Data from the Dense Atmospheric Observing Network to Detect GHG Trends and Anomalies

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ABSTRACT

To provide consistent data about atmospheric greenhouse gases (GHG) of natural and anthropogenic origins for climate scientists and for various agencies and organizations at national levels worldwide, over the next five years Earth Networks will deploy 100 cavity ring-down spectrometers to continuously measure CO_2. It is planned to place instruments at 50 tall towers in the United States, 25 in Europe and 25 around the world.

Data from this network will be used for monitoring and verification, and for inverse modeling to estimate natural and anthropogenic sources and sinks of greenhouse gases. Instruments are calibrated daily using a standard gas mixture, such as reference gases from NOAA. Sampling rate of the raw data from spectrometers is at the sub-minute range. Earth Networks provides data sets with various levels of pre-processing including application of data quality and meteorological filters. Currently, more than 20 instruments have been deployed in the US, and several sites have already accumulated year-long records. Analysis of trends and anomalies using the atmospheric GHG data from Earth Networks' instruments, the implications and the links to changes in regional and local sources and sinks will be discussed in this study. Dense coverage and high sampling rate of the Earth Networks' GHG observing system provides important information for gaining scientific insight into multi-scale processes both at the surface and in the atmosphere.

INTRODUCTION

Over the last two decades, leading researchers around the world have demonstrated that GHG fluxes for specific geographic regions can be estimated by measuring atmospheric concentrations of GHGs. The method can quantify and map both sources and sinks of GHGs and track changes over time. Reports utilizing this approach will provide policymakers with completely independent method to assess the outcomes of their efforts to reduce aggregate emissions in their cities. This "top-down" approach is much less vulnerable to reporting biases than “bottom-up” inventory methods (Nisbet and Weiss, 2010; Cayan et al., 2008).

The top down approach leverages new affordable sensor technology that enables the accurate and reliable continuous measurement of GHG levels in the atmosphere. The method relies on deploying and operating a network of these new, highly capable GHG sensors. Data from these sensors is combined with local observed and modeled weather data, to compute GHG sources and sinks using inverse methods (Lin et al, 2003; Lin and Gerbig, 2005; Gerbig et al., 2011). Since the sensor networks operate continuously and in real time, GHG emissions reports for specific geographic regions can be developed and used in real time as well. Importantly, valuable historical records of atmospheric GHG levels can also be established for local and regional areas (Fischer et al., 2005; Gurney et al., 2011; Kort et al., 2008; Cunnold et al., 2002). These networks can identify and locate fugitive methane leaks, which are emerging as potential major, unaccounted sources of urban GHG emissions. This is a potentially significant gain since methane is 25 times more powerful than carbon dioxide as a greenhouse gas per unit mass emission over a 100-year time horizon (IPCC, 2007).

Today there are only a few dozen continuous or quasi-continuous GHG instruments networked around the globe, including sites operated by Earth Networks, Scripps Institution of Oceanography, NOAA and other leading science and research institutions.

For local and urban scale fluxes to have sufficient accuracy at daily (or even hourly) granularity, which will facilitate adequate comparisons with bottom-up emissions, it is desirable to have high sampling frequency. Many of the previously deployed GHG instruments used in national inversion systems are collecting data where sampling methodology is not continuous, so that a particular short duration event with anomalous levels of methane, for example, would be missed or smoothed with time. Locations of the sites used in national inversion systems are shown in Figure 1, where various types of instruments are indicated. This paper describes Earth Network’s progress in the deployment of a Greenhouse Gas Monitoring network by showing collected data sets and trends.

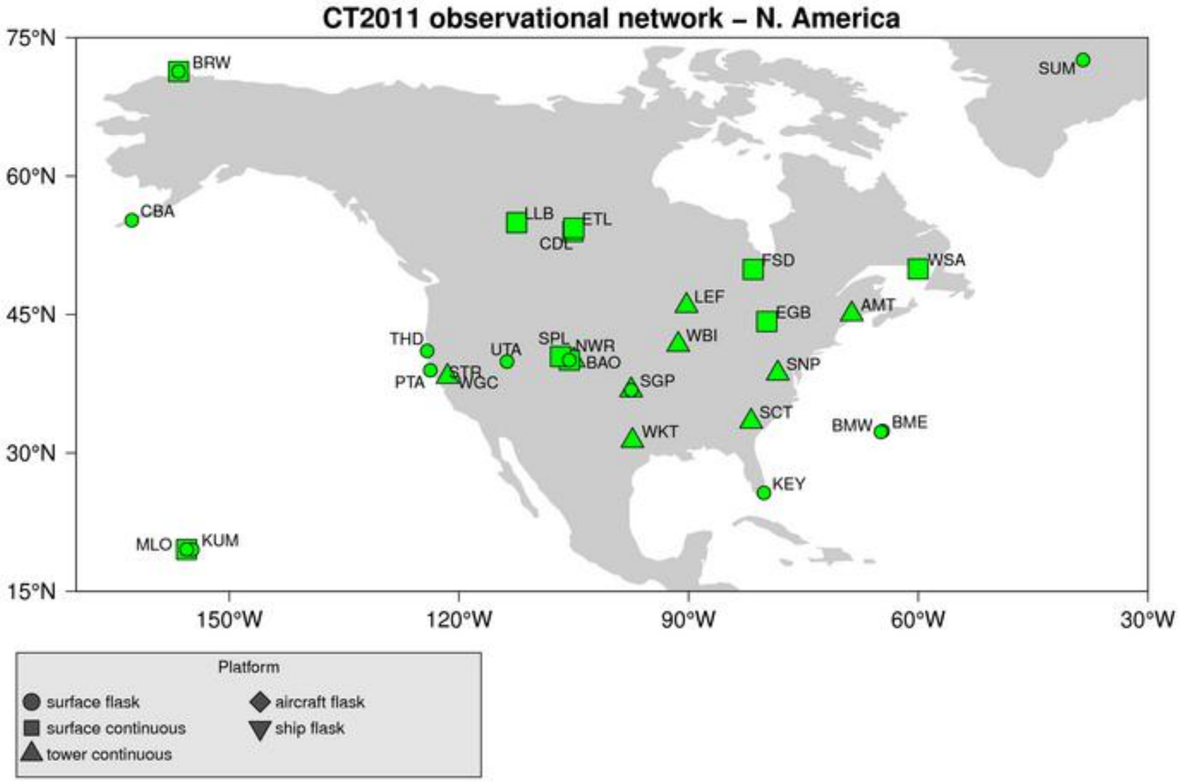


Figure 1. Sites providing observations for ESRL/NOAA global system CarbonTracker.
Source: http://www.esrl.noaa.gov/gmd/ccgg/carbontracker/goals.html

Global Greenhouse Gas Network

In 2011, Earth Networks, Inc. launched a large-scale initiative to deploy 100 cavity ring-down spectrometers (CRDS) continuously measuring CO_2, CH_4 and H_2O. Over the next five years, it is planned to place sensors at 50 tall towers in the United States, 25 in Europe and 25 around the world. Data from this network will be used for inverse receptor-oriented modeling to estimate natural and anthropogenic sources and sinks of CO_2 and CH_4. Instruments are calibrated using a standard gas mixture from the National Oceanic and Atmospheric Administration (NOAA).

Sampling rate of the raw data from spectrometers and collocated weather stations is at the sub-minute range, which is important for identifying both short-duration releases and localized emission sources that are potentially missing in inventories. As of March 2012, Earth Networks, Inc. has deployed 20 instruments in the United States, shown in Figure 2.

Deployed sites:

1	GHG39	Victorville	CA
2	SNDGS	La Jolla	CA
3	GHG09	Munich	ND
4	GHG06	Bagley	MN
5	GHG08	Bremen	IN
6	GHG20	Signal Mountain	TN
7	GHG16	Tateville	KY
8	GHG03	Dublin	GA
9	GHG10	Wedgefield	SC
10	GHG12	Danbury	NC
11	GHG15	Middlesex	NC
12	GHG18	Richmond	VA
13	AWSHQ	Germantown	MD
14	GHG25	Lewisburg	PA
15	GHG01	Bucktown	MD
16	GHG38	Utica	NY
17	GHG19	Hamburg	NJ
18	GHG21	Hamden	CT
19	GHG35	Durham	NH
20	GHG05	Houlton	ME

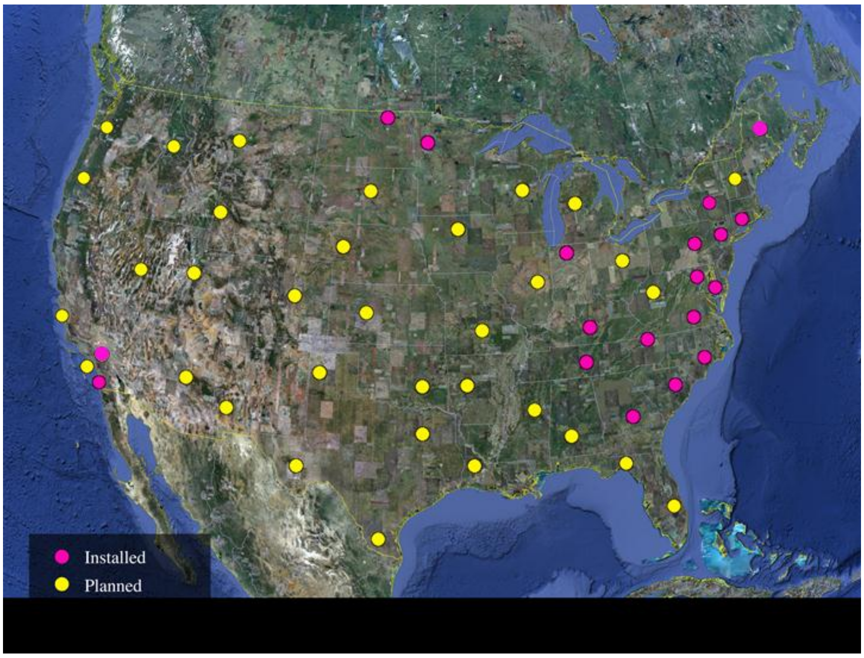


Figure 2. Map of Earth Networks' GHG sites in the US

Network of High-Precision Instruments

Earth Networks and Scripps Institution of Oceanography are working in close collaboration to ensure the GHG observation network produces the highest quality observations. Scripps scientists have played a vital role in advising Earth Networks regarding the calibration system design, network design, data quality methods, and assimilation of data for inverse modeling. In addition, Earth Networks is working closely with world-renowned atmospheric scientists and modeling experts to develop inverse modeling capability. Figure 3 shows a front view and detailed view of Earth Networks' calibration system. The CO_2, CH_4 and H_2O measurements are made using a Picarro G2301 CRDS Gas Analyzer and a custom designed sampling and calibration module interface with software running on the Picarro. Each GHG system is installed at a tall tower with a minimum height of 80 meters. Two sampling inlets are installed at the highest accessible location on the tall tower and a third inlet is installed at 50 meters. An Earth Networks professional grade weather station is also installed at the highest accessible point of the tower at the same height as the two highest sampling inlets.

Ambient air is drawn rapidly at a rate of 10 liters per minute using separate pumps for each inlet. The sampling and calibration module then draws off the main sampling line vertically to ensure that any condensed water is not drawn into the calibration module. The calibration module includes an 8 port valve that allows for air to be sampled from any one of the 3 tower inlets or two standard calibration tanks. The calibration module includes a Nafion drying system designed to dry the air to a -30 Celsius dew point minimizing any requirement to ensure the calibration of H_2O measurements by the Picarro Gas Analyzer.

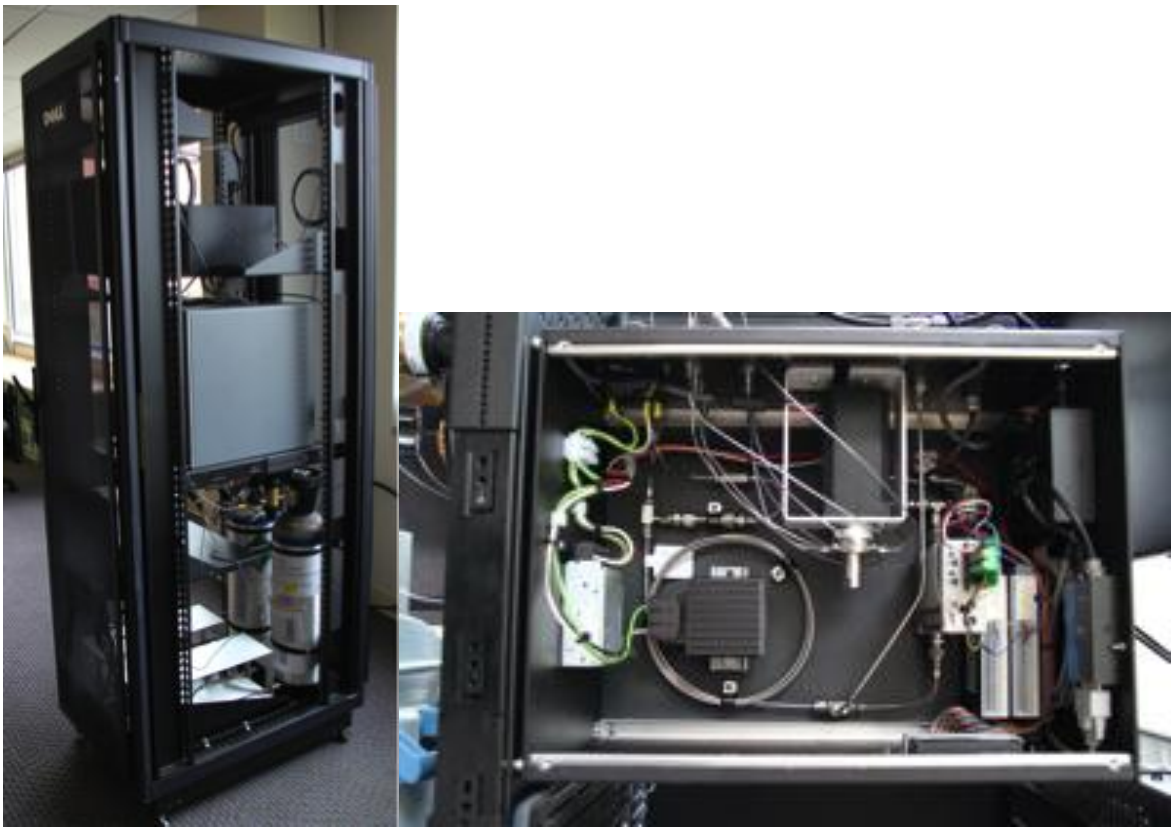


Figure 3. Earth Networks sampling and calibration system.

Earth Networks software running on the Picarro Gas Analyzer acquires CO_2, CH_4 and H_2O readings along with all instrument operational data and calibration system operational data. Instrument operational data is correlated with GHG readings and is used to flag any data acquired while the system is operating outside of normal parameters. Figure 4 shows a graph of methane and Picarro sampling cavity pressure during a pump failure at the GHG01 sampling site in Bucktown, MD. Note that when the pump fails, the pressure inside the Picarro sampling cavity increases rapidly (inset graph) and the CH_4 reading increases rapidly at the same time. The red lines show the automated QC flags applied to the CH_4 data which transition from “pass” to “flagged”.

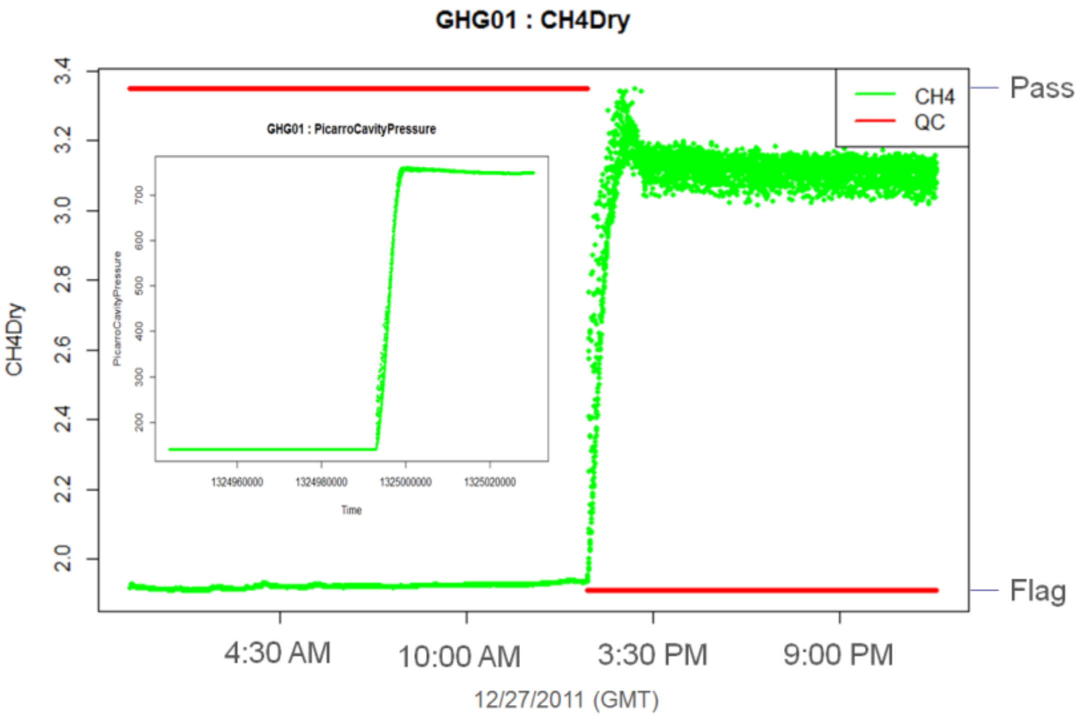


Figure 4. Example of data quality application to pump failure at GHG01

Calibration Procedures

Calibration procedures are applied to raw data operationally and consistently through the entire network of Earth Networks instruments. Figure 3 illustrates two calibration tanks connected to the calibration unit. In a standard setup of the system they are from the NOAA GMD http://www.esrl.noaa.gov/gmd/ccgg/carbontracker/goals.html. Instrumented is calibrated at both tanks subsequently, which allow for detection of problems with either of the tanks, as well as for calibration itself.

Figure 5 shows example datasets used for calibration of the raw observation at the site SNDGS (La Jolla, CA). Figures 5A and 5B show the consistency of the instrument calibration for March 2012 for two tanks. The red line in figures 5A/5B shows the documented value for the NOAA GMD standards. The black dots show the last 10 minutes of data from a daily 30-minute calibration tank run.

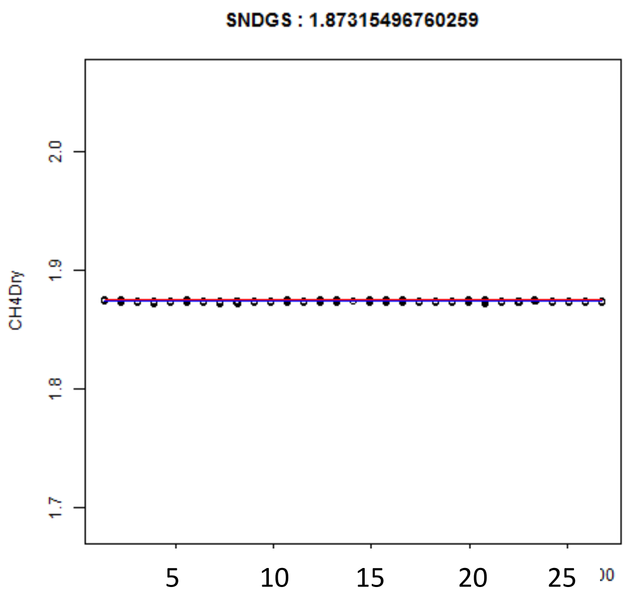


Figure 5A – CH_4 Calibrations for March 2012 for tank 1

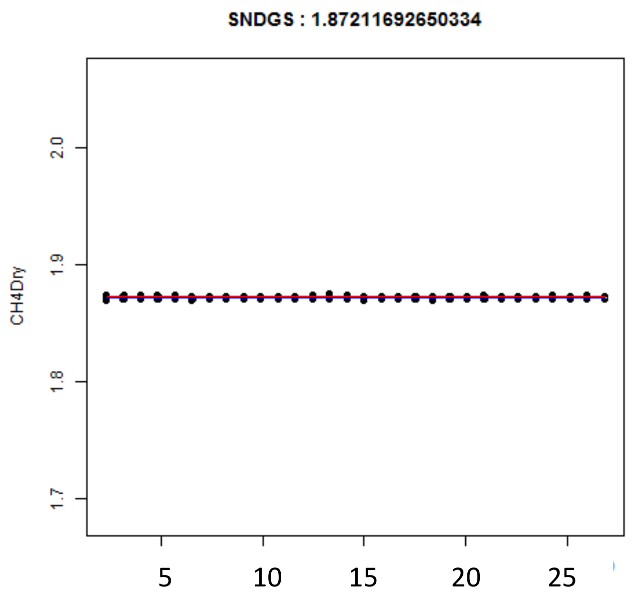


Figure 5B – CH_4 Calibrations for March 2012 for tank 2

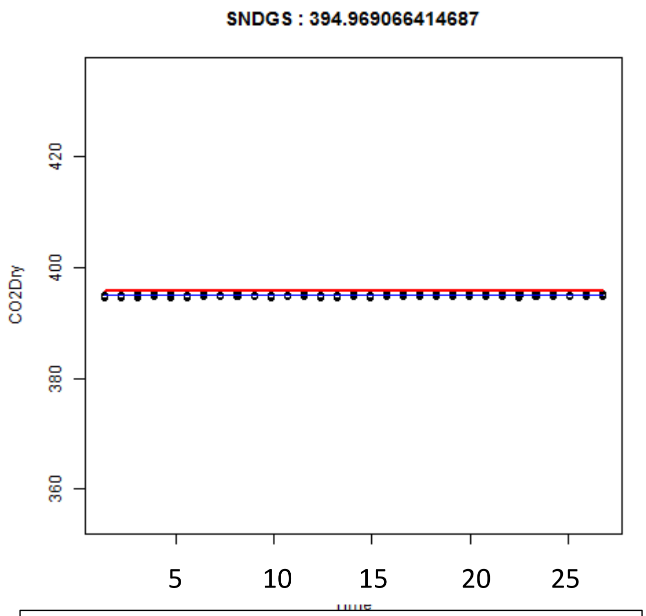


Figure 5C – CO_2 Calibrations for March 2012 for tank 1.

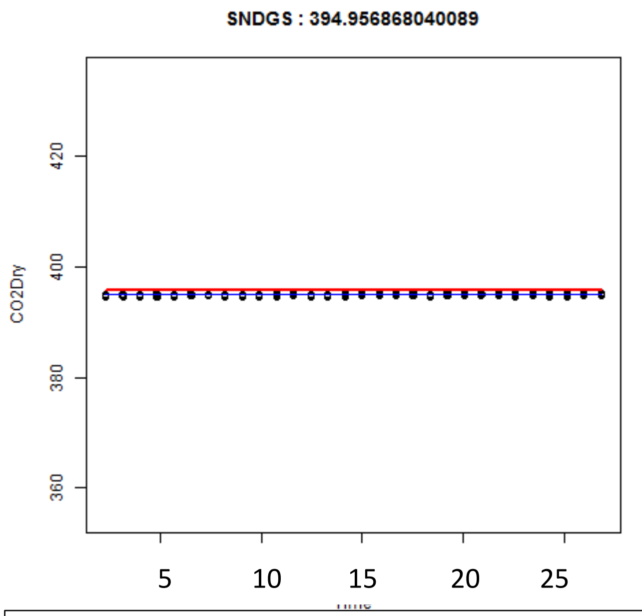


Figure 5D – CO_2 Calibrations for March 2012 for tank 2.

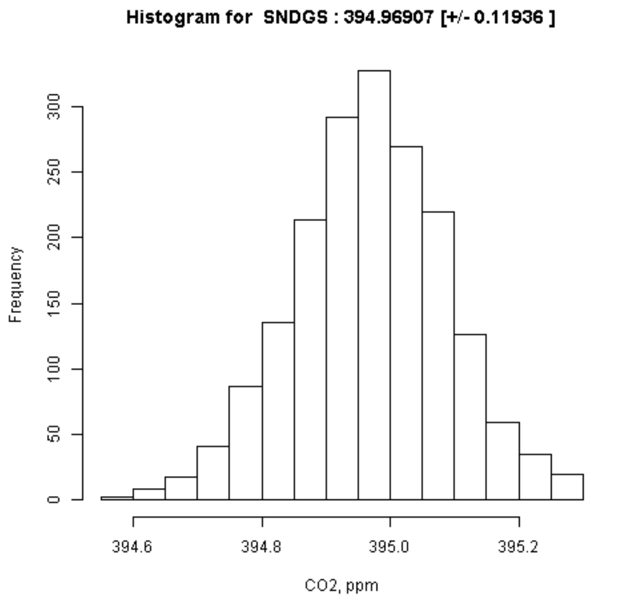


Figure 5E – Histogram of CO_2 Calibration readings for March 2012 for tank 1.

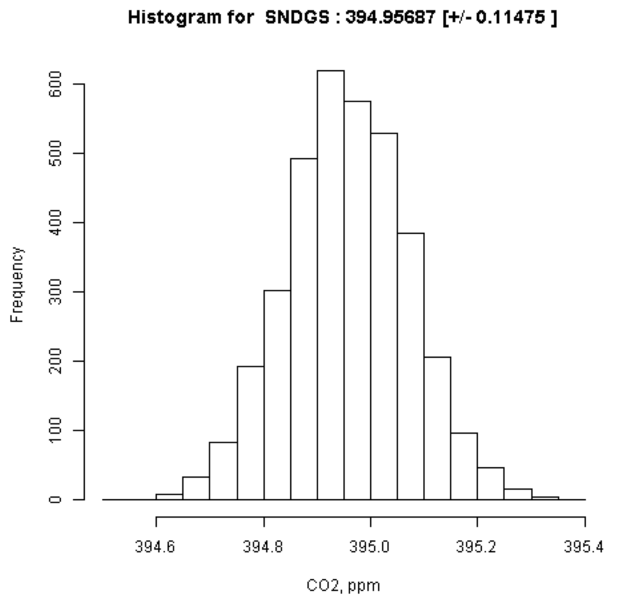


Figure 5F – Histogram of CO_2 Calibration readings for March 2012 tank 2.

Figure 5 – Calibration graphs for GHG location in La Jolla, CA (SNDGS)

Calibrations are run on a 23-hour time schedule so that calibrations are not done at the exact same time each day. Calibrations similar to Figures 5A/5B are shown for CO_2 in figures 5C and 5D, again demonstrating the consistency of the calibration records.

For two sites with the longest deployment record, launched in January 2011 in La Jolla, CA (SNDGS) and at the Chesapeake Bay, MD (GHG01) calibration values for March – August 2012 are summarized in Table 1. Also, this table includes information about AWSHQ site – this is the first urban location where the Earth Networks instrument was deployed. Sampling inlets are at the rooftop of a commercial building in Washington, DC area (Germantown, MD).

Table 1. Calibration data for March-August 2012 for SNDGS, GHG01 and AWSHQ sites with deployment record longer than 1.5 years.

Year: 2012		**March**	**April**	**May**	**June**	**July**	**August**
	Site ID	**Tank 1, CH_4**					
Mean	***SNDGS***	1.873	1.873	1.873	1.876	1.876	1.876
	AWSHQ	1.862	1.862	1.862	1.861	1.862	1.862
	GHG01	1.837	1.837	1.837	1.836	1.836	1.836
Std	***SNDGS***	0.00065	0.00062	0.00066	0.00101	0.00041	0.00036
	AWSHQ	0.00149	0.00038	0.00050	0.00050	0.00052	0.00047
	GHG01	0.00066	0.00061	0.00053	0.00053	0.00052	0.00046
Calibration gas	***SNDGS***	1.873					
	AWSHQ	1.869					
	GHG01	1.845					

		Tank 1, CO_2					
Mean	***SNDGS***	394.97	395.01	394.98	393.60	393.25	393.25
	AWSHQ	394.66	394.40	394.37	394.33	394.34	394.35
	GHG01	385.51	385.49	385.48	385.46	385.47	385.44
Std	***SNDGS***	0.12	0.10	0.12	0.65	0.03	0.026
	AWSHQ	12.05	0.03	0.03	0.04	0.03	0.033
	GHG01	0.05	0.05	0.05	0.05	0.05	0.046
Calibration gas	***SNDGS***	395.68					
	AWSHQ	396.51					
	GHG01	387.66					
Site ID		**Tank 2, CH_4**					
Mean	***SNDGS***	1.872	1.872	1.872	1.875	1.875	1.875
	AWSHQ	1.861	1.861	1.861	1.861	1.861	1.861
	GHG01	1.860	1.860	1.859	1.859	1.859	1.859
Std	***SNDGS***	0.00061	0.00061	0.00066	0.00099	0.00031	0.00030
	AWSHQ	0.00035	0.00043	0.00030	0.00035	0.00050	0.00032
	GHG01	0.00067	0.00059	0.00051	0.00054	0.00047	0.00055
Calibration gas	***SNDGS***	1.872					
	AWSHQ	1.868					
	GHG01	1.868					
		Tank 2, CO_2					
Mean	***SNDGS***	394.96	395.02	394.99	393.61	393.27	393.27
	AWSHQ	393.02	393.05	393.02	392.97	392.99	393.00
	GHG01	392.66	392.64	392.64	392.63	392.64	392.62
Std	***SNDGS***	0.11	0.10	0.11	0.64	0.03	0.03
	AWSHQ	0.03	0.03	0.02	0.03	0.03	0.03
	GHG01	0.06	0.05	0.05	0.05	0.05	0.05
Calibration gas	***SNDGS***	395.71					
	AWSHQ	395.22					
	GHG01	394.85					

Example GHG Data Sets

Earth Networks has been operationally collecting data from 20 locations available since March of 2012. Figure 6 shows a single day of data from the site in Lewisburg, PA. The graph shows periods of where a well-mixed atmosphere is giving similar readings from all three heights as well as periods that are not well mixed where the readings have a high variance between the different heights.

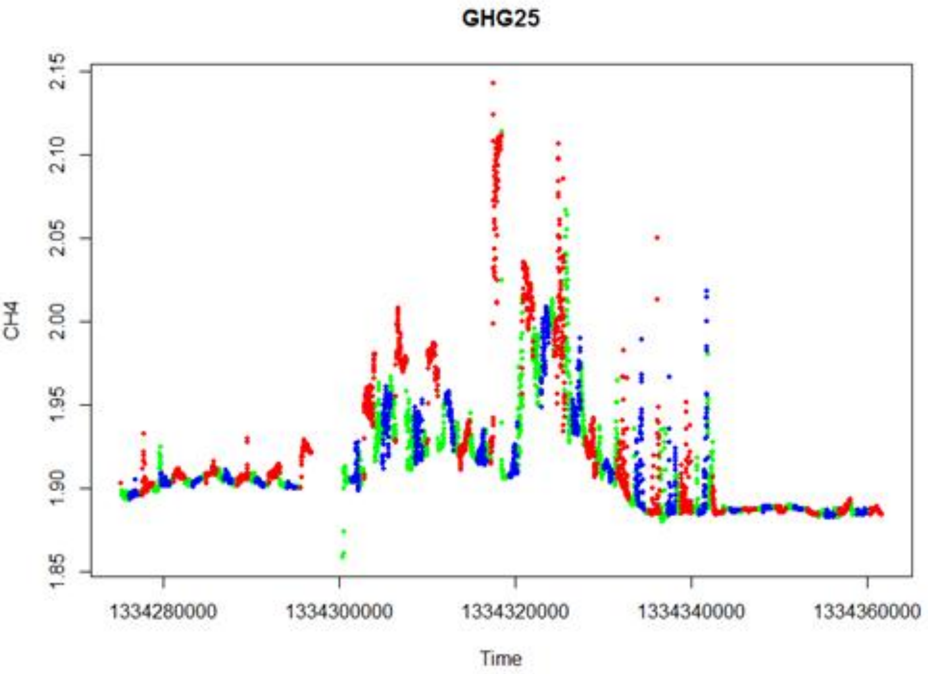


Figure 6. One day of GHG data from Lewisburg, PA

Figure 7 shows methane data at 100-meter height over a 15-day period in March 2012 from multiple network sites in Maryland, Pennsylvania, New York and New Jersey. Note the large spikes of methane for the Pennsylvania location, which is not seen in the other sites data.

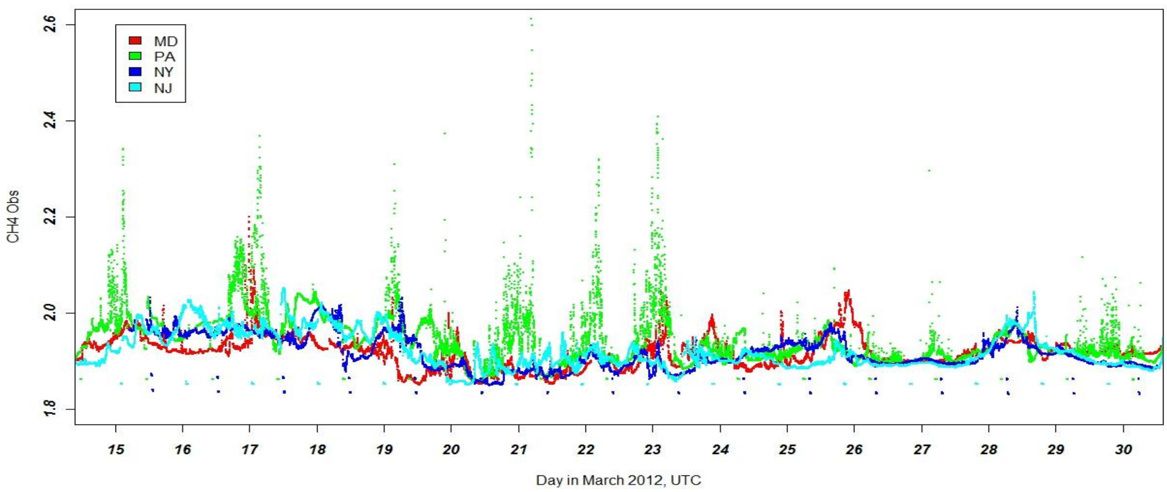


Figure 7. CH_4 data from multiple GHG network sites

These large spikes indicate the presence of potentially large sources of methane. To examine if this type of anomaly is persistent over time, monthly distributions for the sites in Mid-Atlantic region are shown in Figure 8.

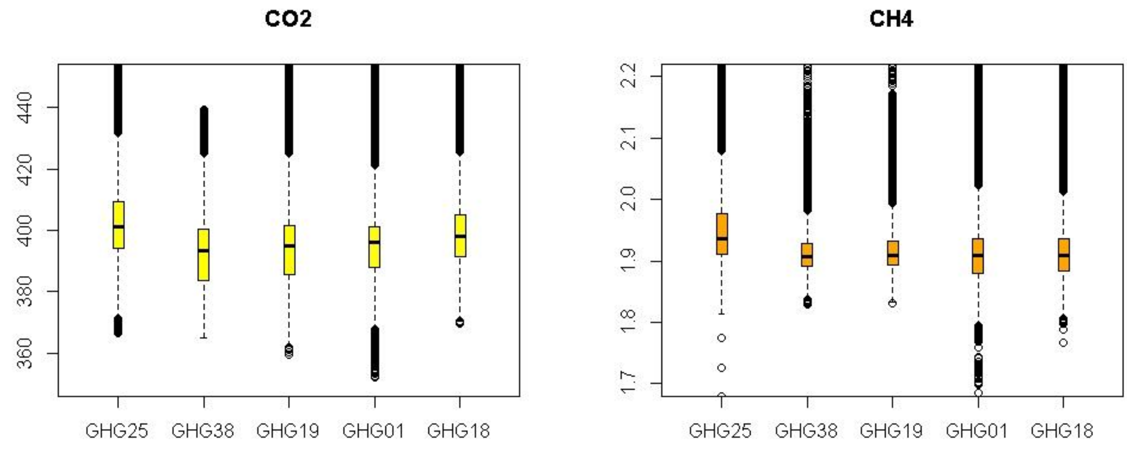
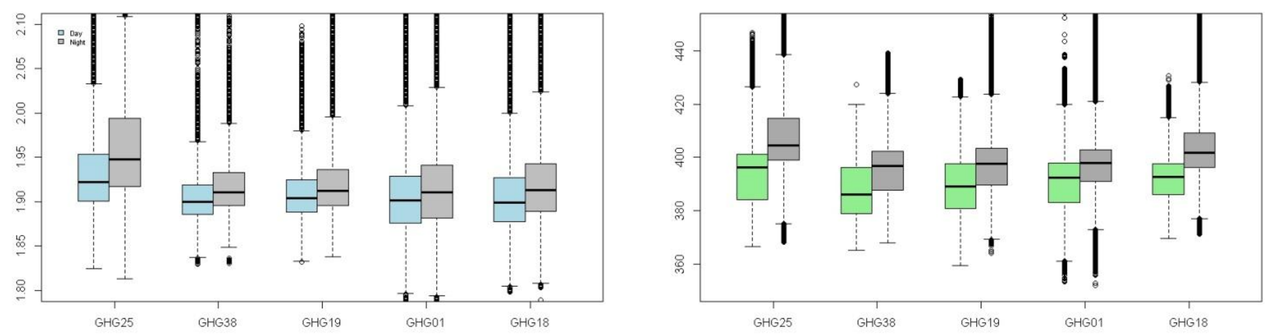


Figure 8. Distributions of CO_2 (left panel) and CH_4 (right panel) observations from Mid-Atlantic region for March-August 2012.



a. Methane observations	b. Carbon Dioxide observations

Figure 9. Daytime (shown in blue and green) and nighttime (shown in grey) distributions of GHG observations from Mid-Atlantic region for March-August 2012: a). CO_2, and b). CH_4.

Figures 10-12 summarize monthly distributions of methane (Fig. 10) carbon dioxide (Fig. 11) and ambient temperature (Fig. 12) at each site in Mid-Atlantic region within six month (March – August 2012). Elevated levels of CH_4 in PA (GHG25) are consistent through this period of time and they are not directly related to monthly temperature variations, as much as seen for CO_2, suggesting that anthropogenic, rather than biogenic, origins of the sources are dominant for this state.

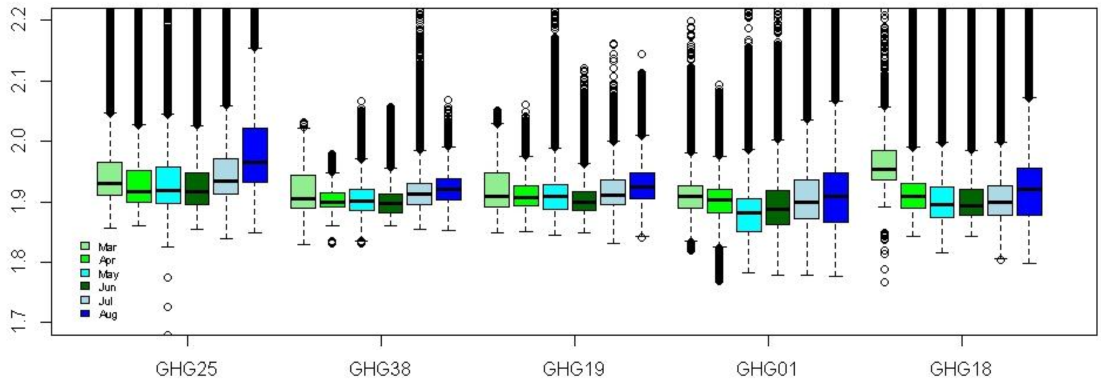


Figure 10. Monthly methane distributions of GHG observations from Mid-Atlantic region for March-August 2012.

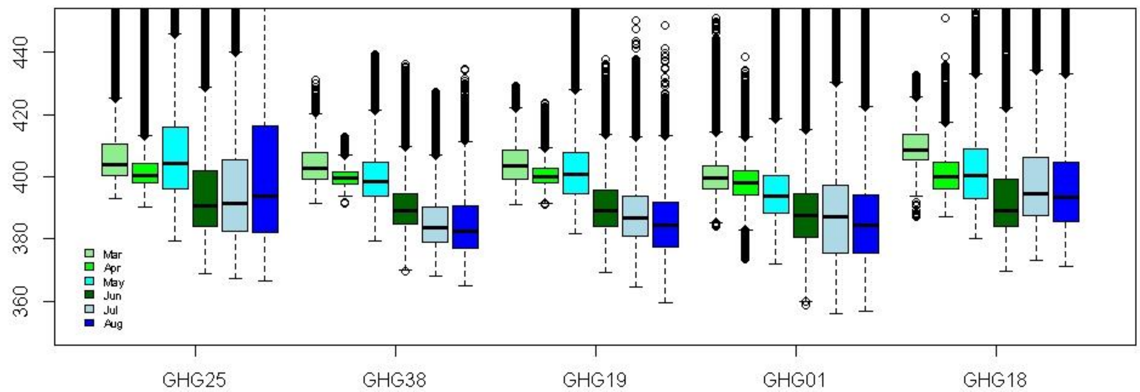


Figure 11. Monthly carbon dioxide distributions of GHG observations from Mid-Atlantic region for March August 2012.

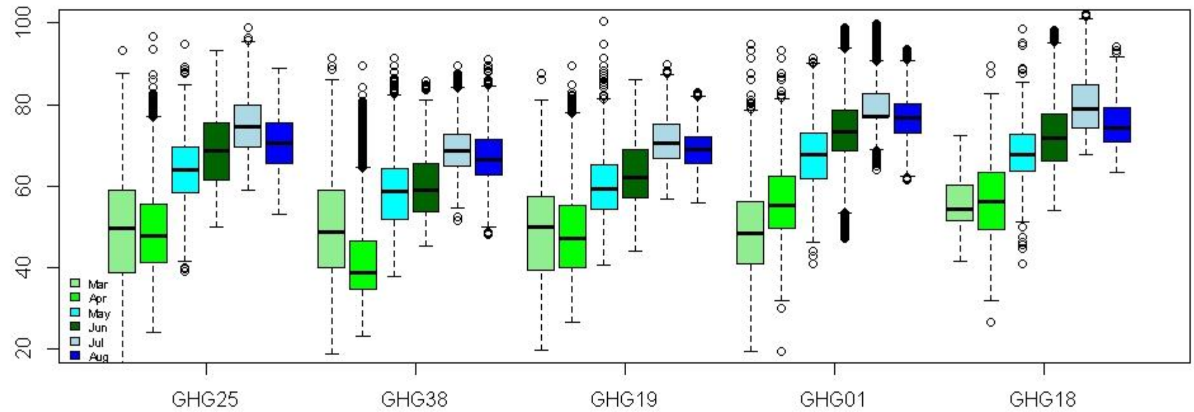


Figure 12. Monthly temperature observations from Mid-Atlantic region for March-August 2012

Additionally, display of hourly averaged observations for all sites within the network allows for identification of anomalies, and multi-month comparison show seasonal trends. Figure 13 shows a "colorgram" of hourly CH_4 and CO_2 data for the month of June. Note the high levels of methane in the northeastern states later in the month of June.

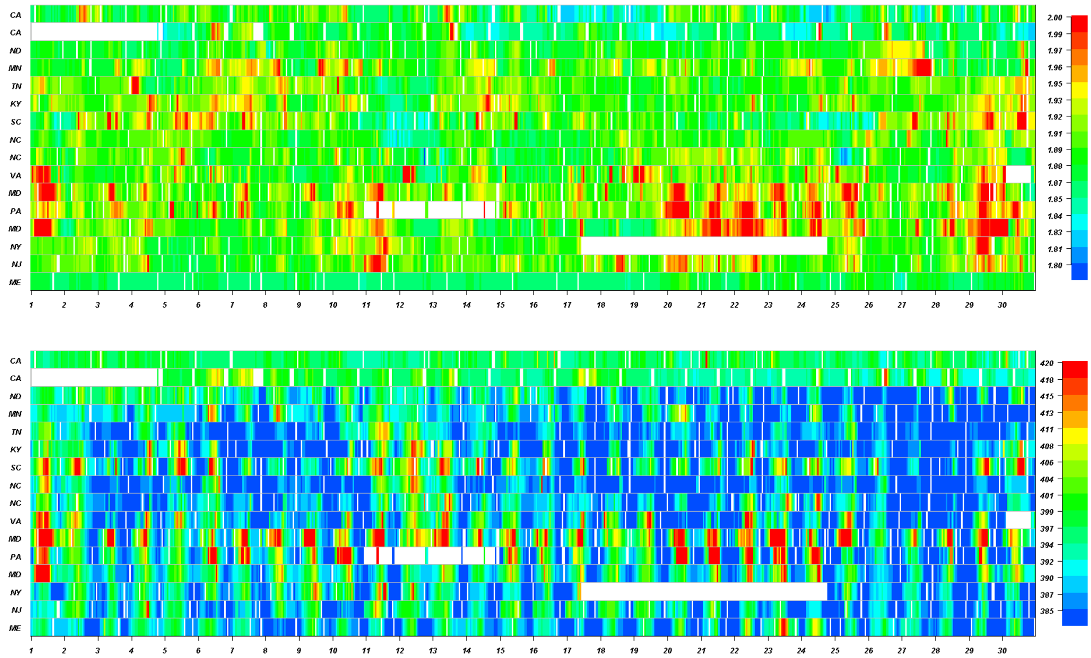


Figure 13. Colorgram of CH_4 (top) and CO_2 (bottom) data in June 2012 from Earth Networks' sites across the US.

Two coastal sites comparison

Comparison of monthly statistics for two sites, deployed in January 2011 and located in coastal settings in California and Maryland (Fig. 14), shows that for GHG01 site there are higher correlations between minimum concentrations and temperatures, as well as between minimum concentrations and LAI (Table 2) than for SNDGS site. This suggests that GHG's in CA are more controlled by anthropogenic activities versus immediate influence of biogenic sinks and sources around GHG01 site. Typical seasonal patterns in temperature, moisture and winds and types of eco-system also differ for these two sites at the east and west coast.

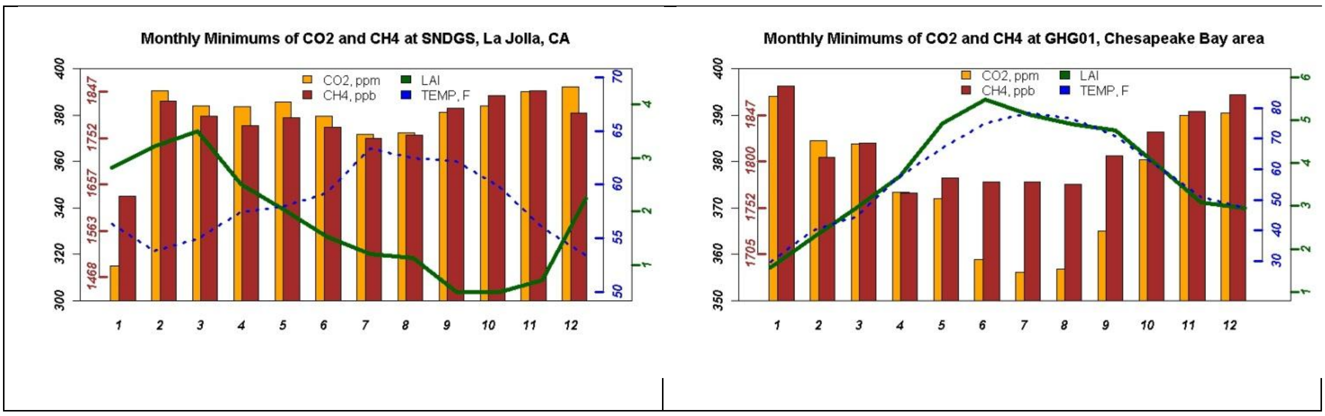


Figure 14. GHG and temperature minimums and LAI monthly statistics for 2011 for two coastal sites: La Jolla, CA (left panel) and Chesapeake Bay, MD (right panel).

Table 2. Correlations between monthly minimums in CO2, CH4, ambient temperature and LAI (leaf index area) for La Jolla, CA (SNDGS) and Chesapeake Bay (GHG01) sites.

Correlation between:	SNDGS	GHG01
CO2 & CH4	0.93	0.84
CO2 & Temperature	-0.13	-0.74
CH4 & Temperature	-0.12	-0.93
CO2 & LAI	-0.31	-0.74
CH4 & LAI	-0.17	-0.91

CONCLUSIONS

Greenhouse gas (GHG) observing networks, such as the one that Earth Networks is deploying and operating, will provide in situ measurements of CO_2, CH_4, and H_2O using high precision instruments to support MRV (measurement, reporting and verification), as well as inverse modeling studies. These types of highly accurate and consistent measurements answer the calls for continuous environmental observations to provide "accurate and timely information on GHG emissions", which is essential for "informing and assessing future climate change policy decisions."(USEPA, 2009).

Steady progress has being made on deployment and operation of the network. Level 0 and Level 1 data sets are currently available. Calibration data analysis allows operational identification of problems with instrument, sampling modules and calibration gas tanks. Based on accumulated data from dense network in Mid-Atlantic region, ambient concentrations of methane and carbon dioxide observed in Lewisburg, PA (GHG25) are higher on average than at other sites in adjacent states.

Robust and detailed observations of surface weather and GHGs from Earth Networks, delivered on a continuous basis, will enable scientists to obtain a detailed picture of the Earth's dynamics. Further, integrating these critical data resources with socio-economic indicators will provide a more holistic and detailed perspective not only for scientists, but also for policymakers and society at large.

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