Using Convolutional Neural Networks to Detect Emissions Plumes From TROPOMI Data

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Context – Quantifying GHG emissions

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- An urgent need to reduce greenhouse gas emissions globally

- Countries need to develop monitoring, reporting and verification systems of GHG emissions to comply with COP Aims (Paris & hopefully Glasgow!)

- Country level annual reporting of GHG emissions is OK but need more precise & more frequent reporting

- We would like to be able to monitor CO_2 emissions from hot spots (e.g. particular cities, a power station)

Context – Quantifying GHG emissions

- Satellite allow global, frequent and continuous observations of atmospheric gases

- There are a number of satellites directly monitoring CO_2 (with more planned)

- If you can detect a hot spot you can quantify emissions from one satellite overpass (with some other data)

However…

- Extracting emissions of CO_2 by looking at satellite data is difficult

- Concentrations of CO_2 are (relatively) homogenous over the globe and therefore its hard to detect a hot spot against the background level

- Monitoring anthropogenic CO_2 from space is complicated by biogenic emissions

Look at co-emitted species from combustion (e.g. NO2 or CO) to detect the hot spots and determine the emissions

TROPOMI NO_2 Observations

- TROPOspheric Monitoring Instrument - observes a number of trace gases (inc. NO_2)

- Launched 13th Oct 2017 (hopefully for at least 7 year mission)

- Resolution of 5 x 3.5 km pixels, swath of 2600 km

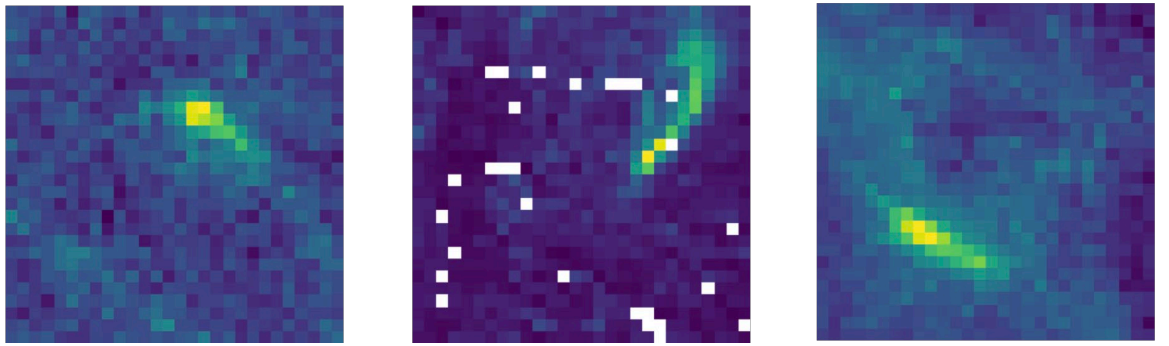
- 13:30 local overpass time (near full earth coverage in a day)

- TROPOMI produces >6GB of NO_2 observations daily - a lot to look through!

What are we looking for? What is a plume?

- A plume is a long "cloud" of pollution spreading out from a point of origin.
- A classic example of a plume is from a smoke stack from a power station or factory
- Could also be large plumes from cities

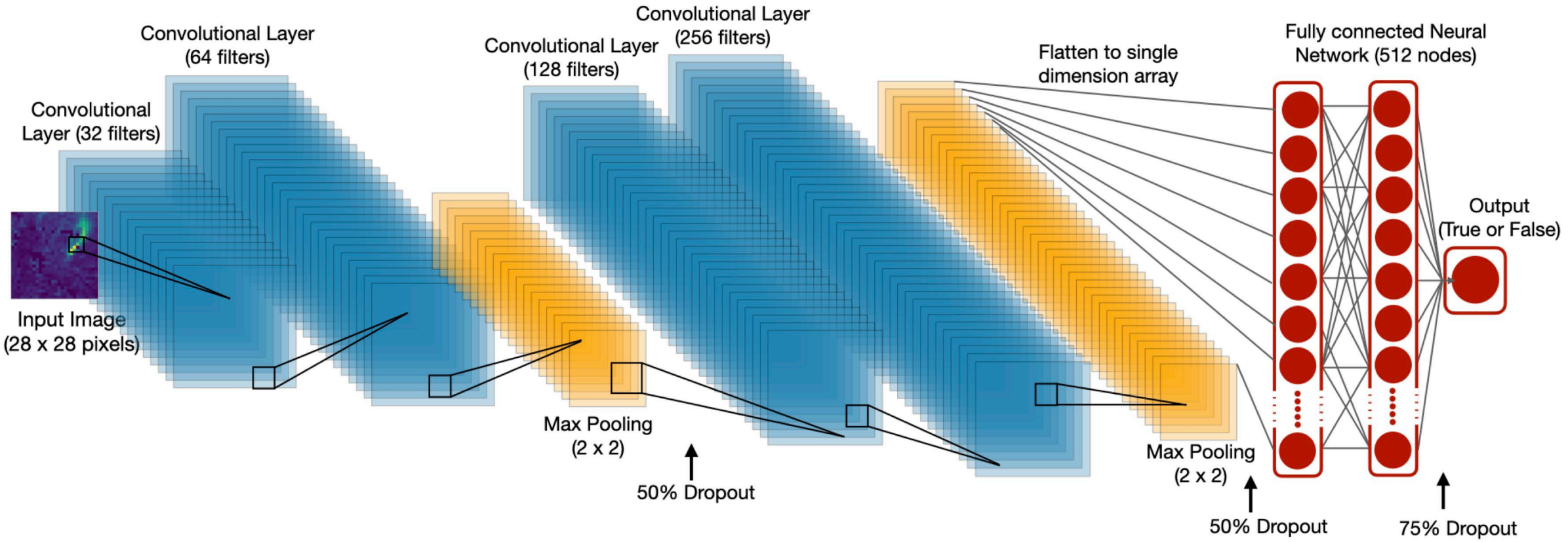
From above they look like this:



Creating a CNN

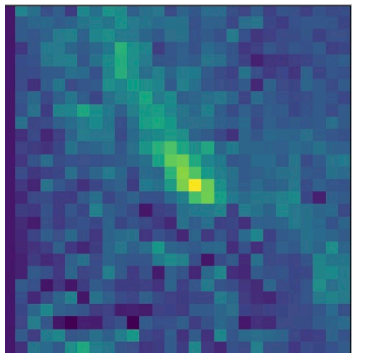
- Aim: Train a machine learning model to detect plumes within the data
- Same principle as any image recognition model (e.g. face recognition)
- Using Google's TensorFlow (Keras)
- Open source Python module that is easy to use (but black box) – ran on GPUs
- Create a convolutional neural network

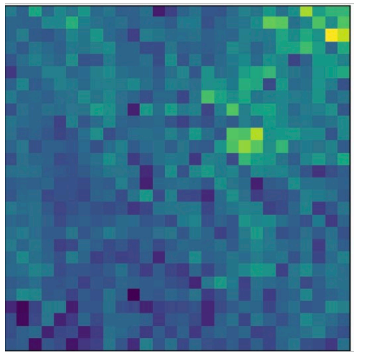
CNN Model Architecture

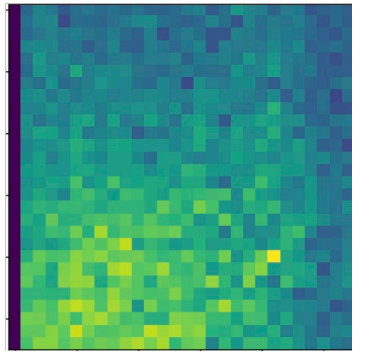


Training the CNN model

- Needs examples of images of both plumes and no plumes (inc. confusing ones)
- Created labelled database of 6,086 images. 50/50 split of plume/no plume
- Tried crowd-sourcing but was unsuccessful
- Global coverage (but skipped over oceans) & all times of year
- Randomly split the data, 80% to train the model & 20% to test performance after training







Model configuration resulted in >90% accuracy

Example CNN Process

- Iterates through satellite swath
- Looks at 28 x 28 pixel image
- Gives confidence that image contains a plume (i.e. 100% = defiantly contains a plume)
- Can extract coordinates of the maximum value of the plume

Separating biomass burning hotspots

- Biomass burning also produces NO_2 plumes. Especially large forest fires.

- Using active fire data we can map where fires coincide with plumes spotted

- Data from the Visible Infrared Imaging Radiometer Suite (VIIRS) - SUOMI NPP satellite (NASA/NOAA)

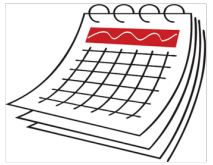
- Give locations and times of fires (at 375 m resolution)

- Any time a fire falls within a plume pixel it is labelled 'biomass burning plume'

- Errors could be introduced here - imperfect system but works ok for now

Plumes of smoke over South Africa seen from ISS

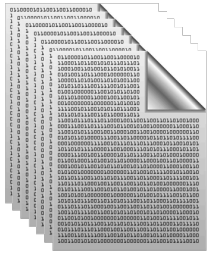
Processing the Data



July 2018 - June 2020

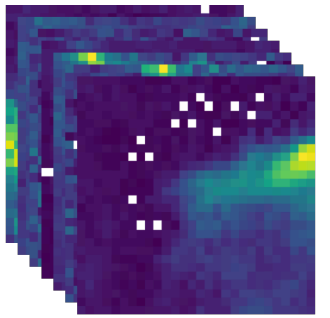
24 months

730 days



~ 14 swaths/files per day

10,220 files (3.2 TB)



Swath = 450 x 3127 pixels

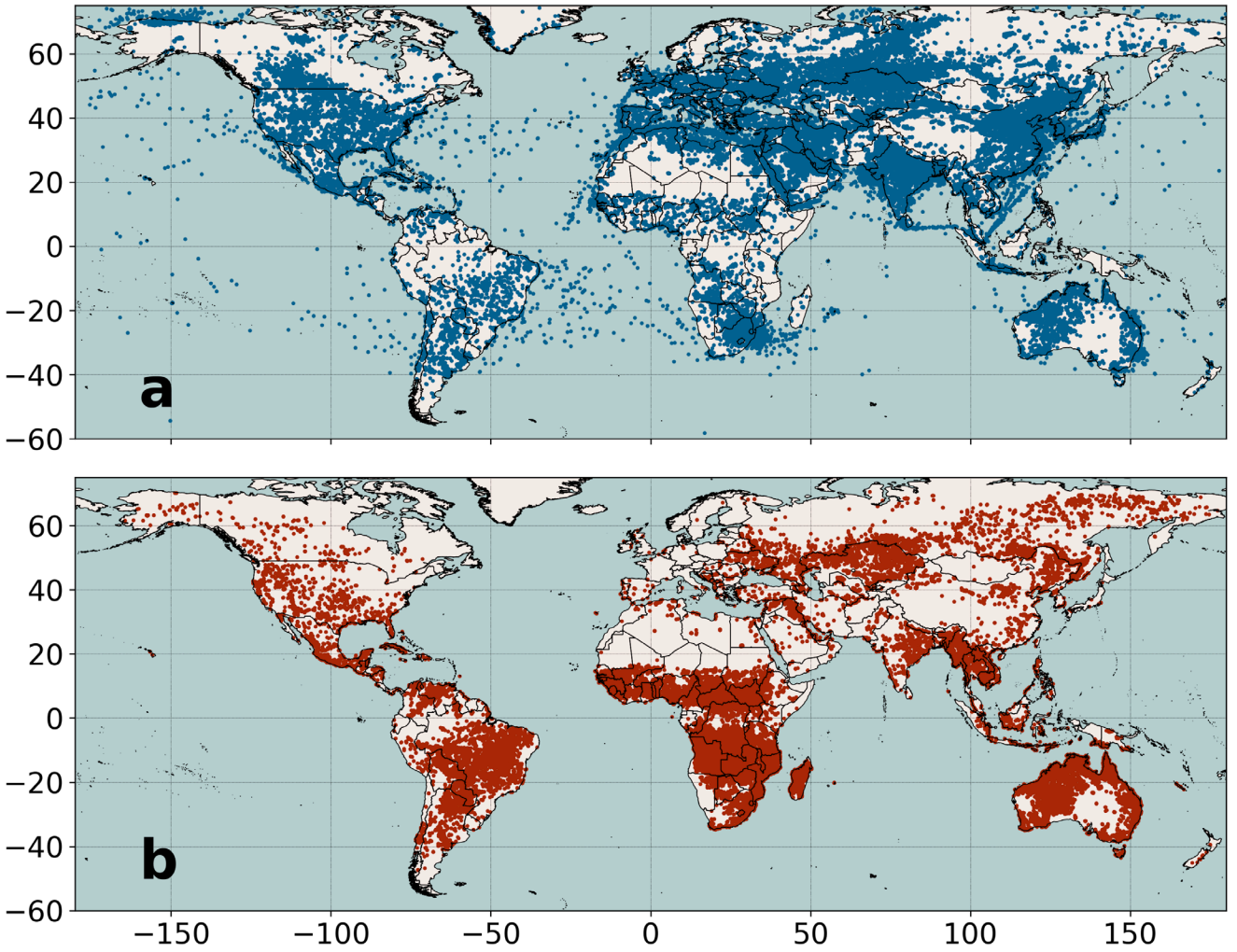
16 x 111 images of 28 x 28 pixels*

1776 images per swath

* Doesn't fit in the swath nicely

>18 million images

- Reduced to 7.2 million after quality control

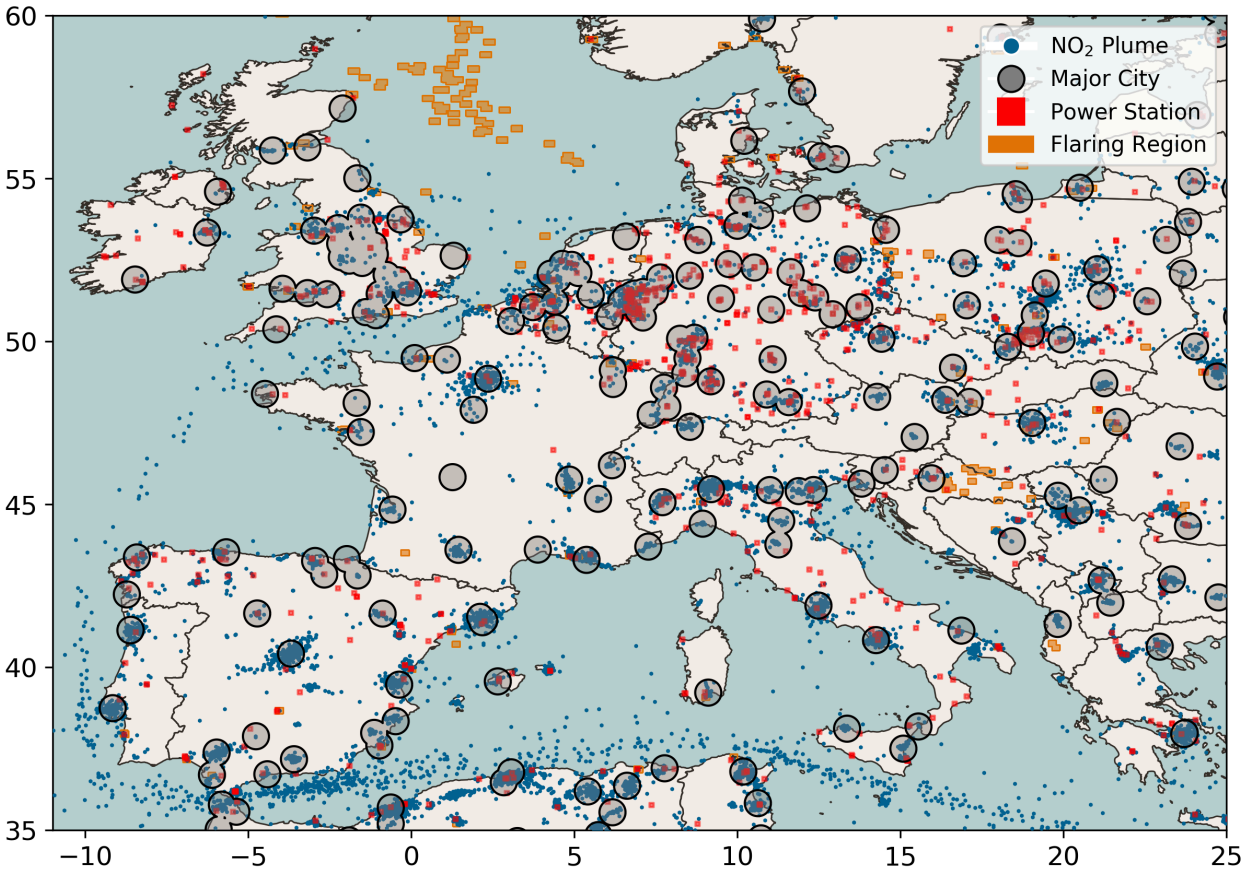


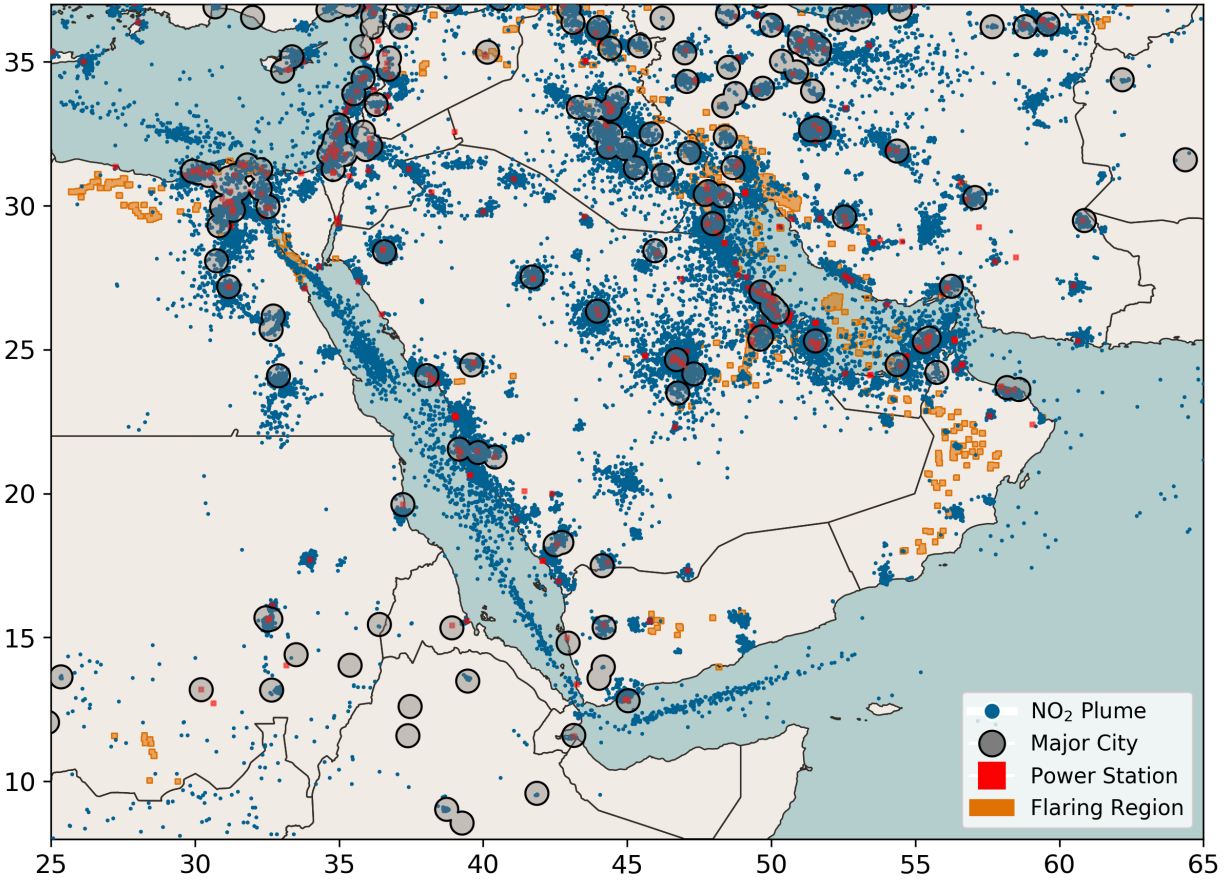
Anthropogenic Combustion Plumes

Biomass Burning Plumes

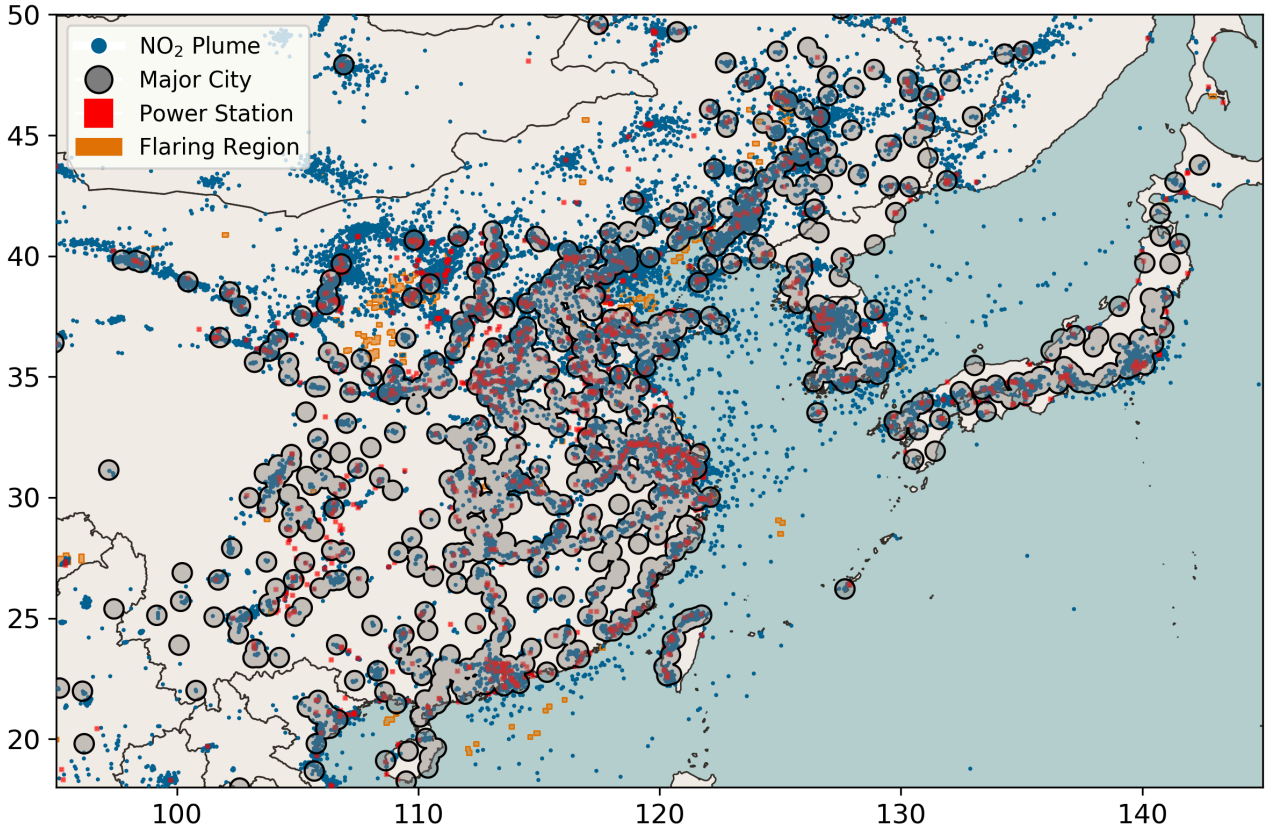
Dots on map much much larger than TROPOMI pixel
- hence saturation

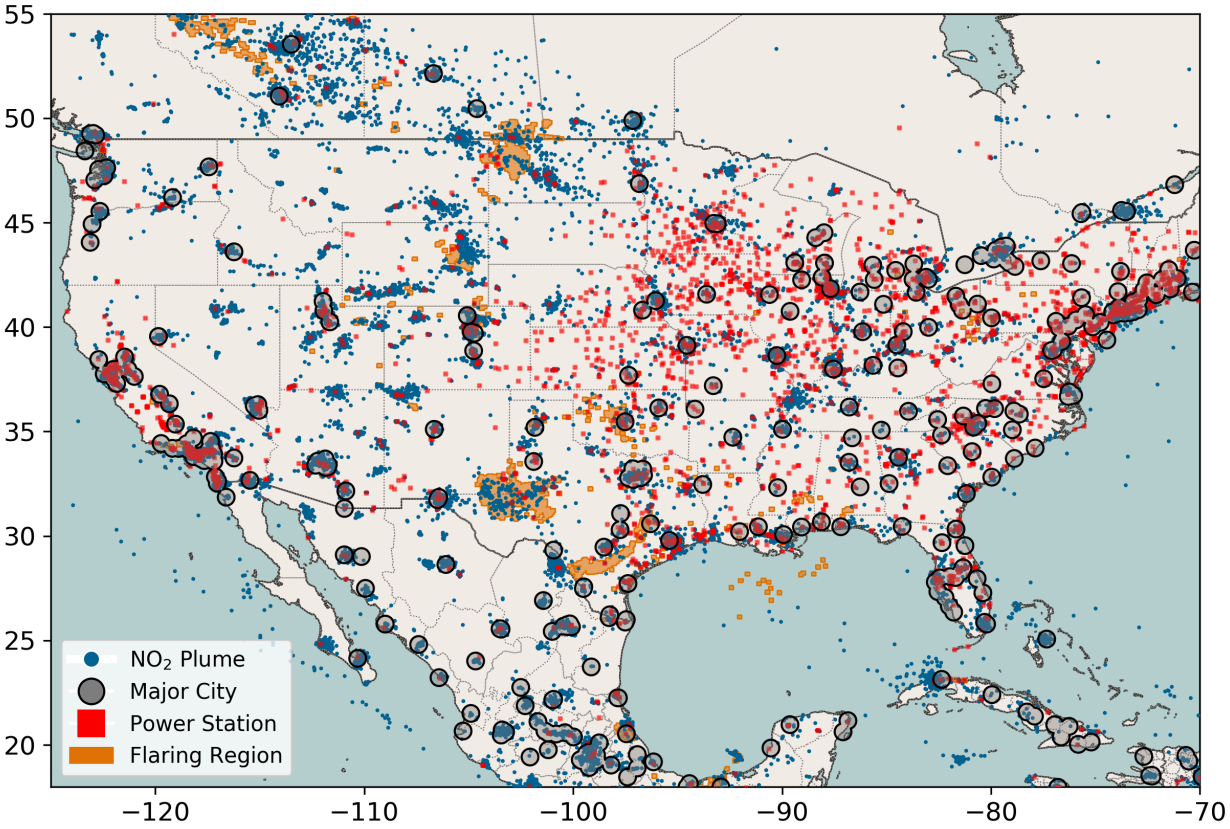
Plume Maps


NO_2 Plume
Major City
Power Station
Flaring Region
60
55
50
45
40
35
−10
−5
0
5
10
15
20
25


NO_2 Plume
Major City
Power Station
Flaring Region
35
30
25
20
15
10
25
30
35
40
45
50
55
60
65

Plume Maps


NO2 Plume
Major City
Power Station
Flaring Region
50
45
40
35
30
25
20
100
110
120
130
140

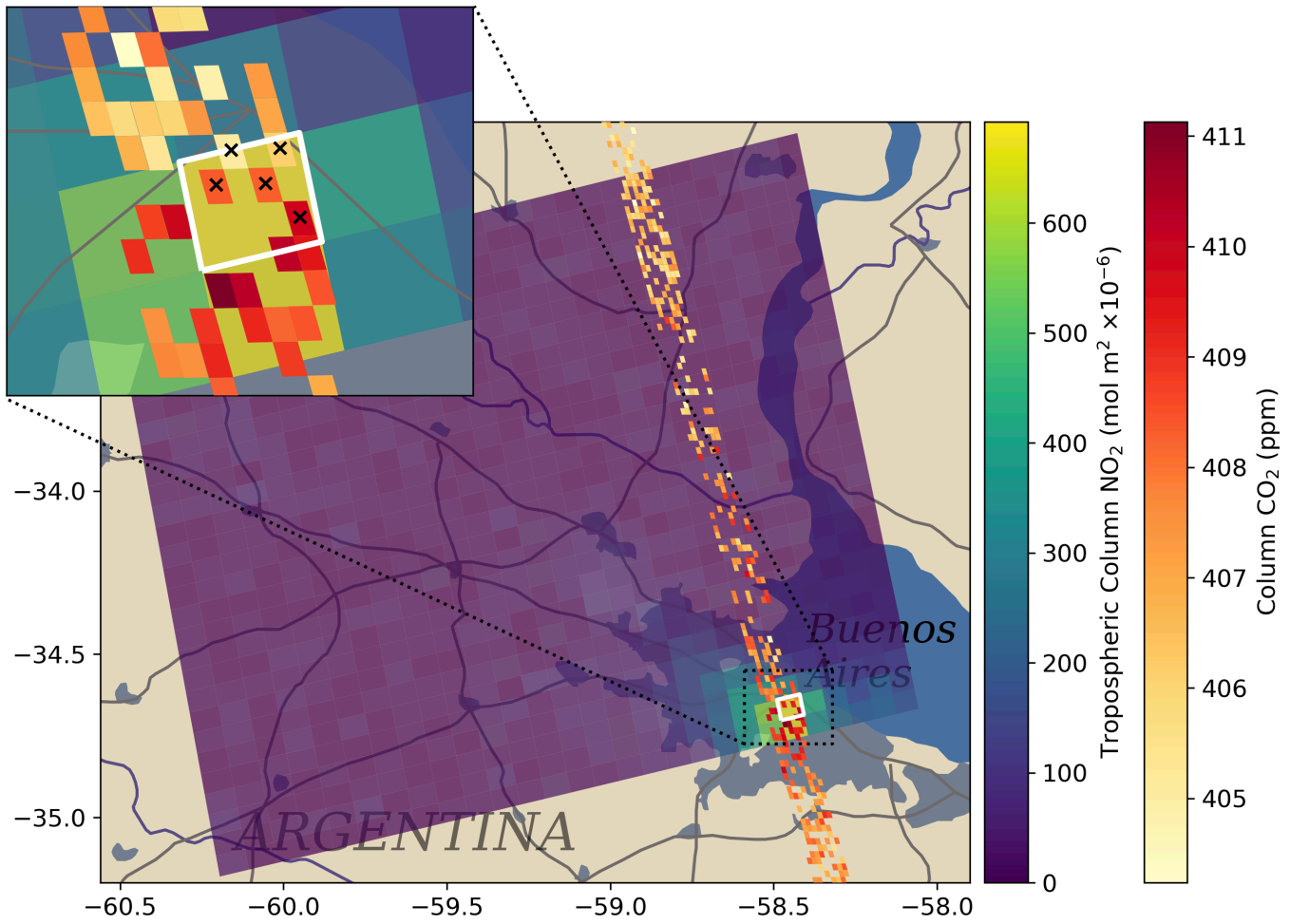

NO2 Plume
Major City
Power Station
Flaring Region
55
50
45
40
35
30
25
20
−120
−110
−100
−90
−80
−70

Online Plume Map

www.ukatmosphere.org/dataplot/plume_map

* Not great on mobile

Use in conjunction with other data

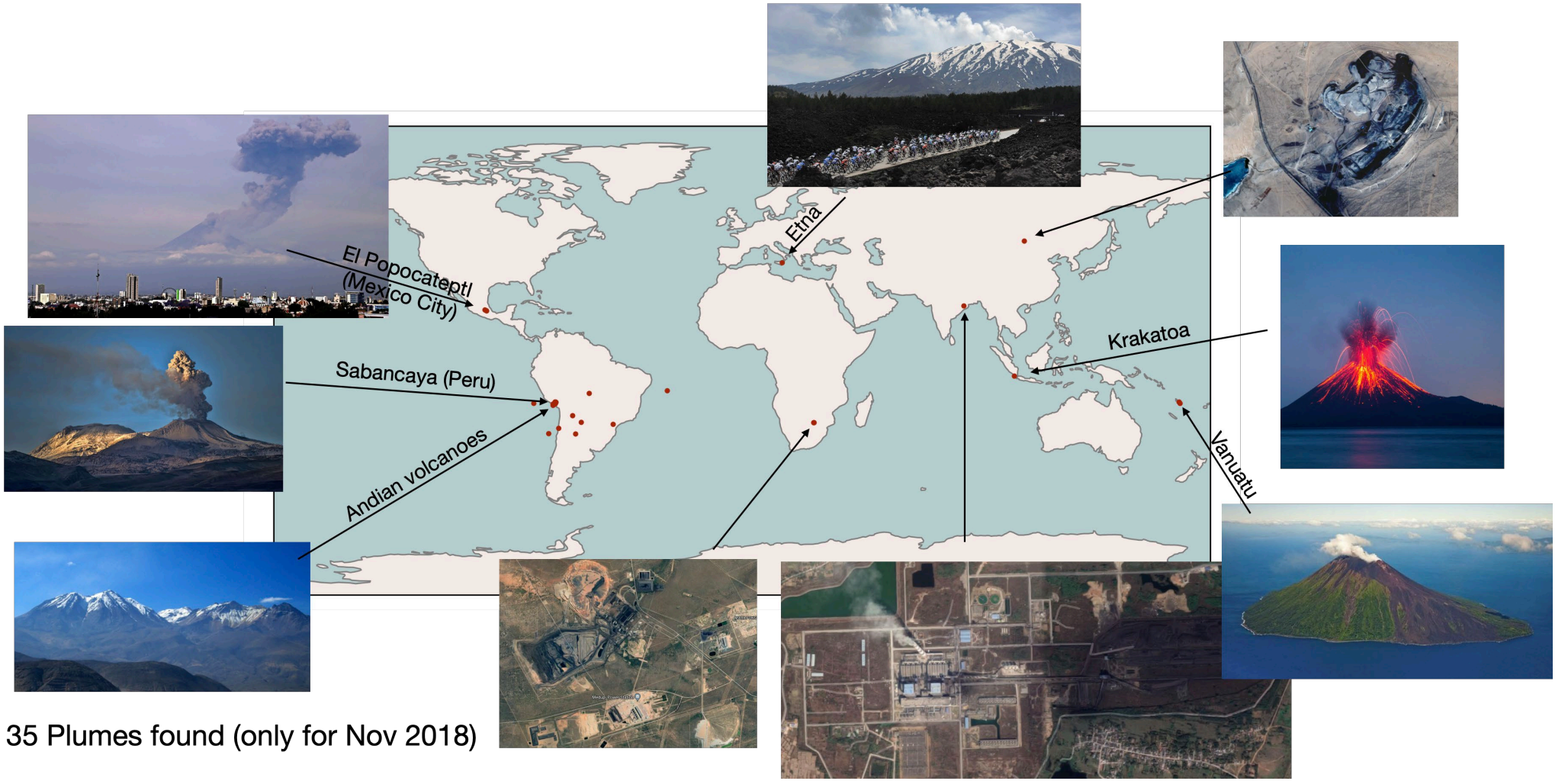


TROPOMI NO_2 (1/16th of swath)

OCO-2 CO_2 (full swath)

- Can look at coincident measurements & ratios between species
- Gives us information on combustion efficiency & potential emissions
- Not currently enough information - more satellites will help!

Using the same CNN but for SO_2



35 Plumes found (only for Nov 2018)

Summary

- Using a convolutional neural network can be a really useful tool for helping to process large amounts of data

- We've shown you can successfully locate major NO2 emission globally

- This will become more and more useful as there is more and more data

- Lots of possible uses for this, directly & indirectly

- Refinements can constantly be made to the model to improve output

Paper:
Automated detection of atmospheric NO2 plumes from satellite data: a tool to help infer anthropogenic combustion emissions
Atmospheric Measurement Techniques

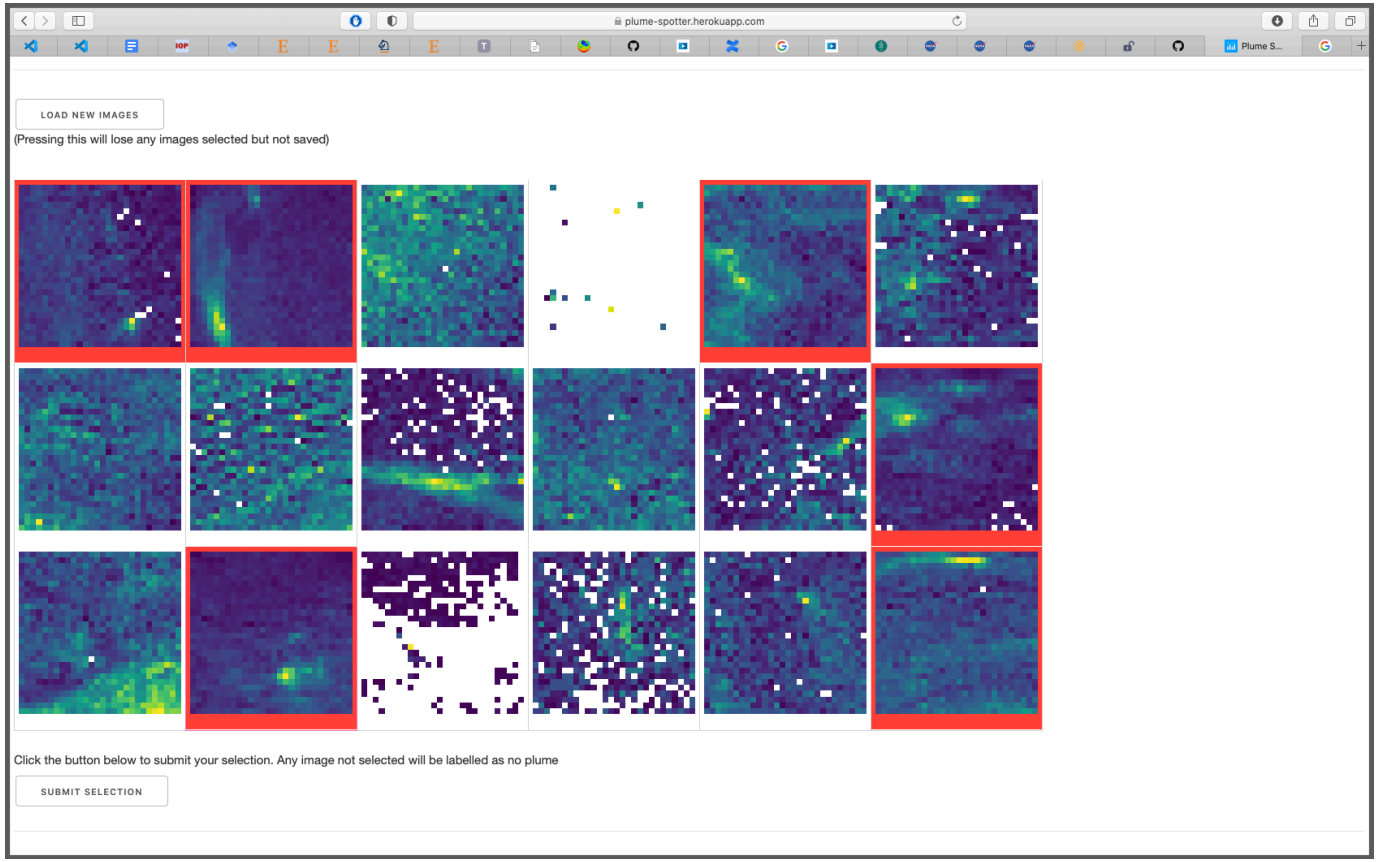
Thanks for listening! Any Questions?

Extra…

Crowd sourcing dataset

- Create a tool for many people to decide whether an image contains a plume (or not)

- Also get data on how many people agree



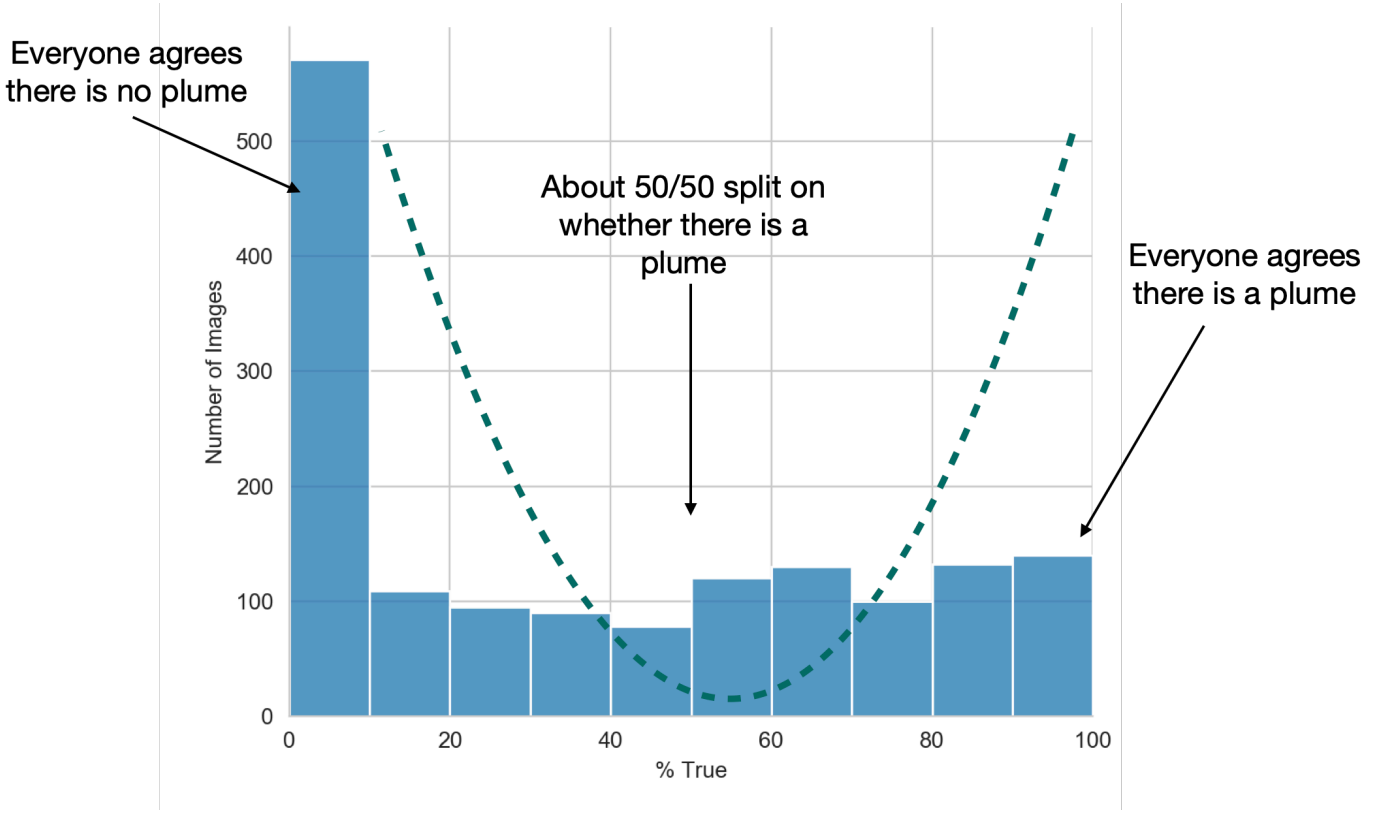
Crowd sourcing datasets

- > 1500 images shown
- > 13,500 individual classifications
- Average 8 classifications per image

…. no real consensus

535 images everyone agrees there is ***no*** plume

109 images everyone agrees there ***is*** plume



Plumes per month