PGW FUTURE CHANGE OF HAIL OVER THE NORTHERN PLAINS AND CANADIAN PRAIRIES BASED ON WRF-HAILCAST SIMULATIONS

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INTRODUCTION

Background:

Hail is a destructive severe weather phenomena that can cause considerable damage to property and agricultural crops. It is therefore important to understand current patterns in the occurrence of severe hail, and how these may shift in the future due to anthropogenic warming. Previous studies have shown decreases in occurrence and size of hail over some regions which have been attributed to increased convective inhibition [Trapp et al., *J. Climate*, 32, 5493-5509 (2019)] and/or melting [Brimelow et al., *Nat. Clim. Change*, 7, 516–522 (2017)].

Objectives:

- To examine future changes in the occurrence of hail over the Canadian Prairies and U.S. Northern Plains using a cloud-hail model forced by a high resolution convective-permitting regional climate model.
- To clarify which processes (melting vs. convective inhibition) might explain any changes observed.

Model Data:

High resolution (4 km) Weather Research and Forecasting (WRF) model output were generated by the National Center for Atmospheric Research (NCAR) from a control (CTRL) simulation and Pseudo-Global Warming (PGW) scenario for the period 2000-2013 over the Continental Unites States (CONUS) (Fig. 1a). CTRL and PGW data were then used as input for a 1D coupled cloud-hail model (HAILCAST) [Brimelow et al., *Nat. Clim. Change*, 7, 516–522 (2017)] for a domain over the Canadian Prairies and U.S. Northern Plains (Fig. 1b).

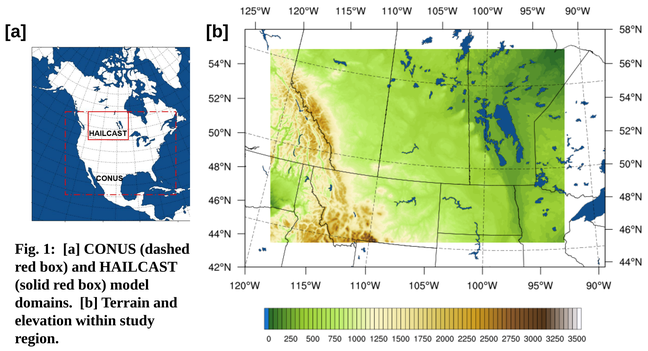

Fig. 1: [a] CONUS (dashed red box) and HAILCAST (solid red box) model domains. [b] Terrain and elevation within study region.

PGW Approach:

The PGW approach [Liu et al., *Clim. Dynam.*, 49, 71-95 (2017)] involves applying future climate perturbations derived from CMIP5 onto the the lateral and initial boundary conditions (ERA-Interim) of the WRF-CTRL simulation (Fig. 2). Spectral nudging was applied at 6 hourly intervals to prevent the general synoptic pattern from diverging. This allows for direct assessment of future changes in key thermodynamic variables onto historical synoptic patterns.

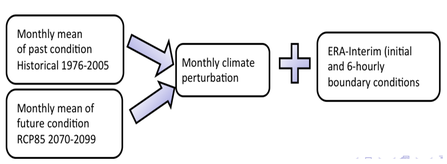

Fig. 2: Schematic showing PGW technique. Source: S. Kurkute, Y. Li. *Pseudo Global Warming approach using 4km WRF model.* CHRM Expert Workshop, 2016.

RESULTS

Occurrence of hail > 0.5 cm across the domain for the CTRL simulation shows a bimodal spatial pattern with non-contiguous maxima over northern Alberta extending south along the foothills, and over the upper Midwest and eastern Prairies (Fig 3a,d). Non-severe occurrences (< 2 cm) show a maximum over Alberta (Fig 3a); whereas severe cases (> 2 cm) show a maximum over the Midwest and eastern Prairies (Fig 3d). A dipole pattern occurs with a region of decreases coinciding with the Midwest/eastern Prairies maxima, and an area of increases over western portions of the domain (particularly Alberta).

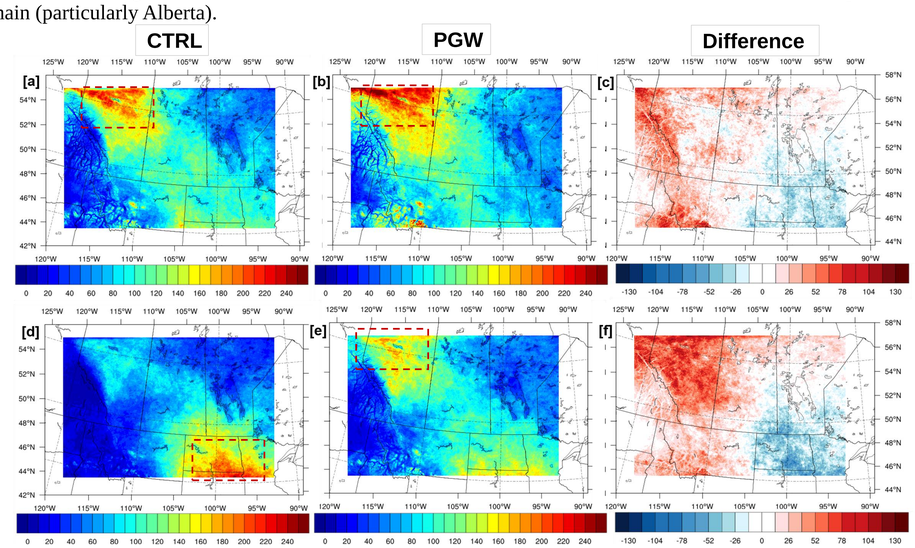

Fig. 3: Total occurrences of hail between 0.5-2 cm (top row), and > 2 cm (bottom row), for the CTRL simulation (left column), PGW simulation (middle column), and the difference between them (right column). Dashed red rectangles highlight maxima in CTRL simulation.

The higher occurrences of severe hail over southeastern portions of the domain are reflected in hailstone metrics (Fig. 4). Southeastern regions have higher mean (Fig. 4a) and maximum diameter (Fig. 4d) of hail in the CTRL simulation. In terms of changes, a similar spatial pattern is seen in maximum diameter as with hail counts (Fig. 4c,f). Mean diameter on the other hand, shows minimal decreases over the southeastern domain. Therefore even though there are less occurrences of hail over those regions, when hail does reach the surface it is on average the same size as in the CTRL simulation.

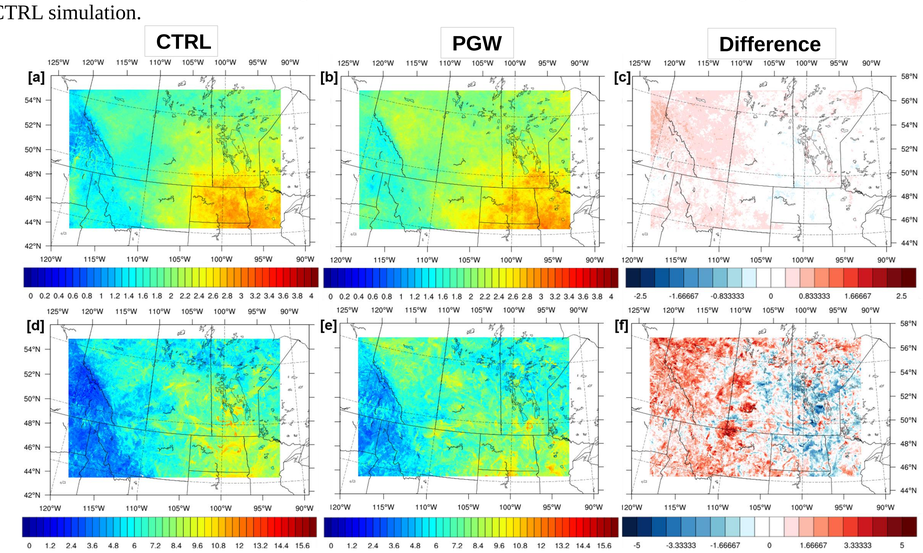

Fig. 4: Parameters describing hailstone metrics: mean diameter (cm) (top row), maximum diameter (cm) (bottom row) for all hail occurrences > 0.5 cm in the CTRL simulation (left column), PGW simulation (middle column), and the difference between them (right column).

DISCUSSION & SUMMARY

Melting:

There is an increase in probability that hailstones of 0.5-1 cm diameter undergo ablation close to the upper limit of their size class in the PGW simulation (Fig. 5a). There is also a considerable increase in the probability that hailstones which experience 0.5–1 cm melting are of that same diameter class. Taken together it suggests that there is a large increase in the likelihood that hailstones in the 0.5-1 cm size class undergo total ablation in the PGW simulation.

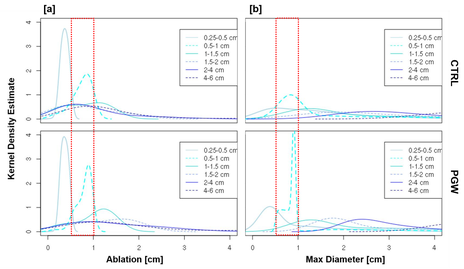

Fig. 5: Kernel density estimates for distributions of: [a] hailstone ablation at specific intervals of column-maximum diameter aloft; and [b] column-maximum diameter aloft for specific intervals of hailstone ablation in the CTRL (top row) and PGW (bottom row) simulations. Dotted red rectangles highlight the 0.5-1 cm intervals.

Convective Inhibition:

In spite of widespread increases in thermodynamic variables such as buoyancy/instability (not shown), parameters related to convective inhibition or capping appear to show a pattern of correlation with decreases in hail occurrence over southeastern regions (Fig. 6b,c). Changes in melt ratio, however do not show a spatially coherent signal (Fig. 6a)

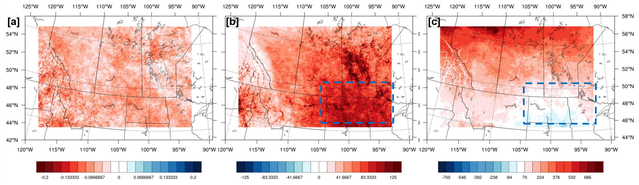

Fig. 6: Comparison of differences between the CTRL and PGW simulation for [a] melt ratio, [b] absolute value of mean convective inhibition (J/kg), and [c] total occurrences of hail potential (convective available potential energy > 200 J/kg) during uncapped conditions (convective inhibition > -20 J/kg). Dashed blue rectangles highlight areas correlated with regions of decreased hail occurrence.

Summary:

- Spatially non-contiguous maxima in hail occurrence occur across the study area
- Decrease in frequency of hail over southeastern portions of domain, but not in mean size of hailstones
- Increases in melt ratio explain reduction in occurrence of small hail (> 1 cm) across domain
- Decreases in occurrence of larger hail over southeast is likely due to increased convective inhibition and a reduction in occurrences of hail potential with uncapped conditions

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