Automated Detection of Atmospheric NO_2 Plumes From Satellite Data: A Tool to Help Infer Anthropogenic Combustion Emissions

Douglas Finch[1,2], Paul Palmer[1,2] & Tianran Zhang[3]

1) National Centre for Earth Observation

2) School of Geosciences, University of Edinburgh

3) King's College London, now at Satellite Vu

THE UNIVERSITY *of* EDINBURGH

National Centre for Earth Observation

NATURAL ENVIRONMENT RESEARCH COUNCIL

Context
Quantifying GHG Emissions

- 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 & 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 CO2 emissions from hot spots (e.g. particular cities, a power station)

COP21 · CMP11
PARIS 2015
UN CLIMATE CHANGE CONFERENCE

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…

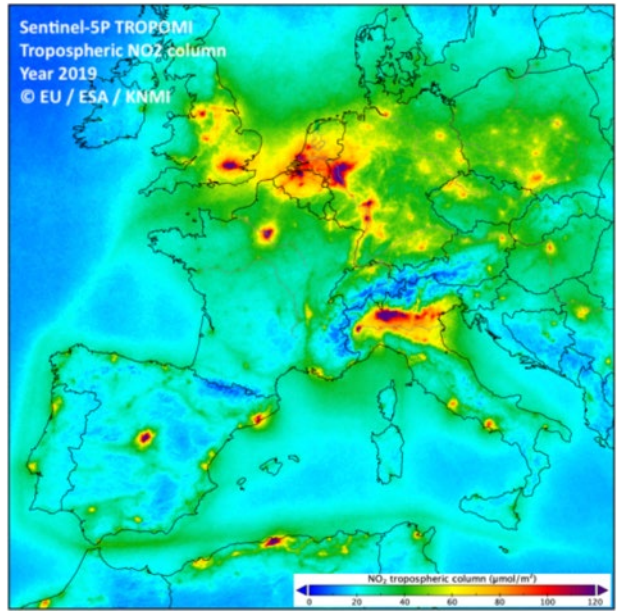
- Extracting emissions of CO_2 by looking at satellite data is difficult
- Concentrations of CO_2 are (relatively) homogenous over the globe and therefore its hard to detect a hot spot against the background level
- Monitoring anthropogenic CO_2 from space is complicated by biogenic emissions

Look at co-emitted species from combustion (e.g. NO_2 or CO) to detect the hot spots and determine the emissions

Finding NO_2 Hotspots

TROPOMI NO_2 Observations

- TROPOspheric Monitoring Instrument – level 2 tropospheric column NO_2 observations
- 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 in around 14 swaths)
- Build up a database of location and time of hotspots from daily data

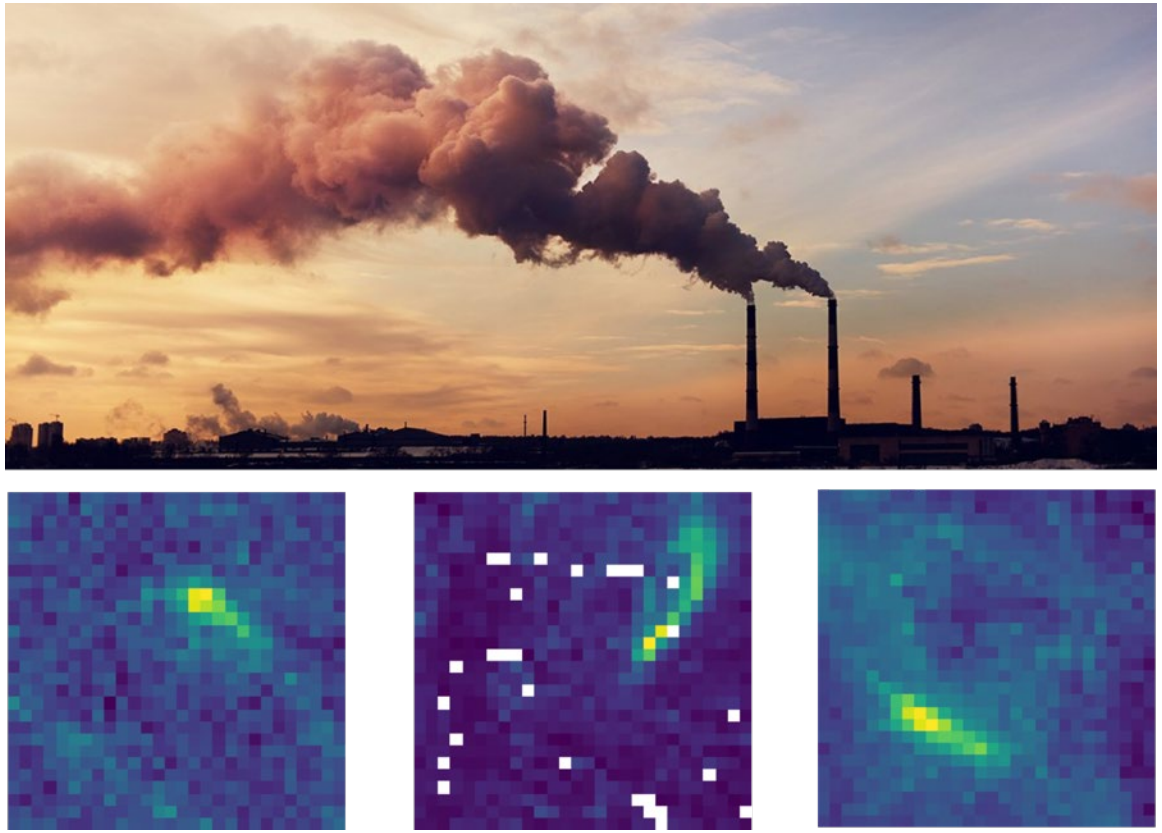


What are we looking for?

Finding Plumes

- 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:



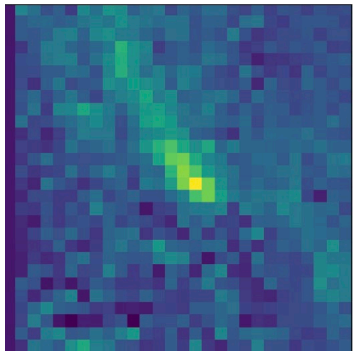
Building a Machine Learning Model

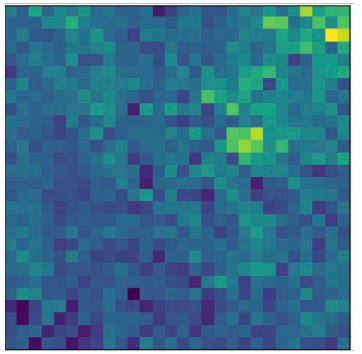
Convolutional Neural Network

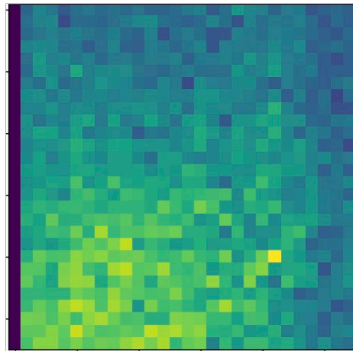
- Aim: Train a machine learning model to detect plumes within the data
- Same principle as any image recognition model (e.g. face recognition)
- Using Google's TensorFlow (Keras)
- Open source Python module that is easy to use (but black box)
- Create a convolutional neural network with multiple convolutional layers to detect features & nodes to find statistical patterns

Training the 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

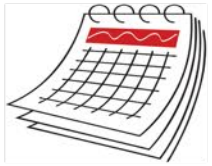






Model configuration resulted in >90% accuracy

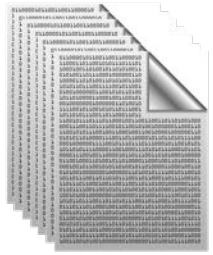
Processing the data



July 2018 - June 2020

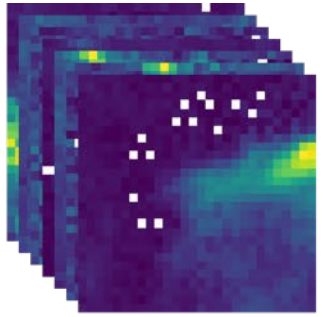
24 months

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

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

Example CNN Process

Latitude: -20.406°
Longitude: -40.498°

*Could be multiple sources within one pixel

Separating Biomass Burning

Convolutional Neural Network

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)

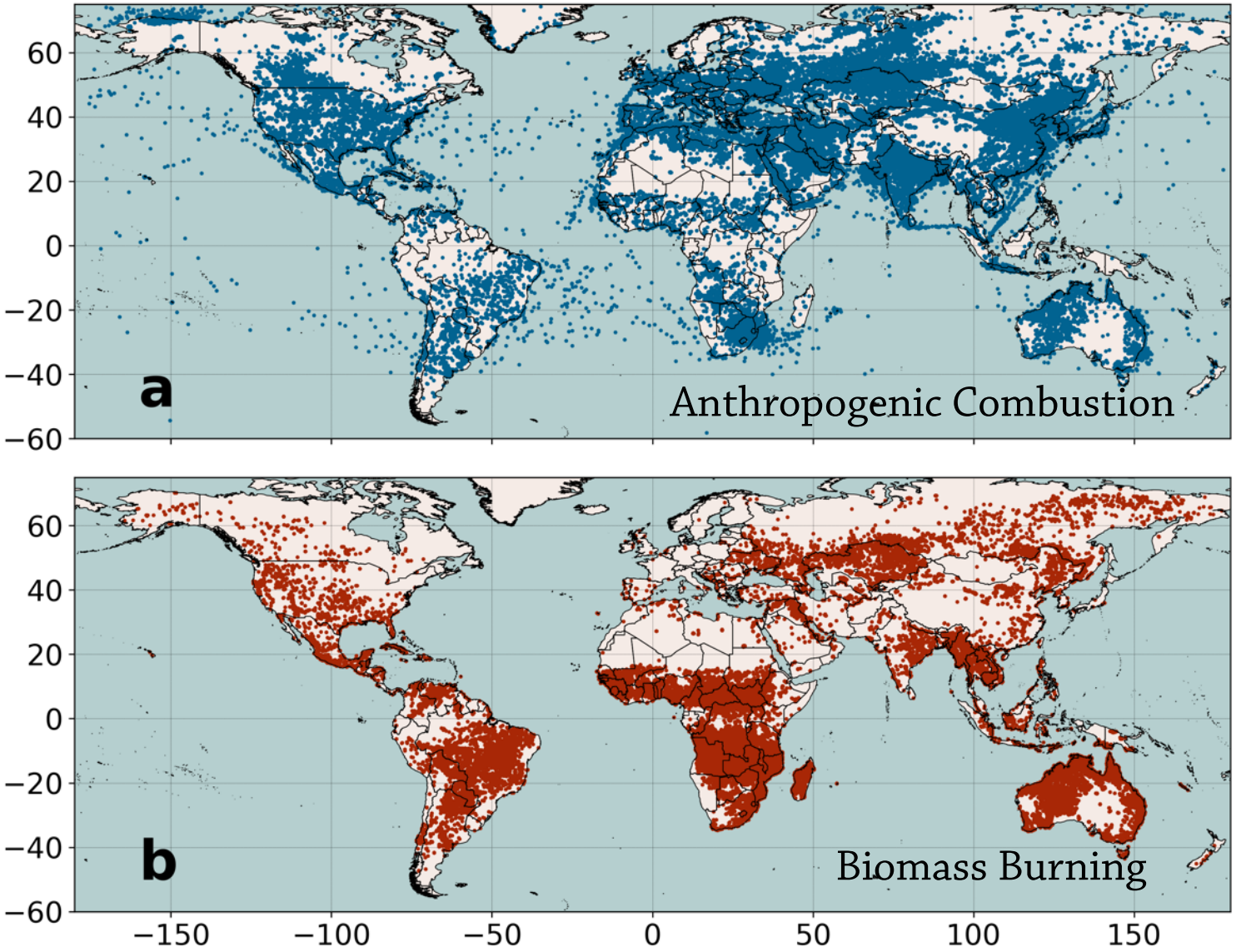
Give locations and times of fires (at 375 m resolution)

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

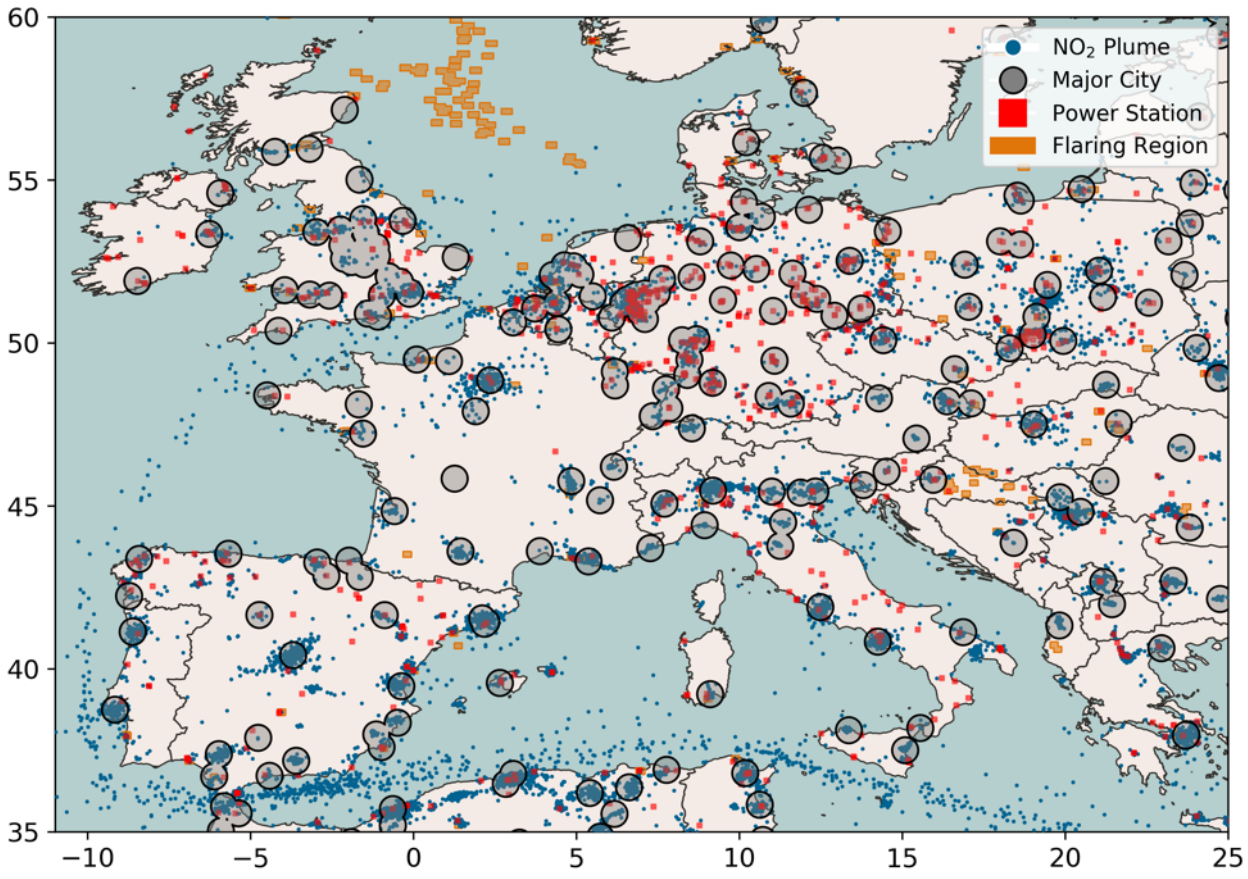
Results

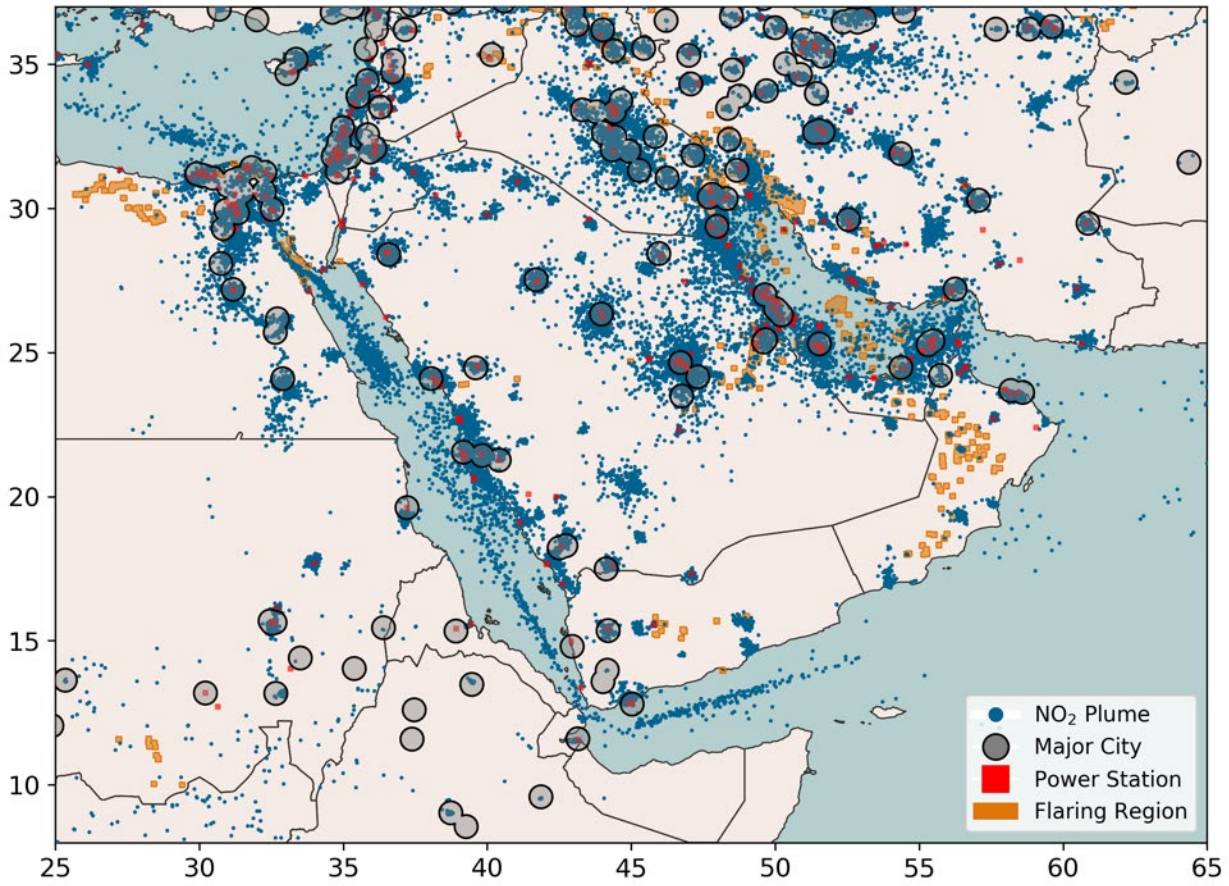


- Found > 310,000 plumes over two years
- Focused around areas you would expect
- Features appear on closer inspection

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

Plume Maps



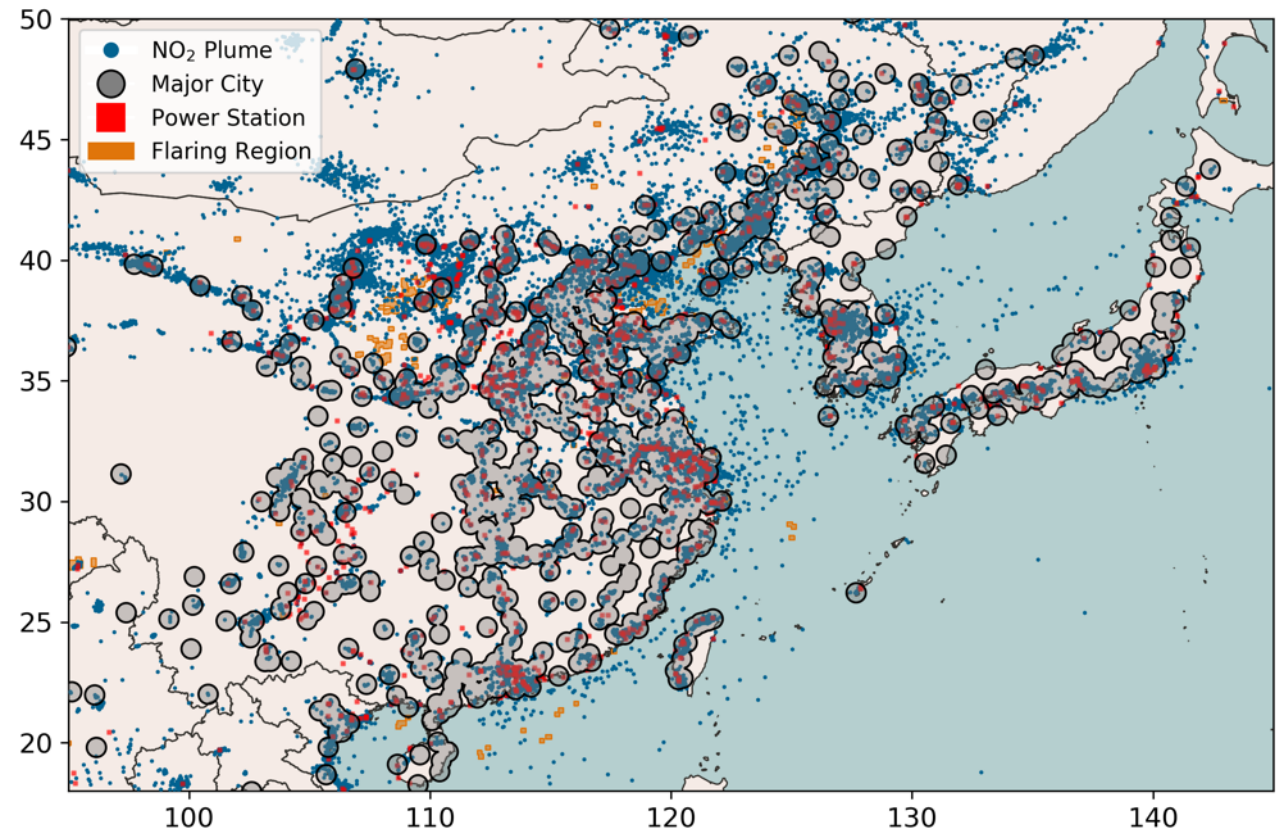


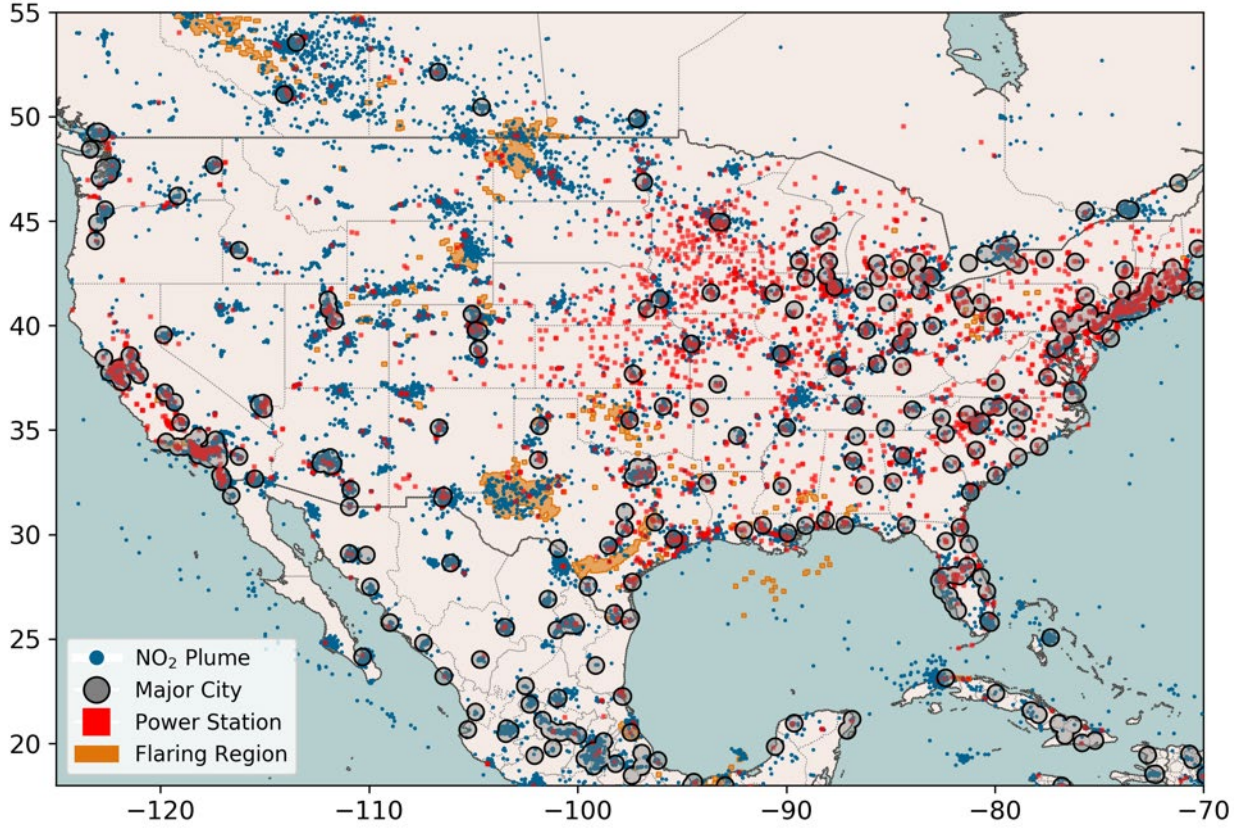
Cities with population > 200,000

Power station locations (Global Power Plant Database)

Night time flaring (skytruth.org/flaring)

Plume Maps



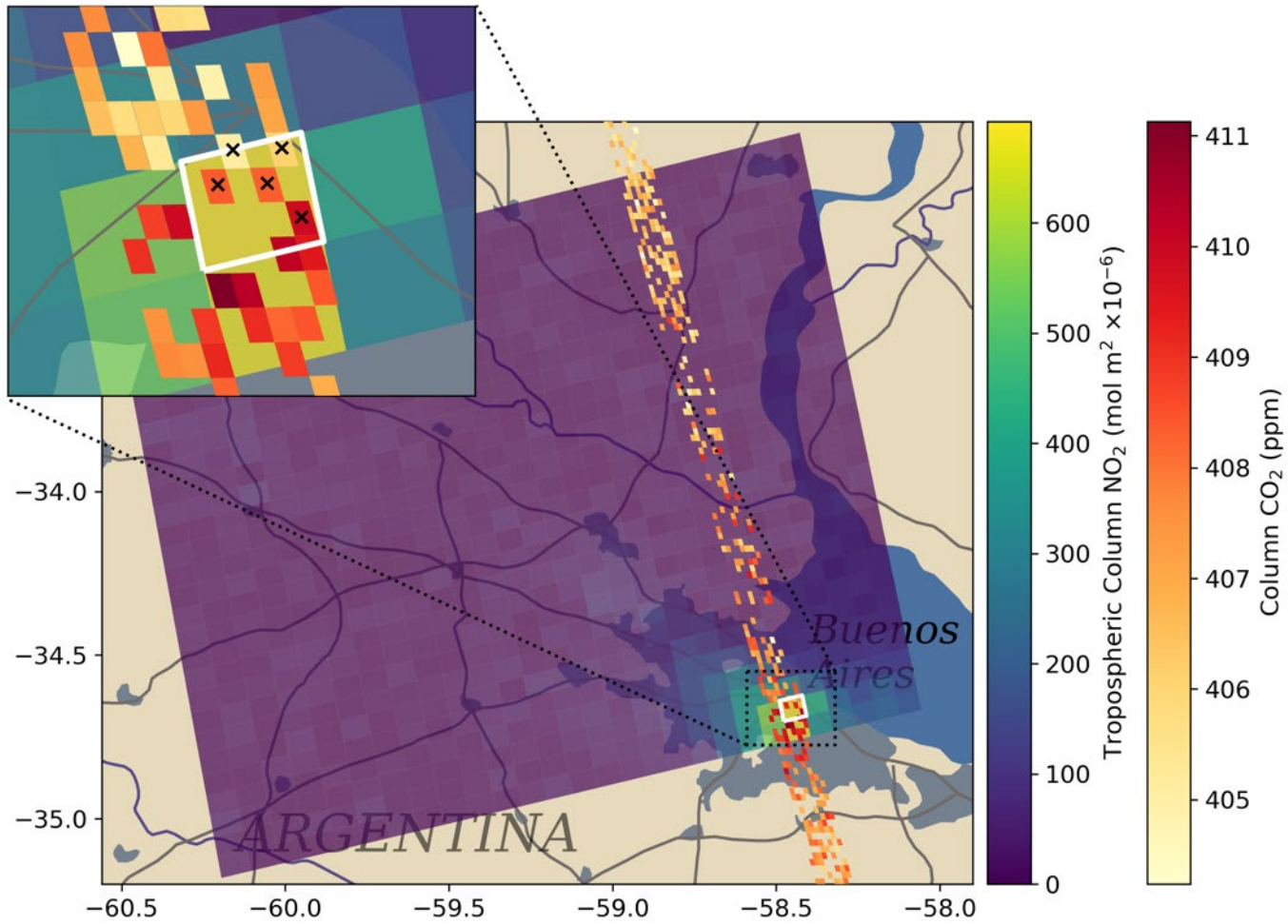


Cities with population > 200,000

Power station locations (Global Power Plant Database)

Night time flaring (skytruth.org/flaring)

Relating Back to CO_2



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!

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 NO_2 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

Online plume map: ukatmosphere.org/dataplot/plume_map