Title: CopterSonde WxUAS Profile Data
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1.0 Dataset Overview

These files contain post processed meteorological and flight data collected by the CopterSonde uncrewed aerial system (UAS) during the M2HATS field campaign. The CopterSondes flew at one locations during the campaign with a maximum altitude of 900 m (3000 ft) above ground level. Flights were conducted approximately every 30 minutes throughout the day.

1.1 Dates: 2023-08-13 to 2023-08-29

1.2 Location: Tonopah, Nevada (38.042, -117.085)

1.3 Estimated data availability

The following tables summarize the number of flights and the approximate altitudes reached at each site during each day where the CopterSonde team deployed. A full list of flight times is provided in the Appendix

Date	# Flights	Max Alt AGL (m)
8/13/23	14	923
8/14/23	16	915
8/15/23	17	905
8/16/23	16	920
8/17/23	17	902
8/18/23	2	988
8/19/23	15	911
8/20/23	2	902
8/22/23	16	906
8/23/23	17	904

8/24/23	15	901
8/25/23	18	909
8/26/23	19	987
8/27/23	16	903
8/28/23	18	905
8/29/23	11	903

2.0 Instrument Description

The original CopterSonde uncrewed aerial system (UAS) was designed to sample the thermo-dynamic and kinematic state of the lower Earth's atmosphere, with a focus on vertical profiles in the planetary boundary layer. It provides the same information as a rawinsonde, but with much more control of its sampling location.

Development began in 2016, for the NOAA-funded EPIC (Environmental Profiling and Initiation of Convection) field campaign, and development has largely continued through support from the National Science Foundation and the University of Oklahoma. The initial design has undergone considerable modification, and the Copter- Sonde UAS is now capable of adaptative atmospheric sampling, real-time data processing and dissemination, longer flight times, and better data quality.

The goal in developing the CopterSonde UAS has been to provide a sensor platform for lower atmospheric sampling that is easy to deploy, delivers reliable data, and facilitates adaptive sampling.

Below is a table of specifications for the current CopterSonde. More detailed information is available in the references at the end of this document

AIRFRAME

Body	Carbon fiber tube (arms), G10 fiberglass (internal structure), and aluminum (connectors and spacers)
Shell	3D printed PLA
Diagonal	50.8 cm
Height	15.2 cm
Fight Controller	Pixhawk Cube

COMMUNICATIONS

Telemetry Frequency	915 MHz
Radio Frequency	2.4 GHz
Transmission Distance	up to 5 km

GPS ACCURACY

Horizontal (RTK enabled)	± 3 cm
Horizontal (RTK disabled)	± 1.5 m
Vertical (RTK enabled)	± 5 cm
Vertical (RTK disabled)	± 3 m

PROPULSION SYSTEM

Brushless Electric Motor

Lifespan	1600 hrs
kV Rating	700 RPM/V
Maximum Thrust	1.23 kg / rotor
Maximum Power	500 W/rotor

T-Style Propellers

Diameter x Pitch	11 x 5.5 in
Material	Carbon Fiber

ESC - Motor Speed Controller

Max. Cont. Current	35 A
Burst Current	45 A
Maximum Voltage	14.8 V (4S LiPo)

POWER

Battery Type	4S Smart LiPo
Capacity	5870 mAh
Typical Endurance	15 min

Meteorological Specifications

THERMODYNAMIC

Primary Variables	T, RH, p
Derived Variables	T_d, T_v, θ, θ_e, θ_ω, r, r_s, q, q_s, e, e_s, LCL, Γ
Accuracy	T: ± 0.1 °C RH: ± 2 % p: ± 1.5 mbar
Logging Rate	10 – 20 Hz

KINEMATIC

Primary Variables	Tilt Angles
Derived Variables	Horizontal wind speed and direction
Accuracy	Speed: ± 0.6 m/s Direction: ± 4°
Logging Rate	10 – 20 Hz

Flight Parameters

Maximum Tilt Angle	40°
Maximum Wind Resistance	22 m/s
Maximum Operating Speed	28 m/s
Maximum Flight Ceiling	6,000 ft AGL
Recommended Operating Temperatures	-20 – 40 °C
Typical Ascent Rates	1 – 5 m/s
Typical Descent Rates	1 – 6 m/s
Weight (sans battery)	1.5 kg
Average All-up Weight	2 kg

For more information regarding CS purchase or other custom-built solutions, please contact us at
oubliss@ou.edu

3.0 Data collection and processing:

Data were collected at three sites simultaneously. Launches were coordinated whenever possible at a 30-minute cadence. Typically, as weather phenomena of interest got near a flight site, this cadence was changed to 15 minutes to capture high rate profiles leading up to the phenomena. For PERiLS, this was typically started approximately an hour before the leading line of storms reached the first profiling site.

Data from the CopterSonde are logged via the Pixhawk autopilot system. This file is converted from a binary format to numerous levels of netCDF file for meteorological analysis. For

simplicity, we have provided only one level of netCDF. The raw autopilot logs are available by request.

The processed files take the raw binary to a radiosonde-like netCDF file. To do this, data are averaged into 5 m height bins and proper calibration coefficients are applied to get the desired meteorological variables. Wind speed is determined from the tilt of the UAS as it counteracts the wind using the method described in Neumann and Bartholmai (2015). More advanced wind estimations are currently being developed and will be released in future versions. The 3 temperature and 3 humidity sensors are averaged together to get the resulting temperature and relative humidity measurement. Before averaging, sensors are quality checked against each other to ensure there is no bad sensor going into the average. Only the ascent portion of the profile is used in the averaging. Prior research has found the descent leg is often contaminated by the rotor wash and is thus not trustworthy.

4.0 Data format:

Data are provided in netcdf format. The typical naming convention is {location}{tailnumber}CMTascent.c1.YYYYMMDD.HHmmss.nc, following closely to ARM file naming convention. The files have time dimensions.
Variables provided:

Name	Dimension	Unit,
base_time	Single value	Seconds (since 00 UTC 1 Jan 1970)
time_offset	Time	Second (since base_time)
time	Time	microseconds since 2010-01-01 00:00:00:00
alt	Time	Meters, altitude MSL
pres	Time	Pascal, pressure
wspd	Time	m/s, wind speed
dir	Time	Deg, wind direction
wind_u	Time	m/s, westward wind component
wind_v	Time	m/s, northward wind component
lat	Time	Deg N, latitude
lon	Time	Deg W, longitude
tdry	Time	Kelvin, dry bulb temperature
mr	Time	g/kg, water vapor mixing ratio
theta	Time	Kelvin, potential temperature
Td	Time	C, dewpoint temperature
q	Time	g/kg, specific humidity

5.0 Data Remarks

Wind speeds using the current linear function often are underestimated by the CopterSonde when they reach 15m/s or greater. New methods are being developed to minimize this underestimation and will be released in new versions of this dataset. However, these wind

speeds were not observed during M2HATS. Very low wind speeds (< 3 m/s) should be treated with high uncertainty.

6.0 References

Bell, T. M., B. R. Greene, P. M. Klein, M. Carney, and P. B. Chilson, 2020: Confronting the boundary layer data gap: evaluating new and existing methodologies of probing the lower atmosphere. *Atmospheric Measurement Techniques*, **13**, 3855–3872, https://doi.org/10.5194/amt-13-3855-2020.

Greene, B., A. Segales, T. Bell, E. Pillar-Little, and P. Chilson, 2019: Environmental and sensor integration influences on temperature measurements by rotary-wing unmanned aircraft systems. *Sensors*, **19**, 1470, https://doi.org/10.3390/s19061470.

Segales, A. R., B. R. Greene, T. M. Bell, W. Doyle, J. J. Martin, E. A. Pillar-Little, and P. B. Chilson, 2020: The CopterSonde: an insight into the development of a smart unmanned aircraft system for atmospheric boundary layer research. *Atmospheric Measurement Techniques*, **13**, 2833–2848, https://doi.org/10.5194/amt-13-2833-2020.

7.0 Appendix

7.1 Full Flight List

Date	Launch time	Duration	Maximum alt (m)
8/13/23	17:00	0:00	914
8/13/23	17:12	8:43	0
8/13/23	17:31	15:25	547
8/13/23	17:51	10:26	35
8/13/23	18:14	9:07	478
8/13/23	18:26	7:36	473
8/13/23	18:55	8:19	306
8/13/23	19:27	8:13	455
8/13/23	19:57	11:26	897
8/13/23	21:45	15:19	901
8/13/23	22:24	14:45	923
8/13/23	22:57	13:31	905
8/13/23	23:26	13:12	898
8/13/23	23:55	10:49	897
8/14/23	00:26	12:13	891
8/14/23	00:46	10:02	903
8/14/23	17:13	14:16	903
8/14/23	17:42	11:11	899
8/14/23	18:11	11:20	899
8/14/23	18:42	10:26	900

8/14/23	19:11	9:56	902
8/14/23	19:41	10:03	901
8/14/23	20:12	9:50	898
8/14/23	20:41	10:07	899
8/14/23	21:11	10:15	900
8/14/23	21:40	10:48	903
8/14/23	22:12	11:11	908
8/14/23	22:40	12:48	901
8/14/23	23:14	9:34	915
8/14/23	23:43	9:27	864
8/15/23	00:13	9:52	898
8/15/23	00:43	10:06	864
8/15/23	17:06	18:04	877
8/15/23	17:39	3:05	2
8/15/23	17:47	9:59	897
8/15/23	18:12	10:09	903
8/15/23	18:42	11:27	901
8/15/23	19:13	10:02	893
8/15/23	19:43	10:32	893
8/15/23	20:13	12:06	904
8/15/23	20:43	10:12	902
8/15/23	21:12	10:41	902
8/15/23	21:42	11:15	905
8/15/23	22:12	11:09	905
8/15/23	22:42	11:06	902
8/15/23	23:15	10:55	889
8/15/23	23:43	9:50	900
8/16/23	00:12	11:35	901
8/16/23	00:41	12:38	887
8/16/23	17:19	9:48	2
8/16/23	17:29	0:28	37
8/16/23	17:41	12:51	901
8/16/23	18:12	11:09	901
8/16/23	19:22	9:27	900
8/16/23	19:43	10:11	900
8/16/23	20:13	10:29	893
8/16/23	20:43	9:32	883
8/16/23	20:57	3:44	3
8/16/23	21:01	1:24	3
8/16/23	22:14	11:15	920

8/16/23	22:43	10:17	918
8/16/23	23:13	10:19	906
8/16/23	23:43	9:54	878
8/17/23	00:13	10:05	900
8/17/23	00:43	11:48	889
8/17/23	17:13	12:29	884
8/17/23	17:45	13:36	900
8/17/23	18:14	8:30	753
8/17/23	18:43	1:09	0
8/17/23	18:45	9:51	899
8/17/23	19:12	10:16	900
8/17/23	19:42	9:47	900
8/17/23	20:11	10:11	900
8/17/23	20:42	11:39	900
8/17/23	20:59	5:18	35
8/17/23	21:41	11:09	900
8/17/23	22:13	9:25	902
8/17/23	22:42	10:30	896
8/17/23	23:12	10:33	899
8/17/23	23:43	9:35	894
8/18/23	00:13	9:38	771
8/18/23	00:42	10:24	988
8/19/23	17:20	15:41	895
8/19/23	17:42	9:07	745
8/19/23	18:14	11:03	895
8/19/23	18:43	1:21	26
8/19/23	18:46	9:53	900
8/19/23	19:14	10:26	900
8/19/23	19:44	9:40	899
8/19/23	20:13	10:19	908
8/19/23	20:44	9:34	888
8/19/23	21:12	11:30	902
8/19/23	21:44	10:08	894
8/19/23	22:13	9:46	897
8/19/23	22:43	10:05	890
8/19/23	23:13	9:57	911
8/19/23	23:43	9:51	903
8/20/23	00:14	9:33	892
8/20/23	00:42	9:50	902
8/22/23	17:07	8:12	3

8/22/23	17:15	8:23	700
8/22/23	17:42	1:11	4
8/22/23	17:44	8:17	698
8/22/23	18:12	9:41	703
8/22/23	18:43	8:27	693
8/22/23	19:11	12:17	897
8/22/23	19:42	10:32	900
8/22/23	20:12	11:16	900
8/22/23	20:43	11:01	900
8/22/23	21:13	9:55	902
8/22/23	21:42	10:40	903
8/22/23	22:13	10:11	906
8/22/23	22:43	9:38	896
8/22/23	23:13	9:46	895
8/22/23	23:43	9:43	886
8/23/23	00:13	10:30	877
8/23/23	00:42	11:20	901
8/23/23	16:59	1:20	33
8/23/23	17:13	10:31	902
8/23/23	17:43	9:53	896
8/23/23	18:13	0:47	91
8/23/23	18:15	9:56	902
8/23/23	19:45	2:22	0
8/23/23	19:52	9:44	901
8/23/23	20:12	11:15	900
8/23/23	20:43	10:11	901
8/23/23	21:13	10:49	896
8/23/23	21:44	9:39	904
8/23/23	22:13	10:19	902
8/23/23	22:43	10:47	900
8/23/23	23:13	10:12	900
8/23/23	23:45	9:50	902
8/24/23	00:14	9:31	901
8/24/23	00:42	11:16	897
8/24/23	17:04	0:25	3
8/24/23	17:13	10:34	883
8/24/23	17:43	9:30	897
8/24/23	18:14	9:15	900
8/24/23	18:43	9:49	899
8/24/23	18:57	9:29	900

8/24/23	20:52	9:48	897
8/24/23	21:13	11:02	899
8/24/23	21:42	11:16	900
8/24/23	22:13	9:55	886
8/24/23	22:42	11:09	901
8/24/23	23:14	9:37	899
8/24/23	23:44	9:24	895
8/25/23	00:13	10:30	900
8/25/23	00:43	9:43	891
8/25/23	16:54	4:15	4
8/25/23	17:21	4:30	101
8/25/23	17:26	1:01	1
8/25/23	17:43	9:47	899
8/25/23	18:13	10:08	900
8/25/23	18:42	11:01	902
8/25/23	19:13	10:27	901
8/25/23	19:44	9:59	888
8/25/23	20:13	10:36	899
8/25/23	20:44	9:55	900
8/25/23	21:16	9:04	852
8/25/23	21:43	10:26	899
8/25/23	22:13	9:56	909
8/25/23	22:43	10:05	895
8/25/23	23:13	10:07	899
8/25/23	23:43	9:43	895
8/26/23	00:13	9:43	898
8/26/23	00:43	10:11	987
8/26/23	17:11	2:28	0
8/26/23	17:14	12:13	896
8/26/23	17:43	13:45	904
8/26/23	17:57	6:12	6
8/26/23	18:04	0:18	23
8/26/23	18:14	9:43	898
8/26/23	18:43	10:14	899
8/26/23	19:14	9:37	893
8/26/23	19:44	10:03	895
8/26/23	20:14	9:45	898
8/26/23	20:43	10:57	900
8/26/23	21:13	10:26	899
8/26/23	21:44	9:47	903

8/26/23	22:14	13:58	907
8/26/23	22:43	13:41	901
8/26/23	23:14	9:42	901
8/26/23	23:43	12:18	897
8/27/23	00:14	10:57	900
8/27/23	00:43	10:03	899
8/27/23	17:02	2:08	6
8/27/23	17:15	10:00	903
8/27/23	18:24	10:01	888
8/27/23	18:43	10:16	898
8/27/23	19:13	10:24	901
8/27/23	19:43	9:42	895
8/27/23	20:14	9:42	898
8/27/23	20:43	10:32	901
8/27/23	21:13	10:02	894
8/27/23	21:44	18:47	894
8/27/23	22:14	10:04	901
8/27/23	22:42	10:57	903
8/27/23	23:13	10:31	902
8/27/23	23:43	10:20	900
8/28/23	00:14	9:59	901
8/28/23	00:43	9:49	901
8/28/23	17:12	11:06	899
8/28/23	17:43	10:27	901
8/28/23	18:13	12:29	695
8/28/23	18:43	10:03	899
8/28/23	19:13	10:20	898
8/28/23	19:43	10:29	900
8/28/23	20:14	9:41	897
8/28/23	20:44	9:54	901
8/28/23	21:13	10:21	899
8/28/23	21:43	10:39	902
8/28/23	22:14	2:50	35
8/28/23	22:18	1:21	9
8/28/23	22:21	10:28	2
8/28/23	22:33	13:18	905
8/28/23	23:11	14:14	898
8/28/23	23:43	10:50	905
8/29/23	00:14	9:34	901
8/29/23	00:43	10:41	900

8/29/23	17:01	2:06	2
8/29/23	17:16	9:32	900
8/29/23	17:30	5:00	0
8/29/23	17:43	11:59	899
8/29/23	18:14	9:28	899
8/29/23	18:29	9:23	902
8/29/23	18:57	9:38	898
8/29/23	21:00	9:30	901
8/29/23	21:13	6:50	903