Crowdsourcing Arctic Navigation

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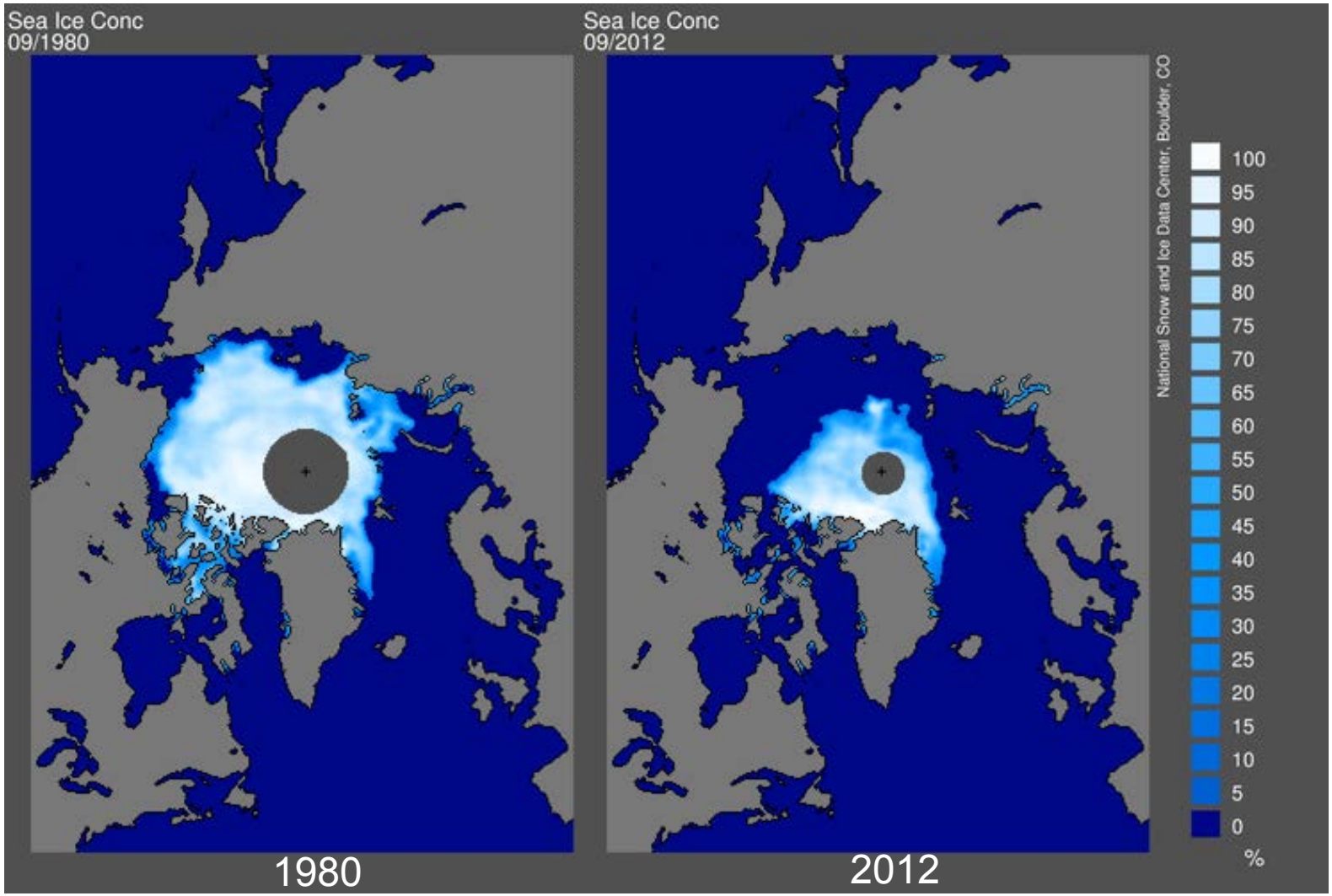
(Adapted from Wikimedia Commons)

Introduction

- Summer Arctic sea ice extent has decreased by more than 50% since 1980.
- There is estimated to a large amount of untapped natural resources in the Arctic, particularly oil (13% of the world's undiscovered reserves) and gas (30%).
- Many motivators such as tourism, fishing, resource exploration/ exploitation, and shipping are attracting operations in the Arctic, our aim is that it is done safely to avoid loss of life and environmental disasters.
- Arctic navigation at sea is plagued by many obstacles such as:
  - Poor sea chart quality
  - GNSS and other navigational aid challenges
  - **Sea ice hazards**

Summer Sea Ice



D. J. Cavalieri, C. L. Parkinson, P. Gloersen, and H. Zwally, "Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data," ed. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center, 1996, updated yearly.

Wikimedia Commons


>2 Collisions / Year
1/6 Ships Lost / Collision
EXPLORER
Chilean Navy

New Ice/Nilas

- <10 cm thick
- Not a danger to ships

Young Ice

- 10 to 30 cm thick
- Potential hazard to non-strengthened ships

First-Year Ice

- 30 cm to 2 m
- Hazard to non-strengthened ships

Multi-Year Ice

- 2m to 4m thick
- Usually covered by thick First-Year Ice
- Polar Class ship for sustained operation

Glacial Ice

- Anywhere from <1m to 5m+
- Danger to all ships

Current Detection Method Breakdown

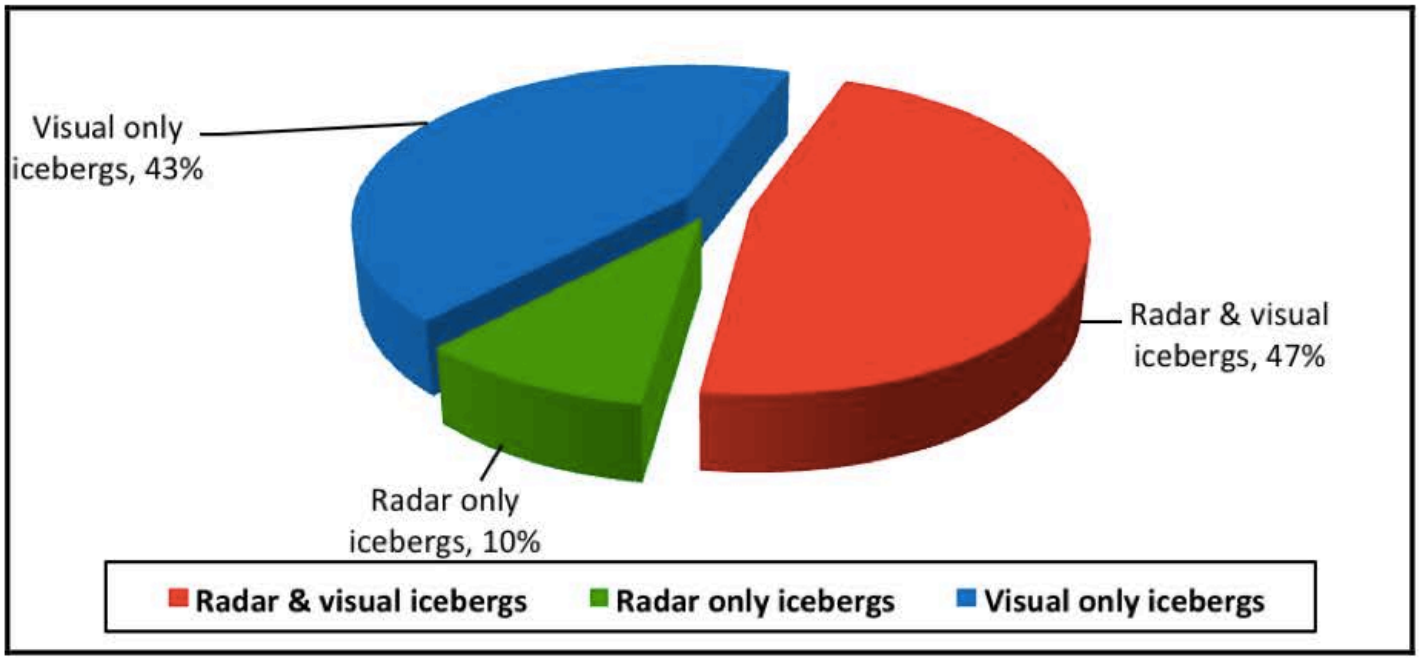
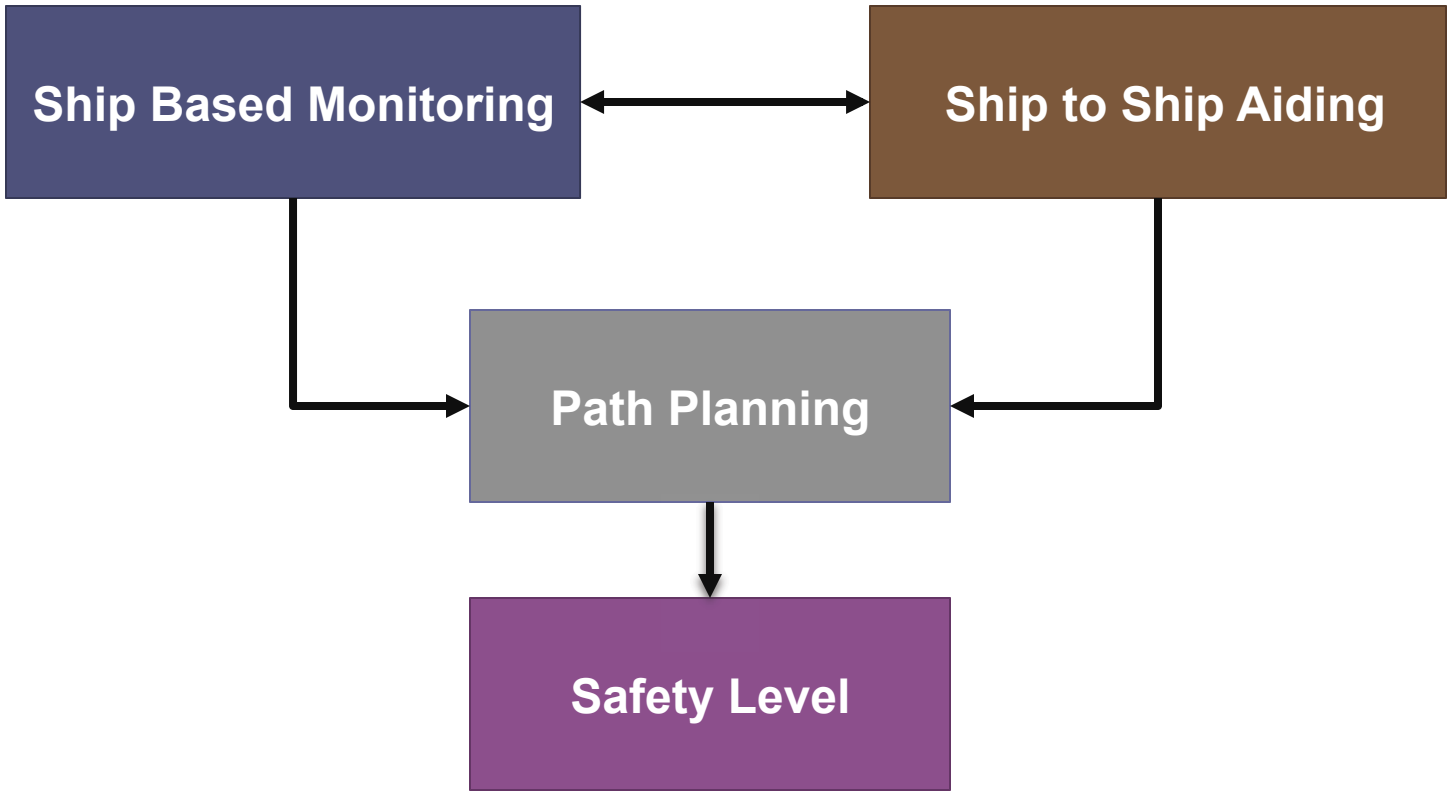
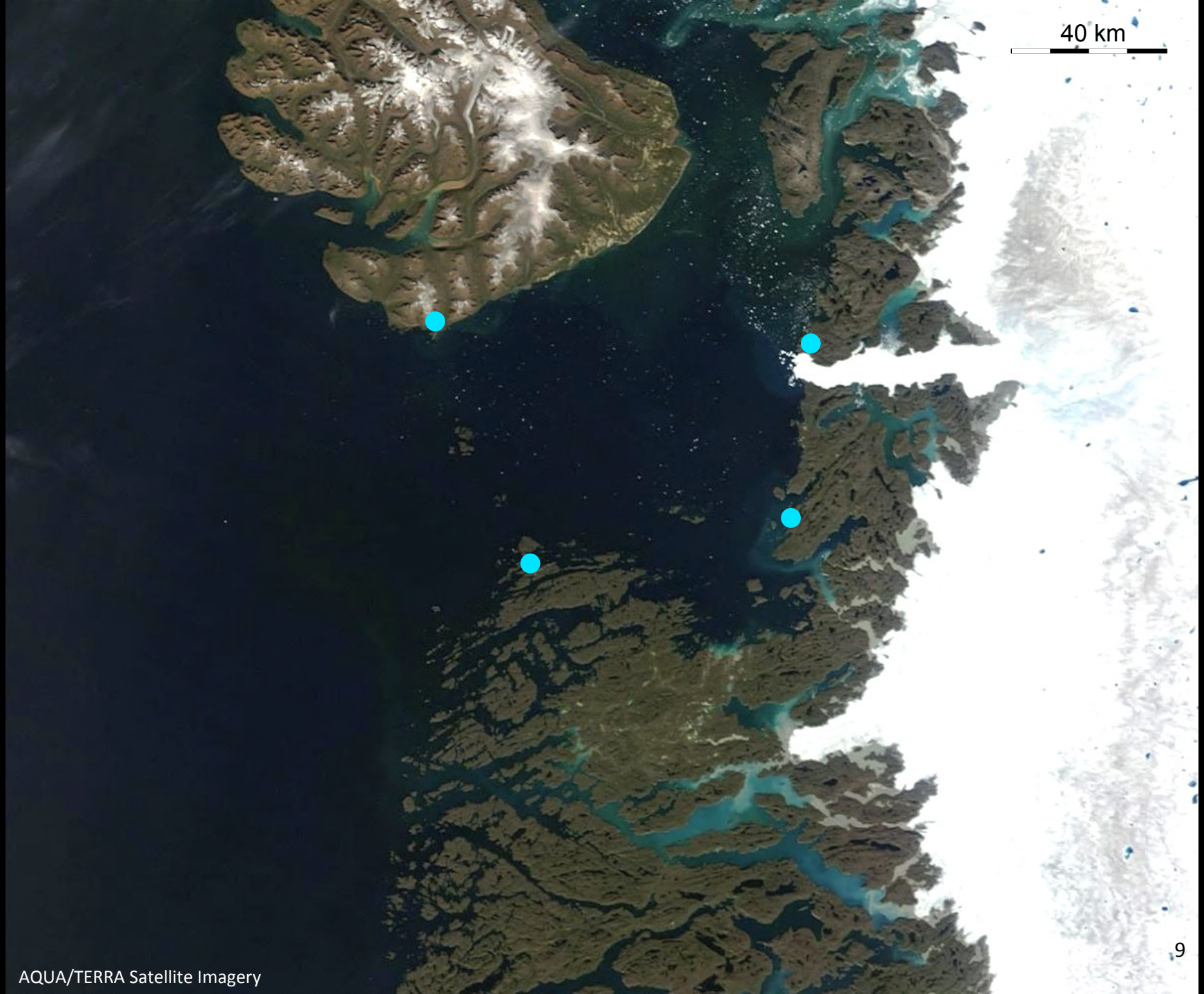


Figure 9. Breakdown of Icebergs by detection method.

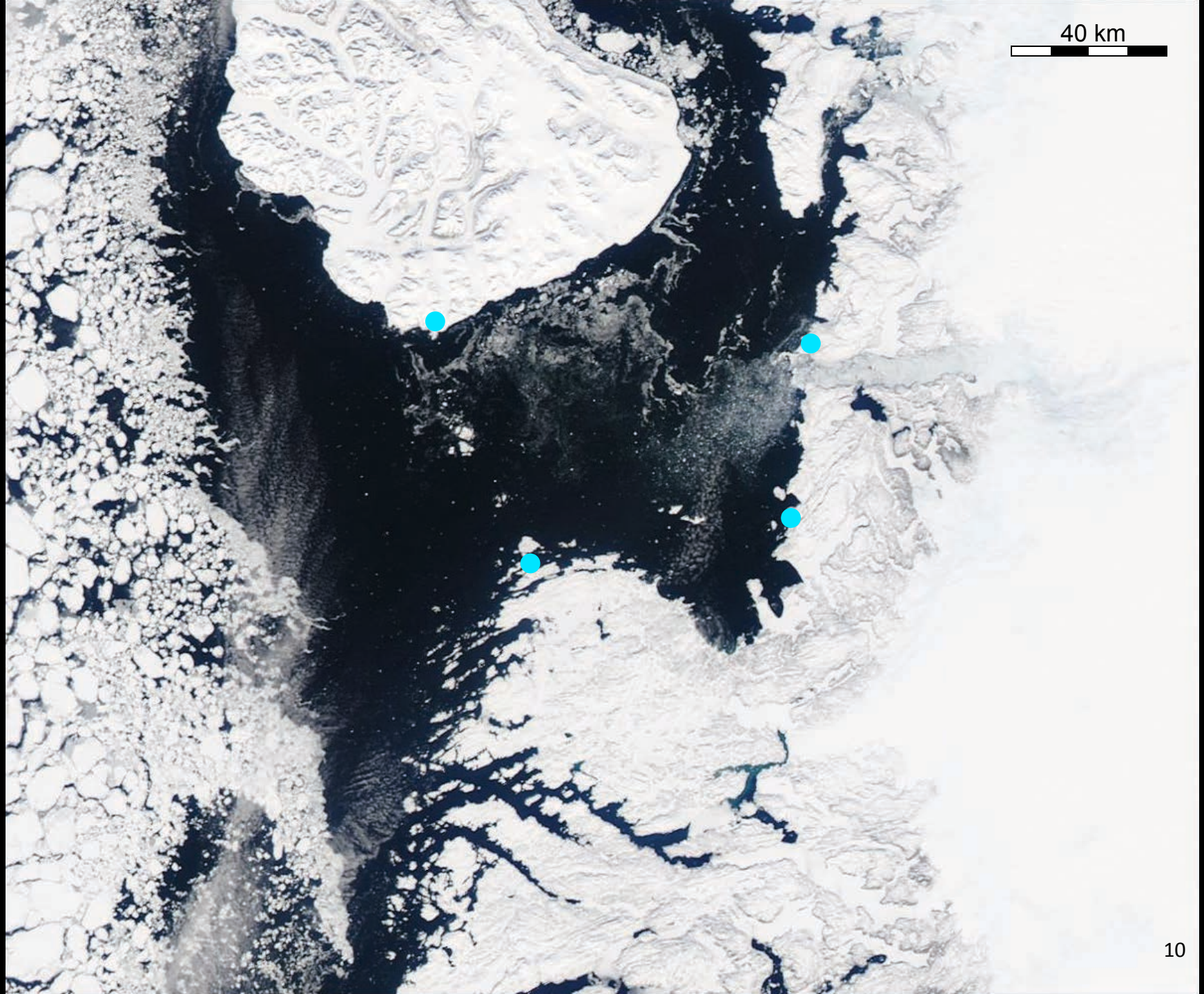
Department of Homeland Security, & United States Coast Guard. (2012). Report of the International Ice Patrol in the North Atlantic (Vol. 98).

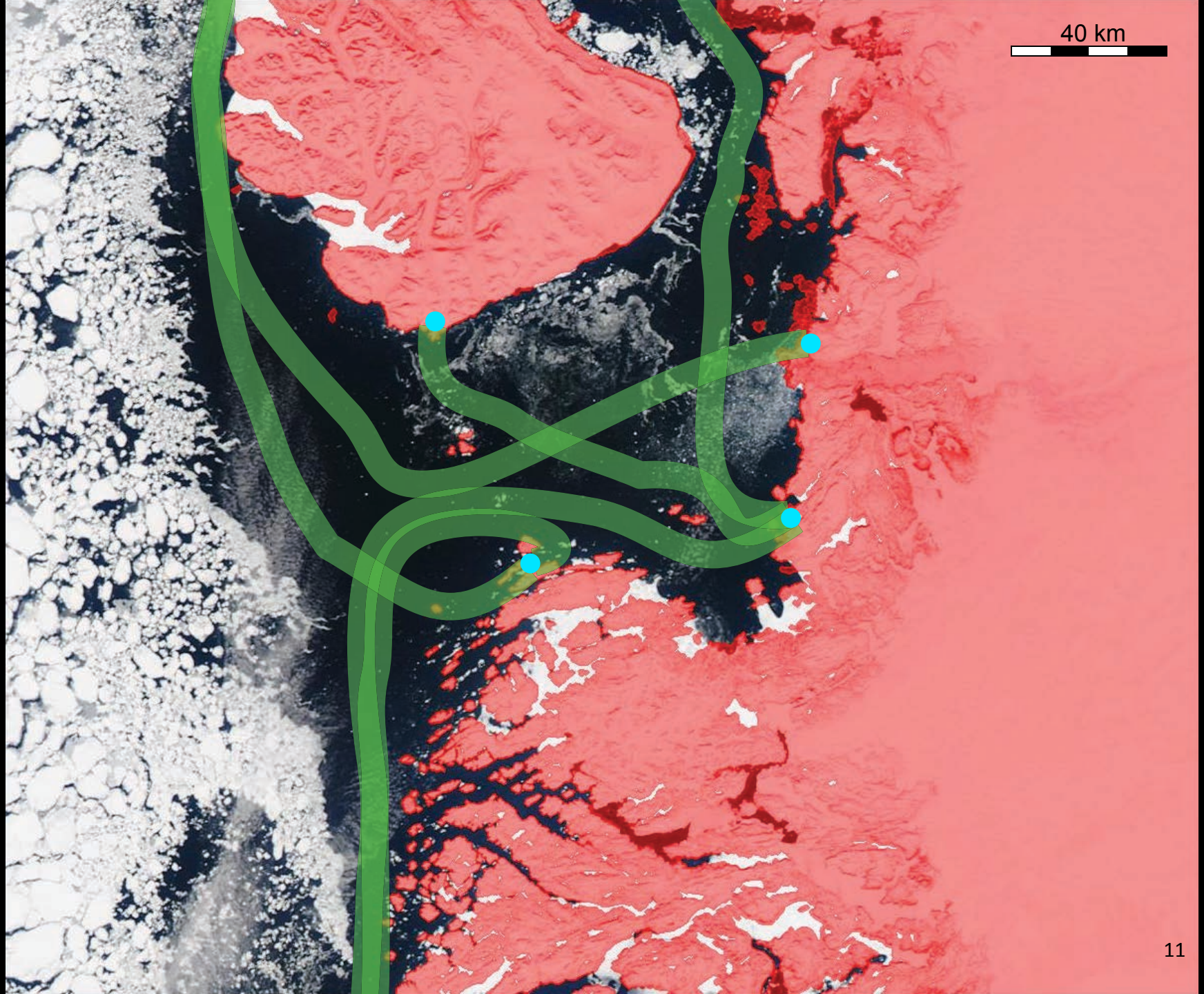
Proposed System

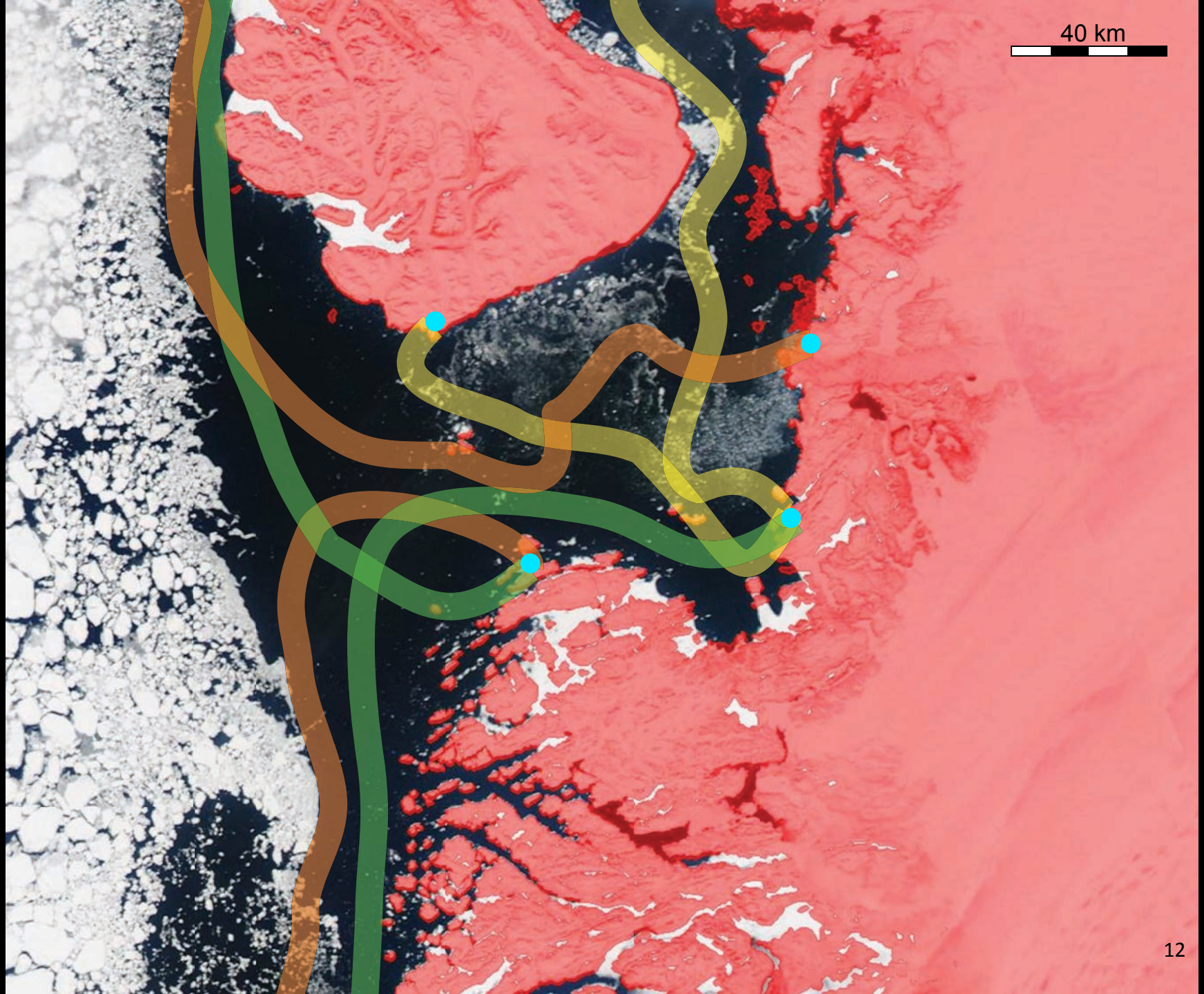


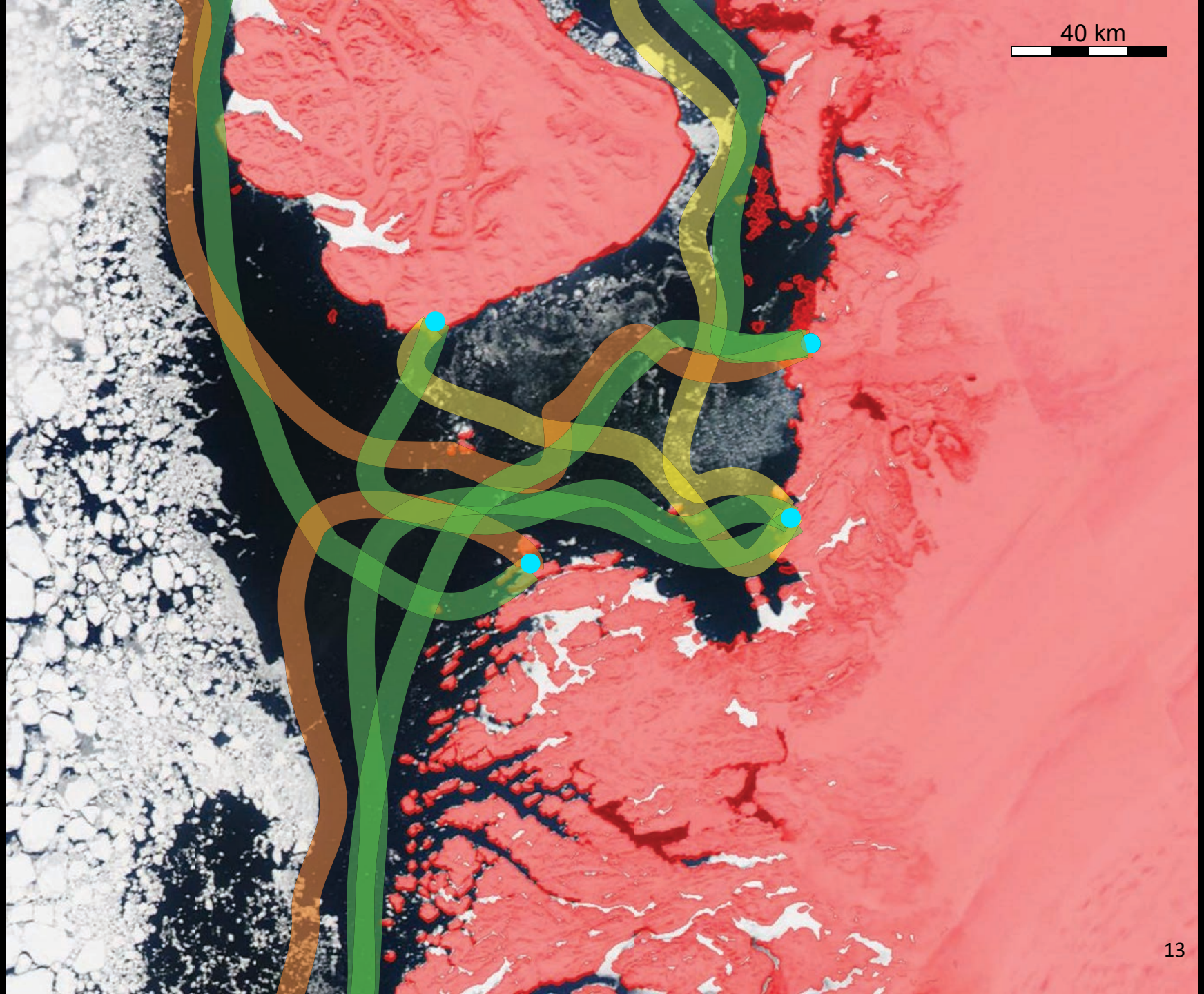


AQUA/TERRA Satellite Imagery


40 km


40 km


40 km


40 km


40 km
What is the path of safest approach?

Google driving to be driverless

Google's modified Toyota Prius uses an array of sensors to navigate public roads without a human driver. Other components, not shown, include a GPS receiver and an inertial motion sensor.

Laser-guided mapping
A rotating sensor with lasers called a LIDAR on the roof scans more than 200 feet in all directions to generate a precise three-dimensional map of the car's surroundings.

Position estimator
A sensor mounted on the left rear wheel measures small movements made by the car and helps to accurately locate its position on the map.

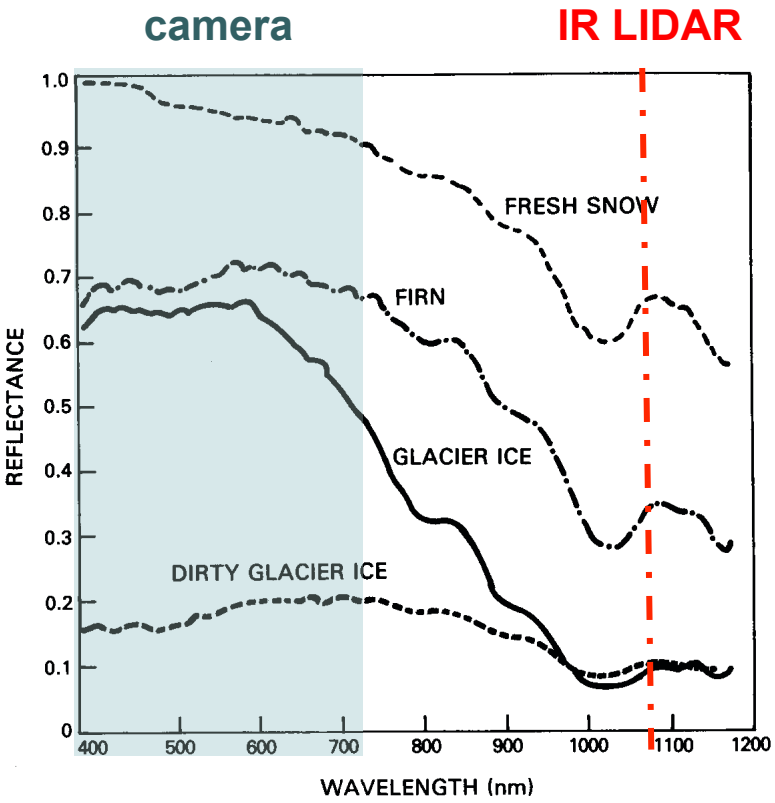
Video camera
A camera mounted near the rear-view mirror detects traffic lights and helps the car's onboard computers recognize moving obstacles-such as pedestrians and bicyclists.

Radar
Four standard automotive radar sensors, three in front and one in the rear, help determine the positions of distant objects.

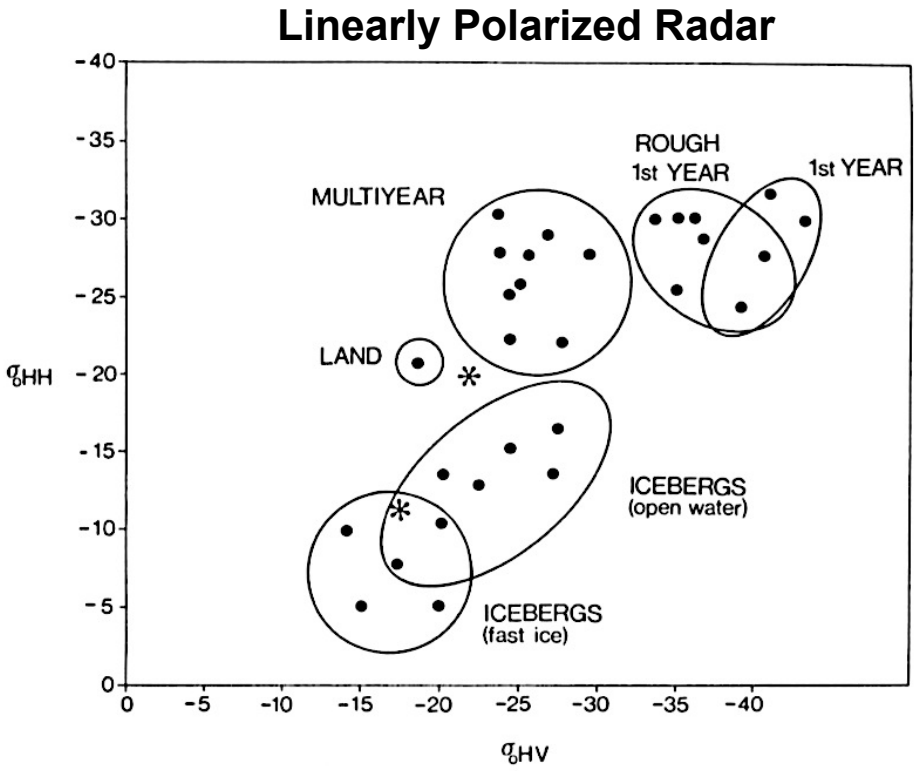
Source: Google

NEW YORK TIMES; PHOTOGRAPHS BY RAMIN RAHIMIAN FOR THE NEW YORK TIMES

Multi-Frequency System

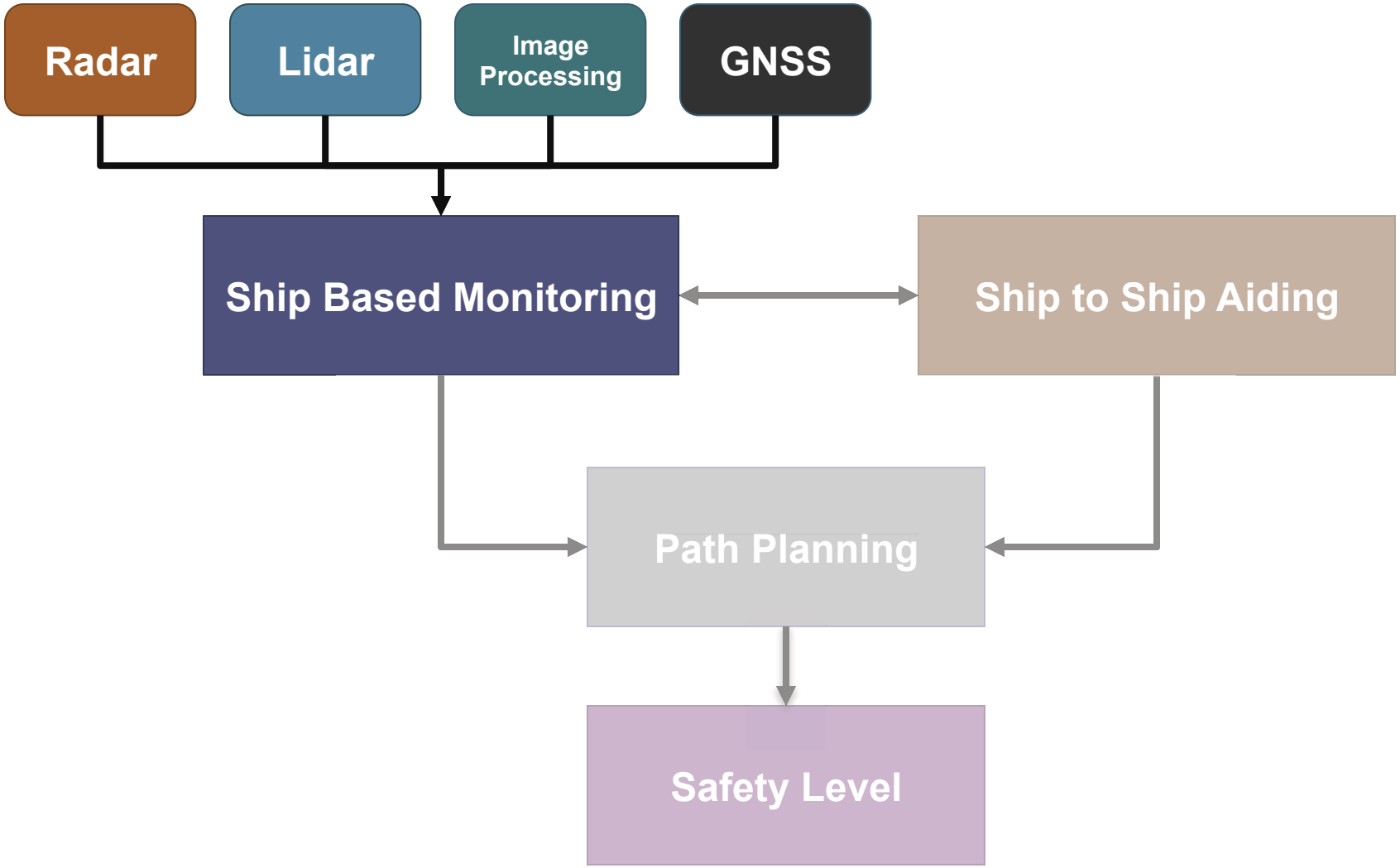


http://www2.hawaii.edu/~jmaurer/albedo/

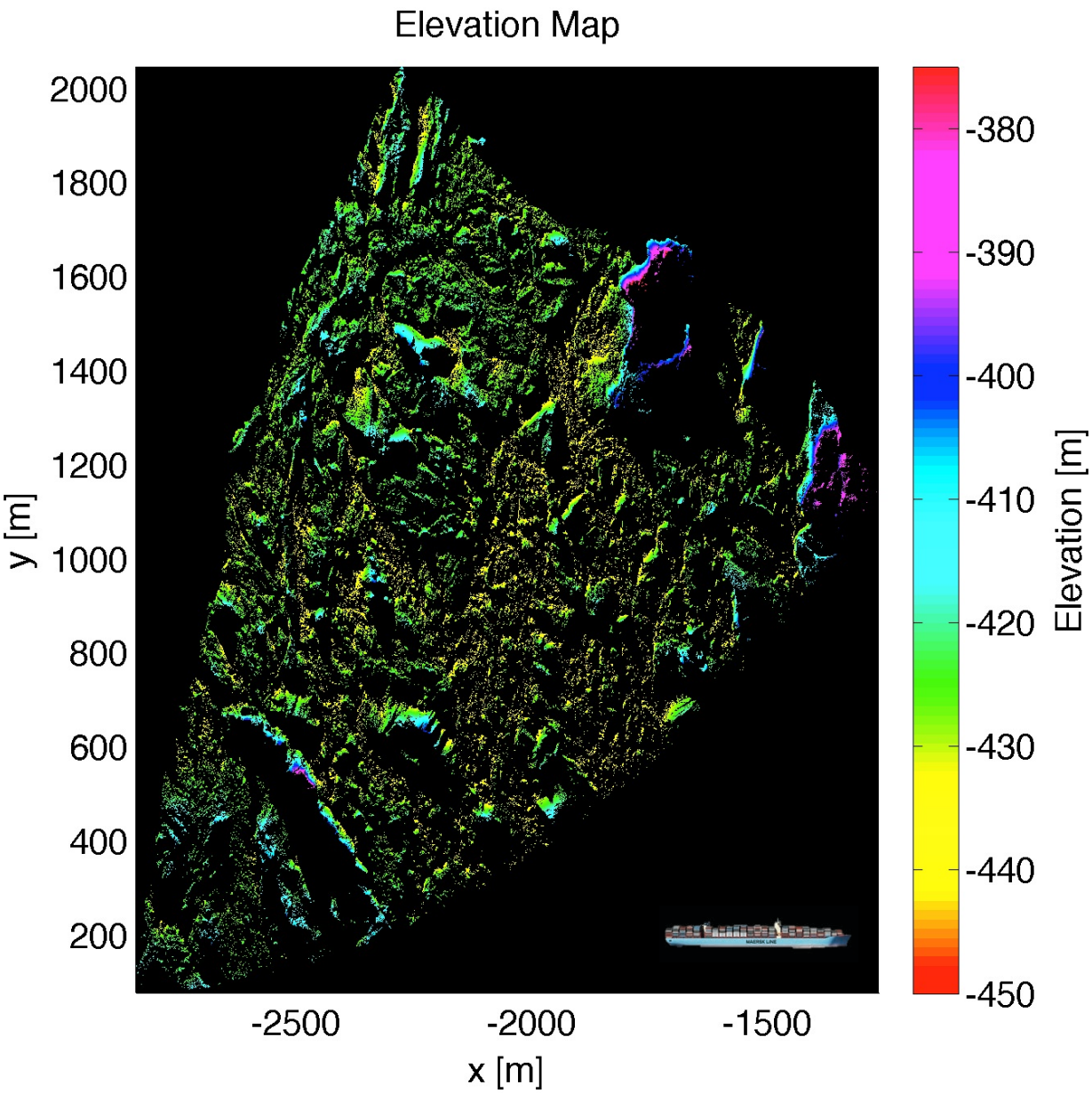


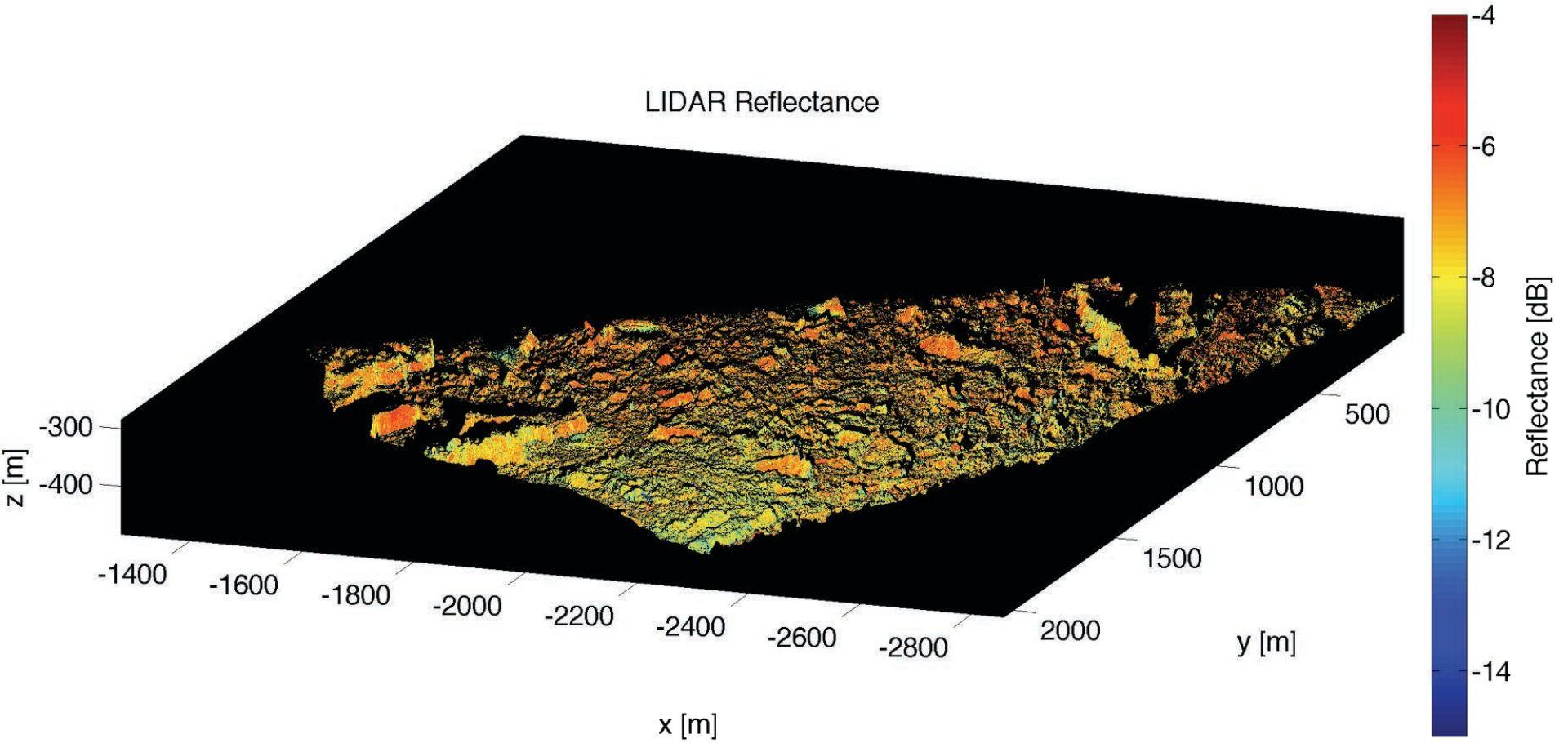
S. Haykin, E. O. Lewis, R. K. Raney, and J. R. Rossiter, *Remote Sensing of Sea Ice and Icebergs*. New York: Wiley, 1994.

Multispectral Sensing

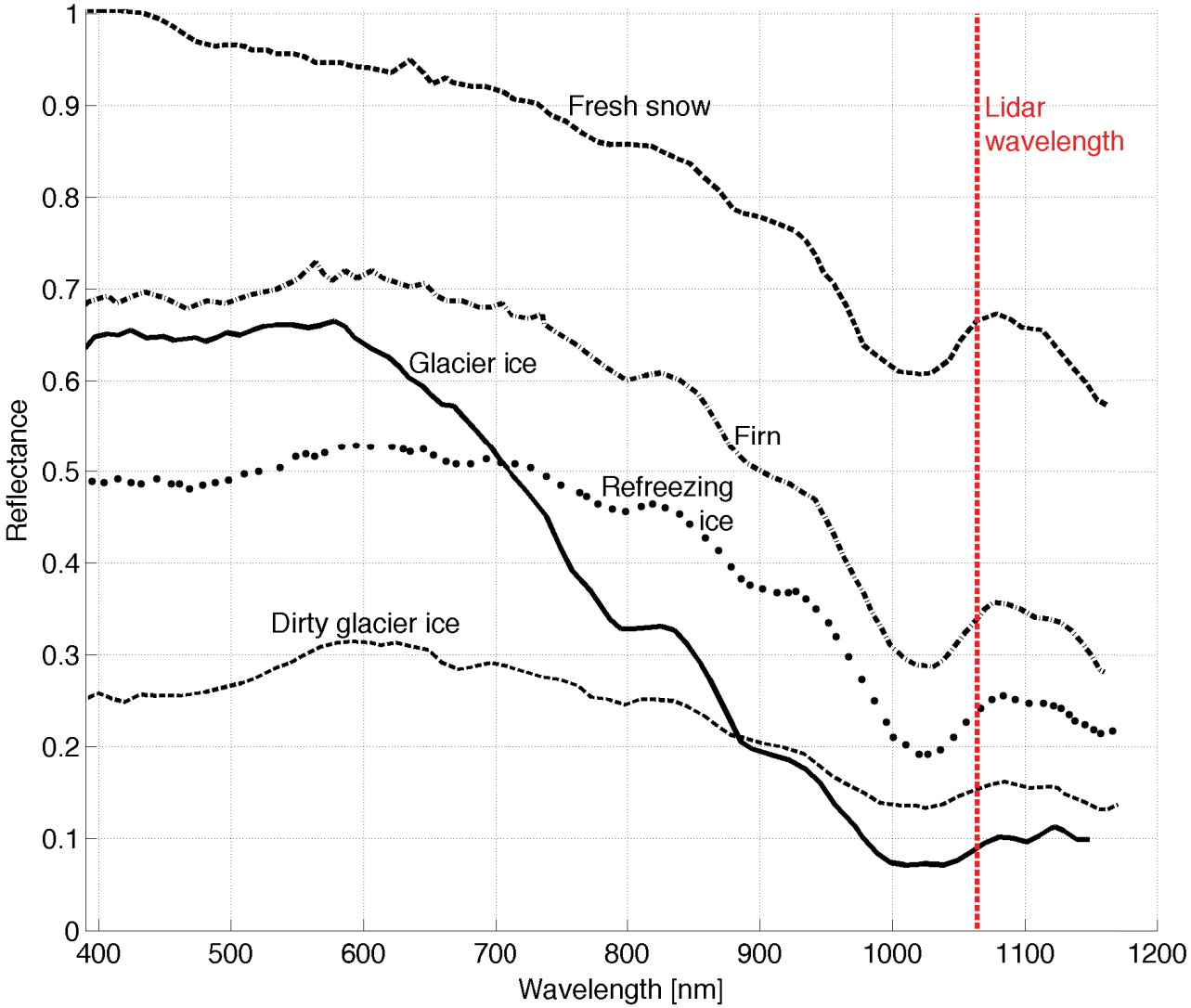



LIDAR
(REIGL VZ 6000)


Elevation Map
2000
1800
1600
1400
1200
1000
800
600
400
200
y [m]
-2500
-2000
-1500
x [m]
-380
-390
-400
-410
-420
-430
-440
-450
Elevation [m]


LIDAR Reflectance
z [m]
-300
-400
-1400
-1600
-1800
-2000
-2200
-2400
-2600
-2800
x [m]
500
1000
1500
2000
y [m]
-4
-6
-8
-10
-12
-14
Reflectance [dB]

Reflectance

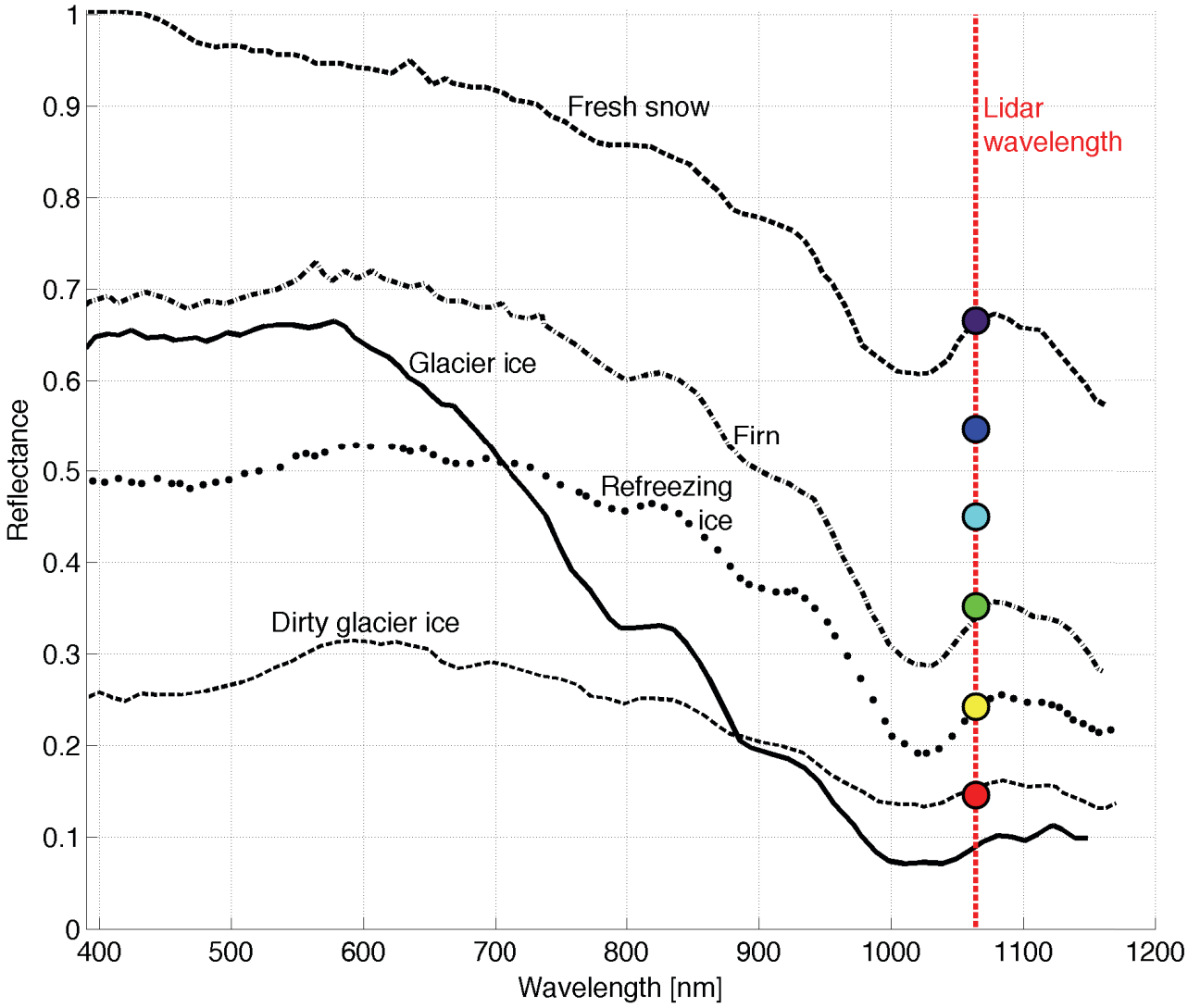


Adapted from: Qunzu, Z., Meisheng, C., Xuezhi, F. et al. (1984) Study on spectral reflection characteristics if snow, ice and water of northwest China. *Sci. Sin.* (Series B), 27, 647-56.

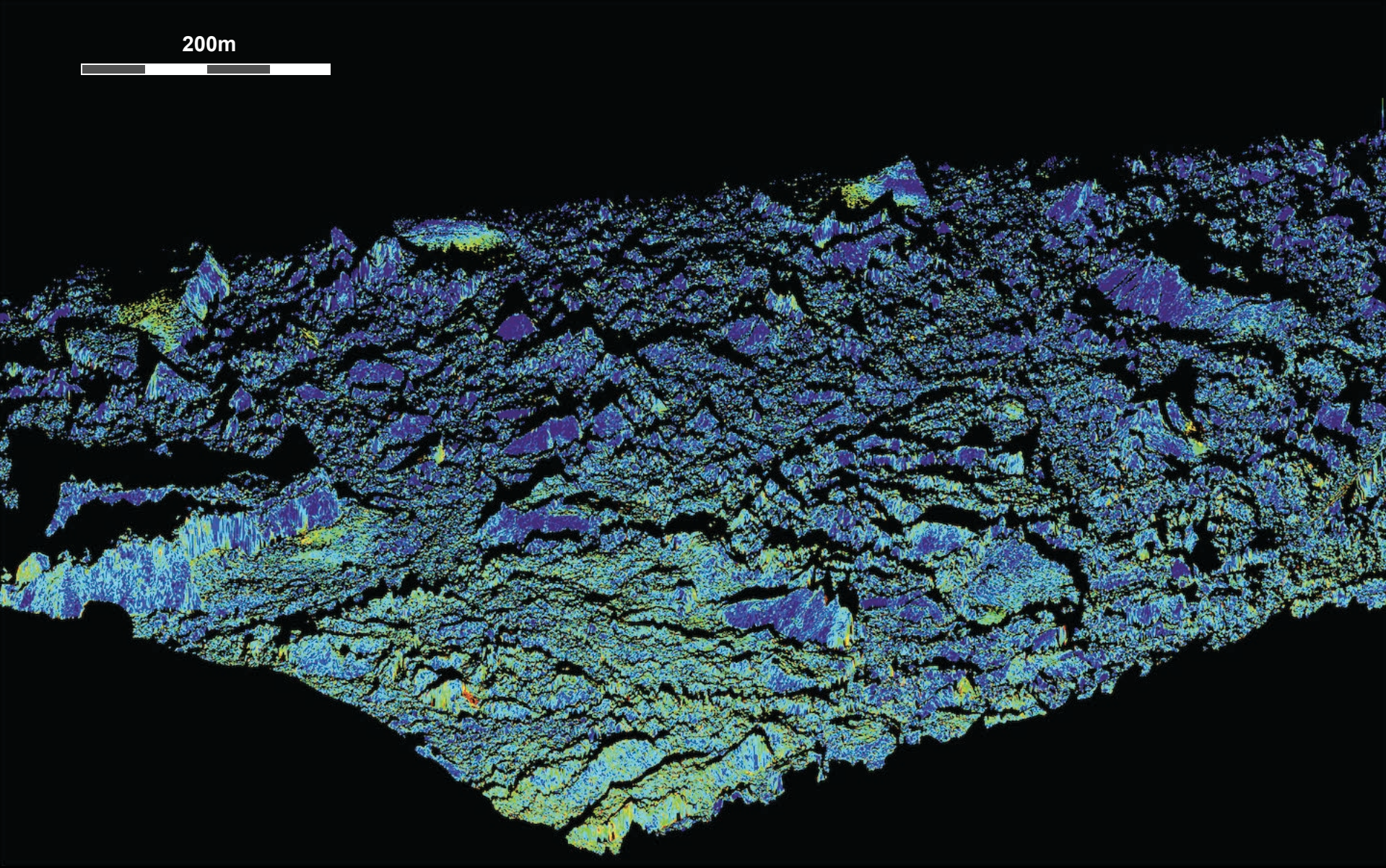
Finding Patterns

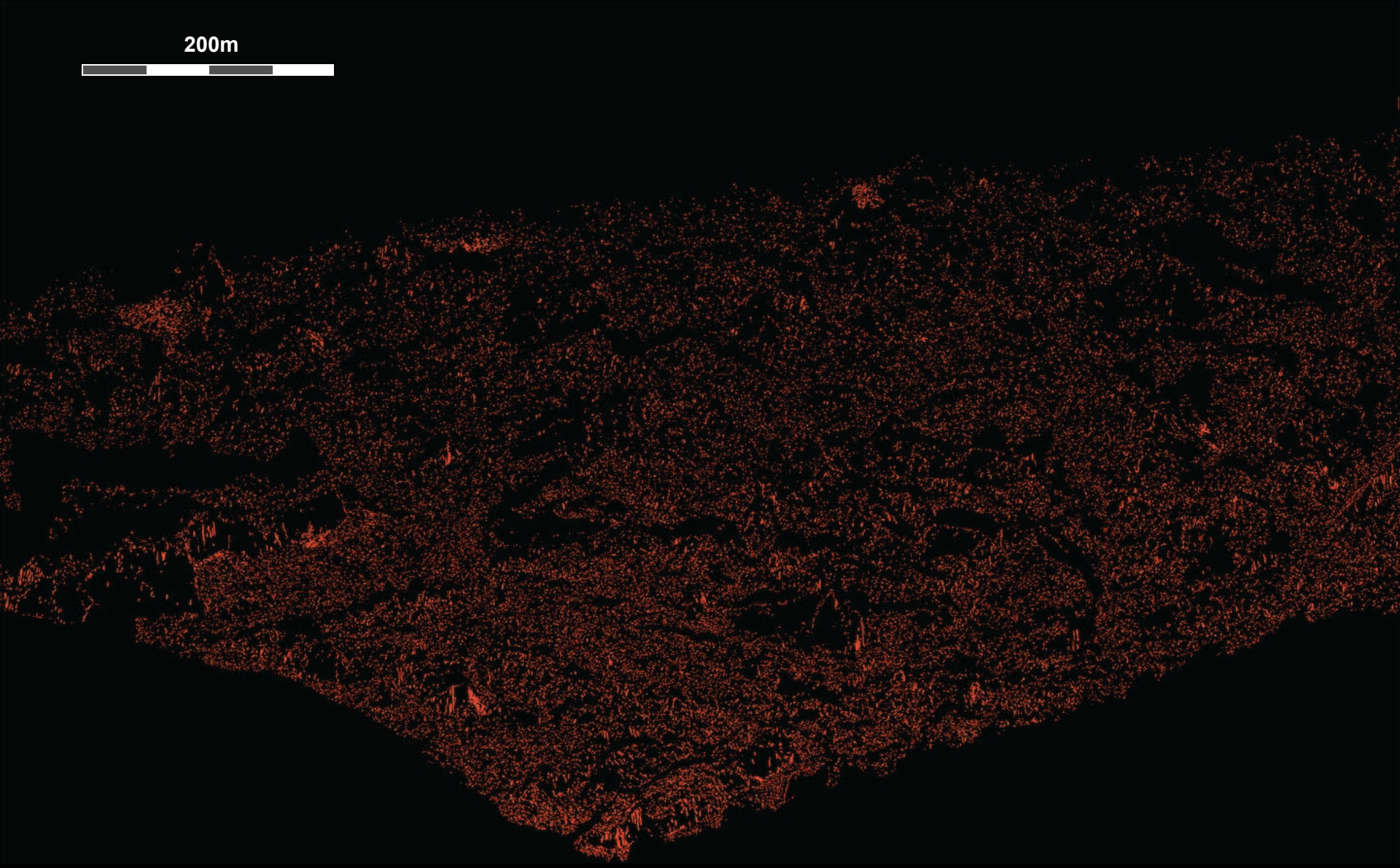
- *k*-Means Clustering is a Machine learning algorithm used for finding patterns (clusters) in large data sets.
- Cluster points based on similar reflectance.

Classification Results



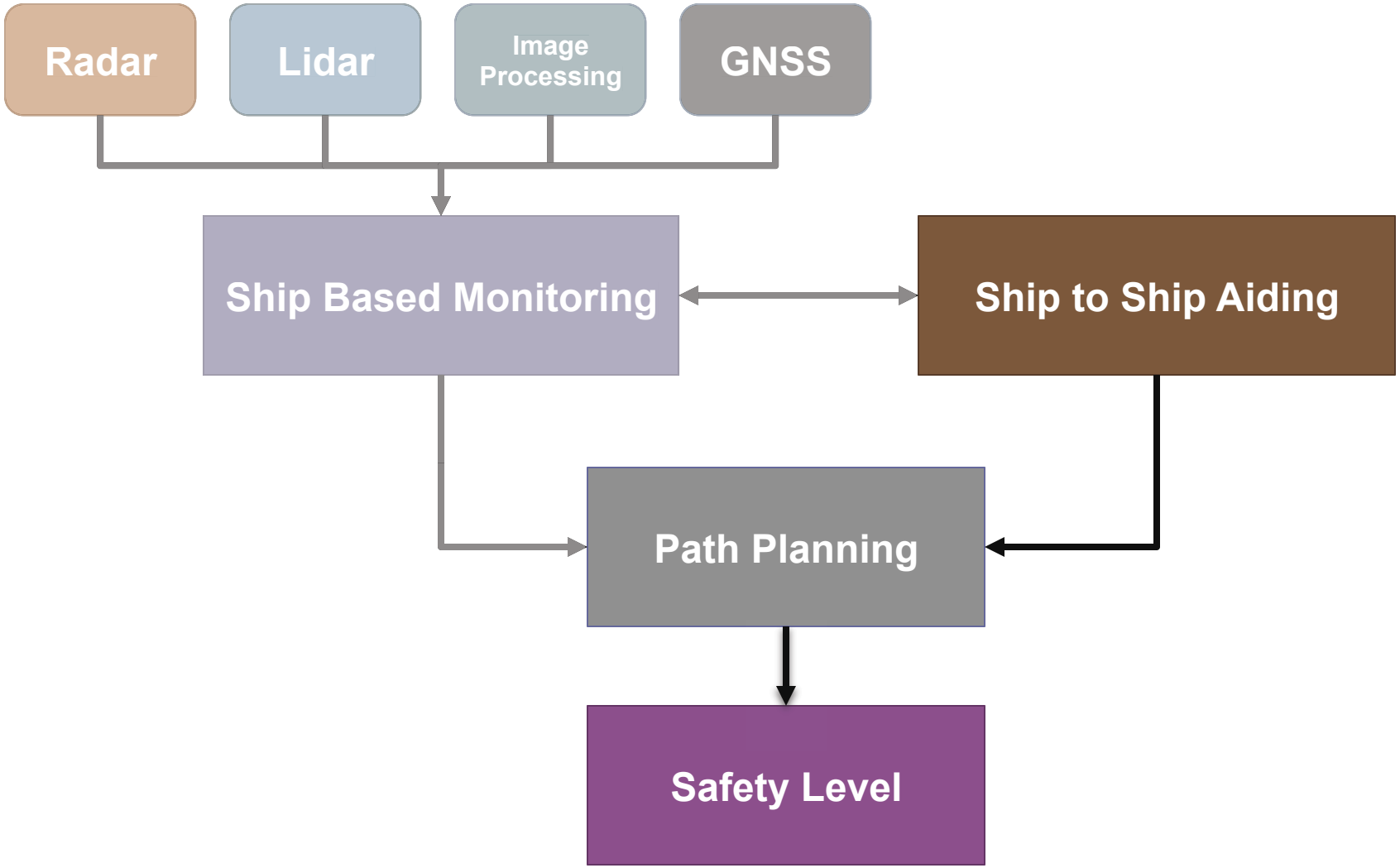
Adapted from: Qunzu, Z., Meisheng, C., Xuezhi, F. et al. (1984) Study on spectral reflection characteristics if snow, ice and water of northwest China. *Sci. Sin.* (Series B), 27, 647-56.


200m
GLACIER (DIRTY)
REFREEZING ICE
FIRN
OLDER SNOW
OLD SNOW
FRESH SNOW



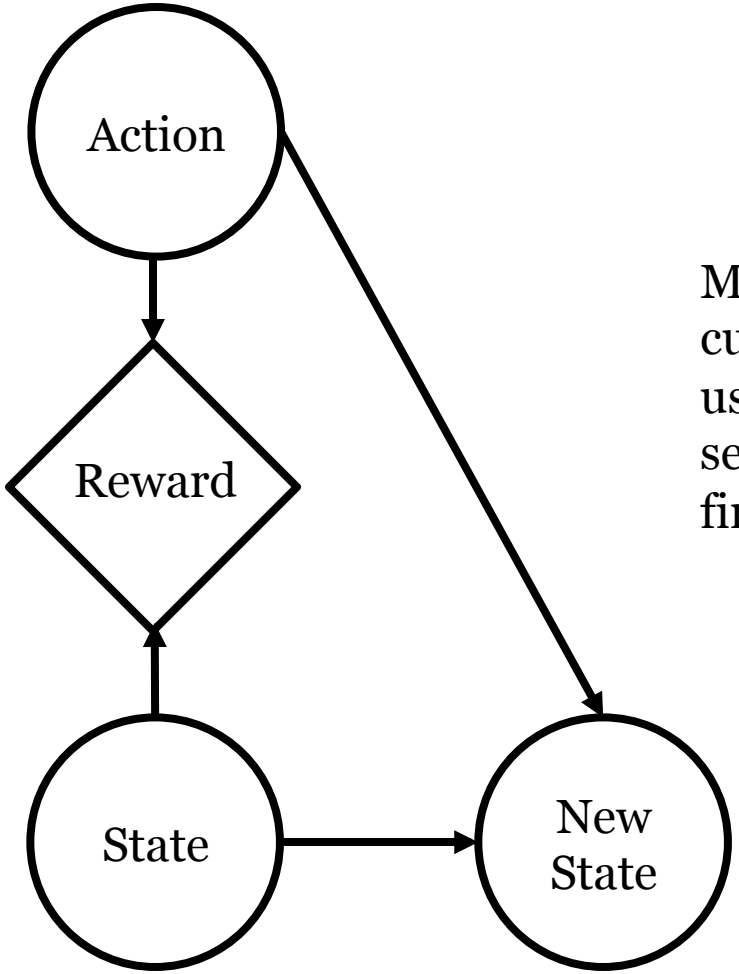
GLACIAL ICE

Crowd Sourcing




40 km
What is the path of safest approach?

Markov Decision Process (MDP)

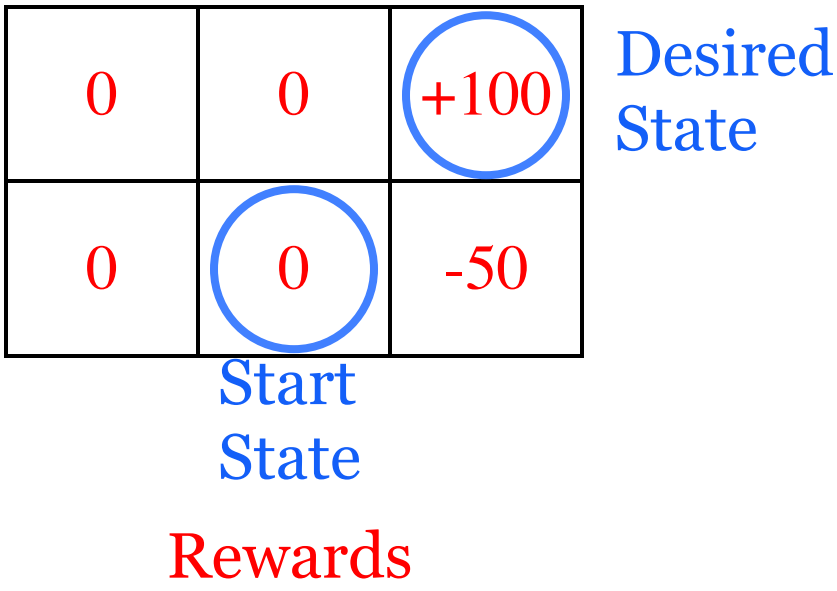


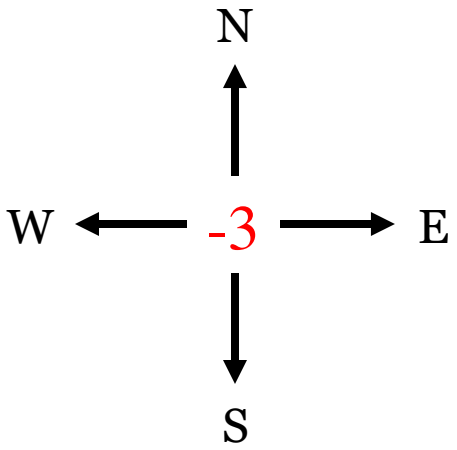
Maximizing the cumulative reward can be used to find the optimal set of actions to achieve a final desired state

Markov Decision Process (MDP) Example

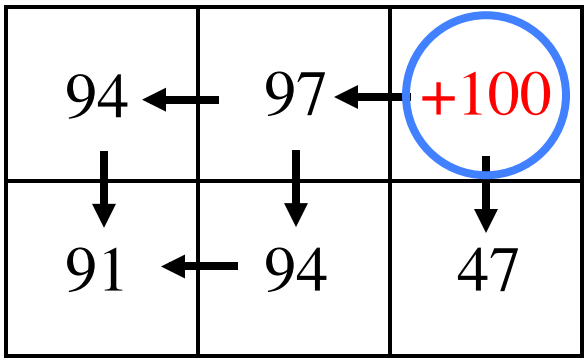
States

Actions



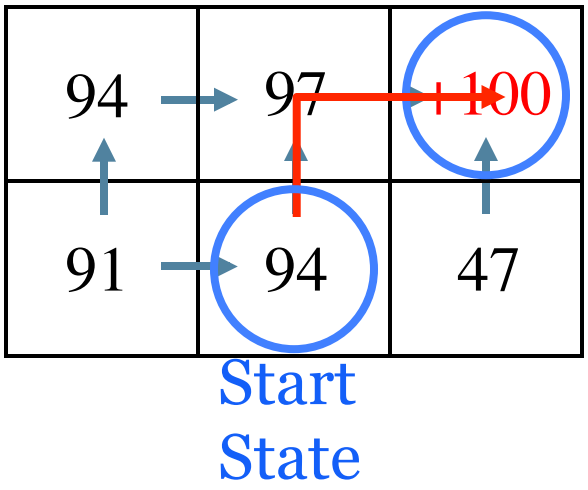


Value Function



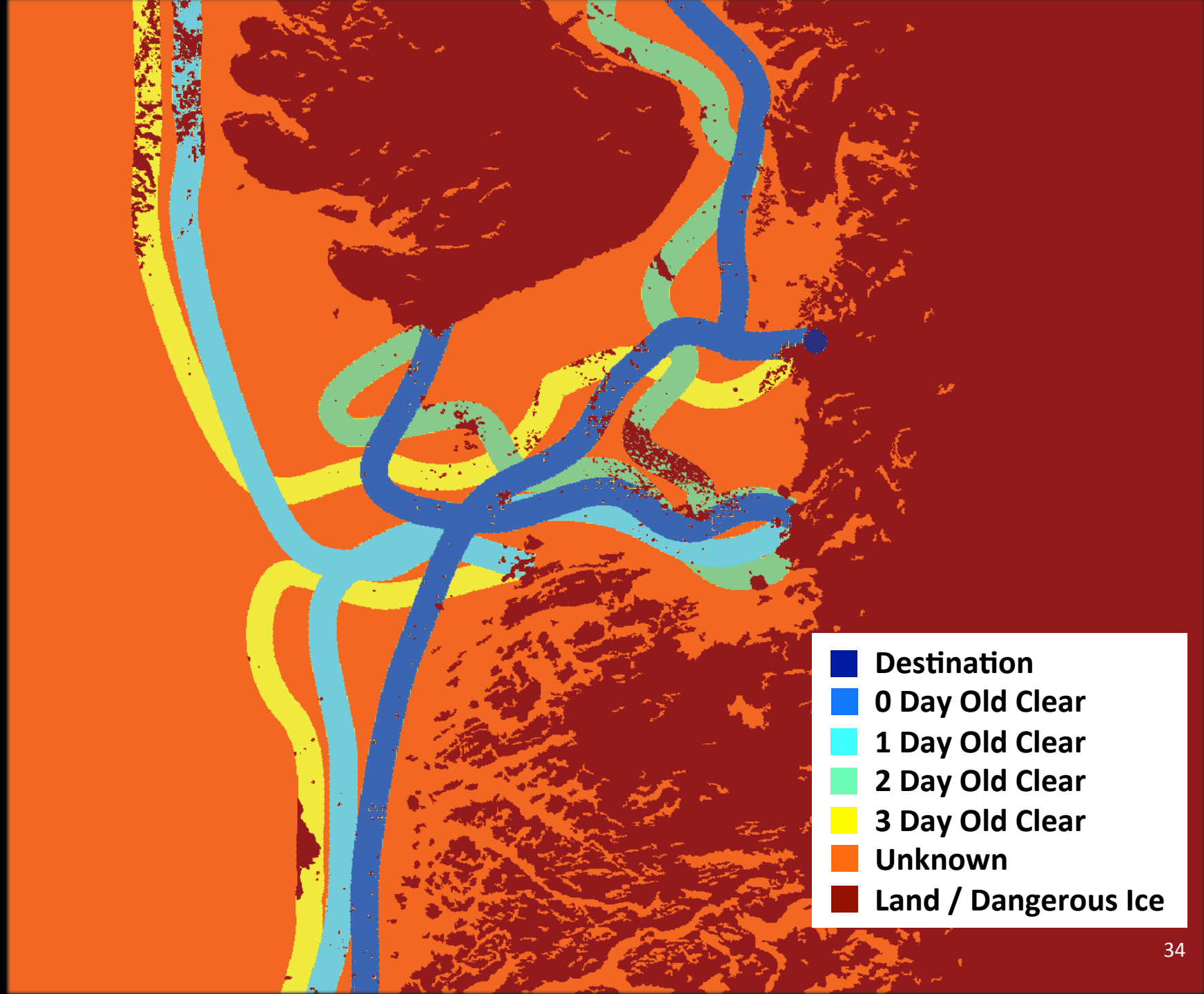
Want to maximize the total cumulative reward along the selected path.

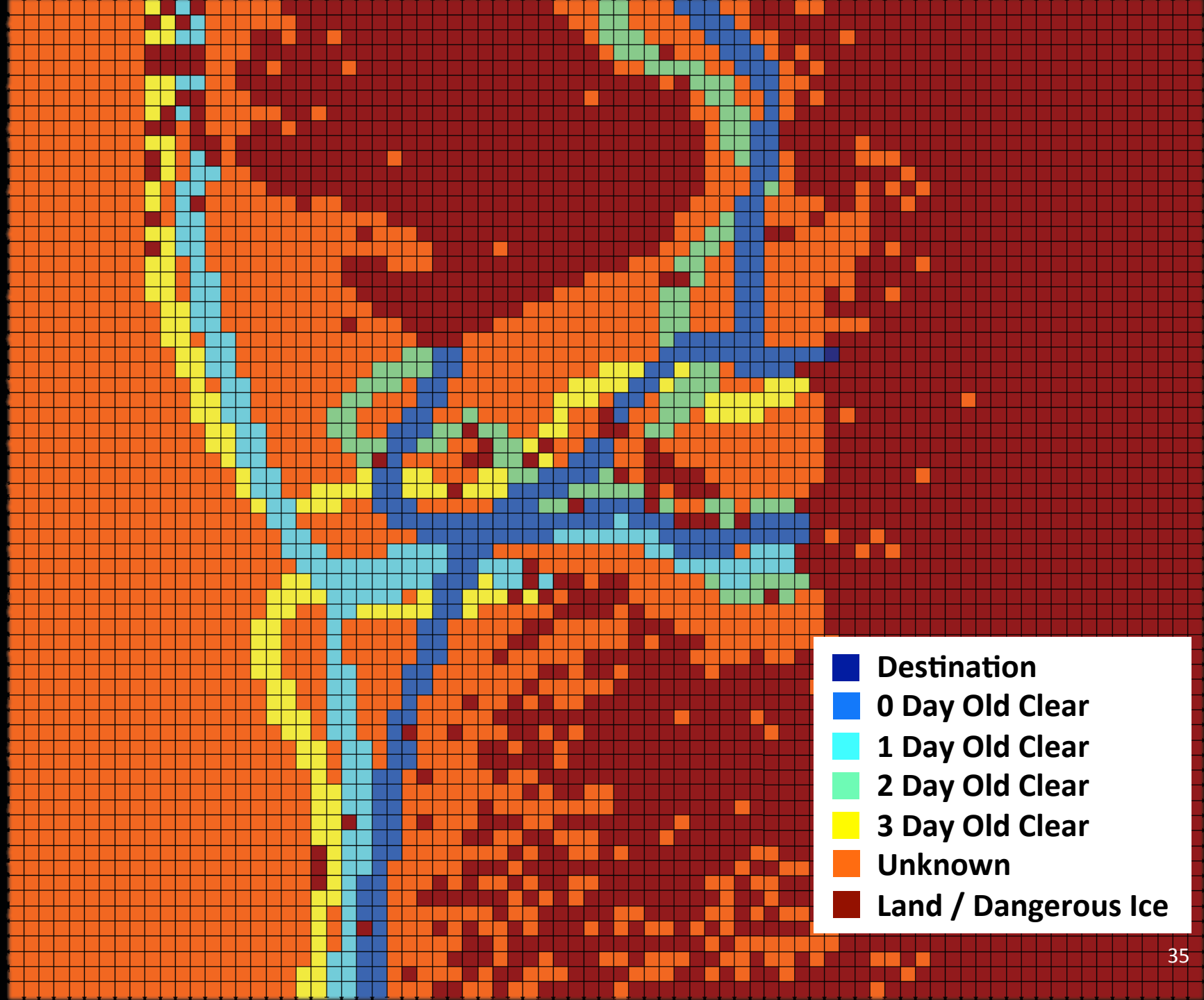
Trajectory

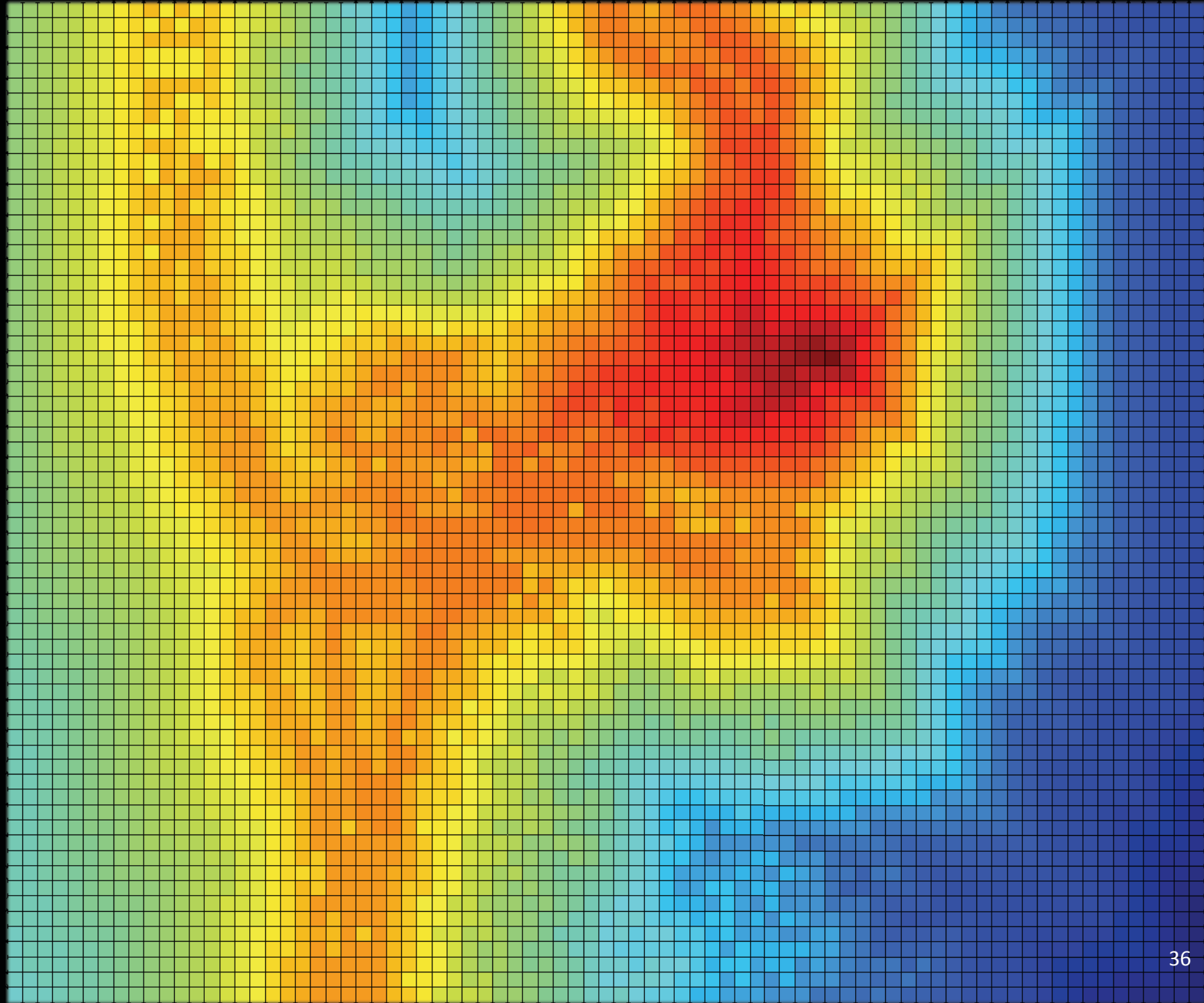


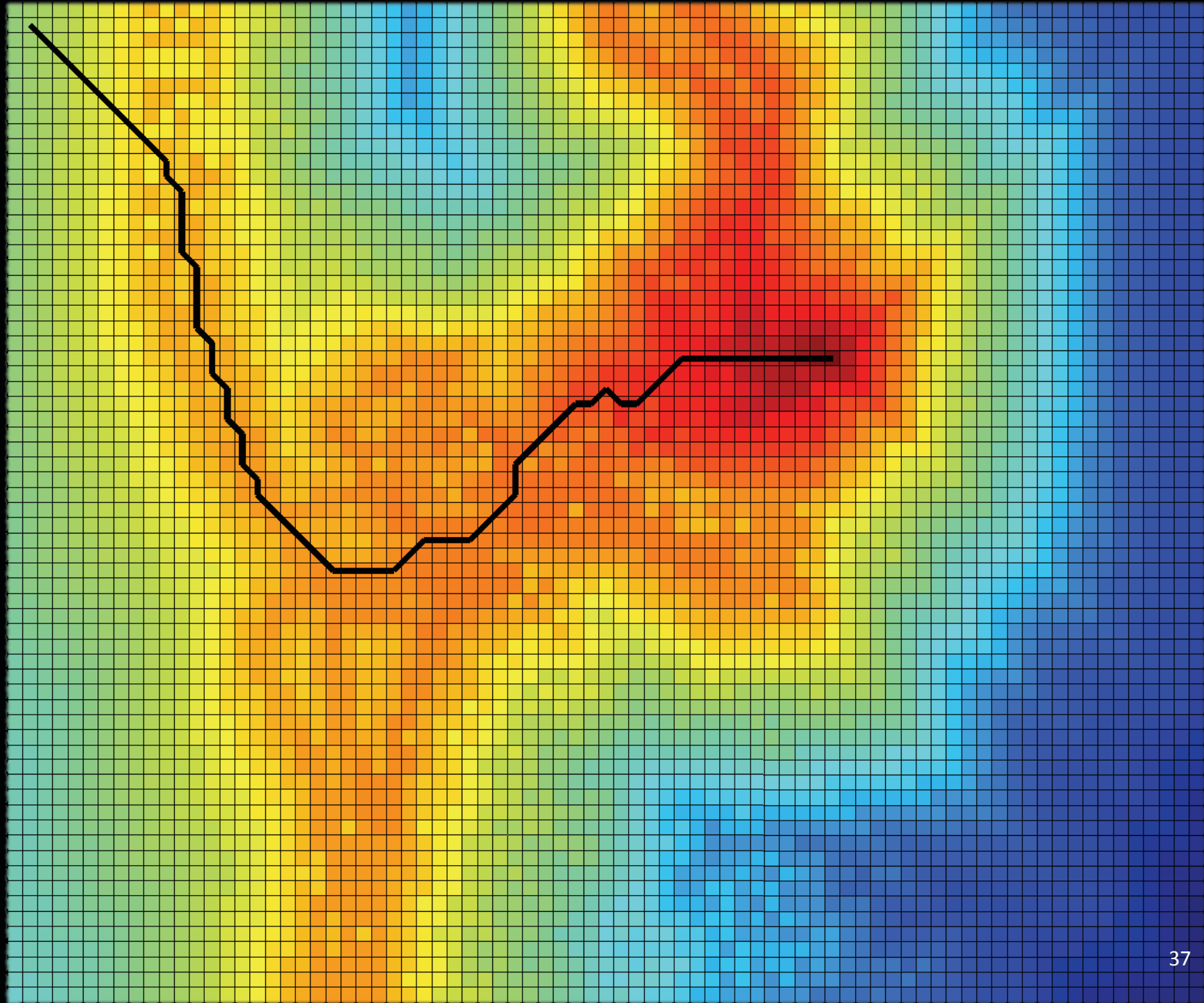
Use greedy algorithm to find the path.

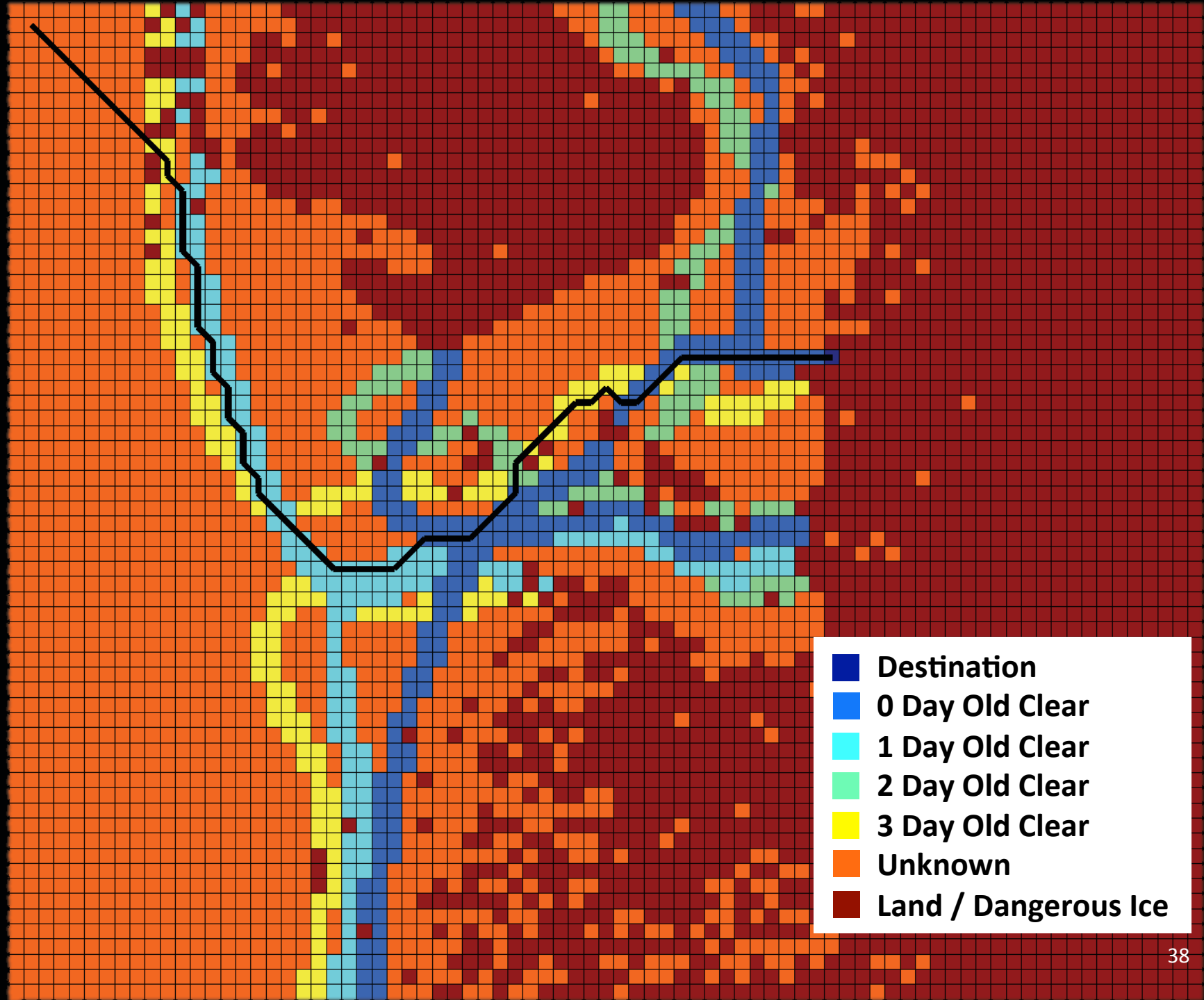

40 km
What is the path of safest approach?


Destination
0 Day Old Clear
1 Day Old Clear
2 Day Old Clear
3 Day Old Clear
Unknown
Land / Dangerous Ice


Destination
0 Day Old Clear
1 Day Old Clear
2 Day Old Clear
3 Day Old Clear
Unknown
Land / Dangerous Ice






Destination
0 Day Old Clear
1 Day Old Clear
2 Day Old Clear
3 Day Old Clear
Unknown
Land / Dangerous Ice

Conclusion

- This system could offer improvements in ice classification by making use of advancements in sensing technology found in autonomous vehicles.
- Need to crowd source the information and tie it together with GNSS to achieve ship to ship consistency. This allows ships to plan paths far ahead of their current position safely and economically.
- Our ultimate if to offer safer ice navigation in the hopes of preventing catastrophic accidents in the future.

Acknowledgements

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Lidar Data:

- **David Finnegan**, Environmental Research Scientist at the Cold Regions Research and Engineering Lab (CRREL) of the USACE
- **Gordon Hamilton**, Assoc. Professor at the Climate Change Institute and School of Earth and Climate Scientists at the University of Maine
- **Leigh Stearns**, Assistant Professor, Department of Geology at the University of Kansas.

Ship Collision Database:

- **Brian T. Hill**, National Research Council of Canada.

References (1)

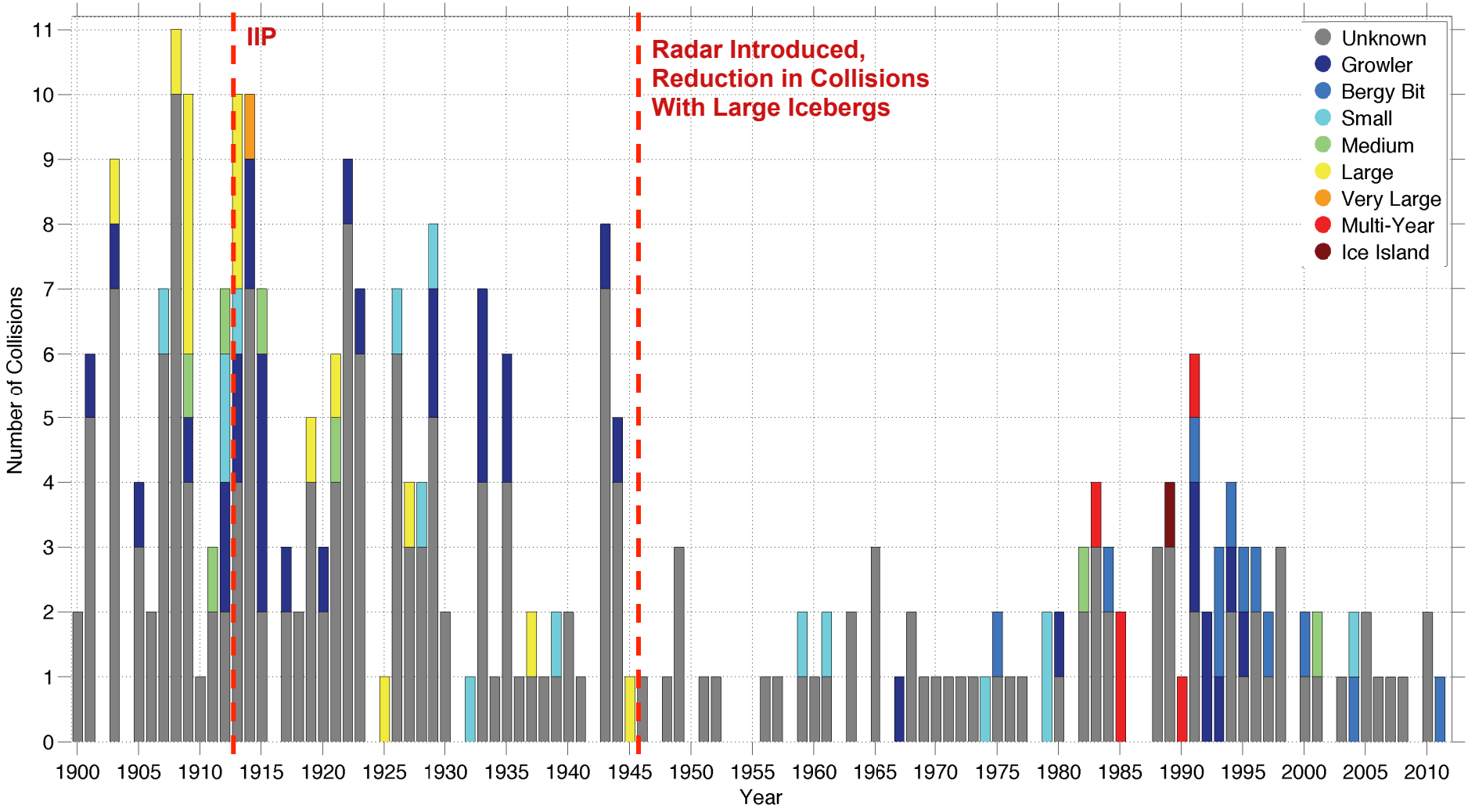
1. D. J. Cavalieri, C. L. Parkinson, P. Gloersen, and H. Zwally, "Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data," ed. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center, 1996, updated yearly.
2. J. E. Overland and M. Wang, "When will the summer Arctic be nearly sea ice free?," *Geophysical Research Letters,* vol. 40, pp. 2097-2101, 2013.
3. [3] D. L. Gautier, K. J. Bird, R. R. Charpentier, A. Grantz, D. W. Houseknecht, T. R. Klett*, et al.*, "Assessment of undiscovered oil and gas in the Arctic," *Science,* vol. 324, pp. 1175-1179, 2009.
4. [4] F. Lasserre and S. Pelletier, "Polar super seaways? Maritime transport in the Arctic: an analysis of shipowners' intentions," *Journal of Transport Geography,* vol. 19, pp. 1465-1473, 11// 2011.
5. Arctic Council, "Arctic Marine Shipping Assessment 2009," 2009.
6. M. Lück, P. T. Maher, and E. J. Stewart, *Cruise Tourism in Polar Regions: Environmental and Social* Washington D.C.: Earthscan, 2010. *Promoting Sustainability?*
7. N. Kjerstad, *Ice Navigation*: Akademika Publishing, 2011.
8. B. O'Connell, "Marine Radar for Improved Ice Detection," in *Proceedings of the 8th International Conference and Exhibition on Ships and Structures in Ice (ICETECH 2008)*, Banff, AB, Canada, 2008.
9. E. O. Lewis, B. W. Currie, and S. Haykin, *Detection and Classification of Ice*. Letchworth, Hertfordshire, England: Research Studies Press ltd., 1987.
10. T. J. Nohara, "Detection of growlers in sea clutter using an X-band pulse-Doppler radar," 1991.
11. T. J. Nohara and S. Haykin, "AR-based growler detection in sea clutter," *Signal Processing, IEEE Transactions on,* vol. 41, pp. 1259-1271, 1993.
12. S. Haykin, E. O. Lewis, R. K. Raney, and J. R. Rossiter, *Remote Sensing of Sea Ice and Icebergs*. New York: Wiley, 1994.
13. Icebreaking Program Maritime Services Canadian Coast Guard Fisheries and Oceans Canada, "Ice Navigation in Canadian Waters," ed. Ottawa, ON, Canada, 2012.
14. Committee on the Assessment of U.S. Coast Guard Polar Icebreaker Roles and Future Needs, M. B. Polar Research Board, Division on Earth and Life Studies,, Transportation Research Board, and N. R. Council, *Polar Icebreakers in a Changing World: An Assessment of U.S. Needs*: National Academies Press, 2007.
15. Finnish Transport Safety Agency, "The Structural Design and Engine Output Required of Ships for Navigation in Ice "Finish-Swedish Class Rules"," ed, 2010.
16. American Bureau of Shipping, "Rules for Building and Classing Steel Vessels: Part 6 Optional Items and Systems, Chapter 1: Strengthening for Navigation in Ice," ed. Houston, TX, 2012.

References (2)

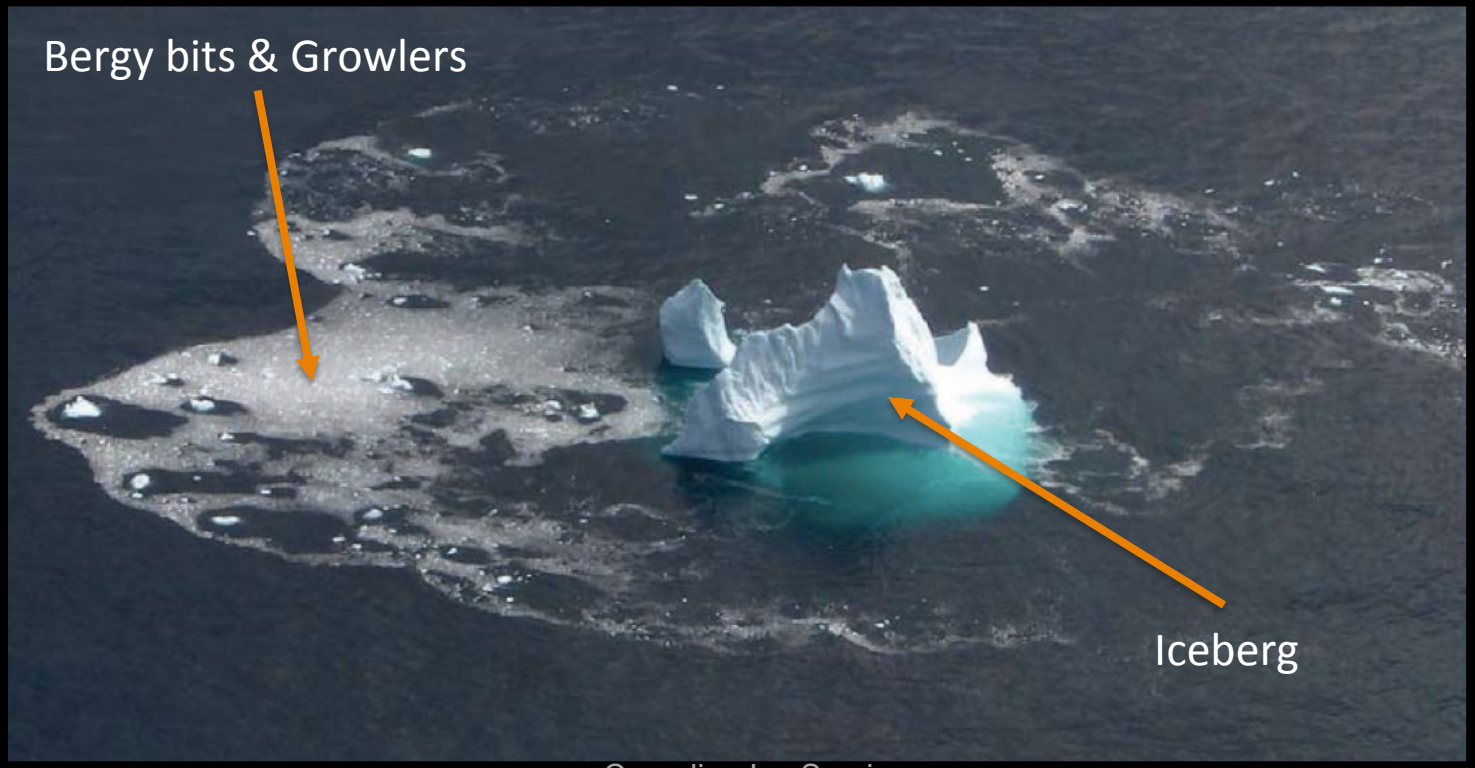
17. Department of Homeland Security and United States Coast Guard, "Report of the International Ice Patrol in the North Atlantic," 2012.
18. National Snow and Ice Data Center. (2014, April). *All About Sea Ice*. Available: http://nsidc.org/cryosphere/seaice/index.html
19. B. Hill, "Ship Collisions with Iceberg Database. Report to PERD: Trends and analysis," TR-2005- 17, 2005.
20. B. Hill, "Ship Collision with Iceberg Database," IR- 2005-27, 2006.
21. S. Thrun, M. Montemerlo, H. Dahlkamp, D. Stavens, A. Aron, J. Diebel*, et al.*, "Stanley: The robot that won the DARPA Grand Challenge," *Journal of field Robotics,* vol. 23, pp. 661-692, 2006.
22. E. Guizzo, "How google's self-driving car works," *IEEE Spectrum Online, October,* vol. 18, 2011.
23. H. A. Murthy and S. Haykin, "Bayesian classification of surface-based ice-radar images," *Oceanic Engineering, IEEE Journal of,* vol. 12, pp. 493-502, 1987.
24. T. J. Nohara and S. Haykin, "Growler detection in sea clutter using Gaussian spectrum models," *Radar, Sonar and Navigation, IEE Proceedings -,* vol. 141, pp. 285-292, 1994.
25. T. J. Nohara and S. Haykin, "Growler detection in sea clutter with coherent radars," *Aerospace and Electronic Systems, IEEE Transactions on,* vol. 30, pp. 836-847, 1994.
26. B. O'Connell, "Ice Hazard Radar," in *Proceedings of the 10th International Conference and Exhibition on Performance of Ships and Structures in Ice (ICETECH 2010)*, Anchorage, AK, USA, 2010.
27. D. K. Hall, A. T. C. Chang, and H. Siddalingaiah, "Reflectances of glaciers as calculated using Landsat-5 Thematic Mapper data," *Remote Sensing of Environment,* vol. 25, pp. 311-321, 8// 1988.
28. Q. Zeng, M. Cao, X. Feng, F. Liang, X. Chen, and W. Sheng, "A study of spectral reflection characteristics for snow, ice and water in the north of China," *Hydrological applications of remote sensing and remote data transmission,* vol. 145, pp. 451-462, 1984.
29. G. X. Gao, L. Heng, T. Walter, and P. Enge, "Breaking the Ice: Navigating in the Arctic," in *Proceedings of the 24th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS 2011)*, Portland, OR, 2011.
30. T. Sundlisæter, T. Reid, C. Johnson, and S. Wan, "GNSS and SBAS System of Systems: Considerations for Applications in the Arctic," in *63rd International Astronautical Congress*, Naples, Italy, 2012.
31. A. Fowler and D. Finnegan. (2013, February 2013) Scanning Glaciers with a Long-range Scanner. *GIM International*. Available: http:// www.gim- international.com/issues/articles/id1964- Scanning_Glaciers_with_a_Longrange_Scanner.htm
32. T. Reid, T. Walter, P. Enge, and A. Fowler, "Crowdsourcing Arctic Navigation Using Multispectral Ice Classification and GNSS," in *Proceedings of the 27th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS 2014)*, Tampa, FL, 2014.

Back Up Slides

Number of Ice Collisions 1900-2011



*Based on data from Dr. Brian T. Hill of the National Research Council of Canada

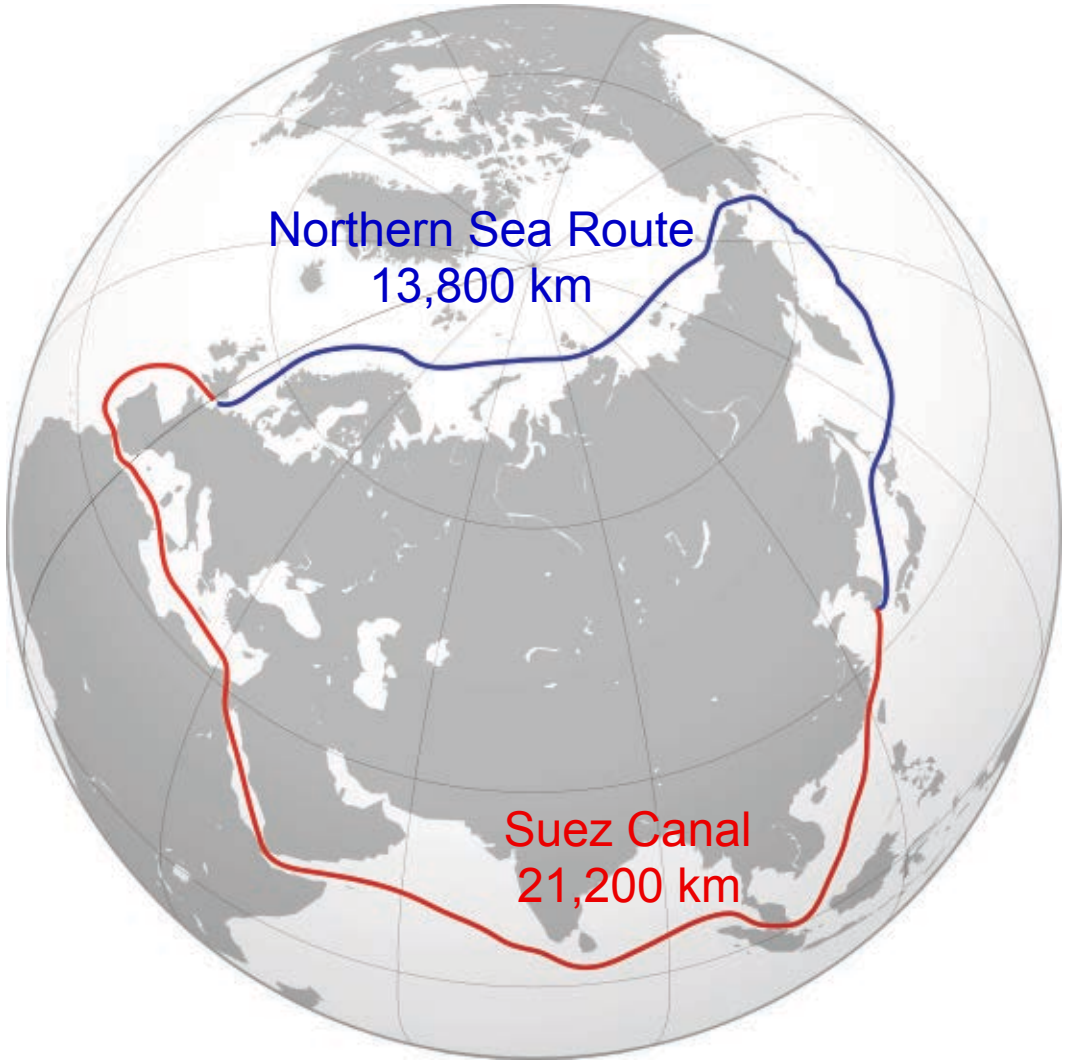


Canadian Ice Service

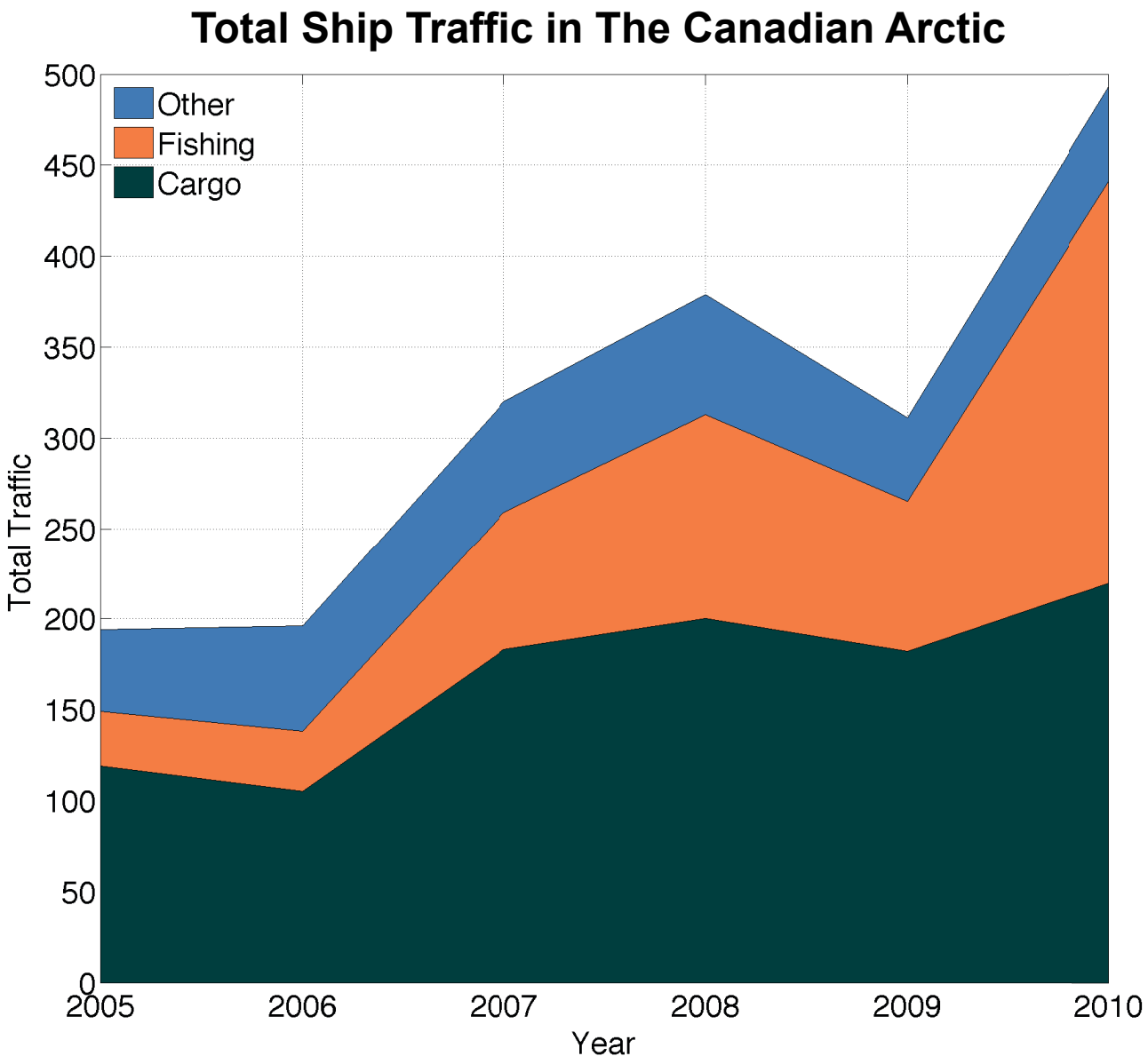
Description	Height Above Sea-Level [m]	Relative Size	Mass [tonnes]
Iceberg	> 5	Merchant Ship	> 180,000
Bergy Bit	1 – 5	Small House	> 5,400
Growler	< 1	Grand Piano	> 120

Lewis, E. O., Currie, B. W., & Haykin, S. (1987). *Detection and Classification of Ice*. Letchworth, Hertfordshire, England: Research Studies Press ltd.

Shipping Routes

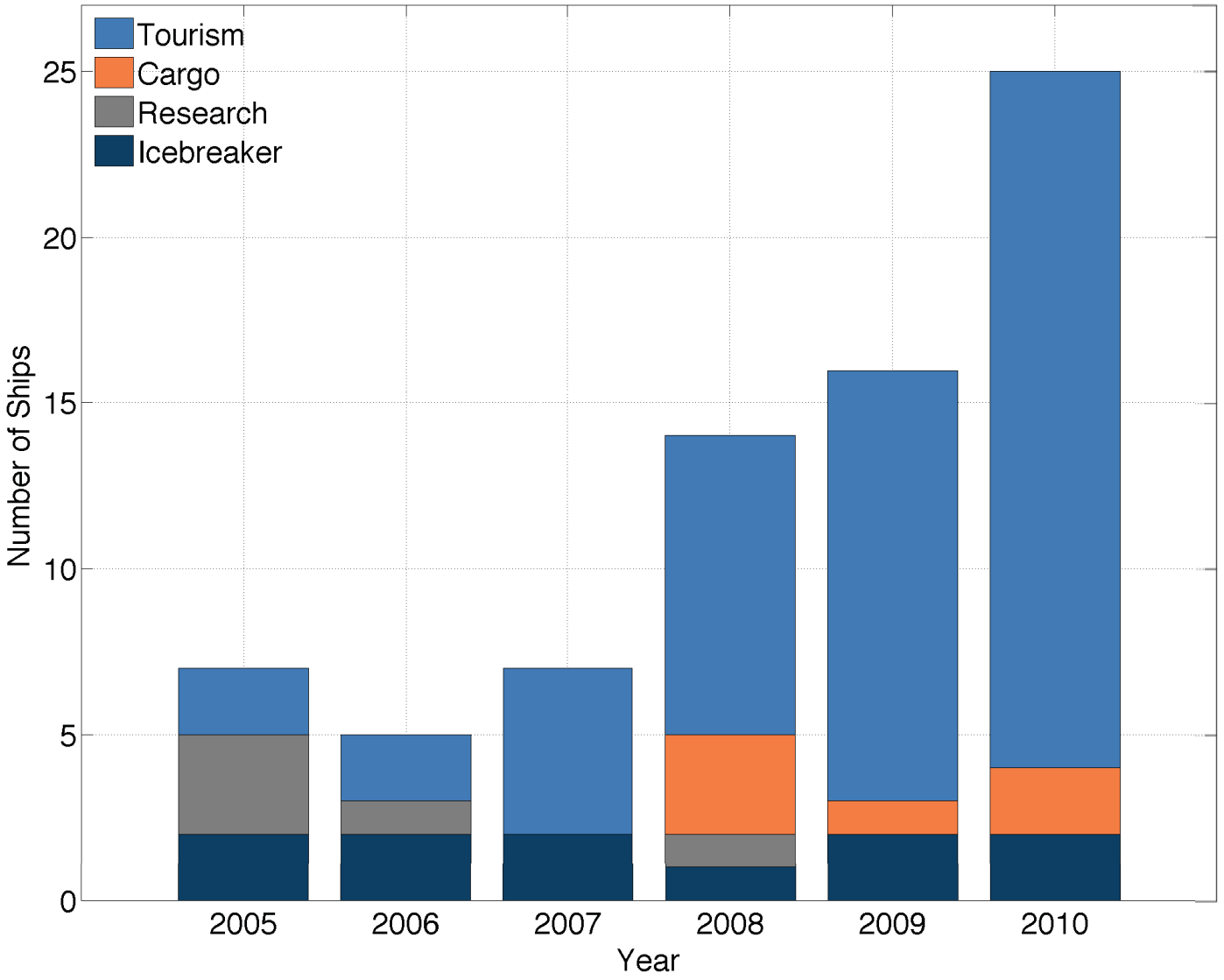


Source: Wikimedia Commons



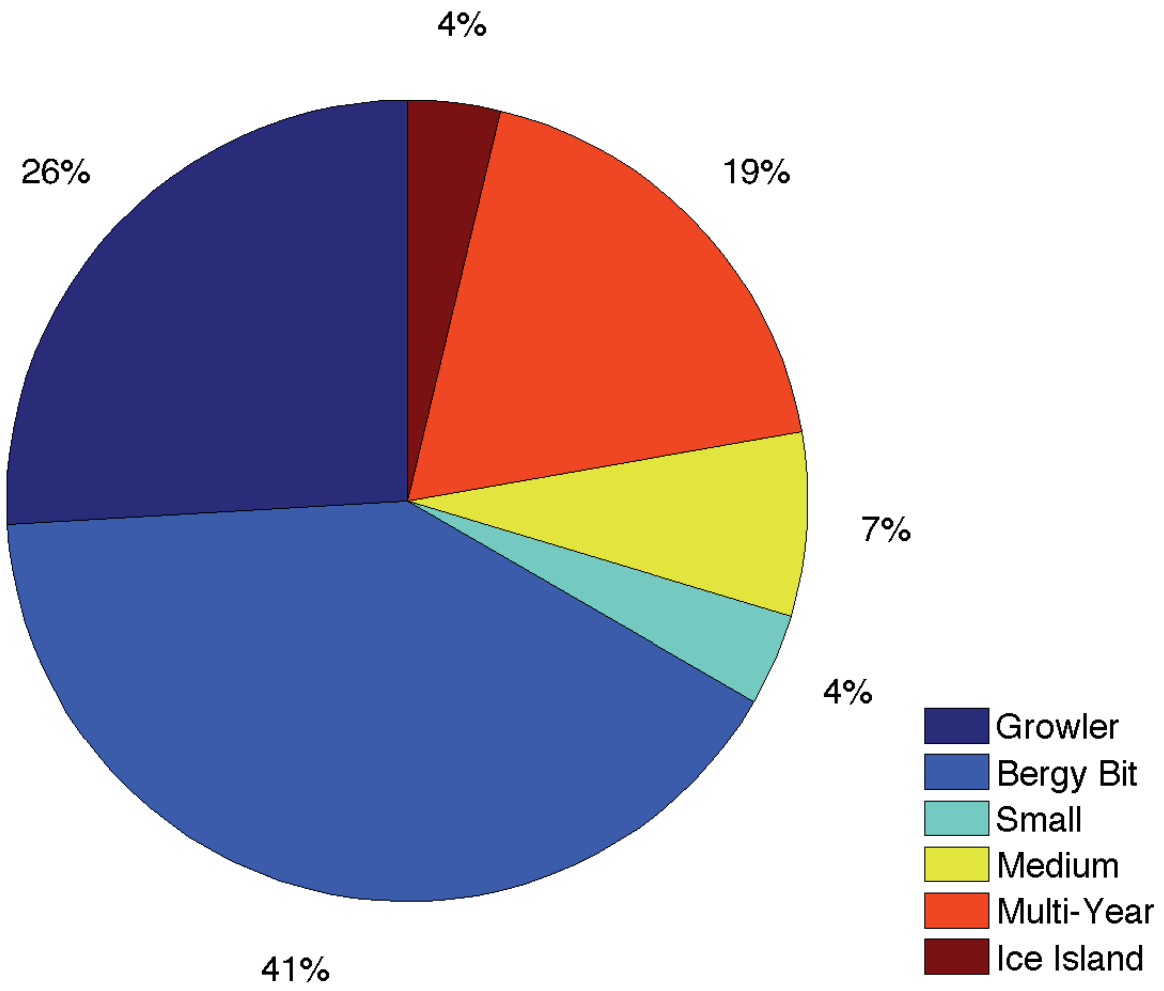
Based on: F. Lasserre and S. Pelletier, "Polar super seaways? Maritime transport in the Arctic: an analysis of shipowners' intentions," *Journal of Transport Geography,* vol. 19, pp. 1465-1473, 11// 2011.

Ship Traffic in The Northwest Passage



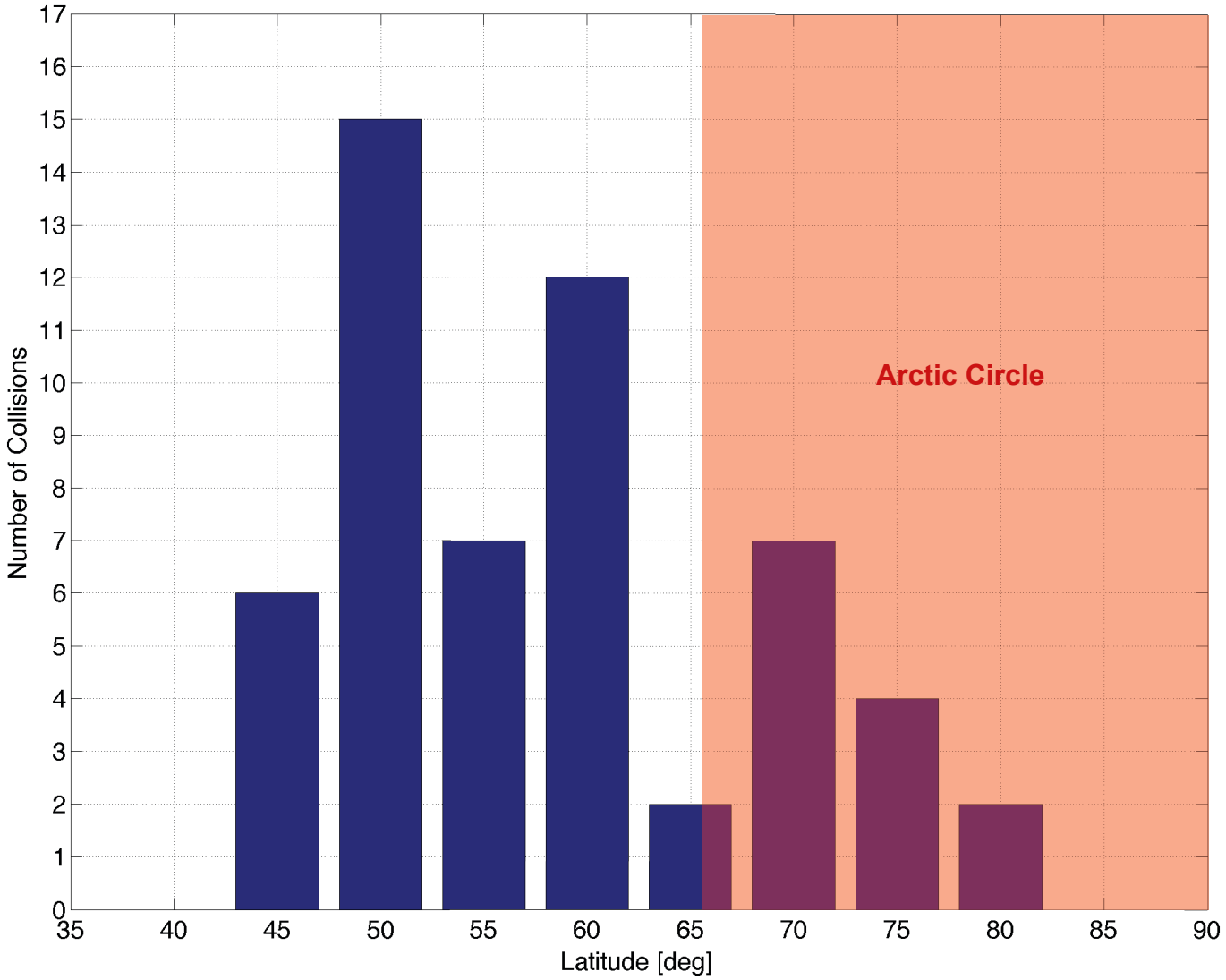
Based on: F. Lasserre and S. Pelletier, "Polar super seaways? Maritime transport in the Arctic: an analysis of shipowners' intentions," *Journal of Transport Geography,* vol. 19, pp. 1465-1473, 11// 2011.

Ship Collision Breakdown by Ice Type 1980-2011



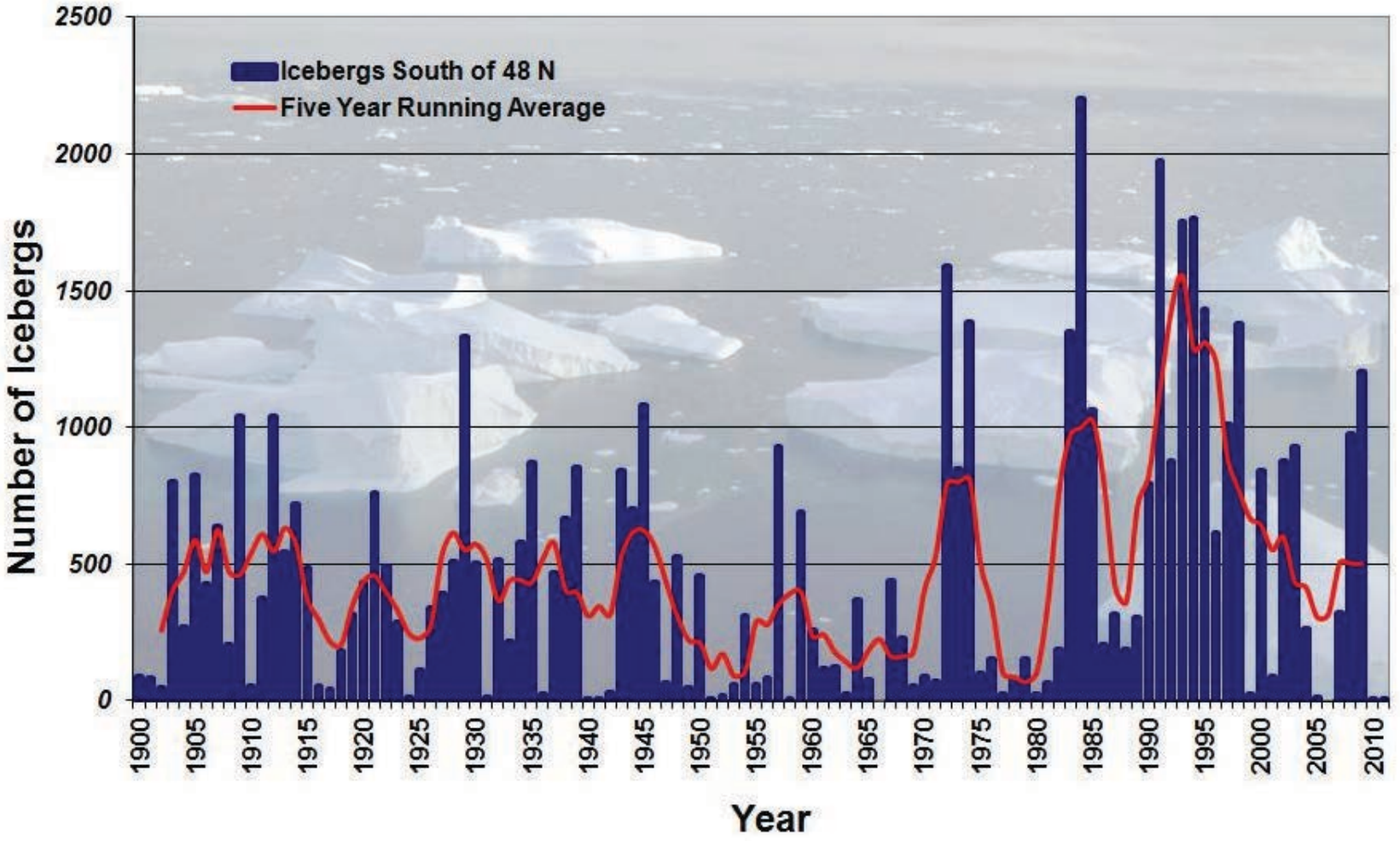
*Based on data from Dr. Brian T. Hill of the National Research Council of Canada

Ice Collision Breakdown by Latitude 1980-2011



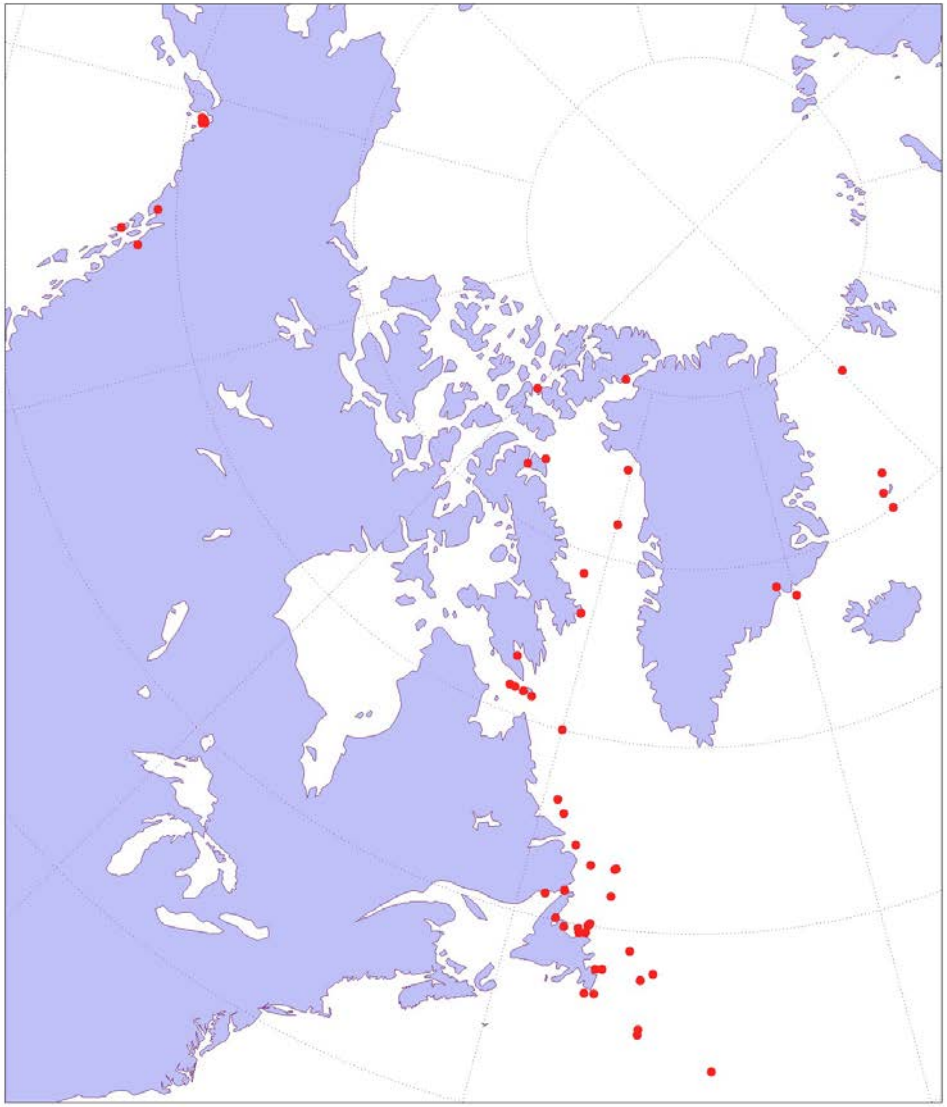
*Based on data from Dr. Brian T. Hill of the National Research Council of Canada

IIP Number of Reported Icebergs 1900-2012



Department of Homeland Security, & United States Coast Guard. (2012). Report of the International Ice Patrol in the North Atlantic (Vol. 98).

Location of Ice Collisions 1980-2011



*Based on data from Dr. Brian T. Hill of the National Research Council of Canada

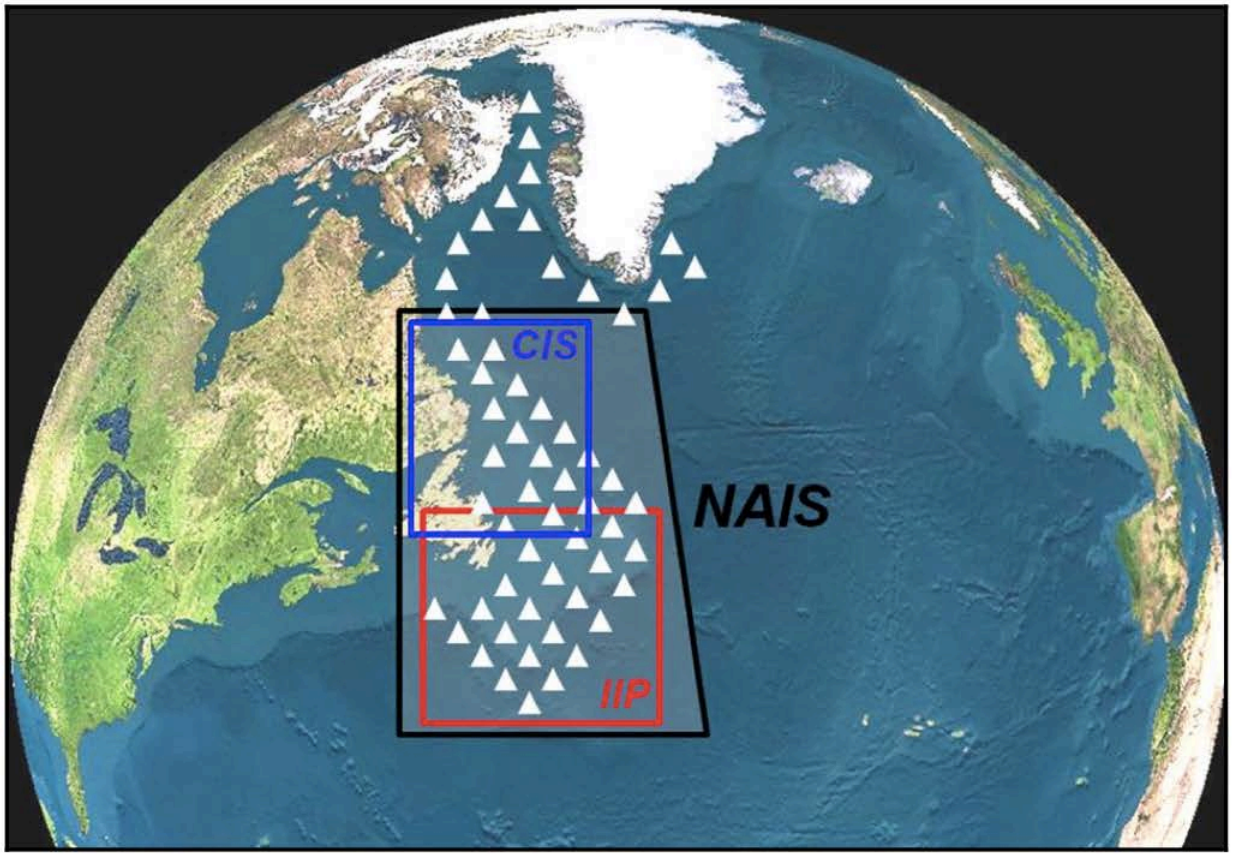
Collisions

Collision Rate*	> 2 Collisions Per Year
Likelihood of Ship Being Lost*	1/6
Probability of Collision**	1/2000
Probability of Ship Being Lost	1/10,000

* Based on data from 1980-2011

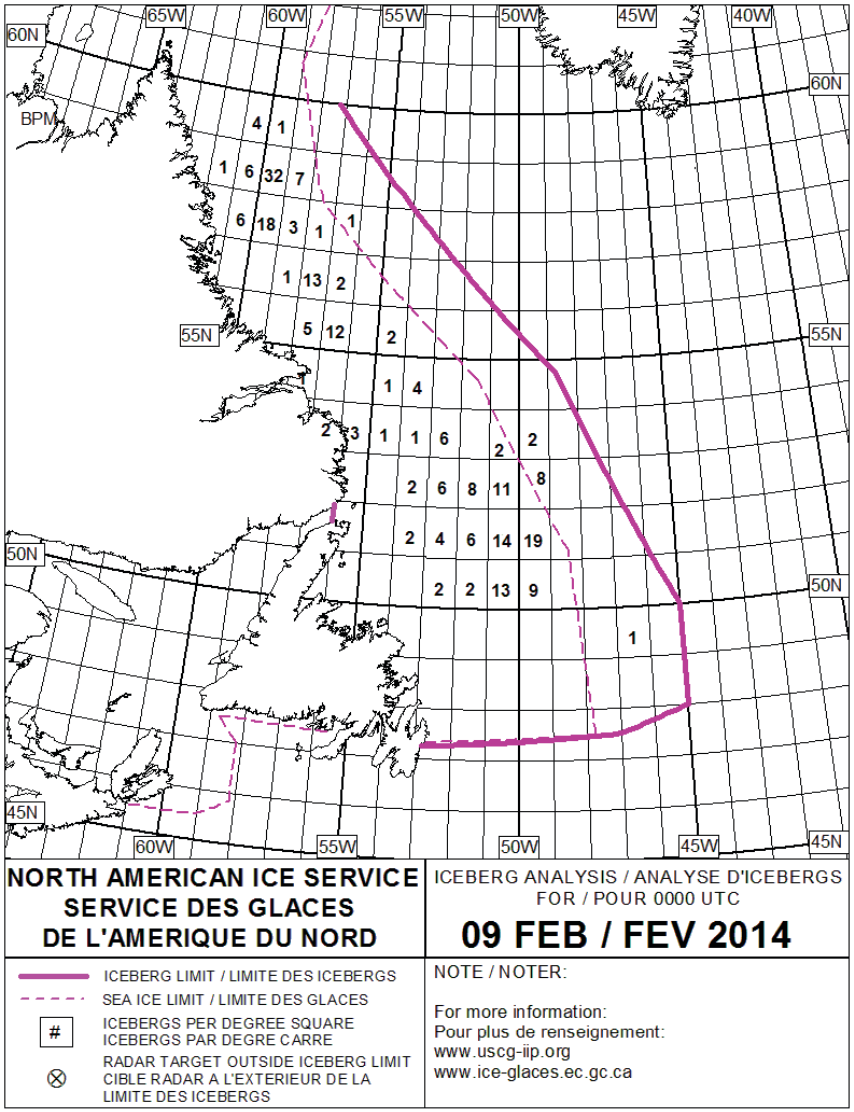
**Based on cargo shipping data over the Grand Banks to and from US and Canadian Ports on the east coast. (B. Hill, "Ship Collisions with Iceberg Database. Report to PERD: Trends and analysis," TR-2005-17, 2005.)

Ice Patrol Coverage



Department of Homeland Security, & United States Coast Guard. (2012). Report of the International Ice Patrol in the North Atlantic (Vol. 98).

Typical Report



Typical Report

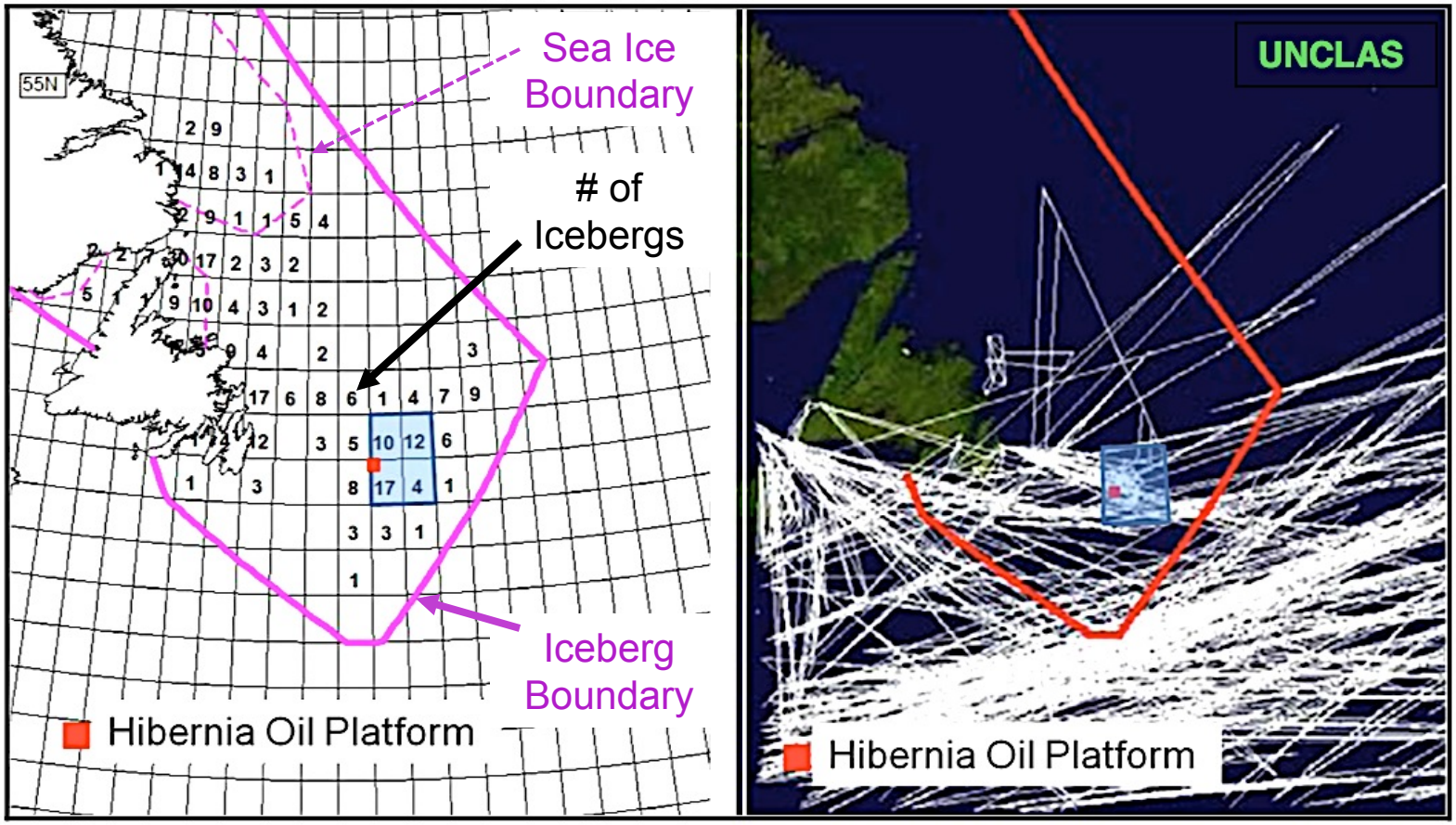
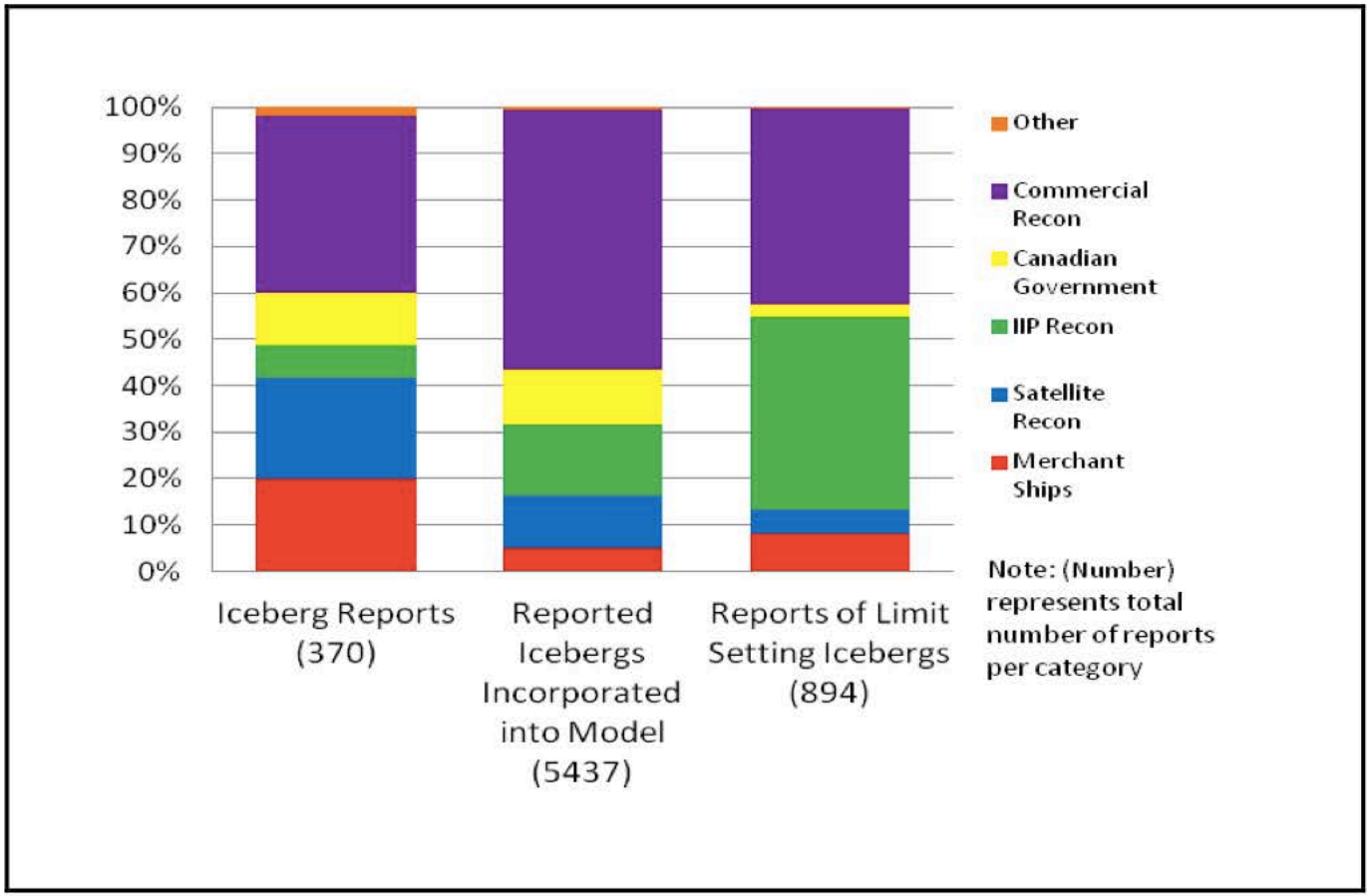


Figure 7: NAIS Iceberg Limit (left panel) and excerpt from MIFFC LANT Analysis for 14-16 May 2012 (right panel).

Department of Homeland Security, & United States Coast Guard. (2012). Report of the International Ice Patrol in the North Atlantic (Vol. 98).

Iceberg Report Breakdown



Department of Homeland Security, & United States Coast Guard. (2012). Report of the International Ice Patrol in the North Atlantic (Vol. 98).

Season	Summer/Autumn				Year Round				
Ice Type	First-Year						Second-Year	Mulit-Year	All
Min Ice	0.15 m	0.25 m	0.35 m	0.5 m	0.7 m	1.0 m	1.3 m	1.8 m	3.0+ m
Polar Class		PC 7	PC 6	PC 5	PC 4	PC 3	PC 2	PC 1	
Baltic Class	IC	IB	IA	IA*					

AHTS Balder Viking
(2000) PC 7
83 m, 13 MW, 6ktonnes

CCGS-Henry Larsen
(1987-) PC 4/5
100 m, 12 MW, 6ktonnes

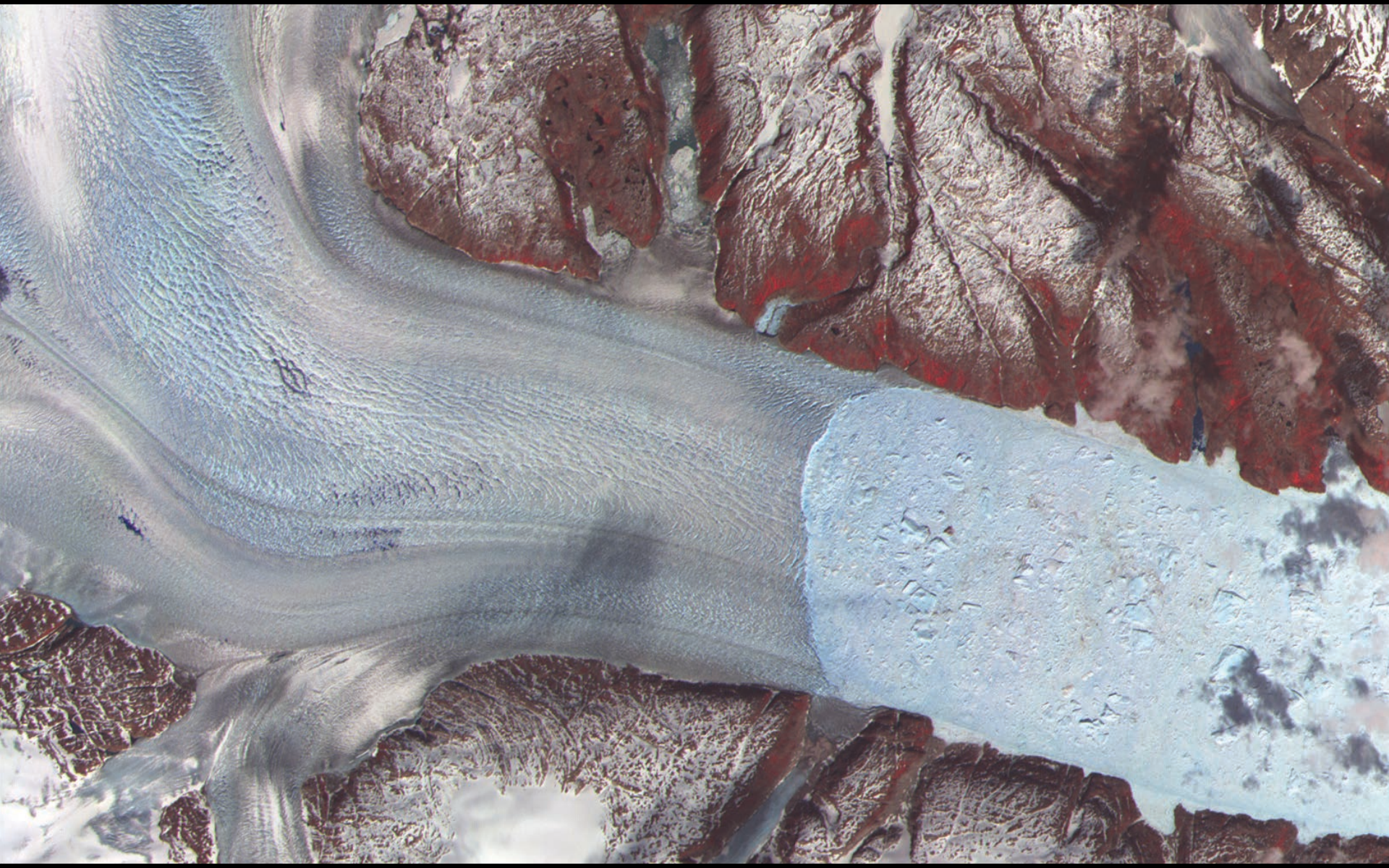
NS 50 Let Pobedy
(2007-) PC 1
160 m, 55 MW (N), 26ktonnes

Sevmorput
(1988-) PC 6
260 m, 30 MW (N), 62ktonnes

MS Norilskiy Nickel
(2006-) PC 4/5
170 m, 13 MW, 30ktonnes

USCGC Polar Star
(1976-2011) PC 2
122 m, 56 MW, 13ktonnes

Data Collection Location



NASA Earth Observatory