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Methane Emissions from Oil Sands Surface Mining Facilities and the Canadian Bakken Shale Oil Fields

Shao-Meng Li

Air Quality Research Division
Atmospheric Science and Technology Directorate
Science and Technology Branch
Environment and Climate Change Canada (ECCC)

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Aircraft Studies of Emissions and Transformation of Oil Sands Pollutants

Shao-Meng Li, Katherine Hayden, John Liggio, Ralf Staebler, Julie Narayan, Andrea Darlington, Amy Leithead, Samar Moussa, Peter Liu, Jeremy Wentzell, Richard Mittermeier, Jason O'brien, Paul Makar, Craig Stroud, Stewart Cober, Doug Worthy

Air Quality Research Division and Climate Research Division, ECCC

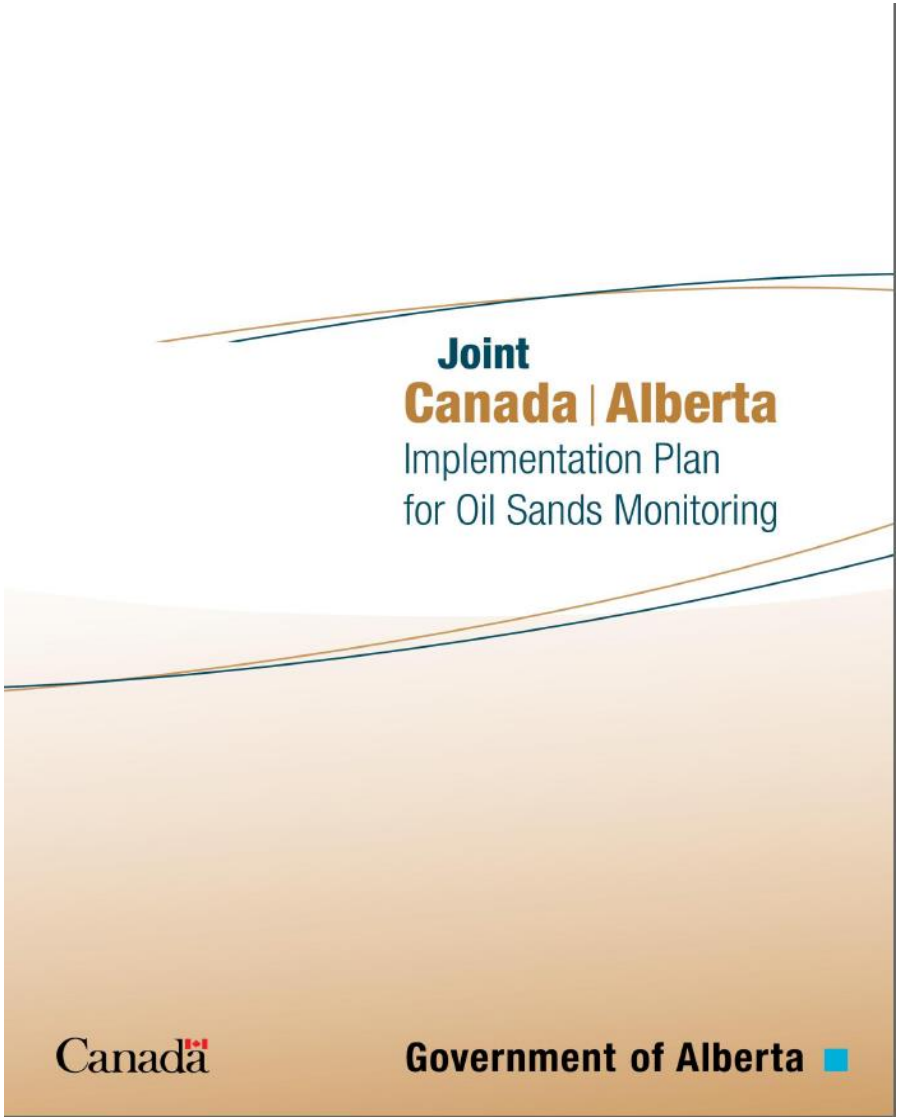
Sabour Baray, Robert McLaren, Mark Gordon

York University

Mengistu Wolde, Paul Kissmann, Robert Erdos, Tim Leslie, Mathew Bastian

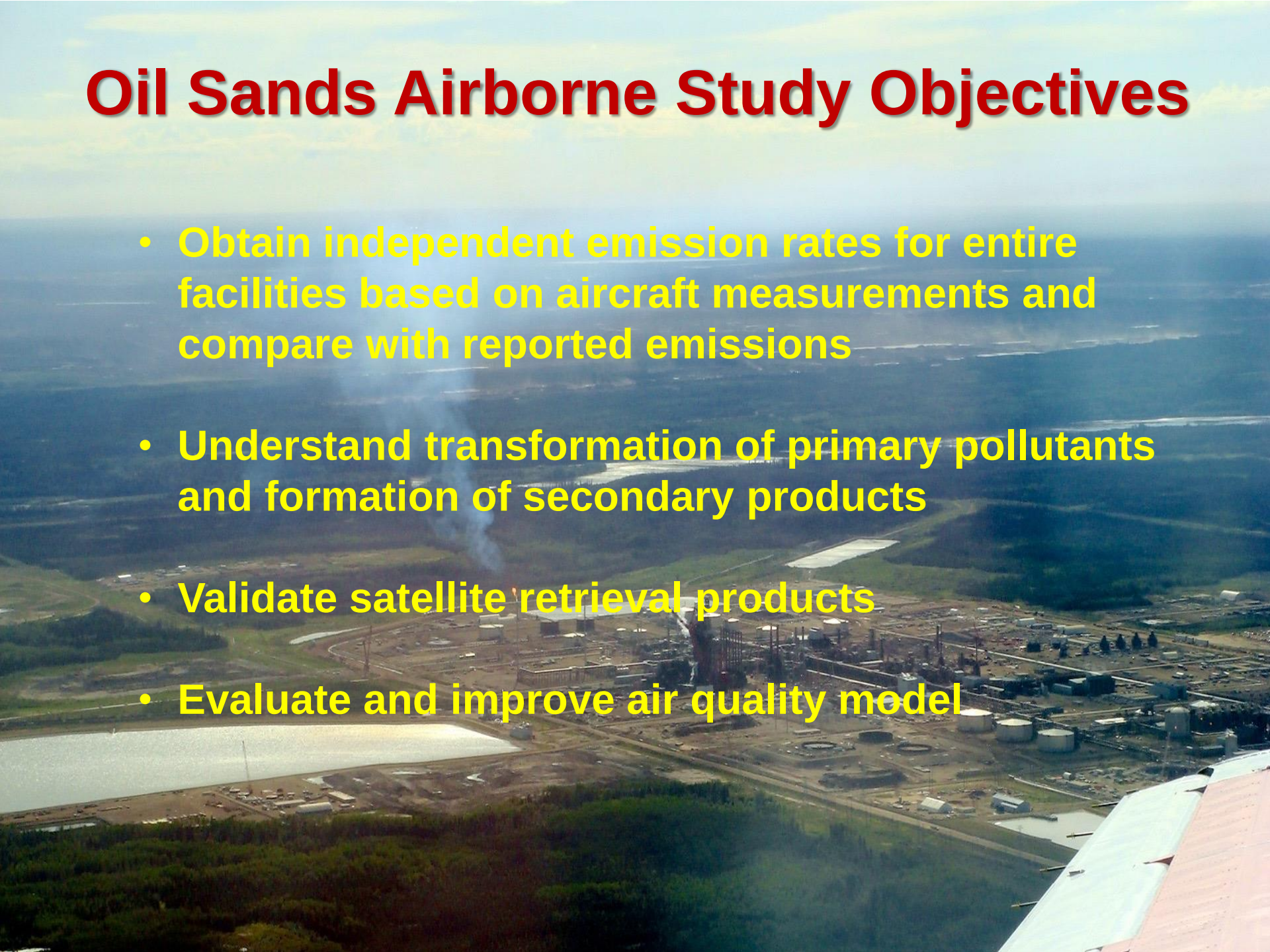
National Research Council, Flight Research Laboratory

Joint Oil Sands Monitoring Plan



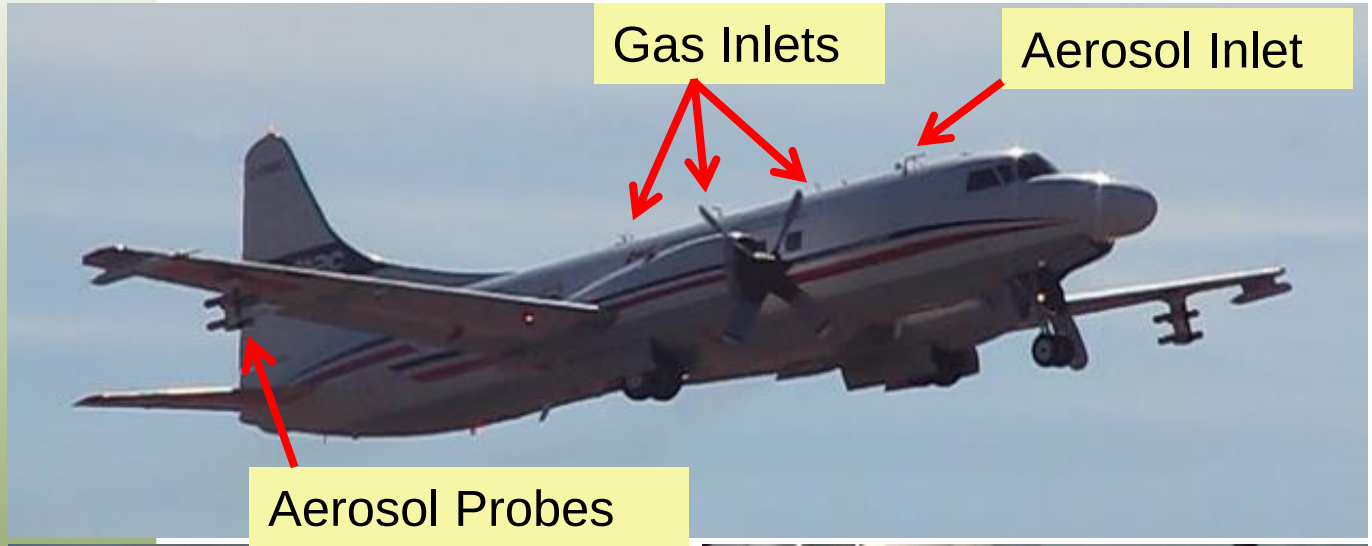
- Driven by the large oil sands development and concerns over its environmental impacts
- Program started in 2012 and continuing
- The overarching objectives of the Joint Oil Sands Monitoring Plan are to determine the cumulative ecosystem impacts of pollutants from oil sands development
- The plan has 3 components
  - Water, Air, Biodiversity

Oil Sands Airborne Study Objectives



- Obtain independent emission rates for entire facilities based on aircraft measurements and compare with reported emissions
- Understand transformation of primary pollutants and formation of secondary products
- Validate satellite retrieval products
- Evaluate and improve air quality model

Aircraft and instruments in 2013 study (Aug to Sept 2013)



Gases, 1-5 sec

- CRDS: CO, CO_2, H_2S, CH_4
- PTR-ToF-MS: VOCs
- Canisters: VOCs
- TECO: NO/NO_2/NOy/O_3/SO_2
- QCL: NH_3, HCHO
- CIMS: Acids

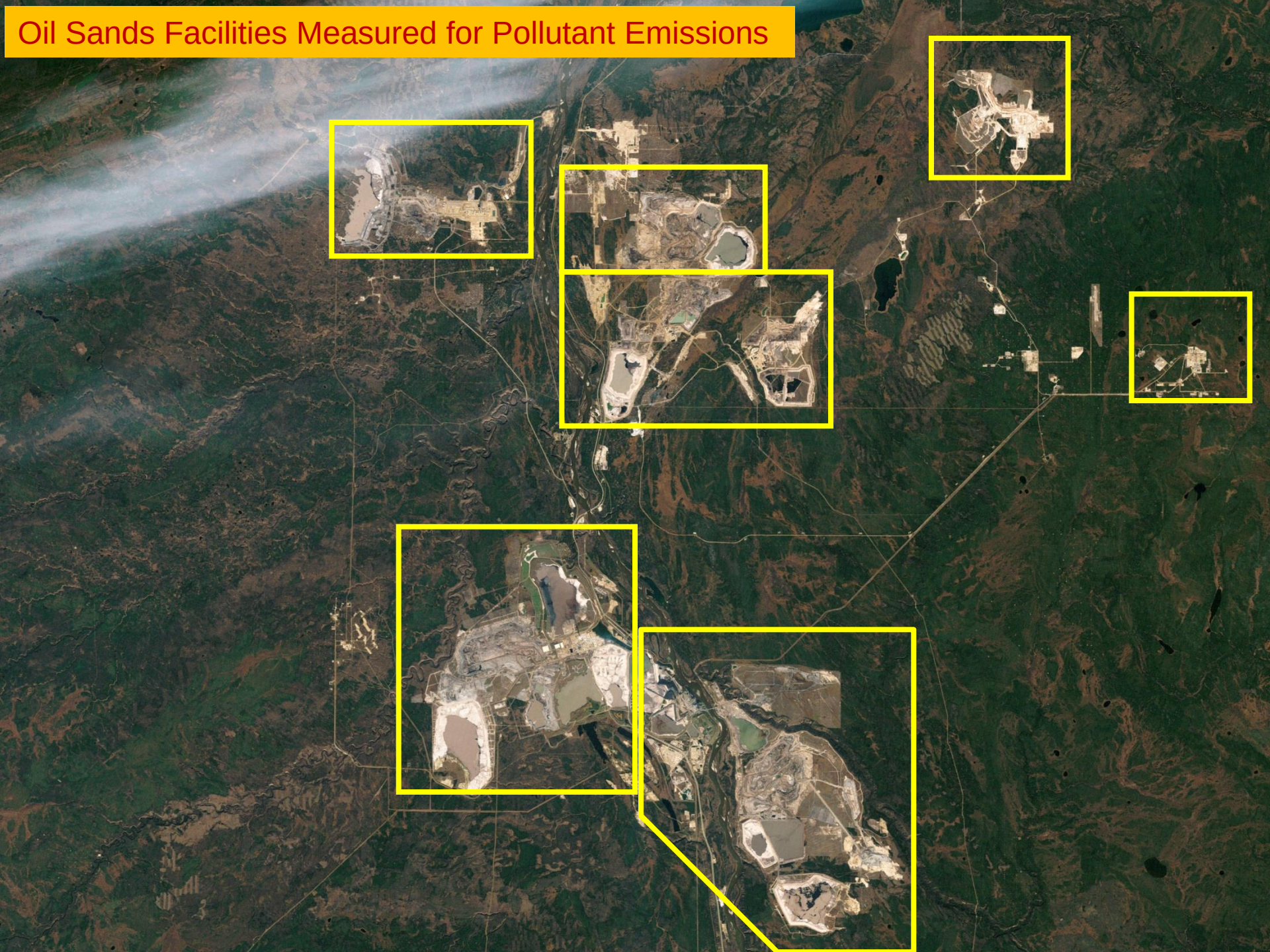
Particles, 1-10 sec

- AMS: composition
- SP2: rBC
- CPC, UHSAS, PCASP, FSSP300: counts and size

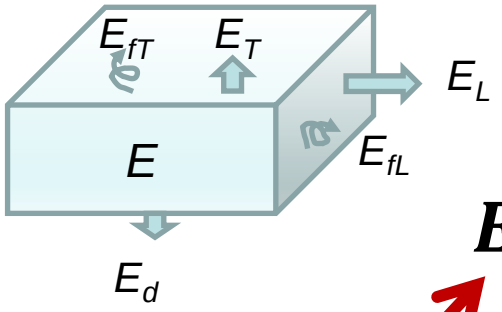
Meteorological and other state parameters

- 3-D wind spd/dir, T, P, RH
- Position (long, lat, alt)
- Turbulence

Oil Sands Facilities Measured for Pollutant Emissions



Top-down Emission Rate Retrieval Algorithm (TERRA): mass balance within an air volume



Emissions = Losses – Change

$$E = E_L + E_{fL} + E_T + E_{fT} + E_d + Ec - E_m$$

Emission Rate

Lateral Transport

Lateral Turb. Flux

Vertical Transport

Vertical Turb. Flux

Deposition to Surface

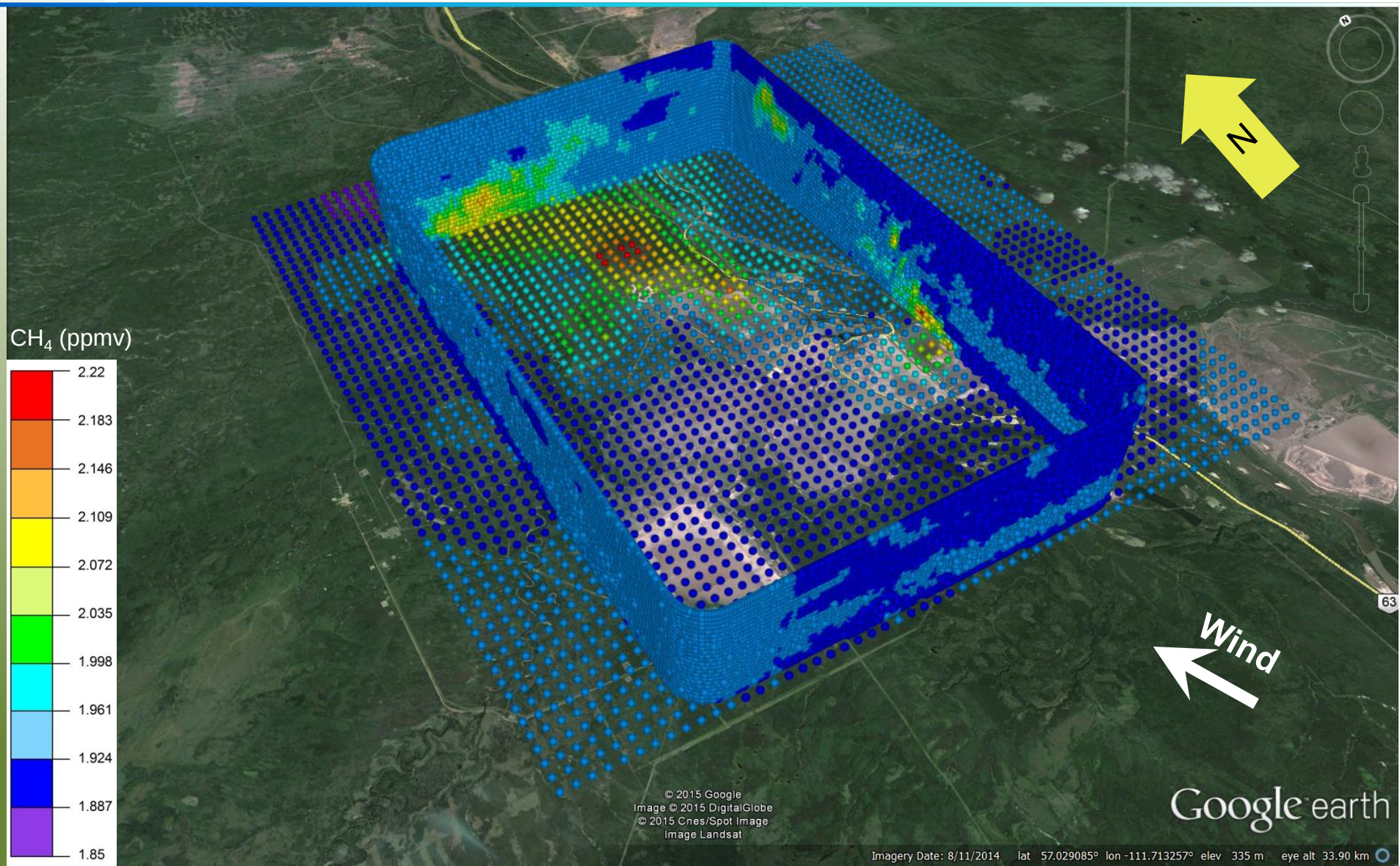
Chemistry

Change in mass

Reference: **M. Gordon*, S.-M. Li*,** R. Staebler, A. Darlington, K. Hayden, J. O'Brien, M. Wolde, Determining air pollutant emission rates based on mass balance using airborne measurement data over the Alberta oil sands operations, ***Atmos. Meas. Tech.,*** 8, 3745-3765, 2015.

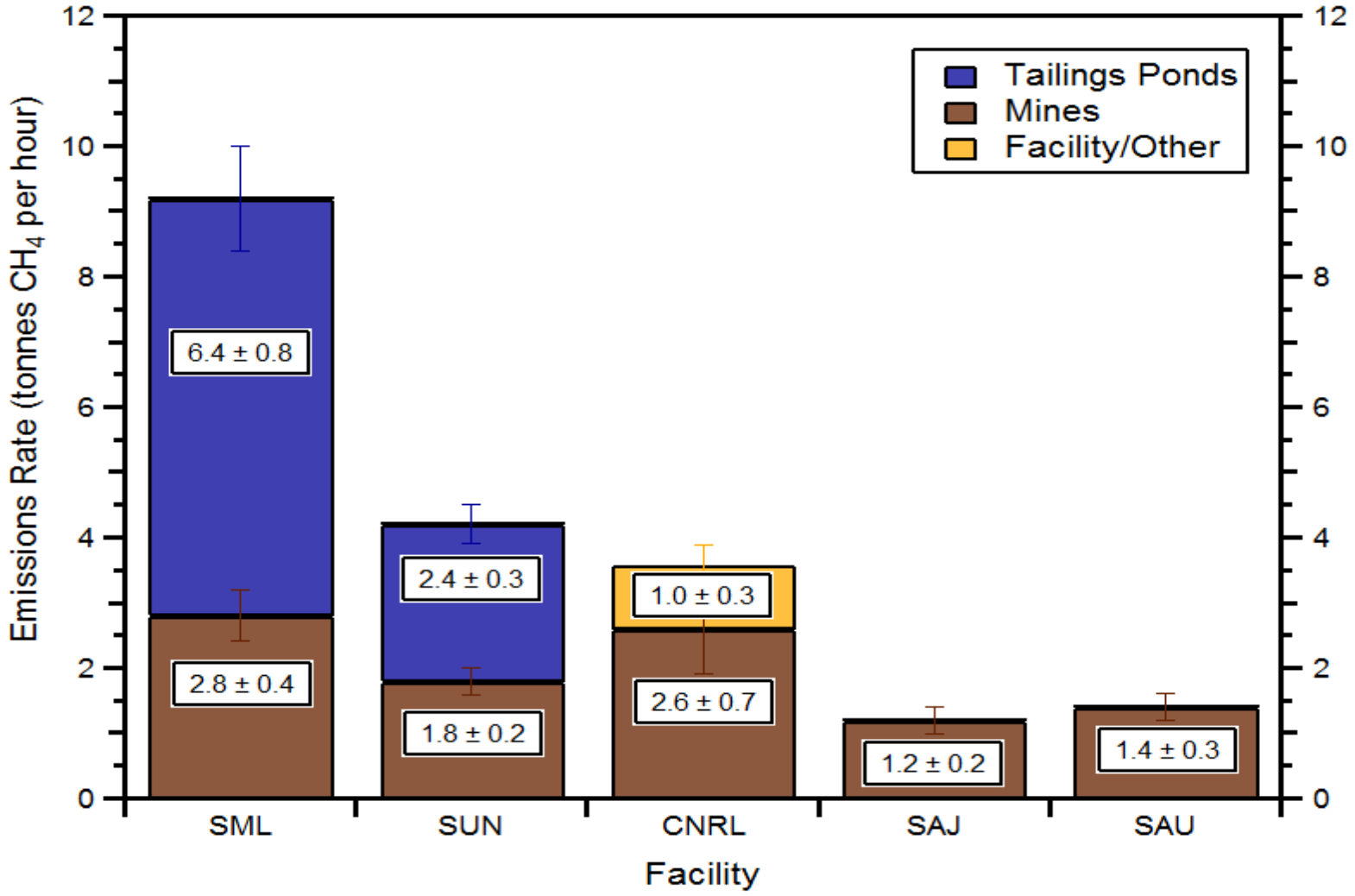
***Corresponding authors**

CH_4 Mixing Ratio 3-D Distributions for the box flight over the Syncrude Mildred Lake facility



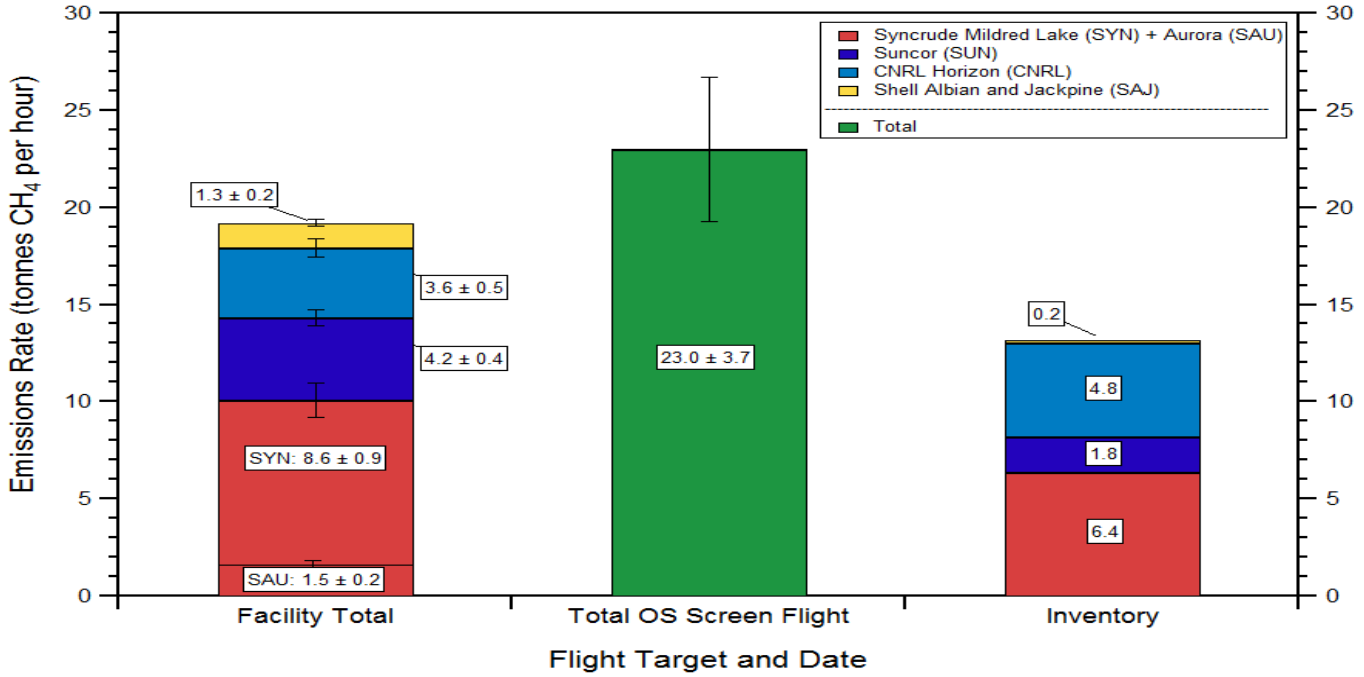
CH_4 emission rates of OS surface mining facilities determined from the aircraft flights

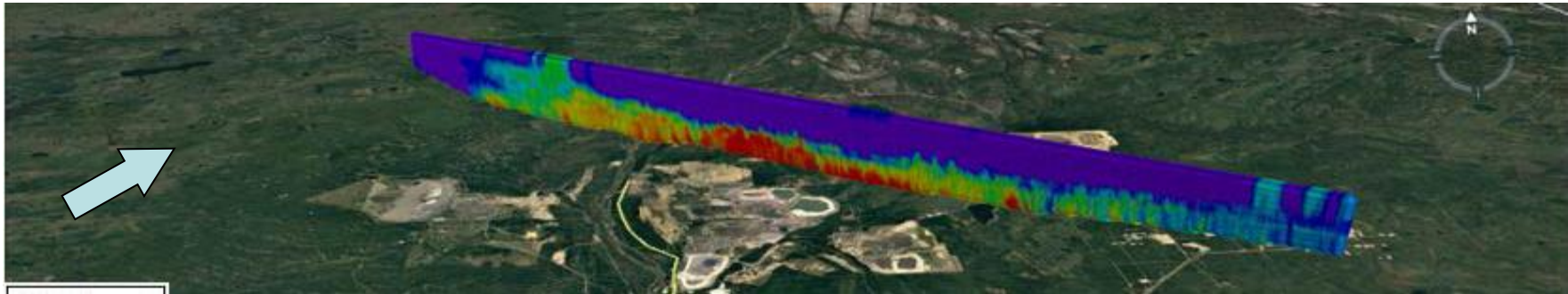
(Baray et al., ACPD, 2017; correspondance to R. McLaren/K. Hayden)



CH_4 emission rates based on atmospheric measurements vs. estimates in Canada's Greenhouse Gas Reporting Program

(Baray et al., ACPD, 2017; correspondance to R. McLaren/K. Hayden)





Summary of CH_4 Emissions from Oil Sands Facilities

- Total measured CH_4 emission rates from 5 surface mining facilities is 19.2±1.1 tonnes CH_4 hr^{-1}
- Tailings ponds accounted for 45% of CH_4 emissions, while mine faces contributed 50%
- The measured hourly CH_4 emission rate from all facilities in the AOSR is 48±8% higher than the hourly rate for 2013 extracted from the Canadian Green House Gas Reporting Program (converted from annual rate)

Baray, S., A. Darlington, M. Gordon, **K.L. Hayden**, Amy Leithead, S.-M. Li, P.S.K. Liu, R.L. Mittermeier, J. O'Brien, R. Staebler, M. Wolde, D. Worthy, S.G. Moussa, **R. McLaren**, Quantification of Methane Sources in the Athabasca Oil Sands Region of Alberta by Aircraft Mass-Balance, **Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2017-925, 2017.**

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Shale Petroleum Extraction Emission CHaracterization (SPEECH) Study

Shao-Meng Li, Ralf Staebler, Julie Narayan, Andrea Darlington, Kathy Hayden, John Liggio, Amy Leithead, Peter Liu, Jeremy Wentzell, Patrick Lee, Richard Mittermeier, Andrew Sheppard, Raymon Atienza, Rajananth Santhaneswaran, Doug Worthy, Morgan Lopez, Bob Kessler, Larry Giroux

Air Quality Research Division and Climate Research Division

Environment and Climate Change Canada

Ian Boelens

Environmental Protection Branch

Environment and Climate Change Canada

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Shale/Tight Oil and Gas Plays in North America

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

SPEECH Study Objectives

- To survey the **Bakken** shale plays in southern Saskatchewan, to determine whether petroleum resource development releases air pollutants to the atmosphere

- To determine the emission rates of CACs (VOCs), GHG/SLCP (CO_2, CH_4, black carbon), and air toxics (H_2S, aromatics) from these development activities

- To provide data that can be used in emission inventory development and for policy making decisions

Measurements during SPEECH

Oct to Nov 2015

- **CH_4, CO_2, CO, CH_4/CO_2 carbon isotope**
- **NO, NO_2, SO_2, H_2S**
- **VOCs** in canisters (**~150 VOCs**)
- **OVOCs + BTEX**
- **Acids** (organic and inorganic)
- **Black carbon**, **$PM_{2.5}$** and particle number size distribution
- **Met** parameters (T, P, RH, 3-d wind speeds, wind direction, turbulence)

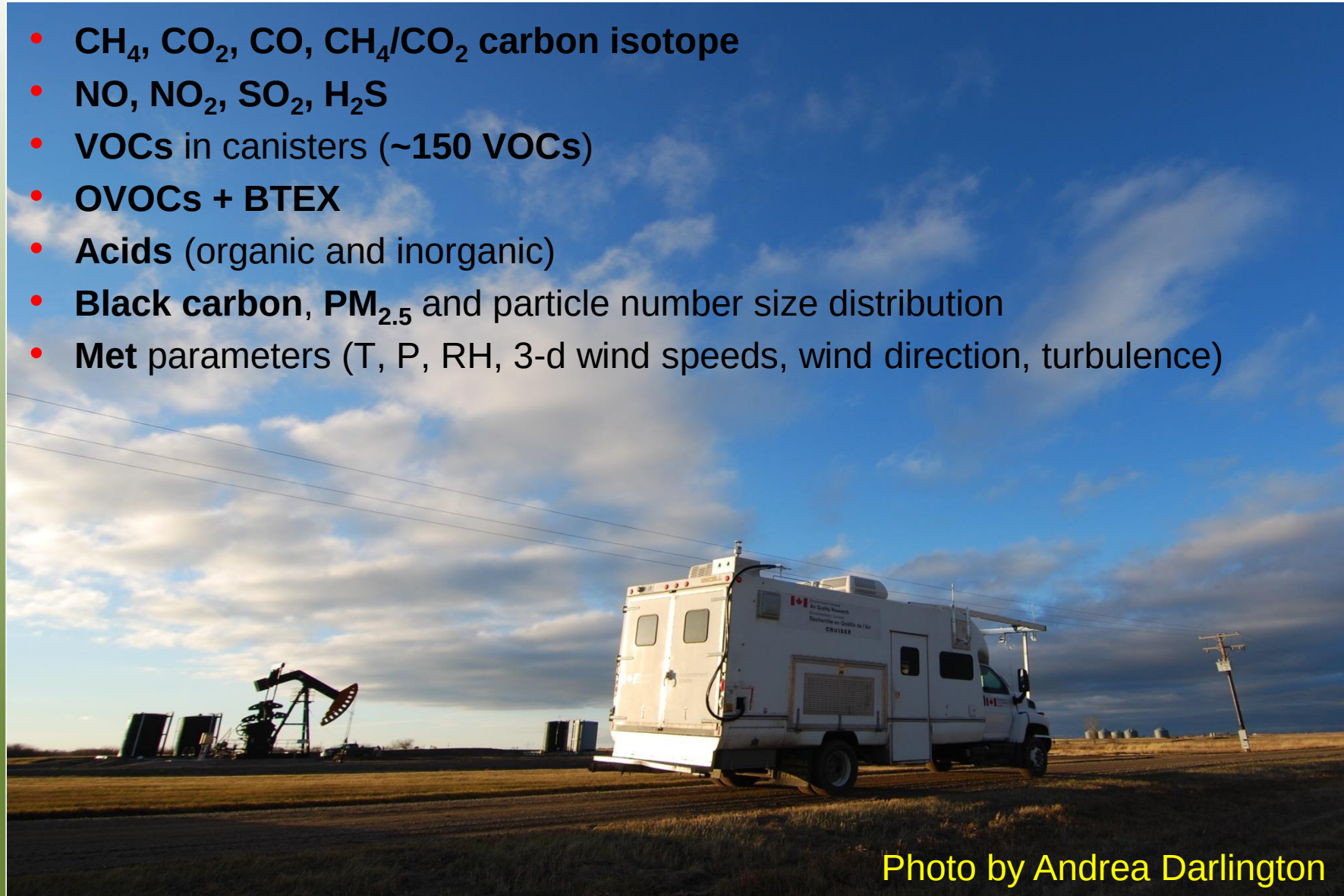
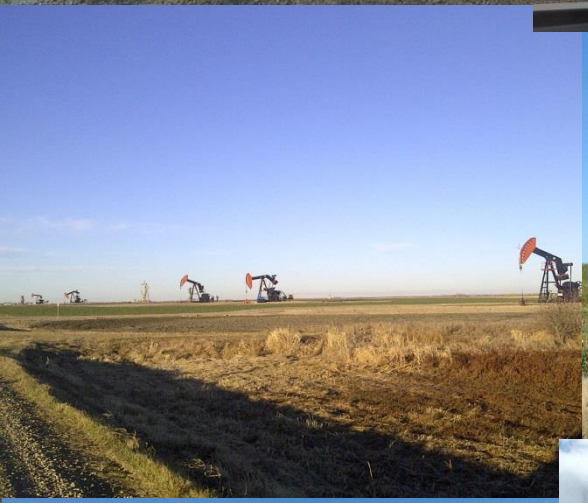


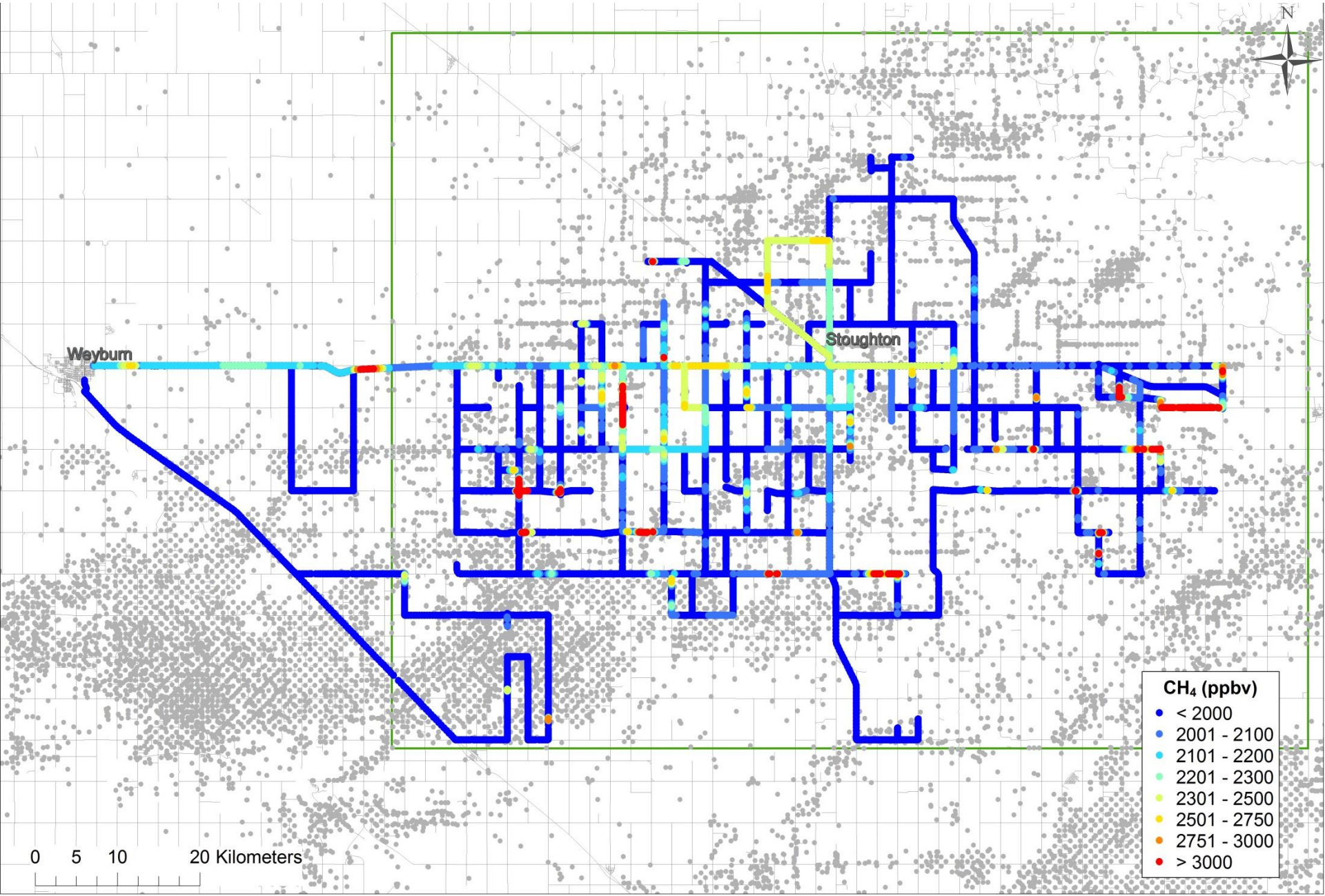
Photo by Andrea Darlington






CH_4 mapping in the Bakken



Histogram of detected CH_4 peaks

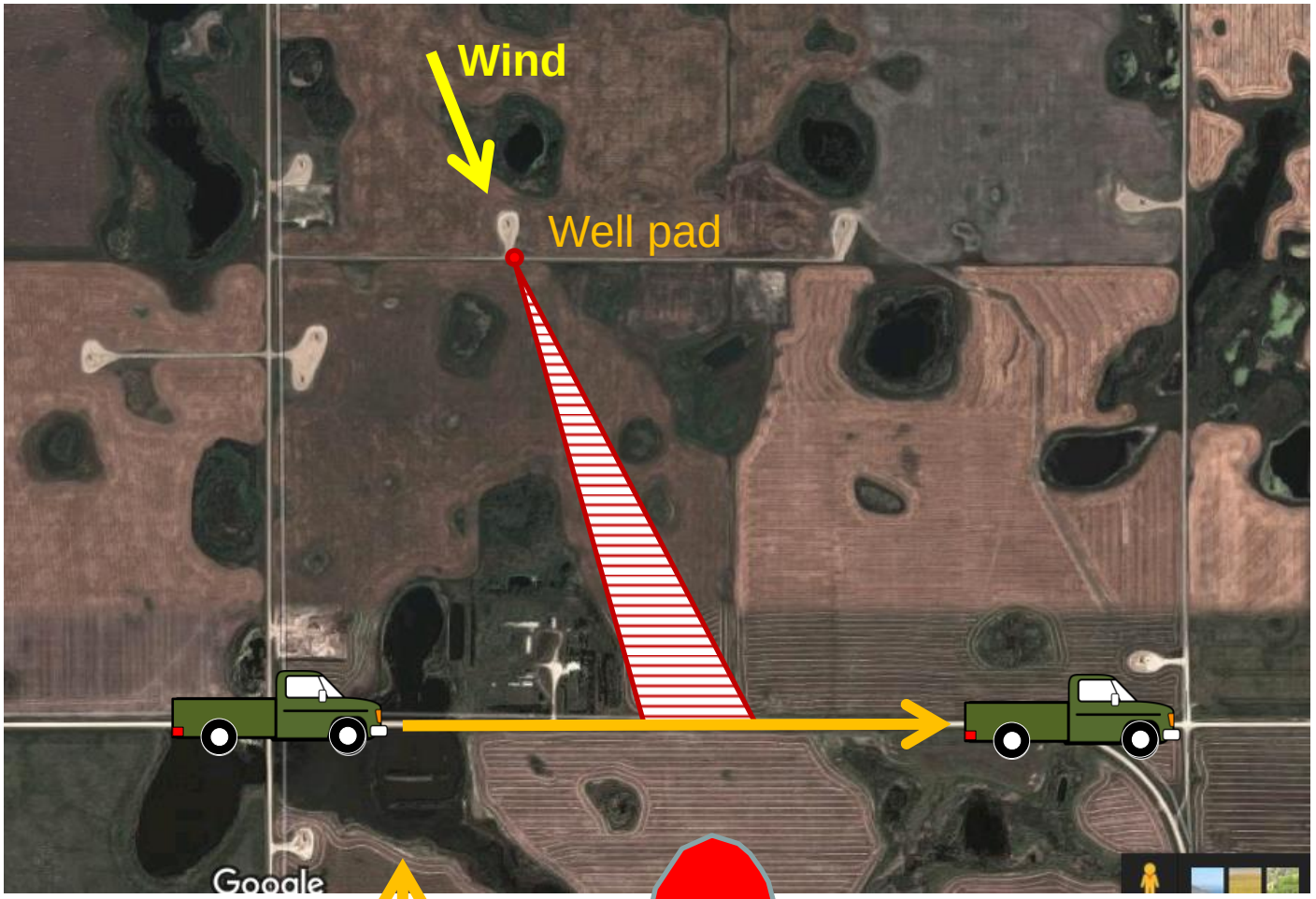
- **Number of CH_4 peaks associated with a well: 3426**
- **Wells/tanks with detectable CH_4 emissions: 2054**

Quantitation of Emission Rates

- **Single target source emission strength**
  - Determine emission rate by **tracer release** experiments at and near identified sources
  - Use a dispersion model coupled with meteorological measurements

- **Upscaling to entire Bakken shale play**
  - Determine all leaks from all shale producing facilities in the Bakken shale play
  - Determine emission rates using dispersion model
  - Identify targets for leaks
  - Relate emission rates to well metadata to provide upscaling of emissions from the Bakken shale play

Tracer Release Experiment Design



Tracer/pollutant Concentration

Transect distance

Conclusions

- In-situ measurements can be used to evaluate emission estimation reporting
  - Top down approach provides a useful method to estimate integrated emissions over a large facility (i.e., oil sands surface mining) and over regions with large number of dispersed small facilities (e.g., oil fields)
  - Bottom up emission measurement approach has the potential to provide emission factors for upscaling to regional scales
- Comparison suggests that measured CH_4 emissions from oil sands surface mining facilities are higher than reported values by about 50%
- For the Bakken shale oil region
  - A large fraction of oil wells have detectable CH_4 emissions
  - Regional emissions are dominated by a relatively small number of large emitters (such as wells or tanks)

Future plans for CH_4 studies, both in oil sands and fracturing operations

- Understand and quantify the regional air emissions associated with the hydraulic fracturing method of gas/oil production.
  - Using the 2015 Bakken measurements, obtain an understanding of the types and magnitudes of emissions (CAC, VOC, GHG, etc.).
- Planning on 2018 aircraft studies, focusing measurements on oil sands (surface mining, in situ, CHOPS, etc) and potentially NE BC, the Bakken, and Montney regions where fracking activities are increasing.
- Based on the results from this work, future work could include additional ground mobile and aircraft studies.