DROUGHT TRENDS ACROSS CANADA

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Knowledge of the past is extremely important when it comes to contemplating future climatic possibilities; for what's happened before can clearly happen again. Hence, this summary briefly reviews the history of Canadian droughts with respect to how they varied over the past several centuries in response to significant changes in global air temperature but very little change in the atmosphere's CO_2 concentration, which exercise provides some idea of how Canadian droughts might possibly vary in the post-Little Ice Age world that is known as the Current Warm Period.

Gan (1998)[1] performed several statistical tests on data sets pertaining to temperature, precipitation, spring snowmelt dates, streamflow, potential and actual evapotranspiration, and the duration, magnitude and severity of drought throughout the Canadian Prairie Provinces of Alberta, Saskatchewan and Manitoba. The results of these several tests suggest that the Prairies have become somewhat warmer and drier over the last four to five decades, although there are regional exceptions to this generality. But after weighing all of the pertinent facts, Gan reported that "there is no solid evidence to conclude that climatic warming, if it occurred, has caused the Prairie drought to become more severe," further noting, in contrast to most climate-alarmist claims, that "the evidence is insufficient to conclude that warmer climate will lead to more severe droughts in the Prairies."

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Working in the same general area, Quiring and Papakyriakou (2005)[2] used an agricultural drought index (Palmer's Z-index) to characterize the frequency, severity and spatial extent of June-July moisture anomalies for 43 crop districts from the agricultural region of the Canadian prairies over the period 1920-1999. This work revealed that for the 80-year period of their study, the single most severe June-July drought on the Canadian prairies occurred in 1961, and that the next most severe droughts, in descending order of severity, occurred in 1988, 1936, 1929 and 1937, for little net overall trend. At the same time, however, they say there was an *upward* trend in *mean* June-July moisture conditions. In addition, they note that "reconstructed July moisture conditions for

[1] http://www.co2science.org/articles/V1/N7/C3.php.
[2] http://www.co2science.org/articles/V8/N19/C2.php.

the Canadian prairies demonstrate that droughts during the 18th and 19th centuries were more persistent than those of the 20th century (Sauchyn and Skinner, 2001)."

In a subsequent study that covered an even longer span of time, St. George and Nielsen (2002)[3] used "a ringwidth chronology developed from living, historical and subfossil bur oak in the Red River basin to reconstruct annual precipitation in southern Manitoba since AD 1409." And their findings? They say that "prior to the 20th century, southern Manitoba's climate was more extreme and variable, with prolonged intervals that were wetter and drier than any time following permanent Euro-Canadian settlement." Hence, it is clear that 20th-century warming, if anything, has led to more *stable* climatic conditions with *fewer* hydrologic extremes (floods and droughts) than was typical of prior Little Ice Age conditions. Consequently, St. George and Nielsen conclude that "climatic case studies in regional drought and flood planning based exclusively on experience during the 20th century may dramatically underestimate true worst-case scenarios." What is more, they indicate that "multidecadal fluctuations in regional hydroclimate have been remarkably coherent across the northeastern Great Plains during the last 600 years," and that "individual dry years in the Red River basin were usually associated with larger scale drought across much of the North American interior," which suggests that their results for the Red River basin likely also apply to the entire larger region.

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Taking an even longer look back in time, Campbell (2002)[4] analyzed the grain sizes of sediment cores obtained from Pine Lake, Alberta, Canada to derive a non-vegetation-based high-resolution record of climate variability over the past 4000 years. Throughout this record, periods of both increasing and decreasing moisture availability, as determined from grain size, were evident at decadal, centennial and millennial time scales, as was also found by Laird *et al*. (2003)[5] in a study of diatom assemblages in sediment cores taken from three additional Canadian lakes. Over the most recent 150 years, however - the last century of which climate alarmists typically characterize as having experienced "unprecedented" global warming - the grain size of the Pine Lake study generally remained above the 4000-year average, indicative of relatively stable and *less* droughty conditions than the mean of the last four millennia.

3 http://www.co2science.org/articles/V5/N44/C3.php.
4 http://www.co2science.org/articles/V6/N2/C2.php.
5 http://www.co2science.org/articles/V6/N19/C2.php.

In a somewhat different type of study in another part of the country, Carcaillet *et al*. (2001)[6] developed high-resolution *charcoal* histories from laminated sediment cores extracted from three small kettle lakes located within the mixed-boreal and coniferous-boreal forest region of eastern Canada, after which they determined whether vegetation change or climate change was the primary determinant of the fire frequency variation they observed, comparing their fire history with hydro-climatic reconstructions derived from $\delta^{18}O$ and lake-level data. Throughout the Climatic Optimum of the mid-Holocene, between about 7000 and 3000 years ago when it was significantly warmer than it is today, they found that "fire intervals were double those in the last 2000 years," meaning fires were only half as frequent throughout the earlier warmer period as they were during the subsequent cooler period. They also determined that "vegetation does not control the long-term fire regime in the boreal forest." Instead, they found that "climate appears to be the main process triggering fire." In addition, they report that "dendroecological studies show that both frequency and size of fire decreased during the 20th century in both west (e.g. Van Wagner, 1978; Johnson *et al*., 1990; Larsen, 1997; Weir *et al*., 2000) and east Canadian coniferous forests (e.g. Cwynar, 1997; Foster, 1983; Bergeron, 1991; Bergeron *et al*., 2001), possibly due to a drop in drought frequency and an increase in long-term annual precipitation (Bergeron and Archambault, 1993)."

Also working in eastern Canada, Girardin *et al*. (2004)[7] developed a 380-year reconstruction of the Canadian Drought Code (CDC, a daily numerical rating of the average moisture content of deep soil organic layers in boreal conifer stands that is used to monitor forest fire danger) for the month of July, based on 16 well replicated tree-ring chronologies from the Abitibi Plains of eastern Canada just below James Bay. Cross-continuous wavelet transformation analyses of these data, in their words, "indicated coherency in the 8-16 and 17-32-year per cycle oscillation bands between the CDC reconstruction and the Pacific Decadal Oscillation prior to 1850," while "following 1850, the coherency shifted toward the North Atlantic Oscillation."

These results led them to suggest that "the end of [the] 'Little Ice Age' over the Abitibi Plains sector corresponded to a decrease in the North Pacific decadal forcing around the 1850s," and that "this event could have been followed by an inhibition of the Arctic air outflow and an incursion of more humid air masses from the subtropical Atlantic climate sector," which may have helped reduce fire frequency and drought severity. In this regard, they further note that several other paleo-climate and ecological studies have suggested that "climate in eastern Canada started to change with the end of the 'Little Ice Age' (~1850)," citing the works of Tardif and Bergeron (1997, 1999), Bergeron (1998, 2000) and Bergeron *et al*. (2001), while further noting that Bergeron and Archambault (1993) and Hofgaard *et al*. (1999) have "speculated that the poleward retreat of the Arctic air mass starting at the end of the 'Little Ice Age' contributed to the incursion of moister air masses in eastern Canada."

Moving back towards the west, Wolfe *et al*. (2005)[8] conducted a multi-proxy hydro-ecological analysis of Spruce Island Lake in the northern Peace sector of the Peace-Athabasca Delta in northern Alberta. Their research revealed that hydro-ecological conditions in that region varied substantially over the past 300 years, especially in terms of multi-decadal dry and wet periods.

[6] http://www.co2science.org/articles/V7/N15/C3.php.
[7] http://www.co2science.org/articles/V7/N47/C2.php.
[8] http://www.co2science.org/articles/V8/N51/C1.php.

More specifically, they found that (1) recent drying in the region was not the product of Peace River flow regulation that began in 1968, but rather the product of an extended drying period that was initiated in the early to mid-1900s, (2) the multi-proxy hydro-ecological variables they analyzed were well correlated with other reconstructed records of natural climate variability, and (3) hydro-ecological conditions after 1968 *have remained well within the broad range of natural variability observed over the past 300 years*, with the earlier portion of the record actually depicting "markedly wetter and drier conditions compared to recent decades."

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Moving all the way to the Pacific coast of North America (Heal Lake near the city of Victoria on Canada's Vancouver Island), Zhang and Hebda (2005)[9] conducted dendroclimatological analyses of 121 well-preserved subfossil logs discovered at the bottom of the lake plus 29 Douglas-fir trees growing nearby that led to the development of an ~ 4,000-year chronology exhibiting sensitivity to spring precipitation. And in doing so, they found that "the magnitude and duration of climatic variability during the past 4000 years are not well represented by the variation in the brief modern period." As an example of this fact, they note that spring droughts represented by ring-width departures exceeding two standard deviations below the mean in at least five consecutive years occurred in the late AD 1840s and mid-1460s, as well as the mid-1860s BC, and were more severe than any drought of the 20th century. In addition, the most persistent drought occurred during the 120-year period between about AD 1440 and 1560. Other severe droughts of multi-decadal duration occurred in the mid AD 760s-800s, the 540s-560s, the 150s-late-190s and around 800 BC. Wavelet analyses of the tree-ring chronology also revealed a host of natural oscillations on timescales of years to centuries, demonstrating that the 20th century was in no way unusual in this regard, as there were many times throughout the prior 4000 years when it was both wetter and drier than it was during the last century of the past millennium.

Two years later, Bonsal and Regier (2007)[10] compared the spatial extent and severity of the 2001/2002 Canadian Prairie drought to previous droughts of this region based on data obtained from 21 reporting stations in southern Alberta, Saskatchewan and Manitoba. This they did for

[9] http://www.co2science.org/articles/V8/N48/C2.php.
[10] http://www.co2science.org/articles/V10/N41/C1.php.

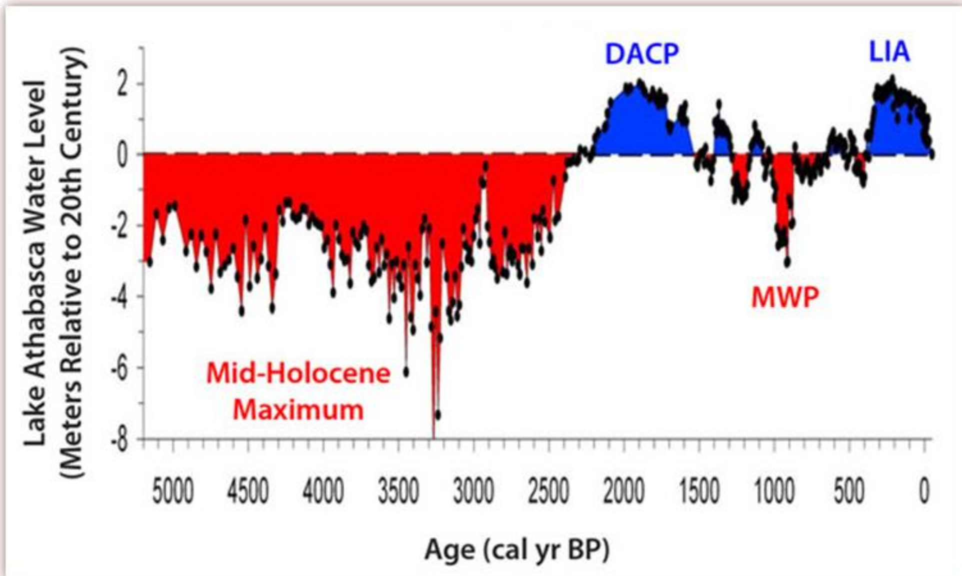
the 1915-2002 period of reasonably extensive instrumental records, using two different drought indicators: the Palmer Drought Severity Index (PDSI) and the Standardized Precipitation Index (SPI) at several temporal scales. And as a result of these efforts, the two researchers determined that "over the agricultural region of the Prairies, 2001 and 2002 generally ranked high in terms of spatial extent and severity of drought," and that "at some stations the 2001/2002 drought was the most severe one on record." *However*, they state that "the SPI and PDSI as drought indicators revealed that the worst and most prolonged Prairie-wide droughts during the instrumental record (1915-2002) ... occurred in the early part of the 20th century (1915 through the 1930s)."

Two more years on, Laird and Cumming (2009)[11] developed a history of changes in the level of Lake 259 (Rawson Lake, 49°40'N, 93°44'W) within the Experimental Lakes Area of northwestern Ontario, Canada, based on a suite of near-shore gravity cores that they analyzed for diatom species identity and concentration, as well as organic matter content. This work indicated there was "a distinct decline in lake level of ~2.5 to 3.0 m from ~800 to 1130 AD." And this interval, in their words, "corresponds to an epic drought recorded in many regions of North America from ~800 to 1400 AD," which they say "is often referred to as the Medieval Climatic Anomaly or the Medieval Warm Period, and encompasses 'The Great Drought' of the thirteenth century (Woodhouse and Overpeck, 1998; Woodhouse, 2004; Herweijer *et al*. 2007)." They also note that the Canadian prairies are currently "experiencing reductions in surface-water availability due to climate warming and human withdrawals (Schindler and Donahue, 2006)," and that "many regions in the western U.S. have experienced water supply deficits in reservoir storage with the recent multi-year drought (Cook *et al*., 2007)." However, they say that "these severe multi-year drought conditions pale in comparison to the many widespread megadroughts that persisted for decades and sometimes centuries in many parts of North America over the last millennium (Woodhouse, 2004)."

Yet another two years later, Wolfe *et al*. (2011)[12] wrote as background material, for what they were about to report, that the level of Canada's Lake Athabasca - North America's ninth-largest lake located in the northwest corner of Saskatchewan and the northeast corner of Alberta between 58° and 60° N - "is a sensitive monitor of climate-driven changes in streamflow from alpine catchments draining the eastern slopes of the Rocky Mountains (Wolfe *et al*., 2008; Johnston *et al*., 2010; Sinnatamby *et al*., 2010)," and that "paleoenvironmental data indicate that the last millennium was punctuated by multi-decadal episodes of both higher and lower Lake Athabasca levels relative to the 20th century mean, which corresponded with fluctuations in the amount and timing of runoff from glaciers and snowpacks (Wolfe *et al*., 2008)." In addition, they say that "the highest levels of the last 1000 years occurred c. 1600-1900 CE [=AD] during the Little Ice Age (LIA), in company with maximum late-Holocene expansion of glaciers in the Canadian Rockies," while at the other end of the spectrum they state that the "lowest levels existed at c. 970-1080 CE at a time of low glacier volume," near the midpoint of the global Medieval Warm Period.

[11] http://www.co2science.org/articles/V12/N33/C2.php.
[12] http://www.co2science.org/articles/V14/N39/EDIT.php.

In their newest study of the subject, the four Canadian researchers expanded the time span of the lake-level history to the past 5200 years, based on new analyses of sediment cores they collected in July of 2004 from *North Pond* (a lagoon on Bustard Island located at the western end of Lake Athabasca); and in doing so they discovered (see the figure below) that "modern society in western Canada developed during a rare interval of relatively abundant freshwater supply - now a rapidly diminishing by-product of the LIA glacier expansion, which is in agreement with late 20th century decline in Athabasca River discharge identified in hydrometric records (Burn *et al*., 2004; Schindler and Donahue, 2006)." And their data suggest, as they describe it, that "the transition from water abundance to scarcity can occur within a human lifespan," which, as they caution, "is a very short amount of time for societies to adapt."



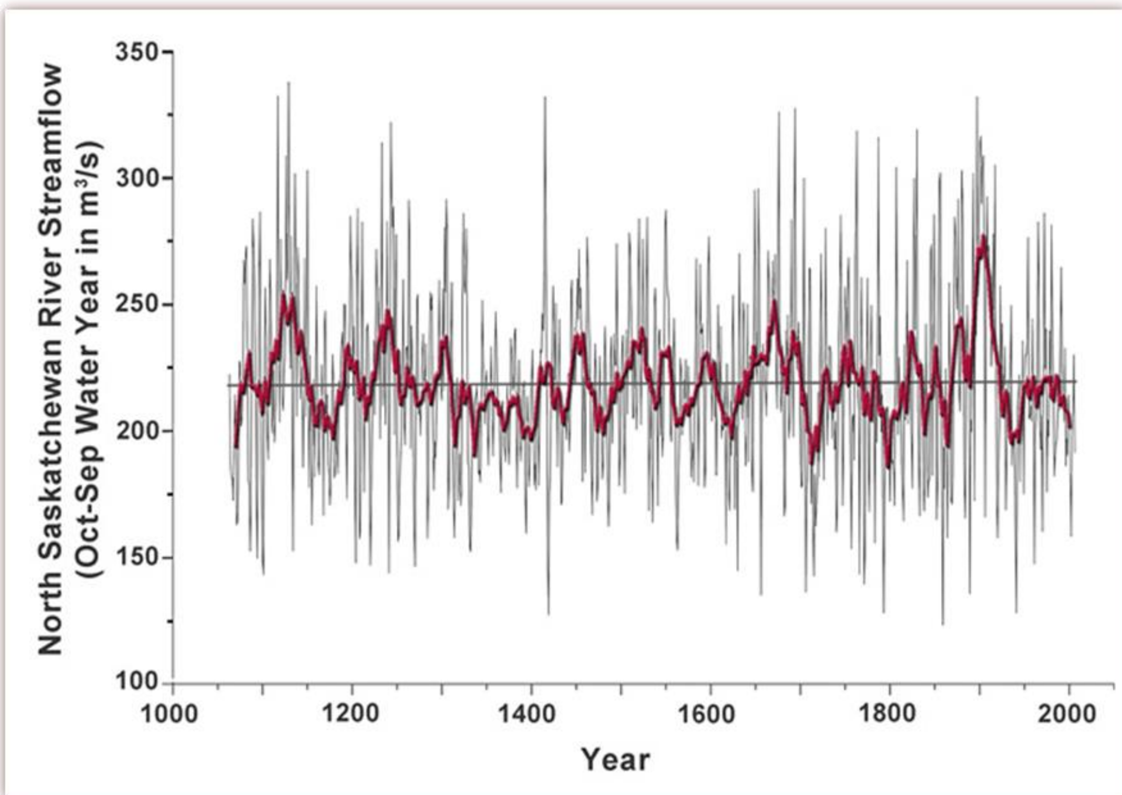
The Reconstructed water level history of Lake Athabasca. Adapted from Wolfe et al. (2011).

The data in the figure above also suggest that the peak warmth of the Medieval Warm Period - *which was unrelated to any change in the atmosphere's* CO_2 *content* - was likely significantly greater than the peak warmth that has been experienced to date during the Current Warm Period. And the rapidly declining water level over *the last couple of decades* - when earth's temperature was near its modern peak, but exhibited very little trend - suggests that lake level could continue its rapid downward course if planetary temperatures merely *maintain* their current values. And, therefore, Wolfe *et al*. conclude, in the final sentence of their report, that "as consumption of water from rivers draining the central Rocky Mountain region is on an increasing trend, we must now prepare to deal with continental-scale water-supply reductions well beyond the magnitude and duration of societal memory."

Continuing in the same vein, Sauchyn *et al*. (2011)[13] have written that "a growing demand for the surface water resources of the Canadian Prairie Provinces has resulted in increasing vulnerability to hydrological drought," citing the studies of Schindler and Donahue (2006) and Wheaton *et al*. (2008); and they further note, in this regard, that "a shift in the amount and

[13] http://www.co2science.org/articles/V15/N32/C2.php.

timing of streamflow represents the most serious risk from recent and projected climate warming in western Canada (Sauchyn *et al*., 2010)," adding that "the Saskatchewan River Basin is among Canada's most vulnerable watersheds, in terms of projected climate changes and impacts, and the sensitivity of natural systems and economic activities to Canada's most variable hydroclimate." Therefore, it is important to know the characteristics of *past* streamflow variability in order to better prepare for future droughts, as well as to determine if extreme droughts that may occur in the future might be due to CO_2-induced global warming *or* if they are within the range of natural variability experienced in the past, when the air's CO_2 concentration was both much lower and less variable than it is currently. Thus the question arises: Is a mere century of real-world data sufficient for these purposes? In a study designed to explore this important question by determining if streamflow variability recorded by the streamflow gauge at Edmonton, Alberta (Canada) over the past *century* (since 1912) is representative of the range of variability experienced there over the past *millennium*, Sauchyn *et al*. (2011) developed a 945-year reconstruction of the annual flow of the Northern Saskatchewan River based on tree-rings collected from seven different sites within the runoff-generating upper basin of the river (see figure below).



North Saskatchewan River reconstructed water year (October to September) flow for the period 1063-2006. Adapted from Sauchyn et al. 2011.

Clearly, the Edmonton stream-gauge record does *not* "represent the full extent of interannual to multidecadal variability in the tree-ring data," for as noted by Sauchyn *et al*. (2011) "there are periods of low flow in the pre-instrumental record that are longer and more severe than those recorded by the gauge" and which "pre-date Euro-Canadian settlement of the region." Two of these extreme events were approximate 30-year droughts, one occurring in the early

1700s and another during the mid-1100s, while one of the two most prominent *mega*-droughts lasted for most of the 14th century, while the other occurred in the latter part of the 15th century.

Sauchyn *et al*. (2011) thus go on to state that "there is less certainty and stationarity in western [Canadian] water supplies than implied by the instrumental record," which they say is "the conventional basis for water resource management and planning" of the region. Likewise, it is clear that their streamflow reconstruction provides a whole *new-and-improved* basis for determining the "uniqueness" of whatever future droughts might occur throughout the region, making it much more difficult for climate alarmists to claim that such droughts were caused by anthropogenic CO_2 emissions, since there was *far* less CO_2 in earth's atmosphere prior to the 1912 start-date of the region's prior streamflow history, when several *way* more serious droughts than those of the past century are now known to have occurred.

Rounding out this historical summary of Canadian droughts is the study of Laird *et al*. (2012)[14], who write that "future extreme droughts, similar to or more extreme than the 'dust-bowl' 1930s, could be the most pressing problem of global warming," citing Romm (2011) and noting, for comparison, that "droughts of unusually long duration" or *mega-droughts* that occurred during the Medieval Climate Anomaly (MCA) [= Medieval Warm Period] "lasted for several decades to centuries thus dwarfing modern-day droughts," as reported by Seager *et al*. (2007) and Cook *et al*. (2010).

Noting further that "one of the predictions of increasing temperatures is decreased lake levels and river flows (Schindler and Lee, 2010)," the eight researchers go on to say that "analysis of longer-term records of past water levels can provide a context for informing water managers on the inherent natural variability of lake levels and their sensitivity to climate change," which is something that is of extreme importance to the entire world. And so they proceed to describe a pertinent study they conducted on six lakes spread across a 250-km transect of the Winnipeg River Drainage Basin of northwest Ontario, Canada, where the land-based pollen data of Viau and Gajewski (2009) suggest the presence of warmer temperatures during the MCA.

The six diatom-inferred decadal-scale two-millennia-long drought records, which Laird *et al*. developed for the six lakes they studied, revealed that what they call "periods of synchronous change" had occurred across all of the six lakes throughout "a period of prolonged aridity during the MCA (c. 900-1400 CE)." And they state that this "general synchrony across sites suggests an extrinsic climate forcing (Williams *et al*., 2011)," with the MCA being part of a set of what they call "inherent natural fluctuations."

In further support of this conclusion, Laird *et al*. write that "a widespread external forcing must be large enough for regional patterns to emerge." And they report, in this regard, that in the Nebraska Sandhills "an analysis of five topographically closed lakes indicated relative coherency over the last 4000 years, particularly during the MCA with all lakes indicating lake-level decline (Schmieder *et al*., 2011)." In addition, they indicate that "in Minnesota, sand deposits in Mina Lake indicate large declines in lake level during the 1300s (St. Jacques *et al*., 2008), high eolian

[14] http://www.co2science.org/articles/V16/N5/EDIT.php.

deposition occurred from ~1280 to 1410 CE in Elk Lake (Dean, 1997) and $\delta^{18}O$ from calcite indicated an arid period from ~1100 to 1400 CE in Steel Lake (Tian *et al*., 2006)," while "in Manitoba, the cellulose $\delta^{18}O$ record from the southern basin of Lake Winnipeg indicated severe dry conditions between 1180 and 1230 CE, and a less-severe dry period from 1320 to 1340 CE (Buhay *et al*., 2009)." And they add that relatively warm conditions during the MCA "have been inferred from pollen records in the central boreal region of Canada and in Wisconsin," citing Viau and Gajewski (2009), Viau *et al*. (2012) and Wahl *et al*. (2012).

These impressive and temporally-coherent findings have several important implications; but the one that is most germane to *climatology* is that if future extreme droughts, such as those that occurred during the MCA, could indeed be the "most pressing problem" of projected *future* global warming, as many climate alarmists contend, then it logically follows that (1) the Medieval Warm Period must have been *far more extreme* in terms of both high temperature values and their duration than anything yet experienced during the Current Warm Period, and (2) the preceding observation is strong evidence that warming considerably in excess of what has been experienced to date in our day and age can readily occur *without any help from rising atmospheric CO_2 concentrations*, which were more than 100 ppm *less* during the Medieval Warm Period than they are today, as is additionally - and convincingly - demonstrated by the great multitude of quantitative and qualitative findings of a host of scientists who have studied both the Medieval and Current Warm Periods throughout the entire world, which findings further suggest that (3) the development of the planet's Current Warm Period may be due to something that is *totally unrelated* to anthropogenic CO_2 emissions.

Warming considerably in excess of what has been experienced to date in our day and age can readily occur without any help from rising atmospheric CO_2 concentrations, which were more than 100 ppm *less* during the Medieval Warm Period than they are today.

In summation, and in view of the numerous similar findings from across a wide and varying geographic area, it would appear that much of Canada has (1) experienced less-variable extreme moisture conditions, as both it and the rest of the world have emerged from the relative cold of the Little Ice Age and are now basking in the greater warmth of the Current Warm Period, and that (2) this finding appears to be independent of the atmosphere's CO_2 concentration.

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