

# A new in-situ aircraft measurement program for CO<sub>2</sub>, CH<sub>4</sub>, and CO in Uganda

Kathryn McKain

Colm Sweeney, Phil Handley, Sonja Wolter, Tim Newberger, Andy Jacobson

NOAA Global Monitoring Laboratory  
(GML)

University of Colorado Boulder  
Cooperative Institute for Research in  
Environmental Sciences (CIRES)

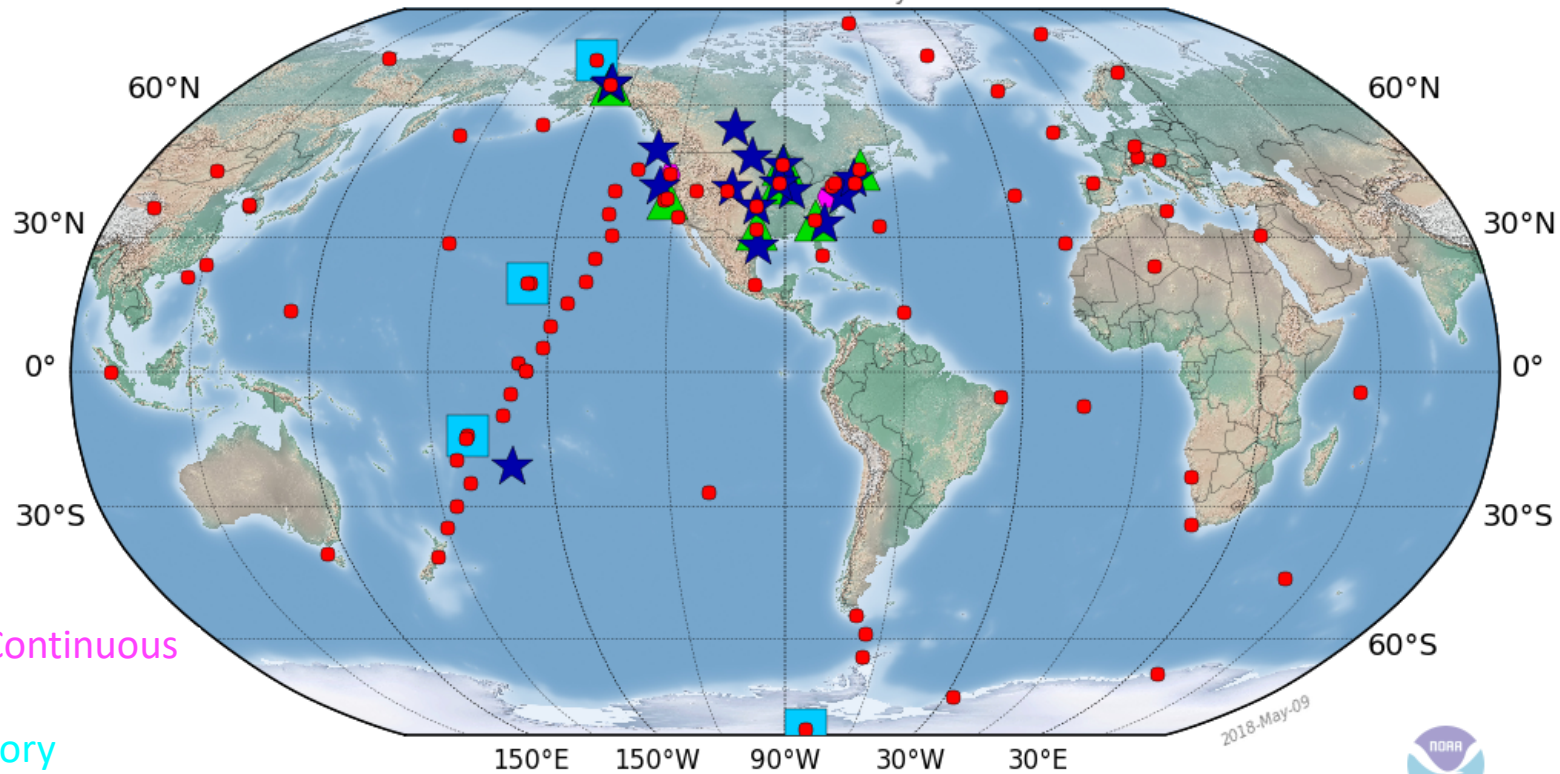


10 June 2021





# NOAA Global Greenhouse Gas Reference Network



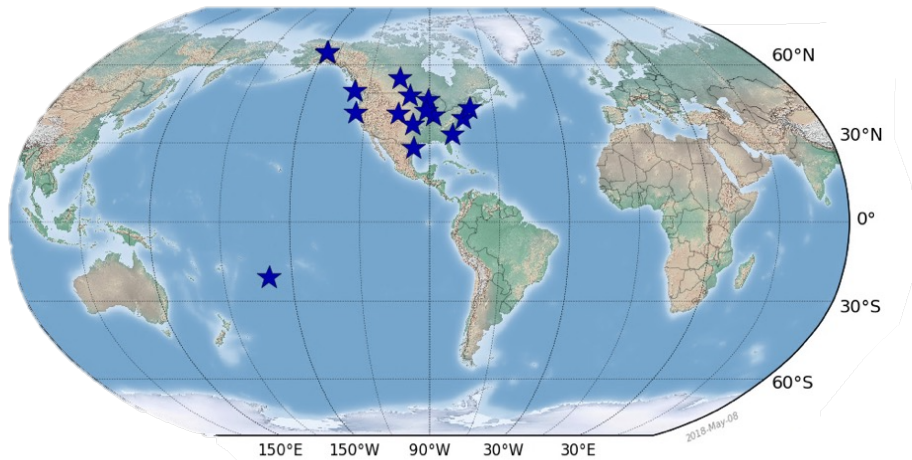
- ★ Aircraft
- Surface Continuous
- ▲ Tower
- Observatory
- Surface Discrete



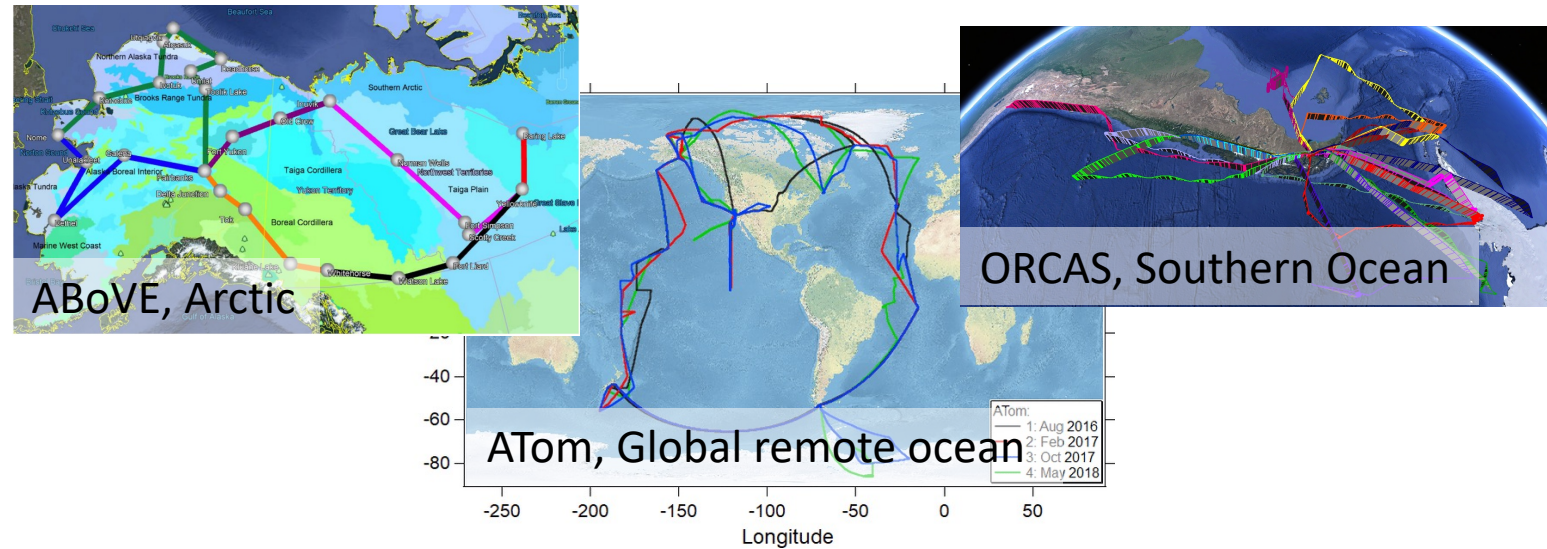
- Long-running in-situ measurements of greenhouse gases ( $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{CO}$ ,  $\text{N}_2\text{O}$ ,  $\text{SF}_6$ ,  $\text{H}_2$ ) at sites around the world from a variety of platforms
- Many discrete samples also analyzed for hydrocarbons, ozone-depleting substances, and isotopes of  $\text{CO}_2$  and  $\text{CH}_4$
- Several gases are carefully calibrated relative to WMO scales
- Intra-laboratory and cross-laboratory comparisons with other labs ensure data quality and compatibility
- Data are combined with those from labs around the world, repackaged, and routinely distributed to modelers
- **Large observational gaps in the tropics, South America, and Africa**

# NOAA Global Monitoring Laboratory Aircraft Program

## Aircraft Network



## Aircraft Campaigns



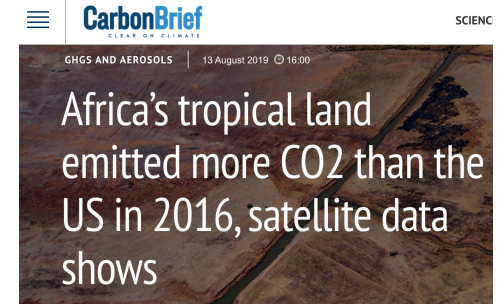
- 13 sites in N. Am. currently
- 15+ yr record at each site
- Private pilots flying small aircraft
- 1-2 vertical profiles per month

- Aircraft measurements are useful because they have:
- Large scale sensitivity to surface fluxes
  - Free troposphere boundary conditions
  - Information about transport and vertical mixing
  - Integrate signals across scales from multiple processes
  - Access remote regions where surface measurements are challenging

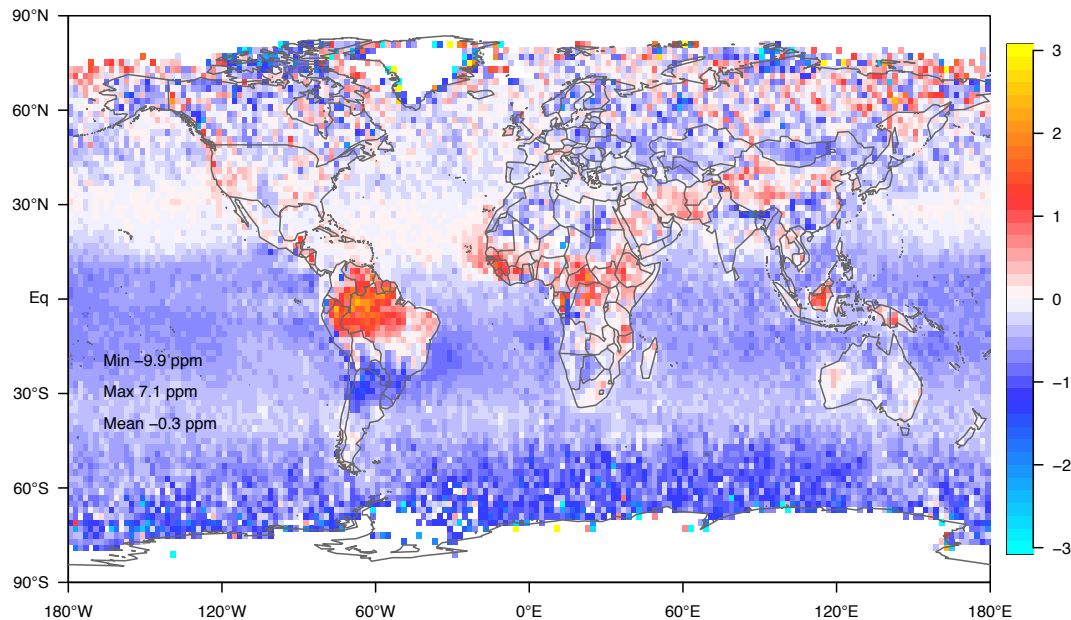


# Motivation for a new in-situ aircraft greenhouse gas measurement program in tropical Africa

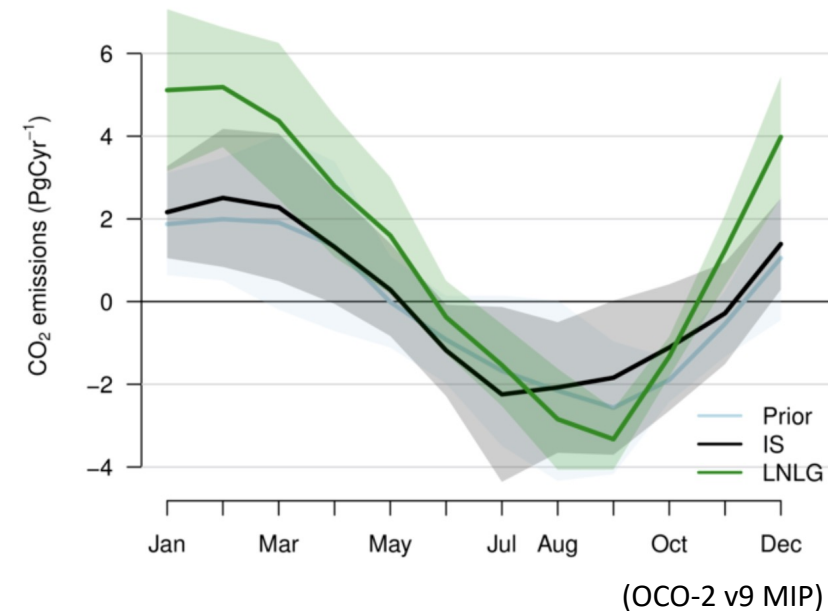
- Large CO<sub>2</sub> signal from tropical Africa seen from OCO-2 but not predicted by terrestrial biosphere models or global inversions constrained by in-situ data.
- Inversions assimilating OCO-2 observations find northern tropical Africa is a larger source of CO<sub>2</sub> by up to ~1.5 PgC yr<sup>-1</sup>.
- Also find significant positive trend in CH<sub>4</sub> emissions using satellite data
- No in-situ data available for evaluation



OCO-2 B10 LN and OG XCO<sub>2</sub> "Signal"



Average land fluxes from north tropical Africa from models assimilating OCO-2 and in-situ data





# Program Design

**Goal:** Aircraft in-situ vertical profile measurements in northern tropical Africa for satellite evaluation and to fill a major gap in the global observing network

**Funding:**

One year of measurements (4-hr flight every 20 days) funded by NOAA Climate Program Office

**Partners:**



modifies and operates jet, turbo-prop, fixed and rotary-wing aircraft to deliver critical airborne services to government and science customers



P R I O R I T Y | 1

a diversified international aerospace and defense company that delivers end-to-end mission services to commercial and government customers by leveraging the best technical and operational capabilities in the world



- Business and Tourism Charter
- Passenger and Cargo
- Medivac
- Disaster Relief
- Aerial and geophysical Survey
- Oil, Gas, and Mining
- Dedicated and ride-along flight opportunities
  
- **Relying on experienced local operator to execute flights**

# Aircraft and Measurement System

- Kampala Executive Aviation (KEA) aircraft charter company in Uganda
- Modified and instrumented Cessna 208B Grand Caravan
- Dedicated and ride-along flight opportunities
- Measurement system designed to be robust, low-maintenance, easy to operate, and quick to load on and off the aircraft
- Installed and operated by KEA without NOAA personnel present due to travel restrictions

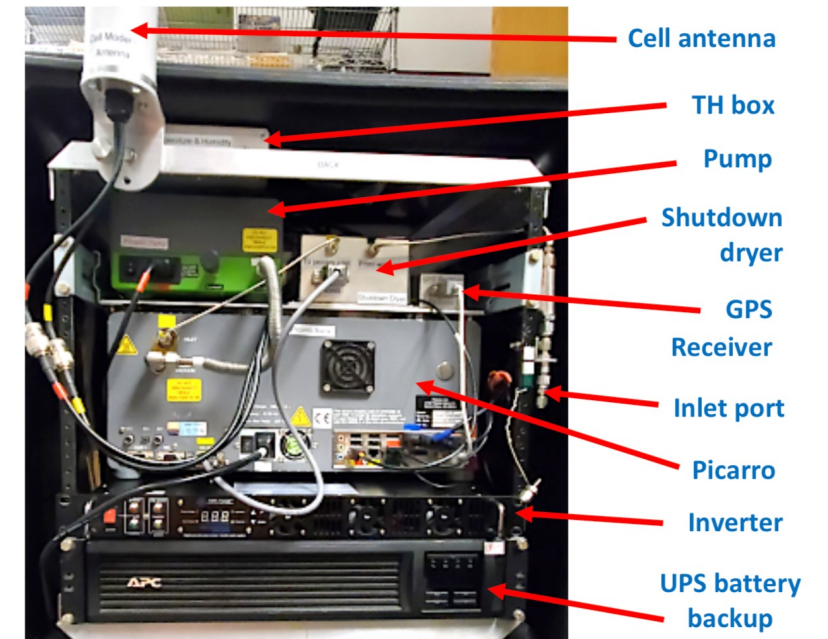
KEA Cessna Grand Caravan



Sample Inlet



Picarro measurement system for CO<sub>2</sub>, CH<sub>4</sub>, CO

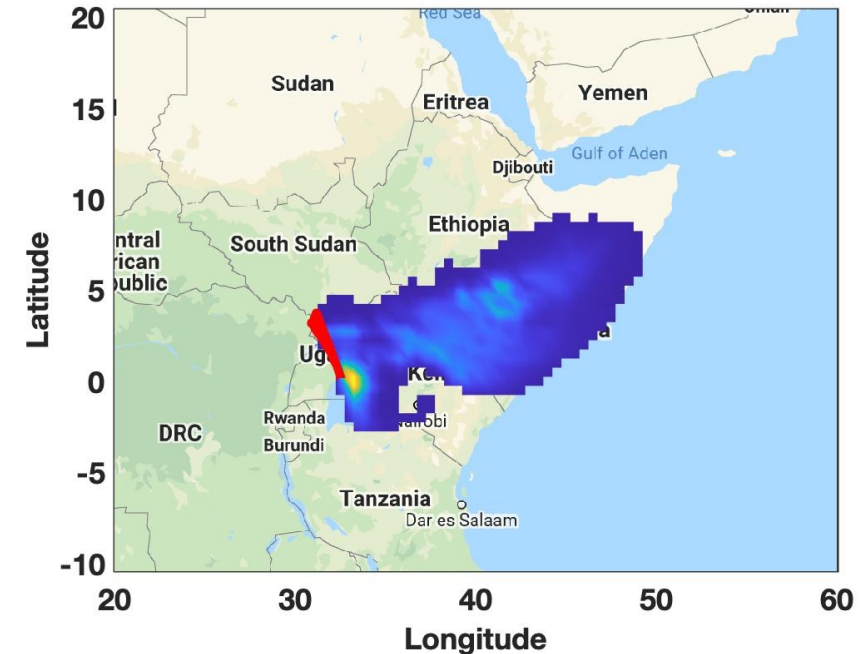
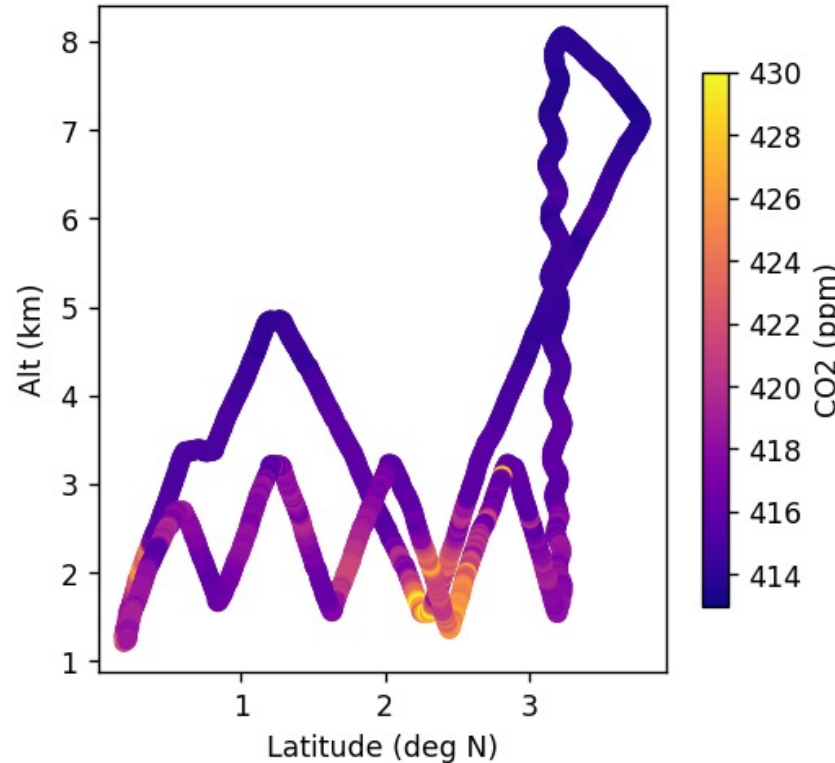
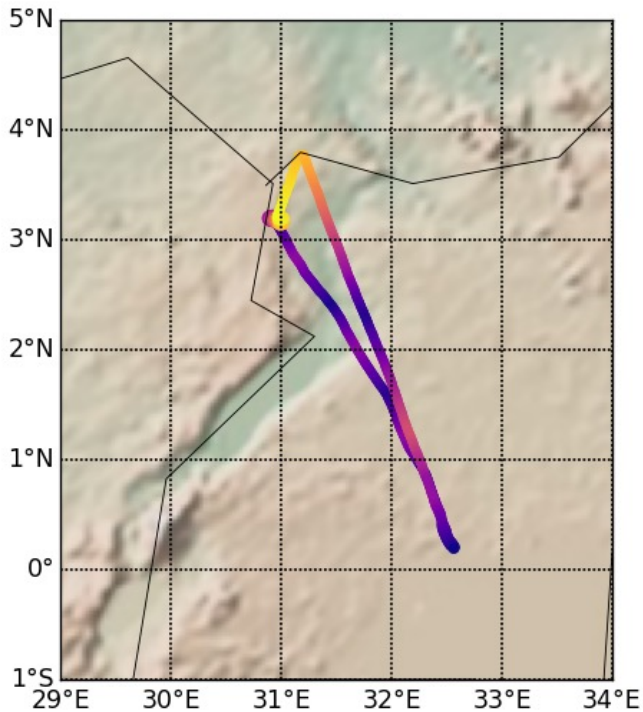




# Data from flight on 2020-12-30: Flight Path

Flight plan designed to sample vertical and meridional distributions across an urban to rural landscape

Aircraft measurements are sensitive to surface fluxes from broad regions



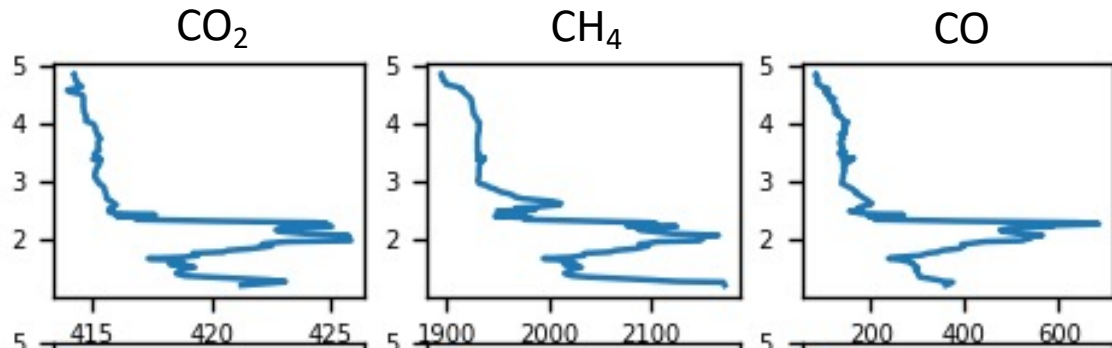
In-situ and satellite CO<sub>2</sub> will be compared:

- Directly by extending vertical profiles and identifying coincident total column observations
- Indirectly via models assimilating satellite data

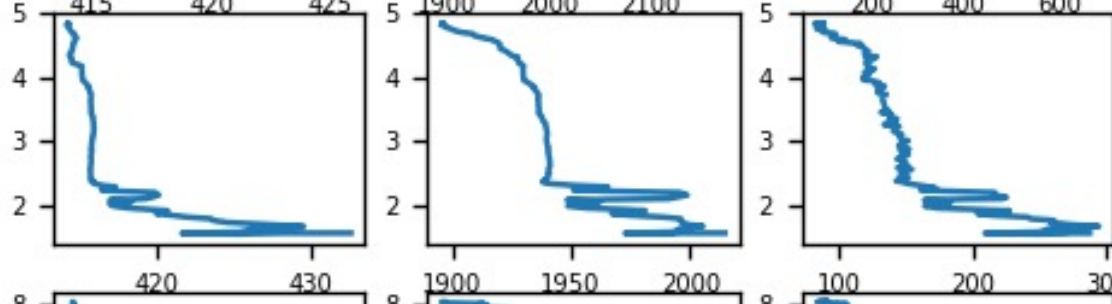
3-day Lagrangian footprint from HYSPLIT and GFS 0.25° meteorology showing the upwind surface influence region for flight measurements (flight track is in red)

# Data from flight on 2020-12-30: Vertical Profiles

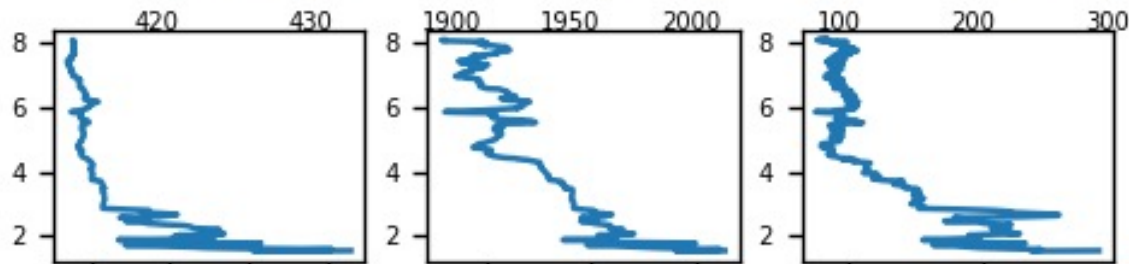
Profile 1  
(South)



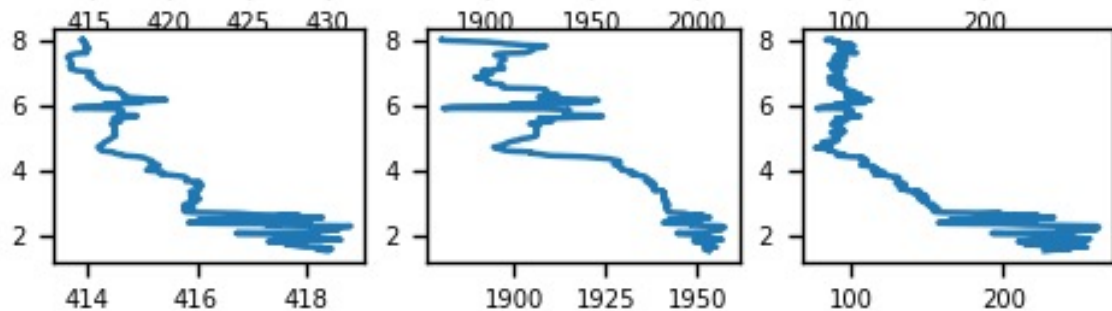
Profile 2



Profile 3

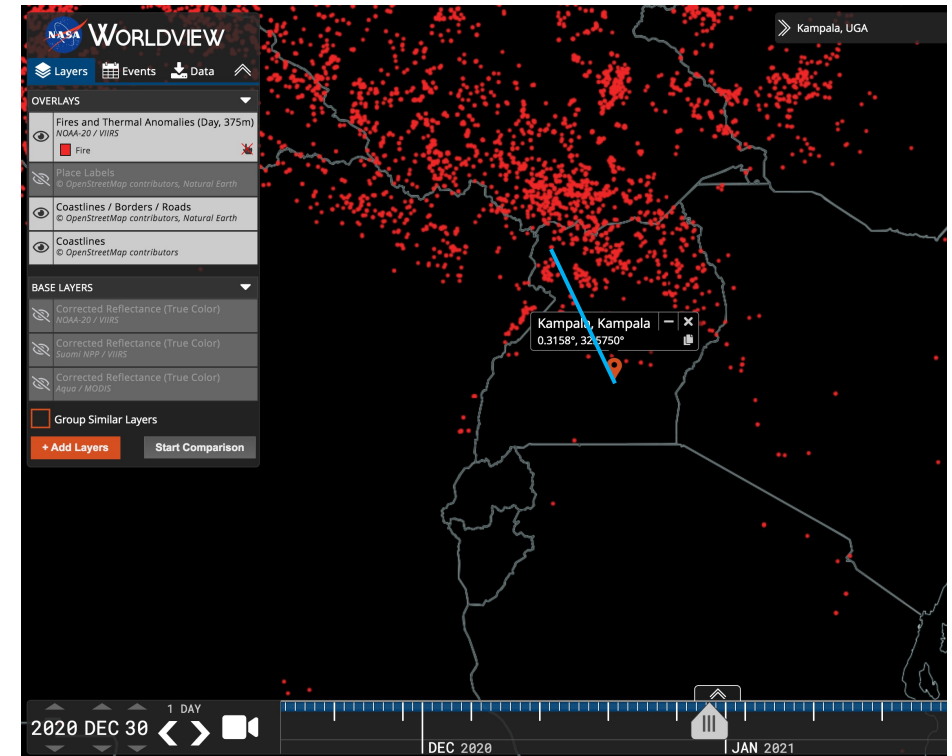


Profile 4  
(North)



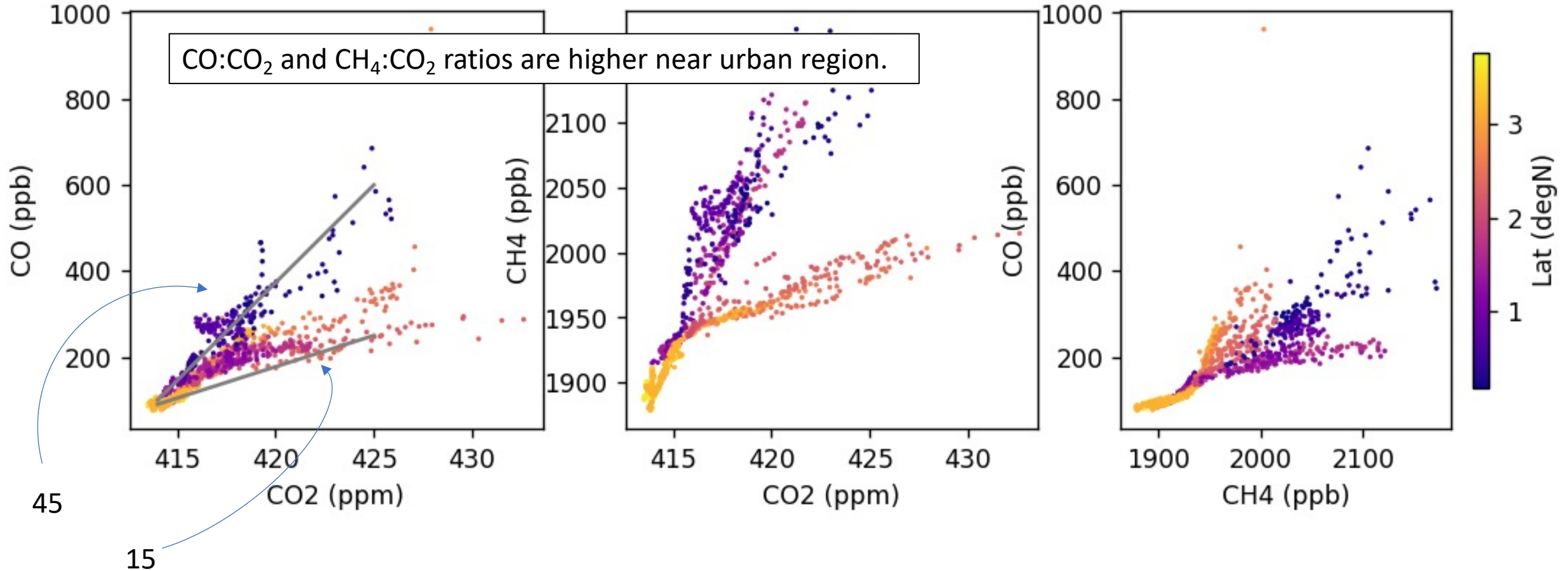
Large enhancements in all gases and complex vertical structure across the flight track.

Outside of Kampala, landscape appears rural with a moderate number of satellite-detected fires in the vicinity.





# Data from flight on 2020-12-30: Tracer-Tracer Relationships



Lagrangian footprints will be generated to facilitate comparison to inventories:

- Emission magnitudes by comparison to observed total concentrations
- Relative mix of sources by comparison to observed tracer-tracer ratios

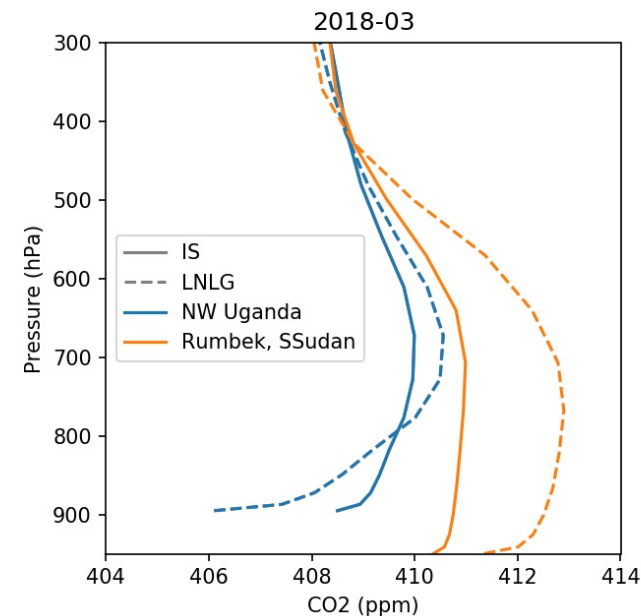
# Challenges and Plans

- Time zone (GMT+3): Working hours in Uganda are ~10 pm – 6 am local time
- Intermittent and low-quality power
- Variable cell signal strength
- Shipping is expensive
- National internet outage and subsequent social media block impacted ALL of our communication tools (except email) in Jan 2021
- Unforeseen supplemental licensing requirement from Uganda Civil Aviation Authority led to 3-month down time during critical observation period (dry season, Feb-April)
- Military control of airspace adds complexity and expense to flight planning
- Current funding for 1-year of dedicated flights 2x/month
  - 6 flights completed to-date
- Ideally would extend measurements for 3 years and expand coverage into South Sudan (8 °N)

**Uganda has blocked social media indefinitely as diplomatic tensions spike with US**



<https://qz.com/africa/1959496/uganda-bans-social-media-again-diplomatic-tensions-rise-with-us/>



Average vertical profiles from posterior concentrations at potential measurement locations in Uganda and South Sudan in March 2018 from model runs assimilated in-situ (IS) and satellite (LNLG) data.



# Summary

- We have established a new aircraft in-situ measurement program for greenhouse gases in Uganda.
- The measurement system is designed to be compact, automated and robust to facilitate operation by the aircraft company and data collection on flights of opportunity.
- The program is designed to rely on an experienced local operator rather than U.S science agency for execution
- Data fill a major gap in the global data coverage.

## Research Opportunities

- Direct comparison of coincident in-situ and satellite observations and indirectly via global models assimilating satellite observations
- Investigation of emission inventories, biomass-burning, and ecosystem flux models, including those that are region specific. Dataset will allow for testing of emissions inventories for both complex urban sources and widespread biomass burning.
- A potentially powerful and unique dataset for investigating a variety of air quality and carbon-cycle questions for the region. Contact: [kathryn.mckain@noaa.gov](mailto:kathryn.mckain@noaa.gov)

