Evaluation of SeaSonde Hardware Diagnostic Parameters as Performance Metrics

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Introduction

The National High Frequency Surface Current Mapping Radar Network (NHFSCMRN) is being developed as a key component of the Integrated Ocean Observing System (IOOS). As an operational component of IOOS, the NHFSCMRN will need to adhere to data processing and operations standards. These standards include best practices in operation and maintenance (O&M) of radar sites. The analysis here endeavors to develop a knowledge base of O&M standards for SeaSonde coastal high frequency radars manufactured by Codar Ocean Sensors Ltd. (COS). The SeaSonde software reports hardware diagnostic statistics, including a number of parameters associated with the operation of the radar transmitter and receiver systems. The goals of this analysis are:

1) collect data from several radar sites to obtain estimates of standard ranges of parameter values, and;

2) determine the suitability of the parameters as operational metrics.

The hardware parameters considered in this analysis, along with their 4-character codes, (from .hdt files) are:

Receiver chassis temperature (RTMP)
AWGIII board temperature (MTMP)
Run-time counter tracks length of time AWG has operated (RUNT)
Front Panel +5VDC supply (SP05)
Front Panel -5VDC supply (SN05)
Receiver +12VDC supply (SP12)
Transmitter chassis temperature (XPHT)
Transmitter amplifier temperature (XAHT)
Transmitter forward power (XAFW)
Transmitter reflected power (XARW)
Phase Lock loop loss (PLLL)

The radial data parameters considered here (from .rdt files) are:

Antenna amplitude correction loop 1 to monopole (AMP1)
Antenna amplitude correction loop 2 to monopole (AMP2)
Total number of radial vector solutions (RADV)
Average number of radial vectors per range cell (RAPR)
Maximum radial range (RADR)
Average bearing of all radial vectors (RABA)

In this analysis, quality assurance (QA) refers to the optimal configuration of a SeaSonde site, in terms of the physical setup, the software settings, and calibration. Quality control (QC) refers to the categorization of data as either accepTable or not accepTable (ie likely containing significant errors). For this analysis, we assess the usefulness of the diagnostic parameters in either determining that the site meets a QA standard, or that the data meets a QC standard.

Datasets Used

Results are based on files from 25 SeaSondes deployed along the coast of California. Parameters in hardware data Tables (.hdt) and radial data Table (.rdt) files are available from the various sites from 7 March 2005 through 27 September 2007 (Table 1). At each site, data is recorded into .hdt tables every 15 minutes, and into .rdt Tables

Table 1. Data availability from each HF site.

Site Code	Begin Date	End Date	.rdt (hrs)	.hdt (hrs)
BIGC	17-Mar-2006	9-Apr-2007	9330	9330
BRKY	5-Jan-2006	20-Jul-2007	8874	13461
COMM	26-Jun-2006	16-Jul-2007	9235	9236
COP1	20-Jun-2006	27-Sep-2007	11118	11118
CRIS	22-Jun-2006	13-Jul-2007	9258	9259
FORT	30-Jun-2006	5-Jul-2007	8883	8893
GCSC	10-Feb-2006	12-Jul-2007	12386	12387
MGS1	1-Mar-2007	27-Sep-2007	5023	5024
MLML	16-Nov-2006	12-Jul-2007	5729	5730
MLNG	31-Jul-2005	16-Nov-2006	7657	11353
MONT	6-Jun-2006	4-Jul-2007	9416	9417
NPGS	1-May-2005	25-May-2007	12402	18115
PESC	8-Jun-2006	13-Jul-2007	9599	9601
PPIN	10-Jan-2006	8-Jul-2007	13038	13038
PSUR	26-Nov-2005	12-Jul-2007	13388	14229
RFG1	3-Dec-2006	27-Sep-2007	7158	6990
RTC1	25-Oct-2005	13-Jul-2007	9549	15025
SCI1	11-May-2007	18-Sep-2007	3139	3139
SCRZ	6-Jan-2006	17-Apr-2007	11173	11174
SDBP	7-Mar-2005	22-Jun-2006	11356	0
SDPL	7-Mar-2005	22-Jun-2006	11356	0
SSD1	20-Jul-2007	27-Sep-2007	1642	1642
TRES	9-Feb-2006	19-Jan-2007	8251	8252

every 10 minutes. Although these data logging rates where found at all sites, the .hdt data can be logged at any user specified interval.

Methodologies

Connections between diagnostic parameters were established based on plots of conditionally averaged data. Conditional averaging was accomplished by sorting one parameter into bins, and averaging other parameters for time periods represented by each of the bins. The results are then plotted against each other to diagnose any relationship. Since many of the diagnostic parameters have values that are site dependent (e.g. total number of radial vector (RADV), we normalize the parameter time series by removing the mean and dividing by the standard deviation. The resulting plots show how one normalized parameter varies versus another parameter.

Prior to computing statistics of the diagnostic parameters, some quality control of the diagnostic data was performed. Obvious bad data were removed, [e.g.removing zeros from voltages (SP05, SN05, and SP12), transmit power measurements (XAFW and XARW), and RADV, RAPR; values less than or equal to zero were removed RTMP, MTMP, XPHT, and XAHT]. Thus, means of temperatures were computed from non-zero, positive values only. Standard values are computed for the radial data parameters (RADV, RAPR, RADR, and RABA) after separating STAT files based on the transmit frequency band of the sites in question.

Analysis of STAT parameters

Statistics of the diagnostic parameters are summarized in Table 2. Along with their 4-character abbreviation, the mean, standard deviation, maximum value, minimum value, number of observations, distribution skewness, and the mean of the upper 5% of values are shown. Note that means of the average bearing of all radials RABA are also given in Table 2. This parameter has an obvious dependence on the configuration of the HF site. The means given here for the 13 and 25 MHz bands simply demonstrate that the majority of these HF sites are on the west coast of North America.

The parameters in Table 2 can be grouped logically in terms of which part of the SeaSonde they describe. The parameters and their groupings can then be arranged in terms of their relationship to one another, as shown in Figure 1. For example, the parameters furthest upstream (top left), related to receiver power, must be at operational levels before any of the downstream parameters can be logged. Parameters further downstream, such as Transmit power (XAFW), do not affect receive voltages, but do affect parameters downstream to which they are connected. For example, very low transmit power impacts parameters further downstream. Some parameters, such as transmit power, are expected to have a linear relationship with downstream parameters, while others, such as the receiver temperature or voltage, are expected to have binary, or on-off, behavior as a threshold is crossed. The reverse of this chart is somewhat true in that good radial data characteristics imply good values upstream. The temperatures are a slight exception to this fact. Temperatures can be out of the typical range for a given site,

Table 2. Statistics of parameters found in STAT files for the 23 SeaSonde sites.

Parameter	Code	Mean	Standard Deviation	Max	Min	N	Skew-ness	Mean of Upper 5%
Receiver Chassis Temp (deg C)	RTMP	26.2	5.9	122.0	8.0	789983	0.2	38.0
AWG Board Temp (deg C)	MTMP	36.5	6.6	59.0	1.0	567881	-0.1	48.3
RunTime (hrs)	RUNT	188	402	4469	-1	795140	5	1603
Receiver +VDC Supply	SP05	5.2	0.1	15.4	5.0	596131	2.1	5.4
Receiver -VDC Supply	SN05	-5.1	0.2	-4.5	-5.8	596131	-0.9	-4.6
Receiver +12VDC supply	SP12	12.3	0.1	12.6	11.9	596131	-0.1	12.5
Transmitter Chassis Temp (deg C)	XPHT	28.9	5.2	46.0	12.0	571090	0.0	39.1
Transmitter Amplifier Temp (deg C)	XAHT	34.5	5.0	50.0	3.0	437712	-0.2	43.7
Transmitter Forward Power (W)	XAFW	52.7	12.5	109.0	1.0	545734	-0.2	77.9
Transmitter Reflected Power (W)	XARW	4.4	4.8	452.0	1.0	561756	3.7	19.3
Phase Lock Loop Loss	PLLL	0.2	2.4	38.0	0.0	795140	11.4	4.8
Amplitude Correction Loop 1 to 3	AMP1	3.2	17.5	893.6	0.0	1114278	19.5	28.9
Amplitude Correction Loop 2 to 3	AMP2	2.0	4.3	677.3	0.0	1114278	42.7	10.8
Total # Radial Vector Solutions:								
13 MHz band	RADV	523	309	3937	1	666081	3	1475
25 MHz band	RADV	276	106	1053	6	22516	1	575
40 MHz band	RADV	960	469	4576	1	368042	2	2364
Average # Solns per Range Cell:								
13 MHz band	RAPR	15	5	50	1	666081	1	28
25 MHz band	RAPR	9	4	36	1	22516	2	20
40 MHz band	RAPR	33	15	208	1	368042	2	79
Maximum Radial Range (km):								
13 MHz band	RADR	75.7	18.7	158.0	0.0	671123	-0.6	116.2
25 MHz band	RADR	29.4	5.2	52.1	0.0	22516	1.0	43.0
40 MHz band	RADR	10.6	2.1	32.9	0.0	368261	-0.7	13.9
Average Bearing of All Radials								
13 MHz band	RABA	-88.4	79.0	180.0	-180.0	671123	2.1	172.3
25 MHz band	RABA	-91.8	84.8	-2.5	-170.3	22516	1.1	-56.5
40 MHz band	RABA	-5.7	72.5	132.5	-152.6	368261	-0.3	98.9

indicating problems with the cooling system, without affecting radial data, but still providing valuable information about the system. It also important to note that external factors not shown in Figure 1 can also affect the radial data parameters. These external factors, such as signal to noise ratio, were not considered here.

The analysis of the parameters and their usefulness as performance metrics addresses each of the parameters based on their groupings shown in Figure 1, with the exception of the radial data parameters. Some of the radial data parameters have a well-

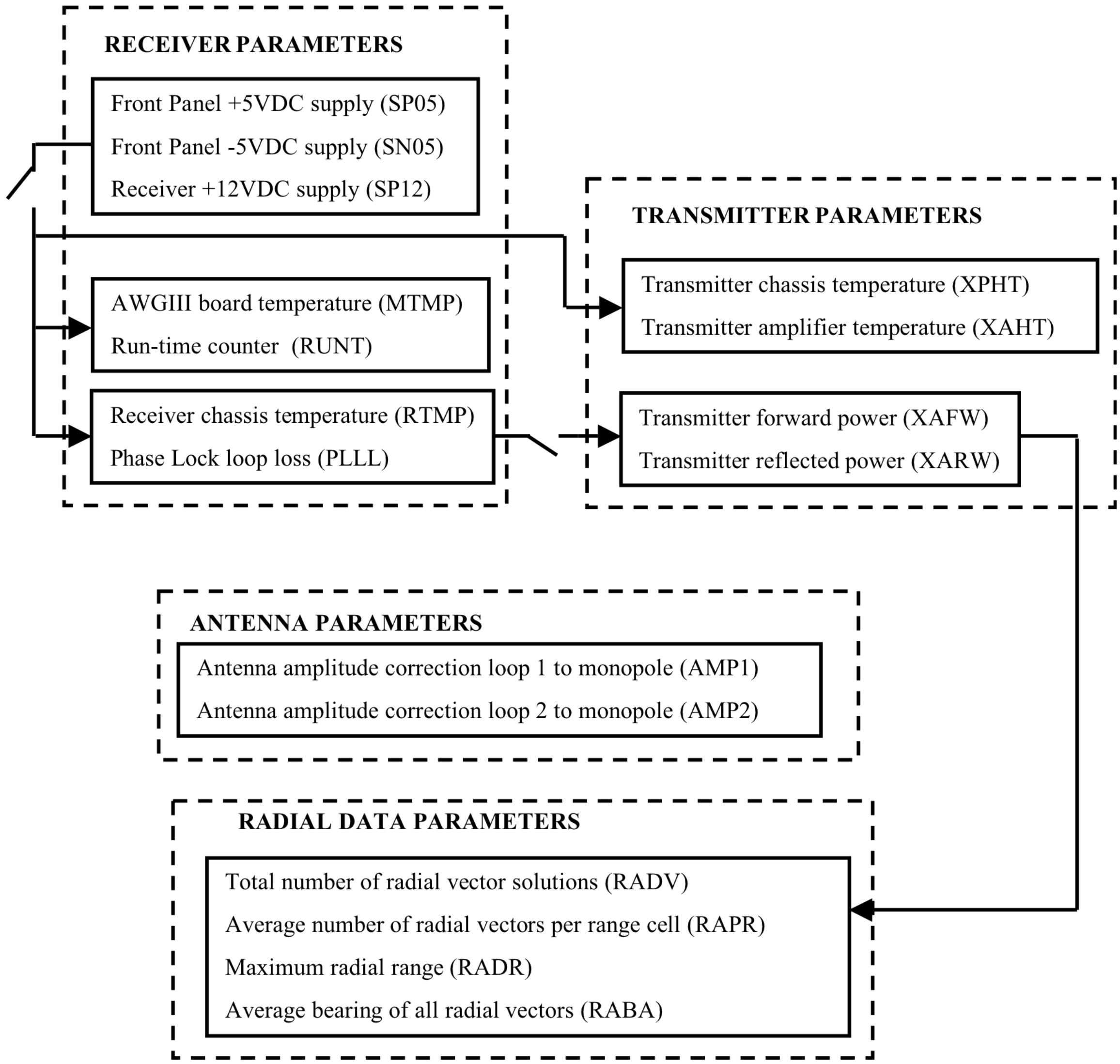

Figure1. Flow chart showing the grouping (dashed lines) of the diagnostic parameters and the relationship between groups (arrows). Sub-optimal parameter values will influence downstream parameters. Parameters upstream of switch symbols affect downstream parameters in a binary fashion, either on or off.

established usage as quality assurance indicators. The maximum radial range (RADR) and total number of radial vectors (RADV) are clear indicators of system health. The average bearing of all radials (RABA) and the average number of radial vector solutions per range cell (RAPR) give an indication of the distribution of radial vectors spatially. Because of their history of usage as QA parameters, and their availability to this analysis, these parameters are used here to evaluate the impact of the other parameters on system health.

Receiver Parameters

Measures of voltage at key locations within the receiver are given by SP05, SN05, and SP12. Very little variation in these parameters was observed in the 23 SeaSondes (Table 2). These parameters are probably most useful to diagnose unusual hardware component failures. According to SeaSonde documentation, for SP05 below 4.7 V the receiver is unavailable to the computer. The minimum observed value of 5.0 indicates that either the minimum voltage was not reached, or the STAT files are not written to when the receiver is not communicating with the computer. It is therefore assumed that these parameters affect the radial data in a binary way. This relationship is indicated by the switch symbol downstream of the receiver parameters in Figure 1. SP12 may affect the radial data in more complex ways than are discernable here, because it is a measure of the voltage supplied to the RF output and the cross loop amplifiers in the receive antenna.

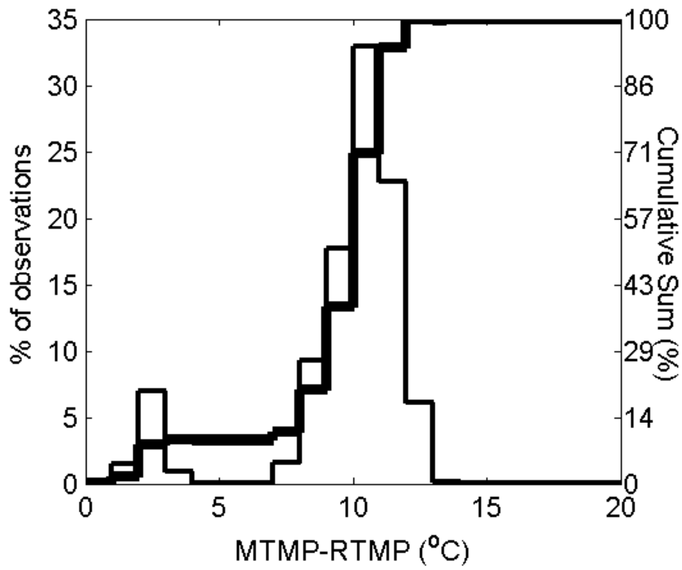

Figure 2. Histogram of difference between receiver AWG board and chassis temperatures.

The run time counter (RUNT) records the time in seconds since the receiver was reset or powered on. Under nominal conditions the receiver does not reset itself,so RUNT data in Table 2 indicates mean run times of over a week (7.8 days) between power cycling. The standard deviation is 402 hours or 16.75 days. This parameter can be used by operators to get an indication of the reliability of the electrical power being supplied to a site, as illustrated by results for individual sites. MGS1 and COP1 have mean RUNT values of 11.6 and 3.4 days, respectively, while SSD1 has a mean RUNT of about 3.5 hours. Frequent power cycling of the receiver at the site at SSD1 results from operating the electrical circuit near maximum capacity, causing brief power outages. According to

SeaSonde documentation, RUNT has a maximum possible value of $1.4x10^8$ seconds, or about 1600 days. The maximum observed here, 4469 hours or ~188 days, is not near 1600 days, but is still quite impressive.

Two parameters provide temperatures of different internal receiver components, the front panel board temperature (RTMP) and the AWG III board temperature (MTMP). Table 2 shows that MTMP is typically just over 10 °C above RTMP in the mean, which is consistent with the manufacturer's stated nominal separation of 6-10 °C. This temperature difference results from the greater power dissipation in the AWG board. Limiting data to MTMP between 0 °C and 100 °C, to remove unrealistic and negative data points (~30% of data), and subtracting RTMP shows that for the SeaSondes reporting here, the difference is greater than 10 °C about 60% of the remaining time (Figure 2). Manufacturer's recommendations indicate that temperature differences greater

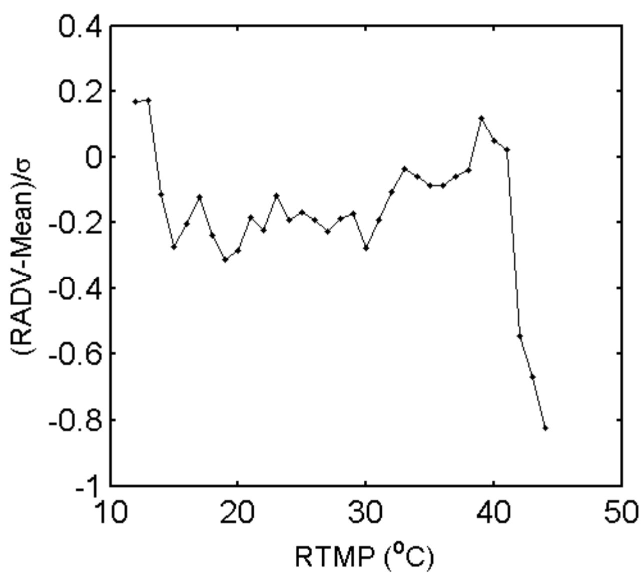

Figure 3. Conditional averages of site by site normalized RADV, for 1 degree bins of receiver front panel temperature (RTMP). The drop in RADV at high temperatures results from the suspension of transmitting above 40 °C for most sites.

than 10 °C suggest poor cooling, which may be the case in many of these systems. Of these two parameters, RTMP can have a direct impact on the downstream parameters. The transmitter drive control in the SeaSonde Controller suspends the transmitter when RTMP exceeds a user configurable value (40 °C by default). This affect is shown in Figure 3. For temperatures below 40 °C, little relationship between RTMP and RADV was found, or expected.

Non-zero values for the Phase Locked Loop Oscillator (PLLL) indicate a problem with the Global Positioning System (GPS) synchronization. The PLLL was found here to be non-zero only a very small fraction of the time overall. Non-zero values were only observed at one of the HF sites (BRKY), where it was non-zero about 25% of the time. This site was not GPS synchronized, and so non-zero values of PLLL did not cause the transmitter to switch off, as indicated by a lack of impact on RADV and RADR (data not shown). While this parameter could be useful to diagnose problems with the GPS synchronization, the remote site warning script (rs_warn.pl) monitors the number of GPS satellites fixes instead, which may provide operators with more useful information. This parameter could become more important as more sites rely on GPS synchronization.

Transmitter Parameters

Mean transmitter amplifier (XAHT) and front panel board (XPHT) temperatures of 34.5 ^{o}C and 28.9 ^{o}C fall well below manufacturer recommended maximums of 50 ^{o}C and 40 ^{o}C (Table 2), likely due to the default cut off maximum of 40 ^{o}C for the receiver front panel temperature. A difference between these two of 10 ^{o}C may indicate cooling system problems (SeaSonde documentations). Figure 4 supports this recommendation,

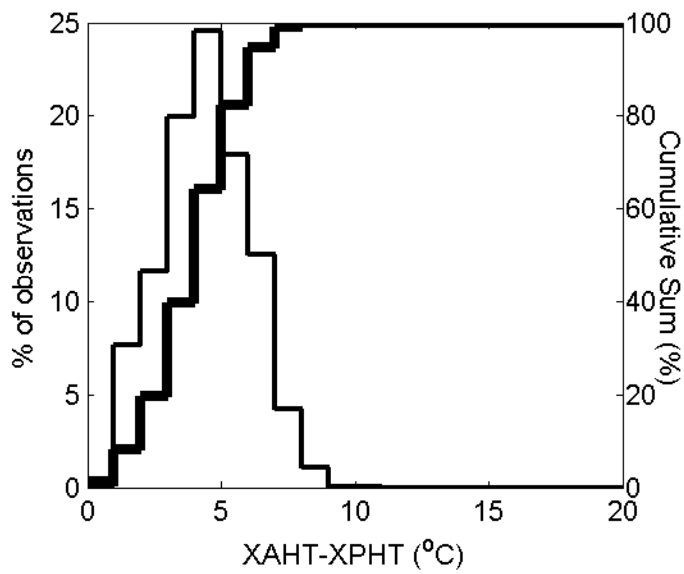

Figure 4. Histogram of difference between transmitter amplifier (XAHT) and transmitter front panel (XPHT) temperatures.

showing that the difference between the two (XAHT – XPHT) is typically about 5 ^{o}C. As shown by Figure 5, these temperatures are highly correlated with RTMP. No connection was observed between XAHT and any of the downstream parameters, as shown in Figure 1. While XAHT is highly correlated with RTMP, the receiver controller software uses the receiver temperature, not from the transmitter amplifier temperature. Other than showing the effect of the high temperature cut off, Figure 6 demonstrates the lack of connection between the transmitter amplifier temperature and transmitter forward power (XAFW).

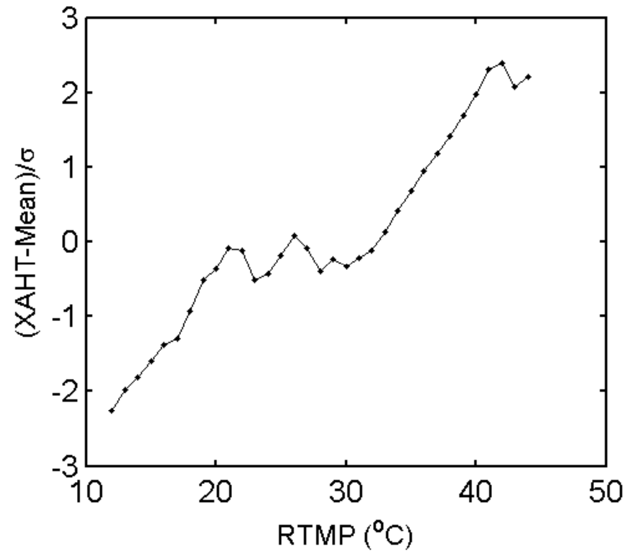

Figure 5. Conditional averages of site by site normalized XAHT, for 1 degree bins of receiver front panel temperature (RTMP).

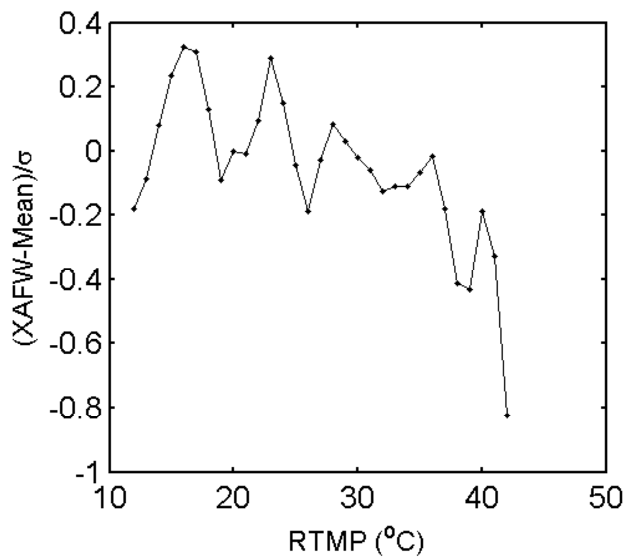

Figure 6. Conditional averages of site by site normalized XAFW, for 1 degree bins of receiver front panel temperature (RTMP). The decrease in XAFW with high temperatures result from the effect of temperature on the amplifier, and the suspension of transmitting above 40 ^{o}C for most sites.

Surprisingly, little connection between radial vector range (RADR) and XAFW is observed (Figure 7). The best explanation for this observation is that most HF sites operate at a user-specified maximum range, which does not vary with transmitted power. Few data points at low XAFW are available to demonstrate the expected result of low range (RADR) at low XAFW. However, Figure 8 shows an expected connection between the number of radial vector solutions (RADV) and transmitter forward power (XAFW).

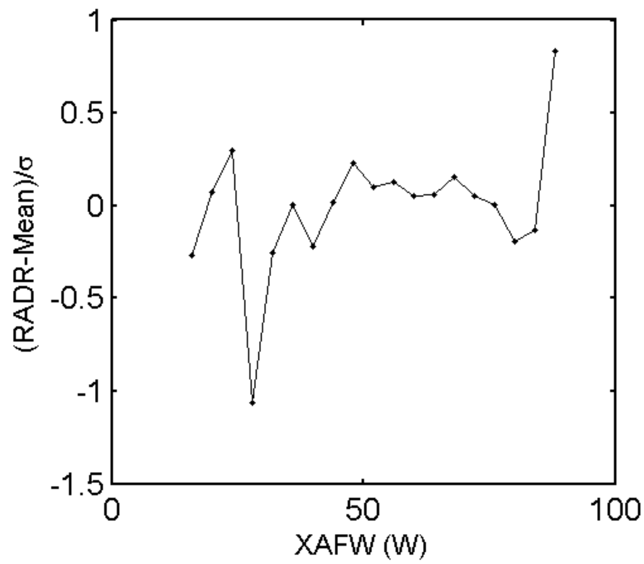

Figure 7. Conditional averages of site by site normalized radial range (RADR), for 4 W bins of transmitter forward power (XAFW).

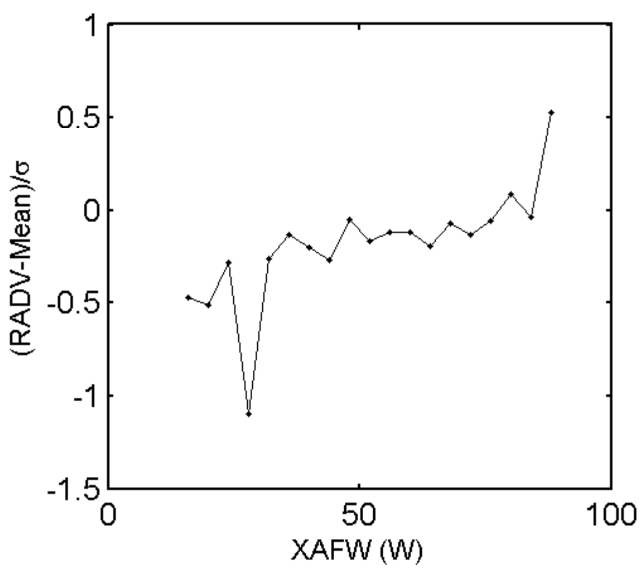

Figure 8. Conditional averages of site by site normalized radial vector count (RADV), for 4 W bins of transmitter forward power (XAFW).

Histograms of XAFW (not shown) show a broad peak around 50 Watts, substantial drop in the number of data points around 30 Watts, and an another smaller peak around 20 Watts. With this distribution in mind, the drop in RADV shown around 30 Watts in Figure 8 probably shows the expected drop in RADV with lower XAFW, a relationship which is then lost in signal from sites with average XAFW around 20 W. An expected relationship between XARW and the radial parameters was not found.

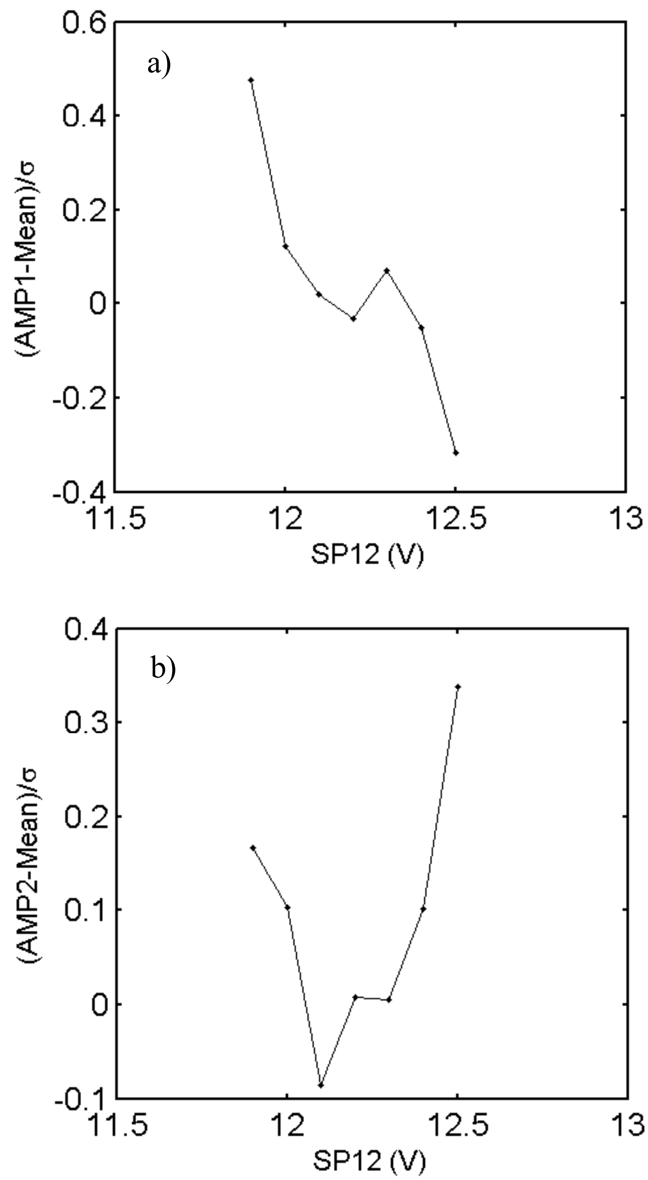

Figure 9. Conditional averages of site by site normalized amplitude ratios (loops 1 and 2 to the monopole, AMP1 and AMP2), for 0.1 volt bins of receiver supply voltage (SP12) .

Antenna Parameters

According to manufacturer documentation, the calculated amplitude corrections for loops 1 and 2 to the monopole (AMP1 and AMP2), should be sTable over time, and any significant changes to these parameters may indicated changes in the antenna pattern measurement (APM) (ref). While a thorough analysis of the relationship between the amplitude corrections and AMPs is outside the scope of this analysis, conceivably, the APM has an influence on the radials parameters. Thus, we investigated the relationship between conditionally averaged RAPR, RADV, RABA, and RADR and the amplitude corrections (AMP1 and AMP2). We found no significant relationship between these parameters, indicating that these characteristics of the radial vector data are not affected by the APM.

The relationship between receiver voltage (SP12), and the calculated receive antenna amplitude corrections (AMP1 and AMP2) is shown in Figure 9. The Figure plots conditionally averaged AMP1 and AMP2 as functions of binned receiver supply voltage (SP12). While trends are apparent in these Figures, the range of the y axis is less than 1 standard deviation.

Discussion

The results given in Table 2 give an indication of standard values. We must note that other than the information contained in the .hdt and .rdt files, no indication of data quality was provided for most of the sites. While we removed the obviously bad data (zeros, negative temperatures, etc.), it is likely that the data contain many sub-optimal parameter values, which then contribute to these statistics. We suggest future analyses determine standard values by using a database of .hdt and .rdt files along with radial files and the complete metadata associated with each site. Knowing when a given site is running optimally or sub-optimally, and why, would be useful in clearly defining QC standards.

Since we used the radial data parameters to evaluate the usefulness of each of the other parameters as indicators of system health, we are constrained by the information that they can convey. The radial data parameters are useful to determine that a site is producing data, but they cannot be used to establish the quality of this data. While it is likely that the data quality is low when parameters are more than a few standard deviations from the mean, this analysis cannot establish this as fact. Because of this limitation, we recommend future analyses of QC to focus on:

(1)site pairs with over-water baselines; or if none exist,

(2) groups of three sites where total vectors from two are used to predict the radials at the third. Site to site comparisons could be used to establish data quality, and then to base the standard values on high quality data.

For QC, the most promising of the parameters analyzed here are the antenna amplitude corrections. Because these parameters may reflect changes in the receive antenna pattern, they have the possibility of determining when an APM is no longer valid, and consequently, when the radial data may contain errors. It is possible that significant changes in AMP1 and AMP2 and their affect on the radial parameters are subtler than would be revealed with our methods.

Summary of Performance Metrics

HFR performance metric recommendations are shown in Table 3. Except where noted, these recommendations are based on the standard values determined here. Performance metrics were determined for all of the parameters specified in the statement

Table 3. Performance metric recommendations.

Parameter	Code	Value	Standard Deviation
Receiver Chassis Temp (deg C)	RTMP	< 40 [(1)]	6.0
AWG Board Temp (deg C)	MTMP	< 50 [(1)]	7.0
MTMP - RTMP (deg C)		< 12	
Receiver +VDC Supply	SP05	> 4.7 [(2)]	0.1
Receiver -VDC Supply	SN05	> 4.7 [(2)]	0.2
Receiver +12VDC supply	SP12	12.3	0.1
Transmitter Chassis Temp (deg C)	XPHT	28.9	5.2
Transmitter Amplifier Temp (deg C)	XAHT	34.5	5.0
XAHT - XPHT (deg C)		> 10 [(2)]	
Transmitter Forward Power (W)	XAFW	53.0	13.0
Transmitter Reflected Power (W)	XARW	5.0	5.0
Phase Lock Loop Loss	PLLL	0 [(2)]	n/a
RunTime (hrs)	RUNT	190	400
Total # Radial Vector Solutions:			
13 MHz band	RADV	520	310
25 MHz band	RADV	280	110
40 MHz band	RADV	960	470
Average # Solns per Range Cell:			
13 MHz band	RAPR	15	5
25 MHz band	RAPR	10	5
40 MHz band	RAPR	30	15
Maximum Radial Range (km):			
13 MHz band	RADR	75.7	18.7
25 MHz band	RADR	29.4	5.2
40 MHz band	RADR	10.6	2.1
Average Bearing of All Radials			
13 MHz band	RABA		80.0
25 MHz band	RABA		80.0
40 MHz band	RABA		70.0

[(1)] Recommendation given by remote site monitoring script rs_warn.pl

[(2)] Recommendation given by SeaSonde Documentation

of work with the exception of the calculated amplitude corrections for loops 1 and 2 to the monopole (AMP1 and AMP2). It is recommended by the manufacturer that these be monitored for significant changes, but this analysis was not able to establish a threshold of significance. As shown in Table 1, the standard deviations of AMP1 and AMP2 are large compared with the means in the data set analyzed. Where noted, metrics were obtained from SeaSonde documentation and from the remote site monitoring script rs_warn.pl. The latter was done at the suggestion of the manufacturer.