Flight Demonstration of a Laser Hygrometer Payload for the ScanEagle UAS

D. Sonnenfroh/Physical Sciences Inc.
S-J. Chen/Physical Sciences Inc.
Mark Zondlo/Princeton University

Paper A021-07, Unmanned Systems in Atmospheric Research I
American Geophysical Union Fall Meeting (Virtual)
7 December, 2020

Acknowledgement: This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of DOE Chicago Ops, under Award Number(s) DE-SC0015104.

Background and Motivation

- Detailed cloud macro and microphysical properties remain a challenging measurement goal.
- Enhanced knowledge of these properties is needed to increase understanding of various cloud processes, including entrainment and droplet growth, that are important in both weather forecasting and climate change.
- Water vapor gradients affects droplet growth rates and, together with temperature, are needed for determination of supersaturation values.
- ***High sensitivity, high accuracy measurements of water vapor and temperature are needed at high spatial resolution, and therefore at high measurement rate.***

(left) ArcticShark - multipayload capable UAS (right) ScanEagle UAS - used on North Slope - Good endurance 1.2M flight hours

Background and Motivation

- Increased temporal and spatial data inputs have been shown to increase the near-term precision of forecasts.
  - ISARRA Flight Week in Boulder, CO in Summer 2018
- Currently Aircraft Meteorological Data Relay (AMDAR) program includes pressure and temperature measurements from commercial aircraft to the weather input data stream.
- Water vapor measurements were added to the AMDAR program in 2005 by including the Water Vapor Sensor System (WVSS-II), a TDL-based sensor.
- UAS's could be added to assets collecting meteorological data for ingestion into numerical weather prediction models once they are integrated into the National Airspace.
- A UAS-grade laser hygrometer payload will be needed for such an extension using UASs such as ScanEagle or ArcticShark.

Laser Hygrometer Payload

Physical Sciences Inc.

VG-2020-161-3

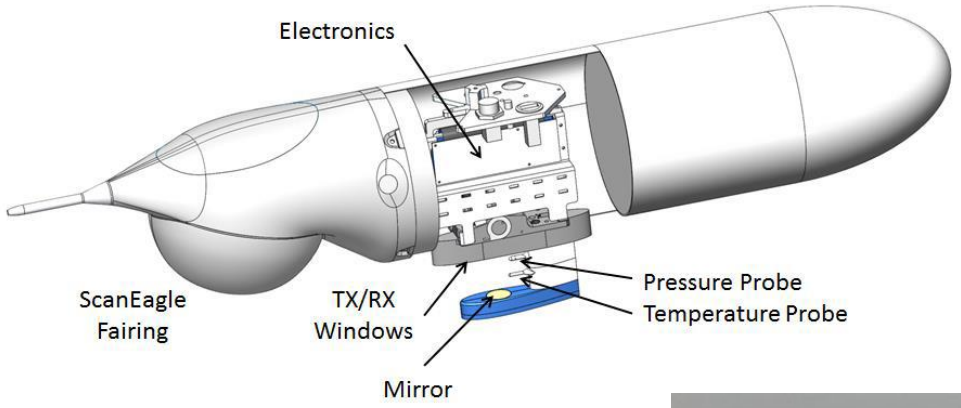
Key characteristics:

- Wavelength: 2.7 μm DFB Tunable Diode Laser (TDL)
- Pathlength: 10 cm
- InAs detector (2 mm diameter)
- Precision: 2 ppmv at 240 K
- Accuracy: 2 ppmv at 240 K
- Reporting Rate: 1 Hz
- Detection Technology: Wavelength Modulation Spectroscopy (WMS) and direct absorption
  - Recovers full waveform
- Custom electronics: system control & data processing
  - Data stored onboard, No telemetry
  - Experimental spectra are fit to Reference spectra
- ***Precision exceeds goals for both direct absorption & WMS under conditions expected in Arctic.***

Aux Sensors

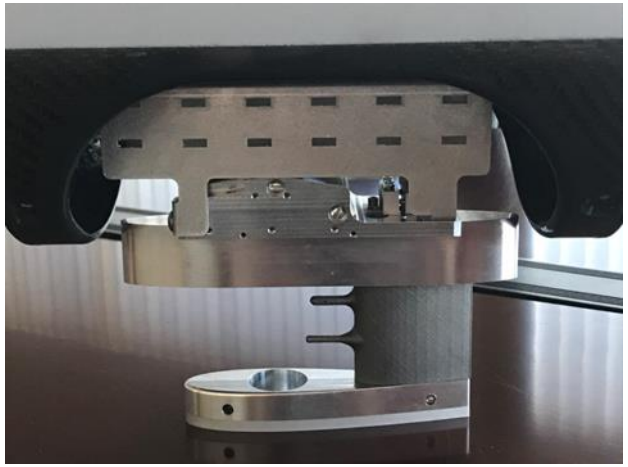
Supplier	Sensor	Accuracy	Precision	Response Time
Pressure Sensors [hPa]				
All Sensors	BARO-A-PRIME-MINI	linearity to 0.25% of full scale		
TE Connectivity	MS5803-01BA HI MS5611-01BA03	1.5	0.012	10 ms
Temperature Sensors [C]				
Heraeus	M222	2	--	3 s
Opsens	OEM-MNT-G1-10-100ST-S OTG-F-10-62ST-0.3PVC	<0.2	0.01	≤10 ms†

† Response 3-5 Hz in deployment



Size, Weight, & Power Budget

Component	Laser Hygrometer Payload	ScanEagle MidBay	ArcticShark WingPod
Size [cm^3]	980 cm^3 (5 in x 6 in x 2 in)	5675 cm^3 (7 in diam x 9 in length)	TBD
Weight [kg]	0.82	3.4	13.6-15.9 (30-35 lbs)
Power [W]	39	60	250 (28 VDC, 10 A)

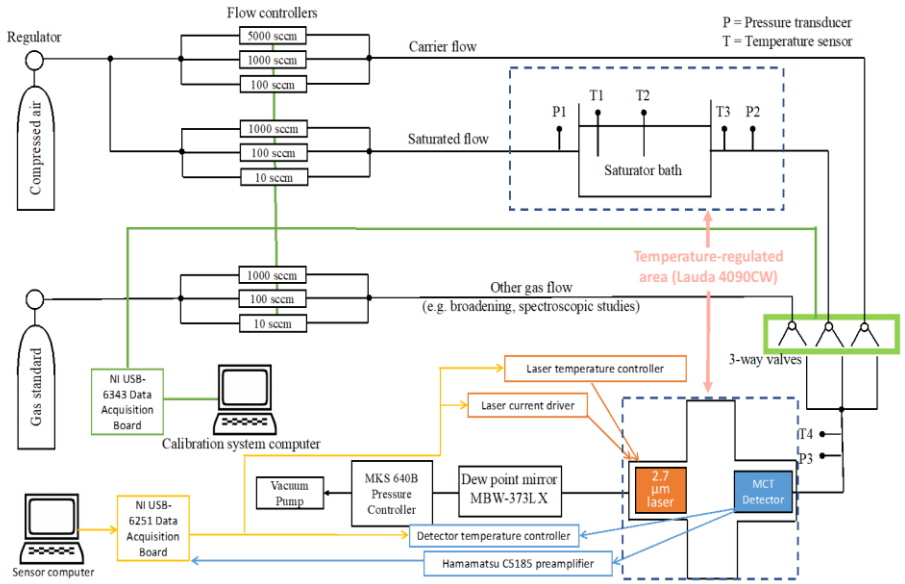


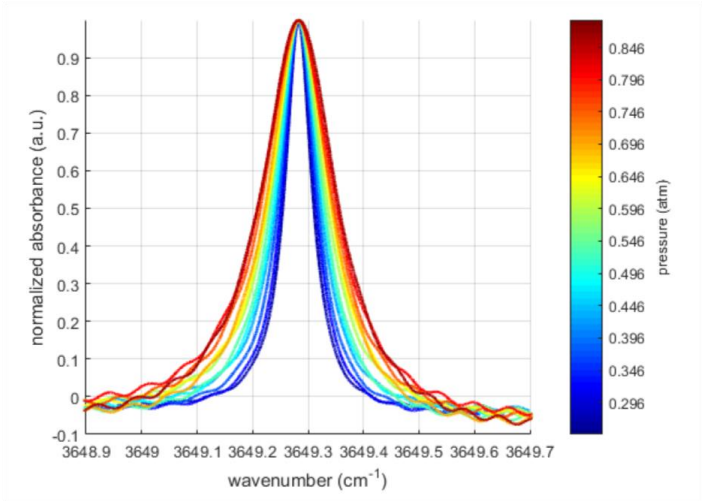
Princeton Calibration Facility

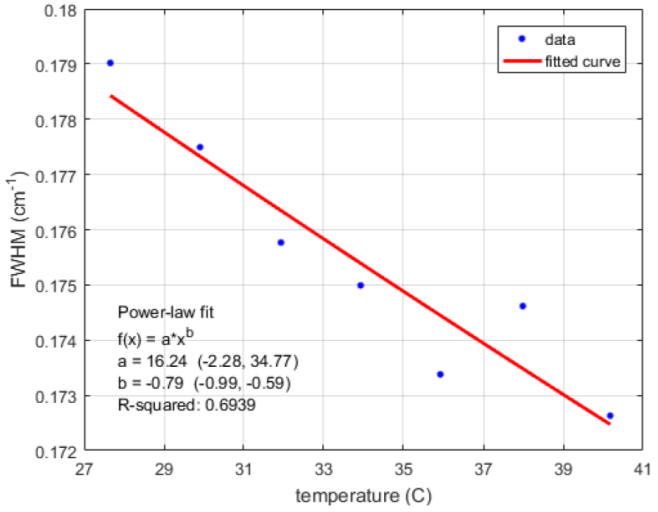
Physical Sciences Inc.

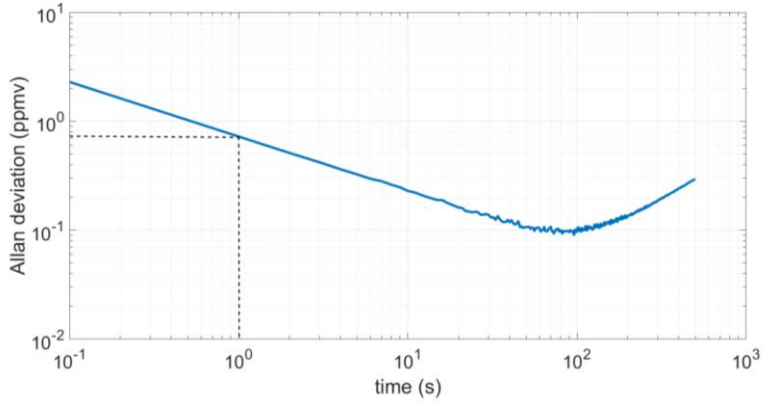
VG-2020-161-4

- Provides calibrations at humidities, temperatures and pressures of lower and middle Arctic and mid-latitude troposphere.
- Based on temperature-controlled ice/water bath. Wet flow diluted with dry flow to create final water vapor concentration
- Pressure controller enables simulation of atmospheric flight conditions.
- Chilled mirror hygrometer for comparison.









Allan deviation plot from a constant flow of 371 ppmv H_2O. At one second integration times, the precision of the sensor is 0.7 ppmv H_2O.

Flight Demonstration on ScanEagle UAS
University of North Dakota

Physical Sciences Inc.

VG-2020-161-5

- UND is a partner in Northern Plains UAS Test Site, 1 of 6 FAA UAS sites
- UND has 5 ScanEagles.
- UND accesses test airspace via COAs
- NP Airspace can provide altitudes of 3-10 kft agl
- Payload demonstrated 22-27 April 2019.
- ***Recorded 6 continuous flight hours of 1 Hz data during a variety of maneuvers.***

(left) ScanEagle launched
(below) ScanEagle recovered with Skyhook

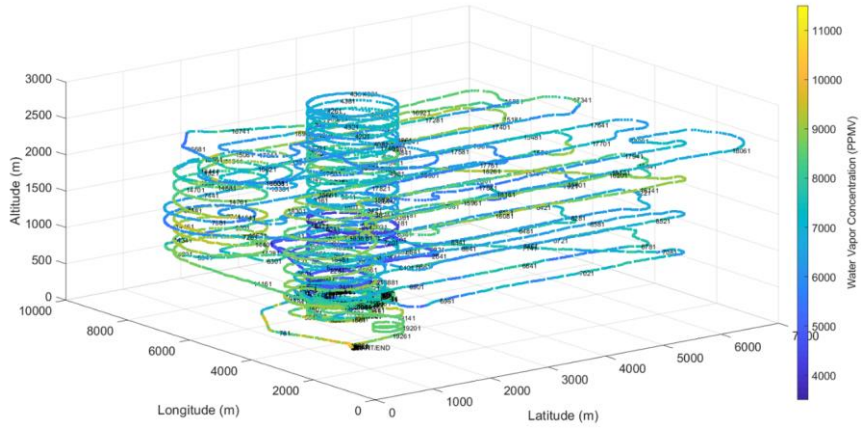
(above) Mayville Airport and 7x6 km flight area

(right) UND ScanEagle ground crew

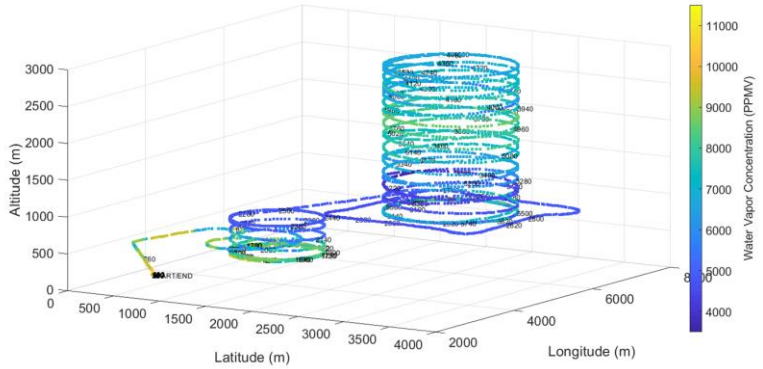
Flight Demonstration on ScanEagle UAS
Example Flight Data

Physical Sciences Inc.

VG-2020-161-6

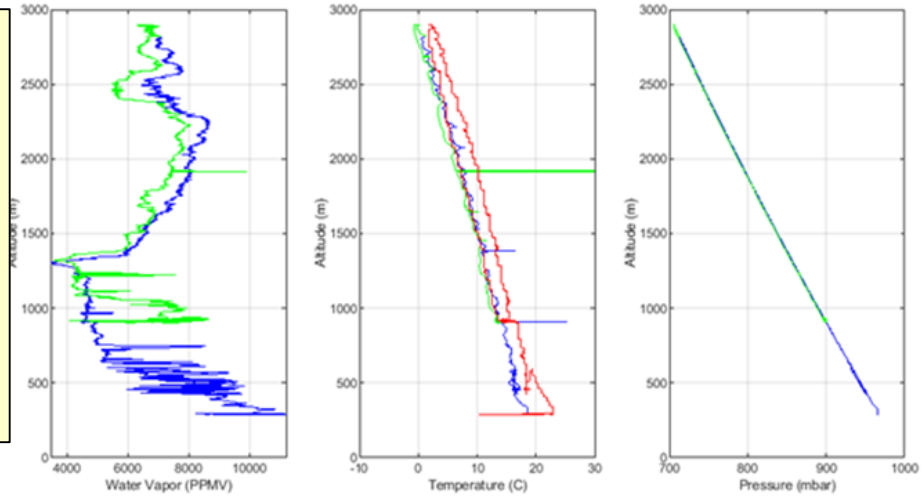


April 24, 2019. Water vapor mixing ratio (ppmv) along ScanEagle flight path (5.5 hours flight time).

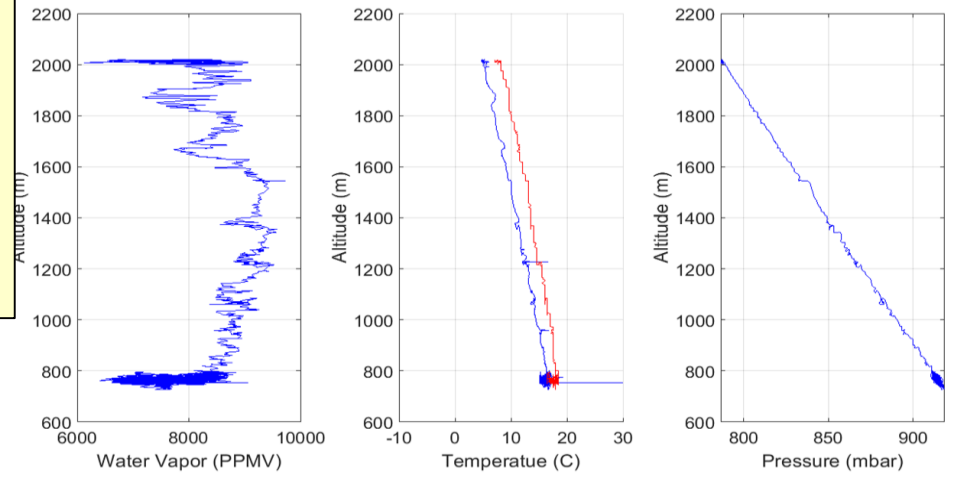


Section of data from Top Figure showing morning vertical spirals. Ascending and descending maneuvers overlapped.

Vertical profiles of water vapor, temperature, and pressure from morning spiral. Data from both ascending (blue) and descending profiles (green) are shown. Red line in temperature plot is data from aircraft temperature sensor.



Vertical profiles of water vapor, temperature, and pressure from the afternoon vertical spiral.



Acknowledgements

SPONSORSHIP

- **Ricky Petty**
  - SC 23.1
  - ARM Aerial Facility (AAF)
  - U.S. Department of Energy
  - Contract number DE-SC0015104

CONTACT INFORMATION

- **Dave Sonnenfroh**
  - Atmospheric Sciences Area Manager
  - Principal Research Scientist
  - Physical Sciences Inc.
  - 978-738-8235
  - sonnenfroh@psicorp.com

- **Mark Zondlo**
  - Associate Professor of Civil and Environmental Engineering
  - Princeton University
  - 609-258-5037
  - mzondlo@princeton.edu