Avoidance of tropical cyclones using the "CYKLON II" program

Omijanie cyklonów tropikalnych z wykorzystaniem programu „CYKLON II"

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Key words: weather navigation, avoidance of cyclone, computational program

Abstract
This paper presents the methodology of constructing a collision avoidance plot "ship – tropical cyclone". The computational algorithm and its testing results are presented. The tests make use of information from the voyage of the ship "Diana" and weather reports and forecasts on the real tropical cyclone Bill, which moved in August 2009 across the North Atlantic.

Słowa kluczowe: nawigacja pogodowa, omijanie cyklonów, program obliczeniowy

Abstrakt
Zaprezentowano metodykę konstruowania nakresu antykolizyjnego statek – cyklon tropikalny. Opisano algorytm działania programu obliczeniowego i podano wyniki jego testowania. Wykorzystano informacje z podróży statku „Diana" i informacje z komunikatów o rzeczywistym cyklonie tropikalnym Bill przemieszczającym się w sierpniu 2009 r. przez Północny Atlantyk.

Introduction

In areas covered by tropical cyclone activity the navigator must maintain a procedure which includes obtaining information, hazard identification, accuracy of calculations done to determine a safe ship's course and speed and decision-making to avoid the dangerous zone of the cyclone.

The Department of Marine Navigation at the Maritime Uniwersity in Szczecin has been working on solutions to the problem of avoiding tropical cyclones since 1980 [1, 2, 3]. The practical implementation of research on this issue was the creation of the computer program Cyclone used for the determination of dangerous courses sector or ascertaining its absence for the assumed course and speed of the vessel with basic parameters of the cyclone known from the reports. The newly-built program is an improved version taking into account the possibility of complex programming of future cyclone and ship positions spanning 72 hours in advance [4]. This function substantially facilitates making decisions on vessel course and / or speed alteration in case a cyclone poses a threat. The basic algorithms of the authors have been maintained. These algorithms require that the following steps should be taken:

- plot the current position of the ship S and the center of a tropical cyclone CT on the chart;
- calculate the radius of the accuracy of the cyclone eye position from issued weather data until the moment of the preventive maneuver:

$$R_0 = \frac{V_c \cdot \Delta t}{n}$$

where n – Rodewald coefficient;

- assume storm zone Δ from the weather report – usually it is the radius of strong winds ≥ 34 knots and from the center of the cyclone area plot the zone of potential danger with the radius: $R_0 + \Delta$;

- from the vessel position draw vectors of the ship velocity V_S and cyclone velocity V_c in the adopted scale;
- from the ship position draw S1 and S2 – tangentials to the circular area of potential risk;
- move the tangentials parallel to reach the end of the cyclone velocity vector plotted from vessel position (S1' and S2');
- make the full circle from the ship position with the radius equal to the ship velocity vector, thus obtaining points of intersection with tangentials S1', S2';
- determine the dangerous sector or sectors SN by joining the points of intersection of tangentials S1' and S2' with the ship position.

In this example, the ship is on a dangerous course (dashed sector). This prompts the navigator to change ship's course or speed, or both at the same time [5]. One conclusion is that the cyclone forecasts and warnings issued three hours after the major observation times include the extrapolated position of the cyclone at the time of broadcast. To define the position of the cyclone as accurately as possible, the change after the time elapsed from the major observation period, usually three hours, is taken into account. The new version of *Cyclone II* will include the whole procedure at the time of obtaining the weather report and the actual position of the vessel and will be extended by route planning for the next hours and days. To this end information on predicted cyclone positions from weather forecasts will be used as well as predicted ship positions.

Description of the program

The program is implemented in the C++ language and allows the user to operate in the Windows environment. It works on two levels – computing and graphics. Graphical presentation provides insight into the computing layer and performs the additional control function. The graphic form is scalable, giving insight into the situational details.

The program includes and is supported by four panels, three of which will be shown in figures 3–14 below:

- two main panels – horizontal and vertical,
- two panels with additional functions.

The main vertical panel includes data from the report on the current position of the vessel and that of the cyclone. These baseline data for analysis are placed in the lower part of the panel. The upper part has additional options for imaging and conversion maps, saving or loading previously saved data. An important part of the panel is information about the results of calculations of the dangerous course sector, closest point of approach (CPA), time to the closest point of approach (TCPA) and the current distance between the ship and the cyclone.

The main horizontal panel contains the data such as the present or future positions of the vessel and the cyclone and boxes for entering data such as the Rodewald's coefficient, date and time of receiving a report on cyclone position and the number of hours the ship and cyclone will take to cover a specific distance, and the date and time of testing. One panel with additional features (PPC – predicted
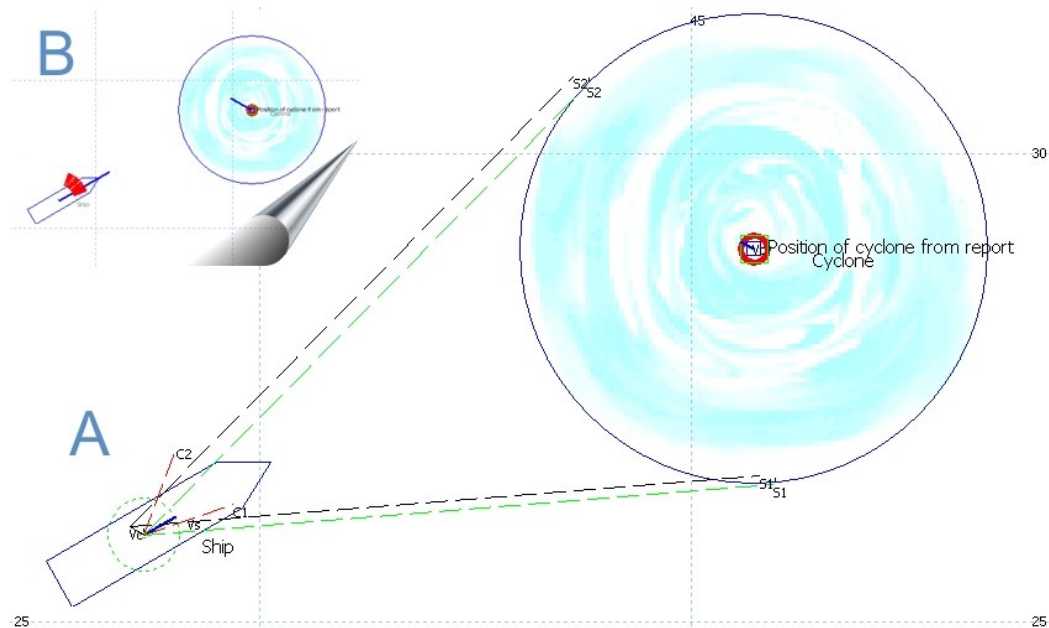

Fig. 1. Example of constructing a collision avoidance plot (A) and its synthetic graphic image presented on the charts (B)
Rys. 1. Przykład budowy trasy unikającej kolizji (A) i jej syntetyczny graficzny obraz przedstawiony na mapach (B)

positions of cyclone) may be activated by pressing the button "S / H panel". It contains important data from forecasts on future cyclone positions ranging from 12 to 72 hours. This allows to calculate future sectors – those safe and dangerous for the ship.

The other panel with additional features (programmable points) can be switched by pressing the "S / H Points". This panel includes many features that can be used for various calculations, such as routing, route changes and other purposes.
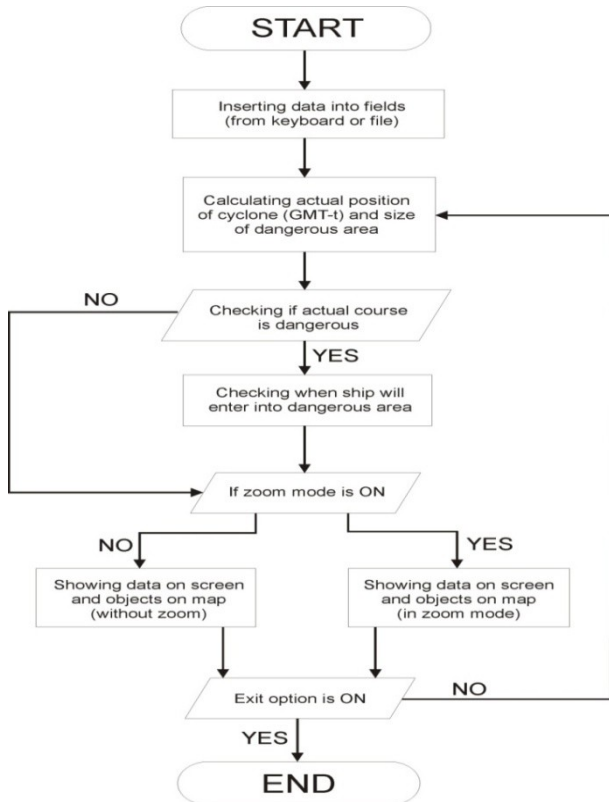

Fig. 2. A simplified algorithm of the program
Rzs. 2. Uproszczony algorytm programu

Testing procedures and methodology

Testing procedures and methodology are based on real tropical cyclone data, transmitted by land-based broadcasting centers. An example message is shown in table 1. The testing presented herein refers to the ship "Diana" sailing from Lisbon to New York. On 20 August 2009, the ship was in position $\varphi = 40°$ N, $\lambda = 040°$ W and at 1500 hours received a report on the tropical cyclone Bill. The analysis of the cyclone position at noon 12.00 UTC indicated its location at 22.1° N, 061.0° W, moving on course 305° at 16 knots. The uncertainty of the cyclone eye position was assumed as 10 Nm. For 1500 UTC the estimated location of the cyclone was 22.6° N 61.7° W and the radius of strong winds over 34 knots ranged from 100 to 225 Nm in the NE sector. The first test should be performed immediately

Table 1. Printout of the weather report on the cyclone Bill from 20/08/2009
Tabela 1. Wydruk raportu pogodowego dla cyklonu Bill z dn. 20.08.2009 r.

ZCZC MIATCMAT3 ALL
TTAA00 KNHC DDHHMM CCA
HURRICANE BILL FORECAST/ADVISORY NUMBER 21
    ... CORRECTED
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL
    AL032009
1500 UTC THU AUG 20 2009

CORRECTED FOR 12 FOOT SEAS

AT 11 AM AST ... 1500 UTC ... THE BERMUDA
    WEATHER SERVICE HAS ISSUED A
HURRICANE WATCH FOR BERMUDA. A HURRICANE
    WATCH MEANS THAT
HURRICANE CONDITIONS ARE POSSIBLE WITHIN THE
    WATCH AREA ... GENERALLY
WITHIN 36 HOURS

HURRICANE CENTER LOCATED NEAR 22.6N 61.7W AT
    20/1500Z
POSITION ACCURATE WITHIN 10 NM

PRESENT MOVEMENT TOWARD THE NORTHWEST OR
    305 DEGREES AT 16 KT

ESTIMATED MINIMUM CENTRAL PRESSURE 951 MB
EYE DIAMETER 20 NM
MAX SUSTAINED WINDS 105 KT WITH GUSTS
    TO 130 KT
64 KT 90NE 45SE 30SW 75NW
50 KT 120NE 90SE 60SW 100NW
34 KT 225NE 200SE 100SW 200NW
12 FT SEAS ... 440NE 320SE 350SW 375NW
WINDS AND SEAS VARY GREATLY IN EACH
    QUADRANT. RADII IN NAUTICAL
MILES ARE THE LARGEST RADII EXPECTED
    ANYWHERE IN THAT QUADRANT

REPEAT ... CENTER LOCATED NEAR 22.6N 61.7W AT
    20/1500Z
AT 20/1200Z CENTER WAS LOCATED NEAR 22.1N
    61.0W

FORECAST VALID 21/0000Z 24.2N 63.8W
MAX WIND 110 KT ... GUSTS 135 KT
64 KT ... 90NE 45SE 30SW 75NW
50 KT ... 120NE 90SE 60SW 100NW
34 KT ... 225NE 200SE 100SW 200NW

FORECAST VALID 21/1200Z 26.6N 66.0W
MAX WIND 115 KT ... GUSTS 140 KT
64 KT ... 75NE 45SE 30SW 45NW
50 KT ... 120NE 100SE 70SW 100NW
34 KT ... 225NE 200SE 120SW 180NW

FORECAST VALID 22/0000Z 29.5N 67.5W
MAX WIND 115 KT ... GUSTS 140 KT
64 KT ... 75NE 45SE 30SW 45NW
50 KT ... 120NE 100SE 70SW 100NW
34 KT ... 225NE 200SE 120SW 180NW

FORECAST VALID 22/1200Z 32.5N 69.0W
MAX WIND 110 KT ... GUSTS 135 KT
50 KT ... 120NE 100SE 70SW 100NW
34 KT ... 225NE 200SE 120SW 180NW

FORECAST VALID 23/1200Z 40.5N 66.5W
MAX WIND 100 KT ... GUSTS 120 KT
50 KT ... 120NE 120SE 70SW 100NW
34 KT ... 225NE 225SE 120SW 180NW

after receiving the cyclone report for the current actual position of the vessel. In this way the ship verifies whether there is a dangerous course sector and if so, what are its boundaries expressed in degrees.

Then the captain introduces the most relevant data with forecasts activating an additional panel from predicted positions of the cyclone (PPC). The computing program will include:

− PPCs, subsequently for periods from 12 to 72 hours;
− expected danger zones due to strong winds ≥ 34 knots (or field of rough or high seas, i.e. over 4 meters) for each predicted hurricane position.

The program also calculates the expected courses and speeds of storm movement and the subsequent estimated positions of the ship, knowing the ship's present speed and course.

Testing results and their interpretation

On 20 August 2009, at 15:00 UTC the ship was in position $\varphi = 40°$ N, $\lambda = 040°$, sailing the course over ground KDD = 270º at a speed of 13 knots in actual weather conditions (V_0 – service speed in calm water = 13.6 knots).

Figure 3 shows the graphic result of the calculation, which indicates that the ship sails a safe course (no-risk sector ahead) and is 1525 Nm from the hurricane eye and 1296 Nm from the zone of strong winds. The closest point of approach (CPA) between the ship and the cyclone with unchanged parameters of the cyclone and the ship will be at 861 Nm at 1200 hours (Time to CPA). The ship does not change its course and speed. The captain successively introduces data on the cyclone position from 12:00 UTC report and from cyclone-related forecasts for 12 to 72 hours ahead by saving and using an additional PPC panel.

Figure 4 illustrates the graphic results of calculations for the predicted position of the storm and the ship after 12 hours from the time of analysis stored in the vertical panel. The cyclone is expected to reach position $\varphi = 24.2°$ N, $\varphi = 063.8°$, and does not pose danger for the ship (no-sector risk – figure 4). Further forecasts for 24 or 36 hours do not create a dangerous course sector for the ship.

In tests using 48-hour forecasts, i.e. for 22.08.2009 at 1200 UTC a dangerous course sector appears bounded by 272° and 358° lines (Fig. 5). Testing using the 72-hour forecast (23.08.2009, at 12:00 UTC) confirms that there is a risk of ship's entering the dangerous zone ($W ≥ 34$ knots – figure 6). At this point the testing on 20.08.2009 at 1500 UTC was completed. The ship's captain may
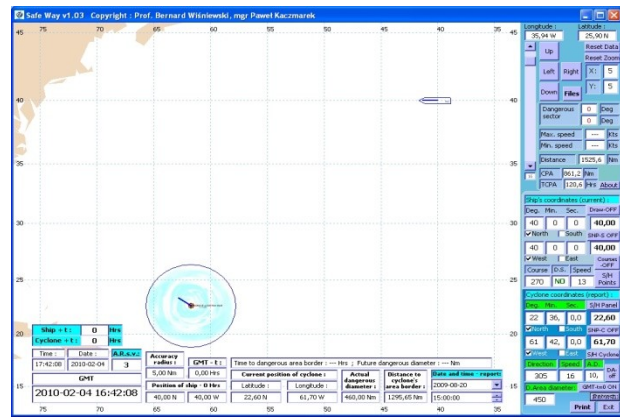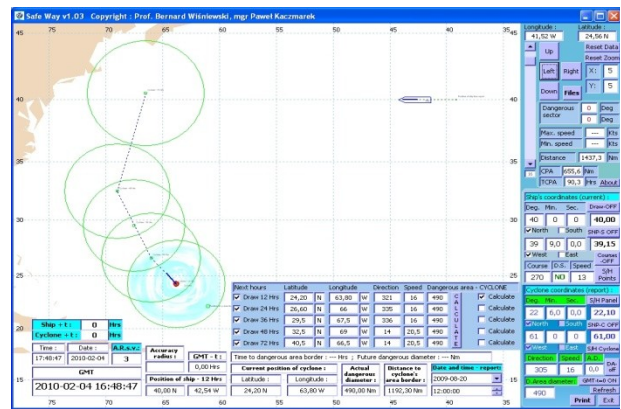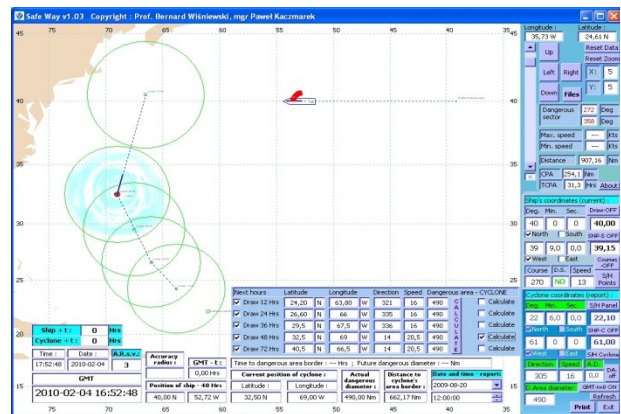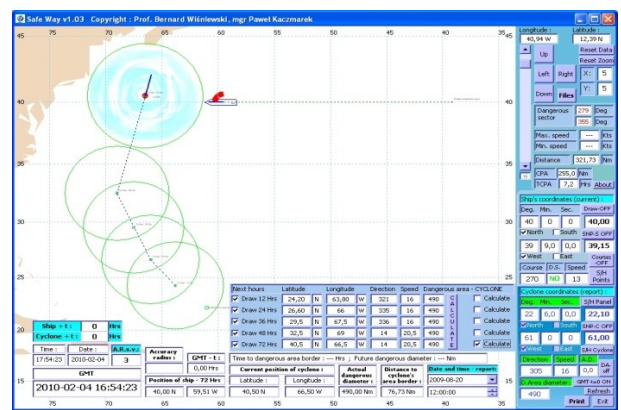

Fig. 3 / Rys. 3

Fig. 4 / Rys. 4

Fig. 5 / Rys. 5

Fig. 6 / Rys. 6

eventually take a decision to maintain the course KDD = 270° and speed of V_s = 13.0 kts until 1200 UTC on 22.08.2009. Between 20 and 22 August 2009 it is obvious that the captain will check cyclone reports to see if there has been a significant change in forecast weather situation.

On 22.08.2009 at 1500 UTC the ship received another message (29) on the cyclone Bill. The relevant data are contained in table 2. The actual position of the cyclone at 1200 UTC was $\varphi = 34.1°$, $\lambda = 68.5°$ and it does not include dangerous courses sector for the ship (Fig. 7). Nevertheless, the ship experiences swell from the cyclone Bill so at 1500 UTC it performs testing by assigning to the cyclone the wave field hf $\geq$ … m within 420 Nm radius in the NE sector. The test results confirm that there is a dangerous sector from 274° to 341°, close to the ship's course 270° (Fig. 8). The ship, plotting further estimated positions and the zone of strong cyclonic waves, decides to alter its course to 230° (Fig. 9). At this time tests are performed for 12 and 24 hour forecasts (Fig. 10 and 11), confirming that the course followed will be safe for one day until reaching the position $\varphi = 36.66°$ N, $\lambda = 058.66°$ W. At this point testing was completed on 22.08.2009.

Table 2. Printout of partial report on the cyclone Bill received on 22.08.2009
Tabela 2. Wydruk raportu częściowego dla cyklonu Bill otrzymany dn. 22.08.2009 r.

HURRICANE CENTER LOCATED NEAR 35.1N 68.6W AT 22/1500Z
POSITION ACCURATE WITHIN 15 NM
PRESENT MOVEMENT TOWARD THE NORTH OR 355 DEGREES AT 20 KT

ESTIMATED MINIMUM CENTRAL PRESSURE 964 MB
MAX SUSTAINED WINDS 85 KT WITH GUSTS TO 105 KT
64 KT 75NE 30SE 30SW 30NW
50 KT 100NE 100SE 80SW 75NW
34 KT 240NE 200SE 135SW 175NW
12 FT SEAS ... 420NE 450SE 540SW 360NW
WINDS AND SEAS VARY GREATLY IN EACH QUADRANT. RADII IN NAUTICAL
MILES ARE THE LARGEST RADII EXPECTED ANYWHERE IN THAT QUADRANT
REPEAT ... CENTER LOCATED NEAR 35.1N 68.6W AT 22/1500Z
AT 22/1200Z CENTER WAS LOCATED NEAR 34.1N 68.5W
FORECAST VALID 23/0000Z 38.0N 68.5W
MAX WIND 85 KT ... GUSTS 105 KT
64 KT ... 75NE 45SE 30SW 45NW
50 KT ... 100NE 100SE 80SW 100NW
34 KT ... 240NE 200SE 135SW 175NW
FORECAST VALID 23/1200Z 42.5N 65.5W
MAX WIND 75 KT ... GUSTS 90 KT
64 KT ... 75NE 50SE 35SW 50NW
50 KT ... 100NE 100SE 75SW 90NW
34 KT ... 240NE 215SE 130SW 160NW
FORECAST VALID 24/0000Z 46.0N 59.0W
MAX WIND 65 KT ... GUSTS 80 KT
64 KT ... 45NE 60SE 45SW 30NW
50 KT ... 90NE 115SE 75SW 60NW
34 KT ... 210NE 240SE 180SW 160NW
FORECAST VALID 24/1200Z 49.5N 49.4W ... BECOMING EXTRATROPICAL
MAX WIND 50 KT ... GUSTS 60 KT
50 KT ... 75NE 90SE 75SW 60NW
34 KT ... 175NE 270SE 270SW 160NW
FORECAST VALID 25/1200Z 52.0N 24.0W ... EXTRATROPICAL
MAX WIND 40 KT ... GUSTS 50 KT
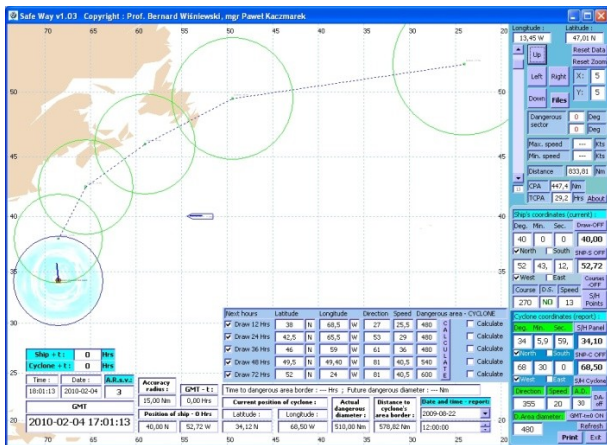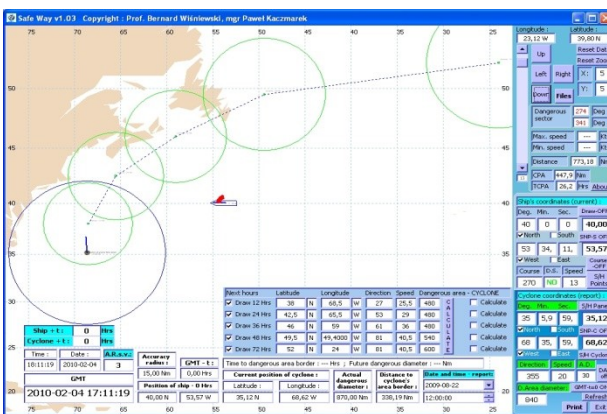34 KT ... 150NE 300SE 300SW 200NW
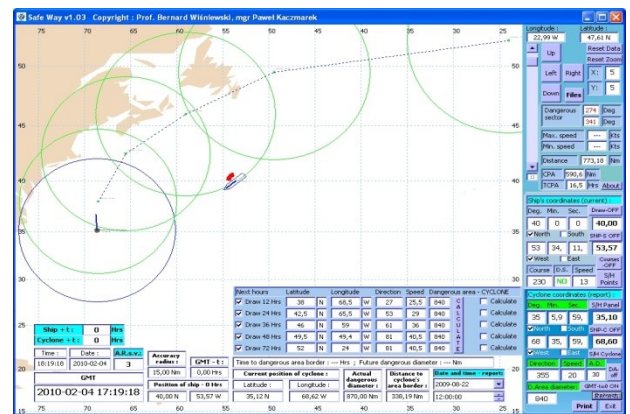

Fig. 7 / Rys. 7
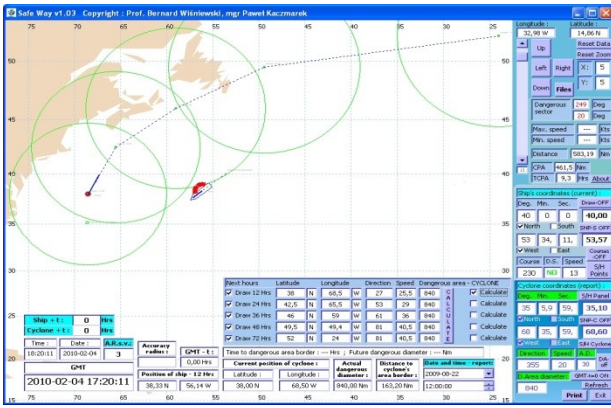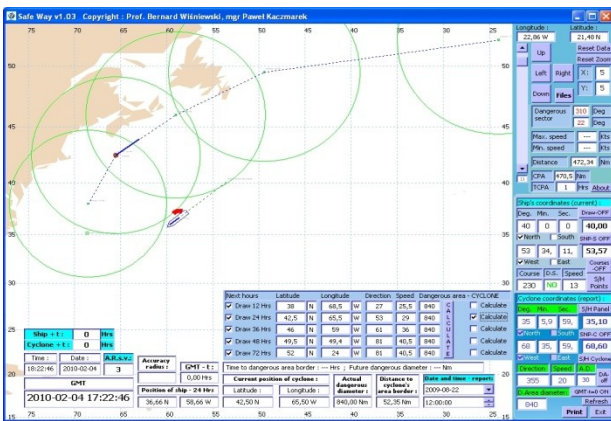

Fig. 8 / Rys. 8

Fig. 9 / Rys. 9

Fig. 10 / Rys. 10
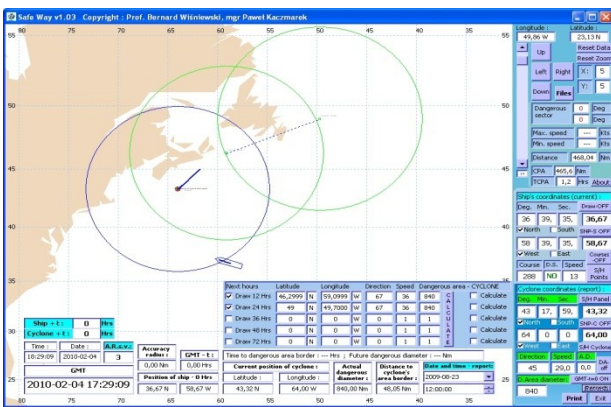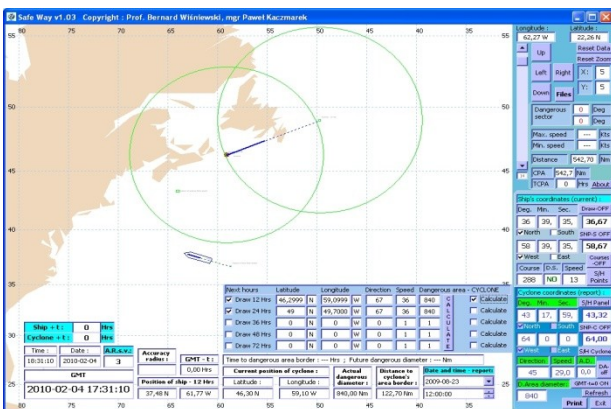

Fig. 11 / Rys. 11

Fig. 12 / Rys. 12
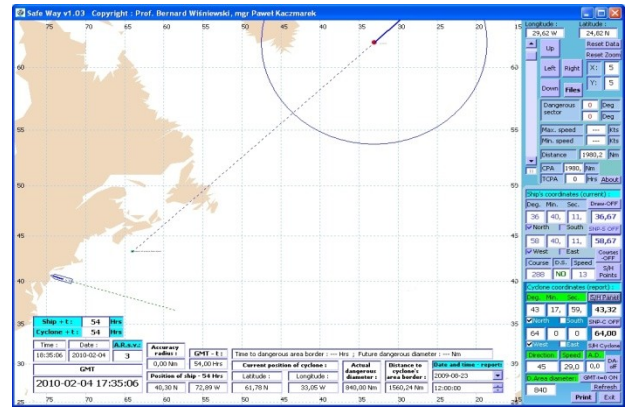

Fig. 13 / Rys. 13

Fig. 14 / Rys. 14

On 23.08.2009 at 1500 UTC, upon testing based on the current report data, the vessel alters its course over ground to 288 degrees heading for its destination, the port of New York (Fig. 12 and 13). After 54 hours (August 25, 2009, 2100 UTC) the vessel arrives at New York roadstead $\varphi = 40.3°$ N, $\lambda = 072.89°$ (Fig. 14).

Conclusions

For the avoidance of tropical cyclones in ocean navigation these authors propose a more perfect version of the program for computing safe and dangerous SECTORS (SN) of ship courses referred to as "Cyclone II".

The results of the accuracy of passing the storm and the relevant procedure presented in this article have been based on tests concerning the route of the vessel "Diana", when in August 2009 it sailed in the North Atlantic when the cyclone Bill was in operation.

To safely avoid the cyclone safely the ship extended its route from Lisbon to New York by about 104 Nm which corresponds to travelling time prolonged by 8 hours. Typically, route changes made to avoid a cyclone delay ship's arrival at its destination by one day. The ship performed successful maneuvers to avoid the cyclone being 338 Nm from its outer field (hf ≥ 4 m), making use of forecast positions of the hurricane and ship covering 72 hour period.

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