Dean&Francis
ISSN 2959-6157

The Mechanism of Sea Ice Melting and Anti-Melting Due to Albedo Feedback and Sea Ice Age-Roughness-Melt Ponds-Albedo Feedback

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Abstract:

This essay focuses on how the albedo feedback and sea ice age-roughness-melt ponds-albedo feedback cause the mechanism of sea ice melting and anti-melting. This essay uses lots of research results to make a carding logic about two albedo feedbacks and uses the relationship deduction and backwards deduction to prove that the two feedbacks are valid. Finally, three Figures prove two theories directly, because Fig. 1 and Fig. 2 have a similar tendency to prove that the sea ice albedo is proportional to the percentage of sea ice area in the total area of ocean, and in Fig. 3, two lines are in perfect accordance with the previous prediction in the Explanation of Sea Ice Age-roughness-melt ponds-albedo Feedback Theory Part. Also, some drawbacks that cause some abnormal values are mentioned in the Discussion Part, for example, albedos of both old and first-year sea ice in four seasons are replaced by other albedos that have a similar occurring situation.The research significance is that searching the mechanism of sea ice melting and anti-melting can help the researches about Arctic Amplification.

Keywords: Arctic sea ice, Albedo, Melt ponds, Sea ice

1 Introduction

Nowadays, the issue of climate change attracts widespread concern. The change of sea ice is one of the parts of the climate change issue. For instance, the sea ice area has decreased from 1979 to the current year in each month of the year [1]. Especially the sea ice area experiences the largest change in summer [2]. Meanwhile, this area change of sea ice will influence structural changes in the communities of two Arctic fjords, which are rocky-bottomed in the Svalbard Archipelago between 1980 and 2010 [3]. What is more, the change of phenology of primary production, with a cascade effect that structures the biodiversity and production of Arctic benthic ecosystems, is caused by an advanced spring sea ice melt and a delayed autumn sea ice freeze-up [4]. Therefore, sea ice should also be researched to solve the problems of climate change.

In this essay, there is an equation of the relationship between sea ice albedo and sea ice area created to illustrate that the sea ice albedo feedback is valid and can cause the mechanism of sea ice melting. Also, there is the backwards deduction, which is used to prove that sea ice age-roughness-melt ponds-albedo feedback can lead to both melting and anti-melting of sea ice in different situations.

2 Data and Method

2.1 Data

About sea ice area and ages, these data come from the National Snow and Ice Data Center(NSIDC). The data on sea ice area is from one file on the NSIDC website [5]. The data on the percentage of sea ice area in different ages is from one map on the NSIDC website [6]. And the numbers are approximate, as they were interpreted visually from the bar graph.

Because of a large amount of data, the data should be selected. About the sea ice area, the values of the sea ice area in 2015 in the North Pole would be chosen by the author as the object to analyze the influence of albedo and sea ice age-roughness-melt ponds-albedo feedback. Table 1 includes these values. About the sea ice ages, the values of the sea ice ages in March and September from 2005 to 2015 in North Pole would be selected by the author as the object to analyze the influence of albedo and sea ice age-roughness-melt ponds-albedo feedback, while the values in September are for the research of melting process and the values in March are for the research of anti-melting process for sea ice age-roughness-melt ponds-albedo feedback. These values can be found on the map on the NSIDC website.

Table 1. The values of the sea ice area in 2015 in the North Pole from link1

Month	January	February	March	April	May	June
Sea ice area/Mkm*2	12. 17	12. 85	12. 78	12. 33	10. 9	8. 7
Month	July	August	September	October	November	December
Sea ice area/Mkm*2	5. 66	3. 63	3. 42	5. 49	8. 48	10. 64

About the albedo of first-year sea ice and old sea ice, there is no exact value, so the albedos of first-year sea ice in summer and winter are replaced by the albedos of pond formation and cold snow, which are 0. 32 and 0, 85, respectively, and the albedos of old sea ice in summer and winter are replaced by the albedos of pond drainage and cold snow, which are 0. 54 and 0 85 respectively [7]. And these values cause the final values, which are shown in Table 2. The reason why the albedos of pond formation, pond drainage, and cold snow could replace the albedos of first-year sea ice and old sea ice in summer and winter is that they are similar to each other due to their similar occurrence. One thing that should be noted is that in spring and autumn, the albedos of old sea ice and first-year sea ice are the mean values of their albedos in summer and winter.

Table 2. The value of the albedos of old sea ice and first-year sea ice in four seasons)

	spring	summer	autumn	winter
Albedo of old sea ice	0. 695	0. 54	0. 695	0. 85
Albedo of first-year sea ice	0. 585	0. 32	0. 585	0. 85

2.2 Method

2.2.1 Explanation of albedo feedback theory

According to the theoretical concept of black body and the basic principles of Physical Optics, there is a common understanding about the albedo and radiation: when the object is darker, its albedo is smaller [8]. That is the reason why the sea has less albedo than the sea ice. So, when there is a trend that sea ice area decreases, decreasing the whole sea surface albedo and more solar heating to the upper ocean will occur, and it will accelerate the melting process of the sea ice, as well as this would attain the cycle that melting of sea ice keeps constant occurrence [9]. That is one mechanism of sea ice melting.

2.2.2 Formula of albedo feedback theory

To make sure that the mechanism of sea ice melting is correct, a relationship is made by the author: the sea ice albedo should be proportional to the percentage of sea ice area in the total area of the ocean. One point that should be noted is that, in this relationship, the total area of the ocean is constant, and the change in the

ISSN 2959-6157

area of the ocean caused by some conditions, such as the rise of sea level, is not considered. And because the albedo of sea ice would be influenced by the sea ice age, the sea ice albedo here would be the average value of sea ice albedos in different sea ice ages. So the relationship could be expressed by the equation: $Seaicearea \propto thepercentageofseaice1area \times albedoofseaice1 + thepercentageofseaice2area \times albedoofseaice2$.

Where sea ice area 1 is first-year sea ice, sea ice area 2 is old sea ice(more than one year).

Also, the sea ice albedo would be influenced by the melt pond, which draws out the subsidiary feedback of the albedo feedback: sea ice age-roughness-melt ponds-albedo feedback.

2.2.3 Explaination of sea ice age-roughness-melt ponds-albedo feedback theory

Melt ponds are shallow water pits that are formed on Arctic sea ice in the period of the warmer months while the ice is melting, and one point should be noted is that the climate and ecosystem of the Arctic are influenced by the melt pond deeply [10]. Compared to unponded and snow-covered ice, melt ponds absorb 2–3 times solar radiation, and they allow sunlight to penetrate the ocean and solar energy to warm the ocean up [10].

So, when melt ponds gradually accumulate in the depressed areas on the sea ice surface, the solar radiation absorbed by melt ponds causes further melting of ice underneath. Following that, the next step depends on the age of sea ice: If melt ponds are formed on older sea ice, which has a relatively rougher surface than new ice, smaller and deeper melt ponds will be formed, and a higher effective albedo will be caused because the smaller melt ponds cannot decrease the whole effective albedo [11-13]. And that is the mechanism of sea ice anti-melting. However, if the sea ice age is young, it can be solved by reverse reasoning that a smaller effective albedo will be formed, and it can cause the furthering melting. That is the other mechanism of sea ice melting.

2.2.4 Deduction of sea ice age-roughness-melt ponds-albedo feedback theory

According to the mechanism of sea ice melting and anti-melting, there are some backwards deductions which can be made: In September, while the summer ends so that the mechanism of anti-melting starts to work, the percentage of older sea ice should be larger than the young sea ice in all sea ice ages and in contrast, the percentage of older sea ice should be smaller than the young sea ice in all sea ice ages in March. And in September, because the area of sea ice is smaller than summer(according to the area of sea ice in 2024 from the link1)due to the large solar radiation absorption in the whole summer, the whole surface albedo can be larger than summer, so that the area of melt ponds can decrease, and by the same reasoning, the area of melt ponds can increase in March. So, if the backwards deduction that the percentage of older sea ice is larger than the young sea ice in all sea ice ages in September is true, it will prove that sea ice age-roughness-melt ponds-albedo feedback is valid because the larger percentage of older sea ice in all ages of sea ice causes the decrease of area of melt ponds in the theory of sea ice age-roughness-melt ponds-albedo feedback. And by the same reasoning, the smaller percentage of older sea ice in all ages of sea ice in March can also prove that sea ice age-roughness-melt ponds-albedo feedback is valid.

3 Results

According to the equation of the relationship between the area of sea ice and sea ice albedo, Figs. 1 and 2 are made.

The y-axis of the line in Fig. 1 is the total sea ice in the North Pole per unit square of megakilometer, and the x-axis of the line in Fig. 1 is twelve months in 2015. So the line in Fig. 1 shows the change of total sea ice area through the different months in 2015. The trend of the line is to decrease first and then increase. The maximum point is between February and March. The minimum point is in March.

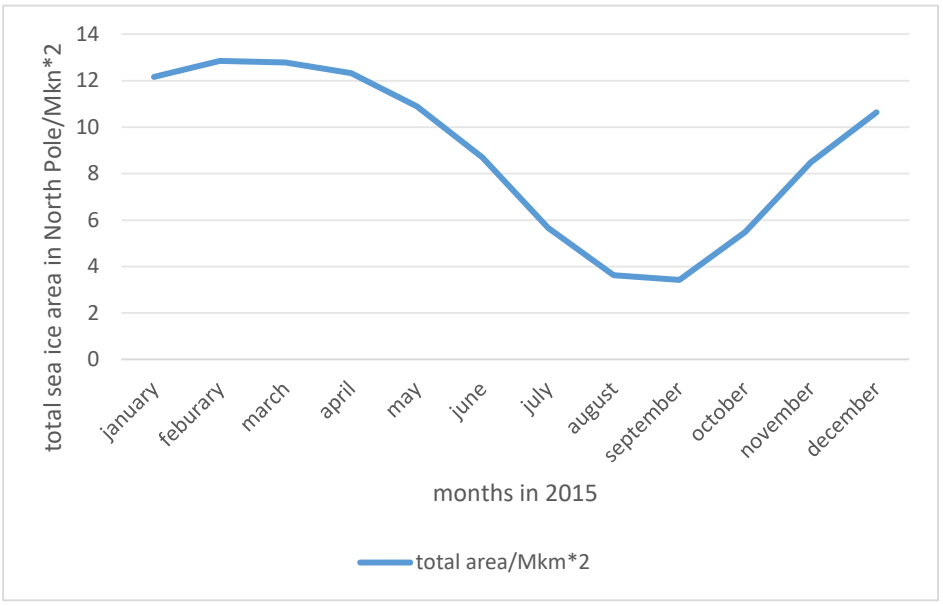

Fig. 1 The variation of total sea ice area in the North Pole in 2015 (Picture credit: NSIDC website).

The y-axis of the line in Fig. 2 is the whole surface sea ice albedo, and the x-axis of the line in Fig. 2 is twelve months in 2015. So the line in Fig. 2 is to show the variation of the whole surface sea ice albedo through the different months in 2015. The trend of the line is to decrease first and then increase. The maximum point is in February. The minimum point is in June.

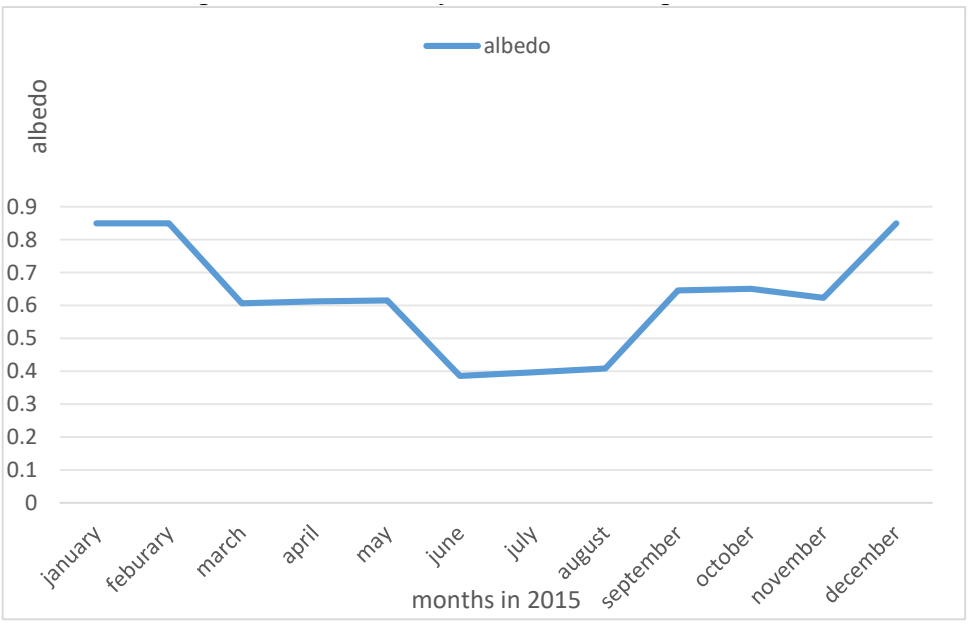

Fig. 2 The variation of sea ice albedo in 2015 (Picture credit: NSIDC website and [7]).

The lines in Fig. 1 and Fig. 2 have approximately similar tendencies, so they can prove that the sea ice area is proportional to the whole surface sea ice albedo, and the albedo feedback is valid. For the theory of sea ice age-roughness-melt ponds-albedo feedback, it can be proved by Fig. 3.

The y-axis of Fig. 3 is the percentage difference of old sea ice area and first-year sea ice area, and the percentage difference is the result of the percentage of old sea ice minus the percentage of first-year sea ice. The x-axis of Fig. 3 is the years between 2006 and 2015. Nearly all the percentage differences in September are positive, and all the per-

ISSN 2959-6157

centage differences in March are negative, which proves that the theory of sea ice age-roughness-melt ponds-albedo feedback is valid.

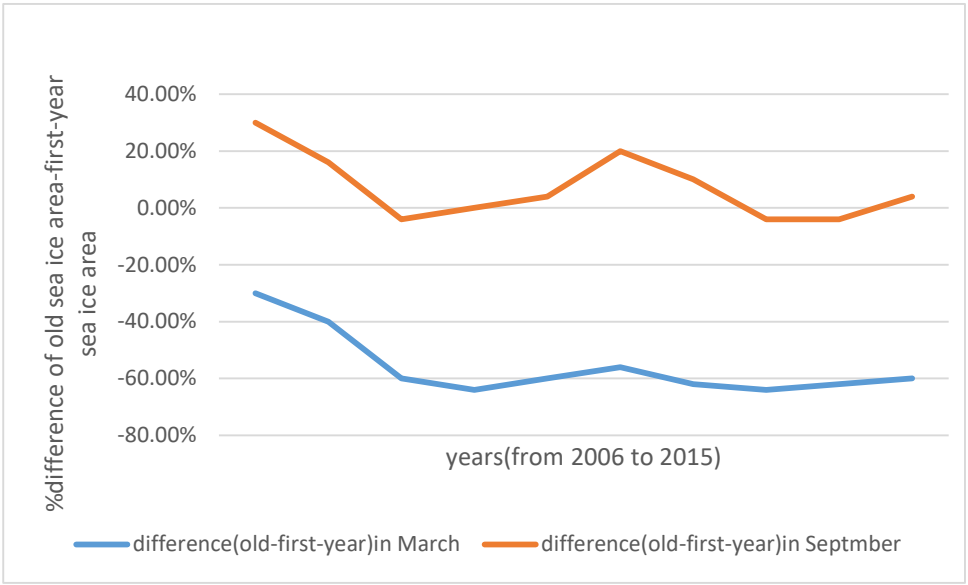

Fig. 3 The %difference between the old sea ice area and the first-year sea ice area in the North Pole. The percentage difference is the result of the percentage of old sea ice minus the percentage of first-year sea ice (Picture credit: NSIDC website).

Although the percentage differences in September should be positive values if the sea ice age-roughness-melt ponds-albedo feedback is valid, it is normal to have an accident because lots of details are ignored in the whole condition.

4 Discussion

The abnormal values which occur in the variation of sea ice albedo in 2015 are because that the albedos of both old and first-year sea ices in different seasons are replaced by other albedos which have the similar occurring situation, but the unusual values of percentage difference between old sea ice area and first-year sea ice area in North Pole in September are not because of the same reason.

For the abnormal values of percentage difference between old sea ice area and first-year sea ice area in September, the factors, such as the more solar energy absorption by ocean with no sea ice, strong southerly winds transporting warm air, can be used to explain the abnormal values, because these factors can cause the historic retreat of Arctic SIE, so that cause the decrease of old sea ice area in September [14].

5 Conclusion

This essay illustrates the mechanism of sea ice melting and anti-melting due to albedo feedback and sea ice age-roughness-melt ponds-albedo feedback, analyzes the whole system of albedo feedback and sea ice age-roughness-melt ponds-albedo feedback, and uses the relationship between sea ice area and sea ice albedo on the whole ocean surface and backwards deduction to prove that the two effects are valid to cause the mechanism of sea ice melting and anti-melting. In the discussion part, there are some factors that are noted to explain why there are some unusual values existing. Also, the essay has some shortcomings such as not taking other external factors into account and not using more accurate data to draw exact values because of research loss.

Nowadays, the research about the sea ice albedos in different sea ice ages is not enough to draw the exact values of the whole sea ice surface albedo, so the author needs to use other data to replace some important values. If more people study the sea ice albedo and draw the exact values about the sea ice albedos in different sea ice ages, the values that are calculated from this essay will be more accurate.

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