Continuous GHG Monitoring at Local to Statewide Scales

William Callahan, Elena Novakovskaia and Christopher Sloop,
Earth Networks, Inc.
12410 Milestone Center Drive, Suite 300
Germantown, MD 20876
bcallahan@earthnetworks.com

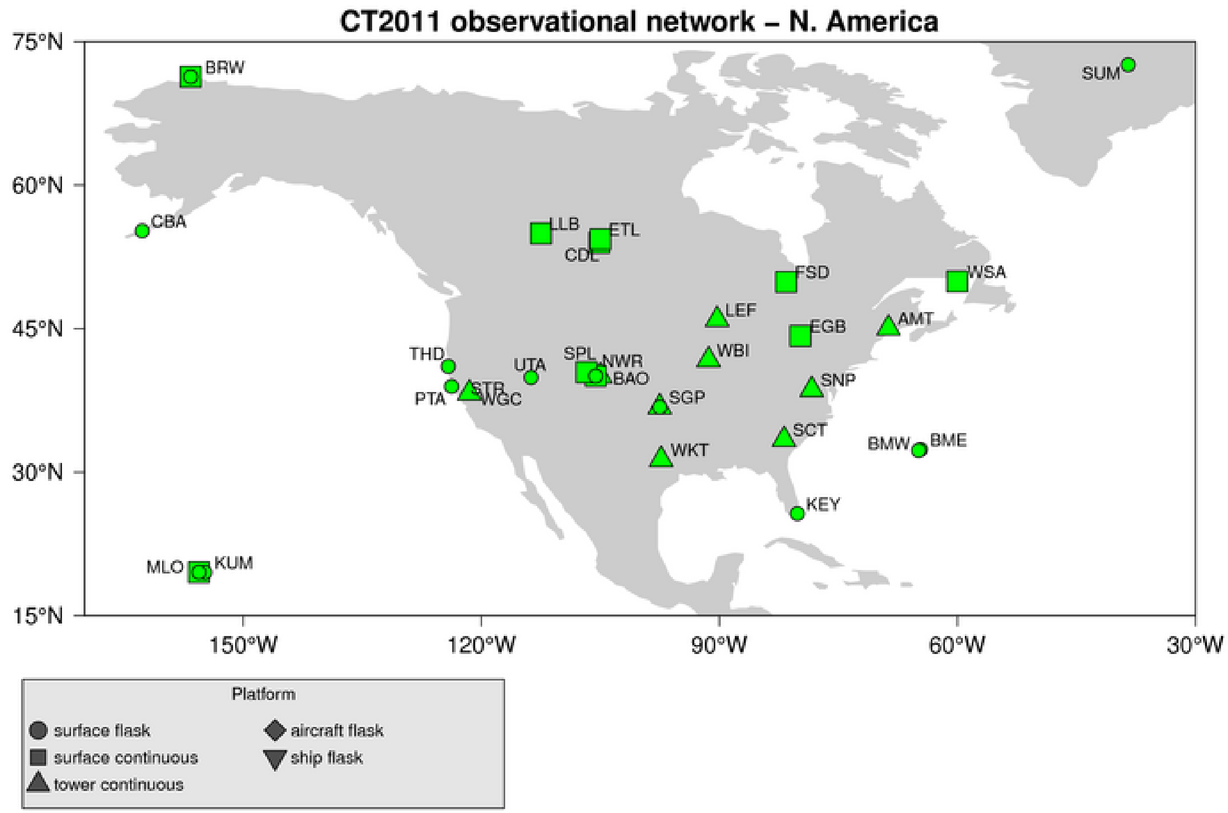
ABSTRACT

Communities and infrastructure exposed to higher than normal ambient concentrations can only be seen through continuous monitoring of near-surface conditions. These atmospheric observations are also an essential piece of information, which enables agencies and businesses to prepare for oncoming events and to respond in a timely manner. Equally important is the knowledge of how anthropogenic activities are linked to frequency and duration of anomalies in the ambient air, their change over time, and how often it is necessary to update the inventories. Over the next five years, Earth Networks will deploy 100 cavity ring-down spectrometers (CRDS) continuously measuring CO_2, CH_4 and H_2O. It is planned to place sensors at 50 tall towers in the United States (20 instruments already deployed), plus 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 NOAA (National Oceanic and Atmospheric Administration). Sampling rate of the raw data from spectrometers and collocated weather stations is at the sub-minute range, which is important both for short-duration accidents and for identification of very localized emission sources that are potentially missing in inventories, which could be at least a few weeks old. Local weather information within urban and populated areas is also critical for receptor-oriented techniques. Observations provided by more than 8,000 Earth Networks' surface weather stations are available in real-time and used in our GHG monitoring system.

INTRODUCTION

Current estimates of air quality conditions and distribution of greenhouse gases at local and regional scales and their long-term impact at nationwide and global scales, depends on the underlying assumptions about emission inventories. Various uncertainties are associated with bottom-up inventories and often times they lack sufficient reliability and timeliness to be used for policy-making. EPA 74 FR 56260 rule on "Mandatory Reporting of Greenhouse Gases" [1] includes provisions to ensure the accuracy of emissions data through monitoring, recordkeeping and verification requirements. Top-down estimates of emissions that use atmospheric observations are being developed to validate the traditionally used bottom-up inventories and provide more timely information on trends in emission levels. In a top-down approach, atmospheric mixing ratio observations are used in combination with inverse models to estimate geographically distributed sources and sinks of greenhouse gasses. Until recently, the number of atmospheric observing sites was increasing slowly, and lacked enough density to resolve emissions at state level within a meaningful range of uncertainties.

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



For top-down estimates of anthropogenic sources 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 that will advance capabilities to better resolve dynamically changing emissions using top-down inversion methodologies at higher resolution regional scales.

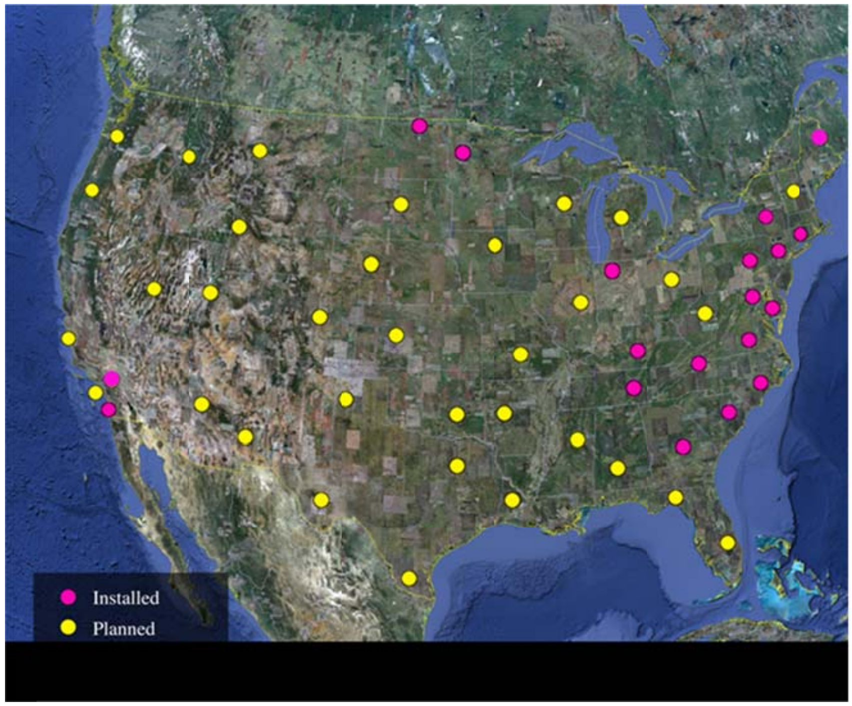
Global Greenhouse Gas Network

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.

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

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

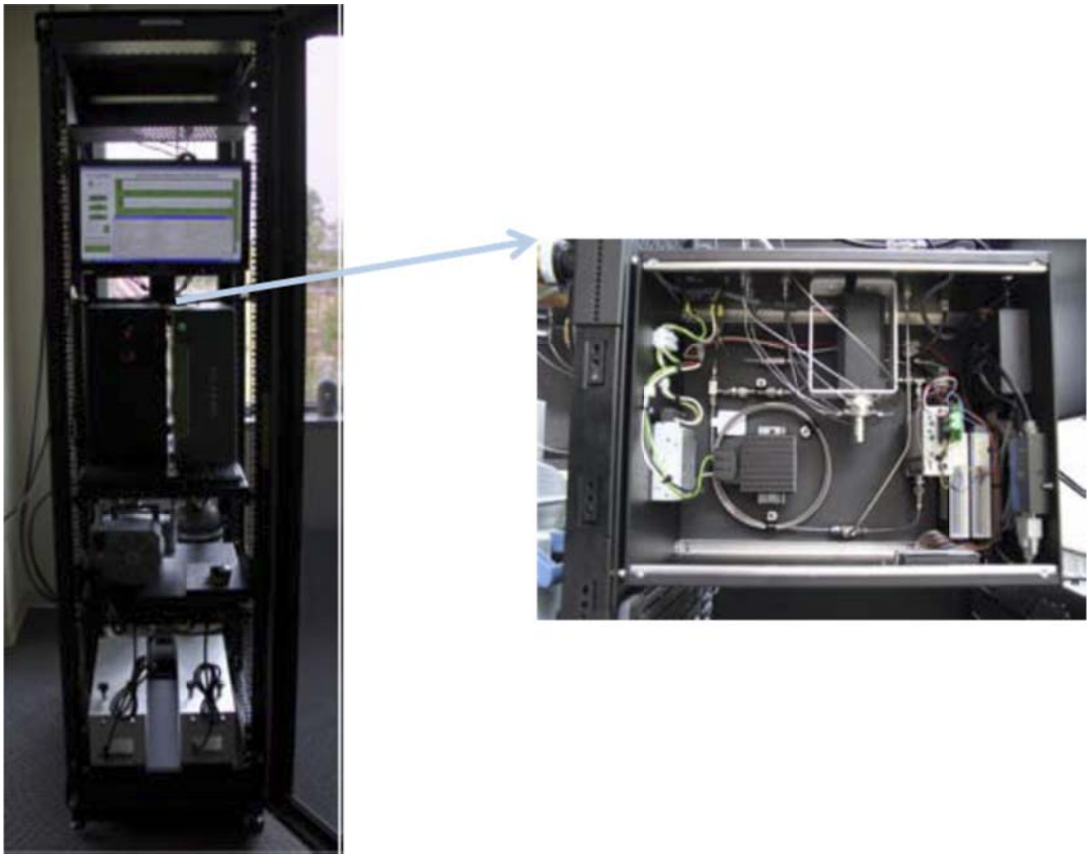


Network of High-Precision Instruments

Earth Networks and Scripps Institution of Oceanography are working in close collaboration to ensure the highest quality observations are produced by the GHG observation network. 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.

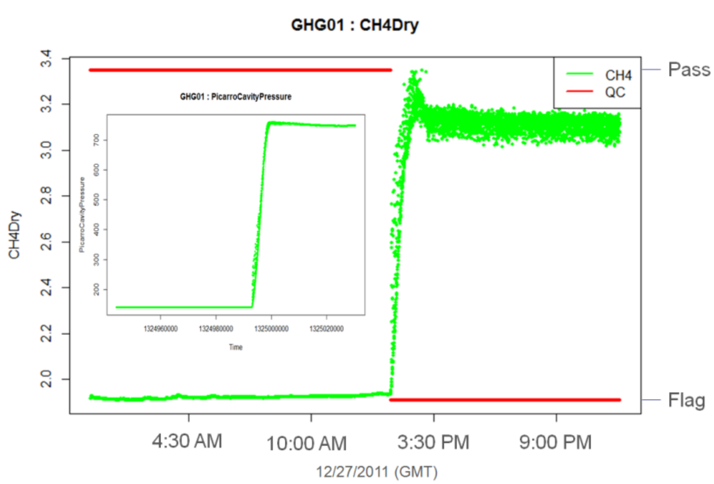
Ambient air is drawn rapidly at a rate of 10 liters per minute using separate pumps for each inlet. The sampling and calibration module then draws off the main sampling line vertically to ensure that any condensed water is not drawn into the calibration module. The calibration module includes an 8 port 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 [2].

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.



Example GHG Data Sets

Earth Networks has been operationally collecting data from 20 locations available since March of 2012. Figure 5 shows a "colorgram" of CH_4 and CO_2 data gathered in the month of June. Note the high levels of methane in the northeastern states later in the month of June.

Figure 5. Colorgram of CH_4 (top) and CO_2 (bottom) data in June 2012 from Earth Networks' sites across the US.

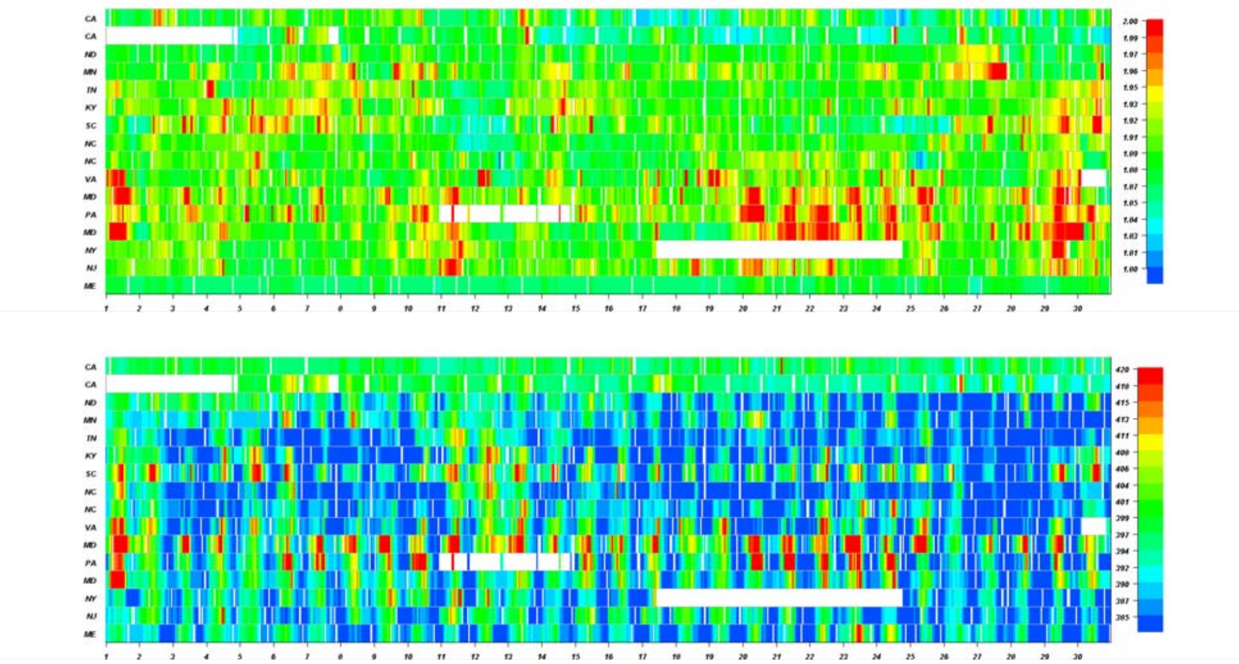


Figure 6 shows a single day of data gathered from the site in Lewisburg, PA. The graph shows periods of where a well-mixed atmosphere is giving similar readings from all three heights as well as periods that are not well mixed where the readings have a high variance between the different heights.

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

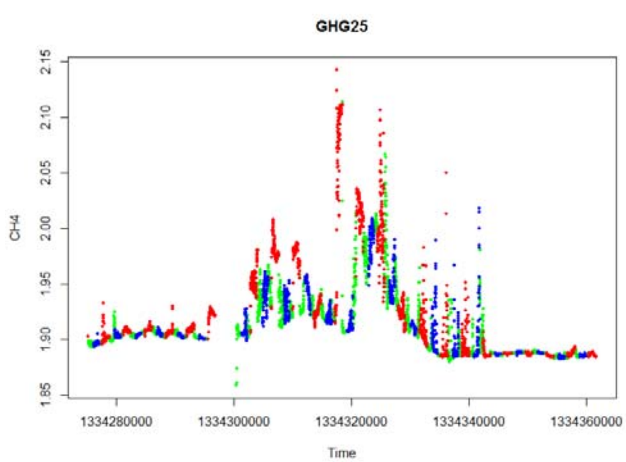
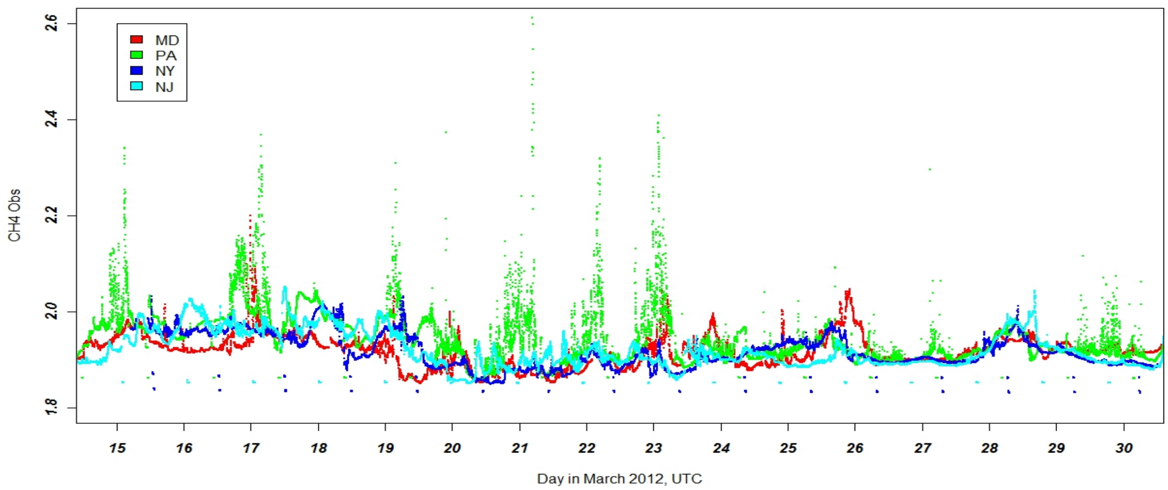


Figure 7 shows methane data at 100 meter height over a 15 day period in March 2012 from multiple network sites in Maryland, Pennsylvania, New York and New Jersey. Note the large spikes of methane for the Pennsylvania location which is not seen in the other sites data. These large spikes indicate the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

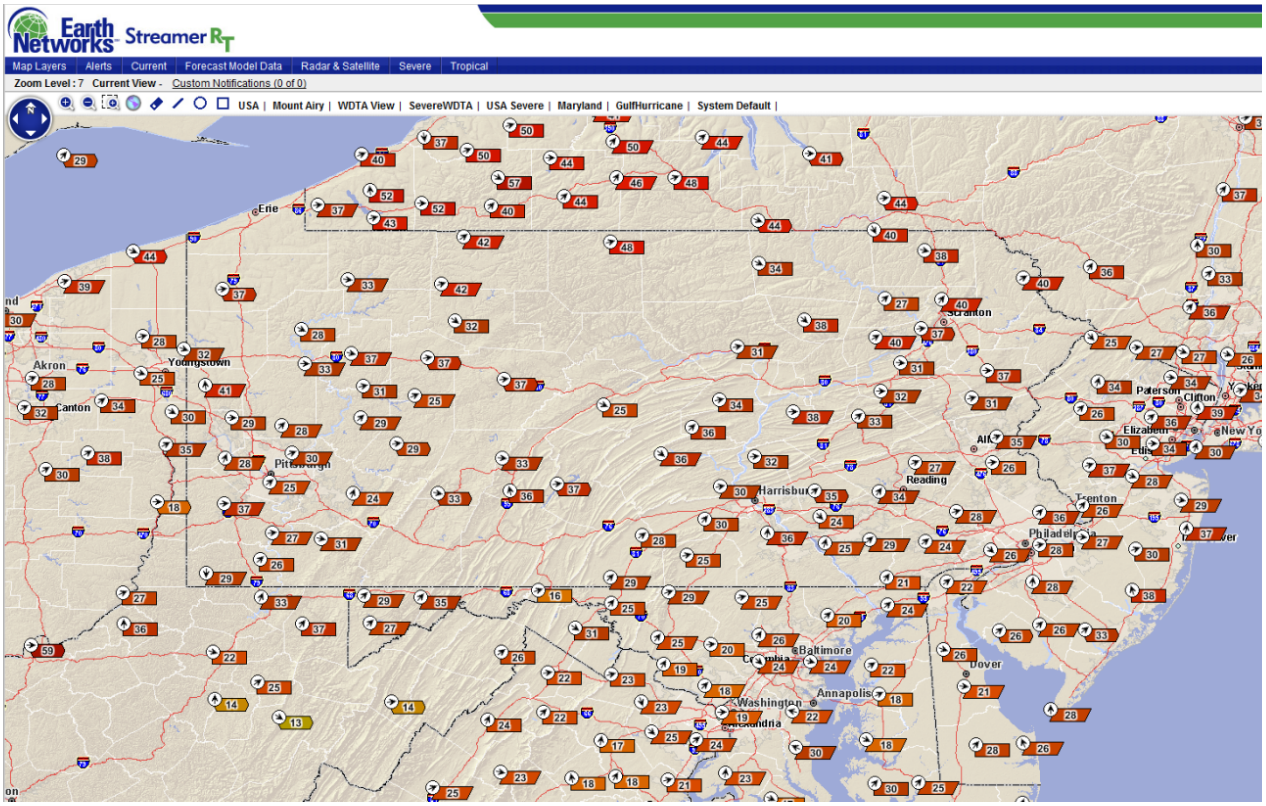
Figure 7. CH4 data from multiple GHG network sites.



Supporting Data Sets

It is critical to get an accurate analysis of the state of the atmosphere at a high time resolution in order to understand sources and sinks of methane and carbon dioxide when using a receptor-oriented approach and inverse modeling methods that rely on winds and boundary layer information. Earth Networks operates several networks of instruments which provide input for our inverse modeling efforts and analysis: 1) a professional grade surface meteorological observation network that provides real time temperature, humidity, winds, pressure and rainfall data for more than 8,000 locations in the United States; 2) a network of microwave radiometers which measure temperature and water vapor to 10 kilometers and 3) a network of total lightning sensors which is critical for identifying turbulent air masses. Figure 8 shows a map of Earth Networks surface observation network, with daily wind gusts (in mph) indicated at various sites. Data are also ingested from other publicly available surface observation networks.

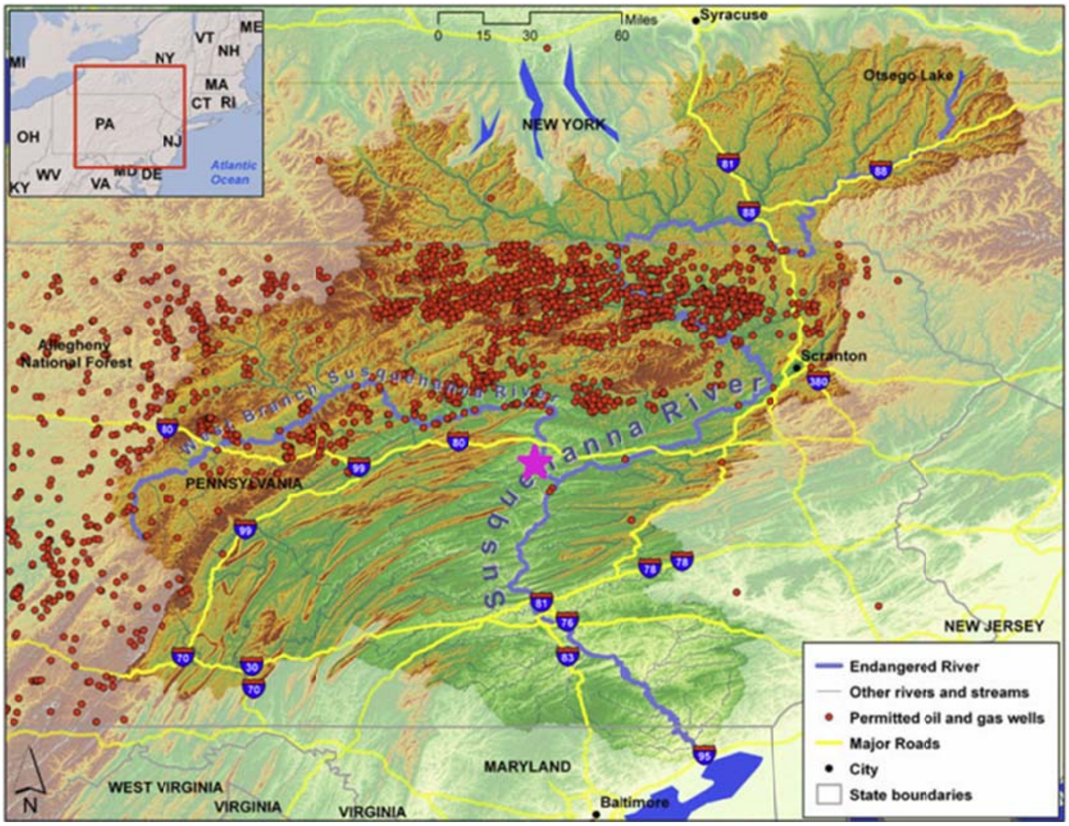
Figure 8. Map of the dense network of surface stations.



Application and Use of GHG Network Data

One potential application of dense GHG network observations would be in relevance to monitoring emissions from gas and oil production in Pennsylvania. Earth Networks is utilizing an inverse modeling approach to determine methane emissions from the wells. Figure 10 shows a map of permitted oil and gas wells in Pennsylvania. The purple star indicates the location of an Earth Networks GHG tower.

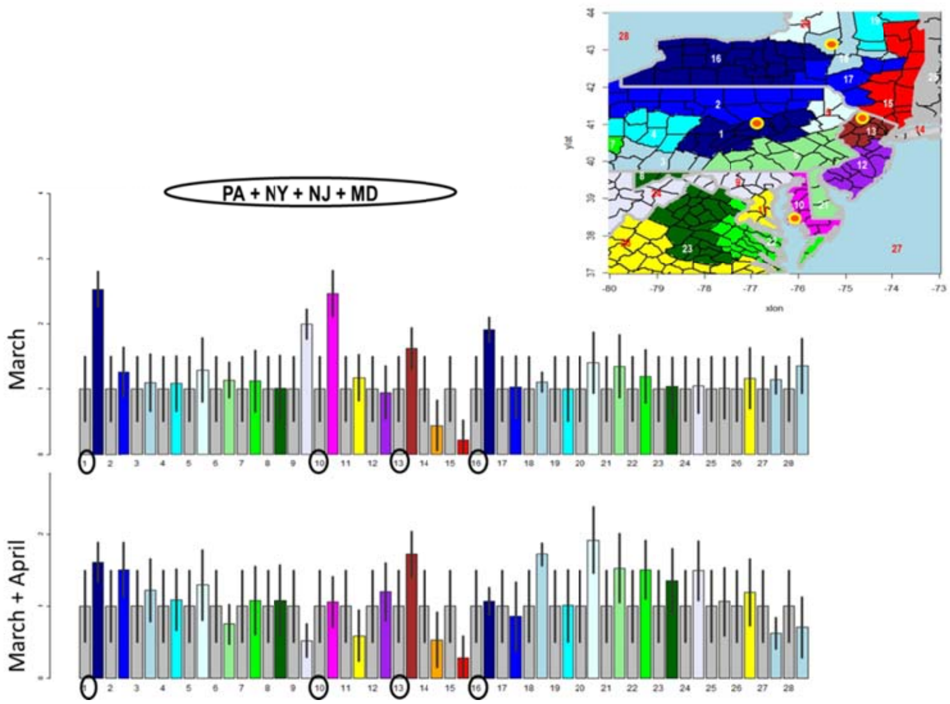
Figure 9. Map of the oil and gas wells in Pennsylvania. Source: *http://www.americanrivers.org/our-work/protecting-rivers/endangered-rivers/endangered-susquehanna.html?gclid=CLC1oq-fj68CFUXc4AodTSv0zA*



The inversion system collects information about geographically-distributed sources in the area by continuously sampling methane mixing ratio in the parcels of air arriving at the tower under varying weather conditions and from different directions. Emissions originating from some locations can reach the tower within 24 hours, while emissions from other locations can take 48-72 hours. There are some areas from where air flows further away from the tower, and samples at the tower are not representative of the sources at these spots on the surface ("blind spots"). To accurately describe contributions which are "surface influences" from surface sources to an air parcel sampled at the tower at a given hour, the Earth Networks inversion system uses coupled WRF (Weather Research and Forecasting[3]) and STILT (Stochastic Time-Inverted Lagrangian Transport[4-8]) modeling tools. The existing dense network of sensors in four adjacent states provides significant advantages versus a single tower, since surface influences for all available towers combined have substantially fewer (if any at all) blind spots during any given period of time (week or month, for example). Additionally, there are available bottom-up methane inventories for the region, such as from the EPA[9] or from worldwide databases (EDGAR[10]). The Earth Networks inversion system divides area into small regions, representative of particular types of methane sources and accounting for administrative boundaries. The system combines observations from the towers with surface influence information and with the bottom-up estimates, and computes the emissions within these regions. Results are typically expressed as factors for ratio between computed emission estimates and bottom-up emission values.

Figure 10 shows preliminary results from an inverse modeling study focused on the northeast United States. The northeast region was divided into 28 sub-regions in which the bottoms-up emissions estimates are compared to estimates computed using a top-down methodology. The grey bar graphs show the prior estimate of emissions derived from the EDGAR 4.2 database within each sub-region along with error estimates. The colored bars correspond to the color of the region shown in the accompanying map. Inversions were run over two example periods of time: the first one includes data just from March 2012 and the second one includes data from March and April 2012. Some similarities and differences can be seen in the two graphs. Region one and two in both graphs have a higher level of estimated emissions than the prior estimate. According to the maps in Figure 10, these are also the regions where there is an increasing number of oil and gas wells. Also, there are regions, such as #10, for example, with higher top-down emissions estimates in March, though the combination of March and April had estimates that were much more in line with the prior estimates. This could be attributable to agricultural activity in this region.

Figure 10. Preliminary inverse modeling results using the data from four Earth Networks' sites.



Further improvements to the inverse modeling methods demonstrated here are contemplated as well as studies to further validate the results.

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."[1].

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 for policymakers and society at large.

References

1. USEPA. “EPA Mandatory Reporting of Greenhouse Gases Rule (74 FR 56260).” http://www.gpo.gov/fdsys/pkg/FR-2009-10-30/pdf/E9-23315.pdf
2. Welp L.R., R. F. Keeling, R. F. Weiss, W. Paplawsky, and S. Heckman. “Design and performance of a Nafion dryer for continuous operation at CO_2 and CH_4 air monitoring sites”. Submitted to Atmospheric Measurement Techniques, 2012.
3. Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W.Wang, and J. G. Powers. “A description of the advanced research WRF version 2, Tech. Note 468+STR”. 2005, 88 pp., MMM Division, NCAR, Boulder, Colo.
4. Gerbig, C., J. C. Lin, S. C. Wofsy, B. C. Daube, A. E. Andrews, B. B. Stephens, P. S. Bakwin, and C. A. Grainger. 2003a. “Toward constraining regional-scale fluxes of CO2 with atmospheric observations over a continent: 1. Observed spatial variability from airborne platforms”, J. Geophys. Res., 108(D24), 4756, doi:10.1029/2002JD003018.
5. Gerbig, C., J. C. Lin, S. C. Wofsy, B. C. Daube, A. E. Andrews, B. B. Stephens, P. S. Bakwin, and C. A. Grainger. 2003b. “Toward constraining regional-scale fluxes of CO2 with atmospheric observations over a continent: 2. Analysis of COBRA data using a receptor-oriented framework”. J. Geophys. Res., 108(D24), 4757, doi:10.1029/2003JD003770.
6. Lin, J. C., and C. Gerbig. 2005. “Accounting for the effect of transport errors on tracer inversions”. Geophys. Res. Lett., 32, L01802, doi:10.1029/2004GL021127.
7. Lin, J. C., C. Gerbig, S. C. Wofsy, A. E. Andrews, B. C. Daube, K. J.Davis, and C. A. Grainger. 2003. “A near-field tool for simulating the upstream influence of atmospheric observations: The Stochastic Time-Inverted Lagrangian Transport (STILT) model”. J. Geophys. Res., 108(D16), 4493, doi:10.1029/2002JD003161.
8. Lin, J. C., C. Gerbig, S. C. Wofsy, A. E. Andrews, B. C. Daube, C. A. Brainger, B. B. Stephens, P. S. Bakwin, and D. Y. Hollinger. 2004. “Measuring fluxes of trace gases at regional scales by Lagrangian observations: Application to the CO2 Budget and Rectification Airborne (COBRA) study”. J. Geophys. Res., 109, D15304, doi:10.1029/2004JD004754.
9. USEPA. “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990– 2002”. U.S. Environmental Protection Agency, Washington, D. C., April 15, 2004.
10. European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency. 2011. “Emission Database for Global Atmospheric Research (EDGAR), release version 4.2.” (http://edgar.jrc.ec.europa.eu)

KEY WORDS

Earth Networks
Greenhouse Gas
GHG
Atmospheric Observations
Ambient Concentrations
CO_2
CH_4
Inverse Modeling
GHG Network
Calibration System
Calibrated
NOAA
Spectrometers
Weather Observations
GHG Monitoring
Greenhouse Gases
GHG Observation
Enviornmental Observation
Continuous Measurement