Measurements in the High Arctic with PARIS-IR

instrument intercomparison and validation between 2006 and 2013

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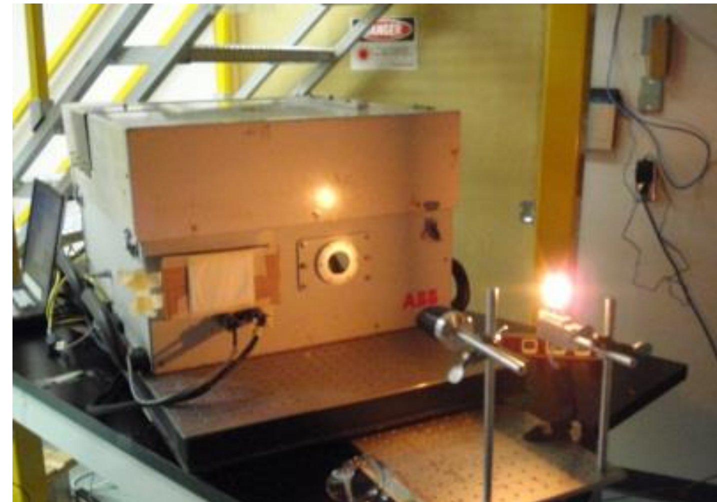
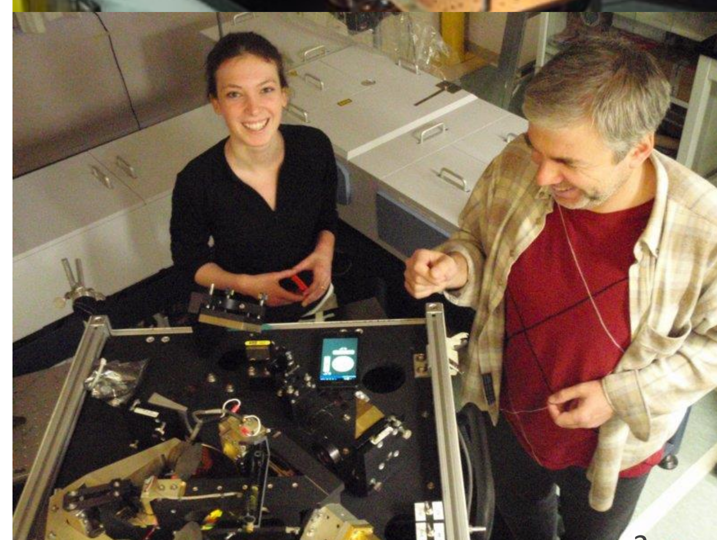
Instrumentation

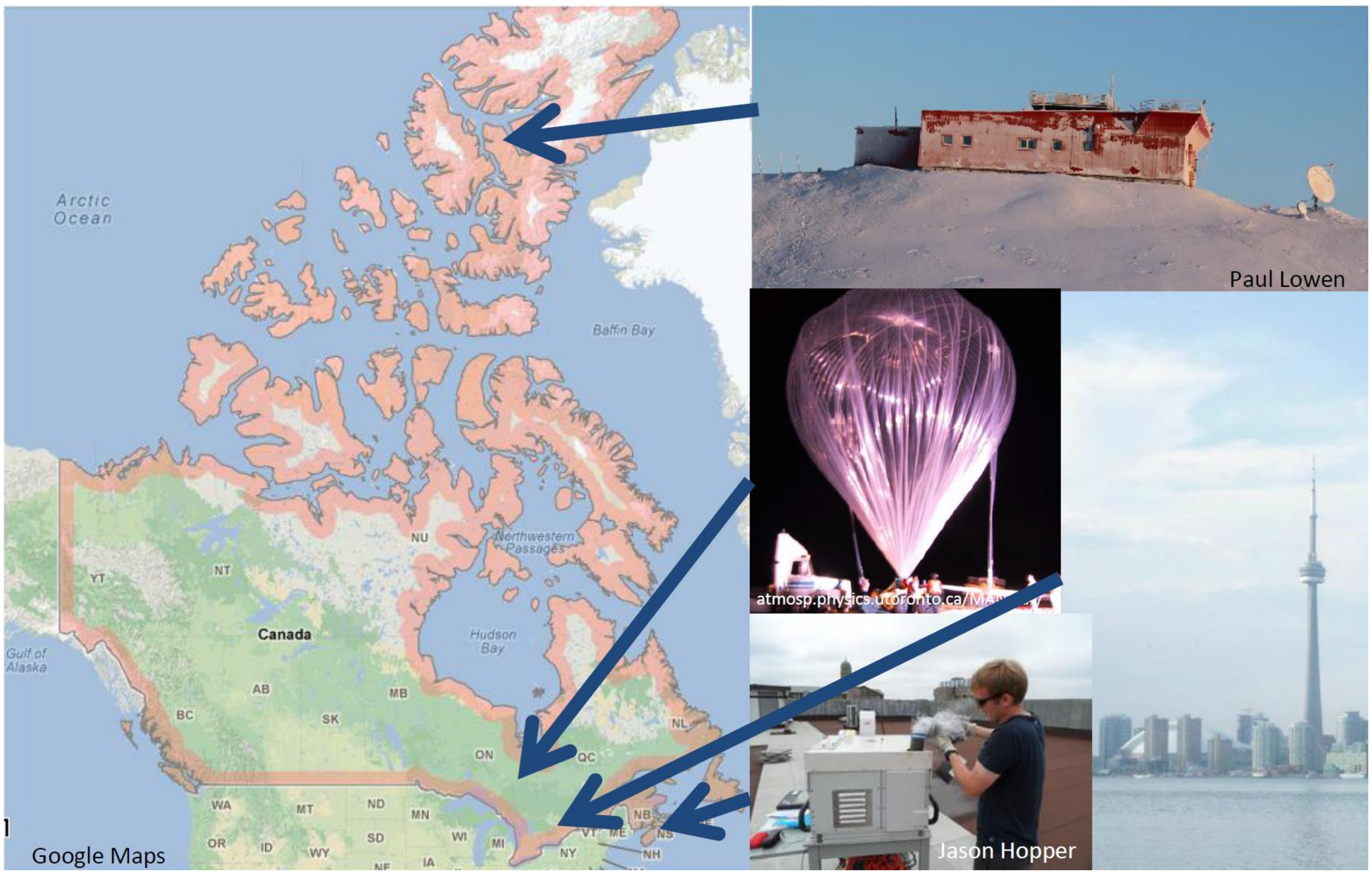
The Portable Atmospheric Research Interferometric Spectrometer for the Infrared

- Spectral range and resolution: 750-4,400 cm^{-1} at 0.02 cm^{-1}
- High temporal resolution for a ground-based FTS: full spectral coverage every 7 min (which consist of 20 co-added spectra)
- As part of the ACE/OSIRIS Arctic Validation Campaigns in Eureka (2004-2015) during spring
- Optimal Estimation Method (OEM) has been applied using SFIT4
- Retrieved species: O_3, HCl, HNO_3, HF, CH_4, N_2O, CO, C_2H_6





PARIS-IR



Eureka:
Canadian Arctic ACE/OSIRIS validation campaigns (2004-present)

Halifax:
BORTAS (2010-11)

Toronto:
(2009, 2011, 2015)

Timmins:
PARABLE flight (2015)

Importance and challenges of intercomparisons

- Ground-based instruments provide valuable data sets for validation of satellite remote-sensing instruments
- Continuing validation confirms that the satellite instruments are still performing well
- Comparisons made in the High Arctic are challenging:
  - Comprehensive understanding of the ground-based instrument (e.g. Averaging Kernel) necessary
  - Need to ensure that the measurement conditions sampled by the two instruments were similar
  - The viewing geometry with respect to polar vortex dynamics is essential

Instrumentation

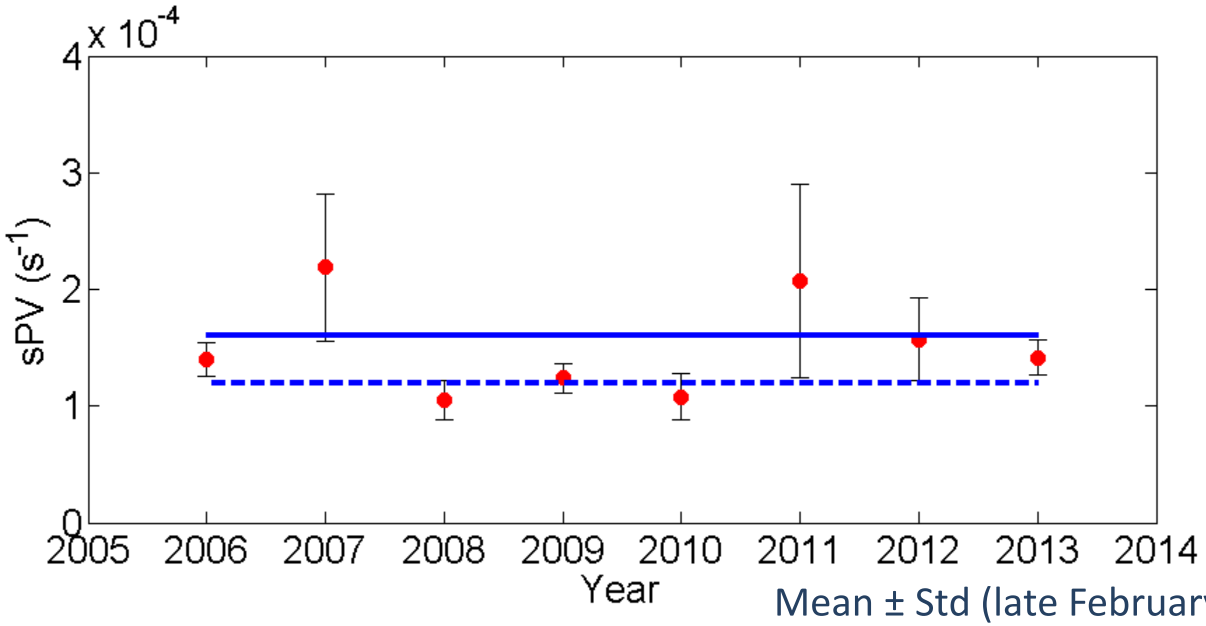
- Bruker 125HR
  - ground-based
  - 700-4,300 cm^{-1} at 0.0035cm^{-1}
  - OEM with using SFIT4
- ACE-FTS
  - space-born
  - 750-4,400 cm^{-1} at 0.02cm^{-1}
  - Non-linear least-squares fitting approach (ACE-FTSv3.5)

Smoothing accounts for the effect of the different resolution of the instruments, using method from Rodgers and Connor (2003):

$$\boldsymbol{x}_{\rm smooth} = \boldsymbol{x}_{\rm a} + \mathbf{A} \cdot (\boldsymbol{x}_{\rm h} - \boldsymbol{x}_{\rm a})$$

Where A is the averaging kernel of PARIS-IR, x_{smooth} is the smoothed, x_a the a priori, and x_h the ACE-FTS or Bruker profile

Derived Meteorological Parameters



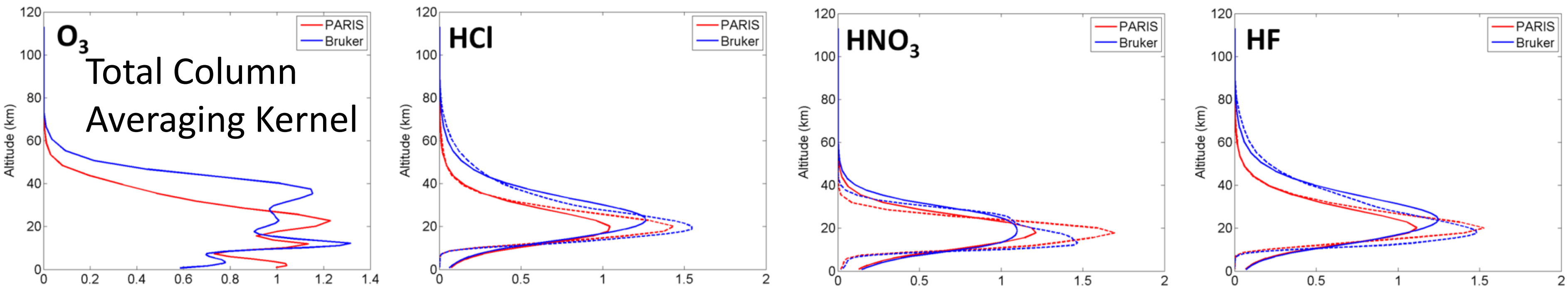
Mean ± Std (late February to early April) at 20 km along line-of-sight of PARIS-IR

Polar vortex

- The scaled potential vorticity (sPV), derived from GEOS-5 analysis (from DMPs), provides information on whether measurements were taken outside or inside the polar vortex (edge: sPV≈1.2×10^{-4} s^{-1}, inside: sPV≥1.6×10^{-4} s^{-1}) (Manney et al., 2007)

- The sPV along the line-of-sight of a measurement is an important criterion to include for the comparison between instruments (ΔsPV≤ 0.3×10^{-4} s^{-1}) because it ensures that similar air masses are observed (Batchelor et al., 2010).

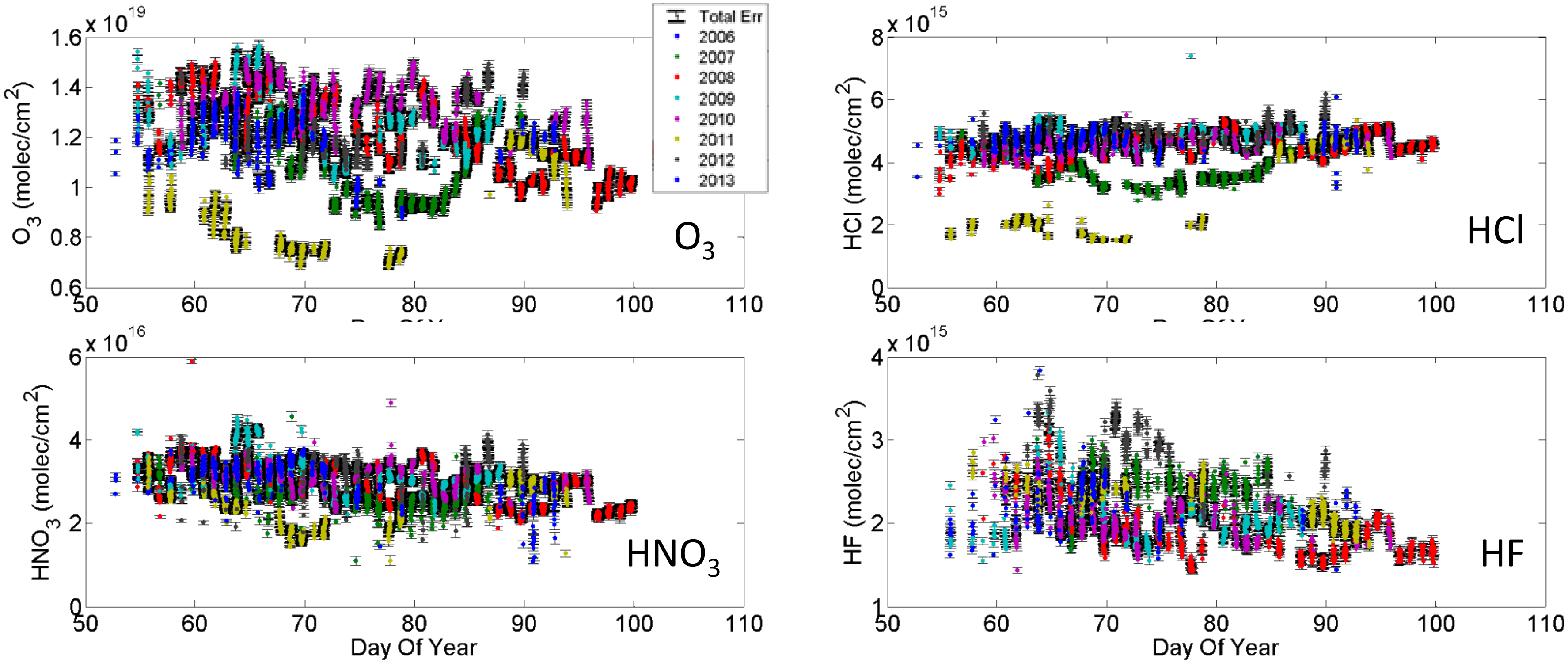
Stratospheric Species



Retrieval specifications

Gas	Microwindows (cm^{-1})	Interfering Species	Total uncert. (%)	DOFS
O_3	1000.00–1004.50	H_2O, CO_2, C_2H_4, O_3 isotopologues	2.5	3.5
HCl	2775.70–2775.80 2925.80–2926.00	O_3, N_2O CH_4, NO_2, O_3	2.5	1.0
HNO_3	867.50–870.00	H_2O, OCS, NH_3	19.0	1.5
HF	4038.81–4039.07 4109.77–4110.07	H_2O, CH_4, HDO	2.9	1.0

Stratospheric Species



- PARIS-IR total column measurements (2006-2013)
- Looking at species related to O_3 depletion in the Arctic, as well as HF (tracer) from late-February to early April
- Exceptionally low O_3, HCl, and HNO_3 in 2011

Trend assessment

To determine whether or not it is a trend, a number of factors need to be considered:

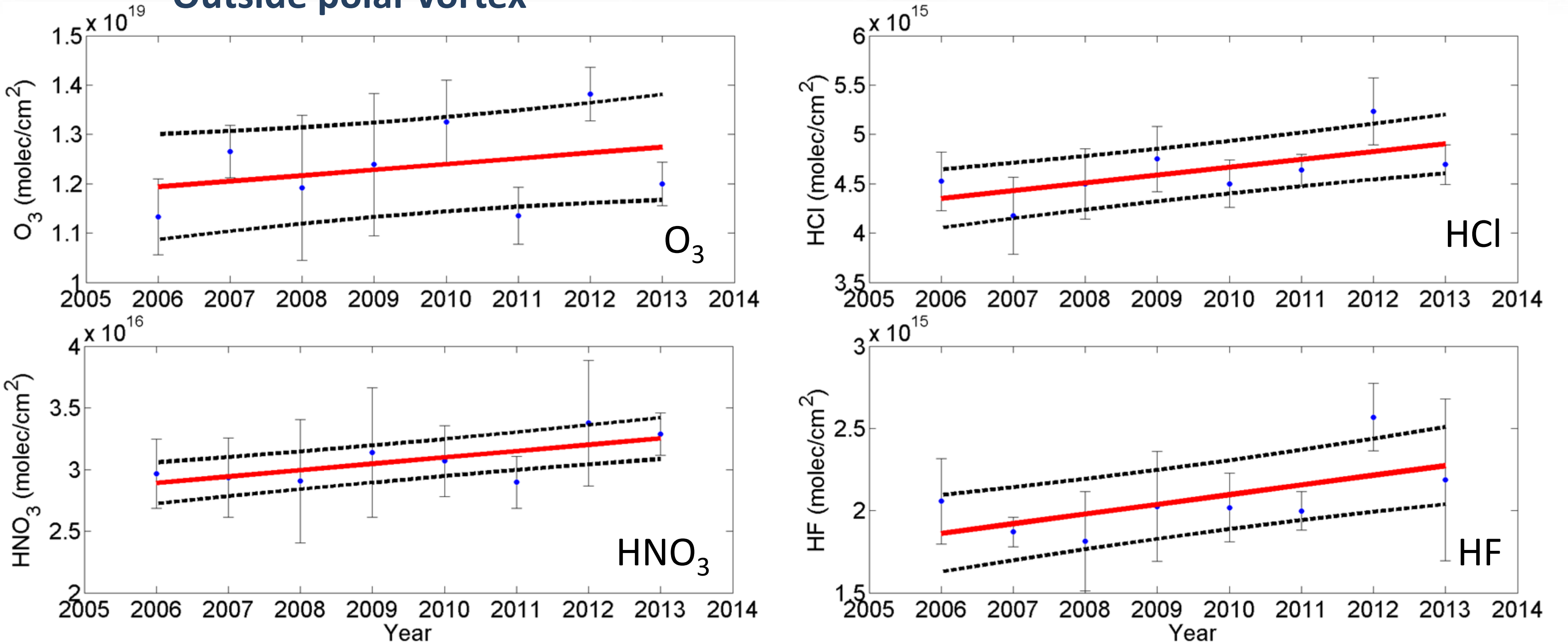
- the time period of the data set,
- the magnitude of the trend w_o,
- the variability σ,
- and the autocorrelation ϕ of the noise of the data set (Weatherhead et al., 1998)

- The minimum number of years n^* that need to be considered to be defined as a trend, can be estimated:

$$n^* = \left[\frac{3.3 \cdot \sigma}{|w_o|} \cdot \sqrt{\frac{1+\phi}{1-\phi}} \right]^{2/3}$$

Stratospheric Species

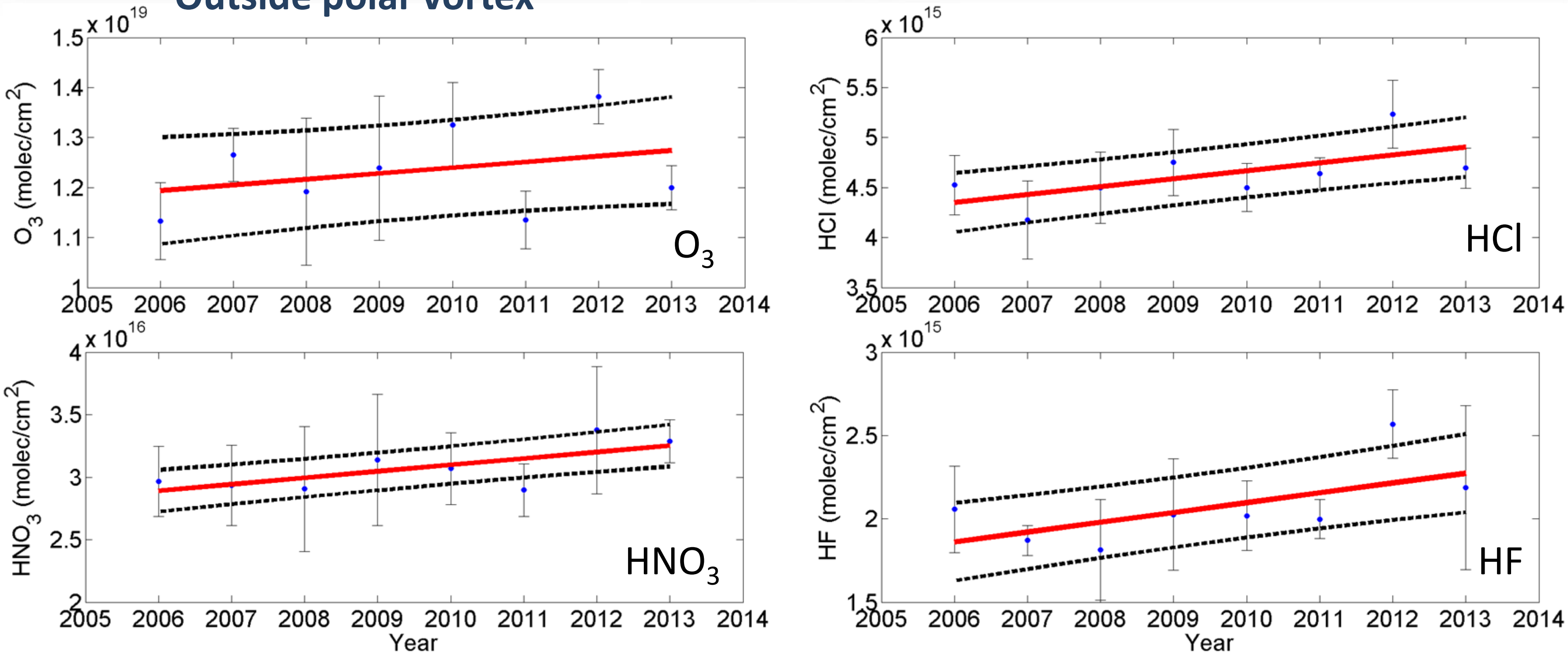
Outside polar vortex



- PARIS-IR total column measurements, mean and std (2006-2013)

Stratospheric Species

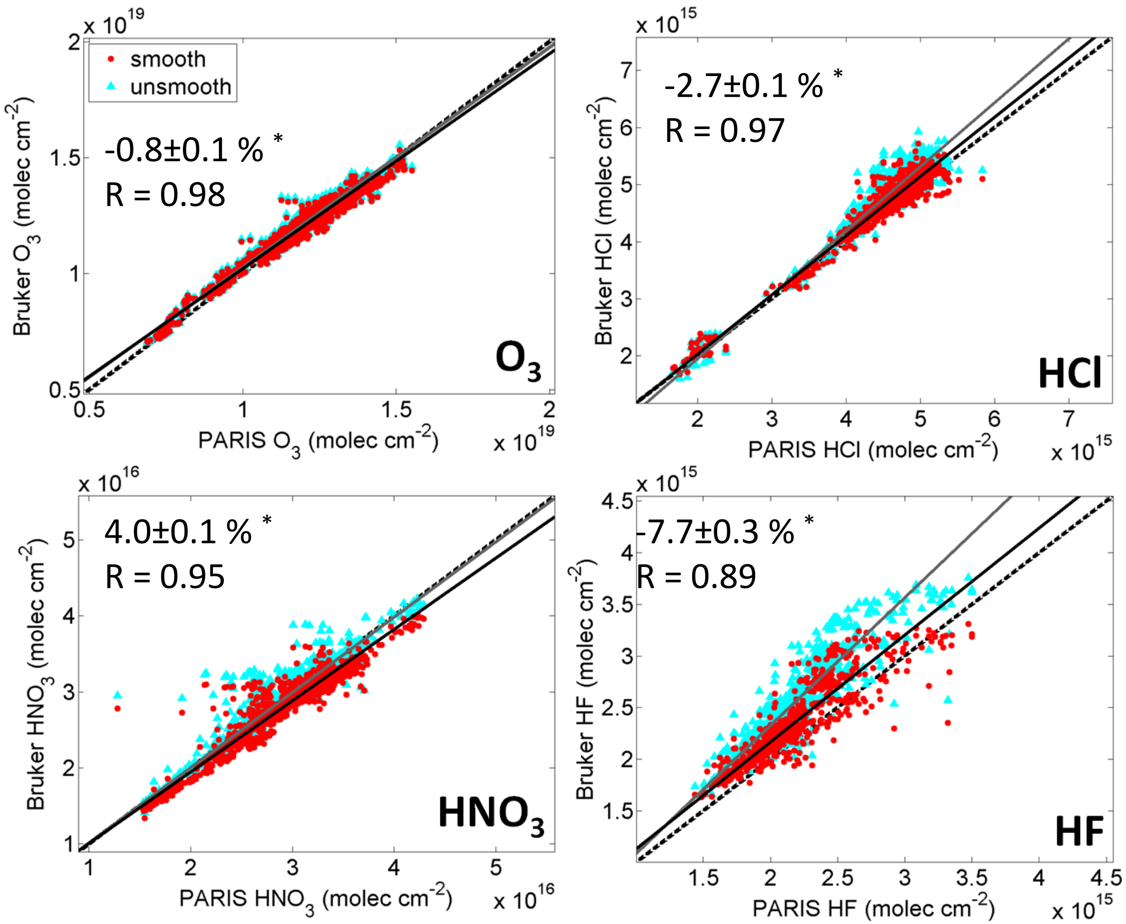
Outside polar vortex



- PARIS-IR total column measurements, mean and std (2006-2013)
- Increasing trends for of O_3 (0.9%yr^{-1}), HCl (1.7%yr^{-1}), HF (3.9%yr^{-1})
- For HNO_3 not enough years available to assess the trend (Weatherhead et al., 1998)

PARIS-IR/Bruker comparison

Diff = (PARIS-Bruker)/[0.5*(PARIS+Bruker)]



Coincidence: Δt ≤ 30 min

- Close to 1-to-1 line
- Very good agreement between the instruments
- Minimal difference of the retrieved columns except for HF
- Small differences between smoothed and unsmoothed columns (except HF)

*Mean difference ± standard error of the smoothed total columns

ACE-FTS comparison

- Partial column (PC) methodology (using smoothed PCs)
- Coincidence time: 12 h, distance: 1000 km
- Included sPV and temperature criteria (sPV≤0.3 × $10^{-4}s^{-1}$ and T≤10K) between 14-36 km (Batchelor et al.; 2010)

PARIS-IR vs. ACE-FTS

	pairs	Diff (%)	R	slope
O_3	118	3.5 ± 0.6	0.92	0.81 ± 0.03
HCl	117	-1.0 ± 0.6	0.95	0.98 ± 0.03
HNO_3	119	5.0 ± 1.1	0.75	0.74 ± 0.04
HF	120	-6.1 ± 1.2	0.59	1.02 ± 0.08

PCs: O_3 (9.5-51km), HCl (9.5-41.5km), HNO_3 (9.5-33.5km), HF(14.5-41.5km)
Diff = (PARIS-ACE)/[0.5·(PARIS+ACE)] (here: smoothed PCs)

Bruker vs ACE-FTS

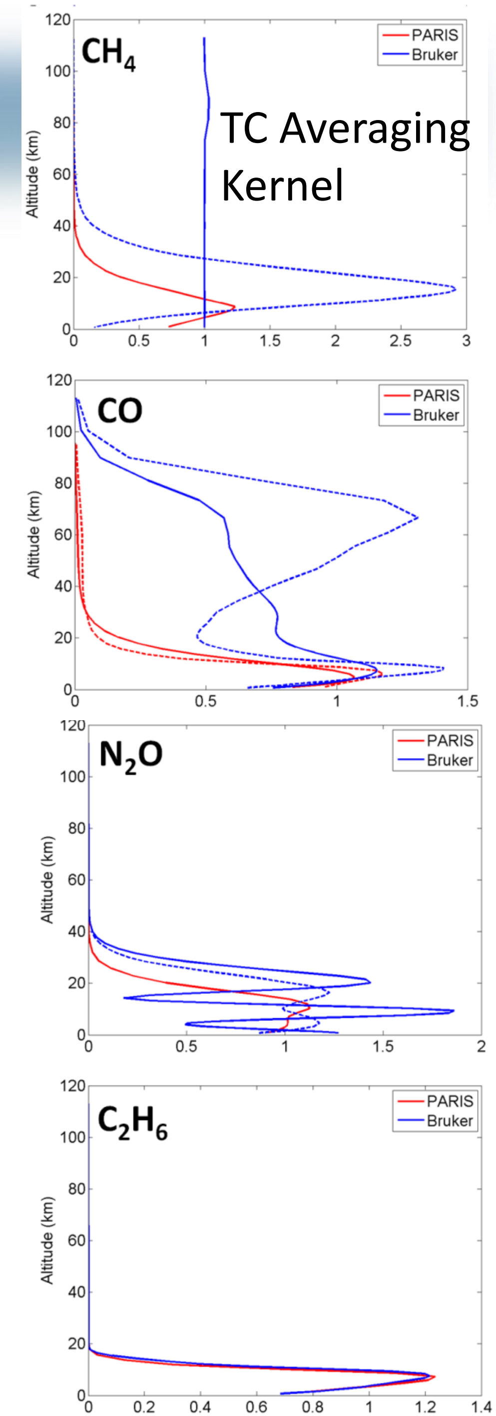
	pairs	Diff (%)	R	slope
O_3	95	3.6 ± 0.6	0.91	0.92 ± 0.04
HCl	94	2.4 ± 0.6	0.92	0.98 ± 0.04
HNO_3	91	1.5 ± 1.0	0.77	0.82 ± 0.05
HF	104	-1.9 ± 1.0	0.84	0.91 ± 0.05

PCs: O_3 (9-48.5km), HCl (9-39km), HNO_3 (9-30.5km), HF(14-39km)
Diff = (Bruker-ACE)/[0.5·(Bruker+ACE)] (here: smoothed PCs)

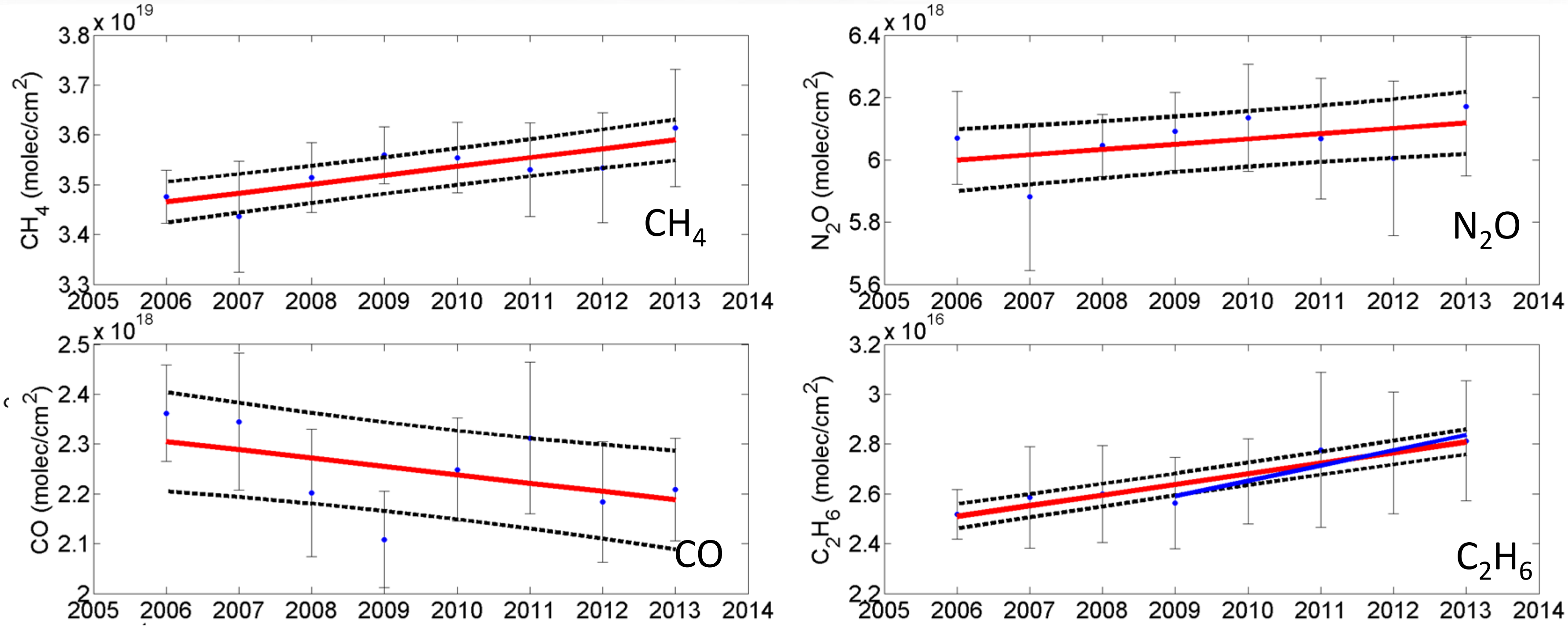
Tropospheric Species

PARIS-IR vs. ACE-FTS

Gas	Microwindows (cm^{-1})	Interfering Species	Total uncert. (%)	DOFS
CH_4	2613.70–2615.40	HDO, CO_2, N_2O	6.8	2.0
	2650.60–2651.30			
	2835.50–2835.80	HDO		
	2903.60–2904.03			
	2921.00–2921.60			
CO	2057.70–2058.00	CO_2, O_3, OCS	3.5	1.5
	2069.56–2069.76			
	2157.50–2159.15	CO,O_3, CO_2, OCS, N_2O, H_2O		
N_2O	2481.30–2482.60	H_2O, HDO, CO_2, O_3, CH_4	3.5	2.0
	2526.40–2528.20			
	2537.85–2538.80			
	2540.10–2540.70			
C_2H_6	2976.66–2976.95	H_2O, O_3	5.0	1
	2983.20–2983.55			
	2986.50–2986.95			



Tropospheric Species

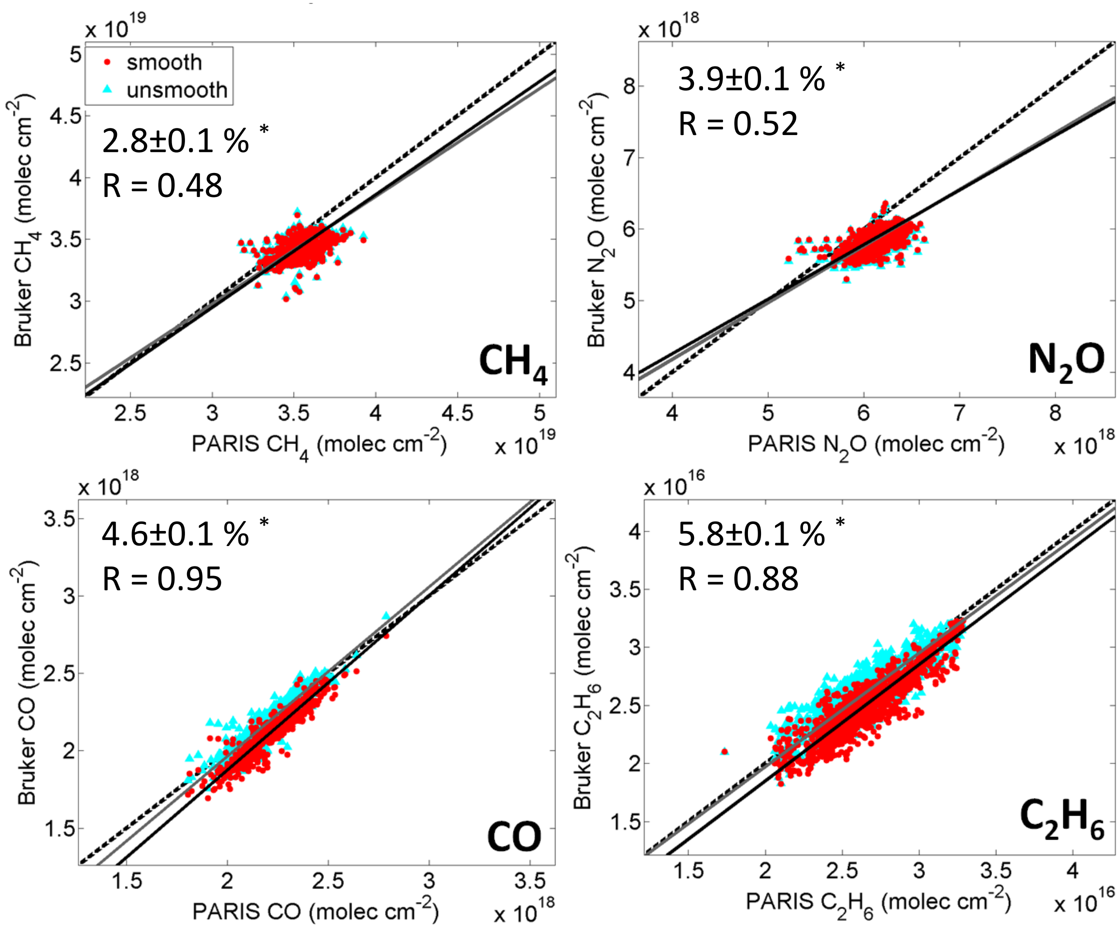


- PARIS-IR total column measurements, mean and std (2006-2013)
- Not strongly influenced by the polar vortex
- CH_4 is increasing (approx. 0.5%yr^{-1})
- Not enough measurements are available to be confident of a trend in CO and C_2H_6 (Weatherhead at al.,1998)
- Increasing C_2H_6 since 2009 (2.3%yr^{-1}), and decreasing CO

PARIS-IR/Bruker comparison

Diff = (PARIS-Bruker)/[0.5*(PARIS+Bruker)]

- Close to 1-to-1 line
- Very good agreement between the instruments
- Minimal difference of the retrieved columns
- Small differences between smoothed and unsmoothed columns
- CH_4 and N_2O are not highly correlated due to the lack of variation in the dataset



Coincidence: Δt ≤ 30 min

*Mean difference ± standard error of the smoothed total columns

ACE-FTS comparison

PARIS-IR vs. ACE-FTS (1000 km)

	pairs	PC (%)	R	slope
CH_4	163	2.7 ± 0.3	0.66	1.07 ± 0.06
N_2O	147	6.1 ± 0.4	0.66	1.06 ± 0.07
CO	137	18.7 ± 1.0	0.50	1.14 ± 0.08

PCs: CH_4 (8-41.5km), N_2O (8-37.5km), CO (9.5-41.5km)
Diff = (PARIS-ACE)/[0.5·(PARIS+ACE)] (here: smoothed PC)

Bruker vs ACE-FTS (1000 km)

	pairs	PC (%)	R	slope
CH_4	60	1.0 ± 0.4	0.75	0.77 ± 0.07
N_2O	84	-2.2 ± 0.4	0.73	0.67 ± 0.05
CO	60	4.5 ± 1.8	0.69	0.64 ± 0.07

PCs: CH_4 (6.5-34km), N_2O (6.5-22km), CO (9-48.5km)
Diff = (Bruker-ACE)/[0.5·(Bruker+ACE)] (here: smoothed PC)

- Partial column (PC) methodology (using smoothed PCs)
- Coincidence time: 12 h, distance: **1000 km**
- Included sPV criterion ($sPV \leq 0.3 \times 10^{-4} s^{-1}$ at 20 km)
- The comparison with C_2H_6 is still in progress

ACE-FTS comparison

PARIS-IR vs. ACE-FTS (500 km)

	pairs	PC (%)	R	slope
CH_4	47	2.9 ± 0.4	0.76	1.08 ± 0.10
N_2O	41	5.8 ± 0.6	0.82	1.11 ± 0.10
CO	40	18.4 ± 1.3	0.72	0.97 ± 0.11

PCs: CH_4 (8-41.5km), N_2O (8-37.5km), CO (9.5-41.5km)
Diff = (PARIS-ACE)/[0.5·(PARIS+ACE)] (here: smoothed PC)

Bruker vs ACE-FTS (500 km)

	pairs	PC (%)	R	slope
CH_4	23	0.8 ± 0.4	0.89	0.82 ± 0.08
N_2O	21	-1.7 ± 0.7	0.89	0.75 ± 0.08
CO	23	2.2 ± 2.6	0.79	0.62 ± 0.08

PCs: CH_4 (6.5-34km), N_2O (6.5-22km), CO (9-48.5km)
Diff = (Bruker-ACE)/[0.5·(Bruker+ACE)] (here: smoothed PC)

- Partial column (PC) methodology (using smoothed PCs)
- Coincidence time: 12 h, distance: **500 km**
- Included sPV criterion (sPV≤$0.3 \times 10^{-4} s^{-1}$ at 20 km)
- A more restricted distance improves the comparison significantly for tropospheric species

Summary and Conclusions

- In the eight years of the study (2006-2013), increasing trends of O_3 (0.9%yr^{-1}), HCl (1.7%yr^{-1}), HF (2.9%yr^{-1}), and CH_4 (0.5%yr^{-1}) have been found
- Trend of HCl and CH_4 is consistent with Mahieu et al.(2014) and Sussmann et al. (2011), respectively
- The recent increase in C_2H_6 is consistent with Franco et al. (2015)

- Excellent agreement between the two ground-based FTSs with differences well with the retrieval uncertainty
- The retrieved columns are highly correlated for the two FTSs

- No trend could be found in the differences if the years are compared individually, only year-to-year variation (2007 and 2011: largest differences)
- The resulting mean biases are small and mainly within the estimated ground-based retrieval uncertainty for all species
- The continuous long-term ground-based FTS measurements show that the data, produced by the instrument on-board SCISAT, are trustworthy measurements between 2006 and 2013

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