Instrument: Vertical Cavity Surface Emitting Laser (VCSEL) hygrometer

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Description:
The VCSEL hygrometer is an open-path, laser-based hygrometer that measures absolute concentration of water vapor (molecules per cm^{-3}) at a rate of 25 Hz. The instrument is designed for operation throughout the troposphere and lower stratosphere. Two water vapor absorption lines are used: a "weak" line at 1853.37 nm for lower tropospheric mixing ratios and a "strong" line at 1854.03 nm for middle and upper tropospheric concentrations. VCSELs have a wide current tuning capability and can probe each line by changing the laser injection current with only slight adjustments to the laser temperature. Switching between the absorption lines generally occurs near a fractional absorption of 10^{-3}, though a hysteresis is built in to prevent rapid switching near this transition (generally a factor of four in each direction). The thresholds for line switching changes slightly with temperature and pressure, but it generally is in the -15 to -25 C frost point range.

Optomechanically, infrared light is end-coupled to a single mode fiber inside the red electronics box which sits inside the cabin below an aperture plate. The instrument will fly one of the most forward, bottom aperture plates for DC3/SEAC4RS. The 29 cm high blue pylon resides above the fuselage skin. The pylon contains two, 1.9 cm diameter dielectric-coated mirrors separated by 14.95 cm where light is passed 25 times between them for a total pathlength of 3.74 m. The VCSEL resides inside the electronics box and stays near cabin temperatures. VCSEL light is coupled into a single mode fiber within 20 microns of the laser facet and thereby prevents residual water vapor inside the cabin from creating an artifact in the measurement. A hermetic, fiberized feedthrough brings the laser light to into the closest mirror where a gradient index lens collimates the light. An extended wavelenght InGaAs detector resides behind the most outboard

mirror mirror which has a lens that collects light from a 7 degree angle and focuses it onto the detector. A bandpass filter removes extraneous light outside a 50 nm window centered at 1850 nm.

Second harmonic detection is used for most of the measurement range except for a range in the middle troposphere where direct absorption is used (when the 2f signal from the 1854.03 nm peak becomes non-linear). Switching between direct and 2f mode for the strong peak takes ~ 1-2 seconds. Switching between the strong line and weak mode takes 4 seconds when working optimally.

Local pressure and temperature are measured on the sensor, though aircraft static temperatures are used as a primary due to adiabatic compression on the VCSEL temperature probe. Flow modeling studies suggest the temperature of the VCSEL sampling region is about 1 K higher than ambient. The VCSEL pressure is the primary pressure sensor and generally agrees well with the aircraft static pressure data except at the highest aircraft speeds where it reads up to 6% higher. Flow modeling calculations suggest this is a real effect, and therefore all concentrations are converted to mixing ratios using the VCSEL pressure.

Data is synchronized by the aircraft GPS pulse-per-second trigger, and an internal clock parses the data into 25 Hz segments.

Performance metrics:

Accuracy: ± 6% mixing ratio + 0.3 ppmv
Precision: ≤3% (1 Hz)
Sampling rate: 25 Hz

Prior field use: START08/PreHIPPO, HIPPO, PREDICT

Standard data products (1 Hz):

Absolute H2O concentration, molec cm-3
mixing ratio (ppmv)
dew/frost point (ºC)
accuracy flag (%)
(25 Hz data available upon request)

Data will be averaged from -x.49 to +x.5 s and reported on the nearest full second (i.e. x.00 s). The dew point will be reported for when the dewpoint is > 0ºC while frost points will be reported for any frost points below 0ªC, for simplicity. The formulation to be used will be D.M. Murphy and T. Koop (2005), *Q.J.R. Meteorol. Soc. 131*, 1539–1565.

Physical specifications:

Designed for forward-most aperture plates on top of NSF G-V
10 W power
5 kg
automated operation

Instrument reference:

M.A. Zondlo, M.E. Paige, S.M. Massick, and J.A. Silver (2010), “Development, flight performance, and calibrations of the NSF Gulfstream-V vertical cavity surface emitting laser (VCSEL) hygrometer”, *J. Geophys. Res,-Atmospheres*, *115*, D20309, doi:10.1029/2010JD014445.