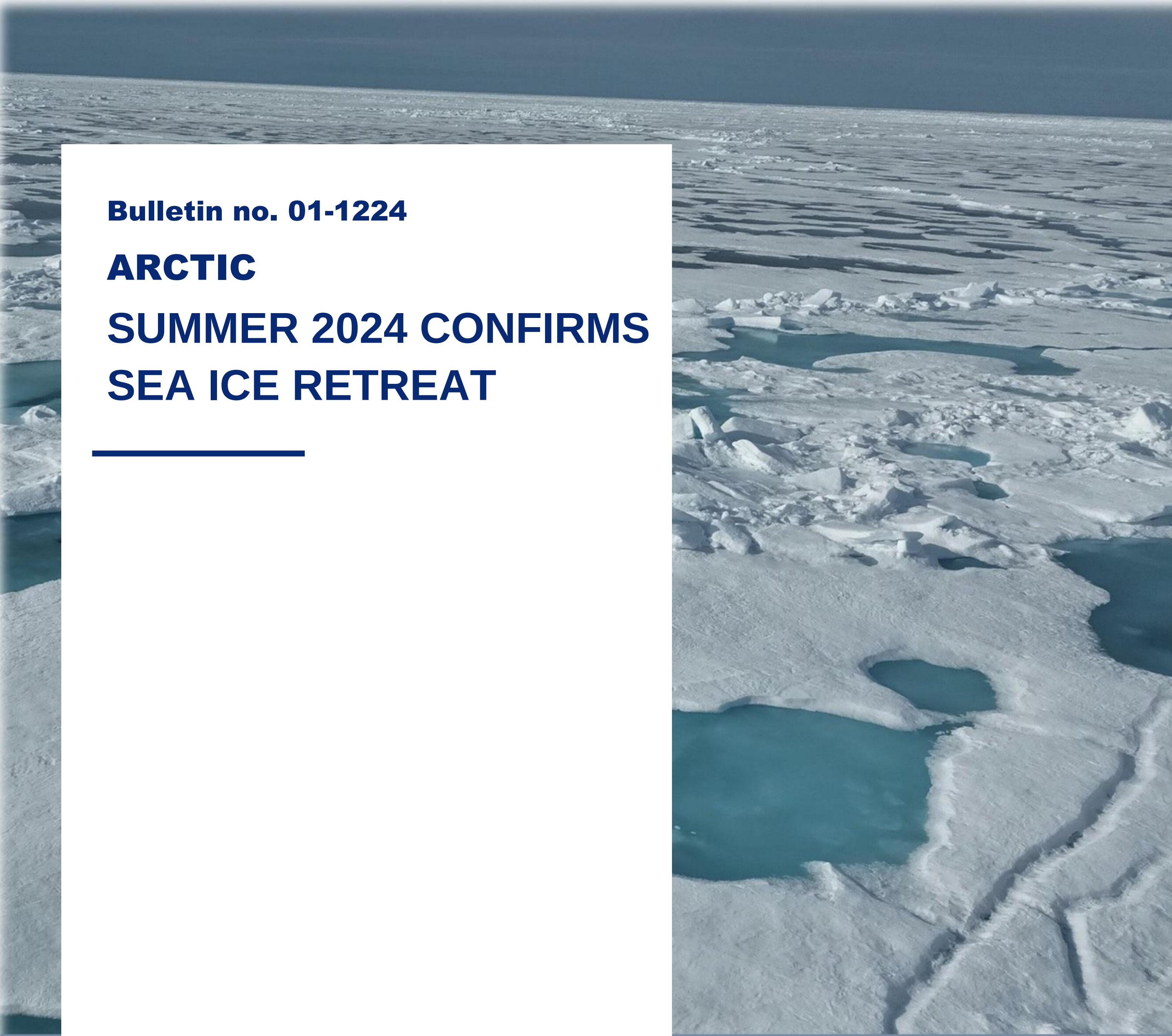

Bulletin no. 01-1224

ARCTIC

SUMMER 2024 CONFIRMS SEA ICE RETREAT

DECEMBER 2024

POLAR WATCH

Polar regions monitoring and forecasting

LE CERCLE POLAIRE
www.lecerclepolaire.com

Polar Watch
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Graphic Designer : Stéphane Hergueta
Published by le Cercle Polaire – December 2024
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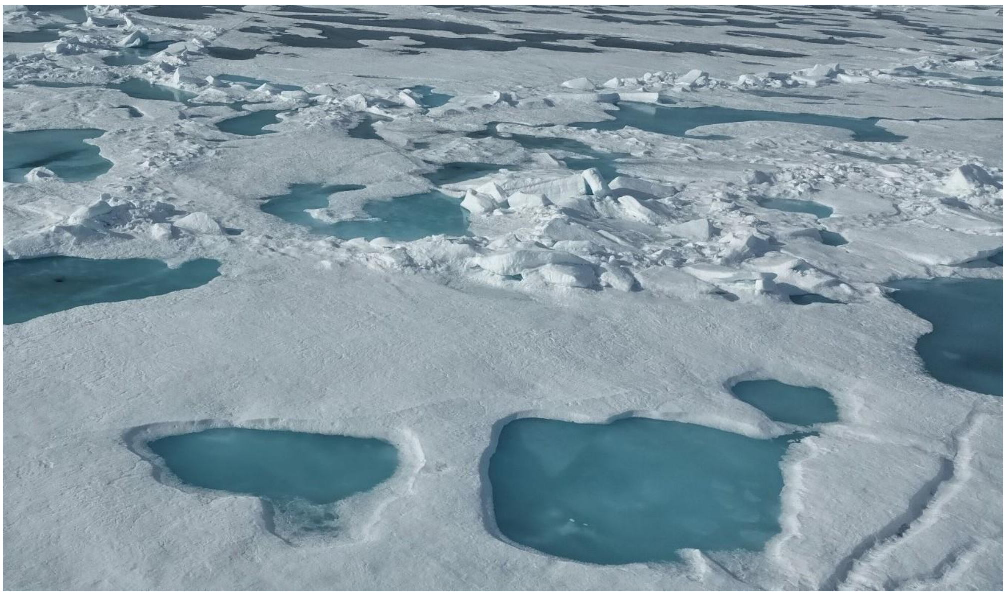
New record for the annual minimum of Arctic sea ice extent

Summer 2024 confirmed the multi-decadal downward trend in sea ice extent, including the Central Arctic Ocean.

Although not a remarkable record in terms of inter-annual anomalies in Arctic sea ice extent, the summer of 2024 confirms the now well established multi-decadal downward trend in the Arctic sea ice cover decreasing in extent and volume, the ice pack becoming less compact in virtually all geographical areas, including the Central Arctic Ocean. This new normal for the Arctic is the result of a warmer climate, the effects of which have been unambiguously felt over the last few decades, and has led to an ice cover which is now more vulnerable to the inter-annual variations present in the atmospheric and oceanic conditions.



The ice pack at the geographic North Pole on July 30, 2024. A highly fragmented ice pack covered with meltwater ponds. *Credit : Le Cercle Polaire*.

"At 4.28 million de km^2, the annual minimum of the sea ice extent in the summer 2024 is the 7th lowest minimum since 1979."

The Arctic sea ice extent reached its annual minimum on September 11, a relatively early minimum even if the exact date remains uncertain due to the lack of data for the days that followed. With an extent of 4.28 million km^2 (Fig. 1), this minimum of 2024 was the seventh lowest since satellite observations of Arctic sea ice began in 1979. However, it did not surpass the record annual minima of 2012 and 2020, when the Arctic sea ice cover shrank to an averaged September area of less than 4 million km^2.

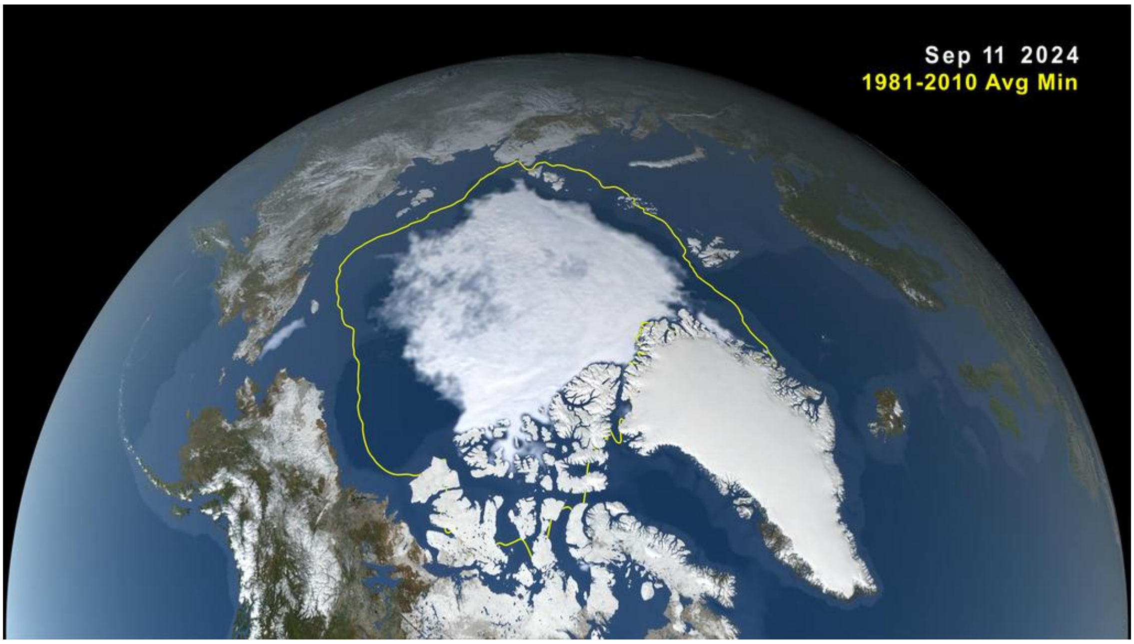


Fig. 1: Arctic sea ice extent on September 11, 2024, superimposed on the climatological average over the 1981-2010 period (yellow outline). *Source : NSIDC/NASA Earth Observatory*

Yet, mid-summer conditions this year suggested a new record: from the last week of July to the end of August, the Arctic sea ice extent stood well below that of recent years over the same period, even closely following the trend observed in 2012 until the beginning of August. However, this rapid decline slowed at the beginning of September, and was followed by a slow recovery from mid-September onwards.

The year 2024 confirms the observation now made every year: since 2007, the averaged sea ice extents for the month of September have, without any exception, been among the lowest recorded in the 46 years of satellite observation (Fig. 2). September 2024, with an average pack ice extent of 4.38 million km^2, ranks sixth in the list of lowest September sea ice extents. The persistence of low September values for almost two decades has contributed to maintaining a relatively strong downward trend in September extent since

1979, between -12 and -14%[1] per decade since 1979, depending on the year in which it is estimated, with the exception of the record rate of -14.3% estimated in 2012, reflecting the abrupt decrease in ice extent that particular year (Fig. 2a). In 2024, this dowanward trend is now estimated at -12.13% per decade, corresponding to an average loss of 78,000 km^2 of pack ice per year, which corresponds to almost 3 times the surface area of Brittany. However, this vision of a monotonous decline in sea-ice extent over recent decades is largely idealized. The year 2007 brought radical changes, not only in the extent but also in the nature of the Arctic ice cover, changes from which it has not recovered since.

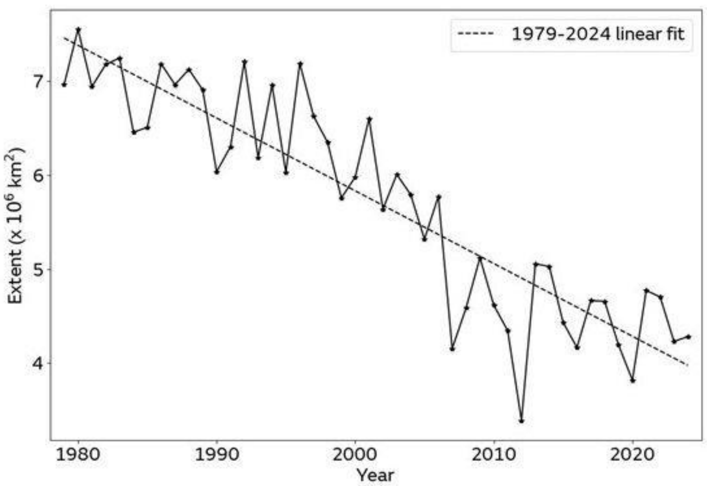


Fig. 2a: Average extent of Arctic sea ice in September over the period 1979-2024. The dotted line represents the linear fit of the extent evolution over this period, equivalent to a trend of -12.13% per decade. *Source: Met Office/NSIDC Sea Ice Index*

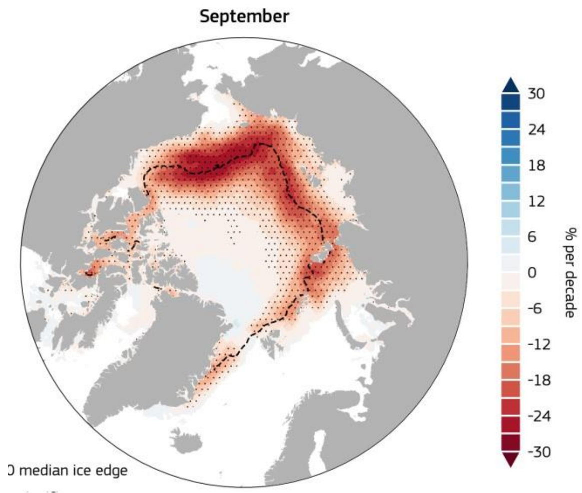


Fig. 2b: Linear trend in Arctic Sea Ice concentration in September over the period 1979-2023. The dotted line delimits the area where this trend is significant.
Source : C3S/ECMWF/EUMETSAT

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The spectacular reduction in sea ice extent in summer 2007 was concomitant to the massive evacuation of multi-year ice[2] from the western Arctic Ocean towards the Greenland Sea. An anomalous atmospheric circulation created by higher atmospheric pressures over Greenland and the Beaufort Sea and lower pressures over the Eurasian coasts had pushed the ice accumulated off the northern coasts of the Canadian Archipelago and Greenland towards the Fram Strait, its main outlet located between Greenland and the Svalbard archipelago. This loss of multi-year ice was never compensated for by the ageing of an equivalent quantity of younger ice, which would

[1] Note that these rates are related to a reference value, the climatological average, calculated as the average over the period 1981-2010. This is the average extent of the ice sheet for September.
[2] Multi-year ice is ice that is more than one year old. The Arctic multi-year ice reservoir is replenished each year at the end of summer by first-year ice that has survived the summer melt.

have remained in the Arctic basin. On the contrary, the progressive thinning of the first-year ice, linked to Arctic warming, made it more vulnerable to atmospheric forcing: shorter growth period, faster melting, accelerated drift and deformation, less compact pack ice - all these factors worked to prevent the reconstitution of the older ice in the following years.

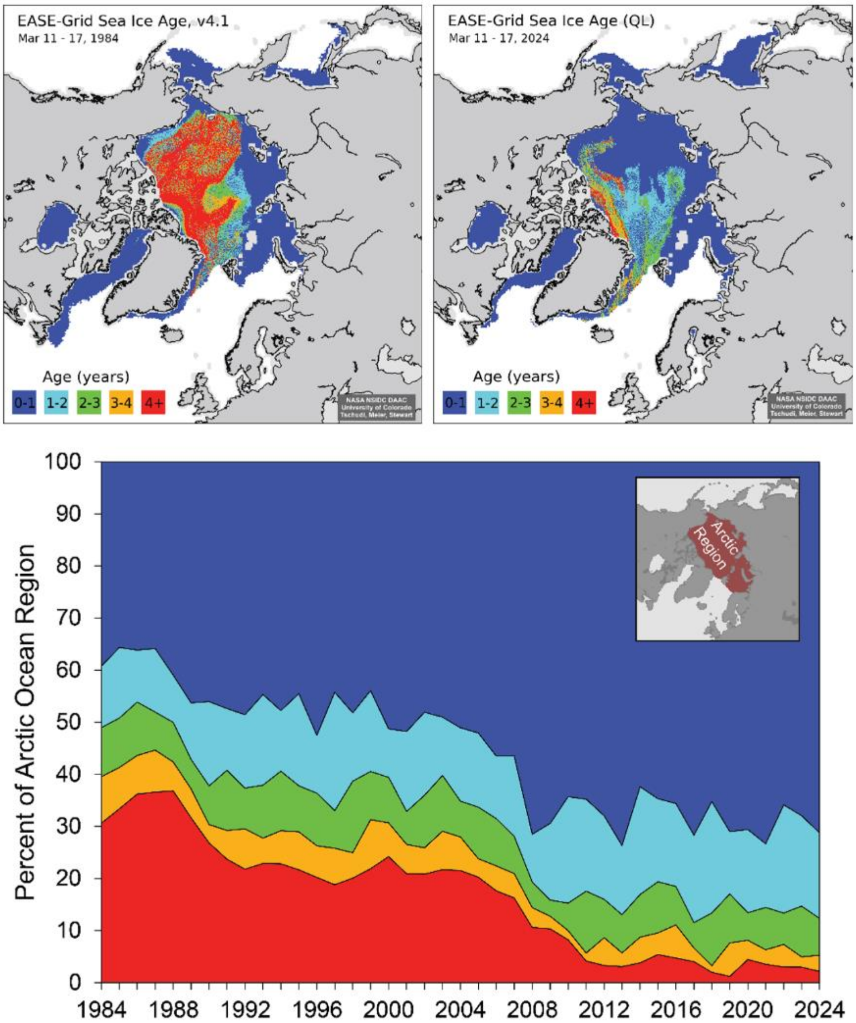

Fig. 3: Evolution of Arctic sea ice age classes over the period 1984-2024 : spatial distribution in the months of March 1984 and March 2024 (top) ; proportion of area occupied as a function of year, for different age classes (bottom). *Source: NSIDC EASE-Grid Sea Ice Age (Tschudi et al. 2019b).*

In the mid-1980s, multi-year ice occupied over 60% of the Arctic Ocean's surface, whereas over the past decade its contribution has dropped to less than 30%, with the winter of 2024 confirming a decrease in second-year ice compared with 2023 (Fig. 3). While the summer of 2007 had marked the start of a sharp decline in the proportion of multi-year ice in the Arctic, 2012 saw another dramatic melting decline due to spectacular melting of the multi-year ice, particularly in the Beaufort Sea. The year 2012 indeed corresponded the almost total disappearance of the oldest (5 years old or older) multiyear ice.

The changing nature of sea ice cover, marked in particular by the massive reduction in multi-year ice in the Amerasian Basin, had repercussions throughout the Arctic Ocean, including the central region where the sea ice cover was previously relatively preserved. Ice concentration, usually considered to be close to 100% in this year-round ice covered region, has largely decreased in some areas, the ice has become thinner and the melt season has lengthened by several days due to earlier melt onset and later freeze-up. In August and September 2024, as in most recent years, ice concentrations in the central Arctic Ocean were everywhere below the monthly climatological mean, with downward trends now significant over the satellite period over a large part of this region (Fig. 2b). These changes may be inducive to a possible increase in human activity in the central region[3] of the Arctic Ocean.

"Sea ice concentration in the Central Arctic Ocean region, usually considered to be close to 100%, has dropped significantly in many areas."

At the same time as the Central Arctic Ocean may become more accessible, navigability conditions in the passages of the North Canadian Archipelago remain uncertain (Fig. 4). Ice conditions in these passages are influenced by the outflow of ice from the Arctic Ocean, which carries along ice originating in the northern coastal areas of the Queen Elizabeth Islands and Greenland, where the thickest and most compact multi-year ice is now confined. This outflow is vulnerable to the atmospheric conditions that control the transport of ice towards and into the passages. The summer of 2024 was remarkable in this respect: while, as is the case almost every year, the “northern route”[4] immediately south of the Queen Elizabeth Archipelago remained partially blocked by ice until mid-September, a reversal of the prevailing winds then opposed to the southward drift of the ice while bringing in warm air, thus maintaining exceptionally low sea-ice conditions in this passage. On October 1, 2024, the “northern route” was ice-free, setting a record for the last 50 years and surpassing the record set in 2011.

[3] As seen last summer when the conventional tourist icebreaker “Commandant Charcot” used the North Pole route (or transpolar route) to reach the Atlantic from the Pacific.
[4] The route through Parry Channel into the Arctic Ocean at M'Clure Strait.

Fig. 4: Ice concentration along the several routes of the Northwest Passage on July 13, 2024. *Source : NASA Earth Observatory/Lindsay Doermann.*

The presence of open water does not mean safer navigation conditions; the latter depends on the level of risk involved, and in particular on the probability of encountering drifting ice on the ship's route. Since 2007, in the Canadian Northern Passages, like the rest of the Arctic, the amount of multi-year ice cover has decreased, largely due to warmer conditions preventing ageing of first-year ice. As a result of a less compact sea ice cover, multi-year ice is now able to flowing in the previously blocked passages of the Queen Elizabeth Archipelago, yet as a weaker, but also more intermittent and less predictable, ice flow than in the passages further west. As long as the multi-year ice outflowing from the Arctic Ocean continues to feed the passages of the North Canadian Archipelago, the navigational risk on these shipping routes will remain high, despite the reduced sea ice cover as a result of global warming (-33% compared with the climatological average for multi-year ice area over the period 2007-2020).

Building reliable projections of Arctic sea ice cover remains a major challenge for anticipating future Arctic Ocean accessibility. The first-order metric for measuring this is the extent of the sea ice cover. However, the evidence of a persistent downward trend over the last 40 years does not allow us to predict what will happen to the ice pack in the years or decades to come. The linear - i.e. constant over time - rate of decline in sea-ice extent (Fig. 2a) is an idealization, and in reality varies according to the periods considered[5], making any extrapolation into the future problematic.

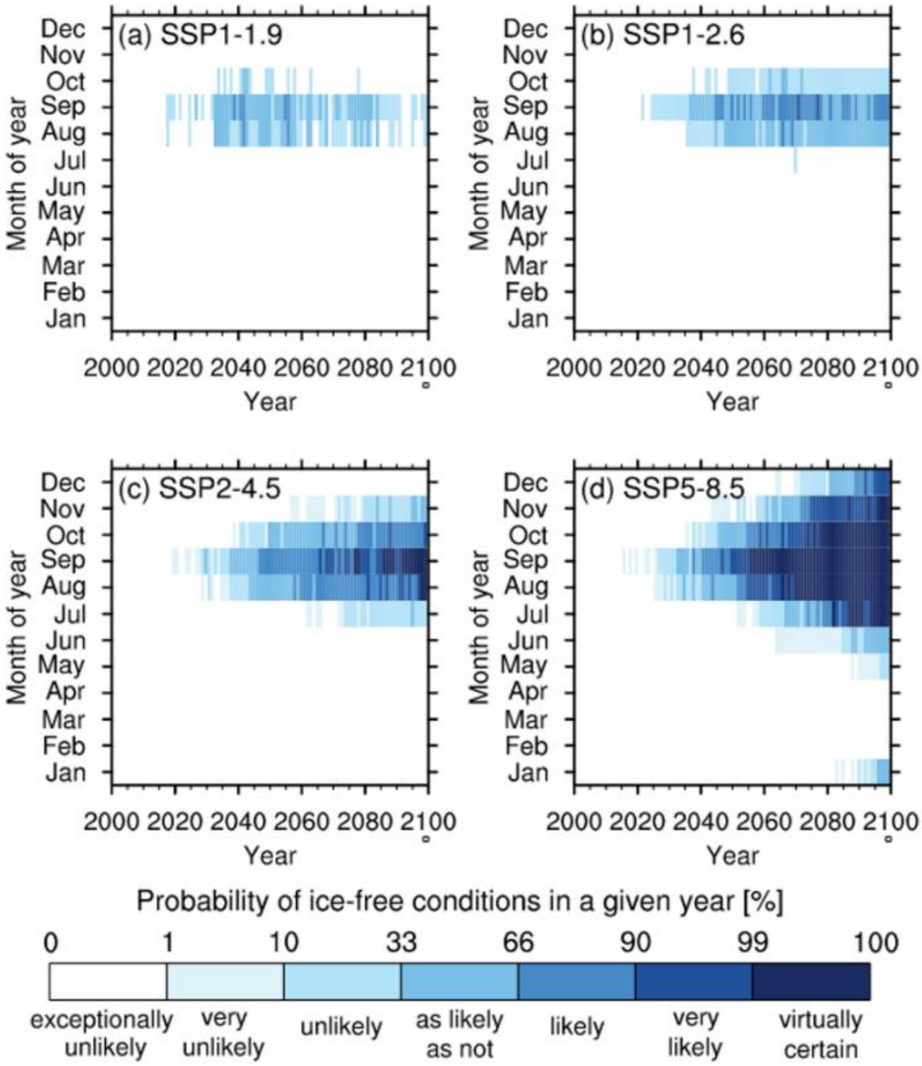

Fig. 5: Probability of occurrence of an ice-free Arctic Ocean (or « blue ocean ») as a function of month and year during the 21st century, for various climate scenarios of greenhouse gas emissions. Analysis of a selection of simulations from the CMIP6 (*Coupled Model Intercomparison Project*) exercise. The SSP5-8.5 scenario assumes high-carbon economic development while the SSP1-1.9 scenario follows the Paris Agreement objective of average warming below 1.5°C. *Source : Jahn et al. 2024.*

Earth system models provide an estimate within the framework of scenarios built on socio-economic assumptions implying different trajectories for future greenhouse gas emissions (from which are derived warming scenarios that vary according to the response of the model scan be derived). The projections derived from these models are fraught with numerous uncertainties, which can be quantified within the framework of

[5] For example, Fig. 2a shows that the linear decrease in sea-ice extent is faster over the period 1996-2007 and slower over the post-2007 period.

intercomparison projects[6], the bulk of these uncertainties being linked to the internal variability of the Earth system (more than 50% of the uncertainty on the September sea ice extent), on top of which are superimposed the uncertainties linked to the realism of emission scenarios and those linked to model imperfections should be added. As a result, we can only refer to probabilities of encountering sea-ice, or eventually, the probability of occurrence of an ice-free Arctic Ocean (or "blue" ocean[7]). For the past fifteen years, scientists have been working at reducing this uncertainty, in particular by selecting the most relevant models and results[8] for their analysis.

It is now considered «likely» (more than 66% of probability) that an isolated event during which the Arctic would be free of ice on average over the month of September will occur as early as the middle of the 21st century (such occurrence being expected earlier by several years, 4 years on average, if daily instead of monthly sea ice extents are considered), and this regardless of the emission scenario (Fig. 5). However, the emission path followed in the future will be crucial because it will determine the frequency, duration and spatial distribution of these episodes of very low sea ice conditions. We are holding all the cards to delay as much as possible the emergence of such conditions that will put huge stress on unique environments and socio-ecosystems whose existence is largely depending on sea ice.

Marie-Noëlle HOUSSAIS
For Polar Watch

[6] Like the *Coupled Model Intercomparison Project*, whose 6th exercise (CMIP6) provided data for the latest IPCC assessment report.

[7] The notion of "blue" ocean is to be contrasted with that of "white" or frozen ocean (Newton et al., 2016). It is now agreed, somewhat arbitrarily, that the Arctic Ocean is free of ice if the extent of the ice pack is less than 1 million km^2.

[8] See for example the summary article by Jahn et al., Nature Reviews Earth and Environment, 2024.

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