UNIVERSITY OF LEICESTER

EM27/SUN ACTIVITIES AT THE UNIVERSITY OF LEICESTER

NEIL HUMPAGE – *UNIVERSITY OF LEICESTER*

HARTMUT BOESCH – *NCEO, UNIVERSITY OF LEICESTER*

WILLIAM OKELLO – *NATIONAL FISHERIES RESOURCES RESEARCH INSTITUTE, JINJA, UGANDA*

FLORIAN DIETRICH, JIA CHEN – *TU MUNICH*

MARK LUNT, LIANG FENG*, PAUL PALMER* – *UNIVERSITY OF EDINBURGH*

FRANK HASE – *KIT*

** ALSO NATIONAL CENTRE FOR EARTH OBSERVATION, UK*

ROBBIE RAMSAY, ANDREW GRAY, JACK GILLESPIE, MATHEW WILLIAMS – *FIELD SPECTROSCOPY FACILITY, UNIVERSITY OF EDINBURGH*

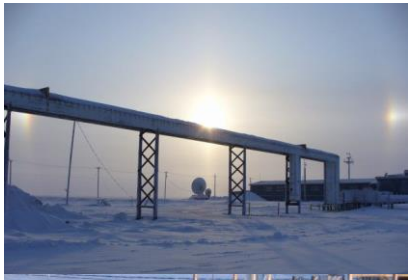
JEROME WOODWARK – *UNIVERSITY OF EDINBURGH*

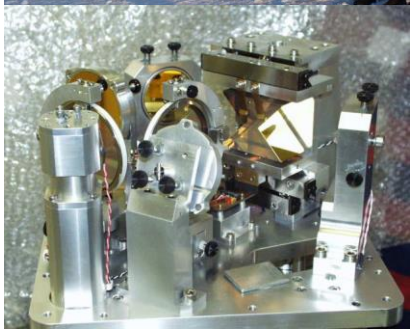
OVERVIEW

- A bit about me…
- Measurements from a tropical location in Jinja, Uganda
- Measurements from an urban location in London, UK
- Some final thoughts

A BIT ABOUT ME…

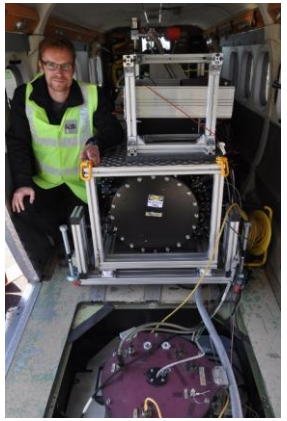
- Undergraduate: MPhys in Physics at University of Oxford
- PhD: Space and Atmospheric Physics group, Imperial College London
  - Worked on TAFTS, an in-house design and build far-infrared FTS (precursor to ESA Earth Explorer FORUM)
  - Operated from aircraft and ground
  - Ground-based campaign in Utqiagvik, Alaska at the NSA ARM site
  - Science focus on cirrus cloud microphysics from far-infrared spectra, water vapour continuum absorption
  - Gained understanding and experience of practical work in field and laboratory, data processing from raw interferograms to calibrated radiance spectra





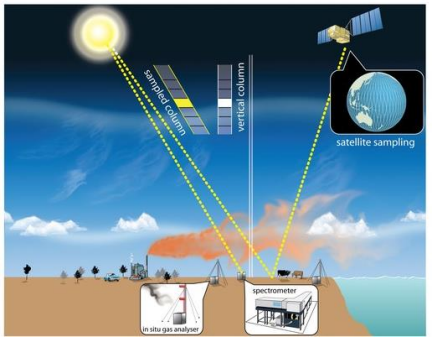
A BIT ABOUT ME…

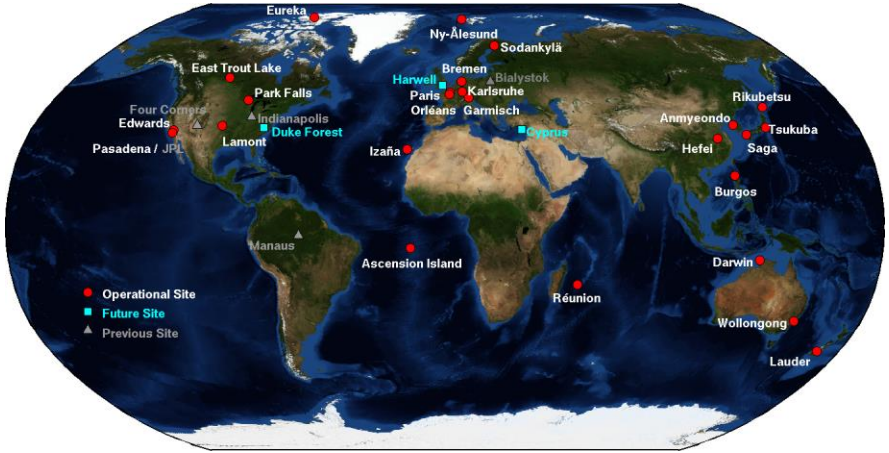
- Postdoctoral research at University of Leicester
- Focus on instrumentation – laboratory, airborne, ground-based, instrument simulation…
- Involved in greenhouse gas remote sensing since mid-2010s
- GHOST: airborne SWIR grating spectrometer designed for NASA Global Hawk
  - Performed radiometric and spectral calibration, developed processing chain starting with raw detector frames (Humpage et al, AMT 2018)
  - Also flown on conventional aircraft



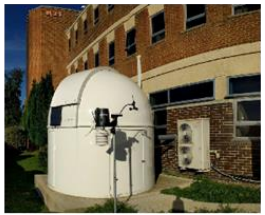
GROUND-BASED REMOTE SENSING OF GREENHOUSE GASES

- Ground based Fourier Transform Spectrometers (FTS) provide accurate CO_2 and CH_4 columns
- Same measurement principle as satellites
- Total Carbon Column Observing Network (TCCON) data is essential to identify and correct for biases
- Gaps in network coverage: South America, Africa, Central and South Asia
- City focus: ground-based remote sensing networks in cities to investigate emissions using e.g. differential column observations
- TCCON sites expensive and logistically challenging to set up… cheaper, portable solution which still provides similar data quality?





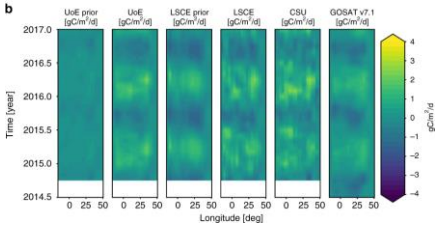
TCCON Harwell (future site)



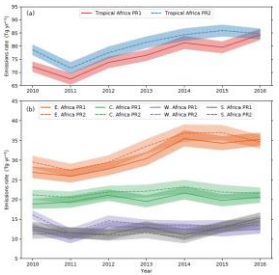
EM27/SUN DEPLOYMENT IN UGANDA: MOTIVATION

- Many studies investigating greenhouse gas emissions in Tropical Africa are based on satellite and model datasets of atmospheric composition

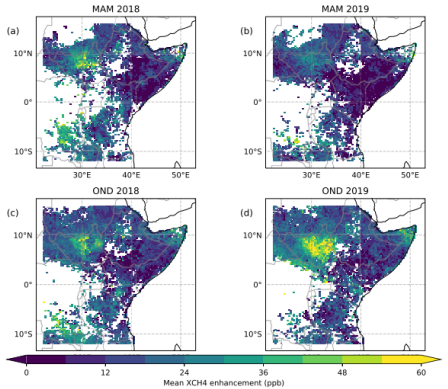
Palmer et al (2019): Unexpectedly large net emissions from tropical Africa in 2015 and 2016

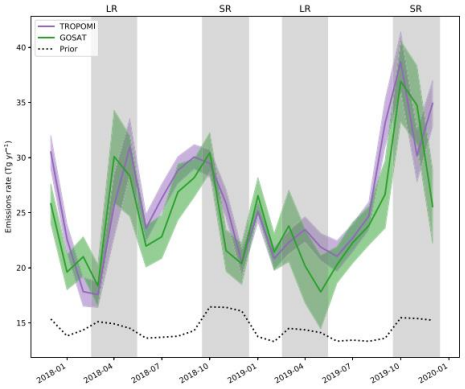


Lunt et al (2019): focus on methane, found robust positive linear trend in tropical African methane emissions over the period 2011 to 2016, consistent with increased wetland extent in the Sudd region



Lunt et al (2021): additional seasonal methane emissions in East Africa linked to anomalously high rainfall during the 2018 long rains and 2019 short rains, due to flooded wetlands

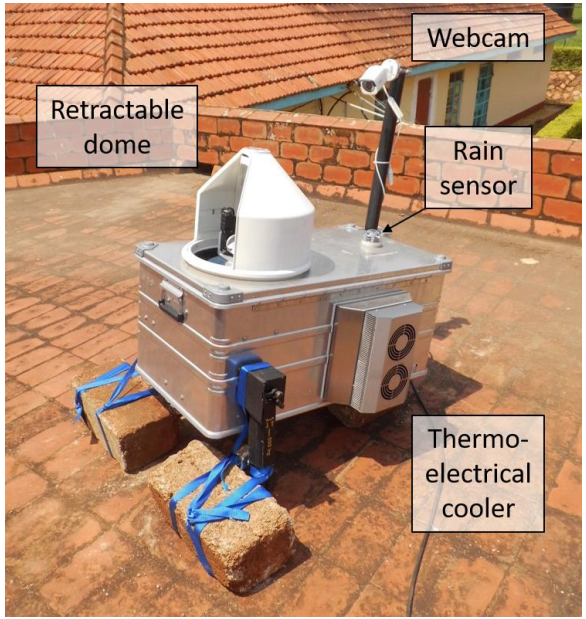




- *How well do these datasets represent what's happening in the atmosphere over the tropical Africa region?*

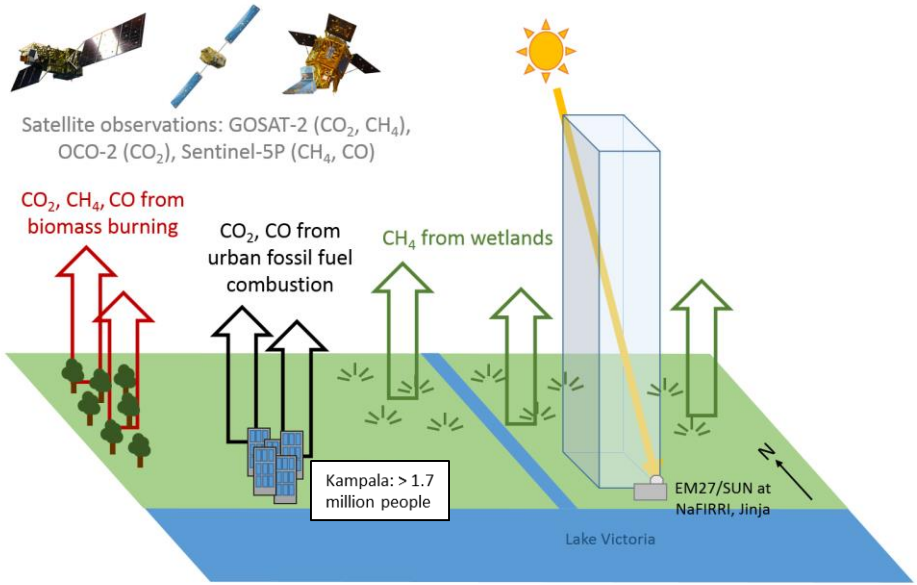
AUTONOMOUS OPERATION IN ALL WEATHER

- Automated enclosure developed by TU Munich (Florian Dietrich, Jia Chen) – *see Dietrich et al (2021) in AMT*
- Enables continuous remote operation via internet connection
- Provides environmental protection and stability:
  - Active cooling and heating
  - Automatic retractable dome triggered by rain sensor
  - Webcam for remote visual inspection
- *Deployment would be near-impossible without this contribution!*



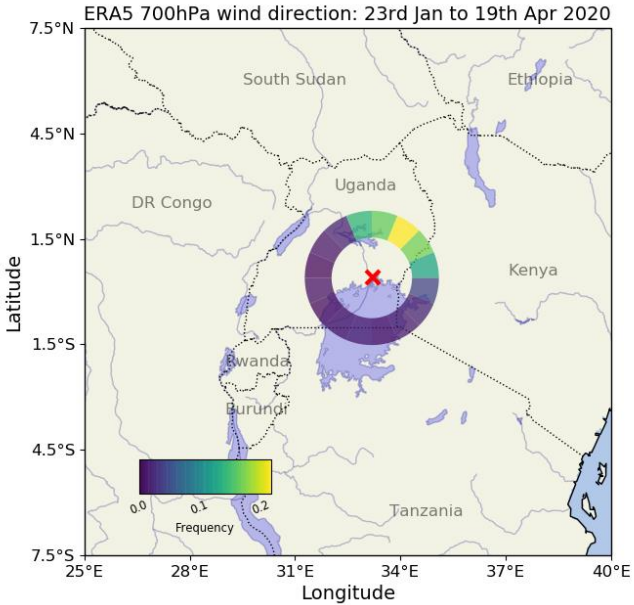
DEPLOYMENT IN JINJA, UGANDA

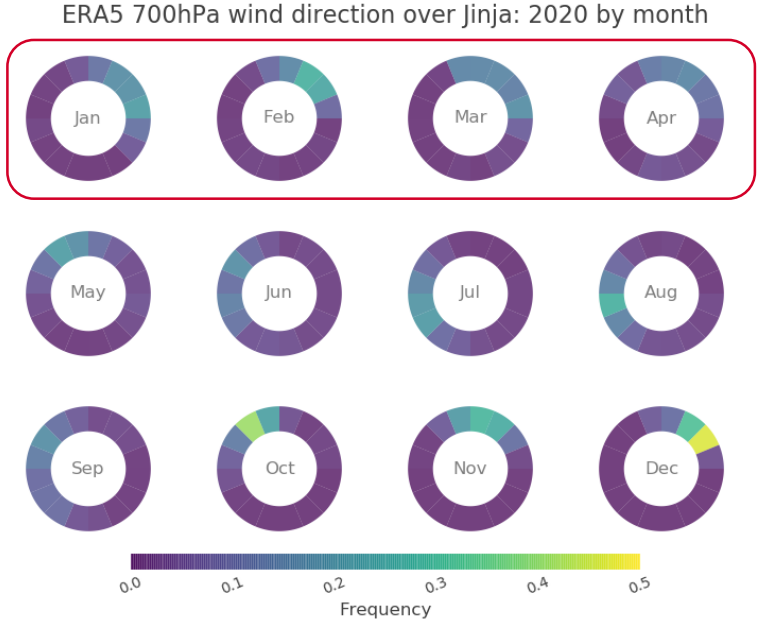
- Part of NERC Global Methane project MOYA
- EM27/SUN and enclosure hosted by NaFIRRI (William Okello)
  - *Partner on-site essential!*
- Operated for an initial 3 month deployment from January to April 2020, data processed using COCCON tools
- Ideal location for methane emissions from wetlands and agriculture, GHGs and carbon monoxide from biomass burning
- Filling gap in satellite and model validation networks over tropical East Africa



METEOROLOGICAL CONDITIONS OVER JINJA

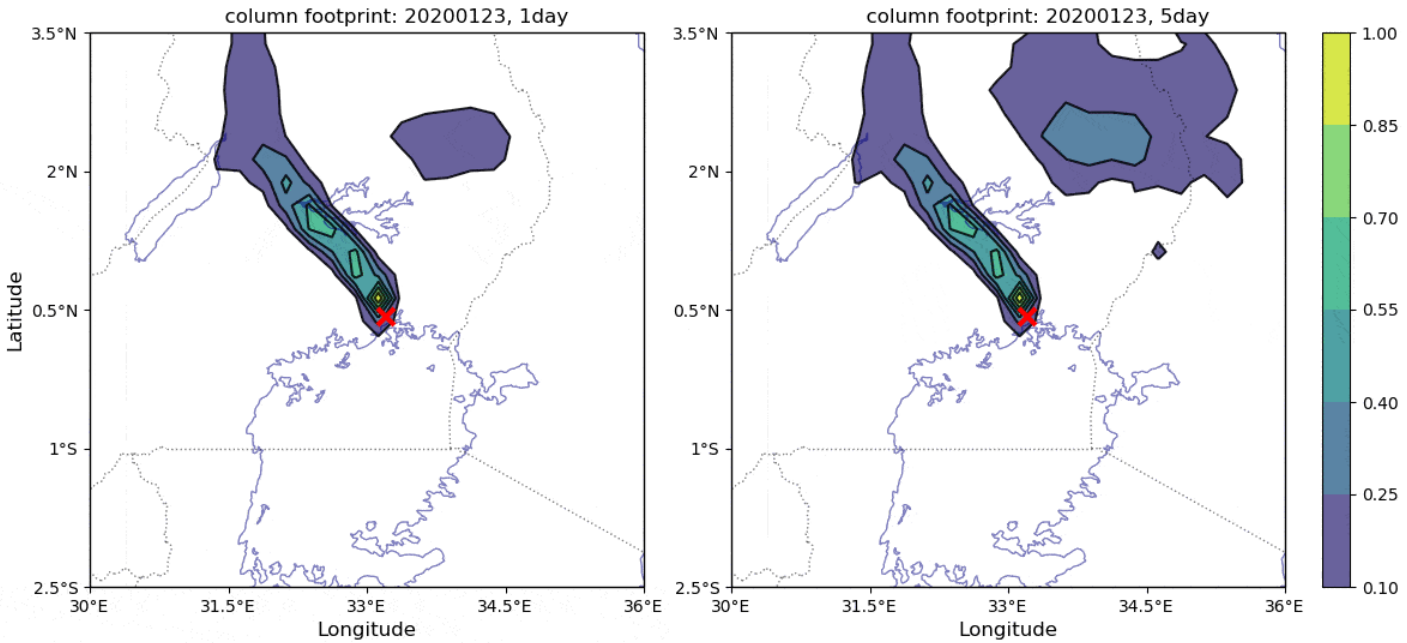
- Wind directions at 700 hPa altitude from ERA5 reanalysis
- Air primarily from northeast during the 2020 observation period → main sources are agriculture and wetlands
- Variable wind direction during the year → range of sources influencing the observed column





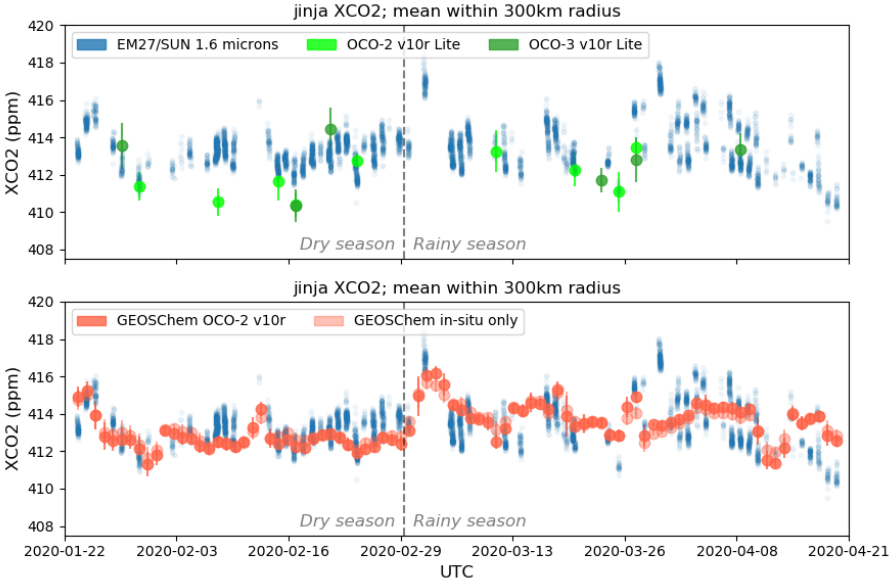
METEOROLOGICAL CONDITIONS OVER JINJA

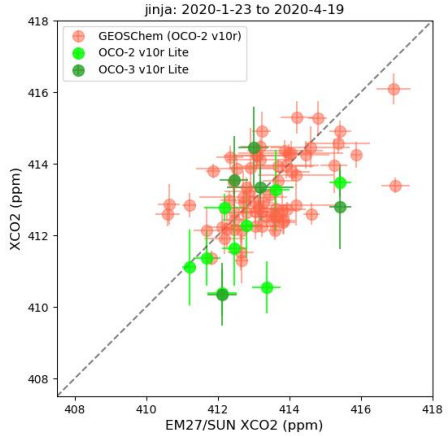
- Back trajectory calculations using NAME (Lagrangian model developed by UK Met Office)
- For each measurement day, calculate contribution of air parcels passing the surface during the previous 1 (left) or 5 (right) days to the atmospheric column over Jinja (weighted by vertical sensitivity of column observation)
- Plots show each day of 2020 measurement period (January 23rd to April 19th)



EM27/SUN DATA FROM JINJA: CARBON DIOXIDE COMPARISONS

- Carbon dioxide:
  - Satellite retrievals: OCO-2 v10r Lite, OCO-3 v10r Lite
  - OCO-2 and OCO-3 data from 2020 recently reprocessed (v10r)
  - Model data: global GEOSChem inversion (Liang Feng, U. Edinburgh) (2.0° x 2.5°)





OCO-2 v10r Lite (N=9) – EM27/SUN: **-0.89 (1.01) ppm**

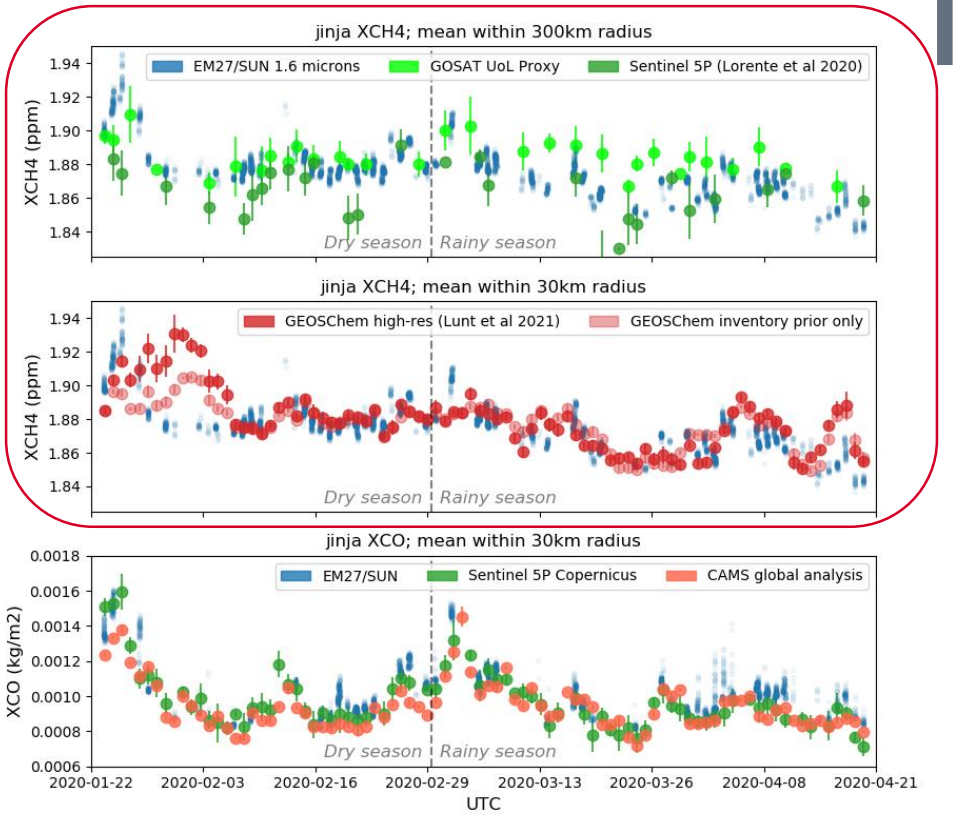
OCO-3 v10r Lite (N=5) – EM27/SUN: **-0.34 (1.60) ppm**

GEOSChem (OCO-2 v10r) (N=60) – EM27/SUN: **-0.12 (1.07) ppm**

Caveats: only 3 months of data, wide spatial colocation, limited number of overpasses due to narrow swath

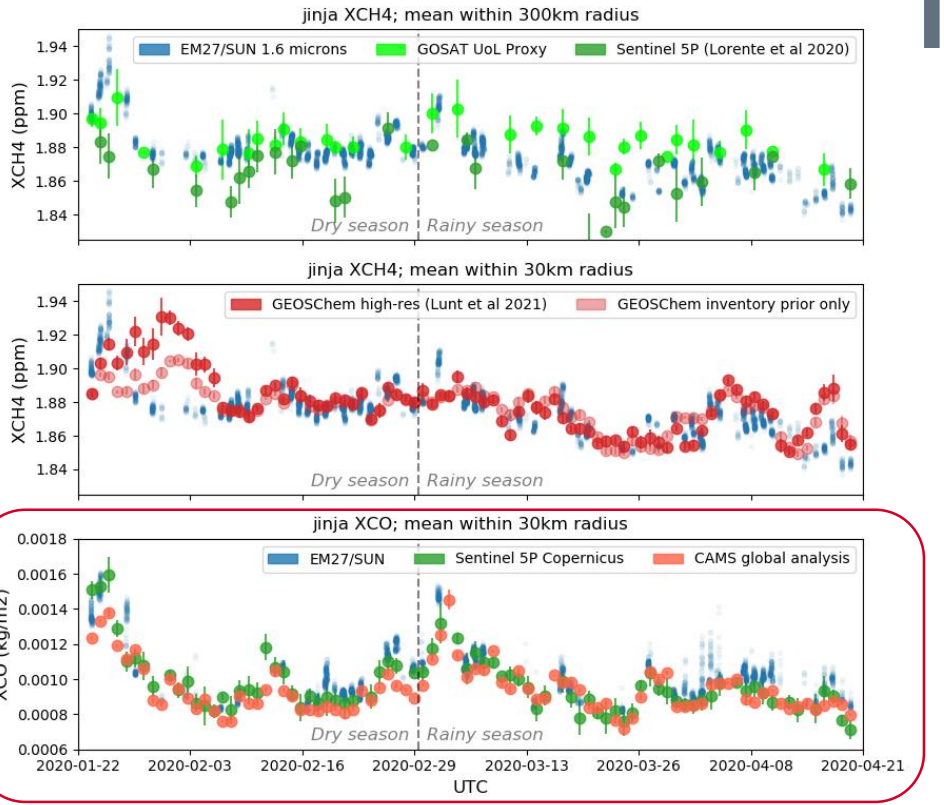
EM27/SUN DATA FROM JINJA: METHANE AND CARBON MONOXIDE COMPARISONS

- Methane:
  - Satellite retrievals: University of Leicester GOSAT proxy (Parker et al 2020, ESSD), SRON Sentinel 5P TROPOMI (Lorente et al 2020, AMT)
  - Model data: high spatial resolution GEOSChem (0.25° x 3125°, Lunt et al 2021, ERL) with and without (i.e. inventory prior only) assimilation of S5P TROPOMI
  - GEOSChem used to infer surface fluxes from satellite data → essential to check that model captures observed variability and trends

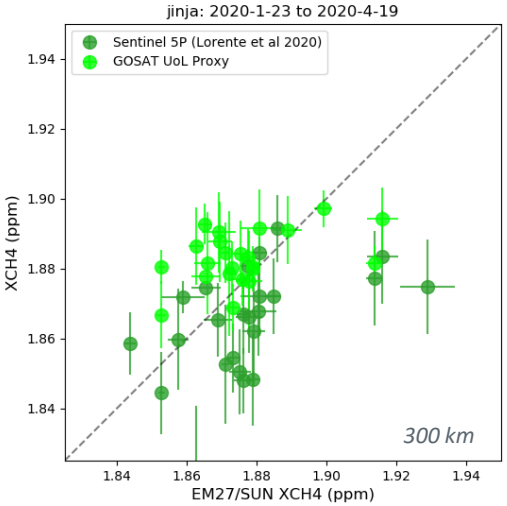


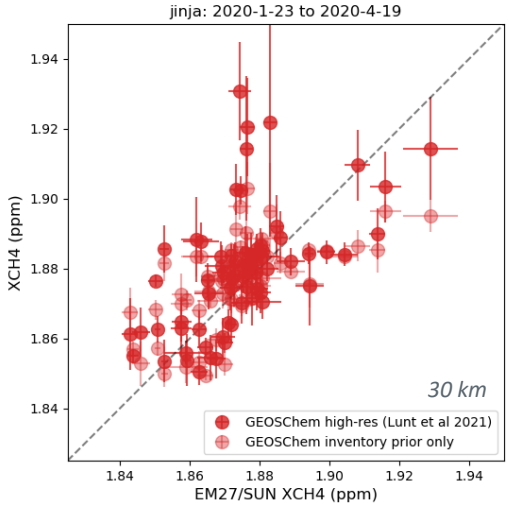
EM27/SUN DATA FROM JINJA: METHANE AND CARBON MONOXIDE COMPARISONS

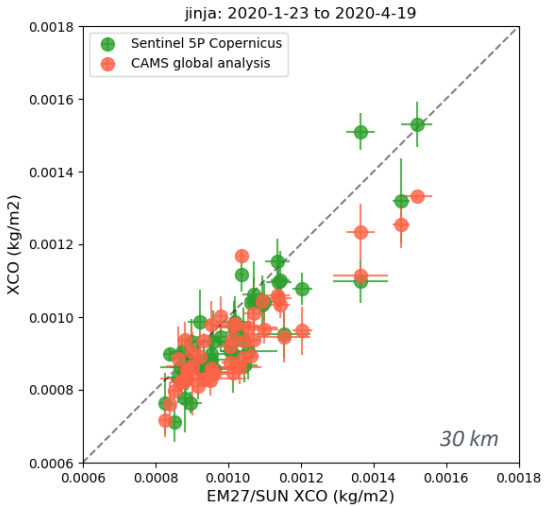
- Carbon monoxide:
  - Satellite retrieval: Copernicus Sentinel 5P TROPOMI (Landgraf et al 2016, AMT)
  - Model data: Copernicus Atmospheric Monitoring Service (CAMS) global analysis (Inness et al 2019, ACP)
  - Useful proxy for biomass burning, other incomplete combustion processes



EM27/SUN DATA FROM JINJA: METHANE AND CARBON MONOXIDE COMPARISONS







GOSAT UoL Proxy (N=23) – EM27/SUN: **6.80 (13.9) ppb**

S5P (N=24) – EM27/SUN: **-14.3 (19.7) ppb**

GEOSChem high-res (N=68) – EM27/SUN: **4.76 (15.7) ppb**

GEOSChem inventory prior only (N=68) – EM27/SUN: **2.48 (12.7) ppb**

S5P Copernicus (N=46) – EM27/SUN: **-5.61 (7.43) x10^{-5} kg/m^2**

CAMS global analysis (N=51) – EM27/SUN: **-8.60 (7.46) x10^{-5} kg/m^2**

Caveats: only 3 months of data, wider spatial colocation for CH_4 satellite retrievals vs. models

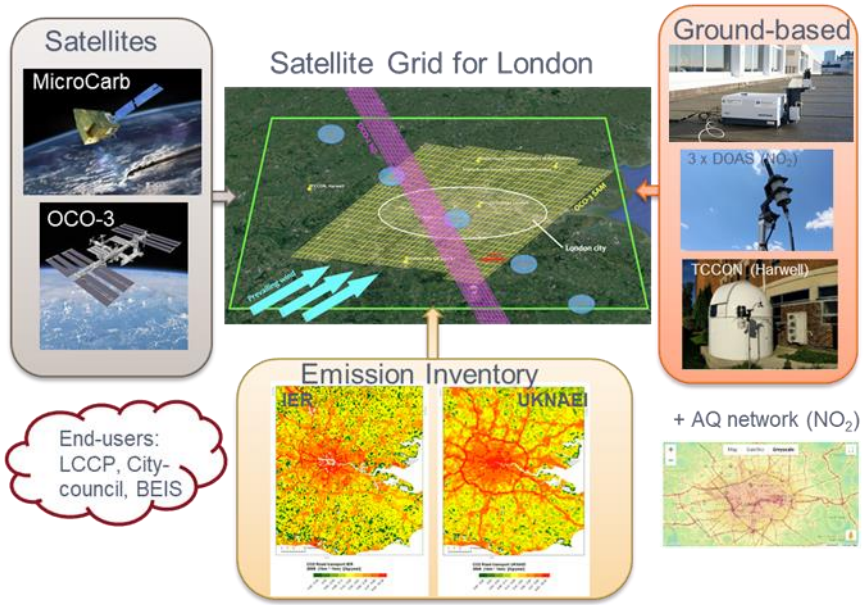
nh58@le.ac.uk / @DrNeilHumpage

SUMMARY AND FUTURE PLANS FOR JINJA

- Bruker EM27/SUN spectrometer operated for three months in Jinja, Uganda using an automated weatherproof enclosure
  - Dataset for validation of Sentinel 5P, OCO-2/3, GOSAT
  - Comparison with GEOS-Chem model runs (Mark Lunt, Liang Feng – University of Edinburgh) – demonstrate validity of models used in other studies
  - Breaking down dataset by local wind direction and speed, dry vs. rainy season to investigate East African GHG sources, in conjunction with Lagrangian transport model (NAME, UK Met Office)
  - Deployment cut short by technical problems, since resolved – *returning to Jinja as part of ESA SVANTE/QA4EO*
  - Lots of collaboration to make this work! Would not be possible without efforts of colleagues at NaFIRRI and TU Munich, in particular

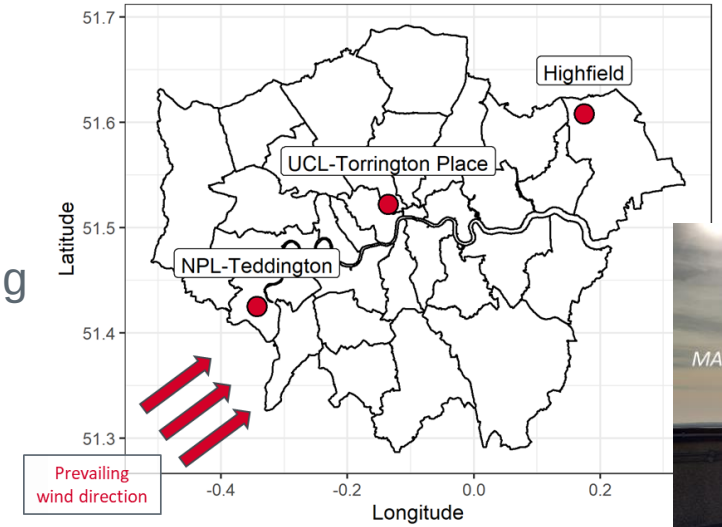
THE LONDON CARBON EMISSIONS EXPERIMENT CONCEPT

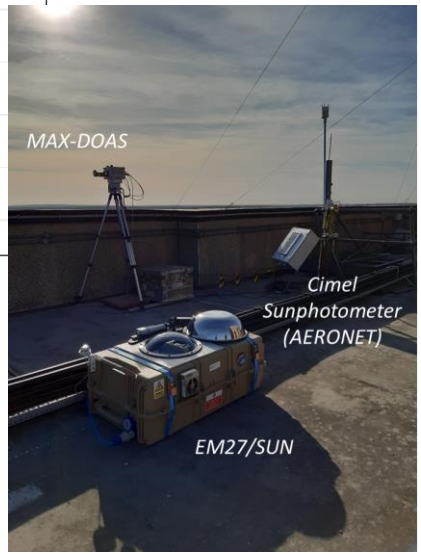
- Part of UK Natural Environment Research Council (NERC) DARE-UK project – see *dareuk.blogs.bristol.ac.uk*
- Establish ground-based remote sensing network (CO_2, CH_4, CO, NO_2, aerosol)
- Combine with city-focused satellites (OCO-3, MicroCarb)
- City-scale modelling to link to emission inventories
- London as testbed for studies on CO_2 emissions

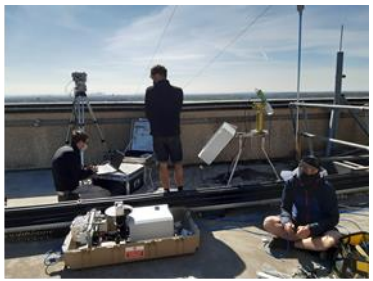


MEASUREMENT LOCATIONS

- Three “nodes” along a SW-NE transect, following the prevailing wind direction:
- SW Node – National Physical Laboratory, Teddington
- Central Node – University College London, Torrington Place
- NE Node – Highfield Residential Tower

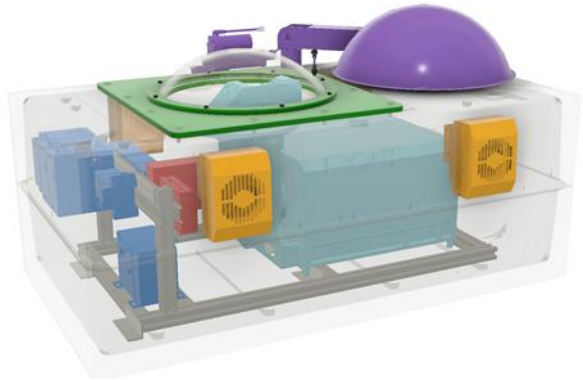






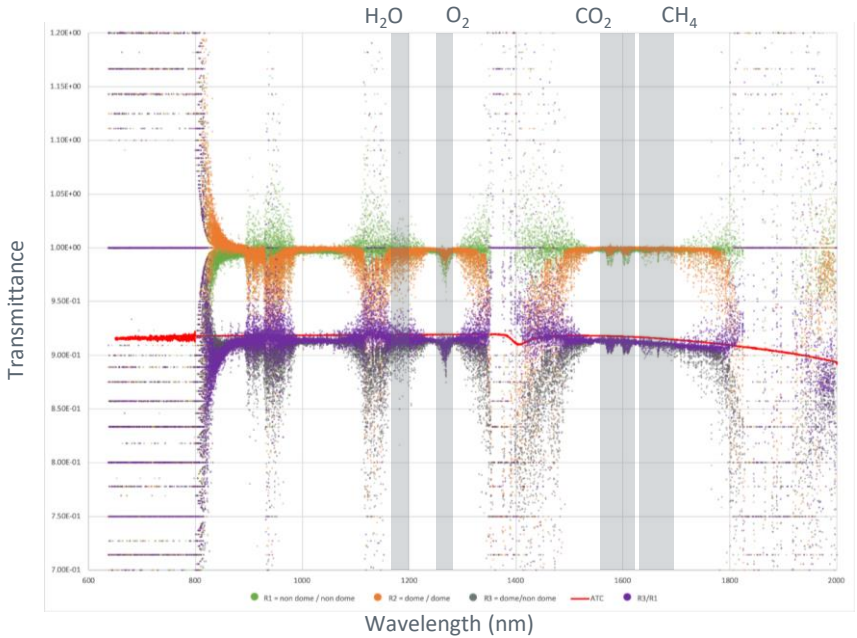
ENCLOSURE DESIGN FOR THE EM27/SUN

- EM27/SUNs are not weatherproof → operate from within an enclosure, which also allows remote and autonomous operation
- Original concept by Heinle and Chen, AMT 2018 (TU Munich)
- Design by Jerome Woodwark (University of Edinburgh)
- Key to CAD rendering:
  - EM27/SUN
  - Power system components: includes UPS in case of sudden interruption of power supply, allowing safe shutdown
  - Control systems: mini-PC controlling spectrometer, other sub-systems, remote access via Internet
  - Thermal control: fan-assisted heating and cooling to prevent extremes of temperature
  - Optical dome mount
  - Movable dome protective cover

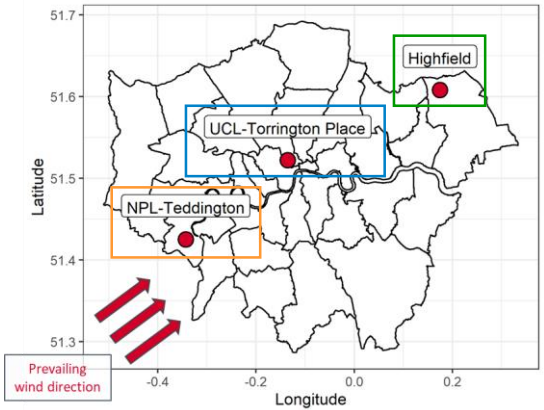


TESTING OF SAMPLE MATERIAL FOR THE PROTECTIVE DOME

- Performed observations in Edinburgh both with and without a sample of dome material (5mm thick optical glass) in the line of sight of the solar tracker
- Check optical transmittance of material at wavelengths used by X_{GAS} retrievals – transmittance estimated from EM27/SUN spectra has same wavelength dependence as transmittance from lab measurement
- Confirmed that slight refraction of incoming light does not impair solar tracker performance

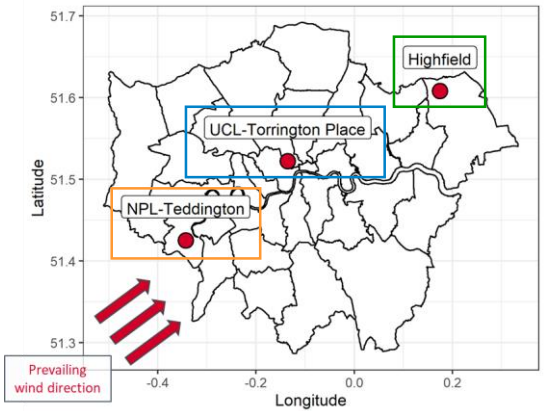


FIRST 10 MONTHS OF EM27/SUN TOTAL COLUMN DATA

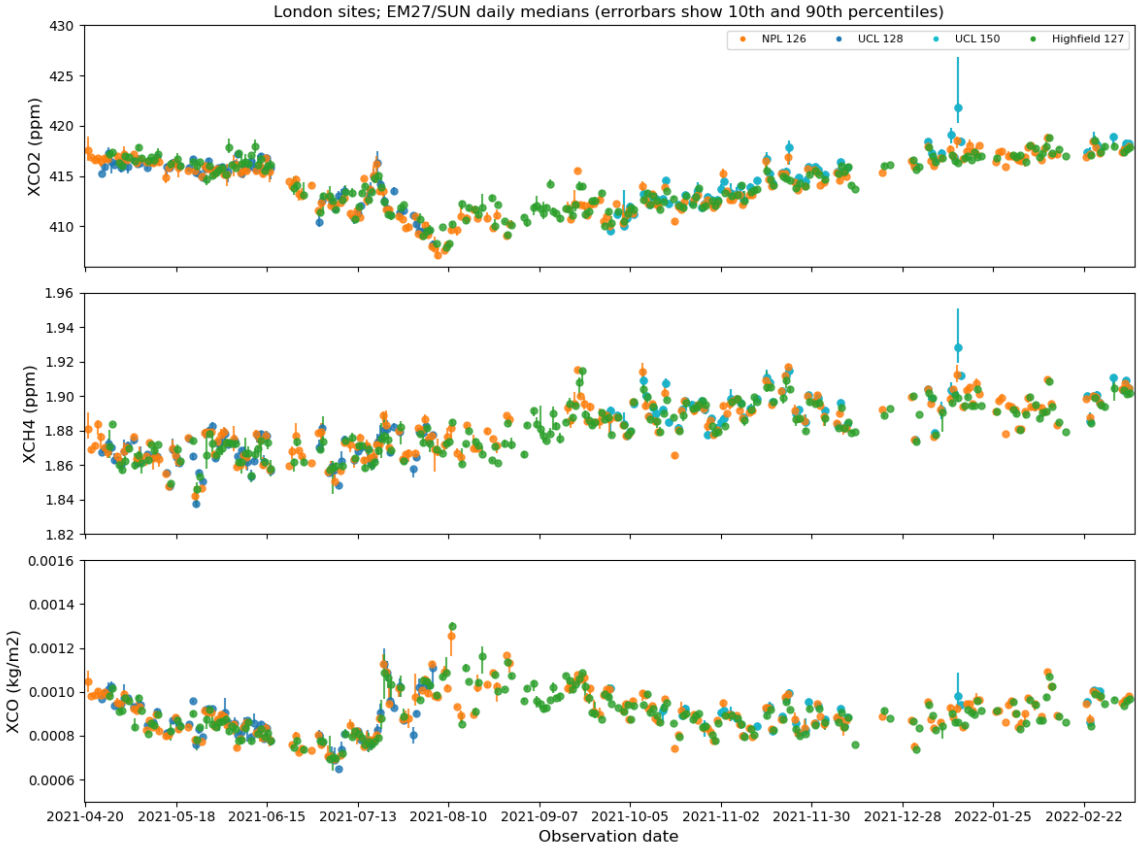


- Automated enclosures allow for very good temporal coverage

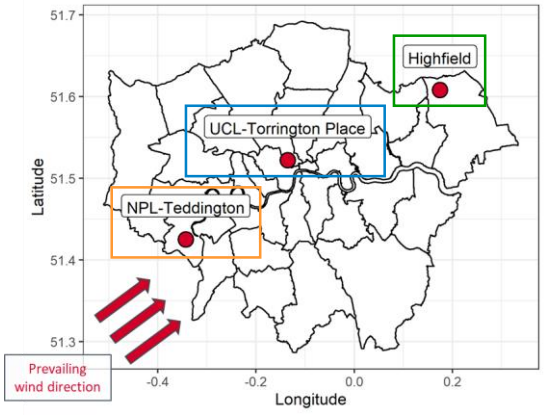
PRELIMINARY COMPARISON WITH SATELLITE DATA



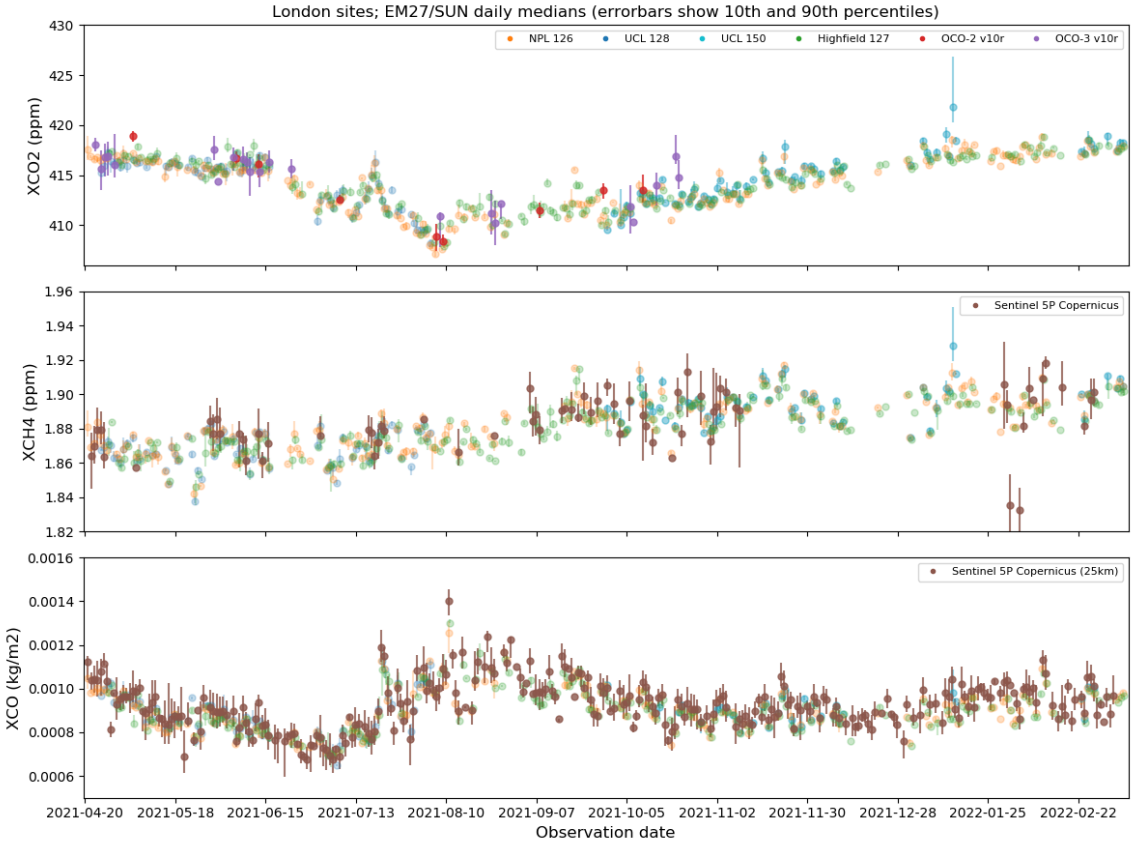
- Daily medians
- 10th to 90th percentile range
- 100km co-location (25km for XCO)
- OCO-2/3 only available until end of October



PRELIMINARY COMPARISON WITH SATELLITE DATA

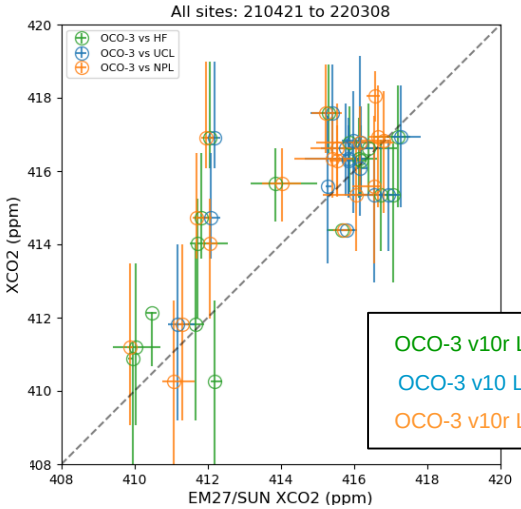


- Daily medians
- 10th to 90th percentile range
- 100km co-location (25km for XCO)
- OCO-2/3 v10r available until end of October



FOCUS ON CARBON DIOXIDE

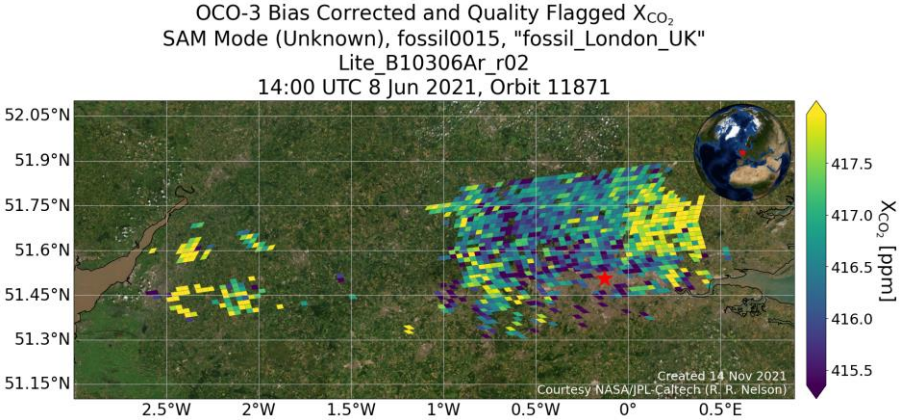
- OCO-2: limited coverage due to narrow swath
- OCO-3: Snapshot Area Map (SAM) mode provides more data, some spatial information (https://ocov3.jpl.nasa.gov/sams/) – v10r data now available!
- Microcarb will provide 'city' imaging mode with similar coverage to OCO-3 SAM

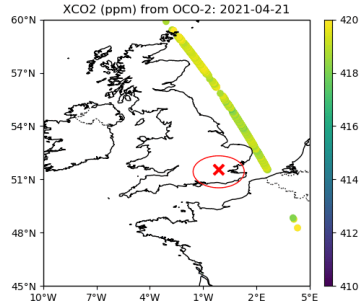


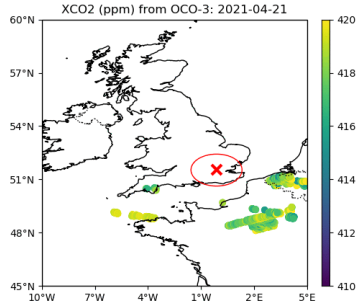
OCO-3 v10r Lite (N=19) – EM27/SUN: **0.42 (2.09) ppm**

OCO-3 v10 Lite (N=15) – EM27/SUN: **0.61 (1.58) ppm**

OCO-3 v10r Lite (N=19) – EM27/SUN: **0.65 (1.95) ppm**

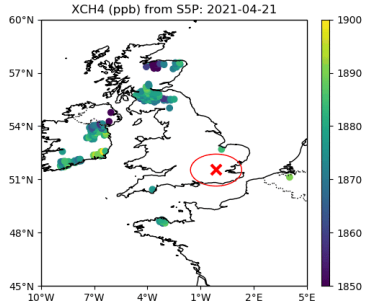


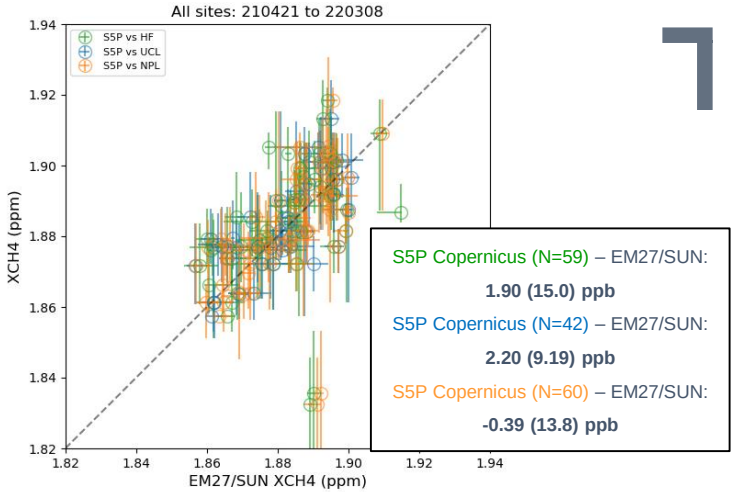


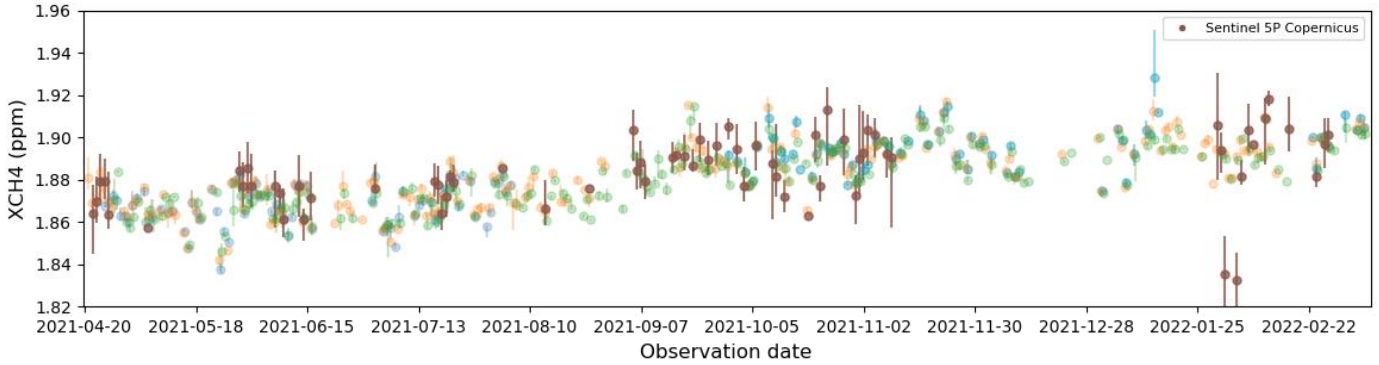


FOCUS ON METHANE

- Publicly available XCH_4 data from the Sentinel-5P Pre-Operations Data Hub (s5phub.copernicus.eu)
- Wide swath with 7km spatial resolution, however retrieval coverage is limited by clouds

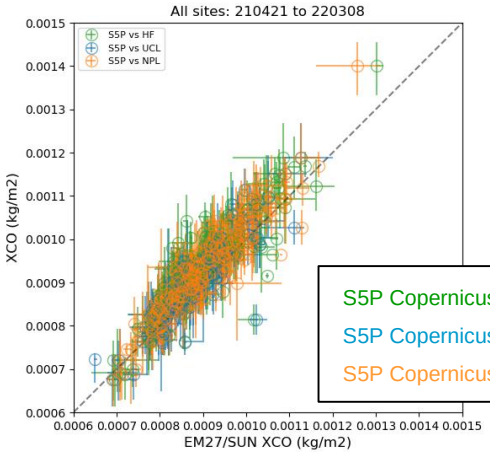






FOCUS ON CARBON MONOXIDE

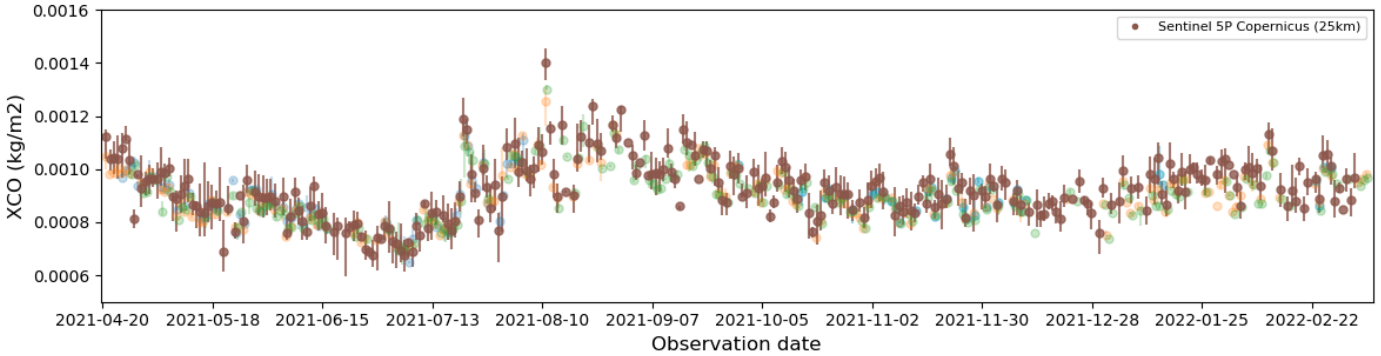
- Publicly available XCH_4 data from the Sentinel 5P Pre-Operations Data Hub (s5phub.copernicus.eu)
- Wide swath with 7km spatial resolution, very good coverage – unlike methane, retrieval works in cloudy conditions
- 25km colocation



S5P Copernicus (N=180) – EM27/SUN: **3.40 (4.90) x10^{-5} kg/m^2**

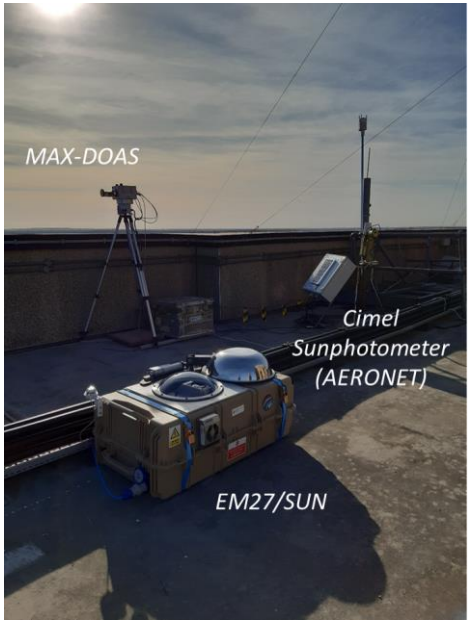
S5P Copernicus (N=102) – EM27/SUN: **1.67 (4.47) x10^{-5} kg/m^2**

S5P Copernicus (N=144) – EM27/SUN: **2.98 (4.06) x10^{-5} kg/m^2**



THE LONDON CARBON EMISSIONS EXPERIMENT - OUTLOOK

- Three observation nodes for ground-based remote sensing of the atmosphere have been set up along a SW-NE transect of London – *all three nodes running since late April 2021*
- Each node hosts:
  - Bruker EM27/SUN spectrometer for greenhouse gas monitoring
  - MAX-DOAS instrumentation for monitoring air quality and other trace gases – *capability to investigate synergy between NO_2 and CO_2*
  - Cimel Sunphotometer (AERONET) – *capability to investigate impact of aerosol on satellite validation*
  - Weather station for local meteorology
- Developed and tested new enclosure design to allow automation of the EM27/SUNs
- Ongoing and future work to incorporate data from city-scale focused satellites, in-situ sampling networks and modelling based on emissions inventories to study London's carbon emissions footprint
- London to be added to OCO-2 target list
- Plan to set up a fourth EM27/SUN and enclosure (belonging to University of Leicester) – support London network by providing background observations outside of the city
  - Data from Harwell TCCON will provide further non-urban observations for comparison



SOME FINAL THOUGHTS…

- Automated enclosures *extremely* useful – allow for high density of observations, observations under intermittently cloudy conditions, deployment in less accessible locations…
- … however, I would still highly recommend having somebody able to access your site to check on any problems in-person!
  - In Jinja, we have an invested partner willing to help troubleshoot any issues
  - Similarly in London, with two of the three sites… Highfield site on a local council managed residential tower block, so any issues there we have to visit the site ourselves

SOME FINAL THOUGHTS…

- A few practical points when identifying potential measurement sites…
  - Access: if you're considering a rooftop, how do you get the instrument and enclosure up there? Is the location secure?
  - Power: how reliable is the mains power source? Do you need to consider a backup in case of power outages?
    - Solar panel + battery combination
  - Data: where are you backing up data locally? How reliable is wired internet for data transfer, remote login?
    - USB modem has worked well in Jinja for remote login, and transferring small numbers of files – needs good cellphone coverage!
- Any other tips or strategies?