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Rip current hazards in South China headland beaches

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ABSTRACT

Beaches and coastal regions are commonly primary tourist destinations. Dollars spent by beach visitors annually provide significant input to local and regional economies. Hazards associated with rip currents can influence the suitably of any given stretch of coast as a recreational resource, and thus impact tourist dollars spent in addition to the safety and well-being of beach visitors. Therefore it is crucial to evaluate the degree of rip current risk along recreational beaches in order to protect human lives, maintain tourist attraction, and aid beach managers. Accordingly, a new rip current hazard assessment method is proposed based on the beach state model. Using the measured morphodynamic parameters (wave parameters, tidal ranges and sediment grain size) of 51 South China beaches, a preliminary assessment of rip current hazards was carried out. Results show that 71% of South China beaches may develop rip currents. The beaches in southern Fujian, Shanwei (in eastern Guangdong) and western Guangdong, and eastern and southern Hainan coasts have the highest risk of rip current development. The evaluation results are consistent with remote sensing observations, and beach incident (drowning and near-drowning) media reports. This paper indicates that the beach morphodynamic model of *Ω-RTR* (dimensionless fall velocity-relative tidal range) is a reasonable method to assess the rip current risk along sandy beaches. This information can aid coastal managers as well as reduce the frequency of rip current related incidents.

1. Introduction

Controlled by waves, tides, tidal currents, as well as antecedent geology, the complex morphology of beaches yield many hidden safety issues and present challenging questions to tourism management. Rip currents, the subject of this paper, present a significant hazard for beach tourists worldwide. In the United States, rip currents account for more than 80% of all surf rescues per year based on estimates from United States Lifesaving Association statistics (USLA, 2012; Brewster and Gould, 2014; Lascody, 1998; Lushine, 1991; Gensini and Ashley, 2010). In Australia, 89% of the more than 25,000 annual surf rescues conducted by lifeguards, lifesavers, and surfers are caused by rip currents with an estimated 40–50 rip-related drownings per year (Short and Hogan, 1994; Herker et al., 2008; SLSA, 2011). Rip currents are responsible for 67% of all individuals rescued by lifeguards on UK beaches, and Royal National Lifeboat Institution (RNLI) lifeguards assisted 12,607 people from 5798 rip current incidents between 2006 and 2011 (Woodward et al., 2013).

By definition, rip currents are strong, jet-like, seaward-directed currents that originate within the surf zone owing to alongshore gradients in wave-induced radiation stresses and pressure (Huschke, 1959; Bowen, 1969; Dalrymple, 1975, 1978; Bascom, 1980; Haller et al., 2002). Average offshore rip current velocities are around 0.3 m/s, and can exceed2 m/sunder certain circumstance (e.g. Lushine, 1991; Huntley et al., 1988; Short and Hogan, 1994; Houser et al., 2011a). These strong currents can quickly carry dispersing material, such as suspended sediments, nutrients and other floating material away from the surf zone into deeper water within minutes. Accordingly, rip currents can be considered an important morphodynamic process that transports both water and sediment, and consequently, drives changes in beach morphology (Brander, 2005).

Rip current hazard mitigation requires a variety of management strategies (Miloshis and Stephenson, 2011; Hatfield et al., 2012; Shaw et al., 2014). Accordingly, beach specific rip current hazard assessments are fundamental to establishing effective management strategies and can provide beach managers with a basis for advising people on how to recognize and avoid rip currents. Beach morphology is an important indicator of rip current risk and has been used in a variety of locations as a beach hazard management

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tool (e.g. Australia (Short and Hogan, 1994; Short, 1996), UK (Scott et al., 2007), USA (Benedet et al., 2004; Houser et al., 2008, 2011a, 2011b), Costa Rica (Arozarena et al., 2015), Brazil (Klein et al., 2003) and Korea (Yang et al., 2014)). Although rip currents are a common physical phenomenon on natural beaches along China's coast, rarely have investigations been carried out addressing both rip current theory and application. This paper focuses on rip current hazard assessment along south China headland beaches, the most common type of beach in South China, and largely relies on beach morphodynamic model.

2. Needs for rip current hazard assessment in China

China has hundreds of excellent beaches along its 18,000 km coastline, which attract large numbers of tourists and local residents. A tourism driven economy is becoming more and more important for China. Chinese marine economic statistical bulletin (2013) shows that the scale of China's coastal tourism economy continues to increase, and the added value reached RMB 7851 billion (about $1282 billion) in 2013, which was the largest component of the marine economy, accounting for 34.6% of the total output value of the marine economy (SOA, 2013). Owing to an overall lack of beach hazard awareness and lack of proper beach management strategies, a large number of beach drowning accidents occur in China every year. Although the exact number of rip current related deaths is difficult to estimate in China because of data gathering limitations, online/internet news can provide some insights into the nature of China's beach related drowning accidents. Table 1 illustrates reported drowning accidents that occurred at Dadonghai Beach, Sanya, Hainan Province, China between 2004 and 2013. Unfortunately, in China, rip currents are not very well understood by most people, including many beach managers. Most Chinese people refer to rip currents as undertow, invisible currents, or rip tides. Many local residents have described the phenomena as *"the seabed is not plain, there are many pits, trenches, and slopes on the seabed, and these pits and trenches easily lead to seawater gathered, and then form the undercurrent."*Thus, a more rigorous understanding of rip current risk is important for the protection of human life in China.

3. Study area and data collection

3.1. Description of the study area

A series of Mesozoic to Cenozoic-age NE–SW and NW–SE striking fault structures influence the coastal geomorphology of the South China coast. The trend, morphology, and pattern for many of the mountain ranges, rivers, coastal capes, bays, peninsulas, and islands were developed along both structural trends, resulting in hundreds of headland beaches forming along the subject coastline. These beaches have variable orientations, with lengths ranging from a few meters to over ten kilometers.

Wave and tide conditions are complex. Under the monsoon background, wave directions vary from NE in winter to SE in summer. Most incident wave directions are NE-E with the dominant wave direction NE in winter, and SE-S in summer. Maximum wave heights occur during the passage of typhoons during summer and fall; however, winter storms can also generate high waves for durations on the order of 10 days. Influenced by the coastal terrain, the distribution of annual mean wave height and period show a gradually decreasing trend from east to west. The annual mean wave height from Southern Fujian to eastern Guangdong and Pear River Estuary is 1.1–1.3 m with wave periods ranging from 3.9 to 5.1 s. Western Guangdong and eastern Hainan Island have an annual average wave height of 0.48–1.0 m and an annual average period of 3.5–4.2 s. The annual mean wave height along Beibu Bay is 0.5–0.8 m with an average wave period of 3.0–3.1 s. The tidal range along the southern Fujian and southern Guangxi coast is the largest at 4.0–6.0 m on average. Microtidal conditions exist from eastern Guangdong to Maomin, with an average tidal range of 1.0–2.0 m, while the tidal range on the east and west sides of Leizhou Peninsula is about 2.0–4.0 m.

3.2. Data collection

In order to investigate the rip currents risk along the South China coast, 51 headland beaches with lengths exceeding 1 km were selected for this study (Fig. 1). Beach morphodynamic parameters are shown in Fig. 2. These data mainly come from CCRBC (1993a, b, and c), CEGCZH (1995), Huang and Ye (1995), Su and Yuan (2004), and Wang et al. (2006). It should be noted that these researchers used different survey data, therefore, wave heights and tidal ranges have some variability along some coastal stretches. However, in those cases, their parameters are typically determined by taking average values. Because the early nearshore wave data in China were gathered using optical wave measurement instruments, wave heights in those data are the highest one-tenth of waves ($H_{1/10}$). The $H_{1/10}$ was transformed into mean wave height by linear wave theory. Tidal range was determined using the average and maximum tidal range. Some beaches lack wave height measurements and tidal range data. For those coastal stretches, data are interpolated from direct measurements made along adjacent and nearby beaches. Sediment grain sizes come from CCRBC (1993c), Wang et al. (2006), Cao et al. (2006), and Li and Zhu (2015).

Table 1
Drowning accidents reported by the online news during 2004–2013.

Date (mm/dd/yy)	Accident	Reference
07/18/2004	3 deaths, 4 rescues	Su (2004)
07/30/2004	12 drownings	Gao (2004)
05/01/2005–05/07/2005	3 deaths, 67 rescues	Su (2005a)
05/09/2005	2 rescues	Zhang and Xu (2005)
08/09/2007	11 rescues	Wang (2007)
08/23/2009	1 death	Zhang (2009)
09/28/2011	1 death	Zhang (2011)
05/07/2012	50 rescues in 5 days	Xu (2012)
06/18/2012	2 deaths	Cai (2012)
06/21/2012	over 70 rescues and 14 deaths from Jan to Jun,2012	Li (2012)
08/05/2012–08/12/2012	4 deaths, many rescues	Li & Wang (2013)
08/01/2013–08/21/2013	Aug 4th, 1 death, 8 rescues. Aug 9th, 1 death, 11 rescues Aug 16th,1 death 4 deaths and over 80 rescues from Aug 1st to 21st.	Zhang (2013)