A MACHINE-LEARNING APPROACH TO STUDYING RELATIONSHIPS BETWEEN EXTREMES IN GEOPOTENTIAL HEIGHT AND SURFACE TEMPERATURE

CVC 604

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1. Introduction

Because of their myriad environmental and societal impacts, weather and climate extremes have been the climate change topic du jour over the past several years. Given their practical importance, the ability to identify, analyze, and understand the drivers and dynamics of extremes in the historical record—and to project and respond to extremes of the future—will certainly remain critical scientific endeavors for some time.

Temperature and precipitation extremes have received the most attention to date. For temperature, most work has focused on analysis of extremes in near-surface air temperature; however, a bevy of recent papers has started to look at extremes in upper-air circulation (e.g., changes in the "waviness" of the flow), which can drive—and to some extent be driven by—temperature extremes and other surface processes (e.g., changes in Arctic sea ice extent and thickness). This is a very active area of research that has led to more than a little bit of interest, news coverage, and even controversy.

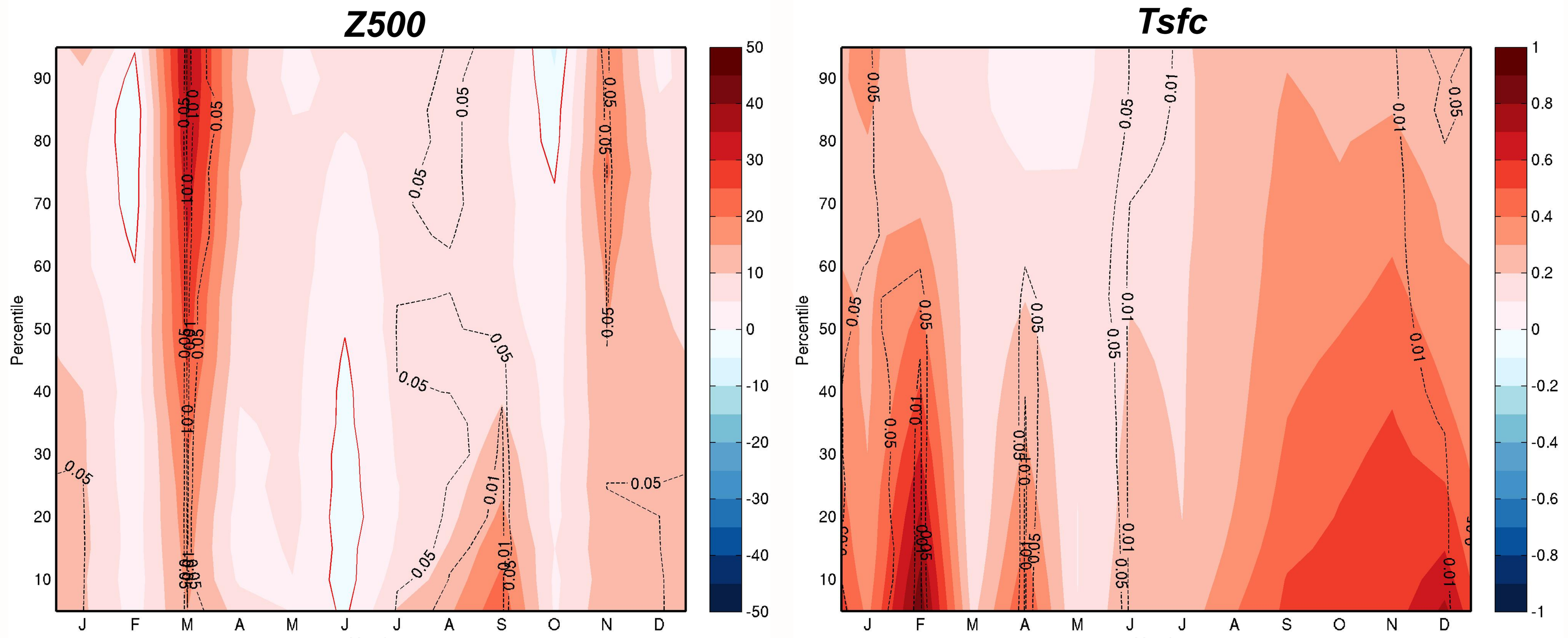
In this ongoing work, we examine occurrences of, and some basic relationships between, 500 mb (Z500) geopotential height extremes and near-surface air temperature (Tsfc) extremes over North America. Our goal is to expand on what has already been observed and reported (i.e., increasing trends in Tsfc hot extremes and even stronger decreasing trends in cold ones).

2. Data and Methodology

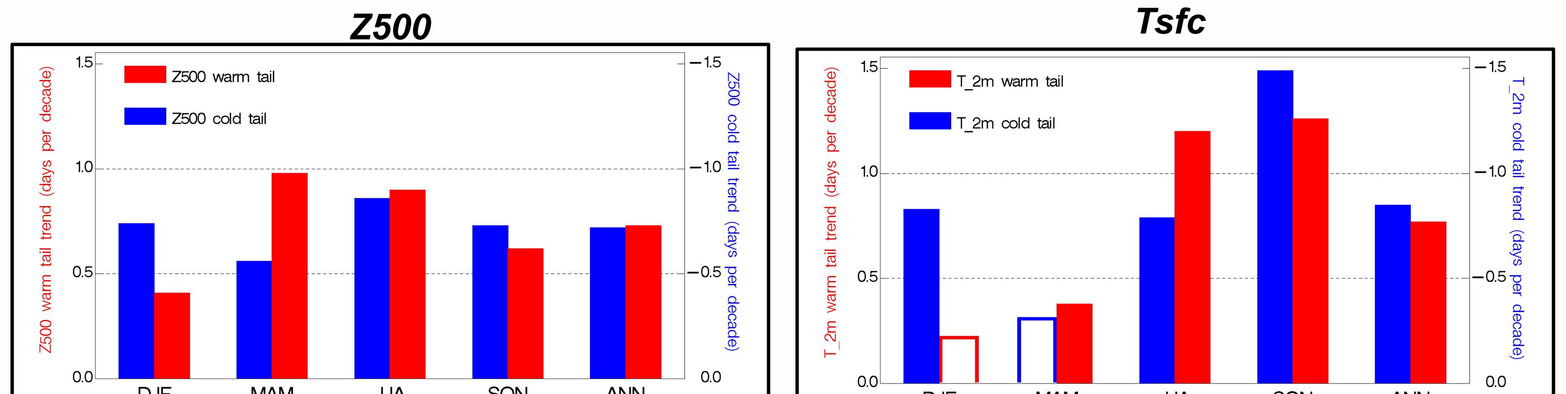
We analyzed daily mean Z500 and Tsfc from both the NCEP-NCAR Reanalysis (R1) and the NCEP-DOE Reanalysis (R2) for the period **1979–2013**. Some sample results from both are shown here (R2 in sections 3 and 4, and R1 in sections 5–7); we've found these datasets to be very similar and will eventually settle on one for a subsequent journal submission.

We examined changes over North America (25°–75° N; 45°–165° W) and computed 5th and 95th percentiles for each variable using a 5-day sliding window centered on each day, yielding a total sample size of 175 daily values (5 days X 35 years) for each day of the year. We then calculated the frequency of 5th/95th percentile (cold/warm tail) exceedance for each grid box (sections 3 and 4). The occurrence and anomaly values (relative to the whole POR) of the Z500 and Tsfc extremes are then used in a "blob-tracking" analysis (section 5) to assess trends in the frequency, duration, magnitude, and area of individual extreme events (section 6).

3. Trends in the frequency of Z500 and Tsfc extremes



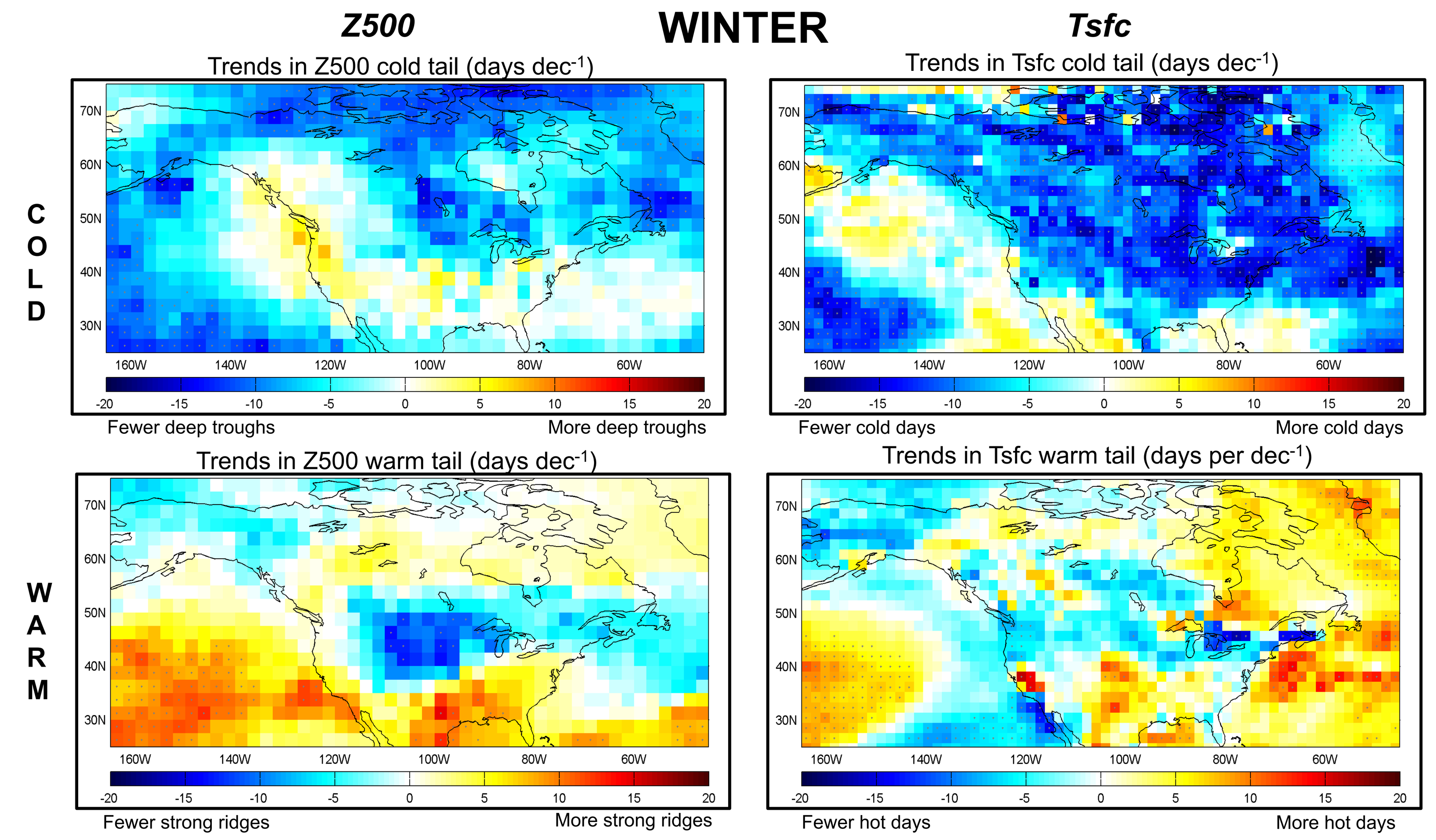
Changes over all percentiles. North America monthly, area-averaged trends over all percentiles, 1979–2013. Z500 trends are in m dec^{-1}; Tsfc are °C dec^{-1}. Dashed lines denote statistical significance at the .01 and .05 levels.

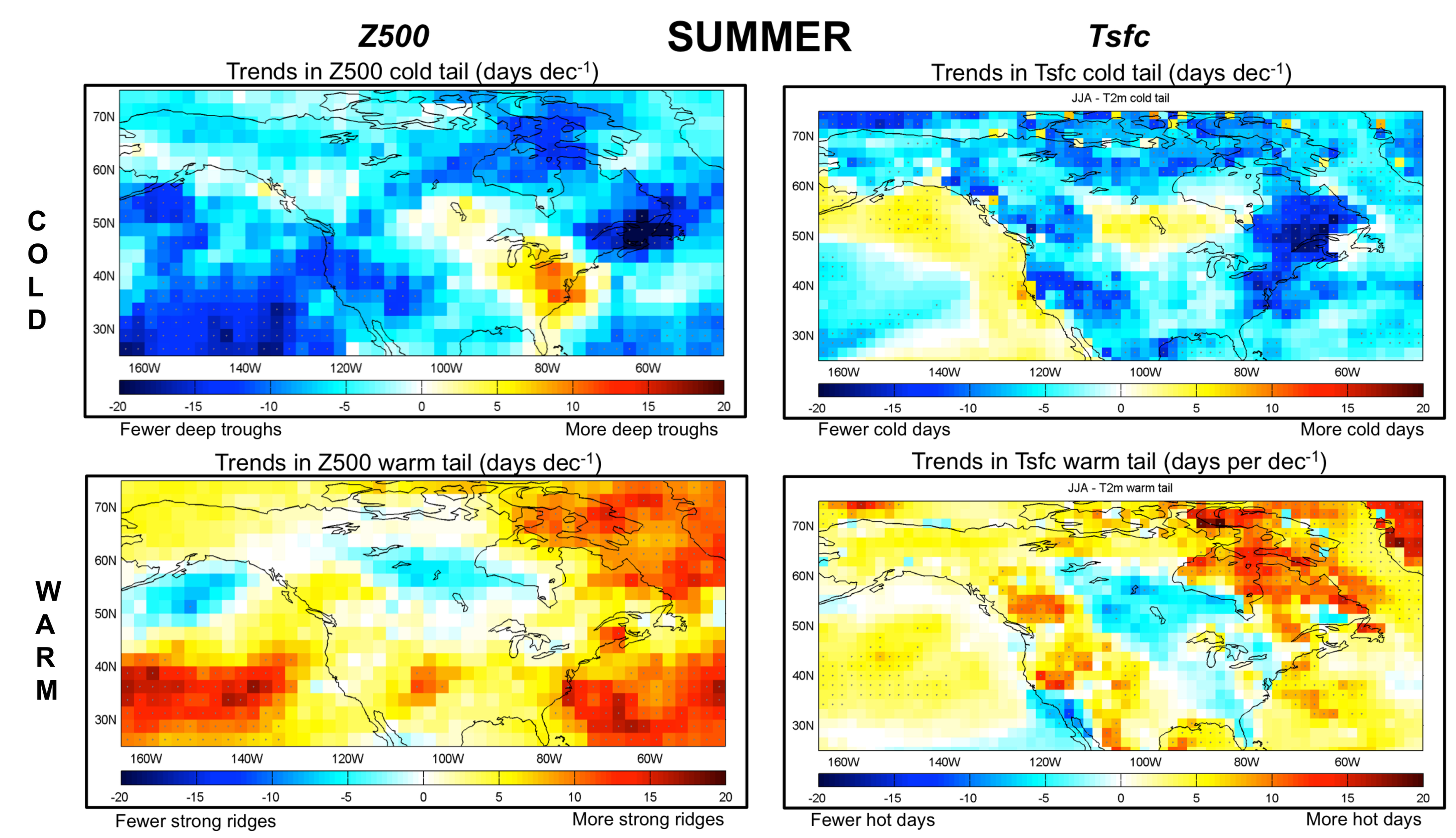


Seasonal changes for the cold/warm tails. Area-averaged trends in frequency of cold/warm tail extremes. Units are days dec^{-1}. Solid bars are significant at the 0.05 level.

- Percentile plots show positive trends in both variables are widespread, but more significantly so for Tsfc, especially in the colder percentiles in autumn (SON) and winter (DJF).
- Frequency trends in Z500 tails are significant across all seasons with cold tail decreases and warm tail increases both implying rising heights.
- On an annual basis, frequency trends for both variables are approximately equal in magnitude and imply a similar rightward shift in both tails of their PDFs.
- The pronounced increasing Z500 trends centered on March, especially in the warmer percentiles, warrant further investigation.

4. Regional Trends in Cold/Warm Tail Frequency



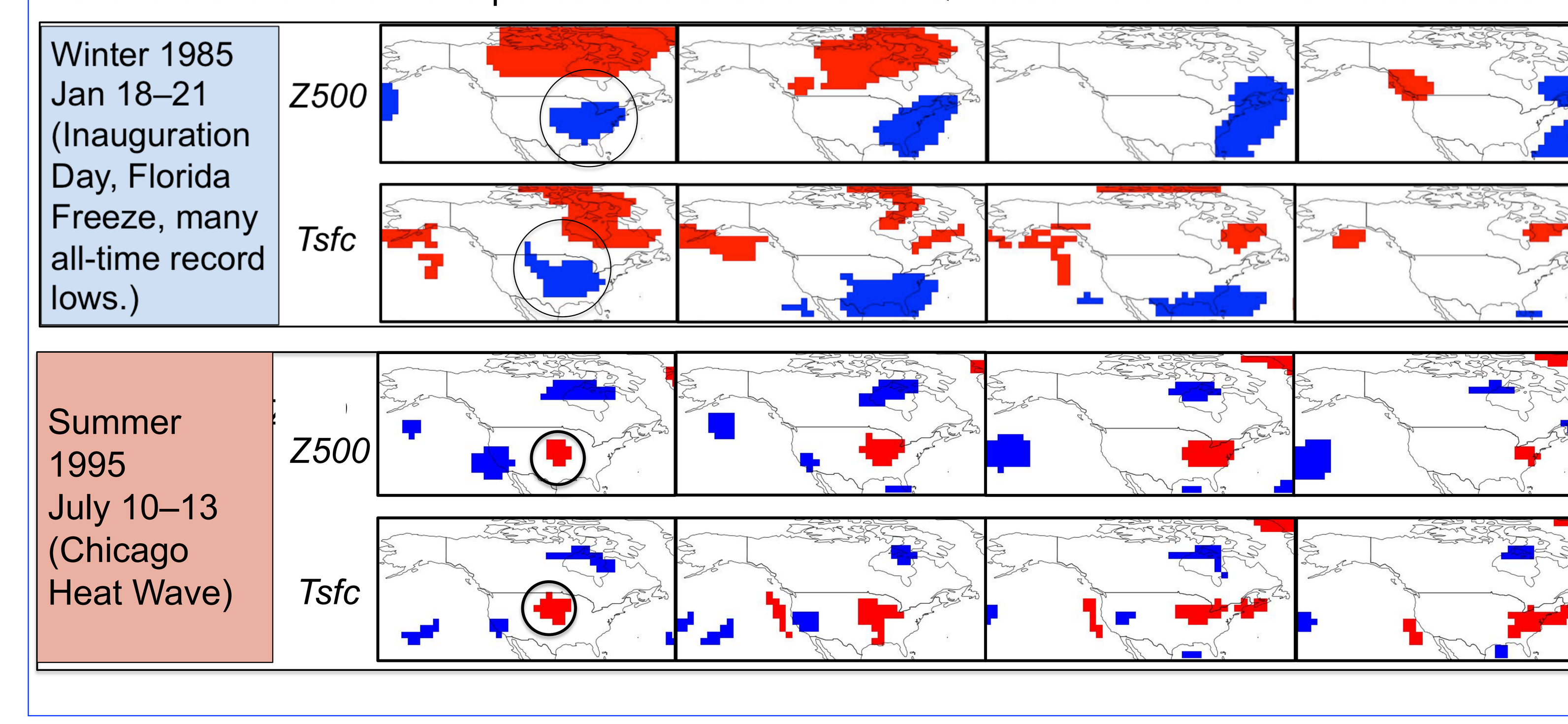


Trends in the frequency of cold/warm tail Z500 and Tsfc days for DJF and JJA.

- Winter decreases in cold tail extremes dominate; warm tail changes are more mixed.
- Summer shows a mid-Atlantic increase in Z500 cold events with a curious and roughly collocated decrease in Tsfc events.
- Summer Z500 warm events have become more frequent; mostly over oceans; more summer Tsfc warm events are largely confined to western US/Canada and northeastern Canada.

5. Cold/Warm Tail "Blob" Analysis

We developed an algorithm that identifies grid box (cell) extremes and groups adjacent cells into a single event (blob). Blobs are then tracked across successive daily fields; those with overlapping cells from day to day were classified as a continuing distinct event, and various daily blob statistics were calculated. Two illustrations of consecutive daily fields for Z500 and Tsfc blobs are shown below for 4-day portions of two famous US extreme events, one cold and one hot. The blob/event of interest is circled on the first day of each series. Videos of the daily fields over the entire 1979–2013 period are available via the QR code in the *More Information* section.



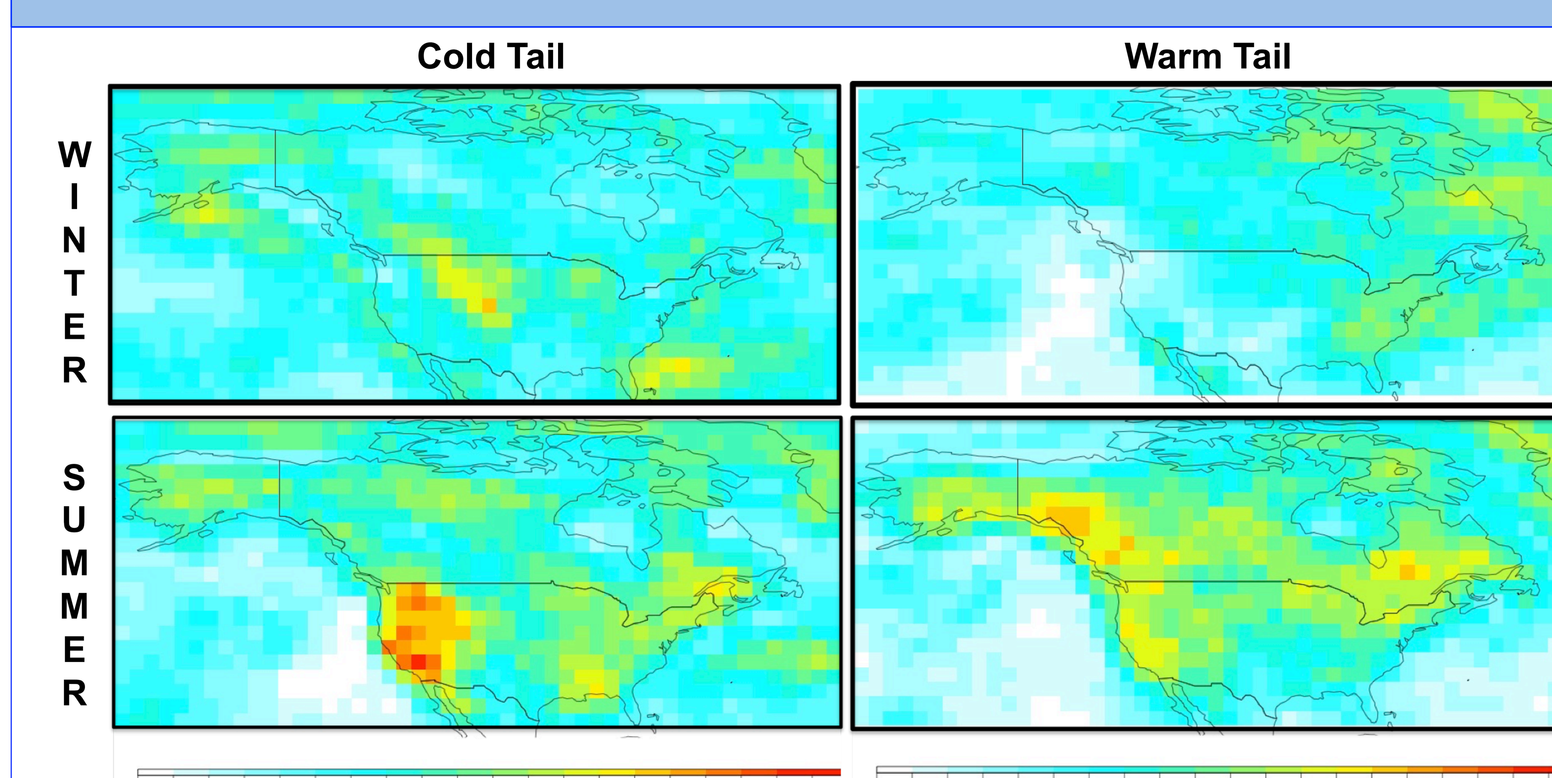
6. Properties of Extremes/Blobs Over 1979–2013

Seasonal statistics for four blob properties of Z500 and Tsfc: magnitude, frequency, surface area, and duration. The sign and level of significance (p<0.05; gray boxes) of trends are shown for each property for both cold and warm blobs, and '0' denotes no significant trend.

Property		Z500				Tsfc			
	Tail	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Magnitude (Z, Temp.)	Cold	+	+	+	+	+	+	+	+
	Warm	0	0	+	+	0	0	+	+
Frequency	Cold	-	-	-	-	-	-	-	-
	Warm	+	+	+	+	+	+	+	+
Surface Area	Cold	-	0	-	-	-	0	-	-
	Warm	0	+	+	+	0	+	+	+
Duration	Cold	0	0	0	0	0	0	0	0
	Warm	0	+	+	0	0	0	+	0

- Fewer (more) cold (warm) tail events are found for both Z500 and Tsfc across all seasons.
- The magnitude of cold tail events has "warmed" for both variables across all seasons.
- The magnitude of Z500 warm tail events has only increased in summer and fall.
- The surface area of cold (warm) blobs has decreased (increased) except for spring (winter).
- The duration of blobs/events has changed minimally; none for cold, mainly summer for warm, which would have implications for heat waves and their impacts.

7. Collocation of Z500 and Tsfc Extreme Events



Percentage of time (1979–2013) when a Z500 extreme was collocated with a Tsfc extreme.

- Extreme events are more "stacked" in summer, corresponding to the northward retreat of the jet stream, less amplified ridges and troughs compared to winter, and a more "equivalent barotropic" pattern.
- The blobs for the Chicago heat wave example above are illustrative of this relationship.

8. Summary

- A tracking algorithm was developed that enables the attributes of individual extreme events in 500 mb height and surface temperature to be calculated and assessed over time using reanalysis data. The algorithm can be applied to percentiles of choice from any gridded data.
- While there is a general correspondence between changes in the tails of the Z500 and Tsfc PDFs over North America, there are seasonal/regional differences, with the Tsfc cold tail changing the most, especially in fall and winter.
- While cold/warm tail events for Z500 and Tsfc have changed in their magnitude, frequency, and surface area, little change in the duration of individual extreme events is detected.

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For cold/warm blob videos on YouTube. →