First retrievals and long-term trend analysis of HFC-23 from FTIR solar spectra at NDACC network stations : a focus on Jungfraujoch

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Introduction

The identification of chlorofluorocarbons (CFCs) as major contributors to stratospheric ozone depletion led to the establishment of the Montreal Protocol in 1987, aimed at regulating CFCs and other ozone-depleting substances (ODS). Initially, hydrochlorofluorocarbons (HCFCs) were introduced as substitutes due to their lower ozone depletion potential (ODP) and reduced atmospheric lifetimes. However, since HCFCs still release chlorine harmful to the ozone layer, they are also being phased out.

Hydrofluorocarbons (HFCs), such as HFC-23 (CHF_3), emerged as chlorine-free alternatives. HFC-23, primarily a byproduct of HCFC-22 production, is utilized in refrigeration and firefighting. Although HFCs do not deplete the ozone layer, they are powerful greenhouse gases with high global warming potentials (e.g., HFC-23 has a 100-year GWP of 14,700). The Kigali Amendment of 2016 was introduced to mandate the gradual reduction of HFCs.

Due to the Montreal Protocol, atmospheric levels of CFCs have decreased, and HCFC concentrations are stabilizing. Conversely, HFCs, particularly HFC-23, have shown a significant increase over recent decades. The monitoring of HFC-23 is crucial for evaluating compliance with the Montreal Protocol and the effectiveness of the Kigali Amendment.

This research is part of an international collaboration between the University of Liège (Belgium), METAS, and Empa (Switzerland), supported by the Physikalisch-Technische Bundesanstalt (PTB) through the provision of SI-traceable spectroscopic data. The primary objective of the project is to conduct the first-ever direct comparison of SI-traceable *in situ* and FTIR time series.

NDACC FTIR observations

The High Altitude Research Station Jungfraujoch, is situated in the Northern Swiss Alps (46.55°N, 7.98°E) at an elevation of 3580 meters above mean sea level (a.m.s.l). HFC-23 total columns are retrieved using the SFIT-4 (v1.0.21) algorithm. This algorithm employs the Optimal Estimation Method (OEM) as described by Rodgers (2000). The retrieval process utilizes a harmonized layering scheme comprising 41 layers, with thicknesses progressively increasing from the station's altitude (3.58 km) up to 120 km. The study encompasses a 39-year period (1986–2025) and incorporates data from three generations of FTIR instruments: a homemade instrument, the IFS-Bruker 120HR, and the IFS-Bruker 125HR.

HFC-23 retrievals above Junfraujoch

The spectral window spanning 1138.5–1160 cm^{-1} was chosen due to the overlapping vibrational-rotational transition bands (ν_2 and ν_5) of HFC-23, while simultaneously avoiding strong absorption features from atmospheric H_2O.

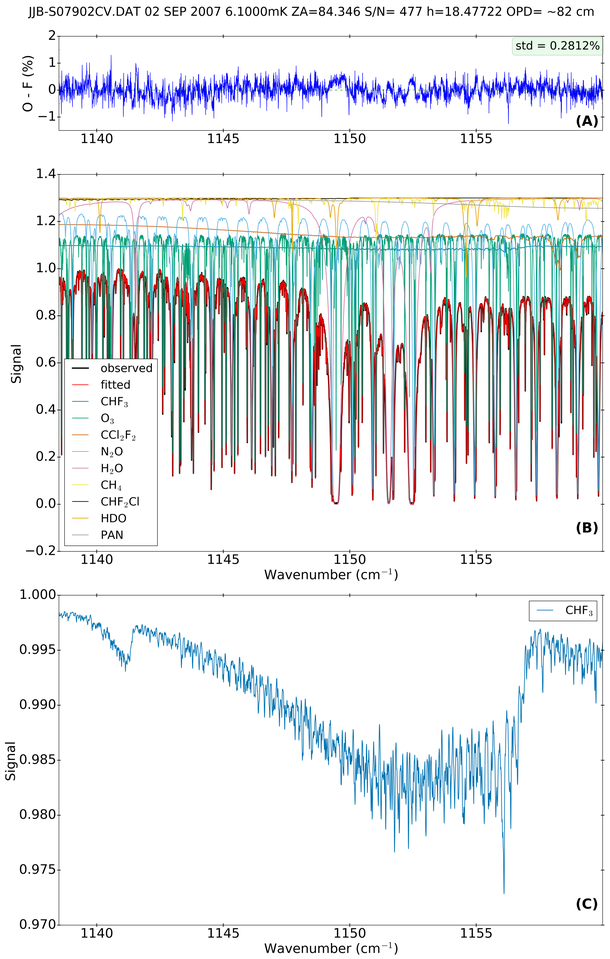

Figure 1. Simulations of the 1138.5-1160.0 cm^{-1} spectral window from a spectrum recorded with the Bruker IFS-120HR FTIR instrument at Jungfraujoch station with an apparent solar zenith angle of 84.3°. The root-mean-square of the fitting residuals (RMS) is 0.28% (panel A). The main interfering species (H_2O, O_3, CCl_2F_2, N_2O, CH_4, CHF_2Cl, HDO, and PAN) are shifted vertically for clarity (panel B). The panel C shows the absorption of the target gas: HFC-23 (around 2.5%).

Long term analysis

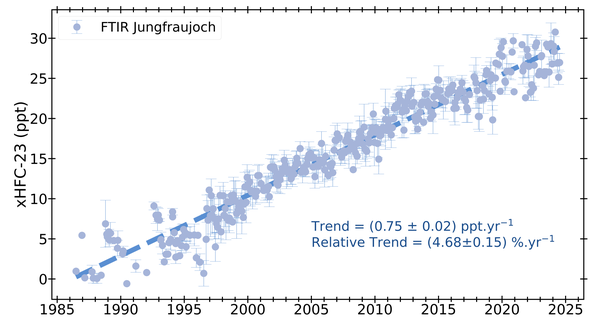

Figure 2. FTIR monthly time series of the HFC-23 dry air mole fraction (xHFC-23) above Jungfraujoch. All verticals bars represent the standard deviations around the monthly means. Total columns have been derived from solar spectra recorded with the homemade and the Bruker IFS-120HR spectrometers and then transformed into xHFC-23.

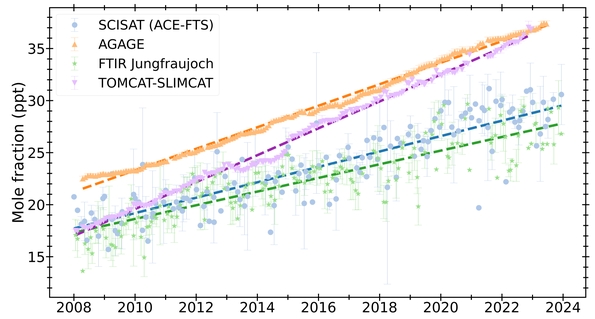

Figure 3. HFC-23 monthly mole fractions from different networks and platforms. All verticals bars represent the standard deviations around the monthly means. The HFC-23 trend from January 2008 to December 2023 using ACE-FTS satellite data between 6.5 - 12.5 km and 40-55°N / -5 – 15°E is 0.74 ± 0.06 ppt.yr^{-1}, Jungfraujoch AGAGE and FTIR trends are 1.03 ± 0.01 ppt.yr^{-1} and 0.66 ±0.05 ppt.yr^{-1} respectively. TOMCAT-SLIMCAT model trend is 1.29±0.01 ppt.yr^{-1}.

Prospects

- A first HFC-23 time series was determined for the Jungfraujoch, incorporating data from three generations of FTIR instruments (1986–2025).
- Need for harmonizing *in situ* and remote sensing data (systematic bias of calibration scales).
- Further work is needed to investigate the seasonality.

References

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[3] World Meteorological Organization (WMO). Scientific assessment of ozone depletion: 2022, gaw report no. 278.