

EXPERIMENTAL RESEARCH OF UHF RADIO BACK-SCATTERED FROM FRESH AND SEAWATER SURFACE

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Abstract—The backscattering experiments of water surface by Ultra-High Frequency (UHF, 300 ~ 3000 MHz) Radar are presented in this paper. In order to study UHF radio propagation and backscatter mechanisms from fresh and salty water surfaces at a very low grazing angle, two experiments are carried out on Yangtze River bridge and cliff which face open sea with the same radar system. The physical parameters of different water surfaces are introduced as well as the signature of backscattered echoes.

1. INTRODUCTION

High frequency(HF) surface wave radar has been developed for nearly forty years. At HF band (3 ~ 30 MHz), the scattering theory of radio wave on rough sea surface has been sophisticatedly developed based on Rice's perturbation theory [1]. The basic physics of backscattering of electromagnetic waves from sea surface was discovered and explained as "Bragg Scattering" by Crombie in 1955. Barrick formulated the theory of first- and second-order backscattering equations in 1972 [1]. HF radio wave propagation modes on rough sea surface have been comprehensively investigated as well.

Regarding UHF radar system, the radio wavelength is less than 1 m, which is relatively shorter compared to the average ocean surface wavelength. Due to high propagating attenuation on sea surface, UHF radar has not been popularly used for ocean remote sensing. Even so, researchers have made some experimental observations: C-CORE of Memorial University Canada developed a coherent Doppler

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UHF radar system in 1999 [2], which works at 462.5 MHz, and the ocean clutter was gathered. In 2003 Forget et al. [3] also developed a coherent pulsed L-band UHF (at 1.238 GHz) radar system; one day experimental test was conducted on the coast of the Mediterranean Sea. Some researchers also developed UHF current radar for measuring river surface current velocity. One typical UHF surface current radar was developed by CODAR company, named RiverSonde. It works at 350 MHz with a bandwidth of 30 MHz and operates at riverside, providing a coverage of current map of interest. A series of field tests using Riversonde have been reported in [4].

Radio Propagation Lab. of Wuhan University started to develop UHF radar for measuring surface dynamics of fresh water in 2004. Some initial results have been collected [5]. Later on, in 2006 a modified system was developed with multi-channel and shorter repetition time (chirp period) by Shen [6]. A field experiment was carried out on the bridge of Yangtze River (working at 305 MHz), which successfully accomplished the ship tracking as well as the surface velocity measurement. Another experiment was conducted on the beach of East China Sea in the summer of 2007 to investigate the surf waves and rip current by UHF radar [7]. During the last two experimental days, the radar was moved onto a cliff, with the same configuration as conducted in Yangtze river experiment. The radio echoes are backscattered from different water surfaces due to material and hydrodynamic variance. Details of the experiments as well as the comparison of the results are given in this paper.

2. UHF RADIO WAVE PROPAGATION AND SCATTERING ON WATER SURFACE

2.1. Physical Parameters of Water Surface

When electromagnetic wave propagates on water surface, radio waves are affected by the physical parameters of both sea and atmosphere. In atmosphere, dielectric constant $\epsilon = 1$, while in the water, the complex dielectric constant $\epsilon = 80 + j\sigma/(\epsilon_0\omega)$, where $\epsilon_0 = 8.5 \times 10^{-12}$ As/Vm is absolute permittivity in vacuum, σ the conductivity, and ω the angular radar frequency. The propagating attenuation of UHF radio wave strongly depends on the imaginary part of ϵ . The conductivity σ is a function of salinity and temperature. We consider a flat homogeneous surface with conductivity σ . The source is taken to be a ground-based vertical electric dipole with current $I(\omega)$ and infinitesimal length dl . The vertical electric field $\psi(\omega)$ at a distance d and time t is given by

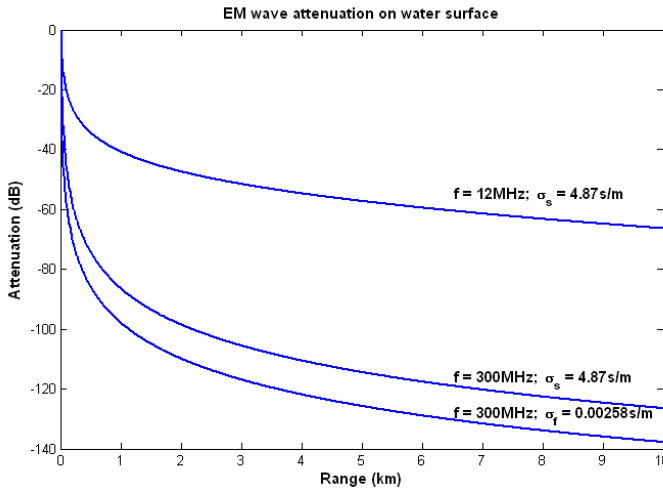


Figure 1. Theoretical radio attenuation on water surface.

[8, 14]

$$\psi(\omega, d, t) = \frac{1}{d} A(\omega, \sigma, d) \exp \left[i \cdot \omega \left(\frac{d}{c} - t \right) \right] \quad (1)$$

where A is an attenuation factor, which is given in [10]

$$A(\omega, p, d) = i\mu_0\omega I(\omega)dl(1 - i\pi^{1/2}p^{1/2}\exp(-p)\text{erfc}(ip^{1/2}))/2\pi \quad (2)$$

where μ_0 is the permeability of free space, $p = (kd/2)(\epsilon_0\omega/\sigma)$, and k is the radio wavenumber. Fig. 1 demonstrates the attenuation dependencies of frequency and conductivity. The numerical results refer to a plane earth with both transmitter and receiver located at water surface. The typical conductivity value of sea water $\sigma_s = 4.78 \text{ s/m}$, and in fresh water $\sigma_f = 0.00258 \text{ s/m}$ (which is the value at Wuhan Yangtze River [9]). Meanwhile, the attenuation of HF (12 MHz) radio on sea surface is also given.

2.2. Water Surface Roughness and Radar Equations

Surface water waves are mainly generated by wind, when wind blows over water surfaces, the ripples are generated, and longer waves are generated due to non-linear wave-wave interactions. At coastal regions, the waves are a combination of wind waves, shoaling waves and swell, which makes the surface more irregular [12]. By contrast, river waves are stationary and either forced by local surface wind or fast moving water hitting slower moving water; the later situation normally

happens where the dam locates in mountain areas. But for our radar experiment, the site selected is a part of middle and lower reaches of Yangtze River, the surface of which is wide and calm. From our first sight of the sea and river surface, the sea wave height is higher than that of the river waves. According to our wave staff records, in most cases, the wave height at the river surface is less 10 cm, but at the coastal region, the wave height is greater than 30 cm. In extreme conditions, the wave height can reach up to 1 m.

According to Bragg theory [1], when the incident electromagnetic waves scattered on rough water surfaces at a small grazing angle, the wavelength of the resonant waves (λ_w) is half of the radio wavelength (λ_r). Resonant waves give the strongest backscattered energy due to Bragg effect, thus, the Doppler spectrum contains two strong peaks; the frequency of which is determined by the phase velocity of the scattering water waves. In no current condition, the locations of the two peaks are symmetric to zero frequency on the Doppler spectrum. In UHF ocean surface remote sensing, the radio wavelength even might be equivalent to the wave height in some conditions. Considering all the external differences, the experimental observations are designed for the preliminary investigation of UHF radio water surface scattering.

When radio waves are scattered from water surface, the received echo (in monostatic condition) can be evaluated by the following radar equation [11]:

$$P_R = \frac{P_T G_T G_R \lambda_r^2 A^4(d)}{4\pi^3 d^3} \cdot \sigma_0 \Delta d \Delta \theta \quad (3)$$

where P_R , P_T are the received and transmitted power; λ_r is the radio wavelength; G_T and G_R are the gain factors of the transmit and receive antennas relative to isotropic; $A(d)$ is the attenuation factor as described in Section 2.1; d is the detecting range. σ_0 is the backscatter cross section per unit area, which is related to incident angle and water surface roughness [13]. Δd , $\Delta \theta$ are the range and angular extent of the spatial resolution cell.

3. RADAR EXPERIMENTS ON YANGTZE RIVER AND EAST CHINA SEA

The UHF radar adopts the Frequency Modulated Continuous Waveform (FMCW) mechanism, utilizing the frequency and phase of echoes to get parameters of surface waves. It operates at a frequency range of 300–330 MHz, and the frequency bandwidth is flexible. The system is configured as a bistatic radar, but still we can use the monostatic method for data analysis due to the short distance between

transmit and receive antennas (nearly 3 ~ 4 m in the river experiment and 6 ~ 8 m in the sea experiment), which means that this distance can be ignored compared to radar ranging (several hundreds meters). The sketch of UHF radar experiment is given in Fig. 2. During the river experiment, the radar was located on the platform which is fixed on the pier for bridge maintenance. The height above water was approximately 17 m. In the sea surface measurement, the radar antennas were located on the cliff which was approximately 50 m above sea level. The depression angle of transmit antenna is nearly $8 \sim 10^\circ$ (defined as α). Echoes are intensified radio backscattering from two oppositely propagating waves traveling along the incidence direction, with a wavelength that is half of the radio waves. In absence of currents, the first-order peaks are located at $\pm\omega_B$, where $\omega_B = \sqrt{2gk_0 \cos \alpha}$ (in which g is the acceleration of gravity; k_0 is the wave number of radio wave; α is the depression angle of transmit antenna, here $\cos(\alpha) \approx 1$). Currents carrying the waves cause an additional Doppler shift Δ on $\pm\omega_B$, which give the radial component of the current velocity by $v_r = \lambda_r \Delta / 2$.

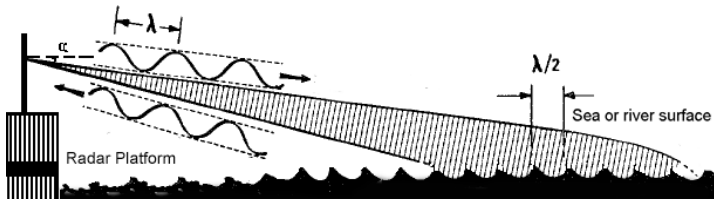


Figure 2. UHF radio scatter on water surface.

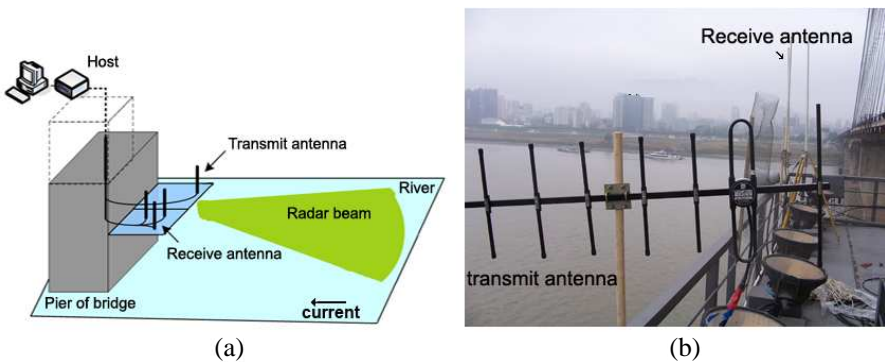


Figure 3. Sketch of experiment on the river (a) and antenna photo (b).

3.1. Experiment on the Bridge of Yangtze River

The radar has been operational since November 2006. The sketch and a photo of radar set-up are given in Fig. 3. The antennas face the upriver direction, which means the current moves towards radar. Yagi is used as transmit antenna, while three monopole antennas are deployed as receive antenna and form a triangle array. MUSIC (Multiple Signal Classification) method is implemented to determine the arrival angle of echoes, and details are given in [6].

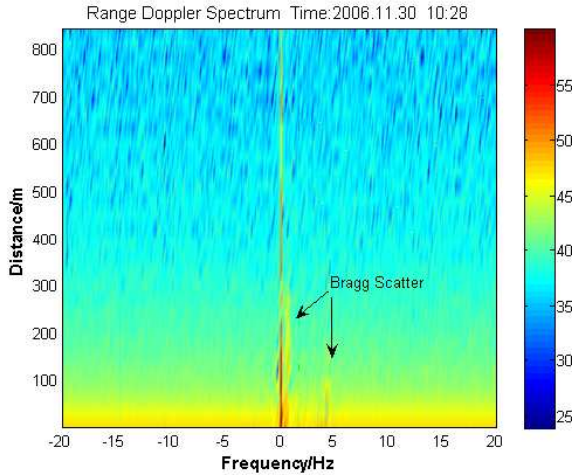


Figure 4. Range-doppler spectrum measured on river surface.

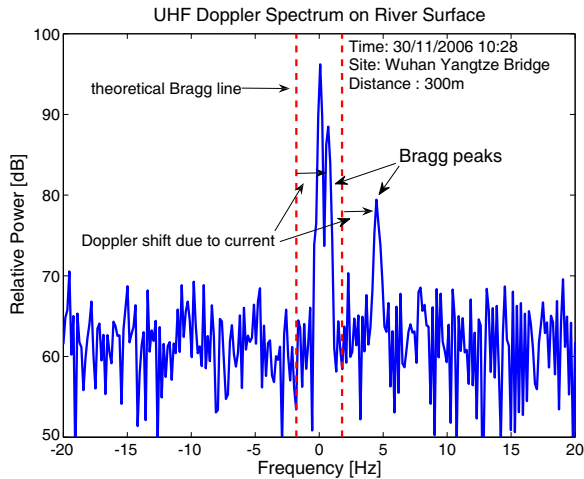


Figure 5. Doppler spectrum at a certain distance.

Figure 4 gives the range-Doppler spectrum of radar echoes. Two short lines appear on it, which are “Bragg peaks”. When wind above river surface blows towards upriver, the energy of left Bragg peak is stronger than that of the right one, which means that the receding waves are stronger than approaching wave component [11]. In Fig. 5, the Doppler spectrum at one certain distance is given. Here, a pair of Bragg peaks appears, the stronger left Bragg peak exceeds the zero frequency due to strong river current (nearly a velocity of 1 m/s). The first-order peaks are relatively sharp, and no high-order backscatter continuum appears on the spectrum. The strong peak at zero frequency is due to strong DC component in radar system.

3.2. Experiment on the Cliff Facing to East China Sea

A UHF radar East China Sea experiment was conducted during Sept. 2007. The triangle receive antenna array was substituted by a single Yagi since there is no vessel surveillance in this experiment. The antenna gain was adjusted to be the same as that in Yangtze river experiment. Radar system was placed on the cliff facing open sea, and the cliff is higher than the platform on the pier of bridge, which means that the radio waves travel longer distance from transmit antenna to water surface with the same incident angle, just as the backscattered radio waves from water surface to receive antenna. Photos of radar experiment are given in Figs. 6(a) and (b).

The range-Doppler spectrum is given in Fig. 7, as discussed above, due to longer radio path in free space. on the Range-Doppler spectrum, the backscattered echoes start to appear at a distance of 200 m (the propagating path in free space is counted for radar ranging). A comparison with Fig. 4 shows that, using the same transmit power, the radio waves propagate a longer distance, which is due to higher

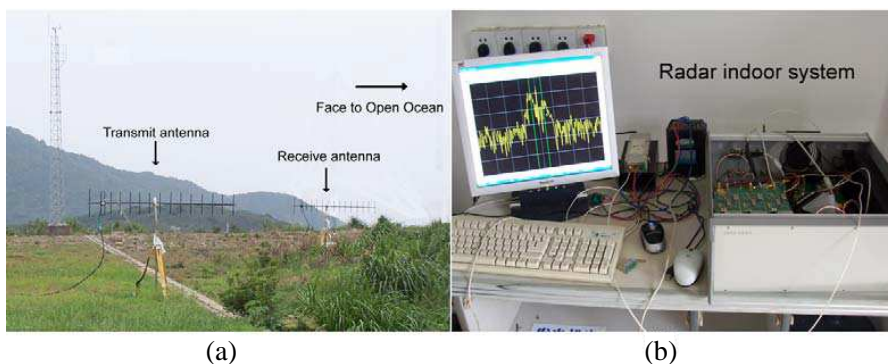


Figure 6. Photos of UHF radar antennas (a) and indoor system (b).

conductivity (salinity). The Doppler spectrum is given in Fig. 8. The Bragg peaks are widened, and the second-order spectrum could not be distinguished. The Bragg peaks are nearly symmetric to zero frequency, which means that there is no additional Doppler shift in backscattered echo due to the stand wave down below the cliff or possible current which is perpendicular to radar look direction passing by the cliff.

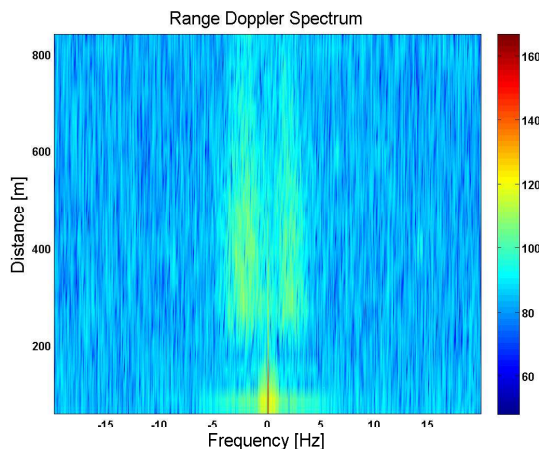


Figure 7. Range-doppler spectrum measured on sea surface.

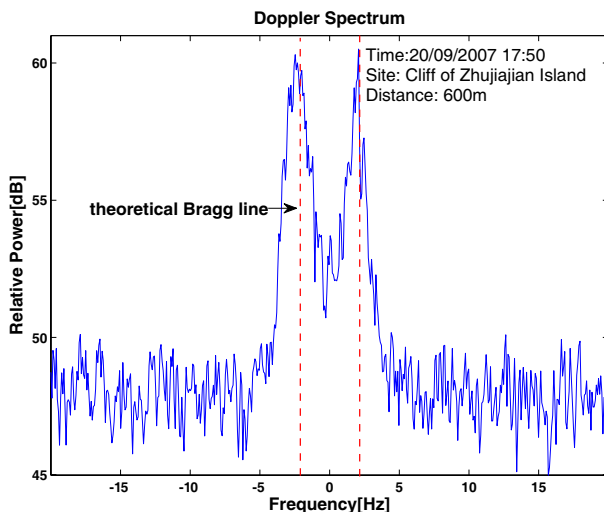


Figure 8. Doppler spectrum of a certain distance.

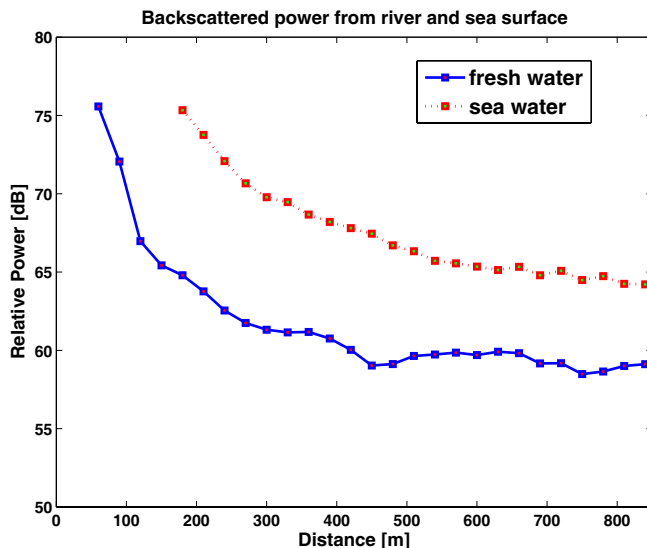


Figure 9. Comparison of backscattered power from fresh and salty water surface.

4. CONCLUSIONS

The paper presents experimental research of the UHF radio propagation and backscattering on fresh and salty (sea) water surfaces. The physical and dynamic parameters of river and sea surface waves are briefly introduced. Two backscattering experiments are presented using the same radar system, and some conclusions are derived from the experimental data. As introduced in Section 2.1, while UHF radar is implemented for water surface dynamic research, the attenuation of radio wave propagating on a water surface has to be investigated. In the conditions of fresh and salty water, the curves of the received backscattered power as a function of distance are depicted in Fig. 9, which is based on the experimental data. The starting point of each curve is at a different distance due to the difference in the distance from the radar antenna to the water surface. The incident angles are same in the two experiments, while the antennas located higher above water surface during East China Sea experiment. The calculation of backscatter power starts from the distance where the radio wave first touches the water surface.

When electromagnetic waves are scattered on the rough water surface at a small grazing angle, the signature of radar Doppler spectrum is related to the water surface dynamics, including currents

and wave height (or slope: h/λ_w , h is the wave height, and λ_w is Bragg wave length), etc. Barrick proposed the mathematical expression of first- and second-order scatters for HF radar surface wave remote sensing. However, the basic requirements in the application of the perturbation method are that: 1) the surface profile variations must be small compared to the radio wavelength; 2) the surface slopes must be much smaller than unity; 3) the impedance of the surface medium must be small in terms of the free-space wave impedance [1]. It transpires that similar restriction in the ensuring procedures leads to simplifications of the analysis. In our UHF river experiment, the river surface height is much lower than the radio wavelength, and the slope of river water is quite small, so it can meet the requirement of perturbation, and the backscattered first-order peaks can be distinguished from the Doppler spectrum, while in the UHF sea experiment, the slope of the ocean waves is much higher than that of the river wave. So the Bragg peaks are smeared by high-order continuum spectrum [1]. As we have seen from the Doppler spectrum at ocean surface (Fig. 8), the peaks are widened due to the high roughness of water surface. The width of the peaks on the Doppler spectrum is closely related to the roughness (or slope) of the water surface.

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