

E. Ray Garnett¹, and Madhav L. Khandekar²

1. Agro-Climatic Consulting, Winnipeg, Manitoba, Canada, formerly of the Canadian Wheat Board

2. Former Environment Canada Scientist, Expert Reviewer IPCC 2007, Climate Change Documents, Markham, Ontario, Canada

Abstract: Since the new Millennium, numerous cold weather extremes (CWE) accompanied by heavy snow falls have been witnessed which have inflicted substantial economic losses worldwide. Among some of the notable cold weather extremes in Canada in the last five years have been: several heavy winter snowfalls in eastern Canada during 2015-2017, one of the heaviest snowfalls in recorded history in Vancouver and vicinity during December 2016 and the Calgary (Alberta) floods linked to sudden melting of heavy snow accumulation during the winter of 2013. These and many other such extreme cold events have inflicted heavy economic losses locally as well as on the regional scale in eastern and western Canada.

This paper examines CWE in Canada and elsewhere and assesses their economic impacts. This is an overlooked issue in the present climate change debate, which has been focused primarily on Warm Weather Extremes (WWE) like heat waves, floods, droughts and their possible linkage to the warming of the earth's climate. The paper further analyzes impact of large-scale atmosphere-ocean circulation patterns and the possible impact of the approaching solar grand minimum on increasing CWE of recent years. Finally, implications of our analysis for projecting future economic losses over Canada and elsewhere are considered.

Key words: cold weather extremes, costs, solar activity

1. Introduction

The ongoing debate over human-CO₂ induced warming of the earth's climate and linkage to extreme warm (EW) events like heat waves, floods, droughts etc. continues unabated. The debate gets into 'high gear' especially when there is an EW event like a severe heat wave, or a protracted drought during the northern hemisphere summer with articles and commentaries linking such EW events to Global Warming (GW) caused by human-CO₂ emissions. For example, during the summer of 2017 over North America, two hurricane strikes on the U.S. Gulf coast plus ongoing forest and wild fires in California,

prompted many environmentalist and climate pundits to opine that such EW events are on the rise and further such events are linked to increasing human-CO₂ emissions worldwide. What was missing in many of these articles was a careful assessment of past WWE events to determine: 1) whether or not such events are indeed on the rise and 2) if so, are human-CO₂ emissions a contributing factor? In the following, we provide a brief overview of the GW science espoused by the International Panel on Climate Change (IPCC), a UN Climate Body with its projections about increasing frequency of such events as the earth's climate warms further.

Following this, we list some of the most severe winters and their impacts in Canada and abroad since the new millennium. The next section analyses the economic impacts of such CWE over Canada in

Corresponding author: E. Ray Garnett, M.Sc., research areas/interests: long-lead forecasting, changing climate. E-mail: edmgar1@mymts.net.

particular as well as over the U.S.A., Europe and elsewhere. A brief section discusses a possible mechanism for the increasing CWE since the new millennium. Finally, implications of our analysis for projecting future weather extremes and economic losses are considered.

1.1 Brief Overview of the Global Warming-Extreme Weather Debate

Since its establishment in 1988, the IPCC has issued several climate change documents (Assessment Reviews) on a periodic basis, the latest being in 2013 September [1]. The scientific basis of the science of climate change is provided in extensive details in many of its documents. The gist of the IPCC science of climate change can be summarized as follows:

"Increasing concentration of atmospheric greenhouse gases (GHGs) and in particular atmospheric CO_2 emissions due to worldwide human activity has led to a warming of the earth's climate by

about 0.8°C since 1950. This warming, if continued unabated, will lead to increasing incidences of extreme weather events like heat waves, floods, droughts, forest fires etc. Further, the global sea level will rise by 25 cm to 50 cm or more by 2100 and this could lead to catastrophic damage to the world's major coastal cities and low-lying countries like Bangladesh, The Maldives in the Indian Ocean and many small Island nations in the south Pacific."

Fig. 1 presents global mean temperature anomalies (base: 1960-2017) and atmospheric CO_2 levels for the same period. The figure reveals that the earth's climate cooled relative to the long term mean between 1960-1975, warmed between 1976 and 1998 by about 0.6°C in tandem with the rise in CO_2 which is commonly referred to as "*Global Warming*". Since about 1998, the earth's climate has not warmed appreciably. This absence of warming for over 19 years is described as the *global warming hiatus*.



Fig. 1 Atmospheric CO₂ (Mauna Loa) and global temperature anomaly (HadCrut4) (source: Google Climate4you, p. 5).

A very recent paper [2] by Christy and McNider obtains a value of 1.1° C for climate sensitivity (that is warming of the earth's climate in the future resulting from a doubling of the present concentration of CO₂). As we discuss later, the earth's climate may not warm much in coming decades as the SUN enters a solar grand minimum during the next decade or so.

Another issue being intensely debated is the excessive warming projected by most climate models

when compared to the observed temperatures trend the likes of which is shown in Fig. 2. Observations show a levelling off in global temperatures since about 2000 and most notably since 2004 with model projections 200% or more of the observed warming since the new millennium. This is in sharp contrast with the study done by Christy and McNider [2] in which the best estimate is for future warming is now about 1°C at most by 2100.



Fig. 2 Observations from satellite and weather balloons for global lower tropospheric temperatures compared to the average or 102 IPCC CMIP-5 Climate Models (Sources: John Christy US, KNMI, The Netherlands).

The IPCC does not provide a definitive physical mechanism for its purported GW/EW link, but offers a simple explanation by arguing that a warmer climate holds more moisture which can lead to excessive rains and floods in some regions, while droughts and reduced rains occur in some other regions. This simple suggestion has morphed into the hypothesis that a warmer climate will bring more rains, floods, and also droughts, heat waves, forest fires etc. The IPCC also projects fewer "Frosts, cool nights and reduced (northern hemisphere) snow cover over mid-and high latitude areas with a high confidence level for the 21st century." We will show that this last statement is completely at odds with reality.

2. Data and Methodology

This is an observational study that uses trend and correlation analysis some of which has come from earlier research. The data sets used in this study are listed in Table 1. The source Agro-Climatic Consulting refers to a dataset compiled by the first author's home-based business.

3. Results and Discussion

3.1 The New Millennium: Beginning of Cold Weather Extremes?

3.1.1 In Canada

(1) The winter of 2002/03 was the first of five extremely cold winters witnessed in Canada with

several dozen extreme cold episodes to eastern Canada [3].

(2) February 2007 brought a major winter storm that affected over 300,000 people in south-eastern Canada and the northeastern United States [4].

(3) The Canadian prairie summer (June-August) of 2009 was the coldest in at least 60 years with temperatures averaging 3°C below normal. From December-August inclusively the Prairies were tied for the coldest nine months in 27 years [5].

(4) The winter of 2011/12 brought record-breaking snow accumulation of over 900cm to Sunshine Village,

a popular ski resort in the Canadian Rockies [6] (see Appendix B2).

(5) During May-June of 2013 Calgary, Alberta, Canada experienced extreme flooding resulting from a melted snowpack that extended from Canmore to Calgary Alberta worsened by several antecedent hydrological events in the Bow River watershed. It snowed almost non-stop between Thanksgiving and Easter. May and June rainfall in Calgary averaged 254 mm (170% of normal) exacerbating the flooding along the Bow River [7].

Monthly Data type	Source	Number of stations	Record Length
Temperature*	Environment Canada	400	1960-2004
Temperature*	Agriculture/Agri-Food Canada	105	2005-2009
Temperature*	Agro-Climatic Consulting	31	2010-2017
Sunspot data	U.S. Geophysical Data Center		1750-2017
API data	U.S. Geophysical Data Center		1967-2017
Northern Hemisphere snow	Rutgers Snow Lab		1967-2017
Canadian prairies*			

Table 1Data sets used in this study.

(A large number of Canadian and international newspapers have been sifted to extract brief reports on worldwide extremes).

(6) The winter 2013/14 was one of the coldest, snowiest and longest winters in almost entire North America in 40 years! Several thousand low temperature records were broken during the winter of 2013/14 and 2014/15 as shown in Fig. 3a and 3b [6].

(7) 2013/14 December-February temperatures averaged -16.2°C, making it the coldest winter for the period 1985-2016 over the Canadian prairies.

(8) Toronto, Ontario in 2013/14 experienced the coldest winter in two decades [8] (see Appendix B3).

(9) The winter of 2014/15 was exceptionally cold in Atlantic Canada and extended over the border into the U.S. northeast. The city of Boston reported record-breaking snow amounts of close to 300 cm (~110 inches). Most of the Canadian Atlantic Provinces and northeast U.S. and saw several heavy snowfalls and blizzards throughout the winter season with snow amounts of 25 cm or more on several occasions [10]. February 2015 Toronto (Canada's

largest city) recorded a low temperature of -35°C for several days. Please see Fig. 3a and 3b) [6].

(10) December-January of 2016/17 brought the longest cold snap in 32 years to the lower mainland of British Columbia, Canada. December-February of 2016/17 the Vancouver airport reported 64 cm of snow which was 200% of normal. February 3, 2017 the Vancouver airport received 12 cm of snow surpassing the previous record. On February 4, 2017Abbotsford B.C received 20 cm of snow breaking the previous record set in 1957 of 7.6 cm [9].

(11) December-February of 2016/17 was also cold and snowy in the Canadian maritime provinces. December 17 brought 52 cm of snow to Halifax 13 times the average. February 16, 2017 Moncton and Halifax received 107 and 80 cm of snow which was 345 and 600% of normal snow respectively. In the spring of 2017 April 4th brought 62 cm of snow to the Gander, Newfoundland Airport which was 400% of the

April average [10]. The Canadian Maritime provinces witnessed heavy to very heavy snow falls during the winter. (Examples Moncton and Halifax received 107 and 80 cm of snow on February 6, 2017, which were 345 and 600% of normal respectively).



Fig. 3a Plots of daily low temperature records broken and tied during the cold months of January 2014 (total of 3544) and February 2015 (total of 4145)



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Fig. 3b Plots of daily low temperature records broken and tied during the cold months of January 2014 (total of 3544) and February 2015 (total of 4145).

(12) As the winter season of 2017/18 approaches (at the time of writing this manuscript), much colder weather has already prevailed over many parts of Canada. As of October 2017, northern hemispheric snow cover was 21.2 mln sq.km, 21% above normal.

Parts of western Canada has received heavy snowfall since mid-November and much colder weather is expected once again over Canada. The province of Newfoundland witnessed a blizzard on December 15-16 with snow falls varying from 15 to 30 cm in

many locales. An extremely cold pattern has swept over most of Canada and parts of the U.S. since the Christmas Eve and may continue until mid-January 2018.

3.1.2 Cold Weather Extremes Elsewhere in the World Is the New Millennium bringing increased cold weather extremes? Observational evidence supports this in other parts of the world such as the U.S., Europe, Russia, India, Bangladesh, China, Japan and southern hemispheric countries. A list of 25 global Cold/Weather Extremes since 2000 is given in Appendix A.

How about Northern Hemispheric snow cover extent which the IPCC has predicted will decline? Fig. 4 shows fall (September-November) Northern Hemispheric Snow Cover extent (NHSC) for the period 1967-2017. A trend line reveals a 1 mln sq km (5 percent) increase. The 51-year mean is 19.3 sq. km which has been matched or exceeded in the last nine years. Snow cover extent has also been at trend or higher since 2009.

Fig. 5 below reveals winter (December-February) Northern Hemispheric Snow Cover extent (NHSC) for the period 1967-2017. The trend line indicates a 1 mln sq km (2-3 percent) increase in NHSC. Since 2010 snow cover extent has been above the trend 6 of the last 8 years. Since 2000 NHSC has been above the 51year mean of 45.64 mln sq. km. 11 of 18 years. December-February of 2010 and 2011 brought the 2^{nd} and 3^{rd} largest snow cover extent in 51 years.



Fig. 4 Fall Northern Hemisphere snow cover extent 1967-2017.



Fig. 5 Winter Northern Hemisphere snow cover extent 1967-2017.

A correlation of -0.29 exists between mean monthly sunspot activity and winter NHSC for the period 1967-2017 (significant at the 5% level, n = 51). Casey (2014) has identified calendar year 2010 as the start of a grand solar minimum or solar hibernation when the Suns activity or output is reduced for decades [4]. Grand solar minimums are associated with several key measurements of the sun, most notably reduced sunspot creation with peak sunspot activity in the 50 sunspots per month or lower range. Grand solar

minimums reoccur about every 200 years. This suggests that NHSC will increase rather than decrease in future years.

3.2 The Economic Losses Due to CWE

3.2.1 Canada

The present debate on climate change often refers to increasing economic losses as a result of warm extremes as identified by the IPCC while making no reference to similar losses related to cold extremes. In view of increasing cold extremes of recent years, it is important to assess how recent cold extremes are impacting Canada's economy.

(1) The cost of the 2013 flooding in Calgary (related to snow melt) is now judged to be the costliest weather disaster in Canada with the loss estimated at between \$3-6 billion and led to a 2 billion drawdown of Canada's Gross Domestic Product (GDP) [7].

(2) The winter of 2013/14 was one of the longest, snowiest in Canada and Toronto (Canada's largest city). According to the Paris based OECD (Organizations for Economic Co-operation Development) the winter severity was linked to the smallest GDP growth rate among the G-7 countries, an estimated economic loss of \$20 billion [8] (Appendix B3).

(3) The OECD blamed several winter blizzards in the northeast U.S.A. and Canada in 2015 for a drawdown of the economy of at an estimated loss of \$10 billion.

(4) Canada's westernmost province (British Columbia) in 2016/17 witnessed one of the severest winters in decades with heavy snow accumulations. The economic loss has been estimated at \$2 billion. Several heavy snowfalls in Atlantic Canada and a powerful blizzard in Newfoundland (Canada's easternmost province) has inflicted an estimated economic loss of .750 million to one billion dollars.

3.2.2 Economic Costs in the U.S.A. and Elsewhere

Using representative numbers for U.S. GDP (Gross Domestic Product) we obtain figures of between 50 and 75 billion dollars for the U.S. as economic losses for each of the winter seasons of 2013/14 and 2014/15. In reality, total economic losses for North America (excluding Mexico) could be as high as about \$US 100 billion, for each of the winters 2013/14 and 2014/15. The losses were primarily due to disruption in transportation, delay and/or cancelation of airline flights, delays in the construction and engineering sector and in loss of revenue to retail businesses as a consequence of fewer customers and poor sales.

A similar calculation can be made for Europe related to the extreme winter conditions in various regions during 2008/09 and 2012/13. Accounting for different socio-economic states for eastern and western Europe, estimates range from 25 to 50 billion dollars (US\$), as direct economic losses in Europe. Indirect losses related to energy need and impact on human health are not taken into account. Japan and China also experienced economic losses in 2013 and 2014 as a consequence of extreme winter conditions estimated at 10 to 25 billion (US\$) dollars.

3.2.3 Atmospheric Dynamics and Mechanics

According to Plimer 80% of the global temperature trend between 1860 and 2010 can be accounted for by solar activity [16]. Similarly, Landsheidt 2000 found that near earth variations in the solar wind, measured by the geomagnetic aa index, correlated well with global temperatures between 1868 and 1988 [17]. The aa index is now commonly referred to as the AP index. Georgieva et al. (2005) demonstrate that the AP index is more representative of solar activity than a monthly count of sunspots and can hence be used as a proxy variable for solar activity [18].

The API behaviour in 2009 was remarkably consistent with 2009 June-August temperatures over the Canadian prairies which were the coldest in at least 60 years as shown in Fig. 6. There was an average of 2 sunspots a month between September 2008 to August 2009 the deepest solar minimum since 1913. For the period 1985-2015 a significant correlation of 0.37 was found between mean monthly AP data and May-July temperatures over the Canadian prairies. These

observations and findings are consistent with Svensmark's global cloud forcing theory discussed by Svensmark and Calder (2007) and Svenmarks et al. (2017) [19, 20].

The primary reason behind the extreme winters of recent years appears to be low solar activity or a correspondingly low API. Soon and Legates in 2013 proposed a link between the recent increase in CWE and low sunspot activity which modulates the Total Solar Irradiance (TSI), which in turn impacts hemispheric temperature gradients [21]. Researchers Van Geel and Ziegler, Benestad and Lockwood et al. also point to a solar link [22-24]. In the case of Europe CWE appears to be the result of low solar activity and a negative phase of the North Atlantic Oscillation (NAO) [25].

The 11-year sunspot cycle has been numbered since 1750 and we are currently in about year 10 of sunspot cycle #24 as shown in Fig. 7. There has been an average of 18 sunspots in recent months which is much lower than the average of 66 sunspots per month for the period 1967-2017. Solar activity can be expected to decline through August of 2018 and through 2020 as



Fig. 6 Mean monthly AP Index 1967-2017.



Fig. 7 Top line is the average of nine sunspot cycles 1902-2009. Second line is sunspot cycle # 24, 2009-2017. Third line is cycle #5, 1798-1810 during the Dalton Minimum.

demonstrated in Fig. 7. Historical sunspot data reveals that between 1814-1823, during the Dalton solar minimum, there was an average of 22 sunspots per month at a time when northern Europe became brutally cold and economic depression ensued [26]. In the winter of 1812/13 Napoleon lost most of his Grand Army of 600,000 as a result of hunger and piercing cold in retreating from Moscow [27].

4. Concluding Remarks

This paper brings out the current reality of climate change as evidenced by the increasing number of cold and snowy extremes worldwide. This is an overlooked issue in the present global warming/climate change debate. The IPCC espoused science has highlighted WWE like heat waves, droughts, floods and fires while ignoring the 'Cold' reality of the earth's climate since the new millennium. Our analysis links these increasing cold/snowy extremes to solar variability and its complex interaction with large scale patterns such as the NAO. The latest paper by Svensmark et al. (2017) shows that increased ionization produced by cosmic rays can lead to the growth of aerosols into cloud condensation nuclei [20]. This mechanism suggests increased cloud cover as the sun enters into a grand solar minimum. A colder climate awaits us.

Acknowledgements

Some of the findings in this paper were presented at the Annual Congress of the Canadian Meteorological Society Congress held in Toronto, Ontario, Canada in June 2017. Cold weather extremes have been extracted from a large source of worldwide weather data and newspaper stories from around the world.

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Appendix A Cold Extremes Elsewhere in the World

1) The Northern Hemisphere witnessed four severe winters in 2002/03, 2005/06, 2009/10 and 2011/12 with the European continent bearing the brunt of the severity [11].

2) The severity of the winter of 2002/03 extended as far south as Vietnam and Bangladesh where several hundred-people died of exposure [11].

3) The winter of 2005/06 was exceptionally cold over most of western and northeastern Europe. In Poland, 23 people were reported to have died as a result of cold and heavy snow blanketing the Baltic coast city of Gdansk [12].

4) In May of 2006 South Africa reported 54 cold weather records [4].

5) In January 2007 Bangladesh experienced the coldest wave in 40 years [4].

6) Snow fell in Buenos Aires Argentina in July of 2007 for the first time since 1918 and temperatures were recorded as low as -25°C [6].

7) In 2007/08 China battled the coldest December-February in 100 years [4].

8) The winters of 2008/09 and 2009/10 were both exceptionally cold and snowy over parts of Western Europe and also in the US Mid-Atlantic States [13-15].

9) The winter of 2009/2010 Scotland suffered some of the coldest winter months in almost 100 years while Siberia witnessed perhaps the coldest winter ever recorded [13-15].

10) June and July of 2010 very cold temperatures lead to several dozen deaths in Argentina and Chile [6].

11) December 2010 Britain recorded its coldest December in 120 years, the second coldest December since records began in 1659 [6].

12) The winter of 2009/10 Beijing had its coldest day in 50 years (near 0°) along with its worst snowfall in decades [4].

13) January 11, 2010 Miami, Florida broke a 1927 record for cold. Later that year December in Orlando, Florida was the coldest on record [4].

14) January 21, 2011 International Falls in Minnesota set a new record of -46°F beating the previous record set in 1954 [4].

15) In early December of 2010 Sweden reported its coldest winter in 100 years [4].

16) Winters of 2011/12 & 2012/13 were very cold and snowy in parts of Central and Eastern Europe and also in parts of North America [6].

17) The Czechoslovakia Republic recorded lows of -40°C in February 2012 for a week that lead to several dozen deaths [6].

18) November 2011 to mid-January 2012 Cordova, Alaska received three times the annual amount of snowfall closing schools down for weeks [6]. Please see **Appendix B1**

19) The Danube River remained frozen till late May 2012[6].

20) In north India, the months of December 2012 and January 2013 were significantly colder than normal leading to several hundred deaths, as reported by the India media [6].

21) The 2013/14 winter was also significantly colder in parts of north Japan and India. In northwest India a snow accumulation of 75cm was reported in January-February 2014 [6].

22) In northeastern states of U.S., the January-March period of 2015 was the coldest since 1895. Boston reported a record-breaking snow amount of 300 cm [6].

23) In February 2015 heavy snow and avalanches in the Panjshir Valley of Afghanistan killed over 200 people [6].

24) The winter months of January and February 2015 were once again significantly colder than normal in north India, causing transportation delays due to heavy fog and affecting lives of 300 million people living in north Indian cities and towns [6].

25) In January 2016 a monster blizzard shut down the Federal government in Washington D.C for a day and caused 4500 flight cancellations. Appendix B4





National Guardsmen dig out from what has been the biggest snowfall in decades in Cordova, Alaska.

The fact that the second tent even of your standards?" Figelsia and his family have been forced to remain inside their fishing lodge for the past nine days. Cordova, a community of 2,200 on the east side of Prince William Sound, is at the heart of a series of storms that have been ravaging parts of Alaska this winter. The latest storm hit much of south-central Alaska, with ava-lanches along the Seward Highway closing the only route south out of Anchorage and cutting off the city anchorage and cutting off the city rom neighbourhoods to the south

Since November, the fishing com-munity of Cordova has received 447 centimetres of snow and 12 snow heavier as it piled up to 18 metres high on roofs. Cordova usually receives about

ture into a cold environment, and it turns into snow," Albanese said. The community has received so much snow it has run out of scoop snow shovels — a special shovel that makes removing snow from roof-tops easier, savs Figelski, who owns

doors. Schools have been closed for a week and are expected to remain closed for another week. With files from Associated Press

B1 Snow Fall was 300% of the annual normal November 2011 to mid January of 2012.



B2 Winter of 2011/12 brings record-breaking snow accumulation of over 900 cm to Sunshine village in the Canadian rockies.



Canada to have lowest first-quarter output in G7 as business reels from season's severe temperatures

DANA FLAVELLE

EDNESS EXPORTS² It's not just the weather that's been frosty. Canada's economic growth has been in the deep freeze this winter and repeated lashings of ice and anow. The team of the state of the state of the state of the worst winter in two decades, according to Environ-ment Canada. The severe weather shut airports, slowed truck delivries, stalled construction and kept consumers at home.

alowed truck deliveries statied construction and log-consumers at how the statied construction and log-tenting bills and rising insurance premiums. And its not over yet. Environment Canada predicts a colder than normal April. While it will feel warmer because the swill be allow arenge, metocorologist Good Coulours will be allow arenge, metocorologist Good Coulours will be allow arenge, metocorologist Good Coulours will be season is technically almost behind us — March 20 is the Golf as last of spring — Comada is still aeling from its impact, ecquomists say.

"Prolonged bouts of cold and significant le precipitation have, and are continuing to have terial impact on output growth," wrote Scotia deputy chief economist Aron Gampel. Canada's economy is expected to grow just (

ths of this year on for Ec stgn TheIIs ted, while the G7 is will fa OECD ain 2.2 per cent, 1 rowth in Japan, Ge And more lies ahea "The United States

head. ates and Canada are both an uneven pattern of growth in part to the disruptive eff ed episo The

ICY continued on B2

Weather woes: Small and big business feeling chill, B2

B3 The Winter of 2013/14 Brings the Coldest Winter in Two Decades to Toronto, Canada.



B4 A Monster Blizzard in late January 2016 in Washington D.C. results in 4500 flight cancellations as reported in the Hindustan Times January 23, 2016.