

HFC-23 long-term trend derived from FTIR solar spectra at the Jungfraujoch NDACC station: Comparison with independent datasets.

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Overview

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Research context

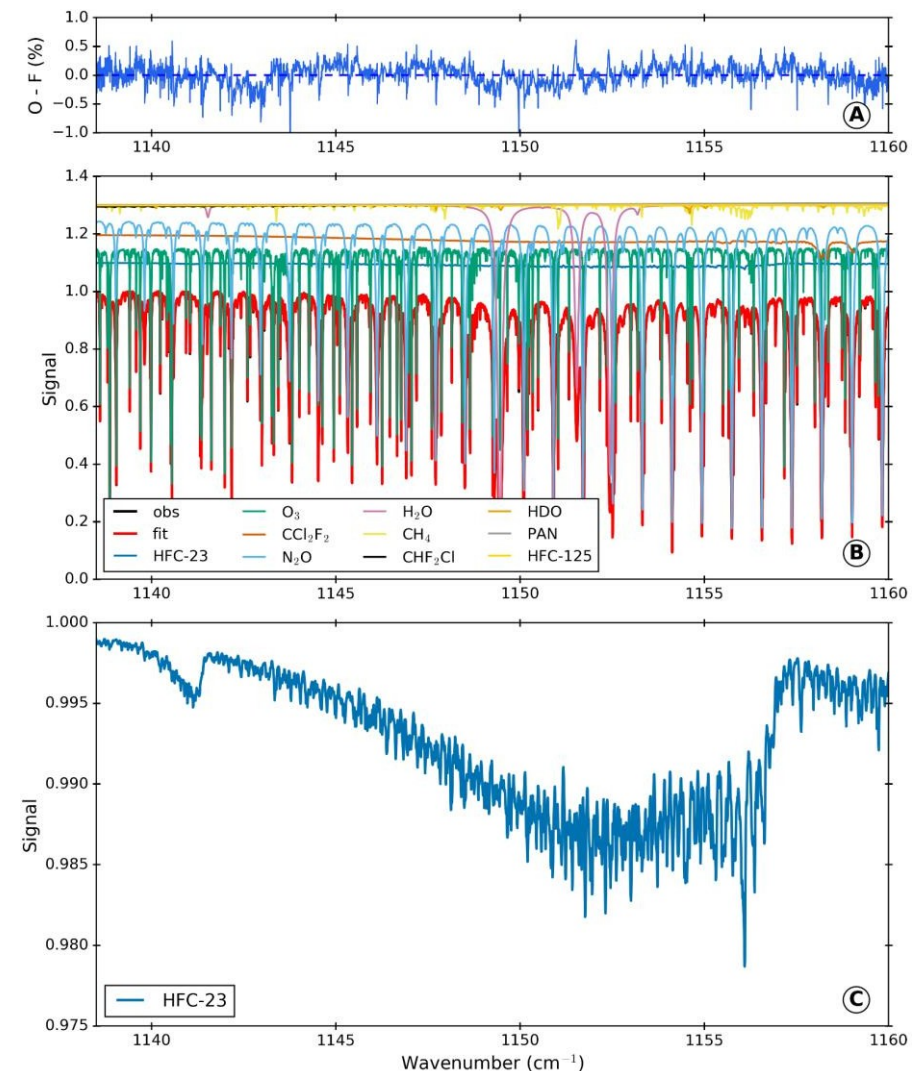
Research context

- ➔ **HFCs as alternatives to CFCs and HCFCs:** HFC-23 (CHF_3) emerged as a **chlorine-free** alternative with **no ozone depletion potential** but a **potent GHG** (GWP₁₀₀ of **14,700**, total atmospheric lifetime of **228 years** [5]).
- ➔ **Regulation:** HFC-23 regulated under the **Kigali Amendment (MP)** and **Kyoto Protocol (1997)**.
- ➔ **HFC-23 main sources and applications:**
 - By-product of HCFC-22 production (2% to 4% rate);
 - Low temperature specialist refrigerant.
 - Firefighting agent.
- ➔ **Impact:** **CFC levels declining, HCFC concentrations stabilizing, but HFCs are rising, including HFC-23** → high-precision monitoring is critical for Kigali Amendment assessment.

HFC-23 retrieval window

HFC-23 retrieval window

- ➔ HFC-23 total columns derived from clear-sky FTIR measurements at **Jungfraujoch station** (46.55°N, 7.98°E, 3580 m a.s.l.).
- ➔ Jungfraujoch observational data base includes high-resolution FTIR observations since **1984**.
- ➔ HFC-23 retrieval strategy applied to **>4200** spectra.



Simulation of the 1138.5-1160.0 cm^{-1} spectral window from a spectrum recorded on March 3, 2025 with the Bruker IFS-125HR FTIR instrument at Jungfraujoch station. The root-mean-square of the residuals (RMS) is 0.18% (panel A). The main interfering species (H₂O, O₃, CCl₂F₂, N₂O, CH₄, CHF₂Cl, HDO, PAN, and HFC-125) are shifted vertically for clarity (panel B). Note the difference in vertical scale in panel C, where the HFC-23 absorption is greatly amplified.

SI-haloVOCs project

SI-haloVOCs project

Standardizing long-term remote sensing and *in-situ* measurements of atmospheric halogenated VOCs based on SI-traceability (3 partners: METAS, Empa and ULiège)

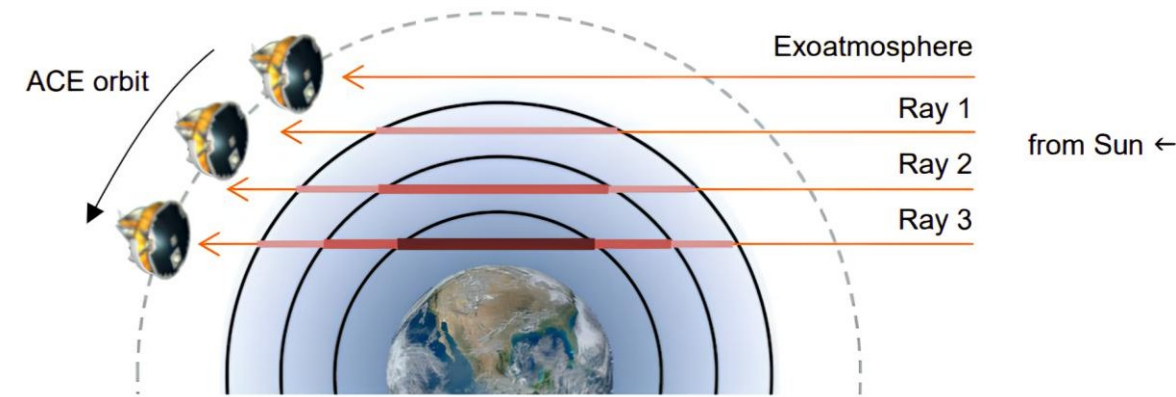
- ➡ **Context:** Need to assess the regulation of halogenated **VOCs** at global and European levels → Use of *in-situ* and **remote-sensing** measurements.
- ➡ **However:** measurements of halogenated VOCs require sophisticated equipment which is sparse.
- ➡ **Combining** long-term *in-situ* and **remote-sensing** measurements would increase global coverage. **However**, to ensure comparability between the ≠ measurement techniques in time and location, **traceability to the SI** must be ensured.
- ➡ **Ultimate aim:** Conduct the first direct intercomparison between **SI-traceable *in-situ*** measurements and **FTIR** time series.

Four independent datasets

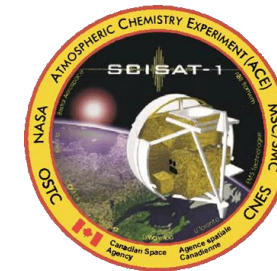
Datasets: ACE-FTS satellite data

Key features

- ➔ **ACE-FTS** aboard the **Canadian SCISAT** satellite, operational since **2004**.
- ➔ The FTIR spectrometer uses **solar occultation** to measure atmospheric profiles.
- ➔ Covers **750–4400 cm^{-1}** spectral range at **0.02 cm^{-1} resolution**, retrieving profiles from the upper atmosphere down to **5 km** (clear-sky conditions).
- ➔ **Level 2 v5.3** (research product) analyzed for **6.5–12.5 km altitude** in the **40–55°N** mid-latitude band.



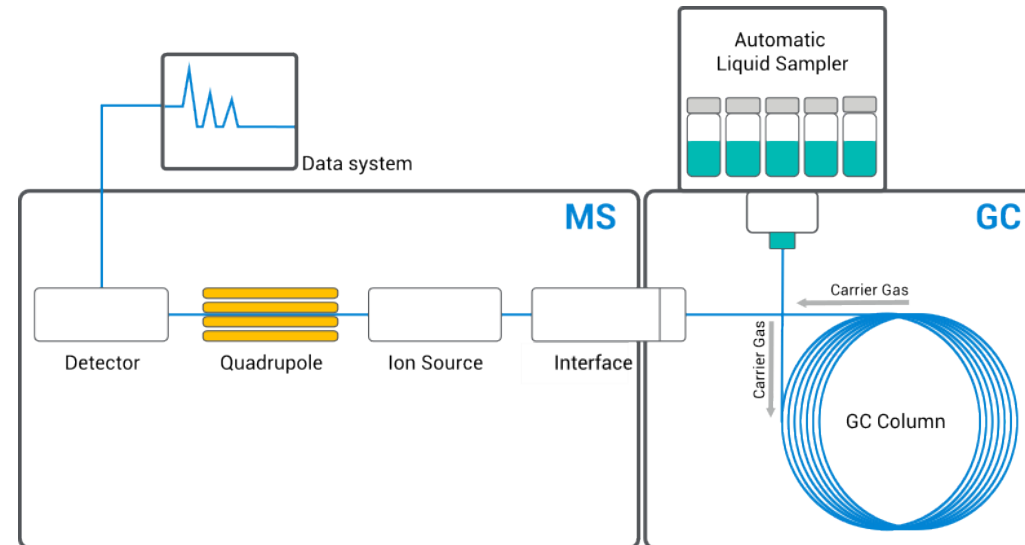
Limb sounding from orbit around the Earth (Lahance et al., 2013).



Datasets: AGAGE *in-situ* data

Key features

- ➔ *In-situ* HFC-23 measurements at **Jungfrauoch** using a **GC-MS system** [7].
- ➔ **Medusa system** preconcentrates **2 L air samples** at **-160°C**, desorbs at **100°C**, and injects into GC-MS for analysis.
- ➔ Reported on the **SIO-07 scale** with **0.6% precision** and **3% accuracy**.



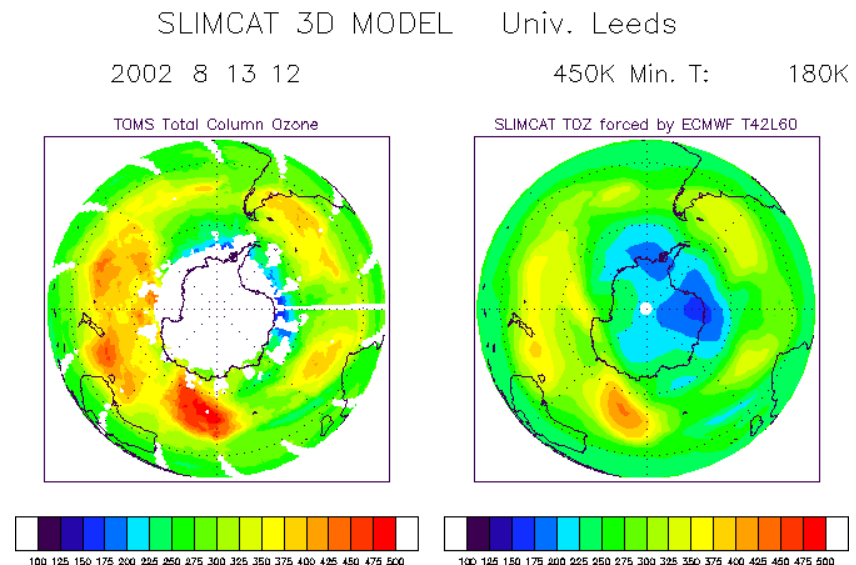
<https://www.agilent.com/en/product/gas-chromatography-mass-spectrometry-gc-ms/gcms-fundamentals>



Datasets: TOMCAT-SLIMCAT model simulation

Key features

- ➔ **Chemical transport model (CTM)** developed by Martyn Chipperfield, University of Leeds.
- ➔ **2.8° × 2.8° horizontal grid, 32 vertical levels** up to **60 km**.
- ➔ Driven by **ECMWF ERA5 meteorology**, with stratospheric chemistry and **WMO/NOAA surface fluxes** for HFCs [9].
- ➔ **Daily sampling** at Jungfraujoch coordinates for direct comparison with FTIR observations.



TOMCAT – SLIMCAT Antarctic Ozone simulation for 2002
(https://tomcat.leeds.ac.uk/tomcat/animations/anim_antarc_o3_2002_toz/)



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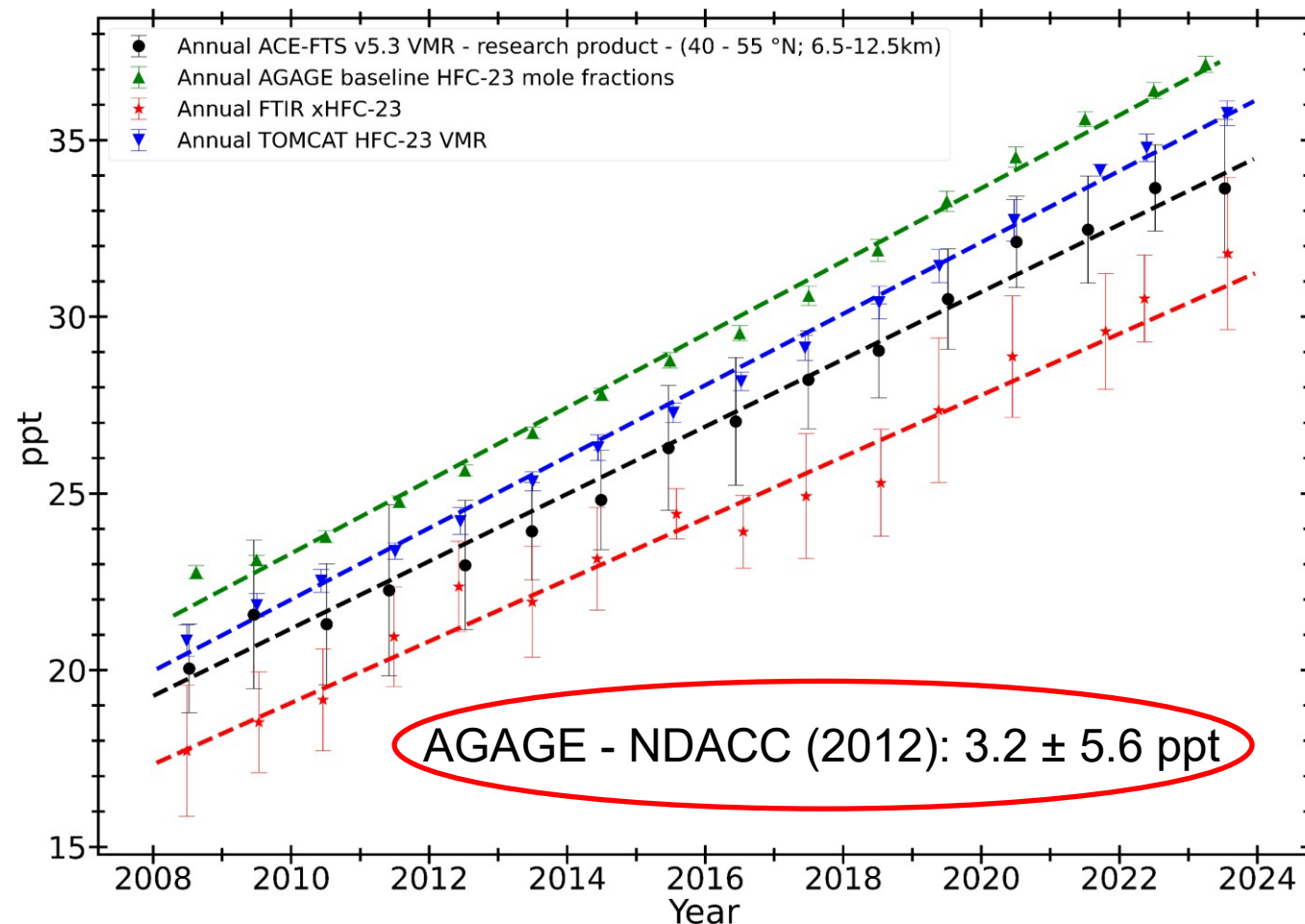
Long-term intercomparison

Long-term intercomparison

Remote sensing, *in-situ* and model datasets (mole fractions)

Dataset	Absolute trend (ppt. yr ⁻¹)	Relative Trend (%.yr ⁻¹)
ACE-FTS	0.98 ± 0.06	3.66 ± 0.23
AGAGE	1.04 ± 0.04	3.52 ± 0.15
FTIR	0.86 ± 0.08	3.52 ± 0.35
TOMCAT	0.99 ± 0.03	3.53 ± 0.10

Consistent!



Annual mean atmospheric HFC-23 mole fractions from 2008 to 2024. Black dots represent ACE-FTS v5.3 (research version) data. Green upward-pointing triangles correspond to AGAGE in-situ measurements at Jungfraujoch. Red stars indicate xHFC-23 from Jungfraujoch FTIR measurements and blue inverted triangles depict xHFC-23 derived from the TOMCAT-SLIMCAT model simulations. One standard deviation around the monthly mean is shown by the vertical error bars. The dashed lines show the linear trends from each dataset.

Note: The linear trend analysis was performed using the algorithm developed by [8]

Conclusions

Conclusions

- ➡ A strategy for retrieving HFC-23 has been optimized and implemented for FTIR observations at the Jungfraujoch station.
- ➡ The cross-validation of independent data revealed similarities (both absolute and relative trends), confirming the validity of our strategy and overall consistency between four independent datasets involving different techniques (*in situ* GC-MS, limb-satellite, CTM model and NDACC-FTIR).
- ➡ We are confident that our strategy could be implemented at other FTIR stations => near-global coverage attainable.
- ➡ The corresponding manuscript has just been submitted to the NDACC_35_SI (ACP).

Appendix: references

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- [3]: **Chipperfield (2006)** *New version of the TOMCAT/SLIMCAT off-line chemical transport model: Intercomparison of stratospheric tracer experiments* **Journal:** *Quarterly Journal of the Royal Meteorological Society* **DOI:** [10.1256/qj.05.51](https://doi.org/10.1256/qj.05.51)
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- [5]: **WMO (2018)** *GAW Report No. 58: WMO Global Atmosphere Watch (GAW) Implementation Plan: 2016–2023* **Type:** Rapport
- [6]: **Boone et al. (2023)** *Version 5 retrievals for ACE-FTS and ACE-imagers* **Journal:** *Journal of Quantitative Spectroscopy and Radiative Transfer* **DOI:** [10.1016/j.jqsrt.2023.108749](https://doi.org/10.1016/j.jqsrt.2023.108749)
- [7]: **Keller et al. (2011)** *Evidence for under-reported western European emissions of the potent greenhouse gas HFC-23* **Journal:** *Geophysical Research Letters* **DOI:** [10.1029/2011gl047976](https://doi.org/10.1029/2011gl047976)
- [8]: **Friedrich et al. (2020)** *A statistical analysis of time trends in atmospheric ethane* **Journal:** *Climatic Change* **DOI:** [10.1007/s10584-020-02806-2](https://doi.org/10.1007/s10584-020-02806-2)
- [9]: **Prinn et al. (2018)** *History of chemically and radiatively important atmospheric gases from the Advanced Global Atmospheric Gases Experiment (AGAGE)* **Journal:** *Earth System Science Data* **DOI:** [10.5194/essd-10-985-2018](https://doi.org/10.5194/essd-10-985-2018)
 - Available at <https://gml.noaa.gov/aggi/aggi.html>