West Antarctic Ice Sheet Firn Temperature Record Continuity and Seasonal Trends: Implications for Determining Emissivity Trends from SSM/I Brightness Temperatures

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Abstract – Firn is compacted, near-surface snow persisting longer than one season but not yet compressed into glacial ice. Knowledge of firn surface temperature (**T_S**) trends across the Antarctic ice sheet is useful for documenting and quantifying change and providing a temporal and spatial context for research during the Antarctic International Polar Year (IPY). Automatic Weather Stations (AWS) provide episodic near-surface temperature (**$T_{AWS} \approx T_S$**) trends at a limited number of sites on the Antarctic continent while satellite passive microwave radiometers aboard the Defense Meteorology Satellite Program (DMSP) Special Sensor Microwave Imager (SSM/I) obtain a nearly continuous daily record of surface brightness temperature (**T_B**) across the entire continent. To a good approximation, **T_B** is equal to the product of the surface emissivity (**ε**) with its actual temperature, **T_{AWS}**.

The ratio of spatially and temporally coincident **T_B** and **T_{AWS}** yields an estimate of **ε** at a specific time and place and can be used to extrapolate **T_S** trends across temporal and spatial gaps in the limited AWS record. The spatial and temporal variability of firn emissivity is not well understood but known to be much less variable than daily **T_S**. Tabulating continuous daily ratios of **T_B/T_{AWS}** yields a firn **ε** trend from which **T_S** data gaps can be filled from **T_B** data or vice versa.

The first step in calculating emissivity trends from satellite and in-situ measurements was to compile a record of **T_{AWS}** across the region of interest. The 2006-7 Antarctic Temperature Mapping team compiled extensive records of **T_{AWS}** from selected stations on the West Antarctic Ice Sheet (WAIS) bordering an interior region without AWS coverage. Daily average **T_{AWS}** records for the AWS sites were obtained from the AWS Project data archive at the University of Wisconsin's Space Science and Engineering Center (SSEC). The stations whose temperature records are included in this compilation are: Brianna (1994-1997), Byrd (1981-99), Elizabeth (1996-99), Erin (1996-99), Patrick (1986-91), Ski Hi (1994-98), Swithenbank (1998-99), and Theresa (1994-99). The AWS temperature data itself constitutes an important record of the WAIS climate since 1980, and is worthy of closer examination before addressing the project's second phase: tabulating SSM/I **T_B** observations and calculating associated emissivity trends using **T_{AWS}** values. For each AWS, a seasonal surface temperature average was determined and compared with those derived for the opposite season and with each other. In addition, for the sites with longer operating records; data from the first half of its operational life was compared with data recorded during its second half. These same trends were used to deduce firn emissivity. As a preliminary step to this next activity**,** **ε** trends at Ski Hi AWS site were derived from archived **T_{AWS}** data coincident daily **T_B** observations. Daily SSM/I values of **T_B** for the Ski Hi site were obtained from Dr. Chris Shuman at NASA Goddard Space Flight Center. Future work will use SSM/I **T_B** data to establish continuous emissivity and **T_S** trends at other AWS and between spatial and temporal data gaps. This work is thus a preliminary step to deriving surface temperature trends across the entire Antarctic ice sheet over the last 28 years. –

Introduction

For several years the threat of global warming has been a major concern among the scientific community. It has been the focus of news reports and documentaries, a major point in most election campaigns and speeches. There is little concrete proof of the existence of global warming, which is a point that is often used to discredit theories backing its existence. By monitoring the rate at which CO_2 is released from the firn we can get an idea of the speed at which the ice is melting at a given portion in the year. Through the analysis of this data we can track the emissivity average which given the direction of the trend may suggest a global warming trend, a static state cyclically fluctuating or a steadily cooling trend, any of which could have a direct effect on the debate as a whole.

Meteorological sciences has perfected the mapping and prediction of weather and temperature trends for populated areas but little focus has been put on the extrapolations of Antarctic weather trends. The technology for gathering the necessary information has been in place for several years. However the AWS stations are remote spanning from the coastal region of Antarctica to the South Pole alone several lines of longitude.

Background

The Center for Excellence in Remote Sensing Education and Research's (CERSER) Antarctic temperature mapping team has been in operation for the last 18 months. The original team composed of our current mentor Dr. Malcolm LeCompte, Jerome Mitchell a current team member and graduating senior, TreAsia Fields, also a current team member, and a past participant of the ONR research program and Demitrius Rorie, a graduate of ECSU and former ONR researcher, it was the goal of the original team to project the emissivity trend for the temperature information recorded by the Ski-high and Sky-Blue dynasty of weather stations.

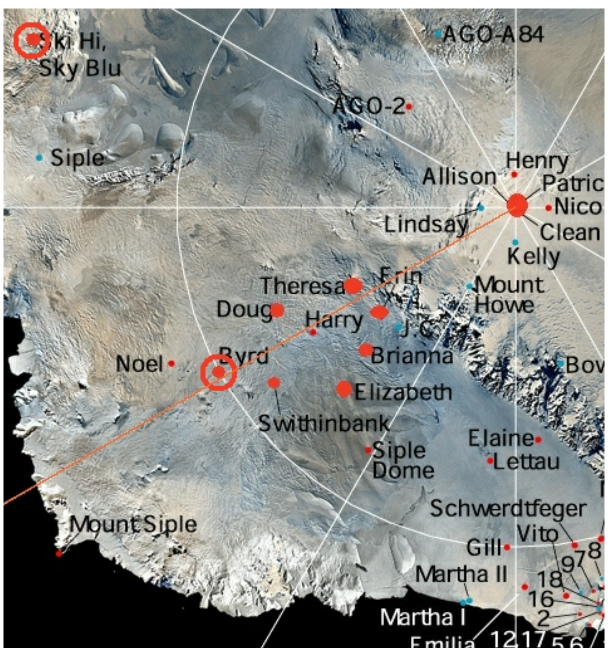
Ski-high and sky blue were originally chosen for their completeness in record and the availability of SSM/I microwave reading for that location. It was the job of this first team to construct a protocol for the manipulation of the raw data sets. The team encountered three difficulties in the manipulation of the data. The first was the overall scope of the data. Each auto mated weather station (AWS), records the temperature constantly reporting it in the form of three hour averages delivering eight averaged values per day. The data had to first be inputed by hand into an excel spreadsheet and then manipulated to produce a daily average and a yearly temperature trend. The second problem faced was the incompleteness of the data. Gaps of missing data spanning weeks, sometimes months of information were present through out the data. The remedy of this problem was found in the text of the team's primary reference Shuman et al, the paper presented formula relating the Antarctic surface temperature to the location SSM/I Brightness temperatures. Thus through the use of these formulas and the SSM/I temperature gaps could be filled in an easy, if tedious manner. In this way the first polar Ice team was able to process the information for ski high and sky blue spanning 1994-95 ant arctic summer season.

The second part of the project was preformed over the summer of 2006, by temporary members to the team Kaiem Frink and Lee Smalls. This phase of the project attempted to carry on the data entry and manipulation of the ski-high information expanding the range of data to cover winter portion of 94 and the end of the 93-94 summer. By the end of the 2006 summer session a complete record of 1994 had been compiled by the polar science team.

This year's team, which is composed of mentor Dr. LeCompte, sophomores TreAsia Fields and Jamika Baltrop, junior Brian Campbell, and graduating senior Jerome Mitchell, began their session with an in-depth review of the past teams methodology and the references used, by the previous teams, to construct the manipulation procedures. Using this knowledge alongside the updated excel programs we developed a stream line process to input the data cutting the entry time considerably. Also helping us in the streamlining of the manipulation procedure was a product of research being done at the University of Kansas. In 2006 Researchers at Kansas published the daily averages for several of the automated weather stations. This effectively removed our need to import and average the 3 hour values the original team based there procedure around. The streamlining of the manipulation process allowed us to focus on some of the more long term goals of the project.

Study Area

One of the long term goals of the project is to use the manipulated data to normalize or project the temperature for the entirety of the Antarctic continent. All data that was selected for this phase of the study was done so based of the distribution of the weather stations. Station were chosen from among those that share a similar longitude but were located over a range of latitudes both to form one boundary to the area and to set up an data set for the evaluation on latitudinal variation of temperature. All points on the same longitude receive roughly the same amount of radiation from the sun but within the polar regions differences in latitude can have drastic effects on the degree of intensity and duration received at a given point



The area chosen to be the focus of this study (fig1) is an area of low relief located in the western portion of this map of Antarctic. The study area for this phase of the project is an area in the western Antarctic which stretches from the Ross Ice Shelf to a ridge of stations located along the 240^{o} line of longitude.

Our record of arctic temperatures begins as early as 1980 with the placement of the AWS known as Byrd and continues until 1999. There are two stations that will play vital structural rolls within our study those stations known as Byrd and the ski-high, sky-blue dynasty. The ski-high, sky-blue dynasty, which was the focus of the phase one and two of the project, was the only station for which the SSM/I data was available.

Methodology

The revised procedure that was established at the beginning of phase three was as follows:

1. The download of information; beginning from the original AWS text files we isolated the desired daily temperature data, recorded in degrees Celsius on to an excel spreadsheet labeled with the exact location in longitude and latitude, name and elevation of the subject AWS site. The daily values were arranged into a single column, and separated by into one year segments.
2. The temperatures from each date were converted to units Kelvin from the original Celsius records using the equation C+273.15. These temps would be used for the rest of the manipulation.
3. A trend chart was developed for each year within the data set from the original page.
4. The data was then placed into the time frame of a signal year and trends were developed from the chronological groups in blocks of five to seven years.
5. Averages were taken for each date over the extent of the recorded history and a trend was developed to show the average trend over the record span. This was also

done on a seasonal basis isolating the Antarctic summer and winter. Further more, creating an average trend for each.
6. With the averages complete we could then begin to develop the emissivity trends using the SSM/I brightness temperatures, according to the guideline outlined in Shuman et al we will use the 30hz frequency because of it close relation to the surface ice temperature. The average and the brightness temperature were found to relate to the emissivity by the equation:

$$E=T_a/T_b$$

   Where T_a is the average temperatures and T_b is the value derived from the SSM/I microwave images.
7. After all of the temperature trends are completed we will use the manipulated data from the stations in accordance with common meteorological formulas for elevation and latitude to project the resulting temperatures to an area containing other AWS station to determine how closely the projected data matches that recorded on site.
8. Once the projection has been tested for error it can then be used to project surface temperatures to the open portions of the Antarctic polar region

Results

1. As of the end of this project session we have completed the input and manipulation of the data sets for eight of the AWS.
2. Of these eight stations we have created graphs for yearly and seasonal trends for the Byrd, Erin, Elizabeth, Swithenbank, Patrick, Theresa and both ski-high and sky-blue.
3. It was the goal of this study to continue past this developing emissivity trends for the subject station. However due to the lack of permission to access the SSM/I brightness temperature for the majority of the station this has only been done for the AWS known as Ski-hi and Sky-blue.

Future Research

Throughout this research project a lot was learned and contributed to the actual layout of research. With the data we have extrapolated and analyzed, the upcoming research team will be close to the point at which the final goal, the projection of temperatures to the study area, will be possible. The continuation of this project would be to use the SSM/I data along with the AWS temperatures to create ratios to construct the emissivity trends and complete the missing data points within the record. The future team will have to choose what time frame to begin the projection, since the projection maps will have to be produced on a daily or weekly basis. However, once a template for this process has been established the time frame for creating the projection maps should be substantially shortened.

After which, the team should be able to calculate the surrounding temperatures in the study area using the temperatures that they have for the specific areas; that way a good approximation of the whole Antarctic ice sheet temperatures will be known. The data calculated will also produce valuable data that scientist and researchers, of this particular area, will be able to use in future studies.

Conclusions

In our project we were limited both by time and by the availability of the data used for the project. However even with the limitations that the information imposed we were able to come to a few interesting conclusions. First, the procedures for the input and manipulation of the data sets developed by this team have significantly streamlined the process involved with the data analysis stage of the project. In the first two stages of the project the scope of the data and the software used for import have limited us to the range of information that could be entered by hand. In these stages we were only able to complete the data set for ski-high through the year 1994. Using the updated version of windows excel we were able to enter entire fields of data at one time. And a template was formed using the initial data provided by the phase 1 and 2 teams making the entry of the necessary conversions and summation more reliable and easier to implement.

Secondly, through the study of the data sets over a wider range of stations we have been able to recognize certain trends within the recorded data, such as one trend missing data within the sets. For the majority of the data the missing values appeared at first to be random and the majority of the missing data was in fact anomalous, with out pattern, but in some instances it was found the discrepancies within the data occur within a given time frame. Ex. for the AWS station, known as Erin, a gap in information appeared in the Antarctic winter starting in July of every year and lasting between one and four months on average. This gave the first indication of that the missing data may be tied to environmental or climatologically conditions.

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