P5.1 Intercomparison between Mobile and Stationary Surface Observing Platforms in VORTEX2

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1. INTRODUCTION

The second Verification of the Origin of Rotation in Tornadoes Experiment (VORTEX2) marked the first time multiple in situ surface observing platforms were deployed on a large scale. If observations obtained by vehicle-borne platforms, such as a mobile mesonet (Straka et al. 1996), are to be analyzed in tandem with observations from stand-alone, stationary platforms such as StickNet (Schroeder and Weiss 2008; Weiss and Schroeder 2008) or tornado pods (Wurman 2008), advantages and limitations unique to each observing platform must be considered. This study will document varying spatial biases induced in mobile mesonet and StickNet data by instrument time constants.

Observations collected during the passage of a Mesoscale Convective System (MCS) across a fine-scale StickNet array near Cherokee, Oklahoma on 15 May 2009 are considered. The passage of the MCS across the StickNet array coincided with a mobile mesonet probe transect, allowing observations from the two platforms to be directly compared. Varying time constants for instrumentation in the two platforms coupled with the translation of the mobile mesonet probe produced periods of dramatically differing observations across the MCS gust front. Causes for the differences in mobile and stationary observations will be presented along with recommendations for future studies utilizing StickNet and mobile mesonet data in tandem.

2. INSTRUMENTATION

2.1. StickNet

Texas Tech University fielded a 24-probe fleet of rugged, rapidly-deployable surface observing platforms known as StickNet in the 2009 and 2010 VORTEX2 campaigns. Of the 24 probes, 14 Type A probes collect thermodynamic data via RM Young 41382, or similar Campbell Scientific HMP45C temperature and relative humidity sensors housed within a 10-plate Gill radiation shield (Gill 1979). A total of 10 Type B probes collect both kinematic and thermodynamic data utilizing a Vaisala WXT510 or WXT520 sensor.

Both Type A and Type B probes are non-aspirated, which results in instrument response times dependent on the ambient wind speed. In order to quantify time constants for StickNet probes a series of experiments were conducted using a wind turbine housed in an approximately 1.2 m circular cross section wind tunnel at the Texas Tech University Wind Science and Engineering Field Site. An HMP45C and WXT520 sensor were mounted to a single platform and the response time for large step changes in temperature and relative humidity were calculated in steady wind speeds produced by the turbine. Time constants were defined as the time period for an instrument to achieve a 1 - exp(-1), or 63.2%, response to the total step change observed. Wind speeds corresponding to each time constant were calculating using an average wind speed recorded by the WXT520 sensor.

Results from the experiments (Figs. 1, 2) show both probes respond slowly to thermodynamic gradients in light winds with generally improving performance as wind speeds accelerate. An exception to this trend occurs at tests performed with an approximately 5.75 m s^{-1} wind speed, which responded more slowly to both temperature and relative humidity changes than tests performed in similar thermodynamic conditions with an approximately 5 m s^{-1} wind speed. The larger time constant was found in both instruments and was reproduced in a second series of experiments.

Wind tunnel, airflow windtable, and numerical modeling studies have found that airflow within Gill and similar radiation shields are not constant throughout the depth of the

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shield and can vary with changing wind speed (Richardson et al. 1999; Lin et al. 2001). Furthermore, Lin et al. 2001 noted the possibility of wake zones developing between plates given a certain wind speed and incident angle. Despite this possibility, Lin et al. 2001 also found that wind speed within a Gill radiation shield increased with increasing ambient wind speed and that change in the turbulent character of the wind could induce large changes in wind flow within the radiation shield. Given the possibility of slight changes in instrument orientation between experiments and the nonuniform wind field produced by the turbine, it is believed that the relatively large time constants for a 5.75 m s^{-1} wind speed are an artifact of the difficulties in calculating a time constant without knowledge of the flow rate within the radiation shield. Due to this uncertainty, it is stressed that the values in Figs. 1 and 2 represent a best estimate of StickNet time constants and will likely deviate from case to case.

Finally, it is apparent that the HMP45C instrumentation on Type A probes produces a superior time constant to the WXT520 sensor. At wind speeds of approximately 10 m s^{-1}, the time constant calculated for the temperature(relative humidity) of the HMP45C is 114(113) seconds faster than the time constant for the WXT520. The degraded response time for the WXT520 sensor is likely due to reduced aspiration from the 6-plate radiation shield utilized.

2.1. Mobile Mesonet

Mobile mesonet probes operated by Pennsylvania State University and the National Severe Storms Laboratory in VORTEX2 were constructed according to the original design of Straka et al. 1996. An HMP45C temperature and relative humidity sensor is housed within a vapor-permeable membrane with a Fenwall Electronics UUT51J1 thermistor to provide relative humidity and slow response temperature readings, respectively. A Yellow Springs Inc. (YSI) 44205 thermistor is also utilized outside of the membrane to provide a fast-response temperature. All instrumentation is contained within an aspirated J-tube to provide moisture and radiation shielding. An aspirated U-tube housing the same instrumentation was included for the 2010 field campaign and has been shown to provide improved response times for fast temperature, slow temperature, and relative humidity (Waugh and Fredrickson 2010). However, as the cases included in this study occurred in 2009, time constant values associated with the J-tube design will be used.

Response times of mobile mesonet temperature and relative humidity observations to a large step change in zero ambient wind are 76 s, 55 s, and 316 s for slow temperature, fast temperature, and relative humidity, respectively (S. Waugh 2010, personal communication). It is stressed that these response times represent the maximum time constants for mobile mesonet data and that introduction of aspiration through ambient wind speed and vehicle translation will result in a significant reduction. Given the difficulty in accurately calculating instrument time constants for varying wind speeds in mobile mesonet data, specific time constants are not available for this study. However, it is worth noting that Straka et al, 1996 found adequate ventilation would result in slow temperature and relative humidity response times of less than 1 minute, which is similar to those observed in higher wind speeds for the HMP45C instrumentation in StickNet.

3. ANALYSIS

On 15 May 2009, VORTEX2 targeted an MCS moving through northwestern Oklahoma, which passed over a 12-probe StickNet array during the period of 2330 – 0000 UTC. During this time period a single mobile mesonet probe (P7) transected the leading edge of the MCS through the StickNet array. P7 began the westward leg of the transect towards the leading edge of the MCS at 2330 UTC, passing six StickNet probes (04B, 05A, 07A, 09A, 10A, and 12A) before beginning the eastward leg of the transect at 2342 UTC and passing the same six probes while exiting the array to the east (Fig. 3). P7 crossed the leading edge of the gust front, visible as a fine-line in WSR-88D data from KVNX, shortly before terminating the westward leg of the transect (Fig. 3b) and remained behind the gust front but ahead of the trailing precipitation for the duration of the eastward transect (Figs. 3c, d).

A scatter plot of P7 versus StickNet observations occurring while P7 was within 200 m of a StickNet probe reveals two distinct "populations" of observations coinciding with the westward and eastward legs of the transect (Fig. 4). Observations from the westward leg of the transect (denoted by warm colors) are both warmer and more moist than observations from the eastward transect occurring behind the gust front (Figs. 4a-c). P7 recorded relatively warmer temperatures and lower relative humidities compared to StickNet probes during the westward transect and cooler temperatures and more moist conditions on the eastward transect (Table 1). The differences in thermodynamic variables recorded by the two platforms produce additional discrepancy in commonly derived variables such as virtual and equivalent potential temperature (θ_v, θ_e). Differences between StickNet temperature and mobile mesonet slow temperature are particularly likely to induce errors in θ_v and θ_e. As slow temperature is utilized by the mobile mesonet for the calculation of water vapor mixing ratio, biases in slow temperature may propagate into θ_v, and θ_e as they are both dependent on water vapor mixing ratio. It is noted that the differences in θ_v and θ_e in Table 1 are mitigated by the opposing fluctuations in temperature and relative humidity. A probe recording similarly warmer conditions to those of the westward transect, but higher relative humidities would produce large positive fluctuations in θ_v and θ_e greater than 1 K. Pressure values between the two probes are well correlated, with the exception of a single StickNet probe which recorded lower pressures than the mobile mesonet during both passages of the probe, likely due to instrument bias and differing elevations (Fig. 4d). The Vaisala PTB series pressure sensors utilized by both StickNet and mobile mesonet probes have a much smaller time constant, resulting in better agreement between the two platforms.

The warmer, less moist conditions recorded by P7 as it travelled westward are consistent with vehicle translation exacerbating spatial biases induced by instrument time constants. As a mobile mesonet probe moving at 13.5 m s^{-1} will travel approximately 800 m before adjusting to its environment assuming a 1 minute time constant, a probe moving into a cooler environment would be expected to carry a warm bias across the gradient. Prior to crossing the gust front, P7 temperature observations correspond well to one minute segments of StickNet data centered on the time P7 was a minimum distance from the StickNet probe (Figs. 5, 6). Fast temperature and relative humidity values remain well correlated to StickNet observations immediately following gust frontal passage over P7 (Figs. 5, 7). However, a considerable lag in the response of slow temperature compared to StickNet values is observed immediately behind the gust front, resulting in upwards of a 1 K bias in P7 slow temperature values (Fig. 6).

P7 occupied a similar storm-relative position immediately behind the gust front throughout the duration of the eastward transect and sampled considerable heterogeneity in temperature and relative humidity within the outflow, but no large step changes. In contrast, the temperature values of each StickNet probe encountered during the eastward transect are rapidly declining (Figs. 5, 6). This decline is representative of StickNet temperature sensors that have not fully responded to the cooler environment behind the gust front.

Average winds speeds observed by StickNet probes for the five minutes following gust frontal passage were approximately 10 m s^{-1}. If StickNet time constants are assumed to be similar to those found in Fig. 1, roughly 1 minute would be necessary for temperature and relative humidity to achieve a 63.2% response to the environment trailing the gust front, with longer times required to achieve a full response. Given the rapid eastward progression of the gust front at about 18 m s^{-1}, StickNet probes would not have fully adjusted to the post-frontal environment until the gust front was at least 1 km past their position.

StickNet relative humidity values behind the gust front do not exhibit the rapid decline of the temperature observations (Fig. 7). A potential explanation for this that thermodynamic gradients along the gust front are not true step changes, but sharp gradients in temperature and relative humidity. The gradient in relative humidity appears to be sharper than temperature across the gust front in P7 time series data (Figs. 5, 7), which suggests that the StickNet relative humidity sensors may have had more time to adjust to their environment prior to the passage of P7 due to a more rapid change in environmental relative humidity. Additionally, considerable heterogeneity is observed in the time series of P7 relative humidity data, suggesting that environmental variability is at least partially responsible for the differing relative humidity values observed by post-frontal StickNet probes.

4. DISCUSSION

It has been shown that conflicting thermodynamic biases can be introduced by instrument time constants when stationary and mobile observational platforms are considered in tandem. These biases are introduced by differential motion with respect to the storm of mobile and stationary platforms. For example, a mobile mesonet probe travelling within a constant storm-relative framework will observe constant conditions given a steady-state storm, whereas a stationary probe may observe drastically different conditions at the position of the mobile probe if it has not fully responded to the passage of a thermodynamic gradient. Conversely, a mobile probe crossing a thermodynamic gradient in an opposite sense to the gradient motion will carry a time constant induced bias deeper into the environment behind the gradient than a stationary probe.

The differing values observed by mobile and stationary observing platforms in the vicinity of thermodynamic gradients have the potential to propagate into and enhance differences in derived variables such as θ_v and θ_e, and will be a source of error in commonly utilized analysis techniques such as time-to-space conversion and subsequent objective analysis (Markowski et al. 2002). In order to apply time-to-space conversion to in situ data collected from both mobile and stationary platforms in the vicinity of a thermodynamic gradient, one must be cognizant of the storm-relative motion of both platform types. If direct comparisons between mobile and stationary probes are available in a similar storm-relative location, it would be possible to utilize both observing platforms in a time-to-space conversion by relocating observations from platforms with larger time-constant induced spatial biases to locations where platforms with a smaller bias observed similar values. In this case, the spatial bias of the data will not necessarily be corrected, but mitigated, so that all probes utilized for time-to-space conversion exhibit similar spatial biases. Similarly, if reliable time constants of instrumentation can be calculated for each observation, each observation can be placed in a best estimate storm-relative position, allowing time-to-space conversion and objective analysis to be performed. However, the sharp kinematic gradients often coincident with thermodynamic gradients in convective storms and varying turbulent character of winds across the kinematic gradients make accurate calculation of time constants a challenging task without direct knowledge of air flow within the thermodynamic sensor housing. Furthermore, thermodynamic gradients within thunderstorms cannot be assumed to be step changes, so observations may be "corrected" to values less appropriate for a certain storm-relative position if the strength of thermodynamic gradients is poorly estimated. If the ability to make direct comparisons between platforms or accurately quantify instrument time constants is not available, a worst-case scenario is to remove thermodynamic observations from platforms exhibiting larger spatial biases in the vicinity of thermodynamic gradients. This method will allow kinematic values of both platforms to be utilized, as well as thermodynamic observations sufficiently removed in space from sharp thermodynamic gradients.

5. RECOMMENDATIONS

A glaring need in this study is the ability to accurately quantify time constants of thermodynamic instrumentation in varying kinematic conditions. Wind tunnel studies of mobile mesonet and StickNet instrumentation within their respective housing at various wind speeds and thermodynamic step changes will allow instrument time constants to be more accurately estimated and applied to situations observed in the field. While errors in time constant calculation will persist due to differing turbulence characteristics between observations made in a wind tunnel and the field, a more accurate estimate of time constants will allow errors introduced in time-to-space conversion of multiple platforms in the vicinity of a thermodynamic boundary to be mitigated.

Additionally, spatial bias analysis of additional cases is required. The 15 May 2009 MCS represents a relatively extreme case of differing spatial biases as mobile mesonet motion was alternately approximately directly across boundary motion on the westward leg of the transect, followed by a period of a relatively constant storm-relative position on the eastward leg. Cases in which more subtle biases induced by differing spatial biases and in which multiple probes of each platform type operated in proximity to one another may allow additional corrective measures for a joint-platform time-to space conversion to be performed.

Finally, as surface observing systems utilized in a severe-storm environment continue to evolve, improved instrument time constants may be obtained through the implementation of different instrumentation or improving the aspiration provided to existing instruments (Waugh and Fredrickson 2010).

6. ACKNOWLEDGEMENTS

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6. REFERENCES

Gill, G.C., 1979: Development of a small radiation shield for air temperature measurements on drifting buoys. Contract No. 01-7-038-827 (11), NOAA Data Buoy Office.

Lin, X., K.G Hubbard, and G.E. Meyer, 2001: Airflow characteristics of commonly used temperature radiation shields. J. Atmos. Oceanic Technol., 18, 329-339.

Markowski, P.M., J.M. Straka, and E.N. Rasmussen, 2002. Direct surface thermodynamic observations within the rear-flank downdrafts of nontornadic and tornadic supercells. *Mon. Wea. Rev.*, **130**, 1692-1721.

Richardson, S.J., F.V. Brock, S.R. Semmer, and C. Jirak, 1999: Minimizing errors associated with multiplate radiation shields. J. Atmos. Oceanic Technol., 16, 1862-1872.

Schroeder, J.L. and C.C. Weiss, 2008: Integrating research and education through measurement and analysis. Bull Amer. Meteor. Soc., 89, 793-798.

Straka, J.M., E.N. Rasmussen, and S.E. Fredrickson, 1996: A mobile mesonet for finescale meteorological observations. J. Atmos. Oceanic Technol., 12, 921-936.

Waugh, S. and S.E. Fredrickson, 2010: An improved aspirated temperature system for mobile meteorological observations, especially in severe weather. Preprints 25th Conf. on Severe Local Storms, Denver, CO, Amer. Meteor. Soc., P5.2.

Weiss, C.C. and J.L. Schroeder, 2008: StickNet – A new portable, rapidly-deployable, surface observing system. Annual Meeting of the American Meteorological Society, New Orleans, LA, Amer. Meteor. Soc., P4A.1.

Wurman, J., 2008: Preliminary results and report of the ROTATE-2008 radar / in-situ / mobile mesonet experiment. Preprints, 24th Conf. on Severe Local Storms, Savannah, GA, Amer. Meteor. Soc., 5.4

Table 1: Difference between StickNet and mobile mesonet observations during period of intercomparison on 15 May 2009. Mobile mesonet values have been subtracted from StickNet values.

Variable	Transect Direction	
Fast Temperature	East	-0.884 K
Slow Temperature	East	-0.657 K
Relative Humidity	East	2.304%
Pressure	East	0.458 hPa
θ_v	East	-0.940 K
θ_e	East	-1.057 K
Fast Temperature	West	0.413 K
Slow Temperature	West	0.690 K
Relative Humidity	West	-1.716%
Pressure	West	0.481 hPa
θ_v	West	0.420 K
θ_e	West	0.845 K

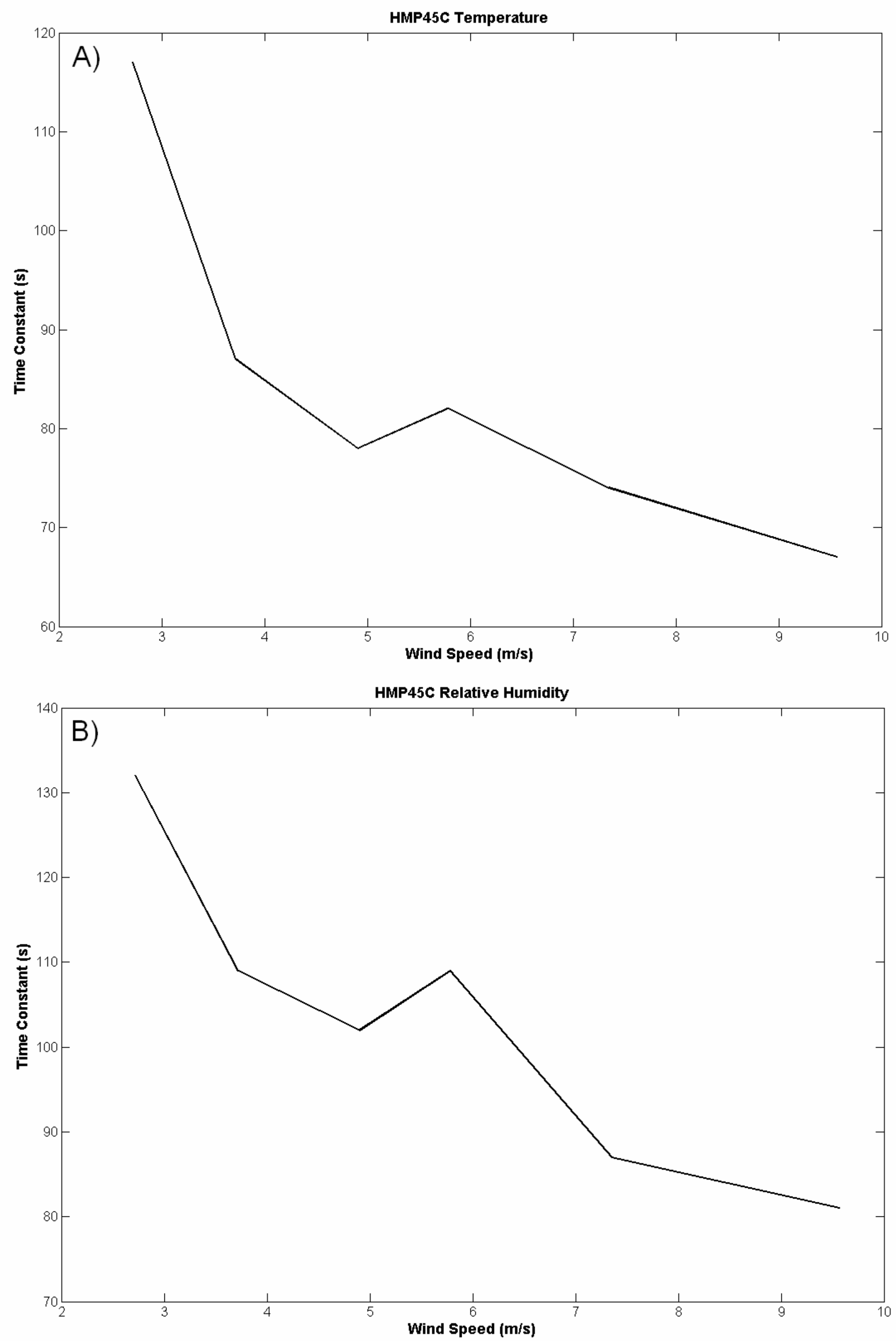

Figure 1: Time constant values (s) calculated for HMP45C sensors housed within Type A StickNet probes for (A) temperature and (B) relative humidity.

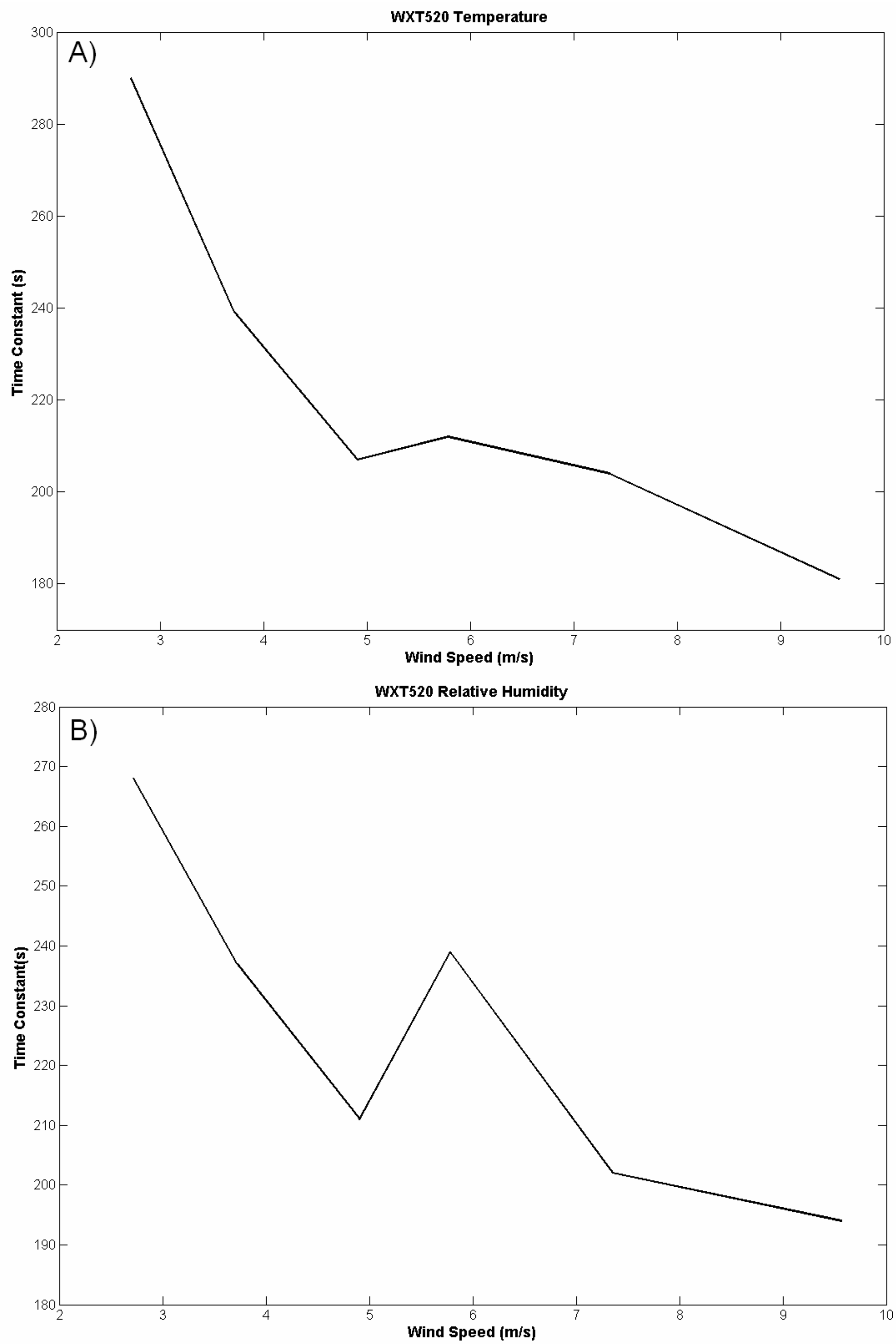

Figure 2: Same as Fig. 1 except for the WXT520 sensor housed within StickNet Type B probes.

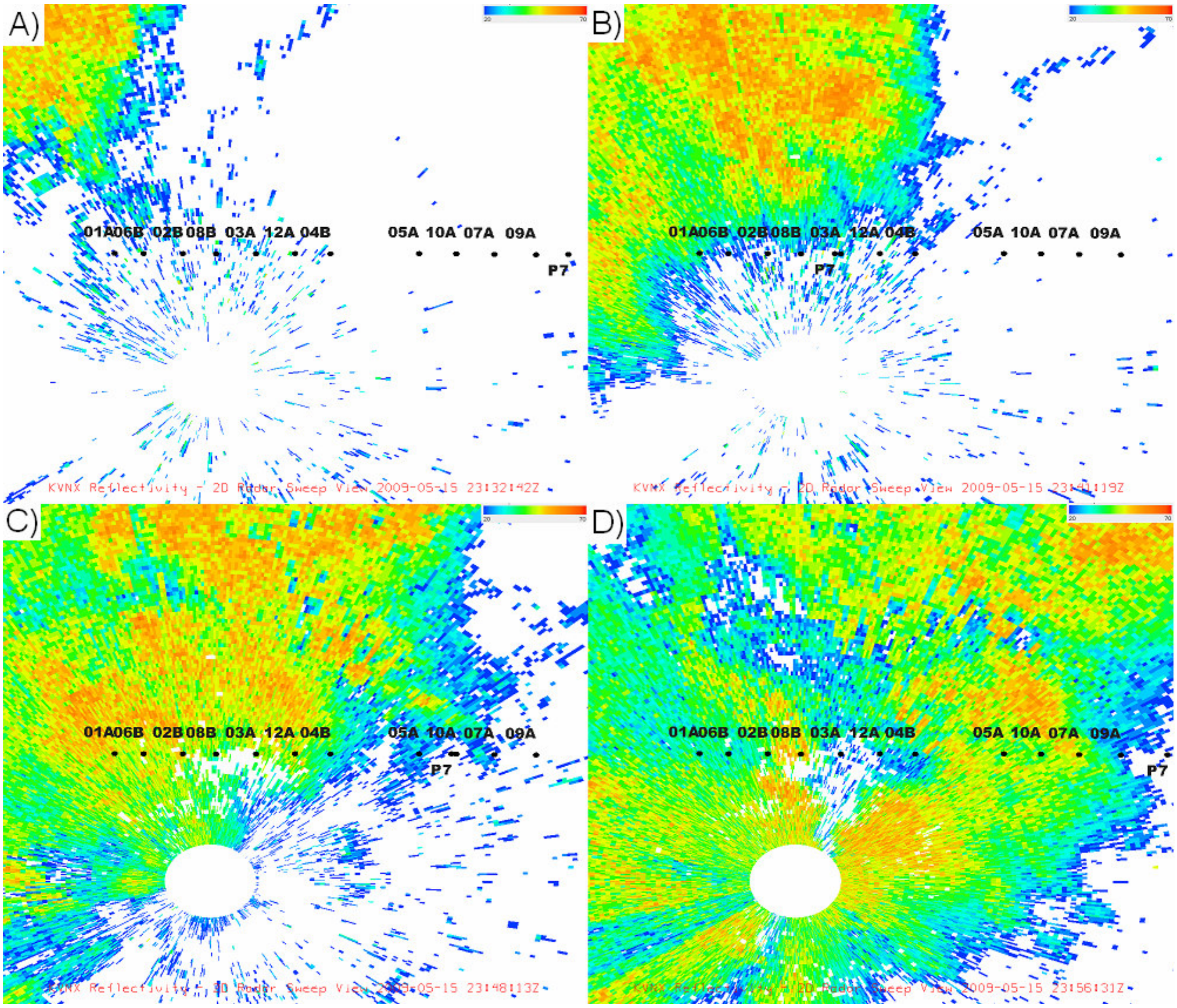

Figure 3: Overlay of StickNet and mobile mesonet probe positions with KVNX 0.5° elevation scan reflectivity (dBZ) . Probe positions correspond to times of (A) 23:30:30 UTC, (B) 23:42:30 UTC, (C) 23:50:00 UTC and (D) 23:55:00 UTC.

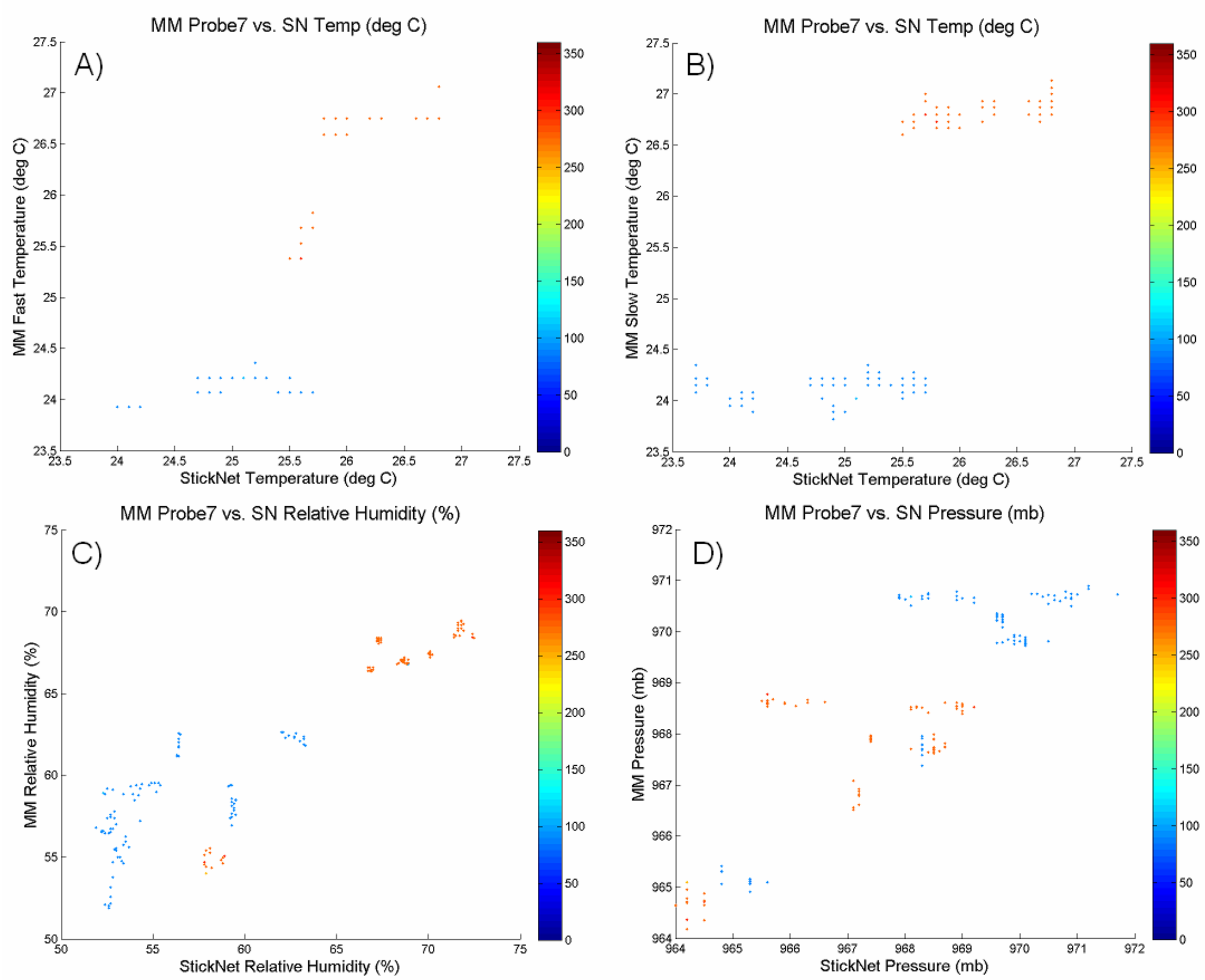

Figure 4: Scatterplot of P7 versus StickNet observation for (A) fast temperature (°C), (B) slow temperature (°C), (C) relative humidity (%), and (D) pressure (hPa). Colorbars represent vehicle heading of P7 in degrees.

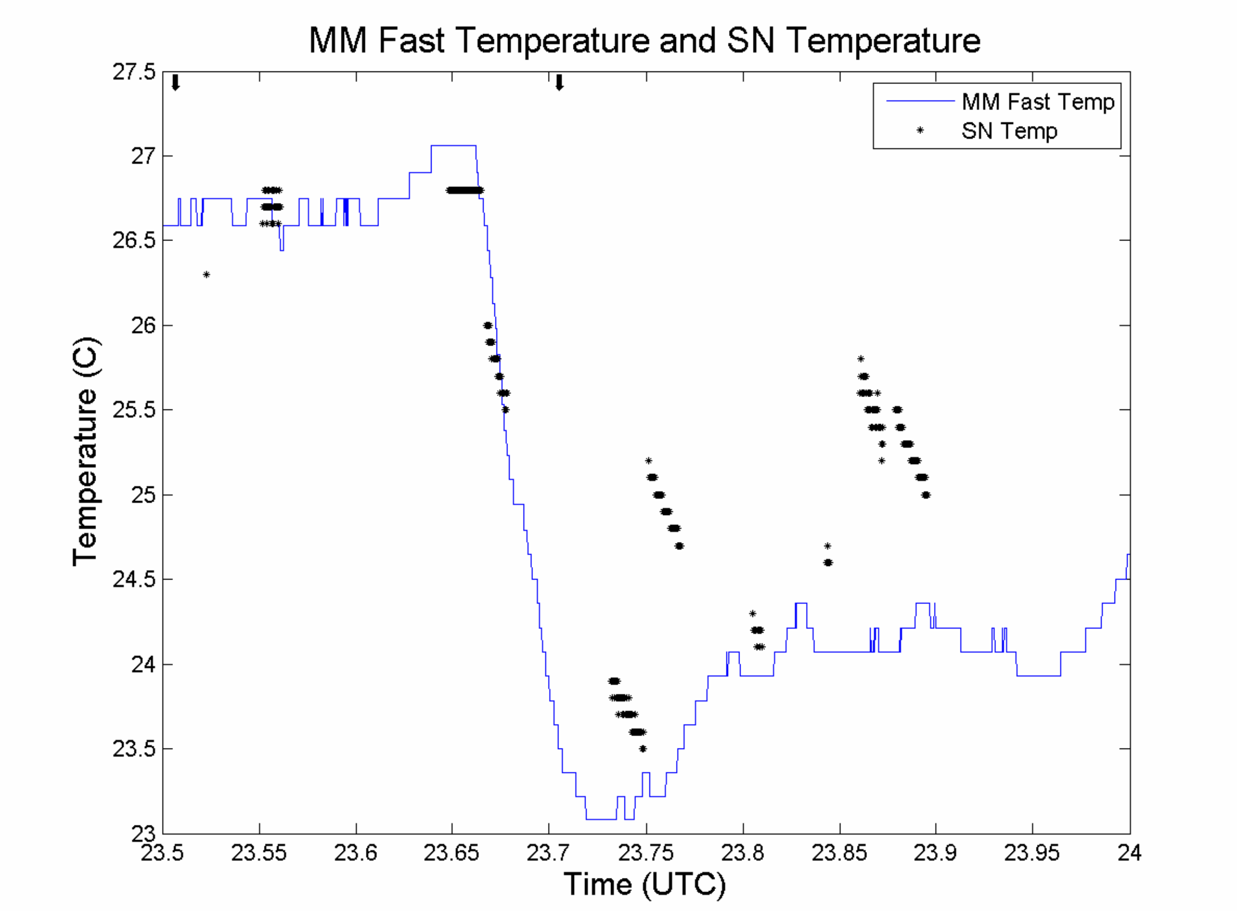

Figure 5: Time series of P7 fast temperature (°C) with 1 minute intervals of StickNet temperature (°C) centered on the time of the closest approach of P7. Thin arrows on upper axis denote beginning and end of westward leg of P7 transect.

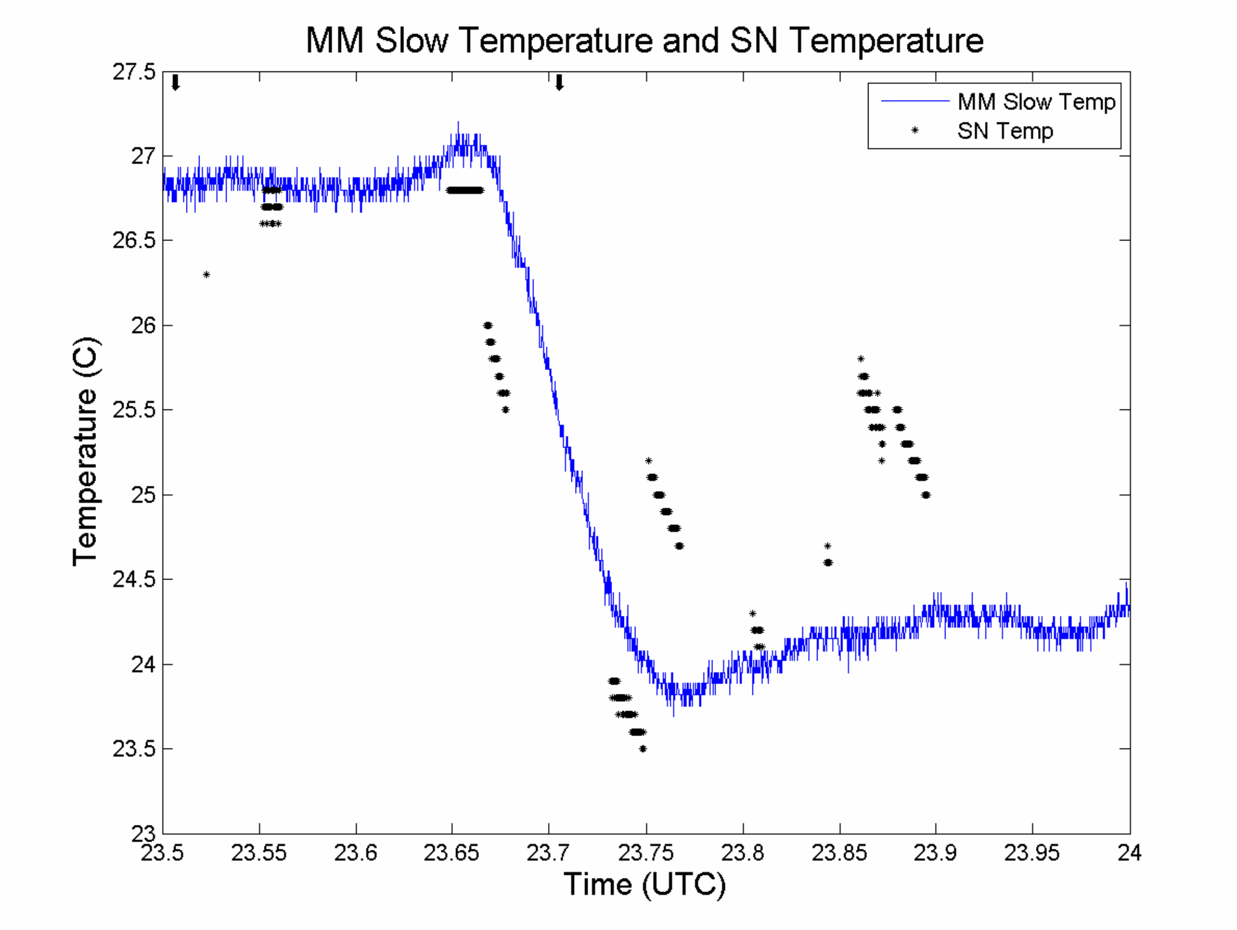

Figure 6: Same as Fig. 5 but for P7 slow temperature (°C).

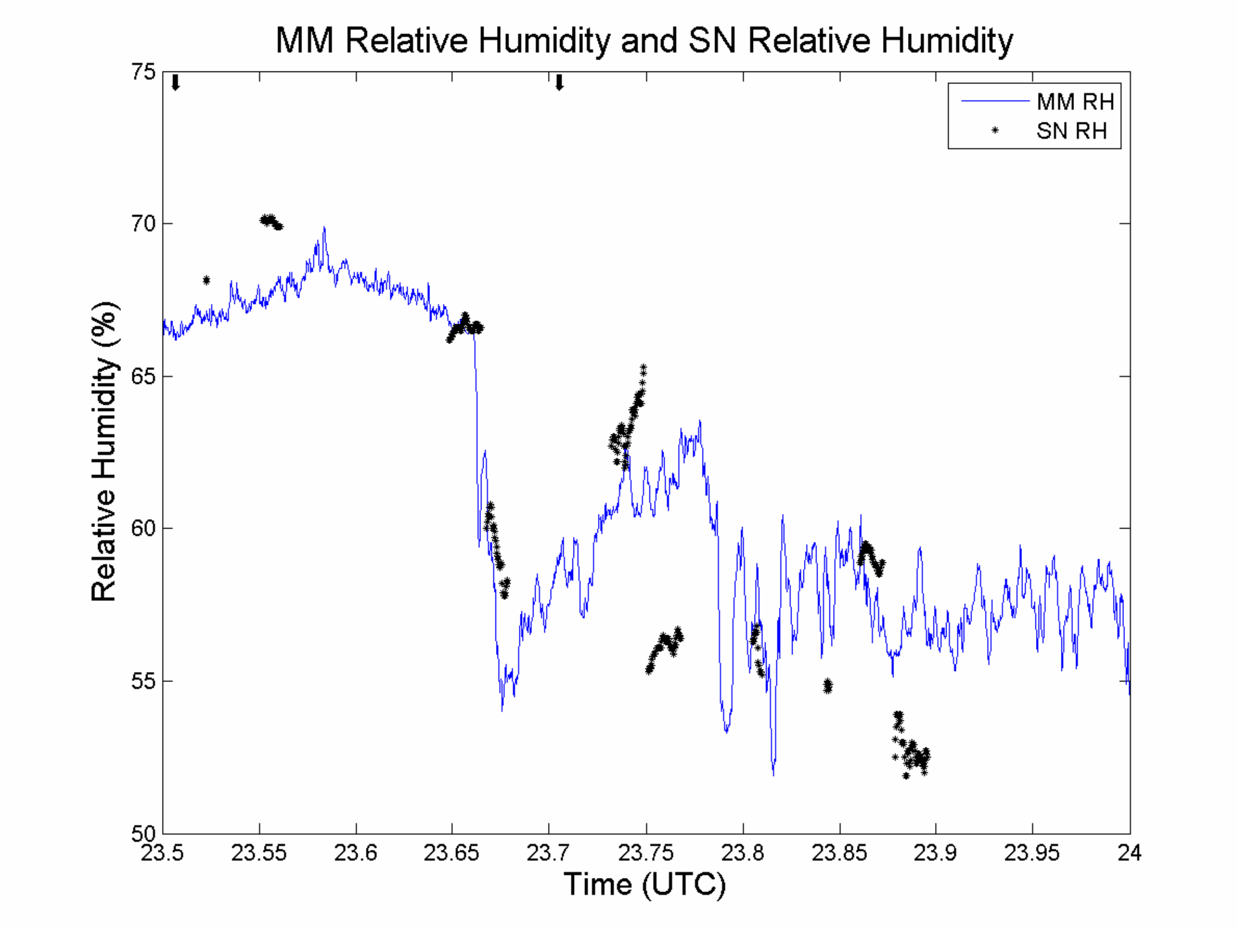

Figure 7: Same as Fig. 5 but for P7 relative humidity (%) and StickNet relative humidity (%).