F-gas emissions monitoring through atmospheric observation

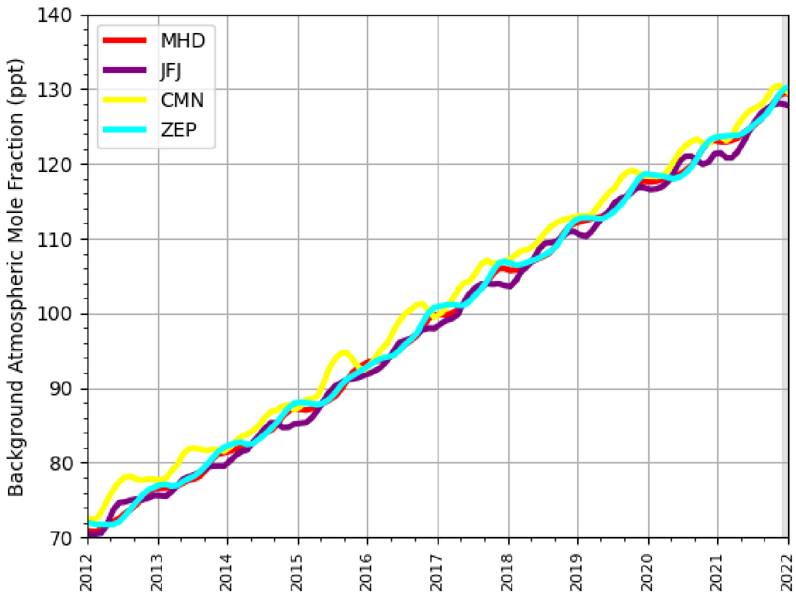
Observations: Jgor Arduini, Tim Arnold, Andreas Engel, Paul Fraser, Arnoud Frumau, Chris Harth, Paul Krummel, Michela Maione, Steve Montzka, Jens Mühle, Simon O'Doherty, Joe Pitt, Chris Rennick, Peter Salameh, Tanja Schuck, Gerry Spain, Kieran Stanley, Martin Vollmer, Ray Weiss, Angelina Wenger, Dickon Young

Modelling: Stephan Henne, Lei Hu, Alistair Manning, Alison Redington, Stefan Reimann, Cathy Trudinger

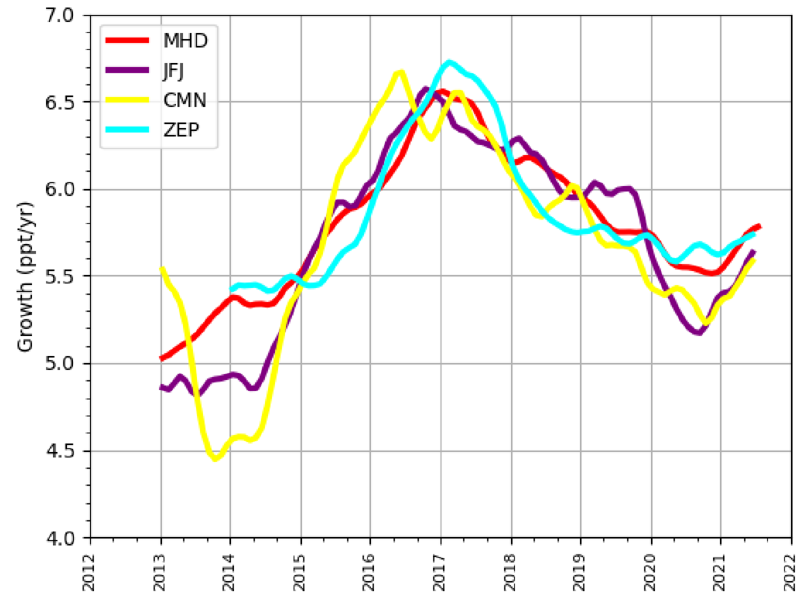
Outline

- Global F-gas concentrations are virtually all rising
- GHG inventory compilers need to estimate national emissions of a wide range of F-gases
- Atmospheric observations can significantly help inventory compilers understand emissions
  - Confirm magnitudes of emission
  - Identify significant emission sources
  - Give an early indication of national emissions

Global Concentration: HFC-134a
(mobile air-conditioner)



(a) N.H. Baselines for HFC-134a 2012-2021



(b) N.H. Baseline Growth for HFC-134a 2012-2021

Consistently growing by more than 5 ppt per year

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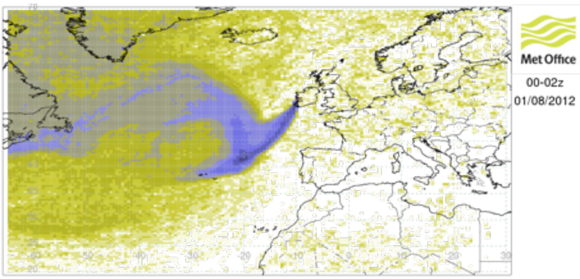
Inversion Systems

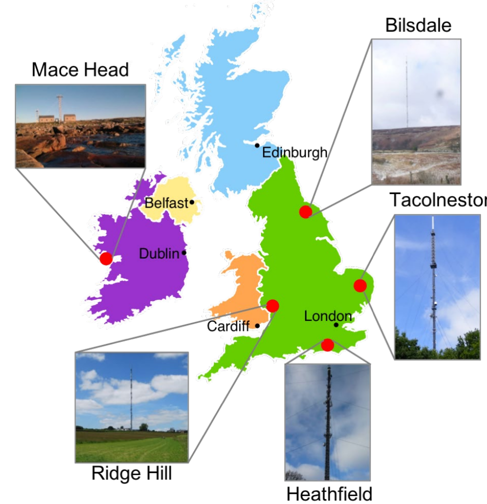
To understand the recent history of the air arriving at measurement stations

Atmospheric Transport Model



Prior Knowledge

Atmospheric Observations of GHG



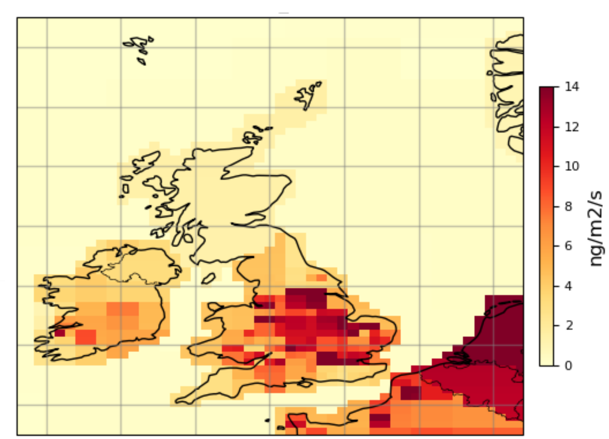
With Estimated Uncertainties

To estimate the surface emissions that best describe the observations

Inverse Modelling System

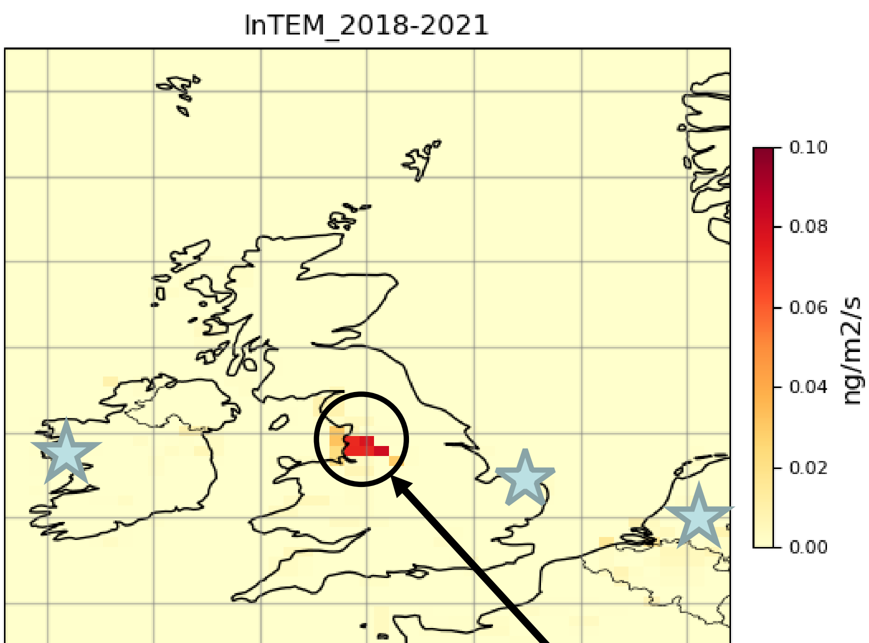
Estimate of surface emissions

Uncertainties Estimated

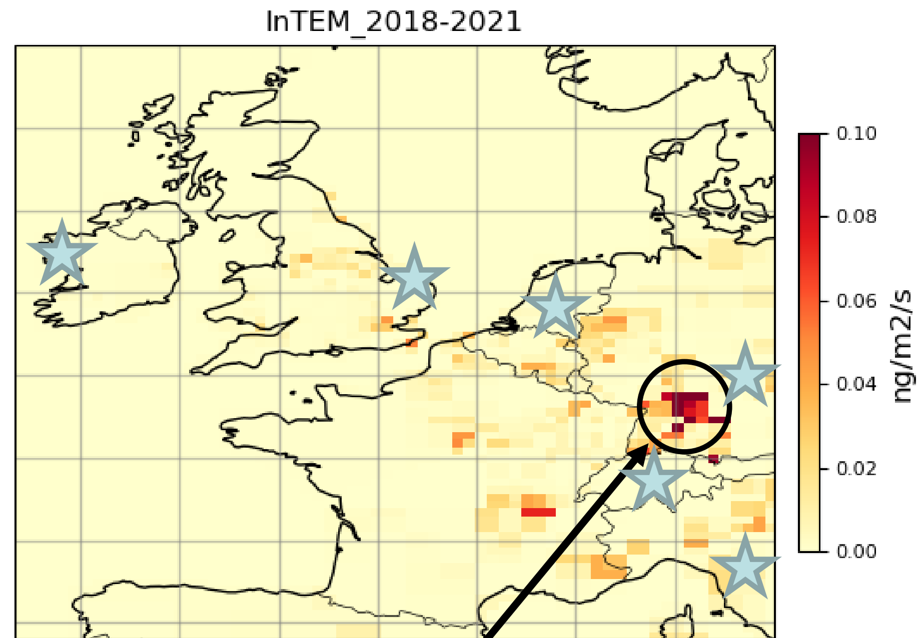


Emission Distributions

PFC-218



SF_6



Identify significant hot spots of emission

☆ F-gas Observation Stations

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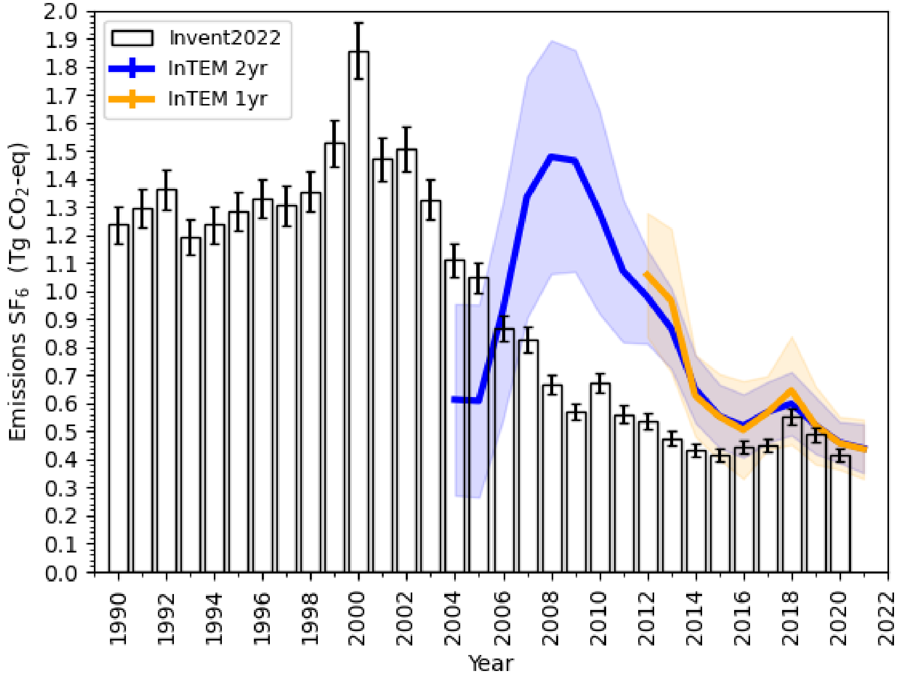
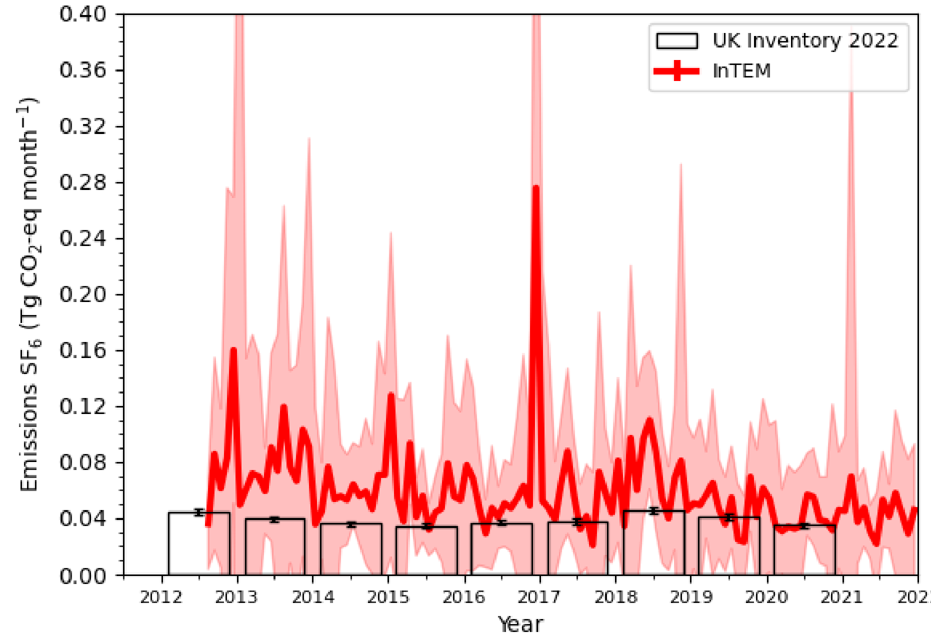
UK SF_6 emissions





- Significant mis-matches identified
- Good agreement confirms inventory
- High temporal resolution helps understand emissions

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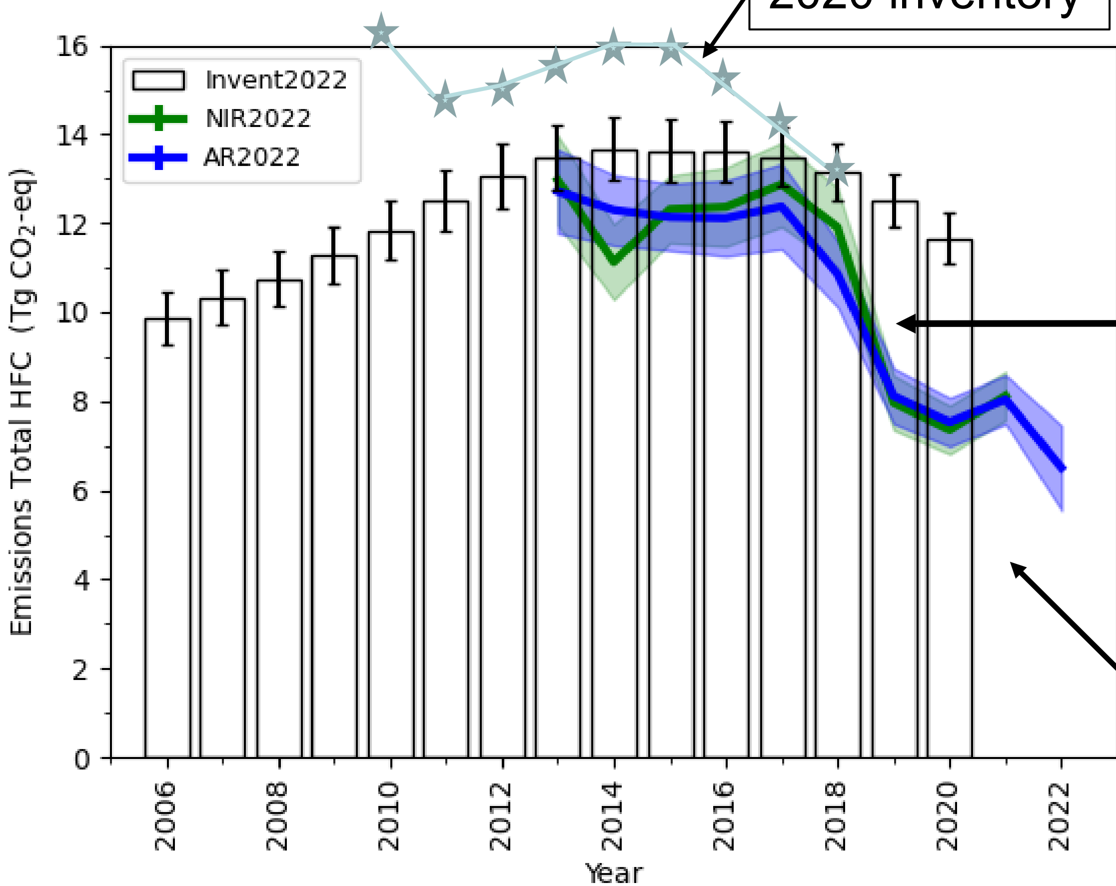
Total UK HFC emissions



2020 inventory

F-gas inventory reviewed following comparison with top-down estimates

Significant fall in UK emissions 2018-2019

Inventory estimates a much slower decline

Early indication of emissions in 2021 and 2022

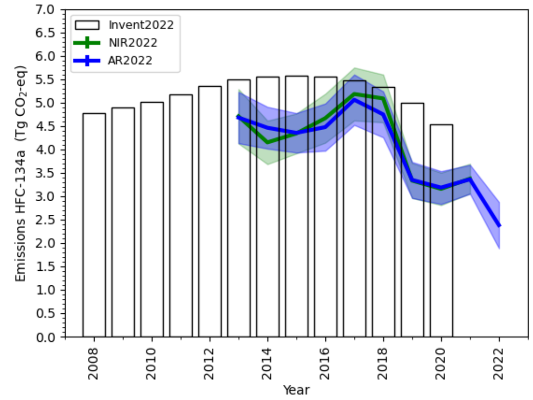
Paper published in 2021 (Manning *et. al.* ACP 2021)

UK HFC emissions by gas

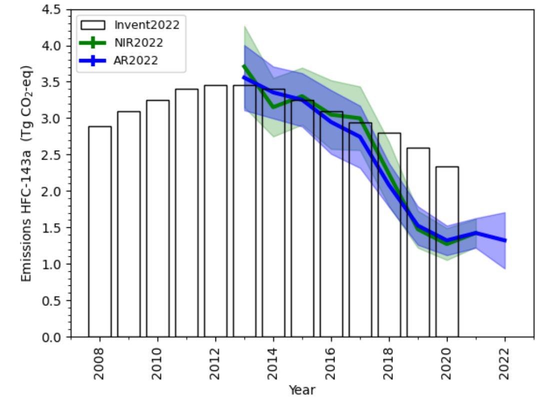
Most significant HFCs

Emissions in Tg CO_2-eq

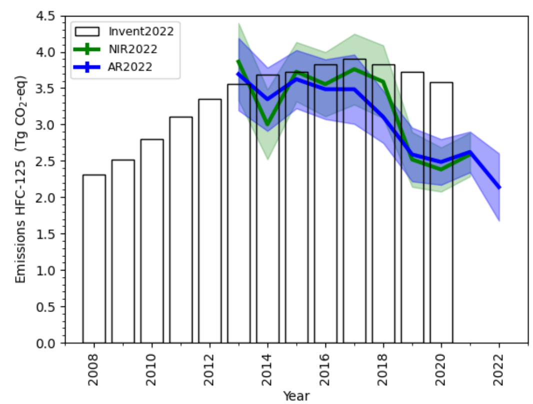
Observed fall in 2018-2019 much greater than reported in Inventory



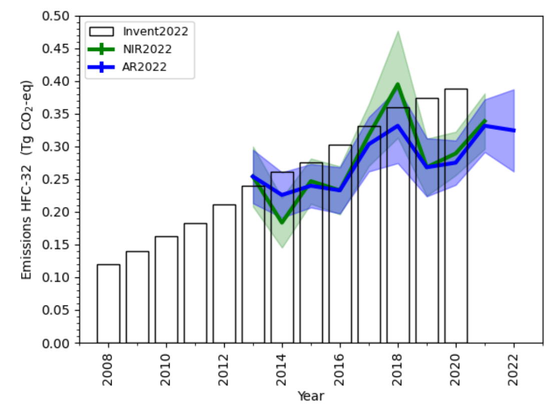
(a) HFC-134a



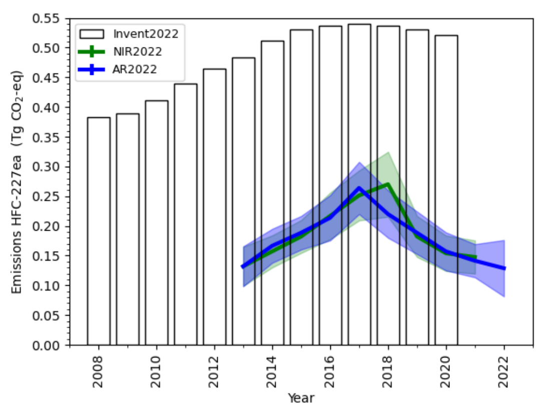
(b) HFC-143a



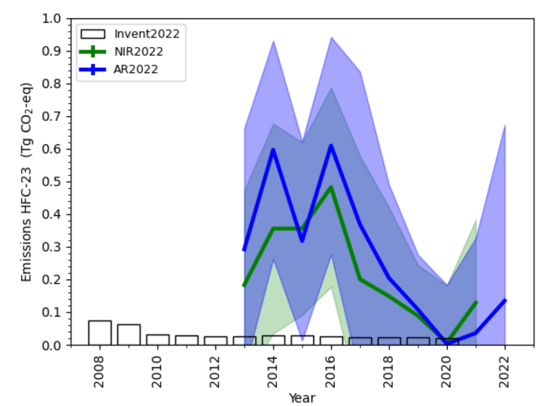
(c) HFC-125



(d) HFC-32

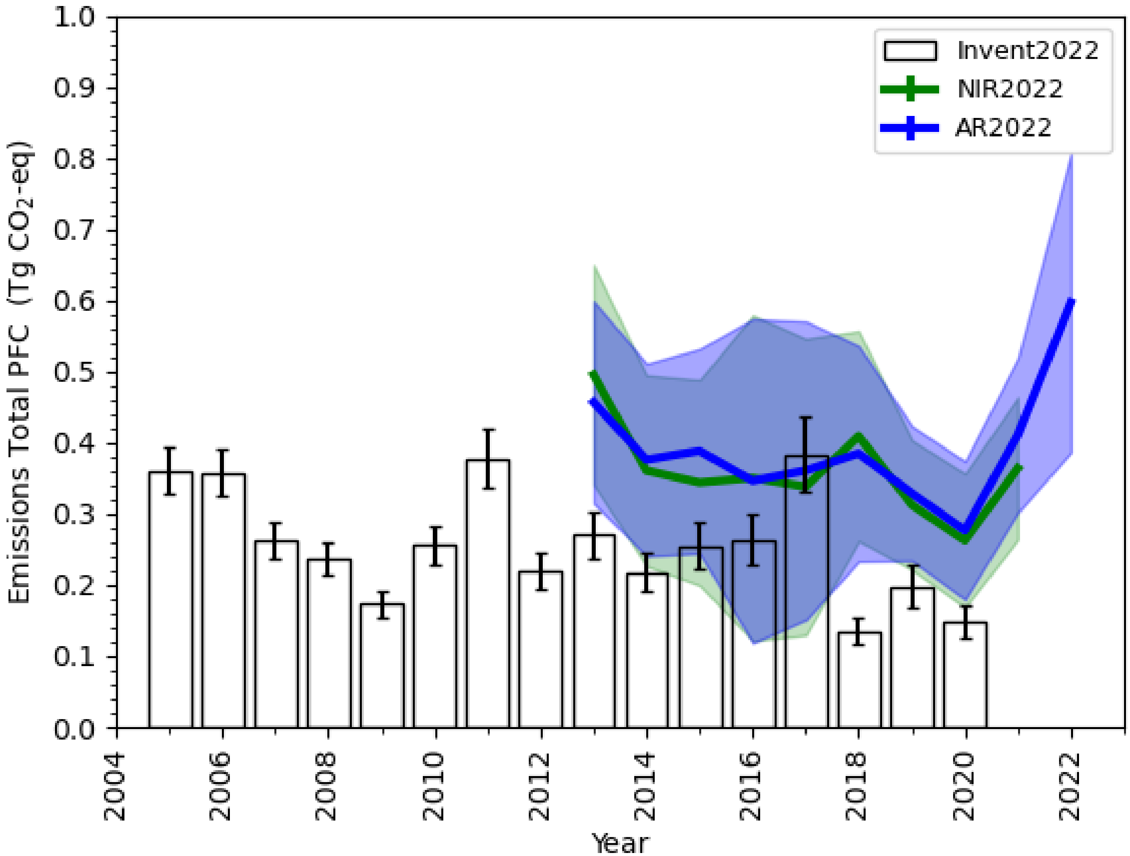


(e) HFC-227ea



(f) HFC-23

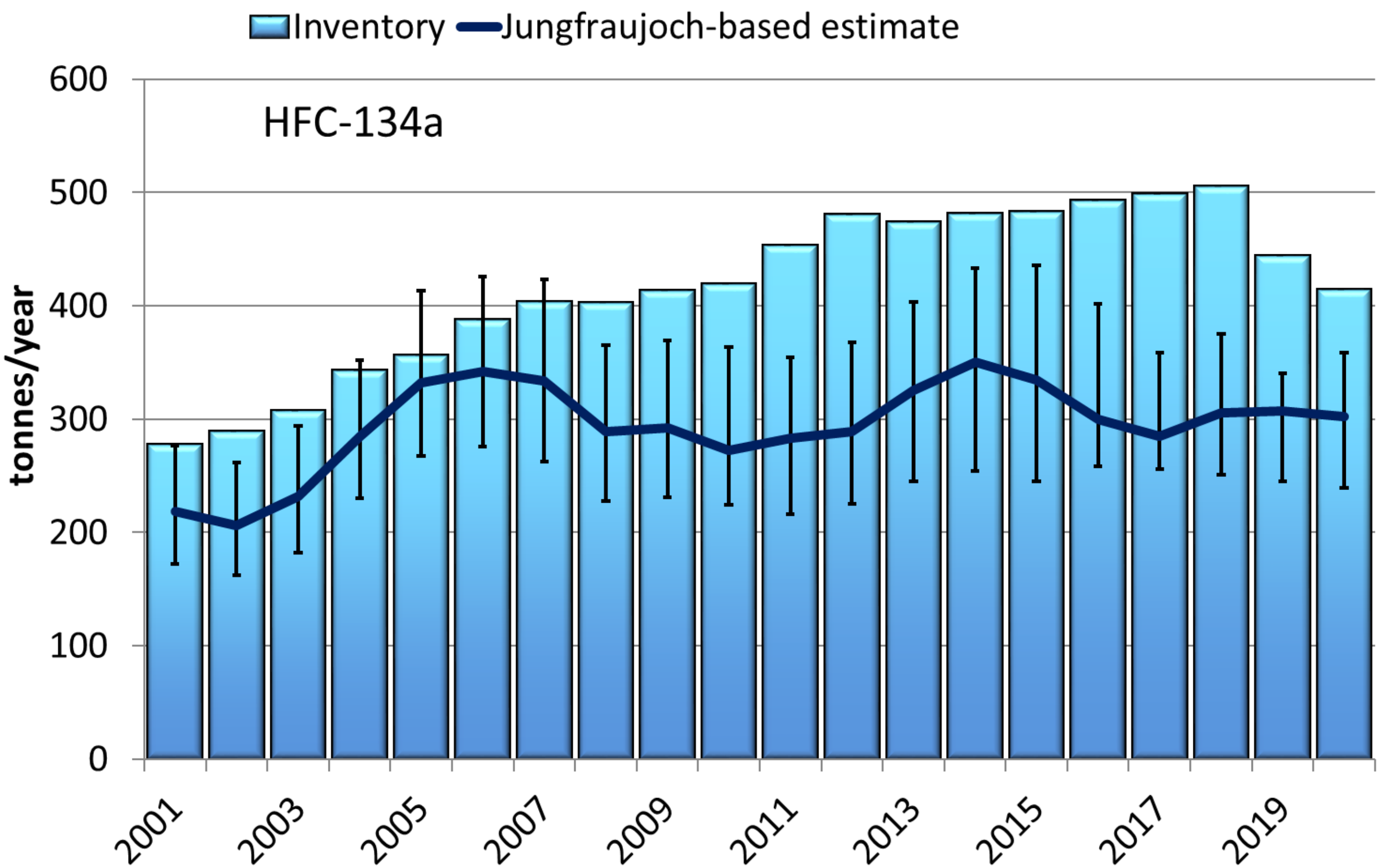
Total UK PFC emissions



Inventory mostly lower than InTEM estimates but uncertainties overlap

Potential sharp rise in 2021 and 2022

Swiss NIR – HFC-134a example



Empa

Inventory higher than top-down estimate

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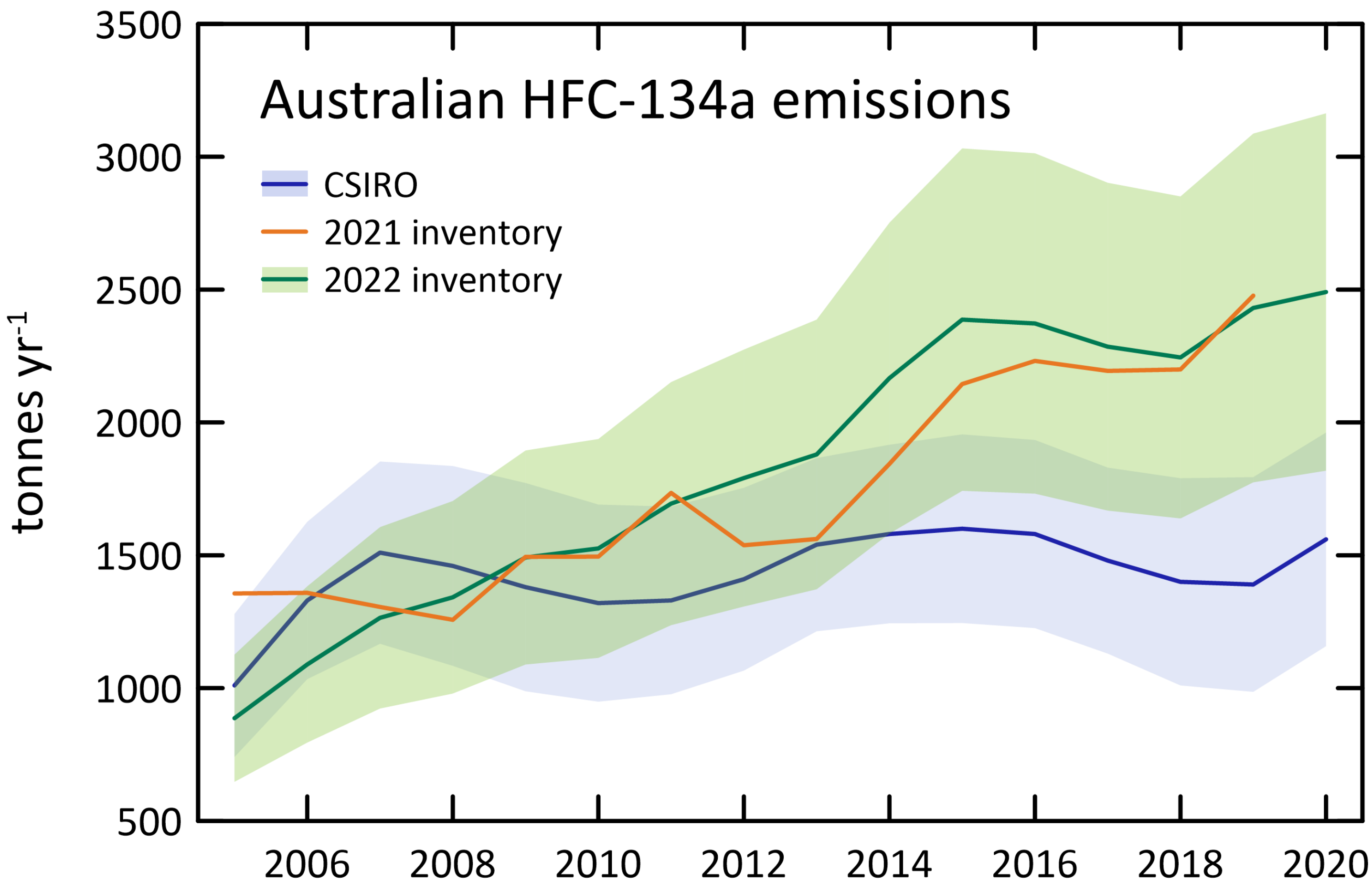
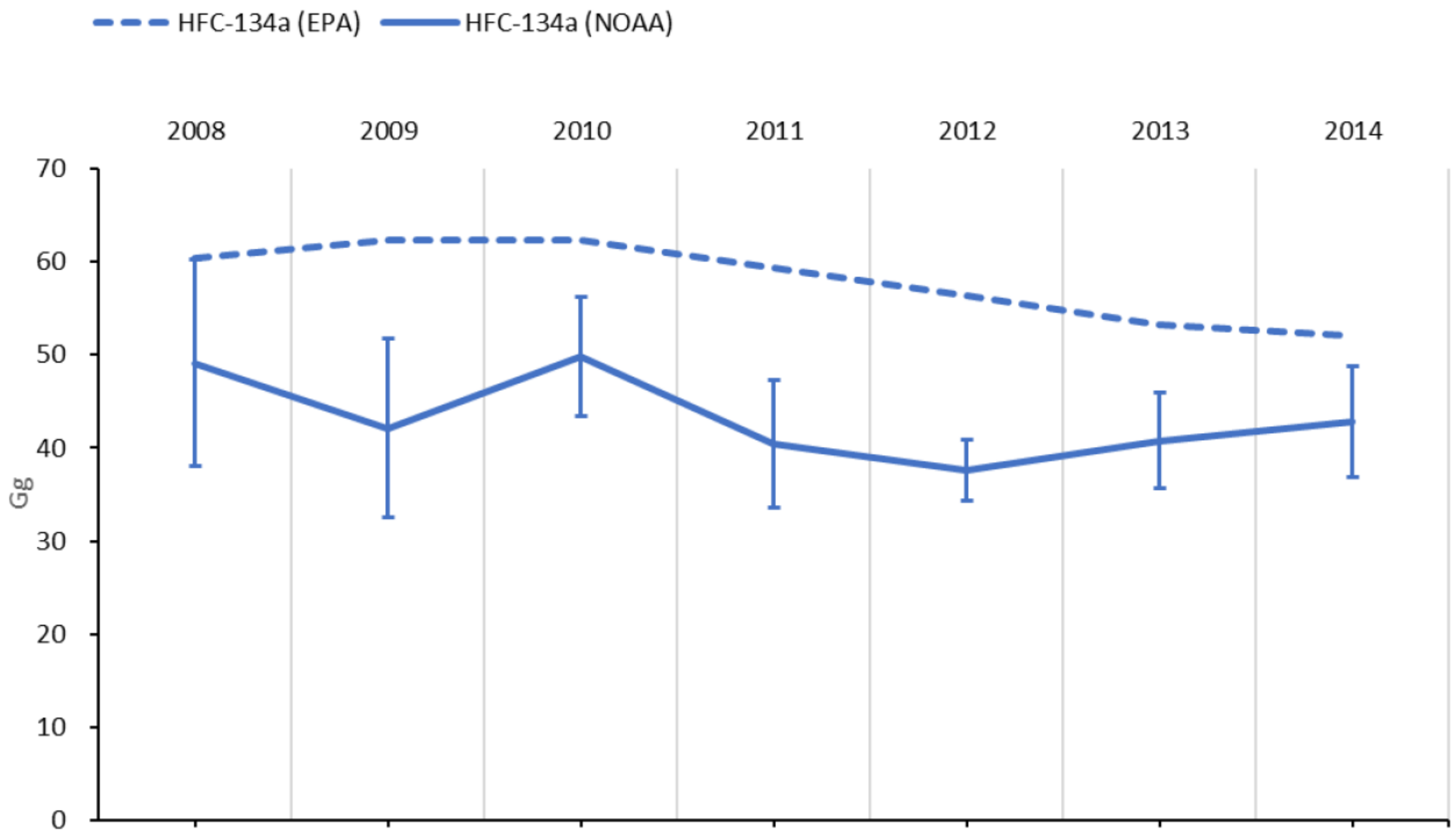
Australian NIR – HFC-134a example



CSIRO

Inventory higher than top-down estimate

USA NIR – HFC-134a example



NOAA

Inventory higher than top-down estimate

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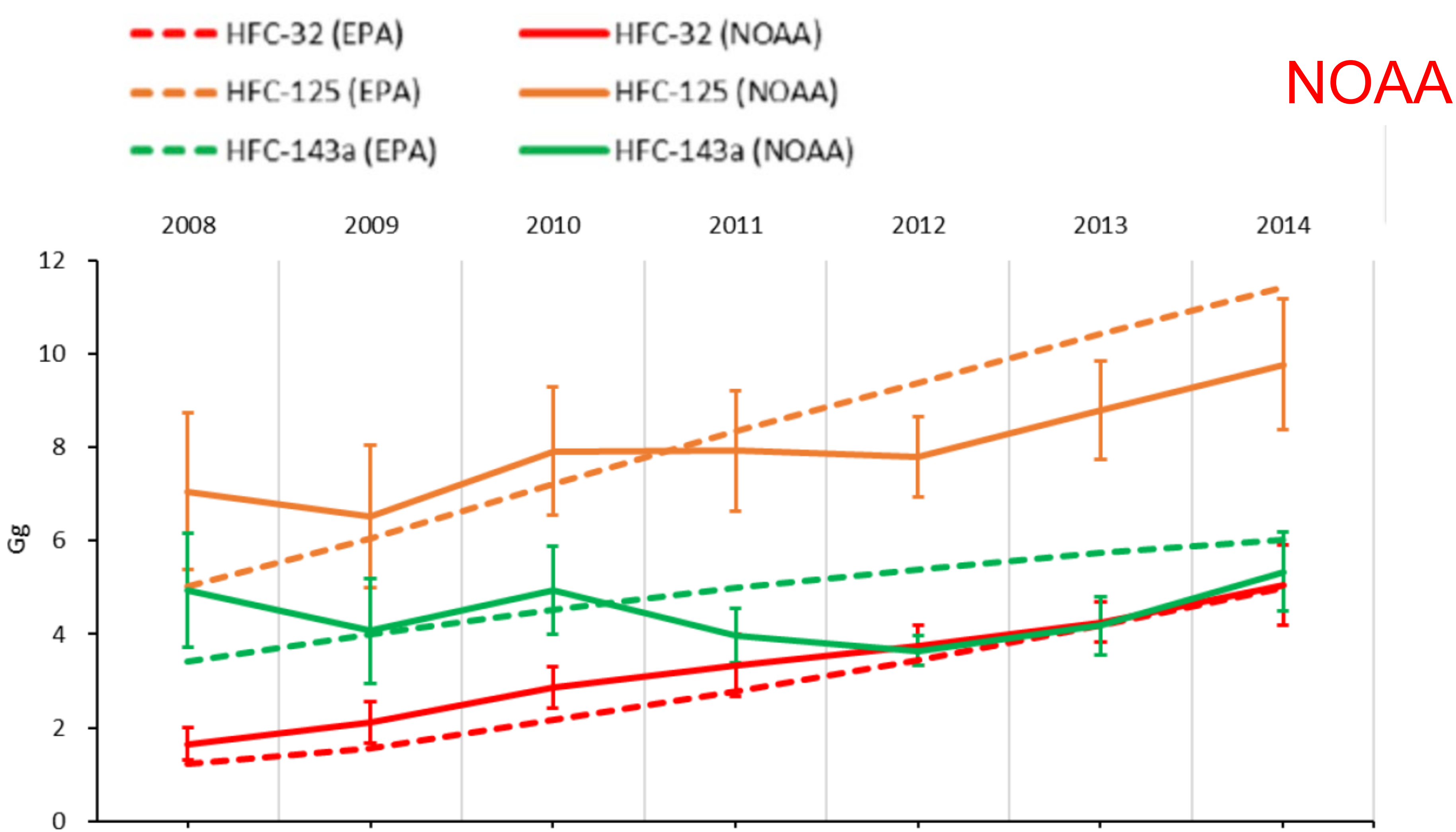
Conclusions

- Global F-gas concentrations are virtually all rising
- Atmospheric observations can significantly help inventory compilers understand emissions
  - Confirm magnitudes of emission
  - Identify significant emission sources
  - Give an early indication of national emissions
- 4 countries currently include ‘top-down’ inversion estimates from atmospheric observations in their NIRs – others are planning to do so
- New EU project PARIS has major focus on F-gases

USA NIR – HFC examples



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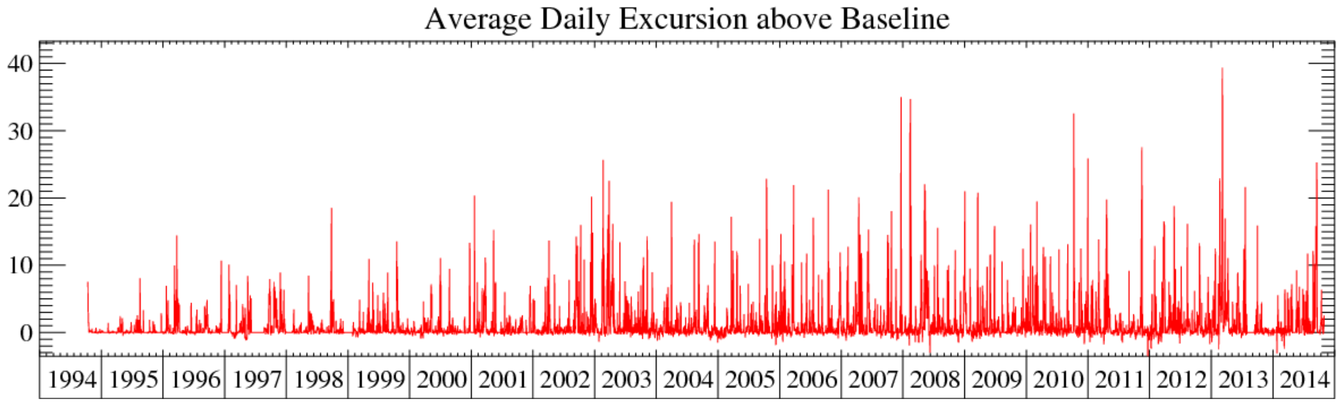
Estimating emissions using Atmospheric Observations

InTEM

Inversion Technique for Emission Modelling



Generate regional emission estimates from ‘polluted’ (above baseline) observations.

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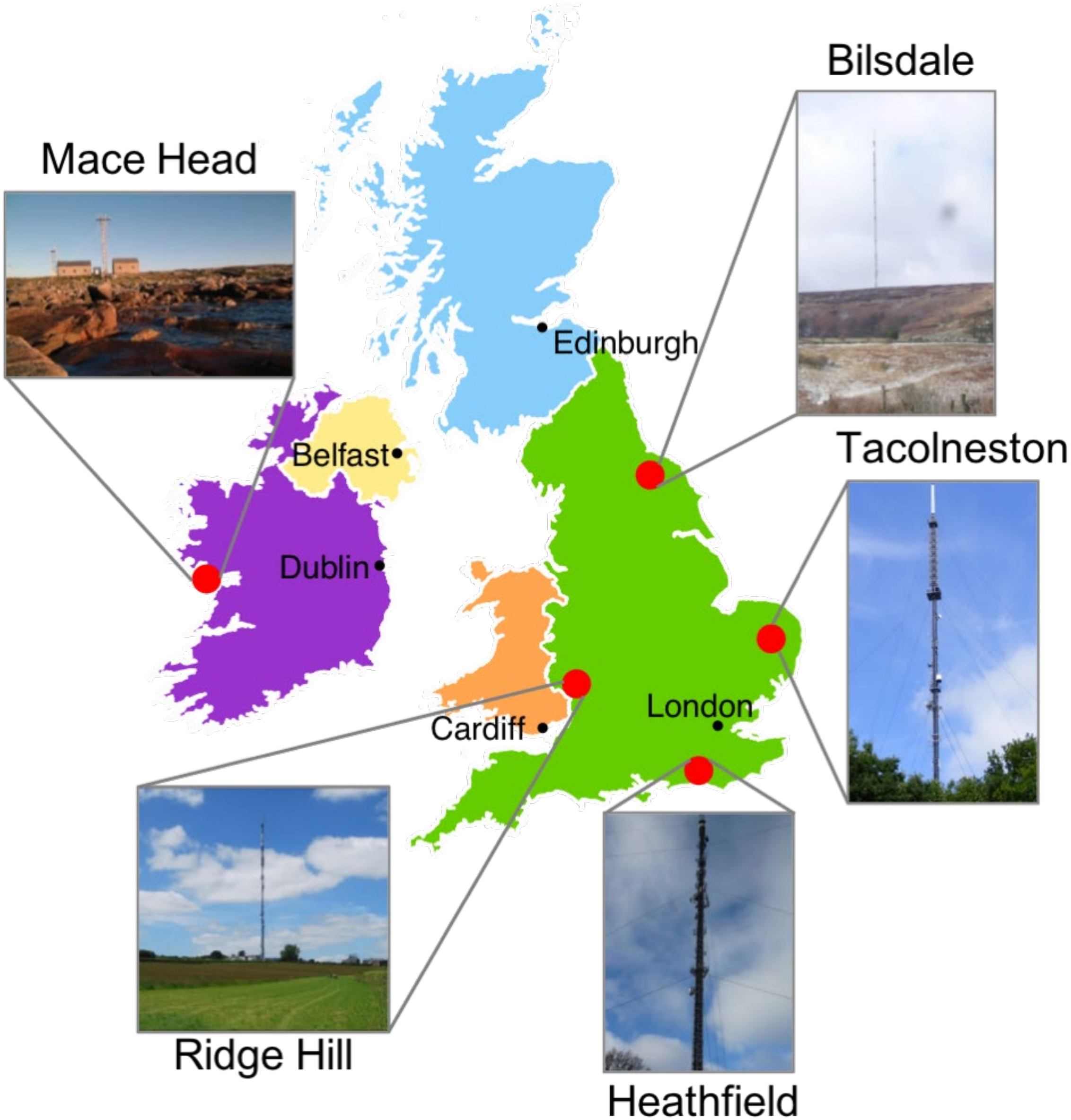

UK DECC

(Deriving Emissions related to Climate Change)

Network of observations

MHD from 1987
TAC & RGL from 2012
HFD & BSD from 2014

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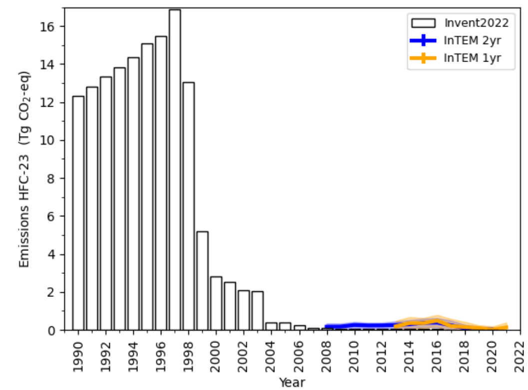
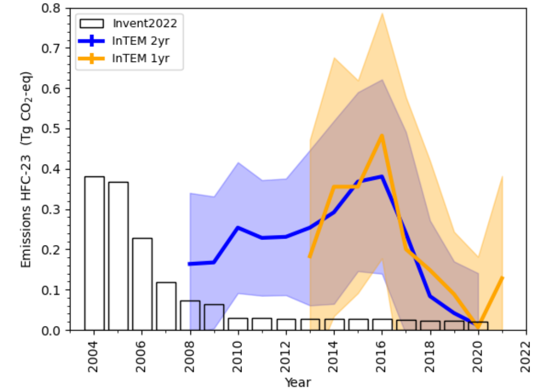
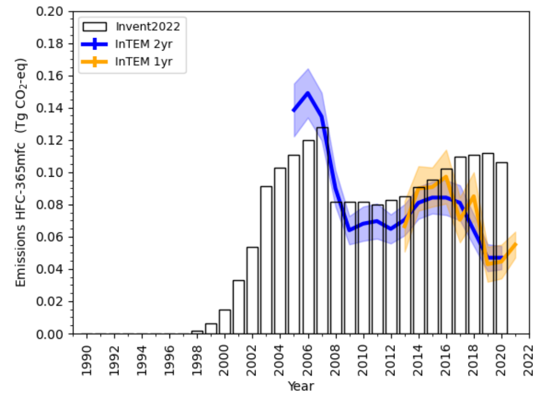
UK HFC emissions



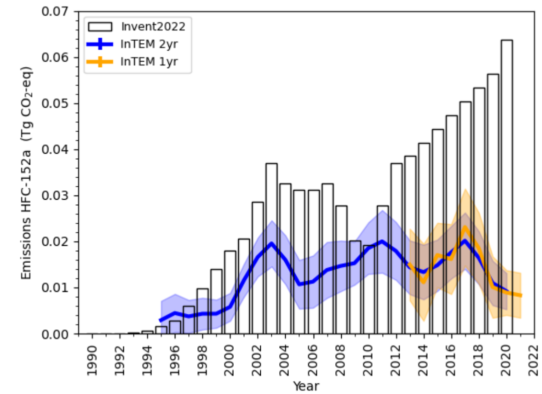
(a) HFC-23



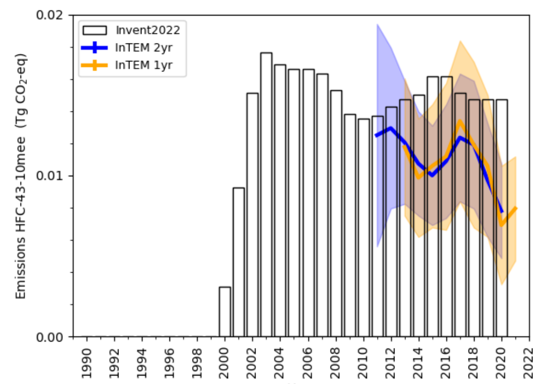
(b) HFC-23



(c) HFC-365mfc



(d) HFC-152a



(e) HFC-43-10mee

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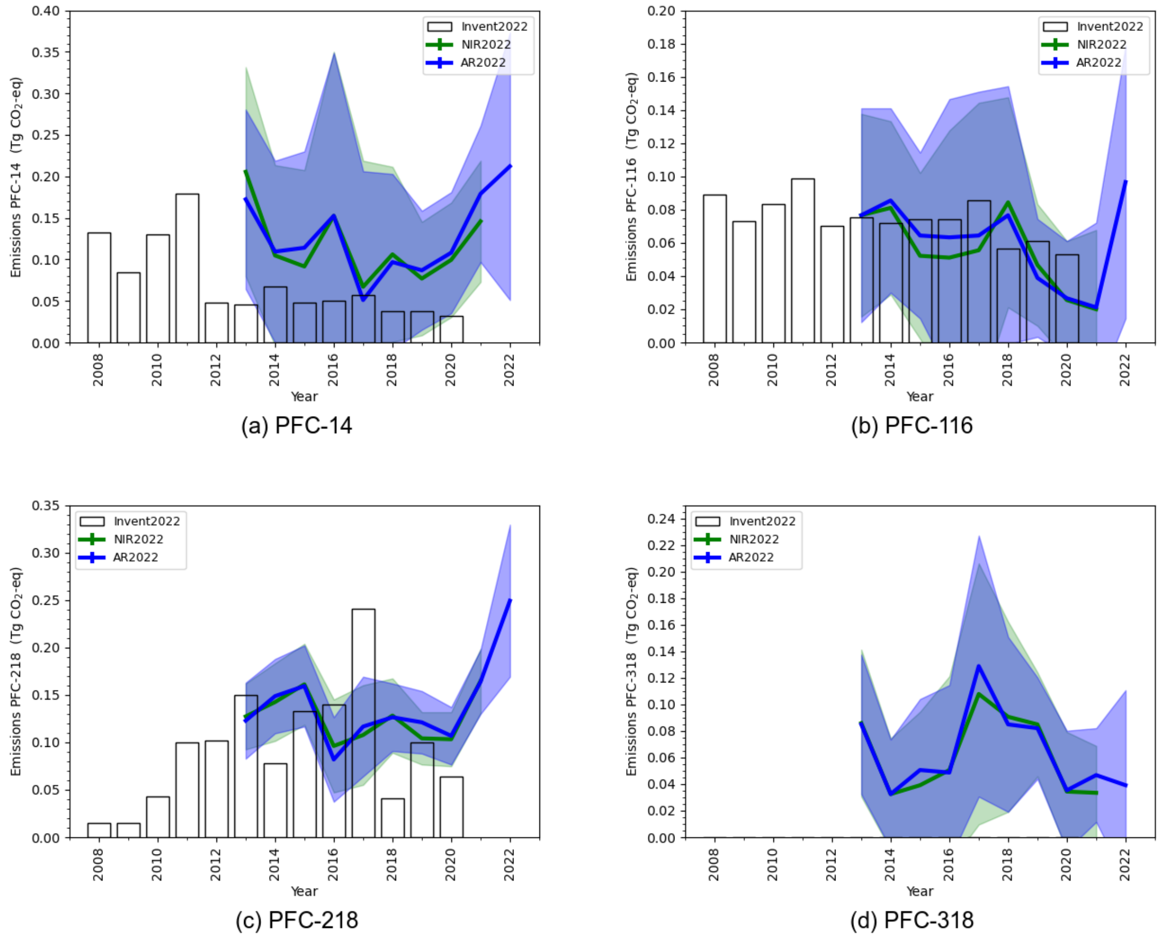
UK PFC emissions by gas

Emissions in Tg CO_2-eq



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InTEM (Inversion Technique for Emission Modelling)

Uncertainty Matrices

$$C = (M'e' - y)^T R^{-1} (M'e' - y) + (e' - e'_p)^T B^{-1} (e' - e'_p)$$

$M' = M$ [t x n] | P [t x p] | F [t x f]

M = Dilution matrix
P = Baseline Adj + Outer Region
F = Location Bias

$e' = e$ [n] | b [p] | q [f]

e = Surface Emissions

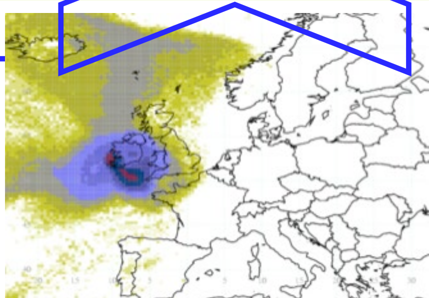
y [t]

Times series observations

$e'_p = e_p \mid b_p \mid q_p$

e_p = Prior Emission

Assume UK prior
Very uncertain



- Air history maps from transport model
- Time-series of relative contributions of each surface source to each observation

B [n' x n'] : Prior uncertainty

R [t x t] : Model-Obs uncertainty

Uncertainty Analysis Matrix

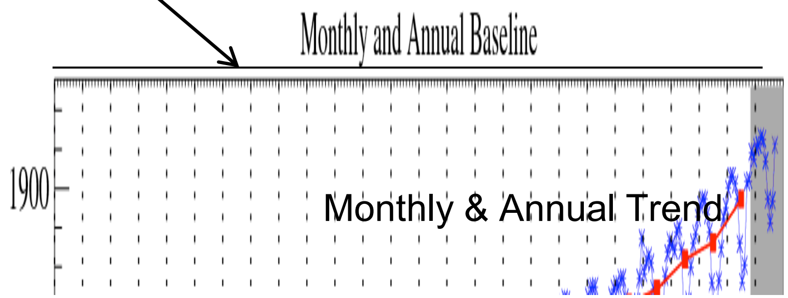
$$A = \left(M'^T R^{-1} M' + B^{-1}\right)^{-1}$$

Baseline Prior adjusted within InTEM

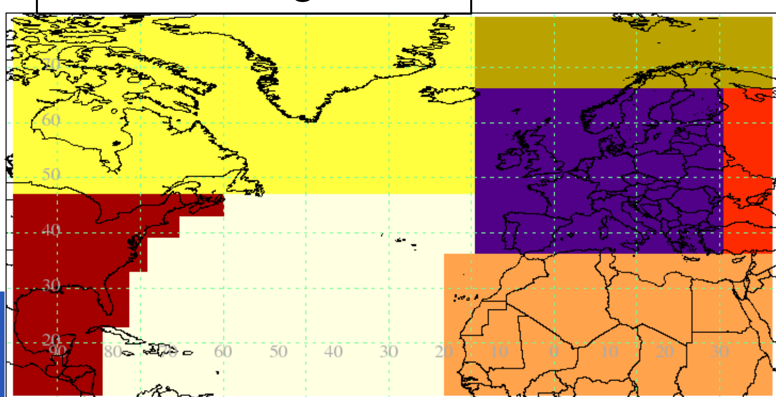
- **Depending on where air enters regional domain**
- **Each station has unique baseline**

1.9 ppm

CH_4



Now also solve for 6 Outer Regions



Baseline modified based on where the air comes from

BASELINE