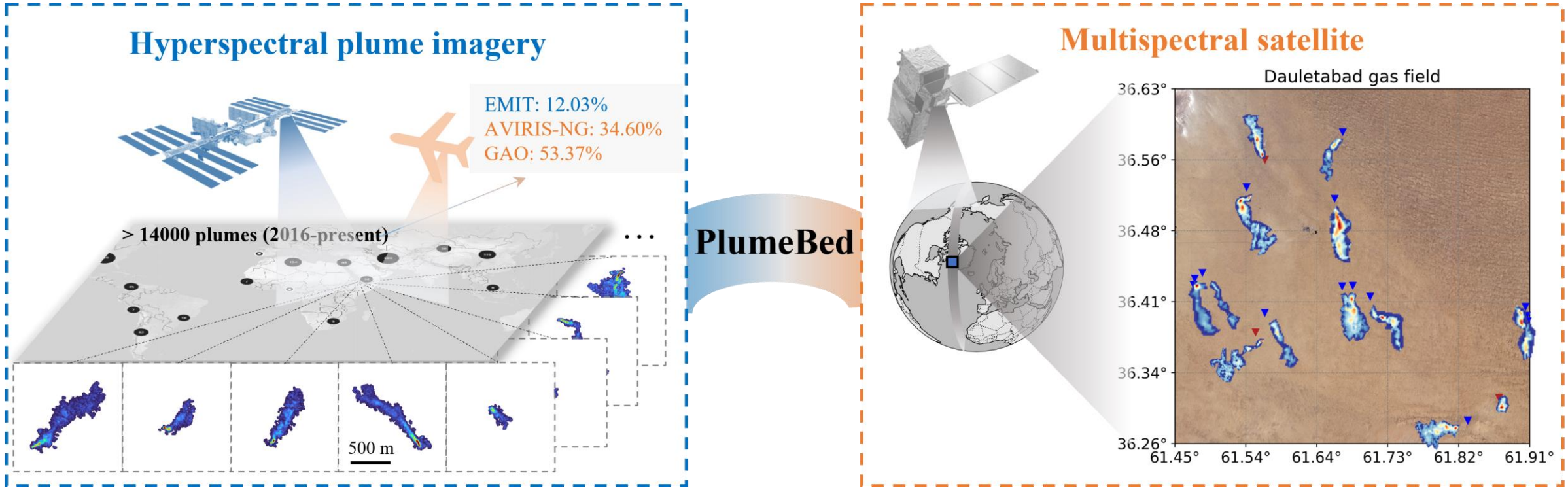
PlumeBed: A multispectral satellite methane plume detector enabled by transfer learning of a multi-source hyperspectral dataset



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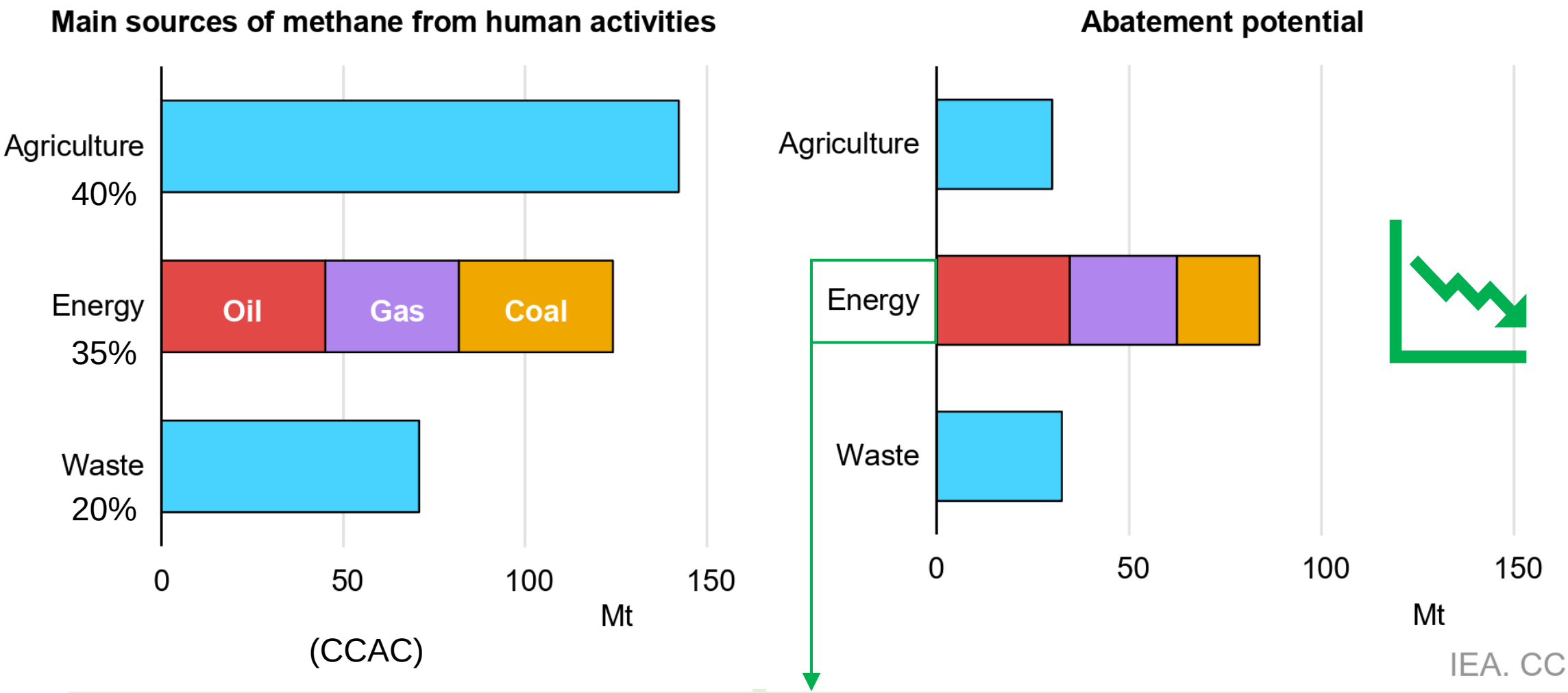
[1] Westlake university, [2] Zhejiang University

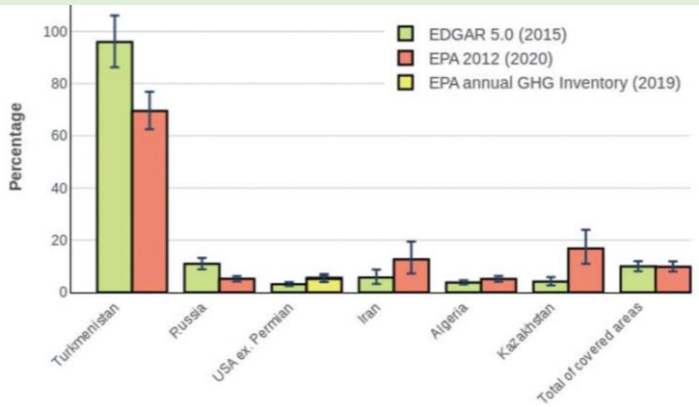
Methane: a powerful greenhouse gas

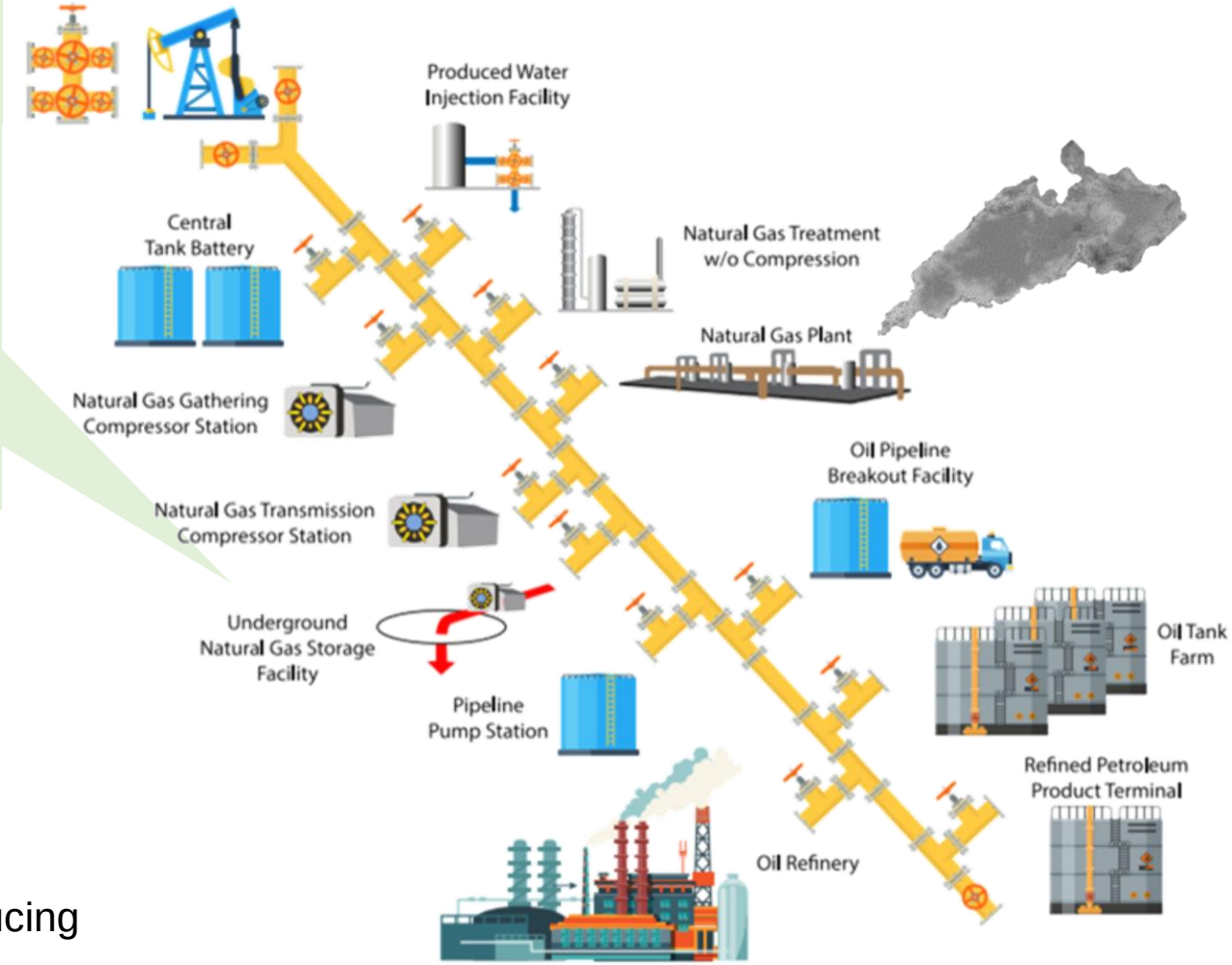


The fossil fuel sector provides us the most cost-effective opportunity to reduce methane.

Methane supper-emitters in O&G fields

Methane point source : small surface infrastructure components that are typically less than 10 m in diameter and emit highly concentrated methane plumes. (Duren et al., 2019)

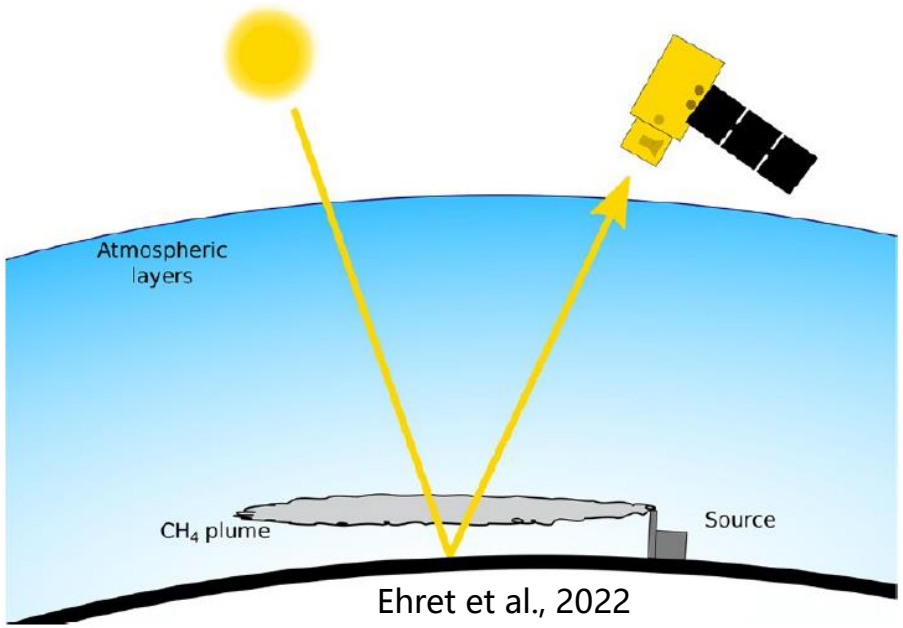




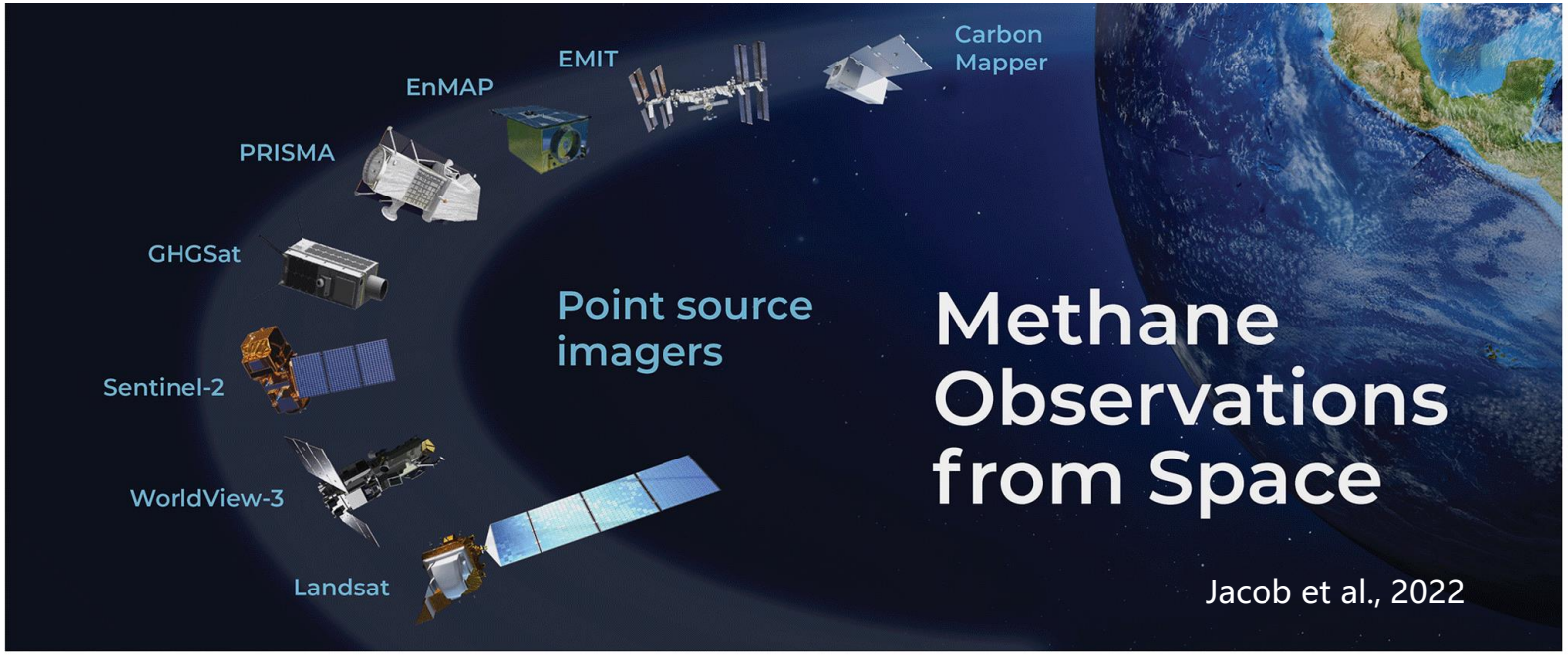
O&G ultra-emitter (> 25 t/h) estimates in six major O&G-producing countries represent 8 to 12% of global O&G CH4 emissions

Lauvaux, Thomas, et al. "Global assessment of oil and gas methane ultra-emitters." Science 375.6580 (2022): 557-561.

Satellite is promising for tracking methane super-emitters



Ehret et al., 2022

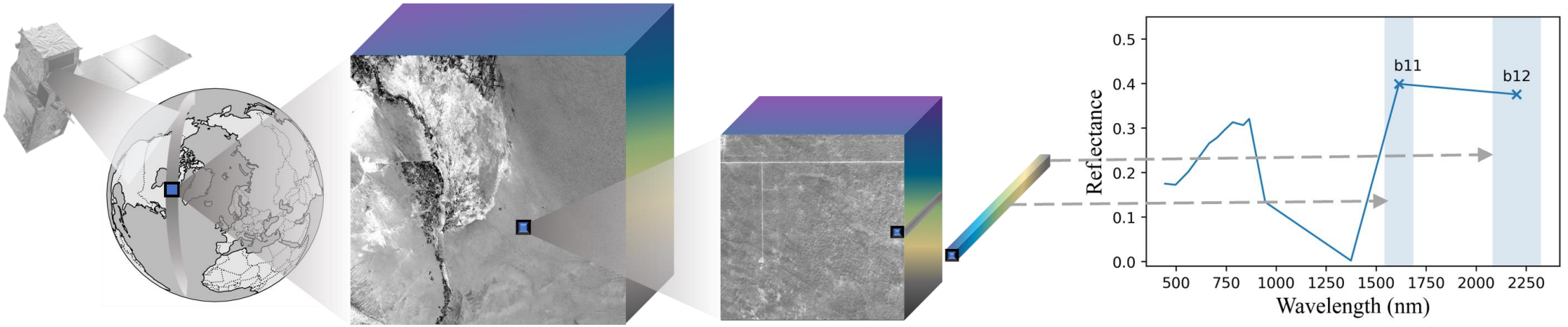


Instrument	GSD (m)	Swath (km)	Band number	Spectral resolution (nm)	Advantages and Disadvantages for methane detection
PRISMA	30	30	239	**10 (Hyperspectral)**	■ High methane sensitivity (detailed plume shapes) □ Low temporal resolution
Sentinel-2	20	290	13	**200 (Multispectral)**	■ Frequent, global observations (mapping large-scale methane leaks) □ Low methane sensitivity

complementary

Methane super-emitters detection by multispectral satellites

- If high-concentration methane emissions are present, the reflectance values in the methane absorption bands would decrease.

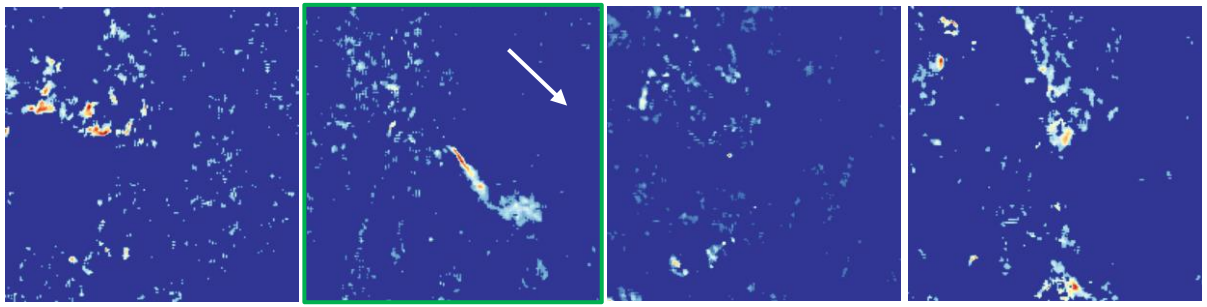


Methane emission signal $\Delta R = \frac{b12/b12_{ref}}{b11/b11_{ref}}$

Methane Plume Detection

Visual identification based on plume morphology and wind speed (accurate but time-consuming)

Automatically identify methane plumes by deep learning models (efficient for large-scale data processing)

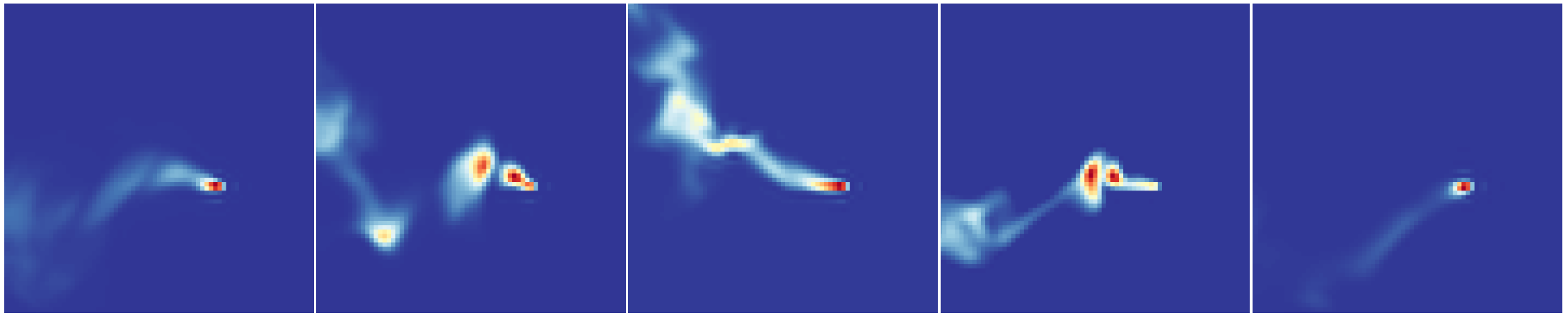


Key challenges in deep learning-based methane plume detection

① Collecting extensive real methane plume images from multispectral satellites is difficult, leading to limited data for training deep learning models.

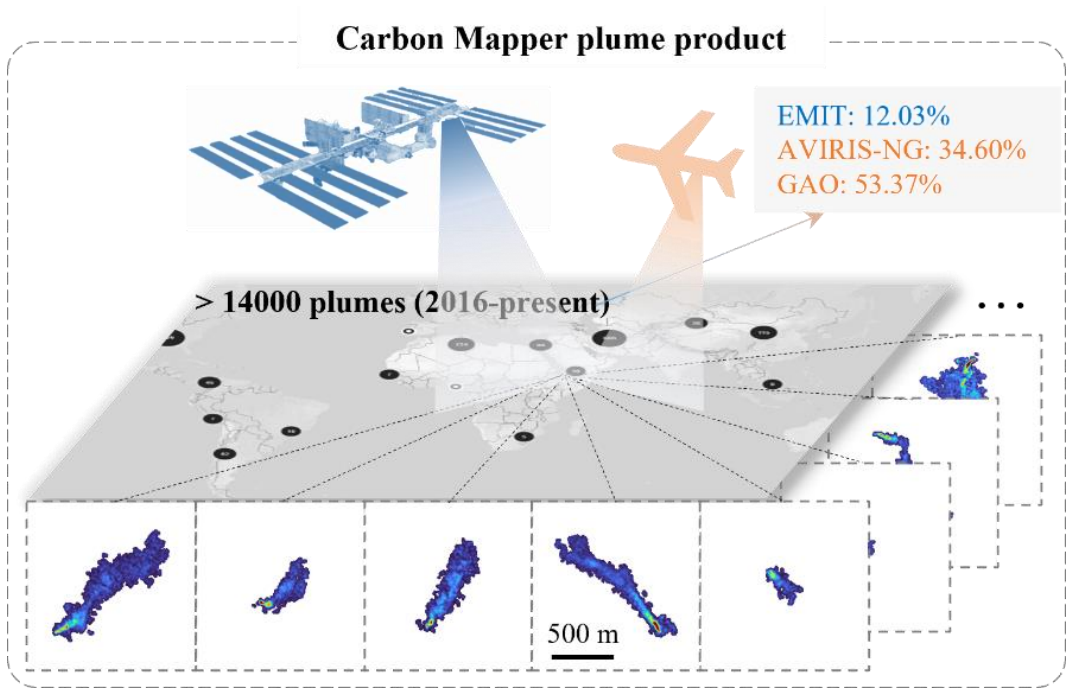
② Simulated plume images have relatively simple morphology and differ significantly from real ones, potentially degrading model performance in real-world scenarios.

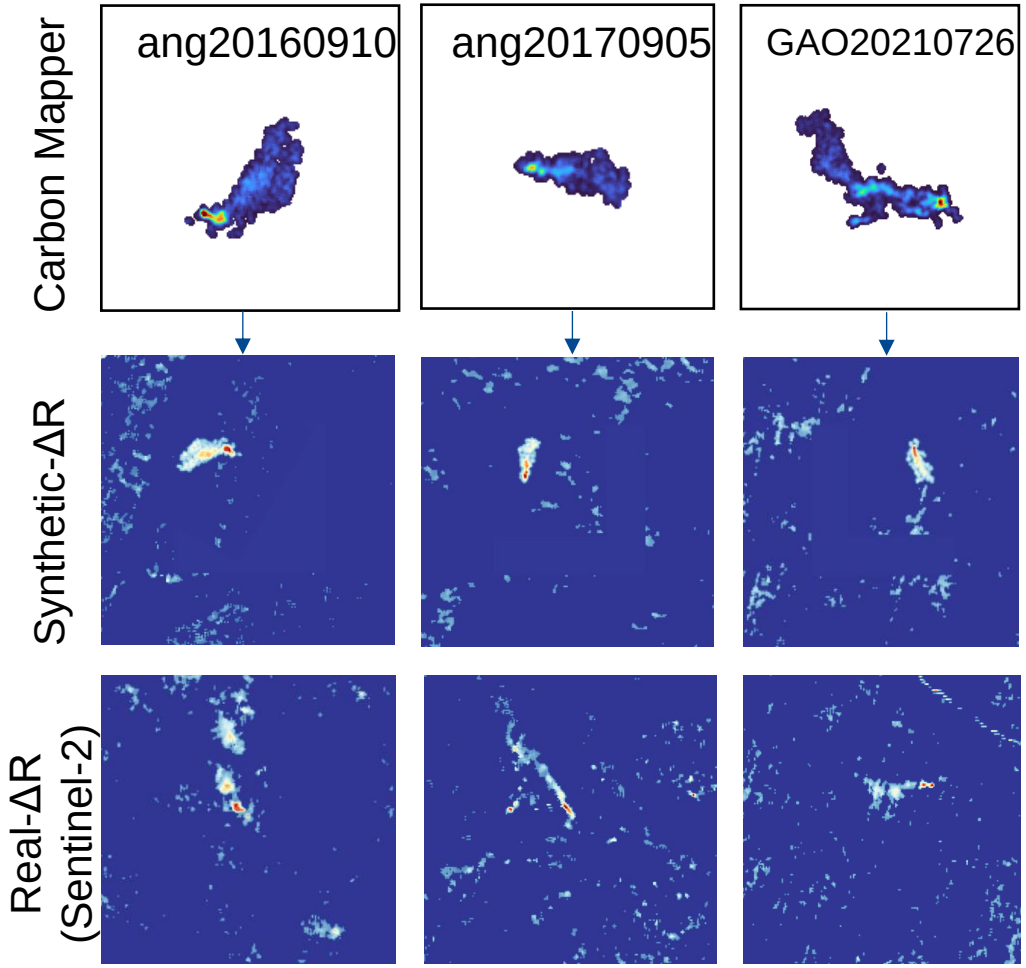
WRF-LES generated methane plume imagery



PlumeBed ——Training Data Generation

- Based on image processing, plumes from Carbon Mapper product are fused with the real backgrounds of Sentinel-2 to generate Sentinel-2 style training data

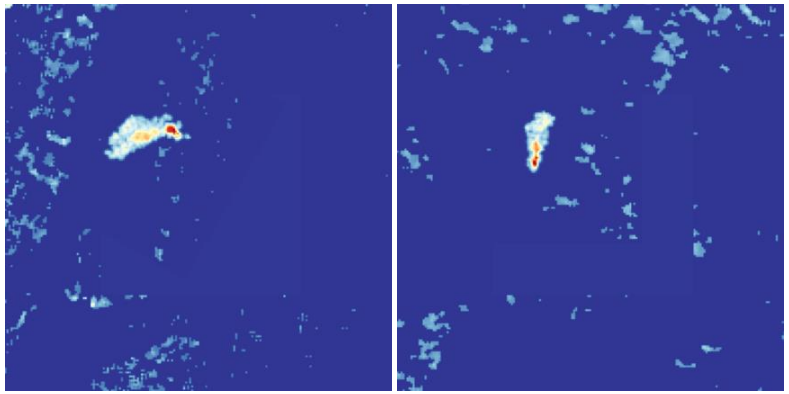


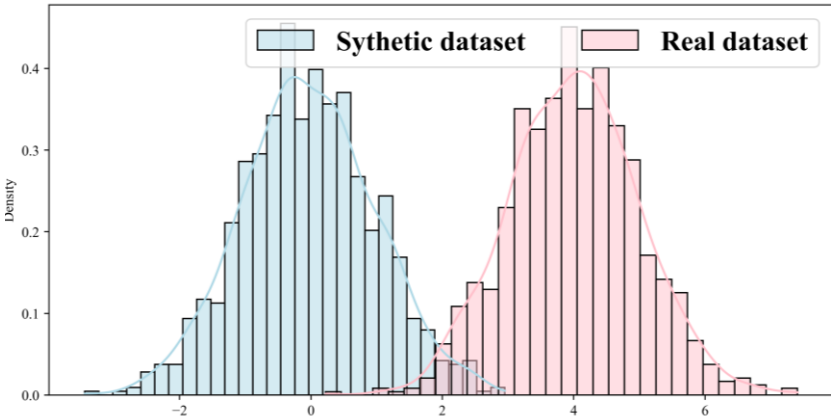


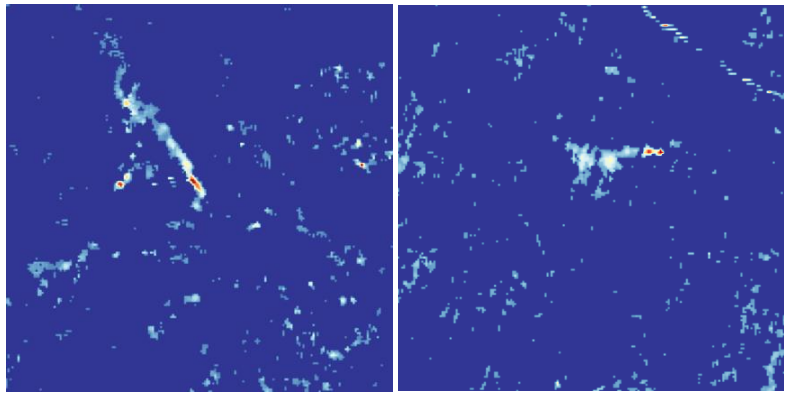
- Contain over 14,000 images of methane (primarily) and carbon dioxide plumes
- Record by multiple hyperspectral instruments
- Plumes have diverse morphologies

https://carbonmapper.org/data

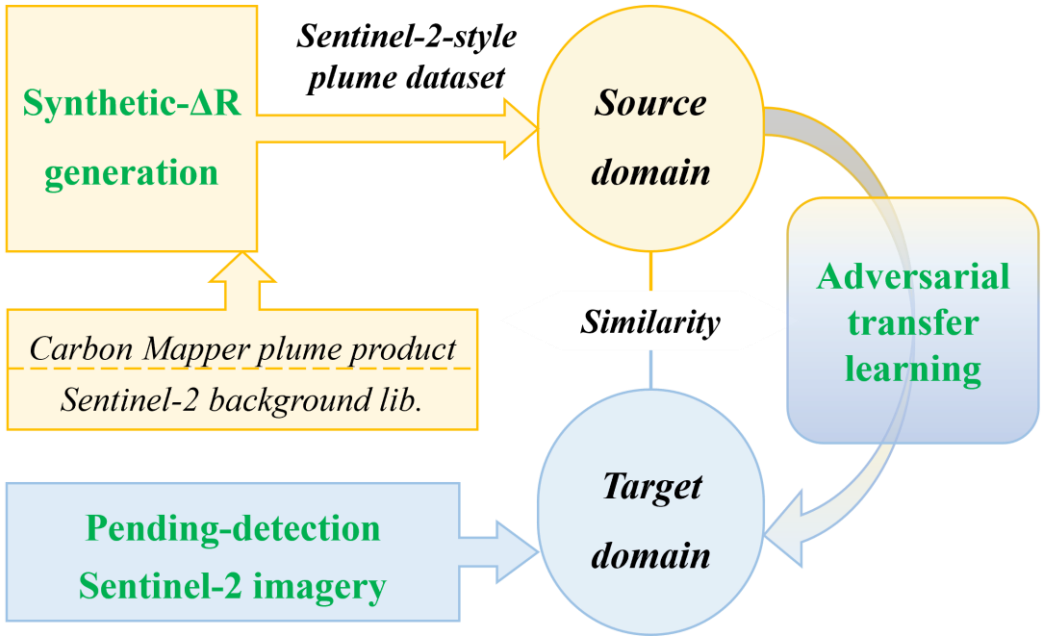
PlumeBed —— Deep Transfer Learning Network （detect plume）







Synthetic data —— **Potential domain shift** —— **Real-world data**

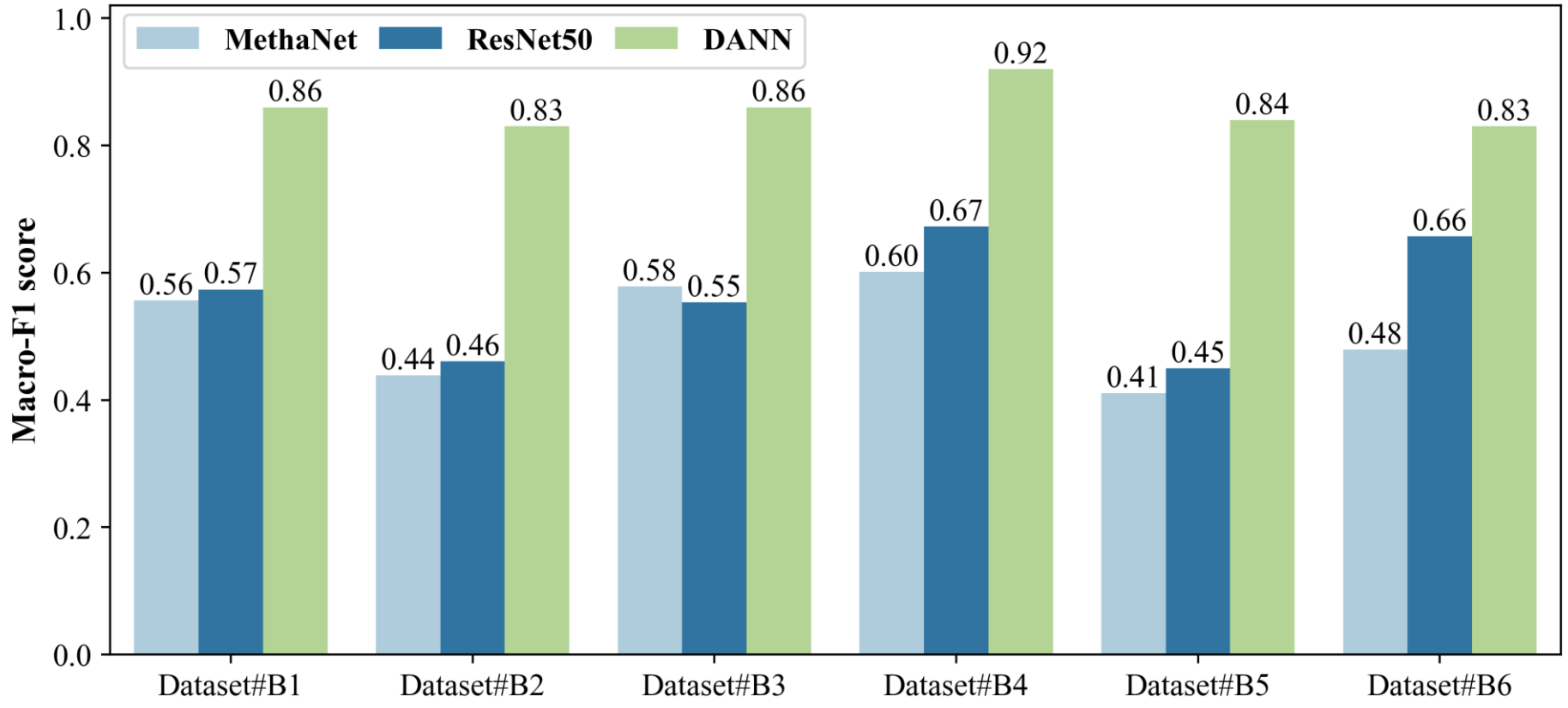


Transfer learning

- Scenarios with limited or hard-to-obtain training data
- Leverage the similarity between source and target domain, transferring labeled knowledge (e.g., plume characteristics) from the source domain to similar detection tasks.

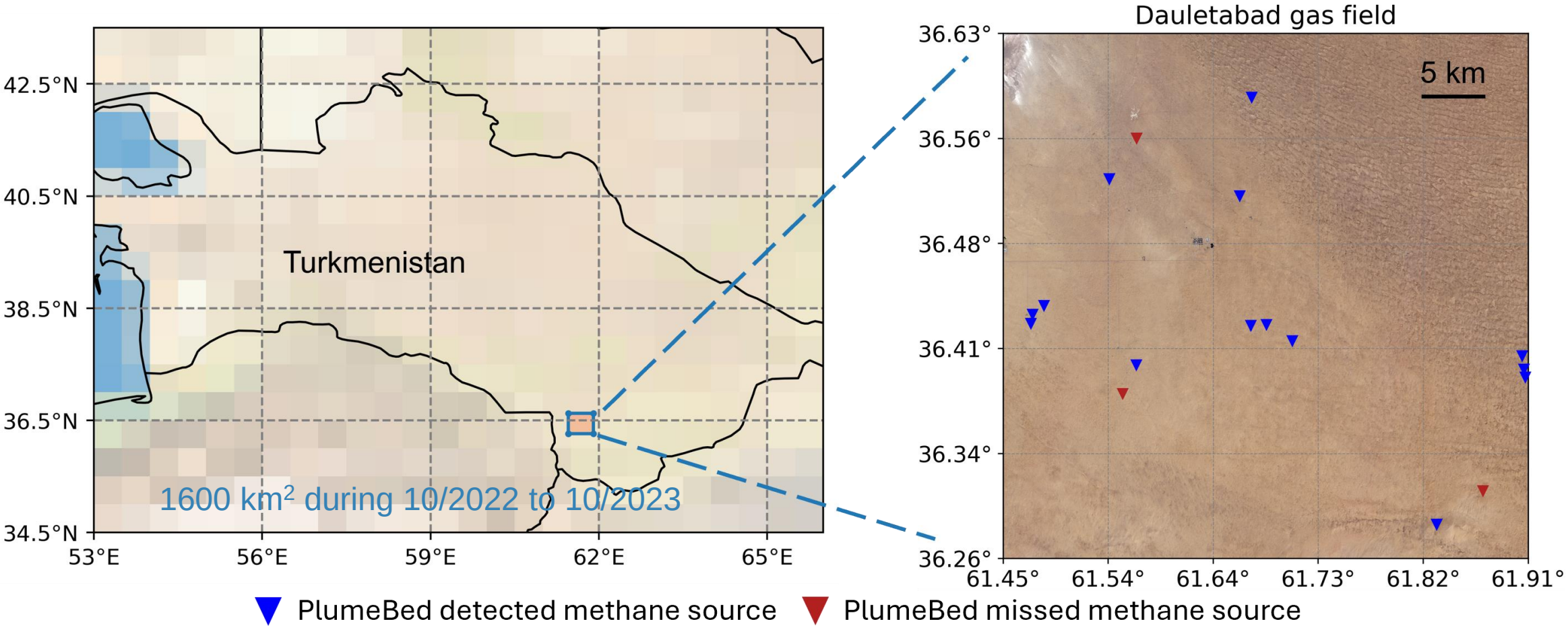
Comparison between PlumeBed and existing deep plume detectors

✓ Collected six real methane super-emitter datasets (Dataset #B1~B6) from three countries (U.S., Algeria, Turkmenistan) as test sets for model evaluation.



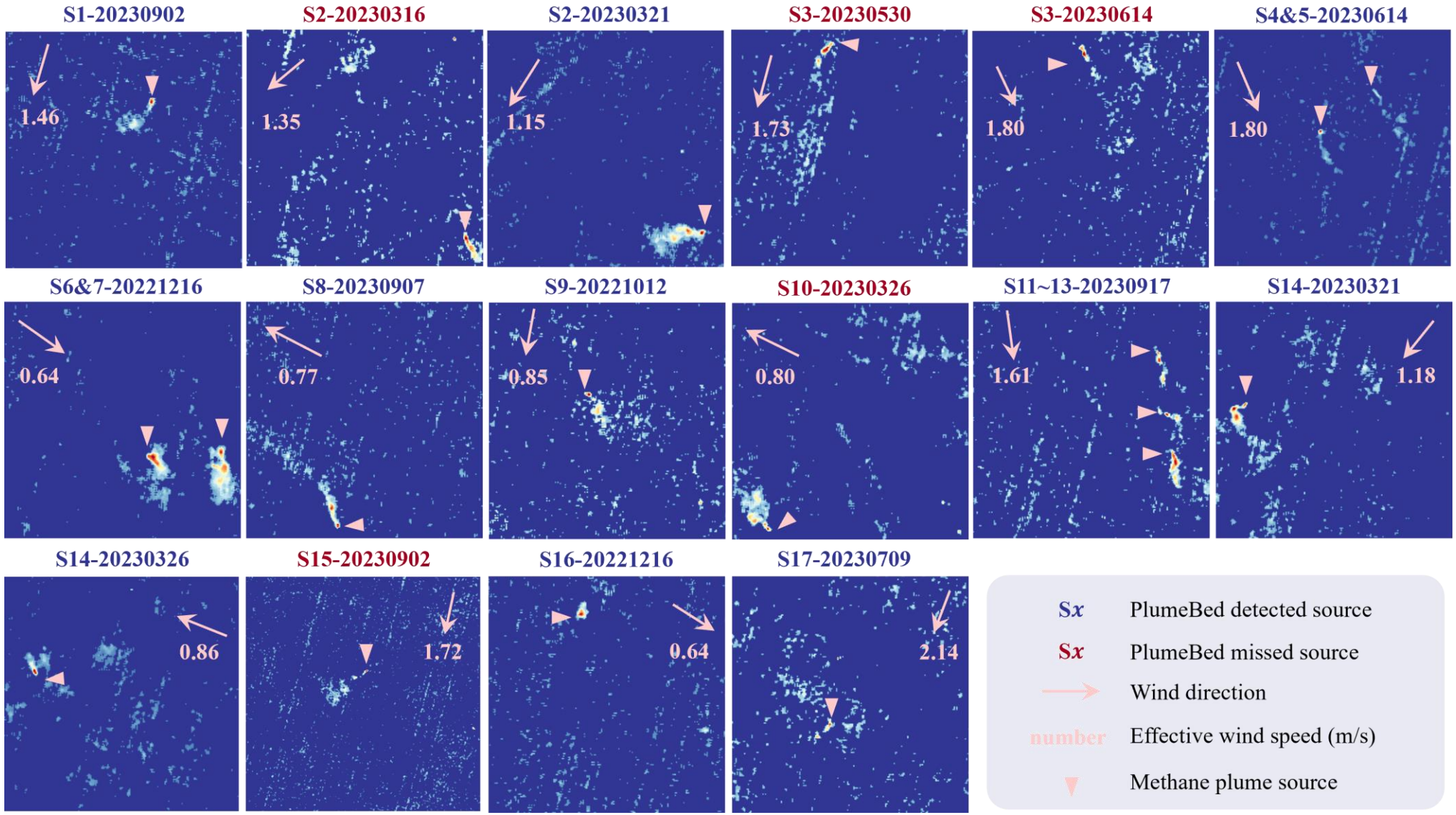
■ PlumeBed significantly outperforms MethaNet and ResNet-50 in synthetic-to-real detection tasks.

PlumeBed rapidly scanned the Dauletabad gas field in Turkmenistan



- PlumeBed reported 14 methane super-emitters (700.1–10,863.9 kg/h), missing 3
- Most of the emission events are associated with pipeline leaks

PlumeBed rapidly scanned the Dauletabad gas field in Turkmenistan



Take home messages

- ✓ The PlumeBed includes a training data generation module and a deep transfer learning detection model.
- ✓ It proposes **generating training data for multispectral satellites based on multi-source hyperspectral plumes**.
- ✓ **Deep transfer learning demonstrates effectiveness** in the synthetic-to-real detection task for methane plume.

To further improve the generalization ability of PlumeBed

- ➢ A de-artifacting algorithm should be added to reduce the false positive rate (2.6%).