

Tropical Cyclones Avoidance in Ocean Navigation – Safety of Navigation and Some Economical Aspects

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ABSTRACT: Based upon the true voyages various methods of avoidance maneuver determination in ship – cyclone encounter situations were presented. The goal was to find the economically optimal solution (minimum fuel consumption, maintaining the voyage schedule) while at the same time not to exceed an acceptable weather risk level.

1 INTRODUCTION

Tropical cyclone avoidance in shipping by merchant ships is a constant element of both ocean and coastal navigation. It has a significant influence upon the economical and safety aspects of the voyage. The key decision in tropical cyclone avoidance is the determining of the moment of the beginning of avoidance manoeuvre and the determining of the correct course and speed with maintaining the commercial and economic viability of the voyage.

By commercial and economic viability of the voyage the following is understood:

- 1 Minimalization of fuel consumption during the avoidance maneuver.
- 2 Maintaining the voyage schedule. Depending by the type of shipping it is understood as:
 - maintaining the charterer speed throughout the voyage – tramping,
 - arrival at the destination port according to the charter party conditions – tramping,
 - arrival at the destination port within the port window – regular shipping.

Three types of encounter situations are possible in open (ocean) areas (Wiśniewski & Kaczmarek 2012):

- 1 Opposite courses – courses of the ship and the cyclone differ by 150° to 210° .
- 2 Crossing situation – courses of the ship and the cyclone cross at an angle of 30° - 90° .
- 3 Overtaking of the cyclone by the ship.

In each of them a certain type of action (course alteration, slowing down or speeding up) is regarded as the most effective one.

Determination of the avoidance maneuver in coastal and restricted waters is a separate issue. Within the area of the tropical storm the wind is very violent and the seas are high and confused. Swell is also high and confused, with several different swell systems, often crossing and interfering with each other. Because of that it is a dangerous threat even to the biggest and well-found ships. The danger is especially enhanced when the ship is caught by the storm in restricted or shallow waters or in the vicinity of land, without adequate room to manoeuvre. It is recommended to remain all the time no less than 80Nm, however, 250Nm is regarded as the safe distance. (UK Hydrographic Office, NP100, 2016) Early and effective action might be essential to preclude any such situation arising. The key decision in tropical cyclone avoidance is the determining of the

moment of the beginning of avoidance manoeuvre and also determining the correct course what might pose a problem in coastal and restricted waters.

There are no recommended actions in terms of efficiency in tropical cyclones avoidance in coastal and restricted waters with regard to type of encounter. Vicinity of land, navigational hazards and obstructions (straits, narrows, shoals and shallow waters) force treatment of each such case individually. The following general strategies can be identified:

- 1 Steaming away from the cyclone at a safe distance and waiting it out.
- 2 Separation from the cyclone by land.
- 3 Waiting out the cyclone in port or other place of refuge.

In this paper all types of encounter situations were discussed and analyzed in the aspects of safety and sea transport economy. The analyzes are based upon the true voyages by ships in the regions where tropical cyclones can be encountered.

2 METHODOLOGY

The following tools were employed:

- ORS (*Onboard Routing System*) BVS 7.0 – Bon Voyage System 7.0 (Applied Weather Technologies, 2014),
- ORS SPOS Fleet Management 7.0.0.1 (Meteo Consult BV, 2009),
- 1-2-3 rule (Holweg, 2000),
- manual anti-collision plot,
- CYKLON programme (Wiśniewski&Kaczmarek 2012) (Wiśniewski 2012),
- shore based weather routing recommendations by AWT.

In cases, where data were available, determined avoidance actions had been evaluated with the use of the weather coefficient $K_{1/3}$ invented by the authors.

Weather data used and their sources:

- the weather data file for ORS BVS containing weather analysis and prognosis up to 16 days in advance (AWT),
- the weather data file for ORS SPOS containing weather analysis and prognosis up to 9 days in advance (SPOS),
- EGC forecasts, outlooks and advisories,
- surface pressure analysis and prognosis charts from JMA (Japanese Maritime Agency),
- typhoon prognosis charts from JMA (up to 120 hrs with 70% probability level),
- typhoon strong winds prognosis charts from JMA (up to 72 hrs),
- weather charts from NOAA (NOAA)

Results obtained were compared. The best solutions in terms of safety and possibility of route execution were chosen.

3 WEATHER COEFFICIENT $K_{1/3}$

Definition of a weather coefficient of difficulty of the sea voyage is given in (Wiśniewski, 1991) and in

(Wiśniewski 1995). These works contain definitions of 2 weather coefficients of difficulty, weather coefficient of difficulty 1 and weather coefficient of difficulty 2, based on the maximum wave height in the whole voyage (coefficient 1) and a height of wave as observed by the navigators (coefficient 2) which the ship would encounter en route in the function of angle of attack and on a calculated or for each ship defined safe/acceptable and dangerous wave heights. Definitions of safe/acceptable and dangerous wave heights are also given in these works.

For evaluation of a safety level of routes tested in this article a modified weather coefficient 2 was adopted (Wiśniewski 1995). The modification lies in replacing the observed wave height h_c with a forecasted significant wave height $h_{1/3}$. A modified weather coefficient $K_{1/3}$ is given by the following formula:

$$K_{1/3} = \frac{1}{n} \sum_{i=1}^n \frac{h_{1/3}(q)}{h_d(q)} (1 + \alpha_d) (1 + \alpha_s) \quad (1)$$

where:

$h_{1/3}(q)$ – significant wave height ($h_{1/3}$) forecasted on a given section of track ($h_{1/3} = 1,1h_c$);

h_c – wave height as observed onboard by the navigators;

$h_d(q)$ – safe/acceptable wave height

h_s – dangerous wave height

$\alpha_d = n_d/n$ – a ratio of number of cases where significant wave heights are equal or bigger than h_d to a total number of observations in a given sector of angle of wave attack

$\alpha_s = n_s/n$ – a ratio of number of cases where significant wave heights are equal or bigger than h_s to a total number of observations in a given sector of angle of wave attack

4 RESULTS

4.1 Typhoon SOUDELOR – restricted and coastal areas

Big (LOA=336m,GT=97500, DWT=71274MT) postpanamax containership has encountered typhoon SOUDELOR during the voyage from Yantian (China, ETD: 07.08.2015 0300UTC,) to Vancouver (Canada, ETA: 19.08.2015, 2100UTC) in August 2015 in coastal and restricted area of the Taiwan Strait and northern South China Sea..

Route as recommended by nautical publications is shown in Fig. 1 (UK Hydrographic Office NP136 2014). It was, however, impossible to steam along it. Immediately after commencement of the voyage the typhoon SOUDELOR was encountered. It was moving WNW from the Philippine Sea over Taiwan towards continental China – Fig. 2.

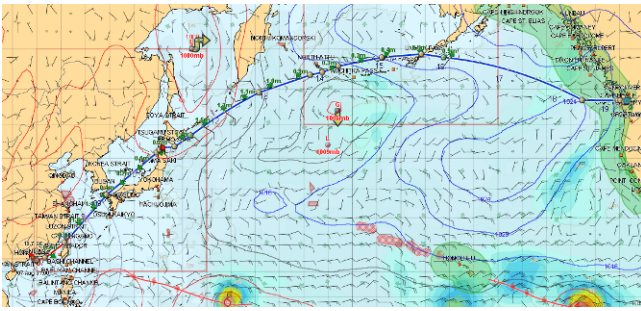


Figure 1. Great circle route Yantian – Vancouver (Own study based on BVS 7.0)

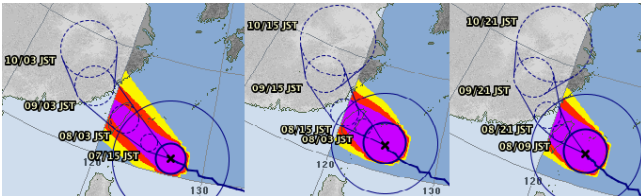


Figure 2. SOUDELOR track in JMA outlooks from 7 and 8 August (JMA)

Three options of avoidance manoeuvre were thus outlined:

- 1 Passing North through the Taiwan Strait crossing-T the typhoon's track.
- 2 Waiting until the typhoon passes by steaming SW from Taiwan in the South China Sea.
- 3 Deviation to SE towards the Luzon Strait and passing S of the typhoon through one of the 3 available deep water passes in the Luzon Strait: Bashi Channel, Balintang Channel or Babuyan Channel.

4.1.1 Avoidance maneuver with the use of ORS BVS 7.0

Testing by BVS carried out on 3, 4 and 5 August generated the routes through the Taiwan Strait. At that time that route was already closed – see Fig. 2. SOUDELOR intensifies and heads WNW. Choice of route through the Taiwan Strait would lead to cross-T the typhoon's track on a restricted area, close to land and shallow waters. Therefore these routes were rejected by the captain.

The option to wait out the typhoon in the south was also rejected as too time consuming.

The correct solution is the route passing through the Balintang Channel in the Luzon Strait, S of Taiwan (the most southern route in Fig. 3). This route has been programmed manually. Distance from the centre of the typhoon along that route was reasonably safe (150-200Nm) and it run through the deep and safe Balintang Channel. Equally deep Bashi Channel, situated farther to the N, was rejected due to insufficient distance from the centre from the typhoon (100Nm) and the Babuyan Channel, situated farther to the S, was regarded navigationally unsafe.

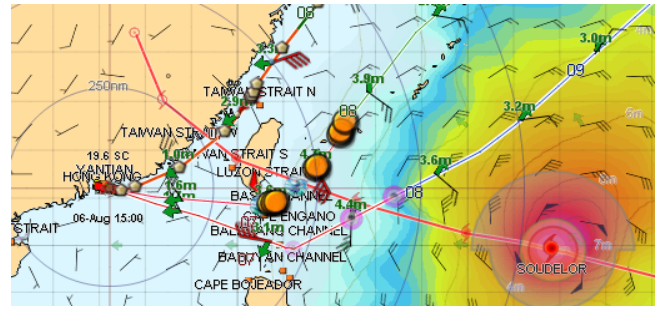


Figure 3. Track of the typhoon SOUDELOR and route through the Luzon Strait (own study based on BVS)

4.1.2 Avoidance maneuver with the use of ORS SPOS 7.0.0.1

ORS SPOS generated the routes through the Taiwan Strait until August 3rd inclusive. Then the SPOS automatic generated routes led through Luzon Strait, initially Bashi Channel (Fig. 4), and from August 6th (Fig. 5) through Balintang Channel.

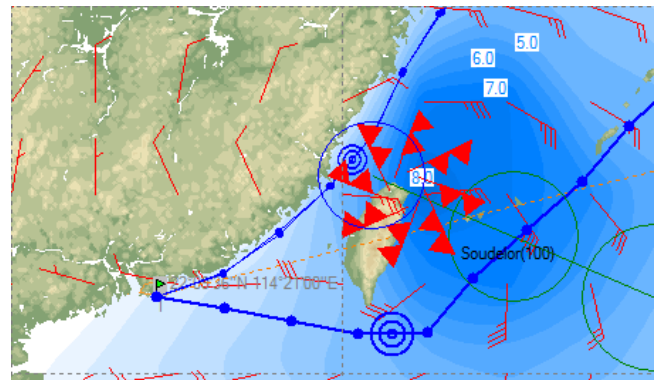


Figure 4. SPOS generated route from 3 August (Own study based on SPOS ORS)

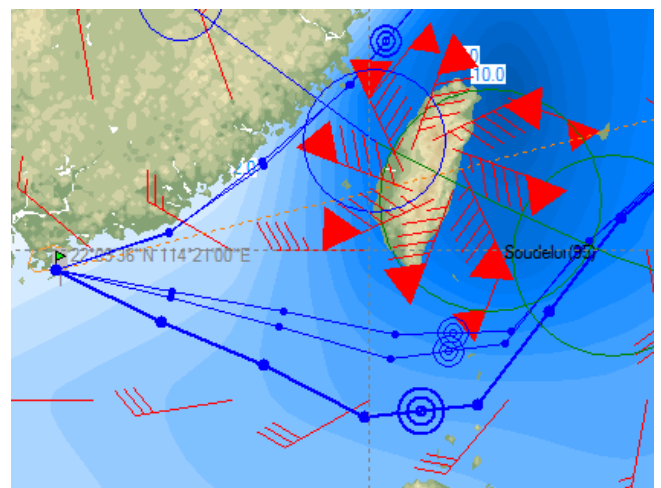


Figure 5. Results of testing in SPOS on 4, 5 and 6 August (Own study in SPOS ORS)

4.1.3 Avoidance manoeuvre by 1-2-3 rule

Current position of the typhoon SOUDELOR together with 34 knots wind zone is marked with the blue colour for August 4th (Fig. 6) and August 6th (Fig. 7) from 1200UTC. Further consecutive positions of the typhoon's eye are marked green. Zones of winds of

velocity of 34kts and more forecasted for cyclone's positions after 24-, 48- and 72 are increased by 100, 200 and 300Nm with regard to radii received in the typhoon warnings according to the 1-2-3 rule methodology. The only reasonable solution obtained by this method is to steam to SW and wait until the typhoon passes. 1-2-3 rule was visualized in the CYKLON interface.

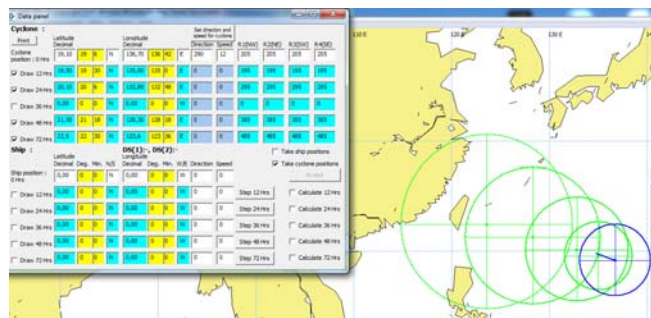


Figure 6. 34 knots wind zone of the typhoon SOUDELOR calculated by the 1-2-3 rule on 4 August (Own study)

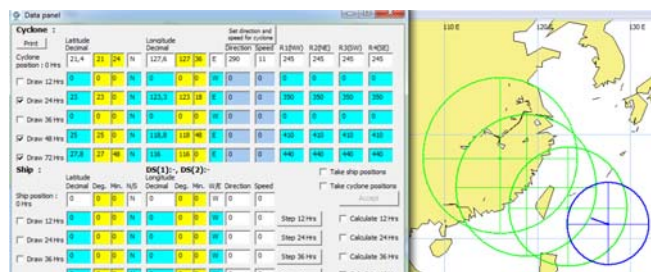


Figure 7. 34 knots wind zone of the typhoon SOUDELOR calculated by the 1-2-3 rule on 6 August (Own study)

4.1.4 Avoidance maneuver with the use of CYKLON programme

The software was fed with the data regarding the typhoon from 7 August 1200UTC, when the voyage had begun. Safe course is 125°. Initially CYKLON had calculated the dangerous courses sector between 015° and 122° (Fig. 8 and 9). After 15hrs the new dangerous sector was 298° and 092°. After 15hrs steaming on course 125° it is safe to 095° towards Balintang Channel – Fig. 10.

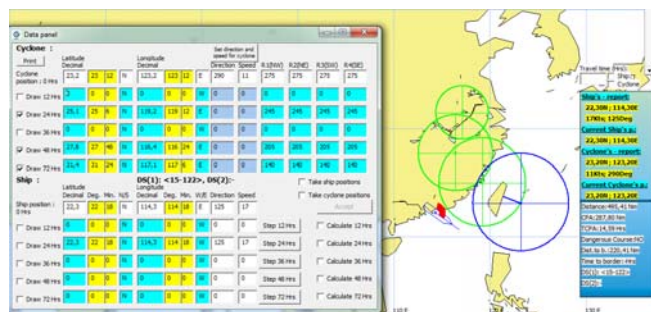


Figure 8. Determining the avoidance manoeuvre with the use of CYKLON programme on 7 August 1200UTC (Own study)

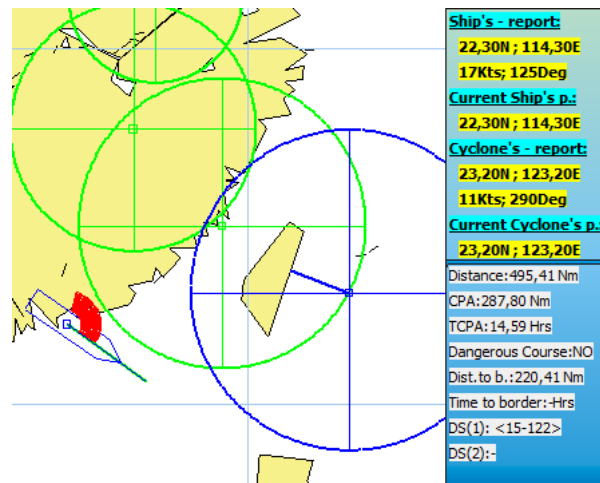


Figure 9. Determining the avoidance manoeuvre with the use of CYKLON programme on 7 August 1200UTC (Own study based on CYKLON)

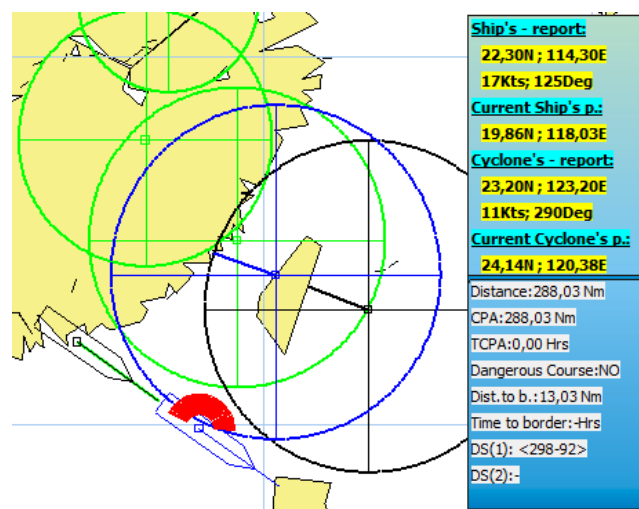


Figure 10. Determining the avoidances maneuver with the use of CYKLON programme on 8 August 0300UTC (Own study based on CYKLON)

4.1.5 Shore based recommendations

Basis of recommendations was the intention to avoid the SOUDELOR's strong winds zone of 35kts and more. Initially passage through Balintang Channel was recommended. On 5th and 6th of August it was changed to Babuyan Channel, situated farther to the south and on August 7th, after the voyage had begun, again the recommendation was changed Balintang Channel.

4.1.6 Summary – typhoon SOUDELOR, coastal and restricted areas

In the analyzed case the correct action was to pass the typhoon from the south and use the land mass of Taiwan as a screening protection for the part of the route. It is the safest and also economically the most viable solution. To wait the typhoon out in the southwest was too time-consuming and would have caused the disruption in the ship's schedule. Route leading through the Taiwan Strait was too risky – required speed was on the limit of ship's propulsion capabilities and was very costly.

4.2 Typhoon MOLAVE – ocean navigation, crossing situation

The determination of the typhoon avoidance manoeuvre in ocean navigation by a big (LOA=336m, GT=97500, DWT=71274MT), powerful and fast (20knots), postpanamax container vessel on a voyage from Yantian (China, ETD= 07.08.2015 0300UTC) to Vancouver (Canada, ETA=19.08.2015 2100UTC) by various methods was analysed.

The recommended route between the two above mentioned ports is the route shown on Fig. 1 (UK Hydrographic Office NP136 2014). However, in an initial, coastal stage of the voyage, typhoon SOUDELOR was encountered (Fig. 2, 3). It prevented the vessel from using the route shown on Fig. 1. Consequently, after numerous testing of other routes and consultation with land based weather routing, the route through the Luzon Strait was chosen, clearing the typhoon SOUDELOR from the south.

In an ocean stage of the voyage the typhoon MOLAVE was encountered. It was moving from the Philippine Sea towards Japan – see Fig. 11 (JMA). The route takes into consideration navigational and legal restrictions – allowed routes in the Bering Sea and Aleutian Chain and the US and Canadian ECA zone (Szymański & Wiśniewski, 2016).



Figure 11. Track of MOLAVE forecasted for 5 days in JMA outlooks 9 and 10 August (JMA, 2015)

4.2.1 Avoidance manoeuvre by the recommendation from shore based weather routing

Shore based recommendations from AWT were received on 6th and 7th of August. They are shown on Fig. 12 together with their navigational parameters. The recommended routes were moved south due to the typhoon MOLAVE developing south of Japan. Bold route on Fig. 12 is from August 7th. Its corresponding navigational parameters in the table below the weather chart are highlighted blue. The route runs too close to the typhoon and generates weather alerts – exceeding the maximum allowed wave height (8m) and wind velocity (34kts). Alerts are marked by violet circles visible along the route on Fig. 12. Finally the AWT had accepted the route passing the MOLAVE from the south and entering the Pacific via the Balintang Channel in the Luzon Strait.

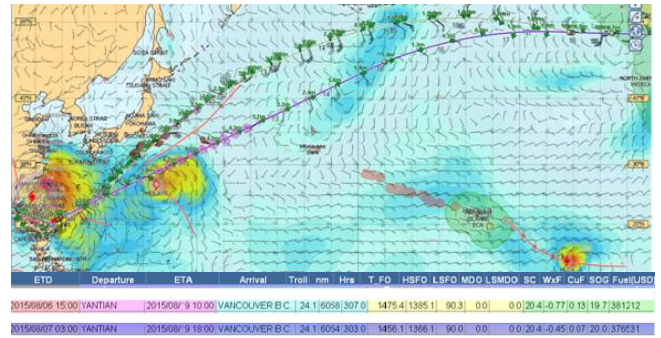


Figure 12. Routes recommended by AWT from August 6th and August 7th and their navigational parameters (own study based on BVS)

4.2.2 Avoidance manoeuvre with the use of ORS BVS 7.0

Planning of the MOLAVE avoidance manoeuvre had begun on 9 August after the successful clearing of the typhoon SOUDELOR on the South China Sea. Optimization used was least fuel with fixed arrival time. Weather limitations were set for maximum 8m swell, seas and significant wave and wind maximum velocity for 34 knots.

Routes generated in the BVS until August 9th run along the coast of Japan from the Pacific side. They clear the MOLAVE from the polar side and place the ship between the typhoon and the land, on a narrow and restricted area (Fig. 13 and 14). The correct route clears the typhoon from the south. It is highlighted blue (bold route) on Fig. 13. It was programmed manually.

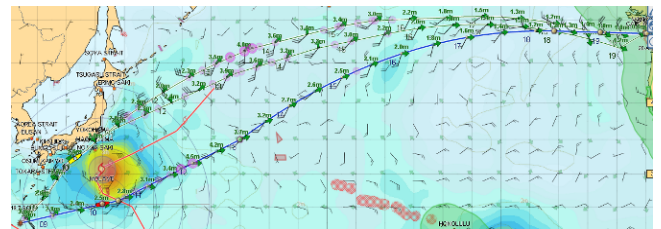


Figure 13. Testing results of routes passing the typhoon MOLAVE on Aug 9th. (Own study based on BVS 7.0)

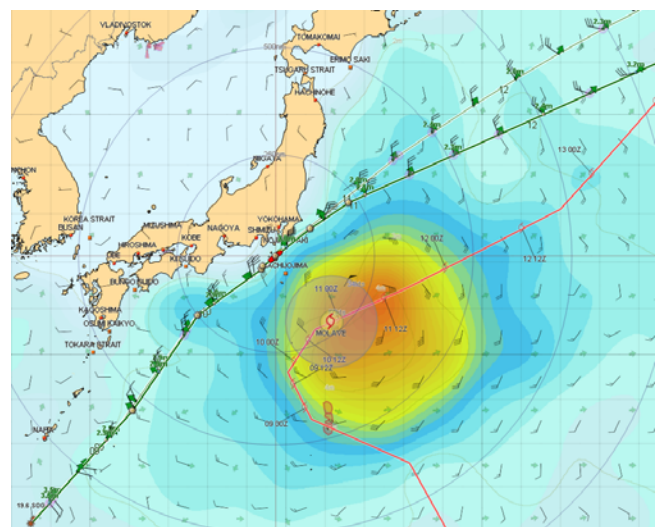


Figure 14. Result of testing in BVS from 9 August – position of the ship and typhoon for 11.08.2015, 0000UTC (Own study based on BVS 7.0)

4.2.3 Avoidance manoeuvre with the use of ORS SPOS 7.0.0.1

Ocean route testing began on 7 August. SPOS ORS enables to programme the minimum distance to the tropical cyclone and tropical depression (Wiśniewski&Szymański 2016).

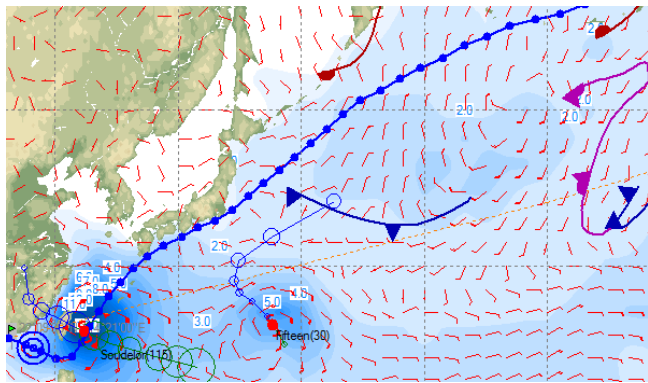


Figure 15. Avoidance manoeuvre in SPOS from 7, 8 and 9 of August (Own study based on SPOS)

Maximum wave heights and wind velocity were programmed as 8m and 34 knots. Minimum distance to typhoon was determined as 250Nm. Type of a chosen optimization was Optimum High&Wide, with speed of 19,5 knots, corresponding to the calm sea speed for the route optimized in BVS 7.0 ORS. Results of testing are presented on Fig. 15. Similar to the BVS system, routes generated in the SPOS system until August 9th run along the southern and eastern coasts of Japan and were clearing the typhoon from the polar side. They placed the ship between the typhoon and the land, in a narrow and restricted area. Consequently, these routes were rejected by the ship's captain.

4.2.4 Avoidance maneuver by the 1-2-3 rule

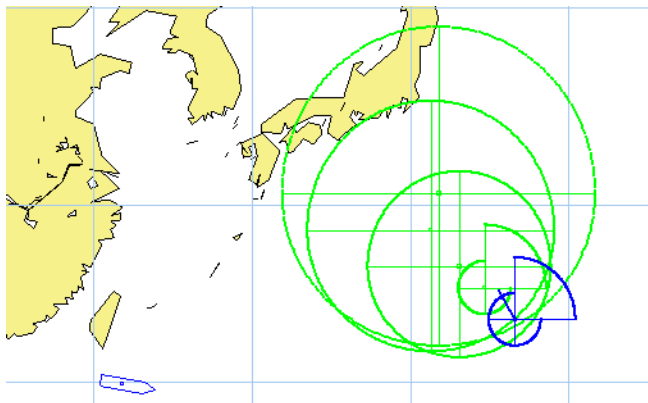


Figure 16. 30 knots wind zone of MOLAVE as calculated by 1-2-3 rule from 8 August for the next 3 days (Own study based on CYKLON)

Blue colour in Fig 16. marks the position of the typhoon MOLAVE together with the 30knots wind zone according to the warning from 8 August, 1200UTC. Green colour circles mark the further position of the typhoon together with the 35 knots wind zones. The 24hrs, 48hrs and 72 hrs predicted zones' radii are increased by respectively 100Nm, 200Nm and 300Nm with regard to values from the warnings, in accordance with the rule methodology.

For visualization of the 1-2-3 rule the CYKLON programme was used.

4.2.5 Avoidance maneuver with the use of CYKLON programme and manual anti-collision plot

Manual anti-collision plot and CYKLON programme have the same source methodology. Their results are shown in Fig. 17 and 18. The software was fed with the data regarding the typhoon from 8 August 1200UTC, when the voyage began.

The safe course is 065°, the software calculated initially the dangerous sector 047° and 061° (Fig. 17), and after 12hrs, for updated positions and forecasts of MOLAVE's movement, the dangerous sector was between 054° and 064° (Fig. 18).

Results obtained by the manual plot are comparable with those obtained by the CYKLON programme.

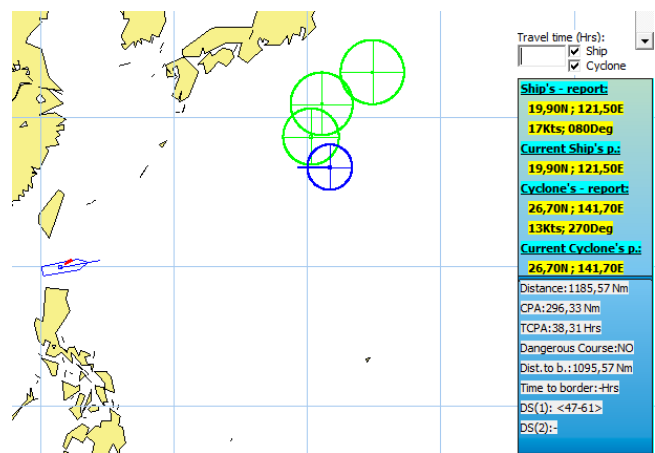


Figure 17. Avoidance manoeuvre by CYKLON programme on 8 August 1200UTC (Own study based on CYKLON)

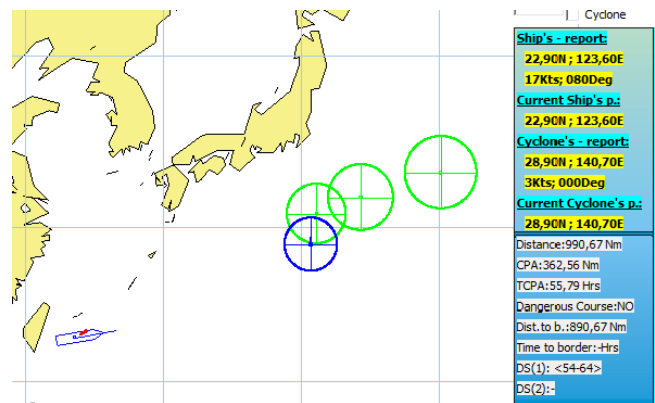


Figure 18. Avoidance manoeuvre by CYKLON programme on 9 August 0000UTC (Own study based on CYKLON)

4.2.6 Summary – typhoon MOLAVE, ocean navigation, crossing situation

Testing by various methods had shown that in the case analyzed the most effective action, both in safety and economic terms, was a course alteration and passing the typhoon from the S.

4.3 Cyclone GASTON – ocean navigation, crossing situation

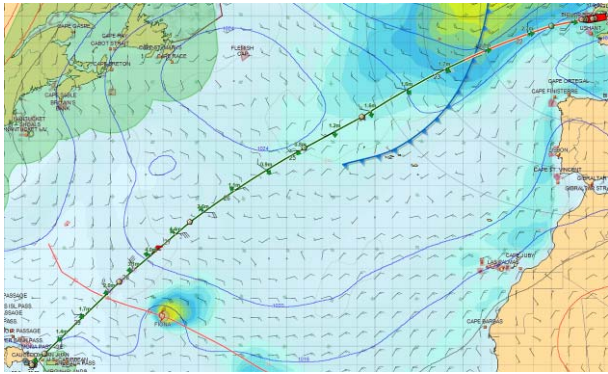


Figure 19. Route Antwerp – Caucedo (Own study based on Bon Voyage system)

Weather routing of a PANAMAX container ship (LOA=281m, GT=46000) from Antwerp(Belgium, Wandelaar pilot station), ETD = 20.08.2016, 2300UTC to Caucedo (Dominican Republic)ETA = 30.08.2016, 1800UTC, was analyzed. The route is shown in Fig. 19. During the voyage the tropical cyclone GASTON was encountered, shown in Fig. 20. Avoidance actions, determined by various tools and methods, were evaluated with the use of weather coefficient $K_{1/3}$. The route was programmed in the ORS Bon Voyage 7.1. Weather data utilized in testing is also from that ORS. Testing was carried out for the whole duration of the voyage, every 6 hours since Bon Voyage provides 6 hrs sampling. It was assumed that acceptable wave height $h_d = 6m$ and dangerous wave height $h_s = 12m$.

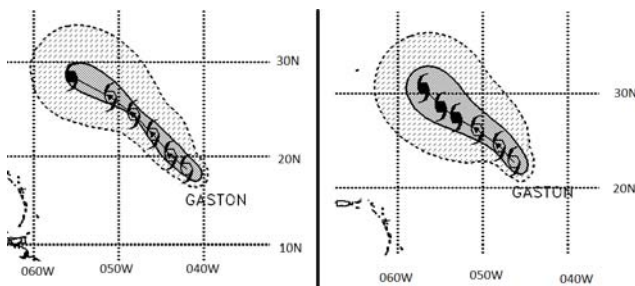


Figure 20. Cyklon GASTON w prognozach NOAA z 25 i 26 sierpnia (NOAA)

4.3.1 Determination of avoidance maneuver with the use of ORS BVS 7.1

Routes were programmed manually in the ORS BVS 7.1. Automatically generated routes did not meet the nautical rules of tropical cyclones avoidance. Two variants of a route were prepared for execution on Aug 26th, 1200UTC: a risky variant (Fig. 21) and a play safe variant (Fig. 22). In both variants the cyclone was passed from the equator side. In a risky variant the route had been programmed on the border of a parametric roll resonance sector. Its track takes the ship closer to the centre of the cyclone (its eye), thus the weather conditions along it will be heavier. For that reason it will rather not be possible to avoid the resonance sector by increasing the speed – see Fig.21. In the play safe variant the end of the ship's vector also lies on the border of resonance sector (Fig.

22), however, due to a more favourable sea state and generally better weather conditions, it would be possible to both increase the ship's speed and alter ship's heading in order to clear the resonance sector.

Risky variant is commercially better than the play safe variant in terms of total distance en route and fuel costs. A breakdown of commercial parameters of the voyage and weather coefficients $K_{1/3}$ for both variants is given in Table1.

Table 1. Commercial parameters and weather coefficient $K_{1/3}$ for risky and play safe route variants (Own study)

Route	Play safe variant	Risky variant
Distance [Nm]	4117	4202
Cost [USD]	458582	476352
Weather coefficient $K_{1/3}$	0,257917	0,272604

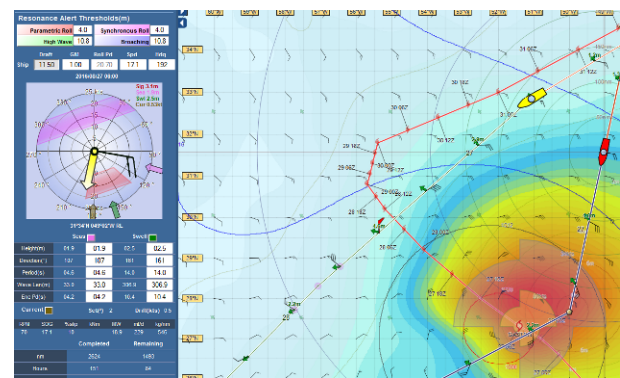


Figure 21. Avoidance manoeuvre in Bon Voyage system – manual programming, risky variant (Own study based on Bon Voyage system)

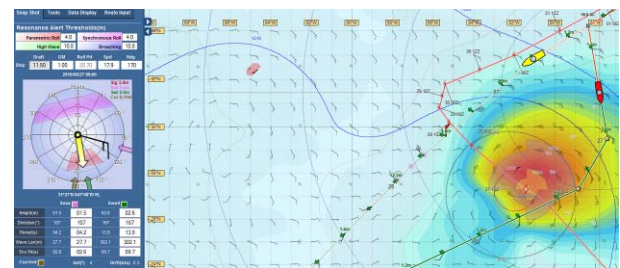


Figure 22. Avoidance maneuver in Bon Voyage system – manual programming, play safe variant (Own study based on Bon Voyage system)

To confirm the outcome, only the time frame of avoidance maneuver for weather coefficient $K_{1/3}$ were taken into consideration, between 26.08, 1800UTC and 28.08, 1200UTC. Weather coefficient $K_{1/3}$ calculated in that way is 0,272604 for a play safe maneuver and 0,341146 for a risky maneuver. Weather coefficients $K_{1/3}$ for routes programmed manually (for both risky and play safe maneuvers) are clearly lower than for routes generated automatically in the Bon Voyage system.

4.3.2 Avoidance maneuvers with the use of CYKLON programme

Safe courses to avoid the tropical cyclone obtained with the use of CYKLON programme (Wiśniewski & Kaczmarek 2010). Results are presented in the Fig.23.

The dangerous courses sector as calculated by CYKLON programme are between 206° a 253°.

Courses 253° and above that cross-T the cyclone track and, because of that, they were rejected. The route with the general course 206° was programmed in the Bon Voyage system and the weather coefficient $K_{1/3}$ was calculated for it. A section of that route together with sections of a risky and play safe maneuver are presented on Fig. 16. Weather coefficient $K_{1/3}$ for the whole route is 0,322958, and for the avoidance time frames $K_{1/3}=0,58125$. A breakdown of weather coefficients $K_{1/3}$ for avoidance maneuvers programmed with the use of CYKLON system and manually in the Bon Voyage system are presented in Table 2.

Table 2. Breakdown of weather coefficients $K_{1/3}$ for some chosen routes (Own study)

Route	Coefficient $K_{1/3}$
Risky manoeuvre, whole route	0,272604
Risky manoeuvre, avoidance time frames	0,341146
Play safe manoeuvre, whole route	0,257917
Play safe manoeuvre, avoidance time frames	0,263542
CYKLON, whole route	0,322958
CYKLON, avoidance time frames	0,58125

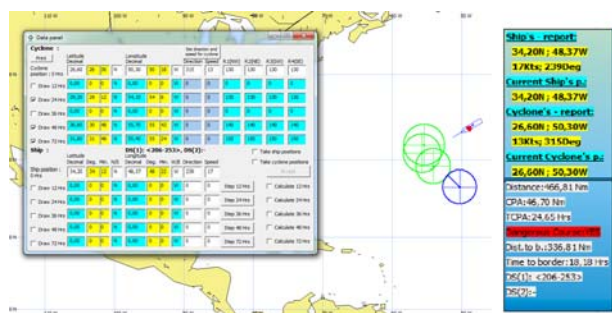


Figure 23. Avoidance maneuvers results of cyclone GASTON obtained with the use of CYKLON programme (Own study based on CYKLON programme)

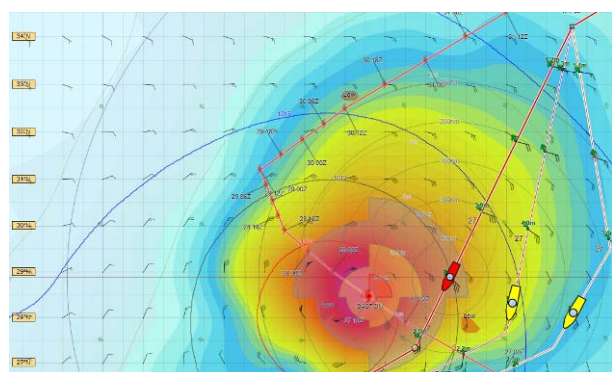


Figure 24. Avoidance maneuvers route sections in CYKLON (red ship symbol) variant and risky and play safe variants in Bon Voyage system (Own study based on Bon Voyage system)

4.3.3 Summary – cyclone GASTON, ocean navigation, crossing situation

Testing by various methods had shown that the most effective action in the case analyzed in the course alteration. Its scope and influence upon the economic results of the voyage and route's weather safety level can be evaluated with the use of weather coefficient $K_{1/3}$.

4.4 Cyklon GASTON – akwen otwarty, kursy przeciwnie

Voyage of a postpanamx containership (LOA=336m, GT=97500) from Gibraltar to New York has been analyzed. ETD GIB = 30.08.2016, 0000UTC (36 00N 007 18W), ETA New York (Ambrose P/S) = 06.09.2016, 0800UTC. During the voyage the cyclone GASTON was encountered, moving after recurving in ENE direction over the central North Atlantic.

Route of the ship together with the track of GASTON is presented in Fig. 25. Weather coefficient $K_{1/3}$, calculated for a timeframe of the closest approach to the cyclone (01.09.2016, 0000UTC – 03.09.2016, 0000UTC), is 0,3625, thus the level of weather risk/safety is acceptable. However, the ship's route crosses-T the track of cyclone and passes it from the polar side of its predicted track what constitutes a violation of nautical rules of cyclone avoidance. Steaming along that route must be seen as a mistake and it could have had disastrous consequences for the ship had the GASTON moved more to the N or NE and had the forecasts for the movement of other tropical systems developing at that time over the Atlantic shown to be correct (Fig. 26). The correct course of action was to steam S of Acors along the Acors High, well visible in Fig. 25. A greater deviation from the original route would have to be necessary, however, the weather risk would have been significantly smaller.

In the analyzed case the effective and efficient maneuver is great course alteration to the south.

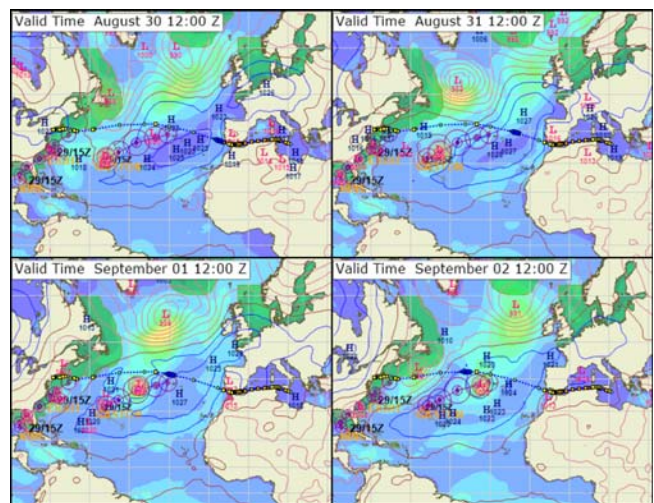


Figure 25. Route Gibraltar – New York and track of GASTON (AWT)

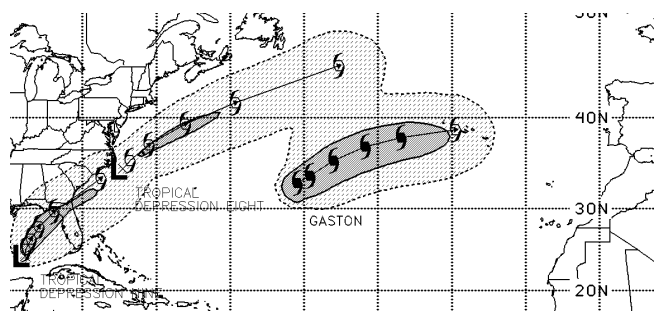


Figure 26. Forecast for two tropical systems in the Atlantic from 31.08.2016, 0300UTC (NOAA)

4.5 Cyclone NICOLE – ocean navigation, overtaking

Weather routing of a PANAMAX container ship (LOA=294m, GT=53000) from Charleston (USA), ETD=12.10.2016, 0300UTC) to Southampton, Nab Tower (Great Britain) ETA=22.10.2016, 0200UTC was analyzed. During the voyage passing the cyclone NICOLE was necessary. It was moving over the central North Atlantic Ocean in NE – ENE, after recurving.

Avoidance action was determined with the use of ORS Bon Voyage 7.1 and evaluated with the use of weather coefficient $K_{1/3}$. Testing was performed for the time of the whole voyage with 6hrs sampling periods. It was assumed that acceptable wave height $h_a = 6m$ and dangerous wave height $h_s = 12m$.

In Figs. 27 – 29 various variants of routes avoiding the cyclone NICOLE were presented. Their navigational and economic parameters are shown in Table 3.

Analysis of data in Table 3 points that in this particular case speed reduction, although effective and justified in the safety aspect, would not have been correct in terms of economic and commercial viability of the voyage. In the route variant recommended by the shore based weather routing (AWT) the speed of the ship would have to be reduced more than the value in the table in order to have acceptable weather conditions throughout the voyage ($K_{1/3} < 0,8$). However, that would cause a delayed arrival in Le Havre and a disruption in ship's whole coastal schedule. A better option is a route programmed manually onboard – slight course deviation towards equator and overtaking the cyclone from the south. This route leads also through better weather conditions ($K_{1/3} \sim 0,6$).

Route generated automatically in the ORS BVS is not realistic operationally – it runs for a long time through ECA zone, there is not enough of ULFSO fuel onboard for this variant to be feasible. Such a route passes the cyclone from the polar side of its track what is a violation of one of the nautical cyclone avoidance rules.

Table 3. Economic and navigational parameters of the 3 variants of a route Charleston – Southampton (own study)

Route	BVS	AWT	Ship's own variant
Cost [USD]	225185	248365	245301
Coefficient $K_{1/3}$	0,5787451,	1,311550,	605814
Distance [Nm]	3572	3858	3915
SC [kts]	15,4	17,2	17,1
SOG [kts]	14,7	16,0	16,4

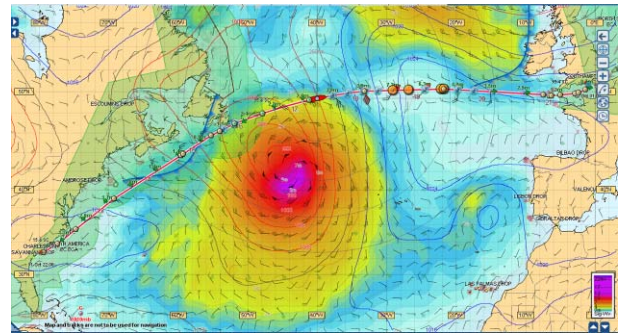


Figure 27. Route Charleston – Southampton, optimization in the Bon Voyage (own study based on the Bon Voyage)

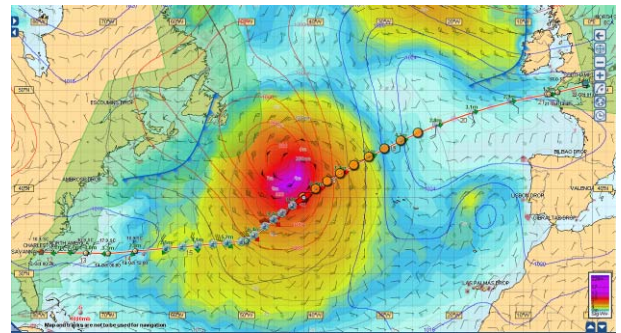


Figure 28. Route Charleston – Southampton, recommendation of the AWT (own study based on the Bon Voyage)

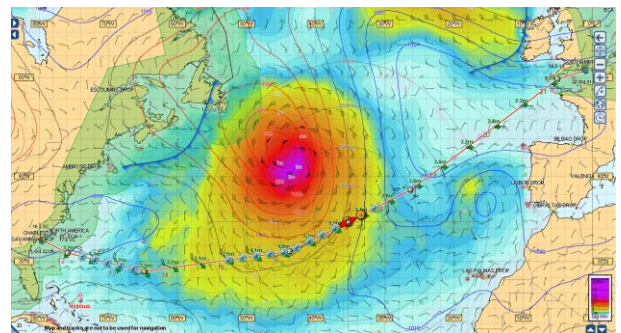


Figure 29. Route Charleston – Southampton, variant programmed manually onboard (own study based on the Bon Voyage)

4.6 Typhoon DUJUAN – coastal and restricted areas

Postpanamax containership (LOA=336m, GT=97500) has encountered the typhoon DUJUAN during the voyage from Yantian (China, near Hong Kong), ETD = 24.09.2015, 0100UTC, to Vancouver (Canada), ETA = 06.10.2015, 2000UTC. The typhoon was moving from the Philippine Sea over the coastal areas of China, Taiwan and Japan. Forecasts of its movement from 23 and 24 September are presented in Fig. 30 and 31. The ship's route was programmed in ORS BVS 7.0.

Analysis of the true and forecasted track of typhoon points that it is in the decisive stage for its further development on September 23. Recurving to N or NE towards Japan is equally probable as further movement WNW towards coastal areas of Taiwan and China.

On the 23 September, before the commencement of the voyage, automatic generation of route in the ORS

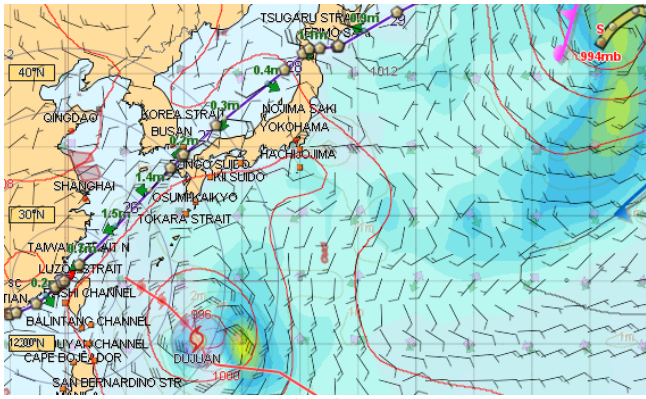


Figure 33. Route utilizing land mass as a „screen“ against the typhoon(own study based on BVS)

4.7 Tropical Storm HERMINE – coastal and restricted areas.

Postpanamax containership (LOA=336m, GT=97500) has encountered the tropical storm HERMINE on the approaches to the Port of New York (Ambrose Pilot Station) on 6 – 9 September 2016. Track of HERMINE and the optimal ship's route as recommended by shore based weather routing is shown in Fig. 34.

In the course of determining the most effective action two options were considered:

- 1 Slow down or drift E of TS HERMINE to wait it over.
- 2 Deep deviation to south from the route, passing the TS HERMINE from S and approach Ambrose P/S from S.

In order to choose the optimal and safe solution it was necessary to cooperate with the shore based weather routing strictly. Option 1), favoured by the ship's command proved to be economically less favourable. It would have resulted in bigger time loss and delay in arrival in port. Option 2) was more favourable. Weather information available onboard were insufficient to correctly assess the situation and timely draw the right conclusions. Movement of the tropical system in the vicinity of the land is very complicated, dependant on many factors and subjected to constant changes. Tools and information available onboard are insufficient to a correct and timely evaluation of such movement. Strict cooperation and consultation with the shore based weather routing is here essential. Shore based weather routing centers have more, better and quicker weather information available and also more capable tools.

In the analyzed case the captain of the ship had concurred with the recommendation of the shore and had executed the deep deviation to the south, passing the TS HERMINE from the south.

Despite the strict cooperation with shore based weather routing delay was unavoidable. Safe approach to Ambrose P/S was only possible 9 September. The recommendation was to remain at all times at least 250Nm from TS HERMINE. On September 4 it became the extratropical storm, however, on 4 and 5 September it intensified and regained its tropical character. Approaches to Ambrose P/S from all directions were thus closed until September 9. The only feasible option was to

wait the storm over at the safe distance, at best on the equatorial side of its predicted track.

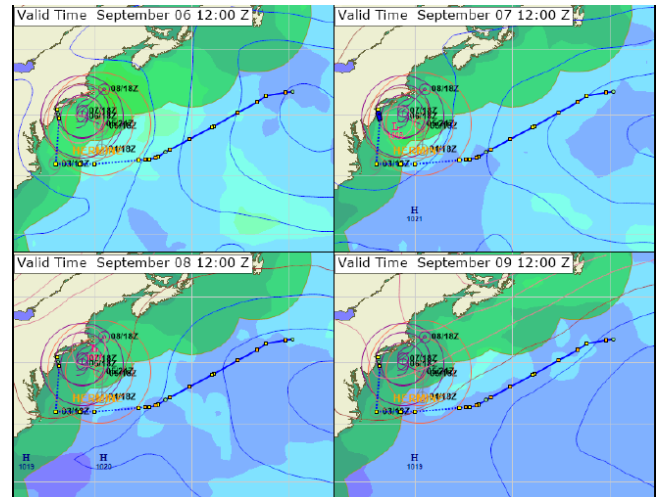


Figure 34. Avoidance of TS HERMINE on the approaches to the Port of New York, September 2016 (AWT)

4.8 Typhoon MEGH – special case

A bulk carrier (LOA=190m, GT=32929) has encountered the typhoon MEGH in an Indian Ocean during the voyage from Singapore to Suez in November 2015. Initially it was the encounter on an open ocean, then both the ship and the typhoon have entered the coastal and restricted area – the Gulf of Aden.

The ship had attempted to overtake the typhoon on November 6 2015, 1200UTC. Fig. 35 depicts the situation in the moment when the overtaking began. The further tracks of both the ship and the typhoon are depicted in Fig. 36.

On November 5 the distance between the ship and the typhoon was 250Nm. Attempt to overtake the typhoon by a slow, low powered ship, on the dangerous semicircle, has to be considered a very risky maneuver. On November 6, 1200UTC, in the moment depicted in Fig. 34, the ship was only 38Nm from typhoon's eye. She would have been in a very unfavourable situation had the typhoon recurved NE, as it could have been expected, at this very moment. Besides, a close analysis of Fig. 36 points to the low effectiveness of the whole overtaking maneuver. The ship was steaming practically near and in the vicinity of the typhoon all the time until November 9. At that time the maximum distance to the typhoon's eyewhich the ship was able to hold, was only 160Nm which is well below the minimum 250Nm as recommended by the nautical publications (UK Hydrographic Office 2015). At that time, on 7 and 8 November, MEGH has reached the hurricane force (12B) with wind velocities exceeding 110kts (0600UTC – 0900UTC, November 8). On November 10 the typhoon weakened and finally broke up upon making the Yemeni coast.

A correct decision in this case was to stay behind the typhoon, to the E and S of it. Attempt to overtake the typhoon should not have been made.

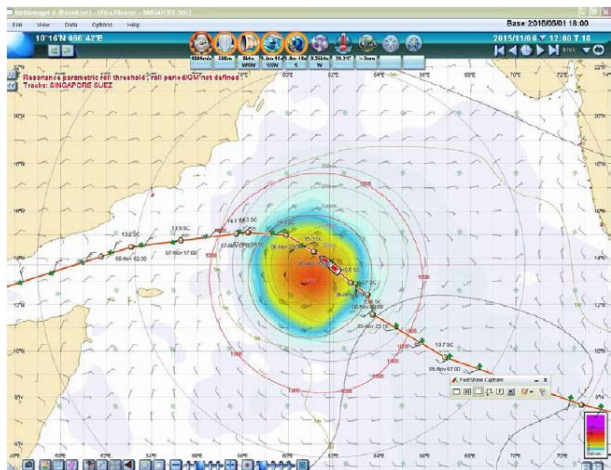


Figure 35. Typhoon MEGH and the route of the ship overtaking it, 6 November 2015, 1200UTC (Deutscher Wetterdienst 2016)

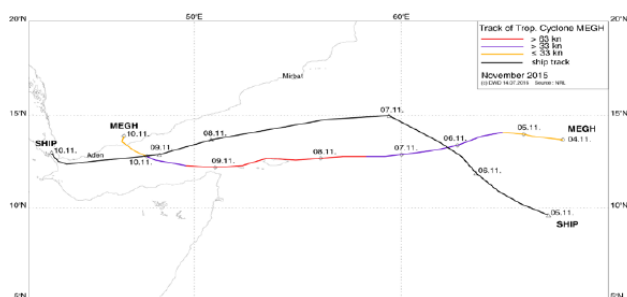


Figure 36. Track of MEGH and the route of the ship overtaking it in the Gulf of Aden in November 2015 (Deutscher Wetterdienst 2016)

5 SUMMARY

Cases presented and their analysis generally confirmed the conclusions entailed in publication (Wiśniewski&Kaczmarek, TRANSNAV 2012).

On an open ocean, in crossing situation, the most effective maneuver in terms of both safety and economy is the a slight alteration of course or speed or both of them together. On opposite courses maneuver assuring the safe avoidance of the cyclone and also better economic results of the voyage is the major alteration of course and passing the cyclone from the equatorial side. Attempts to pass the cyclone on its polar side have to be considered very risky. Such an action is sometimes economically more viable (shorter voyage time, shorter distance, less fuel consumption), however, the risk to be engulfed by the cyclone's strong winds zone and excessive approach to its eye is all too significant. Overtaking of the cyclone should be attempted only by fast, high powered ships, with good seakeeping abilities. Overtaking should be on the equatorial side of the cyclone's track with a minimum distance of 250Nm from cyclone's eye.

Determining of the effective maneuver to avoid the tropical cyclone in the coastal and restricted areas is by all means more difficult than in an open ocean. In the vicinity of the land it is difficult to estimate the movement of the cyclone. There are a lot of factors

influencing its movement. It is often not possible to evaluate them correctly and timely onboard.

Also the character of coastal shipping today, very tiresome and stressful for the ship's command, with many and frequent port calls, natural concentration of the captain and nautical officers on cargo, pilotage, numerous and never ending controls, audits and surveys, does not contribute to the proper and constant weather monitoring.

Assistance of the shore based weather routing is here essential. It monitors the weather situation constantly, has access to many sources of weather data which are not available onboard. It can also utilize the tools which the ships are equipped with.

Action to avoid the tropical cyclone in coastal and restricted areas requires bigger course and speed alterations than in the open ocean. It should not be considered as a deviation but rather as an amendment or change of voyage concept.

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