CarbonARA – Carbon Amazon Research Activity

M.J Wooster[1,2], M. Grosvenor[1], C. Middleton[1,2], S. Taylor[1], F. Owsley-Brown[1], W. Healy[1], L.Aragao[2], J. Tota[3], A. Weiss[4], F. Squires[4], J. Witherstone[4], R. Colombo[5], M. Longa[5], N. Humpage[6,2], T.Julitta[7], D. Houtz[8], L. Horvath[8], F.Tack[9], A.Merlaud[9], A. Marcos[3], R. Silva[3], D. Schuettemeyer[10], C. Albergel[10]

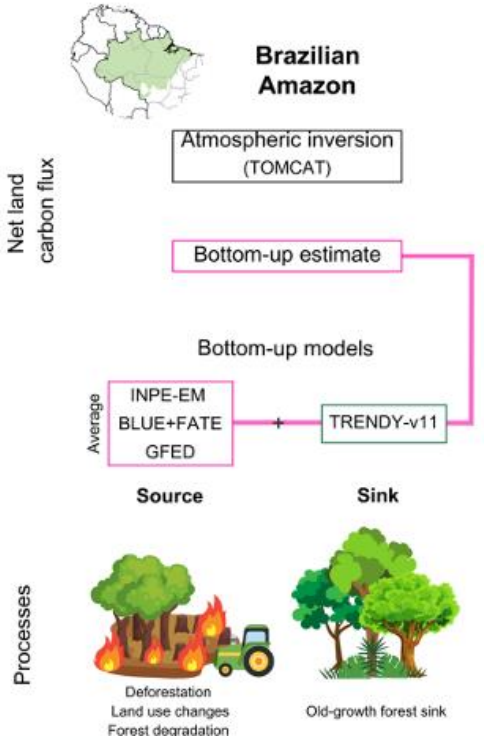
1 King's College London, UK
2 National Centre for Earth Observation, UK
3 Instituto Nacional de Pesquisas Espaciais (INPE), Brazil
4 Universidade Federal do Oeste do Pará (UFOPA), Brazil
5 British Antarctic Survey (BAS), UK
6 University of Leicester, UK
7 JB Hyperspectral GmbH, Germany
8 TerraRad Technologies, Switzerland
9 R. Belgian Institute for Space Aeronomy, Belg.
10 Eurpean Space Agency [ECSAT & ESRIN]

Martin Wooster

March 2026

CarbonARA - Rational

- **Amazon contains ~ 40% of global tropical forest area (60% in Brazil) and ~ 230-280 Pg C (> 50% in trees).**
- **Its climate change mitigation role maybe weakening (forest loss + degradation + fire + climate + drought).**



Discrepancy: Bottom-up calcs[1] suggest a small net C sink (-59 ± 160) but atm. inversions of satellite GHG data a source (+36 ± 125) Tg C yr^{-1}.

[1]doi.org/10.1038/s43247-024-01205-0

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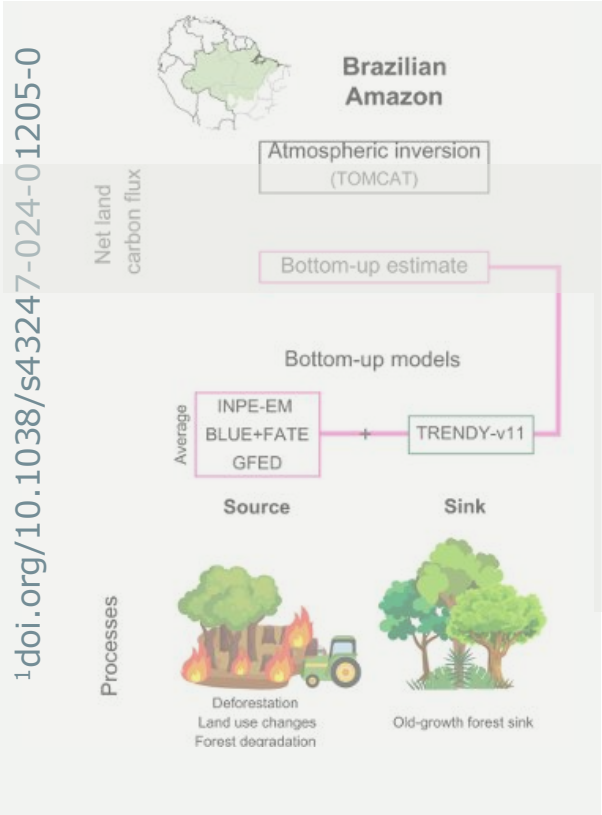

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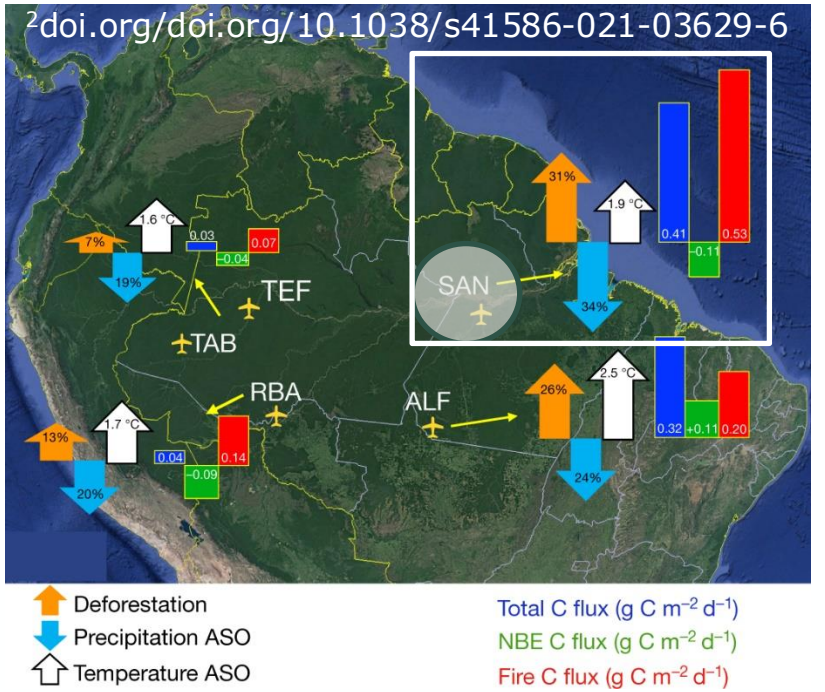
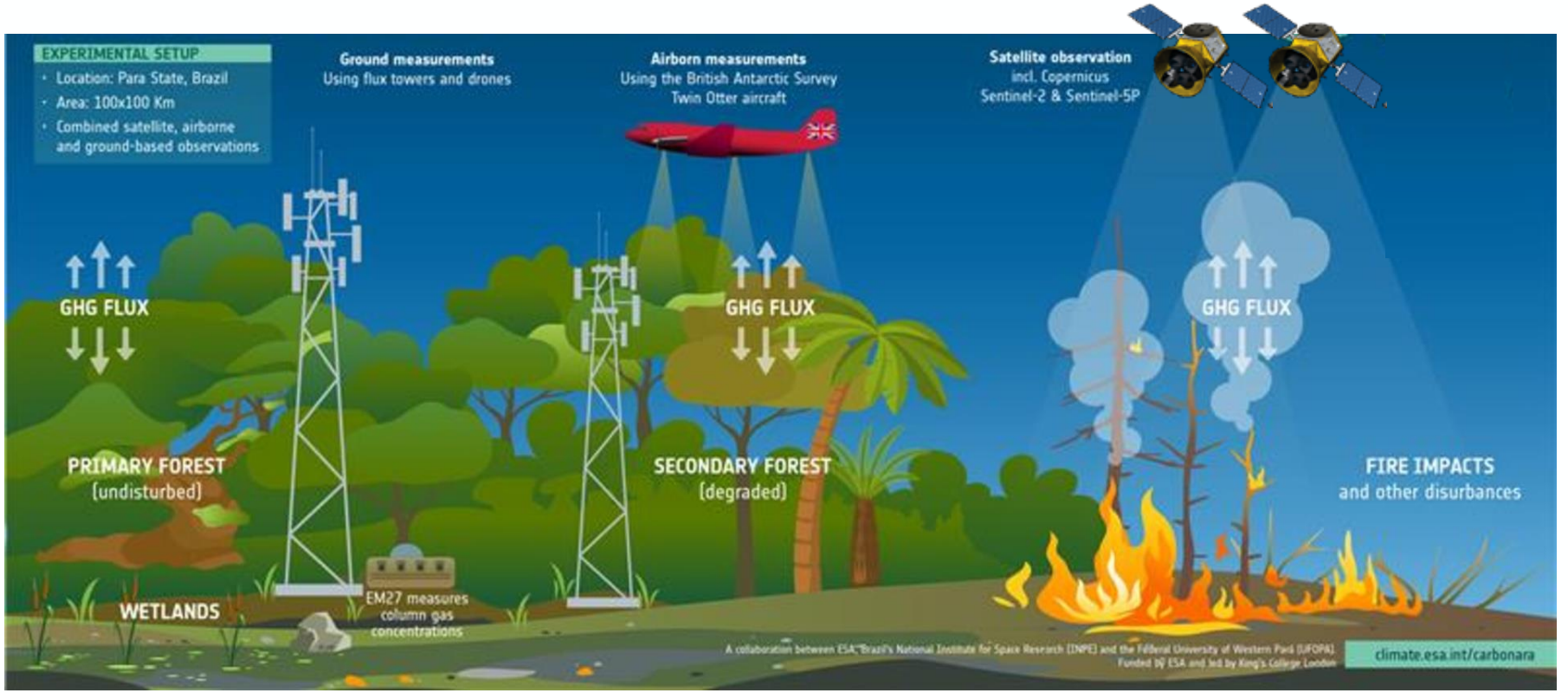
Large spatial heterogeneity: Aircraft CO_2 & CO profiles[2] suggest E. Amazon has highest net C fluxes to atm. (small NBE sink and very large fire source).



Because of its potential as a climate tipping point, the CEOS Strategy (2021) suggests commencement of observational campaigns to reduce uncertainties and deliver greater understanding - as a contribution to the Global Stocktake.

CarbonARA – Objectives in Response to CEOS

- **GHG Quantification & Verification:** Help constrain landscape-scale GHG fluxes across landscapes.
- **Fire Impacts & emissions:** Characterise fire combustion phase, emission factors & test new approaches.
- **Satellite Validation & Interpretation:** Provide airborne & ground data for satellite EO product assessment.
- **Modelling Support:** Data to assist & test C-cycle model development, process understanding & GHG inversions.



Key Activities

Augmented KM67 flux tower (2001+) in primary-forest with many new sensors.

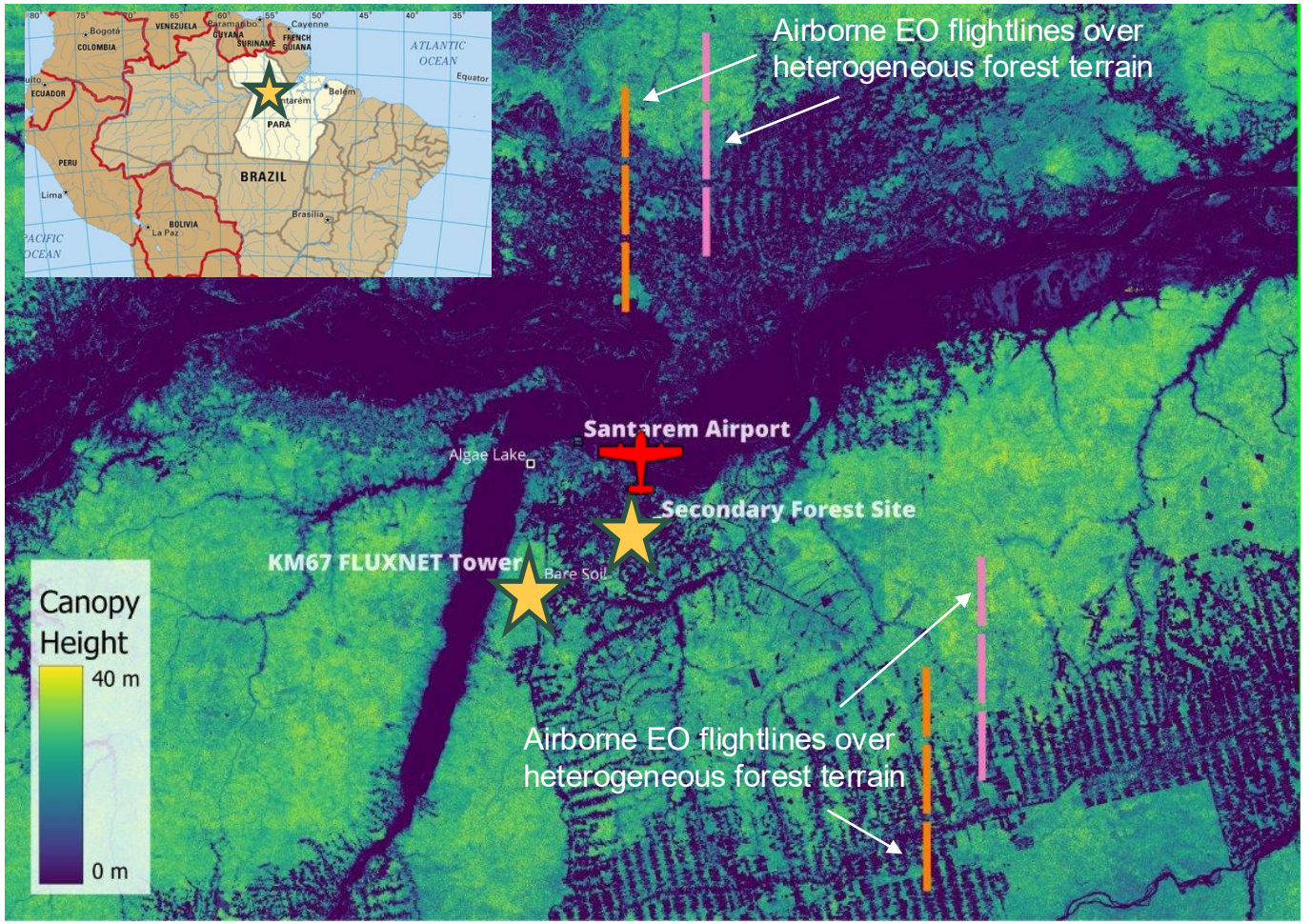
Conducted first airborne EO campaign by a foreign aircraft since NASA in 1990's.

Installed "copy" of KM67 setup in secondary forest for first time.

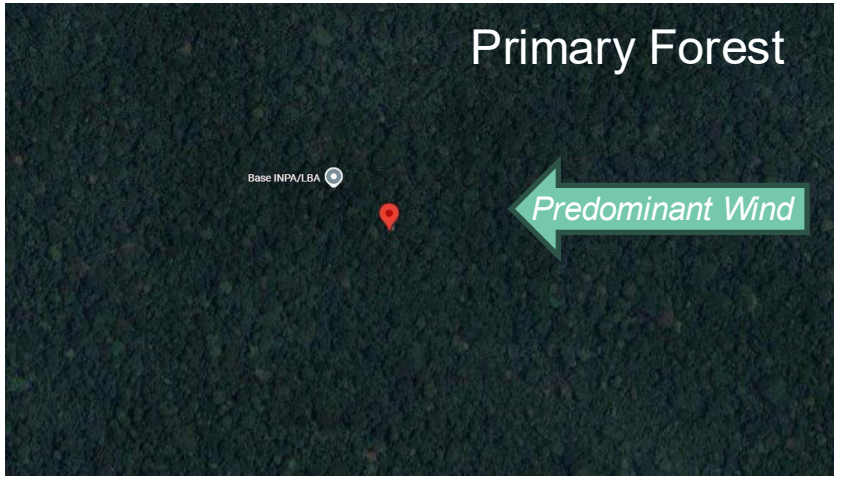
Added new ground sensors (e.g. Pandora, EM27-Sun…)

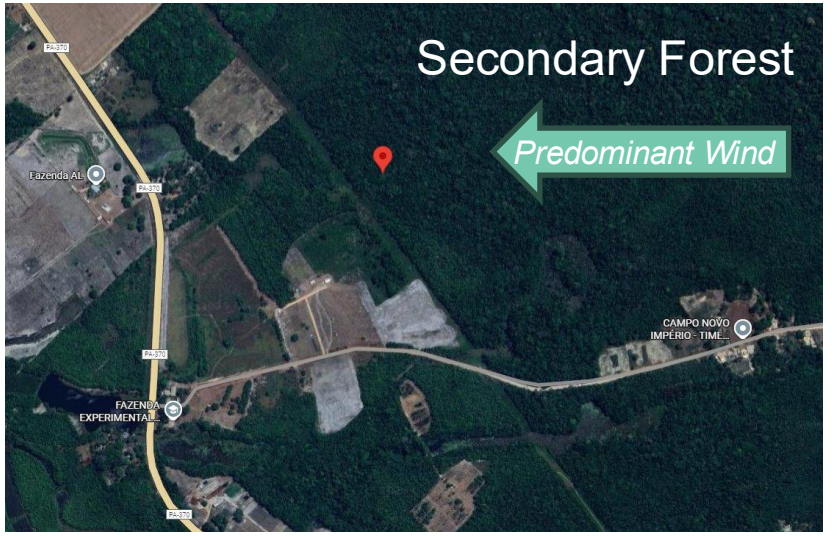
Undertook ground & airborne fire & smoke measurements

Location of Primary & Secondary Forest Towers



Tower-Based Fluxes & EO Sensors

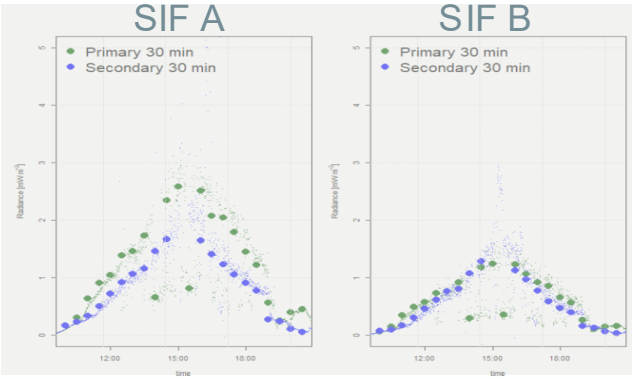


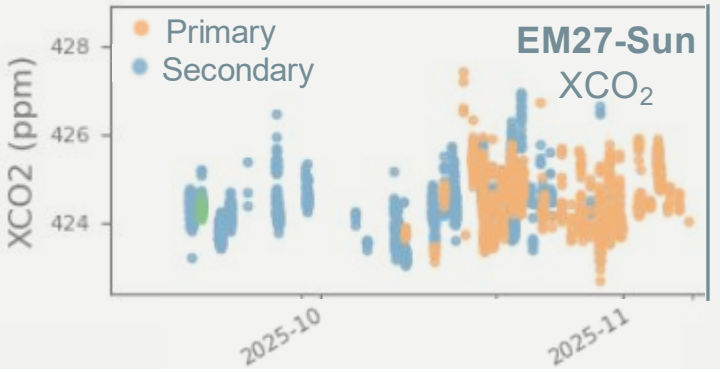


Flux Towers – Instrument Augmentation & New Tower

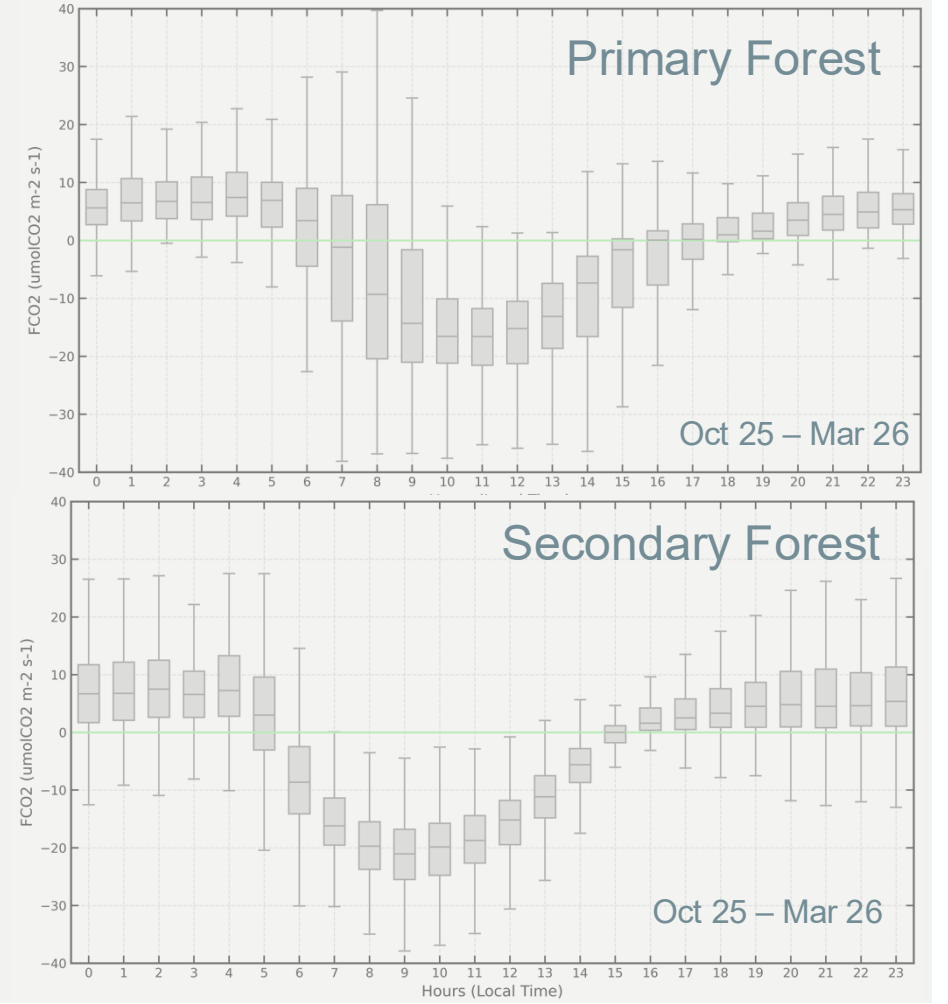
Tower Instrumentation & Example Early Analysis

Instrument	Parameter(s) Derived
EC Systems	NEE (CO_2, CH_4, H_2O fluxes)
FloX (Fluorescence Box)	SIF, NDVI, canopy reflectance
EM27-SUN FTIR	Total column XCO_2, XCH_4, XCO
L-Band radiometer (PoLRa)	VOD, soil moisture
GNSS	Veg. Optical Depth
Thermal Radiometers	Brightness Temperature & LST
Pandora Spectrometer	Atmospheric column (NO_2, O_3 etc)
Meteorological Stations	T, RH, pressure, wind, PAR, radiation
Purple air sensors	Particulate matter





CO_2 Flux Diurnal Cycles



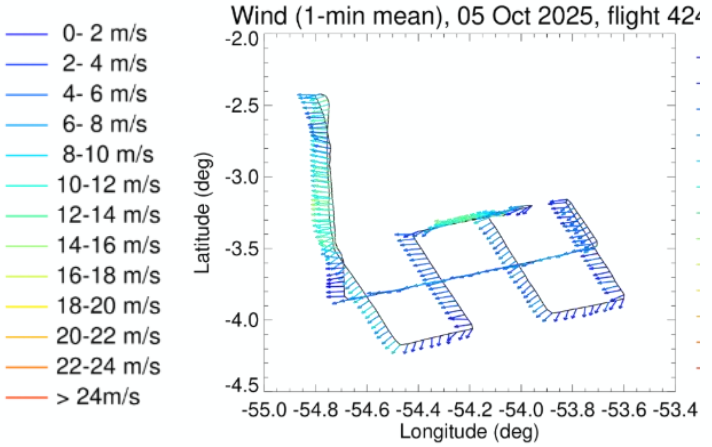
Airborne Sensors Deployed

	Instrument	Description	Purpose
Earth Observation	Specim AisaFENIX 1K	VNIR-SWIR Hyperspectral imager	Landuse mapping, Vegetation abundance (e.g. NDVI), Fire detection Evapotranspiration (ET; coupled with OWL)
	Specim AisaIBIS	VNIR ultra-fine resolution Hyperspectral Imager	Solar induced Fluorescence, K-line emission from fires.
	Specim AisaOWL	LWIR Hyperspectral imager	Land Surface Temperature, vegetation water stress, ET
	InfraTec ImageIR8300	Broadband MWIR thermal camera	Fire Radiative Power measurement, SLSTR validation
	InfraTec VarioCam HD Head	Broadband LWIR thermal camera	Fire Radiative Power (back-up), canopy temperature
	Optris PI400	LWIR thermal camera	Canopy temperature and FRP at larger view angles
	SWING	UV-VIS imaging spectrometer	DOAS measurements of fire plumes (e.g. NO_2)
	PhaseOne	High resolution RGB camera	Context RGB imagery; photogrammetric point cloud, image mosaics, DEMs
Atmospheric Sampling	MIRO MGA-10	Gas Analyser, can measure 10 trace gases	Fire emission ratios, GHG fluxes (experimental)
	DusTrak DRX	Particulate analyser (PM1 PM2.5, PM10)	Particulate concentration in smoke plume
	PAH Sampling System	Filter sampling system	Measure polycyclic aromatic hydrocarbons in wildfire smoke plumes.
	Picarro G2311-f	GHG Gas analyser, 12 Hz sampling rate	CO2, CH4 and H2O mixing ratios. GHG fluxes (prime)
	Grimm OPC	Particulate analyser	Aerosol size range 0.25 – 32 µm.
	CPC 3772	Condensation Particle Counter	Measures aerosol concentration from fires Aerosol sizes >10 nm
	Goodrich Rosemount probes	Measurement of deiced and non-deiced air temperature in flight	Atmospheric boundary layer characterisation
	Brechtel Isokinetic Inlet	Active air inlet	Isokinetic inlet for particulate sampling
	Calibration gas system	Gas Cylinders plus flow control box.	Reference gases for GHG flux measurements

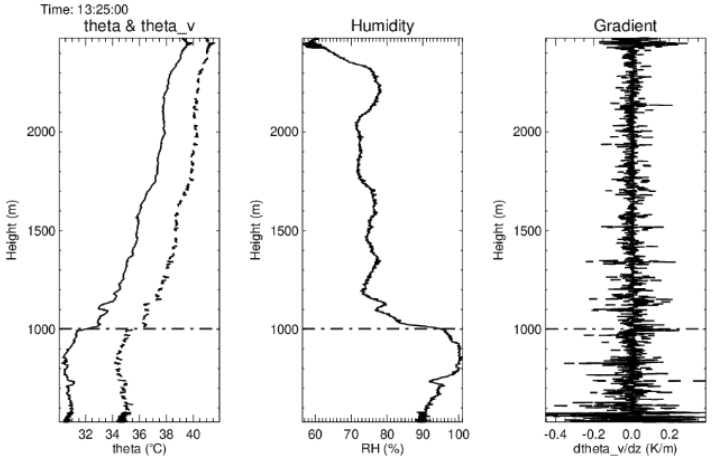

Flight Team in Santarem

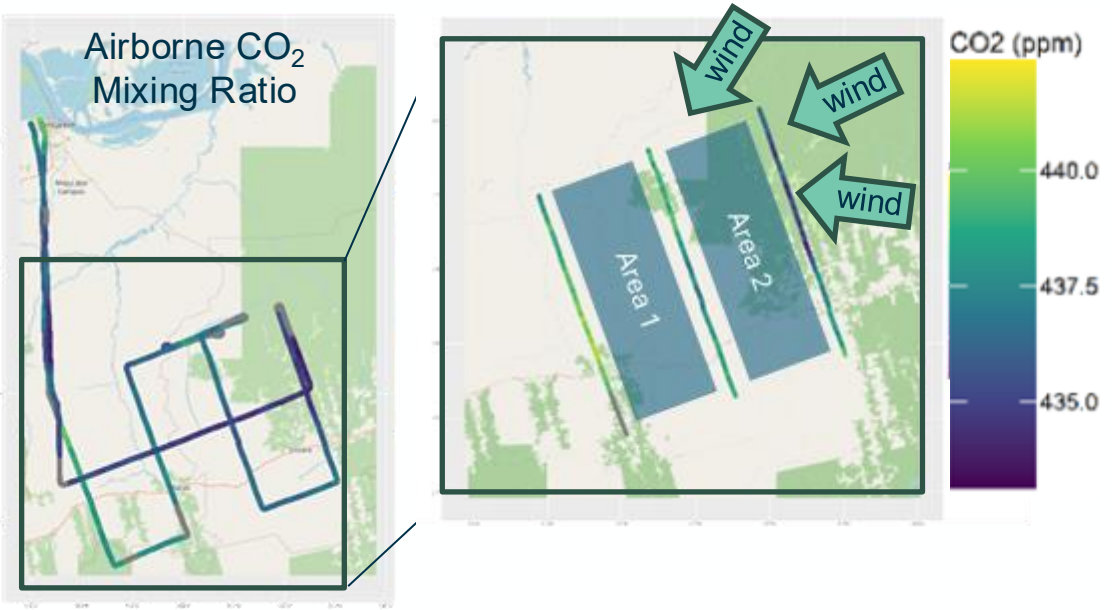
Airborne *In Situ* : Landscape Scale Fluxes of CO_2

Airborne Wind Vectors



Mixing Layer Height Determination





Derived CO_2 Fluxes

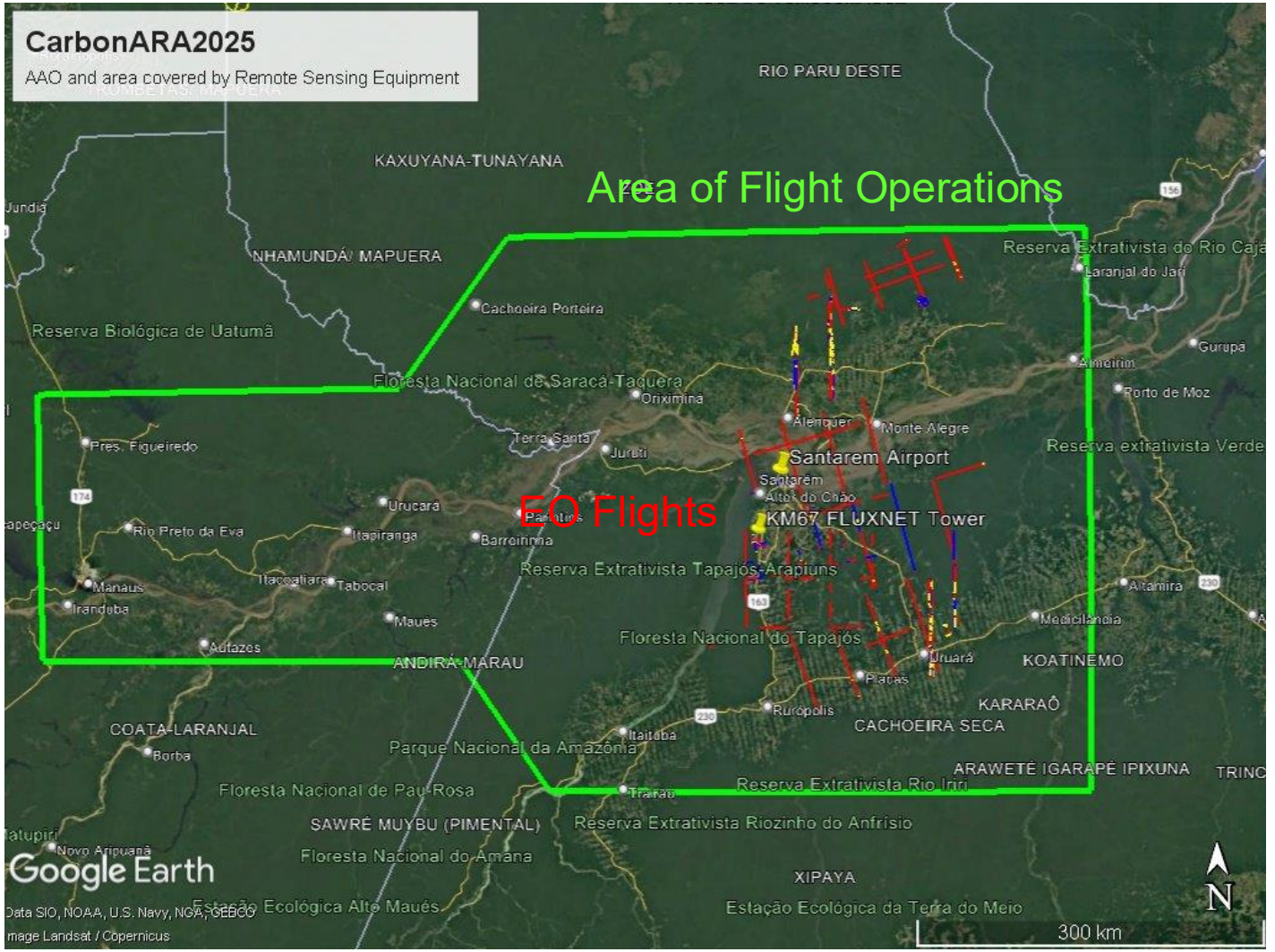
Area 1: **+**2374 mg m^{-2} h^{-1}

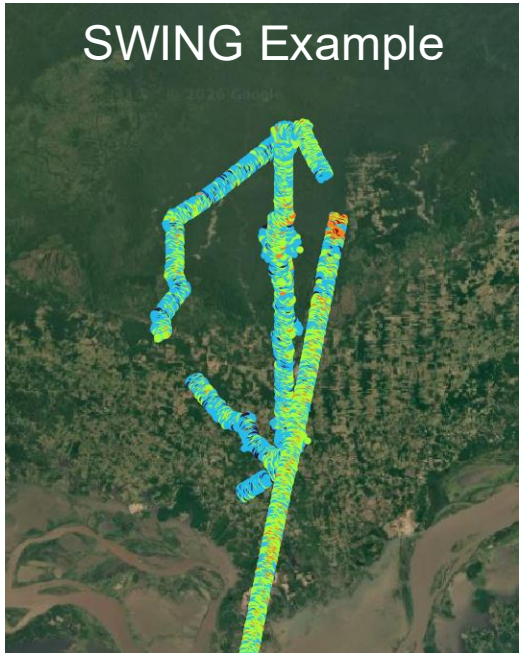
Area 2: **+**4070 mg m^{-2} h^{-1}

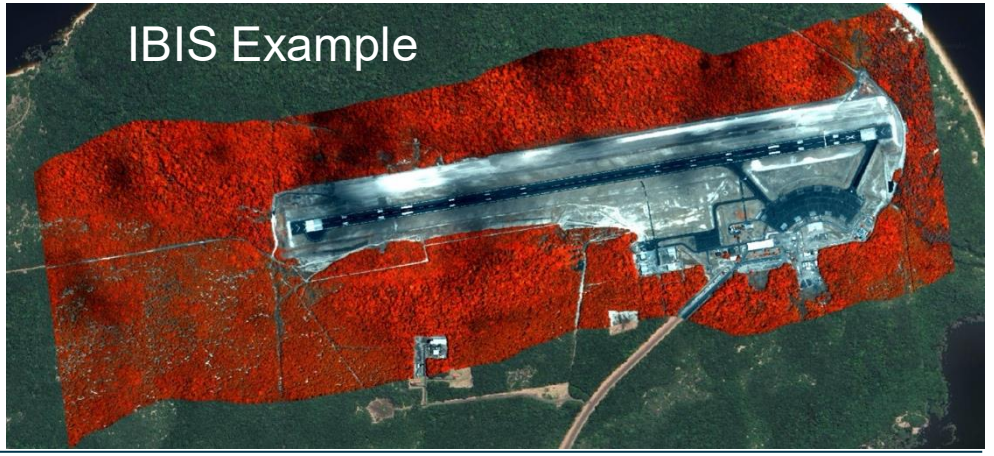
[preliminary results]

Area 1 ~ 15 µmol.m^2.s^{-1}
Area 2 ~ 27 µmol.m^2.s^{-1}

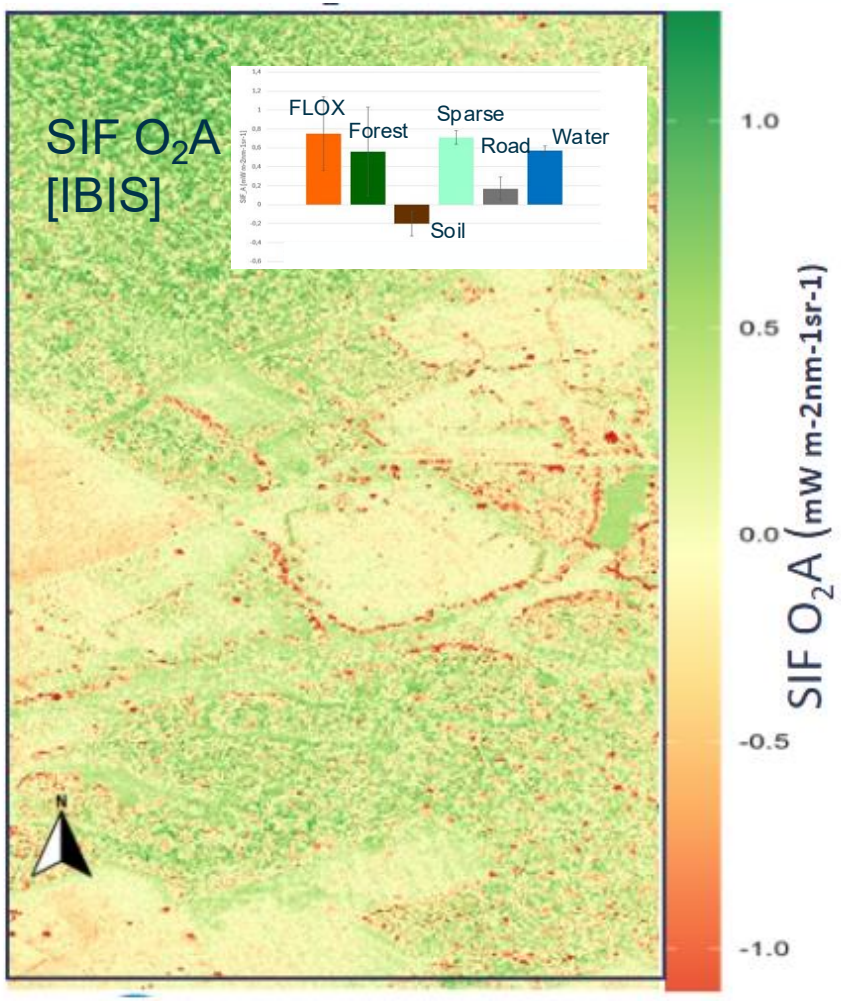
Airborne Earth Observation

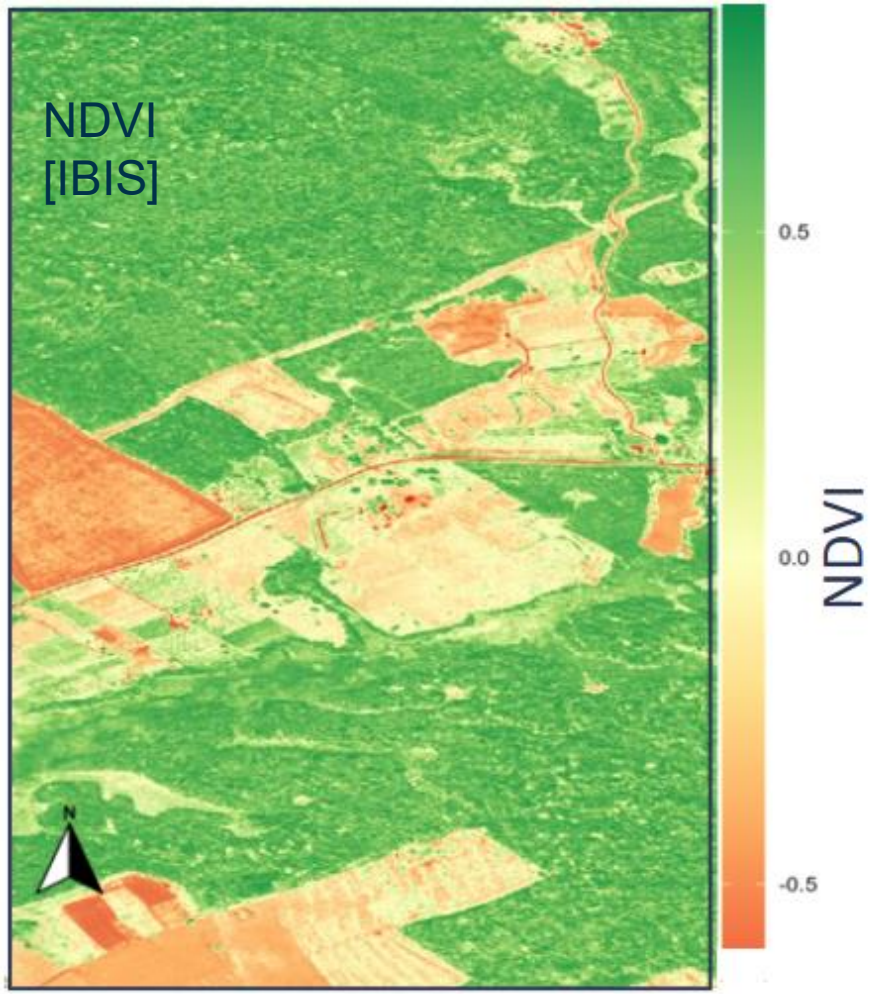






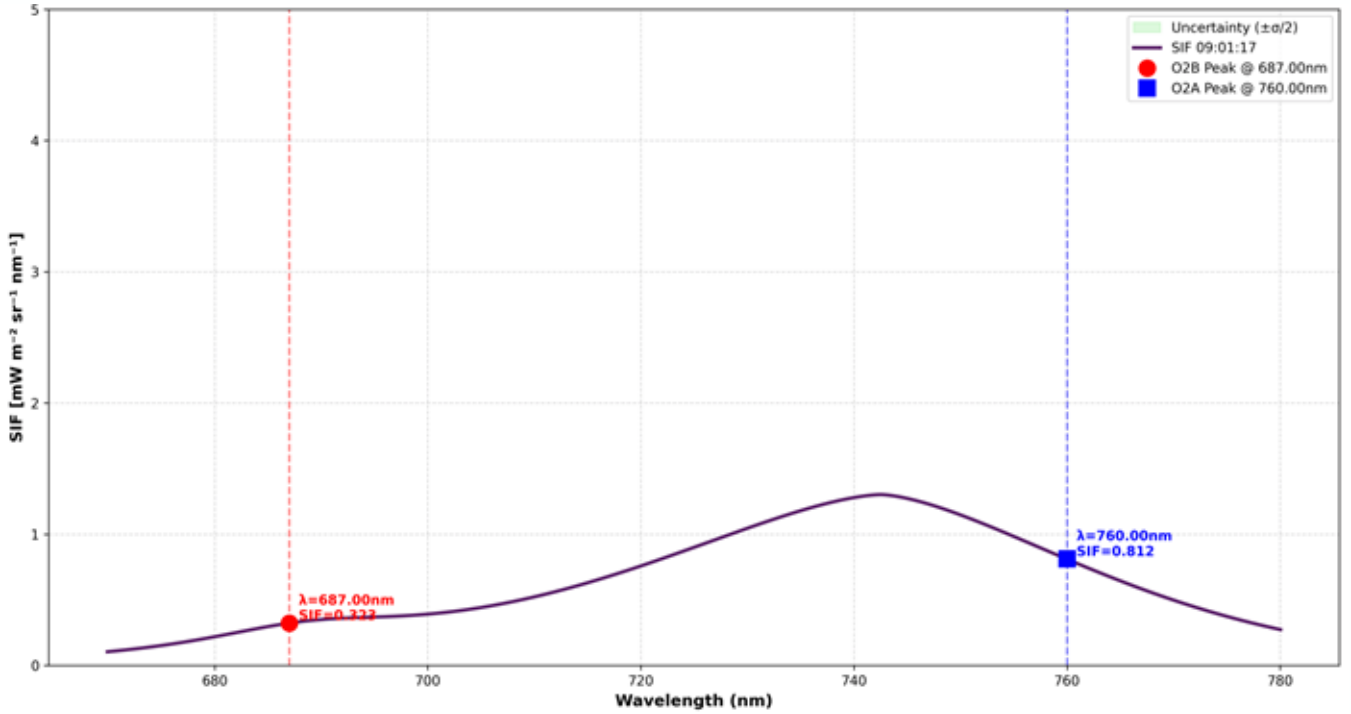
Airborne EO Example: Solar Induced Fluorescence





[Early] SIF Ground & Airborne Intercomparison

Primary Forest Site – 12 Oct 2025



Tower SIF spectra from 9 to 20 UTC (6am – 5pm local time; every 30')

Tower O_2A SIF @761 nm [13:29 UTC]

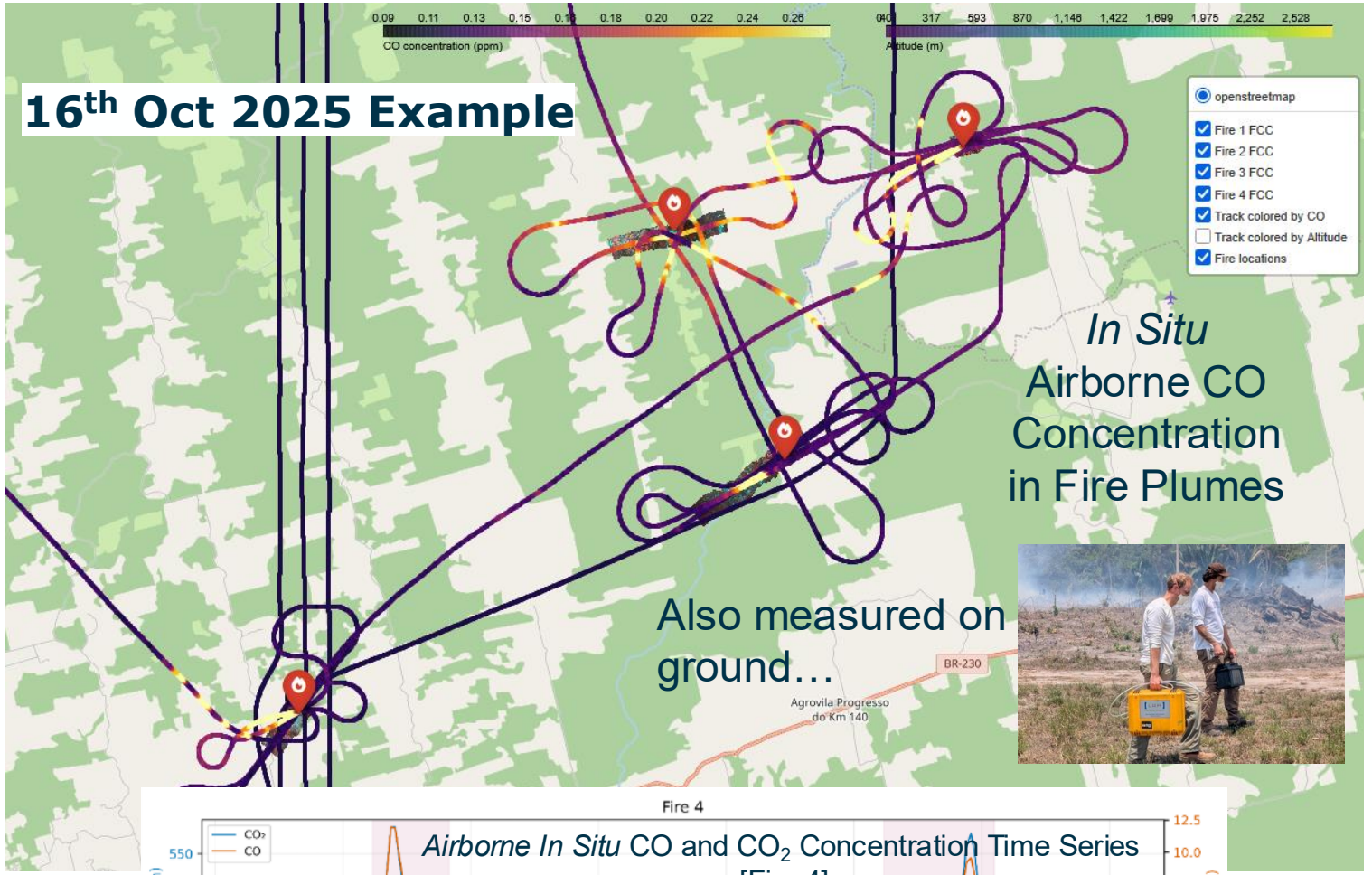
1.46 ± 0.33 mWm^{-2}nm^{-1}sr^{-1}

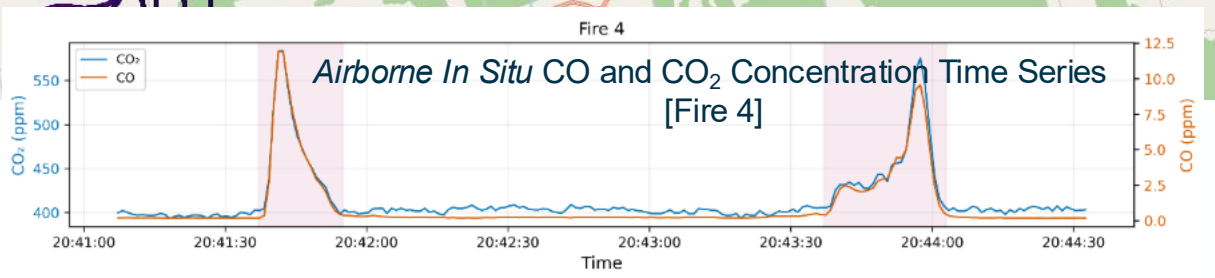
Airborne O_2A SIF @761 nm [13:29 UTC]

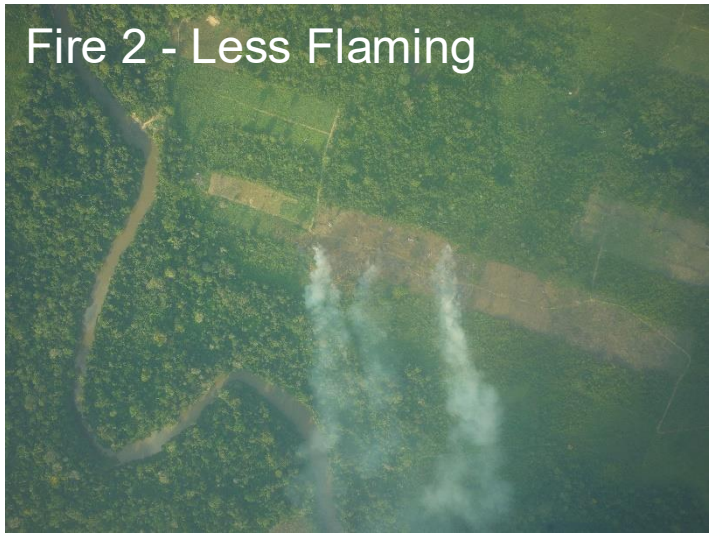
1.71 ± 0.82 mWm^{-2}nm^{-1}sr^{-1}

[Secondary forest appears significantly lower]

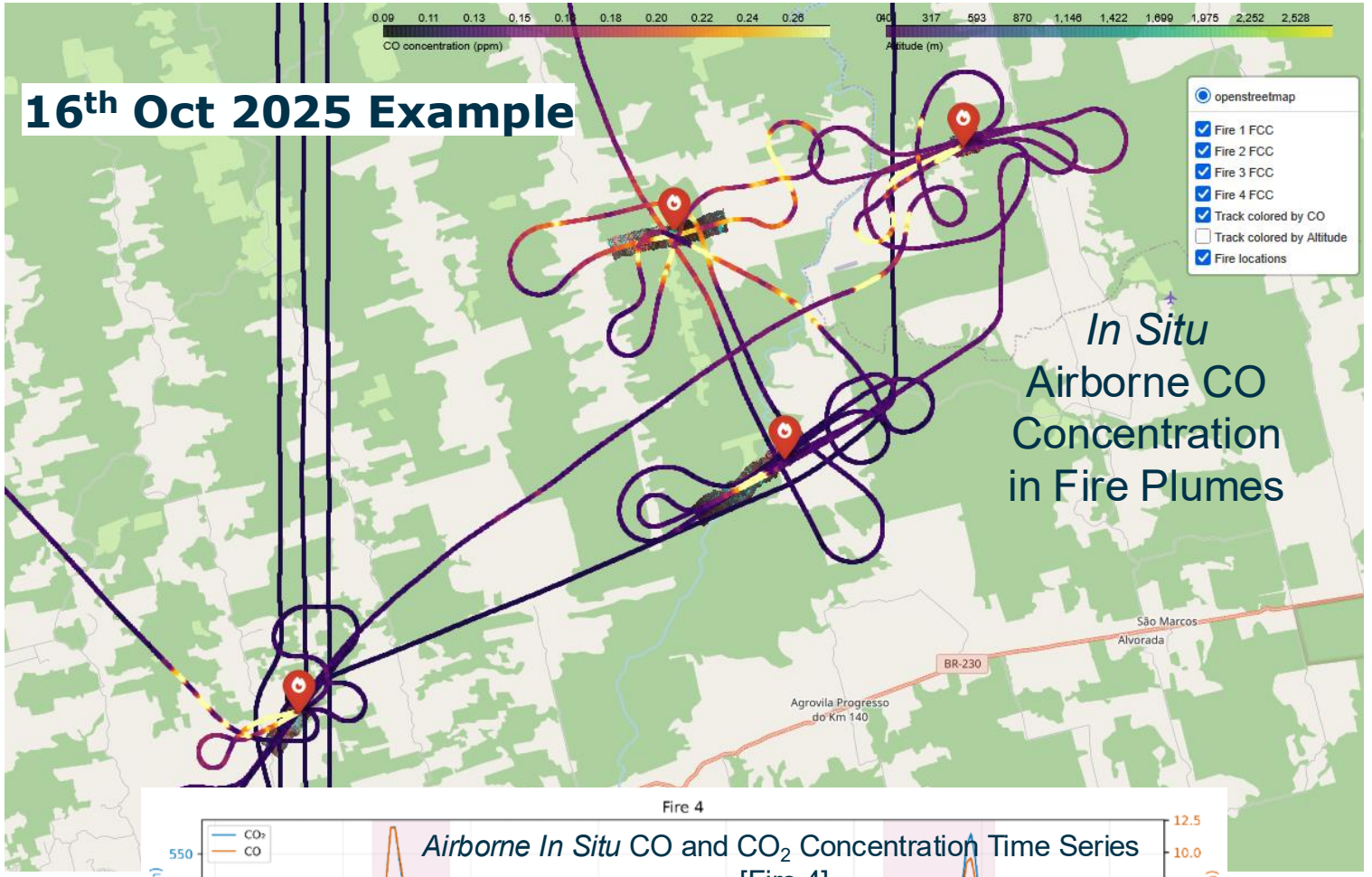
Biomass Burning Fire & Smoke Characteristics

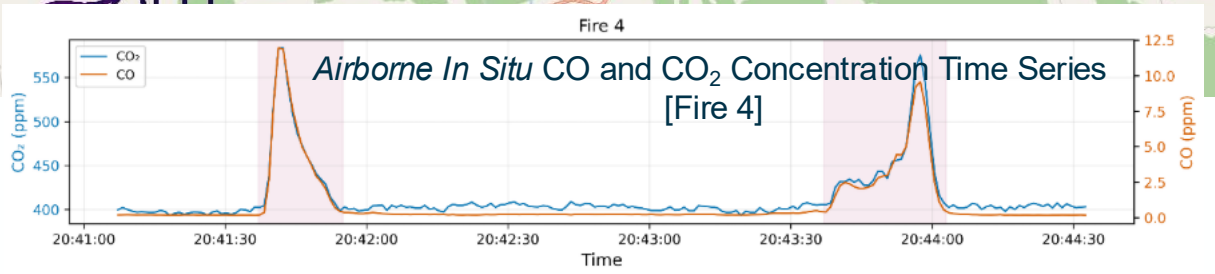




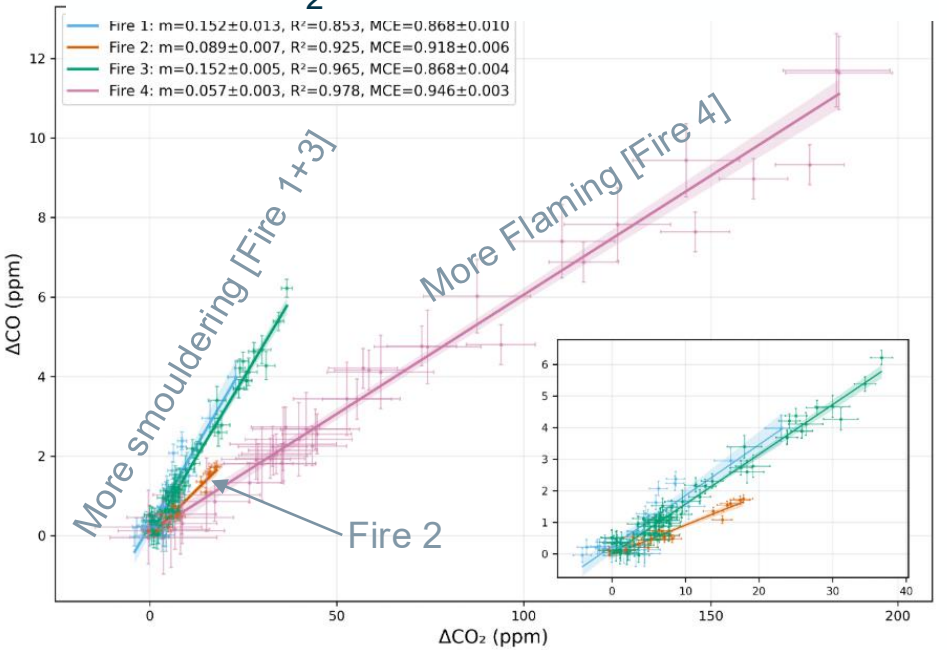


Biomass Burning & Fire Emissions





CO vs CO_2 Ratios in Four Fire Plumes



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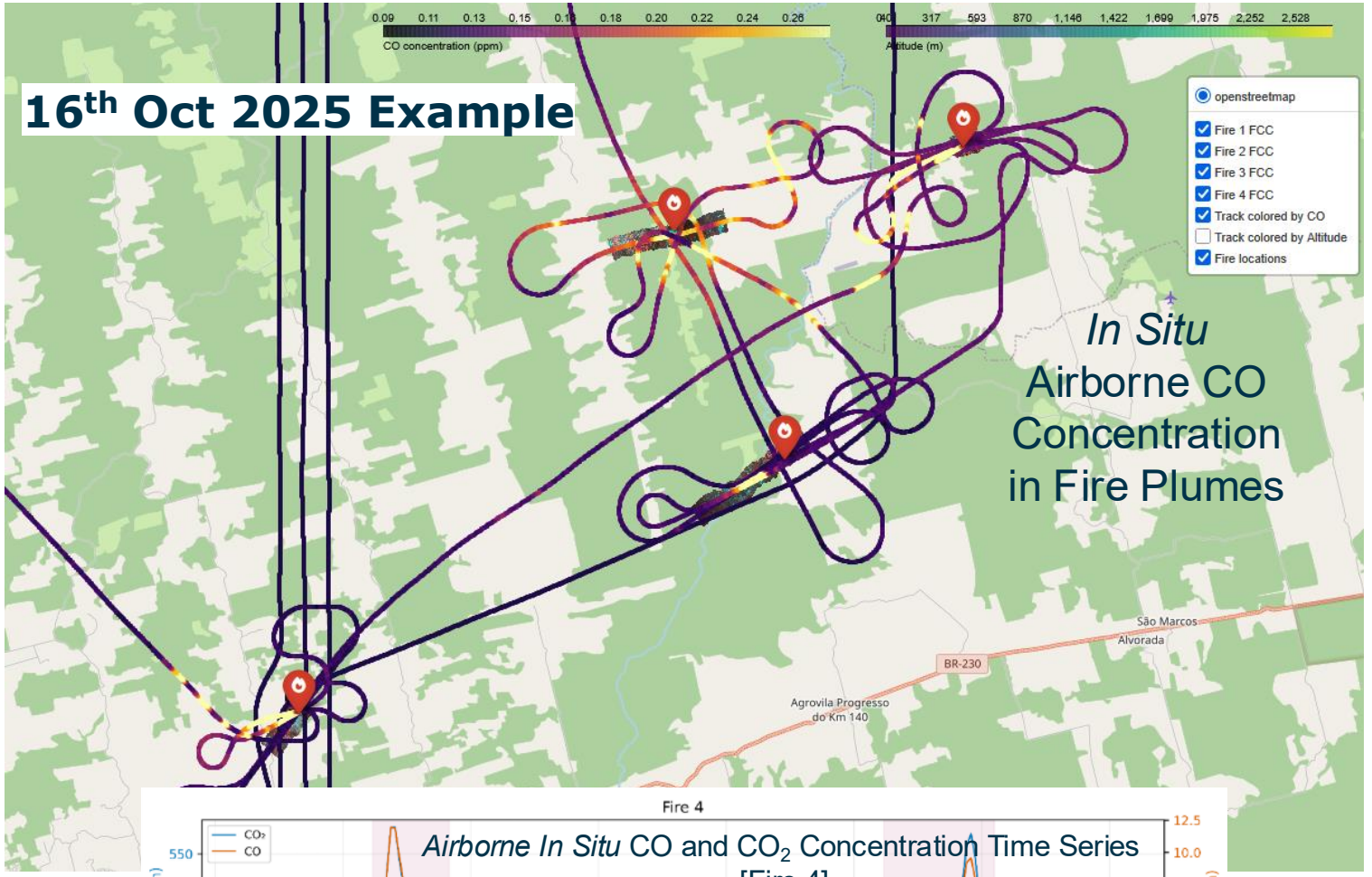

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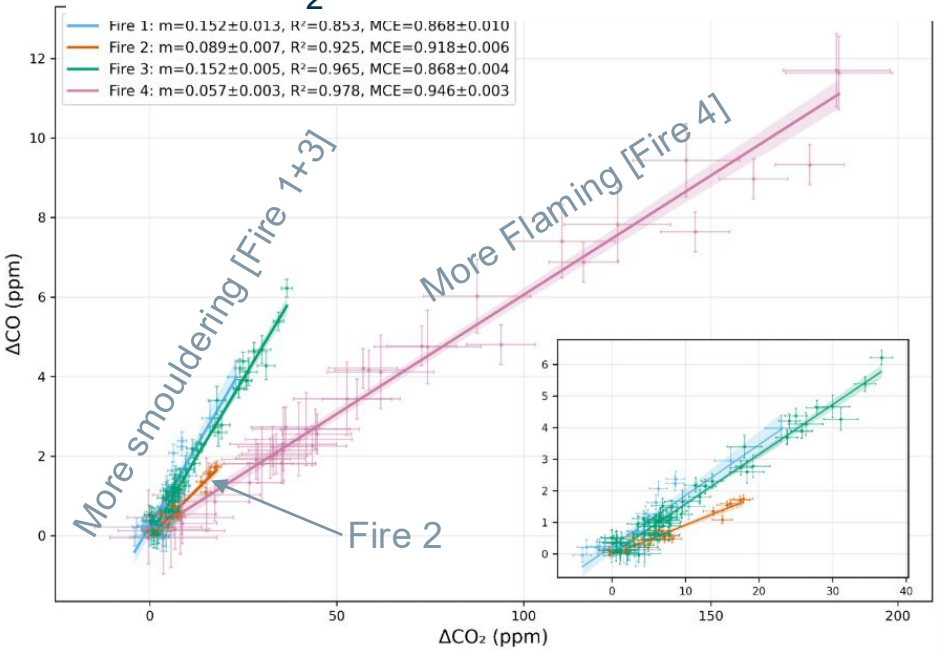
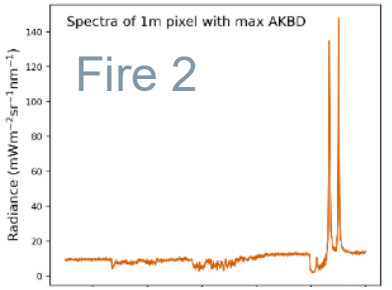
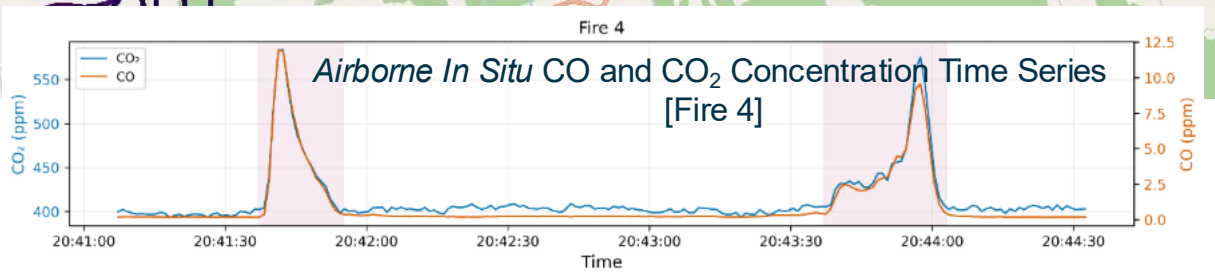
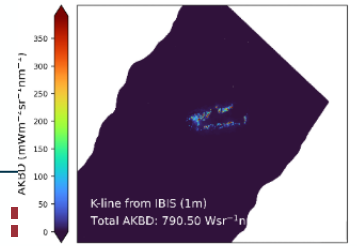
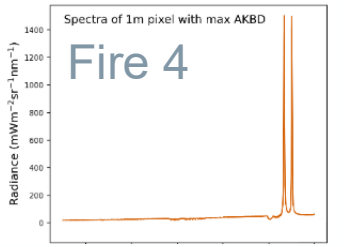






Flaming fire has
10x higher K-line



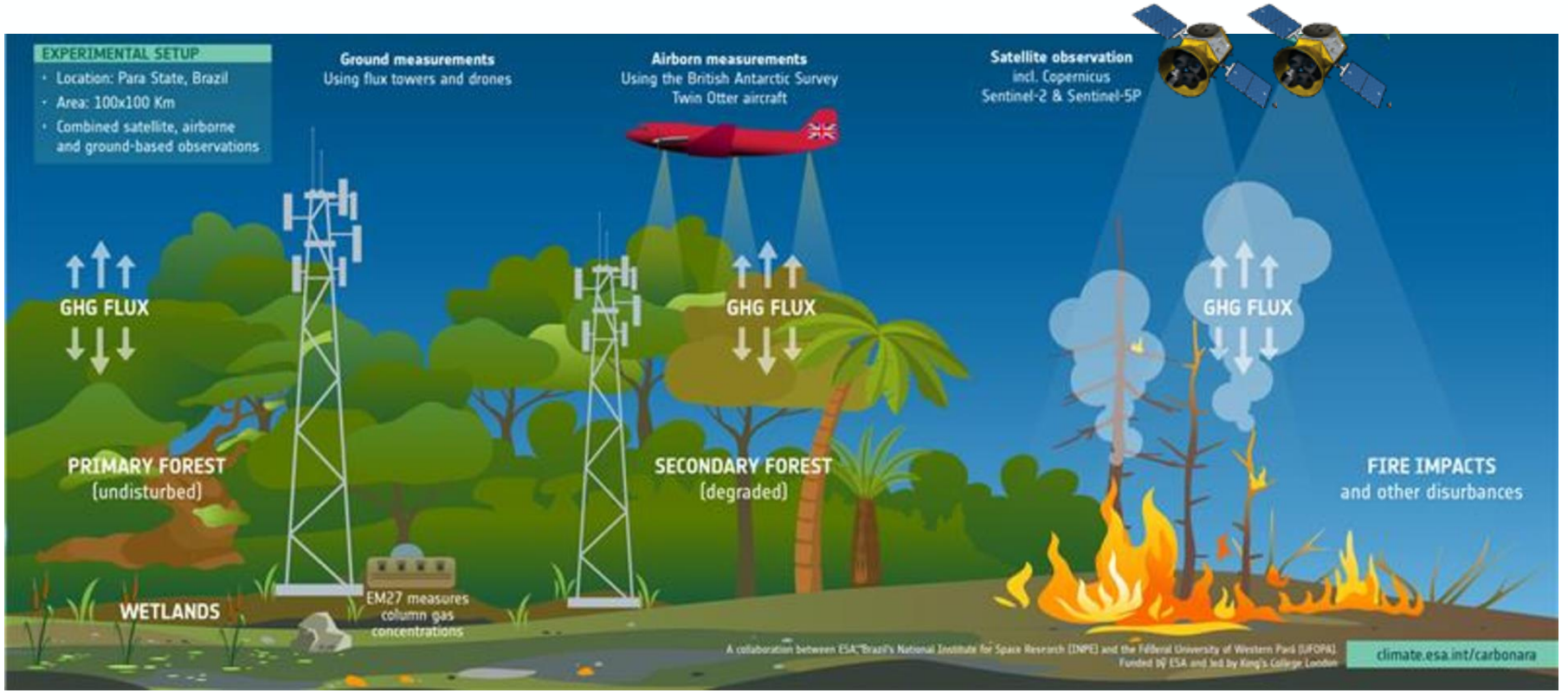


CarbonARA Secondary Forest Tower
Installed Aug 2025

Next Steps: Continue Analysis, Work with Modellers & EO Data Producers, Plan and Implement CarbonARA 2026

CarbonARA – Plans & Key Activities

- Direct response from ESA to CEOS recommendations - led by NCEO-King's College London, INPE & UFOPA.
- Partners included many European and UK collaborators – mostly focused on remote sensing instrumentation.
- Sited in the region of E. Amazon shown to have large net C flux to the atmosphere – close to Santarem.
- In 2025 planned new infrastructure and new sensors, planned airborne campaign and 'roving' fire measures.



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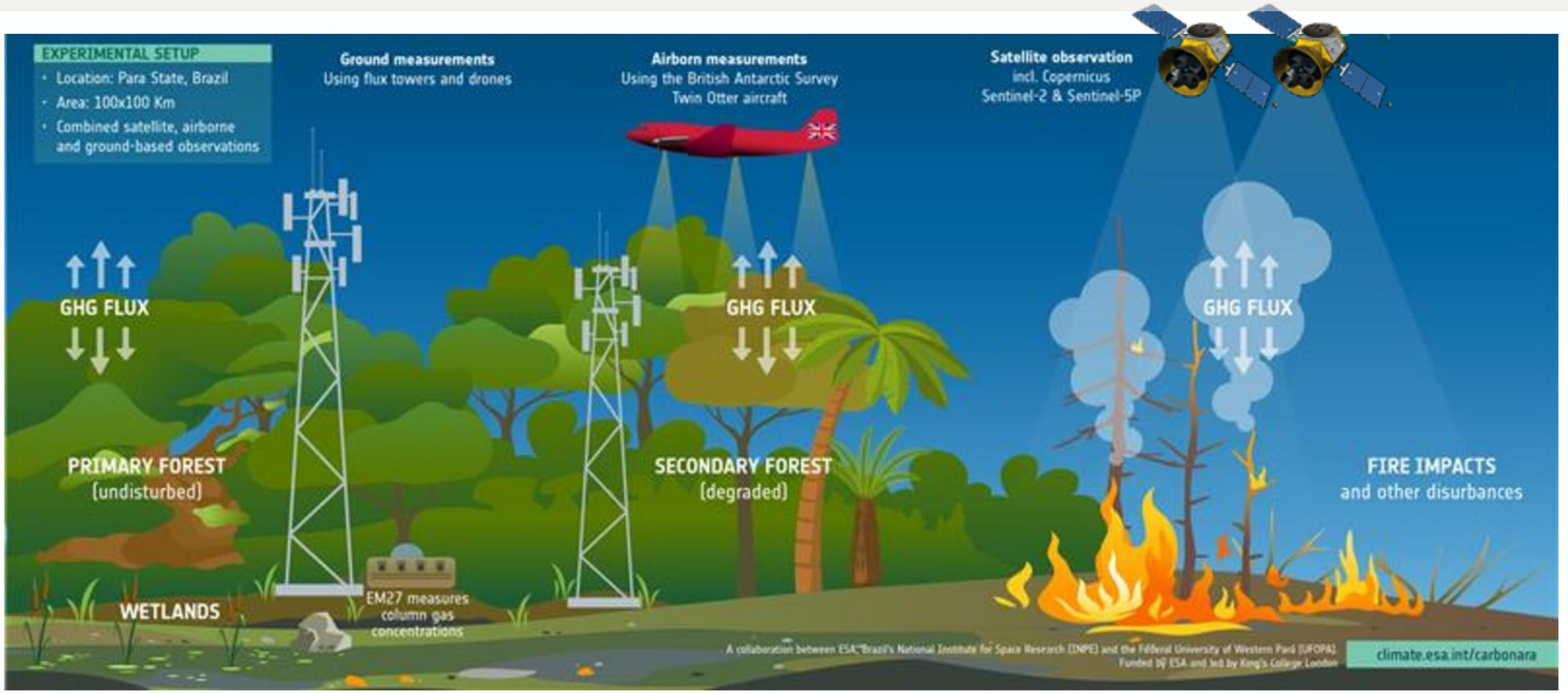

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