Towards an Integrated System for Urban Greenhouse Gas Monitoring and Assessment

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Outline

Methodologies for evaluating urban greenhouse gas emissions

INFLUX long-running GHG "urban testbed" since 2010

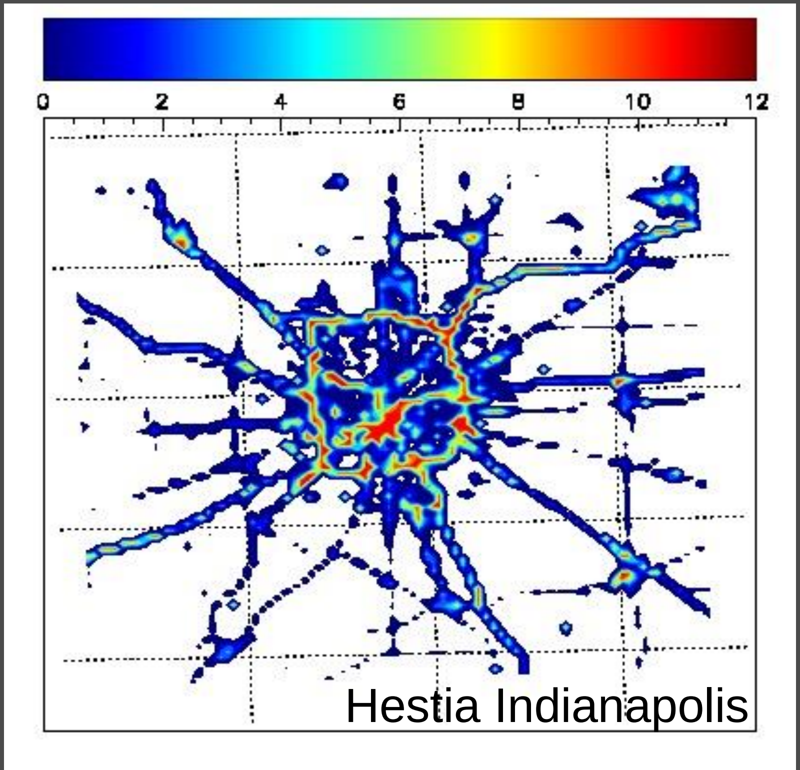
Integrating urban greenhouse gas science with policy

IG^{3}IS and emissions reporting

Example from CarbonWatch, Auckland, New Zealand

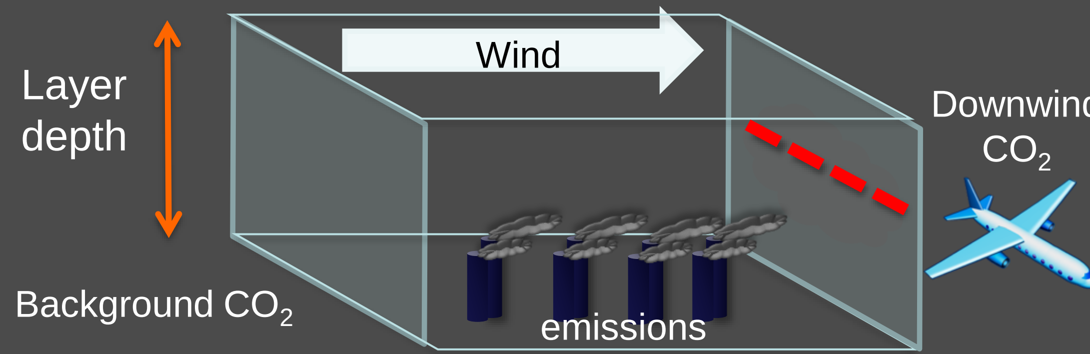
Methods for evaluating urban greenhouse gas emissions

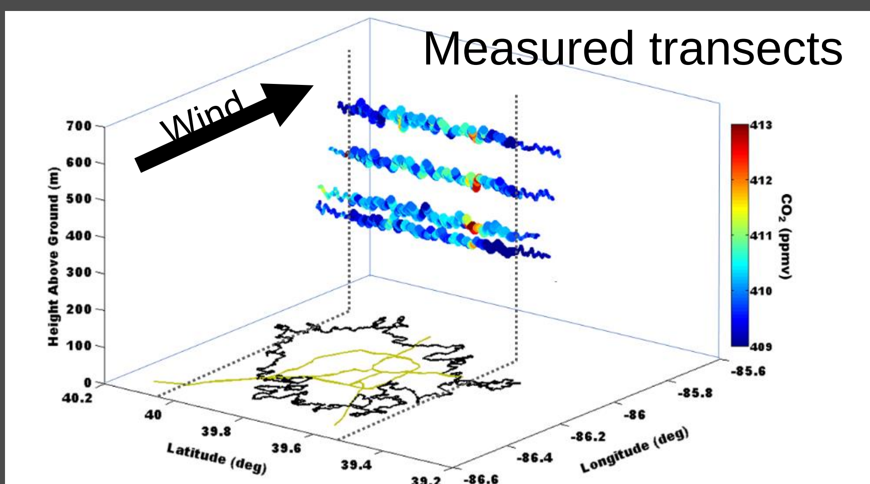
Bottom-up anthropogenic CO_2 emissions Hestia data product

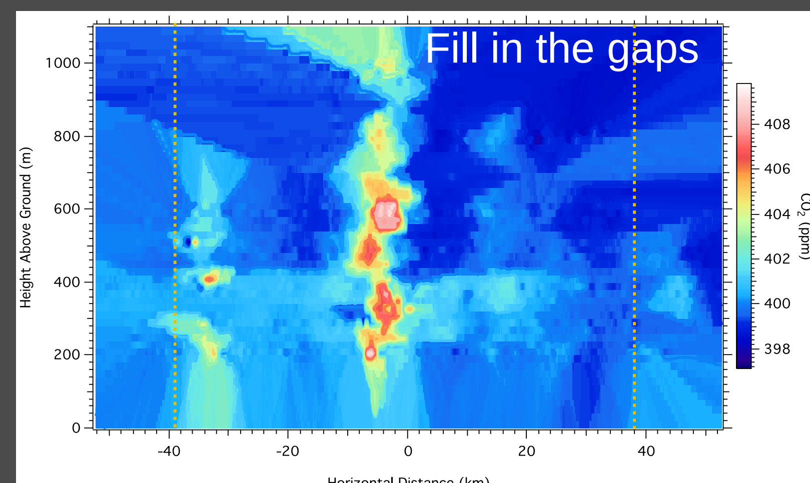


Anthropogenic CO_2 emissions from multiple sources for whole city
Disaggregated in space, time and source sector

Urban mass balance from aircraft measurements







Many cities can be measured using a single aircraft/instrument

Whole city flux determined – not spatially resolved

Heimburger et al., 2017

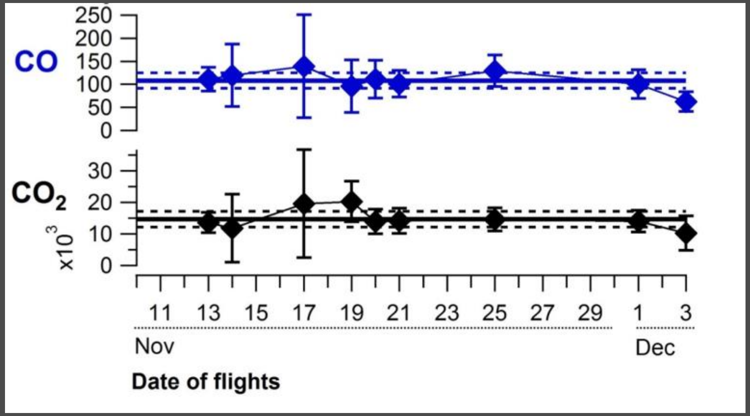
Urban mass balance from aircraft measurements

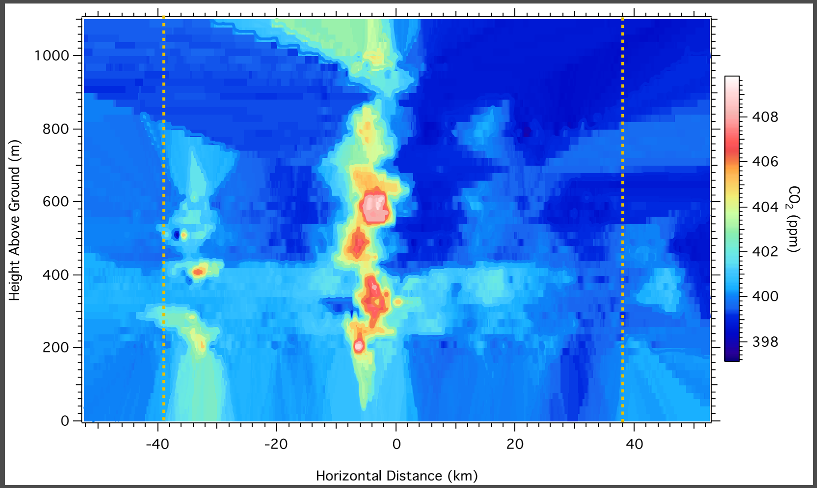
Molar enhancement in air layer

Flux

$$\dot{n}_{CO_2} = V\cos\theta \int_{-b}^{+b} \Delta X_{CO_2} \left(\int_{z_{gnd}}^{z_{PBL}} n_{air}\, dz \right) dx$$

Perpendicular wind speed





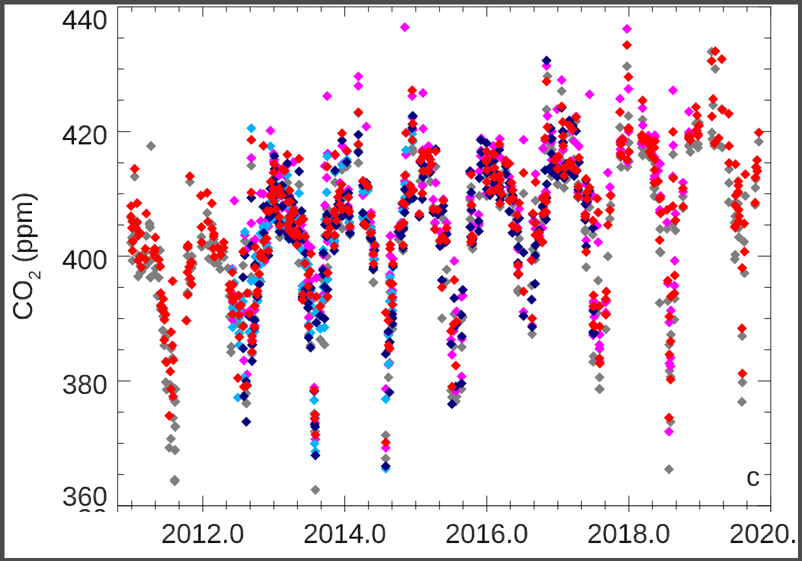
	Emission rate (mol/s)
CO winter 2014	108 ± 16%
CO_2 winter 2014	14,600 ± 17%

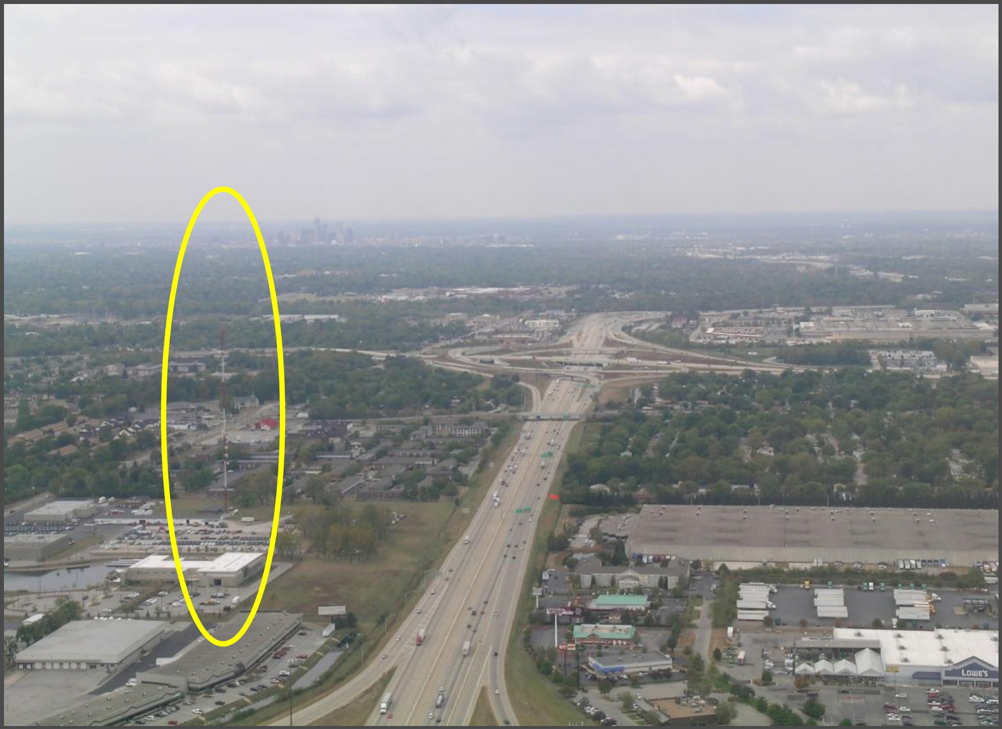
Reduced uncertainties for whole city emissions by averaging over multiple flights

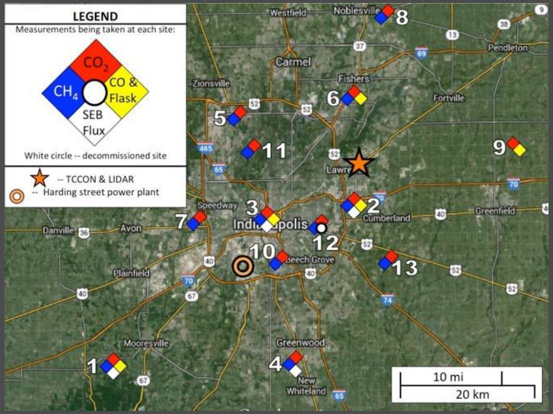
Obtain flux estimates for both CO and CO_2

Heimburger et al., 2017

Top-down urban atmospheric inversion driven by tower observations

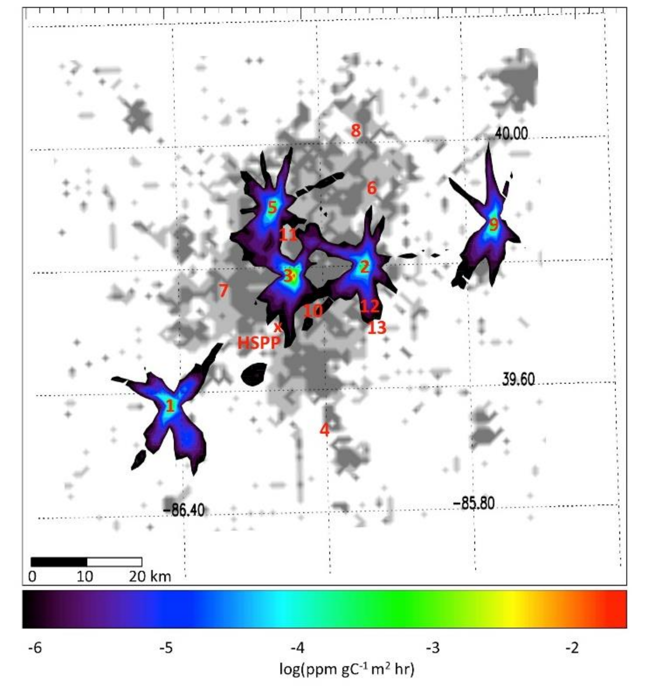






12 towers measuring in situ CO_2 (and CO/CH_4 and multi-species from flasks)

Network design: "footprints"

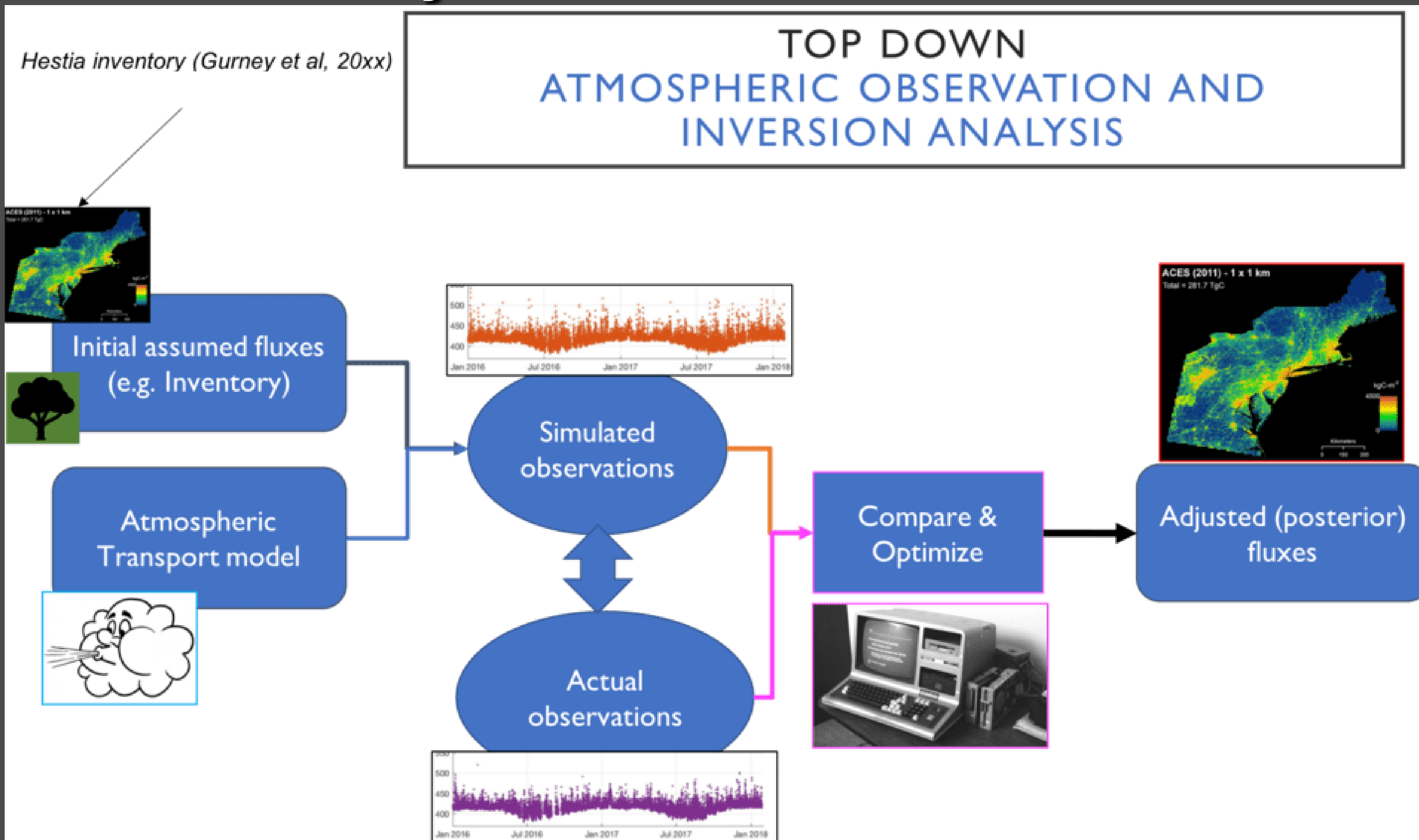


Height, topography and winds determine the "footprint" for each measurement site

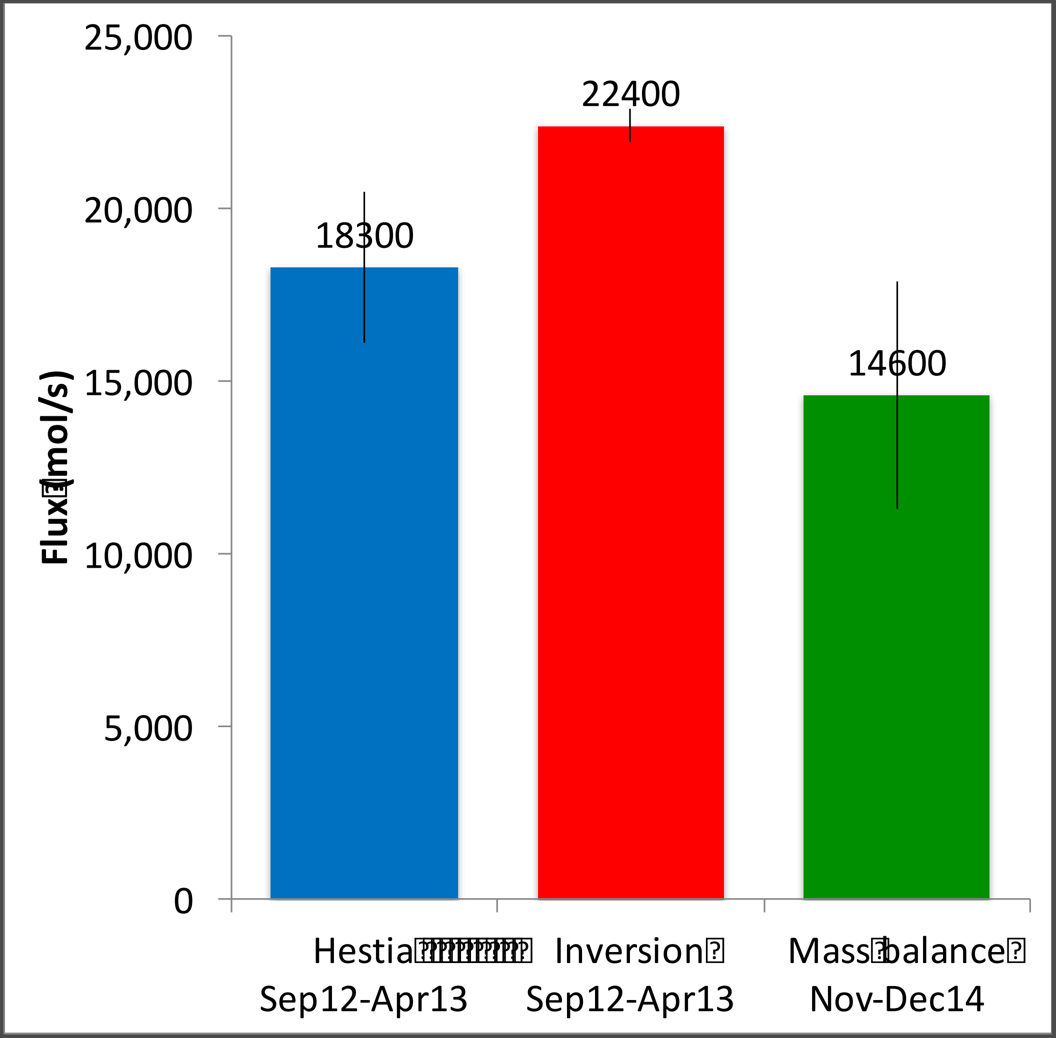
Want enough sites and the right locations to "see" an entire city

Locate on tall towers/buildings to obtain largest footprint with least sites

Top-down urban atmospheric inversion driven by tower observations



Comparison of previously reported Indianapolis whole city CO_2 fluxes for wintertime



Gurney et al, 2012
Lauvaux et al, 2016
Heimburger et al, 2017

Mean flux 18,400 mol/s
± 20%

Range 40% between highest and lowest estimate

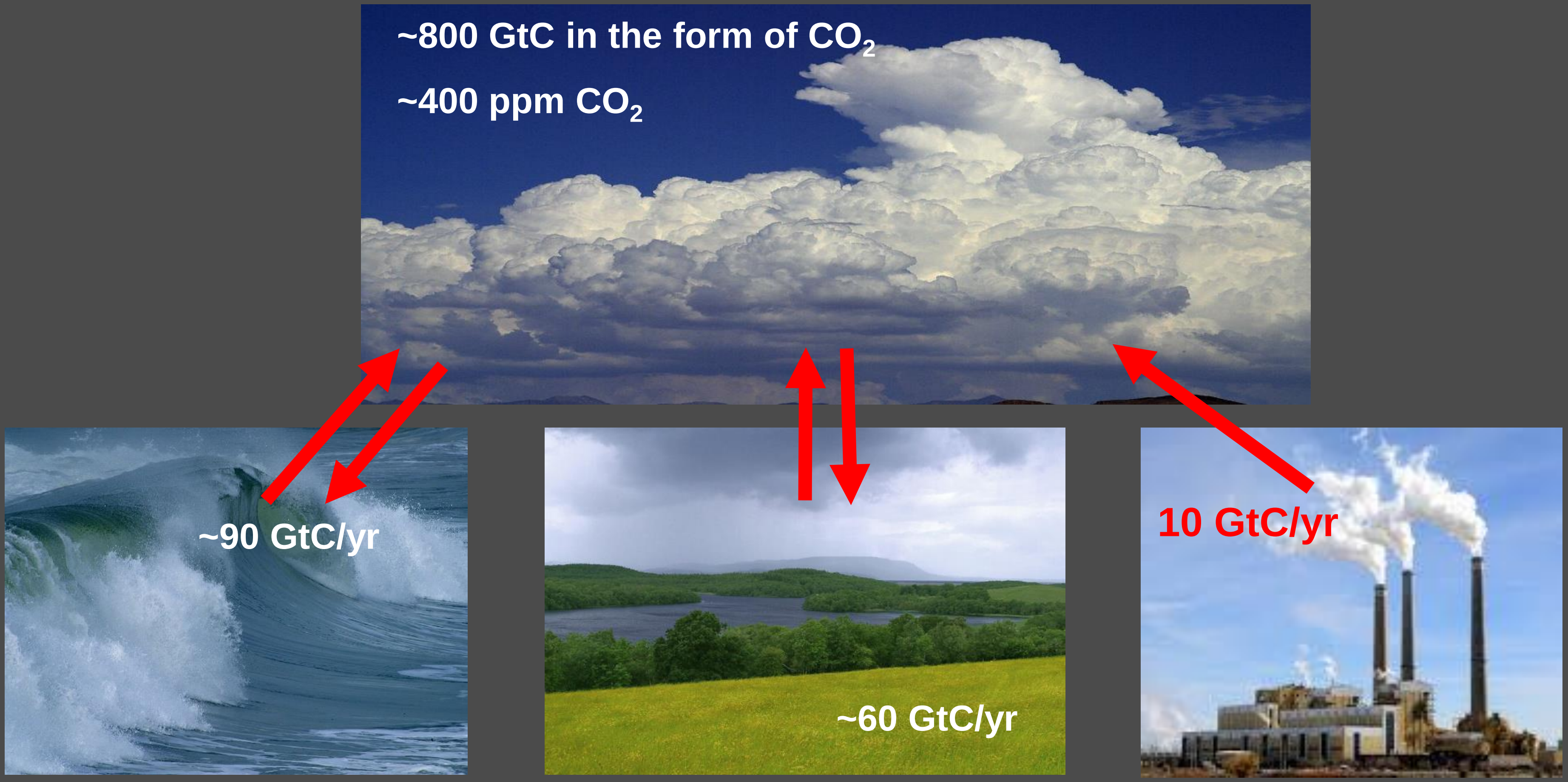
But we are not comparing apples with apples…

	Time period	Time of day	Species measured	Domain	Includes rural bkgd?
Hestia Bottom-up	Sept 2012 - Apr 2013	All	CO_2ff + bioethanol	Full domain	Yes
Inversion/ tower CO_2	Sept 2012 - Apr 2013	All (only mid-afternoon tower data used)	Total CO_2	Full domain	Yes
Aircraft mass balance	Nov – Dec 2014	Mid-afternoon	Total CO_2	Aircraft footprint	No

We can compare apples with apples…

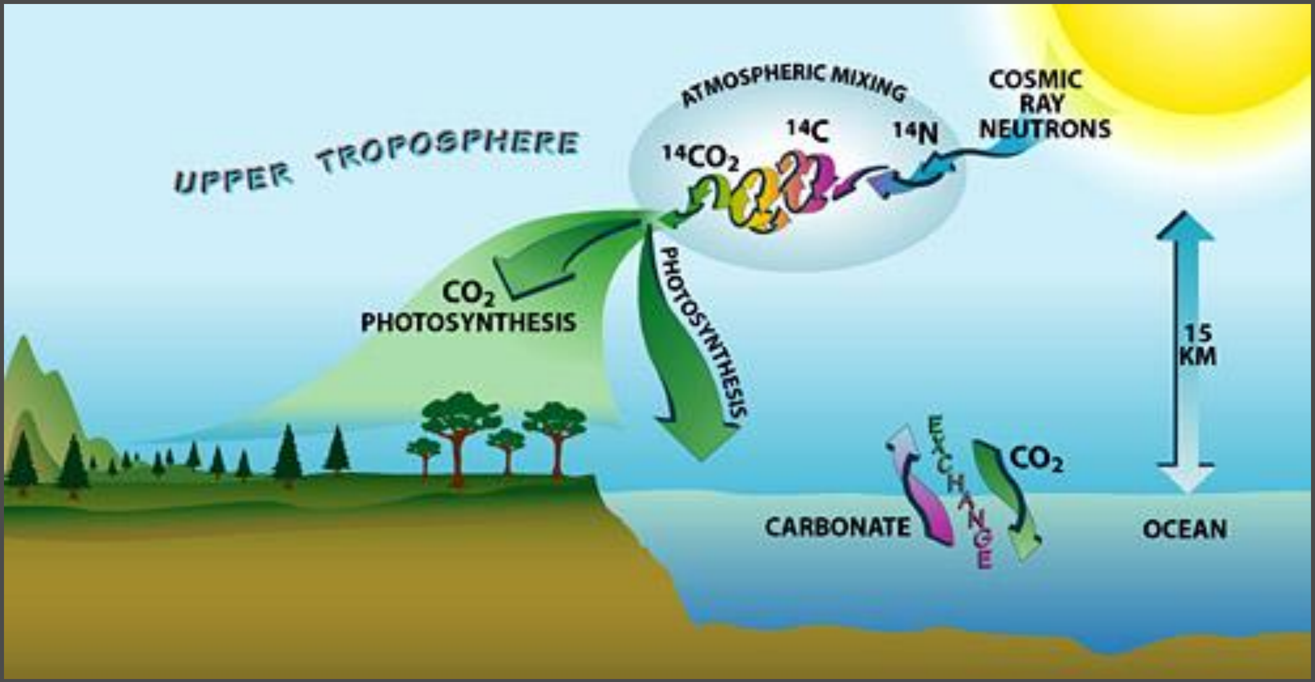
	Time period	Time of day	Species measured	Domain	Includes rural bkgd?
Hestia Bottom-up	~~Sept 2012 - Apr 2013~~ Nov 2014	~~All~~ Mid-afternoon	~~CO_2ff + bioethanol~~ CO_2ff	~~Full domain~~ Aircraft footprint	Yes
Inversion/ tower CO_2	~~Sept 2012 - Apr 2013~~ Nov 2014	~~All~~ Mid-afternoon	~~Total CO_2~~ CO_2ff	~~Full domain~~ Aircraft footprint	Yes
CO_2-based Aircraft mass balance	Nov – Dec 2014	Mid-afternoon	~~Total CO_2~~ CO_2ff	Aircraft footprint	~~No~~ Added
CO-based aircraft mass balance	Nov – Dec 2014	Mid-afternoon	CO → CO_2ff	Aircraft footprint	Added

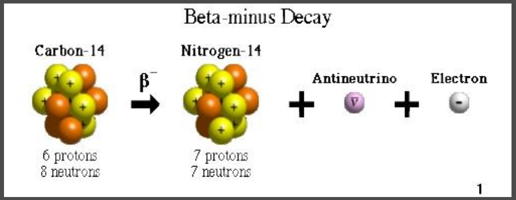
The Carbon Cycle



Cannot distinguish between natural and fossil CO_2 from CO_2 measurements alone

Radiocarbon (^{14}C) dating





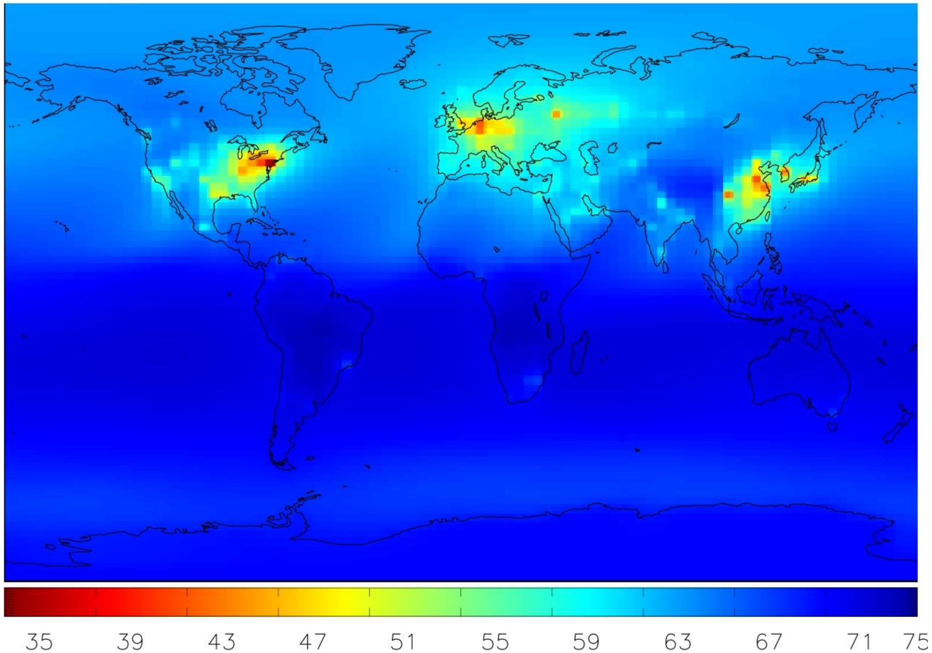
^{14}C is produced naturally in the atmosphere, and moves throughout the carbon cycle

Natural radioactive decay removes ^{14}C from buried/dead objects

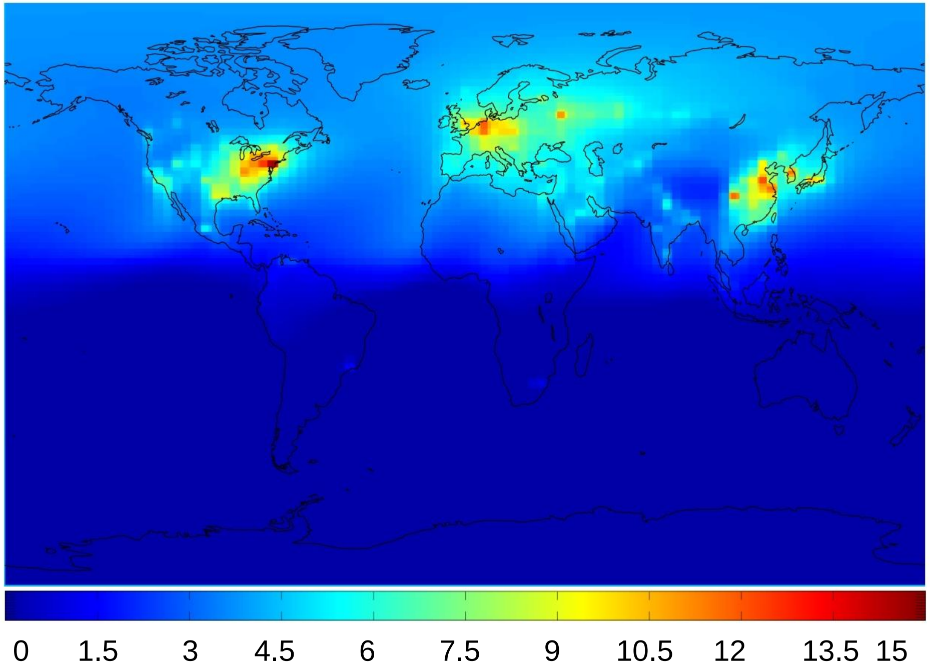
Half-life 5,730 years

Fossil fuels are entirely devoid of ^{14}C

Modelled global surface distribution of ^{14}C in CO_2



$\Delta^{14}CO_2$ (‰)

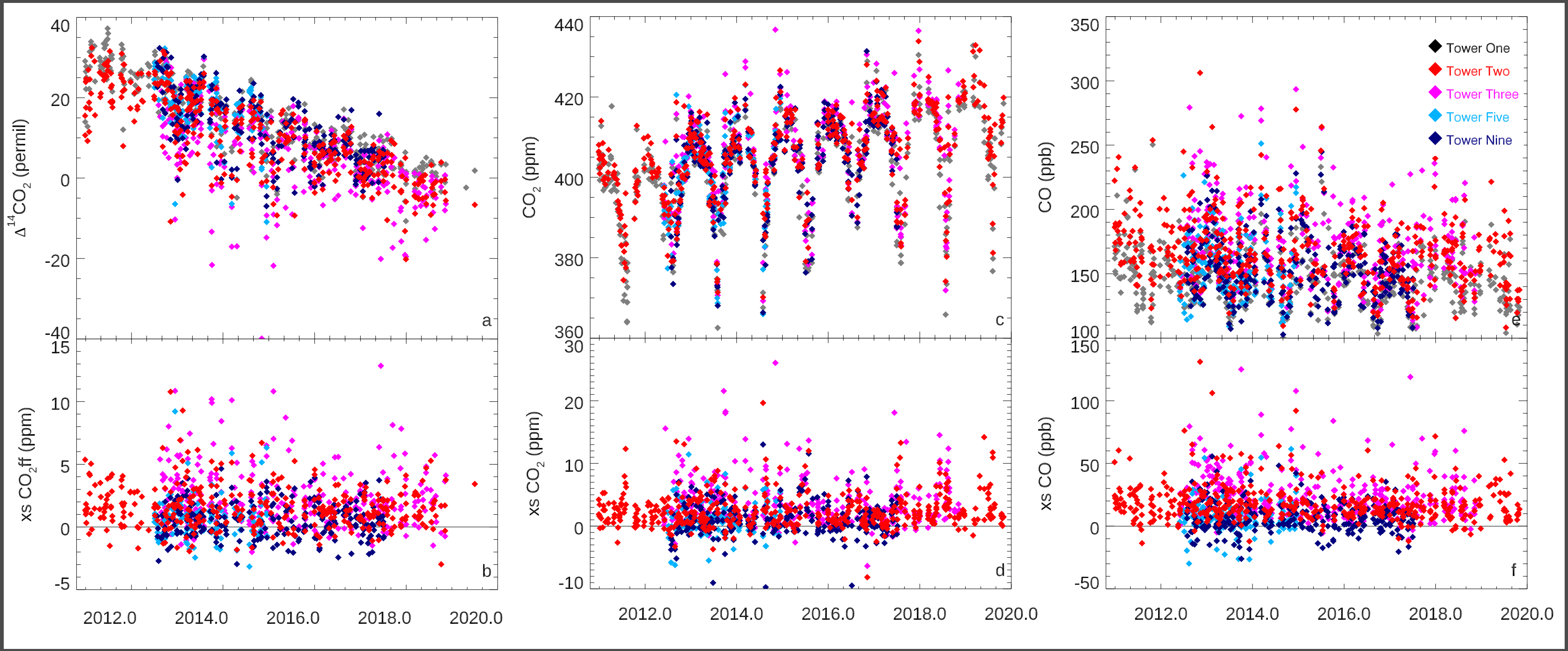


CO_2ff (ppm)

Fossil fuel CO_2 emission pattern very strongly reflected in Northern Hemisphere $\Delta^{14}CO_2$

Turnbull et al., 2009
LMDZ model 2002-2007 surface $\Delta^{14}CO_2$

Flask-based estimates of total CO_2 and CO_2ff Indianapolis in winter



$$CO_2ff = \frac{CO_{2obs}(\Delta_{obs} - \Delta_{bg})}{(\Delta_{ff} - \Delta_{bg})}$$

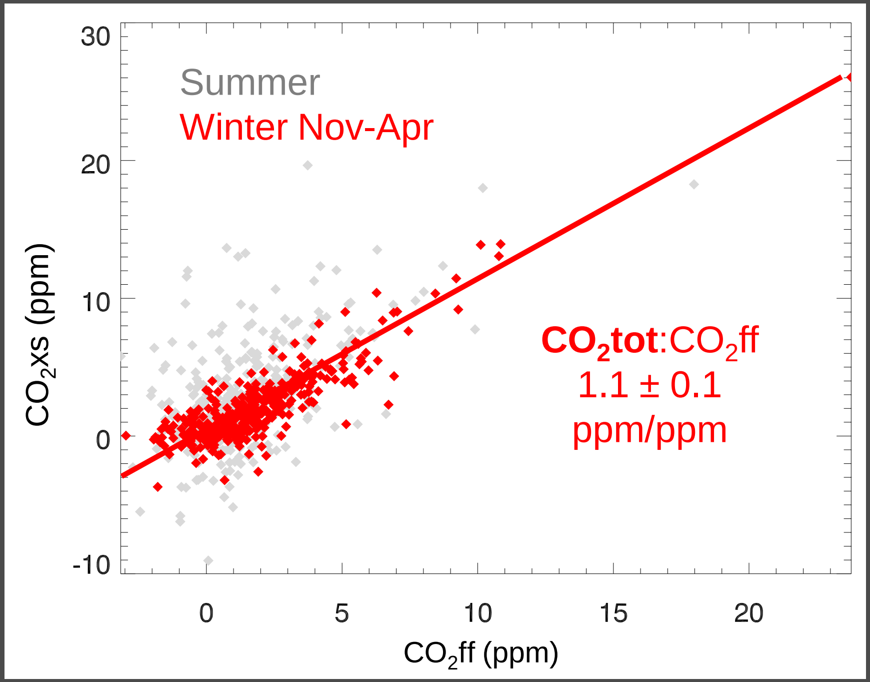
$$CO_2xs = CO_2obs - CO_2bg$$

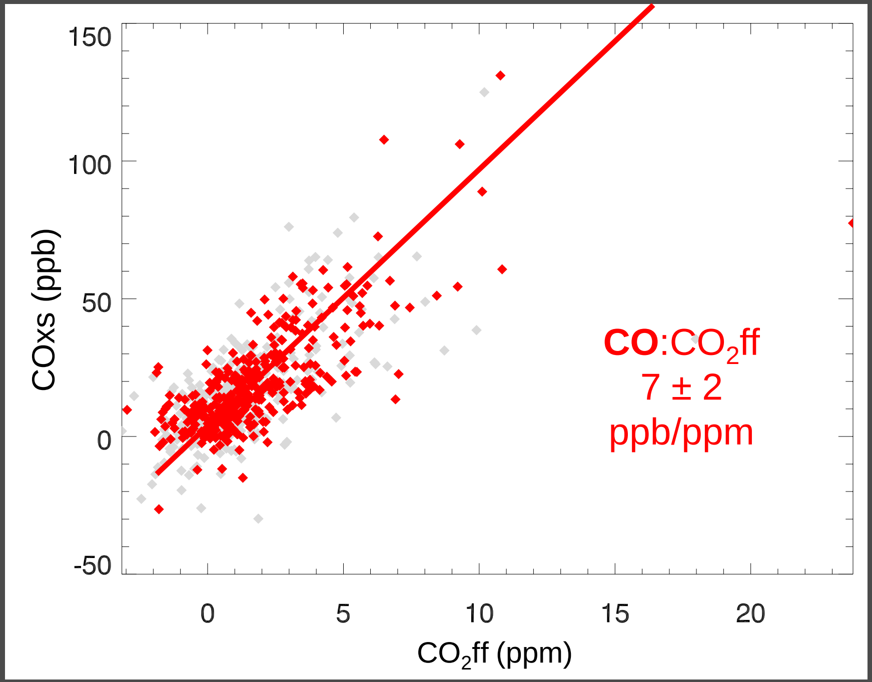
$$CO_{xs} = COobs - CObg$$

Determine enhancements relative to upwind background Tower One

Consistent enhancements in anthropogenic species at downwind towers

Flask-based emission ratios





Determine how much of the CO_2 comes from fossil fuels and how much from other sources (plant photosynthesis/respiration, human/pet respiration, biomass burning)

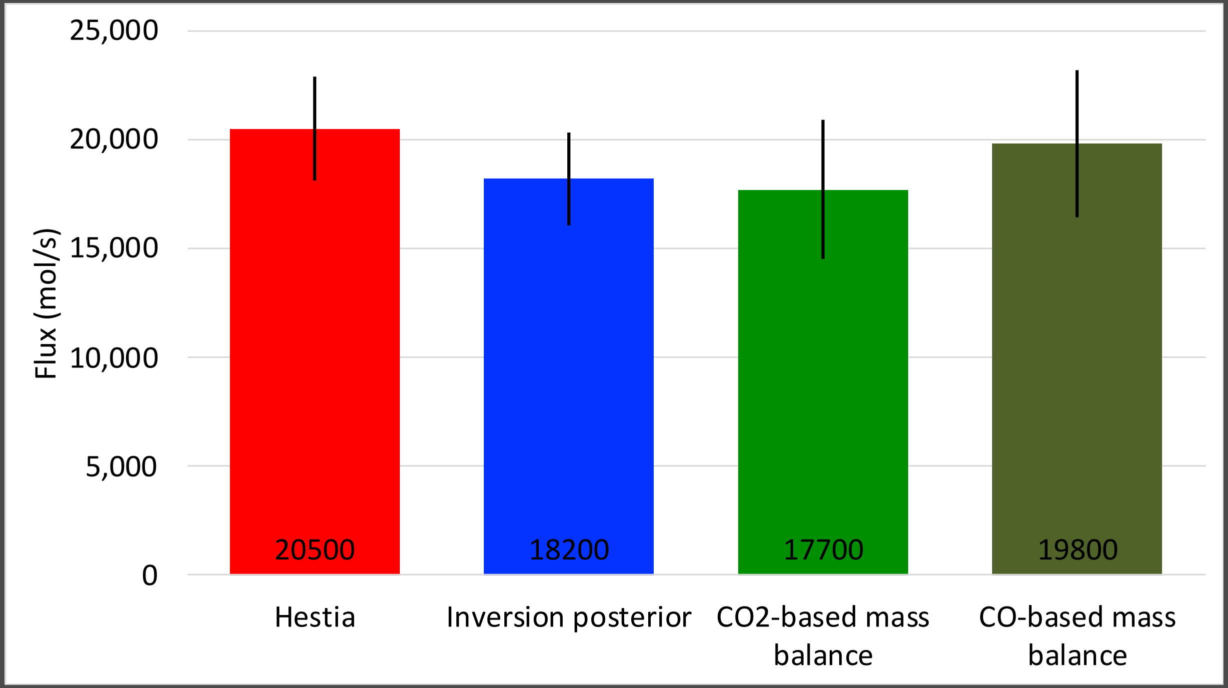
~10% contribution of non-CO_2ff to CO_2 in winter

CO co-emitted with CO_2ff at variable rate depending on combustion conditions - derive ratio empirically from observations

Can then use high resolution CO observations to determine CO_2ff

Turnbull et al., 2015

Apples-to-apples Indianapolis CO_2ff flux comparison



Whole city flux 19,100 mols/s ± 7%

Quantified uncertainty on whole city flux

Agreement is sufficient to evaluate ~10% changes in urban emissions

Urban greenhouse gas science to meet policy needs

World Meteorological Organisation: Integrated Global Greenhouse Gas Information System

WMO's IG³IS program links greenhouse gas measurement scientists with policymakers and other stakeholders

NIST, CO_2-USA, ICOS all working on similar initiatives

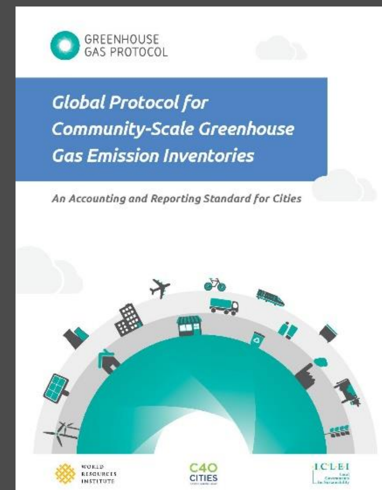
IG³IS exemplar programs:

CarbonWatch NZ – integration of CO_2 observations and policy at national and urban scales

UK, Australia, Switzerland –atmospheric observations of methane and halogenated gasses to improve national inventory reporting to UNFCCC

Environmental Defense Fund – oil and gas methane emissions detection and quantification

Greenhouse gas information in emissions reporting

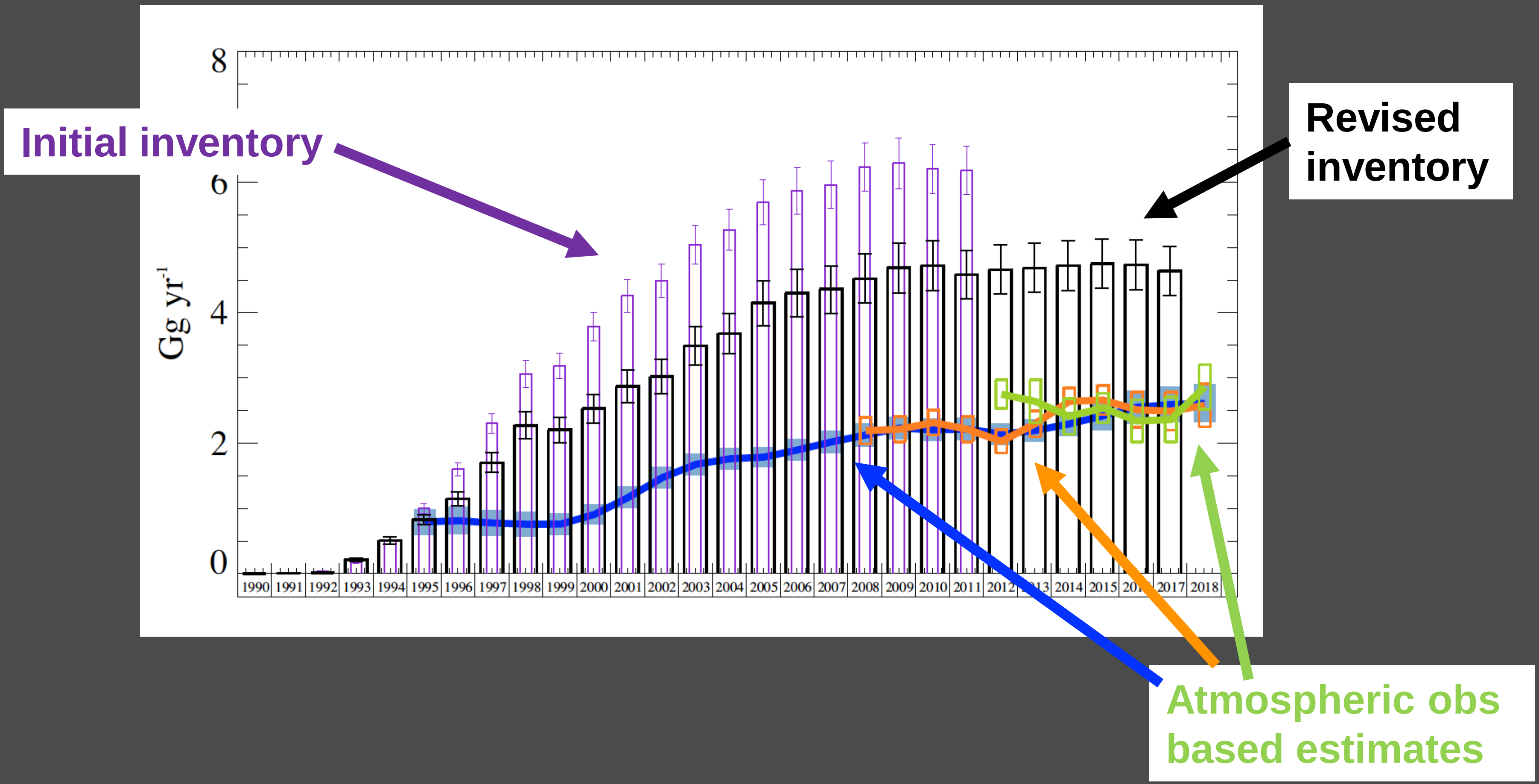


IPCC Taskforce on national Greenhouse Gas Inventories:
National Inventory Reporting for UNFCCC/Paris Agreement
2019 Refinement expands the role of atmospheric observations in national emissions reporting

Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) and similar for urban scale emission reporting

Atmospheric observations and modelling can improve emissions estimates

Atmospheric observations in emissions reporting
Air conditioning gas HFC-134a in the UK



Inventory re-investigated and revised based on atmospheric observations

IG^{3}IS Good Practice Guidelines For Urban Greenhouse Gas Monitoring and Assessment

Integrated Global Greenhouse Gas Information System

Level of sophistication of urban stakeholder needs

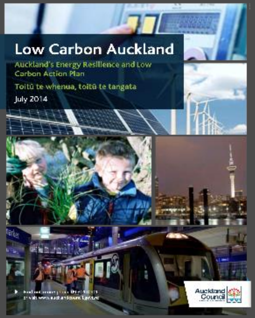
Complexity of solution

Identify major emitters and anomaly detection	Quantification of total GHG emissions	Assessment of GHG emissions per sector	Tracking annual and long-term emission changes	Understand short-term emission changes and spatial patterns	Process understanding of emissions and tracking of mitigation impacts
Inventory validation (A1)	Inventory or emission model (A2)	Sector-specific inventory or emission model (A3)	Continuously updated inventory or emission model (A4)	Temporally and spatially disaggregated inventory or emission model (A5)	Process-based emission model using real-time emission data (A6)
Mobile surveys (B1)	Mass-balance (B2) Radon tracer method (B3)	Multi-tracer ratio observations (B4)	Radon tracer method (B5) Multi-tracer observations (B6)	Mobile surveys (B7) Urban flux towers (B8) Repeated mass-balance (B9)	Urban flux towers (B10) Dedicated field campaigns (B11)
Remote sensing (C1)	DAS using short-term observations (C2)	*DAS using dense observations (C3)* *DAS using multi-species data (C4)*	DAS using long-term observations (C5)	*DAS using dense observations (C6)*	FFDAS DAS using multi-species (C7)

- Currently being drafted for release in late 2020
- First iteration is aimed at the scientific research community
- Future plan to transition these guidelines into documentary standards for practitioners and commercial enterprises

Science to meet policy needs
Example from Auckland, New Zealand

NZ Ministry for the Environment
NZ Climate Change Commission



Auckland Council

Indigenous groups
Ngāti Whātua Ōrākei

Estimate urban biogenic fluxes

- Currently almost entirely unknown
- Will the Million Tree Initiative reduce Auckland's net emissions?
- Develop urban biosphere flux estimates to include in national GHG reporting
- What are the climate impacts of replanting parklands with native forest?

Improve traffic fossil fuel flux estimates

- How might planning decisions change traffic emissions?
- New fuel tax in Auckland in 2018 – did emissions change?

Long term goal is to provide detailed full carbon budget for Auckland

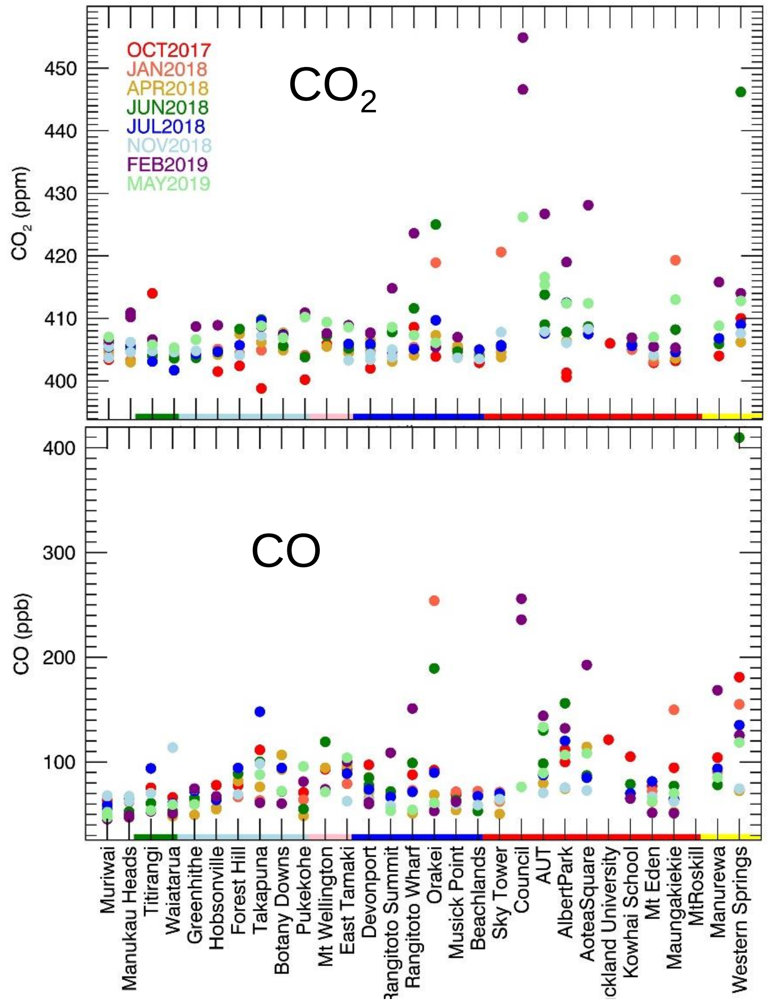
CarbonWatch NZ
GUIDING CARBON MITIGATION STRATEGIES

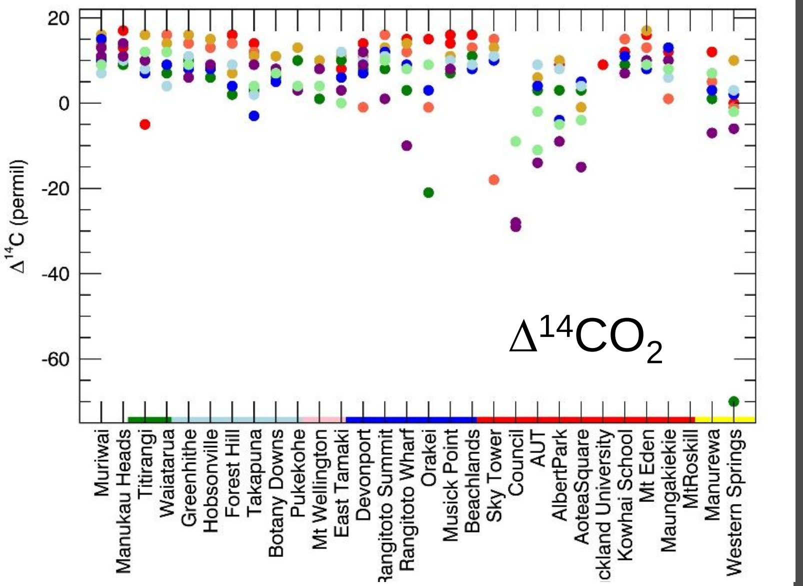
Diagnosing the biogenic CO_2 contribution: flask sampling campaigns

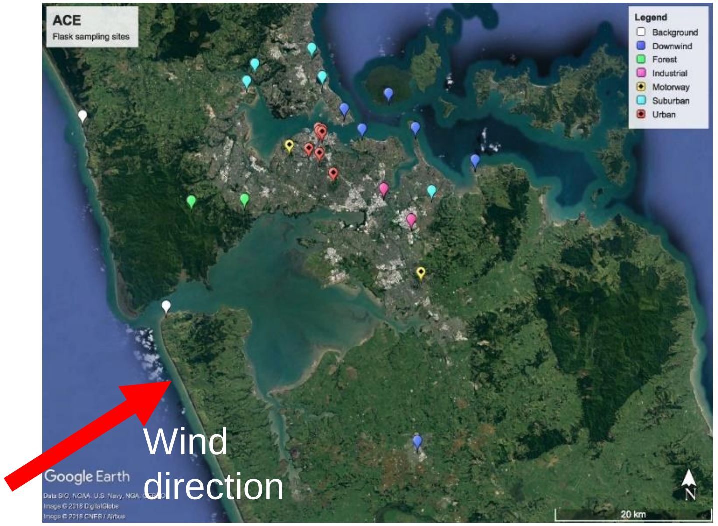
grab flask samples from ~26 sites four times/year

CO_2, CO, CH_4, $^{14}CO_2$

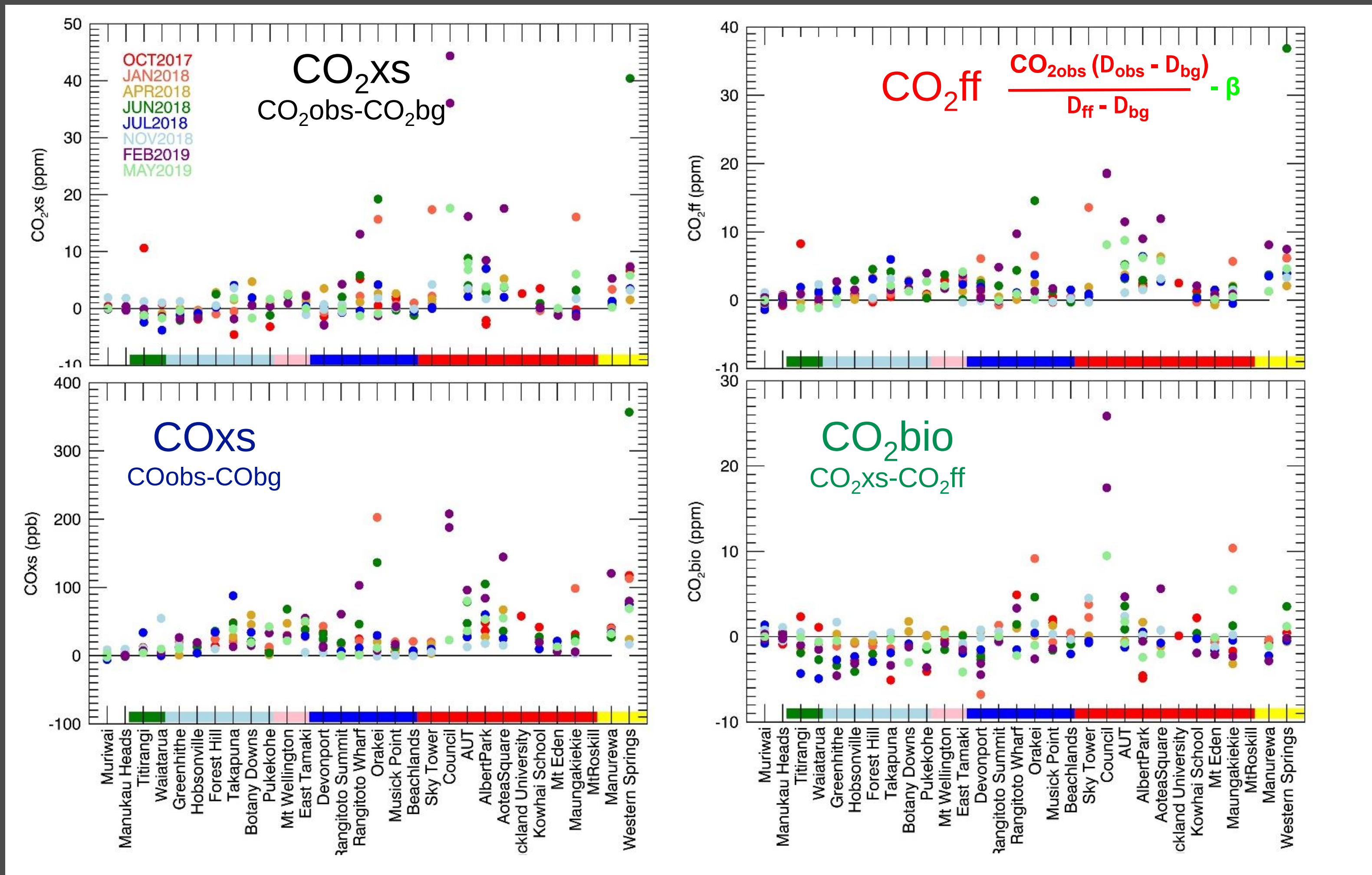
Auckland flask results







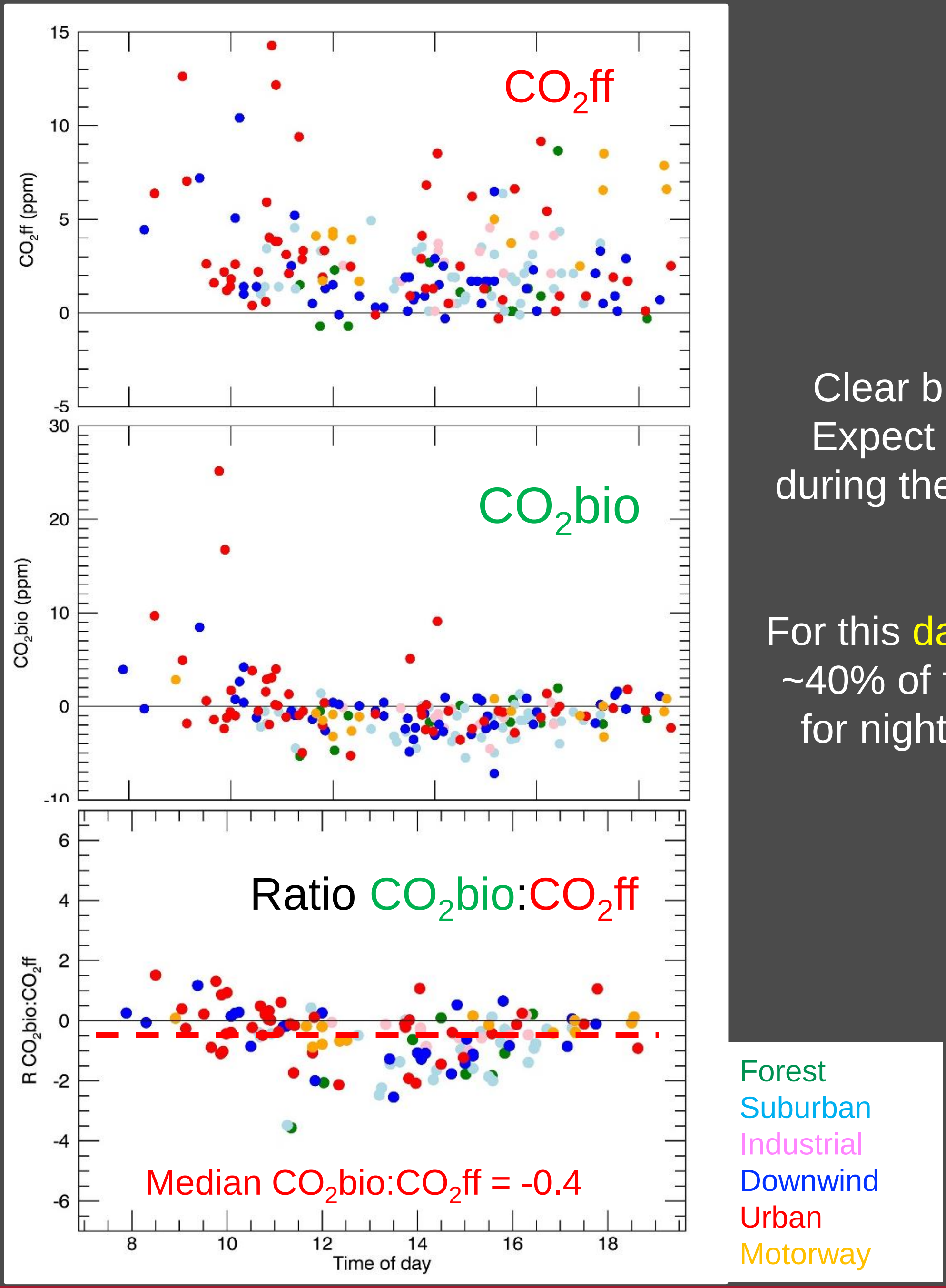
Auckland flask results



Clear enhancements in CO_2ff and COxs at urban sites

CO_2xs and CO_2bio are variable

No obvious seasonality



Auckland flask measurements

No pattern in CO_2ff by time of day

Clear but variable afternoon drawdown in CO_2bio
Expect daily cycle of photosynthetic CO_2 removal during the daylight hours, and respiration CO_2 source at night

For this daytime dataset, net biogenic uptake removes ~40% of fossil fuel CO_2 emissions (does not account for nighttime when photosynthetic uptake does not occur)

Conclusions and outlook

Wean quantify urban CO_2 emissions to better than 10% using multiple methods:

Inventory-based methods - Atmospheric inversion with tower observations - Aircraft-based mass balance

CO_2 source sectors can be separated:

fossil fuel vs biogenic CO_2 – other tracers can separate traffic, power plants, industry, etc

Uptake into policy requires interaction with policymakers and refocusing research to meet their goals

CarbonWatch NZ
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IG3IS Integrated Global Greenhouse Gas Information System

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