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Analysis of northern events on the Gulf of Tehuantepec and their effects on navigation

Análisis de los eventos del norte sobre el golfo de Tehuantepec y sus efectos en la navegación

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Abstract

The maritime areas of greatest risk in the Gulf of Tehuantepec, are derived from the strong winds and waves presented during the northern events that occurred during the cold front seasons, these meteorological phenomena affect activities related to navigation and represent a danger to the civil population due to the strong intensities of the wind and the height of the waves. The objective of the present investigation was to identify the maritime zones of greatest risk to navigation on the Gulf of Tehuantepec, derived from the analysis of the events of the north during the period 2015-2019, with the purpose of warning and making the maritime community aware. regional and national, the areas where the effects of the northern events are more intense. Likewise, for the analysis, interpretation and identification of the northern events, wind data recorded at the Automatic Meteorological Station (EMA) of the Secretary of the Navy (SEMAR), located in the Port of Salina Cruz, Oaxaca, and reanalysis data of the set were used. of wind and wave data from ERA5, for its subsequent processing through the Python programming language for the generation of maps of the variables. This gave as a result that a radius of the first 80 Nautical Miles (NM) of the Port of Salina Cruz, Oaxaca has intense wind and wave conditions during the month of January and very intense conditions appearing in a radius of 120 NM around said zone. Of the 56 northern events associated with cold fronts, 40 were classified as strong and 16 were classified as very strong, being of great relevance to avoid navigation accidents.

Northern events, Gulf of Tehuantepec, Cold fronts, Winds, Salina Cruz

Resumen

Las zonas marítimas de mayor riesgo en el golfo de Tehuantepec, son derivadas de los fuertes vientos y oleaje presentados durante los eventos del norte acontecidos durante la temporadas de frentes fríos, estos fenómenos meteorológicos afectan a las actividades relacionadas con la navegación y representan un peligro a la población civil debido a las fuertes intensidades del viento y altura del oleaje. El objetivo de la presente investigación fue identificar las zonas marítimas de mayor riesgo a la navegación sobre el golfo de Tehuantepec, derivadas del análisis de los eventos de norte durante el periodo 2015-2019, con la finalidad de advertir y hacer de conocimiento a la comunidad marítima regional y nacional, las zonas donde los efectos de los eventos de norte son de mayor intensidad. Así mismo para el análisis, interpretación e identificación de los eventos de norte, se utilizaron datos de viento registrados en la Estación Meteorológica Automática (EMA) de la Secretaría de Marina (SEMAR), ubicada en el Puerto de Salina Cruz, Oaxaca y datos de reanálisis del conjunto de datos de viento y oleaje del ERA5, para su posterior procesamiento a través del lenguaje de programación Python para la generación de mapas de las variables. Esto arrojó como resultado que un radio de las primeras 80 Millas Náuticas (MN) del Puerto de Salina Cruz, Oaxaca se tienen condiciones de vientos y oleaje intensas durante el mes de enero y presentándose condiciones muy intensas en un radio de 120 MN alrededor de citada zona. De los 56 eventos del norte asociados a frentes fríos 40 adquirieron la clasificación de fuerte y 16 la clasificación de muy fuerte, siendo de gran relevancia para evitar accidentes en la navegación.

Eventos de norte, Golfo de Tehuantepec, Frentes fríos, Vientos, Salina Cruz

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Introduction

The Mexican Republic is geographically located in an area that allows it to be affected every year by frontal systems, as a consequence of the incursion of cold air coming from the north pole that occurs in autumn and winter. These frontal systems generate variations in atmospheric pressure, temperature and humidity, being originated when we have the presence of two air masses with different physical properties; some of the changes in the weather that occur with the passage of a frontal system are marked decreases in temperature, wind acceleration and constant precipitation that are usually small and continuous (Trasviña, 1995). If a mass of cold air displaces a mass of warm air, it gives rise to a cold front; during the winter season, polar air masses significantly reinforce the presence and duration of these types of fronts; the anticyclonic circulation (high pressure) associated with a cold front can cause in the Gulf of Mexico, winds that go from north (N) to south (S) and exceed 20 km/hr, this condition is known as a "northerly" event (Silvia, 2001).

The Gulf of Tehuantepec is located in the southeastern (SE) portion of the Mexican Republic; it is the southern border of Mexico's Exclusive Economic Zone in the Pacific Ocean. It is a region of approximately 125,000 km² delimited to the south by latitude 12º North, to the N by the Mexican coast between Puerto Ángel, Oaxaca and Puerto Madero, Chiapas, to the East (E) by meridian 92º West (W) and to the W by meridian 97º W (Gallegos-García and Barberán-Falcón, 1998).

The coastal zone of the Gulf of Tehuantepec is known for being a narrow region that separates the Gulf of Mexico from the Pacific Ocean. In this region, strong channeled winds are generated as a result of the combination of large-scale meteorological conditions and local topographic characteristics, which are known as "nortes" and affect navigation due to the consequences of these events (Romero-Centeno, 2003). Previous studies have shown that high pressure systems formed over the Great Plains of North America move in a SE direction across the United States of America, and some as far as the Bay of Campeche, developing a large pressure differential between the Gulf of Mexico and the Gulf of Tehuantepec.

Campeche Bay developing a large pressure difference between the Gulf of Mexico and the Gulf of Tehuantepec. This pressure gradient produces strong winds from the N across the orographic gap, which can last from several hours to 3 or 4 days, with wind speeds of 72 km/hr and gusts above 108 km/hr, followed by periods of light winds.

These dominant winds from the north enter the Gulf of Mexico without encountering resistance due to the low elevations, presenting high humidity at the moment of entering land in the northern part of the Isthmus. However, they lose humidity as they cross the Sierra Atravesada fog forest, generating precipitation in the north of the Isthmus and producing an orographic rain shadow effect in the south, so these winds arrive dry to the Gulf of Tehuantepec. Finally, the air mass presents the minimum of humidity at the moment of entering the Pacific Ocean through the orographic cleavage known as "La Ventosa" where winds with speeds of 108 km/hr and gusts of up to 180 km/hr have been registered.

Therefore, using meteorological data from the Automatic Meteorological Station (EMA) of the Port of Salina Cruz, Oaxaca, and with reanalysis data from the ERA-5 database, it was possible to carry out a study of northerly events in the Gulf of Tehuantepec, determining the areas of greatest risk to navigation depending on the intensity of the prevailing winds in the area.

In general, when northerlies enter the Gulf of Mexico, they move from the coast of Tamaulipas, advance towards Veracruz, make incursions over the Campeche Sound and cross a good part of the Yucatan Peninsula until they reach the Caribbean Sea. However, not all of them follow this trajectory, since some may deviate to the E of the Gulf of Mexico at any point along the coast in relation to the prevailing weather conditions.

The duration of the northerly effects varies from one day to one week and its penetration to the S is also variable. In general, the northerly condition lasts longer in the N Gulf of Mexico than in the S, but when the associated winds cross the Isthmus of Tehuantepec towards the Pacific coast they are known as Tehuanos (DiMego, 1976).

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The study of cold fronts in Mexico has had different approaches and objectives, such as interannual variability, as well as their relationship with oscillations such as El Niño-Southern Oscillation, and it has even been suggested that northern winds suffer a "canyoning" in their interaction with the orography and that this causes their intensification (Rosas and Luna, 2005).

The coastline of the Gulf of Tehuantepec extends between Salina Cruz and the Dead Sea lagoon and has a sandy barrier physiognomy that favors the establishment of very wide coastal lagoons. These bars are formed by a succession of coastal ridges, which are modeled by the dominant winter wind from N-S direction. The fluvial inputs entrain and accumulate sandy sediments in the lagoon beds and adjacent seabeds (Martínez-Muñoz, 2011). Figure 1 shows the geographic location of the Isthmus of Tehuantepec, showing the elevation in meters above sea level of the continental area on a color scale.

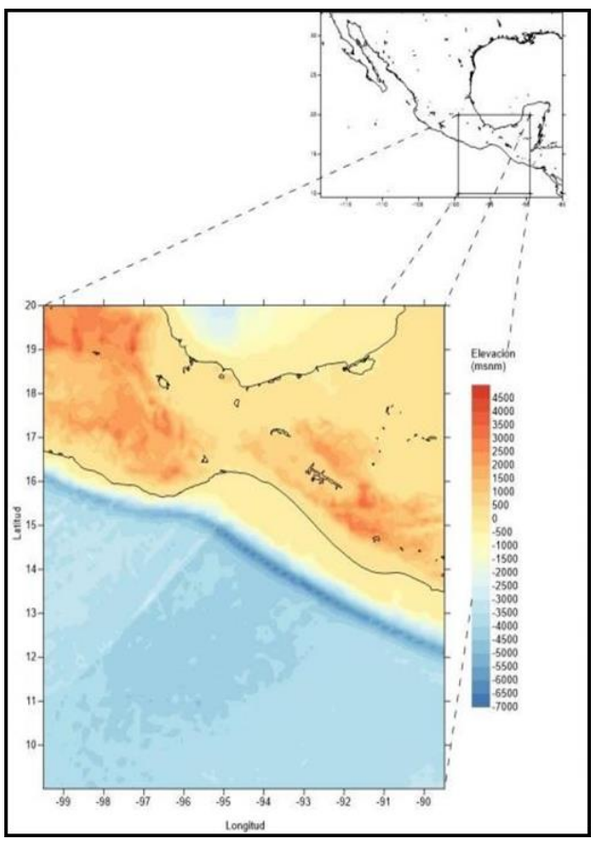

Figure 1 Location of the Gulf of Tehuantepec
Source: Isthmus of Tehuantepec Wind Climatology and ENSO Signal (2003)

The following localities are located in the interior of the gulf and along its coastline from W to E: Punta Chipehua, the port of Salina Cruz, the Huave (Upper and Lower Lagoon) and Mar Muerto lagoon complexes, Puerto Arista, the Joya-Buenavista, Carretas-Pereyra and Chantuto-Panzacola lagoon complexes, Puerto Madero and finally the Suchiate River, which constitutes the border with Guatemala (Martínez-Muñoz, 2011).

Figure 2 shows each of the aforementioned localities, which carry out various maritime activities, which are affected by the northern and southern events (Figure 3).

Figure 2 Coastal localities of the Gulf of Tehuantepec
Source: Structure and distribution of the accompanying fish community in the shrimp fishery (2011)

The region has a warm sub-humid climate, with abundant rainfall in summer (May and July), with a marked dry season in winter (November and February), and a short dry season in summer (August and September). The average temperature of the coldest month is above 18°C, and the annual average is above 22°C. The average annual precipitation on the W and N (central) coast of the gulf is less than 1000 millimeters (mm), while on the east coast it can exceed 1500 mm.

There are two distinct climatic seasons, corresponding to the dry season (November to May) and the rainy season (June to October). During the dry season, there are winds from the north, called "Tehuanos". These winds are the result of large-scale meteorological phenomena and local topographic characteristics, and have been described by various authors.

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To exemplify these winds, we can imagine a large air mass coming from the Gulf of Mexico, which tries to enter the Gulf of Tehuantepec. The passage of this air mass is partially blocked by the Sierra Madre, but this mountain range interrupts in the Isthmus of Tehuantepec, in a strip of 40 kilometers (km) wide (the Chivela pass, according to figure 3), where the average height is only 250 m above sea level. This pass forms a funnel in which a difference in atmospheric pressure is established between the Gulf of Mexico and the Gulf of Tehuantepec, which determines the formation of strong winds blowing in the direction of the Gulf of Tehuantepec. As these winds are cold and dry, they have a high density and penetrate the lower part of the tropical air mass of the gulf, as shown in Figure 3.

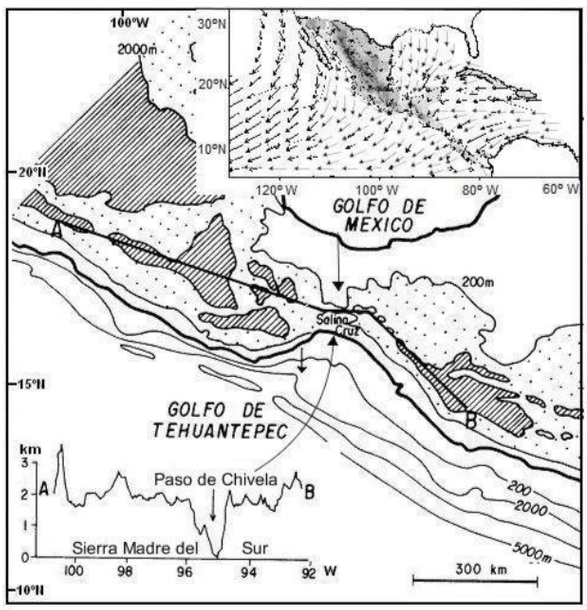

Figure 3 Location of the Gulf of Tehuantepec
Source: Structure and distribution of the accompanying fish community in shrimp fisheries (2011)

Methodology

For the development of the present analysis, the Oceanographic Institute of the Gulf and Caribbean Sea, in support of this research, requested meteorological data corresponding to readings taken by the Automatic Meteorological Station belonging to SEMAR, which is located in Salina Cruz, Oaxaca, corresponding to a temporality that covers from 2015 to 2019. The data recorded by this Meteorological Station are collected and presented on an annual basis, in order to make the conjunction of the database including each year, the programming language C++ was used; and then the tools of the spreadsheet package were used.

In order to purify the database, and considering that a northerly event is characterized by intense and cold winds with predominant direction from the N-Northeast (NE), it was necessary to establish filters in the headings of wind direction and intensity. Likewise, for the analysis of the northern events in the Gulf of Tehuantepec, reanalysis data from the ERA5 dataset (ECMWF fifth generation atmospheric reanalysis of the global climate produced by the Copernicus Climate Change Service (C3S) in ECMWF), which currently has information since 1979 available in regular latitude and longitude grids at a resolution of 0.25 x 0.25, with parameters of 0. 25 x 0.25, with atmospheric parameters at 37 pressure levels, having extracted the meteorological variables of the zonal and meridional components of the wind and the maximum height of the waves, for subsequent processing through the Python programming language (Delgado, 2022).

The first part of this analysis corresponds to the identification of northerly events, considering the months of September to May as the event season, since northerlies generally occur during these months, and this period is also considered the cold front season by the National Meteorological Service.

In the spatio-temporal scale, the events recorded in the port of Salina Cruz, Oaxaca, during the movement of a cold front were taken into account, since the duration of the effects of the north varies from one day to one week and its penetration towards the S is variable.

To compare the wind intensity, we considered the northerly events that acquired the classifications of moderate and higher, i.e., with records >20 km/hr, according to the scale used by the National Meteorological Service for northerly events.

The values used for wind direction were between 315° and 045°, obeying the characteristic of northerly events to have a predominant N-NE direction. Once all the identified northerly events had been validated, the classification and duration items were used to develop the statistics. The result of the statistics of the classification item was represented through graphs for each season of the study period, showing all the northern events recorded by the station and the total monthly and annual events, represented through a bar graph.

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According to what was explained previously, the events registered in the different seasons from 2015 to 2019 of the Automatic Meteorological Station of Salina Cruz, Oaxaca were counted, in Figure 4 a graph is shown that represents the total of events identified during the temporality studied, in which 71. 4% of the events obtained the strong classification, with its highest incidence during the month of January; the very strong classification represented 28.6%, with its highest incidence during the months of November and December, while there was no northern event with the classification of moderate or intense, according to the records of the Meteorological Station.

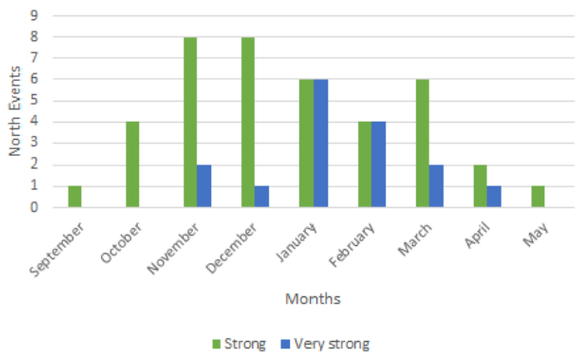

Figure 4 Northern events recorded during the 2015 to 2019 cold front season
Source: Own Elaboration

Subsequently, in order to know the monthly frequency according to the classification of the events during the study period, the total number of events per month recorded by the Meteorological Station was counted, thus selecting the month with the highest number of northern events in order to analyze them by means of reanalysis data obtained from the ERA5 dataset.

Results

Derived from the statistical analysis of the northern events recorded by the Meteorological Station of Salina Cruz, Oaxaca, the month with the highest incidence of events was January, with a total of 12 northern events during the 2015-2019 seasons, being also notorious that, of the 12 northern events occurred, 6 obtained the classification of strong and 6 the classification of very strong.

Based on the analysis of the records of the Meteorological Station of the port of Salina Cruz, Oaxaca, a total of 56 northern events associated with cold fronts were counted, of which 40 acquired the classification of "strong" and only 16 the classification of "very strong", likewise it was observed that within the analyzed period there was no northern event that acquired the classification of "moderate", "intense" and "severe".

With these results and using the reanalysis data, the most significant northerly events during the month of January were selected to be presented graphically as shown in Figure 5.

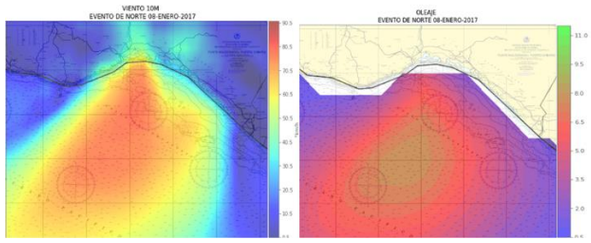

Figure 5 Most intense northern event in the 2015-2019 seasonality
Source: Own Elaboration

Figure 5 shows the most intense northerly event generated during the 2015-2019 season dated January 08, 2017, classified as "very strong", with gusts of 85 km/hr affecting considerably the Gulf of Tehuantepec, as it extended almost 150 MN to the S-SW of the Isthmus of Tehuantepec; with very intense gusts over said area, and a swell of more than 7 meters (m) in height.

A very significant northerly event was observed as it covers almost the entire Gulf of Tehuantepec, with very intense wind gusts even far from the coast, decreasing its intensity after 180 MN to the S-SW of the port of Salina Cruz, Oaxaca.

Another very characteristic event was the one shown in Figure 6 dated January 29, 2018 which presented very peculiar characteristics due to the very extensive effects reached over the Gulf of Tehuantepec and beyond.

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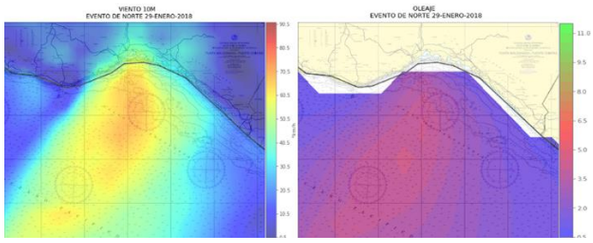

Figure 6 North event presented on January 29, 2018
Source: Own Elaboration

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It is classified as "very strong", with gusts of 80 km/hr and swells of 6.5 m high during an approximate area of 100 MN in the southern direction of the port of Salina Cruz, Oaxaca; decreasing to gusts of 60 km/hr and maintaining this intense intensity beyond 200 MN in the S-SW direction.

This event of north occupied great part of the maritime territory corresponding to the Gulf of Tehuantepec, its intensity is remarkable to be a "very strong" event, but unlike other events with the same classification, this one maintained really intense winds for many nautical miles more.

In order to carry out an ideal comparison between a "very strong" northerly event and a "strong" northerly event, the most significant "strong" northerly events were plotted, the first of them represented in Figure 7.

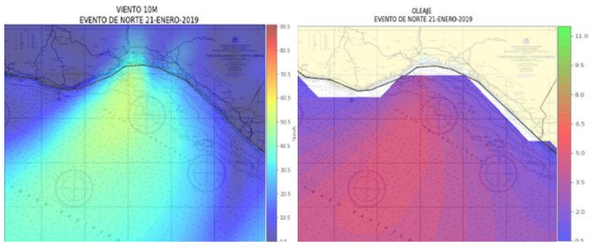

Figure 7 North event presented on January 21, 2019
Source: Own Elaboration

The northern event of January 21, 2019, according to Figure 7, classified as "strong", reached gusts of 55 km/hr and waves of 5.5 m in height, had a maritime zone most affected by its intensity in an area located approximately within 60 nautical miles south of the huave lagoon complex, with a slight curve to the southwest (SW), a pattern that is frequently repeated in each northern even

Finally, Figure 8 plots another "strong" northerly event.

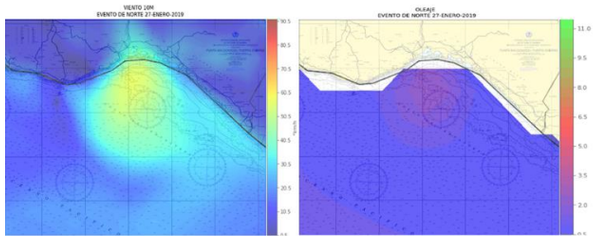

Figure 8 North event presented on January 27, 2019
Source: Own Elaboration

The northerly event aroused on January 27, 2019, observed in Figure 15 and classified as "strong", reached gusts of 50 km/hr and waves of 5 meters high, the cited effects were presented along the 60 nautical miles south of the Isthmus of Tehuantepec, decreasing while entering the SW maritime territory.

Conclusions

By means of the data collected through an automatic weather station, it is possible to perform accurate statistics, in meteorological terms, in order to know the moments with more intense northerly events.

Once the most significant northerly events have been identified, the reanalysis data obtained from the ERA5 data set can be selected and plotted on a grid that, by means of a colored graph, allows us to see the extent and intensity of the northerly events offshore, a place that, due to its own characteristics, does not currently have variable measurement stations.

Derived from the above, the maritime zone of greater risk to navigation derived from a northerly event is located to the S-SW of the Isthmus of Tehuantepec, however, this zone tends to vary its dimensions depending on the intensity of the winds to which this region is subjected, for example, in the case of strong northerly events classified as "strong", "strong", "strong", "strong", "strong", "strong", "strong", "strong", "strong", "strong", "strong" and "strong": for northern events classified as strong, a zone of greater risk is considered to be located within the first 80 NM to the S of Salina Cruz, Oaxaca, with intense wind and wave conditions during this zone within a radius of approximately 40 NM; On the other hand, it is observed that the northern events classified as very strong have a greater risk zone, covering almost the entire Gulf of Tehuantepec.

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This zone is located within the first 150 NM to the S of Salina Cruz, Oaxaca, presenting very intense wind and swell conditions in a radius of approximately 120 NM around this zone.

When comparing the intensity characteristics of the northerly events that occurred during the period analyzed, it was determined that the month of January has the highest incidence of northerly events, with a total of 12 events occurring in that month during the seasons studied, of which 6 were classified as "strong" and the other 6 as "very strong", making it the month in which the conditions for navigation present the greatest risk for daily activities at sea.

The northern events classified as "strong" spread their effects over a smaller area compared to the northern events classified as "very strong", with the S-SW direction of the Isthmus of Tehuantepec being the most affected; while the coastal strip and coastline of the Gulf of Tehuantepec corresponding from W to E that goes from the Dead Sea Lagoon to Puerto Madero, Chipas, is affected to a lesser extent compared to the rest of the gulf, being considered an area of less risk and affectation to the effects of northern events.

Recommendations

In the event that, at any given moment, a ship or vessel is affected by a northerly event, the area from W to E (from the Dead Sea Lagoon to Puerto Madero, Chipas) can be considered as a shelter zone, since this area is less affected by wind and waves, due to its natural characteristics. However, it is suggested to the national maritime community not to expose themselves to this type of natural phenomena, as it is evident that their effects continue to be very strong, even many miles offshore.

The northern events affect the activities carried out by the national maritime community on the Gulf of Tehuantepec in an intense way, it is necessary to keep informed about the meteorological forecasts, in case of going to sea, or sailing near the study area; likewise respect the indications of the Port Captaincy, who is the entity empowered to open and close the port to navigation in case of adverse meteorological conditions.

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