

# Source attribution of halogenated compounds in support of emission inventories for international agreements

**Stefan Reimann**

Martin K. Vollmer

Stephan Henne

Dominik Brunner

Alistair Manning (UK MetOffice)

Lukas Emmenegger



**Empa**

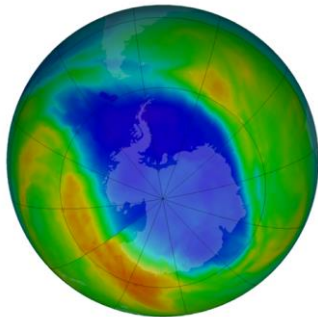
Materials Science and Technology

[stefan.reimann@empa.ch](mailto:stefan.reimann@empa.ch)

# Halogenated Compounds in the Atmosphere

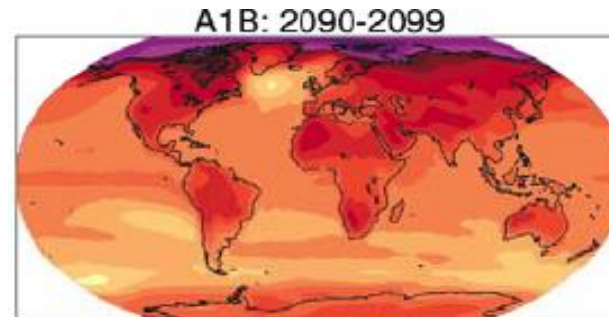
- **Chlorofluorocarbons (CFCs)**  
CFC-11, CFC-12, CFC-13, CFC-11, CFC-113
- **Halons**  
H-1301, H-1211, H-2402, CH<sub>3</sub>Br
- **Solvents**  
CH<sub>3</sub>CCl<sub>3</sub>, CCl<sub>4</sub>,
- **Hydrochlorofluorocarbons (HCFCs)**  
HCFC-141b, HCFC-124, HCFC-22, HCFC-142b

**Ozone Depletion/Global Warming**  
**Montreal Protocol**

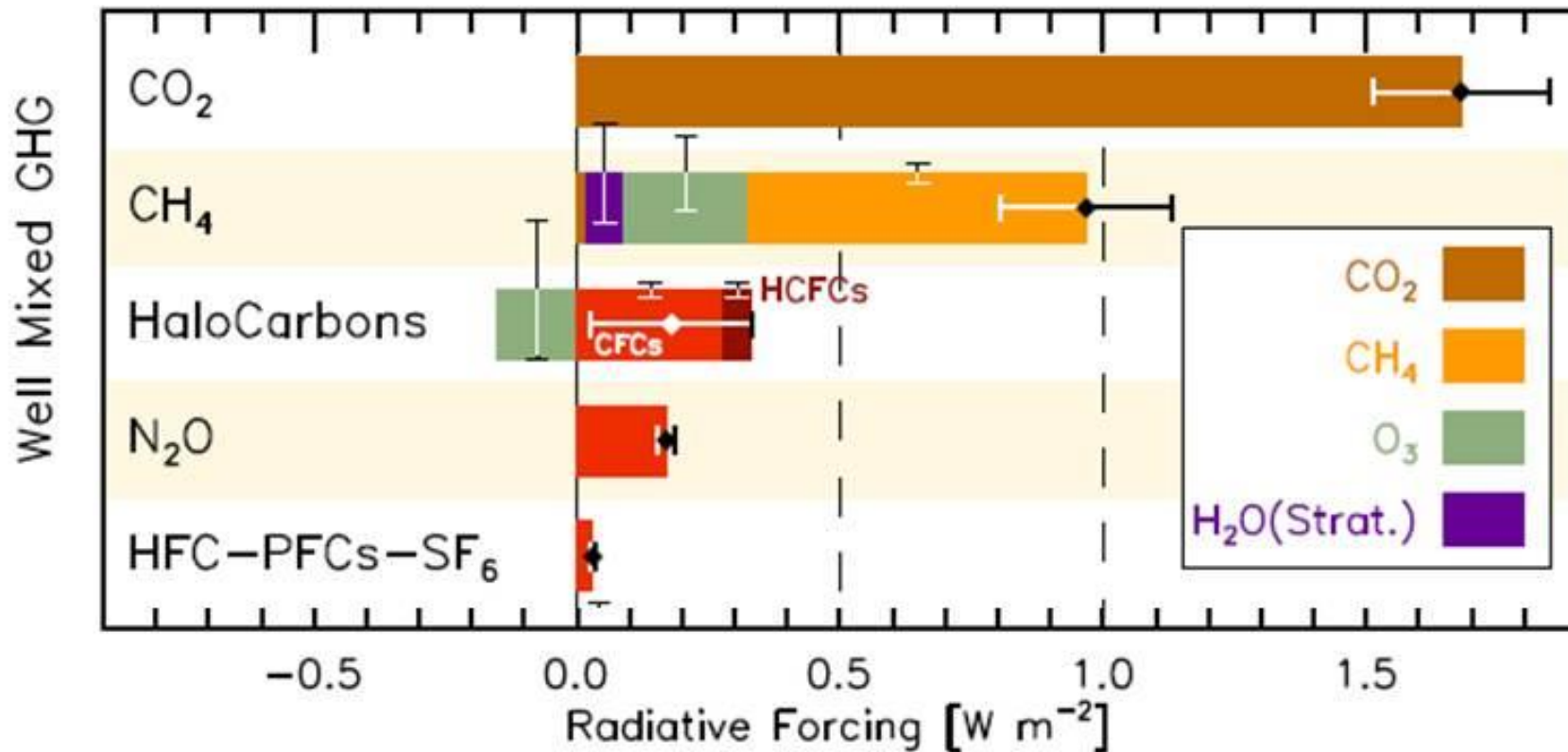


- **Hydrofluorocarbons (HFCs)**  
HFC-23, HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-227ea, HFC-236fa, HFC-365mfc, HFC-245fa, HFC-43-10mee, desflurane
- **Perfluorocarbons (PFCs), etc**  
CF<sub>4</sub>, PFC-218, PFC-318, C<sub>4</sub>F<sub>10</sub>, C<sub>6</sub>F<sub>14</sub>, SF<sub>6</sub>, SF<sub>5</sub>CF<sub>3</sub>

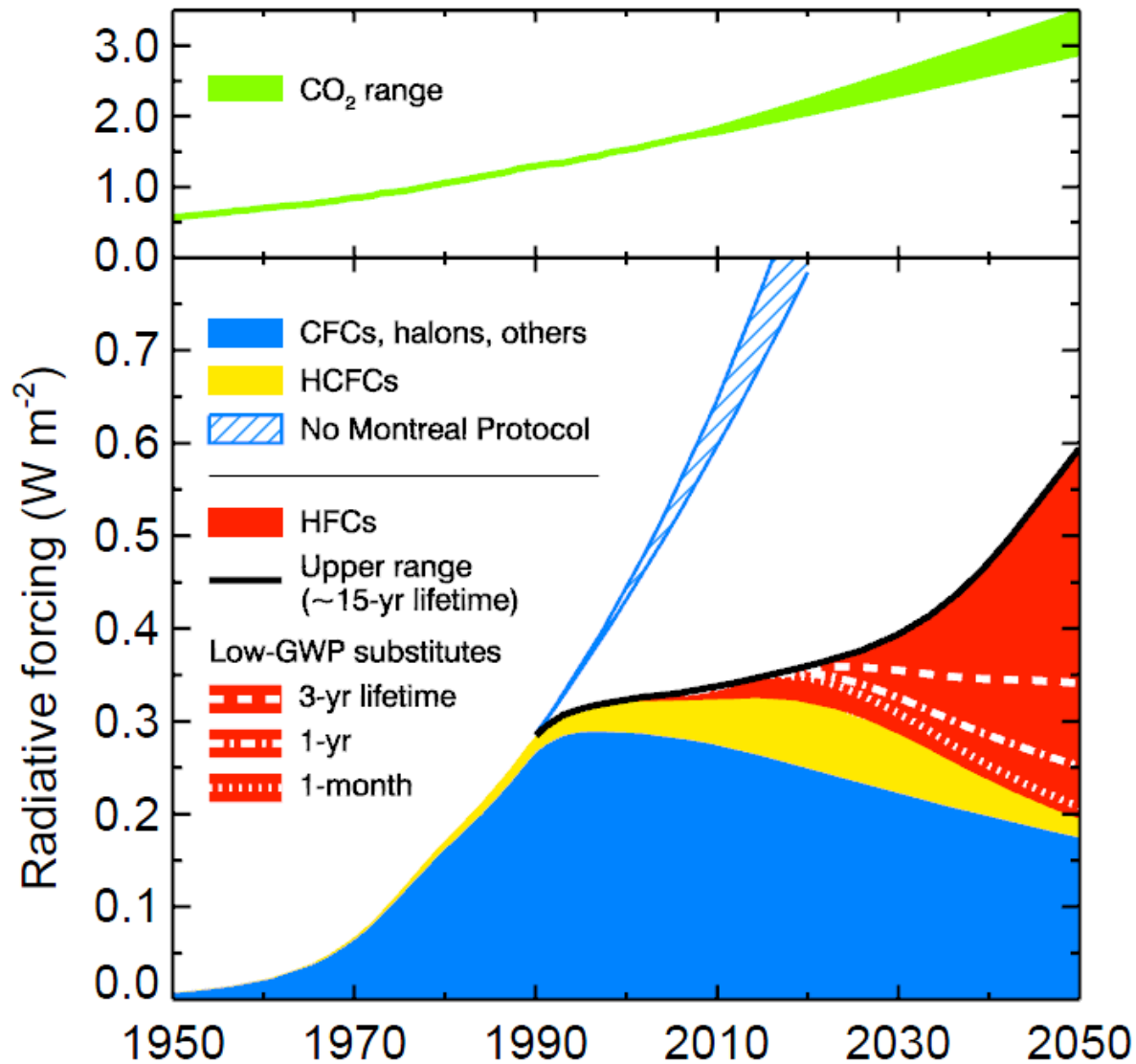
**Global Warming**  
**Kyoto Protocol**



# Halocarbons as Greenhouse Gases



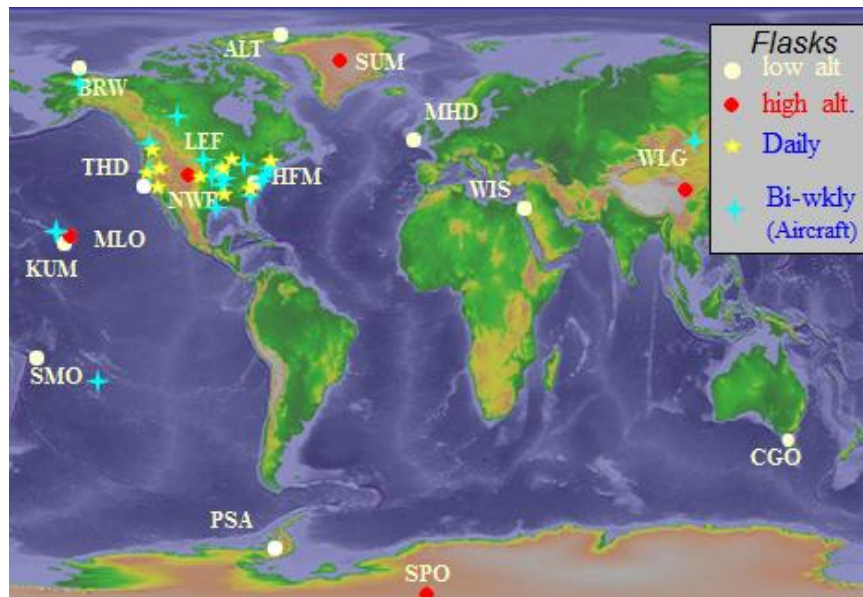
# Halocarbons as Greenhouse Gases: History and Future



# Global Measurements of Halocarbons

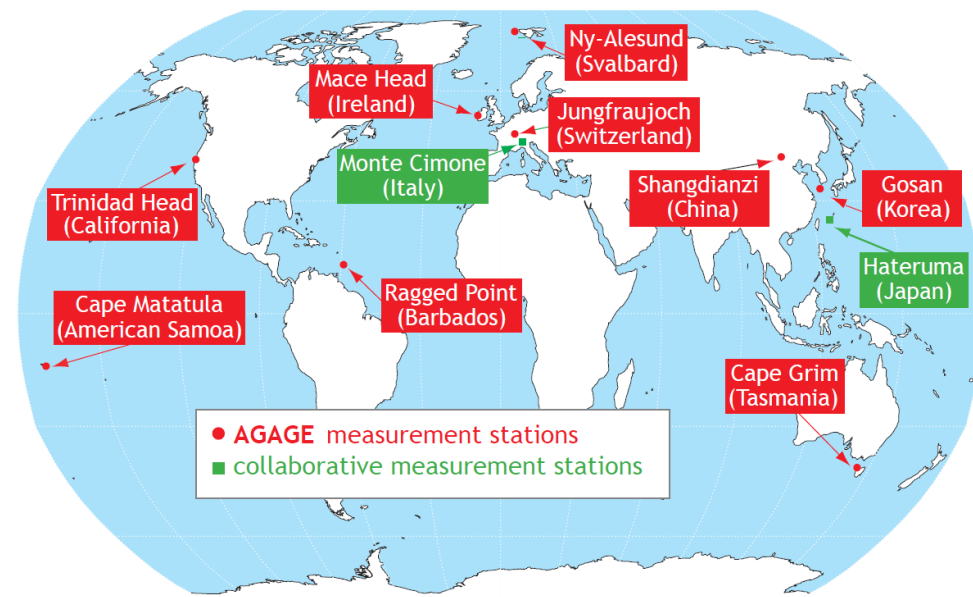
## NOAA/ESRL Network

Halocarbon Surface and Aircraft Sampling



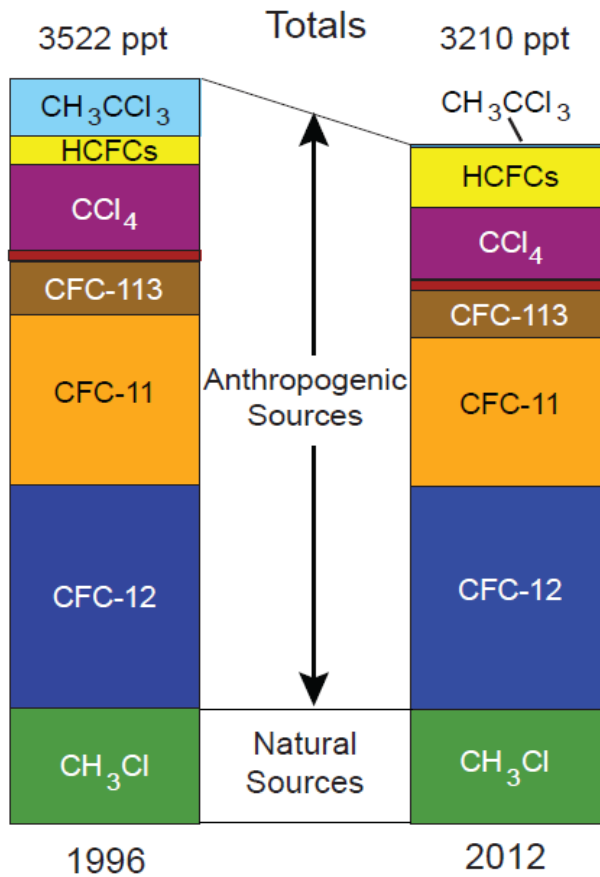
## AGAGE Network

Continuous in-situ Sampling

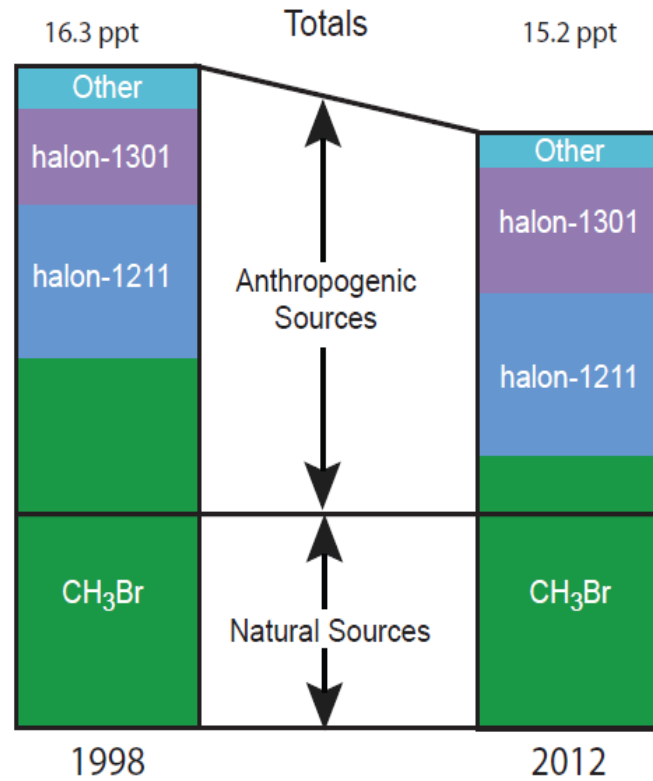


# The Montreal Protocol Everything on Track

Tropospheric Chlorine Source Gases



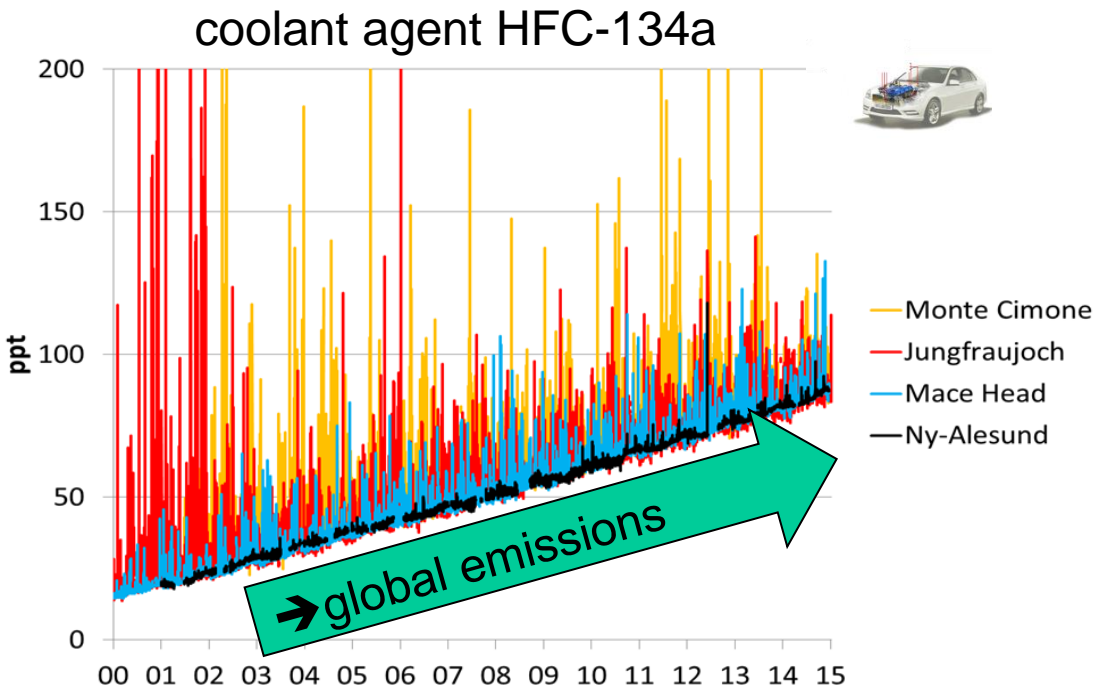
Tropospheric Bromine Source Gases





# The Kyoto-Protocol Emission Estimation world-wide

Box-model approach for estimating global sources



Global box model

$$\frac{B(t)}{\textit{lifetime}} + \frac{dB(t)}{d(t)} = \textit{emission}$$

$B(t)$ : mass of F-134a in atmosphere

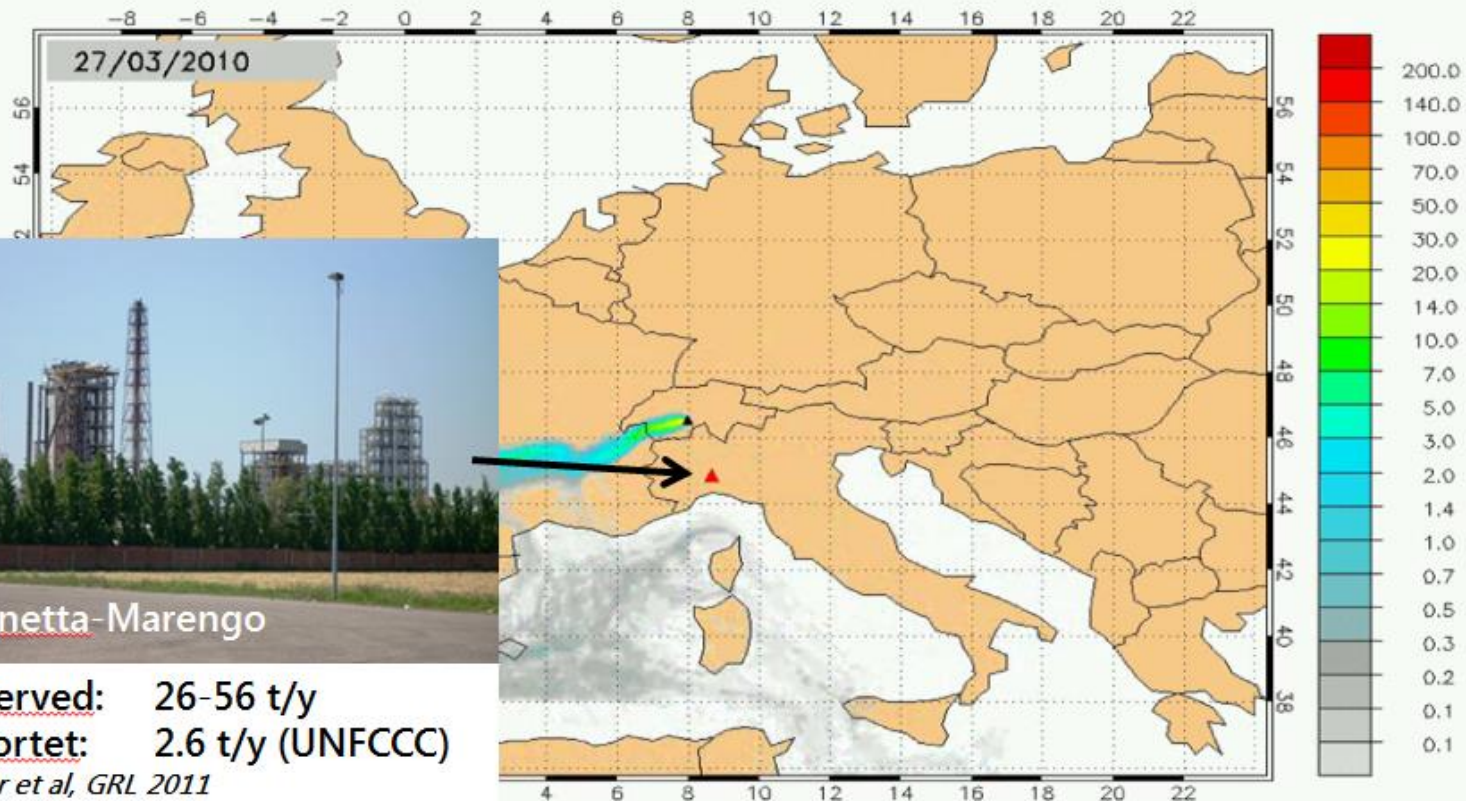
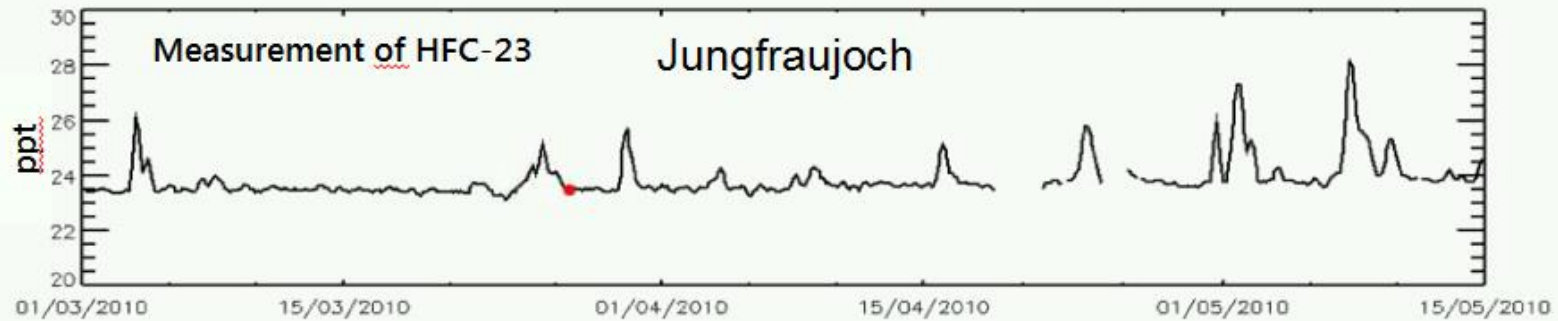
*lifetime*: 14 years

$\frac{dB(t)}{d(t)}$ : rate of change

~160 000 tons/year

**How to derive regional emissions?**

# Example: Combination of Measurements and Models: The "unknown" European HFC-23 source





# How to derive country-based emissions?

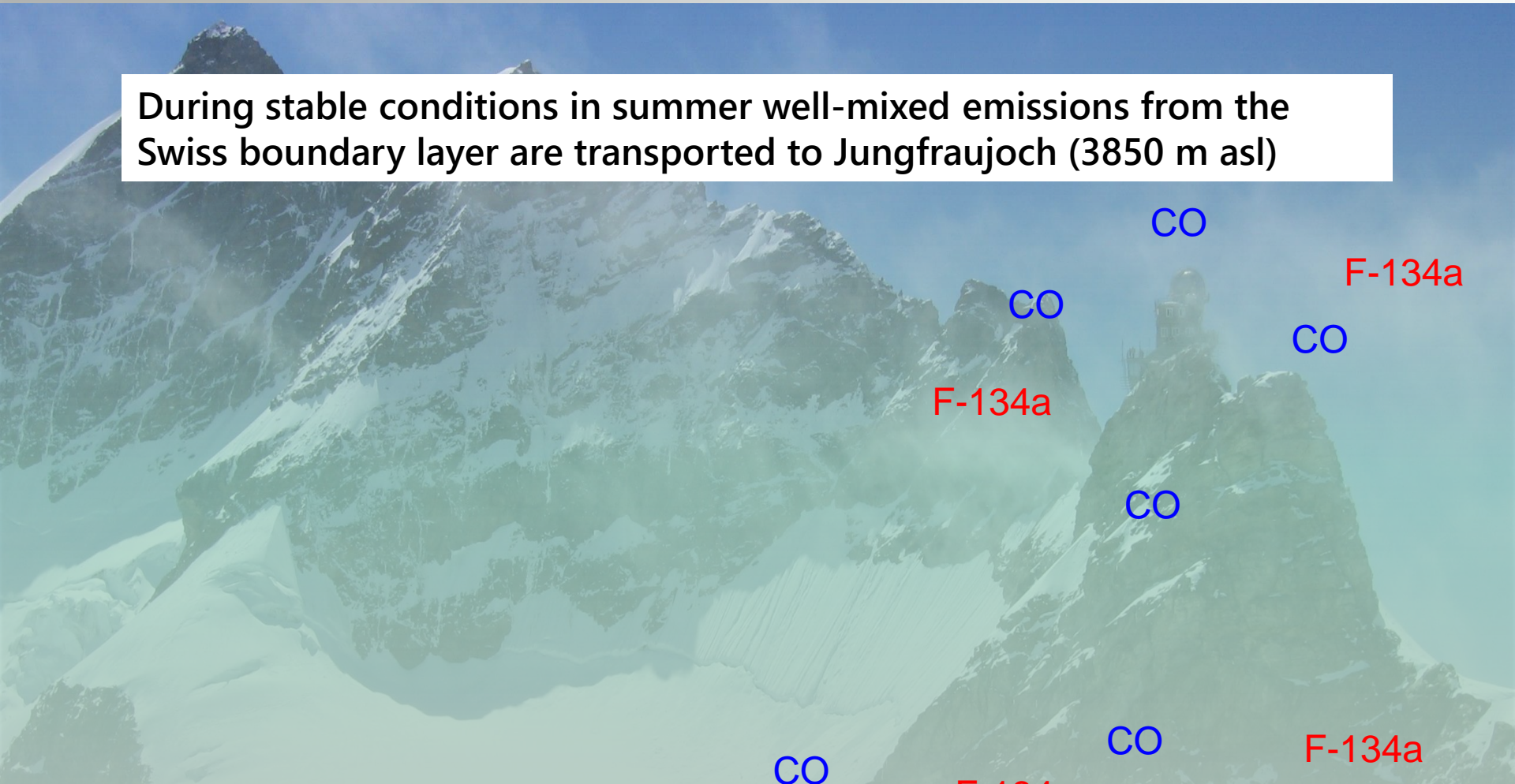




# Top-Down Emission estimation for Switzerland



During stable conditions in summer well-mixed emissions from the Swiss boundary layer are transported to Jungfrauoch (3850 m asl)

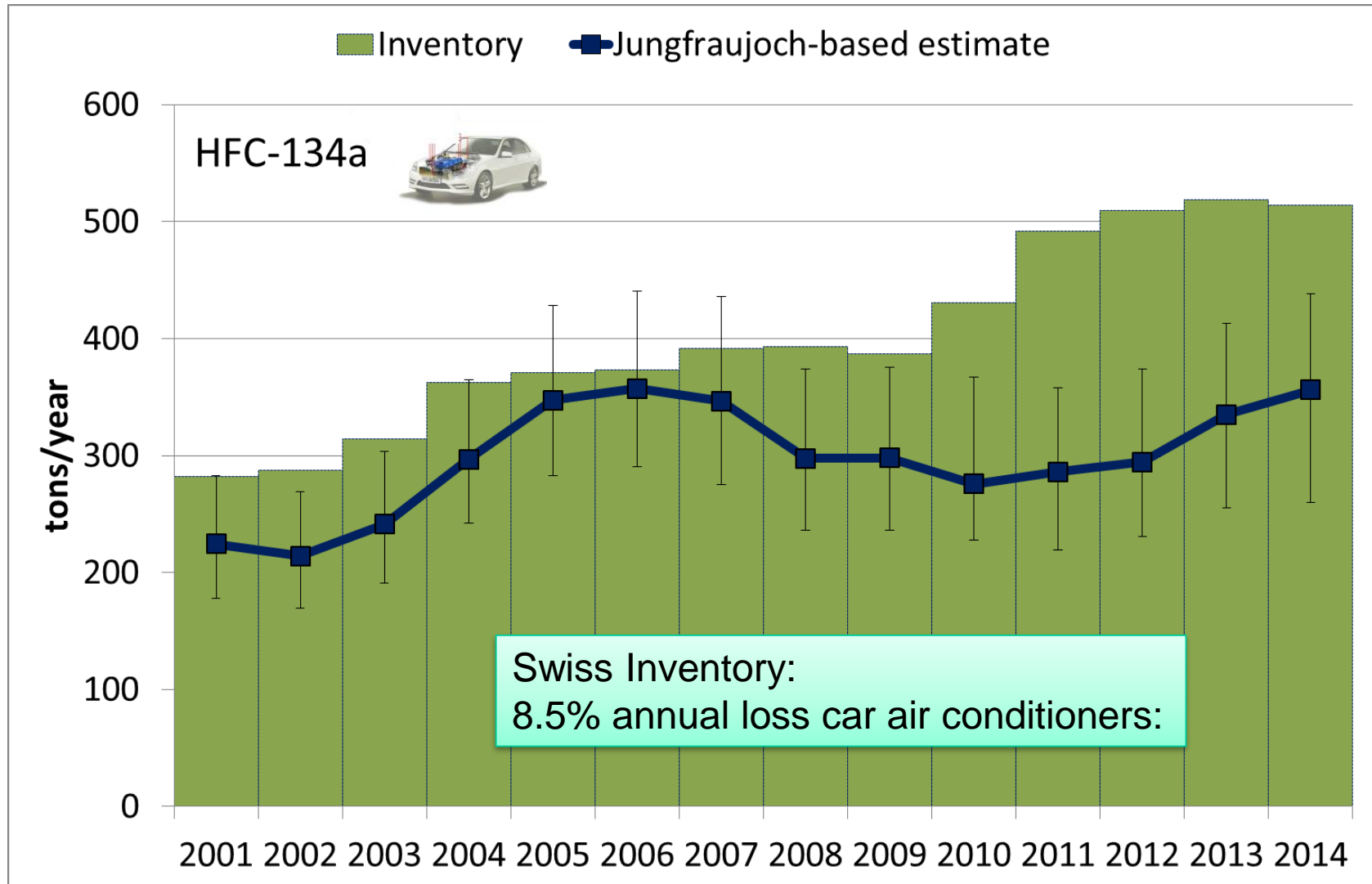


$$\frac{\text{CO inventory}}{\text{CO above background}} = \frac{\text{emission of F-134a}}{\text{F-134a above background}}$$

# Switzerland's Greenhouse Gas Inventory 2001-2014



## Annex 5.1 Independent verification of the National Swiss Inventory for F-gases

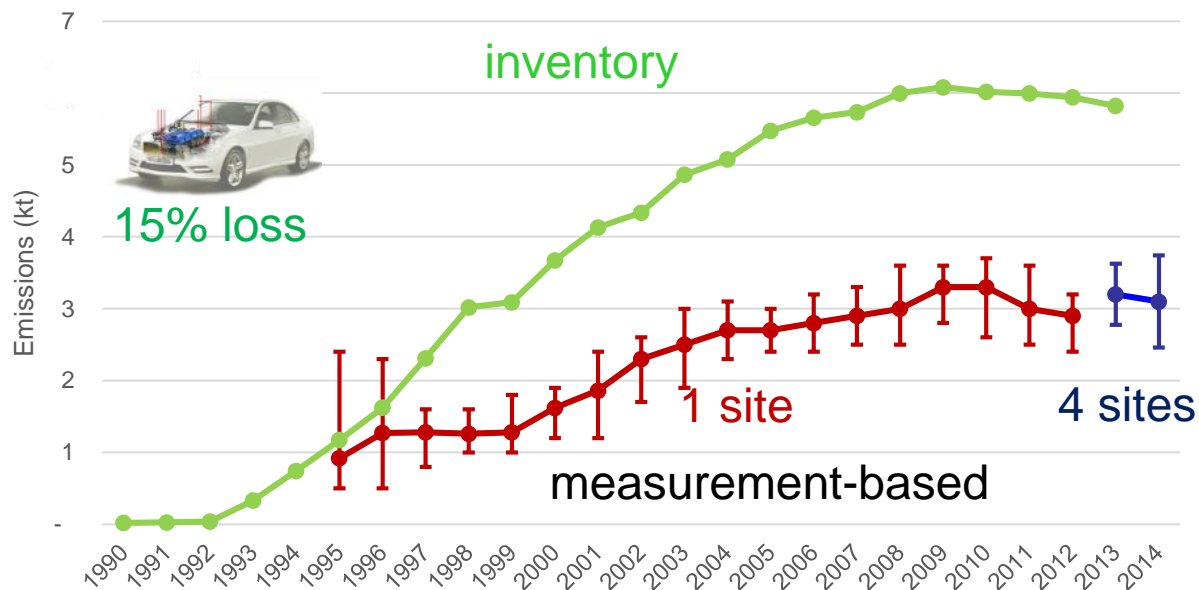
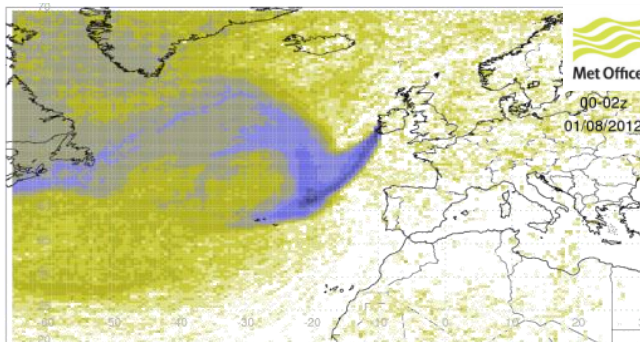


# UK's Greenhouse Gas Inventory 1995-2014

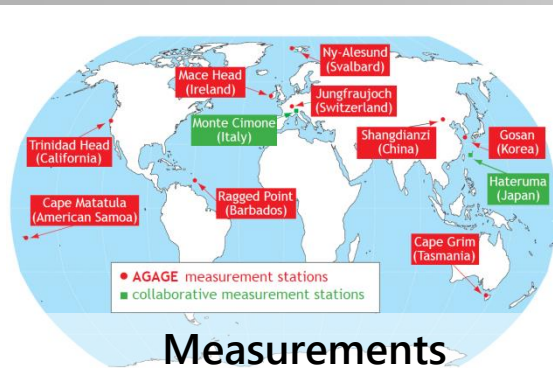


NIR (UNFCCC) Annex 6: Independent verification of the National UK Inventory

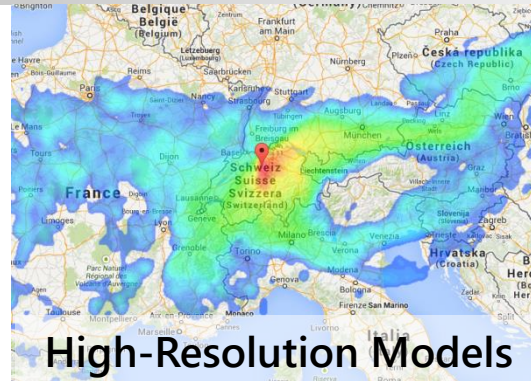
## Mace Head measurements combined with the NAME model



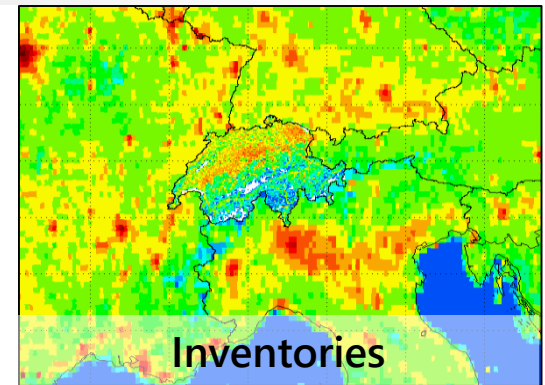
# Inverse Modelling for Inventory Support



Measurements



High-Resolution Models



Inventories

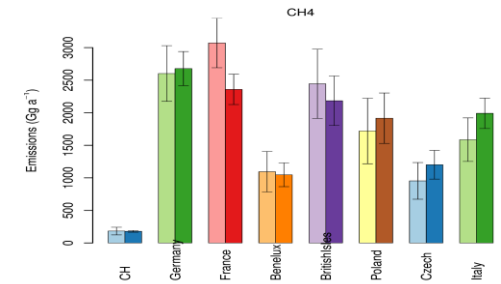
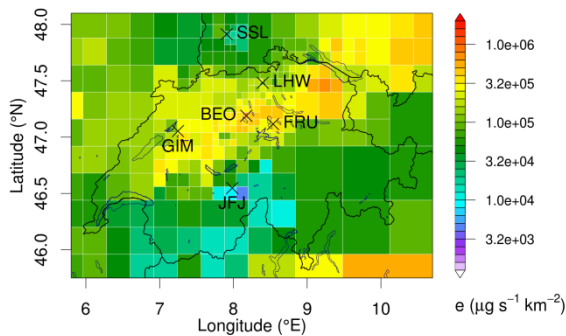
Constituent observations

Simulated flux sensitivities

A priori estimates of surface flux

Inversion algorithm

A posteriori estimates of surface flux



Country total emissions



# HFC Inversion in the EU project INGOS

## Four groups & inversion systems

Empa, Dominik Brunner (WP lead)

Empa2, Stephan Henne

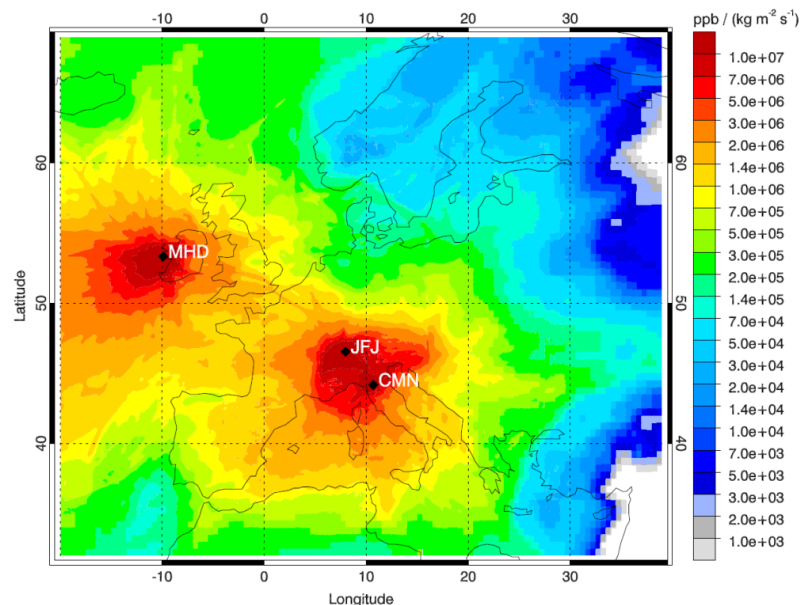
NILU, Rona Thompson

UKMO, Tim Arnold / Alistair Manning

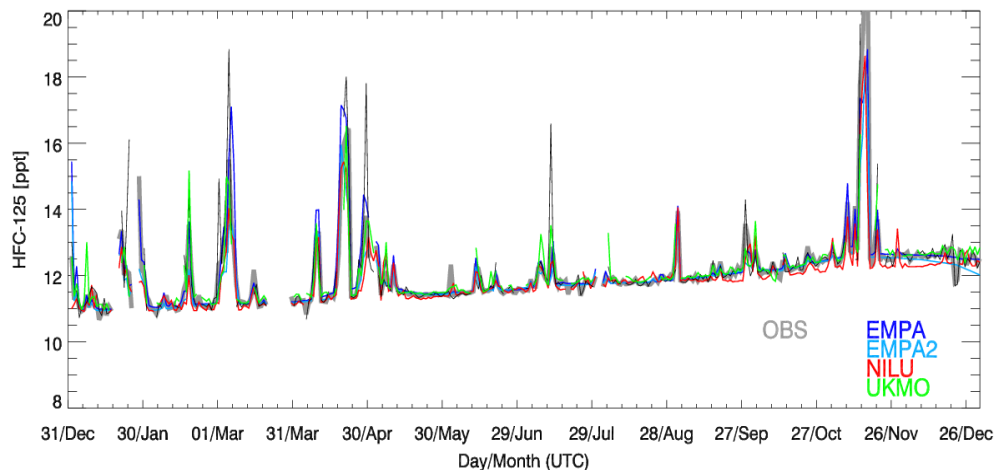
## Three measurement sites

Jungfrauoch, Mace Head, Monte Cimone

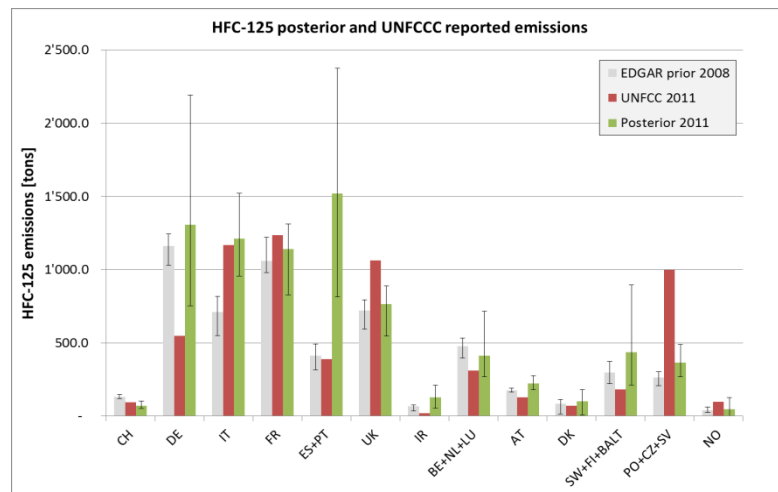
## Annual average sensitivity (footprint)



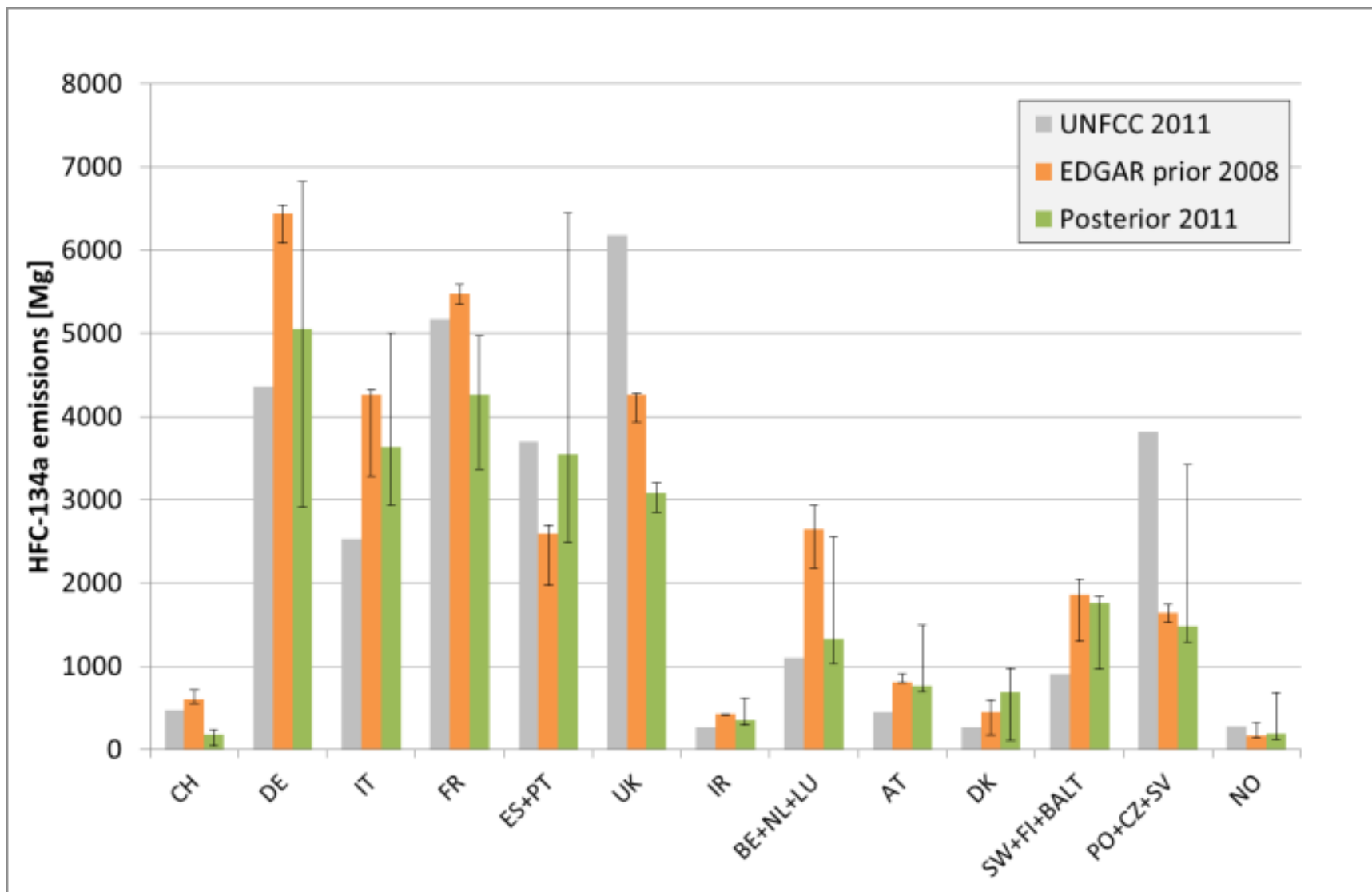
## A posteriori simulation of HFC-125 at Mace Head



## A posteriori HFC-125 emissions per country



# HFC Inversion in EU project INGOS





# Summary and Outlook

- Atmospheric measurements of halocarbons can be used to provide real-world support of inventories used in international agreements.
- The measurement-based approach is essential for identifying gaps and for providing trust between countries and different global regions.
- Measurements and methods for the measurement-based emission estimation have to be performed in a coordinated manner and have to be standardized.