Observations-based tools to support climate mitigation

TRANSFORMANDO LOS SECTORES DEL AGUA Y LOS RESIDUOS
EL DESAFÍO DE LA DESCARBONIZACIÓN

Dr Oksana Tarasova (otarasova@wmo.int)
WMO Infrastructure Department

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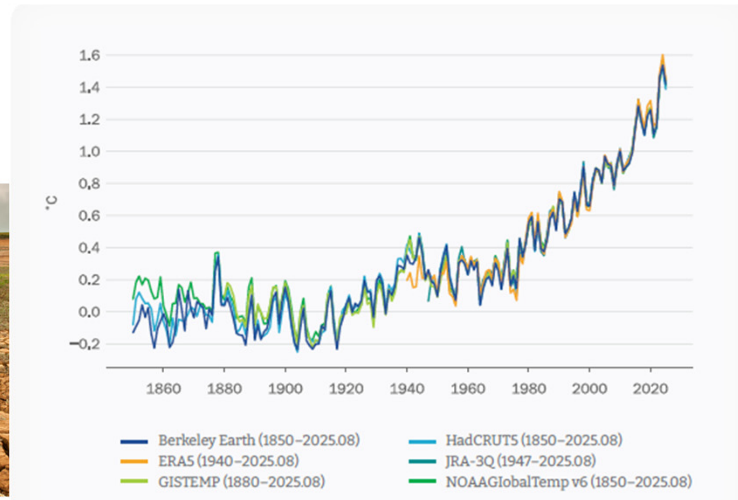
Why do we need to mitigate climate change?



The global mean temperature for January-August 2025 was **1.42°C ± 0.12 °C** and in 2024 it was **1.55 °C ± 0.13 °C** above the 1850–1900 average. The year 2024 was the warmest year in the 175-year observational record.

Mitigation – reducing climate change

The 2025 report of the Lancet Countdown on health and climate change:

- Global economic losses due to weather-related extreme events in 2024 were **$304 billion**, a 58·9% increase from the 2010–14 annual average;
- In 2012–21, global heat-related mortality reached an estimated average **546 000 deaths annually**, a 63·2% increase compared with 1990–99 period.

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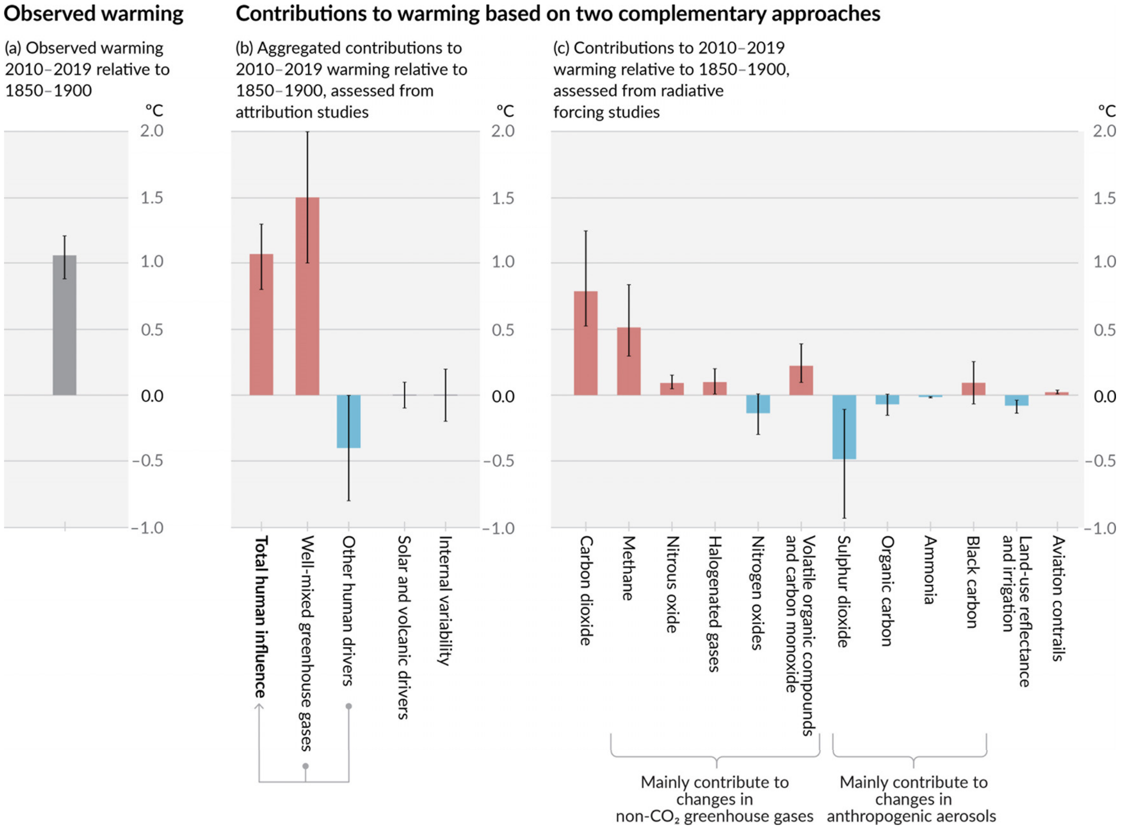
Drivers of climate change



- In order of effect, water vapor, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the most important GHGs.
- Increases in concentrations of CO_2, CH_4 and N_2O due to human activities are the primary drivers of observed climate change (IPCC, 2021).

Impact is defined by the amount of the gases in the atmosphere and their warming potential

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Paris Agreement

- Article 4 refers to emissions peaking and reductions "so as to achieve a balance between **anthropogenic emissions by sources and removals by sinks** of greenhouse gases in the second half of this century".
- Source of commitments: **Nationally Determined Contributions** (NDCs)
- Article 6 calls to deliver an overall mitigation even if market mechanisms are used
- Article 13 calls for **the enhanced transparency** and reporting on national progress

Overall ambition of the Paris Agreement is to limit warming to well below 2 °C above pre-industrial levels while pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels

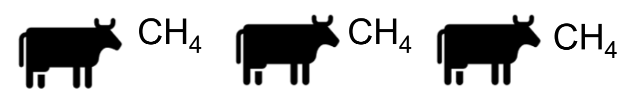
CO_2 concentration in the atmosphere increased by 10% from 358.7 ppm (1994) to **400.3** ppm (2015). It reached **423.9** ppm in 2024.

What is emission inventory (“Bottom-up” estimate)

- **Tiers:** **A tier represents a level of methodological complexity.**
- **Usually three tiers are provided:**
  - Tier 1 is the basic method,
  - Tier 2 - intermediate and
  - Tier 3 - most demanding in terms of complexity and data requirements

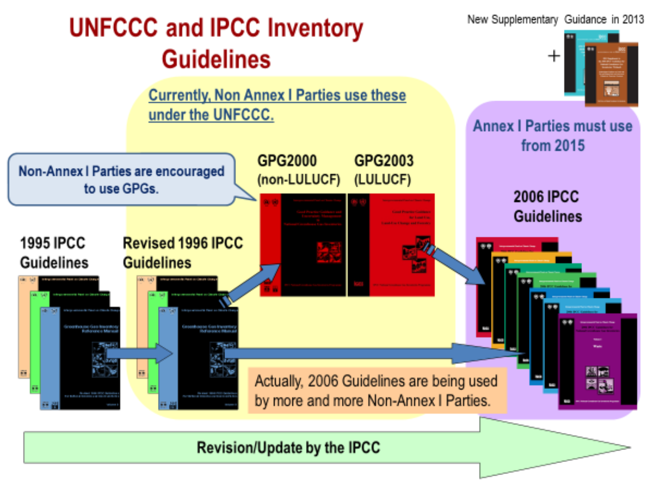
Tiers 2 and 3 are sometimes referred to as higher tier methods and are generally considered to be more accurate

Emissions = Activity data*Emission factor



Category	Activity number	Total per category
Transport	NN	XX Gt
Energy	NN	XX Gt
Agriculture	NN	XX Gt
….	…	…
Total		YY Gt

- Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (1996 Guidelines)
- Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (GPG 2000)
- Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG LULUCF)
- 2006 IPCC Guidelines for National Greenhouse Gas Inventories (**2006 Guidelines**) and 2019 Refinement.



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Requirements related to GHG emission reporting: corporate

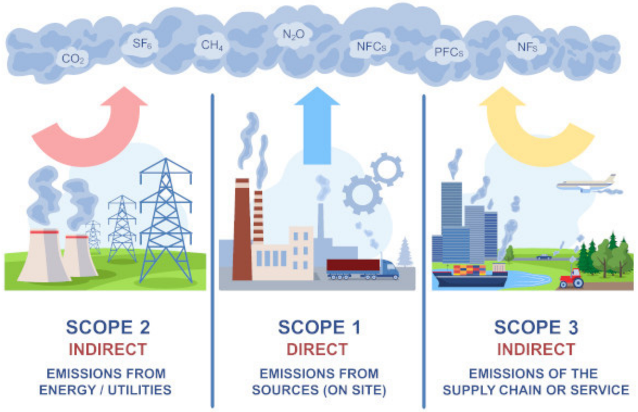
For corporations, emissions fall into three categories:

Scope 1 emissions: those produced directly by the company

Scope 2 emissions: those generated by power and other resources the company uses

Scope 3 emissions: those that result from indirect sources within the supply chain

Measurement techniques vary, including direct monitoring of emissions (e.g. stack measurements) at their source and indirect methods like estimating emissions based on fuel consumption data.



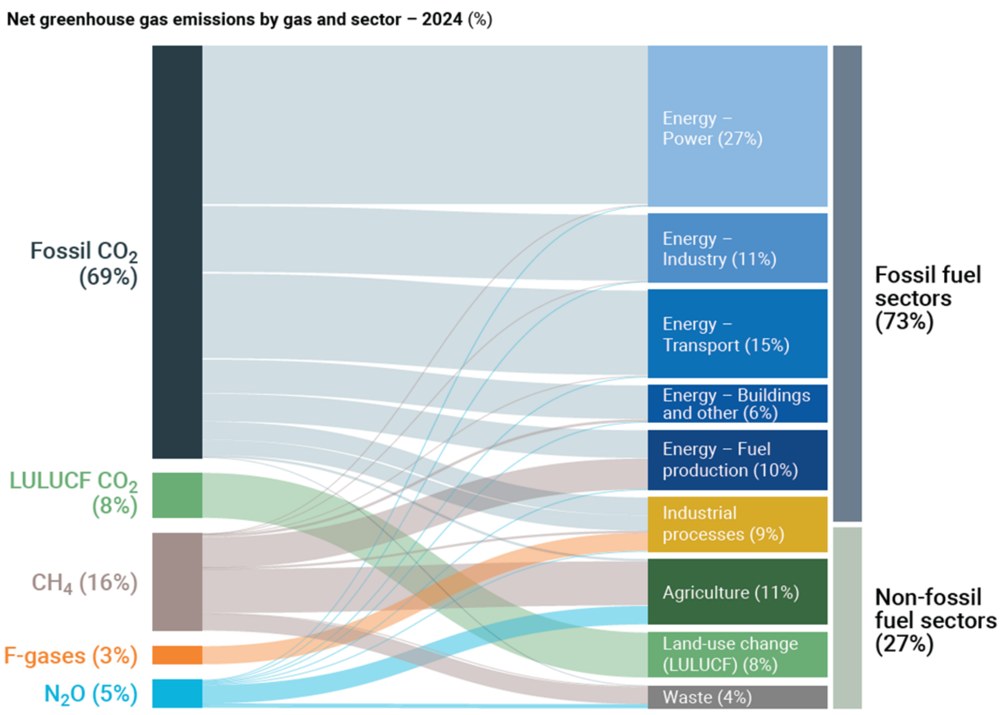
The most widely used GHG accounting tool is **the GHG Protocol Corporate Accounting and Reporting Standard, often referred to as the Greenhouse Gas Protocol**, GHG Protocol or GHGP.

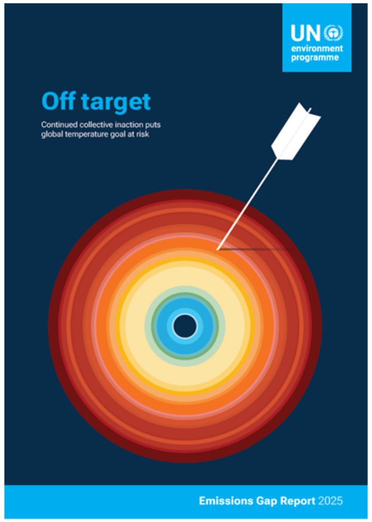
The protocol is developed by the World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD). It provides principles, guidance, tools and methodologies for creating GHG inventories and reporting relevant data.

Non-state entities report emissions along the value chain following "inventory approach"

It is not clear how national and corporate reports overlap as corporate emissions happen in different countries

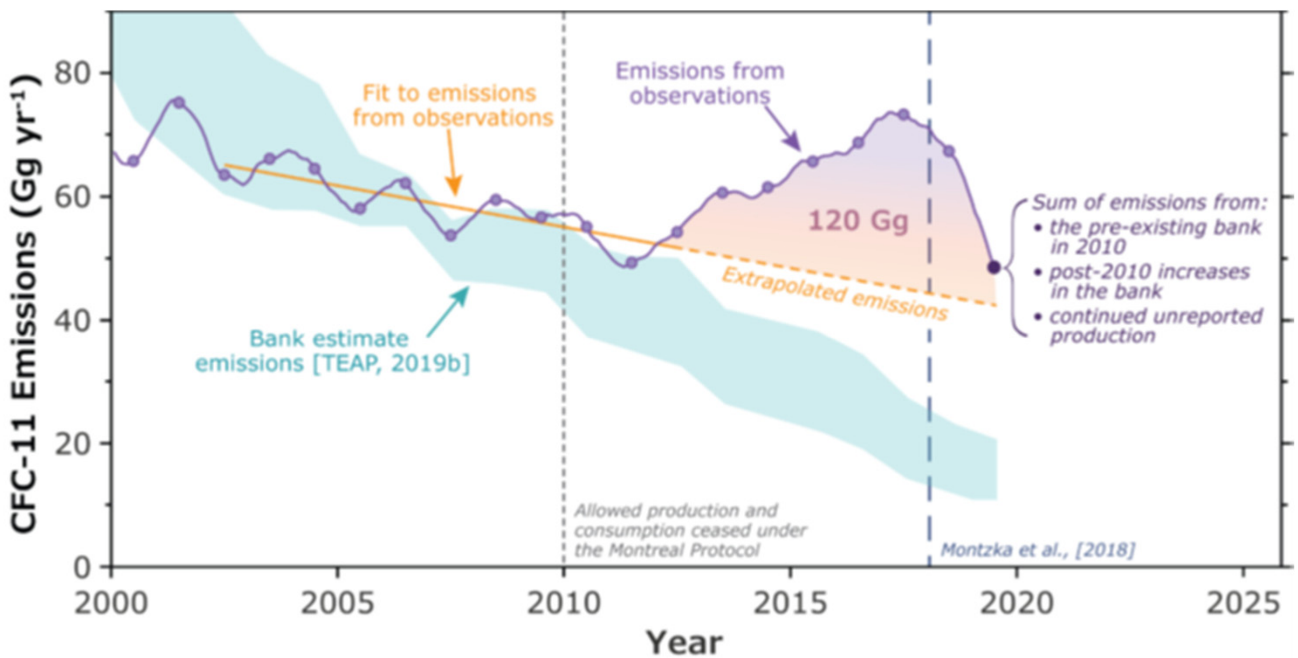
GHG emissions by gas and sector





Ten years on from the adoption of the Paris Agreement, global GHG emissions continue to increase. In 2024, they reached a record of 57.7 GtCO2e, representing a 2.3 per cent (1.4 GtCO2e) increase from the previous year.

How precise are emission inventories?



Atmospheric observations help to support international treaties

Report on unexpected emissions of CFC-11 (WMO, 2021)

How to add “atmosphere” into emission estimates

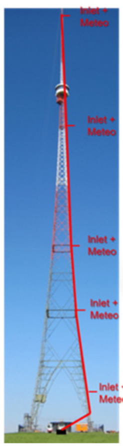
“Top-down” estimate

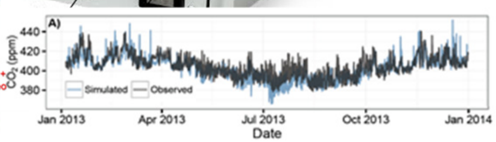
Atmospheric observations and analysis

Ecosystem and ocean observations

Research activities (towards establishment of common standard)

Combination of bottom-up and top-down provides most comprehensive knowledge (combine inventory and observations in a common analysis framework) provides the improved emission estimates





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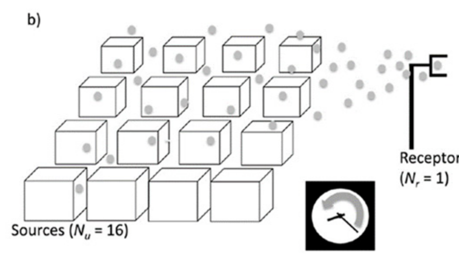

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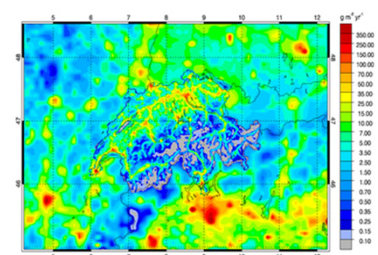

Integrated Global Greenhouse Gas Information System (IG³IS)

… a common framework for provision of **systematic services to the user community** supporting their greenhouse gas emission reduction ambitions

- Support the use of atmospheric data to improve emission and/or uptake estimates
- Consensus on a coherent set of good-practice methods and guidelines
- Quality control (benchmarking)

The solutions is:
- Scalable
- Applicable to different gases
- Transparent
- Based on the most recent science

Range of scales

Industry | **Cities** | **Countries** | **Global Stock taking**

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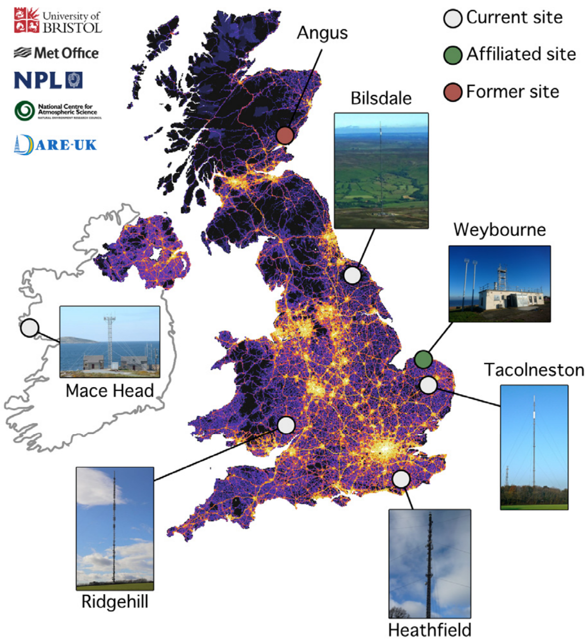
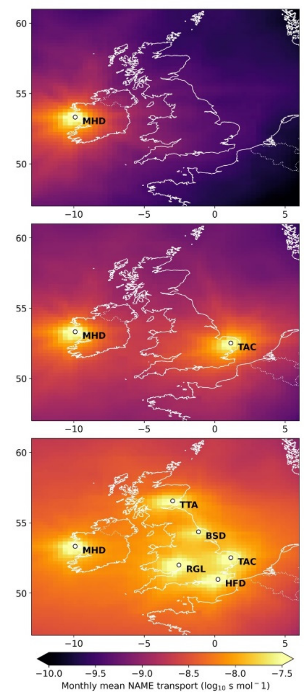
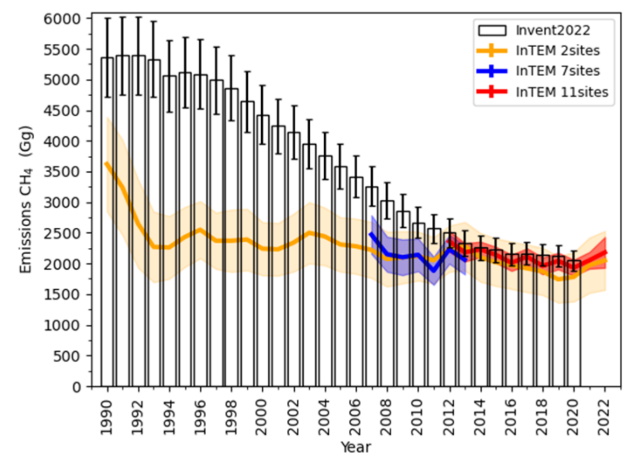
National scale CH_4 emissions in UK



UK CO_2 emissions from the National Atmospheric Emissions Inventory (NAEI)



Impact of number of sites on UK CH_4 estimates



2 sites: MHD, CBW
7 sites: UK + CBW
11 sites: UK + ICOS

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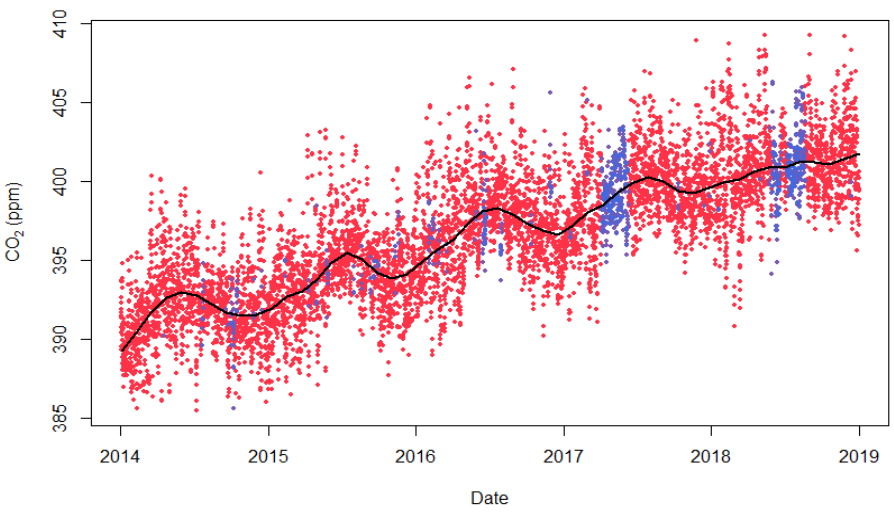
(Slide courtesy: Alistair Manning, UK Met Office)

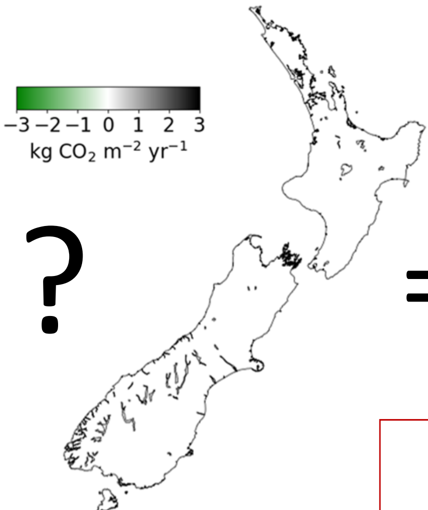


National case for New Zealand

- Three sites with CO_2 and $^{14}CO_2$ measurements
- Larger uptake than prior model or bottom up accounting, particularly in forested regions
- Differences to bottom up accounting partly due to differences between LULUCF and what the atmosphere ‘sees’. These issues are still being resolved.

Inverse modelling of carbon dioxide

Posterior flux



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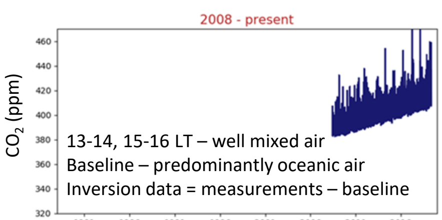
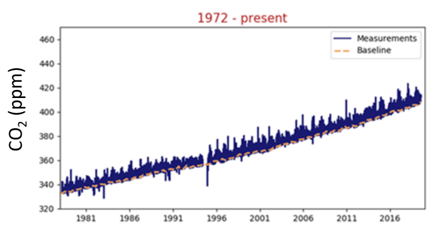
1. Measurements

Baring Head and Lauder





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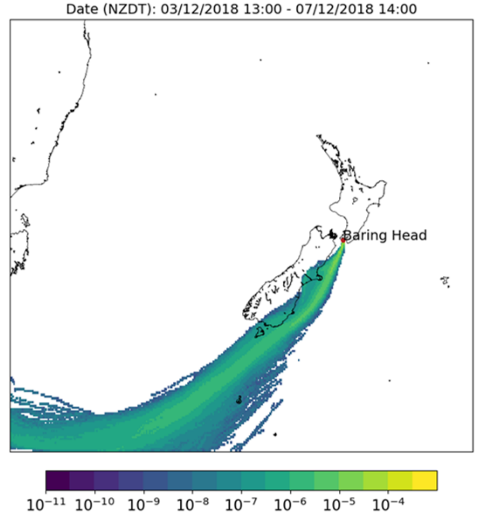
2. Transport model

NAME III Lagrangian dispersion model**



*Driven by meteorology from:
NZLAM (12 km) / NZLAM4 (4 km) / NZCSM (1.5 km)
(Local configuration of the UK Met Office Unified Model)

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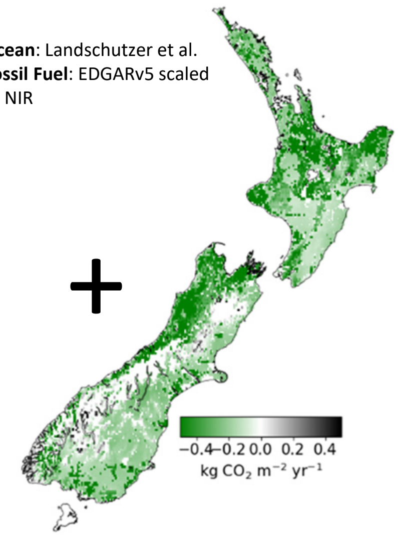
3. Prior fluxes

Biome-BGC and CEN-W terrestrial model output

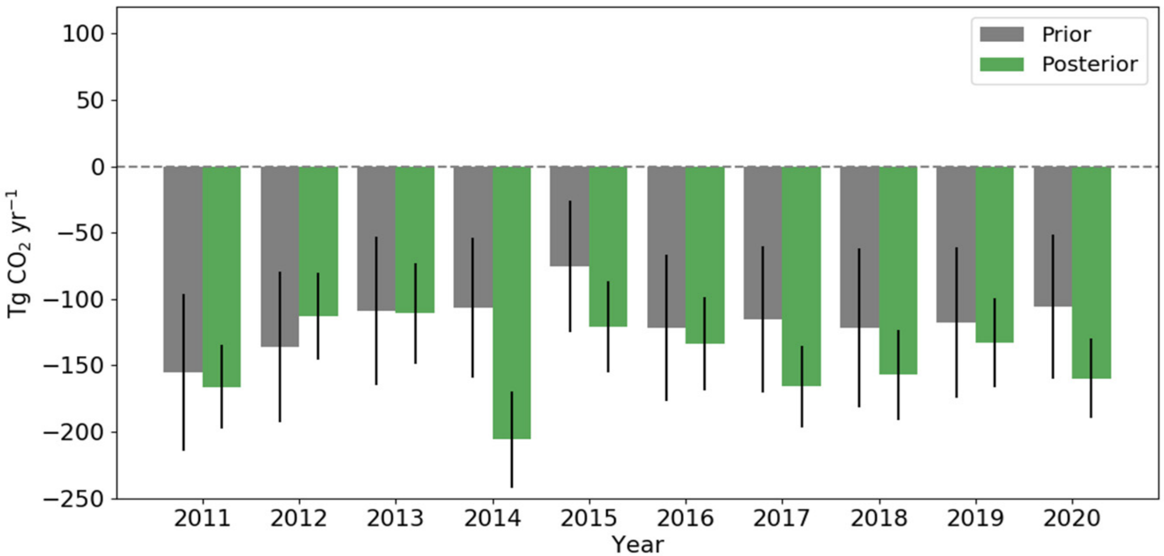
Ocean: Landschutzer et al.
Fossil Fuel: EDGARv5 scaled to NIR



NIWA
Taihoro Nukurangi

CarbonWatch-NZ Results

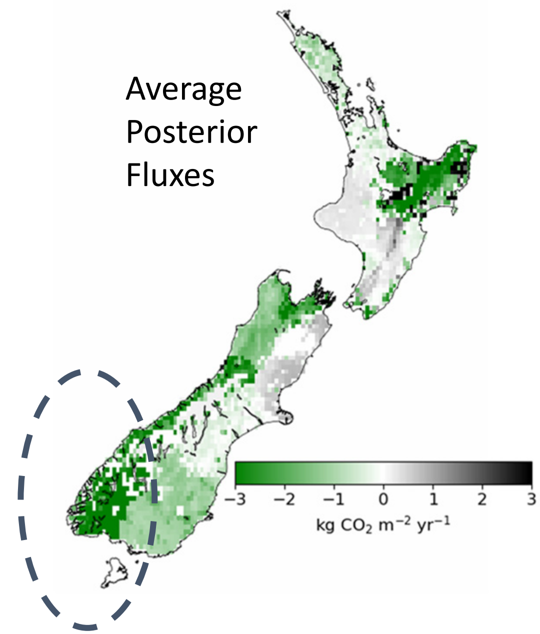
Aotearoa's Terrestrial Carbon Uptake.



Bukosa et al., in prep.

- At present, NZ's ETS incentivizes exotic forests over indigenous forests
- New Zealand's first Emission Reduction Plan includes a shift towards permanent indigenous forest planting for climate.

Average Posterior Fluxes



Even after taking into consideration the differences in accounting, the inverse estimates of the carbon sink remain substantially larger

2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: adding atmospheric observations

- The refinement work does not revise the 2006 IPCC Guidelines, but update, supplement and/or elaborate the 2006 IPCC Guidelines where gaps or out-of-date science have been identified.
- The 2019 Refinement should be used in conjunction with the 2006 IPCC Guidelines.

Emission verifications was identified as one of the gaps

Chapter 6: QA/QC and Verification

CHAPTER 6

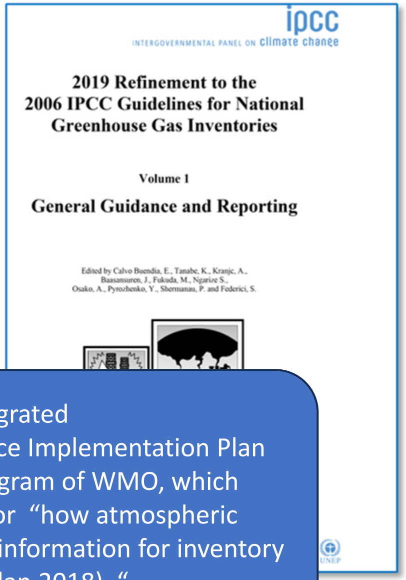
QUALITY ASSURANCE/QUALITY CONTROL AND VERIFICATION

6.10.2 Comparisons with atmospheric measurements

6.10.2.1 INTRODUCTION TO EMISSION ESTIMATES BASED ON ATMOSPHERIC CONCENTRATION MEASUREMENTS

This section addresses the state of science for emission estimates based on atmospheric measurements and their application to comparison with national emission inventories. Since the *2006 IPCC Guidelines* were published, the most notable advances have been achieved in the application of inverse models of atmospheric transport for estimating emissions at the national scale. An increasing number of countries are considering applying such models.

"Atmospheric measurements are being used to provide useful quality assurance of the national greenhouse gas emission estimates (Manning et al. 2011; Fraser et al. 2014; Henne et al. 2016). Under the right measurement and modelling conditions(discussed further in this section), they can provide a perspective on the trends and magnitude of greenhouse gas (GHG) emission estimates that is largely independent of inventories. "



"More details are presented in the Integrated Global Greenhouse Gas Information System (IG³IS) Science Implementation Plan prepared by the Global Atmosphere Watch (GAW) program of WMO, which documents good practice methodological guidelines for "how atmospheric measurements and analysis methods can deliver valuable information for inventory verification"(IG³IS Science Implementation Plan 2018). "

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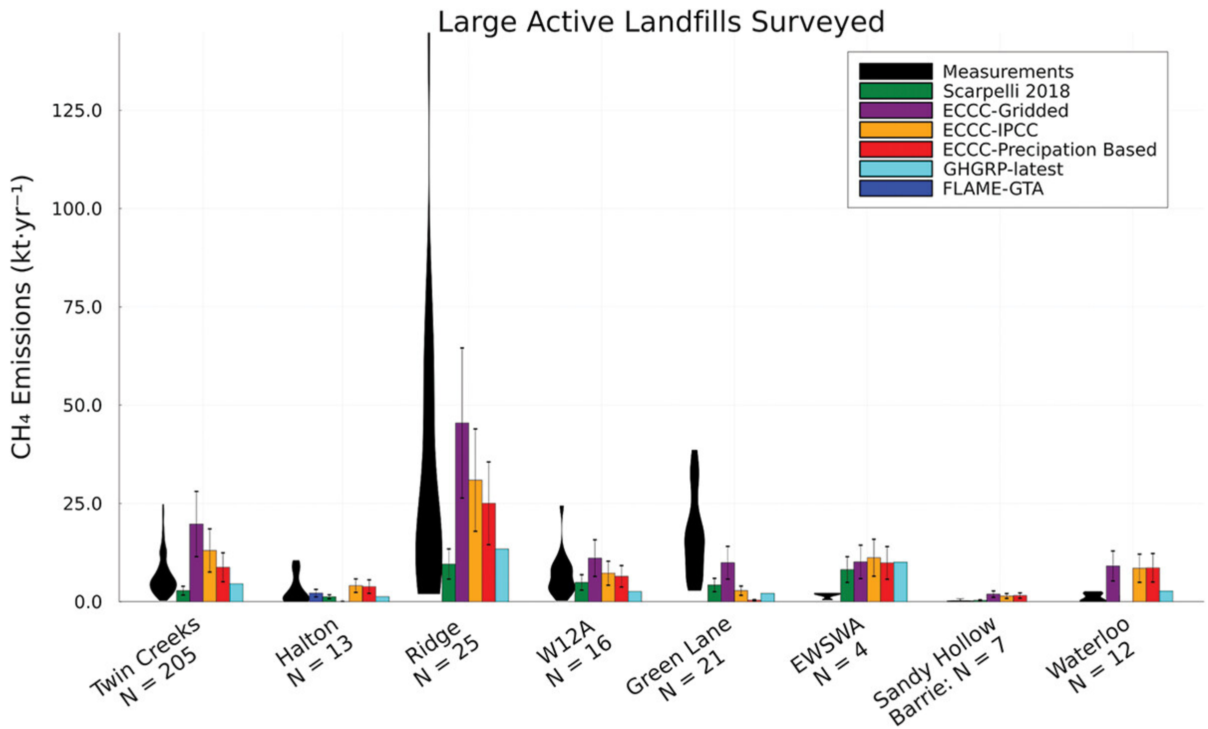
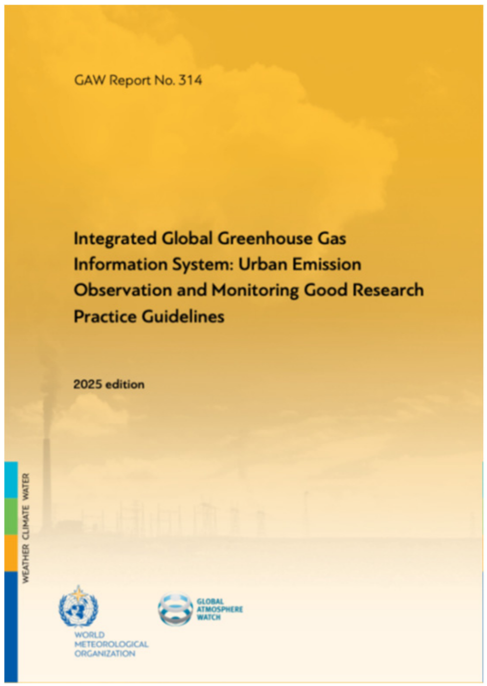
Application at facility scale: waste sector



Measured and inventoried CH_4 emissions from large active landfills in Southern Ontario. Black violin plots show the distribution of the emissions rates we estimate from our measurements. Inventoried emissions rates are shown as bar graphs.

Gillespie, L. D. et al., (2025). Estimating methane emissions from the waste sector in Southern Ontario using atmospheric measurements. Journal of the Air & Waste Management Association, 75(2), 144–163. https://doi.org/10.1080/10962247.2024.2435340

IG³IS Good Practice Guidelines for Greenhouse Gas Information



- **Urban** — 2nd edition released Sept 2025 GAW Report #314
- **National** — Under development for release late 2025
- **Forestry** — in planning stage
- **Facility-scale methane** — In planning stage
- **Others…**

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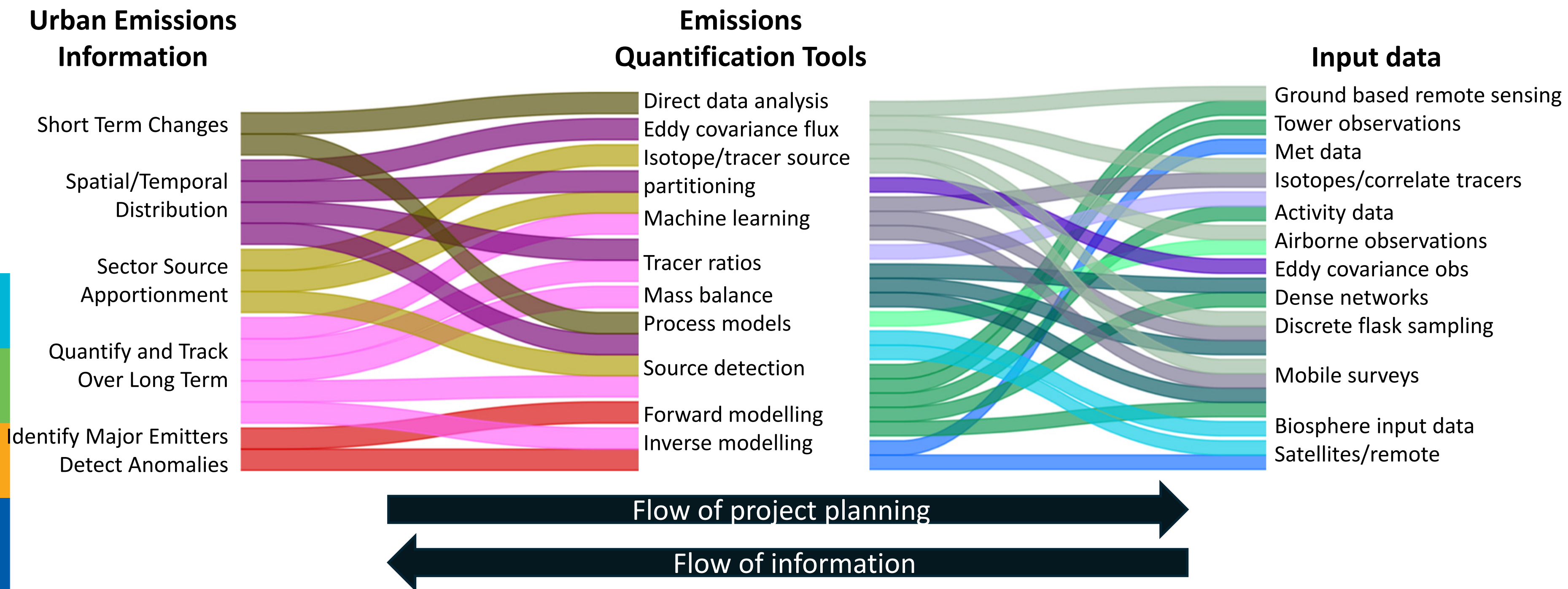
IG^{3}IS Urban Greenhouse Gas Emission Observation and Monitoring Good Research Practice Guidelines



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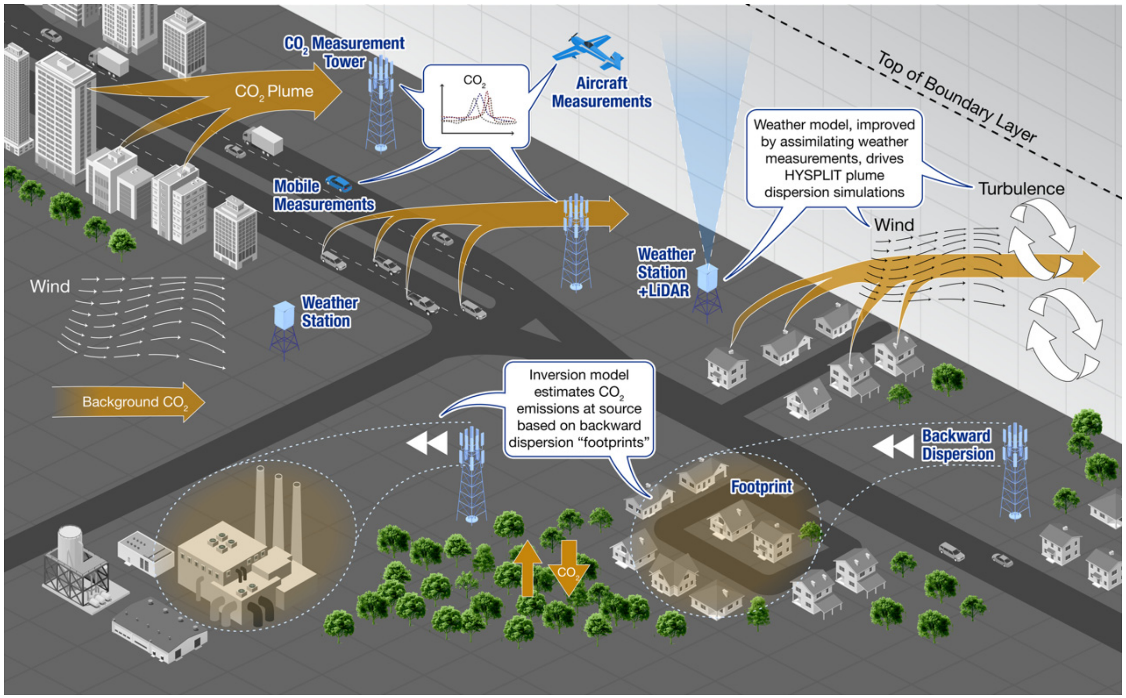

		Spatial scale	Frequency (data resolution)	Ability to separate sectors	Start-up cost	Ongoing cost	Maturity of method	Comments
	Traditional inventory	City total	Annual	•••	•	•	•••	
Process modelling	Models for CO_2ff, Methane, F-gases, N_2O, biospheric CO_2	10–500-m resolution	Hourly	•••	••	••	••	
Computational modelling	Forward modelling	1-km resolution	Hourly	•	•••	••	•••	Computational costs sc with frequency/durati
	Inverse modelling	1-km resolution	Hourly	•	•••	••	•••	Computational costs sc with frequency and spa resolution
	Mass balance analysis	City total	Infrequent snapshots	•	•••	••	•••	Single aircraft/instrum can be used in multip cities
Direct observations	In situ data analysis	Neighbour-hood	Continuous	••	••	•	•••	Useful for outreach ar communication
	Partitioning with isotopes and tracers	Neighbour-hood to city total	Discrete sampling or continuous	•••	•	•	••	
	Tracer ratios	Neighbour-hood to city total	Infrequent snapshots	••	••	•	••	
	Eddy covariance	Neighbour-hood	Continuous with gaps	•	••	••	••	
	Vertical gradients	Neighbour-hood	Continuous with gaps	•	••	•	••	

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Stakeholder engagement as a key IG³IS principle

- The second IG³IS Stakeholder Consultations and User Summit took place in February 2023 and set up the priorities for IG³IS development (see word cloud).
- Continuous engagement is achieved through a webinar series

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Thank you.

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