not provide information that could be linked to particular train movements. So while the data confirmed that dusting had indeed occurred, I did not believe these data would be particularly useful in setting a coal dust emission standard applicable to individual trains.

Second, and more important for my purposes, BNSF and SWA had set up a Track Side Monitor ("TSM") at milepost 90.7. The TSM is a combination weather tower and coal dust monitor that collects data on each train as it passes by the TSM. *See* Exhibit 1. Towers were set up on both sides of the tracks so that dust readings could be made from the downwind tower. The dust monitor on the TSM is a sophisticated electronic device, called an e-sampler, that measures coal dust in the air at five-second intervals. SWA had developed a methodology for summing up all of the dust units recorded by the e-sampler in five-second intervals over the period of time that a particular train was passing the TSM. SWA was also able to identify and exclude from the dust units measured by the e-samplers the dust units that were attributable to the diesel locomotives on the train and the dust units attributable to background dust in the air before and after the passage of the train. The graph attached at Exhibit 2 illustrates the process by which these adjustments to the e-sampler readings were made. Using this approach, SWA was able to calculate a total number of coal dust units measured by the e-samplers for specific trains as they passed Milepost 90.7. The total dust unit calculation for a particular train was called the "Integrated Dust Value" or IDV of that train.

By the time I started working on the coal dust project, SWA had collected IDV data on thousands of trains passing Milepost 90.7. However, not all IDV calculations were considered reliable indicators of the amount of dust attributable to a particular train. For example, if a loaded train passing Milepost 90.7 was closely following another loaded train, it was possible that the coal dust units attributable to the second train were in fact produced by the first train.

Therefore, SWA excluded IDV readings where two trains passed within minutes of one another. Even with these exclusions, SWA had IDV data for several thousand trains.

SWA and BNSF's Technical Research and Development group had also set up several test trains with instruments mounted on the trains. The instruments included an Rail Transport Emission Profiling System ("RTEPS") and Passive Collectors ("PCs"). The RTEPS are essentially mobile weather stations that record real time data regarding ambient conditions (e.g., temperature, rainfall, humidity, wind speed) over the course of a train trip. *See* Exhibit 3. The Passive Collectors are boxes attached to the sill of coal cars that collect coal dust particles as they are blown off of the loaded coal. *See* Exhibit 4. Passive Collectors were generally set up on several different cars in a test train. RTEPS data was recorded over the full length of the train trip and the coal collected in the PCs would be gathered at various intervals along the trip.

Through these three data-gathering approaches, BNSF had collected a vast amount of data on coal dust and coal dust emissions in the PRB. Before attempting to develop a specific coal dust emission standard, I did several analyses of the data collected by SWA to see whether it was possible to isolate specific causes of coal dust emissions from loaded trains. For example, I looked at the data collected by SWA from the Track Side Monitors to analyze the effect of wind and train speed on the emission of coal dust from trains passing Milepost 90.7. I determined the vector speed for each train from the TSM data on the wind speed, wind direction and train speed at the time the train passed Milepost 90.7 and did a regression analysis of vector speed and dusting episodes as measured by the TSMs.

This analysis suggested that the relationship between dusting events and vector speed was not a linear one. Wind was clearly an important factor in dust emissions, but I found that as vector speed increased, the amount of dust emitted from a passing train did not increase in a linear fashion. *See* Exhibit 5. I did additional analyses to determine whether other factors such as time of day would explain the dust events occurring at Milepost 90.7 and found no other significant relationships. I concluded from these analyses that the causes of coal dust emissions at Milepost 90.7 were largely attributable to factors affecting the coal before the trains arrived at the TSM monitoring station. For example, the dryness of the coal by the time a train reached Milepost 90.7 clearly affected the likelihood that dust would be emitted. Wet coal loaded into the coal cars at the mines could dry out at varying rates based on weather conditions. The amount of dust in the coal itself when loaded into the cars would also affect the likelihood of dust emissions at Milepost 90.7.

Creation of an IDV-Based Coal Dust Standard

After working for a few months on the coal dust project, I was asked by William VanHook, Assistant Vice President and Chief Engineer - Systems Maintenance and Planning, the person heading up BNSF's efforts on the coal dust issue, to determine whether a coal dust emission standard could be developed that would identify, on a train-specific basis, trains emitting exceptional levels of coal dust. In response, starting in late 2006, I focused my efforts on the development of a coal dust emission standard.

As noted above, the TSMs mounted at Milepost 90.7 calculated an IDV for each loaded train passing that point on the Joint Line. By late 2006, when I started working on the development of a coal dust emission standard, SWA had made IDV calculations for over 10,000 trains. I concluded that the IDV calculations could be used to set a performance standard that would allow BNSF to identify trains that are producing excessive amounts of coal dust. However, before establishing a specific performance standard, I wanted to be sure that the measurements being made by the e-samplers used to calculate IDV values were reliable. I was somewhat concerned about the month-to-month variation I was seeing in the IDV data that had been collected. Therefore, over several months I worked with SWA to conduct laboratory and field tests of the e-samplers to determine the extent to which the e-samplers could produce varying measurements of the same coal dust source.

In these tests, two e-samplers were placed side-by-side with a common air intake to make coal dust measurements of the same source of coal dust. At Milepost 90.7, we mounted two e-samplers side-by-side and collected dust data from the devices for several months. We also did laboratory tests where we did the side-by-side tests on three additional e-samplers in pairs of two (1/2, 1/3, 2/3). In total, we had nearly 400 data points showing simultaneous measurements from two e-samplers in the side-by-side tests. We found that each of the side-by-side e-samplers generated a somewhat different reading of dust units even though the same source was being analyzed. For example, one e-sampler unit might read 100 dust units while another e-sampler at its side might read 125 dust units from the same dust source. We concluded that the likely cause of this variation was the fact that coal dust particles are not evenly distributed in the air. However, the data we collected from these e-sampler tests allowed us to determine the range of variation in e-sampler readings from a common source. My study results are set out at Exhibit 6.

The variation in e-sampler readings meant that it was not possible to have a high degree of confidence that a particular e-sampler reading of coal dust units could be replicated exactly by other e-samplers measuring the same dust source. However, the test results also made it possible to have a high degree of confidence that a particular e-sampler reading would be within a defined range of possible values as measured by other e-samplers. Therefore, I concluded that a valid standard for coal dust emissions could be based on the e-sampler readings taken at Milepost 90.7 so long as it took account of the variation inherent in the e-samplers measuring coal dust.

To develop an appropriate coal dust emission standard, I started with the IDV data collected from the TSM at Milepost 90.7 on all trains passing that location from September 2005 through August 2007 (excluding the data for trains that passed too close to one another to produce reliable values, as discussed above). As I explained above, the IDV for a particular train represents the number of dust units measured by the e-sampler during the passage of that train by Milepost 90.7. By August 2007, when I began my data analysis, SWA had improved on the development of the IDV calculation by removing additional data associated with locomotives and with background dust values. A description of SWA's improvement upon the IDV calculation is set out in Exhibit 7. The improved IDV calculations are referred to as IDV.2. SWA revised all prior IDV calculations for the trains moving between September 2005 and August 2007 to recalculate IDV.2 values for each train using the improved IDV.2 logic.

I took the IDV.2 calculations for all usable trains from this period and added together the dust units that had been measured for that group of trains over the two-year period. This produced a total of about 2 million dust units. I could then determine an IDV.2 value which, if not exceeded by the trains in the group, would have reduced those 2 million dust units by varying percentages. For example, if my goal was to achieve a 50% reduction in the 2 million dust units, I would seek to identify the IDV.2 value which, if not exceeded by any of the trains in the data set, would have resulted in only 1 million dust units being emitted from the study trains during the study period. For a 75% reduction, I would seek to identify the IDV.2 value which, if not exceeded by any of the trains in the data set, would have resulted in only 500,000 dust units being emitted from the study trains during the study period.

To carry out this analysis, I plotted on a graph the threshold IDV.2 levels on one axis and on the other axis the percentage reduction in dust units for the corresponding threshold IDV.2

levels. *See* Exhibit 8 at BNSF_COALDUST_0039335. Exhibit 8 is an October 9, 2007 internal presentation I made at BNSF describing my methodology. The graph showed the percentage of dust units that would have been reduced if all trains in the data set had been at or below specific "threshold" IDV.2 levels. For example, the graph shows that if no trains operated with an IDV.2 level above 2,000, about 25% of the dust units would have been eliminated. Similarly, if an IDV.2 level of 1,000 had never been exceeded by the trains in the data set, about 50% of the dust units would have been eliminated. I was told by Steve Bobb, the Group Vice President, Coal Marketing, who was an active participant in the coal dust review group at BNSF, that I should strive for a 95% reduction in coal dust. I determined that an IDV.2 level of 134, if never exceeded by the trains in the data set, would have achieved a 95% reduction in coal dust units at Milepost 90.7.

This was not the end of the analysis, however, because it was necessary to take into account the variability in e-samplers. As discussed above, two e-samplers measuring the same coal dust source could produce IDV.2 values within a defined range. To determine the range of variability of the e-samplers, I charted all the data from the side-by-side e-sampler measurement tests from the laboratory and in the field. See the two fitted line plots on Exhibit 8 at BNSF_COALDUST_0039336. Each point on the plot represents the IDV.2 values recorded on two e-samplers that had been placed side-by-side. The chart shows for any given IDV.2 value on Monitor B (x axis) the corresponding IDV.2 value that was produced by Monitor A (y axis) in the side-by-side test. In the right-hand chart, the solid line is the ideal regression line of all plotted values and values between the dashed lines contain 90% of all the values. By using 90% of the values, 5% of the values were above the dotted line and 5% were below the line. This allowed me to account for 95% of the expected variation in the dust monitors. The chart goes past 2,000 but I was interested in what is happening around 134 IDV.2, which I had previously determined to be the threshold IDV.2 value for eliminating 95% of the coal dust units. The chart to the left is a blow up of the chart on the right, focusing on the values only up to 500 IDV.2

To account for the e-sampler variability, I placed a vertical line at 134 on the x-axis. The points along that vertical line indicate that a reading of 134 on Monitor B corresponded to readings on Monitor A of between about 100 and about 300. Therefore, to be within the upper limit of the 90% dotted lines, the value on Monitor A could be as high as 300. I did the same analysis for Monitor A by drawing a horizontal line at 134 from the y axis. Again, to be within the upper limit of the 90% dotted lines, a reading of 134 on Monitor A could have been as high as about 280 on Monitor B. The values of 280 and 300 are close enough that an IDV.2 standard of 300 would give 95% confidence that the actual IDV.2 value of the reading is at least 134. In other words, taking the variability of the e-samplers into account, it is 95% certain that a train producing over 300 IDV.2 dust units is actually producing over 134 IDV.2 dust units.

This is a highly conservative standard. It is certainly possible that a train producing, for example, 250 IDV.2 dust units is actually producing 250 IDV.2 dust units, far in excess of what is needed to eliminate 95% of the coal dust. But given the variability of the e-samplers, it is also possible that the train producing 250 IDV.2 dust units is actually producing less than 134 dust units. Therefore, BNSF set the IDV.2 limit at 300 to make sure that trains in fact producing less than 134 IDV.2 units would not be found to violate the standard.

I then returned to the graph discussed above that compared the percentage reduction of coal dust units to IDV.2 levels. See Exhibit 8 at BNSF_COALDUST_0039337. The data show that at a 300 IDV.2 level, there is a high degree of confidence that coal dust emissions would be reduced by at least 85%. If none of the trains in the data set had an IDV.2 exceeding 300, 85%

of the total coal dust from these trains would have been eliminated. Thus, while BNSF wanted to set a standard that achieved a 95% reduction in coal dust emissions, the variability of the e-samplers required that we accept a somewhat lower reduction. Given the conservative approach I took, I have a high degree of confidence that compliance with the coal dust emissions standard by all trains passing Milepost 90.7 will eliminate at least 85% of the dust emissions at Milepost 90.7.

I conducted a similar analysis to determine a coal dust limit using TSM data for trains passing Milepost 558. *See* Exhibit 9. My analysis of the Milepost 558 data produced an IDV.2 limit of 245.

Verification of the IDV.2 Methodology

Before BNSF established the IDV.2 standard as an operating rule, I wanted to obtain an independent review of the approach I had taken in developing the coal dust emissions standards. I first contacted a firm called Six Sigma Qualtec and provided them with the data set I had used to develop the IDV.2 standard and explained to them BNSF's basic objectives. Qualtec raised two issues with my analysis. First, they noticed that the data had numerous zero values (IDV.2 readings of zero) and they suggested that the zero values should not be used. I disagreed. It is not a valid scientific approach to exclude data unless there is reason to believe the data are flawed or unreliable. Given the highly episodic nature of coal dust emissions, where loaded coal will remain highly stable for periods of time before being released, there was no reason to believe that the zero IDV.2 readings reflected a flaw in the instruments or data; instead, those zero values reflected that certain trains did not emit dust at measurable levels at Milepost 90.7. Qualtec also noted that the variability of the e-samplers was not constant across the entire range of IDV.2 values. While this was true, it was not particularly relevant to the standard BNSF had developed because the variability of IDV.2 values in the range of the standard that I had determined (around 134) was relatively constant.

We contacted another independent Six Sigma firm, Smarter Solutions, to review our standard setting process. Smarter Solutions had a Six Sigma Master Black belt who had worked previously with the type of specialized equipment BNSF was using at the TSMs to calculate IDV.2 values. After reviewing my analysis and the underlying data, Smarter Solutions concluded that it was appropriate to leave the zeros in the analysis. They further concluded that there was no reason to address the fact that variability was not constant over the entire range of IDV.2 values, since variability was relatively constant within the range of values where the standards were being set. Overall, Smarter Solutions agreed that the approach I had taken was a reasonable one. *See* Exhibit 10. In fact, they concluded that BNSF was probably being too conservative, and they suggested that an IDV.2 value of 231.4 could be used as the dust emissions limit at Milepost 90.7. Nevertheless, BNSF chose to remain with its conservative limit of IDV.2 300. BNSF implemented that standard as a Joint Line operating rule and included that standard in BNSF's rules in 2009.

I declare under penalty of perjury that the foregoing is true and correct. Further, I certify that I am qualified and authorized to file this Verified Statement.

Executed on March 15, 2010

Charles Sultana

VERIFIED STATEMENT OF G. DAVID EMMITT

BEFORE THE
SURFACE TRANSPORTATION BOARD

STB Finance Docket No. 35305

PETITION OF ARKANSAS ELECTRIC COOPERATIVE CORPORATION FOR A DECLARATORY ORDER

VERIFIED STATEMENT OF G. DAVID EMMITT IN SUPPORT OF BNSF RAILWAY COMPANY'S OPENING EVIDENCE

My name is G. David Emmitt. I am the President and Senior Scientist of Simpson Weather Associates ("SWA"). SWA is a scientific research and development firm that focuses on environmental and energy issues. For over twenty five years, I have worked at SWA on matters related to fugitive coal dust and its mitigation. SWA was retained by BNSF in 2005 to assist BNSF in understanding the scope of the problem of coal dust escaping from loaded coal trains in the Powder River Basin ("PRB") and to investigate remediation measures. The purpose of my statement is to describe for the Board the extensive data collection and analysis that I and my firm have carried out for BNSF in the past five years to provide BNSF with a quantitative foundation for establishing standards on coal dust emissions.

Background and Experience

In 1975 I received a Ph.D. in Environmental Sciences (Atmospheric Physics) from the University of Virginia, Charlottesville, Virginia. After a post doctorate tenure as a Visiting Scientist at the Max Planck Institute for Meteorology in Hamburg, Germany, I spent the first five years of my career studying hail storms in South Africa while maintaining my association with the University of Virginia as a Research Assistant Professor. In 1981, I accepted a position of Visiting Space Scientist at NASA's Marshall Space Flight Center in Huntsville, Alabama. Since my tenure at NASA, I have continued to be actively engaged in the use of airborne Doppler Wind LIDARs to investigate the atmosphere (tropical cyclones, tornadoes, etc.) and to prepare for a future space-based wind LIDAR. In 1983, I joined SWA and brought my LIDAR research with me. In 1984, I became involved in basic and applied research associated with fugitive dust emissions from coal piles. This interface between the atmosphere and a significant environmental issue became the focus of laboratory, field and theoretical investigations continuing to the present. SWA has become known for its unique expertise in the understanding, monitoring and control of fugitive coal dust emissions from coal storage piles and rail cars. My CV is attached to this statement as an Appendix.

During the past 26 years, I have led a small team of researchers in projects funded primarily by the private sector (coal companies, railroads, chemical companies, and utilities) focused upon reducing product losses from coal storage piles and open rail cars. In addition, I have received funding from the Center for Innovative Technology to develop techniques for imaging the load profiles of coal in rail cars. The scope of our work ranges from the theoretical (mathematical expressions for the propensity of coal to be blown into the air by the action of air in motion) to the operational deployment of scanning lasers to produce 3D images of the coal loaded in rail cars. SWA continues to perform laboratory evaluations of chemical binders, often referred to as "surfactants" or "topper agents," used to control fugitive dust emissions. I use the term "binder" in this statement to refer to these chemical solutions.

SWA is best known for its unique capabilities in the area of fugitive coal dust emissions from rail cars. My first project involving material losses from coal cars was funded by Norfolk Southern Railway ("NS") in 1987, and led to an extensive, five-year study. Through the use of instrumented caboose, laboratory and field experiments, SWA expanded its understanding of how coal is lost during transit and how to reduce those losses through load profiling and chemical binders. SWA also developed unique technologies for assessing coal losses. These technologies include the TrackSide Monitor ("TSM") which is installed next to the tracks to detect and quantify dust emissions from passing trains, the Rail Transport Emission Profiling System ("RTEPS") which is attached to the rear sill of coal cars and the laser based Coal Car Load Profiling System ("CCLPS") which provides a 3D image of the coal load in a rail car. NS continues to operate a program of fugitive dust control and performance monitoring based on SWA techniques in Virginia, Ohio and Pennsylvania, and provides annual reports on its performance.

The Problem of Coal Dust

The scope of coal mining operations and coal transportation in the PRB is impressive. A large amount of coal is moved out of the PRB. Thousands of loaded coal cars are transported over the same rail lines each day. If coal escapes from these loaded cars and is deposited on the right of way, coal will accumulate rapidly. Others have studied the impact of coal deposits on rail ballast integrity and have found that coal dust accumulation has serious adverse effects on rail ballast integrity.

The presence of coal along the right of way on the Joint Line in eastern Wyoming is obvious to anyone that has spent time in the area. In many places, there are visible deposits along the right of way. In other places, removing the small top layer of soil or ballast reveals coal beneath the surface. I have spent much of my professional career working with railroads and I have never seen such extensive right-of-way contamination as that which occurs in the PRB from coal that has escaped from coal cars.

There are a multitude of factors that influence the amount of coal that escapes from coal cars in transit and contaminates the rail ballast. The type of coal at particular mines, the size of the coal loaded into coal cars, the way the coal is processed at the mines, and the way coal is loaded by the mines into coal cars all have an impact on the amount of coal that is lost in transit. Numerous other factors also impact dusting. Weather is an important factor. Dry coal tends to escape from coal cars much more readily than moist coal, so weather conditions that produce dry coal can dramatically affect the amount of coal escaping from coal cars. Wind conditions – particularly the strength and direction of wind relative to the train movement – also affect the amount of coal dust produced by moving coal cars. Train speed is a primary and obvious covariate with coal dust emissions.

Simple observation of coal trains in transit makes it clear that dusting, *i.e.*, instances when dust escapes from the moving car, is highly episodic. Coal dusting does not regularly occur at the same time or place for each coal train. Coal that is moist and relatively stable when loaded can dry out as the train moves through dry air until the coal surface becomes highly unstable. In my experience, a coal train can be moving rapidly with no emission of coal dust and suddenly large plumes of dust can escape with no apparent immediate cause. My opinion is that while the coal from some mines tends to have a higher incidence of coal dusting than others, all mines experience some significant dusting events of their coal during transit.

<u>Coal Dust Data Collection and Analysis</u>

In May 2005, there were two coal train derailments within days of one another on the Joint Line that caused massive dislocations in rail operations in the PRB. I understand that BNSF subsequently concluded that the presence of coal dust in the ballast contributed to those derailments. Shortly after the derailments, BNSF retained SWA to obtain a better understanding of the scope of the coal dust problem in the PRB and to begin to identify ways to remediate coal dust accumulation. A major objective of the work my firm was asked to perform was to rigorously collect and analyze data relating to the loss of coal from the tops of moving coal cars.

Even before I started working with BNSF in 2005, BNSF had been studying the problem of coal dust. An environmental engineering firm, Conestoga-Rovers Associates ("CRA"), had worked with BNSF to get a basic understanding of the scope of the coal dust problem. With CRA's assistance, BNSF had set up dust fall collectors near the rail ballast along the Joint Line to assess the amount and type of coal that was escaping from moving coal cars. BNSF had also looked at ballast samples to determine the extent of fouling produced by the presence of coal in the ballast.

After the derailments, BNSF wanted to expand its data collection efforts and to identify measures that could be taken to remediate coal dust emissions. BNSF retained SWA to assist in those efforts. I have worked extensively with BNSF since 2005 to define the coal dust problem in and near the PRB and to help BNSF keep its shippers informed of BNSF's investigations. I have also kept the Union Pacific Railroad Company ("UP") informed of SWA's work relating to the Joint Line, as UP is a co-owner of the Joint Line. I attended several meetings of the National Coal Transportation Association ("NCTA") and made numerous presentations at those meetings reporting on the research SWA was carrying out for BNSF.

Our efforts for BNSF focused on the following areas.

Load Profiling

One of the first things I did after being retained by BNSF was to advise BNSF on the benefits of changing the profile of the coal loaded into the coal cars. I have studied the dynamics of coal dust emissions extensively. I applied that knowledge in my work with NS to change the loading profile of coal in NS coal cars to reduce the emission of dust from their cars. It was immediately clear to me from my review of coal car loading in the PRB that a change in the loading profile could also bring about a measureable reduction in PRB coal losses during transit.

Coal cars were being loaded with trapezoidal shapes and sharp edges. But as the cars move, the wind and vibration of the cars tend to groom the coal in the cars into a more aerodynamic shape. In this process of self-grooming during transit, substantial amounts of coal are blown around and off of the cars. I advised BNSF that the mines should load coal cars into the shape that would naturally be created by the wind to minimize the disruption of the coal during transit. *See* Exhibit 1.

While I had done studies of the optimal load profile for NS on eastern coal, PRB coal had different characteristics. Therefore, I did additional testing to determine an appropriate profile for the PRB coal. The important issue here was the angle of repose for dry PRB coal. I determined that a 30-degree angle was appropriate – if coal was loaded at an angle exceeding 30 degrees, coal would seek a 30-degree angle as it dried and the loose coal would blow off of the cars as it settled into the 30-degree angle. I provided BNSF with an optimum load profile and helped BNSF convince the mines to modify their loading behavior. *See* Exhibit 2.

We initially encountered resistance from mines in seeking a change in the loading profile. One concern was that a modified loading profile would reduce the amount of coal that could be loaded into the cars. I did some tests with laser imaging and showed the mines that the modified profiles would simply redistribute the coal in the car but would not reduce the amount of coal that could be loaded into the cars. Since then, the mines have modified their loading chutes and the loading profile has improved. *See* Exhibit 3.

I also assisted in conducting field tests to determine the amount of coal dust emissions that could be reduced by loading coal to the proper loading profile. Our initial tests were performed by grooming loaded coal cars with a type of rake attached to a back hoe, although later tests were conducted on coal cars that had been loaded with modified loading chutes. I describe below the process that I developed for testing coal trains in transit using specialized instruments, including a Passive Collector ("PC") mounted on the rear sill of loaded coal cars. A PC is a metal box that captures coal dust blown into the box as the train moves. To test the relative impact of a properly profiled coal car, we attached PCs to the rear sill of cars that had been groomed by the profile bars and to cars that had not been groomed. We collected the coal that accumulated in the different PCs over a train trip and weighed the coal deposits. These simple tests performed on a very limited number of trains suggested that proper grooming of coal cars could achieve in some cases over 30% reduction in coal loss during transit. *See* Exhibit 4. I have subsequently come to believe, based upon dustfall collector data, that in practice the actual reduction in coal emissions from grooming is considerably less than 30%. *See* Exhibit 5 at BNSF_COALDUST_0064122. I believe the substantially smaller benefit we are seeing is likely attributable to widely varying loading practices at the mines, which do not always give proper attention to the load profile during the loading process. Use of a modified loading chute is not enough to ensure proper grooming of coal cars. In order to monitor loading practices and load profiles, SWA will install permanent CCLPS systems. The CCLPS system is a laser imaging system that produces a 3-D image of the loading profile of a passing loaded coal car. *See* Exhibit 6. Our objective is to provide immediate feedback to mine loading operators on the profile of loaded cars so that the mines can refine their loading practices to achieve the proper loading profile.

Track Side Monitors

My work for NS also involved establishing field monitoring stations that can sample the amount of coal dust emitted by particular trains. Building on my NS experience, I provided BNSF with design specifications and instruments for Track Side Monitors. A TSM is a combination of a weather system and a dust monitor mounted on a tower about 60 feet to the side of the track. *See* Exhibit 7. The dust monitor data collected from these instruments is telemetered directly to SWA from Wyoming to Charlottesville, Virginia.

The weather system on the TSM provides real time continuous measurement of wind speed and direction, precipitation, temperature and relative humidity. The dust monitor on the TSM is mounted on the tower at about the height of the top edge of the cars. The dust monitor is an electronic device, the Met One Instruments E-Sampler, which continuously draws in ambient air, passes light through the air and measures the scattering of light that results from particles in the air. *See* Exhibit 8. The dust monitors produce a relative measure of the amount of dust in the air in dust units. The dust monitors are highly sophisticated instruments that are programmed to self-calibrate every 12 hours. They are the only such units that we have found suitable for long-term outdoor operations. It is my view that the E-Sampler dust monitors are the best possible equipment available for field monitoring and sampling of dust emissions from individual moving coal trains. In particular, the continuous sampling of air every five seconds allows measurement of dust emissions over the entire length of the passing train.

Two E-Sampler dust monitors are located at the Milepost 90.7 TSM on the Joint Line, one on a tower west of the tracks and one on a tower east of the tracks. Two E-Sampler dust monitors are also located at Milepost 558.2 TSM on BNSF's Black Hills Subdivision, one on the north and one on the south side of the tracks. Two E-Sampler dust monitors have also been set up at Milepost 693.4 TSM on BNSF's Big Horn Subdivision on the north and south sides of the tracks. At or near each location of the TSM, there is an Automatic Equipment Identifier ("AEI"), or other railroad train presence devices that allow us to identify each passing train. In addition, wheel detectors have been installed on the tracks at each TSM location that indicate train presence. The wheel detectors are also used to determine the train's speed. *See* Exhibit 9 at BNSF_COALDUST_0000693.

As indicated, the E-Sampler monitors dust by continuously sampling the air. Dust monitor readings are collected and stored every five seconds, whether a train is present or not. Wheel detectors and AEI data provided by the railroad indicate when the dust monitor readings can be assigned to a specific train. The dust readings registered by the dust monitors of each five-second sample, which effectively produce a snapshot of that point in time, are then integrated over the entire time period that the train is passing the TSM to determine a relative comparable measure of the amount of dust that was emitted by a passing train. The results can be plotted on a graph. *See* Exhibit 10 at BNSF_COALDUST_0039367.

As seen in the graph, there are spikes in the dust readings associated with the passage of the diesel locomotives. The dust readings associated with the diesel locomotives can be identified and removed from the calculation of the total number of dust units. In addition, it is clear from the graph that the dust monitors register background dust before and after the passage of a train. In order to focus only on the coal dust emitted from a passing train, this background dust reading is also removed from the total. In addition, only the dust values above the background level are included in the calculation. What is left after these adjustments is a reading of the total amount of coal dust, in relative "dust units," that are emitted by a passing train. The total is called the "Integrated Dust Value" or "IDV" of a particular train. The IDV.2 referred to in the BNSF Rules Publication at issue in this case reflects certain improvements in the logic used to calculate the dust units associated with the passing trains, as described in Exhibit 10. Some trains are not assessed an IDV.2 because of high or variable background dust measurements, coincident train passage or equipment malfunction.

The E-Sampler dust monitors used at the TSMs exhibit some variability when measuring coal dust, as do all monitors to some degree. In other words, two dust monitors may give slightly different dust unit readings for the same plume of dust. SWA and BNSF conducted laboratory and field tests of these monitors to determine the extent of the variability. Tests were conducted with side-by-side dust monitors. The variation in dust unit readings from these side-by-side tests appears to be attributable to the fact that individual dust particles have varying size and shape and are not evenly distributed in the air. Thus, even when a common source of coal dust is tested, light will be reflected differently on the different particles in each sample, leading to somewhat divergent readings. Mr. Charles Sultana of BNSF took account of this variability in the E-Sampler dust monitors when he determined the IDV.2 limit that is at issue in this case. BNSF's use of the E-Samplers and the corresponding IDV.2 calculations for individual trains provides BNSF with a reliable way to monitor coal dust levels on a train-specific basis and to identify trains emitting excessive levels of coal dust.

Dustfall Collectors

As I noted above, before I began working for BNSF, BNSF and its consultants at CRA had set up a number of dustfall collectors to get an idea of the amount of coal that was escaping from loaded coal trains. I used SWA's modified dustfall collector design, based upon the American Society for Testing and Materials ("ASTM") standard, and expanded the network of collectors. *See* Exhibit 11 at BNSF_COALDUST_0080213-17. Dustfall collectors are an approved ASTM method of measuring dust fall at specific locations. I also recommended that the dustfall collectors be set up at varying distance from the tracks so that the amount of coal dust could be evaluated as a function of distance from the tracks.

The dustfall collectors cannot be used to determine the amount of coal that is emitted from individual trains. As discussed above, we use the TSMs to measure coal dust emitted from individual trains. Rather, the dustfall collectors measure the coal deposited at a particular location over time. Coal is collected from the dustfall collectors for approximately 30 days and the amount of coal accumulation is measured. Over time, it is possible to detect patterns of coal dust emissions and deposits on the ground. For example, it is clear that coal dust emissions appear to be greatest in winter months, due to higher wind speeds and lower atmospheric moisture. *See* Exhibit 11 at BNSF_COALDUST_0080217. The dustfall collectors will also be a valuable tool to measure the overall impact of dust suppression measures taken by coal shippers when BNSF's coal dust standards go into effect.

Instrumented Trains

Based on my work with NS, I also adopted for BNSF testing devices that can be mounted on individual coal cars on particular trains. The devices consist of a Rail Transport Emission Profiling System and Passive Collectors. *See* Exhibit 11 at BNSF_COALDUST_0080229-30. The RTEPS contains several instruments that are used to monitor various external factors that can affect coal dust emissions. The RTEPS includes an airborne dust monitor similar to the E-Samplers used at the TSMs, a precipitation gauge, a monitor for ambient temperature and relative humidity, a propeller anemometer, an infrared sensor to measure the surface temperature of coal in the car, and a Global Positioning System. The RTEPS is mounted directly onto a car in a test train, usually a car toward the end of the train. The RTEPS collects data for the test train on the ambient stresses (e.g., temperature, wind conditions) applicable over the entire route of the train.

In addition, the instrumented trains contain PCs, which, as described previously, are wind tunnel designed boxes mounted on the rear sill of a coal car. The boxes collect coal that is blown into the boxes over the course of a train trip. These passive collectors are usually mounted on several cars in the test train. Passive collectors are typically mounted at least 20 cars behind the lead locomotive to avoid contamination of the materials collected in the passive collectors by influences of the locomotives. At various intervals along the route, the passive collectors are emptied and the coal accumulated in the collector is weighed.

Since 2005, we have conducted more than 100 tests with the RTEPS/PC instruments. One objective of these tests was to confirm that substantial amounts of coal dust are being emitted from the top of coal cars. In BNSF's discussions with coal shippers and mines, there was some skepticism at first that coal was actually coming off the top of coal cars in significant quantities. The RTEPS/PC analyses showed that there were in fact significant episodes of coal dust emissions along the route of movement. *See* Exhibit 12.

The instrumented trains were also used to test the effectiveness of modifying the loading profile, as discussed above. Instrumented trains were also used to test other possible dust suppression measures, most importantly, the use of binders or surfactants. SWA's efforts to assist BNSF and its shippers to understand the value of binder use is discussed below.

Binder Testing

There is substantial experience outside of the PRB in the use of chemical binders to limit coal dust emissions from moving coal cars. Binders can be used as "body treatments" or "topical treatments." When used as body treatments, the binder is applied before the coal is loaded into the car. As topical treatments, binders are sprayed on top of a loaded coal car. Topical binders limit coal dust emissions by creating a crust of individual particles stuck together that prevents dust from escaping or by creating a flexible, adhesive coating on top of the coal. Binders have been used by NS to control coal dust emissions for their export coal in the East. Binders are also widely used in Canada and in Australia to limit coal dust emissions.

BNSF asked SWA to assist in evaluating the impact of binders on coal dust emissions. Many binders are available for use on loaded coal cars. The various chemicals have different characteristics and varying degrees of effectiveness in coal dust suppression. Indeed, the same chemical binder may act differently when used on coal of different type or mixed with water having differing chemical properties. We performed extensive laboratory tests on different chemical binders to determine whether the products met basic standards. SWA's tests included tests for the depth of penetration by the sprayed surfactant, the curing and drying time and simulated wind/thermal stresses, among other things. *See* Exhibit 13. SWA has tested close to 100 products.

In addition, SWA used the trains set up with RTEPS/PCs to carry out field tests on certain selected binders. Since 2005, SWA has carried out these instrumented train tests on over 100 trains with coal cars that had been treated with binders. The field tests generally involved applying the binder solution on half of the loaded cars on a train and leaving the other half of the train untreated. Passive collectors were mounted on cars in both sections of the test trains. The coal dust from each PC was collected and measured. We found that the effectiveness of binders varied based on the chemical used, the ambient conditions at the time of application, and the care with which the binders were applied. We also found that the binders worked best when applied to loaded coal cars that had been loaded according to our suggested load profile. Our tests showed that coal dust emissions from loaded coal cars could be reduced as much as 95% to 98% when properly loaded and treated with dust suppressing binders. *See* Exhibit 14. It is clear that there are products available to coal shippers and the mines that would effectively eliminate coal dust from moving trains.

BNSF has recently initiated a more extensive field test of binders with the participation of several coal shippers, mines and chemical vendors. The objective of the current field test is to give the interested parties the data that will allow them to evaluate and compare the effectiveness of different chemical binders and to choose optimal mitigation measures. SWA is assisting BNSF in this field test. SWA is conducting laboratory tests on binders that will be used in the field tests to determine whether they meet basic standards necessary to achieve a substantial reduction in coal dust emissions. SWA is also assisting in the preparation of instrumented trains that will be used in the field tests and will be collecting and compiling the data from the test trains to share with participants in the trial.

Based on my research, data analysis and testing of coal dust, I am confident that the use of careful profiling of coal loads and application of appropriate binding agents to the top of loaded coal cars would bring about a reduction of coal dust emissions sufficient to meet BNSF's IDV.2 standard.

I declare under penalty of perjury that the foregoing is true and correct. Further, I certify that I am qualified and authorized to file this Verified Statement.

Executed on March 15, 2010

G. David Emmitt

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EDUCATION:

Ph.D., 1975, University of Virginia, Charlottesville, VA, Major: Meteorology
"Momentum redistribution by enhanced mixing over a heated island"

M.S., 1972, University of Virginia, Charlottesville, VA, Major: Environmental Sciences, "Wind wave prediction on impounded water bodies: a case study, Smith Mountain Lake"

B.S., 1969, Eastern Nazarene College, Wollaston, Massachusetts, Major: Physics

PRESENT EMPLOYMENT:

April 1998-present	President and Senior Scientist, Simpson Weather Associates, Inc.
July 1992-present (int)	Research Associate Professor (Scholar in Residence), University of Virginia, Department of Environmental Sciences

PREVIOUS EMPLOYMENT:

August 1986-April 1998	Executive Vice President & Senior Scientist, Simpson Weather Associates, Inc.
August 1983-August 1986	Vice President, Simpson Weather Associates, Inc.
July 1981 - August 1983	Visiting Space Scientist, Universities Space Research Association, NASA/MSFC, Huntsville, AL

January 1978 - December 1980	Research Assistant Professor, University of Virginia, Department of Environmental Sciences, Charlottesville, VA
August 1978 - July 1981	Cloud Physics Consultant, Butler National Corporation Lenexa, KS
August 1976 - January 1978	Visiting Scientist, Max-Planck Institut fur Meteorologie Hamburg, West Germany
August 1975 - August 1976	Research Associate/Assistant Professor, University of Virginia

PROFESSIONAL ACHIEVEMENTS:

2008: Appointed to the Interactive Information and Processing Systems Committee of the American Meteorological Society
2007: Appointed Member of ISETCSC External Advisory Committee
2006: Nominated for the National Academy of Sciences (Atmospheric Panel)
2005: Member of Mission Definition Team for global laser wind sounder
2004: Selected member of NOAA's Thorpex Science Implementation Team
2002: Elected Fellow, American Meteorological Society
2001: Selected member of NASA's Global Tropospheric Wind Sounder Science Team
2000: Selected member of NASA's Code Y Information Technology Subcommittee of Earth Science Advisory Committee
2000: Elected Chair of NASA's Working Group on Space-based Hydrology Mission
1999: Elected Chair of NASA's Consolidated Space Operations Contract (CSOC) Science Working Group
1999: Selected member of NASA's New Data Information System Study team
1998: Elected Chairman, NASA's EOSDIS Science Panel
1997: Mission Scientist on NASA's Space Readiness of Coherent Lidar Experiment
1996: Chairman, NASA/GSFC's DAAC User Working Group
1994: Received "Heros of Reinvention" Award from Vice President Gore in recognition of work done on NASA's Earth Observing System Data Information System
1993: Appointed to NASA's Focus Team on Science and Data Organization/Access
1992: Selected to serve on NASA/CNES (USA/French) Joint Science Team for a space-based Doppler lidar.

1991: Selected to serve on NASA's EOSDIS Version 0 Science Advisory Panel.
1991: Elected to serve as Chairman of NASA's Hydrologic Cycle Data Access and Archive Working Group.
1990: Selected as member of NASA's Earth Observing System Data Information System Science Advisory Panel.
1989: Selected to serve on NASA's Lidar Atmospheric Wind Sounder Science Team to guide the development, deployment and use of a space-based lidar for global wind measurement.
1988: Served on NASA's GLOBE science committee for research on the global distribution of aerosol backscatter.
1987: Served on EPA's Meteorology Division In-House Peer Review Panel.
1987: Served on the 5-man Cloud/Chemistry Cloud Physics Organization's Experiment Design Committee (DOE/NSF).
1986: Selected to serve on NASA panel for a Lidar Atmospheric Wind Sounder (LAWS) as an EOS facility.
1985: Served as member of the NASA organizing committee for Symposiums and Workshops on Global Wind Measurements.
1985: Served on advisory panel for the SPACE/MIST storm research field experiment (1986).
1984-87: Member of American Meteorological Society's Cloud Physics Committee.
1982: Received NASA Award for work on the design, execution and analysis of a flight program to sample the exhaust cloud associated with the launch of the NASA Shuttle.
1981: Received NASA Group Award for research done with the NASA airborne Doppler lidar wind measurement experiments conducted during the CCOPE in Montana.

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Pu, Z., L. Zhang, and **G. D. Emmitt** (2010), Impact of airborne Doppler wind lidar profiles on numerical simulations of a tropical cyclone, Geophys. Res. Lett., 37, L05801, doi:10.1029/2009GL041765.

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Frank, W., and **G. D. Emmitt**, 1981: Computation of vertical energy fluxes in moist atmosphere. Bound.-Layer Meteor, 21, 223-230.

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Emmitt, G. D. and B. Brummer, 1979: Wind measurements with a ship based

theodolite. Meteor Forschungergebnisse, 23, 53-62.

Emmitt, G. D., 1978: Tropical cumulus interaction with and modification of the subcloud layer. J. Atmos. Sci., 35, 1485-1502.

Garstang, M., P. D. Tyson and **G. D. Emmitt**, 1975: The structure of heat islands. Rev. Geophys. Space Sci., 13, 139-165.

PUBLICATIONS: Conference Proceedings/Presentations

2007: Airborne wind lidar for atmospheric boundary layer research (invited paper) , (G.D. Emmitt), Lidar Remote Sensing for Environmental Monitoring VIII, SPIE Optics + Photonics, San Diego, CA, 28-30 August 2007.

2007: Requirements and technology advances for global wind measurement with a coherent lidar: a shrinking gap (Invited paper), (Kavaya, M.J. Yu, G. J. Koch, F. Amzajerdian, U. N. Singh and G. D. Emmitt), Lidar Remote Sensing for Environmental Monitoring VIII, SPIE Optics + Photonics, San Diego, CA, 28-30 August 2007.

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2006: Observing System Simulation Experiments at NCEP (Masutani, M., J.S. Woolen, S.J. Lord, T. J. Kleepsies, G.D. Emmitt, H. Sun, S. Wood, S. Greco, J. Terry, R. Treadon and K. Campana), Office Note 451, EMC/NCEP/NWS/NOAA

2005: Automated detection of frontal systems from numerical model-generated data (Xiang Li, Rahul Ramachandran, Sara J. Graves, Sunil Movva, Bilahari Akkiraju, **David Emmitt**, Steven Greco, Robert Atlas, Joseph Terry, Juan-Carlos Jusem), KDD 2005: 782-787

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2005: Airborne Doppler Wind Lidar Investigations of OLEs over the Eastern Pacific and the Implications for Flux Parameterizations (Emmitt G.D., C. O'Handley, S. Greco, R. Foster and R.A. Brown), Annual Amer. Met. Soc. Conference ,Sixth Conference on Coastal Atmospheric and Oceanic Prediction and Processes, San Diego, CA, January.

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2004: Combining direct and coherent detection for Doppler wind lidar (G. D. Emmitt),Laser Techniques for Atmospheric Sensing, Maspalomas, Gran Canaria, Spain, 14-16 September.

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2004: Dynamical and microphysical characteristics of turbulent waves in and above the marine boundary layer: an integrated perspective from the TODWL data base (G. D. Emmitt, S. A. Wood, D. Bowdle, R. Foster, S. M. Hannon, and H. Jonsson), Remote Sensing of the Atmosphere, Ocean, Environment, and Space, Honolulu, Hawaii, 8-11 November.

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2003: Observing system simulation experiments for NPOESS – assessment of Doppler wind lidar and AIRS (M. Masutani, J.C. Woollen, S.J. Lord, G.D. Emmitt, S. Wood, S. Greco, T.J. Kleespies, H. Sun, J. Terry, J.C. Derber, R.E. Kistler, R.M. Atlas, M.D. Goldberg, and W. Wolf), AMS The Simpson Symposium, Long Beach, CA, February.

2003: Analysis of simulated observations from a Doppler wind lidar (L.P. Risshojgaard, R. Atlas, and G.D. Emmitt), AMS 12th Conf. Satellite Meteorology, Long Beach, CA, February.

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2003: Recent observing system simulation experiments at the NASA DAO (R. Atlas, G.D. Emmitt, J. Terry, E. Brin, J. Ardizzone, J.C. Jusem, and D. Bungato), AMS 7th Symposium on Integrated Observing Systems, Long Beach, CA, February.

2003: OSSEs to determine the requirements for space-based lidar winds for weather prediction (R. Atlas, G.D. Emmitt, J. Terry, E. Brin, J. Ardizzone, J.C. Jusem, and D. Bungato), SPIE's Laser Radar Technology and Applications VIII, Orlando, FL, April.

2003: Comparisons between modeled and actual performance of Doppler lidar used in atmospheric remote sensing (G.D. Emmitt), AeroSense Photonics for Defense and Security, Orlando, FL, April.

2003: Airborne coherent Doppler lidar: investigation of the marine boundary layer and ocean surface motions (G.D. Emmitt, S. Greco, and C. O'Handley), AeroSense Photonics for Defense and Security, Orlando, FL, April.

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2003: Airborne Doppler wind lidar to evaluate cloud and water vapor motion vectors from GIFTS (G.D. Emmitt), SPIE's 48th Annual Meeting, San Diego, CA, August.

2003: Investigation of backscatter/wind correlations using an airborne 2-micron coherent Doppler wind lidar (G.D. Emmitt and C.O'Handley), SPIE's 48th Annual Meeting, San Diego, CA, August.

2003: Validation of meso-scale model winds in complex terrain and coastal regions using an airborne coherent Doppler wind lidar (G.D. Emmitt, S. Greco, S. Wood, and C. O'Handley, W. Nuss, and D. Miller), ISTP, Leipzig, September.

2003: Processing airborne coherent Doppler lidar returns from the ocean surface and the layer adjacent to the surface (G.D. Emmitt and C. O'Handley), SPIE 5240, Barcelona, Spain, September.

2003: Comparing the potential numerical weather prediction impacts of several

Doppler wind lidar concepts (G.D. Emmitt), SPIE 5234A, Barcelona, Spain, September.

2002: Airborne Doppler lidar surface returns: Data products other than tropospheric winds (G.D. Emmitt and C. O'Handley), SPIE Remote Sensing of the Atmosphere, Ocean, Environment and Space, Hangzhou, China, October.

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2002: 2 μm Doppler lidar returns from water surfaces and the overlying aerosols (G.E. Emmitt, C. O'Handley, J. Rothermel, S. Johnson, D. Bowdle, P. Kromis, B. Bluth and H. Jonsson), SPIE meeting, Seattle, WA, July.

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2002: Impact assessment of a Doppler wind lidar for NPOESS/OSSE (S.J. Lord, M. Masutani, J.C. Woollen, J.C. Derber, G.D. Emmitt, S.A. Wood, S. Greco, R. Atlas, J. Terry, and T.J. Kleespies), AMS Sixth Symp. Integrated Observing Systems, Orlando, FL, January.

2001: Adaptive target of wind observations: the climate research and weather forecasting perspective (G.D. Emmitt and Z. Toth), AMS Fifth Symp. Integrated Observing Systems,
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2001: The challenges of accessing the future impact of space-based Doppler wind lidars while using today's global and regional atmospheric models (S. Wood, G.D. Emmitt, and S. Greco), AMS Fifth Symp. Integrated Observing Systems, Albuquerque, NM, January.

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Masutani, J.C. Woollen, J.C. Derber, R. Atlas, J. Terry, G.D. Emmitt, S.A. Wood, S. Greco, T.J. Kleespies, and V. Kapoor), AMS Fifth Symp. Integrated Observing Systems, Albuquerque, NM, January.

2001: Global wind observational requirements and the hybrid observing system approach (G.D. Emmitt), AMS Fifth Symp. Integrated Observing Systems, Albuquerque, NM, January.

2001: Simulating space-based lidar performance using global and regional scale atmospheric numerical models (G.D. Emmitt and S.A. Wood), Optical Remote Sensing Topical Meeting, Coeur d' Alene, ID, February.

2001: Feasibility and science merits of a hybrid technology DWL (G.D. Emmitt), 11th Coherent Laser Radar Conf., Malvern, England, July.

2001: The impact of Doppler lidar wind observations on a single-level meteorological analysis (L.P. Riishojgàard, R. Atlas and G.D. Emmitt), SPIE Lidar Remote Sensing for Industry and Environmental Monitoring, II, San Diego, CA, July 29-August 3.

2001: Calibration and initial results from the OSSEs for NPOESS (M. Masutani, J.S. Woollen, J. Terry, S.J. Lord, T.J. Kleespies, G.D. Emmitt, S.A. Wood, S. Greco, J.C. Derber, R. Atlas and M. Goldberg), AMS 11th Conf. Satellite Meteor. and Oceanogr., Madison, WI, October.

2000: DLSM: A coherent and direct detection lidar simulation model for simulating space-based and aircraft-based lidar winds (S.A. Wood, G.D. Emmitt and S. Greco), AeroSense 2000, Orlando, FL, April.

2000: Lidar simulations over hurricane Bonnie using CAMEX-3 data, a lidar simulation model and numerical model analyses (S. Greco, S.A. Wood, G.D. Emmitt, M. Nicholls and R. Pielke, Sr.), AMS 24th Conf. Hurr. And Trop. Meteor., Ft. Lauderdale, FL, May.

2000: Hybrid technology Doppler wind lidar: assessment of simulated data products for a space-based system concept (G.D. Emmitt), SPIE Lidar Remote Sensing for Industry and Environment Monitoring, Sendai, Japan, October.

2000: Using coherent Doppler lidar to estimate river discharge (G.D. Emmitt, C. O'Handley, and G.D. Spiers), SPIE Lidar Remote Sensing for Industry and Environment Monitoring, Sendai, Japan, October.

1999: Implementing a Doppler wind lidar on NPOESS using adaptive targeting strategies (G.D. Emmitt, Z. Toth and R. Atlas). AMS Third Symposium on Integrated Observing Systems, Dallas, TX, January 10-15.

1999: SPARCLE: Mission overview and status (G.D. Emmitt, M. Kavaya and T. Miller). 10th Biennial Coherent Laser Radar Technology and Applications Conf., Mt. Hood, OR,
June 28-July 2.

1999: Pointing knowledge for SPARCLE and space-based Doppler wind lidars in general (G.D. Emmitt, T. Miller and G. Spiers). 10th Biennial Coherent Laser Radar Technology and Applications Conf., Mt. Hood, OR, June 28-July 2.

1999: Capitalizing on the SPARCLE investment (G.D. Emmitt and T. Miller). 10th Biennial Coherent Laser Radar Technology and Applications Conf., Mt. Hood, OR, June 28-July 2.

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1998: SPARCLE: A first step towards space-based global tropospheric wind observations (G.D. Emmitt). IGARSS '98 Managing Natural Resources Conf., Seattle, WA, July 6-10.

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CA, July 19-24.

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1997: Optical remote sensors as components of an airborne hurricane observing system (S.A. Wood, G.D. Emmitt and S. Greco). Proc. AMS First Symp. Integrated Observing
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1995: Ground-based Doppler lidar signal processing in the vicinity of strong backscatter and/or wind inhomogeneities using a progressive context method (G.D. Emmitt, S.A. Wood and D.L. Bai) Paper presented at the Optical Society of America's CLEO '95 Meeting, Baltimore, MD, May.

1995: Coherent vs incoherent space-based Doppler lidar sampling patterns: Accuracy and representativeness (G.D. Emmitt). Paper presented at the Coherent Laser Radar Topical
Meeting, Keystone, CO, July 23-27.

1995: A coherent lidar simulation model for simulating space-based and aircraft-based lidar winds (S.A. Wood, G.D. Emmitt, D. Bai, L.S. Wood, S. Greco) . Paper presented at the Opt. Soc. of America's Coherent Laser Radar Topical Meeting, Keystone, CO, July 23-27.

1995: Simulating clouds within a space-based Doppler lidar wind sounder simulation model (G.D. Emmitt and S.A. Wood) Paper presented at the CIDOS-95 Conf., Hanscom
AFB, MA, October 24-26.

1994: Query scenarios for interdisciplinary scientists interfacing with EOSDIS, Version 0, Series II(S.A. Wood, G.D. Emmitt, K. McDonald). Paper presented at AMS Tenth Internat. Conf. on Interac. Info. and Process. Systems (IIPS) for

Meteor., Oceanogr. and Hydrol., Nashville, TN, January 23-28.

1994: Beta testing of EOSDIS Version 0 using query scenarios from interdisciplinary scientists. Poster paper presented at the IEEE 7th Internat. Working Conf. on Scientific and Statistical Database Management, Charlottesville, VA, September 28-30, 280-282.

1994: Ocean wave motion effects on space-based airborne Doppler lidar wind sounders (G.D. Emmitt). Paper presented at the Optical Society of America's Annual Meeting, October 2-7, Dallas, TX.

1994: Resolving ageostrophic winds with a space-based Doppler lidar wind sounder (G.D. Emmitt). Paper presented at the Fifth Symp. on Global Change Studies, Nashville, TN.

1994: A portable scanning lidar for real-time detection of fugitive dust emissions from multisource facilities (G.D. Emmitt). Paper presented at the Eighth Joint Conf. on Appl. Air Poll. Meteor. with A&WMA.

1993: A Continuous Emission Monitoring and Modeling CEM/M) system for fugitive particulate emissions from coal handling complexes (G.D. Emmitt, C. DiMarzio and R. Doll). Paper presented at the 96th National Western Mining Conference and Exhibition, March, Denver, CO.

1993: Simulation of space-based Doppler lidar wind measurements using ground-based single shot observations (G.D. Emmitt, J. Dieudonné, S.A. Wood and L. Wood). Paper presented at the Optical Remote Sensing of the Atmosphere Sixth Topical Meeting, March, Salt Lake City, UT.

1993: Integration of LOWTRAN into global circulation models for observing system simulation experiments (S.A. Wood and G.D. Emmitt). Paper to be presented at the Conference on Atmospheric Transaction Models, June, Boston, MA.

1993: Using ground-based coherent Doppler lidars to evaluate algorithms for shot management and signal processing of proposed space-based wind sounders (G.D. Emmitt). Paper presented at the Coherent Laser Radar: Applications and Technology Topical Meeting, July, Paris, France.

1993: System simulation studies in support of a technology and product demonstration mission for a space-based coherent Doppler lidar wind sounder (G.D. Emmitt). Paper presented at the Coherent Laser Radar: Applications and Technology Topical Meeting, July, Paris, France.

1991: Simulated wind measurements with a low power/high PRF space-based Doppler lidar (G.D. Emmitt and S.A.Wood). Optical Remote Sensing of the Atmosphere, Fifth Topical Meeting, Williamsburg, VA, November 18-21.

1991: Global three-dimensional distribution of LAWS observations based upon aerosols, water vapor and clouds (S.A. Wood, G.D. Emmitt and L.S. Wood). Optical Remote Sensing of the Atmosphere, Fifth Topical Meeting, Williamsburg, VA, November 18-21.

1991: Query scenarios for interdisciplinary scientists interfacing with EOSDIS - A prototyping exercise (G.D. Emmitt, S.A. Wood and E. Calvin). Proc. AMS Seventh Internat. Conf. on Interactive Information & Processing Systems for Meteorology, Oceanography and Hydrology, New Orleans, LA, January 14-18, 246-248.

1991: Using a global spectral model in an observing system simulation experiment for LAWS - An EOS wind measuring system (T.N. Krishnamurti, J. Xue, G. Rohaly, D. Fitzjarrald, G.D. Emmitt, S. Houston and S.A. Wood). Proc. AMS Second Symposium on Global Change Studies, New Orleans, LA, January 14-18, 23-27.

1991: Implications of several orbit inclinations for the impact of LAWS in global climate studies (R. Atlas and G.D. Emmitt). Proc. AMS Second Symposium on Global Change Studies, New Orleans, LA, January 14-18, 28-32.

1991: Simulating thin cirrus clouds in observing system simulation experiments (OSSE) for LAWS (G.D. Emmitt and S.A. Wood). Proc. AMS Seventh Symp. on Meteorol. Observa. and Instru., Special Session on Laser Atmospheric Studies, New Orleans, LA, January 14-18, 460-462.

1991: A reference atmosphere for LAWS trade studies: An update (S.A. Wood and G.D. Emmitt). Proc. AMS Seventh Symp. on Meteor. Observa. and Instru., Special Session on Laser Atmospheric Studies, New Orleans, LA, January 14-18, J94-J97.

1991: Optimal nadir scan angle for a space-based Doppler lidar wind sounder (G.D. Emmitt). Proc. Seventh Symp. on Meteor. Observa. and Instru., Special Session on Laser Atmospheric Studies, New Orleans, LA, January 14-18, J98-J99.

1991: An index of observation opportunities for EOS laser based instruments (G.D. Emmitt). Paper presented at the Second Symp. on Global Change Studies, New Orleans, LA, January 14-18.

1991: Clear line of sight (CLOS) statistics within cloudy regions and optimal sampling strategies for space-based lidars (G.D. Emmitt and G. Séze). Proc. AMS Seventh Symp. on Meteor. Observa. and Instru., New Orleans, LA, January 14-18, 440-442.

1989: Simulation of a space-based Doppler lidar wind sounder - sampling errors in the vicinity of wind and aerosol inhomogeneities (with S. Wood). Fifth Conference on Coherent Laser Radar, Munich, FRG, June.

1989: Simulated space-based Doppler lidar performance in regions of backscatter inhomogeneities (with S. Wood). Optical Society of America's Conference on Lasers and Electro-Optics, Anaheim, CA, January.

1988: Subvisible cirrus in space-based Doppler lidar simulations (with S. Wood). Atmospheric Transmission Conference, AFGL, Hanscom, MA, June.

1988: Ground-based simulation of a space-based Doppler lidar atmospheric wind sounder (with S. Wood). Optical Society of America's Conference on Lasers and Electro-Optics, Anaheim, CA, April.

1988: Direct measurement of boundary layer winds over the oceans using a space-based Doppler Lidar Wind Sounder. American Meteorological Society's Third Conference on Satellite Meteorology and Oceanography, Anaheim, CA, February.

1987: Assessment of error sources for one component wind measurements with a space-
based Doppler lidar (with J. W. Bilbro). Optical Society of America's Fourth Conference on Coherent Laser Radar: Technology and Applications, Aspen, Colorado, July.

1987: Error analysis for total wind vector computations using one component measurements from a space-based Doppler lidar. Optical Society of America's Fourth Conference on Coherent Laser Radar: Technology and Applications, Aspen, Colorado, July 1987.

1987: Impact of a space-based Doppler lidar wind profiler on our knowledge of hurricanes and tropical meteorology (with S. H. Houston). AMS 17th Conference on Hurricanes and Tropical Meteorology, Miami, Fl, April 1987.

1987: A numerical investigation of the role of whisker production in dry ice seeding experiments (with R.D. Farley). AMS 11th Conference on Weather Modification, Edmonton, Alberta, Canada, October 1987.

1986: Assessment of measurement error due to sampling perspective in the space-based Doppler lidar wind profiler (with S. Houston). Second Conference on

Satellite Meteorology/Remote Sensing and Applications, May 13-16, Williamsburg, VA.

1986: Constraints on resolving meso-α and meso-ß phenomena using a space-based Doppler lidar wind profiler (with S. Houston). Second Conference on Satellite Meteorology/Remote Sensing and Applications. May 13-16, 1986, Williamsburg, VA.

1986: Topographical influences on radar echo properties --implications to weather modification projects in mountainous terrain (with W. London). Tenth Conference on
Weather Modification, May 27-30, Arlington, VA.

1986: Dry ice pellet whiskers--laboratory evaluation of their production and potential importance to cloud seeding. Tenth Conference on Weather Modification, May 27-30, Arlington, VA.

1985: Convergence and vorticity structures in convective storm outflows as detected by an airborne Doppler lidar velocimeter. 14th Conference on Severe Local Storms, October 29-November 1, Indianapolis, IN.

1985: Discrimination of local and synoptic scale forcing of cumulus convection along the eastern Transvaal escarpment using Meteosat imagery. Second Annual Conference of the South African Society for Atmospheric Sciences, November 11-12, Pretoria, SA.

1985: Doppler lidar sampling strategies and accuracies-regional scale. Paper presented at the Symposium and Workshop on Global Wind Measurements, July 29-August 1, Columbia, Maryland.

1984: Behavior of cylindrical dry ice pellets in the presence of supercooled water droplets--field and laboratory experiments. Paper presented at the Ninth Conference on Weather Modification, May 21-23, Park City, Utah.

1984: Airborne simulation of a satellite based Doppler lidar (J.W. Bilbro and G.D. Emmitt), Proc. of the SPIE, Vol. 493, National Symposium and Workshop on Optical Platforms, pp. 321-325.

1983: Anatomy of drought. Symposium on Atmospheric Sciences in South Africa, October 18-20, Pretoria, South Africa. (M. Garstang and G. D. Emmitt).

1983: Evolution of the Nocturnal Boundary Layer as Sensed by a Doppler Lidar Velocimeter. Paper presented at 2nd Topical Meeting on Coherent Laser Radar; Technology and Applications, August 1-4, Aspen, Co.

1983: Ground based CO_2 Doppler lidar wind measurements of winds in the vicinity of cumulus convection. Paper presented at 9th Conference on Aerospace and Aeronautical Meteorology of the AMS, June 6-9, Omaha, NE.

1982: Conical lidar scanning from low earth orbit--the effects of meso-α and convective scale atmospheric phenomena. Paper presented at 11th International Laser Radar Conference, July, Madison, WI.

1980: Measurements of wind shear at the Mod-1 site, Boone, North Carolina (M. Garstang, J. W. Snow and G. D. Emmitt). A Collection of Technical Papers, Paper No. AIAA-80-0648-CP, pp. 200-204.

1980: Measurement of wind shear at the Mod-1 site, Boone, North Carolina. Paper presented at AIAA/SERI Wind Energy Conference, April 9-11, Boulder, CO.

1980: Mesoscale nocturnal boundary layer jets. Minisymposium on Mesoscale Phenomena and their Interactions, September, Geophysical Fluid Dynamics Laboratory, NOAA, Princeton, N.J.

1978: Determination of σ by direct and indirect cloud transport measurements. Paper presented at the GATE Symposium on Oceanography and Surface Layer Meteorology, Kiel, West Germany, May 16-20.

1976: Mass and energy transports of convective clouds, G.D. Emmitt, M. Garstang and J. Simpson. Paper presented at the 10th Tech. Conf. on Hurricanes and Tropical Meteorology, AMS, July, Charlottesville, Va.

PUBLICATIONS: Reports

1972: Remote sensing as a source of data for outdoor recreation planning (W.E. Reed, H. G. Goodell and G. D. Emmitt). Final report to Department of the Interior, Bureau of Outdoor Recreation, Contract No. 1-14-07-3, 210 pp.

1974: The structure of heat islands (P.D. Tyson, M. Garstang and G. D. Emmitt, 1974:. Occasional paper #12, Department of Geography and Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa, 71 pp.

1975: The first 1000 m above a GATE ship (M. Garstang, J. Simpson, G. D. Emmitt, G. Barnes, E. Tollerud). Paper presented at the 9th Tech. Conf. on Hurricanes and Tropical Meteorology, Key Biscayne, FL.

1975: Momentum redistribution by enhanced mixing (G.D. Emmitt). Paper presented at the 9th Tech. Conf. on Hurricanes and Tropical Meteorology, AMS, May, Key Biscayne, FL.

1977: The U. S. GATE tethered balloon system: A discussion of the measurements (M. Garstang, G. D. Emmitt, G. Barnes, D. Fitzjarrald, E. Tollerud and J. D. Brown). Part 3 of Report #2 NSF grant #ATM74-21702 and Final Report on NOAA contract #04-6-
158-44067, 89 pp.

1981: Rain Augmentation in Nelspruit (M. Garstang, G. D. Emmitt and B. Kelbe). Final Report to Water Research Commission, Pretoria, R.S.A., p. 266.

1982: MSFC Doppler lidar experiments and operations plans for 1982/83 ground based research (G.D. Emmitt, J. W. Bilbro, G. H. Fichtl and D. Fitzjarrald). ES-84, NASA, Marshall Space Flight Center, Huntsville, AL 35812.

1984: NASA/MSFC ground-based Doppler lidar Nocturnal Boundary Layer Experiment (NOBLEX)(G.D. Emmitt). Prepared for Marshall Space Flight Center, Huntsville, AL, under Contract NAS8-34010. NASA Contractor Report 3778.

1984: Evaluation of two 1-D cloud models for the analysis of VAS Soundings (G.D. Emmitt). Prepared for Marshall Space Flight Center, Huntsville, AL, under Contract NAS8-34767. NASA Contractor Report 3771.

1985: Convective storm downdraft outflows detected by NASA/ MSFC's airborne 10.6 □m pulsed Doppler lidar system (G.D. Emmitt). Prepared for Marshall Space Flight Center, Huntsville, AL, under Contract NAS8-35597. NASA Contractor Report 3898.

1986: Simpson Weather Associates, Inc. and Kansas International Corporation Limited, Program for Atmospheric Water Supply, 1983-86 Final Report to the Water Research Commission, Pretoria, South Africa.

1987: Contributor to Laser Atmospheric Wind Sounder (LAWS); Instrument Panel Report (Chairman R. J. Curran) (G.D. Emmitt), NASA Earth Observing System, Volume IIg, NASA Headquarters, Washington, D.C.

1994: Norfolk Southern Rail Emission Study (NSRES). Final Rept., February.

1999: NASA Post-2002 Land Surface Hydrology Mission Component for Surface Water Monitoring: HYDRO-SAT HYDROlogical SATellite (C. Vörösmarty, C. Birkett, L. Dingman, D. Lettenmaier, Y. Kim, E. Rodriguez and G.D. Emmitt). Report from the NASA Post-2002 Land Surface Hydrology Planning Workshop, Irvine, CA, April 12-14.

PRESENTATIONS: Seminars/Workshops

2007: Integrating airborne DWL and PBL Models in realtime (G. D. Emmitt, C. O'Handley, S.A. Wood and S. Greco), Working Group on Space-Based Lidar Winds, Miami, FL, February 6 -9.

2007: Prospecting for thermals using an airborne DWL (G.D. Emmitt and C. O'Handley), Working Group on Space-Based Lidar Winds, Miami, FL, February 6 -9.

2007: Correlations of wind shear and clouds: numerical model results (S.A. Wood and G.D. Emmitt), Working Group on Space-Based Lidar Winds, Miami, FL, February 6 -9.

2007: Simulations of hybrid DWL performance with GLAS cloud penetrating statistics (G. D. Emmitt and S. A. Wood), Working Group on Space-Based Lidar Winds, Miami, FL, February 6 -9.

2007: Doppler wind lidar flights: prospecting for vertical motions to enhance SkyWalker performance (G. D. Emmitt, C. O'Handley and S. Greco), DARPA , Arlington, VA, January 31.

2006: Adaptive targeting of a space-based Doppler wind lidar: data and technology implications (G. D. Emmitt), SPIE Europe Remote Sensing, Stockholm, Sweden, September 11 – 14.

2006: Using ICESAT observations to obtain CFLOS statisitics for use in the design of space-based lidars (invited paper) (G. D. Emmitt and S. Greco), SPIE Europe Remote Sensing, Stockholm, Sweden, September 11 – 14.

2006: Tropospheric wind profiler: multi-spectral DWL (G. D. Emmitt), NASA/ESTO lidar workshop, Washington, DC, June.

2006: GLAS cloud statistics and their implications for a hybrid mission (G. D. Emmitt and S. Greco), Working Group on Space-Based Lidar Winds, Welches, OR, June 28 – 30.

2006: New sampling perspectives for TODWL (G. D. Emmitt and C. O'Handley), Working Group on Space-Based Lidar Winds, Welches, OR, June 28 – 30.

2006: Development of a remote sensing testbed for tropospheric air quality and winds (M. Newchurch, et.al and G. D. Emmitt), Working Group on Space-Based Lidar Winds, Welches, OR, June 28 – 30.

2006: OSSE plans related to a hybrid mission and ADM follow-on missions (G.

D. Emmitt), Working Group on Space-Based Lidar Winds, Welches, OR, June 28 – 30.

2006: Planning for airborne DWL participation in PARC (G.D. Emmitt and M. Hardesty), Working Group on Space-Based Lidar Winds, Welches, OR, June 28 – 30.

2006: April test train: preliminary CCLPS results, NCTA specials meeting, Denver, CO, June 21.

2006; Optimizing rail availability for PRB coal transport: summary of trends (G. D. Emmitt), NCTA special meeting, Denver, CO, June 21.

2006: Recommendations for the PRB coal loss mitigation program (G. D. Emmitt), NCTA special meeting, Denver, CO, June 21.

2006: Coal loss study update (G. D. Emmitt and E. D. Carre), NCTA workshop, St Louis, MO, February 21.

2006: CCLPS estimates of coal losses by wind erosion (G. D. Emmitt and E. D. Carre), NCTA workshop, St Louis, MO, February 21.

2006: Adaptive targeting schemes and their technology implications (G. D. Emmitt), Working Group on Space-Based Lidar Winds, Key West, FL, January 16.

2006: Latest simulations for a tropospheric wind sounder on NPOESS and beyond (G. D. Emmitt, S. A. Wood, B. Gentry and M. Kavaya), Working Group on Space-Based Lidar Winds, Key West, FL, January 16.

2006: NPOESS P3I and follow-on threshold operational mission (G. D. Emmitt and S. A. Wood), Working Group on Space-Based Lidar Winds, Key West, FL, January 16.

2006: Status of TODWL and GWOLF (G. D. Emmitt and C. O'Handley), Working Group on Space-Based Lidar Winds, Key West, FL, January 16.

2006: Adaptive targeting OSSEs for planning a space-based Doppler wind lidar (G. D. Emmitt, S. A. Wood, S. Greco, M. Matsutani, J. Woolen, Z. Toth and Y. Song), AMS annual meeting, IOAS-AOLS, January.

2005: Using airborne lidar data in models: an adaptive targeting approach (G. D. Emmitt), UAH, Huntsville, AL Seminar series, November 28.

2005: Coal losses from railcars: summary of data analyses (G. D. Emmitt, D. Carre, L.Wood and C. Palomares), NCTA special meeting, Ft. Worth, TX, November 15.

2005: OSSEs at GSFC (G. D. Emmitt and R. Atlas), Working Group on Space-based Lidar Winds, Welches, OR, June 28 – 30.

2005: OSSEs at NCEPm(M. Matsutani, J. Woolen, Z. Toth, G. D. Emmitt and S. Lord), Working Group on Space-based Lidar Winds, Welches, OR, June 28 – 30.

2005: Investigation of the utility of airborne DWL data in mesoscale models (G. D. Emmitt, S. A. Wood and S. Greco, Working Group on Space-based Lidar Winds, Welches, OR, June 28 – 30.

2005: Scaling TODWL and GWOLF performance to space (G. D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, Welches, OR, June 28 – 30.

2005: SNR issues: definitions, theory and practice (G. D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, Welches, OR, June 28 – 30.

2005: Simulating a dual technology DWL at 833 km (G. D. Emmitt, S. Wood, M. Kavaya and B. Gentry), Working Group on Space-based Lidar Winds, Welches, OR, June 28 – 30.

2005: Preliminary results of GLAS data base study of CFLOS statistics (G. D. Emmitt and S. Greco), Working Group on Space-Based Lidar Winds, Sedona, AZ, February 1 – 3.

2005: Mars related opportunities for DWL applications (G. D. Emmitt, G. Koch, M. Kavaya and U. Singh), Working Group on Space-based Lidar Winds,Sedona, AZ, February 1 – 3.

2005: Status of NCEP and GSFC OSSEs with DWLs (S. Lord, R. Atlas, G. D. Emmitt), Working Group on Space-based Lidar Winds,Sedona, AZ, February 1 – 3.

2005: Investigation of backscatter/wind correlations using an airborne 2-micron coherent Doppler wind lidar (G. D. Emmitt, C. O' Handley, D. Bowdle and H. Jonsson), Working Group on Space-based Lidar Winds,Sedona, AZ, February 1 – 3.

2005: Airborne WindSat Validation Program (Gasiewski, A. J, P. Gaiser, H.

Graber, and G. D. Emmitt), White paper submitted to NPOESS (Mango), January 11.

2004: Airborne Doppler lidar for WindSat Cal/Val (G. D. Emmitt, S. A. Wood, C. O'Handley, S Greco, H. Jonsson), WindSat Cal/Val and Science Meeting, Solomons Md, 17-18 November.

2004: The importance of CALIPSO to the design of follow-on lidars, inparticular, Doppler wind lidars (G. D. Emmitt), CALIPSO Workshop, NCEP, Silver Springs, Md., June 10.

2004: Comparison of measured and modeled aerosol backscatter during TODWL/2003 (D. Bowdle, G.D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, Sedona, AZ, January 27-29.

2004: Using surface returns to correct for aircraft motion induced errors (G.D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, Sedona, AZ, January 27-29.

2004: The DSLM on-line (S. Wood and G.D. Emmitt), Working Group on Space-based Lidar Winds, Sedona, AZ, January 27-29.

2004: GWOLF and VALIDAR comparisons (M. Kavaya, G. Koch, G.D. Emmitt, and S. Wood), Working Group on Space-based Lidar Winds, Sedona, AZ, January 27-29.

2004: Comparisons of TODWL soundings with MM5, microwave sounders, towers, and other wind sensors (G.D. Emmitt, S. Wood, S. Greco, and C. O'Handley), Working Group on Space-based Lidar Winds, Sedona, AZ, January 27-29.

2004: Status of IPO-funded hybrid feasibility and airborne testbed (G.D. Emmitt, B. Gentry, M. Hardesty, and M. Kavaya), Working Group on Space-based Lidar Winds, Sedona, AZ, January 27-29.

2004: OSSEs for realistic DWL concepts (G.D. Emmitt and R. Atlas), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2004: Potential contribution of multiple Doppler wind lidars to a prospective CHEM/ CLOUD experiment in Huntsville, Alabama (G.D. Emmitt, M. Newchurch, and D. Bowdle), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2004: Using TODWL and in situ particle probes to understand the backscatter signature of marine, boundary layer organized structures (D. Bowdle, G.D.

Emmitt, and S. Wood), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2004: Using TODWL data to validate marine boundary layer models (R. Foster, R. Brown, C. O'Handley, and G.D. Emmitt), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2004: Hybrid DWL simulations for OSSEs (G.D. Emmitt and S. Wood), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2004: Accuracy of airborne Doppler lidar using threading and ground returns (G.D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2004: Status of TODWL and GWOLF activities and plans for future airborne DWL (G.D. Emmitt, B. Gentry, M. Hardesty, and M. Kavaya), Working Group on Space-based Lidar Winds, Frisco, CO, June 29-July 1.

2003: Simulating cloud and water vapor motion winds form a nature run (C. O'Handley and G. D. Emmitt), March 6.

2003: IPO Cal/Val for a space-based wind observing system (G.D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, Oxnard, CA, February 17-19.

2003: Status of Hybrid DWL study (G.D. Emmitt, S. Wood, and G.D. Spiers), Working Group on Space-based Lidar Winds, Oxnard, CA, February 17-19.

2003: GWOLF 2003 (G.D. Emmitt, C. O'Handley, M. Kavaya and G. Koch), Working Group on Space-based Lidar Winds, Bar Harbor, ME.

2003: IPO-funded airborne lidar experiments: TODWL 2003 (G.D. Emmitt, S. Greco, C. O'Handley, and S. Wood), Working Group on Space-based Lidar Winds, Bar Harbor, ME.

2003: Investigation of the marine boundary layer and validation of numerical models using an ONR/IPO airborne Doppler wind lidar (G.D. Emmitt), NRL seminar, Moneterey, CA, August.

2003: Airborne Doppler lidar for basic atmospheric research and calibration of space-based wind sensors (G.D. Emmitt , B. Bluth and H. Jonsson), NASA/MSFC seminar, Huntsville, AL.

2003: Airborne Doppler lidar investigation of flow within complex terrain and marine boundary layers (G.D. Emmitt), Invited talk, Arizona State University, November.

2002: Hybrid DWL: simulations of expected data products for use in OSSEs (D. Emmitt and S. Wood), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: Status of IPO's Cal/Val study: the TODWL Spring 2002 checkout flights (D. Emmitt, C. O'Handley, and D. Bowdle), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: Investigation of the marine LAS with an airborne Doppler wind lidar (D. Emmitt, C. O'Handley, D. Bowdle), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: Nadir angle dependence of water surface return at 2 microns using TODWL (D. Emmitt and C. O'Handley), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: TODWL: Between flight programs (D. Emmitt and P. Gatt), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: Technology plan for the coherent subsystem of a space-based hybrid Doppler wind lidar (M. Kavaya, A. Amzajerdian, U. Singh, J. Yu, and D. Emmitt), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: Technology roadmap for a direct detection Doppler lidar subsystem (B. Gentry, M. McGill, G. Schwemmer, B. Heaps, and D. Emmitt), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: Status of the Doppler Lidar Simulation Model (DLSM) for GTWS (S. Wood and D. Emmitt), Working Group on Space-based Lidar Winds, North Conway, NH, July 15-18.

2002: A space-based coherent wind lidar point design for the NASA/NOAA Draft Science and Operational Data Requirements (M. Kavaya, D. Emmitt, R. Frehlich, F. Amzajerdian, U. Singh), Working Group on Space-based Lidar Winds, Key West, FL, January 23-25.

2002: Status of TODWL and other IPO funded activities (G.D. Emmitt et al.), Working Group on Space-based Lidar Winds, Key West, FL, January 23-25.

2002: A hybrid DWL concept for instrument and mission analyses (D.Emmitt, B. Gentry, and M. Kavaya), Working Group on Space-based Lidar Winds, Key West, FL, January 23-25.

2002: Discussion of the GTWS reference atmospheres and their use (D. Emmitt), Working Group on Space-based Lidar Winds, Key West, FL, January 23-25.

2001: Status of bracketing OSSEs at NCEP for several DWL notional concepts (G.D. Emmitt), Working Group on Space-based Lidar Winds, Oxnard, CA, February 7-9.

2001: Developing a CAL/VAL plan for a space-based Doppler wind lidar (G.D. Emmitt), Working Group on Space-based Lidar Winds, Oxnard, CA, February 7-9.

2001: IPO funded airborne DWL for CAL/VAL planning (G.D. Emmitt), Working Group on Space-based Lidar Winds, Oxnard, CA, February 7-9.

2001: Updated report on Hybrid technology DWLs (G.D. Emmitt), Working Group on Space-based Lidar Winds, Oxnard, CA, February 7-9.

2000: Adaptive targeting study for DWL operations (G.D. Emmitt, Z. Toth, E. Kalnay, R. Atlas). Working Group on Space-based Lidar Winds, Boulder, CO, June 21-23.

2000: Update on the feasibility study for a hybrid technology DWL (G.D. Emmitt). Working Group on Space-based Lidar Winds, Boulder, CO, June 21-23.

2000: Simulated DWL observations for the global OSSEs at NCEP: Coverage, accuracy, and systematic errors (G.D. Emmitt). Working Group on Space-based Lidar Winds, Boulder, CO, June 21-23.

2000: HYDROSAT: An opportunity for space-based Doppler lidar (G.D. Emmitt). Working Group on Space-based Lidar Winds, Boulder, CO, June 21-23.

2000: Update on IPO-funded wind lidar studies (G.D. Emmitt). Working Group on Space-based Lidar Winds, Daytona Beach, FL, January 26-28.

2000: Status of the Hybrid DWL feasibility study (G.D. Emmitt). Working Group on Space-based Lidar Winds, Daytona Beach, FL, January 26-28.

2000: HYDRA-SAT and the role of coherent Doppler lidar (G.D. Emmitt). Working Group on Space-based Lidar Winds, Daytona Beach, FL, January 26-28.

2000: The role of DWL OSSE's and appropriate metrics for a commercial wind data buy
(G.D. Emmitt). Working Group on Space-based Lidar Winds, Daytona Beach, FL, January

26-28.

1999: Recent results of IPO funded OSSE efforts at NCEP and GSFC (G.D. Emmitt). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: SPARCLE data product validation plan: Mission scientist's assessment (G.D. Emmitt, R. Menzies and D. Bowdle). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: SPARCLE "Challenges" B Pointing (G.D. Emmitt, T.Miller and G. Spiers). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: SPARCLE performance modeling (G. Spiers and G.D. Emmitt). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: Follow on mission(s) for SPARCLE (M. Kavaya, G.D. Emmitt and T. Miller). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: Status of OSSEs at NCEP (R. Atlas and G.D. Emmitt). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: Review of observational requirements for global DWL winds (G.D. Emmitt). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: Adaptive targeting with a space-based DWL (G.D. Emmitt and R. Atlas). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: Update of LITE analyses of cloud and aerosol backscatter statistics (D. Winker and G.D. Emmitt). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: SPARCLE Science Team Meeting (G.D. Emmitt). Working Group on Space-based Lidar Winds, Key West, FL, January 19-22.

1999: Status of the NASA New Millennium Program. Presented for C. Raymond by G.D. Emmitt. Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: Status of wind lidar OSSEs at NCEP (G.D. Emmitt and R. Atlas). Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: SPARCLE: What happened, lessons learned, what next (T. Miller and G.D.

Emmitt). Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: Results of the ALADIN (ISS) impact study. Presented for W. Wergen et al. By G.D. Emmitt, Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: A notional hybrid DWL on the roadmap to an operational system (G.D. Emmitt). Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: Data requirements and specifications (G.D. Emmitt). Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: OSSEs and impact metrics definitions (G.D. Emmitt). Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: Benefits of a pre-data buy DWL demo mission (G.D. Emmitt). Working Group on Space-based Lidar Winds, Mt. Hood, OR, July 6-9.

1999: An overview of the potential space-based application of coherent Doppler lidar to measure the surface velocity of rivers (G.D. Emmitt). NASA-USGS Workshop on Remote Sensing of River Stage and Discharge, Herndon, VA, September 23-24.

1999: Airborne Doppler lidar observations of river transects (MACAWS) (G.D. Emmitt and J. Rothermel). NASA-USGS Workshop on Remote Sensing of River Stage and Discharge, Herndon, VA, September 23-24.

1998: SPARCLE mission science plan (G.D. Emmitt). NOAA Working Group on Space-based Lidar Winds, Key West, FL, January 20-22.

1998: Pointing knowledge: GPS/INS (G. Kamerman and G.D. Emmitt). NOAA Working Group on Space-based Lidar Winds, Key West, FL, January 20-22.

1998: Velocity error budget (G. Spiers and G.D. Emmitt). NOAA Working Group on Space-based Lidar Winds, Key West, FL, January 20-22.

1998: Simulated performance of SPARCLE and follow-on missions (G.D. Emmitt). NOAA Working Group on Space-based Lidar Winds, Key West, FL, January 20-22.

1998: Simulating coherent and direct detection DWLs for IPO OSSEs (G.D. Emmitt). NOAA Working Group on Space-based Lidar Winds, Key West, FL, January 20-22.

1998: The validation program. OSSEs (G.D. Emmitt). NOAA Working Group on Space-based Lidar Winds, Key West, FL, January 20-22.

1998: Calibration of the GPS/INS (G.D. Emmitt and G. Spiers). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1998: Cloud statistics from LITE and relevance to wind lidar performance (D. Winker and G.D. Emmitt). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1998: An approach to evaluating the merits of a hybrid technology Doppler wind lidar (G.D. Emmitt). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1998: Update of target atmospheres for use in DWL concept studies (S. Wood and G.D. Emmitt). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1998: Inverted quasi-conical partial VAD processing of MACAWS data taken during turns (G.D. Emmitt, S. Wood and S. Greco). NOAA Working Group on Space-Based Lidar
Winds, Boulder, CO, July 13-16.

1998: Update on recent OSSEs (R. Atlas, S. Wood and G.D. Emmitt). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1998: What is a useful wind measurement? (G.D. Emmitt). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1998: Review of the lidar working group data requirements (G.D. Emmitt). NOAA Working Group on Space-Based Lidar Winds, Boulder, CO, July 13-16.

1997: Status of performance simulations in support of the shuttle and NPOESS missions (G.D. Emmitt), NOAA Working Group on Space-based Lidar Winds, Daytona, FL, January 21-23.

1997: Issues related to the comparison of DWL technologies and the simulation of their performance (e.g., wallplug efficiences and beta vs. wavelength) (G.D. Emmitt), NOAA Working Group on Space-based Lidar Winds, Daytona, FL, January 21-23.

1997: Proposed role of OSSEs for CAMEX III (G.D. Emmitt), NOAA Working Group on Space-based Lidar Winds, Daytona, FL, January 21-23.

1997: Relevance of LITE data analysis to space-based DWL performance (G.D. Emmitt and D. Winker), NOAA Working Group on Space-based Lidar Winds, Northglenn, CO, July 15-17.

1997: Update on OSSEs for NPOESS and CAMEX III (G.D. Emmitt, S. Wood, L. Wood, and S. Greco), NOAA Working Group on Space-based Lidar Winds, Northglenn, CO, July 15-17.

1997: Status report on NASA's DWL shuttle mission -- The science/data perspective (G.D. Emmitt, S. Wood, and M. Kavaya), NOAA Working Group on Space-based Lidar Winds, Northglenn, CO, July 15-17.

1997: Issues related to DWL scanning, sampling and LOS co-processing (G.D. Emmitt, S. Wood, B. Rye), NOAA Working Group on Space-based Lidar Winds, Northglenn, CO, July 15-17.

1996: Use of MACAWS data to address issues related to a space-based DWL (G.D. Emmitt, S. Greco and J. Rothermel) Paper presented at the NOAA Working Group on Space-Based Lidar Winds, Daytona Beach, FL, February 6-9.

1996: Figures of Merit for DWL OSSEs (G.D. Emmitt and R. Atlas) Paper presented at the NOAA Working Group on Space-Based Lidar Winds, Daytona Beach, FL,February 6-9.

1996: Effects of wind shear on signal processing (G.D. Emmitt) Paper presented at the NOAA Working Group on Space-Based Lidar Winds, Daytona Beach, FL,February 6-9.

1996: Data volume issues for a 2□m small-sat mission (G.D. Emmitt and S.A. Wood) Paper presented at the NOAA Working Group on Space-Based Lidar Winds, Daytona Beach, FL, February 6-9.

1996: Preliminary cloud and cloud porosity statistics from LITE (G.D. Emmitt and D. Winker) Paper presented at the NOAA Working Group on Space-Based Lidar Winds, Daytona Beach, FL, February 6-9.

1995: Use of NASA/NOAA ground-based lidar data to evaluate several signal processing strategies (G.D. Emmitt) Paper presented at the NOAA Working Group on Space-based Lidar Winds, Clearwater, FL, January 31-February 2.

1995: Revised outlook for mid/upper tropospheric returns for a small-satellite wind lidar (G.D. Emmitt) Paper presented at the NOAA Working Group on Space-based Lidar Winds, Clearwater, FL, January 31-February 2.

1995: OSSEs in support of a small-satellite mission (G.D. Emmitt) Paper presented at the NOAA Working Group on Space-Based Lidar Winds, Clearwater, FL,January 31-February 2.

1995: Status of efforts by the U.S.A. Working Group on Space-Based Lidar Winds (G.D. Emmitt and W.E. Baker) Paper presented at the ESA Doppler Wind Lidar Workshop, Noordwijk, The Netherlands, September 20-22.

1993: Update on LAWS data simulations (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, January, Clearwater Beach, FL.

1993: Design considerations for a Quick LAWS (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, January, Clearwater Beach, FL.

1993: Update on ground-based lidar observations (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, January, Clearwater, FL.

1992: Simulated LAWS performance profiles (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, July, Cape Cod, MA.

1992: LAWS power budget simulations (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, July, Cape Cod, MA.

1992: Review of mission science objectives for LAWS (G.D. Emmitt). Paper presented at the LAWS Science Team Meeting, July, Cape Cod, MA.

1991: LAWS, a career in global transports. Seminar given at Florida State University, Tallahassee, FL, January 14-18.

1990: Shot management for LAWS. LAWS Simulation Workshop, March, Goddard Space Flight Center, Greenbelt, MD.

1990: Optimal scanning pattern in partly cloudy regions. LAWS Science Team Meeting, August 1-3, Boulder, CO.

1990: Optimal sampling strategies for space-based laser wind sounders. Seminar at Laboratoire de Météorologie Dynamique, June 8, Ecole Polytechnique, Palaiseau, France.

1990: Preliminary estimates of LAWS global observation opportunities below 15 km. GLOBE Meeting, March 7-8, Huntsville, AL.

1990: Optimal sampling strategies in partly cloudy regions for space-based laser wind sounders. Seminar at Laboratoire de Météorologie Dynamique, Ecole Normal Supérieure, September, Paris, France.

1990: Role of OSSEs in the design of a space-based lidar wind sounder. Seminar at European Center for Medium Range Forecasts, September 4, Reading, England.

1989: LAWS - Can it provide more than just winds? Seminar at NASA Langley Research Center, Hampton, VA, October.

1987: Windstorms: site-specific risk assessment. American International Group's Fall 1987 Seminar on Geophysical Hazards, New York, N.Y., December.

1980: Nocturnal boundary layer measurements made with a tethered balloon. SESAME 1979 Data Users Workshop, January, Boulder, CO.

1979: Seminar on hail suppression and its implications. Departmental Seminar, University of Virginia, April.

1977: Use of direct and indirect estimates of cumulus transports to estimate total active cloud cover. Seminar paper given at MPI fur Meteorologie, Hamburg, West Germany.

1977: Elected to present final report of the GATE Workshop Boundary Layer Group at the International Conference on the energetics of the tropical atmosphere, Tashkent, U.S.S.R., September; report published in proceedings of the conference.

1977: Invited participant at the GATE summer workshop (3 papers), Boulder, Colorado, July 29-August 12.

1977: Technical aspects of tethered balloon operations. Seminar paper given at the Danish Atomic Energy Laboratories, RISϕ, Denmark.

1977: Cumulus convection below cloud base. Seminar paper given at the Danish Atomic Energy Laboratories, RISϕ, Denmark.

1976: Tropical cumulus activity below cloud base. Seminar paper given at MPI fur Meteorologie, Hamburg, West Germany.

1974: Opportunities for physicists in a Department of Environmental Sciences (G.D. Emmitt). Given at Eastern Nazarene College, Wollaston, MA.

RESEARCH

Principal Investigator: NOAA's Integrated Program Office's (IPO) feasibility study for hybrid Doppler wind lidars

Principal Investigator: NOAA's IPO observing system simulation experiments for space-based DWLs

Principal Investigator: NOAA's IPO targeted observing strategies for wind lidars

Principal Investigator: NOAA's IPO calibration/validation plan for space-based DWLs

Principal Investigator: NOAA's IPO twin otter Doppler wind lidar (TODWL) for cal/val strategy development

Principal Investigator: NASA LaRC, Modification of the Doppler lidar simulation model

Principal Investigator: Provincial Energy Ventures Dust Suppression System Design

Principal Investigator: NASA GSFC – GTWS Science Definition efforts

Principal Investigator: Storm top divergence studies using the LAWS, NASA/Marshall Space Flight Center.

Principal Investigator: Cloud top and planetary boundary layer wind measurements using a space-based lidar, SBIR, U.S. Air Force.

Principal Investigator: Simulation experiments to assess LAWS' impact on global climate change modeling, NASA.

Principal Investigator: Vertical velocity structures significant to space-based and ground- based lidar anemometry, CNES, France.

Principal Investigator: Norfolk Southern Rail Study.

Co-Principal Investigator: Interdisciplinary research scenario - Version Ø, NASA.

Principal Investigator: EOS Laser atmosphere wind sounder (LAWS) investigation, NASA.

Principal Investigator: Space-based Doppler lidar sampling strategies -- algorithm development and simulated observation experiments, NASA.

Principal Investigator: PLACEM, Pier IX Terminal Company/Shell Mining.

Principal Investigator, Interdisciplinary research scenario - Version 0, NASA.

Principal Investigator, Airborne/space-based Doppler lidar wind sounders: Sampling the PBL and other regions of significant B and u inhomogeneities, NASA.

Principal Investigator, Lidar mapping of cloud tops and cloud top winds, SBIR, AFGL.

Principal Investigator: Tropospheric wind observations with Doppler lidars: SPARCLE and follow-on missions, NASA.

Principal Investigator: CAMEX-3, NASA.

Principal Investigator, DTA Pile Moisture Modeling project.

Fugitive coal dust emission project at Elk Run Coal Company

Fugitive coal dust emission project for Norfolk Southern

Design of Procontrol System for SINCOR, Jose, Venezuela

VERIFIED STATEMENT OF EROL TUTUMLUER

BEFORE THE
SURFACE TRANSPORTATION BOARD

STB Finance Docket No. 35305

PETITION OF ARKANSAS ELECTRIC COOPERATIVE CORPORATION FOR A DECLARATORY ORDER

VERIFIED STATEMENT OF EROL TUTUMLUER IN SUPPORT OF BNSF RAILWAY COMPANY'S OPENING EVIDENCE

My name is Erol Tutumluer. I am Professor of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign where I have studied and published papers regarding the effect of fugitive coal dust upon railroad ballast. The purpose of my Verified Statement is to describe for the Board my findings that coal dust has a pernicious effect upon railroad ballast.

Introduction

Fouling of the railroad ballast occurs when spaces or voids in this unbound aggregate layer are filled with finer sized materials. As a fouling agent, coal dust from coal trains accumulating in the ballast has become a major concern. I have studied the most probable adverse impacts of coal dust on railroad ballast on drainage and load carrying function, which were previously unknown because of the lack of technical data. As summarized below in my Verified Statement, the physical and mechanical properties of coal dust and other laboratory tests indicate that coal dust is one of the worst fouling agents when compared to mineral filler produced from aggregate breakdown and the fine-grained cohesive subgrade soils. Coal dust particles are mainly sand sized, however, they have lower density and greater plasticity, meaning that they have much greater water holding ability than subgrade soil fines, which are silty and clayey and often plastic (i.e., they possess high moister affinity). As compared to sand particles, coal dust particles greatly reduce the ballast strength, stability, resistance to settlement under unit trains, and ultimately the load-bearing ability of fouled ballast layers. My two major papers concerning fouled ballast are attached hereto as Exhibits 3 and 4. Exhibit 3 is Tutumluer, E., Dombrow, W., and Huang, H., "Laboratory Characterization of Coal Dust Fouled Ballast Behavior," In Proceedings of the AREMA 2008 Annual Conference, Salt Lake City, Utah, September 21-24, 2008. Exhibit 4 is Huang, H., Tutumluer, E., and Dombrow, W., "Laboratory Characterization of Fouled Railroad Ballast Behavior," Transportation Research Record 2117: Journal of the Transportation Research Board, National Research Council, Washington, D.C., 2009, pp. 93-101.

Exposure of coal dust to moisture significantly reduces the friction component of the shear strength and can cause significant reduction in load-bearing capacity. Even more drastic strength reductions can be realized when dry coal dust, never before saturated or soaked in the field and therefore having a high suction potential, is subjected to inundation and 100% saturation. This was exactly the case in 2005 when two derailments occurred on the BNSF/UP Joint Line—there was heavy precipitation after a relatively low level of precipitation for an extended period of time in the region, and in both places where the derailments happened, the ballast was heavily fouled by coal dust. The coal dust caused moisture to accumulate and caused the loss of strength of the track, resulting in the derailments, which threatened to interrupt the supply of coal to power plants.

Education and Experience

My educational background is in Civil Engineering. In 1995, I earned a Ph.D. in Civil Engineering from the Georgia Institute of Technology in Atlanta, Georgia. In 1993, I earned a

M.S. in Civil Engineering from the Georgia Institute of Technology in Atlanta, Georgia. In 1991, I earned a M.S. in Civil Engineering from Duke University in Durham, North Carolina. In 1989, I earned a B.S. in Civil Engineering from the Bogazici University in Istanbul, Turkey.

I am a transportation and geotechnical engineer and serve as Professor of Civil and Environmental Engineering at University of Illinois at Urbana-Champaign ("UIUC"). In October 2006, I was recognized with the Endowed Paul F. Kent Faculty Scholarship for my research accomplishments. In August 2008, I was promoted to full professor position in the Department of Civil and Environmental Engineering. In October 2009, the Department of Civil and Environmental Engineering extended for a new 3-year term my recognition and title of the Endowed Paul F. Kent Faculty Scholar. I have taught graduate and undergraduate courses in transportation soils engineering, subgrade soil and aggregate behavior and stabilization, introduction to transportation engineering, and pavement analysis and design at the UIUC since 1996.

I am an affiliate of the Transportation Research Board, and I have chaired its AFS50(1) subcommittee on "Applications of Nontraditional Computing Tools Including Neural Nets" for the past six years. I currently serve on committees AFP70, AFP30, AFS50, and AFD80 of the Transportation Research Board. I am a member of the AREMA Committee 1 on "Ballast," and I am currently the chair of the Pavements Committee of the American Society of Civil Engineering's Geo-Institute, which has been just recently recognized with the 2010 Committee of the Year Award from the American Society of Civil Engineering ("ASCE") Geo-Institute.

I am currently an Associate Editor for both the ASCE Journal of Computing in Civil Engineering (http://pubs.asce.org/journals/computing/default.htm) and the International Journal of Pavement Research and Technology (http://www.ijprt.org.tw). I also serve as an Editorial

Board Member for the International Journal of Pavement Engineering (Taylor and Francis Group, http://www.tandf.co.uk/journals) and the ASCE International Journal of Geomechanics (http://pubs.asce.org/journals/geomechanics/default.htm). I was the Conference Chair and Proceedings Co-Editor of the Eighth International Conference on the Bearing Capacity of Roads, Railways and Airfields, which was held at the University of Illinois, Champaign, Illinois on June 29-July 2, 2009 (http://www.BCR2A.org). My *curriculum vitae* is attached to this statement as Exhibit 1.

My research areas and expertise include testing and modeling railroad track geo-material (i.e., subgrade soils and ballast/subballast unbound aggregates); use of geosynthetics in railroad track and pavement substructure; shape, texture, angularity characterization of aggregates using video-imaging techniques; modeling of particulate media using discrete and finite element methods; and mechanistic based railroad track and pavement designs. I have authored or co-authored more than 150 technical papers in these areas.

I have extensive experience in studying the effect of coal dust on ballast behavior. I have also studied the potential for developing ground penetrating radar ("GPR") based railway track subsurface condition indices from estimates of track bed materials' physical properties and the recent BNSF project on the characterization of fouled ballast behavior. To study ballast fouling through the use of GPR scanning, I traveled to Gillette, Wyoming on July 22-25, 2007 to collect ballast aggregate samples from the Joint Line. During this visit to the Joint Line, I had a chance to personally observe the coal dust accumulation.

I have also recently studied the effects of accumulation of coal dust in the aggregate ballast layer of the railroad track structure on the BNSF/UP Joint Line and have published two major papers concerning the effect of coal dust upon fouled ballast. The research study focused on large direct shear laboratory tests to measure strength and deformation characteristics of both clean (new) and fouled ballast aggregates at various stages of fouling with (1) non-plastic mineral filler, (2) plastic clayey soil, and (3) coal dust. This study determined material properties that could be used for modeling the ballast behavior and evaluating reductions in strength and stability. The tests were conducted at the University of Illinois on granite and limestone ballast samples. The coal dust was provided by the BNSF from the Joint Line. From the research findings, the two major papers that I previously identified were published. The first of these papers, Exhibit 3 to this statement, presents the test results on coal dust and fouling of granite type ballast material. The second of these papers, Exhibit 4 to this statement, documents the effects of three types of fouling agents: coal dust, non-plastic mineral filler, and plastic clayey subgrade soils. We found that coal dust caused the worst fouling effects and the greatest shear strength loss while non-plastic mineral filler and plastic clayey subgrade soils caused less detrimental effects as fouling agents.

I have extensive experience on other issues relating to railroad track substructure, and that experience is described in Exhibit 2 attached hereto.

Coal Dust Problem

Based upon my specific research regarding coal dust and its impact upon ballast, I have found that coal dust is one of the worst fouling agents when compared to mineral filler produced from aggregate breakdown and the fine-grained cohesive subgrade soils.

Let me start by describing ballast and its purpose. Railroad ballast is uniformly-graded coarse aggregate placed between and immediately underneath the crossties and the rail. The purpose of ballast is to provide drainage and structural support for the heavy weight applied by loaded trains. Proper functioning ballast is critical to maintain operations on high volume tracks, such as the tracks on the Joint Line. For a proper functioning ballast, superior ballast aggregate shape properties, such as an angular crushed stone, and size distribution (gradation) are critical to provide ballast strength and stability. Proper functioning ballast gradation requires large enough spaces or voids between the aggregate to provide adequate drainage. Therefore, for ballast to function properly, it must have sufficiently large voids for drainage and structural stability.

As a section of ballast on the Joint Line ages, it is progressively fouled with fine-grained materials, such as mineral filler, plastic soil fines, and coal dust from coal trains. These materials can fill the voids and cause ballast fouling. The most commonly used method to assess track ballast condition is to check visually for evidence of fouling, pumping, or water accumulation (ponding) at ditches and shoulders. However, the surface of a ballast layer generally has a clean appearance most of the time, and it is often not possible to detect the amount of ballast fouling through visual inspection alone as the clean appearance of the surface of a ballast layer may nonetheless conceal fouled ballast. Another method for testing ballast fouling is ballast sampling and testing through laboratory sieve analyses. This laboratory method can provide some insight into the compositions of the larger aggregate particles and the amount of fines in a particular ballast section. Finally, the use of ground penetrating radar ("GPR") can also indicate the amount of ballast fouling. GPR is a nondestructive means of testing because it scans existing railroad track. The use of GPR, however, is currently at a research stage for future implementation, and it is not yet a standard practice.

Regardless of the method used to test the ballast, fouled ballast occurs when there is the loss of aggregate to aggregate contact because the voids are filled with finer sized materials. In a clean ballast sample, almost all aggregates are supposed to establish contact with each other at the aggregate surface to carry the load (as shown in Exhibit 3, at 21 Figure 2a). As shown in

Exhibit 3, page 21 Figure 2b, dirty or partially fouled ballast has the voids in between contacting aggregates filled with fine particles, but still maintains aggregate to aggregate contact. By contrast, fouled ballast has an excessive amount of fine particles, and the aggregate to aggregate contacts are mostly eliminated (as shown in Exhibit 3, page 21 Figure 2c). The aggregate particle movements are then only constrained by the fine particles filling the matrix or voids between the particles. In regards to excessive fouling conditions, for example, as in the case of 2005 Joint Line derailments when wet coal dust completely filled all voids in ballast and pumping was observed on the surface of railroad track, the low strength of the fouling agent would govern for carrying the wheel load. Hence, train derailments may occur due to unstable support under the crossties.

My research showed that different fouling agents have different effects on ballast based upon the physical and mechanical properties of the fouling agents. There are mainly three types of ballast fouling agents: (1) nonplastic mineral filler; (2) fine-grained and plastic subgrade soils; and (3) coal dust. Plasticity index refers to a certain range of gravimetric moisture content in soils determined in the laboratory as the difference between the liquid limit (at which soil behaves as a viscous fluid) and the plastic limit (lower moisture content at which a thin 1/8-inch soil thread crumbles upon rolling under your palm), and it is obtained from conducting these Atterberg limit tests on soils. The term "nonplastic" therefore refers to the low affinity and moisture absorption or holding ability of mineral fillers. Subgrade soils are fine-grained, i.e., silty, clayey, and are often plastic, meaning that they possess high moisture affinity. In our research study attached as Exhibit 3, coal dust was found to be highly plastic, meaning it has the potential to absorb water like a sponge, and was even more plastic than most commonly found plastic natural clays. Although 76% of coal dust was found to have sand-sized particles with only 24% silt of clay sized, the high plasticity of coal dust is expected to have the most detrimental effects on mechanical properties and impact differently the engineering behavior when they foul clean ballast layers. Our research shows that in rail lines where the ballast is not exposed to coal dust, ballast fouling is due to ballast aggregate gradually powdering, i.e., breaking down, over a period of years. By contrast, in rail lines where the ballast is exposed to coal dust, the ballast is fouled very quickly by coal dust particles that accumulate in the ballast void spaces and have high potential to absorb moisture.

Research Shows That Coal Dust Is One of the Worst Ballast Fouling Agents That Has Been Studied.

I will briefly describe the test protocol we used in our research. We obtained coal dust samples from the Joint Line. In March 2007, BNSF provided four buckets of coal dust samples collected from Milepost 62.4 of the Joint Line. To determine the physical and mechanical properties of the coal dust samples, laboratory tests conducted at the University of Illinois included both dry and wet sieve analyses of the coal dust in compliance with ASTM C 136 and ASTM C 117 test procedures for determining grain size distributions, Atterberg limits, specific gravity, moisture-density compaction relationships, and shear strength properties. We compared the properties of coal dust to the physical and mechanical properties of fine-grained silty and clayey soils to identify coal dust's potential negative impact on railroad track ballast strength characteristics.

In the summer of 2007, BNSF Railway Company representatives in Gillette, Wyoming shipped to the University of Illinois approximately 2 tons of granite aggregate commonly used in the Joint Line railroad track structures as the ballast layer. To determine the physical properties of these granite aggregate materials, laboratory tests conducted at the University of Illinois included grain size distributions, specific gravity, and unit weight properties of the granite aggregate. Using a large direct shear (shear box) testing machine, both clean and coal dust fouled granite ballast samples were then prepared and tested under dry and wet conditions in an effort to investigate shear strength properties in relation to the mechanical functions of railroad ballast.

Several laboratory tests were conducted on the Wyoming coal dust samples obtained from the Joint Line as reported in Exhibit 3. First, mechanical properties of representative coal dust samples were determined for the first time at the University of Illinois through laboratory tests, such as, grain size distribution, Atterberg limits, specific gravity, moisture-density compaction relationships, and shear strength properties. The summary of the test results are as follows:

- Coal dust Liquid Limit ("LL") = 91% – *much* higher than typical weak soils.
- Coal dust Optimum Moisture Content ("OMC") = 35% – *much* higher than typical weak soils.
- Coal dust can absorb and hold a lot of water when compared to typical weak soils such as clays and silts.
- Triaxial shear strength of coal dust at OMC = 3 psi – *very low*.
- Coal dust friction angle at OMC = 33.5 degrees obtained from direct shear tests indicated a large reduction with increasing moisture content.

Then, granite type aggregates—also received from the Joint Line near Gillette, Wyoming and commonly used in the railroad track as the ballast layer—were added coal dust at different percentages by weight and moisture contents to represent coal dust fouling in the field. When fouled samples were tested in large direct shear (shear box) equipment, we found that 25% coal dust by weight of aggregates were enough to fill up all the voids in ballast corresponding to 43% of the total volume. The summary of the test results are as follows:

- The highest shear strength values were obtained from the clean ballast at all applied normal stress levels.