WHITE PAPER

Radar Wind Profiler Specifications Explained

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Change Information

Revision Number	Date	Changes
1.0	October 20, 2008	New
1.1	May 5, 2009	Updates

Table of Contents

1 Executive Summary

Specifying and procuring a radar wind profiler (RWP) is a complex and demanding task. A wind profiler is a major investment, and since it is a remote sensing device, specifying parameters such as height coverage is complicated by issues such as the natural variability of atmospheric conditions, installation site conditions, and customer desired resolution. These issues, along with site selection, site preparation and data communications must be carefully considered in defining the requirement.

This document has been prepared in order to facilitate the RWP requirement definition process that all users must manage. This guide is broken down into: 1) tables of RWP specifications, with typical values and short explanations (***Section 2***), and 2) a "Notes" section which expands on specific RWP topics (***Section 3***). An acronym list and short glossary are also provided at the end of this document (**Section 5**). Please refer to these for clarification.

Before writing a tender, the final users should gather as much information as possible about commercially available wind profilers. It is important to understand what systems already exist, how they are used and their performance. At times, customers can inadvertently require specifications that are either unrealistic or that significantly raise the cost of the system.

Benefits to your organization:

- Creating a good radar wind profiler tender specification reduces the chances of a protested procurement.
- A well written specification reduces chances of confusion during the procurement cycle.
- A good tender ensures that the final user will get the system and the data they need.

2 Radar Wind Profiler Specifications

In this section there are several tables of different types of specifications normally found in a radar wind profiler tender. The tables are arranged so the specification is first listed, then common values, then a general explanation. For specifications where more information is provided, there is a note to see the ***Notes*** section, later in this document.

2.1 General RWP Specifications

Below are general specifications for radar wind profilers. Commonly there are three different types of RWP systems: 1) boundary layer, 2) mid-tropospheric, and 3) full tropospheric. Where specifications differ for each type, the "typical" specifications show the differences.

Table 1. General Specifications

Specification	Typical Value	Explanation
Maximum Height Coverage	*BL: 2 to 3 km* *Mid-Tropospheric: 3 to 14 km* *Tropospheric: 20 km* *80 % Percent Coverage*	Boundary layer (BL) systems often transmit in the high UHF (~1GHz) range, and therefore are limited in height coverage by the physical size of atmospheric turbulence, and atmospheric absorption and attenuation, which typically increase with frequency. To obtain higher altitude data, lower transmit frequencies must be used, such as the 400-500 MHz range or even lower. ►*Please see Notes 3.1 and 3.3 below.*
Minimum Height Coverage	*BL: 75 to 125 m* *Tropospheric: 100-200 m*	A RWP systems first range gate is limited by the antenna type and size, local ground clutter, and transmit pulse length. ►*Please see Note 3.2 below.*

Range Resolution	*50 to 1000 m*	The transmit pulse length affects the lowest possible gate, range resolution, and also can affect maximum height. Typically, small values (50 to 200 m) are used for the BL, whereas larger values (250 to 1000) are used for full tropospheric coverage. Range resolution may also be restricted by emission bandwidth constraints. ►*Please see Note 3.3 below.*
Temporal Averaging	*5 to 60 min*	These are common values, but less than 15 minutes is not recommended depending on location and wind profiler size. Particularly in the boundary layer, lower values may not be representative of the atmosphere due to the variability of the atmosphere and the spatial separation of the antenna beams.
Data Latency	*< 5 min*	This is the time required to calculate and produce a new average wind measurement. This is not usually an issue with modern wind profilers.
Winds Accuracy	*±1 m/s and ±10˚* *(based on hourly averages)*	These are common values for wind profilers, and have been determined by research organizations through long-term comparisons with radiosondes.
Frequency	*USA: 50, 449, and 915 MHz* *International: 50, 449, 482, 915, 1280 MHz etc.*	The profiler transmit frequency is dependent on what country or site the profiler will operate in, as well as the maximum height wind data is required from. ►*Please see Note 3.4 below.*

Transmit Peak Power	*BL: 500 to 2000 W* *Mid-Tropospheric: 1 to 8 kW* *Tropospheric: 1 to 50 kW*	Peak power is the maximum power the transmitter can instantaneously supply. Radar sensitivity is related to average power however, and is determined by the required range resolution and maximum range. ►*Please see Note 3.5 below.*
Antenna Gain, Beamwidth (BW) and Sidelobes	*Main lobe gain and BW:* *BL: 20 to 30 dBi, 12° BW* *Tropospheric: 25 to 35 dBi, <5° BW*	Antenna gain describes increase of power (of the main lobe) in a particular direction. ►*Please see Note 3.6 below.*

2.2 Other System Options

A radar wind profile can be ordered with other options. Listed below are the most common items.

Specification	Typical Value	Explanation
RASS Subsystem	*Option for most wind profilers*	Obtains virtual temperature data from near ground to 1 to 3 km or higher. ►*Please see Note 3.7 below.*
Microwave Radiometer	*Separate system, often used in conjunction with RWP systems*	10 km range with fast retrievals of temperature (~60 seconds), humidity, and liquid water profiles.

Health, Status Monitor with Fault and Status Reporting	*Modular Subsystem, often listed as optional*	Many manufactures offer optional monitor subsystems to determine RWP health. DeTect highly recommends customers utilize a monitor system to help protect the system and alert the user when data quality could be affected by subsystem failure. Many RWP systems operate throughout the world without a monitor system, meaning, often inaccurate data is collected. ►*Please see Note 3.8 below.*
Electronics Shelter or Trailer	*Depends on Customer Requirements*	Almost all RWP systems require that at least some portion of the radar electronics be contained in an environmentally protected and conditioned area. Often since radar systems are in remote locations a shelter is required. There are many possible options for a shelter. ►*Please see Note 3.9 below.*

2.3 Profiler Data Processing System

Below are typical specifications for the profiler data system and associated items. Depending on customer needs, other configurations are available.

Specification	Typical Value	Explanation
Computer System	*Single computer, high-end type*	A modern RWP should utilize a high-end computer system. This usually includes a multi-core CPU, 2 GB or more memory, large hard disk, DVD-RW drive, and high-quality LCD monitor. ►*Please see Note 3.10 below*

Operating System (OS)	*Windows or Linux*	Windows has become more problematic over the years as a reliable OS for unattended operations. DeTect can supply a RWP with either Windows or Linux based systems.
Multi-peak discrimination and QC Software, with Displays	*Extra software, often listed as optional*	This type of software is often listed as an option, but to obtain the most value from the RWP, this software should be utilized. For example, migrating birds can easily interfere with RWP system without multi-peak discrimination software. DeTect highly recommends the customer require this option. ►*Please see Note 3.11 below.*
Data Archive	*All data products*	Should include capability to archive (on hard disk) time series, radial moments, winds and other data products
Remote Displays and other Communication Interfaces	*Depends on customer requirements*	Often a customer may need either remote displays or data communications. It is important to state clearly what is needed in the tender.
Rack-mount	*19" electronics rack*	For BL systems, often they are not rack-mounted. For larger systems, they must be rack-mounted. DeTect recommends rack-mount for all systems to protect and secure all subsystems and cables.
Uninterruptable Power Supply	*2 kVA minimum*	DeTect highly recommends the use of a high-quality UPS for RWP operations (such as Powerware 9125-RM). ►*Please see Note 3.12 below.*
Color Printer	*Laser jet or equivalent*	If a customer wishes to have the RWP vendor deliver a printer, it is best to specify a currently available model.

2.4 Environmental Specifications

The environmental specifications are broken down into indoor and outdoor types.

Specification	Typical Value	Explanation
Temperature	*Indoor Operational:* *10 deg C (50˚ F) →* *40 deg C (104˚ F)* *Outdoor Operational & Outdoor Storage:* *-40 deg. C (-40˚ F) →* *+55 deg C (131˚ F)*	These are common values for operational and commercially available systems. This assumes that the RWP electronics are in an environmentally controlled shelter. For smaller RWP systems, the electronics may be installed outdoors, but this must be specified and could increase cost.
Humidity	*Indoor:* *0 to 95% RH* *non-condensating* Outdoor: 0 to 100% RH	These are common values for operational and commercially available systems. If an environment has a very high rain rate, extra provisions may be required.
Wind Load	*50 m/s (110 MPH) continuous* *60 m/s (135 MPH) gust*	Wind loading is site specific. The wind loading requirement of the antenna and shelter should be the same. Obviously the higher this value, the higher the cost of installation. Local building codes and other requirements may be important and are usually the responsibility of the customer unless otherwise specified.
Rain	*3" per hour* *with 30 MPH wind*	RWP vendor must show that provisions are taken to prevent damage and allow operations

Freezing Rain/Icing	*1" radial ice*	The customer should alert the vendor if this is a common occurrence or not, or if ice accretion is greater than 1".
Snow Loading	*Specified by customer*	Snow loading will affect the antenna design, RASS enclosure and support structures and electronics shelter. Snow loading requirements can be a cost driver and should be specified in conjunction with any local building code requirements.
Dust	*Dust-laden environment*	RWP vendor must make provision for such.
RFI/EMI/EMC	*Normally not specifically specified*	The RWP should be designed to handle most other transmitting devices, but since a RWP deals with such low SNR, it is best if the installation site does not have strong emitters. If possible a spectrum analysis should be performed by a qualified party.
Corrosive Environment	*Usually an option from RWP vendor*	A corrosive environment is any site near salt water body. Extra provision may be required to protect the outdoor equipment.
Lightning	*Incorporated lightning protection measures*	Lightning can cause damage either through direct exposure or through line surges through utilities (phone, electrical, network, etc.). It is important that all external interfaces be protected and that adequate lightning protection measures be in place. Responsibility for some of these items will depend on the nature of the contract, and which party is providing which portion of the installation and shelter, etc. ►*Please see 3.13 below.*

Fencing and Security	*Depends on installation location and division or responsibilities*	Most often, the customer takes care of site issues, such as leveling, installation of utilities, any concrete work, and fencing. DeTect can perform and/or manage these duties if required.

2.5 Miscellaneous Specifications

The following specifications are a "catch-all" for any remaining specifications.

Specification	Typical Value	Explanation
Modular subsystems	*Modular or LRU concept*	This specification indicates that replacement subsystems units should not require tuning or alignment onsite, but should be designed for ease of replacement by a local technician.
MTBF (MTBCF)	*5000 hours*	Typical value for entire radar system. Often listed as MTBF (Mean Time Between Failure), this is better expressed as MTBCF (Mean Time Between Critical Failures) since some RWP subsystems have soft-fail capability.
Safe-fail	*Automatic means to safely shut down system*	Automatic safe shutdown to prevent damage to the system in event of radar or other (e.g., shelter HVAC) subsystem.
Weight Limit for LRUs	*55 lbs (25 kg)*	Common value for maximum weight of replacement modules
Mean Time to Repair	*1 hour*	MTTR: Common value for customers who have purchased onsite LRU replacement modules.

Spares	*Full LRU or minimum*	This depends on the type of operations of the customer and available funds. ►Please see section 3.14 below.

2.6 Customization

Other than for country-wide weather service type networks, RWP systems are typically sold and installed one at a time. Each customer typically utilizes a RWP for a specific and sometimes unique purpose. It is important for the customer to indicate to the RWP vendor (through the tender) as much detail as possible about:

- The installation site (including available main power, communications, soil type, terrain, local ground clutter, etc.)
- Electronics installation location (i.e., will the vendor be required to supply a shelter or will this be customer provided?)
- Intended final use of data (e.g., what is the desired averaging interval, will vendor displays be used or will the RWP interface to other computer systems)
- Special frequency spectrum emission issues or regulations
- Remote control requirement
- Physical and computer security requirements
- Capabilities of maintenance personnel

Note that DeTect can customize the wind profiler, shelter, or site to fit customer requirements.

2.7 Site Selection

Many factors must be considered before installing a radar wind profiler. Wind profilers are very sensitive instruments and can be exposed to interference due to nearby highway-traffic, power lines, trees, towers, radio frequency sources, bird flyways, surface water, and aircraft. Proper siting of the system is very important to obtain the best quality data.

Other factors that must be considered include: availability of electrical power and communications, access to site via roads, proper drainage, and security. In addition, official clearance and approval for radar operations may be required. Also, if a RASS system is used, the loud sound from the RASS system must also be taken into account if siting in or near populated areas.

It is most effective if a DeTect engineer be directly involved with the customer for site selection, traveling with the customer to potential sites. The site survey should occur as early as possible in the procurement process to help the customer understand RWP requirements and reduce the chance of miscommunications or difficulties.

2.8 Site Preparation

After a proper site is selected, there can be significant site preparation required. Depending on the size of the radar, this can include relatively simple items such as ground preparation with weed barrier and gravel, to full environmental impact assessments and permitting, site leveling, provision for water drainage, installation of utilities, installation of security fence concrete pads, or piers, and electrical grounding system.

Because of the significant number of unknown details, site preparation is best handled directly by the customer or their appointed in-country representative. For example, there may be specific local regulations that must be followed for zoning, permitting, drainage, utilities, concrete foundations (e.g., depending on solid analysis), environmental impacts, possible archeological importance, and even potential former waste site. Also, soil conditions, specifically conductivity, will affect the type of lightning suppression system installed.

DeTect will supply the customer with all site requirements and sample site drawings. Furthermore, DeTect will participate and support the customer through site selection and preparation. It is necessary for the customer to obtain zoning approvals, permits, and any other requirement prior to construction or installation of the radar system.

In the tender specifications, there can be wide variations in vendor responses if the customer simple states that the RWP suppliers shall prepare the site. There can be very large differences between the final site designs which can significantly affect price. This is why logistically and cost-wise it is usually best if the customer has the responsibility of preparing the site. A wind profiler manufacture may be very good at building a wind profiler, but it can be very difficult to manage site construction long-distance, especially if it is in another country.

2.9 Testing

Different customers list different requirements for testing. The customer should be aware that that level of required testing, and documentation required for testing can affect the price of the radar. The most important tests are the Factory Acceptance Test (FAT) and the Site Acceptance Test (SAT). Another test is the Site Integration Test (SIT), which might be necessary if the radar is being integrated with other communications and systems. The SIT would take place after the SAT to insure that all control and data transfer is taking place properly.

Sometimes a customer will simply want a final report from these tests. Other times the customer may wish to witness the test and have a formal report and formal sign-off procedures (this may also include a formal test director). The more formal the testing procedures, the more expensive this can become.

For the tender, what is important is for the customer to specifically list their requirements, so there is no confusion about how the test will take place.

2.10 Training

The customer should specify in the tender the amount of training they wish to have. This will depend on the qualifications of the persons using and maintaining the radar. Training can occur either at the vendor’s factory, at the radar site, or both. Here again, what is important is for the customer to determine what amount of training they wish to have and specify this precisely in the tender.

3 Notes for Specifications

In this section additional information is provided for previously listed specifications.

3.1 Data Availability and Height Coverage

The availability of wind data for a RWP system is variable over time and over altitude. As a remote sensing device a RWP depends upon RF backscattering from refractive index fluctuations due to clear-air turbulence. While ubiquitous, turbulence varies with time of day, height above ground level, geographic location, and season. Local weather conditions and climatology can have strong influence upon the strength of turbulence and thereby the signal strength of radar return from the atmosphere. That signal strength also depends upon radar sensitivity, which depends upon radar frequency, transmitter power, and antenna size. Therefore, the height coverage for a RWP system depends upon the radar sensitivity, which can be controlled by design, and the atmosphere, which cannot be controlled.

The availability of virtual temperature data using RASS (Radio Acoustic Sounding System) with the RWP system is also variable over time and over altitude, but for somewhat different reasons. The RASS technique does not rely upon radar return from clear-air turbulence. Rather, with RASS the RF backscatter is from refractive index fluctuations due to sound waves generated and controlled by the RWP RASS system. Height coverage can be limited in high winds which displace the sound waves out of the radar antenna beam. In contrast, temperature measurements made using a radiometer are not impacted by backscatter effects.

As an example of height coverage, Figure 1 shows the data availability of the US NOAA (National Oceanic and Atmospheric Administration) Profiler Network (NPN) of 404-MHz and 449-MHz systems (aggregate of 35 systems).

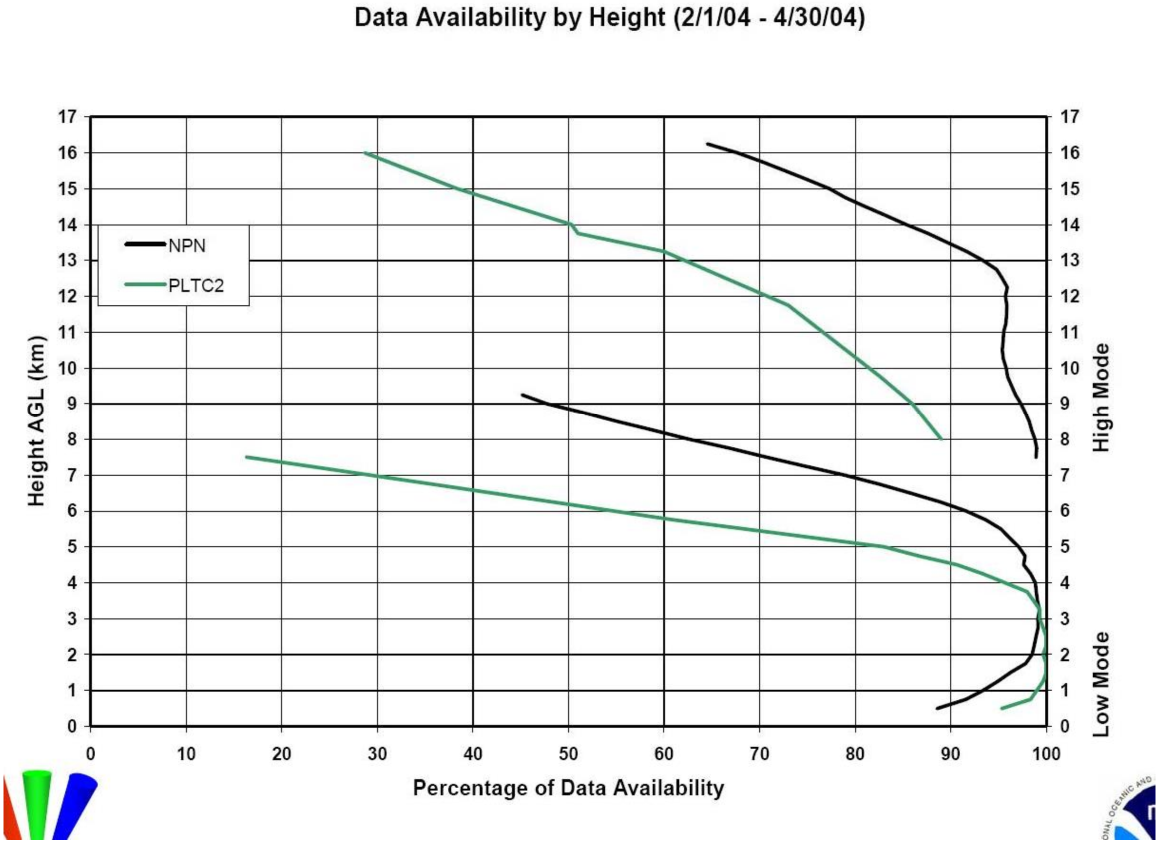

Figure 1. NOAA Profiler Network (NPN) height coverage and percent of data availability over the three-month period 2/1/04-4/30/04. Low and High mode data are shown for the NPN and for the system located at Platteville, Colorado (PLTC2).

Figure 1 reveals the statistical nature of remotely sensed observations by wind profilers. There is virtually no height where data are available 100% of the time. Also, it can be seen that above a certain height data availability decreases very quickly with height. Note the differences in data availability for the Low Mode and the High Mode. The High Mode is achieved by utilizing greater average transmitted RF power than is utilized for the Low Mode. The Low Mode provides better spatial resolution in the lower troposphere.

The “maximum height” for which data are available a certain percentage of the time – Detect recommends an availability of 80% - is an important parameter that can be adjusted depending upon the requirements of the application. Generally, the greater this “maximum height” the larger the transmitter power-antenna aperture product necessary to meet this data availability requirement.

This “maximum height” can be explained by understanding how RWP performance depends upon the intensity of the turbulence in the clear air. Clear-air turbulence is quantified as C_n^2 (known as the turbulent structure parameter of refractive index) which represents the change of index-of-refraction over a defined spatial distance. C_n^2 is dependent on atmospheric temperature and humidity, both of which are episodic and both of which exhibit significant diurnal and seasonal variability, explaining why wind profiler performance changes with atmospheric weather events, with time of day, with time of year, and with geographic location.

Of course, Figure 1 indicates how only certain wind profilers have performed. Predicting how a particular wind profiler will perform requires that clear-air turbulence be modeled. DeTect applies a model for C_n^2 – there is no generally accepted model - with the radar range equation to account for antenna size and efficiency, transmitter power, radar operating frequency, and other parameters which affect the performance of the wind profiler. In Detect’s RWP literature, the maximum height of coverage is identified with that height for which the calculated data availability is 80%. DeTect will perform and elucidate this analysis for any application in which wind profiler technology is being considered.

3.2 Antenna Type and Lowest Range Gate

The radar antenna influences both the “maximum height” and the “minimum height”. The greater the required “maximum height” the larger the antenna should be for increased antenna gain. However, in general the larger the antenna, the higher the first valid range gate or “minimum height” will be. There are several factors that potentially determine the “minimum height” including nearby ground clutter. But an important factor is antenna system “ringing” after transmission. An antenna is a resonant device with many components that may ring after a high-power transmit pulse radiates from the antenna, causing receiver saturation.

Existing RWP systems utilize several different types of antennas depending on the application, the required frequency, and the manufacturer. Each type of antenna has its own characteristics with respect to ringing. Boundary layer systems often utilize microstrip patch, parabolic dish or Yagi array antennas. Tropospheric systems might utilize coaxial-collinear (COCO) array or Yagi array antennas. For example, some 50-MHz systems with large COCO antennas cannot obtain data below a few kilometers due to antenna ringing. Yagi antennas on the other hand tend to be broader band than COCO antennas and thus ring less.

While both “maximum height” coverage and “minimum height” coverage depend on the installation site, DeTect antenna systems are specifically designed to reduce ringing effects and thereby to allow lowest possible height data capture appropriate for and required by the application.

3.3 Radar Sensitivity and Range Resolution

The radar range equation may be used to determine the minimum detectable signal (MDS) for any radar system. This equation takes into account all important gains and losses in the radar system. For a wind profiler, the average transmitter power (in Watts) and effective antenna area (in square meters) are the primary factors affecting the maximum height. The average transmit power and the antenna effective aperture can be multiplied together for a term known as the "power-aperture product." This term is used as a figure-of-merit to talk about the overall sensitivity of a radar system and can be used to compare various radar wind profilers. For example, two wind profilers from two different vendors operating at the same freqquency will have virtually the same performance if their power-aperture products are the same.

The transmit pulse length (which defines the radar range resolution) is also a factor in the radar range equation and radar sensitivity. For a volume scattering radar (like a wind profiler or weather radar), the longer the transmit pulse length the greater the sensitivity and the greater range gate width of the radar. In other words, a profiler with a very long transmit pulse will have a higher maximum height than the same profiler with a setting of short transmit pulse. But the longer transmit pulse radar will have a coarser or lower range resolution. This explains why most radar wind profilers are operated in two or more modes. For example, a common setup would have a less sensitive "Low" mode for gathering high spatial resolution data low (or near) to the ground and a more sensitive "High" mode for gathering data up higher but with lower spatial resolution.

While the transmit pulse width determines the range resolution for independent spatial sampling, it is possible to over-sample. For example, if a transmit pulse would produce an independent range resolution of 1000 meters, it is possible to oversample the received signal to produce a range gate spacing of 100 meters (10 x's oversampling). *This oversampled data product is NOT the same as if the transmit pulse were such as to produce a true 100 meter range resolution.* In the latter case, the radar would be producing independent range gates of 100 meters, whereas with oversampling there is dependency between gates (similar to, but not the same as interpolating). So it is possible to produce artificially higher resolution wind data by oversampling a large transmit pulse using a lower power and lower transmitter cost than would be required for true independent gates.

For example, the U.S. NOAA 404-MHz Profiler Network uses a transmit pulse resolution of 320 meters for the low mode and 900 meters for the high mode. Both modes are oversampled to produce a reported gate spacing of 250 meters. This means the low mode is oversampled by a factor of 1.28 and the high mode by almost a factor of 4. Oversampling degrades the independence of each range gate, and has the effect of smoothing profiles.

Therefore, the terms gate spacing, range resolution, data sampling, wind reporting interval, etc. must be clearly defined so that the specifications for any wind profiler meet the requirements for both height coverage and spatial resolution. These terms are clearly defined in well known radar text books such as Doppler Radar and Weather Observations 2nd Edition, by Richard J. Doviak and Dusan S. Zrnic, 1993; or The Radar Handbook, 3rd Edition, by Skolnik, 2008.

It is important to establish the independent (non-oversampled) range resolution required for any particular application in order to determine the most cost-effective specifications for a wind profiler.

3.4 Transmit Frequency and Maximum Height

The inner scale of turbulence (i.e., the smallest scale) tends to increase with height. Therefore, lower frequency systems are often used to obtain data at higher altitudes, while higher frequency systems are used to obtain data in the boundary layer. Other factors also may influence the choice of transmit frequency including available physical space (this affects antenna size), costs (e.g., for the antenna and transmitter), and allowed center frequency (and corresponding spectrum) defined by the local frequency authority.

Therefore, 915 MHz and 1280 MHz (or similar frequencies) have often been used for Boundary-Layer (BL) systems, 449 MHz has been used for tropospheric systems, and 50 MHz or 200 MHz have been used for stratospheric systems. Particularly for BL systems, antenna size is often required to be small which necessitates the choice of a higher frequency in order to provide sufficient antenna gain. This size requirement may be driven by space limitations or cost constraints.

However, lower frequencies have been used to make wind profiler observations in the boundary layer. For example, 50-MHz systems have been used although obtaining data near the ground is more difficult at this frequency for reasons discussed above (3.2 Antenna Type and Lowest Range Gate). DeTect manufactures both higher and lower frequency BL systems with extensive experience with the scalable 449-MHz RAPTOR design, which can be produced in a smaller size with excellent BL capabilities.

The 50-MHz band of transmit frequencies has been used for systems required to obtain data above 18 km. This is due to the distribution of turbulence in the atmosphere. A wind profiler requires turbules (turbulent structures) with sizes of ½ the radar wavelength to generate clear-air backscatter. At higher altitudes the lower end of the turbulence distribution (inner scale) increases in size and thus the smaller scale turbulent structures are missing in the upper atmosphere. This means that higher frequency radars (with smaller wavelengths) lack any backscattering mechanism and as a result cannot obtain data at higher altitudes. On the other hand, galactic noise tends to increase with longer radar wavelength (lower frequency) until it dominates radar system noise.

For a network of radar wind profilers with different height requirements, a mixture of different frequencies may be employed. For example, at the Kennedy Space Center (KSC) in the US, a

50-MHz system is used to provide coverage at higher altitudes and a network of 915-MHz systems is used to provide coverage in the boundary layer. However, choosing a single frequency in the mid-frequency range (e.g., 449 MHz) can significantly reduce both initial cost and the size and cost of depot repairs and spare parts. In addition, a single-frequency wind profiler will reduce network complexity, schedule time, required operator and maintenance training.

The DeTect RAPTOR 449-MHz range wind profiler is designed to be scalable in size and to provide coverage from the boundary layer to the stratosphere. Most RAPTOR components (such as the antenna elements, transmitter subsystems, data system etc.) are interchangeable between different RAPTOR wind profiler systems. Exceptions include some components that are manufactured to operate at different RF power levels. Those designed for lower power levels tend to be less expensive than those designed for higher power levels. However, the high-power components are interchangeable between all systems. This inter-changeability allows significant savings in the profiler network operations. This also eliminates the need to have multiple vendor sources for different wind profilers selected to meet different height coverage requirements. Furthermore, for country-specific requirements, DeTect can manufacture RWP's tailored for locally mandated and specified frequencies.

3.5 Transmit Power

For wind profiling radars the primary factors determining maximum coverage height are the antenna effective area and the average transmitted power. The average power depends upon both the peak power and the duty cycle. The duty cycle is the fraction of time between transmit pulses that the radar transmitter is actually on. A system with 10-kW peak and with a 1% duty-cycle transmits an average power of 100 W (10,000 x .01). This is the same as the average power transmitted by a system with peak power of 1000 W and with 10% duty-cycle. Both systems would have the same sensitivity if they both had the same antenna.

Depending on your specific needs, DeTect can calculate the size of wind profiler (transmitter power and antenna size) needed to obtain the data required.

3.6 Antenna Gain, Beamwidth and Sidelobes

Antenna gain, beamwidth, and sidelobes are all related to the antenna type and size. A larger antenna will typically have higher main lobe gain, smaller beamwidth, and lower sidelobes. So in general, the larger the antenna the better. Of course larger antennas take more room and are more expensive. Therefore, the requirement for a better antenna must be balanced with space limitations and cost.

The antenna size also affects the height coverage of a wind profiler, which depends upon the combination of transmit pulse length, average transmit power, and antenna size (3.3 Radar Sensitivity and Range Resolution). The transmit pulse length also determines the range resolution. Therefore, once the maximum coverage height and range resolution are specified, the combination of transmit power and antenna size (i.e., power-aperture product) is determined using the radar range equation and a model for C_n^2 . At this point a trade-off is made between transmit power and antenna size. With the additional benefits of larger antenna gain, smaller antenna beamwidth, and lower antenna sidelobes, the recommendation is to use the largest antenna permitted by space and cost constraints.

3.7 Radio Acoustic Sounding System (RASS) Performance

The RASS system provides profiles of virtual temperature by measuring the speed of sound at different levels in the atmosphere. The RASS system is composed of a PC sound card, an audio amplifier, and multiple (usually four) transducer/audio antennas located around the RF antenna. The RASS system generates sound waves with wavelength of half the RF wavelength that propagate nearly vertically above the RF antenna. As these sound waves propagate through the atmosphere they generate perturbations in the refractive index of clear air at exactly the spatial scales necessary to generate backscatter, just as in the case of turbulence. Actually a range of acoustic frequencies is generated because the wavelengths of sound are variable. This explains the “chirp” sound of RASS.

Virtual temperature profiling height coverage is primarily limited by atmospheric attenuation of sound and by high wind speeds that “blow” the sound out of the RF antenna beam. The acoustic wavelength must be half that of the radar wavelength, so that higher frequency RASS cannot obtain temperature information as high as lower frequency systems (i.e., a 449 MHz wind profiler can obtain virtual temperature higher than a 915 MHz wind profiler). Wind speed is also a factor, as the sound wave can actually be blown too far down wind for the radar to see a backscatter signal. Actual performance will be site and atmospheric condition dependent.

3.8 Radar Health and Status Monitoring

Radar Health and Status Monitoring is important to ensure that the wind profiler is operating properly and providing the performance necessary to generate the required meteorological products. While including health monitoring increases the initial up-front cost of a wind profiler to some extent, it more than pays for itself in assuring accurate and high quality wind data and by significantly reducing time to diagnose problems and thus time to repair. Hence, monitoring reduces maintenance costs but it also protects the radar equipment. No sensible driver would operate an automobile without automated monitoring of critical indicators such as cooling system temperature, motor oil level, etc. Similarly, automated monitoring of critical radar components and automated shutdown of the system protects the wind profiler from damage.

Not all commercial wind profilers provide true health and status monitoring. The DeTect RAPTOR design includes a Profiler Health Monitor (PHM) as an integral component of the system to monitor the following critical system parameters:

- Transmitter: 1) temperature, 2) fan status (if utilized), 3) forward RF power, 4) reflected RF power, 5) power supply voltage and current
- Antenna: 1) Return loss or Voltage Standing Wave Ratio (VSWR), 2) Phase-shifter status including current, voltage, switch position/status
- Power Supplies: 1) temperature, 2) all voltages
- Other Important Subsystems: 1) temperature, 2) critical voltages
- Shelter: 1) temperature, 2) humidity, 3) door or gate (for security), HVAC status
- From UPS: 1) Mains voltage, 2) current

Monitoring of the local environmental conditions (e.g., temperature and humidity in the shelter) are important for determining the primary cause of a failure, to help in diagnostics, and to protect equipment.

3.9 Shelter Requirements

While the electronics shelter is not a part of the wind profiler, environmental control is a critical function in support of reliable and sustainable wind profiler operations. The wind profiler antenna is of course located outside, but the rest of the electronics must be housed in a weather-proof climate controlled environment. That housing can be in an existing building structure or a shelter – this could be trailer mounted – specifically designed for the wind profiler.

For proper climate control, the HVAC (heating, ventilating, and air conditioning) system must be sized correctly to support the wind profiler. Under sized HVAC could cause system failure, which could be the single source of most data outages. DeTect recommends the use of two separate HVAC units, for full redundancy and to protect the equipment from damage from overheating.

DeTect recommends attention to the following shelter items:

- Shelter construction material (concrete, fiberglass etc.), maximum empty weight and insulation requirements (wall thickness and construction)
- Floor, ceiling and wall covering
- Underside construction (e.g., steel skid) and how the shelter will be mounted (concrete pier or pad).
- Roof type
- Wind loading and any other environmental factors
- Electrical and other utility surge suppression along with ground bars etc.
- Dual HVAC units

- Interior or exterior lighting
- Any required security features (locks or alarms)
- Any special telephone or network features
- Whether other (customer) items will be located in the shelter
- Other smaller items such as fire extinguisher, work bench, chairs, first aid kit etc.

Some critical items like the HVAC must be considered for the installation of the wind profiler. Other less critical items such as chairs may be added later.

3.10 Data Processor

In many operational wind profiler systems, the data processor, monitor and keyboard are rack-mounted along with all of the other radar electronics. The data processor specifications should reflect this requirement. For example, there are no issues in supplying a customer-requested 21” LCD monitor, except that this will be too large to mount conveniently in the 19” rack. Also, note that in an unattended system, it is usually less important that the monitor be of the highest resolution or quality, since it will only be used during installation and maintenance activities.

DeTect can also supply an additional more traditional desktop system to be placed on an adjoining workspace (desk) if needed for certain sites. This PC could be used for processing data or better viewing of data products. The main data processor computer needs to be close to the receiver/modulator however.

Also, a secondary PC could be placed anywhere on a network connected to the RWP data processor. For example, normally the wind profiler will have its own shelter immediately next to the antenna. If there is a network link (or modem), the data can transferred and displayed on another PC on the network in a nearby building. This secondary PC could utilize one or more higher quality/resolution monitors as well as color laser jet printers.

We also recommend the use of fail-safe hard disk RAID Level 1 (Redundant Arrays of Independent Disks) technology on the main radar data computer, to prevent loss of data or lengthy computer rebuild times. This technology is now inexpensive and can be easily implemented.

3.11 Advanced Signal Detection and Processing

The DeTect RAPTOR wind profiler system includes advanced signal processing for on-line real-time generation of high quality meteorological products. In the past, both commercial and research wind profiler systems have relied upon off-line post processing to generate these meteorological products. Later, as better signal processing techniques evolved, these techniques were offered as options, for an additional cost.

The DeTect RAPTOR design includes the following advanced signal processing and displays:

- Multiple-signal processing algorithms to discriminate radar clear-air return from noise, radio frequency interference, etc.
- Displays for time series of radar signals and moments (radial velocities, signal power, spectral width) in addition to displays of meteorological winds
- High-level quality control (QC) of wind measurements to remove outliers

Just as it is important to understand the differences in radar hardware (e.g., antennas, transmitters, etc.) used with different commercial wind profilers, it is also important to understand the differences in the radar signal processing.

3.12 UPS (Uninterrupible Power Supply)

For most large wind profilers with high-power transmitters, a UPS may be used for the computer, to carry it through ~15-30 minute power outages. A very large and expensive UPS would be needed to power the entire radar during a power outage. One also has to consider transmitting in the summer, when the A/C's are not able to cool during a power outage. Therefore, for mission critical applications, a backup generator must be used in order to maintain wind profiler operations during power outages.

If a large and expensive UPS and/or generator are not available, then it is recommended to use a less expensive UPS (around 2000 VA in size) for only the computer and other small items such as network routers, modems, etc. A rack-mount system works well and allows easy access to the batteries, which are usually replaced every 3-5 years. DeTect recommends that a high quality UPS (e.g., the Eaton Powerware 9125, full double-conversion UPS) be used for the computer equipment. This is especially important wherever power is not reliable (i.e., where sags, surges, spikes or numerous outages are frequent or typical). This UPS provides complete isolation from the main power and significantly reduces the likelihood of main power damage to sensitive items such as the PC. A unit like this also allows many options for monitoring, control and adding external batteries to allow longer runtimes or increased loads.

3.13 Lightning Protection

There are several methods for providing lightning protection. These methods are dependent on the type of instrument installation. For example a tall tower would need different kinds of protection than a radar system.

Providing adequate lightning protection can also be a very large cost driver in a radar wind profiler installation. All DeTect subsystems have surge protection, but the site installation and infrastructure (phones, fence, shelter, electrical, antenna ground plane, etc.) also must be part of a total surge protection system. Some sites may also need more protection than other sites (depending on lightning climatology), so a customer can save money by carefully considering the actual lightning protection required.

DeTect recommends two options for specifying lightning/surge protection for the radar systems:

- The customer can state that the radar system (transmitter, receiver etc.) have built-in surge protection, and

- That the full site lightning protection system will be determined after contract award, so each site can be tailored individually. DeTect can still recommend a lightning protection system (for the site and shelter), but again, since this is a cost driver, the customer may want to consider exactly specifying what the required system shall be so vendor responses are similar in scope and cost.

3.14 Spares

The “minimum spares” kit is designed for customers who do not need an operational level of support. The minimum spares kit includes simple items such as spare cooling fans, a spare mirrored hard disk, spare fuses, spare cables and other small inexpensive items that may fail or be damaged in normal use, and do not require any special tools or test equipment. This option is also often selected by financially constrained customers who cannot immediately afford a full LRU (Line Replaceable Unit or Least Repairable Unit) spares kit.

The “full LRU spares” option is for customers who need true operational support. An onsite full LRU spares kit allows a technician to diagnose and to repair a system, usually within 1 hour of time. This option should be selected for wind profilers used for aviation support or any application where the wind profiler data is used for safety (human or property).

A full LRU spares kit also allows much easier diagnostics of system problems since items can be changed to find the failed component. For example, if there a question of whether the receiver or its power supply has failed, a simple exchange in items allows the technician to quickly diagnose and restore operations.

Another benefit of full LRU spares is mitigating the risk of obsolescence. Usually operational-use customers desire a 10 to 20 year lifetime. By having spare parts already purchased and ready for use, long-term issues like changes in computers or inability to purchase a replacement part are avoided. This is especially important for customers who are operating networks of radar wind profilers. In this case, the customer should choose to stock in their repair depot 1 full LRU spares kit for every 1 to 5 wind profilers in operations.

4 Summary

A radar wind profiler system is a sophisticated data gathering device. Most users have demanding requirements such as fully unmanned operations, high data quality and a 20 year service life.

The information in this document has been provided to allow potential future owners of radar wind profiler systems to write clear tender specifications. A clearly written tender document will insure the customer procures the system they need and will ensure a smoother problem-free procurement.

Different RWP vendors will list specifications differently, so it is important that various terms and requirements be specified in the tender in a way which eliminates any ambiguities. Unfortunately, without this level of detail, a customer may find that they took delivery of a system which does not meet their needs. Also, without well specified requirements, final prices from vendors can vary dramatically and again the customer may not actually receive the data they need.

DeTect is hopefully this document has proved to be useful in understanding and writing your wind profiler specifications. Please contact DeTect for any clarifications, misprints, mistakes or questions.

Figure 2 DeTect RAPTOR system installed in Kuwait; used for Aerostat support.

5 Reference Material

5.1 Acronyms & Symbol

ΔR	Range Resolution (m)
BL	Boundary Layer
BW	Beamwidth
c	speed of light (m/s)
dB	decibels
dBi	dB over isotropic
deg	degrees
COCO	coaxial-collinear antenna
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FAT	Factory Acceptance Test
HVAC	Heating, Ventilating, and Air Conditioning
IPP	Inter-pulse period
km	kilometer
kVA	kiloVolt-Amps
kW	kilowatts
LRU	Line or Least Replaceable Unit
m	meter
min	minutes
MDS	Minimum Detectable Signal
MTBCF	Mean Time Between Critical Failure
MTBF	Mean Time Between Failure
OS	Operating System
QC	Quality Control
PHM	Profiler Health Monitor
RASS	Radio Acoustic Sounding System
RFI	Radio Frequency Interference
RH	Relative Humidity
RWP	Radar Wind Profiler
s	seconds
SAT	Site Acceptance Test
SIT	Site Integration Test
SNR	Signal-to-Noise Ratio
τ	pulse-width (s)
UHF	Ultra High Frequency
UPS	Uninterruptable Power Supply
VSWR	Voltage Standing Wave Ratio
W	Watts

5.2 Glossary

Antenna Effective Area	Physical area of the radar antenna, multiplied by the antenna efficiency.
Antenna Efficiency	Efficiency values depend on type of antenna, but are normally 0.6 to 0.8.
Average Transmit Power	Transmitter peak power multiplied with duty-cycle of the radar.
Dwell	Usually the shortest duration of time for continuously pointing and averaging data (~a few seconds to a minute). Also the Raptor radar control software process is called Dwell.
Duty-cycle	Ratio of the time the radar is transmitting. This is calculated from the total transmit time divided by the inter-pulse period (IPP).
Ground Clutter	Structures, towers, terrain, trees, power lines, busy road ways, etc., of high reflectivity, which can prevent or bias wind gathering in specific heights. Specifically, ground clutter can interfere with the first few gates of wind profiler due to the high reflected power.
Line Replaceable Unit	An LRU is the 'least' replaceable unit or module designated for replacement in the field. Usually there is a requirement that the replacement LRU also not require any extensive testing or tuning to restore the radar to functionality.
Minimum Detectable Signal	The MDS is the smallest signal which the radar system can discern. While dependent on static parameters such as antenna gain or transmit power, the MDS is also dependent on user settings such as range resolution and integration time.
Over-sampling	Sampling the received signal at a higher resolution than the transmit pulse would normally indicate. For example, if the transmit pulse would result in 200 meter range resolution, the receive signal could be sampled at a higher rate (e.g., 2x's) to produce 100 meter range gates. These gates are no independent however, that is, they are not the same as transmitting a shorter pulse to produce true 100 meter range resolution.
Power-aperture Product	Average transmit power multiplied by the antenna effective area (Wm). This term, pulse width, and transmit frequency determine the sensitivity and height coverage of a radar system.
Radar Range Equation	An equation used by radar engineers and meteorologists to determined the sensitivity of a radar system. Variables include

antenna gain, transmit power, pulse length, range to target, and information about the target.

Radial — Describes a measurement made along the main beam of the antenna. This can be along an oblique or vertical pointing angle.

Range Gate — The receiver sampling interval, usually set equal to the range resolution. Also the index of number of samples.

Range Resolution — This is the radial range resolution dictated by the transmit pulse width ($\Delta R = c*\tau/2$, where c is the speed of light and τ is the transmit pulse length).

Sidelobes — An antenna is designed primarily to increase power density in a particular direction (the main beam or lobe). A normal result are diffraction patterns, which cause smaller lobes to form, typically ranging from 15 to 45 dB lower than the main beam.

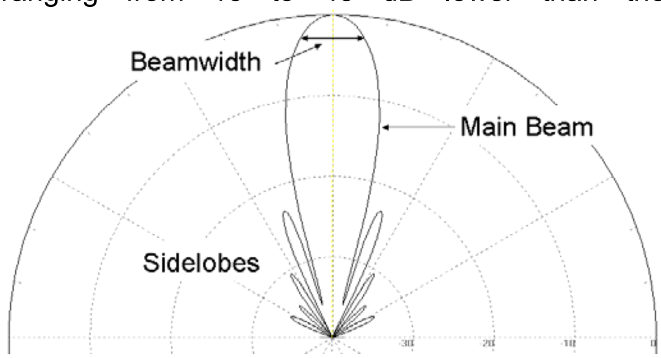

Figure 3 Example antenna beam pattern.

Soft-fail — Term meaning a system or subsystem can fail in a way that still allows data collection (also called “graceful degradation”).

Turbule — In a turbulent field, a turbule is a single turbulent “cell” composed of air of a slightly different index of refraction. When these turbules are ½ the wavelength size of the radar wavelength, there is enhanced backscatter.

5.3 Further Reading

Below are suggested references for further reading about radar wind profilers.

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6 DeTect Information

DeTect, Inc. specializes in remote sensing technologies and systems for aviation safety, meteorology, security surveillance (air, marine and ground), and environmental survey & monitoring supporting projects worldwide. The company is a U.S. corporation (Florida) headquartered in Panama City, Florida, USA with divisional offices in Colorado and Kentucky. DeTect is an emerging small business under NAICS 334511 (DUNS# 134166094).

DeTect customers include the USAF, U.S. Air National Guard (ANG), U.S. Army Corps of Engineers (USACE), NASA, Federal Aviation Administration (FAA), U.S. Geological Survey (USGS), the Government of the United Kingdom Central Science Lab (CSL), Transports Canada (the Government of Canada), U.S. National Oceanic and Atmospheric Administration and major airports and industries worldwide. The company has successfully delivered projects in throughout the U.S., Canada, the United Kingdom, Europe, Africa and Asia.

DeTect products include Radar Wind Profilers, Aircraft Birdstrike Avoidance Radars, Avian Survey & Monitoring Radars, Airspace, Marine & Ground Perimeter Security Radars, Aircraft Detection & Surveillance Radars, NEXRAD Environmental Data Products and Meteorological systems (weather radars, visibility sensors, lightning detectors).

DeTect services include Bird-Aircraft Strike Hazard (BASH) Management, Airfield & Industrial Bird & Wildlife Control, Wind Energy Project Wildlife (Bird & Bat) Impact Assessment, Radar System Solutions Engineering, Design & Development, Environmental Planning & Analysis (NEPA) support, Avian Radar Survey & Risk Assessment, and Data Analysis & Geographical Information Systems (GIS).

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