Fernerkundung von Treibhausgas-punktquellen – Emissionsbestimmung durch Maschinelles Lernen

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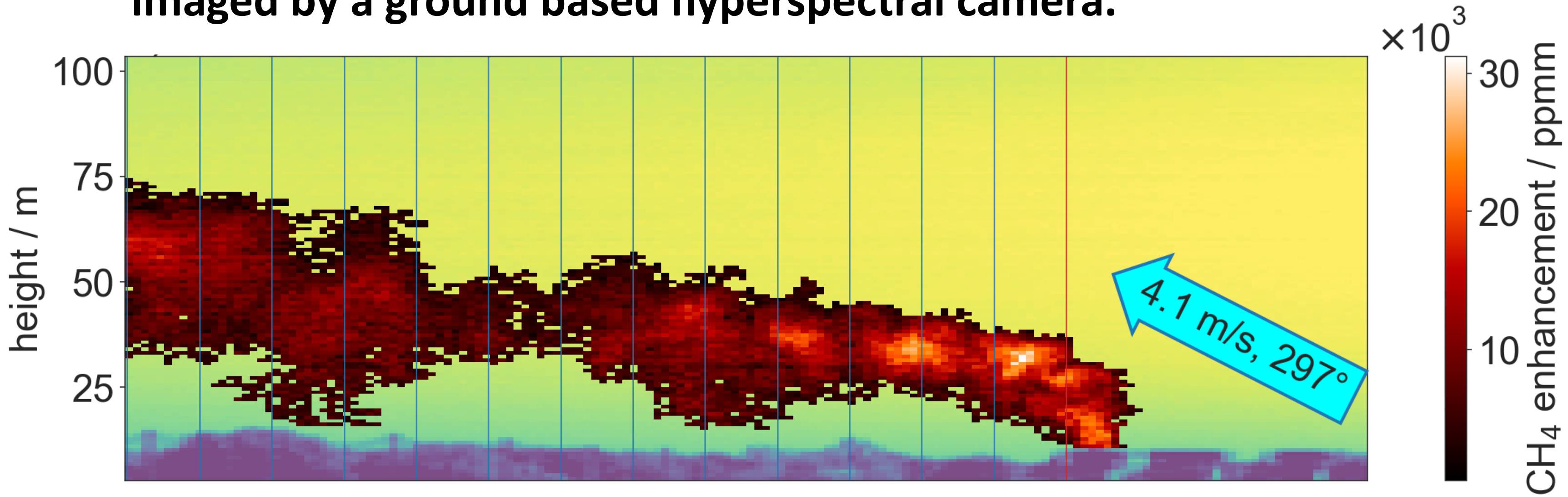
Hyperspectral imaging of greenhouse gas hotspots

CH_4 plume from coal mine ventilation in Poland, imaged by a ground based hyperspectral camera.



- Large localized sources of CO_2 and CH_4 are important contributors to the emission totals (e.g. oil & gas industry, coal mining for CH_4; power plants, industries, volcanoes for CO_2).
- Hyperspectral imaging techniques can observe individual plumes of such hotspots.

[Knapp, M., et al., Environ. Res. Lett., doi:10.1088/1748-9326/acc346, 2023.]

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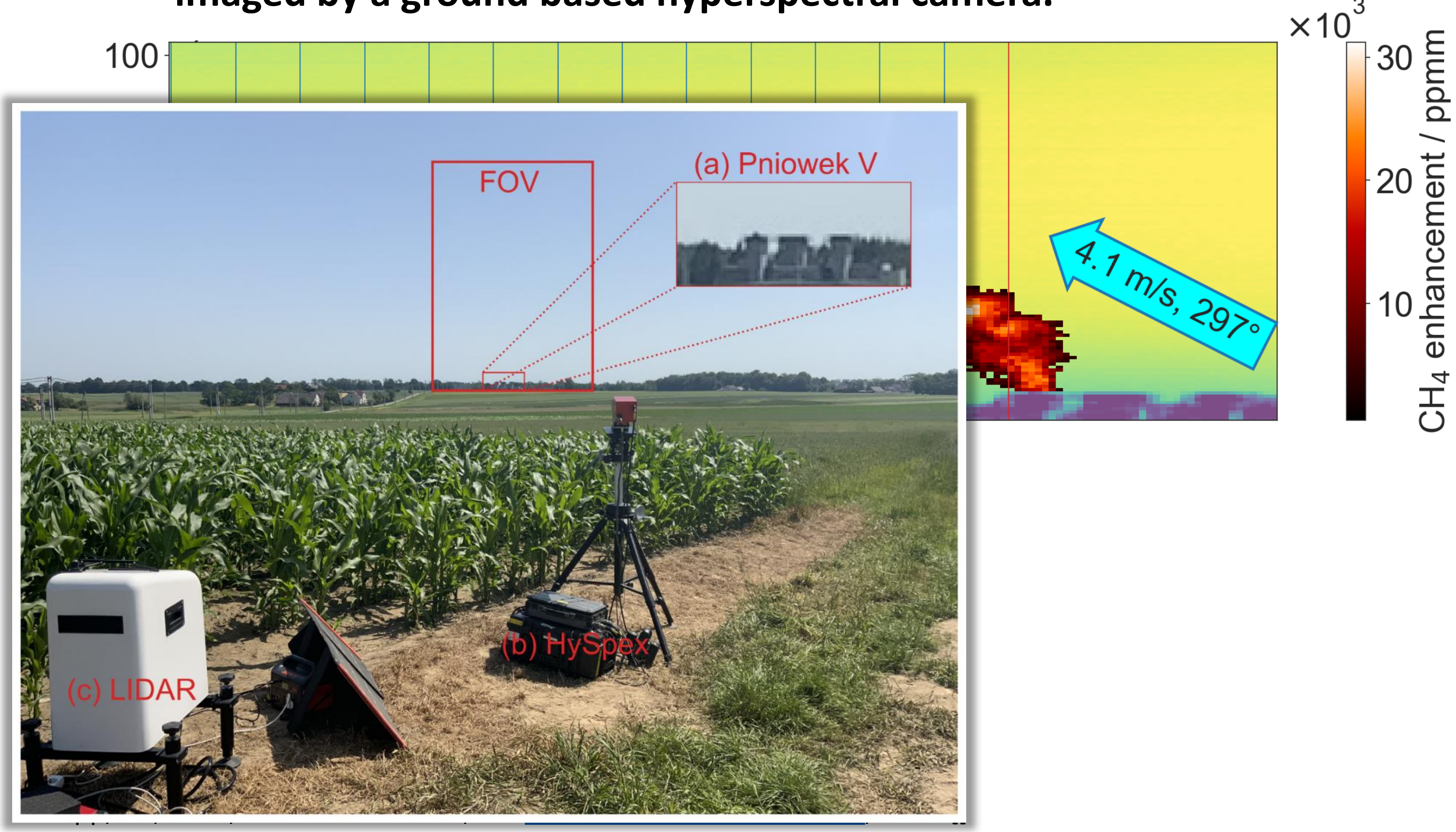

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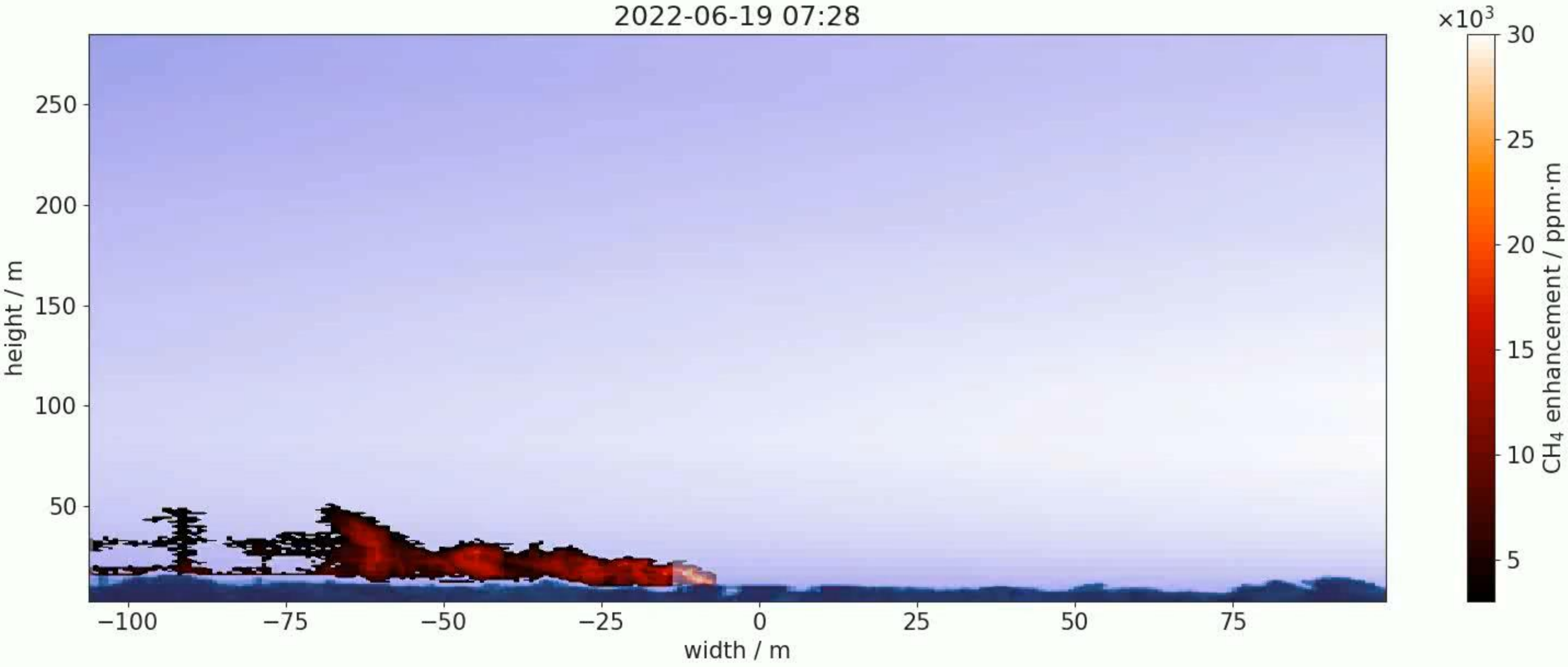
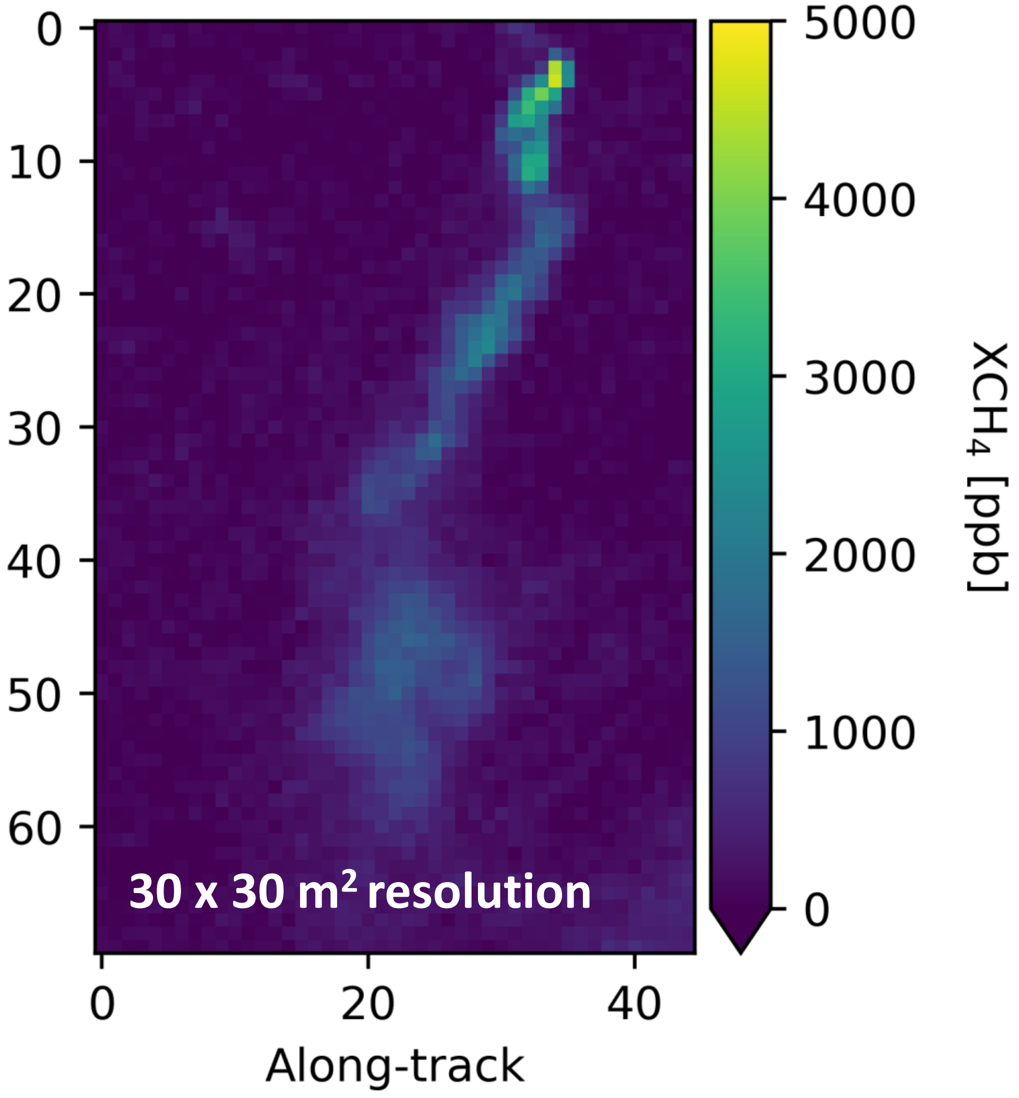


2022-06-19 07:28
height / m
250
200
150
100
50
−100
−75
−50
−25
0
25
50
75
width / m
$\times 10^3$
30
25
20
15
10
5
CH_4 enhancement / ppm·m

Hyperspectral imaging of greenhouse gas hotspots

CH_4 plume from oil & gas production, imaged by the PRISMA satellite



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[PRISMA retrievals by Ida Jandl.]

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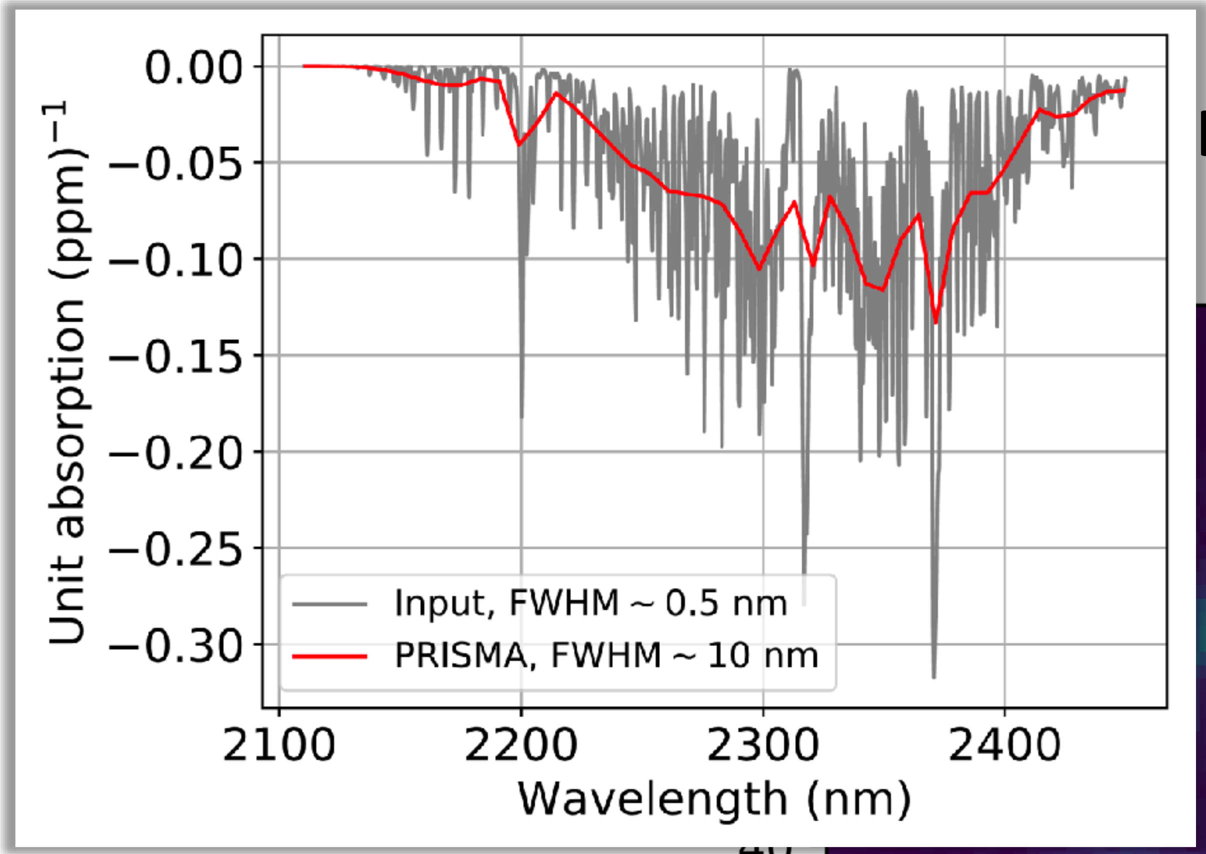
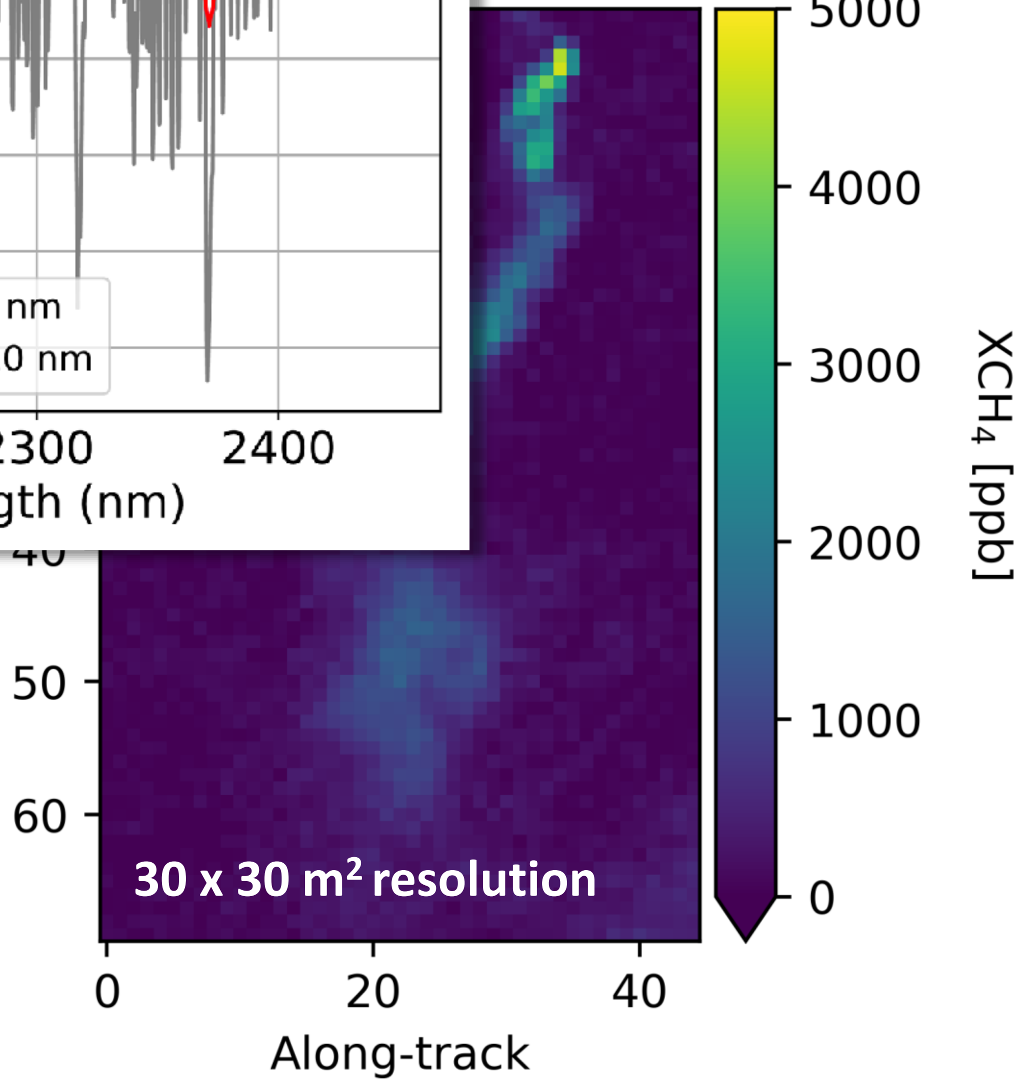


[Guanter, L. et al., RSE, https://doi.org/10.1016/j.rse.2021.112671, 2022]



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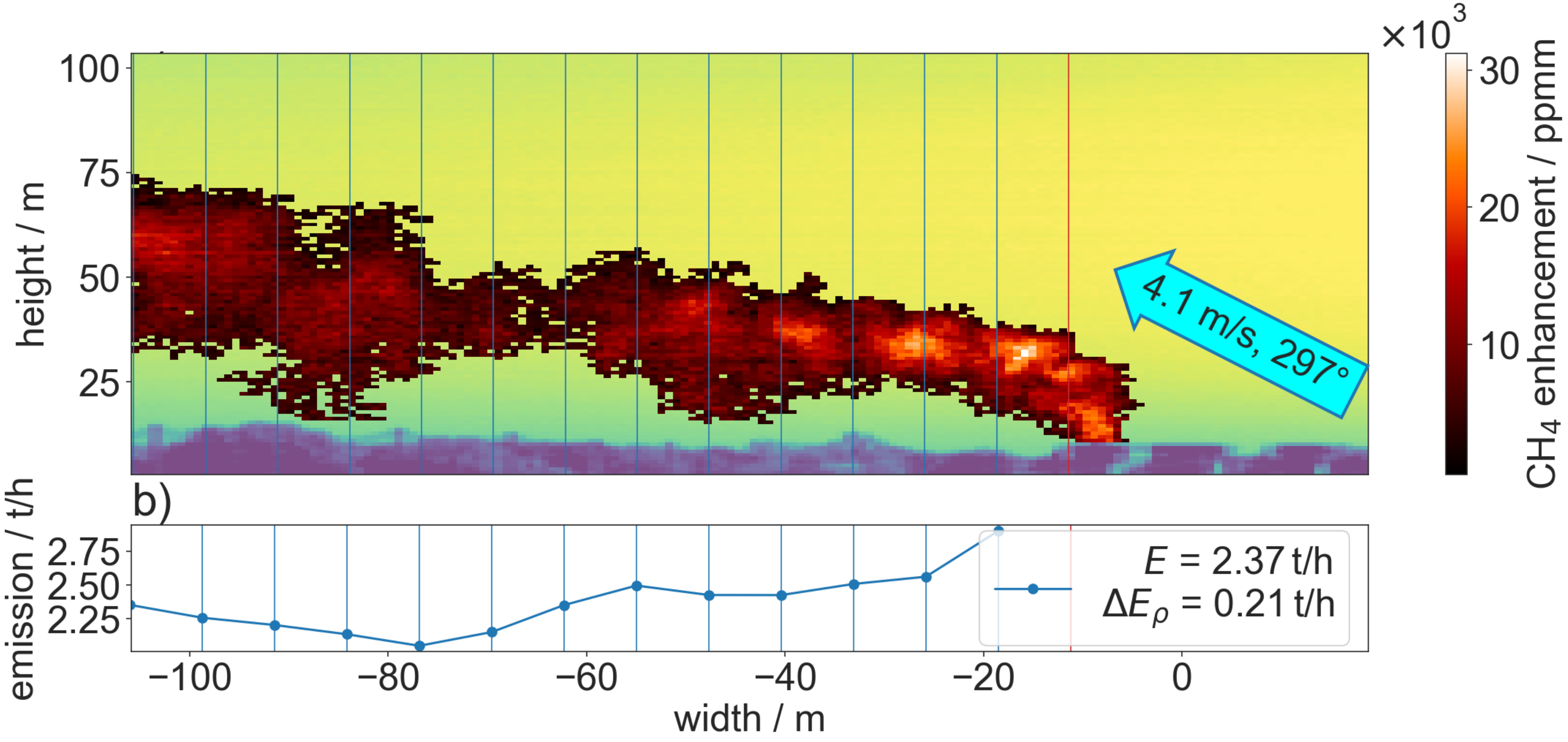
Context: New missions, new methods, new use cases.

- Julia Marshall‘s talk on Wednesday, Session 6b, 9:30-10:30h: **CO2Image**
- My talk on Wednesday, Session 7a „EnMAP II“, 11:00-12:30h: **Fernerkundung von Methanabluftfahnen aus EnMAP Beobachtungen**
- Here: **CO2KI - Methoden der künstlichen Intelligenz zur skalen- und prozessübergreifenden Erfassung von Quellen und Senken von Kohlendioxid**

How to get emission rates from images?



- Turbulent dispersion of the plume out of the source, controlled by various meteorological and surfac parameters.

- Mass balance methods work, but they rely on knowledge of the wind speed and the assumption that an effective wind speed drives a quasi-advective transport:

$E = M_{CH4}/L \times u_{\perp}$

[Knapp, M., et al., Environ. Res. Lett., doi:10.1088/1748-9326/acc346, 2023.]

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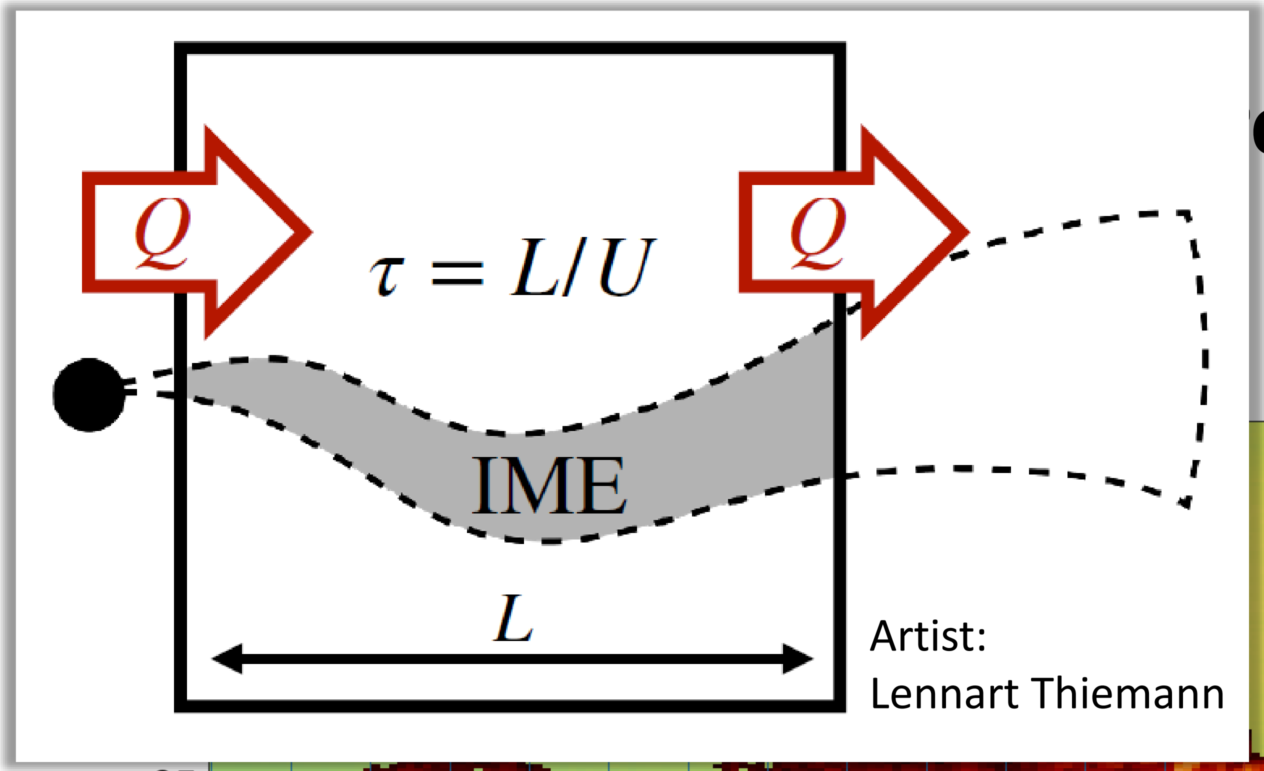

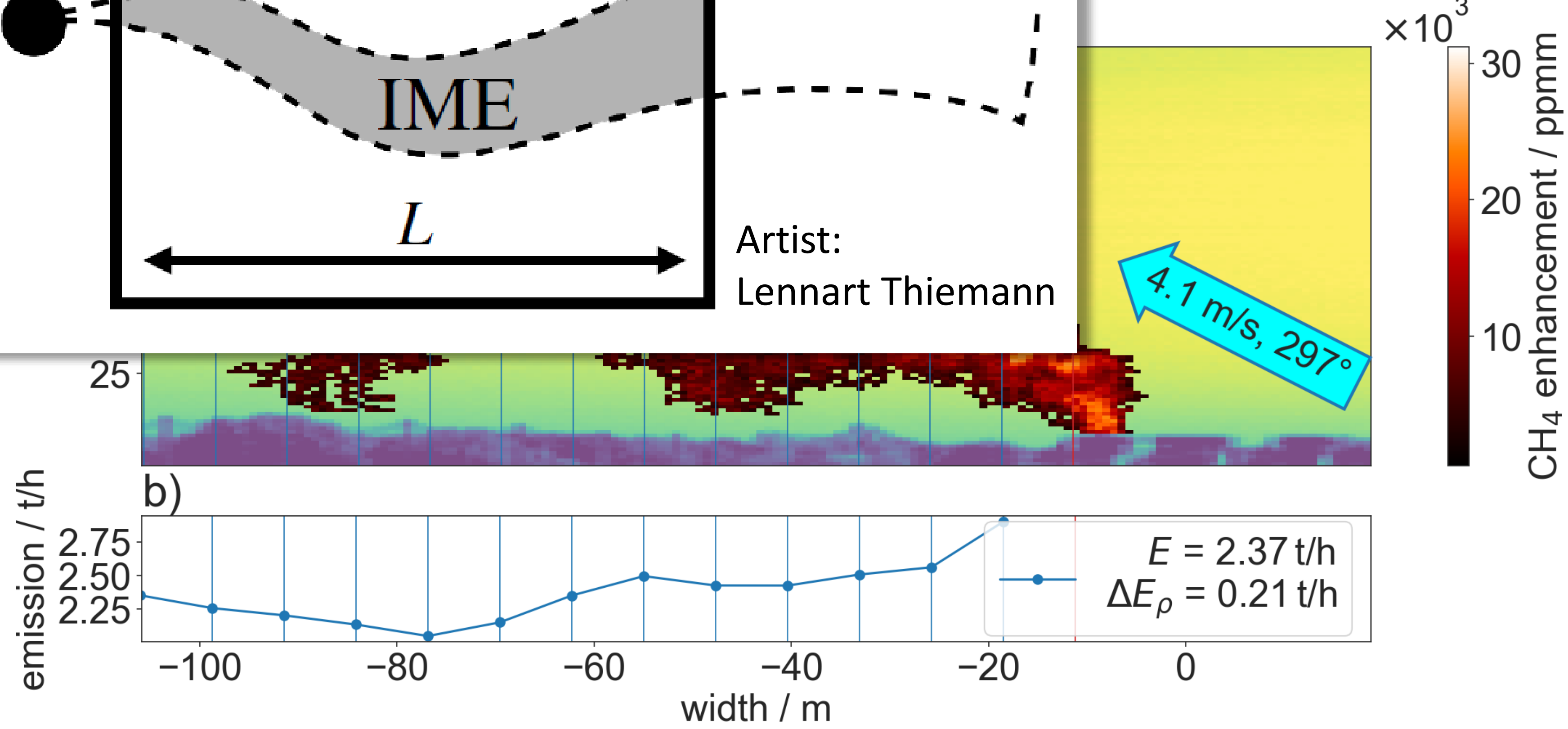

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How to get emission rates from images?

- Gaussian plume inversion
- Source pixel
- Cross-sectional flux
- Integrated mass enhancement (IME)

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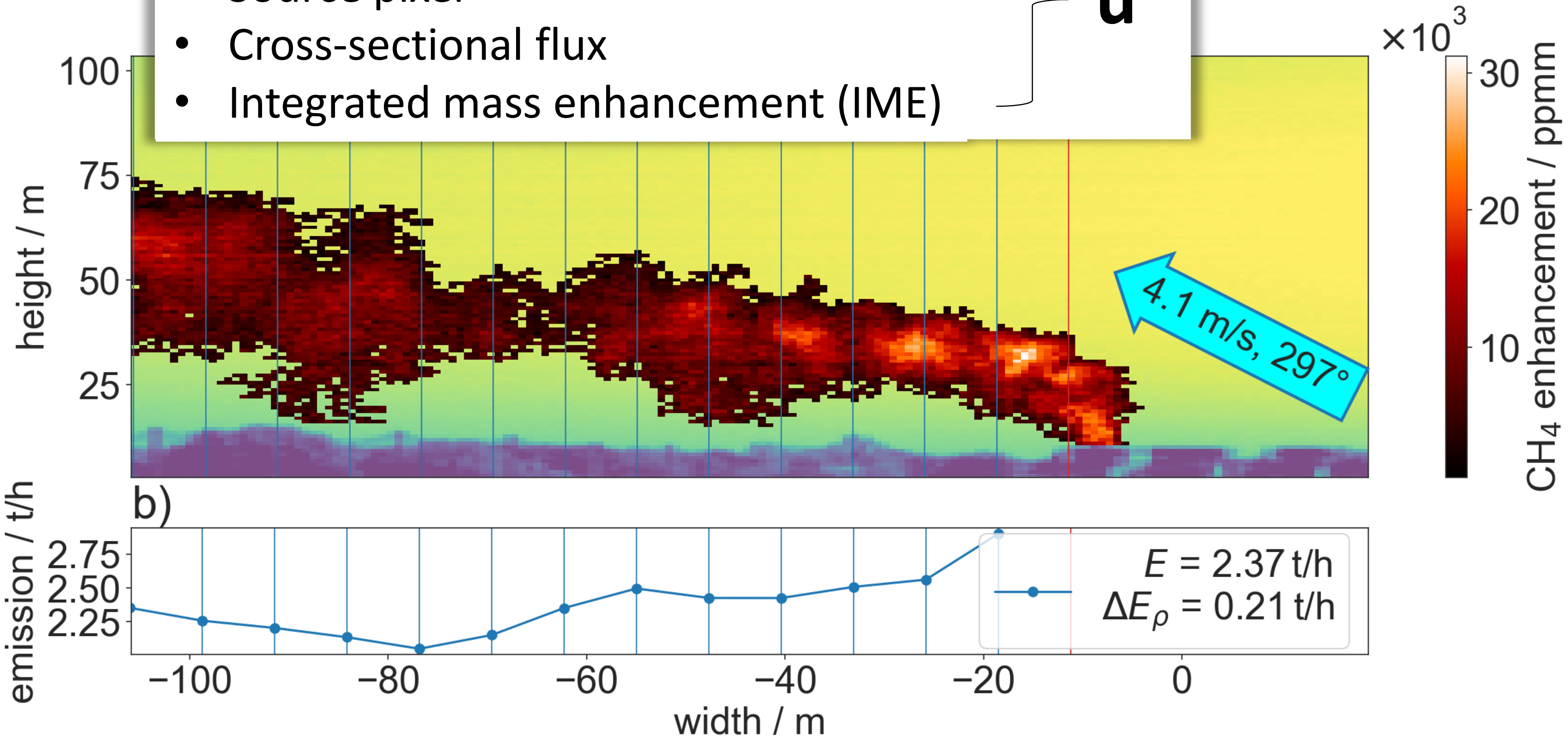

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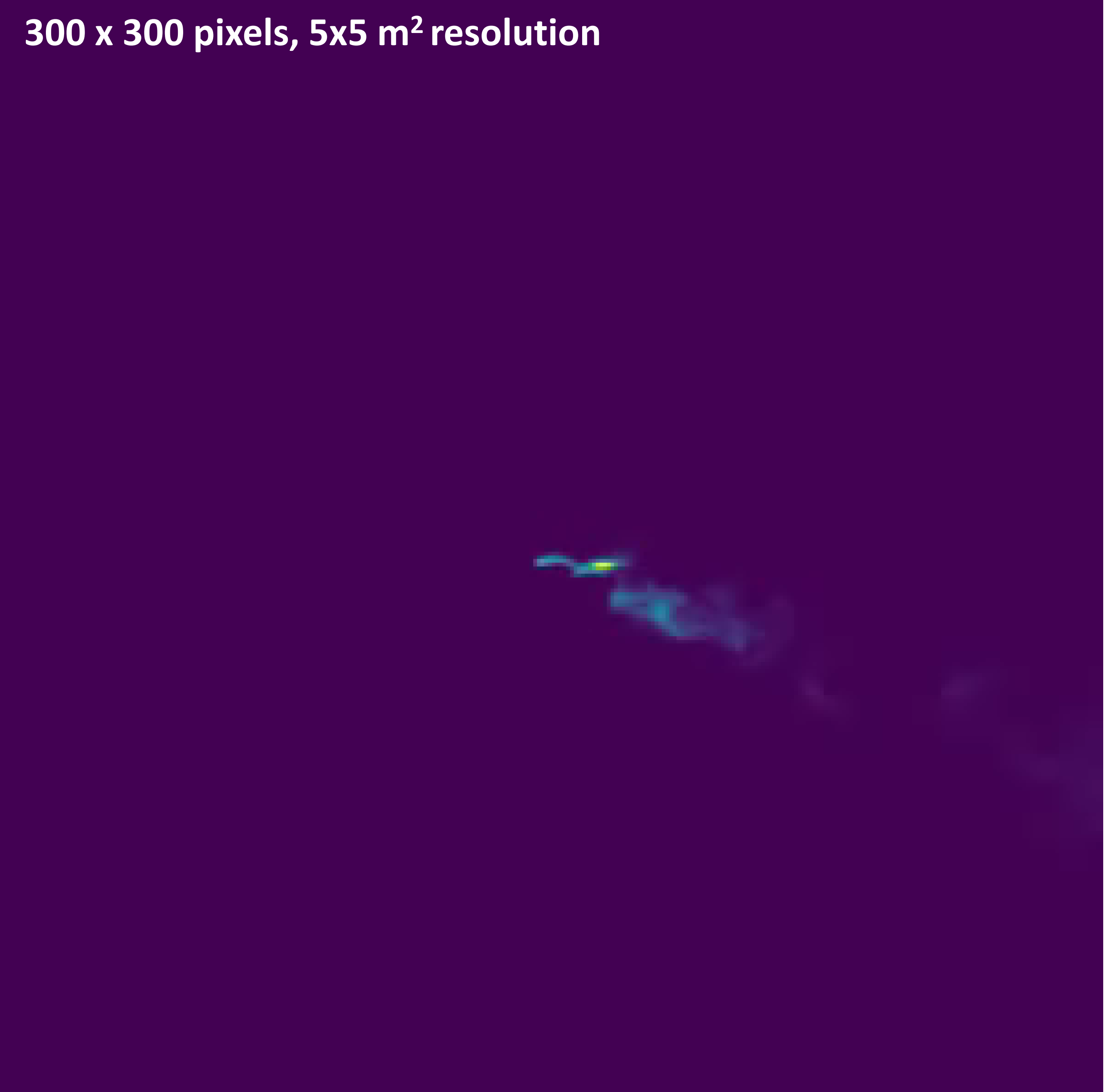
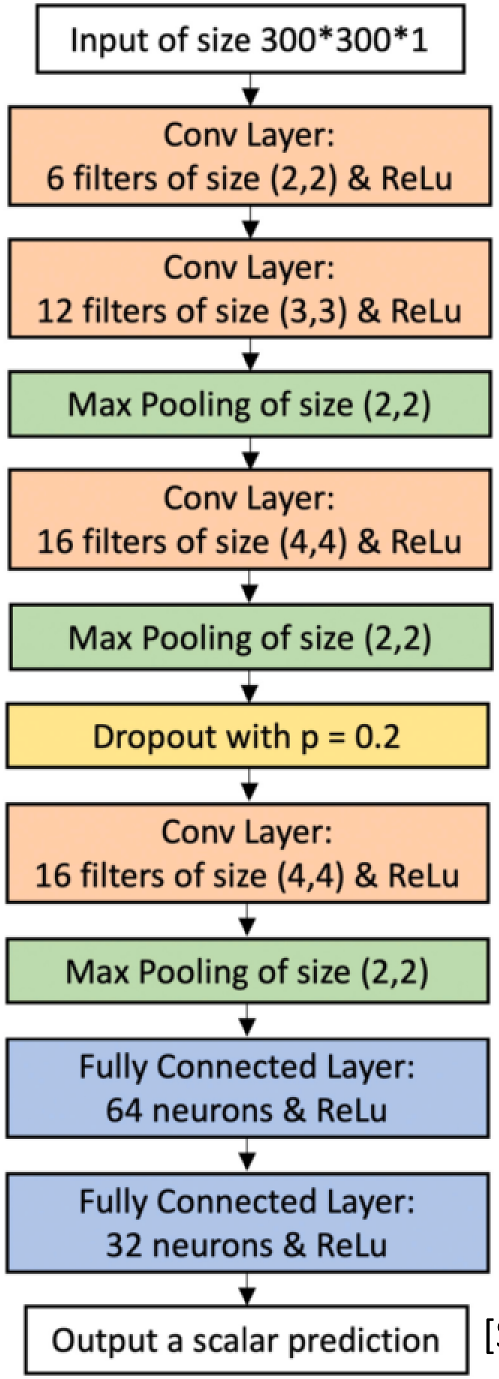


Try AI.

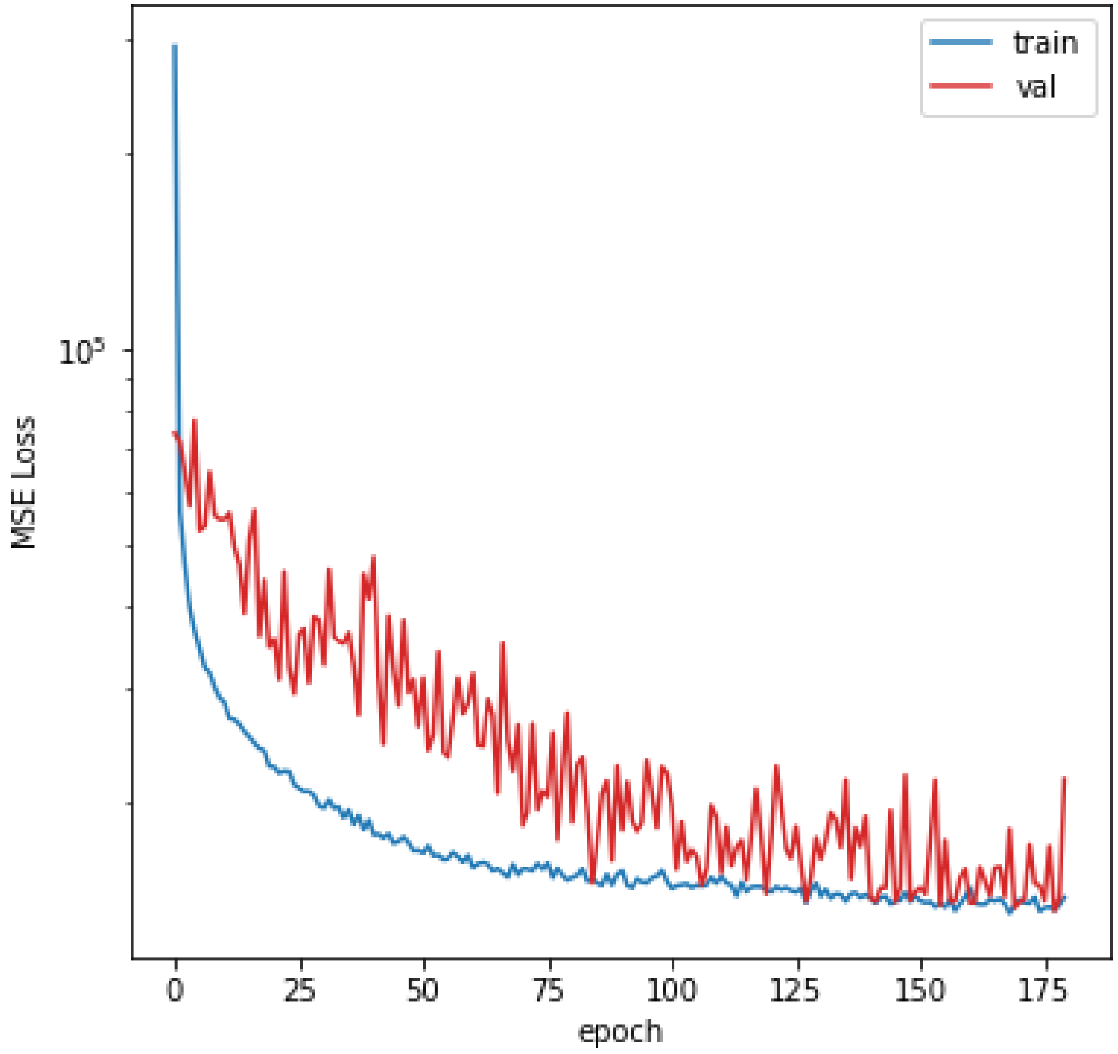
Training data: LES simulations at 5 m resolution

- After one hour of spin-up a snapshot was taken every 10 seconds and is used as an independent turbulent realization.
- Overall 7000 plume snapshots with geostrophic wind speeds ranging from 1 to 10 m/s.
- Add Gaussian noise.

[S. Jongaramrungruang et al., “MethaNet ...“, RSE, https://doi.org/10.1016/j.rse.2021.112809, 2022]



Network architecture



- Starting from the network architecture proposed for MethaNet, we train a convolutional neural network to solve the regression task of flux estimation.
- The optimization criterion is the mean squared error (MSE).
- The available data is split into a training (80%), a validation (15%) and a test dataset (5%).

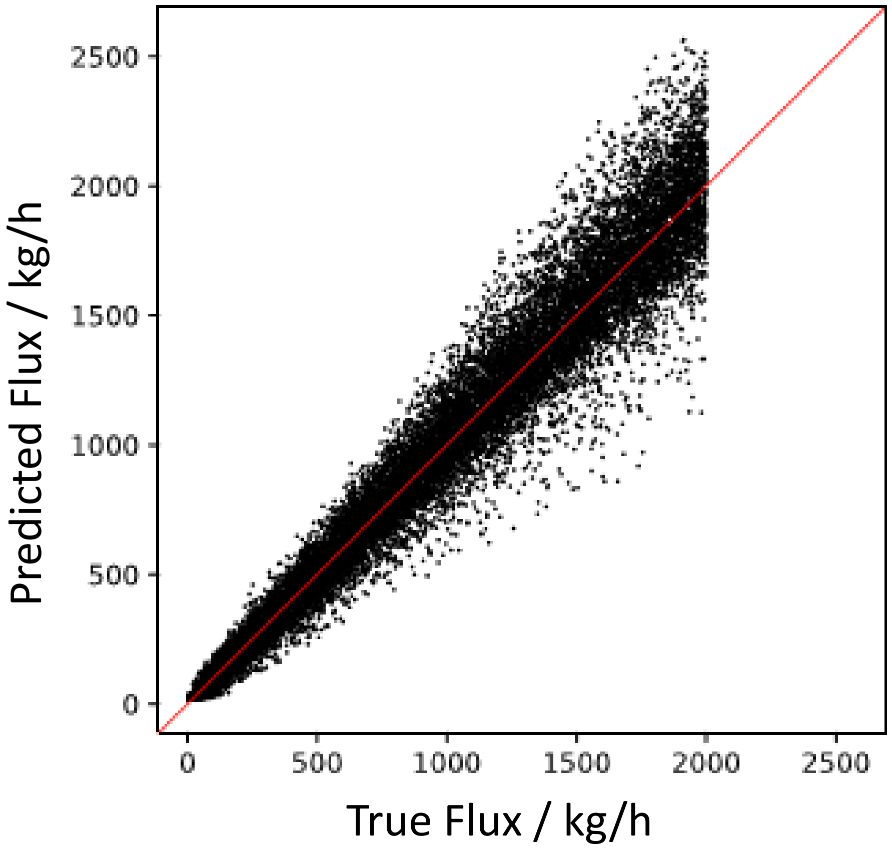
[S. Jongaramrungruang et al., “MethaNet ...“, RSE, https://doi.org/10.1016/j.rse.2021.112809, 2022]

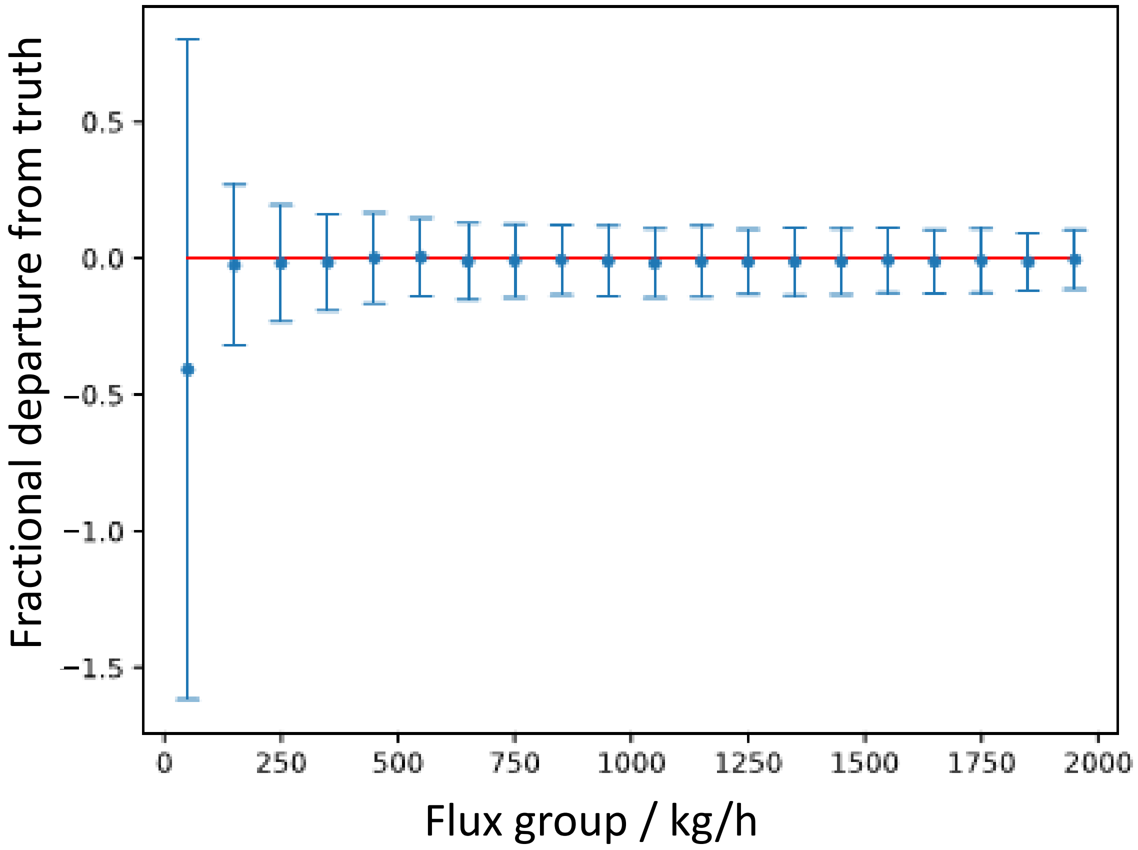
Network performance

The average absolute relative deviation across all plumes is 13.8% and 11.9% for plumes over 40 kg/hr.

100 kg/h appears the detection limit (for the given noise level).

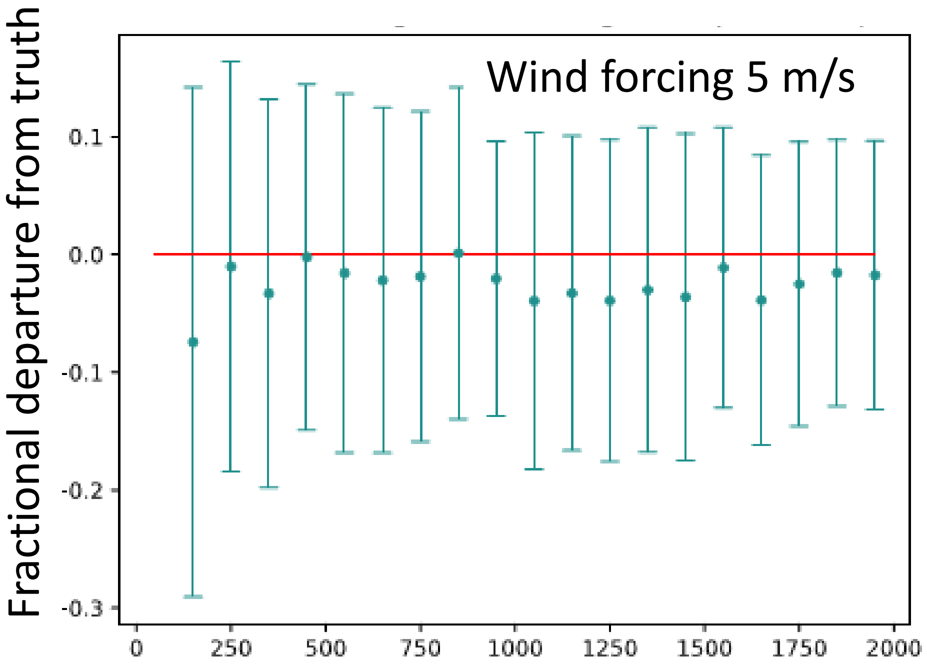
Systematic biases are very small.

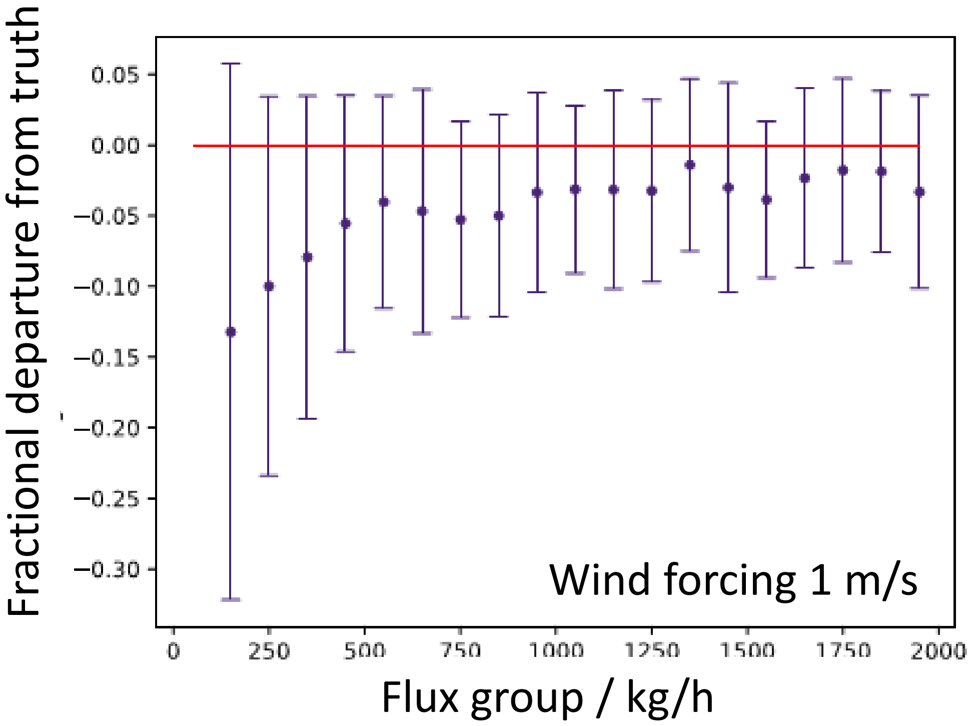


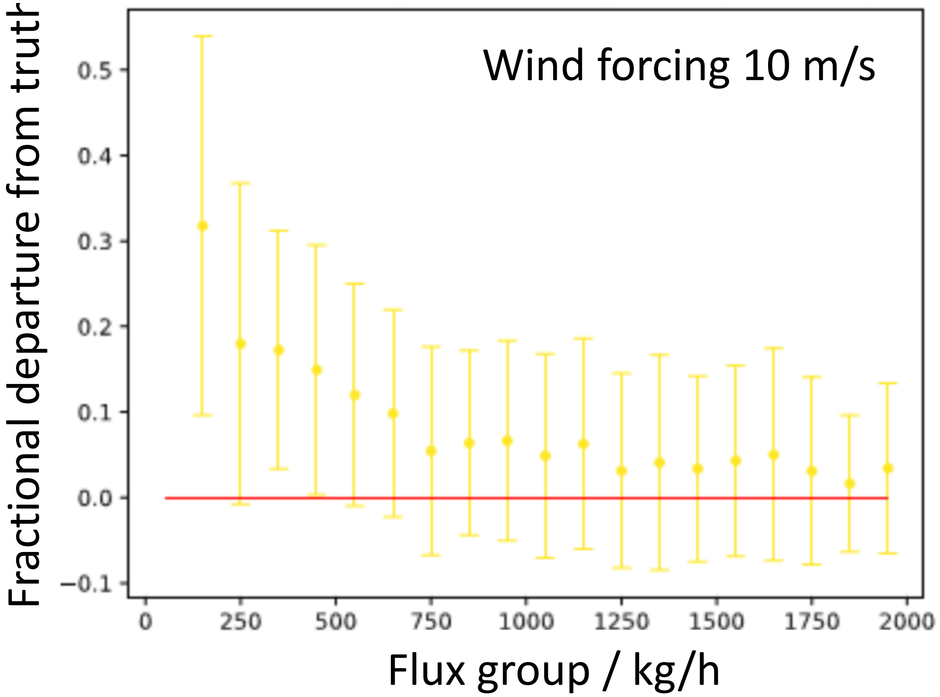


Network performance

Looking closely, the network appears to produce biases for low/high wind speed for low fluxes: training issue?







Conclusions / Outlook

- Hyperspectral imaging from satellites, aircraft and ground is a **tool to infer emission rates of large sources**.

- Emission rate quantification **challenged by turbulent dispersion and uncertain knowledge of transport velocity**.

- Synthetic study with **CNNs operating on LES simulations** shows promising results. Next steps:
  - Optimize network design.
  - Make simulations more realistic.
  - Investigate dependence on spatial resolution.

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