Remote Sensing of Sea Ice Conditions in the Northwest Passage

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1. Introduction

1.1 What is the Northwest Passage (NWP)?

The Northwest Passage is a sea route that connects Baffin Bay to the Beaufort Sea (Figure 1). The route runs through the Canadian Archipelago and offers an important shipping lane (Howell et al. 2022).

1.2 A Decline in Sea Ice

As the Arctic continues to warm, sea ice continues to decline. The NWP was "open" for the first time in 2007 according to satellite observations. An open NWP means that a ship traversing the NWP could make it from one end to the other without navigating through sea ice. In 2008 the NWP was observed to have opened again.

The Arctic is projected to have lost ~13% of its sea ice each year from 1979 until 2017 (Wei et al. 2020). The NWP has opened several times since 2008. One testament to the lack of sea ice in the NWP was the voyage of the *Crystal Serenity* in 2016, a passenger cruise ship that sailed through the NWP.

1.3 Remote Sensing of the NWP

The NWP is roughly 900 miles long (this varies based on path taken) which makes spaceborne observation the ideal method to look at sea ice along the Passage. Examining a closed (2013) and an open year (2016) gives an idea to the environmental conditions required for the NWP to open. By combining both spaceborne observations and reanalysis, the thermodynamic and dynamic influences can be further investigated.

Figure 1: The Northwest Passage and its routes. The main route is drawn in red, with alternate routes in black.

2. Data and Methodology

- **Freezing Degree Days (FDD):** Daily ERA-5 2-meter temperatures are subtracted from the freezing point of sea water (271.15 K) and summed for the month of interest to get the monthly FDD. The 2000-2021 monthly mean FDD is then subtracted from this value to show the FDD anomaly. A larger FDD anomaly indicates a larger number of freezing days, indicating colder conditions.
- **Monthly Averaged 10m Wind Anomalies:** ERA-5 monthly 10m wind anomalies are used as a proxy for the direction in which ice is likely to be transported.
- **Sea ice concentration (SIC):** Downloaded from the NSIDC. SIC data was derived from the Special Sensor Microwave Imager/Sounder (SSMI/S) aboard the USAF Defense Meteorological Satellite Program (DMSP) satellites. Anomalous SIC is found by subtracting the 2020-2021 monthly averaged SIC from the average SIC of a given month and year.

3. Results

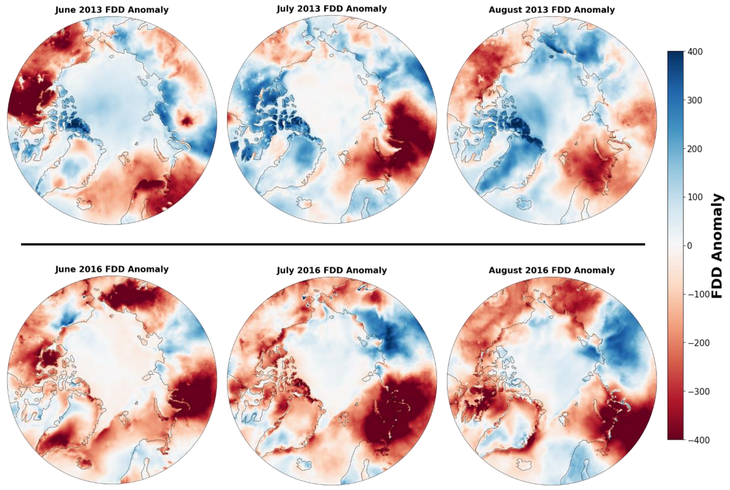

Figure 2: FDD anomaly comparison between JJA of 2013 (top row) and JJA of 2016 (bottom row). Red indicates a decrease in FDD (fewer freezing days) and blue an increase (more freezing days).

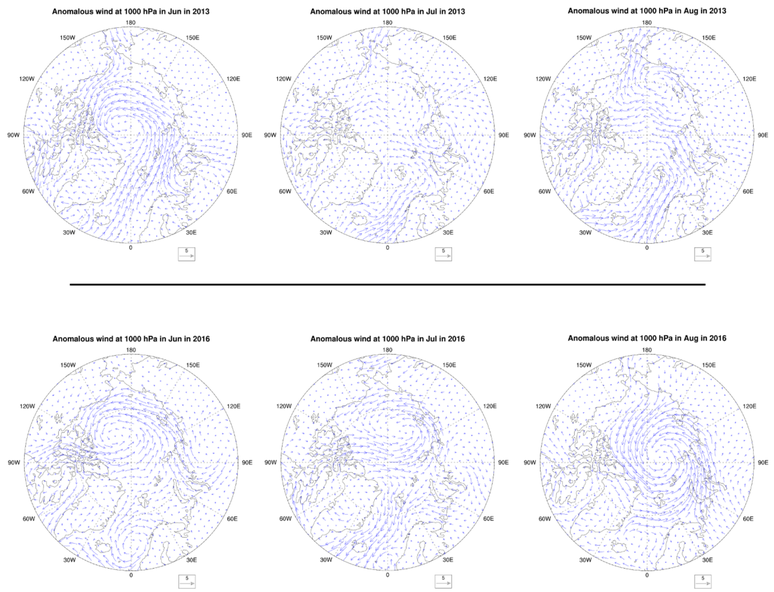

Figure 3: Anomalous winds during JJA of 2013 (top) and JJA of 2016 (bottom).

3.1 Thermodynamic and Dynamic Factors

- Figure 2 shows the FDD anomalies in June, July, and August for both 2013 and 2016. The Canadian Archipelago has lower FDD values during 2016 across all three months, signaling warmer conditions.
- Figure 3 shows the 2016 anomalous wind pattern. In 2016, the anomalous winds are not blowing from the West into the NWP, but in 2013 they are. The wind pattern in 2016 does not favor the transport of sea ice into the Passage.

3.2 SIC Anomalies

- According to Figure 4, there is a slight decrease in SIC compared to the 2020-2021 monthly mean in August of 2016. This is most obvious in the central portion of the Canadian Archipelago.
- The lower SIC corresponds well with lower FDD in 2016, and the 2013 anomalous winds that blow into the NWP from the West correspond well with a higher SIC anomaly in 2013.

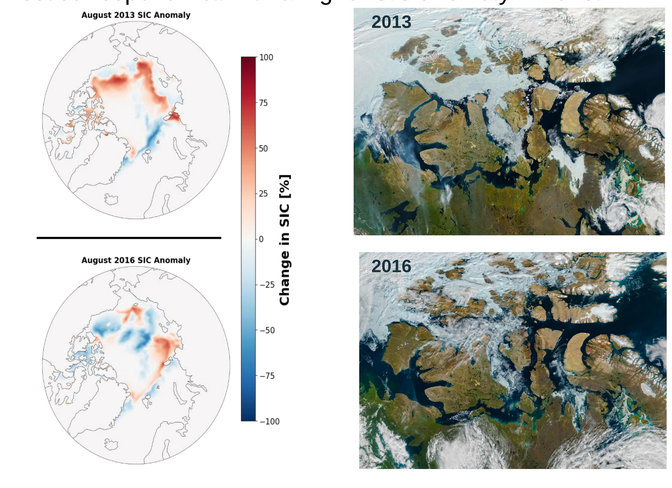

Figure 4: SIC anomaly for August 2013 (top) and 2016 (bottom). Images of the NWP from 2013 (top, MODIS) and 2016 (bottom, VIIRS). Imagery from NASA Earth Observatory.

4. Conclusions

1. **Although these are just two of many years, there seems to be a set of environmental conditions that favor an open NWP.**
2. **Thermodynamic and dynamic factors work in tandem in 2016 to melt sea ice and to keep more sea ice from entering the NWP.**
3. **Analysis of more open/closed years is needed to establish a definitive set of environmental conditions that are favorable to an open NWP.**

What's Next?

- Continuing analysis will determine a "critical month" that would define a tipping point for the opening of the Northwest Passage.
- Can the opening of the Passage be predicted? Machine learning will be employed to help answer this question.
- Can remote sensing be used to predict where in the NWP ships of different ice ratings can safely travel through?

References:

Howell, S. E. L., D. G. Babb, J. C. Landy, and M. Brady, 2022: Multi-Year Sea Ice Conditions in the Northwest Passage: 1968–2020. Atmosphere-Ocean, 0, 1–15, https://doi.org/10.1080/07055900.2022.2136061.

Wei, T., Q. Yan, W. Qi, M. Ding, and C. Wang, 2020: Projections of Arctic sea ice conditions and shipping routes in the twenty-first century using CMIP6 forcing scenarios. Environ. Res. Lett., 15, 104079, https://doi.org/10.1088/1748-9326/abb2c8.