Temporal Changes in Static Stability in Arctic Boundary Layer

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Introduction

Motivation and research objectives

Global climate change is considered to have great impacts on Arctic regions because of the melting of the sea ice. Increases in air temperature during the past several decades have caused changes in other components of the Arctic climate system. For example, air warming of the lower Arctic boundary layer can probably engender changes in the static stability. Previous studies have focused on the surface temperature changes (Bradley and Keiming, 1993) and others did some work about long-term temperature fluctuation (Kaufman et al., 2009).

Despite the great attention brought to the surface temperature changes in Arctic regions, little is known about the variation of vertical temperature profiles or the changes of long-term static stability. Therefore, the objective of this research is to investigate the temporal changes in the atmospheric static stability of the Arctic boundary layer.

Method

The climate station locates at Alert, Nunavut, residing at the most northern land site (82° 30′05″N, 62° 20′20″W) in the Northern Hemisphere. Upper air data obtained from University of Wyoming with height resolution 50 m and time resolution 12 h. Data were utilized to determine the changes in the Arctic boundary layer static stability and equation (1) describes such relation.

$$S = \frac{g}{\theta_v}\frac{\partial \theta_v}{\partial z} \quad (1)$$

The period ranging from 1977 to 2011 was included in the data analyses. Long-term data were averaged from the surface to 2000 m above the ground. Both average virtually potential temperature and its gradient were utilized to yield the static stability. Both wintertime and yearly temporal trends were analyzed to identify the changes in static stability in Arctic boundary layer.

Figure 1. The red triangle shows the location of Alert, Nunavut Canada. This site resides at the most northern land of Northern Hemisphere (82° 30′05″N, 62° 20′20″W). The yellow circle indicates approximately 500 kilometer radius.

Figure 2. The Dr. Neil Trivett Global Atmosphere Watch (GAW) Observatory at Alert, Nunavut. The Observatory is situated 210 m above sea level with the terrain in vicinity between 100 and 150 m (Source: Environmental Canada)

Basic Analyses

Overview of the Static Stability in Alert

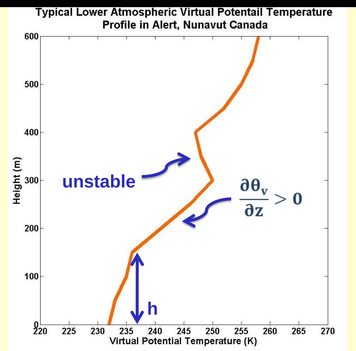

Figure 3. An example of virtual potential temperature. Static stability is proportional to the slope of the profiles as illustrated in the graph. h indicates the height of stable layer

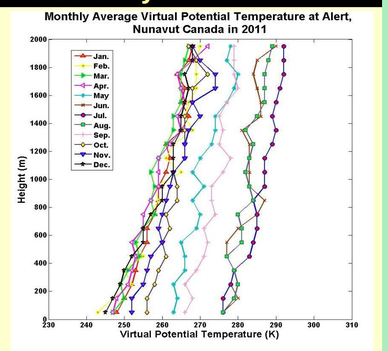

Figure 4. Virtual potential temperature profiles in different months indicated that the depth of the Arctic stably boundary layer is between 200 m and 500 m due to seasonal variation.

Overview of the Stability in Alert

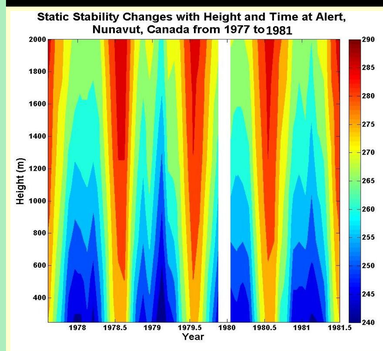

Figure 5. The virtual potential temperature profile from 1977 to 1981. Virtual potential temperature alternate regularly from 240 K to 290 K (The gradient of the color is related to static stability).

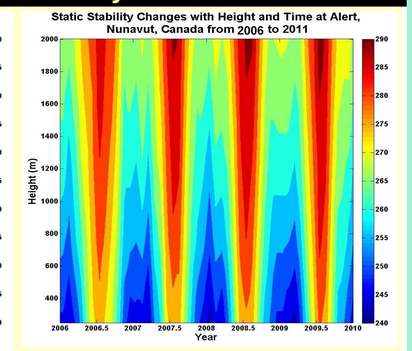

Figure 6. The virtual potential temperature profile from 2006 to 2011. The profile does not change significantly implying a relatively constant static stability in Arctic region in past several decades.

Ice Concentration

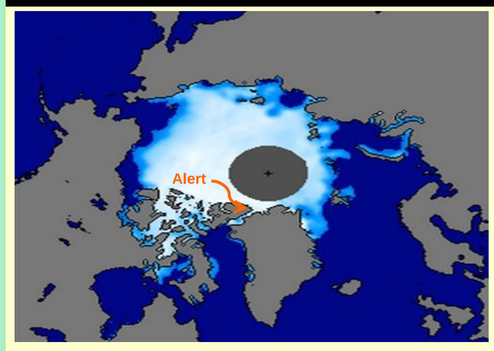

Figure 7. Ice concentration in Arctic region in summer 1979. Darker color represents lower ice concentration. Ices around Alert are mostly white suggesting high concentrations (Image source: NSIDC)

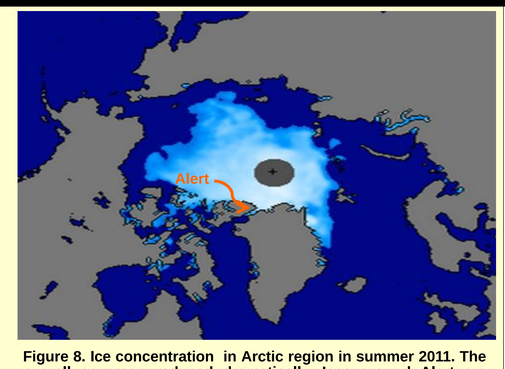

Figure 8. Ice concentration in Arctic region in summer 2011. The overall coverage reduced dramatically. Ices around Alert are partially blue suggesting lower ice concentrations as well (Image Source: NSIDC)

Long-term Profiles

Long-term Profiles of Virtual Potential Temperature and Static Stability at Alert, NU Canada from 1977 to 2011

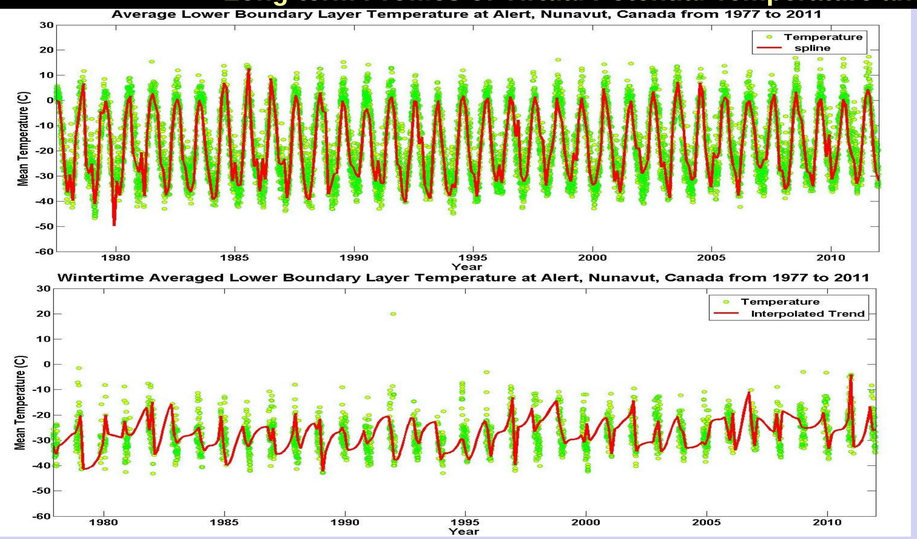

Figure 9. The figure shows the yearly and wintertime daily averaged temperature at Alert, NU. The first graph is fit by the spline and the second graph is fit by the interpolated trend line. Both graphs show the long-term increases of the temperature in the lower atmospheric boundary layer with greater magnitude of fluctuation in recent years. Such increase corresponds to the ice retreats shown in Figure. 7 and Figure. 8.

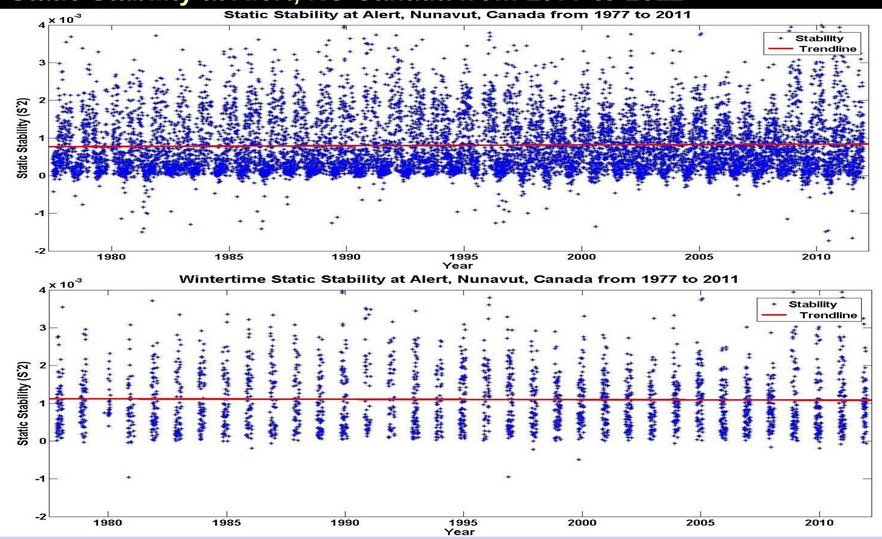

Figure 10. Yearly and wintertime variation of static stability at Alert, NU with trend lines. The figure shows an almost unchanged static stability under a long term scenario with higher averaged value of static stability in wintertime. No significant variations or trends can be found indicating the static stability in Alert, Nunavut remains relatively constant in past several decades compared to the environment changes.

Conclusions

- Melting of the sea Ice has great environmental impacts on Alert, Nunavut in past several decades. The coverage of sea ice around Alert, Nunavut now has both smaller area and lower concentration.
- Such decreasing in ice coverage has led to many consequences, including increasing of the virtual potential temperature and the fluctuation of temperature in lower atmospheric boundary layer.
- Compared to the changes of these factors, the static stability in Alert, Nunavut is considered mostly unchanged in past 35 years with relatively constant values and insignificant trends for both entire year and wintertime only.
- Future studies may focus on other sites in the Arctic regions (e.g., Resolute, NT Eureka, NT and Kotzebue, AK) to determine whether such unchanged static stability is prevail in Arctic regions and find the reason of this phenomenon.

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