



IOOS

Integrated Ocean
Observing System



Manual for Real-Time Quality Control of High Frequency Radar Surface Current Data

A Guide to Quality Control and Quality
Assurance for High Frequency Radar Surface
Current Observations

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Document Validation



U.S. IOOS Program Office Validation

Zdenka S. Willis

Zdenka S. Willis, Director, U.S. IOOS Program Office

05/24/16

Date

QARTOD Project Manager Validation

Joseph Swaykos

Joseph Swaykos, NOAA National Data Buoy Center

05/24/16

Date

QARTOD Board of Advisors Validation

Julianna O. Thomas

Julianna O. Thomas, Southern California Coastal Ocean Observing System

05/24/16

Date

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Revision History

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Endorsement Disclaimer

Mention of a commercial company or product does not constitute an endorsement by NOAA. Use of information from this publication for publicity or advertising purposes concerning proprietary products or the tests of such products is not authorized.

Request to Manual Users

To gauge the success of the QARTOD project, it helps to be aware of groups working to utilize these QC tests. Please notify us of your efforts or intentions to implement QARTOD processes by sending a brief email to data.ioos@noaa.gov or posting a notice at <http://www.linkedin.com/groups?gid=2521409>.

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Acronyms and Abbreviations

AOOS	Alaska Ocean Observing System
APM	Antenna Pattern Measurement
CariCOOS	Caribbean Coastal Ocean Observing System
CeNCOOS	Central and Northern California Ocean Observing System
BF	Beam forming
cm/s	Centimeters per second
CO-OPS	(NOAA) Center for Operational Oceanographic Products and Services
dB	Decibel
DF	Direction finding
DOA	Direction of Arrival
GCOOS	Gulf of Mexico Coastal Ocean Observing System
GDOP	Geometric Dilution of Precision
GLOS	Great Lakes Observing System
HF	High Frequency
hr	Hour
HZM	HELZEL Messtechnik
IOOS	(U.S.) Integrated Ocean Observing System
km	Kilometer
LERA	Least Expensive Radar
MARACOOS	Mid-Atlantic Regional Association Coastal Ocean Observing System
MHz	Megahertz
m/s	Meters per Second
MUSIC	Multiple Signal Classification
NANOOS	Northwest Association of Networked Ocean Observing Systems
NERACOOS	Northeastern Regional Association of Coastal Ocean Observing Systems
NOAA	National Oceanic and Atmospheric Administration
PacIOOS	Pacific Islands Ocean Observing System
QARTOD	Quality-Assurance/Quality Control of Real-Time Oceanographic Data
QA	Quality Assurance
QC	Quality Control
RA	Regional Association
RFI	Radio Frequency Interference
SCCOOS	Southern California Coastal Ocean Observing System
SECOORA	Southeast Coastal Ocean Observing Regional Association
SNR	Signal-to-Noise Ratio
UNESCO	United Nations Educational, Scientific, and Cultural Organization
WERA	Wellen (Wave) Radar

Definitions of Selected Terms

This manual contains several terms whose meanings are critical to those using the manual. These terms are included in the following table to ensure that the meanings are clearly defined.

Beam Forming (BF) System	A BF system is a high frequency radar surface current mapping system that employs a phased-array antenna system to measure the radial direction.
Codable Instructions	Codable instructions are specific guidance that can be used by a software programmer to design, construct, and implement a test. These instructions also include examples with sample thresholds.
Data Record	A data record is one or more messages that form a coherent, logical, and complete observation.
Direction Finding (DF) System	A DF system is a high frequency radar surface current mapping system that employs three orthogonal antenna elements to measure the radial direction.
Message	A message is a standalone data transmission. A data record can be composed of multiple messages.
Operator	Operators are individuals or entities who are responsible for collecting and providing data.
Quality Assurance (QA)	QA involves processes that are employed with hardware to support the generation of high quality data. (section 2.0 and appendix A)
Quality Control (QC)	QC involves follow-on steps that support the delivery of high quality data and requires both automation and human intervention. (section 3.0)
Radial Component	Radial component is the observed surface current speed toward or away from a single HF radar site, and is also often referred to as radial speed, radial velocity, or radial vector. A radial file contains a spatial array of radial components.
Real Time	Real time means that: data are delivered without delay for immediate use; time series extends only backwards in time, where the next data points are not available; and there may be delays ranging from a few seconds to a few hours or even days, depending upon the variable. (section 1.0)
Total Vector	Total vector is the derived surface current velocity, obtained by combining radial components from multiple HF Radar sites. A total vector file contains a spatial array of total vectors.
Threshold	Thresholds are limits that are defined by the operator. They often vary in space and time, and should be readily available to other operators and users.
Variable	Variable is an observation (or measurement) of biogeochemical properties within oceanographic and/or meteorological environments.

1.0 Background and Introduction

The U.S. Integrated Ocean Observing System® (IOOS®) has a vested interest in collecting high quality data for the 26 core variables (U.S. IOOS 2010) measured on a national scale. In response to this interest, U.S. IOOS continues to establish written, authoritative procedures for the quality control (QC) of real-time data through the Quality Assurance/Quality Control of Real-Time Oceanographic Data (QARTOD) program, addressing each variable as funding permits (UNESCO 1993). This manual on the real-time QC of high frequency (HF) radar surface currents represents the ninth core variable to be addressed. Other QARTOD guidance documents that have been published by the U.S. IOOS project to date are listed below and are available at <https://ioos.noaa.gov/project/qartod/#manuals>

- 1) U.S IOOS QARTOD Project Plan dated April 1, 2012.
- 2) U.S. Integrated Ocean Observing System, 2015. Manual for Real-Time Quality Control of Dissolved Oxygen Observations Version 2.0: A Guide to Quality Control and Quality Assurance for Dissolved Oxygen Observations in Coastal Oceans. 48 pp.
- 3) U.S. Integrated Ocean Observing System, 2015. Manual for Real-Time Quality Control of In-Situ Current Observations Version 2.0: A Guide to Quality Control and Quality Assurance of Acoustic Doppler Current Profiler Observations. 51 pp.
- 4) U.S. Integrated Ocean Observing System, 2015. Manual for Real-Time Quality Control of In-Situ Surface Wave Data Version 2.0: A Guide to Quality Control and Quality Assurance of In-Situ Surface Wave Observations. 64 pp.
- 5) U.S. Integrated Ocean Observing System, 2014. Manual for Real-Time Quality Control of Water Level Data: A Guide to Quality Control and Quality Assurance of Water Level Observations. 43 pp.
- 6) U.S. Integrated Ocean Observing System, 2014. Manual for Real-Time Quality Control of Wind Data: A Guide to Quality Control and Quality Assurance of Coastal and Oceanic Wind Observations. 45 pp.
- 7) U.S. Integrated Ocean Observing System, 2015. Manual for Real-Time Quality Control of Ocean Optics Data: A Guide to Quality Control and Quality Assurance of Coastal and Oceanic Optics Observations. 46 pp.
- 8) U.S. Integrated Ocean Observing System, 2015. Manual for Real-Time Quality Control of Dissolved Nutrients Data: A Guide to Quality Control and Quality Assurance of Coastal and Dissolved Nutrients Observations. 56 pp.
- 9) U.S. Integrated Ocean Observing System, 2015. Manual for Real-Time Quality Control of In-situ Temperature and Salinity Data Version 2.0: A

Guide to Quality Control and Quality Assurance of In-situ Temperature and Salinity Observations. 56 pp.

Please reference this document as:

U.S. Integrated Ocean Observing System, 2016. Manual for Real-Time Quality Control of High Frequency Radar Surface Currents Data: A Guide to Quality Control and Quality Assurance of High Frequency Radar Surface Currents Data Observations. 58 pp. <https://doi.org/10.7289/V5T43R96>

This manual is a living document that reflects the state-of-the-art QC testing procedures for HF radar surface currents observations. It is written for the experienced operator but also provides examples for those who are just entering the field.

2.0 Purpose/Constraints/Applications

The HF radar capability was successfully demonstrated decades ago, and its use to observe surface currents is now one of the most robust operational measurements employed by the oceanographic community. The present U.S. IOOS program integrates HF radar observations from 10 participating Regional Associations (RAs), 31 participating organizations, more than a decade of operations, over 130 coastal sites, and almost 8,000,000 data files. The effort is well described in the National Surface Currents Plan (U.S. IOOS 2015). Section 13.5 of that plan provides an overview of the existing and emerging QC techniques and serves as the basis for the QC processes described herein.

2.1 Purpose

The purpose of this manual is to document successful QC techniques already in place, identify any shortcoming of those techniques, and to suggest new QC tests that may be employed as resources and capabilities permit.

QC involves follow-on steps that support the delivery of high quality data and requires both automation and human intervention. QC practices include such things as data integrity checks (format, checksum, timely arrival of data), data value checks (threshold checks, minimum/maximum rate of change), neighbor checks, climatology checks, model comparisons, signal/noise ratios, the mark-up of the data, the verification of user satisfaction, and generation of data flags (Bushnell 2005).

2.2 Constraints

The focus of the manual is on the real-time QC of data collected, processed, and disseminated by the U.S. IOOS RAs. It is limited to the HF radar surface current mapping systems presently used by the RAs, and to the data presently provided from them. Therefore, it addresses these systems and manufacturers:

- SeaSonde® - developed by CODAR Ocean Sensors. Ltd.
- WERA - manufactured by HELZEL Messtechnik (HZM) GmbH
- LERA - developed by Pierre Flament at the University of Hawaii

QC is also constrained to surface current observations. All three systems provide surface gravity wave observations that some data providers/operators deem operational, but there are no wave observations from operational HF radar systems presently occurring within the U.S. For a U.S. IOOS National HF Radar Technical Steering Team position paper on the use of HF radar for wave measurement, see <https://ioos.noaa.gov/project/hf-radar/>. Because of near-zero conductivity, fresh water does not support useful operations; therefore, this manual focuses on installations over brackish and salt water.

In addition, the manual does not focus on the quality assurance (QA) associated with the proper installation and operation of a HF radar site (Voulgaris 2011). Many of these considerations are addressed in the document *Deployment & Setup of a High Frequency Radar for Ocean Surface Current Mapping: Best Practices*, which is specifically for SeaSonde systems and attached here as appendix A. Operators typically monitor the many performance metrics listed in appendix A, table 3 to ensure the health of an HF radar site.

Each system is briefly described in the following subsections.

2.2.1 CODAR SeaSonde®

CODAR Ocean Sensors, Ltd. (CODAR) is the developer and manufacturer of the SeaSonde® compact HF radar system. Its founders were the creators and pioneers of the HF surface-wave radar field, going back 50 years. CODAR offers software for outputting several data product categories, including surface current mapping, wave measurements, tsunami detection, and recently ship detection. The 30-year-old company has a continuous history of HF research and transition to operations. The CODAR compact direction-finding system is the most widely deployed oceanographic HF technology, both within the U.S. (approximately 125 sites) and internationally (hundreds of systems). For frequencies greater than 11 megahertz (MHz), the antenna system combines the transmitting and receiving antennas within a single mast and also eliminates the horizontal ground plane whip antennas. The company headquarters are in Mountain View, California.

2.2.2 WERA

The Wellen Radar¹ (WERA) system was initially developed at the University of Hamburg in 1996. One of the aims was to allow measurements of the ocean wave spectrum, which requires access to the full backscatter Doppler spectrum for all ranges and directions. This access is achieved by applying a beam-forming technique.

The initial design uses a linear array of 16 antennas connected to 16 independent, inter-calibrated receiver channels and beam forming (BF) implemented in software, but it also allows the operator to set up four antennas in a square and use direction finding (DF), if no ocean wave measurements are required. To avoid high-power transmit pulses in the range of some kilowatts as used in former systems, a frequency-modulated continuous-wave signal at 30 watts is transmitted to achieve range resolution. The depth of the range cells can be adopted to the requirements by reprogramming the frequency span of the transmitted frequency chirp. Typical values for a system operated in the 12-MHz frequency band are 130 ranges at 1.5 kilometers (km) resolution.

To reduce the impact of radio frequency interference (RFI), a new technique is implemented within WERA: A signal containing the backscattered echoes superimposed by RFI, as well as a second signal containing RFI only, are received simultaneously. The RFI-only signal is used to mitigate the RFI component within the echo signal, which results in much clearer access to the echoes from the ocean surface and from ships.

Data acquisition can be programmed for different integration times, e.g., about 10 minutes for ocean currents and wind direction and 20 minutes for ocean wave spectra. These short intervals help to track highly variable oceanographic processes, e.g., the impact of a fast-moving meteorological front to the ocean surface. For detection and tracking of tsunamis and ships, data sets with 2 minutes integration time can be processed in real time every 30 seconds.

In 2000, a technology transfer to HZM (<http://www.helzel.com>) began. WERA systems are now manufactured and further developed by HZM, which is located in Kaltenkirchen Germany. About 100 systems have been installed worldwide; about ten are deployed within the U.S. Additional information on WERA is available at <http://ifmaxp1.ifm.uni-hamburg.de/WERA.shtml>.

¹ Wellen Radar is German for wave radar.

2.2.3 LERA

The Least-Expensive-Radar (LERA) was developed at the University of Hawaii Radio Oceanography Laboratory, and several of these phased-array systems are deployed in Hawaii. A new system designed for compact, self-cooling, low-power operations is in development. About nine systems are deployed in the U.S.

2.3 Applications

The QC tests described here can be applied to the Doppler spectra, to the radial components, or to the total vectors. Several manufacturers of ocean observing systems have begun to incorporate QARTOD tests in the sensor itself when possible. In HF radar surface current mapping, the technology is so advanced that much of the QC is already embedded in the acquisition system, especially for QC of the Doppler spectra. Examples may include:

- Noise floor detection and computation
- First-order Bragg peak detection and measurement
- Individual spectrum signal-to-noise ratio (SNR) computation for the first-order peak
- Detection and removal of burst interference (e.g., lightning)
- Detection and removal of ionospheric echo
- Detection and removal of ship echoes
- Detection and removal of some types of RFI

Doppler spectra may be rejected, and radial components may not be produced from them depending on the outcome of these tests. Because these processes influence the production of radial components, they are inherently part of the quality control process for surface currents described in the National Plan (U.S. IOOS 2015).

3.0 Quality Control

To conduct real-time quality control (QC) on HF radar surface current observations, the first prerequisite is to understand the science and context within which the measurements are being conducted. Each HF radar radial site may have unique QC challenges. HF radar measurements can be used to resolve many surface current features, such as oceanic fronts, current shear, divergent and convergence zones; some of these features can be extreme events. Human involvement is therefore important so that solid scientific principles are applied to data evaluation to ensure that good data are not discarded and bad data are not distributed.

The real-time QC of HF radar observations can be extremely challenging. For example, for real-time QC, gradual calibration changes (e.g., changes in antenna patterns) and long-term system responses (component drift) most likely cannot be detected or corrected with real-time, automated QC—at least, not at the present time.

The QC described here may be conducted: 1) within the HF radar data collection system itself, 2) by the local system operator, and 3) national and regional servers. Example of national and regional servers are:

- The University of California San Diego - <http://cordc.ucsd.edu/projects/mapping>
- NOAA’s National Data Buoy Center - <http://hfradar.ndbc.noaa.gov/>
- Rutgers University - <http://marine.rutgers.edu/marcoos/hfradar.htm>

3.1 QC Flags

Data are evaluated using QC tests, and the results of those tests are recorded by inserting flags in the data record. Table 3-1 provides a simple set of flags and associated descriptions. HF radar manufacturers already include additional flags for metadata records to further assist with troubleshooting. For example, CODAR Ocean Sensors (2009) identifies a variety of flags that are unique to SeaSonde systems. For additional information regarding flags, see the *Manual for the Use of Real-Time Oceanographic Data Quality Control Flags* (U.S. IOOS 2014) posted on the U.S. IOOS QARTOD website. Extensive data flagging is already in place for HF radar and serves the observational needs quite well. These flags can be a successful example for other systems.

Further post-processing of the data may yield different conclusions from those reached during initial assessments. Flags set in real time should not be changed to ensure that historical documentation is preserved. Results from post-processing should generate another set of flags.

Table 3-1. Flags for real-time data (UNESCO 2013)

Flag	Description
Pass=1	Data have passed critical real-time quality control tests and are deemed adequate for use as preliminary data.
Not evaluated=2	Data have not been QC-tested, or the information on quality is not available.
Suspect or Of High Interest=3	Data are considered to be either suspect or of high interest to data providers and users. They are flagged suspect to draw further attention to them by operators.
Fail=4	Data are considered to have failed one or more critical real-time QC checks. If they are disseminated at all, it should be readily apparent that they are not of acceptable quality.
Missing data=9	Data are missing; used as a placeholder.

3.2 Sensor Deployment Considerations

HF radars can be deployed in a variety of environments. Section 1 of the Southern California Coastal Ocean Observing System (SCCOOS) Best Practices document (appendix A) discusses the steps to follow when finding a suitable location for an HF radar installation. Figure 3-1 shows an example of a SeaSonde antenna location with desirable features—close to the sea with low elevation and no nearby structures.



Figure 3-1. A 25 MHz combined transmitting and receiving antenna deployed at Cape Henlopen, Delaware.

3.3 QC Test Descriptions

A variety of tests can be performed to evaluate data quality in real time. Some tests may already be embedded in the processing software; others are conducted by the local operator or the National servers. The tests listed in this section (table 3-2) presume a time-ordered series of observations and denote these observations as follows:

Radial velocity: R_{t-2} , R_{t-1} , R_t Total vector: T_{t-2} , T_{t-1} , T_t

Sensor operators need to select the best thresholds for each test, which are determined at the operator level and may require trial and error before final selections are made. A successful QC effort is highly dependent upon selection of the proper thresholds, which should not be determined arbitrarily but can be based on historical knowledge or statistics derived from more recently acquired data. Although this manual provides some guidance for selecting thresholds based on input from various operators, it is assumed that operators have the expertise and motivation to select the proper thresholds to maximize the value of their QC effort. Operators must openly provide thresholds as metadata for user support. This shared information will help U.S. IOOS to document standardized thresholds that will be included in future releases of this manual.

In Table 3-2, tests that apply only to DF systems are marked with an asterisk (*). This condition is further highlighted as needed within each test description in the test exceptions block.

Several additional tests were suggested by experienced operators who reviewed the manual, but details of the tests were not available. In order to ensure these tests remain available for consideration, they have been listed in appendix C, *Additional Potential Quality Control Tests*. As this manual is updated and content for these tests becomes available, they will be incorporated.

Table 3-2. QC tests for real-time HF radar data. Tests with (*) apply only to SeaSonde systems.

Test Type	Test Name	Status	Test Control
Signal (or Spectral) Processing	Signal-to-Noise Ratio (SNR) for Each Antenna (Test 1)	Required	Embedded
	Cross Spectra Covariance Matrix Eigenvalues (Test 2)	Suggested	Embedded
	Single and Dual Angle Solution - Direction of Arrival (DOA) Metrics* (magnitude) (Test 3)	Suggested	Embedded
	Single and Dual Angle Solution - Direction of Arrival (DOA) Function Widths* (3 dB) (Test 4)	Suggested	Embedded
	Positive Definiteness of 2x2 Signal Matrix* (Test 5)	Required	Embedded
Radial Components	Syntax (Test 6)	Required	National
	Max Threshold (Test 7)	Required	Local and National
	Valid Location (Test 8)	Required	Local and National
	Radial Count* (Test 9)	In development	Local and National
	Spatial Median Filter* (Test 10)	Suggested	Local and National
	Temporal Gradient (Test 11)	Suggested	Local and National
	Average Radial Bearing* (Test 12)	Suggested	Local and National
	Synthetic Radial (Test 13)	In development	Local and National
Total Vectors	Data Density Threshold* (Test 14)	Required	Local and National
	GDOP Threshold (Test 15)	Required	Local and National
	Max Speed Threshold (Test 16)	Required	Local and National
	Spatial Median Comparison (Test 17)	Suggested	Local and National

3.4 Test Hierarchy

This section outlines the 17 real-time QC tests that are required or suggested for real-time HF radar measurements. Operators should also consider that some of these tests can be carried out within the instrument, where thresholds can be defined in configuration files. These procedures are written as a high-level narrative from which a computer programmer can develop code to execute specific data flags (data quality indicators) within an automated software program. A code repository where operators may find or post examples of code in use exists at <https://github.com/rowg>. However, HF radar surface current observations are well established, and in most cases the QC applied will be quite uniform. Tests are listed in table 3-3 and are divided into four groups: those that are required, strongly recommended, suggested, or in development.

Table 3-3. QC Tests hierarchy

Group 1 <i>Required</i>	Test 1	Signal-to-Noise Ratio
	Test 6	Syntax
	Test 7	Max Threshold
	Test 8	Valid Location (radial components)
	Test 14	Data Density Threshold*
	Test 15	GDOP Threshold
	Test 16	Max Speed Threshold
Group 2 <i>Strongly Recommended</i>		None.
Group 3 <i>Suggested</i>	Test 2	Cross Spectra Covariance Matrix Eigenvalues
	Test 3	Single and Dual Angle Solution - DOA Metrics (magnitude)*
	Test 4	Single and Dual Angle Solution - DOA Function Widths (3 dB)*
	Test 5	Positive Definiteness of 2x2 Signal Matrix*
	Test 10	Spatial Median Filter* (radial components)
	Test 11	Temporal Gradient
	Test 12	Average Radial Bearing*
Test 17	Spatial Median Comparison (total vectors)	
Group 4 <i>In Development</i>	Test 9	Radial Count*
	Test 13	Synthetic Radial

3.4.1 Signal Processing (or Spectral Processing)

These tests are presently, or likely would be, conducted using algorithms embedded in the data acquisition software.

Test 1 – Signal-to-Noise Ratio (SNR) for Each Antenna (Required)

Ensures that measured signal is sufficiently above a noise level.		
The signal-to-noise ratio (SNR) value should exceed the minimum value (SNRMIN). Different methods may be specified for different HF radar types (antenna configuration). For CODAR, SNRMIN can be set in Header.txt manually or by using Spectra.		
Flags	Condition	Codable Instructions
Fail = 4	SNR for a specific antenna is less than a minimum value. Reject due to low signal level either on the monopole (SNR3) or on both loop antennas (SNR1 and SNR2).	If $SNR3 < SNRMIN$ OR $(SNR1 < SNRMIN$ AND $SNR2 < SNRMIN)$, flag = 4
Suspect = 3	N/A	None
Pass = 1	SNR exceeds minimum on both monopole and either of the loop antennas.	If $SNR3 \geq SNRMIN$ AND $(SNR1 \geq SNRMIN$ OR $SNR2 \geq SNRMIN)$, flag = 1
Test Exception: None.		
Test specifications to be established by operator. Example: SNRMIN=6.0 (dB) (default) (6.0 to 9.0 dB CODAR-recommended).		

Test 2 – Cross Spectra Covariance Matrix Eigenvalues (Suggested)

Test is part of the direction-of-arrival (DOA) decision process about whether to select single or dual angle for radial velocity value.		
A single eigenvalue that is much larger than the others favors a single-angle decision. Two larger eigenvalues favor dual-angle.		
Flags	Condition	Codable Instructions
Fail = 4	All eigenvalues are close to each other.	If Eig1, Eig2, Eig3 within 20% of each other, flag = 4
Suspect = 3	Two eigenvalues are moderately large.	If $Eig1/Eig3 < 2 * Eig2/Eig3$, flag = 3
Pass = 1	One eigenvalue is much larger than other two.	If $Eig1 > 100 * Eig2$ and $Eig1 > 100 * Eig3$, then accept single-angle decision, flag = 1
Test Exception: Does not apply to BF systems.		
Test specifications to be established by operator. For SeaSonde systems, these thresholds are part of preference settings in 'Current' tool.		

Test 3 - Single- and Dual-Angle Solution - Direction of Arrival (DOA) Metrics (magnitude)* (Suggested)

Evaluates whether the DOA response peak power is strong enough to produce good data for the specific DOA solution.

DOA peak power for each solution should be above a specified threshold minimum (PPMIN). For CODAR, MSEL is the multiple signal classification (MUSIC) bearing selected (1=single, 2=dual angle1, and 3=dual angle2) has corresponding output columns in RadialMetric files for MUSIC DOA peak power response, MSR1, MDR1, and MDR2, respectively.

Flags	Condition	Codable Instructions
Fail = 4	DOA response peak power is less than minimum value.	If (MSEL==1 AND MSR1 < PPMIN) OR (MSEL==2 AND MDR1 < PPMIN) OR (MSEL==3 AND MDR2 < PPMIN), flag = 4.
Suspect = 3	N/A	None
Pass = 1	DOA peak power exceeds minimum for specific DOA solution. Applies for test pass condition.	If (MSEL==1 AND MSR1 ≥ PPMIN) AND (MSEL==2 AND MDR1 ≥ PPMIN) AND (MSEL==3 AND MDR2 ≥ PPMIN), flag = 1.

Test Exception: Does not apply to BF systems.

Test specifications to be established by operator.

Example: PPMIN=5.0 (dB)

Test 4 – Single- and Dual-Angle Solution - DOA Function Widths (3 dB)* (Suggested)

Evaluates whether DOA function is too wide to produce good data for specific DOA solution.

DOA function width at 3 dB down from the response peak bearing for each solution should be below a specified threshold maximum (PWMAX). For CODAR, MSEL is the MUSIC bearing selected (1 = single, 2 = dual angle1, and 3 = dual angle2) and has corresponding output columns in RadialMetric files for MUSIC DOA function width—MSW1, MDW1, and MDW2, respectively.

Flags	Condition	Codable Instructions
Fail = 4	DOA function width is greater than maximum value.	If (MSEL==1 AND MSW1 ≥ PWMAX) OR (MSEL==2 AND MDW1 ≥ PWMAX) OR (MSEL==3 AND MDW2 ≥ PWMAX), flag = 4
Suspect = 3	N/A	N/A
Pass = 1	DOA function width is narrower than maximum value for a specific DOA solution. Applies for test pass condition.	If (MSEL==1 AND MSW1 < PWMAX) AND (MSEL==2 AND MDW1 < PWMAX) AND (MSEL==3 AND MDW2 < PWMAX), flag = 1

Test Exception: Does not apply to BF systems.

Test specifications to be established by operator.

Example: PWMAX = 50 degrees

Test 5 - Positive Definiteness of 2x2 Signal Matrix* (Suggested)

Test is part of DOA decision process to specifically check whether dual-angle decision fits the data.

A dual-angle situation implies two signals present from two directions. With this comes a 2x2 signal matrix, whose diagonal elements are the powers from each of the two directions. The off-diagonal elements are complex noise numbers that would be zero under perfect dual-angle, infinite-ensemble average conditions. If these differ significantly from zero and are close to the diagonal elements (a condition described as not positive definite), the dual-angle hypothesis should not apply.

Flags	Condition	Codable Instructions
Fail = 4	Dual angle decision fails because off-diagonal elements are too large.	If $P_1 * P_2 < 3 * C_{12} $, then flag = 4
Suspect = 3	Possibly single or dual angle; other criteria important for decision.	If $3 * C_{12} < P_1 * P_2 < 5 * C_{12} $, then flag = 3
Pass = 1	More likely dual-angle condition.	If $P_1 * P_2 > 5 * C_{12} $, then flag = 1

Test Exception: If the bearings related to the two DOA solutions are less than 15° apart, additional criteria should be used for decision. Does not apply to BF systems.

Test specifications to be established by operator. This test may be used in conjunction with or in place of other DOA decision criteria. Optimal values in the codable instructions should be tested because they may be site-specific, depending on conditions.

3.4.2 Radial Tests

This set of tests is conducted during the development of the radial velocities, or upon the resultant radial velocities. These tests may be carried out at the local, regional and/or national network levels.

Test 6 – Syntax (Required)

A collection of tests ensuring proper formatting and existence of fields within a radial file.

The radial file may be tested for proper parsing and content, for file format (hfrweralluv1.0, for example), site code, appropriate time stamp, site coordinates, antenna pattern type (measured or ideal, for DF systems), and internally consistent row/column specifications.

Flags	Condition	Codable Instructions
Fail = 4	One or more fields are corrupt or contain invalid data.	If "File Format" ≠ "hfrweralluv1.0", flag = 4
Suspect = 3	N/A	N/A
Pass = 1	Applies for test pass condition.	N/A

Test Exception: None.

Test specifications to be established by operator. Acceptable files types, site codes, coordinates, APM names, etc., must be presented. For example, the national network performs the following suite of tests:

- All radial files acquired by HFRNet portals report the data timestamp in the filename. The filename timestamp must not be any more than 72 hours in the future relative to the portals' system time.
- The file name timestamp must match the timestamp reported within the file.
- Radial data tables (Lon, Lat, U, V, ...) must not be empty.
- Radial data table columns stated must match the number of columns reported for each row (a useful test for catching partial or corrupted files).
- The site location must be within range: $-180 \leq \text{Longitude} \leq 180$ $-90 \leq \text{Latitude} \leq 90$.
- As a minimum, the following metadata must be defined:
 - File type (LLUV)
 - Site code
 - Timestamp
 - Site coordinates
 - Antenna pattern type (measured or idealized)
 - Time zone (only Coordinated Universal Time or Greenwich Mean Time accepted)

Test 7 - Max Threshold (Required)

Ensures that a radial current speed is not unrealistically high.		
The maximum radial speed threshold (RSPDMAX) represents the maximum reasonable surface radial velocity for the given domain.		
Flags	Condition	Codable Instructions
Fail = 4	Radial current speed exceeds the maximum radial speed threshold.	If RSPD > RSPDMAX, flag = 4
Suspect = 3	N/A	N/A
Pass = 1	Radial current speed is less than or equal to the maximum radial speed threshold.	If RSPD ≤ RSPDMAX, flag = 1
Test Exception: None.		
Test specifications to be established by operator. The maximum total speed threshold is 1 m/s for the West Coast of the United States and 3 m/s for the East/Gulf Coast domain. The threshold must vary by region. For example, the presence of the Gulf Stream dictates the higher threshold on the East Coast.		

Test 8 – Valid Location (Required)

Removes radial vectors placed over land or in other unmeasurable areas.		
Radial vector coordinates are checked against a reference file containing information about which locations are over land or in an unmeasurable area (for example, behind an island or point of land). Radials in these areas will be flagged with a code (FLOC) in the radial file (+128 in CODAR radial files) and are not included in total vector calculations.		
Flags	Condition	Codable Instructions
Fail = 4	Radial contains a user-defined location flag code in the radial file.	If FLOC exists, flag = 4
Suspect = 3	N/A	None
Pass = 1	Radial does not contain a user-defined location flag code in the radial file.	If FLOC does not exist, flag = 1
Test Exception: None.		
Test specifications to be established by operator. For CODAR systems, the reference file is called AngSeg_XXXX.txt, where XXXX is the four-letter site code of the station and is located in the “RadialConfigs” folder. These vectors receive a code of +128 in the flag column of the radial text file. BF systems use pre-set grid locations for radials.		

Test 9 – Radial Count* (In Development)

Rejects radials in files with low radial counts (poor radial map coverage).

The number of radials (RCNT) in a radial file must be above a threshold value RCNT_MIN to pass the test and above a value RC_LOW to not be considered suspect. If the number of radials is below the minimum level, it indicates a problem with data collection. In this case, the file should be rejected and none of the radials used for total vector processing.

Flags	Condition	Codable Instructions
Fail = 4	Number of radials is less than RC_MIN.	If RCNT < RC_MIN, flag = 4
Suspect = 3	Number of radials is greater than or equal to RC_MIN and less than or equal to RC_LOW.	If RCNT ≥ RC_MIN and RCNT ≤ RC_LOW, flag = 3
Pass = 1	Number of radials is greater than RC_LOW.	If RCNT > RC_LOW, flag = 1

Test Exception: Does not apply to BF systems.

Test specifications to be established by operator. The RC_LOW threshold may be based on the national network performance metric threshold value of 300. The choice of 300 radial solutions came from grouping radial files over a certain time period from all stations, looking at the cumulative density function for counts, and selecting a value around 10%. However, this threshold does not work for all stations. A custom value for a site might be found by following the same procedure for the individual station.

Test 10 – Spatial Median Filter* (Suggested)

Reduces outlier velocities in radials.

A filtered and filled option for radials was introduced in CODAR Radial Suite software release 7. SeaSondeRadialSiteSetup can turn this feature on or off. Another way to do this is to change the value of line 22 in the AnalysisOptions.txt file in the RadialConfigs folder. It can be set to 0, 1, or 2 according to this guidance: 0 = Off, 1 = Area Filter + Interpolation, 2 = Area Filter Only.

The filtering and interpolation parameters are located on line 30 of the Header.txt in the RadialConfigs folder. Only the filtering is described below:

For each radial source vector, the RadialFiller program computes the median of all velocities within radius of $\langle RCLim \rangle * \text{Range Step}$ (km) whose vector bearing (angle of arrival at site) is also within $\langle AngLim \rangle$ degrees from the source vector's bearing. If the difference between the vector's velocity and the median velocity is greater than $\langle CurLim \rangle$ cm/s, then the vector is discarded; otherwise the median velocity is used.

In the codable instructions below, the radial velocity is designated as RV and the set of neighboring velocities is designated as RVNB.

(Information provided by personal communication with Bill Rector at CODAR.)

Flags	Condition	Codable Instructions
Fail = 4	Difference between the vector velocity and the median velocity is greater than the threshold.	If $RV - \text{median}(RVNB) > CurLim$, vector, flag = 4.
Suspect = 3	N/A	None.
Pass = 1	If the difference between the vector velocity and the median velocity is less or equal to the threshold, the vector value is CHANGED to the median value.	If $RV - \text{median}(RVNB) \leq CurLim$, $RV = \text{median}(RVNB)$ and flag = 1

Test Exception: Does not apply to BF systems.

Test specifications to be established by operator. If the feature is turned on, the default values are:
RCLim = 2.1 steps, AngLim = 10 degrees, CurLim = 30 centimeters per second (cm/s)

Test 11 – Temporal Gradient (Suggested)

Checks for satisfactory temporal rate of change of radial components.		
Test determines whether changes between successive radial velocity measurements at a particular range and bearing cell are within an acceptable range. $GRADIENT_TEMP = R_{t-1} - R_t $		
Flags	Condition	Codable Instructions
Fail = 4	The temporal change between successive radial velocities exceeds the gradient failure threshold.	If $GRADIENT_TEMP \geq GRADIENT_TEMP_FAIL$, flag = 4
Suspect = 3	The temporal change between successive radial velocities is less than the gradient failure threshold but exceeds the gradient warn threshold.	If $GRADIENT_TEMP < GRADIENT_TEMP_FAIL$ & $GRADIENT_TEMP \geq GRADIENT_TEMP_WARN$, flag = 3
Pass = 1	The temporal change between successive radial velocities is less than the gradient warn threshold.	If $GRADIENT_TEMP < GRADIENT_TEMP_WARN$, flag = 1
Test Exception: None.		
Test specifications to be established by operator. Example: $GRADIENT_TEMP_FAIL = 54 \text{ cm/s*hr}$, $GRADIENT_TEMP_WARN = 36 \text{ cm/s*hr}$		

Test 12 – Average Radial Bearing* (Suggested)

Check that the average radial bearing remains relatively constant (Roarty et al. 2012).

It is expected that the average of all radial velocity bearings AVG_RAD_BEAR obtained during a sample interval (e.g., 1 hour) should be close to a reference bearing REF_RAD_BEAR and not vary beyond warning or failure thresholds.

Flags	Condition	Codable Instructions
Fail = 4	The absolute difference between the average radial bearing and a reference bearing exceeds a failure threshold.	If $ AVG_RAD_BEAR - REF_RAD_BEAR \geq RAD_BEAR_DIF_FAIL$, flag = 4
Suspect = 3	The absolute difference between the average radial bearing and a reference bearing is less than the failure threshold but exceeds the warning threshold.	If $ AVG_RAD_BEAR - REF_RAD_BEAR \geq RAD_BEAR_DIF_WARN$ AND $ AVG_RAD_BEAR - REF_RAD_BEAR < RAD_BEAR_DIF_FAIL$, flag = 3
Pass = 1	The absolute difference between the average radial bearing and a reference bearing is less than the warning threshold.	If $ AVG_RAD_BEAR - REF_RAD_BEAR < RAD_BEAR_DIF_WARN$, flag = 1

Test Exception: Test becomes less useful as the observation azimuth increases, cannot be used for omnidirectional sites, and does not apply to BF systems.

Test specifications to be established by operator. RAD_BEAR_DIF_FAIL = 30°, RAD_BEAR_DIF_WARN = 15°

Test 13 – Synthetic Radial Test (In Development)

Tests for the difference between actual radial and independent synthetic radial.		
<p>Total maps are computed from a subset of available radar station radial maps. Synthetic radials for the excluded radial maps are back-computed from those totals and compared with observed radials. A synthetic radial velocity (RS) is created for an independent site by using a total vector generated from two or more sites and comparing RS to the actual radial velocity (RA) from the independent site.</p>		
Flags	Condition	Codable Instructions
Fail = 4	The absolute difference between the synthetic radial component R_S and the actual independent radial component R_A exceeds the ΔR_{Fail} threshold.	If $ R_S - R_A > \Delta R_{Fail}$, flag = 4
Suspect = 3	The absolute difference between the synthetic radial component R_S and the actual independent radial component R_A is less than or equal to the ΔR_{Fail} threshold and greater than the $\Delta R_{Suspect}$ threshold.	If $ R_S - R_A \leq \Delta R_{Fail}$ and $ R_S - R_A > \Delta R_{Suspect}$, flag = 3
Pass = 1	Applies for test pass condition.	$ R_S - R_A \leq \Delta R_{Suspect}$, flag = 1
<p>Test Exception: Test cannot be conducted unless three or more sites provide radial components with overlapping coverage.</p>		
<p>Test specifications to be established by operator. Example: $\Delta R_{Fail} = 25$ cm/s, $\Delta R_{Suspect} = 15$ cm/s</p>		

3.4.3 Total Vectors

This set of tests is conducted during the development of the total velocities. These tests may be carried out at the local, regional and/or national network levels.

Test 14 - Data Density Threshold* (Required)

Tests that a sufficient number of radial velocities exist to compute a total velocity vector.

A minimum number of radial velocities (RV_MIN) are required to construct a total velocity vector. RV_CNT is the number of radial velocities available to be used in the calculation.

Flags	Condition	Codable Instructions
Fail = 4	Insufficient number of radial velocities exist.	If $RV_CNT < RV_MIN$, flag = 4
Suspect = 3	N/A	N/A
Pass = 1	A sufficient number of radial velocities exist.	If $RV_CNT \geq RV_MIN$, flag = 1

Test Exception: Does not apply to BF systems.

Test specifications to be established by operator. Recommend $RV_MIN = 3$
 In CODAR software, this is set in line 1 of the AnalysisOptions.txt configuration file; the default value is 2.

Test 15 - GDOP Threshold (Required)

Tests that the uncertainty in velocity due to the geometric relationship between radials is low enough for the vector to be considered valid.

GDOP (Geometric Dilution of Precision) is a scalar representing the contribution of the radial (bearing) geometry to uncertainty in velocity at a given gridpoint. Higher GDOP values indicate larger co-variances associated with the least square's fit used in obtaining the solution. GDOP must be less than a maximum allowed value of GDOP_MAX to pass and less than a GDOP_HIGH value to not be considered suspect.

Flags	Condition	Codable Instructions
Fail = 4	Poor geometric relationship between radials yields a total vector with too much uncertainty to be valid.	If $GDOP \geq GDOP_MAX$, flag = 4
Suspect = 3	The GDOP value associated with a total vector solution may be acceptable.	If $GDOP < GDOP_MAX$ and $GDOP \geq GDOP_HIGH$, flag = 3
Pass = 1	The GDOP associated with the total vector solution is sufficient.	If $GDOP < GDOP_HIGH$, flag = 1

Test Exception: None.

Test specifications to be established by operator.

The national network uses a GDOP_MAX of 10 and a more conservative value of 1.25 for near-real time applications such as Web display.

Test 16 - Max Speed Threshold (Required)

Ensures that a total current speed is not unrealistically high.

Like the maximum radial velocity threshold, the maximum total speed threshold TSPD_MAX represents the maximum reasonable surface velocity for the given domain.

Flags	Condition	Codable Instructions
Fail = 4	Total current speed exceeds the maximum total speed threshold.	If $TSPD > TSPD_MAX$, flag = 4
Suspect = 3	N/A	None.
Pass = 1	Total current speed is below or equal to the maximum total speed threshold.	If $TSPD \leq TSPD_MAX$, flag = 1

Test Exception: None.

Test specifications to be established by operator.

The maximum total speed threshold is 1 m/s for the West Coast of the United States and 3 m/s for the East/Gulf Coast domain. The threshold must vary by region. For example, the presence of the Gulf Stream dictates the higher threshold on the East Coast.

Test 17 – Spatial Median Comparison (Suggested)

Reduces outlier velocities in totals.

Modeled after CODAR’s median filter for radials, this test computes the difference between a total velocity (TV) and the median of a set of total velocities in an area surrounding that vector (TVNB).

For each total source vector, compute the median of all velocities within <TCLim> Grid Steps in u and v directions. If the difference between the vector’s velocity and the median velocity is greater than <TCurLim> cm/s then the vector is discarded.

In the instructions below, the total velocity is designated as TV and the set of neighboring velocities is designated as TVNB. The test rejects the vector when the difference is greater than TCurLim.

Flags	Condition	Codable Instructions
Fail = 4	Difference between the vector velocity and the median velocity is greater than the threshold.	If $TV - \text{median}(TVNB) > TCurLim$, vector is rejected; flag = 4
Suspect = 3	N/A	None
Pass = 1	If the difference between the vector velocity and the median velocity is less or equal to the threshold, the vector passes the test.	If $R = TV - \text{median}(TVNB) \leq TCurLim$, flag = 1

Test Exception: None.

Test specifications to be established by operator. TCLim and TCurLim will be set by the operator and will depend on environmental conditions.

4.0 Summary

The QC tests in this HF radar document have been compiled using the guidance provided by the HF radar committee and valuable reviewers (appendix B), earlier U.S. IOOS/QARTOD manuals, and all QARTOD workshops (<https://ioos.noaa.gov/ioos-in-action/qartod-meetings/>). Test suggestions came from both operators and HF radar data users with extensive experience. The considerations of operators who ensure the quality of real-time data may be different from those whose data are not published in real time, and these and other differences must be balanced according to the specific circumstances of each operator. Although these real-time tests are required, recommended, suggested, or in development, it is the operator who is responsible for deciding which tests are appropriate.

The 17 QC tests identified in this manual apply to HF radar observations from three sensor types and platforms that are used in U.S. IOOS. The existing program has developed QC tests that are documented in this U.S. IOOS QARTOD manual. The QARTOD HF radar committee intends for the QC tests of these programs to be compliant with U.S. IOOS QARTOD requirements and recommendations. The individual tests are described and include codable instructions, output conditions, example thresholds, and exceptions (when applicable).

Selection of the proper thresholds is critical to a successful QC effort. Thresholds can be based on historical knowledge or statistics derived from more recently acquired data, but they should not be determined arbitrarily. This manual provides guidance for selecting thresholds based on input from various operators, but also notes that operators need the subject matter expertise and motivation to select the proper thresholds to maximize the value of their QC effort.

Future QARTOD reports will address standard QC test procedures and best practices for all types of common and uncommon platforms and sensors for all the U.S. IOOS core variables. We anticipate growth in the test procedures that will take place within the sensor package. Significant components of metadata will reside in the sensor and be transmitted either on demand or automatically along with the data stream. Users may also reference metadata through Uniform Resource Locators to simplify the identification of which QC steps have been applied to data. However, QARTOD QC test procedures in this manual address only real-time in-situ observations. The tests do not include post-processing, which is not in real time but may be useful for ecosystem-based management, or delayed-mode, which might be suitable for climate studies

Each QARTOD manual is envisioned as a dynamic document and will be posted on the QARTOD website at <https://ioos.noaa.gov/project/qartod/>. This process allows for QC manual updates as technology development occurs for both upgrades of existing sensors and new sensors.

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Additional References to Related Documents:

Data QC Flags from CSIRO Cookbook

<http://www.nodc.noaa.gov/GTSP/Document/qcmans/qcflags.html>

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Scheme on QC flags, which is a general document that discusses how to write the results of tests, but does not discuss the actual tests.

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U.S. IOOS QARTOD Project Plan, February 18, 2012.

https://www.ioos.noaa.gov/wp-content/uploads/2015/10/qa_qc_projectplan_dec2012.pdf

Supporting Documents Available from the QARTOD Website:

[\(https://ioos.noaa.gov/ioos-in-action/HFR/\)](https://ioos.noaa.gov/ioos-in-action/HFR/)

These documents were particularly useful to the committee and reviewers when developing this manual. They do not contain copyright restrictions and are posted on the U.S. IOOS QARTOD website for easy reference.

Guidelines for Assessing HR Radar Capabilities and Performance

Encoding NetCDF Radial Data in the HF-Radar Network

QA/QC and Related Practices at CODAR

HF-Radar Network Near-Real Time Ocean Surface Current Mapping

Real-Time Quality Control of Current Velocity Data on Individual Grid Cells in WERA HF Radar

Remote Monitoring Checklist

Appendix A. Quality Assurance (QA) Best Practices for Deployment and Setup of SeaSonde®-Type High-Frequency Radar for Ocean Surface Current Mapping

Preface

The use of HF radar for the collection of ocean surface current information in near-real time is quickly expanding. As this national radar network grows and matures, there will be a need for a defined set of best practices for radar system operations and maintenance. In anticipation of this need, the radar operators for the Southern California Coastal Ocean Observing System (www.sccoos.org) prepared this document titled “The Deployment & Maintenance of a High-Frequency Radar (HFR) for Ocean Surface Current Mapping: Best Practices”. The editors’ intentions are that this document may serve as a stimulus for developing a national set of operational best practices. The document defines a set of best practices developed from the collective experience of the operators’ usage of compact direction finding radar systems, specifically, the SeaSonde® family of direction-finding HFRs manufactured by CODAR Ocean Sensors, Ltd. (COS). The best practices discussed in this document focus on the installation, operation, and maintenance of CODAR SeaSondes. Further revisions of this document are expected to expand to include other manufacturers of HF radar equipment.

As with all best practice documents, there is an expectation that this will be a living document that will expand to encompass community feedback and suggestions; corrections, modifications, comments, and additions are welcome from the entire HFR community. The below list of editors may be contacted for any changes or updates. This document should be considered supplementary to manufacturer-provided documentation for products discussed herein. Manuals for the SeaSonde systems are provided by COS in the /Codar/SeaSonde/Docs directory on each computer they ship, as well as on their websites <http://www.codar.com/> and <http://www.seasonde.com/>.

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Editor List (alphabetical order)

Name	Affiliation
Cook, Thomas	Scripps Institution of Oceanography
Hazard, Lisa	Scripps Institution of Oceanography
Otero, Mark	Scripps Institution of Oceanography
Zelenke, Brian	California Polytechnic State University

Deployment & Maintenance of a High-Frequency Radar (HFR) for Ocean Surface Current Mapping: Best Practices

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1 Locating an HFR

Due consideration needs to be given to the amount of time and money it will take to gain/purchase access to, and use of, the intended HFR site. Additionally, sufficient time and money must be allotted for obtaining the required permits to use the land as a HFR site (e.g., Coastal Development Permit) and to operate the HFR (e.g., Federal Communications Commission broadcast permit). It is recommended that any regulatory or governing agencies into whose purview a HFR installation may fall be contacted, well in advance, to determine the preferred method of application and a realistic timeframe for project approval.

An ideal location for a HFR possesses the following characteristics:

- widest possible unobstructed field-of-view of the ocean
- ample room to accommodate the antennas, electronics, and cable-runs
- site which minimizes distance to the water but is safe from waves and splash
- free of obstructions, particularly electrically conductive (e.g., metallic) objects
- onsite electricity
- flat or gently sloping terrain that is easily traversed and free of hazards (e.g., poison oak)
- no radio interference at your permitted frequency¹
- onsite broadband internet connectivity
- secure from damage caused by animals (e.g., cows, bears) and human vandalism
- nearby vehicle access

1.1 Site Requirements

On SeaSondes with separate receive (Rx) and transmit (Tx) antennas, the Rx and Tx should be separated by a minimum distance of one wavelength (λ) based on the center frequency:

$$\lambda = \frac{c}{f}$$

where c , the speed of light in m s^{-1} ($\approx 299792458 \text{ m s}^{-1}$), and f , the center frequency in Hz, will give λ in meters. Additionally, both antennas should be placed no farther from the water than specified in Table 1.

Table 1. Maximum distance to the water for SeaSonde Rx and Tx, based on operating frequency (from COS User's Guide for: SeaSonde Radial Site Antenna Site Selection).

Frequency (MHz)	Maximum Distance to Water (m)
4-6	250
12-14	150
24-27	150
47-50	100

¹ The frequency spectrum should be measured with a spectrum analyzer for 24 hours or more at a given location before selecting it as a HFR site. This will allow broadcast permission to be sought from the FCC more selectively by applying for use of only those applicable frequencies with the least radio noise. Additionally, measurement of the frequency space at a site beforehand will allow identification of any sources of potential interference in advance. Spectrum analyzers are quite expensive and, if one is not available, the SeaSonde can be run in "spectrum analyzer mode" to serve a similar function (contact COS for details).

A HFR site needs to have enough space to accommodate the minimum antenna separation while remaining within the specified distance from the water. Additionally, electrically conductive objects such as metal structures, trees, and power lines should be avoided as these will distort the antenna pattern, thereby degrading data quality. While distortion of the antenna pattern can in some instances be compensated for with an antenna pattern measurement, more severe distortion can invalidate all the measurements made at a HFR site.

With the exception of the SeaSonde hardware and cables, metal objects longer than 1 m should ideally not be within 100 m of either the Rx or Tx. Any metal objects longer than 1 m (e.g., pipes) buried within 100 m of the Rx or Tx should be 10 m or more underground. Metal objects less than 1 m long should be located at least 4 m from both the Rx and Tx and, within that 4 m radius, any buried metallic objects should be underground deeper than 4 m.

Aboveground obstructions are of particular concern (e.g., other antennas, towers, buildings) as these tend to produce more severe distortion of the HFR antenna pattern. Given the height of an obstruction (H) in meters, the minimum distance (R) to either the Rx or Tx is given in meters from:
 $R = 5 \times H$

Cliff faces and steeply sloped ground can also degrade the HFR measurements by acting as a reflector of the transmitted radio signal. Gently sloping or level ground is preferred for a HFR site.

Many operating HFR sites do not meet every one of these criteria and still produce acceptable measurements. When an “ideal” site is not available, consideration should be given to mitigating existing obstructions. COS or another experienced HFR technician should be contacted to determine the likely impact existing obstructions might have on the HFR site.

1.1.1 Power

Electrical power is required at the location of the Tx and Rx chasses. The standard coaxial cables supplied with the SeaSonde HFR system allow a separation of ~250 ft. between the Tx and Rx chasses and the Tx and Rx antennas. Ideally an HFR site should have an existing shelter available within 250 ft. of the HFR site with electrical power for the SeaSonde and associated electronics.

In the case where electrical service from an existing utility power-grid is not already available at the HFR site, a concerted effort should be made to tie the HFR site into the power grid. The power requirements of a HFR site allow extension cables to provide a link to an electrical outlet up to approximately 150 ft. away before voltage loss² becomes a concern. Voltage line loss can be compensated for by using a thicker gauge wire for the extension cord.

An economical solution to accessing electrical power up to 1000 ft. away or more is a “Buck and Boost” transformer. An electrician can install a Buck and Boost transformer at an existing electrical panel or create a sub-panel and install the Buck and Boost at a point along an electrical cable-run. A Buck and Boost transformer raises the line voltage to compensate for line loss. The Buck and Boost transformer can be complemented by a step-down transformer at the HFR site to

² The longer a cable is, the more resistance an electric current encounters. This resistance causes a drop in the voltage of the electric current (i.e., line loss). Too great a drop and the HFR electronics cannot function. An electrician can help determine the voltage drop for a given cable length, with knowledge of the wire gauge and type of electrical connection.

return the voltage to the appropriate level. Use of a Buck and Boost often requires a new breaker to be installed at the electrical panel as well as additional cables of thicker gauge wire to be run to the HFR site. The electrical cable-runs may need to be trenched or placed in conduit aboveground in the appropriate grade of polyvinyl chloride (PVC) pipe (e.g., Schedule 80). Another option is to have power poles erected and overhead electrical wires installed to extend the utility power grid directly to the HFR site.

In those locations where utility grid power is not available, a HFR site can be powered using solar panels, windmills, a generator, or a combination thereof. Assuming continuous operation, the cost of creating off-grid electricity to power a HFR site is in the tens of thousands of dollars. Over the course of a week, the power consumption of an operating HFR was measured by the Center for Coastal Marine Sciences at California Polytechnic State University to be 50.96 KWh. From the formula:

$$\frac{\text{KWh}}{\text{time}} = (\text{continuous watts}) = \frac{50.96 \text{ KWh}}{167 \text{ hours}} = 305.15 \text{ W continuous}$$

this translates to a continuous consumption of approximately 306 W of alternating current (A/C) by the HFR site³.

If local electrical power is unavailable, solar power is a viable alternative. One solar power solution has been developed by Center for Coastal Marine Sciences at California Polytechnic State University. This solar power solution is comprised of 12 solar panels and a full suite of batteries. The panels are mounted on a mobile trailer for ease of placement. Many land owners prefer to have a non-permanent solution that can be moved easily. A full description of two solar power systems can be found in appendices B-C.

1.1.2 Communications

Communication with the HFR site via a broadband internet connection allows for near real-time data transfer and system control. While manually traveling to the HFR site to periodically download data is possible, an internet connection is functionally considered a prerequisite for a HFR site. Additional benefits of an internet connection at the HFR site include the ability to control the radio transmission (a FCC requirement), remote monitoring of the site's operational status, and reduction in on-site maintenance by allowing computer and support functions to be performed remotely.

Best results are achieved with an on-site 10 Mbps or greater Ethernet connection. If such a connection is not available, wireless relay (e.g., 802.11 or 900 MHz) antennas can be used to link the remote site to a hardwired network connection over a distance of kilometers. Wireless relay systems work best when the network connection is within line-of-site of the HFR. Additionally, wireless relay antennas can be used to transfer the wireless internet signal around obstacles, but

³ Power consumption was logged using a Kill A Watt™ (model #P440), manufactured by P3 International. The components of the HFR site included in this measure of power consumption were: a 12 MHz SeaSonde (Tx and Rx chassis with global positioning system [GPS] synchronization), Apple 12" PowerBook G4 laptop computer, NetGear Router (model #WGR614), LaCie 250 GB hard drive (model #300728U), MFJ-993B Antenna Tuner, and WildBlue satellite internet modem. Running amps were approximately 4.05 at 120 V A/C.

with each additional antenna comes the process of seeking the permission of the landowner at that necessary location as well as the cost of the additional equipment.

Satellite internet or cellular broadband should be considered at those sites without a wired internet connection – or where the only wired connection is a telephone modem – and where wireless relay to another network connection is impractical. Service areas for these connections are limited, so satellite internet and cellular companies should be contacted in advance to see if an intended HFR site falls within their coverage area.

Primarily the internet connection at a HFR site is used to send data and screen images. Accordingly, obtaining the maximum upload speed for the internet connection at the HFR site should be the focus. With an upload speed of 128 Kbps or more, real-time screen control and mirroring is possible as well as transfer of lower-level spectral data files. High-speed DSL, cable modems, satellite internet, and cellular broadband can all provide these speeds if an existing network connection is not available. A telephone modem can provide another wired connection to the internet, but this technology is considered obsolete as connection speeds are so slow as to severely inhibit remote maintenance and transfer of all but the highest level data. At minimum, an internet connection for the HFR site needs to be able to transfer the approximately 300 KB hourly .ruv files of radial velocities.

1.2 Climate-controlled Enclosure Specifications

1.2.1 HFR Enclosure

The electronics enclosure selected by SCCOOS is a custom stainless-steel enclosure manufactured by EIC Solutions, Inc. (Figures 1-2). The enclosure is used to provide a self-contained, air conditioned environment for the HFR electronics at those locations where a weatherproof, climate-controlled shelter is not already available. Specifications for the enclosure are as follows (*italics indicate additional components to be installed by the customer*):

- Dual-Access, Floor-mount Enclosure, 36" high × 24" wide × 32" deep
- NEMA 4X (indoor/outdoor use) configuration, welded type 304 Stainless Steel construction
- Front and rear doors, each fully gasketed, hinged left, latched right
- Standard ¼-turn latches on doors, top right latch per door “barrel style” and padlockable (padlocks not included)
- Grounding studs (4) on doors and inside enclosure (*customer to attach two (2) flexible copper grounding wires, one between each adjacent wall and door grounding stud bolt; not included*)
- Two (2) rectangular air conditioner cut-outs and six (6) mounting holes on rear door for Kooltronic (#KNA4C3P21R) 3000 BTU air conditioner (*customer to install air conditioner, not included*)
- One (1) cable exit hole, 64 mm diameter, through lower left-hand corner of side wall (to accommodate Rextec model RG/M63-9 cableway gland, installed by customer, not included)
- Standard 19" rack-mount rails on front and rear sides of enclosure
- Rails to be "side flange style", powder coated (or plated) steel, with punched (not tapped) holes, for use with “clip-nuts” (included)
- Rails to be approx. 32" high and horizontally-adjustable, front-to-rear (two (2) pairs of Ameri-Rack #ASL-2001 sliding rails are to be installed by customer to mount SeaSonde Rx and Tx chasses, not included)
- 1" thick fiberglass insulation, one side foil-faced, installed throughout enclosure
- External mounting tabs (4), stainless steel, welded in place on bottom of enclosure (two on right, two on left)



Figure 1. Interior of empty outdoor electronics enclosure without air-conditioner attached.



Figure 2. View of outdoor electronics enclosure with both doors open. Air conditioner is attached and all HFR electronics are mounted within the enclosure.

The enclosure should be bolted to a pallet to provide ground clearance for front and rear doors. An electrical outlet can be installed inside the enclosure to provide power distribution from electrical wiring entering through the cableway gland.

1.2.2 Air Conditioner

The air conditioner designed to fit the enclosure described in Section 1.2.1 is the 3000 BTU model #KNA4C3P21R manufactured by Kooltronic, Inc. Use of the air conditioner is vital with the above enclosure to provide heat dissipation for the HFR electronics and to prevent corrosion by dehumidifying the incoming air. In a sealed enclosure the Tx and Rx chassis can overheat in less than an hour without air conditioning and will stop functioning.

The KNA4C3P21R is part of the Integrity Series 21 NEMA 4/4X air-cooled panel-mounted stainless steel air conditioners manufactured by Kooltronic. It runs on 11.3 A of 115 V A/C, weighing 76 lb and is 21.19" high × 12.01" wide × 12.48" deep. Mounting of the air conditioner should be done on-site to minimize stress to the mounting hardware in transit. Additionally, the air conditioner should be kept strictly upright during transport as rough handling, laying the air conditioner sideways, or inverting it will destroy the condenser.

1.3 Support Equipment

1.3.1 Data Acquisition

Included with every SeaSonde COS ships is an Apple computer which controls the HFR system. To accommodate the enclosure described in Section 1.2.1 a laptop, rather than a tower, model needs to be requested from COS. The computers ship preconfigured from COS and are ready for on-site installation.

An external back-up hard-drive is recommended for archiving data acquired by the HFR. The interface for the back-up hard-drive can be either FireWire 400 or USB 2.0 to allow for hot-swapping the drive once it nears capacity.

1.3.2 Uninterruptible Power Supply (UPS)

An uninterruptible power supply (UPS) should be used to protect the HFR electronics and provide temporary battery backup in case of power failure. The UPS selected by SCCOOS is Tripp Lite's model #SU1500RTXL2Ua with the optional SNMPWEBCARD. The SU1500RTXL2Ua is a 1500 W UPS in a 2U rack-mount design which provides approximately 30 minutes of battery backup for the HFR during power outages. The SU1500RTXL2Ua acts as a surge suppressor and ensures pure sine-wave power through over-voltages and brownouts. The SNMPWEBCARD is an internal simple network management protocol (SNMP) accessory card for installation in the SU1500RTXL2Ua. The SNMPWEBCARD upgrade allows the electrical power at the HFR site to be monitored and controlled remotely via the internet through a website interface. Given the SU1500RTXL2Ua's 1500 W maximum output, the air conditioner described in Section 1.2.2 cannot be plugged into the UPS as it draws too much power. All other HFR electronics should be plugged into the UPS. Suggested UPS vendors include Tripp Lite, APC and Falcon.

Most UPS systems come with software which can be configured to shut down computers that are connected. Results are mixed with the use of the various software products, especially with compatibility with Mac OS. Additionally, remote power management products may be used as a last ditch effort to reboot computers and hardware using a phone line or IP connection. Power Stone remote power systems have been known to cause problems at several Rutgers sites.

1.3.3 Lightning Protection

Lightning protection may be installed inline on any antenna (e.g., SeaSonde, GPS, communications) as a safety precaution for personnel and radar electronics. Lightning arrestors provide an alternate path to ground during a high voltage surge from lightning strike. There are a variety of designs, but typically the inline gas discharge types are used for RF communications, including HF radar. Lightning arrestors should be placed where the antenna cables enter the enclosure and properly grounded. The SeaSonde receiver and transmitter have different specifications for lightning arrestors, where the transmitter requires a lightning arrestor with 350V sparkover voltage and the receiver requires 90V sparkover voltage. Typically, common lightning arrestors (such as the Altelicon AL-NFNFB) come with gas tubes rated for 90V sparkover voltage. In this case, replacement gas tubes with 350V sparkover voltage can be purchased.

1.4 Networking

With an Ethernet connection at the HFR site, as recommended in section 1.1.2, a router should be used to act as a gateway for the site's internet connection and to distribute connectivity to the various network-enabled components (i.e., laptop and UPS). Additional network security can be achieved by setting up a virtual private network (VPN), which can also allow secure sharing of an existing network connection at a host facility.

The router should have the following ports opened (i.e., port forwarding) to allow communication via the specified protocols/applications:

22	(secure shell [SSH])
80	(hypertext transfer protocol [HTTP])
407	(Netopia, Inc. Timbuktu [®])
409	(Tripp Lite PowerAlert [®])
1417-1420	(Netopia, Inc. Timbuktu)

Incoming access to the HFR site will require the remote user to input an internet protocol (IP) address. Some networks and internet service providers offer a static IP address, a numeric address that does not periodically change. For those HFR sites where the internet service is provided with a dynamic IP address, a dynamic domain name service (DDNS) can be used to frequently query the HFR site's IP address and map it to a static alphanumeric IP address. A static IP address is preferred, over a dynamic IP, since network access to the HFR site can be blocked during the window (typically less than five minutes) between when a dynamic IP changes and the DDNS service checks the dynamic IP.

1.5 Antenna

1.5.1 Antenna

Antenna whips for CODAR Ocean Sensor systems are Shakespeare Style 4208 NAVIGATOR Loran C. The main reason for failure is breakage due to over exposure

Problem: Arcing between antenna mast sections in 13MHz systems utilizing a balun for tuning caused by buildup of salt and/or moisture.

Recommendation: Run an uninsulated cable between the two mast sections and insulate the upper terminal of antenna mast to create sparking point.

1.5.2 Antenna Mount

Stability is maximized when the Rx and Tx antennas are mounted in level concrete pads constructed at the HFR site (without metal rebar to distort the antenna pattern). Anchors for the Rx and Tx antenna guy wires can be incorporated into the concrete pad as well. Cableways can be trenched from the pads to the electronics enclosure to eliminate exposed aboveground wiring. The construction permits, soil disturbance, and additional labor this mounting entails limit its applicability to many HFR sites.

An excellent alternative, innovated by Jim Pettigrew (San Francisco State University, Romberg Tiburon Center for Environmental Studies), is an antenna mount consisting of a length of electrical metallic tubing (EMT) bolted into the 26" Pole Genie® manufactured by Krinner USA, Inc. (appendix A). By drilling a hole through the EMT, the Pole Genie/EMT “spear” can be screwed down into the soil at the HFR site using a metal bar. The antenna mast is then sheathed over the EMT pipe now sticking straight up out of the ground. By electrically isolating the EMT from the antenna mast with plastic bushings, galvanic corrosion is inhibited and the antenna pattern is unaffected. Rotation of the antenna mast on the EMT pole is prevented by drilling holes through the antenna mast, on through the EMT, and then screwing in nylon screw to serve as cotter pins.

For long-range (5 MHz) Tx antennas, a hole needs to be dug around the screw anchor and the EMT cut off just beneath the rim of the hole (former ground level). A Schedule 80 PVC bushing is then used to fit a Schedule 80 PVC flange to the EMT tube. With the flange and bushing secured level to the EMT pipe with epoxy and screws, the flange at the base of the long-range Tx antenna can be mated to the PVC flange and bolted in place. The PVC flange mounted to the ground screw electrically isolates the Tx from the mounting.

Problem: Antenna rotation causing receive antenna to lose data.

Recommendation: Incorporate gyroscope or compass to avoid rotation errors due to wind.

2 HFR Setup

Setup of the HFR site consists of both the hardware and the software. The location and placement of the HFR is discussed in Section 1, including components used and physical layout. With the HFR hardware in place as required by the SeaSonde design, site-specific configuration customizes the HFR to the environment and intended application.

2.1 Long, Medium, and Short-range Configuration

The SeaSondeController and SeaSondeRadialSetup applications, part of COS's radial site software suite, are used to specify the settings necessary for operation of the HFR site (Table 2). The SeaSondeController settings are largely governed by your permitted center frequency and bandwidth, as well as by the amount of forward and reflected power measured by the Transmit Drive Control panel. These values will dictate further settings/setup within the SeaSondeController application.

Table 2. Table of suggested SeaSondeRadialSetup settings for high-resolution, standard-range, and long-range SeaSonde Systems.

Frequency (MHz)	Radial Coverage (minutes)	Radial Output (minutes)	Angle Resolution (°)
4-6	180	60	5
12-14	75	60	5
24-27	75	60	5
47-50	75	60	5

2.2 Antenna Tuning

On Standard-range and High-resolution SeaSondes, adjusting the position of the balun up or down the Rx cable at the antenna can optimize the ratio of forward to reflected power. A prefabricated tuning coil is available from COS for their long-range SeaSonde systems. Given advance notice of the intended center frequency, COS can fabricate a tuning coil for installation with the Tx antenna. The tuning coil is installed as a coupler between the upper and lower halves of the long-range Tx antenna and secured with hex screws.

In systems without a balun, or when tuning with the balun is insufficient (Voltage Standing Wave Ratio [VSWR]>2), an antenna tuner can be used to minimize the reflected power. The antenna tuner selected by SCCOOS is the Dual 300/150 Watt IntelliTuner[®] Automatic Antenna Tuner (model # MFJ-993B) manufactured by MFJ Enterprises, Inc. The MFJ-993B is installed as an intermediary between the Tx chassis and the Tx antenna. By turning off blanking and sweeping in SeaSondeController and appropriately increasing the attenuation to bring transmit power within the tuning limits of the MFJ-993B, the IntelliTuner can automatically tune the antenna to the center frequency. The "semi-automatic" tuning function of the MFJ-993B allows the tuning settings, automatically set when the SeaSonde's transmission was constant, to remain static when blanking, sweeping, and attenuation are restored. The semi-automatic setting also ensures the MFJ-993B will not re-tune the antenna in the event the antenna environment changes (e.g., the Tx falls over).

Regardless of tuning method, it is important to monitor the transmitted and reflected power to diagnose transmitter health and function. Special care should be taken when using automatic tuners, since during a tuner malfunction reflected power will spike.

2.3 Antenna Pattern Measurement

An antenna pattern measurement (APM) is vital to ensuring the accuracy of the surface current data and should be regarded as part of site setup. While the assumption of an “ideal” antenna pattern allows maps of radial currents to be produced by the HFR, this does not account for distortions in the antenna patterns. Often these distortions cause enough inaccuracy in the measurements that the data are invalid without an APM.

The transponder and antenna whips needed to perform an APM are available from COS. Additionally, a GPS, boat, and seawater ground will be needed to perform the APM (backup batteries for the transponder are also recommended). Typically the boat will start 1.5 km down-shore of the HFR site and travel, maintaining the 1.5 km radius, in a semi-circle 1.5 km up-shore and back again (in the case where the HFR is on an island, the boat will make a full circle around the island).

COS produces three documents regarding APMs: User’s Guide for: SeaSonde Radial Site Antenna Pattern Measurement (available from <http://www.codar.com>), APM Crib Sheet for All Systems (available from <http://www.seasonde.com>), and APM Generation and Application (available by request from COS). These documents should be referred to for instructions on how to perform an APM and apply the measured patterns to the HFR. Additionally, COS should be contacted prior to performing the APM for the latest information and for assistance in processing the measured pattern for the HFR site.

3 HFR Software

3.1 SeaSonde software configuration

For the most part, the default SeaSonde software settings have been proven to work well for a typical deployment. In the case that changes are required, it is advisable to check all the configuration files in the RadialConfigs directory for the altered setting, as duplicates exist among the various configuration files. For example, there is an entry for Ionospheric Removal in both the Header.txt and AnalysisOptions.txt files.

3.2 SeaSonde Data Files

The SeaSonde software can produce a variety of output files. Not all of these files are required to be stored during typical operations. A list of SeaSonde data files follows below:

- TimeSeries (Lvl) – Rawest form of data. Not typically stored.
- RangeSeries (Rng) – Output of first FFT. Not typically stored.
- CrossSpectra (CSQ) – output of second FFT. Should be retained if space allows.
- Time Averaged CrossSpectra (CSS) – Running average of CSQ files. Should be retained

For 13 and 25 MHz systems, the CSS files are a 10 minute average, which include 3 CSQ files. For 5 MHz systems, the CSS files are a 30 minute average, which include 3 CSQ files. Radial files are constructed from a series of CSS files and can be produced for ideal and measured beam patterns. It is recommended to produce and store both radial files.

3.3 On site archiving

SeaSonde software includes an archival program called Archivalist. This program can be configured to move files from working directories to archive directories. It is recommended that the archive directories exist on a separate internal disk or partition. Additionally, this archive directory can be easily mirrored to an USB or FireWire connected external hard drive using the rsync utility. One issue when archiving the CSS files is that the CSS file writes information to the resource fork of the file. The resource fork is only supported by Apple HFS or HFS+ file systems and will be lost when transferring to other file systems. The rsync utility is aware of the resource fork and can be configured to retain this data.

3.4 Remote Settings for ingestion into National Network

Recent radial files should be kept in a single static path for acquisition by the COCOMP/National Network. The standard CODAR configuration keeps recent radial files in /Codar/SeaSonde/Data/Radials. In addition, Archivalist should be set to leave enough data in the recent radial data directory to span the longest anticipated network outage length, typically 2 – 4 weeks. This way, data are locally buffered and remain available for near-real time acquisition routines when connectivity is restored.

3.5 Diagnostic reporting

The SeaSonde software provides hardware and software diagnostics that are saved in the DIAG files. An extension of .hdt refers to hardware diagnostics and an extension of .rdt refers to radial diagnostics. Many of these diagnostics are reported within the LLUV radial file. COS is working on a remote site warning script to alert users of out of range variables. This warning script will email users once variables reach a particular threshold, such as low signal to noise. On all the SIO sites, a script independent of the diagnostics files queries the receiver and transmitter to receive pertinent information such as the temperatures, voltages and transmitted power output. This script is configured to provide information on the laptop as well to include disk use and other laptop specific information. Rutgers University developed a site script for checking file size and timestamp accuracy. Emails and text messages are sent based on a size or offset limitation. Other options include posting near real-time radial images and parsed diagnostic data to a website that can be monitored daily for offsets. One diagnostic utility could be based on antenna phase amplitude changes. Ideally phases remain consistent although jumps may occur due to wind waves. A median phase change of 10 degrees is considered significant and may warrant a site visit or new beam pattern. If measured antenna phases differ from sea echo by more than 30 degrees, the measured antenna pattern should be examined. The signal-to-noise (SNR) and noise floor radial diagnostics are based on one range cell. These errors should be calculated for each range cell.

Problem: Remote sites lack automated diagnostic error checking alerts.

Recommendations: Develop and implement automated diagnostic scripts based on variable threshold limits which trigger email or text message warning to users.

Problem: Radiation exposure documentation is incomplete.

Recommendation: COS should provide field monitoring documentation and testing of equipment.

4 Site Maintenance

While the HFR systems deployed by SCCOOS are automated, regular maintenance is necessary to ensure continuous operation. With an internet connection as described in sections 1.1.2 and 1.4, system status can be checked remotely and indeed the data acquisition should be checked daily for each site. Remote access, however, is not a substitute for routine on-site inspections.

4.1 Required Maintenance

Each component at the HFR site should be inspected every site visit to ensure that it is performing the function for which it was installed. An inventory of the equipment placed at the HFR site can be used to guide the site inspection via a review of each component's condition. Typical maintenance includes a check of:

- Rx antenna direction (compass bearing changed?)
- Rx and Tx antenna mounting and masts (secure and level?)
- Signs of corrosion or salt accumulation on antennas, connectors, or electronics enclosure (long-range Tx base and ground plane free of salt?)
- Condition of cable-runs (damage to conduits or cables themselves?)
- Tightness of guy wires (all ropes firm, secure, and free of fraying?)
- Condition of enclosure (clean and free of insects? gland weatherproof?)
- Air conditioner and filter (clean and lubricated)
- Electronics within the enclosure (corrosion or signs of overheating?)
- UPS (replace if expired or if remote monitoring indicated they are not holding charge)
- On-site system status vs. remote diagnostics (the same?)
- Status of backup hard-drive (replace onsite if remote monitoring indicates nearing capacity)

While this list is not exhaustive, it contains maintenance items common to most sites. The unique characteristics of each HFR installation will dictate the maintenance necessary for that site.

4.2 Schedule for Site Visit

The frequency of site visits should be quarterly or greater. System outages or anomalies in the remote diagnostics/data stream will necessitate additional site visits. Additionally an inspection of the HFR site is recommended after extreme storm events (e.g., very high winds, hail, ice storms, floods). A plan for access with the HFR site property owner should be agreed upon in advance of the installation, with the understanding that additional maintenance will be required to respond to outages.

5 HFR Data Management

5.1 Radial File Requirements & Recommendations

The CODAR LonLatUV (LLUV) file format is the recommended output format because it offers extensive metadata for radial measurements as well as hardware diagnostic data. Radial metadata will likely be used by quality assurance algorithms for total vector processing in the near future

while the hardware diagnostic data can be used for near-real time monitoring of system health. The older range-bin format of radial data is acceptable but lacks hardware diagnostic data, radial metadata is minimal and is no longer supported by CODAR. Observed variations in the range-bin file format have been documented and are available through the Radiowave Operators Working Group (ROWG) website (www.rowg.org). LLUV file format specifications are published by CODAR and available through their website (www.codar.com).

Regardless of the format, CODAR radial files must contain the following information in the file name for compatibility with the COCOMP/national network (satisfied by current CODAR naming conventions):

- 4-letter site code (e.g., SDBP)
- Timestamp (GMT or UTC required)
- Patterntype ('s' or 'z' for range-bin format, 'i' or 'm' for LLUV format)

The following information must be kept within the file for compatibility with the COCOMP/national network (satisfied by current CODAR file formats):

- Timestamp
- Timezone (GMT or UTC required)
- Site Location (Lat/Lon)
- 4-letter site code*
- FileType* (i.e., LLUV)
- Patterntype*

* required in LLUV format only

It is not uncommon to see LLUV files that don't have the timezone explicitly stated within them. This is due to multiple timezone configurations that exist in various SeaSonde software applications. It is important to make sure that Time Zone is set correctly in the Header.txt file as well within SeaSondeRadialConfig software for time zone to be correctly set within the output LLUV file. Recommended metadata that will likely become required in the near future are the range resolution and averaging period of the data. Both of these metadata are currently available in CODAR LLUV format data.

5.2 Data Telemetry

Near-real-time data telemetry has been done over FTP and managed by a custom Perl script run through cron on the remote site. The script determines which files need to be sent by comparing files available in the recent radial directory, normally `/Codar/SeaSonde/Data/Radials`, with a log of files that have already been successfully sent to the FTP server. Various other options are available for accomplishing this task including rsync over SSH and solutions provided by CODAR. The HFR_Progs toolbox developed at the Naval Postgraduate School in Monterey, CA and the University of California at Santa Cruz may offer additional options and capabilities for this task.

SIO has phased out its use of its custom Perl scripts used for data telemetry from remote sites in favor of the Antelope solution developed for the COCOMP/National Network. The Antelope solution requires no code installation at the remote site. The only requirements are access over

SSH and the presence of a single static path for recent radial files (see also section 3). Instead of posting data to an FTP server, Antelope stores data to an orbserver which is capable of serving data to the entire HF-Radar Network in real-time. Additional information on Antelope solution for data telemetry is available in ‘Data Management and Real-time Distribution in the HF-Radar National Network’, Terrill et al., IEEE OCEANS06 (available through www.rowg.org). Further integration between Antelope managed data telemetry and CODAR central site processing is being carried out in collaboration with San Francisco State University.

5.3 Local Data Management/Backups

A typical HF Radar deployment produces a variety of files that are updated at a variety of intervals. The first step for a viable data archival strategy is the identification of files to be archived, the interval at which these files are produced or altered, and the amount of space they require compared to your local computing resources. At the very least, it is advisable to save all Cross Spectra (.cs4) data files, and if space allows to save Range Series (.rs) data files. Both of these allow reprocessing radial current and wave data using different configurations, but Range Series can regenerate spectra and diagnostic information. It is also necessary to save deployment specific files contained in the /Codar/SeaSonde/Configs/RadialConfigs, as well as the Track and Time Series files supporting an APM.

6 HFR Quality Assurance (QA)/Quality Control (QC)

6.1 Quality Performance Metrics

UCSB has conducted a preliminary review of performance metrics titled “Evaluation of SeaSonde Hardware Diagnostic Parameters as Performance Metrics”. The study examined a set of hardware parameters and the applicability of utilizing parameters as a diagnostic tool for measuring hardware performance. In summary, HFR performance metric recommendations are shown in Table 3. Except where noted, recommendations are based on the standard values collected during the study. Performance metrics were determined for all of the parameters specified in the study statement of work with the exception of the calculated amplitude corrections for loops 1 and 2 to the monopole (AMP1 and AMP2). The manufacturer (COS) recommended that these parameters be monitored for significant changes. The analysis conducted by UCSB was not able to establish a threshold of significance. Quality performance metrics to establish both QA and QC values is an active area of research and will be addressed in future ROW/ROWG meetings.

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_wam.pl

⁽²⁾ Recommendation given by SeaSonde Documentation

6.2 Quality Assurance (QA)

In this document, QA refers to the optimal configuration of a SeaSonde site, in terms of physical setup, software settings, and calibration, as well as vendor tests performed prior to instrument shipment. Each SeaSonde system undergoes factory calibration of the electronics consisting of a

receiver antenna test, transmitter chassis test, and receiver chassis test. Factory testing is required prior to receipt of a shipment. Further information on these tests should be directed to COS.

Proper location and setup of an HFR site is discussed in section 1, software settings in section 2, and calibration or beam pattern measurements in section 3.

6.3 Quality Control (QC)

In this document, QC refers to assessment of the data output for validity and correctness of measurements. Although using HF Radar to measure surface current velocity and direction has been accepted in the community, the assessment of data quality is an ongoing research area. Members of ROWG have provided discussion notes on this topic and are summarized here.

Needs assessment:

- Establishment of a set of standards for QC of radials, which may not necessarily preclude use from total vector combination
- Development of an automated utility based on specified threshold limits which will notify operator of potential discrepancies in data
- Establishment of a real-time flag for data quality
- Continued comparison with in-situ instrumentation
- Standardized minimum file format and software version for processing on the national server
- Establishment of minimum data storage requirements for reprocessing (e.g., range series, cross spectra)
- Development of a share community HFR toolbox with formal support
- Establishment of metadata requirements for radial and total vector distribution

Potential QC parameters

- Temporal variability
- Spatial variability
- Signal-to-Noise (SNR)
- ALIM settings
- Direction of Arrival (DOA) from MUSIC algorithm
- Radial rms patterns

The need for quality control algorithms and flags within radial and total vector measurements is unquestionable. What those flags and algorithms are requires further discussions and research.

7 Revision History

02/26/2007 Concept of Best Practices document was discussed and outline drafted by Scripps Institution of Oceanography (SIO) personnel: Tom Cook, Lisa Hazard, Mark Otero, and Eric Terrill

03/28/2007 Initial draft was completed by California Polytechnic State University (Cal Poly) staff, Brian Zelenke.

04/04/2007 Document received was modified by SIO staff, Tom Cook, Lisa Hazard, Mark Otero and University of California, Santa Barbara (UCSB) staff, Brian Emery.

01/14/2008 This document has been modified to include input from the September 2007 Radiowave Operators Working Group (ROWG) Workshop funded by the National Oceanic and Atmospheric Administration (NOAA) and hosted at Scripps Institution of Oceanography (SIO). Additions included hardware troubleshooting, quality assurance, and quality control.

Appendix B. QARTOD HF Radar Manual Team

HF Radar Manual Committee and Reviewers	
Name	Organization
Mark Bushnell, Lead Editor	CoastalObsTechServices LLC/CO-OPS
Jack Harlan, Co-Editor	NOAA
Teresa Updyke, Co-Editor	Old Dominion University
Helen Worthington, Editor	REMSA/CO-OPS
Kathy Bailey	U.S. IOOS
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Simone Cosoli	University of Western Australia
Maeve Daugharty	CODAR Ocean Sensors Ltd.
Greg Dusek	CO-OPS
Brian Emery	University of California Santa Barbara
Pierre Flament	University of Hawaii
Klaus-Werner Gurgel	University of Hamburg/Institute of Oceanography
Sara Haines	University of North Carolina
Birgit Hansen	HELZEL Messtechnik GmbH
Mal Heron	IEEE/James Cook University, Townsville, Australia
Anthony Kirinchich	Woods Hole Oceanographic Institution
Mike Kosro	Oregon State University
Jeff Paduan	Naval Postgraduate School
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Julie Thomas	University of California San Diego/Scripps Institution of Oceanography
George Voulgaris	University of South Carolina
Libe Washburn	University of California Santa Barbara
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Brian Zelenke	Bureau of Ocean Energy Management
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Matt Howard	GCOOS/Texas A&M University
Bob Jensen	U.S. Army Corps of Engineers
Chris Paternostro	NOAA/CO-OPS
Mario Tamburri	University of Maryland/Alliance for Coastal Technologies
Julie Thomas	SCCOOS/Scripps Institution of Oceanography/Coastal Data Information Program

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Name	Organization
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Eric Bridger	NERACOOS/Gulf of Maine Research Institute
Jorge Capella	CariCOOS/University of Puerto Rico
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Matt Howard	GCOOS/Texas A&M University
Kelly Knee	MARACOOS/Applied Science Associates, Inc.
Emilio Mayorga	NANOOS/University of Washington
Jennifer Patterson	CeNCOOS/Monterey Bay Aquarium Research Institute
Jim Potemra	PacIOOS/University of Hawaii
Rob Ragsdale	U.S. IOOS
Tad Slawecki	GLOS/LimnoTech
Shane StClair	AOOS/Axiom Consulting & Design
Vembu Subramanian	SECOORA
Micah Wengren	U.S. IOOS
Kyle Wilcox	MARACOOS/Applied Science Associates, Inc.
Darren Wright	SCCOOS/Scripps Institution of Oceanography

U.S. IOOS Regional Associations

Name	Organization
Josie Quintrell	U.S. IOOS Association
David Anderson	CeNCOOS
Debra Hernandez	SECOORA
Barbara Kirkpatrick	GCOOS
Gerhard Kuska	MARACOOS
Molly McCammon	AOOS
Julio Morell	CariCOOS
Ru Morrison	NERACOOS
Jan Newton	NANOOS
Melissa Iwamoto	PacIOOS
Kelli Paige	GLOS
Julie Thomas	SCCOOS

Appendix C. Additional Potential Quality Control Tests

During the review process for the HF Radar QC Manual, several suggestions for potential tests were made by various contributors during manual preparation. The manual was distributed for review several times, but no one offered content for these tests. However, the tests can be reconsidered when the manual is updated.

- Single- and Dual-Angle Solution - DOA Signal Amplitude Matrices
- Signal-to-noise Ratio for Bragg Peaks
- Separation of 1st Order Bragg Lines
- Broadening of Bragg Lines (3 dB)
- Trend Limits
- Spatial Gradient
- Trend Limits for u,v components
- Measured Minus Model