IMPERIAL

NEURAL INFORMATION PROCESSING SYSTEMS

MEQNet: Deep Learning for Methane Point Source Emission Quantification from Sentinel-2 Observations

Di Xu[1,2], Philippa J. Mason[2], Jianguo Liu[2], Yanghua Wang[1,2]

[1] Research Geophysics Academy, Imperial College London
[2] Department of Earth Science and Engineering, Imperial College London

Outline:

Background | Data | Methodology | Results

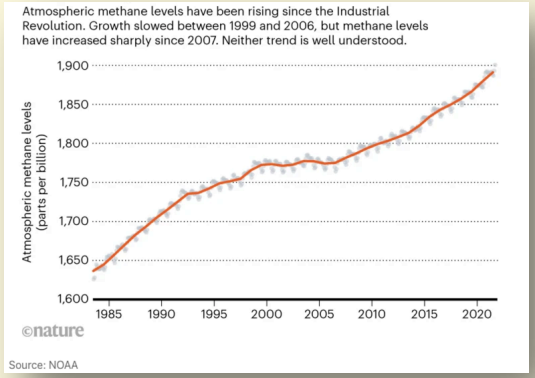
Background

NEURAL INFORMATION PROCESSING SYSTEMS

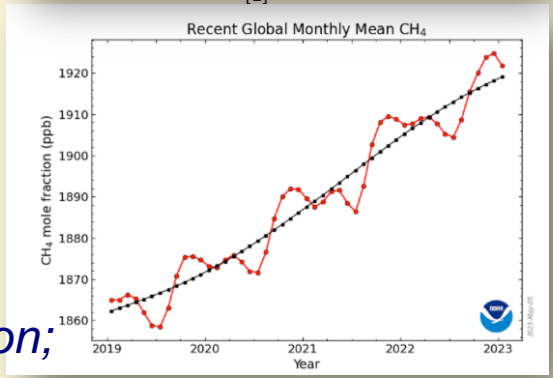
- **Methane**: greenhouse gas, global warming

- **Remote Sensing Instruments**:
  - TROPOMI: coarse spatial resolution
  - PRISMA/AVIRIS-NG: limited spatial coverage
  - Sentinel-2: *higher spatial resolution; broad coverage*

- **Challenges in Current Methods:**
  - Complex Process based on physical model (*Radiative Transfer Model* + *Integrated Mass Enhancement*)
  - Simulated data instead of real data
  - Limited Applicability to Complex Heterogeneous Surfaces



[1]



[2]

✓ *Physics-Guided AI Model; Methane Emission Quantification; Adaptability to Complex Scenarios*

Objective

NEURAL INFORMATION PROCESSING SYSTEMS

➢ *A Deep Learning Framework for Methane Emission Quantification using Sentinel-2 satellite imagery*

- Suppresses surface false positives
- Accelerates large-scale processing
- Generalizes across diverse surface types

Data

- Data Sources

➢ **Carbon Mapper** (2016-2024): plume geometries, column enhancement maps, emission rates

➢ **Sentinel-2 L1C:** 13-band multispectral imagery

➢ **ERA5:** 10-m wind data

- Data Construction

➢ Match **Carbon Mapper detections** with **cloud-free Sentinel-2** on same date

➢ Create **image pairs (T, T–1)** within 1–10 days

➢ Rasterize Carbon Mapper maps to Sentinel-2 grid

➢ Add **negative samples** (no plumes, background CH_4 level)

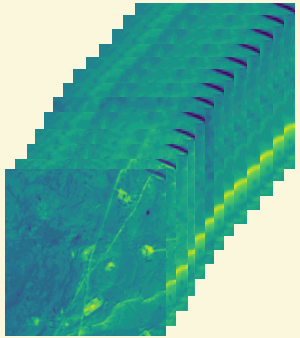
Data

- Overview

Dataset	Positive	Negative	Total
Train	1975	1975	2950
Val	274	274	548
Test (2024y)	251	251	502
Total	2500	2500	5000

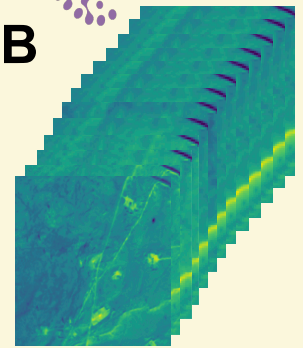
NEURAL INFORMATION PROCESSING SYSTEMS

A



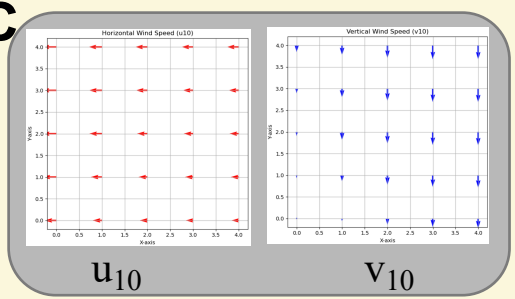
Target Image

B



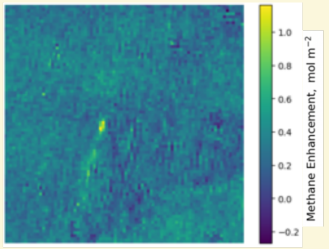
Reference Image

C



10m Wind Field Data

D



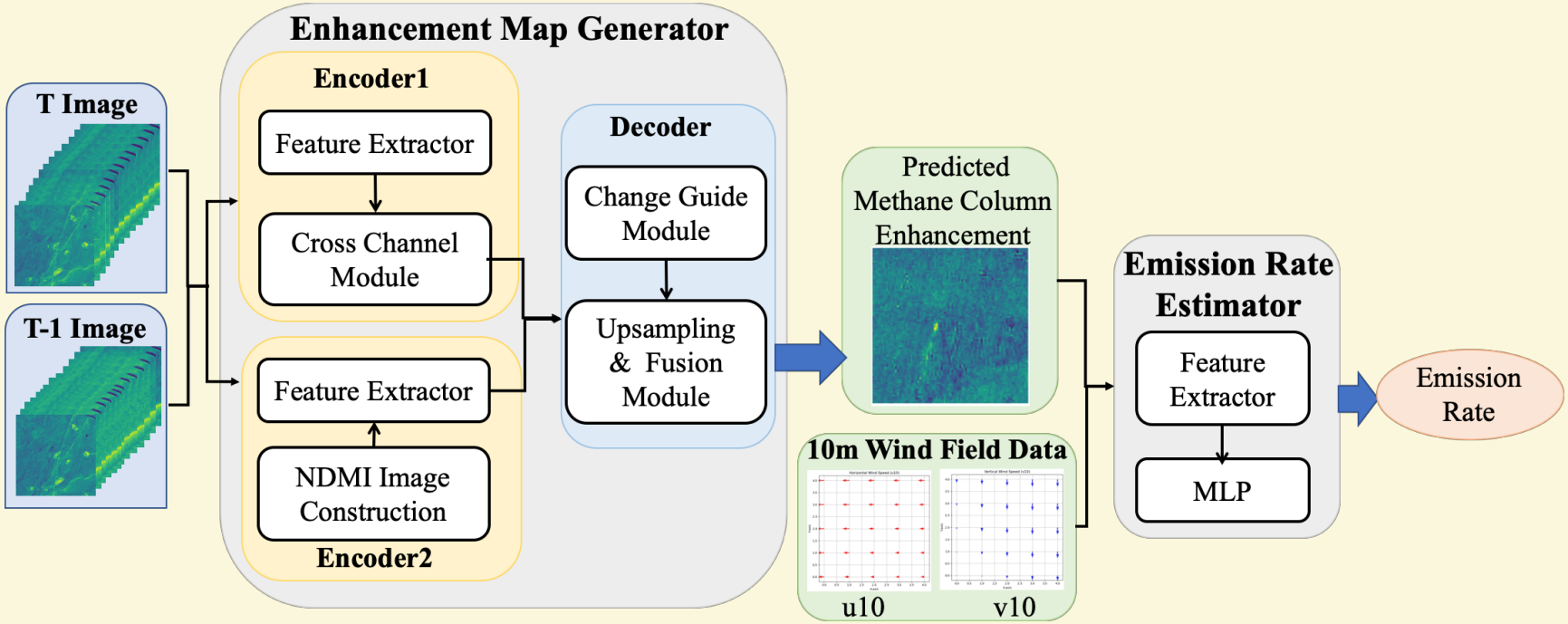
Methane Column Enhancement Imagery

E Emission Rate (kg/hr)

Method

NEURAL INFORMATION PROCESSING SYSTEMS

- Overview——Methane Emission Quantification Network (MEQNet)



Method

NEURAL INFORMATION PROCESSING SYSTEMS

- The Normalized Difference Methane Index (NDMI) is computed as:

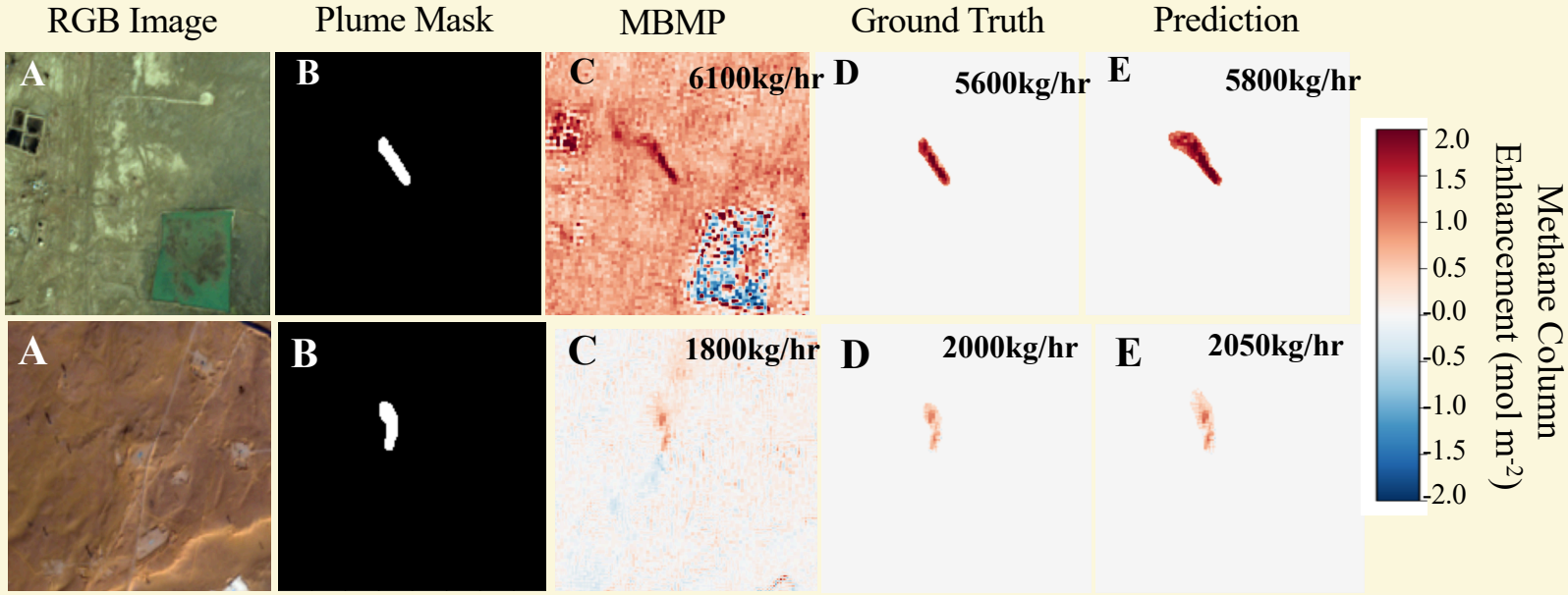
$$NDMI = \frac{b_{11} - b_{12}}{b_{11} + b_{12}}$$

- Joint loss function is calculated as

$$L_{total} = \lambda_{EMG} \cdot \frac{1}{HW} \sum_{x=1}^{H} \sum_{y=1}^{W} \left(E_{x,y} - \hat{E}_{x,y} \right)^2 + \lambda_{ERE} \cdot \frac{1}{N} \sum_{i=1}^{N} \left(R_i - \hat{R}_i \right)^2$$

Results

- Qualitative Results



- MBMP result → diffuse plume, surface noise
- MEQNet → sharp, localized plume, aligned with ground truth

Results

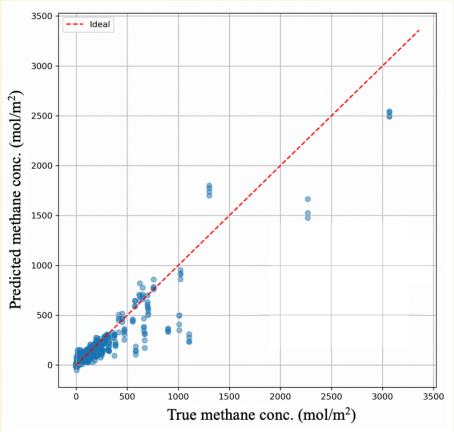
- Quantitative Evaluation

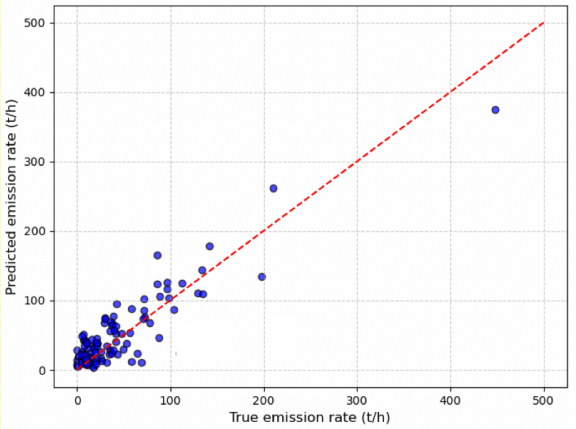
Performance across test set:

✓ Enhancement $R^2 = 0.91$

✓ Emission Rate $R^2 = 0.94$

✓ Processing Time < 2 s / scene





Conclusion

NEURAL INFORMATION PROCESSING SYSTEMS

- Summary

  - ✓ **MEQNet** directly estimates methane column enhancements and emission rates from Sentinel-2 imagery and 10-m wind data.
  - ✓ Exploits **methane-sensitive spectral bands** and **spectral-temporal differences** to separate plumes from background.
  - ✓ **Dataset constructed** from real Sentinel-2 observations with hyperspectral measurements and inventories, covering diverse surfaces.
  - ✓ Validated results show **fast, accurate, and scalable** methane quantification.

Conclusion

NEURAL INFORMATION PROCESSING SYSTEMS

- Future study

  - ✓ **Robustness testing** across diverse surface types
  - ✓ **Generalization** to global methane emission scenarios
  - ✓ **Dataset expansion** for more real-world events
  - ✓ **Refinement of network modules** for further performance improvements

IMPERIAL

NEURAL INFORMATION PROCESSING SYSTEMS

THANK YOU