Regional methane emissions estimates in northern Pennsylvania gas fields using a mesoscale atmospheric inversion system

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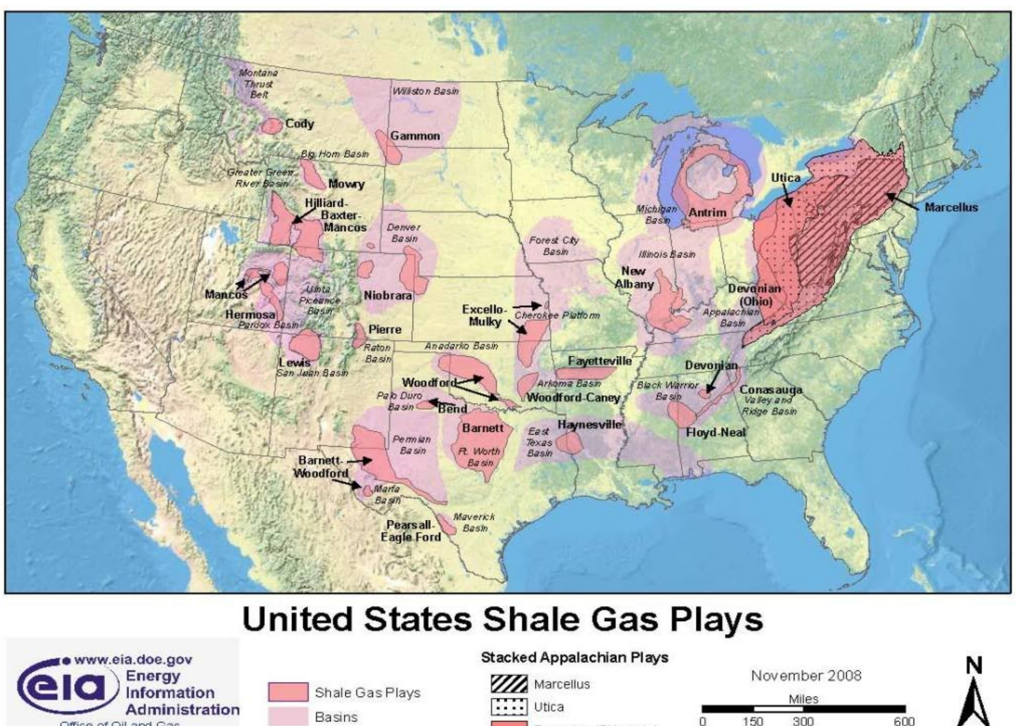
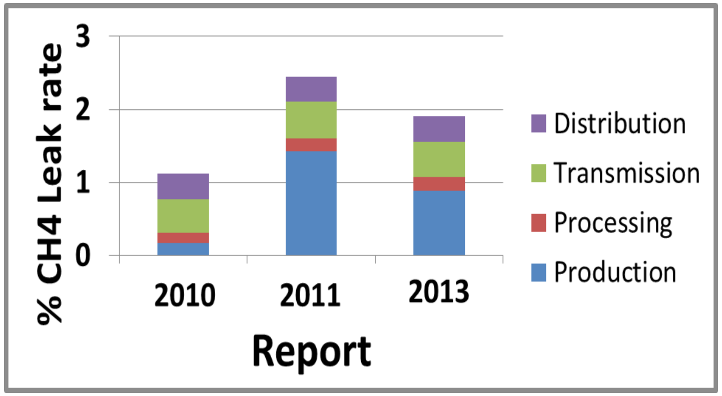


CH_4 emissions from natural gas production activities



Methane leakage as a percentage of production from US EPA reports (USEPA 2010, 2011, 2013) Changes are dominated by estimates of leakage during production

Introduction

- Current inventory method based on activity data: lack of observations and limited evaluation (no uncertainty assessment).

- Few airborne and short-term campaigns showed emissions larger than expected (Petron et al., 2012; Karion et al., 2013), but these approaches are producing estimates over short periods of time (few days per campaign)

- Unreported emissions represent a large fraction of the emissions and the uncertainty occurs during production (leakage), for regulating pressure at the well pads or during distribution to processing facilities.

> **20,000** active oil and gas wells

Yearly natural gas production (2008):

~3,625 Gg / yr

(~1% of US production)

CH_4 emissions

Bottom-up estimate:

46 – 86 Gg / yr

Top-down estimates:
derived from non-methane hydrocarbon measurements and inventories; $\Delta^{14}CO_2$

40 – 272 Gg / yr

CH_4 emission estimates for the Denver-Julesburg basin based on inventory (bottom-up) and atmospheric mass balance calculation (top-down) methods

Regional methane emissions estimates in northern Pennsylvania gas fields using a mesoscale atmospheric inversion system

The Barnett Shale campaign (Texas):

Airborne measurements over a mixed landscape

Data Assimilation impact on Lagrangian plume dispersion modeling

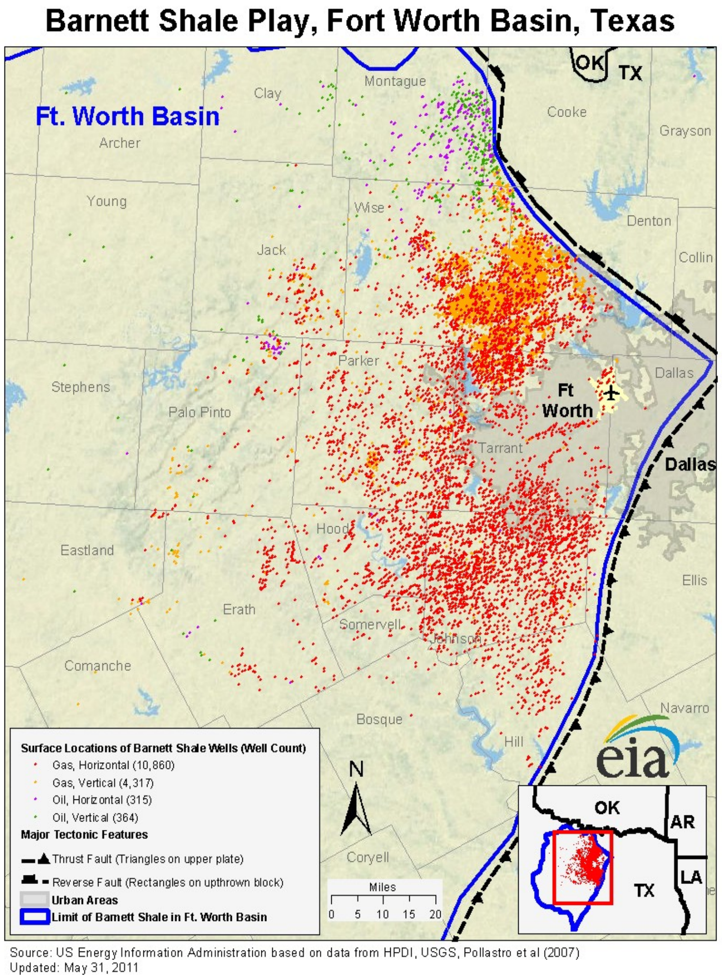
Upcoming 2014-2016 regional campaign in NE Pennsylvania

The summer 2013 Marcellus campaign: mapping CH_4 sources in northeastern Pennsylvania

Implementation of the WRF-FDDA-CH_4 system in NE Pennsylvania

Atmospheric inversion of CH_4 sources

The Barnett shale campaign



Map of the Barnett shale area with the active wells in red (horizontal and vertical drilling) and the urban area of Dallas-Fort-Worth in grey

The Barnett shale aircraft campaign

- 40 trillion cubic feet of natural gas (one of the largest onshore reserves in the US),

- About 10,000 wells over 5 counties, surrounding the urban area of Dallas-Fort-Worth,

- March 2013, NOAA/CU aircraft campaign with continuous CH_4 and C_2H_6 sensors on board

Objectives:

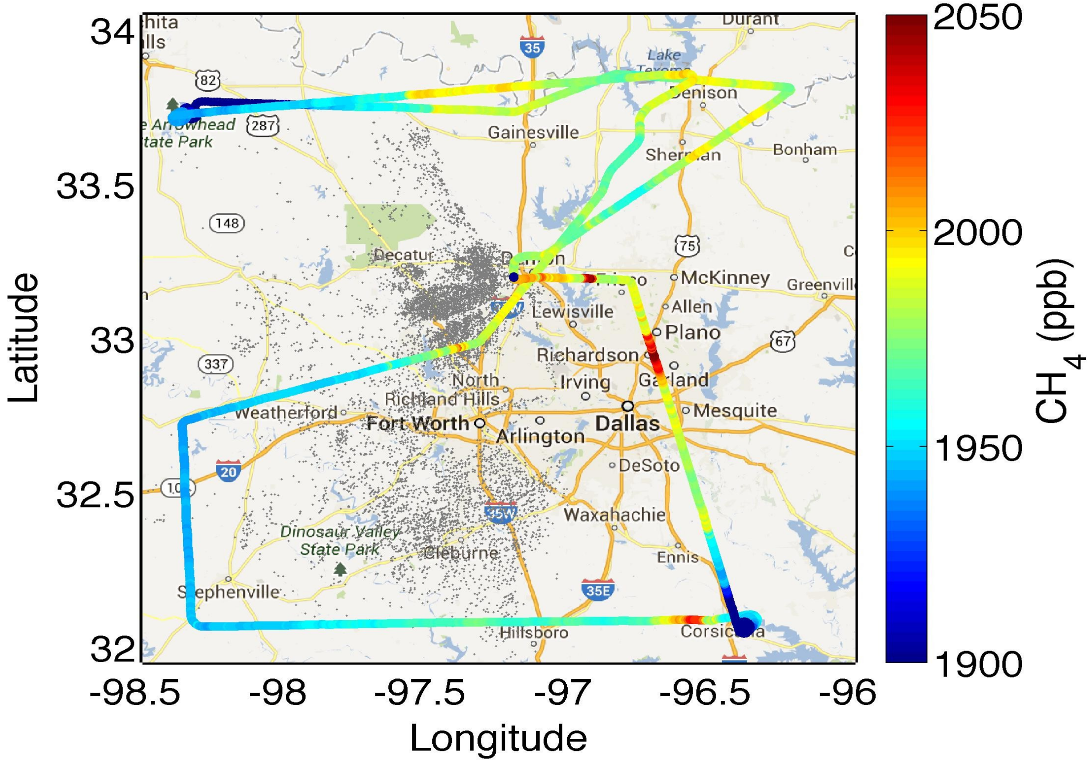
- Quantify the CH_4 emissions from oil and gas operations (mass-balance technique),

Challenges:

- Determine the contributions from other CH_4 sources (landfills, waste treatment plants,...)

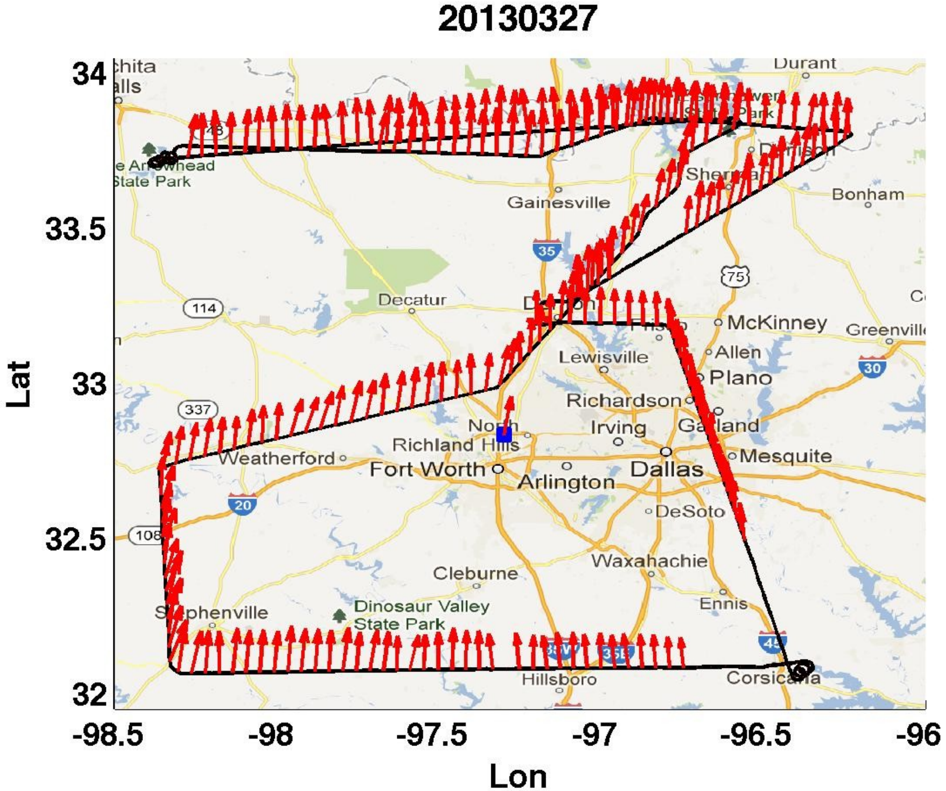
- Separate the urban emissions from oil and gas operations' emissions.

The Barnett shale campaign



Map of the Barnett shale area and methane mixing ratios observed by aircraft during the March 27th flight

Horizontal mean winds observed by aircraft during the March 27th flight



The Barnett shale campaign

WRF-FDDA-CH4 modeling system

- WRF-FDDA system at 9km/3km/1km run over the Barnett shale, coupled to a backward particle model
- Assimilation of operational WMO data (surface stations, RS) with passive tracer Chemistry module
- March 2013: Additional aircraft campaign, and NOAA Doppler Lidar (HRDL – Mike Hardesty, Alan Brewer)

Objectives:

- Generate concentration footprints for aircraft CH4 measurements over the Barnett shale

Challenges:

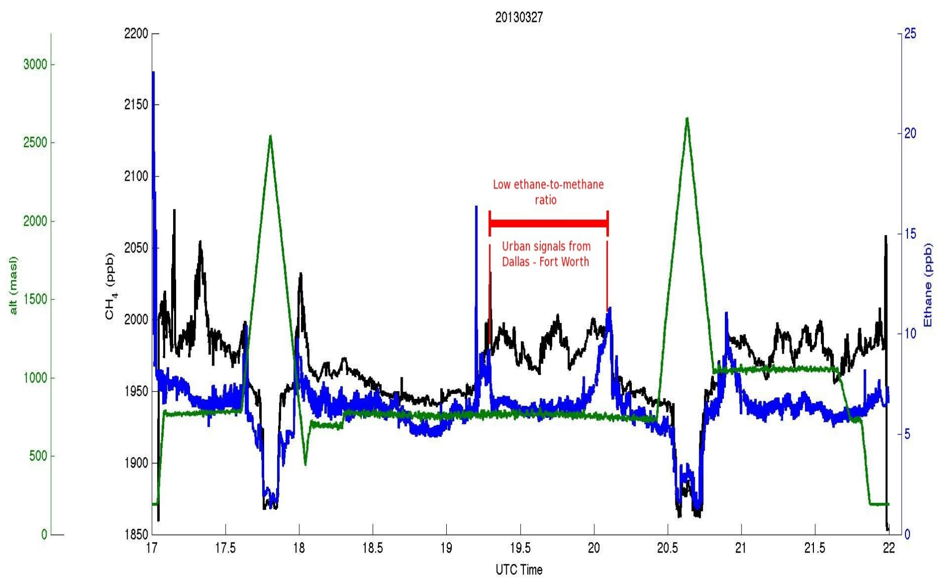
- Separate the urban emissions from oil and gas operations' emissions (wind speed/direction)

Evaluation of the footprint from the urban area of DFW

Urban emissions: low CH_4-to-C_2H_6 ratio

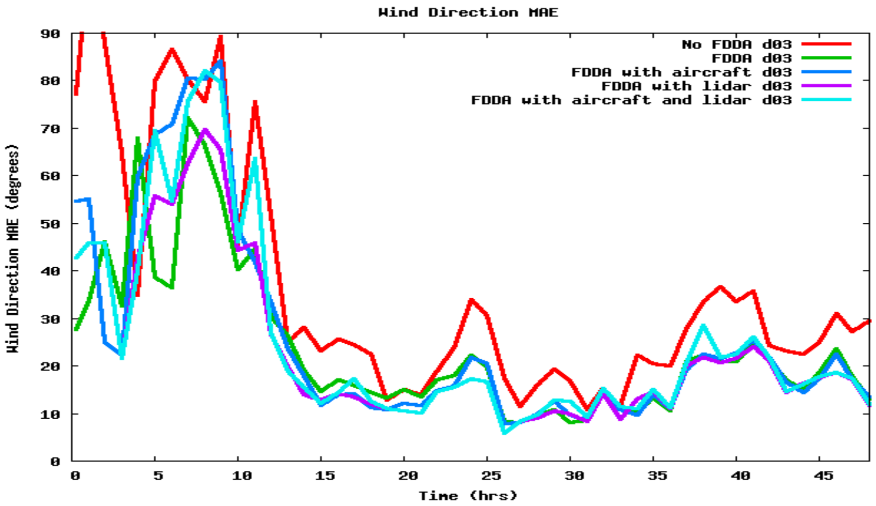
Oil and Gas operations emissions: high CH_4-to-C_2H_6 ratio

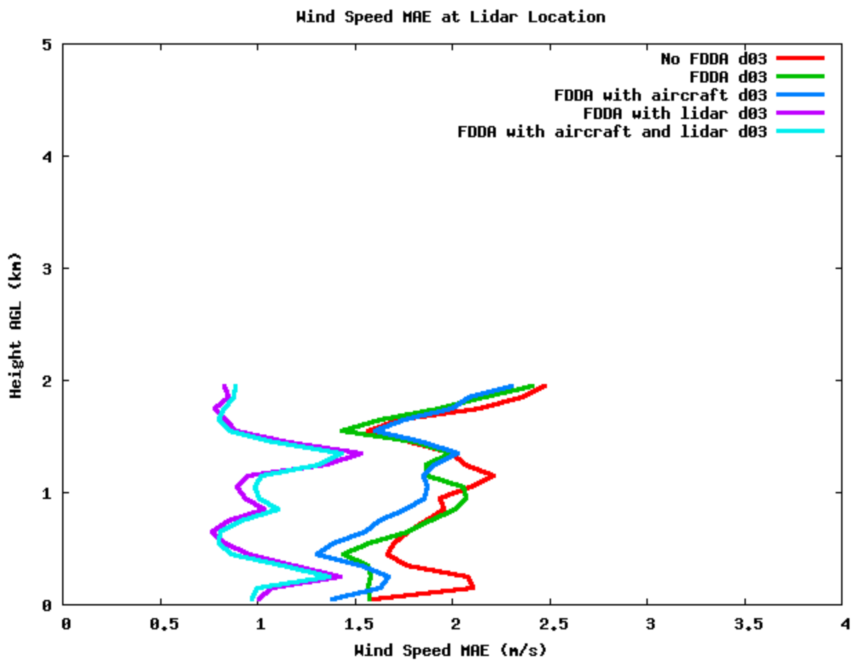
Comparison of WRF-FDDA performances using airborne measurements



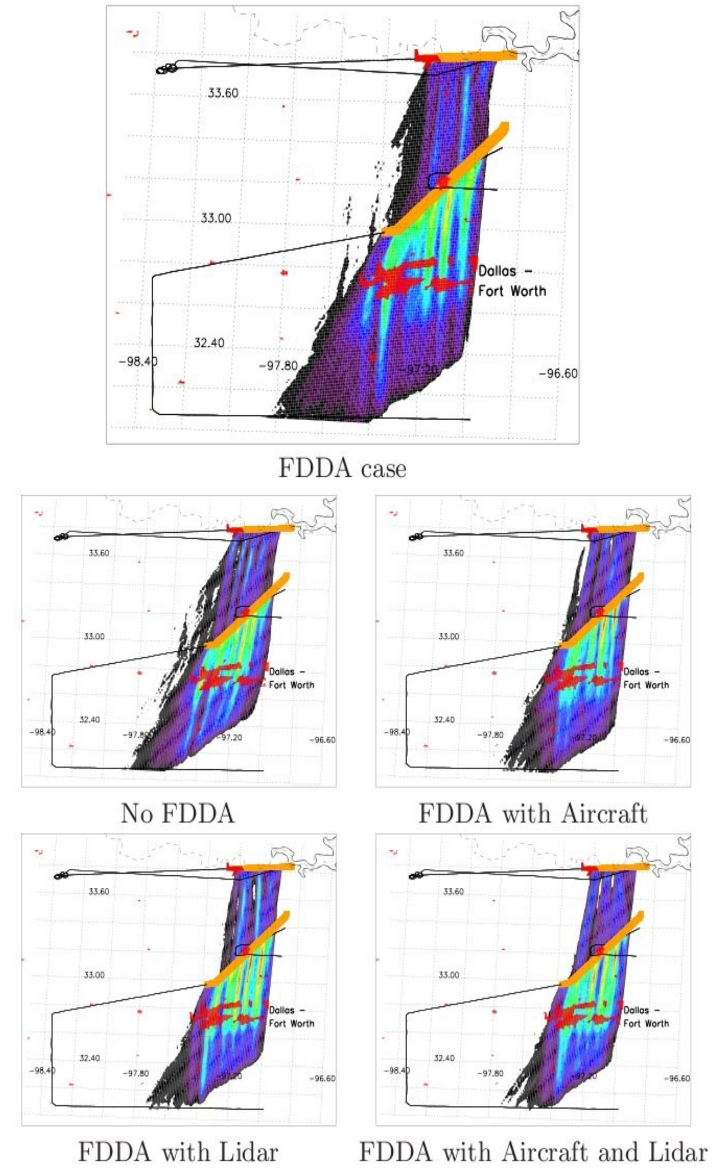
Observed CH_4 and C_2H_6 atmospheric mixing rations for the March 27th 2013 flight

Data assimilation and Lagrangian plume dispersion modeling



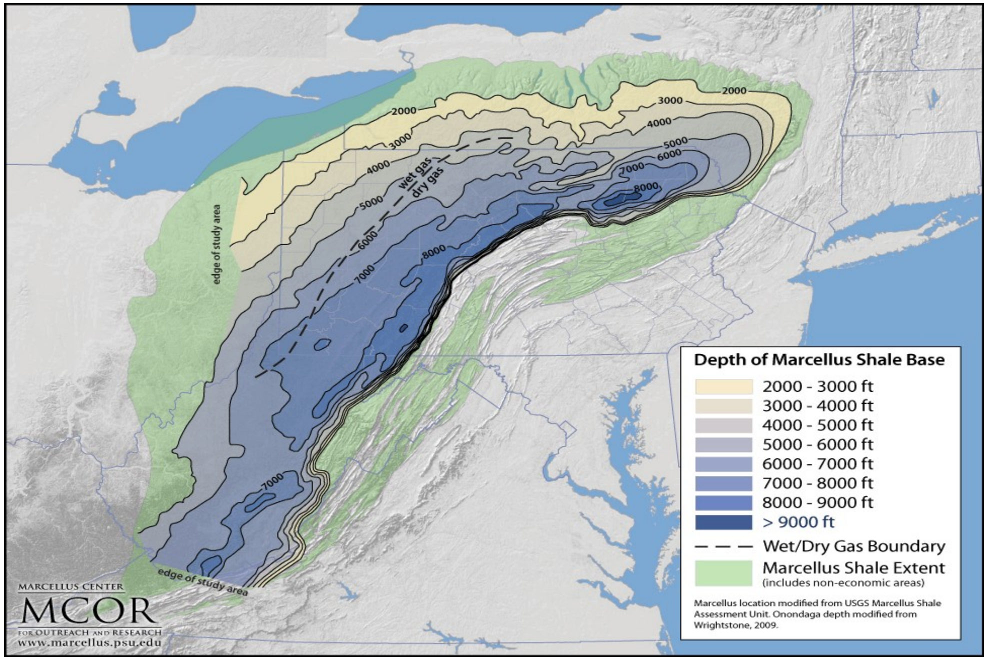


Comparison of modeled and observed horizontal mean wind speed and direction from the HRDL Lidar (lower panel) and from 35 WMO surface stations (upper panel) for March 27th, 2013



Flux footprints at 1km resolution (LPDM backward simulations) using different data sets to constrain the WRF-FDDA model, for March 27th, 2013. The plume corresponds to the city emissions from the Dallas-Fort-Worth area (low ethane-to-methane ratio)

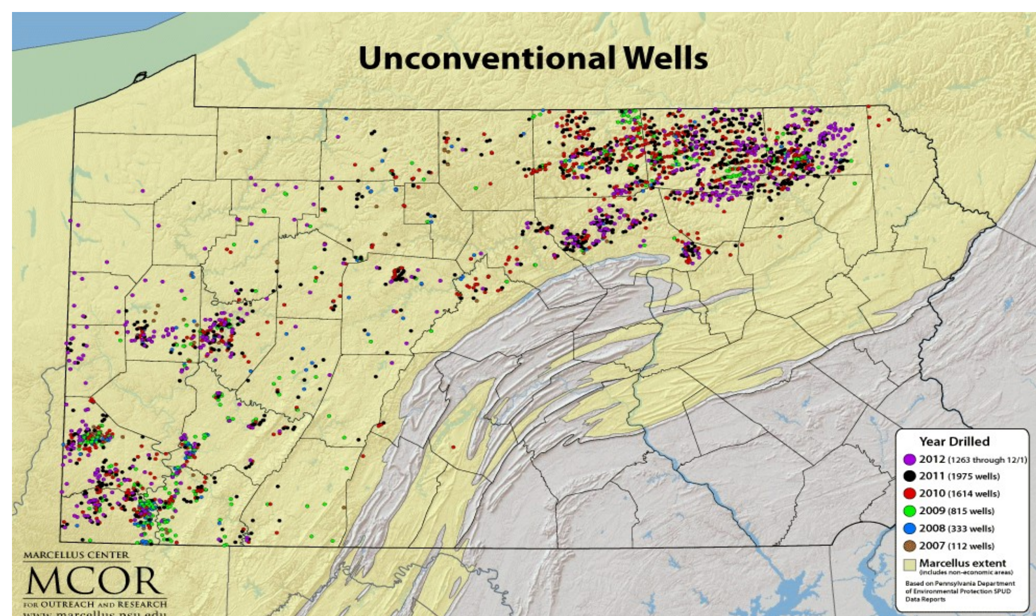
The Marcellus Shale (PA)



- 3^{rd} shale gas reservoir in the US with 2,000 wells in 2011
- Two major areas: wet gas in SW PA and dry gas in NE PA
- Projected to represent 65% of the US gas production from unconventional wells by 2020
- 14,000 permitted wells (most of them are unconventional horizontal drilling)

Regional monitoring of CH_4 emissions

- ***Network of instrumented towers measuring continuously the atmospheric mixing ratios of CH_4 and $^{13}CH_4$***
- ***Use of mesoscale inversion system with the WRF-FDDA-CH_4 system***
- ***Refine emissions maps from activity data to provide a long-term assessment of the leakage rates.***



Instrumentation for the Marcellus Shale campaign

4 towers over the northeastern part of the Marcellus shale
Two-year deployment (2014-2016)

Calibration of CRDS instruments using NOAA standards
- for both CH_4 and $^{13}CH_4$ (precision: 4ppb, 0.1 per mil)

Continuous monitoring within the production area and upwind to sample the background conditions

Discrete samples of 60 trace gases to identify the nature of the emissions and calibrate the instruments

CRDS analyzer deployed in Indianapolis (INFLUX experiment)

Communication tower used for deployment. The CRDS analyzers are installed at the facility near the tower and a tube is deployed on the structure.

Automated flask samplers

Inter-calibration of instruments with flasks using NOAA standards
- for both CH_4 and 13CH_4

Remotely controlled for air sampling at specific times/days

About 60 trace gases measured over an hour

Portable Flask Package for automated sampling of air (remotely controlled by NOAA/CU). 12 Flasks available before replacement

Mesoscale inverse modeling

WRF-FDDA-CH4 modeling system

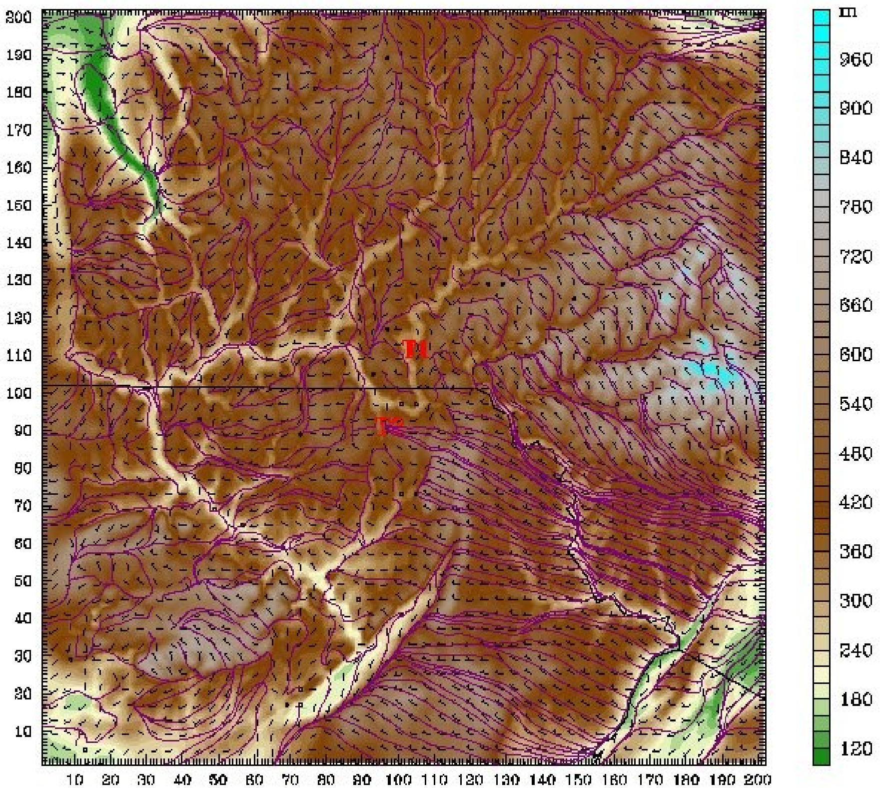
- WRF-FDDA system at 9km/3km/1km run over the Marcellus shale, coupled to a backward particle model LPDM
- Assimilation of operational WMO data (surface stations, RS) with passive tracer Chemistry module
- March 2015: Aircraft campaign, NOAA Doppler Lidar (HRDL), drive-arounds

Objectives:

- Generate weekly CH_4 emissions maps over the NE Marcellus shale at 3km resolution

Challenges:

- Separate the biogenic emissions from oil and gas operations' emissions (isotopes and source mapping),
- Separate past activities from recent operations in the area (isotopic signatures?)



Weather Research and Forecasting model in FDDA mode.
The horizontal mean wind (vectors) and the topography are shown over the 1km domain.

Example of tower footprints (summer 2013)

WRF-FDDA coupled to the LPDM backward particle model

- Atmospheric dynamics from WRF-FDDA used to drive Lagrangian Particle Dispersion Model (Uliasz, 1994)

- System provides 20-minute drivers describing the dynamics (origin of air masses observed around the towers) Inputs are mean wind (u,v,w), Potential Temperature, and Turbulent Kinetic Energy

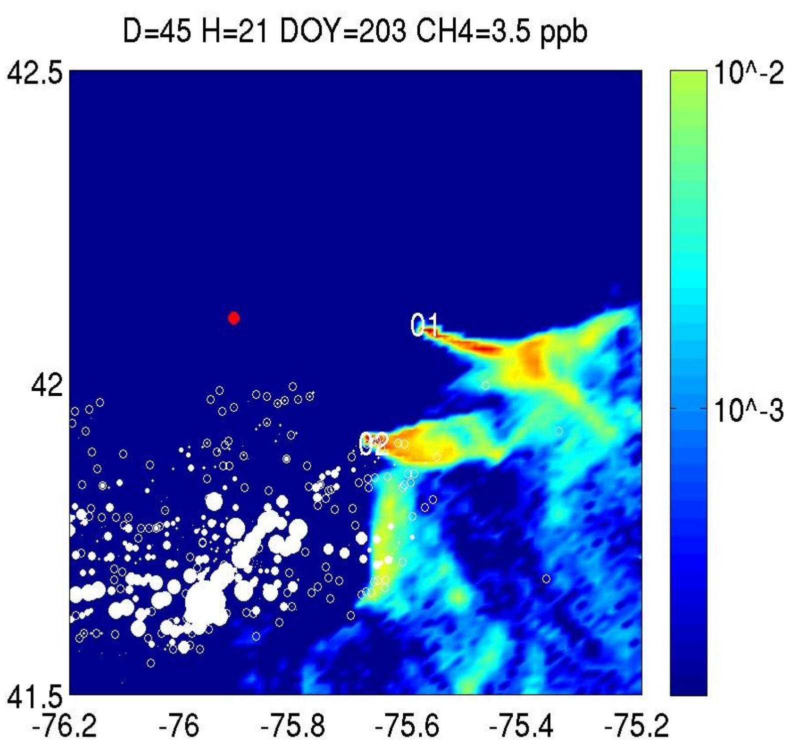
- LPDM used to describe the area of influence by counting particles close to the surface (***Influence functions***)

Summer 2013 experiment

- 2 towers instrumented for 2 months (New York and PA)

- Collected hourly-averaged atmospheric mixing ratios of CH_4

- WRF-FDDA / LPDM system used to generate the first map of CH_4 emissions



Tower footprints in July 2013, 21 UTC, with the corresponding well pads (white circles – scaled with production in the last 6 months – DEP data)

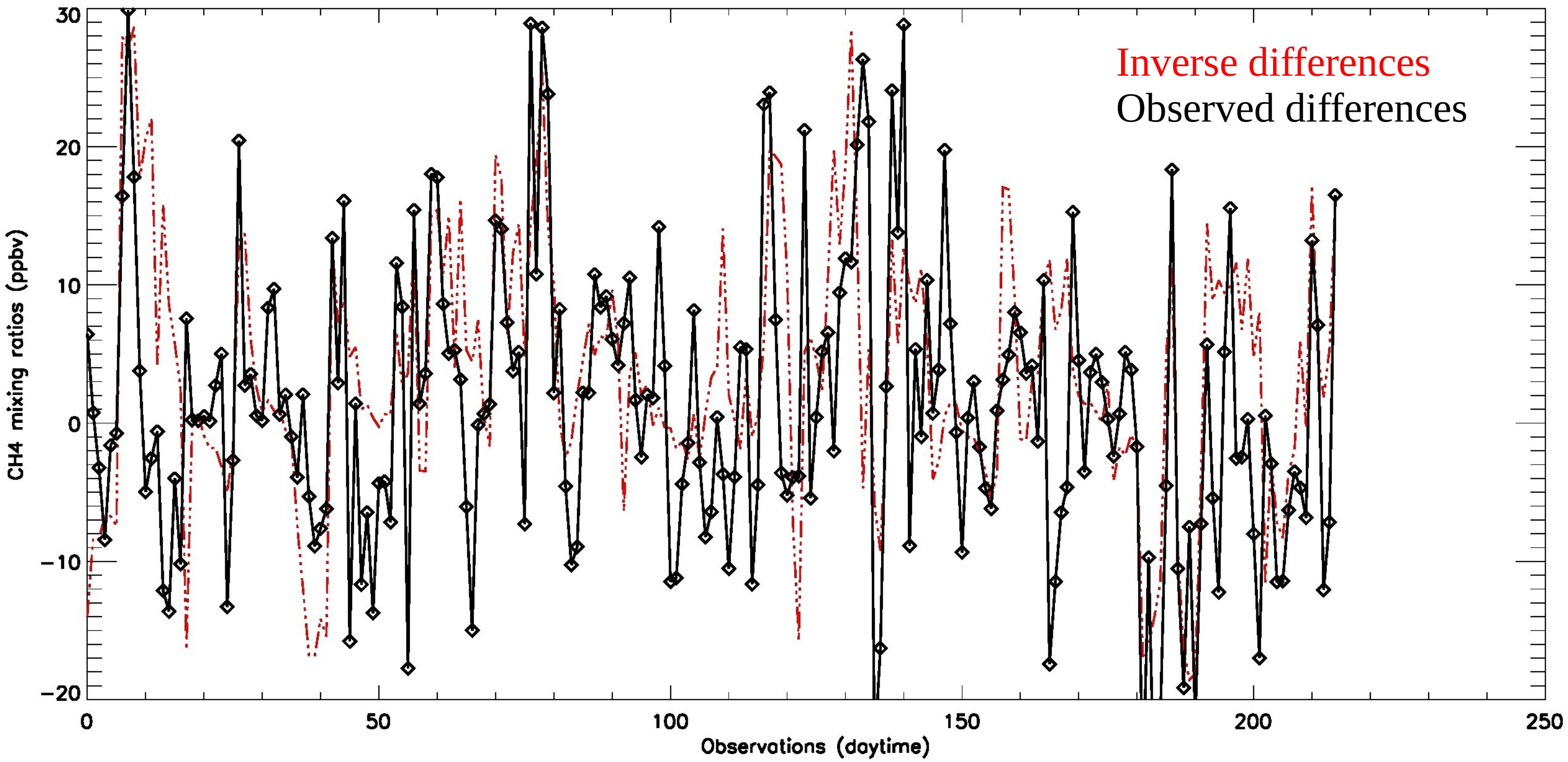
Simplistic inversion for the summer 2013 Marcellus deployment

- Limited uncertainty assessment (no model error, and simplified prior emission error)

- Simple fit of emissions to site-to-site observed differences (NY site – PA site)

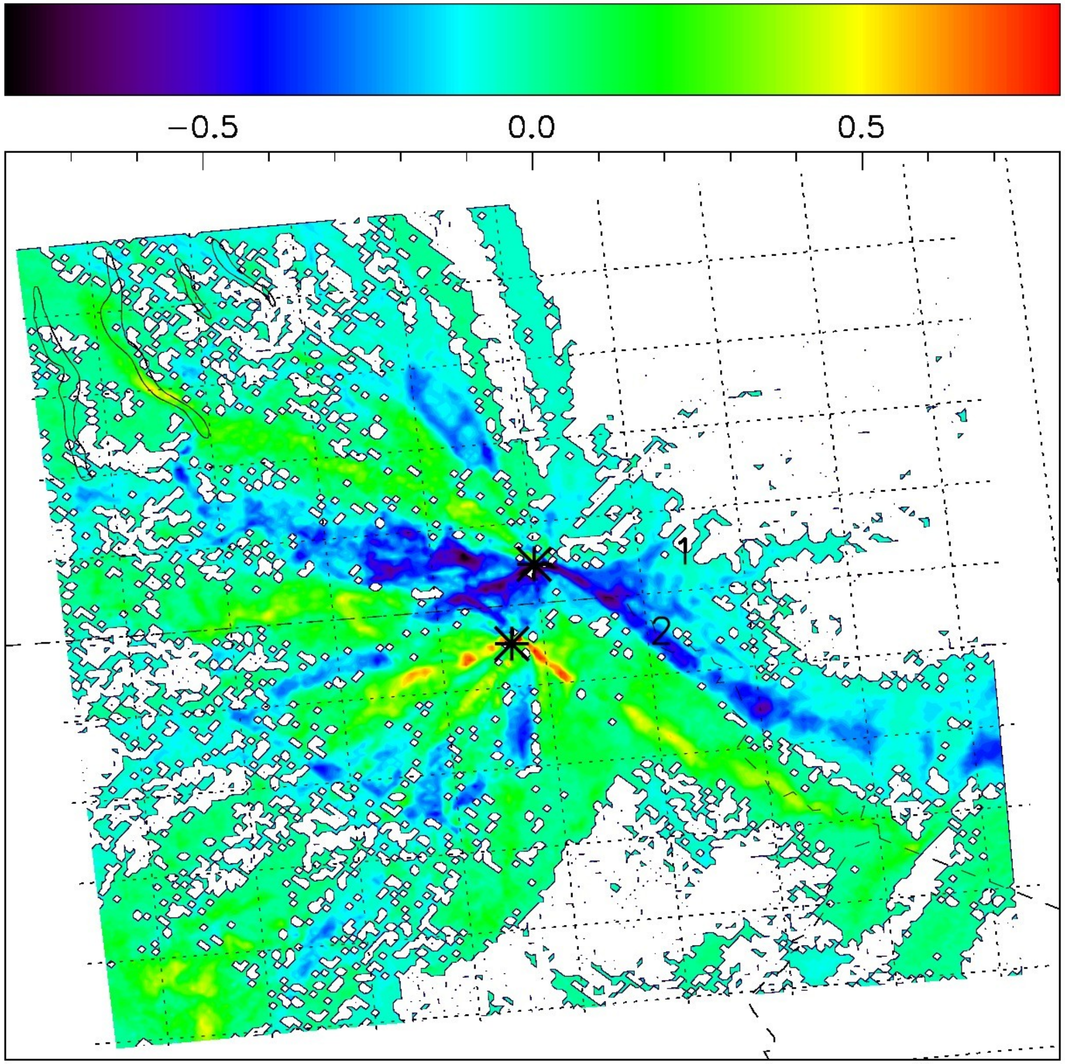
- remove peaks because not mesoscale (local emissions)

Generate a single CH_4 emissions map of the area based on June-July 2013 atmospheric observations



Observed differences of atmospheric mixing ratios of CH4 (NY tower minus PA tower) for June and July 2013 (in black) and simplistic inverse emissions (in red) using daytime hourly measurements (17-22UTC)

Summer 2013 mesoscale inversion

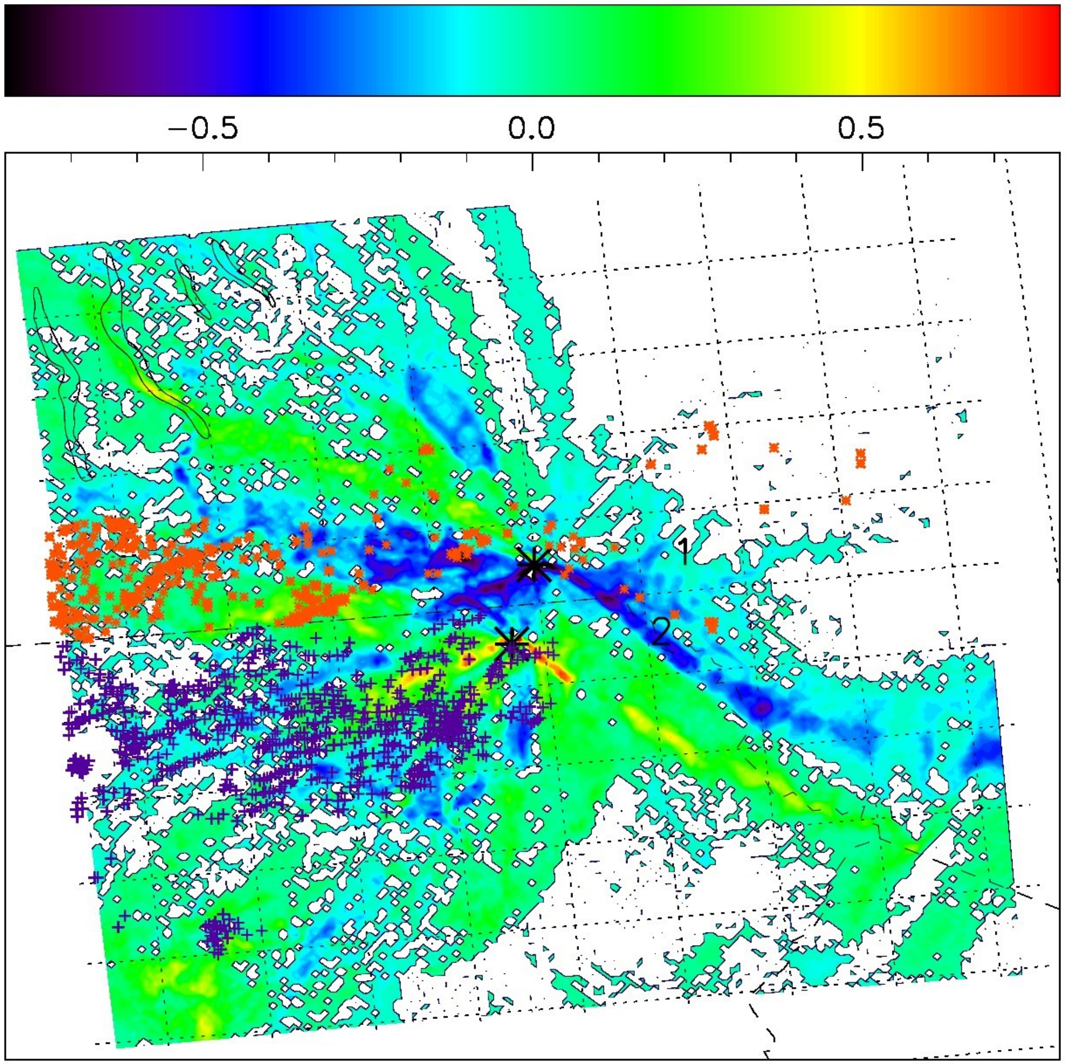


ppm/km-2 averaged over June 8 to July 30, 2013

Maps of CH_4 emissions gradients for June 8 to July 30 2013 using two atmospheric measurement sites (black asterisk)

Positive areas suggest larger emissions from the observed concentrations (site-to-site differences) whereas negative areas correspond systematically to low concentrations (no emission or lower than the rest of the domain)

Summer 2013 mesoscale inversion



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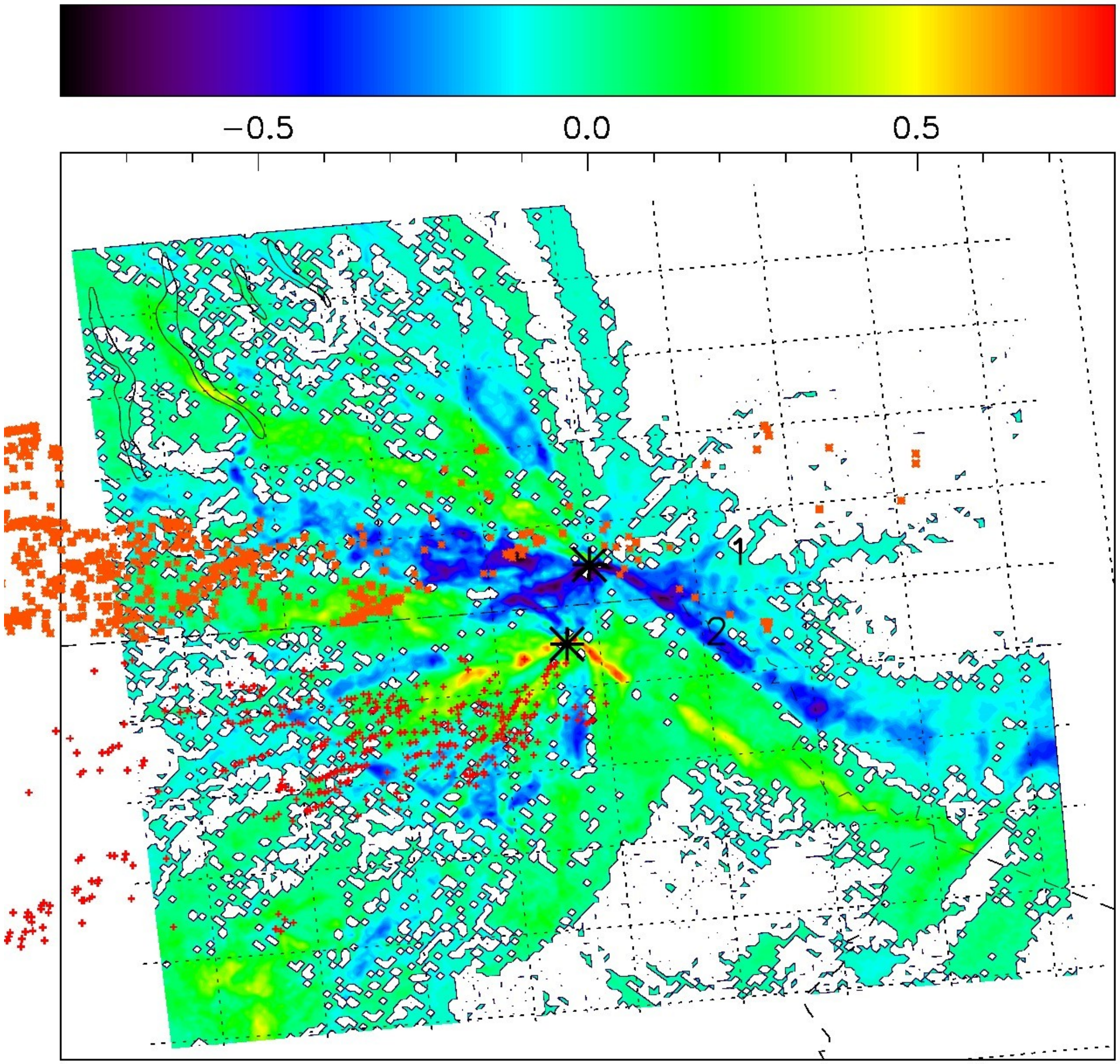

Legend

Conventional wells
NY state

Unconventional wells
High production
PA Marcellus

ppm/km-2 averaged over June 8 to July 30, 2013

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Positive areas suggest larger emissions from the observed concentrations (site-to-site differences) whereas negative areas correspond systematically to low concentrations (no emission or lower than the rest of the domain)

Conclusions

Regional methane emissions estimates in northern Pennsylvania gas fields using a mesoscale atmospheric inversion system

The Barnett Shale campaign (Texas):

WRF-FDDA system able to identify source area with limited errors

Optimal set of meteorological data for the assimilation not yet established

The summer 2013 Marcellus campaign: mapping CH_4 sources in northeastern Pennsylvania

Clear spatial gradients identified by the inversion system (without any prior information)

Need to develop the method to separate the contributors (biogenic vs thermogenic)

Need to refine current inventories to map facilities vs wells vs distribution