

Arctic Sea-Ice: Reflections of What Will Happen in the Future



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Abstract

The Arctic Sea ice is one of the most important climate indicators. In the period 1979–2024, the monthly mean September sea-ice extent minimum has decreased by 40%, highly correlated with the increasing CO₂ concentration in the atmosphere. In the period 1979–2022, the correlation between the sea-ice extent and the $\ln(\text{CO}_2 / \text{CO}_{2, 1979})$ gave a coefficient of determination (R^2) of 0.81, implying that about 80% of the decreasing sea ice extent can be explained by the increasing CO₂ concentration in the atmosphere, while the remainder is caused by natural variability. In general, it is interesting to follow the development of the minimum sea-ice extent in September in the coming years because in addition to impacting the climate, life, nature and economy in the Arctic, it also impacts other parts of the world, for example, the extreme rainfall in the Indian summer monsoon system and the East Asian summer monsoon in China.

Keywords: Sea ice; Arctic; Climate change

Introduction

Summer Sea-Ice Extent (SIE) is one of the most important climate indicators, in particular the September minimum. In the period 1979–2024, the September monthly minimum has decreased by about 40% based on US satellite passive microwave data (Figure 1, <https://iceobs.nersc.no/>) which also show that the winter maximum in March has decreased with about 12% and annually with about 18%. The summer ice in September decrease is primarily forced by the increase in the CO₂ concentration in the atmosphere from a mean of 333ppm in September 1979 to a mean of 422ppm in September 2024, observed at Mauna Loa, Hawaii <https://gml.noaa.gov/>. The variations around the linear decreasing trend line of the SIE are caused by natural variability (Figure 1), as reviewed by Johannessen & Shalina [1] and a recent review of the projections of an ice-free Arctic Ocean by Jahn et al. [2].

Johannessen & Shalina [3] suggested a new “hypothesis that the summer ice will not melt if the Paris Agreement can be reached or nearly be reached”. Furthermore, this was investigated in more detail by Johannessen & Shalina [1] where they correlated the SIE with the $\ln(\text{CO}_2 / \text{CO}_{2, \text{reference}})$, since this is the empirical law for longwave radiation back to space from the surface of the earth [4]. During the period 1979–2022 the coefficient of determination,

R^2 , was 0.81 indicating that about 80% of the decreasing SIE was caused by the increasing CO₂ in the atmosphere, the remaining by natural variability which will vary from year to year, both positive and negative around the decreasing trend line (Figure 1). Using this statistical relationship.

Equation 1:

$$SIE(\text{mill.km}^2) = -16.10 \ln(\text{CO}_2 / \text{CO}_{2r}) + 8.40, \text{ with } SD = 0,50$$

where CO_{2r} is 333ppm, the reference level in 1979. By setting SIE = 0, all of the sea ice in the Arctic Ocean will be melted if the CO₂ concentration in the atmosphere, unlikely, should increase to 563 ± 17.5ppm, which is far above the Paris Agreement of 450ppm in 2060 (Table SPM.1 in IPCC, 2021 [5]). Even if the Paris Agreement cannot be totally reached, a major reduction of the CO₂ emissions is planned in the coming years, supporting the Johannessen & Shalina [1] hypothesis that there will be “no tipping point” for the summer ice.

In this opinion note I will first project SIE for 2023 and 2024 using our statistical equation mentioned above (equation 1) and validate them with the observations of SIE from the Nansen Center in Bergen ice information system (<https://iceobs.nersc.no/>), including the values of the natural variability, secondly,

project the SIE for 2030 since a recent paper by Heuze & Jahn [6] suggested that the first ice free day in the Arctic Ocean could already happen before 2030, thirdly, some reflections about the future of the summer sea-ice extent and fourthly a summary and conclusion.

Hindcast SIE Projections for 2023 and 2024 Compared with Natural Variability

I have used the statistical relationship above (equation 1) to validate the mean September SIE for 2023 and 2024 with the observations, including estimating the values of natural variabilities for these two years (Figure 1), where the CO₂ were 417ppm and 420ppm, respectively, as input to the statistical equation 1 (<https://gml.noaa.gov/>). The mean projected SIE for September 2023 was 4.778 mill.km² compared to the observed

5.101 mill.km² (<https://iceobs.nersc.no/>), indicating that natural variability contributed with 0.323 mill.km² more than the CO₂ projected SIE or about 6.3%. The projected SIE for 2024 had decreased to 4.665 mill.km² compared to the observed of 5.084 mill.km², more than 0.419 mill.km² than the CO₂ projected SIE or about 8.2%. These projections are reasonable when compared with the observations indicating that the natural variabilities during these two years were relatively small, 6–8%. However, as seen from Figure 1, the natural variabilities can be larger, both positive and negative around the trend line, exemplified with the two extremes in 2007 and 2012 which make the exact projection of the summer minimum more difficult, both using this simple statistical model or the more complex global coupled models, e.g., reviewed by Johannessen & Shalina [1].

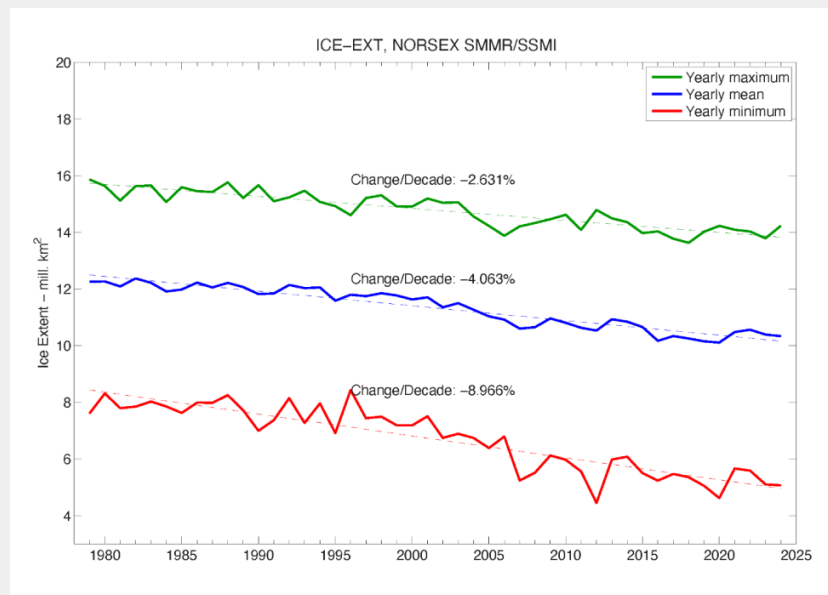


Figure 1: Monthly mean SIE for minimum in September, maximum in March, and annual for the period 1979-2024 in million km² (source: <https://iceobs.nersc.no/>). The solid line indicates the year-to-year values, the dotted line the linear trend.

Sea-Ice-Extent Projection for 2030

As mention above Heuze & Jahn [6] by using several CMIP6 global climate models suggested that the first ice free day in the Arctic Ocean could happens before 2030. Therefore I will use our statistical model mentioned above (equation 1) to project the mean September SIE for 2030 to compare with the result from Heuze & Jahn [6]. However, it should be mention that the daily minimum value in September for 2023 and 2024 were 0,132 and 0,193 mill.km² less that the monthly mean which should be taken into the consideration when comparing our mean September projection with the daily Heuze & Jahn [6] projections. The increase in CO₂ has been in the order of 2.5ppm per year over the last few years (<https://gml.noaa.gov/>). In the following years up to 2030, we will

probably not observe a major reduction of the CO₂ concentration in the atmosphere, which means that the yearly increase will continue to be about 2.5ppm per year reaching 435ppm in 2030 about the same as the Shared Socioeconomic Pathways SSP1-2.6 and SSP4-3.4 in 2030 [7]. Using 435ppm in our statistical equation (equation 1) gives a projected SIE for September 2030 of 4.098 mill.km² which is in large contrast to Heuzé & Jahn [6] where they use several CMIP6 global models to project that “the first ice-free day in the Arctic could occur before 2030 associate with strong winter and spring warming”, a projection that is in contract when compared with my statistical projection above of about 4 mill.km² for the SIE in 2030, even taking the error of SD=0,50 mill.km² into account including the difference between the monthly and daily mean for the September month, mention above.

Reflection about the Future of Sea Ice

The September SIE will probably continue to decrease due to the likely increase of CO₂ concentration in the atmosphere in the coming years in spite of that major reductions are planned. However, it should be mentioned that Johannessen & Shalina [3] studied of how the increasing population of the World could influencing the climate using the Arctic as an example. Here they show that there was a perfect correlation between the increasing population and the CO₂ concentration in the atmosphere for the period 1963-2019 based on the regression equation:

Equation 2:

$$CO_2 = 1,68x(\text{billion})^2 + 1,88x(\text{billion}) + 295,9 \text{ with } R^2 = 1,00, SD = 0,85$$

where CO₂ is ppm, Johannessen & Shalina (2022, figure 2a) [3]. The population increase is projected to 10 billion in 2100 [8]. Inserting 10 billion in the above equation (2) gave a projected CO₂ of 482ppm for the year 2100 which is a worst-case scenario since the planned major reduction of CO₂ into the atmosphere will destroy the perfect correlation between the population increase and the CO₂. By inserting this value of 482ppm in our SIE equation 1 above give a SIE of 2,448 mill.km² in 2100 which is a worst-case scenario. As mentioned above the ice-free Arctic Ocean required that the CO₂ concentration in the atmosphere needed to be 563ppm which then required that the population of the World has to increase to slightly more than 12 billion calculated by equation 2, which according to present projection is not likely. Therefore, my conclusion is that the Arctic Ocean in September will not be ice free in this century," no tipping point", in contract to many other studies on this topic, e.g., reviewed by Johannessen & Shalina [1], however the SIE will be decrease dramatically to less than 2,5 mill. km².

Summary and Conclusion

In this opinion note I have first validated our statistical projection of the SIE for September 2023 and 2024 with observations with reasonable results, also indicating that the values of the natural variability were in the order of 6–8% larger compared to the CO₂ forcing for these two years, which is less than the average of 20% for the period 1979-2022.

Furthermore, I have projected the monthly SIE for September 2030 to be 4.098 mill.km² assuming that the yearly increase in the CO₂ continue as of the last few years of 2,5ppm per year. This is in large contrast to some recent modelling results by e.g., Heuze & Jahn [6] that indicate that the Arctic Ocean will be ice free one day before 2030, which according to my research is not likely to happen. Only time will show?

Finally, I have made some reflections about the future of the sea ice in the Arctic. We have shown that there is a perfect correlation between the population increase and the CO₂ concentration in the atmosphere over the last 6 decades [3]. Furthermore, the

population is projected to increase to 10 billion by 2100 which according to the relation-ship above (equation 2) could in the worst-case result that the CO₂ concentration in the atmosphere will increase to 482ppm resulting in a SIE of 2,448 mill.km² using our SIE equation (equation 1) above. In order to get an ice-free Arctic Ocean, the World population has to increase to slightly more than 12 million people, unlikely to happen. Based on the above my conclusion is that the Arctic Ocean will not be ice free in this century, however in the worst case decrease to less than 2,5 mill. km² which of course is dramatic. If this should happen, it will have tremendous impacts on the climate, life, nature, and economy in the Arctic region, also influencing other parts of the world through teleconnection, e.g., influencing the East Asian summer monsoon in China [9] and the Indian summer monsoon rainfall extremes [10]. In order to keep the summer ice in the Arctic "healthy in the future", this opinion note is another important example that demonstrates how important it is to decrease the CO₂ and other greenhouse gas emissions to the atmosphere, now and in the future, a great challenge for the World.

Data Availability

All data in the text and figures are freely available.

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