Natural causes of ship accidents in the Bermuda region on the example of the El Faro ship

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Abstract. The article describes the crash of the El Faro ship (IMO 7395351) in the Bermuda region. According to the National Transportation Safety Board, causes of its wrecking are natural factors. On October 1, the El Faro ship was already on its way to the storm epicenter. A message sent to the shore said that water was entering the hold, after which communication was terminated. According to investigators, the captain did not show due attention to the cyclonic circulation and did not change the route, leading the ship to the hurricane epicenter. The article analyzes natural causes of the accident, as well as probable El Faro routes, whose timely selection could have reduced the impact of Joaquin. In addition, the article suggests taking into account weather conditions in the area under study.

1. Introduction
Disappearance of ships in the Bermuda Triangle, or their deaths occur no more often than in other areas of the oceans. This fact is due to natural causes - weather and geological conditions [1].

The Bermuda area is difficult to navigate: shoals, tropical cyclones, storms - all these features of the bottom topography, atmospheric circulation and water masses create significant difficulties for the accident-free navigation. The same opinion is shared by the US Coast Guard and the Lloyd’s insurance market [2]. The area is crossed by the main waterways from the Caribbean Sea to Europe, from the east coast of the United States to South America.

The most dangerous natural phenomena in the Bermuda region include tropical cyclones with winds of more than 34 knots, as well as those that have the force of a hurricane with a wind speed of more than 64 knots [3]. It is impossible to record the maximum possible wind speed using the anemometer due to the design peculiarities.

It is known that hurricanes in the Atlantic occur from June to November, but more often in September [3].

Hurricane winds in tropical cyclones cause waves with a height of 11-12 m, increasing to a height of 14-15 m and more [4].

The winter Atlantic is dangerous for shipping. Severe storms can be accompanied by wind speeds of 80 knots or more. In storm zones, navigation is especially dangerous [4].

For example, one day in January, the 22-meter schooner Margo left Bermuda. The weather forecast was good for 50 miles south of Bermuda, but after three hours the winds reached 85 knots, and winds of 50 knots or more were recorded throughout the next week. Since then, nothing has been known about the schooner [5].
Not only fragile yachts, but also cargo ships disappear. On September 29, 2015 the “El Faro” (IMO 7395351) ship with 33 crew members left Jacksonville (USA) for San Juan (Puerto Rico). On October 1, the El Faro sank 40 miles away from Acklins and Crooked Island, the Bahamas. All crew members died [6].

In 2016, the ship remains were discovered at a depth of about 5 kilometers in the Bahamas. The flooding damage was 36 ml. $ [6].

The weather reports were received every 6 hours. When the hurricane began, the captain Michael Davidson changed course to the south and went to bed, since he was sure that the ship would bypass the storm zone behind Hurricane Joaquin; the speed of the ship was 20 knots [6].

According to the recordings, the captain's mates suggested changing the route, but the captain refused. According to the National Transportation Safety Board, after waking up, the captain realized that the ship was already on its way to the storm epicenter. A message sent to the shore said that water was entering the hold, after which communication with the vessel was terminated.

The “El Faro” disappeared into the depths. The ship disintegrated into parts, which were found at a distance of about one kilometer from the main part of the wreckage [6].

According to the investigators, the subordination did not allow crew members to change the route.

The article aims to analyze the choice of routes in order to reduce the impact of weather factors.

2. Methods and materials
To analyze the situation with the "El Faro" in the zone of Joaquin cyclone, weather conditions in the Bermuda region were studied; the recordings of captain's negotiations with the shore were analyzed, the history of Joaquin was investigated; ways to avoid the storm zone were considered, and the real route bypassing the storm zone was studied.

3. Results
Joaquin was first discovered on September 25, 2015 by the US National Hurricane Center (NHC) a few hundred miles south-southwest of the Bermuda. From September 26 to September 29, it developed into a tropical storm on September 30. Having reached the hurricane stage, it was named "Joaquin", becoming the tenth named hurricane in the 2015 season (Figure 1) [7].

By October 3, Joaquin was weakened and headed northeast. It intensified again, with wind speeds reaching 69.4 m/s, which corresponded to category 4. Joaquin lost its tropical cyclone identity at 03:00 UTC on 8 October.

Figure 2 shows information about the coordinates of the center of Joaquin, as well as information about the pressure and wind speed from the beginning of its formation to October 1, 2015. Information for later dates is not provided due to the fact that on October 1 the cargo ship "El Faro" had already sunk [6].

Figure 3 shows Joaquin’s Track. Figure 4 shows the direct route from Jacksonville to San Juan, which was chosen by Captain Michael Davidson. The length of the route was 1097 m.

The El Faro's actual track from Jacksonville to the place of sinking, with a time stamp every 2 hours, deviated slightly from the original route due to the captain's idea of avoiding the hurricane from the south (Figure 5).

The speed of movement relative to the ground from 30.09 to 01.10 is shown in Figure 6 [2].

Figure 5 shows that El Faro passed east of Great Abaco Island in the north of the Bahamas on the afternoon of September 30th. At 6:30 pm, the ship was approximately 60 nautical miles from the Northwest Providence Channel entrance. According to the offshore forecast and Bon Voyage System information (Figure 7), the center of the hurricane was 400 nautical miles southeast of the El Faro.
Figure 1. Hurricane Joaquin’s Storm Path and Zone [7]

Figure 2. Joaquin’s coordinates, pressure and wind speed from 28 September to 2 October 2015 [7].
Figure 3. The Hurricane Joaquin’s Track [8]

Figure 4. The preliminary route of the "El Faro"
Based on the earlier predictions, the El Faro could initially choose an alternative route from Jacksonville to San Juan via the Old Bahama Channel (Figure 8).

Figure 7 shows an alternative route via the Old Bahama Channel.

The El Faro sank on October 1, approximately 40 miles from Acklins and Crooked Island, the Bahamas.

The center of the hurricane was southeast of the El Faro position, approximately 400 miles away [9]. If the captain paid attention to the weather forecast, he could go through the Northeast Providence Channel, enter the Nortwast Providence west of Great Abaco Island, into the Straits of Florida, and later enter the route via the Old Bahama Channel.
Figure 7. Offshore Forecast & Bon Voyage System Information

The pivot point would have been $\varphi = 26^\circ47'1''$N; $\lambda = 076^\circ01'1''$W. The course would have been 2180, 82 miles to the Northeast Providence Channel entrance. The next course would have been 2880 to 110 miles Straits of Florida to the point $\varphi = 26^\circ17'9''$N; $\lambda = 079^\circ05'8''$W walk 54 miles, from which the ship would have headed to the Old Bahama Channel. By changing the route, the vessel would not have got into the front left part of the hurricane (Figure 9).

The actual route of the vessel was different (Figure 10). Figure 10 shows alternative routes.
The real route is pink, the alternative route is green, and the direct route is yellow. The actual route differs from the one chosen during the preliminary study of the route due to the fact that on September 30, the vessel deviated from the course to bypass Joaquin from the south, which was 330 miles away from the vessel's position. Michael Davidson believed the hurricane would move north. According to the VDR radar image, the vessel was sailing west-southwest of the southern tip of San Salvador Island and exiting on the leeward side of the island.

It was already pointless to take any action to avoid the storm zone. From 30.09 to 01.20 the ship continued to sail the course of 1400, and on October 1 it was pulled by a storm into the epicenter of the hurricane (Figures 11-12).

Figure 8. El Faro routes via the Old Bahama Channel

Figure 9. The arrow indicates the bend in the Northeast Providence Channel [6]
Figure 10. El Faro Routing Opportunities to Avoid the Hurricane Joaquin's Storm Zone [6]

Figure 11. El Faro's position regarding the eye of the storm of Joaquin on 09/30/2015 [6]
Figure 12. El Faro’s position regarding the eye of the storm of Joaquin on 10/01/2015 [6]

4. Recommendations
The Mariner’s 1-2-3 Rule, also called the Hazard Rule, is an important guideline for seafarers to avoid tropical storms or hurricane zones (Figure 13) [10].

Figure 13. Illustration of the Mariner’s 1-2-3 rule [10]
The illustration of the Mariner’s 1-2-3 rule [10] refers to the National Hurricane Center (NHC) long-term forecast with errors of 100-200-300 nautical miles at 24-48-72 hours [10]. The danger zone to be avoided is constructed with these errors in mind and then expanded further to reflect the maximum tropical wind speeds (34 knots) predicted in each of these NHC cases.

34 knots or more are chosen as the critical wind speed, since at a higher value, the wind and sea conditions limit the maneuverability of the vessel. At the same time, the options for changing routes are reduced. Thus, the most important tactic is to avoid tropical cyclones which was ignored by Michael Davidson. In addition, it is recommended to expand boundaries of the danger zone, depending on the uncertainty of forecasts [9]. The tropical cyclone hazard zone designated by the 1-2-3 Mariner’s rule is considered to be a closed area for shipping [10].

It is not enough to know and use the rules of divergence from the storm zone. In high-risk situations, decisions should be made by all crew members and hydrometeorological professionals taking into account weather observations. The following recommendations have been developed:

- it is necessary to update publications on bridge management to improve the process of decision-making and include navigation scenarios in stormy conditions for safe navigation;
- it is necessary to include hydrometeorology in the advanced training program for the navigator staff (e.g., characteristics of weather systems, advanced meteorological concepts, maneuvering in severe storms).

5. Conclusion

According to the investigation results, there are several causes of the ship's wreck. The first and foremost is the mistake of captain Michael Davidson, who underestimated the strength of the hurricane and did not change the route. In addition, he did not take necessary actions.

The captain received enough weather information to decide on a safe route; however, he was unable to use the latest weather information to make correct decisions.

This study revealed that the ship did not a properly working anemometer (it did not show the full range of wind speeds). This circumstance deprived the captain of a vital tool for understanding the position of the ship in relation to the storm.

The position of the center of a tropical cyclone, the direction of its movement and the quarter of the cyclone in which the vessel is located are determined according to the following rules:

1. The center of a tropical cyclone is approximately 600 left in the northern hemisphere and 600 right in the southern hemisphere when standing with your back to the wind. If the vessel approaches the center of a tropical cyclone, this angle begins to grow, reaching 90° or more.

2. If the vessel is in the northern hemisphere and falls into the most dangerous quarter of the cyclone, when the pressure drops, the wind begins to change its direction clockwise. In the southern hemisphere, the opposite is true.

3. If the wind direction remains unchanged, the wind speed increases, the pressure drops; it means that the vessel is on the path of the center of the tropical cyclone. If the pressure rises, the center of the cyclone has passed.

4. If the wind changes its direction clockwise, in the northern hemisphere the vessel is in the right rear quarter of the cyclone, in the southern hemisphere - in the left rear quarter. If the wind changes direction counterclockwise: in the northern hemisphere, the vessel is in the left hind quarter, in the southern hemisphere it is in the right quarter.

5. The swell comes from the center of the cyclone in concentric circles.

The cyclone center will always be located in the northern hemisphere to the right, and in the southern hemisphere - to the left of the observer facing the movement of clouds. It is not always possible to apply these rules in practice, since due to the exceptional complexity in a tropical cyclone, it is difficult to measure the values of hydrometeorological elements and observe their changes. Therefore, if it was not possible to establish the quarter in which the vessel is located, then for greater safety, an unfavorable case should be assumed when the vessel is in the most dangerous quarter.
The company bought the Rapid Response Damage Assessment service, but it did not train the crew to use it [6].

The company did not monitor the El Faro's position in relation to the storm and did not provide the captain with support to prevent its consequences, which were fatal to the vessel and the crew.

Additional factors that contributed to the wrecking were the flooding of the cargo hold due to the open watertight hatch, as well as flooding of seawater pipelines. The watertight hatch in cargo hold 3 on the second deck was opened, which allowed inadvertent water ingress, causing the flooding, and reduced the stability of the vessel. Approximately 40 minutes before the sinking, seawater entered ventilation ducts of several main cargo holds, exacerbating the flooding in cargo hold 3 [6].

In addition, the loss of thrust due to the low pressure of the lubricating oil in the main engine (due to prolonged heeling and subsequent flooding through the unprotected ventilation plugs of the cargo holds) caused the tragedy.

The wrecking was facilitated by the lack of a damage elimination plan which would help the crew to determine the seriousness of the situation and respond to the emergency [6].

The wrecking was facilitated by the lack of suitable life-saving equipment.

As a result, one of the "worst catastrophes in the history of the merchant fleet" occurred; it caused the greatest number of deaths in almost forty recent years.

The article made an attempt to explain causes of the accident with a vessel in the Bermuda area. This case is not a manifestation of something supernatural. It is one more proof of underestimation of weather factors. The complex nature of the atmospheric circulation, unpredictable trajectories of cyclonic formations, the rapidly changing state of the sea surface did their disastrous deed: the ship could not cope with the cyclone and sank.

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