Mass spectrometric water vapor measurements in contrails

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Motivation: Accurate, high-resolution in-situ observations of RHi in contrails

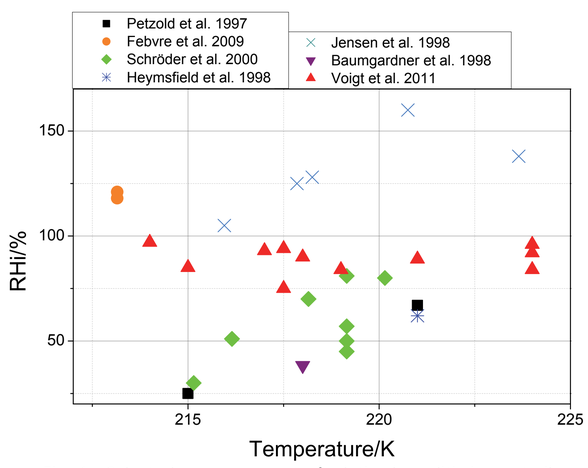

Fig. 1: Selected measurement of relative humditiy in contrails vs Temperature. Two publications report supersaturated conditions , the others consequentely subsaturated environments. Additionally there is a huge spread of more than 100% between different reports.

While contrail formation in principle requires environments which are at least saturated with respect to ice, a majority of in situ observations in contrails show values clearly below ice saturation (Fig. 1). This systematic deviation might be caused by:

- a bias in water vapor measurements
- a bias in temperature measurements
- an effect of contrail dynamics: relative humidity over ice (RHi) decreases due to heating during the descent of the vortices of young contrails (<3min).

Here, we present the first measurements of the Atmospheric Ionization Mass Spectrometer for H_2O, AIMS_H2O, a new technique for accurate high resolution water vapor measurements in the UT/LS. The time resolution of the AIMS_H2O instrument and the in-flight calibration presents a major technical step in the accurate quantification of variable relative humidity fields inside, in the vicinity of, and outside contrails.

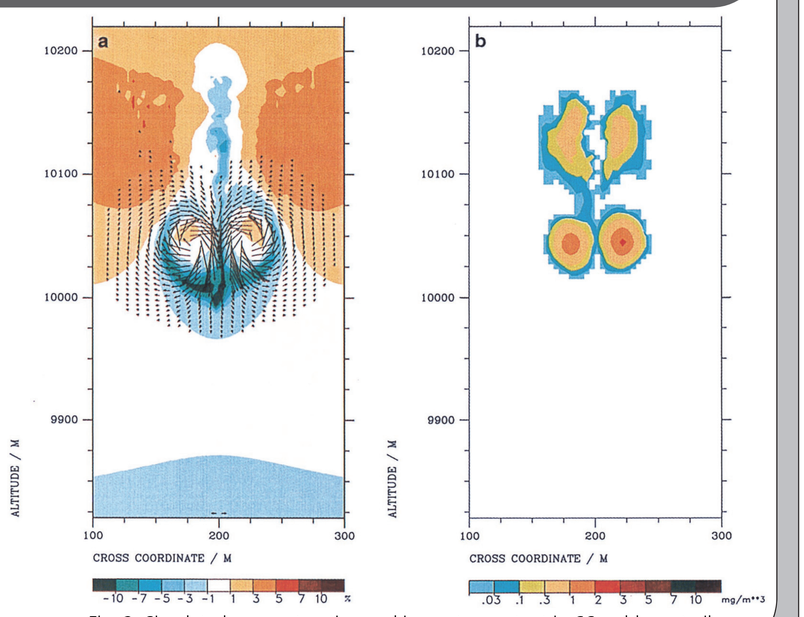

Fig. 2. Simulated supersaturation and ice water content in 66 s old contrail, Sussmann and Gierens, JGR 104, 1999

Method: The AIMS_H2O mass spectrometer

Linear Quadrupole Mass Spectrometry as a new method for high resolution airborne humidity measurements

Detection principle:

- Direct ionization of ambient air using high voltage discharge
- Detection of $H_3O^+(H_2O)_n$ ions (n=1 - 3) with a mass spectrometer
- in-flight calibration standard using the catalytic reaction of H_2 and O_2 on Pt surface (Rollins et al., 2011)

Characteristics:

- Time resolution: 4,2 Hz
- Spatial resolution ~50 m
- dynamic range:
  - 0 - 100 µmol/mol (uncertainty 8 - 12%)
  - 100 - 250 µmol/mol (uncertainty 10 - 15%)

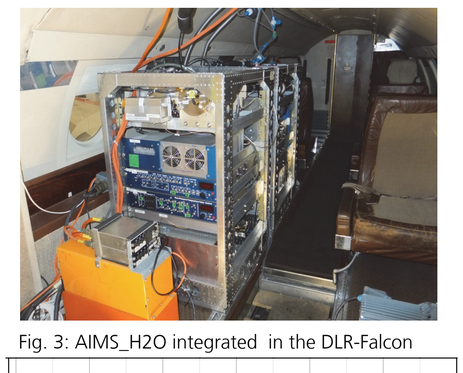

Fig. 3: AIMS_H2O integrated in the DLR-Falcon

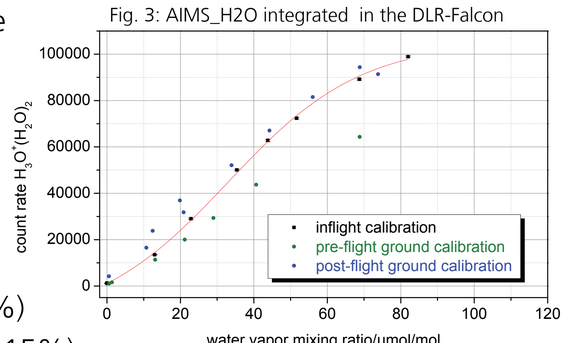

Fig. 4: AIMS_H2O calibration (ground & in-flight)

Campaign: Probing of young contrails during CONCERT2011

Figure 5: B777 contrail

During the Falcon campaign CONCERT2011 we sampled three young contrails with ages of 1 - 7 min with the research aircraft DLR-Falcon. The sampled contrails originated from an A321 and two different B777s.

Fig. 6 shows water vapor mixing ratio (a), RHi (b), particle concentrations and NO_y (c) on flight b on 16 Sept 2011. The Falcon sampled young contrails from a B777 (Fig. 5) and a A321 (yellow shaded).

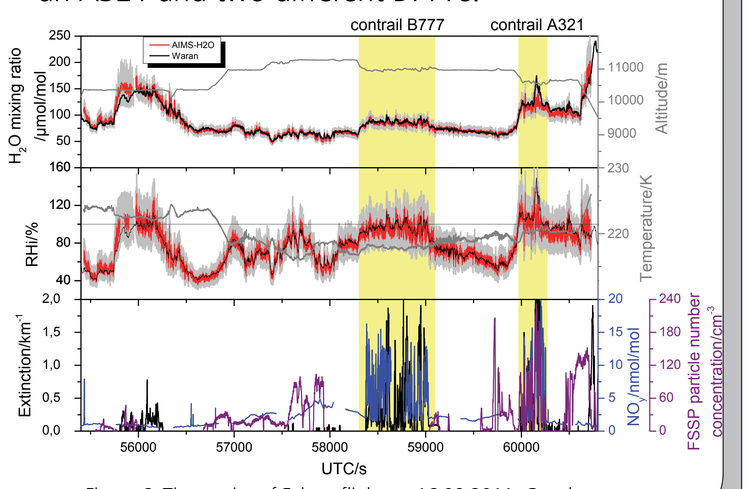

Figure 6: Time series of Falcon flight on 16.09.2011. Grey bars indicate maximum uncertainty for AIMS_H2O measurements.

Results: RHi distribution in young contrails

Classification of RHi in contrail sequence

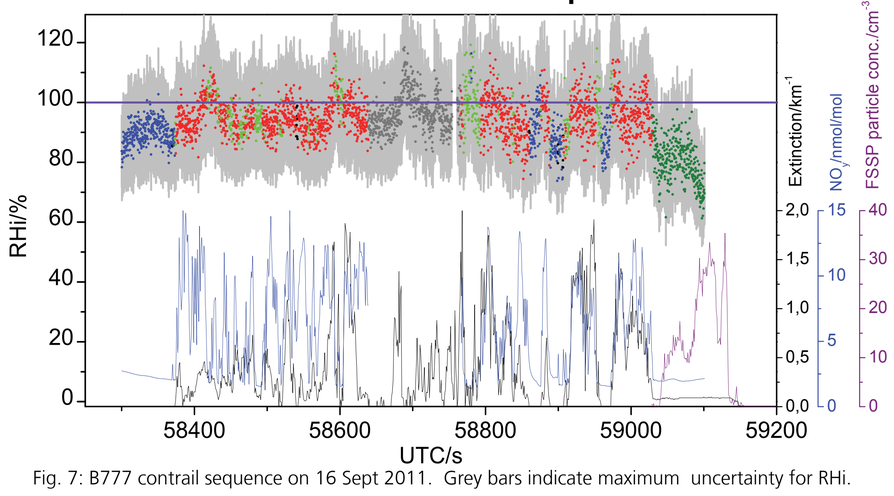

Fig. 7: B777 contrail sequence on 16 Sept 2011. Grey bars indicate maximum uncertainty for RHi.

Classification:

- clear sky: extinction = 0 (no particles) & NO_y < 3 ppb
- cirrus clouds: extinction > 0 & NO_y < 3ppb
- aircraft exhaust without contrail: extinction = 0 & NO_y > 3ppb
- contrail: extinction > 0 & NO_y > 3ppb

Observations:

- descent from clear sky into cirrus region
- alternating cirrus and contrail conditions at constant altitude
- sampling of biomass burning plume near 59050 s UT

RHi PDFs and profiles reveal two different meteorological situations:

- A321 contrail (Fig. 8 a):
  Falcon descents from supersaturated clear sky into cirrus region. Cirrus and clear sky show very similar RHi, while RHi within the contrail is reduced to slightly below 100%.
- B777 contrails (Fig. 8 b & c):
  Falcon descents from subsaturated clear sky conditions to lower altitudes with higher RHi. In both cases, RHi distributions within contrail and cirrus are almost identical, whereas clear sky regions exhibit lower RHi.

Despite different meteorological conditions, RHi distributions inside the different contrails are similar.

Sequence	clear sky		cirrus		exhaust		contrail	
	RHi/%	FWHM/%	RHi/%	FWHM/%	RHi/%	FWHM/%	RHi/%	FWHM/%
16.09.2011 a A321	105	26	106	24	--	--	98	18
16.09.2011 b B777	89	11	95	17	89	14	95	14
24.09.2011 a B777	90	14	95	12	89	15	97	12

Tab. 1: mean RHi and FWHM of RHi distribution in contrails

RHi distributions and profiles in 3 contrails

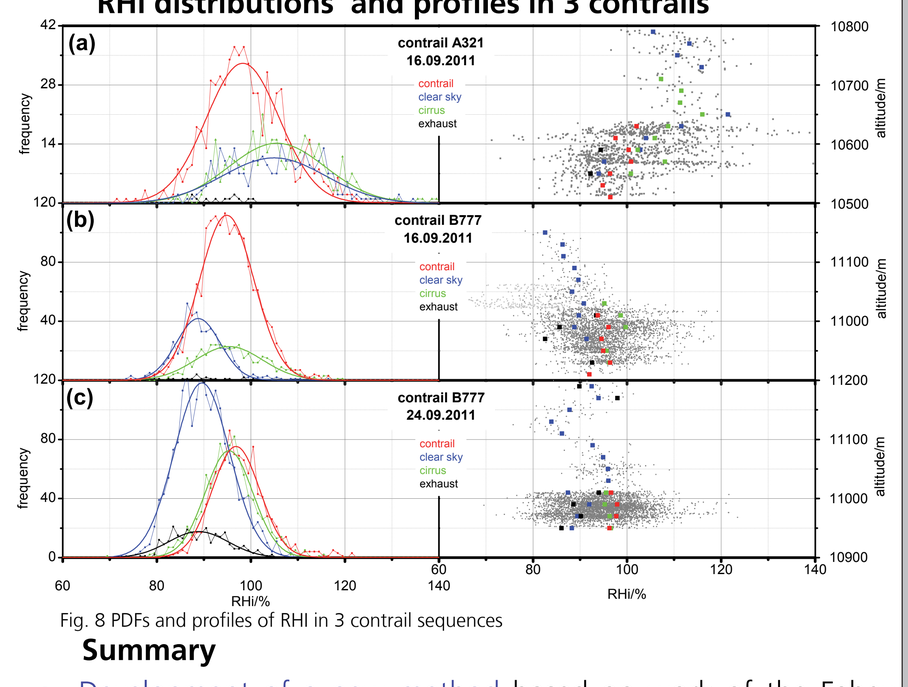

Fig. 8 PDFs and profiles of RHI in 3 contrail sequences

Summary

- Development of a new method based on work of the Fahey group (NOAA) for the accurate detection of H2O in the UTLS region using an in-flight calibration, a gas discharge ion source and a quadrupole mass spectrometer
- High resolution humidity measurements of RHi distributions in and near contrails.
- Unlike most previous observations, in-contrail RHi near 100 %
- Future high resolution observations of H2O required to provide a statistically relevant base for these findings.

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