

Evaluating satellite-based measurements of halogenated gases

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Motivation

Halogenated gases have large global warming potentials and contribute to ozone depletion.

They are in various stages of being phased out, and they remain in the atmosphere due to long lifetimes and gradual elimination from industry.

Their global abundances and trends must be regularly monitored, which can be done using satellite-based instruments.

It is important to check the reliability of these measurements through comparisons with each other ("**intercomparison**") and with other instruments ("**validation**").

Select intercomparison results

First, the consistency between the satellite instruments was determined through **intercomparisons** of coincident profiles: **within [6 hrs, 300 km]**. The median profiles and median differences were compared, as well as the median absolute differences.

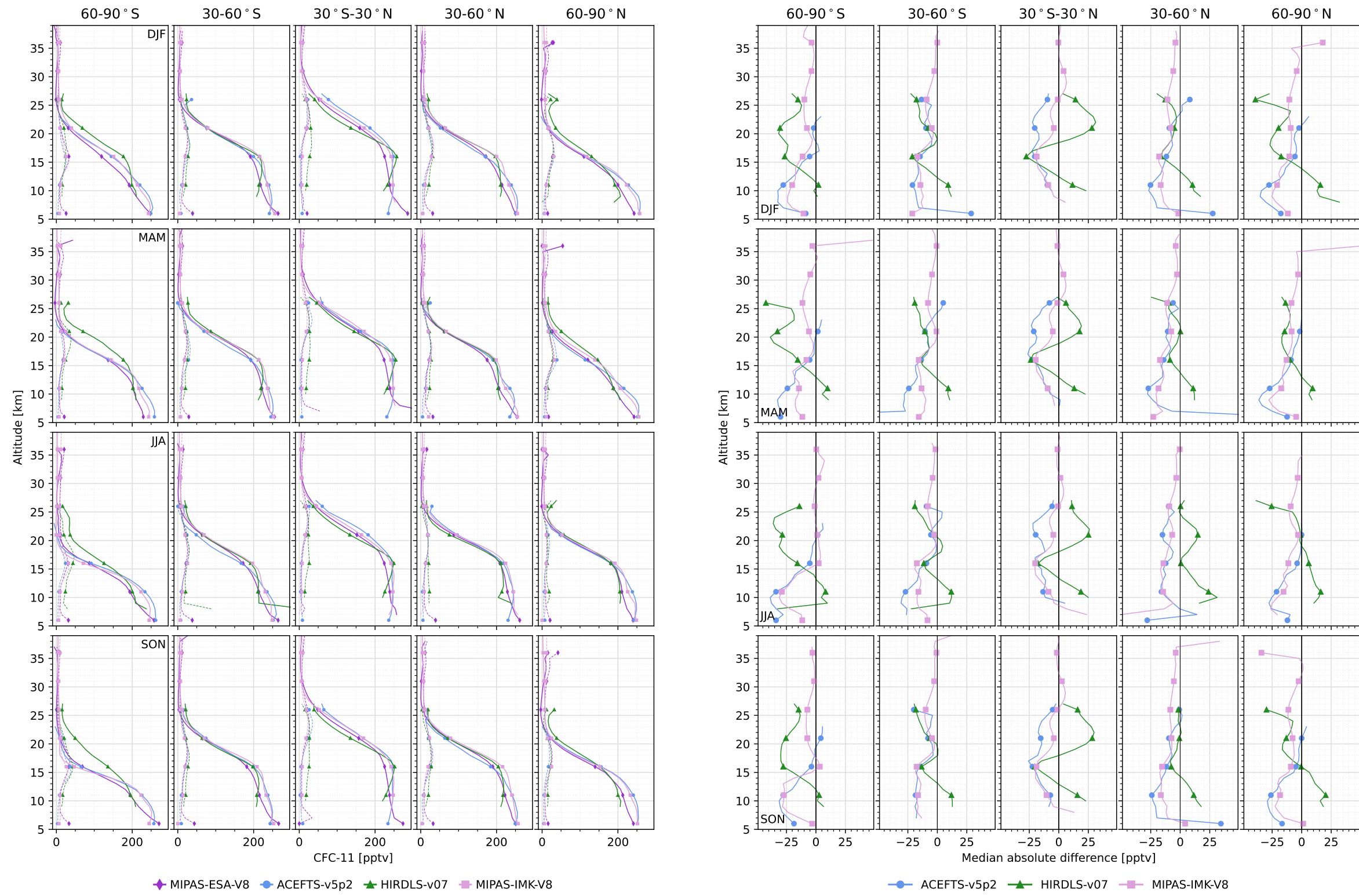


Figure 1: Median VMR and median absolute deviation of the CFC-11 concentration for each instrument. For MIPAS-ESA, all profiles were included in the median. For other instruments, only profiles coincident with a MIPAS-ESA profile were included.

Figure 2: Median absolute difference between MIPAS-ESA CFC-11 and coincident measurements from each other instrument.

MIPAS-ESA has a consistent negative bias compared to ACE-FTS and MIPAS-IMK of up to 15%. The agreement is worse with HIRDLS; the bias has a magnitude of up to 40% (e.g., MAM, 60-90°S).

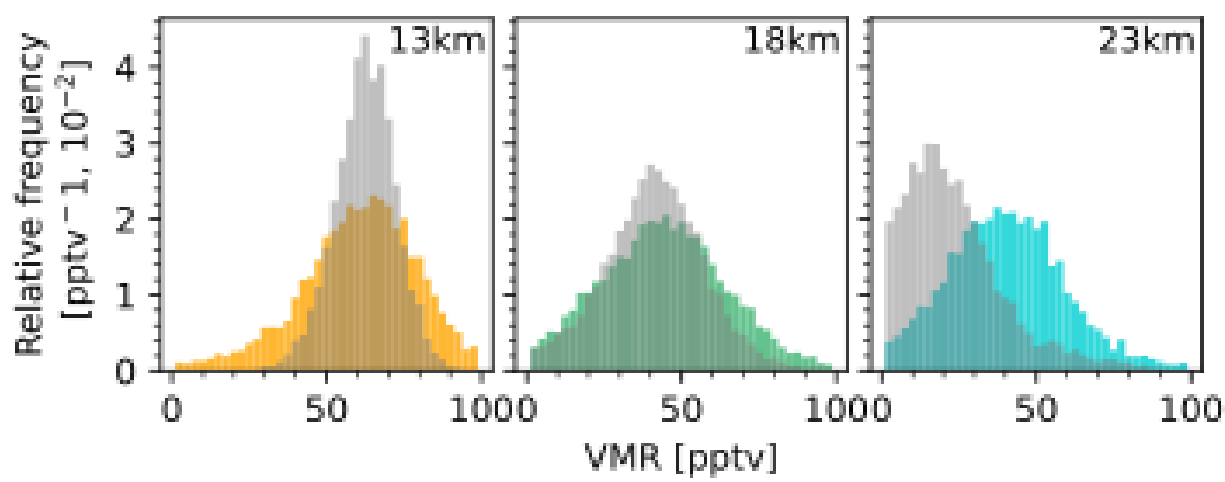


Figure 3: Probability density functions of coincident ACE-FTS (coloured) and MIPAS-IMK (grey) measurements of CFC-113.

The probability density functions of coincident measurements at various altitudes were also compared. The ACE-FTS distributions are wider than the MIPAS-IMK distributions. Ongoing tests are being done to determine whether this is related to the spectroscopic parameters used in the two different retrieval algorithms.

The inter-instrument biases were summarized in grid plots.

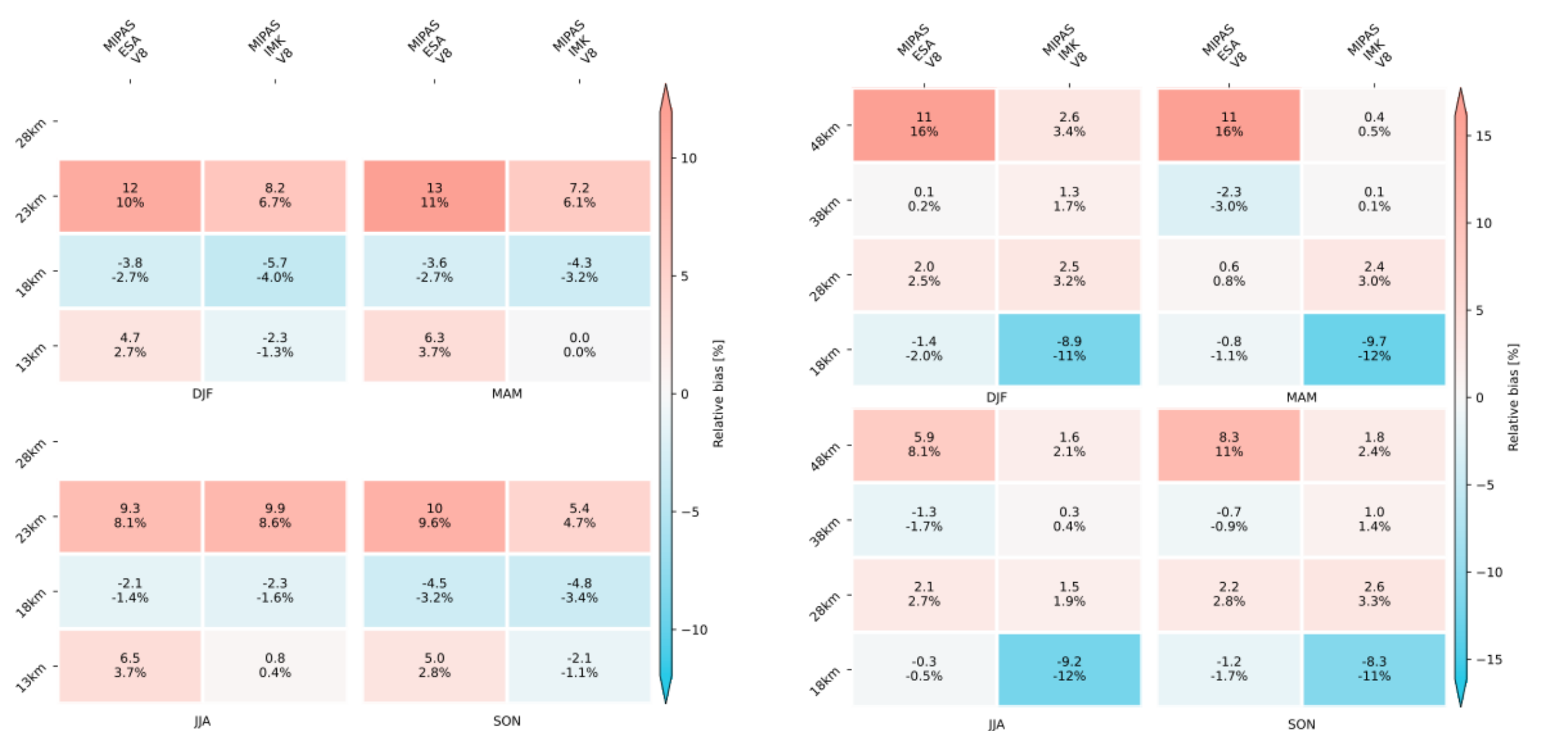


Figure 4: Absolute HCFC-22 bias (in pptv) and relative bias between ACE-FTS and each other instrument.

Figure 5: Absolute CF₄ bias (in pptv) and relative bias between ACE-FTS and each other instrument.

ACE-FTS HCFC-22 has a consistent negative bias at 18 km, but it is always within 4%. The bias at 13 km is also always within $\pm 4\%$. The agreement with the MIPAS datasets is excellent at these altitudes, and still very good at 23 km where the bias is positive and only one comparison (with MIPAS-ESA during MAM) is greater than 10%.

ACE-FTS CF₄ biases are mostly positive (21 of 32 boxes) and within $\pm 4\%$, except when compared to MIPAS-ESA at 48 km, and MIPAS-IMK at 18 km.

Datasets used

Satellite instrument	Platform	Version	Gases	Time period	Latitudes
Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS)	SCISAT	5.2	CFC-11, CFC-12, HCFC-22, CCl ₄ , CF ₄ , CFC-113	Feb 2004-present	85°S-85°N (3 months)
High Resolution Dynamics Limb Sounder (HIRDLS)	Aura	7	CFC-11, CFC-12	Jan 2005-Mar 2008	65°S-82°N (daily)
Michelson Interferometer for Passive Atmospheric Sounding (MIPAS-ESA and MIPAS-IMK)	Envisat	8 (for both)	CFC-11, CFC-12, HCFC-22, CCl ₄ , CF ₄ IMK: CFC-113	Jul 2002-April 2012	90°S-90°N (daily)

Balloon instrument	Flights	Gases	Time period	Latitudes
GLORIA-B	2 (mean profiles)	CFC-11, CFC-12, HCFC-22, CCl ₄	Aug 2021, Aug 2022	46°N, 68°N
MIPAS-B	10	CFC-11, CFC-12, HCFC-22, CCl ₄ , CF ₄	Feb 2002-Sep 2014	5°S, 44°N, 46°N, 68°N
MkIV	18	CFC-11, CFC-12, HCFC-22, CCl ₄ , CF ₄ , CFC-113	Dec 2002-Sep 2023	34°N, 68°N

Select validation results

Next, coincident satellite profiles and balloon profiles from GLORIA-B, MIPAS-B, and MkIV were compared: **within [72 hrs (720 hrs for ACE-FTS), 5° latitude, same side of polar vortex edge]**.

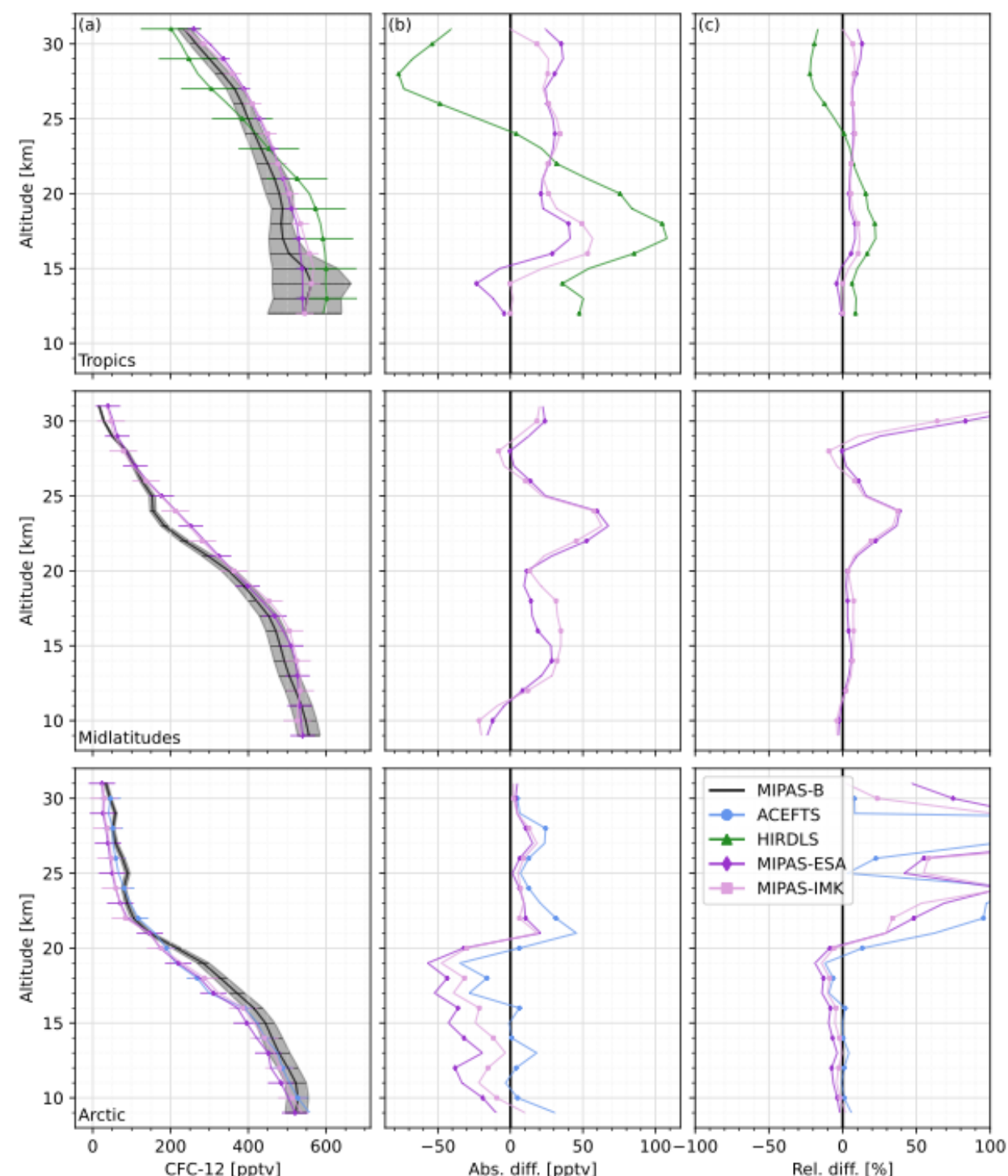


Figure 6: (a) Mean MIPAS-B CFC-12 profiles (black) compared with mean satellite profiles in the tropics (top), the midlatitudes (middle), and the Arctic (bottom). Grey shading represents the reported uncertainty of the MIPAS-B profiles. (b) Absolute difference between each mean satellite profile and the mean MIPAS-B profile (satellite-balloon). (c) Same as (b) but the relative difference.

The satellite profiles are mostly consistent with the MIPAS-B profile, except between 21 and 25 km in the midlatitudes, where they have a positive bias of about 40%. ACE-FTS and both MIPAS datasets have negative biases below 20 km in the Arctic. The HIRDLS profile in the tropics decreases more rapidly with altitude than the other profiles.

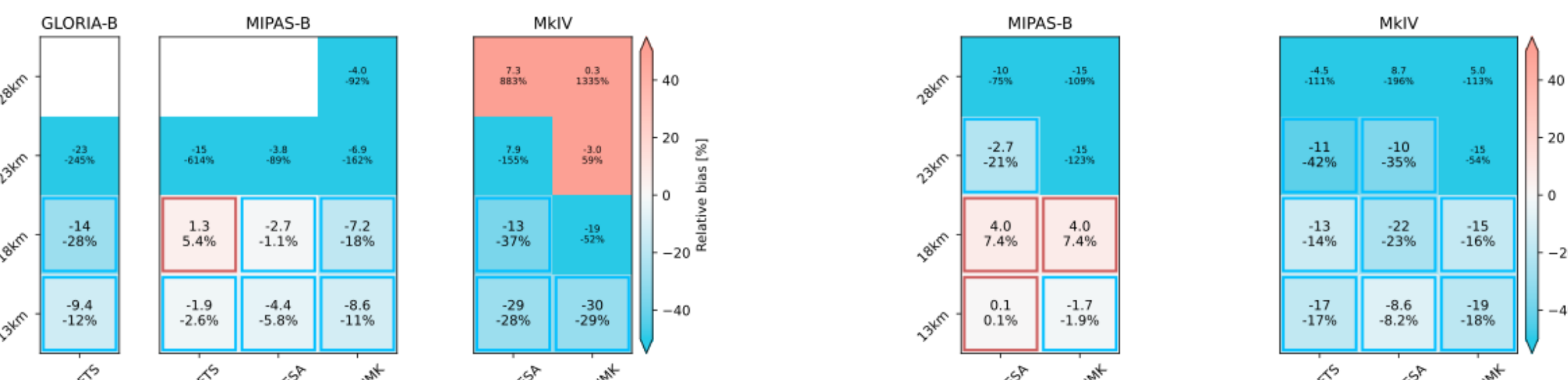


Figure 7: Summary of CCl₄ comparisons in the Arctic. Absolute differences are shown in pptv above the relative differences. Coloured borders indicate where the relative difference is within $\pm 50\%$.

Figure 8: Summary of CCl₄ comparisons in the midlatitudes. Absolute differences are shown in pptv above the relative differences. Coloured borders indicate where the relative difference is within $\pm 50\%$.

The CCl₄ biases are large at and above 23 km due to the small VMRs at these altitudes. Below 23 km, the agreement is best with MIPAS-B; are all within $\pm 20\%$, and 6 of 10 boxes are within $\pm 6\%$. Most of the biases are negative at these altitudes; only 4 of 20 boxes are positive. Compared to GLORIA-B and MkIV, the satellite measurements have substantial negative biases and the agreement is worst with MkIV. This is likely related to a bulge in the MkIV CCl₄ profile at 13-17 km.

Summary

Measurements of **CFC-11**, **CFC-12**, **CFC-113**, **HCFC-22**, **CCl₄**, and **CF₄** from **ACE-FTS**, **HIRDLS**, and **MIPAS** have been evaluated through intercomparisons between satellite instruments and validation against independent balloon-borne measurements from **GLORIA-B**, **MIPAS-B**, and **MkIV**. Select results are presented here, with the full results to be published in two upcoming papers.

Overall, the instruments show good agreement, with generally small differences. In particular, ACE-FTS and MIPAS demonstrate promising consistency, with relatively minor biases, suggesting the potential to combine their measurements into a longer, continuous time series.

The intercomparison and validation results are broadly consistent, but some differences warrant further investigation. For example, CFC-12 measurements agree well across satellite instruments but exhibit a common bias relative to one or more balloon-borne reference datasets. **This highlights the importance of independent validation, as agreement between satellite instruments does not necessarily indicate the absence of systematic biases.**

Acknowledgements

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