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Safety assessment of shipping routes in the South China Sea based on the fuzzy analytic hierarchy process

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ABSTRACT

The shipping routes of the South China Sea (SCS) are of major significance in global trade and global economy. However, the shipping routes of the SCS are frequently threatened by both natural and manmade factors, such as complex submarine topography, extreme weather, and piracy. Previous studies of shipping safety in the SCS mainly focused on the individual ship safety and broader political policies. For this study, we applied spatial analysis to assess shipping safety along shipping routes. First, we extracted the main shipping routes from spatial analysis of the Voluntary Observing Ships data. Then, we used a qualitative review to choose influencing factors on ship safety in the SCS, for which data were available over a comparable time period. Further, annual and four seasonal criteria systems were developed. After factor normalization and mapping, the annual and seasonal navigation environment risk was evaluated along the shipping routes using the fuzzy analytic hierarchy process and geographic information science, and validated by comparison to actual incident reports. Our study shows that (1) the proposed method is a reasonable method of evaluation of navigation environment risk, at least in the SCS; (2) the majority of the shipping routes run from southwest to northeast, reflecting a linear-direction trend; (3) the risk of navigation environment in the SCS gradually decreases from the north to the south with a V-shape spatial distribution, and varies seasonally; and (4) in terms of shipping risk the four seasons are sorted in an ascending order: spring, winter, summer, and autumn.

1. Introduction

The South China Sea (SCS) is a major thoroughfare for worldwide trade. More than half of the world's oil tankers and merchant ships sails through the SCS every year (Rosenberg and Chung, 2008), ranks second only to the Mediterranean Sea in terms of maritime transportation.

Though the safety of shipping in the SCS impacts the global economy, the shipping routes of the SCS are frequently threatened by both natural and human agents. Extreme weather, piracy and armed robbery, and various navigational hazards have resulted in some serious SCS maritime casualties including loss of life and property, and in some cases contributed to environmental disaster (Tsou, 2010).

Recent researches on the shipping safety assessment and risk control have addressed various facets of, and approaches to, the problems. Most notably, accident statistics have been used to present collision models (Kujala et al., 2009), ship security monitoring systems have been designed through simulations (Lee et al., 2004), and human factors including supervision and ship safety culture have been investigated (Heij et al., 2011; Hetherington et al., 2006; Lu and Tsai, 2008). Modeling methods for the assessment of safety and risk at sea for individual ships have been developed (Balmat et al., 2009; Wang, 2002). Specific to the SCS, antipiracy and anti-maritime terrorism policies have been examined from the perspective of geopolitics and international relations (Huang, 2008; Rosenberg, 2009; Rosenberg and Chung, 2008).

The recent work cited above focused on individual ship assessments and broad security policies. However, the ship safety was most significantly correlated to shipping route safety, which is spatially related to geographical position and factors such as wind speed, wave height, and water depth. In this study, we set out to analyze the spatial variation of safety for SCS shipping routes. The three main components of this first spatial analysis of SCS shipping route safety are: (1) to identify the main shipping routes in use in the SCS; (2) to identify and evaluate the specific natural and manmade risks existing in the navigation environment of these shipping routes; and (3) to assess the safety of these shipping

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routes based on the integration of risk data using Geographic Information System (GIS) and Fuzzy Analytic Hierarchy Process (FAHP) calculations.

2. Data and methods

2.1. Study area location, characteristics, and environment

The South China Sea is a marginal sea of Asia bordered by the Chinese mainland and Taiwan to the north, the Philippines to the east, Vietnam to the west, and Brunei, Singapore, and Malaysia to the south (Fig. 1). The SCS connects the Pacific Ocean with the Indian Ocean between these landmasses and island chains, its waters commingling with the Pacific Ocean via the Luzon Strait and Taiwan Strait in the northeast, and with the Indian Ocean through the Malacca Strait in the southwest. The SCS has an area of 3.3 million km^2 excluding the gulfs of Thailand and Tonkin, and up to 3.8 million km^2 if these gulfs are included (Morton and Blackmore, 2001). The SCS is a huge sea basin with great slope decreasing from the margin to the center. The average depth of the water is 1212 m, and the maximum depth is 5559 m (Wang and Li, 2009). Many intrabasinal islands dot the SCS, the largest being Hainan in the northwest and Palawan in the southeast, with hundreds of smaller islands, atolls, submerged reefs and banks notably including the Pratas Islands, Paracel Islands and Spratly Islands.

Because the SCS extends southward from the Tropic of Cancer, it experiences a monsoonal climate created by the influences of the Southwest Monsoon in summer and the Northeast Monsoon in winter. The Southwest Monsoon is rain bearing, but the Northeast Monsoon is stronger and characterized by a more constant dry wind that builds greater wave heights during its occurrence in autumn and winter. Typically, the wind and waves in the northeastern part of the SCS basin are more extreme than in the other basinal areas regardless of season, and in summer and autumn the SCS suffers from frequent tropical cyclones. Although most tropical cyclones are formed in the Western Pacific Ocean to the east of the Philippines, some tropical cyclones build up in the SCS near the Paracel Islands.

2.2. Data and preprocessing

The data involved in this study were organized into the following eight categories:

(1) *Sea surface wind speed data*. A total of 3288 phases of QuikScat daily wind speed grid data from 2000 to 2008 were collected to determine the wind speed at the height of 10 m above sea level. The data were produced by the Remote Sensing Systems (http://www.remss.com, accessed: November 24, 2012) and sponsored by the NASA Ocean Vector Winds Science Team. The grid size of the data is 900 arc second.

(2) *Significant wave height data*. Jason-1 Geophysical Data Record (GDR) data recorded from 2002 to 2011 were collected to acquire significant wave height. The altimeter products were produced and distributed by AVISO (http://www.aviso.oceanobs.com, accessed: October 10, 2012).

(3) *Gridded bathymetric data*. Bathymetric data of the SCS (grid size: 30 arc-second) was collected from the British Oceanographic Data Centre (BODC, http://www.bodc.ac.uk/data/online_delivery/gebco/, accessed: October 11, 2012).

(4) *Tropical cyclone data*. Tropical cyclone tracking information data for events in the SCS from 2002 to 2011 were collected from Unisys Weather (http://weather.unisys.com/hurricane/w_pacific/index.php, accessed: October 12, 2012).

(5) *Piracy and armed robbery (PAR) data*. Piracy and armed robbery incident data for events in the SCS from 2002 to 2011 were collected from the Global Integrated Shipping

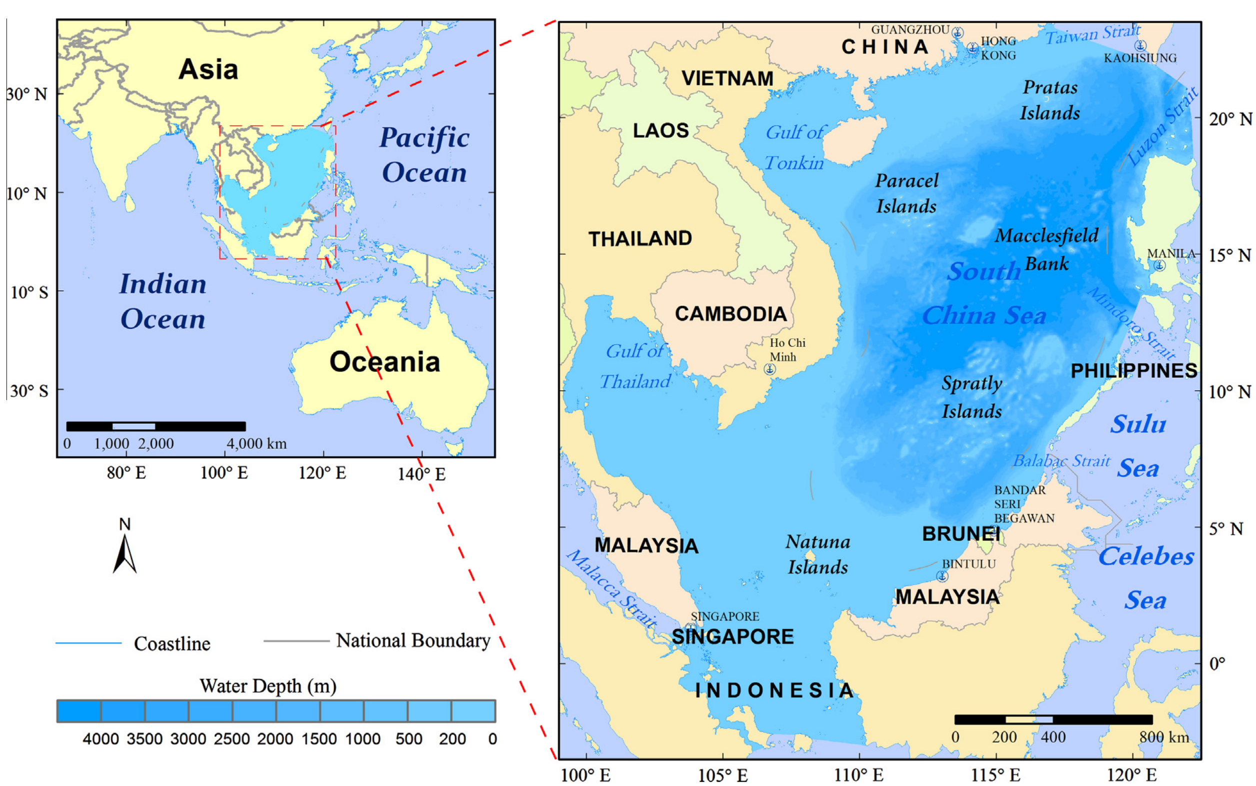

Fig. 1. The location of the South China Sea.