QA/QC & Related Practices at CODAR[1]

A. Site-Specific Practices after Installation That Ensure Quality

Unlike other simpler oceanographic sensors that operate in a much more uniform fashion after unpacking from the box, HF radar data quality depends in a complex manner on the land and ocean environment near the radar site. Two major factors can limit accuracy and must be calibrated carefully right up front. Normally, CODAR staff attend to these calibrations -- supported by the client -- and monitor for optimization over a several-week period after installation:

• **Antenna Pattern Measurement/Calibration:** Most significant errors in current mapping are due to bearing angle errors or biases. The receive antenna in all HF radars is used to determine bearing. Its pattern must be known in order to estimate echo bearing accurately. Idealized "textbook" patterns are distorted by the local environment (including feedline layout) near each antenna element. These should be known and included as calibration in order to remove this source of error from current maps.

CODAR has developed an advanced but simple-to-implement, GUI-driven methodology for measuring antenna patterns and mitigating effects of distortion in current extraction. This presently involves[2] use of a lightweight portable transponder. The latter can be transported on a boat that circles the antenna several hundred meters away (takes less than an hour), or by walking the transponder on land around the front of the receive antenna (if there is enough space to the sea); the first method is preferred. After measurement, the calibration processing (normally based on help from CODAR staff) refines this pattern and includes it in the Configurations folder for real-time processing at that site.

Antenna patterns should be measured/remeasured:
- Just after site installation;
- Whenever the receive antenna and/or cabling is replaced;
- If there is a change in the local environment near the antenna;
- Approximately every two years; this guideline can be modified based on examining amplitude/phase diagnostics, discussed subsequently.

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[1] This document covers only SeaSonde QA/QC from delivery onward as it resides in the purview of the client. It does not cover manufacturing QA/QC which is multi-layered and extensive; documentation on that process is available separately.

[2] CODAR and University of California at Santa Barbara are completing an effort that will allow passing ships of opportunity as targets -- along with AIS vessel positions -- to continuously monitor and update antenna patterns. This software algorithm will run in the background on SeaSonde systems in the future.

• **First/Second-Order Boundary Limit Setups:** Current and wave information in HF radars comes from the first-order (Bragg) and second-order echo spectral regions. It is essential that the software be able to discriminate and separate these echo regions properly. However, these echo regions are very site specific; they depend on the prevailing current and wave climatologies at that location.

Therefore, CODAR staff work with the client to examine data from each new site after installation. Setting these echo spectral boundary limits correctly depends on the interplay of several parameters that are stored in the site's Preferences folder. Normally, CODAR works with the client's data over a period of three months to ensure that these parameters are optimized. This span is necessary to ensure that a full range of site-specific current/wave conditions are encountered. Once these are set correctly for a given site, they need not be revisited again. Default settings are least likely to be correct at higher HF frequencies and where currents are strong.

B. Automatic Algorithmic Removal of Spurious Data

Many years of CODAR experience with HFSWR has revealed at least five types of spurious signals that can be and are mitigated by real-time software filtering algorithms:

- Ship-Type Echo Removal: Ship echoes are large, and range over the same span of Doppler velocities as sea echoes. CODAR scientists have developed and used algorithms for 22 years that identify these echoes and remove them, so that they do not produce spurious current vectors or wave information. This is based on the unique properties of ship echoes: how long they persist in the range and Doppler cells; this type of interference has time scales of several minutes.
- Ionospheric-Type Echo Rejection: At certain times of the day/night, strong echoes from overhead ionospheric layers at ranges between 90 - 250 km can produce spurious current vectors. Algorithms were developed to identify the presence of these echoes and remove them. Sometimes this can leave a gap at the ranges corresponding to the ionospheric echoes, but this is better than wild vectors. Often only one side of the Doppler spectrum (positive/negative) is affected, so that redundant information produces no gaps. There are preference parameters that can be adjusted to optimize performance. This type of interference can persist from one-half to two hours.
- Impulse Removal: Lightning strokes are an example of this, persisting only 10 - 20 milliseconds but very intense. Unless excised, such impulses have the effect of raising the noise floor so that range is drastically reduced. CODAR excises such bursts from the time series before Doppler processing, a procedure in effect

for nearly ten years. This improves the performance greatly, especially when storms or other impulse sources are close by.

- Radio Signal Interference Rejection: Radio interference very often manifests itself in FMCW radars as vertical stripes in colored range/Doppler plots (i.e., appearing at all ranges but in constant-Doppler bands). These have the unique property that they appear at both positive as well as "negative" ranges (the latter being an artifact of the normal in-phase/quadrature radar signal processing; however actual echoes occur only at positive ranges. CODAR developed algorithms several years ago to identify these and use their negative-range images to cancel the interference from positive ranges, nearly always cleaning up the spectra so that Bragg peaks, second-order echoes, and ships are seen clearly. Such radio signals can typically last up to a half an hour or longer.
- Echoes from Offshore Wind Turbines: Occasionally HF radars are accidentally or purposefully sited so that they look out at farms of wind turbines that may be tens of kilometers offshore. These produce Doppler-echo spurs at those ranges that can fall in spectral space where Bragg, second-order, or ship echoes exist. These spurious echo sidebands are produced by the amplitude and phase modulation of the echoes from the blades that rotate at ~15 rpm. CODAR has analyzed and is testing processing methods that place these interfering sidebands outside of the span used for currents (including tsunamis), waves, and ships. When the blade sidebands occasionally do fall within our desired spectral signal space, algorithms will track and remove those offending Doppler cells, because their variation based on blade speed changes is slow enough to follow.

C. "SeaSondeReport" Files Collectable at Radar Sites

In order to facilitate the ability of clients and operators to collect relevant diagnostic information at radar sites (system and information logs) when problems are suspected, CODAR devised an easy-to-use script that an operator can execute. This immediately collects and assembles a zipped archive that can be EMailed as an attachment to CODAR for troubleshooting. We call this attachment a "SeaSondeReport File". There are four levels available: High, Medium, Low, and Web, which grab the same information but for varying amount of time going backward from the present. Their sizes can span between 6 MB and 20 MB. This diagnostic information includes:

- Computer Information Consisting Of:
  - Computer profile: kind, hardware, OS-X version, etc.
  - Crash logs
  - Latest system logs

- SeaSonde Information Consisting Of:
    - Latest radial/elliptical velocity files, latest wave files, and latest spectra
    - Radial 'Configurations' folder
    - SeaDisplay site map
    - Combine 'Configurations' folder
    - RadialSiteStatus which contains the latest RadialWebServer information
    - RadialWebServer Alert logs
    - Diagnostic logs/files (described in next section)
    - SeaSonde Software Version list
    - Catalog listing of all files in the SeaSonde 'Data' folder
    - Sentinel logs ('Sentinel' is the top-level manager algorithm)
    - User-site log (notes logged by persons making changes at the site)

D. Diagnostics Files to Maintain System Quality and/or Troubleshoot

From the beginning of SeaSonde development/operation, CODAR has always maintained ASCII diagnostic files. Entries are written to these diagnostics files as frequently as every ten minutes. These constitute histories of the radar system "health". There are two types of files being constantly recorded: one relating to system/hardware performance and the other to the signal environment being observed. New files are started every week.

CODAR also provides graphic tools that allow the operator to display multiple simultaneous histories for any combination of these user-selectable diagnostics. This can be over hours, a day, week, month, several months, a year, etc. Such combined display histories are extremely valuable in:

- Preventive Maintenance. Viewed on a regular basis (e.g., weekly), they allow the identification of an abrupt or gradual component failure or onset of external signal interference. In most cases, the source of the problem can be narrowed down to a specific component or source of an offending external signal.
- Troubleshooting. When a client or operator encounters the onset of a major defect (for example output current maps show no vectors), the display of the diagnostic files usually reveals the cause. This can be done either by the client/operator or by CODAR staff at the request of the client.

Here is the information monitored and archived in these diagnostics files:

- "HDT" Files (hardware integrity/health). This file begins with Comments that include all receiver, signal, and processing metadata settings, followed by the following columns:

- Time of observation -- expressed in computer log time (minutes)
- Receiver temperature
- AWG (advanced waveform generator) module temperature
- Transmit trip hex code (logs when transmitter shuts off, e.g., due to temperature threshold being exceeded)
- AWG run time code (how long AWG has been running uninterrupted)
- Power supply voltage
- Nominal +5 Volt supply (actual voltage)
- Nominal -5 Volt supply (actual voltage)
- Nominal +12 Volt supply (actual voltage)
- Internal transmit chassis temperature
- Transmit power amplifier module temperature
- Forward power exiting transmitter toward antenna
- Reflected power coming back from antenna into transmitter
- Transmitter power supply nominal +5 Volt supply (actual voltage)
- GPS receiver mode
- GPS display mode
- Phase-lock loop unlock indicator
- High receiver temperature
- Receiver humidity (percent)
- Power supply current (amps)
- External Input A
- External Input B
- Computer uninterrupted run time (minutes)
- Actual date/time of the log entry

- "RDT" Files (received signal characteristics/heath). This file begins with Comments that include all receiver, signal, and processing metadata settings, followed by the following columns. These are calculated from every CSS cross spectral file and/or the short-term radial velocity file created from that CSS:
    - Time from start reference, in seconds
    - Normalized antenna channel amplitude balance from sea echo: Loop #1 to monopole
    - Normalized antenna channel amplitude balance from sea echo: Loop #2 to monopole
    - Antenna channel phase difference balance from sea echo: Loop #1 to monopole
    - Antenna channel phase difference balance from sea echo: Loop #2 to monopole
    - Phase balance difference set used for processing: Loop #1 to monopole

- Phase balance difference set used for processing: Loop #2 to monopole
- Measured noise floor in dBm: Antenna Channel #1
- Measured noise floor in dBm: Antenna Channel #2
- Measured noise floor in dBm: Antenna Channel #3
- Signal (max Bragg peak)-to-noise ratio, dB: Antenna Channel #1
- Signal (max Bragg peak)-to-noise ratio, dB: Antenna Channel #2
- Signal (max Bragg peak)-to-noise ratio, dB: Antenna Channel #3
- Range cell where SNR was maximum
- Number of Doppler cells at all ranges that produced radial velocities
- Percentage of calculated radial vectors that were dual angle
- The count or total number of radial vectors found for that CSS file
- The average number of radial vectors calculated per range cell
- The number of range cells that produced radial vectors
- The maximum range seen for radial current calculation, in km
- The maximum radial velocity seen at all ranges
- The average radial velocity seen at all ranges
- The average of bearings that produced radial velocities for all ranges
- The type of radial velocity file produced. These include the following categories: (i) Ideal-pattern short-time radials; (ii) Measured-pattern short-time radials; (iii) Ideal-pattern merged final radials; (iv) Measured-pattern merged final radials.
- The type of spectra used/available for radial processing: includes CSS, CSA, CSQ cross spectral files.
- The remaining columns contain the complete date and time information

The same type of "RDT" file is produced for bistatic/multi-static operations, where scalar elliptical velocities are calculated rather than scalar radial velocities. These files are called "EDT", and contain essentially the same information and format as that described above for the "RDT" case.

E. "RadialWebServer" to View Summary of Diagnostics, Warnings, and Data

The RadialWebServer is a unique creation done by CODAR about five years ago. It gives limited access to a SeaSonde Radial Site (remote radar) through a web browser like Safari, FireFox, or Explorer (not all browsers may be fully supported). Access is limited to viewing and downloading the site's status, configuration, spectra, diagnostic, wave, and radial data. This can be done from a desktop computer (Mac or PC); from a laptop; from an iPad, or iPhone (as well as other smart phones equipped with a web browser). For example, on an iPad or iPhone, the user can expand a chart or graph to legible size in the normal way by using fingers on the touch-screen to expand the image, thereby enlarging it.

Among the items concisely reported and graphically displayed are:

- Status - Top Level Alerts: This is a listing of any warnings of possible malfunctions or non-normal status indicators.
- Site's More Detailed Status: A listing of the essential information about the site, including location, antenna bearing, signal properties, time at the site, etc.
- Radial Display: Plot the most recent or any radial velocity plot over the past year. This includes averages over a day; those done from ideal or measured antenna patterns, etc.
- Wave Display: Plot a history of the wave information. Can be up to present, or over any past period.
- Spectral Display: Shows the present or allow plotting any echo Doppler spectra within the last year at that site.
- Diagnostic Display: Plot the hardware and data/signal diagnostic history of any parameters available from the Diagnostic files.
- Logs: Allows viewer to look at any critical site logs, or create and download a SeaSondeReport file (described previously).
- Settings: Change the refresh interval and set up the "alert" EMail service.

Note: for security, one cannot use this browser to change or control any of the radar functions, signal, and processing parameters. That must be done from a laptop in a more password-protected procedure.

Detailed information on this RadialWebServer can be found in the following two documents available from the "www.codar.com" website:

- **RadialWebServer User's Guide**
- **RadialWebServer Installation & Administration Guide**

F. Warning Messages Sent to Client/Operator by EMail

The RadialSiteReporter tool monitors the status of the Radial Site and is an important companion of the RadialWebServer. The RadialWebServer uses the results of this tool for the site status, details, and alerts. ***The RadialSiteReporter can also EMail changes in alerts. This tool is scheduled to run once a minute.*** EMail is done by using the command line tool 'sendmail'.

Each alert has four states: *newly tripped*, *still tripped*, *newly cleared*, and *still cleared*. EMail alerts happen only when at least one alert is newly tripped or cleared, upon which all the newly cleared alerts and all new and old tripped alerts are EMailed out.

There are over 120 alert messages that can be sent out when a system or operating defect is encountered. Often several alert messages are triggered together, permitting a more detailed diagnosis of a problem,

The alert messages and more details on setting up this unique CODAR QA/QC service is found in the document: **RadialSiteReporter** on our website: www.codar.com.

G. Real-Time Uncertainties and Error Metrics in Radial Current Files

CODAR for years has outputted uncertainties and other quality metrics, along with the estimated radial velocities, in files with names beginning "RDL". In our standard LLUV format (longitude/latitude/east current velocity/north current velocity), these uncertainties appear as columns to the right of the velocities. Uncertainties are standard deviations calculated from the data themselves. They include:

- Spatial Uncertainty/Quality: This is the standard deviation calculated at the short-term CSS output interval (typically 10 minutes at frequencies above 5 MHz) for all of the individual velocities that fell in a given range/bearing cell.
- Temporal Uncertainty/Quality: This is the standard deviation of the short-term radial velocities (e.g., every 10 minutes) averaged over the user-chosen merging period (e.g., over an hour).
- Velocity Maximum: The maximum of all of the radial velocities used to compute the mean estimate for that range/bearing cell.
- Velocity Minimum: The minimum of all of the radial velocities used to compute the mean estimate for that range/bearing cell. The difference between this and the previous number gives the "span" of velocities from which the mean is constituted, which is another metric of data quality (large spans are suspect).
- Spatial Count: The number of vectors included in the average for the short-time radial estimate (e.g., over 10 minutes) and its uncertainty.
- Temporal Count: The number of vectors included in the average for the merged (e.g., over an hour) radial estimate and its uncertainty.

All of the above metrics give useful information on radial velocity data quality. It is important to note that each of these metrics (as well as the radial velocity itself) is a statistical estimate. Therefore, absolute correlation of a given metric for that time and spatial cell with velocity quality does not always have a one-for-one correspondence.

For example, a large uncertainty does not always mean a bad radial vector; nor is an obvious outlier velocity always accompanied by a large uncertainty metric. Hence, using each uncertainty to threshold to eliminate outlier velocities is not recommended.

However, over a region of space and period of time, studies by Laws (supported by US IOOS) and others show a definite and irrefutable relationship to data quality (documentation is available). Therefore, these metrics are highly useful in assessing data quality and system health. They are also useful as data covariances in numerical models, because there they enter in space-time aggregate/average sense.

Exactly the same uncertainties and quality metrics are outputted -- in the same format -- for bistatic elliptical scalar velocities that are stored as "ELP"-titled files. These metrics all apply to the scalar elliptical velocity component, just as the apply the the radial velocity component for "RDL" files collected from backscatter radar geometries. It is important to note that these uncertainties and metrics do not apply to the u/v components of either of these scalar velocities independently. However, the radial and elliptical uncertainties can be and are propagated through to calculate uncertainties for total vectors produced therefrom; documentation explaining this process are available in the CODAR library.

Although most people ignore these quality metrics that CODAR outputs, we recommend that users consider and use them on a wider basis in order to assess system and data QA/QC because -- as mentioned above -- they have been proven meaningful.

H. "RadialMetric" Data Output Option

A useful way to diagnose possible problems or optimize performance is to process the same raw data sets offline, with a number of different parameter preference settings. A large number of either default or user-selected parameters control the processing and decision making. The final data products (e.g., radial or total vector maps and ASCII files), therefore, have undergone quite a few irreversible steps; in other words, it is not possible to go back to raw data from the much more compact, final data products. Although the raw data can be reprocessed offline in order to evaluate any number of different parameter permutations, CODAR is too often labeled a "black box" where no one can understand or change any of the settings that might have produced different -- or better -- results. However, offline reprocessing of archived raw data is cumbersome and time consuming.

For this reason, with support from NOAA's U.S. IOOS through a contract from Scripps Institution of Oceanography, CODAR has produced and makes available a new, optional ASCII format for radial vector file outputs. This output is called "**RadialMetric**". It is a file that complements and/or replaces the normal ASCII Radial Files created at the SeaSonde radar sites in real time. In this ASCII file are every possible intermediate data product for each range and Doppler cell from which radial vectors are created. In other words, no irreversible steps have been made, and the user can try any combination of different radial processing parameters by manipulating the data within this special RadialMetric file. For example, one can try different MUSIC direction-finding processing parameters; examine whether better quality can be obtained by employing signal-to-noise ratios (SNR) as a filter; average in a different manner over bearing and/or Doppler shift, etc.

This special file output can be requested in the processing control file called "AnalysisOptions.txt". There may be only a few users who are interested in reanalyzing or doing their own optimization studies at this level. The consequences are that these RadialMetric files are much larger (sometimes by a factor of five or more) than the normal Radial File outputs. This has impacts in archival/data transfer considerations. More details about this QA/QC and data optimization tool are found in the document **"RadialMetricDescription.pdf"** from our website www.codar.com.

I. Decomposing Total Vector Maps to Obtain/Compare Radials/Ellipticals

CODAR offers a useful tool to assess data quality in synthesizing total vector maps. The philosophy of this tool and its utility is the following. Total vector maps are normally composed from at least two, and usually more, radial (backscatter) and elliptical (bistatic) sets of vectors -- sometimes four to six. Irreversible steps and averaging processes are applied to all of these radar data sets in synthesizing total vector maps.

- <u>Synthesis of Total Vectors</u>: Here is what happens in synthesizing total vectors. Radials and/or elliptical scalar components of the true total 2D vector field are estimated from several radars (transmitters and/or receivers). Those are then combined at a central site as follows. All of these measured scalar estimates are collected within a circular radius about a given total-vector grid point. The circle radius is user-selectable. The best-fit total vector at the grid point is estimated from all of the constituent scalars. This is usually done as an overdetermined least-squares fitting, but options are available to choose other methods, for example, four nearest neighbors, maximum likelihood (the latter being a weighted least squares approach), optimal interpolation, open-mode analysis, etc. All of these inherently involve averaging many data points together, which is an irreversible process.

- The Quality Issue Being Addressed: There may be a question about the quality or accuracy of these synthesized total vectors. Sometimes there may be an obviously questionable region. In other cases, there may simply be a desire to analyze the constituent synthesis process better, and see whether it appears to be optimal. But the impact of a given radar's scalar input to the resulting 2D vector at any point is no longer obvious. The tool being discussed here allows that decomposition to be made, so that errors or poor data quality from one site's data may now become obvious.
- **"RadialFromCurrent"** Tool: This tool allows one to open a GUI window. Then one drops onto this window: (i) A radial/elliptical site "header" file or the Configuration folder for the sites to be analyzed; (ii) The total vector file that is to be decomposed back into the constituent radials and ellipticals. The tool will then create the decomposed radials and ellipticals that were requested, as a file in the normal LLUV format of the originals.
- How Does This Help?: Now one can look at the decomposed radial vector plot for a constituting site and compare it with the original field that went into the synthesis process. Do this for all the constituent radials/ellipticals. They will not be identical, of course, because of the irreversible averaging that had been done to get the 2D plot. If five sets of radials or ellipticals were used, and four originals and decomposed sets agree well with each other, but one set doesn't, this suggests the culprit. If this happens again and again with total vector files from these sites, this confirms that one site is definitely not healthy; or is at least the weak link in the grouping producing the total vectors.

J. Simulations to Study/Understand Factors Influencing Data Quality

Often one wants to see how well the CODAR processing or MUSIC direction-finding and their controlling parameters works for a given input current pattern. The tools **"CSSim.m"** and **"BSSim.m"** are MATLAB applications with convenient graphical user interfaces (GUIs). These allowa one to set a desired current pattern for study. The purpose is to create "CSS" cross-spectral files for this pattern, also allowing for its evolution with time. These CSS files are the outputs, and are in exactly the same format as those created from "SeaSondeAcquisition" in the field SeaSondes. The ultimate objective is to process these with our normal "Currents" tool, with whatever MUSIC and other processing parameters one wishes to vary. The question to be answered is: how well did I recover the original pattern that was inputted, and hence, which processing parameters work best? Or, where in bearing angle do the radial (or elliptical) velocities fail the worst and why, as I make the current pattern ever more challenging? This is yet another way of "examining and understanding quality."

"CSSim" creates averaged CSS cross-spectral files for backscatter radar geometries. "BSSim" creates averaged CSS cross-spectral files for bistatic radar geometries.

The simulation of sea echo and the resulting cross spectra for input current patterns follows the models for HF sea scatter derived by Barrick ~42 years ago. Highlights of this and the parameter settings available are:

- The ocean wave heights and the scattered signals are zero-mean Gaussian random variables.
- The Bragg wavelengths define the first-order echo used for current extraction.
- Additive Gaussian white noise is added to the Gaussian sea echoes; the user specifies the desired sea-echo signal-to-noise ratio desired.
- The Bragg-wave angular pattern is inputted by the user, usually conforming to the wind-wave pattern. This determines the positive/negative Bragg-peak ratios and appearance.
- The desired current pattern that the user specifies is defined by polynomials of radial velocity as a function of bearing, for each range cell. We usually select and study reasonably complex (but realistic) currents that have both single and dual-angle behavior (and often triple-angle or more) to see how well the MUSIC algorithms will handle known, input, complex current patterns.
- The simulator generates time-series signals for two crossed loop antennas (at whatever orientation the user specifies, plus the omni-directional monopole/dipole.
- The simulator user can assume either idealized sine/cosine/omni antenna patterns, or input an actual set of measured, distorted antenna patterns. The echo signals will depend on these patterns. This allows study of distortion effects on current pattern retrieval.
- The simulation begins by calculating the time series of the sea echo plus noise.
- From this, unaveraged cross spectra (CSQ files) are generated at whatever radar frequency and time-series length the user desires. This defines the Doppler and velocity resolution that will be available upon processing.
- The user specifies how many of these CSQ cross-spectral files are to be averaged to produce a CSS file that is to be written in the same format as the field radar software. This allows study of the effect of spectral averaging on current accuracy.

These programs and user-evolved variations have allowed study of the effect of signal and processing parameters on the retrieved current patterns compared with their inputs. In addition to extensive experience gained by CODAR staff, others have used this tool to study and report on the effects of system and environmental parameters on output current quality. Some of these are: Kip Laws; Tony di Paolo; Simone Cosoli.

K. "GDOSA.m" -- A Simulation Tool to Optimize Geometry for 2D Vector Coverage Quality

In many network scenarios, 2D currents at a point on the ocean are being synthesized from multiple radar looks. These are often overlapping backscatter HFSWRs with more than two able to see that point. More frequently, they include multi-static geometries where a separated transmitter (perhaps from the consecutive adjacent radars in the network) observes that point also. This can increase the coverage area. More often than not, the main advantage lies in the added quality of the resulting 2D total vectors: their increased accuracy and robustness. That is, more data being used in the synthesis of the 2D map gives more accurate total vectors. The question arises: can this added quality be predicted based on site location selections?

CODAR has developed a GUI-based MATLAB tool, **"GDOSA.m"**, to assess total vector coverage and quality based on site locations. Contributing radars can be backscatter and/or bistatic, up to any desired number. The user inputs candidate locations, maximum expected range, and cell size. Assumed is a uniform input measurement error in radial/elliptical constituents. These errors are propagated through to obtain error in the 2D total vectors at each point in the coverage area. This is referenced (normalized) to the assumed input errors (cm/s) in the radials/ellipticals. It includes both: (i) GDOP (geometrical dilution of precision) -- an angle-based error that accounts for input radials, for example, that are close to parallel so that resolution of the perpendicular component becomes difficult. (ii) Varying area resolution and density of the input radials in their polar coordinates and ellipticals in their elliptical system. Hence the name GDOSA that includes both (for geometric dilution of spatial accuracy).

The outputs are maps of color shading within the coverage area, representing quality of the expected 2D vectors. Dark colors are high quality. Contours are also shown for the magnification of error; low numbers represent the lowest error propagation from the constituent inputs at that point. The methodology behind it is precise and described in a widely circulated CODAR document by Barrick titled "***Geometrical Dilution of Statistical Accuracy (GDOSA) in Multi-Static HF Radar Networks***" (2002).

This tool is useful not only for planning and design of new network installations, but also for assessing expected weak and strong areas of 2D vector quality within existing networks.

L. Example of Long-Term QA/QC System/Data Health Assessment Plan

The normal SeaSonde installation and calibration process can take several weeks to deal with site-specific debugging and optimization challenges that typically arise. Some call this the "commissioning" or "certification" period. During this phase, bot CODAR and client are paying close attention to the radar operation and data quality.

After this period, the culture of how the system is maintained over time varies widely, we have found. Worst case, the operator pays little attention to the day-to-day operation or data outputs. When the operator does pay attention, it is often only to observe that there are no radial velocities being produced by the site. Or, that the radial velocities suddenly appear unrealistic. Often the operator also has other non-radar responsibilities or many other radars to attend. Too often only "the squeaking wheel gets the grease" (or attention). We have observed SeaSonde systems that operated nearly continuously for periods of 10 years with almost no attention. Although outputs may continue to look good superficially, inevitable wear by the elements and equipment aging will lead to degradation in quality of output data. This is unfortunate and can be avoided by minimal pro-active attention to the diagnostics being produced and stored in the folder archives.

NOAA's US IOOS has put together a national plan to assess the needs and future for its national HFSWR network. It is called "***A Plan to Meet the Nation's Needs for Surface Current Mapping***", September 2009 (downloadable from the US IOOS website). This is based on inputs from dozens of HFSWR owners and operators in the U.S., tracking the experience from ~130 radars (about 122 of them SeaSondes) that lined our coasts at that time (the number has increased since then). Some of the SeaSondes involved go back 20 years. It was found that approximately two full-time persons (radar technicians) are required to adequately maintain seven SeaSonde radars (and two persons for four WERA radars). We are finding that new networks of SeaSondes being created in many other countries -- particularly in Asia -- rarely maintain this ratio, sometimes dropping below one technician for ten SeaSondes. This is not enough.

As a result, recommend pro-active plans to such clients, that we hope will be seriously considered in order to maintain acceptable QA/QC and head off degradation and failure problems before they occur. One such plan is attached here as a PDF that was prepared for an Asian client with a network of a dozen SeaSondes. It is lain out as a checklist, with tasks to be executed for each radar at regular intervals (as often as once a week). Nearly all of these can be done remotely with internet access; the checks can take less than half an hour. When significant change is encountered, maintenance can be initiated on their own or in consultation with CODAR Support staff.