# Hail Risk and Cropland Exposure Changes in the United States

**Logan R. Bundy [1], Walker S. Ashley [1], Alex M. Haberlie [1], Stephen M. Strader [2], Margo S. Andrews [1], Sean Whelan [1], Evelynn Mantia [1], Vittorio A. Gensini [1], and Allison C. Michaelis [1]**

*[1] Department of Earth, Atmosphere, and Environment, Northern Illinois University, DeKalb, IL*

*[2] Department of Geography and the Environment, Villanova University, Villanova, PA*

## Introduction

- Escalating disasters and losses are a function of climatological risk—the probability of a hazard occurring, the exposure to a hazard, and the vulnerability of the exposed (IPCC, 2014).
- There is uncertainty associated with the magnitude of impacts from cropland expansion (Lark et al. 2015), especially with assessing meteorological perils in agriculture (Steele & Hatfield, 2018).
- The "Expanding Bull's-Eye Effect" (Ashley et al., 2014) has been applied indirectly to agriculture (Bundy et al., 2022, 2024; Li et al., 2019; Lobell et al., 2014) but has fallen short in quantifying the exposure factor as a means for agricultural loss.

## Research Goals

**How will the crop-hail risk landscape change?**

1) Quantify future-projected cropland changes
2) Spatially demonstrate historical and future cropland exposure risk to hail for key U.S. agricultural regions
3) Further the understanding of hail in future climates juxtaposed with future cropland exposure

## Data and Methods

**Data**

- Projected LULC data were developed using the USGS FORE-SCE corresponding to the four major scenario storylines from the IPCC SRES.
  - A1B, A2, B1, B2
- SVRGIS administered by the SPC was used for hail climatology. A hail day is defined as at least one severe hail report (≥ 1.0", 2.54 cm diameter) per day within an 80-km grid.
- WRF-BCC consists of dynamically downscaled convection-permitting regional climate model simulations for HIST; 1990–2005, MID; 2040–2055, and END; 2085–2100 periods over the CONUS (Gensini et al., 2023).

**Methods**

- WRF-BCC future hail projections were used to calculate the average number of severe hail days over 14 complete boreal summer growing seasons (May–October) in the HIST, MID, and END periods.
- HailMC model (Childs et al., 2020) used to investigate the statistical probability of hail impacting cropland for each IPCC SRES scenario.
  - 5,000-year simulation of hail swaths using SVRGIS hail data and 2005, 2055, and 2100 cropland data.

## Crop-Hail Risk

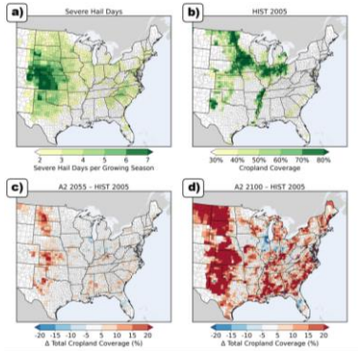



*Figure 1. a) Crop-hail climatology over the May–October, 1990–2020 period, showing average number of severe hail days per growing season; b) percent of each county that is cropland in 2005; c) deltas for county-level cropland percentages for IPCC SRES scenario A2 in 2055 with 2005 historical croplands.; d) deltas for county-level cropland percentages for IPCC SRES scenario A2 in 2100 with 2005 historical croplands.*

**Severe Hail Days**

- Over 7 severe hail days across counties in Kansas, eastern Colorado, and western Nebraska
- At least 3 severe hail days across the Great Plains

**Historical Cropland Coverage**

- Northern Plains: about 37% (85 million acres) of cropland
- Southern Plains: about 21% (49 million acres) of cropland

**Great Plains**

- Increase by 5% or more of cropland coverage by 2055 for 28% of counties
- Increase by 10% or more of cropland coverage by 2100 for 40% of counties

## Hail Impact Monte Carlo Simulations

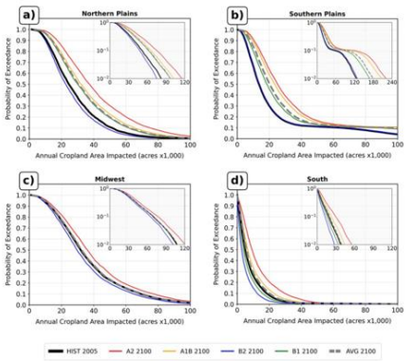



*Figure 3. Probability of exceedance (POE) curves comprising a 5,000-year HailMC simulation of the 2005 annual cropland area impacted by hail (solid black line), the 2100 annual cropland area impacted by hail for each IPCC SRES scenario (A1B, A2, B1, B2), and an average between the four scenarios (AVG) for each region of interest. Each panel contains a subplot of the same POE curves with a log (y) axis.*

**Change by Scenario**

- The Northern and Southern Plains are the only regions with at least 3 of the 4 IPCC SRES scenarios projecting an increase in crop-hail impact.

**Change in AVG 2100**

- Southern Plains: 46% increase
- Northern Plains: 23% increase
- Midwest: 1% increase
- South: 10% increase

## Interaction of Hail Risk with Changing Cropland Exposure

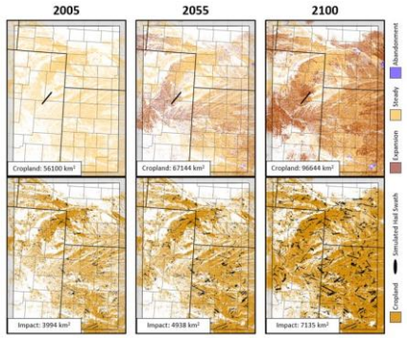



*Figure 2. HailMC simulation atop eastern Colorado, western Kansas, and western Nebraska with A2 2005, A2 2055, and A2 2100 croplands representing the exposure surface. The black lines are from the 500-year HailMC simulation with the top panels showing a single simulated hail swath used as an example to estimate impacts.*

**Great Plains Example**

- Impact increases by 79% (nearly 990,000 acres to 1.7 million acres) over the 95-year period.
- The expanding bull's eye enlarges over time, increasing the chance that hail impacts cropland, which may translate into crop-hail loss. This will vary regionally.

## Changing Hail Risk with Changing Cropland Exposure

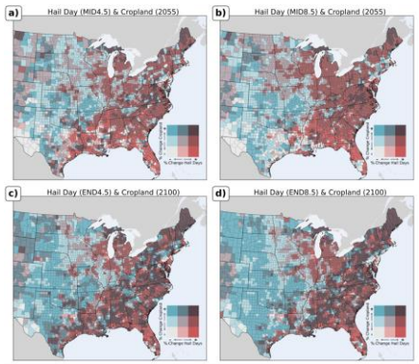



*Figure 4. (top row) Mean percent changes in cropland area by 2055 and percent changes in severe hail days relative to HIST for a) MID4.5 and b) MID8.5. (bottom row) Mean percent changes in cropland area by 2100 and the percent changes in severe hail days relative to HIST for c) END4.5 and d) END8.5. Positive (negative) percent changes refer to hail day or cropland changes >20% (<-20%).*

**MID4.5, MID8.5**

- Southern Plains: fewer hail days and more to little changes in cropland.

**END4.5, END8.5**

- Increase in cropland and decrease in hail days in the Plains.

**East of MS River**

- More hail days accompanied by increased or little changes in cropland area.

## Conclusions

- While the Midwest has the greatest magnitude of cropland and probability of severe hail, it is the juxtaposition of severe hail and projected increases in severe hail that drives crop-hail loss in the Great Plains.
- It is not solely the cropland magnitude that is important in creating major crop yield loss, it is more so how croplands are distributed across the landscape that defines how risk and vulnerability are realized in a major crop loss scenario.
- Crop-hail impacts are not uniform across the landscape. Despite the projected decrease in severe hail days across much of the Great Plains, the projected increases in cropland coverage may still drive an increase of crop-hail losses.
- These results characterize the importance of crop management and sustainability.
- Stakeholders can use these findings to inform data-driven decisions and help communicate agricultural production risk.

## References

Ashley, W. S., Strader, S., Rosencrans, T., & Krmenec, A. J. (2014). Spatiotemporal changes in tornado hazard exposure: The case of the expanding bull's-eye effect in Chicago, Illinois. *Weather, Climate, and Society*, *6*(2), 175–193. https://doi.org/10.1175/WCAS-D-13-00047.1

Bundy, L. R., Gensini, V. A., & Russo, M. S. (2022). Insured corn losses in the United States from weather and climate perils. *Journal of Applied Meteorology and Climatology*, *61*(8), 969–988. https://doi.org/10.1175/JAMC-D-21-0206.1

Bundy, L. R., Gensini, V. A., Ashley, W. S., Haberlie, A. M., & Champion, D. (2024). United States crop conditions: 1986–2022. *Agronomy Journal*, *116*, 1397–1416. https://doi.org/10.1002/agj2.21559

Childs, S. J., Schumacher, R. S., & Strader, S. M. (2020). Projecting end-of-century human exposure from tornadoes and severe hailstorms in eastern Colorado. *Meteorological and population perspectives. Weather, Climate, and Society*, *12*(3), 575–595. https://doi.org/10.1175/WCAS-D-19-0141

Gensini, V. A., Haberlie, A. M., & Ashley, W. S. (2023). Convection-permitting simulations of historical and possible future climate over the contiguous United States. *Climate Dynamics*, *60*(1), 189–126. https://doi.org/10.1007/s00382-022-06300-0

IPCC. (2014). Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White. Cambridge University Press, United Kingdom and New Yo

Lark, T. J., Meghan Salmon, J., & Gibbs, H. K. (2015). Cropland expansion outpaces agricultural and biofuel policies in the United States. *Environmental Research Letters*, *10*(4), 044003. https://doi.org/10.1088/1748-9326/10/4/044003 (6, NY, USA., 2014.

Li, Y., Guan, K., Schnitkey, G. D., DeLucia, E., & Peng, B. (2019). Excessive rainfall leads to maize yield loss of a comparable magnitude to extreme drought in the United States. *Global Change Biology*, *25*(7), 2325–2337. https://doi.org/10.1111/gcb.14628

Lobell, D. B., Roberts, M. J., Schlenker, W., Braun, N., Little, B. B., Rejesus, R. M., & Hammer, G. L. (2014). Greater sensitivity to drought accompanies maize yield increase in the U.S. Midwest. *Science*, *344*(6183), 516–519. https://doi.org/10.1126/science.1251423

Steele, B., & Hatfield, J. L. (2018). Navigating climate-related challenges on working lands: a special issue by the USDA Climate Hubs and their partners. *Climatic Change*, *146*(1–2), 1–3. https://doi.org/10.1007/s10584-017-2094-2

## Acknowledgments

This research was supported by the National Science Foundation Awards 1637225 and 1800582 and National Oceanic and Atmospheric Administration Award NA22OAR4690645.