CoCO2
Prototype system for a Copernicus CO_2 service

A catalogue of published studies on hotspot detection of emissions for CO_2 and CH_4

WP8

coco2-project.eu

Co-ordinated by ECMWF

A catalogue of published studies on the remote sensing of hotspot emissions of CO_2 and CH_4

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Executive Summary

This deliverable entitled: “A catalogue of published studies on the remote sensing of hotspot emissions of CO_2 and CH_4” it is presented as an interactive map, (http://umap.openstreetmap.fr/en/map/published-studies-on-hot-spot-detection-co2-ch4_809410#2/53.2/66.3) embedded into the $CoCO_2$ project website (under development: https://coco2-project.eu/hot-spot-emission-detection-studies). It includes a collection of published studies on satellite identification of hot-spot emissions as an online repository based on a literature review exercise and has an informational purpose to users with different backgrounds as a preparation for the next CO_2M mission. In the context of the user engagement (WP8), we gathered this information to provide future CO_2M users with current state-of-the-art information on research being already done in the field of the detection and quantification of hot-spots emissions by satellites. After consulting with different scientists (e.g. SRON, The Netherlands), we received a positive feedback and heard that it is seen as an useful tool and a good example of literature review which could be even essential for acquiring funding.

1 Introduction

The hot-spot satellite detection interactive map (http://umap.openstreetmap.fr/en/map/published-studies-on-hot-spot-detection-co2-ch4_809410#2/53.2/66.3) is a user-centric interface featuring published studies on hot-spot detection from 2010 to 2021 for CO_2 and CH_4. This first iteration of the hot-spot satellite detection interactive map only allows the user to filter the displayed items by gas and activity. The second iteration of the map, to be implemented in January 2023, will allow for much more advanced filtering by year, gas, activity, geographical zone, and country.

The map is free and accessible to all. It operates on an instance of uMap, an open-source editing tool running on OpenStreetMap. The map is hosted on an OpenStreetMap server based in Europe and doesn't track users or require authentification. A third map iteration could integrate automatic updates via a database process.

Figure 1: Screenshot of hot-spot satellite detection interactive map

2. Description

The collection of satellite detection studies is found at the following link: https://docs.google.com/spreadsheets/d/16QuyAggpR9tOwsIicq3zbY1OrGUeTaILZMh6ryc35nM/edit#gid=1863095822.

They include both CO_2 and CH_4. The studies for each gas are classified by location/name, latitude/longitude, map categories, category/activity source, study year, title, reference, satellite, weblink to study, other info and link to main image.

On the map, the studies were allocated to categories and activity sources as following:

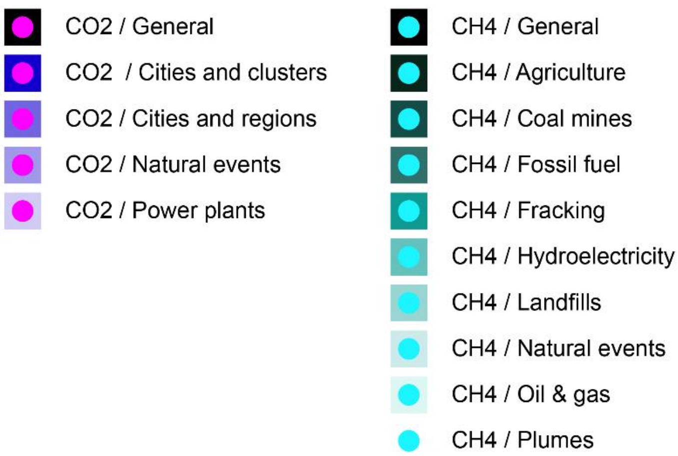

Figure 2: Legend of the interactive map

When selecting the category of interest, one could click on the 'Browse data' and the map will open on the right hand side the list of all studies existing on the map from that specific category. Like this, one user could select the study of interest.

Some examples of hot-spot studies are shown below:

CO_2 power plants studies:

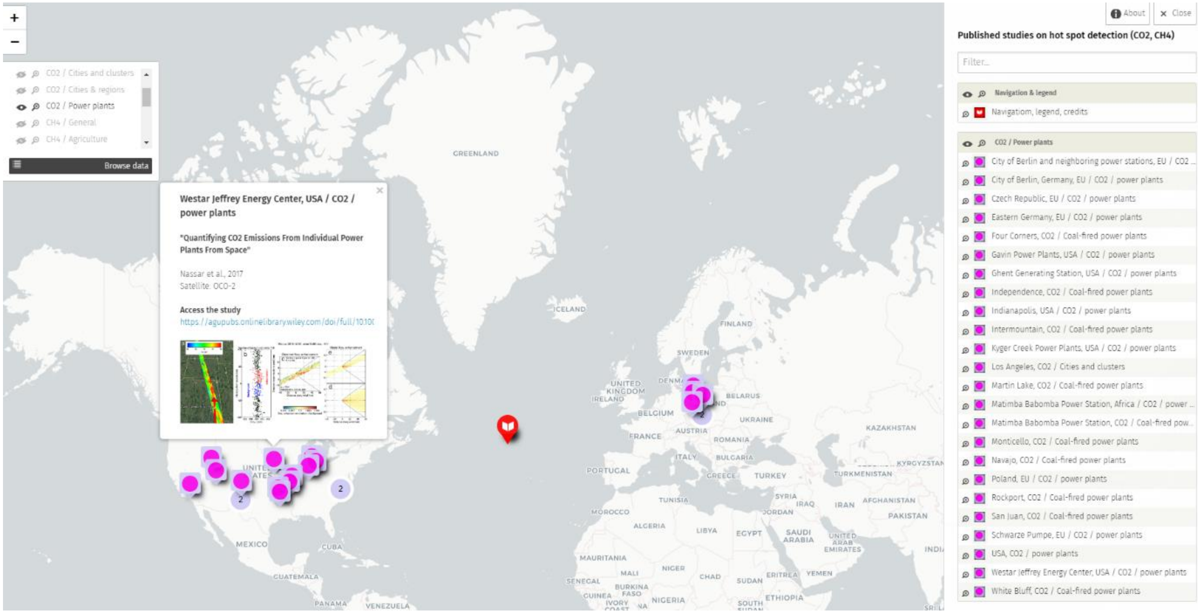

Figure 3: Examples of CO_2 studies on power plants

CH_4 oil & gas studies:

Figure 4: Examples of CH_4 studies on oil & gas

3. Future work

For the moment the map is updated manually. In the near future a hybrid updating system based on the Google doc input file will be put in place. However, it will remain a task for someone to compile and perform every few months literature review and insert new studies to the input file, which will then appear online. Ideally the references and data should be provided by the authors to be added to the repository, and a link to the $CoCO_2$ news/publications website should be established. For continuity beyond the $CoCO_2$ project this deliverable will require a stable budget. Visibility and publicity will be ensured and encouraged during project meetings, conferences and workshop presentations. Improving the map will mostly depend on users feedback and on the authors publicizing their work.

4. References

4.1. CO_2 studies

Bovensmann, H., Buchwitz, M., Burrows, J. P., Reuter, M., Krings, T., Gerilowski, K., Schneising, O., Heymann, J., Tretner, A., and Erzinger, J.: A remote sensing technique for global monitoring of power plant CO_2 emissions from space and related applications, Atmos. Meas. Tech., 3, 781–811, https://doi.org/10.5194/amt-3-781-2010, 2010.

Broquet, G., Bréon, F.-M., Renault, E., Buchwitz, M., Reuter, M., Bovensmann, H., Chevallier, F., Wu, L., and Ciais, P.: The potential of satellite spectro-imagery for monitoring CO_2 emissions from large cities, Atmos. Meas. Tech., 11, 681–708, https://doi.org/10.5194/amt-11-681-2018, 2018.

Brunner, D., Kuhlmann, G., Marshall, J., Clément, V., Fuhrer, O., Broquet, G., Löscher, A., and Meijer, Y.: Accounting for the vertical distribution of emissions in atmospheric CO_2 simulations, Atmos. Chem. Phys., 19, 4541–4559, https://doi.org/10.5194/acp-19-4541-2019, 2019.

Cai, Z., Liu, Y. & Yang, D.: Analysis of XCO_2 retrieval sensitivity using simulated Chinese Carbon Satellite (TanSat) measurements, Sci. China Earth Sci. 57, 1919–1928, https://doi.org/10.1007/s11430-013-4707-1, 2014.

Chevallier, F., Broquet, G., Zheng, B., Ciais, P., and Eldering, A.:Large CO2 emitters as seen from satellite: Comparison to a gridded global emission inventory. *Geophys. Res. Lett.* 49, e2021GL097540. doi:10.1029/2021GL097540, 2022.

Chevallier, F., Zheng, B., Broquet, G., Ciais, P., Liu, Z., Davis, S. J., et al. : Local anomalies in the column-averaged dry air mole fractions of carbon dioxide across the globe during the first months of the coronavirus recession. Geophysical Research Letters, 47, e2020GL090244. https://doi.org/10.1029/2020GL090244, 2020.

Hakkarainen, J., Ialongo, I., and Tamminen, J.: Direct space-based observations of anthropogenic CO_2 emission areas from OCO-2, Geophys. Res. Lett., 43, 11,400– 11,406, doi:10.1002/2016GL070885, 2016.

He, C., Ji, M., Li, T., Liu, X., Tang, D., Zhang, S., et al.: Deriving full-coverage and fine-scale XCO2 across China based on OCO-2 satellite retrievals and Carbon Tracker output. Geophysical Research Letters, 49, e2022GL098435. https://doi.org/10.1029/2022GL098435, 2022.

Heymann, J., M. Reuter, M. Buchwitz,O. Schneising, H. Bovensmann, J. P. Burrows, S. Massart, J. W. Kaiser, and D. Crisp: CO2emission of Indonesian fires in 2015 estimated from satellite-derived atmospheric CO2 concentrations, Geophys. Res. Lett.,44,1537–1544, doi:10.1002/2016GL072042, 2017.

Janardanan, R., Maksyutov, S., Oda, T., Saito, M., Kaiser, J. W., Ganshin, A., Stohl, A., Matsunaga, T., Yoshida, Y., and Yokota, T.: Comparing GOSAT observations of localized CO_2 enhancements by large emitters with inventory-based estimates, Geophys. Res. Lett., 43, 3486– 3493, doi:10.1002/2016GL067843, 2016.

Kaminski T., Scholze M., Rayner P., Houweling S., Voßbeck M., Silver J., Lama S., Buchwitz M., Reuter M., Knorr W., Chen H. W., Kuhlmann G., Brunner D., Dellaert S., Denier van der Gon H., Super I., Löscher A., Meijer Y.: Assessing the Impact of Atmospheric CO2 and NO2 Measurements From Space on Estimating City-Scale Fossil Fuel CO2 Emissions in a Data Assimilation System, Frontiers in Remote Sensing, Vol. 3, https://www.frontiersin.org/articles/10.3389/frsen.2022.887456, DOI:10.3389/frsen.2022.887456, 2022.

Kort, E. A., Frankenberg, C., Miller, C. E., and Oda, T.: Space-based observations of megacity carbon dioxide, Geophys. Res. Lett., 39, L17806, doi:10.1029/2012GL052738, 2012.

Kuhlmann, G., Broquet, G., Marshall, J., Clément, V., Löscher, A., Meijer, Y., and Brunner, D.: Detectability of CO_2 emission plumes of cities and power plants with the Copernicus Anthropogenic CO_2 Monitoring (CO2M) mission, Atmos. Meas. Tech., 12, 6695–6719, https://doi.org/10.5194/amt-12-6695-2019, 2019.

Kuhlmann, G., Brunner, D., Broquet, G., and Meijer, Y.: Quantifying CO_2 emissions of a city with the Copernicus Anthropogenic CO_2 Monitoring satellite mission, Atmos. Meas. Tech., 13, 6733–6754, https://doi.org/10.5194/amt-13-6733-2020, 2020.

Liu, F., Duncan, B. N., Krotkov, N. A., Lamsal, L. N., Beirle, S., Griffin, D., McLinden, C. A., Goldberg, D. L., and Lu, Z.: A methodology to constrain carbon dioxide emissions from coal-fired power plants using satellite observations of co-emitted nitrogen dioxide, Atmos. Chem. Phys., 20, 99–116, https://doi.org/10.5194/acp-20-99-2020, 2020.

Nassar, R., Hill, T. G., McLinden, C. A.,Wunch, D., Jones, D. B. A., & Crisp, D.: Quantifying CO2emissions fromindividual power plants from space.Geophysical Research Letters,44,10,045–10,053. https://doi.org/10.1002/2017GL074702, 2017.

Reuter, M., Buchwitz, M., Schneising, O., Krautwurst, S., O'Dell, C. W., Richter, A., Bovensmann, H., and Burrows, J. P.: Towards monitoring localized CO_2 emissions from space: co-located regional CO_2 and NO_2 enhancements observed by the OCO-2 and S5P satellites, Atmos. Chem. Phys., 19, 9371–9383, https://doi.org/10.5194/acp-19-9371-2019, 2019.

Santaren, D., Broquet, G., Bréon, F.-M., Chevallier, F., Siméoni, D., Zheng, B., and Ciais, P.: A local- to national-scale inverse modeling system to assess the potential of spaceborne CO_2 measurements for the monitoring of anthropogenic emissions, Atmos. Meas. Tech., 14, 403–433, https://doi.org/10.5194/amt-14-403-2021, 2021.

Sierk, B., Bézy, J-L., Armin Löscher, A., Yasjka Meijer, Y.: The European CO2 Monitoring Mission: observing anthropogenic greenhouse gas emissions from space (spiedigitallibrary.org), 2019.

Strandgren, J., Krutz, D., Wilzewski, J., Paproth, C., Sebastian, I., Gurney, K. R., Liang, J., Roiger, A., and Butz, A.: Towards spaceborne monitoring of localized CO_2 emissions: an instrument concept and first performance assessment, Atmos. Meas. Tech., 13, 2887–2904, https://doi.org/10.5194/amt-13-2887-2020, 2020.

Wang, Y., Broquet, G., Bréon, F.-M., Lespinas, F., Buchwitz, M., Reuter, M., Meijer, Y., Loescher, A., Janssens-Maenhout, G., Zheng, B., and Ciais, P.: PMIF v1.0: assessing the potential of satellite observations to constrain CO_2 emissions from large cities and point sources over the globe using synthetic data, Geosci. Model Dev., 13, 5813–5831, https://doi.org/10.5194/gmd-13-5813-2020, 2020.

Wang, Y., Ciais, P., Broquet, G., Bréon, F.-M., Oda, T., Lespinas, F., Meijer, Y., Loescher, A., Janssens-Maenhout, G., Zheng, B., Xu, H., Tao, S., Gurney, K. R., Roest, G., Santaren, D., and Su, Y.: A global map of emission clumps for future monitoring of fossil fuel CO_2 emissions from space, Earth Syst. Sci. Data, 11, 687–703, https://doi.org/10.5194/essd-11-687-2019, 2019.

Yang, E. G., Kort, E. A., Wu, D., Lin, J. C., Oda, T., Ye, X., & Lauvaux, T.: Using space-based observations and Lagrangian modeling to evaluate urban carbon dioxide emissions in the Middle East. Journal of Geophysical Research: Atmospheres, 125, e2019JD031922. https://doi.org/10.1029/2019JD031922, 2020.

Ye, X., Lauvaux, T., Kort, E. A., Oda, T., Feng, S., Lin, J. C., et al.: Constraining fossil fuel CO_2 emissions from urban area using OCO-2 observations of total column CO_2, Journal of Geophysical Research: Atmospheres, 125, e2019JD030528. https://doi.org/10.1029/2019JD030528, 2020.

Zheng, B., Chevallier, F., Ciais, P., Broquet, G., Wang, Y., Lian, J., and Zhao, Y.: Observing carbon dioxide emissions over China's cities and industrial areas with the Orbiting Carbon Observatory-2, Atmos. Chem. Phys., 20, 8501–8510, https://doi.org/10.5194/acp-20-8501-2020, 2020.

Zheng, T., Nassar, R., and Baxter, M.: Estimating power plant CO_2 emission using OCO-2 XCO_2 and high resolution WRF-Chem simulations, Environ. Res. Lett. 14 085001, 2019.

4.2. CH_4 studies

Barré, J., Aben, I., Agustí-Panareda, A., Balsamo, G., Bousserez, N., Dueben, P., Engelen, R., Inness, A., Lorente, A., McNorton, J., Peuch, V.-H., Radnoti, G., and Ribas, R.: Systematic detection of local CH_4 anomalies by combining satellite measurements with high-resolution forecasts, Atmos. Chem. Phys., 21, 5117–5136, https://doi.org/10.5194/acp-21-5117-2021, 2021.

Brandt, A., Heath, A.G., and Cooley, D.: Methane Leaks from Natural Gas Systems Follow Extreme Distributions, *Environ. Sci. Technol.* 2016, 50, 22, 12512–12520, 2016.

Buchwitz, M., Schneising, O., Reuter, M., Heymann, J., Krautwurst, S., Bovensmann, H., Burrows, J. P., Boesch, H., Parker, R. J., Somkuti, P., Detmers, R. G., Hasekamp, O. P., Aben, I., Butz, A., Frankenberg, C., and Turner, A. J.: Satellite-derived methane hotspot emission estimates using a fast data-driven method, Atmos. Chem. Phys., 17, 5751–5774, https://doi.org/10.5194/acp-17-5751-2017, 2017.

Case Studies - GHGSat

Cusworth et al., 2022: Strong methane point sources contribute a disproportionate fraction of total emissions across multiple basins in the U.S. (eartharxiv.org), preprint, 2022.

Cusworth, D. H., Duren, R. M., Thorpe, A. K., Pandey, S., Maasakkers, J. D., Aben, I., et al.: Multisatellite imaging of a gas well blowout enables quantification of total methane emissions. *Geophysical Research Letters*, 48, e2020GL090864. https://doi.org/10.1029/2020GL090864, 2021.

Daniel Zavala-Araiza et al.: A tale of two regions: methane emissions from oil and gas production in offshore/onshore Mexico, Environ. Res. Lett. 16 024019, 2021.

Gonzalez-Valencia, R., Magana-Rodriguez, F., Cristóbal, J., Thalasso, F.: Hotspot detection and spatial distribution of methane emissions from landfills by a surface probe method, Waste Management, Volume 55, Pages 299-305, ISSN 0956-053X, https://doi.org/10.1016/j.wasman.2016.03.004, 2016.

Guha et al.: Greenhouse Gas (GHG) Source Detection and Attribution in the San Francisco Bay Area of California Using a Mobile Measurement Platform - NASA/ADS (harvard.edu), 2016.

Ialongo, I., Stepanova, N., Hakkarainen, J., Virta, H., Gritsenko, D.: Satellite-based estimates of nitrogen oxide and methane emissions from gas flaring and oil production activities in Sakha Republic, Russia, Atmospheric Environment: X, Vol. 11, 100114, https://doi.org/10.1016/j.aeaoa.2021.100114, 2021.

Irakulis-Loitxate I *et al*: Satellite-based survey of extreme methane emissions in the Permian basin *Sci. Adv.* **7** eabf4507, 2021.

Itziar Irakulis-Loitxate, Luis Guanter, Joannes D. Maasakkers, Daniel Zavala-Araiza, and Ilse Aben, *Environmental Science & Technology 56* (4), 2143-2152, DOI: 10.1021/acs.est.1c04873, 2022.

Jacob, D. J., Varon, D. J., Cusworth, D. H., Dennison, P. E., Frankenberg, C., Gautam, R., Guanter, L., Kelley, J., McKeever, J., Ott, L. E., Poulter, B., Qu, Z., Thorpe, A. K., Worden, J. R., and Duren, R. M.: Quantifying methane emissions from the global scale down to point sources using satellite observations of atmospheric methane, Atmos. Chem. Phys., 22, 9617–9646, https://doi.org/10.5194/acp-22-9617-2022, 2022.

Lauvaux, T., C. Giron, M. Mazzolini, A. d'Aspremont, R. Duren, D. Cusworth, et al.: Global assessment of oil and gas methane ultra-emitters, Science, 375 (6580), pp. 557-561, 2022.

Lespinas, F., Wang, Y., Broquet, G. *et al.* The potential of a constellation of low earth orbit satellite imagers to monitor worldwide fossil fuel CO_2 emissions from large cities and point sources. *Carbon Balance Manage* **15**, 18, https://doi.org/10.1186/s13021-020-00153-4, 2020.

Maasakkers, J. D., Omara, M., Gautam, R., Lorente, A., Pandey, S., Toi, P., Borsdorff, T., Houweling, S., and Aben, I.: Reconstructing and quantifying methane emissions from the full duration of a 38-day natural gas well blowout using space-based observations, Remote Sens. Environ., 270, 112755, https://doi.org/10.1016/j.rse.2021.112755, 2022a.

Maasakkers, J.D.; Varon, D.J.; Elfarsdóttir, A.; McKeever, J.; Jervis, D.; Mahapatra, G.; Pandey, S.; Lorente, A.; Borsdorff, T.; Foorthuis, L.R.; et al. Using satellites to uncover large methane emissions from landfills. Sci. Adv. 8, eabn9683, 2022b.

Mazzini, A., Sciarra, A., Etiope, G. *et al.* Relevant methane emission to the atmosphere from a geological gas manifestation. *Sci Rep* 11, 4138, https://doi.org/10.1038/s41598-021-83369-9, 2021.

Pandey, S., Gautam, R., Houweling, S., Van Der Gon, H. D., Sadavarte, P., Borsdorff, T., Hasekamp, O., Landgraf, J., Tol, P., Van Kempen, T., and Hoogeveen, R.: Satellite observations reveal extreme methane leakage from a natural gas well blowout, P. Natl. Acad. Sci. USA, 116, 26376–26381, https://doi.org/10.1073/pnas.1908712116, 2019.

Pandey, S., Houweling, S., Lorente, A., Borsdorff, T., Tsivlidou, M., Bloom, A. A., Poulter, B., Zhang, Z., and Aben, I.: Using satellite data to identify the methane emission controls of South Sudan's wetlands, Biogeosciences, 18, 557–572, https://doi.org/10.5194/bg-18-557-2021, 2021.

Pankaj Sadavarte, Sudhanshu Pandey, Joannes D. Maasakkers, Alba Lorente, Tobias Borsdorff, Hugo Denier van der Gon, Sander Houweling, and Ilse Aben, Environmental Science & Technology 55 (24), 16573-16580, DOI: 10.1021/acs.est.1c03976, 2021.

Plant, G., E.A. Kort, L.T. Murray, J.D. Maasakkers, I. Aben: Evaluating urban methane emissions from space using TROPOMI methane and carbon monoxide observations, Rem. Sens. Environ., 268, Article 112756, 2022.

Scarpelli, T. R., Jacob, D. J., Grossman, S., Lu, X., Qu, Z., Sulprizio, M. P., Zhang, Y., Reuland, F., Gordon, D., and Worden, J. R.: Updated Global Fuel Exploitation Inventory (GFEI) for methane emissions from the oil, gas, and coal sectors: evaluation with inversions of atmospheric methane observations, Atmos. Chem. Phys., 22, 3235–3249, https://doi.org/10.5194/acp-22-3235-2022, 2022.

Schneising, O., Buchwitz, M., Reuter, M., Vanselow, S., Bovensmann, H., and Burrows, J. P.: Remote sensing of methane leakage from natural gas and petroleum systems revisited, Atmos. Chem. Phys., 20, 9169–9182, https://doi.org/10.5194/acp-20-9169-2020, 2020.

Shen, L., Gautam, R., Omara, M., Zavala-Araiza, D., Maasakkers, J. D., Scarpelli, T. R., Lorente, A., Lyon, D., Sheng, J., Varon, D. J., Nesser, H., Qu, Z., Lu, X., Sulprizio, M. P., Hamburg, S. P., and Jacob, D. J.: Satellite quantification of oil and natural gas methane emissions in the US and Canada including contributions from individual basins, Atmos. Chem. Phys., 22, 11203–11215, https://doi.org/10.5194/acp-22-11203-2022, 2022.

Varon, D. J., Jacob, D. J., McKeever, J., Jervis, D., Durak, B. O. A., Xia, Y., and Huang, Y.: Quantifying methane point sources from fine-scale satellite observations of atmospheric methane plumes, Atmos. Meas. Tech., 11, 5673–5686, https://doi.org/10.5194/amt-11-5673-2018, 2018.

Varon, D. J., Jervis, D., McKeever, J., Spence, I., Gains, D., and Jacob, D. J.: High-frequency monitoring of anomalous methane point sources with multispectral Sentinel-2 satellite observations, Atmos. Meas. Tech., 14, 2771–2785, https://doi.org/10.5194/amt-14-2771-2021, 2021.

Varon, D. J., McKeever, J., Jervis, D., Maasakkers, J. D., Pandey, S., Houweling, S., et al.: Satellite discovery of anomalously large methane point sources from oil/gas production. Geophysical research Letters, 46, 13507– 13516. https://doi.org/10.1029/2019GL083798, 2019.

Worden, J. R., Cusworth, D. H., Qu, Z., Yin, Y., Zhang, Y., Bloom, A. A., Ma, S., Byrne, B. K., Scarpelli, T., Maasakkers, J. D., Crisp, D., Duren, R., and Jacob, D. J.: The 2019 methane budget and uncertainties at 1° resolution and each country through Bayesian integration Of

GOSAT total column methane data and a priori inventory estimates, Atmos. Chem. Phys., 22, 6811–6841, https://doi.org/10.5194/acp-22-6811-2022, 2022.

Zhang,Y., R. Gautam, S. Pandey, M. Omara, J.D. Maasakkers, P. Sadavarte, D. Lyon, H. N esser, M.P. Sulprizio, D.J. Varon, R. Zhang, S. Houweling, D. Zavala-Araiza, R.A. Alvarez, A. Lorente, S.P. Hamburg, I. Aben, D.J. Jacob: Quantifying methane emissions from the largest oil-producing basin in the united states from space, Sci. Adv., 6 (17), Article eaaz5120, 10.1126/sciadv.aaz5120, 2020.

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