Leveraging Improved Measurement Coverage to Characterize the Evolution of Oil-Production-Related Emissions around Lake Maracaibo, Venezuela

Brian Nathan, J.D. Maasakkers, S. Naus, R. Gautam, M. Omara, D. Zavala-Araiza, A. Lorente, T. Borsdorff, and I. Aben

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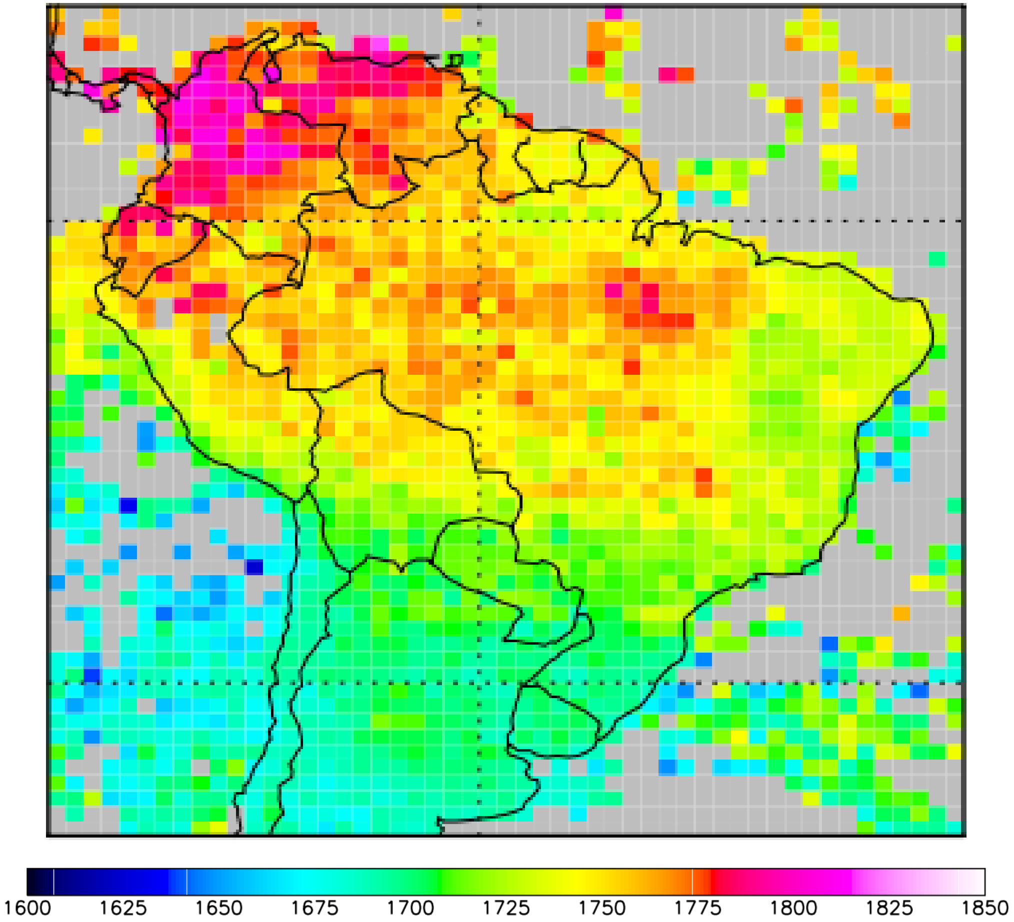
Historical Context

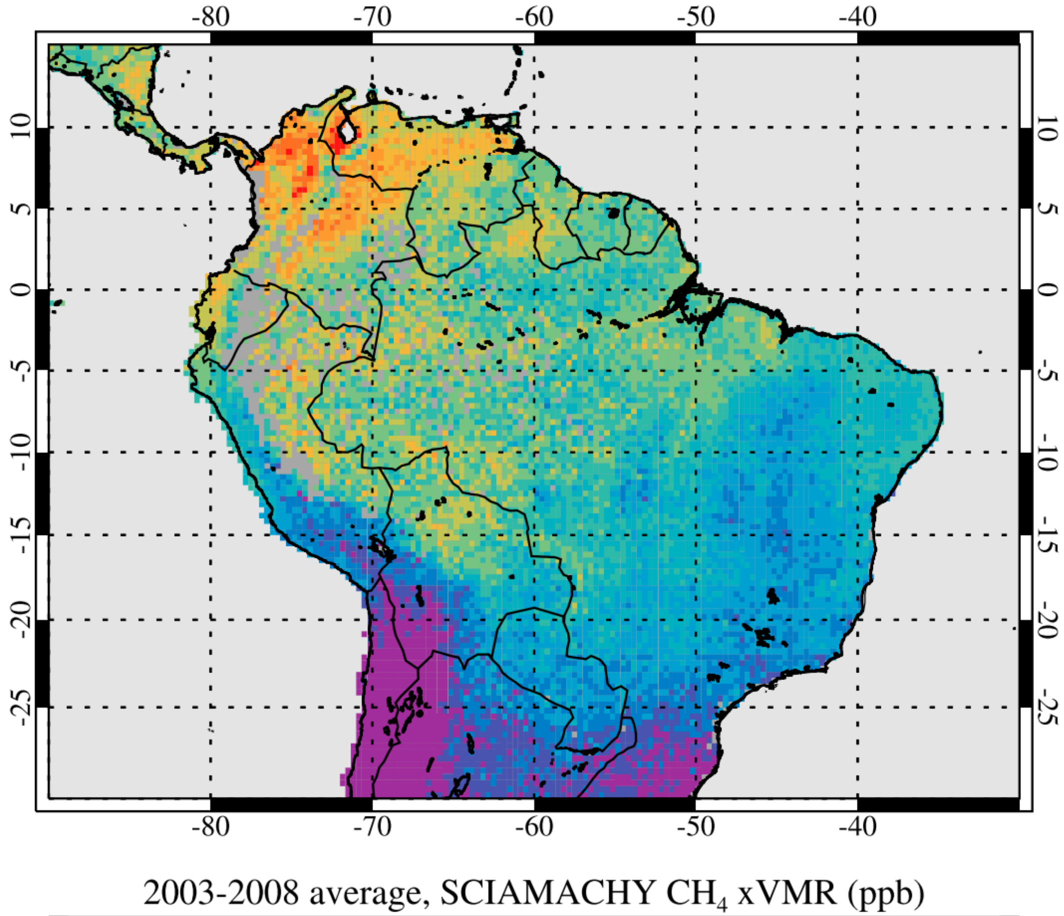
SCIAMACHY Enhancements Around Lake Maracaibo

Meirink et al. (2008)



Sep – Nov 2003

Frankenberg et al. (2011)



Previous global studies, typically relying on SCIAMACHY data, had identified some enhanced signals in the northern part of South America, particularly near Lake Maracaibo

Enhancements Around Lake Maracaibo

Meirink et al. (2008)

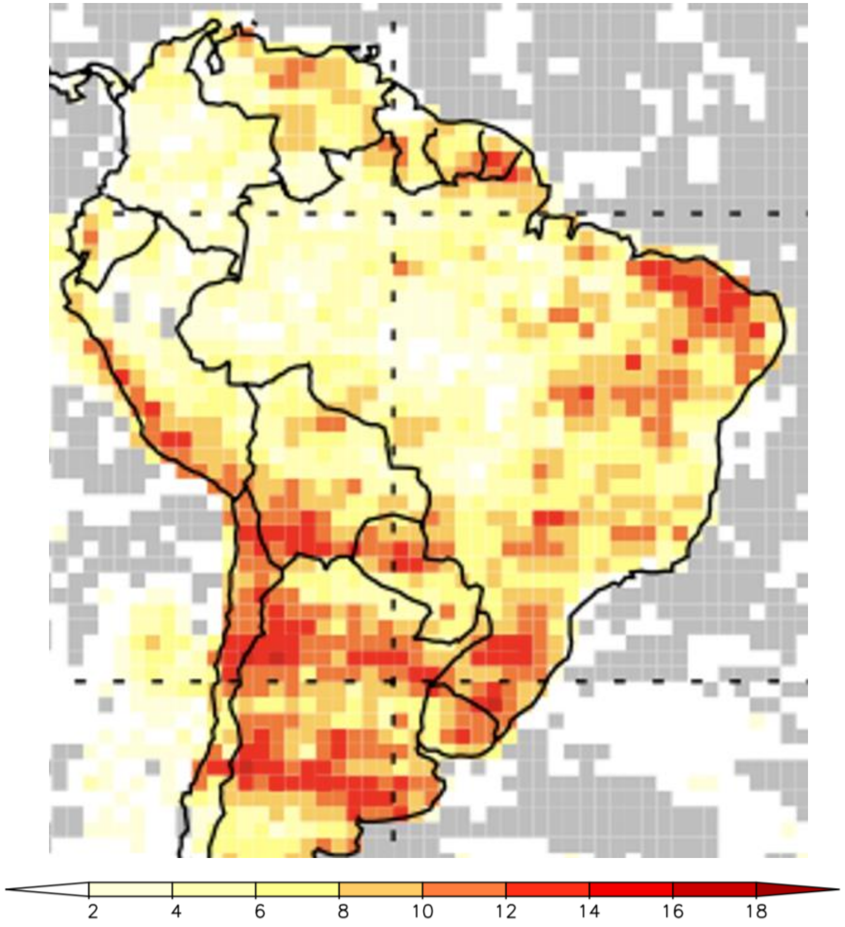
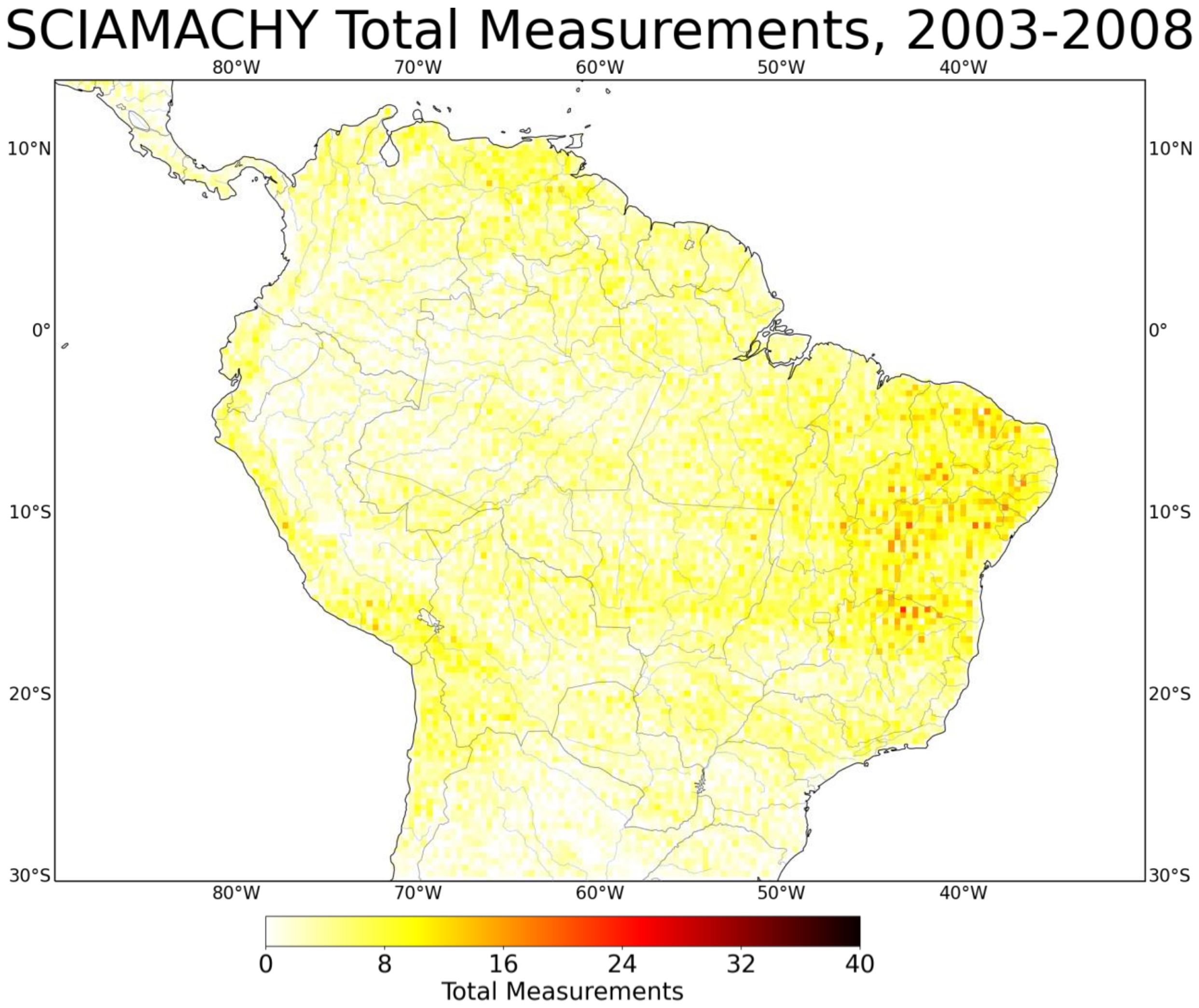
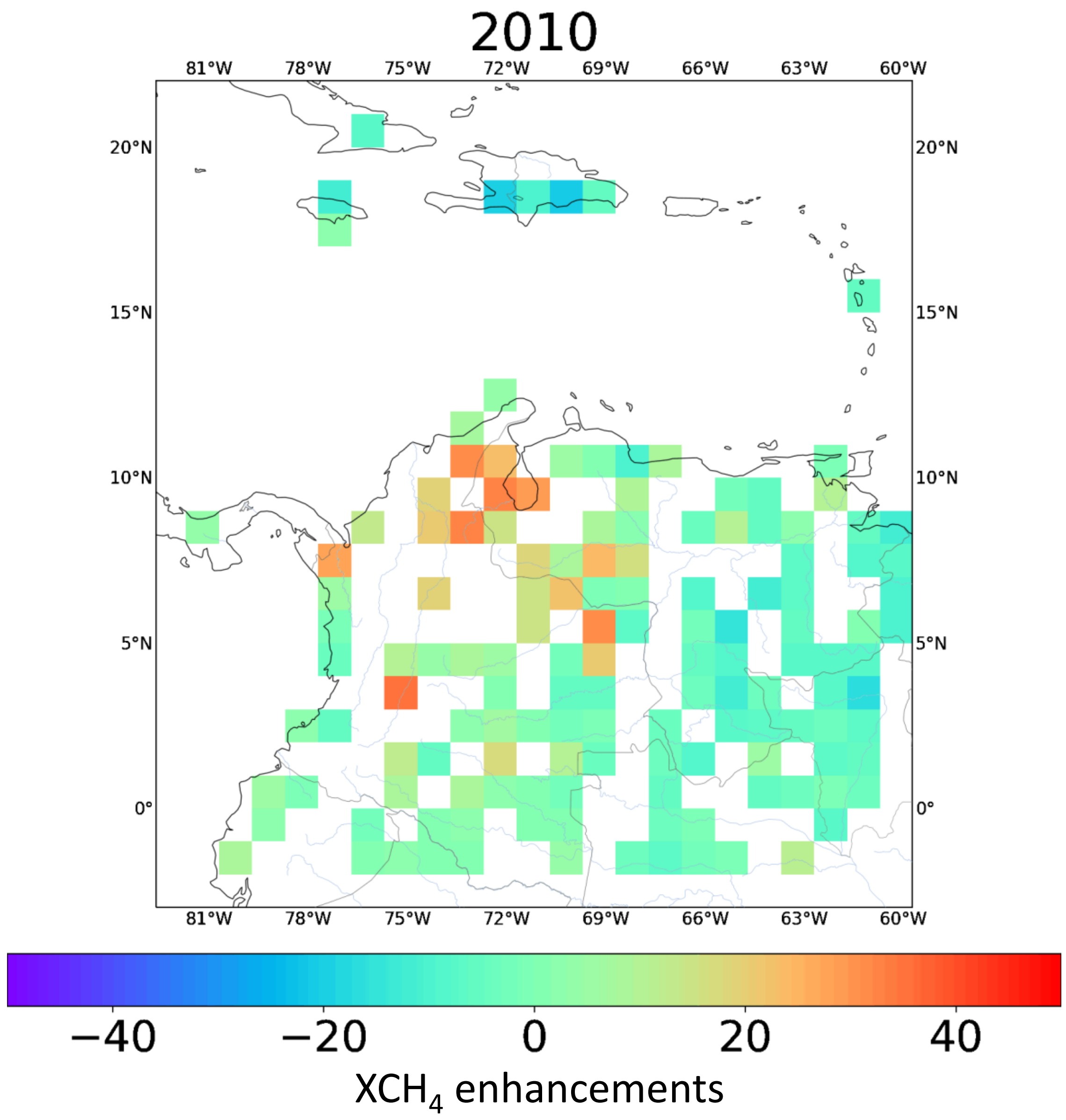


Figure 5. Number of assimilated SCIAMACHY observations per 1° × 1° grid box from 1 September until 1 December 2003.



When filtering out high-uncertainty measurements, longterm averages or coarse aggregations are often required to get some coverage near Lake Maracaibo

GOSAT Longterm Comparison

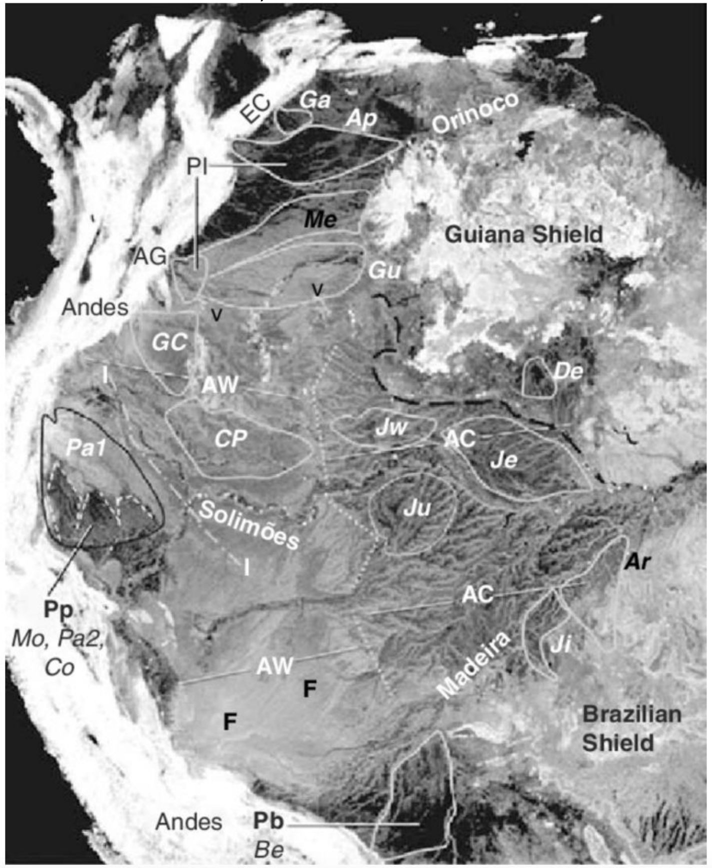


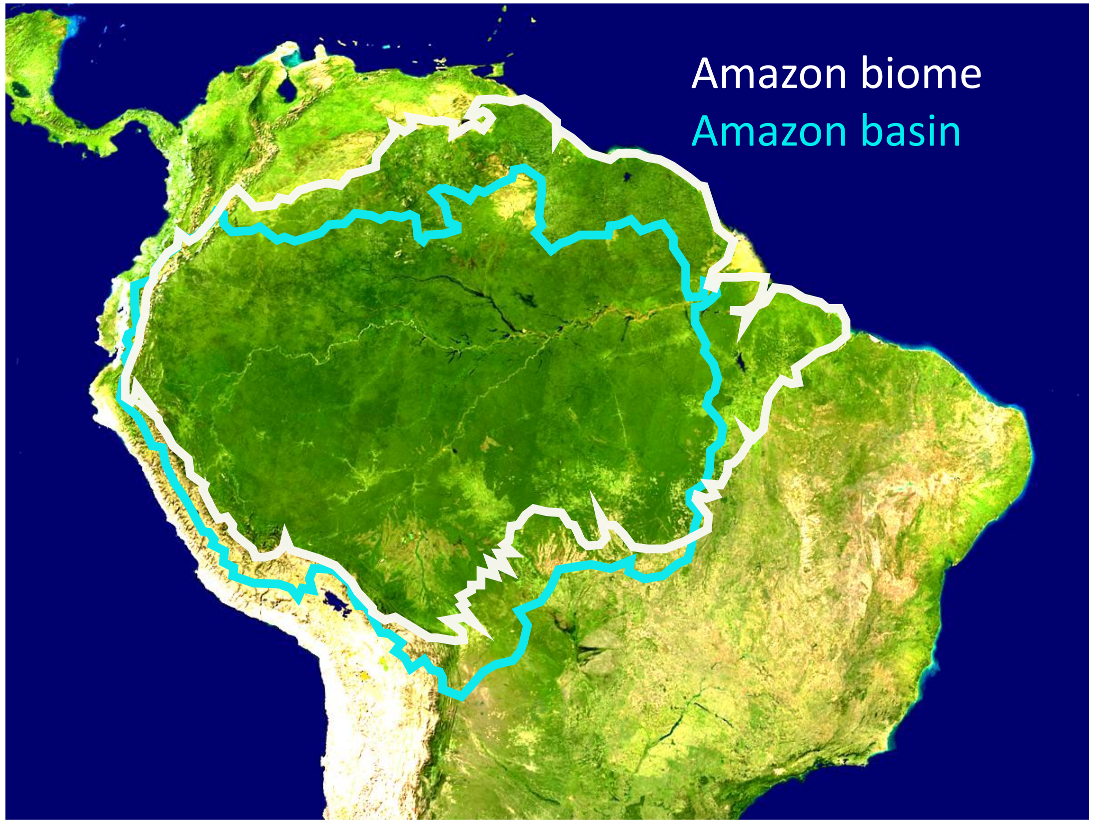
In the years since the end of SCIAMACHY, GOSAT also appears to see some enhanced values around this region, though its periodic orbit leaves some spatial gaps

Difficult Region to Characterize

Multiple Confounding Factors

Source: Wilkinson et al., 2011





By Aymatth2 - Own work derived from WWF map at [1] overlaid on file:South America satellite orthographic2.png (cropped), https://commons.wikimedia.org/w/index.php?curid=56853681

Lake Maracaibo is the "lightning capital of the world", with ~223 flashes/km^2/year

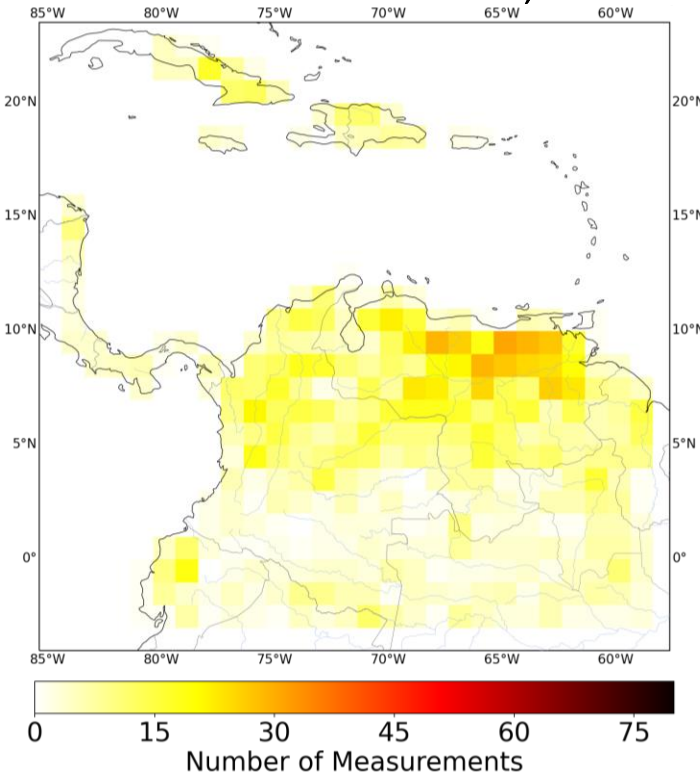
(Albrecht et al. 2016)

The surface roughness provided by the Andes mountains, the low albedo from the Amazon biome, and the persistent cloud cover all pose difficulties for obtaining reliable measurements in this part of the world

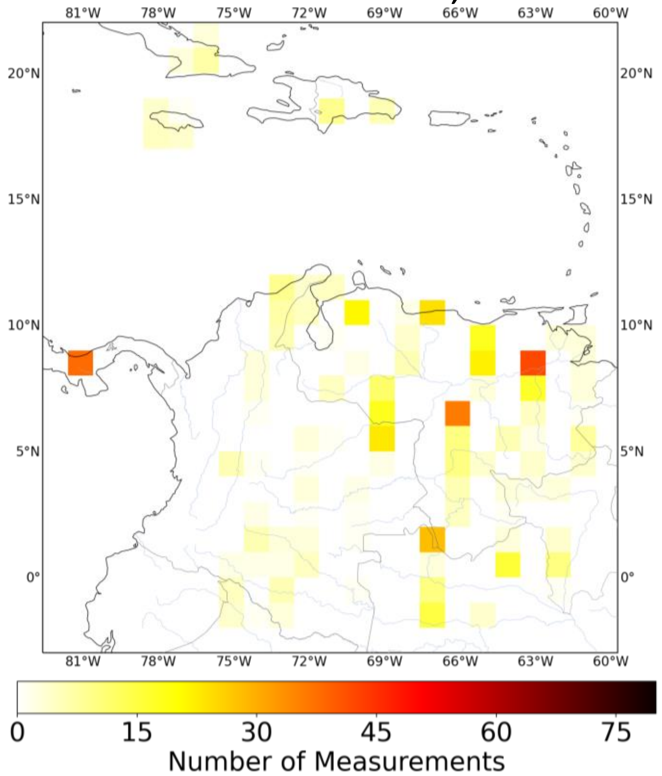
TROPOMI

TROPOMI Advantage: Increased Coverage

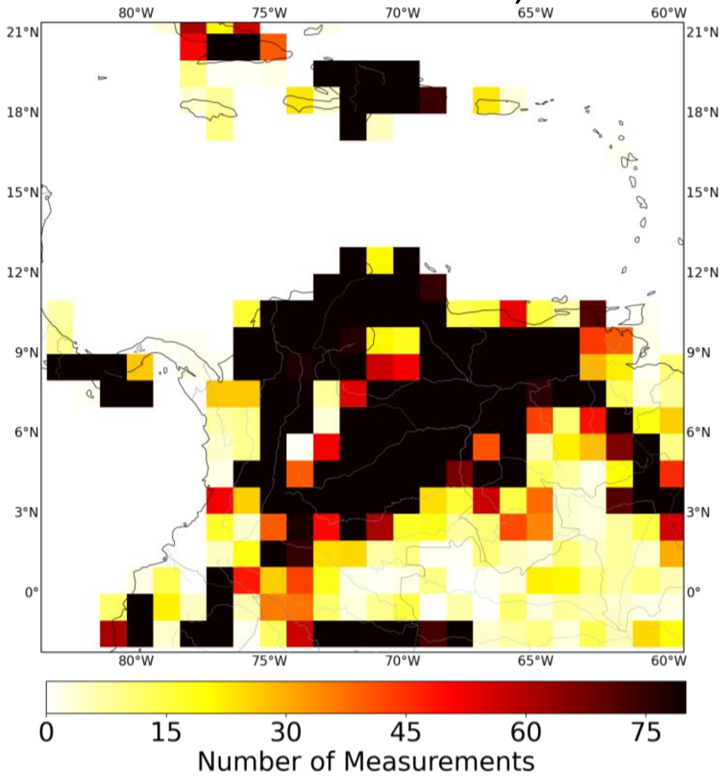
SCIAMACHY No. of Obs., 2010



GOSAT No. of Obs., 2019



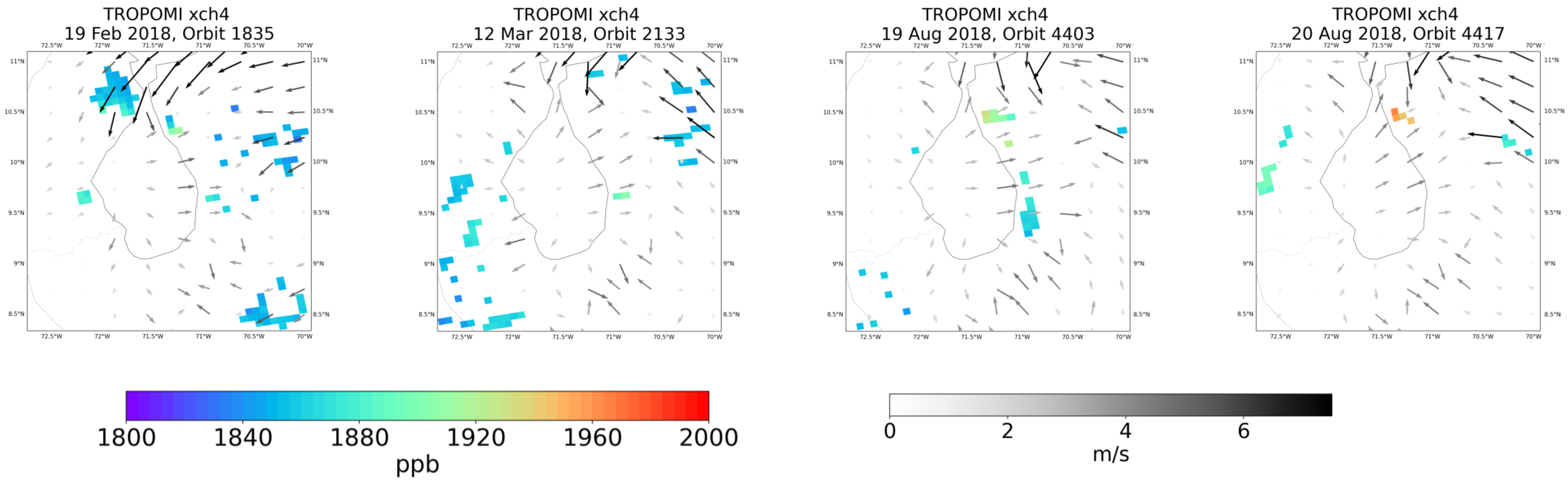
TROPOMI No. of Obs., 2019



- Comparing 1-year, 1-degree aggregated grids
- TROPOMI orbits over this region once per day
  - GOSAT –> on a 5-day repeating orbit
  - SCIAMACHY –> could achieve global coverage in 3 days
- Even with very strict filtering from TROPOMI, many more measurements are available for this region in a short amount of time

Fine Tuning the Filters

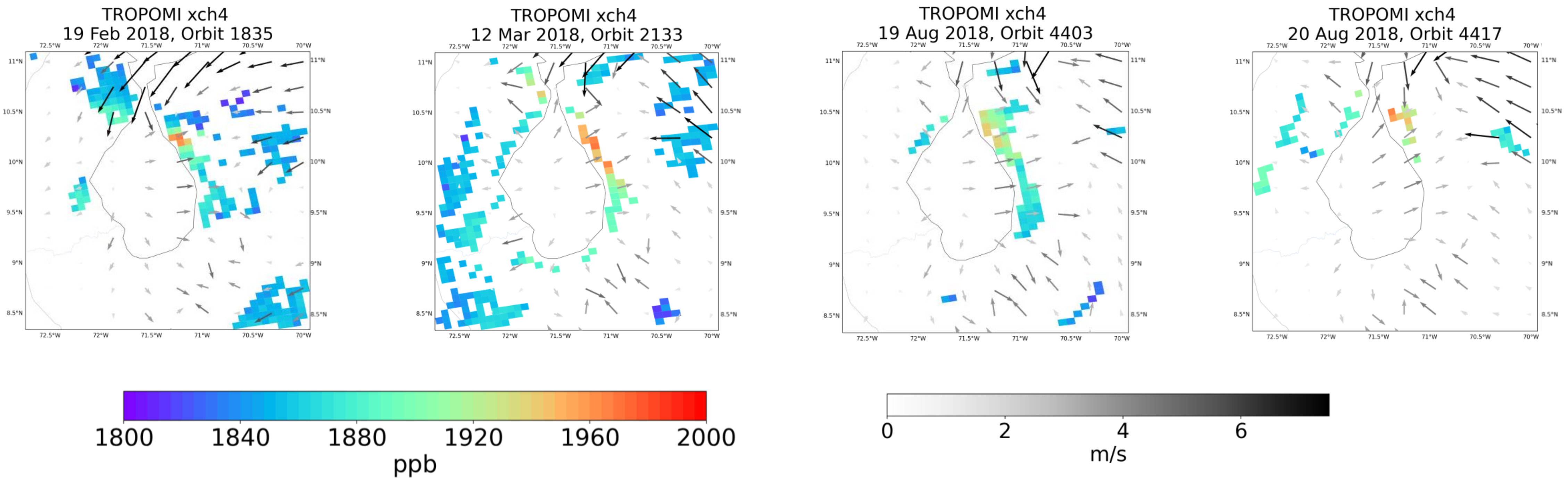
qa=1



The qa=1 filter gives the best data. In a region like this, with such persistent cloud cover, we may want to push the filtering to capture the emission plumes

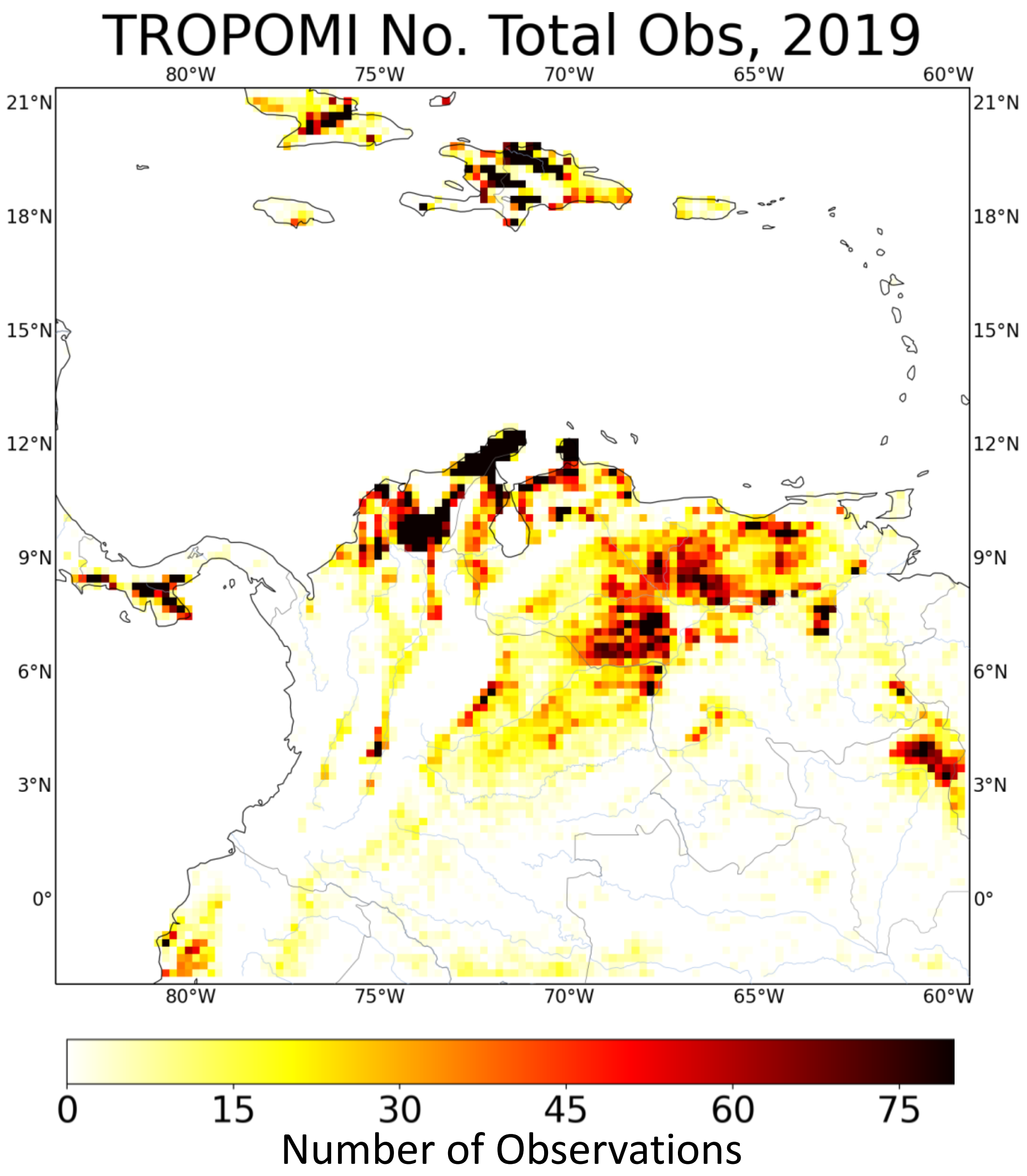
Fine Tuning the Filters

custom filter



The qa=1 filter gives the best data. In a region like this, with such persistent cloud cover, we may want to push the filtering to capture the emission plumes

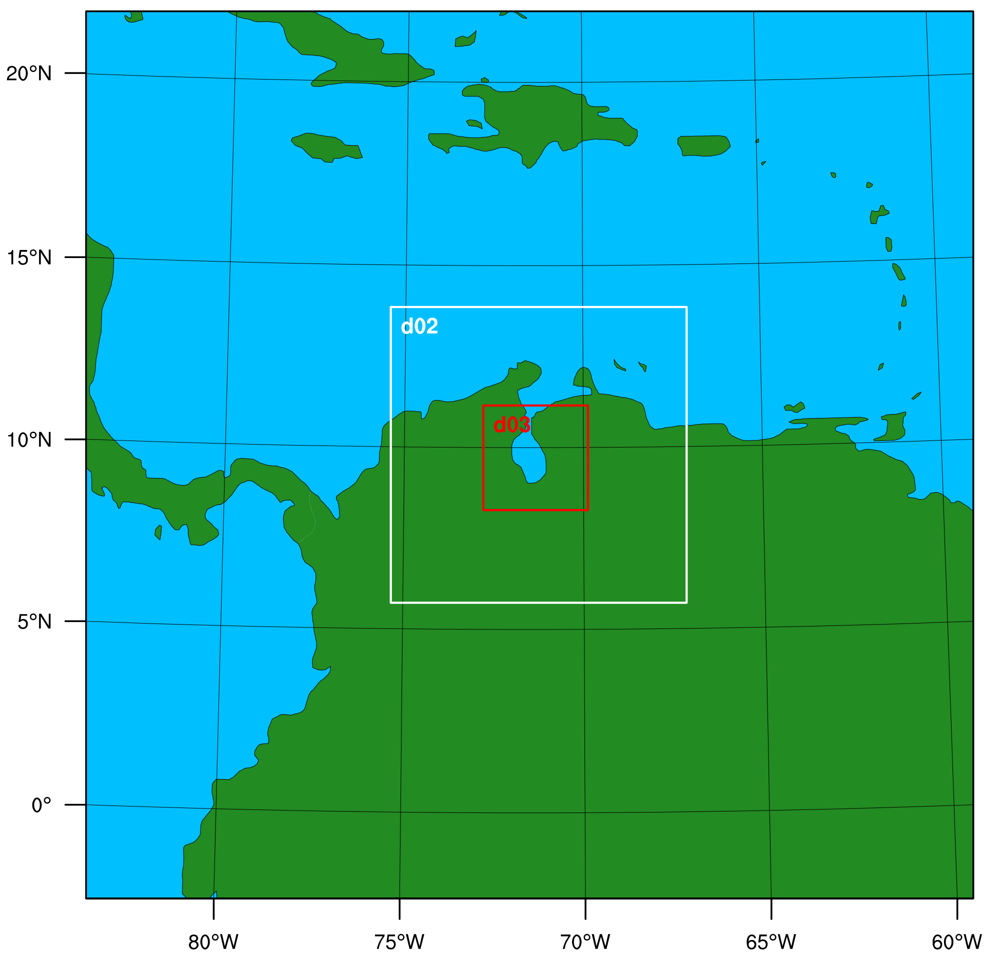
Available Data

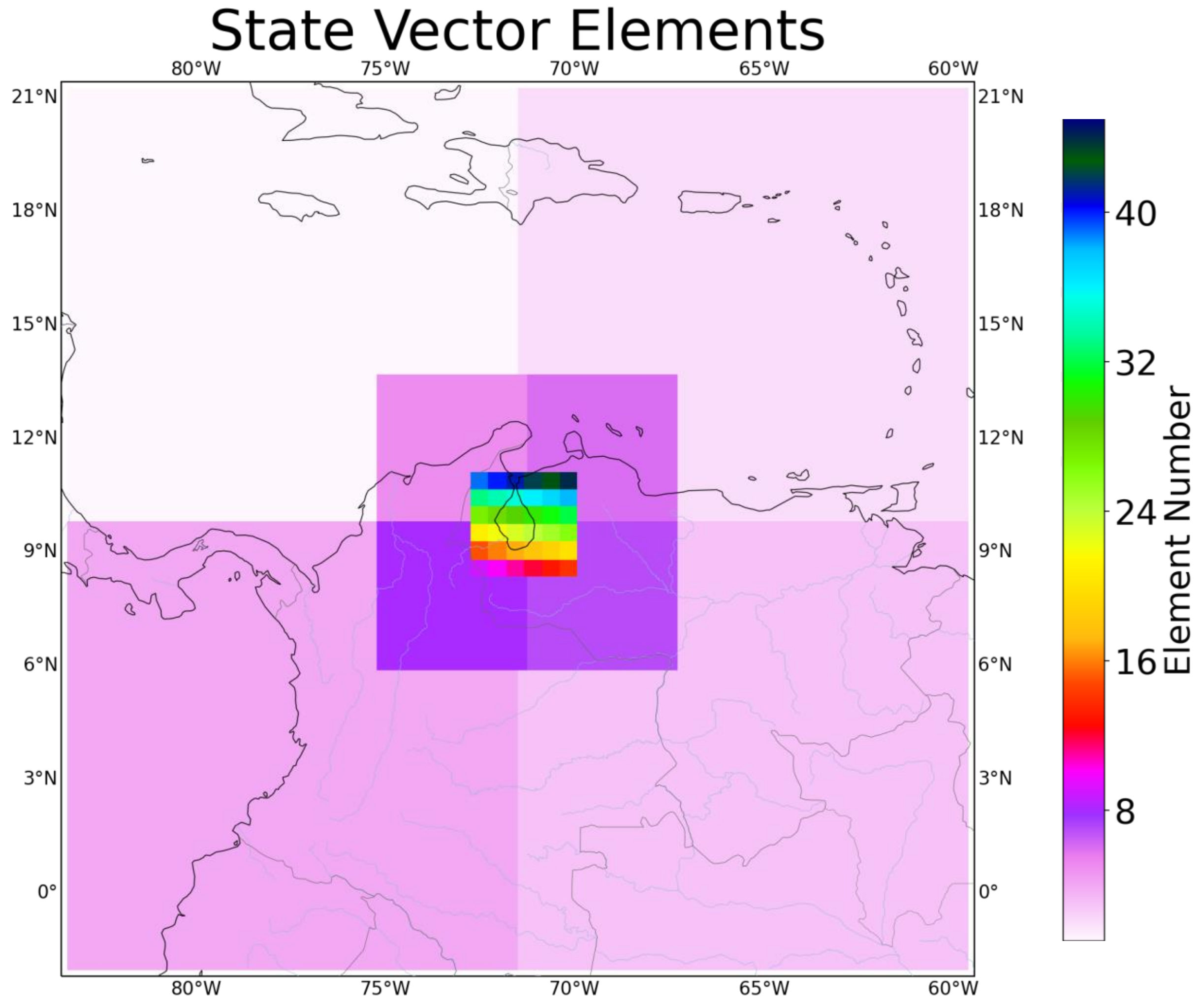


- There is good coverage in the domain now, even at a much higher-resolution aggregation
- Strike balance between being stricter over the Amazon, where low anomalies were seen, and looser over the inner domain, where there was substantial cloud filtering

Quantifying Emissions

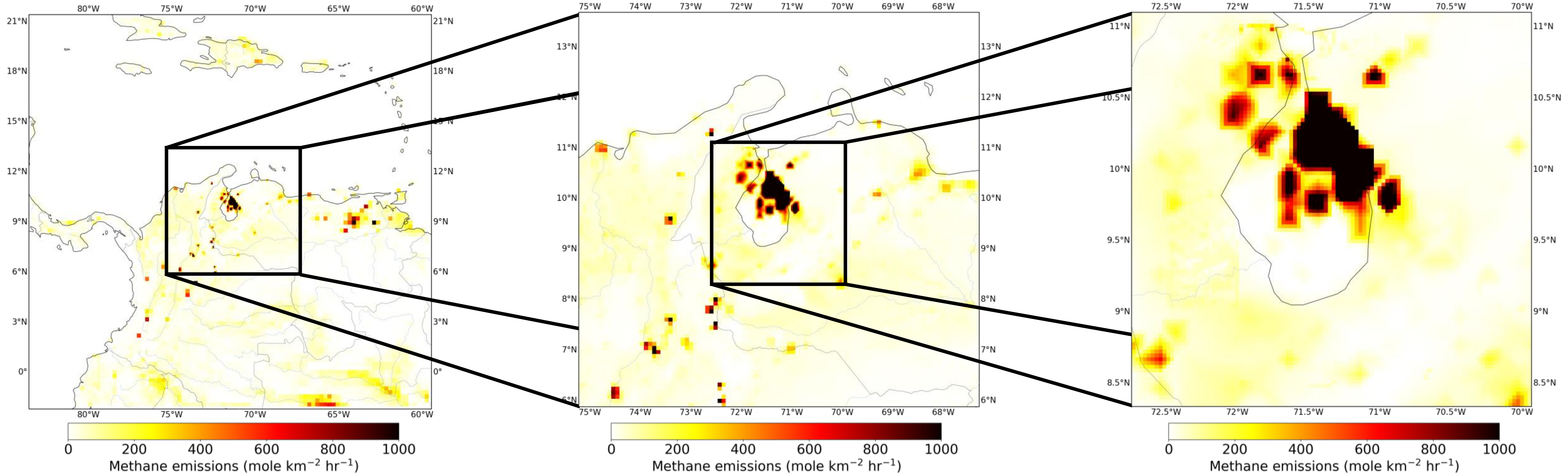
Use WRF for Transport





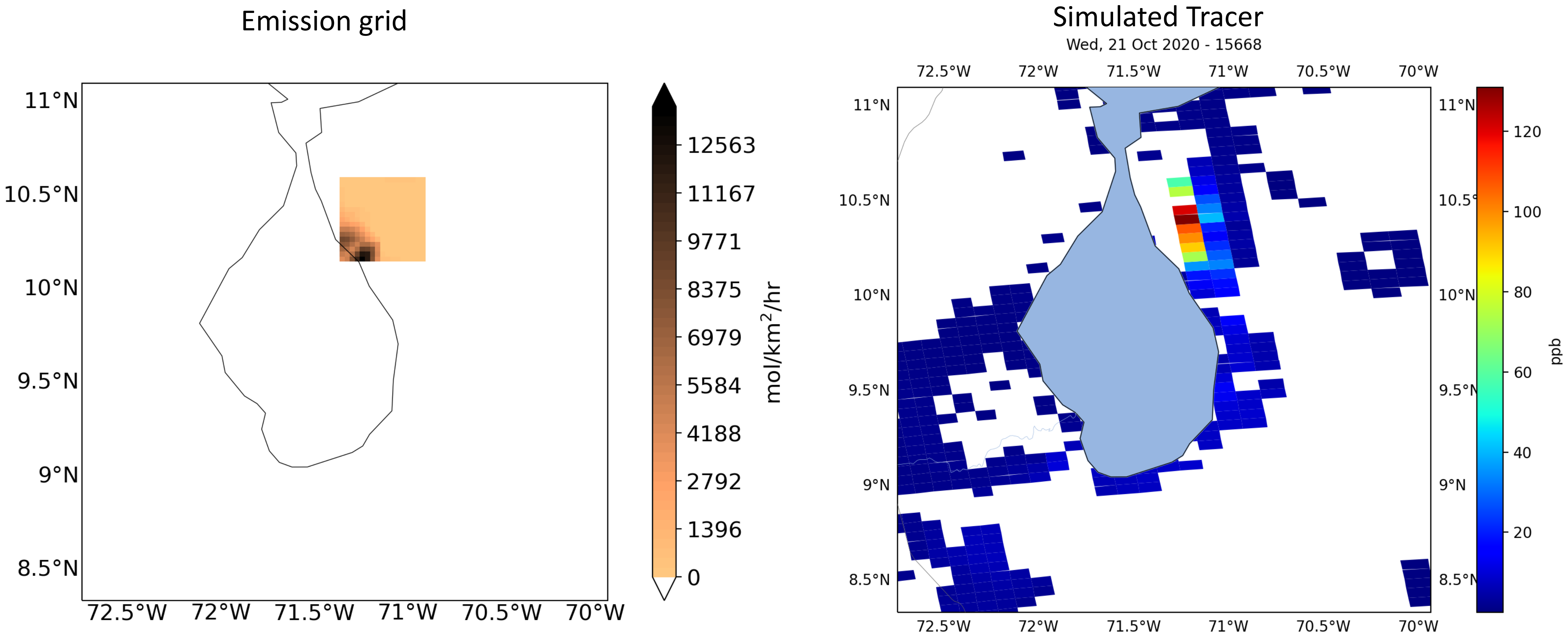
Create a state vector with some coarse buffer, then higher resolution near the domain we're interested in

Regional Emissions



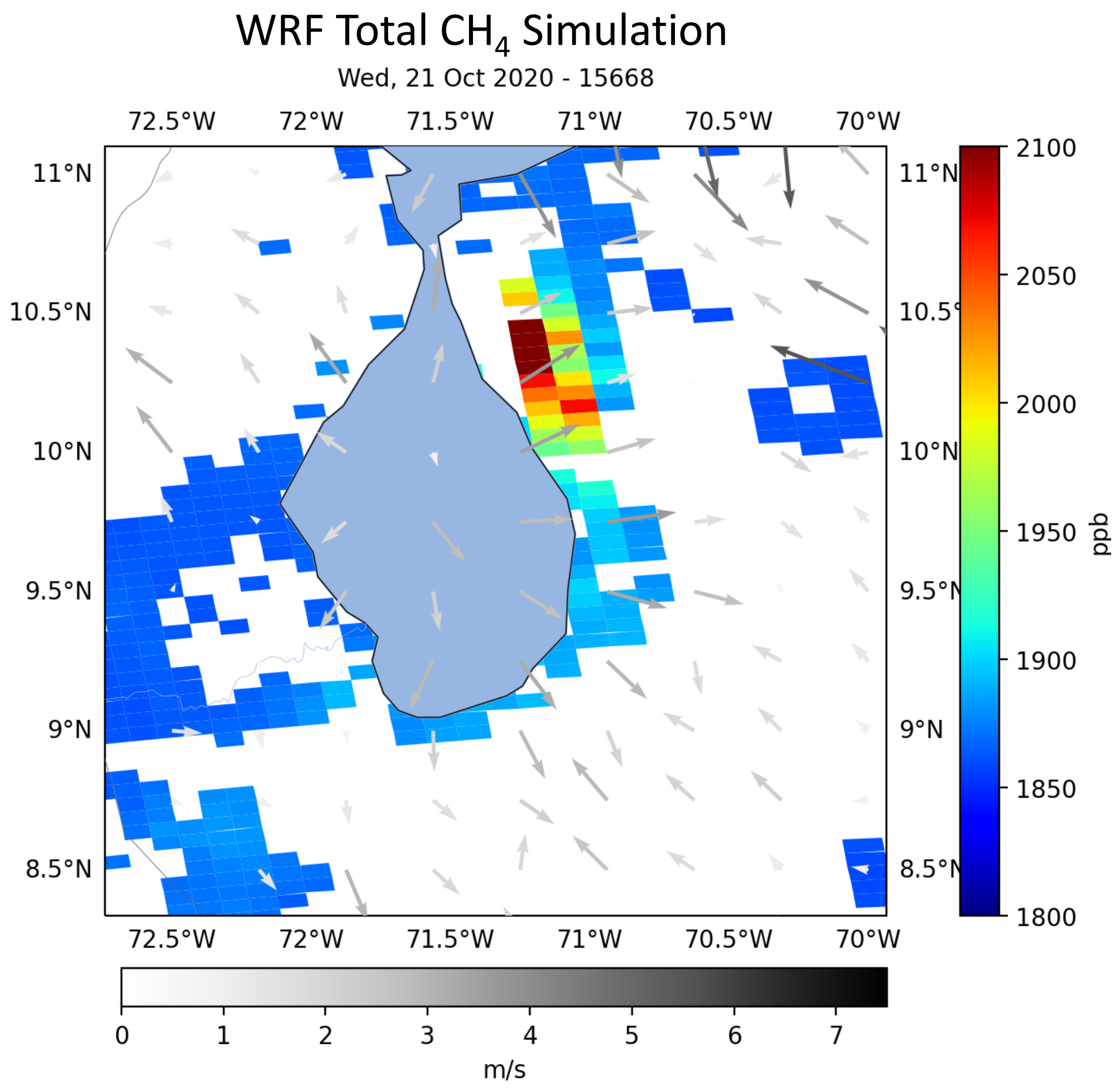
- Bottom-up estimates are particularly high around Lake Maracaibo, where enhancements had been seen by TROPOMI
- Emission field combines all available type of CH_4 emission categories:
  - GFEI (Scarpelli et al. 2019): Oil, Gas, and Coal
  - EDGAR v6 Landfills, Livestock, Waste, Rice, and Other Anthropogenic
  - Wetlands from WetCHARTs (Bloom et al 2017)

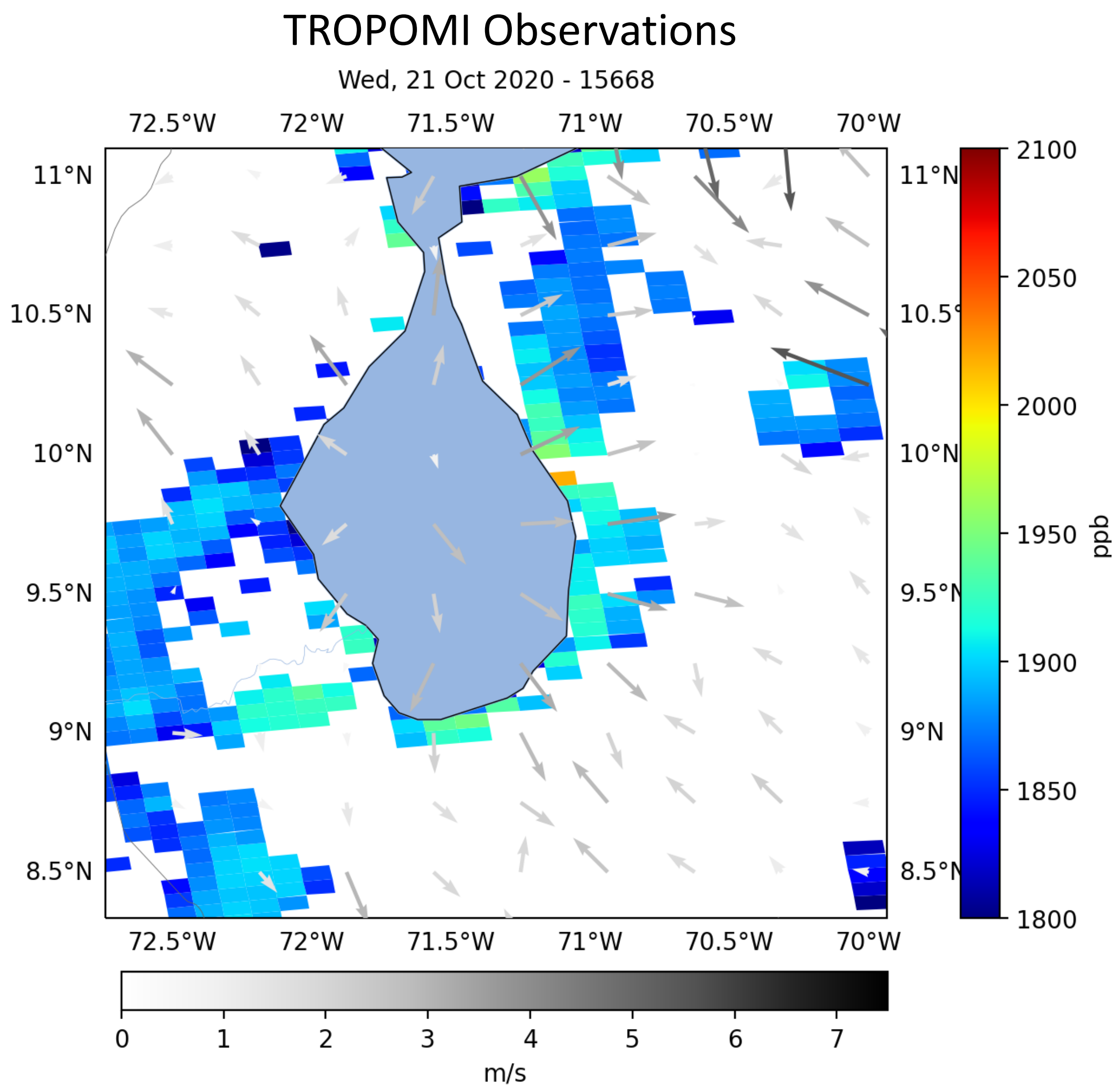
Element Sensitivity



Each state vector element is run independently, and its influence on the total enhancement can be singled out

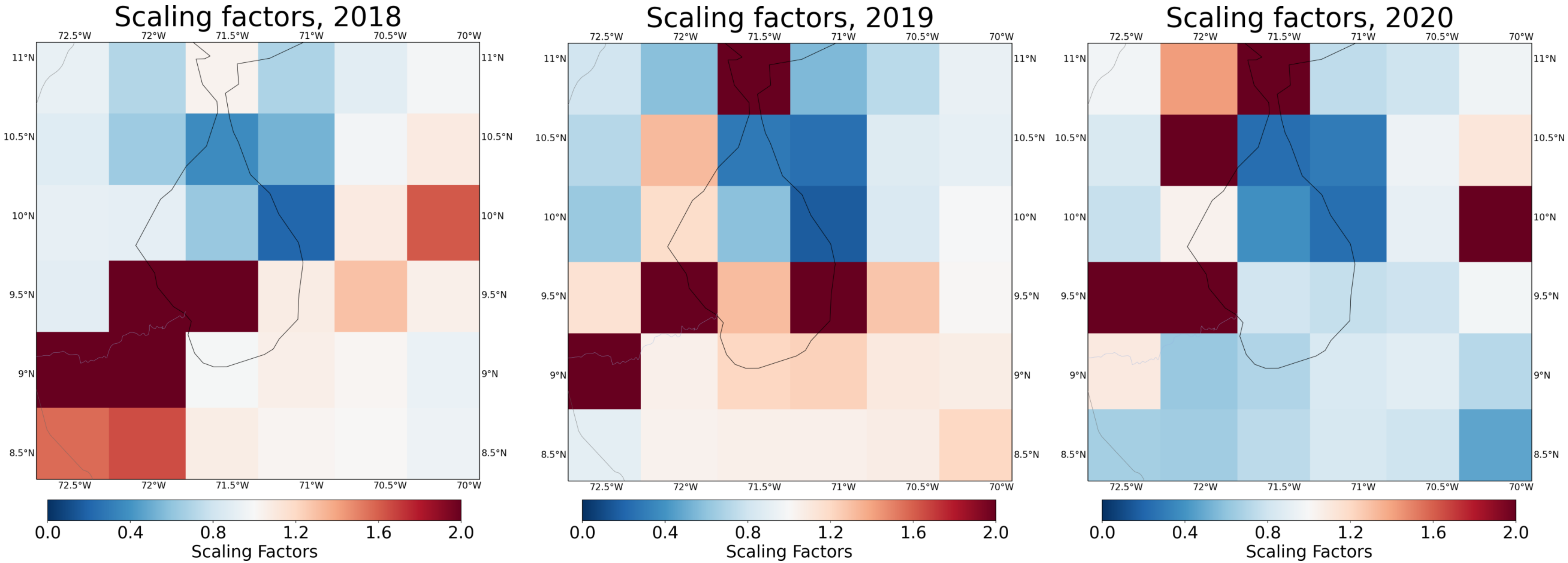
WRF vs. TROPOMI





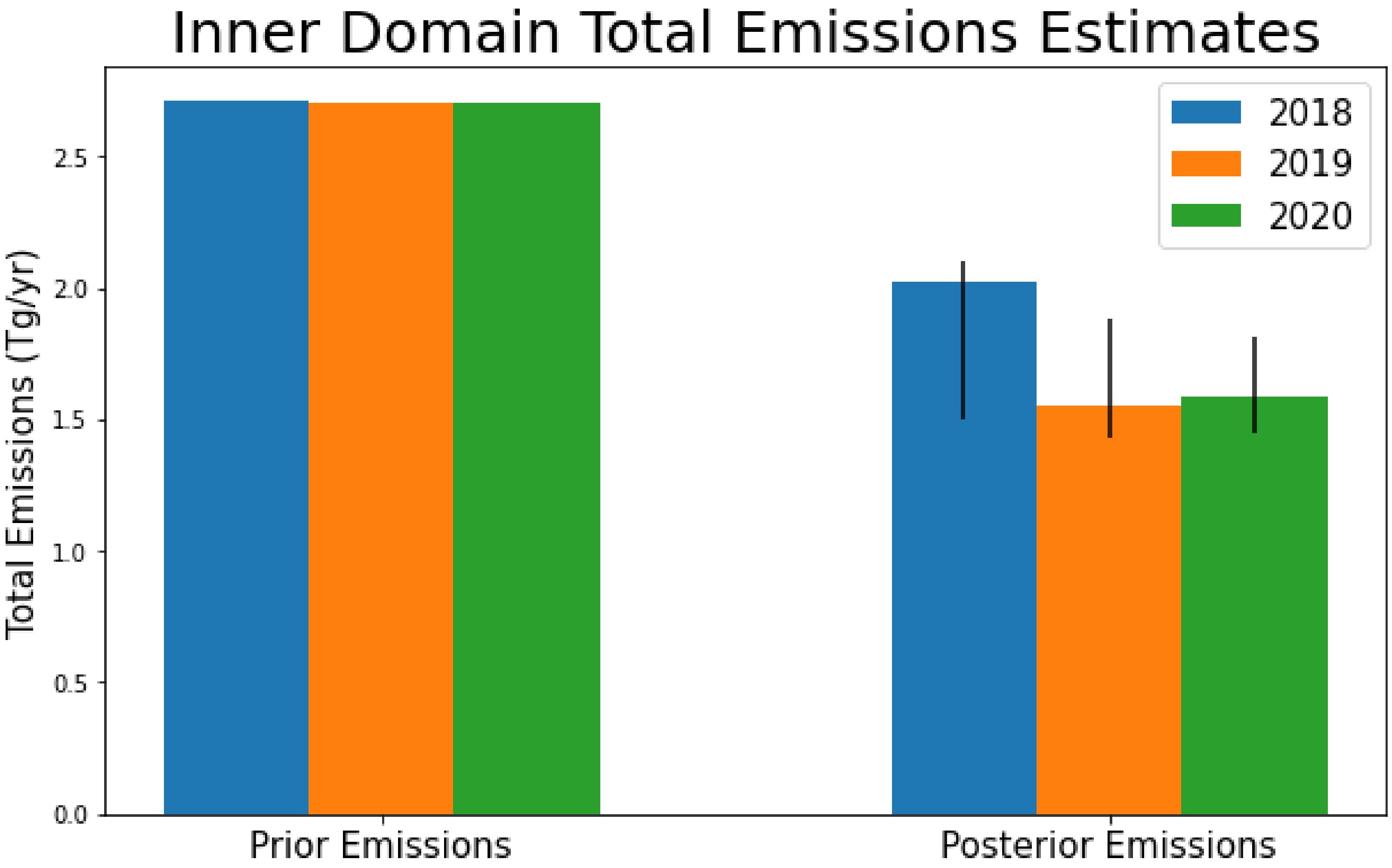
By sampling the WRF output as TROPOMI column measurements, we can do a direct comparison

Year-to-Year Results



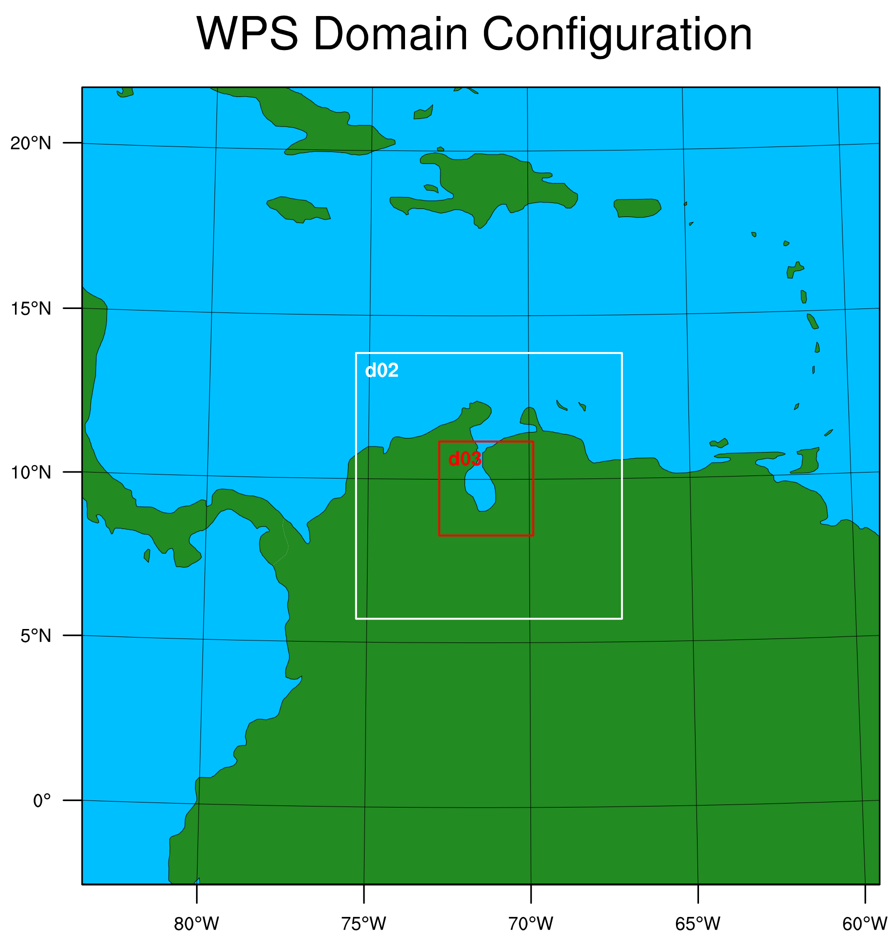
- By incorporating observations for the full year, we can further improve the robustness of the results
- We find a persistent scaling down around the portion of Lake Maracaibo with the most emissions, with respect to our prior estimate

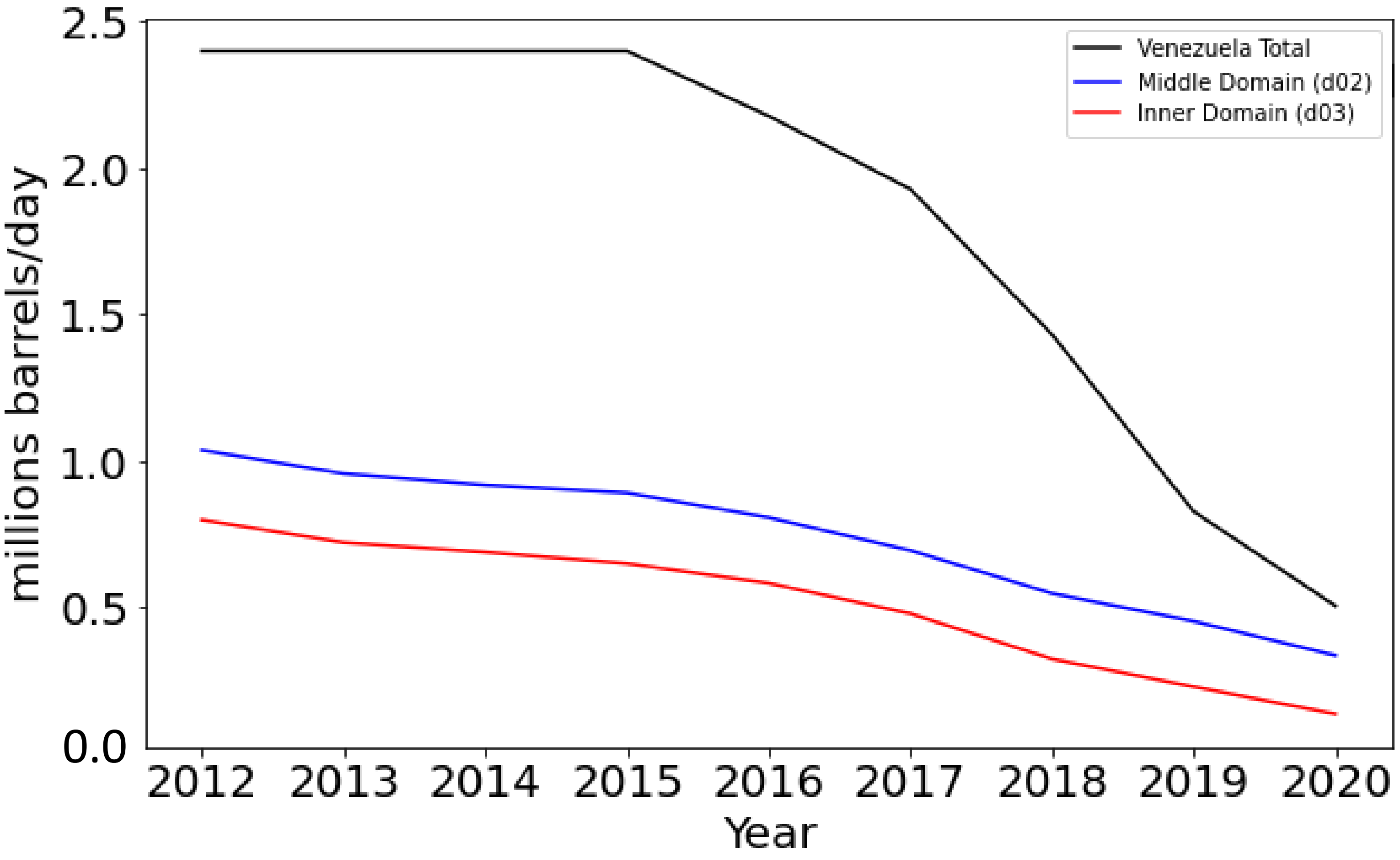
Preliminary Ensemble Posterior Estimates



- Error bars include sensitivity tests related to:
  - Included observations
  - Scaling CAMS (background) yearly vs. monthly.
  - Gaussian and log-normal errors
  - Varying prior errors
  - Varying the regularization parameter (γ)

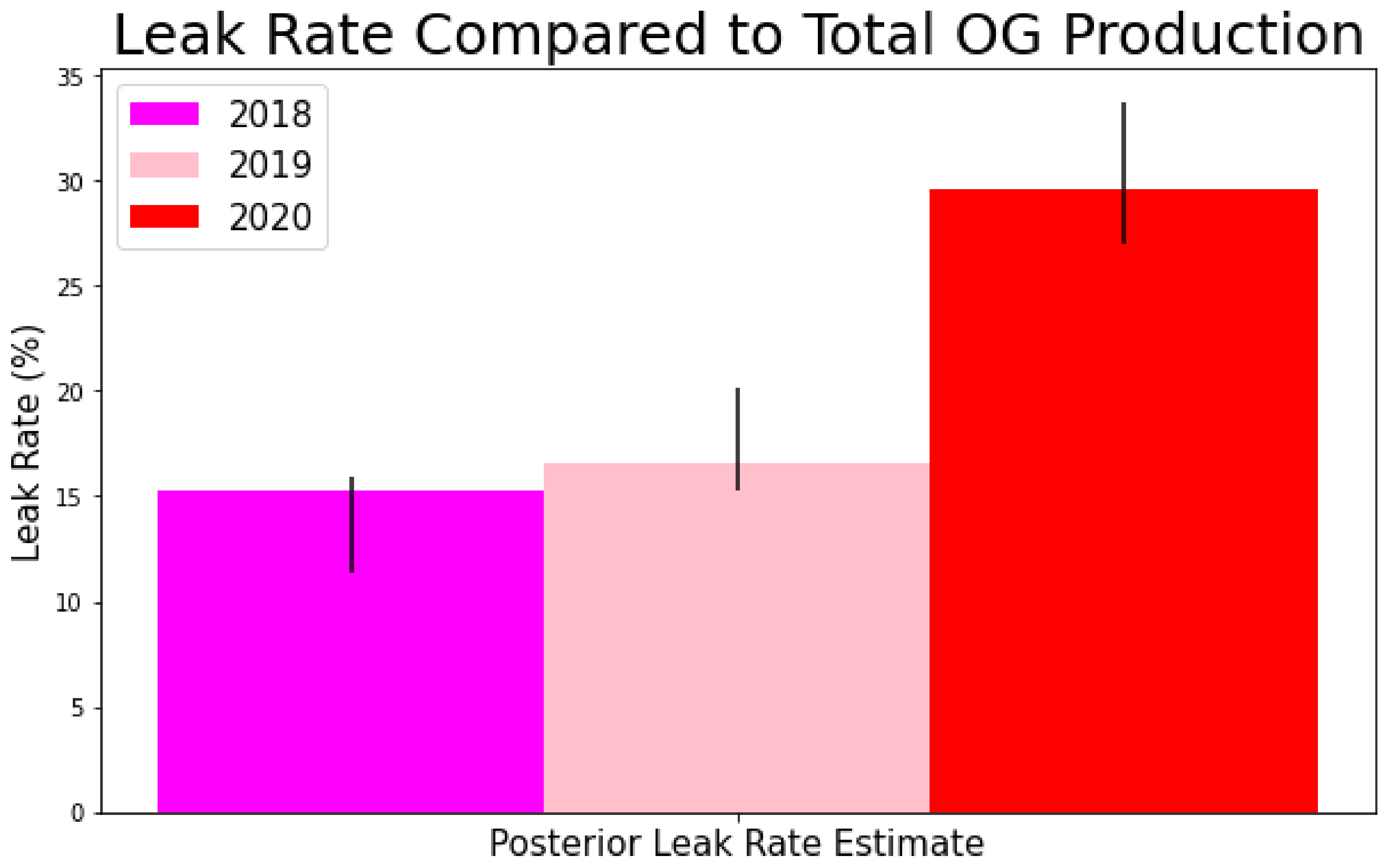
Maracaibo WRF Domain Oil Production





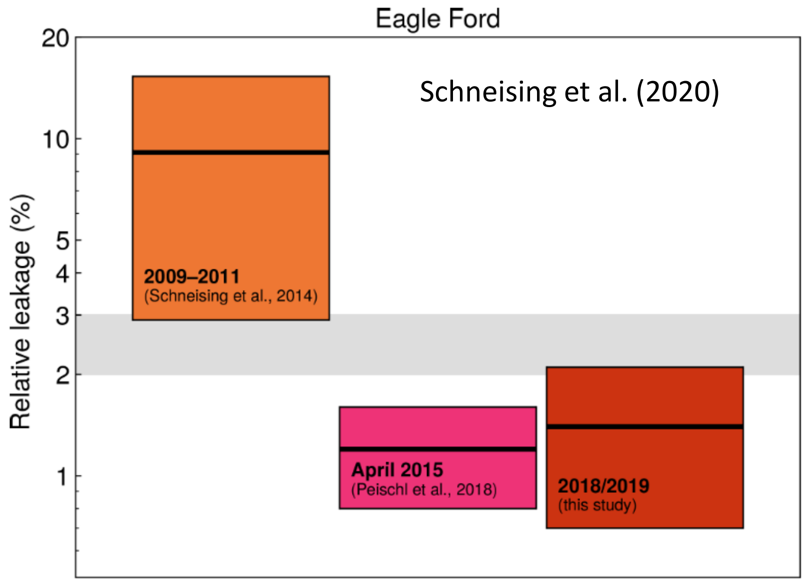
The region near Lake Maracaibo has become an increasingly large percentage of the total Venezuela Oil Production, even as production has drastically dropped off in recent years

Preliminary Leak Rate Estimates



- Leak rates calculated as energy equivalents of oil and gas production in the region (Schneising et al., 2020)
- Found to be *very high*
  - Could be consistent with reporting in recent years of large-scale leaks and pollution around Lake Maracaibo
- Consistent posterior emission numbers between 2019-2020 could indicate some large leak rate that's independent of production

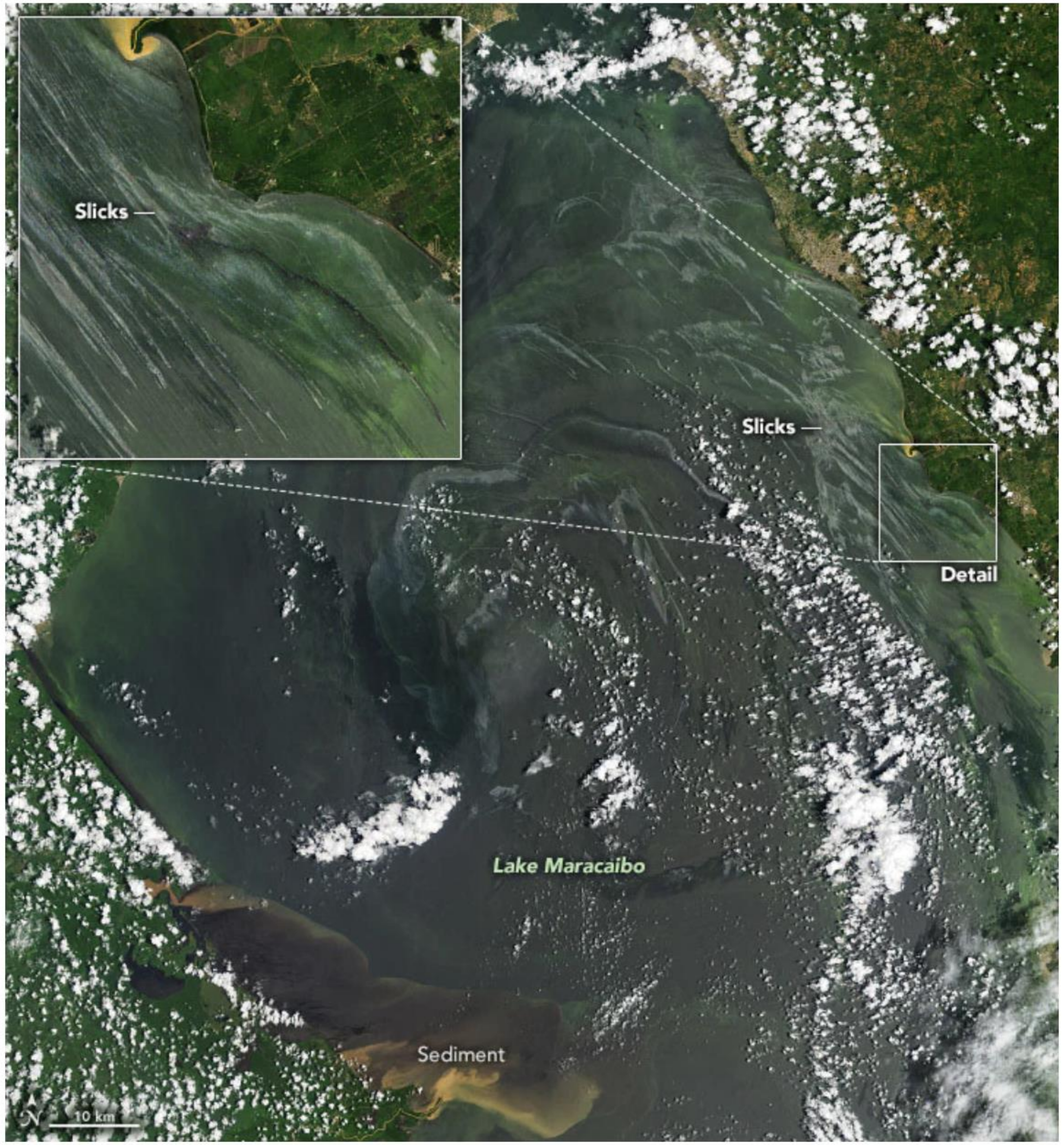
Leak Rate Context



Venezuela's broken oil industry is spewing crude into the Caribbean Sea

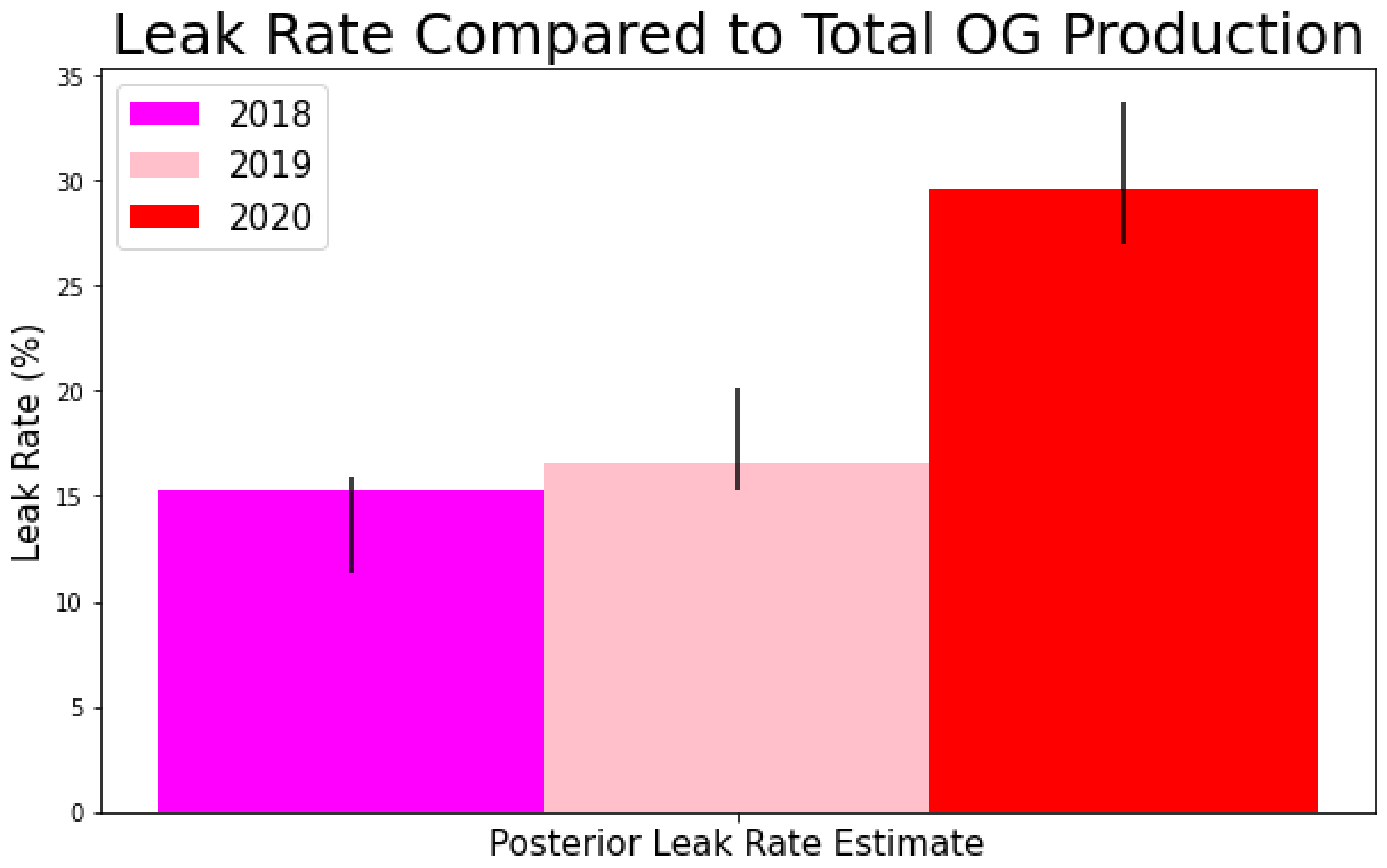
By Mariana Zúñiga and Anthony Faiola
September 24, 2020 at 6:00 a.m. EDT

In the Connecticut-size Lake Maracaibo, thousands of wells now stand broken and useless, with raw crude and natural gas bubbling visibly to the surface. In 2016, the last year data was available, state engineers estimated that tens of thousands of gallons of oil were seeping into the lake each month.



Pollution can be seen in Lake Maracaibo stemming from algae blooms and oil slicks Sept. 10. (Joshua Stevens/NASA Earth Observatory)

Preliminary Leak Rate Estimates



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Providing Country-Level Context

The Integrated Methane Inversion

Integrated Methane Inversion (IMI 1.0): a user-friendly, cloud-based facility for inferring high-resolution methane emissions from TROPOMI satellite observations

Daniel J. Varon[1], Daniel J. Jacob[1], Melissa Sulprizio[1], Lucas A. Estrada[1], William B. Downs[1], Lu Shen[2], Sarah E. Hancock[1], Hannah Nesser[1], Zhen Qu[1], Elise Penn[1], Zichong Chen[1], Xiao Lu[3], Alba Lorente[4], Ashutosh Tewari[5], and Cynthia A. Randles[5]

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[2]Department of Atmospheric and Oceanic Sciences, School of Physics, Peking University, Beijing, China
[3]School of Atmospheric Sciences, Sun Yat-sen University, Guangzhou, China
[4]SRON Netherlands Institute for Space Research, Leiden, the Netherlands
[5]ExxonMobil Technology and Engineering Company, Annandale, New Jersey, USA

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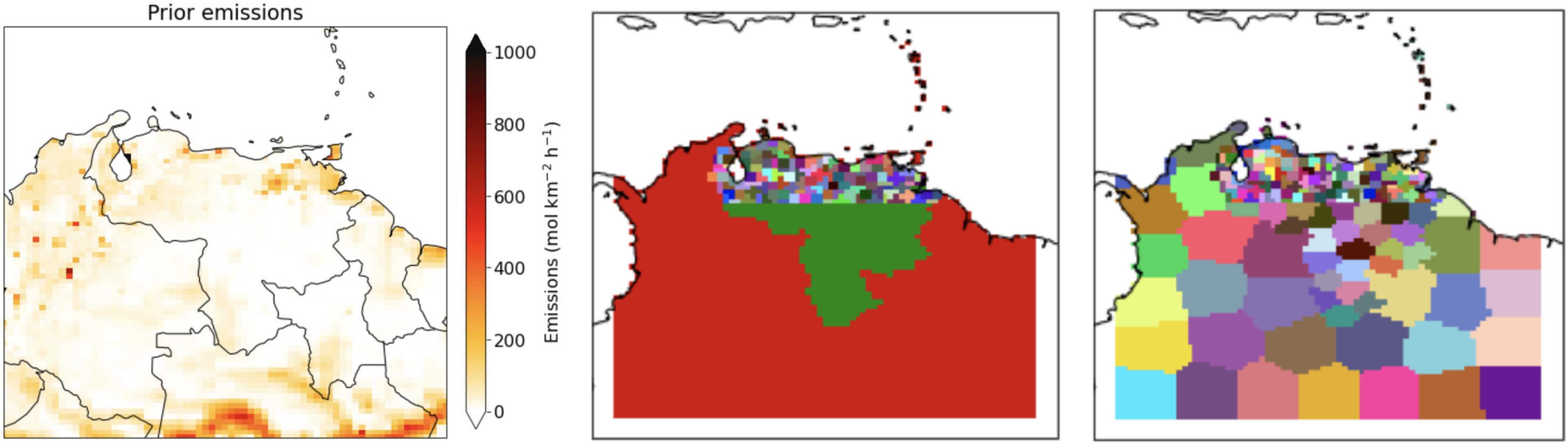
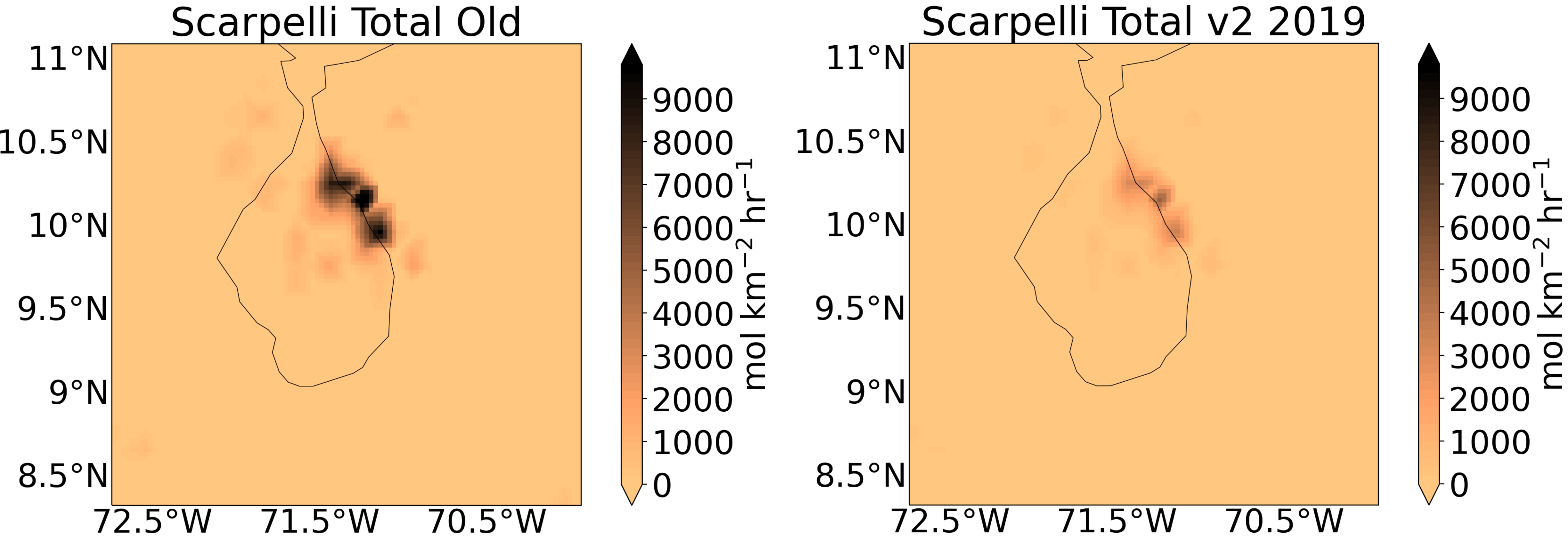
The IMI allows us to calculate inversions with GEOS-Chem simulations, using a set framework that includes TROPOMI measurements

IMI: Custom state vector



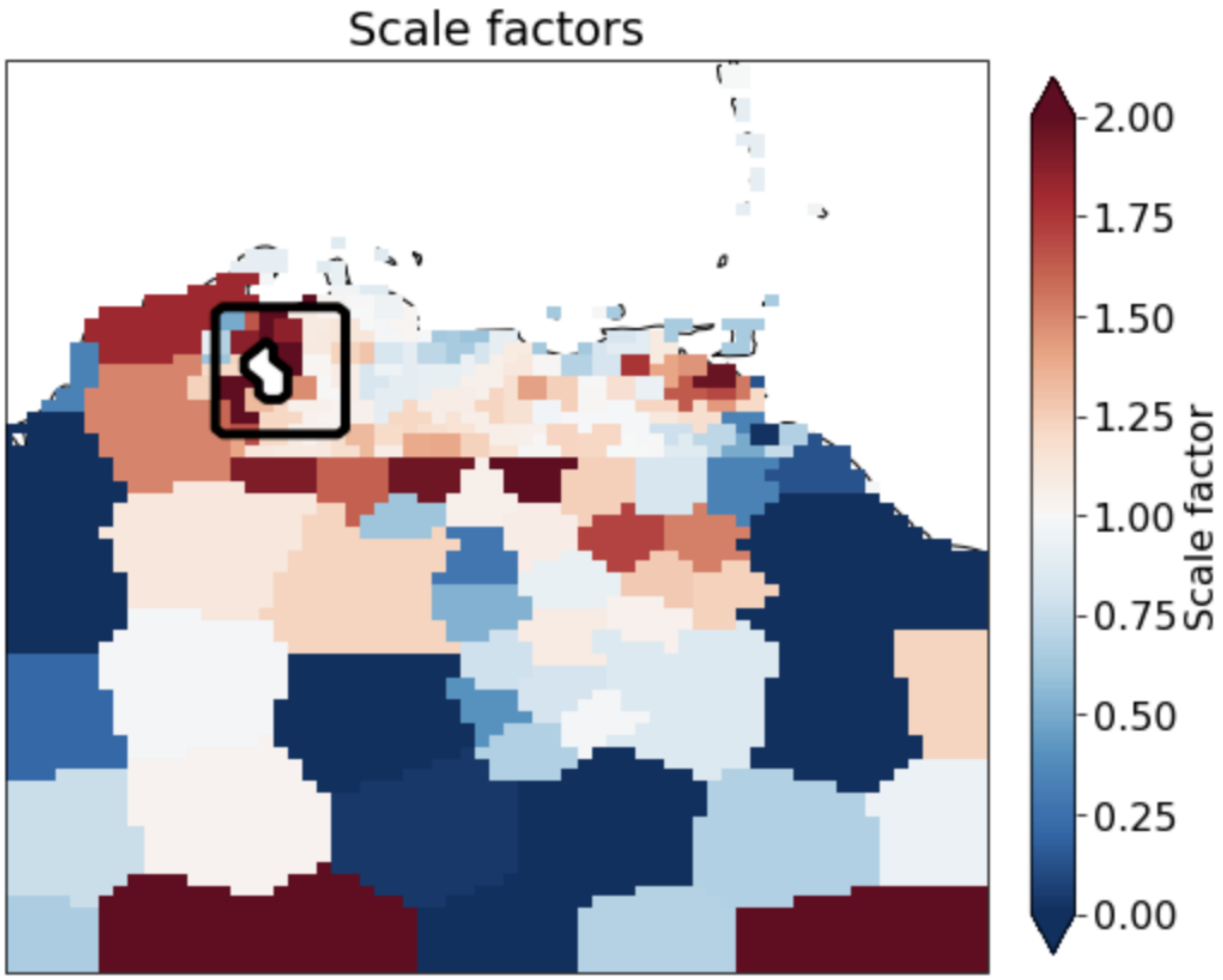
- Want enough elements to characterize high-emission areas without too much CPU cost
  - Use kmeans clustering
  - Divide Venezuela into “North” and “South”, to target clustering to be finer where most of the emissions are
  - Include “buffer” elements for characterizing emissions outside of Venezuela, as well

Important Prior Difference: Scarpelli Update



There was a rather large change in the Scarpelli O&G emissions in this region between the "old" version (2012-scaled) and the 2019 version, following known production patterns

2019 Venezuela Inversion



- **Initial** IMI results following several adjustments to inverse system for the region:
  - Incorporating same observations used in WRF analysis
  - Varying background corrections
- Despite differences (prior, transport model, spatial resolution), there may be agreement between the 2 approaches
  - Further testing needs to be done with the IMI!

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