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Global Warming: The Science of Climate Change
December 12, 2013

Chasing down "Chasing Ice"

Recently I saw the film, "Chasing Ice", a 2012 documentary made by environmental photographer James Balog. The film showed Balog using time-lapse photography to document the retreat of glaciers in the Arctic. The claim is that the melting glaciers are a very visible effect of climate change. The goal of this project is to investigate whether the temperature changes in the surrounding regions near the glaciers that Balog filmed account for the melt and then predict what may happen in the future.

Data and Analysis

By my count, there were 5 glaciers featured the film: Columbia and Mendenhall in Alaska, Ilulissat (also known as Jakobshavn) and Store in Greenland and Solheim in Iceland. Of these, only the Solheim glacier was in the Time Series Browser. I picked 4 weather stations that were close by the Solheim glacier: Keflavikurflu, Vestmannaeyja, Reykjavik and Hofn (http://climatemodels.uchicago.edu/timeseries/#JmyBBD). I also used the CCSM4 model and the historical grid point and rcp85 scenarios for each of the 4 stations. I downloaded the data and imported it into Matlab. I then averaged the data from the 4 stations, averaged the 4 model historical grid scenarios and plotted in Figure 1 the temperature data and the Solheim glacier length versus year.

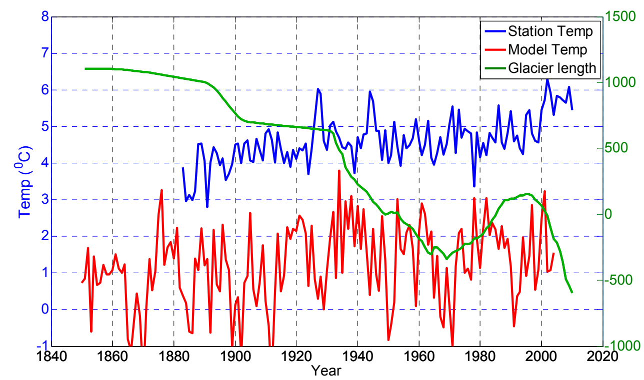

Figure 1: Station and Model temperatures with Solheim glacier length

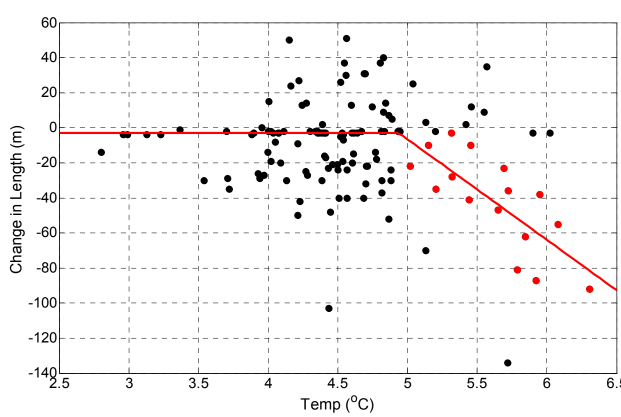

Figure 2: Change in length versus station temperature average.

There are several interesting things to note. First, there is an increase in the glacier length that begins around 1970 and ends before 2000. The temperature data show no significant decline during this period, so it is possible that the increase in glacier extent is due to increased precipitation. Second, after 2000 there is a sharp decrease in the glacier length that corresponds to an increase in temperature according to the station data. No such increase is observed in the model grid point data. Third, the scatter in the data is much larger for the model grid data than for the station data. Fourth, the model data is about 3^0 C lower than the station data.

Based on the observation that the averaged station data better follows the glacier length than the averaged model data --- and ignoring the influence of precipitation on the glacier extent --- I used the station data to find a very simple relation between the glacier length and the temperature. The change in glacier length for each year was found by subtracting from the length for each year the data point for the previous year. A plot of the change in length versus the station data average temperature is shown in Figure 2. Several things to note: There is a large scatter in the data between 4^0 C and 5^0 C presumably due to precipitation, although there could be other reasons. However there appears to be a threshold temperature, just under 5^0 C, beyond which the negative change in the length increases approximately linearly with the temperature. The data points used for the linear regression are marked in red. One might expect this threshold temperature to be around 0^0 C, the melting point of ice. However, the stations are all located at a lower altitude than the glacier, so presumably the threshold temperature for the stations more or less corresponds to the freezing point at the glacier. Also, it was observed that the data points below the threshold temperature congregated around a change in length of -3 m instead of 0 m that was expected.

From the above rather simplistic data analysis a simple algorithm was constructed to predict the change in length of the Solheim glacier as a function of temperature. It is given by:

$$\Delta L = -3\, m \qquad\qquad t < t_{th}$$

$$\Delta L = -57.4\, t + 280.3\, m \qquad t \geq t_{th}$$

where t_{th} is the threshold temperature of 4.9^0 C. This algorithm is shown in Figure 2 by the red line. A reconstruction of the Solheim glacier length using the simple algorithm is shown in Figure 3 along with the actual length. While the reconstruction doesn't reproduce at all the increase in the glacier length between 1970 and 2000, it does yield a change in the glacier length from 1850 to 2010 that is within 14% of the actual change in the length of the Solheim glacier.

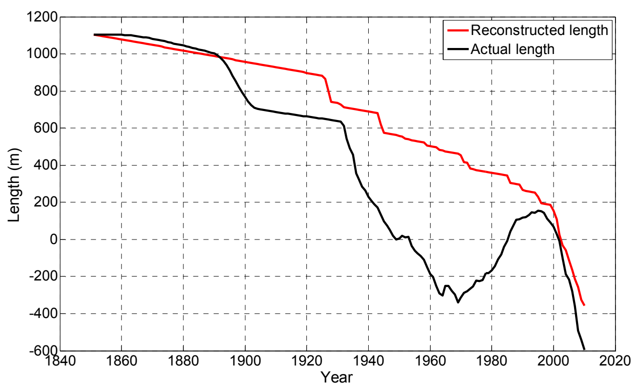

Figure 3: Comparison of reconstructed length of Solheim glacier to actual length

To estimate when the Solheim glacier may be completely gone, the above algorithm was applied to the CCSM4 model using the rcp85 scenario ('business as usual'). The start of the rcp85 data, is contiguous to the red curve of Figure 1 – the model grid data, not the station data. Since I used the average of the 4 stations to derive my algorithm, I had to readjust the rcp85 data to reflect the station data, rather than the model. As seen in Figure 1, there is about a 3.4^0 C difference between the model grid data and the station data. To normalize the rcp85 scenario to the station data, this difference was simply added on to the average of the rcp85 data for the 4 stations. Also, it should be noted that all glacier data given in the Time Series Browser are offset so that 1950 corresponds to a length of 0 m. To remove this offset, the Solheim glacier length in 1950 of 15 km was added to the data. The results are shown in Figure 4 where the thin lines correspond to the historical glacier lengths and average of the 4 station temperatures and the bold lines correspond to the future rcp85 scenario. Note that in Figure 4, all the future temperatures are above the threshold temperature so that only the linear dependence of the change in length on the temperature was invoked. The calculations indicate that the Solheim glacier could disappear entirely by the year 2100 if CO_2 emissions continue on the 'business as usual' path.

Discussion

There are many objections one can make concerning this work. One obvious objection is that the algorithm did not take into account precipitation in analyzing the glacier length. Does precipitation in fact account for the increase in the Solheim glacier length during the period 1970 – 2000? Also, this analysis only considers the length of the glacier, whereas other measurable quantities such as the height and volume of the glacier may

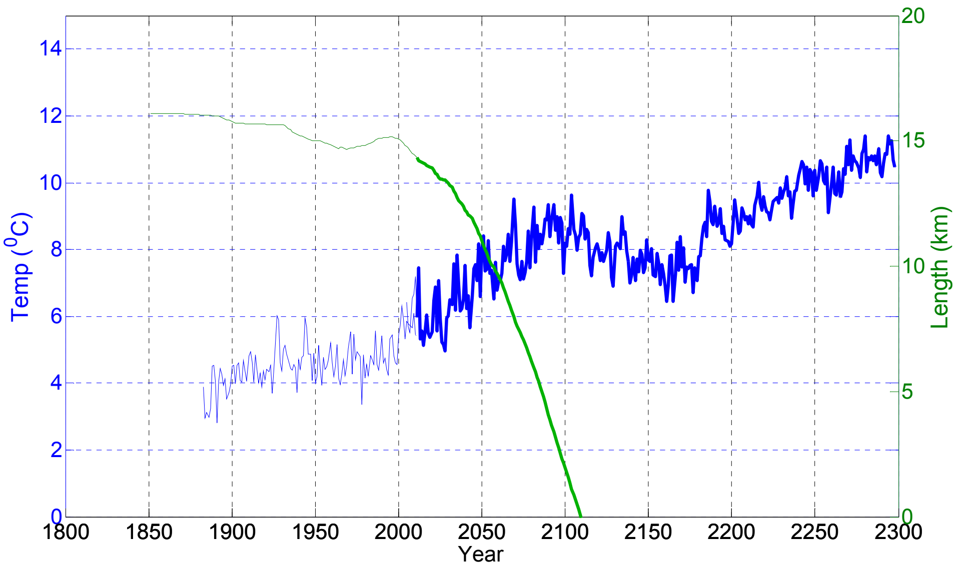

Figure 4: Historical and rcp85 scenario temperatures (in blue) and Solheim glacier historical and calculated lengths (in green)

be important. It is possible that the projection of the glacier length shown in Figure 4 based on the rcp85 scenario is too conservative. Other important physics that was neglected were changes in the surface albedo as more dirt becomes visible and that as the glacier melts, the altitude of the glacier top becomes lower where the temperature is higher. Both effects might act as positive feedback mechanisms that could change the linear regression shown in Figure 2 to be a higher order polynomial.

Still, what I found interesting about this project was that the sharp decrease in the glacier length did seem to occur roughly at the time when the temperature at the nearby stations showed a temperature spike. It was also interesting that one could detect evidence of a threshold temperature for the glacier melt, although my choice of data points for the linear regression was somewhat arbitrary. It should be noted that the temperature spike started around the year 2000 and Balog began his data collection around 2007 or so. If Balog had been taking data from 1970 until 2000, his conclusion about the Solheim glacier might be very different. Mean surface temperature records from NASA GISS (http://data.giss.nasa.gov/gistemp/graphs_v3/) (that is, averaged from stations over a period of 1 year and over the surface of the planet) show steep temperature increases in the period from 1970-2000 and a less steep increase from 2000 or so onward. This is contrary to the temperature records at the 4 stations near the Solheim glacier which don't show a significant temperature increase during this period --- the period of the 'smoking gun', as it was called in the video for this course. In fact, from Figure 1, the Solheim glacier has been in retreat since data was first collected in 1850. This is reflected in the change in length below the threshold temperature being -3 m, rather than 0 m that I would have expected.

Will the Solheim glacier disappear by the year 2100? The website of the British Geological Survey (http://tinyurl.com/nhmhej4) says, "Studies suggest that many of the world's mountain glaciers and small ice caps — like the ones we're studying in Iceland — could shrink dramatically or even disappear by the end of the 21st century." Another website http://tinyurl.com/q68lpeg says, "Iceland's glaciers will vanish within 150-200 years according to glaciologist Helgi Björnsson at the University of Iceland." The short answer to the question: maybe. What's the verdict on Chasing Ice? There is a possibility that Iceland's glaciers may significantly shrink or disappear entirely by the end of the century if changes in CO_2 emission aren't made soon. Balog's film conveys that possibility with astonishingly impressive photography.