SeaSonde Averaging and Ship Removal in CSPro

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Abstract

This note describes the averaging of Doppler spectra and ship removal in CSPro — one of the Radial Tools programs of Codar SeaSonde radar system. The algorithm is explained and some examples are also given.

Contents

List of Tables

List of Figures

1 Introduction

`CSPro` is one of the Radial Tools in Codar SeaSonde programs. It calculates averaged cross spectra of the ocean by an exponential smoother [1] with options to remove ship signals and direct current (DC) signal in the Doppler spectrum. Two simultaneous running averages are computed with different time intervals - a short time interval given by the user and a long, three-hour, averaging interval to capture short-term and long-term variation of the sea echo.

The predecessor of `CSPro` is `CSRAVnn` developed by Don Barrick in 1990(?) which has been updated to `CSPro` by Jimmy Isaacson in 1999(?) to make it more flexible for the user. These are major improvements of `CSPro`.

- It can handle arbitrary numbers of channels (antennas);
- It can start from range files or cross spectra files (`CSRAVnn` works from cross spectra). If the input data are range files, Doppler process is performed first;
- It has a nice display of spectra;
- Multiples copies can run simultaneously which allows the user to either process separate input streams or to process the same input data stream with different settings;
- The intermediate results (averaged spectra) are saved so it can resume faster after interruption due to either power outage or restart.

But the basic algorithm for averaging and ship removal is essentially the same.

Throughout this note, the typewriter font represent the name of a variable in verbatim in the source codes in `CSPro`. When a *bin* or *cell* is mentioned without any specification, it represents a bin in the two-dimensional (2D) range-Doppler space, i.e., at range r and radial velocity (range rate) v_r in Doppler spectrum.

2 Exponential Smoother

An exponential smoother [1] is used in averaging Doppler spectrum which is the result of running fast Fourier transform (FFT) on the range data. When FFT is mentioned in this note, it is to be understood as the second FFT in Doppler process, not the first one for the range process from time series data.

An exponential smoother is a linear filter which employs an infinite impulse response (IIR) filter of first oder and a finite impulse response (FIR) filter of zeroth order. At the n^{th} instant in time, the output b is averaged recursively in time from incoming raw datum u which in our case is the Doppler spectrum (self and cross spectrum) at each bin for each antenna,

$$b_n = (1-w)b_{n-1} + wu_n; \tag{1a}$$

$$b_0 = wu_0; \tag{1b}$$

with w as the FIR coefficient or weight and $1-w$ the IIR coefficient which sum up to be one to ensure a unity frequency response at DC.

$$w = \frac{2}{N_{\text{avg}}+1}; \tag{2a}$$

$$1-w = \frac{N_{\text{avg}}-1}{N_{\text{avg}}+1}. \tag{2b}$$

N_{avg} is the number of periods or sampling intervals. In general, it does not have to be an integer, although `CSPro` enforces it to be an integer. For a stable low pass filter, we require that $0 \leq w \leq 1$. This yields the condition, $N_{\text{avg}} \geq 1$. To be on the safe side, `CSPro` uses a lower limit of 1.1.

Equation (1) can be expanded into a series,

$$b_n = w \sum_{m=0}^{n} (1-w)^m u_{n-m}. \tag{3}$$

This way, it is easier to see that the weights for all past data are exponential with more recent data weighted more heavily. The quantitative significance of our filter parameter N_{avg} will become clearer in the next section.

2.1 Significance of N_{avg} and Filter Properties

Some important properties of a filter are the speed of response and noise reduction. For our SeaSonde filter, these quantities are determined by N_{avg}. Since a large N_{avg} gives more equal weights to all past data from (1a) and (3) hence better noise suppression and slower response are expected.* Much of the formulation in this section follows [1].

The *noise reduction ratio* NRR is the improvement of signal-noise ratio (SNR) at output over the one at input,

$$\text{NRR} = \frac{\text{SNR}_{\text{in}}}{\text{SNR}_{\text{out}}}. \tag{4}$$

NRR can also be shown to be the *attenuation of highest frequency (Nyquist frequency) relative to DC*. This Nyquist frequency should not be confused with the one for Doppler process which is a separate process before smoothing.

To maximize output SNR, i.e., minimizing noise, NRR needs to be small. For additive, white and zero-mean Gaussian noise, NRR becomes inversely proportional to N_{avg},

$$\text{NRR} = \frac{1}{N_{\text{avg}}} < 1. \tag{5}$$

*For a filter of higher order with more zeros (from FIR coefficients) and poles (from IIR coefficients), these properties can be adjusted independently.

The speed of the filter is quantified by the *effective time constant* n_{eff} which is the number of samples it takes to attenuate to an amount ϵ. If N_{avg} is very large, n_{eff} becomes directly proportional to N_{avg},

$$n_{\text{eff}} \approx N_{\text{avg}} \frac{-\ln \epsilon}{2}, \quad \text{if } N_{\text{avg}} \gg 1. \tag{6}$$

N_{avg} can be seen to be the number of samples intervals for the noise power to attenuate to $e^{-2} = 0.14 = -8.7\,\text{dB}$ or we can just call it **9 dB time constant**.

Another quantity is the bandwidth of the low-pass filter. The normalized 3 dB (half-power) cut-off frequency equals the FIR weight for large N_{avg},

$$\frac{f_{\text{cutoff}}}{f_{\text{s}}} \approx w, \quad \text{if } N_{\text{avg}} \gg 1, \tag{7}$$

where f_{s} is the sampling frequency; that is; how often the input stream comes in. It should not be confused with the sampling frequency of the Doppler process which is the same as the pulse repetition rate f_{r}. For an FFT time window T_{FFT}, the sampling interval and frequency are,

$$T_{\text{s}} = \frac{T_{\text{FFT}}}{(\xi)} = \frac{N_{\text{FFT}}}{f_{\text{r}}(\xi)}, \tag{8a}$$

$$f_{\text{s}} = (\xi)\,\frac{f_{\text{r}}}{N_{\text{FFT}}}, \tag{8b}$$

where ξ is included in case of overlapping Doppler process. For now `CSPro` employs non-overlapping running FFT, so the sampling interval is the same as the FFT length and the overlap factor $\xi = 1$. Fluctuations or variations faster the cut-off are greatly attenuated.

In addition to the user given average, `CSPro` calculates another longer (three-hour) average internally. This three hour average is not outputted but written only as a part to restart `CSPro` after interruption. It is also used for thresholding in ship removal. These are discussed in more details in Sections 3.5.4 and 3.5.1.

2.2 Normalization Factor

One thing worthy of notice of a linear filter is the output ramps *up* to steady state. The filtered data is always smaller than the raw data with a "gain factor", albeit smaller than one. Initially, this factor is w (< 1) as in (1b). Then it follows a similar recursive relation as in (1a) and (3),

$$F_n = (1 - w)F_{n-1} + w, \tag{9a}$$

$$= w \sum_{m=0}^{n} (1-w)^m,$$

$$= 1 - (1-w)^{n+1} \to 1, \quad \text{as } n \to \infty, \tag{9b}$$

Suppose the data before contamination by noise are one, the output only approaches one exponentially at infinite samples. The convergence rate and error depend on N_{avg} — it takes N_{avg} samples for the output amplitude to reach $(1-w)^{n+1}$ *below* where it is supposed to be. Naturally, the convergence is slow for a large N_{avg} (small w). For example, for $N_{\text{avg}} = 10$, after 10 intervals, the output amplitude is only 89%, that is -1.0 dB reduction in power. Similarly for N_{avg} of 100, the output amplitude is only 87% (-1.2 dB) after 100 intervals.

3 CSPro

The computation and input parameters of `CSPro` are described in this section. First the overall procedure is described then details are filled in later.

3.1 Overview of the Computation

The schematic flow chart of the averaging and ship removal is outlined in Figure 1.[†] In all computation, the first range bin, or more precisely, the 0^{th} bin ($r = 0$) is discarded.

`CSPro` maintains an internal counter for time intervals (`nStep` in Figure 1 and subscript $_n$ in (1)). At each cycle, the variables for all bins are (re)initialize if necessary, where := represents the assignment operator. These variables are averaged spectra b and a, which represent averaged spectra *with* and *without* ships, and their corresponding quality factors (q_a and q_b). Qualify factor is explained in Section 3.5.3. The reset can be triggered by changes in the site parameters such as frequency settings (see Section 3.5.5), or gap in incoming data above a time given by the user (see Sections 3.2 and 3.5.4). Then the counter is incremented and the threshold for ships is updated accordingly which is discussed in Section 3.5.1. Then the DC signal in Doppler spectrum for all range bins is optionally removed as shown Section 3.4.

If the ship removal is not selected, the averaged spectra are calculated and saved in output `CSS` files directly according to (1). The output files are saved at a user-defined intervals (see Section 3.2). Otherwise, averaged results of bins suspect of containing ships are withheld in buffer until ships move away, or until they are confirmed to be the new

[†] `ACrossSpectraObj` is the class where all computation is carried out. Specifically, the main event happens in the member function `add`.

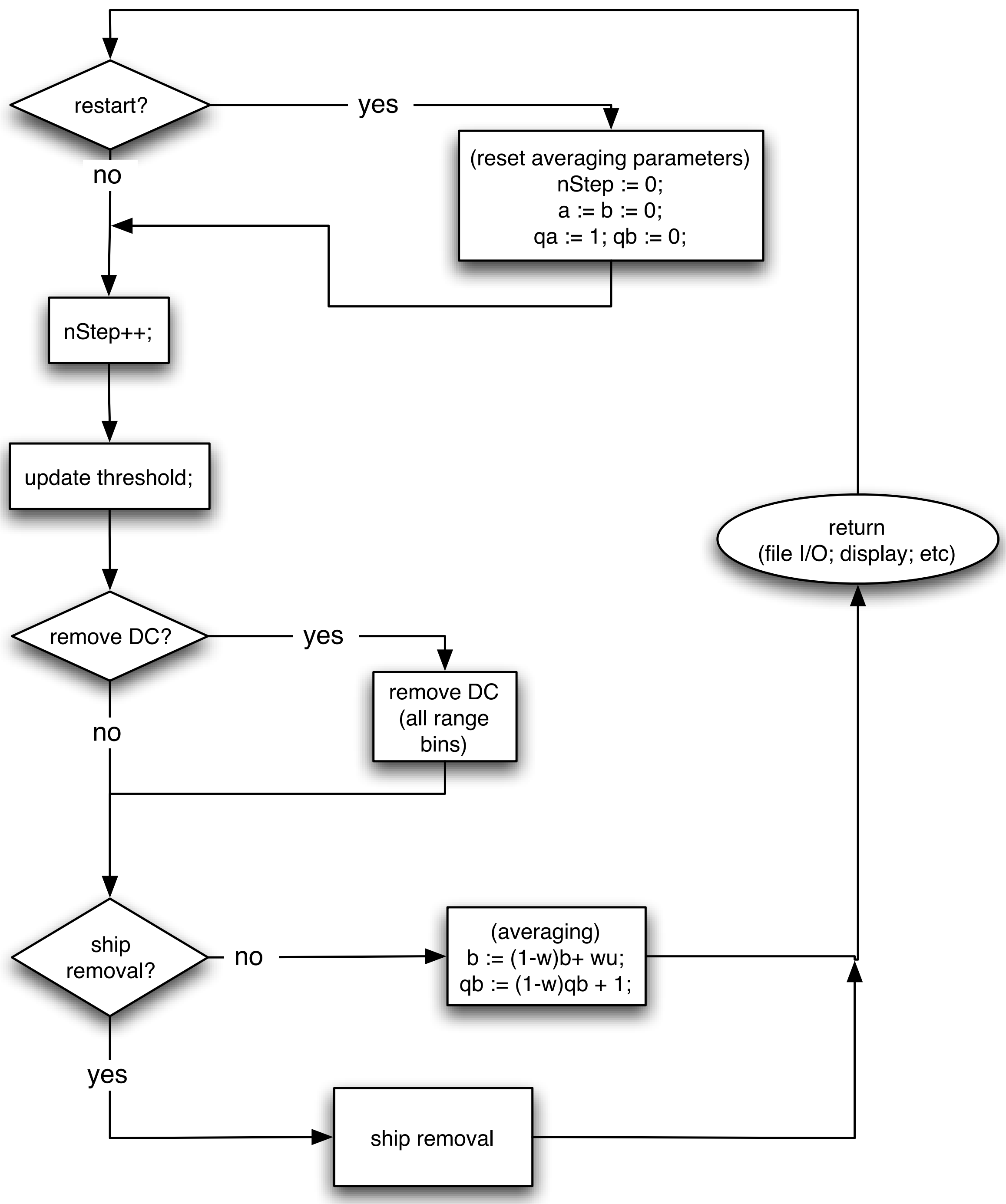

Figure 1: Schematic flow of computation in `CSPro`.

state of the ocean. Then they are released for output or discarded accordingly. The whole process then repeats.

Ship removal and DC removal and some others steps deserve more elaboration in Sections 3.4 and 3.5 that follow. The user has control over some of these decisions. These input parameters are discussed first.

3.2 Input Parameters

`CSPro` reads quite a few parameters from a preference files which gives the user control over the calculation and output options. Only ones that are relevant to the computation are shown here in Table 1. Some are flags for optional processes such as DC removal. An example of a complete preference file with some typical values of all input parameters is given in Appendix A.

`kShip`	:	flag for ship removal (0 or 1)
`thrS`	:	number of intervals to start ship removal process
η (`thrV`)	:	threshold value for ship removal (linear scale)
`xMin`	:	maximum time gap in minutes between input stream
`rmvDC`	:	flag to remove DC signal
T_{avg} (`averagingTimeInMin`)	:	time constant of the smoother in minutes
`outputPeriodMin`	:	output period in minutes

Table 1: User Input Parameters

`xMin` allows the incoming data streams to be interrupted without triggering restart of the averaging process. Note: `outputPeriodMin` is how often the output files are written in disk and does not have to be the same as the T_{avg}.

In addition, `CSPro` also has few preset parameters and conditions. These are hardwired in the source codes thus impose limitations which the user should be aware of. These are discussed in Section 3.5.5.

3.3 Averaging Parameter in `CSPro` and Numeric Examples

N_{avg} is related to T_{avg} for a sampling interval T_s (in (8a)) by,‡

$$N_{\text{avg}} = \frac{T_{\text{avg}}}{T_s} = \frac{60 T_{\text{avg}}(\text{min}) f_r(\text{Hz})}{N_{\text{FFT}}} \,(\xi) \tag{10}$$

‡calculated by member function `reset`

To guarantee a stable low pass filter as shown in Section 2, `CSPro` internally limits N_{avg} to be at least 1.1 should the T_{avg} given by the user be shorter than one sampling interval.

As stated before, `CSPro` also calculates a three hour average internally; it is only done on the power spectra for each antenna (self spectra) and not the cross spectra between antennas. Long average is not saved as output files but used for thresholding for ship removal which is discussed in Section 3.5.1. The interim result of long average is also used to restart the averaging in case of interruption (see Section 3.5.4)

It should be noted that if T_{avg} is much larger compared with the sampling interval, the cut-off frequency of the filter becomes

$$f_{\text{cutoff}} \approx \frac{2}{T_{\text{avg}}}, \quad \text{for } N_{\text{avg}} \gg 1, \tag{11}$$

by (7). That is, for a given averaging time, variations faster than *half* of it is greatly attenuated and can hardly observed.

Let us see some numeric examples. For a repetition rate of 2 Hz and 512-point (non-overlapping) FFT, an hour average results in N_{avg} of 14. This gives a NRR of $1/14 = -11\,\text{dB}$ from (5). For one hour average with the above Doppler parameters, the 3 dB cut-off frequency is $1/32\,\text{min}$. That means, only variation longer than 32 min can be observed. More numeric examples of the filter properties for common settings are given in Table 2 for an FFT of 256 points. f_c is the center frequency and $P_{\text{out}}/P_{\text{in}}$ is the output and input power ratio after N_{avg} samples *without normalization* (see Section 2.2). Note that N_{avg} is also the 9 dB time constant for noise attenuation from (6).

f_c (MHz)	f_r (Hz)	T_{avg} (min)	N_{avg}	NRR (dB)	f_{cutoff} (min^{-1})	$P_{\text{out}}/P_{\text{in}}$ (dB)
4.54	1	15	4	−6.0	1/11	−0.7
4.54	1	30	7	−8.5	1/17	−0.9
4.54	1	60	14	−11.5	1/32	−1.1
13.5	2	30	4	−6.0	1/21	−0.7
13.5	2	60	7	−8.5	1/34	−0.9

Table 2: Filter Properties for Some Common SeaSonde Settings

3.4 DC Removal

When DC removal is chosen, the incoming (raw) data within ±2 Doppler bins totaling five bins around the DC Doppler bin are set to be the average value of these two bins at the edges of this *DC region* for all range. That is, the value at the j^{th} Doppler bin with the

DC region is replaced by

$$u(j) = \frac{1}{2}\left[u(j_{\mathrm{DC}}-2)u(j_{\mathrm{DC}}+2)\right], \quad \forall j \in [j_{\mathrm{DC}}-2, j_{\mathrm{DC}}+2]. \tag{12}$$

Ship removal is not done in this region.

3.5 Ship Removal

The ship removal is done for all Doppler bins except *near DC region* which is a slightly wider than the five-bin DC region shown above. It is defined in Section 3.5.5. The procedure is illustrated in Figure 2. At start (or restart) when the interval counter (`nStep`) is one, the output spectra and quality factors (discussed in Section 3.5.3) and ship counters (N_{a}) for all bins are initialized. If a bin has no ship, the averaging is computed and outputted straightforwardly using (1).

When the ship removal option is on, if a bin may contain a ship for the first time, its ship counter N_{a} is set to zero. This ship counter records the number of intervals of an "alleged" ship persists in a bin. In the mean time, the average is carried out internally in the buffer using the previous average with ship removed (b) and the new raw data (u) without being outputted. Then in the next cycle, this counter is incremented if the high signal persists. This is done until the "alleged" ships move away then this intermediate result (b) is discarded; the new raw data (which should return back to previously low value) are averaged and outputted (a) as usual and copied back to the buffer (b) for the next time when there is a ship.

If the high signal persists after when the "alleged" ship is supposed to be gone, this confirms that the new higher power is a new state of the ocean, rather than a ship, the withheld average (b) then is copied back to the output (a) and the ship counter is reset to be -1 signaling a new state. Then in the next cycle, this bin is not going to be withheld anymore and the averaging is done as usual.

There are few consequences of withholding a bin with high signal. First, this bin becomes more stale due to less frequent update. Since the sea echo usually has a time constant of about 30 minutes from empirical observation by Codar. This is much slower than the time duration a typical ship travels through one range bin. Slightly outdated data in few bins pose no grave problem normally.

If the high signal in this bin happens to be a new state, it still have wait for some time according to the speeds until being confirmed as not a ship. In the interim time, the data in this suspect bin are not outputted and only when they are confirm as a new state is this bin released for output. Consequently a new state is not reflected in output instantaneously. The lag time depends on the Doppler bin (speed). Naturally, large variation of ocean closer to DC has longer lag time.

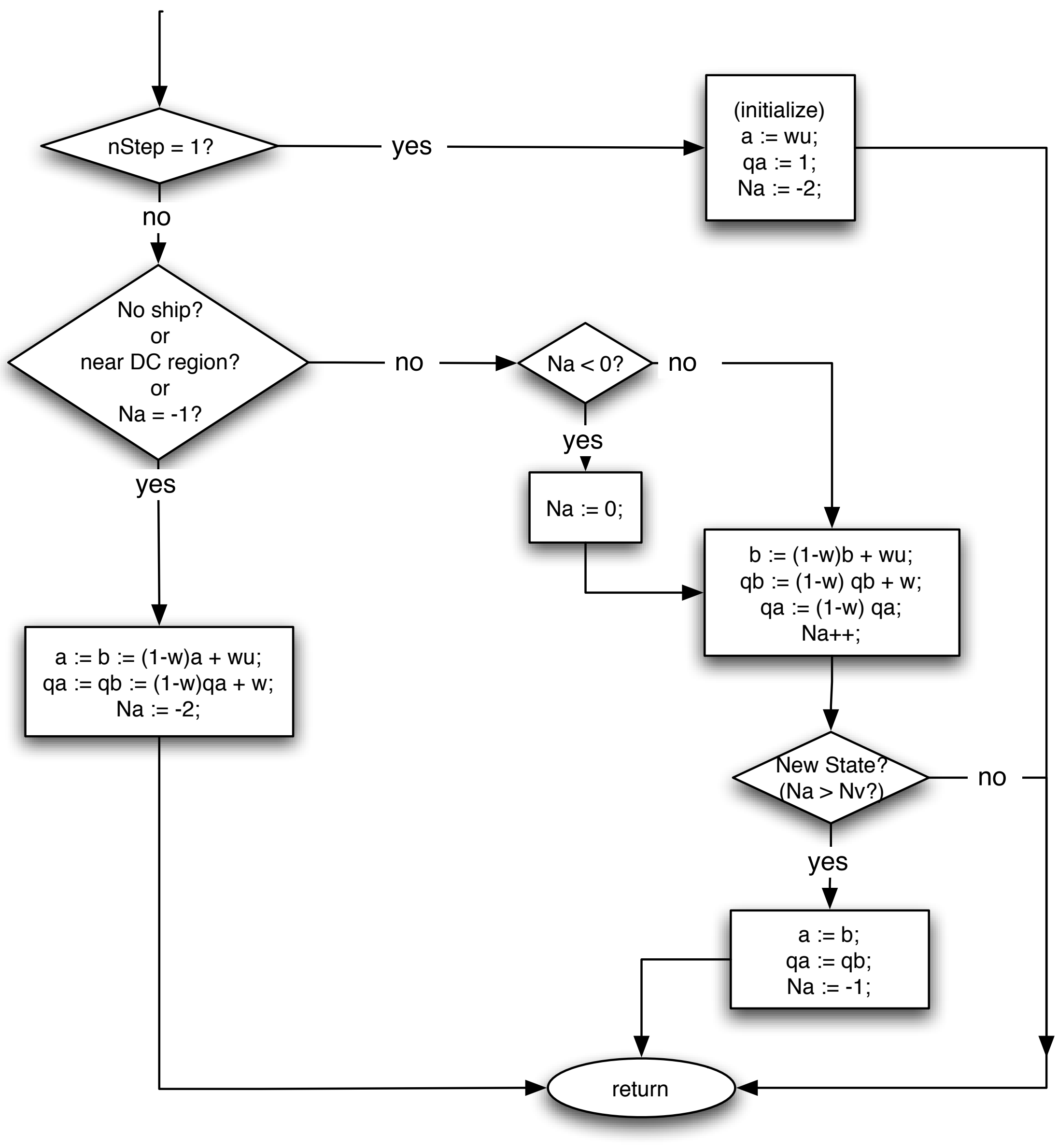

Figure 2: Flow chart of ship removal

A benign side effect of withholding is it provides additional protection against short term interference on top of our exponential smoothing. If the high signal in a bin is interference, which is not uncommon in HF radar, and if the duration is short, lasting less than a ship in the same Doppler bin would persist, it is still withheld. At some future interval, if things are back to normal, then the interim result is discarded; i.e., the interference is prevented from contributing to the output average, just like a ship signal. However, if the duration of this "blip" is shorter than a real ship signal, the withholding time may be longer than necessary resulting a more stale result. Also this only helps in filtering out interferences of duration shorter than or comparable to that of ships in the same Doppler bin; it does not work for interferences lasting longer. The latter would be identified as a new state of the ocean.

In case there are lot of ships or interferences, this withholding can result in very stale output spectra with very little new information included in the averaging. A quality factor thus is provided for each bin as an indicator of how current a bin is. Quality factor is defined in Section 3.5.3.

3.5.1 Thresholding for Ships

How to determine if a bin may contain a ship is explained now. When the power of a bin in the incoming (raw) spectrum is larger than the corresponding value of long average (three hour) spectrum of *any* of the antennas by a threshold η given by the user, this bin is flagged as suspect of containing a ship[§]. The logical evaluation is

$$\text{no ship} = \left(\frac{u}{a_3} > \eta\right)? \quad \forall \text{ antennas,} \tag{13}$$

where the subscript $_3$ emphasizes that this is the three hour averaged (power) spectrum. The above evaluation is for power in linear scale, not log scale (dB). It is carried out for all bins except near DC region where ship removal is skipped which is defined in Section 3.5.5.

As shown in Section 2.2, the averaged output are always lower in magnitude than the input for an IIR filter. For example, Table 2 shows that for one-hour average, the output power is still more than 1 dB lower after an hour. If nothing is done to remedy this situation, the incoming spectrum (u) can easily exceed the output (a_3) in the thresholding in (13) initially and become misidentified as a ship. In order to compare the two fairly, caution must be taken. `CSPro` takes care of this in two ways:[¶] firstly before some intervals specified by the user (`thrS`), the threshold is set to be a very large value (10^{16} or 160 dB) which guarantees that ship removal is not done before that; secondly the threshold is

[§] see member function `thrCMP` and `oldShip`

[¶] in member function `update`

normalized by factor F_n in (9b) at each output step,[‖]

$$\eta_n = \begin{cases} 10^{16} & \text{for } n < \texttt{thrS}, \\ \frac{\eta}{F_n} & \text{otherwise} \end{cases}. \tag{14}$$

3.5.2 Ship Counter

Ship counter used in withholding bins is essential for determining withholding time and warrants further explanation. A ship in the j^{th} Doppler bin has the radial velocity,

$$v_r = (j - j_{\text{DC}})\Delta v, \tag{15}$$

where Δv is the Doppler bin size. Δv depends on the wavelength λ_{c} of the radar system at the center frequency and length of FFT in Doppler processing,

$$\Delta v = \frac{\lambda_{\text{c}}}{2} \frac{f_{\text{r}}}{N_{\text{FFT}}}. \tag{16}$$

For a range bin size of Δr, we expect it to only observable for a certain duration. Ideally, this time is just $\Delta r / v_r$. This finite duration is our a basis for distinguishing between a ship signal and a new sea state.

In the beginning or restart, the ship counter N_{a} is set to be -2 indicating a normal state (no ship) (see Figure 2). When the incoming signal power in a bin is identified as a possible ship signal by (13), the N_{a} is set to be 0. It then starts to count the number of intervals that this "alleged" ship is visible in this bin. In the next interval, if the high signal persists, the ship counter at this suspect bin is incremented and the value is compared with the ship intervals for this bin (N_{v}) — the expected number of intervals for the ship of this speed to persist in a range bin. Ideally, this interval should be just $\Delta r / (v_r T_{\text{s}})$. By making use of (15), (16) and T_{s} in (8a), `CSPro` calculates N_{v} for the j^{th} Doppler bin as

$$N_{\text{v}}(j) = \begin{cases} \text{ceil}\left(\zeta \frac{2\Delta r}{(j - j_{\text{DC}})\lambda_{\text{c}}}\right) & \text{for } j \in [j_{-2}, j_{+2}] \\ N_{\text{v}}(j_{\pm 2}) & \text{otherwise} \end{cases} \tag{17}$$

The ceil function makes sure that it would wait for at least until next interval. The extra form factor $\zeta = 1.2$ is to account for the widening of a peak due to Hamming window in Doppler processing. This allows extra time for the tail of a peak to pass through a range bin. $j_{\pm 2}$ are the Doppler indices for the *second order* region in Doppler spectrum which are defined in Section 3.5.5. For the noise wings beyond (higher speed), N_{v} is limited to be the same the two edge Doppler bins at the second order region, thus allowing extra withholding time (*why?*).

[‖] Alternatively, one can also scale the output data. This is what is done in IIR back ground for the ship detection —- the normalization is done on the averaged background power instead of the threshold. [2].

Note that the aliasing effect is not considered in calculating N_v in (17) so for a ship with radial velocity higher than the "Nyquist" velocity, our N_v is going to be overestimate, as the ship moves faster through a range cell and the raw data are withheld longer than necessary. This make the output more stale. However, this should not cause any disaster.

If a bin with high signal persists after N_v intervals when a ship of the same speed is supposed to be linger, i.e., $N_\mathrm{a} > N_\mathrm{v}$, it indicates that this is a new state of the ocean, then the N_a is set to be -1 representing a new state. This allows the bin to be released to output in the next interval also the ship counter is reset to -2 representing a new normal state.

3.5.3 Quality Factor

Quality factor q is an indicator between one and zero signalling how current a bin has been. One means all past data in a bin has been included in the averaging while zero means none of past data is being used (always containing ships or high signal) and it is completely outdated.

At (re)start, quality factor is initialized to be one for all bins. Under normal condition, that is, when the bin has no ship thus not withheld, the quality factor follows the same recursive relation as the normalization factor in (9a). As time goes on, it should approach one. When a bin is withheld, the second term $w \times 1$ in (9a) should be replaced with zero:

$$q_n = (1-w)q_{n-1} + w \times \begin{cases} 1 & \text{no ship} \\ 0 & \text{bin is withheld} \end{cases} . \tag{18}$$

The quality factor q_a (with ship removed) is outputted only when the ship moves away or it is a persistently high signal (new state), just like the corresponding averaged spectrum (a) (see q_a and q_b in Figure 2).

When the quality factor of a bin is less than 50%, its spectral power of antenna 3 which is the monopole for standard SeaSonde is flipped to negative value to indicate a possible problem at this bin for diagnosis purpose. This sign reversal is done even when there are more than three channels.

3.5.4 Restart

The intermediate averages are saved in a file named `CSPro_SIA`'s after each raw cross spectra has been added to the running average. When `CSPro` is launched it looks for the `SIA`s file and read it if it exists and matched the input parameters used last time, it would use the saved average to start averaging, thus saving time to ramp up to the steady state.

3.5.5 Presumptions and Limitations

There are a few presumptions and hard-wired parameters that `CSPro` has made. Some of them have been discussed. Here a summary is given.

Three Hour Long Average As stated earlier, `CSPro` calculates two simultaneous running averages. The short average time is user defined. The internal long average is used for ship removal and restart after an interruption. Currently, it is set to be *three hour* average.

Preset Conditions on Doppler Process If the input files are range files, `CSPro` performs Doppler processing into cross spectra before averaging. The FFT length is restricted to be power of 2 between 16 and 8196, which should be adequate. Hamming window is applied before FFT. The Doppler process (running FFT) is non-overlapping for now.

Note that the order of Doppler frequency bins order after Doppler processing in SeaSonde starts from $-N_{\mathrm{FFT}}/2+1$, and the last bin is $N_{\mathrm{FFT}}/2$, spaced Δv apart. This is one bin off from the more common order which starts from $-N_{\mathrm{FFT}}/2$ to $N_{\mathrm{FFT}}/2-1$.

The form factor in calculating ship intervals in range bin in (17) is 1.2 for now. This and the choice of window could be made to be more adjustable in the future.

Aliasing in Doppler process is also not considered. This could result in more stale output average in a rare occasion that a ship does move faster the "Nyquist" velocity, as discussed in Section 3.5

DC Region The DC region for DC removal is defined as ±2 bins around around the DC Doppler bins, totaling five bins. This region is skipped in ship removal.

Near DC Region Near DC region is larger than DC region and ship removal is also skipped as discussed in Section 3.5, also see Figure 2. This region is defined as offset by *one ninth* around the DC Doppler bin with bin number (zero-based index) as,

$$j \in \left[1-\frac{1}{9}, 1+\frac{1}{9}\right] j_{\mathrm{DC}}. \tag{19}$$

Second Order Region of Bragg Peaks Doppler indices in the second order region is calculated by `CSPro` from the (positive) Bragg peak of first order,

$$j_{\pm 2} = j_{\mathrm{DC}} \pm 0.175 \frac{\sqrt{f_{\mathrm{c}}(\mathrm{MHz})}}{\Delta f_{\mathrm{Dopp}}}, \tag{20a}$$

$$= j_{\mathrm{DC}} \pm 1.72 j_{\mathrm{Bragg}}, \tag{20b}$$

where $\Delta f_{\mathrm{Dopp}} = f_{\mathrm{r}}/N_{\mathrm{FFT}}$ is the Doppler bin size in frequency unit and j_{Bragg} is the positive Bragg peak index. The sign is negative on the negative Doppler side and positive on the right side.

Start Threshold and Normalization As shown in Section 3.5.1, before the onset of ship removal specified by user, the threshold is set to be a 10^{16}. This should be high enough such that no bin is identified as a ship. (Alternatively, the output could be normalized.)

Conditions for Reset In addition to data gap above some time given by the user, `CSPro` also resets and reinitialize all variables accordingly when any of the system setting changes such as number of channels, number of range cells, FFT length, site name, average time. But `CSPro` does allow some leeway in the differences of frequency parameters as below. BW is the bandwidth of the SeaSonde radar system.

$$\delta f_{\mathrm{c}} = 10\,\mathrm{kHz}, \tag{21}$$

$$\delta f_{\mathrm{r}} = 0.01\,\mathrm{Hz}, \tag{22}$$

$$\delta \mathrm{BW} = 10\,\mathrm{Hz}. \tag{23}$$

Appendices

A An Example Preference File

The preference file is a text file. Texts follow on the same line are treated as comments. Most of the parameters are self-explanatory.

An Preference File

```
!CSPro Preferences Version  5  2006/02/24  11:25:48.        !  1. Title, version#, and creation date and time
/Codar/SeaSonde/Data/Spectra/SpectraSeries/                 !  2. Path to input files folder
/Codar/SeaSonde/Data/Spectra/SpectraToProcess/              !  3. Path to output files folder
/Codar/SeaSonde/Data/Spectra/SpectraSeriesProcessed/        !  4. Path to undeleted and processed input files folder
/Codar/SeaSonde/Data/Pictures/                              !  5. Path to automatic plot images folder
/Codar/SeaSonde/Data/Pictures/Spectra/                      !  6. Path to scripted plot images folder
*NULL*                                                      !  7. Path to 'header' file folder
/Codar/SeaSonde/Data/Processing/                            !  8. Path to 'CSPro_LastInOut' file folder
/Codar/SeaSonde/Data/Processing/                            !  9. Path to 'CSPro_LogFile' file folder
RawCSFiles                    ! 10. Type of input files? (RangeFiles/RawCSFiles)
AveragedCS NoRawCS NoV5 Ext      ! 11. Output file types? (Ave/NoA  RawCS/NoRawCS), format version (V5/NoV5, NoV5 == vers 4), file extension option (Ext/NoExt)
NoDel  SaveIA    Match        ! 12. Delete/NoDelete input files? (Del/NoD), Save/load IAs - intermediate averages (Sav/NoS), loaded IAs must Match xxx_LastInOut (Match/NoMat)
 1  2  3                      ! 13. List of channels to be used (active channels)
  1  1024                     ! 14. First and last range cells to be processed
CSS                           ! 15. Base name of averaged cross spectra files (CSA, CSS, etc.)
 15                           ! 16. Averaging period in minutes
 10                           ! 17. Output period in minutes
  8                           ! 18. Start thresholding after this # input files
 12.0                         ! 19. Threshold value
 1                            ! 20. Ship removal algorithm (0==none, 1==original, 2==new)
  60                          ! 21. Maximum time gap before restarting the running average (Minutes)
NoRemoveDC                    ! 22. Remove cross-spectra DC regions when averaging? (RemoveDC/NoRemoveDC)
WhenNeeded                    ! 23. Always/WhenNeeded use the alternate frequency, etc..
  12.500                      ! 24. Alternate frequency in MHz
  50.000                      ! 25. Alternate band width in KHz
  2.00                        ! 26. Alternate sweep repetition frequency in Hz
 Down                         ! 27. Alternate direction of the sweep is up (Up/Down)
Ave   Show   -90.000          ! 28. Autoplot data kind (Unav/Av/Inter), Autoplot Show/Hide, max dBm scale
DtPict NoJpeg                 ! 29. Autoplot output Pict (Pict/NoPict/DtPict), Autoplot output Jpeg (Jpeg/NoJpeg/DtJpeg)
dBm Stats                     ! 30. Autoplot type (dBm/Phase/6dBm), Data stats or annotation (Stats/Nostats)
1RC    7   8  21              ! 31. Autoplot style - single RC or stacked (1RC/3RC), range cell(s) to plot
NoSmoo    4                   ! 32. Autoplot smoothing (S/N), # smoothing points (4 == default)
```

References

[1] S. J. Orfanidis, *Introduction to Signal Processing*, ch. 9. Prentice-Hall, 4th ed., 1996.

[2] P. Kung, "Background calculation in codar ship detection," Internal, Codar, 2002.