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Field campaigns of the autonomous, closed-path, airborne TDLAS Hygrometer SEALDH-II and traceability to the German Primary Humidity Standards.

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Airborne hygrometry is often demanded in scientific flight campaigns to provide datasets for environmental modeling or to correct for water vapor dilution or cross sensitivity effects in other gas analytical techniques. Water vapor measurements, however, are quite challenging due to the large dynamic range in the atmosphere (between 2 and 40000 ppmv) and the high spatio-temporal variability. Airborne hygrometers therefore need to combine a large measurement range with high temporal resolution to resolve - at typical airspeeds of 500 to 900 km/h - atmospheric gradients of several 1000 ppmv/s. Especially during the ascent into the upper troposphere, hygrometers need to work at high gas exchange rates to minimize water vapor adsorption effects. On the other hand, water vapor sensors are difficult to calibrate due to the strong water adsorption and the lack of bottled reference gas standards, which requires pre- or/and post-flight field calibrations. Recently in-flight calibration using an airborne H_2O generator was demonstrated, which minimizes calibration drift but still imposes a lot of additional work and hardware to the experiments, since these kind of calibrations just transfer the accuracy level issues to the in-flight calibration-source. To make things worse, the low gas flow (1-5 std l/min, compared with up to 100 std l/min in flight for fast response instruments) adheres critical questions of wall absorption/desorption of the source and instrument even during the calibration process.

The national metrological institutes (NMIs) maintain a global metrological water vapor scale which is defined via national primary humidity generators. These provide for calibration purposes well-defined, accurate water vapor samples of excellent comparability and stability traced back to the SI-units. The humidity calibration chain is maintained via high accuracy (but rather slow) Dew-Point-Mirror-Hygrometers as transfer standards. These provide a traceable performance and calibration link to any industrial or research laboratory hygrometer. To establish metrological traceability in field and particular in airborne hygrometers is however challenging and requires fast, field-compatible, metrologically qualified transfer hygrometry standards to link the metrological and the environmental sciences water scales.

The SEALDH (Selective Extractive Airborne Laser Diode Hygrometer) development started 3 years ago and aims at filling this gap by using Tunable Diode Laser Absorption Spectroscopy (TDLAS) with a special, calibration-free data evaluation [1]. Previously developed, laboratory-based TDLAS instruments, such as [2] [3], were starting points to develop an autonomously operating, extractive water vapor sensor in a compact 19” 4 HU form factor. This new airborne package and far-reaching developments [4] in hard- and software allow an autonomous, low maintenance, airborne operation. SEALDH-II can be used in a calibration-free field sensor mode (with an absolute, metrologically defined uncertainty of 4.3% +- 3ppmv). The response time is mainly limited by the gas flow and significantly below 1 sec with a precision down to 0.08 ppmv (1σ, 1sec) measured at 600 ppmv and 1000 hPa. The excellent long-term stability of SEALDH-II ($<1\%$ over a time span of 18 months), makes it also well suited as a transfer standard. The metrologically validated range of the spectrometer spans about 5 to 30 000 ppmv.

In 2012/2013 the SEALDH-II instrument has been operated for over 50 hours on several airborne science missions: DENCHAR, AIRTOSS-I, and AIRTOSS-II. No failures occurred and all data were provided to the science community. In addition SEALDH-II participated in AquaVIT-II, an international water vapor instrument comparison and the follow-up campaign of AquaVIT-I [5]. Most important, SEALDH-II was validated in long-term studies over 18 months, directly at the National Primary Humidity Generators at PTB. These humidity standards represent the top of the German hygrometry calibration hierarchy, and are internationally validated [6] and embedded in the global metrological water scale. We will present the result of the first SEALDH-II flights in scientific campaigns and the outcome of the first-ever primary validation of an airborne, calibration-free TDLAS hygrometer. Furthermore we will discuss the benefits of the tracing back of field instruments to primary standards

also in order to promote a stronger linkage between meteorological and metrological gas scales.

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