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Interim Cumulative Year 1 Report for the Period 9/27/2013 – 7/15/2014.

NASA Contract NNH13CK02C

AER Project P1864

Prototype Monitoring, Reporting and Verification System for the Regional Scale: The Boston-DC Corridor

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1 Scope

1.1 Identification

This “Interim Cumulative Year 1 Report” describes progress for AER Project 1864 (P1864) on “Prototype Monitoring, Reporting and Verification System for the Regional Scale: The Boston-DC Corridor” funded by NASA under the Carbon Monitoring System program. The period covered is 9/27/2013-7/15/2014. Formal quarterly reports covering the first 3 quarters have been submitted separately, and a full annual report covering Year 1 will be submitted by October 15, 2014.

1.2 Project Overview

The goal of the proposed research is to design a measurement network and develop an accompanying atmospheric modeling framework for downscaling the current NASA CMS flux products to the regional and local scales pertinent to Monitoring, Reporting, and Verification (MRV). The proposed research is being carried out in collaboration between Atmospheric Environmental Research, Inc. (AER; PI: Thomas Nehrkorn), Harvard University (PI: Steven Wofsy), Boston University (PI: Lucy Hutyra), Goddard Space Flight Center (PI: James Collatz), Earth Networks (PI: William Callahan), Sigma Space (PI: Phil DeCola), and Collaborators Crystal Schaaf (University of Massachusetts, Boston) and Charles E. Miller (Jet Propulsion Laboratory).

2 Current Progress

2.1 Technical exchange meetings

A combination of project-wide conference calls, individual phone calls and email exchanges, and separate in-person meetings have been used to coordinate the work for this project.

An in-person meeting was held at Harvard (on Nov. 4, 2013) to establish personal contacts between members of the technical groups in the Boston area (AER, Harvard, BU, and UMB), as well as with other team members attending in person (William Callahan) and via phone (Phil DeCola). The discussions centered on overall project plans, near-term goals related to the deployment of the additional observing systems funded as part of the project (See Section 2.2 below), and latest results from independently funded work using the Boston network observations and WRF-STILT modeling framework.

During the second quarter, Steve Wofsy and Lucy Hutyra held a project meeting for the independently funded IDS project at Boston University, and Thomas Nehrkorn attended the meeting to facilitate knowledge and technology transfer between these projects.

Most recently, a series of additional weekly phone calls between Harvard University, Earth Networks, and AER were used to work out the details of the integration of the Earth Networks GHG data with the Boston network sensors.

Several members of the project team have joined the CMS Working Group on Atmospheric Validation, and Thomas Nehrkorn and Lucy Hutyra gave a presentation describing this project at the most recent telcon of this Working Group on June 25. Team member Jim Collatz also gave a presentation at this telcon, primarily covering work funded by a separate CMS project.

2.2 Observational Network

The design and management of the observational network was an important focus of the work during year 1:

- Leveraging existing procedures and infrastructure employed by Earth Networks for the storage and dissemination of the greenhouse gas (GHG) tower measurements, an account was set up on the Amazon cloud storage server (S3) to store and manage the data collected as part of the Boston network.
- Earth Networks enhanced the reliability of existing GHG towers by conducting site visits to towers that were experiencing connectivity issues, and identifying and correcting the issue that was causing data gaps. Past data gap filling was initiated during the first quarter.
- Harvard and ENI have coordinated plans for joint monitoring of Boston network and ENI data availability, quality, and calibration. The GHG stations were transitioned to ENI operations. Monitoring and rapid response to faults have been implemented, and ENI and Harvard designated individuals to serve as the respective points of contacts for the ENI and Boston network GHG stations. GHG data from the Earth Networks sensors were examined thoroughly for the 2012-2013 period to determine data availability, calibration history, and any potential data quality issues for each site. Based on the analysis of that data, a time period will be chosen for which we will exercise the modeling framework for the Boston-DC corridor (WRF-STILT and top-down inversion of CO_2 fluxes), using the existing network (prior to the deployment of the additional sensors performed under this contract). The results will provide a baseline for future analyses using the enhanced network.
- Plans for cross-site calibration checks are being formulated by the respective points of contact at Harvard (Maryann Sargent) and ENI (Amanda Long).
- The Picarro operated by the University of Massachusetts, Boston and located on Thompson Island was brought back online and connected to the rest of the Boston network.
- The siting of the additional Earth Networks GHG tower in the New York City (NYC) area was initiated early on in the first quarter. Earth Networks and Sigma Space coordinated the negotiations with the owners of potential sites to enable the colocation of the GHG tower and mini MPL laser in the NYC area. A preliminary list of potential sites in Long Island was expanded to include additional sites further west upon an initial examination of dominant wind directions from surface observing stations. Four representative sites were then selected for a detailed meteorological analysis to determine the sensitivity of measurements to surface fluxes from the surrounding area (See Section 2.3 below). As a result of these investigations, a prioritized list was identified, and Earth Networks initiated discussions with the tower owners. The selection of the NYC area site for the additional Earth Networks (ENI) greenhouse gas (GHG) measurements and collocated Sigma Space miniMPL was finalized during the first quarter. Based upon the scientific assessment completed the previous quarter and the results of negotiations with tower owners a cell phone tower in Mineola, Long Island was selected. Both the GHG sensor and the miniMPL were installed at the site on April 16-17, and are now both producing data.
- A number of potential sites for the second mini MPL unit were considered, including locations in the Philadelphia area (if suitable co-located GHG measurement sites could be identified), the greater Washington, DC area, and other GHG sensor locations. A candidate site for the deployment of the remaining miniMPL unit has been chosen: the Earth Networks GHG tower in Lewisburg, PA. It is a site that primarily samples incoming air, and the boundary layer height information available from the miniMPL at that location will be valuable in assessing the representativeness of the measured GHG concentrations as background values. In addition, it fills a geographic gap in miniMPL

coverage between those located in the greater Boston and DC areas (see Figure 8). Arrangements for the deployment are being finalized.

2.3 Modeling Framework

The WRF-STILT modeling framework was used to examine the sensitivity of different potential GHG tower sites to surface fluxes in the greater NYC area. We made use of previously completed WRF runs for the Boston metropolitan area that included coverage of the NYC area. The NARR reanalyses provided the initial and lateral boundary condition data, as well as the data required for analysis nudging (of the outer-most model grid). These runs used WRF version 3.4.1 and 41 levels in the vertical, but are otherwise identical to the setup used in the "Turb-U" Salt Lake City runs described in Nehrkorn et al. 2013[1]. The model domains consisted of a set of 4 nested grids, with grid spacings of 27, 9, 3, and 1 km (see Figure 1 below). While the innermost domain (1 km, with the urban canopy model parameterization activated) does not extend over the NYC area, the 3 km domain covers NYC and its surroundings, allowing the computation of back trajectories with moderately high resolution fields, which are adequate for the present purpose of identifying the primary source regions for the potential GHG tower sites.

Four representative sites were selected for detailed analysis: a tall tower (receptor at 75m AGL) and a short tower (25m AGL) in Long Island, and a tall tower each in Brooklyn and the Bronx. Footprints from 5-day back trajectories were computed for hourly measurements for an entire year (September 2012 – August 2013). The results show the primary upstream influence extending west from the measurement locations in all four locales, but with some important seasonal differences: mean upstream influences have a distinct northern component in some months (primarily winter and spring, see the March 2013 footprints shown in Figure 2), whereas the summer months exhibit a stronger southern component (see, for example, July 2013 shown in Figure 4). Comparing these footprints with one important emissions sector, the pattern of traffic-related CO2 emissions shown in Figure 3, illustrates the fact that all four sites would provide some coverage of emissions from the major traffic arteries (and associated urban emissions from other sectors), with sites to the north and northeast (like the Bronx site) providing better sampling of Manhattan Island during summer months, whereas the Long Island sites would provide better sampling during cold season months with sampling patterns as in Figure 2. The Brooklyn site has a substantial footprint over New York harbor, and we have eliminated this site from further considerations to limit complications associated with marine boundary layer influences.

Further analysis was conducted on the results obtained from the WRF-STILT modeling framework to identify areas requiring improvement. An interesting result from modeling of methane concentrations in the Boston area is the diurnal variation of modeled vs. observed concentration at two Boston locations: Boston University (BU, 29m AGL) and the Prudential tower (PRU, 251m AGL). As shown in Figure 5, there are systematic differences between the observed and modeled mean diurnal cycles, and they differ between the two locations. At BU, modeled nighttime concentrations are consistently too high, whereas at the PRU location, they have a small negative bias during fall and winter, and no appreciable bias in spring and summer.

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1 Nehrkorn, T., J. Henderson, M. Leidner, M. Mountain, J. Eluszkiewicz, K. McKain, and S. Wofsy, 2013: WRF simulations of the urban circulation in the Salt Lake City area for CO_2 modeling. *J. Appl. Meteor. Climatol.*, **52 (2)**, 323–340, doi: 10.1175/JAMC-D-12-061.1.

Since methane emissions do not have a pronounced diurnal signal, these biases reflect deficiencies in the modeled transport, particularly boundary layer mixing. At the BU location, the nighttime boundary layer is probably too shallow in the model, which would result in positively biased simulated methane concentrations within the boundary layer. At the PRU location, the nighttime peaks (modeled and observed) are lower than at BU, likely because the sensors are high enough to be located above the nighttime boundary layer at least some of the time. The consistently higher nighttime observations in fall and winter could be caused by modeled PBL depth that are too shallow, or by unresolved small-scale mixing at the building scale.

An initial independent evaluation of the meteorological simulations was conducted by comparison with available standard meteorological data. Mean diurnal cycles of 2m temperature and 10m winds at close-by observing locations, Boston Logan airport (KBOS) at Boston Harbor, and the Bedford airfield (KBED) located just outside the Boston metropolitan area, are shown in Figure 6. Both show simulated nighttime temperatures that are consistently too low, consistent with an overly stable (and presumably shallow) boundary layer. Wind speeds are generally too strong over land (a known problem with this version of WRF), and too weak at the Boston harbor location, with little dependence on the time of day. The bubble plot shown in Figure 7 illustrates that negative wind speed biases are restricted to coastal locations, while weak to moderate positive biases are prevalent elsewhere. We have also acquired high-resolution surface and building level observation data from Earth Networks and other sources, and are evaluating their usefulness for purposes of model verification.

We have begun an analysis of the collocated BU miniMPL data, to allow a more direct comparison of the WRF-simulated and observed boundary layer height. To date this analysis has focused on the two one-week periods of 23 -29 September 2012 and 15 -21 August 2013. For these periods daily time-height plots of aerosol normalized relative backscatter (NRB) and NRB processed with a First Derivative Gaussian (FDGauss) filter have been generated as shown in Figure 9 for the case of 25 September 2012. The FDGauss filter is applied to the NRB data so that the aerosol gradients that typically correspond to transitional levels in the atmosphere (e.g. the top of the planetary boundary layer) are more identifiable. Simulated planetary boundary layer (PBL) heights from WRF have been added to the plots as solid black lines to obtain a qualitative assessment of the model's performance and identify time periods during which the model simulation is suspect. For the case of 25 September 2012 the model simulates the morning growth and afternoon height of the PBL reasonably well, but does poorly in simulating the PBL height at night and during the afternoon collapse phase. Currently, collaborators Yanina Barrera of Harvard University and Dr. Philip DeCola of Sigma Space Corporation are working to refine an algorithm to retrieve the PBL heights from the FDGauss filtered backscatter data so that more quantitative assessments of the model simulations of the PBL height can be performed.

In preparation for the required WRF simulations for the corridor, we are leveraging work being conducted under a separately funded effort to evaluate WRF-STILT performance in the DC area during the Metrex experiment. As part of that effort, the performance of WRF-STILT in simulating controlled tracer releases will be evaluated for different WRF configurations. Results from this examination will guide our choices for the corridor runs.

The flux model formulation is continuing for both the biogenic and anthropogenic components. One focus has been the generation of high-resolution (in space and time) traffic-related emissions. Figure 10 shows an example of the temporal disaggregation, in which the high spatial resolution annual mean data are disaggregated in time using data from automated traffic recorders (ATRs). The hourly time structure for emissions was calculated using hourly vehicle counts reported by

ATRs in the following states: Connecticut, Maryland, Massachusetts, New Hampshire, New York, Pennsylvania, Vermont and Virginia. After completing data quality assurance for all available data in region, the final data comprised of 142 ATR reports across six states. For each 1 x 1km grid cell in our on-road emissions layer, we assigned the hourly time structure from the nearest ATR station. The distance between each grid cell and ATR is calculated using a cost-surface that restricts the distance calculation to the land surface. With each grid cell assigned an appropriate hourly time structure, we then distribute the annual on-road CO2 emissions into hourly shares for each grid cell.

2.4 Resources

2.4.1 Hardware and Software

Purchase orders for both miniMPL budgeted in the contract were issued by AER to Sigma Space, and the purchase and shipment for one of the units (to be installed on Long Island) was completed.

2.4.2 Personnel

Postdoctoral researcher Andy Reinmann joined the team at Boston University. He will spear-head the effort to downscale the CMS flux product. Post-doctoral researcher Maryann Sargent joined the team at Harvard. She will take over some of the observing network responsibilities. The team at AER lost Janusz Eluszkiewicz, who passed away unexpectedly on May 27, 2014.

2.4.3 Travel

The project PI (Thomas Nehrkorn) and Co-Investigators Janusz Eluszkiewicz and Jim Collatz all attended the CMS Science Team Meeting at the Jet Propulsion Laboratory (Pasadena, CA) on Nov 5-7, 2013. Thomas Nehrkorn presented a project overview, and all three participated in breakout sessions and plenary discussions.

Lucy Hutyra delivered an invited talk at the OCO-2 applications workshop in Maryland on April 3, 2014 describing this project and expected benefits from OCO-2 data.

2.4.4 Government Furnished Equipment (GFE)

None.

3 Analysis of Current Progress and Research Results

3.1 Difficulties Encountered

None.

3.2 Research That Has Failed

None.

3.3 Current Plans

In the coming quarter we will complete the installation of the miniMPL at the Lewisburg, PA location. Ongoing efforts in the miniMPL data analysis and flux model formulation will continue. We will analyze results from WRF sensitivity experiments, and perform one or more WRF-STILT simulations for the corridor for a time period representative of the baseline network configuration. Cross-calibration between the Boston and Earth networks sensors will be completed.

3.4 Publications

Plans for work to be performed under this project were included in a talk at the American Geophysical Union Fall 2013 meeting:

Wofsy, S. C., K. McKain, J. Chen, P. Levi, E. Gottlieb, L. Hutyra, S. M. Raciti, N. G. Phillips, W. Callahan, P. Decola, T. Jones, J. D. Hegarty, T. Nehrkorn, M. Mountain, J. Eluszkiewicz and C. Sweeney, 2013: Measurements and modeling of CH_4 and CO_2 in the Boston Metro area and Northeastern Megalopolis. *2013 Fall Meeting*, American Geophysical Society, San Francisco, CA, abstract A44F-04.

Work funded by this project was presented in a talk at the European Geophysical Union General Assembly 2014:

Philip DeCola, Taylor Jones, Steven Wofsy, Kathryn McKain, Jia Chen, Yanina Bererra, Elaine Gottlieb, Thomas Nehrkorn, Jennifer Hegarty, Janusz Eluszkiewicz, John Henderson, Marikate Mountain, Lucy Hutyra, and William Callahan, 2014: Measurements and modeling of greenhouse gases and the planetary boundary layer for the Boston metro area and the Northeastern Megalopolis. *Geophysical Research Abstracts*, **Vol. 16**, EGU2014-15753, 2014, *EGU General Assembly 2014*

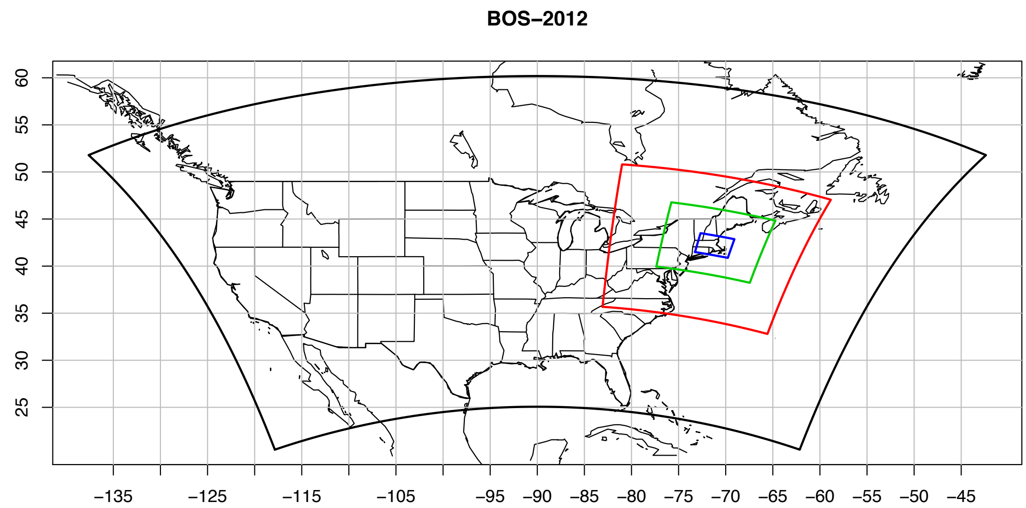

Figure 1: WRF domains used for Sep 2012 – Aug 2013. Back trajectories for the NYC receptors were computed using domains d03 (green), d02 (red), and d01 (black).

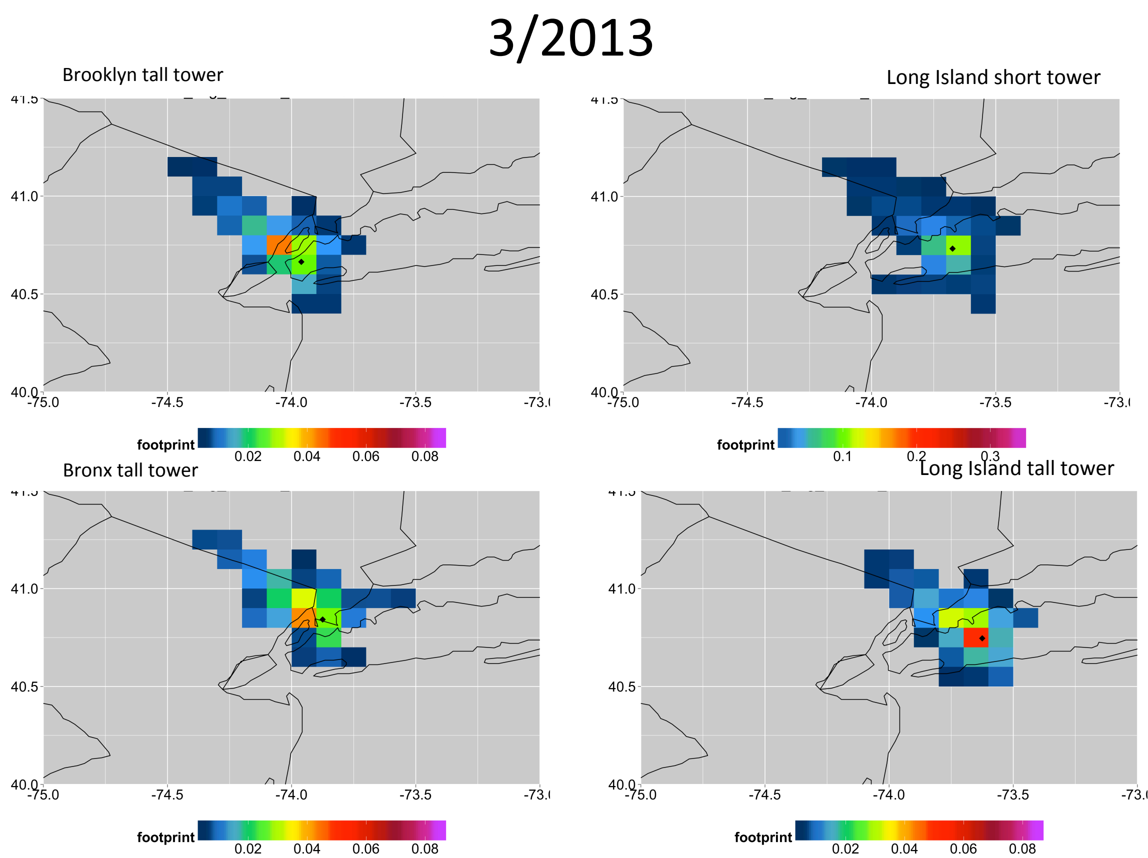

Figure 2: Monthly average footprints for March 2013. Notice the change in scale for the short tower (top right panel).

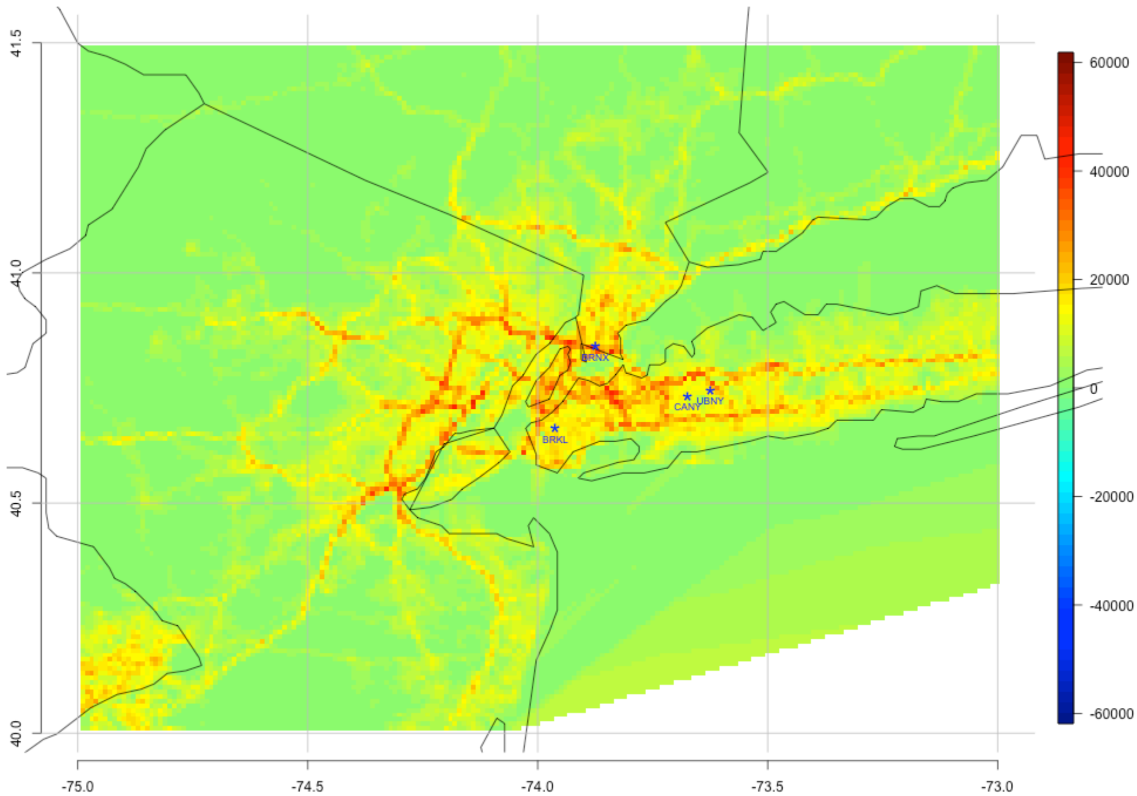

Figure 3: Traffic-related CO2 emissions, plotted on the same map background as the footprints in Figure 1. The sites of the four potential GHG tower locations are shown as blue asterisks.

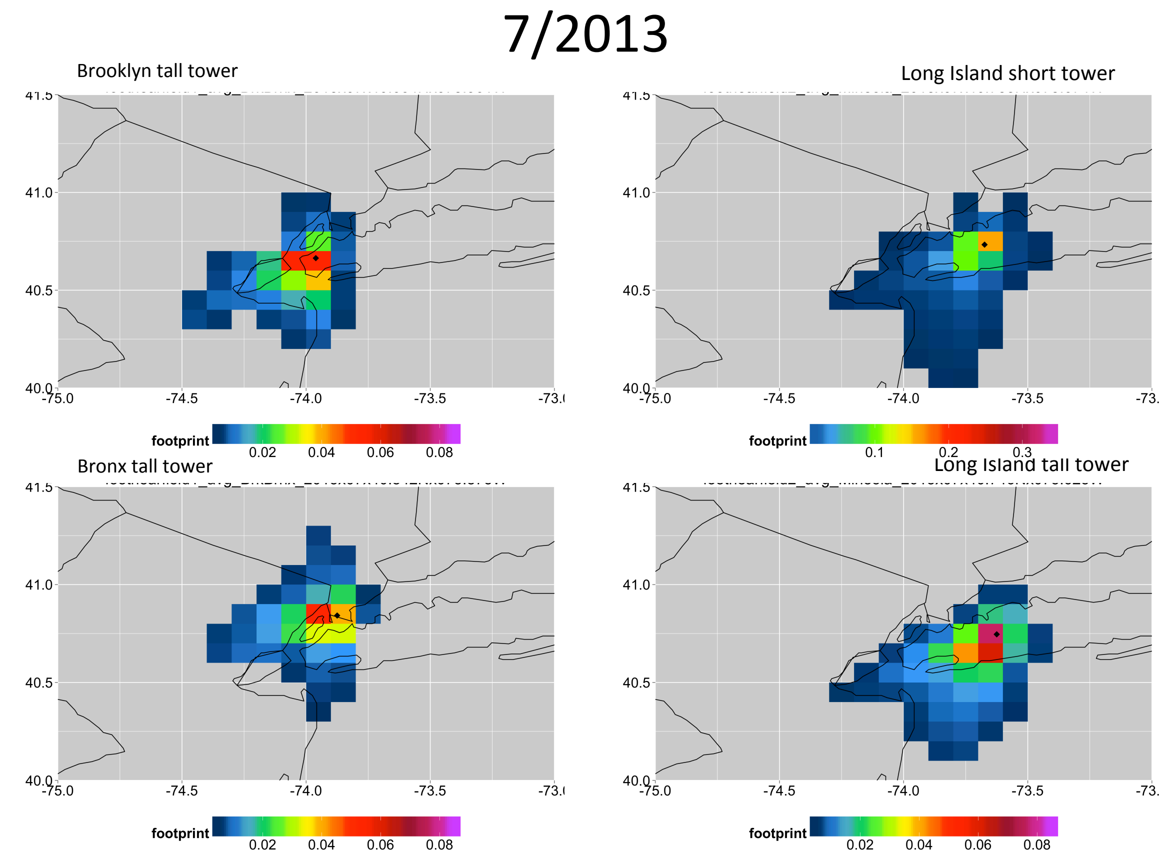

Figure 4: Monthly mean footprints for July 2013.

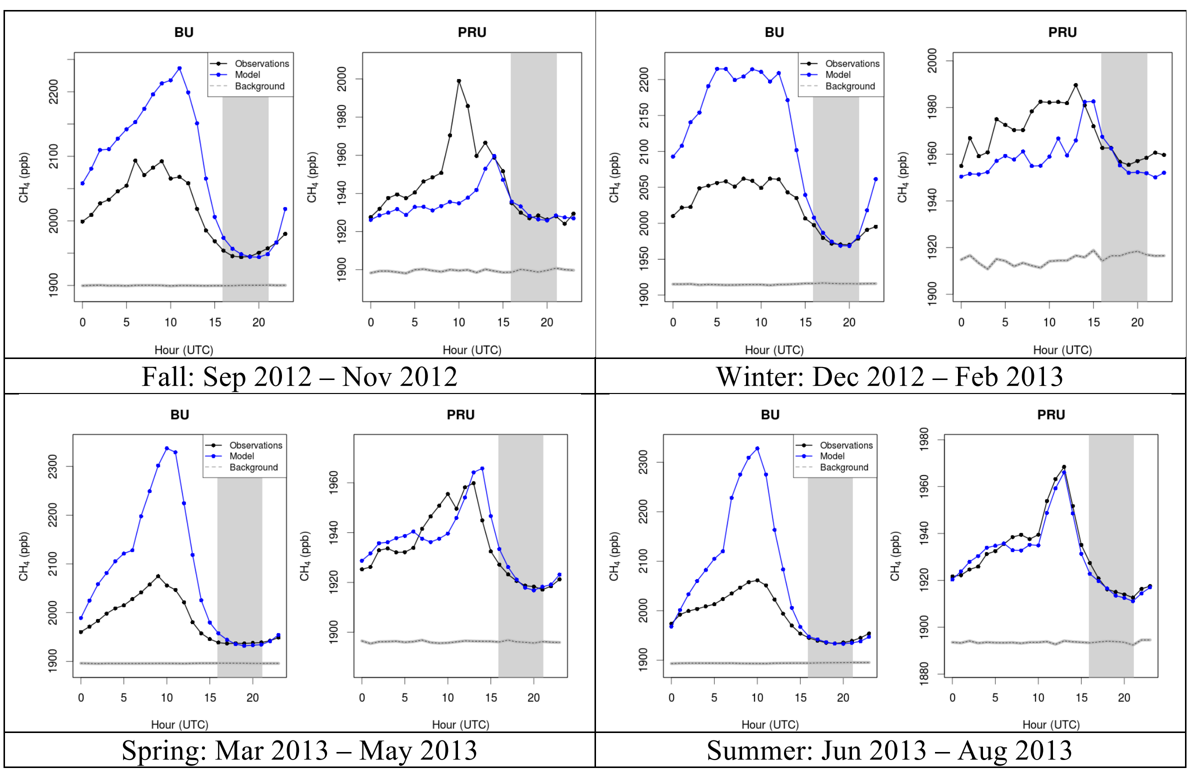

Figure 5: Mean diurnal modeled (blue) and observed (black) methane concentration at the Boston University (BU) and Prduential tower (PRU) locations. Modeled values are adjusted to fit the midafternoon (shaded area) observations. Note the change in scale between panels.

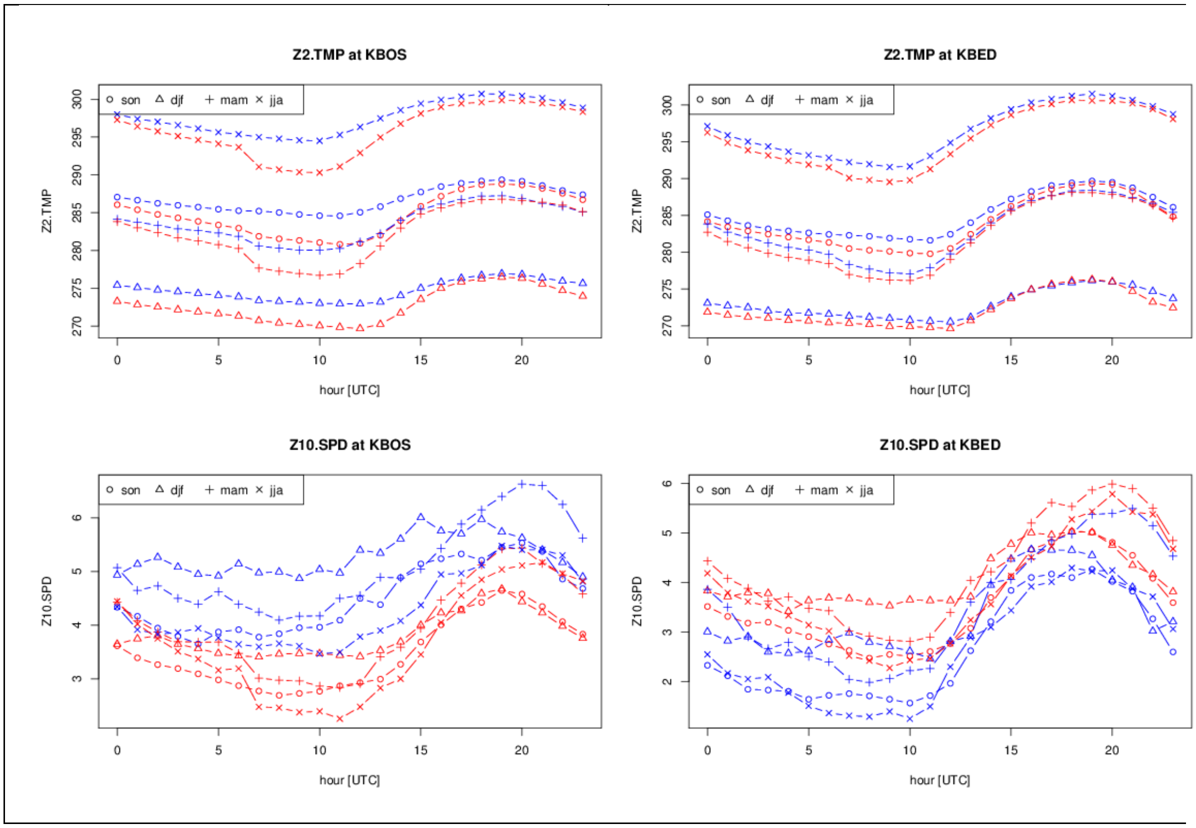

Figure 6: Mean diurnal cycle of observed (blue) and simulated (red) 2m temperature (top) and 10m wind speed (bottom), by season, for the same time period shown in Figure 1. Results for KBOS are shown on the left, KBED on the right.

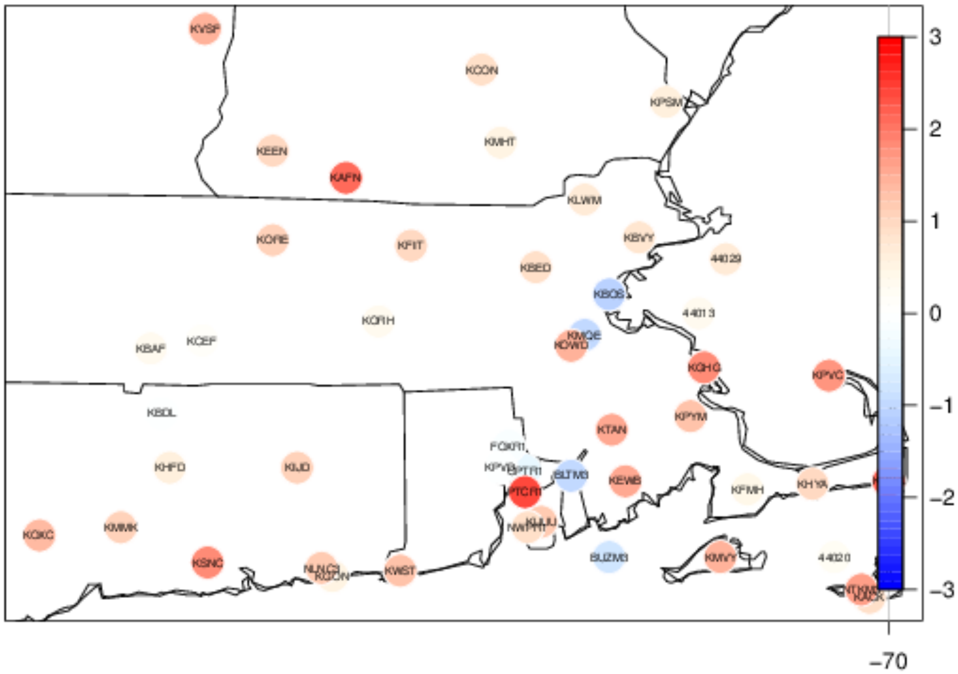

Figure 7: Bubble plot of annual average 10m wind speed bias (simulated - observed, in m/s). Labels correspond to observing stations.

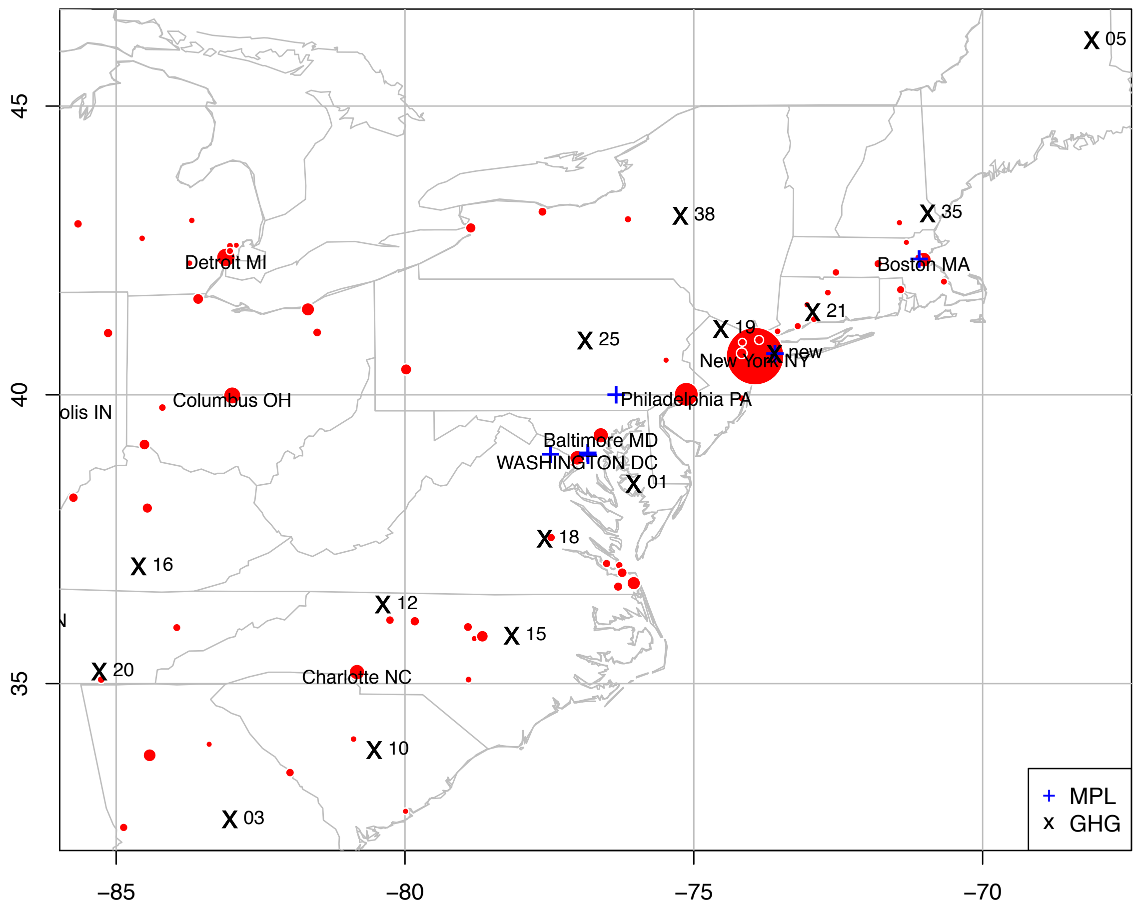

Figure 8: Map of Boston-DC corridor showing location of major population centers (red circles, area proportional to population), Earth Networks GHG towers (black X with labels), and past and current miniMPL sites (blue crosses). Currently operating sites are in Boston, Long Island, and the DC area. The proposed new minMPL deployment is in Lewisburg, PA (GHG tower 25).

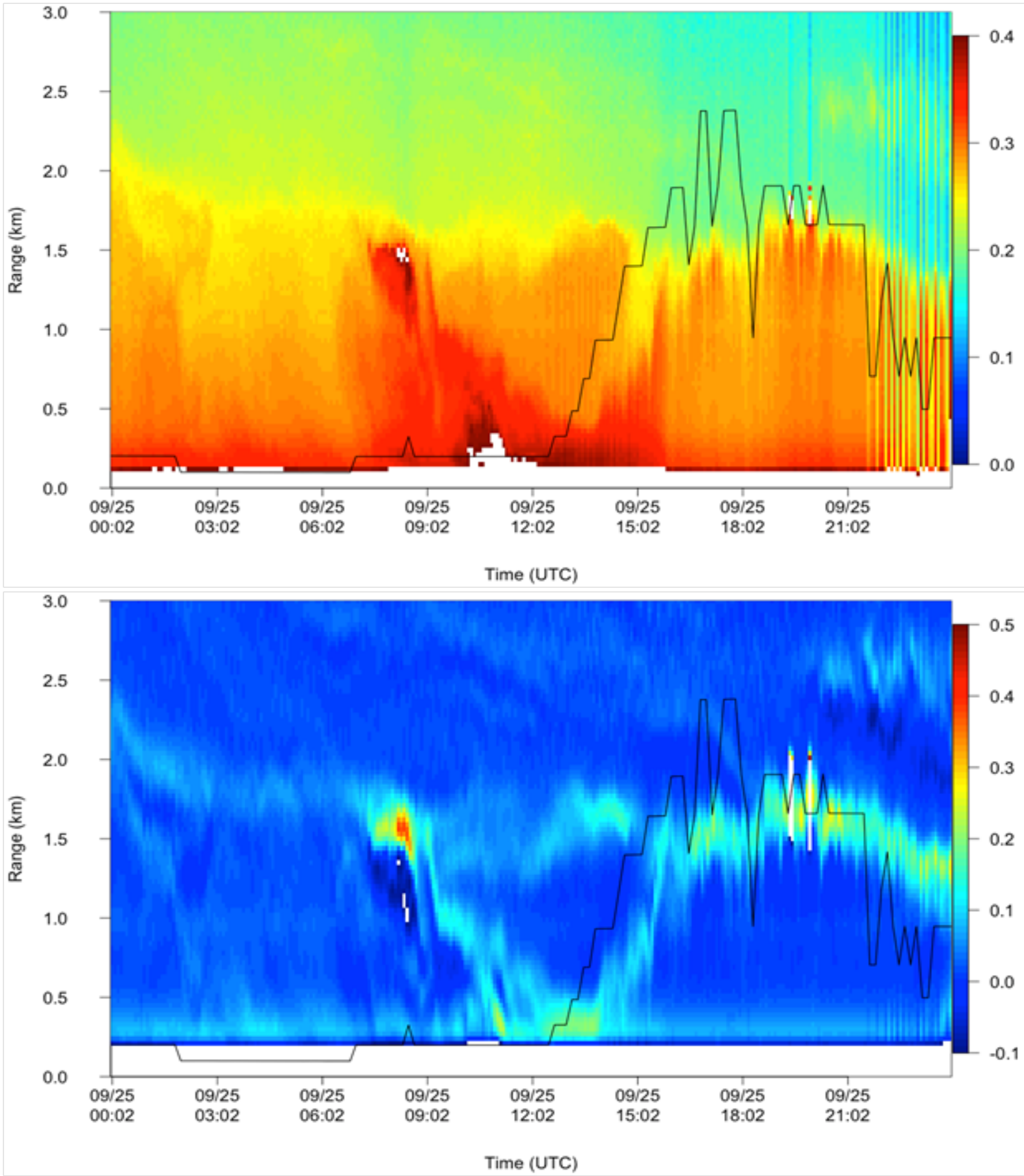

Figure 9: Aerosol normalized relative backscatter (top panel) and first derivative Gaussian filtered normalized relative backscatter (bottom panel) for 25 September 2012. The planetary boundary layer height simulated by WRF is plotted as solid black lines.

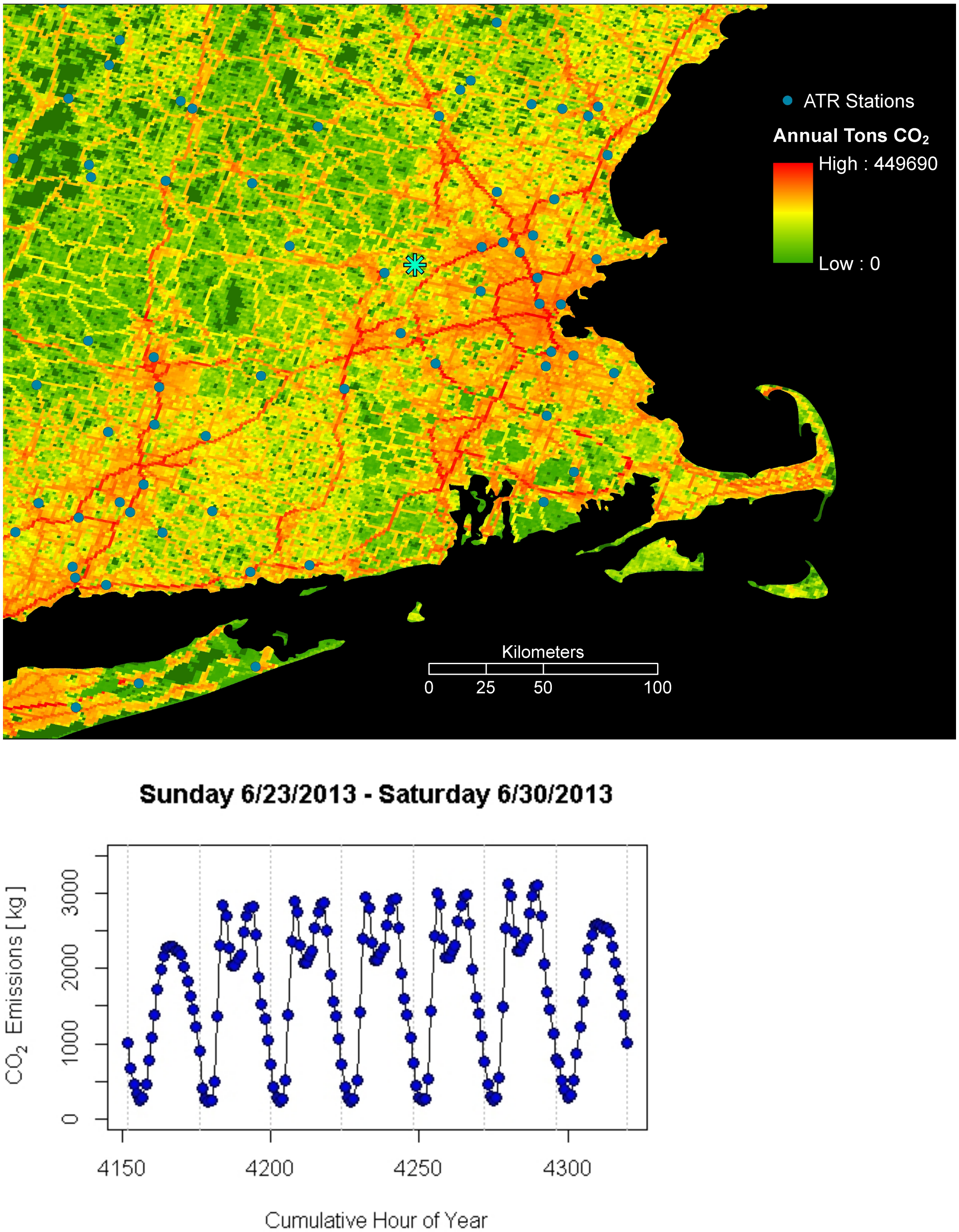

Figure 10: Temporal disaggregation example. The top panel is a map of annual average traffic-related CO2 emissions for a Southern New England region. Blue dots are locations of Automated Traffic Recorders (ATRs), and the blue star marks the location of the subarea for which hourly data are shown in the lower panel for one week in June 2013.