HIAPER VCSEL hygrometer: laboratory and initial flight tests

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A new water vapor instrument is being developed for the NSF/NCAR High-performance Instrumented Airborne Platform for Environmental Research (HIAPER) Gulfstream-V aircraft. Water vapor plays critical roles in the climate, chemistry, and dynamics of the troposphere and stratosphere. Unfortunately, measurements of atmospheric water vapor are challenging due to its extreme heterogeneity, large dynamic range (six orders of magnitude in absolute concentration), and efficient adsorption to instrument surfaces. These challenges are exacerbated when flying on a platform such as HIAPER with its high speed, large vertical and horizontal sampling capabilities, and fairly small payload.

To help overcome the intrinsic challenges of water vapor measurements as well as those derived from sampling on HIAPER, a new hygrometer is being developed using a vertical cavity surface emitting laser (VCSEL) operating near a wavelength of 1854 nm. The large current tuning range of the VCSEL (5 nm) allows for both a weak (1853.37 nm) and strong (1854.03 nm) absorption line of water vapor to be probed with the same laser, allowing for a large dynamic range. The laser is kept inside the aircraft while light is passed to the open-path cell through a fiber optic. Thus, no purging of water vapor in the optical train is necessary. The 25-pass external, optical cell is compromised of two 1.9 cm diameter mirrors separated by 15 cm. Figure 1 shows a photograph of the instrument. The blue pylon extends 29 cm from the surface of the fuselage. Local temperature and pressure are also measured near the optical path. Specifications for the instrument are detailed in Table I.

Figure 1. Photograph of the Southwest Sciences' VCSEL hygrometer showing the electronics box (red), aperture plate (gold), and pylon (blue). Light is passed 25 times between mirrors at the front of the pylon. The electronics box resides inside the aircraft immediately below the pylon.

The small size of the optical cell coupled with the fiber optic allows for some unique studies to be conducted in the laboratory. Experiments are being conducted to examine the accuracy, precision, and drift of the sensor over a range of pressures and temperatures. For example, Figure 2 shows an Allan deviation plot for a constant flow of ~ 2 ppmv H_2O at ambient, laboratory conditions. Short-term precision at 1 Hz is ~ 4% of the signal. Longer-term drifts on timescales up to ~ 1.5 hours (one tenth the sampling time) do not influence the measurement. Longer experiments are planned.

Table I. HIAPER VCSEL specifications

Parameter:	**Specification:**
Dew / frost point range	+30°C to –92°C (1 ppmv at 70 hPa)
Detection limit (S/N=1, 1 Hz)	0.03 ppmv
Frequency	25 Hz
Accuracy (1 Hz)	5% over range noted above
Precision (1 Hz)	≤3% over range noted above
Power	15 W at 110 VAC
Mass	6 kg including pylon
Size	25 × 18 × 40 cm (L × W × H)
Operation	Unattended

The first flight tests of the HIAPER VCSEL hygrometer were conducted in April and May as part of the NSF Pacific Dust Experiment. Figure 3 shows the performance of the VCSEL hygrometer in marine stratocumulus clouds. Fine scale structures are observed that are impossible to see with the chilled mirror hygrometer. The VCSEL data is also reasonably well-correlated with the 1 Hz cloud particle measurements. Such data will be inherently useful to assess cloud microstructure, dynamics, and nucleation processes. Unfortunately, due to problems with the thermal control of the laser, the instrument generally did not report data in the upper troposphere.

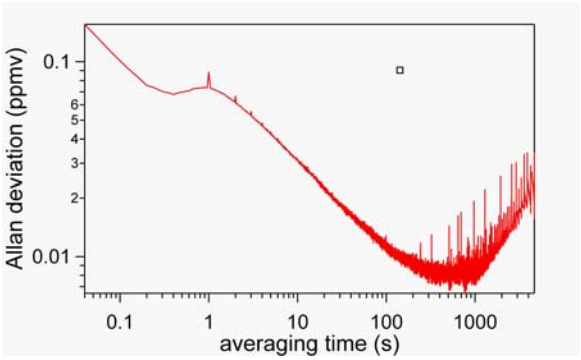

Figure 2. Allan deviation plot for ~ 2 ppmv H_2O at laboratory conditions (T=295 K, P=780 hPa). Precision for 1 Hz measurements is ~ 4% of the signal, and long-term drift on the timescales up to 1.5 hours doesn't degrade the measurement.

Additional flight tests were conducted in July 2007 as part of the HIAPER Experimental Flight Tests (HEFT-07) campaign. Four flights were made out of Broomfield, Colorado, over a two week period. A new thermal control mechanism for the laser allowed for robust testing of the instrument in the upper troposphere, though a problem with a fiber optic collimator prevented us from realizing the full 25 pass system (17 passes instead were used in HEFT-07). Nonetheless, the instrument performed very well at the cold conditions near the tropopause. For example, Figure 4 shows a one minute segment of data taken at 14.8 km (134 hPa) near frost points of –78ºC (~ 3.2 ppmv). The standard deviation of the HIAPER VCSEL water vapor data for the most constant segment around 00:17:45 UTC is ±0.07 ppmv (1σ) or about 2% precision. Clearly, some of the variation shown in Fig. 4 consist of real atmospheric changes in water vapor. We expect further improvements upon the signal-to-noise with more refined temperature and linelocking control of the laser and some additional sensitivity from achieving the 25 passes upon fixing the collimator alignment.

Now that the VCSEL hygrometer has shown proof-of-concept under a wide range of flight conditions, we are focusing more on calibrations of the instrument, particularly at levels less than 25 ppmv. Specifically, we are using standard dilution of flows where one flow is saturated in a water-ice bath and the other flow is dried through an acetone/dry ice bath. We are also examining the spectroscopy in greater detail to enable more accurate fits of the data and refining the laser temperature control and linelocking algorithms to improve precision. Absolute calibrations and intercomparisons with fifteen other research-grade water vapor sensors will also be conducted at the AIDA International Water Vapor Campaign in October 2007 in Karlsruhe, Germany. The final flight test opportunity for the VCSEL hygrometer will be in February 2008.

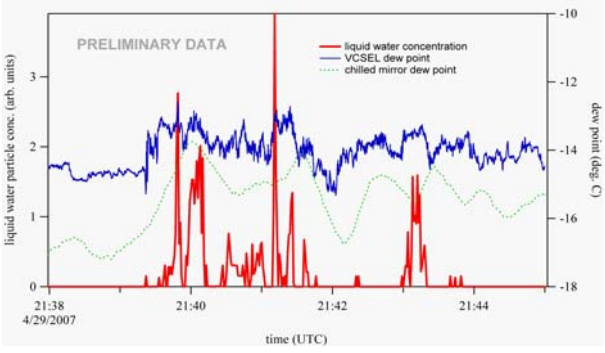

Figure 3. Preliminary data on HIAPER showing the VCSEL hygrometer dew point (thin solid line), chilled mirror hygrometer dew point (dotted line), and a proxy for cloud particles (thick, solid line).

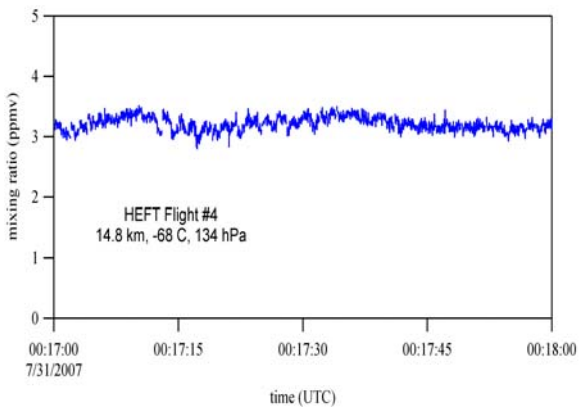

Figure 4. Data taken near the tropopause at 14.8 km at a frost point near –78°C during the HEFT campaign.