Poster Session
Introduction to High-Frequency ocean radar network operated by Korea Hydrographic and Oceanographic Agency

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High-Frequency(HF) ocean radars measure surface current velocity by analyzing the echo of transmitted signal reflected through the Bragg scattering with half wavelength of electromagnetic waves at the ocean surface. At least two or three radial velocities are required for two-dimensional vector map in order to reduce errors of geometrical dilution of precision(GDOP)(Chapman and Graber, 1997). Hourly surface current are derived on a Cartesian grid by the least square fitting with radial velocities. In general, the range of land based HF Radar is 10-150 km and 0.3-5 km spatial resolution in near real-time measurement and the coverage and resolution depend on HF Radar operating frequency and bandwidth, respectively. Recently, advanced signal and data processing enabled to ship detection(Ponsford et al., 2001; Dzvonkovskaya et al., 2008) and tsunami measurement(Lipa et al., 2006; Gurgel et al., 2011; Grilli et al., 2015)

In December 2007, oil spill occurred due to collision between a large tanker and a barge near the port of Daesan on the west coast of Korea, which is the main seaway of petrochemical complex and major ports. After Korea’s worst oil spill incident, the need for HF Radar which can observe a wide range of surface current was greatly increased. Korea Hydrographic and Oceanographic Agency(KHOA) has started installing HF radars for the safety of the vessel in major ports and waters of Korea from 2006 and providing data through a website (www.khoa.go.kr). 44 HF radars, more than 70% of total 60 HF radars in Korea, have been installed in 18 major waters by KHOA in various of the frequency range from 5 to 42MHz until 2017(Fig. 1).
To minimize the damage from a maritime accident in major ports and sea areas where no HF radar is installed, two 25MHz low power HF radars (CODAR) were introduced in 2016. The low power consumption allows to operate HF Radar system in site without any infrastructure with alternative energy sources such as solar or wind power. Even it can be operated using generator in a short period.

The first test operation of low power HF Radar was successfully carried out with quick installation and a near real-time surface current observation. The comparison with the existing HF radar has a good correlation higher than 0.9. It is now being used to support maritime accident such as oil spill, emergency replacements due to failure of HF Radar in site and verification of HF Radar data but the use of low power HF radars are expected to expand more in the future.


Current observation in Hyuga-Nada by the High-Frequency Ocean Radar

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1 Introduction

Hyuga-Nada is the eastern area off Miyazaki Prefecture of Kyusyu Island in Japan (Fig.1), the Kuroshio approaches this area. Therefore, the irregular fast current over 1m/s in Hyuga-Nada due to the Kuroshio onshore intrusion (Okada, 2003) affects fishery activities and fishery resources variations. However, the knowledge about current variations in Hyuga-nada was insufficient.

Therefore, we installed the HF ocean radars to observe current at Miyazaki port and Kiyotake river in Miyazaki Prefecture from 2015 to March 2017 by collaborative investigation with University of the Ryukyus. As a result, we obtained the radial current data of HF ocean radar that was high correlation with mooring buoy, but the inaccurate composite current from two radar sites due to small cross-angle was a problem (Oshiro, 2017). Because of the solving small cross-angle problem, the current observation by HF ocean radars at Miyazaki port and Noshima fishing port have started from March 2017.
This report outlines the current observation in Hyuga-Nada, and the current accuracy of HF Ocean radar. And then we reveal the current variations in Hyuga-Nada by using the HF ocean radar data.

2 Method (HF Ocean Radar and In-Situ observation)

The system specification of the HF ocean radar is shown in Table 1, the antenna type of ocean radar is an array phased system (Fig.2). The antenna which is both transmission and reception have the advantage to achieve greater sensitivity (Shearman, 1986). In practical observation, integration of several data is used for improving SNR.

We installed the HF ocean radar to observe current at Miyazaki port (MIYA) and Noshima fishing port (NOSI) in Miyazaki Prefecture from March 2017 by collaborative investigation with University of the Ryukyus. We steer 12 beams per 7.5° steps from 153° to 70.5° at MIYA site and that from 105° to 52.5° at NOSI, which direction is measured by clockwise from the North (Fig.1). Because one direction takes 10 minutes, all 12 directions takes 120 minutes. The HF ocean radar transmits high-frequency radio waves toward the ocean surface and receives the backscattered wave from ocean surface waves of a half wavelength of...
transmitted radio wave by Bragg resonant condition. The radial current velocity is obtained by the difference frequency from the Doppler frequency corresponding to the phase velocity of ocean waves by the Bragg resonant condition (when we use 24.5MHz, Doppler frequency is 0.505 Hz). One HF radar site observes only radial current velocity, so the vector current is determined by measuring more than two radar sites in different directions (Fig.3).

The in-situ current data at 10m depth under sea surface by ADCP (JRC, NJC-30C-10, 240kHz) with artificial fish reef (Fig.1, Umi.4) have used for comparison to the current of HF ocean radar. We used the current data in observation cell of HF radar near Umisachi 4.

3 Result
The radial current of HF radar at MIYA had no correlation during a period, the lowest correlation from June to July in particular. On the other hand, the radial current of HF radar at NOSI had positive correlation during a period. But the radial current of HF radar at NOSI was not observed such as in-situ current over 100cm/s from September to October. Therefore, the composite current vector had been affected by each radial currents. In poster presentation, we will elucidate the cause of the low precision and the revision methods of low precision. And then we reveal the current variations in Hyuga-Nada by using the HF ocean radar data.

Reference
HF Radar Observations of Surface Circulation in the Nanwan Bay (Southern Taiwan)

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1 Introduction
Nanwan Bay, a southward semi-enclosed basin located at the southernmost tip of Taiwan and adjacent to the north of Luzon strait, is famous with well-developed fringing reefs distributed along the coast. It is bounded by two capes and the distance between east and west caps is 12 km. In this area, its biodiversity is not excessive exploited by humans due to the active management of Kenting National Park. On the other hand, and perhaps more importantly, tidal effects and the phenomenon of cold-water upwelling sustains the coral ecology immune to the effects of climate change (Lee et al., 1999a; Lee et al., 1999b).

In this study, we have tried to use hourly HF radar surface current maps to develop tools for calculating relative vorticity, vertical velocity gradient and automatic eddy detection mechanism to monitor the eddy characteristics of the flow field. We expect that these analytical tools will provide monitoring data for the water temperature variation of cold water intrusion.

2 Research Data Sets
The marine environmental data adopted in this study includes HF radar surface currents, tides and sea water temperature with different instruments.

We mainly analyze hourly sea surface currents with spatial resolution of 1x1 km measured by HF radar around Nanwan bay between April 11th and May 7th in 2017. Three sets of 13 / 24MHz CODAR SeaSonde systems have been set up in the area around the Nanwan Bay (i.e. BABY, NAWN and MABT stations) by the Taiwan Ocean Research Institute.
A tidal gauge station named Houbihu provides sea level height every six minutes by the Central Weather Bureau (CWB). Sea water temperatures in different depths are collected by a Mooring CTD located at 23 m-deep at NanWan inner shore. The coverage of HFR surface current map and locations of these instruments are shown in Figure 1.

3. Results and Discussion

3.1 Tidal modulation and water temperature drops

The observation tide and sea water temperature in Nanwan bay during the two spring tides from April 11 to April 16, and from April 26 to May 1 are shown in Figure 2(a) and (b), respectively. According to the tidal phase and water temperature drop, we propose a new classification method for the phenomena of cold water instrument into three categories. As shown in the Figure 2, phenomenon A presents temperature drops between the small flood and small ebb during the spring tide. Phenomenon B depicts temperature drops are obvious near sea floor only (not significant in the surface) during early period of ebb tide. Phenomenon C has smaller temperature drop during ebb tide.

3.2 Eddy and water temperature drops

In this study, we develop algorithms for eddy detection, vorticity and divergence of current field. The relationship between characteristics of current field and the upwelling phenomena are then analyzed. We expect to understand the mechanism by which the upwelling flow occurs in the Nanwan Bay area.

The characteristics of the ocean circulation in the Nanwan Bay in the space-time domain are analyzed with continuous high-resolution HFR surface current maps. In addition to the conventional tidal current analysis, the Angular Momentum Eddy Detection and tracking Algorithm (AMEDA) automated eddy detection method (Vu et al., 2017) is adopted to track the process of eddy formation and dissipation in the Nanwan Bay area. With this algorithm, we may establish database of eddy characteristics (e.g. radius, strength, centers, shapes, size, time of occurrence and duration).

And we also calculate the distribution of relative vorticity $\xi$ in space according to equation (1).

$$\xi = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

where $u$ is the velocity of longitude, $v$ is the velocity of latitude

Further, consider the velocity divergence of the incompressible fluid equal to
zero, and then we may estimate the vertical velocity gradient of the flow field from the radar observed horizontal velocity.

\[ \nabla \cdot F = 0 \rightarrow \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \rightarrow \frac{\partial w}{\partial z} = -(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}) \] (2)

As Figure 3 shows the characteristics of surface current and water temperature during ebb tide on April 26, the phenomenon of water temperature drop fits to phenomenon A, which cold water and warm water mixing well in the water column from surface to bottom. In Figure 3(a), there is a relatively large counterclockwise eddy with the radius 4 to 5 kilometers and the duration of the eddy is 2.5 hours. However, we do not get enough upwelling evidence from the distribution of velocity divergence analysis as shown in Figure 3(b).

4. Conclusion

In this study, a new three categories classification for the phenomena of cold water intrusion is proposed. And we developed algorithms for eddy detection, vorticity and divergence of current field for continuous high-resolution HFR surface current maps. As the results show, that AMEDA offers an automatic and reliable algorithm for the operational HFR data in eddy detection. Based on these new analysis tools, we found that the cold water upwelling and the mixing phenomena in water column from surface to bottom might be related to the eddy strength of surface current field. Finally, we demonstrate the integration of HFR and mooring CTD data could offer good information for the study of upwelling phenomena in Nanwan Bay.

![HFR surface current map at 2017/04/11 16:00 (LCT)](image)

Figure 1 The illustration of HFR surface current map and location of instruments.
Figure 2 Sea level and water temperature variation during two spring tides (a) from April 11th to April 16th, and (b) from April 26th to May 1st.

Figure 3 Characteristics of (a) relative vorticity (b) vertical velocity gradient derived from HFR data. The eddy centers (black dots) and the characteristic eddy identified by the algorithm for eddy (red lines). The gray line is lifetime of the long-lived eddy. The events of A-5.

Reference

Three-years Analysis on Coral Spawn Transport around the NanWan Bay, TAIWAN

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1 Introduction
NanWan Bay, a popular resort in Taiwan, is famous for beautiful beach and coral reef ecology. The ocean current in this area is mainly dominated by tides. When spring tides occur in the NanWan Bay, there is an obvious phenomenon that upwelling of cold water intrusion into the shallow region of NanWan Bay (Lee et al., 1997 & Hsieh et al., 2008). Coral reefs face serious threats from natural disturbances and human impacts, such as typhoons, coral bleaching, overfishing, habitat loss, sedimentation, sewage discharge, eutrophication, and oil pollution over the past few decades, these factors resulted maybe effect coral cover and reduce coral larval.

Around the NanWan Bay area, the Taiwan Ocean Radar Observing System (TOROS) based on the CODAR SeaSonde High Frequency Surface Wave Radar (HFSWR) observed hourly surface currents. We tried to evaluate the coral larval spread with the observed surface current maps recent 3 years (2015, 2016 and 2017). The assessment of coral larval trajectories and settlements were simulated by GNOME (General NOAA Operational Modeling Environment) model, then examined with Lagrangian PDFs (Probability Density Functions) of the dispersed particles.
2 Methods

During the recent 3 years, coral spawning period between April to May, a joint observation was executed by TORI and the layout of observation facilities. In order to evaluate where the coral larval spread in the NanWan Bay, hourly 1.0 x 1.0 km grid ocean surface currents, which mainly observed by three CODAR SeaSonde standard radar systems, are combined by the Optimal Interpolation (OI) method (Kim et al., 2007).

Before the spread simulation, we compared the HFSWR flow pattern with ship-board ADCP by 2015’s results as shown in Figure 1. Then, the HFSWR ocean surface currents are validated with the ADCP current velocities measured by bottom-mounted and moored data buoy in time series, respectively. The correlation coefficients (R) and root mean square difference (RMSD) of these comparisons are shown in Figure 2. In the GNOME simulation, not only the surface current by TOROS HFSWR network but also the surface current wind field data offered by Taiwan Central Weather Bureau are included. Hence, with these Eulerian and Lagrangian approaches, we have enough confidence in the surface current maps measured by the TOROS network in the NanWan Bay. The seafloor in the outlet of the Third Nuclear Power Plant at depth shallower than 5 m was mainly covered by rocky bottom with reef organisms of middle density. In addition, rocky bottom covered by reef organisms of high density was located off Houbihu area (Tian et al., 2006). We release particles in the night between May 8 to 12 at the hot spot of Coral spawning which (marked with a red star in Figure 3).

3 Conclusion

Example in 2015’s results, after 5 days simulating, those particles spread into different areas. Estimate about 60% coral larvae drift and settle on the beach of Houbihu marine protected areas and east coast of NanWan Bay. The coral larvae spatial distributions probability density show in Figure 4. Moreover, small parts of the coral larvae may flow through the cape of Eluanbi and transferred to the east coast of Taiwan with ocean currents (Hsu et al., 2016). Compare the estimated coral settlement places with the map of coral coverage and benthic community structure of NanWan, we also found that the estimated place for
settlement have good agreement with the distribution of coral reef in NanWan Bay. The 2015's conclude that the HFSWR observed surface current data may have potential to track the whereabouts of the marine larvae and might be one of the quantitative/qualitative information for the coral conservation and restoration works.
References


Hsieh Meng-Sung, 2008: A study of the characteristics of tidally induced eddies in Nan Wan Bay, *Degree Master of Science in NTOU*.


Parameterization of Regional Ocean Model for Physical Interpolation of Tidal Currents in the Ariake Sea JAPAN from Tidal Constituents measured by VHF Radar Using Green's Function Approach

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1 Introduction
Ariake Sea, a semi-enclosed shallow embayment located in the Kyushu Island Japan (Fig. 1), has a large semi-diurnal tidal amplitude ranging 3 to 5 m, subsequently inducing strong tidal currents. Our Institute had installed VHF Radar along the coast from 2005 to 2008 to investigate tidal currents in the sea area in front of the Isahaya Bay in the high spatial and temporal resolution.

The current requires two radial velocities in overlapping area because Radar measures only the radial velocity (Chapman et al., 1997). This means that radial velocities are abandoned in non-overlapping area on calculating the current field. The physical interpolation using the regional ocean model and the data assimilation is useful to estimate the current fields from whole the radial velocity. We applied the Green’s Function Approach (Menemenlis et al., 2005) to calibrate the model parameter and estimate the tidal current fields in this study.

2 Method
2.1 Observation
The frequency of the VHF radar is 41.9 MHz and the range and azimuth resolutions are 0.5km and about 8 deg. The radar covers a range of approximately 30 km from the site (Fig. 2). The radial tidal constituents were calculated from the radial velocities every 500m along 8 radial beams from two stations and in 30 minutes from 2005 to 2008. We calculated 4 tidal constituents (M2, S2, O1, K1) from the radial velocities and tide levels of 3 tide
gauge. All the phase of tidal constituents for current and level were adjusted to the phase of tide level equals 0 at Oura.

![Map of Ariake sea and the location of VHF radar sites](image1)

![Radar sites and beam](image2)

### 2.2 Model and GFA (Green's Function Approach)

We employed a 2-D model using ROMS (Regional Ocean Model Systems) (Shchepetkin and McWilliams, 2009) and calculated the tidal currents with 3 domains (Fig. 3) of which horizontal resolutions are about 2km, 1km and 0.5km. The four control parameters; (1) the magnitude and (2) the phase lag of tidal current ellipses and sea levels from a global tidal model results for boundary conditions, (3) the horizontal viscosity and (4) the sea bottom drag coefficient, were calibrated by GFA.

### 3 Result

The Objective function became stable and minimum in one or two iterations of GFA for all the horizontal resolutions (Fig. 4). The calibrated parameters suggest that (1) boundary conditions, the magnitude and phase lag, need not to be changed, (2) the bottom drag coefficient needs to be about 1.8 E-3, (3) the bottom drag coefficient is important to adjust the phase lag between tidal velocities and tide level, and (4) the viscosity ranges from 10 to 50 m²/s, suggesting that the viscosity is less sensitive for the model. Moreover the magnitude, phase lag and the drag coefficient are independent on the grid resolutions. The physical interpolation represents the horizontal distribution of the tidal currents and sea level in whole area of the Ariake Sea (Fig.5).
Figure 3 Model domain and bathymetric

Figure 4 Objective function

Figure 3 Physical Interpolation of M2 currents (the upper panels represent the amplitude of M2 tidal ellipses. The lower the phase)
4 Summary

We calibrated the boundary condition for the tide and model parameters by applying GFM to the model and radar observations. The model parameterization using Green’s Function approach employed all the radial constituents in the overlapping and non-overlapping area by two radar stations and provides us the physical interpolation of tidal currents in the whole model domain. The physical interpolation represents the horizontal distribution of the tidal currents and sea level in whole area of the Ariake Sea, in which radars were not able to cover.

Reference


Development of HF ocean radar for current and verification of the observation data comparing with drift buoy

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1. Introduction

HF ocean radar has been used for wide area where of monitoring ocean state effectively, at low cost. Many countries are using HF ocean radar to observe the ocean current. SETsystem has developed HF ocean radar since 2014 and its prototype came out in 2017. We are going to introduce specifications/features of the prototype HF ocean radar, called "SEODAE", and results of performance test.

2. Hardware

2.1. Characteristics of Hardware

"SEODAE" hardware consist of modules for system expandability and maintenance. The module system of “SEODAE” has minimized incoming noise signals from outside, and has improved the stability of the system. Four RX channels are provided so that the user can select how to configure the receive antenna (DF or Phased Array). “SEODAE” chooses the FMICW method in initial setting. If users want to choose the FMCW method, they can change the method by simple adjustment. The separation distance between Tx and Rx antennas and unwanted emission are minimized by the combination of Hard- and soft-switches. <Table 1> and <Fig 1> are shows hardware characteristics and configurations.

<table>
<thead>
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<th>Item</th>
<th>specification</th>
<th>Item</th>
<th>specification</th>
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<td>Transmission type</td>
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<td>Detecting range</td>
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</tr>
<tr>
<td>RX antenna</td>
<td>DF or Phase Array</td>
<td>Tx. Power</td>
<td>~40W</td>
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<td>Operating Frequency</td>
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<tr>
<td>Band Width</td>
<td>100~200KHz</td>
<td>Sampling Rate</td>
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</tr>
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<Table 1> Hardware Specifications
2.2. Result of Field Test

We had detected the 1st Bragg signals as far as the 45km sea area (Fig 2). The 2nd Bragg signals were appeared within 10km (Fig 3). The effects of sea surface winds and the detection of ships were appeared too (Fig 4).

3. Software

3.1. Characteristics of Software

SEODAE's software consists of 1) Control and Monitoring S/W, 2) Extraction of Ocean Current Velocity S/W, and 3) Current Velocity Map S/W. The Control and Monitoring S/W controls hardware of SEODAE and shows the first FFT (Fast Fourier Transform) of observation data. The extraction of ocean current velocity S/W extracts the Doppler component from the observation data and calculates the velocity vector of the radial direction for Radial Velocity Map (RVM). The algorithms which is applied for the extraction of ocean current velocity S/W were developed by SETsystem (1st order Bragg Peak Detection Algorithm)/Directional Finding Algorithm. The Current Velocity Map S/W makes a Current Velocity Map by combining the results of two or more stations. <Fig 5> is the flow of data processing and software configuration.

3.2. Compare with Tidal data

SEODAE's software has been tested by comparing the observation data with the tidal data. The observation data of <Fig 6> and <Fig 7> shows that ocean current is changing from high tide to low tide, about 15:00 in 04/23/17. The West Sea Tidal data (Table 2) from KOHA (Korea...
4. Verification of observational data

To verify the durability and performance of SEODAE, we have measured ocean current since 04/01/17 in Byonsan Peninsula (Republic of Korea). During this time, correlation analysis between observation data and Drift Buoy (8Km, 17Km away), stationary Buoy (30km away) was performed.

4.1. Compare “SEODAE” with Drift buoy

In order to verify measurement performance, the drift buoy was installed at near the Byonsan Peninsula on 05/25/17 (17km from radar) and 06/08/17 (8km from radar) each other. Correlation analysis between the current velocity components (U, V) of “SEODAE” data and the Buoy’s 1 hour average data was performed. The results of correlation analysis are shown as Table 3.

4.2. Compare “SEODAE with stationary buoy

Correlation analysis between observation data and stationary buoy’s data was performed too. The buoy was 30km away from the radar site. We did the correlation analysis from 06/08/17 to 06/18/17. The analysis method was same as 3.1. The result of correlation analysis is shown as Table 4.

5. Conclusion
"SEODAE" hardware has the properties of expandability, easy maintenance, multi configuration (antenna, Tx type) etc. Field test result has shown that the “SEODAE” can measure ocean current up to 45km. Furthermore, it has also shown the detection of 2nd Bragg signal, the effects of sea surface wind and the detection of ships.

“SEODAE” software's performance was verified by comparing with CODAR current data and tidal data. “SEODAE” current data has shown the similar trend with CODAR current data. Tidal time from “SEODAE” data matched real tidal time.

In order to verify the performance of “SEODAE”, current data was compared with the data of drift buoy and stationary buoy. The correlation coefficient between “SEODAE” and drift buoy was 0.95 (RMSD = 4.27~18.94 cm/s) and the correlation coefficient between “SEODAE” and stationary buoy was 0.82 (RMSD = 21.61 cm/s). The reason why correlation coefficient with stationary buoy is lower may be the distance between the buoy and radar, 30 km away from radar. The location of stationary buoy would have an effect on the result too, which have 2.5m below sea level.

SETsystem is trying to improve the performance of “SEODAE”. We are developing ship detection algorithm, wave measurement algorithm, etc. “SEODAE” was participated in national research program for current and wave.

6. Reference

Sea Surface Observations Using a 52-MHz VHF Radar With Multireceiver Imaging Technique

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1 Introduction

The pulsed radar operated at the very-high-frequency (VHF) band between 30 and 300 MHz is not only one of the powerful instruments for observing the dynamic atmosphere, but also for remote sensing of the sea surface for a long time (Bass et al., 1968; Barrick, 1971; Balsley et al., 1987).

To investigate the sea surface in the Taiwan Strait, the Chung-Li VHF radar system (52 MHz) was operated during mid-October and mid-November, 2015. The observation was carried out by using a four-element Yagi antenna for transmission of radar waves, and four vertical dipole antennas for collecting the radar returns from the ocean surface. Radar echoes were received and processed by four independent and identical receivers. Transmitting and receiving antennas had a 3-meter separation between adjacent antennas and were aligned with the coastline (Fig. 1). The maximum range that the sea echoes can be effectively detected was approximately between 20 and 25 km for the present experiment, and evident semidiurnal variation in the time series
of echo intensity was clearly identified. In addition to the echo intensity and Doppler velocity, the directions of arrival (DOA) of radar echoes, determined by using the imaging technique of the optimization Capon method with the four-channel echoes, were also employed to examine the characteristics of tidal waves and sea currents.

2 Experimental Setup and Capon Beamforming

Fig. 1 indicates the location of the radar as well as the arrangement of the antennas. The red cross is the transmitting antenna, and the four yellow crosses are the receiving antennas. The beam axis direction was pointed horizontally and to 50° north by west. The full-half-power beamwidth in the horizontal plan was ~90°. Fig. 2 shows the physical antenna array.

Radar parameters were given as follows. Inter-pulse-period was 0.001 s and coherent integration was 256, resulting in a sampling time of 0.256 s. Radar pulse length was 2 μs and a matched filter was employed for reception, corresponding to a 500 KHz receiver bandwidth. The number of sampling range cells was 300 with a sampling step of 2 μs, giving a range resolution of 300 m. 128 data points were taken to calculate a Doppler spectrum and three of the spectrum were averaged. As a result, the total echo intensity, the Doppler velocity and spectral width of the first-order sea echoes with a time resolution of about $128 \times 0.256 \times 3 = 98.304$ s were obtained. The total echo intensity was calculated with the raw data after removing the DC component, and the Doppler velocity and spectral width were retrieved from Gaussian fitting around the first-order Doppler components. The peak location and standard deviation of the fitted Gaussian curve were assigned as the Doppler velocity and spectral width, respectively.

The Capon method can retrieve the angular echo power distribution (brightness distribution) with the data received by a set of receivers, and it can be used in both time and Doppler frequency domains (Capon, 1969; Palmer et al., 1998). In this study, the calculation in time-domain was executed to obtain the brightness distribution as a function of angle.

3 Observations

Fig. 3 shows the sea echo intensity observed by VHF radar during 10 and 13 Nov, 2015, and also displayed is the echoes taken from the CODAR radar (located about 8 km northeast from the VHF sea radar and operated at the frequency of around 4.58 MHz). As seen, the maximum detectable range of the VHF sea echoes varied in a period of about half day. Investigation shows that
the echo intensity oscillated in a semidiurnal period almost through the detectable range. It is thus suspected that the semidiurnal lunar tide is responsible for the semidiurnal oscillation in the VHF echo intensity. By contrast, the characteristic of semidiurnal oscillation in both echo intensity and detectable range was absent in the CODAR sea echoes.

Fig. 4 (left) exhibits an example of the angular-range brightness distribution retrieved by the Capon method with the four channel echoes. The angular extent was set between -50° and 50° with respect to the beam axis direction, and an imaging step of 0.5° was given in the retrieval processing. Small open circles indicate the locations of brightness centers (or echo centers) in the range cells.

Fig. 4 (right) shows the histograms of echo center locations through range for the VHF observation shown in Fig. 3. A dramatic change in the echo center location took place between 15 and 25 km. Beyond the range of twenty-something kilometers, the SNR was very low and could be ignored.

More examinations will be made for the characteristics of oscillations in echo intensity, echo center, Doppler/radial velocity, spectral width, and so on. Their temporal and range relationships are worthy of studying with the VHF sea radar.

Reference


Figure 1 Radar location (121°01′E, 24°01′N) and antenna arrangement.

Figure 2 Photo of VHF sea radar.

Figure 3 Range-time intensities of sea echoes observed by (upper) 52 MHz and (lower) 4.85 MHz CODAR radars. Distance of the two radar sites is ~8 km.

Figure 4 (left) Brightness distribution and echo center (circle) retrieved by CRI method. (right) Histogram of echo centers for the time period of 10-13 Nov, 2015.
Detection of digital TV signal scattered by sea surface

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1 Introduction

It is necessary to remotely measure the surface flow in coastal waters for the ecological study of coastal marine organism and to provide information necessary for the safety of marine sports and diving workers. Although the coastal ocean current can be measured using conventional radar (¹), in this study we observed it using passive radar using a terrestrial digital television-broadcasting (DTV) signal and found the spectrum considered as Bragg scattering.

2 Passive radar system

We constructed passive radar system that uses Ch13 to 17 of DTV signals. Figure 1 shows a photograph of the antennas used in this study. These antennas are installed at the height of 20 m of a tower about 70 m away from the coast. The tower is located in the Okinawa Electromagnetic Technology Center (OETC). Although strong sea surface scattering can be expected by using vertically polarized waves rather than horizontally polarized waves, the high power DTV signal, which can be used in this experiment, are horizontally polarized waves. We used a horizontally polarized planar antenna for direct wave reception and used a horizontally polarized antenna which was rotated 90 degrees to detect vertically polarized wave for scattered wave reception.

After converting the signals received by these antennas to a center frequency of 80 MHz, the bandwidth was limited to 32 MHz and sampled at 64 Msp. The cross correlation of the two sampled signal sequences was acquired every 10 ms. Then, two-dimensional Fourier transform was performed on the resultant complex sequences value of 10 seconds. Furthermore, a range Doppler map was generated by incoherent averaging the results for 100 seconds.
3 Detection of radio wave scattering by sea surface

On Okinawa Island, DTV waves covering the southern part of the island are transmitted from Tomigusuku-Takayasu transmission station (TX-T, ch13, 15,17) and Kakazu transmission station (TX-K, ch14, 16). Fig.2 shows the positions of the transmission points (TX-T, TX-K) and the reception point (OETC). Scattering from the sea surface in the west of the reception point is the observation target. For example, Fig.3 shows a range-Doppler map obtained by analyzing the signal of ch15 (transmitted from TX-T by ERP 10.6kw). In the figure, the horizontal axis represents the pseudo-distance before bistatic distance correction and the colors represent the normalized correlation amplitude. The frequency displacement due to Bragg scattering was calculated to be about +/- 2.2Hz. Because this observation is of bistatic reception, the observed frequency displacement is considered to be smaller than the calculated value. Since the beam of the antenna is wide, incoming scattering waves of various frequencies are considered to be received.

4 Future plans

We are planning to introduce a phased array system that separates the direction of arrival of signals in order to confirm whether the observed echoes are due to Bragg scattering.

Figure 1 Two planer antennas used for receiving
Figure 2 Positions of transmitting points, reception point and expected area for scattering. The distance between the transmission point and the reception points is about 38 km.

Figure 3 Echoes appearing to be Bragg scattering.
Reference

Ionospheric clutter detection and removal of CODAR sea echoes

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More than 17 sets of HF CODAR-SeaSonde radars have been implemented around Taiwan for the purpose of routine monitoring of waves and currents. The radar echoes are susceptible to ionospheric clutters to degrade the quality of observed wave and current (Figure 1). Therefore, how to detect and remove the ionospheric clutter from the contaminated sea echoes are crucial issues in ocean remote sensing. In this study, an algorithm of detecting ionospheric clutters in the spectral domain of the CODAR sea echoes is developed. The phase and coherency of the cross spectrum of a pair of echo channels are computed to serve as key parameters for ionospheric clutter detection, in which the signal-to-noise ratio of the radar returns is carefully calculated. We then use an imaging process technique to identify and highlight the ionospheric clutters such that the range and time that the ionospheric echoes occurred can be determined (Figure 2). A Gaussian fit method is employed to determine the mean and spread of the first order Bragg spectral component of the sea echoes. The ionospheric clutters are then replaced by the interpolated data of the adjacent sea echoes (Figure 3). With this procedure combined with MUSIC algorithm, the spatial distribution of the ocean currents are recalculated and the result shows that the distribution of the ocean current is much more reasonable and realistic.
Figure 1 CODAR spectrum contaminated by Ionospheric clutter.

Figure 2 Ionospheric clutter detection through cross-spectrum and image process.
Figure 3 Comparison of interpolation and original data points (black lines) of first order Bragg peak through range gates. Dash lines are the spread of the first order Bragg spectral component of the sea echoes. Red lines are the maximum range of the interpolated data.

Reference
An availability of antenna pattern based on the AIS information

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1 Introduction

In order to study the coastal marine environment, a high frequency ocean radar system (HF radar / Sea Sonde by CODAR Ltd.) has been operated on the Tsugaru Strait between Honshu and Hokkaido in northern Japan, and has observed sea surface current since 2014. We introduced the antenna pattern measuring (APM) system based on AIS information into the radar system. An availability of the AIS-APM system was examined using moored current meter data.

2 Observation

2.1 HF radar

Three ocean radar stations were installed in the eastern part of the Tsugaru Strait in the spring of 2014 (Fig. 1). Details of the radar system are summarized in Table 1. The radial vectors are obtained every 30 minutes (averaged for 75 minutes) and the vectors are synthesized to be 2D current. In this presentation, we will use the radial data but not 2D current data.

### Table 1. About the HF radar system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>13.921–13.971 MHz</td>
</tr>
<tr>
<td>Radar type</td>
<td>FM1CW</td>
</tr>
<tr>
<td>Transmitted Power</td>
<td>Ave. 50W (Max 100W)</td>
</tr>
<tr>
<td>Antenna</td>
<td>Dipole/Cross Loop</td>
</tr>
<tr>
<td>bearing discrimination</td>
<td>5 degree</td>
</tr>
<tr>
<td>Resolution in range</td>
<td>~3 km</td>
</tr>
</tbody>
</table>

![Fig. 1 Current map obtained from our HF radar system. Red star is in-situ obs. station.](image)
2.2 Antenna Pattern

The latest standard measurement of an antenna pattern was done in March 2016 by transponder. At the Ohata station, the AIS antenna pattern measurement system (AutoAPM Kit with AIS) was installed in March 2015. Currently, the ocean radar is applying the antenna pattern created by that system in spring 2015. AIS data has been continuously accumulated. It is possible to create antenna patterns derived from AIS at any time after the spring of 2015.

2.3 In-situ mooring observation

The mooring observation of the electromagnetic current meter (AEM-USB / JFE Advantech Co., Ltd.) has been carried out five times in total so far for validation of the radar data. Here we use the mooring data obtained during ~1 month of Fall 2016. The mooring point is the st. CM 2 in the Tsugaru Straight (shown in Fig. 1). The mooring system has vertically three current meters. We use the current data obtained by the shallowest equipment (about 2.5 m depth). The current meter was set to burst mode in which measurement was repeated 30 times at 1 second intervals every 10 minutes. In order to compare with the averaging time (75 minutes) of the radar data, the in-situ observations were averaged for 80 minutes.

3 Results and discussions

Radial data of St. Ohata derived from several antenna patterns (Table 2) were compared with in-situ current meter observation at St. CM2. These radial data were processed by a distance-weighted mean at a radius of 6 km around the St. CM2. The in-situ observation at CM2 was processed by vector decomposition into the direction from St. Ohata to St.CM2.

<table>
<thead>
<tr>
<th>AP No.</th>
<th>Method</th>
<th>Obs. Time</th>
<th>Bearing Smoothing</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP1</td>
<td>Transponder</td>
<td>Mar. 2015</td>
<td>16 degree</td>
</tr>
<tr>
<td>AP2*1</td>
<td>AIS-APM</td>
<td>Mar. 2015</td>
<td>10 degree</td>
</tr>
<tr>
<td>AP3</td>
<td>AIS-APM</td>
<td>Sep. 2016*2</td>
<td>10 degree</td>
</tr>
<tr>
<td>AP4</td>
<td>AIS-APM</td>
<td>Sep. 2016*2</td>
<td>5 degree</td>
</tr>
</tbody>
</table>

*1: Applied now to our radar system.
*2: Close to in-situ observation period.
Fig. 2a is a time series comparison of the radial data calculated using AP2 to the in-situ observation. As it can be assumed that the in-situ observation is more accurate than radar data, the radar observation can be an underestimation. Fig. 2b is a plot of the radar data against to in-situ observation. The slope of regression line is 0.53 (i.e. radar data is ~50% smaller than in-situ observation). At similar plot but for AP3, the slope is 0.60 (not shown in figure). AP 4 gives the best result (Fig. 2c and 2d). Slope of the radar to in-situ plot is 0.63.

As AIS-APM can follow the time change in antenna pattern, it will be useful for improving the quality of radar data. On the other hand, the AIS-APM is a high load for present system.

Results for the other two radar stations will also be exhibited on the poster.

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Fig. 2 Comparison of radar data and in-situ observation. a) : Time series. b) : Plot of radar data vs. in-situ observation. These two graphs are for radar data using AP2. c) and d) : Similar to a) and b), respectively, but for radar data using AP4.
Near-Field HFSWR Detection/Warning of Tunamis -- Fact and Myth

Poster Submission

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1 Background
The mechanism whereby HF radars see tsunamis was discovered four decades ago (Barrick, 1979). These very long waves in shallow water generate a back-forth orbital velocity of the short Bragg waves that shows up as a component of current. It was not until the catastrophic Banda Aceh earthquake and tsunami of 2004 -- in which a quarter million perished -- that significant attention focused on how to recognize these tsunami signals in the Bragg Doppler echoes. But no radars were operating that could have captured those tsunami signals from that event. Following the 2011 Tohoku Japan tsunami, a number of radars on several continents recorded raw data from which tsunami detection algorithms could be developed and optimized. CODAR SeaSondes saw this and subsequent weaker tsunami signals in 26 distinct cases.

2 Technical Approach to Tsunami Detection
Our approach has been to use only a single site's radial velocity pattern for detection. Several papers have been published (listed on the poster) that describe a "q-factor" pattern-recognition algorithm. This must find the unique, usually weak tsunami signature in a stronger background surface-flow field. Our post-processed results have shown possible warnings between 4 and 45 minutes. Detections of course are limited to the radar's coverage area. Detection comes from orbital velocity strength which depends on depth, further restricting range to the continental shelf. Within the tsunami community, this coincides with what is called the "near field" with respect to the coastal impact zone. Excluding the radar's first range cell, the math of a tsunami wave is "linear" in this near field, simplifying the model we developed. We use our model to forecast warning time and relate the radar-observed velocity to the tsunami height desired by warning centers. Our simple but adequate linear
model that runs on a laptop computer contrasts with the worldwide "far-field" tsunami forecast models like "MOST", used by NOAA's Tsunami Warning Centers.

2.1 Synopsis of Understanding -- True and Not So True Factoids

Much activity, workshops, presentations, and proceedings have ensued over the past five years. Our purpose in this poster is to summarize what we know, separating facts from anecdotal speculation and simply erroneous statements.

2.1.1 A "shallow-water" tsunami wave is unique, in that its orbital velocity is essentially constant vs. depth, i.e., no vertical shear.

2.1.2 Two velocities are associated with tsunamis: orbital velocity (tens of cm/s) and profile velocity (hundreds of km/h). Orbital velocity is like a particle velocity, and transports the Bragg-scattering waves.

2.1.3 The tsunami orbital velocity sensed by the radar depends on depth to the inverse three-quarters power law. This is a strong depth dependence, increasing HF tsunami observability rapidly as it moves toward shore over the continental shelf.

2.1.4 Tsunami height has a weaker depth dependence, i.e., inverse one-quarter power.

2.1.5 Tsunamis have two sources: seismic subsea events (earthquakes) and atmospheric fronts moving across the sea surface (generating what are called meteo-tsunamis). After initiated, their propagation laws are the same.

2.1.6 An atmospheric front or storm passing across the sea surface often generates a flow pattern due to wind stress. Usually this wind-driven change in surface flow is not a meteo-tsunami, although frequently it has been erroneously called that.

2.1.7 Such an atmospheric front moving across the ocean can generate an actual meteo-tsunami when the frontal velocity is near equal to the shallow-water wave velocity for a given depth. This is known in this community as "the Proudman resonance effect. From that point on, it propagates according to the shallow-water dispersion relation.

2.1.8 Why is this an important distinction? Because a tsunami model useful for forecasting gives the both orbital and profile velocities. But a wind-stress-driven surface flow does not follow this relation -- it moves at the speed of the atmospheric low-pressure storm event.

2.1.9 Our model for near-field tsunami propagation is based on two simple equations: Newton's second law (force = mass x acceleration) and incompressibility of water. It leads to the following linear second-order partial
differential equation that is easily solved with MATLAB:

$$\nabla \nabla \cdot (d \tilde{v}) - \frac{1}{g} \frac{\partial^2 \tilde{v}}{\partial t^2} = 0$$

where \( \tilde{v} \) is the horizontal tsunami orbital velocity; \( d \) is water depth; and \( g \) is the gravitational constant.

2.1.10 To solve this, one specifies an initial condition (tsunami wave farther out) and boundary condition at the coast (e.g., reflecting). Example solutions are shown in the poster and in movies.

2.1.11 It remains linear in the velocity solution for a tsunami, until water depth is less than about four meters (within the first range cell). Shoreward of that point, the wave crests and breaks as its energy is dissipated into other forms (e.g., as it runs up onto the beach, between trees and buildings).

2.1.12 Scales for tsunamis that are mathematically important (both time and space) for modeling and radar observations are large. E.g., spatial scales of hundreds of kilometers for its wavelength; tens to hundreds of kilometers per hour for its profile propagation velocity; and time scales of tens of minutes. Hence bathymetry resolution scales required for modeling can be quite coarse for tsunami waves, time increments for Doppler processing can be 2 – 4 minutes.

2.1.13 It is often incorrectly claimed that long phased-array receive antennas are more useful than compact single-mast SeaSonde antennas for tsunami detection. But for sea echo the higher directive gain of a narrow phased-array beam is exactly cancelled by the larger surface-scatter area contained in the broad-beam pattern of the compact antenna. This has been confirmed by measurement and theory. Their average maximum ranges are the same.

2.1.14 Several have speculated that the HF radar can best observe tsunami waves far out, at the edge of the continental shelf, because fine-scale surface and short-time features appear there, due to nonlinear interactions. This is unsupported speculation that is easy to disprove; there are no such features. The strongest observable tsunami features occur close in, at the shallowest depths.

2.1.15 The tsunami pattern-recognition algorithmic module (called q-factor for SeaSondes) is the first step in an end-to-end procedure to generate robust warnings for effective use by national tsunami warning centers. Other required steps include filtering and correlations with other information. These additional required steps are outlined in our poster. CODAR has patents pending on this
end-to-end system.

2.1.16 Metrics to optimize any end-to-end HF radar tsunami alert system are: false alarm rate and probability of detection. Of these two metrics, the goal is to optimize all software algorithms in this chain (introduced in prior bullet) so as to minimize the former while maximizing the latter.

References