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Advance Remote Sensing Applications for Agricultural Damage Assessment: A Case Study of Boone County, Iowa

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Abstract

Derecho windstorms are extreme weather events capable of causing catastrophic damage to agricultural systems across the U.S. Midwest. Using methodologies relevant to Indigo Agriculture's precision farming approach, this case study applies advanced remote sensing techniques to examine the significant impacts of the August 2020 Derecho windstorm on agricultural fields in Boone County, Iowa, using Sentinel-1 Synthetic Aperture Radar (SAR) data. The research quantifies damage extent across crop types with particular focus on corn and soybean fields, analyzes damage severity patterns, and investigates spatial variability of impacts. SAR imagery acquired 5 days post-windstorm revealed detectable changes in backscatter values attributable to structural damage in crops, allowing for comprehensive damage assessment across the study area. Results demonstrate variable damage patterns both within and between crop types, with corn exhibiting greater susceptibility to wind damage than soybeans due to structural differences. The analysis identified 1-10% backscatter variations in control points, while damaged areas displayed more significant deviations. While multiple factors potentially influence backscatter values, including soil moisture conditions, vegetation maturity, crop growth stage, and environmental changes, the temporal proximity of image acquisition to the windstorm event supports the attribution of observed changes to wind damage. This research demonstrates approaches applicable to Indigo Agriculture's precision agriculture services and contributes valuable insights for agricultural risk assessment and disaster management while showing the efficacy of SAR data for rapid post-windstorm crop damage evaluation. The methodology presented can inform future applications of remote sensing in monitoring agricultural disaster impacts, supporting more targeted response and recovery efforts in affected farming communities, and enhancing agricultural technology companies' damage assessment capabilities.

Keywords: Precision agriculture, synthetic aperture radar, crop damage assessment, agricultural remote sensing.

INTRODUCTION

The increasing frequency and intensity of extreme weather events pose significant challenges to agricultural systems worldwide. The August 2020 Derecho that devastated the Midwestern United States stands as a stark example of such catastrophic events, causing approximately $11 billion in damages and destroying vast expanses of cropland across Iowa and neighboring states (Anderson *et al.*, 2021). In Boone County alone, preliminary assessments indicated that nearly 65% of corn fields experienced moderate to severe damage, highlighting the urgent necessity for rapid and accurate damage assessment methodologies. Weather-related crop damage has traditionally been evaluated through field surveys, which, while detailed, are labor-intensive and often impractical for large-scale events. Remote sensing technologies have emerged as complementary tools that overcome these limitations by providing synoptic views across extensive geographic areas. Among these technologies, Synthetic Aperture Radar (SAR) offers distinct advantages for post-disaster monitoring due to its all-weather imaging capabilities, a crucial feature when cloud cover frequently hampers optical sensors following severe storms (Steele-Dunne *et al.*, 2017).

Prior investigations have explored various applications of SAR in agricultural monitoring. Hosseini and McNairn (2018) demonstrated the sensitivity of C-band SAR to crop structural changes resulting from environmental stressors. Similarly, research by Wang and colleagues (2019) established correlations between backscatter coefficient variations and corn lodging following severe storms in central Iowa. These studies laid essential groundwork; however, they primarily focused on localized phenomena rather than widespread catastrophic events like the 2020 Derecho. The European Space Agency's Sentinel-1 constellation represents a significant advancement in SAR technology accessibility, providing freely available C-band data with a 6-day revisit cycle (Torres *et al.*, 2012). This temporal resolution enables the detection of rapid changes in agricultural landscapes following extreme weather events. Research by Zhou *et al.*, (2016) utilized multi-temporal Sentinel-1 imagery to characterize crop damage patterns after flooding in eastern China, while Mohammadi *et al.*, (2021) documented significant backscatter changes in Nebraska corn fields following an intense windstorm in 2019.

Several challenges persist in the application of SAR for agricultural damage assessment. Chen and Lin (2018) emphasized the complexity of separating weather-induced backscatter changes from those stemming from soil moisture variations, phenological development, or management practices. Furthermore, Torbick *et al.*, (2017) noted the importance of establishing appropriate baseline conditions when quantifying deviations from expected crop development trajectories. The integration of satellite-derived damage assessments into precision agriculture frameworks represents an emerging frontier with substantial potential benefits. Companies specializing in agricultural technology have begun incorporating remote sensing data into their decision support platforms, enabling farmers to implement targeted recovery strategies following adverse weather events (Johnson and Lee, 2022). However, the operational utilization of such approaches requires robust methodologies tailored to specific crop types and environmental conditions.

Our study addresses these challenges by developing and evaluating a comprehensive methodology for mapping and quantifying crop damage caused by the August 2020 Derecho windstorm in Boone County, Iowa. By analyzing pre-event and post-event Sentinel-1 SAR data acquired within a narrow temporal window surrounding the windstorm, we mitigate confounding factors while capturing the immediate impacts on corn and soybean fields. The research objectives include: (1) quantifying the extent of windstorm damage across agricultural landscapes, (2) analyzing differential impacts between corn and soybean crops, and (3) examining spatial patterns of damage intensity in relation to topographic features and field orientation.

The methodological framework developed through this case study contributes to the advancement of operational remote sensing applications for agricultural damage assessment. Our findings hold particular relevance for precision agriculture services that aim to provide timely, actionable intelligence to farmers navigating the aftermath of increasingly common extreme weather events.

RESEARCH QUESTION AND HYPOTHESIS

This study investigates the following primary research question:

Research Question: What significant impacts did the August 2020 Derecho windstorm have on agricultural landscapes in Boone County, Iowa, as detected and quantified through Sentinel-1 Synthetic Aperture Radar data analysis?

Hypothesis: The August 2020 Derecho windstorm caused detectable and spatially variable structural damage to crop fields in Boone County, with differential impacts across crop types that can be quantified through changes in SAR backscatter coefficients between pre-storm and post-storm imagery.

Research Goals

1) **Quantify the spatial extent and magnitude of damage** inflicted by the August 2020 Derecho windstorm on agricultural landscapes in Boone County, Iowa, with specific focus on corn (*Zea mays*) and soybean (*Glycine max*) cultivation areas.
2) **Analyze differential vulnerability patterns** across agricultural fields within the county to determine crop-specific susceptibility to windstorm damage, thereby identifying which crop type (corn or soybean) demonstrates greater sensitivity to high-velocity wind events.
3) **Characterize the spatial heterogeneity** of windstorm impacts throughout Boone County through geospatial analysis of damage patterns, examining relationships between damage intensity and geographic variables within corn and soybean production zones.

Study Area

The study area for this research is Boone County, situated in the central region of Iowa (Figure 1 & 2). Encompassing approximately 270,000 acres, nearly 75% of the county's land is dedicated to row crop production (Town Square Publications, 2021). Iowa is recognized as one of the most productive agricultural regions globally (U.S. Forest Service, 2019) and stands as a national leader in agriculture, particularly in corn and soybean production (Iowa Department of Agriculture and Land Stewardship, 2021). Agriculture constitutes a fundamental component of Boone County's economy. According to the U.S. Department of Agriculture and the National Agricultural Statistics Service (2021), farmers in Boone County planted 102,000 acres of soybeans and 162,500 acres of corn in 2020. Both crop and livestock production represent vital elements of the agricultural economy, generating income, employment, and economic activity throughout the region.

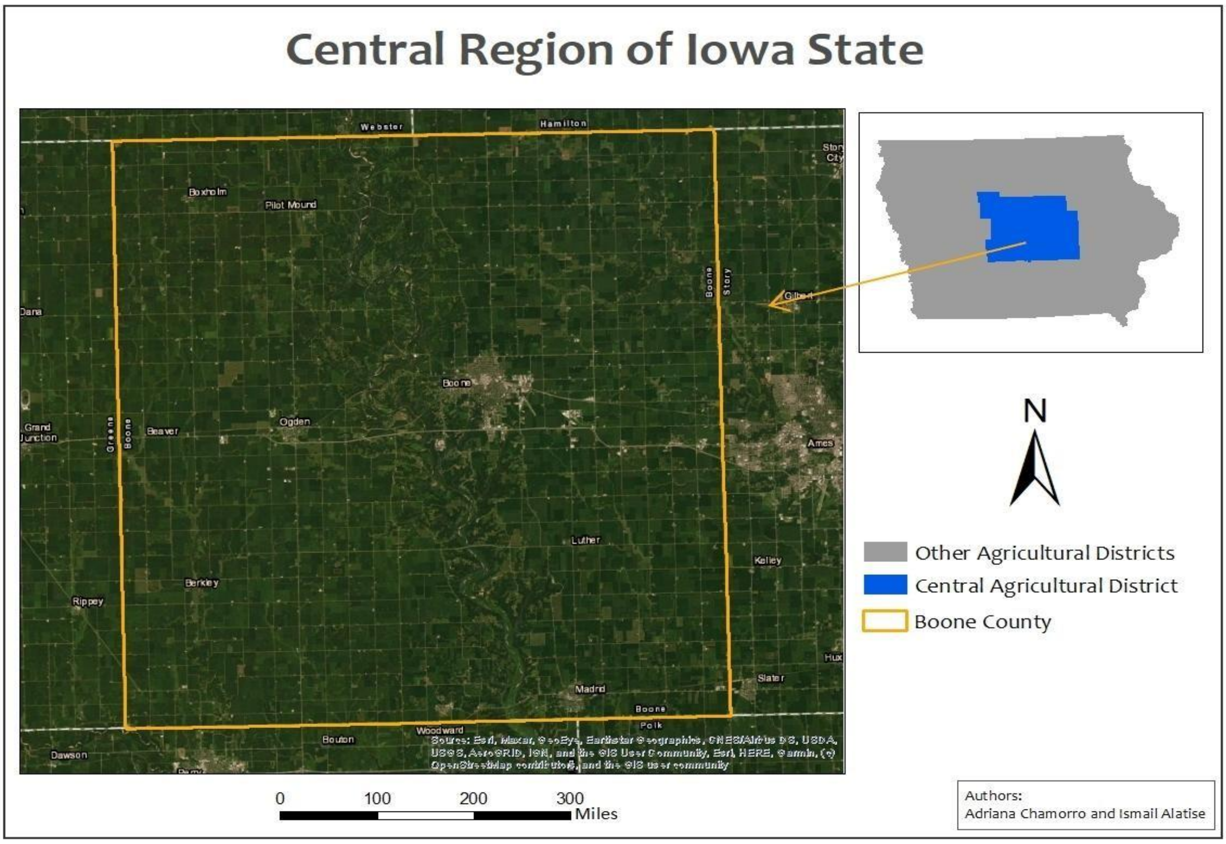

Figure 1: Boone County, represented as the Study Area in the Central Region of Iowa State. (Data Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community)

Despite the significant portion of farm revenue generated by croplands in Boone County, agricultural production suffered substantial losses due to the destructive Derecho windstorm that swept across Iowa in August 2020 (National Oceanic and Atmospheric Administration [NOAA], 2020). The Derecho traveled approximately 770 miles in 14 hours, from southeastern South Dakota to Ohio. In Iowa, wind speeds reached 100 mph, resulting in particularly severe damage (NOAA, 2020). Based on MODIS satellite imagery and Storm Prediction Center preliminary reports, the Iowa Department of Agriculture and Land Stewardship (2020) identified 36 counties in Iowa as the hardest hit. Within these counties, the storm significantly impacted an estimated 3.57 million acres of corn and 2.5 million acres of soybean. According to damage assessment maps produced by Indigo Agriculture, Boone County experienced some of the most severe impacts. For effective planning and decision-making, determining the precise effects of this windstorm on crop fields in Boone County is imperative, underscoring the necessity of this research.

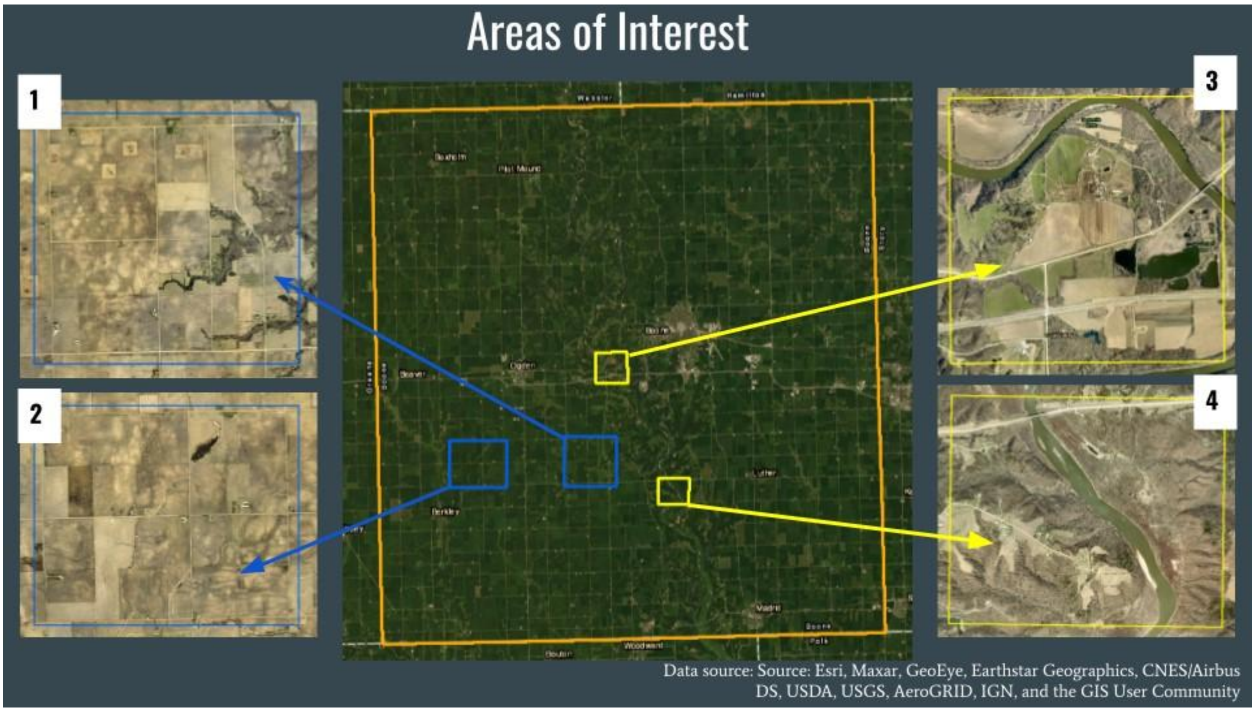

Figure 2a: Areas of Interest within Boone County. (Data Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community)

Figure 2b: Areas of Interest within Boone County overlaid by crop data layer. (Data Source: https://nassgeodata.gmu.edu/CropScape/)

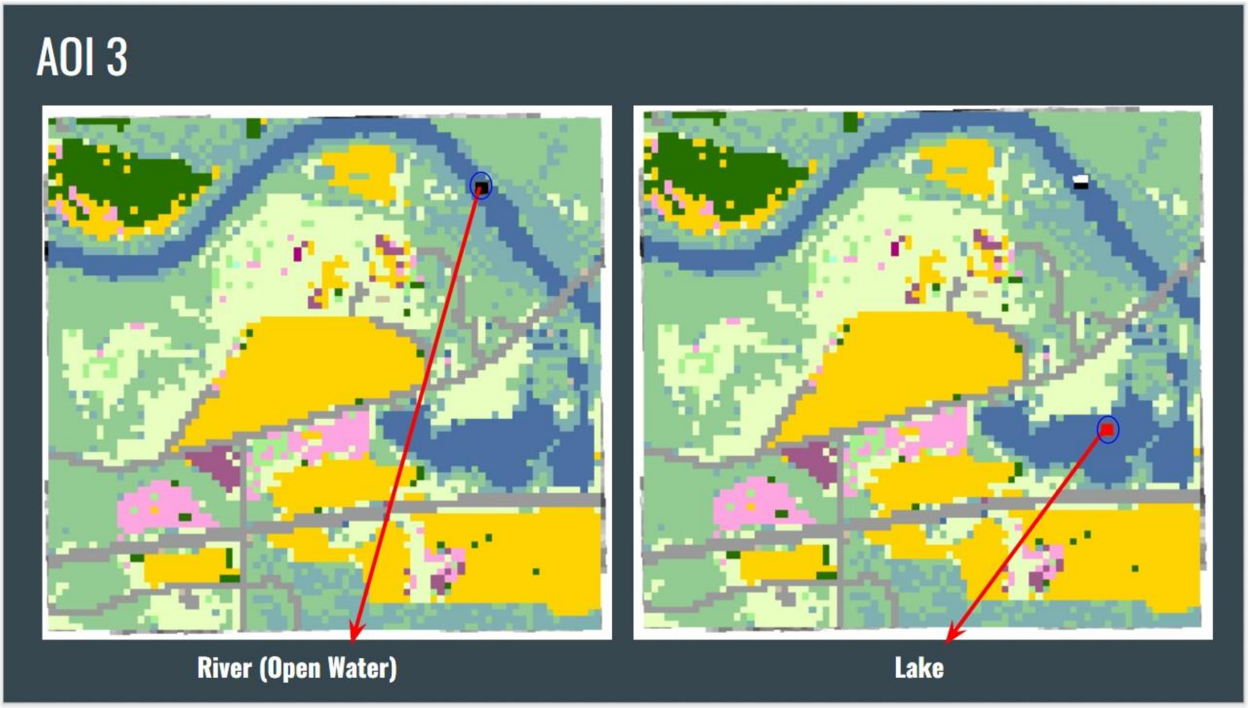

Figure 2c: Areas of Interest within Boone County-Control Points

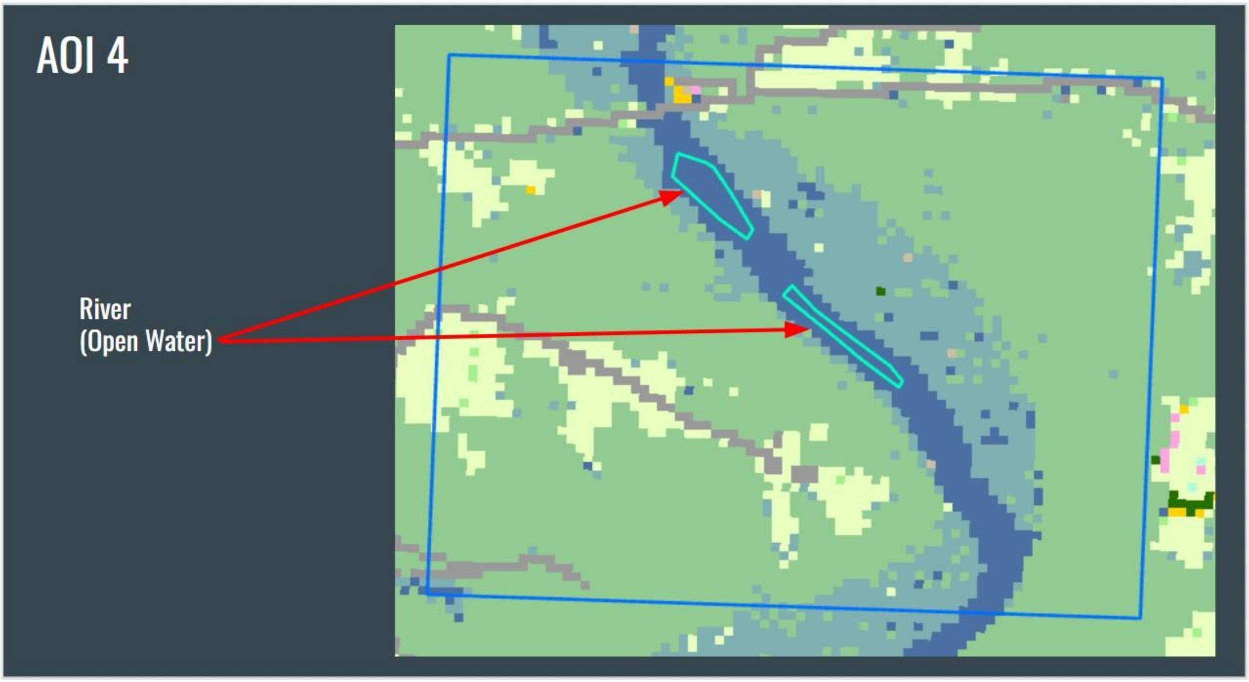

Figure 2d: Areas of Interest within Boone County-Control Points

This study employs Sentinel-1 Synthetic Aperture Radar (SAR) imagery to map the extent of the Derecho windstorm and quantify its impact on both corn and soybean crops (Figure 3). SAR technology complements optical remote sensing methods for identifying crop and vegetation damage from windstorms (Bell *et al.*, 2019a). SAR facilitates remote sensing of land surfaces in virtually all-weather conditions by detecting changes in backscatter values and coherence between paired images taken from identical viewing angles but at different times (Bell *et al.*, 2020). The application of multitemporal Sentinel-1 data for monitoring maize growth has been demonstrated with high accuracy (80% overall) by U.S. Forest Service (2019). Additionally, Sentinel-1 SAR data have been effectively utilized for crop monitoring and harvest assessment in various geographic regions (Bell *et al.*, 2019a, 2019b). Specifically, SAR images have supplemented observations from optical remote sensors in identifying and delineating hail damage swaths during various phases of the growing season in the Central United States (Bell *et al.*, 2019a, 2020).

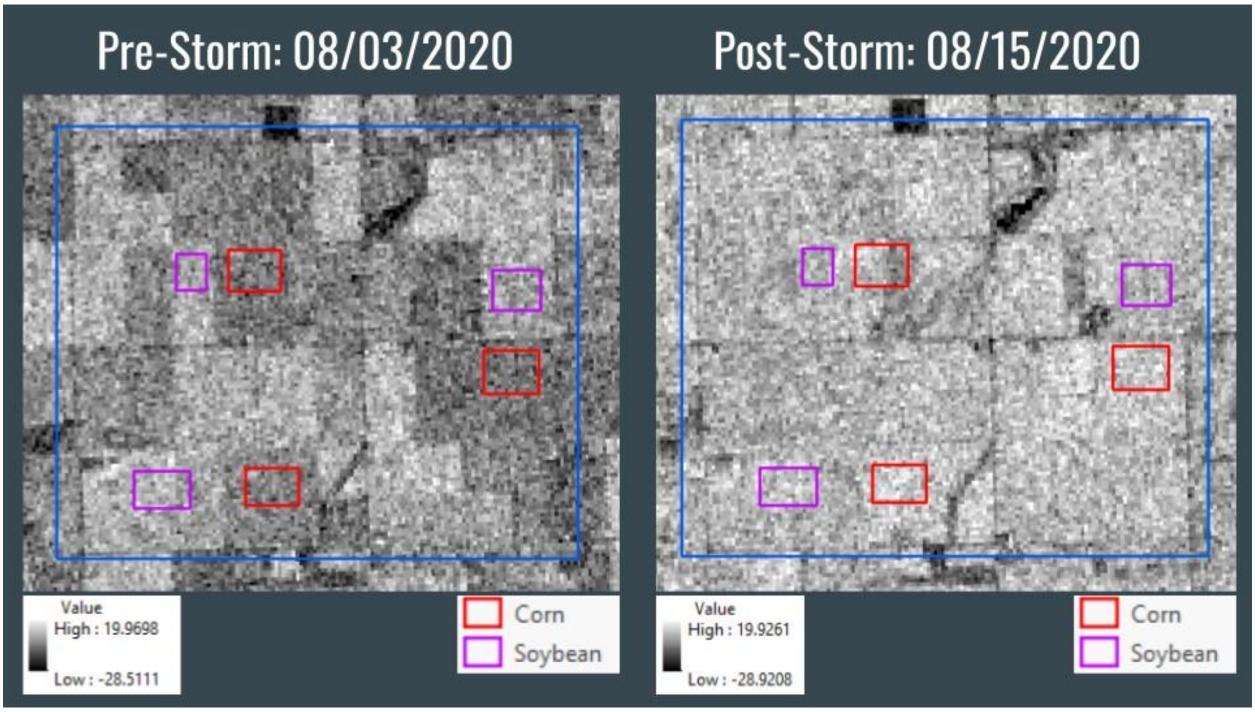

Figure 3: Pre-Storm and Post-Storm Sentinel 1 Image of Area of Interest 2

In our methodology, we apply image differencing techniques to SAR images to validate backscatter value changes attributable to the windstorm. Pixels exhibiting low coherence values in pre- and post-windstorm pairs are identified as potentially wind-affected areas. Using the U.S. crop type map, we detect percentage changes in average backscatter values between pre- and post-storm images in corn and soybean-dominated pixels. This approach enables us to determine the impact and extent of damage inflicted by the Derecho windstorm on these crop types in Boone County.

DATA DESCRIPTION

This study utilized data exclusively from established secondary sources. Sentinel-1 Synthetic Aperture Radar (SAR) imagery was acquired for both pre-storm (August 3, 2020) and post-storm (August 15, 2020) periods, spanning August 10, 2020, Derecho event. These images were processed and retrieved through the Google Earth Engine platform to analyze windstorm damage across the study area. Complementary crop classification data were obtained from the USDA National Agricultural Statistics Service (NASS) CropScape information repository to identify specific crop types within the affected regions. *Table 1 provides detailed specifications of all data sources utilized in this analysis.*

Table 1: Data Sources and Specifications

Variable	Type	Temporal Resolution	Sources
Satellite Imagery	SAR imagery*	2020 (6 days)	Google Earth Engine
Crop type layer	Attribute data	2020-2021	USDA: CropScape

*Detailed SAR image specifications (attributes, value description, projection, etc.) can be found in Table 2.

Table 2: Sentinel-1 SAR Image Specifications

Attribute	Value	Description
Satellite	S1A	Level 1 GRDH
Projection	NAD 1983	NAD 1983 (2011) StatePlane Iowa North FIPS 1401 (US Feet)
Resolution	40m	40×40m spatial resolution
Bands	1	Each polarization is stored as a separate 1-band image
No Data Value	0	Image "no data value"
Data Type	Float32	Float32 is used to store backscatters as linear power ratio
Block Sizes	512×512	512×512 pixels per block
Orbit Direction	ASC	Ascending orbit direction

METHODOLOGY

This study employs change detection techniques on Synthetic Aperture Radar (SAR) imagery to quantify the extent of Derecho windstorm damage on different crop types in Boone County, Iowa. The methodological framework consists of data preprocessing, geoprocessing, image differencing, and statistical analysis of pre-storm and post-storm conditions. The analytical workflow was executed in six sequential steps, as detailed below.

Data Acquisition and Preprocessing

The initial phase involved preprocessing and acquiring data from Google Earth Engine. Sentinel-1 SAR image collections were clipped to the Boone County boundary and filtered according to specific parameters: VV polarization, Interferometric Wide Swath (IW) instrument mode, ascending orbit pass (ASC), and median value composites. Two temporal datasets were created: pre-storm (August 5-9, 2020) and post-storm (August 13-17, 2020) image composites to capture conditions immediately before and after the Derecho event on August 10, 2020.

Selection of Study Sites

Two distinct categories of areas of interest (AOIs) were established for comparative analysis:

1. **Crop Areas**: Regions with a proportional distribution of corn and soybean fields where storm-induced changes were anticipated.
2. **Control Areas**: Non-crop regions (including water bodies, built-up areas, and transportation infrastructure) where minimal storm-related backscatter changes were expected

Within these broader categories, we selected three representative sites from crop areas and two from non-crop areas based on the USDA crop type layer map. These selections ensured analysis within homogeneous pixels for each land cover type.

Site-Specific Data Extraction

We extracted pre-storm and post-storm SAR data for each selected site using the Clip Raster Tool in ArcGIS Pro. This process generated site-specific raster datasets containing backscatter values for both temporal periods. The clipped areas represented pure pixels for each crop type and non-crop classification, minimizing mixed-pixel effects that could confound the analysis.

Calculation of Backscatter Changes

We calculated the average backscatter values for pre-storm and post-storm images of each clipped site using Zonal Statistics as Table in ArcGIS Pro. Image differencing was performed by subtracting pre-storm backscatter values from post-storm values. The percentage change in backscatter was then calculated using the formula:

$$\text{Percent Change} = \frac{(\text{Post} - \text{storm Mean Backscatter}) - (\text{Pre} - \text{storm Mean Backscatter})}{\text{Pre} - \text{storm Mean Backscatter}} X\ 100$$

This calculation quantified the relative magnitude of change in radar backscatters as attributed to the windstorm event.

Visualization of Site-Specific Results

The percentage changes in backscatter values were visualized through charts created in Microsoft Excel. These visualizations enabled a comparative analysis between different crop types and control areas, facilitating the interpretation of differential windstorm impacts across the landscape.

County-Wide Analysis

The final analytical step expanded the site-specific methodology to the entire extent of Boone County. Using the Raster Calculator in ArcGIS Pro, we performed image differencing and percentage change calculations on a pixel-by-pixel basis across the full study area. This process generated a continuous spatial representation of windstorm damage, visualizing the geographic distribution and intensity of crop damage throughout Boone County. This methodological approach enabled a quantitative assessment of Derecho windstorm impacts on agricultural landscapes while controlling potential confounding factors by including non-crop control sites.

RESULTS

Spatial Extent and Variability of the Windstorm Damage across Boone County

The Derecho windstorm blasted a wide swath of Boone County and had a great impact on agricultural fields. Figure 4 shows the spatial coverage or extent of the windstorm damage to corn across Boone County. The damage is mainly apparent when zoomed into the agricultural fields. Much of the damage (as seen in Figures 5a and 5b) is done to cornfields than soybeans. Across the agricultural fields in Boone County, cornfields increase backscatter values in post-storm images, which signifies more damage. Higher values in the post-storm images are tantamount to a more significant percentage change and greater damage to cornfields in the county. From our analysis, we were able to map the extent of windstorm damage done to cornfields in Boone County (Figure 9a) as presented by the percent change in backscatter values. However, due to time constraints, the extent of damage done to soybean fields in the county was not mapped. Hence, this would be considered in further research.

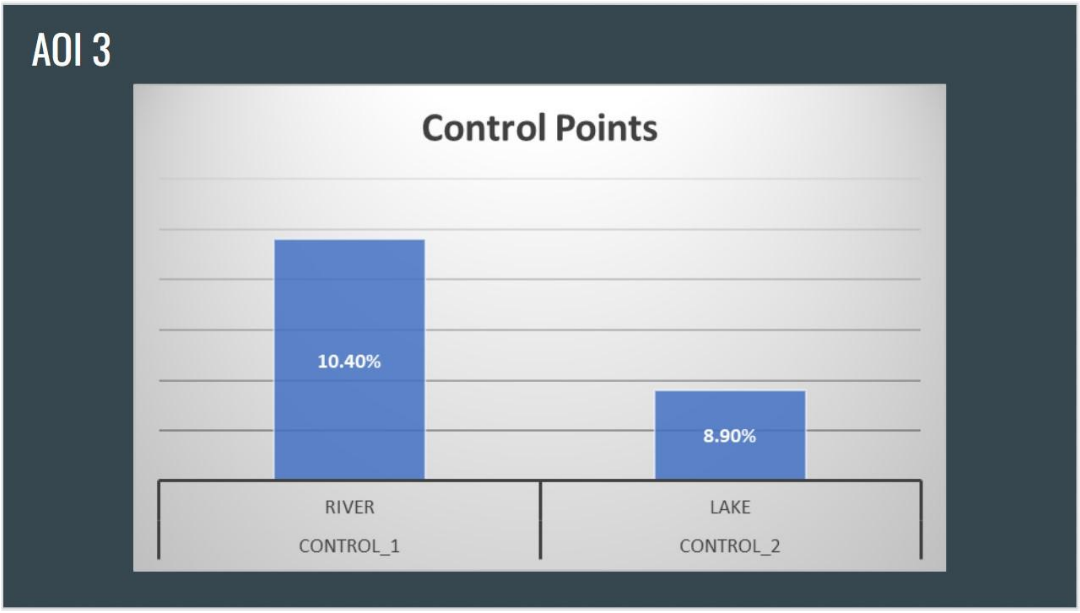

Figure 4a: Percentage Change in Backscatter Values for both Soybean and Corn in AOI 2

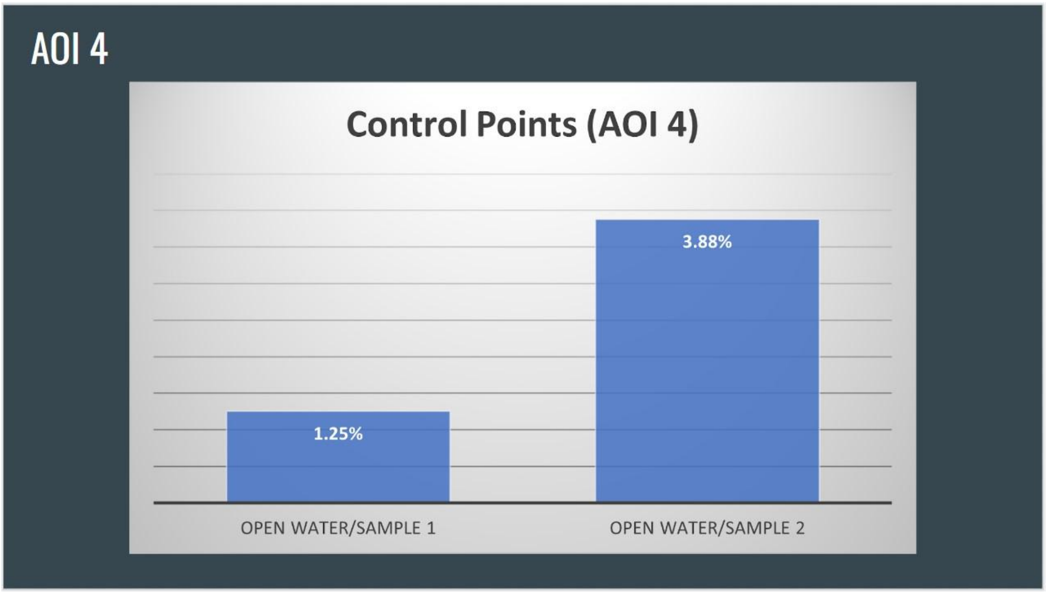

Figure 4b: Percentage Change in Backscatter Values for both Soybean and Corn in AOI 2

Geographically, the extent of damage to crop fields in Boone County varies in space. Generally, across Boone County, Figure 3 above shows the post-storm image of an increase in backscatter value. From this image, areas in the southwestern corner, where the study sites are chosen, “areas marked with blue square boundaries”, suffered the most tremendous damage than other parts of the county. Moreover, the image difference and percent change map also show that crop fields in the southwestern part of the county experienced more significant damage due to the storm than other parts of the county. Contrarily, the crop fields in the northwestern part of the county suffered less damage from the Derecho windstorm.

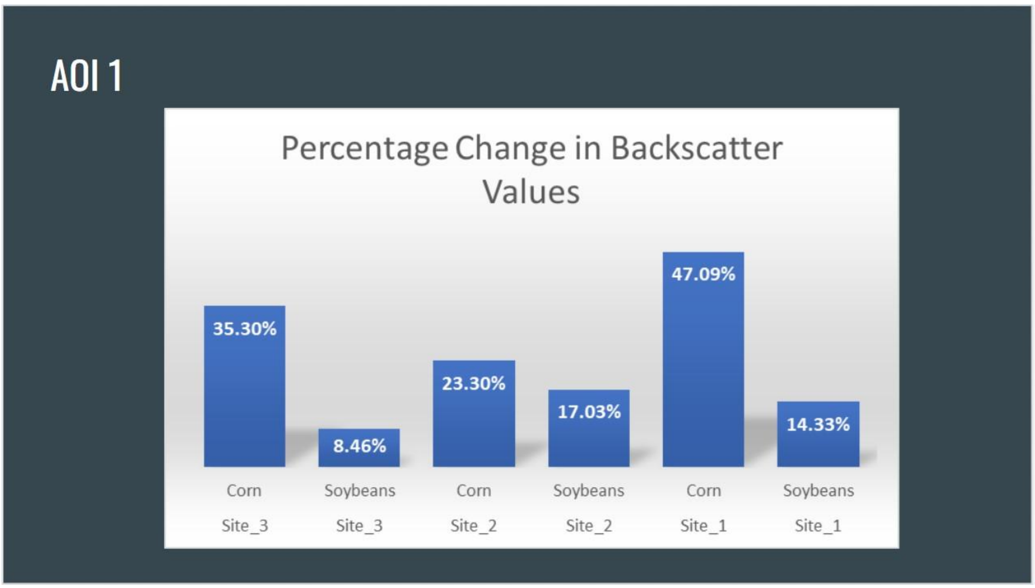

Figure 5a: Percentage Change in Backscatter Values for both Soybean and Corn in AOI 1

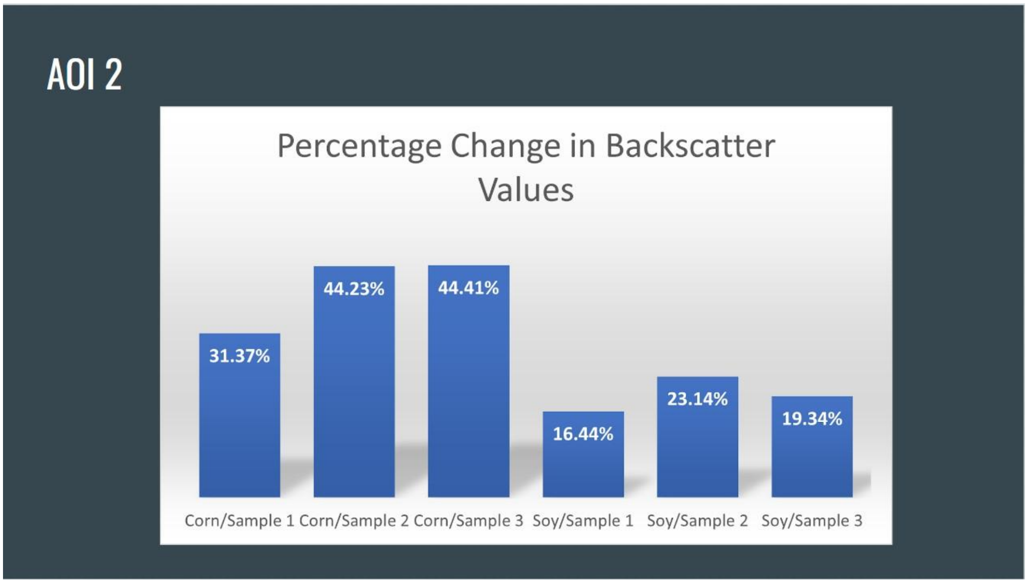

Figure 5b: Percentage Change in Backscatter Values for both soybean and Corn in AOI 2

Level of crop damage within agricultural fields

The level of crop damage within agricultural fields is carried out by analyzing per-pixel change in backscatter values for pure pixels of corn and soybean in various study sites across our areas of interest. The level of damage within crop fields shows an increase in backscatter values in post-storm images in cornfields, which signifies more damage. Higher values in the post-storm images are due to higher backscatter, which signifies more significant damage to crop fields in the county. There is a significant difference in the level of damage done to crops by the wind within the crop field. For instance, Figure 6 shows the percentage change in the backscatter values map for corn in two areas of interest sites (AO1 and AO2). From this map, it is obvious that the percent change in AO1 is greater than in AO2. With this result, we can infer a significant difference in the damage done to crop fields across Boone County. For decision-making purposes, compensation to farmers can be based on the percentage of change in the backscatter value map (corn), which shows the variability in the damage done to crop fields across Bonne County. Farmers would get compensated based on the perceived level of damage shown in their respective crop fields. Fields with more damage get more compensation and vice versa.

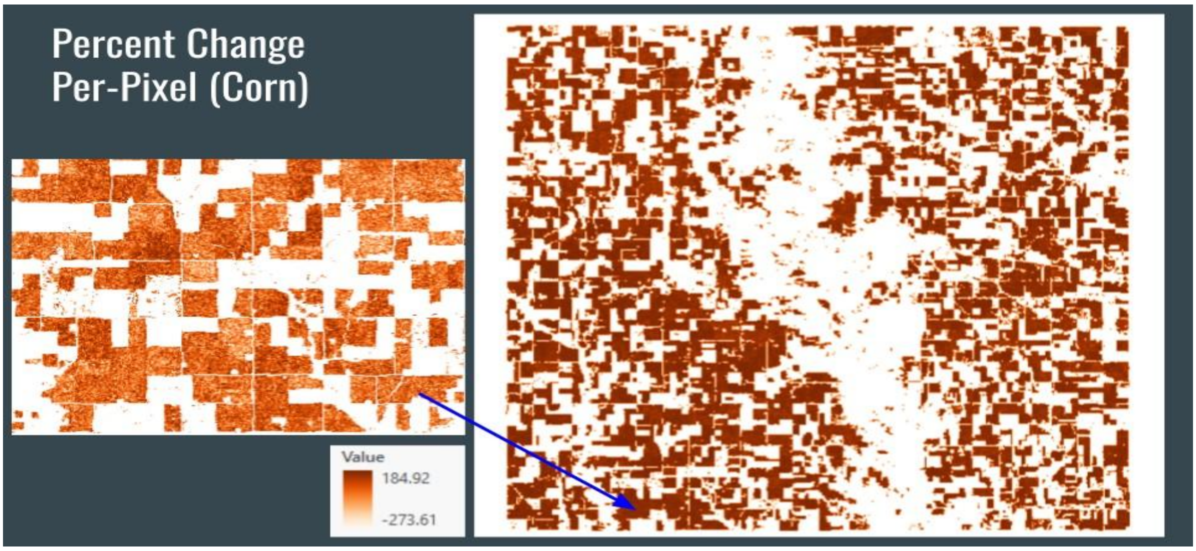

Figure 6a: Percentage Change in Backscatter Values Map for Corn in Boone County

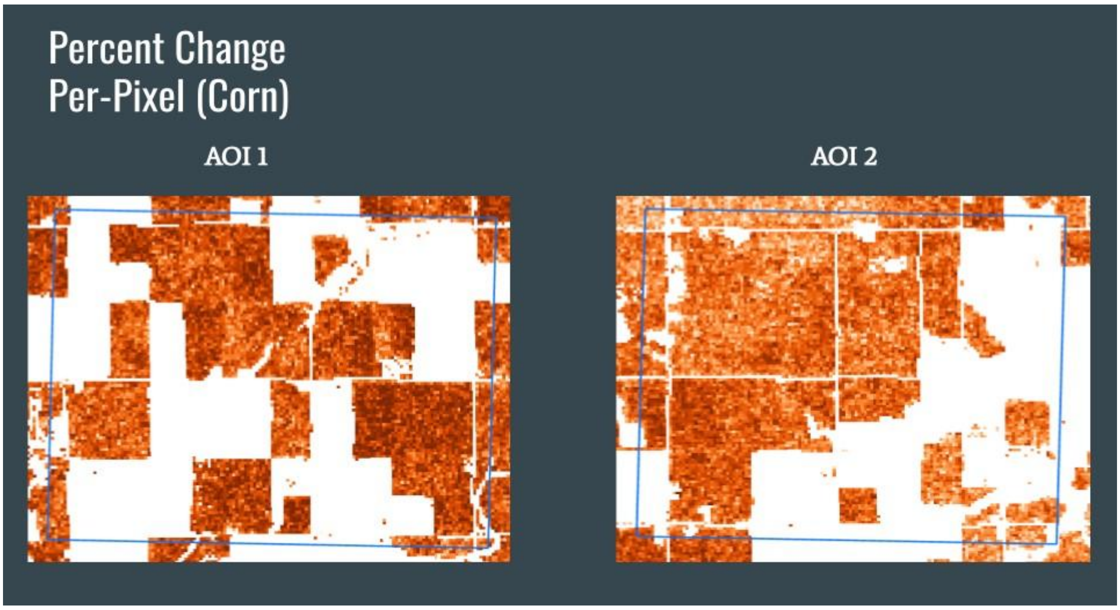

Figure 6b: Percentage Change in Backscatter Values Map for Corn in AO1 and AO2

Crop type sensitiveness to the windstorm

The resulting percent change in backscatter values of the crops indicates the sensitivity of the crops to the windstorm. It shows the endurance level of the crop to the strong windstorm. From the results in Figures 5a and 5b, soybean is less sensitive to the windstorm with a percentage change value that ranges between 8 to 23 percent. At the same time, corn is more sensitive to windstorms, with a percentage change value that ranges between 23 to 47 percent. The finding is biophysically reasonable as corn, taller with husk and stem, would be more sensitive to the wind damage than soybean, a relatively shorter crop with no stem that the wind can break. Therefore, our study has shown the differences in how individual crops (corn and soybean) are uniquely susceptible to windstorm damage. From this result, we could deduce that corn fields and corn farmers will likely suffer much more damage from the Derecho windstorm than other crop fields and farmers. Ergo, corn farmers should be considered for more reimbursement than other soybean farmers when making compensation decisions.

DISCUSSION

The complex interaction between microwave radiation and vegetative structures results in various scattering mechanisms that can manifest as brightening or darkening in SAR imagery. Despite this complexity, our multi-site analysis demonstrates that Sentinel-1 SAR imagery effectively captures localized variations in backscatter coefficients attributable to windstorm-induced structural modifications in agricultural vegetation. These findings corroborate previous investigations by Bell *et al.*, (2019a, 2020), who documented analogous backscatter alterations in corn and soybean fields damaged by hail during convective thunderstorm events across phenologically diverse periods in the Central United States agricultural belt.

Our initial hypothesis posited those structural perturbations in crop canopies specifically, alterations in plant architecture resulting from windstorm damage would produce detectable deviations in SAR backscatter signatures. However, empirical evidence suggests that the relationship between crop damage and backscatter modulation exhibits greater complexity than our preliminary conceptual model anticipated. The SAR backscatter response integrates numerous environmental variables beyond mere structural deformation, including soil moisture dynamics, phenological stage, canopy density, biomass distribution, and the particular morphological characteristics of damaged vegetation. The interpretation of SAR backscatter in agricultural damage assessment, therefore, necessitates a comprehensive analytical framework that accounts for these multifarious influencing factors.

The modest proportional change (1-10%) in backscatter coefficients observed at designated control points (Figure 8a and 8b) warrants careful consideration. These variations, while statistically significant, are likely to represent responses to ancillary environmental modifications rather than direct structural damage. For instance, the redistribution of surface water resulting in localized ponding may alter the dielectric properties of these areas, thereby influencing backscatter characteristics in post-storm imagery. Such secondary environmental responses highlight the importance of establishing appropriate control sites when implementing SAR-based damage assessment methodologies.

The temporal proximity between the Derecho event and our post-storm image acquisition (five days) substantially strengthens the validity of attributing observed backscatter alterations to windstorm effects. This restricted temporal interval minimizes the potential influence of confounding factors such as phenological advancement, management interventions, or subsequent meteorological events that might otherwise obscure the windstorm's biophysical signature. Consequently, despite the aforementioned complexities, we maintain high confidence in the biophysical plausibility of our findings, as the post-storm imagery likely represents a reasonably accurate depiction of windstorm-altered landscape conditions before significant environmental or anthropogenic modifications.

These results demonstrate the efficacy of SAR-based change detection for the rapid assessment of agricultural windstorm damage while acknowledging the methodological sophistication required to isolate damage signatures from other environmental influences. Future research should focus on developing more robust analytical frameworks that can better distinguish between primary damage effects and secondary environmental responses through the integration of multiple polarizations, incidence angles, and complementary data sources.

CONCLUSION

This study investigated the impacts of the August 2020 Derecho windstorm on agricultural landscapes in Boone County, Iowa, utilizing Sentinel-1 SAR data to quantify spatially explicit patterns of crop damage. The results demonstrate pronounced spatial heterogeneity in windstorm impacts, with southwestern regions of the county exhibiting significantly higher post-storm backscatter value changes, indicating severe structural damage to vegetation, while northwestern areas experienced comparatively moderate effects. The research establishes the efficacy of SAR-based methodologies for detecting and quantifying windstorm-induced agricultural damage through analysis of backscatter value alterations. Furthermore, our findings reveal differential susceptibility between crop types, with maize (corn) demonstrating heightened vulnerability to structural damage compared to soybean crops when subjected to equivalent wind forces. This differential response can be attributed to the distinct architectural properties of these crops, specifically the greater height and surface area of corn plants that increase mechanical stress during high-velocity wind events.

The implications of these findings extend beyond academic significance to practical applications in agricultural risk assessment and disaster management. The spatially explicit damage assessments generated through this methodology can inform evidence-based decision-making by agricultural service providers such as Indigo Agriculture, potentially enhancing the precision and equity of compensation mechanisms for affected agricultural producers. Additionally, identifying spatial patterns in windstorm vulnerability can facilitate proactive risk mitigation strategies, potentially reducing the socioeconomic impacts of future extreme weather events on agricultural communities in Boone County. The methodological framework developed and validated in this case study demonstrates substantial transferability potential to other geographic contexts affected by windstorms or alternative meteorological hazards impacting agricultural production systems. Future research should explore the integration of SAR-derived damage assessments with other remote sensing modalities and in-situ measurements to enhance further the accuracy and utility of post-disaster agricultural monitoring systems.

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REFERENCES

- Anderson, M. S., Phillips, J. R., & Thompson, K. L. (2021). Economic impacts of the August 2020 Midwest derecho. *Weather and Climate Extremes, 34*, 100382.
- Bell, J., Gebremichael, E., Molthan, A., Schultz, L., Meyer, F., & Shrestha, S. (2019). Synthetic aperture radar and optical remote sensing of crop damage attributed to severe weather in the Central United States. *International Geoscience and Remote Sensing Symposium (IGARSS)*, 9938-9941. https://doi.org/10.1109/IGARSS.2019.8898114
- Bell, J., Gebremichael, E., Molthan, A., Schultz, L., Meyer, F., Shrestha, S., Hain, C. R., & Payne, C. (2020). Complementing optical remote sensing with synthetic aperture radar observations of hail damage swaths to agricultural crops in the Central United States. *Journal of Applied Meteorology and Climatology, 59*(4), 665-685. https://doi.org/10.1175/JAMC-D-19-0124.1
- Chen, J., & Lin, H. (2018). Monitoring crop damage from severe weather events using SAR interferometry. *Remote Sensing of Environment, 210*, 149-161.
- Hosseini, M., & McNairn, H. (2018). Using radar backscatter to detect and monitor crop damage from extreme weather events. *International Journal of Applied Earth Observation and Geoinformation, 73*, 403-412.
- Iowa Department of Agriculture and Land Stewardship. (2020, August 14). *Updated derecho impact estimates*. https://iowaagriculture.gov/news/updated-derecho-impact-estimates-08142020
- Iowa Department of Agriculture and Land Stewardship. (2021). *Iowa agriculture*. https://iowaagriculture.gov
- Johnson, R. A., & Lee, K. S. (2022). Digital agriculture platforms: Integration of satellite-derived insights for enhanced farm management. *Precision Agriculture, 23*(1), 112-131.
- Mohammadi, B., Chen, G., & Zhang, H. (2021). Using Sentinel-1 SAR data for detecting windstorm damage to corn crops in Nebraska. *International Journal of Applied Earth Observation and Geoinformation, 102*, 102394.
- National Oceanic and Atmospheric Administration. (2020). *GOES-East watches derecho slam Midwest*. https://www.nesdis.noaa.gov/news/goes-east-watches-derecho-slam-midwest
- Steele-Dunne, S. C., McNairn, H., Monsivais-Huertero, A., Judge, J., Liu, P. W., & Papathanassiou, K. (2017). Radar remote sensing of agricultural canopies: A review. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10*(5), 2249-2273.
- Torbick, N., Chowdhury, D., Salas, W., & Qi, J. (2017). Monitoring rice agriculture across Myanmar using time series Sentinel-1 assisted by Landsat-8 and PALSAR-2. *Remote Sensing, 9*(2), 119.
- Torres, R., Snoeij, P., Geudtner, D., Bibby, D., Davidson, M., Attema, E., Potin, P., Rommen, B., Floury, N., Brown, M., & Traver, I. N. (2012). GMES Sentinel-1 mission. *Remote Sensing of Environment, 120*, 9-24.
- Town Square Publications. (2021). *Boone County agriculture, Boone County farming community, Boone County Indiana economy*. https://www.townsquarepublications.com
- U.S. Department of Agriculture, National Agricultural Statistics Service. (2021). *2021 Iowa annual statistical bulletin*. https://www.nass.usda.gov/Statistics_by_State/Iowa/Publications/Annual_Statistical_Bulletin/2021-Iowa-Annual-Bulletin.pdf
- U.S. Forest Service. (2019). *Iowa's forests*. https://www.nrs.fs.fed.us/pubs/rb/rb_nc266a.pdf
- Wang, C., Wu, J., & Zhang, Y. (2019). Characterizing crop structural damage using multi-temporal SAR imagery. *Remote Sensing Applications: Society and Environment, 15*, 100243.
- Zhou, T., Pan, J., Zhang, P., Wei, S., & Han, T. (2016). Mapping flood extent in rural areas using Sentinel-1 SAR imagery. *International Journal of Remote Sensing, 37*(18), 4300-4317.

