Ice Supersaturation in the Upper Troposphere and Lower Stratosphere using the NSF G-V VCSEL hygrometer

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Introduction

Water vapor detection in the upper troposphere and lower stratosphere (UT/LS) impacts weather and climate prediction and our understanding of atmospheric dynamics. Our instrument is a vertical cavity surface emitting laser (VCSEL) hygrometer mounted onboard the NSF Gulfstream V research aircraft during the START08 field campaign. The VCSEL hygrometer measures water vapor concentration *in situ* using an open path cell. The instrument operates at the wide range of temperatures, pressures and humidities seen in the UT/LS. It also has a finer resolution than chilled mirror hygrometers and does not suffer from hysteresis problems found in enclosed tunable diode laser instruments, both of which are also onboard the aircraft and are common in water vapor detection. We are analyzing our data to investigate the extent and degree of ice supersaturated regions in the UT/LS in the context of other species measured onboard the aircraft. The conditions required to achieve relative humidities with respect to ice greater than 100% are poorly understood. However, this appears to occur more frequently than expected. This influences cloud formation and, consequently, the greenhouse effect caused by water vapor.

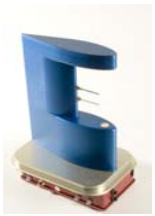
The VCSEL Hygrometer

• Vertical cavity surface emitting laser measures water concentration directly in the atmosphere outside of the NSF Gulfstream V aircraft at a rate of 25 Hz.

• Makes spectroscopic measurements using a modified form of Beer's Law (wavelength modulation spectroscopy, 2f).[1] The absorbance in the optical path is proportional to the water vapor concentration.

• The VCSEL operates at 1854 nm using 3 modes of operation to probe two H_2O absorption lines: 2f weak (1853.37 nm), strong direct, and strong 2f (1854.03 nm).

• Beam passes 25 times within an optical open-path cell with a pathlength of about 3.75 m.

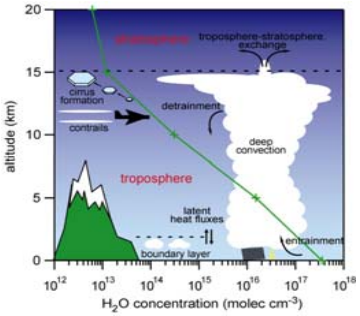


The START08 Field Campaign

The Stratosphere-Troposphere Analyses of Regional Transport 2008 (START08) campaign was based at the National Center for Atmospheric Research (NCAR) in Boulder, CO. It studied the chemical and dynamic characteristics of the extratropical upper troposphere and lower stratosphere (UT/LS) in order to gain a better understanding for weather prediction and climate change models.

The National Science Foundation's Gulfstream V aircraft served as a platform for the campaign. There were 18 flights in two deployments from April 21-May 16, and June 16-28, 2008. A typical flight was 7-8 hours. Flights ranged between about 25° to 63° latitude over the North American continent.

The VCSEL hygrometer's measurements will be used to observe unusual levels of water vapor concentration relative to ice in the UT/LS. It does not appear to be uncommon to find regions of cloudy or clear air with relative humidities greater than 100%. The VCSEL data was used to find these supersaturated regions, and by comparing with the platform's other instruments they can be used to determine the conditions that lead to ice supersaturation.[2-4]



The NSF G-V platform was chosen for its high altitude range, covering the troposphere into the tropopause and the lower stratosphere.The VCSEL instrument can detect the wide range of concentrations found in the humid troposphere and the dry stratospheric air.

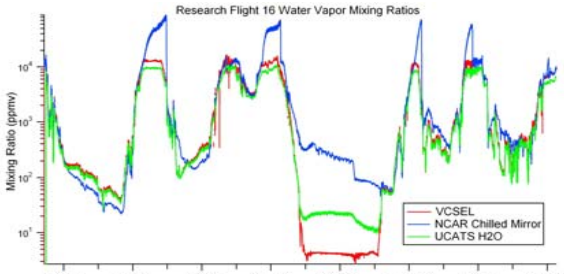
Comparison with other START08 Instruments

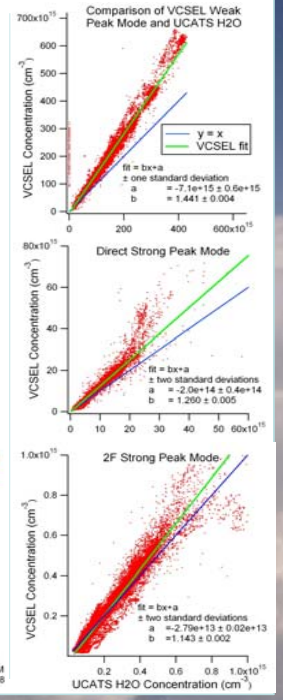
Two other instruments measured water vapor (all data preliminary):
• NOAA UCATS : A closed path tunable diode laser (1370 nm) (Elkins)
- Samples air through an inlet into the aircraft
- Measures content as a mixing ratio (ppmv)
• NCAR Chilled Mirror – Responsive , temperature based
- Cools to maintain constant ice layer on mirror
- Examines light reflected from ice to derive dew/frost point

First we examined our data with those of the other instruments. VCSEL agrees with UCATS for high concentrations. UCATS likely has outgassing problems, with a slow response to low concentrations. Chilled mirror has a "runaway" reaction to high concentrations and loses reliability at low concentrations (dew point less than -60 °C).

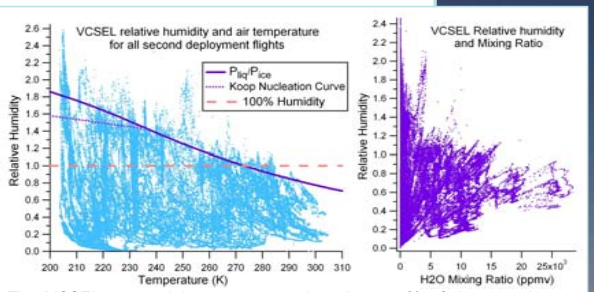
An example flight shows each instrument's characteristic features. UCATS has an outgassing issue at low concentrations. Chilled Mirror disagrees at both extremes.▼

All 3 VCSEL modes read ► higher than UCATS except at low mixing ratios due to UCATS outgassing problems.

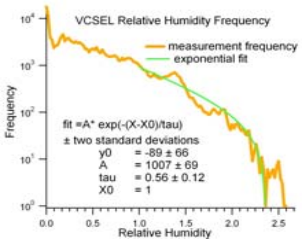




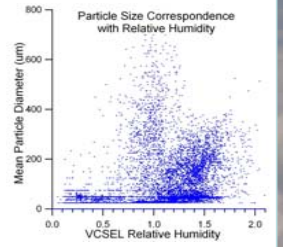
Results from all Second Deployment Flights



The VCSEL reported ice supersaturation about 11% of the experiment. Humidities above the Koop homogeneous ice nucleation curve [3] (dotted line, above) do not agree with conventional ice microphysics but are consistent with recent observations.[2] Those above the P_{liq}/P_{ice} line are probably an artifact of imperfect calibration, which is relatively greater at lower mixing ratios (at lower temperatures). Most of the unlikely measurements were made when the mixing ratio was very low.



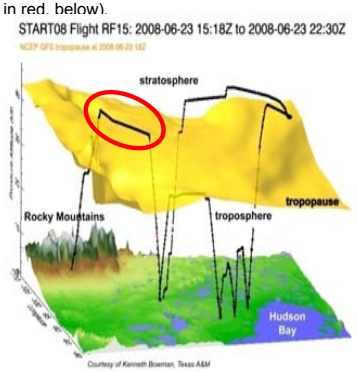
Typically, we should expect an exponential decay of frequencies of RH > 100%.

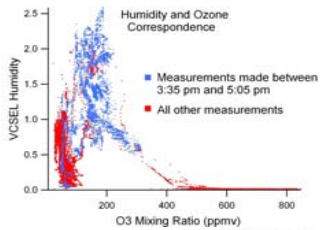


Larger particles were clustered at 100% and 140% humidity.

Case Study – Research Flight 15

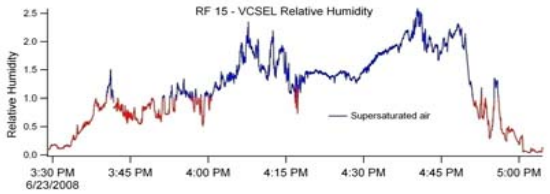
A period of supersaturation lasted over an hour while the G-V flew along the tropopause (circled in red, below).





Humidity peaked at mid-range levels of ozone, a stratospheric tracer.

Supersaturation occurred at the tropopause, where tropospheric and stratospheric air mixed.



Conclusions

The VCSEL showed good agreement with established sensors, but did not have the hysteresis or outgassing problems common among them.

Ice supersaturation observed 11% of the time in the extratropics, consistent with satellite observations. [4,5]

Supersaturations beyond the ice nucleation threshold were observed and require further study.

It appears that supersaturated air is primarily found around the tropopause. It is probably created when moist tropospheric air rises to this level and cools. These regions may tend to form larger ice particles.

Supersaturated regions can extend for hundreds of kilometers in the horizontal.

Additional calibrations are needed for very low mixing ratios .

References

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