QA/QC Manual for Coastal HF Radar

- Indian Coastal Ocean Radar Network (ICORN)

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EXECUTIVE SUMMARY

The Coastal and Environmental Engineering(CEE) division at National Institute of Ocean Technology (NIOT), Chennai operates and maintains a coastal High frequency radar network for measuring surface currents and waves along the Indian coast. The **I**ndian **C**oastal **O**cean **R**adar **N**etwork (**ICORN**) runs six HFR system along the east coast, and a pair of systems along the West coast and the Andaman Islands. Out of these, four systems are supported by permanent infrastructure, and the remaining systems are housed in temporary (Containers) arrangements. Each site is provided with an electrician and security personnel's to assist in the operation, maintenance and watch keep. All the sites are remotely monitored from the central station at NIOT. Installation of these systems was completed by 2010, and since then data is being received at the central servers at NIOT and INCOIS in near real time. ICORN uses long range systems (Transmit Frequency- $\sim$ 5MHz) which can cover $\sim$ 200 km offshore from a remote station at the shore and provide surface current maps in every one hour. The objective of this program is to measure and distribute high quality surface current and wave data to the scientific community. CEE group at NIOT uses HFR derived data for coastal Engineering applications, like sustainable shoreline management project under 12^{th} five year plan. ICORN also provides guide lines to the user community for basic quality control methods to be applied on the data. The potential of HFR systems are enormous and can be employed in various facets of operational oceanography and applied research.

Acknowledgements

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List of Abbreviations

NIOT	**N**ational **I**nstitute of **O**cean **T**echnology
ICORN	**I**ndian **C**oastal **O**cean **R**adar **N**etwork
CEE	**C**oastal and **E**nvironmental **E**ngineering
INCOIS	**I**ndian **N**ational **C**entre for **O**cean **I**nformation **Services**
HF	**H**igh **F**requency
CODAR	**C**oastal **O**cean **D**ynamics **A**pplications **R**adar
QA	**Q**uality **A**ssurance
QC	**Q**uality **C**ontrol
MUSIC	**MU**ltiple **SI**gnal **C**lassification
SNR	**S**ignal to **N**oise **R**atio
HFRNet	**HF- R**adar **N**etwork
ORB	**O**bject **R**ing **B**uffer

List of Symbols

λ	Wavelength of surface wave	m
λ_T	Wavelength of Transmitted signal	m
V_r	Radial component of velocity	$\mathrm{m\,s^{-1}}$
θ	Incident angle of signal	rad
ω	angular frequency	rad

Chapter 1

Basics of HF Radar measurement

1.1 Introduction

High Frequency Radar (HFR) is a tool for synoptic online mapping of surface current fields and the spatial distribution of the wave directional spectrum. HFR systems map surface currents in wide swaths of coastal waters up to 200 km off shore, 24 hours a day, and in all weather conditions. The physics behind HF radar is fairly straightforward. A transmitter broadcasts electromagnetic waves usually between 3 and 45 MHz. A vertically polarized HF signal is propagated at the electrically conductive ocean water surface, and can travel well beyond the line-of-sight.These signals scatter off waves on the ocean surface in many directions. But, the radar signal will return directly to its source only when the radar signal scatters off a wave that is exactly half the transmitted signal wavelength. The scattered radar electromagnetic waves add coherently resulting in a strong return of energy at a very precise wavelength. This is known as the Bragg principle, and the phenomenon 'Bragg scattering'. Since there are abundant waves of all wavelengths present in the ocean, there are always plenty of waves that fit this criterion.

In ideal conditions with ideal ocean waves, we can predict the frequency of the returning signal based on the Bragg principle (it is half the wavelength of the transmitted signal) and its calculated phase speed (how quickly it moves). Of course in the real world, ocean waves are never ideal, but for these purposes they are close enough. Surface currents, however, cause these waves to move. The returning signal exhibits an additional Doppler-frequency shift from the theoretical wave speed under the influence of the underlying current. In the absence of ocean currents, the Doppler frequency shift would always arrive at a known position in the frequency spectrum. The additional shift in the frequency accounts for the current. The frequency increases if the current pulls the waves towards the transmitter and decreases if it pushes them away. By measuring this Doppler shift, we can determine the speed of the currents towards or away from the transmitter. To calculate the directions of the currents, we need a second HF radar installation measuring the same currents from a different angle. The location of the second site depend on the frequency of operation. Detailed description of the radial current measurement is provided in section 1.2. The waves are measured from the second order spectra in the sea echo spectra, details are provided in section 1.3.

1.2 Radial Current mapping

The basic mechanics of an HFR system is the analysis of a back-scattered radio wave. The HFR system works very much like a radio station in that it emits a radio signal. While a radio station does not monitor the signal that is scattered back to the station, a HFR site uses this back-scattered radio wave to calculate surface currents. The omni-directional transmitter antenna radiates signal in all directions and the receiver antenna unit, which consists of three colocated antennas, oriented with respect to each other on the x, y, and z-axes receives the backscattered echo. The cross loop antennas are able to separate returning in all 360 degrees with respect to the monopole antenna. For mapping 2D currents, the radar needs to determine three pieces of information:

1. Range of the Target
2. Speed of the Target
3. Bearing of the scattering source (Target)

1.2.1 Range of the Target

Most of the conventional radar systems measure the distance to a target by measuring the time delay of the return signal. If the speed of the signal and the time is known, then the total distance traveled can be calculated. The range to the target would then be half the total distance. The problem with this method is that HFR system needs to be resolved to very fine grid points (about 1 km). Since it does not take very long for a signal travelling at the speed of light to move 1 km, a very sensitive watch is needed. CODAR overcomes this by modulating the transmitted signal with a swept-frequency signal and demodulating it properly in the receiver, the time delay is converted to a large-scale frequency shift in the echo signal. The frequency of an modulated signal increases linearly with time (as shown in Figure 1.1).

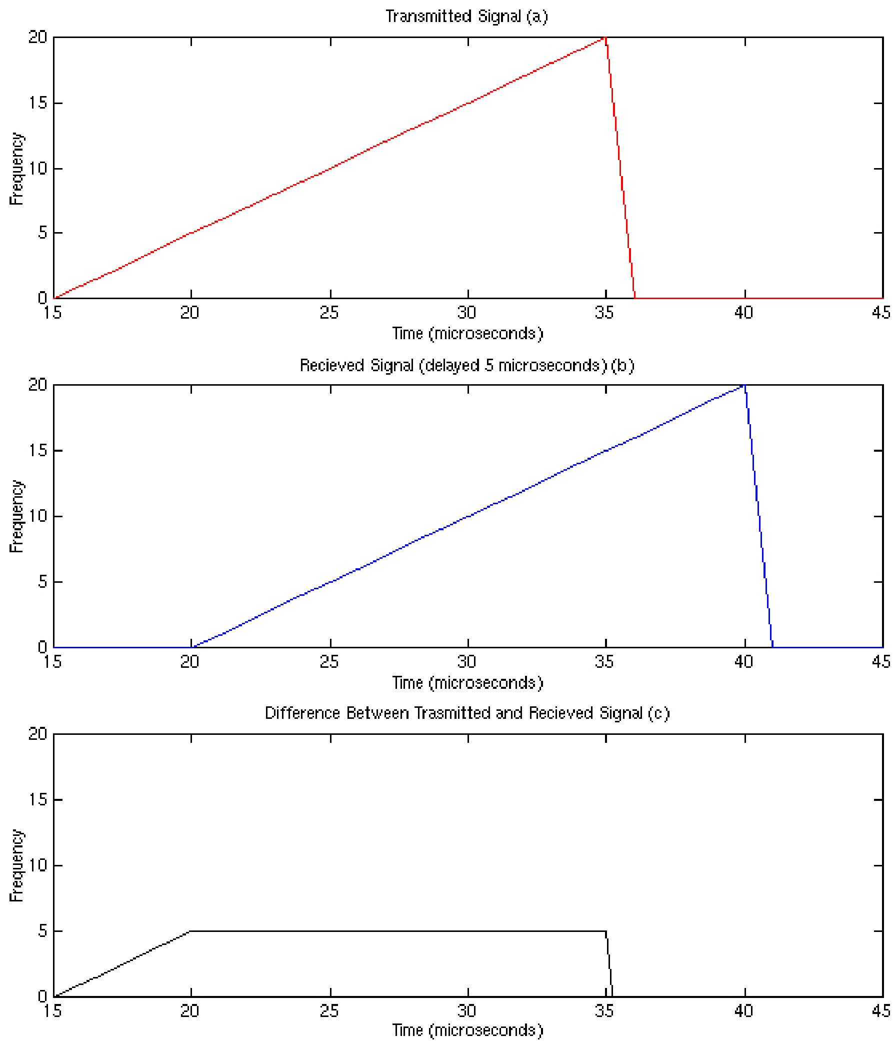

FIGURE 1.1: Range of the target

The time delay can therefore be measured by subtracting the return signal (b) from the transmitted signal (a). The difference (c) will be equal when both signals are present since they both increases at the same rate. So, higher the frequency of the horizontal line, the further away the target. This time delay is then used to determine the range to the target. The first digital spectral analysis of the signal extracts the range or distance to the target, and sorts it into range 'bins' (typically set to 32 bins for long range systems but capable up to 64 bins).

1.2.2 Speed of the Target

The speed of the target is obtained from the second spectral processing of the signals from each range bin. It gives the Doppler-frequency shifts due to the presence of the current and wave motions. Since the ocean surface scatters a signal in many different directions, but the resonant Bragg Scattering basically amplifies the scattered signal directed toward the receiver using resonant theory.

$$\lambda = \frac{\lambda_{radar}}{2cos\theta} \tag{1.1}$$

Where:

λ : Wavelength of surface waves

θ : Incident angle of the signal

Since the CODAR antennas are very close to sea level, the incident angle of the signal is assumed to be zero. This assumption reduces the above equation to:

$$\lambda = \frac{\lambda_{radar}}{2} \tag{1.2}$$

Therefore the signal that traveled a whole wavelength further will line up the first signal. When all of the scattered signals directed toward the receiver are in lined up, each signal is added to the other and results in a stronger signal. All of the above equations assume that the surface waves are not moving. In fact the waves are moving and a moving wave will change the frequency of the return signal. This phenomenon is known as the Doppler Shift. The frequency of a signal scattered by a moving wave will be shifted depending on the velocity of the surface wave. If the wave is approaching the receiver, the return frequency increases. On the other hand, a wave moving away from the receiver will return a lower frequency. Therefore the shift will be positive if the wave is moving toward the receiver and negative if the wave is moving away from the receiver. The following equation is used to measure the magnitude of the frequency shift:

$$\Delta f = \frac{2V_r}{\lambda} \tag{1.3}$$

where:

Δf : Wavelength of surface waves

V_r : Radial component of velocity

Using linear wave theory the velocity of the surface waves can be calculated. the solution to the above equation will give the size of the Doppler shift for an approaching and receding wave. Note that the magnitudes will be the same with the exception of the sign. An example of a return signal is shown in the Figure 1.2 below. Notice how the size of the two peaks is amplified by the Bragg Scattering. The relative size of the peaks tells us which way most of the waves are moving. In the Figure 1.2 the negatively shifted peak is larger and therefore it can be said that the wind is forcing most of the waves offshore (i.e. an offshore breeze is present).

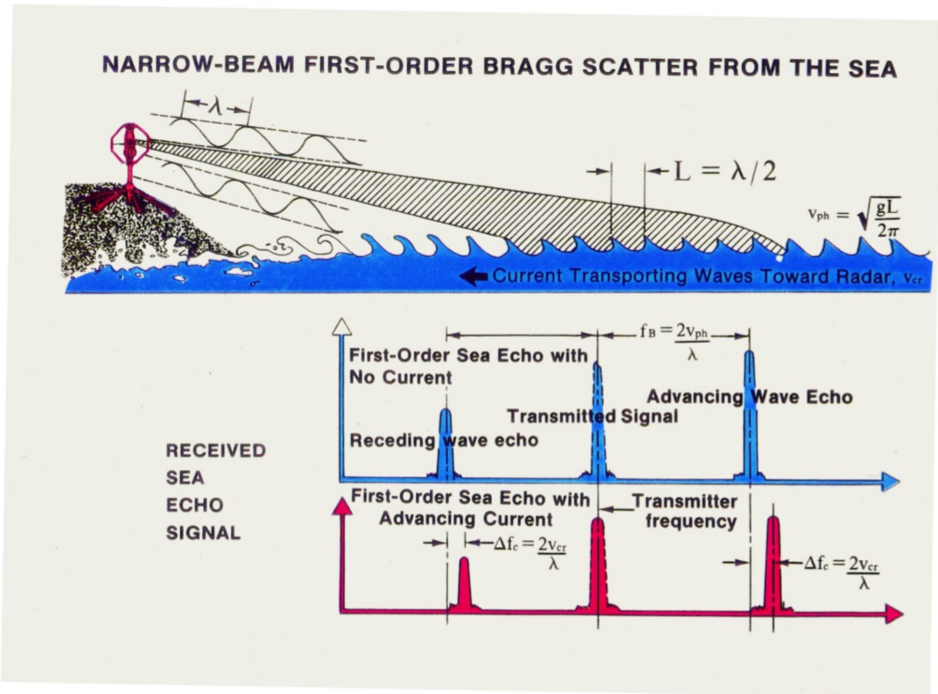

FIGURE 1.2: Radar spectrum [courtesy:CODAR]

The Doppler shift calculated by Eq 1.3 is assuming that there is no surface current changing the motion of the waves. So, the current can be calculated by measuring the frequency shift from the original Doppler shift caused by the wave motion. If there is no current then the Doppler shift caused by the surface wave motion will not be changed. If however, the surface current is not zero, the frequency will be shifted further depending on the magnitude and direction of the current (see the Figure 1.2). The Doppler equation is used again to calculate the velocity of the target using the frequency shift measured by the receiver antenna. Note that only radial velocity is calculated (moving toward or away from the receiver), therefore atleast two site to determine the total current vector at a given point.

The length of the time series used for the spectral processing dictates the velocity resolution;

$$r = \frac{\lambda_{radar}}{2T} \tag{1.4}$$

Where:

r : resolution of velocity measurement

λ_{radar} : wavelength of transmitted signal

T : length of the time series

At 5 MHz for a 1024-second time-series sample, this corresponds to a velocity resolution ~3 cm/s. The velocity accuracy is a separate quantity; it can be better or worse than this depending on environmental factors.

1.2.3 Bearing of the Target

After the range and their radial speeds have been determined by the two spectral processing steps outlined above, the final step involves extraction of the bearing angle to the patch of scatterers Codar (*Codar Ocean Sensors - Introduction to HF Radar Technology*). This is done for the echo at each spectral point (range and speed) by using simultaneous data collected from the three colocated directional receive antennas or phased array antennas. The complex voltages from these three antennas are put through a 'direction-finding' (DF) algorithm to get the bearing. WERA systems use beam-forming methods to determine the direction of arrival of backscattered echo, whereas CODAR uses direction-finding algorithm MUSIC (MUltiple SIgnal Classification) to determine the bearing of the received signal. At the end of these three signal-processing algorithms, surface-current radial speed maps are available in polar coordinates i.e., the radial speeds on the ocean are specified vs range and bearing about the origin, which is the radar site.

1.3 Wave Measurement

The wave height parameters are derived from second order characteristics of the sea-echo spectra. Wave measurements are obtained by applying inverse methods to the power spectrum. This process though numerically complex for the full directional spectrum, is again easier when the spectrum is from a single range-direction cell Wyatt (2005) and Lipa and Nyden (2005).

1.4 Type of HF Radar Data files

HF Radar data can be divided mainly into three types according to the different level of processing.

1). Spectra data

2). Radial vector data

3). Wave data

4). Diagnostic Files

5). Total current vector data

1.4.1 Spectra data

The radial spectra are the initial data obtained from the HF Radar from sweeps of the radar. The Spectra can be stored after particular intervals for different purposes such as for detection of Tsunami and for obtaining waves and currents. We discuss both the case below.

1.4.1.1 Spectra for Tsunami

The spectra for tsunami detection is stored about every 2-4.5 min.from the spectra sweeps depending on the operating frequency and sweep rate.

1.4.1.2 Spectra for Waves and Radials Cross spectra

Cross Spectra files are produced by a HFR Radial Site. They contain a snapshot in time of the ocean state in a cross spectra format, which is computed from nominally three antenna measurements. This data represents the reflected energy at each detectable range distance and radial Doppler velocity as well as the cross spectra ratios of the antennas compared to each other. The cross spectra files are then used to calculate radial velocity vectors and ocean wave states. The spectra for waves and currents are stored at an interval of 18 minutes for the low-frequency systems to 4 minutes at the upper frequencies. These data are then averaged over a user-selected time period (typically an hour for long-range), to create a radial vector map at the radar station.

1.4.2 Radial Vector Data

Each radial vector describes the measurable portion of a current vector in relation to the remote site. The radial velocity is measurable portion of the current velocity moving towards or away from the HFR system. Current velocities, which run perpendicular to the HFR system,, will have a zero radial vector component, while current velocities, which run directly towards or away from the HFR system, will have a 100 percent radial vector component. A positive radial velocity is moving towards the HFR system, while a negative radial velocity is moving away from the HFR system. The radial bearing angle indicates the direction out from the HFR system to where the radial vector is located. The radial range cell minus one multiplied by the distance between range cells plus the first range cell distance indicates how far away the radial vector is located.

1.4.3 Wave data

Wave files provide the wave height, wave period and wave and wind direction in every half an hour (for long-range system).

1.4.4 Diagnostic Files

The diagnostic files produced in every 10 minutes at the site provides the working condition of various electronic components of the system (Temperature, resistance, transmitted power, reflected power etc..). This data helps is monitoring different components and smooth running of the system.

1.4.5 Total Current Vector Data

Radial speed maps from at least two radars are normally used to construct a total vector from each site's radial components. At the central data combining station, the radial vector maps from multiple radar stations are merged to create a total velocity vector current map.

Chapter 2

Indian Coastal Ocean Radar Network

2.1 Introduction

Coastal and Environmental Engineering Division (CEE) of NIOT operates and maintains a network of HFR systems along the Indian coast and Andaman Islands known as Indian Coastal Ocean Radar Network (ICORN) as a part of Indian Ocean Observation Network (OON) project of MoES. The First phase of the installation of HF radar systems started in 2008 and was completed by 2010. Out of 10 sites 6 are located along the east coast of India, a pair covering Gulf of Khambhat in Gujarat and remaining two are in Andaman Islands. Location and coverage of the HFR stations at each state is provided in Figure 2.1. ICORN uses compact direction-finding(DF) systems (SeaSonde) manufactured by CODAR Ocean Sensors, USA. SeaSonde systems have a transmitter antenna (height 7 m) and a receiver antenna (height 4 m) with two magnetic dipoles (named loop1 and loop2) and one electric monopole. Remote stations are named with 4 characters for their identification, usually they bear the first four letters of the local town.

In Tamil Nadu (Cuddalore – CUDA, Kalpakkam – KALP), Andhra Pradesh (Machilipatanam – MACH, S Yanam – YANM), Odisha (Gopalpur – GOPA, Puri – PURI), Gujarat (Wasi borsi – WASI, Jegri – JGRI), Andaman Islands (Port Blair – PTBL, Hut bay – HTBY). The radial files carry these names and corresponding timestamps for each data in the archive. The size of the radial data files are of the order of 200 Kilo bytes (Kb) and are transferred to the central servers at NIOT and INCOIS through V-SAT/GPRS network every one hour for radial velocity, 30 minutes for waves and every 10 minutes for the site diagnostic files. Diagnostic files help in analysing the current working condition of various components of the system and aid in the Quality Assessment/Quality control (QA/QC) procedures of the data (Jena et al. (2018)). The flowchart of the data management of the ICORN is provided in Figure 2.2.

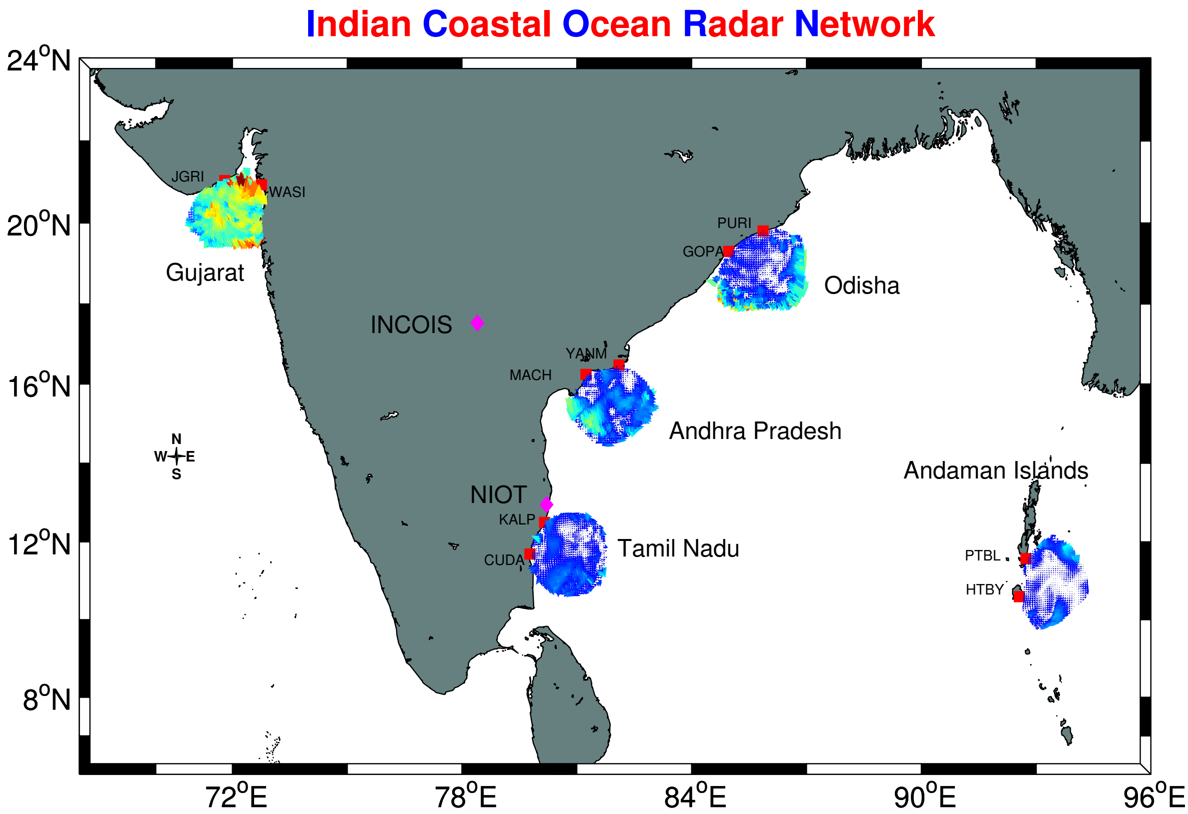

FIGURE 2.1: The radar stations are depicted by the solid red squares and the 2D surface current maps are plotted at each paired sites. The central data servers at NIOT and INCOIS are marked by magenta color diamond markers.

Percentage of availability of surface current data in ICORN during 2008 to 2017 is provided in Table 2.1. Lower percentages of data at certain sites are either due to natural disasters or technical glitches in the equipments. ICORN provides data to the researchers on a request basis through INCOIS. Presently the main users of this data are academia (Coastal Zone Management Studies - Anna University, Andhra University, Annamalai University- Chidambaram, Indian Institute of Technologies - Chennai, Mumbai, Khargapur and Bhubaneswar) and research institutes (NIO - Goa, IGCAR - Kalpakkam, SAC - Ahmedabad, NODPAC - Kochi, Visakhapatnam, NPOL - Kochi, NRSC, Hyderabad).

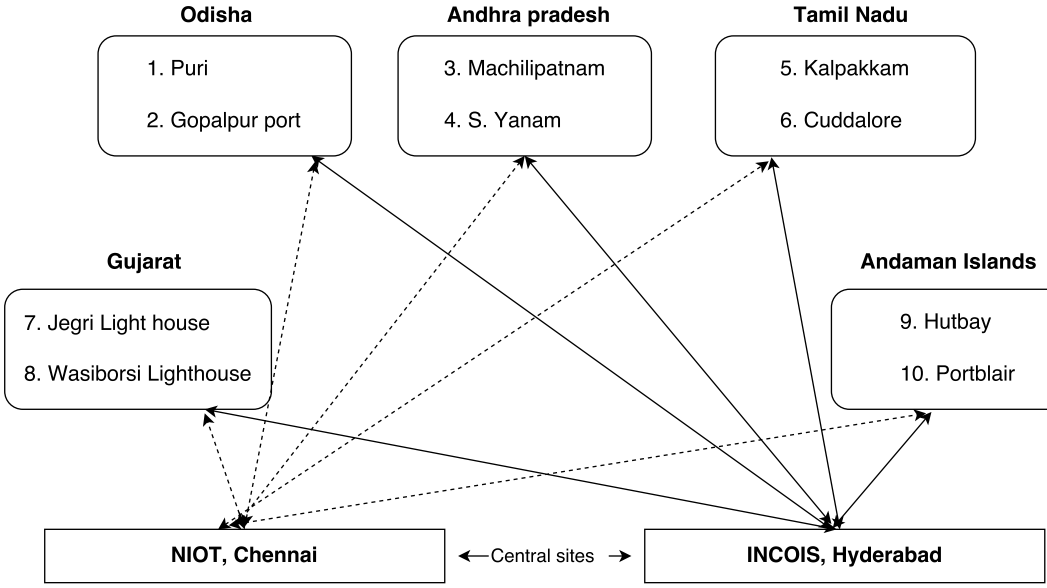

FIGURE 2.2: Flowchart showing the data transfers from remote sites to the central station and vice verse

TABLE 2.1: Percentage availability of Current data from ICORN at different sites during 2008 to 2017

State	Year / Site	2008 (%)	2009 (%)	2010 (%)	2011 (%)	2012 (%)	2013 (%)	2014 (%)	2015 (%)	2016 (%)	2017 (%)	2018 (%)
Tamil Nadu	CUDA	12	84	61	90	24	56	96	94	97	95	95
	KALP	53	91	99	99	95	52	97	96	96	98	97
	Combined	11	76	61	84	24	48	93	90	93	92	93
Andhra Pradesh	MACH	10	59	82	90	68	68	85	67	98	88	88
	YANM	2	10	45	64	66	25	81	78	83	86	88
	Combined	2	8	41	54	43	16	69	59	81	79	75
Gujarat	WASI	NA	35	72	76	80	93	71	35	62	8	94
	JGRI	NA	55	89	83	78	43	83	82	65	61	87
	Combined	NA	29	65	65	66	41	57	33	58	7	83
Odisha	GOPA	NA	15	45	76	37	49	2	97	87	93	88
	PURI	NA	7	73	87	23	26	73	95	88	96	96
	Combined	NA	7	44	67	16	22	2	93	82	90	83
Andaman Islands	PTBL	NA	NA	47	74	60	62	63	97	93	98	97
	HTBY	NA	NA	57	89	81	47	93	52	88	95	93
	Combined	NA	NA	42	67	48	36	60	51	82	93	84

Legend (cell colours): green $\geq 70\%$; yellow $\geq 50 < 70\%$; orange $< 50\%$; blue Not installed

Chapter 3

Quality Assurance/ Quality Control (QA/QC)

3.1 Need for quality control

The HF Radar data is obtained by remote sensing technology, with no part of the equipment in direct contact with water and the instrument measure surface currents to a very reliable level. This necessitates frequent checks and maintenance of the system to obtain continuous data and to avoid the possibility of erroneous in data archived over time for various scientific use. The uncertainties associated with HFR measurements are: (a) variations of the radial current field within the radar scattering patch and over the duration of the radar measurement; (b) Error from calibration (Antenna Pattern measurement) or from first order line determination; (c) Interferences in spectral data from power-line disturbances, ionosphere clutter, radio frequency interferences, or other environmental noises Rubio et al. (2017). These uncertainties will affect the spatial and temporal resolution of the data. Frequent calibration and validation exercises are carried out to minimize the discrepancies in the current and wave measurement. To remove and check all these irregularities there is a need for Quality Assurance (QA) and Quality Control (QC) which will give the user the methods and criteria for the usage of the HF radar data. This manual intends to put forward any possibilities of error creeping in to the data and also briefs about problems one might face when working with a HF Radar system.

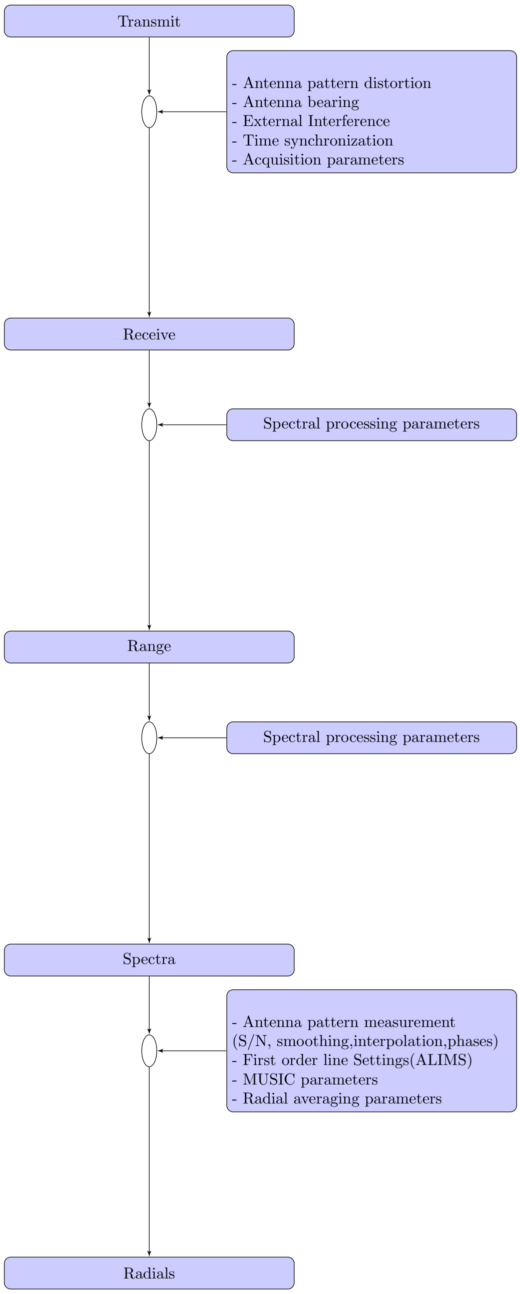

FIGURE 3.1: Flowchart of the main stages in the production of SeaSonde radials and the major factors that affect data quality.[courtesy:CENCOOS]

3.2 Methodology adopted for QA/QC

For the optimal measurement ocean surface current radial velocity of each remote sites are configured with adequate quality control parameters. Various factors that affects the data quality during the production of radial velocity vectors are detailed in the Figure 3.1. The best configuration of each SeaSonde site determined by the operator includes the optimization of software settings, such as the 1st-order line settings (a.k.a. ALIMS), radial averaging, and MUSIC parameters. As the highest quality radials are always produced when a SeaSonde has been properly calibrated via an antenna pattern measurement (APM), only measured radials produced with such an APM can be considered fully quality assured. Steps taken for maintaining the quality of the data are explained in coming sections.

3.3 Antenna Pattern Measurement (APM) of HF Radar System

Validation of the installation is done by Antenna pattern measurements (APM). This is done to check if there are any factors such as ferromagnetic materials or other materials in the vicinity of the radar which may interact with other the Bragg Echo. The rule of thumb is to keep them away by more than one wavelength(λ). The APM has been done mainly in two ways

- Walking APM– This is obtained by moving a signal source, such as a transponder, around the receive antenna with walking so that the signal can be used to calibrate the antenna response at all bearings from which sea echo is received.
- Boat APM– It is obtained by moving a signal source around the receive antenna in a boat.The boat APM costs time and money and is dependent on local weather conditions. But the boat APM is preferred over walking APM as it configures the system more precisely.

Precautions to be taken during APM

- Cover whole area from where the Bragg Echo is expected
- The pattern should be taken at a distance more than one wavelength (λ)
- Keep one λ distance from other objects that may interfere with the APM data
- Do walking pattern in shallow waters
- Do boat pattern in Deep waters

Ideal Pattern Characteristics

- There should be less spikes and dips in the patterns
- The amplitudes between the loops should be balanced
- Nulls from one loop correspond to center of other loop antenna lobe
- A concentric circle should intersect a lobe only at two points
- Less distractions in the vicinity gives clear pattern

According to the measured APM derived data, the bearing of the receiving antenna is fixed. The HF Radar data that comes to the NIOT central site mainly consist of the radials and the waves from the various regional sites. All the data from the individual sites are transmitted to the central site through Hughes V-sat system.

3.4 Quality control stages

Radial data is quality controlled during each of three main processing stages:

- On-site at the Radar installation during production of geo referenced radial velocities with bearing determination from raw signal voltages figure
- Upon acquisition of radial data by HFRNet Portals
- During processing for production of synoptic surface current maps

The details of the radial QC are documented below along with work in progress aimed at delivering the next generation of QC metrics.

3.4.1 On-Site Radial Velocity QC

Radial velocities derived from surface ocean back scatter of HF-Radar are dependent upon the quality of Doppler spectra formed from the reflected energy. Prior to estimating radial velocities, the manufacturer's software performs quality control on the Doppler spectra to ensure they are of suitable quality for velocity estimates. The internal software parameters used to determine whether spectra are acceptable have been empirically derived and refined over twenty years of research, development and user feedback. These tests include, but are not limited to:

- Noise floor detection and computation
- First order Bragg peak detection and measurement (Doppler frequency limits of first order are determined in CODAR systems)
- Second order peak detection and measurement
- Individual spectrum signal to noise ratio (SNR) computation for the first and second order peak
- First to second order ratio measurement

Doppler spectra that do not meet these criteria are rejected and radial velocities are not produced from them. Since these processes influence the production of radial velocities they are inherently part of the quality control process for surface currents.

3.4.2 HFRNet Portal QC

Radial data QC is performed upon file acquisition by HF-Radar Network (HFRNet) Portals and consists of basic file integrity and consistency tests. Any given radial file must pass all QC tests before being placed in the object ring buffer (ORB) for distribution in the network. Performing basic QC on files upon acquisition prevents incomplete files from entering the network and allows downstream quality control to focus on specific tests such as radial velocity uncertainty. The specific tests performed on radial velocity files upon acquisition by a Portal are described below. Radial files failing to meet these criteria are not placed on the ORB for distribution.

3.4.2.1 File Format Independent Tests

All radial files, regardless of format, must have a timestamp consistent with the current date or a past date, not a date in the future. This test was established in order to protect against occasional files with timestamps from the far future (i.e. year 2040). Currently, 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.

3.4.2.2 CODAR Range-Bin Format Tests

Range-bin format files are converted to LLUV format before distribution through the ORB. Several QC tests are performed upon converting the file including:

- The file name timestamp must match the timestamp reported within the file
- Files must contain radial data (bearing, velocity & uncertainty)
- As a minimum, the following metadata mustbe defined:
  - Site code (obtained from filename)
  - Timestamp (obtained from filename)
  - Site coordinates (reported within file)
  - Antenna pattern type (measured or idealized, obtained from filename)
  - Timezone (UTC or GMT only accepted, reported within file)

3.4.2.3 LLUV Format Tests

Before placing LLUV format files on the ORB the following tests are performed:

- The file name timestamp must match the timestamp reported within the file
- Radial data tables (Lat., Lon., 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 <=Longitude <180

  - 90 <=Latitude <90

- As a minimum, the following metadata must be defined:
  - Filetype (LLUV) Site code
  - Timestamp
  - Site coordinates
  - Antenna pattern type (measured or idealized)
  - Timezone (UTC or GMT only accepted)

3.4.3 Surface Current Processing

Once radial data arrives at an HFRNet Node it is available for integration with other radial velocity measurements from neighboring sites through surface current mapping. The HF-Radar Network's primary proto-operational product is the generation of real-time velocities (RTV) which are ocean surface currents mapped from radial component measurements. There are three general steps in producing RTVs:

1) Radial data QC
2) Surface current mapping
3) Resolved surface current QC

3.4.3.1 Radial Velocity QC

Questionable radial velocity measurements are removed prior to mapping surface currents in order to reduce error. Two criteria must be met in order for a radial measurement to be used in deriving RTV solutions. The radial velocity must be (a) below the maximum radial magnitude threshold and (b) located over water. The maximum radial magnitude threshold represents the maximum reasonable radial magnitude for the given domain. Landmasking of radial solutions is performed using polygons derived from the World Vector Shoreline database. Radial velocities derived from CODAR systems are additionally filtered by the vector indicator flag value when reported. Vector flag values of +128 indicate that the radial velocity is outside of the angular sector coverage filter area and should not be used for total processing Radials are files with one dimensional current speed files obtained for various bins from the HF Radar. Two radials combined together will give the direction of the current at the respective bins. The more the size of the radial file means the more data obtained from the site. The parameters in the radial file includes Longitude, Latitude, U comp, V comp, VectorFlag, Spatial quality Temporal quality, Velocity Maximum, Velocity Minimum, Quality DV Count, Quality RT Count, X Distance, Y Distance, Range, Bearing, Velocity, Direction and Spectra. The radials are stored in the folder radials that can be accessed from the central site. The folder will be at Desktop > Codar Data> Radial-Sites, and is shown in Figure 3.2.

The individual sites have their own folders into which the radials are stored. The primary check of the data includes the size of the radials that have arrived from each

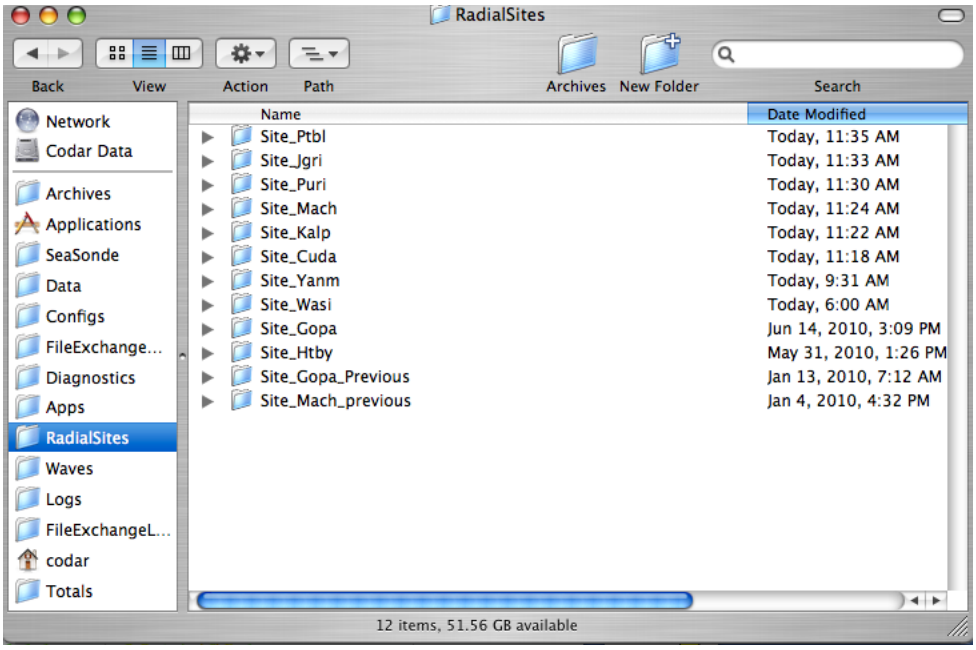

FIGURE 3.2: Screen shot of the File system in Central station

site. Normally a good radial will have a size more than about 150KB. This value will change according to the respective site conditions. Standard size range of the data for individual HF Radar sites are given in the Table 3.1

Even though the data is expected to be of this size there will be situations where the data will be very well less than the ones listed above. This could arise due to the local conditions or due to various atmospheric interference's. The diurnal variation of the ionosphere also affects the data quality and size of the data. For instance the size of the data can reduce to a very low value which in turn may reduce its quality. The lowest limit of the data that can be considered to be useful is set to be 20Kb. Any value less than that would be considered as 'no data' and will be rejected from further usage.

3.4.4 Surface Current Mapping

Surface currents are mapped on to regional grids based on equidistant cylindrical projections with resolutions of 500m,and 6km. Regional grids have been developed for the East Coast of India and West coast of India. In order to reduce the solution space, grid points over land and near the coast (within $\frac{1}{2}km$) are removed. Surface currents are derived using a least squares fit to radial velocities (following Gurgel (1994)) within

TABLE 3.1: Data sizes of radial data from different sites

No	Site Name	Site code	State	Normal size of radial
1.	Cuddalore	CUDA	Tamil Nadu	>180 Kb
2.	Kalpakkam	KALP	Tamil Nadu	>180 Kb
3.	Machilipatanam	MACH	Andhra pradesh	>150 Kb
4.	Yanan	YANM	Andhra pradesh	>180 Kb
5.	Puri	PURI	Orissa	>150 Kb
6.	Gopalpur	GOPA	Orissa	>180 Kb
7.	Wasi Borsi	WASI	Gujarat	>100 Kb
8.	Jegri	JGRI	Gujarat	>100 Kb
9.	Port Blair	PTBL	Andaman Is.	>100 Kb
10.	Hut Bay	HTBY	Andaman Is.	>100 Kb
11.	Periyakuppam	PERU	Tamil Nadu	>300 Kb
12.	Chinnakuppam	CHIN	Tamil Nadu	>300 Kb

a pre-defined distance from each grid point. Radials must come from at least two different sites and there must be at least three radials available in order to produce a velocity estimate for a given grid point. The search radius around each grid point is approximately 30% greater than the grid resolution. Actual search radii for each grid resolution defined are given in Table 3.2. The contribution of each site's radials to solutions for a given resolution are currently determined solely by the site's operating frequency. Sites operating near 25 MHz and higher contribute to solutions at 0.5 km resolution, 5 MHz contribute to solutions at 6 km resolution. Site selection for each resolution will eventually be determined by the radial range resolution instead of operating frequency.

TABLE 3.2: Grid resolution and search radius

Grid resolution(km)	Search radius(km)
0.5	.75
6.0	10

We get both the direction and the speed from the Totals. The total file also provides various statistical values such as the Standard Deviation and covariance which will help us to determine the quality of the data. The Total file includes Longitude, Latitude, U comp, V comp, Vector Flag, U StdDev, V StdDev, Covariance, X Distance,Y Distance, Range, Bearing and Velocity Direction.Totals are produced by the CODAR software automatically from radials of the two respective sites and stored in Desktop > Codar Data> Totals.

The preliminary check for the Totals is also similar to that was done for the Radials. The size of the Totals will depend on the two radials received from the adjacent HF Radar installations simultaneously for a time. More the size of the Total means the quality and continuity of the corresponding Radials has been good. The Total files can be viewed using the 'Text Editor'. Codar also provides 'Sea Display' software to view the totals in the graphical mode. Totals of the individual regions will be normally will be of the size as is given in Table 3.3

Surface currents derived from integrated radial velocity measurements must not exceed the following thresholds:

- Maximum total speed threshold
- Maximum Geometric Dilution of Precision (GDOP) threshold

Like the maximum radial speed threshold, the maximum total speed threshold represents the maximum reasonable surface velocity for the given domain. The maximum total current threshold is 2.5 m/s for the Gujarat coast and 2.0 m/s for the east coast of India. GDOP is a scalar representing the contribution of the radial (bearing) geometry to uncertainty in velocity at a given grid point. Higher GDOP values indicate larger covariances associated with the least square's fit used in obtaining the solution. The GDOP maximum threshold is 10 for all domains. However, near-real time applications such as web display apply a more conservative maximum threshold of 1.25

TABLE 3.3: Total current data size

No	Total Station	Normal size of Total
1	Tamil Nadu	>150 Kb
2	Andhra pradesh	>150 Kb
3	Orissa	>150 Kb
4	Gujarat	>100 Kb
5	Andaman Is.	>100 Kb
6	Tamil Nadu(25 MHz)	>250 Kb

to the RTV solutions. The group adopted some of the quality checks and practices followed by IOOS (2016)

The quality control procedures check list that has been following in remote sites as well as central station are added in the Appendix A. Content of a typical Radial data file, Total data file and wave file are given in Appendix B,C, and D.

3.5 Summary

Responding to clear requirements for increased and improved coastal surface current measurements throughout the Indian coastal waters, NIOT has developed this manual. HF radar systems are the most cost-effective technology for meeting the regional coastal ocean observation systems.Numerous applications of HFR data have already been underway and have proven to be effective for near-real time decision making. Examples include hazardous spill tracking and response, wastewater pollution tracking, and marine navigation. Assimilation of HFR data into circulation models has been shown to increase model nowcast/forecast accuracy. Providing the HFR data and products requires a national data server and management infrastructure. For the past 10 years, NIOT and INCOIS under MoES has funded the development of this infrastructure and provides valuable oceanographic data to the scientific community.Under this Plan, the national capability would add increased quality control, archiving, regional operational model assimilation of HFR data, transitioning regionally-developed products to national application.

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Appendix A

Table for Daily status Report

Date :							Daily Status Report							
Total Site	Radial Site	Time of Check HH:MM	Controller Configuration Parameters	Latest File at Combine Site	Radial Max Range	RX Temps	RX Voltages	RX Humidity	TX Temps	TX Voltages	TX Amplifier Temp	Site Alerts	Action Taken	Pending Issues/Remarks
Total site 1	Radial site 1	09:00												
		13:00												
		17:00												
	Radial site 2	09:00												
		13:00												
		17:00												

TABLE A.1: Daily QA/QC report format

Appendix B

Radial file


```
%CTF: 1.00
%FileType: LLUV rdls "RadialMap"
%LLUVSpec: 1.18  2012 05 07
%UUID: 5FB50B68-C8CF-4292-8972-8BC647BD01AF
%Manufacturer: CODAR Ocean Sensors. SeaSonde
%Site: Cuda ""
%TimeStamp: 2017 11 01  18 00 00
%TimeZone: "IST" +5.500 0 "Asia/Calcutta"
%TimeCoverage: 180.000 Minutes
%Origin:  11.6862333   79.7733167
%GreatCircle: "WGS84" 6378137.000  298.257223562997
%GeodVersion: "CGEO" 1.57  2009 03 10
%LLUVTrustData: all %% all lluv xyuv rbvd
%RangeStart: 1
%RangeEnd: 34
%RangeResolutionKMeters: 5.824900
%AntennaBearing: 148.0 True
%ReferenceBearing: 0 True
%AngularResolution: 5 Deg
%SpatialResolution: 5 Deg
%PatternType: Ideal
%PatternDate: 2011 10 10  10 20 44
%PatternResolution: 1.0 deg
%TransmitCenterFreqMHz: 4.400000
%DopplerResolutionHzPerBin: 0.000488281
%FirstOrderMethod: 0
%BraggSmoothingPoints: 3
%CurrentVelocityLimit: 150.0
%BraggHasSecondOrder: 0
%RadialBraggPeakDropOff: 125.890
%RadialBraggPeakNull: 100.000
%RadialBraggNoiseThreshold: 4.000
%PatternAmplitudeCorrections: 1.0003  1.0003
%PatternPhaseCorrections: 92.00  112.90
%PatternAmplitudeCalculations: 8.7619  249.1347
%PatternPhaseCalculations: 66.10  115.10
%RadialMusicParameters: 40.000 20.000 2.000
%MergedCount: 5
%RadialMinimumMergePoints: 1
%FirstOrderCalc: 1
%MergeMethod: 1 MedianVectors
%PatternMethod: 1 PatternVectors
%TransmitSweepRateHz: 1.000000
%TransmitBandwidthKHz: -25.733913
%SpectraRangeCells: 57
%SpectraDopplerCells: 2048
%TableType: LLUV RDL9
%TableColumns: 18
%TableColumnTypes: LOND LATD VELU VELV VFLG ESPC ETMP MAXV MINV ERSC ERTC XDST YDST RNGE BEAR VELO HEAD SPRC
%TableRows: 903
%TableStart:
%%   Longitude   Latitude    U comp   V comp  VectorFlag    Spatial   Temporal   Velocity   Velocity  Spatial  Temporal X Distance  Y Distance    Range  Bearing   Velocity  Direction   Spectra
%%     (deg)       (deg)     (cm/s)   (cm/s)  (GridCode)    Quality    Quality    Maximum    Minimum    Count    Count      (km)        (km)      (km)   (True)    (cm/s)     (True)   RngCell
     79.7898292  11.7363125   0.660    2.032          0     999.000    999.000     -2.137     -2.137        1        1     1.8000      5.5398    5.8249    18.0     -2.137      198.0         1
     79.7941956  11.7347034   0.835    1.967          0     999.000      4.763     -2.137     -2.137        1        4     2.2760      5.3618    5.8249    23.0     -2.137      203.0         1
     79.7984029  11.7327255   2.176    4.091          0     999.000     12.484     -4.633     -4.634        1        2     2.7346      5.1431    5.8249    28.0     -4.634      208.0         1
     79.8024193  11.7303936   0.937    1.443          0       0.832      5.663     -1.305     -2.137        2        4     3.1725      4.8852    5.8249    33.0     -1.721      213.0         1
     79.8062140  11.7277256   0.804    1.028          0       0.832      2.962     -0.472     -2.137        2        3     3.5862      4.5901    5.8249    38.0     -1.305      218.0         1
     79.8097583  11.7247418   1.458    1.563          0       4.994    999.000      7.851     -2.137        2        1     3.9726      4.2601    5.8249    43.0     -2.137      223.0         1
     79.8130251  11.7214649   7.774    6.998          0     999.000    999.000    -10.460    -10.460        1        1     4.3287      3.8976    5.8249    48.0    -10.460      228.0         1
     79.8159896  11.7179198   8.355    6.294          0       0.832      2.497     -9.628    -11.292        2        2     4.6520      3.5055    5.8249    53.0    -10.460      233.0         1
     79.8186292  11.7141336   3.930    2.455          0       5.826    999.000      1.192    -10.460        2        1     4.9398      3.0867    5.8249    58.0     -4.634      238.0         1
     79.8209239  11.7101351 -11.074   -5.640          0       0.832      7.620     12.845     12.012        2        4     5.1900      2.6444    5.8249    63.0     12.428      243.0         1
```

Appendix C

Total file


```
%CTF: 1.00
%FileType: LLUV tots "CurrentMap"
%LLUVSpec: 1.17  2011 06 20
%UUID: 8F8D69AC-9F3B-4A74-A2A0-3B071B27F591
%Manufacturer: CODAR Ocean Sensors. SeaSonde
%Site: Apco ""
%TimeStamp: 2018 11 03  15 00 00
%TimeZone: "IST" +5.500 0 "Asia/Kolkata"
%TimeCoverage: 150.000 Minutes
%Origin:  16.0000000   82.0000000
%GreatCircle: "WGS84" 6378137.000  298.257223562997
%GeodVersion: "CGEO" 1.57  2009 03 10
%LLUVTrustData: all %% all lluv xyuv rbvd
%GridAxisOrientation: 0.0 True
%GridCreatedBy: SeaDisplay 5.1.3c
%GridVersion: 4
%GridTimeStamp: 4  2007 12 01  00 00 00
%GridLastModified: 2008 03 18  18 48 22
%GridAxisOrientation: 0.0 DegNCW
%GridAxisType: 6
%GridSpacing: 6.000 km
%AveragingRadius: 10.000 km
%DistanceAngularLimit: 25.0
%CurrentVelocityLimit: 140.0 cm/s
%TableType: LLUV TOT4
%TableColumns: 16
%TableColumnTypes: LOND LATD VELU VELV VFLG UQAL VQAL CQAL XDST YDST RNGE BEAR VELO HEAD S1CN S2CN
%TableRows: 926
%TableStart:
%%  Longitude   Latitude    U comp   V comp  VectorFlag   U StdDev    V StdDev   Covariance  X Distance  Y Distance    Range   Bearing   Velocity  Direction  Site Contributors
%%    (deg)       (deg)     (cm/s)   (cm/s)  (GridCode)    Quality     Quality     Quality      (km)        (km)       (km)    (True)     (cm/s)    (True)    #1   #2
    80.8824441  15.3464546  -30.535   22.808          0     999.000     999.000     999.000   -120.0000    -72.0000  139.9428   239.0     38.113     306.8      1    4
    80.9388751  15.2382936  -97.203   73.966          0     999.000     999.000     999.000   -114.0000    -84.0000  141.6051   233.6    122.145     307.3      3    2
    80.9385984  15.2925145  -93.764   64.200          0      17.650       5.120      89.470   -114.0000    -78.0000  138.1304   235.6    113.637     304.4      3    3
    80.9383210  15.3467350  -42.252   30.186          0     999.000     999.000     999.000   -114.0000    -72.0000  134.8332   237.7     51.927     305.5      3    3
    80.9380428  15.4009553  -34.861   10.891          0     999.000     999.000     999.000   -114.0000    -66.0000  131.7270   239.9     36.523     287.3      3    4
    80.9377638  15.4551754   -7.230   -7.009          0     999.000     999.000     999.000   -114.0000    -60.0000  128.8255   242.2     10.070     225.9      2    3
    80.9952449  15.1301158 -104.023   71.871          0      86.350      22.500    1855.350   -108.0000    -96.0000  144.4991   228.4    126.437     304.6      4    1
    80.9947229  15.2385590  -87.691   60.582          0      23.320       4.990     115.290   -108.0000    -84.0000  136.8211   232.1    106.583     304.6      3    4
    80.9944608  15.2927802  -51.398   39.703          0      18.890       4.760      89.600   -108.0000    -78.0000  133.2216   234.2     64.947     307.7      6    3
    80.9941980  15.3470011  -14.784    7.112          0      15.650       3.930      61.470   -108.0000    -72.0000  129.7998   236.3     16.406     295.7      6    4
    80.9939344  15.4012218  -13.667   -1.508          0      23.660      10.930     216.320   -108.0000    -66.0000  126.5701   238.6     13.750     263.7      5    3
```

Appendix D

Wave file

```
%CTF: 1.00
%FileType: WVMD WVM7 "Wave History"
%UUID: E76BAB5A-CD4D-48AB-8F21-A5599E3A49A3
%Manufacturer: CODAR Ocean Sensors. SeaSonde
%Site: Cuda ""
%TimeStamp: 2017 04 01  00 00 00
%TimeZone: "IST" +5.500 0
%Origin:  11.6862333   79.7733167
%%
%%
%% Note: Parameters for Last processed item...
%TimeCoverage: 1.000 hours
%RangeResolutionKMeters: 5.82888 km
%AntennaBearing: 148.0
%RangeCells: 57
%DopplerCells: 1024
%TransmitCenterFreqMHz: 4.400000
%TransmitBandwidthKHz: -25.733913
%TransmitSweepRateHz: 1.000000
%CoastlineSector: 26.0 166.0  %% Start CW to Stop in Deg NCW
%CurrentVelocityLimit: 150
%BraggSmoothingPoints: 3
%WaveBraggNoiseThreshold: 3.2
%WaveBraggPeakDropOff: 100.0
%WaveBraggPeakNull: 50.1
%MaximumWavePeriod: 17.0
%WaveBearingLimits: 26.0 166.0  %% Start CW to Stop in Deg NCW
%WaveMinDopplerPoints: 10
%WaveUseInnerBragg: 0  %% 0 No, 1 Yes
%WavesFollowTheWind: 0  %% 0 No, 1 Yes
%WaveMergeMethod: 1  %% 0 None, 1 Average, 2 Median
%%
%Distance: 5.82890 km
%RangeCell: 1
%TableType: WAVL WVM7
%TableColumns: 17
%TableColumnTypes: TIME MWHT MWPD WAVB WNDB ACNT DIST RCLL WDPT MTHD FLAG TYRS TMON TDAY THRS TMIN TSEC
%TableRows: 1306
%TableStart:
%%  Time       --------Wave--------   Wind
%% FromStart  Height Period   Dir.     Dir. Spectra  Distance  Range Doppler  Wave   Vector    Time
%% (seconds)   (m)    (s)    (deg)    (deg)  Count     (km)    Cell  Points  Method  Flag     Year Mo Dy  Hr Mn  S
         0  999.00 999.00 1080.0    31.9      5      5.8289     1      0      1       2      2017 04 01  00 00 00
      1800  999.00 999.00 1080.0    31.9      5      5.8289     1      0      1       2      2017 04 01  00 30 00
      3600  999.00 999.00 1080.0    31.9      5      5.8289     1      0      1       2      2017 04 01  01 00 00
      5400  999.00 999.00 1080.0    33.9      5      5.8289     1      0      1       2      2017 04 01  01 30 00
      7200  999.00 999.00 1080.0    38.0      5      5.8289     1      0      1       2      2017 04 01  02 00 00
      9000  999.00 999.00 1080.0    36.0      5      5.8289     1      0      1       2      2017 04 01  02 30 00
     10800  999.00 999.00 1080.0    44.0      5      5.8289     1      0      1       2      2017 04 01  03 00 00
     12600  999.00 999.00 1080.0    52.0      5      5.8289     1      0      1       2      2017 04 01  03 30 00
     14400  999.00 999.00 1080.0    58.0      5      5.8289     1      0      1       2      2017 04 01  04 00 00
     16200  999.00 999.00 1080.0    64.0      5      5.8289     1      0      1       2      2017 04 01  04 30 00
     18000  999.00 999.00 1080.0    68.0      5      5.8289     1      0      1       2      2017 04 01  05 00 00
     19800  999.00 999.00 1080.0    66.0      5      5.8289     1      0      1       2      2017 04 01  05 30 00
     21600  999.00 999.00 1080.0    62.0      5      5.8289     1      0      1       2      2017 04 01  06 00 00
     23400  999.00 999.00 1080.0    56.0      5      5.8289     1      0      1       2      2017 04 01  06 30 00
```