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Optimizing Marine Radar Performance in Enhancing the Safety of Navigation

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Original scientific paper

This paper analyses the accuracy and reliability of radar detection of vessels. For safe navigation it is of vital importance to recognize radar limitations in real conditions when exposed to various types of interefernces. The focus of this research was on non-intentional interferences such as sea and atmospheric interference, the so-called sea and atmospheric clutters which greatly influence the accuracy and reliability of radar performance. For data processing and simulation the corresponding simulation software, Computer Aided Radar Performance Evaluation Tool-CARPET (version 2.13), was used. The article compares the results of the detection range in conditions of free space propagation (Free Space Prograpation Detection Range) and under the influence of the above mentioned clutters when interferences and oscillations of the propagation range appear and as a consequence of the so-called dazzle camouflage of ships in a noise circle where the ship sails undetected. Such research is of special importance for educating and schooling marine officers, especially deck officers, in thematic units dealing with accuracy and reliability of marine radars exposed, in this particular case, to unintentional environmental clutters.

Keywords: *detection, marine radar, power, range, safe navigation, sea and atmospheric clutters*

Optimizacija rada brodskog radara u funkciji povećanja sigurnosti plovidbe

Izvorni znanstveni rad

U radu se analiziraju točnost i pouzdanost radarske detekcije plovila, jer je za sigurnost plovidbe važno prepoznati ograničenja radara u realnim uvjetima uporabe kad je izložen različitim vrstama smetnji. Težište istraživanja bilo je usmjereno na nenamjerne smetnje kao što su morske i atmosferske smetnje, odnosno tzv. morski i atmosferski *clutteri* koji utječu na točan i pouzdan rad radara, a za obradu podataka i simulaciju korišten je odgovarajući simulacijski program Computer Aided Radar Performance Evaluation Tool-CARPET, inačica 2.13. U članku su komparirani rezultati dometa detekcija radara u uvjetima slobodne propagacije (*Free Space Propagation Detection Range*) i u uvjetima utjecaja prije spomenutih smetnji kada se pojavljuju interferencija i oscilacije dometa detekcije radara, a kao posljedica tzv. maskiranje pozicije broda u šumnom krugu kada brod kao plovilo ostaje nezamijećen. Ovakva istraživanja posebno su važna za školovanje i obrazovanje pomorskih časnika, a posebno časnika palube, u tematskim cjelinama koje se odnose na točnost i pouzdanost rada brodskog radara koji je izložen, u ovom slučaju nenamjernim, smetnjama okoline.

Ključne riječi: brodski radar, detekcija, domet, morske i atmosferske smetnje, sigurnost plovidbe, snaga

1 Introduction

It is a well-known fact that radar jamming can seriously jeopardize safety of navigation. It is therefore extremely important to recognize radar limitations in real conditions when exposed to various types of clutters. The clutters can be classified into two groups: unintentional (e.g. sea and atmospheric clutters, etc.) and intentional clutters caused by electronic warfare (EW). This paper first analyses the influence of unintentional clutters and then the influence of intentional clutters. For data processing a simulation software CARPET (version 2.13) was used.

The first part of this paper focuses on quantitative data indicating a permanent increase in traffic and accidents at sea due to deficiencies in the safety of navigation, whereas the second part focuses on optimizing the power and propagation range in relation to sea and atmospheric clutters in the process of detecting vessels at sea. The final part contains comments on phenomenon of interferences and oscillations of the propagation range caused by sea and atmospheric clutters.

2 Safe sailing

A constant increase of marine traffic increases the possibility of accidents at sea. The main and the most frequent sailing route in the Adriatic Sea is the one linking the north Adriatic ports to the Strait of Otranto where merchant ships, sailing yachts, fishing ships, warships and other non-merchant ships navigate in national and international territories [1]. Navigation safety is directly dependent upon traffic density of the routes. Traffic data on major Adriatic ports and main ports, yachts, fishing and non-merchant vessels are therefore essential for the distribution of the sailing load and determining high-risk areas. Data collected back in September 2008 testify the amount of traffic load [2]. According to the collected data, the average number of ships sailing was 73.5, standard error 2.55. The highest number of recorded ships sailing was 159; average speed in the observed period was 12.2 knots, 8 % of vessels sailing at speed above 20 knots (the fastest vessel was sailing at the speed of 35.1 knots). In the observed period 273 ships were tankers (oil, chemical and gas), i.e. 20 %, whereas 10 % of vessels reported dangerous cargo on board. Of the total number of monitored ships, 68 of them were flying the Croatian flag, 9 of which were passenger ships, 17 speedboats and 9 tankers. The sailing routes of the North Adriatic (west Istria) had an average load of 7.67 ships (max 19 and min 1), while other areas recorded 1.1 (max 6 and min 0), the area of central Adriatic 4.625 (max 13 and min 1) and the area of Palagruza 3.2 (max 10 and min 0) [3]. This load and existence of gas platforms in the North Adriatic in the immediate vicinity of sailing routes render the situation more complex and exposed to marine accidents.

According to the records of the competent ministry and the National Centre for Search and Rescue at Sea there is an ongoing trend of increasing marine accidents and the number of cargo and other larger ships accidents is also on the rise [4]. The highest number of accidents in the North Adriatic is caused by sudden stormy and hurricane winds, but it is necessary to point out that the deficiencies of ships in the navigation safety category in the period between 2002 and 2011 ranged from 11 to 15 %, and as such represents the biggest limitation [5].

The increased possibility of accidents at sea (between ships, ships and boats, ships and platforms, accidents on ships and fishing boats and gas-underwater constructions) requires an efficient supervision and management of marine traffic in the area of exploitation field; i.e. high-risk areas in the North Adriatic, but also the prevention of possible accidents at sea caused by asymmetrical threats. For example, for gas platforms inside the security procedures of owners the following risks have been defined: sailing in, and/or the anchoring of unauthorized vessels or mooring, danger of a crash/collison of vessels and terrorism. The stated risks, although defined, are not sufficiently analyzed nor are there any procedures on how to act during such risks. The current owners' estimate (*Inagip*) is that chances of damage caused by terrorist or similar attacks and ships collision are very low, which is why the procedures have not been adequately technically or tactically processed [6]. The reason for such conclusions comes from the fact that so far no endangerment of platforms by terrorist, criminal or pirate attacks has been recorded [7].

Contemporary threats to safe navigation require a comprehensive approach, meaning it is necessary to increase the surveillance and management abilities in marine traffic in a way which will meet the threat and not only eliminate its consequences. It is therefore necessary to develop tools and indicators for predicting and preventing, in other words removing potential system limitations which can endanger and degrade the basic features and parameters essential for safe sailing. One of such parameters is definitely propagation range of the ship radar.

3 Power and detection range

The basic role of a radar is to search the space and detect objects (targets) of certain characteristics. In this respect there are two very important parameters: power and propagation range and equally important, the type of object; the important data connected to the power and propagation range. Namely, we distinguish two types of radars; radars with passive and radars with active echo. In the first case the density power reflected from the detected object (reflecting back to the receiver), other than radar parameters, distance and atmospheric conditions, depends on the dimension and shape of the object (detection target) i.e. the vessel cross-section. In the latter case the radar signal activates a special transmitter (located on the board) which radiates one or more impulses of electromagnetic energy back to the radar. This type of transmitter is called the transponder and the target cross-section has no effect on the power density reflected from the detected object. In both cases, propagation range is influenced by the radar horizon, i.e the combination of the curvature of the Earth and the atmospheric conditions on the observed location. Propagation range of the radar horizon is therefore valid for standard atmospheric conditions (temperature and humidity) because otherwise sub-refraction would appear (radar beam bends upwards because the air above the sea is warmer than the atmosphere) i.e. super-refraction (radar beam bends downwards because the air above the sea is colder than the atmosphere). Radar horizon [7] is calculated in the following way (1):

$$R_h=2.2(h^{0.5}{}_{antenna}+ h^{0.5}{}_{boat}) \quad (1)$$

where:

R_h – radar horizon [NM, nautical mile],

$h_{antenna}$ – height of radar antenna [m],

h_{boat} – height of boat above sea level which is detection target [m].

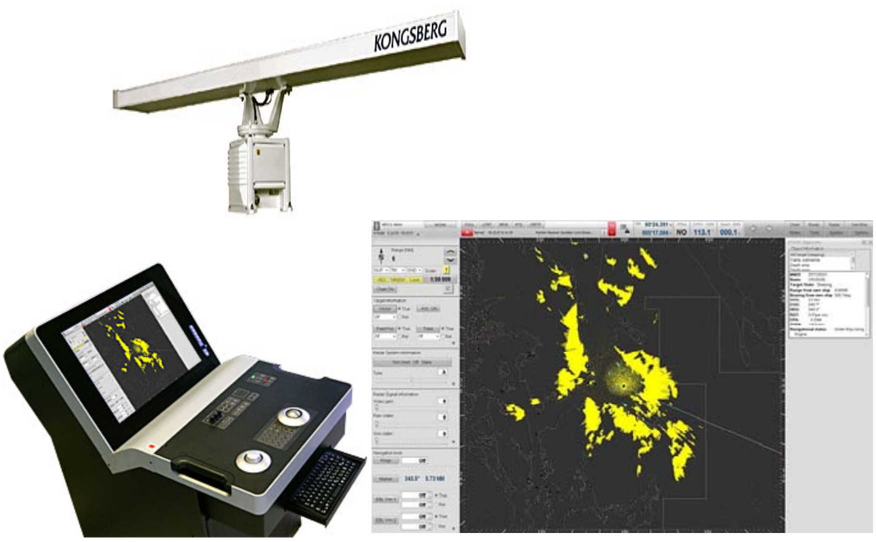
For example, if the detection target is a fishing boat whose height above sea level is h_{boat} = 1.7 m, and the radar is on the other ship with a radar antenna $h_{antenna}$ = 8.12 or 25 m, then the radar horizon is R_h = 9, 10.5 or 14 NM. Therefore, regardless of the radar power, the propagation range will not be higher than the radar horizon because the curvature of the Earth and the atmospheric conditions do not allow it. Radars are therefore placed as high as possible so that the radar horizon would not influence the propagation range. According to the *International Maritime Organization*-IMO standard for small 10 m long ships without a radar reflector, the height above sea level is 2 m, whereas with SOLAS ships (>5000 gross tons, cargo liner ship) the height above sea level is 10 m. For the purposes of establishing detection range the following three (sailing) ship categories have been defined:

Category A - coastal fishing boats, sailboats, speedboats, etc. (target radar cross section $\sigma = 3\ m^2$; boat height above sea level h_{boat}= 2 m)

Category B - small metal boats, fishing boats, patrol boats, etc. (target radar cross section $\sigma = 100\ m^2$; boat height above sea level h_{boat}= 5 m)

Category C - larger vessels, cargo ships, etc. (target radar cross section $\sigma = 10{,}000\ m^2$; ship height above sea level h_{boat}= 12 m)

In determining the required power and real propagation range, apart from determining radar horizon, it is necessary to look back on the ways of locating the object with the help of impulse radar such as boat radar, e.g. KonsbergMaritime K-Bridge ARPA radar, Figure 1.



Radar functions

Range scales	11 (0.125 – 96 nm)
Manual and automatic clutter reduction	Yes
Bearing scale	Always gives the correct bearing from own ship
Electronic Bearing Lines (EBL):	2
Variable Range Makers (VRM)	2
Parallel index lines:	Yes
Square radar picture	Yes - 27% larger radar area covered

ARPA Functions

Target tracking:	Up to 100 simultaneous radar targets
Maximum target speed:	100 km relative
Target tracking range:	24 nm
AIS:	Target presentation and operation of AIS

Scanner and transceiver

X-band	(9,410 + / - 30 MHz) 12 or 25 kW transceivers
S-Band	(3,050 + / - 10 MHz) 30 kW transceivers

Figure 1 **Konsberg Maritime K-Bridge ARPA radar [8]**
Slika 1 **Konsberg Maritime K-Bridge ARPA radar [8]**

The above is an example of a detection based on a single echo and a concept of statistical decision making [9].

3.1 Radar equation

Free space propagation R_{fsp} in Free Space Propagation Detection Range (FSPDR), therefore without sea and atmospheric interferences, the so-called *clutters*, can be determined on the basis of the following radar equation [7]:

$$R_{fsp} = \{P_t \cdot G_t^2 \cdot \sigma \cdot \lambda^2 / [k \cdot T_A \cdot (4\pi)^3 \cdot B_n \cdot F_n \cdot SNR_{min}]\}^{0.25} \quad (2)$$

where:

R_{fsp} – free space propagation range [m],
P_t –transmitter power delivered to antenna [W],
G_t – antenna gain,
σ –target radar cross section [m^2],
λ – wavelength at X-band or S-band [m],
$k = 1.38 \cdot 10^{-23}$ J/ºK – Boltzmann constant,
T_A – antenna temperature [ºK], standard temperature is 290ºK,
B_n –system noise bandwidth [Hz],
F_n – noise factor,
SNR_{min} – signal-to-noise ratio (detection threashold).

Antenna gain in the transmitting G_t and receiving G_r in the observed radar equals i.e. $G_t = G_r$, and is calculated according to the relation [9]:

$$G_t = 20000/(\theta_H \cdot \theta_V) \quad (3)$$

where:

θ_H – horizontal antenna beamwidth [º],
θ_V - vertical antenna beamwidth [º].

For example, if the beamwidth is $\theta_H = 1.23^\circ$ and $\theta_V = 20^\circ$, antenna gain is then $G_t = 20000/(1.23^\circ \cdot 20^\circ) = 813$ or 29.1 dB.

If we introduce radar factor F_r as a parameter:

$$F_r = P_t \cdot G_t^2 / (k \cdot T_A \cdot B_n \cdot F_n) \quad (4)$$

The radar equation (2) takes on the following form:

$$R_{fsp} = \{F_r \cdot \sigma \cdot \lambda^2 / [(4\pi)^3 \cdot SNR_{min}]\}^{0.25} \quad (5)$$

For example, for transmitter power $P_t = 25$ kW, antenna gain $G_t = 29$ dB, system noise bandwidth $B_n = 2$MHz and noise factor $F_n = 3.98$ or 6 dB, radar factor is $F_r = 4.95 \cdot 10^{23}$ or 237 dB.

When we wish to express free space propagation range in nautical miles (NM), then the relation (5) takes a different form:

$$R_{fsp} = \{k_{NM} \cdot F_r \cdot \sigma \cdot \lambda^2 / SNR_{min}]\}^{0.25} \quad (6)$$

when:

R_{fsp} – free space propagation range [NM]
$k_{NM} = 5.72 \cdot 10^{-17}$ – conversion coefficient

In the case of a specific type of radar and for a certain detection threshold in a given frequency band (e.g. X-band), the radar equation takes the following form:

$R_{fsp} = k_{det} \cdot \sigma^{0.25}$ (7)

where:

$k_{det} = (5.72 \cdot 10^{-17} \cdot F_r \cdot \lambda^2/SNR_{min})$ –coefficient of detection [NM/m^2],

σ – target radar cross section [m^2].

For example, for the radar wavelenght $\lambda = 3.15 \cdot 10^{-2}$ m and detection threshold SNR_{min}=17.78 or 12.5 dB, the detection coefficient is k_{det}=6.26 NM/m^2 or 8 dB. Namely, if the relation (7) transforms into decibels, the equation is:

$R_{fsp}\ [dB//NM] = 10 \log k_{det} + 2.5 \log \sigma = 8 + 2.5 \log \sigma$ (8)

Starting from the above stated, Table 1 shows typical examples of radar parameters for marine use in X-band, and Table 2 calculations for coefficient of detection and range of various types of radars for specific vessels.

Table 1 **Typical parameters of civil marine radars in X- band [10]**
Tablica 1 **Tipični parametri civilnih radara za pomorsku namjenu u X-bandu [10]**

Type of radar	**A**	**B**	**C**	**D**	**E**
R_{fsp} (NMi)	16	48	96	120	120
P_t (kW)	2,2	4	12	25	50
θ_H (°)	6,2	2,4	1,8	1,23	0,95
θ_V (°)	25	27	25	20	20
G_t (dB)	21	25	26	29	30
F_n (dB)	10	6	6	6	6
B_n (MHz)	7	3	3	3	3
F_r (dB)	201	219	227	235	241

Table 2 **Detection coefficient and propagation range for specific vessels [7]**
Tablica 2 **Koeficijenti detekcije i domet radara za karakteristične tipove brodova [7]**

Radar power	**P_t (kW)=2.2**	**P_t (kW)=4**	**P_t(kW)=12**	**P_t (kW)=25**	**P_t (kW)=50**
k_{det} (dB)	**-1.0**	**3.51**	**5.51**	**7.51**	**9.01**
R_{fsp} (NM) (Smaller Fishing Boat σ ~ 5m^2)	1.2	4.62	8.22	11.22	13.45
R_{fsp} (NM) (Larger fishing boat σ~1000 m^2)	4.46	17.41	30.97	41.68	50.58
R_{fsp} (NM) (Bulk carrier σ ~ 5,000 m^2)	6.66	26.00	46.23	63.09	75.50
R_{fsp} (NM) (Warship σ ~ 50,000 m^2)	11.85	46.23	82.22	112.20	134.28
R_{fsp} (NM) (Tanker σ ~ 1,000,000 m^2)	25.00	97.94	174.18	237.68	284.44

Using relations (7) and (8), a correlation diagram of propagation range for various transmitter powers in relation to target radar cross section was made.

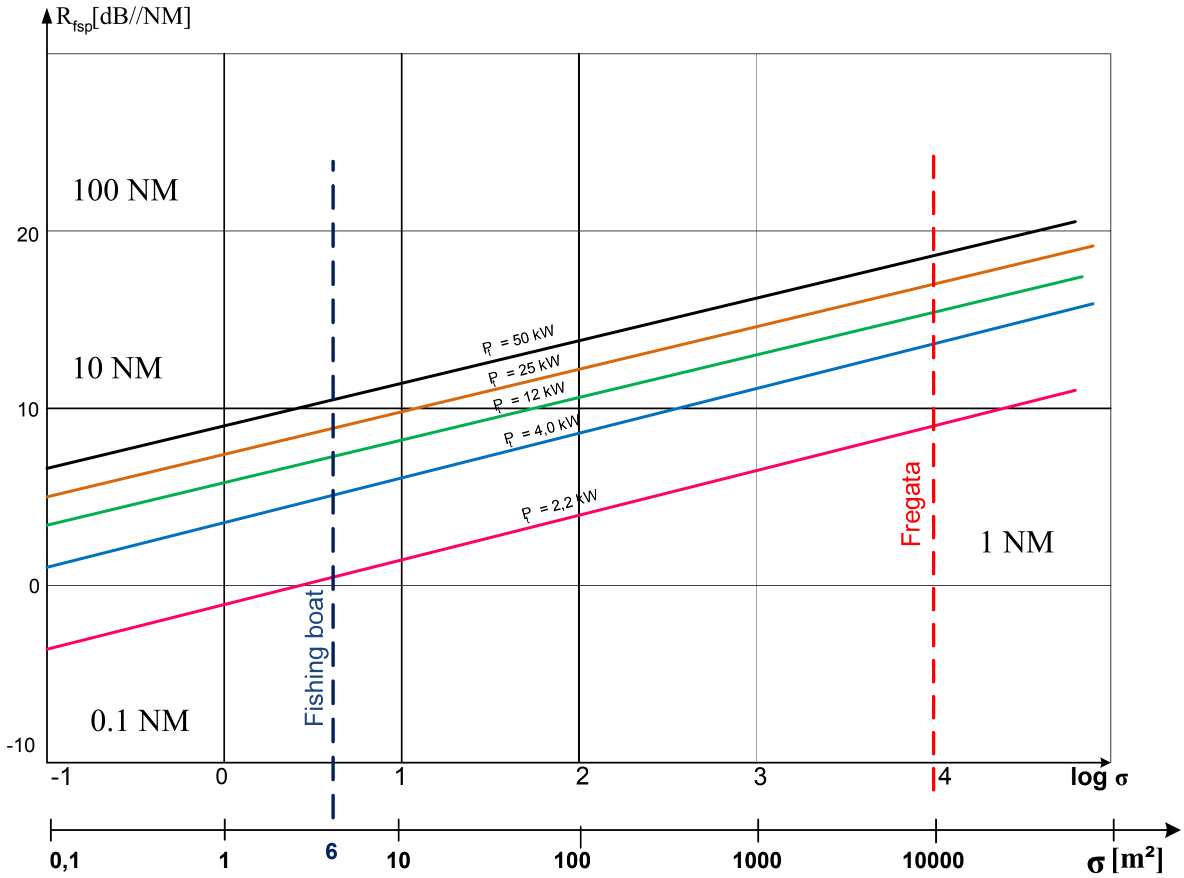


Figure 2 **Propagation range in relation to target radar cross section [7]**
Slika 2 **Domet radara u odnosu na refleksijsku radarsku površinu broda [7]**

The diagram in Figure 2 clearly shows how the propagation range increases with the radar power increase, while the radar factor and detection coefficient remain unchanged.

3.2 Detection threshold

Signal-to-noise ratio $(S/N)_0$ = DT is called *Detection Threshold;* where S stands for received signal power (RSP), and N is received noise power (RNP). The key question in determining detection threshold, i.e. determining propagation range is how to determine and set the optimal detection threshold, i.e. signal-to-noise ratio which will enable the sailing vessel to be detected (*Signal-to-Noise ratio at with detection occurs*, SNR_{min}). Namely, if the detection threshold is too low, too much false detection will occur, whereas if too high, the real detection might not occur. The choice of the minimal detection threshold SNR_{min} depends on the probability of detection *p(D)* and the false-alarm probability *p(FA)*, (*FA – False Alarm*). Figure 3 shows the characteristic of the probability of detection on the basis of one impulse in correlation with the detection threshold with the false-alarm probability as a parameter.

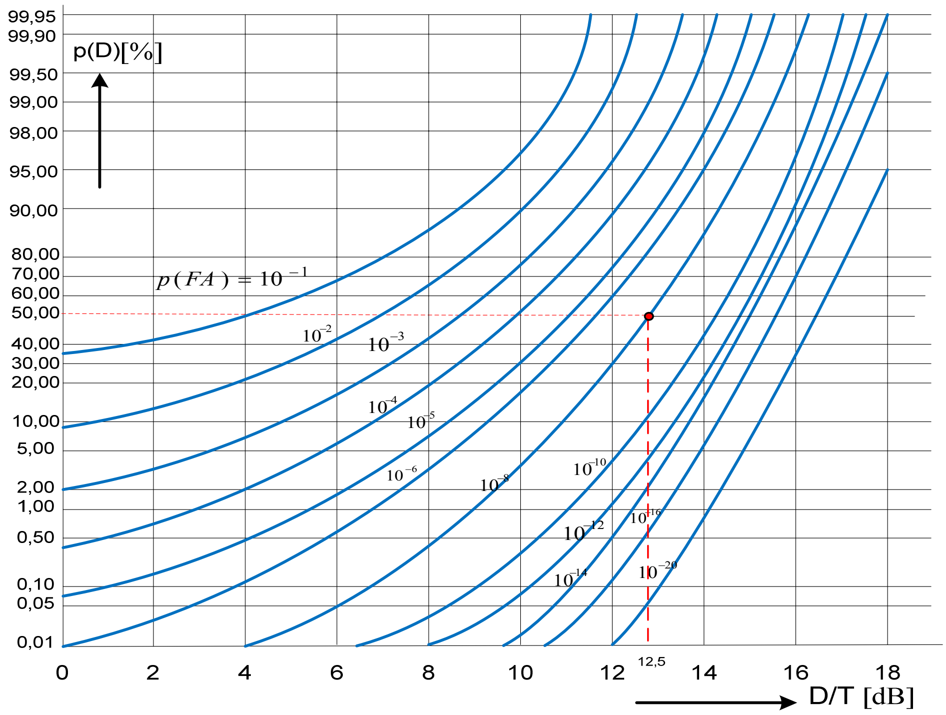


Figure 3 **The characteristic of the probability of detection on the basis of one impulse in correlation with the detection threshold with the false-alarm probability as a parameter for linear and square radar detectors [9]**

Slika 3 **Karakteristika vjerojatnosti detekcije na temelju jednog impulsa u ovisnosti o pragu detekcije uz vjerojatnost lažne uzbune kao parametra za linearne i kvadratne radarske detektore [9]**

The series of characteristics in Figure 3 show that for the detection range of 12.5 dB the probability of detection will be *p(D)* = 0.5 (50%), with the false-alarm probability *p(FA)* = 10^{-8}.

With a constant detection threshold, the false-alarm probability *p(FA)* remains unchanged regardless of the real noise-to-signal ratio, whereas the probabilty of detection *p(D)* rises rapidly with the rise of that relation and the rise becomes sharp the higher the detection threshold is. Therefore, if the power and noise statistics (Gaussian distribution) remain unchanged, with a constant detection threshold, we will attain a constant value of false alarm. Such radars are called radars with a CFAR receiver (*Constant False Alarm Rate*).

3.3 Sea and atmospheric clutter

Cross-section of water waves (*Sea Clutter*) and dispersed water droplets (*Rain Clutter*) limit cross-section, especially of smaller vessels, and this cross-section depends on two groups of influences. Firstly, cross-section of sea surface is conditioned by wave height, speed of wind, length and size of the area over which the wind is blowing, or by the direction of the waves in relation to the radar beam. It is also important to know if the waves are rising or descending and if there are potential pollutants influencing surface tension. Secondly, cross-section is dependent upon radar parameters such as: frequency, polarization, the angle of incidence between the radar and sea micro cross-section and size of radar cell.

"Noise circle" of clutters spreads from the centre of the radar display towards the end of the display, and the radius of the noise circle is proportionate to the height of the radar antenna above sea surface. For example, from a 50 m height, radar creates a 3 km radius on the display, and from a 600 m height the radius increases to 30 km. Vessels in those circles are “protected” and cannot sail unnoticed by the radar, fishing and sport boats especially. Radar cross-sections of ships longer than 35 m are normally bigger than the typical sea clutter and are detectable by removing the noise circle and reducing radar receiver sensitivity in that area. Unlike the radar horizon, when the height of the radar contributes to the increase of the propagation range, in the case of sea clutters the height negatively affects the propagation range and vessel detection, because it increases the noise circle making the vessel sail undetected.

Apart from the influences of the sea, the noise caused by rain is also important. The influence of the rain is evident in camouflaging the reflections of objects in the area caught by rain. When the vessel is behind the rain volume, the influence is double: the wave front of the rain creates an atmospheric clutter with fake reflections, whereas while passing through the rain front to the vessel and back, electromagnetic energy is absorbed. For example, absorption of electromagnetic energy during heavy rain is about 1dB/km, which diminishes the power of the radar signal of a vessel at 9GHz frequency and at the distance of 20 km by a 100 times (20dB) in comparison to the standard atmosphere.

All of the previously stated facts are to be taken into consideration during software simulation of radar propagation range which was done, as mentioned in the introduction, with the help of CARPET (version 2.13), a computer-aided radar performance evaluation tool. The hypothetical target detection, as stated before, consisted of the three categories of vessels (A, B and C).

4 Simulation

Simulation parameters are shown in Table 3, and Figures 4 to 6 are diagrams of *Detection Probability* and *Recieved Power*.

Table 3 **Parameters of computer simulation of CARPET - Computer-Aided Radar Performance Evaluation Tool [11]**
Tablica 3 **Parametri računalne simulacije PC programa CARPET [11]**

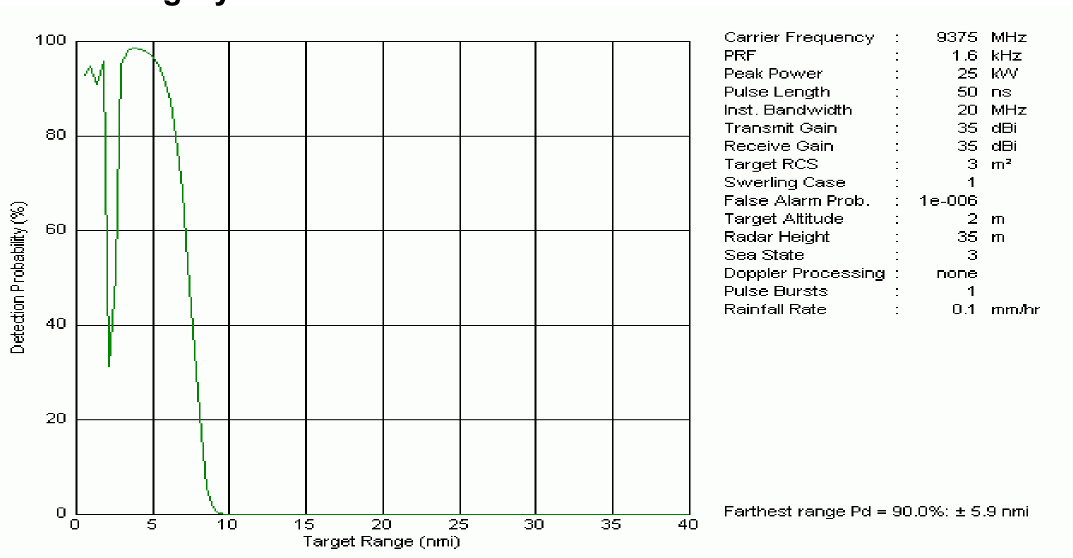
Input parameters	Value
Propagation	
Atmospheric Pressure	1020 mbar
Humidity	60%
Air Temperature	13 °C.
Water Temperature	11 °C.
Wind Force	1 Bfrt
Wind Direction	0 deg
K-Factor	1.33
Refractivity	328 Nunit
Sea Salinity	26%
Sea State	3
Clutter	
Land Reflectivity	-38 dB
Rainfall Rate	0.1 mm/hr (not present)
Min Range Rain	1 km
Max Range Rain	30 km
Max Height Rain	3 km
Transmitter	

Input parameters	Value
Carrier Frequency	9375 MHz
Peak Power	25 kW
Pulse Length	0.05 us/0. 250 us
Inst. Bandwidth	20 MHz/8 MHz
PRF	1.6 kHz/2.0 kHz
Antenna	
Antenna Type	Rectangular
Azimuth Beamwidth	0.4 deg
Elevation Beamwdth	18 deg
Transmit Gain	35 dBi
Polarization	Circular
Receive Gain	35 dBi

The results obtained from the computer simulation are presented for each category of vessels (A, B and C) through two diagrams: a) detection probability and b) received signal power, both in relation to the propagation rate.

Based on results shown in Figures 4 to 6 and Table 4, there is a cumulative demonstration of the biggest propagation ranges for the before mentioned categories of vessels. It is also important to emphasize that the suggested height (of the radar antenna) h_{antenna} = 35 above sea level, that the detection probability of the target was p(D) = 90% and false-alarm probability p(FA) = 10^{-6}.

4.1 Category A



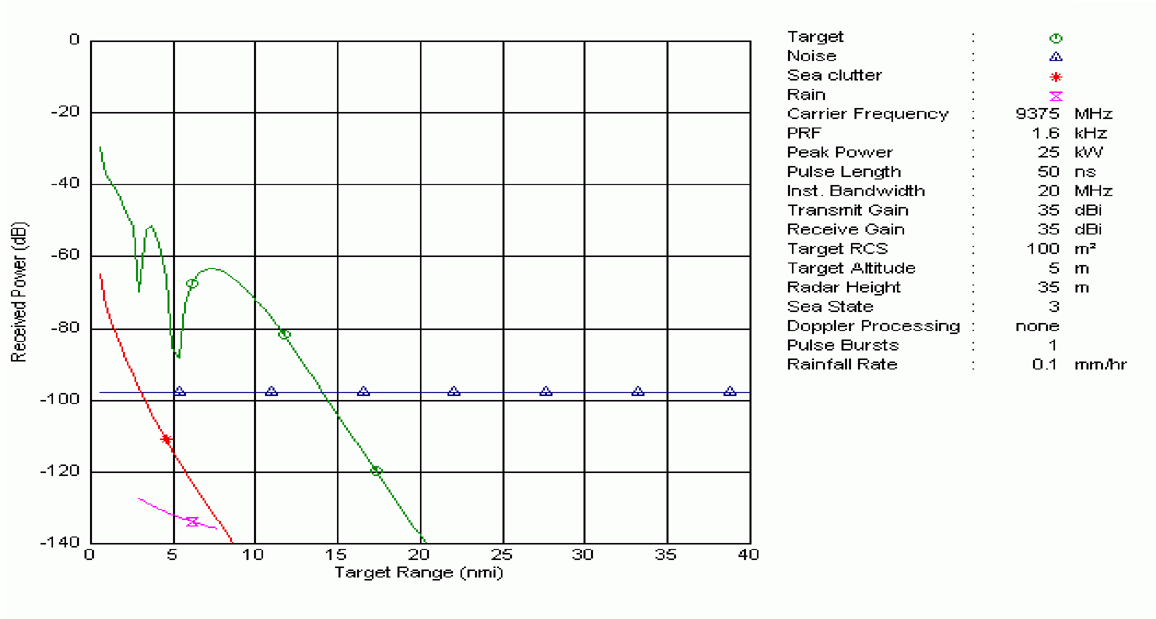


Figure 4 **Detection probability and recieved power diagrams for smaller boats [11]**
Slika 4 **Dijagrami vjerojatnosti detekcije i detekcije prijemne snage za manje brodice [11]**

4.2 Category B

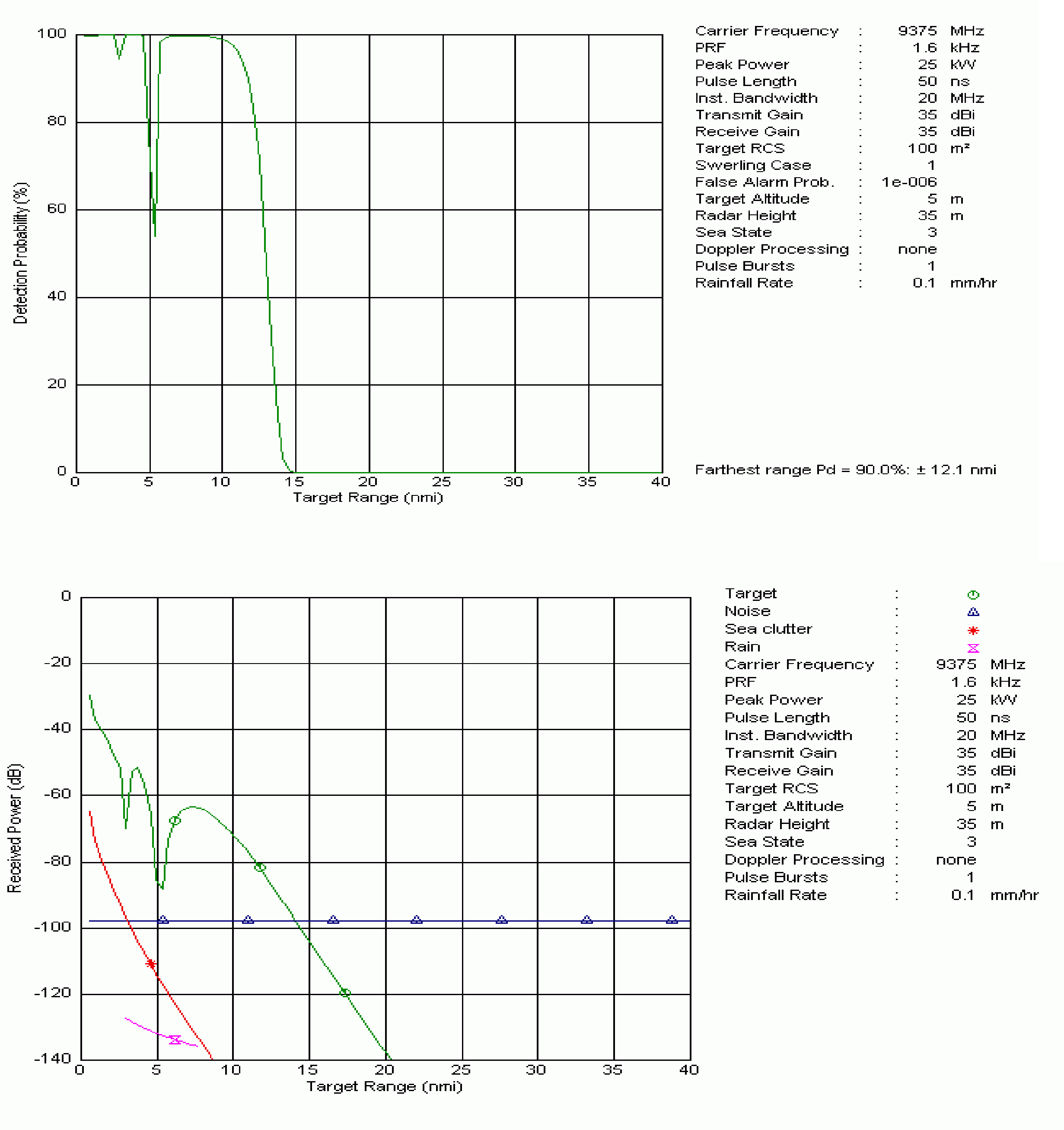


Figure 5 **Detection probability and recieved power diagrams for medium-sized boats [11]**
Slika 5 **Dijagrami vjerojatnosti detekcije i detekcije prijemne snage za brodove srednje veličine [11]**

4.3 Category C

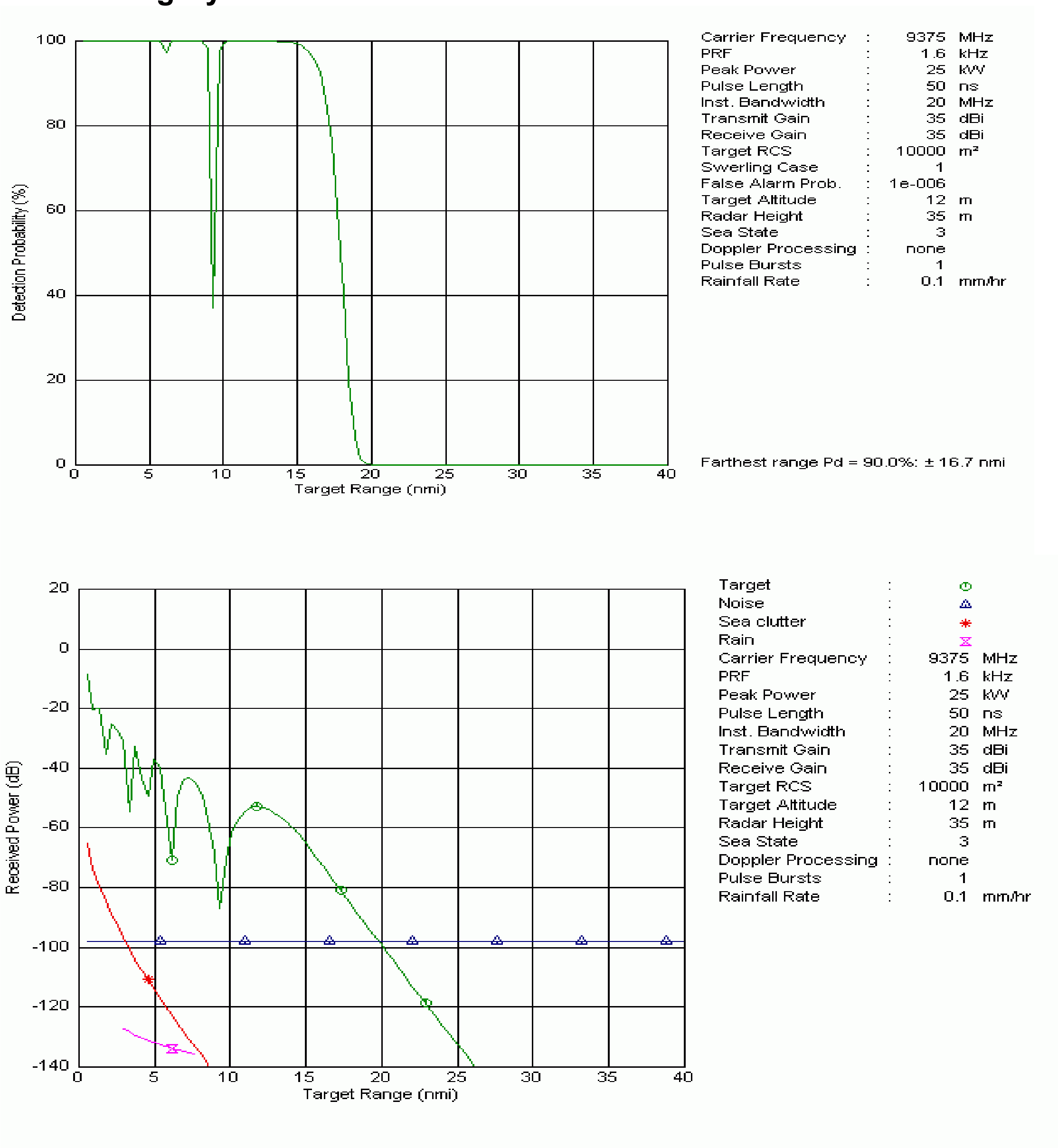


Figure 6 **Detection probability and recieved power diagrams for larger boats [11]**
Slika 6 **Dijagrami vjerojatnosti detekcije i detekcije prijemne snage za velike brodove [11]**

Table 4 **Propagation range with p(D)=90% detection probability and *p*(FA) = 10^{-6} false alarm probability**
Tablica 4 **Domet radara pri vjerojatnosti detekcije *p*(D)=90% i vjerojatnosti lažnog alarma *p*(FA) = 10^{-6}**

Boats	$\sigma[m^2]$	h_{boat}(m)	Propagation Range [NM]
Category A	3	2	5.9
Category B	100	5	12.2
Category C	10,000	12	16.7

Figure 7 shows a comparison of data on propagation range obtained on the basis of computer simulation defined by IMO standard (minimal object detection range in *clutter*-free conditions).

Based on results shown in Figure 7, we can deduce that the propagation range is above the minimal demands of the IMO standard in *clutter*-free conditions. The mentioned results are inserted in the propagation range diagram in Figure 2 as follows (Figure 8).

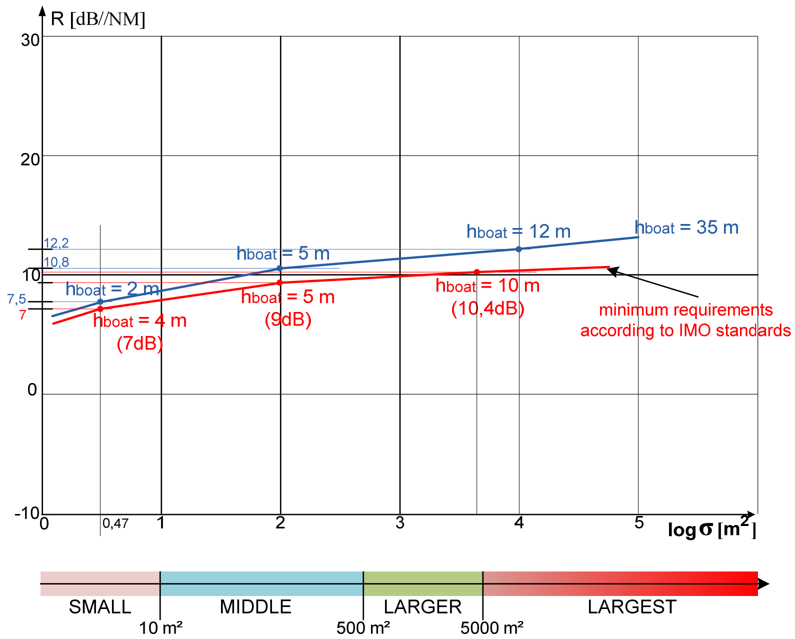


Figure 7 **A comparative diagram of propagation range determinad on the basis of a computer simulation and according to IMO standard [7]**
Slika 7 **Usporedni dijagram dometa radara određenog na temelju računalne simulacije i prema IMO standardu [7]**

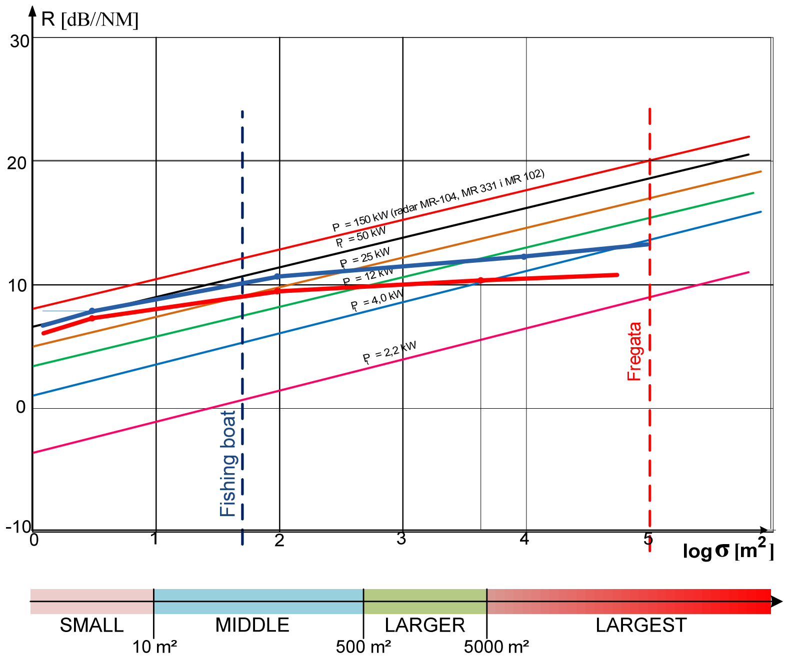


Figure 8 **A comparison of the propagation range [7]**
Slika 8 **Usporedni prikaz dometa radara [7]**

Based on Figure 8 we can deduce that:

- 2.2 and 4.0 kW radars satisfy the criteria set by the IMO standard for operating in *clutter*-free conditions,
- small and medim-sized vessels will sail undetected by weaker radars (2-2; 4 and 12 kW) and stronger radars will be needed for safe detection (25, 50 or 150 kW),
- larger vessels can be detected by weaker radars (4.0 and 12 kW) because of their larger target radar cross section.

4.4 The influences of *clutters* to propagation range

Diagrams shown in Figures 4 to 6 show variations in propagation ranges. For ships in category A (target radar cross section $\sigma = 3$ m^2; height of ship above sea level $h_{boat} = 2$ m) it is a confirmed fact that due to *clutter* influences there is a significant fall in propagation range from 16 NM (radar horizon) to 5.9 NM. Apart from this, we can conclude that due to interferences and variations in propagation range it is possible to “camouflage the location of the ship” in noise jamming, as shown in Figure 9.

Figure 9 **Camouflaging the location of the ship in noise jamming**
Slika 9 **Maskiranje pozicije broda u šumu smetnje**

Critical distance in which this camouflage can be done is 2.5 NM, which is manifested on the propagation curve as a sudden fall. In the case of vessels in category B (target radar cross-section $\sigma = 100$ m^2; height of boat above sea level $h_{boat} = 5$m) there is also a fall in propagation range from 18.6 NM (radar horizon) to 12.1 NM, i.e. for vessels in category C (target radar cross section $\sigma = 10.000$ m^2; height of ship above sea level $h_{boat} = 12$m) propagation ranges falls from 22 NM (radar horizon) to 16 NM. Cumulative results are shown in Figures 10a, b and c.

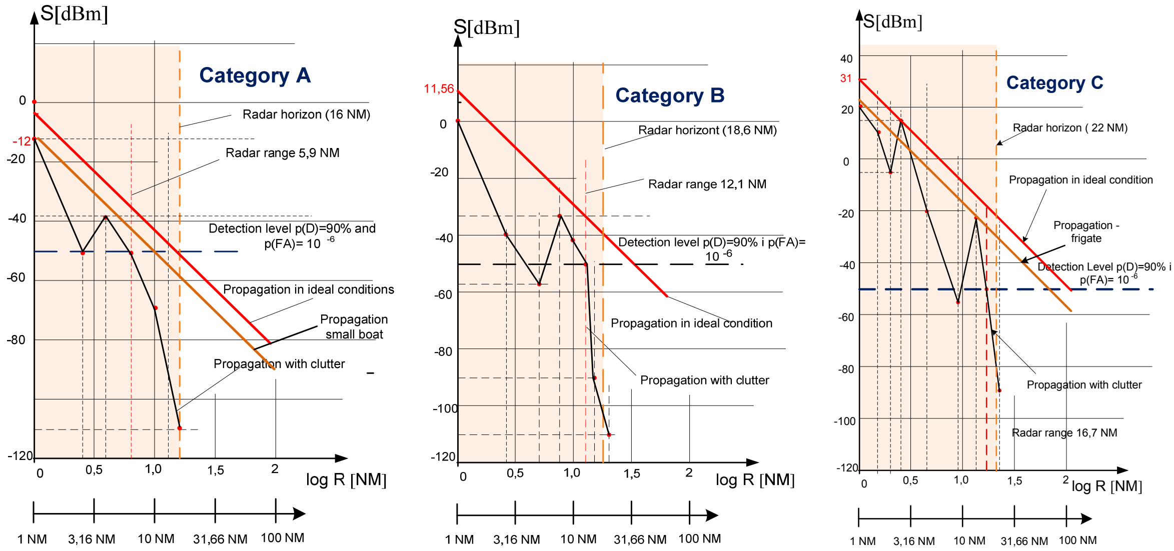


Figure 10 (A, B, and C) **Cumulative results of clutter influencnes on propagation range [7]**
Slika 10 (A, B i C) **Zbirni rezultati utjecaja smetnji (*cluttera*) na domet radara [7]**

It is also necessary to point out that the simulation was carried out in sea state 3 because according to [24] it was established that the following sea states are present in the Adriatic in view of their frequency: sea state 1 (11.2 %), sea state 3 (31.7 %), sea state 4 (40.2%) and sea state 5 (12.8%). Therefore, in a large number of cases there are waves of $H_{1/3}$ from 0.5 to 4 metres high, which greatly influences the correct radar functioning and vessel detection at sea. For the purposes of comparison of the data measured by Tabain [24], the data from the Weather and Sea State Monitoring Service were collected in the first 6 months of the year 2012 at the location of Mali Losinj (Table 5).

Table 5 **Sea state at the location of Mali Losinj (the first 6 months of 2012) [13]**
Tablica 5 **Stanje mora u prvih 6 mjeseci 2012. godine na lokaciji Mali Lošinj [13]**

A total number of measurements: 364					
Sea state	**1**	**2**	**3**	**4**	**5**
Wave height (m)	0-0.1	0.1/0.5	0.5-1.25	1.25-2.5	2.5-4
Descriptive evaluation	calm	smooth	slight	moderate	rough
Number of measurements	148	137	56	17	1

We can clearly see from Table 5 that sea state in the first six months of 2012 varied from calm to slight, and that 18 measurements showed moderate to rough waves. Table 6 shows data on wind speed measured at Porer, Mali Losinj and Veli Rat stations in the first 6 months of 2012.

Table 6 **Wind speed in the first 6 months of 2012 at Porer, Mali Losinj, and Veli Rat stations [13]**
Tablica 6 **Brzine vjetra u prvih 6 mjeseci 2012. godine na postajama Porer, Mali Lošinj i Veli Rat [13]**

Porer - TOTAL NUMEBR OF MEASUREMENTS: 179					
	Wind speed - Porer				
(m/s)	0-5.4	5.5-10.7	10.8-17.1	17.2-24.4	24.4-
Beaufort	0-3	4-5	6-7	8-9	10-
Number of measurements	3	91	46	22	17
Mali Losinj - TOTAL NUMEBR OF MEASUREMENTS: 178					
	Wind speed - Mali Losinj				
(m/s)	0-5.4	5.5-10.7	10.8-17.1	17.2-24.4	24.4-
Beaufort	0-3	4-5	6-7	8-9	10-
Number of measurements	9	91	65	13	-
Veli Rat - Dugi otok - TOTAL NUMEBR OF MEASUREMENTS: 178					
	Wind Speed - Veli Rat				
(m/s)	0-5.4	5.5-10.7	10.8-17.1	17.2-24.4	24.4-
Beaufort	0-3	4-5	6-7	8-9	10-
Number of measurements	24	79	61	13	1
TOTAL	**36**	**261**	**172**	**48**	**18**

From Table 6 we can clearly see that the most frequent wind speed varied from 5.5 to 10.7 m/s (49 %) and then from 10.8 to 17.1 m/s (32%) i.e. the most frequent wind was ranging from 4 to 7 Beaufort. The amount of rainfall was measured in weather stations in Rovinj and Pula in the first 6 months of 2012. The results are shown in Table 7.

Table 7 **Rainy days with the amount of rain in the first 6 months of 2012 at stations in Rovinj and Pula [13]**
Tablica 7 **Kišni dani s količinama kiše u prvih 6 mjeseci 2012. godine na postajama Rovinj i Pula [13]**

THE TOTAL NUMBER OF RAINY DAYS: 64					
	Amount of rain (mm)				
	0.1-1	1.1-3.0	3.1-5	5.1-9	9-
The number of rainy days	14	14	10	11	15

5 Conclusion

The research carried out, the data collected and the corresponding analysis indicate a need for a permanent monitoring of the state in the surrounding and optimization of radar functioning during sea and atmospheric *clutters***.** All of the mentioned has particular importance in schooling and educating marine officers, especially deck officers, in thematic units dealing with accuracy and reliability of marine radars exposed, in this particular case, to non-intentional environmental clutters**.** Insufficient study of the influences of clutters on the correct functioning of radars can lead to a reduced safe navigation and safe sailing.

This fact is extremely vital when sailing in high-risk sailing zones [14]: west coast of Istria, high-caution sailing areas (gas platforms), central Adriatic, and the area of Palagruza, because the sailing load and traffic density in these zones steadily rise every year. What confirms this fact is the increased number of accidents at sea, and according to reports by port authorities in the period from 1999 to 2010 in the Adriatic Sea the following was noted: boats sinking (94 cases), crashes (57 cases), flooding (89 cases), stranding (485 cases), fire (77 cases), incapacitation and floating (918 cases).

All of these cases point to the need for optimization of safe navigation, and marine radars in conditions of weak visibility and bad atmosperic conditions are irreplaceable in detecting and locating a vessel and other facilities in the immediate vicinity. Therefore, there is an urgent need for permanent research and education to recognize radar limitations in real conditions when exposed to various types of clutters. With the help of the CARPET software, a research was carried out to evaluate sea and atmpospheric influences on the accuracy and reliabiltiy of radar detection at sea.

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