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Is Diminishing Solar Activity Detrimental to Canadian Prairie Agriculture?

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Abstract

During the grain growing months of May-July, the mean temperature on the Canadian prairies has cooled down by 2°C in the last 30 years. The cooling appears to be most certainly linked to diminishing solar activity as the Sun approaches a Grand Solar Minimum in the next decade or so. This cooling has led to a reduction in Growing Degree Days (GDDs) and has also impacted the precipitation pattern. The GDDs in conjunction with mean temperature and precipitation are important parameters for the growth of various grains (wheat, barley, canola etc.) on the prairies.

In this study, we investigate the impact of declining GDDs and associated temperature and precipitation patterns on Prairie grain yields and quality. Our analysis shows that there has been a loss of about 100 GDDs over the time frame of 1985-2019. The loss in GDDs is also linked to some of the large-scale Atmosphere-Ocean parameters like the Pacific Decadal Oscillation (PDO), North Pacific Index (NPI) and Arctic Oscillation (AO). Our analysis suggests grain yield and quality could be significantly impacted in the coming years as solar activity continues to diminish.

Keywords: Canadian Prairies, Solar Activity, Cooling, Growing Degree Days, Yield, Quality

Introduction

The Canadian prairies produce up to 75 million tonnes of grain annually (primarily wheat, barley, oats) and oilseeds (primarily canola) during the summer months of June-August. Canada is a major grain exporting country with the market value of the grains at about 30-40 billion US dollars. The Canadian Prairie agriculture provides livelihood for several thousand farming communities and is a valuable year-round business activity for the prairies. A good grain harvest in a given year depends critically on avoiding various summer weather & climate extremes which can adversely or favorably impact grain yield and quality (Garnett and Khandekar 2015, 2017). Wheaton describes how the droughts of 2001 and 2002 affected Canada's national GNP, which fell $5.8 billion during 2001 and 2002 with the biggest loss occurring in 2002 at $3.6 billion.

The most severe impact of extremely low temperatures affecting spring wheat came in 1992 and 1993 after the 1991 Pinatubo volcanic eruption. Summer temperatures were 2°C below normal resulting in a record low prairie protein content of 12% and fusarium head blight in Manitoba in 1993. In those years 75% of the spring wheat crop fell into the bottom two grades of #3 Canada Western Spring wheat and Feed wheat (Garnett and Khandekar, 2015). Buyers of Canadian spring wheat pay a premium for high quality and protein wheat for making bread and other edible products (Garnett, 2002). The 1992-1993 experience suggests that extremely low summer temperatures are more likely to affect quality than yield. In years in which record spring wheat yields were recorded, such as 2013, June-August temperatures averaged very close to the 35 years mean of 16.9°C.

Solar activity and variability are most commonly depicted using a solar cycle diagram as shown in Figure 1. The diagram shows variations in the 11-year sunspot cycles for the period 1900-2018. The impact of solar variability on the earth's climate has been extensively studied by a large number of scientists over the last 50 years. Among some of the important studies are those of Eddy (1976), Reid (1997), Plimer (2009) and Archibald (2014). These and many other studies have now helped improve our understanding of the sun/climate link. Many solar scientists are now of the opinion that the Sun is the primary driver of the earth's climate.

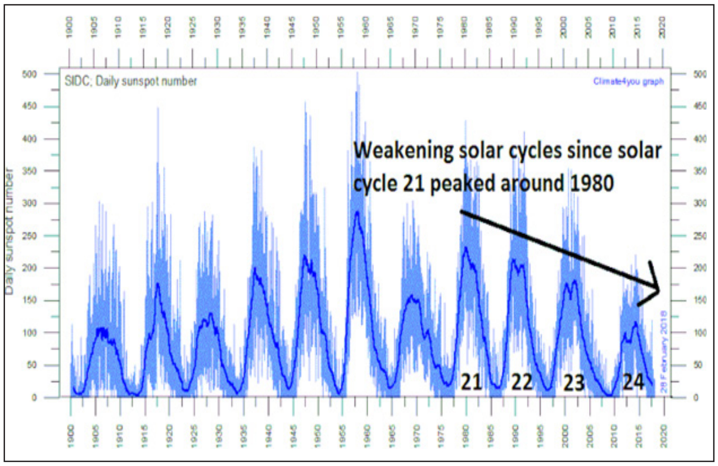


Figure 1. The 11-year sunspot cycle 1900-2018

Using a study from the 1970s Archibald (2014) warns that during 2014-2024 a 2^0C cooling could keep the Canadian wheat crop from ripening before the first frost. His prediction is supported by the research of Christensen and Lasson (1991) who demonstrate that global temperature is better correlated with the length of the previous cycle than with the amplitude of the coincident cycle. Butler and Johnson (1996) confirm the theory with a two-hundred-year temperature record at the Armagh Observatory in Northern Ireland.

Garnett *et al.* (2006) show that wettest May-Julys on the Canadian prairies occur with less than 70 sunspots/month while driest May-Julys are experienced with over 100 sunspots per month. This is in line with the findings of Svensmark and Friis-Christensen (1997) and Svensmark *et al* (2017) who describe a solar link to cosmic ray flux and global cloud coverage. Garnett and Khandekar (2015) find that wet (dry) summers are cool (hot) summers (r = -0.31 **).

Data, Study Area and Research Methods

The datasets used in this study are listed in Table 1. Agro-Climatic Consulting (ACC) refers to the first authors home based business. In this investigation, we treat the extremely cold June-August temperatures of 1992 and 1993 as outliers. Ranking, correlation, composite and trend analysis research methods were used.

Mean monthly solar activity during 1985-2019 was 54.2 sunspots. One S.D. is 44. Maximum solar activity was in 1990 averaging 154 sunspots/month while the lowest was in 2009 averaging 2 sunspots/month.

Figure 2 shows the location of 31 stations used to represent monthly temperatures for the period 2008-2019. Only stations that reported 80% of the time were used. Four Canadian prairie agricultural ecological zones are also shown based on the work (Padbury et al., 2002). Wheat is the largest crop grown on the Canadian prairies; however, canola has surpassed spring wheat in production.

Table 1. Data sets used in this study.

Monthly Data Type	Source	Number of Stations	Record Length
Temperature	Environment Canada	More than 100	1984-2007
Temperature	Agro-Climatic Consulting	31	2008-2019
Sunspots per month	U.S. Geophysical Center		1750-2019
AP Index	Climate 4 You		1984-2019
Pacific Decadal Oscillation	JIASO, University of Washington		1984-2019
Pacific North American Teleconnection	U.S. Climate Prediction Center		1984-2019
North Pacific Index	U.S. Climate Prediction Center		1984-2019
Arctic Oscillation Index	U.S. Climate Prediction Center		1984-2019
Grade Pattern & Protein Content	Market Analysis Group (MAG) Agriculture & Agri-Food Canada (AAFC)		1973-2019

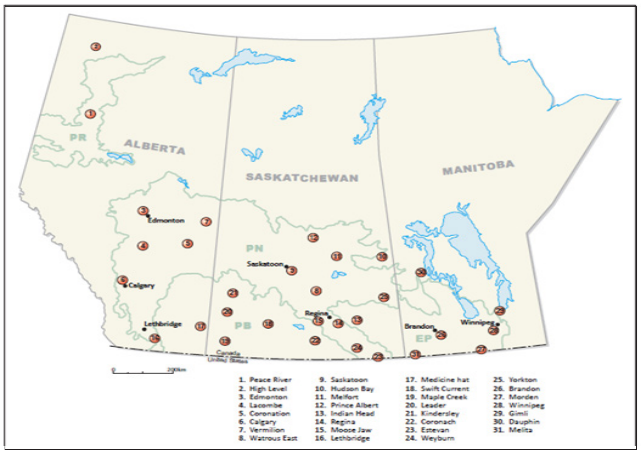
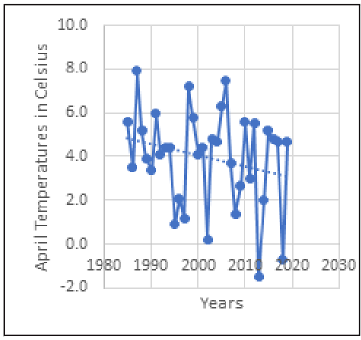


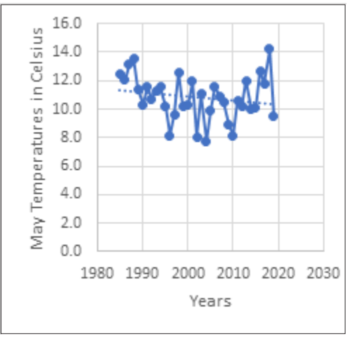
Figure 2. Station locations and ago-eco regions of the Canadian prairies from (Padbury *et al.,* 2002).

Results and Discussion

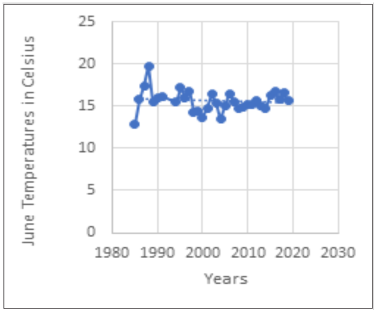
We first graphed the mean temperatures of April, May, June, July and August, the traditional growing season months. It revealed a 2°C cooling in April, a 1^{0}C cooling in May, a slight cooling in June and a nearly flat to slightly upward trend in July and August. These graphs suggest that planting is now occurring later in the growing season.



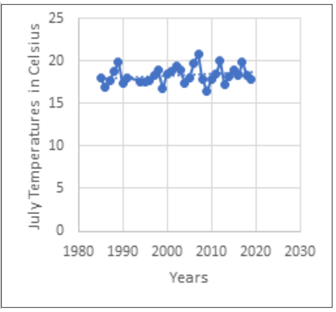
April



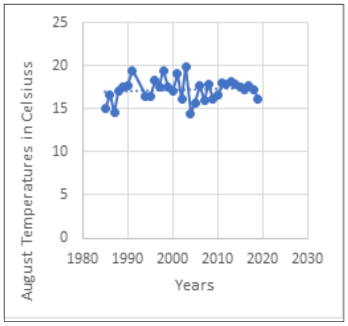
May



June



July



August

Next, we converted mean temperatures for the above months into GDDs as shown in Table 2. Schwanz (1997) describes how the GDD concept is used in scheduling planting and harvesting dates and selecting different plant varieties for different soil types. Spring wheat GDDs are calculated by subtracting a base temperature of 5°C from the mean monthly temperature and then multiplying by the number of days in the month. It requires 96 calendar days or 1080 GDDs to mature spring wheat and 112 days to mature canola. A base temperature of 0 is used with canola (Saiyid *et al.,* 2009) (Harker *et al.,* 2012). Spring wheat and canola are planted between the first week in May through the first week in June and harvested between mid-August to mid-October (Stefanski *et al* 1994).

The extremely low GGDs in 1985 could have been a factor in the mediocre yield of 1.73 t/ha. The amount of top-grade red spring wheat that year was half of the 10-year average. The market value loss in an extremely low GDD growing season such as 1985 is estimated at $250 mln Cdn for red spring wheat alone. In 2018 spring wheat made up 22% of the field crop area, (Wild Oats News Letter, June 30, 2020). With spring wheat about a quarter of the crop area, the total market value loss, when canola and other crops are included, could conservatively be 1 $blnCdn.

The market value loss assumes production of 20 mln tonnes, a price of $235/tonne for 13.5% protein #1 Canada Western Red Spring wheat (CWRS), with discounts of $5, $20 and $45 for #2 and #3 and feed wheat respectively when, comparing the 1985 and 10-year average grade patterns.

Garnett and Khandekar (2010) describe the prairie summer of 2010 as the wettest in 60 years, averaging 152% of normal rainfall April-September. It has been called the year that $3bln washed away. In 2010 there was only 11% in the top grade, a 30% drop from the 10-year average and protein content was below average.

Table 2. The conversion of mean monthly temperatures to GDDs.

	April	May	June	July	August	Period
Mean Temperature °C	4.0	10.8	15.5	18.2	17.1	1985-2019
Growing Degree Days (GDDs)		180	315	409	372	
Accumulated GDDs		180	495	904	1276	
1988		267	711	1136	1508	
1985		229	466	869	1183	
2004		85	424	895	1188	

Note: The base mean temperature at which spring wheat will germinate and grow is 5°C (41ºF)

3.1 The Solar influence on June-August Temperatures

Correlation analysis was done between June-August sunspot activity versus June-August mean temperatures and is shown in Table 3. The correlations are based on the agricultural year that begins in September of the previous calendar year and concludes the following August when crops ripen. It also captures the previous fall when soil moisture recharge can be important to yield. Garnett *et al.,* 2006 find similar and more frequent correlations between solar activity and May-July precipitation. The weaker correlations in Table 3 suggest that precipitation is more sensitive to solar activity than temperature.

Table 3. Correlation coefficients summer sunspots vs summer temperatures

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Period
Sunspots	0.32*	0.23	0.16	0.26	0.27	0.17	0.23	0.30*	0.20	0.27	0.20	0.32*	1985-2019

Figure 3 depicts what can be expected in summer GDDs with different levels of solar activity. It was created by ranking GDDS from highest to lowest and then grouping solar activity into three groups of four years representing the highest, median and lowest for the period. The correlations in Table 3 and this composite support the hypothesis that high (low) solar activity is conducive to a high (low) number of GDDs in June-August. The composite enables operational research.

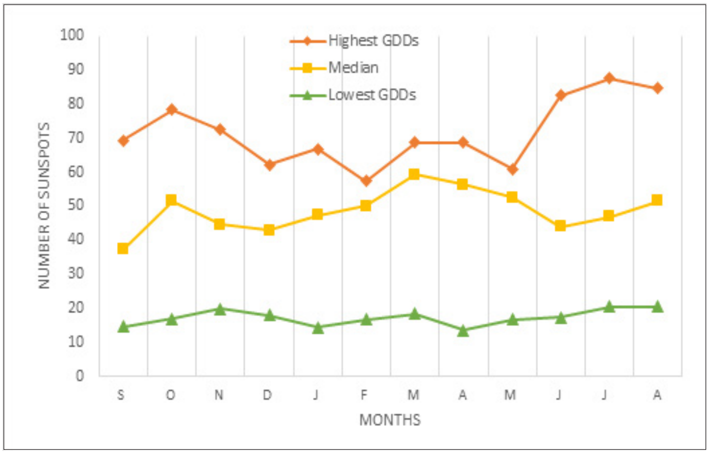


Figure 3. Number of sunspots prior to the highest (1988, 1991, 2003, 2012) median (1995, 2011, 2013, 2014) and lowest (1985, 2004, 2005, 2009) GDDS summers

In the very low GDD summers of 1985, 2004, 2005 and 2009 the average top grade of #1Canada Western Red Spring (CWRS) was 33% versus 10-year average of 41%. Protein content was equal to the 10-year average at 13.5%.

To further illustrate the solar effect on June-August GDDs, mean June-August sunspot activity was ranked from highest to lowest and is shown in Table 4. Figure 4 shows this ranking of June-August average sunspot activity. Figure 5 reveals the cooling trend after the ranking. The end points of the trend line (1150 and 1080) in Figure 5. indicate a loss of 70 GDDs or 2 GDDs/year during 1985-2019.

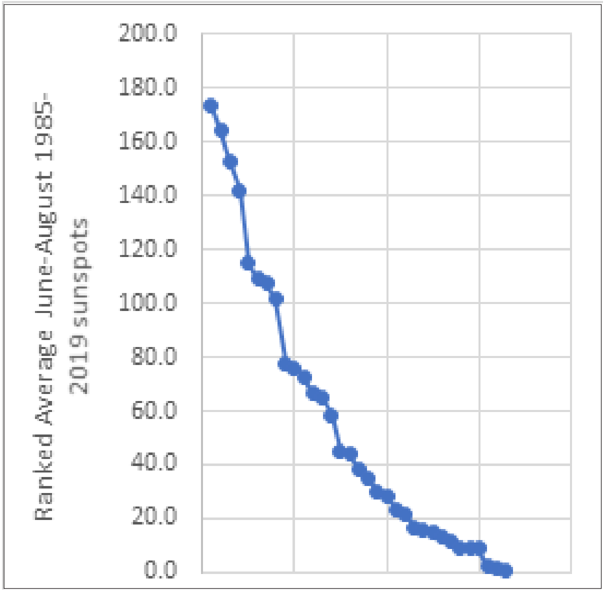


Figure 4. Ranked average June-August sunspot activity

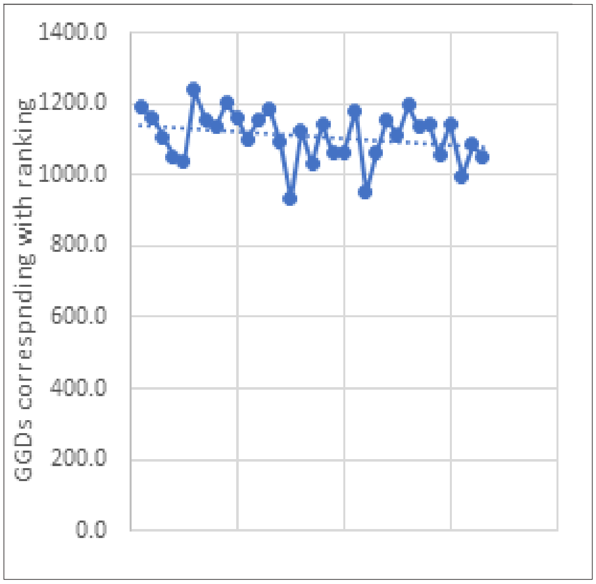


Figure 5. GDDS that correspond with ranked sunspot activity

Table 4. Ranked average of June-August sunspot activity, year and GDDs.

Ranked Solar Activity June-August	Associated Year	Corresponding Number of Growing Degree Days
173.2	1991	1189.5
164.0	1989	1163.0
152.7	1990	1108.1
141.8	2000	1052.0
115.0	1999	1036.0
109.1	1988	1241.4
107.4	2001	1157.0
101.4	2002	1136.0
77.8	2003	1204.0
76.2	1998	1162.0
72.7	2014	1103.0
66.4	2015	1157.4
64.7	2012	1185.9
58.5	2013	1093.5
45.1	2004	933.3
43.8	2011	1128.0
38.6	2005	1032.6
35.0	2016	1144.6
29.7	1987	1063.3
28.5	1994	1110.0
23.3	2017	1182.6
22.0	1985	952.2
16.4	2010	1066.0
15.8	1997	1156.3
14.8	1995	1110.3
13.0	2006	1198.0
11.5	1996	1135.0
9.3	2007	1146.0
8.9	1986	1057.2
6.5	2018	1145.0
2.2	2009	997.0
1.4	2008	1087.0
0.9	2019	1051.0

In Figure 6 below sunspot cycle #24 is compared with nine sunspot cycles during the 20th century and cycle 5 during the Dalton minimum of 1798-1809. The 11-year sunspot cycle has been numbered since the mid-18th century. In 2020 we are in year 11 of cycle 24 shown by the second line in Figure 6 (the 11th interval and point 12 on the x axis). The agricultural year is from September of the previous calendar year until August when crops ripen. As of May 2020, in agricultural year 11 there has been an average of 1.9 sunspots per month. Based on 9 cycles during the 20th century sunspot activity can be expected to remain very low for a few years. A recent study suggests that sunspot cycle 24 is ending in 2020 (Whitehouse, 2020).

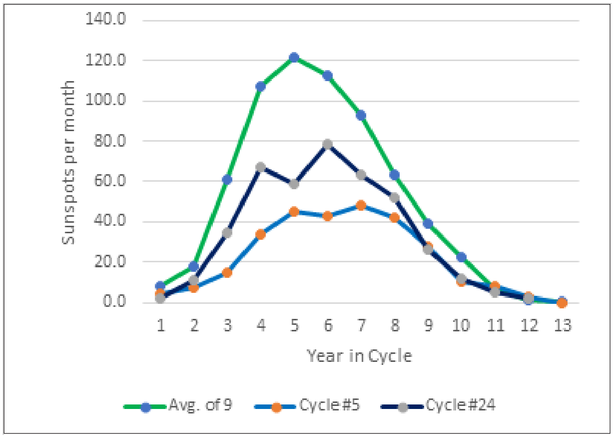


Figure 6. Top line is the average of nine sunspot cycles 1902-2009. Second line is sunspot cycle # 24, 2009-2020. The third line is cycle #5, 1798-1810 during the Dalton Minimum

The Dalton Minimum and Maunder Minimums were part of a cold period between 1650-1850 which was stressful for most of Europe with food wars and tens of millions of deaths as a result of extreme cold and a lack of heating in most homes. In 1816 the 11-year sunspot cycle peaked at 35 sunspots per annum versus the normal of 100 Plimer (2009) Soon and Yaskell (2003). There has been an average of 37 sunspots in cycle 24. How many sunspots will there be in cycle 25?

3.2 The Atmospheric-Oceanic influence on GDDs in May and June-July

The most dominant predictor of May and June-July GDDs was the Pacific Decadal Oscillation (PDO). It is a long-lived El Niño-Southern Oscillation (ENSO)-like pattern of Pacific Ocean climate variability, whose climatic fingerprints are most visible in the North Pacific-North American sector with secondary signatures in the tropics. Its behaviour during the 20th Century is shown in Figure 7.

Landsheidt (2001b) hypothesizes that the 22-year or Hale cycle of solar activity is associated with ENSO events over the decades and that it is conceivable that the state of the inter-decadal PDO constrains the envelope of interannual El Nino/Southern Oscillation Index (ENSO) variability. The magnetic polarities reverse each 11-year cycle returning to their original state in the Hale cycle. The Hale cycle started in 1996 and has lasted until 2020, during which Landsheidt anticipated La Nina conditions and a negative PDO. Figure 7 shows that he correctly forecast a negative PDO through 2007 which has trended downward since 1985.

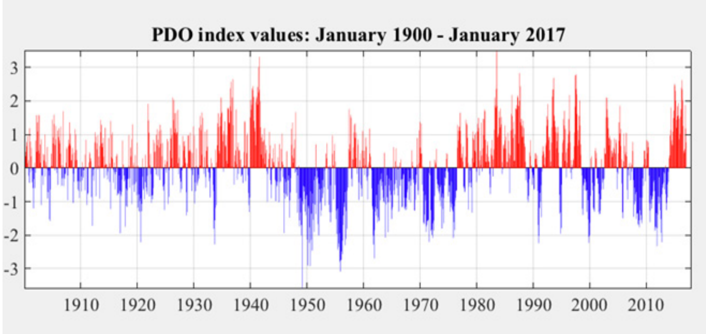


Figure 7. The Pacific Decadal Oscillation (PDO) January 1900-2017

Figure 8 shows a loss of 25 GDDs in May (end points of 195 to 170). Possible predictors were explored to explain this decline, namely sunspots, PNA, PDO and AO indices in which the PDO and PNA indices emerged as the most promising as shown in Table 5.

Table 5. Correlation coefficients of PDO and PNA versus May GDDs

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
PDO	0.34**	0.37**	0.39***	0.36**	0.31*	0.37**	0.34*	0.30*	0.16	0.12	0.19	0.12
PNA	-0.49***	-0.03	-0.05	0.11	0.19	0.08	0.10	0.03	-0.10	0.24	0.05	-0.30*

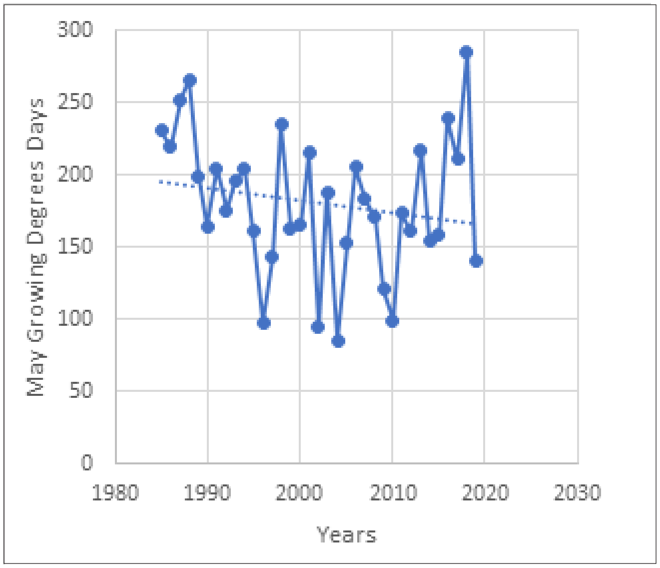


Figure 8. May GDDs 1985-2019

Correlation coefficients of the PNA and PDO indices versus May GDDs appear in Table 5. In Figure 9 the statistically significant months of December through April are accumulated to 'depict the sustained forcing of the PDO on May GDDs'. May is a key planting time when a certain amount of GDDs are needed to promote germination and tillering. Figure 9 allows for operational research on forecasting May GDDs.

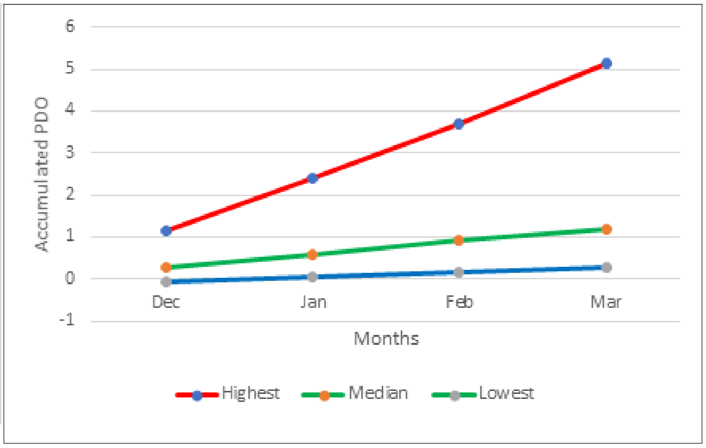


Figure 9. Composite of accumulated PDO values leading up the highest (1987,1988, 2016, 2018) median (1992, 2003, 2007, 2011) and lowest (1996, 2004, 2009 2010) May GDDs for the period 1985-2019.

Next, we looked into possible drivers of June-July GDDs which account for 700 of the 1080 or 65% of the GDDs required to mature spring wheat. Exploratory correlation analysis was done with sunspot, AP, PNA, PDO, AO and NP indices versus June-July temperatures. Table 6 shows the most promising predictors.

Table 6. Correlation coefficients of PDO, NPI and AO indices vs June-July GDDs

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
PDO	0.21	0.27	0.23	0.21	0.26	0.29*	0.26	0.39**	0.31*	0.40***	0.39**	0.30*
NPI	0.24	-0.19	0.01	-0.19	0.06	0.01	0.03	-0.27	-0.07	-0.12	-0.02	0.17
AO	0.17	-0.06	0.18	0.04	0.36**	0.18	0.11	-0.11	-0.04	0.09	0.28*	0.20

For Table 3, 5 and 6. ***1% level of significance 0.41, ** 3 % level of significance 0.349* 5% level of significance 0.296,

Stem extension, heading and flowering typically occurs in June and July when important spring wheat yield determining processes occur. Greatest water usage and vegetative growth occur during these months with temperature and radiation speeding up or slowing down water usage (Garnett, 2002). Crops grown in different climatic areas require different amounts of water that imparts an effect on the yield of the crop. For instance, the wheat crop requires 450-650 and rice 450-700 mm during the total growing period in which temperature is important (Brouwer and Heibloem, 1986). (Plimer, 2009) describes how very low temperatures in February of 2008 destroyed 40% of Vietnam's rice crop and killed 33,000 head of livestock. Could rice yields be more sensitive to extremely low temperatures than dryland spring wheat?

Table 6 shows the correlation coefficients between AO, PDO and NPI indices and June-July GDDs. Figure 10 depicts the sustained forcing of AO, PDO and NPI drivers on June-July GDDs. When operational research is done with Figure 10 the NPI anomaly sign is reversed to capture its persisting effect. It has also been made proportionate to other indices by dividing the input by six. Operational research with this composite provides general guidance as to June-July GDDs as early as April. This forecasting approach has been compared to canonical correlation analysis (CCA).

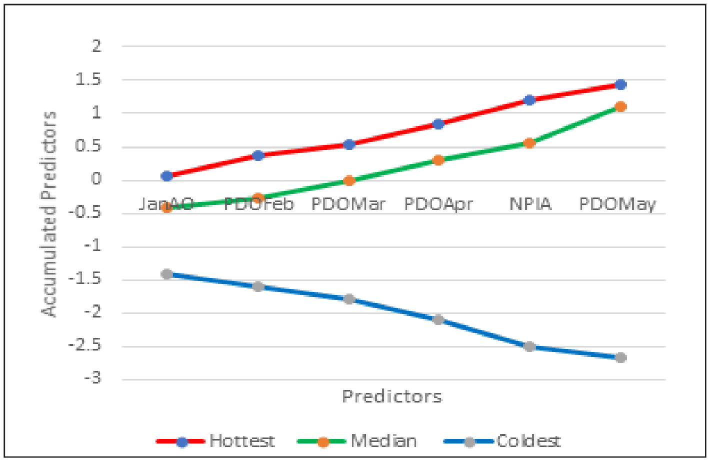


Figure 10. Composite of statistically significant AO, PDO and NPI predictors leading up to the four hottest (1988, 2002, 2006, 2007) four median (1991, 1996, 2003, 2011) and four coldest (1985, 1999, 2004, 2009) June-Julys for the period 1985-2019.

Landscheidt (2003), Archibald (2014), Morner (2015) and Whitehouse (2020) warn that planet earth could be entering a grand solar minimum. During agricultural years 2019 and 2020 (the past 21 months) there have less than 9 sunspots/month. Since September 2019 (Agricultural year 2020) there has been an average 1.9 sunspots/month, the lowest since 2009. In 2009, on August 26th, 2009 only 10% of the prairies harvest was complete versus the average of 50% (Ray Garnett Climate and Crop Letter August 26, 2009).

In short, when GDDS in May fall below 150 and June-August GDDs fall below 1000 GDDs it is expected that the top-grade red spring will fall 30-50% with an associated market value loss of $250 mln dollars for red spring wheat alone. The loss in growing degree days during May-August is linked to both low solar and atmospheric-ocean drivers with the solar influence most prominent in June-August and atmospheric-ocean influence more prevalent in May and June-July. Operational research with these composites provides a means of anticipating Canadian prairie May-August GDDs.

Summary and Conclusions

This research demonstrates the solar influence on spring wheat growing degree days (GDDS) from June through August. A loss of close to 100 GDDs was evident for the period 1985-2019, with a loss of 70 GDDs in June-August and a further loss of 25 GDDs in May. During agricultural year 11 (2020) of cycle #24 there has been an average of 2 sunspots per month. Based on the average of 9 cycles during the 20th century solar activity is expected to remain very low in agricultural years 12 (2021) and 13 (2022). Svensmark *et al.,* 2017 propose that increased ionization produced by cosmic rays (during low solar activity) can lead to growth aerosols into cloud condensation nuclei. This mechanism suggests increased cloud cover as the sun enters a grand solar minimum. Also revealed is the influence of Atmospheric-Oceanic drivers, such as the PDO, on Canadian prairie GDDS in the months of May and June-July. In essence, low solar activity, a negative PDO, the El Nino phase of ENSO and a negative PNA in the months leading up to and during the growing season may produce cooling and excess rain that results in inferior quality and yields.

A 1975 Newsweek article entitled 'The Cooling World' is a reminder of the 1970s when scientists were concerned about the impact of a cooling climate on world grain production. As the sun approaches a grand solar minimum there is a risk of the Canadian prairies becoming colder and wetter which is detrimental to grain growth and quality. This study also raises questions about GDD losses in other high latitude agricultural areas of northern Europe, Siberia and southern areas of Argentina and Chile.

Selected Glossary of Terms

The El Nino/Southern Oscillation (ENSO) in combination with the Indian monsoon system constitutes the largest single source of inter-annual climatic variability on a global scale, which has wide-ranging effects that are often severe. The Southern Oscillation is the difference in sea level pressure between Darwin and Tahiti. A positive (negative) SOI is indicative of La Niña (El Niño) conditions and colder (warmer) than normal sea surface temperatures in the eastern equatorial Pacific.

North Pacific Index (NPI) is the area weighted sea level pressure over the region 30ºN-65ºN, 160ºE-140ºW.

Pacific North American Teleconnection Index (PNA) is a derivative index of the El Niño/Southern Oscillation index and is typically positive during El Nino and negative during La Nina during the winter months. During the April to May period research has shown that zonal flow (negative PNA index) is associated with wetter cooler weather while meridional flow (positive PNA Index) is associated with drier hotter weather over the Canadian prairies.

Pacific Decadal Oscillation (PDO) is a long-term ocean temperature fluctuation in the Pacific Ocean, which waxes and wanes about every 20-30 years. When the index is positive the west Pacific becomes cool and a wedge in the east Pacific warms. The pattern reverses with a negative PDO. A positive (negative) PDO in the months leading up to the growing season tends to have warmer, drier (cooler, wetter) influence on the Canadian prairies growing season weather.

Solar Hibernation is a historic reduction in the energy output of the Sun that occurs about every 200 years. Earth has been experiencing solar hibernation since 2010 as a consequence of the Eddy solar minimum. Historical solar minimums in the past have been as follows: Dalton of 1795-1825, Maunder of 1645-1715, the Sporer of 1450-1540 and Wolf of 1280-1340. These were all periods of global cooling Casey (2014) Archibald (2009) and Plimer (2009).

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