Antarctic Firn Annual Emissivity Trends at the Ski Hi Automatic Weather Station from in-situ and 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 ($\mathbf{T_S}$) trends across the Antarctic ice sheet is useful for documenting and quantifying change and providing a temporal and spatial context for measurements made during the Antarctic International Polar Year (IPY): 2007-2009. Automatic Weather Stations (AWS) provide intermittent daily near-surface temperatures ($\mathbf{T_{AWS}} \approx \mathbf{T_S}$) at a limited number of sites on the Antarctic ice sheet, 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 ($\mathbf{T_B}$) across the entire continent. The Rayleigh-Jeans Approximation suggests that, $\mathbf{T_B}$ should be very nearly equal to the product of the surface emissivity ($\boldsymbol{\varepsilon}$) with the actual surface temperature, ($\mathbf{T_S}$) although the actual magnitude of $\boldsymbol{\varepsilon}$ is uncertain.

The ratio of spatially and temporally coincident $\mathbf{T_B}$ and $\mathbf{T_{AWS}}$ yields an estimate of $\boldsymbol{\varepsilon}$ at a specific time and place and can be used to extrapolate $\mathbf{T_S}$ 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 $\mathbf{T_S}$. Tabulating continuous daily ratios of $\mathbf{T_B/T_{AWS}}$ yields an approximate firn $\boldsymbol{\varepsilon}$ trend from which $\mathbf{T_S}$ data gaps can be filled from $\mathbf{T_B}$ data or vice versa. A least squares technique was used to derive an analytic function providing $\boldsymbol{\varepsilon}$ variation with the Julian date.

The ECSU summer 2007 URE Antarctic Temperature Mapping Team created an analytic model of annual emissivity ($\boldsymbol{\varepsilon}$) at the Ski Hi AWS from 1994-1998 using previously compiled satellite and in-situ AWS temperature records and satellite microwave brightness temperatures. (AWS temperatures were obtained from the AWS Project data archive at the University of Wisconsin's Space Science and Engineering Center (SSEC). Values of $\mathbf{T_B}$ (1994-1998) for the Ski Hi site were obtained from Dr. Chris Schuman at NASA Goddard Space Flight Center.) The 2007 URE work was thus a necessary intermediate step towards deriving surface temperature trends across the entire Antarctic ice sheet over the last 28 years.

INTRODUCTION

The goal of this research project was to create an analytic model of annual emissivity ($\boldsymbol{\varepsilon}$) at the Ski Hi AWS from 1994-1998 using previously compiled satellite and in-situ AWS temperature records and satellite microwave brightness temperatures from instruments like Special Sensor Microwave/Imager (SSM/I). To complete creating a formula for calculating emissivity trends at the Ski Hi AWS, we had to rely on the readings from an automatic weather station. An *automatic weather station* (AWS) is an automated version of the traditional weather station, either to save human labour or to enable measurements from remote areas. The system may report in near real time via the Argos System and the Global telecommunications system, or save the data for later recovery. Most automatic weather stations contain thermometers for measuring temperature, anemometers for measuring wind, hygrometers for measuring humidity, and barometers for measuring pressure. Some of them even have ceilometers for measuring cloud height, rain gauges for measuring rainfall, and present weather sensors and/or visibility sensors. Unlike manual weather stations, automatic weather stations cannot report the *class and amount of* clouds. Also the rainfall measurements are a bit problematic, especially for snow, as the gauge must empty itself between observations. For present weather, all phenomena which do not touch the sensor (say fog patches) remain unobserved. The first AWS's were often placed where electricity and communication lines were available. Nowadays, the solar panel, wind-generator and cellphone technology have made wireless AWS's easier to place.

The configuration of an AWS may vary due to the purpose of the system but typically consists of: a weather-proof enclosure containing the data logger, rechargeable battery and telemetry (optional), meteorological sensors, solar panel or wind generator, and mast. Enclosures used with AWS are typically weather proof fiberglass, ABS or stainless steel. The ABS plastic enclosures are light weight and inexpensive. They are commonly used in mass-produced AWS's but are less secure and rugged than the 2 alternatives. The fiberglass enclosure is used when chemical resistivity including corrosion from water is required. These enclosures are middle of the range and are subject to fiberglass deterioration. The stainless steel enclosures are the optimum choice and typically come in either 316 s/s or 304 s/s. They are rugged, vandal proof and corrosion/chemically resistant. These enclosures are also expensive and can typically cost more than double the same sized fiberglass enclosure. The main power source for an AWS is a solar panel connected in parallel with a solar regulator and re-chargeable battery. As a rule of thumb, solar output is at its optimum for only 5 hours each day. As such, mounting angle and position are vital. In the Northern Hemisphere the solar panel would be mounted facing South vice versa for the Southern Hemisphere. The angle of the panel differs from place to place but it should never be mounted with an angle of 5 deg as dust build up will dramatically decrease the panels output.

A number of sized masts are used with AWS: 2M(6'),3M(10'),10M(33'),30M(100'). Other sizes are available on request but typically these sizes have been used as standards for differing applications. The 2M(6') mast is used for the measurement of parameters that effect a human subject. The mast height is referenced to head height. The 3M(10') mast is used for the measurement of parameters that effect crops (such as wheat, sugar cane etc). The mast height is referenced to crop top. The 10M(33') mast is used for the measurement of parameters without interference from objects such as trees, buildings or other obstructions. Typically the most important weather parameter measured at this height is wind speed and direction. The 30M(100') mast is used for the measurement of parameters over stratified distances for the purposes of data modelling. A common application is to take measurements of wind, humidity and temperature at 30M(100') at 10M(33') and at 2M(6'). Other sensors are mounted around the 2M or lower height. The Special Sensor Microwave/Imager (SSM/I) is a seven channel, four frequency, linearly-polarized, passive microwave radiometric system which measures atmospheric, ocean, and terrain microwave brightness temperatures at 19.35, 22.24, 37.00, and 85.80. NOAA's National Climatic Data Center (NCDC) is undertaking the task of recovering SSM/I data starting from the first successful launch of the F-8 platform in 1987. The first SSMIS sensor is onboard the DMSP F-16 platform that was launched on October 18, 2003. The SSMIS sensor is a passive conically scanning microwave radiometer that combines and extends the current imaging and sounding capabilities of three previously separate DMSP microwave sensors: the SSM/T-1 temperature sounder, the SSMI/T- 2 moisture sounder, and the SSM/I. The SSMIS instrument measures microwave energy at 24 discrete frequencies from 19 to 183 GHz with a swath width of 1700 km. All of these components help to make AWS that were used at the Ski Hi site in Antarctica.

Complications and Failures

The Ski Hi AWS orginally started collecting data in 1994. In 1995, problems started to arise. This year, a horrendous snow storm occurred on the continent of Antartica with dangerously strong winds and infinite amount of snowfall. During that storm, the satellite was completely destroyed, not being able to collect any data from the near-surface snow like they were normally doing. Although the ground AWS was damaged, there was still the SSM/I microwave brightness temperature satellite taking temperature readings once a day as it orbit the earth. But starting in the month of October, the satellite stopped recording data. Scientist took this as satellite failure from the SSM/I but due to this failure, no data was recorded from either the Ski Hi AWS on the ground or the SSM/I satellite orbiting the earth. This left big gaps in the data reported back by the scientist as shown in Figure 1.

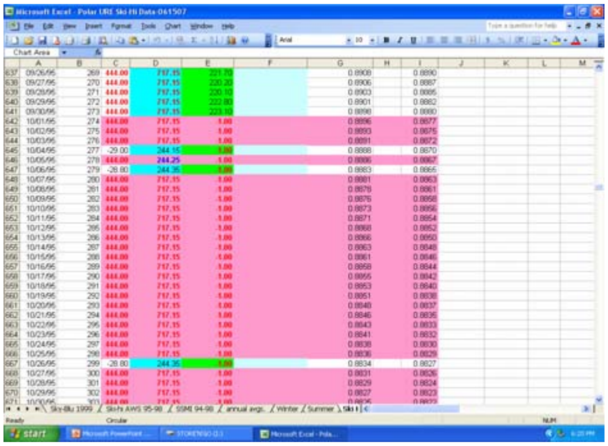

Figure 1: Excel Spreadsheet that displays the data recorded for the year 1995 at the Ski Hi

AWS. As shown, there were big gaps starting in October of this year that left scientist with no data, therefore no emissivity trend could be calculated

Both satellites were replaced by 1996 and data was continuously collected from 1996 to 1998. There were more days where the AWS satellite and in-situ and the SSM/I satellite did not record temperatures but not enough days to not provide accurate data.

Old Methods for Calculating Emissivity Trends

After the data was collected at Ski Hi AWS, it was provided to other scientist at NSIDC and CReSIS. The information was then put into an Microsoft Excel Spreadsheet and given to scientist to calculate the emissivity trends for the years data was recorded and possibly fill in gaps that were in the data from satellite failure. A polynomial formula was created using Microsoft Excel and was the following:

$(4.619155E\text{-}15)*X^6 - (5.75054E\text{-}12)*X^5 + (2.883465E\text{-}9)*X^4 - (7.337887E\text{-}7)*X^3 + (9.634711E\text{-}5)*X^2 - (5.779393E\text{-}3)*X + 1.008391$

In this equation, X is the variable for the equation in which you would put the Julian date. This is a very complex formula and would not provide the most accurate emissivity trends for the data because it was computer generated. But from this formula, a general emissivity model equation was created:

0.895+0.014*SIN(X*2.43*PI()/365-(0.65*PI()))

The variable for this equation is once again was X and represented the Julian date. Using this equation, they were able to create a graph for the year 1994 that is shown in Figure 2.

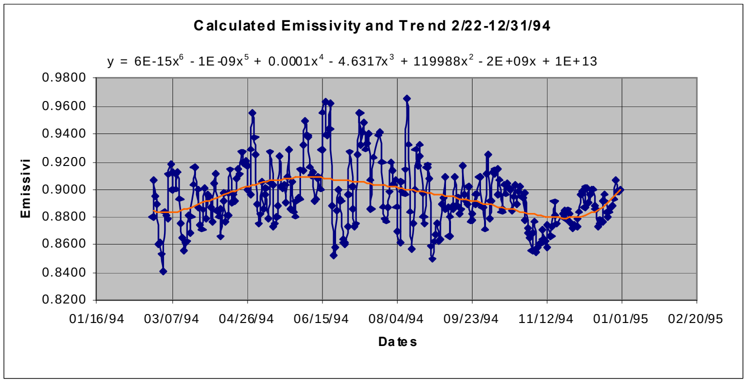

Figure 2: This graph was created from the general emissivity formula that was created. It displays the date on the x-axis against the calculated emissivity on the y-axis for the year 1994.

Although the formulas created were a great first step, scientist wanted a better formula for calculating emissivity trends so that if temperature gaps were filled in, the most accurate estimations could be recorded.

New Methods

Other scientist and undergraduate researchers tried to create new processes to get the most accurate emissivity trends and temperature readings for the data at Ski Hi AWS. But it was not until 2007 that this was done. In 2007, the Ski Hi AWS data was presented to our research team for the Undergraduate Research Experience in Ocean and Marine Science and Grid Programming (URE OMS/Grid). Under the guidance of Dr. Malcolm Lecompte, we were to observe the data from the Ski Hi AWS, find a way to create a formula that would provide the best emissivity trend for each year, and fill in the temperature gaps for the years the data was collected. To get the best emissivity trend, we needed to adjust the amplitude, frequency, phase change, and the off-set (y-intercept) of the original emissivity model to get the lowest squared fit, what we called Chi. Chi was created from this formula:

$$\text{Chi} = \frac{\text{Emissivity Model}}{\text{Emissivity Trend}}$$

For each year, the emissivity model was used and manipulated to find the lowest values of the amplitude, frequency, phase change, and the off-set. The values of each year were then averaged into one equation that would provide the best emissivity trends for each year and be able to accurately fill in the gaps for the days where satellite failure occurred and no temperature data was recorded.

Results

From the data we were given and the methods we used to calculate an emissivity data equation that would provide the best emissivity trend and fill in the temperature gaps, this formula was created:

0.899+0.04904*SIN(X*2.33*PI()/365-(0.61*PI()))

This equation was compared to equations that were also created from AWS in Antarctica, Cathy and Kenton. When compared, we were amazed at how astoundingly close the three equations were. From our equation we were able to create graphs for each year that are shown in Figures 3A, 3B, 3C, and 3D.

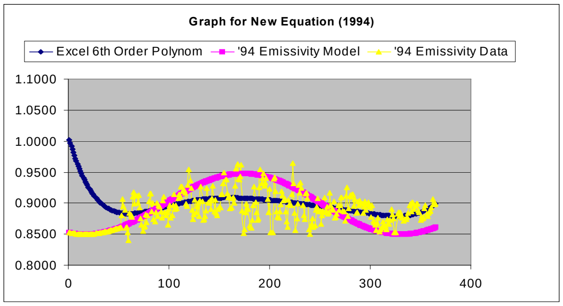

Figure 3A: Graph created from new emissivity data equation for the year 1994.

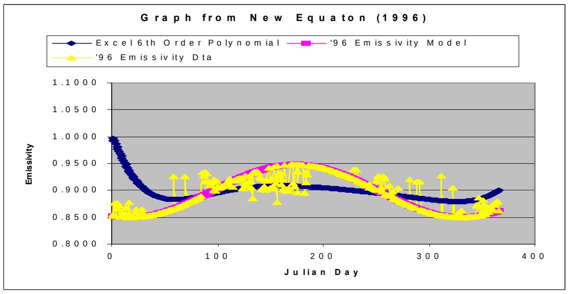

Figure 3B: Graph created from new emissivity data equation for the year 1996.

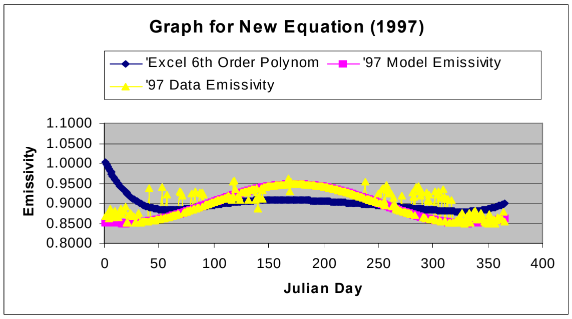

Figure 3C: Graph created from new emissivity data equation for the year 1997.

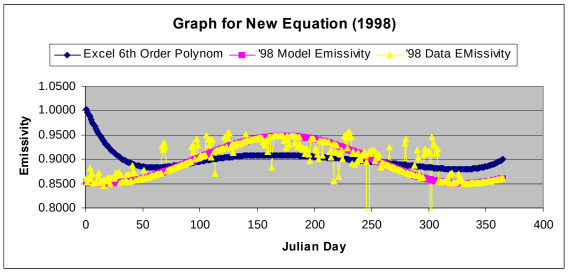

Figure 3D: Graph created from new emissivity data equation for the year 1998.

We were also able to fill in temperature gaps that were created due to satellite failure in various years. The data is shown in Figure 4.

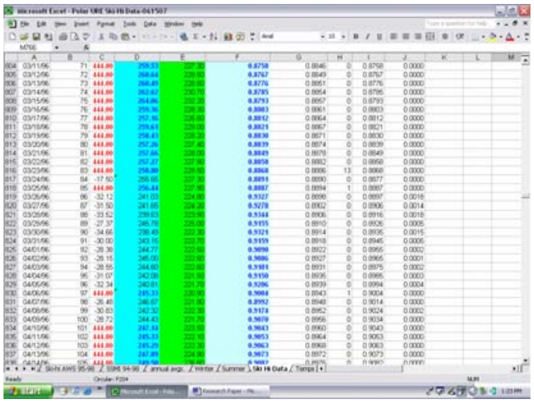

Figure 4: Example of how temperature data that was once empty from no temperature being recorded at the Ski Hi AWS is now filled in due to the new emissivity data equation.

One tedious but very important step was done for the data at the Ski Hi AWS. Although the emissivity trends and temperature gaps were filled in from our emissivity data equation, we still did not get a chance to go back and look at 1995. Because there was so much data missing from 1995, we were not able to use our equation to fill in the gaps.

Future Work

The continuation of this project would use the SSM/I - AWS temperature 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. Since only one weather station was used,, weather stations Noel and Theresa will need to be included to get the most accurate data. With this, Ski Hi **ε** trends will be compared with **ε** trends derived at selected stations on the West Antarctic Ice Sheet (WAIS) bordering an interior region without AWS coverage. The other AWS stations whose temperature records could provide the basis for calculating emissivity trends are: Brianna (1994-1997), Byrd (1981-99), Elizabeth (1996-99), Erin (1996-99), Patrick (1986-91), Swithenbank (1998-99), and Theresa (1994-99). Also, a computer program could be created that will automatically calculated an emissivity trend for each year that data at the AWS was collected annually.

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