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Report to: Damascus Citizens for Sustainability
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Baseline Methane Emissions in Damascus Township, Wayne County, Pennsylvania

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EXECUTIVE SUMMARY

A baseline data set has been collected for Damascus Township, Wayne County, Pennsylvania. To our knowledge, this is the first ever environmental baseline for methane in ground-level air. The data have been compiled, processed, and examined and found to be of high quality. The data indicate relatively low and reasonably consistent methane concentrations throughout the Township. Since no standard criteria for such baselines currently exist, we elected to define for present purposes baseline criteria that could be readily applied by anyone using commonly available spreadsheet software, e.g., Microsoft Excel. For Damascus Township this approach showed that 99% of all data in any similar future methane survey should be less than 2.01 ppm, 99.9% should be less than 2.68 ppm. Appropriate methods can be applied to the baseline data set to extract baseline methane levels for any specific location along the surveyed roadways. Other implications of the data, and related data from other locations in the Marcellus Shale region are briefly discussed.

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[2] President of Gas Safety, Inc. with 30 years experience in gas leak detection and measurement, related regulatory compliance, and training.

BACKGROUND

Out of concern for the residents and property owners of Damascus Township (Wayne County, PA), Damascus Citizens for Sustainability (DCS) sought a means by which an environmental baseline for methane in ground-level air could be economically acquired. Such a baseline would enable early detection of environmental contamination from gas well drilling. Ambient air contamination is most readily detected and quantified if baseline data is collected before any contamination occurs. Recently developed technology for measurement of trace gases in the environment offers a useful approach to development of baseline data, early detection of contamination from gas drilling, and verification of actual contamination. Further, this technology in combination with sufficient geological information on faults and fractures could enable pre-drilling identification of lands likely to develop methane migration problems even at considerable distances from the source gas well.

Methane is the lightest, most mobile component of natural gas, and makes up at least 85% of the volume of natural gas, and typically 95% or more of Marcellus Shale gas. Methane is lighter and less viscous than air. Consequently it will move farther and faster than any other contaminant that might be released from shale gas wells. The same properties also cause methane to disperse rapidly once it has reached the open atmosphere. Nevertheless, methane is the first and most rapidly dispersing contaminant likely to be detected from a shale gas well.[3]

The rapid dispersion of methane once it has been released into the open atmosphere implies the need for analytical instrumentation capable of accurately and consistently measuring trace levels of the gas. Previously the potential usefulness of methane as an indicator of environmental contamination from gas wells or other sources was limited by the difficulties involved in effective air sampling and analysis for trace levels of the gas. Measurement of low but environmentally important levels of methane in air required special sample collection work in the field followed by transport to a lab for analysis using sophisticated laboratory instruments. Recent developments in analytical technology, i.e., cavity ring-down laser spectroscopy, have made it possible to measure very low levels of methane in the field continuously with continuous logging of results. The instrumentation is rugged enough for routine field use and capable of measuring methane concentrations consistently to levels of parts per billion (compared to parts per million for most previously used methods). Depending on the instrument configuration, methane measurements are made continuously every 1-5 seconds. Typically the instrument is operated in parallel with a GPS unit (internal or external) and tags each methane measurement with location data. Whenever this combination of both the methane measurement and GPS technology is active it will continuously determine and record the time, location, and methane concentration in the air, every 1-5 seconds, wherever the instrument has been. This

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[3] The single exception to the broad usefulness of methane as an indicator contaminant is during the drilling of the well. Free-flowing methane (natural gas) may or may not be encountered during drilling of the well, i.e., before hydraulic fracturing. When there is no free-flowing methane, other potential contaminants might appear first, e.g., drilling fluids, flowback water. Reports to date suggest free-flowing methane is frequently encountered during the drilling (before hydraulic fracturing) of shale gas wells. Hence, the cases in which methane is not the most likely first contaminant are probably few.

was the instrument combination used for baseline data collection in Damascus Township.

Gas Safety, Inc. (GSI) offers methane measurement services based on this new technology, including environmental methane surveys. DCS engaged GSI to measure and document methane levels in ambient ground level air in Damascus Township. DCS and GSI believe this is a first ever effort to document existing baseline ground-level methane for any area anywhere.

Like any effort to measure and document environmental conditions, this first ever effort to do so for ground-level methane would have to fill three requirements. (1)The materials and methods would have to be appropriate to the purpose. Equipment had to be in good working order and functioning normally throughout the data collection work. (2)The collected data would have to be of verifiable technical quality. (3)The results would have to be consistently plausible for the area being surveyed.

Fulfilling requirement (1), the instrument used, produced by Picarro, Inc. [www.picarro.com] has an onboard monitoring and control system. The instrument was calibrated by the manufacturer to an accuracy within 2% of the actual methane level. That is, an indicated methane level of 2 ppm indicates the actual level is somewhere between 1.96 and 2.04 ppm. This inaccuracy does not reflect instrument limitations, but limitations of the accuracy of reference gas samples used during calibration. The instrument stability and function was verified by the manufacturer on 16 May and repeatedly tested for stability until the Damascus Township baseline work began. The instrument self-monitoring and control capabilities and calibration history assured the technical quality of the data.

Fulfilling requirement (3), the plausibility of the data for the conditions in Damascus Township would be determined by examining consistency of the data with respect to itself and to similar data previously collected in other similar areas.

The contracted field data collection work was carried out on 30 and 31 August and 4 and 5 September 2012. The data was subsequently compiled, processed and analyzed by GSI. The work, data and findings are documented in this report. The digital time, location and methane concentration data are too voluminous for presentation with this report, and have been separately submitted to DCS.

NOTE: All figures follow the narrative section of this report. This report includes one table that is presented in the section “Basic Statistical Summaries of Data”.

FIELD WORK

In order to facilitate as much coverage of the Township in the available time as possible, and to avoid concerns or delays related to private property rights, all measurements were taken driving on public roadways. Figures 1.A. and 1.B. provide reference views of the roads driven and general area covered by the methane survey of the Township. The air sample intake was positioned to ride, pointing downward, behind the vehicle ≈12 inches (30 centimeters) above the road surface. Roads were driven at the posted speed limit or slower if necessitated by road conditions. GSI experience has shown this approach is adequate for detection of even relatively weak methane sources under most circumstances. Reasonable efforts were made to run the instrument over every public roadway in the Township at least twice during the methane baseline survey field work. Due to the complexity of the system of roadways in the Township, doubling back over some previously surveyed areas was necessary, causing some roads to be surveyed more than twice. Portions of Lassley and Brucher Roads were surveyed only once due to uncertainty about public or private ownership. Approximately 230 miles of roadways were surveyed on each of the two 2-day surveys. None of the survey days covered exactly the same routes or road driving patterns.

DATA COMPILATION AND PROCESSING

Data is logged by the instruments as data lines in a digital data file. Each line will have several data types, including time, latitude, longitude, methane, and various types of data used by the instrument to monitor and assure proper function. During the Damascus Township baseline work each data line included individual values for 24 active data types. The number of data lines recorded on each of the survey field work days were as follows:

30 August 38,368 lines of data
31 August 38,061
4 September 42,673
5 September 38,557

The instrument automatically records and starts a new digital data file about every hour to produce data logs as files of sizes (usually around 6,000 lines of data) that are reasonably easy to handle and to reduce risk of data loss. It is not practical or even advisable to turn off the instrument when making necessary vehicle stops, e.g., for re-fueling, meals, U-turns, navigation, crossing contract area boundaries, etc. Running the instrument during these times, however, produces a data set with geographically disproportionate amounts of data for such locations. In order to develop a more geographically representative data set, the data collected at such stop locations are manually identified and reduced or removed from the baseline data set.[4] Following removal of such data, the amount of data analyzed for each survey day were as follows:

30 August 25,831 lines of data
31 August 33,586
4 September 38,158
5 September 31,339

Since conditions, e.g., wind, barometric pressure, that vary on a daily basis do affect methane concentrations in the air, the data set for each day was evaluated separately. The data was compiled, processed, and analyzed using Microsoft Excel (version 12.2.8) for spreadsheet work and Google Earth (version 6.0.3.2197) for mapping and visualization. The distribution of measured methane levels among selected ranges was determined using the FREQUENCY function in Excel (use of some other functions is precluded by the large amount of data or by the time required for calculations for such large amounts of data).

RESULTS

Visualization is the most convenient first approach to attempting to understand data sets the size of the methane data files generated during the GSI Damascus Township Methane Baseline survey runs, i.e, more than 25,000 methane data points in each of 4 data sets. Two different approaches to visual examination of large data sets are presented in Figures 2.A. and B. and 3.A. through 3.D.

Plots of Survey Data on Remote Imagery

Figures 2.A. and 2.B. present the methane data for all 4 survey runs superimposed using Google Earth on aerial/satellite imagery of the Township (and surrounding areas). Comparison of Figure 2.A. to Figure 1.A. (showing public roads surveyed) can provide a visual appreciation of patterns of variability in methane levels over the Township. Methane levels are lower generally

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[4] Survey vehicle stops or maneuvers that result in generation of fewer than 50 or so data lines for a single location are not modified. Those that generate in the range of 50-1000 data lines are usually reduced by removing multiple random blocks of data to reduce the number of data lines to ≈50. Since extreme high methane data values are a concern in developing a conservative baseline data set, care is taken to assure random data removal leaves an at least proportionate number of extreme high values. In some conditions blocks of data are replaced with average values for each such block. Though this average-replacement approach is better for protecting the local mean effects of such stops, it is not preferred because it reduces the influence of extreme high values and complicates plotting of results. Removed blocks of data are set aside within the data file to allow baseline data analysis to be performed on a more geographically representative data set. That is, no data is permanently deleted from the original data file. In fact, some of the removed blocks of data are particularly useful for understanding the capabilities of the instrumentation and methane movement at specific locations.

in the southern approximately 1/3 of the Township and in areas that appear to be forested (moderate to darker green colors in the image) throughout the Township. Higher methane levels are more common in the northern approximately 2/3 of the Township, and are predominantly associated with crop, pasture, residential or other areas where forest vegetation is no longer present (light green to beige colors in the image).

Figure 2.B. shows higher methane peaks occurred primarily in the areas of generally elevated methane levels shown in Figure 2.A. The higher peaks were clustered in the north central part of the Township (relative size of these peaks compared to other areas with gas drilling is discussed later in this report). Visual review and analysis of these images at higher resolution (not shown in this report) indicated most of the highest peaks occurred near the feed lots and animal pen facilities on cattle farms. Visual field observations during the surveys, and on return trips to locations of elevated methane levels, consistently confirmed the association of the highest methane levels with the presence of cattle or cattle pen areas on farms. In one case, a methane peak occurred when a small herd of cattle crossed the road in front of the methane survey vehicle. The only live directly observed association was always between the presence of methane and live cattle. However, since the cattle observed were usually in or near a pen or lot, the possible importance of manure packs in those lots could not be distinguished from that of the cattle. Minor methane peaks were typically associated with the presence of residential or other structures, and presumed related to on-site sewage systems.

Conventional Graphs of Survey Data

Another visual approach to understanding such a volume of data is to plot the methane data against a consistent related parameter. In the case of the methane survey data, elapsed survey run time is such a consistent related parameter. Figures 3.A. through 3.D. show a series of graphs covering roughly 4 consecutive hours of methane survey work on 5 September. It should be kept in mind that time is the important parameter for this data presentation, not location. During the first roughly one hour (Fig. 3.A.) the vehicle was parked, hence, methane was moving to the vehicle. During the other three roughly one hour intervals (Figs. 3.B.-3.D.) the vehicle was in motion, i.e., the vehicle was moving to the methane.

During the time period shown in the first graph (Figure 3.A.) the vehicle was parked in Tyler Hill, approximately 500 feet from a cattle pen area of a local farm. The cattle were not visible from where the vehicle was parked, but their presence was verified later after the elevated methane levels were noticed to have occurred repeatedly in this area. The large number of pronounced methane peaks during this period were almost certainly due to methane from the cattle or cattle pen drifting over the car parked beside Route 371. The graph gives a clear impression of the intermittency of methane concentrations due to such a source. The intermittency is likely due to intermittency of release of methane by the cattle or pen residues and variations in wind and mixing of the methane after it is released at the source. Wind was minimal at the time this data was collected.

Figures 3.B-3.D. show similar graphs for the following roughly 3 hours when the vehicle was in motion surveying extended parts of the Township. In comparison to the time near the cattle lot at the beginning of the survey run (Figure 3.A.), the lower number and sizes of methane peaks can be easily seen. The sizes of measured methane peaks are presumed to indicate relative sizes of methane sources. The stability of the background methane level during the roughly three hours away from the cattle pen is shown by the extended flat line sections of Figs. 3.B.-3.D. Over the roughly 3 hours shown in Figures 3.B. through 3.D. there were only 4 peaks over 2 ppm while during the roughly 1 hour period ≈500 feet from the cattle pen peaks over 2 ppm were too numerous to count. This comparison serves to illustrate the reliability of the instrument in detecting low level methane sources (e.g., cattle). The graphs also show visually that for areas of the Township surveyed on this 5 September run, the methane baseline away from distinct methane sources was below 1.8 ppm.

Basic Statistical Summaries of Data

Another approach to examining the quality of and understanding the baseline methane data is to consider some basic statistical summary information. Factors such as atmospheric pressure, wind speed and direction, can affect ambient air methane levels and vary over short time periods, including hour-to-hour. In numerous cases high methane peaks were present at a given location on one sample date and not on the next, or in some cases even when sampled more than once on the same day. In some cases differences in wind conditions caused the methane to be detected on one side of a farm on one date and on another side on another date. Consequently, methane data was summarized for each survey day. Additionally, an exceptional, anomalously large methane peak not clearly associated with a cattle farm was encountered at the extreme northern end of Meadow Lane north of Tyler Hill and measured for an extended period (about 20 minutes) during the survey of 31 August. Due to the high concentrations of methane and the prolonged period, hence large number of measurements in the data file, the data for that date were examined both with and without the Meadow Lane methane anomaly data. Table 1 shows the summary data for each survey day including the maximum and minimum methane levels, total number of methane measurements, the number of methane measurements greater than 3 ppm and less than 1.8 ppm, and the 95th, 99th, and 99.9th percentiles[5] of methane level measurements.

Table 1. Basic statistical summaries of Damascus Township methane baseline survey data. Each day covered a different section of the Township with necessary overlaps.

[5] A percentile is the value below which a given percentage of data points occur. Example: If 95% of all data values are below 2.01, then 2.01 is the 95th percentile.

Survey Date	30 Aug 2012	31 Aug 2012	4 Sep 2012	5 Sep 2012	31Aug 2012 w/anomaly
			Methane (ppm)		
Maximum	3.735	3.585	4.021	3.071	4.703
Minimum	1.765	1.766	1.700	1.707	1.766
			Number of Methane Measurements		
Total	25,831	33,586	38,158	31,339	38,061
>3ppm	28	12	10	2	562
<1.8ppm	10,027	40	36,067	30,821	40
			Percentiles of Methane Measurements (ppm)		
99.9th	2.01	2.55	2.68	2.25	3.11
99th	1.92	2.01	2.00	1.83	2.05
95th	1.90	1.91	1.84	1.76	1.91

Comparison of the maximum methane levels indicate similarity of high end data on the 30 and 31 August survey dates, but quite different high end data on the 4 and 5 Sep survey dates. The similarity of 30 and 31 August, however, disappears if the Meadow Lane anomaly data are included. This confirms the intensity of that anomaly. It is important to note that the Meadow Lane anomaly present on 31 August was no longer present during the 4 September survey in the same area, as many other peaks present on one survey date or time were not present on the next or previous. The methane maximum at the Meadow Lane anomaly (4.703 ppm) was transient, lasting only a few seconds. That Meadow Lane maximum was only approached elsewhere by two 4.021-ppm readings occurring for less than 2 seconds with a rapid drop to baseline (Schuman Road at State Route 1016). These 30 data points at only two locations were the only cases in over 130,000 data points that exceeded 4 ppm. For comparison, during road surveys in the Dimock, PA area on roads in the vicinity of shale gas wells readings greater than 5 ppm were common, as were readings in the 10-20 ppm range on public roads in the vicinity of a sizeable methane migration impact area associated with a shale gas well in Leroy Township, Bradford County, PA [http://www.damascuscitizensforsustainability.org/wp-content/uploads/2012/07/CAC-Leroy-060812-report.pdf, and, http://www.damascuscitizensforsustainability.org/wp-content/uploads/2012/08/Leroy2-072512-report-FINAL.pdf].

The minimum methane levels were consistent over all four survey dates. Minimum methane levels presumably are least affected by unusual methane sources, and so, should be more consistent over time than higher methane levels. If minimum methane levels varied substantially, then instrument function would have to be considered more carefully. The Damascus minimum methane data indicated normal instrument function and supported the general quality of the data.

Examination of the numbers of total methane measurements, and those greater than 3 and less than 1.8 ppm indicate the 31 August survey had substantially fewer measurements less than 1.8 ppm than the other three survey dates. The 3-ppm upper criterion level was selected as a round value that appeared to be rare in Damascus Township. The less-than-1.8-ppm level was selected to distinguish data from each survey run, hence, the times and areas covered by each, with respect to a value lower than the generally accepted global mean methane levels of slightly above 1.8 ppm.[6] The 31 August survey covered the areas of highest methane levels in the Township (see Figures 2.A and 2.B.). The distinctiveness of 31 August, therefore, indicates that the areas of generally elevated methane levels are more consistently above a global mean level. In contrast, the large proportion of values below 1.8 ppm on the other survey dates indicate areas and times in Damascus Township that methane levels were below the global mean. The 30 August survey had the highest number of measurements greater than 3 ppm and 5 September the lowest. However, inclusion of the Meadow Lane anomaly data increases the 31 August greater-than-3-ppm data count well above any other date, indicating again how uncommonly high the maximum methane levels were at that anomaly.

The percentiles[3] of the methane measurement data for each survey date provided further indications of the similarities and differences across days, and consistency of the methane baseline data. The 95th and 99th percentiles are reasonably similar for all dates (largest difference between dates, 0.15 ppm and 0.22 ppm, respectively), indicating the lower 99% of methane data are reasonably similar across survey dates. Even when the Meadow Lane anomaly data are included in the 31 August survey data, the percentiles are not changed substantially, except the 99.9th percentile, again indicating the consistency of the data over the four surveys.

The descriptive statistical summary data in Table 1 indicate the methane measurements collected over the four days of methane survey work are consistent. The data also provide means by which to define and select appropriate baselines for methane in ground level air in Damascus Township.

RECOMMENDED BASELINES

GSI suggests two broad types of baselines. One is a general Township baseline. The other is a location specific baseline.

The General Area Baseline

The general Township baseline is to be regarded as the normal methane condition in ground level air in the Township. It is based on conditions that can be considered normal or typical in the Township generally regardless of location. A general baseline value is important for assessing future changes in broad area methane levels, e.g., for evaluating whether or not the

[6] http://www.esrl.noaa.gov/gmd/aggi/

results of a future methane survey indicate new or unusual sources of methane have developed in the Township. The baseline should be conservative, i.e., favor high values in order to avoid false alarms regarding possible future methane contamination sources. The recommended baseline should be based on statistical criteria that are readily obtainable for large methane data sets. The percentiles based on frequency distributions provide such readily obtainable statistical summary. For the present, GSI recommends the highest value for each percentile listed in the table above (under "Percentiles of Methane Measurements (ppm)") be defined as the broad area baseline measures. The recommended general area Township methane baseline measures for similarly run surveys are then as follows:

95% of all methane data should be less than 1.91 ppm
99% of all methane data should be less than 2.01 ppm
99.9% of all methane data should be less than 2.68 ppm

If any of these measures are not met, further investigation to determine the cause of increased methane levels should be undertaken.
Further, all methane measurements in excess of 3 ppm should be regarded as elevated, and the probable source should be verified as soon as practical.
All methane measurements in excess of 4 ppm should be regarded as exceptional, and the source should be identified and confirmed as soon as practical.

Specific Location Baselines

Baseline criteria for specific locations within the Township survey area should be extracted from the full baseline data set. As a result of this methane baseline survey, in most cases there are now at least two sets of methane data covering the area around any given location. It is, however, important to recognize that the survey vehicle is moving constantly over the road near most specific locations. A short time is required for the sampled air to travel from the sample intake through the sample tube into the laser chamber. That sample tube transit time causes the methane data for a given location to be offset in data plots from the actual location, in proportion to the speed of the vehicle. This off-set is not important for general area baseline studies, but it is for evaluation of methane concentrations at specific locations. Further, the baseline data for a given location should not be regarded as the value of the single methane measurement nearest the location of interest, even if the vehicle speed off-set has been accounted for. An array of data points surrounding the location of interest should be selected from each survey run, and appropriate statistical tests applied to establish a confidence level regarding whether a given methane result is consistent with previous methane baseline data for the location. It should be noted that methane levels at almost all locations in Damascus Township were at local baseline levels. For such locations, the locations specific baseline will be the measured local baseline, which can be directly extracted from the original data.

CONCLUSIONS

A baseline data set has been collected for Damascus Township, Wayne County, Pennsylvania. The data have been compiled, processed, and examined and found to be of high quality. The data indicate relatively low and reasonably consistent methane concentrations throughout the Township, leading to a set of baseline measures including that 99% of all data in any similar future methane survey should be less than 2.01 ppm, 99.9% should be less than 2.68 ppm. Appropriate methods can be applied to the baseline data set to extract baseline methane levels for any specific location along the surveyed roadways.

RECOMMENDATIONS AND FURTHER DISCUSSION

On potential natural seepage of deeper source methane from faults/fractures

The general distribution of peak and elevated methane values were consistent with cattle operations being the strongest methane sources in the Township. However, the distribution of methane levels and peaks over the Township suggest geological features, most likely deep faults, may be affecting methane concentrations. Further, a 20-minute period of locally extreme methane levels that occurred on 31 August at the northern extreme of Meadow Lane was not clearly associated with cattle or other obvious potential methane source. At least one other lower, but location anomalous methane peak of unclear cause was also observed. It would be advisable to determine the source of methane at these two locations to resolve whether surface biological sources or releases of deep geological methane, or both, might be involved. If natural surface connections to deep geological methane sources do occur at such sites, then gas drilling in such areas may connect with fault/fracture networks potentially leading to uncontrollable gas flows to unforeseeable areas out to unpredictable distances. At this point, however, it is important to state that there are a variety of other possible methane sources that could have caused these two presently unexplained methane peaks.

The methane data collected away from locations with peak values in Damascus, suggest broader, more diffuse sources of methane may be influencing background methane levels. Data collected away from methane peak areas in parts of Dimock and Leroy (and surrounding) Townships also suggest such an influence. The data seem to indicate, as have data from previous geological investigations by Fountain and Jacobi[7], that methane from deep sources may be naturally seeping at low rates to the atmosphere through faults and fractures. Further, the extent and

[7] Fountain, John C., and Robert D. Jacobi. Detection of Buried Faults and Fractures Using Soil Gas Analysis. Environmental & Engineering Geoscience, Volume VI, No. 3, August 2000 (Summer), pp. 201–208.

intensity of such fault/fracture systems in the Marcellus region appears to be almost unknown.[8] It would seem that areas underlain by such fault/fracture systems, if drilled and fractured, might present practically unavoidable risks of loss of control of gas flows.

On the effectiveness of methane baselines and fugitive gas detection

Using appropriate cavity ring-down laser spectrometry instrumentation, the relative importance and ease of detection of fugitive methane emissions can be considered by comparison of some of the methane data collected by GSI to date. To begin, consider that among the over 130,000 data points used to verify the quality and consistency of the Damascus Township methane baseline data, only 30 exceeded 4 ppm. Two of those greater-than-4-ppm readings occurred in less than two seconds as a "puff" of methane passed the vehicle while at a navigation stop (Schuman Road at State Route 1016). All the others ranging from 4.019 to 4.703 ppm occurred at the Meadow Lane methane anomaly, again as an apparent cloud of methane passed by the survey vehicle stopped at that location for a period of about 20 minutes. When this Meadow Lane site was surveyed again on 4 September, methane readings were stable and at local background levels. These greater-than-4-ppm values seem striking in the context of other background and peak values encountered during the surveys of Damascus Township.

GSI has collected similar methane survey data in portions of Leroy and surrounding Townships, Bradford County and Dimock Township, Susquehanna County, PA. In those townships GSI was contracted to survey public roads for ground level methane concentrations suspected of being present due to previous or ongoing methane migration events. In the vicinity of some (randomly encountered) gas wells in the Dimock area methane readings greater than 5 ppm were common, reaching a maximum of 16 ppm. On public roads in the area impacted by the methane migration in Leroy Township methane levels in the 5-20 ppm range were repeatedly encountered at the same locations at different times on 8 June 2012, and again on 25 July 2012. Other third party field observations in the area indicate the methane surface flows causing that measured Leroy methane peak were ongoing over that period. It seems, therefore, highly likely that the measured methane peak in Leroy was sustained at least over that 47-day period.

Figures 4 and 5 provide graphic representations of comparisons of elevated methane levels in Damascus to those in Leroy and Dimock Townships. Figure 4 is a Google Earth based graphic presentation of similarly shaped methane peaks in Damascus and Dimock Townships with equivalent visual scaling, making the difference in the relative sizes of the large peaks readily apparent. The two peaks were chosen as the largest peaks of similar shape in the two Townships. Both peaks have a definitive major peak, a secondary minor peak and a long "tail", which remains above baseline for the Dimock peak beyond the bounds of the image. The Damascus peak returned to baseline methane levels within about 0.6 miles of the apparent foot

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[8] Jacobi, Robert D. 2002. Basement faults and seismicity in the Appalachian Basin of New York State. Tectonophysics 353:75- 113.

of the peak. The Dimock peak did not fully return to baseline for 2.9 miles from the apparent foot of the peak. This may have been in part due to methane from another source to the north and east. There were two gas wells in that area. It is appropriate to note that the Dimock peak in Figure 4 was truncated on the south (right side in the image) when the survey vehicle had to turn around before the end of the peak was encountered. It is not known how far south the peak actually extended. Also, the Damascus peak was measured on a single pass on the local public road, and the Dimock peak was encountered on two passes on the public road, but not present on two other passes sometime later. This is a common observation often related to a change in wind direction.

Figure 5 is a graph of methane concentrations over the ≈160-second time periods of the highest measured methane levels in Leroy and Damascus Townships. Again, the contrasts between the methane levels at the two locations are readily apparent. Baseline methane levels (≈1.9 ppm) were similar at both locations, indicated by the dashed gray line in the figure.

So, the data available to this point suggest that elevated methane levels in ground level ambient air associated with fugitive methane from shale gas wells are markedly higher and more sustained over time and distance than the transitory methane peaks due to normal, local, usually biogenic, methane sources, and are readily detectible and quantifiable by GSI ground-level methane surveys (using cavity ring-down laser spectrometry instrumentation).

On the relationship of fugitive methane in air and water

The GSI Leroy and Dimock methane in ground level air data clearly indicate elevated methane in ground level air occurs in areas where groundwater has been impacted by methane migrations. The contamination of ground water by fugitive methane in the Dimock area is now well known. Among 8 residential water wells known to GSI in the vicinity of the Leroy methane migration impact area, 7 are heavily contaminated with methane. In contrast GSI is unaware of reports of unusual methane contamination in water wells in Damascus Township. The presently available data, therefore, lead to a preliminary conclusion that methane contamination of ground level air and ground water are related. Further work is needed to confirm the reliability of this relationship and how its expression may vary across areas with different geological characteristics.

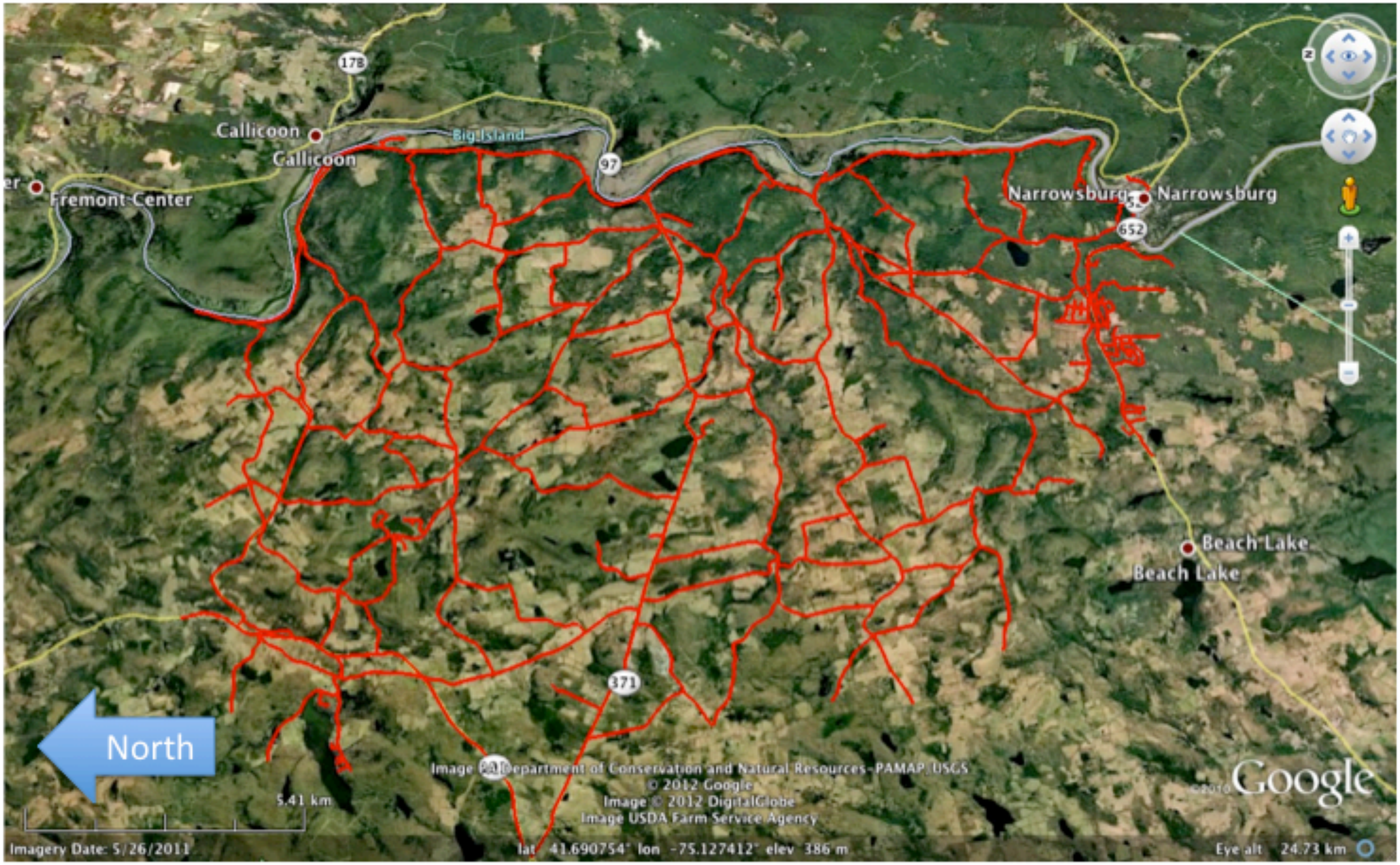

FIGURE 1.A. Damascus Township Methane Baseline
Red lines indicate the roads surveyed.

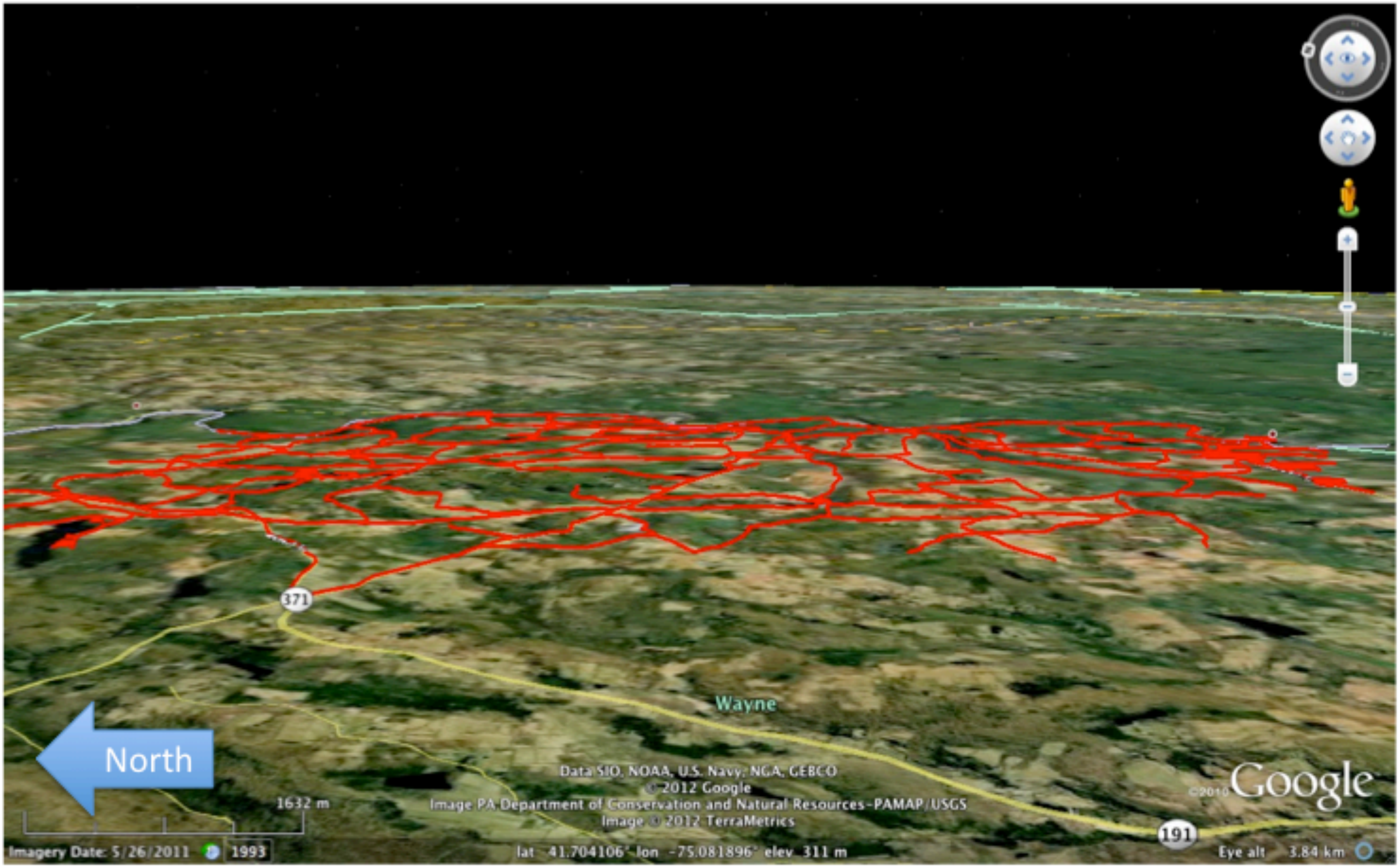

FIGURE 1.B. Damascus Township Methane Baseline
Red lines indicate the roads surveyed. Oblique view west to east.

Figure 2.A. Methane levels are indicated by the red markings in this overhead image of the area of Damascus Township. Data was processed to reduce visibility of values below and exaggerate visibility of values above 1.9 ppm. Compare to Figure 1.A.

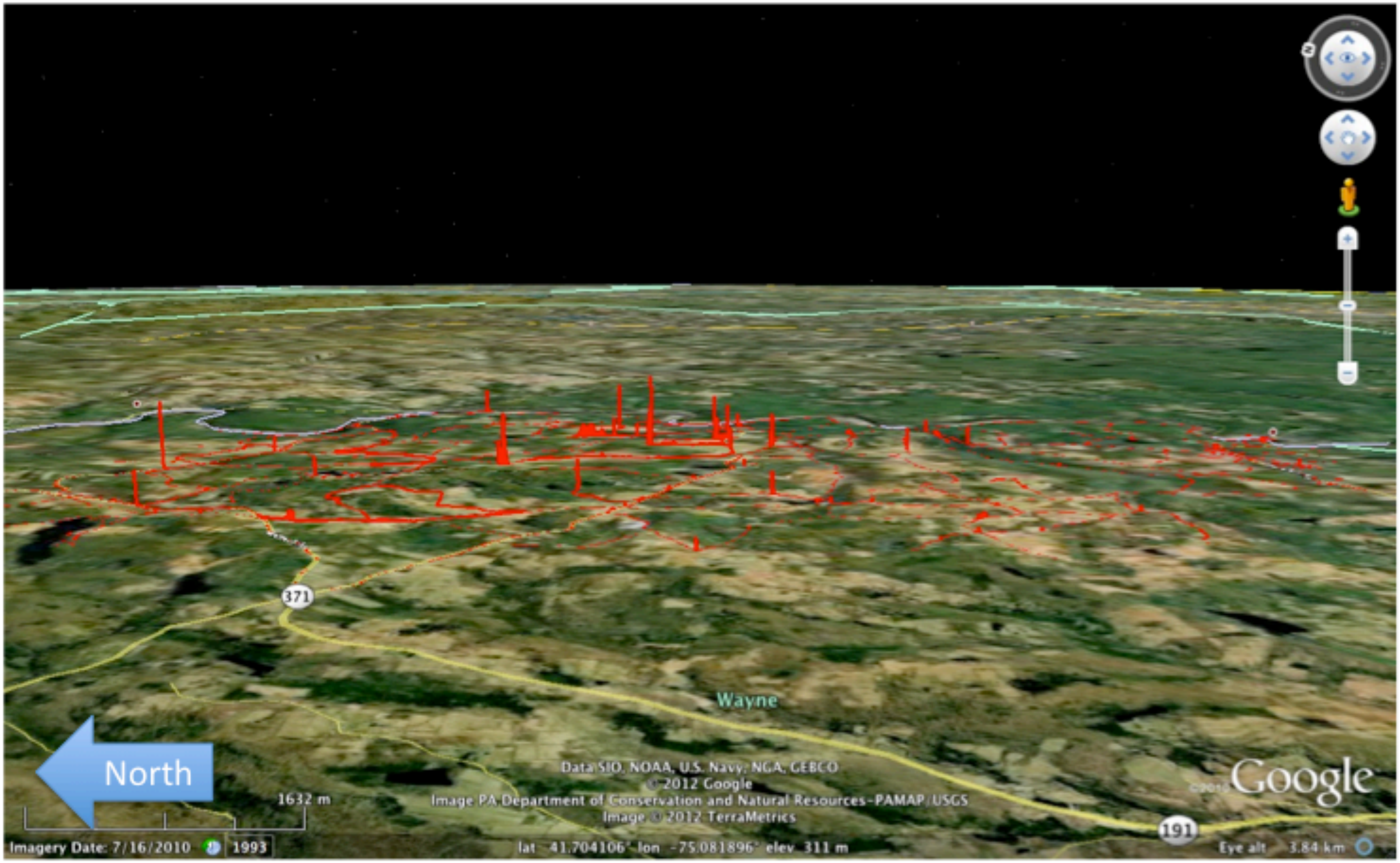

Figure 2.B. Methane levels are indicated by the red markings in this overhead image of the area of Damascus Township. Data was processed to reduce visibility of values below and exaggerate visibility of values above 1.9 ppm. Compare to Figure 1.B. Highest peak near center of image is 4.328 ppm methane.

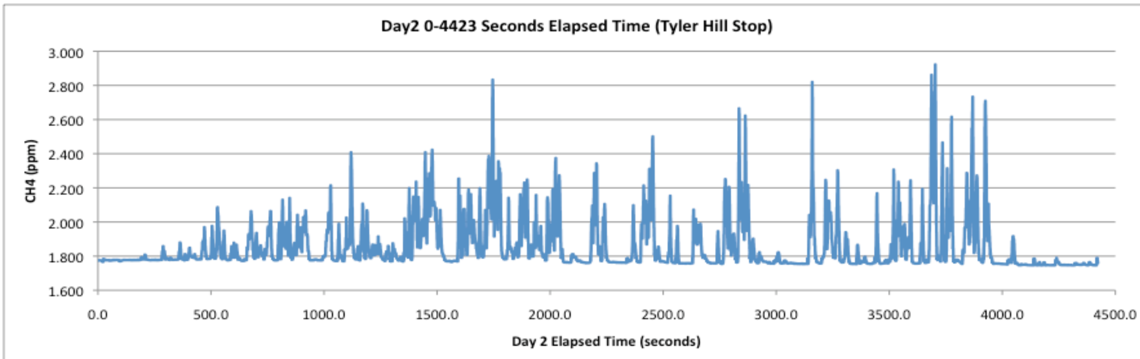

Figure 3.A.

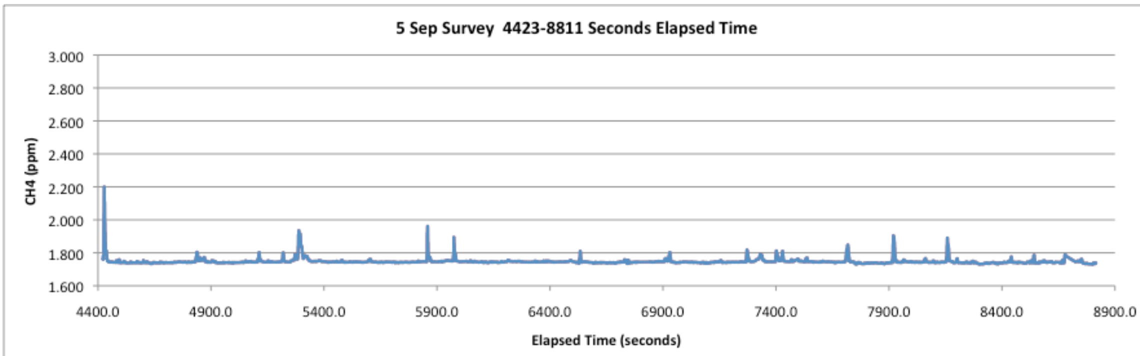

Figure 3.B.

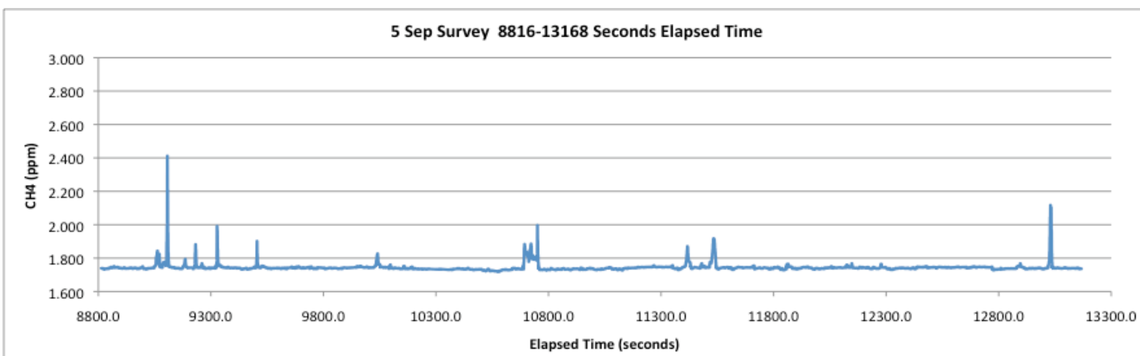

Figure 3.C.

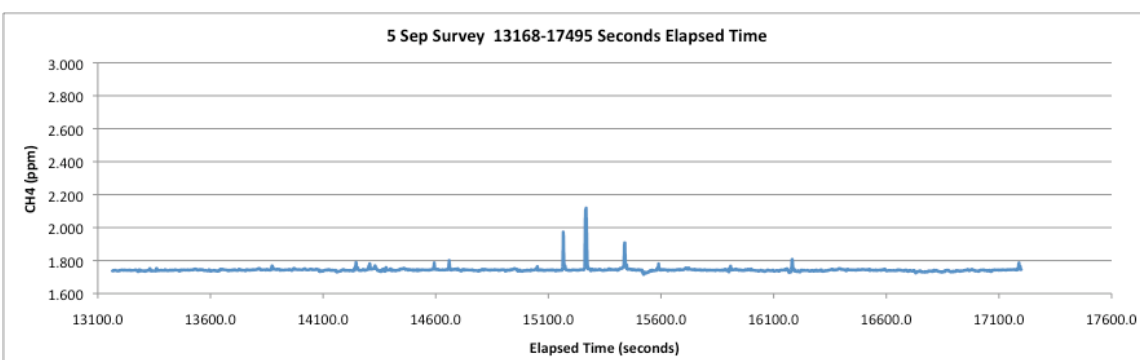

Figure 3.D.

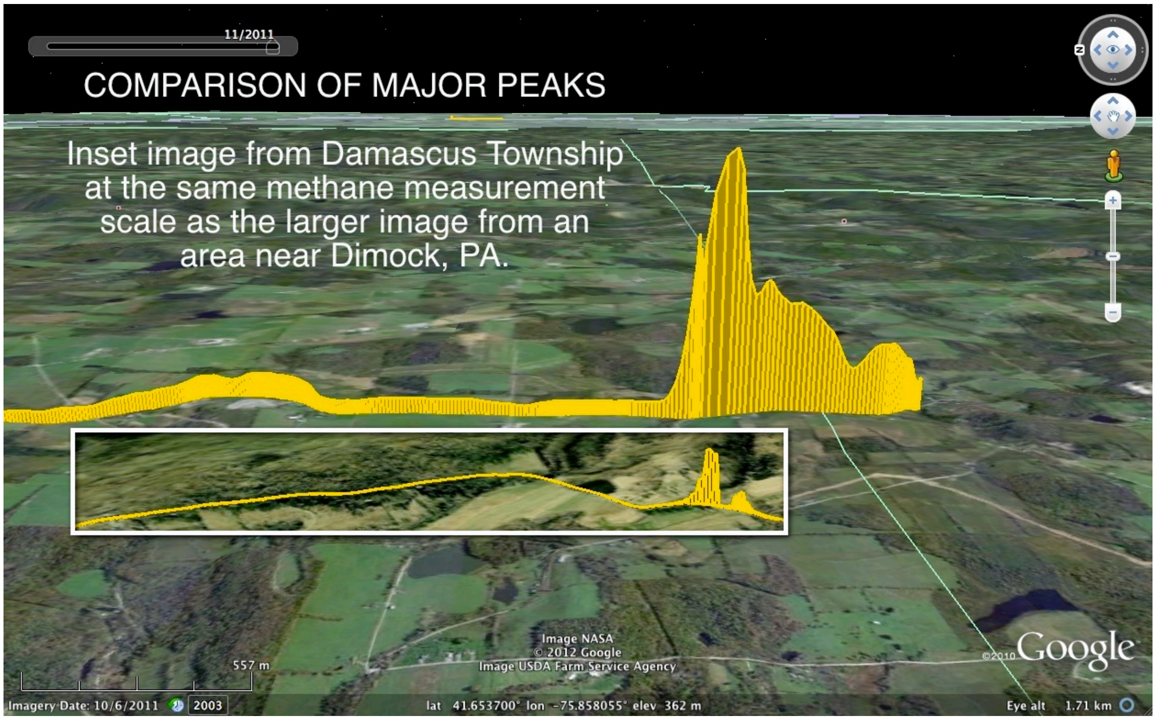

Figure 4. This image shows, on comparable landscape and with equal methane measurement scale, graphs of ambient air methane concentrations (in yellow) at groud level, along a stretch of road in Dimock Township, Susquehanna County (main image) and one in Damascus Township (inset). Shale gas development was advanced in Dimock Township (started in 2008), while most of Damascus Township was leased but there has been no shale gas drilling at the time of data shown in these images. These two stretches were chosen for comparison because they both featured peaks in methane concentration among the largest in the respective townships, with similar shapes: an extended tail on one side and secondary peak on the other. The Dimock peak maximum is 15.4 ppm compared to 3.5 ppm in Damascus. The Damascus peak returned to local baseline (≈1.9ppm for both areas) at 2.9 miles from the apparent foot of the peak, meaning the Dimock plume covers a wide area. Yellow curves ("curtains") indicate locations and levels of methane readings.

Credit:© GasSafety,Inc. prepared using Google Earth. Main image credits: Imagery NASA 10/6/2011, Image USDA Farm Service Agency, © 2012 Google. Inset image credits: Imagery date 10/6/2011, Image © 2012 TerraMetrics, Image PA Department of Conservation and Natural Resources-PAMAP/USGS, © 2012 Google

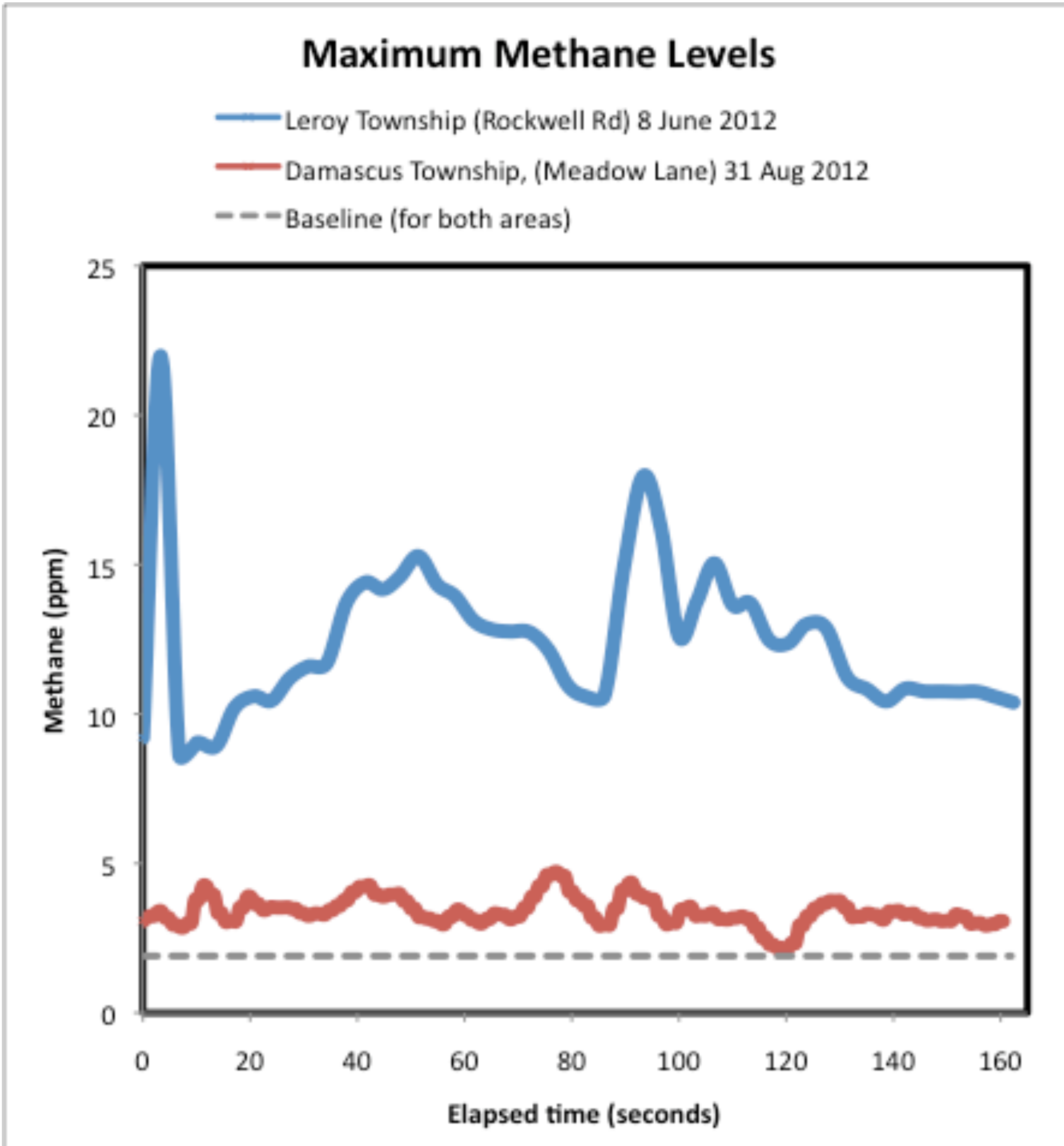

Figure5. Methane concentrations at the locations and times of maximum measured methane in ground level air in Leroy and Damascus Townships. The data cover approximately 160 seconds of elapsed time with the methane survey equipment operating but the survey vehicle stopped. The Leroy Township location was on Rockwell Road adjacent to an area of surface methane emissions associated with a methane migration event from a shale gas well. These levels were present on 8 June and again on 25 July 2012, and repeatedly on both of those dates. The Damascus Township location was the highest level encountered and occurred as an apparent transient level, appearing unstable when measured for about 20 minutes on 31 August 2012, with normal background levels present again on 4 September 2012.