Ice and Climate Project

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1 Introduction

This report analyses the impact of persistent cloud cover on the surface energy balance (SEB) over the Antarctic Peninsula using data from the weather station on the Larsen C Ice Shelf. The specific weather station chosen is AWS 15. The key components of the SEB for snow and ice surfaces are upward and downward fluxes of short wave (SW) and longwave (LW) radiation, sensible heat flux (SHF), latent heat flux (LHF) and the ground heat flux (Gs). All these components are linked to the Melt (M_{surf}) via the following formula

$$M_{surf} = SW_{down} - SW_{up} + LW_{down} - LW_{up} + SHF + LHF + Gs \tag{1}$$

This sign convention is adopted because the data available consists of positive values only.

The correlation between each individual component of the SEB and the cloud cover is examined. This is used to predict the melt and temperature of the ice shelf for 100 percent cloud cover. The results are shown in chapter 3 and discussed in chapter 4.

2 Implementation

This project uses a python based Jupyter notebook which adjusts the variables of the SEB, described in section 2.1 and closes the SEB again after the adjustment. The later is discussed in more detail in section 2.2. Our code is enclosed to this document.

2.1 Adjustments

The mean cloud cover recorded at the weather station AWS 15 over the Larsen C Ice Shelf is 66.21 percent. The objective is to extrapolate this cloud cover to 100 percent for each data point. To achieve this, the correlation between cloud cover and each component of the surface energy balance (SEB) is analysed using a linear regression. For each energy variable, the code fits a linear model using cloud cover as the independent variable, aiming to determine how changes in cloud cover correlate with fluctuations in the respective energy flux. As an example the linear regression for LW_{down} is shown in figure 1. Correlations for the remaining components can be found in the accompanying document.

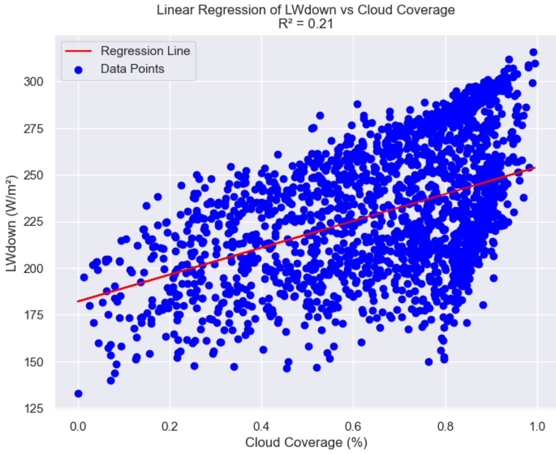

Figure 1: The correlation between cloud cover and the incoming long wave radiation is shown for each data point in blue. The fit obtained via a linear regression is shown in red.

SEB component	slope
LW_{down}	72.02
LW_{up}	3.07
SW_{down}	-149.12
SW_{up}	-117.98
SHF	-23.2
LHF	-4.23
Gs	-7.68

Table 1: Slope of the linear regression between cloud cover and each component of the SEB

The slopes obtained with the linear regression are represented in table 1. These values are used to adjust each data point accordingly. This adjustment takes into account the initial cloud cover and extrapolates the data to full coverage assuming a linear relationship as follows:

$$x^{adj} = x_i + \text{slope} \cdot (1.0 - \text{cloud cover}) \tag{2}$$

for each component x of the SEB where x_i is the initial and x^{adj} the adjusted value. If the values of the adjusted long- and shortwave radiation fluxes become negative, the value is set to zero.

2.2 Closing the SEB

In the previous step, we determined the impact of cloud-cover to the different terms of the SEB-equation. We used linear regression to extrapolate all SEB-data points to a cloud-cover of 1 corresponding to the weather always being cloudy. The result are the adjusted SEB-terms, i.e. $SW_{up}^{adj}, SW_{down}^{adj}, LHF^{adj}$ etc. In the following, we will leave out the superscript to simplify notation.

In the next step, we want to measure the impact of the adjusted SEB-terms. If one or several terms in the SEB equation (1) are changed, we expect the surface temperature T_{surf} and surface melt M to change. This is because several terms, namely SHF and LW_{up}, are dependent on the surface temperature. We use the following formulas:

$$LW_{up} = -\sigma \cdot (T_{surf}^{adj})^4 \tag{3}$$

$$SHF(T_{surf}^{adj}) = SHF + c \cdot U_{10m} \cdot (T_{original} - T_{surf}^{adj}) \tag{4}$$

Here, σ is the Boltzmann constant and c is the exchange coefficient which we determine from the data. Note that in this formula, SHF corresponds to the Sensible Heat Flux that is already adjusted to the cloud-cover condition.

Our goal is to close the SEB-equation, i.e. find a surface-temperature and melt term so that the SEB-equation (1) holds true. Our method proceeds in the following way:

1. Set $M = 0$ and use a bisection method with initial values $T_{init} = T_{old} \pm 50K$ to find T_{surf}^{adj}.

2. If the algorithm finds a solution where $T_{surf}^{adj} < 0$, we return this T_{surf}^{adj} together with $M = 0$.

3. If $T_{surf}^{adj} \geq 0$, we set it to zero and return the melt $M(T_{surf} = 0)$ together with $T_{surf} = 0$.

3 Results

The results of our algorithm can be seen in Figure 2. Here, we show the melt and surface temperature returned by our method and compare it to the original values. We find an average temperature increase of $\Delta T = 1.71K$. The average melt per day decreases: $\Delta M = -0.34 \frac{W}{m^2}$.

We also consider the annual cycle: The temperature increase is relatively constant over the course of the year. The melt, however, is unchanged for the cold months (May-October) and the difference in melt can only be seen during the warmer months (November-February).

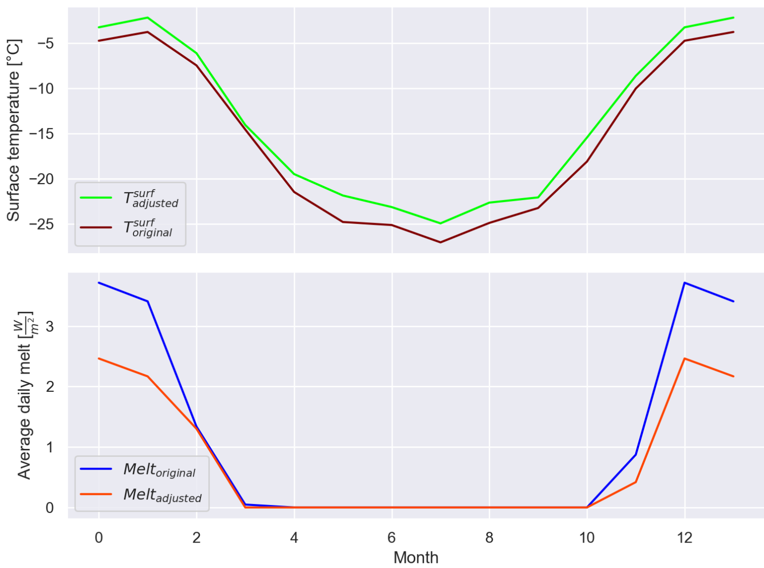

Figure 2: Impact of "Always cloudy" on the daily melt and average surface temperature at our given location. The plots compare the original values with the results after the adjustment. The x-axis shows the months of the year ranging from January (left) to December (right).

Furthermore, we show a comparison of the radiation fluxes before and after the adjustment in Figures 3 and 4. We see the biggest change in LW_{down}, i.e. in the incoming longwave radiation. We observe very little changes for LW_{up}. The shortwave radiation fluxes SW_{up} and SW_{down} are both reduced in a very similar way.

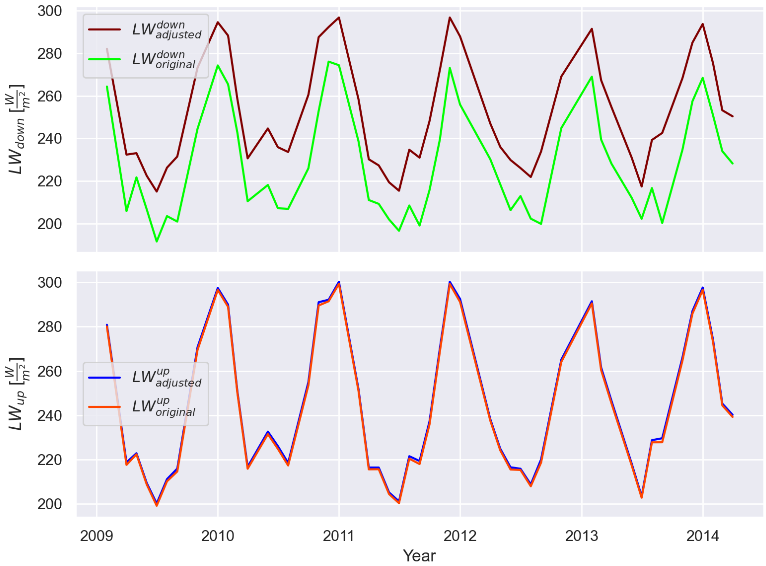

Figure 3: Impact of "Always cloudy" on the longwave radiation (LW) at our given location. LW_{down} and LW_{up} denote incoming and outgoing longwave radiation, respectively. The plots compare the original values with the results after the adjustment.

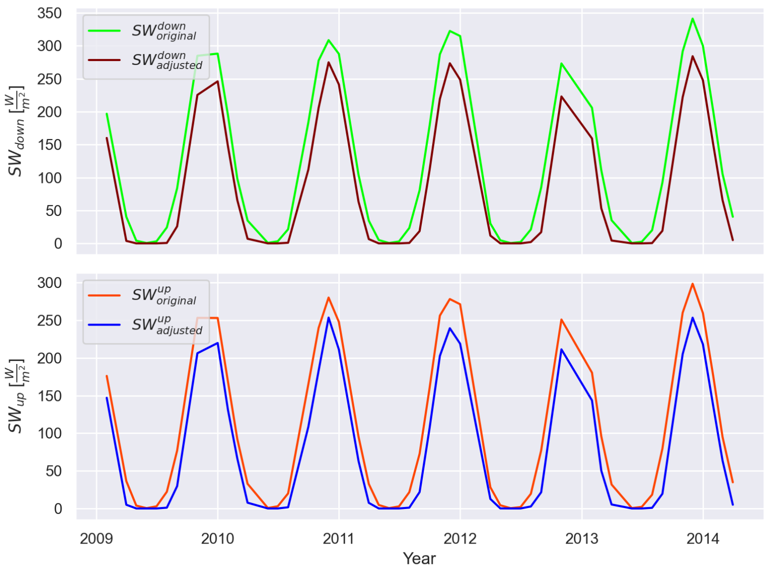

Figure 4: Impact of "Always cloudy" on the shortwave radiation (SW) at our given location. SW_{down} and SW_{up} denote incoming and outgoing shortwave radiation, respectively. The plots compare the original values with the results after the adjustment.

Lastly, Figure 5 demonstrates that the sensible heat fluxes SHF and LHF are

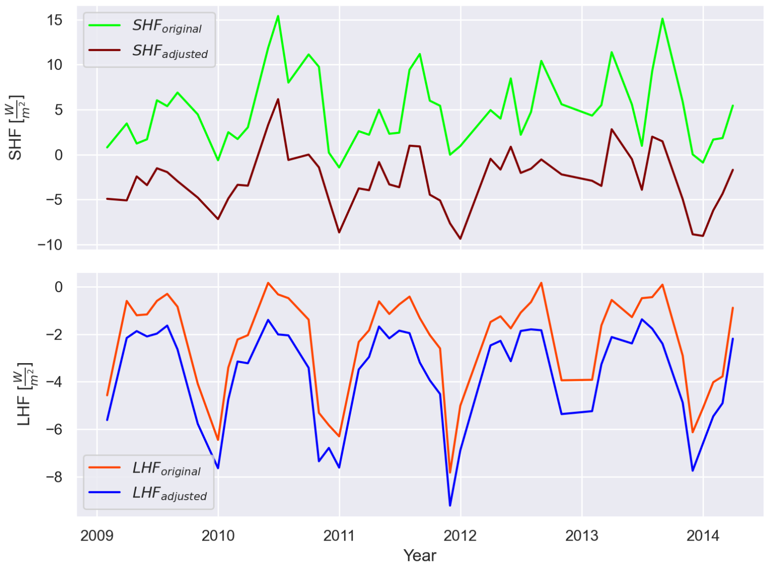

Figure 5: Impact of "Always cloudy" on the heat fluxes at our given location. SHF and LHF denote sensible and latent heat flux, respectively. The plots compare the original values with the results after the adjustment.

both reduced as a result of our adjustment. It is worth noting, however, that the absolute values of the heat fluxes (and with it its changes due to the adjustment) are significantly smaller than the (changes of the) radiation fluxes.

4 Discussion

As described in chapter 3 the biggest impact of persistent cloud cover on the SEB is an increase in incoming LW radiation. This is to be expected since a significant amount of incoming LW radiation is emitted by clouds, so more clouds result in more incoming LW radiation. This increase in LW radiation contributes to the rise in surface temperature, as the Earth's surface absorbs this radiation and warms up. Additionally, clouds trap LW radiation, leading to a generally higher average surface temperatures compared to clear-sky conditions.

The second largest contribution to the SEB based on our model is the net short wave radiation. This is likely due to the lower transmissivity of the atmosphere because of the increase in clouds. This reduces SW_{down} and since SW_{up} and SW_{down} are linearly related through the albedo, their change is highly correlated. This also means that the effect of the increased cloud cover of the SW radiation partially

cancels, since they have an opposite effect on the SEB.
While the LW radiation leads to an increase in temperature, which would suggest a higher melt rate, the SW radiation counterbalances this effect by reducing the amount of energy available for the melting of the ice. This suggests that cloud cover despite increasing the surface temperature also reduces the amount of melt of the ice sheet.
It should be highlighted that this report assumes a linear correlation between the cloud cover and the components of the SEB. Further these components are linearly extrapolated to full coverage. This provides a good approximation of the problem at hand but limits the model to linear relationships between the variables.
The accuracy of the results could be further increased by considering the influence of other factors like wind, humidity, atmospheric temperature etc. on the components of the SEB in order to extract a more detailed relation to the cloud cover.

5 Conclusion

In summary, this report provides an overview over how persistent cloud cover influences the surface energy balance at the Antarctic Peninsula. The results demonstrate that while cloud cover increases surface temperatures through LW radiation, it also reduces melt due to weakened SW radiation. These findings offer insights into the future stability of ice shelves in a warming climate, where cloud cover patterns may shift.