The Variation Characteristics of Temperature in Barrow Alaska During 1925-2018

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Abstract. By using the Mann-Kendall mutation test, Morlet wavelet analysis, correlation analysis, linear trend regression methods, the variation of temperature in Barrow, from the Barrow Airport monthly temperature data, is analyzed during 1925-2018. The whole tendency of annual change of temperature in 94 years is rising, with the trend approximately 2.8℃/100a. Before 1976, the mean annual temperature fluctuated downward, and after that, it showed an obvious upward trend nearly 9.3℃/100a, which indicated that Barrow experienced a process from cooling to rapid warming. Winter showed the most significant increasing trend among four seasons, with the average rate 4.27℃/100a, which is more than three times as high as that in summer (1.38℃/100a), right corresponding to the characteristic of Arctic amplification. The mutation of mean annual temperature occurred around 2005, and the value of temperature existed in a primary period of 15 years and a sub-cycle of quasi-8, quasi-28 years. At the end, great debates about the truth of temperature rising, mechanisms of Arctic amplification and the effect of it are demonstrated. The relevant conclusions are of reference value to the trend of temperature change in Arctic area and to the comprehension of Arctic amplification and global warming.

1. Introduction
Climate change has become one of the most severe global issues in recent decades. And among all factors of the climate, temperature plays the most significant role. Therefore, temperature features in different regions are the basis of further researches on climate change. In recent years, as the accumulation and abundance of observational data, a variety of researches on climate change in different areas have been completed, such as Deliguigu’s research on the mean annual temperature in recent 30 years of Tibet Plateau[1], RoziMamat-Abulaiti’s research on the climate change in Yili area of Xinjiang[2] as well as Zhang Keyang’s research in the Daxing’anling area[3]. While the whole global warming speed has slowed down in recent years[4]. In contrast to other areas, the north pole tends to accelerate its warming speed, with the rising rate twice in average and more than three times in winter. This phenomenon is called Arctic amplification[5], which mainly occurs in winter before the sea ice melts. Arctic amplification plays a crucial role in global warming, which can lead to a series of climate response. Compared with 1980s, more than a half sea ice has disappeared in summer[6]. The least sea ice cover records have been successively broken after 2006. People begin to notice that non-ice summer will finally come to the north pole in the near future[7]. Besides, methane is released outside due to the melt of the frozen soil[8]. And, ice melting can reduce the density of seawater, which can weaken the North Atlantic Radial Circulation[9] and, further, affect the whole ocean current. In addition, accelerated melting of sea ice and frozen soil will also cause disturbances in the Arctic ocean and terrestrial ecosystems, which will lead to changes in ecosystem productivity, animal habitats, and the spread of pathogens and pests[10]. In recent researches, scientists also find that the increasing extreme weather...
events in mid-latitude areas are possibly due to the high temperature in Arctic[11]. So, clarifying the driving mechanism of Arctic amplification is not only a requirement of climate change theoretical research, but also of great significance for climate prediction. Crook suggests that the reflection rate of sun radiation, a positive feedback mechanism, is the main factor of Arctic amplification [12]. Cao Yunfeng believes that the nature of this phenomenon can be analyzed via the energy balance in arctic regions [13]. Nowadays, it is still a great challenge for scientists to figure out the truth of this.

Barrow is located in the northernmost part of the American continent in Alaska, with a typical polar climate caused by the high latitude and strong polar winds. Under this circumstance, the climate change in Barrow could reflect the situation in the whole Arctic areas to some extent. In this paper, an explicit temperature feature in Barrow is showed and we can find that it totally agrees with the feature of the Arctic amplification. Non-parametric statistical test methods including Mann – Kendall mutation test and Morlet wavelet analysis are used to find a mutation year of the change of annual mean temperature and to analyze its periodic feature. In addition, linear regression method is applied to analyze the trend of temperature. Furthermore, the monthly temperatures in Barrow Airport station from 1925 to 2018 are selected to finish the study. The author hopes that this study will be helpful to elucidate the Arctic amplification and attribute to the further studies on polar climate.

2. Result and analysis

2.1. Annual trend

As is shown in fig.1, the whole tendency of annual mean temperature in Barrow is rising, with the rate 2.8℃/100a. In 2016, it reached the maximum -7.2℃, while the lowest one, -15.2℃, occurred in 1964. However, it does not always show an increasing trend. Before 1976, the mean annual temperature fluctuated downward with a decreasing rate -2.88℃/100a, while after that, it showed an obvious upward trend approximately 9.3℃/100a. The absolute value of the rising rate in recent 43 years is more than three times as high as that of the decreasing trend in the first 50 years, which intensifies the fact that the climate warming in arctic areas is significant in recent 40 years.
2.2. Seasonal trend

Figure 2. Annual changes and trends of average temperature in four seasons in Barrow.

Obviously, the discrepancy of the feature of mean temperatures in Barrow among four seasons is significant. The mean temperature in spring is -16.4°C, with the highest value -11.8°C in 1998 and the lowest one -20.8°C in 1964. The average temperature in autumn is -8.8°C, and the highest value -3.3°C occurred in 2016 while the lowest one -14.7°C occurred in 1998. While autumn has a higher temperature than spring, they share a same increasing rate, 2.7°C/100a. As to another two seasons, the mean temperature in winter is -25.2°C. It reached its coldest record -32°C in 1925 while peaked at -17.8°C in 2017. Clearly, winter owns the highest increasing rate 4.3°C/100a, which is consistent with Arctic amplification. On the opposite, there is only a slight rising rate 1.4°C/100a in summer, lower than one third of that in winter. So the temperature in summer reveals a great stability with a mean value 3.2°C. The difference between its highest value 6.1°C in 1989 and its lowest one 0.7°C in 1969 is only 5.4°C. It is clear that more frequent high temperature weather in Barrow has occurred in recent year, which means the warming speed does not slow down. On the contrary, it accelerates the warming progress as the result of Arctic amplification.

2.3. Mutation test

Figure 3. Mann-Kendall mutation detection of mean annual temperature in Barrow.
Fig. 3 shows the result of M-K nutation test. As we can see, the statistic UF fluctuated approximately twice from 1925 to 1950, indicating that an obvious periodicity, about 15 years, was showed in these years. Between 1950 and 1998, the UF statistic was below 0 for a long time, and even crossed the 0.05 confidence line in the 1970s, which means the average temperature in Barrow decreased dramatically in this period, with some short-cycle fluctuation. Ending the decline trend in 1976, the UF value began to rise, back above 0 in 1998, and after that, the UF value rose almost straightly, crossing the 0.05 confidence in 2005, without any periodicities and any downward trends, which suggests that the mean temperature increased significantly after 2005 and would keep the strong rising trend in the future. In addition, the intersection of the UF line and the UB line in 2005 also points out that the 2005 was the mutation year of annual mean temperature in Barrow. The mean temperature would increase dramatically after 2005 and even would accelerate the warming speed in the next few years.

2.4. Periodicity analysis

![Real contour map (left) and wavelet variance chart (right) of mean annual temperature wavelet coefficient in Barrow.](image)

The Morlet wavelet test is applied to study the periodicity of temperature time series in Barrow from 1925 to 2018. Fig. 4 shows the period of the annual mean temperature time series and its distribution in the time domain. In accordance with the real contour map, there exist roughly three kinds of cycles, 5-8 years (small scale), 14-18 years (mesoscale) and 27-30 years (large scale). Furthermore, the 5-8 small-scale fluctuation showed a weak effect before 1950 and after 1980. On the opposite, it dominated the middle 30 years (consistent with the result of the M-K mutation test). On the contrary, as to the 14-18 mesoscale vibration, it demonstrated a significant dominance before 1950, and then became relatively weak in the next 40 years. After 1990, it appeared to recover its strength and revealed a successively intensifying trend. In contrast to the other two cycles, the mesoscale one gives the greatest stability and significance. As to the 27-30 large-scale fluctuation, the contour line was incomplete and sparse before 1975, indicating that the large-scale periodicity was not a significant attribute in these years. After 1975,
the contour line gradually became intensive and did not close, so the large-scale vibration would continually aggrandize in the future.

From the peak of wavelet variance, we can know that the change of annual mean temperature in Barrow has three main periods of quasi-8a, quasi-15a, and quasi-28a in the past 94 years. The first main period is nearly 15a, while the other two share a similar strength as the second main period together.

3. Analysis summary
In this paper, monthly temperature data between 1925 and 2018 from Barrow airport station are used to analyze the annual change of temperature and give the result below:

Firstly, the whole trend of annual mean temperature in Barrow is rising in the past 94 years, with the rate 2.8℃/100a. Before 1976, the mean temperature fluctuated downward, then showed an obvious upward trend nearly 9.3℃/100a, with the mutation occurring in 2005. So far, the maximum annual mean temperature reached -7.2℃ in 2016.

Secondly, In contrast to other three seasons, winter shows the most significant rising trend as high as 4.3℃/100a, which is twice higher than that in summer, only 1.4℃/100a. And the highest record for different seasons occurred in 1998, 1989, 2016 and 2017 respectively. According to these, the climate warming in Barrow is obvious especially in winter, and more frequent high temperature records tend to occur in recent years, which totally agrees to the Arctic Amplification.

Thirdly, As to the periodicity of temperature, mesoscale vibration dominated the first 30 years before 1950 with the main period 15a, while in the middle 40 years, annual mean temperature tended to fluctuate in a small-scale cycle with the main period around 8a. 14-18a mesoscale and 27-30a large-scale fluctuation appeared to intensify their dominance after 1990, while small-scale vibration gradually lost its effect. In the future, mesoscale and large-scale fluctuation will be the main attribute of annual mean temperature in Barrow.

4. Discussion
Although an increasing trend of mean temperature in Barrow is significantly showed in this paper, there still exist a couple of debates of whether the global temperature is truly increasing or not. Arctic amplification means that a great deal of energy is accumulated in Arctic areas leading to an acceleration of warming. However, based on energy conservation law, earth’s energy should be conserved in balance, which suggests that the energy can only be transferred from one place to another, but not increase out of thin air. Overland J E[14] pointed out that the mean temperature in mid-latitude regions of the northern hemisphere, such as Siberia areas, is decreasing significantly in recent decades, which is possibly due to the accelerating warming speed in Arctic areas. This totally opposite trend between two areas is called ‘Seesaw Effect’, suggesting that the energy is transferred from mid-latitude regions to high-latitude regions with some uncertain mechanisms. According to this, some believe that the global temperature is not rising, but just that the energy is transferred from some areas to another, and thus leads to local heating or cooling. So, it is a great challenge to find out a balance point of the global energy and give its clear mechanism. Only in this way could we know exactly whether our earth is warming or not.

Arctic amplification is significantly showed in the paper, but, its exact driving mechanisms are under so many researches and debates. The sea ice melting speed in Arctic is accelerating rapidly, which can decrease the reflectivity to the solar radiation and thus absorb more energy from it. This is called the sea ice albedo feedback (SIAF) [15], which is a positive feedback mechanism leading to an obvious acceleration of warming in Arctic. This theory has been thought to be the main mechanism of Arctic amplification for years. However, recent researches show that the direct polar energy transfer through ocean or atmosphere circulation (especially the one through Barents Sea) play a more critical role. Actually, even in the circulation theory, there still exists a controversy about which kind of circulation is the driving mechanism and which is the result. Scientists used to believe that the ocean circulation drives the polar energy transfer, which suggested that the warmer Atlantic Ocean brings more heat to Arctic and then causes a rising temperature. However, scientists gradually find that the north Atlantic
radial circulation is weakening[16] in recent decades, which shows a completely opposite trend of Arctic amplification. Based on magnitude analysis, they point out that it is the circulation of atmosphere, but not ocean, that play the principal role in the polar energy transfer [17]. Under this circumstance, it is clear that the weakening of Atlantic circulation is the result of Arctic warming that the continuous sea ice loss could lead to a decline in the density of surface water, then the deep convection process in the sea will slow down and thus weaken the radial circulation. The connection and interaction between atmosphere and ocean circulation are still under further researches. As we can see, there exist many debates among warming mechanisms, which provides scientists with a great challenge in the future.

Although there exist many unknown mechanisms of global warming, it has exerted severe effects on the whole earth, especially in Arctic areas. Some researches of phenology show that Arctic warming has caused a gene evolution of animals in Arctic especially for polar bears. Their food is lack due to the loss of sea ice, because it is harder to hunt seals in water than on the ice surface. Under this circumstance, they are forced to move to the south and compete with brown bears or gray bears on the Asia or America continent, which can cause a biological fusion of these bears, with the result of gene evolution. If any creatures cannot adapt to the climate change, they may be extinct. For human beings, extreme weathers including flood, drought, hot weather and cold weather can exert a bad influence on their agricultural activities.

Therefore, what can people do for climate change? The release of greenhouse gases are always thought to be the main factor leading to global warming. Hence, measures are supposed to limit the release of emissions. However, even if political leaders decide to take dramatic actions to limit worldwide consumption of fossil fuels, it is probably too late to prevent significant increase in global temperature and sea levels. Under this circumstance, more clean energy should be found and new technologies are ought to arise to minimize the carbon emissions. This should be the main goal for scientists in future.

5. Conclusion
In this paper, a clear temperature feature from 1925-2018 in Barrow is showed through linear regression method, Mann-Kendall mutation detection algorithm and Morlet wavelet algorithm. We find that the annual mean temperature experienced a process from cooling (before 1976) to rapid warming (9.3°C /100a after 1976). Winter showed the most significant warming trend (4.3°C /100a), which totally agrees with the Arctic Amplification. And there exists three kinds of cycles, 5-8a small scale, 14-18a mesoscale and 27-30a large scale. The small-scale vibration dominated the middle 40 years, while the mesoscale one was active in the first 30 years and played a crucial role in recent decades. In the future, both mesoscale and large-scale fluctuation will play the most significant role.

As we can see from figure 1, the annual mean temperature in Barrow showed an obvious downward trend before 1976, which is significantly opposite to its whole trend, with some unknown mechanisms. In addition, the analysis only shows the temperature feature in Barrow, lacking other factors like precipitation, winds, clouds, ice concentration or solar radiation, especially geographic features. All of those can make contribution to the climate change in Barrow, even can exert a great influence on the whole Arctic area. Hence, more factors are supposed to be coupled in the next research, so that explicit mechanisms of climate change in Arctic areas can be clear in the future.

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