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# CONTEMPORARY CLIMATE CHANGE IN HIGH LATITUDES OF THE NORHTERN HEMISPHERE: DAILY TIME RESOLUTION

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## ABSTRACT

Significant climatic changes over the high latitudes in the 20th century have been reflected in many atmospheric, oceanic, and terrestrial variables. While changes in surface air temperature and precipitation are most commonly addressed in the literature, changes in their derived variables (variables of economic, social and ecological interest based upon daily temperatures and precipitation) have received less attention. In practice, these and other indices are often used instead of "raw" temperature and precipitation values for numerous applications that include modeling of crop-yields, prediction and planning for pest management, plant-species development, greenhouse operations, food-processing, heat oil consumption in remote locations, electricity sales, heating system design, power plant construction, energy distribution, reservoir operations, floods and forest fires. These indices provide measure for the analysis of changes that might impact agriculture, energy, and ecological aspects of high latitudes over the past 50 years.

**Key words**: climate change, high latitudes, weather derivatives

## INTRODUCTION

The list of the variables of economic, social and ecological interest based upon daily temperatures and precipitation being considered in this paper includes: frequency of extremes in precipitation and temperature; frequency of thaws; heating degree days; growing season duration; sum of temperatures above/below a given threshold; days without frost; day-to-day temperature variability; precipitation frequency; precipitation type fraction; frequency of rain-on-snow events; and Keetch-Byram (Soil Moisture) Drought Index (KBDI; Keetch-Byram 1968).

## 1. DATA

We performed our analysis on the 1950-2001 period using a subset of about 1500 stations north of 50°N from the recently created Global Daily Climatology Network archive (GDCN, Gleason et al. 2002; Figure 1). When considering temperature variations over Canada within this data set for 210 Canadian stations with homogenized temperature time series (Vincent and Gullett 1999), a priority was given to these high-quality data instead of the observations in the GDCN. Precipitation time series for the former USSR (fUSSR) and Canada were homogenized to account for changes in instrumentation and observational practice as described in Groisman and Rankova (2001) and NCDC (1998).

Fig. 1. Map of GDCN stations north of 50°N with more than 25 years of valid daily data.

## 2. RESULTS

### 2.1. Frequency of extreme events

To define ***"heavy" precipitation*** events, we used an upper monthly fraction (> $2\sigma$) of precipitation events over 0.5 mm ("non-nonsense" precipitation events). $\sigma$ is estimated using maximum likelihood estimates of gamma-distribution for each month during the 1961-1990 reference period. This approach picks up "unusual" precipitation events throughout the year rather than concentrating on the most humid season (summer over most of the Arctic). We found a general increase (by 12% per 50 yrs) of the frequency of annual heavy precipitation events, but all of this increase comes from Eurasia while in North America changes are insignificant.

***Unusually cold and/or warm days*** affect the "usual" cycle of the Arctic ecosystem and numerous human activities. During the past fifty years, the frequency of these days has systematically changed with a general climate warming. For example, we found a significant decrease in very cold nights over the Arctic in winter (by 60%), spring (by 95%), and summer (by 70%) but not in autumn. Here very cold nights were defined as those with daily minimum temperature, $T_{min}$, below the mean monthly values by more than two standard deviations for each month.

### 2.2. Thaw days

A day with thaw (snowmelt) can be defined as a day with snow on the ground when the daily mean temperature is above –2°C (Brown 2000). During these days snow deteriorates, changes its physical properties, and eventually disappears. In winter and early spring in high latitudes, thaws negatively affect transportation, winter crops, and sustainability of the natural environment, including vegetation and animals. In late spring, intensification of thaw conditions leads to earlier snow retreat and the onset of spring. Gradual snowmelt during the cold season affects seasonal runoff of the northern rivers, reducing the peak flow of snowmelt origin and increasing the mid-winter low flow. Figure 2 shows the circumpolar change in the frequency of days with thaw during the past fifty years. Statistically significant increasing trends for winter and autumn are of 1.5 to 2 days per 50 years and constitute a 20% (winter) to 40% (autumn) increase in the thaw frequency during the second half of the 20th century.

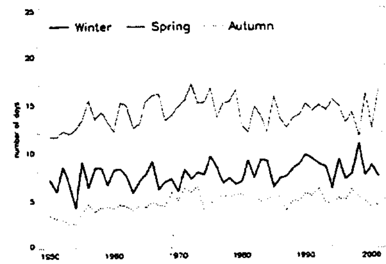



Fig. 2. Circumpolar frequency of seasonal number of days with thaw area averaged over Alaska, Canada, and the former USSR. From the top to bottom: spring, winter, and autumn.

### 2.3. Heating degree-days, duration of growing season, and sum of temperatures above/below a given threshold.

Heating degree-days are the sum of positive mean daily temperature ($T_{mean}$) anomalies from the base temperature $(T_{base} - T_{mean})_+$. For calculations shown in Figure 3 we used $T_{base}$ equal to 18°C (a compromise between 65°F routinely used in the United States and 17°C used in Norway). Heating degree-days closely correlate to energy consumption for heating and have numerous other practical implications (Guttman and Lehman 1992). Figure 3 shows a statistically significant decrease in annual heating degree-days during the past 50 years of 6% per 50 years over the entire Arctic, with a maximum absolute and relative reduction in heating-degree days over western Canada and Alaska (of 9% and 8% per 50 years, respectively). In Eurasia, significant reductions in heating degree-days are observed over Russia (6% to 7% per 50 years). This indicates that there have been reduced heating costs in relative terms.

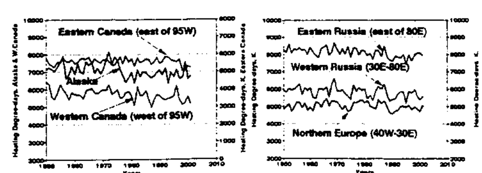



Fig. 3. Annual number of heating degree-days area-averaged over Alaska, Canada, Northern Europe, and Russia north of 50°N.

The duration of the growing season defined by the dates of steady (at least 5-day-long) transition of mean daily temperatures across +10°C is used to define "growing season" in the high latitudes. A threshold of +10°C was selected to account for the continental climate of the Arctic where daily temperatures as high as 5°C can be accompanied by nighttime frost which is unfavorable for vegetation growth. We found that during the past fifty years, the largest absolute and relative changes in duration of the growing season occurred over Alaska and western Canada (15 and 10 days or 19% and 8% per 50 years respectively). Another region of significant increase of the growing season duration is Russia (from 7 in the East to 10 days in the West, or 8% per 50 years). On average over the entire land area north of 50°N, we found a 6% increase per 50 years in the duration of the growing season.

Sums of mean daily temperatures above specific thresholds (5°C, 10°C, or 15° C) are used in bio- and agro-climatology to define the northernmost limits of expansion of different vegetation species including crops. The ongoing warming of the high latitudes causes shifts in these sums and, therefore, creates a potential to change these limits. We found a 12% per 50 years increase over the entire Arctic (with the strongest increases over North America and Siberia) in the sums of mean daily temperatures above 15° C. This result supports the increase in "greenness" of the high latitudes (reported recently from satellites; Myneni et al. 1997), provides a longer time scale (compared to the remote sensing results), and quantifies the "greenness" changes.

To characterize the severity of the cold season, a sum of negative temperatures can be used. Time series of this characteristic for winter and for the entire cold season indicate that the annual "severity" of the cold season has substantially decreased everywhere except eastern Canada. The mean circumpolar decrease in winter is 13% per 50 years (in absolute value of negative temperature sums).

### 2.4. Days without frost

The length of the frost-free period is among the most carefully monitored variables in the Arctic. The regionally averaged duration of the frost-free period varies from less then 100 days in Alaska to more than 150 days in Fennoscandia and has increased (by 7% per 50 years) over most of the Arctic except Europe. It is interesting to note the increase in the frost-free period in Eastern Canada (by 8% per 50 years, or by 9 days) where the duration of growing season changed insignificantly.

### 2.5. Day-to-day temperature variability

The very high day-to-day temperature variability affects the quality of living in the high latitudes, causing a variety of transportation and health problems and requiring additional construction expenditures. Figure 4 depicts major seasonal tendencies in this variability during the past fifty years. It shows a decrease in day-to-day mean square root variability of daily temperature in all seasons. In spring and summer seasons this decrease (about 7% per 50 years) is statistically significant at the 0.01 level.

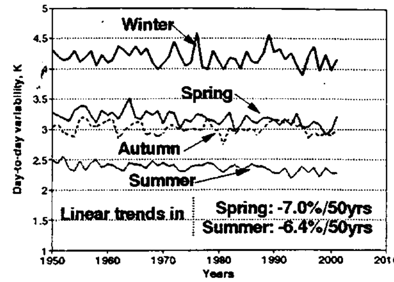



Fig. 4. Seasonal variations in the day-to-day temperature variability area-averaged over Alaska, Canada, Northern Europe, and Russia north of 50°N.

### 2.6. Precipitation frequency

Reporting changes in precipitation frequency in the Arctic is not a trivial task due to a significant fraction of very light precipitation events (e.g., traces) comparable to the gauge precision. To avoid uncertainties with measurement of ephemeric amounts of precipitation and instability with time of precision of their reporting, we assessed climatology and trends of annual number of days with precipitation above 0.5 mm. We have not detected significant changes in wet days over North America, Northern Europe, and western Russia and found a significant decrease in wet days over eastern Russia by 7 days (~7%) per 50 years. This last feature was first reported by Sun et al (2001) for eastern Russia south of 60°N and is remarkable because it is accompanied by an increase in heavy precipitation in the same region (Section 2.1).

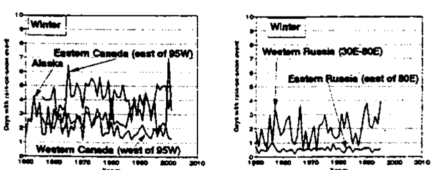
### 2.7. Liquid and frozen precipitation

Karl (1998) reported a century-long increase in high-latitudinal precipitation that is reproduced also by contemporary GCMs (Kattsov and Walsh 2000). For the land regions north of 50°N, rainfall contributes about three quarters of the annual precipitation total. We found a significant (6% per 50 years) circumpolar increase in annual rainfall. This increase is partially due to an additional fraction of liquid precipitation in the intermediate seasons. Groisman and Easterling (1994) and Mekis and Hogg (1999) reported an increase in annual snowfall north of 55°N over North America. However, a significant redistribution between liquid and frozen forms of precipitation has occurred in the humid southern parts of the Arctic south of 55°N in North America and south of 60°N in Eurasia (since the mid-1950s). Thus, while cold season precipitation increased over most of the high latitudes its frozen component has not notably changed.

## 2.8. Rain-on-snow events

Rain falling on snow causes more rapid snowmelt and, when the rainfall is intense, may result in flash flooding. Along the western coast of North America rain-on-snow events is the major cause of severe flash floods. Figures 5 and 6 show the frequencies of the rain-on-snow events over northern North America and Russia and their changes during the past fifty years. A formal criterion was used to define these events: number of days with rainfall ≥ 1 mm when snow depth is ≥ 3 cm without accounting for ripening of the snowpack. Figure 6 shows a significant increase in the frequency of rain-on-snow events (*as defined above*) in winter over western Russia (by 50% per 50 years) and a significant reduction of similar size over western Canada. In spring, there is a significant increase of rain-on-snow events over Russia (mostly over its western part), but there is also a significant decrease of the frequency of these events in the western Canada. This decrease is mostly due to snow cover retreat.

Fig. 5. Climatology of winter (left) and spring (right) rain-on-snow events (number of days with rainfall ≥ 1 mm when snow on the ground is ≥ 3 cm).

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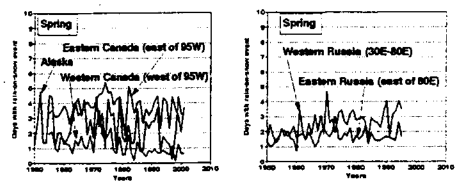


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Fig. 6. Regional variations of rain-on-snow events in (a) winter and (b) spring.

## 2.9. Keetch-Byram Drought Index

Numerous naturally caused fires that are difficult to fight due to the difficulty of reaching occur each summer throughout boreal forest and tundra. To characterize the level of potential fire danger, numerous indices have been suggested. While other indices require additional data, the Keetch-Byram Drought Index (KBDI; Keetch and Byram 1968) uses only readily available daily temperature and precipitation information. It estimates soil moisture deficiency. The logic behind the index is that wet soil suppresses wild fires while dry soil organic matter enhances the severity of these fires. We found that dryer soil conditions have increased slightly in Russia and central Canada but decreased over southeast and southwest of Canada. The frequency of unusually dry summer and spring conditions (days with the anomalous high KBDI values) has increased in Siberia and Alaska.

# 3. CONCLUSIONS

In the previous section we have presented information about changes in nine climatic derivatives with economic, social and ecological implications over the high latitudes of the Northern Hemisphere during the past fifty years. These changes imply increases and decreases in risk. Whatever "interpretations" would be assigned to these observed changes, it is important to note that many of them have been significant enough to be noticed above the usual "weather" noise level during the past fifty years and thus should be further investigated in order to better understand and adapt to their impacts.

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