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WR 2120 WEATHER RADAR IN SUPPORT OF NAVIGATION SAFETY – OPERATIONAL EXPERIENCE

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ABSTRACT

In the 1950s, radars began to be used for meteorological purposes, i.e. to detect and track storms and precipitation. A new field of knowledge has emerged: weather radar, which studies the differences between the reflections of radar signals obtained from different types of clouds and precipitation. Weather radar is a device used to observe precipitation: its location, intensity, type and movement. This data is used in forecasting the future location and intensity of rainfall. The general principle of operation of meteorological radars, and their construction, are like other types of radars, and the parameters and method of performing measurements (wavelength, resolution, range, scanning method, etc.) have been adapted to the measurements of meteorological objects. The aim of the article is to present the basics of radar meteorology by illustrating the structure and principles of operation of a weather radar, presenting the WR 2120 radar installed at the Polish Naval Academy along with its products, and the impact of the information obtained on navigational safety at sea. The main research methods used during the implementation of the article were the analysis of literature related to the topic and observations made on the WR 2120 weather radar. An obvious fact is the short period of observations due to the operating time of the radar in the METOC laboratory. The general conclusions that arise are the advantage of weather radars over other means of transmitting the meteorological situation in the ability to observe "live", which is particularly important in detecting and tracking zones of intense rainfall and storms that affect safety. The current use of weather radars at sea is related to fixed installations (permanent offshore installations, drilling ships, platforms, floating oil storage facilities, etc.) where there is no need to use stabilization of antenna arrays. The future and widespread use of weather radars at sea may be related to the use of antenna stabilizing platforms. However, this is currently the future. Looking at military applications (air, landing operations, SAR, RAS, etc.), it will probably be possible very soon.

Keywords—weather radar, radar meteorology, safety at sea.

1. INDRUCTION

In the mid-20th century, the 1950s were the period of the first use of radar by meteorologists to detect and track storms and various types of precipitation. With this application emerged a new field of knowledge called radar meteorology, which deals with the study of the differences between the reflections of radar signals obtained from different types of clouds and precipitation and the development of products obtained from radar observations. Currently, in shipping, aviation, communications, armed forces and meteorology, we cannot imagine the lack of data from a device such as radar. RADAR (**RA**dio **D**etection **A**nd **R**anging) **-** a device whose principle of operation is based on the use of the ability of the observed objects to reflect the electromagnetic radiation sent in their direction. The radar was already known in the thirties of the twentieth century, and today it is the result of many years of research. The first radars were used only for remote detection of aircraft and ships. The period in which electromagnetic field theories were developed can be considered the beginning of the development of radiolocation. A precursor in this field was James Clerk

Maxwell (1831–1879), who proved that electricity and magnetism are two types of the same phenomenon – electromagnetism. In turn, the German physicist Heinrich Hertz (1857–1894) showed that electromagnetic waves are reflected by metal objects and are refractive when passing through a prism made of dielectric. Hertz used a device with a design similar to the modern pulse radar, creating the basis for the development of radar. The results of Heinrich Hertz's experiments were used by another scientist, the German engineer Christian Hülsmeyer. At the beginning of the 20th century, he built a device that was a monostatic pulse radar (a transmitter and receiver of a radar placed in one device) and an improved version of the Hertz device. In 1904, it was patented. However, it did not meet with interest and was soon forgotten. Hülsmeyer is generally considered to be the designer of the first radar (range 3 km) [Tuszyńska I., 2015, p. 10].

The period preceding World War II and the war time was extremely important for the development of radar technology for military applications. A breakthrough came with the use of the magnetron in 1940, which made it possible to reduce the size of the radar, especially its antenna. Another achievement of radar were radars operating in the 3 cm band. A big qualitative leap in the design of civilian and military radars was the use of digital systems, which allowed for a significant improvement in the accuracy and reliability of the devices. The next step is the use of computers in radar imaging and data processing systems. Designs of military importance were ahead of systems with civilian purposes. Weather radar is a device used to observe precipitation: its location, intensity, type and movement. This data is used in forecasting the future location and intensity of rainfall. The general principle of operation of meteorological radars, and their construction, are like other types of radars, and the parameters and method of performing measurements (wavelength, resolution, range, scanning method, etc.) have been adapted to the measurements of meteorological objects.

The aim of the article is to present the basics of radar meteorology by illustrating the structure and principles of operation of meteorological radar, presenting the WR 2120 radar installed at the Naval Academy together with its products and the impact of the information obtained on navigational safety at sea. The article presents the previous experience gained during the operation of the radar in the meteorological and oceanographic laboratory METOC of the Polish Naval Academy.

The main research methods used during the implementation of the article were the analysis of literature related to the topic and observations made on the WR 2120 weather radar. An obvious fact is the short period of observations due to the operating time of the radar in the METOC laboratory.

The article has been prepared in the following order and consists of an abstract and introduction constituting the first part and other four parts. The second part describes the basic principles of operation of weather radar. The third part shows the Furuno WR 2120 weather radar. The fourth part illustrates the navigational safety support provided by weather radars, while the fifth part presents the operational experience of radar WR 2120 in the Polish Naval Academy. The article ends with a summary containing the conclusions that come to mind from the conducted studies of the topic and the operational experience gained at the Polish Naval Academy and is also the beginning of a discussion on the possibility of using weather radars to improve the navigational safety at sea.

2. BASIC PRINCIPLES OF OPERATION OF WEATTHER RADAR

The principle of operation of meteorological radar is based on the radiation of pulses of electromagnetic waves into space, which are concentrated in a narrow beam, and then the reception of waves reflected from objects in the atmosphere. The principle of operation of the meteorological radar is illustrated in simplified Fig. 1. Of course, the situation presented in the figure is a perfect example of meteorological radar, because the beam of electromagnetic wave passes through the area of precipitation, is reflected in its space and returns to the antenna. In fact, interference and reflections of electromagnetic waves from spatially differently located masses of humid air or other objects are often encountered.

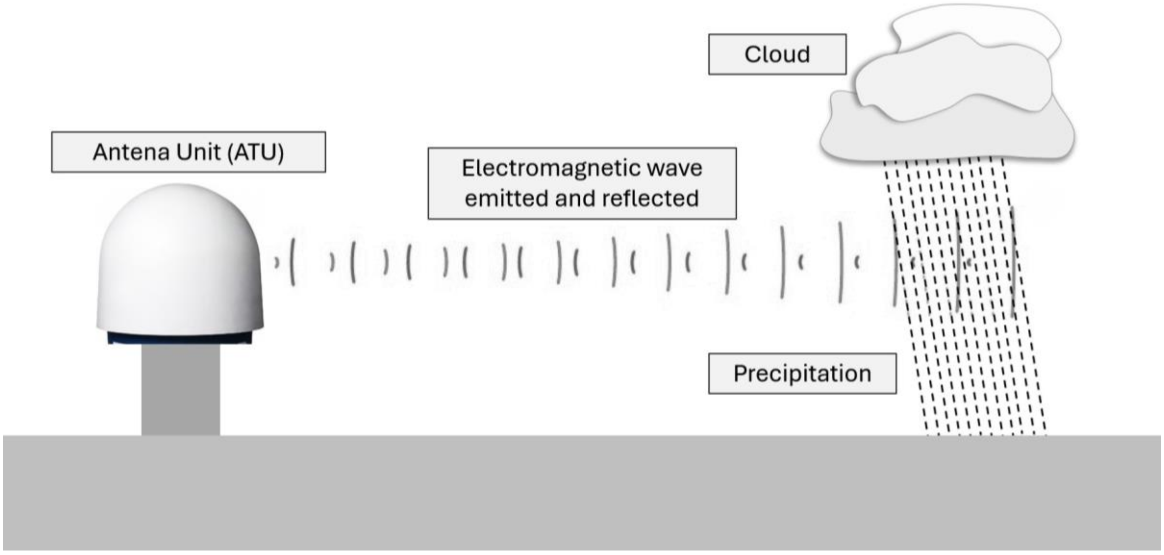


Fig. 1. The principle of operation of a weather radar [own study].

The basic task of the radar is to collect data and then process it by specialized software. The radar antenna can be controlled so that it collects information close to the ground or placed at any angle in relation to the earth's surface. Thanks to this, the overview of the space above the radar can be performed in a vertical or horizontal cross-section. The basic ways of obtaining radar information are spatial searches of the atmosphere. Classical scan measurements are optimized for measuring Z [dBZ] reflectivity up to a range of 250 km around the radar and an altitude of 20 km. The initial processing of the received signal takes place at the radar station and is carried out by the radar processor. The processor performs pre-processing of the data from the scan. The result of this process is a source of data for further processing in the radar system. The acquired information is processed by the radar system into a very large number of different products according to specialized algorithms built not only based on knowledge in the field of radar meteorology, general meteorology, climatology, but also taking into account exact sciences [Tuszyńska I., 2011, pp. 9–11].

A simplified diagram of the meteorological radar is shown in Fig. 2. Of course, not all elements of the radar were shown in the diagram due to the complexity of its design.

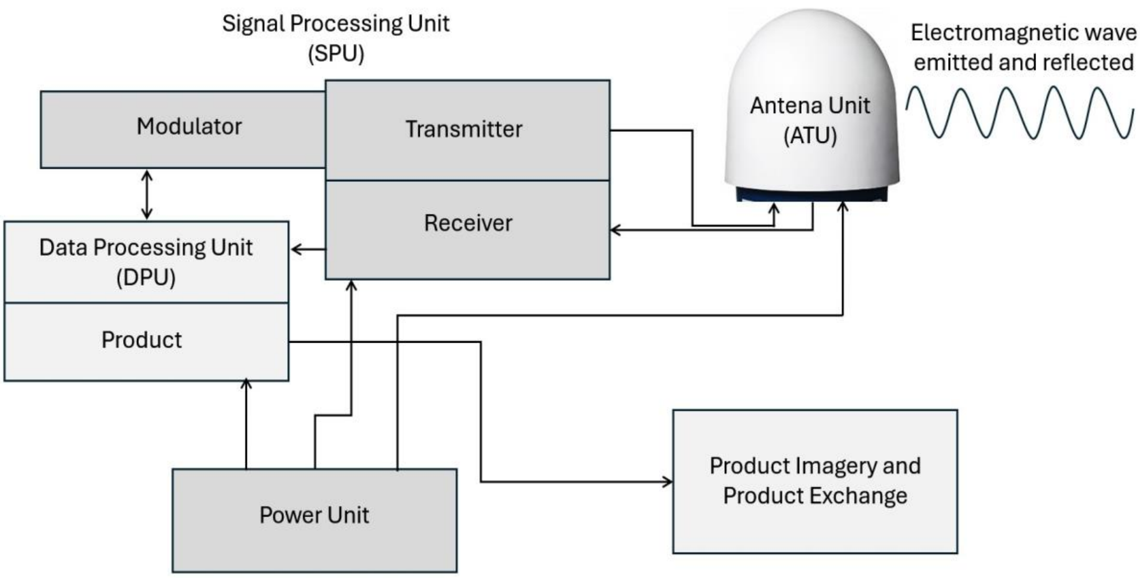


Fig. 2. Simplified weather radar diagram [own study].

Weather radars are characterized by the following technical parameters:

1. Transmitter power – ***Pt*** during the pulse [kW].
2. Radar wavelength – $\boldsymbol{\lambda}$ [cm].
3. Width (length, duration) of the pulse – ***t***, usually expressed in [µs].
4. Pulse repetition frequency – ***Fp***. Usually several hundred (sometimes over 1000 [imp/s]).
5. Antenna beam width – $\boldsymbol{\theta}$ [º].

The most important parameter of weather radars is the length of the emitted wave at which the radar operates. There are three frequency bands (wavelengths) used in meteorology:

- S band – 10 cm wave (3,000 MHz) - used in radios for long-range observations in the tropical zone and for observing dangerous weather phenomena.
- C band – 5.6 cm wave (6,000 MHz) - used in radars for long-range observations in the temperate climate zone.
- X-band – wave with a length of 3.2 cm (10,000 MHz) – used in radars for short-range observations and in the polar climate zone.

The beam width of a weather radar antenna is an important parameter of its operation. The antenna beam does not have a sharp boundary and is described by a bell curve. The larger the beam (stronger the directivity of the antenna), the better the resolution of information in azimuth and elevation, and therefore the better the coordinate accuracy. At a certain angular distance from the beam axis, secondary maxima occur, these are the so-called sidelobes, their size and position have a significant impact on the range of permanent echoes (from ground objects) [Moszkowicz S., Tuszyńska I., 2006, p. 10]. Meteorological radar beams are most often called "pencil" beams because they are circular in shape both vertically and horizontally and their diameter is approximately 1º. The beam in low-power radars is 2.7º (example: Furuno WR 2120 weather radar) [*FURUNO Weather Radar Specifications Comparison*, p. 1, 2020].

In radar meteorology, a detectable meteorological object means such a concentration of hydrometeors in its volume (in the atmosphere) that causes the power of the backscattered signal received by the radar to be higher than the noise power and sensitivity of the receiver of a given radar device. This definition shows that the detectability of a meteorological object depends, among other things, on the technical parameters of the radar device. When electromagnetic waves pass through objects, secondary radiation is excited in each particle. Some of the energy is absorbed and converted into heat. The remaining energy is dissipated in all directions, including towards the radar device (backscatter). The frequency of the scattered wave is the same as the frequency of the incident wave [Tuszyńska I., 2015, p. 15]. What distinguishes weather radar from navigation, artillery or warning radars is the shape (circular characteristics) of the emitted electromagnetic wave. When the radar beam encounters a cloud, only part of it is reflected and returns to the antenna, while the remaining beam passes through the cloud structure, making it possible to observe clouds further away up to approximately 300 km (but usually up to 250 km). Precipitation clouds are illuminated by electromagnetic waves.

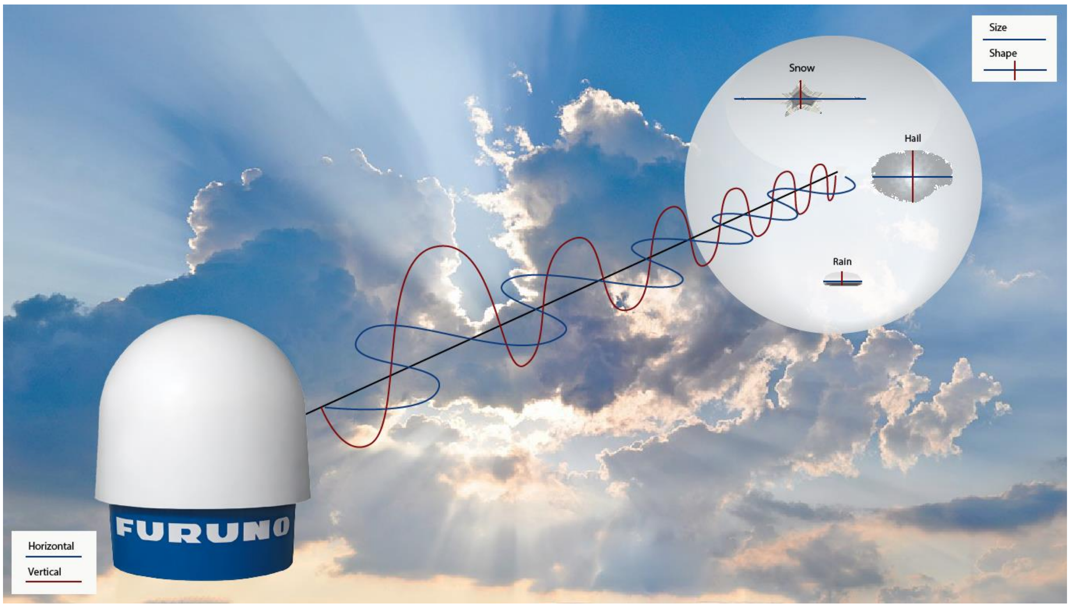


Fig. 3 Dual polarization of electromagnetic waves used in meteorological radars [WR-2120, 2024].

Classic weather radar sends a beam of microwaves with linear horizontal polarization. This means that the electric vector of the (electromagnetic) wave oscillates in one plane (horizontal). The reflection of an electromagnetic wave from the surface of a dielectric (water) is in fact a wave generation as a result of changes in the orientation of the water's electric dipoles, forced by the incident wave. For precipitation, a theory was created linking depolarization with the position of the main particle axes, which are approximated by small ellipsoids and the reflected signal is differentiated depending on the polarization of the incident wave, because the radar sending the wave "sees" a hydrometeor with a dimension that is dominant in the plane of polarization of the wave sent in his direction. We all probably know that the shape of a freely falling drop depends on its size. The smallest drops are almost perfectly round, while large drops tend to "flatten" when falling. The reduction in the "vertical diameter" of the drop is greater the greater the volume of the drop and its falling speed. When sweeping such flattened drops with a radar beam, the returning signal depends on the plane of wave polarization. When performing radar measurements with a dual-polarization radar, we measure both drop diameters along two planes (vertical and horizontal) resulting from the radiation of hydrometeors in the meteorological structure, simultaneously with waves of vertical and horizontal polarization. As a result, two different values of the signal reflected from the same drops are obtained, and then the signals transmitted in two mutually perpendicular directions are compared with the return signals. In the case of drops whose diameters are larger than 1 mm, measurement with a horizontally polarized wave gives a higher value of reflectivity than with a vertically polarized wave (reflectivity Z is the sum of the sixth powers of the drop diameters) in the radiated volume of the atmosphere. By comparing the signals received in two mutually perpendicular directions, we can assess the size of the dominant droplets. Obtaining such information results in a more accurate conversion of reflectivity into precipitation intensity [Tuszyńska I., 2011, pp. 8–9]. The double polarization of the electromagnetic wave used in meteorological radars is illustrated in Fig. 3 [*WR 2120*, 2024].

Currently, most weather radars are Doppler radars, which use the Doppler effect to measure the speed of water droplets, ice crystals, snowflakes, hail and others in clouds and precipitation moving with the wind. The Doppler radar receiver has a reference generator with extremely high frequency stability, which allows a comparison to be made with the frequency received by the radar. This difference is the Doppler frequency, which is a measure of the speed of the reflecting object. With Doppler radar, we can only measure the speed of the detected object when the object is moving into/away from the radar. An equally important application of the Doppler effect is the use of the so-called constant echoes, which are non-meteorological echoes and originating from terrain obstacles (mountain, hill, etc.), for the elimination of the so-called constant echoes, which are non-meteorological echoes, and have a zero velocity [Dyrcz C., 2024].

3. WEATHER RADAR FURUNO WR 2120

3.1. TECHNICAL DATA

The WR 2120 weather radar installed at the Polish Naval Academy is a device integrated with a server and two interactive monitors located in the meteorological and oceanographic laboratory METOC and Naval Radar Trainer. Integrated meteorological radar in the Polish Naval Academy is presented in a block diagram in Fig.4.

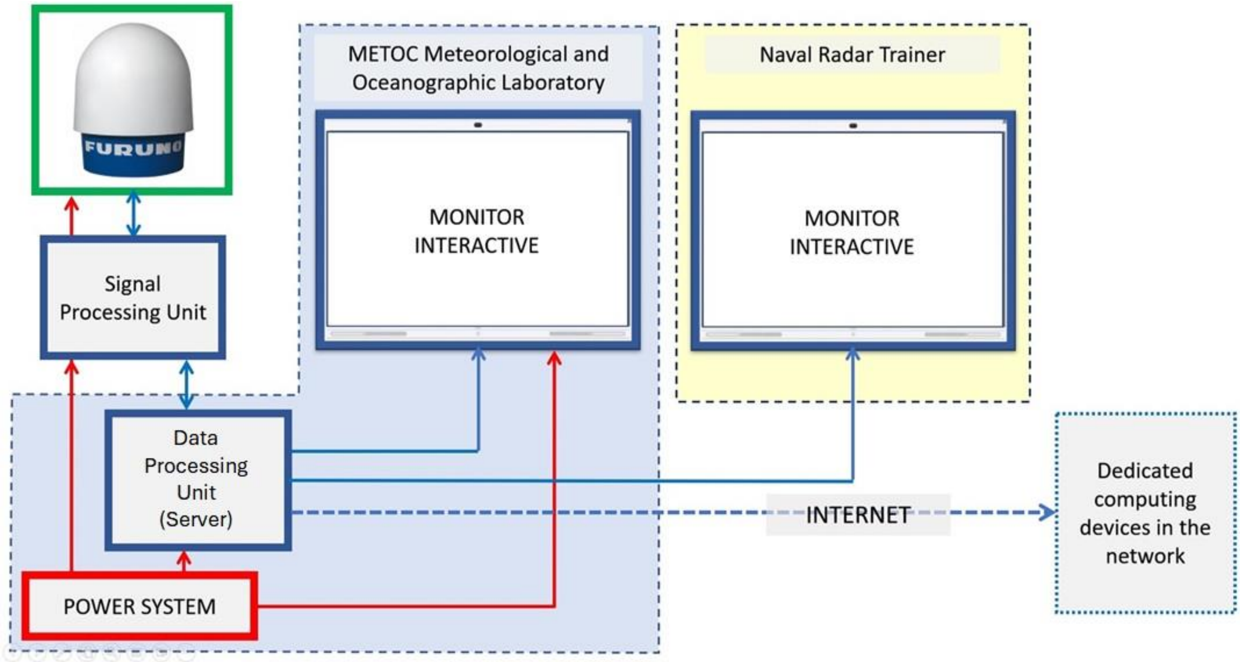


Fig. 4. Integrated meteorological radar station in the Polish Naval Academy [own study].

The basic technical data of the WR 2120 radar are summarized in Table 1. Of course, these are only data on important parameters important for teaching and training purposes.

Table 1. Basic technical data of the WR 2120 Weather Radar.

Parameter	***Values***
1.	*2.*
Polarization Type	*Dual polarization (horizontal and vertical)*
Operating frequency	*9.4 GHz (X-Band)*
Beam width	*2,7° (both horizontal and vertical beams)*
Pulse width	*0.5-50 μs*
Maximum power in pulse	*100 W*
Antenna elevation angle	*-2 do 182°*
Antenna horizontal angle	*360°*
Radamel size *ATU weight*	*1 m* *65 kg*
Observation range	*70 km*
Beamwidth	*2.7°*
Doppler speed	*+/- 64 m/s*
Maximum Wind Speed	*90 m/s*

Parameter	***Values***
1.	*2.*
Output parameters	*Reflectivity factor (Zh/Zv), Doppler velocity (V), Doppler velocity width (W), Cross polarization difference phase (fdp), Specific difference phase (KDP), Correlation coefficient (rhv), Differential reflectivity (ZDR), Rainfall intensity (R)*
Power	*100-240 VAC, 470 W typ.*
Max. power supply	*650 W max.*
Data format	*HDF5, CF/Radial, CF-Compliant NetCDF (rain only), Grib2 (rain only) (Other specific formats are on demand)*
Available data formats	*Binary, CSV, JPEG, CF/Radial, Opera Odim HDF5, NEXRAD Level 2*
Maximum wind survival speed	*90 m/s*
Transmitter type	*Solid-state*

The operational range of the WR 2120 weather radar is 70 km. An illustration of the operating range of the radar installed at the Polish Naval Academy is shown in Fig.5.

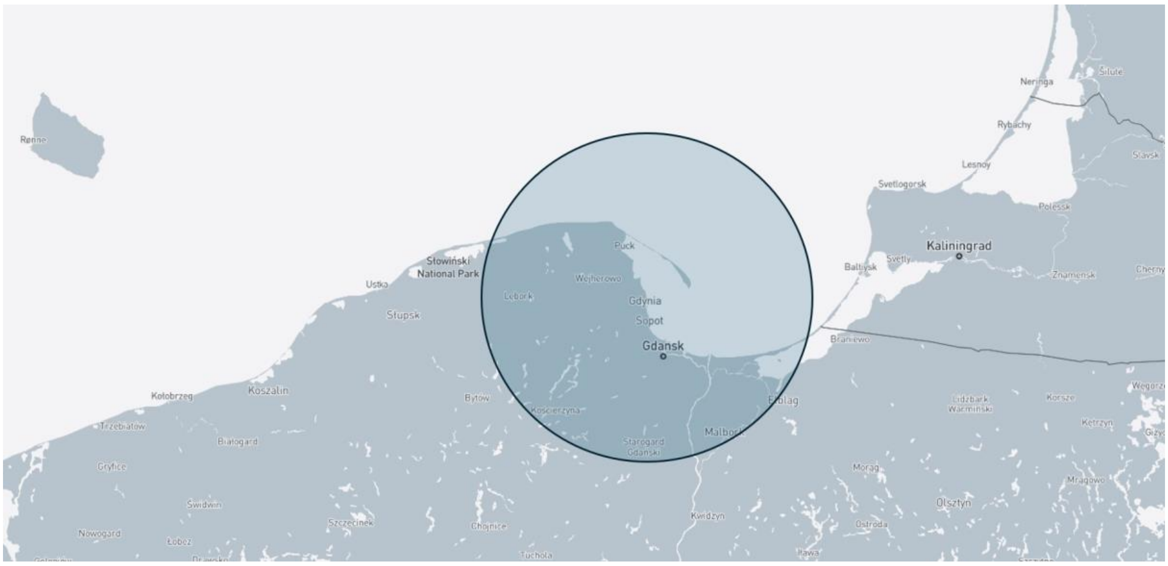
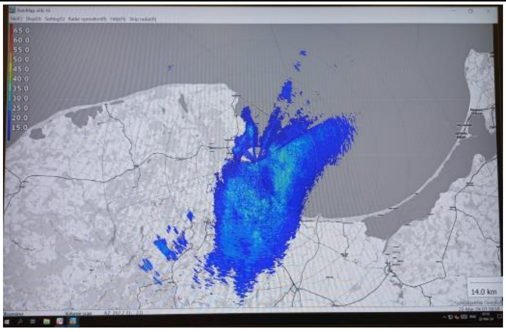
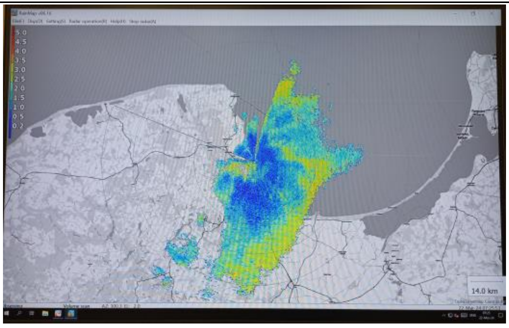
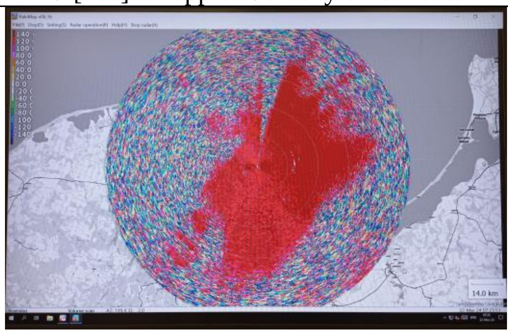
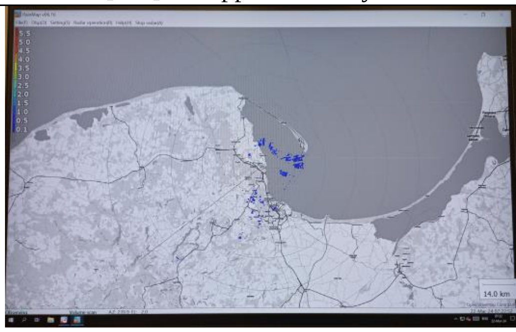
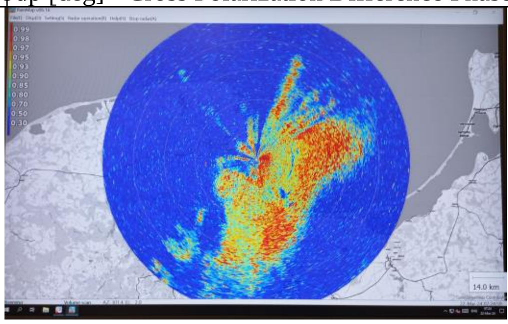
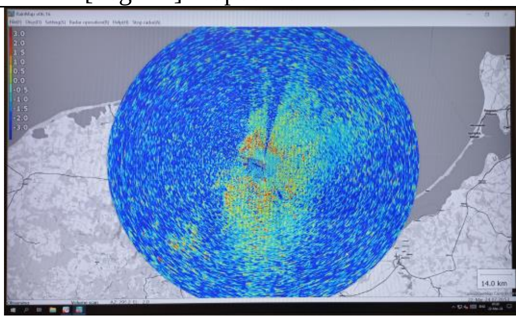
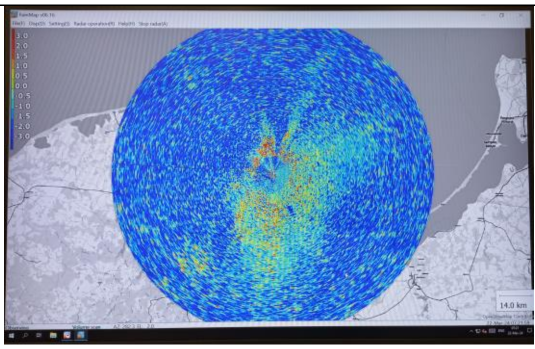


Fig. 5. The range of operation of the WR 2120 weather radar mounted on the building of the Polish Naval Academy in Gdynia [own study].

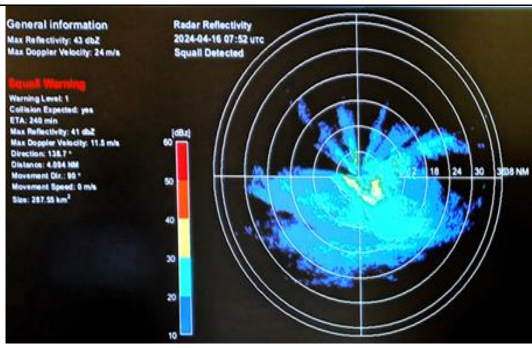
3.2. DISPLAY DATA TYPES

Weather radars process the acquired information into products presented on physical maps of the radar area of operation, which are described in legends containing a scale of colors assigned to specific parameter values. For example, Fig. 6 illustrates the radar products of the Furuno WR 2120 meteorological radar located at the Naval Academy in Gdynia. The WR 2120 radar provides 12 products generated from the data obtained in operational mode. It should be noted here that there is a large variety of radar products, which depends on the computer programs used in radar and collective systems processing data obtained during operation [Dyrcz C., 2024].

 R [mm/h] – Rainfall Intensity	 Zh [dBZ] – Reflectivity Factor Horizontal
 Zh_corr [dBZ] – Reflectivity Factor Corrected	 Zv [dBZ] – Reflectivity Factor Vertical
 V [m/s] - Doppler Velocity of rain area	 W [m/s] – Doppler Velocity Width
 φdp [deg] - Cross Polarization Difference Phase	 KDP [deg/km] – Specific Differential Phase
 ρHV – Correlation Coefficient Between Two Polarizations	 Zdr [dB] – Differential Reflectivity Factor



Zdr_corr [dB] – Differential Reflectivity Factor Corrected



SWS – Squall Warning System

Fig. 6. Examples of WR 2120 weather radar products from March 22, 2024 at 0714-0726 LT, and SWS of April 16, 2024 at 0752 LT

The radar products provided by the WR 2120 weather radar are as follows:

- **R** [mm/h] - Rainfall Intensity - convert using where larger Zh and R values = heavier rain,
- **Zh** [dBZ] - Reflectivity Factor Horizontal - Raindrop distribution and density, where dBZ is reflectivity (relative to decibel) and units of Z [mm^6/m^3] derived from the standard weather radar equation. dBZ (decibel relative to Z) a logarithmic, dimensionless unit, in weather radar used to compare the equivalent reflectivity factor (Z) of a radar signal reflected off a remote object in [mm^6/m^3] to the return of a droplet of rain with a diameter of 1 mm (1 mm^6 per m^3). It is proportional to the number of drops per unit volume and the sixth power of drops diameter and is used to estimate rain or snow intensity. Reflectivity factor Z is equal to:

$$Z = 200R^{1.6}\ [mm^6/m^3] \tag{1}$$

where

R – rainfall intensity rate in [mm/h].

Fig. 7 illustrates the color gradient coloration for Zh and Zv data expressed in [dBZ] and the corresponding R values.

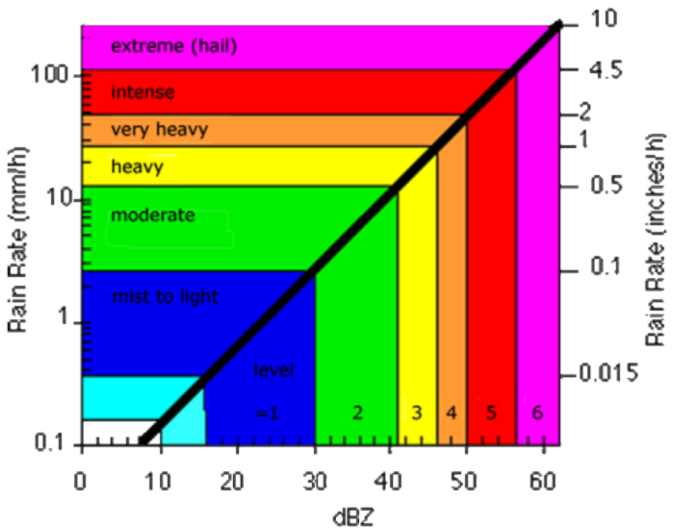


Fig. 7. The color gradient coloration for Zh and Zv data [Technical Training Course, p. 76].

Zh reflectivity factor is generally derived from the horizontal polarity of a polarimetric weather radar. Zh is also used for precipitation classifications when used with Zv and other data. For example: Zh is high and Zdr is low indicates hail. Larger Zh and R corresponds to heavier rain/hail.

- **Zh corr** [dBZ] - Reflectivity Factor Corrected,
- **Zv** [dBZ] - Reflectivity Factor Vertical. The horizontal and vertical image color graphs look similar but actual data is different and specific to the individual polarity. This information provides the necessary data to determine the precipitation size, shape, and classification.
- **V** [m/s] - Doppler Velocity - determines velocity of rainfall where positive value (+) = away from radar and (-) minus value = toward radar. 2D and 3D velocities are also calculated from this information,
- **W** [m/s] - Doppler Velocity Width - is the standard deviation of V and is spread by disturbance, noise, etc. and normally used to reject noise from V,
- **φdp** [deg] - Cross Polarization Difference Phase - phase shift difference between horizontal and vertical polarized pulses,
- **KDP** [deg/km] - Specific Differential Phase (shift) [Range differential of φdp] – difference between horizontal and vertical propagated pulses where: > horizontal = (+) shift and > vertical = (-) shift. Mainly used for heavy rain observation and not dependent on transmit / receive power. Attenuated (slowed) signal recovery is possible without TX/RX calibration. High concentrations of small raindrops yield a higher KDP than lower concentrations of large raindrops. Heavy rain area has a high KDP. Hail, snow and ice crystals lack specific orientations yielding near zero KDP,
- **ρHV** - Correlation Coefficient Between Two Polarizations - correlation between horizontal and vertical pulses. It mainly used for classification of particles (rain, sleet, snow, hail, volcano ash etc.),
- **Zdr** [dB] - Differential Reflectivity Factor - this parameter determines reflectivity difference. Also use for classifications Example: Zh is high, Zdr is low (≈1): indicates hail. In addition, this parameter will be used to evaluate system quality. Zdr is difference of reflectivity for each polarization. This parameter is also use for classification.

$$Zdr = 10 \log (Zh/Zv) \text{ [dB]} \tag{2}$$

where

Zh – Reflectivity Factor Horizontal,

Zv – Reflectivity Factor Vertical,

- **Zdr_corr** [dB] - Differential Reflectivity Factor Corrected.
- **SWS** – Squall Warning System. The SWS software is developed by Department of Civil Engineering, Aalborg University, Denmark. The SWS is a decision support tool and it is not designed to make automatic decision and control as part of any operational system or procedure. Application of the system is only subject to the judgement and good seamanship of the operator. Under no circumstances should the operator base decision on this system alone. The SWS is based on weather radar measurement and analysis. The weather radar generates new observational data, which is analyzed every 5 minutes. The radar scans 360 degrees azimuth at different elevations in order measure the precipitation at different heights relative to the horizon. The SWS only uses one elevation for analysis. The remaining elevations are saved for reference and later offline analysis.

The active elevation can be selected by the user and is saved in the configuration files. The SWS uses a combination of two data sets: Reflectivity and Doppler velocities. Reflectivity is a measure for the microwave reflection from hydrometeors back to the radar. The size of reflection is dependent on drop size and precipitation type (liquid, snow, ice, hail or a combination). The Doppler velocity is measured as the radial velocity of the hydrometeors. It indicates the movement along the scan line of every radar beam. Both reflectivity and Doppler velocity are high in relation to squall lines. The system scheduler is automatically started when the computer boot [*Operation manual for Squall Warning System*, p. 4–5].

A color scale is used to determine the values of individual coefficients and data obtained from the WR 2120 radar. Scale label it indicates the signal level of displayed image by color. The upper color means stronger signals and the lower color means weaker signals. These scale labels colors and values correspond to the observation data type. The size of label on the screen depends on available left side screen area. Scale label of coefficient values of individual WR 2120 radar products is shown in Fig. 8.

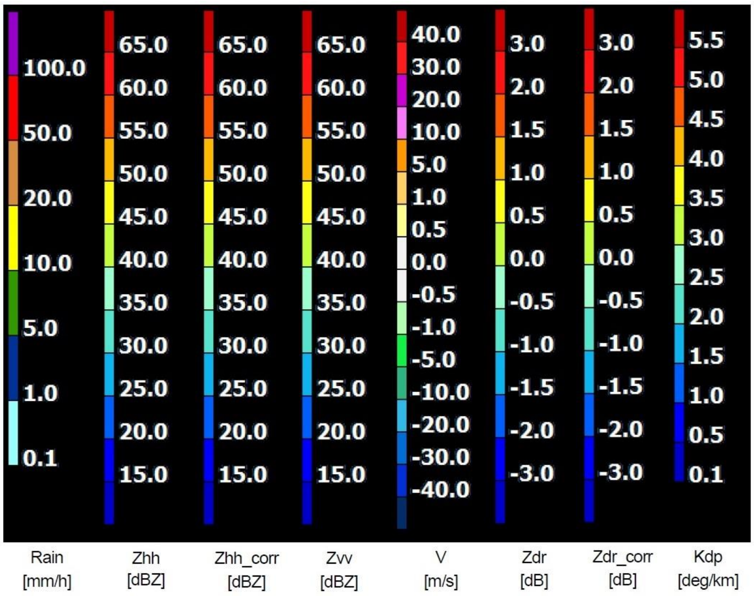


Fig. 8. Scale label of coefficient values of individual WR 2120 radar products [Operational Manual, p. 31].

4. NAVIGATION SAFETY SUPPORT

Weather radars provide detailed weather condition observations that are critical for crew, shipboard and helicopter operations safety. The continuous, real-time weather information includes storm location, precipitation, visibility and Doppler velocity, maximizing operational drilling efficiency. The installation of the Furuno WR 2120 weather radar on the oil rig and the drilling ship is shown in Fig. 9 [*Compact X-band Dual Polarimetric Doppler Weather Radar*, p. 5].

Fig. 9. WR 2120 weather radar used on the oil rig and the drilling ship [Compact X-band Dual Polarimetric Doppler Weather Radar, p. 5].

Current and possible support for navigational safety using weather radar is following:

- Current information on the meteorological situation around conducting activities at sea.
- Type determination of precipitation (drizzle, rain, snow, hail, etc.).
- Monitoring and supervision of offshore installations.
- Drillship safety.
- Platform safety.
- Safety of service units.
- Monitoring of weather in offshore waters, anchoring and movement of floating oil storage facilities (Floating Production Storage).
- Monitoring navigational safety of selected naval operations of naval forces (air, amphibious, SAR, RAS, etc.) - future.

Examples of using the SWS in offshore operations are presented in Fig. 10.

Vessel name	BONGA FPSO
	
Vessel type	FPSO (Floating Production Storage and Offloading System)
Operation area	Nigeria (120 km south-west of Niger Delta)
Operation period	2017 till now
Weather radar	1 x WR-2100
End customer	Shell Petroleum Nigeria
Project Information	https://www.offshore-technology.com/projects/bonga/

Vessel name	LIZA DESTINY
	
Vessel type	FPSO (Floating Production Storage and Offloading System)
Operation area	Guyana (200 miles from shore)
Operation period	2020 till now
Weather radar	2 x WR2120 (One for backup)
End customer	Exxon mobile
Project Information	https://corporate.exxonmobil.com/Locations/Guyana/Guyana-project-overview#LizaPhaseProjectDescription

Fig. 10. Examples of using the Squall Warning System (SWS) in offshore operations [FURUNO Weather Radar, p. 45, 2020].

The use of the SWS system on ships and marine structures is becoming more and more common and necessary to ensure safety at sea. Most likely, this trend will be observed much more intensively in the near future. The frequency of repetition of dangerous meteorological phenomena due to climate change is observed, and therefore safety at sea will require meteorological protection in the area of human activity at sea.

5. OPERATIONAL EXPERIENCE

Experience resulting from the operation and operation of the WR 2120 weather radar installed in the meteorological and oceanographic laboratory of the Polish Naval Academy is limited by time. The ability to operate and use weather radar is related to reading and attempting to use the radar products presented below. The main conclusions that have been drawn are related to the current location of the ATU, which is temporary at this stage.

Experience from short operation of the WR 2120 weather radar

- Conducting analyses of particularly dangerous phenomena.
- Tracking and determining the direction of movement of storm structures and their speed.
- Monitoring the movement of storm cells using information from SWS.
- Determination of the intensity and areas of precipitation.
- Determining the direction and speed of movement of precipitation areas.
- Define warnings using information from SWS.
- Identify interference zones.
- The current location of the ATU is not final, due to the zone of interference caused by the newly built multifunctional block of the Academy.

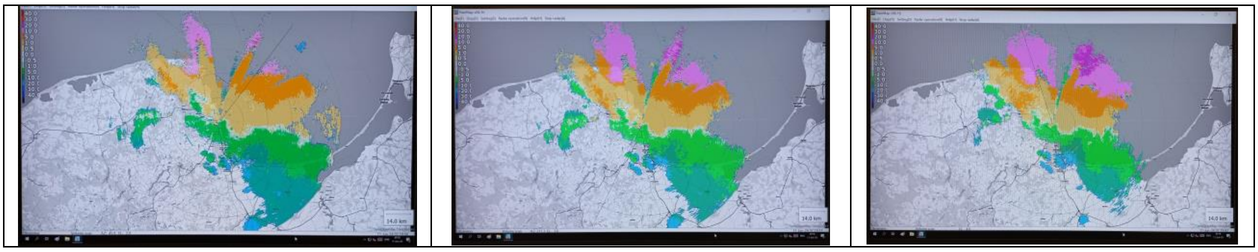


Fig. 11. Doppler velocity of rain area V [m/s] imaging on June 11, 2024 at 0719LT for the antenna elevation angle (from the left respectively) 2, 3 and 4 degrees.

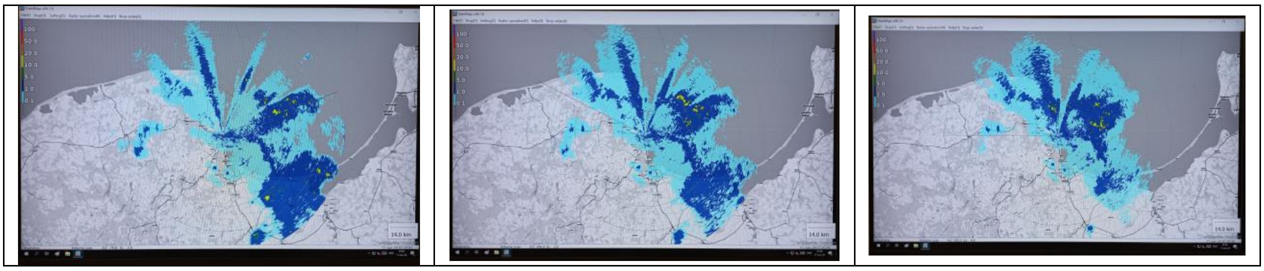


Fig. 12. Rainfall intensity R [mm/h] on June 11, 2024 at 0720LT for the antenna elevation angle (from the left) 2, 3 and 4 degrees.

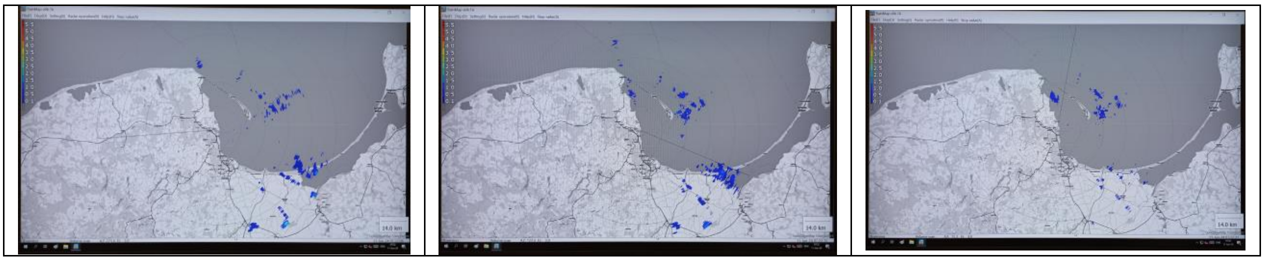


Fig. 13. Display of Specific Differential Phase KDP [deg/km] on June 11, 2024 at 0722 LT for the antenna elevation angle (respectively from the left) 2, 3 and 4 degrees.

Figures 11, 12 and 13 show the most frequently used products of the WR 2120 weather radar, which allow the determination of basic weather elements and their location in the radar's operating area. The illustrated situation shows the passage of the front in the radar operational area on June 11, 2024 in the morning. Respectively, Fig. 11, 12 and 13 from the left show the situations for antenna elevation angles of 2, 3 and 4 degrees. The figures show "dead zones" due to terrain obstacles, but the greater the antenna elevation angle, the smaller these areas are. Each type of radar product clearly defines the values of the data presented.

6. CONCLUSIONS AND DIDCUSION

Summing up the issues presented above, the following conclusions were drawn:

1. Weather radar (meteorological radar) is a device for observing precipitation (location, intensity, type and movement). These data are used to forecast not only the future location and intensity of precipitation, but also other meteorological elements. The general principle of operation of the weather radar and its construction is similar to other types of radars, while the parameters and method of performing measurements (wavelength, resolution, range, scanning method, etc.) are adapted to the measurements of meteorological objects.
2. Weather radars are, next to meteorological satellites, the only devices with which it is possible to remotely study the state of the atmosphere and the weather-forming phenomena occurring in it with high spatial and temporal resolution. The advantage of meteorological radars over meteorological satellites is the possibility of "live" observations, which is particularly important in detecting and tracking zones of heavy rainfall and storms affecting safety. This proves in favor of the weather radar in terms of the speed of obtaining meteorological information.
3. The current use of meteorological radars at sea is associated with fixed platforms (fixed offshore installations, drilling vessels, exploration, production, transmission, storage platforms, etc.), where there is no need to use platforms stabilizing radar antennas. The future and wide application of meteorological radars at sea may be related to the use of antenna stabilization platforms, which with such a specific sounding beam must be extremely precise. However, even without this structural element, the use of weather radar increases on large and stable floating objects.
4. References in the text of the article to the WR 2120 meteorological radar currently used at the Naval Academy are information from the short-term use of this device. The radar is currently used for teaching, training and research in the field of monitoring navigational safety. However, attention is paid to the use of radar in selected naval operations, which include air operations, amphibious operations, SAR, RAS, etc. This is the future, which is worth talking about based on the possibilities created by the meteorological radar.

Writing this article and drawing generalized conclusions is the initiation of a discussion on the use of weather radars to improve the safety of human activities at sea. This discussion should be particularly important for the future in times of climate change, which is characterized by an unprecedented intensity of dangerous weather phenomena. Extreme storms, hurricanes, strong winds, and dangerous weather phenomena are observed more and more often. Weather radar is a device that provides a multitude of meteorological information and, together with integrated warning systems, warns against dangerous phenomena at sea. As we gain experience and conduct research, this voice will become stronger and stronger and will serve to improve the safety of human activities at sea,

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