Using Machine Learning to Identify Air Pollution Plumes from EO Data

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Introduction

- Emission inventories can be temporally and geographically crude.
- Satellites can provide information about atmospheric concentrations more quickly than emission inventories are updated
- Can we develop machine learning models to identify pollution plumes, therefore informing us about emissions on a near real time basis?

Objective

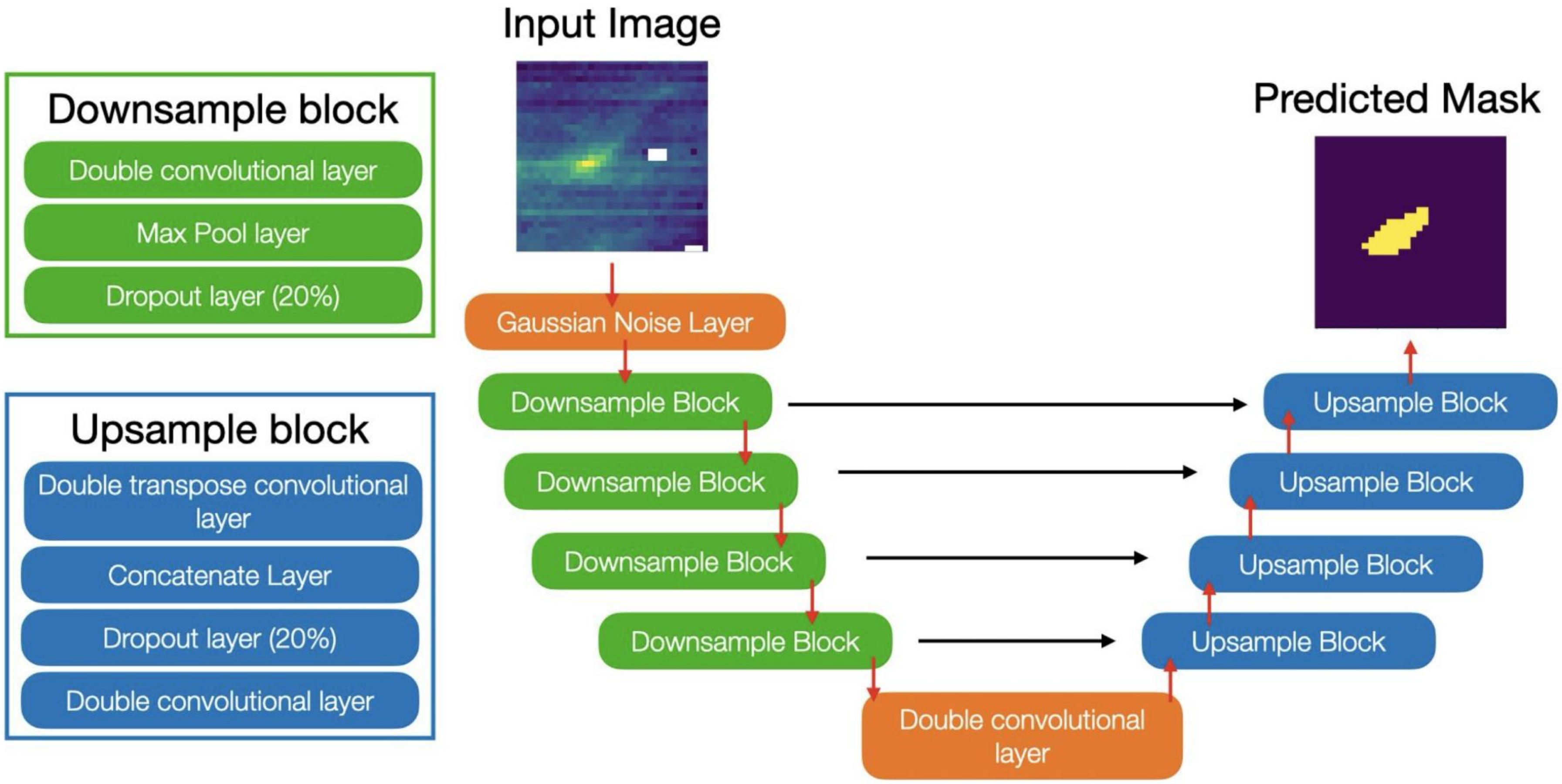
- Develop a database containing plume information for SO_2, NO_2 and CH_4

Data Use

- We use TROPOMI level 2 data to develop three machine learning models (for SO_2, NO_2 & CH_4).
- NO_2 & SO_2 products have a spatial resolution of 3.5 x 5.5 km. CH_4 has a resolution of 5.5 x 7.5 km.
- Near global coverage on a daily basis.
- TROPOMI swath is split into 32 x 32-pixel images
- Each image has the standard TROPOMI QA applied and is normalized.

Developing Plume Detection Models

- All three models are U-Net style with similar architecture
- Allows the model to detect patterns in the image and build a plume mask the same shape as the input image
- The entire TROPOMI swath is rebuilt by merging the predicted masks



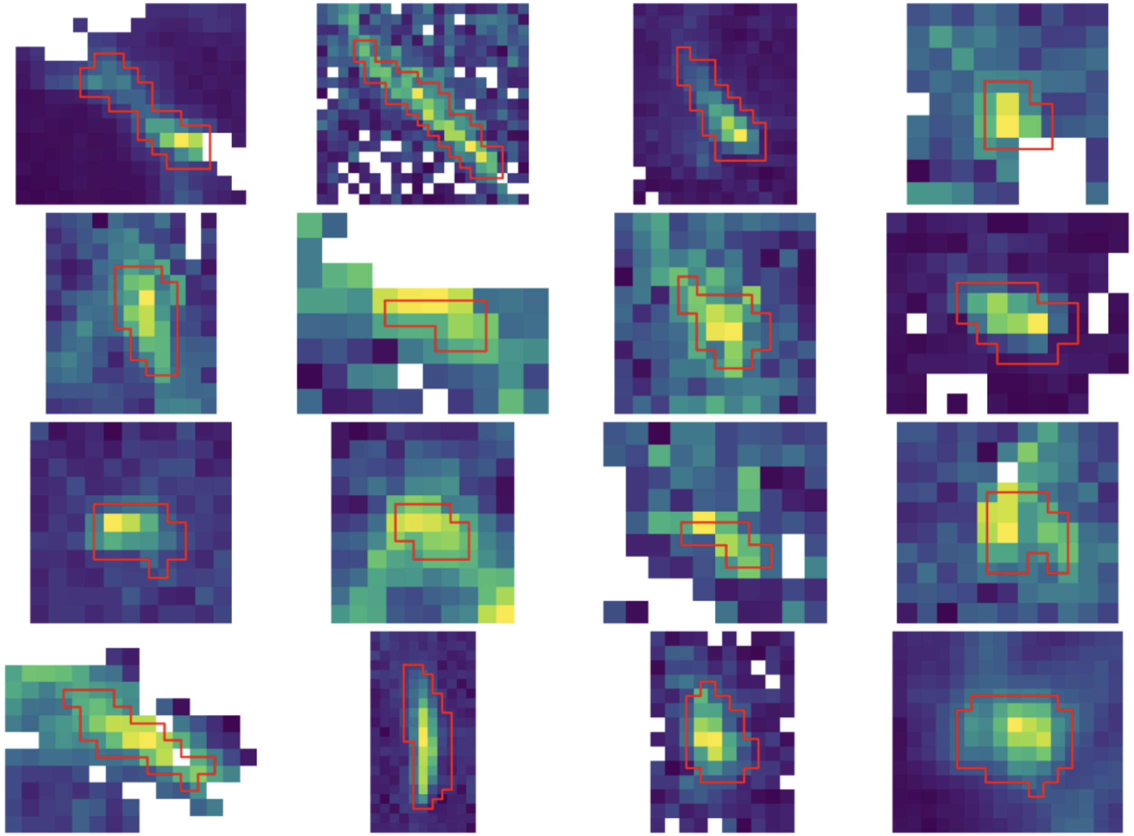
Model Output

- We store plume location, time, predicted boundary, species concentration and wind data (among other metrics)
- Plumes can be nearly any shape or size (some filters applied)
- Ran the detection model from May 2018 – July 2023

Species	Number of Plumes
SO_2	67,317
CH_4	8,057
NO_2	116,743*

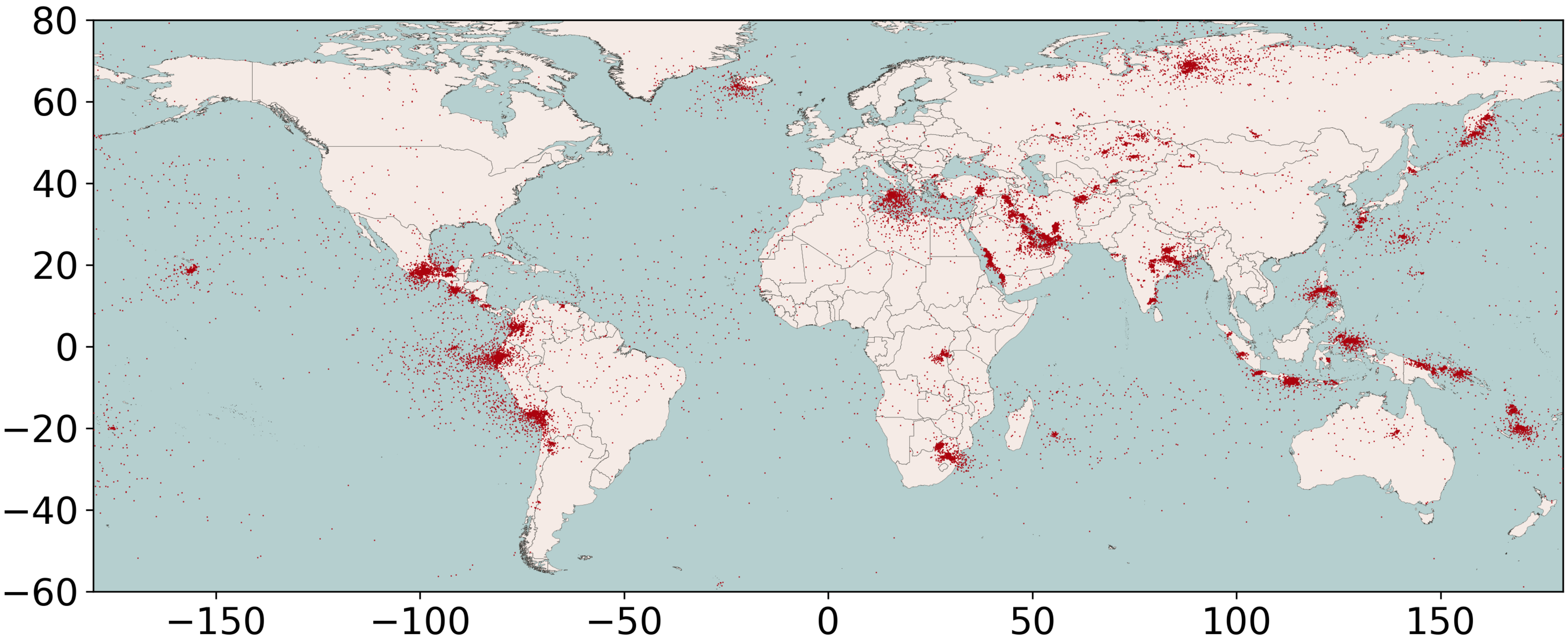
(*Only 2021)

Example plumes and masks



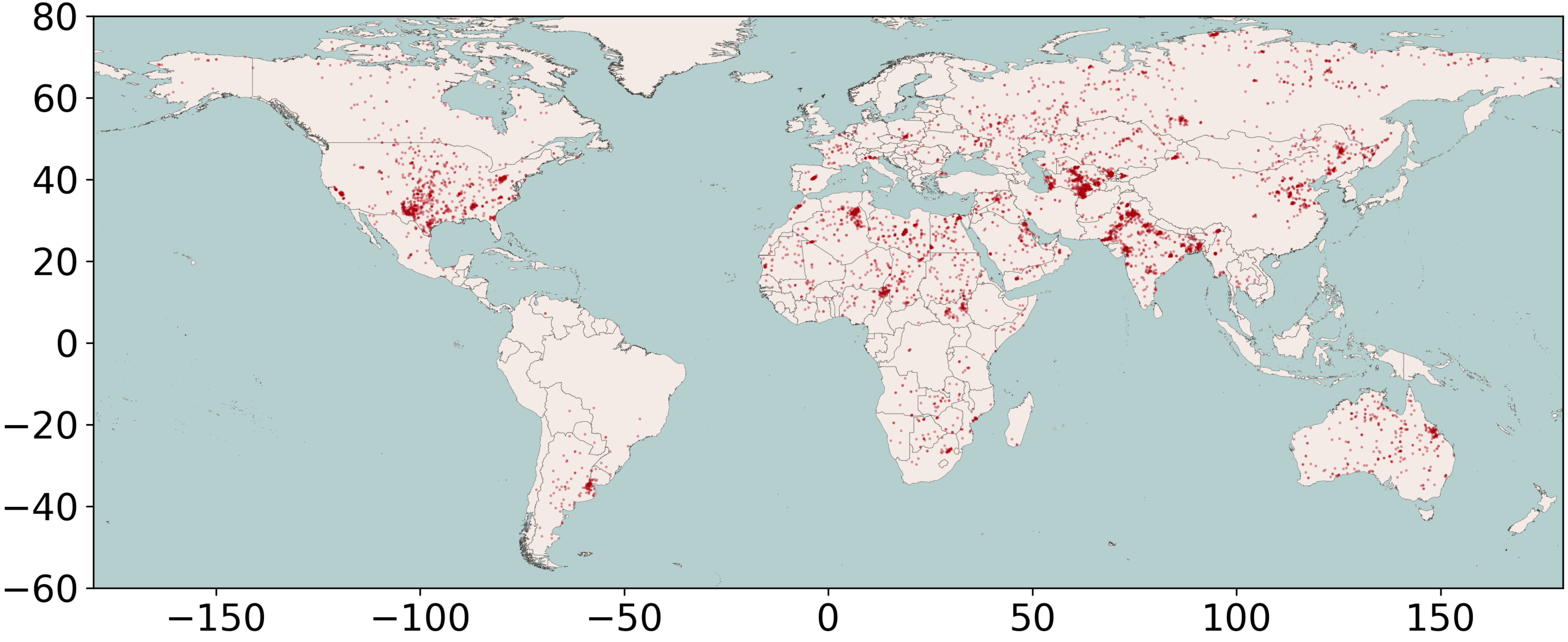
SO_2 Global Map

Precision: 0.81 Recall: 0.79



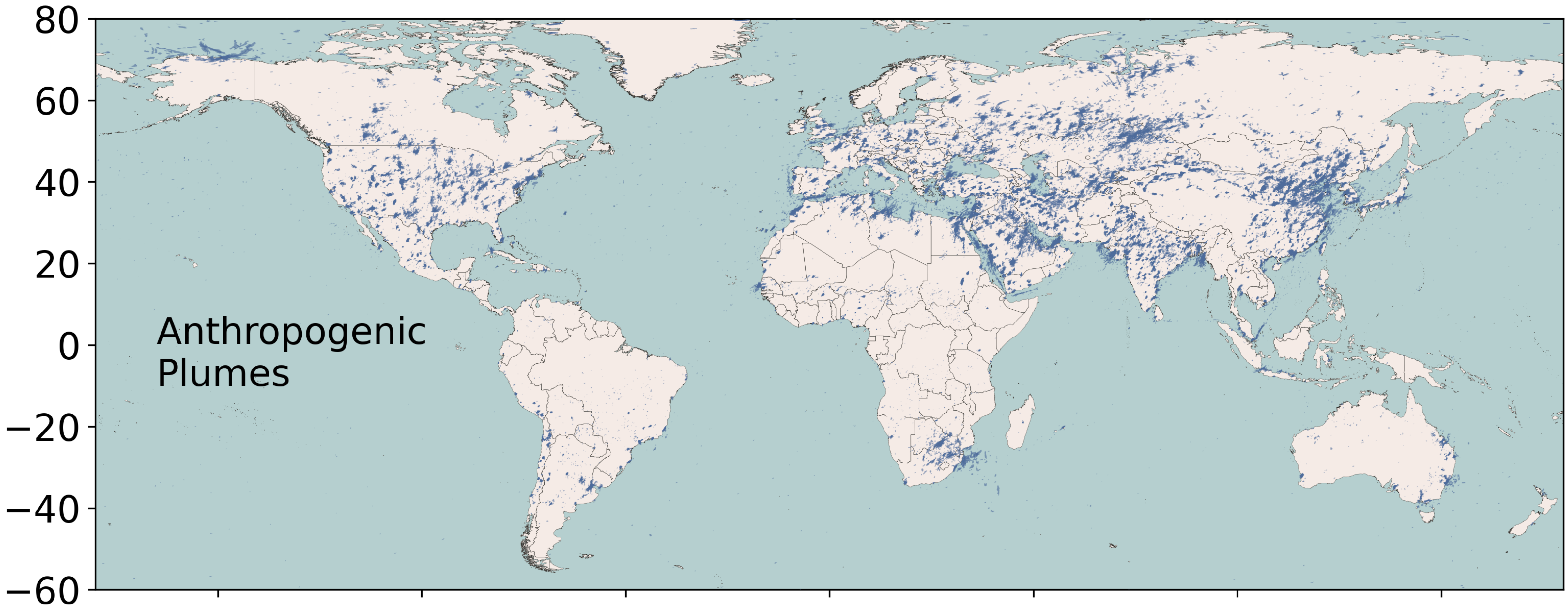
CH_4 Global Map

Precision: 0.74 Recall: 0.74

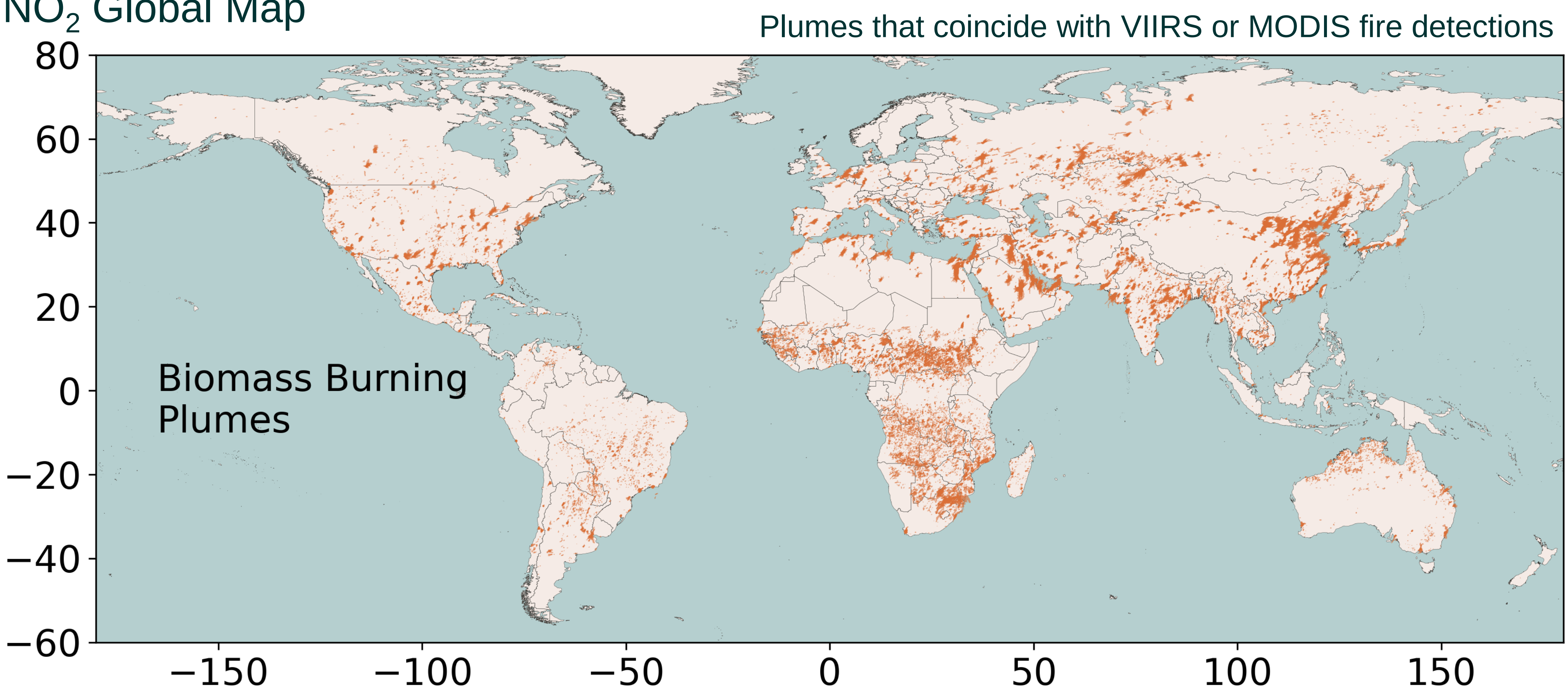


NO_2 Global Map

Precision: 0.77 Recall: 0.75



NO_2 Global Map

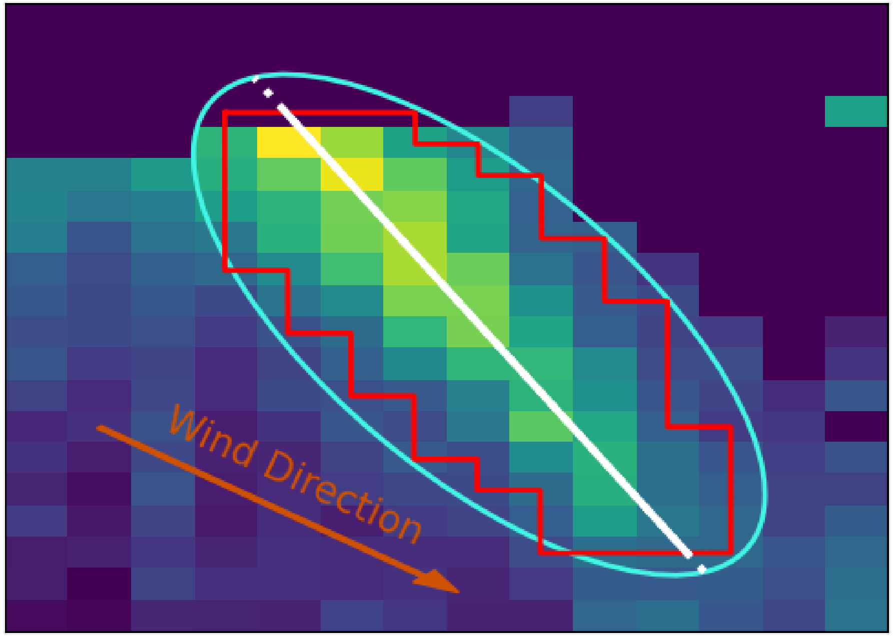


Estimating Emission Rates

- We can estimate an emission rate associated with each plume based on the predicted boundary and wind data
- Wind data used is 10 m U & V wind fields from ECMWF (included in the TROPOMI files)

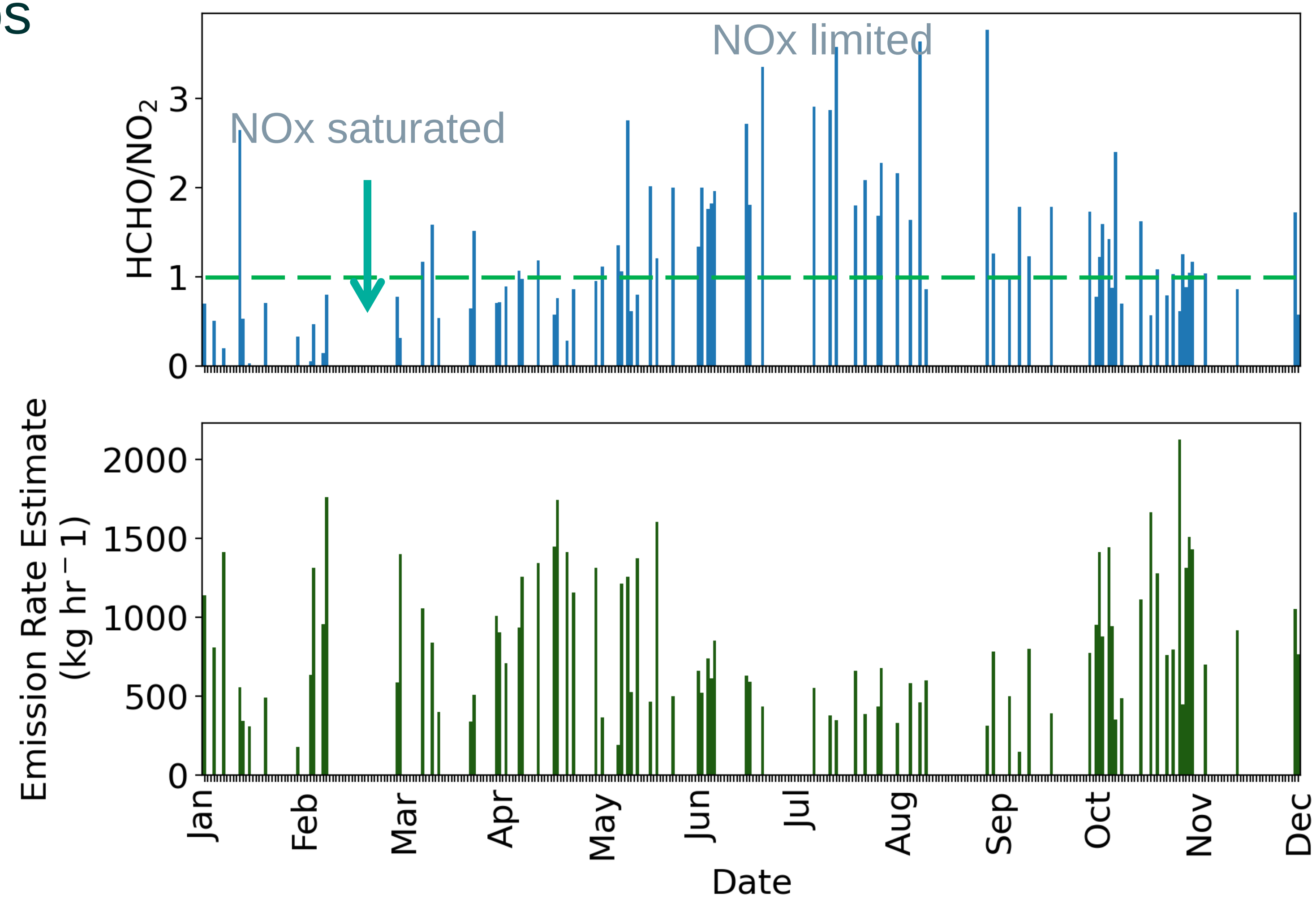
1. Find area of each pixel
2. Calculate mass of species per pixel
3. Subtract background from plume mass
4. Fit an ellipse around the boundary
5. Find length of ellipse longest axis
6. Get windspeed within the plume

Emission rate = mass x windspeed x plume length

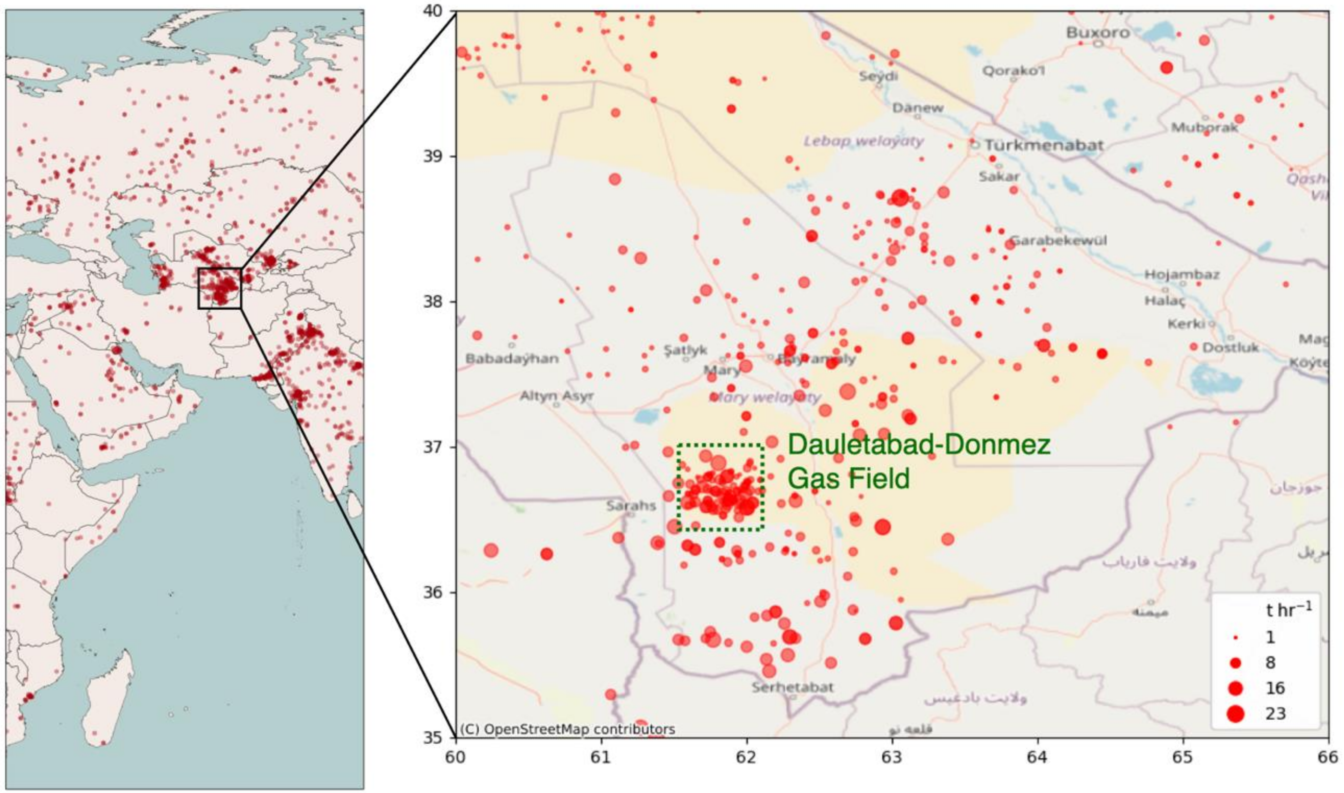


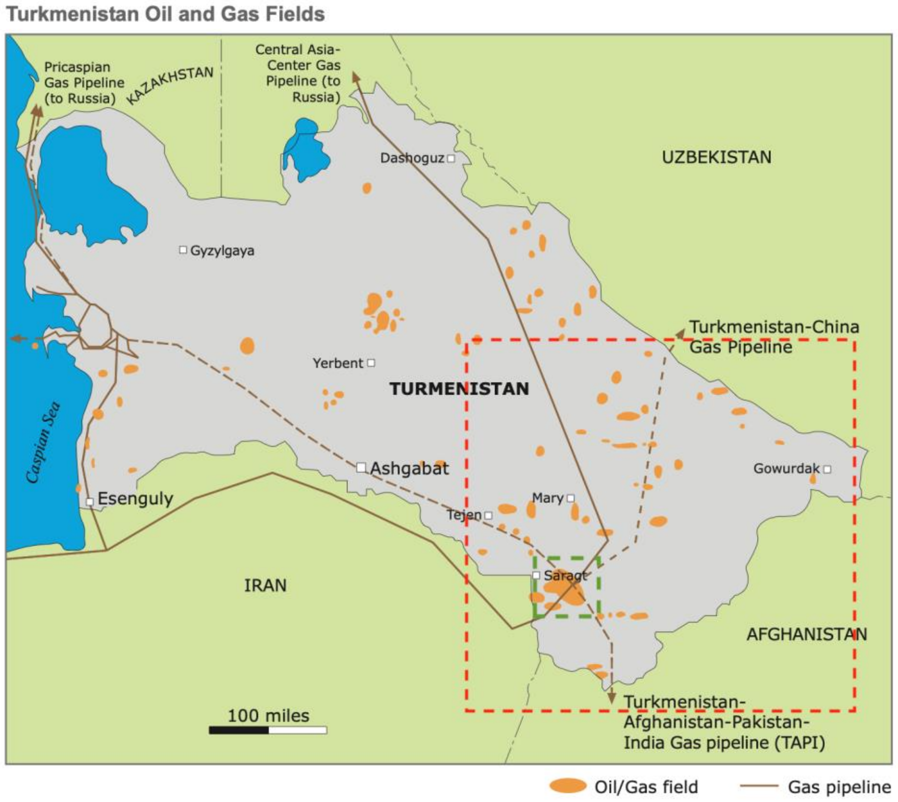
Case Study – HCHO:NO_2 Ratios

- HCHO:NO_2 ratio can tell us about the photochemical environment
- HCHO values can be extracted from plume locations
- 86 plumes over Alexandria, Egypt – large port
- The larger the emission rates (possibly more shipping emissions?) increases the HCHO:NO_2 ratio



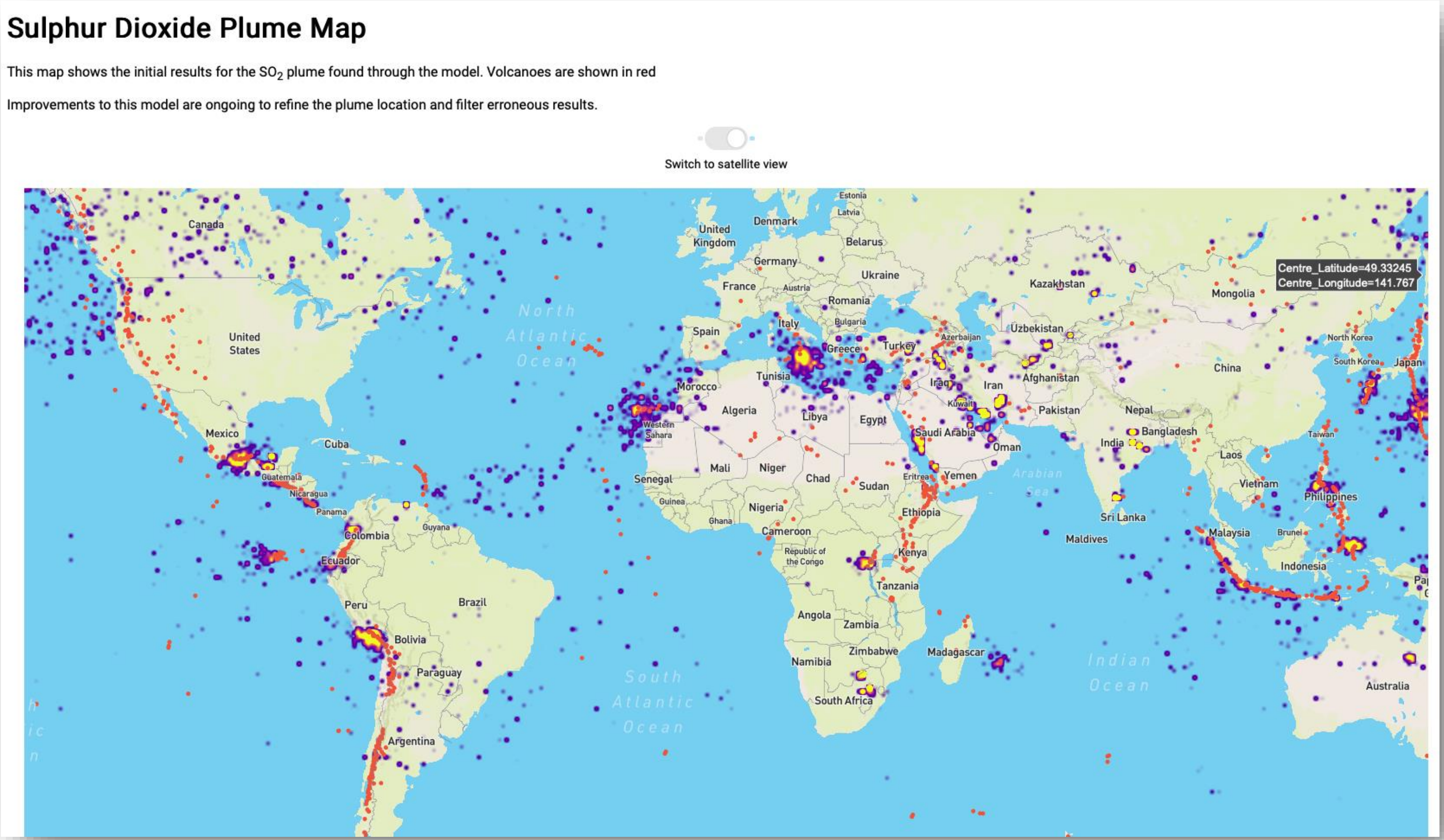
Case Study – CH_4 from Oil Fields





- We can see clusters of methane plumes from a known oil field in Turkmenistan.
- Although there is also noise about, some of it lines up with other smaller oil fields

Data Availability – eoplumes.com



- All this data will be available on our project website
- Site is currently out-of-date
- Latest data will be published later in the year
- Zoomable maps, quick look statistics and downloadable data will be available

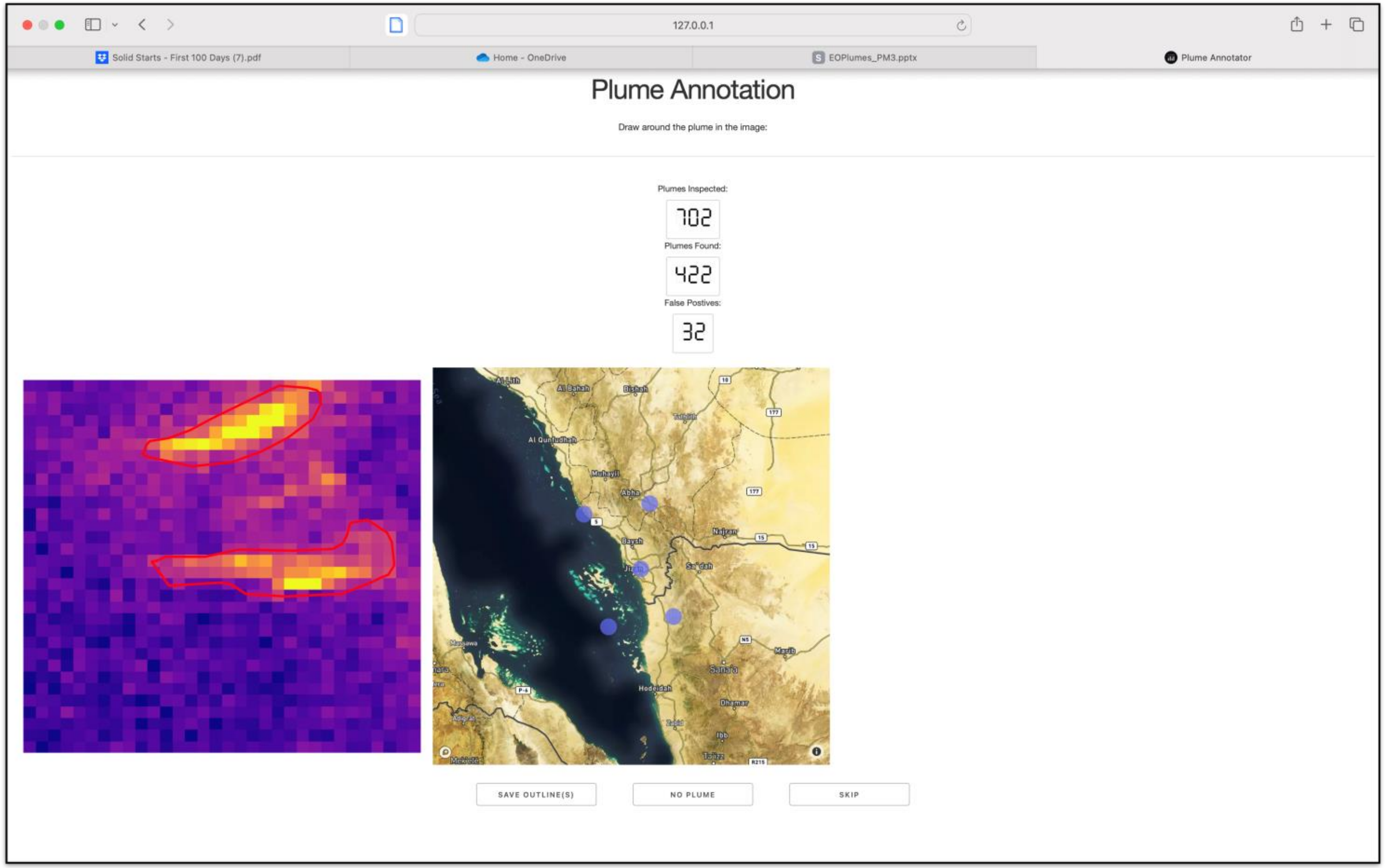
Summary

- We've created promising plume detection models for SO_2, NO_2 and CH_4
- The models results gives us confidence that they are doing what we expect (although there is always room for improvement)
- The workflow created allows to go from swath to emission estimates in around 30 seconds
- This database will be available to all later in the year – we'd like the community to be able to use this information in new and innovative ways

Thank you – any questions?

Extra slides

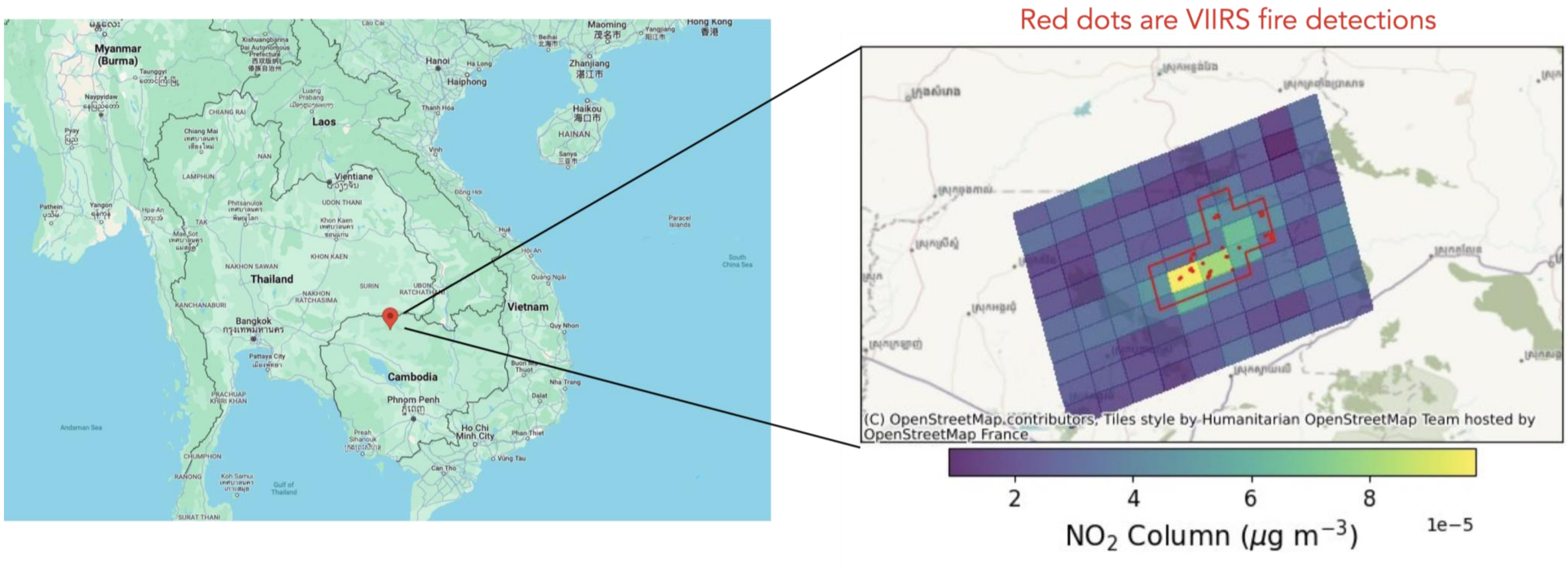
Plume Labelling



- Created an app to run locally
- Went through images and draw round plume shapes
- Showed location of plume alongside image as a sanity check
- Saved drawn outline as binary mask for model training

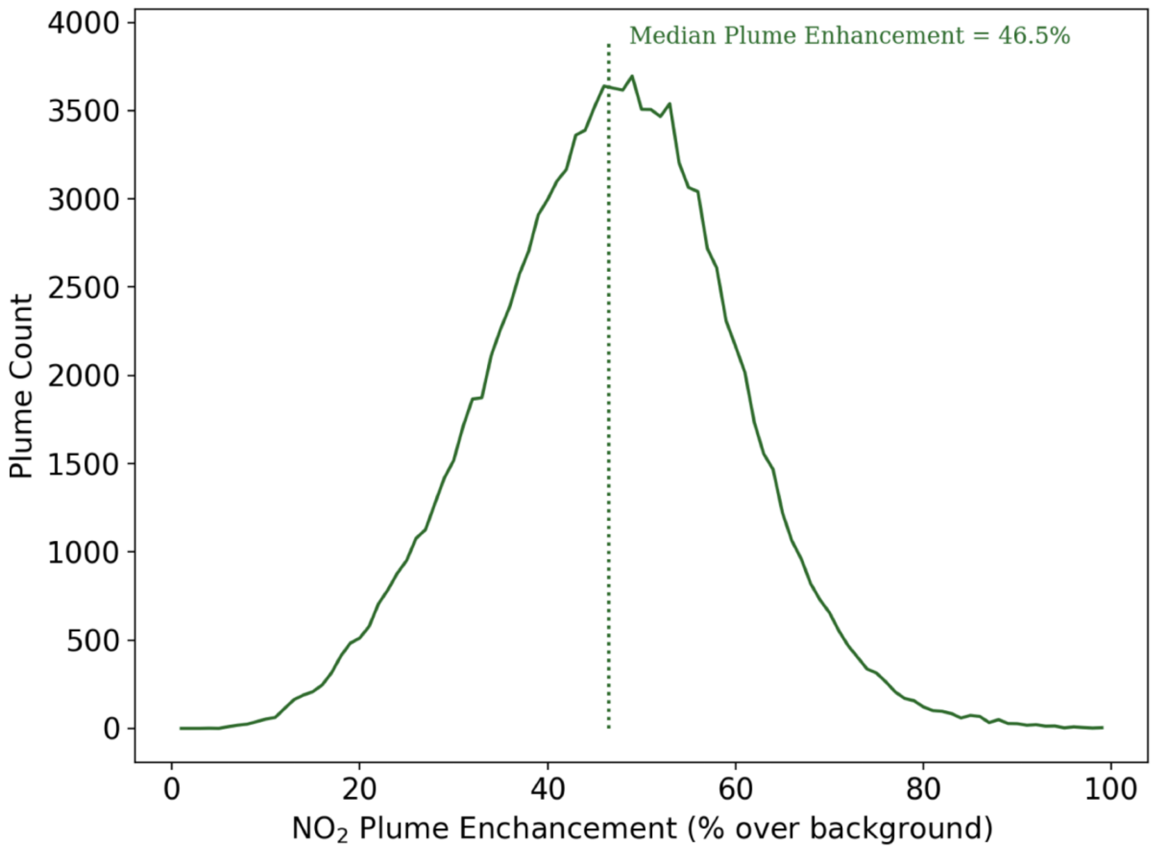
Separating Biomass Burning

- Where a plume boundary contains a detected fire from VIIRS or MODIS on the same day – classify as BB



Detection Limits (NO_2)

- Model works on shapes and gradients and therefore relies on how well a plume stands out from the background, not absolute concentration
- We can compare the median background to the median concentration within the plume to get an idea of normal plume enhancement



Minimum enhancement = 3% enhancement
1st percentile enhancement = 16% enhancement