Proximity of Commercial Maritime Traffic to the Arctic Marginal Ice Zone, 2012–2023

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Session: Navigating a Changing Arctic: Innovations for Sustainable Maritime Development

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BACKGROUND

- Arctic vessel traffic has increased
  - Number vessels: ↑25% (2013–2019) (PAME 2020)
  - Distance sailed: ↑75% (2013–2019) (PAME 2020)
- Sea ice is a navigational hazard for most ships
- Ships beset, structural damage, course change, delays
  - November 2021: Early freeze-up traps 18 ships on NSR
  - January 2017: Two bulk carriers, two icebreakers beset near Pevek
  - September 2013: Tanker collision with sea ice, structural damage
- Risk = Likelihood x Consequence

Photo by USCG PO1 Sara Mooers.

Photo by ESL Shipping, from Barents Observer.

PAME (2020) Arctic shipping status report (ASSR) #1, www. pame.is

GOAL:

Visualize **where** vessels are operating in or near the Arctic Marginal Ice Zone (MIZ) over past 12 years. Information can guide emergency planning and preparedness in the short term and inform priorities for sustainable Arctic shipping development in the long term.

RESEARCH QUESTIONS

(1) Are ships spending more time in the MIZ in recent years?

(2) Where are ships encountering the MIZ?

(3) Are those location consistent over space and time?

METHODS

Study Site

Latitudes > 66.5°N

Month of September

- Lowest annual sea ice extent
- Highest annual traffic volume
- High MIZ spatial coverage (July-Sep)

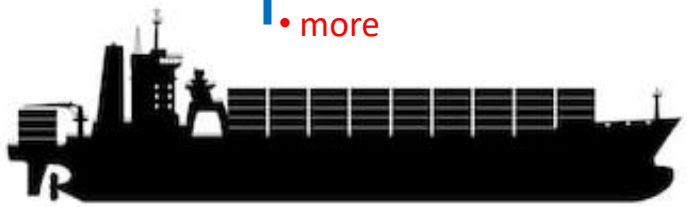
Years 2012–2023 (n = 12)

METHODS

AIS data

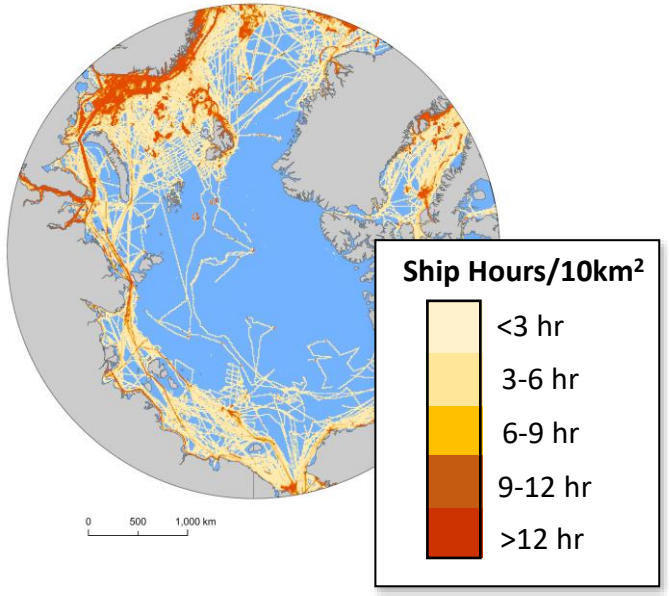
Report

- Date, time
- MMSI (unique ID)
- Latitude-Longitude
- Type of vessel
- Course
- Speed in knots
- Heading
- IMO Number
- Ship and cargo type
- more



MONTHLY

(Shown: September 2023)



Maritime Traffic Data

Global Maritime Traffic Density Service (GMTDS)

Open-source, global coverage
Satellite-based Automatic Identification System (AIS)
Ships >300 GT and others – Class A transceivers
Temporal resolution: **Month**
Spatial resolution: **1 km²** (aggregated: 10 km²)
Metric: **Ship hours**

globalmaritimetraffic.org

METHODS

Sea Ice Data

U.S. National Ice Center usicecenter.gov

Satellite-borne passive microwave products
Daily sea ice shapefiles
September 1-30, 2012–2023

Marginal Ice Zone (MIZ)
10–80% surface ice concentration

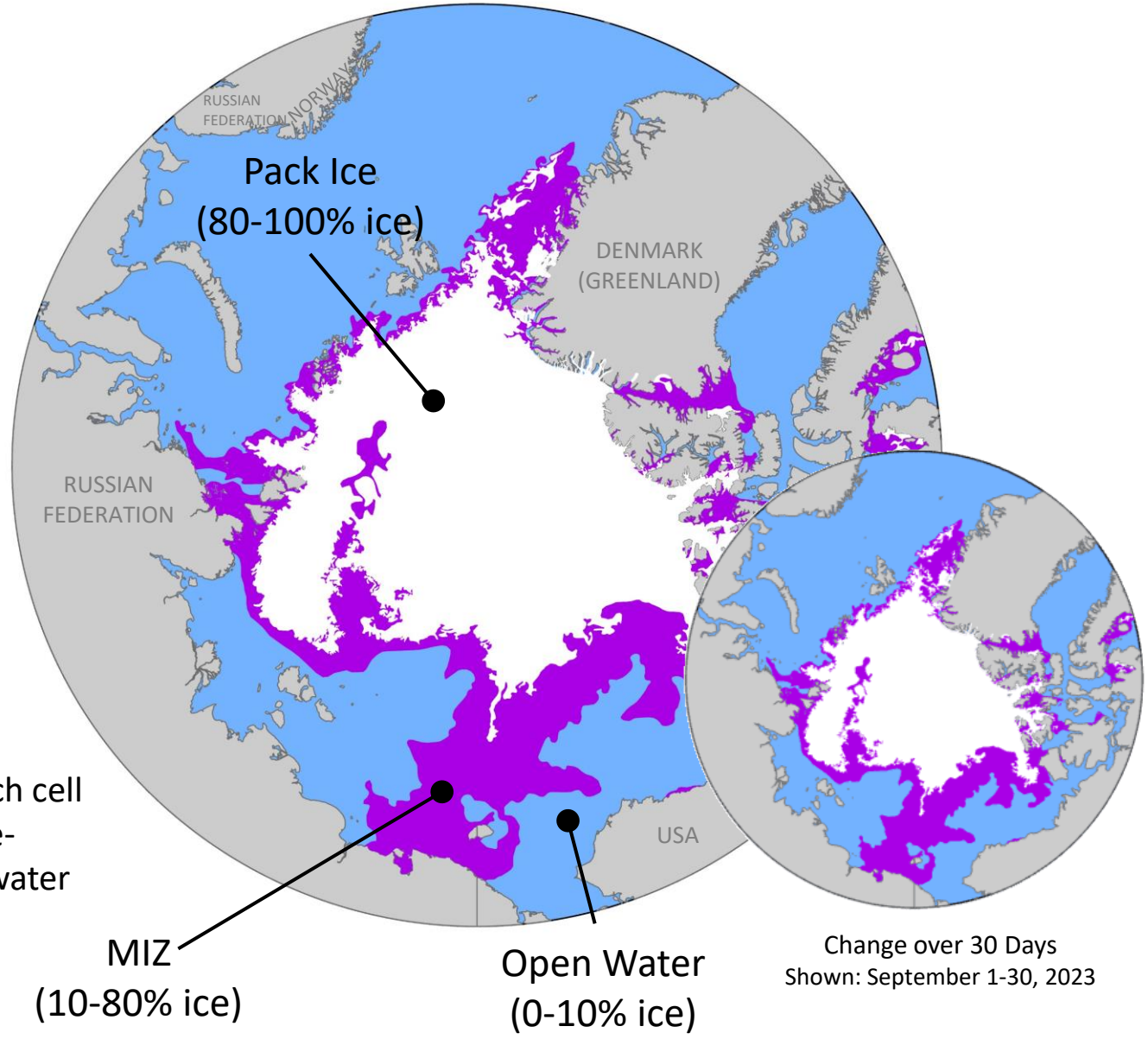
Pack Ice
80–100% surface ice concentration

Data Analysis (ArcGIS Pro 3.1.2)

- Uploaded sea ice .shp files, applied 10 km^2 grid
- For each year, summed # days w/ice coverage in each cell
- In cells with ice coverage ≥ 1 day, calculated % of ice-covered days with MIZ coverage vs. pack ice, open water

DAILY

(Shown: September 1, 2023)



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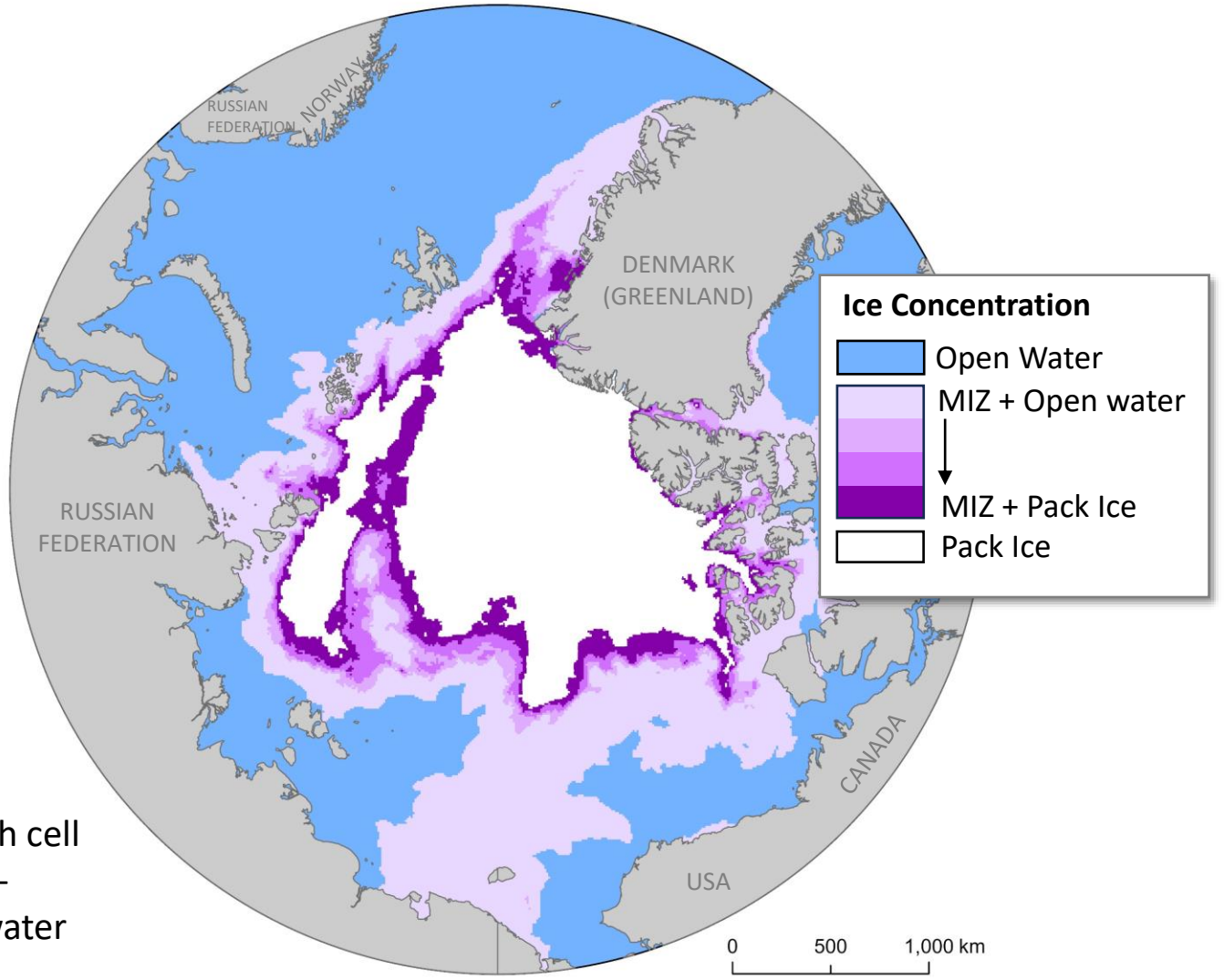


Spatial resolution: 10 x 10 km
Projection: WGS 1984 Stereographic North Pole

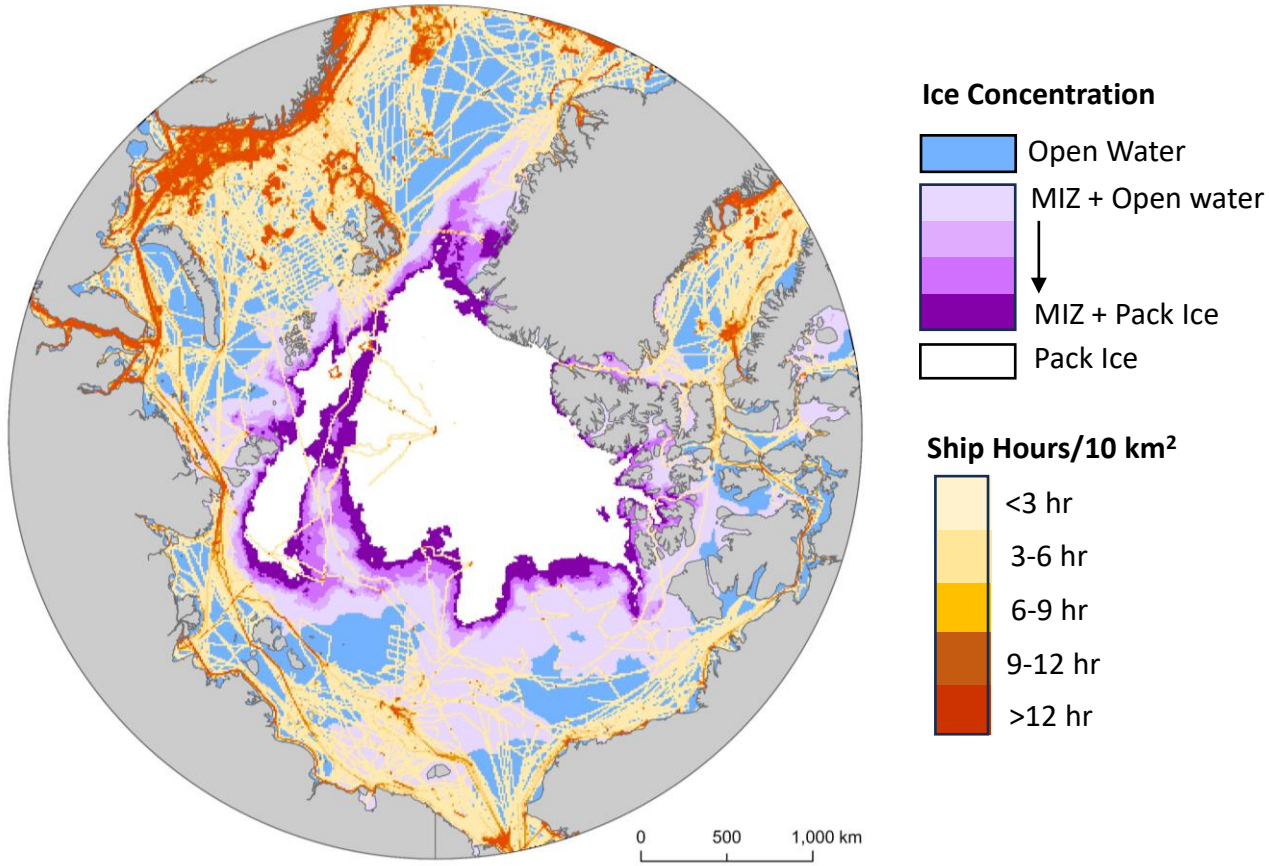
METHODS

All Ship Hours above 66.5 °N

September

2023
2022
2021
2020
2019
2018
2017
2016
2015
2014
2013
2012

(Shown: September 2023)



Spatial resolution: 10 x 10 km
Projection: WGS 1984 Stereographic North Pole

Shown: All ship types = Tankers, tug-tow, icebreakers, cargo vessels, fishing vessels, research vessels, other types (e.g., passenger, hovercraft), unidentified

RESULTS

Temporal Trends 2012-2023

- Arctic Marginal Ice Zone (MIZ) Coverage

  Interannually variable, slight positive trend

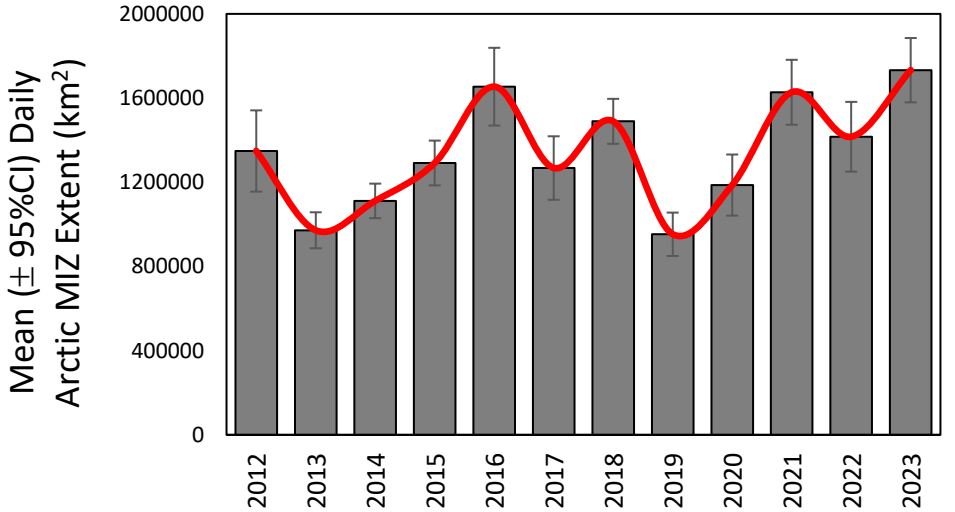
- Ship Hours North of 66.5 °N

  Observed ↑ **385%** over 12 years

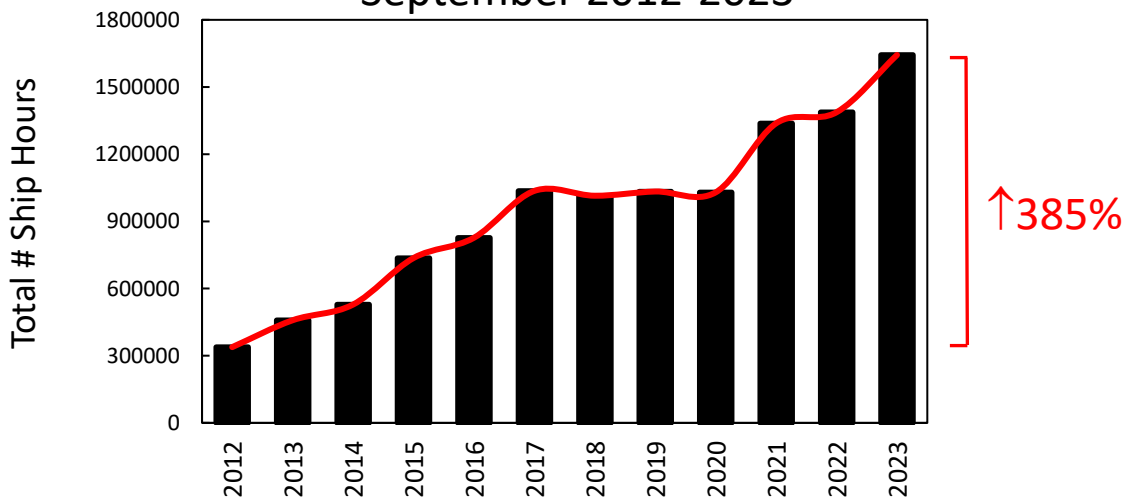
  Average = 16% increase year-over-year

Number vessels: ↑25% (2013-2019) (PAME 2020)
Distance sailed: ↑75% (2013-2019) (PAME 2020)
Ship hours: ↑125% (2013-2019) (this study)

Arctic Marginal Ice Zone (MIZ) Spatial Extent
September 2012-2023



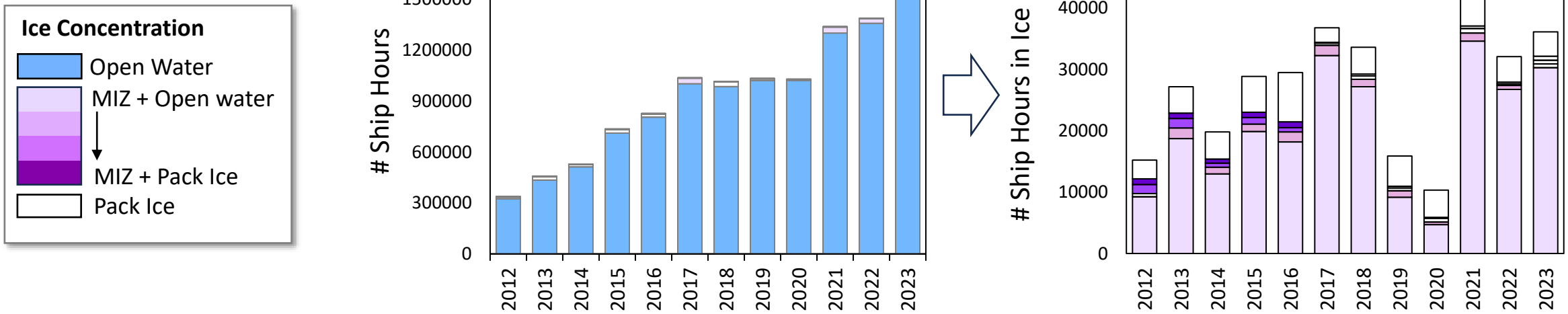
Total Ship Hours >66.5 °N
September 2012-2023



PAME (2020) Arctic shipping status report (ASSR) #1, www. pame.is

RESULTS

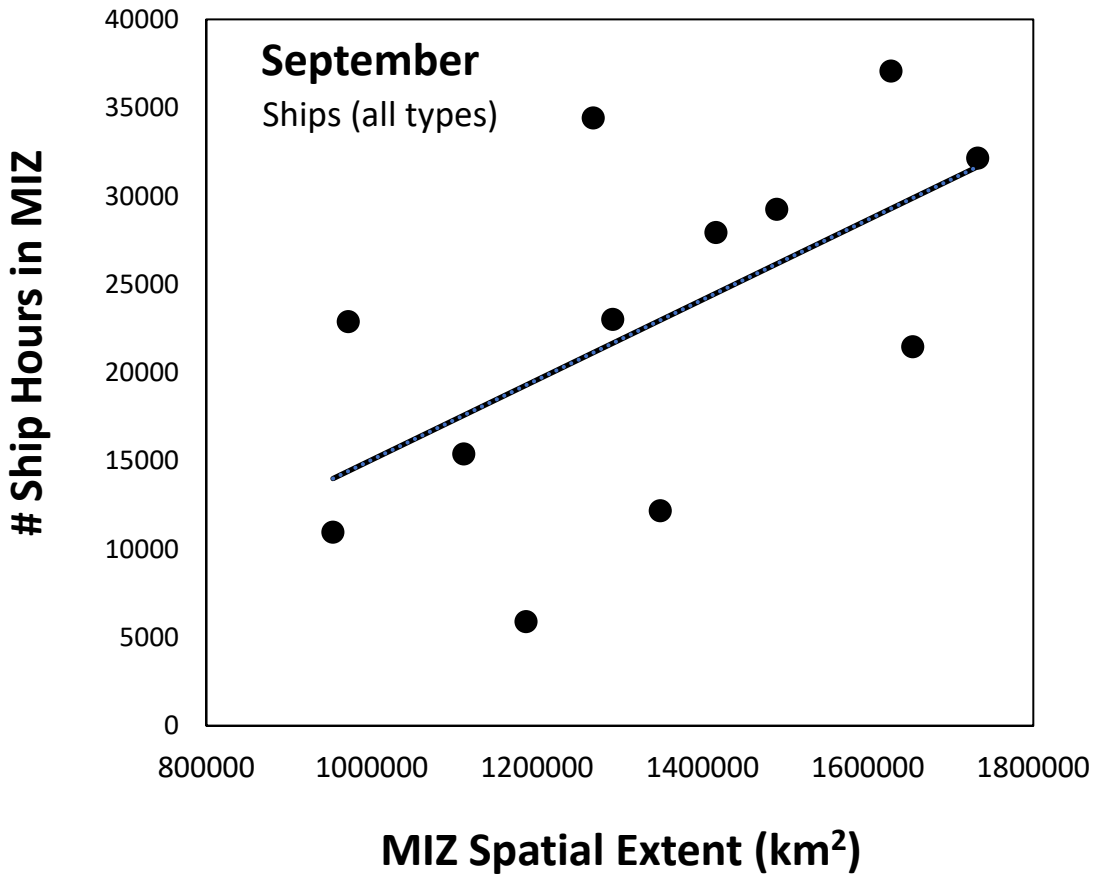
Ship Hours in Open Water, MIZ and Pack Ice in September by Year



- Most ship hours = open water
- Most ship hours in ice involved water that transitioned between MIZ and open water (the outer ice edge)
- Overall, a positive trend in ship-ice hours but considerable interannual variability, e.g., 2019 and 2020

RESULTS

Ships in Arctic MIZ relative to MIZ Spatial Extent

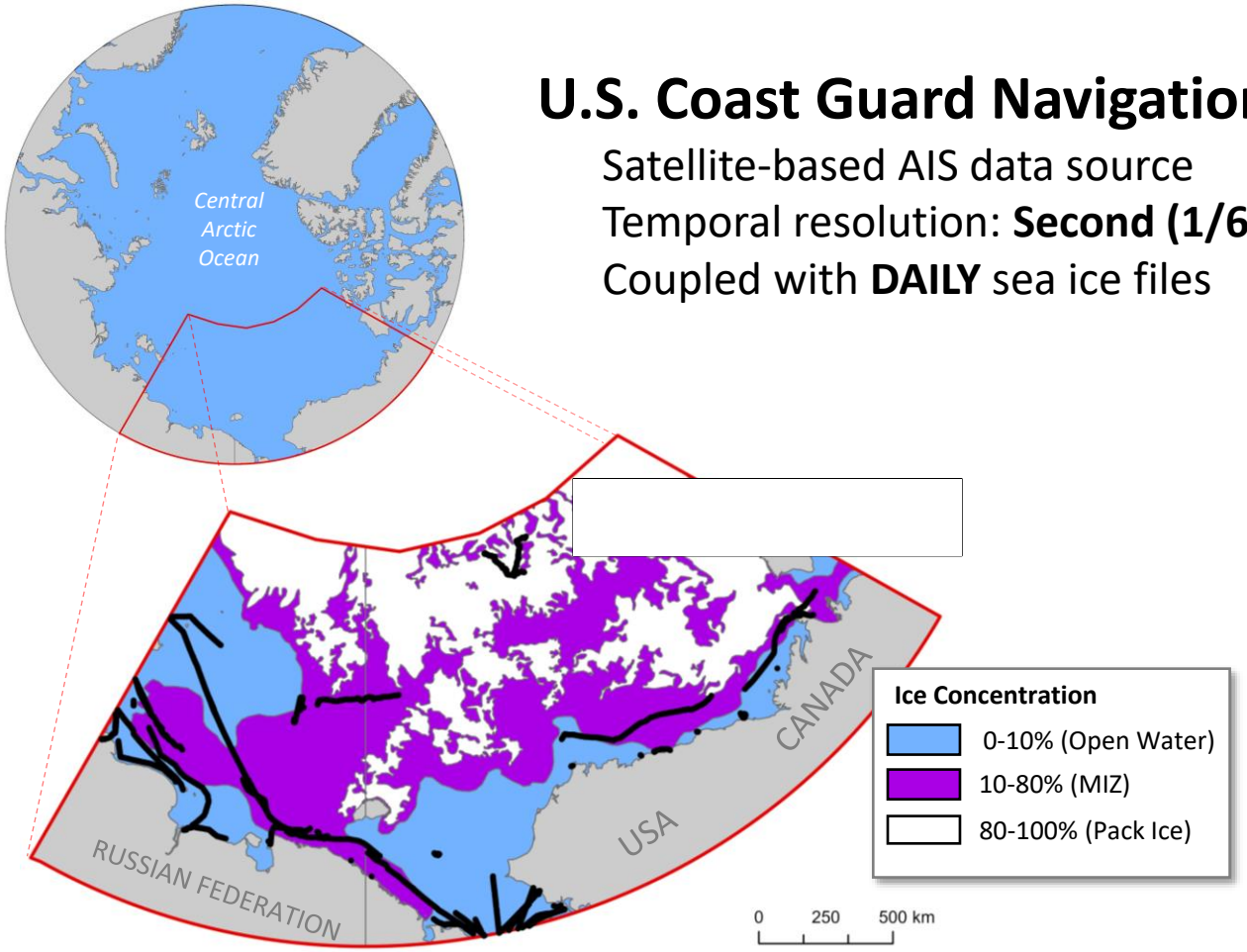


- Greater MIZ coverage = More ship hours in MIZ
  - Suggests ship operations despite MIZ presence
  - Some ships may seek ice, slower travel in ice
- Other studies observe increases in MIZ coverage
  - Soleymani and Scott (2023): Significant ↑ in MIZ fraction of total sea ice extent, 1980s to 2010s
  - Frew et al. (2023): 2–3-fold ↑ July MIZ ice cover (% summer ice) from 1980s to 2010s, projected ↑ into 2040
- Temporal mismatch may overestimate time ships spend in ice?

Frew, Feltham, Schröder, & Bateson. (2023) The Cryosphere, preprint, June 2023
Soleymani and Scott (2023) Environmental Research Letters 18 124002

RESULTS

Case Study: September 1-30, 2021

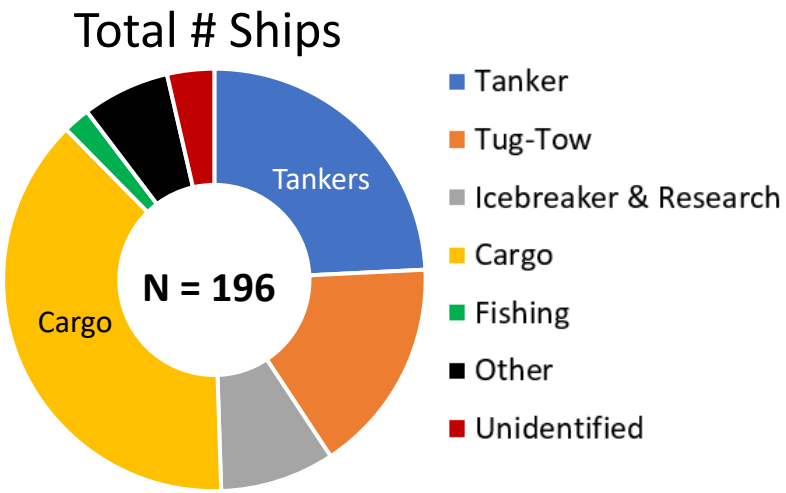


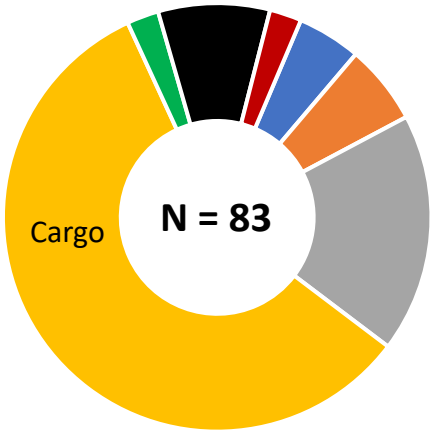
U.S. Coast Guard Navigation Center

Satellite-based AIS data source

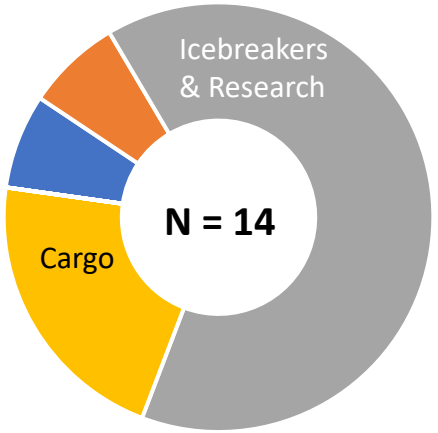
Temporal resolution: **Second (1/60 minute)**

Coupled with **DAILY** sea ice files





Ships in MIZ
(42% of total)



Ships in Pack Ice
(7% of total)

RESULTS

- Ship-Ice hours widespread across Arctic Ocean
  - -- Coastal (MIZ)
  - -- Some very remote (pack ice)
  - -- Widespread in East Siberian Sea, Chukchi Sea, Beaufort Sea
  - -- Few ship hours north of Greenland, Canadian Arctic Archipelago
- Highlights need for cooperation
  - -- Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic (2011)
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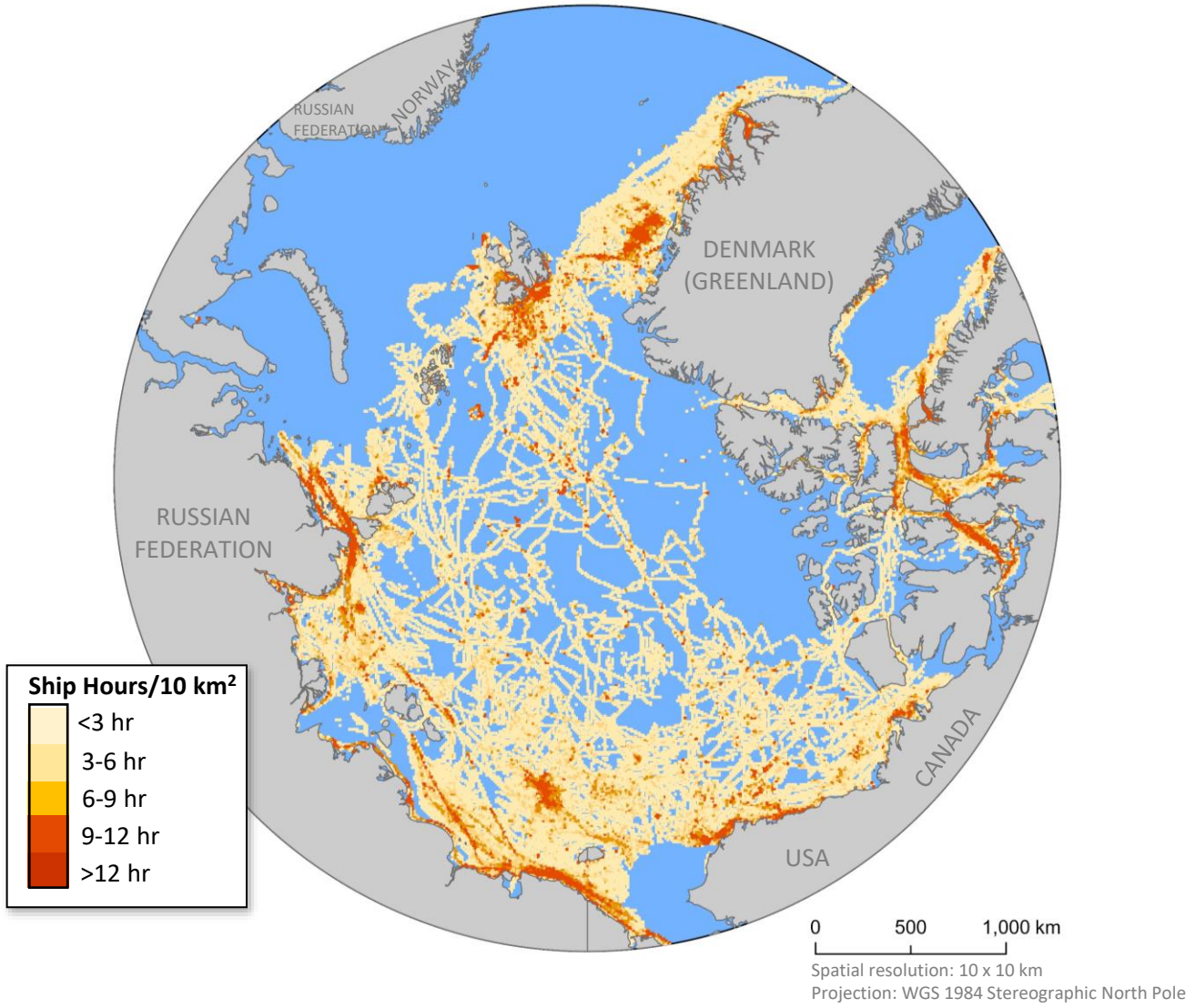
SHIPS (ALL TYPES) IN ICE-PRONE WATER

September 2012-2023 combined



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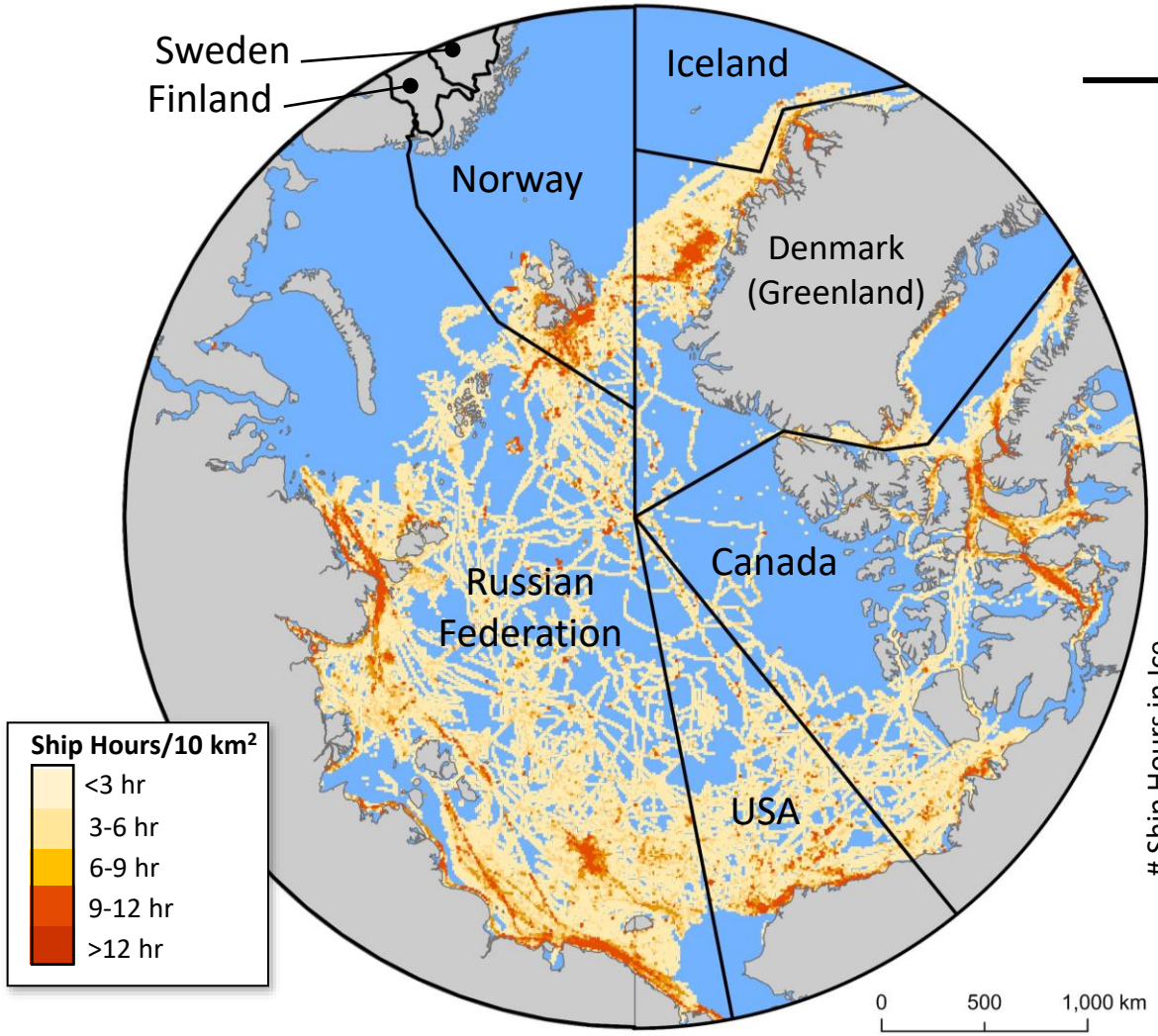

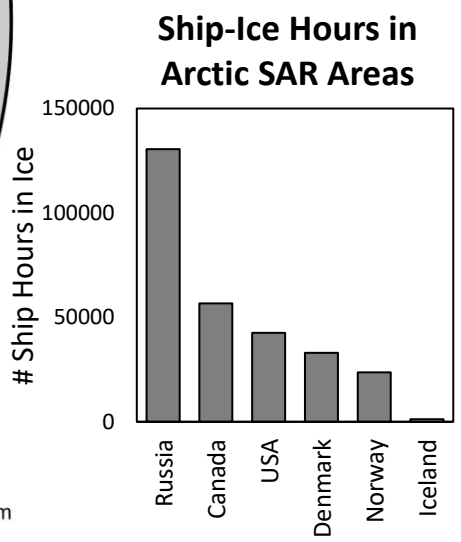

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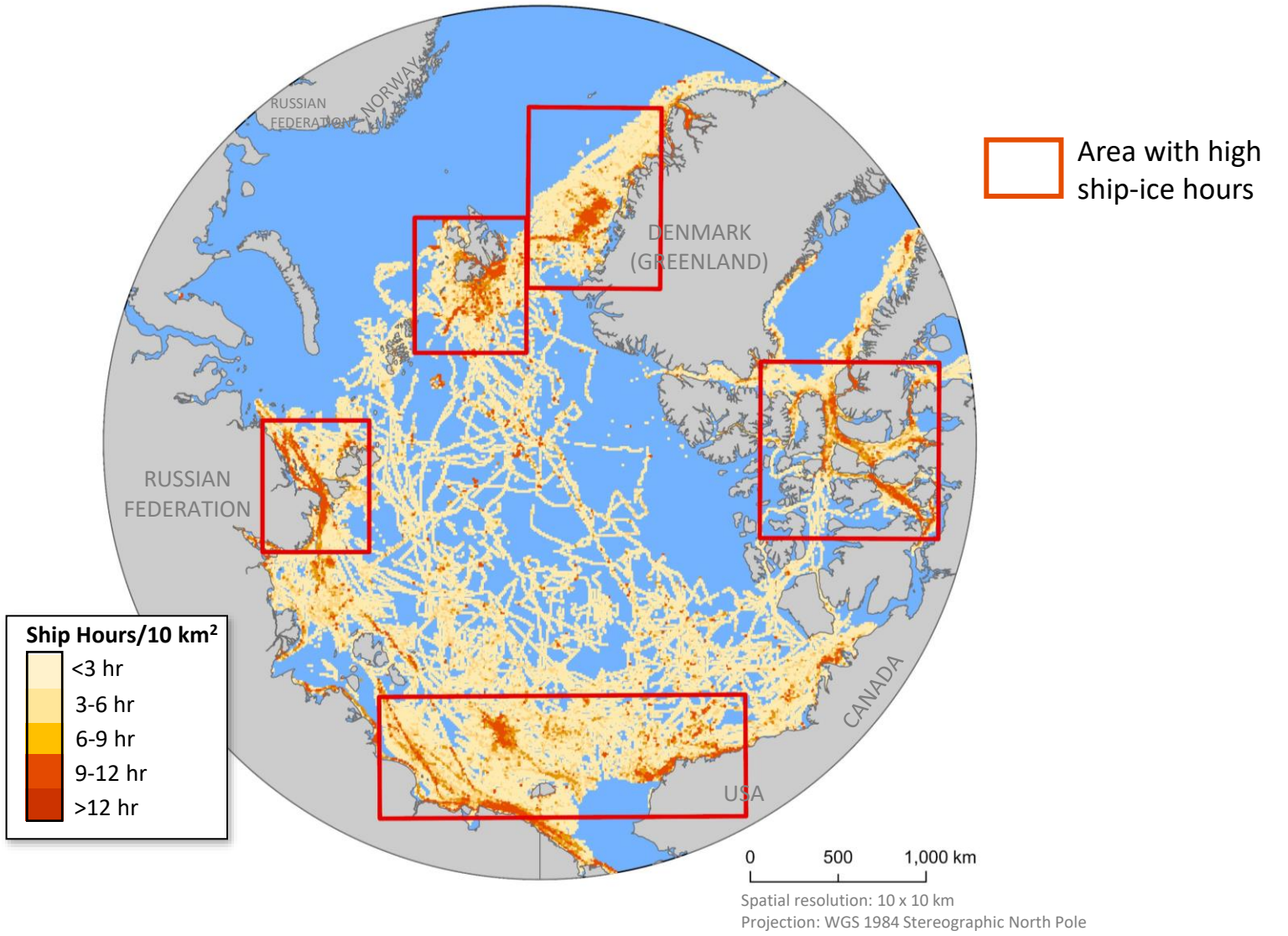

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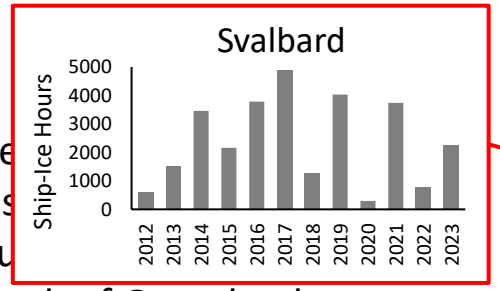

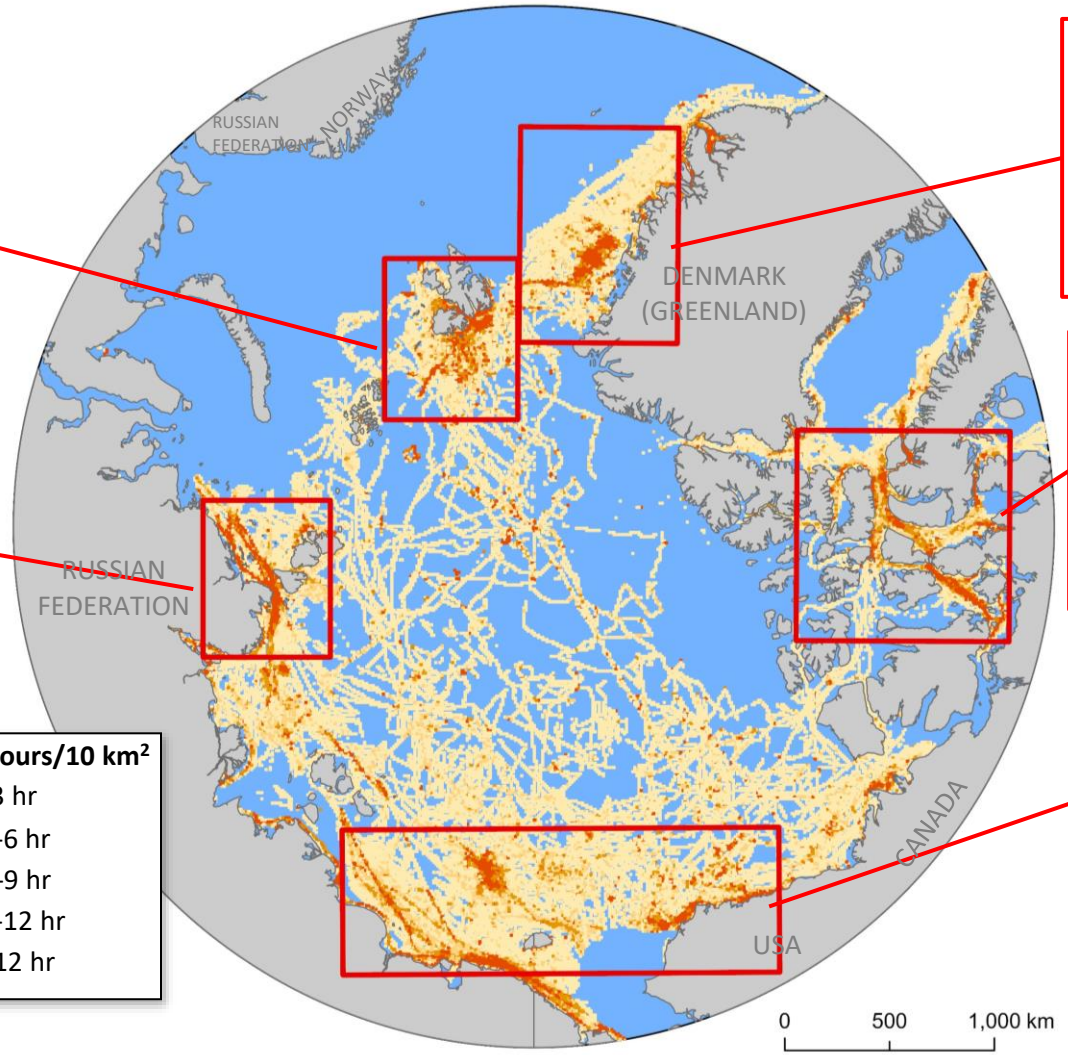

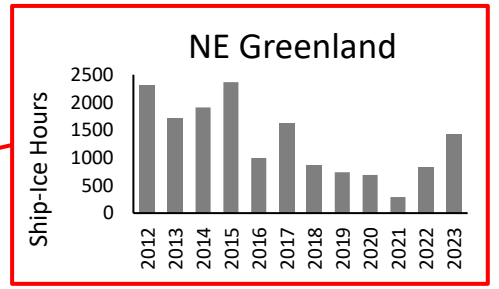

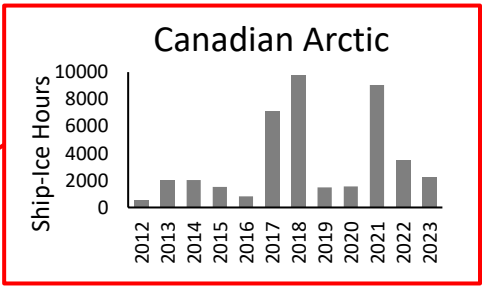

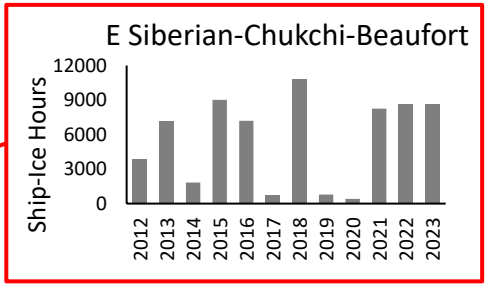

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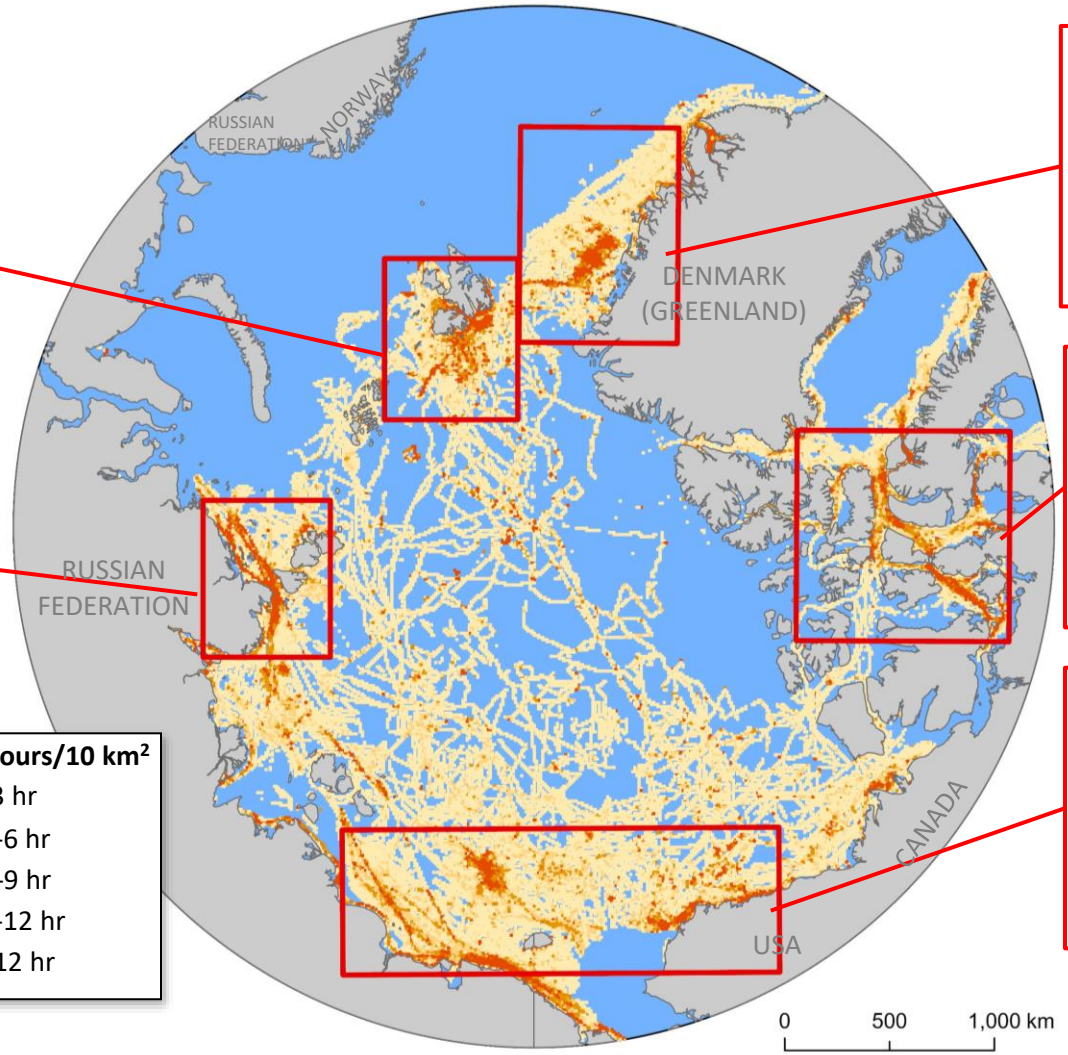
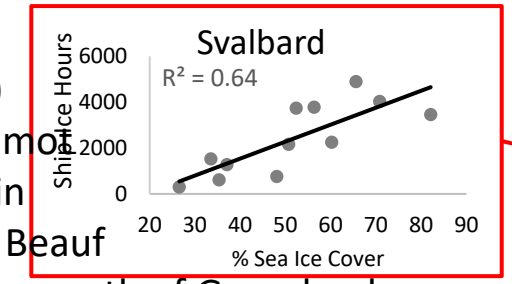
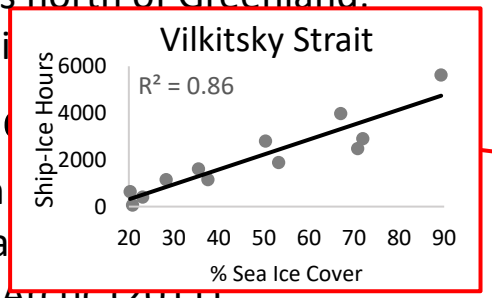
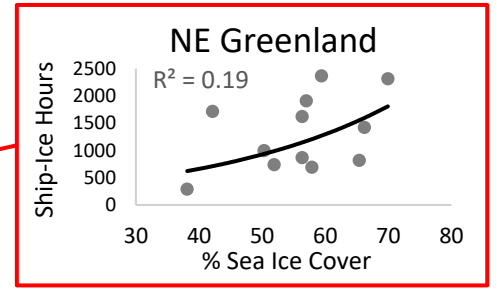
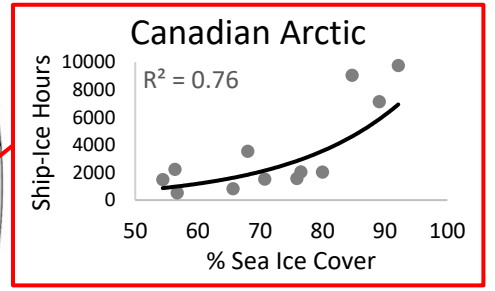
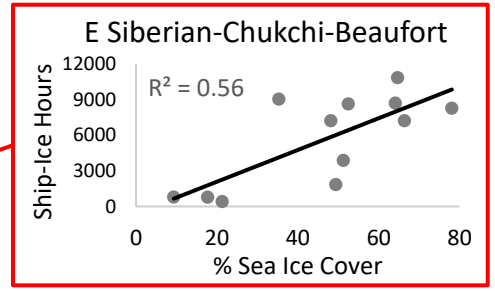








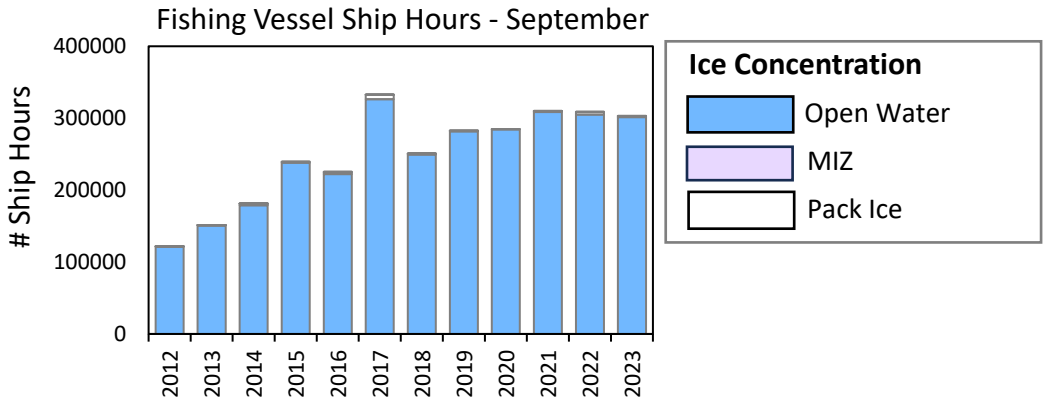


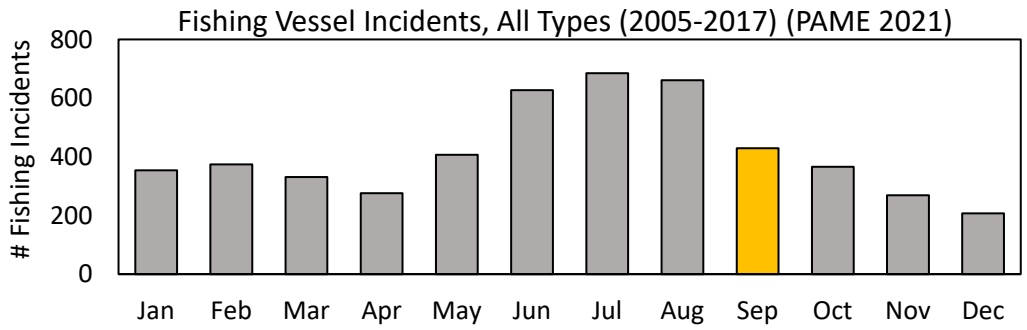


Spatial resolution: 10 x 10 km
Projection: WGS 1984 Stereographic North Pole

RESULTS

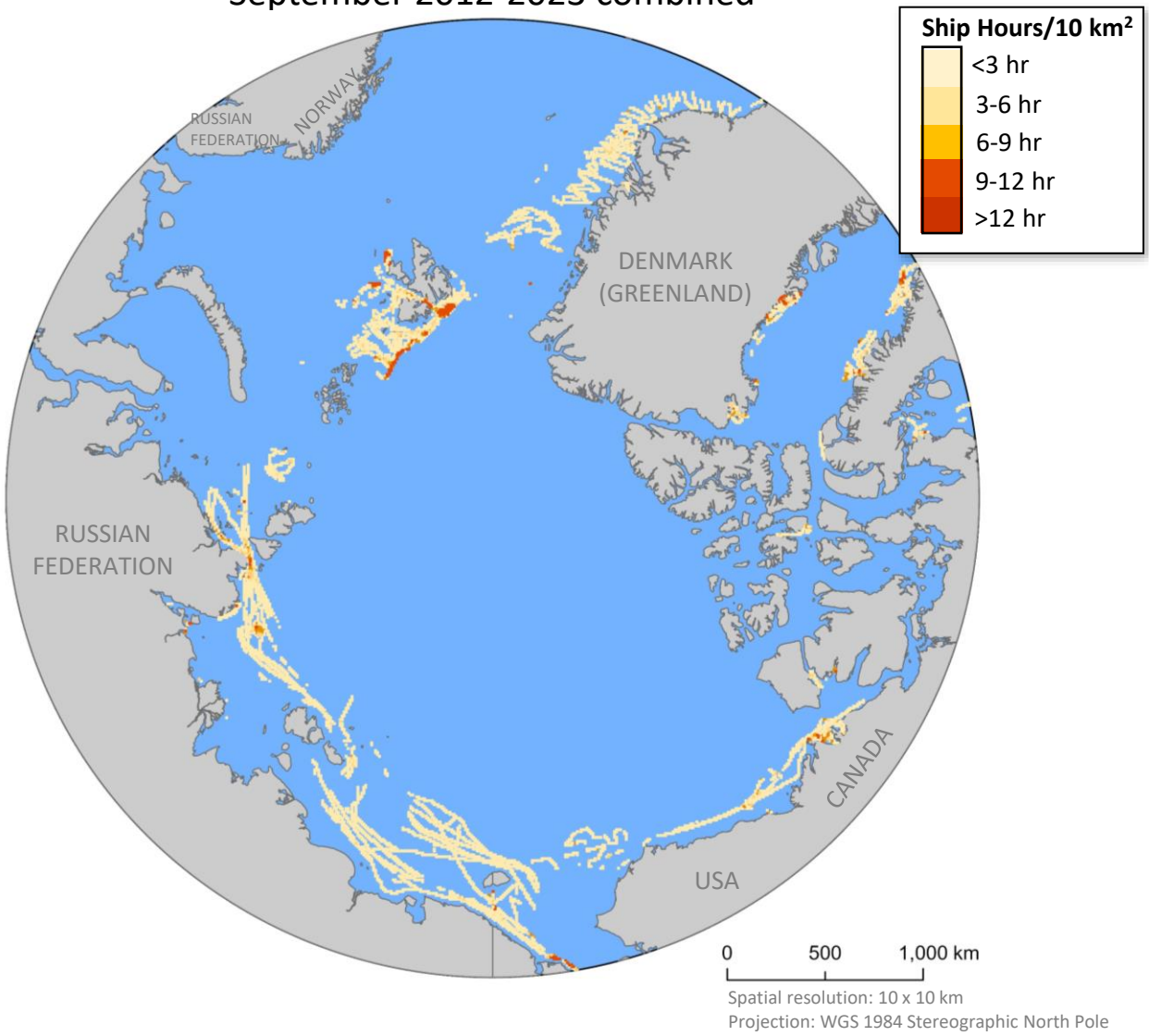
- Fishing vessels: 18-36% of all ship hours
- Higher number of incidents (PAME 2021)
- Arctic MIZ vs Pack Ice





FISHING VESSELS IN ICE-PRONE WATER

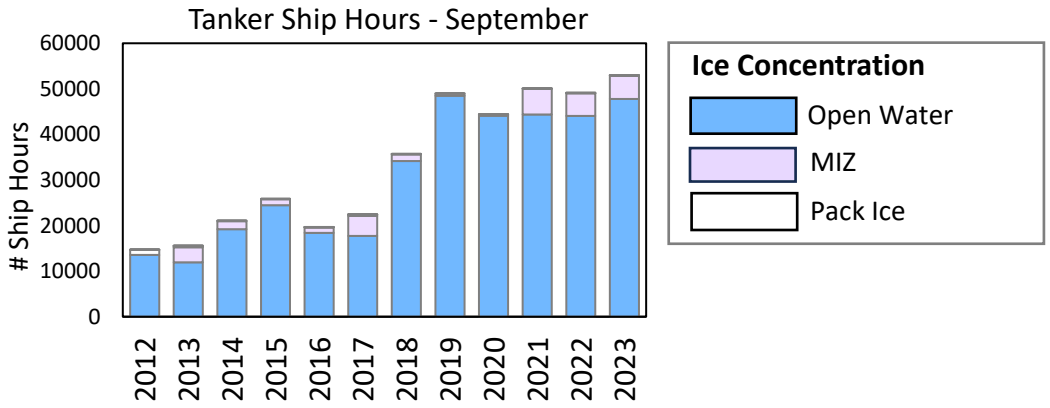
September 2012-2023 combined

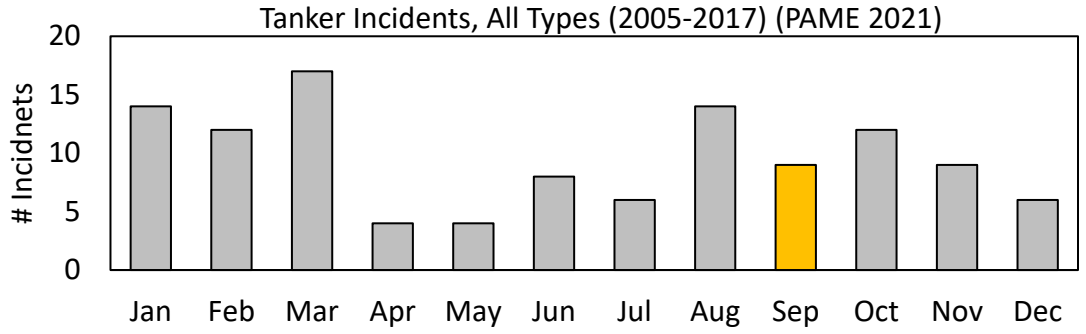


PAME (2021) Compendium of Arctic Ship Accidents (CASA)

RESULTS

- 2-5% of all ship hours (2012-2023)
- Human and environmental health
- Traditional-subsistence harvest
- Areas of heightened cultural significance

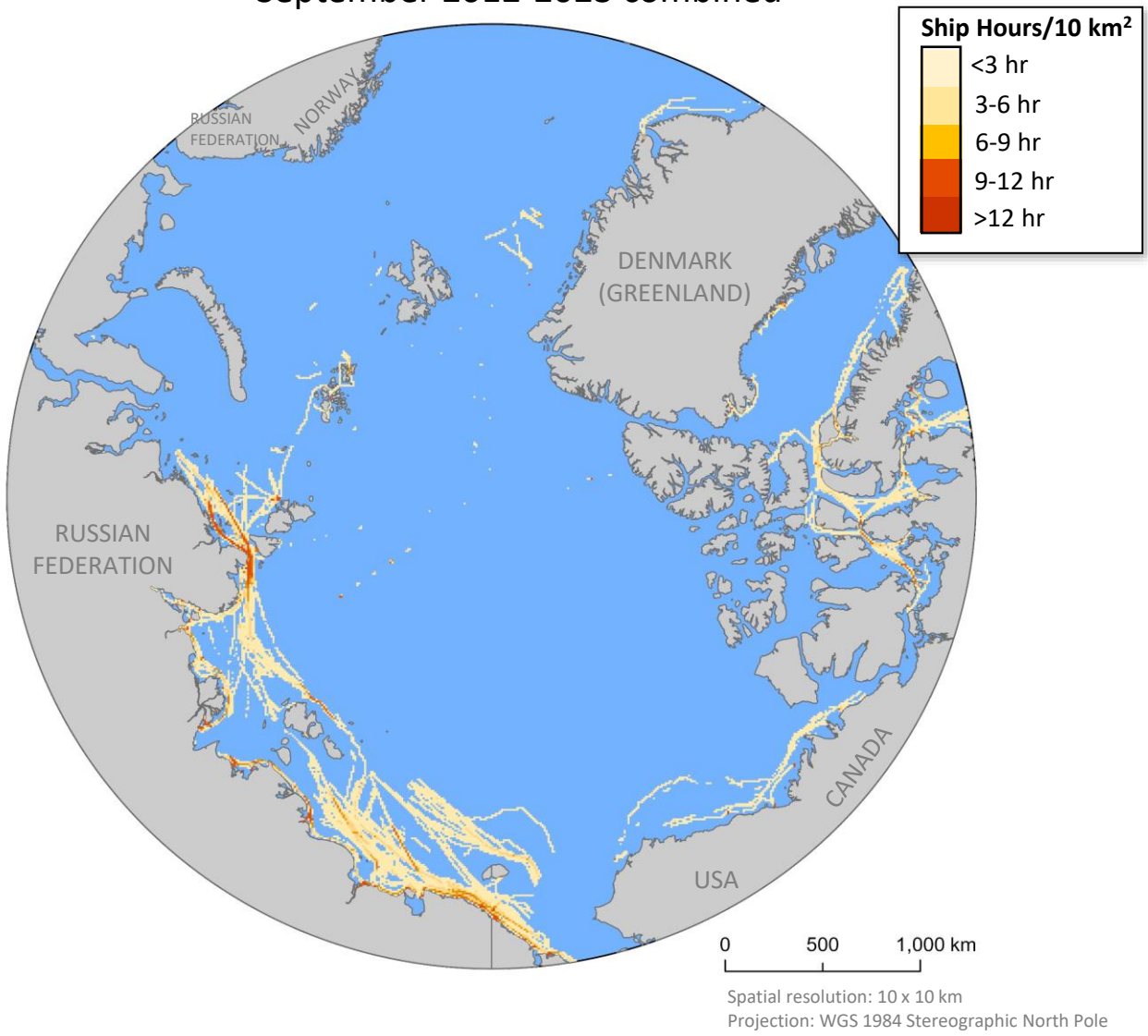




PAME Compendium of Arctic Ship Accidents (CASA)(2021)

TANKERS in ICE-PRONE WATER

September 2012-2023 combined



Spatial resolution: 10 x 10 km
Projection: WGS 1984 Stereographic North Pole

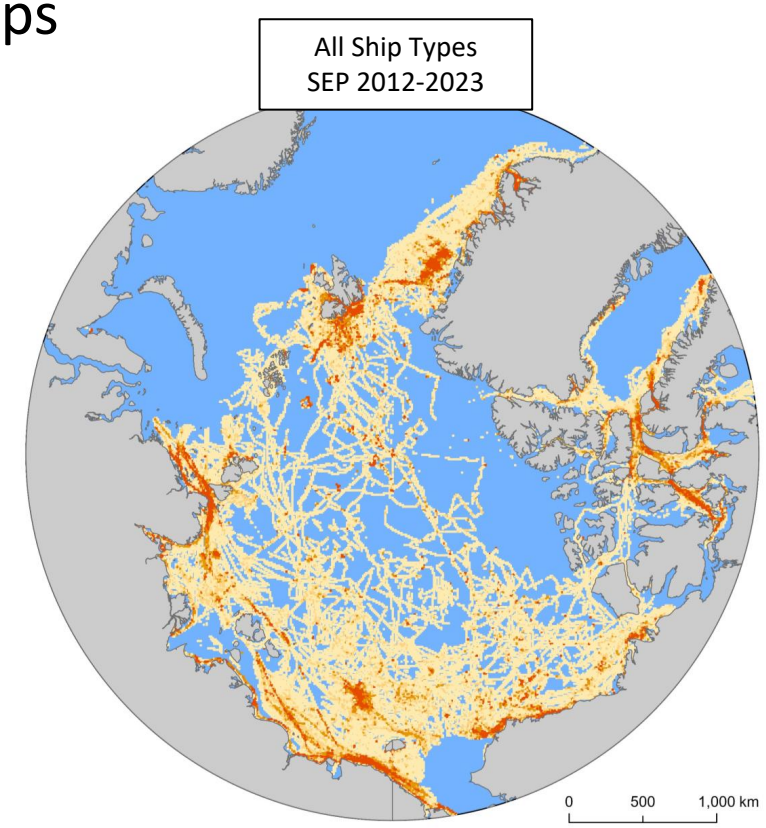
CONCLUSIONS

- Ship hours in the Arctic Ocean have increased 385% since 2012
- If MIZ coverage expands as projected, we may see more ships operating in ice-prone water in the future
- Ship hours in ice-prone waters occurred across the Arctic Ocean and were widespread in the East Siberian Sea, Chukchi Sea, and Beaufort Sea

  MIZ freeze-up is occurring later in year (1979-2021) in this region (Meier & Stroeve 2022)

  Years with unusually early freeze may be especially problematic

  Early freeze conditions and besetting incident involving 18 ships in December 2021



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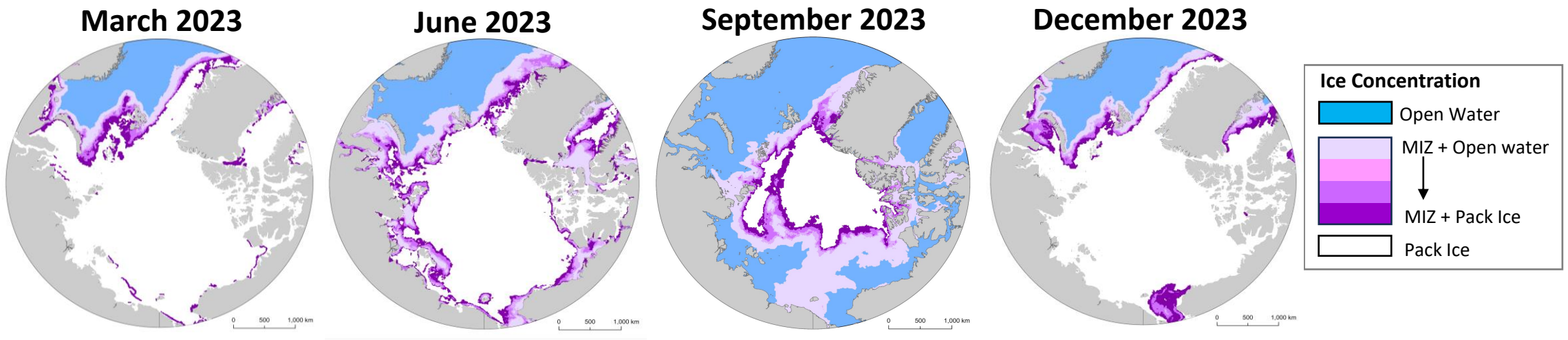
Meier, W.N. and J. Stroeve. (2022) An updated assessment of the changing Arctic sea ice cover. Oceanography 35(3-4): 10-19.

CONCLUSIONS

- We identified areas with especially high ship hours in ice-prone water

  Locations may be prioritized for emergency planning, but ship-ice exposure varied year-to-year.

  Remote ship-ice hours may also warrant attention.
- Documented ship-ice accidents, do they correspond to the areas we highlight? What is the role of MIZ seasonality?
- With ongoing climate change, regulators, emergency responders, and the maritime industry may have trouble adapting to high levels of environmental variability.



ACKNOWLEDGEMENTS

U.S. Coast Guard Center for Arctic Study and Policy

U.S. Coast Guard Navigation Center

U.S. Coast Guard Academy

LITERATURE CITED

Esri (2022) World countries (Generalized) [shapefile].

Frew, R, D Feltham, D Schröder, and A Bateson. 2023. Toward a marginal Arctic sea ice cover: changes to freezing, melting and dynamics. The Cryosphere June 2023, preprint.

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PAME (2020) Arctic Council Working Group on the Protection of the Arctic Marine Environment (PAME), Arctic shipping status report (ASSR) #1, https://www.pame.is/projects/arctic-marine-shipping/arctic-shipping-status-reports

PAME (2021) Arctic Council Working Group on the Protection of the Arctic Marine Environment (PAME), Underlying Data for the Compendium of Arctic Ship Accidents (CASA) Project: Final Report (May 2021)

Soleymani, A. and K.A. Scott (2023) Arctic marginal ice zone interannual variability and change point detection using two definitions (1983-2022) Environmental Research Letters 18 124002.