UTC from cellular, unorganized convection in eastern Colorado. Weak and scattered convective cells were initiated along and trailing the gust front. The gust front passed over FP2 at 01 UTC and FP3 at 0154 UTC... It was cooler and moister behind the gust front.* The gust front dissipated in reflectivity by 04 UTC but was still evident as a convergence zone in the velocity field. This velocity convergence persisted through 06 UTC without a corresponding fine line in reflectivity. By 0747 UTC, elevated convection was initiated near that convergence boundary. It evolved into a linear band by 09 UTC and dissipated after that.
IOP17	**MCS**	2015-07-01 02:00	MCS mission over Northwestern Missouri and Southeastern Nebraska. From Matt Parker, MCS coordinator of the day: *We collected data depicting a strong LLJ, widespread CI in and near the target area, and a cluster-like MCS. All three aircraft flew over the instrumentation, and we have some excellent profiles as well as depictions of stratiform precipitation. Two*

IOP	Mission Type	Start Date/Time (UTC)	Notes
			MCVs also moved through the radar hexagon. All in all, a profitable case (even though it was not a high-end MCS).
UFO8A	**MCS**	2015-07-02 00:00	From the Chief-Scientist Summary: *Today's forecast included a very high probability of an MCS developing along the I-70 corridor in Missouri and moving SSE overnight. The MCS group considered a full mission, but it was felt that the parts of Missouri where radars could be sited (for this case, largely within 100 km of Kansas City) would capture convection too early in the evening. In fact, this scenario is largely what unfolded, with supercells developing in the Kansas City metro area by 23Z and a linear zone of convective initiation beginning to fill in along I-70 by 00Z.*
UFO8B	**Bore**	2015-07-02 02:00	From the Chief-Scientist Summary: *As expected, a N-S oriented outflow did emanate from the dying convection right along I-70 and moved at about 13.8 m/s towards the East. FP3 launched soundings an hour (230Z) before the targeted boundary made it to Brewster and nearly 20 minutes (4Z) after it passed.*
UFO9	**CI**	2015-07-03 00:00	From the Fixed-PISA Summary: *FP soundings taken at 03 and 06 UTC plus additional at FP6. CI occurred most likely surface based*
IOP18	**CI**	2015-07-04 02:00	From Jim Wilson and Tammy Weckworth: *We had an amazing number of facilities that collected data prior to the first storm initiation. While there was not a major initiation episode, CI did occur in the general area forecast. One of the study factors will be why the number of initiations were limited and why they were concentrated in a rather small area. Another interesting study would be if the inflow and outflow from the long-lasting hail storm remained elevated.*
IOP19	**Bore**	2015-07-04 20:00	Assets were deployed near North Platte, Nebraska. The MCS that was hoped to develop with a subsequent bore never grew upscale in the time allotted. No data was obtained on an MCS or a bore. There was some CI around S-Pol. The DC-8 conducted a shortened mission and the P-3 and King Air flights were scrubbed.
IOP20	**MCS**	2015-07-06 00:00	An MCS mission in SE South Dakota and NE Nebraska highlighted by three bow echoes and bores on its south side. The ground assets were north of Yankton, South Dakota. The P-3 flew five pseudo dual Doppler legs along convective lines and eight spiral ascents/descents. Two of the spirals were behind a developing bow echo just north of the radar array and one was in the rear inflow region of another bow that developed over the array. The King Air flew further south, intercepting a bore several times. CI occurred along this bore. The DC-8 also flew with the objective to validate RainCube data with a ground-based radar.
UFO10	**MCS**	2015-07-07 00:00	The DC-8 flew a mission around an MCS in southern Missouri and northeast Oklahoma. Multiple passes over a moving and changing system were conducted for RainCube. FP2 and FP6 released radiosondes at 00, 03 and 06 UTC.
UFO11	**CI**	2015-07-08 00:00	A CI UFO mission with soundings from FP2/4/5 at 02/04/06 UTC, CLAMPS soundings from the FP3 site at 00/02/04/06 UTC and MISS and MGAUS soundings at 00/02 UTC.
IOP21	**MCS**	2015-07-09 00:00	An MCS mission in the Texas panhandle with ground crews east of Amarillo and a P-3 flight and a DC-8 flight shared with the CI mission. An MCS developed in the Texas panhandle, starting as a convective line and expanding to several complex lines and a very large stratiform region. The P3 flew two pseudo-dual Doppler legs along convective lines and a large number of spiral ascents/descents in a broad stratiform area. Two spirals were behind a line where a bow had yet to develop, continuing behind the

IOP	Mission Type	Start Date/Time (UTC)	Notes
			line as the bow developed. The bow was just west of the ground array. The DC-8 characterized the environment ahead of the line. The ground crews documented severe winds and complex line structure and a strong gust front.
IOP22	CI	2015-07-09 00:00	A CI mission with ground assets around S-Pol and a King Air flight and a DC-8 flight shared with the MCS mission.
IOP23	MCS	2015-07-10 00:00	An MCS mission in the Texas panhandle with ground crews east of Amarillo.
IOP24	CI-LLJ	2015-07-10 00:00	A CI-LLJ mission with ground assets around S-Pol and a King Air flight.
IOP25	Bore	2015-07-11 00:00	A bore mission in SC Nebraska and NC Kansas.
IOP26	CI-LLJ	2015-07-11 22:00	A CI-LLJ mission around central/western Kansas. Objectives were to sample the early evolution of the LLJ, the forecasted strong gradient of wind speed along its western edge, the convergence near the northern terminus of the LLJ, and any CI within the IOP area. All FPs/MPs released sondes at 00/0130/03/0430/06 UTC and FP2/FP3 also released at 2200 UTC. The King Air flew an E-W line just between S-Pol and FP3. The DC-8 flew a lawn mower pattern. The King Air and DC-8 conducted an intercomparison after the Ci-LLJ mission was complete.
UFO12	MCS	2015-07-12 01:00	An MCS UFO conducted by the NOAA P-3 in northern North Dakota. This mission was a bust. Forecast was for an MCS to develop in North Dakota. Only two cells developed. One moved into Canada and the other was sampled by the tail radar on four passes.
IOP27	MCS	2015-07-13 00:00	An MCS mission conducted by the NOAA P-3 and ground crews in SE Minnesota. A beautiful squall line formed and moved through southern Minnesota, right through the array in an environment with extreme instability, but high winds were not maintained at the surface after dark. The P-3 collected many pseudo-dual Doppler legs behind the system and a good sounding, surface, mobile radar, and MPISA data set was collected. There was also quite a bit of pristine CI observed near T-WOLF and SPARC in NE Iowa.
IOP28	MCS	2015-07-14 00:00	An MCS mission conducted by ground crews in western Indiana. It was not a high-end MCS, but vigorous CI was sampled with upscale growth right in the radar array. Soundings were taken on both the warm and cool side of the outflow from earlier supercells and MMs reported a 4C temperature gradient. CLAMPS provided BL profiles including a period in which the BL was lifted with CI shortly after.
IOP29	CI	2015-07-14 00:00	A CI mission in western Kansas. A cluster of storms formed in SW Kansas and grew into an MCS during the night. There was a mixture of surface-based and elevated CI, along with at least two bores. The King Air and DC-8 observed large moisture gradients and moisture pockets. Frequent soundings were released by MIPS, MP4, and the FPs. The MAX, NOXP and S-Pol collected surveillance scans and RHIs on the MCS. RaXPOL and the PX-100 also collected data.
IOP30	CI	2015-07-15 00:00	A CI mission in western Kansas. Most of the initiation was surface based, but an excellent data set was collected on a large MCS with multiple bow echoes and heavy rains. The wave-like structure of the cells that formed behind the gust front were of particular interest.
IOP31	MCS	2015-07-16 00:00	An MCS mission in Kansas and Nebraska that also had CI and bore components. A left-moving supercell accelerated the timing and organization of convection in the MCS radar domain. There was a report of 69 mph winds early and then it grew upscale, became elevated, and later

IOP	Mission Type	Start Date/Time (UTC)	Notes
			produced a severe-warned bow echo on the eastern side of the radar array. The formation of a nice LLJ was documented by CLAMPS and the King Air flew the inflow region of the upscale growing MCS. T-mode CI was sampled and lots of WAA generated convection over the cold pool. Bores were reported in the systems closer to Hays. A great data set.
IOP	**Mission Type**	**Start Date/Time (UTC)**	**Notes**

3.0 Lessons Learned

The data set collected by the ARM instruments during AS-PECAN will be very valuable. In particular, the deployment of the AERIs at each of the six fixed PISAs provides a uniform water vapor and temperature profiling capability across the PECAN domain, which will be very important for future analysis that assimilate these data into cloud-resolving models.

Unfortunately, however, significant amounts of data were lost by two of the AERI systems (Fig. 1). The internet bandwidth at the fixed PISA sites was very small, and hence only housekeeping data were being transmitted to the PECAN project team and the AERI instrument mentors. Each AERI had an external disk mounted to it to store data collected during the IOP. At the conclusion of the experiment, it was discovered that two of these external disks had failed (at fixed PISAs 5 and 6, at Brewster and Hesston, respectively), and thus the data were irretrievably lost. In retrospect, each AERI system should have used at least two external disks for safeguarding the data, or weekly sneakernetting of the data should have been conducted.

Additionally, the AERI deployed at fixed PISA 2 (Greensburg) had come directly from Australia (from the decommissioned TWP sites); it literally was received from the shipping company and deployed directly into the field for PECAN. Unfortunately, it was not recognized until later that this AERI system was not running well and was unable to keep its detector at cryogenic temperatures. The AERI mentor team is investigating the quality of the data to see if there are any periods when the data can be used. We knew there would be more risk associated with this AERI system because of the lack of time to evaluate the system's health before the campaign.

Figure 1 shows a timeline of when data were available from each AERI system during PECAN.

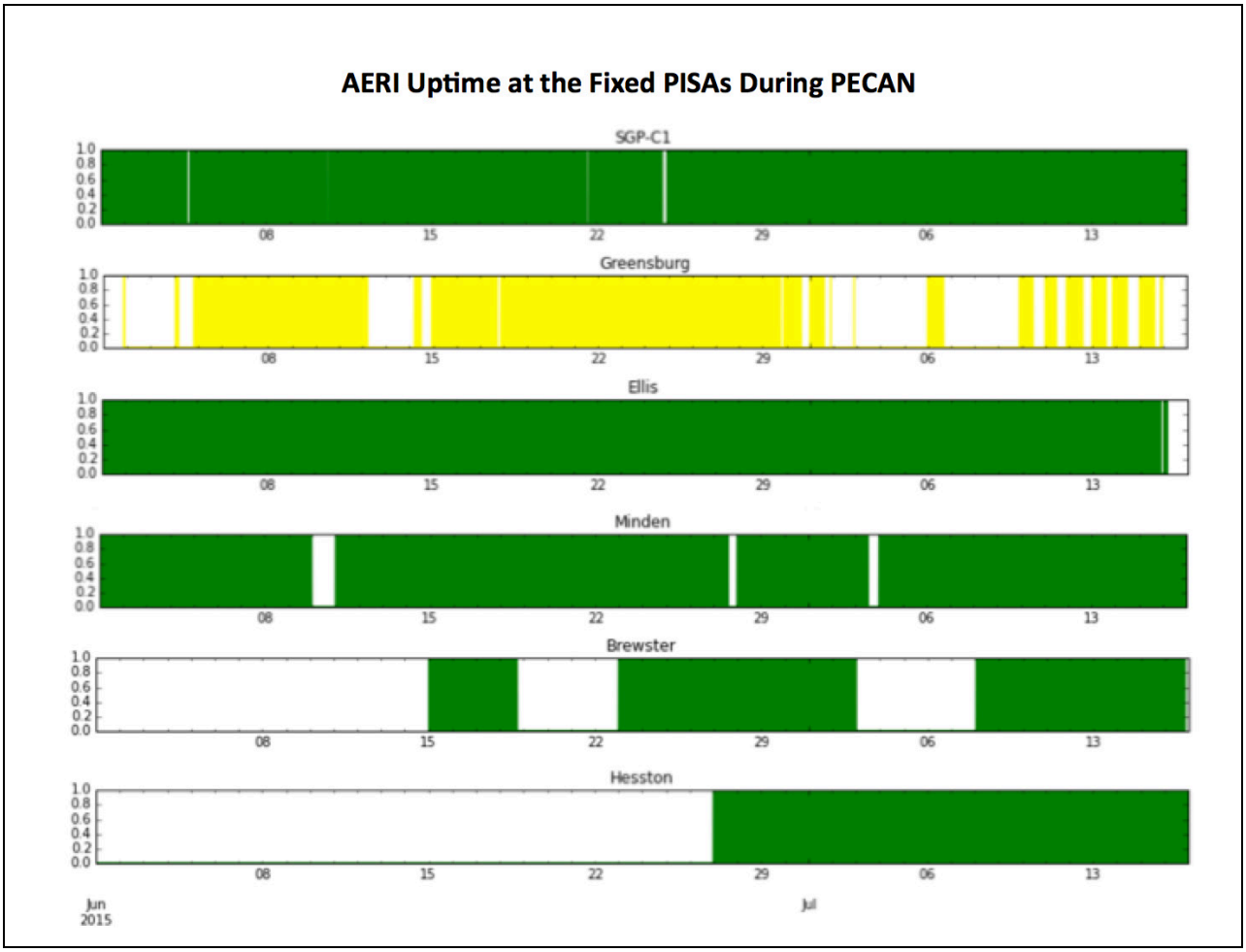

Figure 1. The green areas denote when AERIs at each fixed PISA (1 through 6 from top to bottom) were operating well over the 6-week PECAN period from 1 June through 15 July 2015. The AERI data quality at fixed PISA 2 (Greensburg) is currently unknown.

The met tower observations and the radiosonde profiles at fixed PISA 6 in Hesston are of high quality and will be an important part of the data analysis.

The ARM Doppler lidar, which was deployed with the other instruments in mobile PISA #3 (which was known as the SPARC system from the University of Wisconsin-Madison), operated well throughout the experiment. Like all of the other mobile PISAs, the SPARC redeployed every day to a new location and typically collected data for 4 to 12 hours during each IOP. In this mode, the Doppler lidar was placed on the ground next to the SPARC trailer (see Fig 2 for an example). The Doppler lidar performed a plane-parallel-indicator (PPI) scan at 70 degrees elevation every 2 minutes, with a sequence of 1-s vertical stares in between. The PPI scans were analyzed using the velocity-azimuth-display (VAD) technique to derive horizontal winds. The vertical stare data will be used to derive profiles of the variance and skewness of the vertical winds, similar to the ARM Doppler Lidar Profiles (DLPROF) value-added procedure (http://www.arm.gov/data/vaps/dlprof).

Figure 2. The University of Wisconsin-Madison SPARC facility, which was designated mobile PISA #3, during PECAN. The ARM Doppler lidar is shown deployed on the surface beside the trailer. The SPARC facility included an AERI and a High Spectral Resolution Lidar (HSRL) on board, and was able to launch radiosondes.

4.0 Results

The scientific analysis of the PECAN data sets has only just begun, as it took many months to perform the initial processing and quality control. There were some presentations at the 2016 Annual American Meteorological Society (AMS) meeting in New Orleans that used data from AS-PECAN; however, peer-reviewed manuscripts have not yet been produced.

5.0 Public Outreach

There were several public outreach events during PECAN. The ARM Facility's communication team produced 1-page handouts that were provided at each of these events.

The first occurred on 28 May 2015 in Hesston, Kansas. The town of Hesston was demolished nearly 25 years ago by an EF-5 tornado, and thus the residents of the town were very interested in this field experiment. Dave Turner and colleagues from the University of Oklahoma brought mobile PISA #1 (also known as the OU/NSSL CLAMPS system) and a mobile mesonet to the Hesston City Library, which advertised the event. Ken Cook, the Science Operations Officer from the National Weather Service Forecast Office in Wichita, also joined the event. Over 30 people from Hesston turned out for this event.

A large PECAN-wide outreach event was organized on 30 May 2015 in Ellis, Kansas. This event took place at the airport, and virtually all of the mobile facilities were present. Short presentations were given by the NSF program manager and the National Severe Storms Laboratory (NSSL) director, and representatives from several of the nearby National Weather Service Forecast Offices attended. It was estimated that over 200 people from the community attended this event.

Several other PECAN outreach events were conducted, including an open house at the Salina, Kansas, airport on 6 July. PECAN field work was featured in several newspaper articles, local TV news bulletins, radio interviews, magazines, blogs, etc. Several of these can be found at http://pecan15.org/home/ .

Figure 3. The PECAN mobile instruments at the Ellis, Kansas, airport during the PECAN public relations (PR) day on 30 May 2015.

6.0 AS-PECAN Publications

6.1 Journal Articles/Manuscripts

None yet.

6.2 Meeting Abstracts/Presentations/Posters

Geerts, B, T Weckwerth, D Parsons, and C Ziegler, 2015. "The 2015 Plains Elevated Convection At Night (PECAN) campaign: overview and preliminary results." Oral presentation at the 16th American Meteorological Society Conference on Mesoscale Processes, Boston MA, 3-6 August 2015.

Loveless, DM, N Smith, CM Rozoff, TJ Wagner, DD Turner, WF Feltz, and S Ackerman, 2016. "High temporal resolution ground-based observations of an eastern Kansas bore during the PECAN field campaign." Oral presentation at the 96th annual American Meteorological Society Meeting, New Orleans, LA, 10-14 January, 2016.

Weber, K, TM Weckwerth, and PD Blanken, 2016. "Using profiles of water vapor, vertical wind, temperature, and pressure from continuous-operated instruments to characterize turbulent patterns and fluxes between the surface and boundary layer during the PECAN 2015 field campaign." Poster presentation at the 96th annual American Meteorological Society Meeting, New Orleans, LA, 10-14 January, 2016.

Weckwerth, T, et al., 2015. "The 2015 Plains Elevated Convection At Night (PECAN) campaign: preliminary results." Oral presentation at the 37th American Meteorological Society Radar Meteorology Conference, Norman, OK, 14-18 October.

Turner, DD, SM Spuler, TM Weckwerth, and K Weber, 2016: Ground-based water vapor profilers: A comparison and combination of spectral infrared retrievals and differential absorption lidar observations. Oral presentation at the 96 annual American Meteorological Society Meeting.

7.0 References

Geerts, B, D Parsons, C Ziegler, T Weckwerth, D Turner, J Wurman, R Rauber, M Parker, R Schumacher, M Coniglio, K Haghi, W Gallus, B Demoz, K Knupp, R Ferrare, X Wang, J Hanesiak, and J Moore. 2016. "The 2015 Plains Elevated Convection At Night (PECAN) field project." *Bulletin of the American Meteorological Soc*iety; in preparation.

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