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PRELIMINARY PERFORMANCE CHARACTERISTICS OF A 28 m^2 APERTURE - 449 MHZ WIND PROFILING RADAR

Herb Winston
Vaisala Incorporated
Boulder, Colorado, 80301, USA

Daniel Wolfe
National Oceanic and Atmospheric Administration
Environmental Technology Laboratory
Boulder, Colorado, 80305, USA

Introduction

The United States Air Force operates a network of tethered "lighter-than-air" aircraft (aerostats) along the southern U.S. border. Having volumes of up to 18,000 cubic meters and supporting flight altitudes up to 5,000 meters, each Tethered Aerostat Radar System (TARS) carries aloft a surveillance radar that is used to observe aircraft entering U.S. airspace (Figure 1). Like any aircraft, aerostats can only operate safely within certain operational constraints. Wind and turbulence are the most important factors affecting Aerostat flight time and safety.

In support of the TARS program, the Air Force contracted with the National Oceanic and Atmospheric Administration (NOAA) Environmental Technology Laboratory (ETL) to deploy a mid-tropospheric radar wind profiler (RWP) with advanced signal processing, remote data display, and control capability at its operational TARS site in Ft. Huachuca, Arizona, USA. The purpose of this program is to evaluate the application of operational RWP data on Aerostat flight operations and to demonstrate the performance characteristics of the RWP with the topology that was defined by NOAA in response to the Air Force's upper-air data requirements.

Figure 1. Aerostat system deployed by the US Air Force

The program was also undertaken to evaluate the sensitivity of RWP-derived winds to different signal processing schemes in an attempt to enhance data quality, improve altitude coverage and increase temporal data resolution.

System Description

The Air Force's eight km. altitude requirement allows for a smaller antenna array and lower

Figure 2. 449 MHz 28m^2 Aperture RWP antenna, TARS site in F. Huachuca, AZ, USA.

transmitted power than systems currently operated throughout the central US and parts of Alaska as part of the NOAA's Profiler Network (Chadwick et.al., 1988). The resulting system operates at 449 MHz and utilizes two orthogonal arrays of twelve, 18-element coaxial-collinear (Co-Co) antennas (Figure 2). A 2 kW solid-state amplifier drives this 28 square meter antenna array. The antenna has a row-to-row phasing of 60 degrees implemented using delay cables and RF switches to change array axis and off-axis pointing angle. An environmentally-controller shelter is located directly adjacent to the antenna, which houses the computers, receiver, amplifier and the beam steering unit.

Commercially-available components integrated into the system include a Control/Data Processing subsystem, antennas and a beam steering unit provided from Vaisala Inc.'s (Boulder, CO) LAP® RWP product line and a solid state amplifier provided by Delta Sigma, Inc. (Corona, CA.). ETL's experimental Signal Processing Software (SPS) provides the meteorological products from RWP averaged Doppler spectra (Wolfe, et. al., 2001). It differs from the traditional consensus signal processing (Strauch, 1984) in recognizing that averaged Doppler spectra may contain multiple spectral peaks. Multiple data channels at different ranges, different times, and on different antenna beams are analyzed from the spectra level up to the meteorological parameter calculations to determine which signals are wind-induced. A confidence parameter is calculated and carried along with the data at each level. During

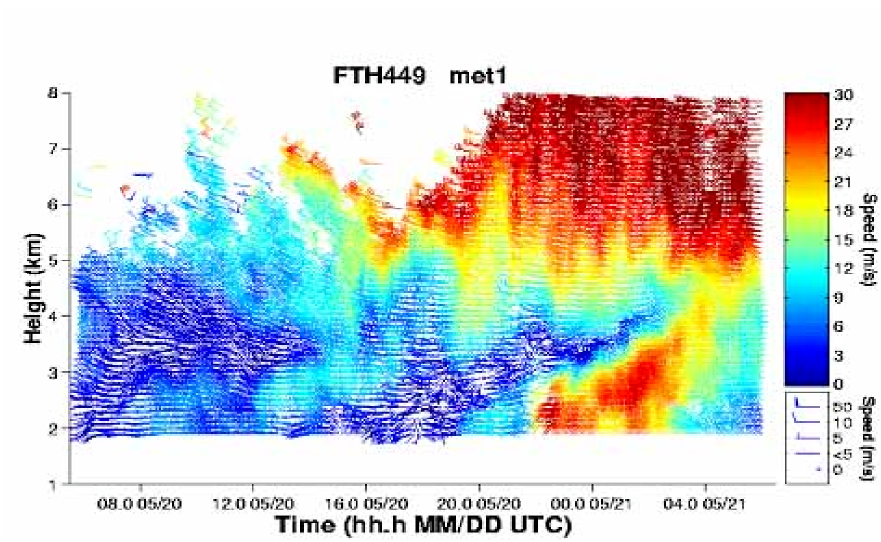


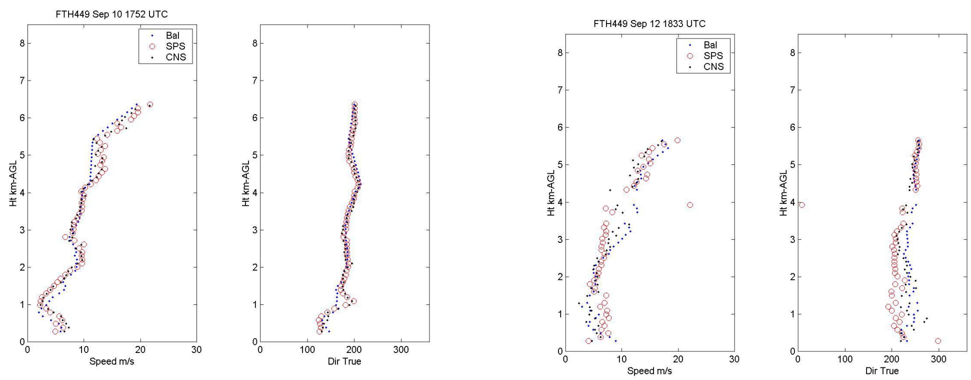
Figure 3. Sample data collected from a 28m^2 aperture 449 MHz wind profiling radar. Data is presented at 100m vertical resolution with a 5-minute update cycle of 15-minute time-averaged winds.

Aerostat operations, wind data are sent directly to the TARS site for real-time presentation on a PC. Data are operationally updated every five minutes utilizing a 15-minute sliding window (Figure 3). The data are ingested also by a specialized third-party software suite that analyzes and displays stresses placed on the aerostat by the measured wind profiles.

Wind Data Analysis

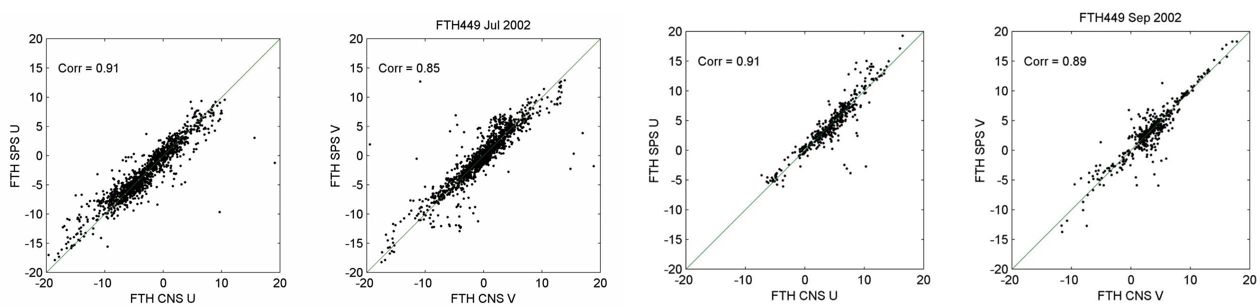
The SPS software was integrated into the 449 MHz system with the objective of providing improved data quality, improved altitude coverage and increased temporal data

An independent verification data set was collected from two separate upper-air rawinsonde sounding systems. One rawinsonde data set was collected between July 1 and July 30, 2002 from the Air Force's Electronic Proving Ground (EPG) meteorological support facility, which is located 9 km due north of the RWP site. This July data set consists of 20 upper-air soundings taken at 1200 UTC each day. The second verification data were collected from a second rawinsonde system co-located with the RWP site. Rawinsonde launches were conducted by on-site operators during meteorologically interesting events from September 10 through 17, 2002. A total of ten



(a) (b)

Figure 4. Sample sounding intercomparisons for September 10, 2002 (a) and September 12, 2002 (b). Displays are representative of the "higher quality" and "lower quality" agreement between the radar-derived winds and rawinsonde data. Dotted lines represent rawinsonde winds; asterisks, CNS-derived winds; and circles, SPS-derived winds.



(a) (b)

Figure 5. Scatter plots of u and v for SPS-derived and CNS-derived wind components for the July (a) and September (b) data sets.

resolution. Earlier assessments suggested that improved data quality was attained through the SPS algorithm's ability to extract atmospheric signal and produce winds where conventional signal processing had failed previously. In an attempt to quantify these earlier findings, a verification/data intercomparison program was undertaken.

soundings were collected duing this September verification period. The RWP data used for this analysis consists of 30-minute wind averages collected at one hundred meter vertical resolutions. Data were collected to an altitude of 8 km at eighty discrete levels. Rawinsonde wind speed and direction data are linearly interpolated to the same eighty wind levels available by the RWP. This provided both

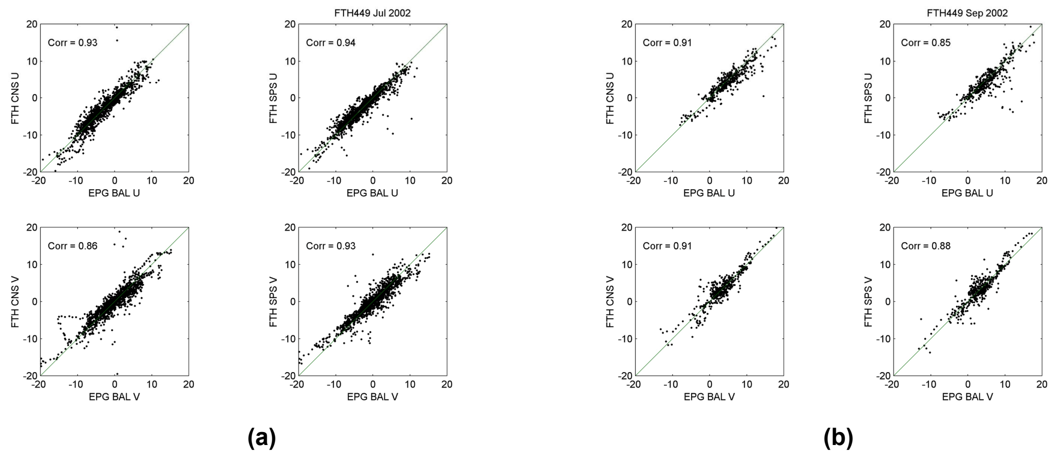


Figure 6. Scatter plots of u and v for SPS vs. rawinsonde and CNS vs. rawinsonde derived wind components for July (a) and September (b) verification data sets.

temporal and spatial consistency between the rawinsonde measurements and the two independent RWP signal processing schemes. Data were required from each of the three independent data sets: Signal Processing Software (SPS); consensus (CNS); and rawinsonde (BAL), to be included in the analysis. Of twenty-four hundred potential data points (80 levels x 30 data sets) a total of 1713 independent data points were identified. 1274 points are from the July data set, and the remaining 439 points are from the September data set.

two algorithms show reasonably good agreement. Correlation coefficients of 0.91 and 0.85 were computed for the July data set and coefficients of 0.91 and 0.89 were computed for the September data set for u and v, respectively. The higher correlation of the u-component likely results from the stronger prevailing westerly winds, which are enhanced by the SSE-NNW running Huachuca mountain range. The mountains have a maximum elevation of 2251m (MSL). The RWP is located approximately 10 km east of the mountain range and is at an elevation of 1441m.

Table 1. Regression Coefficients for Balloon/CNS, Balloon/SPS and CNS/SPS u, v, horizontal wind speed and direction for July and September verification data sets. Speeds are in m/s and directions are in degrees.

	July 2002			September 2002		
	Balloon/CNS	Balloon/SPS	CNS/SPS	Balloon/CNS	Balloon/SPS	CNS/SPS
R(u)	0.93	0.94	0.92	0.91	0.85	0.91
R(v)	0.86	0.93	0.85	0.91	0.88	0.89
R(speed)	0.87	0.93	0.88	0.88	0.86	0.90
R(direction)	0.84	0.83	0.81	0.62	0.59	0.80

Two sample sounding intercomparisons are presented in Figure 4. These data are representative of the data collected by the RWP using the CNS (*) and SPS (O) methods and compared to rawinsonde data. Interestingly, both wind profiling radar algorithms successfully pick out the gross features of the fairly complex wind field. This is evident by the radar systems ability to identify multiple and localized maxima and minima within the rawinsonde-measured wind field.

Scatter plots for the CNS- and SPS-derived horizontal u and v wind components for the July and September periods appear in Figure 5. The

Scatter plots of the u and v wind components from the two signal processing techniques compared to the rawinsonde verification data are presented in Figure 6. The associated statistics are listed in Table 1 and Table 2. The July data resulted in SPS-derived correlation coefficients of 0.94 and 0.93 as compared with the 0.93 and 0.86 for the CNS method. The correlation coefficients are reversed in the September data, having values of 0.91 and 0.91 for the CNS algorithm as compared with 0.85 and 0.88 for the SPS algorithm. These preliminary results do not support early claims of overall superiority of the multi-peak picking algorithm over standard consensus algorithms.

Table 2. Mean and standard deviations of balloon-, CNS- and SPS-derived u, v, horizontal wind speed and direction for July and September verification data sets. Speeds are in m/s and directions are in degrees.

	July 2002			September 2002		
	Balloon	CNS	SPS	Balloon	CNS	SPS
Mean u	-2.97	-3.0	-2.93	4.87	4.35	4.32
Mean v	-0.46	-0.52	-0.36	3.28	3.39	3.28
Mean speed	6.96	6.63	6.33	7.79	7.38	7.47
Mean dir.	135.3	139.2	137.7	233.1	226.4	225.7
STD u	5.1	5.3	4.7	4.31	3.91	4.17
STD v	5.8	5.5	5.1	4.35	4.43	4.78
STD speed	4.55	4.83	4.07	3.45	3.29	3.72
STD dir.	92.1	96.1	95.3	46	51.6	55.9

While they suggest that the SPS algorithm can improve performance - as evidenced during the July evaluation period - this conclusion can not be generalized. At times of strong atmospheric signals and under limited clutter conditions, both SPS and CNS are expected to perform comparably. More analysis is, however, needed to determine if SPS is better able to find atmospheric signals in the upper gates where signal-to-noise ratios are significantly reduced. This will be the subject of further analysis.

Conclusion

The above analysis provides preliminary insight into the operational characteristics of a reduced-aperture 449 MHz lower tropospheric RWP and the performance of Consensus and SPS signal processing techniques. In an attempt to validate the earlier studies that claimed superior data quality from implementation of the SPS algorithm over Consensus, the analysis performed in this study does not support this claim. Rather, this study illustrates that that additional analysis is required to allow better understanding of the SPS algorithm's strengths and, perhaps more importantly, its weaknesses.

NOAA plans to supply Vaisala's new Digital IF receiver as part of the second RWP delivery to the USAF's TARS site in Cujoe Key, Florida, USA in 2003. This new architecture provides its own multi-peak selection algorithm (Griesser, 1998) as well as innovative wavelet clutter rejection method (Jordan, 1997). Future evaluations should include these additional signal processing techniques with an objective to identify the optimum algorithm combinations in support of the Air Force's aerostat program.

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