Temporal variation in snow cover over sea ice in Antarctica using AMSR-E data product

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ABSTRACT

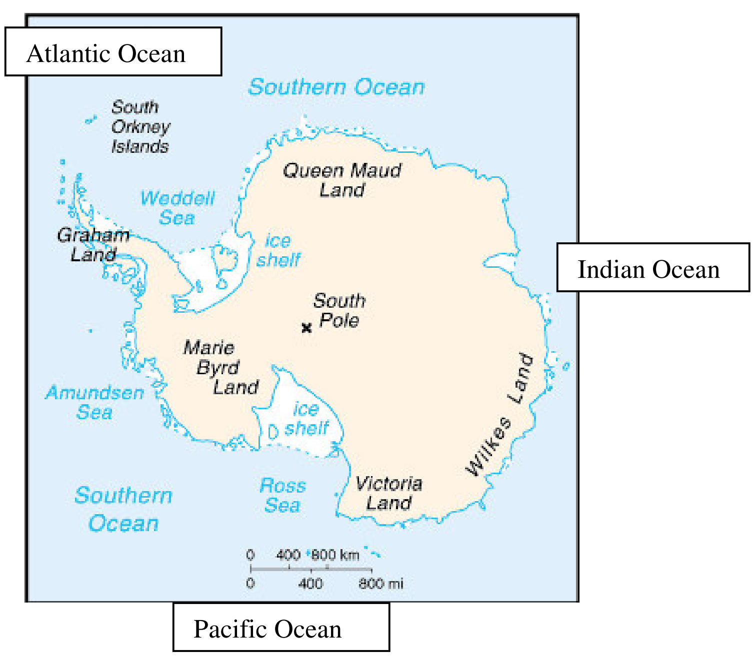
A study of the variation in snow cover over Antarctic sea ice was performed using AMSR-E/Aqua data products available from the National Snow and Ice Data Center. Daily data images from four monthly intervals representing the austral seasons were analyzed for both 2004 and 2005 calendar years. The mean and maximum snow depth and snow area coverage were determined using threshold regions of interest with ENVI software. Areas of maximum and minimum snow cover were determined for weekly intervals during the study period. Results of the study indicated that snow over sea ice has the lowest area coverage in January (Summer) and the greatest area coverage in October (Spring) and generally decreased in total area between Summer of 2004 and 2005. The mean and maximum snow depths were greater in January 2005 and occurred later in the month as compared to 2004. A comparison of mean snow depth to the area of snow coverage shows a clear trend indicating a wet season in Summer months and a relatively dry period throughout the remainder of the year. This information corroborates the hypothesis that sea ice areal extent affects the local precipitation patterns. As the least area of sea ice is present in the Summer months, more near surface ocean water is exposed to evaporation, resulting in greater snow precipitation (wet season). The trends observed between 2004 and 2005 indicate that sea ice area has decreased in the Summer months and snow precipitation has increased. Additional investigation related to sea ice surface temperatures, local precipitation data, and cyclical trends, such as the Antarctic Oscillation (AAO) and El Nino/Southern Oscillation (ENSO) must be studied to better understand the long term effects of global warming on Antarctica.

INTRODUCTION

Sea Ice forms as saline ocean water freezes on the surface in polar regions. Sea ice is seasonal in the Antarctic and can vary from a minimum in the austral summer month of January (approximately 2.5 million square kilometers) to a maximum in the early spring month of October (approximately 20 million square kilometers). For comparison, the entire continental land mass of Antarctica comprises about 14 million square kilometers, of which 98 percent is covered by continental ice sheet.

Global concerns over climate change have increased over the past decade as mounting evidence of significant warming trends have been documented, and scientific research has been focused on evaluating the effects of these trends. Observed changes in sea ice extent provide important data for the study of these trends. The presence of sea ice in the Antarctic regulates heat exchange, moisture, and salinity in the southern oceans (NSIDC, 2005). By insulating warmer ocean water from the cold polar atmosphere, the presence of sea ice affects evaporation rates, cloud formation and precipitation. In the context of global warming from greenhouse gas accumulations, there are currently two opposing views regarding changes in sea ice as the ocean surface temperature warms (Xie,2004). The first view is that sea ice cover will decrease (at peak season) as a result of the increased ocean temperature. The second view is that the sea ice cover will increase as a result of increased snowfall over the sea ice and lower overall salinity in the surface ocean layer from fresh meltwater influx.

Researchers have utilized satellite measurements from the Special Sensor Microwave/Imager (SSM/I) and Scanning Multichannel Microwave Radiometer (SMMR) to study changes in Antarctic sea ice (Cavalieri, et al., 2003). These studies have indicated that the extent of Antarctic sea ice decreased in the early to mid 1970's, however has shown trends of general increase from the late 1970's to 1998. Although variability was large depending upon the areas investigated, their results generally indicated that the greatest increases occurred in the Pacific Ocean, Ross and Weddell Seas. Decreases in sea ice extent were noted in the Indian Ocean and Amundsen Sea. Similar increases from 1979 to 2002 were reported by Liu, et al. (2004) with greatest increases in the central Pacific Ocean.



STUDY AREA AND DATA USED

For this study, data was obtained from the National Snow and Ice Data Center (NSIDC) using the Earth Observing System (EOS) Data Gateway. Data from the Advanced Microwave Scanning Radiometer- Earth Observing System (AMSR-E) instrument aboard the NASA Aqua satellite provides passive microwave measurements of land, ocean, and atmospheric parameters for the investigation of water and energy cycles. The study area encompassed the southern hemisphere of the earth in the polar latitudes of Antarctica. Data sets for the Antarctic region available from the AMSR-E instrument were obtained within the following bounds:

Latitude (degrees)	Longitude (degrees)
39.23	317.76
39.23	42.24
-41.45	225.00
-41.45	135.00

The data product [AMSR-E/Aqua Daily L3 12.5 km Tb, Sea Ice Conc., & Snow Depth Polar Grids] obtained from the NSIDC (Cavalieri and Comiso, 2004) is updated daily and is provided in digital HDF format. The AMSR-E instrument provides passive microwave data including horizontally and vertically polarized brightness temperature (Tb) from 6.9, 10.7, 18.7, 23.8, 36.5, and 89 gigahertz (GHz) frequencies. The spatial resolution of the data (pixel size) is 12.5 km by 12.5 km.

The snow depth data is provided in centimeters (cm) by NSIDC as a Level 3 data product and has been pre-processed as described in their literature. The SD algorithm (Markus and Cavalieri, 1998) first uses the AMSR-E Level 2 brightness temperature [AMSR-E/Aqua L2A Global Swath Spatially-Resampled Brightness Temperatures (Tb)] to correct for sea ice concentrations. The brightness temperatures are corrected as follows:

$$T_B = T_{Bi}\,C + T_{Bw}\,(1-C)$$

Where: $T_{Bi} = T_B$ of sea ice
T_{Bw} = mean T_B of open water (constant)
C = sea ice concentration computed from the NT2 algorithm

The snow depth (SD) is determined using the brightness temperature of sea ice (T_{Bi}) for vertically polarized 37 GHz and 19 GHz frequencies as follows:

$$SD = -2.34 - 771(T_{Bi\ 37V} - T_{Bi\ 19V}) / (T_{Bi\ 37V} + T_{Bi\ 19V})$$

The Level 3 data product is computed as a running average of SD over the past 5 days (preceding the reported date of the file).

Over 200 images were obtained for calendar years 2004 and 2005. One-month intervals were selected based on the austral seasons. The month intervals were selected as follows:

- January (Summer)
- April (Fall)
- July (Winter)
- October (Spring)

METHODS

The objective of this study was to examine the temporal changes (time-series) on a seasonal and interannual scale of the snow coverage and snow depth on Antarctic sea ice. Daily images were imported directly to ENVI software and opened as an external HDF file. The daily files were compiled into monthly composite image files and saved in ENVI standard format. Eight (8) image files were generated representing the seasonal changes over the 2-year interval of study. Because the HDF data were not converted, geo-referencing information was not retained.

Using the ENVI software, Regions of Interest (ROIs) were defined using threshold criteria to remove background information peripheral to this study. The following codes apply to the data:

- 0 to 109 = snow depth over sea ice (cm)
- 110 = missing data
- 120 = continental land
- 130 = ocean

All pixels below 110 were screened out of the ROIs, yielding only the area of snow cover present over sea ice. The statistics for snow depth (minimum, maximum, mean, and standard deviation) were computed for each day of the month for the ROI. These statistics were imported to an Excel spreadsheet for further analysis.

Based on the computed statistics from each day of the image, the monthly grand mean was determined. To determine minimum and maximum threshold values, the 90% confidence interval (2 standard deviations above and below the mean value) were computed for each daily mean value. Since data sets were not normally distributed, the minimum threshold value determined in this manner was often negative. Since a negative snow depth is not possible, the minimum threshold was set at 2 centimeters. The maximum threshold value was determined based on the 90% confidence level using the monthly grand mean.

In this manner, threshold ROIs were again used to examine areas of maximum and minimum snow depth on the sea ice over time. Each monthly composite image was screened for these thresholds at weekly intervals (4 days per month). The results of these analyses were plotted using Excel software.

DISCUSSION AND RESULTS

The following results derived from the analysis of data during this study are presented below. The minimum area of snow cover over sea ice occurs in January (austral Summer) and ranged from 2.9 million square kilometers (km^2) in 2005 to 3.7 million km^2 in 2004. The snow area in 2004 was generally greater than in 2005 during this period. The maximum area of snow cover over sea ice occurs in October (austral Spring) and ranged from 18.3 million km^2 in 2004 to 18.7 million km^2 in 2005 and was generally consistent during this time interval.
Overall, the snow area was greater in 2004 than in 2005, as shown in Figure 1.

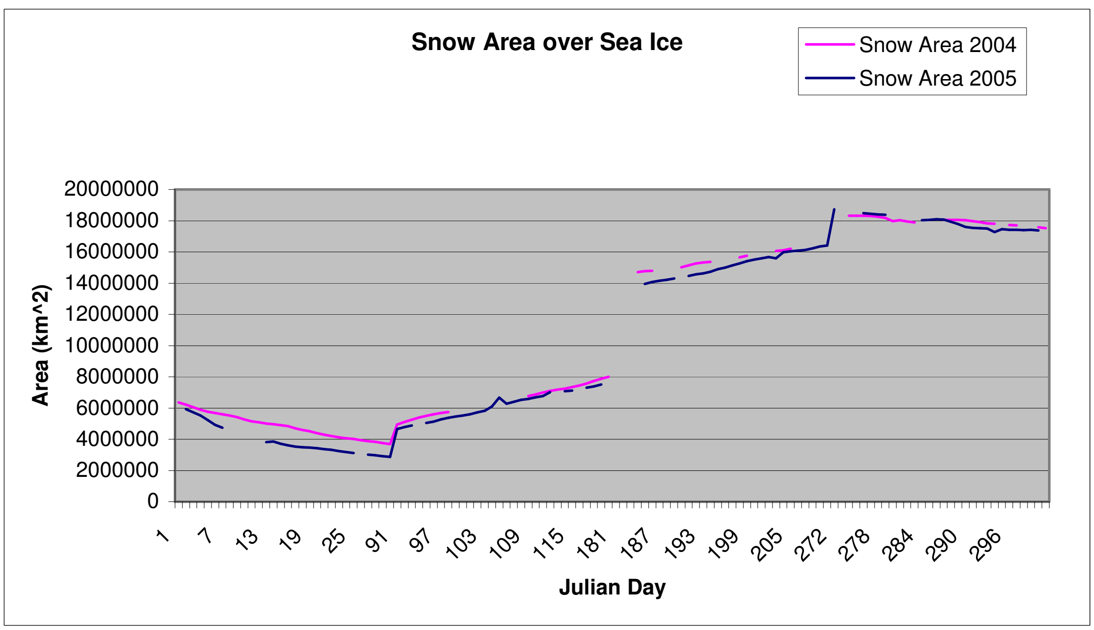


Figure 1

The mean snow depth and maximum snow depth as a function of time is shown in Figure 2. In general, the mean snow depth is relatively consistent between 2004 and 2005, however the peak timing is offset in January (austral Summer) and the mean value is greater at this peak. The maximum snow depth is also greater in 2005 during the January interval. This implies that the area of sea ice is less in 2005 and allows greater evaporation of moisture from the ocean, resulting in more snow precipitation. During the austral Spring (October), the overall area of snow cover on sea ice increased slightly in 2005 and the maximum values of snow depth also increased, however, these effects appear to be localized as the mean values of snow depth did not increase significantly.

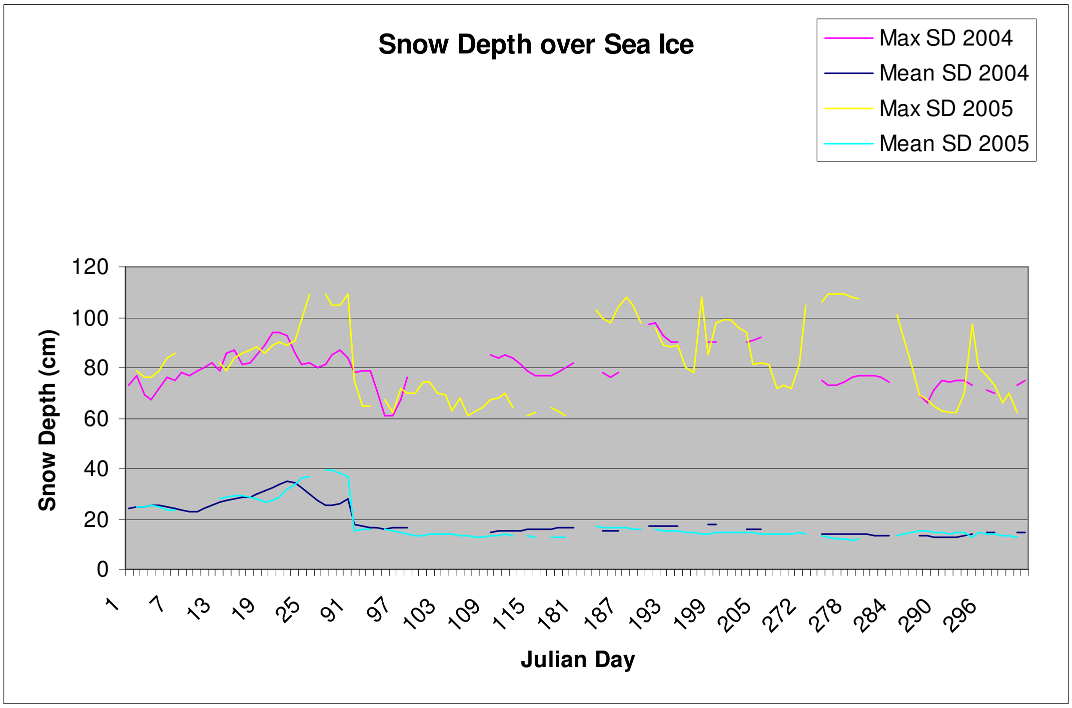


Figure 2

To further compare snow depth data, the total snow area was plotted versus the mean snow depth as shown in Figure 3. This graph illustrates that the austral Summer time shows the least amount of snow area coverage, but has the greatest mean snow depth. The austral Spring shows the greatest snow area coverage with the least snow depth. Based on these data, it appears that Antarctica has a wet season (Summer) and the remainder of the year remains relatively dry.

These data support the hypothesis that the extensive sea ice coverage during the Winter and Spring months provides and insulating effect, reducing evaporation of ocean water and subsequent precipitation (as snow). In regard to global warming considerations, the reduced sea ice area coverage shown in 2005 also corresponds with greater mean snow depth values of 2005 (over those of 2004). In 2004, the mean snow depths in Winter are slightly greater, as is the area of snow coverage over sea ice.

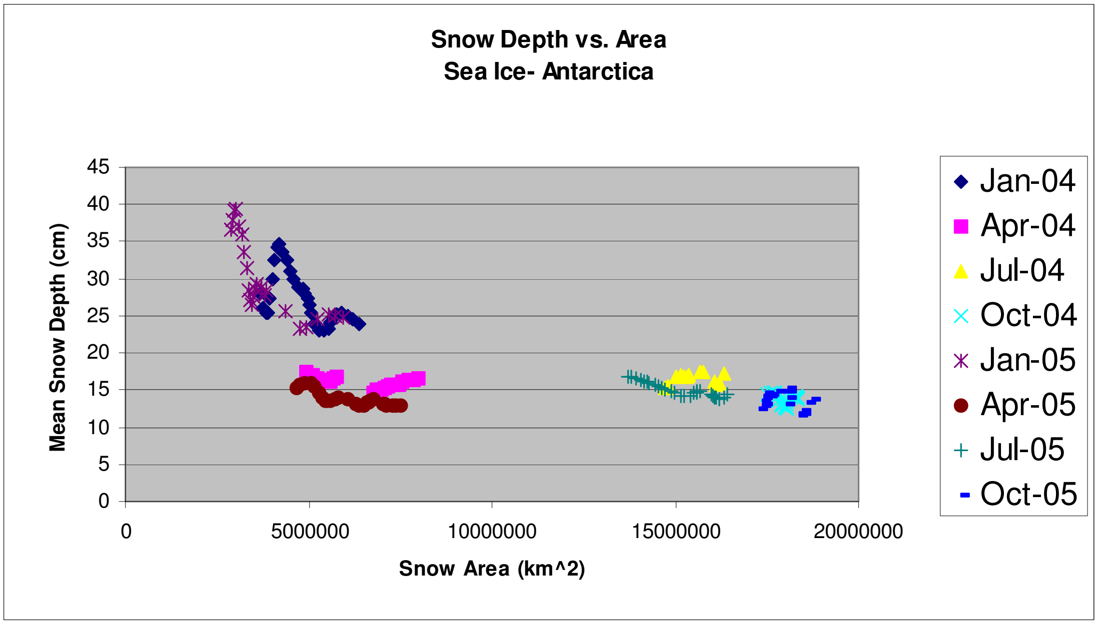


Figure 3

Using the threshold Regions of Interest (ROIs) for minima and maxima (based on the monthly grand mean), the images were evaluated for changes in snow area coverage in weekly intervals (4 weeks per month). An example of the threshold ROI produced for a single day is shown in Figure 4 below. In general, maximum areas tended to exist in the central portions of the ice sheet and minimum areas were present along the edges of the ice sheet.

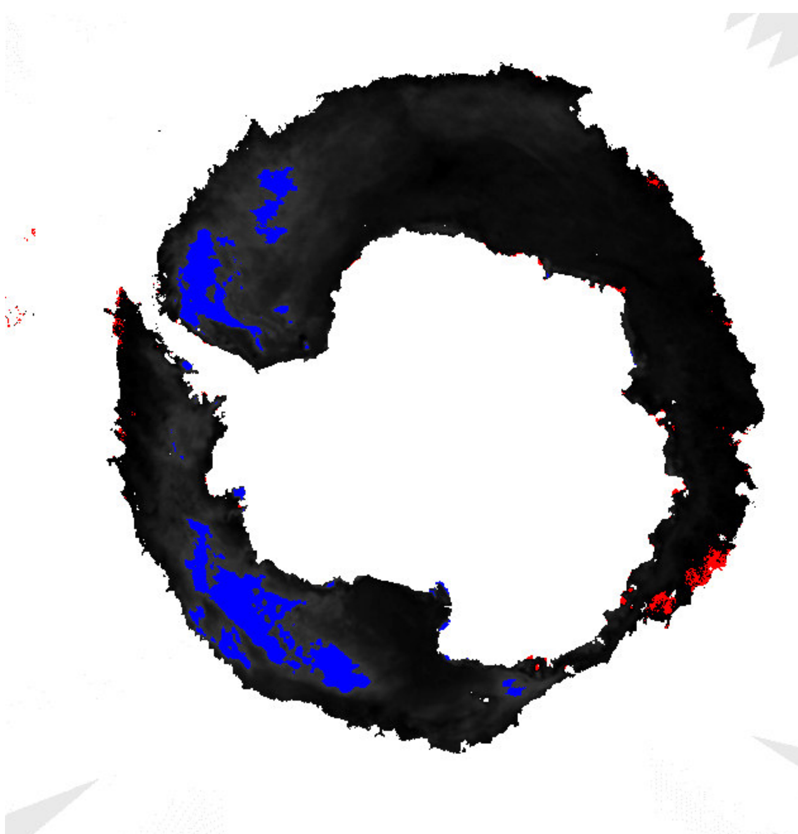


Figure 4

October 1, 2004
Blue = Maximum Area
Red = Minimum Area

Because of seasonal variations in the total area of snow cover on the sea ice, the maximum area and minimum area computed using the ROIs were normalized based on the total area and reported as the Area Ratio. Figure 5 shows the Minimum area and Maximum area for each year (as Area Ratio) plotted against time.

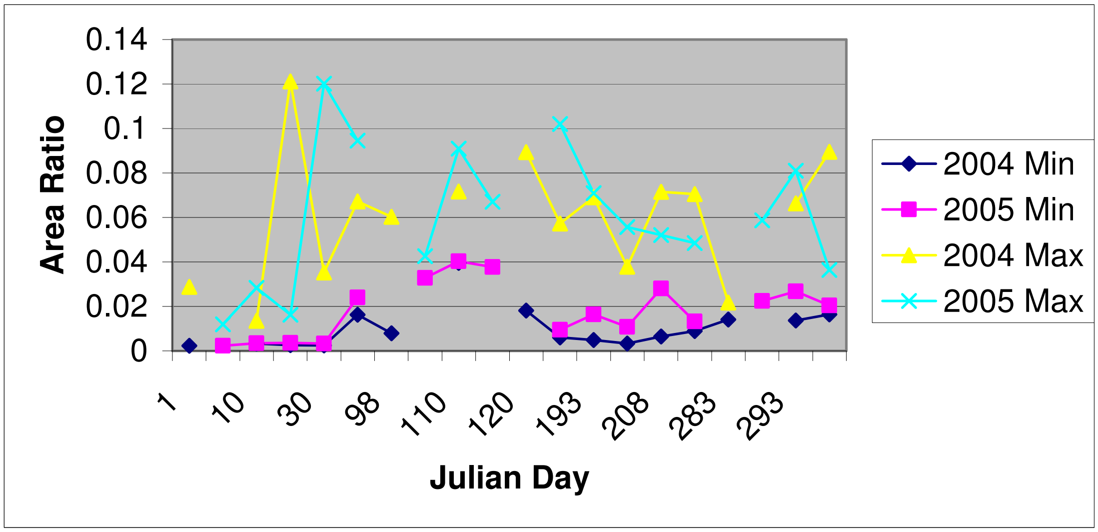


Figure 5

The purpose of Figure 5 is to examine the relationship between the relative maximum and minimum snow areas (areas with snow depth greater than 2 standard deviations above the grand mean or areas with less than 2 cm) with temporal variation inter-seasonally and inter-annually. The maximum area results appear to be inconclusive with no clear trends indicated. However, the minimum area data indicate that the greatest relative minimum areas tend occur in the Fall. This result was consistent between 2004 and 2005. This means that a relatively larger area has less snow depth over sea ice in the Fall season.

CONCLUSIONS

The analysis of AMSR-E/Aqua Daily L3 12.5 km Tb, Sea Ice Conc., & Snow Depth Polar Grids data product from the NSIDC for four monthly and seasonally different time intervals during 2004 and 2005 allowed comparison of snow depth and area coverage over sea ice in Antarctica. The results of the study indicated that snow over sea ice has the lowest area coverage in January (Summer) with approximately 3 million square kilometers and the greatest area coverage in October (Spring) with approximately 18 million square kilometers. There is generally a decrease in total area between Summer of 2004 and 2005. There is a no significant change in total area between Spring of 2004 and 2005.

Mean snow depth was consistently greater in the Summer month. The mean and maximum snow depths were greater in January 2005 and occurred later in the month as compared to 2004. A comparison of mean snow depth to the area of snow coverage shows a clear trend indicating a wet season in Summer months and a relatively dry period throughout the remainder of the year. This information corroborates the hypothesis that sea ice areal extent affects the local precipitation patterns. As the least area of sea ice is present in the Summer months, more near surface ocean water is exposed to evaporation, resulting in greater snow precipitation (wet season). The trends observed between 2004 and 2005 indicate that sea ice area has decreased in the Summer months and snow precipitation has increased, thus supporting the occurrence of this mechanism.

However, in the Winter and Spring months, the sea ice extent and mean snow depth did not appear to vary significantly between years. The increasing ocean temperatures in the Southern Oceans resulting from global warming effects are likely to continue the trend of reducing sea ice extent during Summer months and increasing snow precipitation. A longer-term study is needed to establish the trends and mechanisms involved these precipitation patterns. Additional investigation related to sea ice surface temperatures, local precipitation data, and cyclical weather trends, such as the Antarctic Oscillation (AAO) and El Nino/Southern Oscillation (ENSO) must be studied to better understand the long term effects of global warming on Antarctica.

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