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Have Heat Waves Become More Intense and Frequent in North America in the Past 40 years?

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1. Introduction

Extreme events, especially heat waves, have become more frequent and intense in recent decades, likely associated with global warming. Heat waves have directly impacted human health, caused large-scale crop damage, e.g., on U.S. corn and soybean crops, and caused livestock losses. This study uses the extreme detection indices products (Collow et al., 2016, and Thomas et al., 2020) derived from the NASA Modern-Era Retrospective Analysis for Research and Applications version 2 (MERRA-2) data to address whether heat waves have become more intense and frequent in North America in the past 40 years. We also examine in-depth the recent heat wave in June 2023 in Canada and the associated drought and wildfire events and compare them with previous years. This study uses additional data products for in-depth investigation, including hourly surface temperature from Phase 2 of the North American Land Data Assimilation System (NLDAS 2.0).

In this study, we will **demonstrate how to efficiently conduct long-term time-series data analysis**, which involves a large volume of data, using various data services developed at NASA GES DISC, such as Giovanni, data rod, Zarr store, and Thematic Real-time Environmental Distributed Data Services (THREDDS) Data Server (TDS). These services facilitate studying extreme events efficiently by subsetting and downloading the long-term time series.

2. Data and Data Service at GES DISC

Table 1: The Data and Data Service to Subset a Time Series

Data Service Name	Highlighted Functions	Data Collection Frequency, variables	Time Spent to Subset a Time Series	Output Format	Tutorial
Giovanni	Get a recurring time series over a shaped region	M2SMNXEDI_2 Monthly, HWF	<5 minute to subset 528 months (1980.01-2023.10)	netcdf, csv, png,	
TDS	Subset a time series over a bounding box	M2SMNXPCT_2 Monthly, T2MMAX & PRECTOT	7 seconds to subset 528 months over CONUS (1980.01-2023.10)	netcdf, csv, geocsv, xml	
Data rod	Subset a very long time series (e.g., at hourly frequency) at a point location	NLDAS_FORA0125_H_v2.0, Hourly, Tair	<1 minute to subset 121813 hours (1990-01-01T00 to 2023-11-26T00	text, png	
Cloud Giovanni Cache Zarr store	Subset a very long time series (e.g., at hourly frequency) over a region	GPM_3IMERGHH_06, Half hour, precipitationCal	<1 minute to subset 374200 half hours (2000-06-01T00 to 2021-11-26T00	HDF5	

References:

Collow, A., M. G. Bosilovich, and R. D. Koster. 2016. Large Scale Influences on Summertime Extreme Precipitation in the Northeastern United States Journal of Hydrometeorology JHM-D-16-0091.1 [10.1175/jhm-d-16-0091.1]

Thomas, N. P., M. G. Bosilovich, A. B. Marquardt Collow, et al. R. D. Koster, S. D. Schubert, A. Dezfuli, and S. P. Mahanama. 2020. Mechanisms Associated with Daytime and Nighttime Heat Waves over the Contiguous United States Journal of Applied Meteorology and Climatology 59 (11): 1865-1882 [10.1175/jamc-d-20-0053.1]

3. Rising Temperature over North America

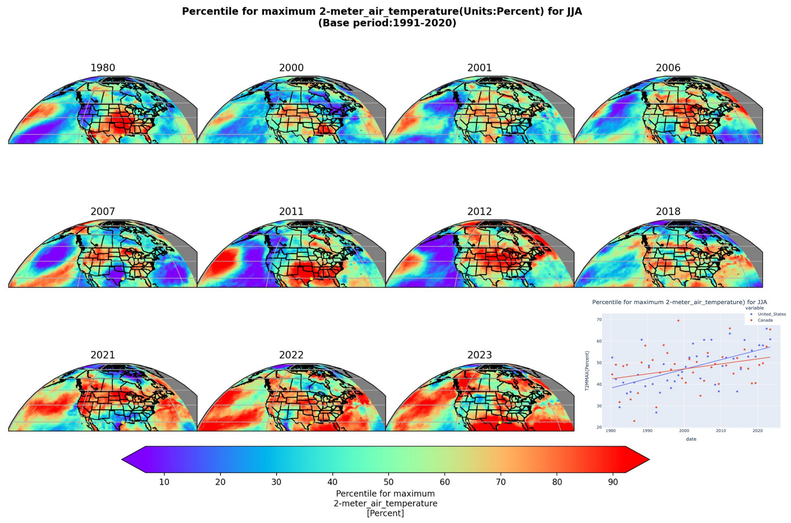

Figure 1: Yearly comparison of the percentile for maximum 2-meter air temperature averaged over Summer-JJA (Units: Percent) in the years with heat waves reported in North American history. The time series of the country-averaged values are plotted in the right lower panel. (Variable shortname: T2MMAX; Collection shortname: M2SMNXPCT.2). This figure was plotted by Python using the aggregated data extracted by the ***TDS***.

Summary: The percentile for the maximum 2-meter air temperature during summer time (JJA) has been rising from 1980 to 2023 in both the U.S. and Canada, especially in the U.S., with increasing ~20 percentiles over 44 years. The heat wave patterns are different in each heatwave year. In 2023, eastern and western Canada and central and southern western U.S. persistently experienced scorching summers beyond the 90 percentile.

4. Rising Precipitation over North America

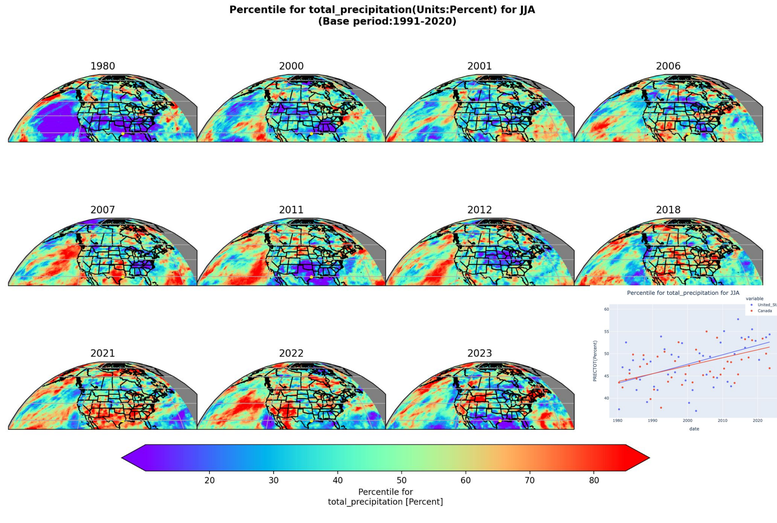

Figure 2: Same as Figure 1 but for the percentile for total precipitation (Units: Percent).

Summary: The percentile for the total precipitation during summer time (JJA) has been rising from 1980 to 2023 in both the U.S. and Canada, especially in the U.S., with increasing ~10 percentiles over 44 years. The precipitation patterns are different in each heatwave year. However, the dry conditions (Figure 1) generally accompanied the hot conditions (Figure 1). In 2023, eastern and especially western Canada experienced dry summers below the 20 percentile, which provided the climate conditions for severe wildfires in Canada this summer. In addition, the central and southern western U.S. also experienced dry conditions.

5. Rising Heat Wave Frequency in the United States after 2000

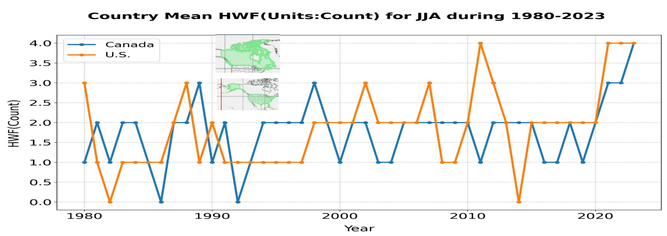

Figure 3 The Country-mean heat wave frequency over Canada and United States for JJA from 1980 to 2023 (Units: count). (Variable shortname: HWF; Collection shortname: M2SMNXEDI_2.). This figure was plotted by Python using the aggregated data extracted *by **Giovanni**.*

Summary: Over the U.S., it is clear that Heat Wave Frequency (HWF) during summer (JJA) increased after 2000 by one day per month compared to the previous decades. In the last three summers, 2021, 2022, and 2023, in the U.S., the JJA has had more heat waves consistently by two counts per month than in the previous years. In Canada, the last three summers also have more heat waves than the earlier years, although the rising trend is less apparent than in the U.S. The HWF is defined as the number of days satisfying the heat wave criteria, i.e., the maximum 2-meter air temperature exceeds the 90th percentile for at least three consecutive days in that month. The daily percentiles were calculated using a running window of +/- 7 days centered on each day of the year for the climatology period of 1991 through 2020.

6. Heat Wave Duration and Intensity at Two Cities

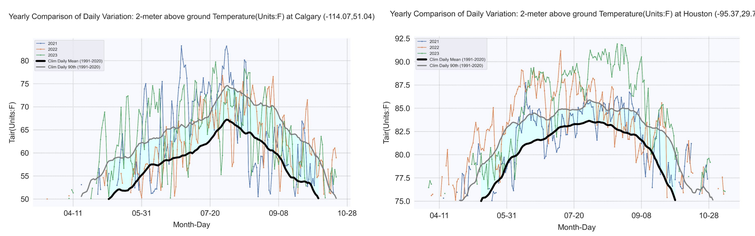

Figure 4: Yearly comparison of daily variation of 2-m above ground temperature at a city at Calgary, Alberta, Canada (51.0447 °N, 114.0719 °W) (left panel), and at Houston, Texas, U.S. (29.77°N, 95.37°W) (right panel). (Variable shortname: Tair; Collection shortname: NLDAS_FORA0125_H_v2.0). The thick black line are the rolling (14-day windows) daily mean during 1991-2020, and the gray thick line above is the rolling mean (14-day windows) of the 90th percentile daily mean during 1991-2020. This time series are plotted by Python using the aggregated data extracted by the ***datarod service***.

Summary: In Calgary, the 2023 heat waves started in April and continued through October. The daily 2-m air temperature in 2023 (in green line) was far above the 90th percentile for more than five consecutive days (in gray line) as early as April and May, when disastrous Alberta wildfires occurred, and persistently through June, when Alberta wildfires intensified. At Houston, the duration and intensity of heat waves in 2023 exceeded other years.