HAGAR-V: A new airborne five channel instrument for in situ measurements of tracers with a wide range of lifetimes to study UTLS transport

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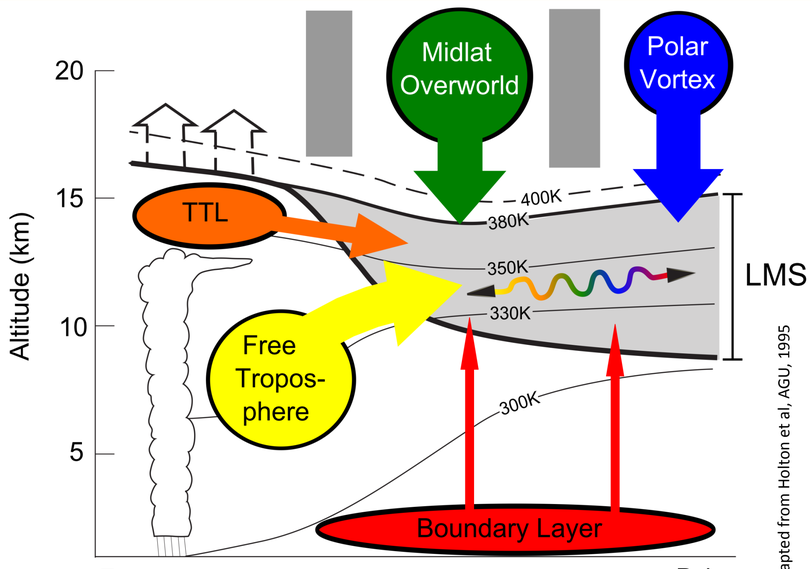
Motivation

- The **upper troposphere/lower stratosphere (UTLS)** is a key region in the climate system.
- Radiative forcing is sensitive to the distribution of greenhouse gases (H_2O, CO_2, CH_4, O_3) in the UTLS.
- Greenhouse gas distributions in the **lowermost stratosphere (LMS)** particularly, are determined by transport and mixing of air masses from various regions with widely differing chemical composition.
- Time scales for transport along the various pathways, and for mixing in the LMS, range from days to years.
- Recent observations indicate that transport patterns and transport times may be changing.



Transport pathways into the **lowermost stratosphere (LMS)**

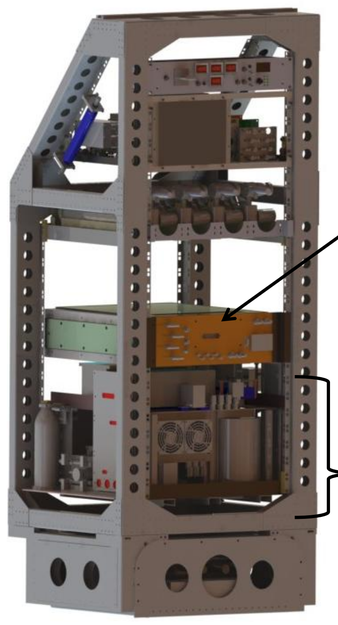
General objectives

- What is the relative importance of different transport pathways into the lowermost stratosphere (LMS)?
- What are the transport times along these pathways?
- What are the time scales for mixing within the LMS?

Method: analysis of chemical tracers

Distributions of tracers with a **wide range of lifetimes** ⟺ Pathways and time scales of transport and mixing

New instrument for in situ tracer measurements on board HALO



HAGAR-V (High Altitude Gas AnalyseR-V)

Modernized and extended version of HAGAR instrument on M55 Geophysica

5 channels in 3 modules for in situ tracer measurements:

2-Channel GC/ECD-Module
for long-lived tracers
- direct sample injection
- separation on packed columns
- electron capture detection (ECD)

2-Channel GC/MS-Module
for short- and long-lived tracers
- sample enrichment on cold traps
- separation on capillary columns
- mass spectrometric (MS) detection

NDIR-Module for CO_2
- Detection: IR-absorption

Total weight: 128.5 kg + 32 kg Rack

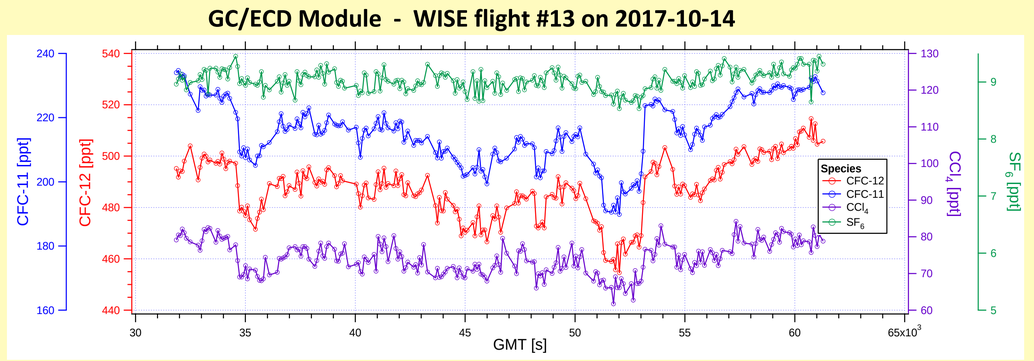
Target Species	Photochemical lifetime	Contribution to strat. organic chlorine[d]	Time resolution
SF_6	3200[a] yr		90 s
CH_4	136[b] yr		
CFC-12	102[b] yr	32.1 %	
CFC-113	93[b] yr	6.8 %	
CFC-11	52[b] yr	21.6 %	
CCl_4	44[b] yr	10.4 %	
CFC-113	93[b] yr	6.8 %	180 s (per channel)
CFC-11	52[b] yr	21.6 %	
CH_3Cl	51[b] yr	16.5 %	
CH_2Cl_2	632[c] days	1.4 %	
$CHCl_3$	601[c] days	0.5 %	
C_2Cl_4	439[c] days	0.1 %	
n-&iso-Butane	7[c] days		
CO_2	~ infinite		3 s

a Ravishankara et al., 1993
b Stratospheric lifetime, SPARC lifetime assessment report, 2013
c Local lifetime at 15 km, 20°N/S, calculated from photo chemical kinetic data
d Calculated from WMO-Scientific Assessment of O_3 Depletion, 2014

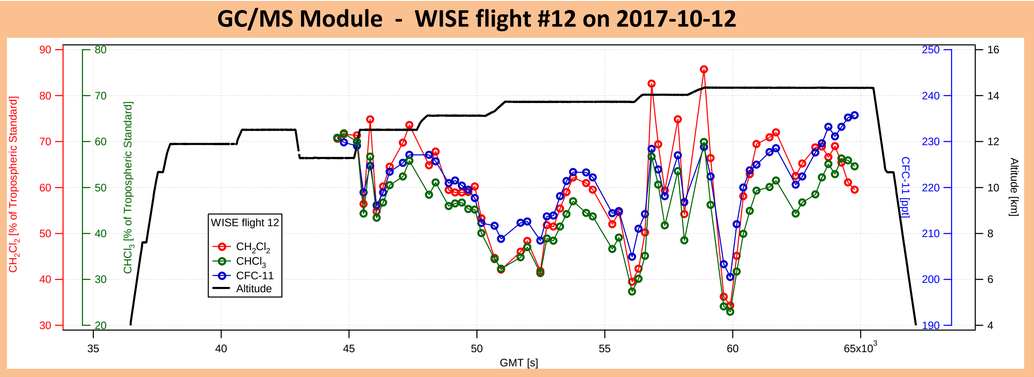
- Measurement of tracers with a **wide range** of photochemical **lifetimes** to investigate **transport** and **mixing**
- Species measured by HAGAR-V cover **~90%** of the organic **chlorine** entering the stratosphere

Measurement examples from the WISE mission

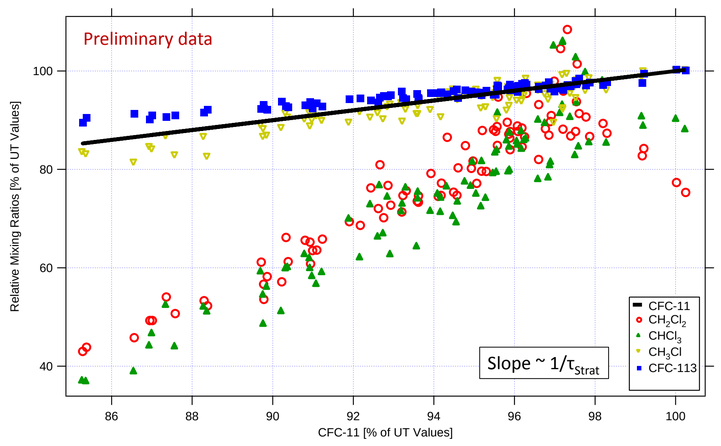
GC/ECD Module - WISE flight #13 on 2017-10-14



GC/MS Module - WISE flight #12 on 2017-10-12



Correlation of short and long-lived tracers



WISE flight #12 on 2017-10-12

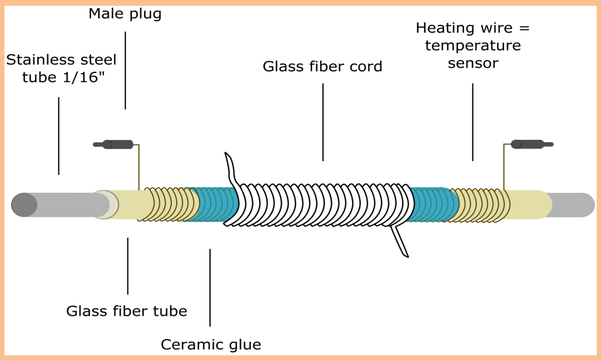
Preliminary data from GC/MS-Module

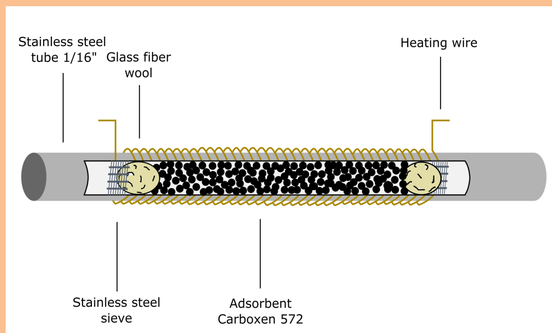
Mixing ratios are plotted in normalized units relative to upper tropospheric values for all species, such that the correlations converge in the upper troposphere at the point 100%:100%.

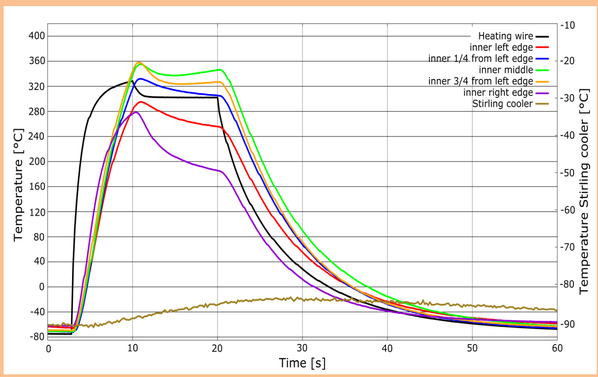
The slope of each correlation is inversely proportional to the stratospheric lifetime of the respective species.

Correlations of VSLS (Very Short Lived Species) like CH_2Cl_2 and $CHCl_3$ with long lived tracers (here CFC-11) exhibit **more scatter** than correlations between long lived tracers because **tropospheric sinks of VSLS** induce gradients in the upper troposphere.

Novel thermal desorption system for GC/MS-Module



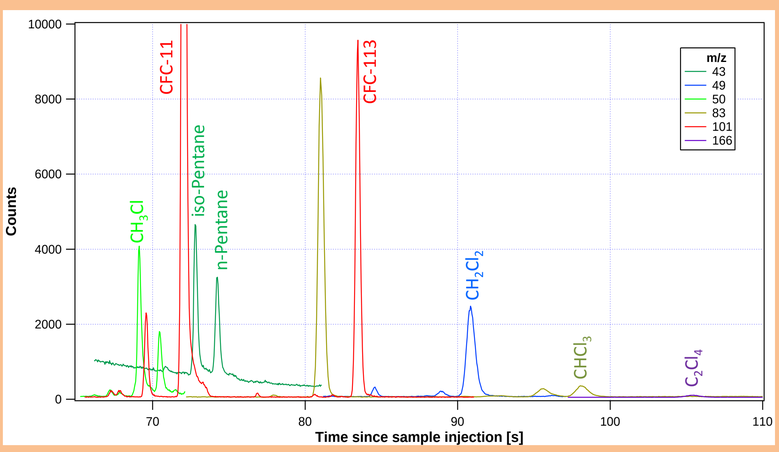




Enrichment & thermal desorption unit for GC/MS-Module

- Per channel one **adsorbent** filled stainless steel tube is wrapped with a **heating wire** which at the same time is used as a **temperature sensor**.
- The system is thermally coupled to a **stirling cooler**.
- Heating rates larger than **100K/s** are achieved inside the tube, with temperature differences along the tube of ±~50K and a very good reproducibility.
- Cooling rates inside the tube were determined to be up to **-30K/s.**

Example chromatogram of GC/MS-Module



WISE flight #12 on 2017-10-12

Single injection of one GC/MS channel

- The species of interest appear within a time window of 40s. The second channel runs countercyclical to use the detector during the waiting time of the first channel.
- Some of the prominent peaks (e.g. at m/z=83, 101, 50) still have to be identified.
- By using the electron ionization mode peaks do not necessarily need to be chromatographically separated.

HAGAR-V measurements during PGS and WISE missions