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Emissions Preparation for High-Resolution Air Quality Modelling over the Athabasca Oil Sands Region of Alberta, Canada

J. Zhang[1], Q. Zheng[1], M.D. Moran[1], P.A. Makar[1], A. Akingunola[1], S.-M. Li[1], G. Marson[1], K. Chiu[1], N. Dulong[1], M. Gordon [2], R. Melick[3], and S. Cho[3]

1. Air Quality Research Division, Environment Canada, Canada
2. Department of Earth and Space Science and Engineering, York U., Toronto, ON, Canada
3. Alberta Environment & Sustainable Resource Development, Edmonton, AB, Canada

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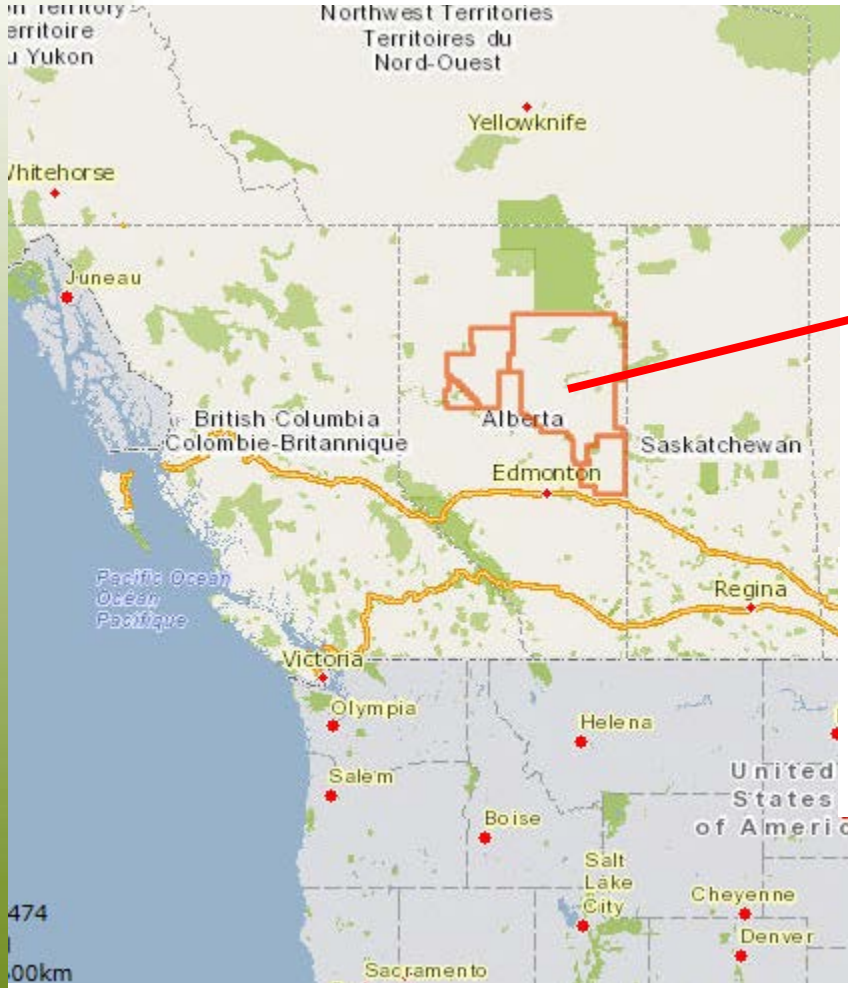
Presentation Overview

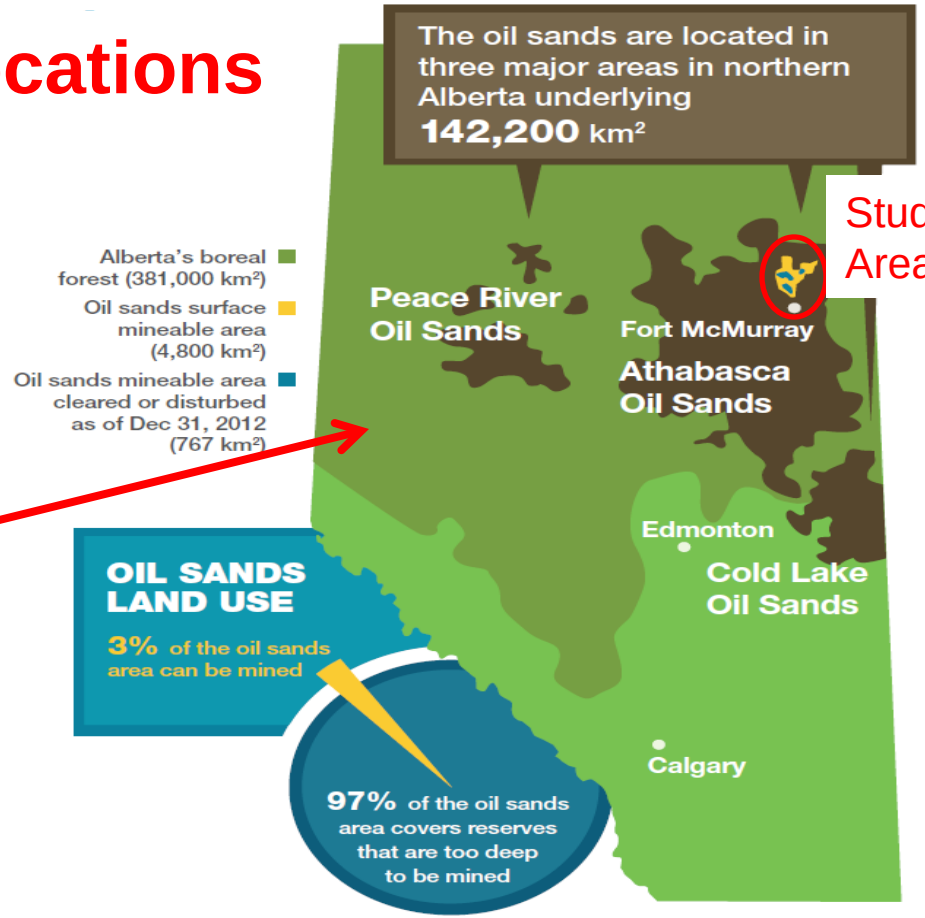
- Joint Oil Sands Monitoring (JOSM) Plan:
  - Joint federal and Alberta governments initiative
  - One sub-project: creation of emissions files for air quality (AQ) modelling in this region
- Topics to be covered:
  - Introduction to Alberta's oil sands and main sources of emissions
  - 2013 summer field study in this region
  - Methodology applied to emissions preparation for AQ modeling
  - One example showing AQ model forecast for flight planning during the field study
  - One example showing how aircraft measurements can help in emissions estimates

Introduction to Athabasca Oil Sands

- Oil sands (OS) are a natural mixture of sand, clay, and water, saturated with bitumen
- 71% of global OS reserves are in Alberta, Canada.
- Two primary methods of extraction:
  - open-pit surface mining
  - in-situ techniques
- Due to the nature of the extraction methodology, emissions are mostly from the surface mining area over the Athabasca Oil Sands Region (***AOSR***) of northeastern Alberta
- Large source of air pollutants in Alberta:
  - 2nd largest source of SO_2
  - 3rd largest source of industrial NO_x emissions
  - significant sources of industrial PM, CO and VOCs

Oil Sands Geographic Locations

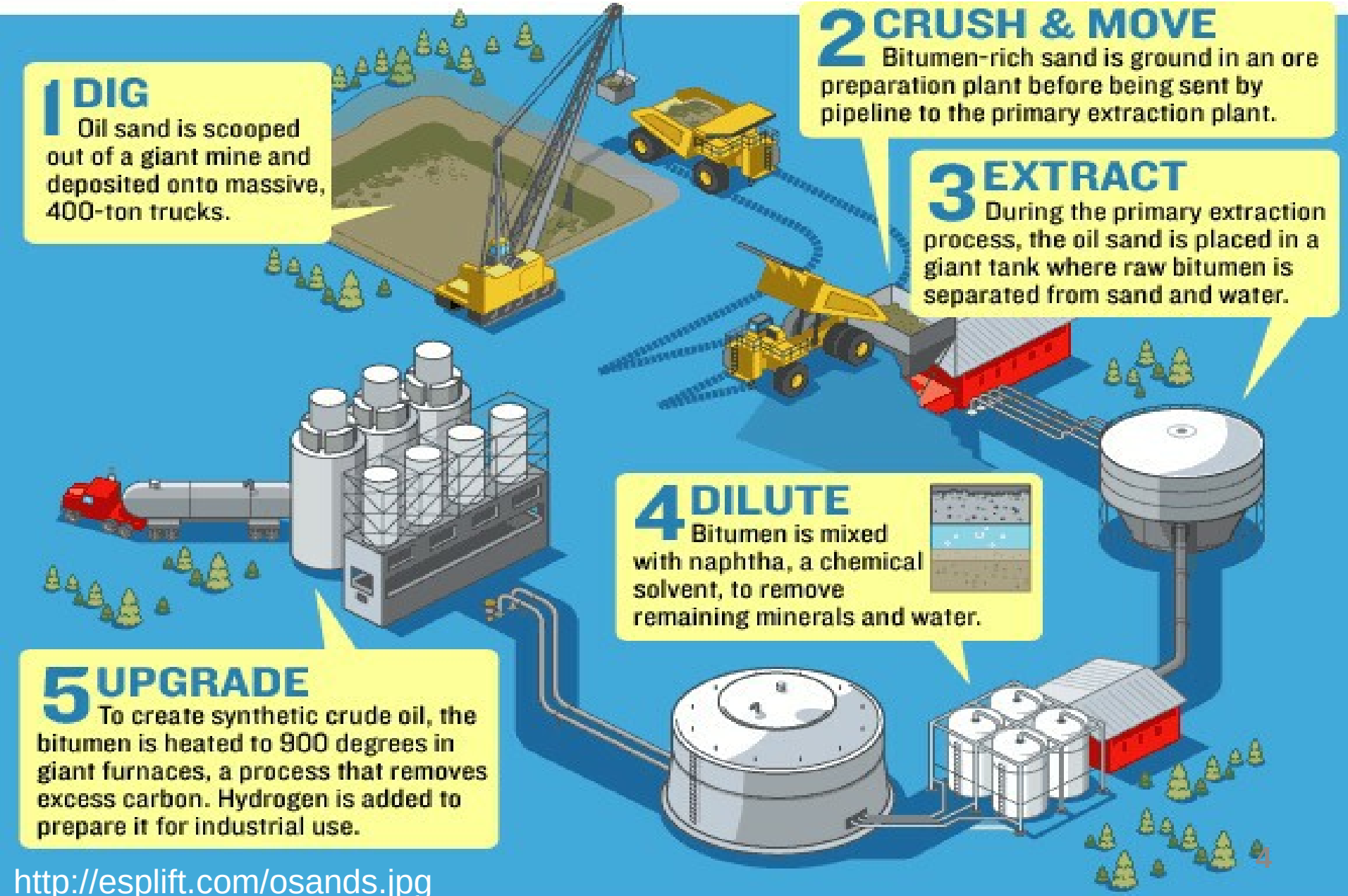




http://www.energy.alberta.ca/OilSands/960.asp

http://jointoilsandsmonitoring.ca/pages/map.aspx

Overview of Oil Sands Surface Mining Processes



http://esplift.com/osands.jpg

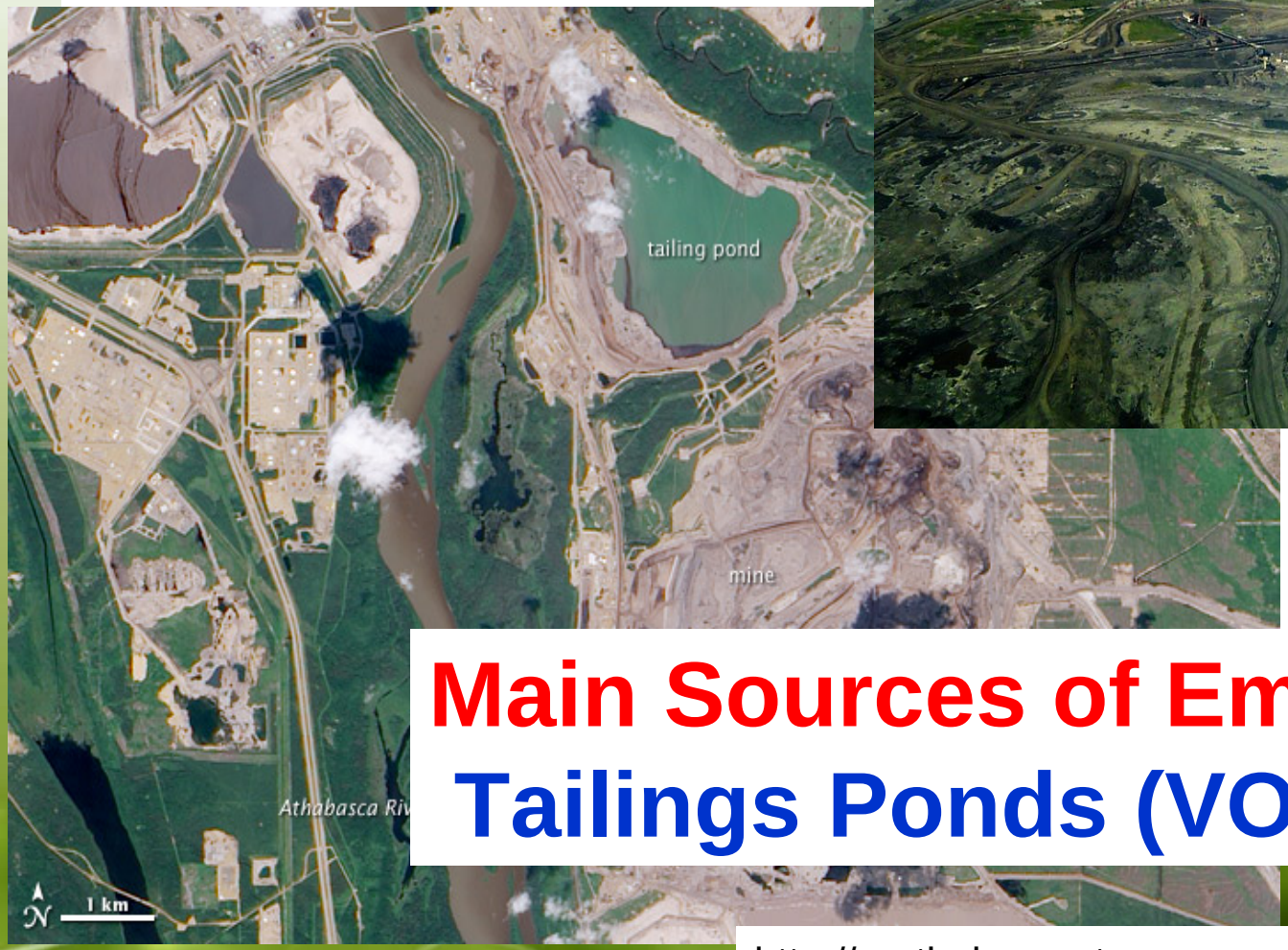
Main Sources of Emissions:
Surface Mining (fleets and mine faces)

- Mine fleets are sources of NO_x and CO emissions, while mine faces are sources of VOCs emissions.

http://activerain.trulia.com/blogsview/687418/the-giants-of-mining

- In 2013, tailings ponds in the Alberta oil sands covered an area of about 77 square kilometres (30 square miles)

http://www.oilsands.alberta.ca/FactSheets/Tailings_FSht_Sep_2013_Online.pdf



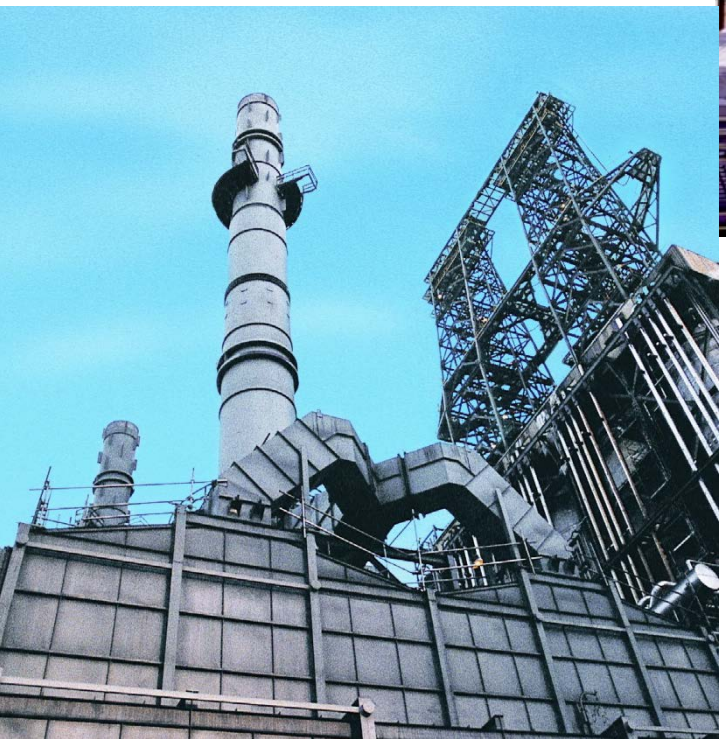
Main Sources of Emissions: Tailings Ponds (VOCs)

http://earthobservatory.nasa.gov/IOTD/view.php?id=40997

Main Sources of Emissions:

Upgrading Plants

- Various combustion sources and industrial processes
- Sources of SO_2, NO_x, CO, PM and VOCs



- Upgrading is to transform bitumen into synthetic crude oil
- There are 2 broad types of upgrading: primary and secondary upgrading

Monitoring a Changing Environment

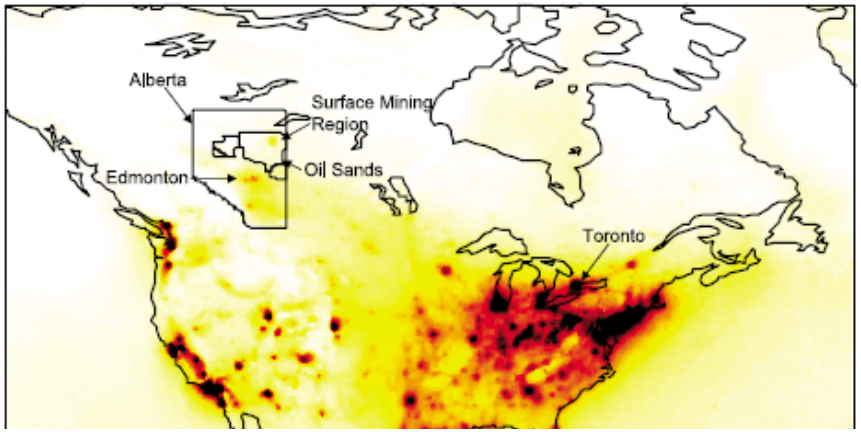
- Extraction and processing of crude oil from oil sands has undergone a rapid expansion.
- Estimating environmental impacts of the emissions associated with this expansion may be accomplished using air-quality models.
- However, the models need:

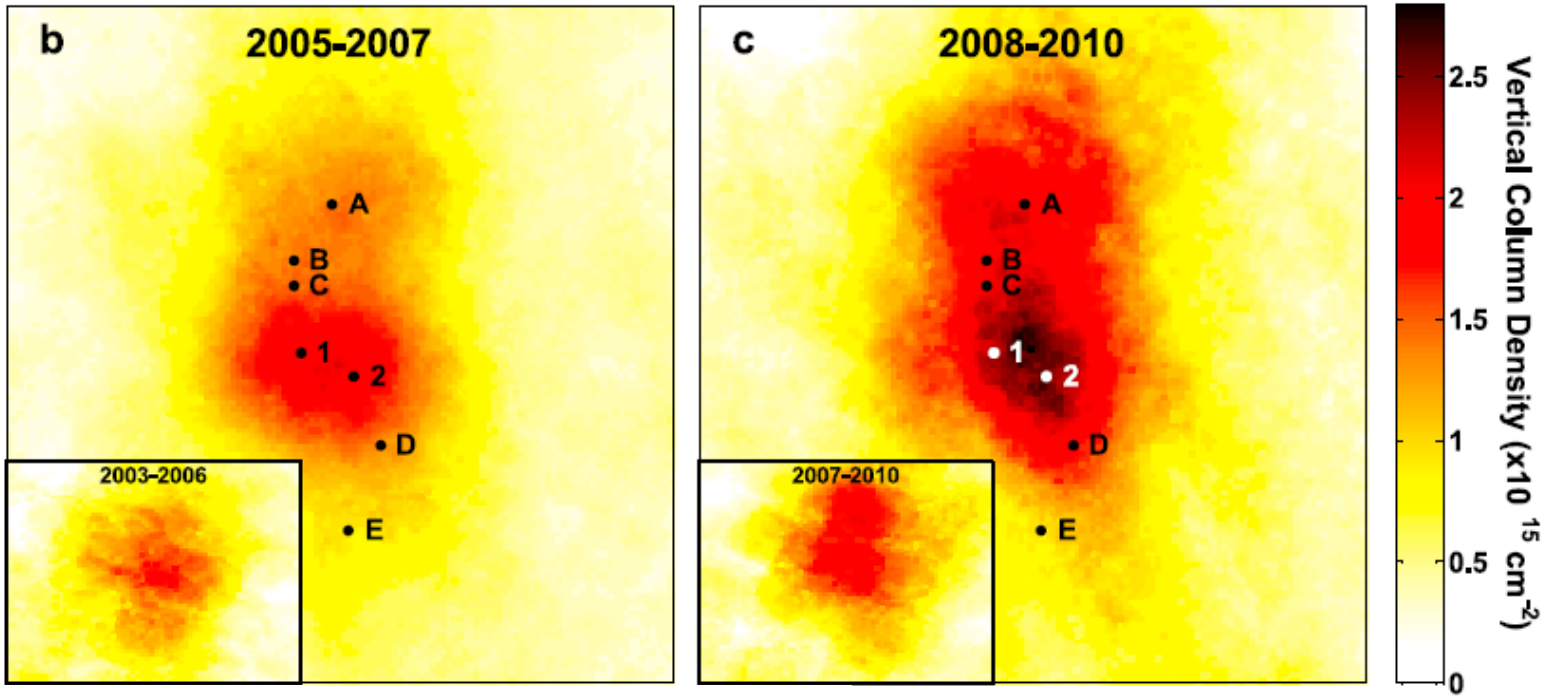
  - Accurate emissions data, in order to provide accurate results

  - Time and speciation-resolved observations in order to evaluate processes

Satellite-Measured Increase in NO_2 Column Density in AOSR

The increase of NO_2 vertical column density indicates that NO_2 emissions increased significantly from the 2005-2007 period to the 2008-2010 period





McLinden et al., 2012, Geophysical Research Letters

2013 Summer Field Study

- An intensive air quality monitoring field study, including aircraft and special surface measurements, was carried out in the AOSR during summer 2013 to better understand impacts from oil sands developments and evaluate model process representation.
- Environment Canada's GEM-MACH AQ modelling system was set up at model grid spacing down to 2.5 km to conduct nested AQ modeling to provide forecast guidance for airborne laboratory flight planning and later post-study analysis
- Accurate emissions information inputs will improve the AQ modeling

Aerial Overview of the Study Area

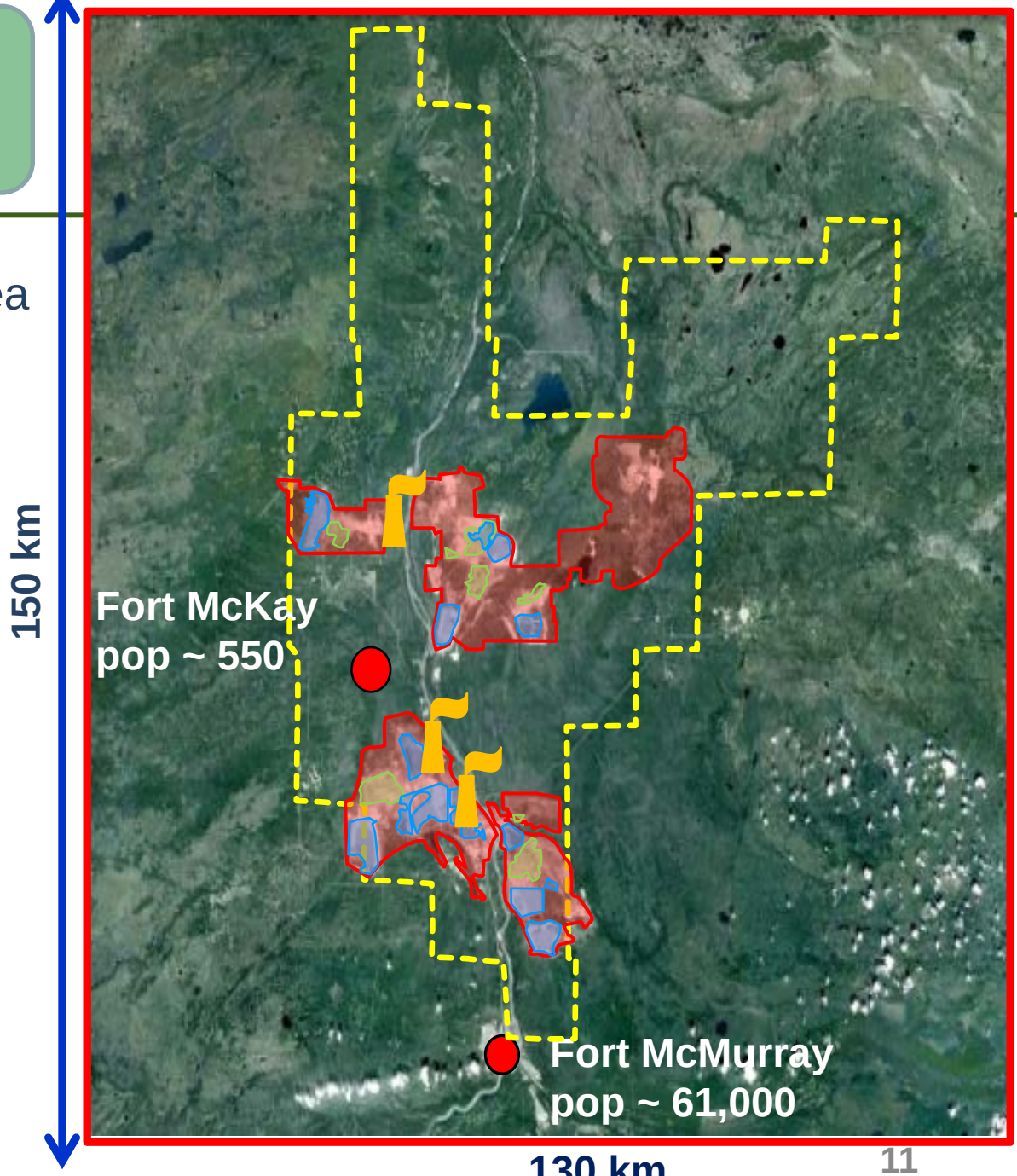
oil sands Minable Area
~ 4,800 km^2

active mining area

mine pits

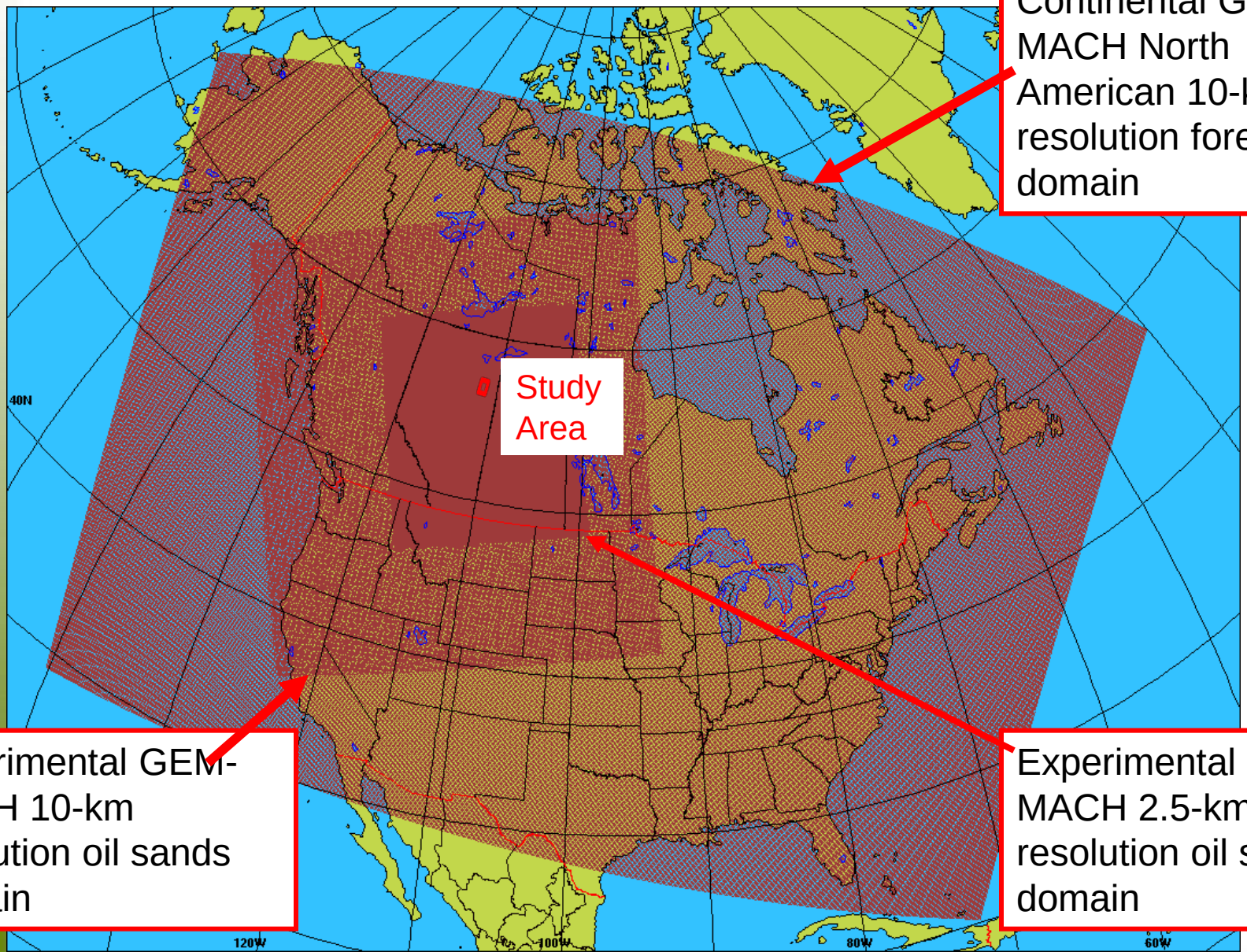
tailing ponds

upgrader facilities (3)



Li et al, 2014, AGU

Nested Domains: 3 Levels of Nesting for Environment Canada GEM-MACH AQ Model



Major Accomplishments

- Review and select the most robust and relevant information from existing inventories, and measurements from CEMS and during abnormal operating conditions
- Allocation of emissions *within* each Oil Sands facility using spatial surrogates
- Creation of monthly profiles based on statistics of mined oil sands and bitumen production for temporal disaggregation of annual emissions to each month
- VOC chemical speciation based on source type: mine face, plant, and tailing ponds
- Potential improvements to emissions estimates and emissions processing for air quality modeling based on aircraft observations

Review of 9 Emissions Inventories

Range of base years: 2006 to 2010

As part of the work, several different sources of information were reviewed and compared in order to build an improved data base:

- The Cumulative Environmental Management Association (CEMA) Air Working Group Emission Inventory
- The Lower Athabasca Regional Plan (LARP) Emissions Inventory
- Environmental Protection and Enhancement Act (EPEA) Approvals Emissions Data
- The Alberta Industrial Air Emissions Survey
- The Alberta Air Emissions Inventory (AAEI)
- The Canadian National Pollutant Release Inventory (NPRI)
- The Canadian Air Pollutant Emissions Inventory (APEI), including NPRI for facility reported data along with emission estimates for other sources
- The Wood Buffalo Emissions Inventory
- Two EPEA Approval Applications / Environmental Impact Assessments inventories (Frontier and Voyageur South)

Emissions Inventories Review (2)

Different spatial coverage

Inventory Name	Geographic Scope
CEMA Inventory	Lower Athabasca Region
LARP Inventory	Lower Athabasca Region
EPEA Approvals	Entire Province
Alberta Industrial Air Emissions Survey	Entire Province
Alberta Air Emissions Inventory	Entire Province
National Pollutant Release Inventory	All of Canada
Air Pollutant Emissions Inventory	All of Canada
Wood Buffalo Emissions Inventory	Wood Buffalo Environmental Association (WBEA) Airshed Zone
EPEA Approval Application & EIA (various inventories)	Variable, project specific

Emissions Inventories Review (3)

Different levels of detail

Inventory Name	Level of Detail
CEMA Inventory	Release point (e.g., stack)
LARP Inventory	Release point (e.g., stack)
EPEA Approvals	Facility totals, some release point
Alberta Industrial Air Emissions Survey	Release point (e.g., stack)
Alberta Air Emissions Inventory	Combination of release point, facility total, regional area & mobile sources
National Pollutant Release Inventory	Facility total, some source categories
Air Pollutant Emissions Inventory	NPRI + UOG + sector totals of area and mobile sources for the whole province/region
Wood Buffalo Emissions Inventory	Release point (e.g., stack)
EPEA Approval Application & EIA (various inventories)	Release point (e.g., stack)

Emissions Inventories Review (4)

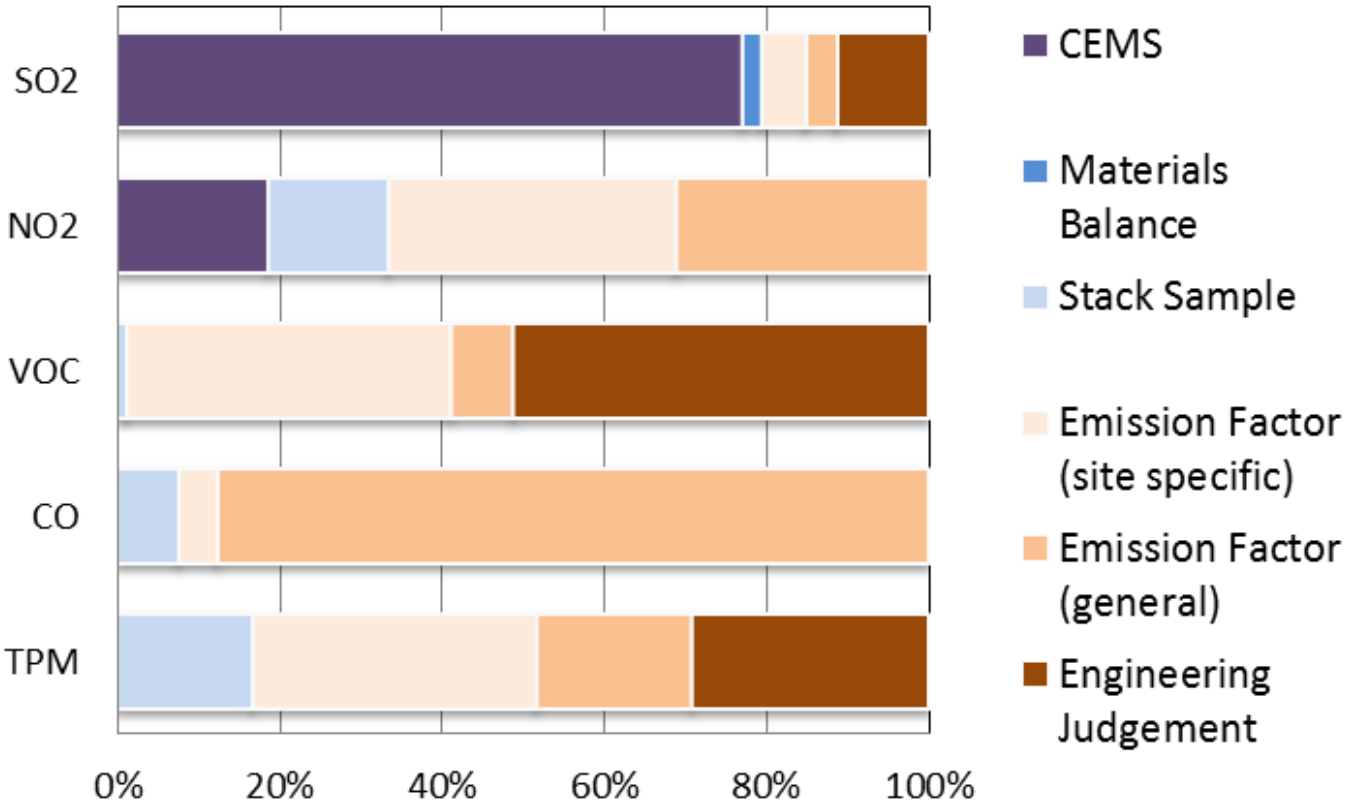
Different emissions totals for the same oil sands area

Inventory	NOx (tonnes / year)	SO_2 (tonnes / year)	CO (tonnes / year)	$PM_{2.5}$ (tonnes / year)	VOC (tonnes / year)
CEMA Total Oil Sands (2009/10)	81,125	115,746	42,669	4,482	32,292
LARP Total Oil Sands (2006)	83,246	113,886	51,317	5,857	80,648
EPEA Approvals Total Oil Sands (2010)	66,839	113,550	n/a	n/a	n/a
Industrial Survey Total Oil Sands (2008)	63,164	117,819	25,875	3,896	47,176
AAEI Oil Sands Facilities in LARP (2008)	62,621	107,185	25,413	3,871	46,044
NPRI Oil Sands In-Situ Extraction and Processing + Oil Sands Mining Extraction and Processing + Bitumen and Heavy Oil Upgrading Sector Totals (2010), Excludes Mine Fleets	44,318	113,138	24,075	2,003	73,835
APEI Total Alberta Oil Sands + Mine Fleets (2010)	94,167	113,150	59,634	3,699	77,859

This table shows the variation across different inventories, which were constructed for different purposes and different inventory years. As a result, agreement on totals across inventories is not expected.

Criteria Air Contaminants (CAC) quantification profile

- Sorted by decreasing level of estimation accuracy

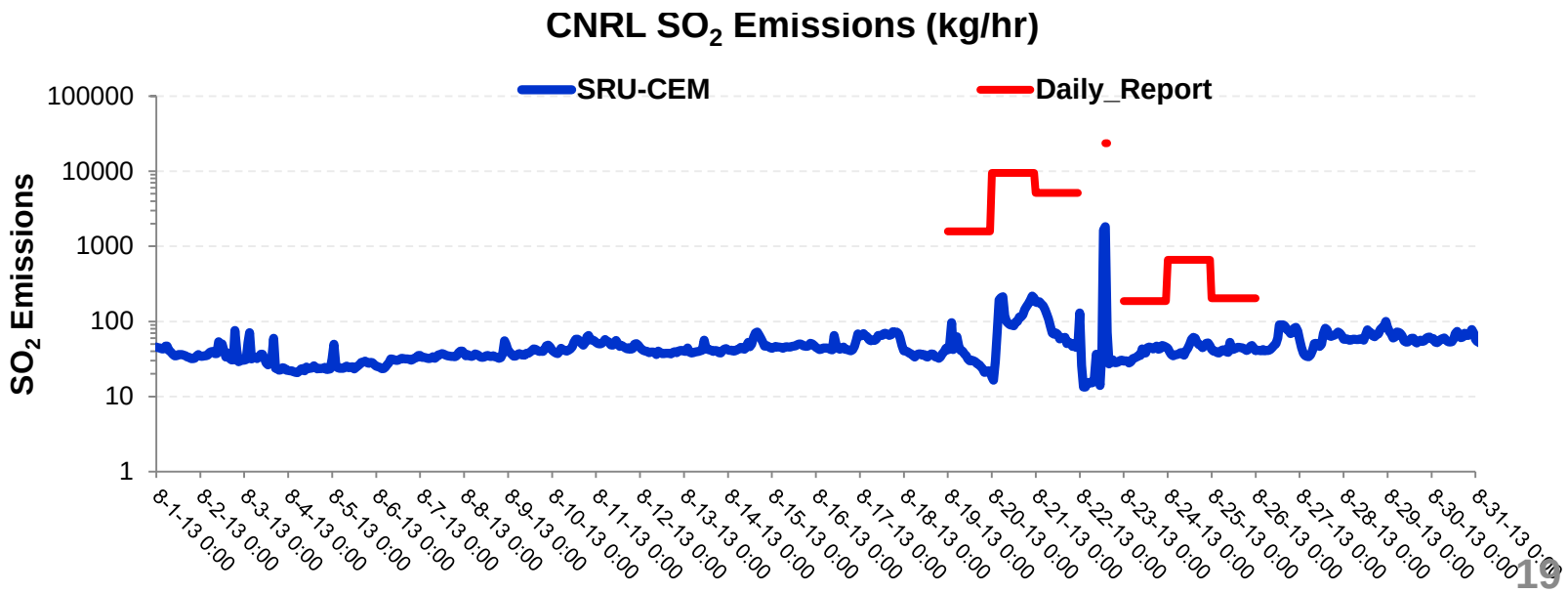


Quantification of CAC emissions from non-conventional O&G, 2008 ESRD Industrial Survey

Emissions Inventories Review (5)

CEMS measurements and emissions under abnormal conditions

- CEMS have been installed on some of the large stacks to measure SO_2 and/or NO_x emissions
- Hourly SO_2 and/or NO_x emissions measured by 20 CEMS at four Athabasca oil sands facilities for August and September, 2013 were made available courtesy of Alberta Environment and Sustainable Resource Development
- Additional SO_2 emissions during abnormal operating conditions through flaring stacks can be more than one order of magnitude larger than those during normal conditions.



JOSM Emissions Inventory Requirements for AQ Modeling

- Representation of 2013 emissions (Aug-Sept 2013 field study)
- Pollutants: CO, NO_X, SO_2, PM_{10}, $PM_{2.5}$, NH_3, VOCs
- Detailed stack-level emissions for the study area
- Detailed non-point source emissions for the study area
- Industrial point sources outside the study area
- Industrial and non-industrial area and mobile sources for the entire modelling domain
- Appropriate chemical speciation and temporal profiles, up-to-date spatial surrogates
- New Source Classification Codes (SCCs) if required

JOSM Emissions Inventory Development for AQ Modeling

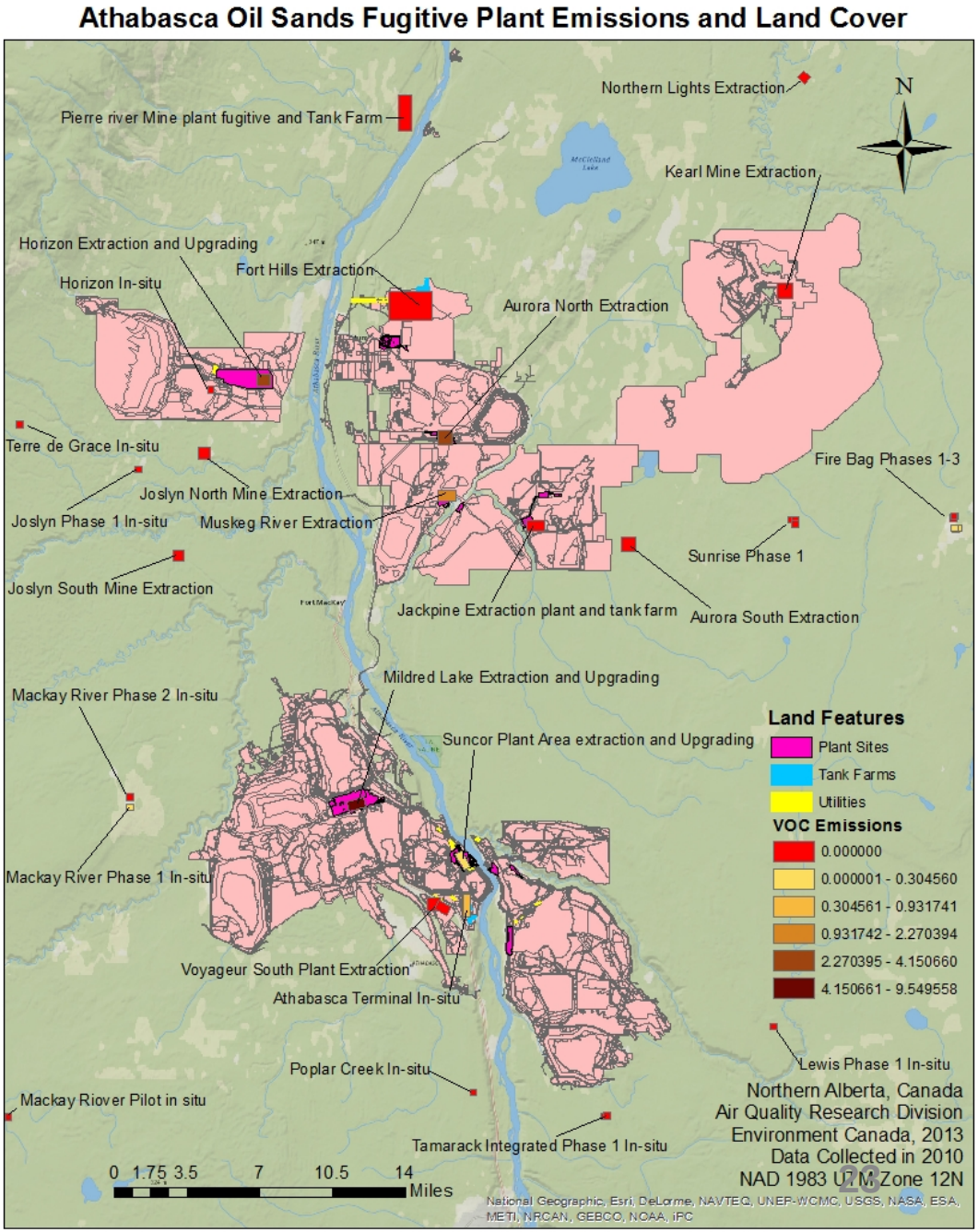
- Inventory selection
  - Within study area:
    1) CEMS SO_2 and/or NO_X emissions if available
    2) 2010 CEMA inventory with VOC emissions scaled up to 2010 NPRI levels
  - Outside study area:
    1) 2010 APEI inventory
- Gap Filling
  - 2013 NPRI used to fill gaps in the study area, such as:
    1) Emissions from the new Imperial Kearl facility
    2) NH_3 emissions
    3) Fugitive dust emissions
  - Included flaring SO_2 emissions during abnormal operating conditions if available

Nine New Source Classification Codes Were Created

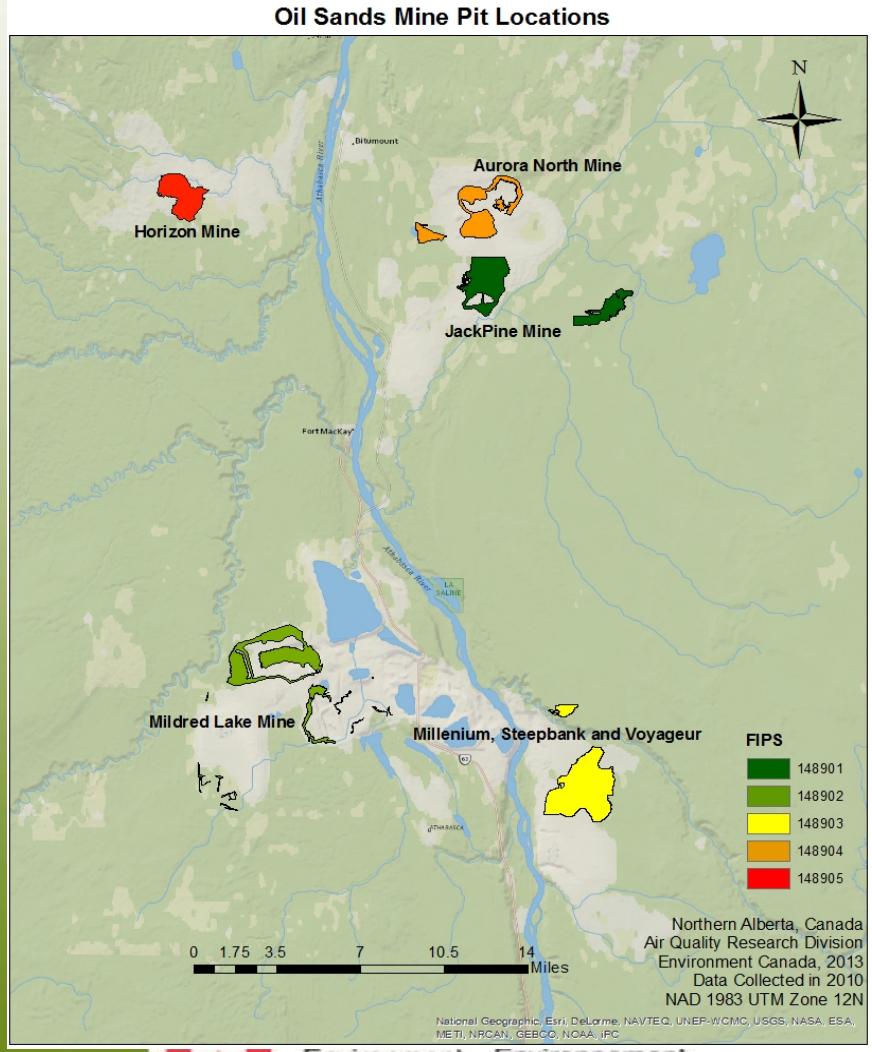
SCC code	SCC description
23100000EX	Extraction-only plants
23100000UP	Integrated extraction and upgrading plants
23100000IS	In situ plants
23250000MF	Mine face
2501000P01	Tailings pond(s) for Shell Muskeg River and Imperial Kearl sites
2501000P02	Tailings pond(s) for CNRL Horizon site
2501000P05	Tailings pond(s) for Syncrude Aurora North site
2501000PSU	Combined tailing pond for Suncor Millennium site
2501000PSY	Combined tailing pond for Syncrude Mildred Lake site

Spatial Allocation of Emissions

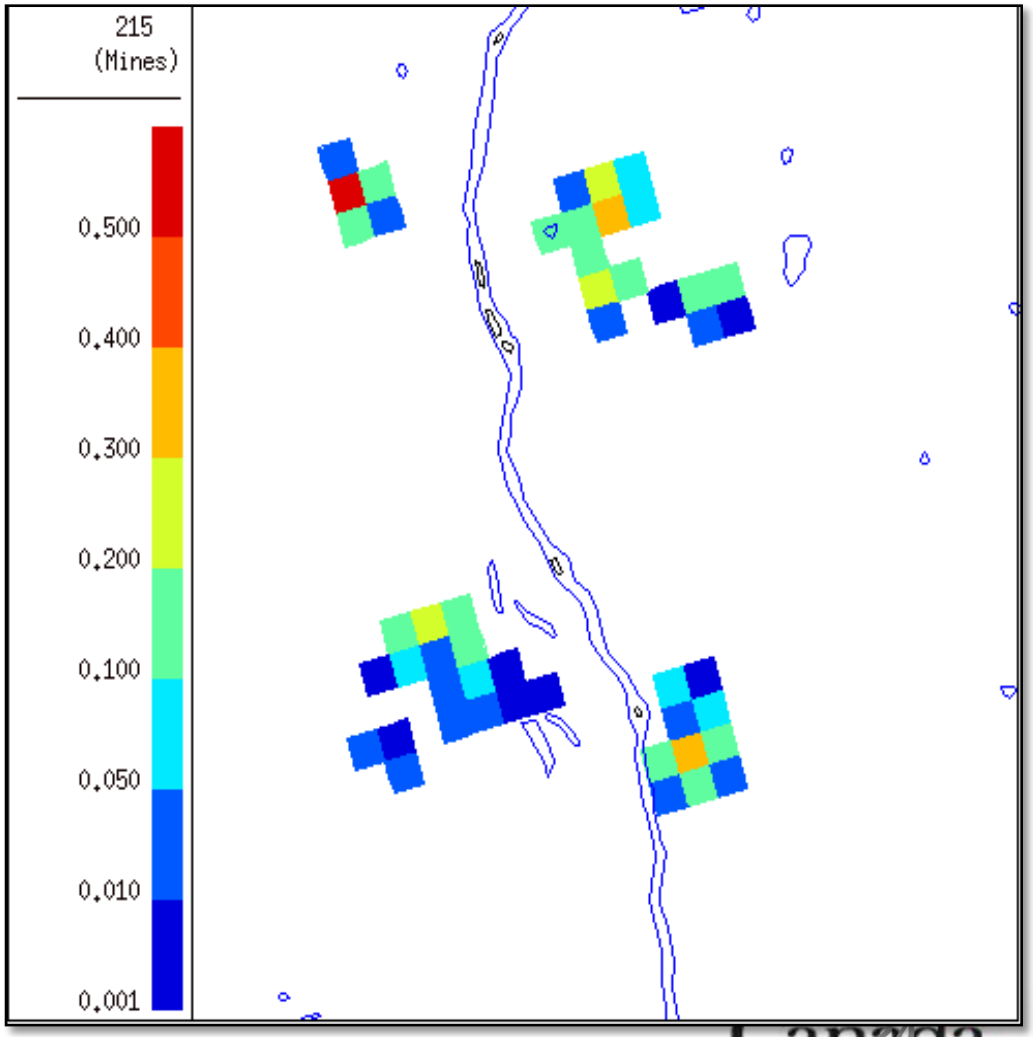
- It is not appropriate to treat emissions from each facility as point sources because of the large size (~ 10 km) of the facilities and the 2.5 km model resolution
- Spatial surrogates have been developed to allocate emissions *within* each facility to model grid cells



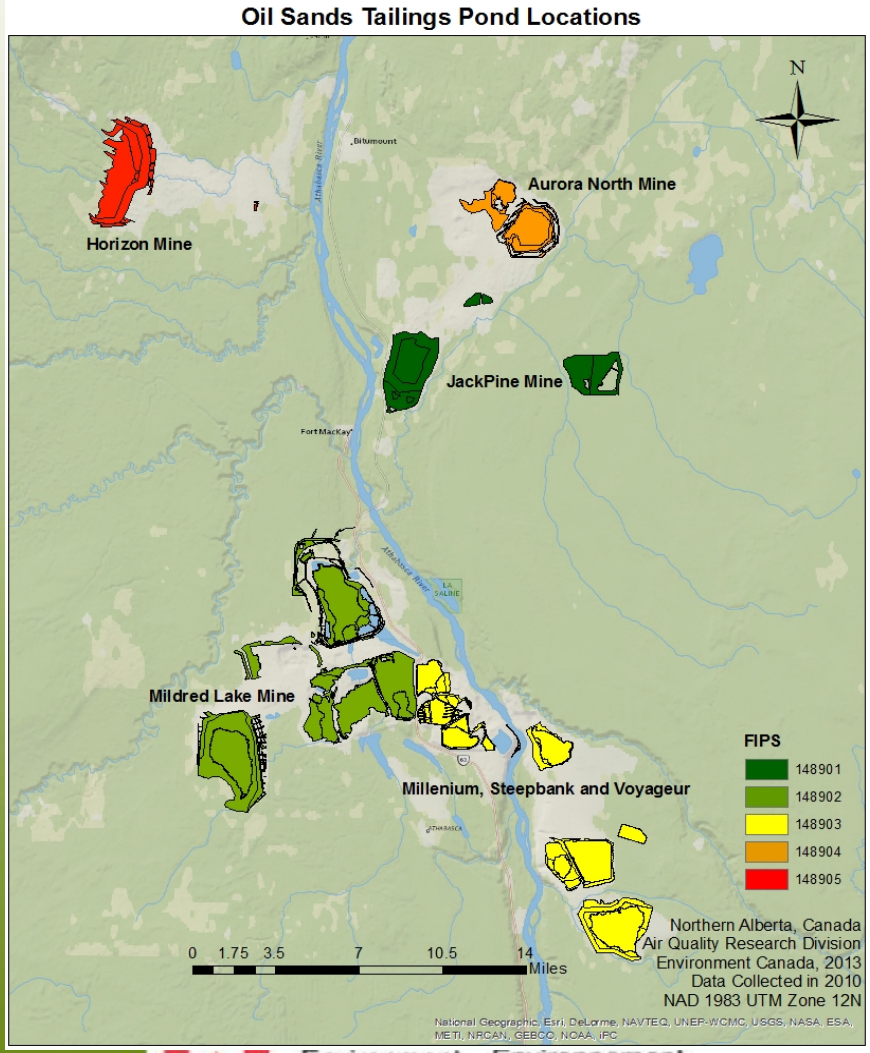
Operating Mine Pit Locations in 2010



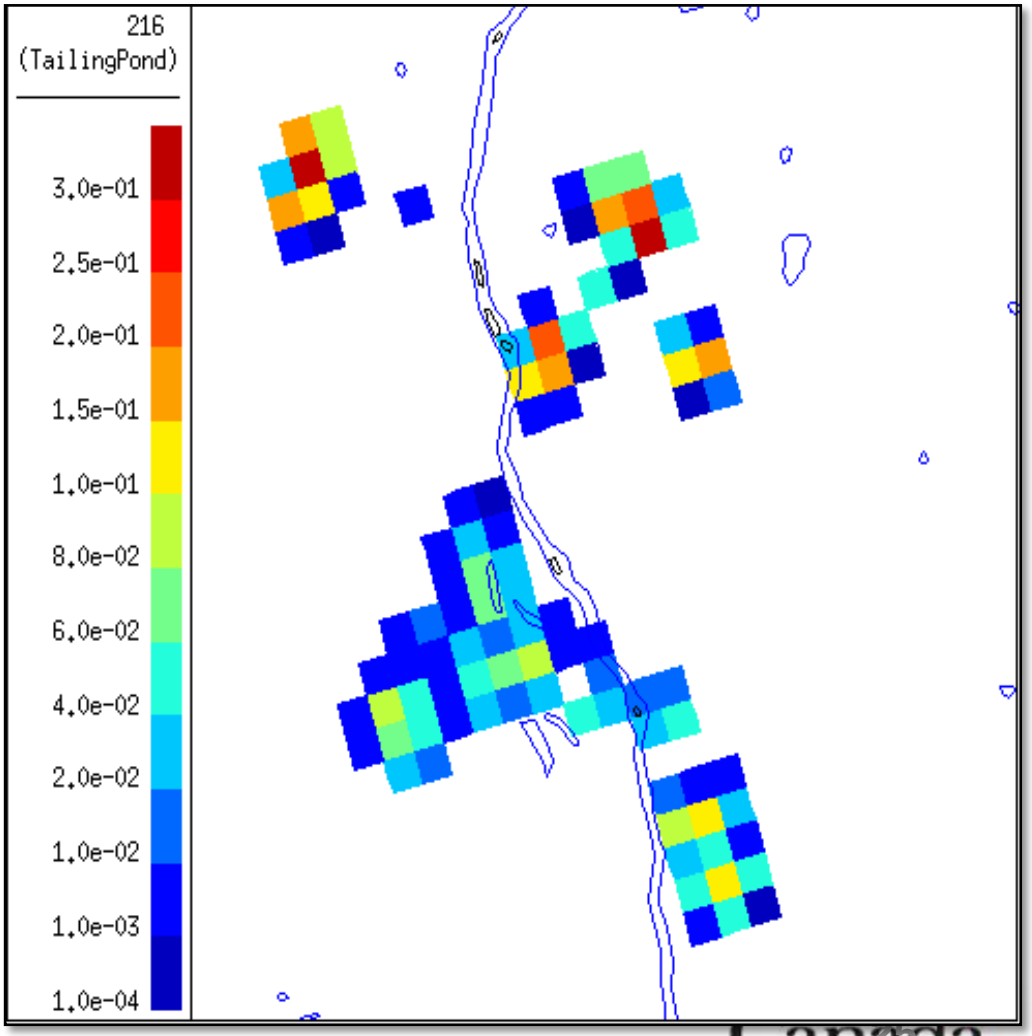
Spatial Surrogates Generated for Distributing Mine-Related Emissions



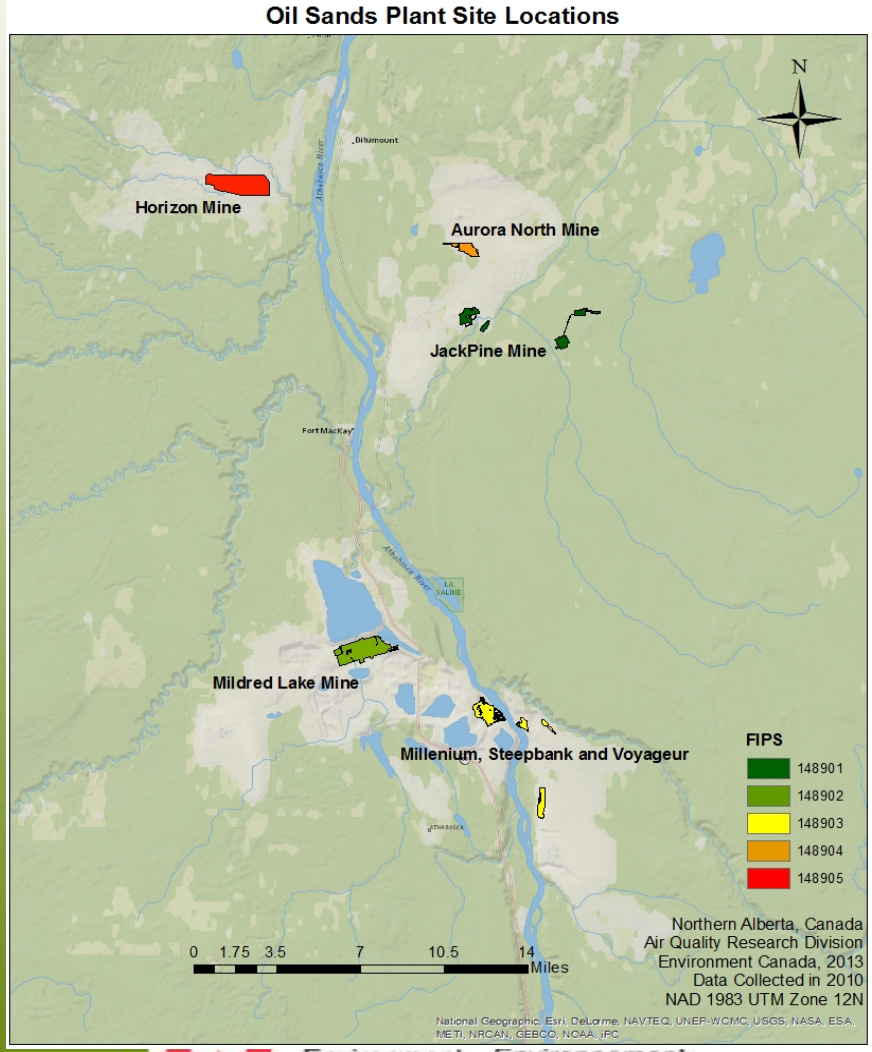
Existing Tailings Pond Locations in 2010



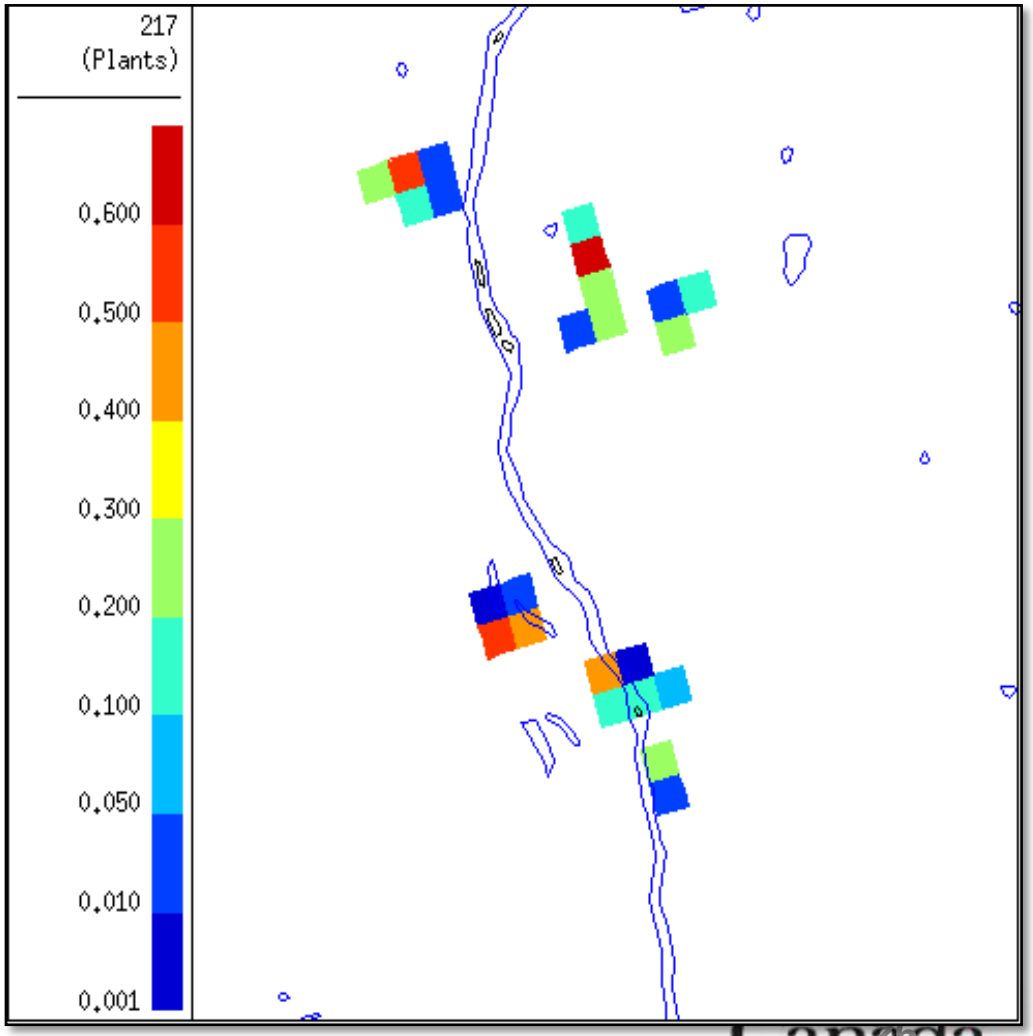
Spatial Surrogates Generated for Distributing Tailings Pond Emissions



Existing Plant Locations in 2010

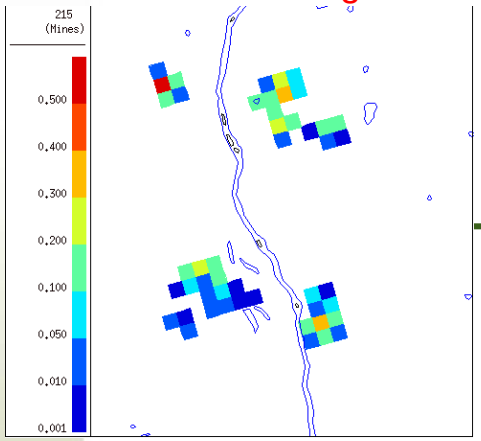


Spatial Surrogates Generated for Distributing Plant Emissions

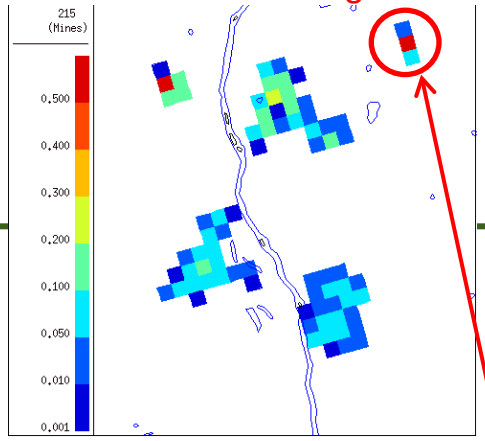


Updates to Spatial Surrogates for 2013 Field Study Based on 2013 Satellite Images

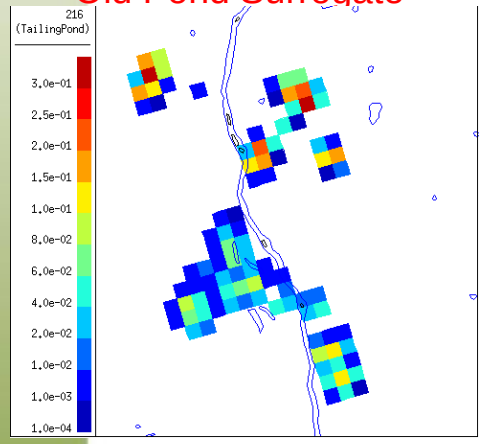
Old Mine Surrogate



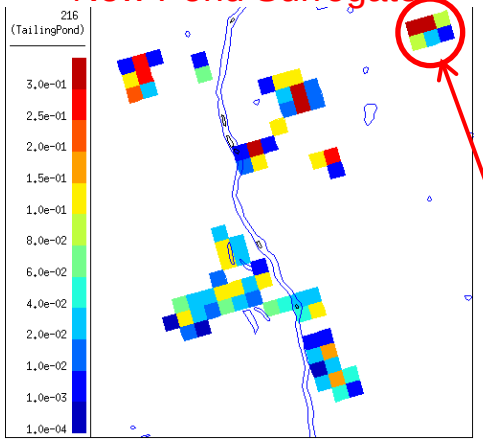
New Mine Surrogate



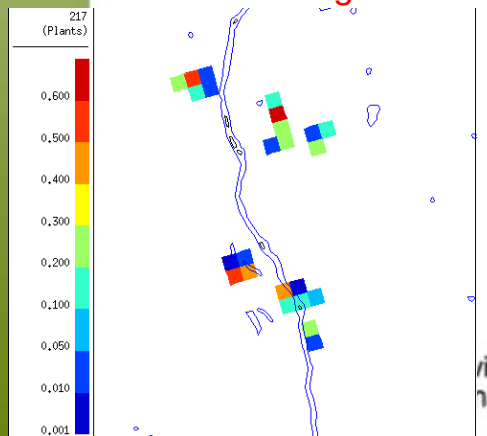
Old Pond Surrogate



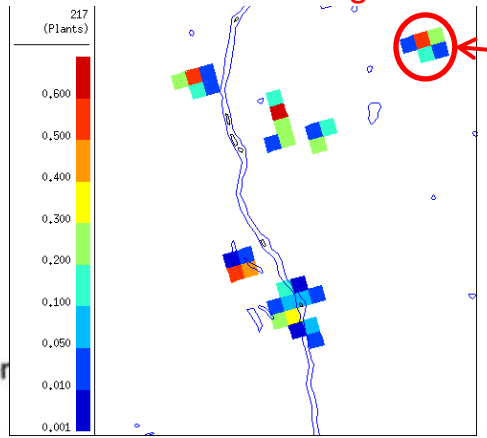
New Pond Surrogate



Old Plant Surrogate



New Plant Surrogate

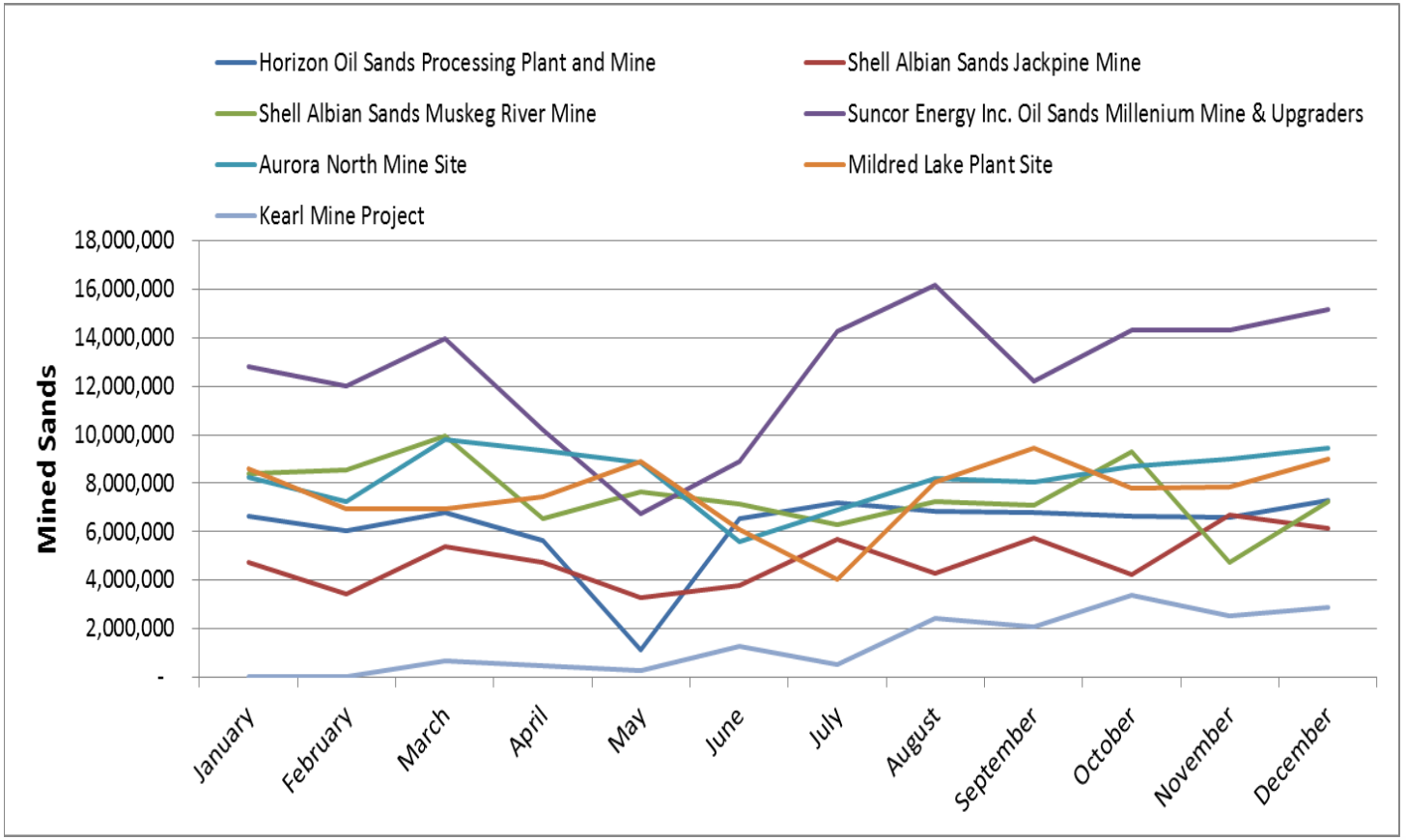


New Imperial Kearl Mine

Temporal Disaggregation of Emissions

- Inventories give annual totals, but hourly emissions are required by model
- Monthly temporal profiles were generated based on 2013 monthly statistics of mined oil sands (for mine fleet emissions) and bitumen production for each facility (for plant emissions). Weekly and diurnal profiles are assumed uniform under normal operating conditions

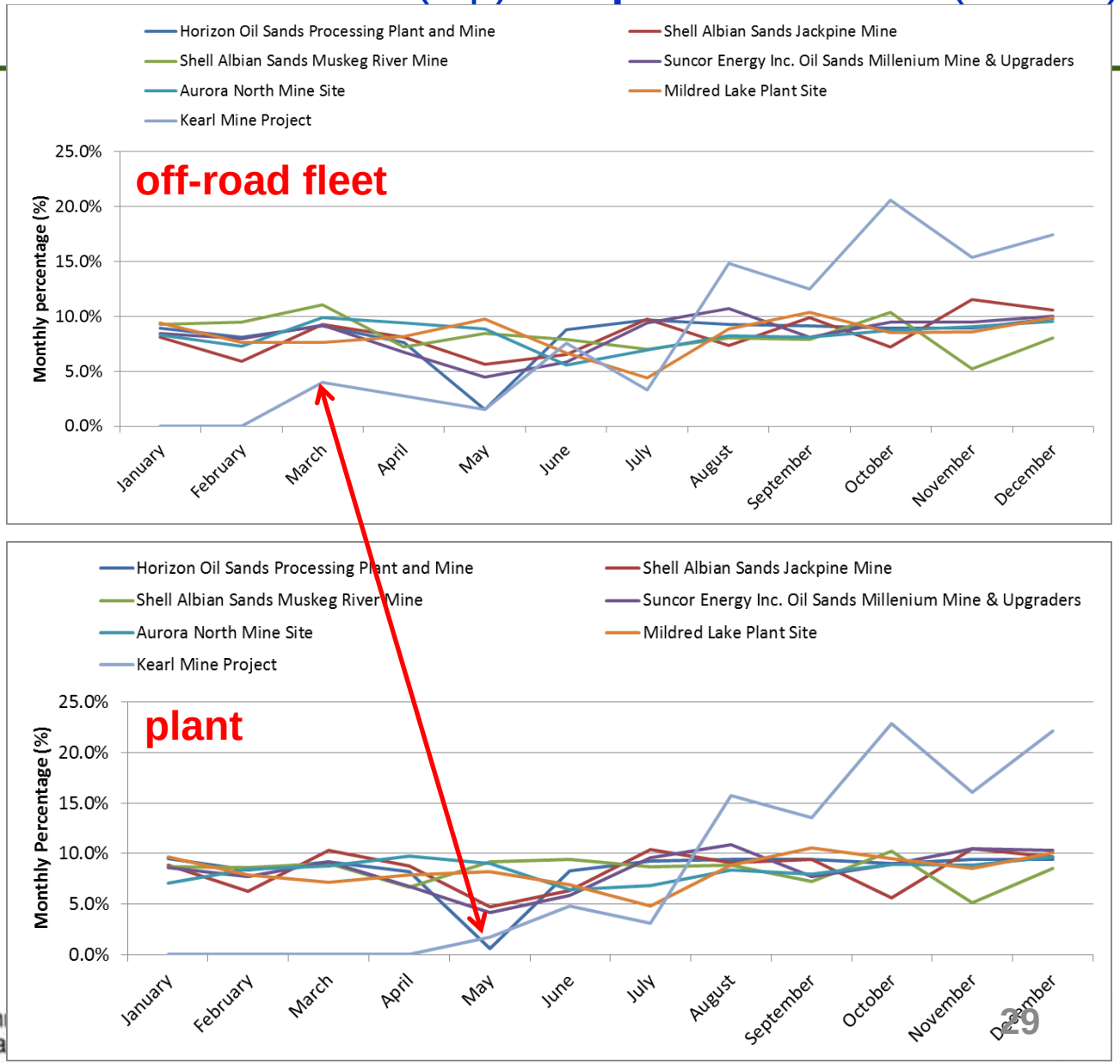
- Mined oil sands vary from month to month and from facility to facility
- Bitumen production statistics have a similar trend (not shown)



Temporal Disaggregation of Emissions(2)

Monthly profiles created for **off-road fleet** (top) and **plant** emissions (bottom)

- Temporal data sources: monthly "mined oil sands" for the off-road fleet emissions and "bitumen production" for plant emissions.
- The two monthly profiles generally resemble each other.
- There is about two months lag from extraction (March) of oil sands to significant bitumen production (May) for the new Kearl Mine facility



VOC Chemical Speciation

- Solvents used to extract crude bitumen from oil sands varies from facility to facility
- VOC emitted from different tailings ponds within the same facility can be different too
- Detailed VOC species (~300) are reported to NPRI by facilities under *Canadian Environmental Protection Act*. However, it is a facility total
- The CEMA inventory, on the other hand, has proposed VOC speciation profiles for various types of plants and tailings ponds
- Therefore VOC speciation profiles used were based on CEMA profiles

VOC Chemical Speciation (CEMA)

VOC Emitted from Plants

VOC Species	Integrated Extraction and Upgrading Plants (UPGRD)	Extraction only Plants (EXTRC)	In situ Plants (INSTU)
Paraffins carbon bond (C-C)	70.7	89.9	96.7
Terminal olefin carbon bond (R-C=C)	5	0.45	0
Toluene and other monoalkyl aromatics	5.7	0.13	0.12
Xylene and other polyalkyl aromatics	9.9	0.034	0.041
Formaldehyde	0.033	0.001	0
Acetaldehyde	0	0	0
Ethene	0.16	0.023	0
Isoprene	0.0041	0	0
Methanol	0	0	0
Ethanol	0	0	0
Internal olefin carbon bond (R-C=C-R)	0.62	0.29	0
Propionaldehyde and higher aldehydes	0.17	7.4	0
Terpene	1.3	0	0
TOTAL	93.5871	98.228	96.861

*** Based on limited speciation profiles at representative facilities**

VOC Chemical Speciation (CEMA)

VOC Emitted from Tailings Ponds

Solvent Type (If available)	Paraffinic	Hydrotreated Naphtha	Untreated Naphtha	N/A	N/A	N/A
Tailings Type/ VOC species	**Primary / Secondary (POND1)**	**Primary / Secondary (POND2)**	**Primary / Secondary (POND4)**	**Primary (POND3)**	**InPit (INPIT)**	**Recycle (POND5)**
Paraffins carbon bond (C-C)	54.42	51.33	62.58	55.05	63.31	53.85
Terminal olefin carbon bond (R-C=C)	0.47	0.3	7.15	2.42	1.02	11.07
Toluene and other monoalkyl aromatics	0.42	0.71	6.31	10.82	15.94	12.08
Xylene and other polyalkyl aromatics	40.11	44.7	22.46	20.18	14.64	21.16
Formaldehyde	0.05	0	0.079	0.066	0.1	0.081
Acetaldehyde	0.0075	0	0	0.014	0.05	0
Ethene	0	0	0	0	0.0025	0
Isoprene	0.019	0	0	0.0023	0.0008	0.0043
Methanol	0.23	0	0	0.89	0.00041	0
Ethanol	0.0046	0	0	0	0.00033	0
Internal olefin carbon bond (R-C=C-R)	0.37	0.26	1.04	1.49	0.15	1.29
Propionaldehyde and higher aldehydes	0.24	0.036	0.017	0.24	1.18	0.012
Terpene	0.64	0.11	0	0.15	0.49	0
TOTAL	96.98	97.45	99.64	91.3	96.8	99.5

***Mostly based on surface flux chamber measurements conducted at representative facilities**

AQ Model Forecast for Flight Planning during the Field Study

104 km length, 100 km radius: 20 minutes + 3 minutes turn time per leg. 4 cross-sections = 92 minutes

Centroid: 57°51'5.18" N 111°32'54.31" W
= 57° 51.0863333' N, 111° 32.90516667' W

105 km length, 50km radius: 20 minutes + 3 minutes turn time per leg.
3 cross-sections = 69 minutes each (do twice).

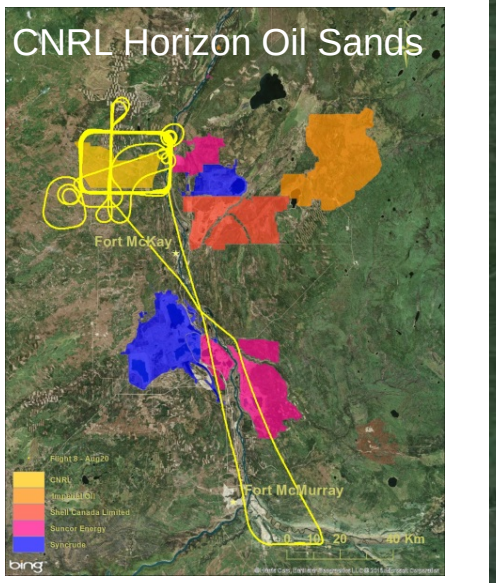
+ 50 km to first cross-section from airport
+50km back from first cross-section to airport
+ 50km return between cross-sections = 40 minutes.

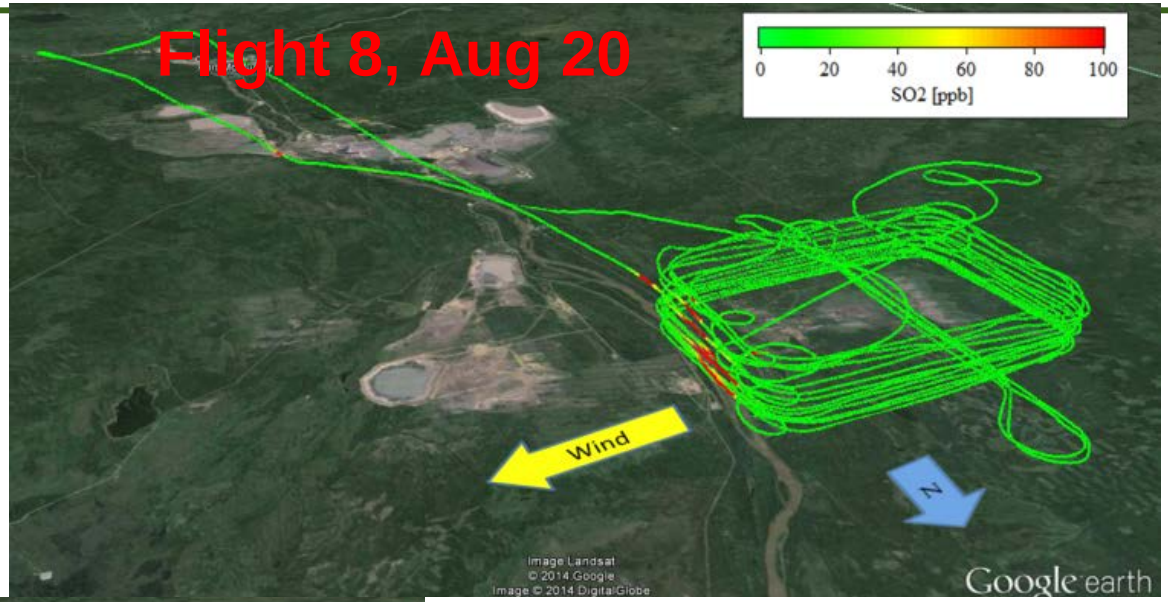
Aircraft Campaign During the 2013 Summer Study

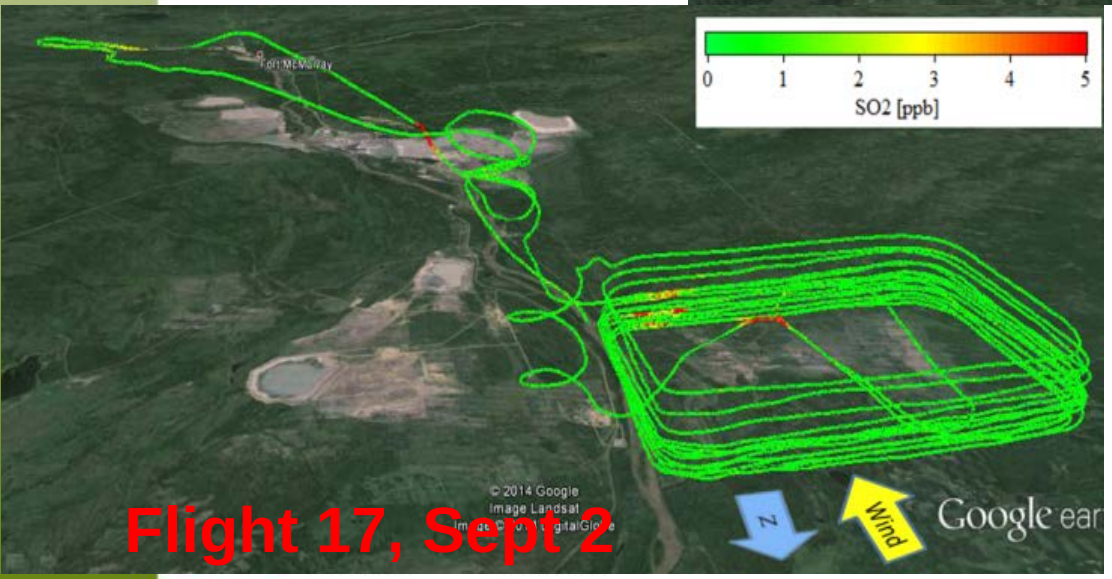
- 22 flights (84 hours airborne) were flown during Aug. 13 – Sept. 7 period in support of the following goals:
- To provide data for satellite retrieval validation
- To understand the transport and transformation of primary pollutants
- **To quantify emissions of criteria air contaminants (CACs) and other air pollutants through ambient air measurements in the oil sands region**
- **To evaluate and improve a high-resolution air quality model – GEM-MACH model**

Emissions Estimation Based on Aircraft Observations

Top-down Emission Rate Retrieval Algorithm (TERRA: *Gordon et al., 2015)*







1) Aircraft measured high SO2 emissions during abnormal operation event on Aug. 20
2) Primary results showed that uncertainty of the TERRA estimation is within 20% of observed / reported emissions.
3) Detailed VOC species observed by aircraft will also be used to evaluate current VOC speciation for AQ modeling

Conclusions

- This work has resulted in an **improved emissions inventory** in the study area for the JOSM project
- Emissions inventory analysis is an important step for emissions processing
- For large facilities, spatial allocation of emissions within a facility is necessary for high-resolution modeling
- The inventory used should match the modelling period as closely as possible, particularly for the Oil Sands area due to its rapid development
- Aircraft observations can provide valuable information for top-down emissions estimation
- Work is ongoing to further improve the inventory being used for GEM-MACH modelling for the oil sands

THANK YOU