

NASA DEVELOP National Program

Summer 2016 Project Proposal

NASA Ames Research Center

San Francisco Bay Area Health & Air Quality

Understanding Methane Source Emissions from Local Sources using Satellite, Aircraft, and Ground-based Measurements

Project Overview

Objective: To examine the spatial distribution and temporal variation of methane (CH₄) emissions in the San Francisco Bay Area using prior satellite, aircraft, and ground-based measurements, and spatial inventory data

Fall 2016 – To assess and compare CH₄ and carbon dioxide (CO₂) concentrations in the San Francisco Bay Area using satellite, aircraft, and mobile and stationary ground-based measurements

Community Concern: Methane (CH₄) is the second most important anthropogenic greenhouse gas (GHG) in terms of radiative forcing, with a global warming potential of 34 on a 100-year time scale (IPCC 2013). Increases in CH₄ emissions influence the climate in two main ways: directly, by increasing the absorbing capacity of infrared radiation; and indirectly, by contributing to higher concentrations of tropospheric ozone (O₃), an air pollutant associated with diminished air quality and adverse health effects. In the San Francisco Bay Area, and major populated areas, CH₄ emissions occur from a variety of human-induced sources, such as livestock, landfill, and wastewater, and are often not well-quantified. The Bay Area Air Quality Management District (BAAQMD) uses traditional bottom-up methodologies to produce source-specific emissions estimates for their regional GHG inventory; however, these budgets have high uncertainty associated with them. While the bottom-up approaches provide a basis of understanding, recent literature argues that bottom-up methodologies are underestimating CH₄ emissions by ~50% in many areas of California, including the Bay Area (Fairley and Fischer, 2015). In order to address the gap between top-down and bottom-up estimates, this project proposes to utilize data at three different scales: satellite, airborne, and ground-based. The understanding of the spatial distribution and temporal variation of CH₄ will contribute to identifying areas of concern to be further investigated, discerning the major CH₄-emitting sectors, and helping establish the BAAQMD's Bay Area Greenhouse Gas Monitoring Network.

National Application Area(s) Addressed: Health & Air Quality

Study Location: San Francisco Bay Area, California

Study Period: January 2005 to December 2015

Advisor(s): Dr. Abhinav Guha (Bay Area Air Quality Management District), Dr. Laura Iraci (ARC), Dr. Josette Marrero (NASA Postdoctoral Program), Dr. Warren Gore (ARC), Dr. Emma Yates (Bay Area Environmental Research Institute), Dr. Juan Torres-Pérez (Bay Area Environmental Research Institute)

Source of Project Idea: This project began with a conversation regarding collaboration on a project with the NASA AJAX team. Joy “Chewie” Chen, who works for the Bay Area Air Quality Management District (BAAQMD), opened the conversation with Dr. Phil Martien and Dr. Abhinav Guha. The project was sparked when Dr. Martien and Dr. Guha brought attention to the gap between bottom-up and top-down CH₄ source estimates and their goals in establishing a Bay Area GHG monitoring network.

Partner Overview

Partner Organization(s):

Organization	POC (Name, Position/Title)	Partner Type	Boundary Org?
Bay Area Air Quality Management District (BAAQMD)	Dr. Abhinav Guha, Senior Air Quality Engineer; Dr. Phil Martien, Air Quality Engineering Manager	End-User	Yes
NASA Alpha Jet Atmospheric experiment (AJAX)	Dr. Laura Iraci, Atmospheric Chemist, PI; Dr. Emma Yates, Atmospheric Chemist; Dr. Josette Marrero, Atmospheric Chemist; Dr. Warren Gore, Chief ARC Atmospheric Branch	Collaborator	No

End-User Overview

End-User's Current Decision Making Process:

To align with BAAQMD's methane Regional Climate Protection Strategy, BAAQMD is implementing the Bay Area Green House Gas Network. The goal of this network is to record ambient trends in levels of GHGs across the Bay Area over a continuous time-scale, detect emission 'hotspots' and generate source-specific information, and develop robust emissions measurements at regional and local scales. The plan exists in two phases: 1) establishing a long-term ambient GHG monitoring network at four sites consistent with protocols of international atmospheric monitoring networks (Appendix 2), and 2) designing and fabricating a mobile GHG measurement platform (instrumented Air Monitoring Van, AMV) equipped with analyzers capable of measuring isotopic methane ($^{13}\text{C} - \text{CH}_4$), CH_4 , CO_2 , and nitrous oxide (N_2O) in ambient air at fast temporal rates. With a more accurate record of CH_4 in the San Francisco Bay Area, the BAAQMD will be able to make proactive and well-informed regulatory measures aimed at their goal of reducing GHG emissions 80% below 1990 levels by 2050.

End-User's NASA Earth Observations Capacity:

The BAAQMD is a public agency responsible for air quality management in the nine Bay Area counties: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, southwestern Solano, and southern Sonoma. While they have an extensive air quality monitoring system across the nine counties of the San Francisco Bay Area, they have not utilized NASA Earth observations to inform their ongoing GHG monitoring work. They are familiar with literature that has used NASA Earth observations, but have not yet incorporated or collaborated with NASA in this regard. This project will build the capacity of the BAAQMD to supplement ground-based measurements with airborne and remotely-sensed measurements.

Collaborator & Boundary Organization Overview

Collaborator Support:

Bay Area Air Quality Management District (BAAQMD)

Dr. Abhinav Guha will support the team as a project advisor. He will help with questions pertaining to location and distribution of methane emissions in the region, and estimating GHG source emissions. He will also be involved in assessing the methodology, discussing analyses, and verifying the scientific rigor of the results. Dr. Guha's involvement will ensure that the goals of the project align with satisfying BAAQMD's goals in establishing a Greenhouse Gas Monitoring Network.

Dr. Phil Martien will assist Dr. Guha in overseeing the work with the ARC DEVELOP team to ensure that the goals of the project are aligned with the goals of BAAQMD's methane Regional Climate Protection Strategy.

NASA Alpha Jet Atmospheric eXperiment (AJAX) performs regular missions to measure ozone and greenhouse gases, including CO₂ and CH₄, across California and Nevada. AJAX collects data on a regular basis over multiple seasons, providing data to complement surface and tower-based observations, as well as providing validation data for satellite sensors over months and years. AJAX normally performs two flight missions each month, and often several more when examining a specific area or case of interest (e.g. a CH₄ leak). Flight plans are normally confirmed a week prior to the flight, depending on pilot availability and flight conditions. For the first term of this project, the AJAX team will provide airborne data from previous flights ranging from 2011 to 2015. They will also support this project by holding in-person meetings with participants, during which they can help with questions about using airborne data, and provide advice on methodology and analyses. This project proposes a unique opportunity to collaborate with a team conducting continual airborne missions from the NASA Ames Research Center. ARC DEVELOP collaboration with AJAX in this project will help lessen the gap between bottom-up and top-up measurements to align with BAAQMD goals in estimating emissions.

Boundary Organization Dissemination:

Bay Area Air Quality and Management District (BAAQMD)

The Air District is a public agency that measures and records air quality data via their monitoring stations; these data are available to the general public through the data portal on their website. The products of the ARC DEVELOP-AJAX-BAAQMD collaboration, which will a project report, project video, and presentation, will be made available through the agency's web portal to the general public. The information will also be used to evaluate the spatial distribution of the region's GHG emissions inventory, and the project report will be cited in the updated inventory report wherever appropriate. The agency also regularly engages with the California Air Pollution Control Officers Association (CAPCOA), Association of Bay Area Governments (ABAG), and planning agencies at the city and county level. This report will be cited and made available to a host of end-user agencies as well.

Project Communication & Transition Overview

In-Term Communication Plan:

The team will hold telecons with AJAX and the BAAQMD twice a month each term (4 telecons/term). The main POC for this communication will be Vickie Ly, the current Assistant Center Lead; as well as Chippie Kislik, the current Center Lead; and the Team Lead of each respective term. Email communication will supplement communication in between telecons.

Transition Approach

At the end of the first term in early August 2016, the team will hold an in-person meeting with Dr. Abhinav Guha, Phil Martien, and the AJAX team, and present the results from the first phase, and discuss plans for the next phase. The second term will culminate in mid-November with an in-person presentation to BAAQMD in San Francisco, CA, to share the results from the project. Results and manuals produced from this project will also be emailed to the BAAQMD at the end of each term. The end-users will incorporate the ARC DEVELOP team's analyses into the implementation of the Bay Area Greenhouse Gas Monitoring Network. Software release will not be required.

Letters of Support:

Bay Area Air Quality and Management District, Dr. Phil Martien, Air Quality Engineering Manager

Earth Observations Overview

Earth Observations:

Platform & Sensor	Parameter(s)	Use
Aura, Tropospheric Emission Spectrometer (TES)	CH ₄ (mid to lower troposphere)	To map spatial distribution of CH ₄ and create a time series of CH ₄ budget. This will help end-users gain a spatial understanding of CH ₄ in the San Francisco Bay Area. TES operational time range is from 2004-current.
SCanning Imaging Absorption spectroMeter for AtmosphericCHartographyY (SCIAMACHY)	Total Vertical column CH ₄	To quantify and visualize vertical column CH ₄ emissions in localized areas. SCIAMACHY data will provide a "historical" vantage and serve to supplement TES data. Ultimately, these two platforms will assist the end-user in creating a spatially-resolved inventory of CH ₄ in the Bay Area. SCIAMACHY operated from 2003-2012.
Aqua, Atmospheric Infrared Sounder (AIRS)	CH ₄ (mid troposphere)	To map spatial distribution CH ₄ . This will help the end-users gain a spatial understanding of CH ₄ in the San Francisco Bay Area. AIRS operational time range is from 2012 - current
USGS / NOAA	Wind speed/direction Pressure	To inform the atmospheric variables influencing the CH ₄ time series derived from satellite data.
NASA Alpha Jet Atmospheric eXperiment (AJAX)	CH ₄ , CO ₂ , and H ₂ O altitude, pressure, temperature, 3-D wind speed	Aboard the H211 aircraft, the Picaro GHG is a commercial sensor (model 2301-m) that measures CH ₄ , CO ₂ , and H ₂ O. The MMS will provide important pressure, temperature, 3-D wind data. Data from AJAX will provide localized data of fine scale spatial resolution to supplement satellite data.
Suomi NPP, VIIRS	Temperature	To understand the fluctuations in CH ₄ in terms of changes in seasonality.
Terra, MODIS	Landcover	To classify land cover, land cover change, and the associated

		industries contributing to anthropogenic and natural CH ₄ .
Landsat 5 TM, 7 ETM+, 8 OLI	Landcover	To classify land cover, land cover change, and the associated industries contributing to anthropogenic and natural CH ₄ .

Ancillary Datasets:

BAAQMD ground stations: CH₄ concentrations

BAAQMD mobile instrumented van measurements: CH₄ concentrations

National Elevation Dataset

California Department of Water Resources, Association of Bay Area Governments, Air Resource Board: Diaries, Landfill, Natural gas, Refineries, Wastewater treatment plants

US Census: Population Density

Department of Transportation: On-road mobile emissions

Models:

TerrSet's Earth Trends Modeler (POC: James Toledano, Clark Labs/ Clark University)

Decision Support Tool & End-Product Overview

End Products:

End Product(s)	Partner Use	Datasets & Analyses	Software Release Category
Overview Map of CH ₄ distribution for San Francisco Bay Area	This map will provide a spatially-resolved distribution of CH ₄ across the 9 counties, as observed by satellite imagery. Moreover, this map will serve as an "overview" of CH ₄ concentrations across the SF Bay Area, with the goal of detecting CH ₄ hotspot areas. This will build upon the work of Fischer and Jeong (2015) and provide a big picture understanding of CH ₄ emissions in the Bay Area, laying the groundwork for further on-ground investigation.	CH ₄ data from TES, AIRS, and SCIAMACHY. CH ₄ retrievals from existing NASA AJAX flight data will be used to validate satellite observations.	1
CH ₄ budget time series in San Francisco Bay Area	The time series will serve to understand inter-annual and seasonal trends in CH ₄ concentrations and emissions. The time series will be used to assess and understand CH ₄ fluctuations and the seasonal and anthropogenic influences on the CH ₄ budget over the past 10 years. Also, this time series will be used to detect CH ₄ anomalies.	The time series will be based on TES data and compiled in TerrSet's Earth Trends Modeler. This will be delivered in the form of graphs and visualizations.	1
Updated Bottom-up GHG Emissions Inventory	An examination and update of the current activity data will provide BAAQMD with a more accurate assessment of how	Activity data will come from BAAQMD's GHG emissions inventory, California Department	

	<p>much methane is being emitted from the Bay Area. Currently, the activity data does not include dairy locations, capped natural gas wells locations and emissions, or natural gas distribution lines. An updated emissions inventory will also serve as a guide for the aircraft and instrumented Air Monitoring Van measurements for further ground investigation.</p>	<p>of Water Resources (Dairies), and the Air Resource Board.</p>	1
<p>Guide for aircraft and instrumented Air Monitoring Van measurements</p>	<p>This detailed guide will serve as a plan for the summer and fall 2016 terms. In collaboration with BAAQMD and AJAX partners, this guide will serve as a roadmap to schedule conducting runs with BAAQMD's Air Monitoring Van and AJAX flights. This will be delivered in the form of a written plan of flight dates, times, and areas.</p>	<p>Synthesized data from NASA AJAX, TES, and SCIAMACHY will be used in ENVI and Google Earth to design a detailed guide and map. BAAQMD's current CH₄ emission inventory will be evaluated to narrow down isolated sources that are prime candidates for airborne investigations. The updated emissions inventory and land cover data from Landsat and Terra MODIS will be used to classify anthropogenic and natural sources of CH₄.</p>	1
<p>Comparison of CH₄ concentrations from satellite, aircraft, and fixed ground stations</p>	<p>In comparing CH₄ at three different scales, BAAQMD will be able to examine correlation of CH₄ concentrations between bottom-up and top-down approaches. This will require comparing column CH₄ concentrations versus in-situ CH₄ concentrations. Furthermore, the comparisons will illuminate trends not captured in previous literature using solely ground-based data. The results will be able to shape future measurement approaches and practices and provide BAAQMD with a better understanding of the gaps</p>	<p>This will utilize emissions data from TES, AIRS, and SCIAMACHY, previously observed data from AJAX, and BAAQMD's fixed ground stations in the Bay Area. This will be delivered in the form of graphs.</p>	1

	between bottom-up and top-down measurements.		
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End-User Benefit:

Successful regulation of greenhouse gas emissions calls for an improved understanding of current CH₄ emission sources. It also relies heavily on an emissions inventory that is supported by actual top-down measurements and reduced uncertainties in the inventory estimates for each source sector. The products from this project will serve to understand the spatial distribution and temporal variation of CH₄ across San Francisco Bay Area. Evaluation of the satellite imagery data from the first term will help BAAQMD understand the spatial and temporal variation of CH₄ and CO₂ emissions as observed through top-down approaches. The significance of using a rich satellite dataset is that it will introduce existing and available top-down datasets to the end-users, who previously have not used satellite data.

Furthermore, an improved emissions inventory that incorporates finer-scale and updated activity data will provide a more accurate assessment and account of CH₄ emissions. This will allow a critical evaluation of the bottom-up inventory and an accounting of missing and underestimated GHG sources. Furthermore, the results of the first term along with the prior aircraft data will set the stage for the second term, where the ARC DEVELOP team will coordinate where flight and driving paths will be taken by aircraft and an instrumented Air Monitoring Van to collect CH₄ data from specific sources. This will assist the end-users to derive emission ratios that can be directly compared against those in the bottom-up inventory. In capitalizing on satellite measurements, aircraft, and mobile ground-based, this project will provide BAAQMD with a more comprehensive examination of CH₄ sources in the SF Bay Area with top-down and bottom-up approaches.

Project Timeline & Previous Related Work

Project Timeline: 2 Terms: 2016 Summer to 2016 Fall

Multi-Term Objectives:

Term 1 (Proposed Term): Summer 2016 (ARC) – San Francisco Bay Area Health & Air Quality

In order to address the discrepancy in bottom-up estimates, this project will compare data at different spatial scales: airborne and satellite (top-down approaches), and ground-based (bottom-up approaches). The first term will focus on creating a map of CH₄ distribution and a CH₄ budget across the nine counties of the SF Bay Area by utilizing remotely sensed data from SCIAMACHY, TES, and AIRS. Secondly, the ARC DEVELOP team will create a time series of CH₄ fluctuations to examine seasonality and anthropogenic inputs. With existing data from AJAX flight missions, the team will compare satellite data to airborne data. The team will also work to update the current BAAQMD emissions inventory with relevant spatial activity data from the California Department of Water Resources, Association of Bay Area Governments, and California Air Resource Board. The DEVELOP team will collaborate with the NASA AJAX team and the BAAQMD partners to identify areas of interest where further air quality investigations will be conducted by aircraft and a mobile platform (instrumented Air Monitoring Van), and create flight and drive plan to be conducted during the Summer and Fall 2016 terms. Telecons will be held twice a month with the AJAX team and BAAQMD partners.

Term 2: Fall 2016 (ARC) – San Francisco Bay Area Air Quality and Health II

The second term will build upon the first term to focus on both CH₄ and CO₂ by capitalizing on data from three different platforms: satellite, aircraft, and an instrumented Air Monitoring Van. Using the spatially-resolved map of CH₄ emissions and the planned

guide prepared in the first term, the scheduled flights and drives will be conducted, and the ARC DEVELOP team will focus on analyzing and synthesizing the data from the AJAX instruments and BAAQMD vehicle. If the results from the first term reveal an area of interest (e.g. Sonoma dairies, natural gas production in Solano or Contra Costa Co.), the ARC DEVELOP team will dedicate time to investigating a specific case. Furthermore, the ARC DEVELOP team will test the accuracy of bottom-up to top-down sources by comparing CO₂ data from the flights and drives to CO₂ data from OCO-2, GOSAT, Aura OMI. The ARC DEVELOP team will continue to communicate with the AJAX team and BAAQMD partners, and hold telecons twice a month. The project will culminate with an in-person hand-off and presentation at the BAAQMD headquarters in San Francisco, CA.

Related DEVELOP Work:

Summer 2015 (JPL) – Los Angeles Health and Air Quality: Identifying Urban Emission Patterns in the Los Angeles Megacity
Summer 2014 (LaRC) – Texas Health and Air Quality: Evaluating the Application of DISCOVER-AQ Data to Monitor Air Quality in Houston, TX
Spring 2013 (SSC) – Appalachia Health & Air Quality: Comparison of NASA OMI and MLS Ozone Products with USDA Forest Service Ground-Based Ozone Monitoring Data for USDA Forest Service Air Quality / Forest Management Decision Support

Project Needs/Requests

Participants Requested: 4

Software & Scripting:

ArcGIS – Map CH₄ concentrations
ENVI – Map CH₄ concentrations, Classification of Landsat and MODIS images (also ArcGIS)
R studio – Statistical analyses
TerSet Earth Trends Modeler, Climate Change Adaptation Modeler – Create time series to assess seasonal and anthropogenic fluctuations in CH₄ and identify localized sources of CH₄.

Notes & References:

Notes: The end-user has a specific interest in CH₄ because it is a pollutant that has not received as much attention as CO₂. For this reason, we designed this project to be focused on CH₄ to better contribute to their Regional Climate Protection Strategy goals.

References:

IPCC Fourth Assessment Report: Climate Change 2013. 2.10.2 Direct Global Warming Potentials. https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

Fairley, D. and M. L. Fischer. 2015. Top-Down Methane Emissions Estimates for the San Francisco Bay Area from 1990 to 2012. *Atmospheric Environment*. doi:10.1016/j.atmosenv.2015.01.065

M. L. Fischer and S. Jeong. 2015. Evaluating Bay Area the Methane Emission Inventory.

Miller, S., Wofsy, S.C., Michalak, A.M., Kort, E.A., Andrews, A.E., Biraud, S.C., Dlugokencky, E.J., Eluszkiewicz, J., Fischer, M.L., Janssens-Maenhout, M., Miller, B.R., Miller, J.B., Montzka, S.A., Nehrkorn, T., and Sweeney, C. 2013. Anthropogenic Contributions of Methane in the United States. *PNAS*. 110, 50, 20018–20022.

Wecht, K. J., D. J. Jacob, C. Frankenberg, Z. Jiang, and D. R. Blake (2014), Mapping of North American methane emissions with high spatial resolution by inversion of SCIAMACHY satellite data, *J. Geophys. Res. Atmos.*, 119, 7741–7756, doi:10.1002/2014JD021551.

Wong, K. W., Fu, D., Pongetti, T. J., Newman, S., Kort, E. A., Duren, R., Hsu, Y.-K., Miller, C. E., Yung, Y. L., Sander, S. P. Mapping CH₄ : CO₂ ratios in Los Angeles with CLARS-FTS from Mount Wilson, California. Atmos. Chem. Phys. 15, 1, 241-252

NASA AJAX:

http://geo.arc.nasa.gov/ajax/ajax_index.html

Bay Area Air Quality and Management District:

<http://www.baaqmd.gov/>

<http://www.baaqmd.gov/plans-and-climate/climate-protection/climate-protection-program>

Air District Monitoring Plans – For DEVELOP program.pdf (prepared by Dr. Abhinav Guha)

Appendix 1: Maps provided by BAAQMD

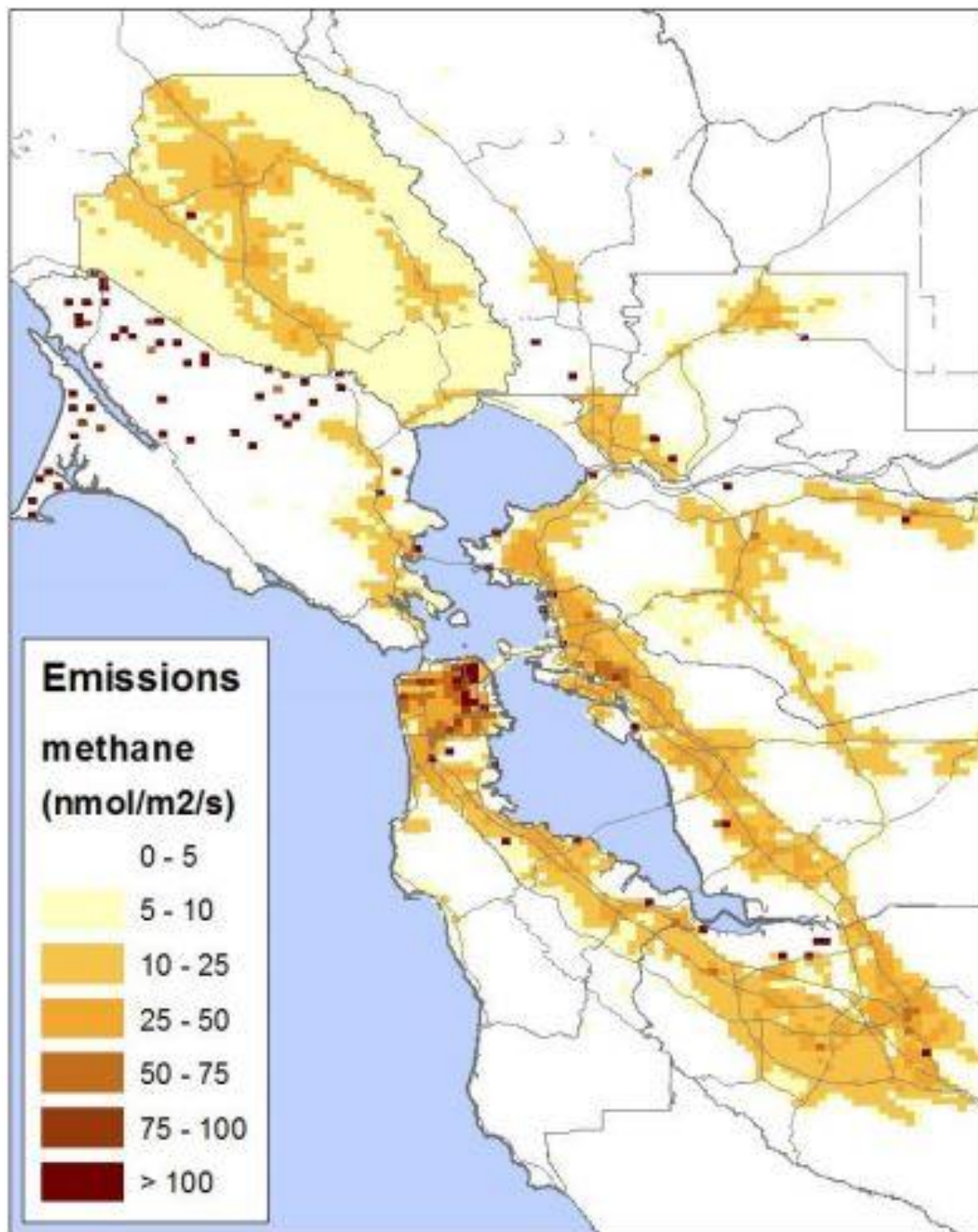
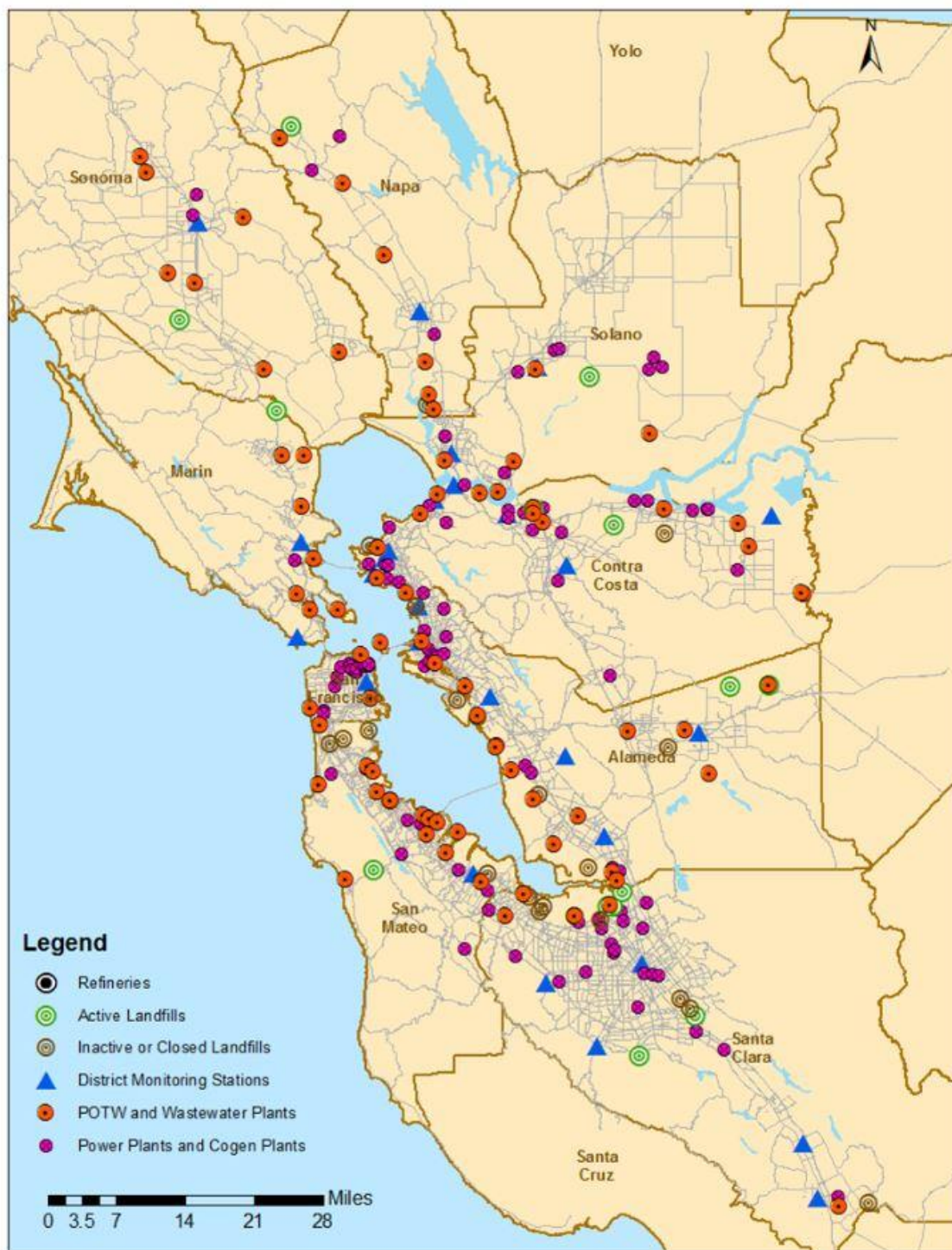


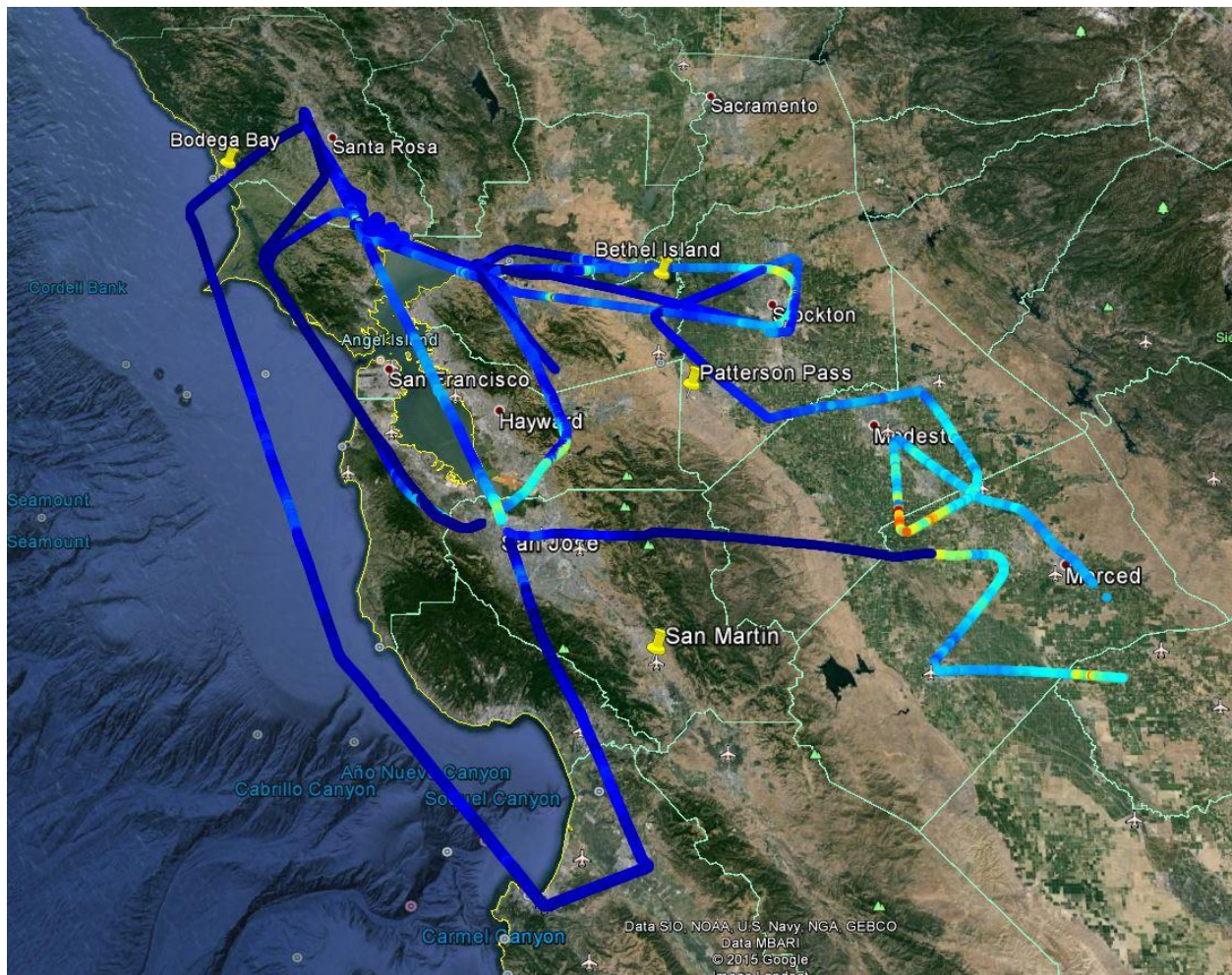
Figure 1. A spatial representation of CH₄ emissions distribution over the San Francisco Bay Area derived from bottom-up inventory data *(please note that this map is incomplete and does not have all the source sectors represented and should be used just to obtain a perspective of gridded inventory in the region)*.



Map of anthropogenic activity of the San Francisco Bay Area and BAAQMD Monitoring Stations.

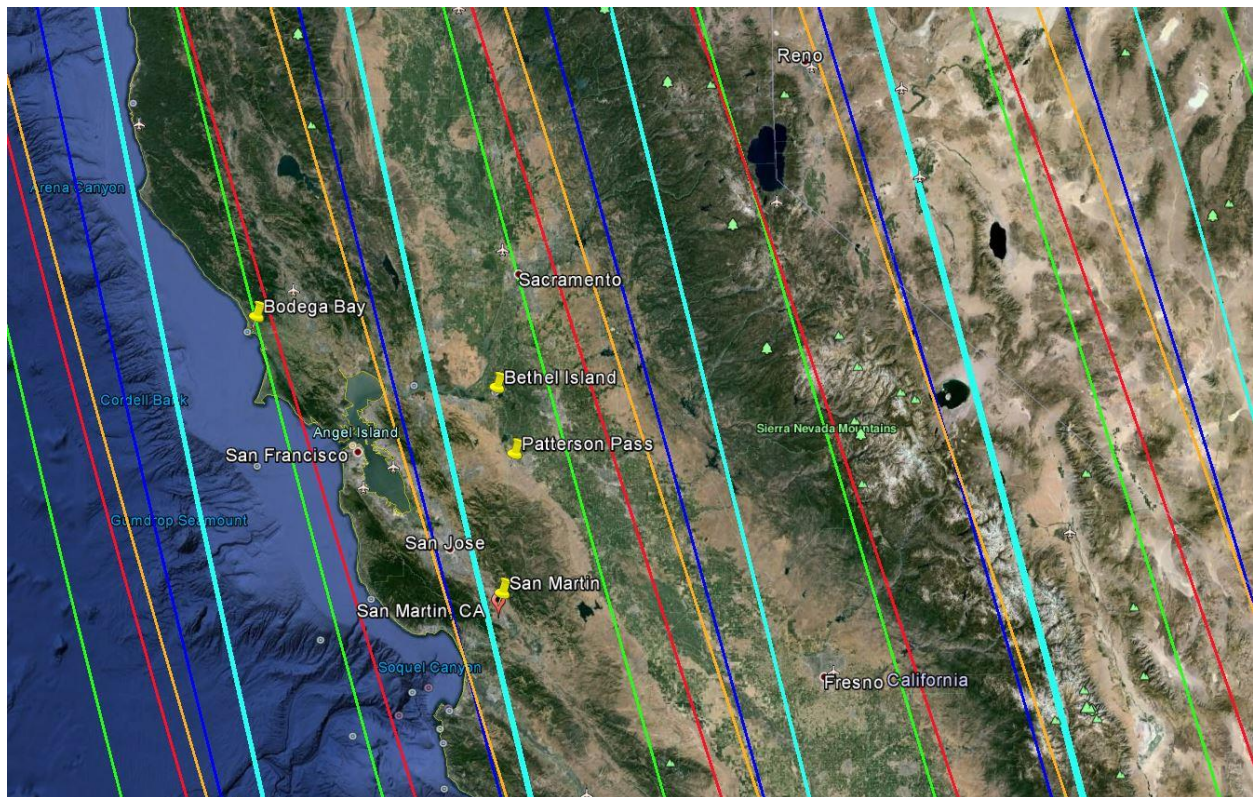
This map provides a general understanding of the spatial distribution of landfills, wastewater plants, power plants, and refineries. Note that this map does not detail natural gas production, a major source of GHG emissions (CH_4). Please do not distribute without permission.

Appendix 2: AJAX Flight Paths

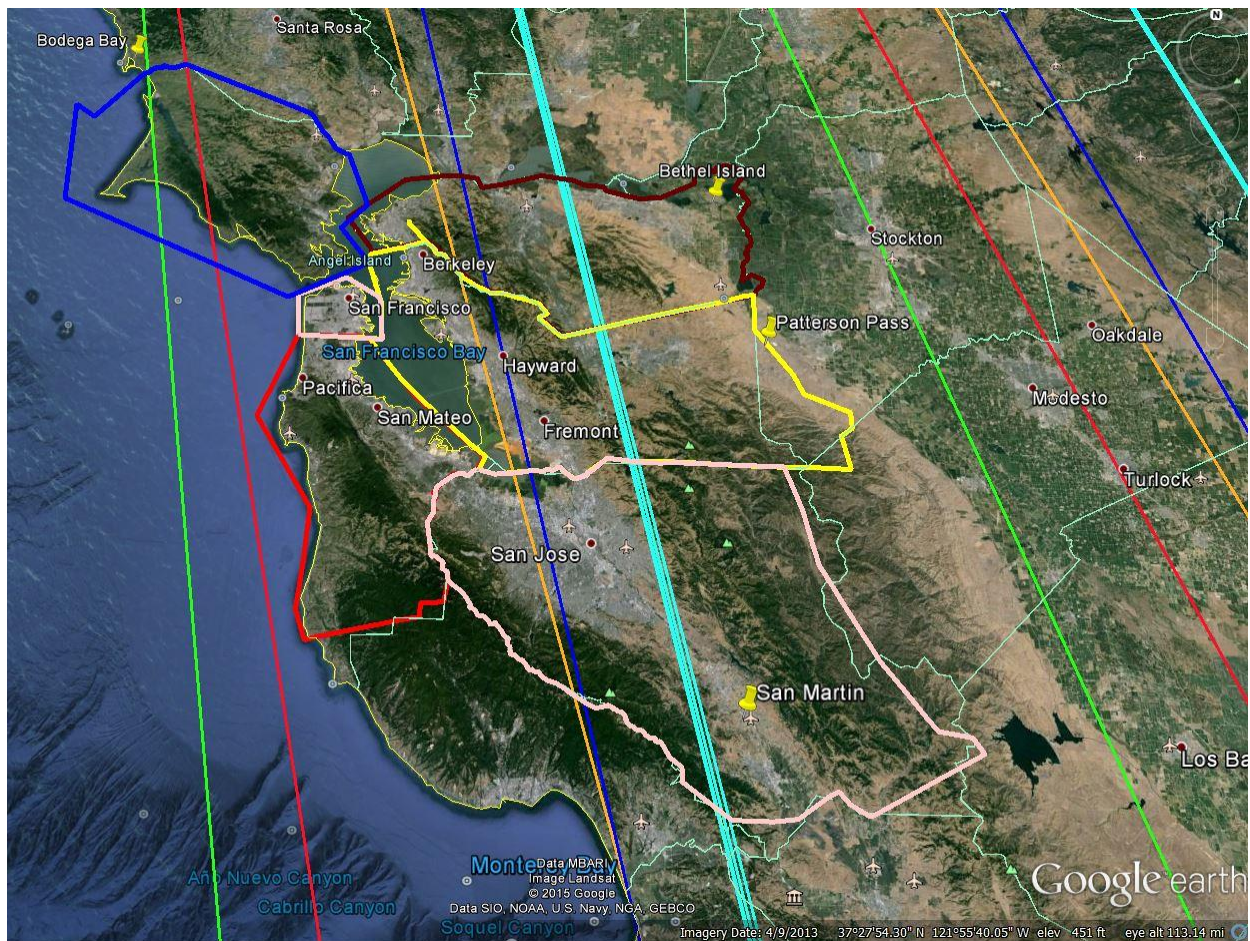


A sample of recorded AJAX CH₄ flight missions over the SF Bay Area. Tracks show the flight paths and recorded CH₄ concentrations (light blue indicating higher concentrations, dark blue indicating lower concentrations). Thumb-tack points indicate the four existing fixed ground stations that are a part of the BAAQMD GHG Monitoring Network in the Bay Area monitoring CH₄ concentrations: Bodega Bay, Bethel Island, Patterson Pass, San Martin. These flights overlap with the current BAAQMD ground stations. *Please do not distribute without permission.*

Appendix 3: OCO-2 Flight Paths



OCO-2 observing tracks over San Francisco (SF) Bay Area and BAAQMD ground stations. Thumbtack points indicate the four existing BAAQMD ground stations in the Bay Area: Bodega Bay, Bethel Island, Patterson Pass, San Martin. OCO-2 data would be used in the second term.



OCO-2 observing tracks over the SF Bay Area. OCO-2 flights overpass areas that BAAQMD has identified as “communities of concern,” including San Jose, Fremont, Hayward, and the eastern extents of the SF Bay Area, as well as the test site of Bodega Bay. BAAQMD has identified CO₂ as their second highest priority for the GHG Monitoring Network. Comparing satellite observations against existing AJAX and mobile and stationary ground-based CO₂ data would provide insight into the comparison between top-down and bottom-up emission estimates.