The Impact of Precipitation and Temperature on Honey Yield in the United States

by

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Abstract

This thesis examines what effect climatic factors such as precipitation, maximum temperature levels, and minimum temperature levels throughout the U.S., have on honey yield. Using Bee Informed Partnership (BIP) survey data accompanied with climate data from across the U.S., and honey yield data from the National Agricultural Statistics Service (NASS), we examine the effect of monthly average precipitation and temperature on honey yield. We constructed two models to test these effects. In our first model, we found that the race of the bees, the age of the queen, the experience of the beekeepers, one precipitation, and one temperature variable were significant. In our second, fixed effect, model, we found that the year, both Growing Degree Day (GDD) variables, and two of the precipitation variables were significant.

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Introduction

The western honeybee (*Apis mellifera*) provides a greatly valued pollination service for many agricultural crops, and it ranks as the most common species of pollinator for crops around the world. (Hung et al. 2018). Hung et al. (2018) also state that it seems unlikely that any other pollinator species contends with honeybees in worldwide importance.

According to Hellerstein et al. (2017), almost 35 percent of the world's agricultural crops rely on pollinators, such as honeybees, to reproduce. Over the last decade, annual losses of managed honeybee colonies have been high. Dating back many decades, records show a great change in the number of honeybee colonies in the U.S. As the number of honey-producing colonies declined from 5.9 million to 2.3 million over about a sixty-year period from 1947 to 2008, some regions of the United States have seen above average increases or decreases in colony numbers (Hellerstein et al. 2017). As the world's population continues to grow exponentially, a worldwide food shortage is inevitable.

The economic impact of honeybees is extremely significant. In 2016, commercial honeybee keepers in the U.S. produced honey valued at $336 million (USDA-NASS 2017) and they also earned $354 million from pollination services (USDA-NASS 2016c) (Hellerstein et al. 2017). With a value of $366 million in 2016, it is imperative to understand the causes of increased or decreased honey yield.

Honey yield in the U.S. is often thought to be affected by colony collapse disorder, which is the unexplained loss of managed honeybee colonies (VanEngelsdorp et al. 2009). Some sources of this rapid dying off of honeybee colonies include the varroa mite and dangerous pesticide usage on the agricultural crops that honeybees pollinate (VanEngelsdorp et al. 2009). Although colony collapse disorder may play a major role in honey yield, one sometimes overlooked source of increased or decreased honey yield is the climate. The climate is important to honey yield because honeybees leave their colony to forage during the warm seasons and cluster together in their hives during the cold seasons (Hellerstein et al. 2017).

In a comprehensive literature study on climate change affecting crop yield, Kang et al. (2009) states that with increasing temperatures and changes in precipitation, water availability and crop production are likely to decrease in the future. Meanwhile, climate variability is one of the top factors influencing crop production on a yearly basis (Kang et al. 2009). Kang et al. (2009) concludes that food security is increasingly important for humans around the world, and that the availability of food and the quality of the food are the biggest challenges for scientists due to changing climate.

One major crop that relies on pollination services of honeybees is the almond. A little more than half of the country's honeybee colonies are transported to pollinate almonds in California during the month of February (Hellerstein et al. 2017). We see that climate factors such as too low or too high temperatures could greatly affect not only the pollination of almonds in California, but also the honey yield of each colony.

The increase or decrease of honey yield could also be directly linked to the health and well-being of the honeybees. Honeybee well-being is affected by a number of factors including insect pests (e.g., varroa mites), pesticides, and various other diseases (Hellerstein et al. 2017). One indicator of honeybee health could be the honey yield. Decreased honey yield could tell us there was an above average amount of precipitation in the foraging months, and could also reveal higher or lower temperature averages in the foraging months. Understanding the effect climate variables such as precipitation and temperature have on honey yield could be a very important factor in determining the causes of fluctuating honey yield.

Objective

The objective of this thesis is to identify the key determinants of honey yield through two different models. Our first model is a simple linear model using Bee Informed Partnership (BIP) survey data and monthly climate data obtained through Oregon State University's Parameter-elevation Regressions on Independent Slopes Model (PRISM). Our second model is a fixed effect model using honey yield data from the National Agricultural Statistics Service (NASS). We are interested in determining the impacts that precipitation levels and temperature have on honey yield. By achieving this objective, we will be able to identify and understand the most important months for honey yield and predict the effect climate change will have on honey yield.

Literature Review

Although there is not much literature on honey yield available, there have been a few studies that take a closer look into the causes of increased or decreased honeybee foraging and the effect of climate change on crop yield, which could link directly with changes in honey yield.

Hung et al. (2018) conducted a study of the importance of honeybees as pollinators in natural habitats using several varying temperature variables and different variables measuring precipitation. They conclude that the average proportion of floral visits contributed by honeybees was double that contributed by all bumblebee species. This is another testament to the great importance of honeybees in our world. Their results concluded that the proportion of visitations by honeybees increases with higher overall temperature and less seasonality (Hung et al. 2018). In their paper, they state that the analysis of how honeybee visitation correlates with environmental variables reveals correlation with both climatic and geographical predictors.

Another study, (Barganska et al. 2016), discusses that honeybees are bio indicators for contamination of the environment around their colonies. A period of intensive work begins with the first spring flight when the temperature reaches 12-15˚ Celsius, and it ends with the last flight before the winter season (Barganska et al. 2016). This is an important statement because we see how impactful the temperature can be for honeybees. If the temperatures are higher or lower than normal in the honeybee's respective location, the bees could become confused and begin their foraging too early or even too late in the pollination season. This would directly affect honey yield in said colonies. Barganska et al. (2016) states that honeybees mainly fly in dry conditions and that the optimal temperature for their foraging is 20-25˚ Celsius. If the temperature goes below 7-10˚ Celsius, bees become immobile due to the cold, and temperatures above 38˚ Celsius cause bee activity to slow down due to the heat (Barganska et al. 2016). Once again, these statements made throughout their paper indicate the importance of precipitation levels and temperature to honeybee foraging, which leads directly to the yield of honey.

It is well documented that Growing Degree Days (GDD) have a nonlinear effect on crop yield and that a temperature higher than a certain threshold may harm the growth period of crops (Schenkler et al. 2009). As seen later in this thesis, we use GDD as an independent variable in one of our regressions to determine its impact on honey yield in the United States.

A study by Miao, Khanna, and Huang (2016), investigates what impact climate and crop prices have on both the yields and acreage of corn and soybean crops in the United States. They show that GDD above 32 degrees Celsius have a negative impact on the corn and soybean crop yields. We can conclude that this yield reduction of corn and soybeans due to the changes in GDD also applies to honey yield, because honey yields are expected to be correlated with crop yields.

Change in climatic conditions from year-to-year is believed to be one of the major determinants of the fluctuations in crop yield (Isik et al. 2006). By developing an econometric model of crop yields, Isik et al. (2006) determined that climate change will more than likely have significant impacts on the crop yield variability. Because the climate change projections have distinct impacts on the mean crop yields, yield variability, and covariance, the mix of crop production and the acreage given to each crop are expected to change in the future (Isik et al. 2006). With crop production and crop acreage bound to reduce in the future because of climate change, we may see a reduction in honey yield as well, especially if those crops reduced are ones that honeybees frequently pollinate. By seeing fluctuations in honey yield and possibly having a lower honey yield in the future, Lobell et al. (2010) states that having an improved understanding of the potential effects of climate change on crop yields is central to planning appropriate and timely responses.

Data and Econometric Model

For our first model, we utilize zip code level BIP survey data (purchased from the University of Maryland) as well as zip code level PRISM Climate Group data. The BIP survey is a survey sent out to beekeepers across the U.S., and it asks specific questions about each beekeeper's operation. Questions range from asking about each beekeeper's zip code to demographic questions about each beekeeper. Some of these questions ask for honey yield in pounds per colony, their operation type, the location of their colonies, and the age of the queen bees in each of their colonies. We utilized BIP survey data from January of 2017 to April of 2018 in order to preform our analysis. The survey responses were extensive, including 2,652 observations. The PRISM Climate data was obtained and downloaded online through the PRISM Climate Group website[1]. We downloaded monthly precipitation, minimum temperature, and maximum temperature values on a 4km-by-4km grid level for every month for the years 1981 to 2018. We then mapped the grid level data to zip code level data.

[1] The PRISM Climate Group website can be reached at the following address: http://www.prism.oregonstate.edu/

The variables we obtained from the BIP survey are the survey year, the location of each beekeeper's colonies on a zip code level, operation type, race of the honeybees, queen bee age, honey harvest months, honey produced in pounds per colony, each beekeeper's experience in the industry, and the age of each beekeeper.

After obtaining the precipitation and temperature data from the PRISM Climate Group, we combined the monthly averages for each climate variable from January of 2017 to April of 2018. We chose to only go up to April of 2018 because our BIP data ceased at April of 2018. After merging the climate data with the BIP data, we used the variable LastHarvest to determine the last month each beekeeper harvested honey from their colonies. Using this LastHarvest variable, we were able to identify the three months prior to the last harvest month. We used this as a way to determine which months were most important to the harvest of honey. We then gathered the precipitation and temperature values for the four months for each beekeeper, creating variables m1, m2, m3, and m4 with "m" standing for month, 4 standing for the last harvest month, and 1, 2, and 3 standing for the three months prior to the last harvest month. For instance, if m4 represents July for a specific beekeeper, then m3, m2, and m1 are June, May, and April, respectively.

For the state-level honey yield analysis, we decided to create a weather index. In order to achieve this goal, we returned to the PRISM Climate Group website, and downloaded the same monthly values for precipitation and temperature, but this time we obtained the averages from 1981 to 2018. We decided to make the weather index span 20 years, from 1999 to 2018. We gathered and merged all 20 years of climate data with the original climate data from January of 2017 to April of 2018 based on zip code levels. We then obtained a 20-year monthly average for each climate variable to begin creating our index. To achieve this we created dummy variables for each previously mentioned m1, m2, m3, and m4. Table 1 goes into further explanation of the variables used as well as lists the summary statistics for model 1.

Let y_i denote honey yield in pounds per colony of beekeeper i. Let $M1precip_i$, $M2precip_i$, and $M3precip_i$ denote the precipitation level associated with beekeeper *i* in the three months prior to the honey harvest month, and let $M4precip_i$ denote the precipitation level associated with beekeeper *i* in the honey harvest month. Let $M1tmin_i$, $M2tmin_i$, and $M3tmin_i$ denote the minimum temperature level associated with beekeeper *i* in the three months prior to the honey harvest month, and let $M4tmin_i$ denote the minimum temperature level associated with beekeeper *i* in the honey harvest month. Let $M1tmax_i$, $M2tmax_i$, and $M3tmax_i$ denote the maximum temperature level associated with beekeeper *i* in the three months prior to the honey harvest month, and let $M4tmax_i$ denote the maximum temperature level associated with beekeeper *i* in the honey harvest month. Let $\mathbf{Z}_i$ denote a vector of other variables associated with beekeeper *i*'s honey yield, such as the race of the queen bee, queen bee age, years beekeeping, and beekeeper age. The model can be written as,

$$\mathrm{y}_i = \beta_0 + \beta_1 M1precip_i + \beta_2 M2precip_i + \beta_3 M3precip_i + \beta_4 M4precip_i + \beta_5 M1tmin_i + \beta_6 M2tmin_i + \beta_7 M3tmin_i + \beta_8 M4tmin_i + \beta_9 M1tmax_i + \beta_{10} M2tmax_i + \beta_{11} M3tmax_i + \beta_{12} M4tmax_i + \boldsymbol{\gamma}\mathbf{Z}_i + \in_i, \quad (1)$$

where $\beta_0, \beta_1, \beta_2, \ldots, \beta_{12}$ and $\boldsymbol{\gamma}$ are coefficients to be estimated, and $\in_i$ is an error term.

Our second, fixed effect, analysis uses state level honey yield data measured in pounds per colony downloaded from NASS (National Agricultural Statistics Service) for the years 1987-2018. We again used the PRISM climate data. We then merged the honey yield data and six months of precipitation data (April-September) by state Federal Information Processing Standards (FIPS) code and year.

After merging the two data sets into one, we then decided to define a threshold for each month of precipitation data in order to get a better look at the impact of precipitation on honey yield. To achieve this, we defined the threshold for each month of precipitation data as the simple average of precipitation for each of the six months of precipitation data for each state.

After determining the average precipitation level for each state and for each month of data, we created twelve more variables that show if each precipitation level is below or above the calculated threshold for each month. For example, if the precipitation level in April (PPT 4) was less than the threshold for April, the precipitation level for April was subtracted from the threshold, creating the value for PPT 4 Below Threshold to determine how much below the threshold the precipitation level for April was. If the precipitation level in April was more than the threshold for April, the threshold value was subtracted from the precipitation level, creating the value for PPT 4 Above Threshold to determine how much above the threshold the precipitation level in April was.

Another set of variables we used is called Growing Degree Days. These variables include GDD 0-28 and GDD 28. The GDD 0-28 variable explains the range of 0 to 28 degrees Celsius that is optimal for crop yield, and the GDD 28 variable explains the level of over 28 degrees Celsius, which is viewed as bad for crop yield. These two variables, along with the other fourteen variables are explained further along with the summary statistics in Table 2.

Let y_{it} denote honey yield in pounds per colony of state *i* in year *t*. Let $ppt4below_{it}$ denote the precipitation level below the threshold associated with state *i* in the 4^{th} month in crop year *t*, and let $ppt4above_{it}$ denote the precipitation level above the threshold associated with state *i* in the 4^{th} month in crop year *t*. These two variables are repeated all the way to $ppt9below_{it}$ and $ppt9above_{it}$. Let $\mathbf{Z}_{it}$ denote a vector of other variables associated with state *i*'s honey yield in crop year *t*, such as the year, GDD 0-28, and GDD 28. The model can be written as,

$$y_{it} = \beta_0 + \beta_1 ppt4below_{it} + \beta_2 ppt4above_{it} + \beta_3 ppt5below_{it} + \beta_4 ppt5above_{it} + \beta_5 ppt6below_{it} + \beta_6 ppt6above_{it} + \beta_7 ppt7below_{it} + \beta_8 ppt7above_{it} + \beta_9 ppt8below_{it} + \beta_{10} ppt8above_{it} + \beta_{11} ppt9below_{it} + \beta_{12} ppt9above_{it} + \boldsymbol{\gamma} \mathbf{Z}_{it} + \varepsilon_i + \epsilon_{it}, \quad (2)$$

where $\beta_0, \beta_1, \beta_2, \ldots, \beta_{12}$ and $\boldsymbol{\gamma}$ are coefficients to be estimated, ε_i represents time-invariant and unobservable factors that could affect honey yield, and ϵ_{it} is an error term.

Results

In our first model, we found statistically significant demographic results as well as a few significant climate variables. Seen in Table 3, the demographic variables Italian Race, Queen Age, and Years Beekeeping are all statistically significant, while M2 Precipitation has a significant negative correlation with honey yield and M1 Temperature Minimum has a significant positive correlation with honey yield. With the Italian race bees being a majority of the bees in our data, we see that this specific race of bees has a positive effect on honey yield. Queen age and years of experience in beekeeping also have a positive effect on the honey yield. We see that the more years of experience each beekeeper has, the higher their honey yield will be. With more precipitation in month 2 (M2 Precipitation), we see a negative impact on honey yield, and with a mild minimum temperature in month 1 (M1 Temperature Minimum), we can see a positive impact on honey yield.

We find several statistically significant results from our second, fixed effect model shown in Table 3. The variables Year, GDD 0-28, GDD 28, PPT 5 Above Threshold, and PPT 6 Above Threshold all have significant effects on honey yield. The variable Year being significant shows us that as time passes, there is a negative impact of climate change on honey yield. We can see that the two GDD variables show a positive effect on honey yield when the temperature is in the range of 0 to 28 degrees Celsius and a negative effect when the temperature is above 28 degrees Celsius. Perhaps the most interesting results are the Above Threshold variables for the two months of May and June. As seen in Table 3, there is a negative impact on honey yield when the precipitation in these two months is above the threshold for each month.

Conclusion and Discussion

In our first analysis, we used BIP data and PRISM Climate Group weather data in order to run a regression to see how demographic factors such as queen age, beekeeper age, race of the honeybees, and the number of years beekeeping, as well as monthly precipitation levels and monthly temperature levels have on the yield of honey in pounds per colony. We find a significant and positive correlation to honey yield with the Italian race of bees, the age of the queen, and the years of experience beekeeping, while M2 Precipitation is significant and negatively correlated with honey yield and M1 Temperature is significant and positively correlated with honey yield.

In our second analysis, we used NASS honey yield data, PRISM data, and GDD data to see the impact the climate data has on honey yield. We find that the variables Year, GDD 28, PPT 5 Above Threshold, and PPT 6 Above Threshold are all significant and negatively correlated with honey yield, while GDD 0-28 is significant and positively correlated with honey yield.

There are a few suggestions for further research. Honey yield is not crop yield, so we infer that the weather thresholds for corn and soybeans, as discussed in this thesis, may not be optimal thresholds for honey yield. It might be better to identify and use thresholds for honey yield rather than following the thresholds for crop yield. The growing season we used in our analysis was April to September. To account for orange blossoming in California, March to August might be a more reasonable growing season to use in further analysis. For the variable Queen Age, instead of coding the queen age from 1 to 4 as we did, it may be more beneficial to the analysis to use a middle value for the queen age and include a quadratic term for queen age in the regression. For our second model, the construction of the "above threshold" and "below threshold" variables may cause a collinearity issue, and there may exist a multicollinearity issue when so many climate variables are included in a single model. Further analyses may want to include interaction terms for weather variables with a regional fixed effect to determine the weather impacts on honey yield across various regions in the United States.

In conclusion, without the honeybee the world could plummet into a food shortage, greatly endangering the human population. Climate change and fluctuating precipitation levels could not only reduce honey yield but could also push honeybees towards extinction. It is important that others continue this study on the determinants of honey yield. It is likely possible that there are still many aspects of climate change and fluctuating precipitation levels that we do not yet fully understand.

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Table 1. Variable Explanation and Summary Statistics for Model 1

Variable	Explanation	Obs.	Mean	Std. Dev.	Min	Max
Italian Race	Race of the honeybees	2,004	0.465	0.499	0	1
Queen Age	Age of the queen bee	2,004	2.280	0.807	1	4
Years Beekeeping	Years of beekeeping experience for each beekeeper	2,004	9.679	10.986	1	65
Beekeeper Age	Age of each beekeeper	2,004	4.881	1.148	1	8
M1 Precip Deviation	Precipitation level difference of month 1 (in millimeters) between years 2017-2018 and the 20 year index	2,004	14.865	47.716	-139.084	309.695
M2 Precip Deviation	Precipitation level difference of month 2 (in millimeters) between years 2017-2018 and the 20 year index	2,004	14.430	50.959	-225.350	255.617
M3 Precip Deviation	Precipitation level difference of month 3 (in millimeters) between years 2017-2018 and the 20 year index	2,004	1.258	53.217	-134.900	230.979
M4 Precip Deviation	Precipitation level difference of month 4 (in millimeters) between years 2017-2018 and the 20 year index	2,004	1.393	59.638	-175.070	1027.001
M1 Temp Min Deviation	Minimum temperature level difference of month 1 (in degrees Celsius) between years 2017-2018 and the 20 year index	2,004	0.602	1.663	-7.361	4.175
M2 Temp Min Deviation	Minimum temperature level difference of month 2 (in degrees Celsius) between years 2017-2018 and the 20 year index	2,004	0.194	1.360	-10.520	3.870
M3 Temp Min Deviation	Minimum temperature level difference of month 3 (in degrees Celsius) between years 2017-2018 and the 20 year index	2,004	-0.175	1.156	-11.320	3.995
M4 Temp Min Deviation	Minimum temperature level difference of month 4 (in degrees Celsius) between years 2017-2018 and the 20 year index	2,004	0.103	1.371	-10.984	6.137
M1 Temp Max Deviation	Maximum temperature level difference of month 1 (in degrees Celsius) between years 2017-2018 and the 20 year index	2,004	0.348	1.496	-4.427	6.172
M2 Temp Max Deviation	Maximum temperature level difference of month 2 (in degrees Celsius) between years 2017-2018 and the 20 year index	2,004	-0.123	1.363	-3.849	5.232
M3 Temp Max Deviation	Maximum temperature level difference of month 3 (in degrees Celsius) between years 2017-2018 and the 20 year index	2,004	-0.257	1.117	-3.835	3.989
M4 Temp Max Deviation	Maximum temperature level difference of month 4 (in degrees Celsius) between years 2017-2018 and the 20 year index	2,004	-0.024	1.402	-3.859	4.849

Notes: Italian Race: Coded 1 for Italian race and 0 for non-Italian race; Queen Age: Coded 1 for less than 6 months old, coded 2 for between 6 months and 1 year old, coded 3 for between 1 and 2 years old, coded 4 for older than 2 years; Beekeeper Age: Coded 1 for 18-24 years old, coded 2 for 25-34 years old, coded 3 for 35-44 years old, coded 4 for 45-54 years old, coded 5 for 55-64 years old, coded 6 for 65-74 years old, coded 7 for 75-84 years old, coded 8 for 85 years old and above

Table 2. Variable Explanation and Summary Statistics for Model 2						
Variable	**Explanation**	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**
Honey	Honey produced in pounds per colony	1,368	60.596	21.991	10	190
Year	The year of each honey harvest and each year of precipitation data	1,797	2000.14	10.597	1981	2018
GDD 0-28	Growing degree days from 0 to 28 degrees Celsius	1,429	3518.78	560.530	2424.91	6826.47
GDD 28	Growing degree days above 28 degrees Celsius	1,429	75.826	69.983	1.19189	477.104
PPT 4 Below Threshold	Precipitation level in April below the threshold of each state	1,797	12.514	19.660	0	101.441
PPT 4 Above Threshold	Precipitation level in April above the threshold of each state	1,797	12.485	25.936	0	229.849
PPT 5 Below Threshold	Precipitation level in May below the threshold of each state	1,797	14.200	21.947	0	110.27
PPT 5 Above Threshold	Precipitation level in May above the threshold of each state	1,797	14.200	27.914	0	262.425
PPT 6 Below Threshold	Precipitation level in June below the threshold of each state	1,797	15.070	22.605	0	141.804
PPT 6 Above Threshold	Precipitation level in June above the threshold of each state	1,797	15.070	30.825	0	234.387
PPT 7 Below Threshold	Precipitation level in July below the threshold of each state	1,797	12.284	18.704	0	92.607
PPT 7 Above Threshold	Precipitation level in July above the threshold of each state	1,797	12.455	25.606	0	250.125
PPT 8 Below Threshold	Precipitation level in August below the threshold of each state	1,797	12.128	19.112	0	90.905
PPT 8 Above Threshold	Precipitation level in August above the threshold of each state	1,797	12.149	26.058	0	295.985
PPT 9 Below Threshold	Precipitation level in September below the threshold of each state	1,797	14.735	21.215	0	99.145
PPT 9 Above Threshold	Precipitation level in September above the threshold of each state	1,797	14.735	31.065	0	212.876

Table 3. Regression Results for Model 1 and Model 2			
Dependent Variable			
Honey Produced (in pounds per colony)			
Independent Variables for Model 1	**Coef. For Model 1**	**Independent Variables for Model 2**	**Coef. For Model 2**
Italian Race	0.074***	**Year**	-0.284***
	(0.027)		(0.055)
Queen Age	0.012***	**Growing Degree Days 0-28**	0.013***
	(0.002)		(0.005)
Years Beekeeping	0.040**	**Growing Degree Days 28**	-0.056**
	(0.020)		(0.023)
Beekeeper Age	-0.001	**PPT 4 Below Threshold**	-0.002
	(0.043)		(0.026)
M1 Precipitation	0.001	**PPT 4 Above Threshold**	-0.015
	(0.001)		(0.018)
M2 Precipitation	-0.001***	**PPT 5 Below Threshold**	-0.003
	(0.001)		(0.022)
M3 Precipitation	0.000	**PPT 5 Above Threshold**	-0.061***
	(0.001)		(0.017)
M4 Precipitation	0.000	**PPT 6 Below Threshold**	0.001
	(0.000)		(0.024)
M1 Temperature Minimum	0.056**	**PPT 6 Above Threshold**	-0.038**
	(0.023)		(0.016)
M2 Temperature Minimum	0.025	**PPT 7 Below Threshold**	0.040
	(0.025)		(0.027)
M3 Temperature Minimum	-0.010	**PPT 7 Above Threshold**	-0.026
	(0.028)		(0.019)
M4 Temperature Minimum	-0.027	**PPT 8 Below Threshold**	-0.001
	(0.025)		(0.026)
M1 Temperature Maximum	-0.034	**PPT 8 Above Threshold**	-0.009
	(0.023)		(0.018)
M2 Temperature Maximum	0.012	**PPT 9 Below Threshold**	0.028
	(0.028)		(0.024)
M3 Temperature Maximum	-0.007	**PPT 9 Above Threshold**	0.006
	(0.032)		(0.015)
M4 Temperature Maximum	0.032		
	(0.027)		