International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R M.1874-1
(02/2013)

Technical and operational characteristics of oceanographic radars operating in sub-bands within the frequency range 3-50 MHz

M Series

Mobile, radiodetermination, amateur and related satellite services

International Telecommunication Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from http://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Recommendations

(Also available online at http://www.itu.int/publ/R-REC/en)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	Fixed service
M	**Mobile, radiodetermination, amateur and related satellite services**
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2013

RECOMMENDATION ITU-R M.1874-1

Technical and operational characteristics of oceanographic radars operating in sub-bands within the frequency range 3-50 MHz

(Question ITU-R 240/5)

(2009-2010-2013)

Scope

This Recommendation provides technical and operational characteristics of oceanographic radars for use in sharing and compatibility studies and spectrum planning and systems deployment within the 3 to 50 MHz band. It provides the relevant characteristics of short-range, standard range, long-range, very-long range and high-resolution oceanographic measurement systems.

The ITU Radiocommunication Assembly,

considering

a) that there is a need to operate oceanographic radar systems in the radiodetermination[1] service, using spectrum in the 3 to 50 MHz frequency range;

b) that WRC-12 allocated a number of frequency bands between 3 and 50 MHz for operation of these radars;

c) there is global interest in deploying operational systems on a worldwide basis;

d) that performance, functions and data requirements normally determine the range of spectrum that can be used by ocean observing radar systems,

recognizing

that representative technical and operational characteristics of oceanographic radar systems are required for spectrum management and deployment planning,

recommends

1 that the technical and operational aspects of oceanographic radars contained in the Annex should be considered when conducting sharing and compatibility studies with systems in other services;

2 that the technical and operational aspects of oceanographic radars contained in the Annex should also be taken into consideration for planning purposes.

---

[1] The radiolocation and radionavigation services are sub-services of the radiodetermination service.

Annex

Technical and operational characteristics of oceanographic radars operating in sub-bands within the frequency range 3-50 MHz

1 Introduction

A significant percentage of the world's population lives within 50 miles of the coastline heightening the need for accurate, reliable and detailed measurements of coastal environmental variables.

Just as the winds in the atmosphere provide information about where and when weather systems occur, ocean currents determine the movement of oceanic events. These two dynamic flows are used to determine where pollutants, man-made or natural, will travel. Presently, ocean current measurements are not as readily available as winds.

Because of this, there is an increasing interest in the ability to accurately measure the currents and waves in coastal waters. Radar systems operating at frequencies higher than 50 MHz are limited in their ability to provide data meeting current range, accuracy and resolution requirements. The global oceanography community is planning for the implementation of coastal sea surface monitoring radar networks. The benefits to society for improved measurement of coastal currents and sea state include a better understanding of issues like coastal pollution, fisheries management, search and rescue, beach erosion, maritime navigation, sediment transport and tsunami and associated surface wave resonance response (see the Appendix). Coastal radar measurements of the sea surface provide support to meteorological operations through the collection of sea state and dominant ocean wave data. In addition, oceanographic radar technology has applications in global maritime domain awareness by allowing the long range sensing of surface vessels. This will benefit the global safety and security of shipping and ports[2].

The need for additional data to mitigate the effects of disasters, including tsunamis, to understand climate change, and to ensure safe maritime travel has led to the consideration of operational use of oceanographic radar networks on a global basis.

Implementation of these systems in Japan is shown in Figs 1 and 2.

[2] Use of Coastal Ocean Dynamics Application Radar (CODAR) Technology in the United States of America Coast Guard Search and Rescue Planning, David Ullman; James O'Donnell; Christopher Edwards; Todd Fake; David Morschauser; Coast Guard Research and Development Center Groton CT.

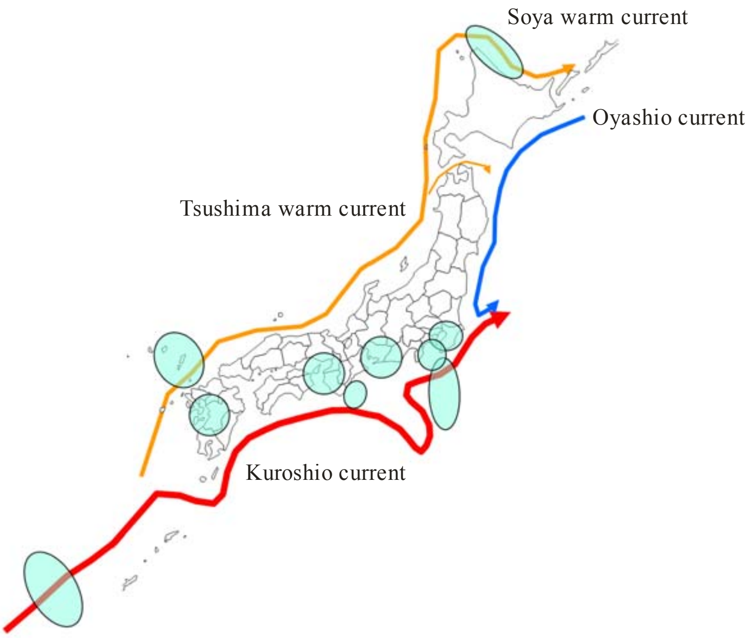
FIGURE 1

An example of the observed surface current by oceanographic radars in the Tokyo Bay Watch System operated by Ministry of Land, Infrastructure, Transport and Tourism, Japan

M.1874-01

FIGURE 2

Oceanographic radars in Japan
(observation areas are shown for each fixed radar site)

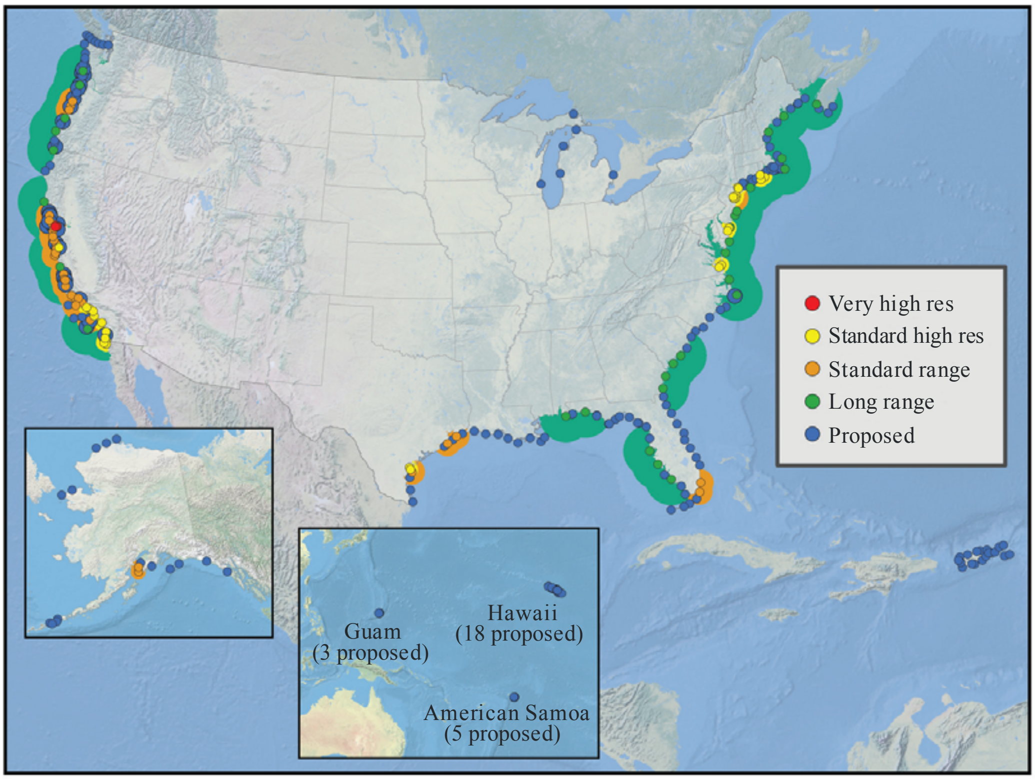


M.1874-02

As of 2009, 143 oceanographic radars spread unevenly throughout the United States of America coastal regions (this total includes radars that are not currently operating on a regular basis). Nearly all of the oceanographic radar systems in the United States of America are owned and operated by university research departments. Existing and proposed oceanographic radar sites for the United States of America, the Pacific Islands and the Caribbean Regions are shown in Fig. 3.

FIGURE 3

Existing and proposed oceanographic radar sites for the United States of America, the Pacific Islands and the Caribbean Regions



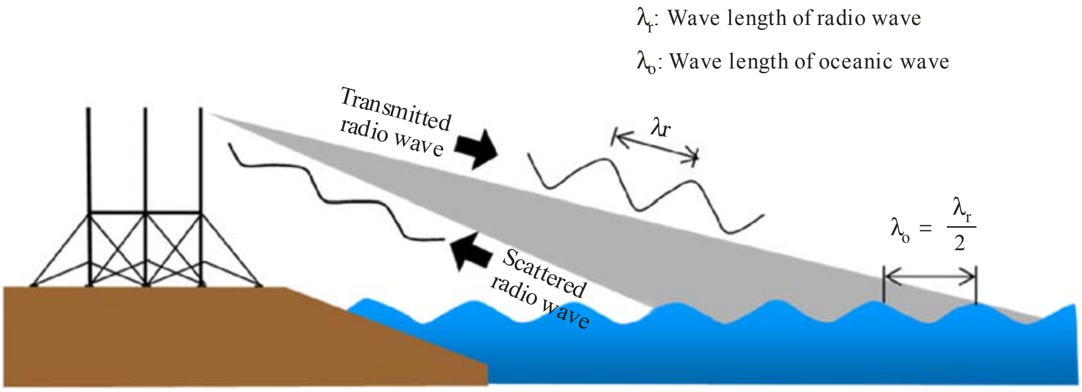
The establishment of a network of oceanographic radar monitoring sites is included in the integrated ocean observing system (IOOS) Development Plan and is part of the global ocean observing system (GOOS) which, in turn, is a substantial component of the global Earth observing system of systems (GEOSS).

2 Principle of operation

In oceanographic radars using Bragg scattering[3], the frequency range of 3 to 50 MHz (wavelength of 100 to 6 m) is very useful in measuring ocean waves driven by wind (see Fig. 4). Spatial resolution of the radar is limited by the bandwidth of the signal e.g. the bandwidths of 100 and 300 kHz give resolutions of 1.5 km and 500 m, respectively[4].

FIGURE 4

Schematic image of radio wave propagation and a Bragg scattering



The objectives of these systems are to: obtain continuous, real-time information for environmental operation (e.g. pollution collection and control), provide disaster-mitigation services (e.g. tsunami wave detection), provide maritime-safety services (e.g. oceanic-current monitoring sea state observation) by oceanographic radars.

The physical parameters that are measured by oceanographic radars and associated performance requirements dictate the frequency ranges that will support data collection. Oceanographic radars for ocean observing utilize the rough surface of the ocean to measure ocean currents and sea state. When the wave spacing on the ocean surface is equal to the half wavelength of the frequency used by the oceanographic radar, a strong signal is reflected back in the direction of the radar. This is the phenomenon known as Bragg scattering. The frequency range 3 to 50 MHz is very useful for oceanographic observing radar operations since ocean waves are always present where the wave spacing matches the radar's operational frequency. The higher temporal resolution is to be pursued for disaster-mitigation purposes while the higher spatial resolution is to be pursued for environmental operation. In addition, measurement of Doppler shift of the signal returns allows operators to measure other properties of sea state and currents.

The two main transmission techniques which are used in oceanographic radars are CW pulses and linear FMCW chirps. Table 1 is a list of the parameters which are associated with a typical oceanographic radar.

---

[3] When the transmitted surface wavelength is equal to the half-wavelength of the surface wave in the Ocean, a strong reflected signal will be reflected back in the direction of the radar.

[4] Resolution L, speed of light c (= 300 000 km/s) and bandwidth fc has relation of $fc = c/2L$.

TABLE 1

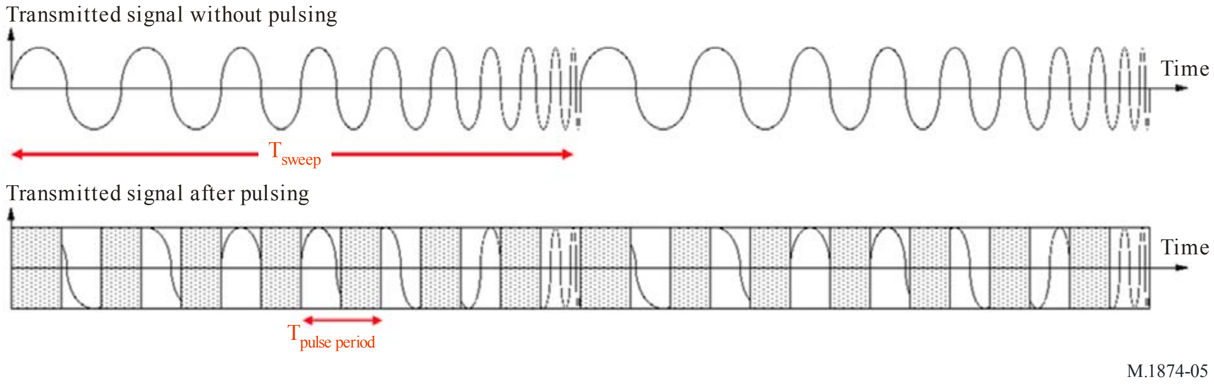
List of parameters of typical oceanographic radar waveforms

Centre frequency (MHz)	Sweep bandwidth (kHz)	Sweep time (Tsweep) (s)	Pulse period (Tpulse period) (µs)	Duty cycle (%)
4.53	25.6	1	1 946	50
13.46	49.4	0.5	669	50
24.65	101	0.5	486	50

Figure 5 illustrates the waveform structure of typical oceanographic radars. The waveform at the top of the picture represents an FMCW signal. The waveform on the bottom is representative of a gated signal.

FIGURE 5

Typical oceanographic waveform structures

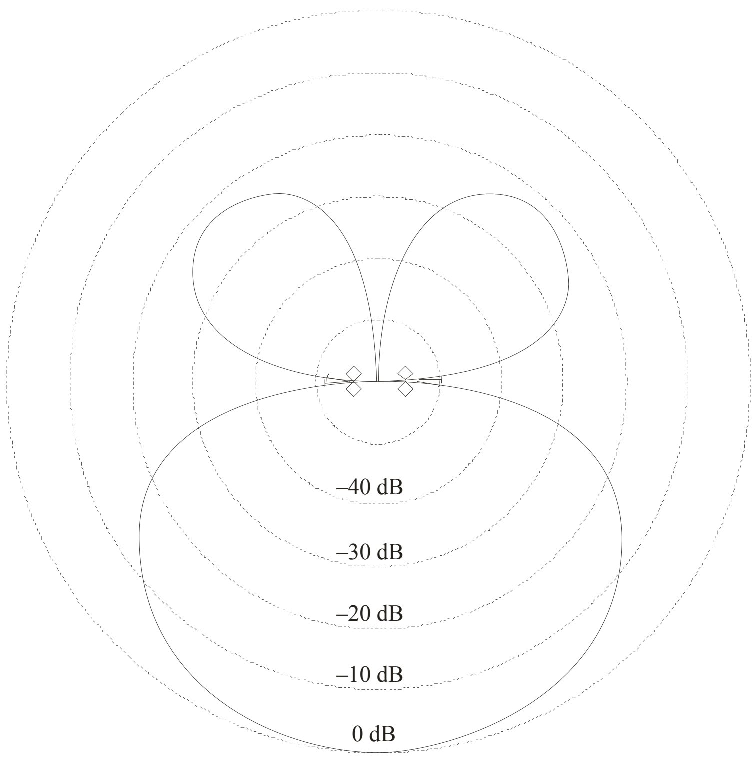


3 Oceanographic radar antennas

A variety of antenna types are currently used with oceanographic ocean observing radar systems. Some systems utilize either a 3-element Yagi antenna or phased-array system to sweep in the azimuthal direction using multiple sets of Yagi antenna for transmission, limiting the geography over which the oceanographic radar signal is propagated. Figures 6, 7 and 8 illustrate some typical oceanographic radar antenna patterns.

FIGURE 6

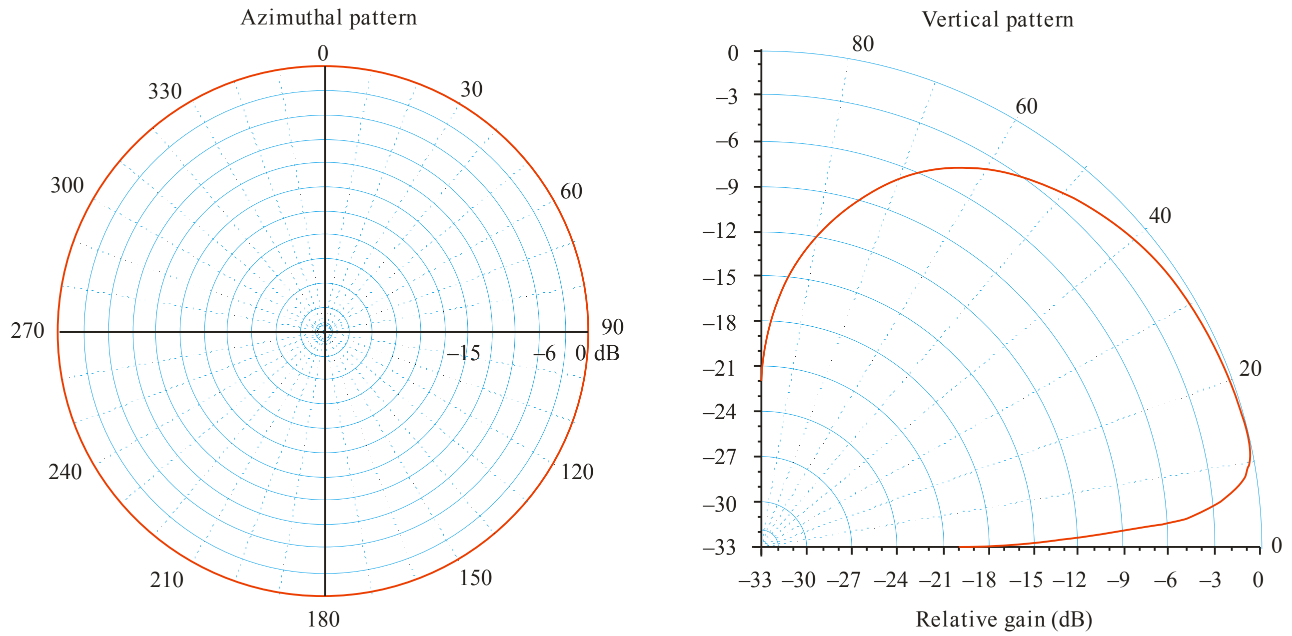
Typical oceanographic radar antenna patterns
(4 vertical monopole array)



M.1874-06

FIGURE 7

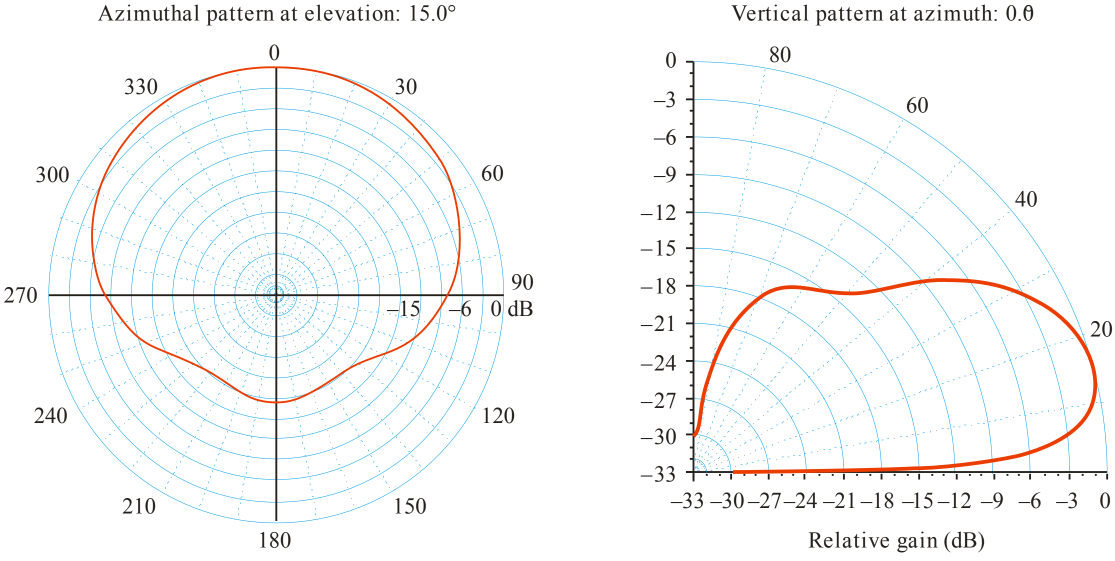
Typical oceanographic radar antenna patterns
(omnidirectional; left: azimuthal, right: vertical)



M.1874-07

FIGURE 8

Typical oceanographic radar antenna patterns
(directional, 3 elements Yagi; left: azimuthal, right: vertical)



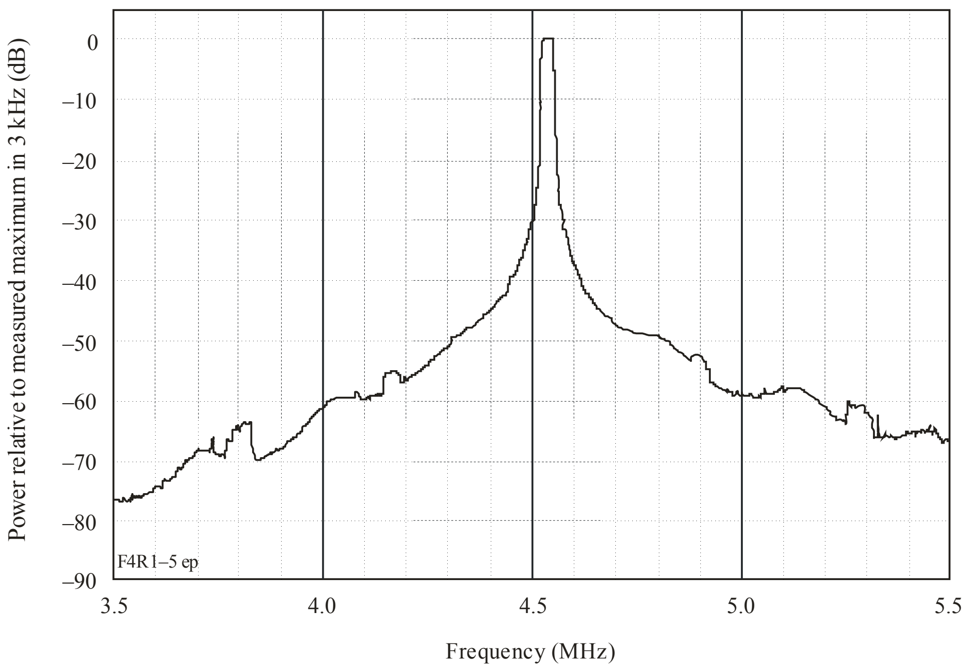
M.1874-08

4 Transmitter emissions

Figures 9 and 10 illustrate typical 4.5 MHz and 24 MHz oceanographic radar emissions.

FIGURE 9

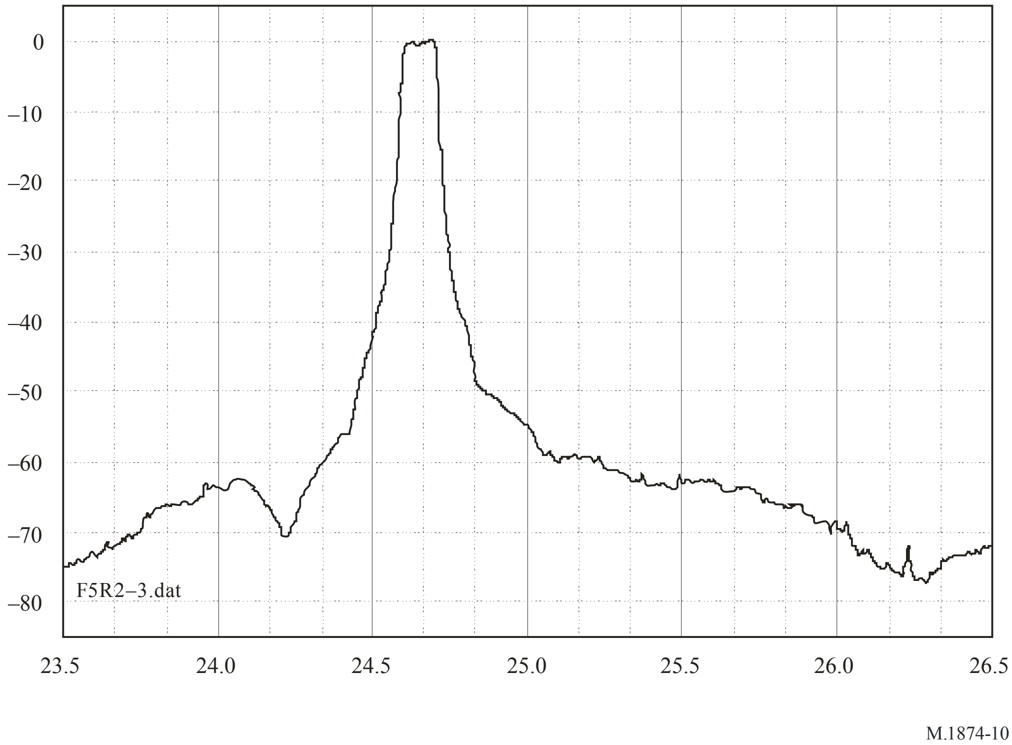
4.5 MHz oceanographic radar emission



M.1874-09

FIGURE 10

24 MHz oceanographic radar emission



5 System characteristics

Tables 2 through 4 contain a summary of RF characteristics for representative oceanographic radar systems for ocean monitoring at frequency ranges within 3 to 50 MHz.

TABLE 2

Characteristics of generic oceanographic radars for ocean observing using frequency modulated interrupted continuous wave (FMICW)

Characteristics	Units	System 1 5 MHz	System 2 13 MHz	System 3 25 MHz	System 4 42 MHz
Function		Long-range oceanographic measurements	Standard oceanographic measurements	High-resolution oceanographic measurements	
Maximum operational (measurement) range(1)	km	170-200 (average during daytime)(2)	60-90 (average during daytime)(2)	30-50 (average during daytime)(2)	15-25 (average during daytime)(2)
Range of user selectable range resolution	km	3-12(3)	2-3(3)	0.3-2(3)	0.3-1(3)
Typical sweep bandwidth	kHz	25(3)	50(3)	100(3)	125(3)
Frequency range(4)	MHz	4-6(4)	12-14(4)	24-27(4)	40-44(4)
Typical peak power used Maximum system capability – Peak power into antenna	W	50 80			50 80(100)
Pulse widths	µs	1 000-2 000	300-600		30-100
Maximum duty cycle	%	50			
Pulse rise/fall time	µs	16/32	16		8/16
Transmitter tuning method		Digital			
Receiver tuning method		Digital			
Output device		Gated FET (Class AB operation)			
Transmitter stability	ppm	0.001			
Receiver stability	ppm	0.001			
Transmit antenna pattern type		Omnidirectional (in horizontal plane)			
Transmit antenna type		Quarter-wave monopole with ground plane			

TABLE 2 (*continued*)

Characteristics	Units	System 1 5 MHz	System 2 13 MHz	System 3 25 MHz	System 4 42 MHz
Antenna polarization		Vertical			
Antenna main beam gain	dBi	8			
Transmit antenna elevation beamwidth	degrees	35			
Transmit antenna azimuthal beam width		Omnidirectional			
Transmit antenna horizontal scan rate		Fixed antenna			
Transmit antenna height	m	10	4	2	1.2
Receive antenna pattern type		Electric and magnetic dipoles			
Receive antenna type		Two crossed loops and a monopole as single unit			
Receive antenna polarization		Vertical			
Receive antenna main beam gain	dBi	5			
Receive antenna elevation beamwidth	degrees	45			
Receive antenna azimuthal beamwidth	degrees	90-360			
Receive antenna horizontal scan rate		Fixed antenna			
Receive antenna height	m	4			
Receiver IF 3 dB bandwidth	Hz	500			
Receiver noise figure	dB	12 with pulsing			
Minimum discernible signal	dBm	–147 (500 Hz RBW[(5)]) (specified system noise level)			
Sweeping interval	s	0.5 to 1.0			

TABLE 2 (*end*)

Characteristics	Units	System 1 5 MHz	System 2 13 MHz	System 3 25 MHz	System 4 42 MHz
Transmitter emission bandwidth 3 dB 20 dB	kHz	 26 58	 54 70	 105 150	 128 170
Suppression of harmonics		Yes			

(1) Range depends on a number of environmental factors: external noise, significant wave height, current speed, location of radar (such as proximity to water, nearby obstructions), and the operating frequency.

(2) Range reduces significantly during night time.

(3) While the sweep bandwidth is adjustable (higher bandwidth produces higher resolution data), the systems are normally operated at the typical sweep bandwidths specified due to limited available bandwidth, and the need to coexist with other radio systems.

(4) Specifies the frequency range for optimum performance from a scientific perspective. Entire frequency range not needed for operations.

(5) RBW stands for resolution bandwidth.

TABLE 3

Characteristics of generic oceanographic frequency modulated continuous wave (FMCW) radars

Characteristics	Units	System 5 8 MHz	System 6 12 MHz	System 7 16 MHz	System 8 25 MHz	System 9 42 MHz
Function		Very long-range oceanographic measurements	Long range oceanographic measurements	Standard oceanographic measurements	High-resolution oceanographic measurements	Best resolution short range measurements
Maximum operational (measurement) range	km	150-300 (average during daytime)(1)	100-150 (average during daytime)(1)	50-100 (average during daytime)(1)	30-60 (average during daytime)(1)	10-20 (average during daytime)(1)
Range resolution	km	3-12	1-3	1-3 High resolution mode: 0.5 km	0.5-2 High resolution mode: 0.25 km	0.15-0.5
Sweep bandwidth	kHz	50-12.5	150-50	300-50	600-75	300-1 000

TABLE 3 (*continued*)

Characteristics	Units	System 5 8 MHz	System 6 12 MHz	System 7 16 MHz	System 8 25 MHz	System 9 42 MHz
Frequency range	MHz	6-9	11-14	14-18	24-27	40-44
Average power into antenna (= peak power)	W	30 7 per antenna				
Pulse widths		No pulse				
Maximum duty cycle		Continuous wave				
Pulse rise/fall time		Continuous wave				
Transmitter tuning method		Digital (DDS)				
Receiver tuning method		Digital (DDS)				
Output device		Solid state, bipolar (Class AB operation)				
Transmitter stability	ppm	0.1/year				
Receiver stability	ppm	0.1/year				
Transmit antenna pattern type		Directional > 90% energy within ±60° beamwidth				
Transmit antenna type		4 vertical monopole rectangular array 0.5 × 0.15 wavelength				
Antenna polarization		Vertical				
Antenna main beam gain	dBi	5 to 8				
Transmit antenna elevation beamwidth	degrees	25 to 35				
Transmit antenna azimuthal beamwidth	degrees	120				

TABLE 3 (*continued*)

Characteristics	Units	System 5 8 MHz	System 6 12 MHz	System 7 16 MHz	System 8 25 MHz	System 9 42 MHz
Transmit antenna horizontal scan rate		Fixed antenna				
Transmit antenna height (m)		< 10	< 6	< 4	< 3	< 2
Receive antenna pattern type		Directional with beamwidth of ±3 to ±15°				
Receive antenna type		Monopole array (4 to 16 monopoles)				
Receive antenna polarization		Vertical				
Receive antenna main beam gain	dBi	10 to 18				
Receive antenna elevation beamwidth	degrees	35				
Receive antenna azimuthal beamwidth	degrees	6 to 30 depending on array size				
Receive antenna horizontal scan rate		Fixed antenna				
Receive antenna height	m	< 10	< 6	< 4	< 3	< 2
Receiver IF 3 dB bandwidth	kHz	No IF used. Baseband bandwidth is 1.5				
Receiver noise figure	dB	8				
Minimum discernible signal	dBm	−142 in 1 500 Hz RBW[(2)] (specified system noise level)				

TABLE 3 (*end*)

Characteristics	Units	System 5 8 MHz	System 6 12 MHz	System 7 16 MHz	System 8 25 MHz	System 9 42 MHz
Instantaneous bandwidth 3 dB 20 dB 60 dB	kHz	0.2 0.6 30				
Suppression of harmonics	dBc	< −60				
Sweep interval	ms	200 to 500	130 to 500		130 to 250	

(1) Range reduces significantly during night time.

(2) RBW stands for resolution bandwidth.

TABLE 4

Characteristics	Units	System 10 9.2 MHz	System 11 24.5 MHz	System 12 24.5 MHz	System 13 41.9 MHz
Function		Long-range oceanographic measurements	Standard oceanographic measurements		High-resolution oceanographic measurements
Maximum operational (measurement) range	km	200-300	50-70		20-25
Range resolution	km	6.8	1.5		0.5
Sweep bandwidth	kHz	22	100		300
Frequency range	MHz	9.2	24.5		41.9
Peak power into antenna	W	1 000	100	200	100
Pulse width	μs	1 330	488		244-280
Maximum duty cycle	%	50			
Pulse rise/fall time		Smoothed(1)			
Transmitter tuning method		Digital			

TABLE 4 (*continued*)

Characteristics	Units	System 10 9.2 MHz	System 11 24.5 MHz	System 12 24.5 MHz	System 13 41.9 MHz
Receiver tuning method		Digital			
Output device		Gated FET (Class AB operation)			
Transmitter stability	ppm	0.03/year			
Receiver stability	ppm	0.03/year			
Transmit antenna pattern type		Directional			
Transmit antenna type		3-element Yagi	8 sets of 3-element Yagi	3-element Yagi	
Antenna polarization		Vertical			
Antenna main beam gain	dBi	6	15	6	
Transmit antenna elevation beam width	degrees	30	25		
Transmit antenna azimuthal beam width	degrees	120	15	120	
Transmit antenna horizontal scan rate		Fixed antenna	Fixed antenna phased array 60 min per 12 direction	Fixed antenna	
Transmit antenna height[(2)]	m	10	2-14		
Receive antenna pattern type		Directional			
Receive antenna type		16 sets of 2-element Yagi	8 sets of 3-element Yagi		
Receive antenna polarization		Vertical			
Receive antenna main beam gain	dBi	16	15		
Receive antenna elevation beam width	degrees	30	25°		
Receive antenna azimuthal beam width	degrees	8-10	15°		

TABLE 4 (*end*)

Characteristics	Units	System 10 9.2 MHz	System 11 24.5 MHz	System 12 24.5 MHz	System 13 41.9 MHz
Receive antenna horizontal scan rate		Fixed antenna DBF(3)	Fixed antenna phased array 60 min per 12 direction	Fixed antenna DBF(3)	
Receive antenna height(2)	m	10	2-14		
Receiver IF 3 dB bandwidth	Hz	200			
Receiver noise figure	dB	17 with pulsing	12 with pulsing	13 with pulsing	
Minimum discernible signal	dBm	−157 (1 Hz RBW(4))	−162 (1 Hz RBW(4))	−161 (1 Hz RBW(4))	
Transmitter emission band width	kHz	25	110	320	
Suppression of harmonics		Yes			
Sweeping interval	s	0.7	0.5	0.25	

(1) Pulse edges are shaped to control its spectrum. The steepness is specified indirectly via the spectrum.

(2) Feed point height in the antenna array from ground level.

(3) Digital beam forming.

(4) RBW stands for resolution bandwidth.

Appendix

Case study of oceanographic radar application

Detection of surface wave resonant response of tsunami

1 Overview

At 1446 hours on March 11, 2011 Japan Standard Time (JST), M9.0 Great East Japan Earthquake and associated tsunami waves attacked Pacific coast. We would like to express our sincere condolence for casualties, and thank for worldwide assistance and sympathies given on us.

This short contribution will introduce how the oceanographic radar contributes to the detection of the tsunami wave at coastal zone, and puts emphasis on importance of new allocations to the RLS for oceanographic radar applications with appropriate regulatory provisions for a possible sharing with existing services to enable the most efficient use of the spectrum and mitigate interference to existing services.

2 Tsunami at Pacific coast in Japan

The maximum run-up height was more than 39 m in North East area of Japan (Fig. 11: by the 2011 Tohoku Earthquake Tsunami Joint Survey Group, http://www.coastal.jp/ttjt/). The height of tsunami and width of inundation area was a historical size, and more than 500 km^2 area had been affected.

The tsunami waves reached the continental shelf slope south of the Kii Channel, western part of Japan (Fig. 12), at around 1620 hours on March 11, 2011 JST about 1.5 hours after the earthquake. Prolonged and larger oscillations in the channel had made inundation damages. In Tachibana Port on the western coast of the channel, an inundation height of about 3.5 m was observed. In Kainan Port (KA in Fig. 12) on the eastern coast of the channel, the maximum wave height of about 2.6 m was observed about 4.5 hours after the first tsunami arrival as shown in Fig. 13.

3 System used

The detection was made by the typical oceanographic radar System 12 of this Recommendation. The radar has directional antenna system (consists of 1 transmission and 8 receive antennas of 3-element Yagi) with digital beam forming. The azimuthal resolution is 7.5 degrees in the cover angle of ±45 degrees. The system is operated as FMICW (frequency modulated interrupted continuous wave) with a centre frequency of 24.515 MHz and a sweep bandwidth of 100 kHz, resulting in a range resolution of 1.5 km. These specifications allow to detect surface-current with high spatiotemporal resolution special distribution.

In a normal operation mode, the surface radial velocity map is measured hourly. As an ad-hoc operation mode, continuously transmitted and receiving the signal enable to obtain the velocity map every 2-3 min. The oceanographic radar had been operating in the ad-hoc operation mode from 1700 hours on March 11 to 1630 hours on March 19, 2011 JST.

Not only the oceanographic radar, but also the sea surface elevation data obtained in the channel (KA and KO) and on the continental shelf slope (WA) was also used for the analysis. The data at KA were obtained by the Geospatial Information Authority of Japan. The data at KO and WA, obtained by the Nationwide Ocean Wave Information Network for Ports and Harbours (NOWPHAS) was provided by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

4 Observation results

The first tsunami wave reached WA at around 1620 hours on March 11. It then reached KO at around 1700 hours and KA at around 1705 hours as shown in Fig. 13. The first wave height at KA (168 cm) can be roughly explained by the shoaling of the incident wave at WA (63 cm) on the continental shelf, while that at KO (66 cm) on the western side of the channel was almost the same as that at WA (63 cm), likely due to a combination of bathymetry-induced wave refraction and shoaling effects.

At WA and KO, the wave height gradually decreased with time and was smaller than 15 cm at 1200 hours on March 12. In contrast, at KA, although the wave height of the first to third waves gradually decreased, it rapidly increased from the fourth wave due to resonance of the surface waves. The maximum wave height reaching 262 cm was observed at the seventh wave at around 2130 hours at KA. The surface wave resonance oscillation at KA resulted in wave height greater than 50 cm observed at around 1200 hours on March 12.

From the first to third wave with larger radial velocity amplitudes, the phases in the distant ranges lead those in the closer ranges (Fig. 14). The phase relationship gradually changed after the third wave to become out of phase from 2000 hours to 2300 hours followed by establishment of in-phase relationship throughout the range from 1.5 to 30 km along the radar beam due to the occurrence of surface wave resonance. The phase relation change is evident in the time series diagram of the radial velocities at HF-12K and HF-24K (Fig. 14). From the first to the third waves, the phase at HF-12K lagged behind that at HF-24K by about 4 min. Given that the average water depth between the two points is 50 m, the travel time of the tsunami wave is estimated to be about 8 min, which is shorter than the observed time lag, suggesting that the propagation direction of the first three waves would be different from that of the radar beam.

5 Conclusions

The tsunami waves propagated from the continental shelf slope to the inner part of the Kii Channel as progressive waves until the third wave, and then natural oscillations were excited by the waves. It caused secondary oscillations in the channel and inundation on the coasts[5].

The major advantage of the oceanographic radar is thought to be the range from shore at which the tsunami can be detected; however, additional technical and operational studies are needed[6, 7].

---

[5] Hinata, H. *et.al.*, Propagating tsunami wave and subsequent resonant response signals detected by HF radar in the Kii Channel, Japan, *Estuarine, Coastal and Shelf Science*, 95: 268-273, 2011.

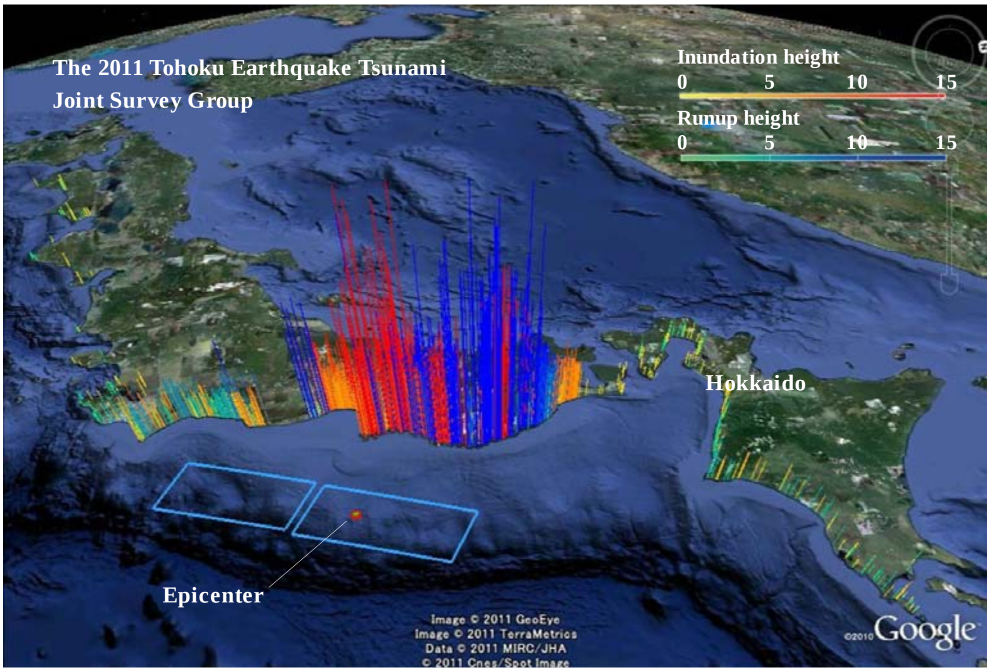
[6] Lipa *et al.*, Japan Tsunami Current Flows Observed by HF Radars on Two Continents, *Remote Sens*.3: 1663-1679, 2011.

[7] HELZEL Messtechnik GmbH. WERA Ocean Rader in Chile Observed Tsunami Signatures after the Earthquake in Japan on March 11, 2011, *Press Release* on May 2011, (http://www.helzel.com/files/432/upload/Tsunami/Press-Release-Tsunami-WERA-2011.pdf).

This finding adds a new role of oceanographic radar to measure the detailed surface-current fields with high spatiotemporal resolution for understanding detail processes of resonant response to tsunami wave in channels. Since resonant response could excite higher waves than original input waves, it is another important issue to be prepared against unexpected disasters.

FIGURE 11

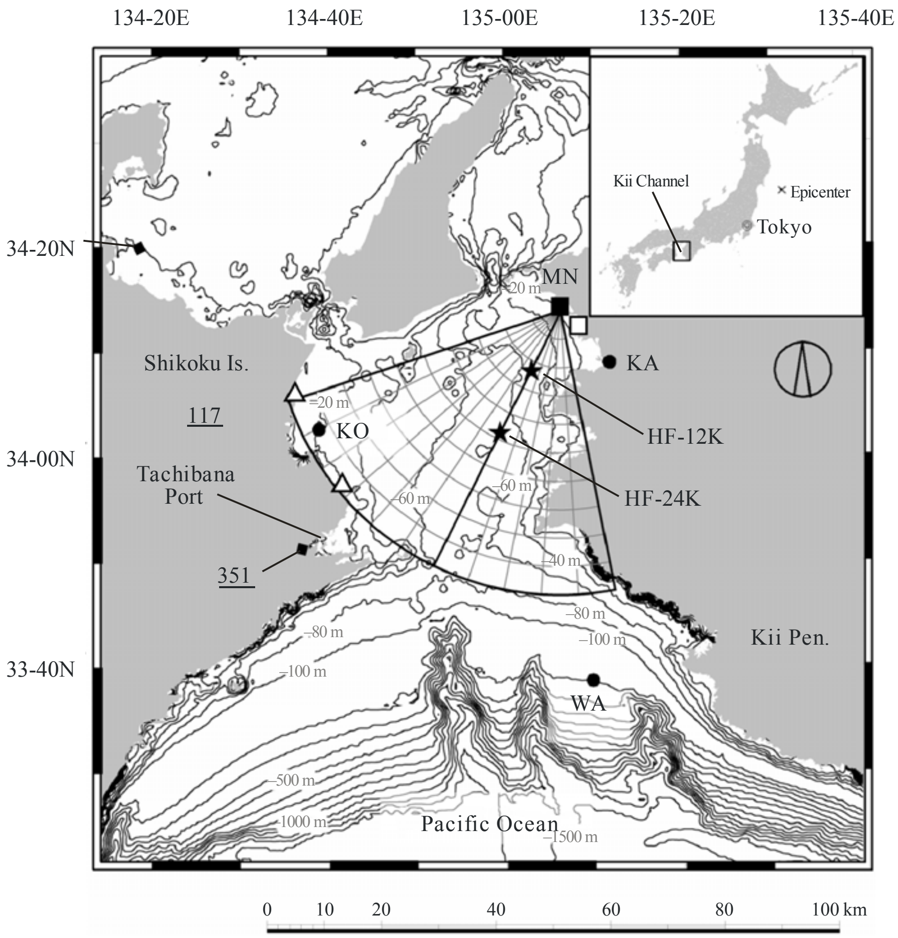
Inundation and run-up height map by the 2011 Tohoku Earthquake Tsunami Joint Survey Group (http://www.coastal.jp/ttjt/)



M.1874-11

FIGURE 12

Map of oceanographic radar systems (squares and triangles) and sea surface elevation monitoring systems (solid circles) in the Kii Channel, western coast of Japan



M.1874-12

FIGURE 13

Detailed sea surface elevation at WA, KO, KA and radial velocity at HF-12K (12 km offshore from the radar)

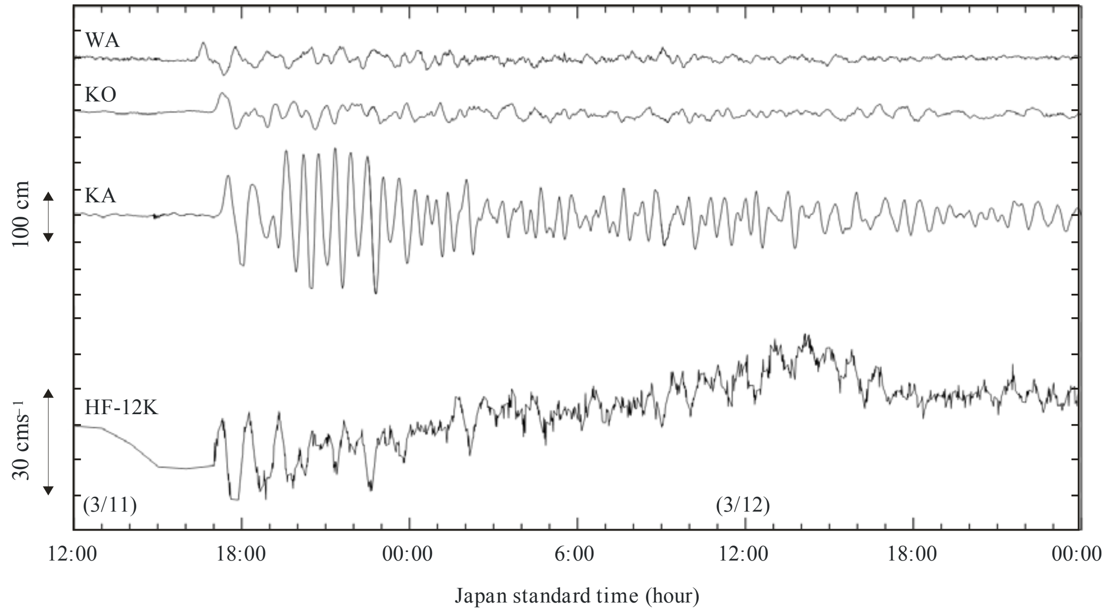


FIGURE 14

Time-distance (top) and time series diagram (bottom) of radial velocities for 12 hours from 1700 hours, March 11, 2011