<u>Title:</u> Measuring Path-Averaged PM Concentrations Over Intermediate Path Lengths
<u>PI:</u> Brent W. Auvermann, Professor and Extension Specialist, Amarillo
<u>External Partner:</u> Kori Moore, Utah State University/Space Dynamics Laboratory
<u>Amount Requested Per Year:</u> $100,000 FY14; $100,000 FY15

<u>Executive Summary</u>

During the past year, we have assembled new evidence that doubling the stocking density in cattle feedyards reduces downwind concentrations and emission rates of coarse dust. The technique by which we measured (pseudo-)path-averaged dust concentrations during our 2012 study, however, was an innovation borne of necessity and does not yet enjoy wide recognition within the research community. We have identified a promising instrument based on eye-safe, widely accepted lidar technology that appears likely to fill the void in our inventory of dust-monitoring instruments for use with ground-level, agricultural area sources (GLAAS) like cattle feedyards and dairies.

We propose a two-year study that will validate this technology in a commercial feedyard setting, providing high-resolution but path-averaged concentration measurements across a wide, ground-level, plume cross-section. In FY14, we will leverage existing monitoring infrastructure at a cooperating feedyard to validate the use of eye-safe lidar, an optical instrument, in conjunction with periodic recalibration against mass-based standards, to generate a concentration distribution across a broad (>800 m wide) plume of fugitive dust from a cattle feedyard. The FY14 work will involve long-term, continuous monitoring of dust concentrations across the plume using both existing, real-time, gravimetric monitors and optical point monitors to develop a solid, multi-seasonal calibration data set for the FY15 work. Throughout, we will also run our mobile monitoring platform to collect the same kind of pseudo-path-averaged data that we collected in our 2012 stocking-density study, by which we will generate a calibration data set that can be used for retrospective validation and interpretation of data from the 2012 study.

The primary products of this research will be (1) a validated method of measuring the path-averaged dust concentrations in real time at path lengths suitable for GLAAS but capable of simultaneous, fine resolution within the plume in settings where researchers need to discriminate between neighboring treatments within the GLAAS (e.g., in abatement-measures studies), (2) one or more competitive proposals to the National Science Foundation's Major Research Instrumentation program for acquisition of multiple lidar units, and (3) a retrospective means of interpreting, and adding scientific value to, the extensive database of pseudo-path-averaged dust concentrations collected during the 2012 stocking-density study with an otherwise unvalidated, mobile monitoring platform.

<u>Goal</u>

The primary goal of the proposed research is to devise an accurate, repeatable method of measuring spatially resolved mass concentrations of aerosol continuously, in real time, across a fugitive dust plume from a ground-level, agricultural area source, in such a way that instantaneous, path-averaged concentrations within the plume can be computed over arbitrary path lengths within that plume. *Such a method will dramatically advance our capabilities to resolve spatial trends within the plume that can be attributed to the side-by-side implementation of abatement measures within large area sources*.

Objectives

1. Build an adequate, multi-seasonal database of coincident particle-mass and size-resolved particle-volume concentrations at a commercial cattle feedyard that permits detailed calibration of lidar ("light radar" or "LIght Detection and Ranging").
2. Calibrate the Utah State University Space Dynamics Laboratory (USU-SDL) compact eye-safe lidar system (CELiS) for use in transverse profiling of fugitive dust plumes between 350 and 3000 meters wide (common feedyard dimensions).
3. Demonstrate that a properly calibrated CELiS is able to resolve concentration differences within feedyard plumes over path lengths as low as six meters (6 m).
4. Develop a lidar-based method for retrospective interpretation of pseudo-path-averaged concentration data collected by a mobile monitoring platform in a 2012 evaluation of stocking density effects on feedyard dust emissions.

Background

The cattle-feeding industry has long insisted that the development and evaluation of abatement measures be the central focus of industry-sponsored air-quality research. In early 2012, our project team was approached by JBS Five Rivers Cattle Feeding to assist them with a controlled study of stocking density manipulation for control of fugitive dust emissions from one of their large cattle feedyards in the northern Texas Panhandle. At that time, the instrumentation available to Texas A&M AgriLife Research-Amarillo for measuring dust concentrations included only (a) Federal Reference Method (FRM) gravimetric samplers and tapered-element oscillating microbalances (TEOMs), which measure time-averaged and time-resolved concentrations, respectively, at *single points* within a dust plume, and (b) long-path visibility (LPV) transmissometers, which measure time-resolved, *path-averaged* concentrations over a *minimum* path length of 800 meters. By contrast, *the experimental designs available to us in the commercial feedyard setting required a very different monitoring capability*, which we did not have: time-resolved concentrations averaged over path lengths of 100-300 meters.

Not wanting to miss this golden opportunity to respond to the overture for full-scale abatement-measures research, we devised a customized, mobile monitoring platform to measure what might be termed *pseudo-path-averaged* dust concentrations. This monitoring platform, shown in figure 1, consisted of an all-terrain vehicle with a battery-operated optical particle sizer (OPS; Model 3330, TSI, Inc., Shoreview, MN) and a global positioning system receiver (GPS; Model "Dakota 20," Garmin, Inc., Olathe, KS) mounted on the ATV. The two instruments' clocks were closely synchronized so that we could easily build a position-vs.-concentration dataset from their respective output files.

The site of our stocking-density study was a small portion of feedyard "F" (FYF), which has a one-time capacity exceeding 50,000 head of beef cattle. The study domain consisted of two parallel rows ("J" and "K") of 19 pens each on the extreme upwind (S) side of the feedyard, the feed and working alleys of which were oriented E-W, or perpendicular to the prevailing wind direction (figure 2). This orientation of the pens allowed us to block the pens together in such a way that under prevailing winds and with low background dust from the upwind rangeland, we could be reasonably confident that the dust in the air immediately downwind of the pens would reflect the emissions from the three discrete treatments that were applied to the pens. Further, because we were working on the extreme upwind side of the yard (where the dust plume has not yet built to its downwind depth above ground), we mounted the sampling inlet for the OPS at a nominal height of 22” above ground level, right in the middle of the expected plume.

The three stocking-density treatments applied to the three blocks of pens were as follows:

TREATMENT	CTRL	TRT1	TRT2
J-Row Block	Pens J11-J19	Pens J6-J10	Pens J1-J5
K-Row Block	Pens K11-K19	Pens K6-K10	Pens K1-K5
Cattle Spacing	150 ft^2 hd^{-1}	75 ft^2 hd^{-1}	75 ft^2 hd^{-1}
Method	Industry Standard	Doubled Animal Numbers per Pen	Pen Area Reduced 50% by Fence

Treatments 1 and 2 were designed to achieve twice the industry-standard stocking density by two different means, both of which would have the combined effect of (a) concentrating excreted moisture on half the area per animal, (b) increasing the proportion of the pen area effectively shaded from solar radiation by the animals’ bodies, and (c) increasing the spatial density of compactive effort imposed on the corral surface by the animals’ hooves. Assuming that the combined effect would reduce dust emissions, the sponsor’s additional interest was the relative cost of each method, considering both the actual expenditures associated with maintaining electric cross-fencing (TRT2) and the financial losses associated with degraded feed efficiency where linear bunk space per animal was effectively cut in half (TRT1). For our purposes, however, the primary question was, “are the mass concentrations, mass emission rates per unit area (emission fluxes), and mass emission rates per animal unit (emission factors) of fugitive dust significantly reduced by the combined effects of doubled stocking density?”

Our monitoring approach, therefore, was to run the mobile monitoring platform in very slow circuits, or loops, around the project area, traveling at a ground speed of about 1 mph and focusing these monitoring activities on the well documented “evening dust peak” (nominally from 5-10 pm). With the OPS set to compute 1-minute averages during a single 30-minute loop, we obtained 15 data points upwind and 15 data points downwind of the pens during each circuit, roughly half of which were associated with the CTRL pens and half associated with the pens with doubled stocking density. We ran these monitoring circuits from June to October 2012 whenever labor was available, dusty conditions prevailed, and winds were light to moderate and generally southerly. We then created our position-vs.-concentration datasets and computed sub-circuit path averages that were associated with each of the three treatment blocks, taking into account the average wind direction during each circuit.

A detailed exposition of the results (which were, incidentally, favorable; see figure 3) is beyond the scope of this proposal and has been presented elsewhere (Bush and Auvermann, 2013). For purposes of this proposal, we emphasize that *any spatial averaging of the one-minute concentration data along the segments of the monitoring path that isolated each treatment block was at best a process of pseudo-path-averaging*. Moreover, the path lengths associated with segments effectively isolating the three blocks of pens were on the order of 100 to 200 meters, *well below the* *minimum path length required to use our LPV transmissometer* (Upadhyay et al., 2008). We were, in short, using a plausible but unvalidated monitoring approach that makes statistical analysis and data interpretation highly speculative, especially when it comes to publication in a scientific journal.

Still, the experimental design of the pens and source areas is precisely the kind of design we expect for a wide range of abatement-measures research at the full, commercial scale. Detailed, full-scale evaluation of e. g. solid-set sprinklers, manure-harvesting activities, and/or surface mulches would necessarily involve very similar settings. We need a monitoring technique that is much better suited to such a research geometry than our mobile platform, that generates true path-averaged concentrations rather than pseudo-path-averages, and that can be tied directly to methods already widely accepted in the broader scientific literature. Lidar is a prime candidate for such a technique, and at the conference in Denver where our stocking-density research was first presented, we were approached by scientists from Utah State University who were eager to show us a candidate lidar that they had developed for just these specialized, agricultural applications. This proposal is the fruit of that emerging collaboration.

<u>Methods, Deliverables, and Timeline</u>

We propose a two-year project (a) that leverages existing monitoring infrastructure on a cooperating cattle feedyard ("FYC") and (b) that positions us to link the results of this work with the ongoing research funded under this program for the FY12-13 biennium for the purposes of refereed publications and external proposals.

Objective 1 (FY2014). The first year of the project is essentially accumulating the collocated optical and gravimetric data that are essential to calibrating an optical technique like the lidar for use in mass-concentration measurement. During the past two years, we have deployed multiple TEOMs, instrument towers, a vertical lidar ceilometer, contrast-photometry targets, and wireless networking infrastructure along the downwind edge of FYC. In particular, we are now able, with the E-W linear array of TEOMs, to approximate the time-resolved, spatial distribution of PM_{10} *mass* concentration along the feedyard's downwind boundary. During the past three months, we have arranged to borrow indefinitely from USDA-ARS/Bushland four identical devices analogous to our OPS (Model DustTrak II, TSI, Inc., Shoreview, MN), which we will collocate with four of the TEOMs so as to generate simultaneous gravimetric and optical concentration data across all four seasons of the year. We will also deploy a 3-D sonic anemometer alongside our existing weather station at FYC, as needed for Objective 2.

Objective 2 (FY2014). Raw and summarized data will be provided to our partners at SDL on a quarterly basis. SDL scientists will prepare CELiS calibration curves from those data and adjust their standard operating procedures, if necessary, to accommodate any source-specific characteristics of the calibration data.

Objective 3 (FY2015). We will conduct, in conjunction with our partners at SDL, a five-day proof-of-concept campaign (see Appendix A, Section 2.2.1, "Task 1: Campaign 1") with the CELiS deployed at the western end of our existing monitoring area at FYC. The precise scheduling of this campaign will necessarily depend on both long-range weather forecasts and availability of SDL personnel to conduct the lidar campaign.

Objective 4 (FY2014, FY2015). During both the calibration-data and lidar-campaign phases of the project, we will periodically deploy our mobile monitoring platform immediately downwind of the TEOM array and other instrumentation deployed in the monitoring area. The pseudo-path-averaged data from the mobile platform will be compared with TEOM, DustTrak II, and lidar data to determine the extent to which the mobile-platform data from the 2012 stocking-density study can be retrospectively interpreted with greater certainty and improved comparability to standard research/ monitoring techniques.

Individual Responsibilities

Dr. Brent Auvermann (PI) will be responsible for overseeing the deployment, operation, maintenance, and data acquisition associated with Objectives 1 and 4. He will also serve as the single point of contact for our partners at SDL.

Mr. Kori Moore, SDL, will be responsible for coordinating and executing the calibration and field-campaign activities associated with Objectives 2 and 3. The scope of work represented by Mr. Moore's responsibilities is detailed in Appendix A.

Leveraging Resources

Prior Efforts and Success

During the past biennium (Sep 2011 - Aug 2013), we have submitted the following proposals for funding relevant to agricultural air quality. Successful or pending proposals are identified in **bold type**.

Auvermann, B. W. 2013. At last! A second, independent method: Estimating fugitive PM_{10} flux from commercial cattle feedyards using the "integrated horizontal flux" approach. Submitted to the Texas Air Research Center. $58,908. (pending)

Auvermann, B. W. 2013. Federal compliance monitoring of ambient fine particulate matter in Amarillo, TX. Submitted to Texas Commission of Environmental Quality. $12,454. (funded)

Auvermann, B. W. 2012. Anatomy of the evening PM_{10} peak at cattle feedyards. Submitted to the Texas Air Research Center. $44,064. (funded at $26,429)

Auvermann, B. W. 2012. Federal compliance monitoring of ambient fine particulate matter in Amarillo, TX. Submitted to Texas Commission of Environmental Quality. $11,305. (funded)

Auvermann, B. W., T. Kwon, R. E. DeOtte, S. Tao, and K. D. Casey. 2011. Laboratory and field validation of a spatially distributed, wireless sensor network for monitoring fugitive PM_{10} and NH_3 emitted by ground-level area sources. Submitted to the USEPA Next Generation of Air Monitoring Technologies program. $500,000; Auvermann share $227,172. (rejected)

Faulkner, B., and B. W. Auvermann. 2012. Regulatory implications of feedyard air quality research in Texas and Kansas, 2001-2012. Supplemental/redirected funding through the Federal Air Quality Initiative (Dr. J. M. Sweeten, Project Director). $23,249 (Auvermann share $12,000). (funded)

Pinedo, P., B. W. Auvermann, and B. Pinchak. 2012. Dynamics of animal activity and its association with peak particulate matter emissions at cattle feedyards. Submitted to the Texas Cattle Feeders Association. $12,556. (rejected)

Marek, G. W., K. Heflin, and B. W. Auvermann. 2012. Evaluating the dust abatement potential of stocking density manipulation as an alternative to feedlot sprinkler irrigation. Submitted to the Texas Cattle Feeders Association. $15,225. (rejected)

Targeted Future Sources and Seed-Funding Plan

During the next biennium, we expect to submit proposals *at least* to the following grant programs to leverage this work:

NSF Major Research Instrumentation program, 2014, acquisition of eye-safe lidar for path-averaged aerosol monitoring near ground-level area sources, $500,000

Texas Cattle Feeders Association, 2014, preliminary evaluation of feed supplements to reduce animal activity and associated dust emissions at cattle feedyards, $20,000

USEPA Science to Achieve Results program, 2014 and/or 2015, commercial-scale evaluation of fugitive-dust suppression techniques at cattle feedyards using eye-safe lidar, $250,000

Budget

Non-Equipment Direct Costs

FY2014 - $87,500

Personnel. We request $55,000 to underwrite the salaries and wages of Research Associate (Jack Bush; 0.7 FTE), Extension Associate (Kevin Heflin; 0.4 FTE), and student workers (n=2; 1000 person-hours/year).

Materials and Supplies. We request $15,000 for the purchase of software site licenses and upgrades; replacement pumps, pump-rebuild kits, filters, and other consumables for TEOMs and optical monitors; electrical and electronics supplies for repair and maintenance of line-power and DAQ systems; and shop supplies.

Other Direct Costs. We request $4,500 to underwrite state vehicle mileage; $5,000 to underwrite electrical utilities and wireless broadband internet service supporting our remote instrumentation at FYC; and $8,000 for specialized calibration and repair services (contingencies) for our aging TEOMs and our borrowed DustTrak II optical monitors.

FY2015 - $100,000

Personnel. We request $25,000 to underwrite the salaries and wages of Jack Bush (0.25 FTE) and Kevin Heflin (0.15 FTE).

Materials and Supplies. We request $5,000 for the purchase of replacement pumps, pump-rebuild kits, filters, and other monitoring consumables.

Other Direct Costs. We request $60,000 to underwrite a subcontract to SDL for "Campaign 1" as described in Appendix A (see esp. Sections 4-5). We will pursue funding for "Campaign 2" from external sources. We request $5,000 to underwrite electrical and internet utility contracts; and $5,000 for specialized calibration and repair services.

Justification for Capital Equipment

FY2014 - $12,500

A 3-D sonic anemometer and peripherals/cables/fittings (est. $2,500) will be required (see Appendix A, Section 3) to support SDL's lidar-data interpretation algorithms.

Our existing 4-wheel ATV for the mobile monitoring platform is nearing the end of its useful life (12 years). We are requesting $7,500 to replace the ATV, as it is a vital utility tool for all of our field operations.

We need to replace two staff workstations that are incompatible with the Windows 7 operating system and therefore do not meet AgriLife IT's security specifications. We propose to replace them at a combined cost of $2,500.

FY2015 - $0

No capital equipment is requested for FY2015.

APPENDIX B - Photos

Figure 1. Mobile monitoring platform for 2012 stocking-density study.

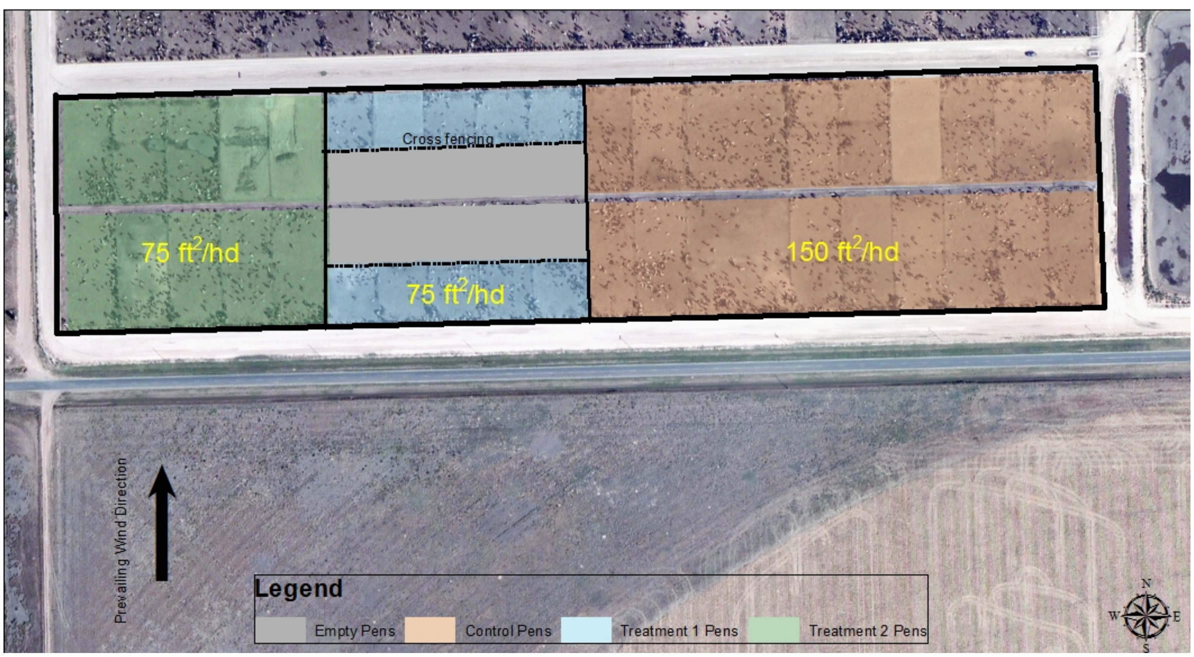

Figure 2. Two rows of pens at FYF used for the 2012 stocking-density study. The green area corresponds to Treatment 1, the blue area to Treatment 2, and the brown area to the Control treatment as outlined in the table on page 3 of the proposal.

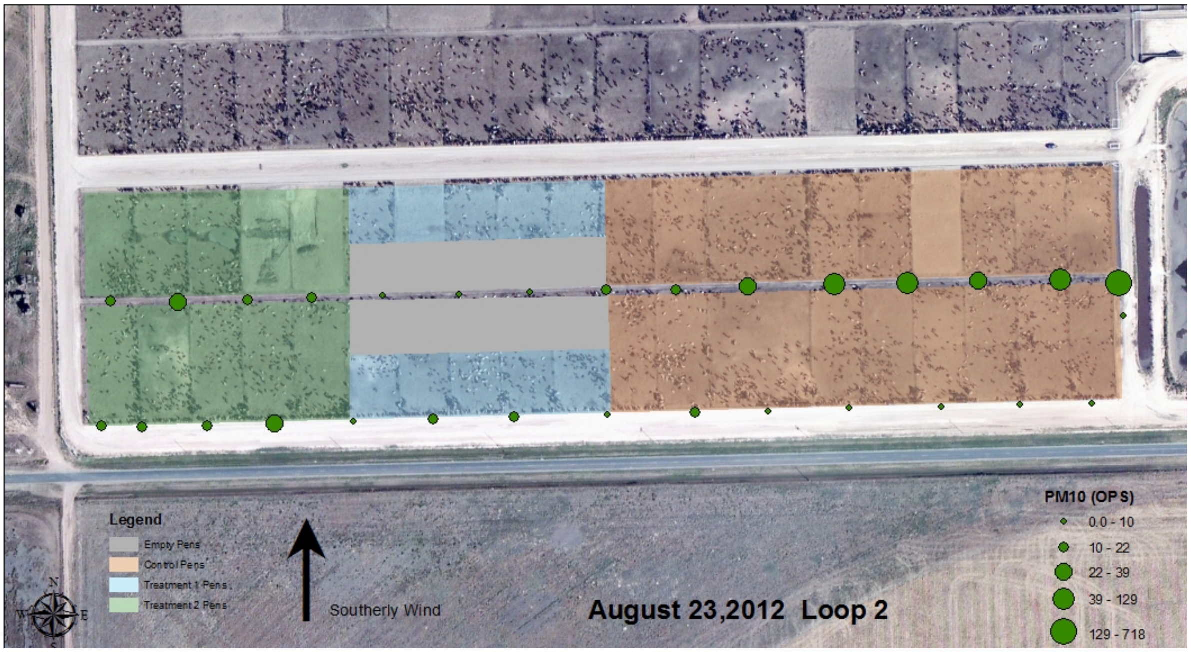

Figure 3. Example monitoring data (1-minute average concentrations) from the optical dust monitor on the mobile platform during a 30-minute circuit around the “J” row of pens. Larger green circles represent higher dust concentrations. The sizes of the circles downwind of the green and blue areas are a combined effect of reduced emission fluxes AND different source geometries, given that the source area in the blue block of pens excludes cattle from the area nearest the downwind monitoring segment.

APPENDIX C - Progress report on FY2012-13 funding

Summary. Our project team received a two-year grant for FY2012-13 to underwrite field implemen-tation of an "integrated horizontal flux" monitoring system at Feedyard C. We have made reasonable progress toward the objectives and deliverables, but overly optimistic scheduling and some important contingencies have combined to put us behind schedule as per the original timeline and milestones.

Current status. The 30' and 50' towers (four total), three TEOMs, and the ceilometer have been installed at FYC (figure C1). The three TEOMs and the ceilometer have operated continuously since the fall of 2011; the ceilometer (figure C2) has now been taken off-line to protect its sensitive optical glass until we are able to begin our intensive monitoring campaigns. We have successfully fabricated and mounted the aluminum instrument supports for the 2-D sonic anemometers, temperature/RH probes, and miniature Kwon nephelometers for both the fixed-mast, 30' towers (figure C3) and the tram-equipped, 50' towers (figure C4). The identical instrument supports have been fabricated for the telescoping, fixed-mast, 75' towers but have not yet been mounted pending installation of the towers. Serial data-acquisition connectivity with the Vaisala temperature/RH probes and 2-D sonic anemometers has been established through our serial/ethernet converters and has been verified in our instrumentation laboratory, and LabVIEW code has been successfully written to poll the sensors.

The 30' and 50' towers were not installed until fall 2012 because of a critical equipment failure in our 1980s-vintage boom/bucket truck, which we use to erect the towers safely and efficiently. During practice runs with the 30' towers at Bushland during spring 2012, the truck's transmission failed, making it impossible to adjust the truck's position as needed when erecting a tower. During the summer of 2012, when we were also presented with an important "research target of opportunity" (our JBS Five Rivers-initiated stocking-density study), our team stripped the truck of its non-essential components - it was formerly a military deicing truck at Sheppard AFB - completely rebuilt its transmission, and located replacements for its badly cracked, non-highway-worthy tires, which were replaced in early fall 2012. The bucket truck is now fully operational and roadworthy, and it has also passed an independent safety inspection for which we commissioned an independent inspector.

As detailed in the accompanying proposal, we were approached by JBS Five Rivers Cattle Feeding to assist them with a stocking density evaluation for dust control at Feedyard "F" (FYF). This was an exciting invitation, primarily because our first attempt to validate this method of dust control was poorly designed (ca. 1999-2000) and inconclusive. Executing this "research target of opportunity" required that we move our weather station from FYC to FYF; deploy three of our TEOMs, our monitoring trailer and PC, our 30 kW diesel-powered generator, and our wireless LAN system to FYF for the entire summer and early fall. It also required constant travel back and forth to FYF to assist with mobile monitoring activities, corral-surface assessments, manure-harvesting activities, collection of TEOM, GPS, and nephelometer data, and genset maintenance.

The “all-hands-on-deck” nature of the stocking-density study made it a significant sink of valuable personnel time, but it should redound to Texas A&M AgriLife Research’s long-term benefit as both (a) an important contribution to the cattle-feeding industry’s need for abatement-measures evaluations and (b) a source of preliminary data to support proposals for external funding.

Figure C1. Looking east along the downwind edge of Feedyard C, the 30’ and 50’ towers (n=4) are visible.

Figure C2. The CL31 lidar ceilometer is the white unit (R) in this enclosure, and we have collected about 8 months of preliminary data with it. It has been taken off-line for now to protect its optical surfaces until our field campaigns can get underway.


Figures C3 (L) and C4 (R). At left, one of two 30’ towers downwind of FYC, with its three fixed, aluminum instrument-support masts attached and visible. At right, one of two 50’ towers with its single, tram-mounted instrument-support mast visible.

APPENDIX D - References

Bush, K. J., and B. W. Auvermann. 2013. Evaluating the dust-abatement potential of stocking density manipulation at open-lot cattle feedyards. Presented at "From Waste to Worth: Spreading Science and Solutions," Denver, CO, 1-5 Apr.

Upadhyay, J. K., B. W. Auvermann, A. N. Paila, and N. Hiranuma. 2008. Open-path transmissometry to determine the atmospheric extinction efficiency of feedyard dust. *Transactions of the ASABE* 51(4):1433-1441.

Brent Walter Auvermann

Professor and Extension Specialist/Environmental Systems
Texas A&M AgriLife Extension Service (65%), Texas A&M AgriLife Research (35%)
Department of Biological and Agricultural Engineering, Texas A&M University
6500 Amarillo Blvd. West, Amarillo, TX 79106-1796
b-auvermann@tamu.edu

Education

Colorado State University, Ft. Collins, CO
Ph. D. in Chemical and Bioresource Engineering, 1996
Texas A&M University, College Station, TX
M. S. in Agricultural Engineering, 1990
B. S. in Agricultural Engineering, 1986
Texas Tech University, Lubbock, TX
Courses toward the B. S. in Electrical Engineering, 1982-1983

Professional Employment History

Texas A&M AgriLife Extension Service, Amarillo, TX
Professor/Extension Specialist, 2008-present
Associate Professor/Extension Specialist, 2002-2008
Assistant Professor/Extension Specialist, 1995-2002

Selected Publications

Sharratt, B., and B. W. Auvermann. 2013. Dust pollution from agriculture. Accepted for publication in: van Alfen, N. (ed.). *Encyclopedia of Agriculture and Food Systems*. Amsterdam: Elsevier B. V. (in press)

Sweeten, J. M., K. Heflin, B. W. Auvermann, K. Annamalai, and F. T. McCollum. 2013. Combustion-fuel properties of manure or compost from paved or unpaved cattle feedlots as modified by annual precipitation. *Transactions of the ASABE* 56(1):279-294.

Preece, S. L. M., B. W. Auvermann, J. C. MacDonald, and C. L. S. Morgan. 2013. Predicting the heating value of manure with visible and near-infrared spectroscopy. *Fuel* 106(1):712-717.

DeLaune, P. B., J. C. MacDonald, and B. W. Auvermann. 2012. Manure and runoff water quality from feedlots as affected by diet and pen surface. *Transactions of the ASABE* 55(6):2319-2324.

Buttrey, E. K., N. A. Cole, K. H. Jenkins, B. E. Clark, F. T. McCollum, S. L. Preece, B. W. Auvermann, K. R. Heflin, and J. C. MacDonald. 2012. Effects of 20% corn wet distillers grains plus solubles in steam-flaked and dry-rolled corn-based finishing diets on heifer performance, carcass characteristics, and manure characteristics. *Journal of Animal Science* 90(13):5086-5098.

Bonifacio, H., R. G. Maghirang, E. Razote, J. P. Murphy, J. P. Harner III, and B. W. Auvermann. 2012. Particulate matter emission rates from beef cattle feedlots in Kansas - reverse dispersion modeling. J*ournal of the Air & Waste Management Association* 62(3):350-361.

Eigenberg, R. A., B. L. Woodbury, B. W. Auvermann, D. B. Parker, and M. J. Spiehs. 2012. Energy and nutrient recovery from cattle feedlots. *ISRN Renewable Energy* (doi: 10.5402/2012/723829).

Hiranuma, N., S. D. Brooks, J. Gramann, and B. W. Auvermann. 2011. High concentrations of coarse particles emitted from a cattle-feeding operation. *Atmospheric Chemistry and Physics* 11(16):8809-8823.

Sakirkin, S. L. P., C. L. S. Morgan, J. C. MacDonald, and B. W. Auvermann. 2011. Effect of organic carbon source on the predictive ability of visible near infrared diffuse reflectance spectroscopy in characterizing solid cattle manure. *Applied Spectroscopy* 65(9):1056-1061.

Guo, L., R. G. Maghirang, E. B. Razote, and B. W. Auvermann. 2011. Laboratory evaluation of the dust control effectiveness of pen surface treatments for cattle feedlots. *Journal of Environmental Quality* 40(5): 1503-1509.

Todd, R. W., N. A. Cole, K. D. Casey, R. Hagevoort, and B. W. Auvermann. 2011. Methane emissions from southern High Plains dairy wastewater lagoons in the summer. *Animal Feed Science and Technology* 167(1): 575-580.

Vanderlick, F., R. McGee, C. B. Parnell, Jr., B. W. Auvermann, B. Lambeth, S. Skloss, and D. Roark. 2011. Comparison of TEOM and gravimetric methods of measuring PM concentrations. *Journal of Natural and Environmental Sciences* 2(1):19-24.

Bonifacio, H., R. G. Maghirang, E. B. Razote, B. W. Auvermann, J. P. Harner III, J. P Murphy, L. Guo, J. M. Sweeten, and W. L. Hargrove. 2011. Particulate control efficiency of a water sprinkler system at a beef cattle feedlot in Kansas. *Transactions of the ASABE* 54(1):295-304.

Rhoades, M., D. B. Parker, R. Todd, N. A. Cole, E. Caraway, B. W. Auvermann, D. R. Topliff, and G. L. Schuster. 2010. Continuous ammonia emission measurements from a commercial beef feedyard in Texas. *Transactions of the ASABE* 53(6):1823-1831.

Sakirkin, S. L. P., B. W. Auvermann, and C. L. S. Morgan. 2010. Effect of sample pre-processing and data post-processing methods on the determination of ash content in solid cattle manure with visible near-infrared diffuse reflectance spectroscopy. *Transactions of the ASABE* 53(2):421-428.

O'Connor, A. M., B. W. Auvermann, D. Bickett-Weddle, S. Kirkhorn, J. M. Sargeant, A. Ramirez, and S. G. Von Essen. 2009. The association between proximity to animal feeding operations and health outcomes in community members: a systematic review approach to evaluating the evidence. *PLoS ONE* 5(3): e9530. doi: 10.1371/journal.pone.0009530.

Hiranuma, N., S. D. Brooks, D. C. O. Thornton, and B. W. Auvermann. 2009. Atmospheric ammonia mixing ratios at an open-air cattle feeding facility. *Journal of the Air & Waste Management Association* 60(2):210-218.

Preece, S. L., C. L. S. Morgan, B. W. Auvermann, K. Wilke, and K. Heflin. 2009. Determination of ash content in solid cattle manure with visible near-infrared diffuse reflectance spectroscopy. *Transactions of the ASABE* 52(2): 609-614.

Upadhyay, J. K., B. W. Auvermann, A. N. Paila (graduate student), and N. Hiranuma (graduate student). 2008. Open-path transmissometry to determine the atmospheric extinction efficiency of feedyard dust. *Transactions of the ASABE* 51(4):1433-1441.

Hiranuma, N., S. D. Brooks, B. W. Auvermann, and R. Littleton. 2008. Using environmental scanning electron microscopy to determine the hygroscopic properties of agricultural aerosols. *Atmospheric Environment* 42(9): 1983-1994.

Cole, N. A., R. Todd, B. W. Auvermann, and D. B. Parker. 2008. Auditing and assessing nutrient management for air quality. *The Professional Animal Scientist* 24(1):1–22.

Kalbasi, A., M. Schutz, and B. W. Auvermann. 2008. Carcass rendering system for farm mortalities: a review. *Journal of Environmental Engineering and Science* 7(3):199-210.

Wyatt, T. A., R. E. Slager, J. DeVasure, S. Von Essen, B. W. Auvermann, T. Mathisen, and D. J. Romberger. 2007. Feedlot dust stimulation of interleukin-6 and -8 requires protein kinase C-epsilon human bronchial epithelial cells. *American Journal of Physiology-Lung Cellular and Molecular Physiology* 293(5):L1163-L1170.

Kalbasi, A., S. Mukhtar, S. E. Hawkins, and B. W. Auvermann. 2006. Design, utilization, biosecurity, environmental and economic considerations of carcass composting. *Compost Science and Utilization* 14(2):90-102.

Von Essen, S. and B. W. Auvermann. 2006. Health effects from breathing the air near CAFOs for feeder cattle or hogs. *Journal of Agromedicine* 10(4): 55-64.

Razote, E. B., R. G. Maghirang, B. Z. Predicala, J. P. Murphy, B. W. Auvermann, J. P. Harner III, and W. L. Hargrove. 2006. Laboratory evaluation of the dust-emission potential of cattle feedlot surfaces. *Transactions of the ASABE* 49 (4):1117-1124.[1]

Kalbasi, A., S. Mukhtar, S. E. Hawkins, and B. W. Auvermann. 2005. Carcass composting for management of farm mortalities: a review. *Compost Science and Utilization* 13(3):180-193.

Parker, D. B., L. J. Perino, B. W. Auvermann, and J. M. Sweeten. 2000. Water use and conservation at Texas High Plains beef cattle feedyards. *Applied Engineering in Agriculture* 16(1):77-82.

Parker, D. B., B. W. Auvermann, and D. L. Williams. 1999. Comparison of evaporation rates from feedyard pond effluent and clear water as applied to seepage predictions. *Transactions of the ASAE* 42(4):981-986.

Selected Awards

G. B. Gunlogson Countryside Engineering Award, American Society of Agricultural and Biological Engineers, 2013.

Superior Service Award (Specialists category), Texas AgriLife Extension Service, 2012.

N. Mitchell Young Extension Worker award, American Society of Agricultural and Biological Engineers, 2004.

R. E. Stewart Engineering-Humanities award, American Society of Agricultural Engineers, 1991.

National Excellence in Multistate Research Award, Experiment Station Committee on Organization and Policy (ESCOP), June 2011. (USDA-NIFA Multistate Research Committee S-1032)

Vice Chancellor's Award in Excellence for Research, Texas A&M AgriLife, 2009.

Texas Environmental Excellence Award-Agriculture, Texas Commission on Environmental Quality, 2010.

Kori D. Moore

Environmental Engineer II
Space Dynamics Laboratory
1695 North Research Park Way
North Logan, UT 84341

Phone: (435) 713-3848
Fax: (435) 713-3402
Email: kori.moore@sdl.usu.edu

EDUCATION

Ph.D. Civil and Environmental Engineering — Expected 2014
UTAH STATE UNIVERSITY, Logan, UT

M.S./B.S. Civil and Environmental Engineering (Concurrent Program) — 2007
UTAH STATE UNIVERSITY, Logan, UT

- M.S. Thesis: Derivation of Agricultural Gas-Phase Ammonia Emissions and Application to the Cache Valley

EMPLOYMENT HISTORY

2007 - Present
Space Dynamics Laboratory and Energy Dynamics Laboratory
Utah State University Research Foundation
North Logan, UT
Civil/Environmental Engineer II

2005 - 2007
Utah Water Research Laboratory
Utah State University
Logan, UT
Research Assistant

2003 – 2005 Summers
Summer Undergraduate Research Experience
Global Change Education Program
2004, 2005 Aerodyne Research, Inc.
Billerica, MA
2003 Pacific Northwest National Laboratory
Richland, WA
SURE Fellow

SELECT PEER REVIEWED ARTICLES

Moore, K.D., M.D. Wojcik, R.S. Martin, C.C. Marchant, G.E. Bingham, R.L. Pfeiffer, J.H. Prueger, and J.L. Hatfield. 2013. Particulate emissions calculations from fall tillage operations using point and remote sensors. *J. Environ. Qual.* doi: 10.2134/jeq2013.01.0009.

Marchant, C.C., K.D. Moore, M.D. Wojcik, R.S. Martin, R.L. Pfeiffer, J.H. Prueger, and J.L. Hatfield. 2011. Estimation of dairy particulate matter emission rates by lidar and inverse modeling. *Trans. ASABE* 54(4):1453-1463.

Rogers, P.C., K.D. Moore, and R.J. Ryel. 2009. Aspen succession and nitrogen loading: a case for epiphytic lichen as bioindicators in the Rocky Mountains, USA. *J. Veg. Sci.* 20: 498-510.

Bingham, G.E., C.C. Marchant, V.V. Zavyalov, D.J. Ahlstrom, K.D. Moore, D.S. Jones, T.D. Wilkerson, L.E. Hipps, R.S. Martin, P.J. Silva, and J.L Hatfield. 2009. Lidar based emissions measurements at the whole facility scale: method and error analysis, *J. Appl. Remote Sens.*, 3(1); 033510.

V.V. Zavyalov, C.C. Marchant, G.E. Bingham, T.D. Wilkerson, J.L. Hatfield, R.S. Martin, P.J. Silva, K.D. Moore, J. Swasey, D.J. Ahlstrom, and T.L. Jones. 2009. Aglite lidar: calibration and retrievals of well characterized aerosols from agricultural operations using a three-wavelength elastic lidar, *J. Appl. Remote Sens.*, 3(1): 033522.

Martin, R.S., P.J. Silva, K. Moore, M. Erupe, and V.S. Doshi. 2008. Particle composition and size distributions in and around a deep pit swine operation, *J. Atmos. Chemistry*, 59(2), 135-150.

SELECT PROCEEDINGS/REPORTS/PRESENTATIONS

Moore, K.D., M.D. Wojcik, C.C. Marchant, R.S. Martin, R.L. Pfeiffer, J.H. Prueger, J.L. Hatfield. 2011. "Comparisons of measurements and predictions of PM concentrations and emission rates from a wind erosion event," Paper, Presentation, and Poster #11020, ASABE International Symposium on Erosion and Landscape Evolution, Anchorage, AK, September, 2011. – *3rd Place, Student Poster Competition*.

Martin, R., K. Moore, M. Mansfield, S. Hill, K. Harper, H. Shorthill. Final Report: Uinta Basin Winter Ozone and Air Quality Study. EDL/11-039. Submitted to Uintah Impact Mitigation Special Service District.

Moore, K., R. Martin, W. Bradford, C. Marchant, M. Wojcik. 2010. "Deriving empirical relationships between aerodynamic and optical aerosol measurements", Poster #2.F.29, AAAR 29th Annual Conference, Portland, OR, October 2010.

Wojcik, M.D., K.D. Moore, R.S. Martin. 2010. "Successful strategies for using lidar for particle characterization of point and diffuse area sources", Paper # 352, AWMA International Specialty Conference on Leapfrogging Opportunities for Air Quality Improvement, Xi'an, Shaanxi Province, China.

Going, C., G. Bingham, N. Pougatchev, E. Day, K. Moore, R. Martin, and E. Reese. 2008. "Multi path FTIR agriculture air pollution measurement system," Paper Number 08, 2008 ASABE Annual International Meeting, Providence, RI, June, 2008.

Moore, K. & V. Doshi. 2005. Indoor/Outdoor particulate matter concentration and composition at four schools in the Cache Valley. Presented at the Air & Waste Management Association's 98th Annual Conference, Student Poster/Paper Competition. Minneapolis, MN, June, 2005. - *1st Place, Undergraduate Division*

AFFILIATIONS

Air and Waste Management Association, since 2004
American Association for Aerosol Research, since 2007
American Society of Agricultural and Biological Engineers, since 2007

Space Dynamics
LABORATORY
Utah State University Research Foundation

Texas Feedlot Lidar Particulate Matter Study

Rough Order of Magnitude (ROM)

Submitted To:
Brent Auvermann, Ph.D.
Texas A&M AgriLife Extension
6500 Amarillo Boulevard West
Amarillo, TX 79106

Submitted By:
Space Dynamics Laboratory
A Unit of the Utah State University Research Foundation
1695 North Research Park Way
North Logan, Utah 84341

PROPRIETARY DATA NOTICE

This proposal contains data that shall not be disclosed outside Texas A&M AgriLife Extension and shall not be duplicated, used or disclosed – in whole or in part – for any purposes other than to evaluate this proposal. If, however, a contract is awarded to this offeror as a result of – or in connection with – the submission of this data, Texas A&M AgriLife Extension shall have the right to duplicate, use or disclose the data to the extent provided in the resulting award. This restriction does not limit Texas A&M AgriLife Extension's right to use information contained in this data if it is obtained from another source without restriction. The data subject to this restriction are contained in sheets marked "Proprietary."

DOCUMENT NUMBER: SDL/13-318
REVISION: –
DATE: 21 MAY 2013

CHANGE RECORD

REV	DATE	DESCRIPTION OF CHANGE	ALTERED BY
–	21 May 2013	Original Release	–

TABLE OF CONTENTS

1. INTRODUCTION

The Space Dynamics Laboratory (SDL), a not-for-profit unit of the Utah State University Research Foundation (USURF), is pleased to provide this Rough Order of Magnitude (ROM) proposal for two field studies of particulate matter (PM) concentrations immediately downwind of cattle feedyards in northern Texas using a light detecting and ranging (lidar) system. This ROM is designed to support Texas A&M AgriLife Extenstion in its mission to accomplish the following objectives: 1) demonstrate the capability of an eye-safe lidar built by SDL to accurately detect and quantify PM plumes emitted by the feedlot, specifically PM with an equivalent aerodynamic diameter less than or equal to 10 μm in diameter (PM_{10}); and 2) utilize this lidar system to assess the effects of different stocking densities (area per animal) on downwind PM concentrations.

The lidar system to be deployed is the Compact Eye-Safe Lidar System (CELiS) developed by SDL (Figure 1). It is a tactical, tripod-mounted lidar operating at a wavelength of 1.5 μm with a bin length of 6 m and an operational range of 350 to 3000 m. In-situ measurements of optical particle size distribution and mass concentration are used in algorithms developed by SDL to convert the lidar return signal to particle volume and mass concentrations.

Figure 1. A photograph of the CELiS instrument.

2. SCOPE OF WORK

2.1 MANAGEMENT TASKS

SDL will plan, organize, monitor, and control the work necessary to implement the technical tasks described herein. SDL will provide overall cost, schedule, and contract management for this effort. SDL will provide program status reports summarizing the task progress and any issues affecting the program cost or schedule.

2.2 TECHNICAL TASKS

SDL will perform the following technical tasks in order to meet the two objectives stated in Section 1.

2.2.1 Task 1: Campaign 1

SDL will conduct a field study lasting 5 days at Feedyard "C," located in Randall County, Texas, USA (34.657799 N, 101.789343 W) in cooperation with Dr. Brent Auvermann, Texas A&M AgriLife Extension. The purpose of this campaign is to: 1) validate the use of SDL's lidar ensemble to estimate path-averaged, ground-level mass concentrations of fugitive PM_{10} downwind of a commercial-scale cattle feedyard, using as reference standards a linear array of tapered-element oscillating microbalances (TEOMs; model 1400ab, Thermo Fisher, Inc.); and 2) validate the use of SDL's lidar ensemble to measure the distribution of feedyard PM_{10} particle concentration across a transverse cross-section of the whole feedyard dust plume, using as reference standards an array of tower-mounted optical monitors (TSI OPS, DustTrak II, other similar monitors).

Collected lidar data will be analyzed in order to yield PM_{10} mass concentrations in each range bin. This analysis will require optical particle size distribution information and mass concentration information, to be provided by the TSI OPSs (or other similar monitors) and the Thermo Fisher TEOM, respectively. The product of this validation effort will be the raw data, analyzed data, and a summary of the analysis and findings of the comparison between the PM_{10} concentrations calculated from lidar data and those measured by the TEOM.

A pre-deployment site visit will be performed at the first of period of performance (PoP) to assess the site and instrumentation layout in order to verify the suitability of the site and optimize deployment of CELiS. A site visit to the feedlot selected for Campaign 2 will also be conducted at this time.

2.2.2 Task 2: Campaign 2

Contingent upon successful completion of Task 1 (Section 2.2.1), SDL will conduct a field study lasting 12 days at Feedyard "F," located in Hartley County, Texas, USA (35.849299 N, 102.474753 W) in cooperation with Dr. Brent Auvermann, Texas A&M AgriLife Extension. The purpose of this campaign is to measure true path-averaged PM_{10} mass concentrations at maximum spatial resolution (6 m) at 1 meter height above ground level downwind of cattle pens subjected to two stocking-density treatments, 75 ft^2/head and 150 ft^2/head.

Collected lidar data will be analyzed in order to yield PM_{10} mass concentrations in each range bin. This analysis will require optical particle size distribution information and mass concentration information, to be provided by the TSI OPSs (or other similar monitors) and the

Thermo Fisher TEOM, respectively. The product of this validation effort will be the raw data, analyzed data, and a summary of the analysis and findings of the comparison between the PM_{10} levels detected downwind of the two stocking density treatments.

A pre-deployment site visit is planned to be conducted on the same trip as the pre-deployment site visit for Campaign 1 (see Section 2.2.1).

2.3 TRAVEL

This proposal includes the following travel for the technical tasks described in Section 2.2.

# of Trips	Destination	# of Travelers	Duration	Purpose
1	Amarillo, TX	1	3 days	Pre-deployment site visit
1	Tulia, TX	3	9 days	Campaign #1
1	Hartley, TX	2	16 days	Campaign #2

2.4 PERIOD OF PERFORMANCE

The period of performance (PoP) for this effort is June 1, 2014, through October 30, 2014. Task 1 will take place in June through July 2014, with Task 2 scheduled for August through October 2014.

2.5 DELIVERABLES

SDL will provide the following deliverables.

CDRL No.	Title	Format	Due
1	Results from the Texas Feedlot Lidar Particulate Matter Study, Campaign 1	Summary document with associated raw and analyzed data	July 31, 2014
2	Results from the Texas Feedlot Lidar Particulate Matter Study, Campaign 2	Summary document with associated raw and analyzed data	October 30, 2014

3. CUSTOMER FURNISHED EQUIPMENT/INFORMATION

SDL assumes that the Texas A&M AgriLife Extension Service will provide the following items necessary for this effort:

Item #	Item	Needed By
1	Optical particle counter(s) reporting particle size distribution deployed on-site throughout the duration of lidar measurements during each campaign. Access to raw data will be required.	Start of each campaign
2	Instruments measuring particulate matter mass concentrations deployed on-site throughout the duration of lidar measurements during each campaign. Access to raw data will be required.	Start of each campaign
3	Meteorological instruments measuring air temperature, humidity, barometric pressure, wind speed, and wind direction. Wind speed and direction should be monitored using a 3D sonic anemometer. Access to raw data will be required.	Start of each campaign

4. ESTIMATED COST

SDL/USURF proposes a Cost Plus Fixed Fee (CPFF) type contract. The estimated (ROM) cost for this effort is $123,443 as shown in the following table. Table 1 provides a summary of the estimated cost for both tasks, and a total cost. The cost associated with Task 1 is $58,970; the cost associated with the performance of Task 2 is $64,473. All associated direct and indirect costs have been included in this estimate.

Table 1. Summary of Total Estimated Costs for the Proposed Field Studies

	Campaign 1	Campaign 2	Total
Labor	39,062	43,476	85,538
Travel	19,908	17,997	37,905
Total	58,970	64,473	123,443

5. ROM ASSUMPTIONS

Days required to travel between Logan, Utah and northern Texas for the pre-deployment site visit and the field campaigns have been included in the trip duration. A single day of travel (each way) is budgeted for air travel and 2 days of travel (each way) are budgeted when traveling by vehicle; standard GSA travel rates are assumed.