Beyond the Graticule: Spatially Explicit Methane Inventories Using Discrete Global Grids

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Problem: Inadequate Spatial Grids Limit Action

Existing GHG inventories are spatially inconsistent, poorly georeferenced, and difficult to integrate. Particularly, gridded methane inventories are often built on **latitude–longitude grids** (graticule), which vary in cell size and shape across latitudes. This introduces spatial inconsistencies that:

- Inflate emission densities in high-latitude regions
- Complicate direct inter-cell comparisons and integration
- Distort visualization and interpretation

These limitations result in **spatially biased emission data**, ultimately introducing limitations for accurate emission attribution, root cause analysis, mitigation planning, and multi-sensor data integration.

Opportunity: A Global, Uniform, Hierarchical Spatial Framework for GHG Data

What if emissions from every facility, basin, region, or country could be georeferenced to a **single, equal-area, hierarchical space-time grid**? Such a framework would unlock:

- Seamless reconciliation of bottom-up and top-down approaches
- Precise source attribution across spatial and administrative boundaries
- Consistent integration of multi-source and multi-temporal data

Beyond emissions values, this grid system can also serve as a flexible **data container** to organize associated metadata such as facility characteristics, equipment type, operational history, and other contextual information essential for root cause analysis and targeted mitigation.

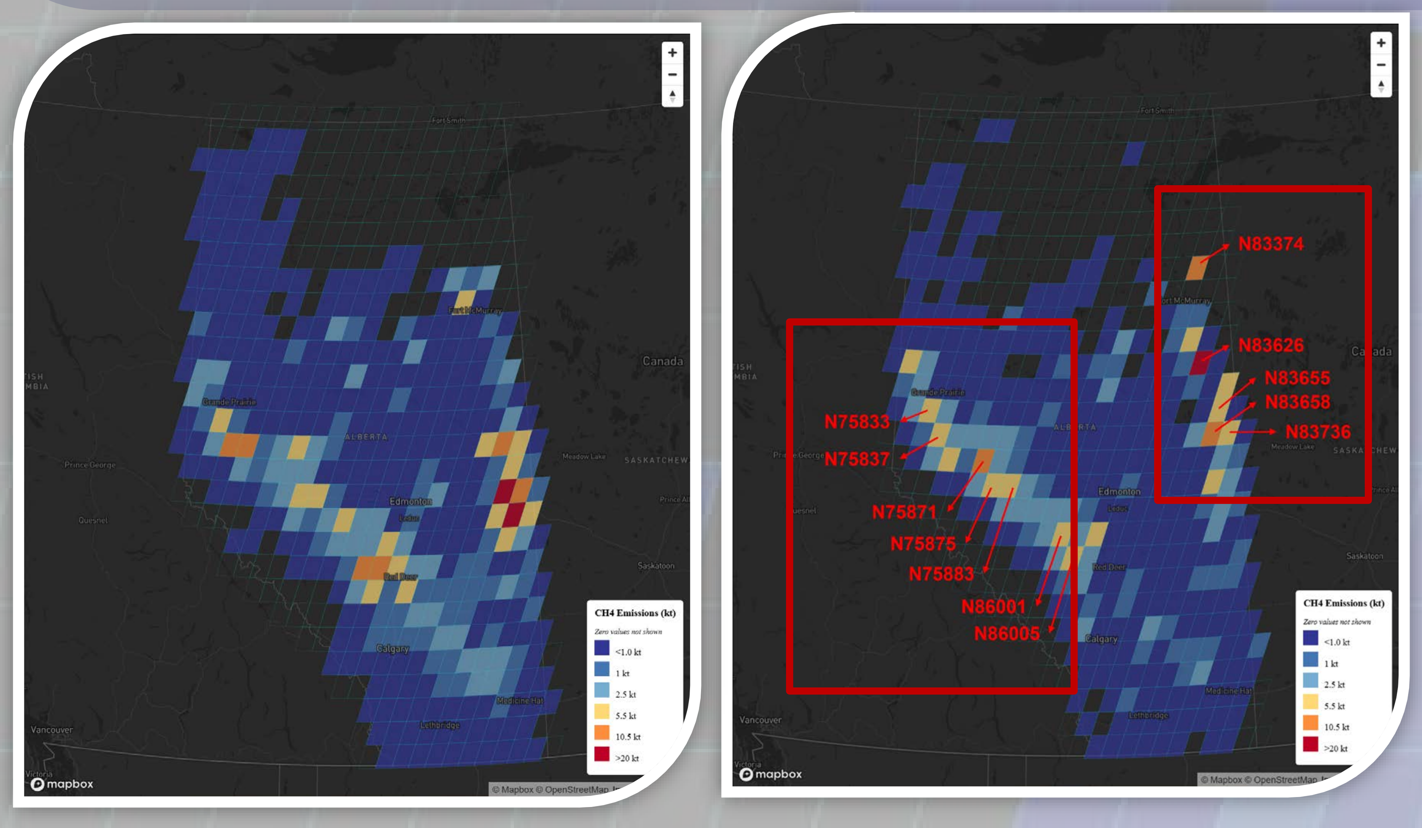


Fig.2 Methane emission grids for Alberta from this study and from Scarpelli et al. [3], both shown using rHEALPix at resolution 5.

What We Achieved: A New Framework for Monitoring, Reporting, and Mitigation Planning

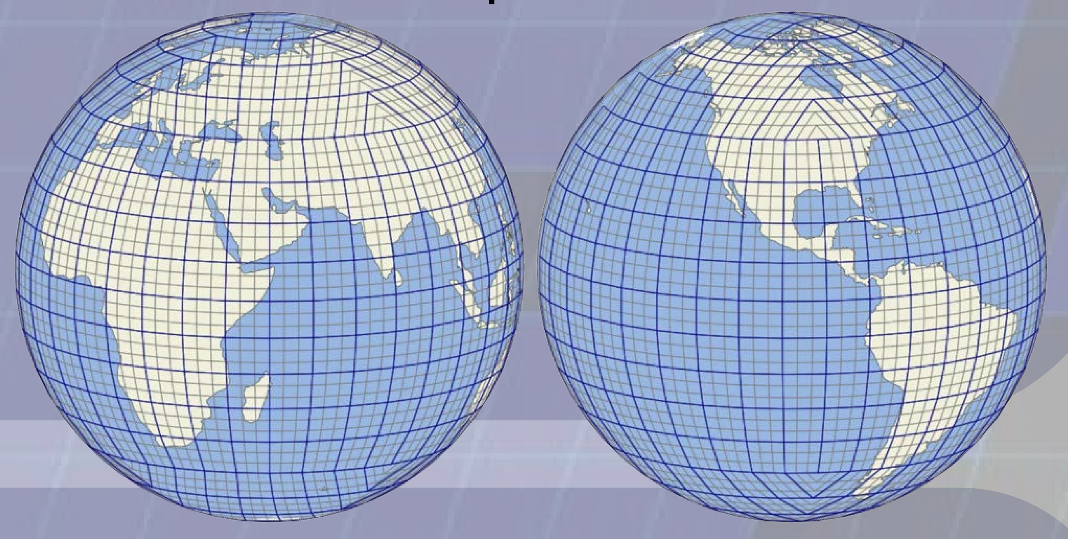
- True emission **intensity comparisons** across space and time
- Consistent **aggregation at any scale** (facility/ basin/national)
- Precise **hotspot tracking** and trend monitoring over time
- Informed **monitoring design** (optimized aerial survey and satellite observation planning)

What We Did: Aggregate Alberta Upstream O&G Emissions onto rHEALPix DGGS

In this study, monthly emissions were derived from the **Petrinex** which reports volumes of gas used in fuel, flare, and venting activities from 2020 to 2023. Methane emissions were calculated using activity-specific emission factors and gas composition parameters from the Alberta Greenhouse Gas Quantification Methodologies.

Facility locations were georeferenced using the **Oil and Gas Infrastructure Mapping database** [1], enabling spatial alignment of emissions with infrastructure. Emissions were aggregated into equal-area grid cells using the **r**earranged **H**ierarchical **E**qual **A**rea iso**L**atitude **Pix**elization (rHEALPix) **D**iscrete **G**lobal **G**rid **S**ystems (DGGS) [2] at resolution level 9, where each cell covers approximately 0.22 km^2. Fig.1 illustrates the rHEALPix at levels 2 and 3. A point-binning operation mapped each facility to its corresponding DGGS cell, and emissions were summed per cell. The rHEALPix hierarchical indexing system was then used to aggregate emissions to coarser resolutions for multi-scale analysis. The existing graticule-based dataset by Scarpelli et al. [3] was converted to the rHEALPix DGGS for comparison.

Fig.1 Illustration of rHEALPix DGGS (N_side=3) at resolution levels 2 and 3.

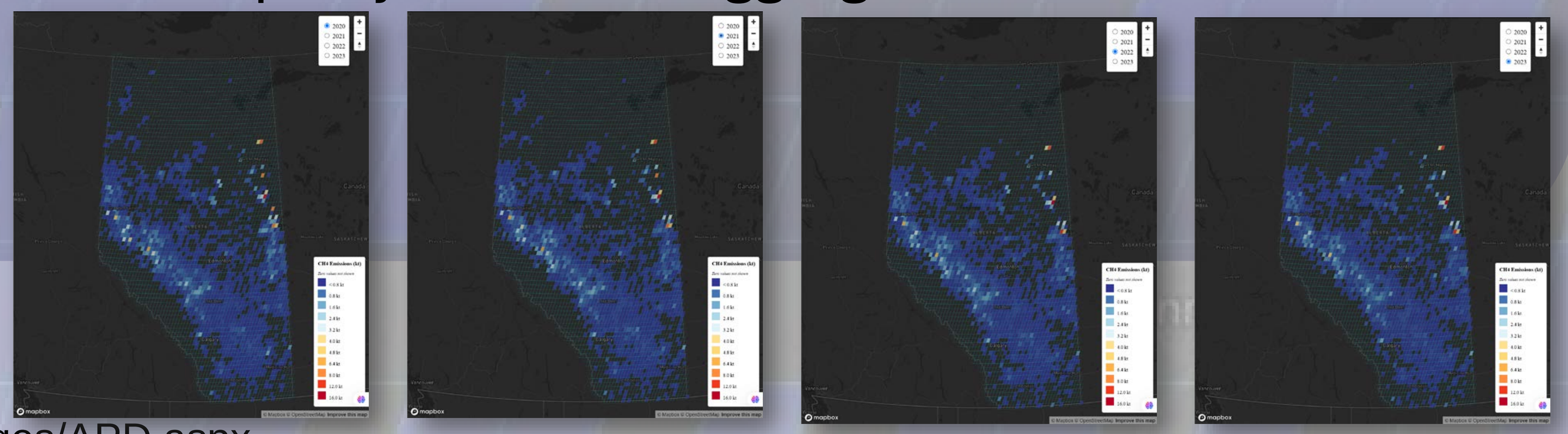


What We Found: Concentrated Emissions in Hotspot Grids

Spatial analysis using rHEALPix showed that methane emissions in Alberta's upstream O&G sector are highly concentrated in a small number of persistent hotspots. At resolution 5, the **top 5%** of grid cells accounted for **over 34% of total** annual emissions among years. These **hotspot emission gids** were mainly located in the Deep Basin and Athabasca oil sands (or CHOPS) regions (Fig.2). As resolution increased, emissions became more concentrated, reflected by rising Gini coefficients. Fig.3 shows the spatial distribution of upstream methane emissions from 2020 to 2023 at rHEALPix resolution 6.

When compared to the 0.1° × 0.1° gridded inventory by Scarpelli et al. [3], converted to rHEALPix, we found **moderate spatial correlation** at coarser resolutions (r = 0.53 - 0.58 at level 5), which **declined sharply** below r = 0.1 at finer levels (Fig.2). It reflects the methodological differences in emission allocation and the limitations of proxy-based disaggregation.

Fig.3 Spatial distribution of Alberta's upstream intended O&G methane emissions from 2020 to 2023 (left to right) at rHEALPix resolution 6.



FUNDING

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DATA AVAILABILITY

The original Alberta Conventional Volumetric Data used in the study are openly available via Petrinex at https://www.petrinex.ca/PD/Pages/APD.aspx.

REFERENCES

[1] Omara M, Himmelberger A, MacKay K, Williams JP, Benmergui J, Sargent M, Wofsy SC, Gautam R (2024) Constructing a measurement-based spatially explicit inventory of US oil and gas methane emissions (2021). Earth System Science Data 16 (9):3973-3991. [2] Gibb R (2016) The rHEALPix discrete global grid system. Paper presented at the IOP Conference Series: Earth and Environmental Science, 9th Symposium of the International Society for Digital Earth (ISDE), Halifax, Canada, October 5-9. [3] Scarpelli TR, Jacob DJ, Moran M, Reuland F, Gordon D (2022b) A gridded inventory of Canada's anthropogenic methane emissions. Environmental Research Letters 17 (1).