Title: NSSL Mobile Mesonet Quality Controlled (QC) Meteorological Data (TORUS - 2019)

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1.0 Data Set Overview:

This document describes data characteristics from National Severe Storms Laboratory (NSSL) mobile mesonet (MM) observations provided in support of the Targeted Observations using Radars and UAS in Supercells (TORUS) from May 13 to June 15, 2019. The NSSL mobile mesonets were operated during TORUS in collaboration with teams from the University of Oklahoma (OU)/CIMMS, the University of Nebraska, Colorado University, the University of Michigan, the University Texas Tech, and the Aircraft Observation Center. Mobile mesonet instrumentation were mounted on two NSSL vehicles (denoted by vehicle IDs Probe 1, Probe 2), as well as a CIMMS owned vehicle (denoted LIDAR) and two rental vehicles (denoted Far Field Sounding and Windsond).

2.0 Instrument Description:

The NSSL mobile mesonet vehicles during TORUS consisted of a 2019 Ford F-250 (Probe 1), a 2014 Dodge Ram 1500 (Probe 2), a 2019 Chevy Silverado (Far Field), a 2019 Ram 2500 (Windsond), and 2007 Ram 1500 (Lidar 1/2) equipped with a roof-mounted meteorological instrumentation rack (including data-logger) combined with interior-mounted computing and communications hardware. The Far Field vehicle due to the rental conditions prevented such an installation and was therefore located in the bed of the truck. Due to this installation, the surface observations from the Far Field should only be trusted when stationary. Measured MM variables are described in sections 3.0, 4.0, and 5.0 below.

The instruments in use during the TORUS project are listed below along with various specifications and accuracies.

Sensor Specifications

Tfast – 109SS (Stainless Steel)
    Measurement Range: -40° to 70°C

Accuracy: ±0.02°C*

Temperature (Tslow) & Relative Humidity (RH) - HMP155

Relative Humidity (RH)

Measurement Range: 0.8% to 100% RH, non-condensing

Accuracy at 20°C (field-calibrated against references)*: ±0.6% (0% to 40% RH);
±1% (40% to 97% RH)

Response Time*: 20 s with membrane filter (at 20°C, 90% response)

Temperature (Tslow)

Measurement Range: -80° to +60°C

Accuracy*: ±(0.226 + 0.0028 * temperature) °C (-80°C to +20°C)
±(0.055 + 0.0057 * temperature) °C (+20°C to +60°C)

Pressure - PTB210:

Operating Range: 500 … 1100 hPa

Linearity**: ±0.1 hPa

Hysteresis: ±0.05 hPa

Repeatability: ±0.05 hPa

Wind Speed & Direction - RM Young 05103 Wind Monitor:

Range: 0-100 m/s (224 mph), 0- 360°

Accuracy: Wind Speed: ±0.3 m/s (0.6 mph) or 1% of reading Wind Direction: ±3 °

Threshold: Propeller: 1.0 m/s (2.2 mph)
Vane: 1.1 m/s (2.4 mph)

Vehicle Heading (Stationary) - KVH C100 Fluxgate:

Accuracy: ±0.5° or ±10 mils RMS

Repeatability: ±0.2° or ±5 mils RMS

Resolution: 0.1° or 1 mil

*While various instruments specify a particular accuracy, it takes a finite amount of time for these sensors to respond to a given change, known as the response time or time constant. This response time is a combination of every factor influencing the measurement being made and thus represents an unknown quantity as it is impossible to completely describe every scenario in which the sensors are being used. Thus, the HMP155 U-tube (Tslow) temperature sensor for example may have a specified accuracy of ± 0.2°C at 20°C, but may take upwards of 30 minutes to reach a final temperature following a large step change in the environment (e.g., Waugh 2012, Fig. 12). In contrast, the 109 (Tfast) probe responds within a few tens of seconds to the environmental step change. This is of particular concern when dealing with rapidly changing environments. Do not equate the accuracies listed above to an absolute accuracy in heterogeneous ambient conditions.

**Regarding the use of pressure, it is worth noting that in general pressure changes by roughly 1 mb every 10 m in vertical displacement. Therefore, when examining changes in pressure, care should be taken to decide whether that change is due to environmental factors or simply changes in altitude. This also ties in to the relative accuracy of GPS units for altitude.

For questions, comments, concerns, or more information, contact the NSSL/Field Observation Facilities Support (FOFS) Mobile Mesonet Lead: Sean Waugh (sean.waugh@noaa.gov)

3.0 Data Collection and Processing:

These mobile mesonet datasets combine all periods of data collection on a given operation day. This includes periods where all platforms ferry from the morning launch point to the initial target weather location, followed by mobile legs. Additionally, any random periods where data were collected not necessarily associated with a deployment are also included in the processed file. These NSSL mobile mesonet data records are obtained at a nominal spacing of 1 Hz. There may be rather infrequent missing 1 Hz records or small groups of consecutive records, due to QC removal of those few records that were deemed incorrect or questionable data for a variety of reasons discussed in section 4.0. The QC process has objectively detected and removed the latter infrequent corrupted records from the archived datasets.

All temperature, relative humidity, and wind sensors on the NSSL mobile mesonet systems were calibrated by the Oklahoma Climate Survey (OCS) instrumentation laboratory prior to the TORUS field phase.

Users of these data are advised to heed QC flags in their processing or plotting software, etc, to gracefully detect and if necessary avoid using flagged records. QC flags are meant to indicate periods where data <u>may</u> be considered questionable relative to prescribed threshold values, however a note of caution. Users are cautioned against using the QC flags as absolute truth, as some erroneous data points may be missed during the QC process due to the subjective threshold values. Similarly, some valid data points may be flagged during the QC process. As such, it is up to the discretion of the end user to determine which data points should and should not be included in analysis.

Since it's possible that TORUS missions extended late into the night of the next (UTC) day after deployment (but typically did not continue past ~ 12 UTC the following morning), the time variable has been computed in UTC floating-point hours relative to 0000 UTC on the day of initial deployment. Consequently, decimal time during Night #1 will be greater than 24.0 UTC.

4.0 Data Format:

Each file contains the mobile mesonet data for a specific vehicle for one mission day (IOP). All files end with the suffix ".qcd" to indicate that quality control has been performed on the data. Each record of a QC data set includes data quality flags as described below.

The filenames have the following structure:

{platform name}_{date of IOP in YYMMDD}_met.qcd,

where "_met" refers to a quality-controlled data set which contains only the significant MM meteorological variables (example: MM2_150710_met.qcd).

The date listed in the file name is the date that operations began or were decided upon, regardless of when data collection actually started for a given platform. As such, DOUBLE CHECK THE IOP AND TIMES YOU ARE INTERESTED IN AND MAKE SURE YOU RETRIEVE THE PROPER FILE.

The files are composed of space-delimited, fixed-width, ASCII records in the following format:
ID Time Lat Lon Alt Tfast Tslow RH P Dir Spd qc1 qc2 qc3 qc4

ID: The vehicle ID from the list of vehicles
Time: UTC time in decimal format. Times that cross 0000 UTC (i.e., 24.0) are reported as decimal time referenced to the IOP date (e.g., 0030 UTC on the second day would be 24.5)
Lat: Latitude in decimal format. Four decimal places corresponds to order 10 m precision, which is somewhat better than the likely accuracy of the GPS position (see note in section 6).
Lon: Longitude in decimal format
Alt: GPS altitude in meters above Mean Sea Level (MSL)
Tfast: Fast response temperature in Celsius
Tslow: Slow response temperature in Celsius. As detailed in section 5, the slow-response temperature sensor is located behind a microporous membrane along with the RH sensor. The role of the microporous membrane is to protect the RH sensor from contamination.
RH: Derived relative humidity (%). This value is derived from the measured Tfast, RH, and pressure values following Richardson et al. (1998) as detailed in section 5.
P: Pressure in millibars
Dir: Derived ambient ground-relative wind direction in degrees relative to North (i.e., wind from the indicated direction). This utilizes the vehicle heading as measured either by the fluxgate compass or the GPS. Vehicle motion has been removed from the reported value. A note regarding this derivation and magnetic declination is in section 5.
Spd: Derived ambient ground-relative wind speed in meters per second. Vehicle motion has been removed from the reported value.
qc1: Panel temperature flag, set to 1 if the panel temperature on the data logger (DL) changes by a sufficiently large amount. Useful for diagnosing DL bias errors due to system

voltage drops and also determining potential areas of interference to the DL (e.g., as possibly caused by radio interference).

qc2: Vehicle motion flag, set to 1 if the vehicle is stationary or nearly so. Users are advised to suspect and possibly ignore data when vehicle is stationary, due to probable biases caused by inadequate ventilation of temperature/RH sensors. Derived winds could also be questionable due to reliance on fluxgate compass or else the deleterious influence of local vehicle effects.

qc3: Vehicle acceleration flag, set to 1 if the vehicle speed or direction changes rapidly. Due to potential time lags between the GPS and the wind response, large vehicle speed/direction changes are flagged as the derived winds may not be accurate. This flag will also trigger either if the GPS drops out for a record or if the vehicle direction changes appreciably while the vehicle is stationary.

qc4: Sanity check, set to 1 if any of the listed variables fall outside a normal operating range. Variables checked: latitude, longitude, temperature, relative humidity, pressure, wind direction, wind speed, vehicle direction, vehicle speed, DL time, GPS time.

To simplify the column spacing of the output files and keep consistency between units, a 4 letter ID was used for each of the vehicles. These designations are as follows:

Probe 1 – Prb1
Probe 2 – Prb2
Lidar – LIDR
Far Field – FFld
Windsond – WinS

5.0 Data Remarks:

Straka et al. (1996) described the original VORTEX-1994/1995 mobile mesonet system and data processing, while Ziegler et al. (2004) described the redesigned and refabricated IHOP-2002 mobile mesonet instrumentation rack. During TORUS several of the temperature sensors and the RH probe were housed within an NSSL-designed temperature shield known as the “U-tube”. Those interested in learning more about the U-tube should contact its designer Sean Waugh (sean.waugh@noaa.gov), or are encouraged to read the master’s thesis that describes its design and initial testing (Waugh 2012).

Note on Tfast: The Tfast sensor is located within the “U-tube” as mentioned above to provide reliable temperature measurements while reducing temperature measurement errors associated with effects such as wet-bulb evaporative cooling and solar radiation heating. The aspirated enclosure proceeds from and improves on the earlier "J-tube" enclosure (Straka et al. 1996). Users should employ Tfast for all temperature or temperature-related quantities. Tfast measurements have been determined to be reliable even when vehicles are stationary due to internal aspiration (Waugh 2012).

Note on Tslow and RH: The Tslow and RH sensors are located inside a trapped volume enclosed by a microporous membrane that protects the RH probe from being contaminated by pollutants in the air stream (Waugh 2012). Although the membrane is porous to water vapor molecules (thus vapor pressure is equilibrated across the membrane), the temperature response of the volume inside the membrane is slowed and thus the measured Tslow and RH are not representative of the ambient environment outside of the membrane. Instead, a dew point (which is conserved across the membrane) is calculated using the Tslow and measured RH. Then, the dew point and Tfast are used to derive the ambient RH which is reported in the QC data following Richardson et al. (1998).

Note on Derived Wind Direction and Speed while moving: The mesonet program derives the ambient wind direction and speed in real time while the vehicle is moving, by subtracting the car vector from the measured wind vector. However there may be cases where while moving, the logger data drops out for a record or two and records a value of zero for the wind speed and direction. This will result in an incorrectly derived wind direction and speed as the program sees a zero relative wind vector while moving. The QC process will likely not flag these events, thus it is up to users to identify these random, rare, sudden deviations from the derived winds.

Notes on Wind Direction and Speed at low speeds: Users are cautioned against relying on wind speed or direction data in low vehicle ground speeds or while stationary (~ 2-3 m/s or below). At these times, local variations and accelerations caused by the vehicle itself become more prominent and can heavily influence the derived winds. Periods of stationary measurements should be checked for consistency before use. Similarly, periods of low ambient winds are difficult to derive on a moving platform particularly at higher vehicle speeds. The small deflection of the anemometer is difficult to pick out amongst the stronger component of the vehicle motion. As such the variability of the derived winds increases as the true ambient wind decreases.

Note on GPS accuracy: The GPS on the mobile mesonet allows for fairly accurate position measurements in the horizontal (typically <15 m), but can have much less accuracy in the vertical. The accuracy at any given moment can vary significantly according to the constellation of satellites available, but is not uncommon to be on the order of +/- 120 m. As such, caution must be used when utilizing the altitude measurements provided in this data set.

There are occasions where the offset that is applied to the wind vane is incorrect. This can be due to improper alignment during installation, physical impacts such as hail stones, or drift on the potentiometer. If the offset is incorrect, by even a few degrees, the resulting derived wind directions are erroneous and in need of correction. This is done post project, using an iterative method to settle in on a wind direction where the derived winds agree while stationary and while moving, and/or while moving in opposite directions on transect legs. This process is completed manually on a case by case basis and may or may not correct all affected files. Below is a list of platforms and dates that have been corrected for this project. This process creates new files with the "_corr" extension on the filename to distinguish it from the non-corrected files. If any files are suspected to contain these errors, please contact Sean Waugh immediately.

Corrected offset dates:

Probe 2: 5/13 – 5/18, original offset -166.4, new offset -137

Finally, on May 27th, 2019 Probe 1 encountered severe hail which critically damaged the wind monitor on top of the mobile mesonet rack. This damage completely destroyed the nose cone and twisted the body of the vane itself, leading to erroneous derived winds. Therefore, all winds for the remainder of the deployment cannot be trusted and will be flagged on Flag 4. This starts at approximately 0100 UTC on May 28th ,2019 through visual inspection of the data. End users are cautioned when utilizing derived winds near this time. As with the previous corrections, the "_corr" filename will be used.

For more information please contact either Sean Waugh. Full data sets containing all recorded information are available upon request.

6.0 References:

Richardson, S. J., S. E. Fredrickson, F. V. Brock, and J. A. Brotzge, 1998: Combination temperature and relative humidity probes: avoiding large air temperature errors and associated relative humidity errors. Preprints, 10th Symposium on Meteorological Observations and Instrumentation, Phoenix, AZ, USA, American Meteorological Society, 278–283.

Straka, J.M., E.N. Rasmussen, and S.E. Fredrickson, 1996: A mobile mesonet for finescale meteorological observations. Journal of Atmospheric and Oceanic Technology, 13, 921-936.

Waugh, S., 2012: The "U-Tube": An improved aspirated temperature system for mobile meteorological observations, especially in severe weather. M.S. Thesis, University of Oklahoma, Norman, OK, 76 pp., [URI: http://hdl.handle.net/11244/24679]

Ziegler, C. L., D. Kennedy, and E. N. Rasmussen, 2004: A wireless network for collection and synthesis of mobile mesoscale weather observations. J. Atmos. Oceanic Technol., 21, 1659-1669.