Methane Emissions from the Baltimore-Washington Area: Airborne Observations and Comparison with Inventories

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Outline

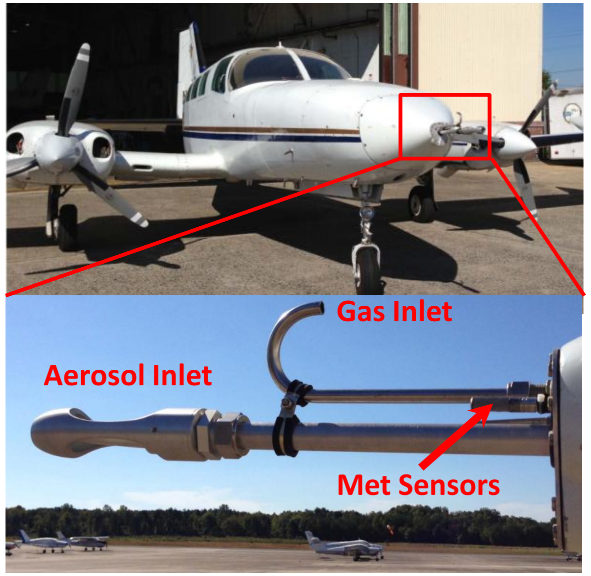
- Aircraft measurements and mass balance approach for CH_4 emissions
- Comparison with CH_4 Emission inventories
- CH_4 emissions based on CO & CO_2 inventories and observed CH_4/CO & CH_4/CO_2 ratios

Close collaboration with NIST & MDE.

- CO_2 is the big climate forcing factor.
- Initial results indicate emissions inventories for CO_2 are good to within 10-15%.
- It is not possible to do better with current technology, but we're working on improvements.
- Methane (CH_4) is harder to quantify.
- There are many sources of methane natural gas delivery systems, waste water treatment, agriculture, and landfills.
- UMD is working with MDE to improve CH_4 emissions estimates.

UMD Cessna & Purdue Duchess Research Aircraft

UMD Cessna



GPS Position (Lat, Long, Altitude)

Met (T, RH, P, wind speed/direction)

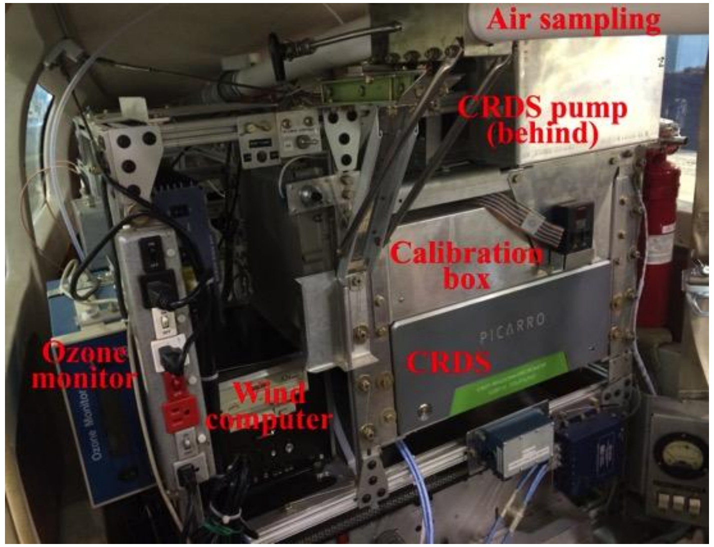
Trace gases:

- O_3: UV Absorption, modified TECO
- SO_2: Pulsed Fluorescence, modified TECO
- $CH_4/CO_2/CO/H_2O$: Cavity Ringdown, Picarro
- NO_2: Cavity Ring Down, Los Gatos
- NO: Chemiluminescence, modified TECO
- VOCs: grab canisters/GC-FID

Aerosol Optical Properties:

- Scattering: b_{scat} (@450, 550, 700 nm), Nephelometer
- Absorption: b_{ap} (565 nm), PSAP
- Black Carbon: Aethalometer

Purdue Duchess



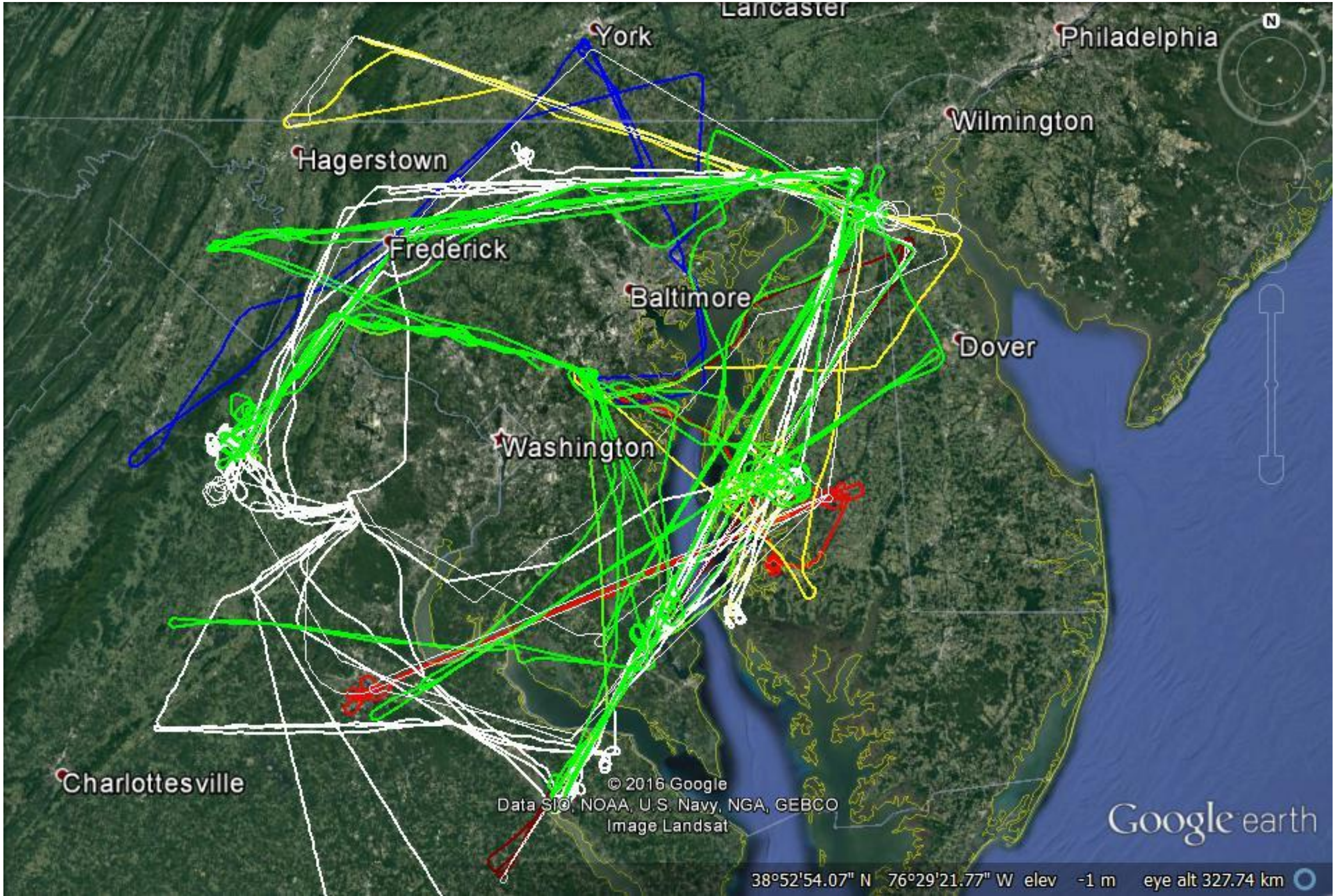
GPS Position (Lat, Long, Altitude)

Met (T, RH, P, 3-D wind by BAT)

Trace gases:

- O_3: UV Absorption, 2B Technology
- CH_4/CO_2: Cavity Ring Down, Picarro
- NO_2: Cavity Ring Down, Los Gatos

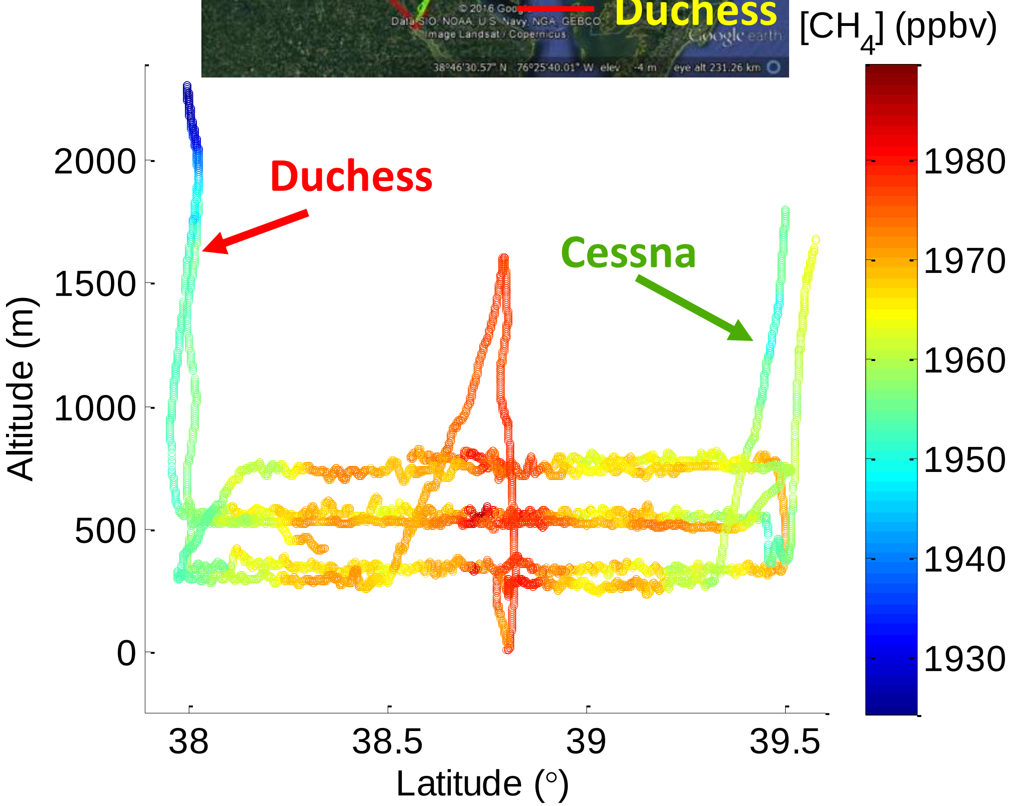
FLAGG-MD Flights during Winter 2015 and 2016



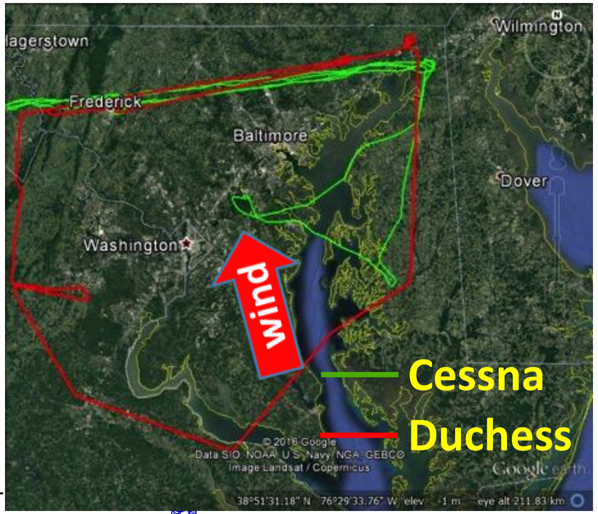
Different Flight Patterns in Winter 2015 and 2016

Flights on 2/19/2015

FLAGG-MD 2015: Both aircraft did level transects

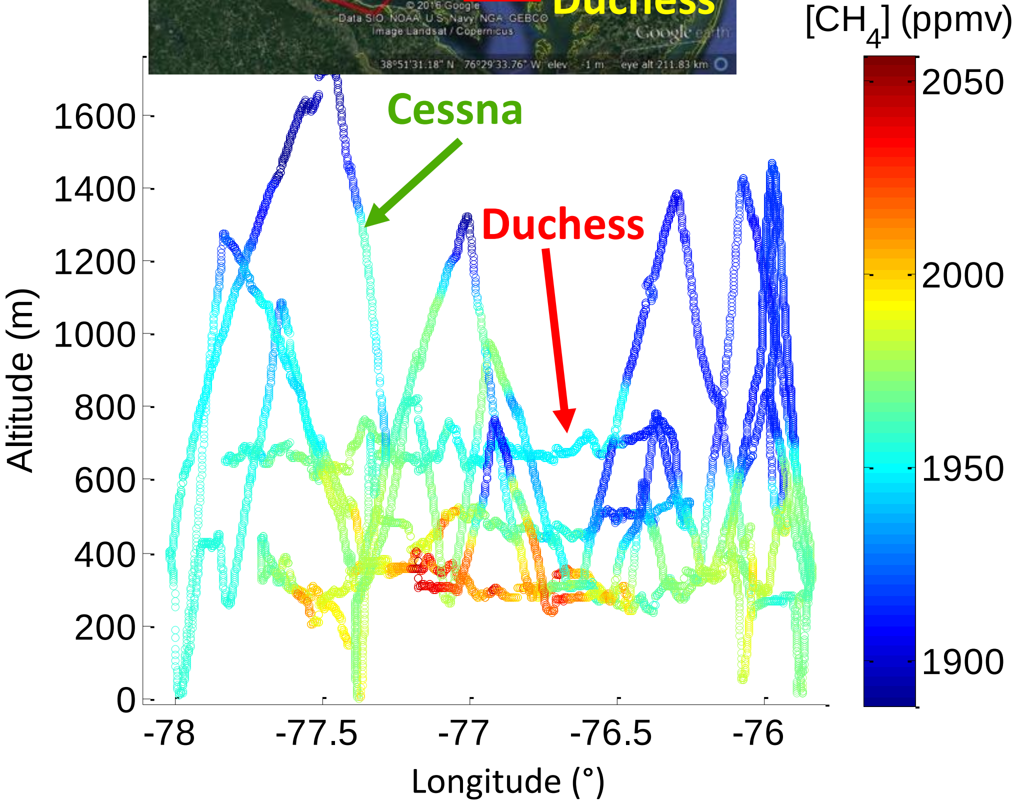


Flights on 2/19/2016



FLAGG-MD 2016:

- **The Cessna did continuous vertical profiles downwind.**
- **The Duchess did upwind survey & level transects downwind.**



Mass Balance Approach to Estimate Emission Rates

Mass Balance Experiment (MBE) approach:

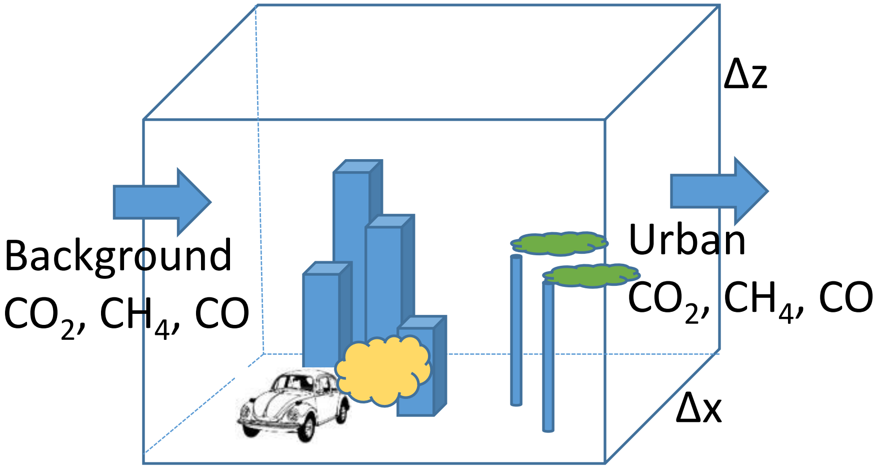
$z_i \quad +x$

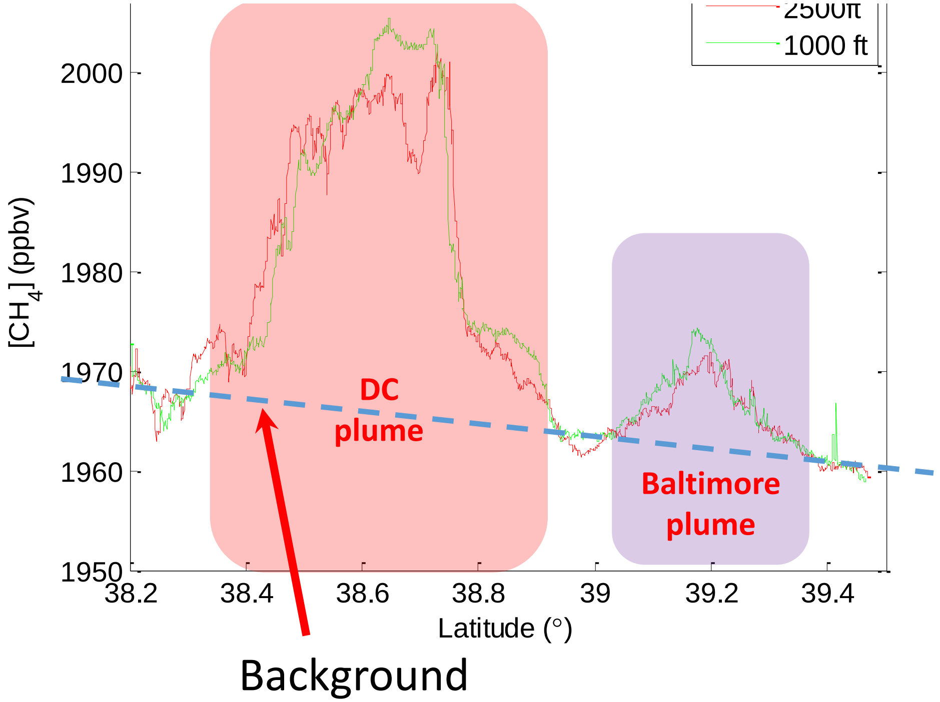
What comes out of the box minus what went in is the flux.

[C] : concentrations (downwind)

$[C]_b$: concentration in background

$U_\perp$: perpendicular wind speed





Estimated GHG Emissions from the Baltimore-Washington Area

FLAGG-MD winter 2015

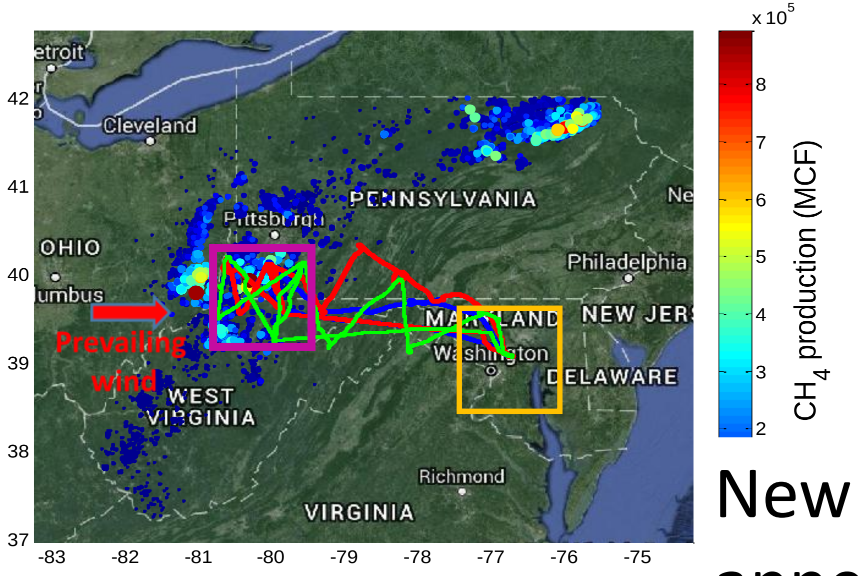
Flight Date	Flux(CO_2) (moles s^{-1})	Flux(CH_4) (moles s^{-1})	Flux(CO) (moles s^{-1})
2/6/15	94,500	557	521
2/13/15	71,000	290	281
2/18/15	91,200	795	--
2/19/15	156,800	932	567
2/20/15	118,100	518	753
2/23/15	107,900	641	417
2/24/15	110,300	476	640
2/25/15	108,500	602	571
2/27/15	78,800	540	--
Mean±1σ	104,000 ±25,000	595±184	536±152

FLAGG-MD winter 2016

Date	Flux(CO_2) (moles s^{-1})	Flux(CH_4) (moles s^{-1})	Flux(CO) (moles s^{-1})
02/08/16	73,200	418	430
02/12/16	93,000	350	510
02/17/16	107,800	1,078	365
02/18/16	98,100	373	611
02/19/16	142,800	722	688
Mean±1σ	103,000 ±25,600	588±312	521±131

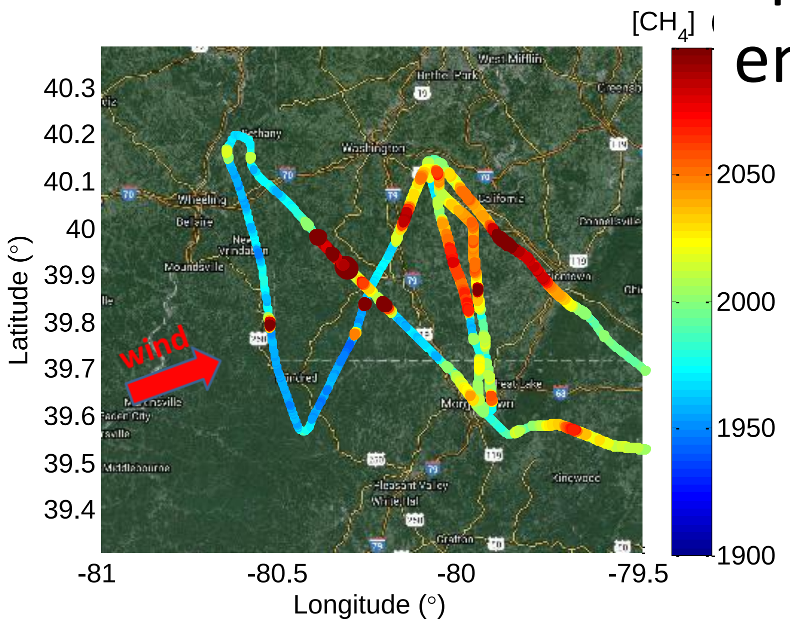
Mean CH_4 emission rate: 592 ± 248 moles s^{-1}

600 moles/s ~ 30,000 tons/yr



CH_4 Emissions from the SW Marcellus

New Regulations on finishing appear to have improved emissions.

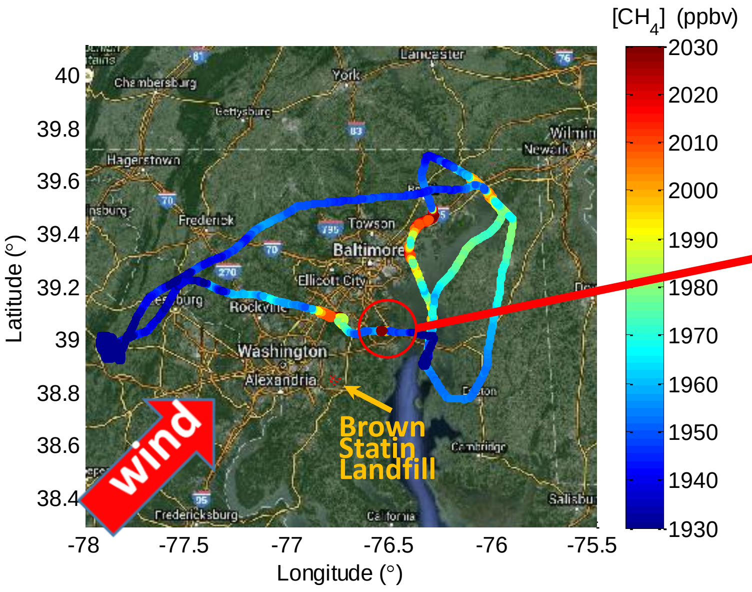


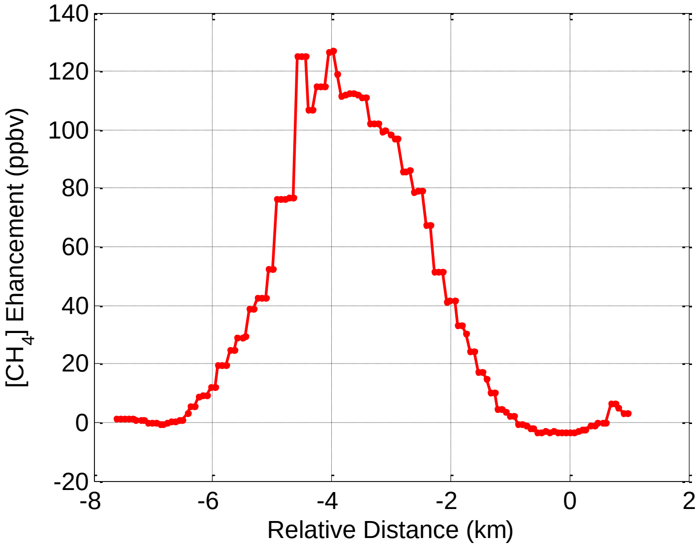
			)	WD (deg)	PBL Height (m AGL)	CH_4 E.R. (moles s^{-1})
8/25/15	1,967±22	2,023±39	9.7±1.4	260±12	2,200	2,391
8/29/15	2,016±16	2,119±50	6.6±1.4	226±13	1,950	2,315
9/14/15	1,960±28	2,032±37	9.6±1.2	283±12	1,500	2,156

From Marcellus (55x77 km): 2,287 ± 120 moles CH_4 s^{-1}

From Balt-DC (75x95 km): 592 ± 248 moles CH_4 s^{-1}

Example Point Source: CH_4 from Brown Station Landfill





Measured 21 times over 7 flights.

Flight #	CH_4 Emission Rate (moles s^{-1})
RF1	57.4
RF2	55.7
RF4	51.8
RF5	64.7
RF6	65.3
RF7	36.0
RF8	69.1
Mean	57.1 ± 11.1

EPA GHGRP CH_4 emission rate for this landfill: 15.5 moles s^{-1}

A factor of 3.7 higher than the value in GHGRP

Mass Balance vs. Inventories

Landfill (# of transects/flights)	Mass Balance Flux Range** (moles CH_4 /s) - Average of all transects	2015 EPA (moles CH_4/s)	2014 MDE (moles CH_4/s)	2012 Maasakkers (moles CH_4/s)
Brown Station (21/7)	24.6 – 64.0	*3.44 or 15.5**	6.14	8.52
Eastern Sanitary (3/1)	9.9 – 49.5	4.54	6.85	10.01
Quarantine Road (7/3)	1.35 – 2.94	3.33	17.6	3.11
Harford Waste (2/2)	2.22 – 8.50	5.42	3.52	5.52
Reichs Ford (3/2)	12.8 – 26.2	5.88	1.83	4.96
Route 40 West (3/3)	2.66 – 10.01	6.89	10.23	6.70

* EPA GHGRP requires landfills with a gas collection system (Brown Station has a gas collection system) to estimate their emissions in two ways. Typically, the higher of the two results is reported as the “official” value, but in Brown Station’s case, the lower number (3.44) was reported instead of the higher number (15.5).

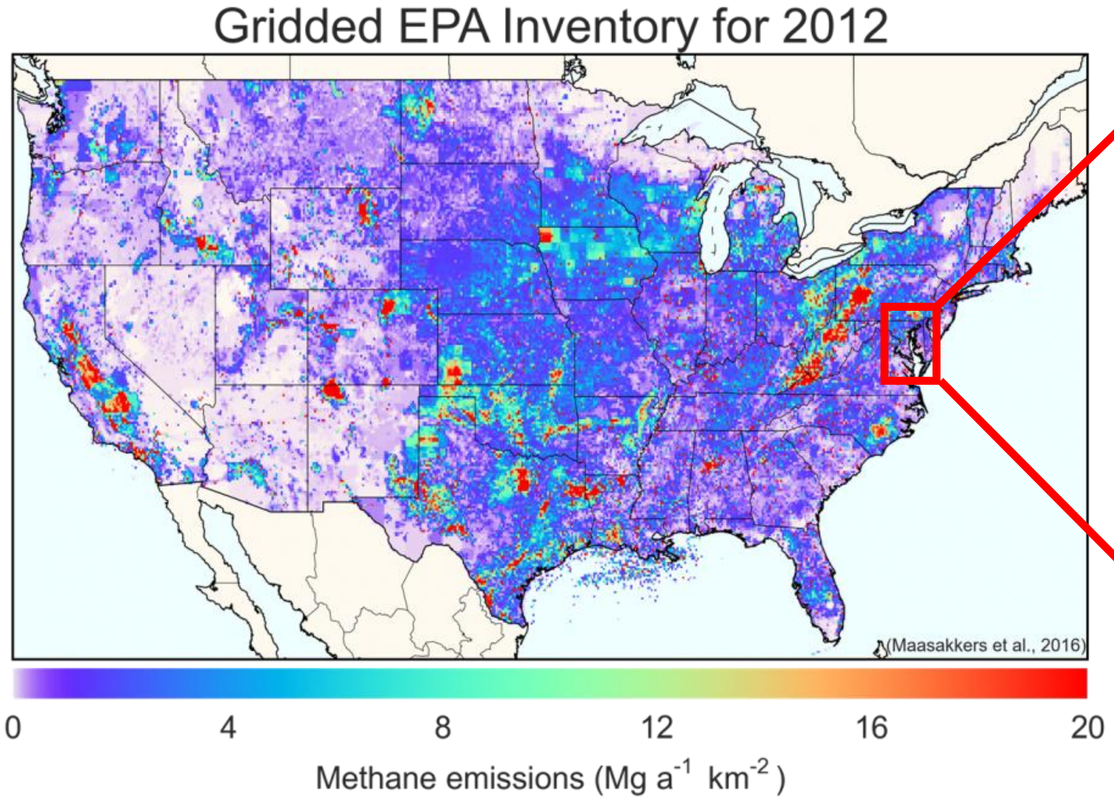
**Flux range computed by varying horizontal transect width by 10% and PBL height by one-sigma.

New gridded US CH_4 NEI for 2012 (0.1° x 0.1°)

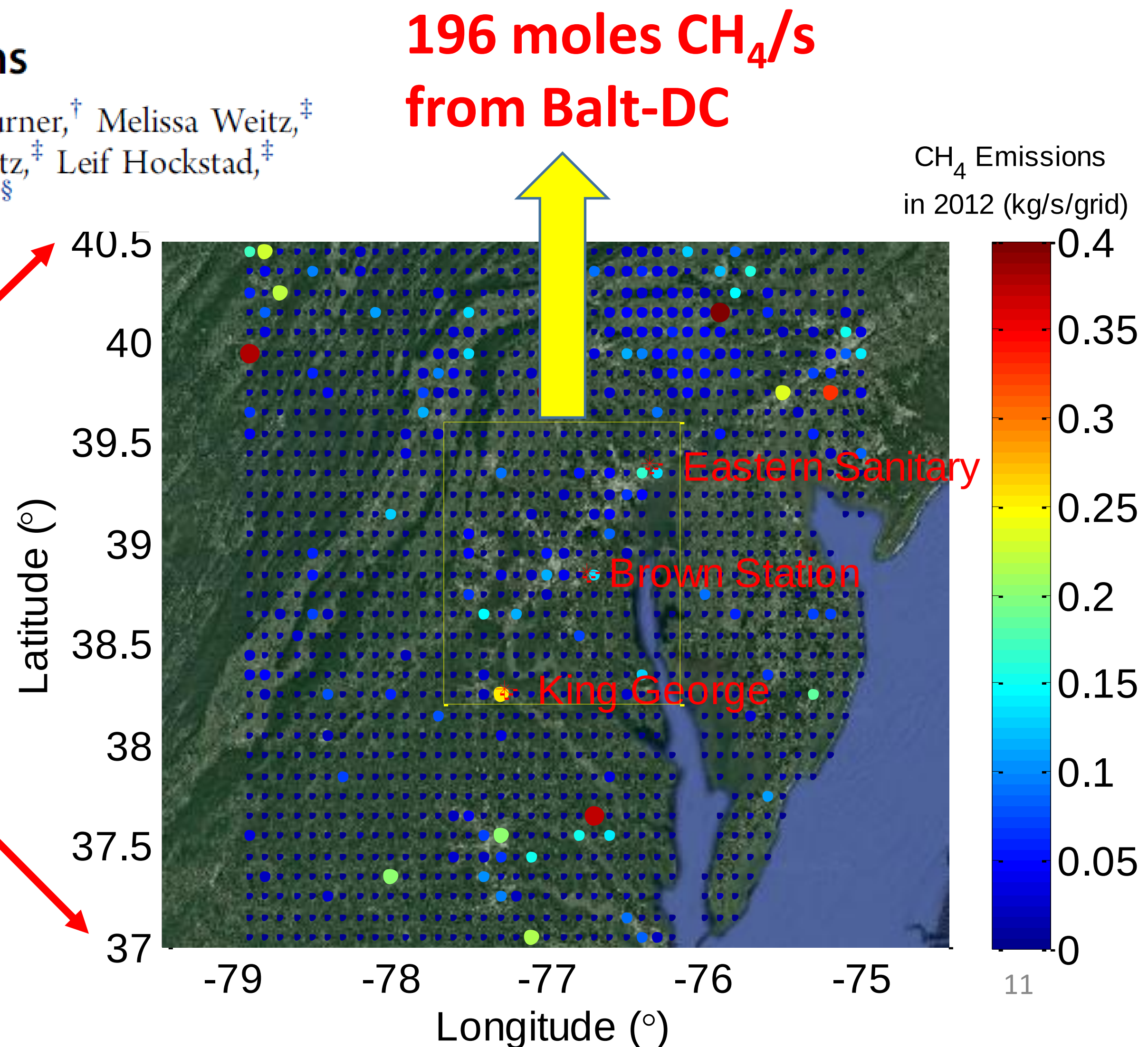
Environmental Science & Technology
Article
pubs.acs.org/est

Gridded National Inventory of U.S. Methane Emissions

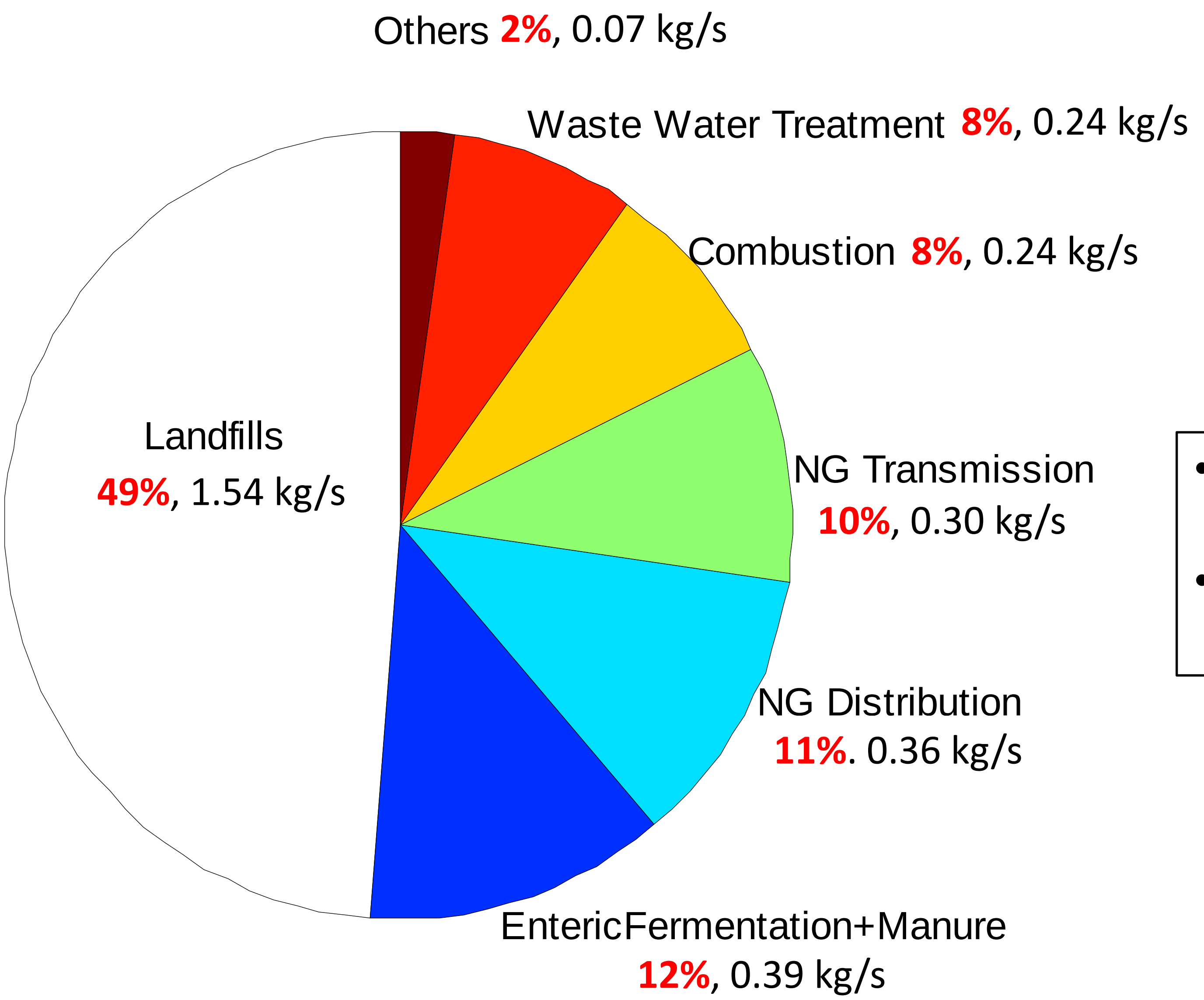
Joannes D. Maasakkers,*[†] Daniel J. Jacob,[†] Melissa P. Sulprizio,[†] Alexander J. Turner,[†] Melissa Weitz,[‡] Tom Wirth,[‡] Cate Hight,[‡] Mark DeFigueiredo,[‡] Mausami Desai,[‡] Rachel Schmeltz,[‡] Leif Hockstad,[‡] Anthony A. Bloom,[¶] Kevin W. Bowman,[¶] Seongeun Jeong,[§] and Marc L. Fischer[§]



Includes all methane emissions included in the National Greenhouse Gas Inventory.



CH_4 Emissions from Sources in Balt-DC in CH_4 NEI 2012

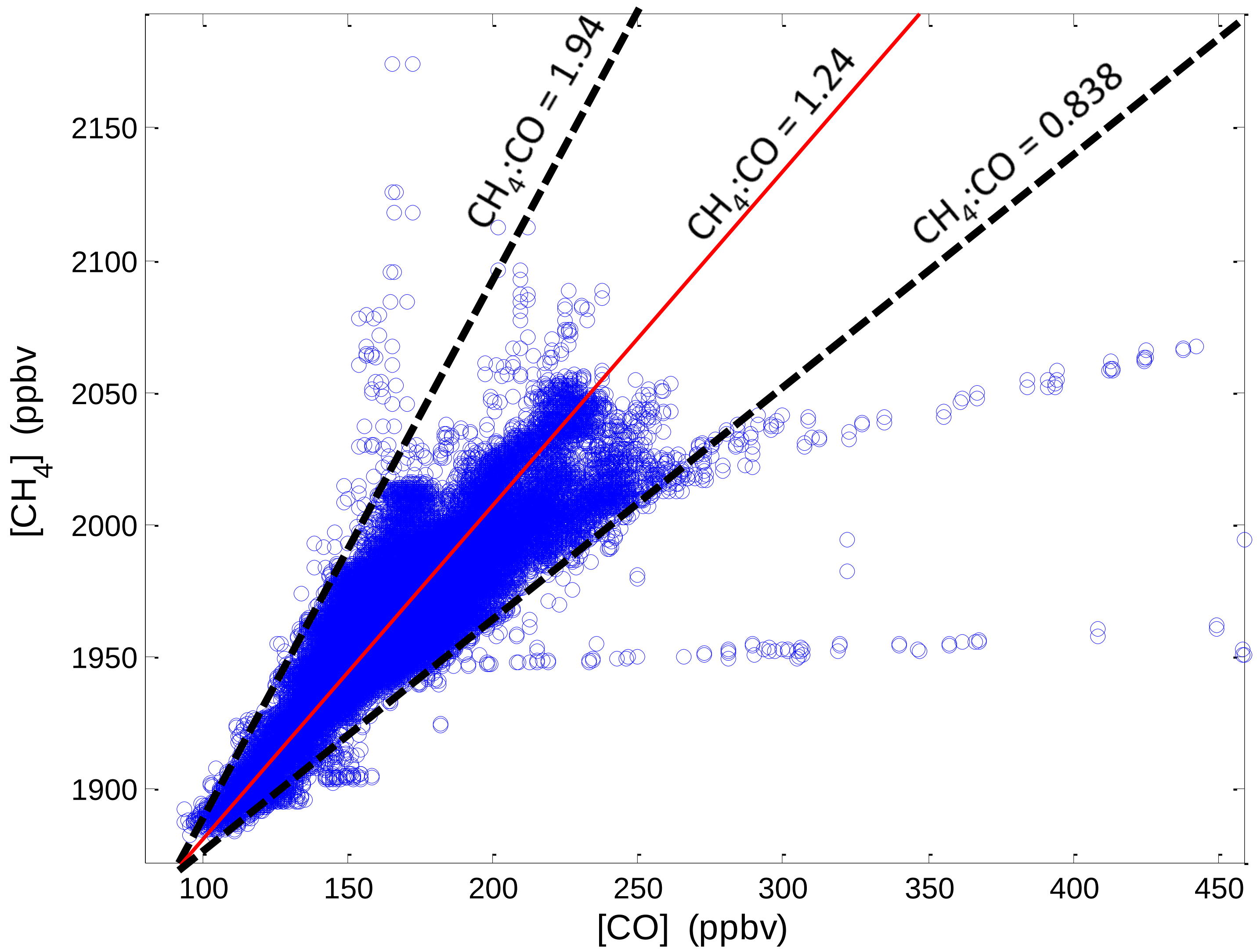


- Landfills are a major CH_4 source.
- CH_4 emissions from NG system may be under-estimated.

An alternative approach – CO_2 and CO emissions well constrained and we can use ratios to learn about the methane flux.

CH_4 Emission Estimate using CH_4/CO Ratio and CO Emissions

FLAGG-MD winter 2015

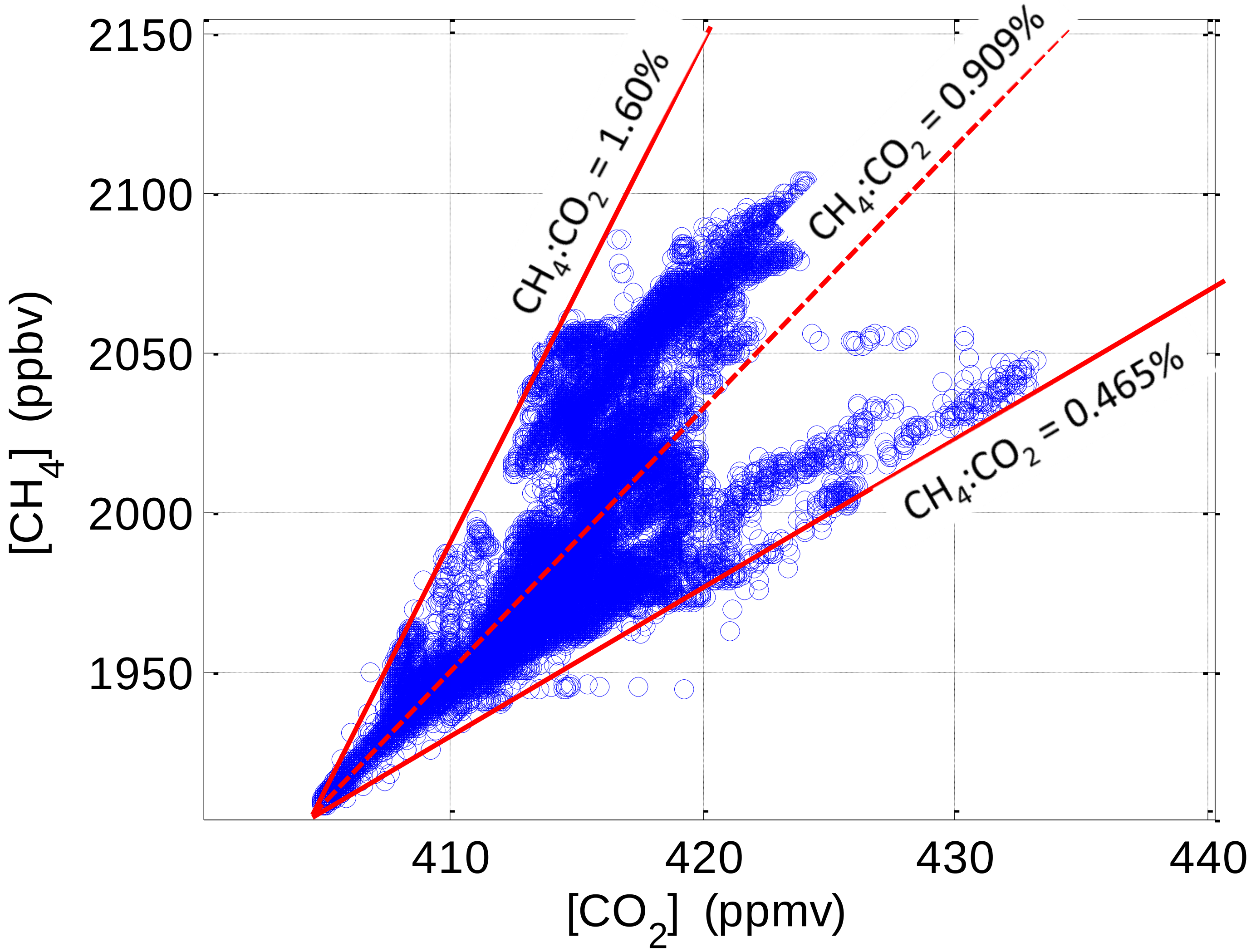


- Total CO emissions from Balt-DC in EDGAR v4.3 2010: **0.459 MMtons/yr**

- The total CH_4 emissions based on CH_4 to CO ratio: **642 moles CH_4 s^{-1}** (436 – 1,003 moles CH_4 s^{-1})

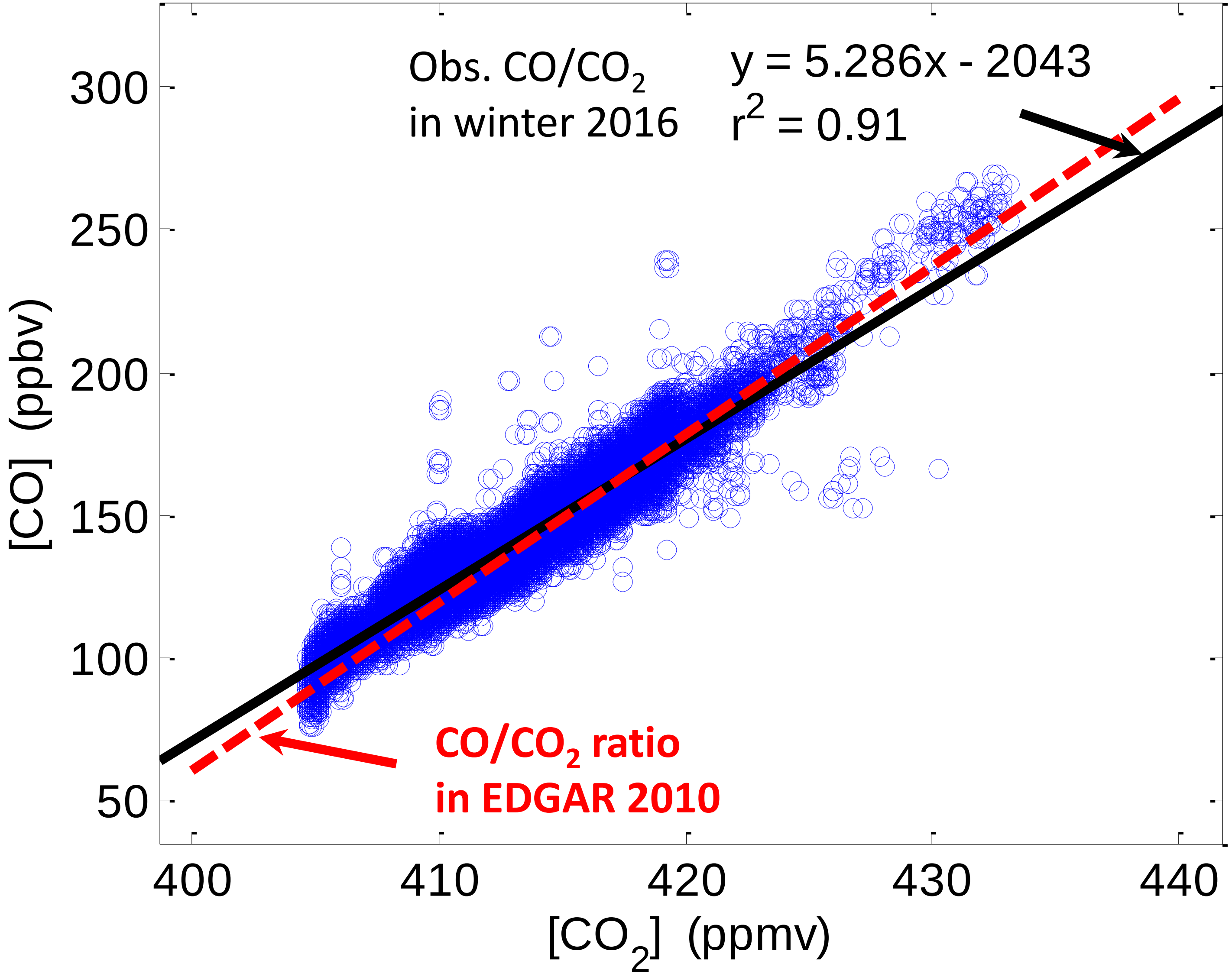
CH_4 Emission Estimate using CH_4/CO_2 Ratio and CO_2 NEI 2014

FLAGG-MD winter 2016



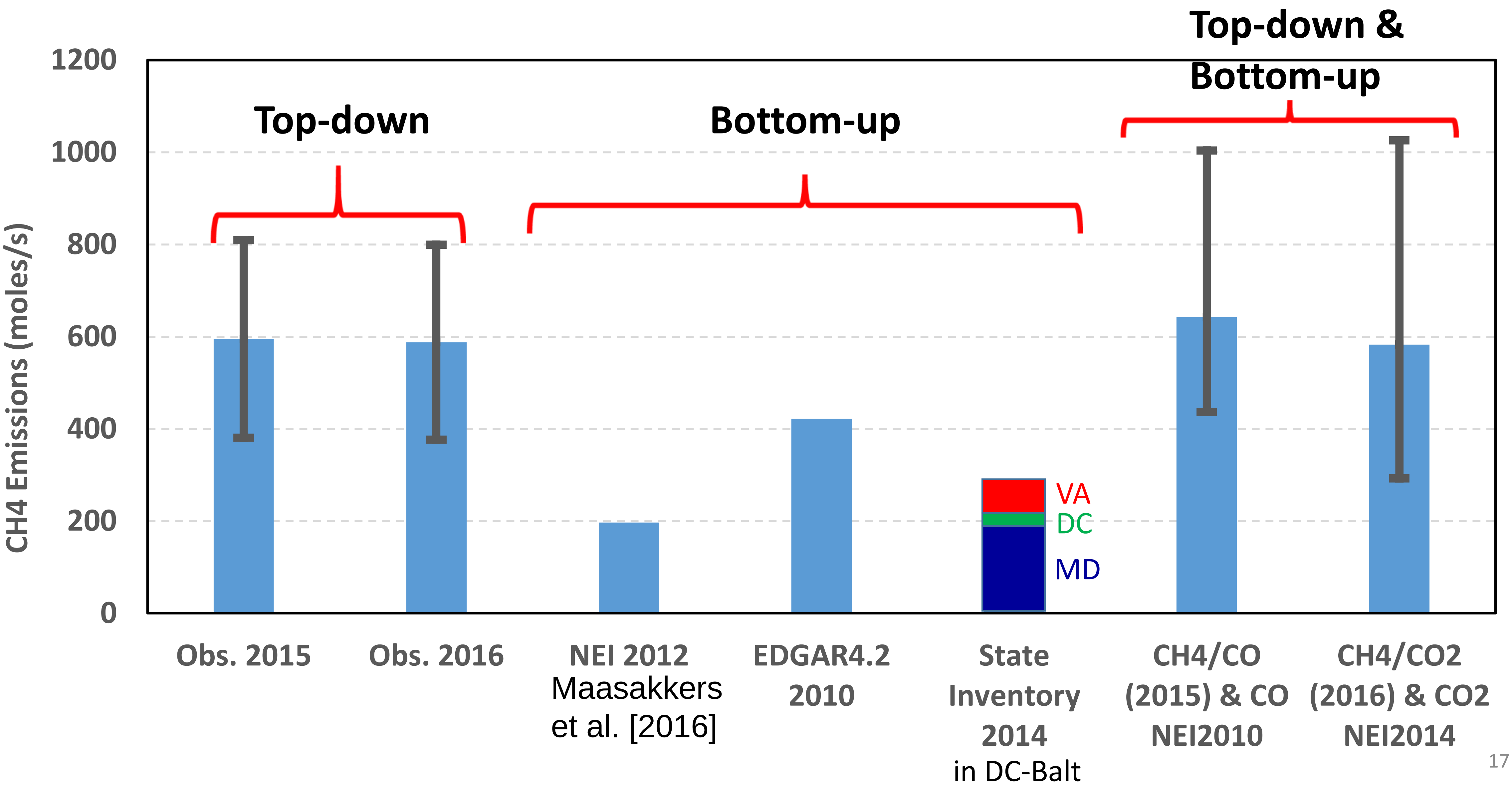
- Total CO_2 emissions from Balt-DC in NEI2014: **89.0 MMtons/yr**
- The total CH_4 emissions based on CH_4 to CO_2 ratio: **583 moles CH_4 s^{-1}** (293 – 1,029 moles CH_4 s^{-1})

CO to CO_2 ratio: Observed vs. EDGAR Emissions



- Observed CO to CO_2 molar ratio = 0.53% (black line)
- CO to CO_2 molar ratio in EDGAR 2010 emission inventory: 0.59% (red dashed line)

CH_4 Emissions from the Balt-DC Area: Top-down vs. Bottom-up



Summary

- UMD is working with MDE to fine tune emissions inventories. CO_2 is the big player with CH_4 ~10% of total.

- Estimated total emissions of CH_4 from Balt/Wash area:

  595±184 moles CH_4 s^{-1} in winter 2015

  588±312 moles CH_4 s^{-1} in winter 2016 (**~30,000 tons/yr**)

- Major CH_4 sources in the area: landfills and broadly, NG system.

- Direct observations of CH_4 emissions 1.4 to 3 times higher than inventories.

- Only flew in winter so far; need summer flights.

Extra Slides

Summary

- UMD is working with MDE to fine tune emissions inventories. CO2 is the big player.

- Only flew in winter so far; need summer flights.

- Estimated total emissions of CH_4 from Balt/Wash area:

  595±184 moles CH_4 s^{-1} in winter 2015

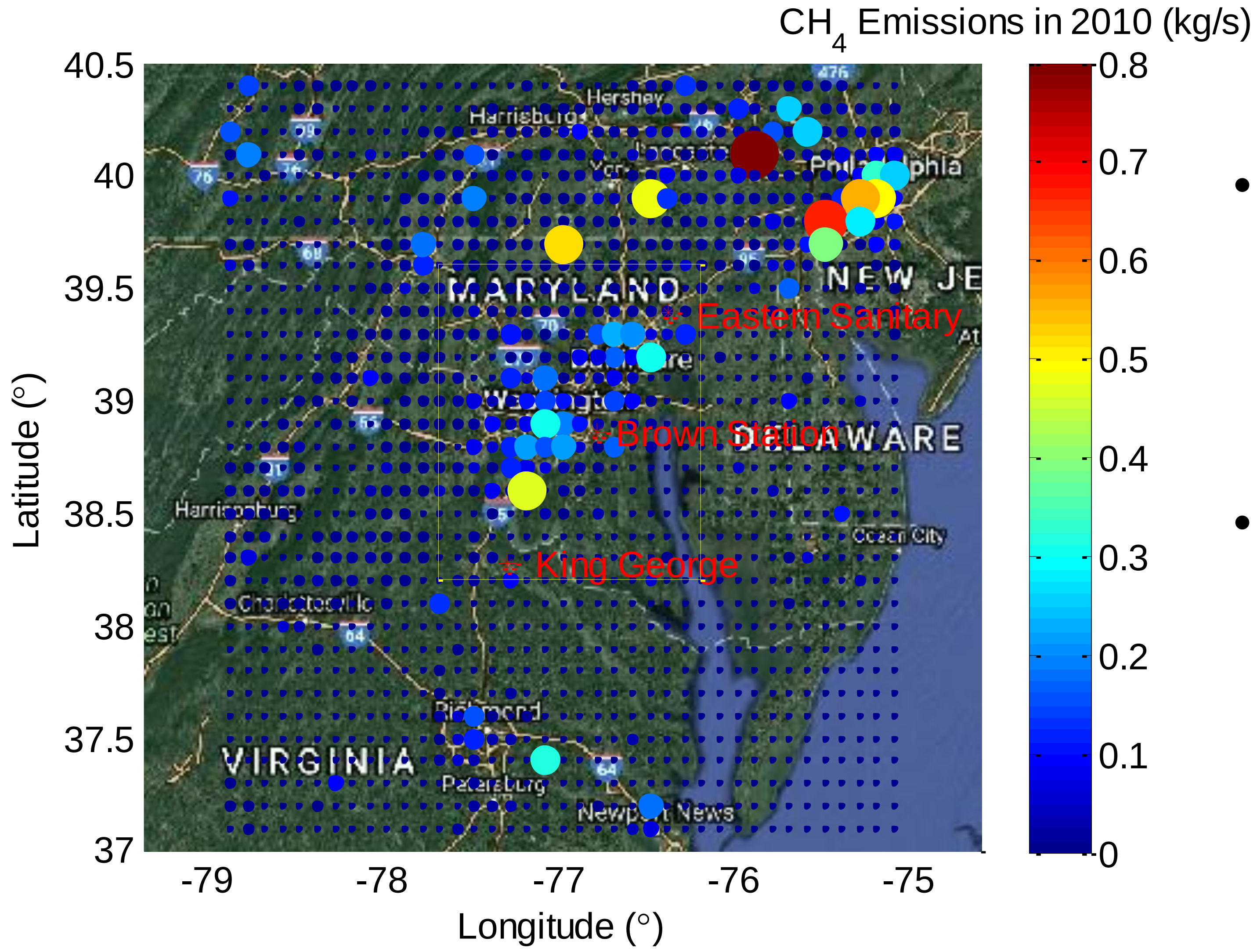
  588±312 moles CH_4 s^{-1} in winter 2016 (**~30,000 tons/yr**)

- Major CH_4 sources in the area: landfills and broadly, NG system.

- Compared to CH_4 emission inventories:
  (1) Observed CH_4 emissions are higher than the US NEI 2012 by a factor of 3
  higher than the state EI by a factor of ~2
  higher than the EDGAR 2010 by a factor of 1.4.
  (2) Observed CH_4 emissions is similar to CH_4 emissions inferred from CO and CO_2 NEI with observed CH_4/CO and CH_4/CO_2 ratios.

EDGAR4.2 Global 0.1° x 0.1° CH_4 Emission Inventory 2010

Data source: http://edgar.jrc.ec.europa.eu/gallery.php?release=v42FT2010&substance=CH4&sector=TOTALS



- The total CH_4 emissions in the yellow rectangle (an approximately surveyed area) is **421 moles CH_4 s^{-1}**.
- Issues with EDGAR emissions: mainly allocated based on population instead of source locations.

Mass Balance – CH_4 from DC/Baltimore

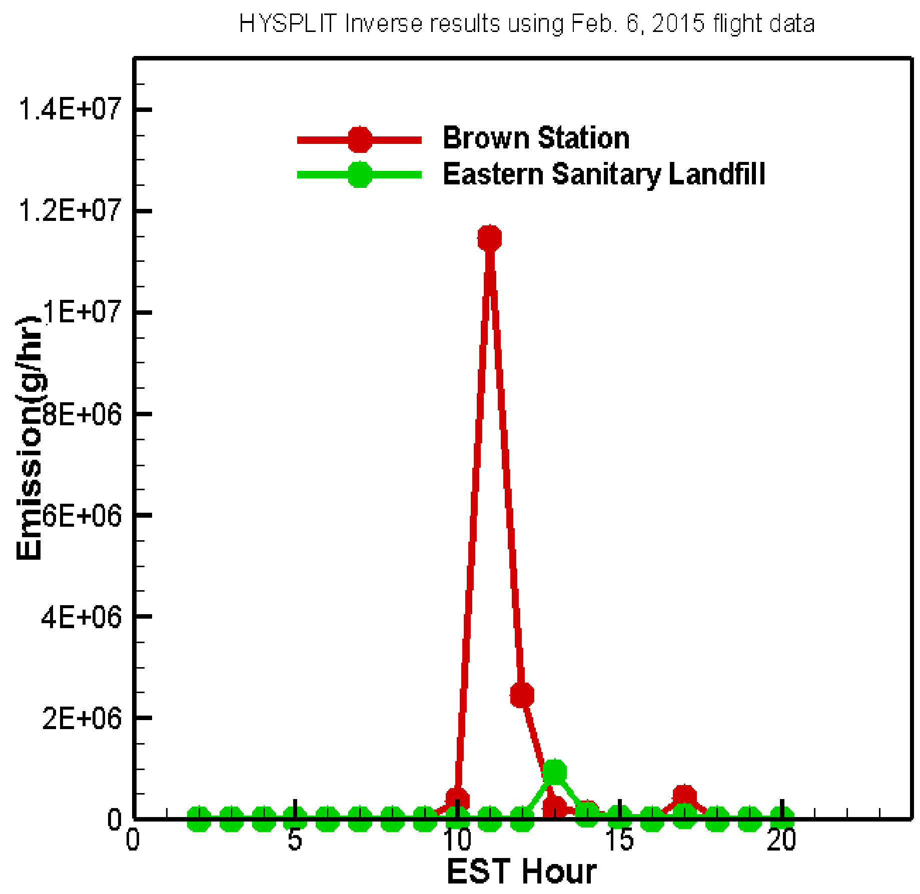
Flight Date	Emission Rate (moles CH_4 s^{-1})	Emission Uncertainty Range – Horizontal Bounds* (moles CH_4 s^{-1})	Flux Uncertainty Range – PBL Depth** (moles CH_4 s^{-1})	Flux Uncertainty Range – Horizontal Bounds & PBL Depth Combined*** (moles CH_4 s^{-1})
2/13/15	193	177 – 201	145 – 241	133 – 251
2/19/15	1260	1230 – 1270	853 – 1670	830 – 1680
2/20/15	509	452 – 509	351 – 667	311 – 667
2/23/15	157	141 – 169	110 – 204	99.0 – 219
2/24/15	951	857 – 1180	705 – 1200	633 – 1490
2/25/15	183	172 – 187	97.5 – 269	90.6 – 274
Mean	**542**	**505 – 586 (-6.8% / +8.1%)**	**377 – 709 (-30.% / + 31%)**	**349 – 764 (-36% / +41%)**

*Flux range computed by varying horizontal transect width by 10%

**Flux range computed by varying PBL height by one-sigma

***Flux range computed by varying horizontal transect width by 10% and PBL height by one-sigma.

Date Assimilation Using HYSPLIT: Collaboration with NOAA/ARL



Tianfeng Chai and Ariel Stein (NOAA/ARL)

Method

A variational data assimilation method is used to find the sources with which HYSPLIT would reproduce concentrations that match best with the observations.

Assumptions

- The two landfills causes for the measured excess CH_4.
- The CH_4 emissions of the landfills vary each hour.

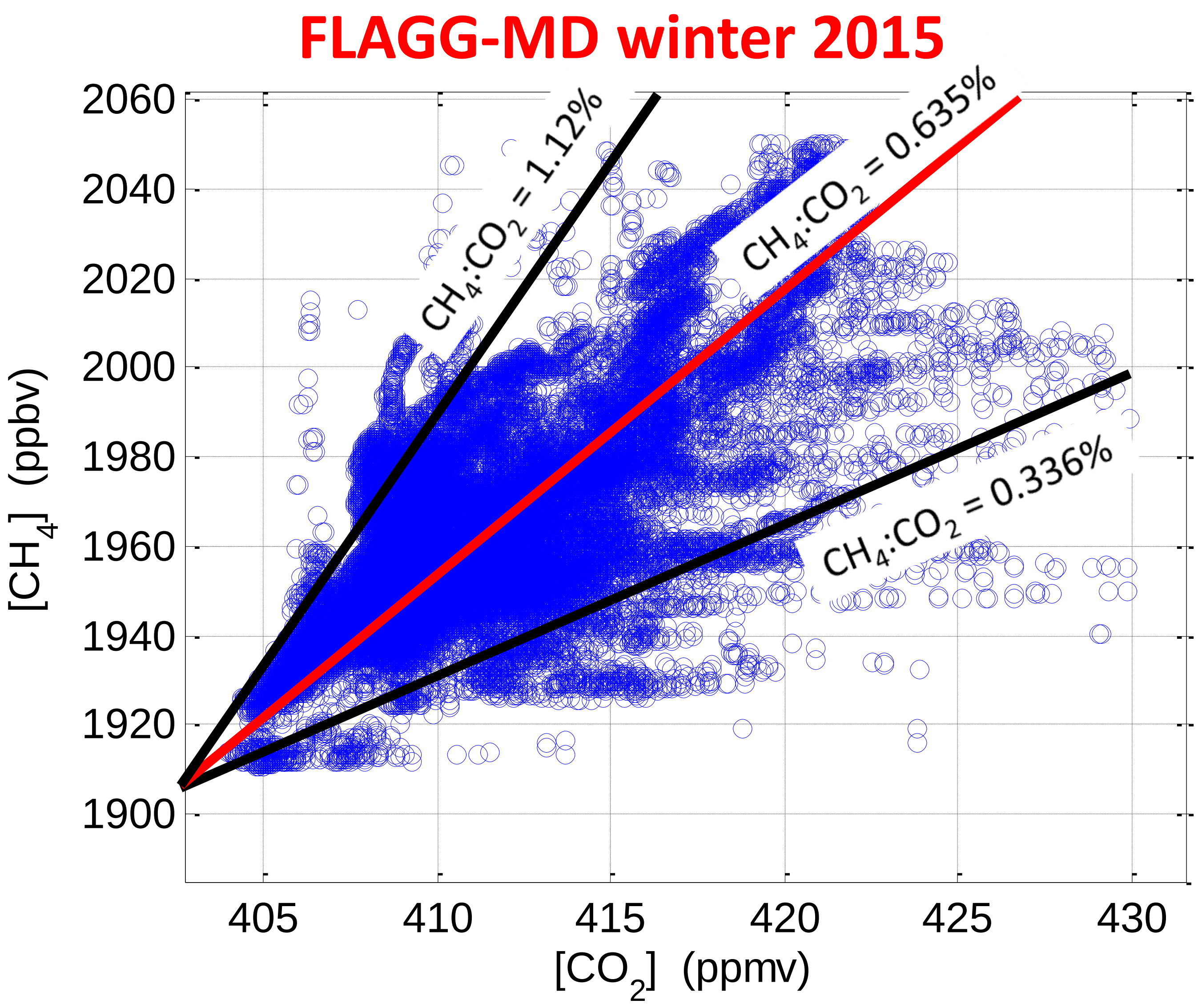
Two major limitations

- There are other sources that contribute to the excess CH_4.
- Meteorological fields in the HYSPLIT dispersion model has uncertainties.

Ongoing work

- To add more sources + constant emissions from landfills
- To use ensemble runs to include uncertainties of meteorological fields

CH_4 Emission Estimate using CH_4/CO_2 Ratio and CO_2 NEI 2014

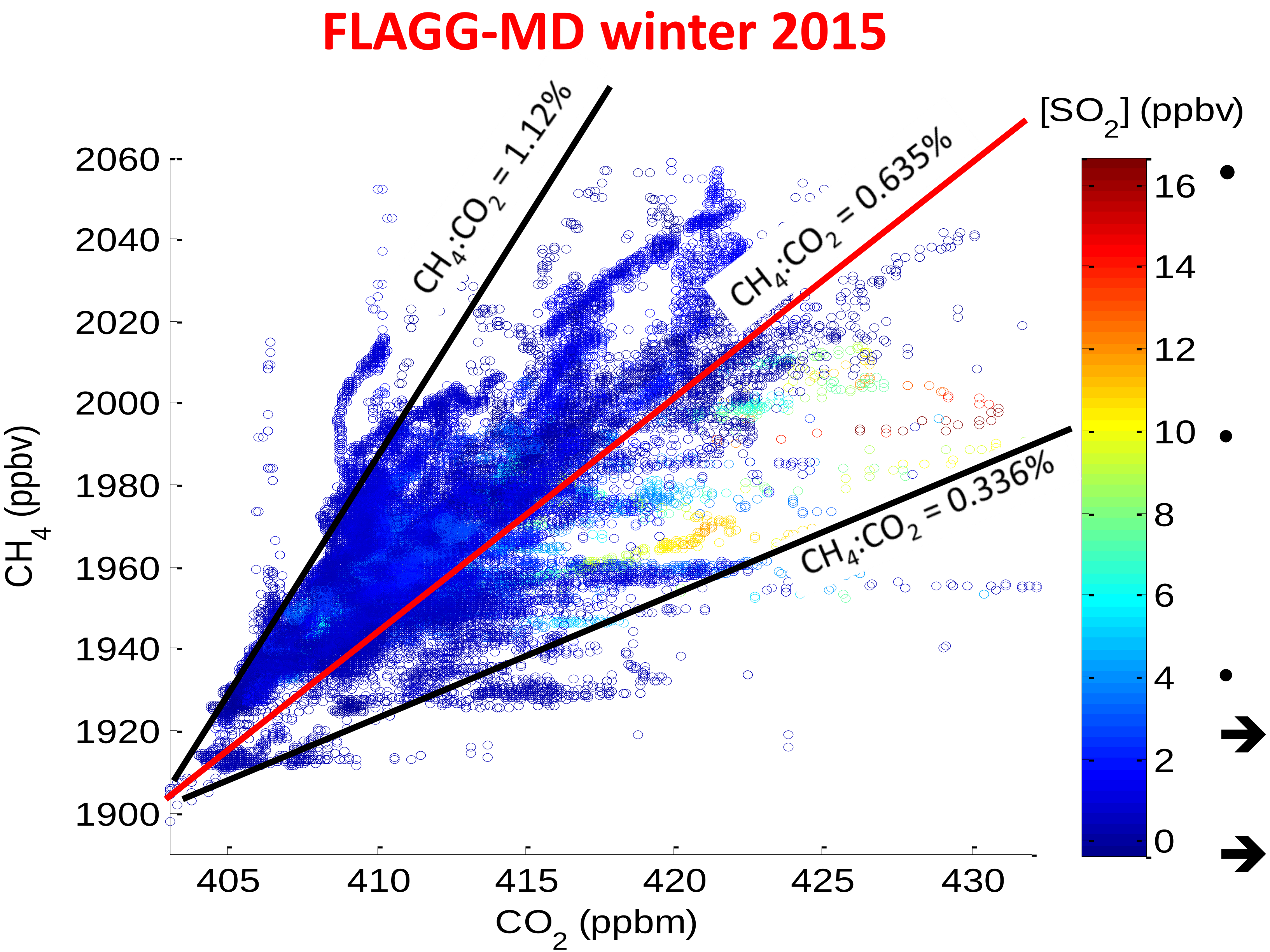


- Total CO_2 emissions from Balt-DC in NEI2014: **89.0 MMtons/yr**
- The total CH_4 emissions based on CH_4 to CO_2 ratio: **6.6 kg CH_4 /s** (3.5 – 11.6 kg CH_4/s)
- Cold winter in 2015

➔ expected more CO_2 emissions due to heating

➔ A larger inferred CH_4 emission rate

CH_4 Emission Estimate using CH_4/CO_2 Ratio and CO_2 NEI 2014



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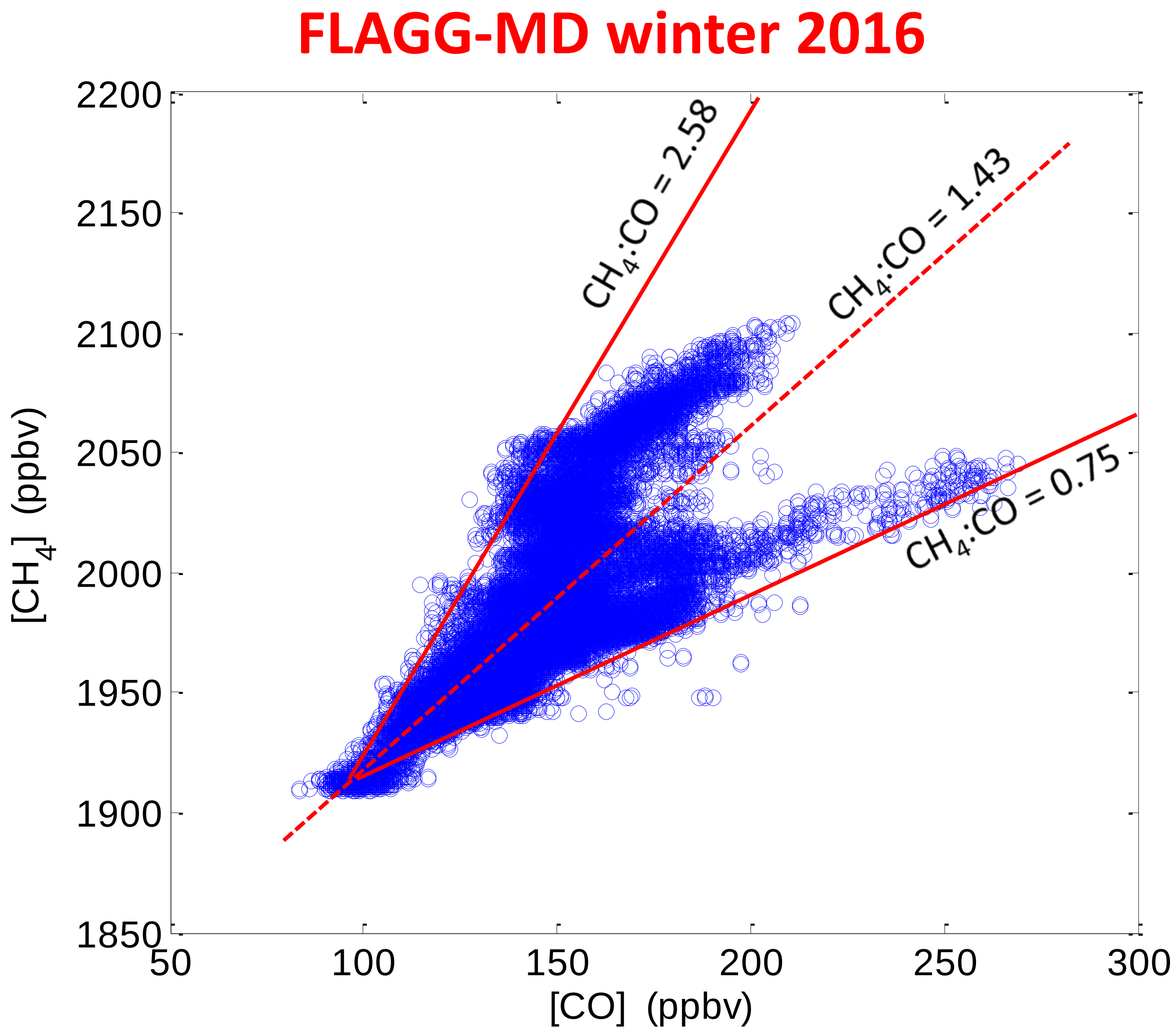
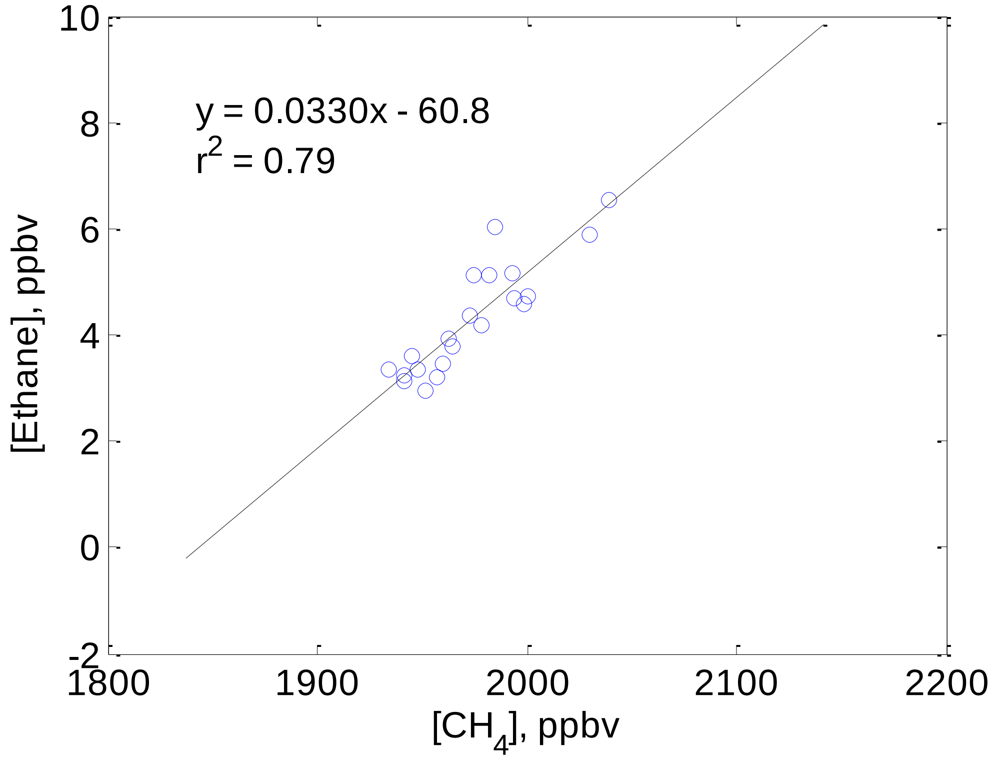


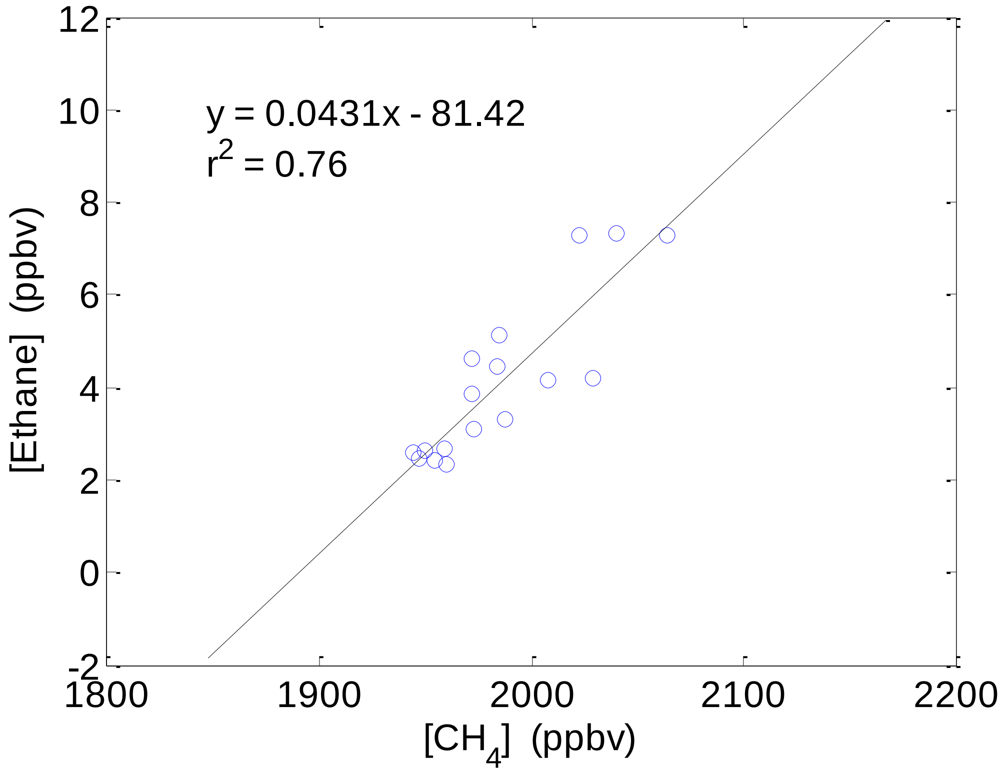
- Total CO emissions from Balt-DC in EDGAR v4.3 2010: **0.459 MMtons/yr**
- The total CH_4 emissions based on CH_4 to CO ratio: **11.8 kg CH_4 /s** (6.2– 21.4 kg CH_4/s)

Observed C_2H_6-to-CH_4 Ratio

FLAGG-MD winter 2015



FLAGG-MD winter 2016



- Mean C_2H_6-to-CH_4 ratio in natural gas of Baltimore Gas & Electric: 0.1045
- Other major CH_4 sources (landfills, enteric fermentation, waste water treatment) has little ethane emissions.
- Emissions from the NG system account for 32% (2015) and 41% (2016) of total CH_4 emissions.

CH_4 Emission Estimate from Unaccount-for NG

- Total NG delivered to the Balt-DC area in February 2015: **54,495 million CF in Feb. 2015**.

- Lost & unaccounted-for (LAUF) NG : **3.34% of total NG delivered** (PHMSA data)

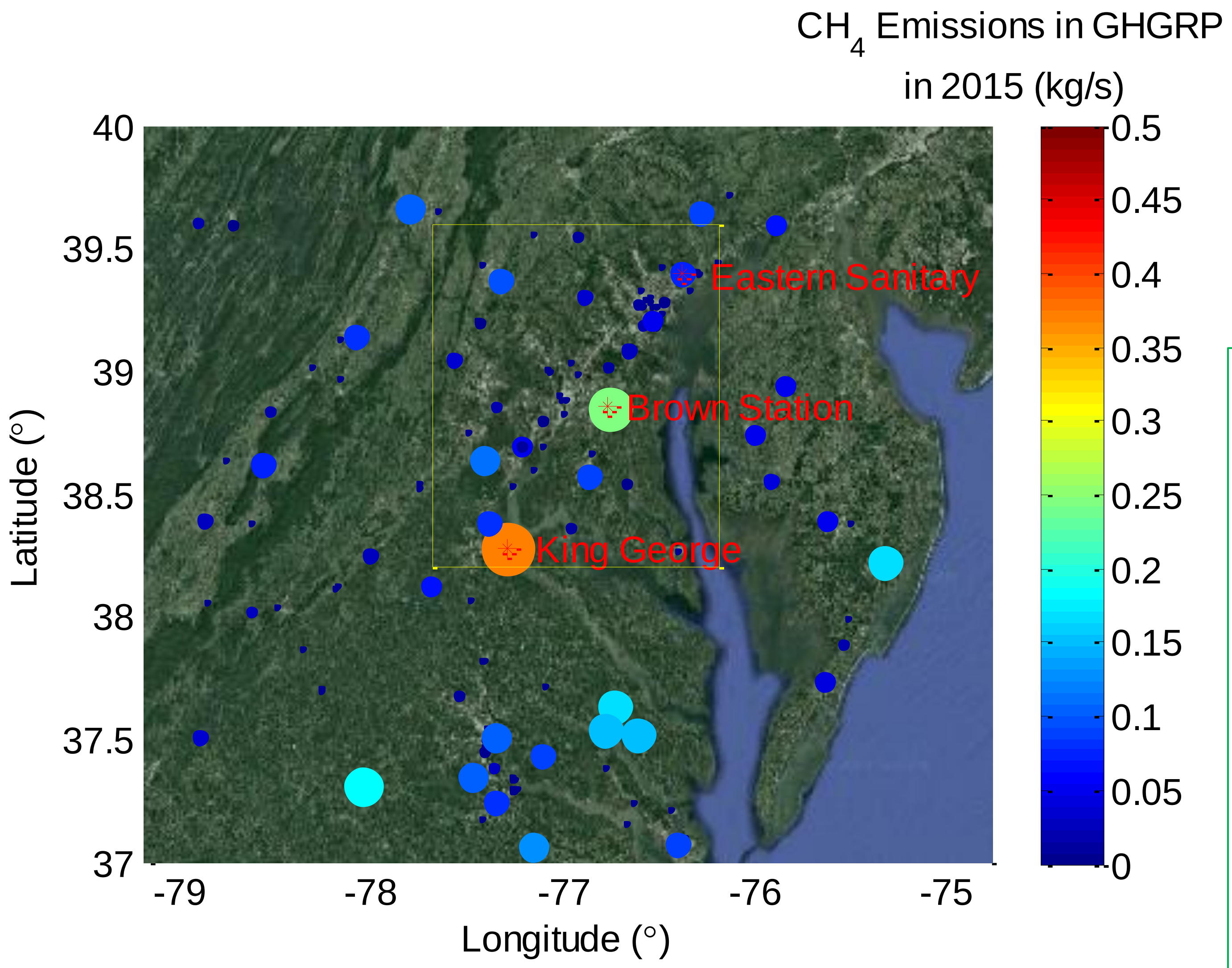
- **Total lost & unaccounted for (LAUF) gas : 12.9 kg CH_4/s**

- Not all LAUF gas is leaked into the atmosphere because besides leaks, unaccounted-for gas is also due to gas theft, accounting & meter errors, etc.

- The worth of the LAUF gas = 54,495 x 10^6 CF x 3.34% x \$0.012/CF

  = \$22 M in Feb. 2015

Facility level CH_4 Emissions in EPA's GHGRP (excluding emissions from Petroleum & NG System)



- Mostly landfills
- The total CH_4 emissions (other than the NG system) from the yellow rectangle is **1.21 kg/s**

Based on the unaccounted-for natural gas and other CH_4 sources in GHGRP, the total CH_4 emission rate from the Balt-DC area:

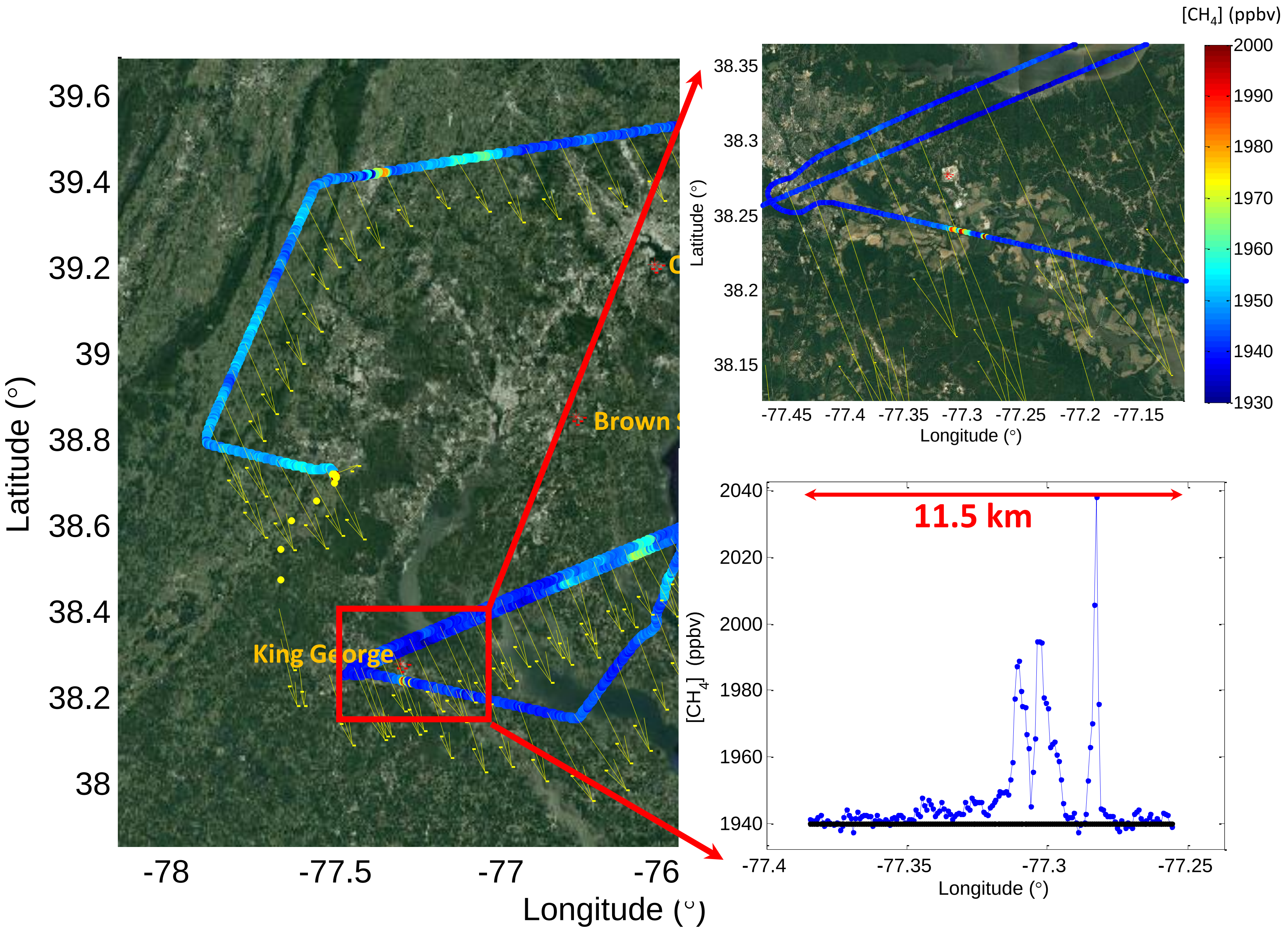
$$12.86 + 1.21 = 14.07 \text{ kg/s}$$

This may overestimate CH_4 emissions since not all LAUF gas is emitted into the atmosphere.

Brown Station – Mass Balance Calculations

RF	Mass Balance Flux (moles / s) (Mean of flux calculated on each individual transect)
1	30.7
2	44.7
4	31.9
5	59.9
6	21.1
7	71.8
8	66.3
Mean ± St. Deviation	**46.6 ± 18.3**

CH_4 emissions from King George Landfill

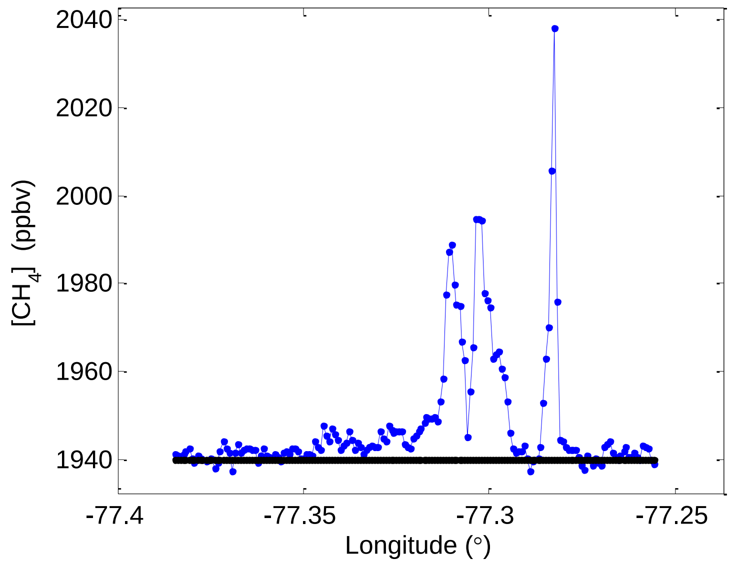


Estimate of CH_4 Emissions from King George Landfill

Mass Balance Experiment (MBE) approach:

$$\boxed{E.R._{CH_4} = \int_0^{z_i} \int_{-x}^{+x} ([C] - [C]_b) \times U_\perp dxdz}$$

[C] : concentrations (downwind)
$[C]_b$: concentration in background
$U_\perp$: perpendicular wind speed



CH_4 emission rate from King George landfill **based on a single downwind transect**:

24.0 moles CH_4 s^{-1} , or <u>12,100 tons CH_4 yr^{-1}</u>

This is close to EPA's GHGRP CH_4 emission data for this landfill:
<u>11,800 tons CH_4 yr^{-1}</u>