Supplementary Material: The Risk of Synoptic-Scale Arctic Cyclones to Shipping

Alexander F. Vessey[1,2], Kevin I. Hodges[2,3], Len C. Shaffrey[2,3], and Jonathan J. Day[3]

[1]AXA XL, 20 Gracechurch Street, London, UK, EC3V 0BG
[2]Department of Meteorology, University of Reading, Earley Gate, Reading RG6 6BB, UK
[3]National Centre for Atmospheric Science, University of Reading, Earley Gate, Reading RG6 6BB, UK
[4]ECMWF, Shinfeld Park, Reading RG2 9AX, UK

Correspondence: Alexander F. Vessey (alecvessey@hotmail.co.uk)

Table S1. Distances between major ports in Europe and North America to major ports in Asia when using Arctic routes, or mid-latitude routes (the Suez Canal Route between Europe and Asia, and the Panama Canal Route between North America and Asia). The distances have been calculated on Google Earth (Google, 2021), and are given to the nearest hundred nautical miles (nm).

Departure Port	Destination Port	Distance Using Mid-Latitude Route	Distance Using Arctic Route (1979-2020 mean Sept. Arctic Sea Ice extent)	Arctic Minus Mid-Latitude Route (1979- 2020 Sept. Arctic Sea Ice extent)
Rotterdam	Tokyo	11,300 nm	7,000 nm	**-4,300 nm**
Rotterdam	Shanghai	10,500 nm	7,900 nm	**-2,600 nm**
New York and New Jersey	Tokyo	9,700 nm	7,400 nm	**-2,300 nm**
New York and New Jersey	Shanghai	10,700 nm	8,300 nm	**-2,400 nm**

Table S2. Time, vessel name, type of incident and whether the vessel was damaged or lost of shipping accidents following the intersection of a ship track within a radius of 3° of the location of Arctic cyclones' maximum 10 metre wind speeds greater than 17 ms^{-1}. Shipping incident data from PAME (2023).

Time of Incident (YYYY/MM/DD)	Vessel Name	Type of Incident	Vessel Lost or Damaged	Vessel Tonnage	Consequences
2011/07/04	Arctic Hawk	Fire	Damaged	17	Marine Casualty
2011/07/22	Barge 210	Allision	Damaged	1255	Marine Casualty
2011/09/11	Barge 211	Equipment failure	Damaged	1016	Marine Casualty
2013/07/28	Tony Saganna	Set Adrift	Damaged	40	Marine Casualty
2013/10/12	Beauty Bay	Fire	Damaged	196	Marine Casualty
2013/11/15	AP 1-88-8701	Equipment failure	Damaged	18	Marine Casualty
2015/08/22	Capt Frank Moody	Collision	Damaged	166	Marine Casualty
2016/01/02	Arctic Hawk	Loss of electrical power	Damaged	17	Marine Casualty

Table S3: Time, vessel name, type of incident and whether the vessel was damaged or lost of shipping accidents following the intersection of a ship track within a radius of 3° of the location of Arctic cyclones' maximum maximum significant wave heights are greater than 2.5 m. Shipping incident data from PAME (2023).

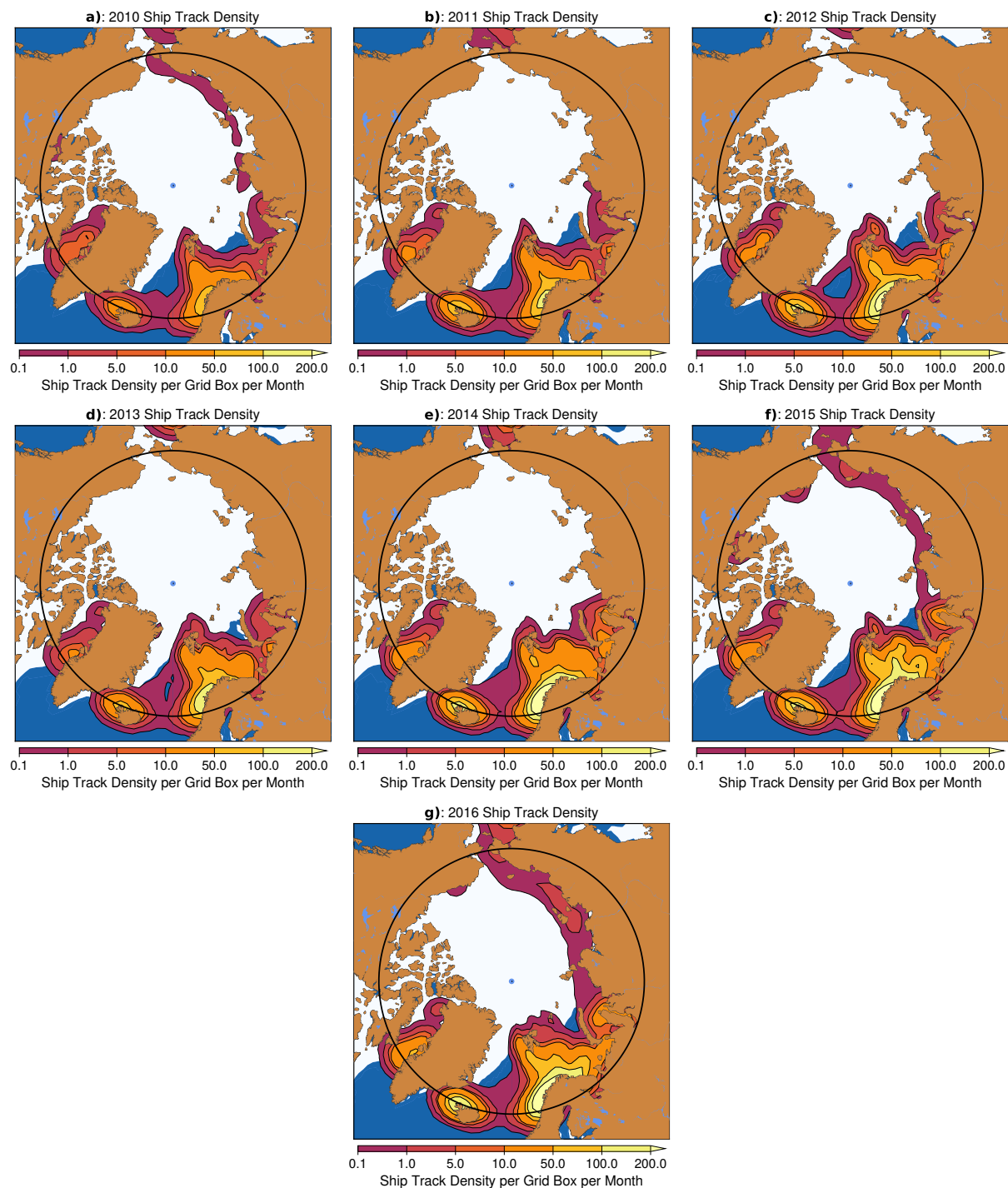| Time of Incident (YYYY/MM/DD)	Vessel Name	Type of Incident	Vessel Lost or Damaged	Vessel Tonnage	Consequences
2011/07/04	Arctic Hawk	Fire	Damaged	17	Marine Casualty
2011/07/23	Barge 210	Allision	Damaged	1255	Marine Casualty
2013/07/28	Tony Saganna	Set Adrift	Damaged	40	Marine Casualty
2013/10/12	Beauty Bay	Fire	Damaged	196	Marine Casualty
2015/08/22	Capt Frank Moody	Collision	Damaged	166	Marine Casualty

Figure S4. Ship track density per year from 2010 to 2016 from the Berkman et al. (2020) Arctic shipping dataset. **(a)** 2010, **(b)** 2011, **(c)** 2012, **(d)** 2013, **(d)** 2014, **(f)** 2015, **(g)** 2016. Mean HadISST Arctic sea ice concentration is also shown in white, where sea ice concentration is greater than 15%. The white line indicates the perimeter of Arctic sea ice extent. The solid black line indicates the Arctic Circle (66.3°N).
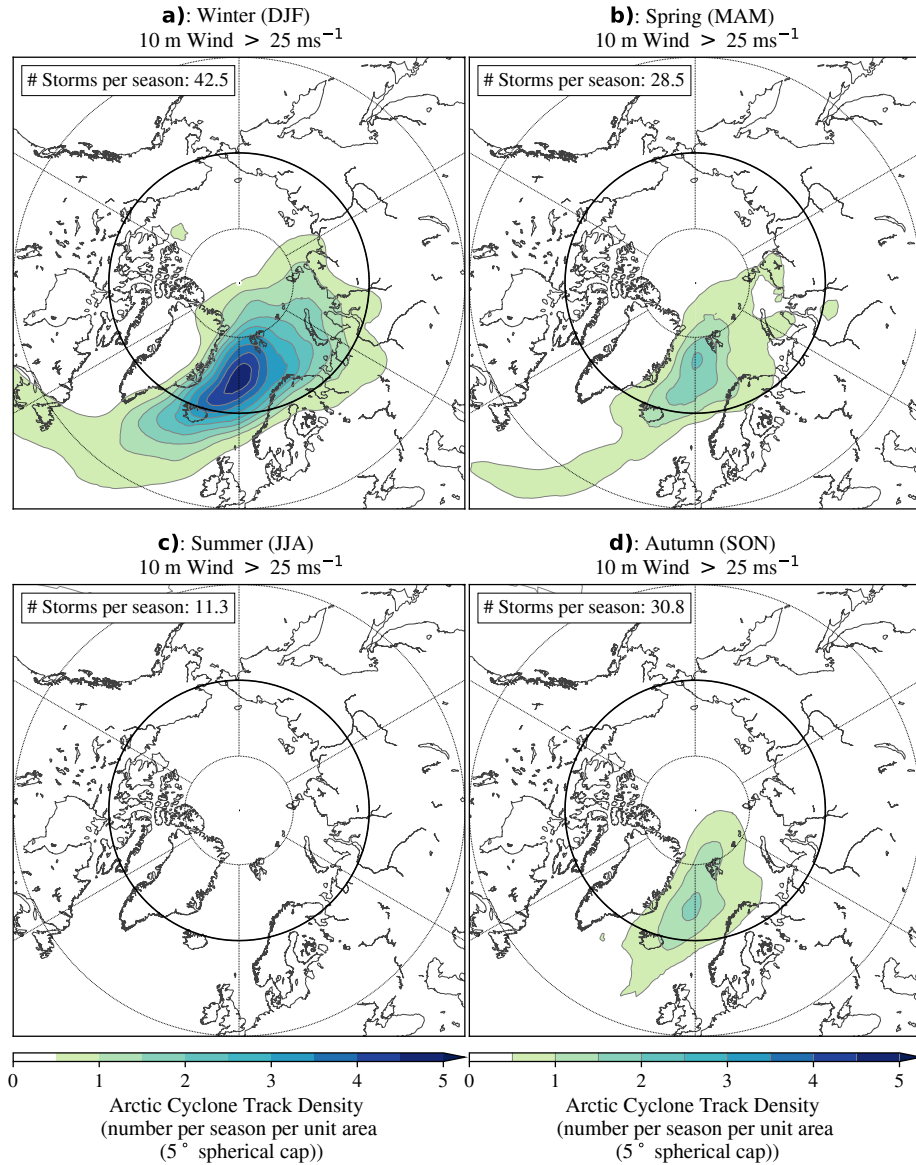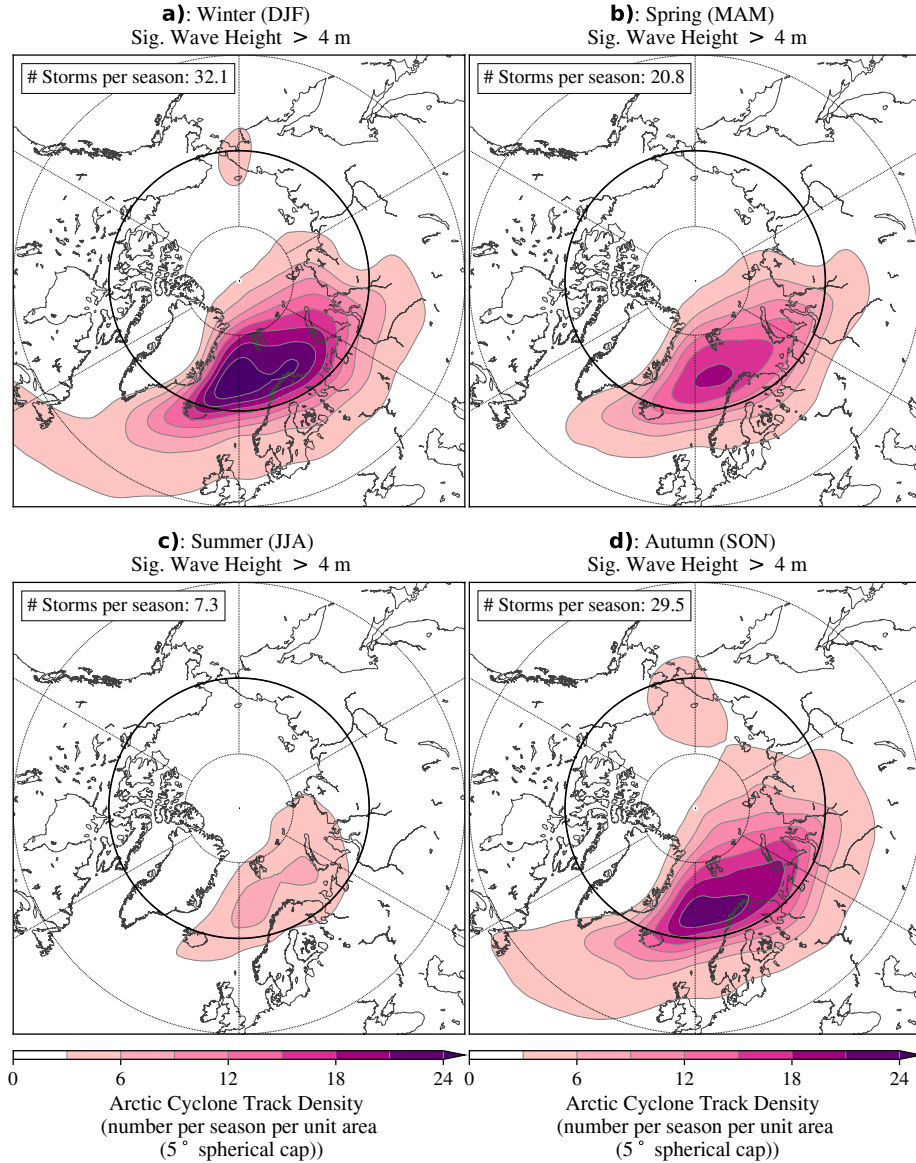
Figure S5. Track density per season of **a)** winter (DJF), **b)** spring (MAM), **c)** summer (JJA) and **d)** autumn (SON) cyclones that have maximum 10 metre (m) wind speeds in the Arctic (66.3°N) greater than 25 ms^{-1}. Based on the ERA-5 reanalysis dataset between 1979-2021 in spring (MAM), summer (JJA) and autumn (SON), and 1979/80-2020/21 in winter (DJF). Track density indicates the number of cyclones that travel over a grid point and has units of number per season per unit area (5° spherical cap, approximately 10^6 km^2). Longitudes are shown every 60°E, and latitudes are shown at 80°N, 66.3°N (bold) and 50°N.

Figure S6. Track density per season of **a)** winter (DJF), **b)** spring (MAM), **c)** summer (JJA) and **d)** autumn (SON) cyclones that have maximum significant wave height including tide and swell in the Arctic (66.3°N) greater than 4 m. Based on the ERA-5 reanalysis dataset between 1979-2021 in spring (MAM), summer (JJA) and autumn (SON), and 1979/80-2020/21 in winter (DJF). Track density indicates the number of cyclones that travel over a grid point and has units of number per season per unit area (5° spherical cap, ≈ 10^6 km^2). Longitudes are shown every 60°E, and latitudes are shown at 80°N, 66.3°N (bold) and 50°N.
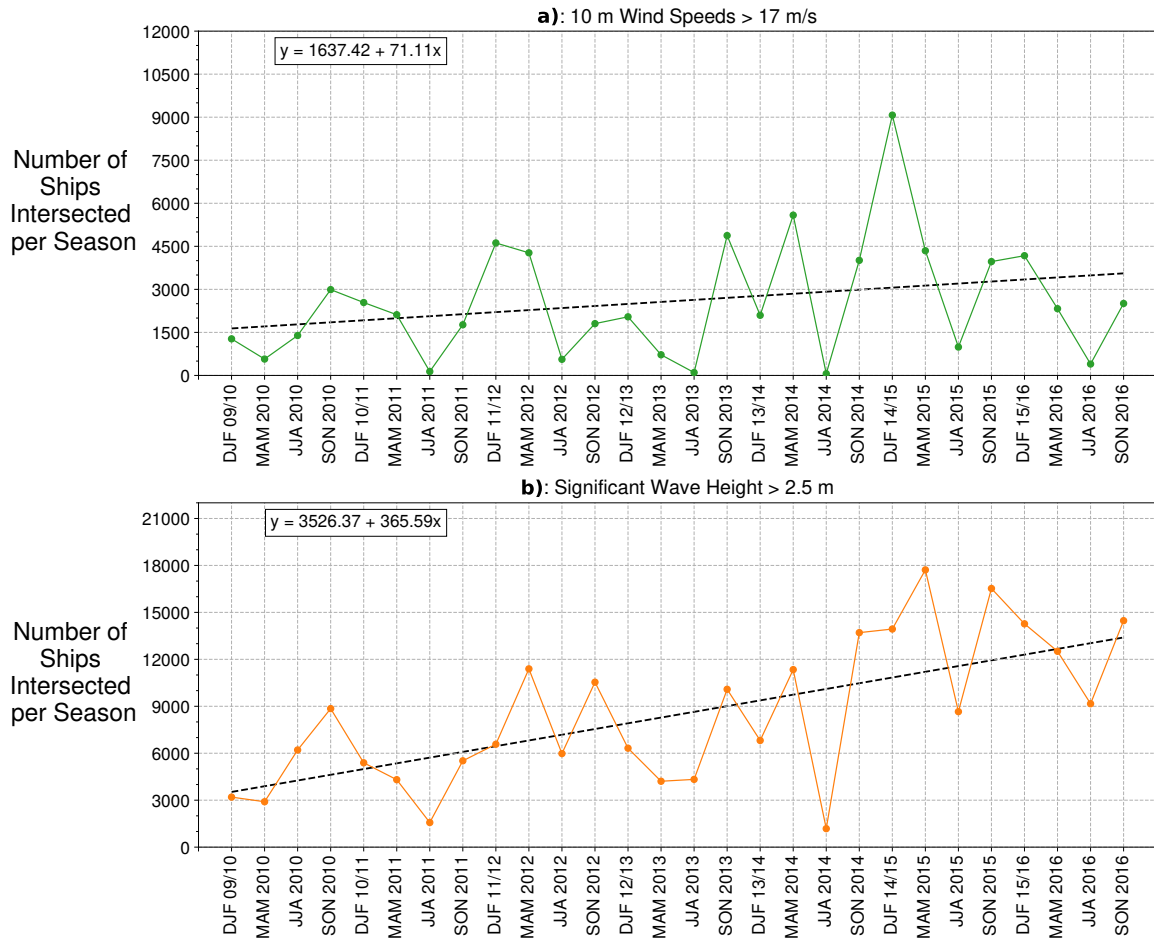
Figure S7. The seasonal (winter - DJF, spring - MAM, summer - JJA and autumn - SON) number of intersections between ship tracks within a radius of 3° of the location of Arctic cyclones' maximum **a)** 10 metre wind speeds which are greater than 17 ms^{-1} and **b)** 10 metre wind speeds which are greater than 17 ms^{-1} significant wave height (including tide and swell) greater than 2.5 m in the Arctic, from December 2009 to December 2016.
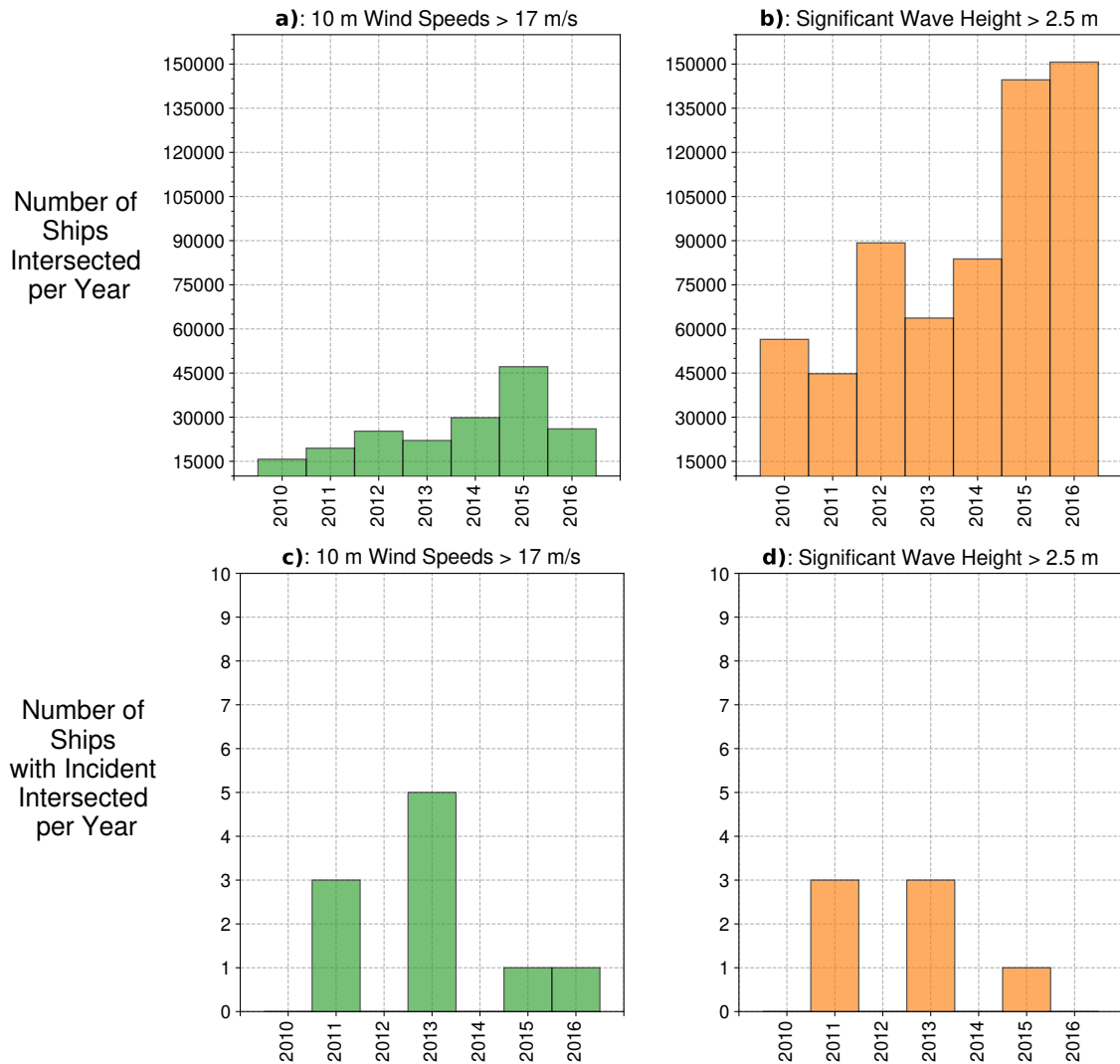
Figure S8. The annual number of intersections between ship tracks north of the Arctic Circle (66.3°N) within a 5° radius of an Arctic cyclones' (any cyclone to travel north of 66.3°N) maximum **a)** 10 metre wind speeds greater than 17 ms^{-1} and **b)** significant wave height including tide and swell greater than 2.5 m, between January 2010 and December 2016. **c)** and **d)** show the number of shipping incidents north of the Arctic Circle (66.3°N) that were reported within 48 hours of a ship track and cyclone intersection.
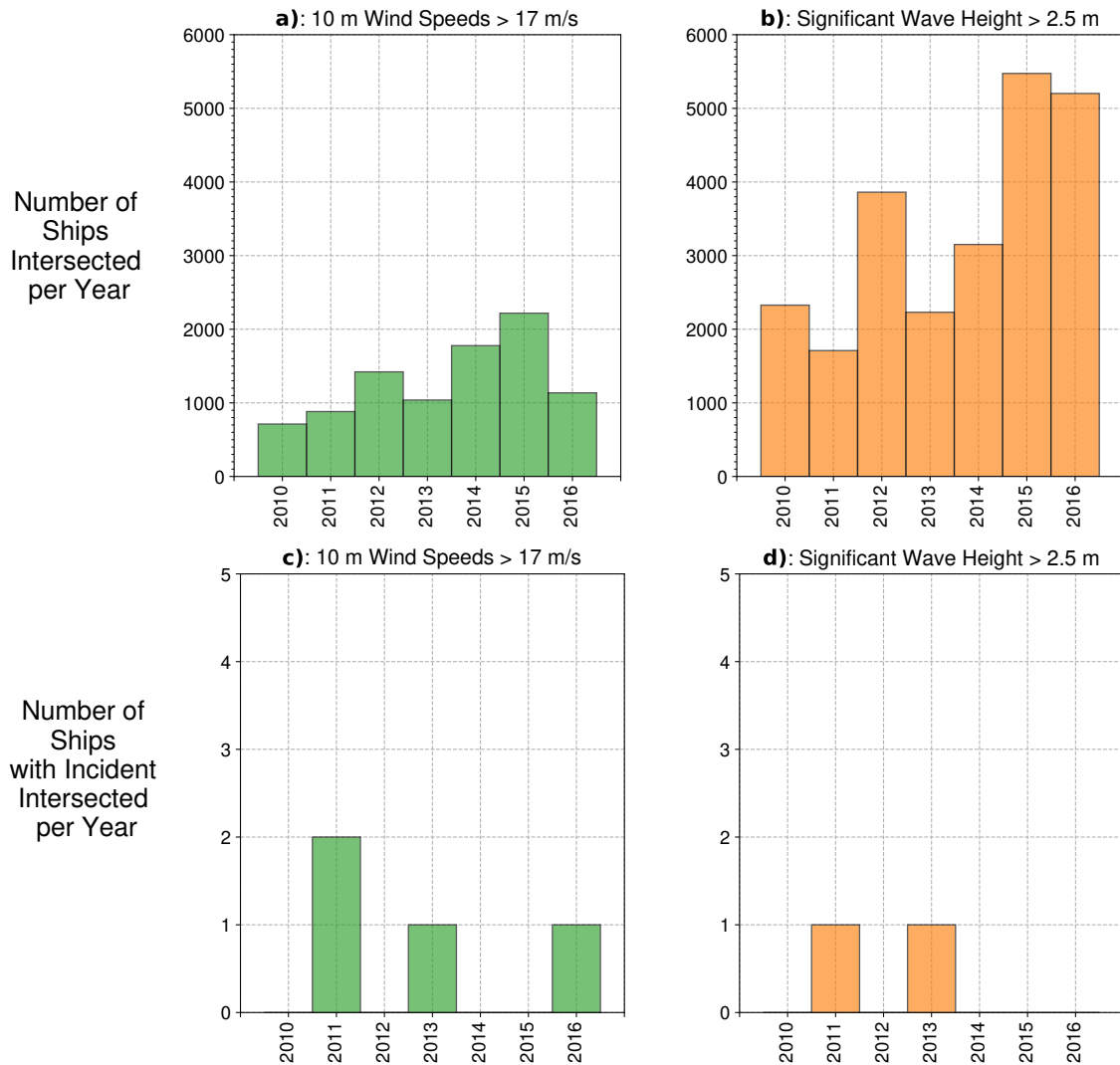
Figure S9. The annual number of intersections between ship tracks north of the Arctic Circle (66.3°N) within a 1° radius of an Arctic cyclones' (any cyclone to travel north of 66.3°N) maximum **a)** 10 metre wind speeds greater than 17 ms^{-1} and **b)** significant wave height including tide and swell greater than 2.5 m, between January 2010 and December 2016. **c)** and **d)** show the number of shipping incidents north of the Arctic Circle (66.3°N) that were reported within 48 hours of a ship track and cyclone intersection.

References

Berkman, P., Fiske, G., and Lorenzini, D.: Baseline of next-generation Arctic Marine Shipping Assessments–Oldest continuous Pan-Arctic Satellite Automatic Identification System (AIS) data record of maritime ship traffic, 2009–2016, Arctic Data Center. https://arcticdata.io/catalog/view/doi% 3A10, 18739, 2020.

Google: Google Earth Pro, pp. Accessed 18 Jan 2023, https://www.google.com/intl/en_uk/earth/desktop/, 2021.

PAME: Compendium of Arctic Ship Accidents, pp. Accessed 30 May 2023, https://www.pame.is/projects–new/arctic–shipping/pame–shipping–highlights/457–compendium–of–arctic–ship–accidents, 2023.