Changes in North American Atmospheric Circulation and Extreme Weather: Evidence of an Arctic Connection

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Introduction

We test the hypothesis that Arctic amplification (AA) of global warming remotely affects middle latitudes by promoting a weaker, wavier atmospheric circulation conducive to extreme weather. The study is based on the late-21st century over greater North America using the CESM Large Ensemble.

Data

- 40 independent realizations from the Community Earth System Model (CESM) Large Ensemble (LENS)
- Years 1920-2100
- Past forcing, 1920-2005: observed radiative
- Future forcing, 2006-2100: RCP8.5 emissions scenario
- Greater North America (160°W- 50°W)

Methods

Sinuosity: A Measure of Circulation Waviness

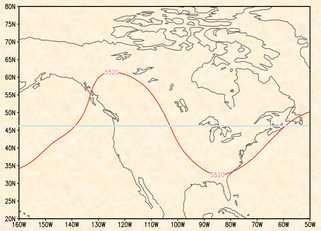

Fig. 1. Example of sinuosity metric. Red line is the daily mean 5520 m isohypse at 500 hPa across our study domain. The blue line is the shortest possible distance of this height contour, such that the areas poleward of this line and poleward of the isohypse are equal. Sinuosity equals the ratio of the length of the isohypse to the length of the blue line. Aggregate sinuosity (ASIN) is the weighted mean of five isohypses (5760m, 5640m, 5520m, 5400m, and 5280m) representative of mid-latitude circulation.

Sinuosity Quantifies Extreme Circulation Conditions

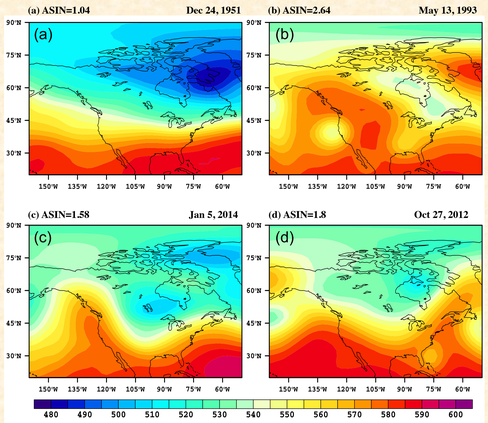

Fig. 2. Examples of extreme circulation states, illustrated by 500 hPa geopotential heights (dm). (a) Lowest aggregate sinuosity on record, (b) Highest sinuosity, (c) "Polar Vortex" event in Jan 2014 (ASIN = 95th percentile for Jan), and (d) Superstorm Sandy (98th percentile for Oct).

Future Climate Changes, Late 21st Century

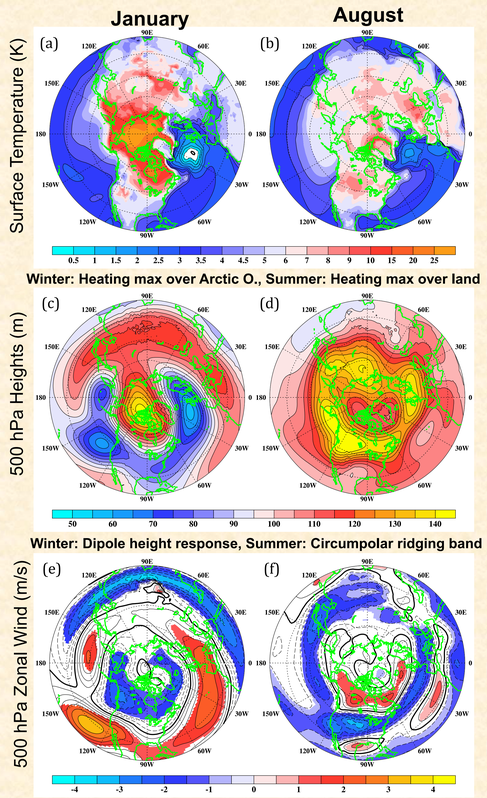

Fig. 3. Late-21st century (2081-2100) changes in (a, b) Surface temperature, (c, d) 500 hPa heights, and (e, f) 500 hPa zonal wind speed in (left) January and (right) August. Shaded regions denote where the ensemble-mean changes exceed the intra-ensemble standard deviation.

Wavier Circulation where Zonal Wind Weakens

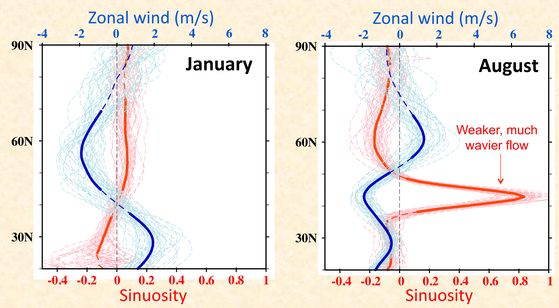

Fig. 4. As in Fig. 3 but for changes in zonal wind speed and sinuosity in Jan and Aug over greater N. America. Thin lines = individual ensemble members, and bold lines = ensemble mean. Solid bold lines are where the ensemble-mean change exceeds the intra-ensemble standard deviation.

Summer Drying over Great Plains

August Rainfall declines in Future over Plains

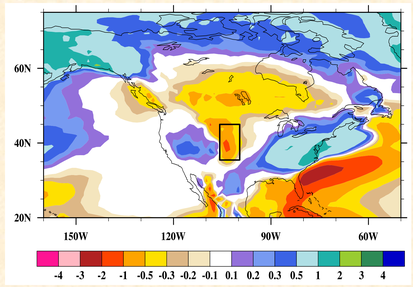

Fig. 5. Future changes (2081-2100) in August precipitation (mm day^{-1}). The box over the Great Plains denotes the region of especially pronounced drying and warming.

Atmospheric Ridge Pattern during Driest Augusts

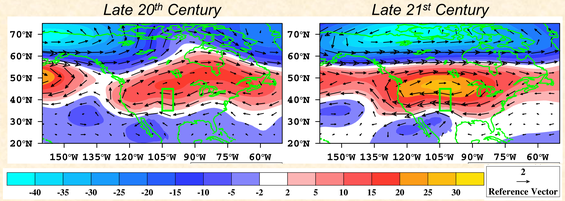

Fig. 6. 500 hPa heights (m) and wind velocity (m s^{-1}) anomalies in LENS on the driest 5% of August months in the late 20th and late 21st centuries, relative to each time period's climatology.

Dependence of Summer Heat and Rainfall on Zonal Wind Speed

Hot, Dry Summer Days in Plains when Circulation is Weak

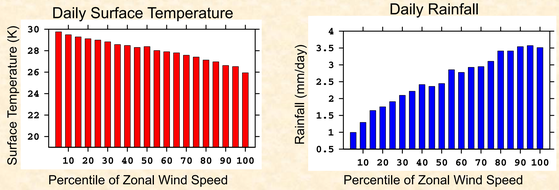

Fig. 7. Daily mean surface temperature and rainfall over the Great Plains box (see above) for all August days during the late 21st century as a function of the 500 hPa zonal wind speed percentile (late 20th century results are similar).

Future Summer Circulation Weakens in Plains

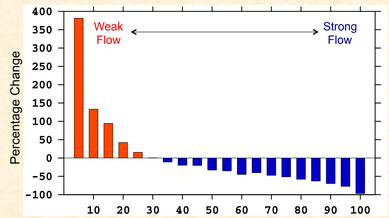

Fig. 8. Change in August wind speed frequency in the late 21st century vs. the late 20th century.

Possible Role of Snow Cover Loss as a Circulation Driver

Snow Cover Diminishes in Future

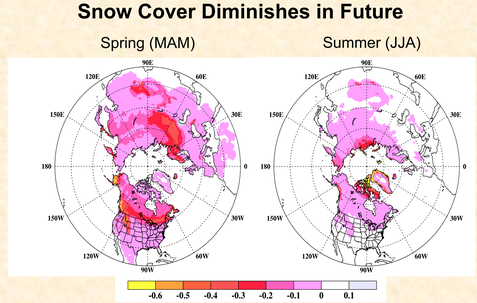

Fig. 9. Late 21st century changes in spring and summer snow fraction in LENS.

Simulated Impact of Total Snow Cover Removal (CCSM3): Similar to Projected Future Circulation Change

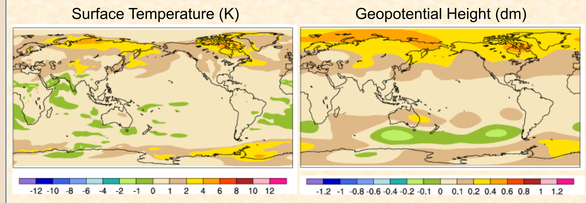

Fig. 10. Changes in summer surface temperature and 500 hPa heights in a CCSM3 model run driven by contemporary greenhouse forcing but with all terrestrial snow cover eliminated.

Conclusions

- Arctic Amplification promotes regionally varying ridging aloft and strong seasonal differences in circulation patterns (Fig. 3)
- Changes in circulation strength and waviness are inversely correlated in both winter and summer (Fig. 4)
- Weaker and wavier summer circulation over Plains favors extreme heat and dryness (Fig. 5 – 8)
- Circumpolar band of atmospheric ridging in summer that promotes Plains drought may be forced by declining snow cover (Fig. 9–10)

Next Steps

- Revise manuscript in review in *Journal of Climate*

  Vavrus et al. (2017): Changes in North American atmospheric circulation and extreme weather: evidence of an Arctic connection.
- Evaluate snow cover-summer circulation linkage more rigorously

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