

## Title: Combined Mesonet and Trackers

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## CoMeT Overview

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For MITTEN-CI, the University of Nebraska-Lincoln operated two Combined Mesonet and Trackers (CoMeT-2 and CoMeT-3) and Central Michigan University operated 1: CoMeT-Alpha. CoMeTs are Ford Explorers (model years 2017 [CoMeT-2], and 2019 [CoMeT-3 and CoMeT-Alpha]) with forward-mounted suites of meteorological sensors and dual moonroofs, combining the capability of a mobile mesonet to collect near-surface observations with the capability of an uncrewed aircraft systems (UAS) tracker vehicle, which enables an observer in the second row of seats to see the aircraft and maintain compliance with Federal Aviation Administration policies on UAS operation.

## Instrument Description

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The specific sensors included on each CoMeT are summarized in the table at the end of this section. In general each CoMeT collects observations of slow temperature and humidity at ~2 m above ground level (AGL) using a Vaisala HMP155, fast temperature at ~2 m AGL using a Campbell Scientific 109SS-L thermistor, pressure at ~2.5 m AGL using a Vaisala PTB210 barometer with a Gill pressure port, wind speed and direction at ~3.25 m AGL using an R.M. Young 05103 propeller anemometer, position using a Garmin 19x HVS receiver, and vehicle heading using a KVH Industries C-100 fluxgate compass. The HMP155 and 109SS are shielded and aspirated within a U-tube (Waugh 2021). Fast temperature and corrected RH measurements (using sensors housed within the U-tube) have a time constant of 10-12 s based on data collected across a temperature and RH shock during the CLOUD-MAP 2017 calibration/validation tests on 26 June 2017. Vehicle speed was < 10 kts for this test. Manufacturer specifications for these instruments are given in Table 1 of Hanft and Houston (2018). This list of sensors is also included in the CoMeT data file metadata.

Slow Temperature Slow RH	Vaisala HMP155E Part #: E1AA11A0B1A1A0A
Fast temperature	Campbell Scientific 109SS-L12-PW
Pressure	Vaisala PTB-210

	Part #: A1A1B Gill Pressure Port Part #: 61002
Wind	RM Young 05103-L20-PW Part #: 18435-244
GPS	Garmin GPS 19x HVS (NMEA 0183) Part #: 010-01010-00
Compass	KVH C-100 Part #: 01-0177-15
Logger	Campbell Scientific CR6-WIFI-XT-SW Part #: 28385-6

## Data Collection and Real-Time Processing

The reported measured quantities are summarized in the table below.

Quantity	Units	Source
Epoch time	Seconds	GPS
Latitude and longitude	Degrees	GPS
Altitude	m	GPS
Pressure	hPa	PTB210
Temperature (fast)	deg C	109SS-L
Temperature (slow)	deg C	HMP155
RH (slow)	%	HMP155
Vehicle speed	m/s	GPS
Vehicle heading	deg	C-100 and GPS

In addition to the measured variables, several derived variables are calculated.

### Corrected/fast relative humidity (%)

Relative humidity is adjusted to the fast temperature following Richardson et al. (1998) and Houston et al. (2016).

Corrected/fast relative humidity is calculated using,

$$RH = 100 \frac{e}{e_s} \quad (1)$$

where vapor pressure and saturation vapor pressure are calculated using the August–Roche–Magnus formula (Lawrence 2005) with coefficients from Alduchov and Eskridge (1996):

$$e_* = 6.1094 \exp \left[ \frac{17.625 \cdot T_*}{243.04 + T_*} \right]. \quad (2)$$

For  $e$ , the slow dew point temperature ( $T_{d\text{-slow}}$ ) is used for  $T_*$  in (2) and is calculated using

$$T_d = \frac{B\gamma}{A - \gamma} \quad (3)$$

where

$$\begin{aligned} \gamma &= \ln(0.01 \cdot RH_*) + \frac{AT_*}{B + T_*} \\ A &= 17.625 \\ B &= 243.04 \end{aligned} \quad (4)$$

and slow temperature ( $T_s$ ) and slow  $RH_{slow}$  are used for  $T_*$  and  $RH_*$ , respectively. For  $e_s$ , fast temperature ( $T_{fast}$ ) is used in (2).

### Water vapor mixing ratio (g/kg)

Water vapor mixing ratio  $q_v$  is calculated using (2), with  $T_{fast}$ , and  $RH_{fast}$ , described above, to get  $e$  and

$$q_v = 622 \frac{e}{p-e}$$

to get  $q_v$ .

### Dew point temperature (°C)

The reported dew point temperature is calculated using (3) and (4) with  $T_{fast}$  and  $RH_{fast}$  for  $T_*$  and  $RH_*$ , respectively.

### Potential temperature (Kelvin)

$$\theta = T_{fast} \left( \frac{10^5}{p} \right)^{\frac{R_d}{C_{pd}}}$$

### Virtual potential temperature (Kelvin)

$$\theta_v = \theta(1 + 0.61q_v)$$

### Equivalent potential temperature (Kelvin)

The expressions use for the calculation of equivalent potential temperature are from Bolton (1980):

$$\begin{aligned} \theta_e &= T_m \exp \left[ \left( \frac{3376}{T_{LCL}} - 2.54 \right) q_v (1 + 0.81q_v) \right] \\ T_m &= \theta \left( \frac{T_{fast} + 273.15}{\theta} \right)^{0.286q_v} \end{aligned}$$

$$T_{LCL} = 55 + \frac{2840}{3.5 \ln(T_{fast} + 273.15) - \ln(e) - 4.805}$$

Intercomparisons between the two CoMeTs were performed. In these intercomparisons, the vehicles were parked adjacent to each other aligned perpendicular to (and facing into) the wind. To minimize engine heating effects, intercomparisons were only conducted when the wind speed was >10 kts.

## Data Format

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Original data files for each deployment are saved as text files and then converted to NetCDF. NetCDF versions have units that are CF compliant and may not match the original units in the txt files. The naming convention for the NetCDF files is as follows:

UNL.CoMeT{N}.{YYYYMMDD}.{HHMM}.L2\_2024.{post-processing codes}.nc

Example: UNL.CoMeT3.20190627.1931.L2\_2024.g1.f1.nc

The date and time correspond to the start of observation collection (in UTC). Post-processing codes are included to track modifications to the raw data. These codes are closely connected to error flags associated with each record. Each letter corresponds to a particular instrument:

- g: GPS
- p: Barometer
- tf: Fast temperature
- ts: Slow temperature
- rh: Relative humidity
- f: Compass
- w: Wind monitor
- a: All instruments

Each number corresponds to a particular post-processing action described below.

Measured and derived variables are included in the following table.

Variable Heading	Standard Name	Units
time	Time	seconds since 00:00:00, 01-01-1970
Alt	Altitude	meters
lat	Latitude	degrees north
lon	Longitude	degrees east
fast_temp	Air Temperature	kelvin
slow_temp	Air Temperature	kelvin

pressure	Air Pressure	pascals
logger_RH	Relative Humidity	percent
calc_corr_RH	Relative Humidity	percent
wind_speed	Wind Speed	meters per second
wind_dir	Wind From Direction	degrees
vehicle_dir	Vehicle Direction	degrees
dewpoint	Dew Point Temperature	kelvin
mixing_ratio	Humidity Mixing Ratio	g/g
theta	Air Potential Temperature	kelvin
theta_v	Virtual Potential Temperature	kelvin
theta_e	Equivalent Potential Temperature	Kelvin
error_flag		

The error\_flag variable is a string that ties into the post-processing codes listed above. Not all post processing codes relevant for a particular file are applied to all records. Thus, error flags could differ across records for a given file.

All instruments will have an associated code but will have a “0” if the datum is unaffected by post processing. The format for a record’s error flag is as follows:

a#g#-p#-tf#-ts#-rh#-w#-f#

where the letter corresponds to a particular instrument (see above) and “#” is a number reflecting the bitwise accumulation of post processing corrections.

Level	Bits
1	1
2	2
3	4
4	8

For example, if the pressure sensor has undergone level 1 and level 3 processing for a given record, the “p” error flag for that record would be “p05”. If the sensor has undergone level 2 and level 4 post processing, the error flag for that record would be “p10”.

## Post-Processing Codes

Code		Description
Instrument	Level	
a	1	Exact correction. Intermittent missing data reprocessed from raw data
g	1	Exact correction. GPS position reprocessed from raw data
	2	As far as we can tell this is an exact correction to an error in the GPS time. During the corrected time periods the time suddenly went backwards ~250s and stayed at this offset for 750s when it corrected itself. The offset was applied to the “time warp” period.
	3	Exact correction. Vehicle speed was improperly logged so it's reprocessed from raw data.
p	1	No correction, data removed. Malfunctioning pressure sensor or raw data not archived to perform pressure correction. Replaced pressure, water vapor mixing ratio, potential temperature, virtual potential temperature, and equivalent potential temperature with missing value.
	2	Approximate correction. A bias in pressure as a function of flow speed across the Gill pressure port was discovered. The correction was developed by S. Waugh: $p = p_0 + 5 \times 10^{-7} V^3 - 1 \times 10^{-3} V^2 - 6 \times 10^{-5} V$ where $p_0$ is the uncorrected pressure in hPa and $V$ is the vehicle-relative flow (raw anemometer speed) in m/s.
f	1	No correction, missing data. Fluxgate compass inoperable. Heading replaced by GPS heading. When the vehicle is stationary, wind speed and direction are ordinarily calculated using the fluxgate compass heading but, for this error, winds when stationary are calculated using GPS-derived vehicle heading
ts	1	No correction, data removed. Replaced slow temperature, corrected/fast relative humidity, dew point temperature, water vapor mixing ratio, virtual potential temperature, and equivalent potential temperature with missing value.
	2	Flagged for potential contamination by vehicle heat when the wind speed is light (<1 m/s) or the vehicle-relative wind velocity has a component towards the front of the vehicle.
tf	1	No correction, data removed. Replaced fast temperature, corrected/fast relative humidity, dew point temperature, water vapor mixing ratio, potential temperature, virtual potential temperature, and equivalent potential temperature with missing value.
	2	Flagged for potential contamination by vehicle heat when the wind speed is light (<1 m/s) or the vehicle-relative wind velocity has a component towards the front of the vehicle.
rh	1	No correction, data removed. Replaced slow RH, corrected/fast relative humidity, dew point temperature, water vapor mixing ratio, virtual potential temperature, and equivalent potential temperature with missing value.

	2	Flagged for potential contamination by vehicle heat when the wind speed is light (<1 m/s) or the vehicle-relative wind velocity has a component towards the front of the vehicle.
W	1	No correction, missing data.
	2	Approximate correction. Recalculation of winds because WNDDIROFF (used in the logger script) was wrong.
	3	Approximate correction. Large spikes in wind speed are removed. Done through correction to u and v and, thus, wind direction is also corrected.
	4	Flagged for potential errors due to large vehicle acceleration. Flag set if vehicle speed changes by more than 2 m/s (over 1s) or direction changes by more than 2° (over 1s). These thresholds are used for flagging NSSL mobile mesonet data (S. Waugh, personal communication 2025).

## References

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