WVSS-II Assessment at the DWD

Deutscher Wetterdienst / German Meteorological Service
Climate Chamber of the Meteorological Observatory
Lindenberg

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1 Background

Since 1999 the DWD within the network of European meteorological services takes part in E-AMDAR (EUMETNET Aircraft Meteorological Data Relay). Worldwide, the AMDAR aircraft, up to now successfully collecting meteorological data, such as pressure, temperature, and wind, will have to be additionally equipped with sensor units for the humidity. Besides of 25 aircraft initially used for that purpose in the USA, three aircraft of the E-AMDAR fleet had been selected to carry the airborne humidity sensor type WVSS-II of SpectraSensors Inc., USA. The operation experience of the last years led to several re-engineering steps for this system. Prototype units of the latest WVSS-II version were subject of climate chamber tests at the Sterling Field Support Center of the NOAA National Weather Service (see test report of May 2009).

The WMO AMDAR Panel and E-AMDAR recommended to do an independent additional test at the facilities of the DWD.

2 Introduction

In the time frame from May 18 to June 11, 2009 the WVSS-II has passed through the climate chamber test at the Meteorological Observatory of the DWD. The main part of the measurement procedures is done.

The specimen (see Fig. 1) having been tested is the following one:

Type:	WVSS-II (Version 3)
Part Number:	01023-10200
Serial Number:	0302, Rev F
Manufacturer:	SpectraSensors Inc., USA
Manufacturing Date:	April 2009

The complete system consists of

- the Air Sampler, the intake and outlet unit to be mounted on the aircraft skin,
- the System Electronics Box (SEB), consisting of the Laser, the sampling tube for the absorption path, and the corresponding electronics,
- the hoses for the connection between the Air Sampler and the SEB.

Only the SEB and the hoses have been installed in the climate chamber.

Fig. 1: The System Electronics Box (SEB) of the aircraft humidity sensor type WVSS-II, Version 3 (2009).

3 The climate chamber

3.1 Setup

The climate chamber of the DWD consists of a pressure and humidity controlled vessel inside a larger temperature controlled chamber.

The block diagram (see Fig. 2) gives an overview of the different components.

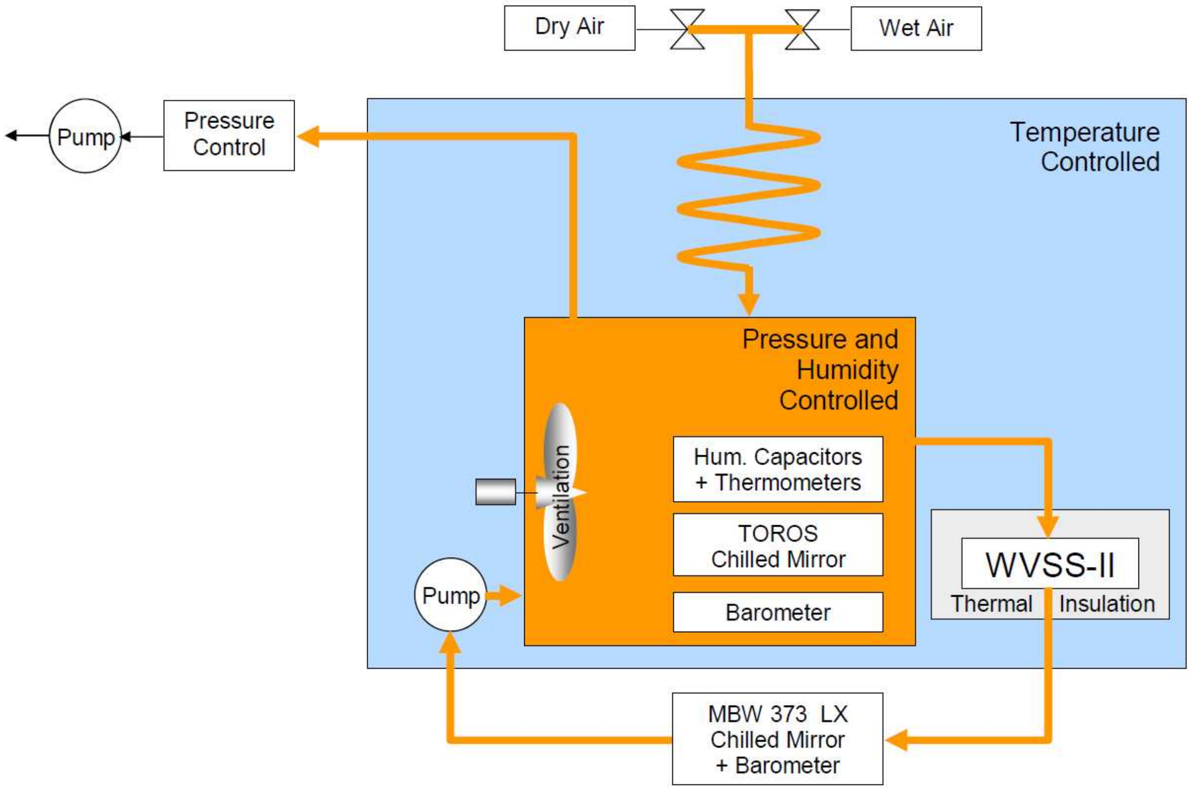

Fig. 2: Block diagram of the DWD climate chamber at the Meteorological Observatory Lindenberg, Germany.

The WVSS-II has been installed inside the temperature controlled chamber; however, the Sensor Electronics Box (SEB) was thermally insulated to keep the operation temperature within the range specified by the manufacturer SSI. This configuration is equivalent to the arrangement in a typical aircraft installation. The sampled air was pumped inside a closed loop containg the SEB, a MBW 373 chilled mirror hygrometer, and the inner vessel in which pressure and humidity are controlled. A supply of a well stabilized mixture of dry and wet air comes from outside and is cooled to internal temperature while passing through a long pipe coil. Pressure control is achieved by aligning inflow against outflow.

Fig. 3 shows the arrangement of components inside the temperature controlled chamber. The WVSS-II as well as the pump of the sampling air circuit are enclosed by insulation material.

Data output via serial interface (type ARINC 429) was read by an external computer.

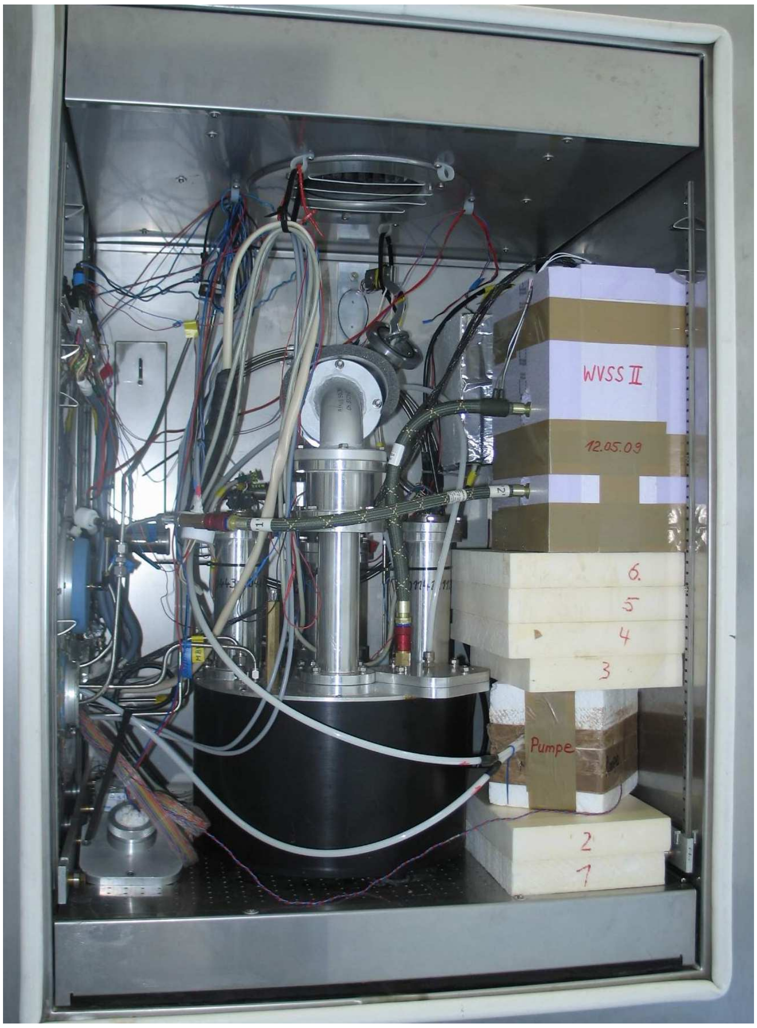

Fig. 3: View into the climate chamber's temperature controlled bin. The black vessel in the middle is the humidity and pressure controlled bin.
(DWD, Meteorological Observatory Lindenberg, Germany).

3.2 Performance

The climate chamber may cover the following atmospheric conditions:

- Pressure: surface pressure (> 1000) to 5 hPa
- Temperature: + 30 to - 90 °C
- Dewpoint: + 20 to -75 °C

A sophisticated dehumidifier in combination with dry nitrogen allows generating humidity levels as low as 0.003 g/kg at surface pressure. At low pressures, the lowest mixing ratios achievable are somewhat higher. Some re-engineering in the pressure controlled capsulation of the climate chamber is planned to improve the low pressure characteristics.

3.3 References

Two different chilled mirror hygrometers were used as reference instruments:

1) Manufacturer: MBW Calibration Ltd., Switzerland
Type: 373 LX
Range (dew/ frost point): - 95 to + 20 °C
Accuracy (manufacturer's spec.): 0.1 K for dew point and frost point
Location within test configuration: outside of the chamber but within the sample air circuit of pump, inner bin, and WVSS-II (see Fig. 2)

2) Manufacturer: Central Aerological Observatory, Russia
Type: TOROS
Range (dew/ frost point): - 75 to + 29 °C
Accuracy (manufacturer's spec.): 0.4 K for dew point, 0.8 K for frost point
Location within test configuration: inside of the pressure and humidity controlled vessel (see Fig. 2)

Not all of the assessment's calibration points could be tested simultaneously by both of the chilled mirrors. Occasionally the measurement cycle of one or the other hygrometer did not reach stable control. These readings could clearly be identified and were subsequently rejected. The calibration points, during which both reference instruments functioned properly , were used for a direct comparison of both. Fig. 4 shows the relative deviations between MBW and TOROS. The mean difference between both instruments ranges from 0 % at 10 g/kg to -10 % at 0.1 g/kg, with TOROS giving lower values than MBW. These differences correspond to a frost point difference of up to 1 K, which is still within the combined specifications for these instruments.

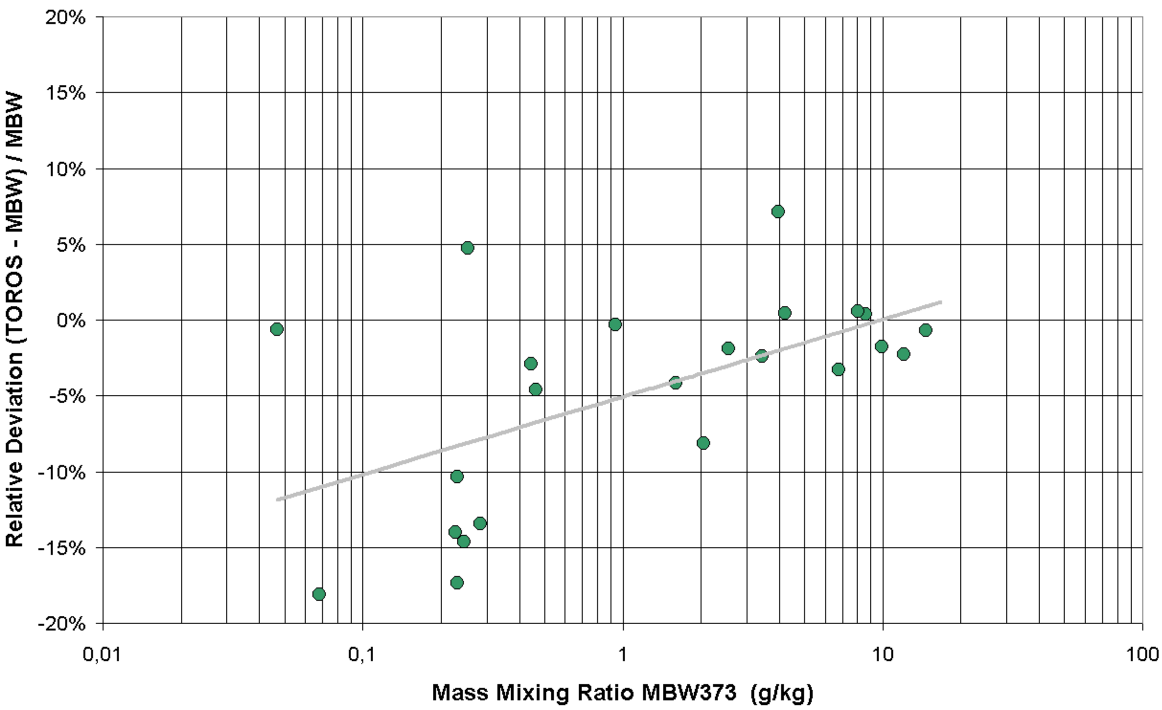

Fig. 4: Relative deviation between the reference sensors MBW 373 and TOROS.

4 Calibration test points

Most calibration test points were taken at surface pressure. Only those measurements were considered for which a stable plateau of at least 100 s could be maintained within the system and for which both reference sensors provided a stable dew point or frost point measurement. Under these requirements a total of 57 calibration tests was achieved.

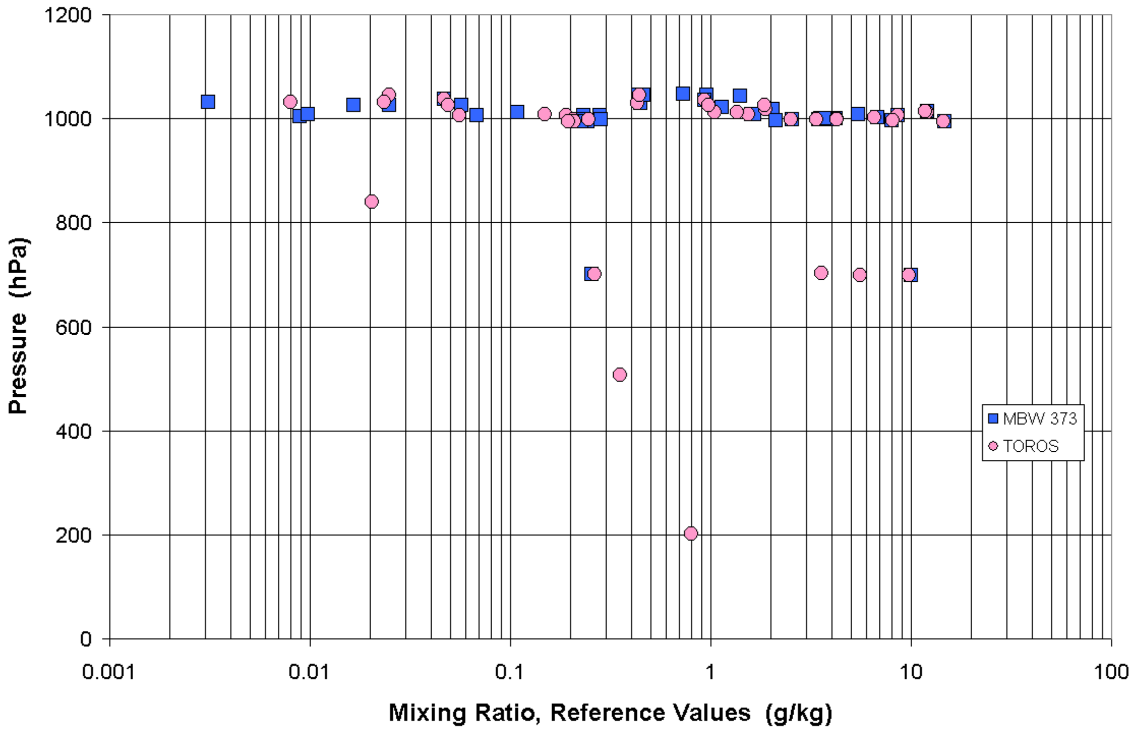

Fig. 5: Water vapour reference measurements as function of mixing ratio and pressure level. Data for the two different reference sensors MBW 373 and TOROS are shown separately.

5 Results of WVSS-II

5.1 Air temperature in the absorption path

The temperature of the sampling air ranged between - 54°C and + 23°C. The air is heated by the inlet hose and by powerful wall heating elements of the sampling tube to a temperature of up to + 37°C, before being pumped through the sensor electronics box of the WVSS-II. Even at intake temperatures of - 54°C the sampling air in the absorption path stayed around + 36°C (see Fig. 6). The flow rate through the sensor was about 1 l / min. During flight operation this flow rate is expected to be larger. The intake and outlet unit, the so called Air Sampler, once was designed to achieve at least one complete flush of the sampling tube within a second (> 1.5 l / min).

The ambient air temperature is not expected to have a significant influence on the measurement process and it is assumed that

- leftover inhomogeneities of the temperature field across the absorption path are sufficiently small,
- the temperature sensor is at a representative location.

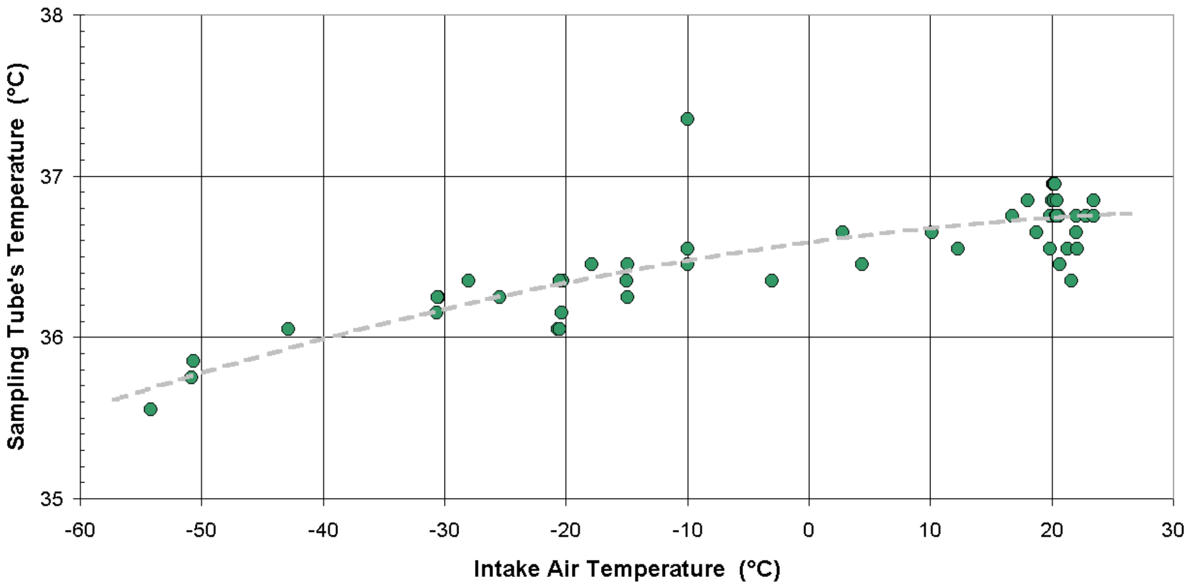

Fig. 6: The air temperature inside of the sampling tube versus the intake air temperature at a flow rate of 1 l/min.

5.2 Pressure Uncertainties

The comparison of the WVSS-II pressure sensor with the reference sensor of the climate chamber shows relative deviations between -7 % and +3 % (see Fig. 7). The calibration of the 2f absorption process is supposed to be insensitive to such systematic errors in the pressure reading. The deviation should at least stay constant over the period between the calibration dates.

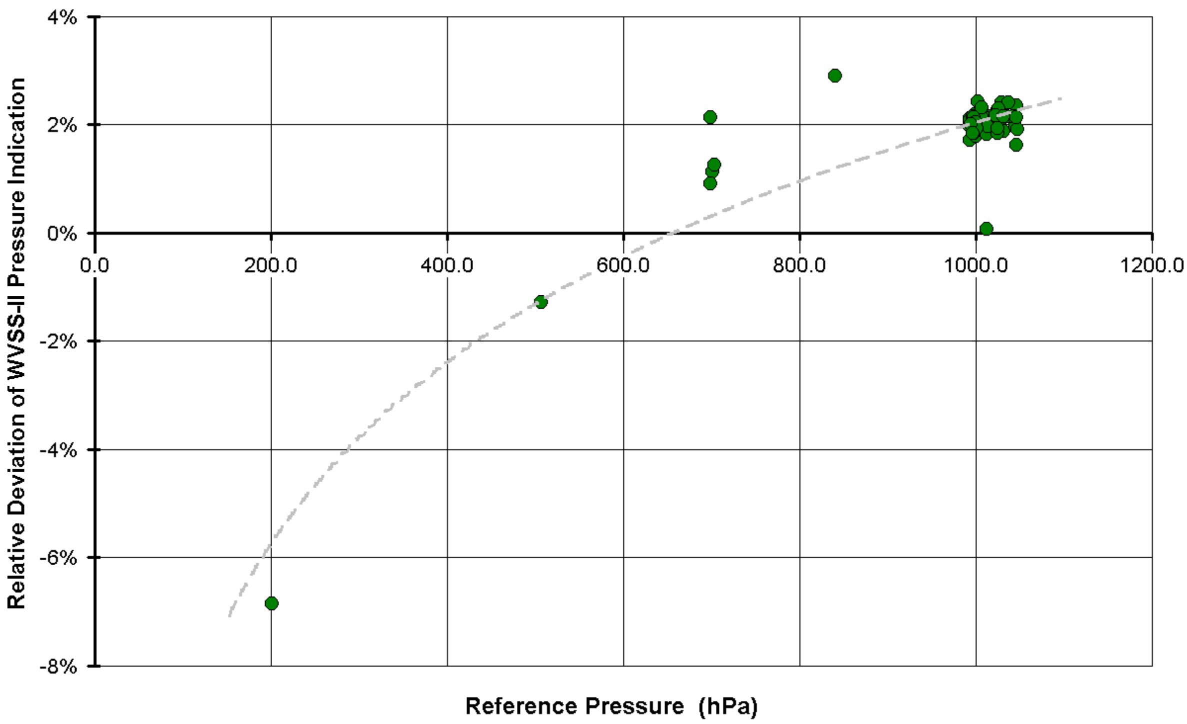

Fig. 7: The relative deviation of the WVSS-II's pressure readings against the climate chamber's measurements.

5.3 Characteristic of the WVSS-II's water vapour mixing ratio readings

For the complete range of the climate chamber's humidity values the WVSS-II correctly gives stable responses. Fig. 8 shows that the results are near by the ideal line. Even at an extremely low humidity value of 0.003 g/kg the WVSS-II reacts reasonably. Because of some actual limits for very low pressure operation of the chamber these values were obtained in the range of 800 to 1050 hPa. The most extreme set point in the NOAA test at 200 hPa and 24 ppmv has been emulated at 1032 hPa by 0.003 g/kg (5 ppmv) to get to the same vapour density as the intrinsic physical parameter for the absorption. The detection limit seems to be definitely lower than that of the predecessor version (having been at about 0.05 g/kg at ground pressure). With the humidity values actually being reproducible by the DWD climate chamber the lower sensitivity bound of the WVSS-II unit S/N 0302 could not be reached.

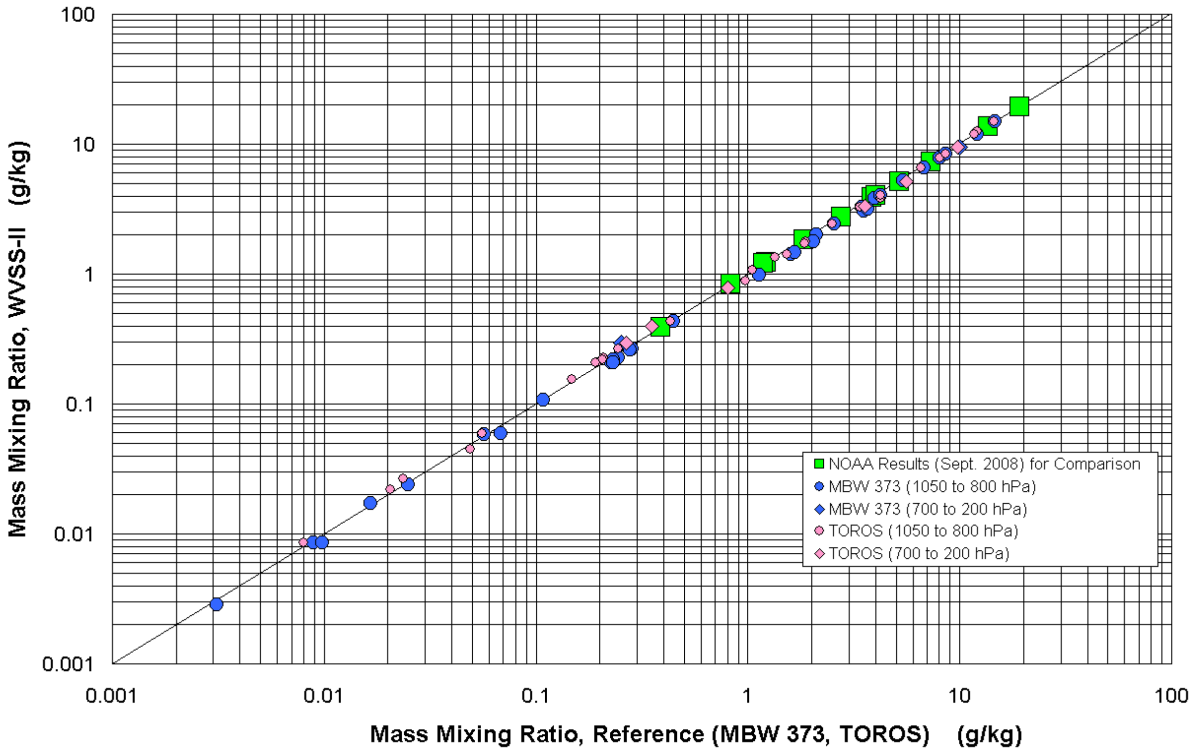

Fig. 8: The WVSS-II's mixing ratio readings plotted in a log-log diagram against the climate chamber's reference measurements. The differently marked data points distinguish

- the reference sources (MBW 373, TOROS)
- the air pressure ranges (1050 to 800 hPa, 700 to 200 hPa)
- the NOAA test results of September 2008.

The diagram (Fig. 9) with the relative deviations from the reference values shows

- in the range of 1 to 10 g/kg a small tendency to a dry bias of around 5 to 7 %,
- below 0.5 g/kg most of the readings keep within ± 10 %.

Considering the accuracies especially at the low humidity values we have to keep in mind the limits of the absolute references themselves: uncertainties between 0.1 and 0.8 K in the dew point or frost point could lead to deviations of up to 10 % at a mixing ratio level of 0.1 g/kg (see also Fig. 4).

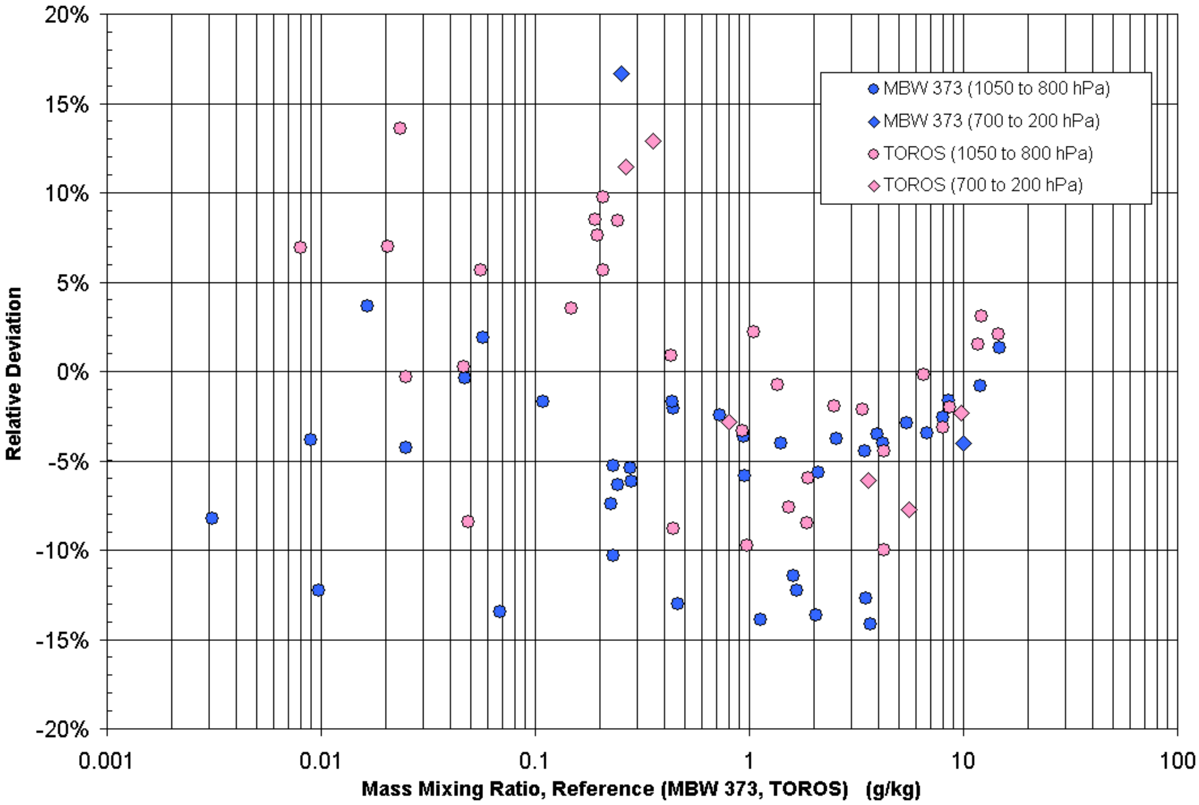

Fig. 9: The relative deviations of the WVSS-II values against the references.
The differently marked data points distinguish
- the reference sources (MBW 373, TOROS)
- the air pressure ranges (1050 to 800 hPa, 700 to 200 hPa).

6 Conclusions

The smallest mixing ratio value taken during the test was at m_0 = 0.0031 g/kg (5 ppmv) at an air pressure p_0 = 1032 hPa and a temperature of - 54.2 ℃. The co rresponding water vapour density ρ_{H2O} as the primary physical parameter for the absorption at the sampling tube's temperature T_{Tube} = 308.65 K (+ 35.5 ℃) then is

$$\rho_{H2O} = \frac{m_0\ p_0}{T_{Tube}\left(R_{dry} + m_0\ R_{H2O}\right)} = 3.6\ \frac{mg}{m^3}$$

with:	R_{dry}	= 287.0586 J / kg / K	(gas constant of dry air)
	R_{H2O}	= 461.525 J / kg / K	(gas constant of water vapour)

The WVSS-II detection limit now is proven to be equal to or lower than this value. If we conserve this vapour density and calculate back to a mixing ratio m_{UA} at the upper atmosphere level of p_{UA} = 200 hPa , assuming the same T_{Tube} value, we get:

$$m_{UA} \approx m_0\ \frac{p_0}{p_{UA}} = 0.016\ \frac{g}{kg} \quad (=\ 26\ ppmv)$$

This humidity indication or even a lower one should be verifiable with the WVSS-II at the flight level of 200 hPa as the DWD climate chamber did with 0.0031 g/kg at ground pressure. At this pressure and with the ISA-Stratosphere temperature of – 56.5 ℃ the tested WVSS-II unit can do the traceable measurement of a relative humidity of 30 % (here: referred to the saturation pressure over ice). Now, the sensitivity of the WVSS-II touches the upper Troposphere or lower Stratosphere.