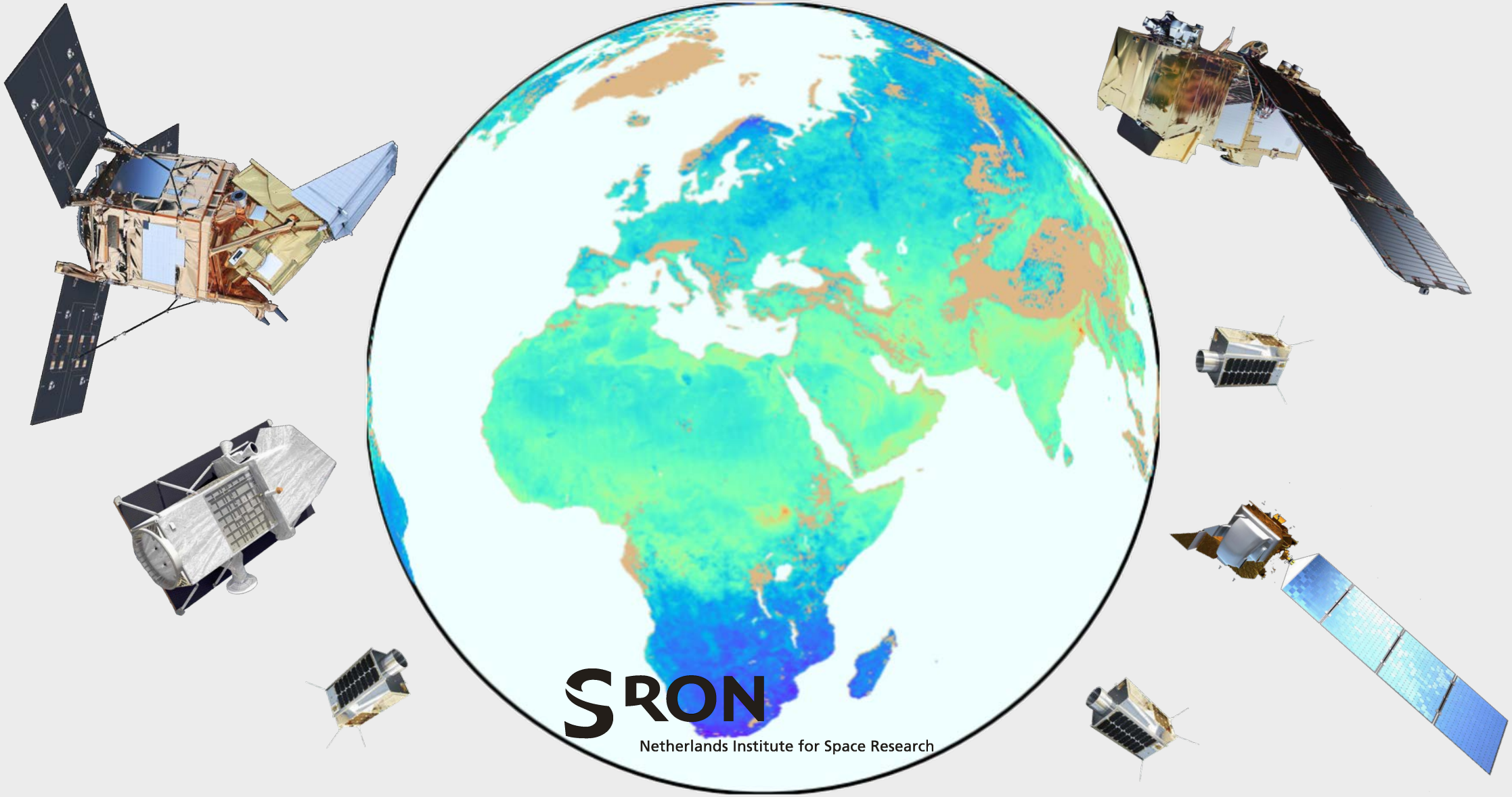

Detection and Quantification of Methane Super-Emitters by Combining Multiple Satellite Instruments

Joannes D. Maasakkers[1], Berend Schuit[1], Gourav Mahapatra[1], Sudhanshu Pandey[1], Pieter Bijl[1], Allard Veenstra[1], Alba Lorente[1], Szu-Tung Chen[1], Pratik Sutar[1], Sander Houweling[1,2], Daniel Varon[3,4], Dylan Jervis[3], Jason McKeever[3], Itziar Irakulis-Loitxate[5], Luis Guanter[5], Daniel H. Cusworth[6,7], Ritesh Gautam[8], Mark Omara[8], and Ilse Aben[1]

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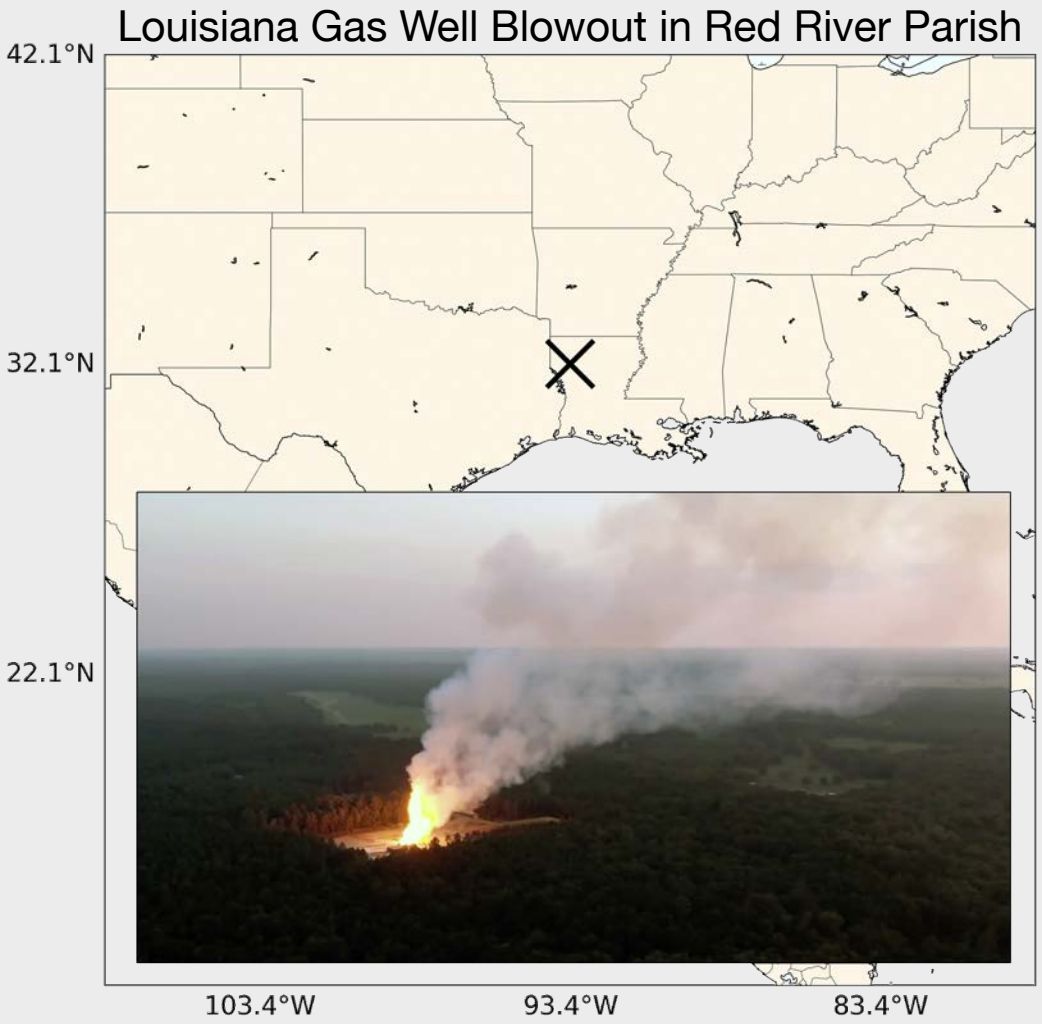
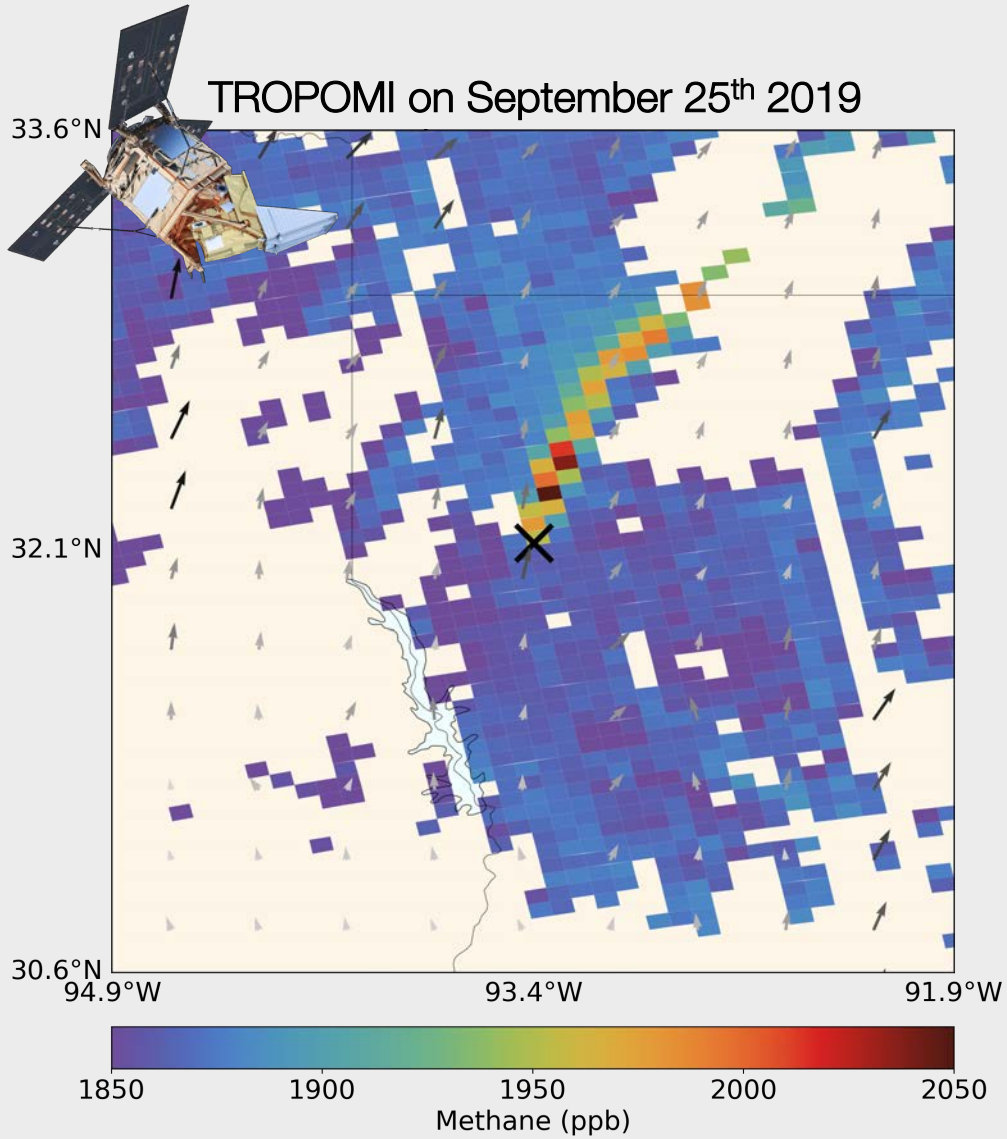
1. SRON Netherlands Institute for Space Research
2. Vrije Universiteit Amsterdam
3. GHGSat Inc
4. Harvard University
5. Universitat Politècnica de València
6. University of Arizona
7. Carbon Mapper
8. Environmental Defense Fund

Image credit: GHGSat/ESA/ASI/NASA

TROPOMI monitors methane around the world on a daily basis

Using TROPOMI, we can detect methane plumes around the world, but only the largest and most isolated plumes can be attributed to single facilities.

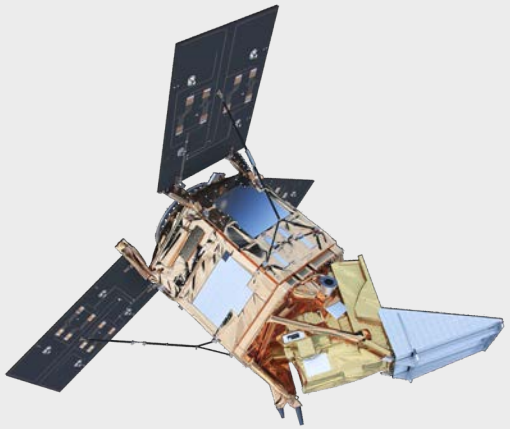




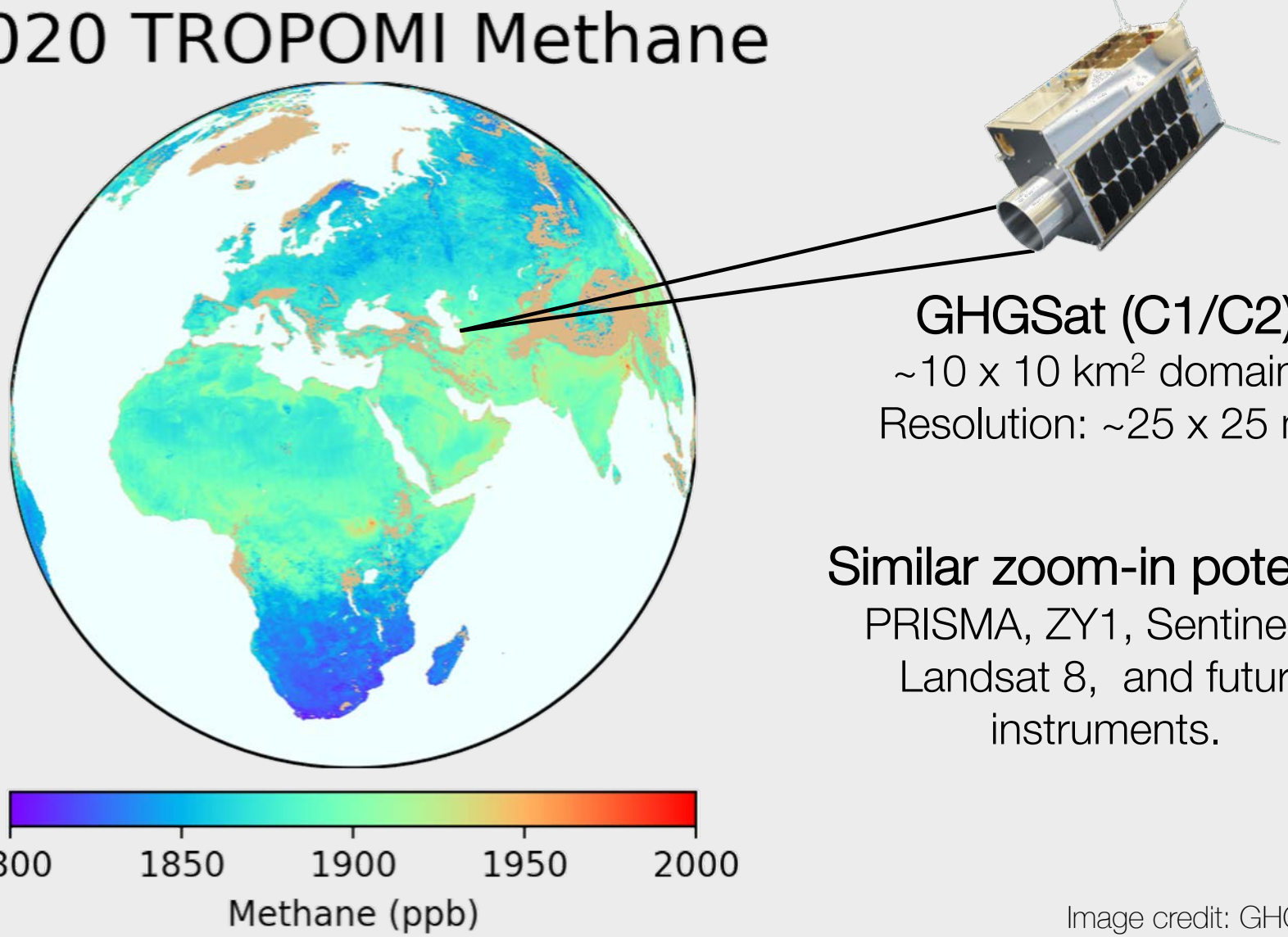
Maasakkers et al. (2021), Drone footage: Phin Percy Jr., Image Credit: ESA

Combining different instruments to fully understand methane emissions

We detect plumes in TROPOMI data to guide high-resolution instruments towards super-emitters.



TROPOMI (Sentinel-5P)
Daily global coverage
Resolution: 5.5 x 7 km^2



GHGSat (C1/C2)
~10 x 10 km^2 domains
Resolution: ~25 x 25 m^2

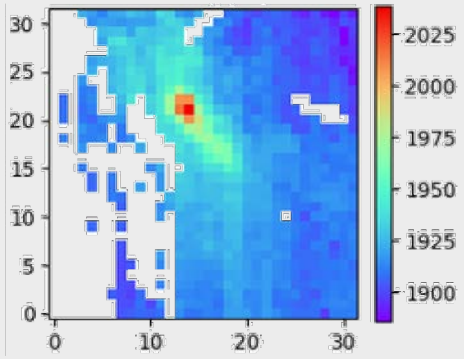
Similar zoom-in potential
PRISMA, ZY1, Sentinel-2, Landsat 8, and future instruments.

Image credit: GHGSat/ESA

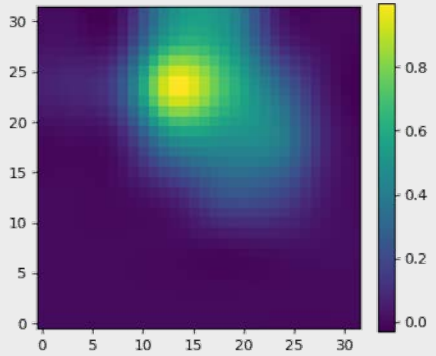
Detecting plumes in the TROPOMI methane data

We use the combination of two machine learning methods, a convolutional neural network and a support vector classifier, to automatically detect methane emission plumes.

Methane scene (ppb)



Class Activation Map



Detect plume-like features

Convolutional Neural Network (CNN) trained on ~2500 unique scenes consisting of 32x32 TROPOMI pixels each.

Identifies ~0.8% of scenes as potential plumes.

Schuit et al. (in prep)

Detecting plumes in the TROPOMI methane data

We use the combination of two machine learning methods, a convolutional neural network and a support vector classifier, to automatically detect methane emission plumes.

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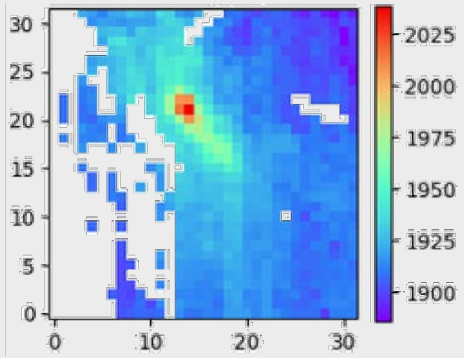
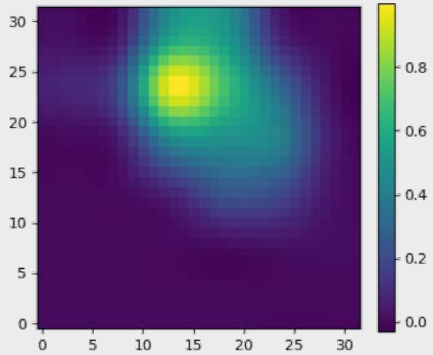
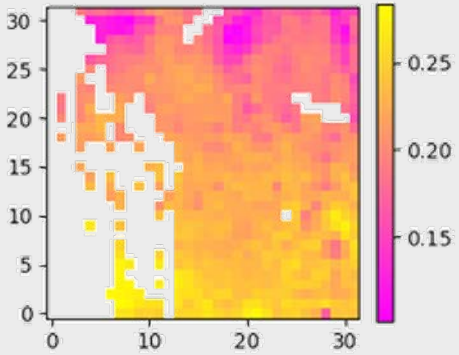


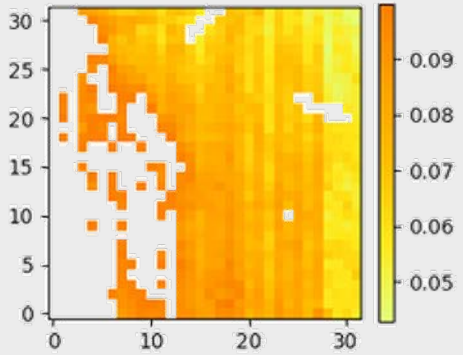
Class Activation Map



Surface Albedo



Aerosol Optical Depth



Detect plume-like features

Convolutional Neural Network (CNN) trained on ~2500 unique scenes consisting of 32x32 TROPOMI pixels each.

Identifies ~0.8% of scenes as potential plumes.

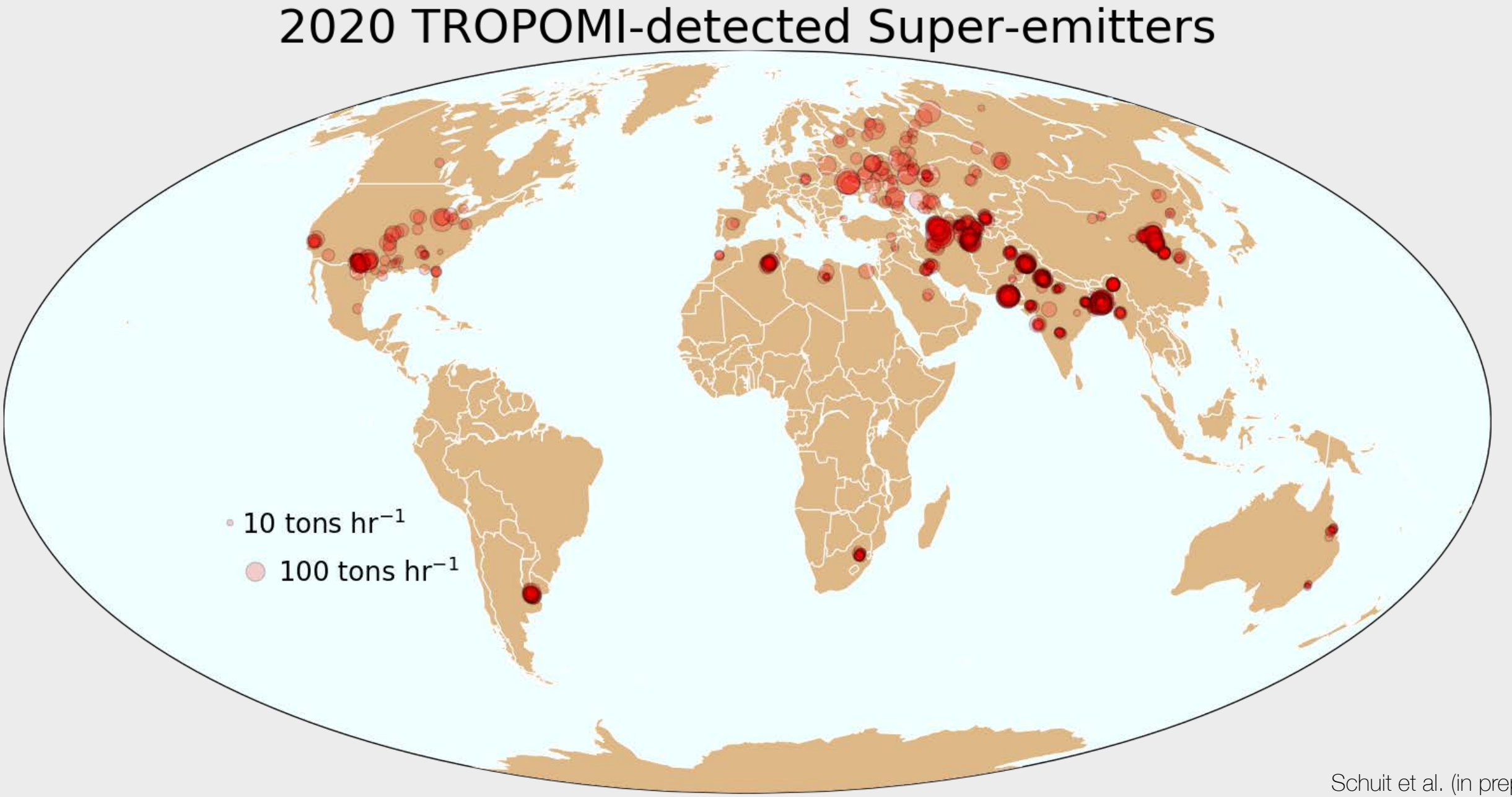
Confirm it is an actual emission plume

Support Vector Classifier (SVC) incorporating supporting data like the albedo and aerosol optical depth.

Filters out half of the scenes as artefacts.

Schuit et al. (in prep)

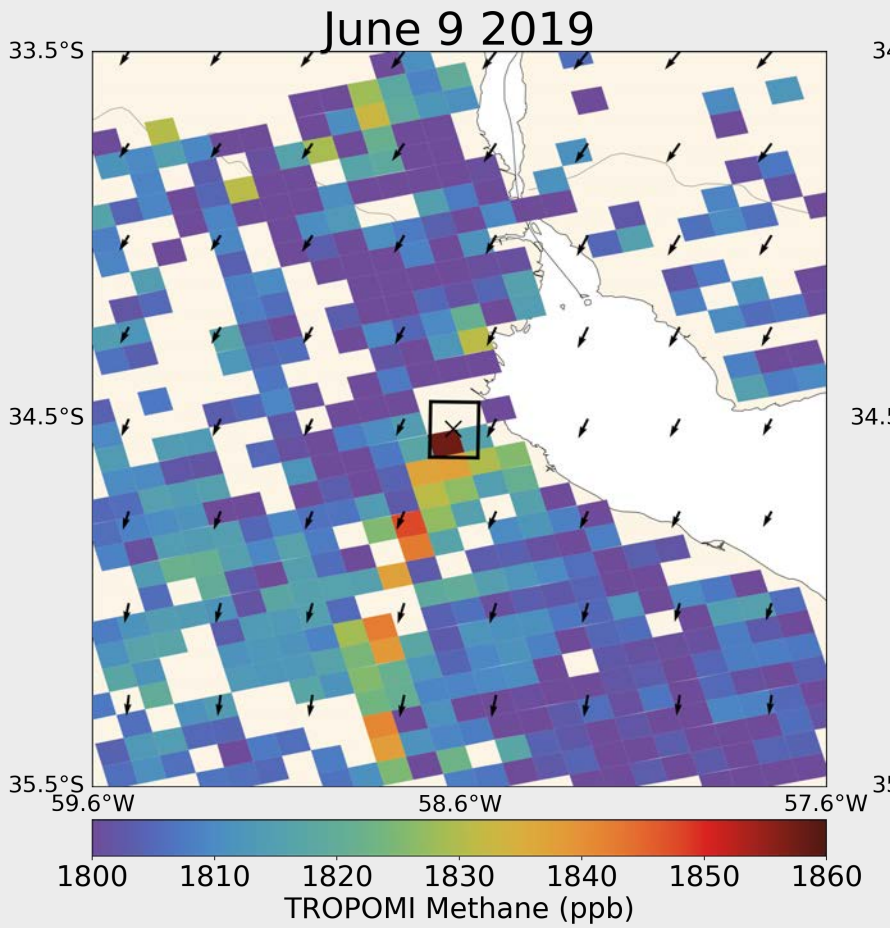
We detect methane plumes around the world in 2020

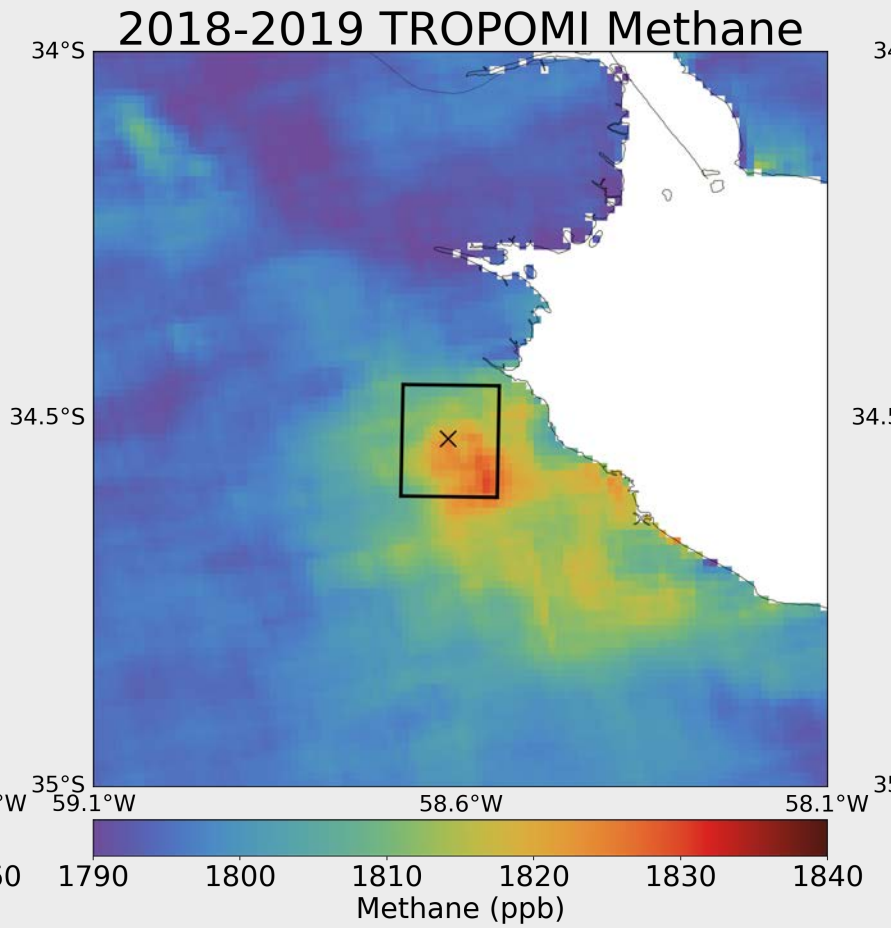


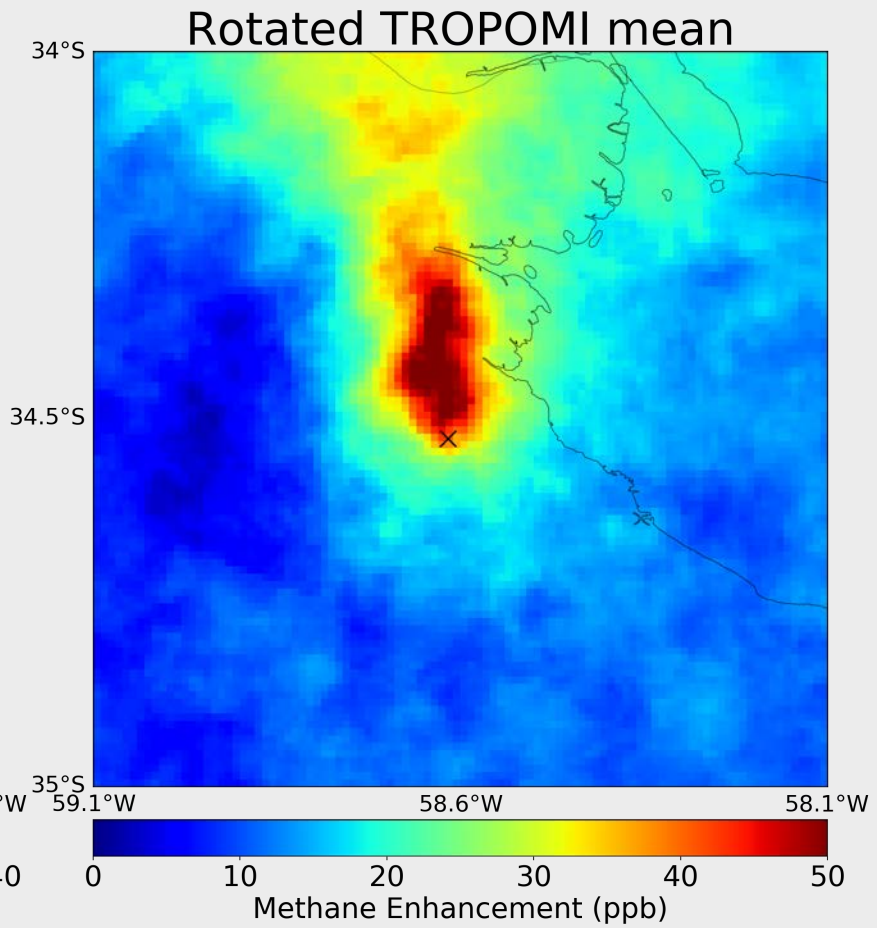
Schuit et al. (in prep)

We detected persistent emissions from Buenos Aires (Argentina)

To pinpoint the source's location to guide high-resolution satellites, we rotate daily TROPOMI images so the wind is blowing northward and average the resulting plumes. The source's location will be the point where downwind concentrations are always larger than upwind concentrations.



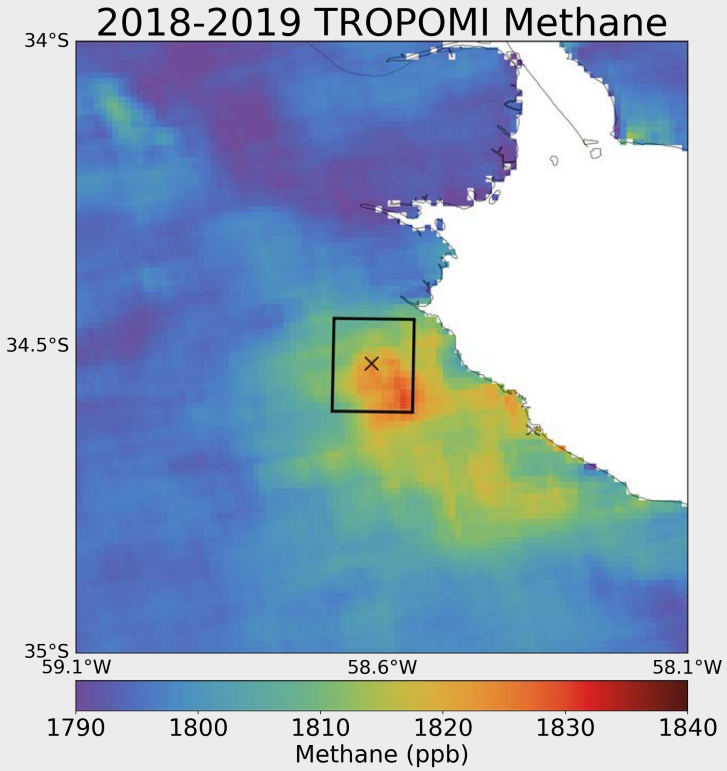


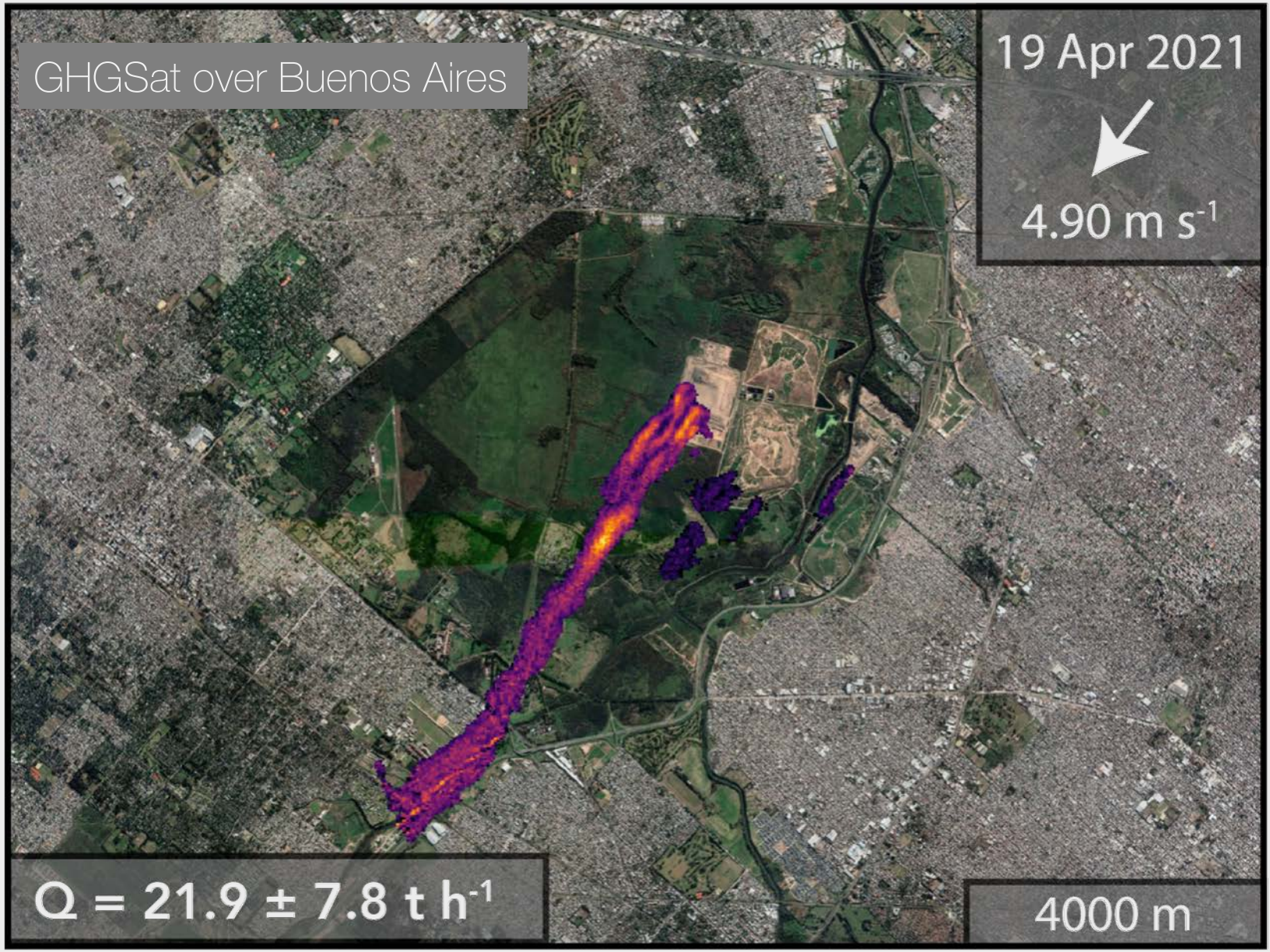


Maasakkers et al. (in prep). Wind data: ERA5 (Hersbach et al., 2020)

We detected persistent emissions from Buenos Aires (Argentina)

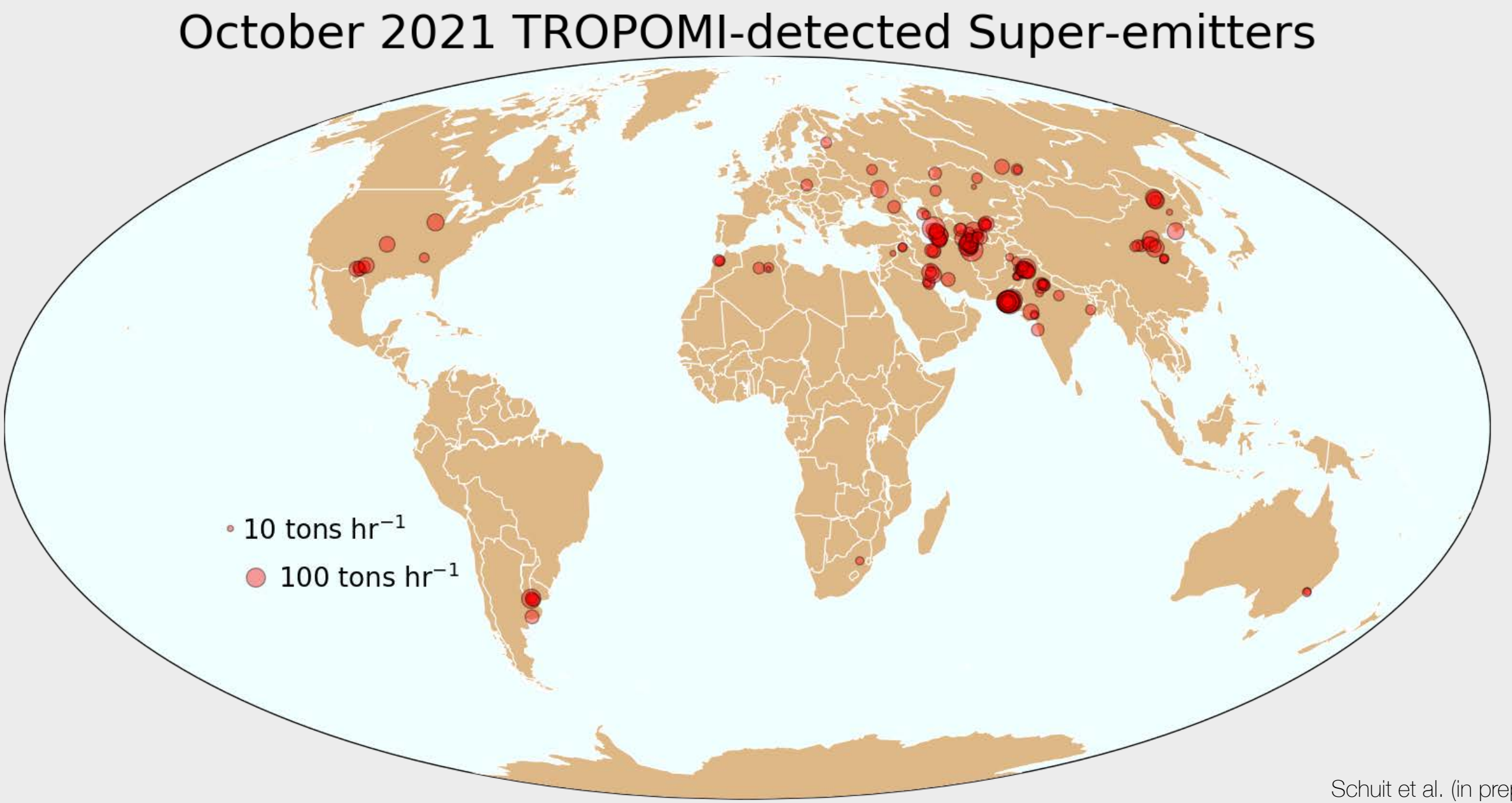
GHGSat finds large emissions from the Norte III landfill in Buenos Aires. Our TROPOMI inversion estimates urban emissions 2.8 (2.6-3.0) times higher than bottom-up estimates. Based on GHGSat observations, about half comes from the landfill.





Maasakkers et al. (in prep). Wind data: GEOS-FP (GMAO, 2021)

Our detections from last month included several hits over Delhi



Schuit et al. (in prep)

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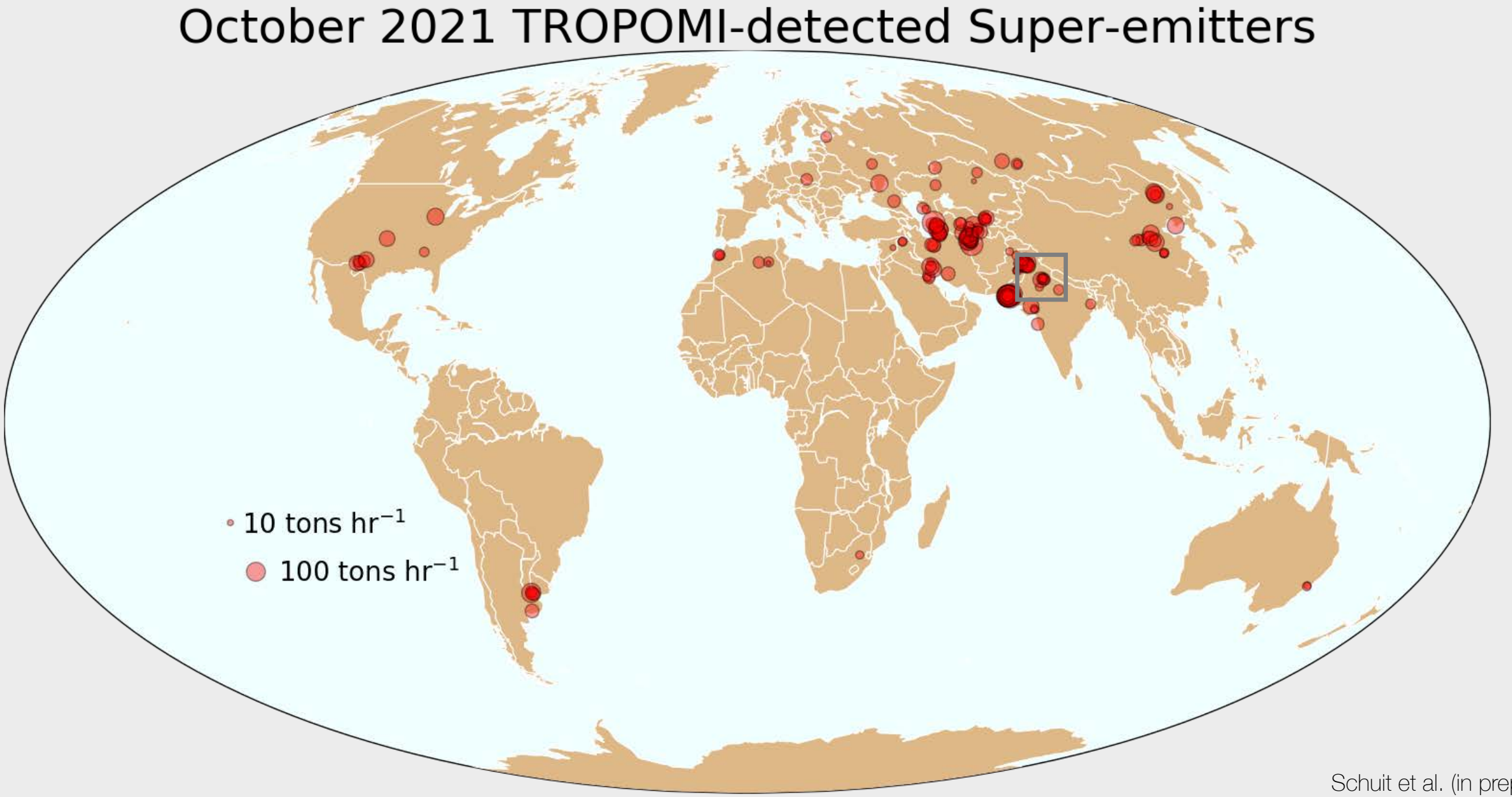
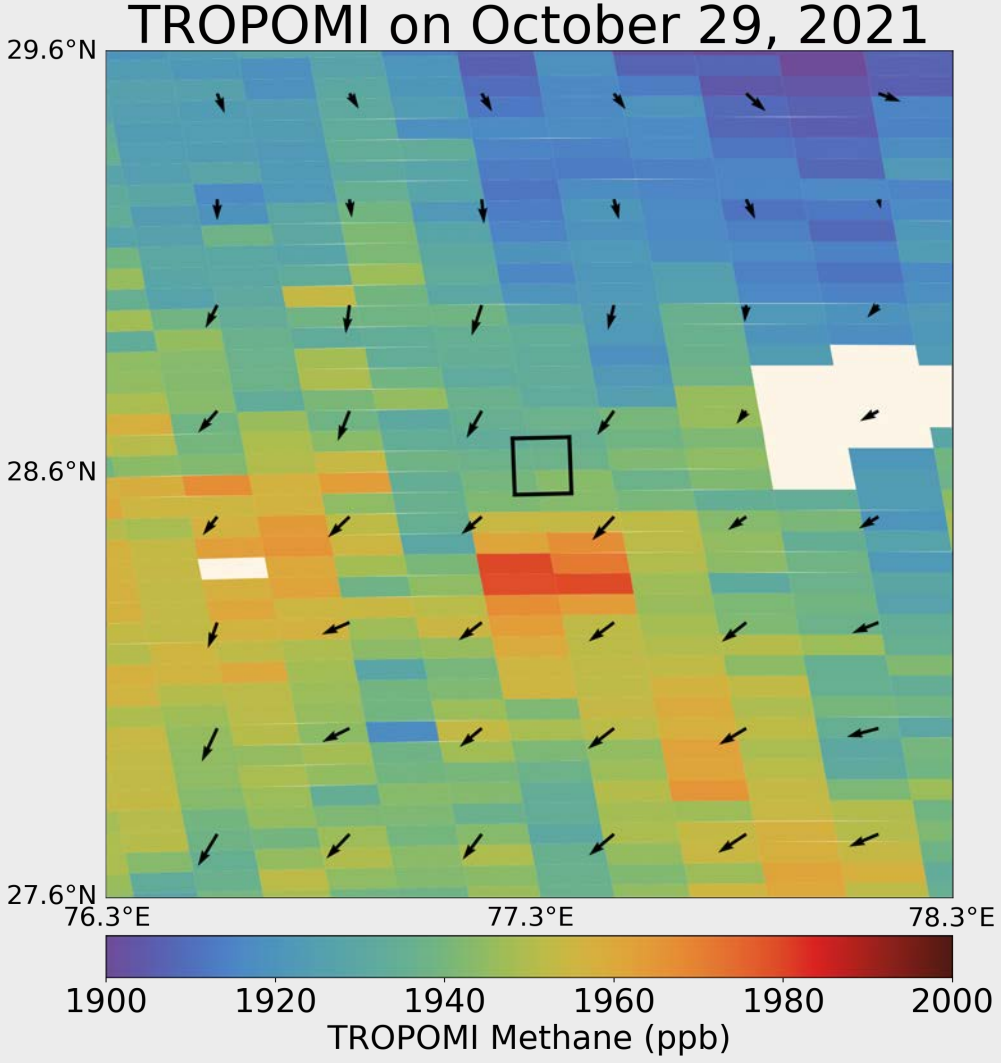
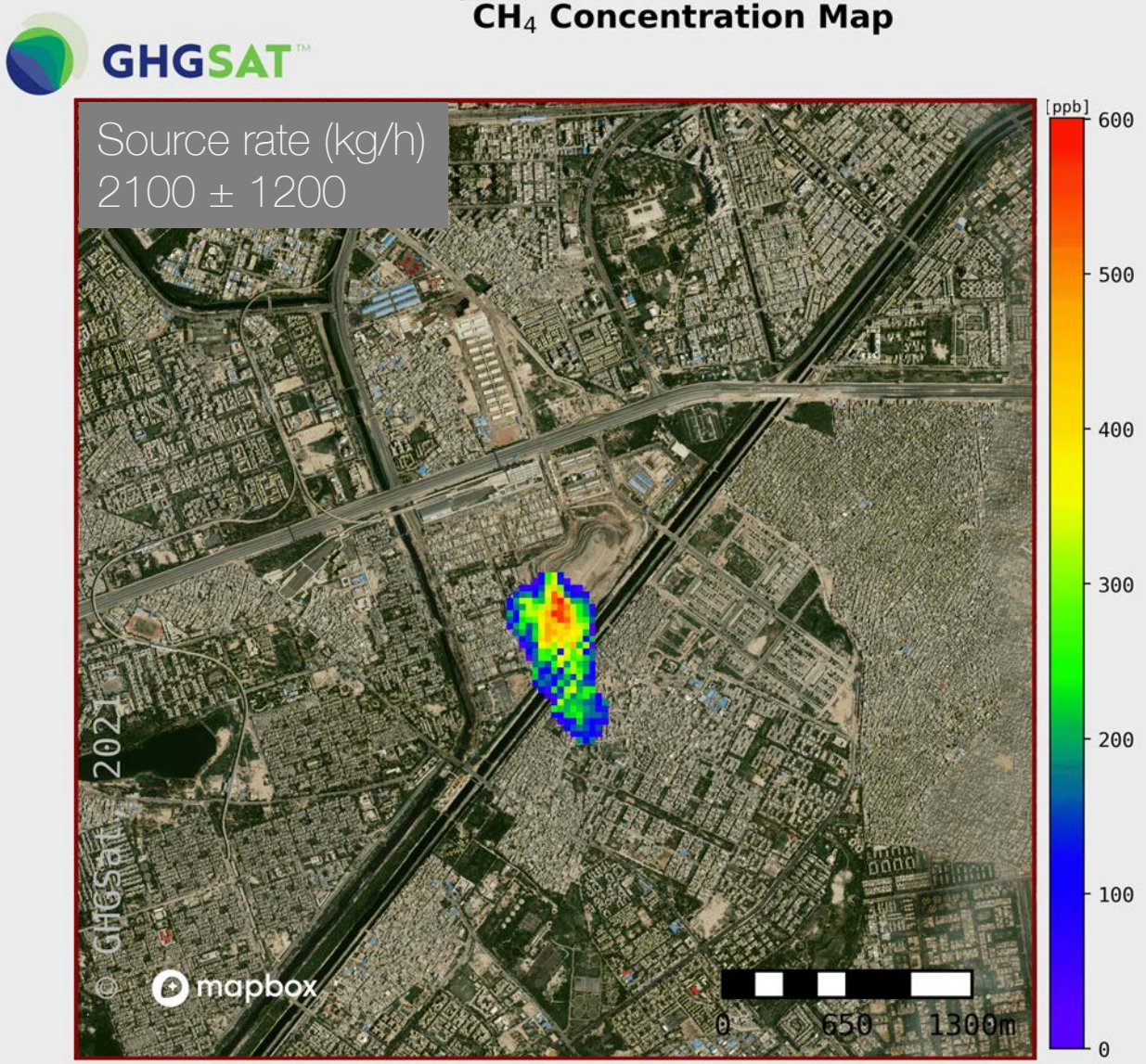


Schuit et al. (in prep)

We can apply the TROPOMI-GHGSat synergy around the world

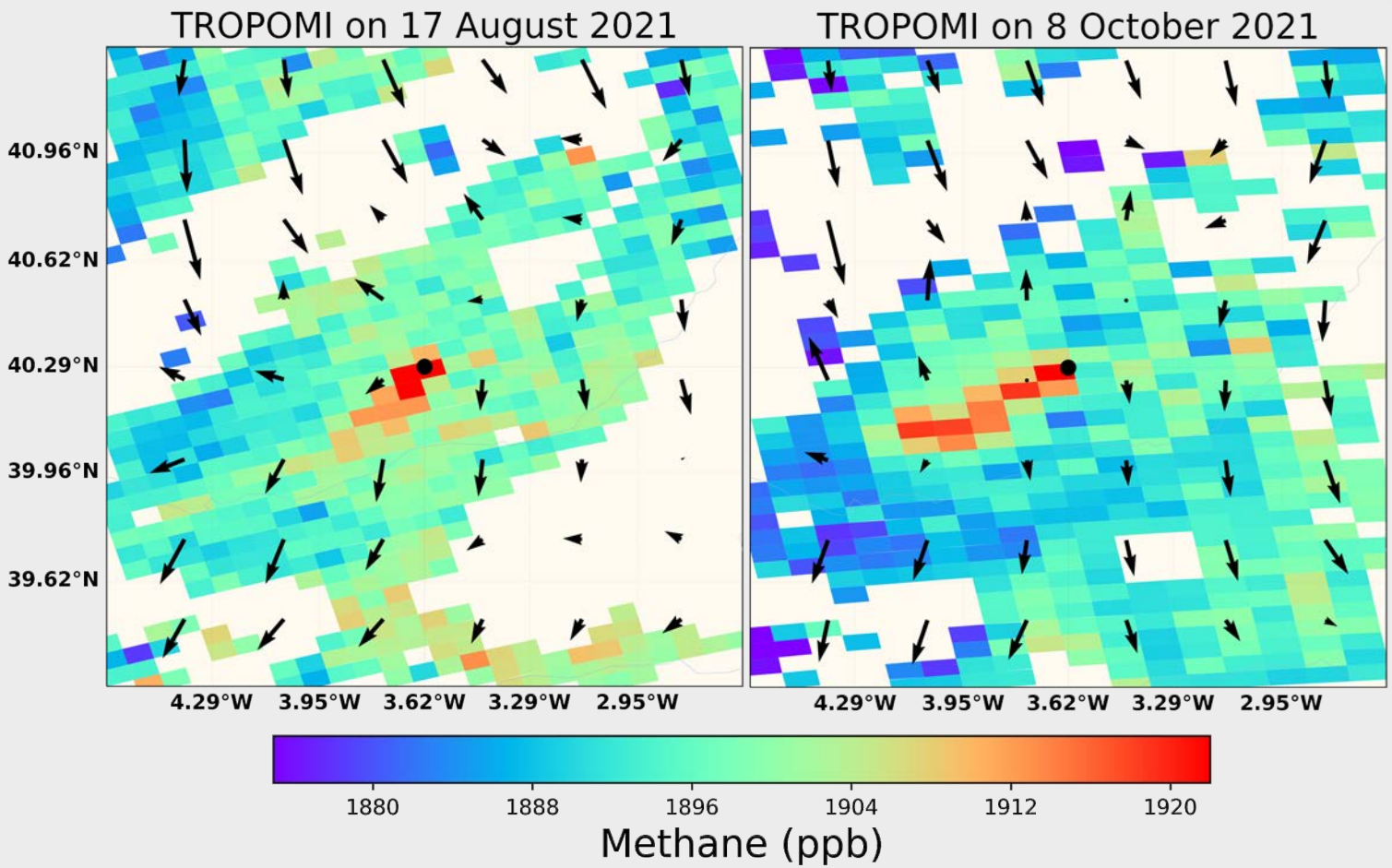
Last month, we detected a TROPOMI plume over Delhi while a targeted GHGSat observation showed a concurrent plume from the Gazipur landfill.





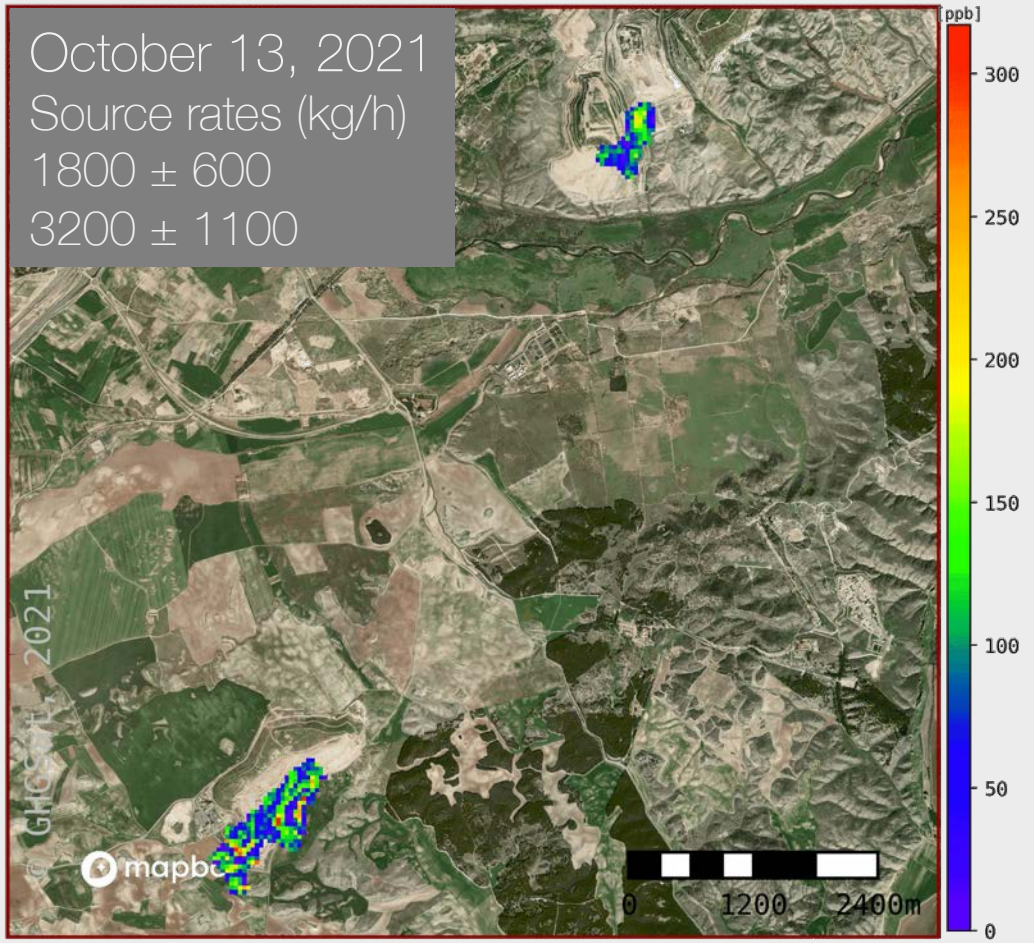
Landfill emissions are also detected in Europe

Guided by long-term TROPOMI data, GHGSat detected large emissions from landfills near Madrid on multiple days in 2021.



GHGSAT™

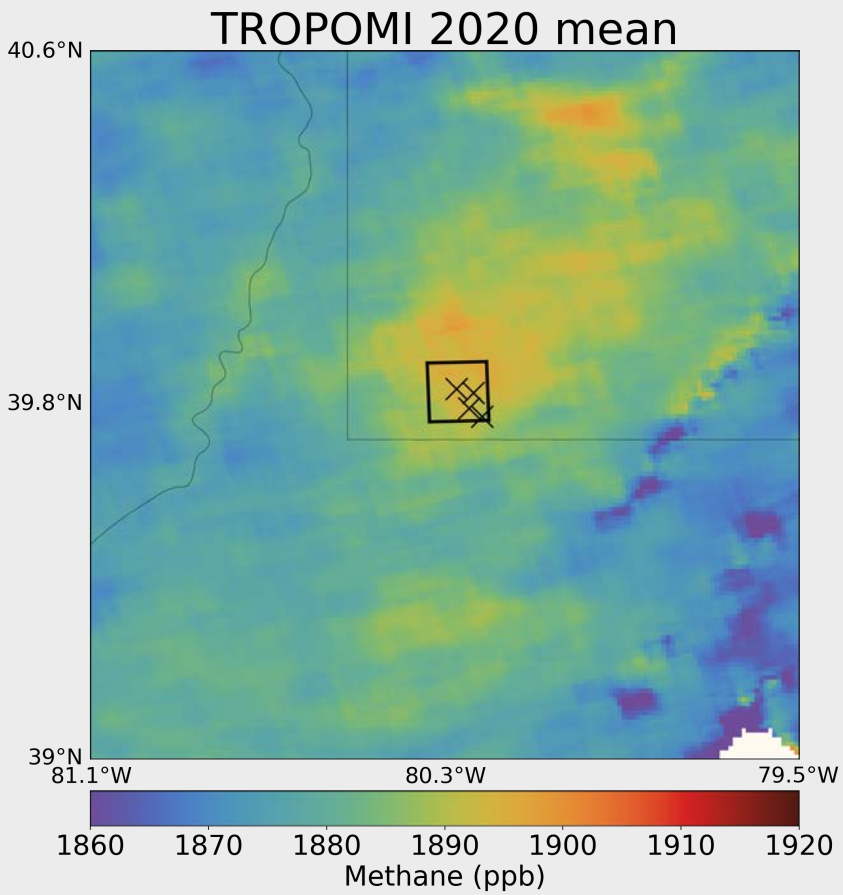
Landfill - Madrid, Spain
CH_4 Concentration Map

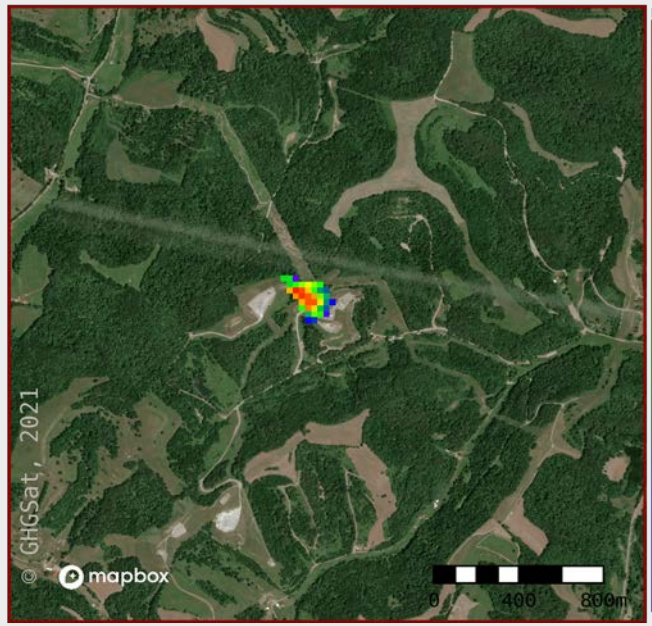


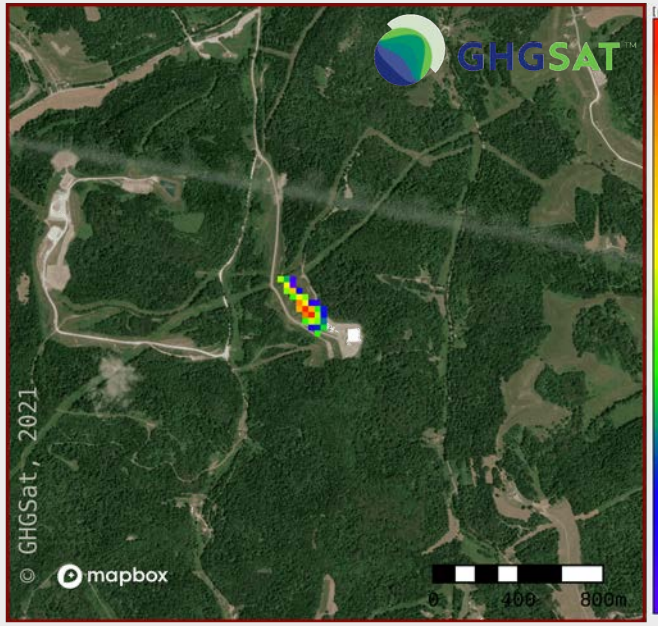
Also see: ESA web story from November 11

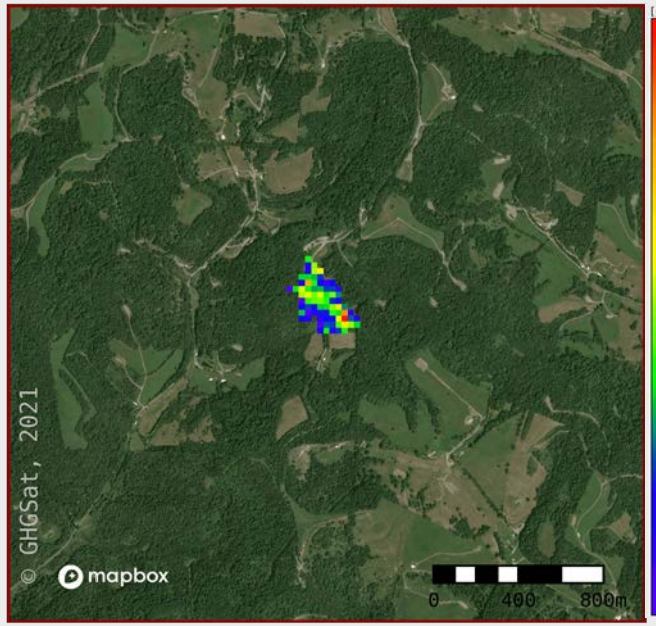
These synergies work for all kinds of source types

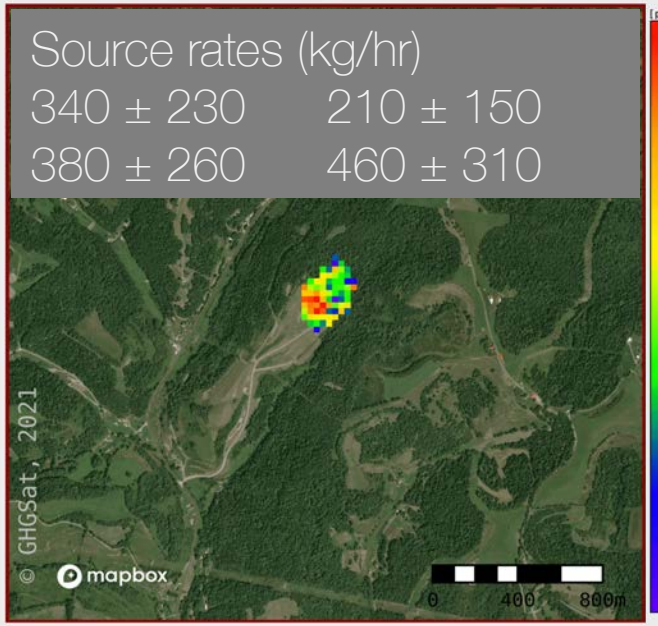
Guided by TROPOMI, GHGSat detected four individual plumes from coal mining in Pennsylvania (US) on October 11, 2021.





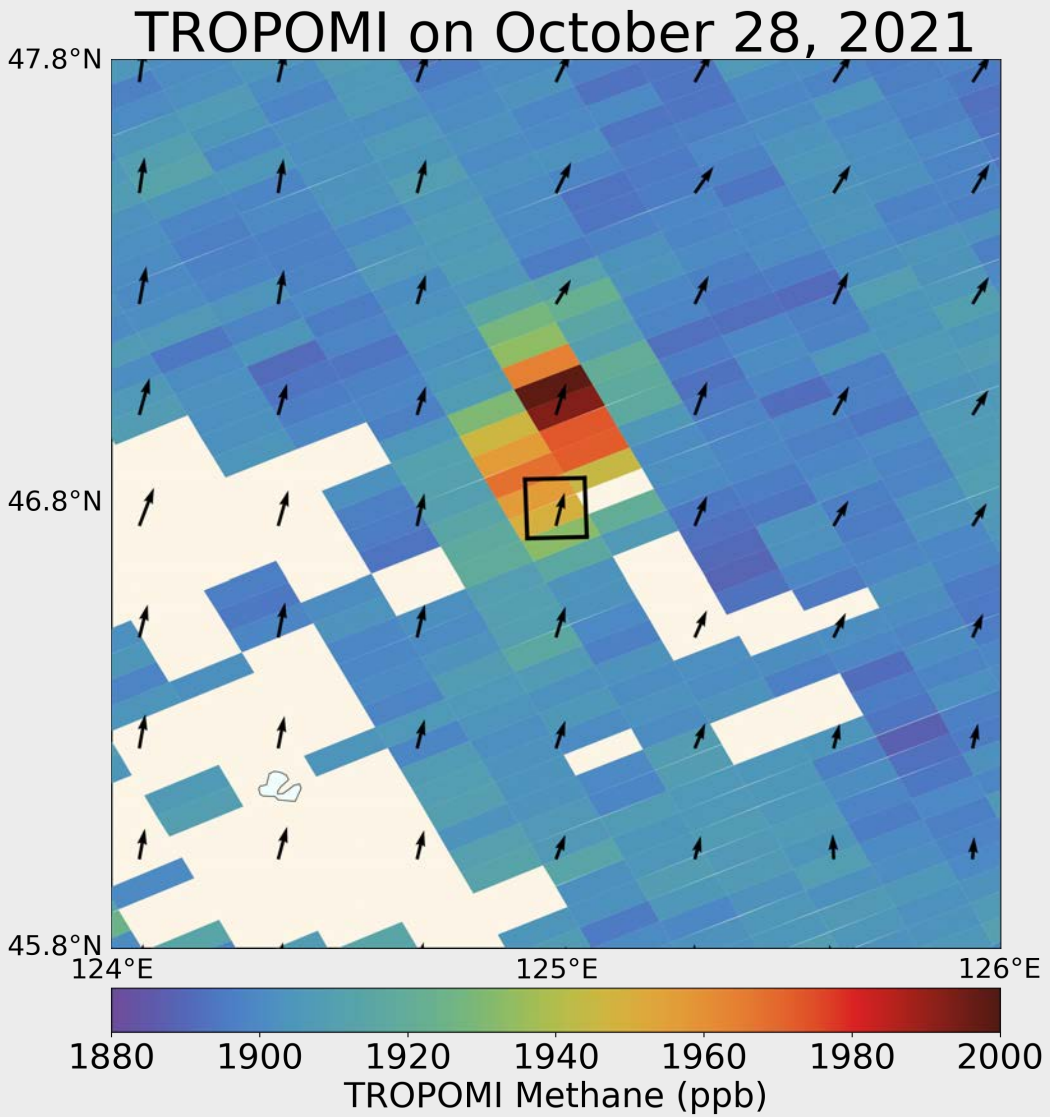






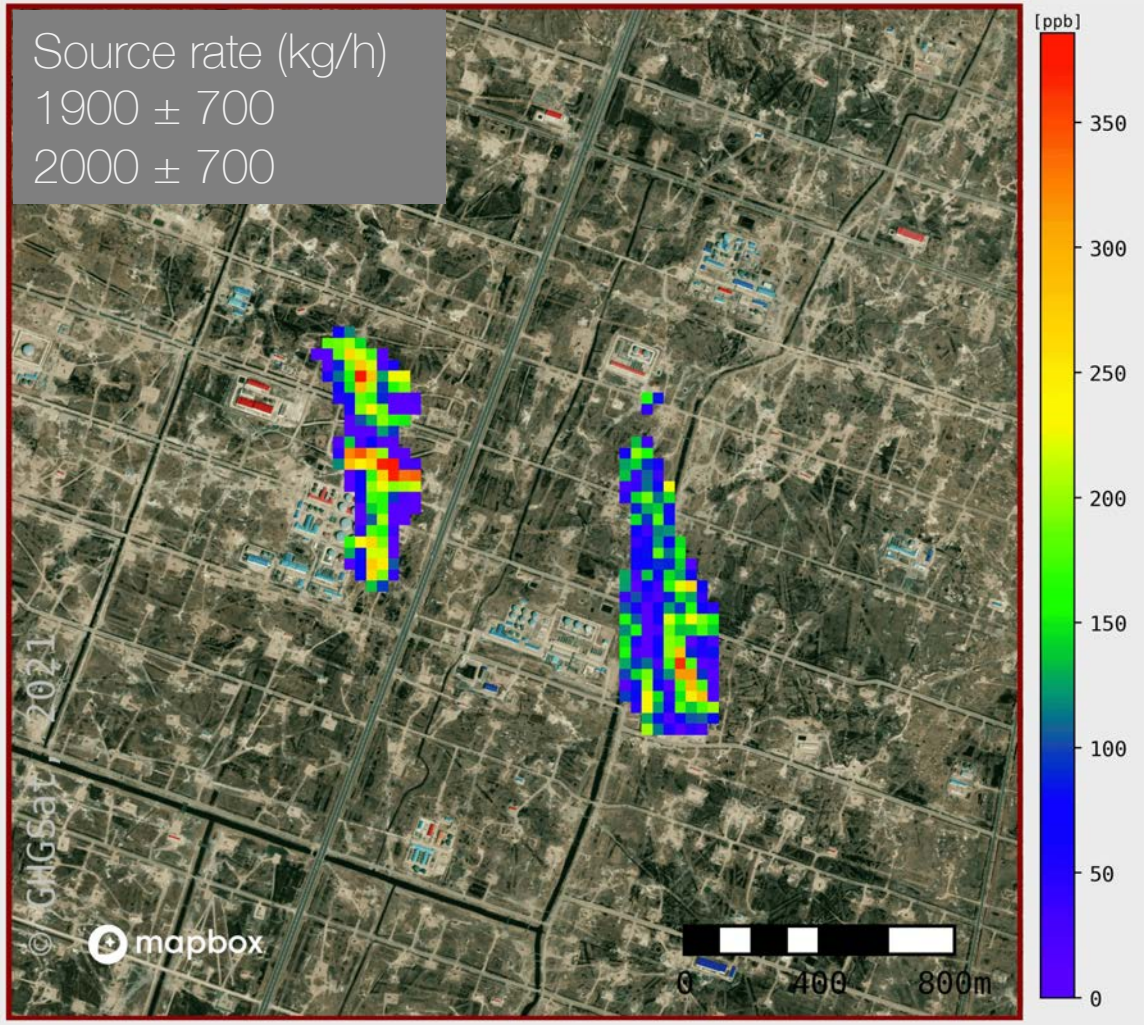
We can combine TROPOMI and GHGSat detections on individual days

Both TROPOMI and GHGSat detected plumes over a Chinese oil field on October 28.



GHGSAT™

Daqing Oil Field
China
CH_4 Concentration Map



Background Image:
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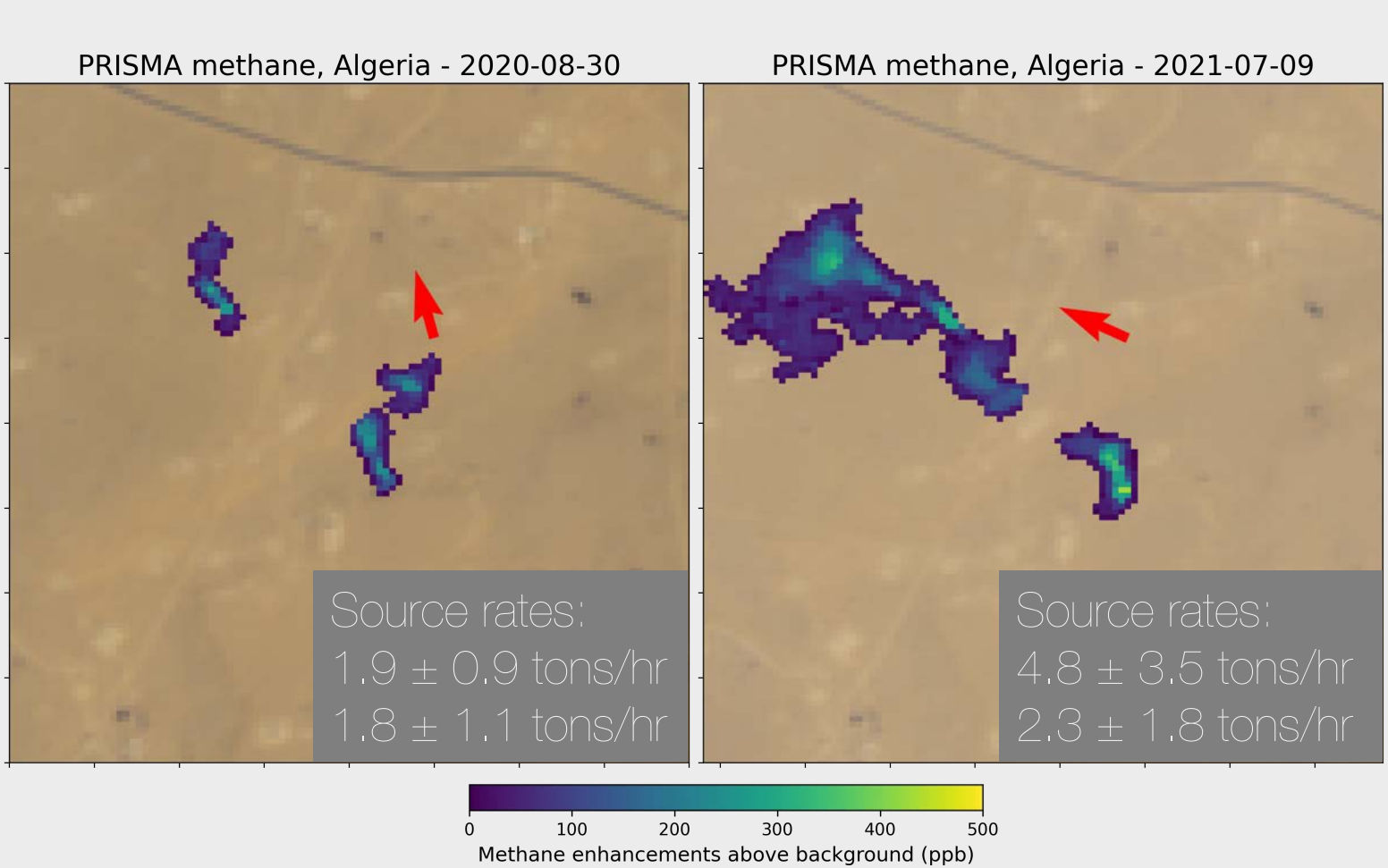
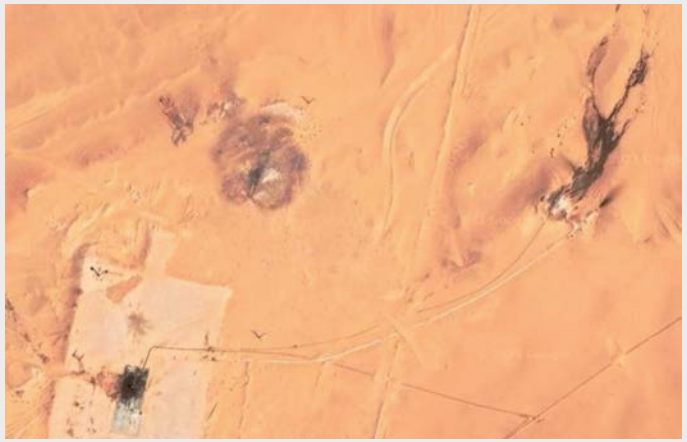
Hyperspectral instruments like PRISMA can provide additional coverage

We made several detections related to oil and gas over Algeria using TROPOMI. Hyperspectral instruments like PRISMA can provide additional facility-level observations.

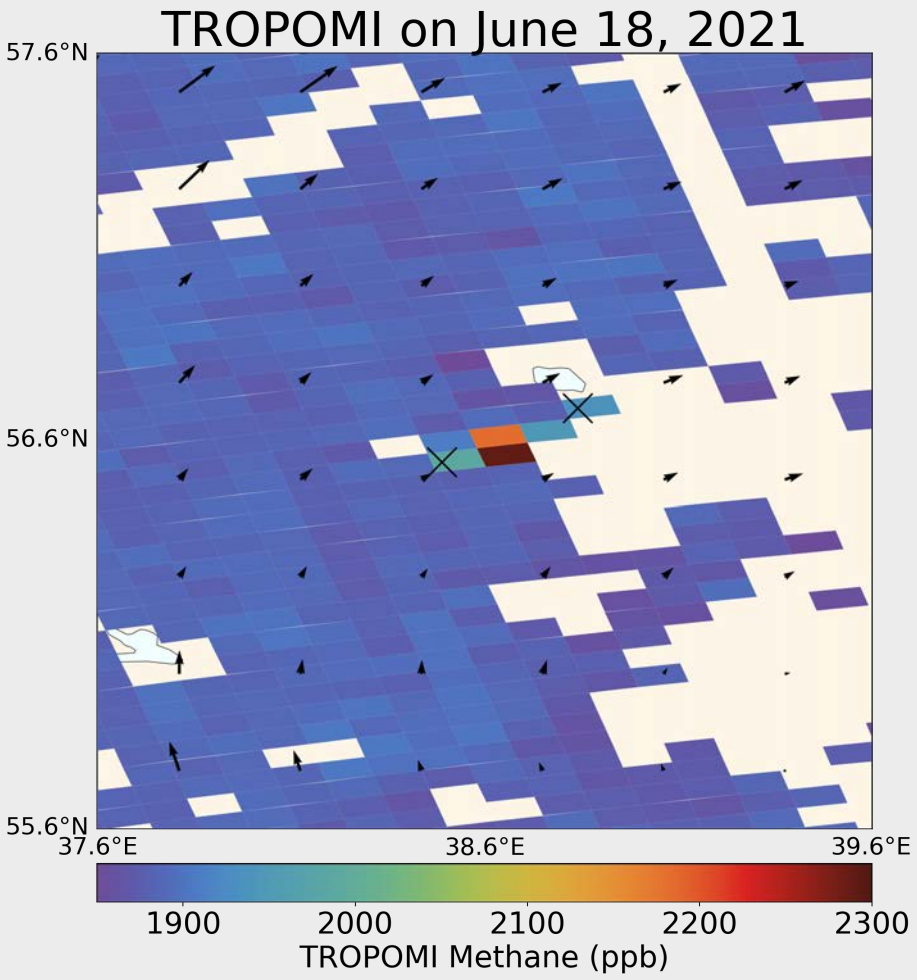


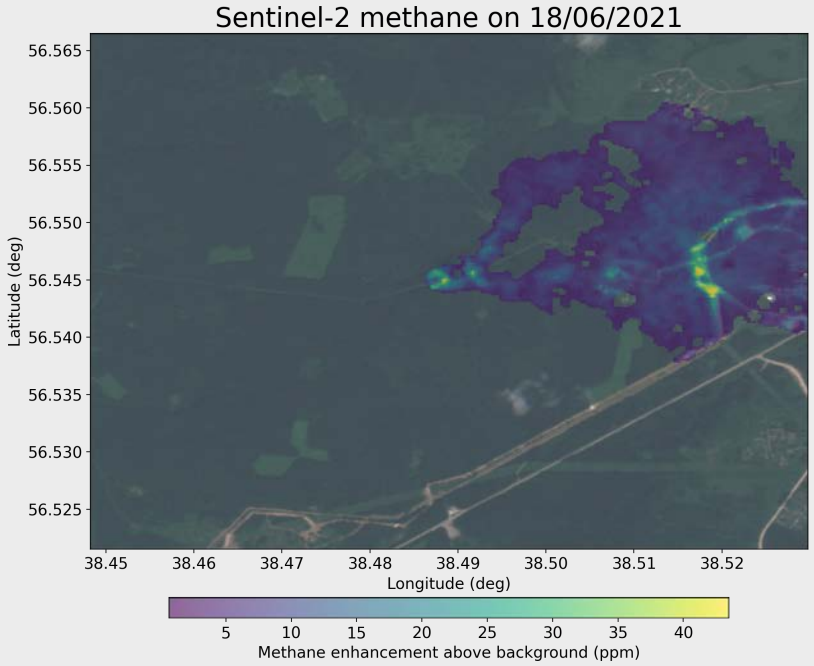


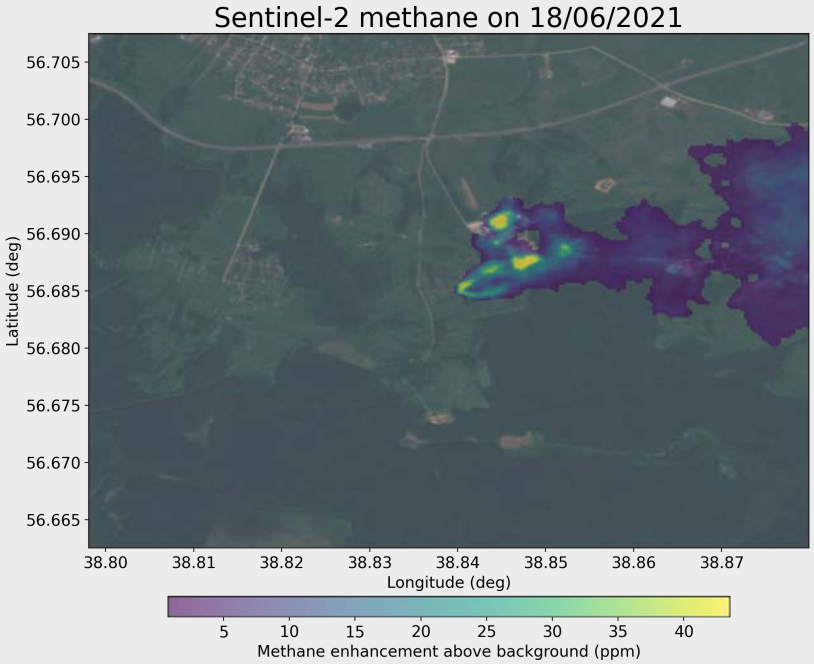
Also see: Cusworth et al. (2020); Guanter et al. (2021); Irakulis-Loitxate et al. (2021). Image credit: Google Maps

Sentinel-2 also allows us to look at one-time events with focused analysis

We detected a large plume over Russia in June 2021. Analyzing multispectral Sentinel-2 data for this event allows us to identify the facilities responsible for the TROPOMI enhancements.







Also see: Varon et al. (2020); presentations by Itziar Irakulis-Loitxate and Sudhanshu Pandey

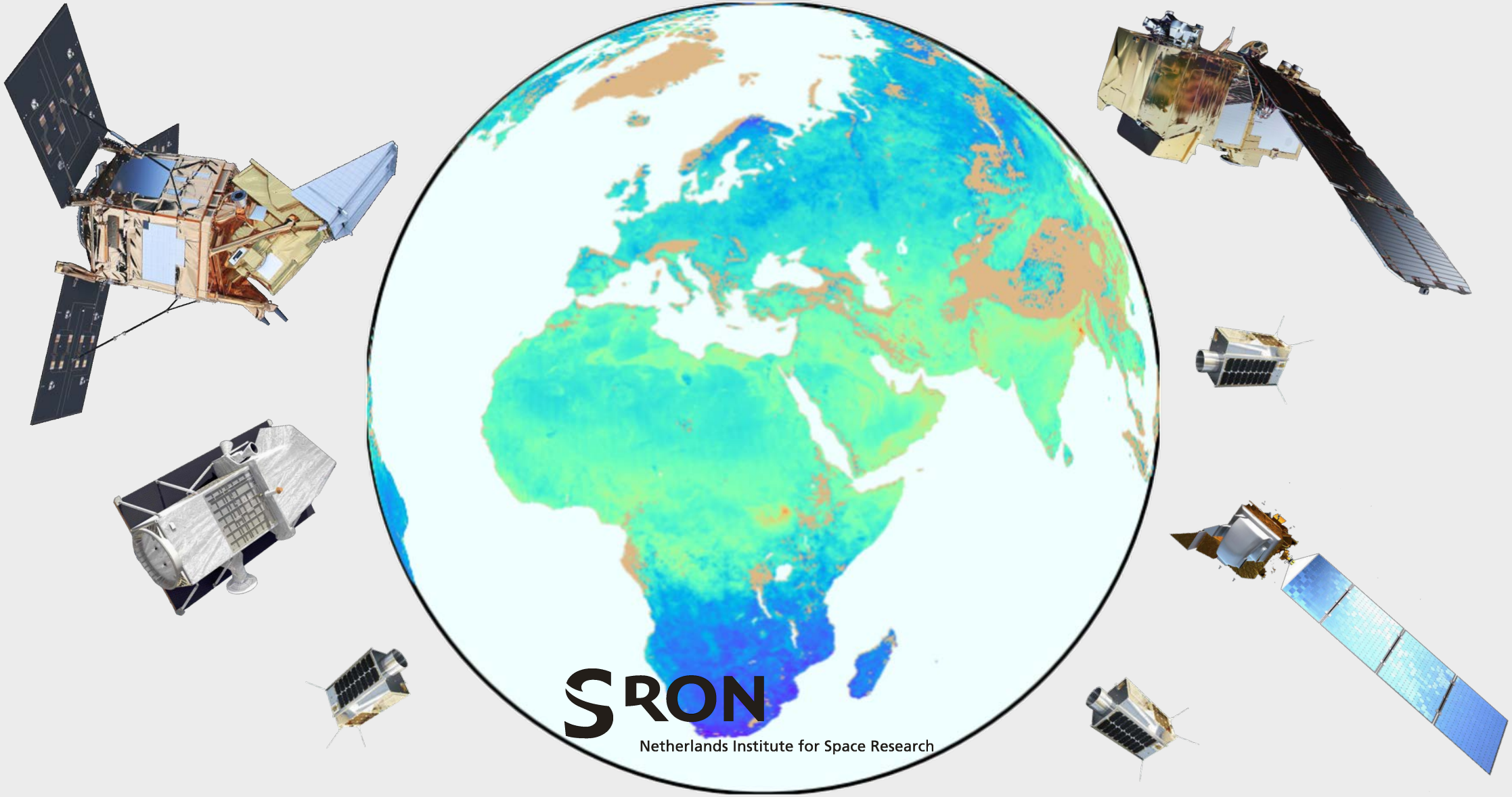


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Image credit: GHGSat/ESA/ASI/NASA