Quantifying methane point sources from fine-scale (GHGSat) satellite observation of atmospheric methane plumes

Daniel J. Varon[1,2], Daniel J. Jacob[1], Jason McKeever[2], Berke Durak[2], Dylan Jervis[2], Yan Xia[3], Yi Huang[3]

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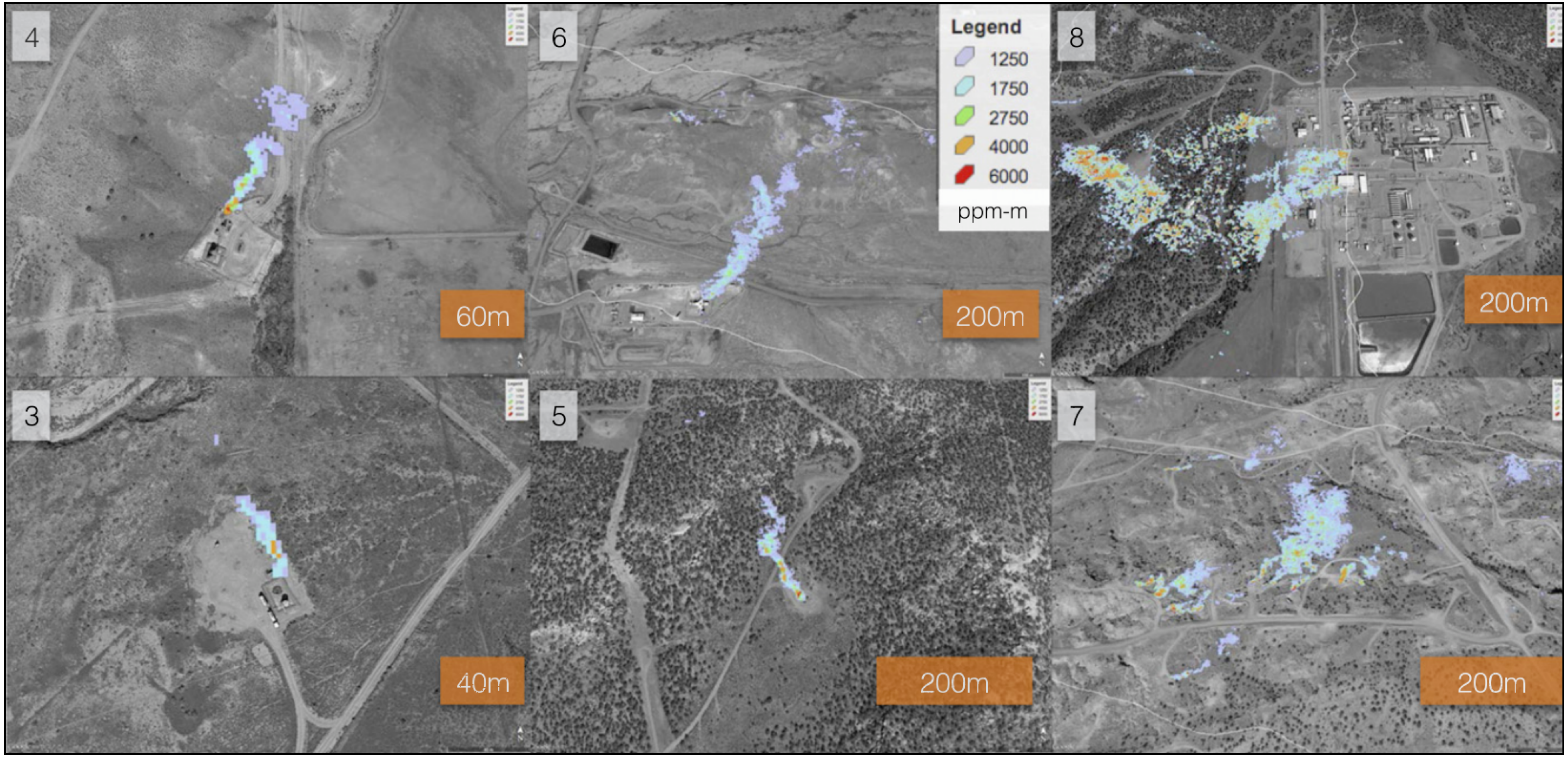
[2] GHGSat, Inc., Montréal QC.
[3] McGill University, Montréal QC.

GHGSat poster:

- **B1.4, Jason McKeever**: GHGSat: Towards an Operational Constellation, **W 10:15-12:00.**

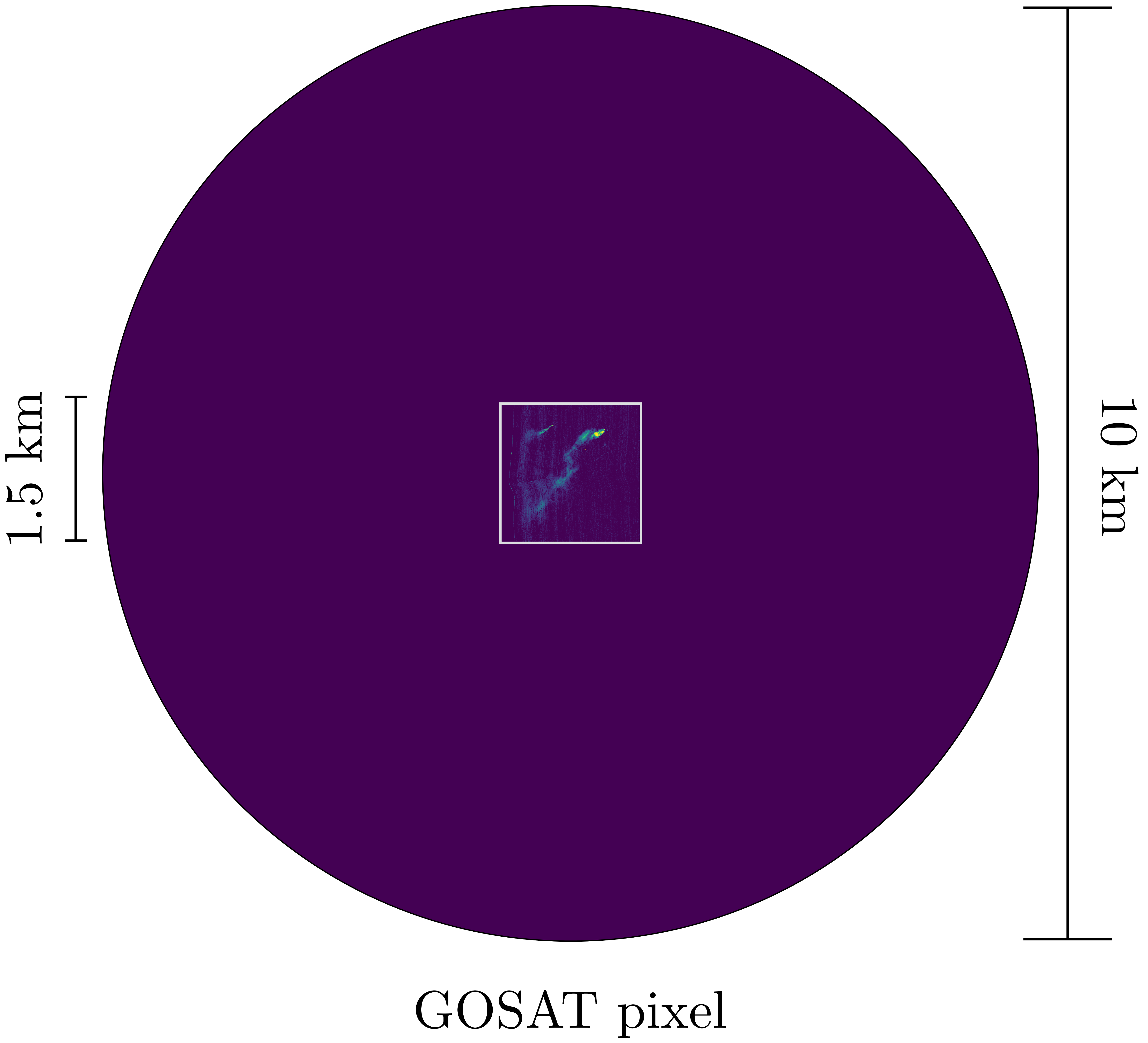
Methane is emitted by a very large number of small point sources

AVIRIS airborne remote sensing observations:



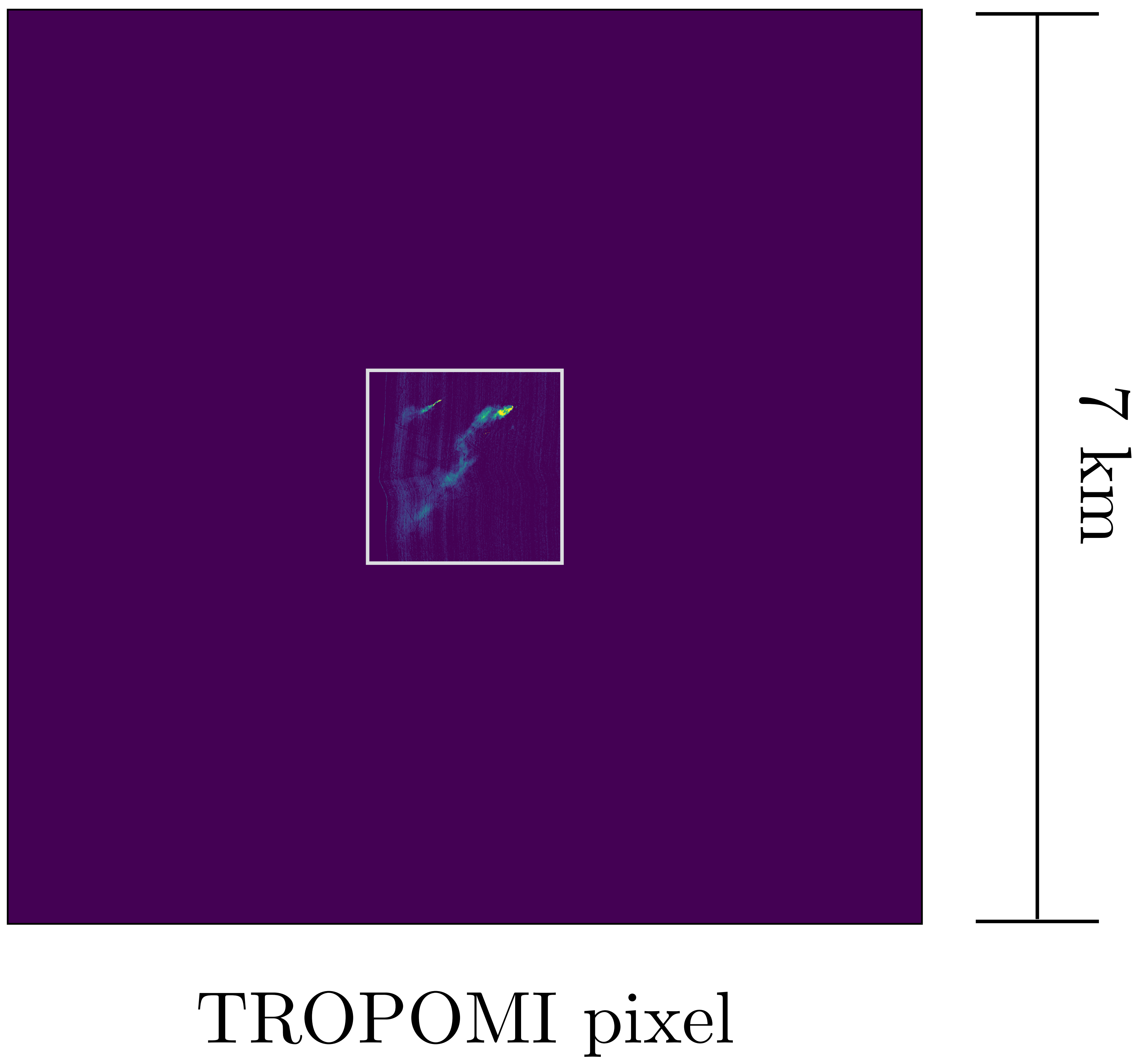
Frankenberg et al., (2016)

Conventional methane-observing satellites have limited ability to quantify point sources



GOSAT/TROPOMI specs:

* Column precision: 0.1-1%
* Pixel resolution: 1-10 km



AVIRIS imagery courtesy of Dr. Andrew Thorpe, NASA JPL

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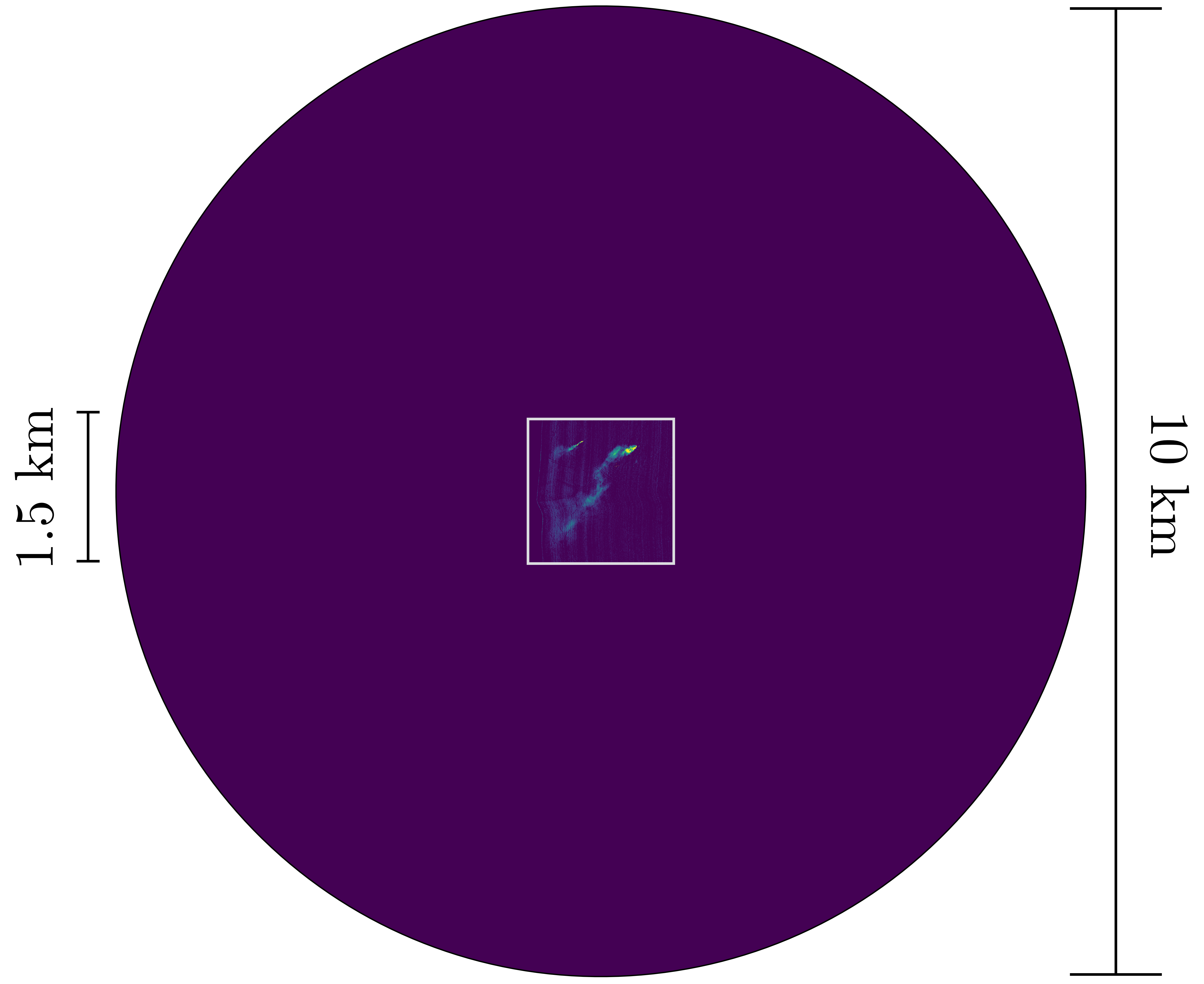

GOSAT pixel

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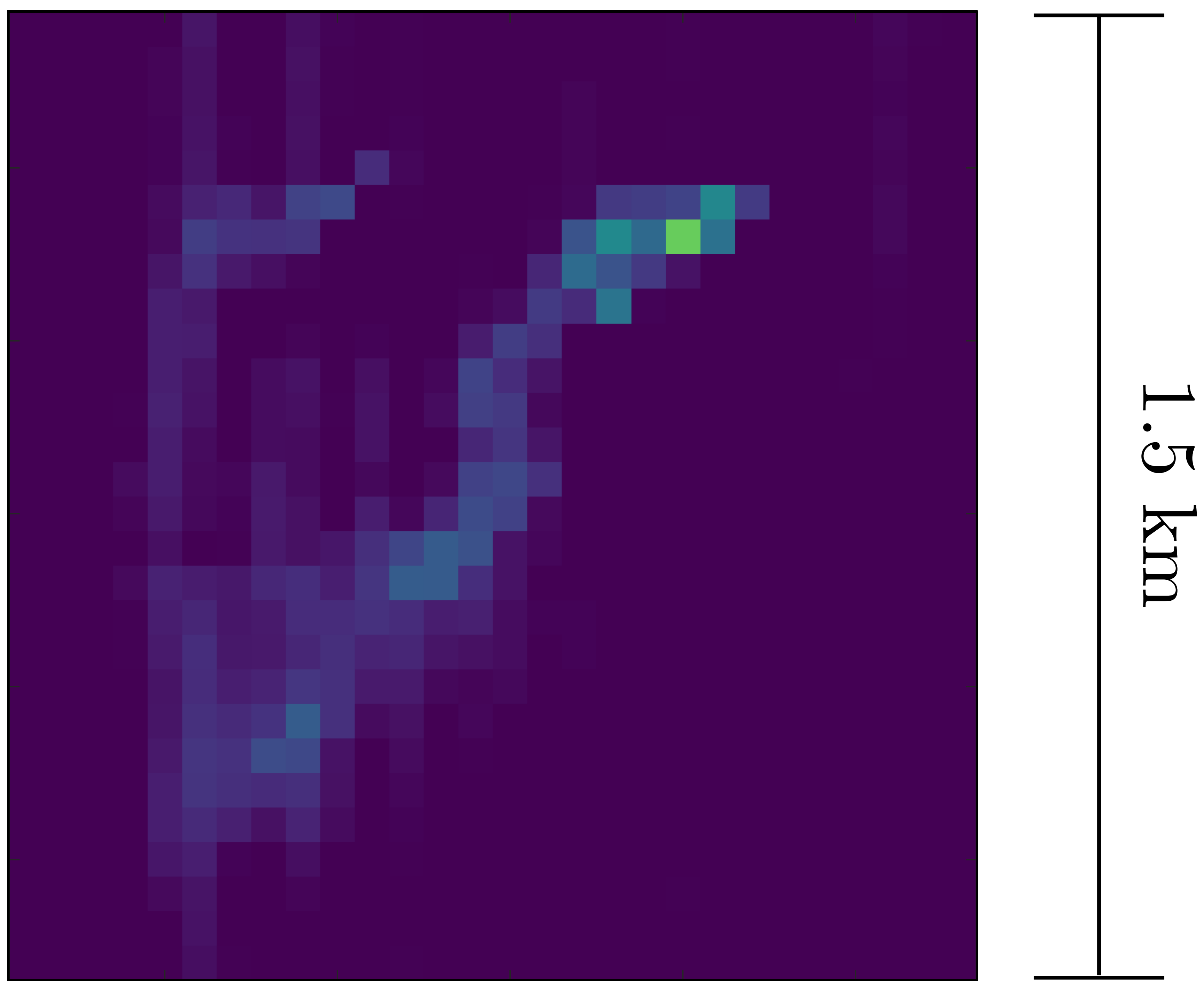

GHGSat imaging resolution

AIVRIS imagery courtesy of Dr. Andrew Thorpe, NASA JPL

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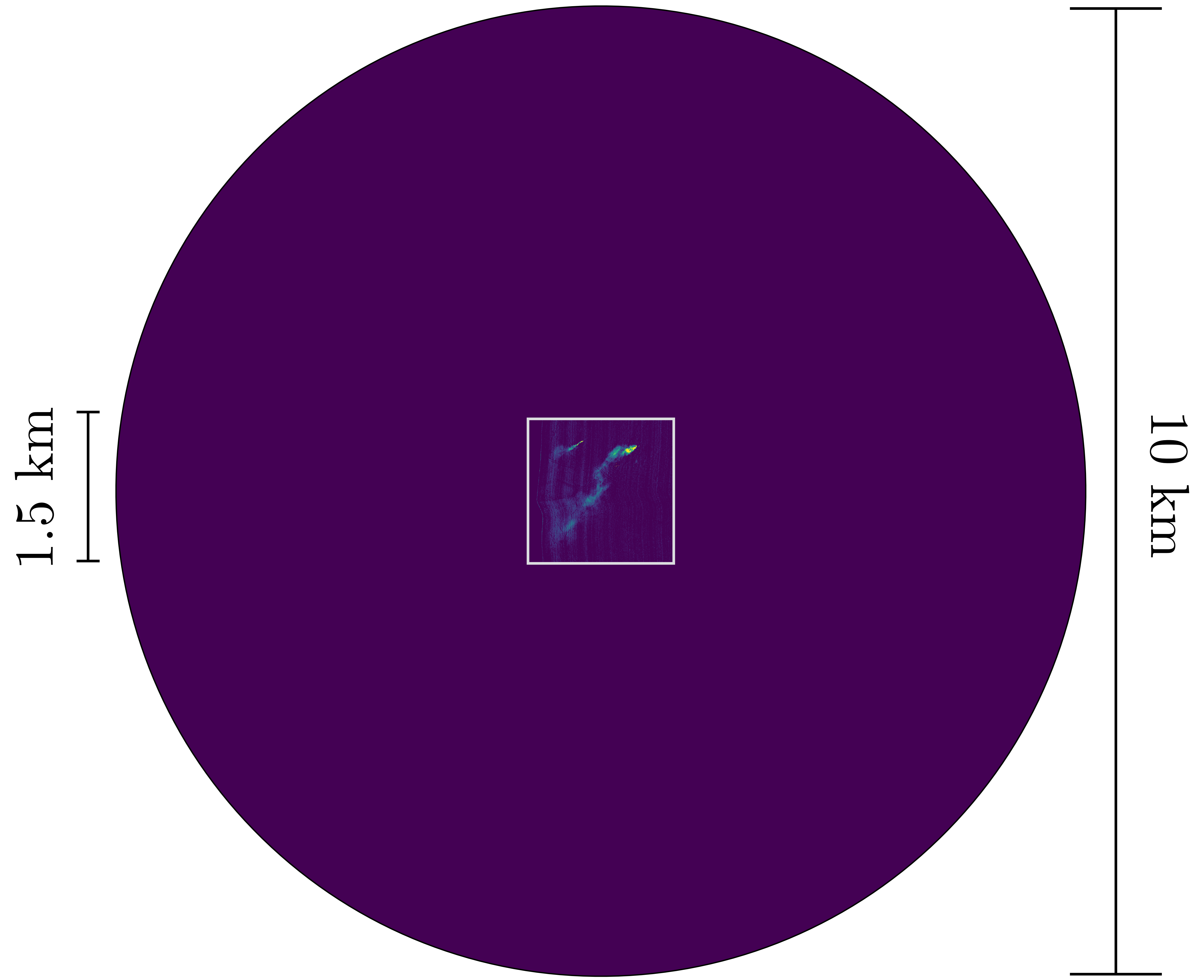

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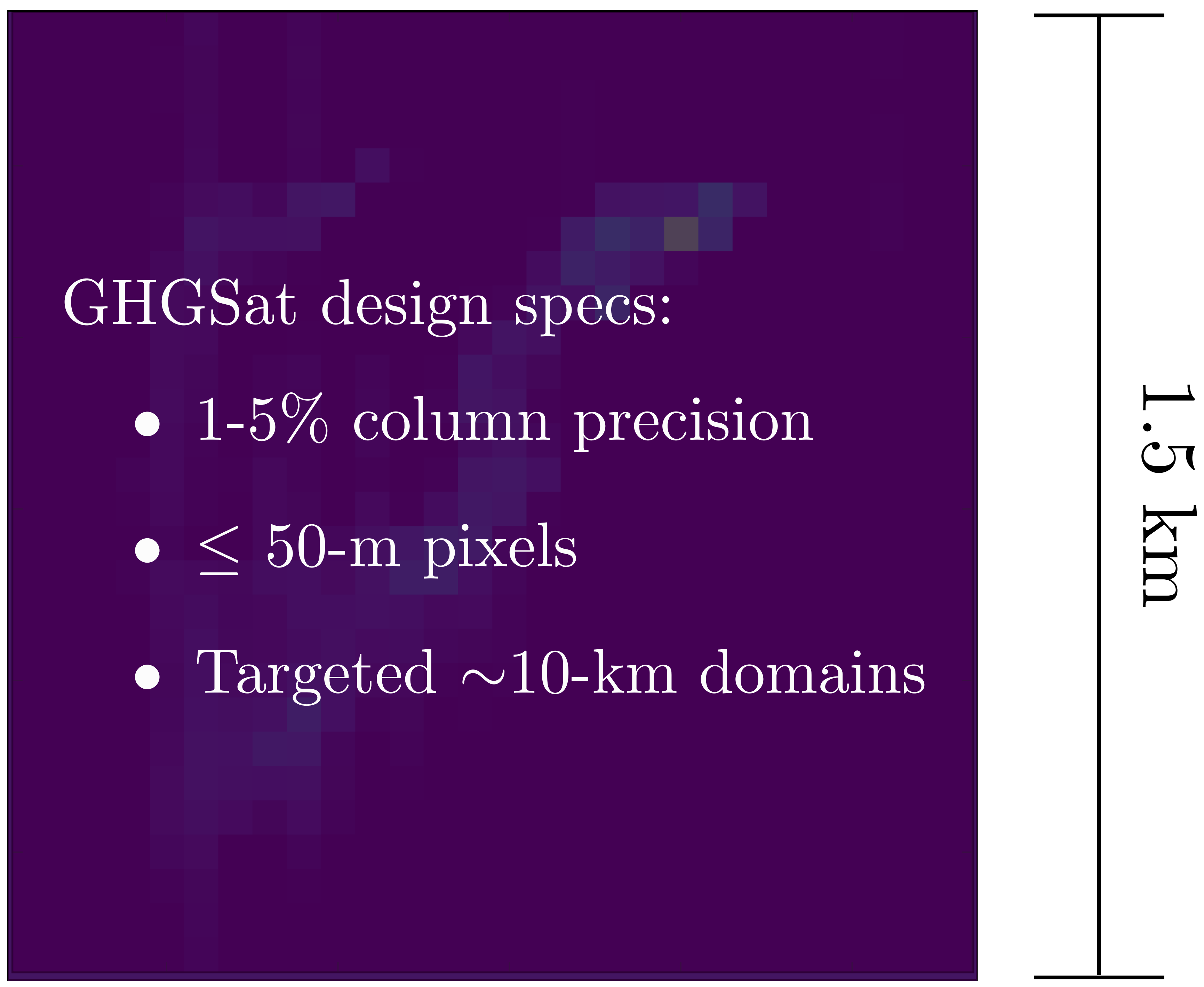
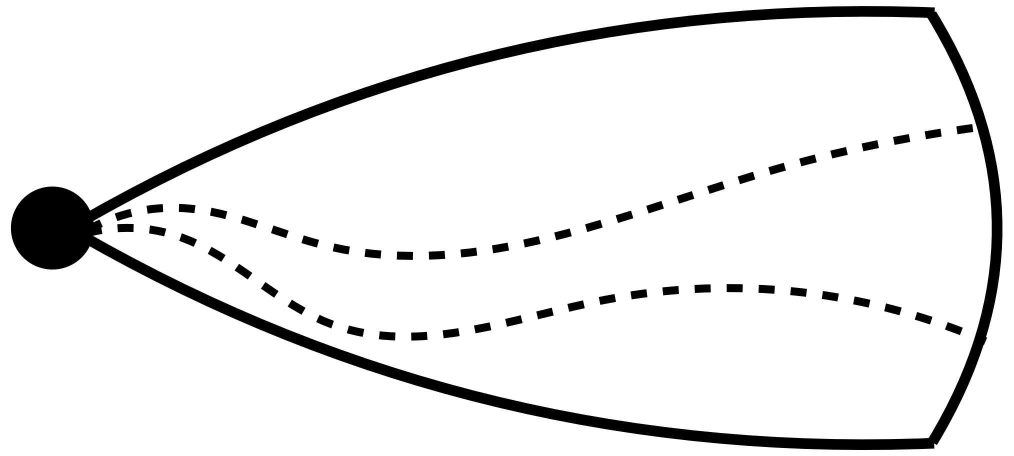


GHGSat imaging resolution

AVIRIS imagery courtesy of Dr. Andrew Thorpe, NASA JPL

Four methods for retrieving point sources from observations of column plumes



$$Q = U\Delta\Omega(x,y)\left(\sqrt{2\pi}\sigma_y(x)e^{\frac{y^2}{2\sigma_y(x)^2}}\right)$$

Gaussian plume inversion

$$Q = \frac{UWp}{g\Omega_a}\Delta\Omega$$

Source pixel mass balance

$$Q = \int_{-\infty}^{\infty} U(x,y)\Delta\Omega(x,y)dy$$

Cross-sectional flux

$$Q = \frac{1}{\tau}\text{IME} = \frac{U_{eff}}{L}\text{IME} = \frac{U_{eff}}{L}\sum_{j=1}^{N}\Delta\Omega_j A_j$$

Integrated Mass Enhancement (IME)

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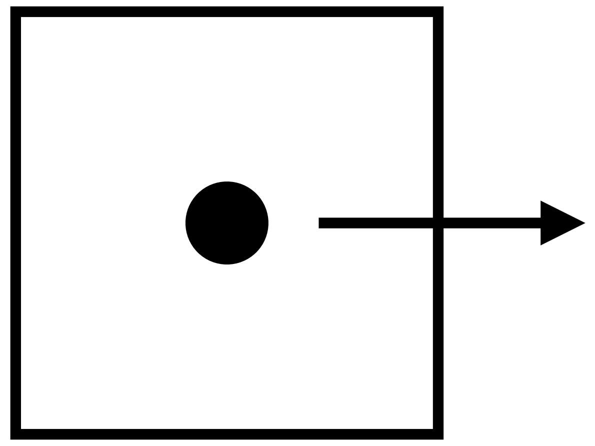

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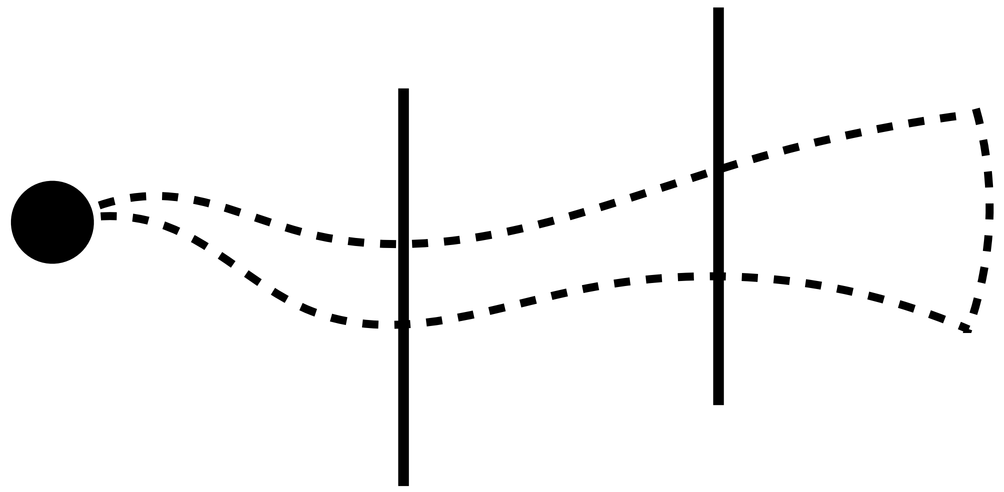

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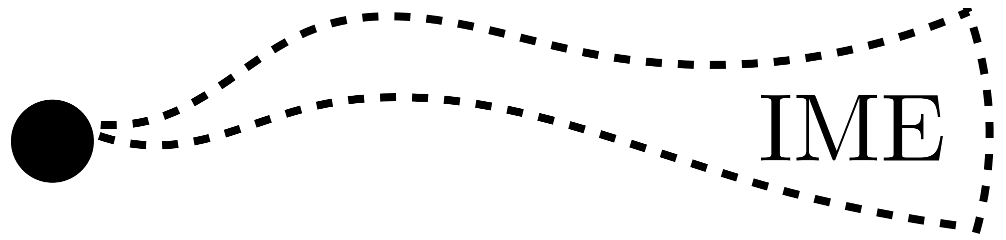

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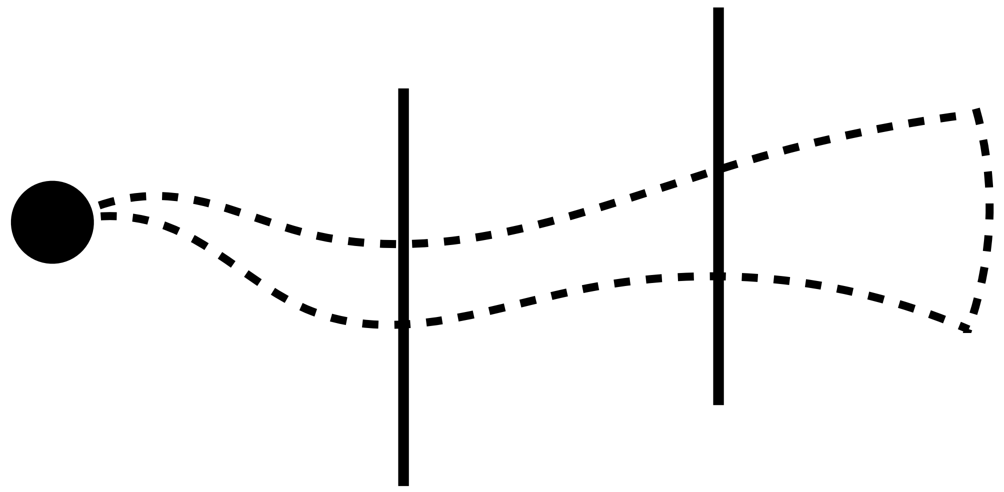

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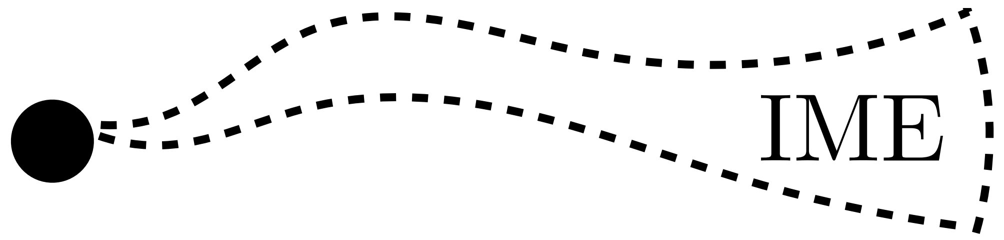
Cross-sectional flux ✓



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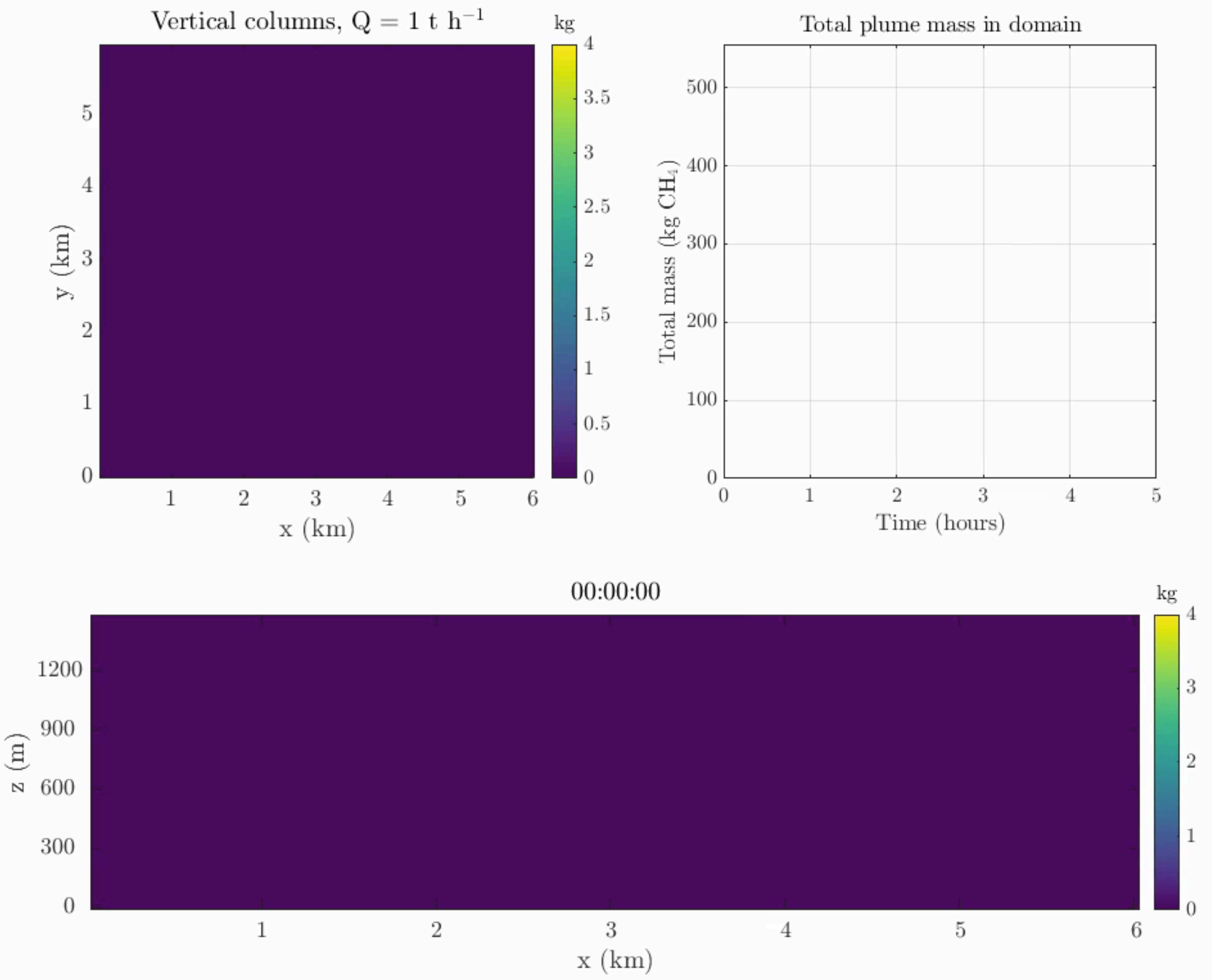
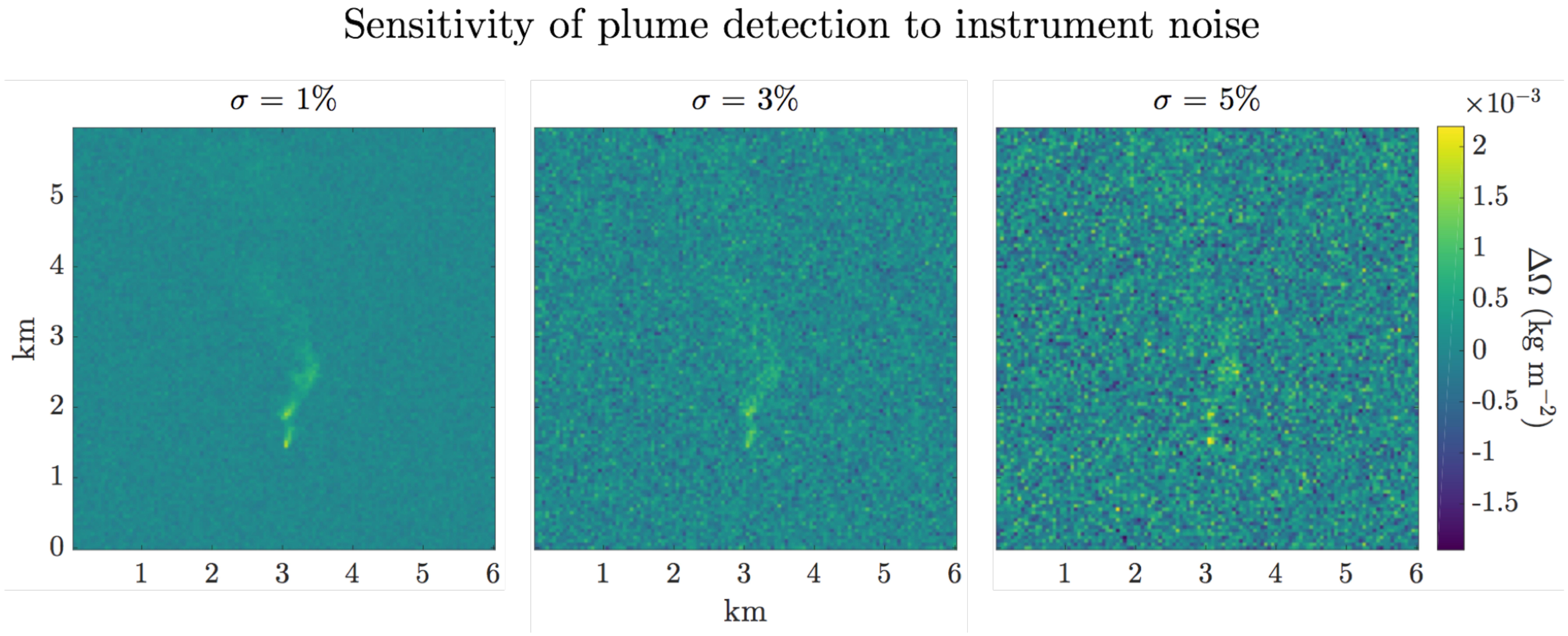
Integrated Mass Enhancement (IME) ✓

WRF-LES: Large Eddy Simulations of methane point sources at 50-m resolution



LES ensemble of 15 simulations.

GHGSat pseudo-observations produced by column integration & addition of noise



Computing the source rate by the IME method

Frankenberg et al., (2016): $IME = \sum_{j=1}^{N} \Delta\Omega_j A_j$

$\Delta\Omega_j$ = jth column enhancement [kg m^{-2}]
A_j = jth pixel area [m^2]

Computing the source rate by the IME method

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Taking this one step further...

$$\Rightarrow \; Q = \frac{1}{\tau} IME = \frac{U_{eff}}{L} IME$$

U_{eff} = Effective wind speed [m s^{-1}]
τ = dissipation time scale [s^{-1}]
L = dissipation length scale [m]

Computing the source rate by the IME method: Inferring the plume mass (IME)

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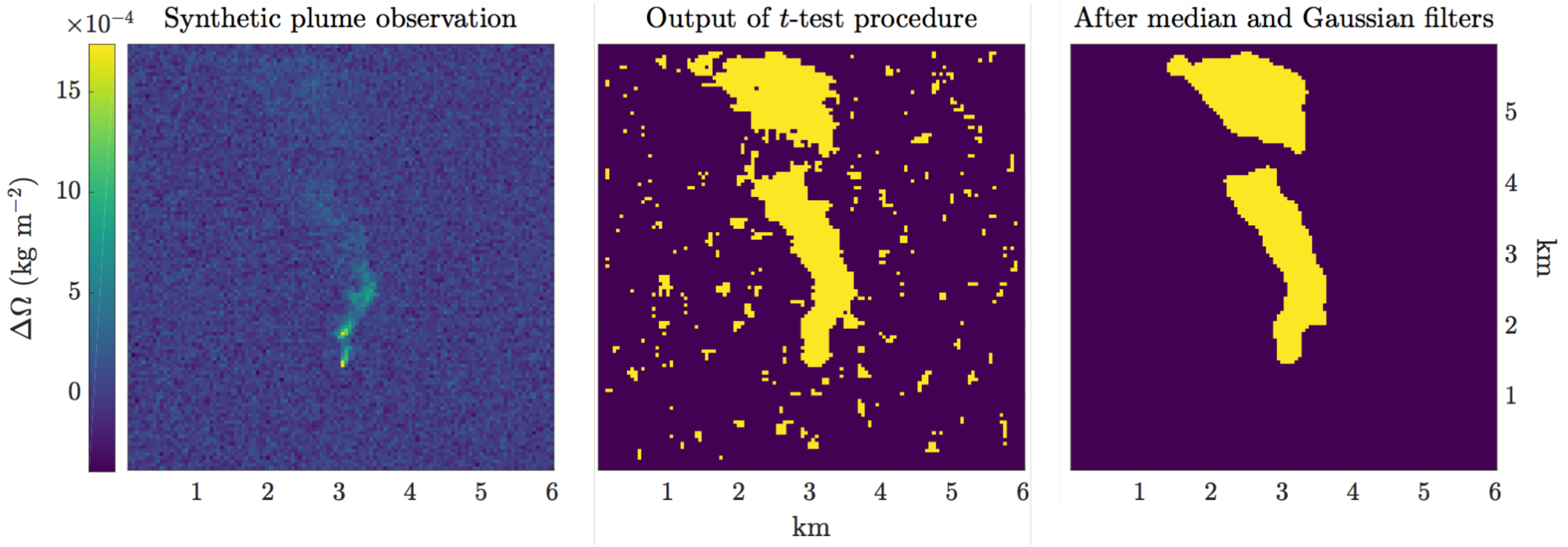

Computing the source rate by the IME method: Inferring the plume size (L)

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U_{eff} = Effective wind speed [m s^{-1}]
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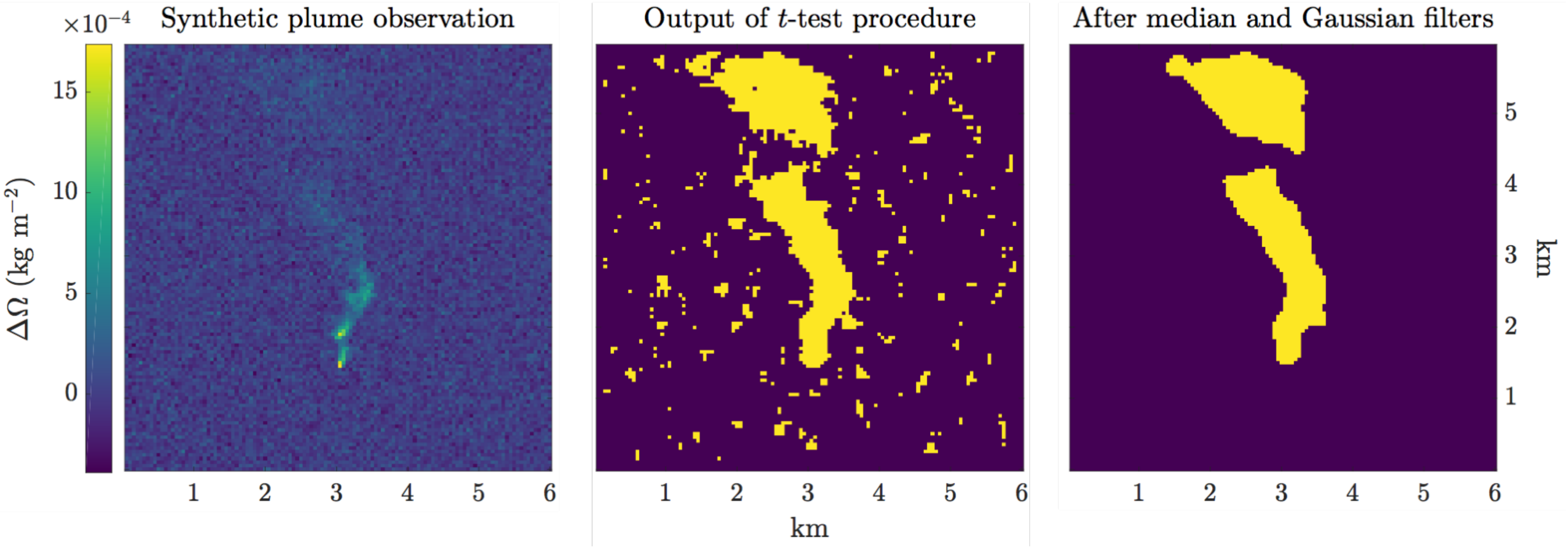
$$L = \sqrt{A_M} = \sqrt{\Sigma_{j=1}^{N} A_j}$$



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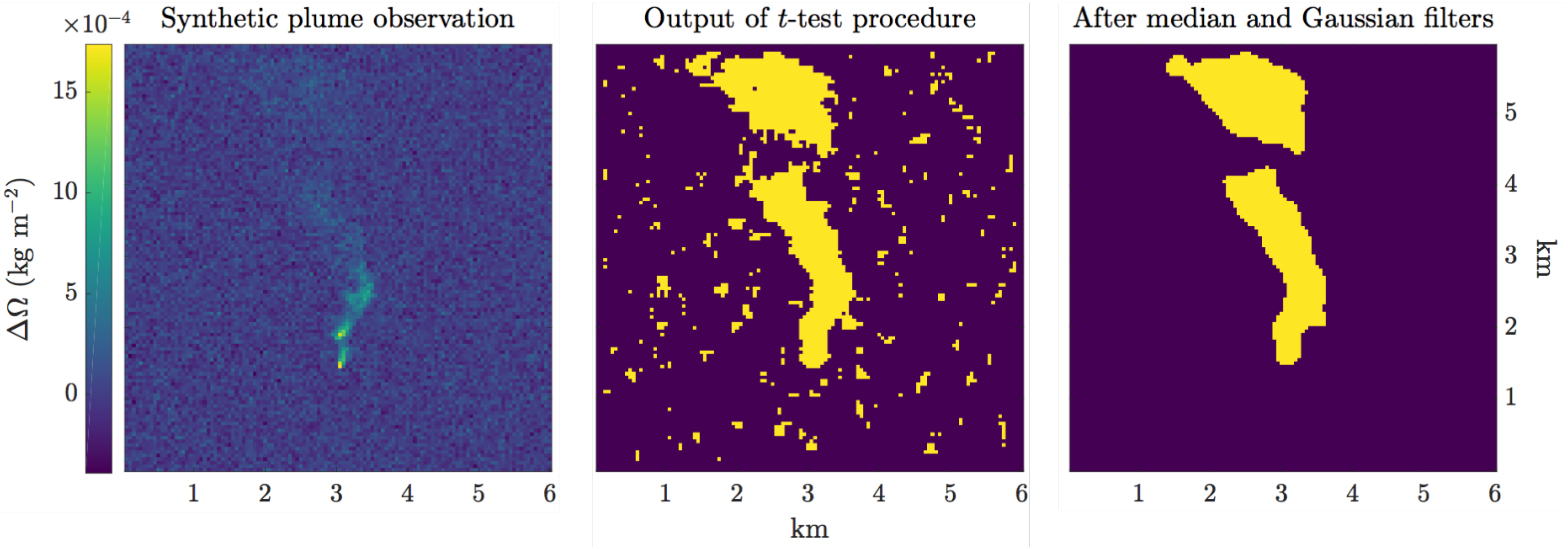

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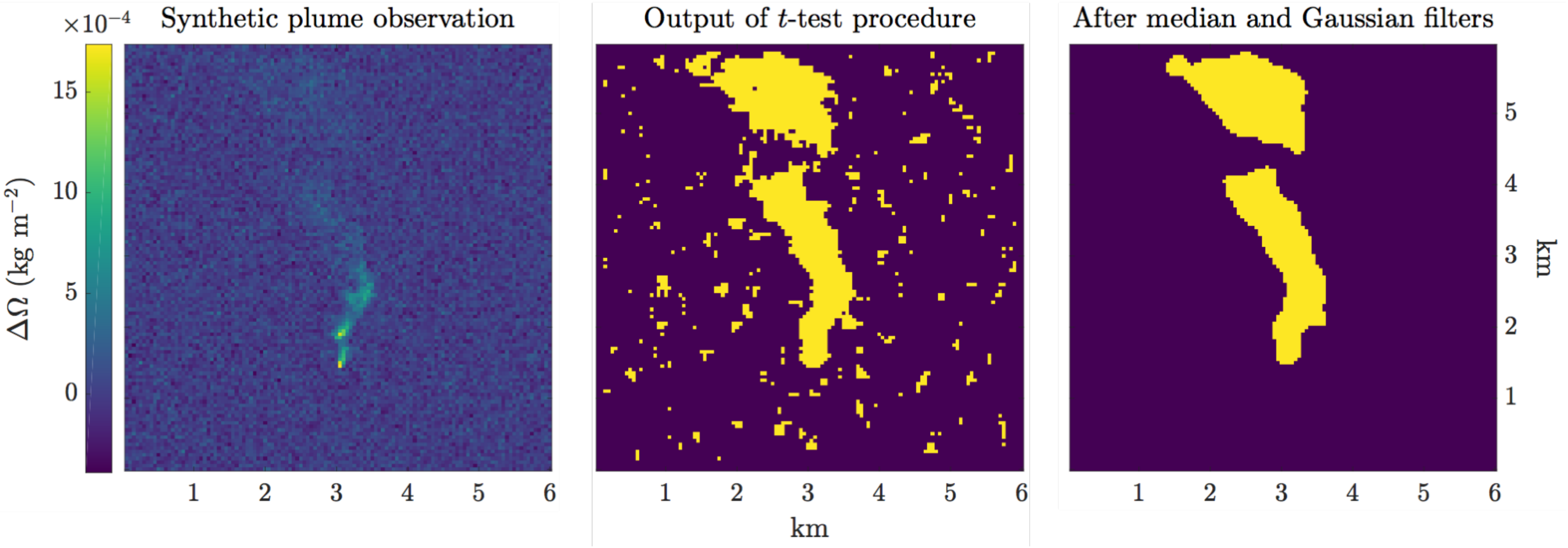
Taking this one step further...

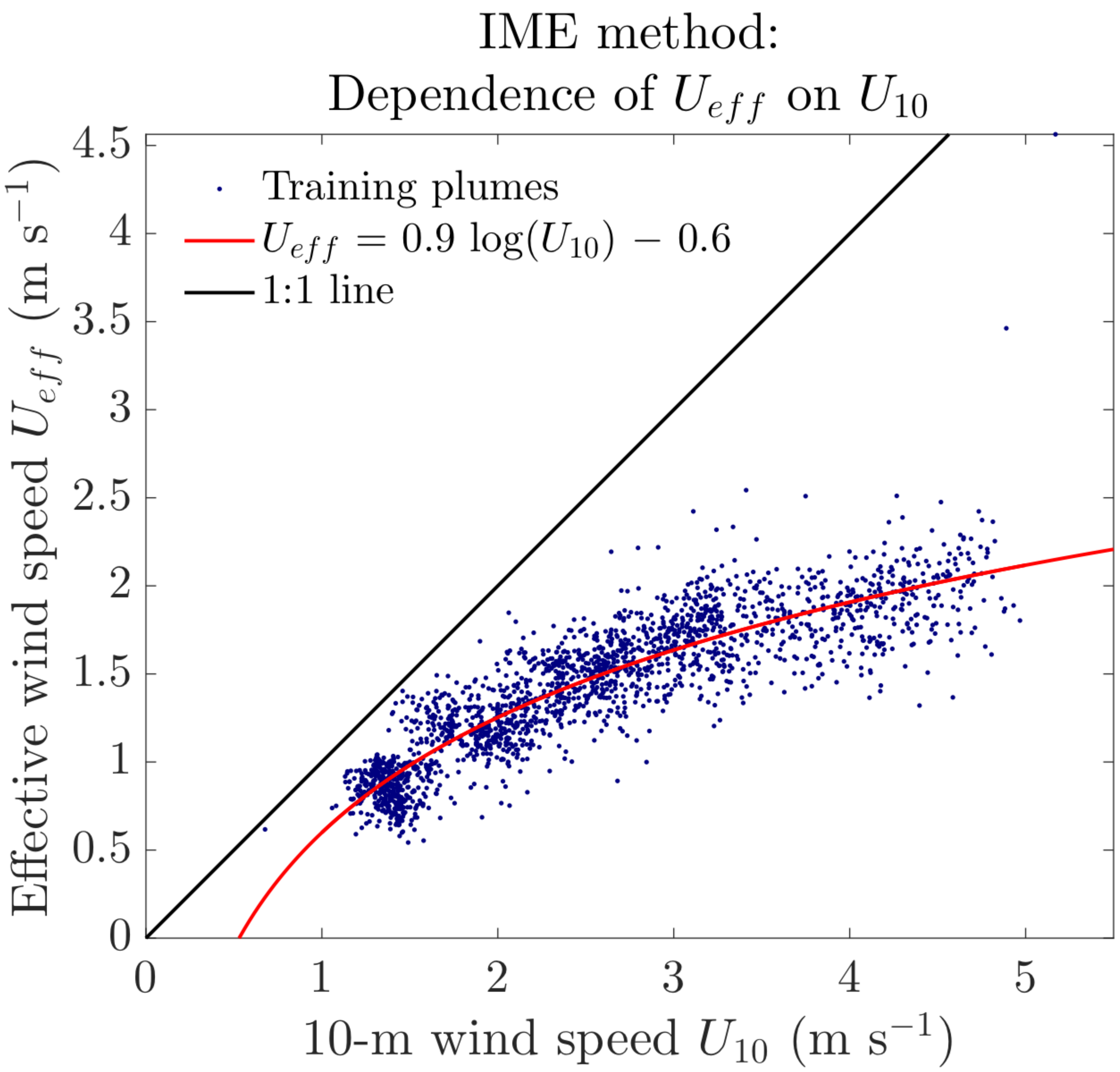
$$\Rightarrow Q = \frac{1}{\tau} IME = \frac{f(U_{10})}{L} IME$$

U_{eff} = Effective wind speed [m s^{-1}]
τ = dissipation time scale [s^{-1}]
L = dissipation length scale [m]

$$L = \sqrt{A_M} = \sqrt{\Sigma_{j=1}^{N} A_j}$$



Inferring U_{eff} from the 10-m wind speed U_{10}



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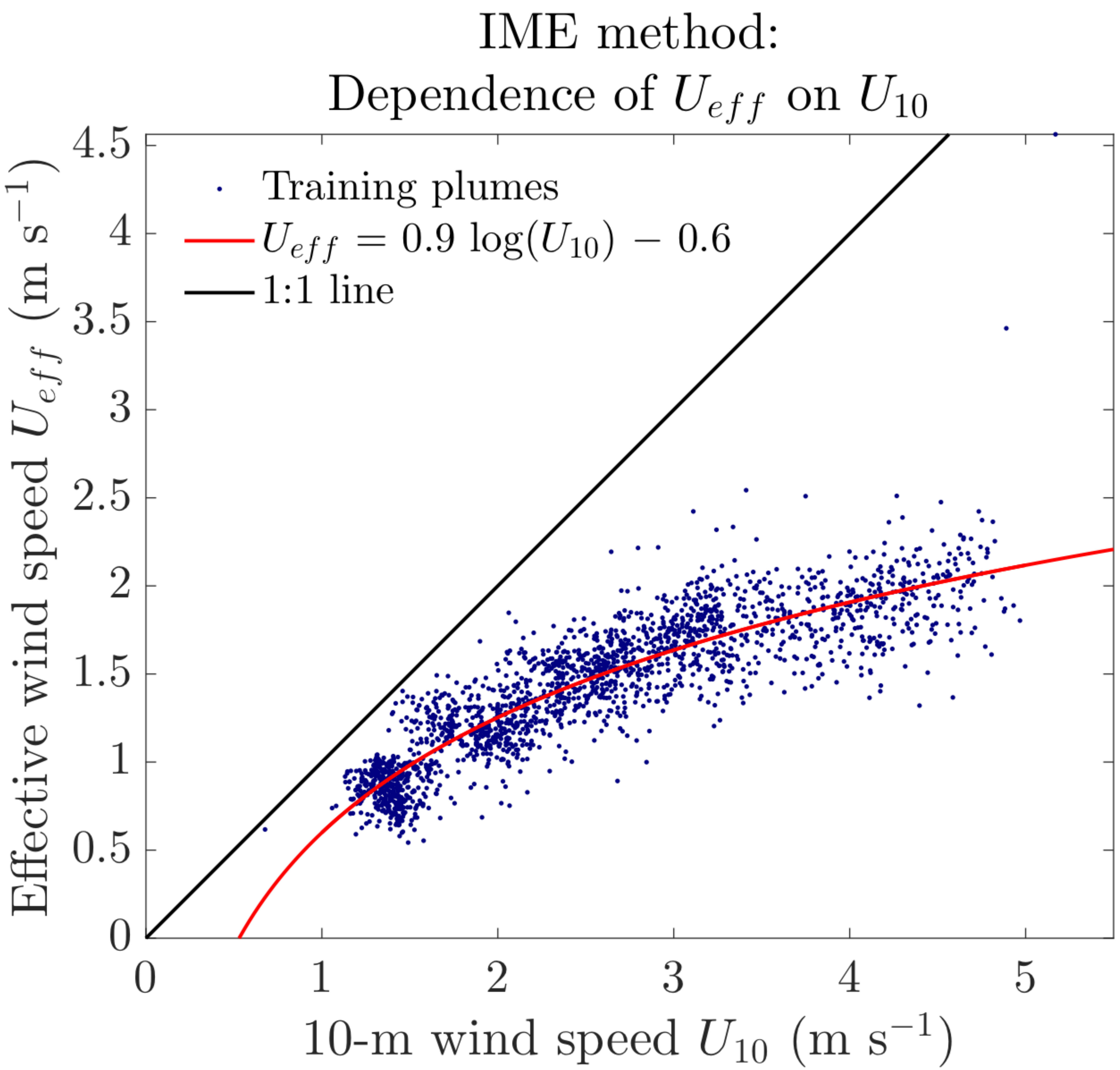
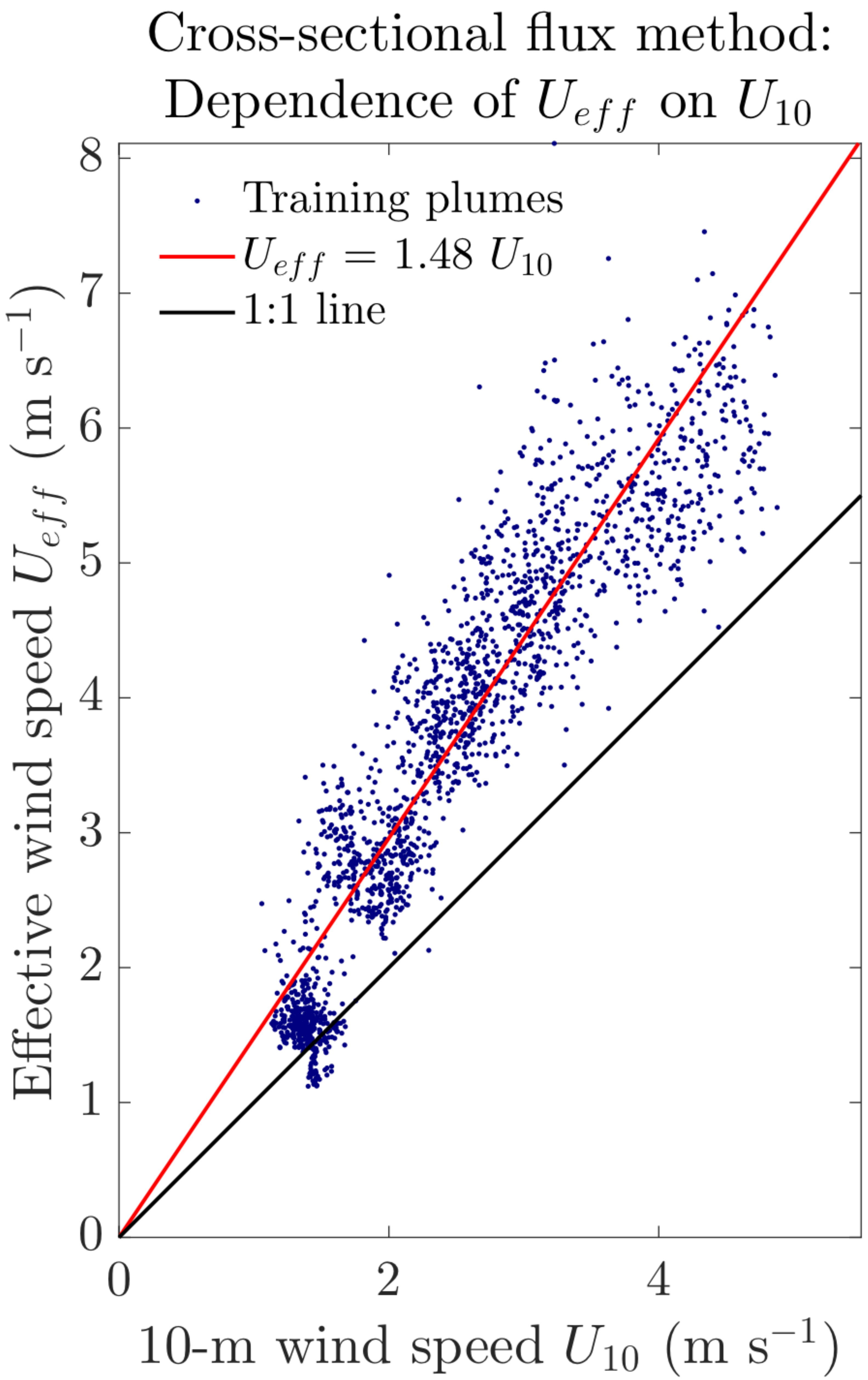
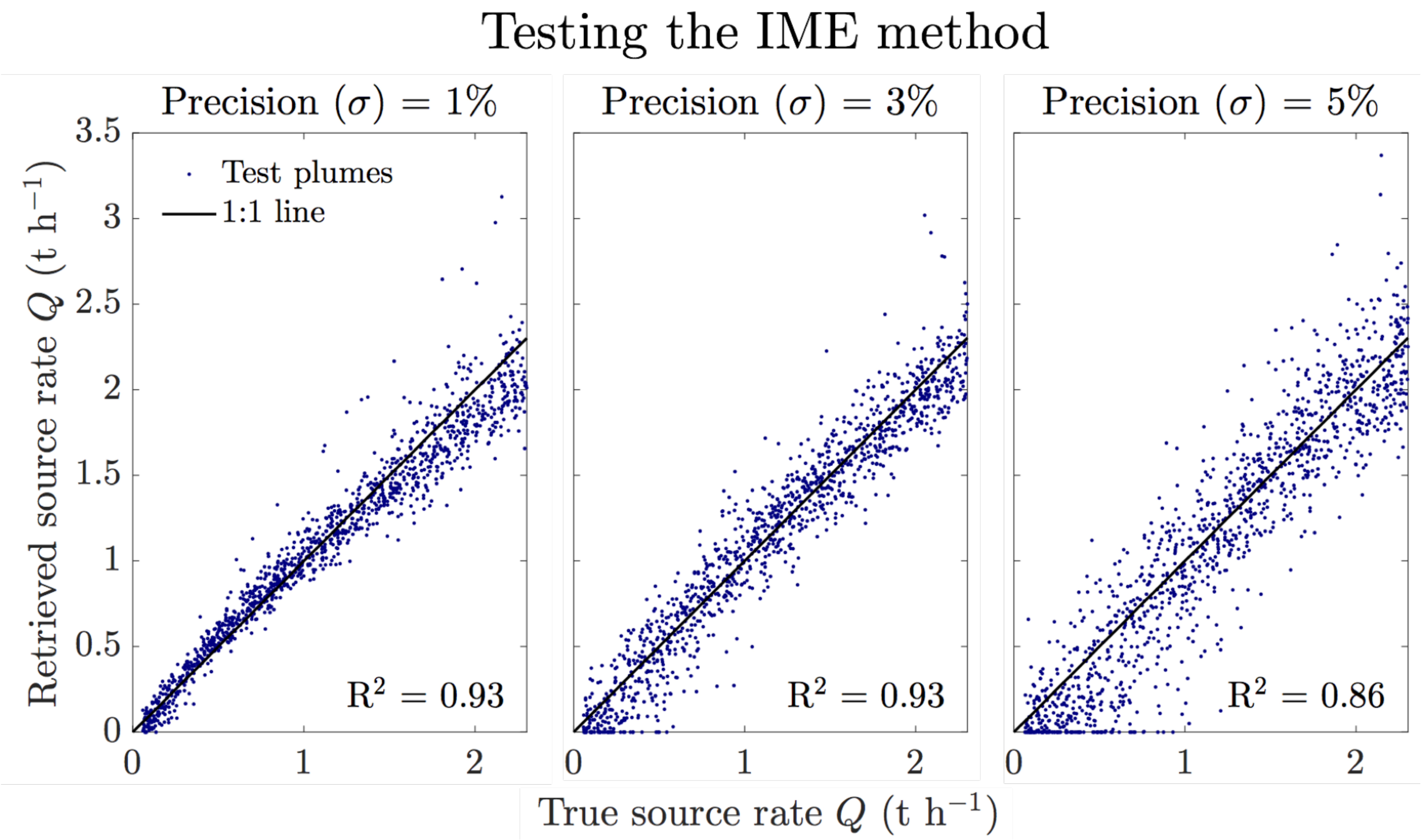
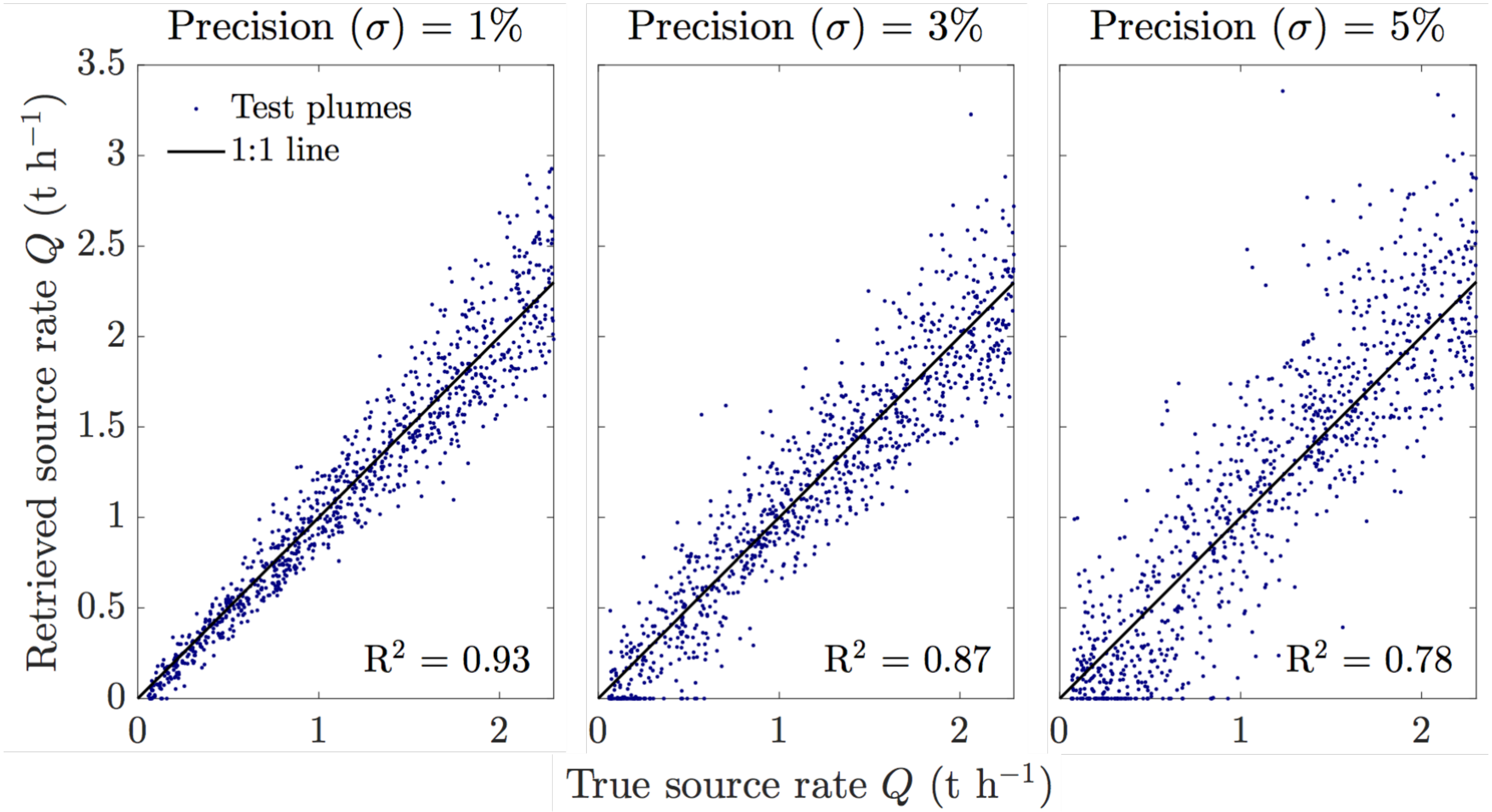





Testing the IME method
Precision (σ) = 1%
Precision (σ) = 3%
Precision (σ) = 5%
Test plumes
1:1 line
Retrieved source rate Q (t h⁻¹)
3.5
3
2.5
2
1.5
1
0.5
0
R² = 0.93
R² = 0.93
R² = 0.86
0
1
2
True source rate Q (t h⁻¹)

Testing the cross-sectional flux method



Source rate error standard deviations

Method	Instrument precision			Local wind speed estimate
	1%	3%	5%	
IME	0.07 t h^{-1} + 5%	0.13 t h^{-1} + 7%	0.17 t h^{-1} + 12%	15-50%
Cross-sectional flux	0.07 t h^{-1} + 8%	0.18 t h^{-1} + 8%	0.26 t h^{-1} + 12%	30-65%

$7 \to 2$ m s^{-1}

- IME method more precise than cross-sectional flux method.
- Sources > 0.5 t h^{-1} accounting for 75% of U.S. GHGRP emissions can be retrieved usefully.
- Lack of local wind data may dominate error for low wind speeds.

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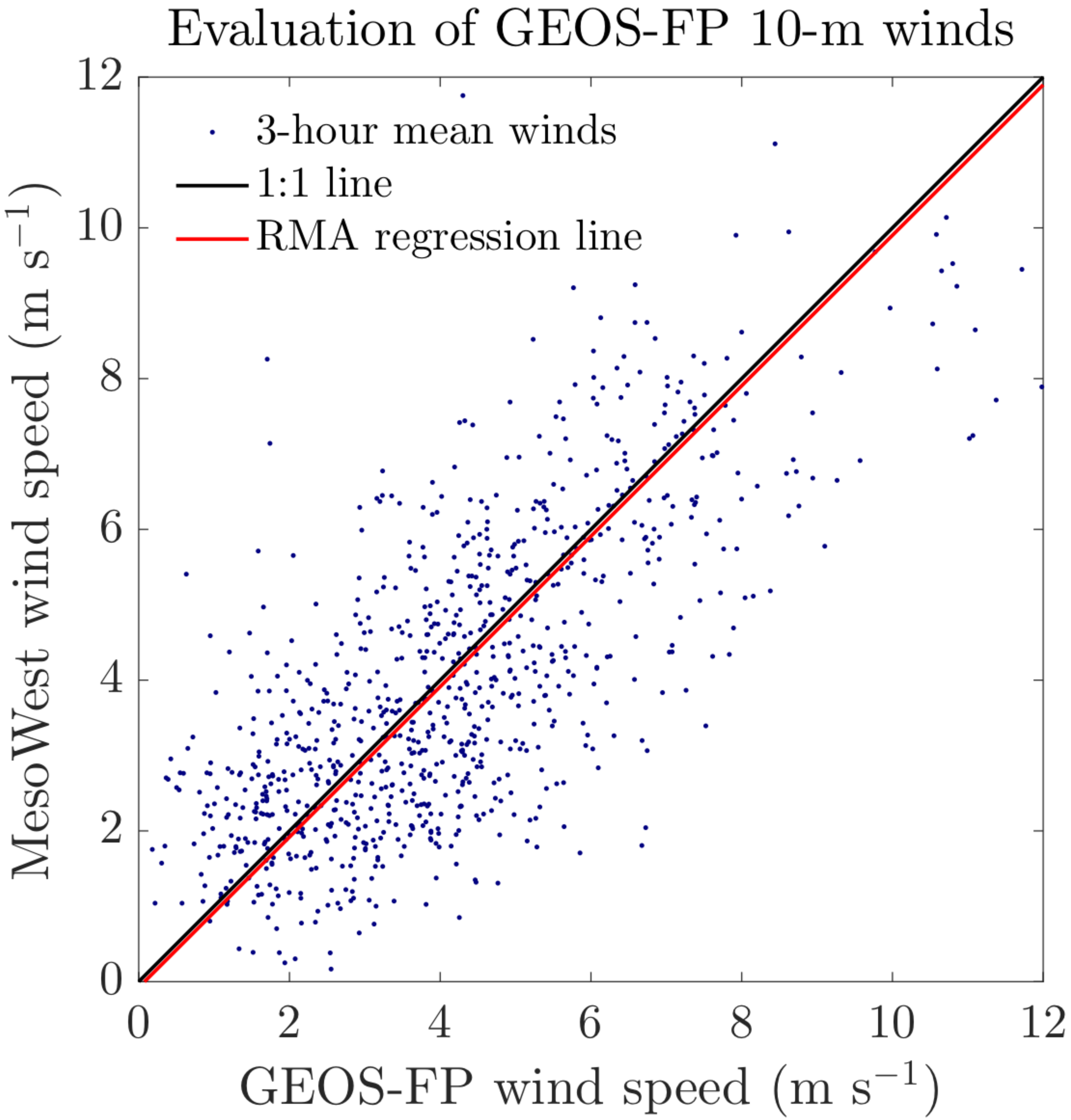
What if you don't have local observations of U_{10}?



Additional retrieval uncertainty from using GEOS-FP to estimate local U_{10}:

IME method:	15-50 %
Cross-sectional flux method:	30-65 %