KECK GEOLOGY CONSORTIUM
PROCEEDINGS OF THE TWENTY-THIRD ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

ISSN# 1528-7491

April 2010

Andrew P. de Wet
Editor & Keck Director
Franklin & Marshall College

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lanc. Pa, 17604

Lara Heister
Symposium Convenor
ExxonMobil Corp.

Keck Geology Consortium Member Institutions:

Amherst College, Beloit College, Carleton College, Colgate University, The College of Wooster, The Colorado College Franklin & Marshall College, Macalester College, Mt Holyoke College, Oberlin College, Pomona College, Smith College, Trinity University Union College, Washington & Lee University, Wesleyan University, Whitman College, Williams College

---

2009-2010 PROJECTS

SE ALASKA - EXHUMATION OF THE COAST MOUNTAINS BATHOLITH DURING THE GREENHOUSE TO ICEHOUSE TRANSITION IN SOUTHEAST ALASKA: A MULTIDISCIPLINARY STUDY OF THE PALEOGENE KOOTZNAHOO FM.

Faculty: Cameron Davidson (Carleton College), Karl Wirth (Macalester College), Tim White (Penn State University)

Students: Lenny Ancuta, Jordan Epstein, Nathan Evenson, Samantha Falcon, Alexander Gonzalez, Tiffany Henderson, Conor McNally, Julia Nave, Maria Princen

COLORADO – INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO.

Faculty: David Dethier (Williams) *Students: Elizabeth Dengler, Evan Riddle, James Trotta*

WISCONSIN - THE GEOLOGY AND ECOHYDROLOGY OF SPRINGS IN THE DRIFTLESS AREA OF SOUTHWEST WISCONSIN.

Faculty: Sue Swanson (Beloit) and Maureen Muldoon (UW-Oshkosh)

Students: Hannah Doherty, Elizabeth Forbes, Ashley Krutko, Mary Liang, Ethan Mamer, Miles Reed

OREGON - SOURCE TO SINK – WEATHERING OF VOLCANIC ROCKS AND THEIR INFLUENCE ON SOIL AND WATER CHEMISTRY IN CENTRAL OREGON.

Faculty: Holli Frey (Union) and Kathryn Szramek (Drake U.)

Students: Livia Capaldi, Matthew Harward, Matthew Kissane, Ashley Melendez, Julia Schwarz, Lauren Werckenthien

MONGOLIA - PALEOZOIC PALEOENVIRONMENTAL RECONSTRUCTION OF THE GOBI-ALTAI TERRANE, MONGOLIA.

Faculty: Connie Soja (Colgate), Paul Myrow (Colorado College), Jeff Over (SUNY-Geneseo), Chuluun Minjin (Mongolian University of Science and Technology)

Students: Uyanga Bold, Bilguun Dalaibaatar, Timothy Gibson, Badral Khurelbaatar, Madelyn Mette, Sara Oser, Adam Pellegrini, Jennifer Peteya, Munkh-Od Purevtseren, Nadine Reitman, Nicholas Sullivan, Zoe Vulgaropulos

KENAI - THE GEOMORPHOLOGY AND DATING OF HOLOCENE HIGH-WATER LEVELS ON THE KENAI PENINSULA, ALASKA

Faculty: Greg Wiles (The College of Wooster), Tom Lowell, (U. Cincinnati), Ed Berg (Kenai National Wildlife Refuge, Soldotna AK)

Students: Alena Giesche, Jessa Moser, Terry Workman

SVALBARD - HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC, SVALBARD, NORWAY.

Faculty: Al Werner (Mount Holyoke College), Steve Roof (Hampshire College), Mike Retelle (Bates College)

Students: Travis Brown, Chris Coleman, Franklin Dekker, Jacalyn Gorczynski, Alice Nelson, Alexander Nereson, David Vallencourt

UNALASKA - LATE CENOZOIC VOLCANISM IN THE ALEUTIAN ARC: EXAMINING THE PRE-HOLOCENE RECORD ON UNALASKA ISLAND, AK.

Faculty: Kirsten Nicolaysen (Whitman College) and Rick Hazlett (Pomona College)

Students: Adam Curry, Allison Goldberg, Lauren Idleman, Allan Lerner, Max Siegrist, Clare Tochilin

Funding Provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782) and ExxonMobil

Keck Geology Consortium: Projects 2009-2010
Short Contributions – SVALBARD

HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC, SVALBARD, NORWAY

Project Faculty: ***AL WERNER***: Mount Holyoke College
STEVE ROOF: Hampshire College
MIKE RETELLE: Bates College

DIRECTLY-CONTROLLED LICHEN GROWTH CURVES FOR WESTERN SPITSBERGEN, SVALBARD

TRAVIS BROWN: College of Wooster
Research Advisor: Greg Wiles

METEOROLOGICAL AND GLACIAL ABLATION CONTROLS ON ANNUAL SEDIMENT ACCUMULATION AT LINNÉVATNET: SVALBARD, NORWAY

CHRISTOPHER FISHER COLEMAN: Wesleyan University
Research Advisor: Suzanne O’Connell

LINNÉ GLACIER METEOROLOGICAL STUDY OF SURFACE ABLATION DURING THE 2006-2008 ABLATION SEASONS

FRANKLIN DEKKER: Franklin & Marshall College
Research Advisor: Christopher J. Williams

MODERN SEDIMENTATION PROCESSES IN A PROGLACIAL LAKE, LINNÉVATNET, SVALBARD, NORWAY

JACALYN GORCZYNSKI: Mount Holyoke College
Research Advisor: Al Werner

334 YEARS OF CLIMATE CHANGE RECONSTRUCTED FROM VARVED SEDIMENTS: LINNEVATNET, SVALBARD

ALICE NELSON: Williams College
Research Advisor: Mea Cook

SEDIMENT CHRONOLOGY DEFINED BY CESIUM-137 IN THE DEEP MAIN BASIN OF PROGLACIAL LINNÉVATNET, WESTERN SPITSBERGEN, SVALBARD

ALEXANDER NERESON: Macalester College
Research Advisor: Karl Wirth

ALKENONE-INFERRED TEMPERATURE RECONSTRUCTION FROM KONGRESSVATNET, SVALBARD

DAVID A. VAILLENCOURT: University of Massachusetts Amherst
Research Advisors: William J. D'Andrea and Steven T. Petsch

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lancaster Pa, 17603
Keckgeology.org

LINNÉ GLACIER METEOROLOGICAL STUDY OF SURFACE ABLATION DURING THE 2006-2008 ABLATION SEASONS

FRANKLIN DEKKER
Franklin & Marshall College
Research Advisor: Christopher J. Williams

INTRODUCTION

The magnitude of glacier ablation varies at daily and annual scales because of variations in meteorological factors. The weather dynamics that control ablation are unique to glaciers of a particular geographic region and even between glaciers within regions. Predicting the magnitude of ablation for a particular year has implications for water resource management, environmental reconstructions and glacial lake sediment budgets. Complicated energy balance equations are often used to model ablation (Hock 2005), however, simpler methods that utilize only air temperature measurements have been shown to predict ablation with accuracy comparable to energy balance equations (Hock 2005). Air temperature equations are successful because the latent and sensible heat flux parameters at the core of energy balance models are highly correlated to air temperature (Ohmura 2000, Hock 2005). Migala et al. (2006) used cumulative air temperature and cumulative surface lowering over one ablation season to develop an empirical equation that predicted ablation on Svalbard's Hans Glacier, located 110 km south of Linnébreen on Spitsbergen's west coast. The air temperature equation developed was able to predict ablation within 10% of direct measurements over a 15 year period.

This project attempts to conduct a similar study on Linné Glacier (i.e. Linnébreen). Linnébreen has a mass balance record back to 2003 when Jack Kohler of the Norwegian Polar Institute installed ablation stakes. In 2006, weather sensors and an acoustic surface lowering measurement device were installed on the glacier to collect weather and surface lowering data. A huge area of Svalbard is covered with glacier ice, but only 0.5% of that ice mass has had mass balance continually studied (Hagen et al. 1993). The meteorological and ablation record from Linnébreen is a valuable resource for climate science research that has yet to be fully evaluated. The goal of this project is to (1) determine how air temperature, incoming solar radiation, wind speed, and precipitation correlate with dialy ablation on Linnébreen, and (2) develop an empirical equation based on temperature parameters that can reliably forecast ablation. The over-arching long term goal is to infer past annual glacier mass balance from meteorological data extending back to 1912 A.D.

METHODS

Data Collection

Meteorological data were collected by two arrays of automatic weather sensors. One station was situated on the glacier approximately 375 m from the toe (105 m asl) and the second station was located approximately 7 km down the valley and 1 km from Lake Linné. The on-glacier array was attached to ablation stake #2 and recorded air temperature, precipitation, and surface lowering using a Campbell Scientific Corporation SR50 acoustic distance sensor (Logan, Utah). Dates with usable SR50 surface lowering data were 7/23–8/25/2006, 6/3–8/16/2007, and 7/15–7/25, 8/8–8/27/2008. The down-valley station has an uninterrupted record of incoming solar radiation, wind speed, and air temperature from 2004 to 2009. The down-valley station temperature record is longer and was used to generate and test temperature based glacier surface lowering equations.

Early spring and late summer ablation stake measurements were made by Jack Kohler. These height measurements of the snow and ice before and after the ablation season were used to quantify the sur-

	BW	BS	BN	Surface Lowering (cm)	G T (oC)	DV T (oC)	G T max (oC)	DV T max (oC)	Wind Speed (m/s)	Precipitation (cm)	Total Solar Radiation (W/m2)
7/23/2006 - 8/25/2006 (34days)											
Total	0.74	-1.88	**-1.14**	**127.4**							
Mean				3.7	4.1	6.1	5.8	7.3	1.8	1.1	4098.4
Max				7.4	7.3	9.6	10.5	11.8	5.5	7.4	7613.8
Min				0.6	1.9	3.5	3.2	5.4	0	0	1992.7
6/3/2007-8/17/2007 (75days)											
Total	0.72	-1.48	**-0.76**	**276.4**							
Mean				3.7	5.8	5.7	10.4	7.1	2.9	1.2	7375.2
Max				12.3	12.1	11.3	18.1	14.1	6.2	20.2	15809.6
Min				0.9	1.4	1.4	2.9	2	0.5	0	1882.5
7/15/2008 - 7/25/2008 and 8/7/2008 - 8/27/2008 (31days)											
Total	0.79	-1.13	**-0.34**	**90.5**							
Mean				2.9	4.2	5.9	7.2	7.5	2.6	2.2	9704.2
Max				7.3	7.9	10.1	13	12.6	5.9	11.2	15473.7
Min				-0.5	0.6	2.7	2.1	4.2	1	0	3991.2

Table 1: Linnébreen surface lowering and meteorological conditions during each analysis period. Annual mass balance measurements are given as the winter balance (BW), the summer balance (BS) and the net balance (BN). The down-valley station temperature data are noted with "DV" and the on-glacier temperature data are marked "G." Means and totals were arrived at using daily data.

face lowering for each season. Measurements taken at ablation stake #2 were used for this study. REU students took additional physical measurements of glacier surface lowering every other day between 7/24 – 8/13/2006.

Data Analysis

Weather parameters and surface lowering data were first organized into a summary table for the dates when surface lowering data were available (Tab. 1). This generally defined site conditions and highlighted potential trends affecting ablation. Regression analysis was performed using JMP8 statistics software. All weather parameters were individually plotted against surface lowering values. The strength of correlation between individual meteorological factors and surface lowering was quantified in R^2 values (Tab. 2). The analysis was performed at daily and 5 day intervals to determine if a multiday time scale supplied more information on surface lowering.

Development of Polynomial Surface Lowering Equations

Empirical equations were generated for each individual season (2006, 2007 and 2008) to model surface lowering according to the method used by Migala et al. (2006). Two equations were made for

Table 2. R^2 Values: Regression of Weather Parameters vs. Surface Lowering

DAILY	**2006**	**2007**	**2008**	**All Years**
Mean Air Temperature (G)	0.043	**0.283**	**0.231**	**0.102**
Mean Air Temperature (DV)	0.073	**0.113**	**0.300**	**0.125**
Maximum Air Temperature (G)	(n) 0.009	0.109	**0.185**	**0.029**
Mean Max Air Temperature (DV)	0.031	**0.146**	**0.310**	**0.136**
Mean Wind Speed	(n) 0.004	0.013	0.015	0.009
Total Precipitation	0.002	0.003	(n) 0.012	(n) 0.090
Total Solar Radiation	(n) 0.006	**0.132**	(n) 0.048	0.001
5 DAY BLOCKS	**2006**	**2007**	**2008**	**All Years**
Mean Air Temperature (G)	0.630	**0.286**	**0.739**	**0.323**
Mean Air Temperature (DV)	0.579	0.117	**0.799**	**0.181**
Mean Max Air Temperature (G)	0.355	0.090	**0.851**	0.140
Mean Max Air Temperature (DV)	0.616	0.146	**0.804**	**0.203**
Mean Wind Speed	(n) 0.010	(n) 0.016	0.178	0.000
Total Precipitation	(n) 0.431	(n) 0.000	(n) 0.045	(n) 0.016
Total Solar Radiation	0.228	0.051	0.029	0.007

Table 2. R^2 values indicate the strength of correlation between meteorological factors and surface lowering. Values shown in bold were statistically significant (p-value<0.05). Values accompanied by "(n)" showed a negative sloping regression and are not considered significant. Temperature consistently had the strongest correlation with surface lowering. Correlations were better at 5 day rather than daily scales (Fig. 2). The significance of daily correlations was aided by higher n values.

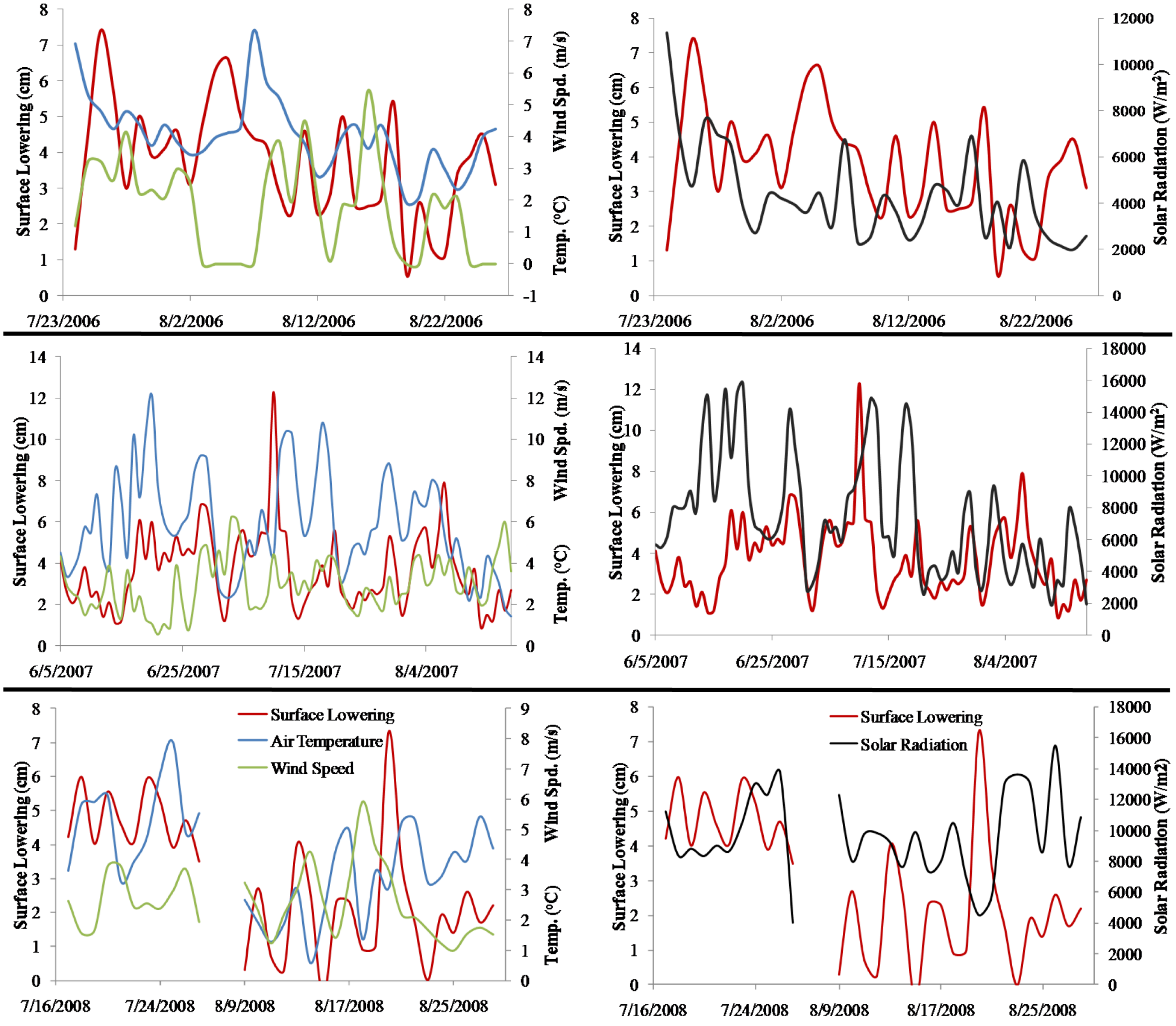

Figure 1. A group of charts that depict incoming solar radiation, air temperature, and wind speed in relation to daily surface lowering from the 2006, 2007 and 2008 analysis periods. Some peak values seem to correlate but controls on surface lowering appear complex.

each year, one using cumulative mean temperature and the other using cumulative max temperature as factors controlling melt. Cumulative temperature parameters were plotted in Microsoft Excel against cumulative surface lowering, and a second order polynomial equation was fit to each plot. The polynomial equations solve for cumulative surface lowering (cm) from inputted cumulative temperature values. Polynomial equations and linear equations generate similar end-of-season melt totals, but the polynomial equations more accurately depict daily melting during the season.

The accuracy of each equation was tested at the seasonal scale by calculating the percent difference between actual and calculated surface lowering. The results of the 2006 cumulative max temperature equation were plotted along with physical measurements taken every other day and SR50 measurements for the period 7/24 – 8/13/2006 for short timescale assessment (Fig. 3). Snow-melt and ice-melt were not differentiated in the data set. An

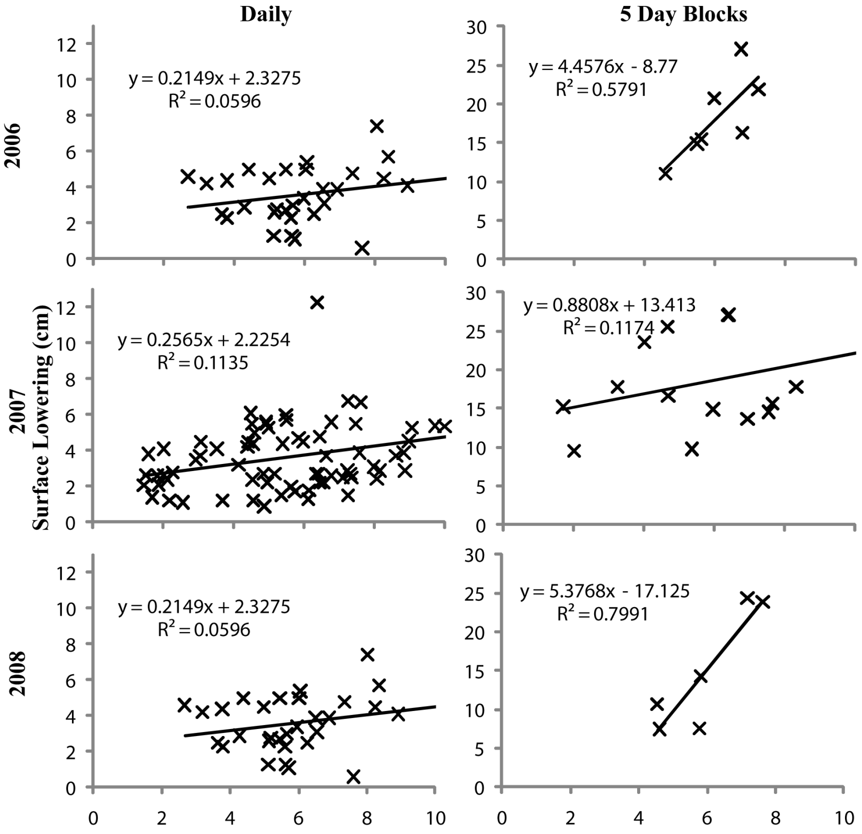

Figure 2. Examples of the regression analysis to determine the strength of meteorological parameter correlation to surface lowering (Tab. 2). Shown here is mean down-valley temperature plotted against surface lowering. All correlations improve from the daily to the 5 day data intervals. Only the 2007 and 2008 daily regressions and the 2008 5 day regressions were statistically significant (p-value<0.05)(Table 2).

ice-snow interface temperature logger indicates the snow cover melt date for 2007, while the 2006 and 2008 SR50 lowering records start after the snow cover melted. The annual date of snow cover loss is unknown before 2006 so it is more useful to have a composite equation to predict the total surface lowering during the ablation seasons prior to 2006 rather than two equations differentiated between snow-melt and ice-melt.

RESULTS

The mean daily surface lowering for the 2006 and 2007 records was 3.7 cm, while for 2008 it was 2.9 cm. The 2008 net mass balance was also the least negative of the three seasons (Table 1). Plots of daily surface lowering along with temperature, wind speed and solar radiation factors show some correlation of peak values, but controls on surface lowering appear complicated (Fig. 1).

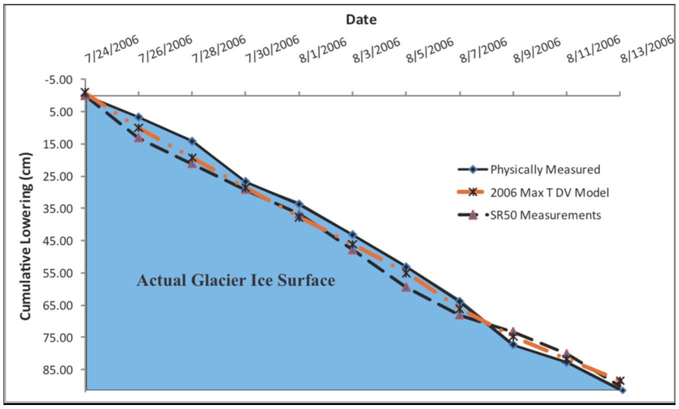

Figure 3. Equation 2 is tested over a shorter time scale here, using physically measured cumulative lowering between 7/24-8/13/2006. The SR50 acoustic distance measurements are shown for comparison. The lowering over this 18 day period was predicted to within 2 cm using cumulative max air temperature inputted into Equation 2 (Lowering = -0.0007(∑TmaxDV)^2 + 0.7037(∑TmaxDV) - 6.4114, R^2 = 0.9982).

Statistical Analysis

The regression analysis showed that 5 day blocks of meteorological data had better correlation with surface lowering (higher R^2 values) however, some analysis of 5 day parameters were not significant ($p\text{-value}>0.05$), possibly because of low n values (Table 2; Fig. 2). Air temperature parameters had the highest R^2 values. Year 2007 was an exception that showed lower air temperature R^2 values but remained statistically significant. Wind speed, precipitation and solar radiation analysis provided R2values signifying weak correlation with surface lowering. The analysis of parameters from all years combined yielded weaker correlations than in 2006 or 2008 alone.

Polynomial Equations

Second order polynomial equations were fit to plots of cumulative mean temperature vs. cumulative surface lowering and cumulative max temperature vs. cumulative surface lowering for each season. Year 2006 equations are (1) and (2), 2007 equations are (3) and (4) and 2008 equations are (5) and (6) (Fig. 4).

(1) Lowering =
$$-0.0009(\Sigma T_{mean}DV)^2 + 0.8214(\Sigma T_{mean}DV) - 6.0133,$$
with $R^2 = 0.9982$

(2) Lowering =
$$-0.0007(\Sigma T_{max}DV)^2 + 0.7037(\Sigma T_{mean}DV) - 6.4114,$$
with $R^2 = 0.9982$

(3) Lowering =
$$-0.001(\Sigma T_{mean}DV)^2 + 1.039(\Sigma T_{mean}DV) + 8.5577,$$
with $R^2 = 0.9954$

(4) Lowering =
$$-0.0006(\Sigma T_{max}DV)^2 + 0.8119(\Sigma T_{max}DV) + 3.5141,$$
with $R^2 = 0.9968$

(5) Lowering =
$$-0.0012(\Sigma T_{mean}DV)^2 + 0.6965(\Sigma T_{mean}DV) + 0.9577,$$
with $R^2 = 0.9964$

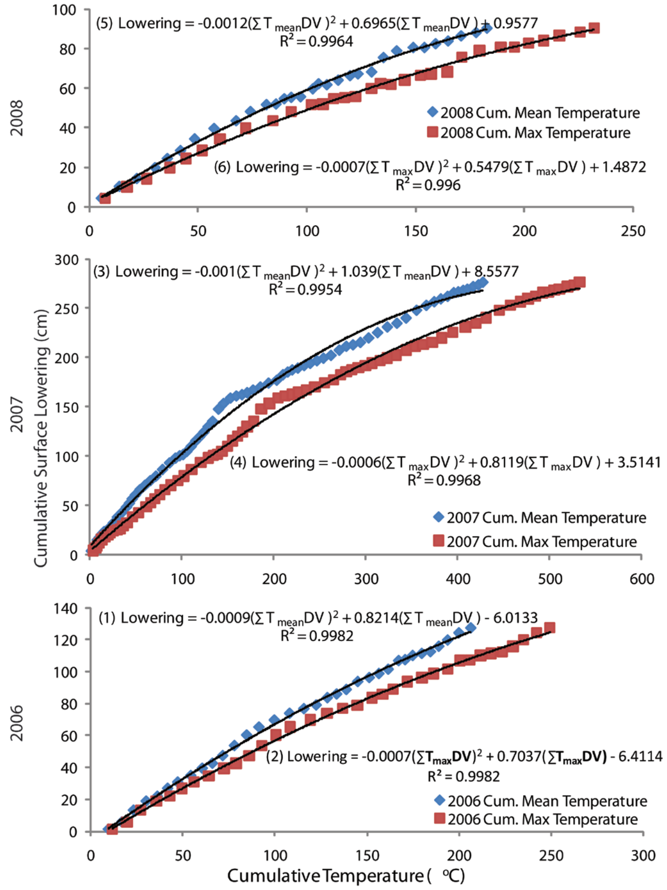

Figure 4. Second order polynomial equations fit to plots of cumulative temperature and surface lowering. An equation was made for both mean and max temperature accumulation during each year. These equations have potential to reconstruct surface lowering before mass balance measurements were available (2003).

(6) Lowering =
$$-0.0007(\Sigma T_{max}DV)^2 + 0.5479(\Sigma T_{max}DV) + 1.4872,$$
with $R^2 = 0.996$

The cumulative temperature factors for each ablation season (June-Aug.) from 2005-2008 were inputted into equations (1-6) and the equation performance varied considerably. The 2007 mean temperature Equation 3 predicted lowering closest to actual lowering. The percent difference between the sum of surface lowering over the four ablation seasons provided by Equation 3, and the direct measurement was only 7% (1094 cm to 1173 cm). The 2007 cumulative max temperature Equation 4 yielded a difference of 50%. The 2006 Equations 1 and 2 were comparable to Equation 4, and yielded results differing from the actual by 48% and 57%. The 2008

Equations 5 and 6 however showed differences from physical measurements by 127% and 116% (263 cm and 310 cm vs. 1173 cm). The 2007 curve is fairly linear except for one multi-day anomaly beginning on 7/7/2007, which is the same date that snow cover was lost according to the ice-snow interface temperature logger (Fig. 4).

During the 7/24–8/13/2006 period, cumulative max temperature was used to test Equation 2 for shorter time scales. The Equation 2 lowering results for 7/24–8/13/2006 shows a close prediction of lowering (Fig. 3). The generated surface lowering value was within 2 cm (1%) of the physically measurement on the final day.

DISCUSSION

Air Temperature

Regression analysis shows significant correlation ($R^2>0.5$ and p-value<0.05) between air temperature and surface lowering for several 5-day data blocks (Tab. 2). Similar to Migala et al. (2006), it was found that 5 day periods yielded better correlations than daily data. The 5 day down-valley max temperature for the 2008 season had the highest statistically significant correlation value ($R^2=0.851$, p-value=0.009). There were many days in the 2007 record; therefore a high n value improved statistical significance, while there was still weak correlation for undetermined reasons.

Wind, Solar Radiation and Precipitation

Previous studies have found that either wind speed or solar radiation is often weakly correlated with glacier melt (Ohmura 2000, Migala et al. 2006). On Linnébreen, both wind speed and solar radiation showed weak correlation. Wind speed and solar radiation measurements may not accurately represent on-glacier conditions because they were collected several kilometres down-valley. Future studies of Linnébreen would be aided by the installation of an anemometer, and incoming and outgoing solar radiation sensors on the glacier, which could allow for more accurate description of meteorological effects.

Precipitation is included in energy balance equations as rain-suppled sensible heat flux (Hock 2005). Just as Migala et al (2006) found on Hans Glacier, precipitation was not significantly correlated with surface lowering on Linnébreen.

Second Order Polynomial Equations

The use of polynomial equations to correlate cumulative surface lowering and cumulative temperature was successful on the Hans Glacier (Migala et al. 2006). On Linnébreen, this method has some success depending on the temporal scale and quality of the SR50 record. The year 2007 record showed weak regression correlations between temperature and surface lowering (Tab. 2), but actually had the strongest relationship with cumulative temperature equation (within 7% over 4 years). This could be because the 2007 SR50 record spanned nearly the entire ablation season so the equation modelled season-end cumulative lowering values better than year 2006 equations. The 2006 data period spanned 34 days and reached 127 cm surface lowering, while 2007 data spanned 75 days and reached 276 cm, 2008 only totalled 90.5 cm surface lowering (Tab. 1). The mean annual physically measured surface lowering between 2005-2008 was 293 cm. The 2008 equations were also skewed because a break in the SR50 record meant that cumulative temperature and lowering were not truly cumulative since days were missing. The break and shortness of the 2008 data are thought to explain its poor performance. The poor results from 2008 equations and the strong performance of the 2007 Equation 3 indicate that complete ablation seasons are needed to generate equations that perform well.

Air temperature data from the down-valley station were used to generate the polynomial equations because it was the longest record and it has been found that weather stations located away from glaciers often have better ability to simulate ablation (Ohmura 2001). Lang and Braun (1990) reported that stations further from glaciers are less affected by advection and more clearly report energy inputs.

Equation 2 was applied to a shorter time scale and the equation reliably predicted surface lowering (Fig. 3). Equation 2 predicted the lowered surface to within 2 cm, only 1% away from the physical measurement at the end of the 18 day period. Equation 2 was used here because cumulative max air temperature was the parameter used with the most success by Migala et al. (2006). The use of cumulative air temperature parameters is supported by Daly et al. (2000) and Shea et al. (2007) who report cumulative air temperature controls, or correlates to glacier mass balance.

CONCLUSION

Cumulative air temperature significantly correlates with cumulative glacier surface lowering and can effectively model glacier surface lowering (Fig. 3), whereas, non-cumulative air temperature correlations were good for some individual years but not combined years (Table 2). Air temperature, or energy balance parameters correlated with air temperature likely drive ablation on Linnébreen. The cumulative air temperature approach has parallels to heating degree-day ablation modelling, but the cumulative air temperature method has the advantage of showing magnitude above 0°C. Heating degree-day models are limited to solving mass balance over an entire ablation season, while cumulative air temperature values can be used to predict lowering over any temporal interval. Air temperature equations for Linnébreen could be improved if more SR50 records spanned entire seasons. The results for this study are presented in surface lowering (cm), but the proper unit for mass balance measurement is water equivalences. Observations on the date of snowmelt and snow density beneath the sensor would make it possible to calculate this unit and extrapolate ablation to points on the glacier with differing elevation. Finally, a long-term temperature record could be adapted to Linnébreen, so ablation could be modelled back to 1912 A.D. with air temperature equations.

ACKNOWLEDGEMENTS

Thank you to my adviser Chris Williams, whose help was instrumental. Thank you to Al Werner, Steve Roof and Mike Retelle for assistance developing my project. Thank you to the Keck Svalbard students, to UNIS for logistical help and the Keck Geology Consortium for making this possible.

REFERENCES

Daly, S. F., Davis, R., Ochs, E. And Pangburn, T., 2000, An approach to spatially distributed snow modelling of the Sacramento and San Joaquin basins, California: Hydrological Processes, v. 14, p. 3257-71.

Hagen, J. O., Melvold, K., Pinglot F., and Dowdeswell, J. A., 1993, On the net mass balance of the glaciers and ice caps in Svalbard, Norwegian Arctic: Arctic, Antarctic, and Alpine Research, v. 35, p. 264–270.

Hock R., 2005, Glacier melt: a review of processes and their modelling: Progress in Physical Geography, v. 29, p. 362-291.

Lang, H., and Braun, L., 1990, On the information content of air temperature in the context of snow melt estimation: Hydrology of Mountainous Areas, v.190, p. 347-354.

Migala, K., Piwowar, B. A., and Puczko, D., 2006, A meteorological study of the ablation process on Hans Glacier, SW Spitsbergen: Polish Polar Research, v. 27, p. 243-258.

Ohmura, A., 2000, Physical basis for the temperature-based melt-index method: American Meteorological Society, v. 40, p. 753-761.

Shea, J. M., and Marshall, S. J., 2007, Atmospheric flow indices, regional climate, and glacier mass balance in the Canadian Rocky Mountains: International Journal of Climatology, v. 27, p. 233-247.