STA4000 Final Report - Summary
Investigation on Iceland Population Growth and Climate Change

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December 16, 2009

1 Introduction

Scientists have argued the possible relationship between population growth with climate change. But the impact of climate change to social unrest and population is never analyzed quantitatively. The goal of the project is to investigate the relationship between the Iceland population growth and the climate change before the industrialization.

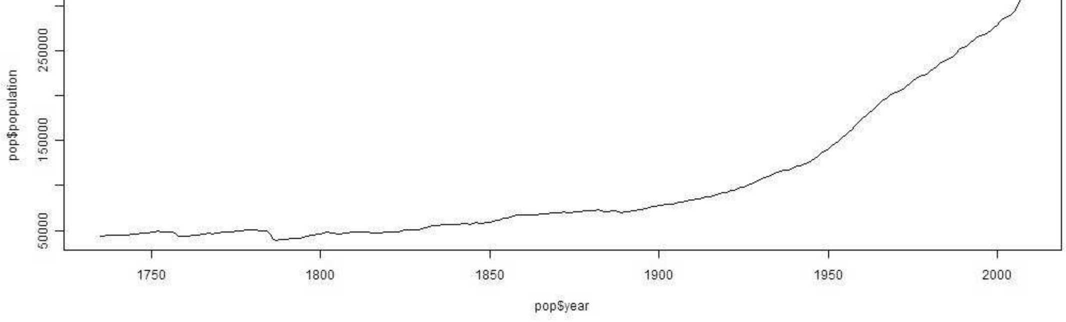
The reason we choose Iceland is it has a relative stable and simple population structure (Most of Icelanders are farmers and fishers before industrialization). And Iceland population growth was less affected by the immigrations and wars due to its location.

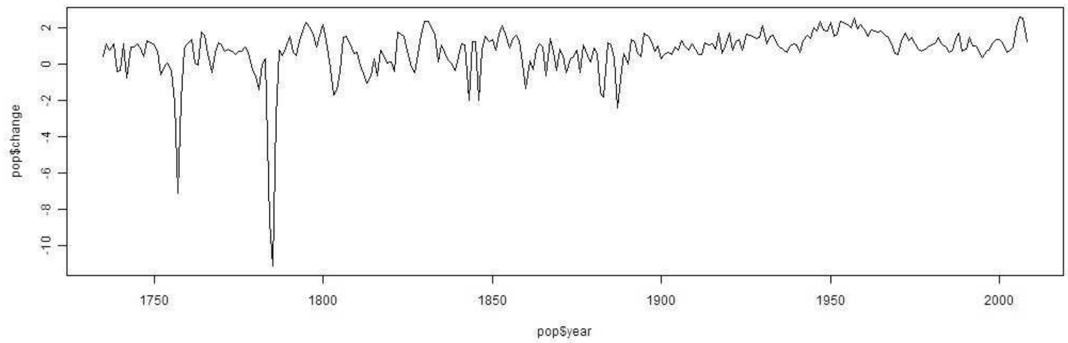
The measured temperature in Iceland is only available for the recent 150 years. But we use the the ice core record in Greenland to reconstruct the past northern Iceland temperature. Then we compare the reconstructed temperature with population growth in Iceland.

This report summarizes the main findings from our analysis. The detailed analysis and evidence is available on "STA4000 Final Report - Detailed Analysis".

2 Initial investigation on the data set

The annual official census data in Iceland is available from Statistics Iceland official web site. The following 2 figures shows the population and the growth rate of Iceland from 1735.





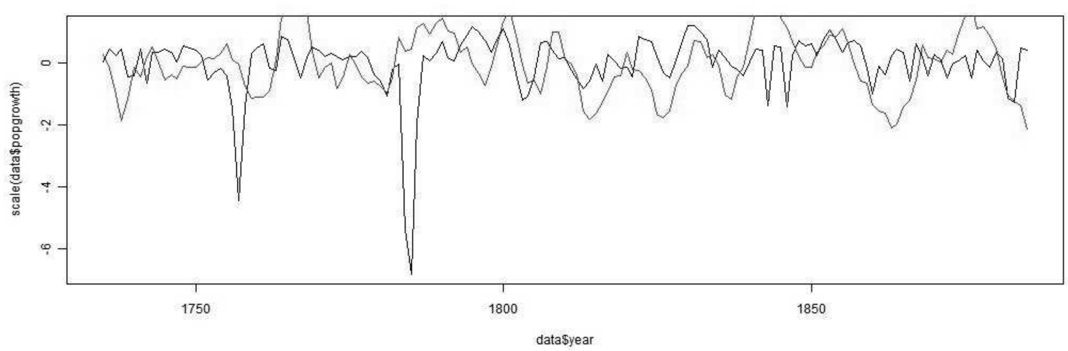
The population in Iceland grew from 43,678 in 1735 to 78,203 in 1900 (projecting an annual growth rate of 0.36). But it has expanded 4 times during the last century (projecting an annual rate of 1.31). The second figure also indicate the growth rate is more stable after 1900. These observations can be explained by the improvement of the living standard by the modern industrialization.

The volcanos in Iceland are very active. There are 12 big volcano eruptions from 1700. The largest population decreases (around 1757 and 1784) is caused by 2 volcano eruptions during the 18th century. A list of large volcano eruption events can be found from Global Volcanism Program of Smithsonian Institution website.

The last century coincide the global warming. And the population growth may not be related to the population growth because of the improvement of the living standard by the modern industrialization. So maybe we should concentrate our analysis on the pre-industrialization era.

The measured temperature from Iceland is only available for the recent 150 years. But we successfully reconstruct the Iceland temperature of past time by using the Greenland ice core data (more details on section 3).

The following figures represent the standardized population growth and 5 year moving average of the reconstructed temperature from 1735 to 1885. The population growth and temperature share the same increase and decrease pattern.



It looks like both the volcano eruptions and the temperature has some effect on the population growth rate.

3 Reconstruct Iceland Temperature from Greenland Ice Core Data

Ice core from ice sheet and ice caps are recognized as a best source to build the past climatical and environmental conditions. Recent ice coring projects in Greenland and Antarctica have successfully yield climate information back to hundreds of thousands of years. The climate systems of northern Iceland and southern Greenland is similar which give us the hope to use Greenland ice core data to reconstruct northern Iceland temperature.

The isotopic ratio $\delta^{18}O$ from ice core are widely used as a proxy for temperature. Several paper (Wikipedia ...) suggest a linear relation between the $\delta^{18}O$ and the temperature. The annual $\delta^{18}O$ of 4 Greenland ice core sites (Crete, Dye2, Milcent and CampCentury) for the last 1000 years can be downloaded from NOAA website.

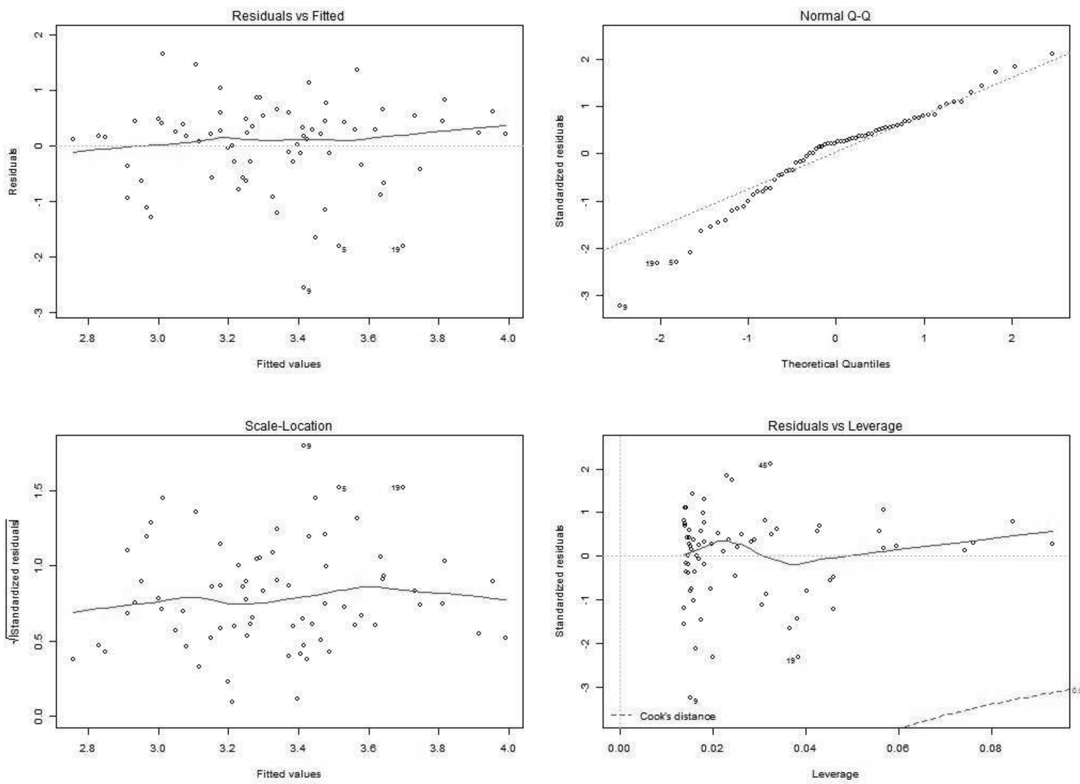
The northern Iceland temperature is calculated as the average of the measured temperature of 4 northern Iceland cities (Akureyri, Grimsey, Teigarhorn and Stykkisholmur).

Our approach is to use the measured northern Iceland temperature and corresponding $\delta^{18}O$ from Greenland ice core sites. Find the best ice core site to model the Northern Iceland temperature.

We find the Crete ice core data is the best in modeling the Northern Iceland temperature. because it gives the highest correlation and best linear regression fit.

	year	Crete	Dye2	Milcent	CampCentury	temp_n_iceland
temp_n_iceland	0.50	0.33	0.06	0.24	0.14	1.00

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	12.2250	3.0173	4.05	0.0001
Crete	0.2599	0.0881	2.95	0.0043



The equations for the linear model is:

$$t_n = 0.2599 * \delta^{18}O_n + 12.2250 \tag{1}$$

where t_n stand for northern Iceland temperature of year n. $\delta^{18}O_n$ stand for the annual average isotopic ratio in Crete ice core for year n.

This means a increase of 1‰ of $\delta^{18}O$ in Crete ice core is corresponding to 0.2599°c increase of northern Iceland temperature from 1884 to 1967.

We then plug in the $\delta^{18}O$ in Crete ice core data from 1700 to 1884 to this equation to reconstruct past northern Iceland temperature for 18th and 19th century.

4 Linear model by using indicator for post-volcano years

We notice the big population drops (less than -2%) all happened within 5 years after each volcano eruptions. So first we tried to use indicator to identify post volcano eruptions years. E.g. For the volcano eruption on 1755, the volcano indicator for 1755, 1756, 1757, 1758, 1759 is set to 1.

We tried the following linear model:

$$popgrowth = volcanoindicator + t_{ma5} + year \tag{2}$$

But this model didn't give us consistent results. We got different outputs by applying the indicator to 4 or 5 post volcano years with different temperature moving averages (3, 4, 5 years moving averages).

Volcano eruptions are rare events. We found the effect on volcano eruptions on population growth is decreasing over time. The 2 volcano eruptions in 18th century cause big population drops in Iceland. But volcano eruptions in 19th century has much less effect on population growth. And further investigation found the effect of volcano also depend on it's locations and severity measured by VEIs (The Volcanic Explosivity Index, a relative measure of the explosiveness of volcanic eruptions). The VEIs for volcano eruptions from 18th century may not be reliable because we only have documentary evidence.

5 Linear model by excluding post-volcano years

So it's wise to exclude the post-volcano years in our model. After removing data from 5 post-volcano years, the highest correlation is found on population growth and 3, 4, 5 year moving average of temperature (0.30, 0.31, 0.26).

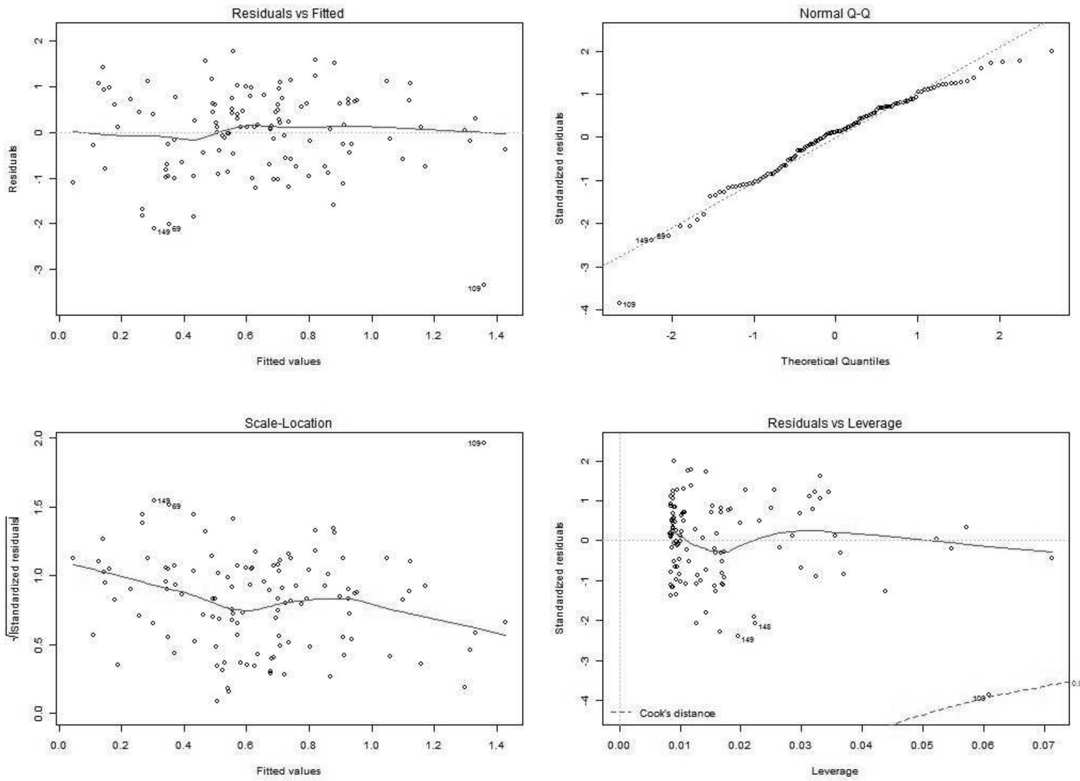
	popgrowth	temp	temp_ma2	temp_ma3	temp_ma4	temp_ma5
popgrowth	1.00	0.10	0.22	0.30	0.31	0.26

	popgrowth	temp_ma6	temp_ma7	temp_ma8	temp_ma9	temp_ma10
popgrowth	1.00	0.21	0.18	0.18	0.19	0.20

The linear regression model output and diagnostic diagrams are as follow. We choose the 4 year moving average because it is most correlated with reconstructed temperature and the gives the best linear fit (smallest p-value and residual errors).

$$populationgrowth = \beta_0 * t_{ma4} + \beta_1 \quad (3)$$

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-5.7614	1.8151	-3.17	0.0019
temp_ma4	1.9441	0.5509	3.53	0.0006



The diagnostic diagrams of the linear model is good. The residuals have constant variance. The temperature looks normal from qq plot. We also tried different date ranges (1735-1860) and different moving averages (3, 4, 5 years) and excluding different post-volcano years (3, 4, 5 years). All of them give similar results in terms of p-values, coefficients which suggests the model is pretty stable.

6 Conclusion

The volcano eruptions in Iceland do have a big effect on population growth in Iceland, especially within the 5 years after each volcano eruption. The effect is more significant on 18th century than 19th and 20th century as people get more knowledge of volcanos and are more prepared for the eruptions.

Because of the similarity of the climate system between south Greenland and north Iceland. We use the northern Iceland measured temperature from 1884 to 1967 to calibrate the ice core data. We are able to use the $\delta^{18}O$ of Crete ice core site in Greenland to reconstruct northern Iceland temperature from 1700 to 1885. The statistics model suggest a increase of 1‰ of $\delta^{18}O$ in Crete ice core is corresponding to 0.2599°C increase of northern Iceland temperature from 1884 to 1967.

The statistical model suggest during the non-volcano years from 1735 to 1885, Iceland population growth rate fluctuated with the reconstructed temperature. Population growth rate of one year is correlated (0.3) with average annual temperature of the past 4 years. And as average annual temperature of the past 4 years decrease/increase by 1 degree, the population growth rate decrease/increase by 1.94% with a standard error of 0.55%.

References

[1] Iceland Census Population Data
http://www.statice.is/?PageID=1406&src=/temp_en/Dialog/varval.asp?ma=MAN00000%26ti=Population+-+key+figures+1703-2009+++%26path=../Database/mannfjoldi/Yfirlit/%26search=HAGSKINNA%26lang=3%26units=number

[2] Large Holocene Eruptions
http://www.volcano.si.edu/world/largeeruptions.cfm

[3] Greenland Ice Core data
http://www.ncdc.noaa.gov/paleo/icecore/current.html

[4] CAMP CENTURY DELTA 18-O ANNUAL AVERAGES
http://www.ncdc.noaa.gov/paleo/icecore/greenland/gisp/campcentury/campc.html

[5] CRETE 1984 SITE B DELTA 18-O DETAILED
http://www.ncdc.noaa.gov/paleo/icecore/greenland/gisp/crete/crete.html

[6] MILCENT 1973 DELTA 18-O ANNUAL AVERAGES
http://www.ncdc.noaa.gov/paleo/icecore/greenland/gisp/milcent/milcent.html

[7] DYE 2 DELTA 18-O ANNUAL AVERAGES
http://www.ncdc.noaa.gov/paleo/icecore/greenland/gisp/dye2/dye2_data.html

[8] GISS Surface Temperature Analysis
http://data.giss.nasa.gov/gistemp/station_data/