

The Evaluation of Maritime Search and Rescue Ability by Using Virtual Probability Circle Based on GIS

Ruirui Wang

Beijing Forestry University

Wei Shi (✉ bnuvictor@hotmail.com)

Chinese Academy of Sciences, Institute of Geographic Sciences and Natural Resources Research, State Key Laboratory of Resources and Environmental Information Systems, 11A, Datun Road, Chaoyang District, Beijing 100101, China

Xingwang Chen

Beijing Forestry University

Research Article

Keywords: Maritime SAR, Virtual probability circle, GIS, Accessibility

Posted Date: December 8th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-115003/v1>

License:  This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

The Evaluation of Maritime Search and Rescue Ability by using Virtual Probability Circle based on GIS

Ruirui Wang,^a *Wei Shi,^b and Xingwang Chen^a

^aBeijing Forestry University, College of Forestry, No. 35 Tsinghua East Road Haidian District, Beijing 100083, China

^bChinese Academy of Sciences, Institute of Geographic Sciences and Natural Resources Research, State Key Laboratory of Resources and Environmental Information Systems, 11A, Datun Road, Chaoyang District, Beijing 100101, China

E-mail: bnuvictor@hotmail.com

Abstract: Geographic information system (GIS) is widely used to solve the problems about spatial decision making and strategy planning. However, the potential application in maritime search and rescue (SAR) strategic planning still needs to be opened up. With the theory of accessibility, a new evaluating model of maritime SAR ability was proposed to assess the efficacy of the SAR unit serving a certain sea area by using a key indicator named virtual probability circle (VPC) which stand for the extent of how difficult or how long the SAR vessels reaching the accidental site. In this article, an application to the South China Sea area is shown. Comparing with the SAR abilities before and after new bases settled, the results indicate that the model provides good opportunities for improving maritime management.

Keywords: Maritime SAR; Virtual probability circle; GIS; Accessibility

1. Introduction

Accessibility is an important indicator for state evaluating and strategy planning related to distance or time in geography (Walter and Hansen, 1959^[1]; Geertman and Eck, 1995^[2]). Accessibility can be expressed both by vector or raster data model in GIS (Chen, Feng and Cheng, 2007^[3]). In regular applications under GIS, accessibility was usually revealed as time-cost or spatial distance (Geurs, Montis and Reggiani, 2015^[4]; Niedzielski and Boschmann, 2014^[5]).

The describing on accessibility usually induced in two ways: 1) the accessibility of ability,

expressing the cost for reaching somewhere else, such as distance between points (Delmelle and Murray, 2012^[6]; Kwan, 2010^[7]), time-cost between areas (Geurs and Wee, 2004^[8]; Weiss, Nelson and Gibson et al., 2018^[9]), cost in traffic networks (Bowen, 2000^[10]; Calvin and Paul, 2012^[11]; Litman, 2017^[12]; Wang, Liu and Mao, 2018^[13]), et al; 2) the ability of radiation, expressing the profits getting from the area effecting. For example, job opportunities in certain area (Gao, Mokhtarian and Johnston, 2008^[14]), public services extent (Luo and Wang, 2003^[15]; Paez, Mercado and Farber , et al., 2010^[16]; Sung, 2012^[17]), et al.

But in same regional area, accessibility should be indicated as a sum of the probability in a certain area. Maritime search and rescue is the special field. Traditional SAR capability research pay more attention to in specific search and rescue behavior (Wu, Qian and Sun, 2008^[18]; Ni, Qiu and Su, 2010^[19]) or the simulated ocean currents predicted search locations (Breivik and Allen, 2008^[20]; Breivik and Arthur, 2013^[21]). The researches involving national or regional SAR capability evaluation is not much (Azofra, Pérez-Labajos and Blanco et al., 2007^[22]; Li, Zhang and Wang, 2010^[23]). Shi (2014)^[24] proposed time accessibility into SAR capability evaluation for evaluating the SAR abilities of countries, which could be used to guide the deployment of rescue forces.

The shorter responding time for searching and rescuing emergencies such as accidents or pirates attacking in the sea area, the higher the successful rate. But there exists a dialectical relationship (Miller, 1991^[25]) between the SAR success rate and SAR success time-cost in a certain sea area, when SAR units unchanged.

Virtual probability circle (VPC) was proposed for describing an extent which is covering the area of available probability for SAR. SAR probability radius and SAR probability time-cost were proposed to reveal the situation of SAR ability in certain area. It is very helpful for evaluating SAR efficiency, comparing policy effective, establishing effective emergency rescue mechanism and maintaining navigation safety in certain sea areas.

2. The Model for Evaluating Maritime Search and Rescue Ability based on Virtual Probability Circle

Virtual probability circle (VPC) is a virtual circle in the extent the cumulative probability

matching a specified criteria. When cumulative probability over 1, the radius of VPC stands for the distance between the center of VPC and SAR unit. The definition is shown in Fig.1.

With the definition of VPC, the model for evaluating Maritime SAR ability is divided into three main steps: 1) modeling the distribution probability of patrol vessels; 2) calculating the SAR probability radius from accident area to vessels; 3) calculating the SAR probability time from accident area to vessels. The corresponding flowchart is presented in Fig.2.

These steps, which are useful for modeling suitable, will be explained in details as follows.

2.1. Distribution probability of patrol vessels

The assignment of the patrol missions usually submit to two principles: (1) where ships distributing more where need more patrol vessels; (2) due to supply and berth patrol vessels likely are cruising near base ports. The distribution probability of patrol vessels in the model was based on the two key points above.

2.1.1 Calculating the density of normal sailing ships

In this study, We use Voluntary Observing Ships (VOS) data to reveal the distribution of normal sailing ships. The international scheme by which ships plying the various oceans and seas of the world are recruited by National Meteorological Services (NMSs) for taking and transmitting meteorological observations is called the World Meteorological Organization (WMO) Voluntary Observing Ships' scheme (NOAA, 2017)^[26]. VOS data can reflect the distribution of ships nearby by including the location and trajectory of the ships attended in scheme.

In this study, VOS data in South China Sea from 2010 to 2015 are collected and analyzed as sample data. The distribution and density of ships in sample sea area (South China Sea) is presented in Fig.3 .The density of ships at any point expressed in Equation (1).

$$Den_{ship} = f(p), p(x, y) \in \{Area\} \quad (1)$$

Where, $p(x, y)$ denotes a point located in an assigned *Area*.

In Fig.3 (a), the green points represent sailing ships. In Fig.3 (b), the value of blue color represents the density of ships, the deeper the color in blue, the thicker density of ships in the sea area.

2.1.2. Calculating the distance from ports to patrol vessel

The routes by which patrol missions start and end at port of homeland which is limited by law and supply; therefore, the farther vessels away from port, the lower their probability becomes. In this study, it is assumed that the probability density of patrol ships decreases linearly with distance. The distance from ports to patrol vessel is represented in Equation (2):

$$Dis_{port} = Min(d_i), i = 1, 2, \dots, n \quad (2)$$

Where, d_i is the distance from port i to vessel.

2.1.3. Calculating the distribution probability of patrol vessels

With the above principles, assume that the distributed probability of patrol ship appearing in any sea area is P_{vessel} which is expressed in Equation (3). This value is closely related to the ships density, the number of vessels and the distance to ports.

$$P_{vessel} = \frac{Den_{ship}}{Dis_{port}} \times Num_{vessel} \quad (3)$$

In Equation (3), Den_{ship} denotes any point of the density distribution for all ships in a large sea area, Dis_{port} denotes the minimum distance of any point from ports of homeland to patrol vessels, Num_{vessel} denotes the number of patrol vessels which are available in relevant sea area.

2.2. SAR probability radius from accident area to vessels

The SAR probability radius from accident area to vessels is a probability value defined as the radius of a virtual circle which covers the area can nearly find one patrol vessel in probability. The formula of this probability value is expressed in Equation (4):

$$\sum P_{vessel} \approx 1, P_{vessel} \in Circle(Radius_{SAR}) \quad (4)$$

Where, $Circle(Radius_{SAR})$ stands for the virtual circle area centered at accident area, P_{vessel} is the distribution probability of vessel appearing, $Radius_{SAR}$ stands for the radius of the virtual circle.

2.3. SAR probability time from accident area to vessels

Time of SAR depends on three factors: distance from vessel to accident area, distribution probability of vessels and top speed of vessel.

$$Time_{SAR} = \frac{\sum P_{vessel} \times Dis_{vessel}}{v_{top} \times \sum P_{vessel}}, \quad P_{vessel}, Dis_{vessel} \in Circle(Radius_{SAR}) \quad (5)$$

In Equation (5), Dis_{vessel} stands for the distance from accident area to the point vessel probably located, P_{vessel} stands for the distribution probability of vessel appearing. The range of Dis_{vessel} and P_{vessel} were defined in the virtual circle area where can find one patrol vessel in probability with the radius valued as $Radius_{SAR}$. Top speed of vessel v_{top} is a vital parameter. On one side it decides the real time for SAR, on the other side it is a mark of the vessel's ability. In this study, top speed is set as 30 knot with a purpose to simplify calculations.

3. Sample areas and data

South China Sea is selected as the sample area, which is one of the largest marginal seas of west Pacific Ocean, with an area of about 3.5 million square kilometers, a depth of 1200 meters in average, the South China Sea is almost surrounded by mainland, peninsulas and islands, connects China, Vietnam, Malaysia, Indonesia, Philippines and other countries (Fig.4).

South China Sea is associated with many important channels between the Pacific Ocean and the India Ocean, such as Strait of Malacca, Java Sea, Luzon Strait. This sea area is the main of East Asian countries' foreign trade, is one of the busiest waterways in the world, accounted for over half of the total freight trade, passing through over 1 hundred thousand ships every year.

As an important force on maritime security, China Coast Guard (CCG), there are 28 offshore patrol vessels (Wikipedia, 2018)^[27] which belong to CCG Nanhai Branch and have more than 1000 tons displacement, were selected as principal searchers and rescuers. Four ports (Fig.4, Table 1), Guangzhou, Sanya, two ports in mainland, and Yongxing (Xisha islands), Yongshu (Nansha islands) two ports in reefs area, were set as bases for supply and berth. The model of improved distribution probability for maritime search and rescue was proposed for comparing the SAR capabilities in different base layout conditions.

4. Experiment and analysis

The results took account of the distribution range and probability of patrol vessel from bases

from Guangzhou/Sanya or Guangzhou/Sanya/Xisha/Nansha and the SAR ability to 9 assumed accident locations (Table 2, Fig.5) in sample sea area are gotten by calculating the SAR probability radius and SAR probability time from accident area to vessels by using the “Spatial Analyst Toolbox” option of ArcGIS.

The results (Table 3, Fig.6) indicated that the SAR situation in sample sea area changed a lot before and after bases setting in Xisha and Nansha, due to southward dispersing of vessels, the SAR radius and time were (1) stretched a little in northern South China Sea, the SAR radius increasing about 80 n miles, the SAR time increasing about 1.5 hours in Dongsha area, the SAR radius increasing about 40 n miles, the SAR time increasing about 0.8 hours in Xisha area; (2) no radical changes in central South China Sea, the SAR radius maintaining at about 200 n miles, the SAR time maintaining at about 4.4 hours in Zhongsha area, the SAR radius maintaining at about 300 n miles, the SAR time maintaining at about 7 hours in Huangyan area; and (3) obviously shorten in southern South China Sea, the SAR radius and SAR time decreasing about half in Nansha area. Especially in south area of Nansha, the SAR radius decreasing about 350 n miles (from 690 to 345), the SAR time decreasing about 9 hours (from 17.05 to 7.95) in Nansha 5. Therefore, when new bases settled, the ability of SAR in 8 hours over most of the sample area (north than 4°N), and in 24 hours over the whole sample sea area will be able to achieve with existing patrol vessels.

5. Conclusion

In this paper, a model for evaluating Maritime SAR ability based on VPC was proposed. Focusing on the effect of spatial configuration of SAR bases, SAR probability radius and SAR probability time were proposed to reveal the situation of Maritime SAR ability in certain area.

The application to the South China Sea area was shown. Four bases including two mainland ports and two island ports, 28 patrol vessels belong to China Coast Guard were selected as SAR bases and principal searchers and rescuers. The results indicated that the SAR situation in the sample sea area improved significantly after new bases settled.

The model will be helpful for evaluating SAR efficiency, comparing policy effective, establishing effective emergency rescue mechanism and maintaining navigation safety.

Although there are still something can be improved in this model: (1) VOS data can reveal the behavior of limited number of big ships which had the conditions to attend to the schema, and can't stand for small boats with a huge number, such as fishing boats; (2) the number of patrol vessels assigned to different SAR bases was not mentioned, which will affect the distribution probability of patrol vessels; (3) the performance parameters of patrol vessels should be taken into account, such as cruising radius, maximum speed or helicopter capacity.

Data Availability

The datasets generated during and analysed during the current study are available from the corresponding author on reasonable request.

Author contributions statements

Ruirui Wang and Wei Shi wrote the main manuscript text and prepared all figures. Xingwang Chen reviewed the manuscript.

Competing interests statement

The authors declare no competing interests.

Acknowledgments

This paper is sponsored by the National Natural Science Foundation of China (No. 41971376).

References

- [1]Walter G. Hansen. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners*, 25(2):73-76.
- [2]Geertman S M, Eck J R V. (1995). GIS and models of accessibility potential: an application in planning. *International Journal of Geographical Information Systems*, 9(1):67-80.
- [3]Chen J, Feng L U, Cheng C. (2007). Advance in Accessibility Evaluation Approaches and Applications. *Progress in Geography*, 26(5):100-110.
- [4]Geurs K T, Montis A D, Reggiani A. (2015). Recent advances and applications in accessibility modelling. *Computers Environment & Urban Systems*, 49:82-85.
- [5]Niedzielski M A, Boschmann E E. (2014). Travel Time and Distance as Relative Accessibility in the Journey to Work. *Annals of the Association of American Geographers*, 104(6):1156-1182.
- [6]Delmelle E M, Li S, Murray A T. (2012). Identifying bus stop redundancy: A gis-based spatial optimization approach. *Computers Environment & Urban Systems*, 36(5):445-455.
- [7]Kwan M. (2010). Space - Time and Integral Measures of Individual Accessibility: A Comparative Analysis Using a Point - based Framework. *Geographical Analysis*, 30(3):191-216.
- [8]Geurs K T, Wee B V. (2004). Accessibility evaluation of land-use and transport strategies:

- review and research directions. *Journal of Transport Geography*, 12(2):127-140.
- [9]Weiss D J, Nelson A, Gibson H S, et al. (2018). A global map of travel time to cities to assess inequalities in accessibility in 2015. *Nature*, 553.
- [10]Bowen J. (2000). Airline hubs in Southeast Asia: national economic development and nodal accessibility. *Journal of Transport Geography* 8, 25-41.
- [11]Calvin P T, Paul A Z. (2012). High-resolution spatio-temporal modeling of public transit accessibility. *Applied Geography* 34, 345-355.
- [12]Litman, T. (2017). Evaluating accessibility for transportation planning. *Victoria Transport Policy Institute*.
- [13]Wang L, Liu Y, Mao L, et al. (2018). Potential Impacts of China 2030 High-Speed Rail Network on Ground Transportation Accessibility. *Sustainability*, 10.
- [14]Gao S, Mokhtarian P L, Johnston R A. (2008). Exploring the connections among job accessibility, employment, income, and auto ownership using structural equation modeling. *Annals of Regional Science*, 42(2):341-356.
- [15]Luo W, Wang F. (2003). Measures of Spatial Accessibility to Health Care in a GIS Environment: Synthesis and a Case Study in the Chicago Region. *Environment & Planning B Planning & Design*, 30(6):865-884.
- [16]Paez A, Mercado R G, Farber S, et al. (2010). Accessibility to health care facilities in Montreal Island: an application of relative accessibility indicators from the perspective of senior and non-senior residents. *International Journal of Health Geographics*, 9(1):1-15.
- [17]Sung J P. (2012). Measuring public library accessibility: A case study using GIS. *Library & Information Science Research* 34, 13-21.
- [18]Wu Z D, Qian C C, Sun F. (2008). The Application of Ocean Ambient Information in the Salvage, *Hydrographic Surveying and Charting* 28, 23-27.
- [19]Ni Z, Qiu Z P, Su T C. (2010). On predicting boat drift for search and rescue, *Ocean Engineering* 37, 1169-1179.
- [20]Breivik Ø, Allen A A. (2008). An operational search and rescue model for the Norwegian Sea and the North Sea, *Journal of Marine Systems* 69, 99-113.
- [21]Breivik Ø, Arthur A A. (2013). Advances in search and rescue at sea, *Ocean Dynamics* 63, 83-88.
- [22]Azofra M, Pérez-Labajos C A, Blanco B, et al. (2007). Optimum placement of sea rescue resources, *Safety Science* 45, 941-951.
- [23]Li Z, Zhang R, Wang B. (2010). Grade Evaluation of Maritime Rescue Based- on Environmental Risk Analysis, *Research on Waterborne Transportation* 1, 9-12.
- [24]Shi W, Su F, Zhou C. (2014). A temporal accessibility model for assessing the ability of search and rescue in Nansha Islands, South China Sea. *Ocean & Coastal Management*, 95(4), 115 46-52.
- [25]Miller H. (1991). Modelling accessibility using space-time prism concepts within geographical information systems. *International Journal of Geographical Information Systems*, 5(3):287-301.
- [26]NOAA. (2017). *The WMO Voluntary Observing Ships (VOS) Scheme*, http://www.vos.noaa.gov/vos_scheme.shtml.
- [27]Wikipedia.(2018). *China Coast Guard*. https://en.wikipedia.org/wiki/China_Coast_Guard

MAIN FIGURES

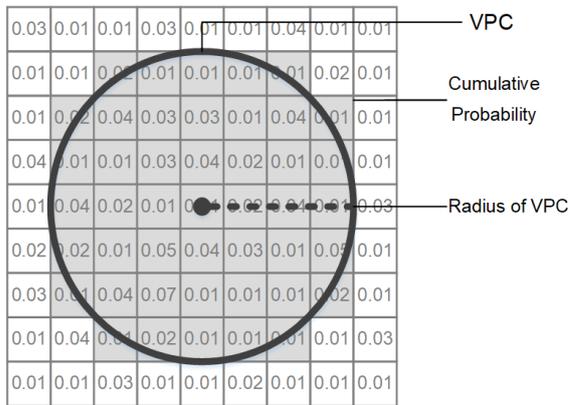


Fig.1 Definition of Virtual probability circle

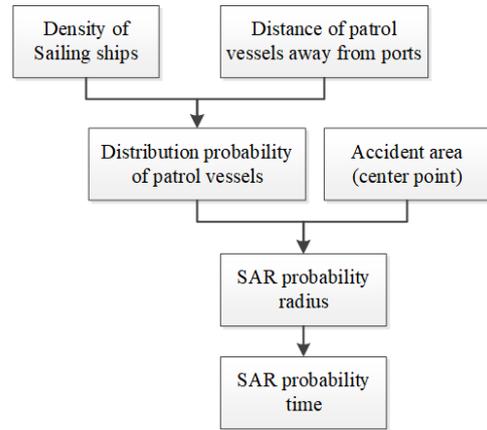


Fig.2 Flowchart of the model for evaluating maritime search and rescue ability based on VPC

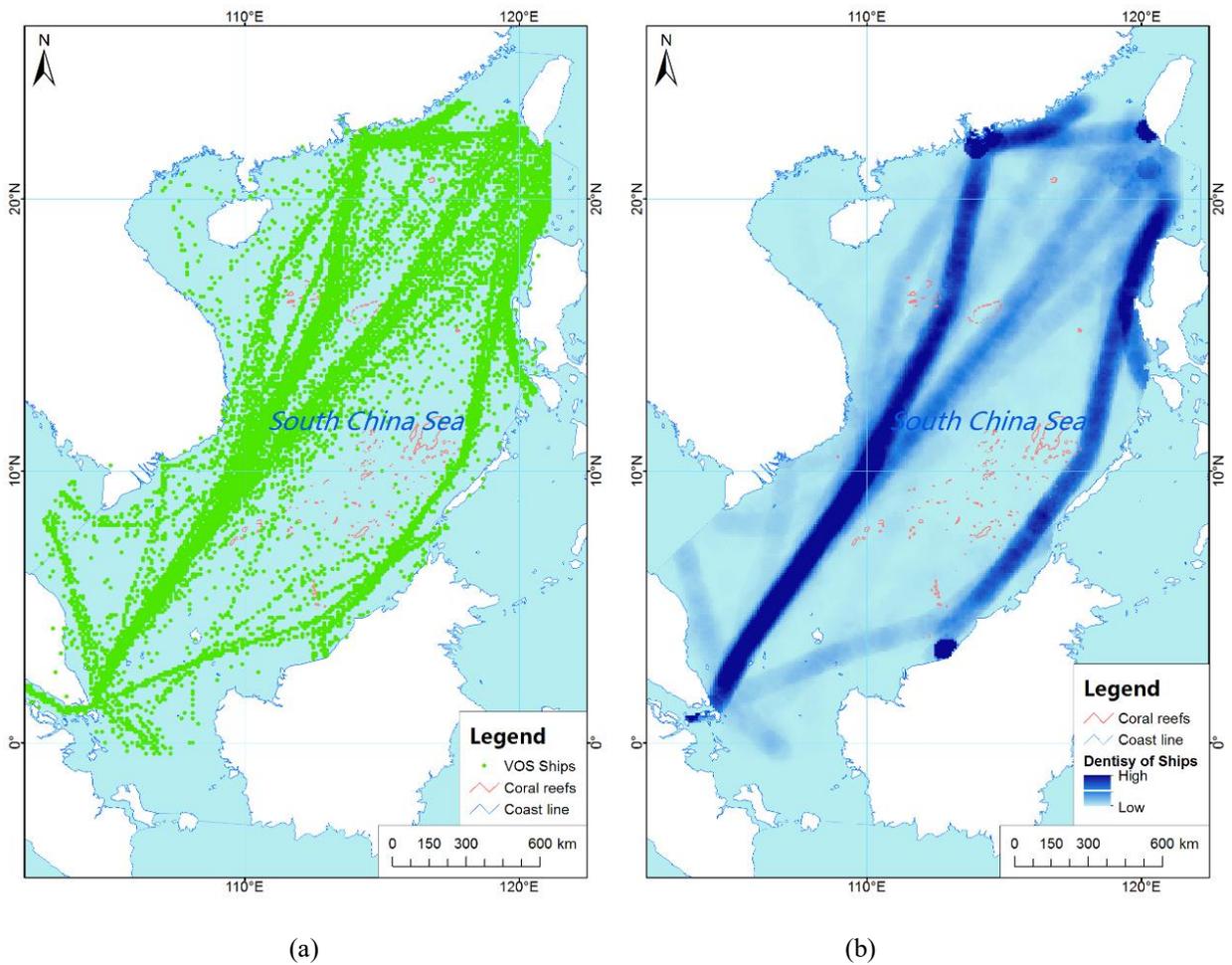


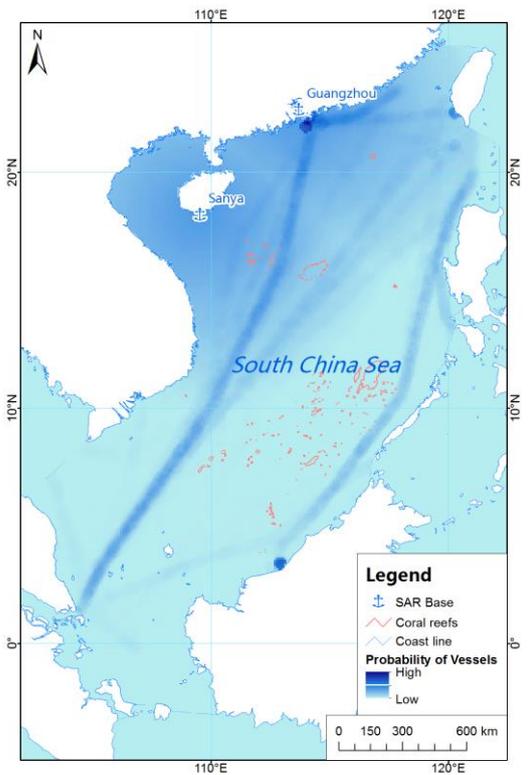
Fig.3 The distribution (a) and density (b) of ships in sample sea area (South China Sea)



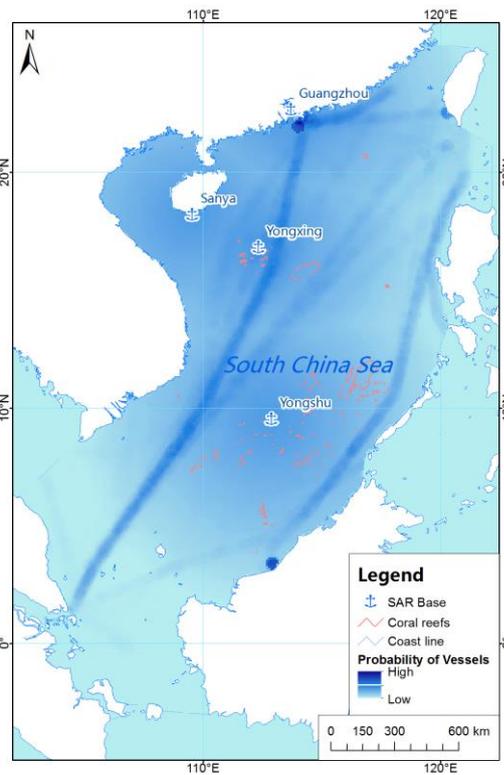
Fig.4 South China Sea and distribution of SAR bases



Fig.5 Locations of accident targets in sample sea area



(a)



(b)

Fig.6 Distribution of patrol vessels in South China Sea, (a) bases in Guangzhou and Sanya, (b) bases added Xisha and Nansha.

MAIN TABLES

Table 1 Seaports selected as SAR bases

Name	Location	Type
Guangzhou	Guangdong	Mainland
Sanya	Hainan	Mainland
Yongxing	Xisha	Reef island
Yongshu	Nansha	Reef island

Table 2 Assumed locations of accident targets in sample sea area

Order	Name	Longitude	Latitude
1	Dongsha	116.80 E	20.69 N
2	Xisha	111.67 E	16.50 N
3	Zhongsha 1	114.32 E	15.84 N
4	Zhongsha 2	117.76 E	15.15 N
5	Nansha 1	114.46 E	11.41 N
6	Nansha 2	116.46 E	9.70 N
7	Nansha 3	113.85 E	7.51 N
8	Nansha 4	109.70 E	7.69 N
9	Nansha 5	112.17 E	3.96 N

Table 3 Results of SAR radius and time to accident targets from north and south bases

Order	Name	SAR Radius from G/S* (n mile)	SAR Radius from G/S/X/N* (n mile)	SAR Time from G/S (hr)	SAR Time from G/S/X/N (hr)
1	Dongsha	165	245	3.64	5.16
2	Xisha	150	190	3.29	4.08
3	Zhongsha 1	200	204	4.41	4.41
4	Zhongsha 2	310	284	7.55	6.39
5	Nansha 1	330	208	8.18	4.56
6	Nansha 2	455	256	11.97	5.41
7	Nansha 3	510	219	12.73	4.56
8	Nansha 4	492	234	11.54	4.97
9	Nansha 5	690	345	17.05	7.59

*G/S means Guangzhou/Sanya, G/S/X/N means Guangzhou/Sanya/Xisha/Nansha

LEGENDS

(1) In Fig3, The distribution and density of ships in sample sea area (South China Sea) was presented, In Fig.3 (a), the green points represent sailing ships. In Fig.3 (b), the value of blue color represents the density of ships, the deeper the color in blue, the thicker density of ships in the sea area.

(2) In Fig4, the blue symbol represent four ports which were set as bases for supply and

berth ,Guangzhou, Sanya, two ports in mainland, and Yongxing (Xisha islands), Yongshu (Nansha islands) two ports in reefs area.

(3)In Fig5, the black symbol represent the locations of accident targets in sample sea area.

(4)In Fig6, distribution of patrol vessels in South China Sea was presented,the blue symbol represent four ports which were set as bases for supply and berth , the value of blue color represents the probability of vessels, the deeper the color in blue, the higher probability of vessels in the sea area.

Figures

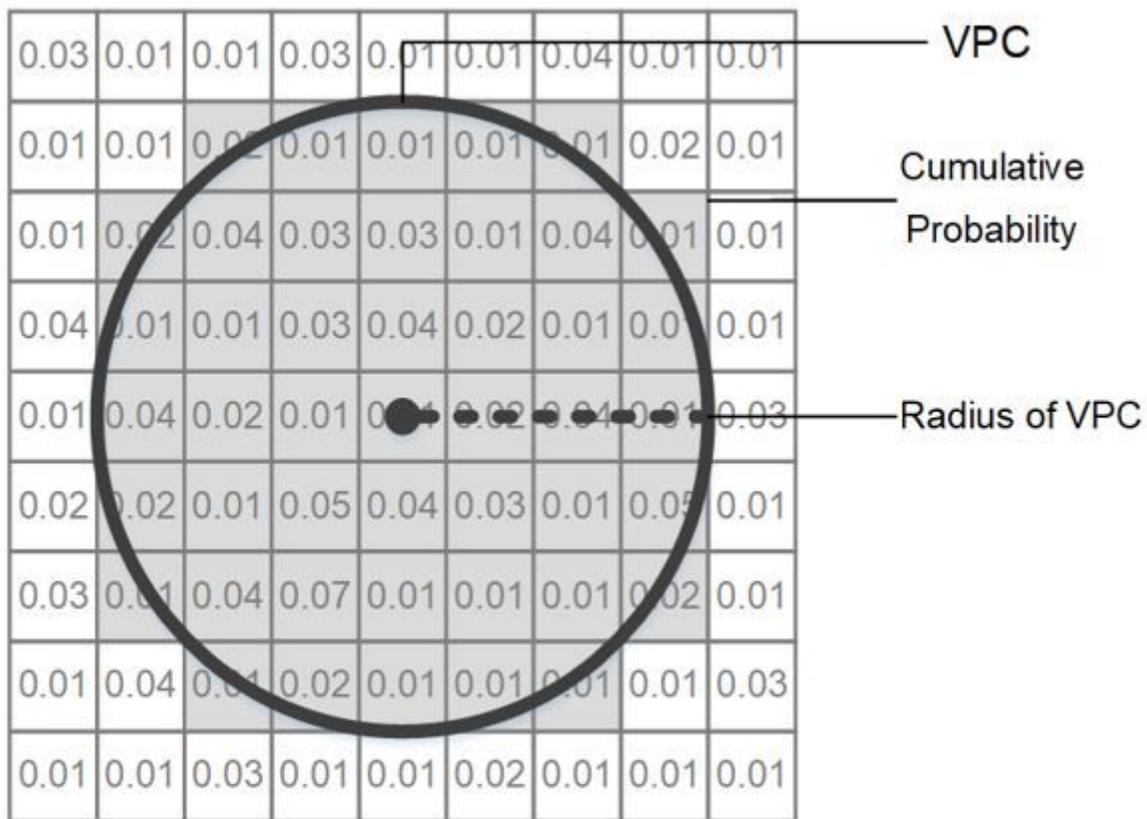


Figure 1

Definition of Virtual probability circle

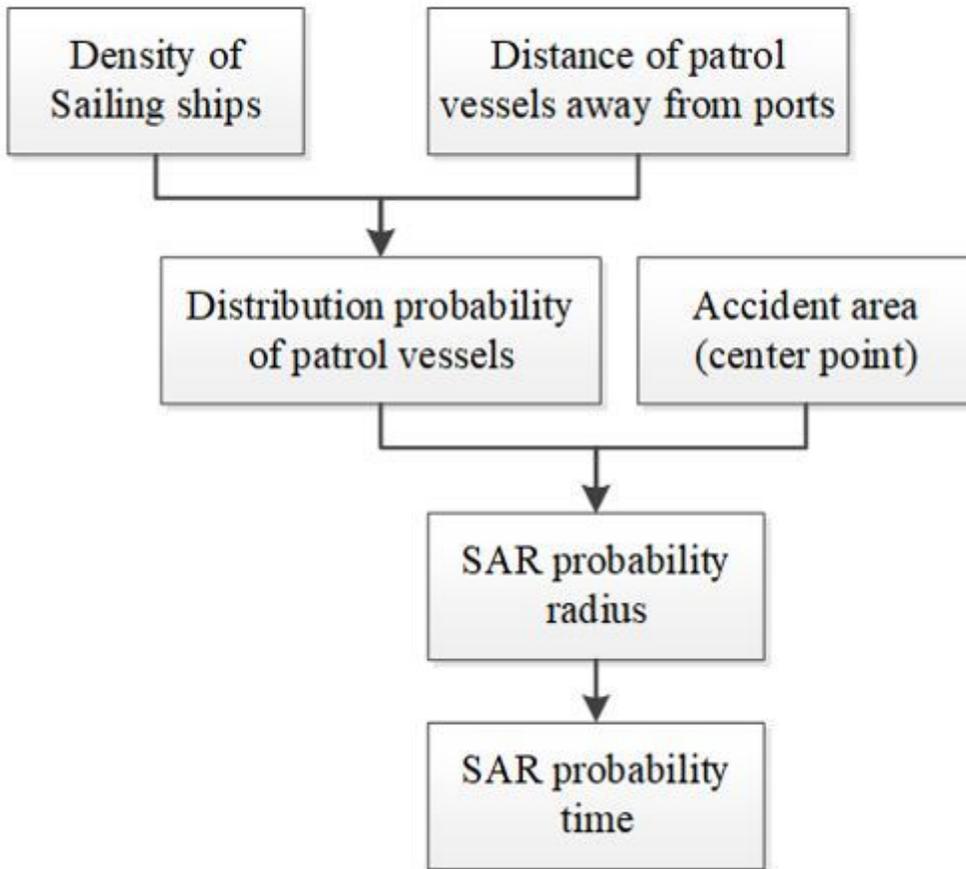


Figure 2

Flowchart of the model for evaluating maritime search and rescue ability based on VPC

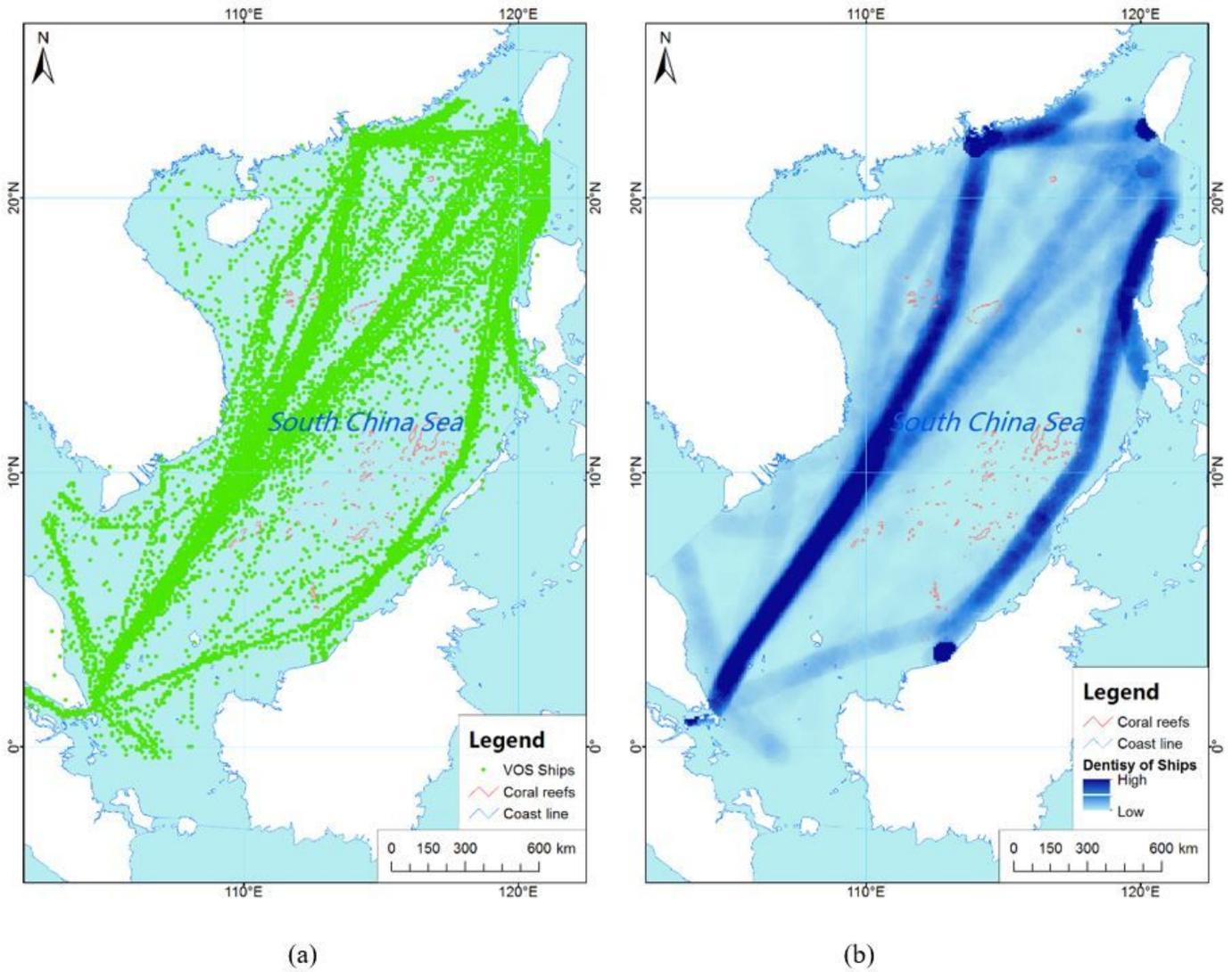


Figure 3

The distribution (a) and density (b) of ships in sample sea area (South China Sea) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



Figure 4

South China Sea and distribution of SAR bases Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



Figure 5

Locations of accident targets in sample sea area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

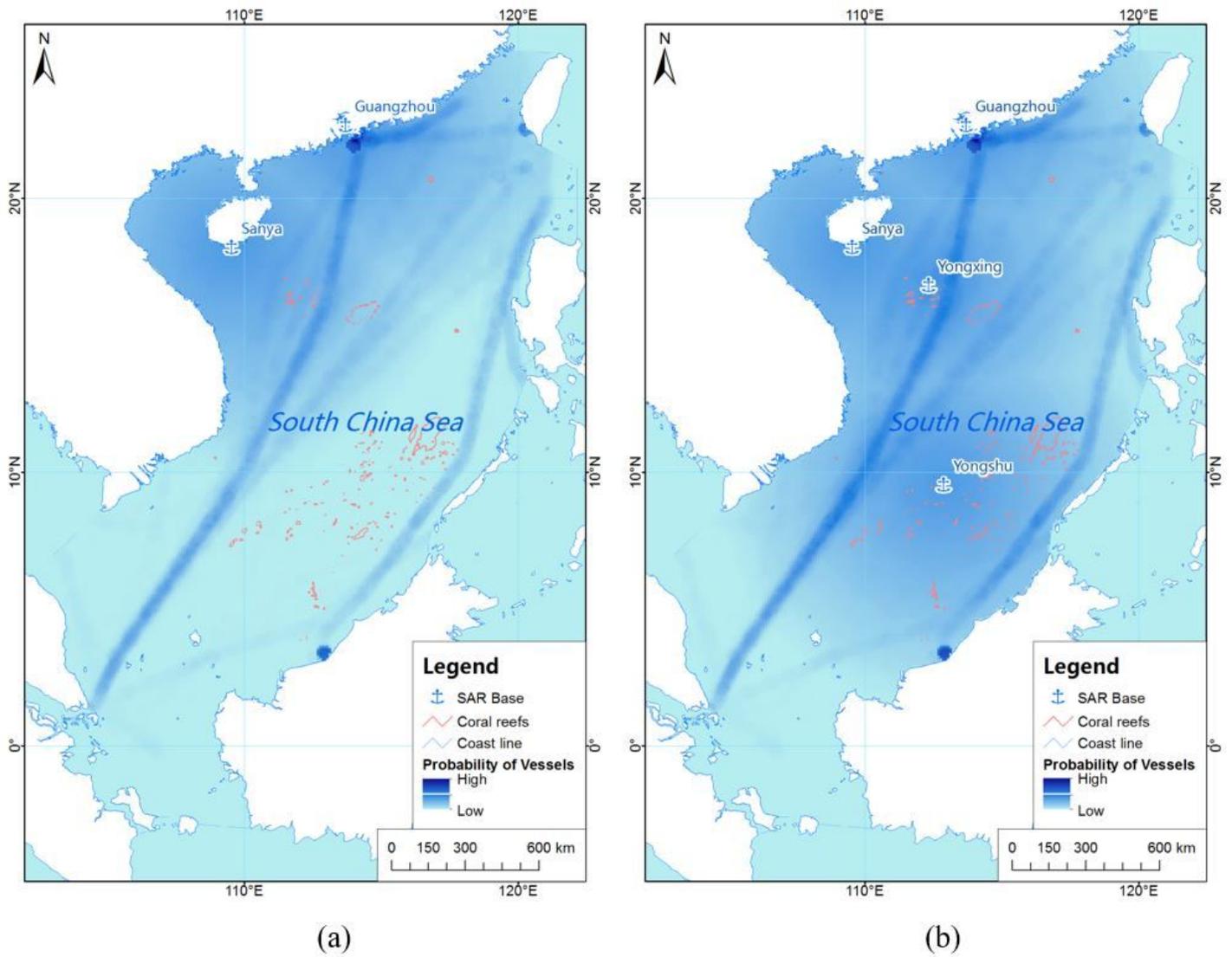


Figure 6

Distribution of patrol vessels in South China Sea, (a) bases in Guangzhou and Sanya, (b) bases added Xisha and Nansha. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.