

基于迁移学习的Sentinel-2卫星 甲烷点源探测

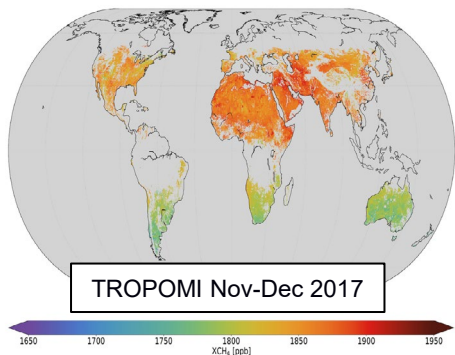
赵淑韬 张羽中

2025. 10. 19

不同空间尺度的监测需求

国家/全球尺度

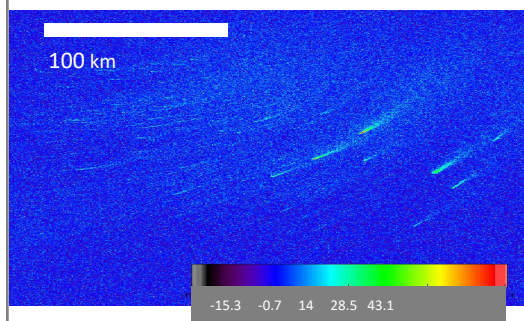
碳盘点



5-10 km 分辨率

区域/盆地尺度

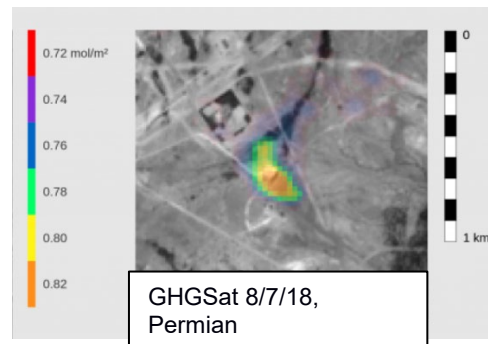
国家管理



~500-1000 m 分辨率

点源尺度

行业管控

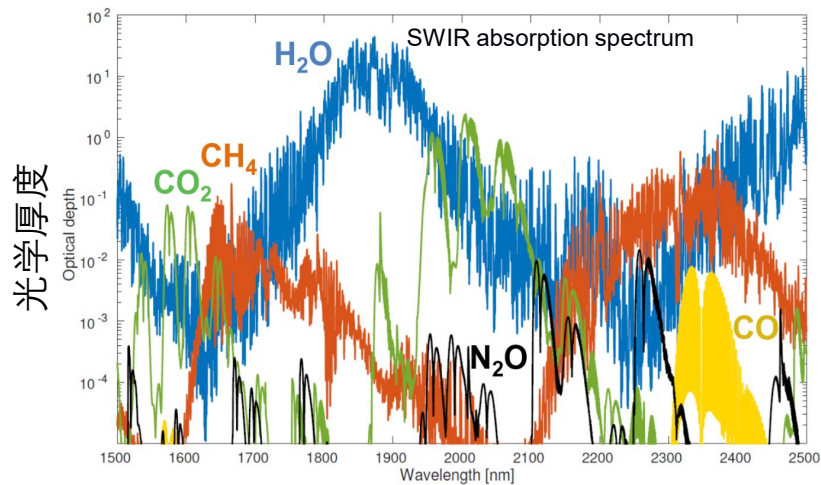


~10 m 分辨率

甲烷卫星观测

覆盖全球、连续运行

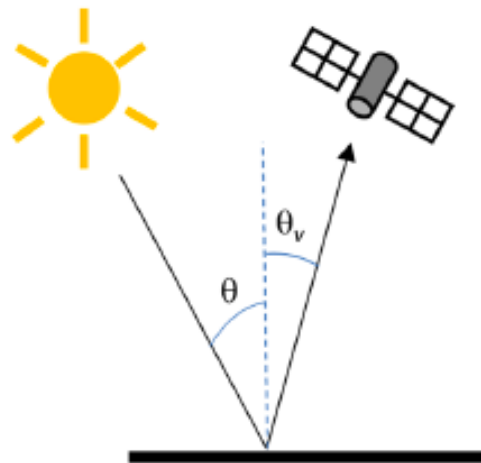
短波红外波段



↑
1.65 μm

↑
2.3 μm

太阳光后向散射



光程中的吸收
→ 甲烷浓度

区域型 vs. 点源型卫星

区域型

TROPOMI GOSAT

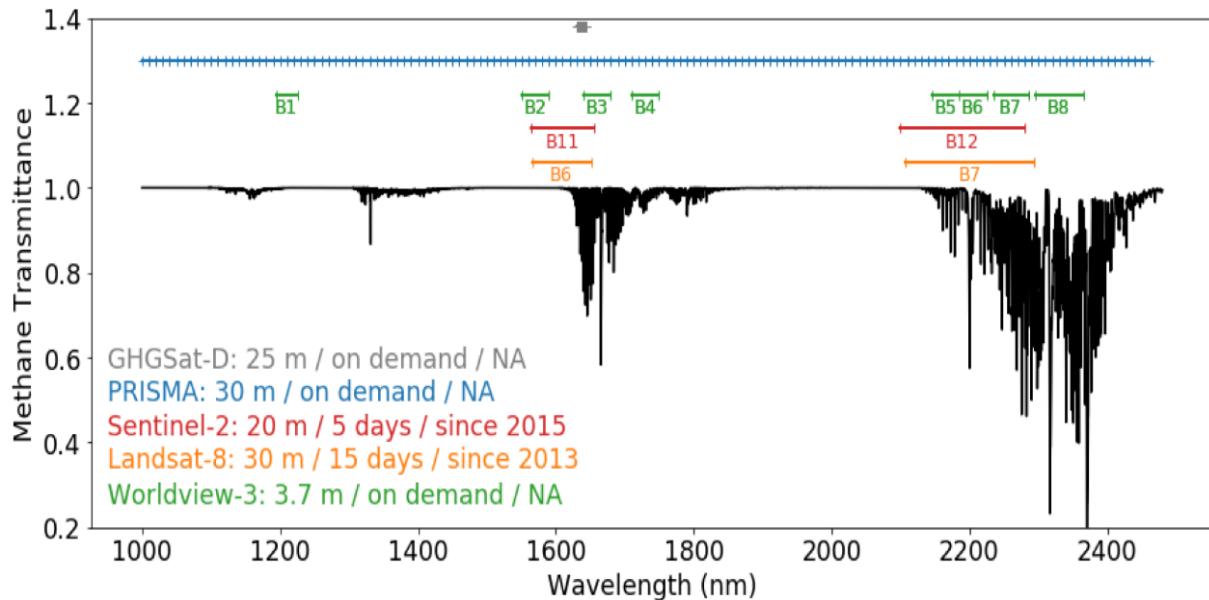
超高光谱 浓度精确
空间分辨率低（几公里）

点源型

Sentinel-2 Landsat

高分5号 EMIT GHGSat

多/高光谱 浓度不精确
空间分辨率高（几米）



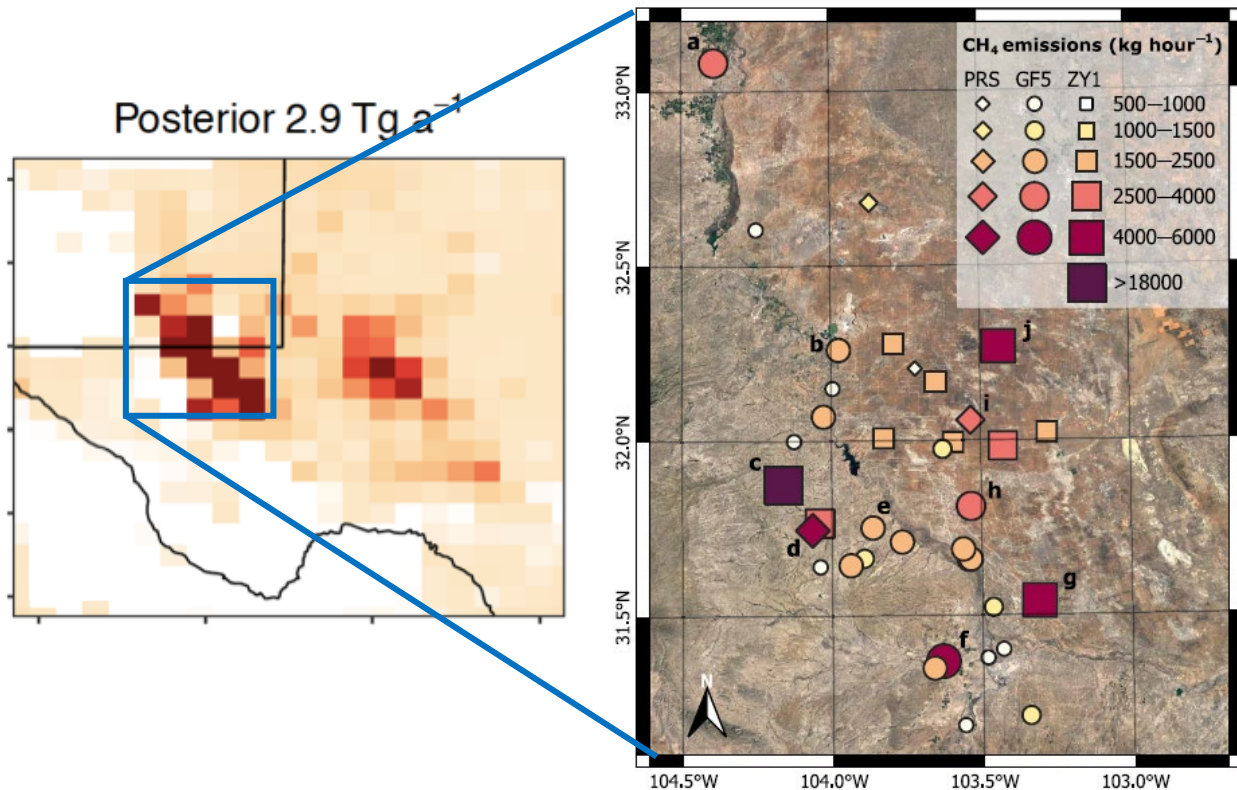
Sánchez-García et al., 2021

点源监测卫星

Instrument	Launch date	Pixel size (m ²)	Coverage	Return days	Spectral resolution (nm)	Data availability
GHGSat	2016	25×25	targeted	1-7	0.3-0.7 (hyperspectral)	commercial
PRISMA	2019	30×30	targeted	30	10 (hyperspectral)	upon request
GF-5	2021	30×30	targeted	?	10 (hyperspectral)	upon request
WorldView-3	2014	3.7×3.7	targeted	1	50 (multispectral)	commercial
Landsat-8	2013	30×30	global	16	200 (multispectral)	public
Sentinel-2	2015	20×20	global	2-5	200 (multispectral)	public

- Multispectral satellites (**Sentinel-2** and Landsat-8) have methane-sensitive channels, high spatial resolution, as well as global coverage and frequent observations, making it suitable for long-term monitoring methane point sources of the O&G fields worldwide.

高光谱卫星点源探测 —— Permian 盆地



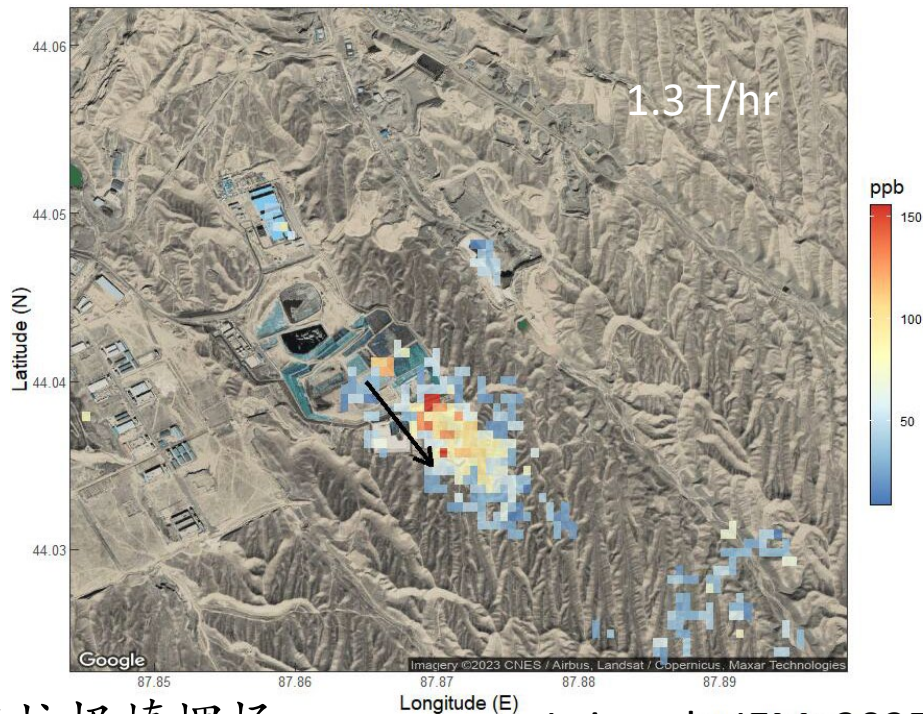
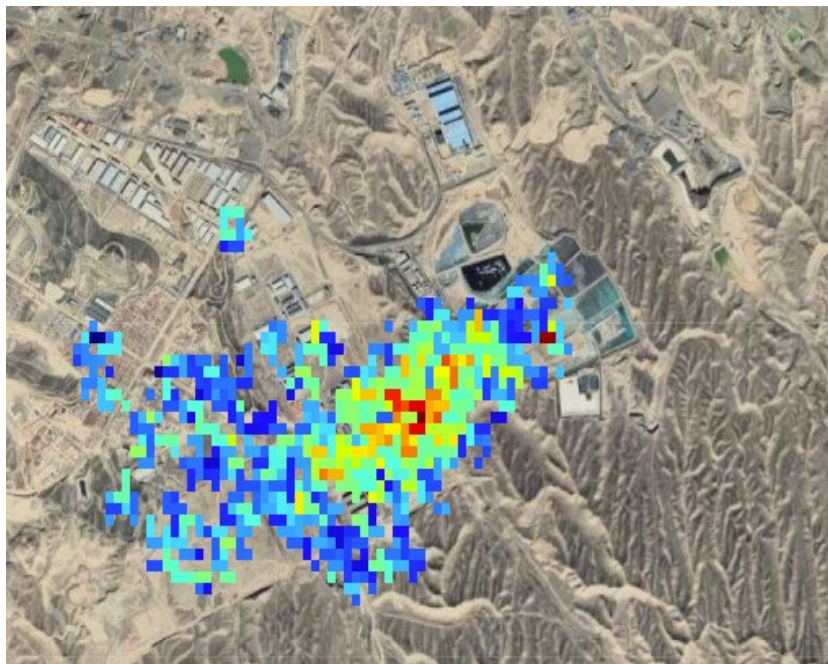
- PRISMA
- 高分5号
- 资源1号

- 19个点源
- >500 kg/hr
- 区域总量的30%–50%

高光谱卫星探测垃圾填埋场甲烷排放

GHGSAT, EMIT, PRISMA, GF-5, GF-5B

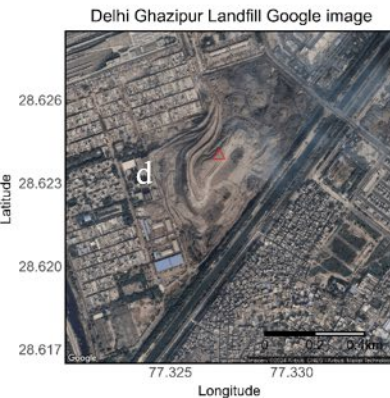
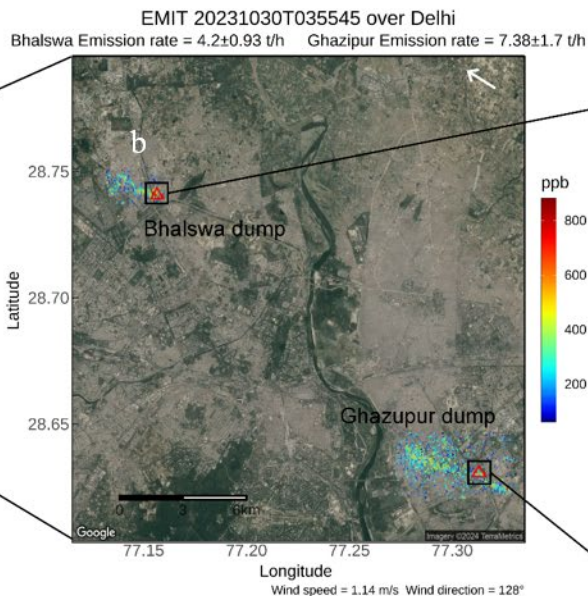
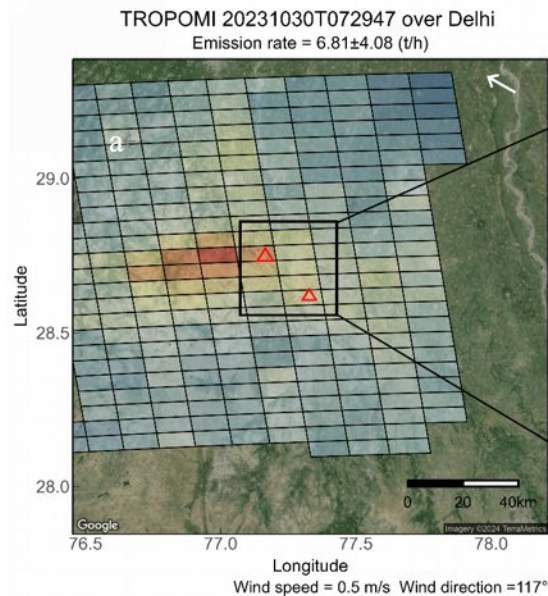
探测到中国6处垃圾填埋场排放
0.5 – 3 T/hr



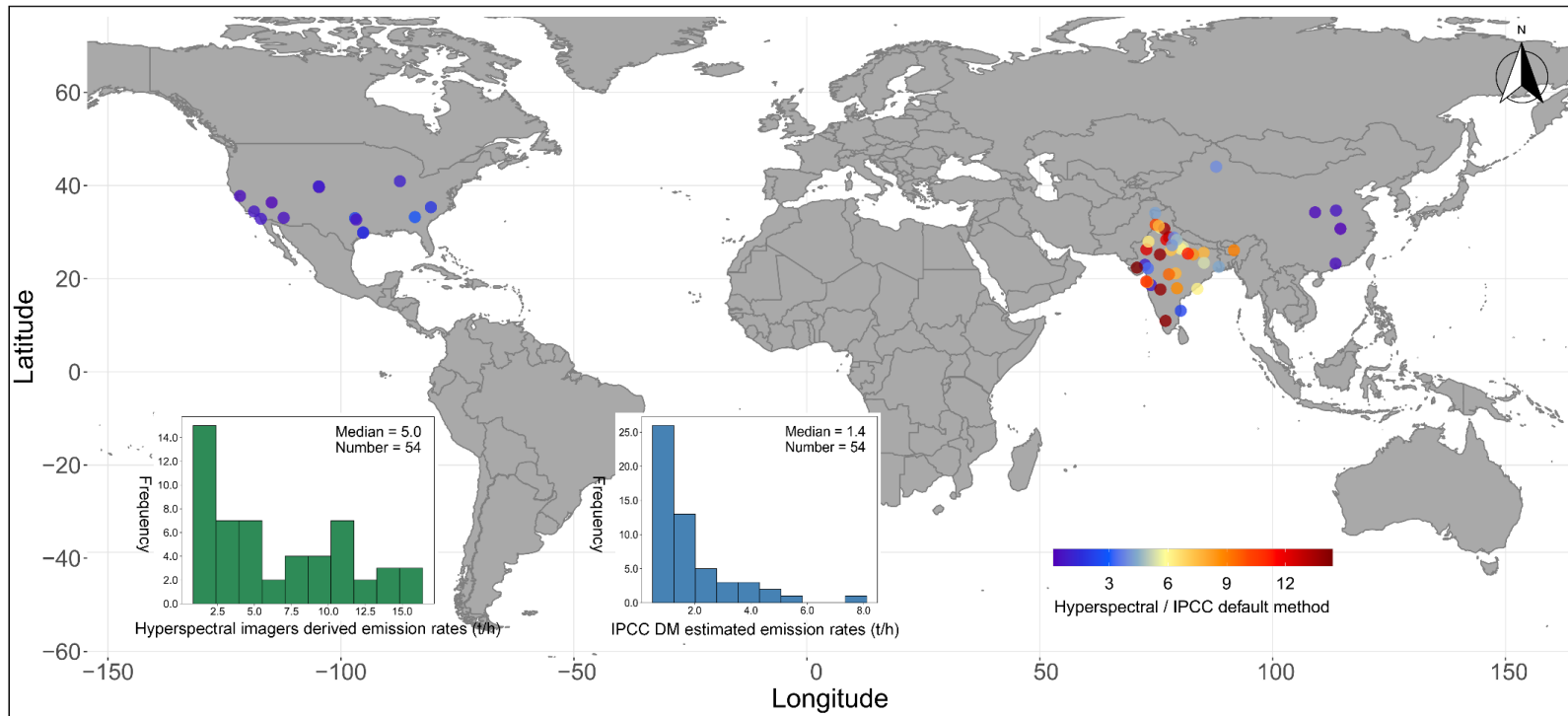
乌鲁木齐米东垃圾填埋场

Lei et al., JEM, 2025

高光谱卫星探测垃圾填埋场甲烷排放



高光谱卫星探测垃圾填埋场甲烷排放

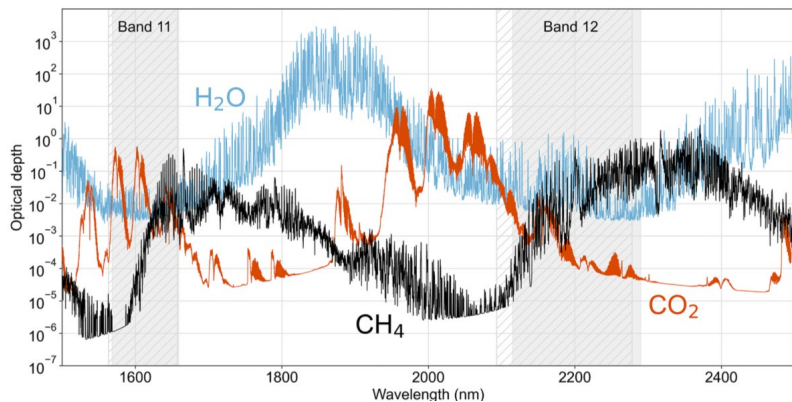


点源监测卫星

Instrument	Launch date	Pixel size (m ²)	Coverage	Return days	Spectral resolution (nm)	Data availability
GHGSat	2016	25×25	targeted	1-7	0.3-0.7 (hyperspectral)	commercial
PRISMA	2019	30×30	targeted	30	10 (hyperspectral)	upon request
GF-5	2021	30×30	targeted	?	10 (hyperspectral)	upon request
WorldView-3	2014	3.7×3.7	targeted	1	50 (multispectral)	commercial
Landsat-8	2013	30×30	global	16	200 (multispectral)	public
Sentinel-2	2015	20×20	global	2-5	200 (multispectral)	public

- Multispectral satellites (**Sentinel-2** and Landsat-8) have methane-sensitive channels, high spatial resolution, as well as global coverage and frequent observations, making it suitable for long-term monitoring methane point sources of the O&G fields worldwide.

多光谱点源型卫星

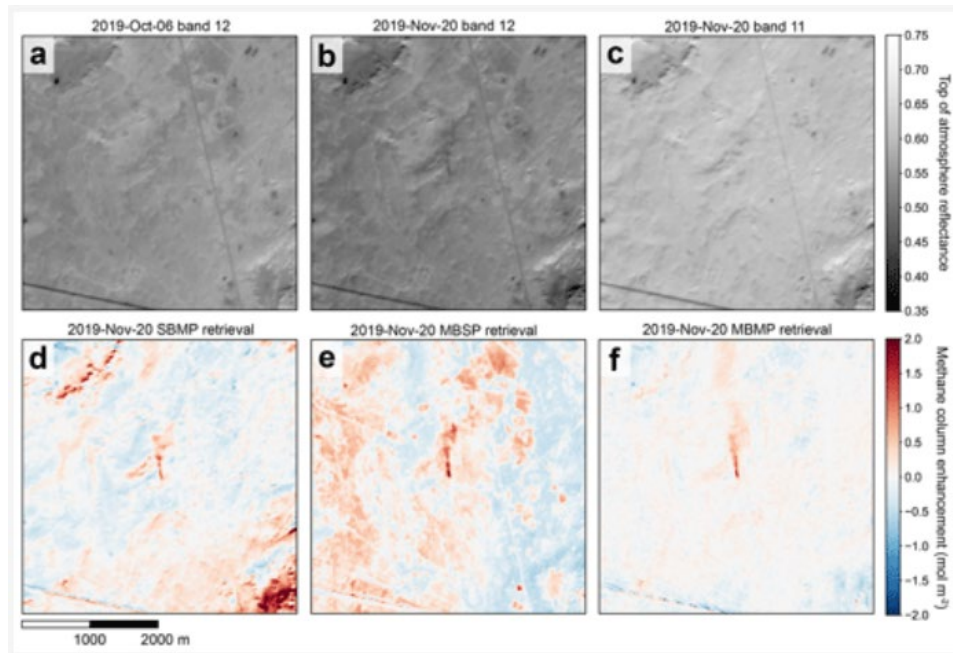


单波段反演

$$\Delta R_{\text{SBMP}} = \frac{cR_{12} - R'_{12}}{R'_{12}}$$

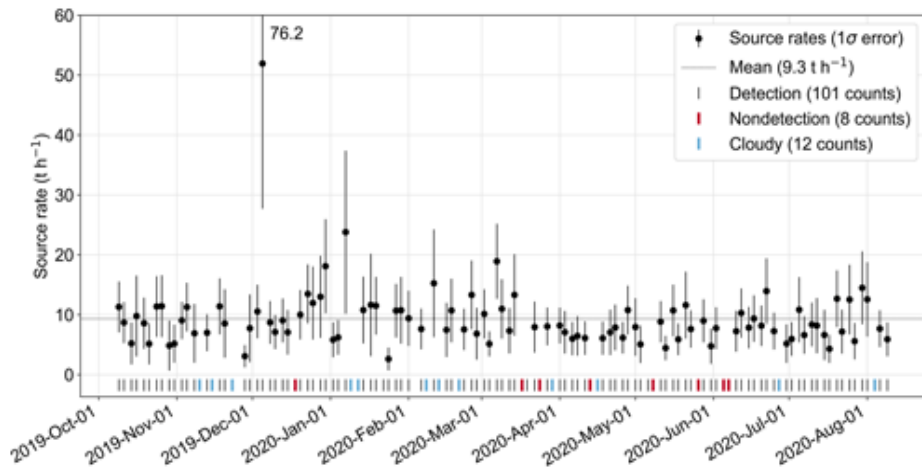
二波段反演

$$\Delta R_{\text{MBSP}} = \frac{cR_{12} - R_{11}}{R_{11}}$$

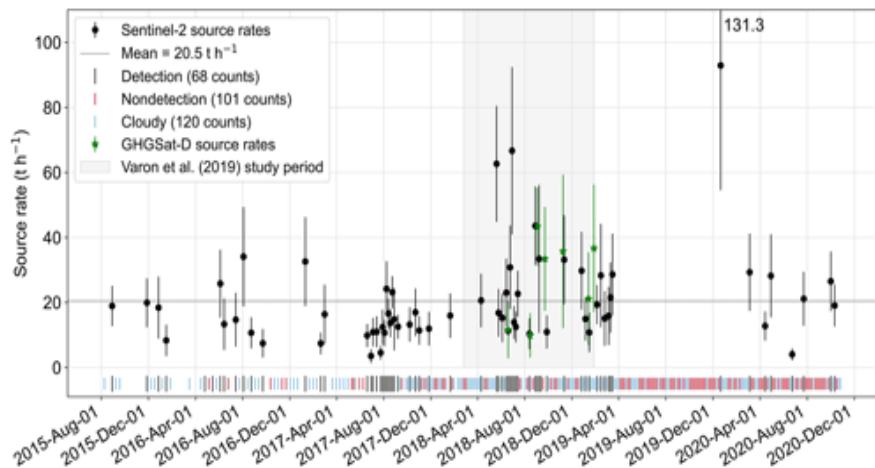


Varon et al, 2021

Sentinel-2点源探测



the Hassi Messaoud oil field

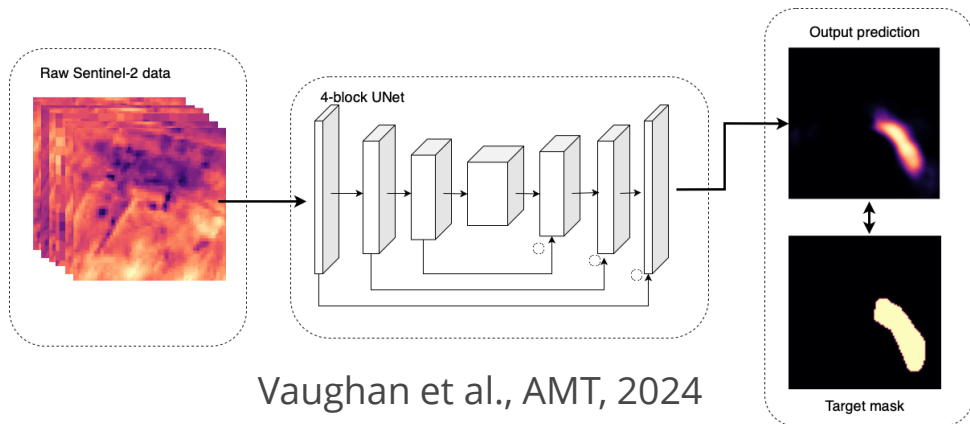


Korpezhe compressor station, Turkmenistan

Varon et al, 2021

多光谱大型点源自动识别

CH4Net

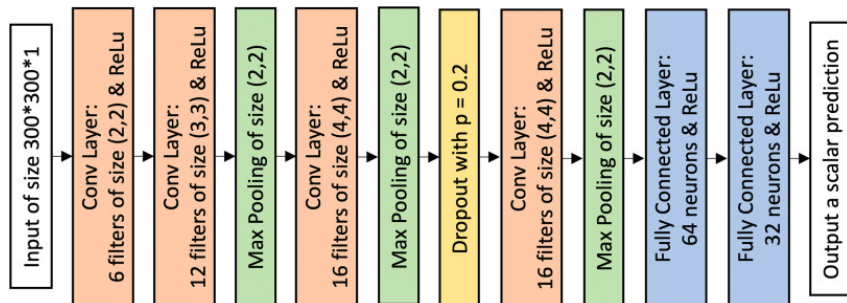


U-Net

23 个已知点源
训练、验证

数据量受限

MethaNet



CCN

利用模拟数据
训练

“真实性”受限

Jongaramrungruang et al., RSE, 2022

多光谱大型点源自动识别

光谱分辨率低
信号干扰大

自动检测难

1. 计算甲烷浓度的变化量 (ΔX_{CH_4})

从光谱信号中提取甲烷浓度信息

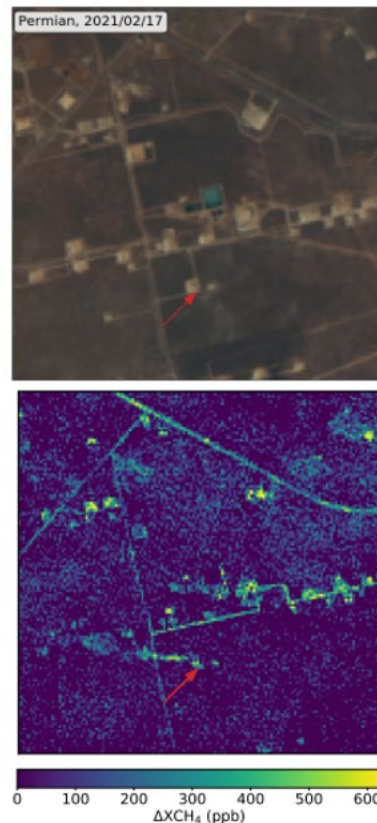
2. 识别甲烷烟羽

从甲烷浓度场中分辨出有效信号、定位排放源位置

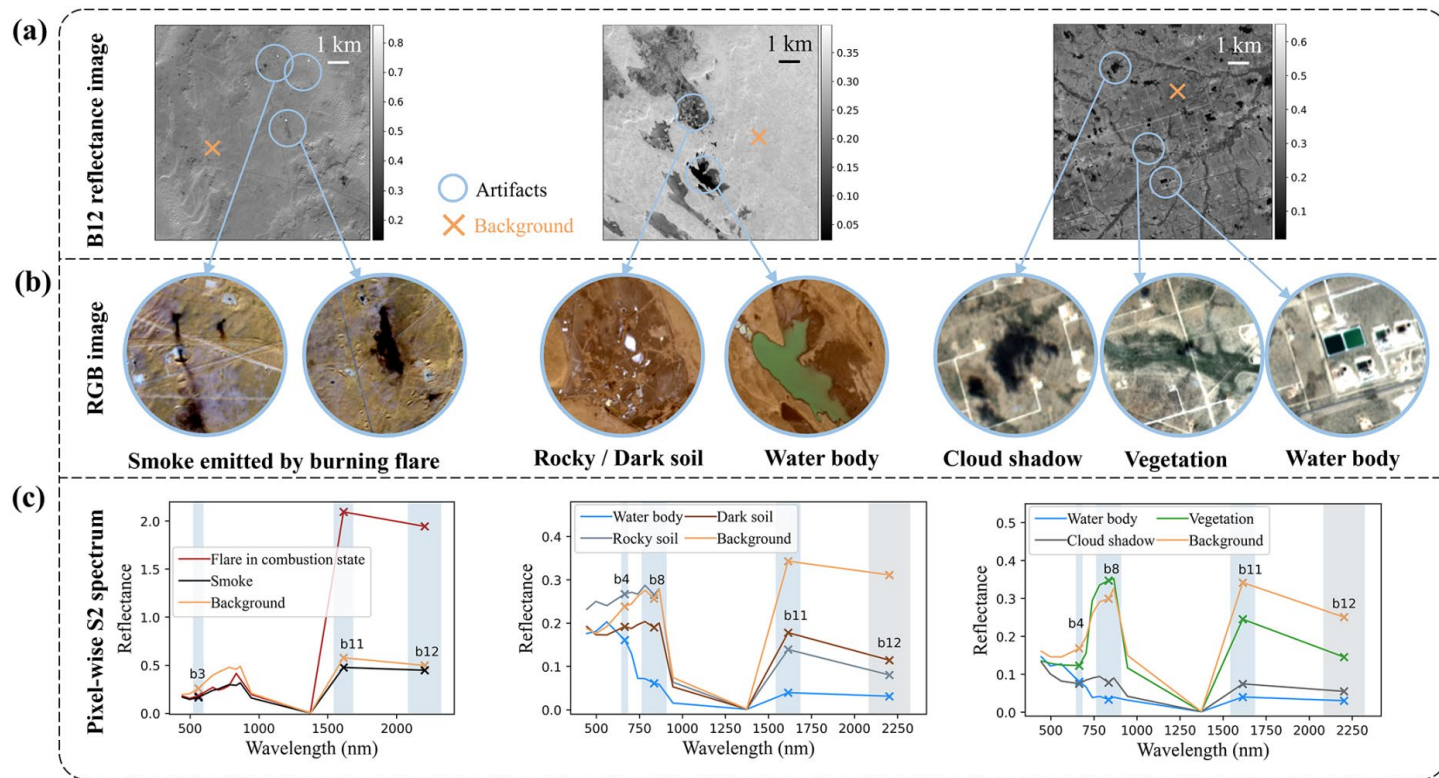
3. 排放源判定

利用辅助信息判断排放源

4. 排放通量估算

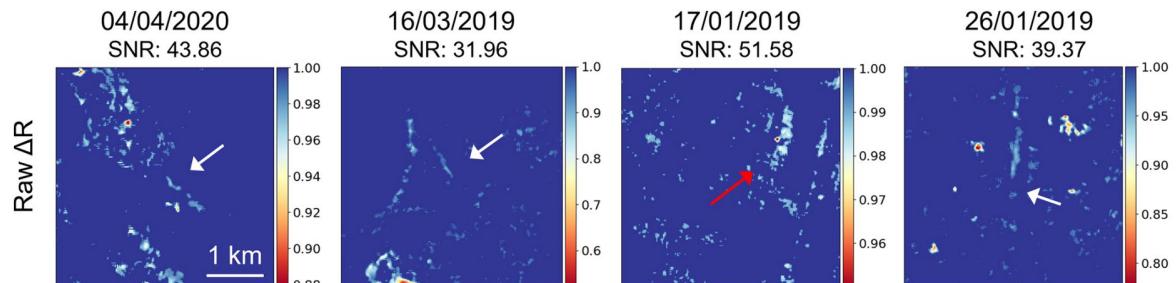


降伪影干扰——Low-reflectance artifact detection (LRAD)算法

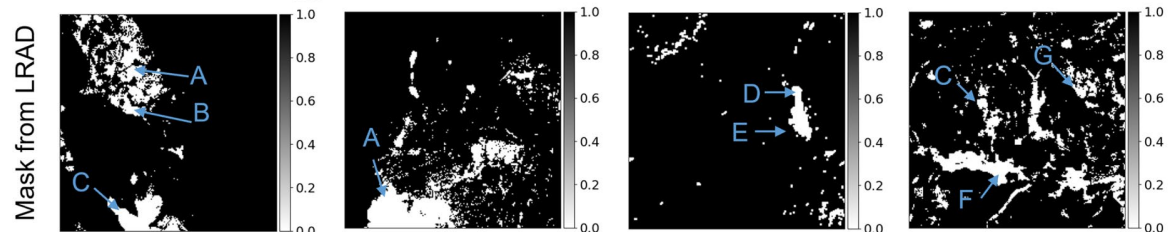


降伪影干扰——Low-reflectance artifact detection (LRAD)算法

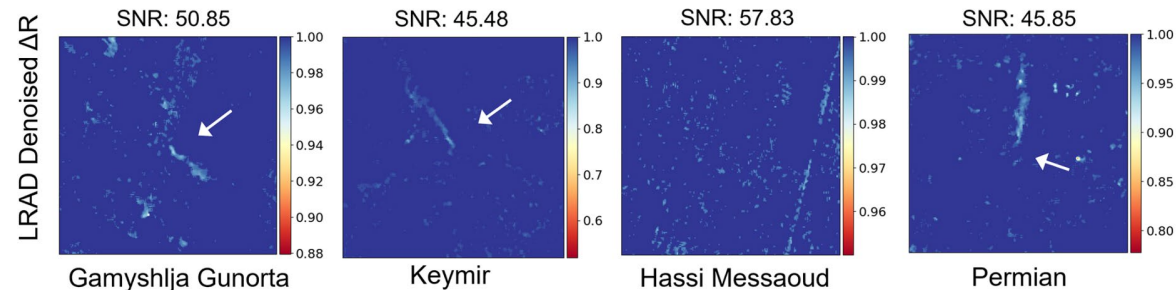
原始 ΔR 图像



LRAD掩膜



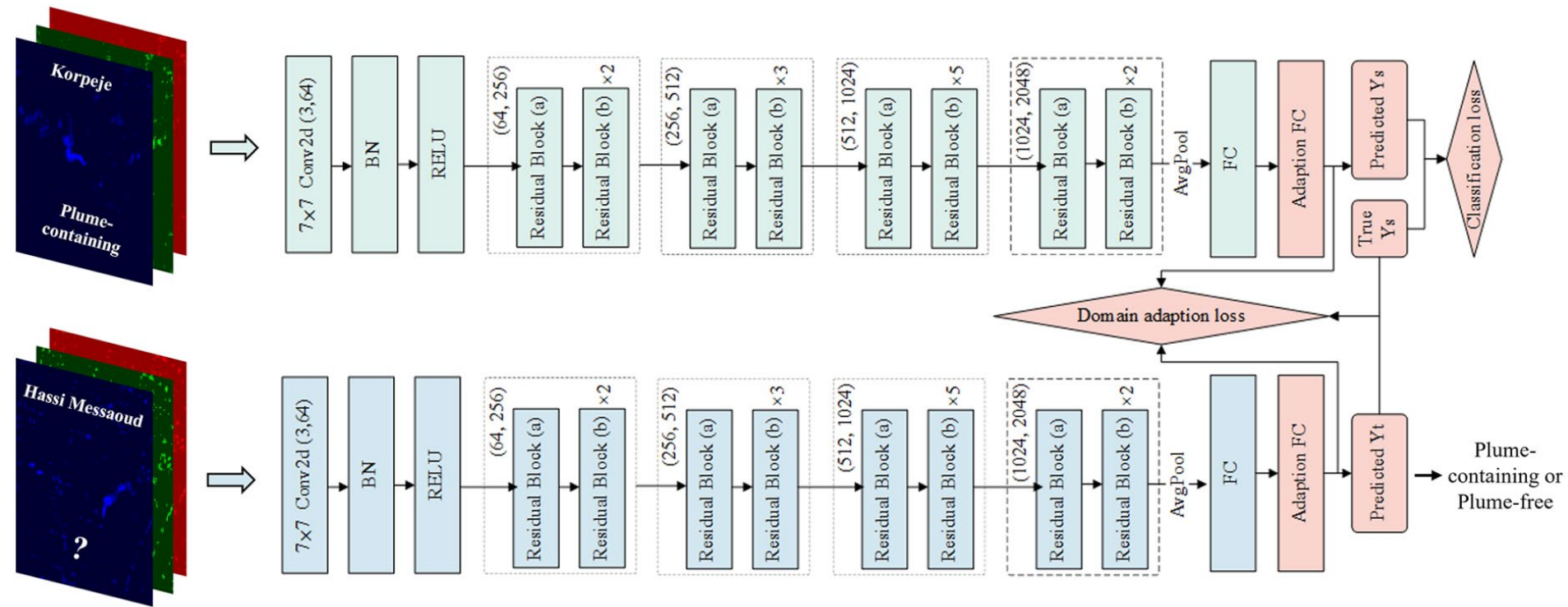
去噪后 ΔR 图像



A:Dark soil | B:Rocky soil | C:Water | D:Burning flare | E:Smoke | F:Vegetation | G:Cloud shadow

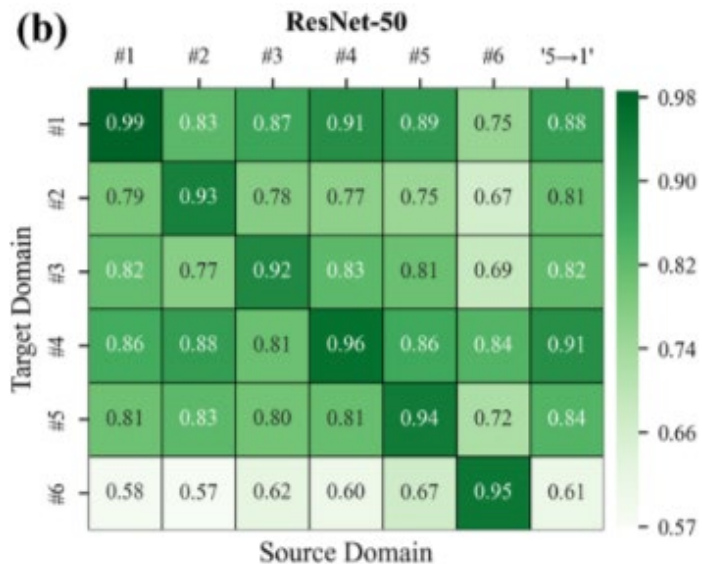
迁移学习——Deep subdomain adaptation network (DSAN)

增强跨地域应用的能力：A地学习，B地应用

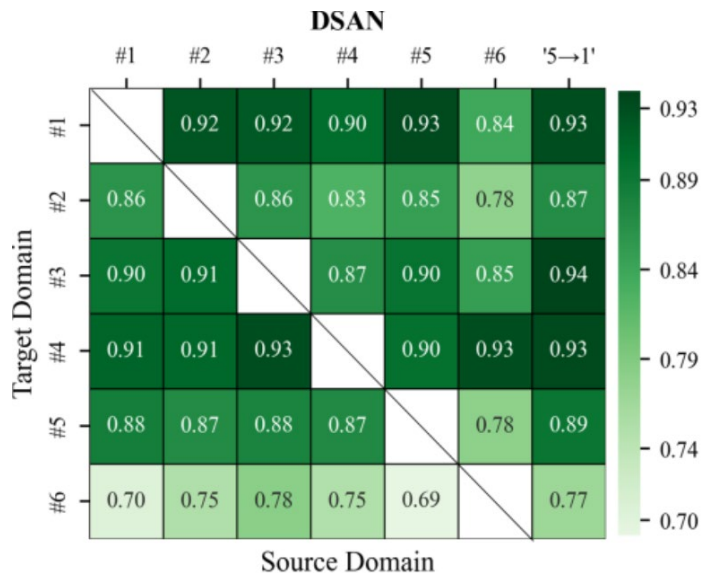


迁移学习训练Sentinel-2甲烷烟羽检测器

传统机器学习方法



迁移学习



非对角线表示跨地区应用

迁移学习训练 Sentinel-2 甲烷烟羽检测器

挑战：有效样本少，难以训练高准确率的检测器

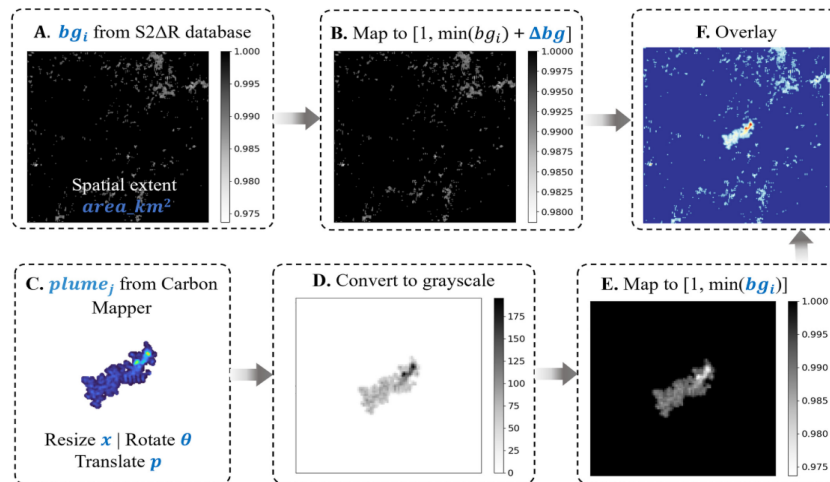
基于高光谱卫星烟羽生成训练数据 → 多光谱卫星烟羽检测器

Carbon Mapper Level 3A (L3A)

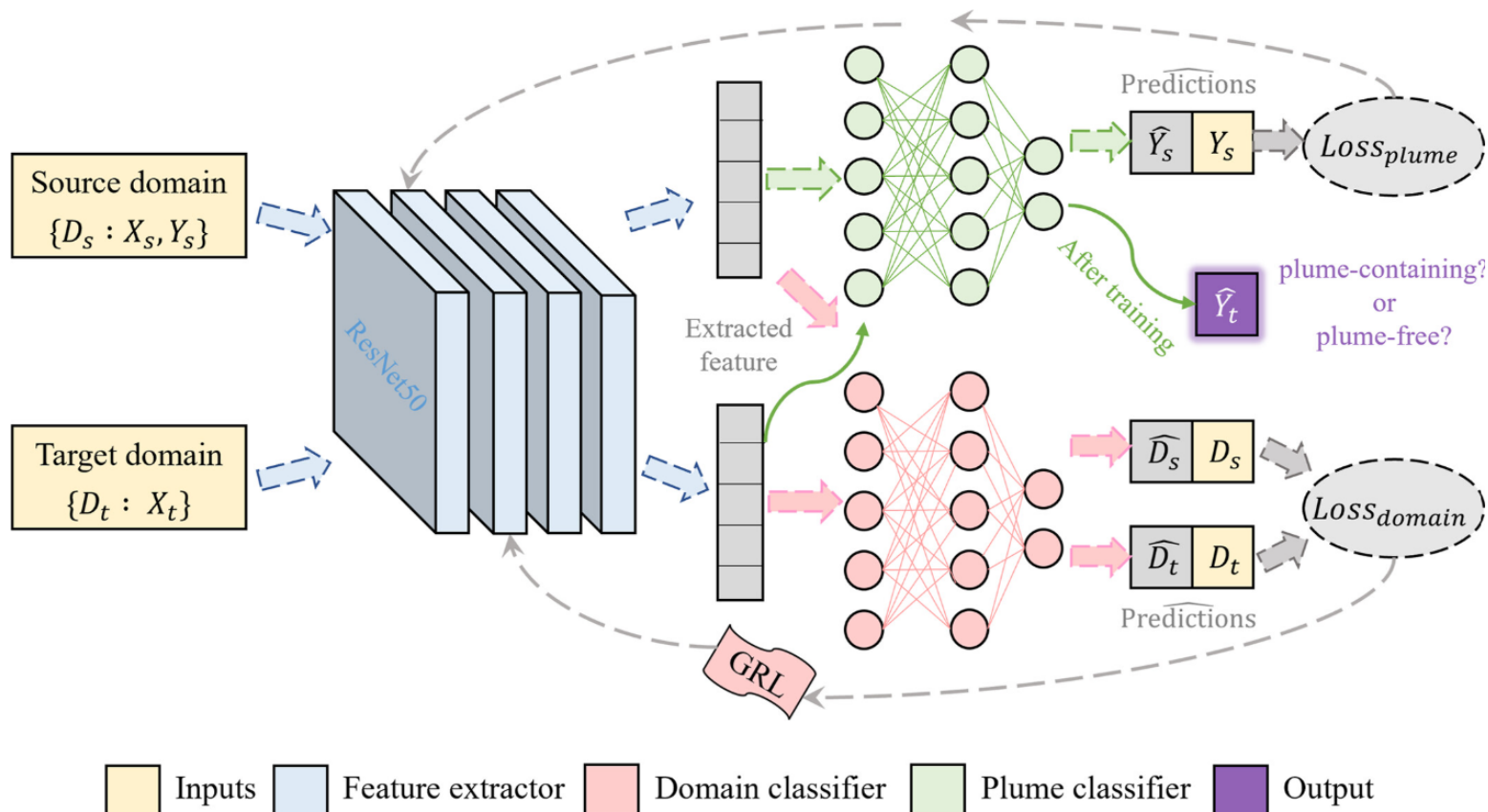
[\[https://data.carbonmapper.org\]](https://data.carbonmapper.org)

- 14,000 高光谱烷烟羽
- 飞机遥感
 - 53% 亚利桑那大学
 - 35% NASA AVIRIS-NG
- 卫星：12% — NASA's EMIT

合成训练数据：烟羽(高光谱)+背景(多光谱)

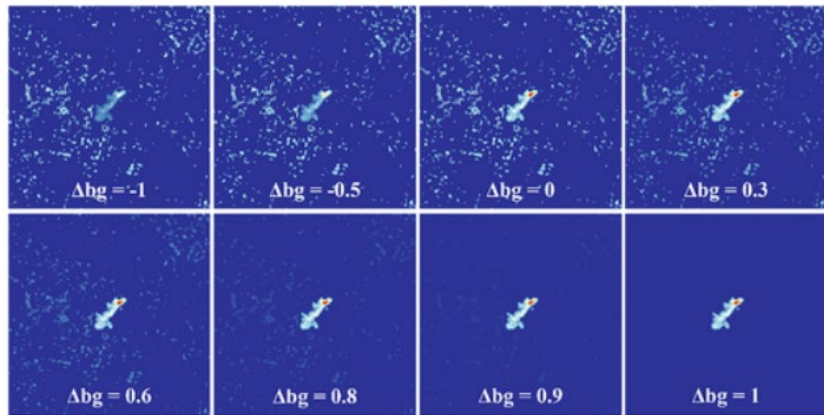


迁移学习训练Sentinel-2甲烷烟羽检测器



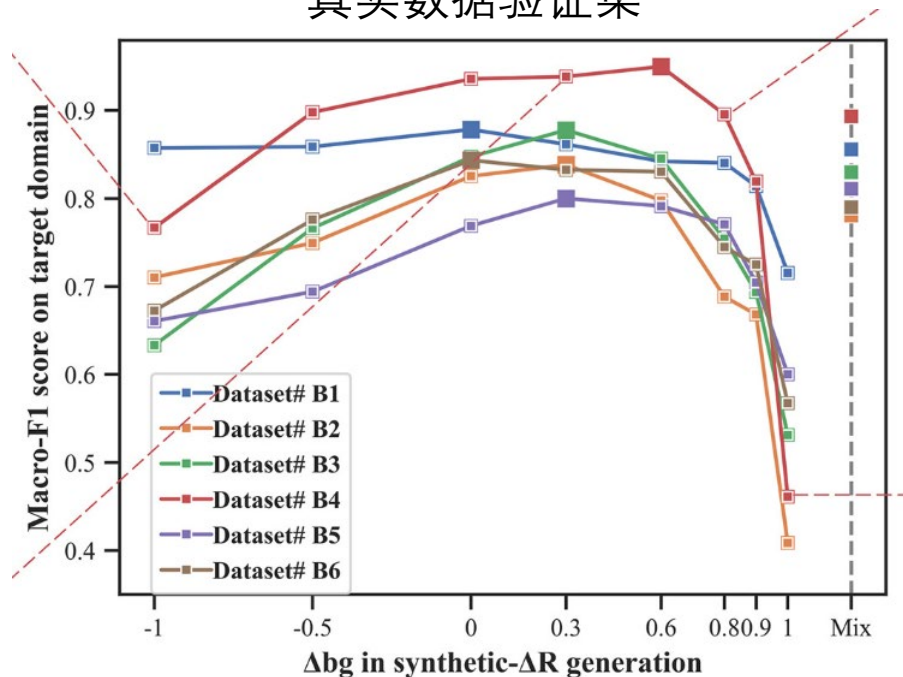
训练数据信噪比对检测效果的影响

信噪比不同的训练数据



信噪比过高或过低都不利于检测效果

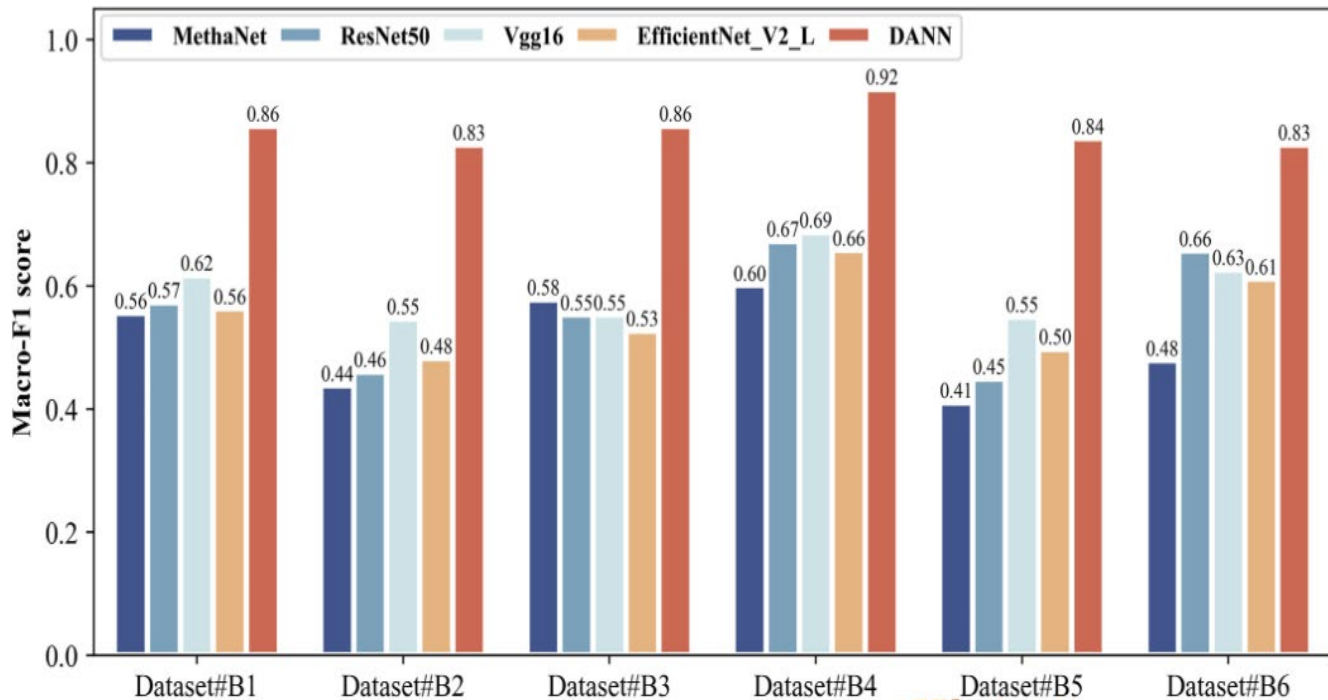
真实数据验证集



Zhao et al., JGR, 2025

与其它已有算法的比较

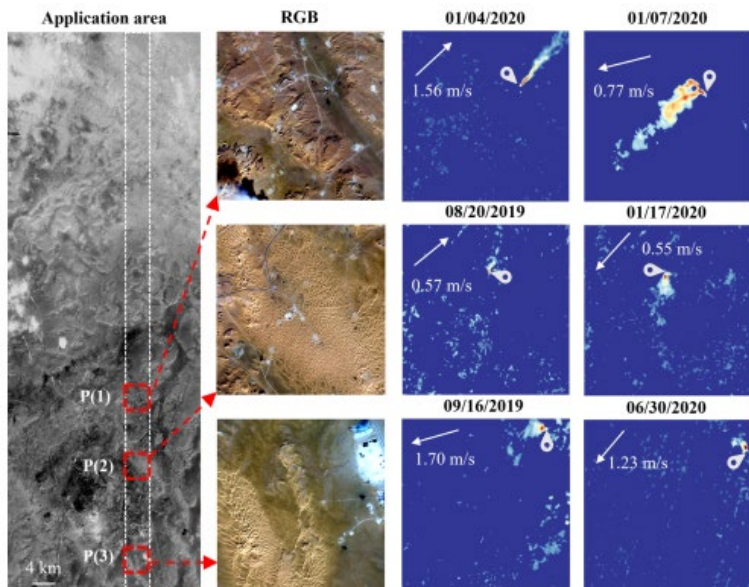
非迁移算法的深度学习模型



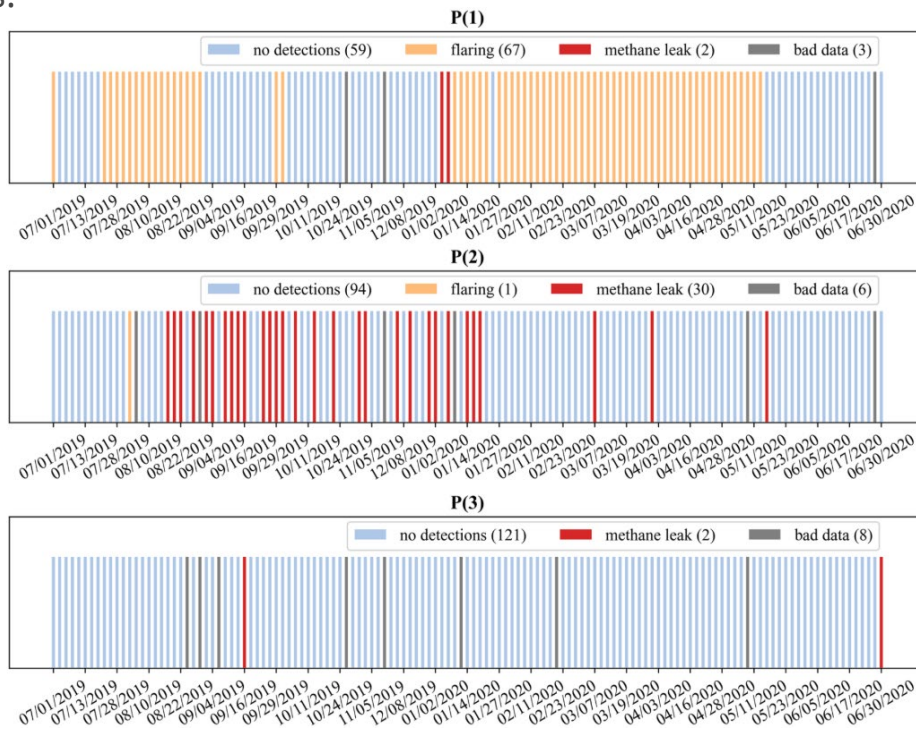
自动探测
效果评估

真实场景应用—— Hassi Messaoud O&G field in Algeria

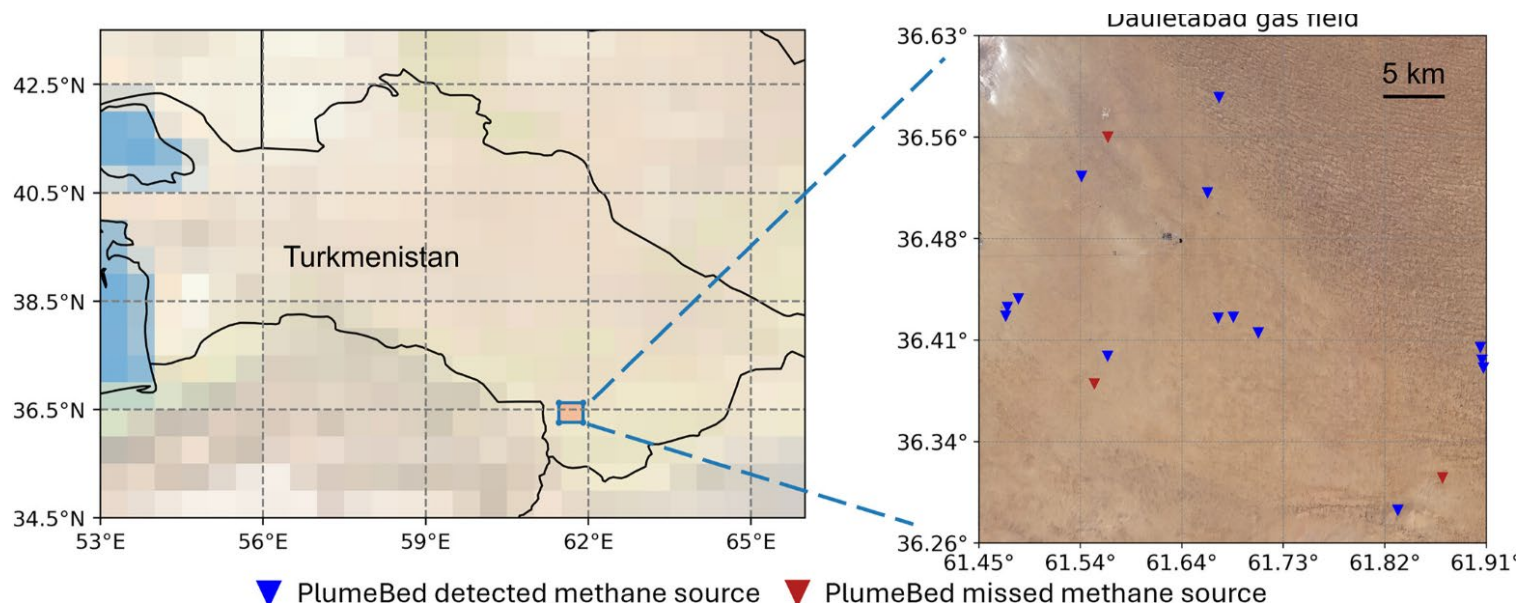
3527 images (200 pixels by 200 pixels) for 1 year, yielding 3168 negative (plume-free) and 369 positive (plume-containing) detections.



P(1): 31.8651°, 6.1683° | P(2): 31.7566°, 6.1864° | P(3): 31.5846°, 6.4878°

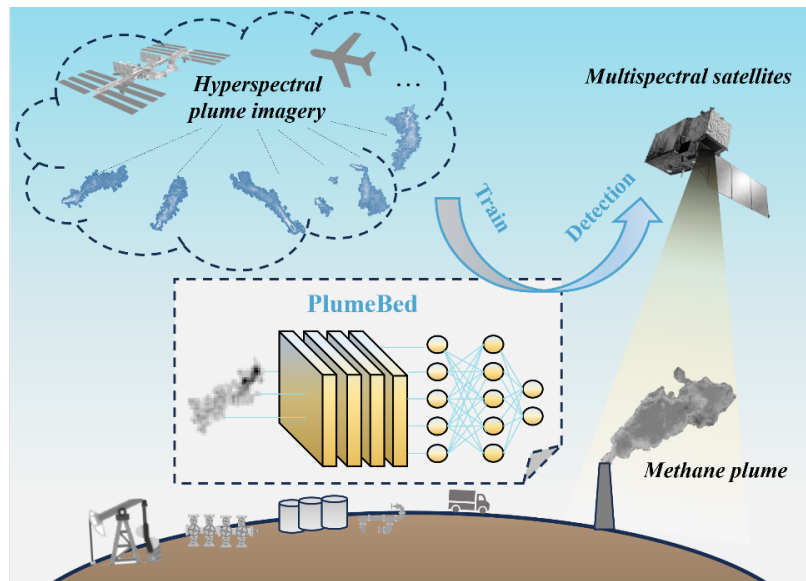


真实场景应用——Dauletabad Gas Field



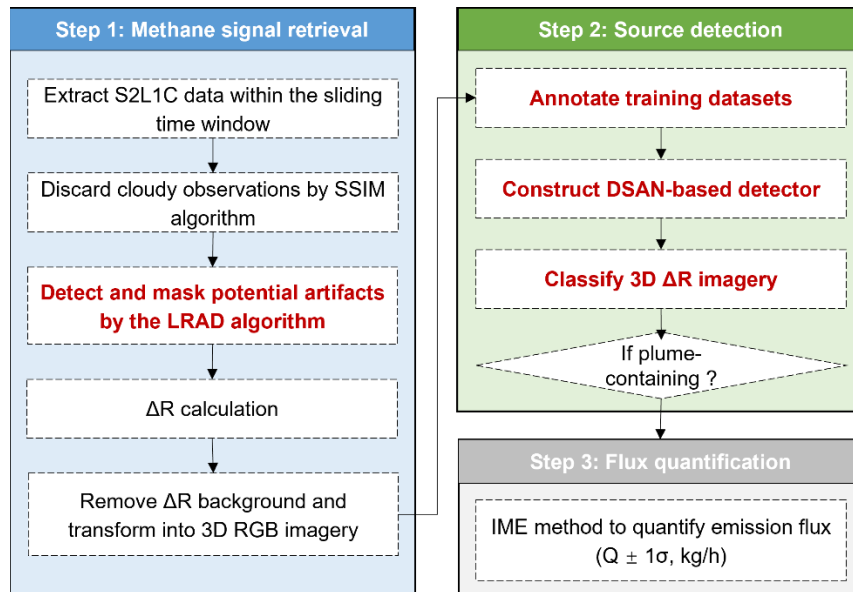
Spatial extent (area_k ^{m2})	Number of produced ΔR images	TP ^a	TN ^b	FP ^c	FN ^d	Macro-F1 score
16	5358	11	5199	143	5	0.5577

2017-2023年甲烷点源排放与背景数据



<https://www.aers-cloud.org.cn/>
融合产品/甲烷点源排放

2017-2023年甲烷点源排放图像数据



<https://www.aers-cloud.org.cn/>
融合产品/甲烷点源排放图像

多光谱大型点源自动识别

海量大数据
计算效率低

测量精度低
自动检测难

1. 计算甲烷浓度的变化量 (ΔX_{CH_4})

从光谱信号中提取甲烷浓度信息

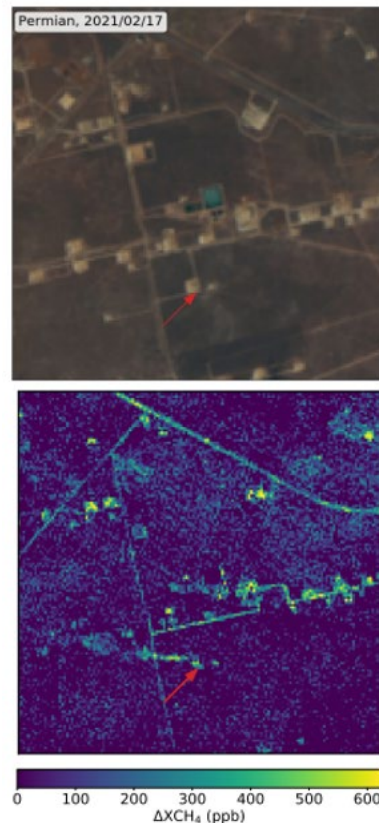
2. 识别甲烷烟羽

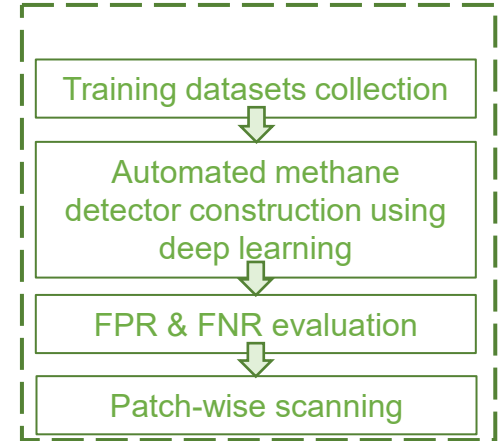
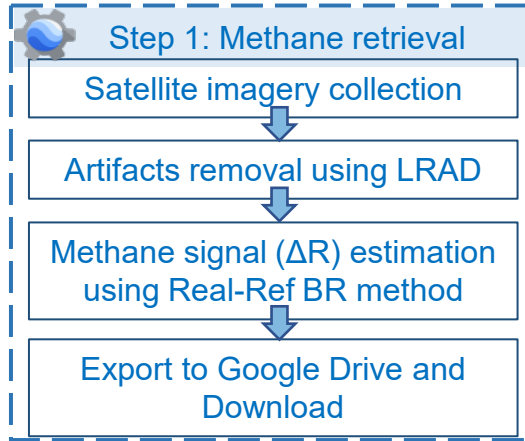
从甲烷浓度场中分辨出有效信号、定位排放源位置

3. 排放源判定

利用辅助信息判断排放源

4. 排放通量估算



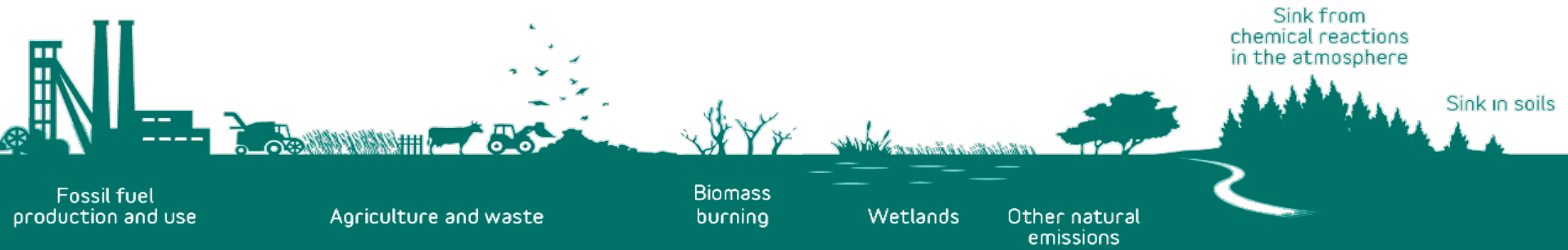


Positives



总结

- 卫星甲烷观测发展迅速。在监测甲烷排放、为减排提供信息方面有很强的应用前景。
- 多光谱点源型卫星观测应用于大型甲烷排放的监测。
- 基于迁移深度学习可以部分解决自动检测器样本缺少、普适性差的问题。
- 自动扫描检测算法假阳性仍较高。



Science



西湖大學
WESTLAKE UNIVERSITY

工学院
SCHOOL OF ENGINEERING

碳监测

CARBON MONITORING

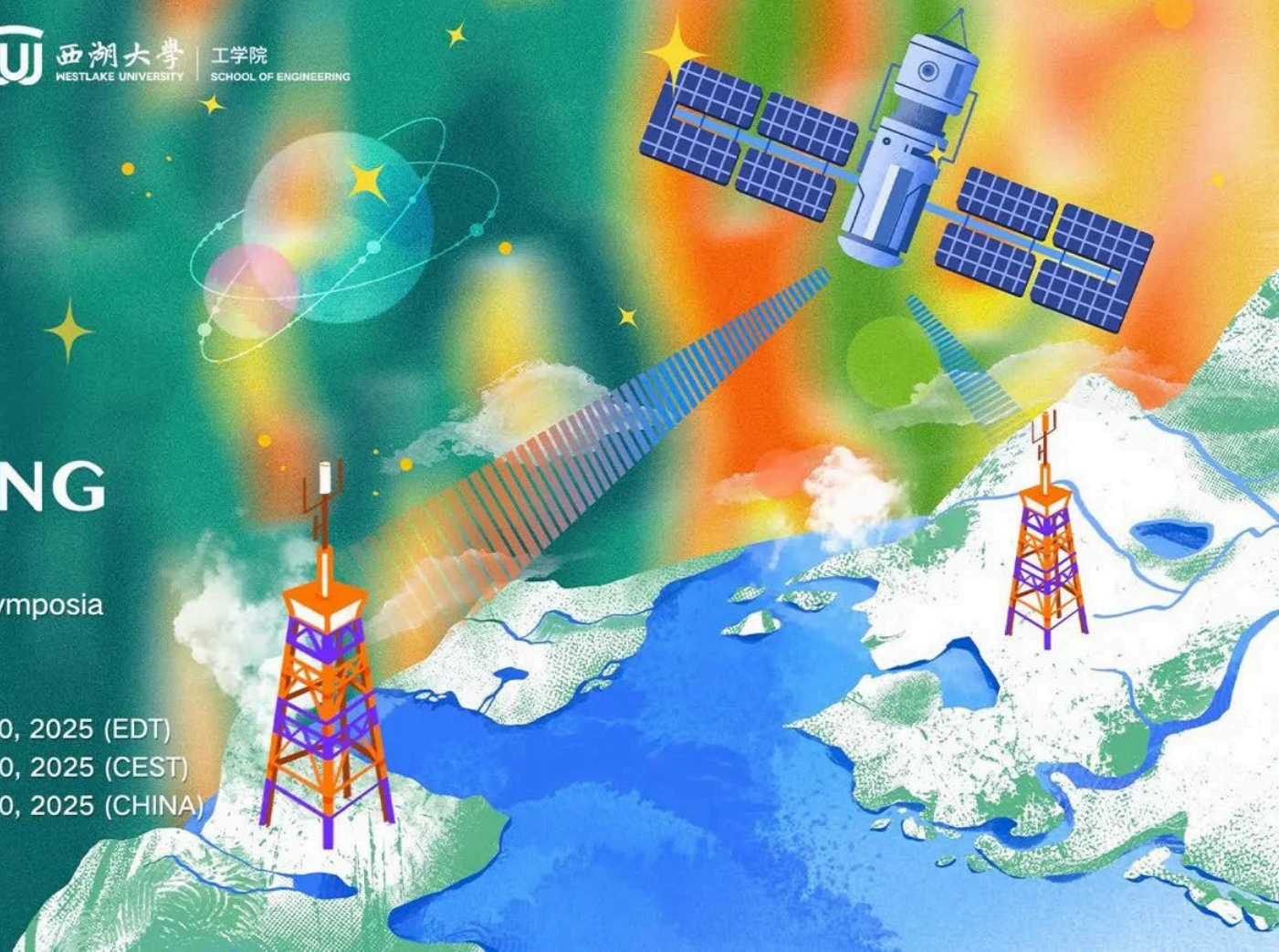
2025 Westlake × Science Symposia

Symposium #4

08-10 am, Thursday, October 30, 2025 (EDT)

02-04 pm, Thursday, October 30, 2025 (CEST)

08-10 pm, Thursday, October 30, 2025 (CHINA)





Dr. Euan Nisbet

20:00-20:30

Royal Holloway, Univ. of London & Cambridge University

大气甲烷监测：方法、发现及其对管控全球甲烷收支的启示

Monitoring Atmospheric Methane: How We Do it,
What We Learn, and the Lessons for Bringing the
Methane Budget under Control



Dr. Ben Poulter

20:30-21:00

Spark Climate Solutions

北极-寒带地区甲烷收支：为什么应警惕气候变暖加剧温室气体排放并实施全面监测？

Arctic-Boreal Methane Budget: Reasons for
Concern and for Integrated Monitoring of
Warming-Induced Greenhouse Gas Emissions



Dr. Daniel Cusworth

21:00-21:30

Carbon Mapper

从卫星视角看甲烷超级排放源的全球分布

The Global Distribution of Super-Emitting Methane
Point Sources as Detected by Satellites

Vhall直播间注册

手机端：扫描下方二维码注册



ZOOM直播间注册

手机端：扫描下方二维码注册



Science B站直播间观看



直播时段内进入Science B站直播间