SYNTHETIC APERTURE RADAR AND OPTICAL REMOTE SENSING OF CROP DAMAGE ATTRIBUTED TO SEVERE WEATHER IN THE CENTRAL UNITED STATES

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Introduction

Damaging hail and wind from severe thunderstorms threatens agricultural areas annually, especially across the central United States where agriculture is prevalent.

On average, these storms produce $160 - $580 million worth of damage in the US every year[1] and contribute significantly to food prices, crop insurance, and agricultural related stocks. However, hail damage is not regularly ground-surveyed like tornadoes.

Optical (visible, NIR, and SWIR) remote sensing techniques have been shown to successfully identify and monitor hail damage swaths[1].

Techniques of identification and monitoring hail damage swaths from synthetic aperture radar (SAR) are currently unexplored.

We hypothesize that hail-damaged cropland will exhibit lower power return than surrounding healthy vegetation due to changes in the geometry of the targets. Further analysis is needed to determine a threshold for future automated monitoring of hail damage swaths.

Background

Optical

Passive optical remote sensing instruments measure reflected sunlight from Earth's surface in the visible, near infrared, and short wave infrared wavelengths.

Normalized Difference Vegetation Index (NDVI) measures the greenness and health of vegetation using the Red and NIR optical bands[2].

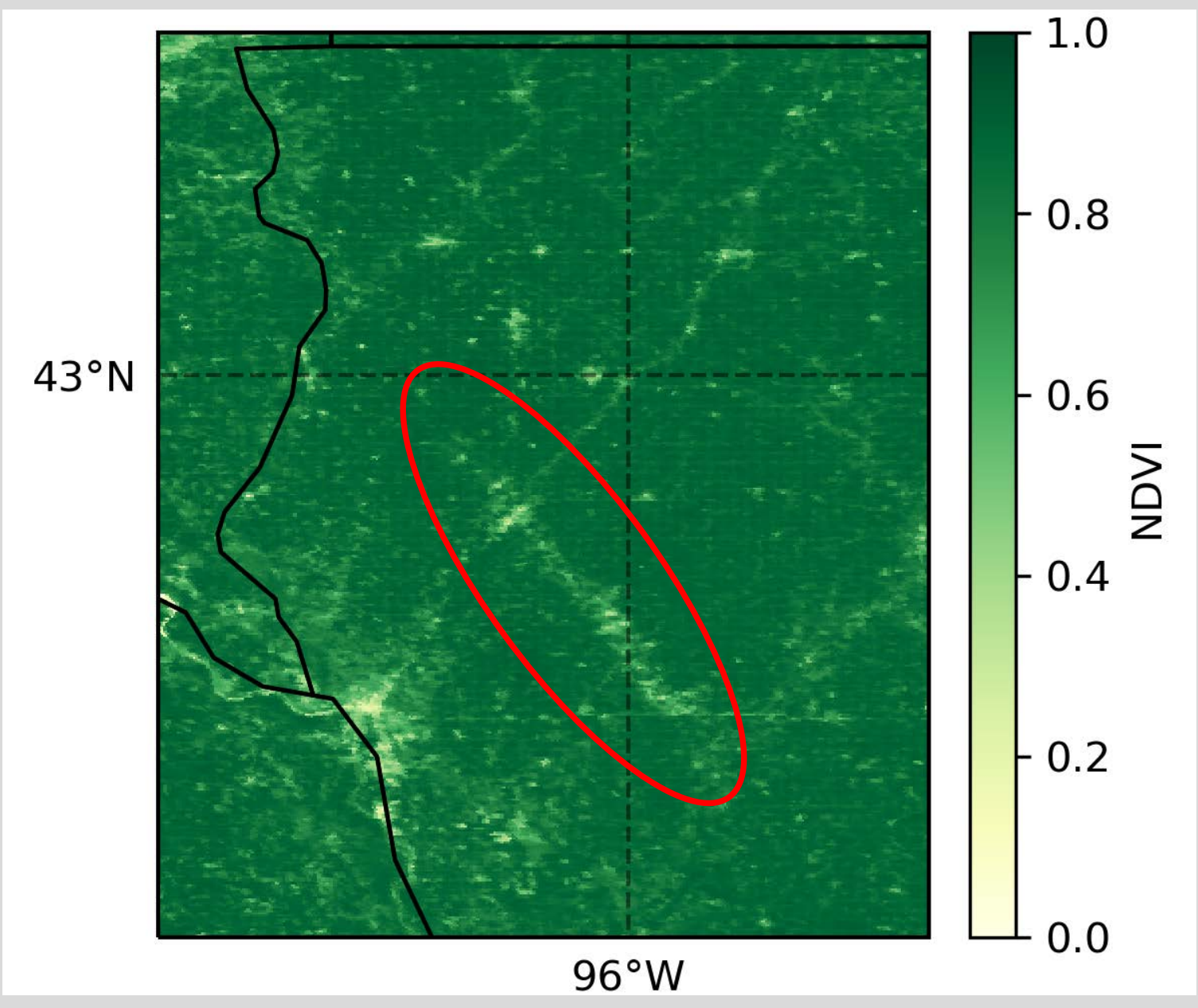
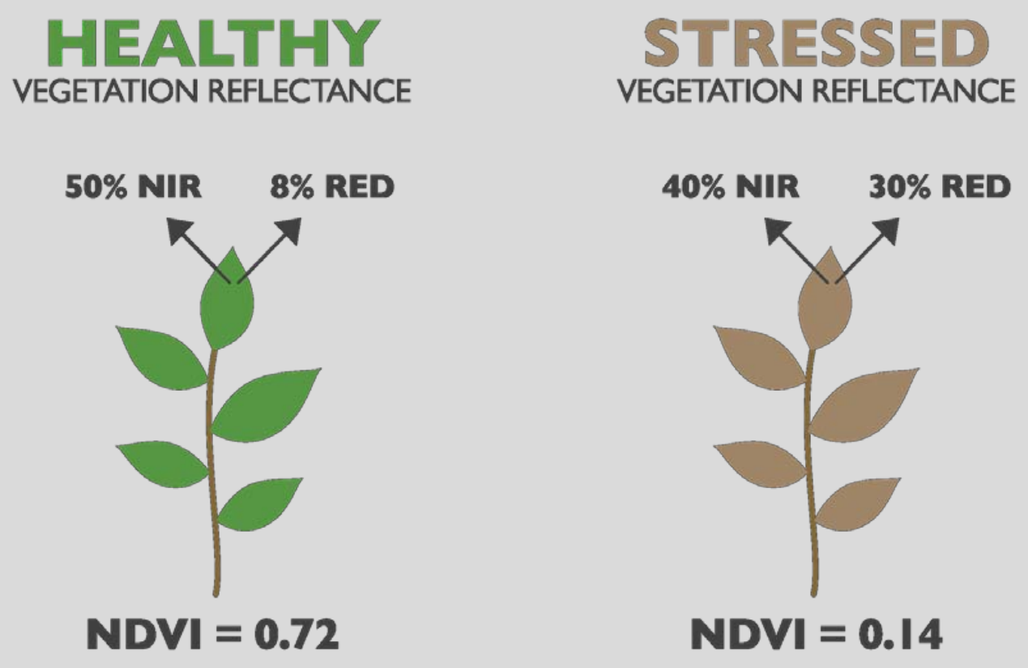


Fig. 1. NDVI map from 20 June 2016 showing post storm hail scar

0 to +1 scale. Higher values = healthier, greener vegetation



$$\text{NDVI} = \frac{\text{NIR - RED}}{\text{NIR + RED}}$$

Fig. 2. Normalized Difference Vegetation Index Example[3]

Areas of large NDVI change (Figs. 1 and 2) can be a good indicator of potential damage sustained by crops.

Optical based techniques are limited to daytime cloud-free conditions, unlike SAR sensors.

Synthetic Aperture Radar (SAR)

SAR is an active remote sensing system that emits microwave signals of known wavelength and measures the amount of backscattered signal to the sensor (phase and amplitude information) from the target object. The amplitude (intensity) component of the backscattered signal can be converted to decibels (dB) for analysis.

Unlike passive optical sensors that rely on daylight and cloud-free conditions, SAR systems can acquire Earth observations during day or night, and in the presence of cloud cover.

Signals are sent and received at the sensor in multiple polarizations (orientation); vertical (V) or horizontal (H). E.g. sent vertical, received horizontal (VH).

Different polarizations can interact with the same target uniquely, resulting in differences in backscatter and measured dB values.

The changes in both amplitude and phase (degree of similarity) between two images acquired at different times can be expressed in terms of coherence/correlation coefficient (γ).

SAR measured reflectance values from healthy and damaged cropland can vary greatly due to differences in backscatter as shown in Fig. 3.

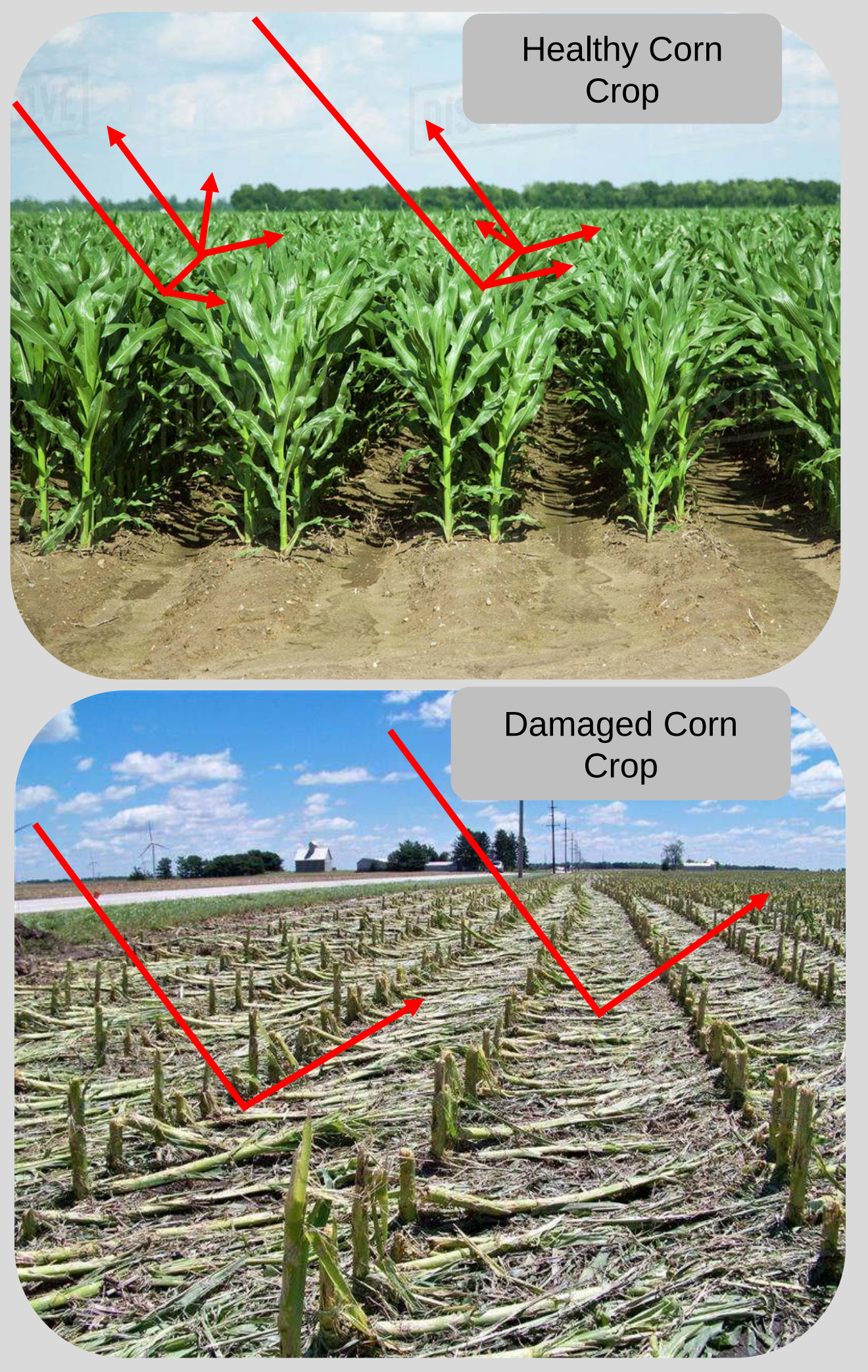


Fig. 3 Example of backscattered signal from healthy and damaged corn

Methodology

The extent of hail damage was hand-digitized in ArcMap using MODIS RGB's and Maximum Estimated Size of Hail (MESH) products (Figs. 4 and 5) . A 5 km and 10 km buffer was created around damaged cropland to distinguish undamaged background from damaged area (Fig. 5).

Valid cropland pixels within the study area were identified using the Crop Data Layer (CDL) to isolate corn and soybeans identified areas[1].

SAR dB values were extracted from valid cropland pixels for damaged and background areas within our study area and used to calculate statistics.

Data	Details	Source
NDVI images	250m NDVI product	NASA MODIS
SAR Images	25m SAR dB images, VV and VH polarizations	European Space Agency Sentinel 1 A/B
MESH	Ground RADAR based product to estimate extent and size of hail after large storms	NOAA
CDL	crop-specific land cover data layer generated yearly from Remote Sensing and extensive ground truthing	USDA NAAS

Damaged and background dB values were analyzed for statistically significant patterns similar to NDVI that can be used to identify hail damaged cropland and monitor regrowth.

Coherent Change Detection (CCD) analyses were carried out to further support the SAR amplitude-based delineation of the hail damage extent.

Two coherence pairs derived from pre-event, as well as pre-and post-hail Single Look Complex (SLC) image pairs were used in the analyses.

References and Acknowledgements

We would like to our colleagues at the Alaska Satellite Facility (ASF) for all their help in the processing of the Sentinel-1 data as well as helping MSFC develop synthetic aperture radar (SAR) knowledge.

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[1] Bell, J. R., and A. L. Molthan, 2016: Evaluation of approaches to identifying hail damage to crop vegetation using satellite imagery. *J. Operational Meteor.*, ***4*** *(11), 142-159.*
[2] Jones, H. G., and R. A. Vaughan, 2010: *Remote Sensing of Vegetation. Oxford University Press, 353 pp.*
[3] Sara Antognelli, 2018: NDVI and NDMI vegetation Indices: Instructions for use. Accessed 25 July 2018, https://www.agricolus.com/en/indici-vegetazione-ndvi-ndmi-istruzioni-luso/
[4] Preiss, M., & Stacy, N. J. (2006). Coherent change detection: Theoretical description and experimental results (No. DSTO-TR-1851). Defence Science and Technology Organisation Edinburgh (Australia).

Case Study : 5 August 2018—Central Nebraska

Fig. 4. Aqua MODIS True Color RGB from 12 August 2018 showing hail damage swath in central Nebraska, USA.

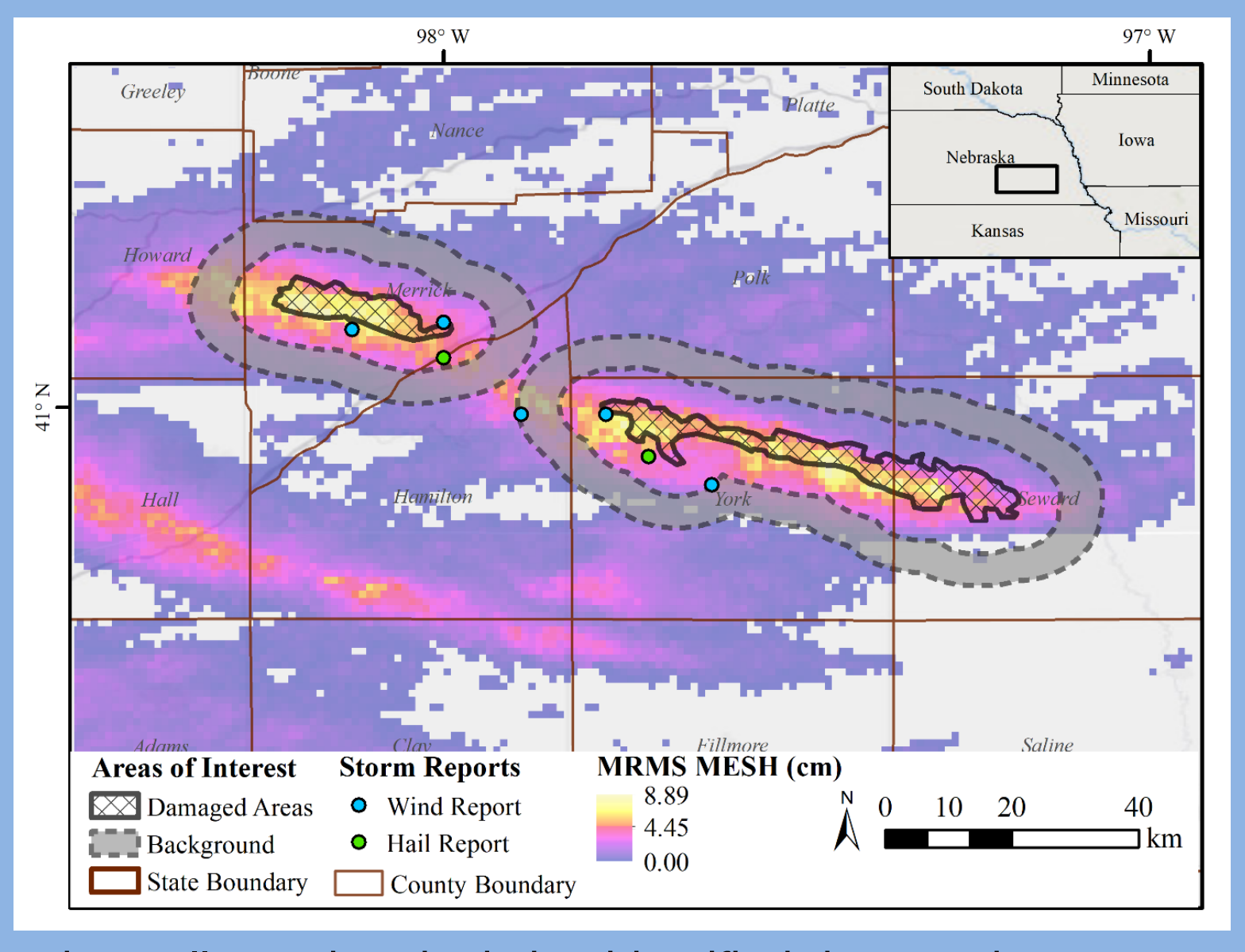

Fig. 5. Illustration depicting identified damaged areas and buffers for separating damaged areas from the non-damaged background (Bell et al. 2019).

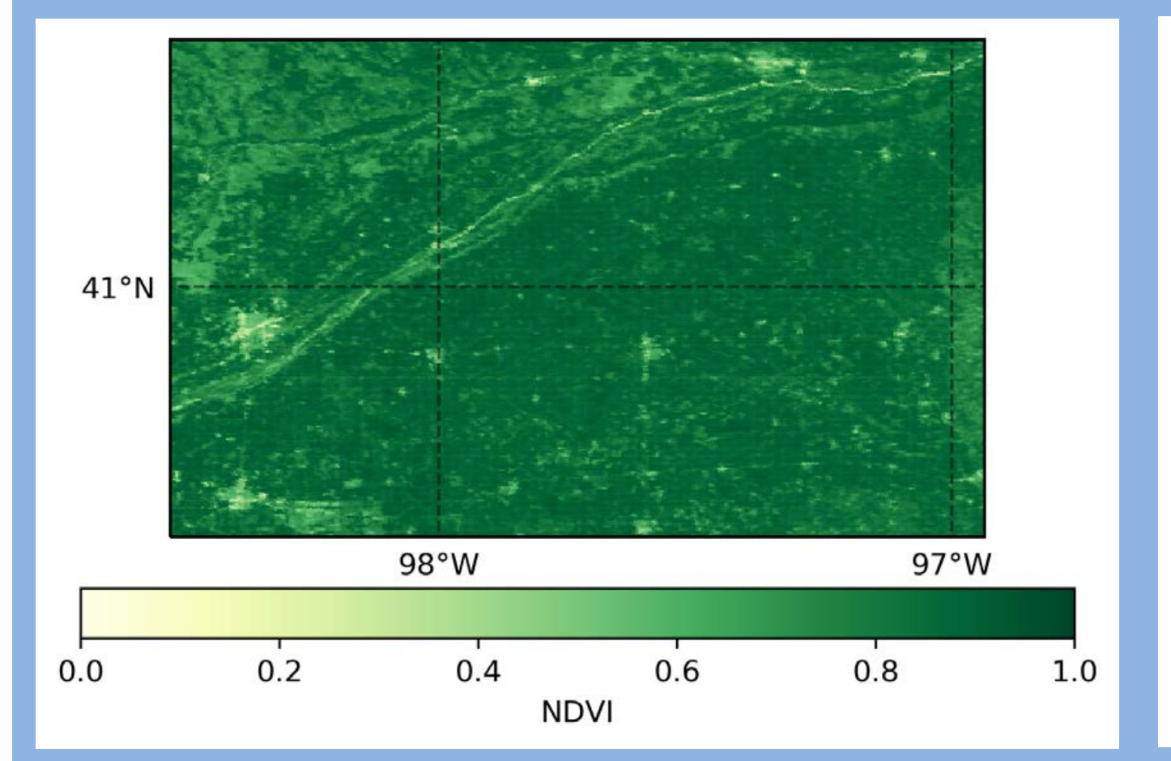

Fig. 6. Pre-storm NDVI conditions acquired by Aqua MODIS on 2 August 2018.

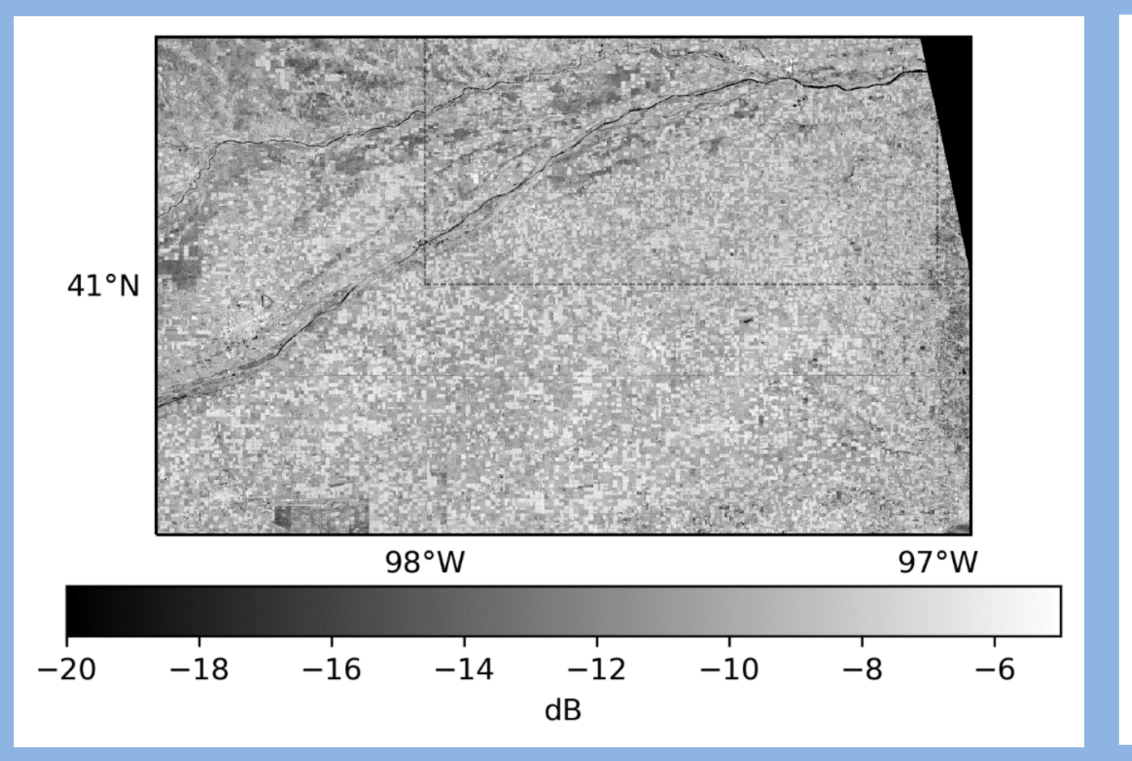

Fig. 7. Pre-storm VV imagery acquired by Sentinel-1A on 31 July 2018.

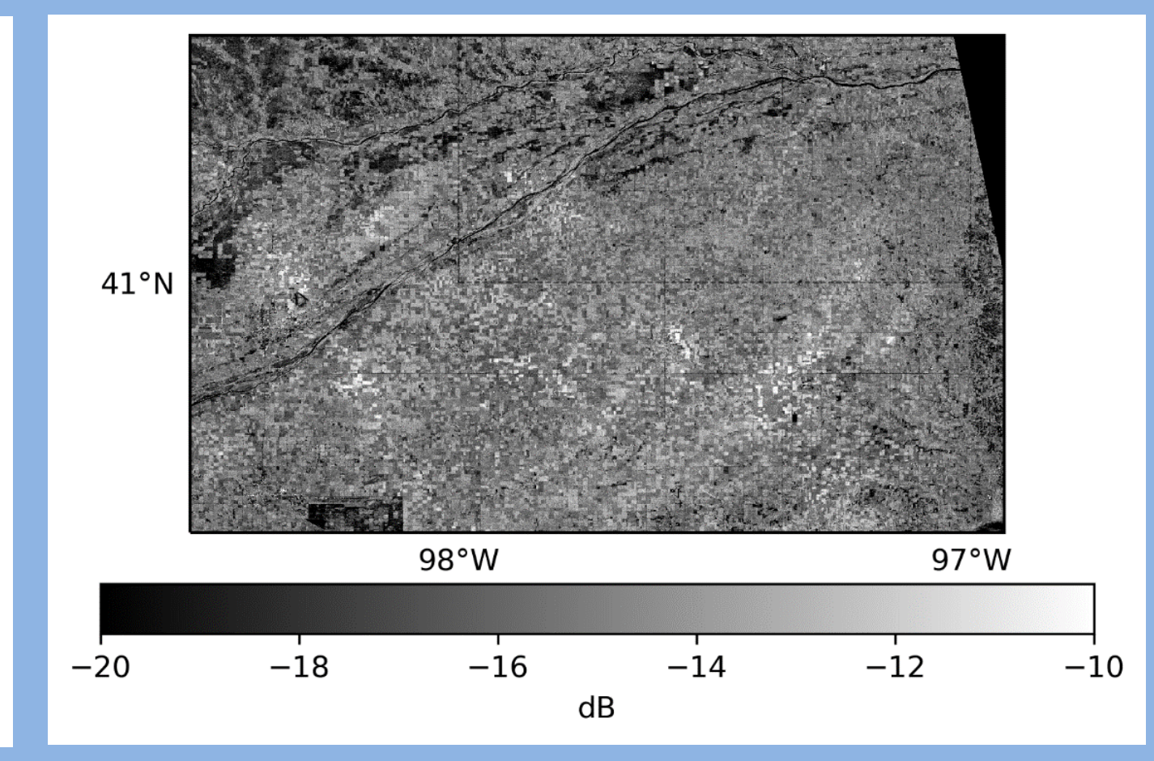

Fig. 8. Pre-storm VH imagery acquired by Sentinel-1A on 31 July 2018.

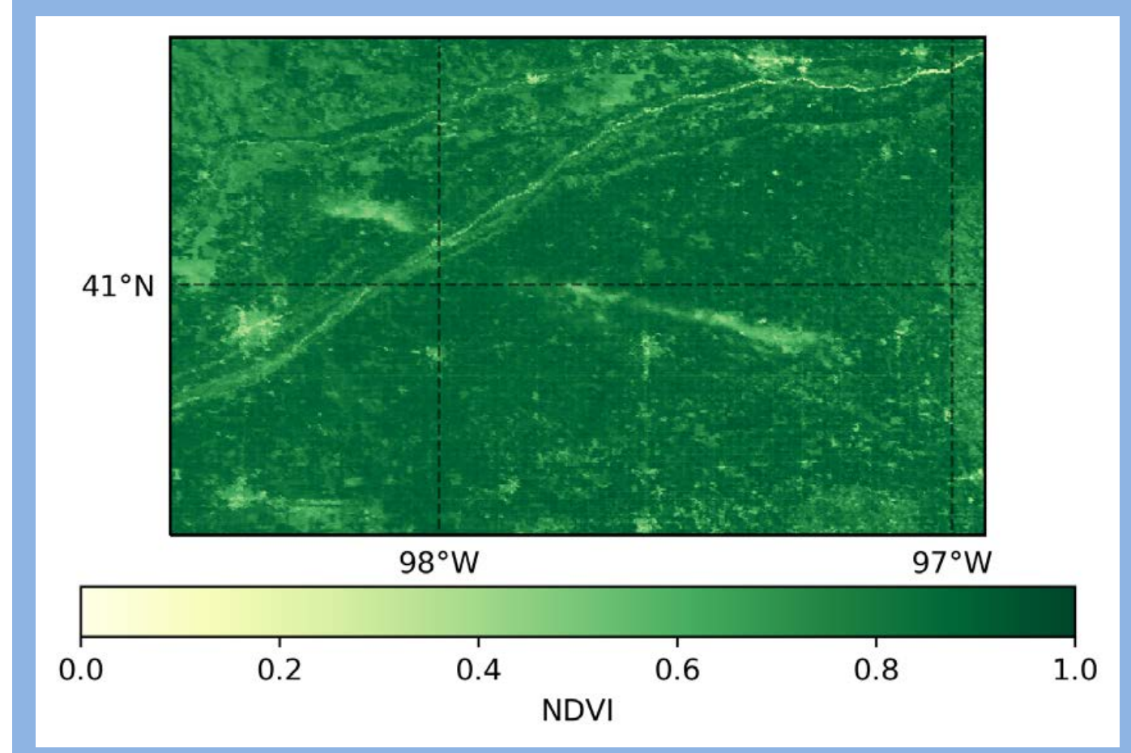

Fig. 9. Post-storm NDVI conditions acquired by Aqua MODIS on 12 August 2018.

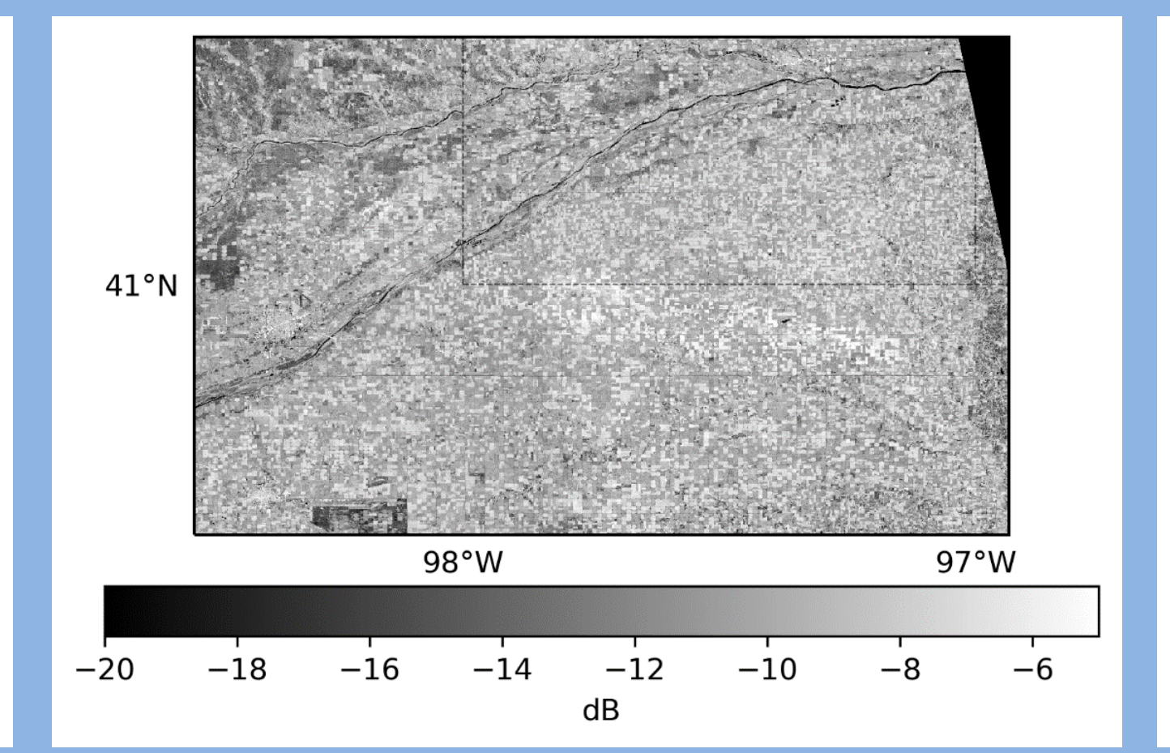

Fig. 10. Post-storm VV imagery acquired by Sentinel-1A on 12 August 2018.

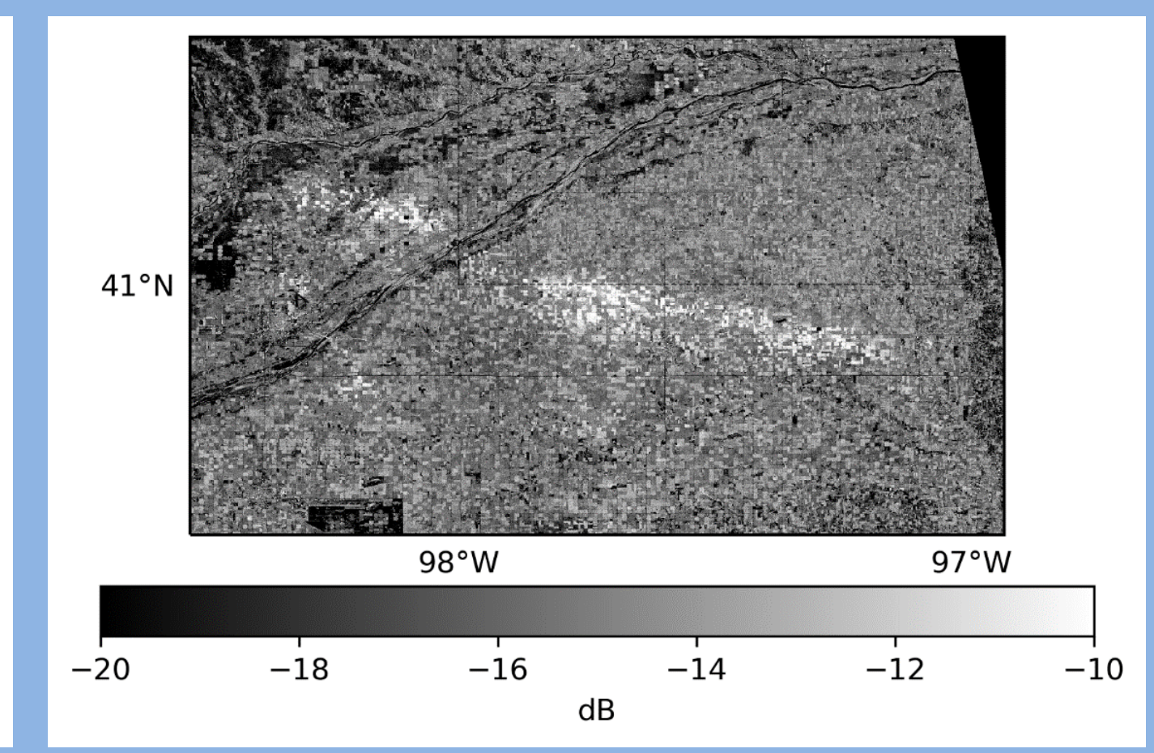

Fig. 11. Post-storm VH imagery acquired by Sentinel-1A on 12 August 2018.

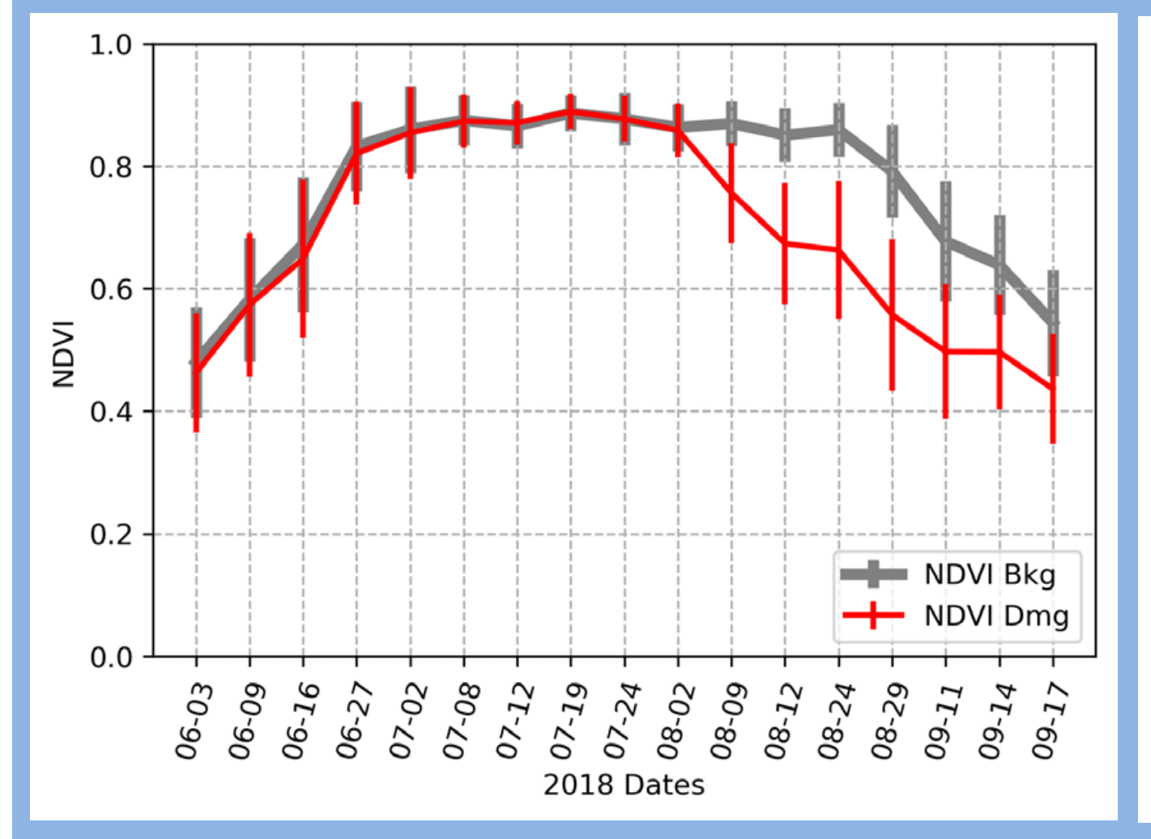

Fig. 12. Growing season time series for mean NDVI values for CDL identified corn crops. Vertical bars are 1 standard deviation.

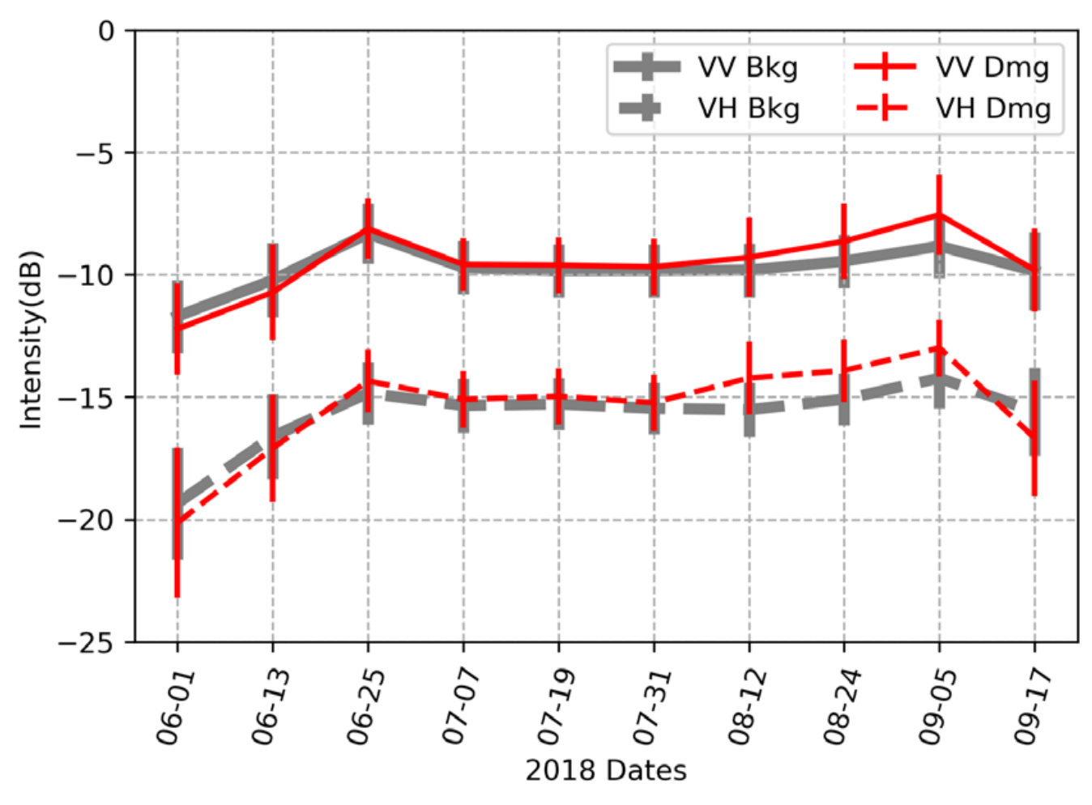

Fig. 13. Growing season time series for Sentinel-1 mean dB values for CDL identified corn crops. Vertical bars are 1 standard deviation.

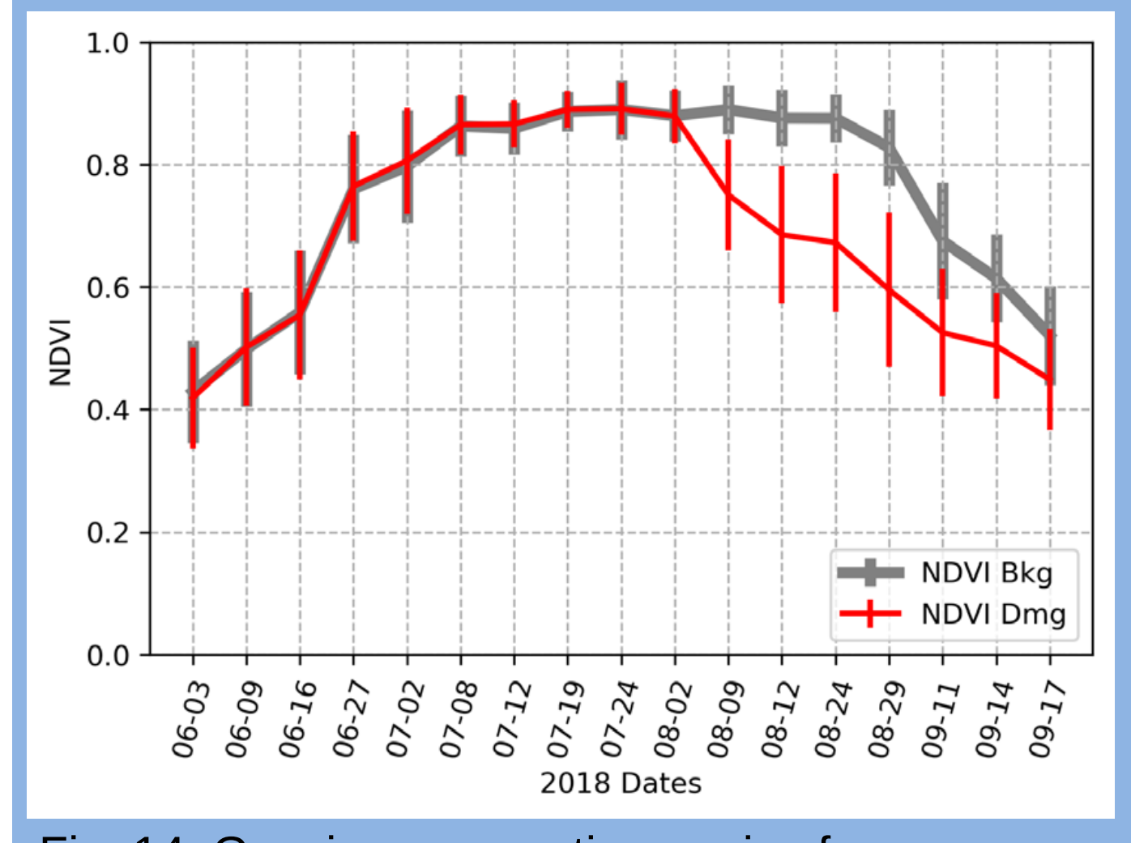

Fig. 14. Growing season time series for mean NDVI values for CDL identified soybean crops. Vertical bars are 1 standard deviation.

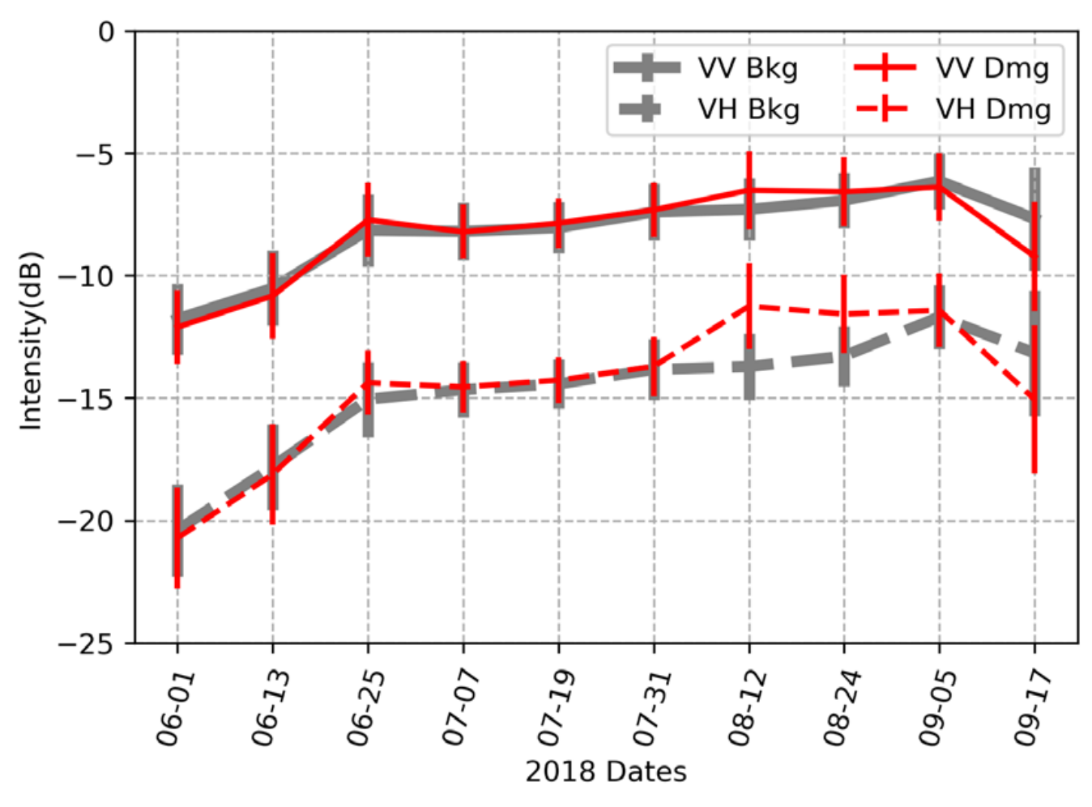

Fig. 15. Growing season time series for Sentinel-1 mean dB values for CDL identified soybean crops. Vertical bars are 1 standard deviation.

A strong thunderstorm with hail sizes ranging from 2.54 cm to 5.08 cm (1.0 to 2.0 in) moved through south-central Nebraska on 6 August 2018. This storm produced a near 90 km long swath with width ranging from 3 to 6 km.

NDVI analysis shows expected separation from background and damaged crop pixels post storm. The undamaged crops in the background with a consistent NDVI, until the fall harvest began later in the season. The damaged crops saw a steady decline throughout the rest of the time series (Figs. 12 and 14).

Similar to responses from crops in early growth stages, SAR backscatter from hail damaged areas, especially the VH component, is expected to be low due to the loss/damage of crop structures and absence of volumetric scattering as a result of the damaging storm.

In this particular case study, the storm event occurred during mid-late growing stages (as shown on the NDVI plots- Figs. – and --) of the affected crops – a period of highest water demand for some of the affected crops (e.g. corn).

A combination of (partial) toppling and presence of water-saturated soils and possibly standing water attributed to irrigation has resulted in increases in SAR backscatter (Figs. 13 and 15) within the hail affected region ascribed to the combined effects of double-bounce and volumetric scattering mechanisms.

Coherence Analysis

Coherent Change Detection (CCD) procedures were applied to three SAR images to validate the inference of change in the individual SAR images and backscatter attributed to the hailstorm.

Pixels with low coherence values (less than 0.3) in the pre- and post-hailstorm pair (31 July and 12 August 2018) were initially identified as possible hail-affected pixels.

In a bid to exclude low coherence pixels attributed to sources other than the hailstorm (human activity, natural vegetation growth, change in surface water levels), a second pre-hailstorm coherence product was generated using the pre-hailstorm image SLC acquisitions (19 July and 31 July 2018).

Pixels with low coherence values (less than 0.3) in the two pairs of products were deemed to be caused by incidents or processes other than the hailstorm and subsequently were excluded from the final output (Fig. 16).

Pixels along the track of the storm underwent a significant decline (Fig. 16) in coherence values (up to 90% drop in some cases) and such drop within a short period of time (12 days) can only be attributed to a major event, such as hailstorm, not to the agricultural growth cycle of the crops.

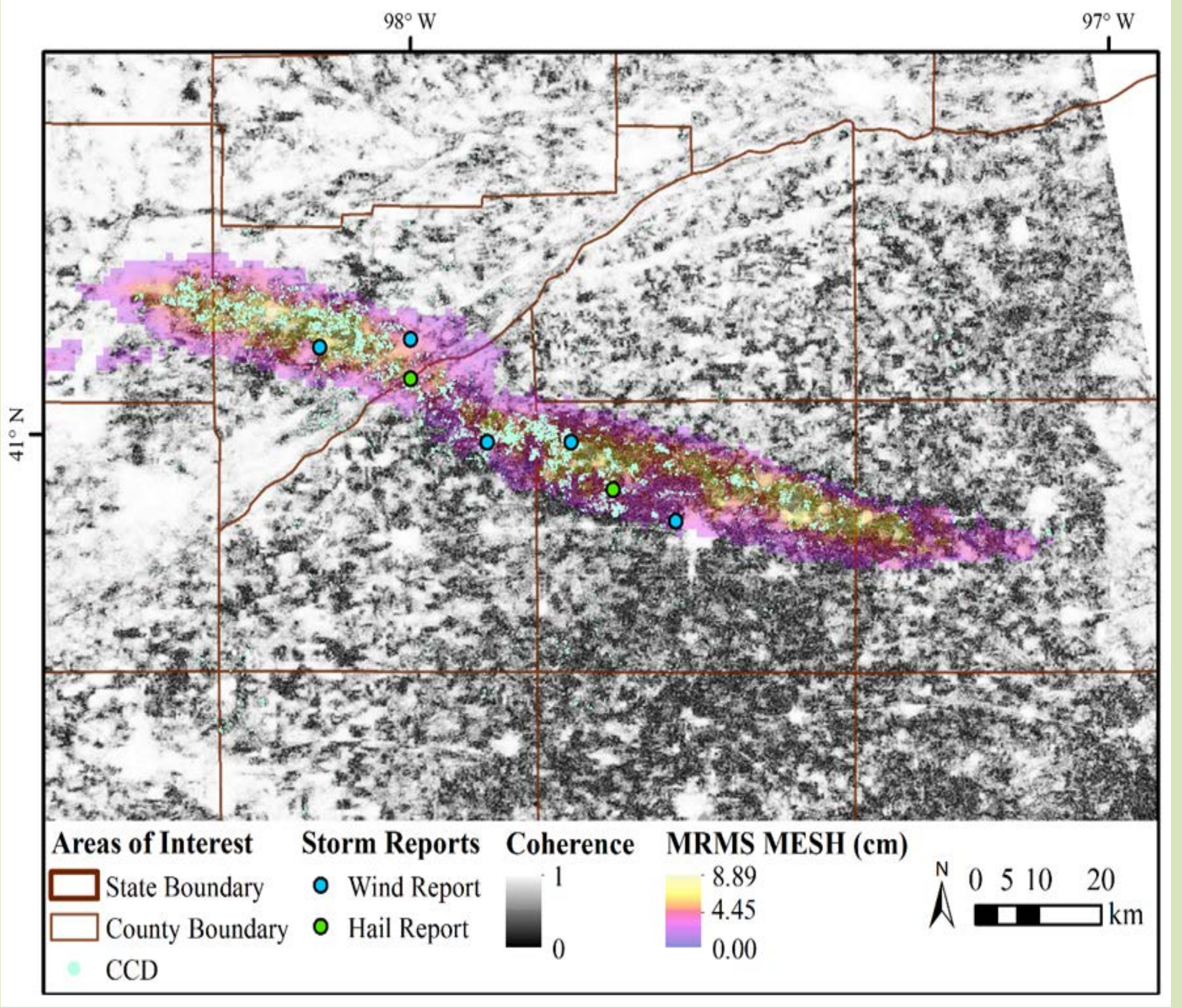

Fig 16. CCD based mapping of hail damage swath for the 2018 hailstorm event in South Central Nebraska.