

Radar Wind Profiler (RWP) and Radio Acoustic Sounding System (RASS) Instrument Handbook

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March 2020



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Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

ACAPEX	ARM Cloud Aerosol Precipitation Experiment
AMF	ARM mobile facility
ARM	Atmospheric Radiation Measurement
AT	Acceptance Test
BBSS	balloon-borne sounding system
BSRWP	beam-steered radar wind profiler
CF	Central Facility
COMBLE	Cold-Air Outbreaks in the Marine Boundary Layer Experiment
DQO	Data Quality Office
ENA	Eastern North Atlantic
FA	final amplifier
FFT	fast Fourier transform
FMC-BL	full motion control–boundary layer
GPS	Global Positioning System
IMU	Inertial Measurement Unit
MAGIC	Marine ARM GPCI Investigations of Clouds
MARCUS	Measurements of Aerosols, Radiation, and Clouds over the Southern Ocean
MII	Modulator, Intermediate Frequency and Interface
MOSAIC	Multidisciplinary Drifting Observatory for the Study of Arctic Climate
NSA	North Slope of Alaska
QC	quality control
RASS	radio acoustic sounding system
RWP	radar wind profiler
SGP	Southern Great Plains
SNR	signal-to-noise ratio
UTC	Coordinated Universal Time
VAP	value-added product

Contents

Acronyms and Abbreviations	iv
1.0 General Overview	1
2.0 Contacts	1
2.1 Mentors	1
2.2 Vendor/Instrument Developer	2
3.0 Deployment Locations and History	2
4.0 Near-Real-Time Data Plots	3
5.0 Data Description and Examples	3
5.1 Data Formats	3
5.1.1 Wind Profile Data.....	3
5.1.2 Virtual Temperature Profile Data.....	5
5.1.3 Precipitation Operation	7
5.2 Data File Contents.....	8
5.2.1 Data Types.....	8
5.2.2 Primary Variables and Expected Uncertainty	9
5.2.3 Data Quality Flags.....	10
5.3 Annotated Examples.	12
5.4 User Notes and Known Problems	12
5.5 Frequently Asked Questions	12
6.0 Data Quality	14
6.1 Data Quality Health and Status	14
6.2 Data Reviews by Instrument Mentor.....	14
6.3 Data Assessments by Site Scientist/Data Quality Office	15
6.4 Value-Added Products	15
7.0 Instrument Details.....	16
7.1 Detailed Description.....	16
7.1.1 List of Components	16
7.1.2 System Configuration and Measurement Methods	16
7.1.3 Specifications	18
7.2 Operation and Maintenance	18
7.2.1 User Manual	18
7.2.2 Routine and Corrective Maintenance Documentation	18
7.2.3 Software Documentation.....	18
7.3 Glossary.....	18
7.4 Acronyms	18
8.0 Citable References	19
9.0 Bibliography	20

Figures

1	Calculated moments for the vertical beam (precpmom, high power mode) at SGP I9, Billings, Oklahoma on 2018-04-21.....	5
2	RWP low- (left) and high- (right) power consensus-averaged winds recorded on 2020-02-26 at the SGP I8 Facility.	5
3	An example of a 24-hour display of RASS virtual temperature (units in C ^o).	6
4	An example of adaptive algorithm’s operation switching from wind mode to precipitation mode only when precipitating conditions have been identified.	7
5	Precipitation effect on the consensus winds.	10
6	Low- (bottom) and high- (top) power winds (left) and SNR (right) affected by migrating birds.	11

Tables

1	ARM RWP deployment history at observatories and mobile facilities.....	2
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1.0 General Overview

The radar wind profiler (RWP) is an active remote-sensing instrument that can routinely, and virtually unattended, observe wind and turbulence in the troposphere through scattering from clear-air irregularities of the atmospheric refractive index (Gage and Balsley 1978). The principle of Doppler radars in general is based on sending electromagnetic pulses in the vertical and several tilted directions (vertical and oblique beams) and measuring the signal that is scattered back by atmospheric turbulence at all heights and received at the antenna. The RWPs provides measurements of backscattered signal strength and wind profiles nominally between 0.1 km and 6 km. The RWP operation assumes that the wind field is homogeneous over the spatial separation of the antenna beams, which is a safe assumption under stable atmospheric conditions. However, the wind may be different between the beams due to significant changes in the wind field, resulting in erroneous wind calculations. Therefore, the radial measurements are averaged over a sufficient time period to validate the assumption of homogeneity.

Prior to 2010, a radio acoustic sounding system (RASS) was incorporated with the RWP to obtain virtual temperature profiles at the Atmospheric Radiation Measurement (ARM) user facility's Southern Great Plains (SGP) observatory. However, after 2011 the acoustic transmitters are no longer included in the systems. 915 MHz RWPs are deployed at ARM sites in the United States, while for most foreign deployments 1290 MHz systems are used.

The second ARM Mobile Facility (AMF2) was designed to be frequently deployed at sea; therefore, it has a 1290 MHz full motion control-boundary layer (FMC-BL) RWP system developed by DeTect, Inc. (currently Radiometrics) that is capable of changing the beam-pointing angle on a pulse-by-pulse basis so that it can compensate for ship motions during shipborne deployments.

2.0 Contacts

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3.0 Deployment Locations and History

Table 1 shows RWP deployment history at ARM observatories and mobile facilities. Locations marked with (*) are shipborne mobile deployments, and the field campaign name is used as its location.

Table 1. ARM RWP deployment history at observatories and mobile facilities.

Site	Location	Facility ID	Mfr	Freq (MHz)	Description/ Modes	Start date (MM/YYYY)	End date (MM/YYYY)
SGP	Lamont, OK	C1	Vaisala	915	Winds/RASS	11/1992	03/2011
		C1	Vaisala	915	Winds/Precip	03/2011	03/2019
		C1	Vaisala	915	Adaptive	03/2019	08/2019
		C1	Radiometrics	915	Winds/Precip	08/2019	Present
	Beaumont, KS	IF1	Vaisala	915	Winds	09/1996	03/2011
	Medicine Lodge, KS	IF2	Vaisala	915	Winds	09/1996	09/ 2008
	Meeker, OK	IF3	Vaisala	915	Winds	09/1996	02/2009
	Tonkawa, OK	IF8	Vaisala	915	Winds/Precip	05/2011	05/2018
		IF8	Vaisala	915	Adaptive	05/2018	Present
	Billings, OK	IF9	Vaisala	915	Winds/Precip	05/2011	03/2019
		IF9	Vaisala	915	Adaptive	03/2019	Present
	Lamont, OK	IF10	Vaisala	915	Winds/Precip	04/2011	03/2019
IF10		Vaisala	915	Adaptive	03/2019	Present	
NSA	Barrow, AK	C1	Vaisala	915	Winds/Precip	04/2001	10/2017
ENA	Graciosa, Azores	C1	Scintec	1290	Winds/Precip	09/2014	Present
AMF1	Niamey, Niger	NIM M1	Vaisala	915	-	04/2006	01/2007
	Black Forest, Germany	FKB M1	Vaisala	1290	-	03/2007	08/2007

	Shouxian, China	HFE M1	Vaisala	1290	-	09/2008	12/2008
	Azores	GRW M1	Vaisala	1290	-	04/2009	12/2010
	Nainital, India	PGH M1	Vaisala	1290	-	11/2011	03/2012
	Cape Cod, MA	PVC M1	Vaisala	915	-	07/2012	07/2013
	Manacapuru, Brazil	MAO M1	Vaisala	1290	-	03/2014	12/2015
	Ascension Island	ASI M1	Vaisala	1290	-	06/2016	10/2017
	Walla Walla, WA	WWL	Vaisala	915	-	05/2015	05/2017
	Cordoba, Argentina	COR M1	Vaisala	1290	-	09/2018	05/2019
	Nordmela, Norway	ANX M1	Vaisala	1290	-	09/2019	-
AMF2	Steamboat Springs, CO	SBS M1	Vaisala	915	-	11/2010	03/2011
	Gan Island, Maldives	GAN M1	Radiometrics	1290	-	11/2011	02/2012
	MAGIC*	MAG M1	Radiometrics	1290	-	12/2012	06/2013
	Hyytiala, Finland	TMP M1	Radiometrics	1290	-	01/2014	08/2014
	ACAPEX*	ACX M1	Radiometrics	1290	-	01/2015	02/2015
	McMurdo, Antarctica	AWR M1	Radiometrics	1290	-	12/2015	01/2017
	MARCUS*	MAR M1	Radiometrics	1290	-	10/2018	03/2018
	MOSAIC*	MOS M1	Radiometrics	1290	-	09/2019	-
AMF3	Oliktok, AK	M1	Scintec	915	Winds/Precip	08/2014	08/2017

4.0 Near-Real-Time Data Plots

Data collected by the RWPs can be viewed in near-real time through the Data Quality Office's (DQO) [Quick Plot Browser](#).

5.0 Data Description and Examples

5.1 Data Formats

5.1.1 Wind Profile Data

The data produced by this instrument come in three forms: raw spectra, moments, and time-averaged profiles.

- **Spectra:** The spectra are the most basic form of data produced by the present version of this instrument. The method by which the spectra are obtained is discussed below in section 7.1.2. They display the energy content of the scattered signal over the range of Doppler shifts observed from each pointing direction and power level of the wind profiler. There is a single spectrum for each range gate, pointing direction, and power level, and each spectrum represents an average of several (e.g., 60) individual spectra obtained over several seconds (e.g., 30).
- **Moments:** The moments data are calculated directly from the spectral data by integrating across the Doppler frequency domain, and basically represent the spectrum as a whole. At each range gate, beam pointing direction, and power level, four quantities are calculated:

1. Mean Doppler shift: The first moment of the spectrum, f_D calculated roughly as:

$$\bar{f}_D = \frac{\sum_{i=f_1}^{f_2} f_i S(f_i)}{\sum_{i=f_1}^{f_2} S(f_i)} \quad \text{Eq. 1}$$

where $S(f)$ is the power at frequency f and f_1 and f_2 are the minimum and maximum frequencies, chosen about a mid-point frequency associated with the maximum signal power level.

2. Doppler width: The width of the spectrum, V_D , calculated as:

$$V_D = 2 \sqrt{\frac{\sum_{i=f_1}^{f_2} ((f_i - \bar{f}_D)^2 S(f_i))}{\sum_{i=f_1}^{f_2} S(f_i)}} \quad \text{Eq. 2}$$

3. Noise level: This value is calculated using methods described by Hildebrand and Sekhon (1974), based on the assumption of a Gaussian noise spectrum such that the variance of the spectral points should be equal to the square of their mean value divided by the number of spectral averages. Using this fact, the signal region is separated from the noise region and helps to define the minimum (f_1) and maximum (f_2) frequencies above.
4. Signal-to-noise ratio (SNR): This value is calculated from the ratio of $S(f)$ to the noise level determined above.

The moments data can be very useful in determining atmospheric structure on time scales as fine as a few minutes. Figure 1 shows an example of the moments data set for the high-power vertical beam (low power not shown), with the SNR at the top, the vertical velocity in the middle, and the spectral width at the bottom panels. Note that the vertical velocity definition is such that positive is downward, towards the antenna. In this example, the vertical velocities, the SNR, and the spectral width are all affected by rainfall (large downward motion associated with energy scattered from falling rainfall rather than atmospheric structure) at about 0500 UTC until the end of the day.

- **Time-averaged profiles:** These consist of values calculated over a user-defined period (usually 1 hour for ARM data) normally calculated using consensus averaging (see section 7.1.2) to eliminate values at times and heights with unacceptable data. These quantities include the wind speed and direction for each height, and the radial wind speed and the SNR along each transmit direction. Figure 2 is an example of a 24-hour period of profiler winds at high and low powers portrayed using wind barbs.

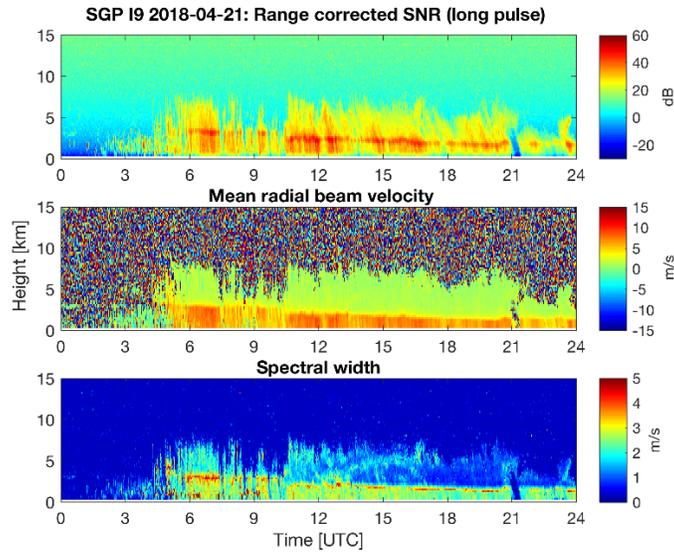


Figure 1. Calculated moments for the vertical beam (precpmom, high power mode) at SGP I9, Billings, Oklahoma on 2018-04-21.

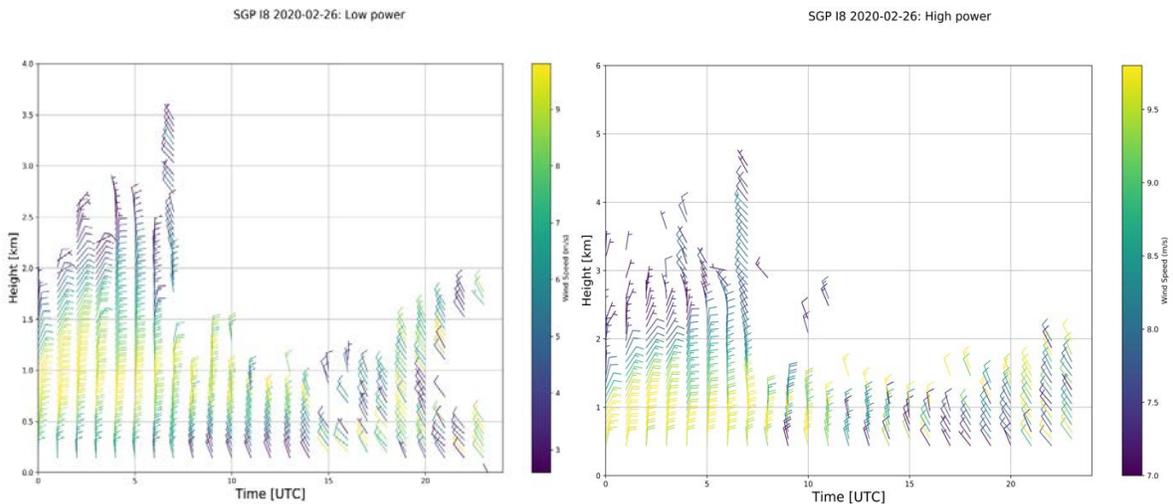


Figure 2. RWP low- (left) and high- (right) power consensus-averaged winds recorded on 2020-02-26 at the SGP I8 Facility.

5.1.2 Virtual Temperature Profile Data

RASS data is similar in format to the wind data, consisting of spectral, moments, and consensus-averaged data files. When RASS was operational at the ARM SGP site, it normally operated only during the first 10 minutes of the hour. There are a few differences in the data:

- **Spectra:** The spectral data are determined in the same manner as is the wind profile spectral data. However, because the speed of sound is considerably larger than normal atmospheric wind velocities, the size of the fast Fourier transform (FFT) necessary to cover both large and small Doppler shifts is relatively large (2048 points nominally). To save space, only selected points around zero (atmospheric motion) and around 340 m/s (the speed of sound) are saved. There is a single spectrum

for each range gate. Because there is only a single power level and pointing direction (vertical), there is normally only one spectrum per range gate. The spectrum represents an average of several individual spectra obtained over several seconds (e.g., 30) similar to the wind analysis. However, because of the large number of points, only about 10–15 spectra per time interval are averaged.

- **Moments:** The moments data are processed much the same as the wind data. However, there are two signal sources to consider: Because the true velocity of the propagating sound wave, c , depends on the motion of the atmosphere, i.e.:

$$c = v_r + 20.05\sqrt{T_v} \quad \text{Eq. 3}$$

where v_r is the air speed along the direction of the sound and T_v is the virtual temperature, it is sometimes necessary to compensate for this motion when calculating T_v . Even though the vertical motion (the direction of the propagating sound wave) is usually small, there are situations where it is important, such as convective conditions (vertical velocities on the order of 5 m/s at times) and orographic forcing. Unfortunately there are also occasions where the use of the corrected value is not propitious, such as during precipitation, when detected descending motion is not due to air motion. Thus, moments similar to those calculated for the wind profiles are determined for both the vertical air motion and the vertically moving sound pulse.

- **Time-averaged profiles:** These, once again, are calculated in a manner similar to the time-averaged wind profile estimates. However, the calculated virtual temperature (in degrees Celsius) is produced with and without a correction for the sensed vertical atmospheric motion. A 24-hour display of virtual temperatures is often displayed, as shown below in Figure 3. Note that each “hour” value, while depicted as “filling” an entire hour, is in fact representative only of the first 10 minutes of that hour unless the profiler is configured to operate RASS for longer, or different, time periods.

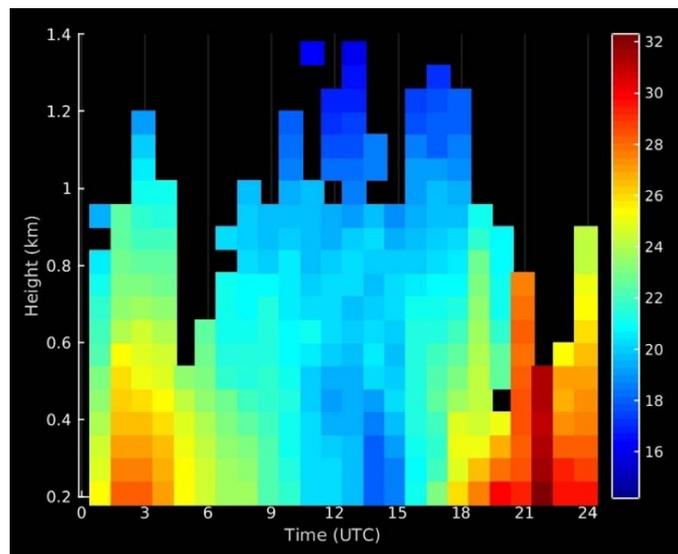


Figure 3. An example of a 24-hour display of RASS virtual temperature (units in C°).

5.1.3 Precipitation Operation

Along with the wind mode operation when the RWP's cycle through oblique and vertical beams (at least three beams are necessary for wind determination), the four RWP's at the SGP Central and Intermediate Facilities operate in a precipitation mode in conjunction with cloud scanning radars. In this mode, the RWP's transmit only in the vertical direction with shorter averaging times and larger spectral domains. In this mode they are not able to obtain winds very efficiently. However, they can sample precipitation quite well up to as high as 16 km. In this case, they measure the fall velocity of rain or snow, relative to the air motion. In conjunction with some assumptions regarding the relationship between terminal velocity of water/snow and the spectrum of the fall velocities, updraft/downdraft locations and magnitudes can be determined. Particularly in parallel with scanning Doppler radar measurements, these measurements can contribute to a better understanding of in-cloud processes.

Because the wind measurements are compromised by the fall velocities and improved understanding of in-cloud processes require high-temporal-resolution precipitation measurements, an “adaptive” algorithm has been implemented at all four SGP sites since 05/2018 to operate only in precipitation mode when precipitating conditions are identified via real-time monitoring of moments data. Figure 4 shows the SNR, the vertical velocity, and the spectral width collected with the wind mode up to about 2025 UTC, when precipitating conditions are identified by the algorithm and the profiler switches to operating in precipitation mode providing high-temporal-resolution vertical beam low- and high-power measurements.

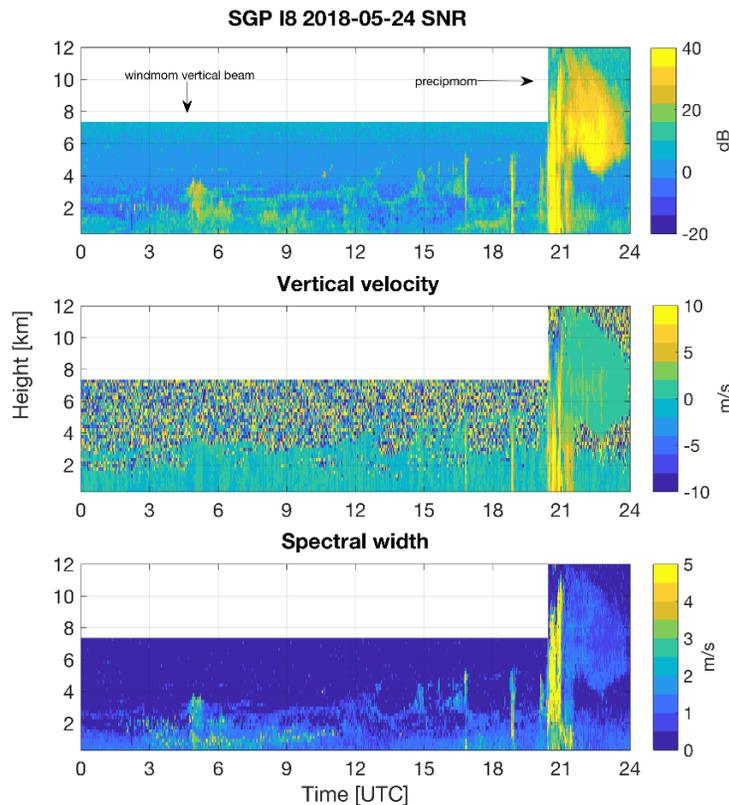


Figure 4. An example of adaptive algorithm’s operation switching from wind mode to precipitation mode only when precipitating conditions have been identified.

5.2 Data File Contents

The file structures described below are similar for both the wind and precipitation mode operation, with the precipitation mode only having the vertical component.

5.2.1 Data Types

5.2.1.1 Wind Profile Data

- Spectral Data
 - At each height, beam pointing direction, and power level:
 - Spectral amplitude (at each bin of FFT).
- Moments Data
 - At each beam pointing direction, and power level:
 - At each range gate:
 - Mean Doppler shift (in % of Nyquist frequency)
 - Spectral width (in % of Nyquist frequency)
 - SNR level (in dB)
 - Noise level (in dB)
- Average Data
 - At each power level:
 - At each range gate:
 - Wind speed (in m/s)
 - Wind direction (degrees relative to true north)
 - For each beam pointing direction:
 - Radial wind speed (positive = toward the antenna)
 - Number of moments that passed consensus criteria
 - Average SNR

5.2.1.2 Virtual Temperature Profile Data

- Spectral Data
 - At each height:
 - Spectral amplitude (at selected bins of FFT).
- Moments Data
 - At each range gate:
 - Mean Doppler shift of vertical atmospheric motion (in % of Nyquist frequency)
 - Spectral width of vertical atmospheric motion (in % of Nyquist frequency)
 - SNR level of atmospheric portion of spectrum (in dB)
 - Noise level of atmospheric portion of spectrum (in dB)
 - Mean Doppler shift of acoustic signal (in % of Nyquist frequency)
 - Spectral width of acoustic signal (in % of Nyquist frequency)
 - Noise level of acoustic signal portion of spectrum (in dB)
 - SNR level of acoustic signal portion of spectrum (in dB)

- Average Data
 - At each height:
 - Virtual temperature (C°)
 - Corrected (for vertical motion) virtual temperature (C°)
 - Vertical wind speed (in m/s, positive upward)
 - Number of moments that passed consensus criteria for:
 - Uncorrected virtual temperature
 - Corrected virtual temperature
 - Vertical motion
 - SNR (in dB) for:
 - Uncorrected virtual temperature
 - Corrected virtual temperature
 - Vertical motion

Additional information may be found in the netCDF file header descriptions for RWP data ordered from the [ARM Data Center](#).

5.2.2 Primary Variables and Expected Uncertainty

The primary quantities measured with the RWP system are the intensity and Doppler frequency of backscattered radiation. The wind speed is determined from the Doppler frequency of energy scattered from refractive index fluctuations (caused primarily by moisture fluctuations but also, to a lesser extent, by temperature fluctuations) embedded within the atmosphere; the virtual temperature is determined from the Doppler frequency of microwave energy scattered from acoustic energy propagating through the atmosphere.

Definition of Uncertainty

The primary observed quantities are Doppler frequency and signal amplitude. Note that the observed quantities above are not the principal quantities of interest to most scientists. The derived quantities of most interest to scientists are the wind speed, wind direction, vertical wind speed, and virtual temperature as a function of height. The accuracies of these quantities, while dependent upon the accuracy of the frequency measurement, are also affected by atmospheric effects and vary considerably according to conditions. The wind speed is derived from measurements from, normally, five beams. Because the individual components are not collocated in space, horizontal homogeneity is assumed to derive the wind vector at a single height. Furthermore, the data are sampled at equal time intervals along each transmit direction. Thus, the vertical beam is sampled at larger height intervals than are the tilted beams (by $1/\sin[\text{elevation angle}]$). This difference is approximately 3%, which can be significant at large ranges. For example, at a nominal height of 1000 m (tilted beams), the vertical beam information is derived from 1035 m, which can be significant in some situations

- Nominal accuracy for wind speed: 1 m/s
- Nominal accuracy for radial wind components along the pointing direction of the transmitter (e.g., vertical velocity): 0.5 m/s
- Nominal accuracy for wind direction: 3°
- Nominal accuracy for virtual temp: 0.5 K

These figures are the result of more than one year of daily and multi-day comparisons with winds derived from the balloon-borne sounding system at the Central Facility of the Southern Great Plains observatory.

5.2.3 Data Quality Flags

No flags are applied during the data ingest of the consensus-averaged winds and virtual temperatures. However, the data are examined regularly by the instrument mentor for quality assurance: files are created and maintained by the DQO on a monthly basis for each of the instruments that determine locations (temporally and spatially) where data should be eliminated based on a brute force, multi-pass comparison with data from neighboring points (above, below, before, and after). This routine eliminates most of the questionable data. However, several situations defy straightforward objective analysis routines, most of which can be delineated by subjective analysis. This is done monthly by the instrument mentor. The primary situations that can create seemingly good, but actually erroneous, data include:

- **Precipitation:** Both rain and snow are excellent sources of scatter of electromagnetic radiation; thus, they have the potential to provide considerable increases in the effective range for useful data. However, precipitation generally has a heterogeneous spatial distribution on the scale of the separation of the transmitted beams. This can lead to significant errors in the estimates of the true wind speed. Rainfall is more amenable to objective analysis detection because it usually has a large downward velocity in comparison to atmospheric motion. Snow, on the other hand, has quite small terminal velocities. Figure 5 shows the effect of precipitation on the consensus winds on 2018-04-22 at the SGP I9 facility. The precipitation lasts up to 0500 UTC, with the peak precipitation at around 0300-0400 UTC, and is expressed as increased SNR on the left panel extending up to 5 km. During this time window while the height coverage of wind profiles is increased, the wind speed estimates, especially during peak precipitation times, may be adversely affected.

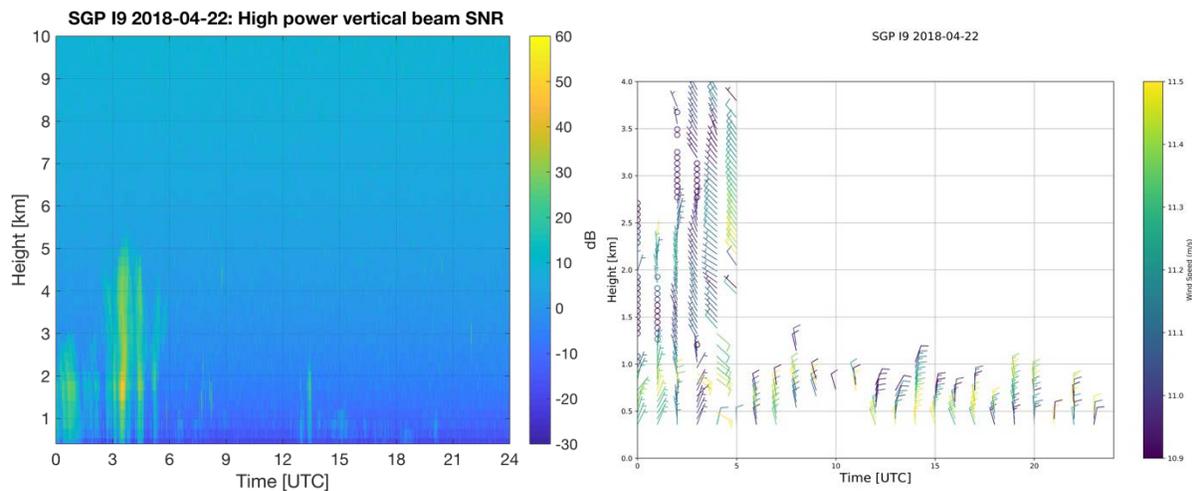


Figure 5. Precipitation effect on the consensus winds.

- **Birds:** The effects of birds, particularly migrating birds, is both difficult to detect and significant. The profiler is sensitive not only to the motion of the bird itself, but to the motion of its wings. During migrating seasons (fall and spring), nighttime winds from the north (fall) and south (spring) are often affected by these effects. The birds generally fly along the direction of the wind and increase the detected wind speed by 5 m/s or more (Coulter and Holdridge 1996, Pekour and Coulter 1998).

Figure 6 shows the low- (bottom) and high- (top) power winds (left) and SNR (right) that are affected by migrating birds. Note the obvious wind direction shift near 2000 hours local standard time for roughly a 5-hour period. In this case, the winds were light enough that the birds flew north anyway. In cases when the winds are directly along the direction of the birds' desired direction of flight, the evidence is quite difficult to determine using the wind barb plot alone. Note the "random-type" strong reflections around 0.7 km on the low-power SNR. These are characteristic of migrating bird signals. Note also that the signature for the high-power returns is considerably different from the low-power returns because of the considerably longer transmit pulse duration used. Finally, it can be noted that in this case the high-power winds are more affected at lower altitudes than are the low-power winds. Obviously, purely objective analysis is difficult in these cases.

- 60-Hz noise:** When 60-Hz noise gets directly into the analyzed Doppler signal it is detected approximately as a Doppler shift associated with a radial wind speed of 10 m/s. Because the Nyquist frequency for winds is often near 10 m/s, the noise signal is sometimes aliased back into the spectrum as well. Depending on which antenna beam is affected, very large deviations in wind speed can occur. Some of these are easily removed, but some provide consistent values not completely removed by some objective analysis routines. In addition, it reduces the range of accessible data.

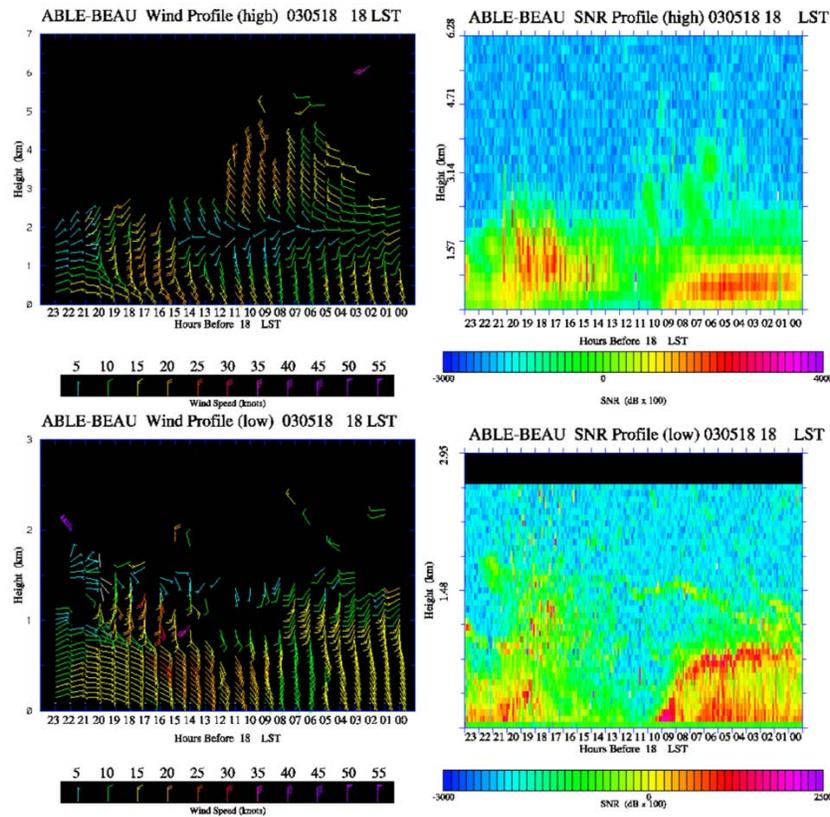


Figure 6. Low- (bottom) and high- (top) power winds (left) and SNR (right) affected by migrating birds.

5.3 Annotated Examples.

Examples are provided throughout the handbook.

5.4 User Notes and Known Problems

- **April 9, 1997:** A noise peak in the spectra of the intermediate facility profilers located at +/- 60 Hz from 0 was reported. This was a relatively serious problem because it effectively raised the minimum detectable signal level from -22 dB to -16 dB, a factor of 4. We still do not know the true cause of the problem, except that it appeared to be a 60-Hz noise problem. However, actions taken at Beaumont, including adjusting, but not changing, the configuration of the ground wires has considerably reduced the occurrences of “bad” accepted data due to 60-Hz noise (75 % approximately) and reduced the minimum detectable SNR level to about -20 to -21 dB. At Medicine Lodge, maintenance on the phase shifter assembly in December 1999 apparently changed the configuration in some minor way so that it also is reporting much less “bad” data and has a minimum SNR level near -20 dB. In both cases, however, the minimum SNR level is due to the 60-Hz noise. At Meeker, the problem has never been quite so severe and has a minimum SNR value near -19 to -20 dB.
- **Spring, 2019:** The 1290 MHz Scintec RWP at the Eastern North Atlantic site started demonstrating degradation of sensitivity. The Scintec radar engineer evaluated the profiler on site from July 8 to July 12, concluding that the antenna and the phase shifter are dramatically affected by heavy corrosion and cannot be repaired. The profiler will become operational again after the purchase and installation of new components.
- **October 14, 2019:** A noise peak in the spectra at the SGP I10 facility located at about +/- 60 Hz from 0 was noticed. Both internal and external potential sources of interference were considered; thorough evaluation of the RWP system components was performed. As a result, it was found that the outdoor cables passing through conduit were dramatically affected by the moisture accumulation inside the conduit, which was causing the problem.
- **November 2019:** During the initial setup and data validation stage of the Cold-Air Outbreaks in the Marine Boundary Layer Experiment (COMBLE) deployment of the AMF1, it was noticed that the 1290 MHz RWP was not switching beams. Through thorough evaluation of system components it was determined that some of the phase shifter relays were not working, while all relays were affected by age and corrosion. All phase shifter relays were upgraded for the remainder of COMBLE.

5.5 Frequently Asked Questions

- Why don't the profiler values of winds and/or temperature agree with values from the radiosonde balloon-borne sounding system (BBSS)?
 - The RWP provides values averaged over (nominally) 1 hour while the BBSS obtains only a grab sample at one instant in time at each height.
 - The balloon from the BBSS travels with the mean wind; hence, it is not collocated with measurements from the RWP.
 - The RWP values are volume averages over (nominally) 60–240 meters in height by 9 degrees horizontally.

- The BBSS measures temperature; the RWP measures virtual temperature.
- The RWP may be detecting birds rather than the true wind.
- What are the factory-recommended calibration procedures?

The only true calibration procedures are carried out during the Acceptance Test (AT) that is performed immediately before the instruments are put into service. These are carried out by the vendor and the instrument mentor. They include the following:

- **Output power:** Measured at the output of the final amplifier/preamplifier, including both forward and reflected power measurements (3990 W and >500 W for 50 MHz and 915 MHz, respectively).
- **Center frequency:** Transmit frequency (49.8 MHz and 915 MHz for the 50 MHz and 915 MHz RWPs respectively) is measured using a signal generator input to the receiver.
- **Doppler direction:** Using a special control parameter file, small signal frequency differences are analyzed to determine the appropriate sign of the analyzed frequency difference.
- **Dynamic range:** A signal generator with variable attenuator is used as input to the system to establish a dynamic range of at least 55 dB.
- **System sensitivity:** A signal generator is used to establish a minimum detectable level of at least -127 dBm.
- **Range verification:** A delay line is used to establish range accuracy of +/- 30 m.
- What are the factory-recommended performance checks?

These include visual inspection, system power, timing, data transfer, antenna integrity, and RASS (if applicable) operation verification. Additional performance checks suggested by the vendor include:

 - Control lights
 - Date and time accuracy
 - Final Amplifier current stationary
 - Appropriate antenna rotation
 - Data appearance
 - SNR levels unchanged
- What are the mentor calibration procedures?
 - There are no “mentor calibration procedures” other than comparison of data with other available sources of data. This, however, is more of a QC check.
- What are the mentor performance checks?
 - Regular noise level checks
 - Regular final amplifier current checks
 - Daily data existence
 - Inspection of vertical time section of winds/temperatures and moments

- Continuous (daily) maximum height attained monitoring
- What is the standard schedule of calibrations and checks, and is any data affected or lost during the procedures?
 - Factory calibrations are done at the time of installation. All data during the basic factory calibration, that 1–2 days, is lost.
 - Other checks are designed for site operators to perform (daily, monthly and yearly preventative maintenance). No data is affected/lost during these checks.
- Does storage media exist on the instrument system to back up data and store it for delayed data ingest?
 - The hard disk can hold spectra and consensus files for approximately 12 days. It can hold consensus-only data for 1 year. An optical disk can hold spectral data for 12 months.

6.0 Data Quality

As with all ARM instruments, data quality is a critical issue for RWP and RASS units.

6.1 Data Quality Health and Status

The [Data Quality Office](#) website has links to several tools for inspecting and assessing RWP data quality:

- [DQ Explorer](#)
- [DQ Plot Browser](#)
- [NCVweb](#): Interactive web-based tool for viewing ARM data.

The tables and graphs shown contain the techniques used by ARM data quality analysts, instrument mentors, and site scientists to monitor and diagnose data quality.

6.2 Data Reviews by Instrument Mentor

- Quality control (QC) frequency: Daily
- QC delay: Instantaneous; daily
- QC type: Min/max flags, graphical plots, intercomparisons
- Inputs: Raw data
- Outputs: Summary reports

Data QC procedures for this system are mature.

1. Data flags:

A procedure used to be in place for several years that produced a parallel datastream to the “.a2” data, which consists of consensus-averaged wind and temperature profiles produced by the wind profiler. These data are unchanged from the original data but have

an additional data field consisting of flags referring to data that are questionable. The flags were determined based on differences between successive wind or temperature variables. Comparisons are made both in time and space and both forward and backward (i.e., comparisons with previous and successive values at a given height as well as comparisons with values above and below at a given time.) If the values exceed defined limits, they are flagged.

2. Comparison with radiosonde data:

Every routine launch of radiosondes by the BBSS used to be compared in wind speed, wind direction, and virtual temperature between the BBSS and the 50 MHz and 915 MHz profilers at the Central Facility. The approach taken was to compare all values of “good” profile values with BBSS values averaged over nearly the same height interval. The differences are used to produce the mean, standard deviation, maximum, minimum, and number of values. These data are appended to a file that dates back to June 20, 1995. Summary plots of these data are inspected to determine degraded system performance (Coulter and Lesht 1997). The statistics of the differences were inspected daily.

3. Estimated maximum height of return:

The daily data from 915 MHz wind profilers are used to determine the maximum height attained in at least 25%, 50%, and 75% of the profiles during each 24-hour period. These data are appended to a file (for each site) beginning January 25, 1993 (915 MHz at CF), March 24, 1994 (50 MHz at CF), and January 1, 1997 (915 MHz at intermediate facilities). These data are plotted occasionally to determine trends that might indicate hardware problems.

4. Daily inspection:

Vertical time sections of hourly averaged wind and temperature profiles over a 24-hour period are visually inspected on a daily basis for system and operation consistency.

6.3 Data Assessments by Site Scientist/Data Quality Office

All DQO and most site scientist techniques for data assessment have been incorporated within [DQ Explorer](#).

6.4 Value-Added Products

Many of the scientific needs of the ARM user facility are met through the analysis and processing of existing data products into value-added products (VAPs). Despite extensive instrumentation deployed at the ARM sites, there will always be quantities of interest that are either impractical or impossible to measure directly or routinely. Physical models using ARM instrument data as inputs are implemented as VAPs and can help fill some of the unmet measurement needs of the ARM facility. Conversely, ARM produces some VAPs, not to fill unmet measurement needs, but to improve the quality of existing measurements. In addition, when more than one measurement is available, ARM also produces “best-estimate” VAPs. For more information see <https://www.arm.gov/capabilities/vaps>.

7.0 Instrument Details

7.1 Detailed Description

7.1.1 List of Components

The 915-MHz and 1290-MHz radar wind profilers are manufactured by Vaisala Corp. They comprise a single-phased microstrip antenna array consisting of nine “panels” (most systems have only four panels). The antenna is approximately 4-m square and is oriented in a horizontal plane so the “in-phase” beam travels vertically. Below is a list of components for these RWPs:

- Antenna assembly, including the clutter fence
- Computer, including the radar processing unit
- Final Amplifier (FA)
- Modulator, Intermediate Frequency and Interface unit (MII)
- Phase shifter
- FA power supply.

The 1290-MHz beam-steered RWP (BSRWP) is manufactured by DeTect, Inc. It has phase control over each of the 64 discrete elements to enable beam pointing on a pulse-by-pulse basis. Below is a list of components for the BSRWP:

- Antenna assembly, including the clutter fence
- Computer, including the radar processing unit
- High-power amplifier
- GPS compass, including a 3-GPS antenna receiver system and an Inertial Measurement Unit (IMU)
- Transmit/Receive switch
- Profiler health monitor
- Intermediate Frequency Conditioner.

7.1.2 System Configuration and Measurement Methods

The radar wind profilers operate by transmitting in two different vertical planes and receiving backscattered energy from refractive index fluctuations that are moving with the mean wind. By sampling in the vertical direction and in two tilted planes, the three components of motion can be determined. The systems (Vaisala and Scintec) consist of a single-phased array antenna that transmits alternately up to five pointing directions: one vertical, two in the north-south vertical plane (one south of vertical, one north of vertical), and two in the east-west vertical plane (one east of vertical, one west of vertical). The non-vertical beams are tilted at about 14° from vertical.

Radial components of motion along each pointing direction are determined sequentially. It takes, nominally, 30-45 seconds (dwell time) to determine the radial components from a single pointing direction. Thus, at the SGP site the system currently cycles through three beams (two obliques and vertical) at low power, and then cycles the three beams again at a high-power (longer pulse length) setting. Then the whole process is repeated. About three minutes elapse before the system returns to the beginning of its sequence. Within an averaging interval, the estimates from each beam-power combination are saved; these values are examined and compared at the end of the period to determine the consensus-averaged radial components of motion.

Consensus averaging consists of determining if a certain percentage (e.g., 50 %) of the values fall within a certain range of each other (e.g., 2 m/s). If they do, those values are averaged to produce the radial wind estimate. The radial values are then combined to produce the wind profile. The results of this averaging process are what are reported in the “.a2” data files produced by the ARM data system. Included in these files are height, speed, direction, radial components, number of values in consensus, and SNR.

During a single time period over which the system operates in a single pointing direction (dwell time), the data that are produced in the “.a1” and “.a0” files are created. The system transmits pulses at about 1–10 kHz rate into the atmosphere. The backscatter from each transmit pulse is sampled at, for example, a 1 MHz rate. This results in 1 sample every 150 minutes in range. The samples at each range gate are averaged together (time domain integration) over some number (e.g., 100) of pulses to produce a phase value for input into a FFT. After (e.g., 64) values are produced, the FFT is performed (one for each range gate). This process takes on the order of one second. A number (about 30) of these spectra are then averaged together during the dwell time. At the end of the dwell time we have produced a single averaged spectrum from each range gate along the designated pointing direction. The spectra themselves are placed in the “.a0” data files.

The spectra are analyzed by the system before moving to the next pointing direction. This analysis produces estimates of the SNR, the noise, the mean velocity (proportional to frequency), and the spectral width at each range gate. This is the information that is stored in the “.a1” data files. Both the “.a1” and “.a0” data files thus have information at about same (dwell time) intervals; however, the data sequences vary among pointing directions and output powers.

A note of warning about the mean values in the “.a1” files. The values are in % of full scale times 100, where full scale is the Nyquist velocity of the spectrum. Thus, velocity estimates are determined by multiplying the “mdf” column by the “oband” or “vband” values (described in the metadata) and dividing by 10,000.

RASS operation is essentially the same, except that the averaging time is about 10 minutes and only a single pointing direction (vertical) is used. Also, the atmosphere is “seeded” with a sound wave; the index of refraction changes created by the sound wave are the signal source. To sample both the sound wave (speed about 340 m/s) and the atmosphere (to remove air velocity from temperature estimates), a larger FFT is required (2048 points). This requires a smaller number of points for each time domain integration and increases the processor time required to calculate the FFT. The “.a0” files again are spectra; however, only a portion of the spectra are reported, namely a region near 0 Doppler shift to account for atmospheric motions and a region around the expected speed of sound. The “.a1” files now consist of moments and widths from both the atmospheric portion of the spectrum and from the acoustic portion (the main contributor to the temperature calculation). The “.a2” files consist of profiles of temperature and number of consensus values.

7.1.3 Specifications

- Frequency: 915 or 1290 MHz
- Maximum range: 3–6 km (16 km for precipitation detection)
- Range gate: 0.06–1 km
- Pulse length: 60, 100, 200, 400 m
- Number of spectra per average spectrum: 1-100
- Number of pulse/time domain integrations: 1-1000

7.2 Operation and Maintenance

7.2.1 User Manual

A user manual is available to the mentor for the RWPs, with one copy kept at each site.

7.2.2 Routine and Corrective Maintenance Documentation

Routine preventative maintenance procedures (weekly, monthly, yearly) as well as a corrective maintenance procedure are designed by the mentor for the site operators to perform. These include factory-recommended procedures (preventative and corrective) for inspecting the antenna, clutter screen, cables and electronics. ARM operations maintains the corrective maintenance records in an online database.

7.2.3 Software Documentation

Software documentation provided by the vendors is maintained by the mentor and is also available to the site operators on the instrument computer.

7.3 Glossary

See the [ARM Glossary](#).

7.4 Acronyms

See the [ARM Acronyms](#).

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