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Navigable windows of the Northwest Passage

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ABSTRACT

Artic sea ice loss trends support a greater potential for Arctic shipping. The information of sea ice conditions is important for utilizing Arctic passages. Based on the shipping routes given by "Arctic Marine Shipping Assessment 2009 Report", the navigable windows of these routes and the constituent legs were calculated by using sea ice concentration product data from 2006 to 2015, by which a comprehensive knowledge of the sea ice condition of the Northwest Passage was achieved. The results showed that Route 4 (Lancaster Sound – Barrow Strait – Prince Regent Inlet and Bellot Strait – Franklin Strait – Larsen Sound – Victoria Strait – Queen Maud Gulf – Dease Strait – Coronation Gulf – Dolphin and Union Strait – Amundsen Gulf) had the best navigable expectation, Route 2 (Parry Channel - M'Clure Strait) had the worst, and the critical legs affecting the navigation of Northwest Passage were Viscount Melville Sound, Franklin Strait, Victoria Strait, Bellot Strait, M'Clure Strait and Prince of Wales Strait. The shortest navigable period of the routes of Northwest Passage was up to 69 days. The methods used and the results of the study can help the selection and evaluation of Arctic commercial routes.

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1. Introduction

19 September 2014, Canada's merchant ship "NUNAVIK" of FEDNAV INTERNATIONAL LTD. departed from Deception Bay and arrived at the port of Yingkou of China in 15 October, and became the first merchant ship passing through the entire Arctic Northwest Passage successfully. It is foreseeable that with global warming continuing, merchant ships operating between ports of Atlantic and ports of Pacific may divert to the Northwest Passage, which would decrease the distance up to 9000 km compared with the traditional routes via the Suez Canal, the Panama Canal, and the Horn of Africa. This has positive effects on global extraction of natural resources, transportation, and international trade. However, the development of Arctic commercial shipping routes largely depends on sea ice conditions along shipping routes. The sea ice conditions are not only important for the safety of navigation, but also determine the navigable period, the most important factor for analyzing the economy of the Arctic passage.

Studies on sea ice conditions of the Northwest Passage are related to the influence of sea ice on navigation from the perspective of transportation, which receives less attention. At present, most studies mainly focus on sea ice identification, deriving its information using remote sensing (Drinkwater et al., 1991; Haarpaintner and Spreen, 2007; Markus and Dokken, 2002; Shi and Wang, 2012; Spreen et al., 2008), and analyzing spatio-temporal changes of sea ice (Brown and Arrigo, 2012; Drobot and Maslanik, 2003; Howell et al., 2008; Kwok et al., 1996; Wensnahan et al., 1993). Studies involving Arctic passage include: Jie Su used quantitative indicators, such as melting period, light-ice period, ice-free days and light-ice days, to describe the characteristics of sea ice extent change of the Northwest Passage, and chose typical points on routes to represent the details of sea ice conditions (Jie et al., 2010). Qiang Fu identified critical water areas along the Northwest Passage by using "Admiralty Sailing Directions", and analyzed sea ice conditions with sea ice concentration product data (Qiang, 2012). Howell and Yackel analysed the relationship between sea ice conditions and shipping activities on the Northwest Passage (Howell and Yackel, 2004). However, these studies lack consideration for the needs of transportation, and concern less sea ice conditions of shipping routes and its characteristics, which cannot support the selection and evaluation of the routes sailed by merchant ships. Though "Admiralty Sailing Directions" provides a lot of information about Arctic marginal seas to facilitate the navigation of ships in this area, which has a great reference value for

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the safety of navigation, it lacks the temporal information of sea ice conditions of shipping routes, hardly supporting the development of the Arctic shipping.

Based on the routes of the Northwest Passage given by the "Arctic Marine Shipping Assessment 2009 Report" (Arctic Council, 2009), this study calculated the navigable windows of routes and their legs by using sea ice concentration product data from 2006 to 2015, and got a comprehensive knowledge of the sea ice condition of the Northwest Passage, which is important for the future development and use of the Northwest Passage.

2. Northwest Passage and data description

2.1. The Northwest Passage

The Northwest Passage is the name given to the various marine routes between the Atlantic and Pacific oceans along the northern coast of North America that span the Canadian Arctic Archipelago. According to "Arctic Marine Shipping Assessment 2009 Report", there are five recognized routes, with variations, through the Archipelago (Table 1). These routes share Labrador Sea, Davis Strait and Baffin Bay in the east (except for Route 5, which passes through Hudson Strait), and Bering Sea, Bering Strait, Chukchi Sea and the Beaufort Sea in the west. Of these routes, Route 1 and Route 2 have deeper water, while the others restrict the vessels with a draft less than 10 m due to shallow shoals and rocks. This study divided these routes into 17 separate legs to facilitate the analysis because these routes overlap in some segments (Table 2, Fig. 1).

2.2. Data description

Ten years of sea ice concentration product data with 6.25 km spatial resolution from 2006 to 2015 are used, which is developed by the PHAROS (PHysical Analysis of RemOte Sensing images) Team of the University of Bremen. Due to the replacement of satellites, the sea ice concentration product data are derived from the data of three microwave sensors, the Advanced Microwave Scanning Radiometer (AMSR-E) (2006–Oct. 2011), the Special Sensor Microwave Imager/Sounder (SSMIS) (Nov. 2011–Jul. 2012), and the Advanced Microwave Scanning Radiometer 2 (AMSR2) (Aug. 2012 to data) respectively. Although SSMIS have a different frequency of 91 GHz compared with AMSR-E and AMSR2 (89 GHz) and a coarser spatial resolution, the same algorithm and the spatial resolution were applied to achieve the best compatibility. The data value is from 0 to 100 with 0 representing ice free and 100 a full ice coverage respectively. Missing or wrong data is marked as NaN (Not a Number) values.

Table 2
Legs' names and their numbering.

No.	Leg's name	No.	Leg's name
1	Lancaster Sound	10	Viscount Melville Sound
2	Leg 2	11	Amundsen Gulf
3	Peel Sound	12	Barrow Strait
4	Prince of Wales Strait	13	Bellot Strait
5	Prince Regent Inlet	14	Coronation Gulf
6	J.R.S.-R.S.-S.S.	15	Dease Strait
7	Franklin Strait	16	Dolphin and Union Strait
8	Queen Maud Gulf	17	M'Clure Strait
9	Victoria Strait		

3. Navigable windows of the Northwest Passage

Navigable window of shipping route reflects the sea ice conditions of water areas sailed by ships. It is defined as the navigable period and its start/end date of water areas sailed by ships, where ships can sail without icebreaker assistance.

3.1. Technology roadmap

(1) Data preprocessing mainly contained two steps: stacking sea ice concentration data of one year into one data set in order to calculate the navigable windows of shipping routes; projection transformation (see Fig. 2).
(2) According to the definition of navigable window and the 40% of sea ice concentration under which Chinese "Yongsheng" Ship (icebreaking capability PC6) can sail on the Northeast Passage without icebreaker assistance, 40% of sea ice concentration was selected as the threshold to calculate the navigable windows of shipping routes. In practice, the shipping route was overlaid on the yearly sea ice concentration data set. So, the yearly sea ice concentration of each pixel passed by the shipping route can be extracted. The first day of the opening of the pixel on the route was taken as the start date of navigable window when the sea ice concentration of three consecutive days were all less than 40%, and the last day was taken as the end date of navigable window when the sea ice concentration of three consecutive days were all greater than 40%.
(3) According to the navigable windows of the routes and their legs, the sea ice conditions were compared and analyzed in order to acquire a comprehensive knowledge of the navigable windows of the Northwest Passage.

In addition, data anomalies or data missing were unavoidable for satellite data, and they were corrected by interpolation. All images processing were finished with ENVI (Environment for

Table 1
The routes of the Northwest Passage and their legs.

No.	Routes (east to west)	Composition of legs (Table 2)
1	Lancaster Sound – Barrow Strait – Viscount Melville Sound – Prince of Wales Strait – Amundsen Gulf.	1-12-10-4-11
2	Same as 1 but substitute M'Clure Strait for Prince of Wales Strait and Amundsen Gulf. Collectively Lancaster Sound – Barrow Strait – Viscount Melville Sound is known as Parry Channel.	1-12-10-17
3A	Lancaster Sound – Barrow Strait – Peel Sound – Franklin Strait – Larsen Sound – Victoria Strait – Queen Maud Gulf – Dease Strait – Coronation Gulf – Dolphin and Union Strait – Amundsen Gulf.	1-12-3-7-9-8-15-14-16-11
3B	A variation of 3A. Rather than following Victoria Strait on the west side of King William Island, the route passes to the east of the island following James Ross Strait – Rae Strait – Simpson Strait.	1-12-3-7-6-8-15-14-16-11
4	Similar to 3A. Rather than following Peel Sound on the west side of Somerset Island, the route passes to the east of the island through Prince Regent Inlet and Bellot Strait.	1-5-13-7-9-8-15-14-16-11
5	Hudson Strait – Foxe Channel – Foxe Basin – Fury and Hecla Strait – Gulf of Boothia – Bellot Strait – remainder via routes 3A, 3B or 4.	2-13-7-9-8-15-14-16-11

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