

# Spatially Distributed Hygrometer Measurements

# Introduction

- Measuring moisture content, movement, composition, etc. at any given time is one of the most difficult, yet essential aspects of Atmospheric Thermodynamics
- Popular instruments used to measure relative humidity, directly or indirectly, include psychrometers and hygrometers
- Wet and Dry Bulb psychrometer is a type of hygrometer that uses two thermometers (pictured), in order to indirectly measure the relative humidity of the air
- By exposure to air particles through movement, a wet bulb temperature is recorded as water evaporates from damp cotton, and a dry bulb temperature is recorded that gauges the temperature of the air

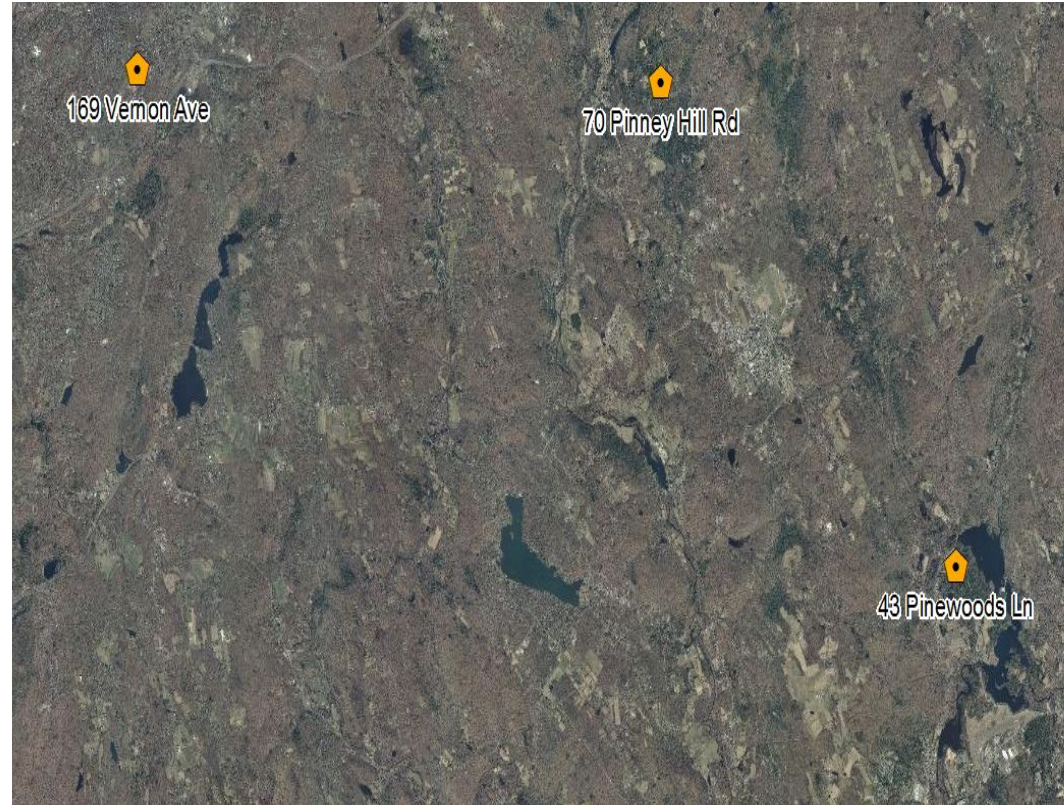


# Methodology and Data Collection

- Measurements taken after sunset, night temperatures, cooling
- Timed 5 minute measurement rather than continuous to ensure wet bulb stays wet
- Measurements taken between 7pm and 9pm
- Calibration required for more accurate measurements. Allow hygrometer to adjust to outdoor temperature for 15-20 minutes.
- Sources used for data comparison:
  - Quality Controlled Local Climatological Data (QCLCD) (Version 2.5.11)
    - Monthly Data with hourly measurements for the state of Connecticut
    - If hygrometer measurement was taken after 18:51 but before 19:51, the values for 18:51 were used. If measurement was taken after 19:51, the values from the 19:51 readings were used.
    - Downloaded in .txt format for Oct. and Nov. from <https://www.ncdc.noaa.gov/qclcd/QCLCD>
  - UConn weather station data
    - Daily Archive Records for T and Humidity with measurements recorded every five minutes throughout the course of the day
    - An average representative value was taken for each day based on the times of measurement for the hygrometers
    - <http://137.99.85.41/weather/index.html>

# Spatial Distribution of Hygrometers

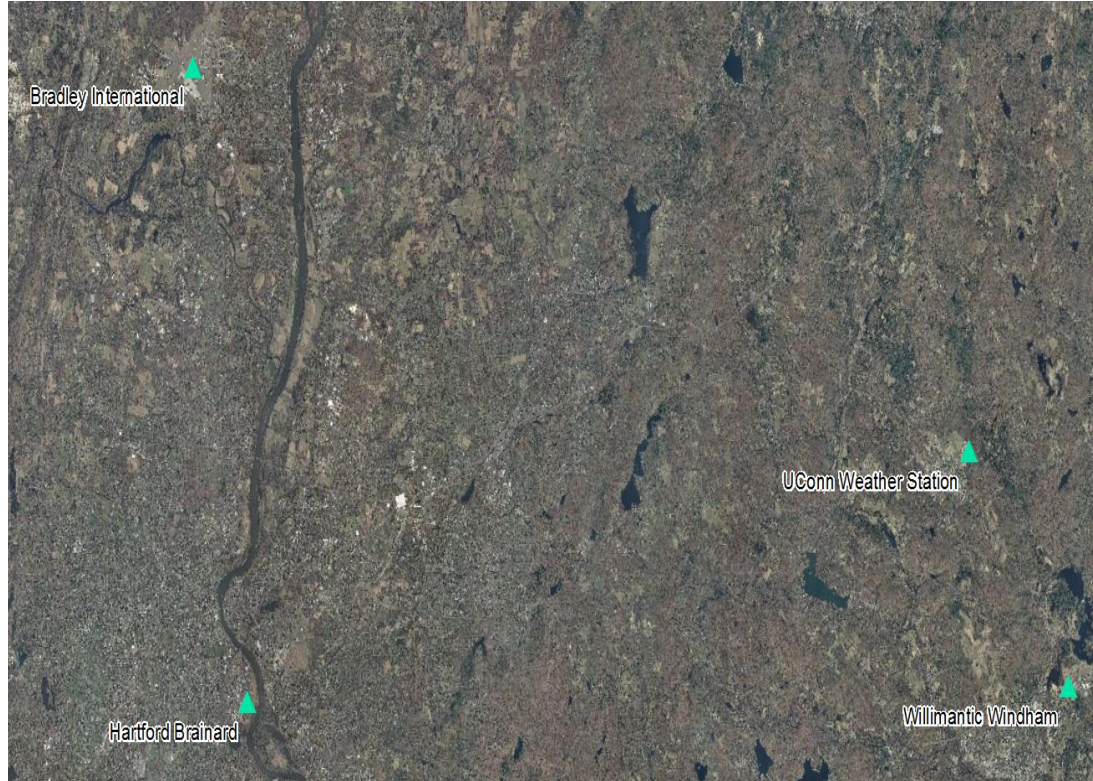
- 3 Locations
  - A : 43 Pinewoods Ln, Mansfield Center
  - B : 169 Vernon Ave, Vernon
  - C : 70 Pinney Hill Rd, Willington
- Distance from A  $\rightarrow$  B = 31.3 km
- Distance from B  $\rightarrow$  C = 18.4 km
- Distance from C  $\rightarrow$  A = 15.8 km
- Area enclosed by ABC = 108 sq. km



Spatial Distribution of Hygrometer Station Locations



# Spatial Distribution of Weather Stations



Windham → UConn : 12.78 km

UConn → Bradley: 52.39 km

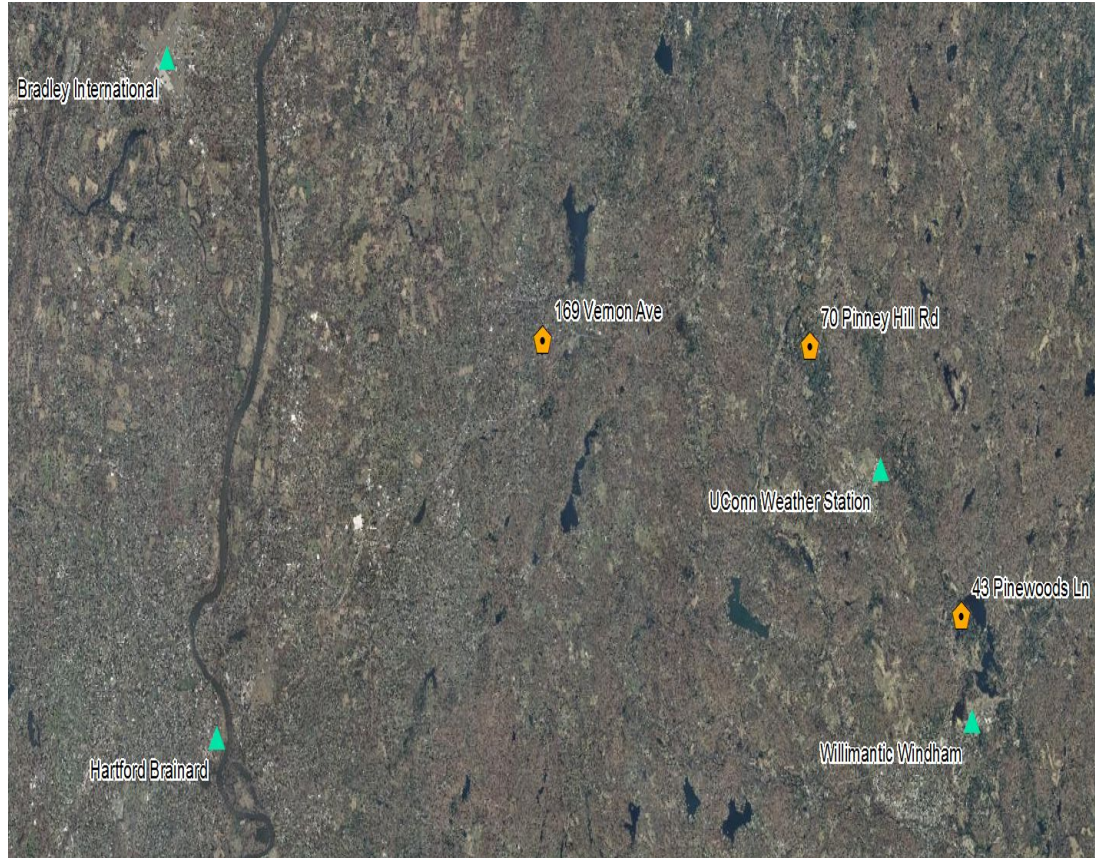
Bradley → Brainard: 30.23 km

Brainard → Windham: 51.99 km

Station Network Area Coverage: 998 km<sup>2</sup>

Spatial Distribution of Meteorological Station Locations

# Spatial Distribution of All Stations



UConn Weather Station is the closest for Stations B (Pinney Hill Rd) and C (Vernon Ave)

$B \rightarrow \text{UConn} = 23.97 \text{ km}$

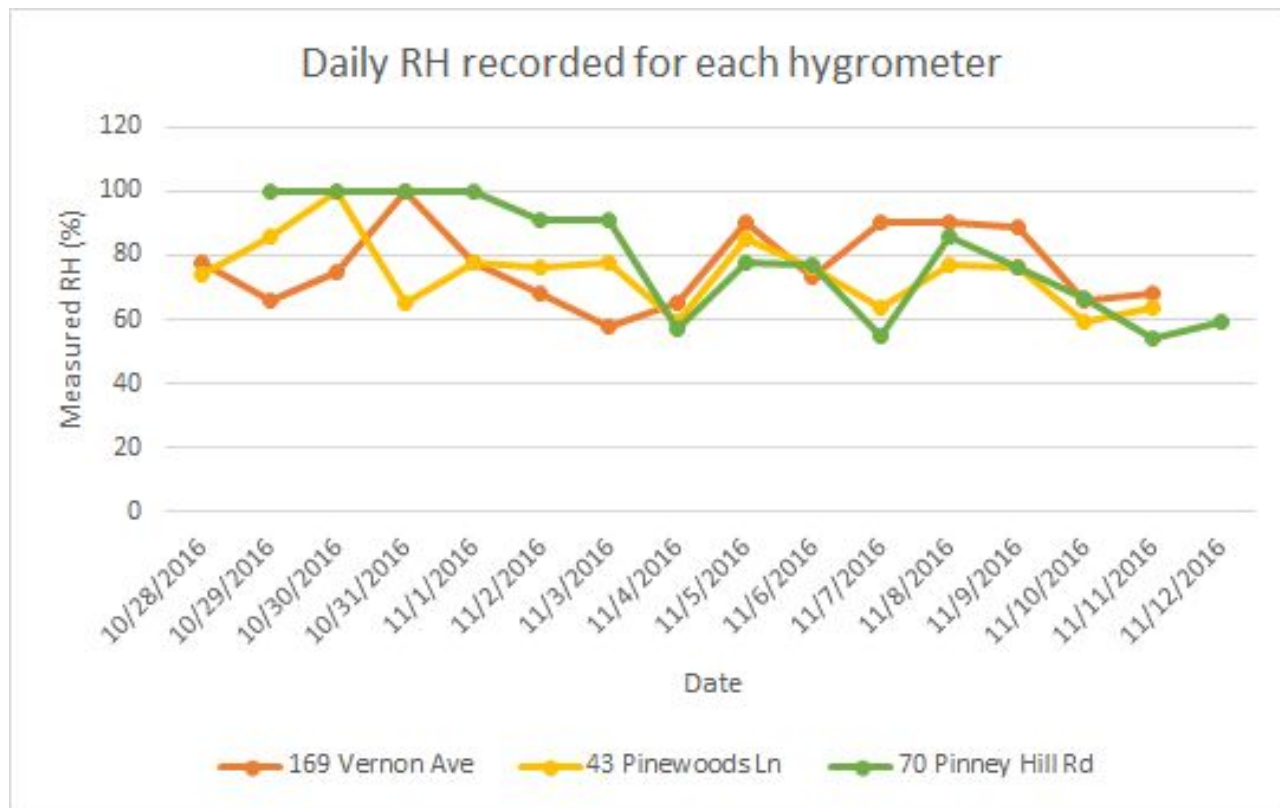
$C \rightarrow \text{UConn} = 7.28 \text{ km}$

The Willimantic Windham station is nearest to Station A (Pine Woods Ln)

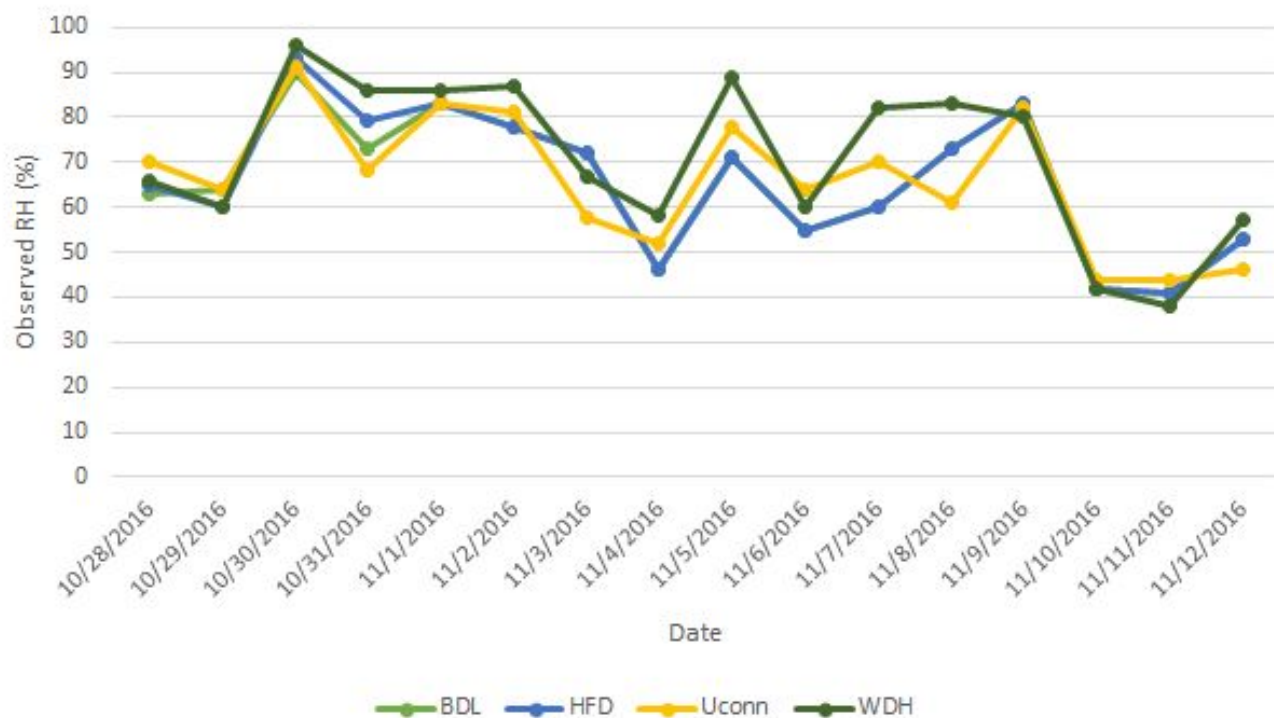
$A \rightarrow \text{Windham} = 4.71 \text{ km}$



# Results

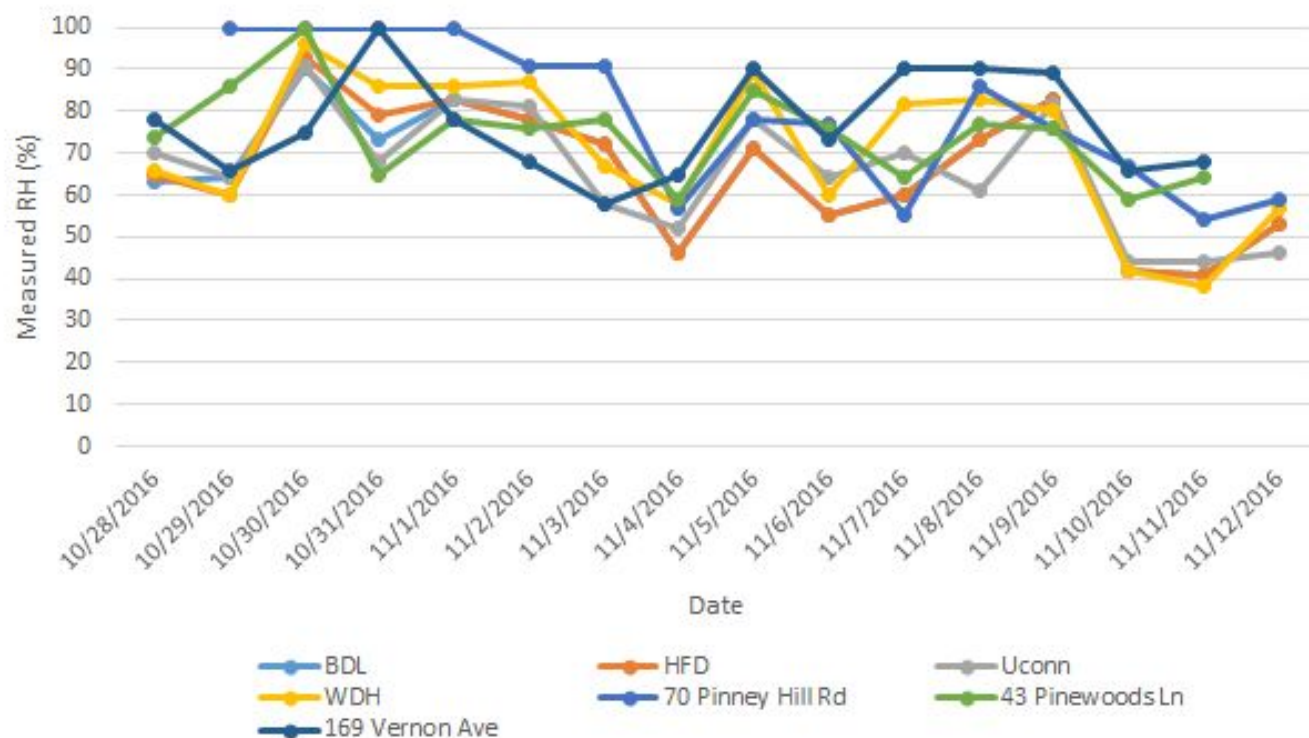


RH observations amongst reference stations





# RH observations for all stations

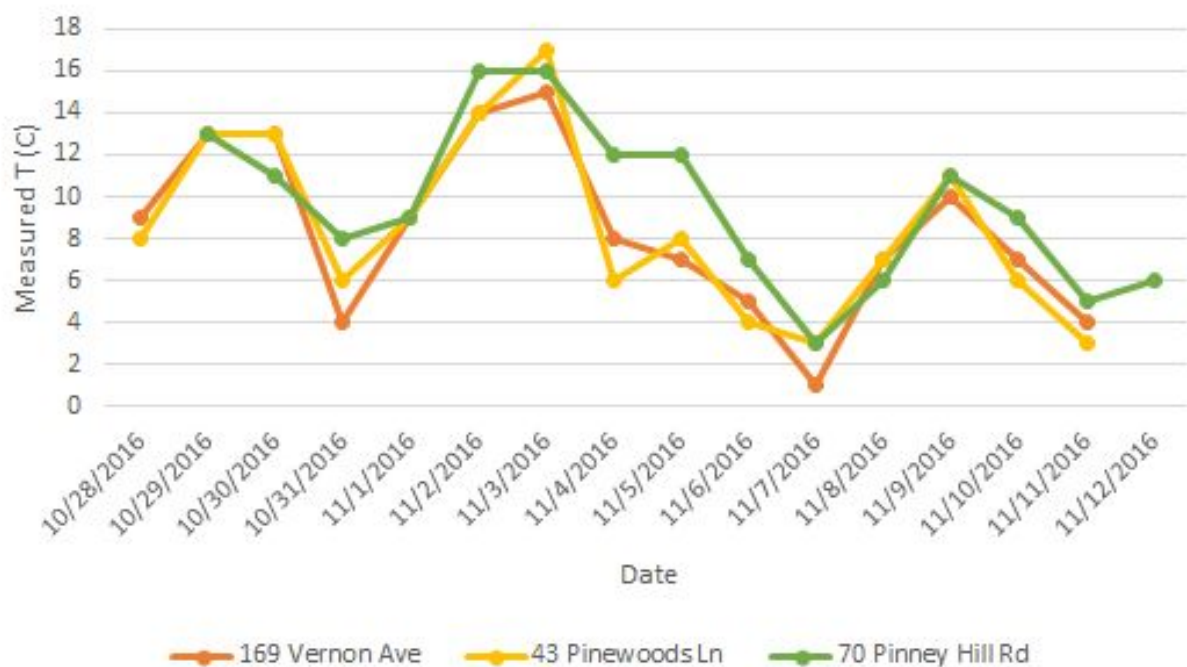


# Data Analysis

- ANOVA for station data showed no statistical difference in location.
  - Compared each experimental location to the nearest station.
- ANOVA comparing the experimental locations showed no statistical difference between locations.
  - ANOVA with and without data points taken before 7:00 pm or after 8:00 pm.
- Paired t-test ( $\alpha = 0.05$ ):

Paired t-test	P value	RMSE	Mean bias
All locations	8.0E-5	16.2%	9%
Location A only	0.13	13.5%	5%
Location B only	0.021	16.9%	10%
Location C only	0.005	17.9%	12%

Daily T recorded for each hygrometer

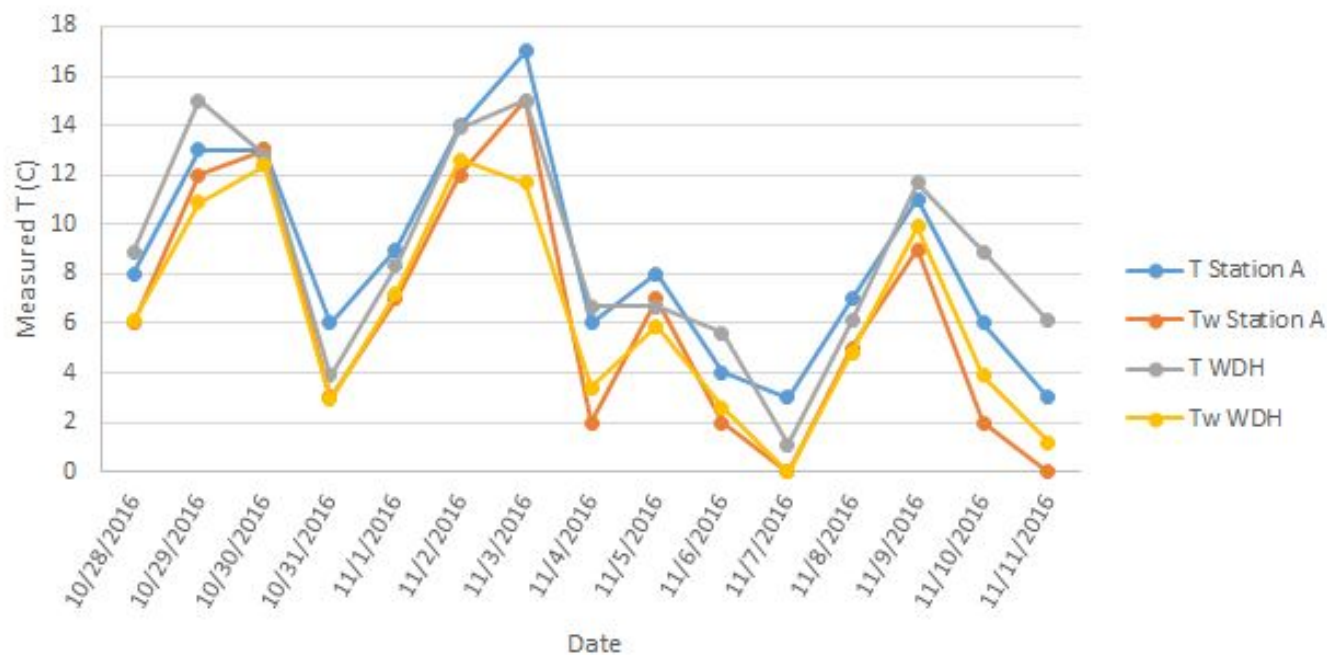


T vs. Tw for Station A





T vs. Tw for Station A vs. Reference Data from WDH

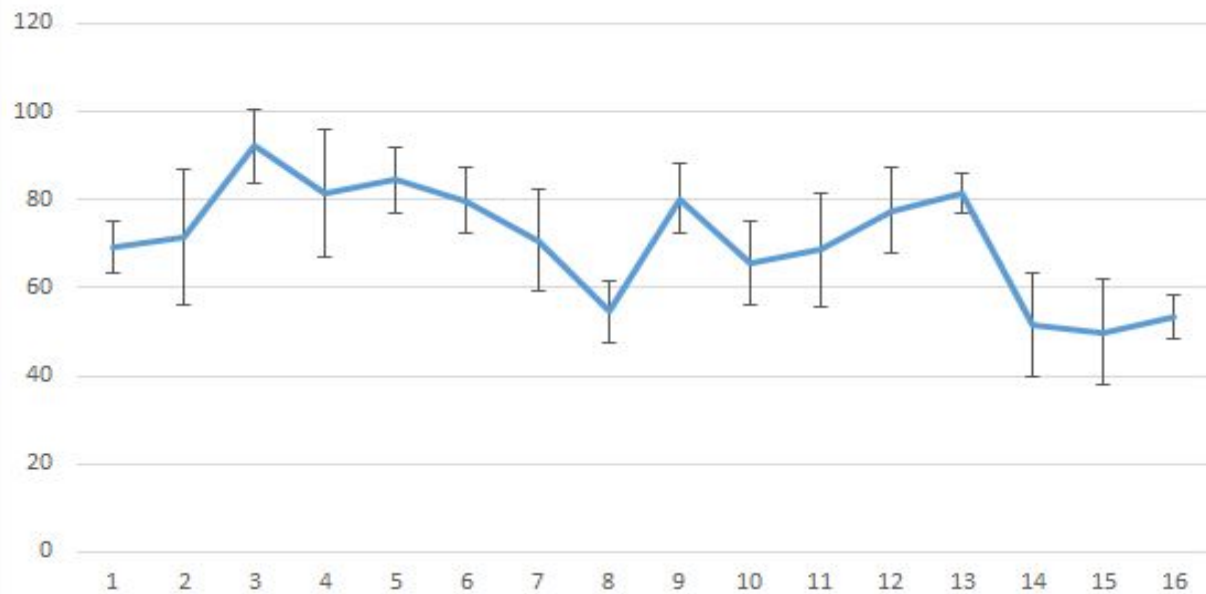


T vs. Tw for Station C



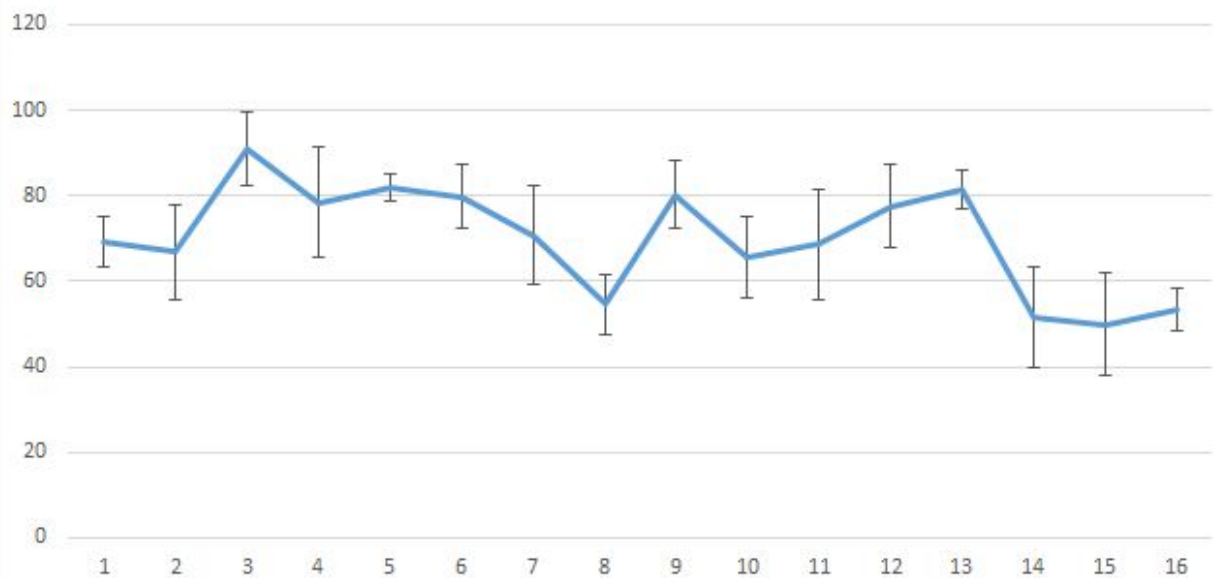
Experiment	Description	Overall Mean	SD	n
a	18:51 (all)	69.88715596	15.70265	109
b	19:51 (all)	71.15321101	15.56418	109
c	19:51 (no 13:30 or $Tw > T$ )	70.41619048	15.13691	104
d	18:51 (no 13:30 or $Tw > T$ )	69.10190476	15.21847	104

Mean with SD error (all compared to 19:51 airport times)





Mean with SD error (19:51) (no 13:30 or Tw>T)



# Conclusion

- Paired t-test comparison of all experimental data(excluding outliers) to nearest station data shows significant difference in RH values.
- Paired t-test for individual locations results in location A RH values statistically indifferent, while locations B and C result in significant difference in RH values.
- Hygrometer measurements using this method may result in accurate results as demonstrated at location A.
- Future studies aimed at interpolating station data to get a better representative comparison of RH



*Questions wake people up. They prompt new ideas. They show people new places, new ways of doing things.*

**Michael Marquardt**

# References

1. Wallace J., and P. Hobbs, Atmospheric Science, An Introductory Survey, Academic-Press, 2006, 2<sup>nd</sup> edition.
2. Dingman, S.L., Physical Hydrology, Second Edition, Waveland Press Inc., 2002.
3. Chow, V.T., D.R. Maidment, and L.W. Mays, Applied Hydrology, McGraw-Hill, 1988.
4. Wexler, Arnold, and W. G. Brombacher. *Methods of measuring humidity and testing hygrometers*. US Government Printing Office, 1951.

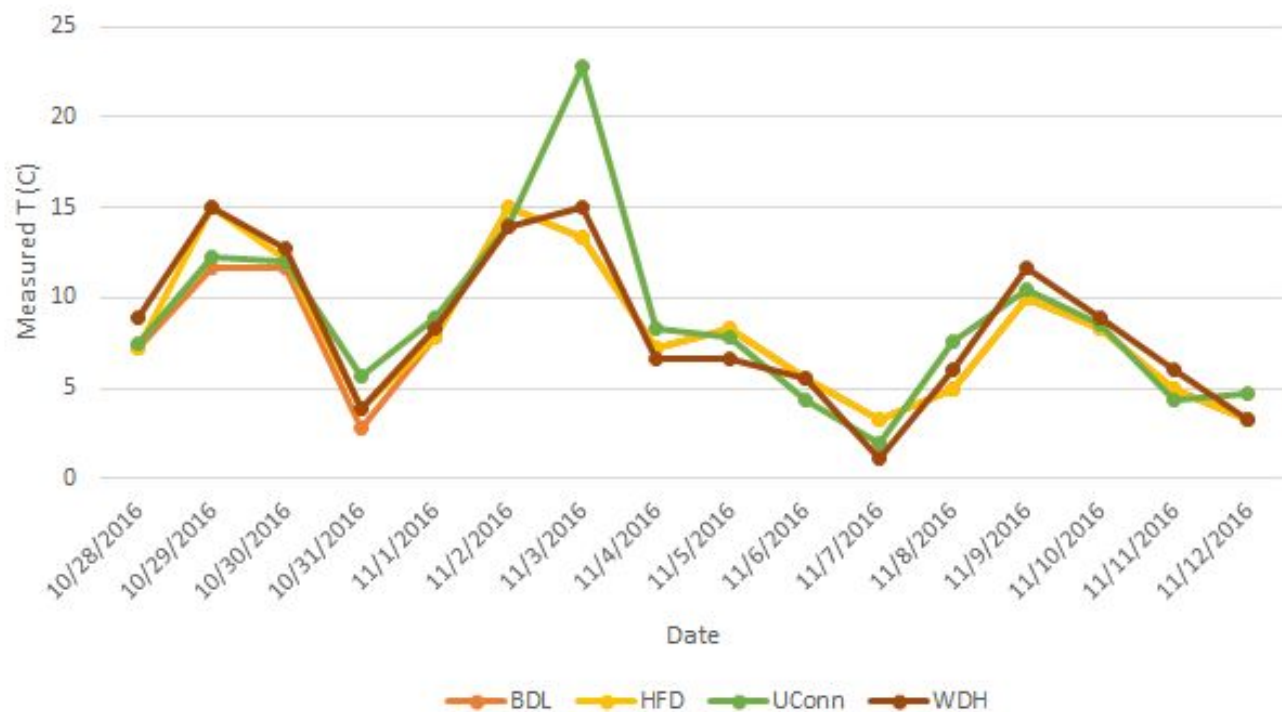


# Supplementary Slides

Date	Mean	SD
10/28/2016	69.33333	5.785038
10/29/2016	72.33333	16.70529
10/30/2016	92.14286	8.55236
10/31/2016	81.57143	14.36265
11/1/2016	84.42857	7.457818
11/2/2016	79.85714	7.515064
11/3/2016	70.81429	11.63793
11/4/2016	54.71429	7.06433
11/5/2016	80.28571	7.91021
11/6/2016	65.71429	9.586697
11/7/2016	68.71429	12.86746
11/8/2016	77.57143	9.76144
11/9/2016	81.28571	4.535574
11/10/2016	51.71429	11.78579
11/11/2016	50	12.09683
11/12/2016	53.6	4.97996

Date	Mean	SD
10/28/2016	69.33333	5.785038
10/29/2016	66.8	10.91788
10/30/2016	90.83333	8.565434
10/31/2016	78.5	12.97305
11/1/2016	81.83333	3.188521
11/2/2016	79.85714	7.515064
11/3/2016	70.81429	11.63793
11/4/2016	54.71429	7.06433
11/5/2016	80.28571	7.91021
11/6/2016	65.71429	9.586697
11/7/2016	68.71429	12.86746
11/8/2016	77.57143	9.76144
11/9/2016	81.28571	4.535574
11/10/2016	51.71429	11.78579
11/11/2016	50	12.09683
11/12/2016	53.6	4.97996

T observations for reference stations



T vs. Tw for Station B



# Data and Error Analysis

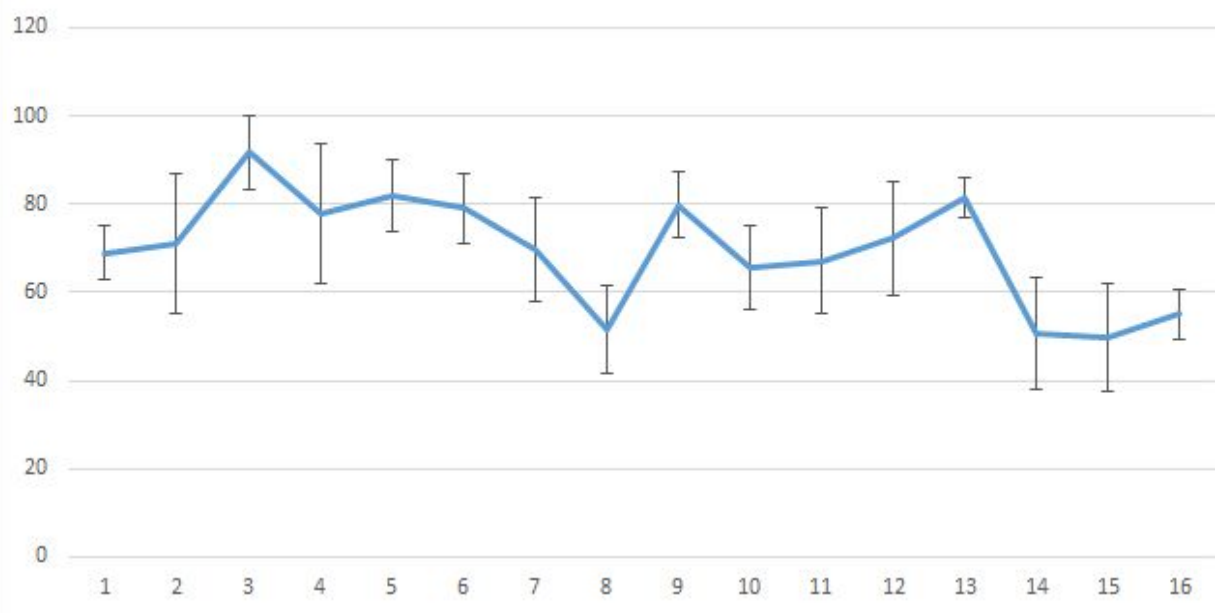
- We analyzed the results, and calculated the daily and overall sample mean and standard deviation for:
  - Hygrometer measurements only taken between 18:51 and 19:51, compared against UConn, and airport station hourly data recorded at 18:51
  - Hygrometer measurements only taken after 19:51, compared against UConn, and airport station hourly data recorded at 19:51
  - All Hygrometer measurements, compared against UConn, and airport station hourly data recorded at 18:51
  - All Hygrometer measurements, compared against UConn, and airport station hourly data recorded at 19:51
  - All Hygrometer measurements (except an outlier measurement taken at 13:30), compared against UConn, and airport station hourly data recorded at 18:51
  - All Hygrometer measurements (except an outlier measurement taken at 13:30), compared against UConn, and airport station hourly data recorded at 18:51

# Data and Error Analysis

- All Hygrometer measurements (except an outlier measurement taken at 13:30 and measurements where the Wet Bulb T > Dry Bulb T), compared against UConn, and airport station hourly data recorded at 18:51
- All Hygrometer measurements (except an outlier measurement taken at 13:30 and measurements where the Wet Bulb T > Dry Bulb T), compared against UConn, and airport station hourly data recorded at 18:51

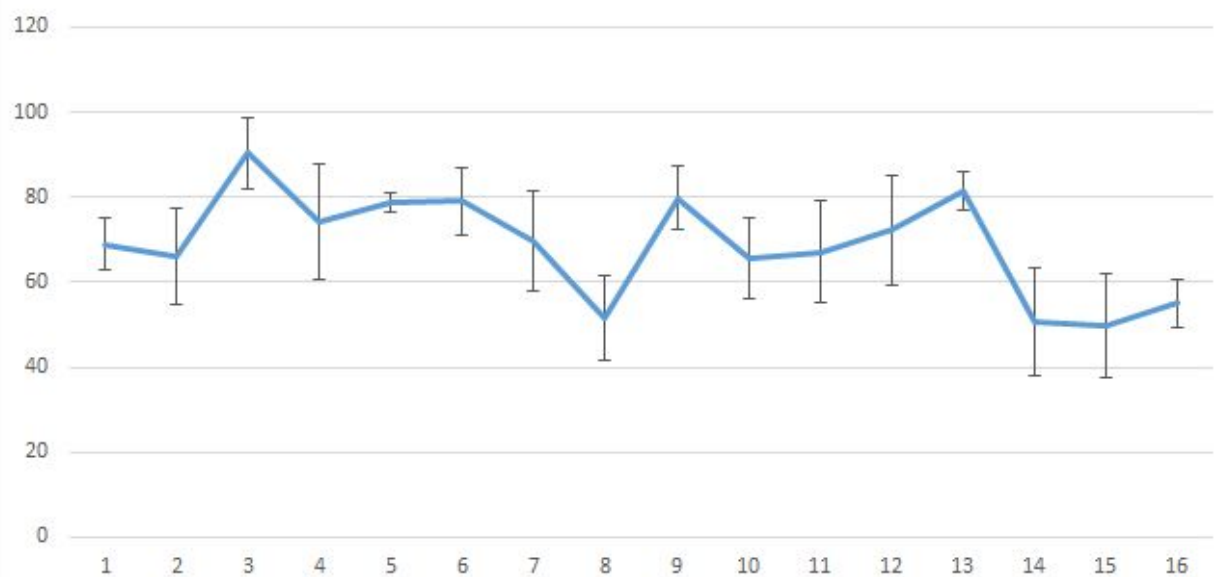
Description	Overall Mean	SD	n
18:51 (all)	69.88715596	15.70265	109
19:51 (all)	71.15321101	15.56418	109
18:51 to 19:51 only	69.55	15.91	103
after 19:51 only	69.4	14.81	20
19:51 (no 13:30)	71.53853211	15.95052	108
18:51 (no 13:30)	70.27247706	16.11624	108
19:51 (no 13:30 or $T_w > T$ )	70.41619048	15.13691	104
18:51 (no 13:30 or $T_w > T$ )	69.10190476	15.21847	104

Mean with SD error (all compared to 18:51 airport times)

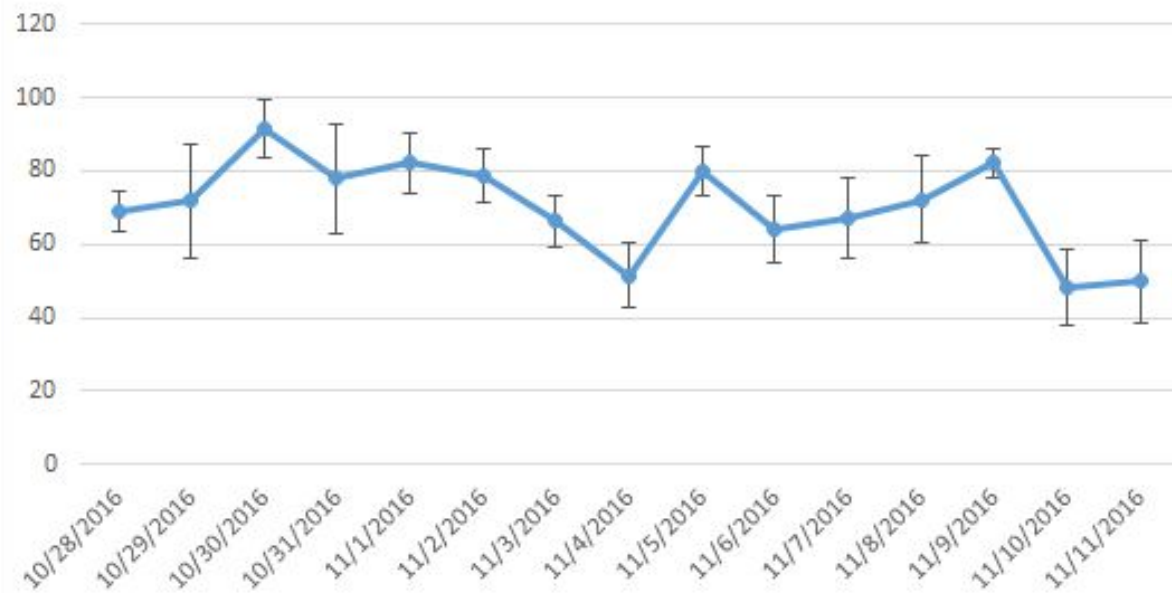




Mean with SD error (18:51, no 13:30 or Tw>T)



Mean RH (no values before 19:00 or after 20:00)





**Table S8. Mixing Ratios determined from the Skew T - ln P chart for each Temperature measured in this experiment. These values were used for consistency when calculating RH.**

Temperature	Mixing Ratio (g/kg)	Temperature	Mixing Ratio (g/kg)
-5	2.6	7	6.1
-4	2.8	8	6.8
-3	3	9	7
-2	3.4	10	7.6
-1	3.6	11	8
0	3.8	12	8.7
1	4	13	9.3
2	4.4	14	10
3	4.7	15	10.5
4	5	16	11
5	5.5	17	11.9
6	5.8		

Reference Station	Coordinates
HFD	Lat. = 41.736, Long. = -72.650
BDL	Lat. = 41.937, Long. = -72.681
WDH	Lat. = 41.741, Long. = -72.183
UConn	Lat. = 41.815, Long. = -72.240