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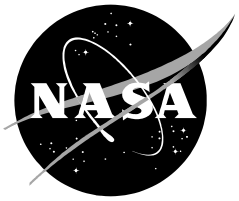

RSA/Legacy Wind Sensor Comparison. Part I: Western Range

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March 2006

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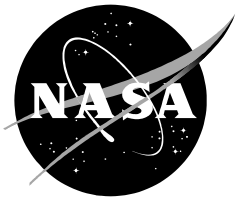

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March 2006

Acknowledgements

The authors thank Dr. Francis J. Merceret of the Kennedy Space Center Weather Office for his guidance.

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Executive Summary

The goal of this study was to evaluate the performance of ultrasonic wind sensors being used to replace mechanical wind sensors at the Western Range (WR) at Vandenberg Air Force Base, California. Launch Weather Officers, forecasters, and Range Safety analysts need to understand the performance of wind sensors at the WR and Eastern Range (ER), at Cape Canaveral Air Force Station, Florida, for weather warnings, watches, advisories, special ground processing operations, launch pad exposure forecasts, user Launch Commit Criteria (LCC) forecasts and evaluations, and toxic dispersion support. The current weather tower wind instruments are being changed from the Legacy cup-and-vane sensors to ultrasonic sensors through the Range Standardization and Automation (RSA) program. The Legacy sensors measure wind speed and direction mechanically. The ultrasonic RSA sensors have no moving parts. Previous studies have shown these differences in wind measuring techniques have caused differences in the statistics of peak wind speed. The 45th Weather Squadron (45 WS) and the 30th Weather Squadron (30 WS) requested the Applied Meteorology Unit (AMU) to compare data between RSA and Legacy sensors to determine if there are significant differences. This report addresses the comparison of Legacy and RSA wind speed and direction sensors on the WR.

A 26-day archive of 1-minute WR Legacy and RSA wind data was provided to the AMU by the 30 WS. The period-of-record (POR) was 29 May–23 June 2005 at the following 5 towers: 301, 300, 102, 60 and 54. The 5 towers were instrumented at numerous levels, ranging from 12 ft to 300 ft. The WR Legacy data archive covered a 6-hour interval from 1600–2200 UTC each day and included the 1-minute average wind speed/direction and the peak wind speed/direction used to evaluate LCC during operations.

The Legacy wind data was obtained from a cup-and-vane system with the vane (direction) and cups (speed) mounted separately, but at the same level. The RSA wind data was obtained from an ultrasonic-type sensor that derives wind speed and direction from the effect of wind on the transit time of ultrasonic pulses between three electro-acoustic transducers configured in an equilateral triangle. Each level had one Legacy system and 2 RSA sensors. The Legacy system was mounted on the corner of the tower facing the predominant wind direction whereas the two RSA sensors were mounted on corners opposite one-another, but not on the same corner as the Legacy System. Data from a total of 34 RSA sensors, collocated in pairs with Legacy speed/direction systems were used.

The AMU first matched the 6-hour time series of 1-minute wind speed and direction information from every day for all three sensors at all levels of each tower. The Legacy wind direction information was then used to obtain samples with all sensors on the upwind side of the tower. This procedure was followed to minimize effects of tower obstruction on the sensor inter-comparisons. A total of 153,961 1-minute comparisons of Legacy versus RSA wind information were obtained after the screening process.

The overall comparison of all the data resulted in the following:

- Overall Average Speed: Legacy 10.35 kts, RSA 10.15 kts, RSA:Legacy Ratio 0.981
- Overall Peak Speed: Legacy 13.30 kts, RSA 14.05 kts, RSA:Legacy Ratio 1.056

The AMU also examined each pair of Legacy/RSA and RSA/RSA sensors for consistency in wind speed and wind direction. This procedure identified several RSA sensors with systematic differences from the Legacy wind speed and/or direction and the other collocated RSA sensor. Nine of the RSA sensors showed variable differences from the Legacy sensor in average wind speed patterns. Four RSA sensor pairs showed differences in wind direction from the Legacy sensor in the range of 15 to 30 degrees. However, wind direction readings from these 4 RSA sensor pairs were much closer to each other, suggesting possible problems with the Legacy wind sensor direction.

The AMU used the Legacy wind sensors as “reference” sensors and identified 18 RSA sensors with the closest agreement to their collocated Legacy sensor, based on comparisons of wind speed and direction. The 18 RSA sensors were used to define a composite average-Legacy/RSA comparison and the peak wind speed data from the same 18 RSA sensors were used to define a composite peak-Legacy/RSA wind speed comparison.

Comparisons of the 18 sensor composite were slightly different than the overall comparison cited above.

- Composite Average Speed: Legacy 10.31 kts, RSA 10.57 kts, RSA:Legacy Ratio 1.025
- Composite Peak Speed: Legacy 13.42 kts, RSA 14.48 kts, RSA:Legacy Ratio 1.079

The positive bias in the composite RSA average wind speed increased from +0.5 kts at 15 kts, to +1 kt at 25 kts. The positive bias in the composite RSA peak wind speed increased from +1 kt at 15 kts to +2 kts at 30 kts.

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1. Introduction

Launch Weather Officers, forecasters, and Range Safety analysts need to understand the performance of ultrasonic wind sensors at the Western Range (WR) at Vandenberg Air Force Base, California, and Eastern (ER) Range at Cape Canaveral Air Force Station, Florida. Data from wind sensors are used for weather warnings, watches, advisories, special ground processing operations, launch pad exposure forecasts, user Launch Commit Criteria (LCC) forecasts and evaluations, and toxic dispersion support. Through the Range Standardization and Automation (RSA) program, the current weather tower wind instruments are being switched from the Legacy cup-and-vane sensors to ultrasonic sensors.

The Legacy sensors measure wind speed and direction mechanically, but the ultrasonic RSA sensors have no moving parts. These differences in wind measuring techniques have been found to cause differences in the statistics of peak wind speed (Lewis and Dover 2004). The 45th Weather Squadron (45 WS) and the 30th Weather Squadron (30 WS) requested that the Applied Meteorology Unit (AMU) compare the data between Legacy and RSA sensors to determine if there are significant differences between the systems. This report addresses the comparison of Legacy and RSA wind speed and direction sensors on the WR.

2. Data and Sensor Description

The 30 WS identified 5 WR towers to be used in the comparison of Legacy and RSA wind sensor data. Table 1 gives the tower numbers and sensor levels used in this study, with available data indicated by the letter "Y." The wind sensors transmitted speed and direction readings every second to a local processing system. The local processing system computed and recorded the following, based on the 1-second sensor readings.

- One-minute average wind speed,
- One-minute average wind direction,
- Peak wind speed during the one-minute interval, and
- Direction of peak wind speed.

Table 1. Sensor levels for RSA and Legacy wind data from the 5 WR towers used in this study. Data from one Legacy and two RSA sensors were obtained at each level marked with the letter "Y."

Level (ft)	Tower **301**	Tower **300**	Tower **102**	Tower **060**	Tower **054**
300	**Y**	**Y**	-	-	-
204	**Y**	**Y**	-	-	-
102	**Y**	**Y**	**Y**	-	-
054	**Y**	**Y**	**Y**	**Y**	**Y**
012	**Y**	**Y**	**Y**	**Y**	**Y**

The Legacy wind data was obtained from TG1500 cup-and-vane systems, from Met One Instruments, Inc., with the vane (direction) and cups (speed) mounted separately, but at the same level. The RSA wind data was obtained from WS425 ultrasonic sensors, from Vaisala, that derive wind speed and direction information from the effect of wind on the transit time of ultrasonic pulses between three electro-acoustic transducer pairs. Each level had one Legacy system and 2 RSA sensors. The Legacy system was mounted on the corner of the tower facing the predominant wind direction whereas the two RSA sensors were mounted on corners opposite one-another, but not on the same corner as the Legacy System. Data from a total of 34 RSA sensors, collocated in pairs with Legacy speed/direction systems were used.

Figure 1 shows a picture of the Legacy and RSA wind sensors at the 12 ft level on Tower 102 at the WR. The Legacy cups can be seen in the middle-right portion of the image. The RSA2 ultrasonic sensor can be seen in upper-center, inside the dashed black circle. The RSA1 ultrasonic sensor is on the opposite side of the tower and parts of it are just visible under a loop of wire at the same level as the Legacy cups near the center of the image.

Figure 1. Legacy and RSA wind sensors at the 12 ft level on Tower 102 at the WR. The Legacy cups can be seen in the middle-right. The Legacy wind vane is obscured by the electronics box. The RSA1 ultrasonic sensors can be seen in upper-center, inside the dashed black circle.

2.1. Legacy Wind Sensors

The Legacy wind sensor system, Model TG1500 by Met One Instruments, Inc., is comprised of a wind vane that aligns itself with the wind direction and a set of cups that spin at a rate directly proportional to the wind speed (see Figure 1). Instrument specifications are advertised as an accuracy of ± 0.15 kts or 1% of wind speed, whichever is greater, and a distance constant of 5 ft. The wind speed and direction information is output every second and a local data processing system determines the one-minute average and peak conditions.

The Legacy wind speed and peak wind speed were recorded to the nearest knot and the average and peak wind directions were recorded to the nearest degree.

2.2. RSA Wind Sensors

The Vaisala WS425 Ultrasonic Wind Sensor has an array of three equally spaced ultrasonic transducers in a horizontal plane (Vaisala 2004). The sensor measures the time it takes for ultrasonic pulses to travel from one transducer to the other, in both directions. The transit time increases on upwind paths and decreases on downwind paths, the difference being proportional to the wind speed component along the path. Within every second 32 raw wind-speed estimates are derived along each of the three paths. A proprietary algorithm is used to quality-control the raw data and produce a 1-second wind speed/direction reading. These 1-second data are used to produce a 1-minute average wind speed/direction reading and a peak wind speed/direction reading each minute. Instrument specifications are advertised as an accuracy of ± 0.26 kts, or 3% of wind speed, whichever is greater, and a distance constant of virtually zero.

The RSA average and peak wind speed data were recorded to the nearest 0.2 m/s (~ 0.39 knot) and the average and peak wind direction data were recorded to the nearest degree.

3. Analysis Procedure

The analysis procedure was designed to compare Legacy and RSA sensor readings at the highest temporal resolution available and to avoid wind sheltering effects by the tower. This was accomplished by first matching times series minute-by-minute for all three sensors (Legacy, RSA1 and RSA2) at each level on each tower. The Legacy wind direction at each level on each tower was then used to separate the matched time series into three sectors. The sectors were upwind of the tower for each of the three possible comparisons:

- Sector 1: Legacy versus RSA1,
- Sector 2: Legacy versus RSA2, and
- Sector 3: RSA1 versus RSA2.

3.1. Extract Data Minute-by-Minute

Time series of wind speed and direction were obtained for each RSA sensor on each tower at each level. The corresponding Legacy sensor data were matched, minute-by-minute. There were some cases where the Legacy average wind speed or peak wind speed was missing. For these rare cases the corresponding RSA fields were still used for the RSA-to-RSA comparison.

3.2. Wind Sector Filter

The wind direction filter was based on the instrument mounting scheme for each tower and was designed to avoid effects of wind flow around the tower. This was done by restricting data for each sensor pair to wind flow from the upwind side of the tower. Figure 2 shows a schematic of the mounting scheme for the Legacy and RSA wind sensors used on each of the 5 towers. Note that the RSA sensors were mounted on opposite corners of the tower, while the Legacy sensor was mounted on one of the remaining two corners; the corner facing the dominant wind direction. There was one mounting scheme for each tower and sensors at different levels on the same tower were mounted using the same scheme.

Figure 2 also defines 3 wind-direction sectors. Sector 1 was used for comparing the Legacy and RSA1 sensors. Sector 2 was used for comparing the Legacy and RSA2 sensors, and Sector 3 was used for comparing the RSA1 and RSA2 sensors. The sectors were defined so that the sensor data used in the comparison would always be from the upwind side of the tower, also avoiding wind flow parallel to the sides of the tower by at least 15 degrees.

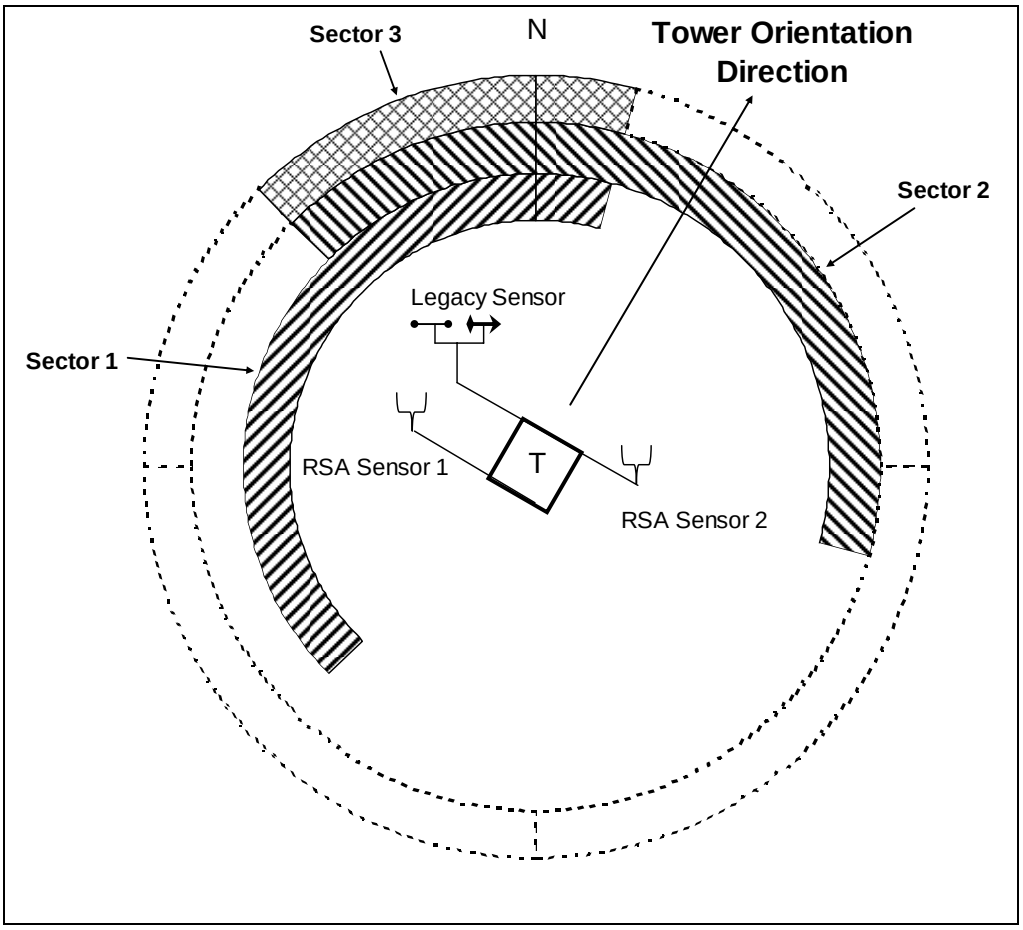

Figure 2. Schematic of Legacy and RSA instrument configuration and wind-direction sectors used for wind speed comparisons. Sector 2, spanning the Tower Orientation Direction (TOD) +/- 75°, was used for comparing the Legacy and RSA 2 sensors. Sector 1, spanning the {TOD – 90°] +/- 75°, was used for comparing the Legacy and RSA 1 sensors. Sector 3, spanning 60° from [TOD -75°] to [TOD -15°], was used for comparing the RSA 1 and RSA 2 sensors. Wind direction from the Legacy sensor was used as the reference.

Table 2 shows tower orientation angles and wind direction sectors used to constrain the comparison of wind sensor data to the up-wind side of the tower.

Table 2. Tower orientation angles and wind sectors used in sensor comparisons for 5 towers on the WR. See Figure 2 for a schematic depiction of the sectors.

Tower	Orientation	Sector 1	Sector 2	Sector 3
301	030°	225° → 015°	315° → 105°	315° → 015°
300	030°	225° → 015°	315° → 105°	315° → 015°
102	040°	235° → 025°	325° → 115°	325° → 025°
060	012°	207° → 357°	297°→ 087°	297° → 357°
054	020°	215 → 005°	305° → 095°	305° → 005°

Table 3 lists the sample size, in minutes, for each sector, and sensor pair, after filtering by wind direction.

Table 3. Sample size, in minutes, after the time series for each sensor pair was filtered by the wind direction sectors listed in Table 2.

Tower	Level (ft)	Sector 1 Legacy versus RSA1	Sector 2 Legacy versus RSA2	Sector 3 RSA1 versus RSA2
301	*300*	**4070**	**5617**	**3591**
301	*204*	**5328**	**4536**	**4278**
301	*102*	**5605**	**4904**	**4825**
301	*054*	**5687**	**4889**	**4865**
301	*012*	**5041**	**4910**	**4304**
300	*300*	**919**	**3462**	**875**
300	*204*	**6500**	**3710**	**3702**
300	*102*	**3817**	**3536**	**2929**
300	*054*	**4851**	**4719**	**2795**
300	*012*	**6378**	**3012**	**2989**
102	*102*	**6949**	**1332**	**1328**
102	*054*	**6984**	**1501**	**1497**
102	*012*	**6690**	**1669**	**1669**
060	*054*	**7123**	**1586**	**1584**
060	*012*	**7442**	**1564**	**1552**
054	*054*	**2503**	**7538**	**2495**
054	*012*	**2767**	**6822**	**2760**
Total	*All Levels*	**88654**	**65307**	**48038**

Figure 3a shows how the total sample size from sectors 1 and 2 is distributed across Legacy average wind speeds. The average sample size distribution has a single mode at 8 kts and falls to zero at 29 kts. The distribution is right-skewed with a mean value of 10.35 kts, somewhat higher than the mode. Figure 3b shows how the total sample size from sectors 1 and 2 is distributed across the Legacy peak wind speeds. The peak sample size distribution has a single mode at 11 kts and falls to zero at 35 kts. The peak distribution is also right-skewed with a mean value of 13.30 kts, somewhat higher than the mode.

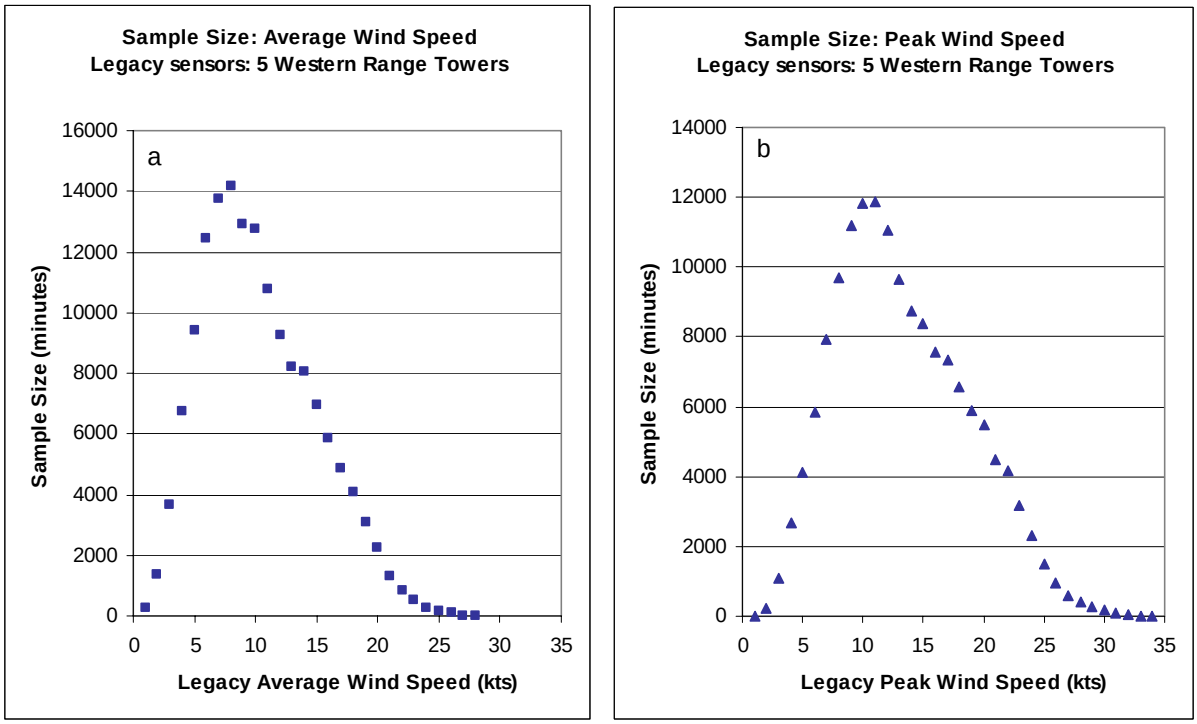

Figure 3. (a) Sample size for average and (b) peak wind speed data for all 17 Legacy sensors on 5 WR towers. The period-of-record is 29 May – 23 June 2005. Total sample size is 153,961.

4. Results

The results of the sensor comparison are presented in this section in three different ways:

- Overall composite results,
- Sensor-by-sensor comparisons, and
- Composite results from the most consistent sensors.

The sensor-by-sensor comparisons were done for each Legacy/RSA pair and for each RSA/RSA pair. The self-consistency check of the RSA–to-RSA comparisons provided some indications of questionable performance by a limited number of Legacy sensors.

4.1. Overall Composite Results: Average and Peak Wind Speeds

Data used for the overall composite results were obtained by first matching time series from all sensor pairs, minute-by-minute, and then excluding data from wind directions affected by the towers, as described in Section 3. The Legacy wind direction information was used to obtain samples with all sensors on the upwind side of the tower. A total of 153,961 one-minute comparisons of Legacy versus RSA wind information were obtained after the screening process.

The overall comparison of all the screened data resulted in the following:

- Overall Average Wind Speed: Legacy 10.35 kts, RSA 10.15 kts, RSA:Legacy Ratio 0.981
- Overall Peak Wind Speed: Legacy 13.30 kts, RSA 14.05 kts, RSA:Legacy Ratio 1.056

Average wind speeds sampled during the period-of-record (POR) were from 1 to 28 knots and the ratio of RSA-to-Legacy average wind speed was found to vary from 0.95 to 1.08 over the interval from 2 to 25 knots where the sample size exceeded 30. Peak wind speeds sampled during the POR were from 2 to 34 knots and the ratio of RSA-to-Legacy peak wind speed was found to vary from 1.05 to 1.09 over the interval from 5 to 31 knots where the sample size exceeded 30.

In order to depict the variability of the RSA/Legacy ratio over the full range of observed wind speeds, the AMU also computed the overall results for the 34 RSA sensors conditioned on the Legacy average and Legacy peak wind speeds. That is, for all Legacy one-minute average wind speeds of 1-knot at all levels on all towers, the corresponding RSA one-minute average wind speed was computed from data at all levels on all towers. This procedure was followed for all Legacy average wind speeds, knot-by-knot, up to 25 knots. The results are plotted in Figure 4a. The results were truncated at 25 knots, because above 25 knots the sample size for Legacy average wind speeds fell below 30 one-minute-averages and the comparison results became noisy. Also, for all Legacy peak wind speeds of 2-knots, the corresponding average of all RSA peak speeds was computed. This procedure was followed for all Legacy peak wind speeds, knot-by-knot, up to 31 knots. The results are plotted in Figure 4b. At wind speeds above 31 knots the sample size for Legacy peak wind speeds fell below 30 and the comparison became noisy, so results were truncated at this threshold.

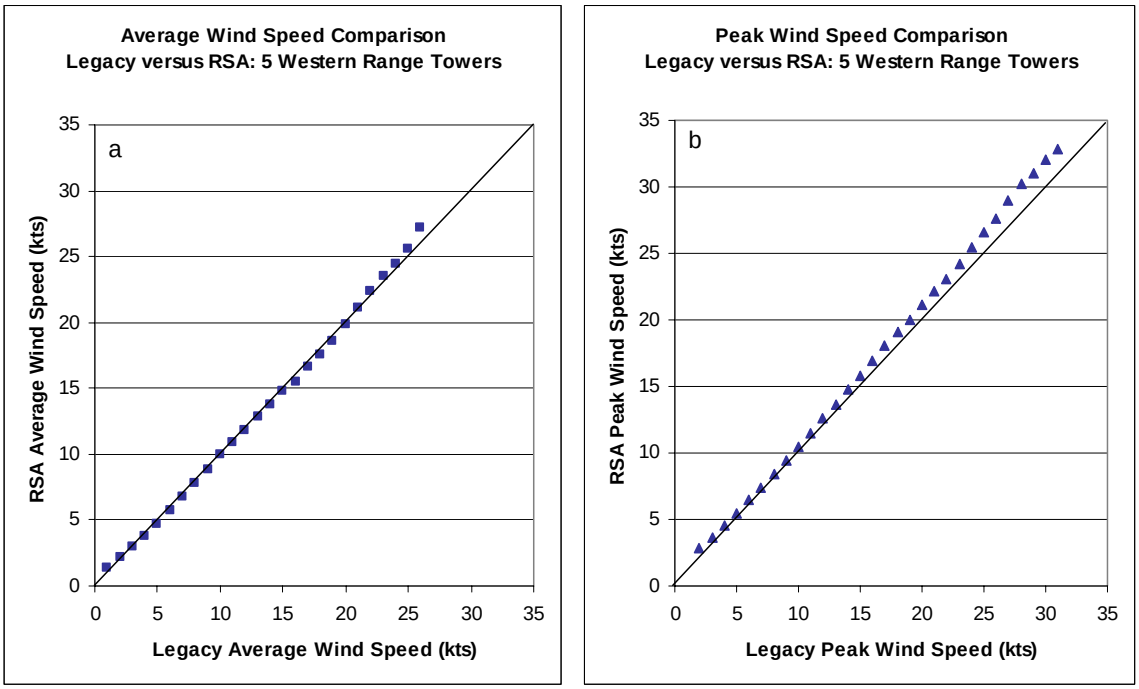

Figure 4. (a) Average and (b) Peak wind speed comparisons for all 34 sensors pairs on 5 WR towers. The period-of-record is 29 May – 23 June 2005. Total sample size is 153,961. Each data point plotted had at least 30 one-minute samples. The diagonal 1:1 line indicates a perfect linear relationship.

4.2. Sensor-by-Sensor Comparisons

The Legacy/RSA comparisons shown in Figure 4a and Figure 4b reveal the composite behavior of all 34 RSA wind sensors with respect to all 17 Legacy wind sensors for the one-minute average and peak wind speed data. A more detailed sensor-by-sensor comparison was also made to assess the consistency and reliability of the individual RSA sensors.

Although the Legacy sensor was used as the reference sensor, an effort was also made to compare the RSA sensors to one another. This procedure was used to identify possible cases where the Legacy sensor data could be deemed questionable, if it did not agree with the RSA sensor data, but wind speed and direction readings from the two RSA sensors were consistent with each other.

4.2.1. Conditional Wind Speed Averages

Figure 5 shows conditional averages of each of the 34 RSA sensors with respect to their collocated Legacy sensor. These were computed in the same manner as the curve shown in Figure 4a, for the wind direction sectors given in Table 2. The majority of comparisons are tightly clustered just above the 1:1 line that runs diagonally from point 0,0 to point 35,35. However, there are 9 comparisons plotted with connecting lines having substantial deviations above and below the 1:1 line. These 9 sensors were labeled as outliers in this initial comparison.

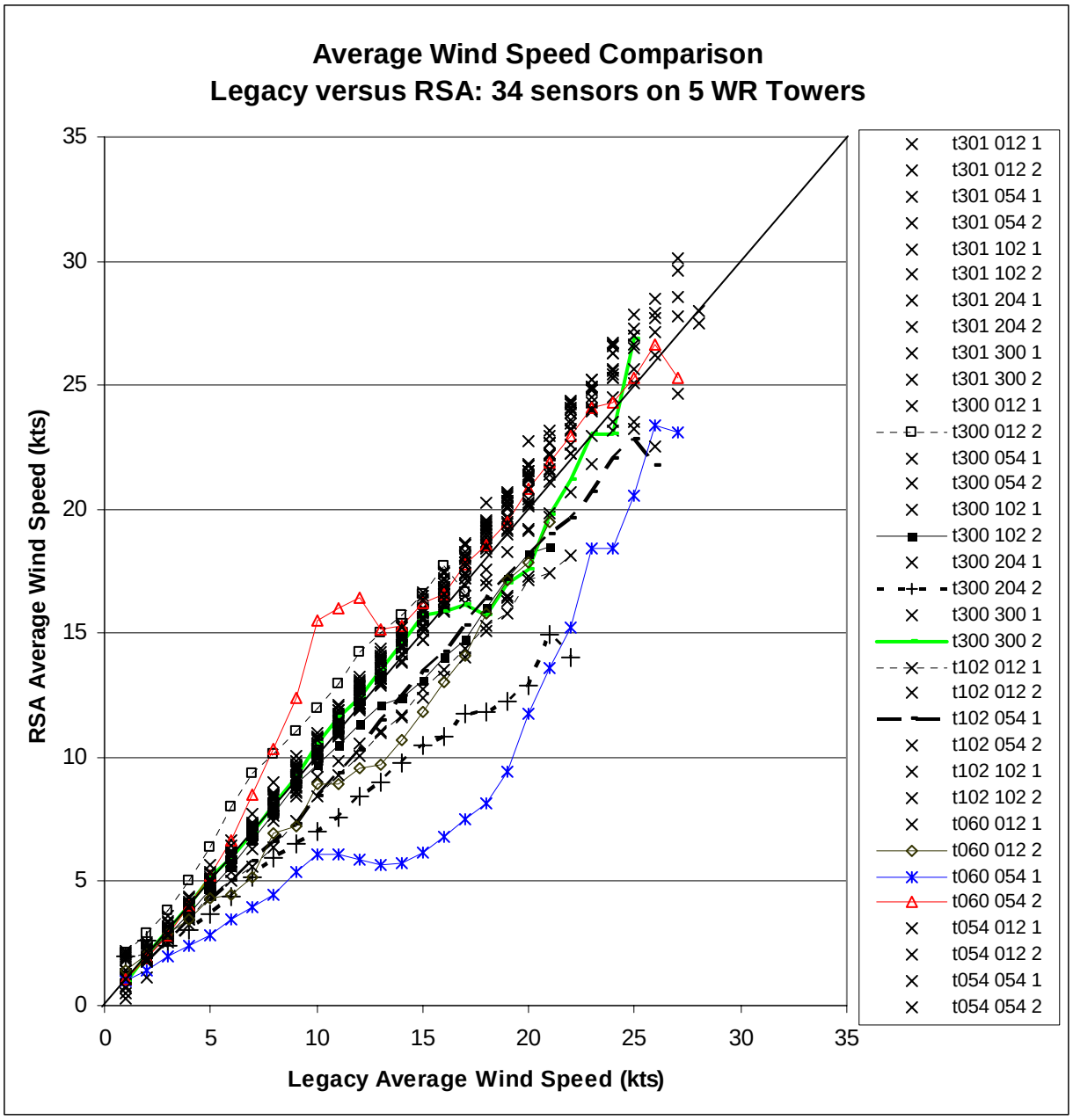

Figure 5. Average wind speed comparisons for each of the 34 Legacy/RSA sensors pairs on 5 WR towers. Period-of-record is 29 May – 23 June 2005. The legend indicates tower, level and RSA sensor number. Nine RSA sensors are marked as outliers by dashed and solid lines. At ~ 25 kts the number of samples becomes small (< 30) for each sensor and the comparisons become noisy. The 1:1 diagonal line is solid, extending from the point 0,0 to the point 35,35, indicating an unbiased agreement between sensor readings for data points falling along the line.

It is interesting to note that 7 of the 9 RSA outliers identified in Figure 5 represent one member of the pair of RSA sensors at a particular level on a particular tower. For those 7 cases the other RSA sensor agrees well with the Legacy sensor. Only one level on one tower (Tower 060, 054 ft level) shows both RSA sensors with variable wind speed differences from the Legacy sensor. In this case the 2 RSA sensors show distinctly different patterns in Figure 5.

4.2.2. Bias of Average Wind Speeds

For each of the 17 wind sensor platforms on the 5 towers, the matched time series in Sectors 1, 2 and 3 were used to compare overall average wind speeds between RSA-Legacy pairs and RSA-RSA pairs. The results were listed in Table 4. Bias was defined as RSA – Legacy average wind speed difference. Values in bold type are the 9 outliers identified in Figure 4, plus RSA2 at the 204 ft level on Tower 301 with a bias value of 1.27 kts, the highest value of the remaining sensors. Note that the bias between RSA sensors computed from data in sector 3 is not exactly the same as that inferred from the sector 2 and sector 3 comparisons. This is because the wind sectors used to filter the data were different for the RSA1 and RSA2 sensors. However, the RSA-RSA bias is generally consistent with those inferred from the RSA-Legacy biases.

Table 4. Bias, in knots, of average wind speed for sensor-to-sensor comparisons. Bias values in **bold type** are the 9 outliers identified in Figure 5, plus RSA2 at the 204 ft level on Tower 301.

Tower	Level (ft)	Sector 1 RSA1 - Legacy	Sector 2 RSA2 - Legacy	Sector 3 RSA1 - RSA2
301	*300*	1.06	1.07	-0.20
301	*204*	0.01	**1.27**	-1.28
301	*102*	0.92	0.86	0.26
301	*054*	0.26	0.66	-0.35
301	*012*	0.03	0.05	-0.03
300	*300*	0.16	**0.06**	0.22
300	*204*	0.23	**-2.88**	3.43
300	*102*	0.15	**-0.58**	0.90
300	*054*	0.18	-0.82	1.06
300	*012*	0.09	**1.80**	-1.53
102	*102*	0.08	0.28	0.63
102	*054*	**-1.49**	0.65	-.77
102	*012*	**-1.62**	0.20	-1.15
060	*054*	**-4.94**	**1.57**	-6.40
060	*012*	0.08	**-2.33**	2.66
054	*054*	0.26	0.08	-.39
054	*012*	0.68	0.01	0.30

4.2.3. Standard Deviation of Differences in Average Wind Speeds

For each of the 17 wind sensor platforms on the 5 towers, the matched time series in Sectors 1, 2 and 3 were used to compute the standard deviation of differences in average wind speeds between RSA-Legacy pairs and RSA-RSA pairs. Differences were computed from the one-minute average wind speed data. The results were listed in Table 5. Values in bold type are the 9 outliers identified in Figure 4, plus RSA2 at the 204 ft level on Tower 301 with a standard deviation value of 1.16 kts.

Table 5. Standard deviation, in knots, of differences in one-minute average wind speed for sensor-to-sensor comparisons. Values in **bold type** are the 9 outliers identified in Figure 5, plus RSA2 at the 204 ft level on Tower 301.

Tower	Level (ft)	Sector 1 RSA1 - Legacy	Sector 2 RSA2 - Legacy	Sector 3 RSA1 - RSA2
301	*300*	1.20	1.19	0.32
301	*204*	1.23	**1.16**	1.31
301	*102*	1.38	1.14	1.23
301	*054*	0.81	0.93	0.57
301	*012*	0.80	0.88	0.67
300	*300*	0.70	**1.74**	0.68
300	*204*	0.88	**1.90**	2.23
300	*102*	0.76	**1.23**	1.33
300	*054*	0.75	1.15	1.19
300	*012*	0.67	**1.94**	1.94
102	*102*	1.02	1.23	0.93
102	*054*	**1.34**	0.99	1.18
102	*012*	**1.36**	0.94	1.09
060	*054*	**3.70**	**2.72**	3.49
060	*012*	0.78	**2.42**	2.14
054	*054*	0.99	1.19	0.67
054	*012*	0.96	1.09	0.71

The overall average standard-deviation of differences in wind speed for the RSA 24 sensors not classified as outliers thus far was 0.99 kts. This value is encouraging, given the precision to which the wind speed values were reported (Legacy 1 kt; RSA 0.4 kt), the expected accuracy of the Legacy (± 0.15 kt) and RSA (± 0.26 kt) sensors and effects of small scale turbulence. The overall result for the 10 RSA sensors classified as outliers thus far, having values indicated in bold type in Table 4 and Table 5above, was a standard deviation of 1.95 kts.

4.2.4. Direction Differences

For each matched time series the average and standard deviation of direction differences were calculated. This procedure was followed for all 3 sectors for each of 17 sensor levels on the 5 towers. The comparisons of wind direction differences are listed in Table 6. Difference values in bold type are the 9 outliers in Figure 5, plus the RSA2 sensor at the 204 ft level on tower 301, and an additional 8 RSA sensors with directional differences from the Legacy sensor exceeding 13 degrees (mean and standard deviation).

Table 6. Difference and standard deviation, in degrees, of one-minute average wind direction for sensor-to-sensor comparisons. Difference values in bold type are the 9 outliers in Figure 5, plus RSA2 at the 204 ft level on tower 301, and an additional 8 RSA sensors with directional differences from the Legacy sensor exceeding 13 degrees (mean and standard deviation).

Tower	Level (ft)	Sector 1 RSA1 - Legacy	Sector 2 RSA2 - Legacy	Sector 3 RSA1 - RSA2
301	*300*	**-35 +/- 28**	**-32 +/- 26**	-4 +/- 02
301	*204*	8 +/- 03	**6 +/- 03**	6 +/- 05
301	*102*	-3 +/- 06	-6 +/- 03	3 +/- 05
301	*054*	6 +/- 03	-1 +/- 03	7 +/- 02
301	*012*	0 +/- 07	-4 +/- 07	5 +/- 02
300	*300*	5 +/- 02	**6 +/- 02**	-1 +/- 02
300	*204*	-1 +/- 04	**0 +/- 12**	-1 +/ 12
300	*102*	**-15 +/- 15**	**-21 +/- 14**	6 +/- 02
300	*054*	**-16 +/- 38**	**-17 +/- 35**	1 +/- 03
300	*012*	6 +/- 06	**0 +/- 14**	6 +/- 13
102	*102*	-4 +/- 05	-3 +/- 04	-2 +/- 01
102	*054*	**-3 +/- 05**	-2 +/- 05	-1 +/- 02
102	*012*	**-14 +/- 18**	**-16 +/- 19**	2 +/- 03
060	*054*	**3 +/- 11**	**2 +/- 12**	1 +/- 03
060	*012*	5 +/- 07	**2 +/- 07**	3 +/- 02
054	*054*	1 +/- 05	6 +/- 05	-6 +/- 01
054	*012*	0 +/- 07	8 +/- 08	-9 +/- 02

The listing of sector 3 directional differences in Table 6 indicates that the RSA-to-RSA comparisons were remarkably consistent, even for the 8 RSA-to-Legacy directional differences that exceeded 13 degrees. This result suggests that the Legacy directional readings for those 4 Legacy sensors (tower 301, 300 ft; tower 300, 102 ft; tower 300, 054 ft; and tower 102, 012 ft) may have some problems.

4.3. Best Composite Results: Average and Peak Wind Speeds

The 18 RSA sensors that showed the most consistent performance, with respect to the Legacy sensors, can be inferred from Table 6 by excluding all RSA sensors with directional differences in bold type. These 18 RSA sensors were used to produce composite comparisons, following the procedure described in Section 4.1. The results for average wind speed are shown in Figure 6a and the results for peak wind speed are shown in Figure 6b.

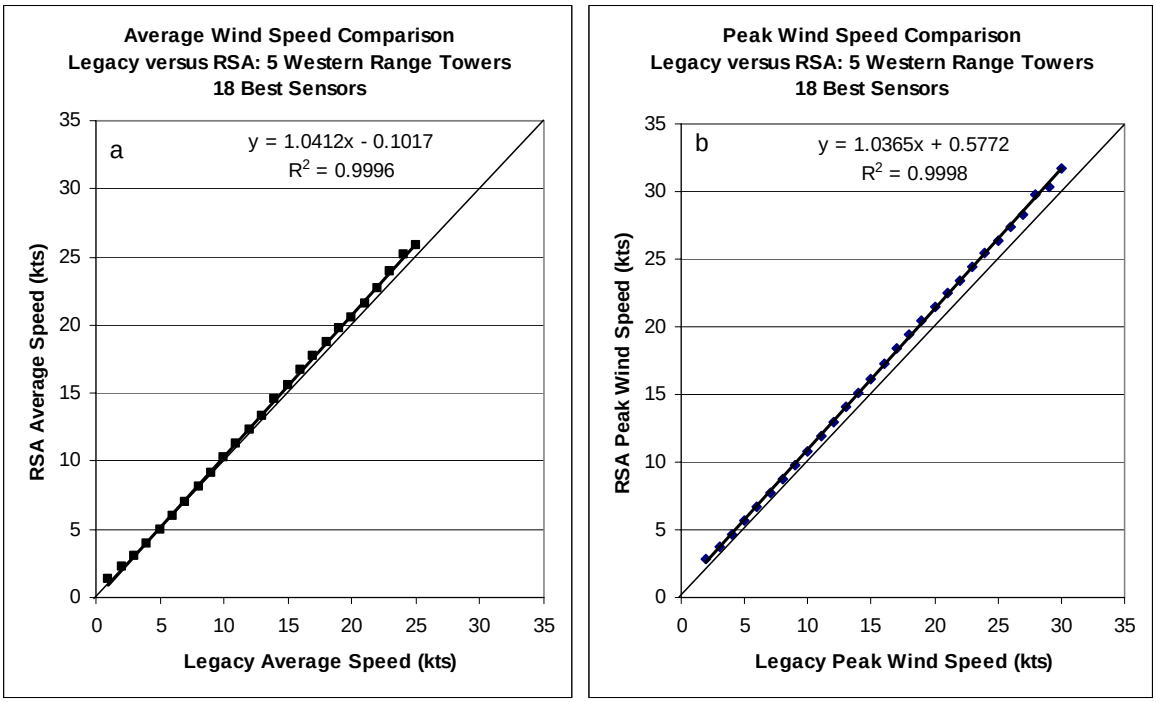

Figure 6. (a) Average and (b) Peak wind speed comparisons for the best 18 RSA sensors on 5 WR towers. Period-of-record is 29 May – 23 June 2005. Total sample size is 87,894. Each data point plotted had at least 30 one-minute samples.

Figures 6a and 6b include linear regression lines with the following equations:

- Figure 6a: RSA(average) = 1.0412*Legacy(average) – 0.1017 kts
- Figure 6b: RSA(peak) = 1.0365*Legacy(peak) + 0.5772 kts

The results shown in Figure 6 can be summarized by noting that the positive bias in the 18-best composite RSA average wind speed increased steadily from +0.5 kts at 15 kts, to +1 kt at 25 kts. The positive bias in the 18-best composite RSA peak wind speed was larger, increasing steadily from +1 kt at 15 kts to +2 kts at 30 kts.

5. Conclusions

The RSA program is changing wind-measurement instrumentation on wind towers from the current Legacy mechanical systems to an RSA ultrasonic system with no moving parts. Launch Weather Officers, forecasters and Range Safety analysts need to understand the performance of the new RSA sensors and possible impacts on weather warnings, watches, advisories, special ground processing operations, launch pad exposure forecasts, user LCC forecasts and evaluations, and toxic dispersion support. This AMU report addressed the comparison of Legacy and RSA wind speed and direction sensors on the WR.

A large sample of data from Legacy and RSA wind sensors on 5 WR towers was provided by the 30 WS and analyzed by the AMU to characterize potential differences in average wind speed, peak wind speed and wind direction. The Legacy system uses a vane to measure wind direction and spinning cups to measure wind speed. The RSA system relies on the effect of wind on the transit time of ultrasonic pulse between closely-spaced ultrasonic transducers in a triangular array.

A total of 153,961 one-minute data samples, observed during the 26 day interval from 29 May to 23 June 2005, were compared for 5 WR towers. Sensor heights ranged from 12 to 300 ft. Each sensor level had 1 Legacy sensor and 2 RSA sensors. Comparisons were made between each Legacy/RSA pair and each RSA/RSA pair on each level. Only data from the upwind side of each tower were used in the comparisons. A total of 34 Legacy-to-RSA sensor pairs and 17 RSA-to-RSA sensor pairs were analyzed.

The overall comparison of all the data resulted in the following:

- Overall Average Speed: Legacy 10.35 kts, RSA 10.15 kts, RSA:Legacy Ratio 0.981
- Overall Peak Speed: Legacy 13.30 kts, RSA 14.05 kts, RSA:Legacy Ratio 1.056

The AMU also examined each Legacy/RSA sensor-pair and each RSA/RSA sensor-pair for consistency in wind speed and wind direction. This procedure identified numerous RSA sensors with systematic differences from the Legacy wind speed and/or direction and the other collocated RSA sensor. Nine of the RSA sensors showed substantial differences from the Legacy sensor in average wind speed patterns. Four RSA sensor pairs showed differences in average wind direction from the Legacy sensor in the range of 15 to 30 degrees. However, wind direction readings from these 4 RSA sensor pairs were much closer to each other, suggesting possible problems with the Legacy wind direction sensor.

The AMU used the Legacy wind sensors as the “reference” sensors and identified 18 RSA sensors with the closest agreement, based on differences in speed and direction. The 18 RSA sensors were used to define a composite average-Legacy/RSA comparison. The peak wind speed data from the same 18 RSA sensors were used to define a composite peak-Legacy/RSA comparison.

Comparisons of the 18 sensor composite were slightly different than the overall comparison cited above.

- Composite Average Speed: Legacy 10.31 kts, RSA 10.57 kts, RSA:Legacy Ratio 1.025
- Composite Peak Speed: Legacy 13.42 kts, RSA 14.48 kts, RSA:Legacy Ratio 1.079

The positive bias in the composite RSA average wind speed increased steadily from +0.5 kts at 15 kts, to +1 kt at 25 kts. The positive bias in the composite RSA peak wind speed was larger, increasing steadily from +1 kt at 15 kts to +2 kts at 30 kts.

5.1. Future Work

The AMU is also processing a large sample of Legacy and RSA wind sensor data from the ER. A final report on the ER comparison will be generated in the near future.

References

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List of Acronyms

30 WS	30th Weather Squadron
45 WS	45th Weather Squadron
AMU	Applied Meteorology Unit
ER	Eastern Range
LCC	Launch Commit Criteria
POR	Period of Record
RSA	Range Standardization and Automation
TOD	Tower Orientation Direction
UTC	Coordinated Universal Time
WR	Western Range

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