A preliminary evaluation of GHGSat for methane emissions monitoring over Canada

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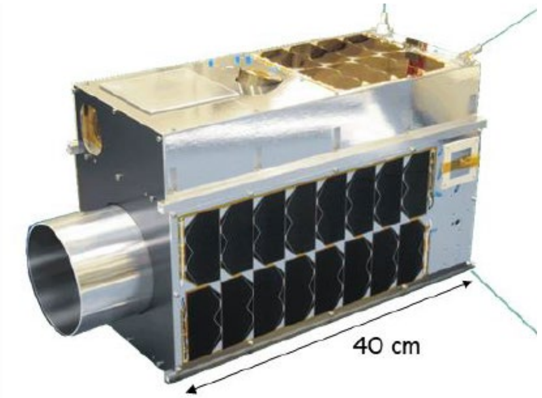
ESA Living Planet Symposium • 2022 May 26


Depiction of GHGSat

GHGSat (https://www.ghgsat.com/en/)



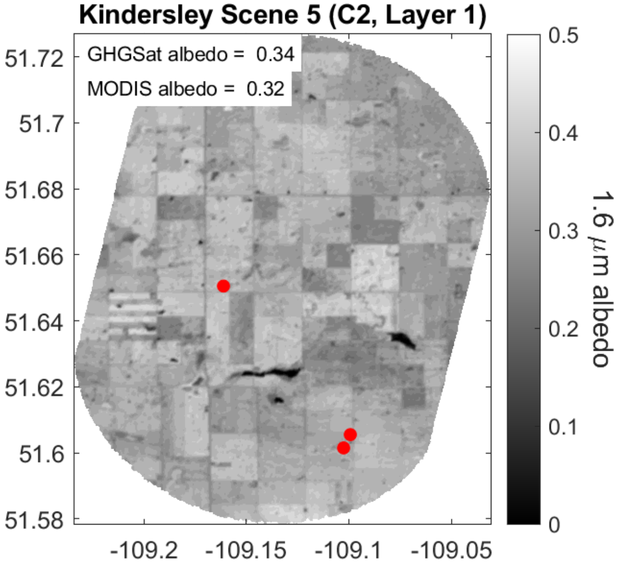
- A small, Canadian company that develops and launches its own satellites to monitor methane emissions
  - GHGSat-D (Claire) launched in 2016 -- Demonstration and some commercial
  - GHGSat-C1/C2 (Iris/Hugo) launched in 2020/21 -- First commercial sensors
  - C3-C5 successfully launched May 25, 2022
  - Plan to launch C6-C12 by end of 2023 (with C12 being for CO_2 emissions)
- These are micosatellites (15 kg); high-spatial resolution (25-50 m); acquisition currently limited to one ~12x12 km^2 scene per orbit (~450 scenes per month per satellite)
- GHGSat uses Fabry-Perot spectrometers that observe reflected sunlight spectra in the shortwave IR, 1.6 μm
- Instrument and algorithm paper, and emissions from GHGSat-D published in the scientific literature
  - First results from C1 should be published soon

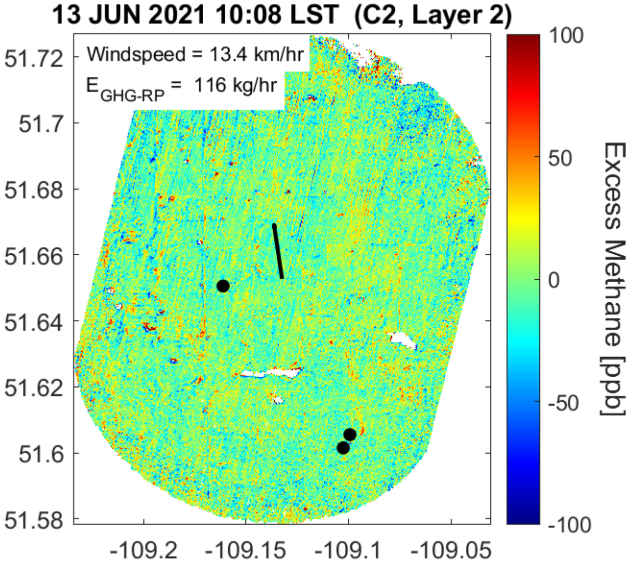
Goals of this study

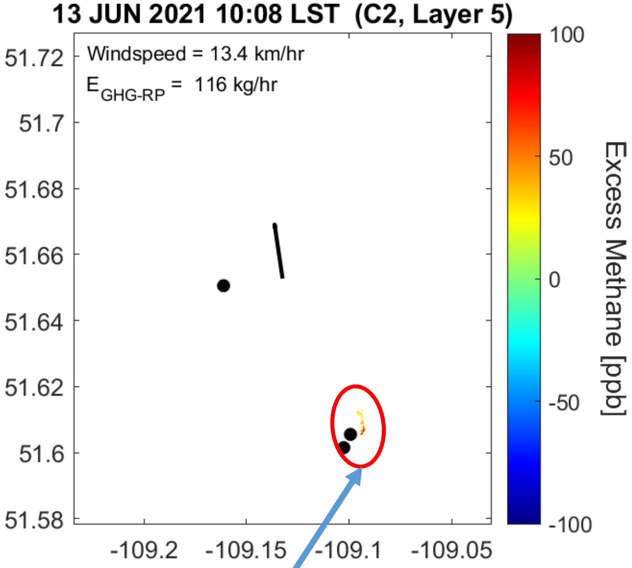
- To better understand GHGSat capability for methane emissions monitoring over Canada; to accomplish this:
  - Quantify the precision of the retrieved (excess) methane, the emissions detection limit, and other important quality parameters
  - Use a combination of GHGSat data and plume modelling, combined with different emissions algorithms
  - Address how GHGSat would support applications such as Canadian regulatory reporting

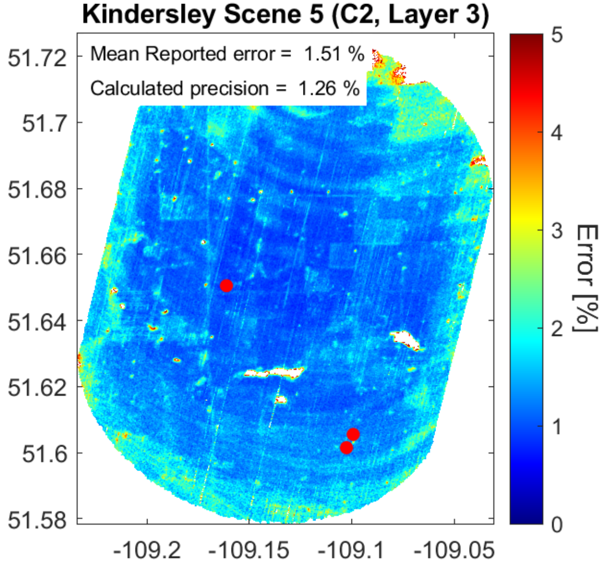
- Currently (May 2022), ECCC has acquired ~140 scenes for analysis
  - Some from a European Space Agency-sponsored project “Evaluation of GHGSat-Iris observations of methane for emissions monitoring over Canada”; other from contracts
  - Roughly equal numbers from GHGSat-C1 (C1) and GHGSat-C2 (C2)
  - Of the 140, 5 of these scenes have a plume detected; 5 others are “maybe”

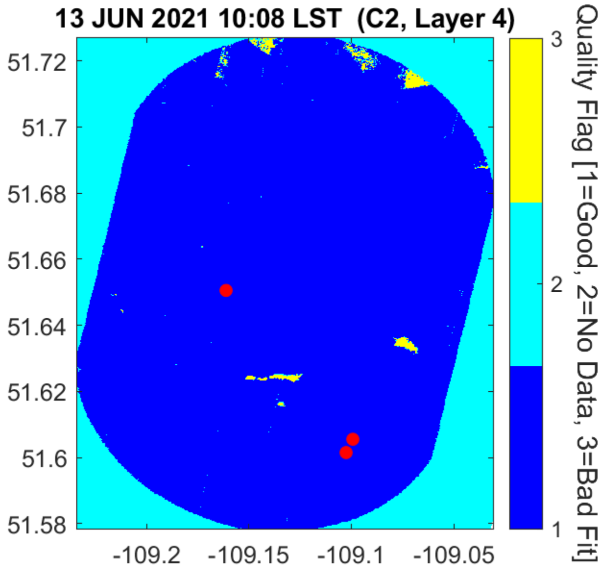
Best Example: Kindersley, Saskatchewan – 13 June 2021 – plume detected

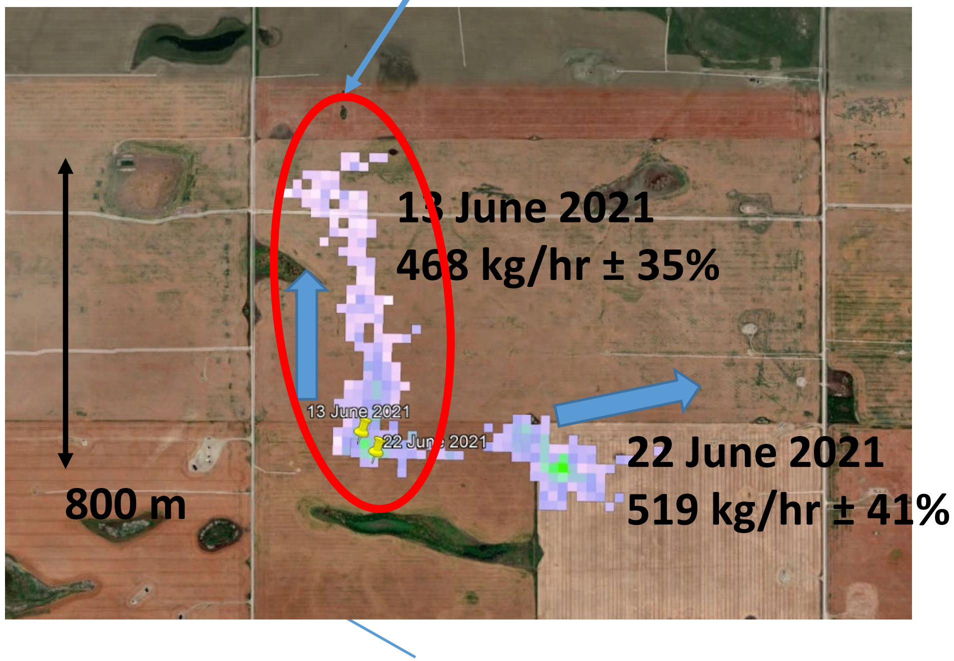

Kindersley Scene 5 (C2, Layer 1)


13 JUN 2021 10:08 LST (C2, Layer 2)


13 JUN 2021 10:08 LST (C2, Layer 5)


Kindersley Scene 5 (C2, Layer 3)


13 JUN 2021 10:08 LST (C2, Layer 4)



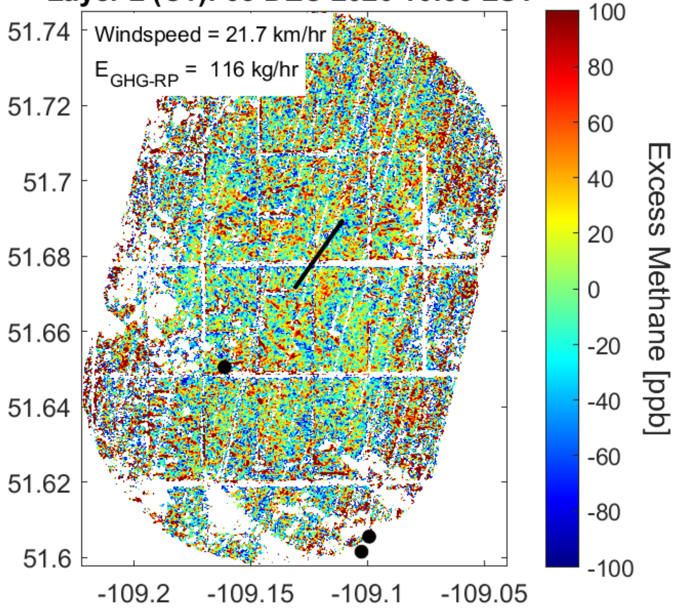
13 June 2021
468 kg/hr ± 35%

22 June 2021
519 kg/hr ± 41%

Other Examples

C1

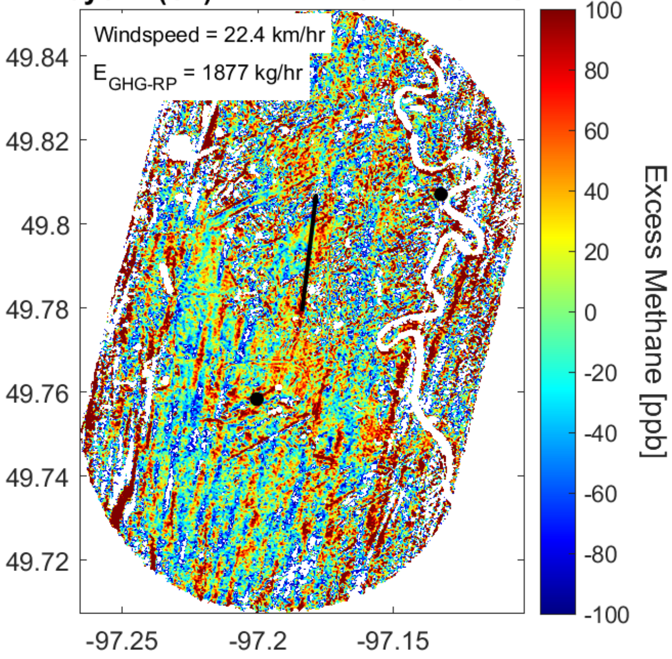
Layer 2 (C1): 03 DEC 2020 10:59 LST



Windspeed = 21.7 km/hr

E_{GHG-RP} = 116 kg/hr

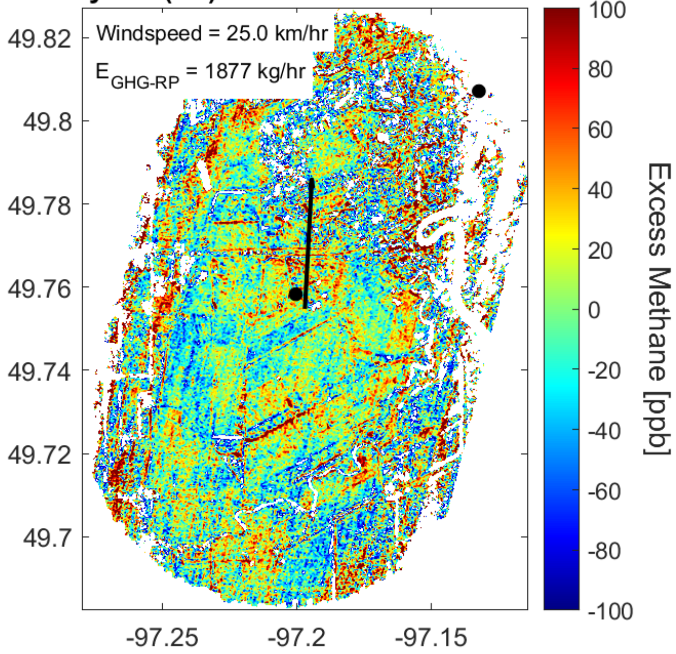
Layer 2 (C1): 12 MAR 2021 11:07 LST



Windspeed = 22.4 km/hr

E_{GHG-RP} = 1877 kg/hr

Layer 2 (C1): 07 OCT 2021 10:54 LST

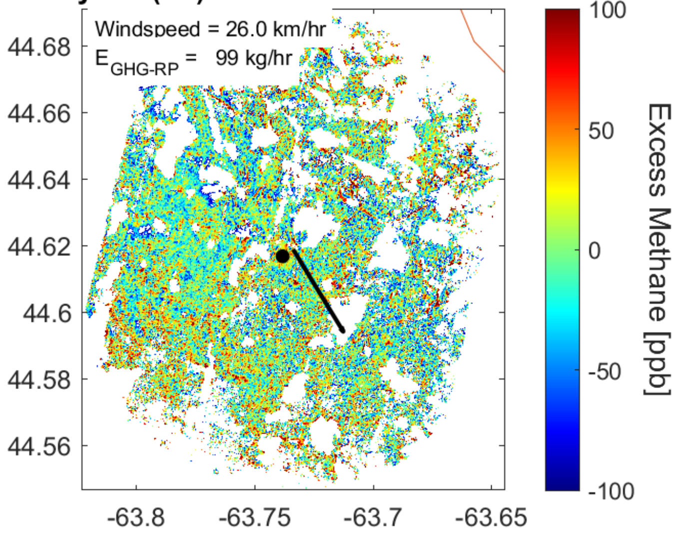


Windspeed = 25.0 km/hr

E_{GHG-RP} = 1877 kg/hr

C2

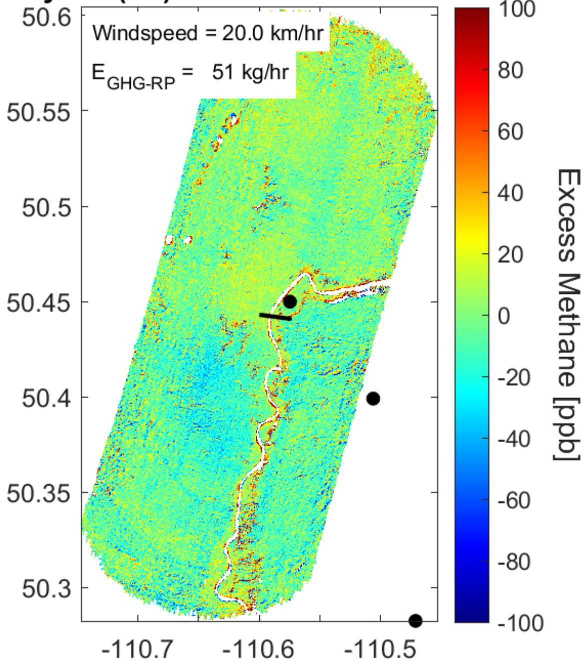
Layer 2 (C2): 11 NOV 2021 10:02 LST



Windspeed = 26.0 km/hr

E_{GHG-RP} = 99 kg/hr

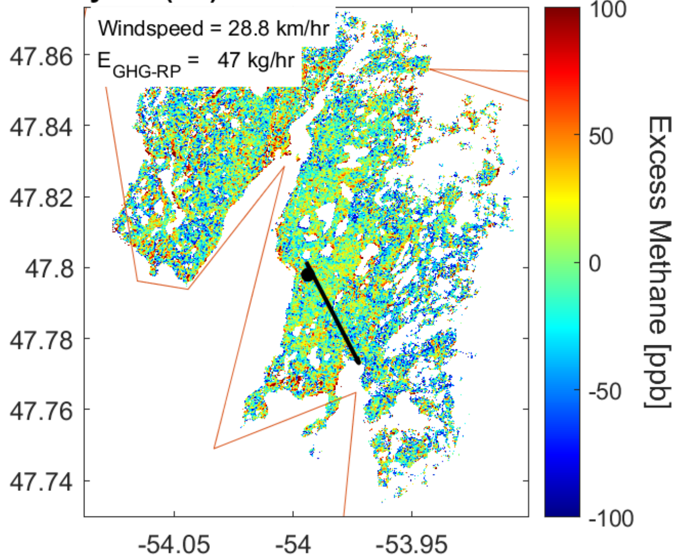
Layer 2 (C2): 10 NOV 2021 10:15 LST



Windspeed = 20.0 km/hr

E_{GHG-RP} = 51 kg/hr

Layer 2 (C2): 06 NOV 2021 09:60 LST

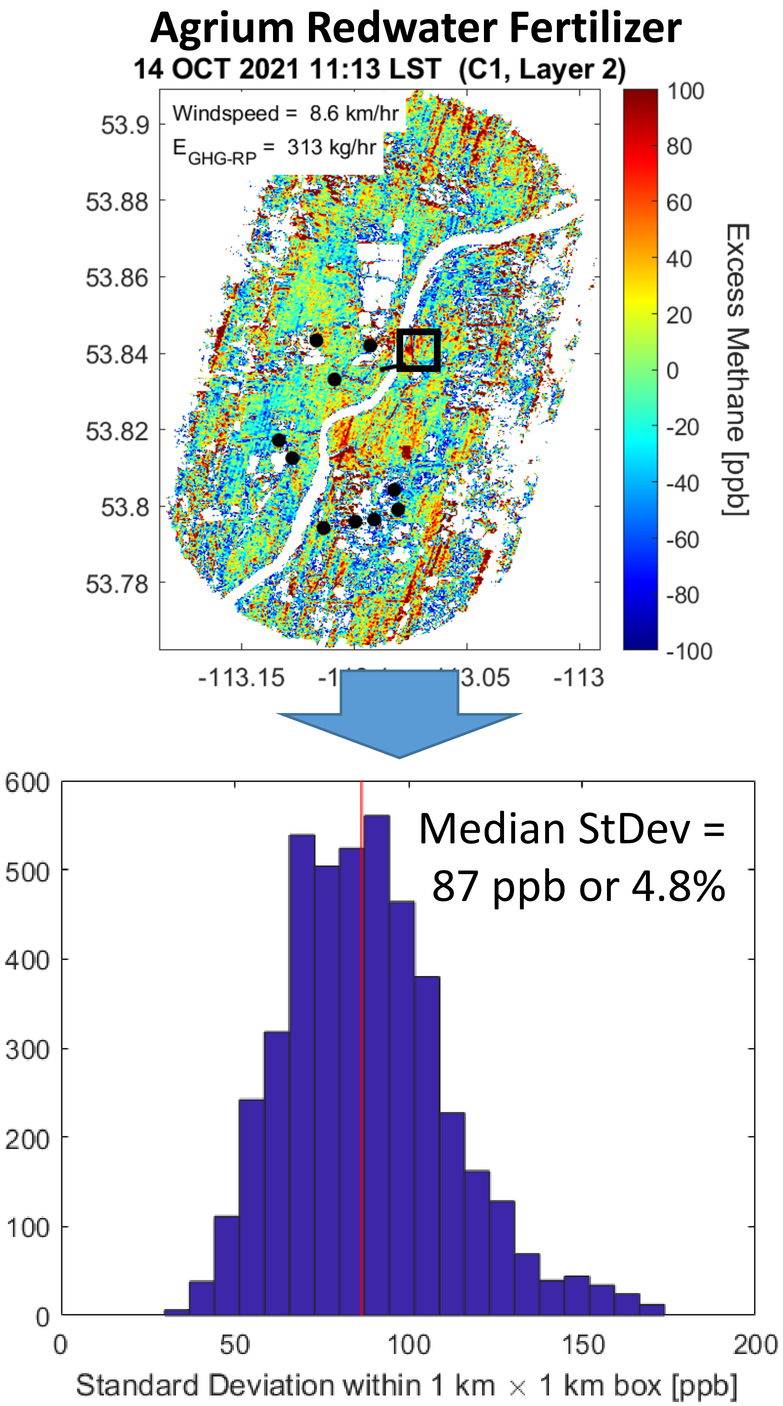


Windspeed = 28.8 km/hr

E_{GHG-RP} = 47 kg/hr

Scene analysis

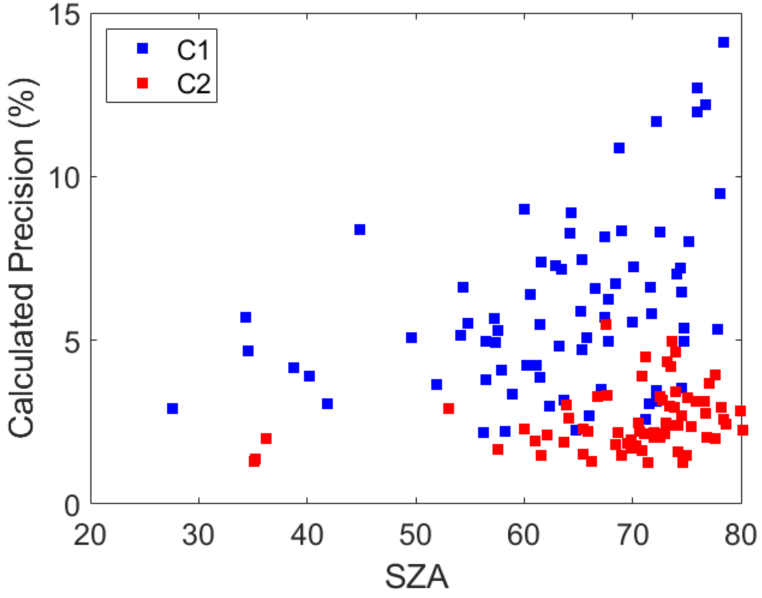
- Precision is estimated from the excess-methane scenes
  - ➢ Assume that the variability in the excess methane across a scene is dominated by random errors from the instrument and retrieval
  - ➢ Calculate the standard deviation or RMS over some portion of the scene
  - ➢ Use this median as the precision
    - ❑ Move 1 x 1 km^2 box around over domain; Require >1/2 of pixels within box to be "good"; Allows for real variability, or larger scale effects


Agrium Redwater Fertilizer

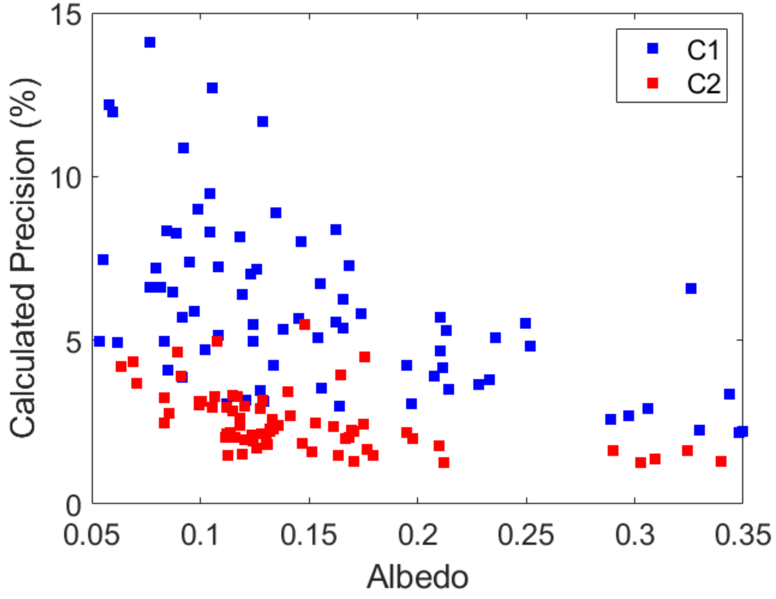
14 OCT 2021 11:13 LST (C1, Layer 2)

Median StDev = 87 ppb or 4.8%

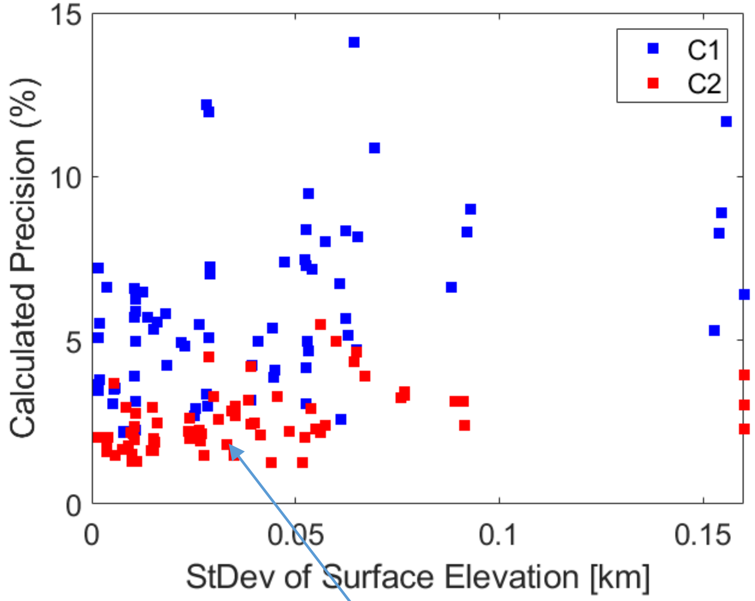
C1 shows worse precision with low Sun; C2 less obvious



better precision over brighter surfaces



Uneven terrain leads to worse precision



- A reliable precision model will allow an estimate of expected precision at locations or times of year where we do not have observations
- Scenes were fit to a multi-linear model

$$\sigma = a_1 + \underset{\text{Sun angle}}{\boxed{a_2 \cdot \mu + \frac{a_3}{\mu}}} + \underset{\text{Reflectivity}}{\boxed{a_4 \cdot \lambda}} + \underset{\text{Surface}}{\boxed{a_5 \cdot z}}$$

The better performance of C2 is due to the inclusion of an additional filter limiting the wavelengths and other modifications

σ is precision; a_i are the fitted coefficients;

μ is ~1-airmass, $\mu = 1/\cos\theta_0$, and θ_0 is the solar zenith angle

λ is the surface albedo – GHGSat scene-average used in fit

z is the standard deviation of elevation over a scene

Scene analysis

- The C1 multi-linear fit yields, for σ in %:

$$\sigma = -2.58 + \underbrace{2.22\,\mu + \frac{7.21}{\mu}} - 10.14\,\lambda + 27.35\,z$$

This indicates precision improves with larger SZA, until about 56^{o}, where is gets worse

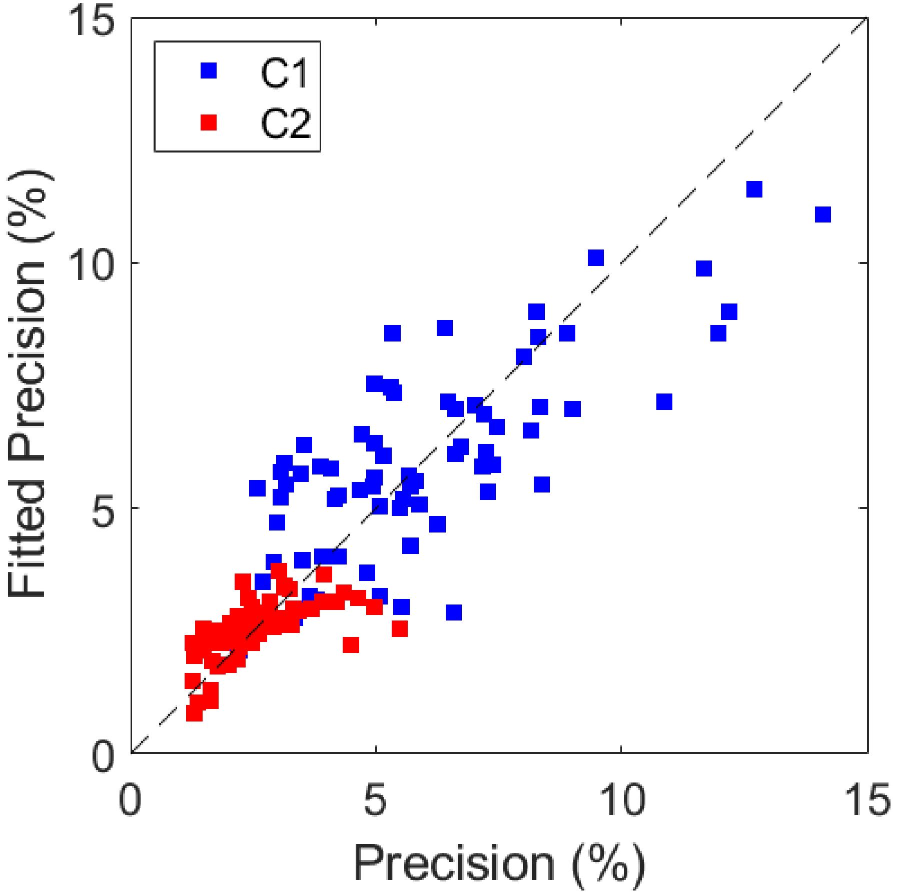
This means an increase in albedo of 0.1 leads to roughly a 1% improvement in precision

Going from a z of 0 to 0.15 km makes the precision worse by 4%

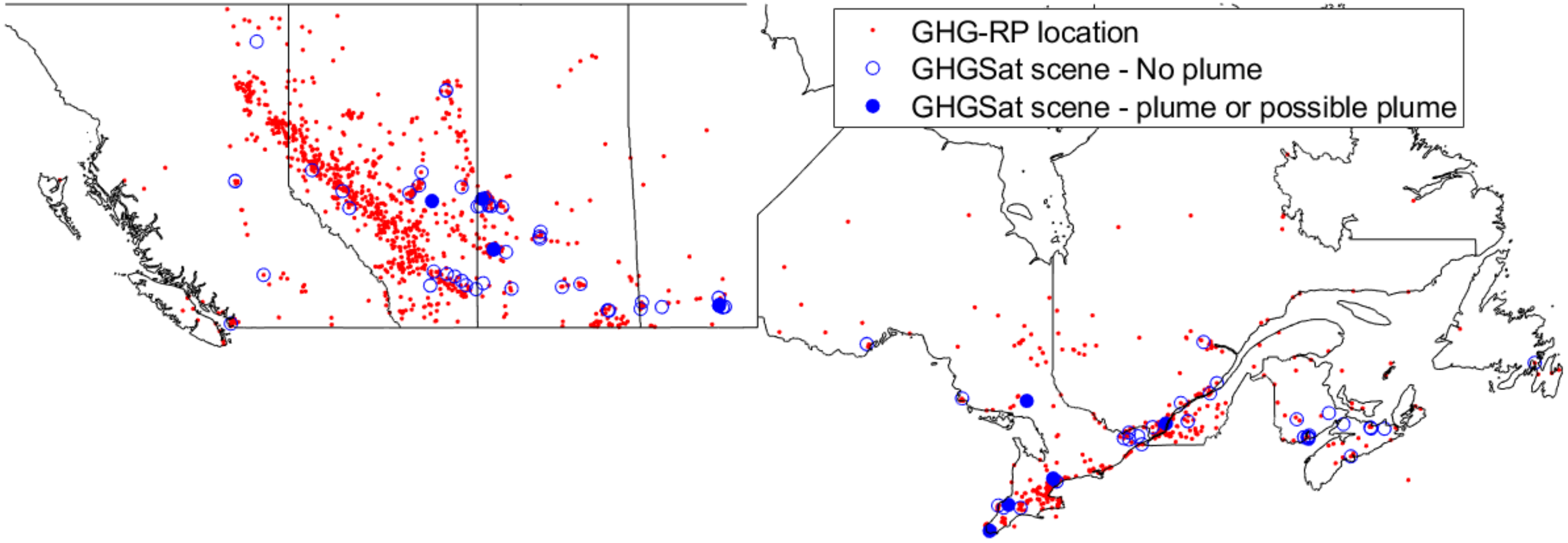
- C2:

$$\sigma = 2.38 + 0.19\,\mu + \frac{0.49}{\mu} - 6.71\,\lambda + 8.37\,z$$

Correlation (C1+C2) = 0.87

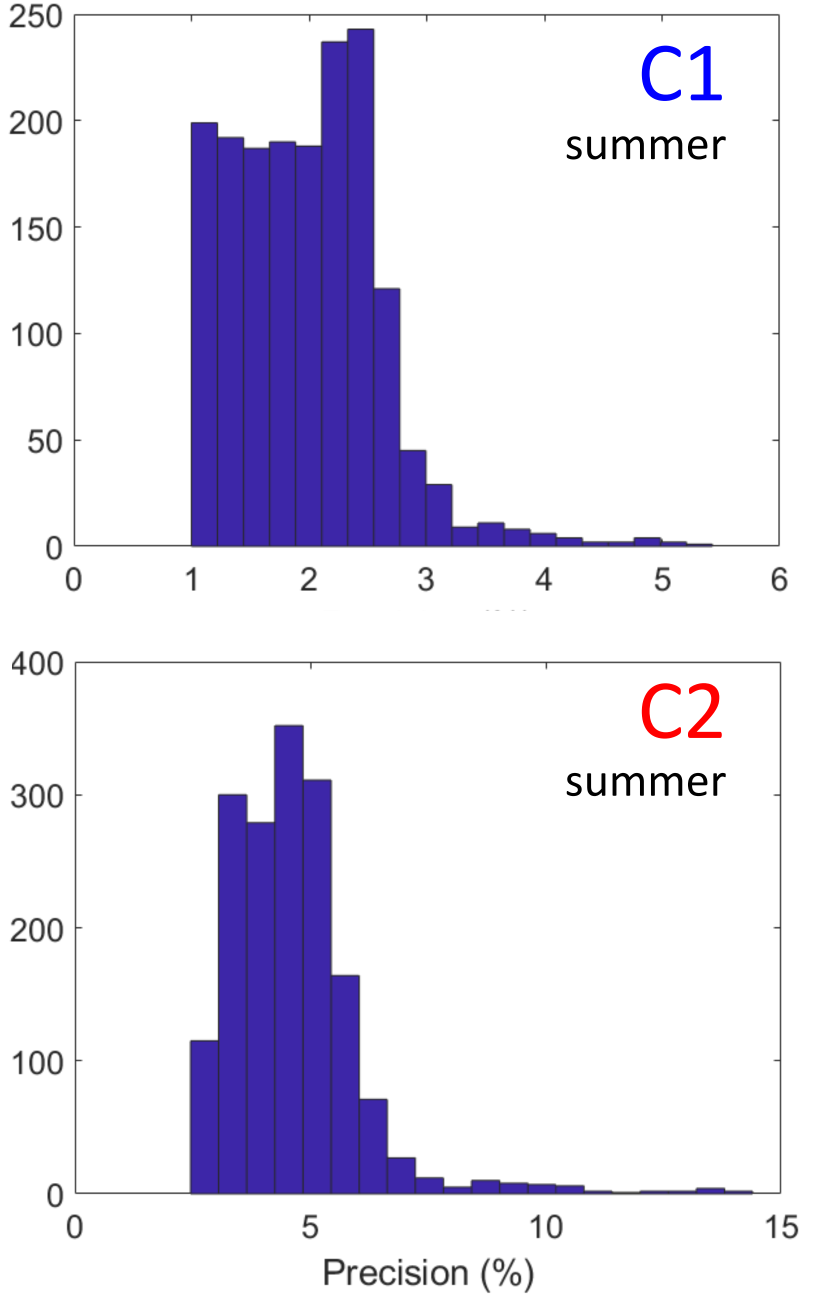


Scene analysis



Satellite	Mean calculated precision [%]	Mean fitted precision [%]	Mean prediction over GHG-RP locations [%] (summer / winter)
C1	5.9	5.9	4.6 / 6.9
C2	2.5	2.5	2.0 / 2.7

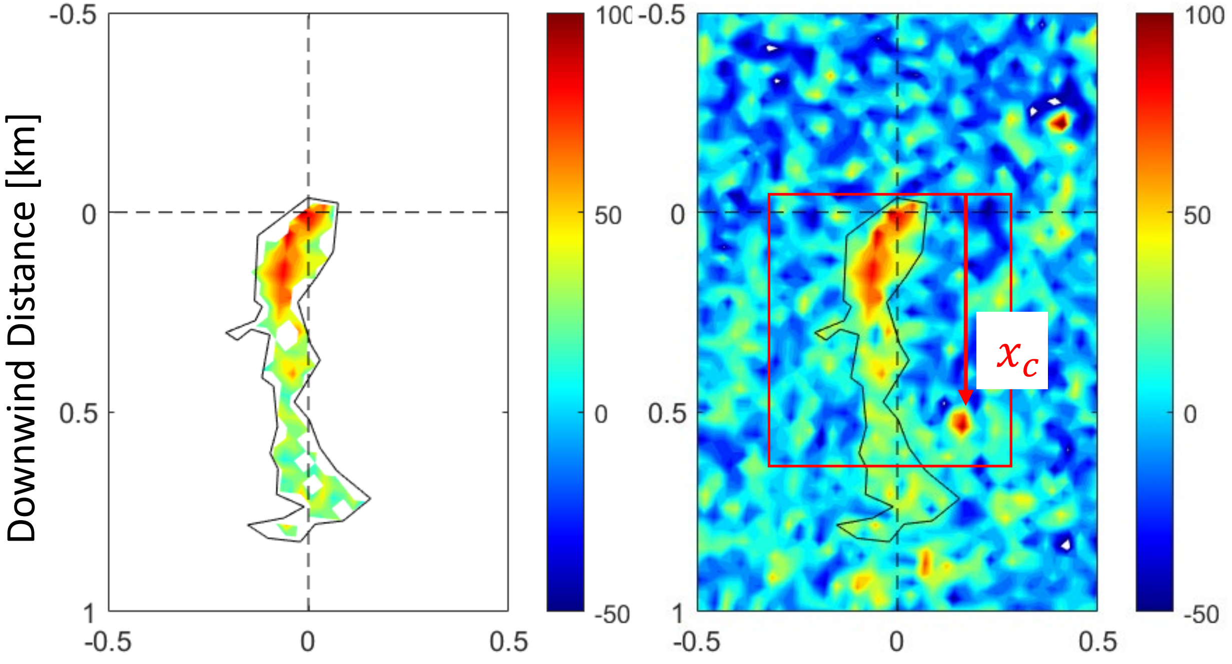
Precision prediction over all GHG-RP locations



Calculating Emissions

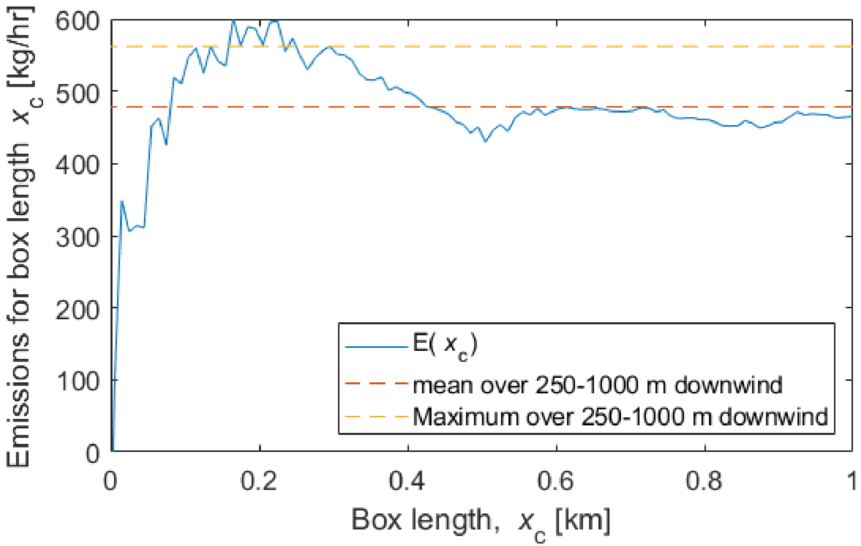
- Multiple approaches will be used to calculate emissions on both real and simulated GHGSat observations; these all require wind information which is obtained from a forecast or reanalysis
- Initially we are using a variant of the Integrated Mass Enhancement method (IME)

e.g., Kindersley, 13 June plume, rotated so wind out of north

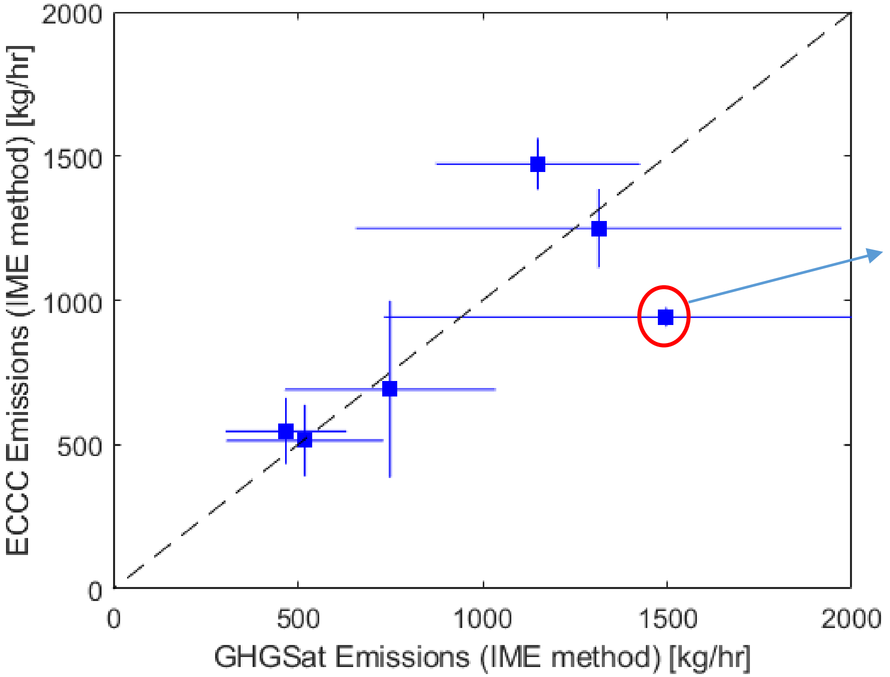

Excess methane

No Plume mask

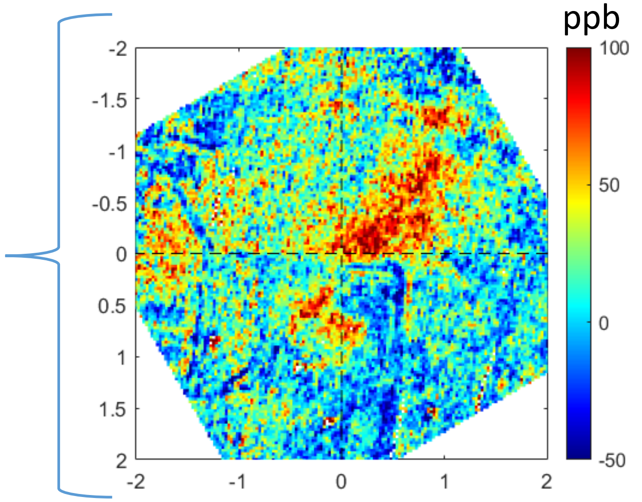
- An initial effort is to explore an IME method $[\boldsymbol{Q = m \cdot u / x_c}]$
- Bias removal using a plane (no plume mask), fit to the excess methane using data within 2 km, but outside of the plume zone box



Emissions



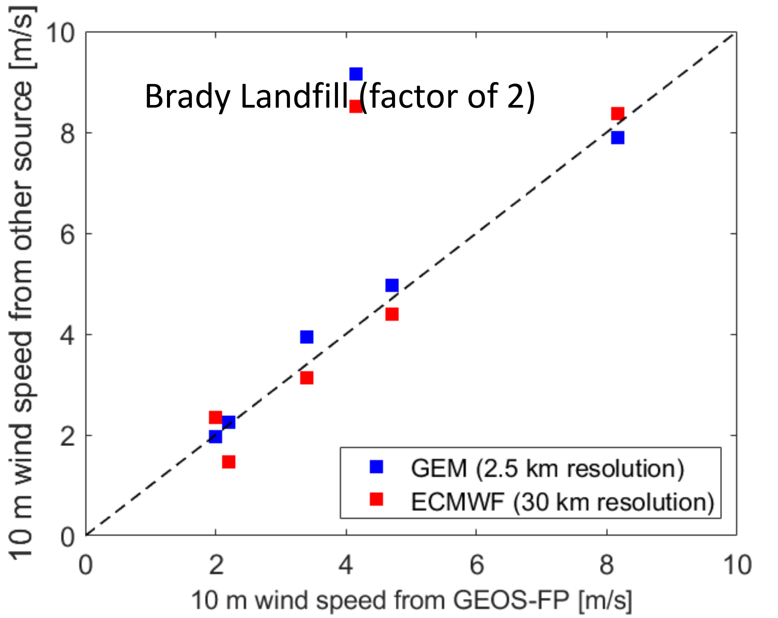
Lachenaie Landfill, 24 July 2021



More complicated plume, wind direction changing downwind

- Source of winds can be important

Comparison of wind speed from different centres



Brady Landfill (factor of 2)

Caveats:

- The GHGSat-identified emissions co-ordinates were used in the ECCC analysis
- **ECCC-IME uncertainties are not complete – they do not include wind speed and other terms**

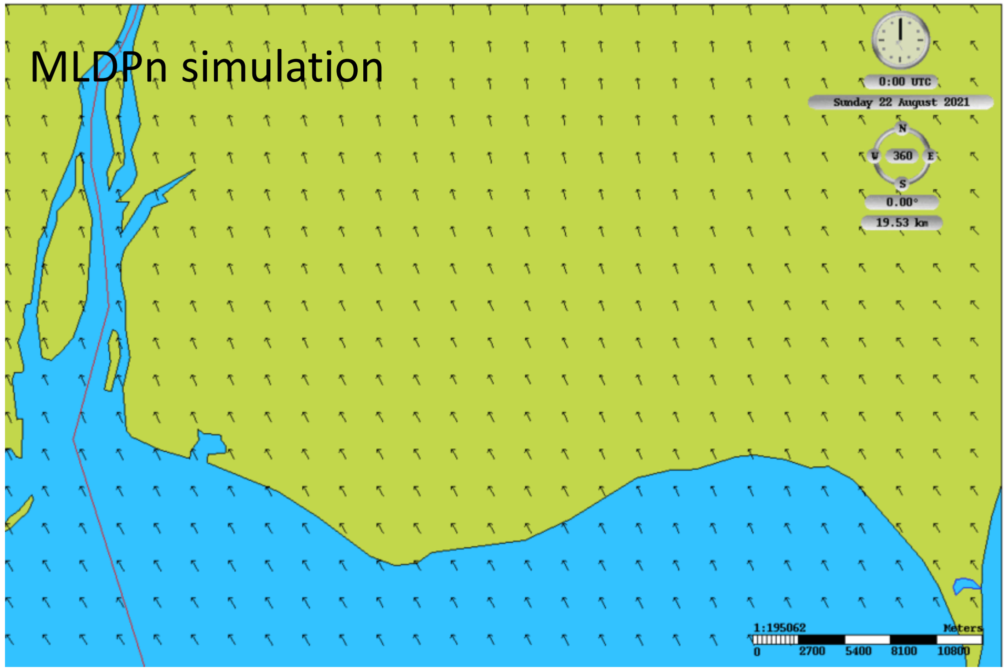
Initial takeaways

- Very Good agreement for 4 of 6 plumes; exploring additional methods for more complex plumes
- Windspeed important but products can sometimes vary widely

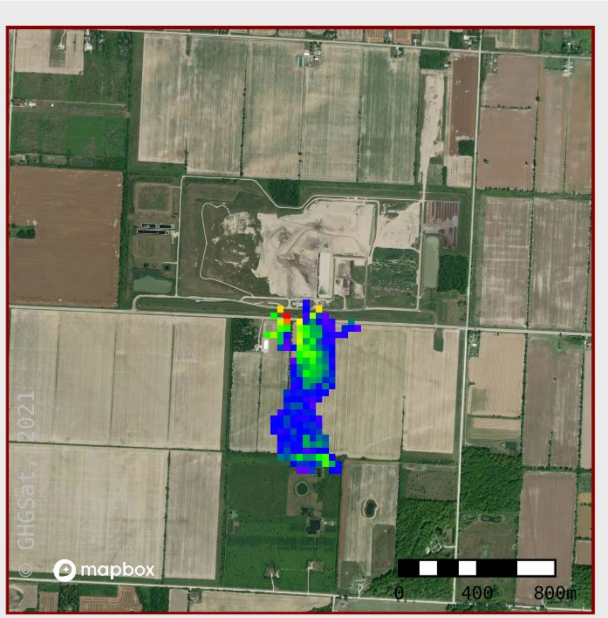
Creating synthetic GHGSat observations

- Purpose: To better understand GHGSat emission uncertainties and detection limits, particularly at locations where we do not have actual observations
- Use the ECCC emergency response plume model*, and add noise appropriate for that location/observation, date/time, and satellite → apply emissions algorithms

  * MLDPn (Modèle Lagrangien de dispersion de particules d'ordre n), doi:10.1080/07055900.2014.1000260



MLDPn simulation



GHGSat-C1 plume observed at 16:25 UTC

Summary and Next Steps

- Sun angle, albedo, and terrain roughness explain most of the scene-to-scene variability in precision and can be used to predict the precision at other locations
- Integrate additional emissions approaches into analysis and conduct more thorough comparisons
- Generate more synthetic GHGSat scenes to test emissions algorithms and estimate detection limits
- Possibly acquire additional scenes during summer; possibly from newer (C3-C5) satellites
- Co-ordinating GHGSat overpass with blowdown event – comparing bottom-up emissions with different algorithms applied to GHGSat observations
- Place results in context of Canadian methane emissions