SCHOLARLY REVIEW

Change in sea ice in Hudson Bay, Canada since 2000: An analysis on ice-free periods and maximum concentrations

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Author Biography

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Abstract

Sea ice is a climate indicator because of its sensitivity to climate change. This study aims to acknowledge and understand the influence of climate variations on the Hudson Bay area and its possible ecological implications. Results using remote sensing data from ECCC Ice Forecasts and Observations show a continuous decline in yearly average sea ice concentration, accompanied by variations in seasonal ice-free patterns. Intra-year viability has also increased, reflecting a greater instability of annual ice cycles. These findings represent the changes in Hudson Bay's cryosphere and also help to address the need for consistent monitoring of sea ice and the development of climate change mitigation strategies. This study analyzed changes in patterns of Hudson Bay, Canada's sea ice concentration variability in relation to temperature fluctuation from the year 2000 onward up to August 2024.

Keywords: Sea ice; Arctic and subarctic ice; Polar regions; Cryosphere; Remote sensing; Hudson Bay; Climate change; Ocean-atmosphere interactions

Introduction

Sea ice, which grows and melts within ocean waters, forms a barrier between the ocean and the atmosphere, changing the characteristics of the surface heat, moisture, and momentum fluxes. This dynamic barrier is not constant throughout the year; rather, the extent of Arctic sea ice varies dramatically over a year, reaching its maximum in late February or March before melting during the spring and summer to reach its minimum yearly spread in early September (Meier et al., 2014).

Aside from the periodic seasonal changes, climate change has greatly influenced all aspects of sea ice, such as its concentration, thickness, and duration of coverage. An important role that sea ice serves is the indicator of changes in a global climate where sea ice (light-colored) reflects more solar energy to space than water, therefore maintaining Earth's energy balance and polar regions' temperatures (United States Environmental Protection Agency, n.d., para. 2).

Considering the impact of climate change on sea ice extent, concentration, and stages of development or the other way around where sea ice impacts the climate, we need to consider the current climate change situations in Canada. According to Environment and Climate Change Canada's 2024 Spring Climate Trends and Variations Bulletin, the national average temperature for the spring of 2024 was 2.5 °C above the baseline average (the mean over the 1961–1990 reference period), based on preliminary data, which has ranked the 4th warmest observed spring since nationwide recording began in 1948 (Environment and Climate Change Canada, 2024). Rising temperature is just one of the various influences climate change has brought to Canada; some other ones include shifting rainfall patterns, extreme weather events, and rising sea levels.

More specifically, Hudson Bay, a seasonally ice-covered inland marginal sea of the Arctic Ocean located in northeastern Canada, has an increased temperature by more than 1 degree Celsius over the past three decades, a lengthened ice-free period, and shifts in seasonal patterns (Stroeve et al., 2024). In recent years, according to the Canadian Ice Service (2024), from November 2023 to January 2024, the surface air temperatures were 2-5 degrees Celsius above the climatological mean. Sea ice loss in Hudson Bay would greatly impact the climate and weather patterns of the surrounding regions and the nearby marine, coastal, and terrestrial ecosystems. For example, as polar bears' most southerly habitats, the lengthened ice-free period presents difficulty for the polar bear populations in the Bay Area (Stroeve et al., 2024).

This study sought to understand the impact of influencing factors, such as temperature and CO2 concentrations, on patterns of the Arctic sea ice, specifically on Hudson Ba,y which is crucially important to the surrounding and even global environment. This study assesses the patterns and trends of the Hudson Bay area sea ice concentrations since 2000 and its possible correlation with the local temporal variations, especially by analyzing the ice-free period and maximum concentrations. An important reason for choosing this rather recent time frame is that, due to technological changes, systematic and regular observations of ice and snow surfaces—using ships, aircraft, and satellites—are possible only over the last few decades.

Methodology

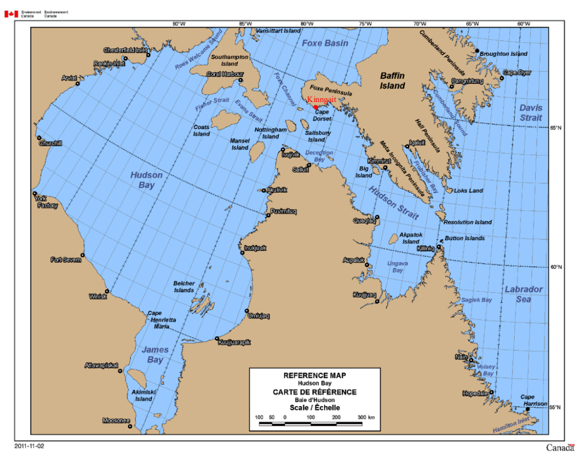
Area of Study

Hudson Bay, a large saltwater body and the world's second-largest bay with an area of 1,230,000 km², receives fresh water from river flows and permafrost (Hansen, 2020). Surrounding Hudson Bay is the Hudson Bay Lowland, which is climate-sensitive to the waterbody, containing permafrost and being full of marshes, peat, and ponds. When the bay is covered with sea ice, it prevents a warming effect on the air and keeps the temperature low; as the ice quickly retreats in June and cloudiness and fog increase, the water temperature rises to 10 degrees Celsius in July and August as a result of the influx of freshwater (Marsh, 2009). The Hudson Bay area covers polar, subarctic, and humid continental climates though with very low year-round average temperatures, having a January temperature average of -29°C and a July temperature average of 8°C(The Editors of Encyclopaedia Britannica, 2024).

Hudson Bay is a part of the Arctic Ocean, though not necessarily in the Arctic Circle (International Hydrographic Organization, 2022). The Canadian Ice Service refers to Hudson Bay as the area defined in Figure 1, including James Bay, Foxe Basin, Hudson Strait, Davis Strait, and Labrador Sea areas.

Figure 1

Hudson Bay regional ice chart extent and location of Kinngait within the area, from the Canadian Ice Service Ice Climatology reference maps (Government of Canada, 2024).



This study used Kinngait station (climate ID: 2400636), Nunavut, as the primary source for air temperature data analysis, marked in Figure 1 (labelled initially as Cape Dorset by Canadian Ice Service, which is its former name). Kinngait station (64° 13 '50.9"N 76° 31' 49.4"W) is located on an island south of Cape Dorset, off the Foxe Peninsula of southwestern Baffin Island, and facing the Foxe Channel (Government of Nunavut, n.d.).

Data Collection & Analysis

To evaluate the ice concentrations, the total ice concentration data was collected from the Government of Canada (2024) Environment and Climate Change Canada(ECCC) Ice Forecasts and Observations, which covers current conditions, forecasts, historical data, alerts, climate change, and natural hazards of ice in navigable waters. As addressed in Chapter 2 of MANICE, ice observations involve methods including aerial, satellite, and ship-based observations to secure consistent and precise data collection. The Canadian Ice Service Archive and Ice Application and Data manages a vast collection of historical ice data and provides data in weekly regional ice charts. The data collected for this study contain Total Ice Concentration (CT). This study considered the sea ice concentration from two perspectives: the annual maximum concentration and the ice-free period.

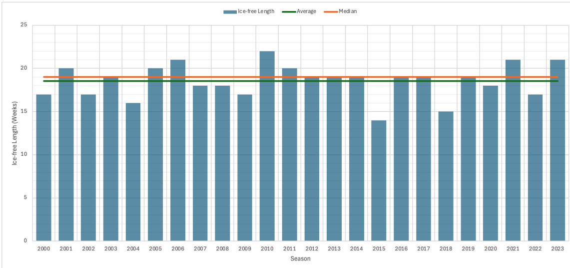
This study assessed temporal data from the Kinngait station (Figure 1) due to its consistency and accessibility among stations of the Government of Canada in the Hudson Bay near-water area, though it would represent a relatively more northern, nearer to the Arctic Circle perspective regarding temperature patterns. The data of Kinngait station would also indicate the relationship between Hudson Bay's sea ice and its very local climate conditions, though that might mean it would be harder to account for any changes for Hudson Bay as a whole to this very specific climate condition represented by the data from Kinngait.

Results

Ice-free means that a certain waterbody holds less than 15% or 0.15 ice concentration, defined based on the threshold for sea ice extent. In Figure 2, Hudson Bay's ice-free length is represented in weeks per year. With a mean of approximately 18.5416 and a median of 19, this figure embodies a slightly negative-skewed distribution, which indicates ice-free period lengthening and a certain lower-than-average outlier.

Figure 2

Number of weeks of ice-free per year from 2000 to 2024 in Hudson Bay, with annual, average, and median lengths (Government of Canada, 2024).



2010 exhibits the largest ice-free duration, with 22 weeks (22/52 weeks, above 42% of the year is ice-free for Hudson Bay). Other longer ice-free periods include 2006, 2021, and 2023, with 21 ice-free weeks. The ice-free periods can start as early as the first week of July and end as late as the last week of November for Hudson Bay. Comparatively, on the lower side, 2015 and 2018 had 14 and 15 weeks being ice-free, as ice is mostly present in July and November. On the other hand, by comparing the mean, maximum, and minimum temperatures of Kinngait, Nunavut on respectively longer and shorter ice-free period years, which are 2006, 2010, 2021, and 2023 for long ice-free period years and 2015, and 2018 for short ice-free period years (Figure 3), there are some observable correlations.

Figure 3

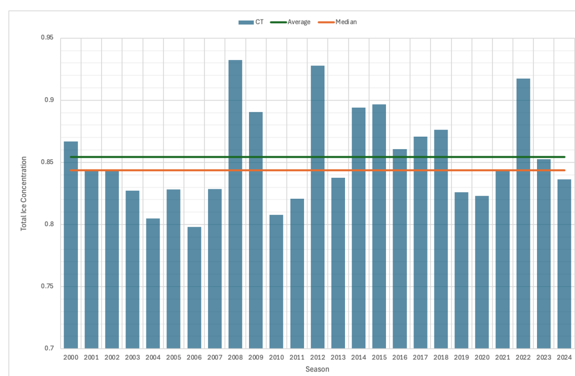
The September to November mean, maximum, and minimum temperatures of 2006, 2010, 2015, 2018, 2021, and 2023 in Kinngait, Nunavut.

There were no direct correlations between lower July and August temperatures and ice presence. However, a positive correlation exists between higher minimum temperatures from September to November and less ice presence or an ice-free situation. This is exemplified by, for example, 2015 and 2018, which are the two years with the shortest ice-free periods and lowest minimum temperatures, both reaching below negative 20 degrees Celsius.

The maximum CT indicates the highest recorded weekly CT in the year. Figure 4 shows a positively skewed distribution with an annual average of 0.854232 and a median of 0.8436. Maximums occur from January through April. Showing no consistent regular patterns, there are a few peaks: as high as 0.9324 in 2008, as well as in 2012 and 2022, which reached above 0.9. Some fluctuations happened between 2004 and 2007, where the maximum remained below average and reached its lowest in the evaluating period in 2006 with a 0.7980 CT.

Figure 4

Annual maximum total ice concentration (CT), average, and median maximum CT for Hudson Bay from 2000 to 2024.



Discussion

The ice-free period in Hudson Bay has been lengthening with an average of 19.25 weeks annually from 2000 to 2024. Some noticeable high and low peaks include: in 2010, the length of the ice-free period was the highest since 2000, reaching 22 weeks; in years 2006, 2021, and 2023, this was 21 weeks; on the contrary, 2015 and 2018 had shorter ice-free periods of 14 and 15 weeks respectively. These ice-free periods can start early in July and end late into November.

Though there is no observable direct correlation between Kinngait's July and August temperatures and the ice presence of Hudson Bay, if we only compare 2006 and 2010 to 2015 and 2018, the correlation of temperature and ice-free is present, which seems not to be the case for 2021 and 2023, this might suggest that climate change in recent years made ice presence more correlated to other factors than the temperature of the same time. In addition, the higher minimum temperature in September, October, and November months correlate to longer ice-free periods and lower total ice concentration, which can also be inferred to slower ice formation. However, there is no correlation between maximum temperature and ice presence, possibly indicating that maximum temperature has a lesser impact on ice loss.

The maximum total ice concentration in Hudson Bay since 2000 shows variations between years. The analysis presents several higher outlier data points without consistent long-term patterns and does not correspond with the years that have shorter ice-free periods, which may suggest that the intra-year ice presence and ice-free periods have no direct influence on each other; the maximum CT also tends to be around twice the yearly average, corresponding to high intra-year variability and ice's sensitivity to seasons in Hudson Bay.

Seasonal Summary of North American Arctic Waters Spring 2024 reports that sea ice thickness was thinner than usual over most areas at the end of winter and spring 2024. Sea ice formation was about a week slower than normal, thickening to medium first-year ice during the first week of February. It took until the third week in April for most of the ice in Foxe Basin to thicken to predominantly thick first-year ice, around 8 weeks slower than the climatological median (Canadian Ice Service, 2024).

The annual change of lengthened ice-free period observed in Figure 2 may be attributed to the increasing temperature anomalies over recent years, which have altered the seasonal ice cycle. As mentioned, from November 2023 to January 2024, the surface air temperatures were 2-5 degrees Celsius above the climatological mean (Canadian Ice Service, 2024). Consequently, several weeks ago, sea ice formation occurred later than usual over most of the Hudson Bay area.

Regarding maximum CT, the peaks appear not to have regular patterns, which may be understood as long-term patterns in ice concentration, which are more complex than recent climatological anomalies alone, while the seasonal variability intensified.

Johannessen and Shaline (2023) emphasized the seasonal differences in Arctic sea ice extent and recognized that intra-year fluctuations are more substantial than annual changes. Also, there is a long-term decline trend in ice coverage, regardless of regional variations. However, differences in focus may influence the understanding of results as the area of study, Hudson Bay, is less broad and can be more influenced by regional patterns; the Hudson Bay area is also mainly situated south of the Arctic Circle and is not covered by sea ice all year round. Johannessen and Shaline (2023) also examined the empirical relationship between monthly CO2 concentration and the arctic sea ice extent and concluded that CO2 concentration is the primary driver of the decline in sea ice coverage. CO2 emission can largely contribute to global warming, for example, the increasing surface air temperature, which is an influencing factor contributing to the observed findings.

Wang et al. (2021) analyzed the glacier area variation in the Kaidu-Kongque river basin, Southern Tianshan Mountains, concerning its relationship with various climate change factors from 2000 to 2020. The Kaidu-Kongque River basin is a sub-basin of the Tarim River basin in the Xinjiang Uygur Autonomous Regions of China; it is located in the central Asia-Mongolian Plateau and is a temperate continental desert zone. Using the Annual Percentage of Area Changes (APAC), Wang et al. (2021) stated that glacier shrinkage was pronounced during 2000-2005; the rate of deglaciation had a slight decrease during 2005-2015; and the glacier shrinkage accelerated in 2015-2020. The fluctuation is consistent with the variability observed in Hudson

Bay's maximum total ice concentration and lengths of ice-free periods. This might suggest that the climatic factors affecting ice and glacier variations may act comparably in climate-sensitive regions despite geographic differences.

Hudson Bay's ice-free periods do not directly correlate with July and August temperatures in evaluated years. Specifically, high minimum temperatures in September through November showed a more consistent relationship with extended ice-free conditions. On the other hand, Wang et al. (2021) reported APAC to have straightforward relationships with air temperature: APAC has a negative correlation with summer 5-year moving average temperature (5-MAT) and a positive correlation with winter 5-MAT. Wang et al. (2021) summarize that glaciers have a response, such as accelerated melting, ice retreat, and ice thinning, to climate change, especially solar radiation, air temperature, precipitation, wind and cloud cover. While Wang et al. (2021) observed nonlinear relationships between glacier area and air temperature, Hudson Bay's ice-free period and maximum CT appear to have a more complex, possibly non-linear pattern in response. Connecting back to the findings of Johannessen and Shaline (2023), high intra-annual variability in Arctic regions and seasonal shifts, rather than annual averages, may be more indicative of ice dynamics in subarctic and Arctic areas. These findings suggest that while broader climate patterns, especially temperature, affect Hudson Bay and the Kaidu-Kongque River Basin, local climate and hydrological factors unique to each region also play substantial roles in respective ice and glacier dynamics.

Conclusion

By assessing weekly total concentration data provided by Environment and Climate Change Canada, this study found that change in sea ice concentration in Hudson Bay, Canada, since 2000 with a focus on ice-free periods and maximum concentrations, can identify a few key findings: a lengthened ice-free period, with the longest recorded being 22 weeks in 2010, and longer ice-free periods is positively correlated with higher minimum temperatures between September and November; the maximum sea ice concentration shows a positively skewed distribution, indicating the decline in annual maximum concentration, but no consistent long-term patterns.

The variability and irregularity in Hudson Bay's sea ice concentration underscore the need to understand global and regional climate. Global factors, such as rising temperatures and CO2 levels, might be highly contributory to the above findings; on the other hand, local influencing factors specific to Hudson Bay may be able to explain the change of sea ice with a special holistic view that should be incorporated.

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