SPAFACON2021

Papers from the SEAMEO SPAFA International Conference on SOUTHEAST ASIAN ARCHAEOLOGY AND FINE ARTS

13 - 17 December 2021

Editor: Noel Hidalgo Tan

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INTRODUCTION

This volume contains the extended abstracts from the papers presented at the SEAMEO SPAFA International Conference on Southeast Asian Archaeology and Fine Arts, which was held online from 13 to 17 December 2021. Also known as the SPAFACON2021, this conference was organised online due to the pandemic. Despite the disruption brought about by Covid-19 to our in-person events, training programmes and field research, it is heartening to see that archaeology and cultural heritage has continued under new modes of communication and collaboration.

This fourth iteration of the SPAFACON is also scheduled a year earlier than our usual triennial cycle to commemorate the 50th anniversary of SEAMEO initiating a centre dedicated towards archaeology and the fine arts. Over the past year, SPAFA has also been highlighting this legacy of international cooperation and capacity-building by sharing our photographic archives on our social media.

I am delighted by the high level of enthusiasm and intellectual curiosity brought by the participants to the conference. During our call for papers we received close to 90 submissions, but owing to the pressures of time and the online format, we were only able to accept 34 papers for the conference. The variety of papers present here, although a small set compared with our usual proceedings, reflects the breadth of the centre's ambit – covering not just archaeology, but also performing arts, visual arts, museum studies, and other aspects of Southeast Asian cultural heritage.

I would like to thank all the participants, without whom this conference would not be possible in its present form, in particular, our Governing Board members who represent every country in Southeast Asia, and to the Ministry of Culture, Thailand and the Ministry of Education, Thailand for their long-standing support of SEAMEO SPAFA and its activities.

Mrs Somlak Charoenpot
Centre Director
SEAMEO SPAFA

Sequential Least-Cost Path Sailing Model for Early 17th Century South China Sea: Digitally Navigating the Selden Map of China

10792/pqcnu8815a-05
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Abstract

During the 17th century, Southeast Asia was a bustling hub of maritime commerce. The Selden Map of China depicts some of the trade routes in the area and is drawn in a way which allows their sailing durations to be measured. This information is used in the development of a sequential least-cost path sailing model that utilizes deterministic time-series wind data. The model can be used to simulate the optimized routes and durations between any points A and B in the South China Sea. With minor modifications, the method is applicable to other time periods and geographical settings.

Keywords

GIS; Least-cost path; Sailing; Selden Map of China; Southeast Asia; South China Sea

Introduction

During the Early Modern Period Southeast Asia (SEA) played a major role in international trade. Situated between the cultural and economic powerhouses of China and India and as a producer of luxury and bulk goods in high demand, it was an important part of the Maritime Silk Route. Due to geography and the natural rhythm of the East Asian monsoon wind patterns, SEA had a commanding view over the maritime trade flowing through the area.

The Selden Map of China offers us a glimpse of these networks in the early 17th century. The period 1570–1630 has been called "the boom years" for the region (Reid 1988: 16–24) and the Selden map shows some of the trade routes that criss-crossed in the area at the time. The map is drawn in a unique way, which allows the sailing durations of those routes to be calculated. In my recent article, I used this information to construct a directed sailing model based on sequential least-cost path analysis and deterministic time-series wind data. The model can be used to simulate the optimized route and sailing duration between any points A and B in the South China Sea. In this paper, I will briefly present how the model works. The study is a part of the '*Ports and harbours of Southeast Asia: Human-environment entanglements in Early Modern maritime trade networks*' project.

Research History

Ancient seafaring has been modelled on computers since the 1970s, and in the 21st century it has become a more established field of study (for listings of previous studies see Davies and Bickler 2015: 215–218, table 1; Slayton 2018: 48–61, table 1; for more recent studies see e.g. Alberti 2018; Gal et al. 2021; Gustas & Supernant 2019; Jarriel 2018; Kealy et al. 2018; Perttola in press, Safadi & Sturt 2019). During this time, various methods have been developed to simulate different modes of seaborne movement, which can address drifting along the currents and/or winds, paddling/rowing, sailing or some combination of the above depending on the region, time period and research question under study. The models can be further classified into drifting simulations, where only the starting point is known, and directed simulations, in which also the end point of the voyage is set in advance. Here I will limit the discussion to studies that model directed sail-powered voyages using the ArcGIS's least-cost pathing tools and their horizontal factor (HF) functionality (for a more comprehensive look at the research history, see e.g. Slayton 2018: 48–61).

The first such seafaring model was created by Leidwanger (2013; 2014: 9, fig. 4–5; see also 2020: 139–151). It simulated sailing in the ancient eastern Mediterranean based on modern yearly wind speed and direction, and the resulting cost distance time bands indicate the sailing time needed reach every other cell in the research area from the starting point using an optimal route. Due to the use of a HF the model is anisotropic: the cost of movement is dependent on the direction of travel, or in simplified terms, it is easier to sail downwind than upwind. Alberti (2018) developed the method further by creating an ArcGIS toolbox to automate the process and by using monthly mean winds. In addition, he calculated the least-cost paths between the start and end points of some ancient eastern Mediterranean voyages and compared the simulated sailing durations to the reported ones. His results matched the historical accounts fairly well with some tendency toward overestimation. In my recent addition to the discussion (Perttola in press), I have suggested a novel way of incorporating dynamic time-series wind data into the least-cost path analysis. The method will be expanded upon in the next section.

Method

In short, least-cost pathing is based on assigning a cost to movement and finding a route along which the accumulated cost is the lowest possible (Esri 2020a, 2020b). For this purpose, the research area is divided into a regular grid and a cost is assigned to each cell depicting for example energy consumption, price or – as in this case – time required to move across it in the prevailing wind. The cost raster can be used to calculate cost distance that tells the minimum accumulated cost needed to reach each cell from the chosen source cell. Furthermore, a least-cost path to a destination cell can be computed from the cost distance and backlink rasters. In other words, the analysis allows us to find the fastest route and travel duration between points A and B.

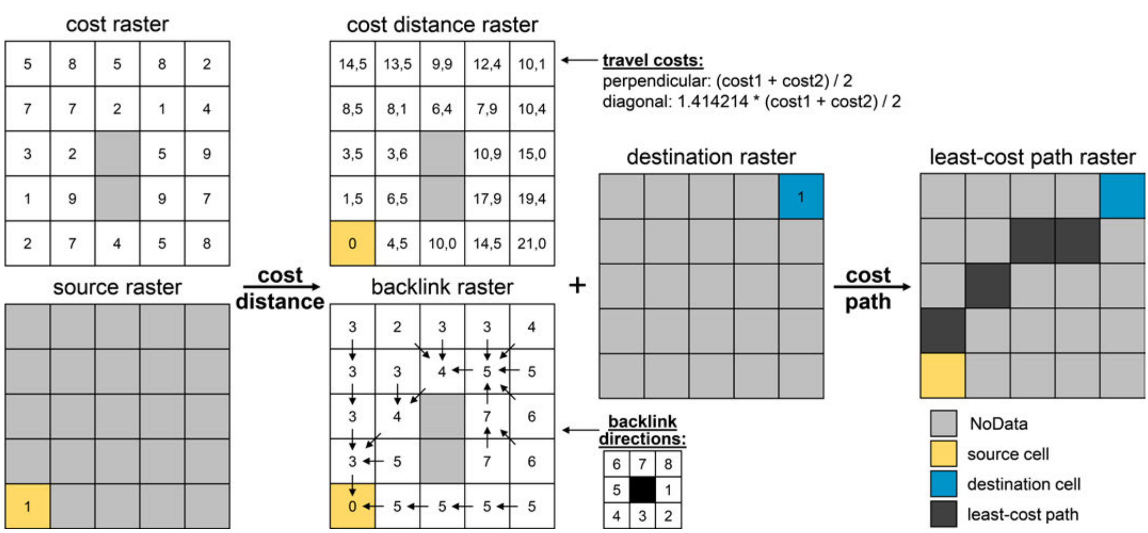

Fig. 1 The principles of cost distance and least-cost path analyses without the use of a HF (Esri 2020a, 2020b). Source: Perttola in press.

In the form above the analysis is only isotropic, i.e. the cost of movement is the same regardless of the movement direction, but it can be made anisotropic by using a horizontal and/or a vertical factor (Esri 2020c). The vertical factor can be disregarded because at sea the "landscape" can be assumed to be flat. Instead, a horizontal factor in conjunction with wind direction data is used to modify the cost and, in other words, change the speed of the ship accordingly. The performance values of historical ship types can be measured from sailing tests done on reconstructions (e.g. Nomoto et al. 2003) or estimated from historical accounts (Whitewright 2011). During my research I was unable to find this data for historical junks and therefore had to choose a roughly comparable substitute for my study. The polar chart used in this study (fig. 2) comes from latteen/settee rigged vessels of the Mediterranean and the Red Sea (ibid.), and therefore depicts more a generalized ship of the era than specifically junks. If performance data for junks becomes available, it is possible to incorporate it into the model and further refine the results. When the polar chart is transformed into a HF table it can be inputted to the ArcGIS's Cost Distance tool. The simulated ship's ship-speed-to-wind-speed ratio is set to 0,4 (cf. e.g. Nomoto et al. 2003: 143–144, fig. 13) until 25 knot wind speed, after which the speed starts to decline as seen in figure 3.

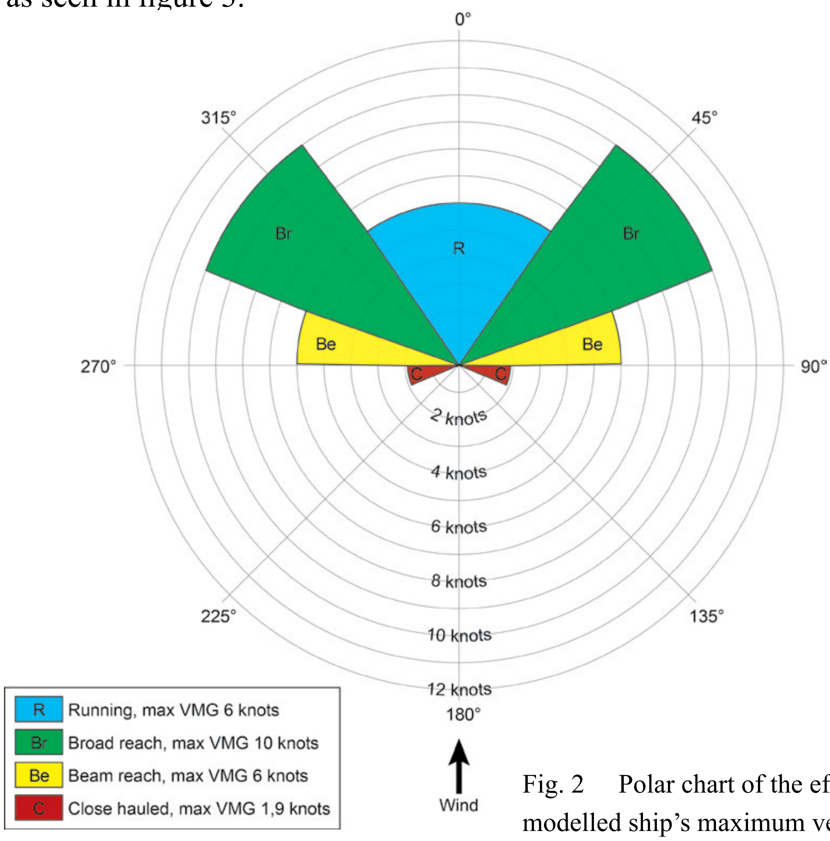

Fig. 2 Polar chart of the effects of points of sail on the modelled ship's maximum velocity made good (VMG) when wind is blowing from the south (adapted from Whitewright, 2011: 14). Source: Perttola in press.

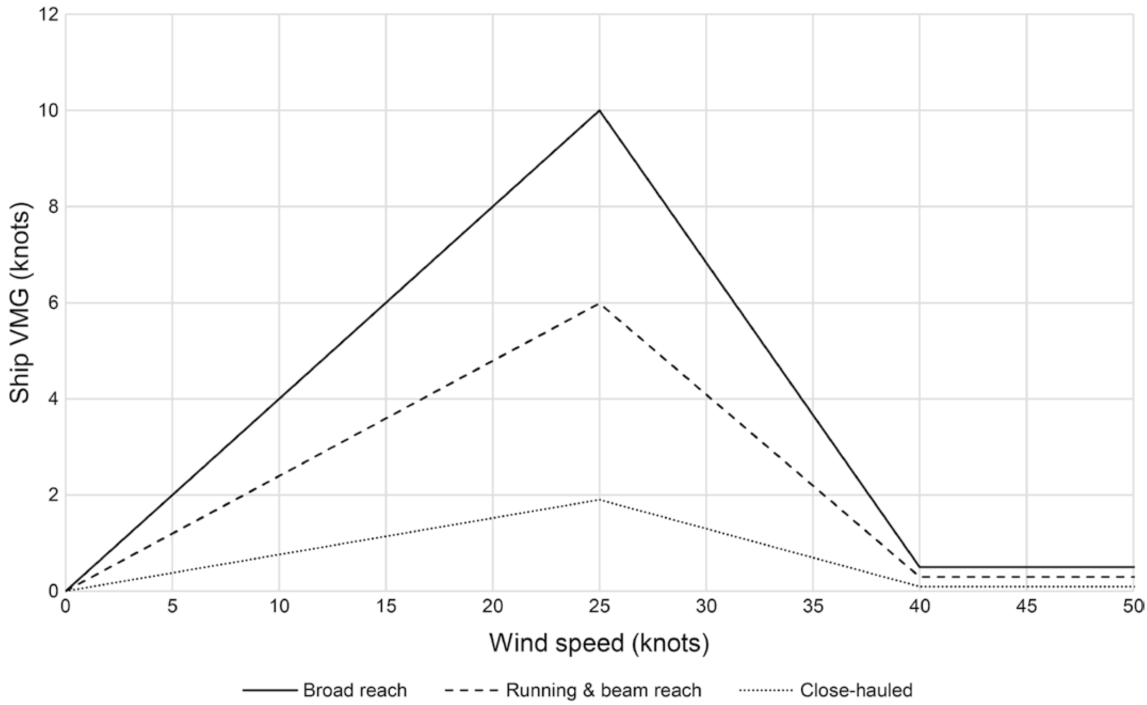

Fig. 3 Ship's VMG in relation to wind speed in different points of sail (Perttola in press).

During a single least-cost path analysis only one wind speed and direction data raster can be inputted to the process. In other words, the winds remain static no matter how long the voyage takes. While other modelling methods have been able to incorporate dynamic winds (e.g. Davies and Bickler 2015), previous ArcGIS based least-cost path models relied on mean wind data. However, it is possible divide the least-cost path analysis into segments by 1) calculating what point the vessel has reached in for example six hours, 2) choosing that point to be the new source point, 3) updating the wind data accordingly, and 4) repeating the process until the final destination is reached (Perttola in press). Doing this manually is not feasible on longer voyages as it would mean repeating the same operating steps several dozens or hundreds of times. The process can be automated with the use of Python macros (fig. 4).

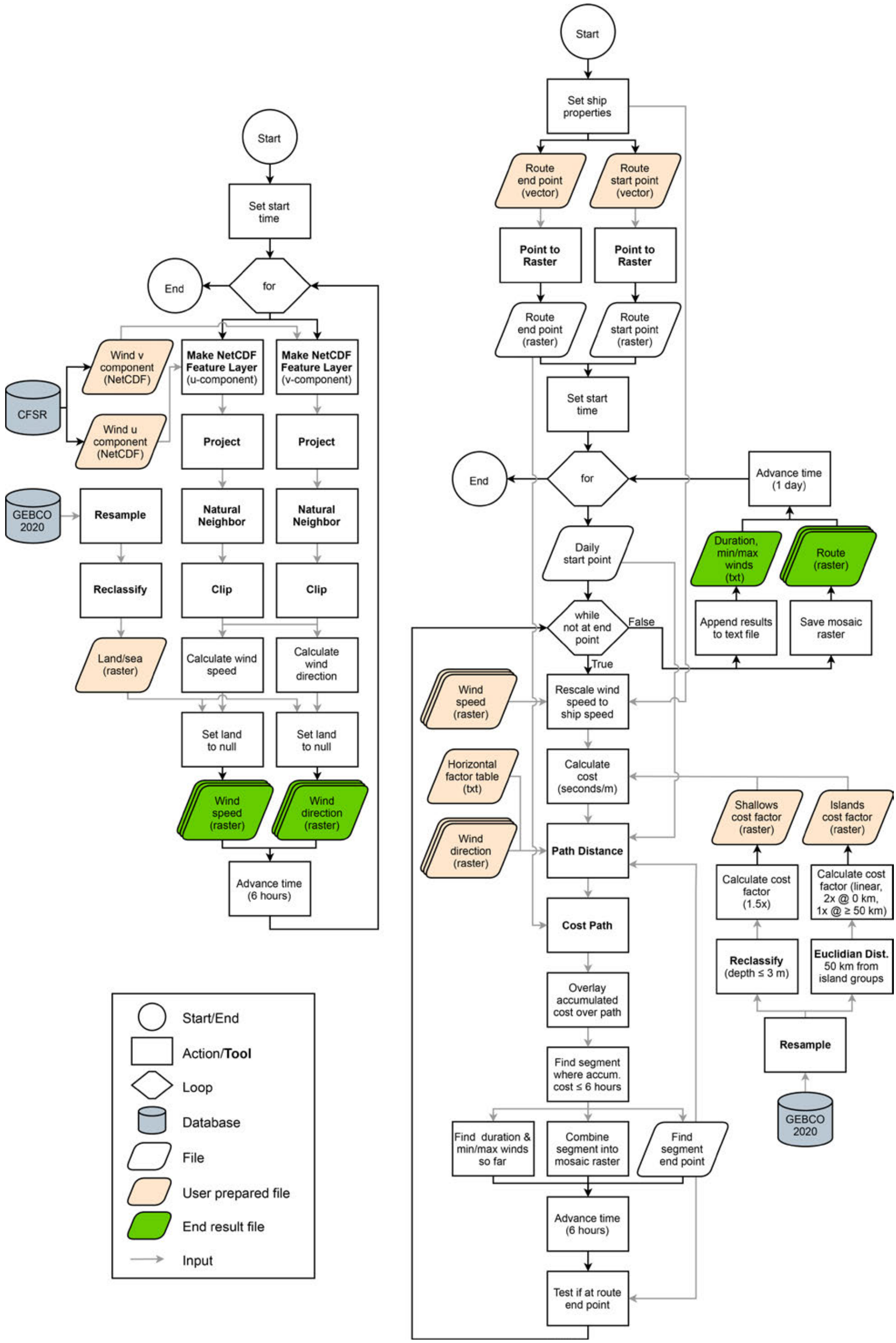

Fig. 4 Simplified flowcharts of the macros. Source: Perttola in press.

The macro is split into two parts: the first batch processed the wind data into a form that is usable in ArcGIS's Path Distance tool and the second one performs the segmented least cost path analysis. The analysis can also be set to repeat at the desired interval, for example a new ship to depart daily throughout the year. The wind data is taken from the Climate Forecast System Reanalysis dataset (CFSR; Saha et al. 2010), which has a 0,5° x 0,5° (c. 56 km at the equator) spatial and hourly temporal resolution. Wind speeds have recently decreased due to climate change (e.g. Xu et al. 2006) so the earliest possible data – i.e. the near surface winds from 1979–1980 – were selected to be in more line with the circumstances of the early 17th century. In addition, data from the General Bathymetric Chart of the Oceans' GEBCO_2020 global gridded ocean and land terrain model (GEBCO Compilation Group 2020) is used to differentiate land from sea and to introduce extra movement cost in proximity to certain island groups and in shallow parts of the ocean.

The Selden Map of China

The simulated sailing durations need to be compared against historical accounts in order to validate the model, and this is where the Selden Map of China (*Dongxiyang Hanghai Tu*, Nautical Chart of the Eastern and Western Seas; fig. 5) comes into play. The map dates to c. 1619 (Batchelor 2013: 55) and is remarkable in many ways, of which the most important ones for this study are 1) it covers the whole of Southeast Asia in addition to China, 2) there are several trade routes marked on the map and 3) it is drawn in a way that allows the sailing durations to be calculated for the routes (Batchelor 2013: 43–49; Brook 2015: 11–13, 87–88, 105–109, 162–163; Davies 2013: 98–99; Nie 2019: 9–15). The latter is possible because of the scale bar at the top of the map. Although its units are not marked on the map, the current consensus is that the major division depict days and the minor 2,4-hour ship's watches (*geng*) (ibid.). In addition, the route line segments are accompanied by compass headings. In other words, the map functions as a visual rutter.

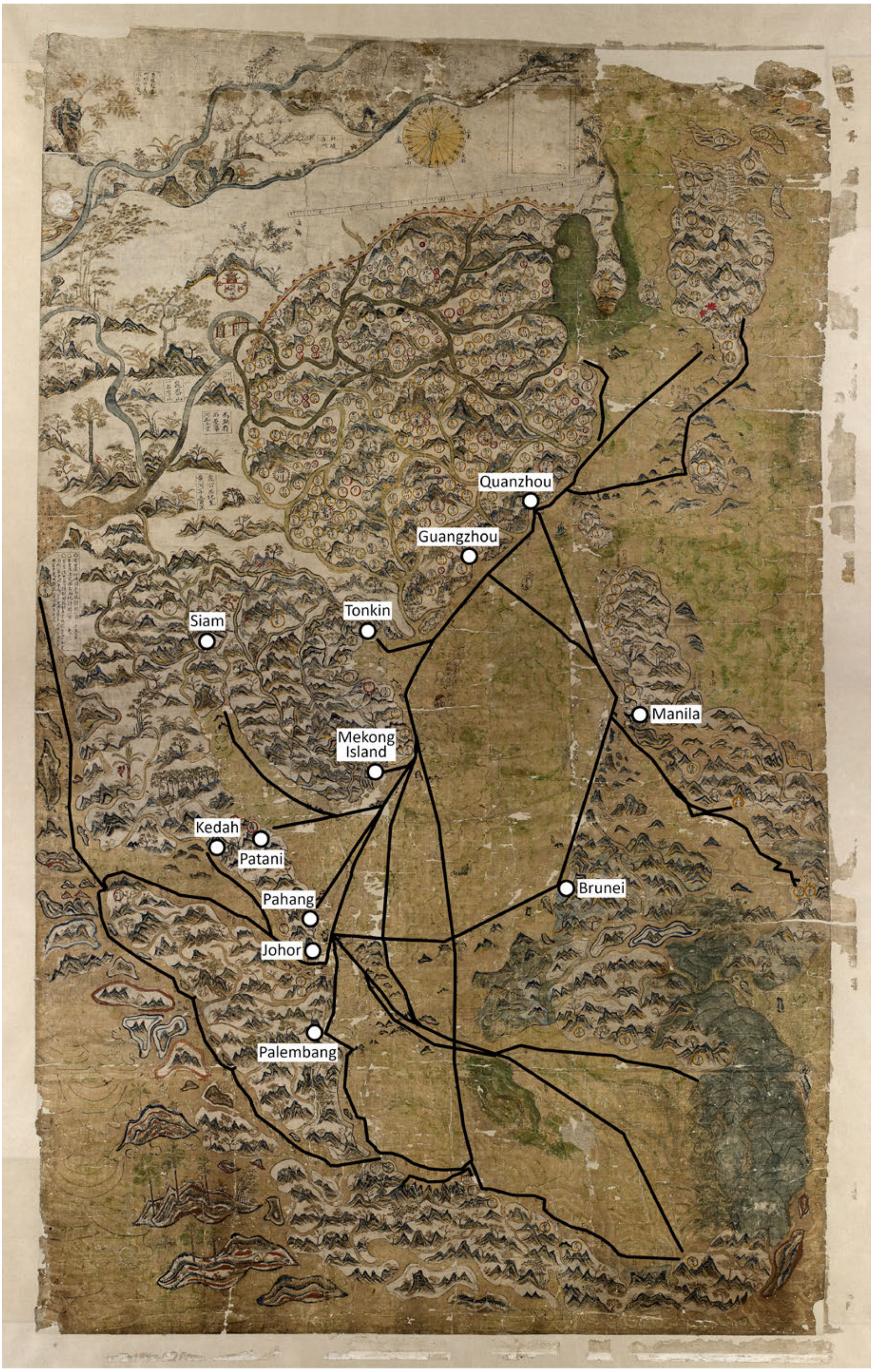

Fig. 5. The Selden Map of China. The routes and ports used in modelling are emphasized by the author. The naming convention follows Batchelor (2013: fig. 2). Photo: The Bodleian Libraries, University of Oxford, MS. Selden Supra 105, Map recto (CC-BY-NC 4.0). Source: Perttola in press.

Consequently, the map can be scaled in GIS, the routes replicated as polylines and their lengths/durations computed. For example, the route from Quanzhou to Mekong Island takes 10,85 days of sailing according to the map. Measured on a modern map, the length of a similar route is c. 2300 km resulting in an average speed of 4,8 knots, which is well within the sailing capabilities of historical junks. Most likely the Selden map routes are based on typical voyages made in good wind and weather conditions, but the map itself does not offer us any clues on when these were to be expected. The wind patterns in the South China Sea area are governed by the East Asian Monsoon: during the winter monsoon (November to March) winds blow generally speaking from northeast, but for the summer monsoon (April to September) they switch to the opposite direction. This has the effect of making sail-powered maritime travel and trade highly cyclical in nature. Hence, the least-cost path analyses discussed in the next section are done throughout the year. Also, Quanzhou has been recognized as a central port on the Selden map (Batchelor, 2013: 49; 2015; Brook, 2015: 113; Nie, 2019: 32–33) and is set as the starting or ending point for many of the calculations.

Results and Discussion

To validate the model, least-cost paths and their durations were calculated from Quanzhou to other Selden map ports for the first days of each month (table 1). During the analysis a small time skip happens when switching from one 6-hour segment to the next because the accumulated cost to the furthest point on the least-cost path is somewhat less than 6 hours. The results are therefore expressed as two numbers: the lower is the total accumulated cost and the higher is based on full 6-hour cycles spent on the voyage. The results show that the fastest modelled voyage (fig. 6a) underestimates the Selden map 6 cases out of 11 by some days, and if the routes were simulated daily it is very likely that even lower values would be found. However, I would argue that some overestimation is to be expected: it is unlikely that the map is based on a "high score table" of the fastest voyages ever made. Other possibly contributing factors are that the simulation is free to choose an optimal course and not follow the coast as the routes on the Selden map often do, the winds in 1979 could be unusually advantageous or that the ship properties used are too optimistic. All things considered, the model matches the Selden map data fairly well.

Table 1 Distances and sailing durations from Quanzhou to Selden map ports in the study area for ships launched every first day of a month based on the winds of 1979–1980 (Perttola in press). The fastest voyages on a route are marked with green if it underestimates or with orange if it overestimates the Selden map durations (for their routes, see Fig 6a).

Selden map route				Simulated sailing durations (days; accumulated cost & loop based duration)											
From Quanzhou to	Dist. on modern map (km)	Dist. on Selden map (days)	Avg. speed (knots)	1.1.	1.2.	1.3.	1.4.	1.5.	1.6.	1.7.	1.8.	1.9.	1.10.	1.11.	1.12.
Brunei	2350	13,10	4,0	10,17 10,25	53,95 57,25	25,30 26,50	29,46 30,75	109,51 115,50	79,60 84,50	117,68 122,50	87,94 91,50	39,31 40,50	31,50 32,75	100,45 106,25	13,67 14,00
Guangzhou	620	2,70	5,2	4,57 4,75	3,11 3,25	2,89 3,00	4,33 4,50	3,23 3,25	11,16 12,00	28,97 30,25	4,02 4,25	13,38 14,00	3,19 3,25	3,13 3,25	2,78 3,00
Johor	3280	17,15	4,3	16,05 16,25	25,90 26,50	39,93 43,75	77,17 81,25	173,66 181,25	143,87 150,25	112,92 116,75	83,12 85,75	52,55 54,75	27,45 28,00	21,55 22,00	13,21 13,50
Kedah	4000	22,55	4,0	32,61 34,00	54,79 58,75	59,35 65,50	101,51 107,00	206,35 216,75	176,45 185,75	150,44 157,50	120,70 126,50	90,12 95,50	59,84 63,75	64,17 70,75	58,15 63,75
Manila	1160	6,70	3,9	38,39 41,50	37,09 39,75	14,60 15,50	16,53 17,25	15,15 15,50	41,55 43,25	29,94 31,25	22,57 23,00	39,40 40,75	7,91 8,25	13,88 14,75	21,25 22,50
Mekong Isl.	2300	10,85	4,8	9,98 10,25	15,05 15,25	22,92 23,50	26,38 27,00	103,37 108,00	73,61 77,00	96,05 99,75	65,35 68,75	36,24 37,75	17,30 17,75	11,56 11,75	9,28 9,50
Pahang	3070	15,40	4,5	14,95 15,25	20,59 21,00	31,75 33,75	43,89 45,75	155,01 162,50	125,42 131,50	113,10 116,50	83,36 85,50	49,95 51,75	23,89 24,50	16,06 16,25	11,93 12,00
Palembang	3640	19,30	4,2	17,58 17,75	32,53 33,25	61,66 68,25	119,55 131,50	190,12 199,75	160,87 168,75	131,83 138,75	102,13 107,75	64,23 68,25	43,32 46,75	27,87 28,75	14,99 15,50
Patani	3050	15,10	4,5	14,36 14,50	19,12 19,50	27,71 28,50	31,77 32,75	133,16 138,50	103,24 107,50	109,35 113,25	79,71 82,25	47,99 50,00	20,83 21,25	14,90 15,00	12,16 12,25
Siam	3880	18,25	4,8	20,68 21,00	30,65 31,75	30,22 31,25	34,89 35,50	139,82 146,00	109,97 115,00	125,06 132,75	103,89 110,00	65,04 70,75	52,19 56,00	29,02 31,00	20,03 20,50
Tonkin	1650	7,50	4,9	11,57 11,75	11,55 11,75	11,67 12,00	12,29 12,75	12,52 13,00	20,25 21,00	37,32 38,75	8,67 8,75	18,44 19,25	8,33 8,50	10,97 11,25	9,29 9,50

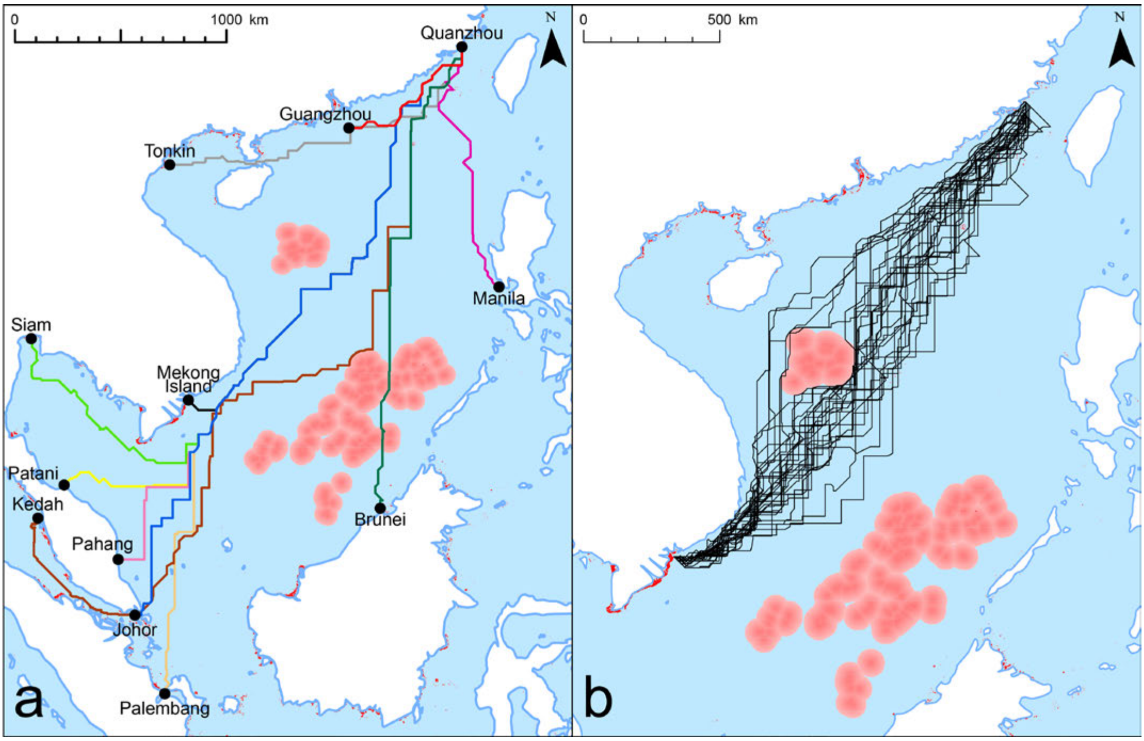

Fig. 6 a) Fastest simulated routes from Table 1. b) Simulated routes from Quanzhou to Mekong Island for November launch dates (Perttola in press). The extra cost for island group proximity is marked with light red and shallows with red. Source: Perttola in press.

The route Quanzhou – Mekong Island was chosen for a more detailed daily analysis (fig. 6b and 7). A ship departing from Quanzhou could reach Mekong Island in less than c. 30 days from the start of January to mid-April and again from mid-September to the end of December with November being the fastest month on average. To the opposite direction, the favourable window is much shorter from early May to mid-August with June as the fastest on average. In both directions the winds are quite dependable, but the favourable sailing season comes to a very abrupt end. The switch between the monsoons happens very quickly and setting sail just a few days late could lead to major delays. However, when interpreting least-cost path results one must keep in mind that least-cost path analysis is not good at simulating tacking properly and can instead take very adventurous routes that no real sailor would consider. The high values should therefore be understood more as periods when sailing was not likely to be attempted than actual sailing durations.

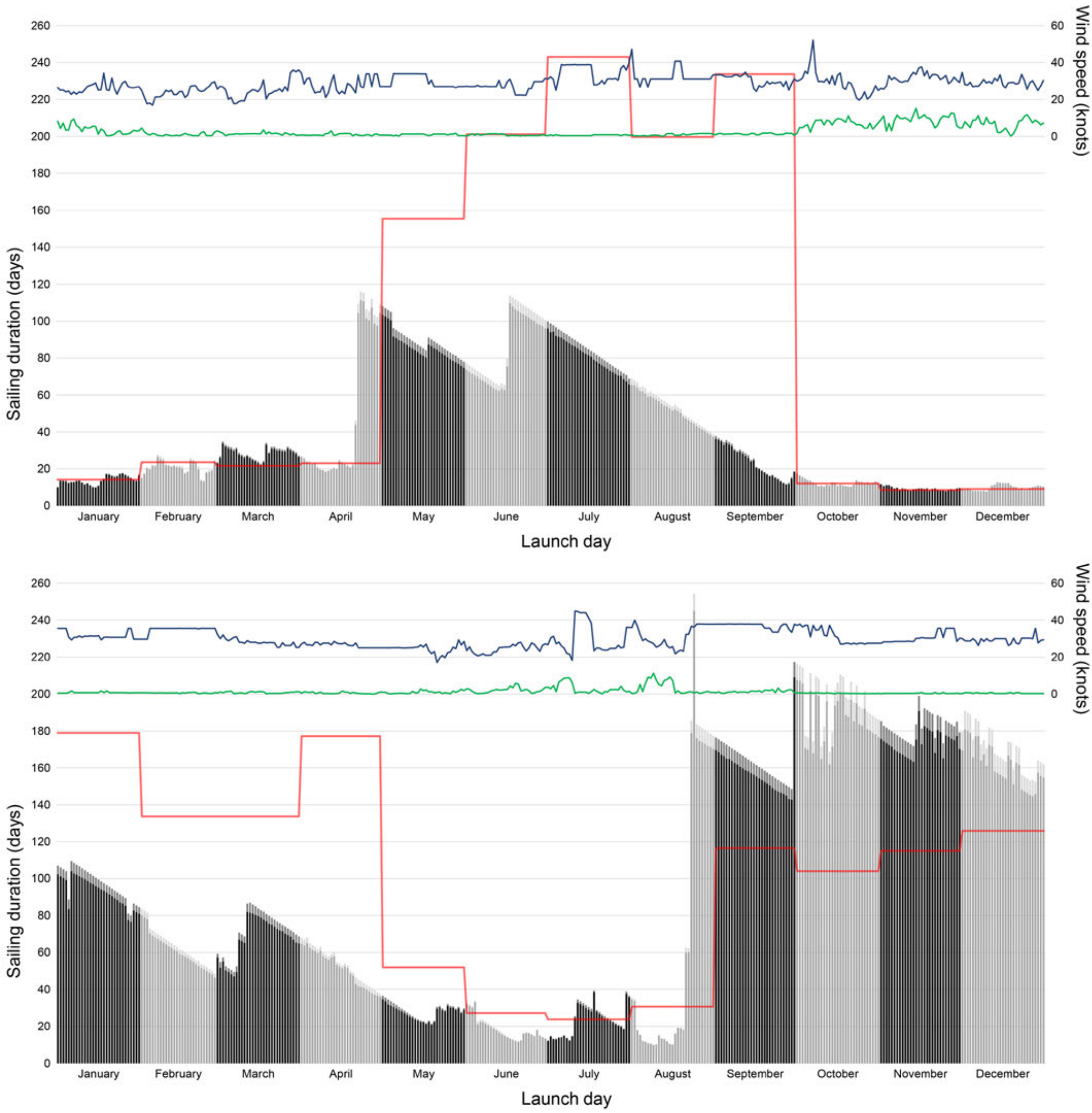

Fig. 7. Daily simulated sailing durations on the routes Quanzhou – Mekong Island (top) and Mekong Island – Quanzhou (bottom). The accumulated cost is shown in darker and loop-based duration in lighter gray). The red line denotes the sailing duration calculated from monthly mean winds. Minimum and maximum winds encountered on the route are marked with green and blue lines respectively. Source: Perttola in press.

Since the writing of my article (Perttola in press), I have analysed also the route Johor – Palempang and Palempang – Johor daily in the same manner (fig 8). The distance between these ports as marked on the Selden map (i.e. not including the travel up river Musi) with some extrapolation is c. 2,75 days. The best months for departing from Johor are January and December and on the opposite route from June to August. In general, sailing from Palempang to Johor was easier than vice versa.

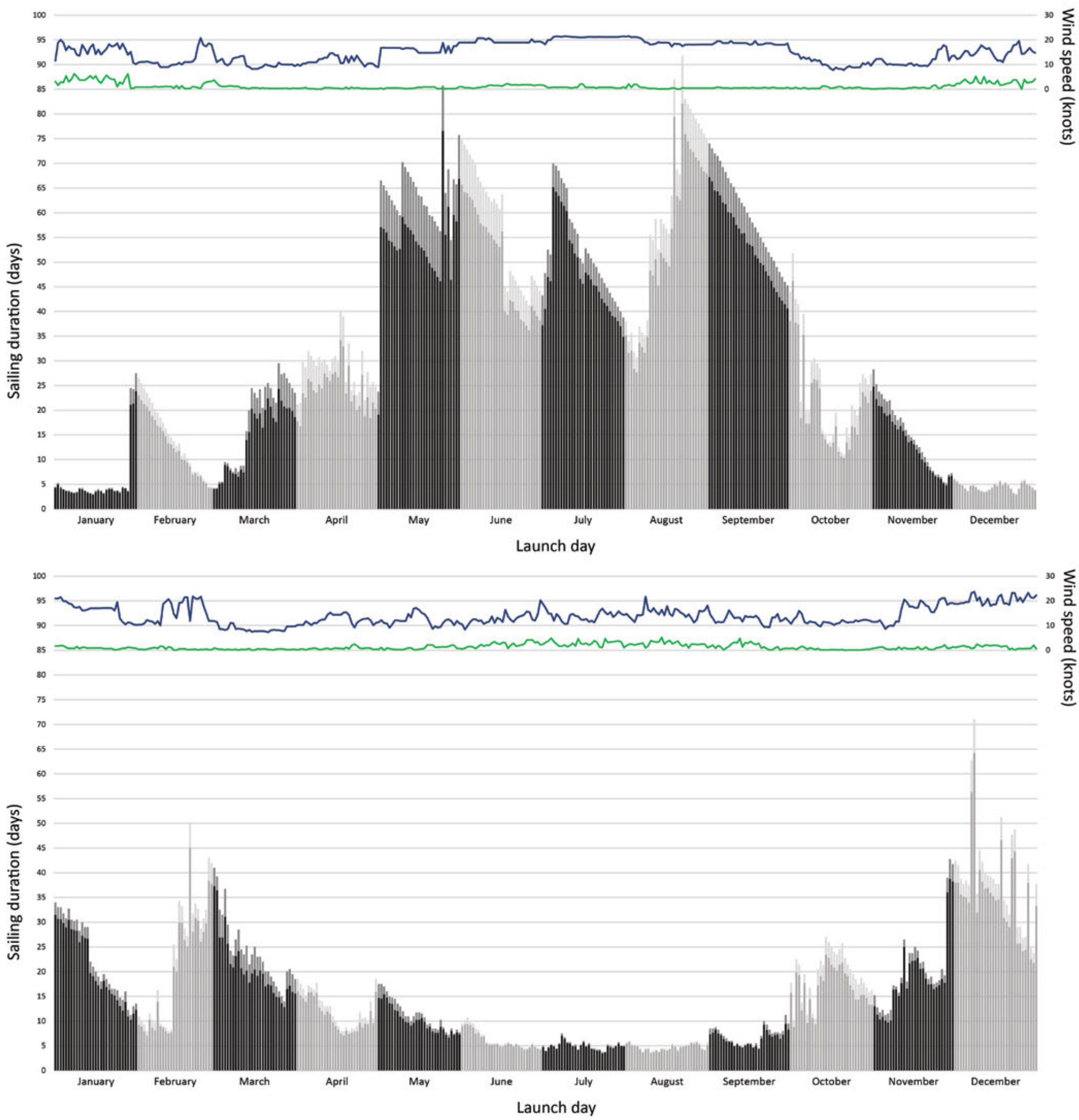

Fig 8. Daily simulated sailing durations on the routes Johor – Palempang (top) and Palempang – Johor (bottom). The accumulated cost is shown in darker and loop-based duration in lighter gray). Minimum and maximum winds encountered on the route are marked with green and blue lines respectively. Source: Wesa Perttola.

Conclusions

The development of the sequential least-cost path analysis was successful, and it offers a new option to the modelling of directed sail-powered voyages based on deterministic time series wind data. It can be used to estimate the sailing durations for voyages not present on the Selden map and helps us visualize the effect of changing wind patterns in terms of time spent at sea. Moreover, the method can be employed to other regions, time periods and ship types with minor modifications to the macros. Through analysing how ships and their crews moved through maritime space and time, we will better our understanding on how trade networks – and the human interactions behind them – worked in the past.

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