Driving Forces Behind Himalayan Glacial Melt.

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Abstract

In this study we take a look at the driving forces behind glacial melt in the Himalayas, through the use of a simple model that is driven by atmospheric remote sensing data. There are many uncertainties associated with the measurements including low spatial resolution and possible backscatter of the highly mountainous region. We have shown that a 10% change in albedo has a large impact on glacial melt. Also interannual precipitation changes have little effect on the magnitude of glacial melt. Although there is still much work to be done accounting for refreezing factors and latent heat transfer, gathering improved data of direct mass balance measurements as well as surface albedo.

I. Introduction

In these studies we try to ascertain which variables have the biggest impact on glacial melt in the Himalayas. Both glaciers in the Himalaya and other high altitude mountain ranges have been melting over the last couple decades (Dyurgerov, 2005). Variables of precipitation, incoming radiation, bright band height, and surface albedo are looked at. Using these variables to drive a simple model, sensitivity studies were preformed holding different variables constant. These models were made to resemble two separate Himalayan test glaciers by using elevation data from (Dyurgerov, 2005). These two test glaciers being Changemakhan Glacier (27°57'N, 88°41'E) with a height of 4840m-5520m, that we'll call Glacier 1, and Dunagri (30°33'N, 79°54'E) with a height of 4240m-5150m, that we'll call Glacier 2.

II. Data and Methods

A. Data Sources

For this project many different data sets were used. For precipitation different data sets from the Tropical Rainfall Measuring Mission's (TRMM) precipitation radar instrument were used. Including the 3A25 data set which has 5°x5° gridded rainfall data set averaged for each month from 1998-present. As well as a merged product 3B43 which merges data from high quality TRMM IR measurements with either Climate Assessment and Monitoring System (CAMS) or Global Precipitation Climatology Centre (GPCC) rain gauge data. Rain gauge data direct from GPCC, their full data reanalysis product, was also used. For the second test glacier data from the Indian Institute for Tropical Meteorology's (IITM) longest Instrumental Rainfall Series of the Indian regions, region North Mountainous India. Bright band data taken along with 3A25 product, gives average bright band height averaged per month and over 5° grid. The Bright Band is a signal in radar profiles that is visible because when a snowflake begins to melt the radar sees it as a very large rain drop and has a very "bright" reflectivity. Once it completely melts the snowflake is seen as raindrop and has a lower reflectivity. An adjustment 300m up of the bright band was made based on findings in (Okamoto, 2004). This is because the melting layer that is indicated by the bright band is fairly large and an adjustment needs to be made. Radiation data was taken from the Clouds and the Earth's Radiant Energy System (CERES) project, SRBAVG

data product. Surface albedo was estimated from (Ohmura 2001), and changed as a tuning parameter and for sensitivity studies.

B. Temperature Based Model

The first model that was derived is a simple temperature based mass balance equation taken from (Singh and Kumar 1996)

$$B_n=(P-(\Phi*T))*P_w*\Delta_t$$

B_n, being change in mass balance per unit area in units Kg/m^2, P, being precipitation in units of mm/Month, Φ being the melt factor in our case $6.29*10^{-8}$ m/s*°C, T, being temperature in °C, P_w being the density of water in our case 1000 kg/m^3, and Δ_t, being the time period in seconds in our case a month. The temperature data is taken from using the bright band height as the 0° isotherm and using US standard Atmosphere vertical profile, of -0.65°C per 100m elevation. The precipitation value is only added to the equation when the temperature is below 0° C, otherwise any rain that would fall above freezing would be runoff. In the same way the melt term is not applied unless the temperature is above the freezing point, because of this the model is dependent on the height of the bright band, which is used to determine 0°C. This model fails to take into account the complexities of the planet's energy budget and is solely dependent on two variables which lead to the development of the radiation based model.

C. Radiation mass balance model

For the second model both shortwave and longwave radiation was taken into account to determine melt. The model is adapted from (Ohmura 2001)

$$B_n=(P-(S(1-a)+L_n))*P_w*\Delta_t$$

The differences in this equation from the previous equation is that $\Phi*T$ has been replaced with $-(S(1-a)+L_n)$, with S, being incoming shortwave radiation in W/m^2, data from CERES, multiplied by one minus the albedo (a) to get the fraction of that radiation that is not reflected by the surface. L_n, is the net longwave radiation calculated by the CERES project. Similar to the temperature based equation, only when the temperature is above 0°C will the melt factor be applied and below the precipitation factor be applied. Also if the net radiation is negative, as it can be in the fall, the melt factor is not applied. This is because when the net radiation is negative the glacier is giving off energy and cooling itself. The radiation data goes from 1988-2004, whereas TRMM, where the bright band and precipitation data come from, was launched in December 1997. This only allows for a time period of less than 10 years.

D. Correlation of Bright Band Height with Temperature

In order to extend the bright band data back to match the radiation data. The 10 year record of bright band is correlated to Remote Sensing System's Microwave Sounding Units (MSU) record

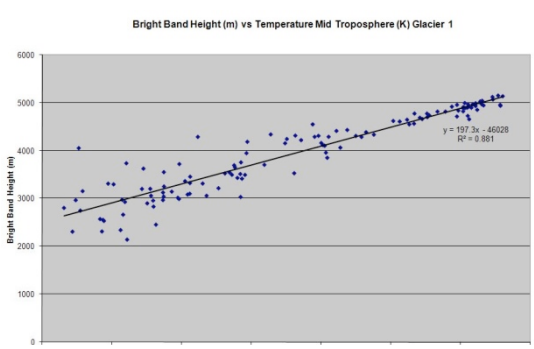

Figure 1 (Correlation for Glacier 1)

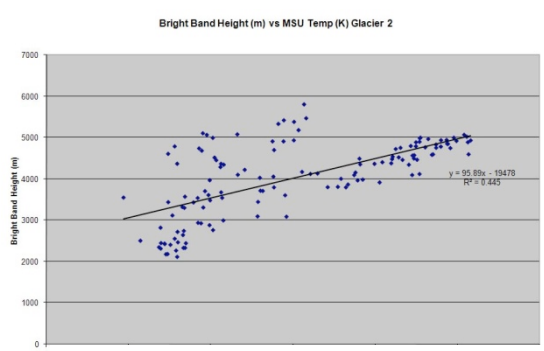

Figure 2 (Correlation for Glacier 2)

for the mid-troposphere. The Mid-troposphere data is used because the relative weighting function they use puts the elevations the glaciers are in, into that channel. The function taken from that correlation, the bright band heights for the period of 1988-1997 are extrapolated (fig. 1-2).

III. Results

A. 1st Model Run

In the first run of the model the 3A25 5°x5° gridded data set from TRMM's precipitation radar instrument was used along over the period of 1998-2008. The goal of this run was to look at the sensitivity of the melt factor to changes. The melt factor of 6.29×10^{-8} m/s*°C is compared to 20% above and below (fig.3). All of the values for glacial melt are far greater than the recorded values from INSTAAR from the early 80's. This is most likely due to the lack of the correction from (Okamoto, 2004) which would have raised the bright band 300m and increased the melt.

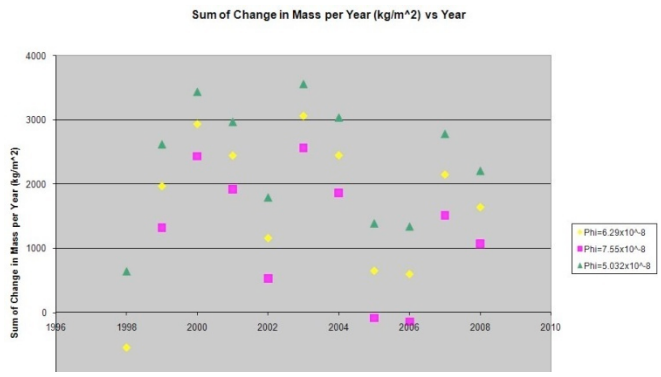

Figure 3 (1st Model Run)

B. 2nd Model Run

For the second model two changes were made. The 3A25 0.5°x0.5° gridded data set was used for precipitation. As well as the correction from Okamoto, 2004 was added. After these changes the melt dropped substantially (fig. 4) due to the fact that the precipitation was decreased by removing data from monsoonal lowland areas and moving the bright band up 300m for every measurement.

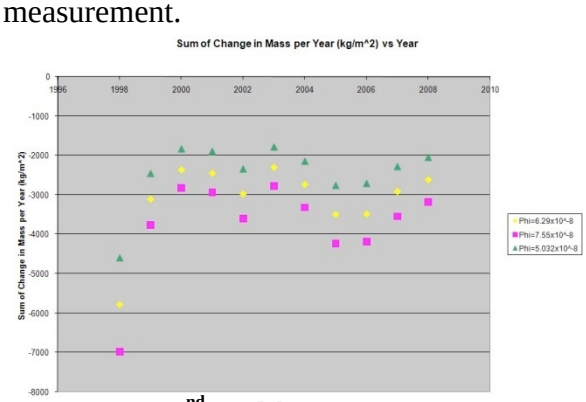

Figure 4 (2nd Model Run)

C. 3rd Model Run

In order to more accurately portray the precipitation, the precipitation radar on TRMM can produce error on high topography, the 3rd run uses the TRMM 3B43 which combines the PR with other sources such as the GPCC and CAMS. Which brings the values into the right range but still has too high of an interannual variability (fig 5) to be realistic. The first three models show that a 20% change in melt constant has a minimal effect on melt.

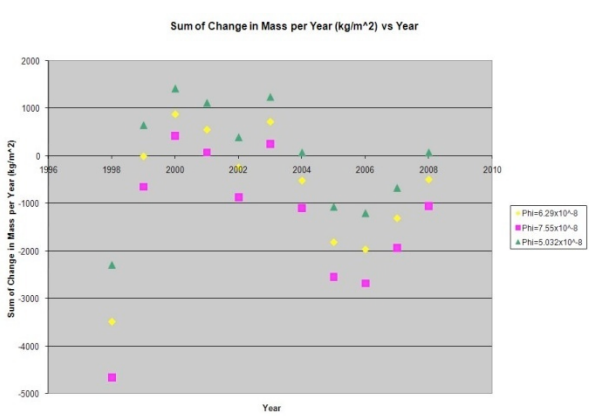

Figure 5 (3rd Model Run)

D. 4th and 5th Model Run

For the 4th model the radiation equation is first used, while still using the TRMM 3B43 for precipitation. With the new equation a sensitivity study on albedo can be done to see how sensitive the glaciers are to changes in albedo. It also brings down the scale of the interannual variations down to plus or minus a couple thousand kg/m^2 (fig 6). Also this model produced a good section of when in the year the melt occurs (fig 7). For the 5th model run the 3B43 precipitation is averaged over the 10 year period it is available, and the average value is inputted for every year. This allows the time period to be extended to the end of the radiation data set, 1988-2004, as well as a sensitivity study on the effect of precipitation (fig. 8), which shows that variation in precipitation has little effect on annual melt.

E. 6th and 7th Model Run

The final 2 runs use data from the second test glacier so they have a broader elevation 4200m-5100m, but less maximum height. The second glacier is further northwest than the first. Precipitation data comes from the IITM, for the entire Northern Mountainous India region. This model has the closest values to the INSTAAR values for the 80's as any other (fig. 9) and stays relatively close to realistic values except for an outlier in 1999. The model output follows a similar pattern to that of the bright band height in July (fig. 10). With these two models a sensitivity study shows that a small change 1% in albedo can lead to a very large change in melt as well as reinforcing that precipitation has little effect.

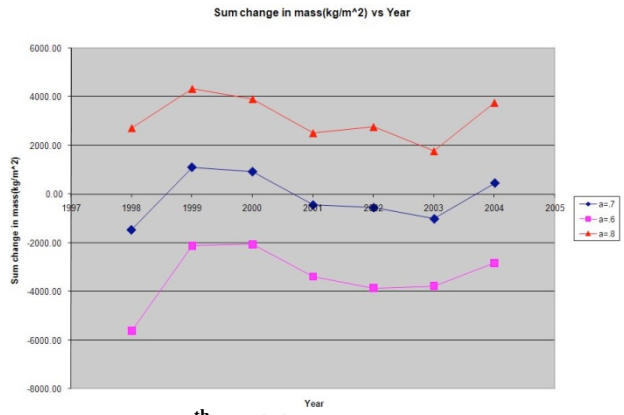

Figure 6 (4th Model Run)

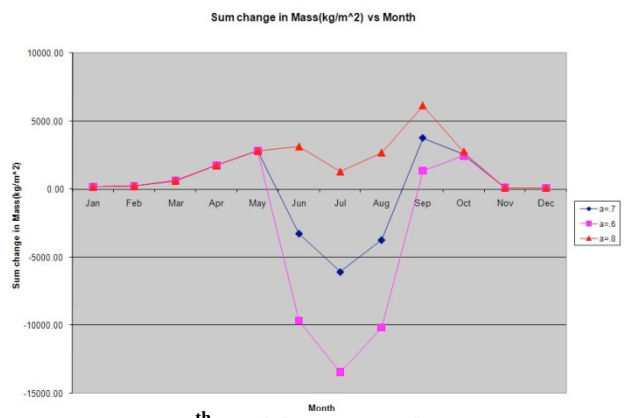

Figure 7 (4th Model Run Month)

IV. Uncertainties

There are many uncertainties and errors associated with our measurements. The only resolution able to give a consistent bright band data point over a large timeframe is 5°x5° gridded product. This is most likely to due to the low occurrence of stratiform clouds in the region and time period (1 month), which is the only cloud type to give a strong bright band. For all Himalayan glaciers there is a very small amount of in situ data on almost every feature of them including mass balance. This makes it nearly impossible to not only ground truth the remote sensing data but to have a source to compare the model output to. The satellites used in this study, TRMM and multiple MSU's, were not designed to sense in highly mountainous regions. Backscatter of the radar and infrared instruments on TRMM off the mountains can add error to our measurements. Rain gauges were also used in this study from the TRMM merged Product (GPCC, CAMS) and IITM. There are not many rain gauges in either region, for the Northern Mountainous India from IITM's data set there are only 10 gauges from 1901-2005 (Singh et. al. 2008).

V. Conclusion

Even with the large amount of error associated with the measurements a number of conclusions can be drawn from these models. These models show that albedo has a large effect on glacial melt, 10% changes in it can double the mass loss. As well that interannual variability in precipitation has little effect on the magnitude of glacial melt. Through this study we developed a model to run sensitivity studies on different variables effect on glacial melt. A model through using albedo as a tuning parameter can be brought closer to any direct (remote or in situ) mass balance measurements. There is still more work ahead for this project and many improvements that can be made. A refreezing factor (Hock 2005) should be added to the model equation to account for ice that has melted that refreezes into the glacier rather than running off. Factors for latent heat flux might also be developed to account for the heat transfer associated with the melting, freezing and evaporation of the water. Collection of on glacier albedo could prove very useful to improve the model, possibly from the Moderate Resolution Imaging Spectroradiometer (MODIS) or in situ observations. If the absolute error of some or all of the measurements used to drive the model were calculated there would be a better sense of how accurate the model can be in evaluate the mass balance. Being able to evaluate mass balance using atmospheric data could prove useful in building a record of glacial melt and predicting its future.

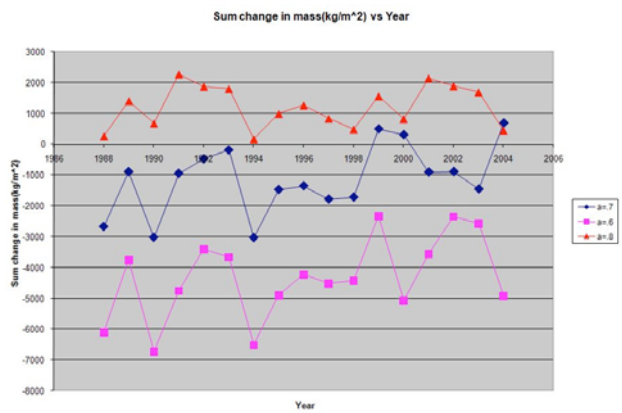

Figure 8 (5th Model Run)

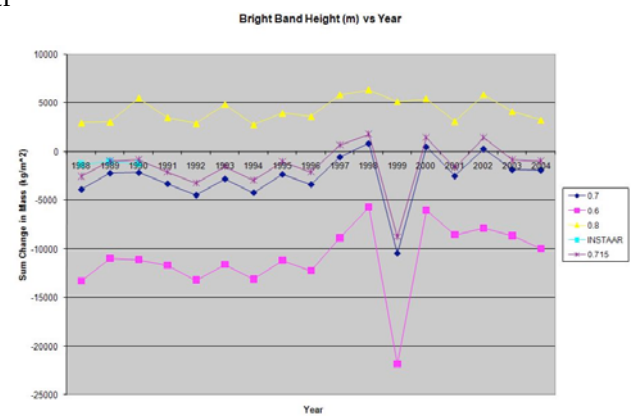

Figure 9 (6th Model Run)

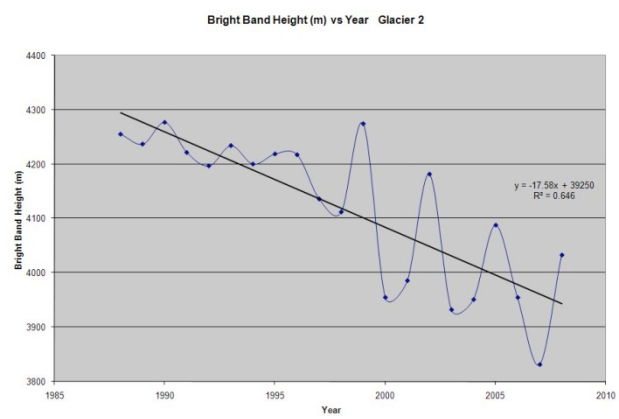

Figure 10 (Bright Band height Glacier 2)

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